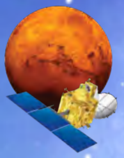
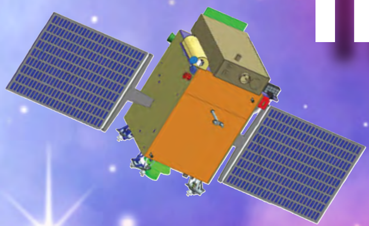
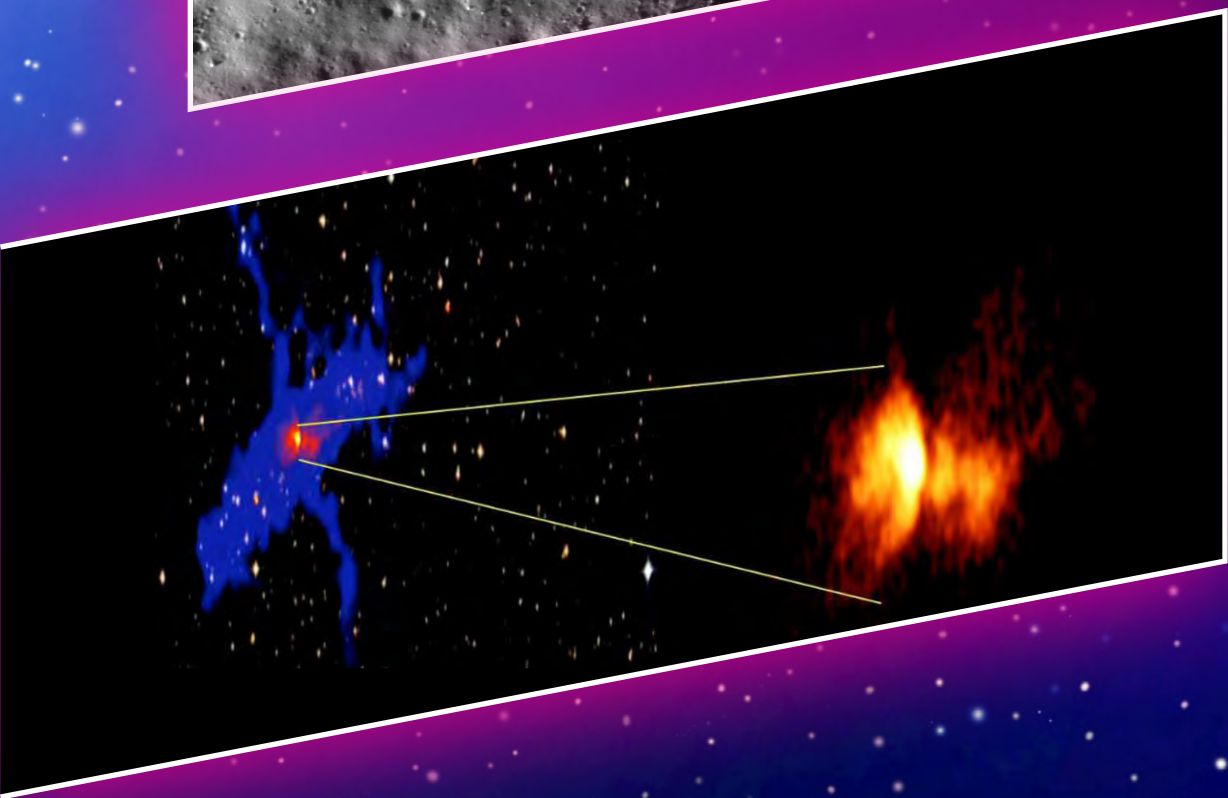



SPACE RESEARCH IN INDIA





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Cover Page Images:

Upper: Highest resolution image of the region (-70.588°, 22.933°) between Manzinus C and Simpelius N by OHRC on Chandrayaan-2 orbiter

Lower: AstroSat UVIT observations of butterfly Nebula showing the extended emission region

SPACE RESEARCH IN INDIA

July 2020 – December 2021

A Report of the

Indian National Committee for Space Research (INCOSPAR)

Indian National Science Academy (INSA)

Indian Space Research Organisation (ISRO)

For the

44th COSPAR Scientific Assembly

16 July – 24 July 2022

Athens, Greece

INDIAN SPACE RESEARCH ORGANISATION
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FOREWORD

Space science research has always been a driving force of ISRO's endeavours starting from the early days of sounding rocket investigations of the upper atmosphere. As ISRO's access to space using indigenous launch vehicles grew both in lift-off capacity and frequency of launch opportunities, the science community in India has benefitted from a significant increase in access to space for science experiments.

With the successful science missions Chandrayaan-1, Mars Orbiter Mission (MOM), AstroSat and Chandrayaan-2, ISRO has demonstrated its capability in planning and executing major science missions.

This period also yielded significant scientific results by institutions and universities in India. Some of the important results from AstroSat, MOM, Chandrayaan-2 missions are summarized in this report. The report covers an increasing involvement of Indian institutions in space science research and the expanding research programs.

The space science missions planned for future includes the Aditya-L1 mission, a dedicated solar observatory to be positioned at Lagrange point 1 in the Sun-Earth system, to study solar corona heating, UV irradiance and in-situ particle and field measurements with linkage to space weather. XPoSat, an X-ray polarimetry mission, is getting ready to decipher polarimetry, spectroscopy and timing information for various bright astronomical sources in X-rays. Chandrayaan-3 mission is aimed at demonstrating landing and roving on the lunar surface for conducting in-situ study of the lunar surface and is in the advanced stage of realisation. Feasibility studies are progressing for a future joint mission with JAXA for the exploration of the permanently shadowed regions in lunar South Pole.

In Chandrayaan-1 and AstroSat, ISRO enabled opportunities for collaborative contributions from International agencies and institutes on science payloads. More opportunities have opened up for international co-operations in space science, especially in joint development of scientific payloads and data analysis. In order to expand the space science research horizons and facilitate more opportunities for the national researchers in space science, ISRO will have more focused collaborative efforts with international agencies and institutes towards realization of advance space missions and science payloads.

At this juncture, I am happy to present the INCOSPAR report to the 44th COSPAR Scientific Assembly to be held at Athens, Greece during 16-24 July 2022. I hope that the information on space science activities in India, provided in this report, will be an important reference to the international scientific community.

I wish the 44th COSPAR Scientific Assembly every success.

सोमनाथ

Date: June 24, 2022

(सोमनाथ एस / Somanath S)

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Chairman, Indian National Committee for COSPAR

PREFACE

With great pleasure I introduce the report on Space Research in India, prepared for the 44th COSPAR Scientific Assembly, 16 – 24 July 2022, Athens, Greece, by the Indian National Committee for Space Research (INCOSPAR), Indian National Science Academy (INSA), and Indian Space Research Organisation (ISRO). The report gives an overview of the important accomplishments, achievements and research activities conducted in India in several areas of near-Earth Space, Sun, Planetary Science, and Astrophysics for the duration of one and half years (July 2020 – Dec 2021). This report also provides glimpses of capacity building activities in space science research, academic courses offered on space science and technology, national and international collaborations in space science and technology, laboratories and facilities established at various institutes and centres contributing to space science exploration and research in India, to name a few.

The Indian space science community has been active in the domains related to Astronomy and Astrophysics, Solar Physics, Space Weather and Sun-Earth connection, Space and Atmospheric Sciences, Planetary Science, Geomagnetism and Geosciences. This report describes highlights of the research from the studies on oceanography, atmospheric structure and dynamics, clouds and convective systems, aerosols, radiation and trace gases, weather and climate change, middle atmosphere, ionosphere, magnetosphere, solar wind and space weather, lunar and planetary studies, Sun and the solar system bodies, stars, galaxies, galactic and extragalactic astronomy and cosmology.

In the area of planetary science, the Chandrayaan-2 orbiter is providing high-quality remote sensing and in-situ observations of the Moon with eight scientific payloads on-board; the data are made available to public with more than 2800 worldwide registered users. Chandrayaan-2 science results have provided new insights to the lunar science research, which include characterization of hydration features on surface, characterization of young, fresh lunar crater floors, global distribution of Argon-40 in the lunar exosphere, study of the geotail dynamics at lunar distances, detection of minor elements, such as Cr and Mn from the orbiter, and mapping of sodium distribution for the first time.

The Indian Mars Orbiter Mission (MOM) continues to orbit Mars completing more than seven years of operations around Mars. The enhanced escape of Martian atmosphere during global dust storm is one of the major science results of MOM.

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AstroSat, India's first multi-wavelength astronomical mission has successfully completed six years of operation on 28 September 2021. The space-based observatory operates on proposal basis and is open to astronomy community since October 2016. Currently, AstroSat has a registered user base of around 1600 from 48 countries. In the first six-years, AstroSat has produced more than 250 refereed publications with more than thousand conference proceedings, GCN circulars, Astronomer's telegrams, and other non-refereed publications. During the last one and half year period, several interesting and important science outcomes have emerged from AstroSat data. The discovery of young main-sequence stars in the bulge of M31 outside the nucleus is a breakthrough result. The other notable results are the first detection of FUV photons from Lyman Alpha from the galaxy AUDFs01 at a distance of 9.3 billion light years, the detection and characterisation of star formation in and around Jellyfish galaxies, the rotation of the black hole in a binary at a speed close to the maximum possible speed of spin and the detection of 500th GRB.

The Indian space programme is currently engaged in developing its near future space science missions Aditya-L1, XpoSat and Chandrayaan-3. Aditya-L1 will be the first space based Indian mission to study the Sun. The spacecraft to be placed in a halo orbit around the Lagrangian point 1 (L1) of the Sun-Earth system will provide a greater advantage of continuous observations of the solar corona, as well as the eruptive activities from the Sun. XPOSAT, an upcoming astronomy mission, will be a unique one, as it will decipher polarimetry, spectroscopy and timing information from the same platform for various selected astronomical sources in X-rays. It will be the first dedicated Indian satellite for Polarization measurement in medium-energy X-rays. Chandrayaan-3 mission, India's third mission to the Moon, is aimed at demonstrating landing and roving on the lunar surface for conducting in-situ measurements of the surface thermo-physical properties, elemental composition and electron density variations in the vicinity of the landing site.

A second exoplanet (inflated Hot-Jupiter) has been discovered by India, orbiting too close to a star with a mass of 1.5 times that of our Sun and located 725 light years away. This discovery is made using PARAS spectrograph on the 1.2-m telescope of Physical Research Laboratory at Mt. Abu.

I would like to thank all the scientists who have provided inputs on the space research activities being carried out in their respective Institutes and Departments to prepare this report. I would like to acknowledge the hard work put in by Science Programme Office, ISRO HQ, Bangalore for compiling and editing the report on behalf of INCOSPAR.

Prof. (Dr.) Anil Bhardwaj

Chairman, Indian National Committee for COSPAR

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CHAPTER-1

ORGANISATIONAL STRUCTURE AND SCIENCE ACTIVITIES

1.1 INTRODUCTION

The first steps of Indian space science exploration started with the investigations of the Earth's upper atmosphere and ionosphere. The initial scientific motivation was to study equatorial electrojets. In the year 1963, the first sounding rocket was launched from the Thumba Equatorial Rocket Launching Station (TERLS) near Thiruvananthapuram. These sounding rockets were meant to investigate the upper atmospheric regions using rocket-borne instruments. Sounding rocket launched are conducted periodically from Thumba, a place near southern tip of India very close to the Earth magnetic equator. The rocket based experiments provided initial opportunities to conduct the scientific investigations of high altitudes upper regions of magnetic equator which was not accessible through balloons and satellites. Presently more than 3500 rocket launches have been carried out successfully by ISRO with national and international participation. The TERLS Range is dedicated to the United Nations since 1968 and all member countries of the UN are welcome to use this facility for various scientific research. Presently RH-200, RH-300 Mk-II and RH-560-Mk-III sounding rockets are operational with payload capacity ranging from 8 to 100 kg and apogee range of 80 to 475 km. Since then, the ISRO has developed the technologies for various launch vehicles, satellites and payloads and the Indian Space programme has grown from humble beginnings to achieve our vision of utilization of space for societal development. The seeds sown more than six decades ago have fructified to yield indigenous capabilities to achieve independent access to space along with a plethora of space-based services which are transforming India. The space science and exploration missions undertaken during the next level of growth of the space programme such as the Chandrayaan-1, Mars Orbiter Mission, Astrosat and Chandrayaan-2 missions are yielding valuable scientific data and are contributing to the global knowledge base of the cosmos. ISRO is also planning a human space flight mission in low earth orbit in near future which will open opportunities for microgravity experiments for various cutting edge scientific investigations.

1.2 ORGANISATION OF SPACE RESEARCH

INDIAN NATIONAL COMMITTEE FOR SPACE RESEARCH (INCOSPAR)

Indian National Committee for Space Research (INCOSPAR) is one of the committees of the Indian National Science Academy (INSA), which is the national adhering organisation to the International Council of Scientific Unions (ICSU), and a member of ICSU Council. Presently Dr. Anil Bhardwaj is the Chairman of INCOSPAR and Dr. K Rajeev is the national representatives at COSPAR Council. INCOSPAR has the following terms of references.

I. To recommend and promote national activities and international co-operation in space exploration and space research.

II. To provide necessary liaison with the COSPAR of ICSU, and encourage participation in international activities which contribute to the peaceful uses of outer space.

1.3 SPACE COMMISSION, DEPARTMENT OF SPACE AND INDIAN SPACE RESEARCH ORGANISATION

The Space Commission and the Department of Space (DOS) were established by the Government of India in 1972 to promote development and application of space science and technology for identified national socio-economic objectives. The Space Commission lays down the framework of important space activities and advises the Government on major policies related to India's space programme. DOS functions directly under the Prime Minister of India. Shri S. Somanath is the present Chairman of the Space Commission, Secretary to the Government of India in DOS and Chairman of the Indian Space Research Organisation (ISRO).

The Indian Space Programme is directed towards the goal of self-reliant use of space science and technology for national development, its main thrusts being:

I. Satellite telecommunications, navigation, television and radio broadcasting

II. Satellite remote sensing for resource survey and management, environmental monitoring and meteorological services.

III. Development and operationalization of indigenous satellites and launch vehicles for providing these services.

DOS is responsible for carrying out space research and related activities in the country through ISRO's constituent units and major autonomous institutions. DOS is also the nodal department for implementation of the on-going National Natural Resources Management System (NNRMS). The Organisation chart for Department of Space, ISRO and its major establishments are shown in Figure.1

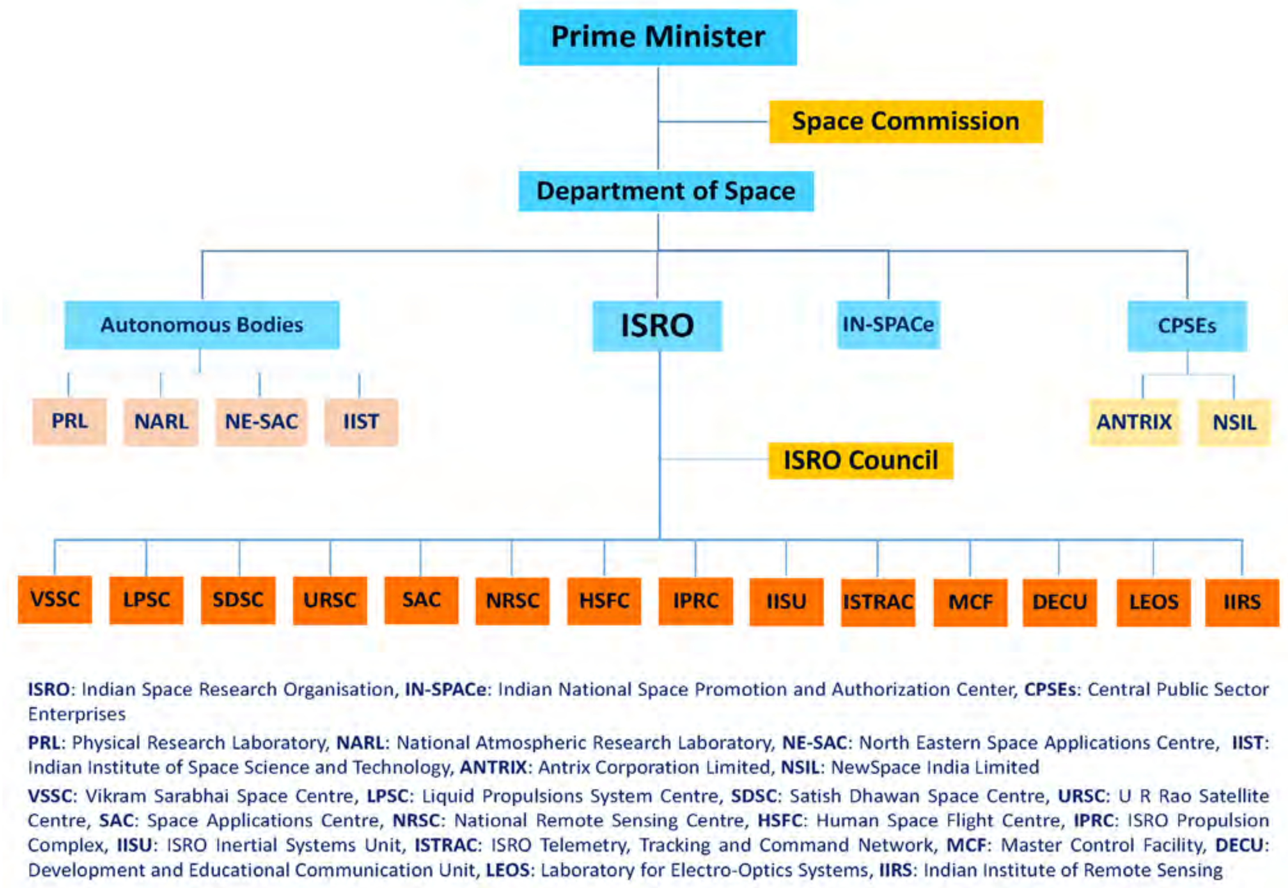

Figure 1: Organisation chart of DOS/ISRO

Starting from the sounding rocket experiments in early 1960's, Indian space science program has grown to more complex astronomy and planetary missions. Figure 2 shows the six decades of the Indian space science missions at a glance.

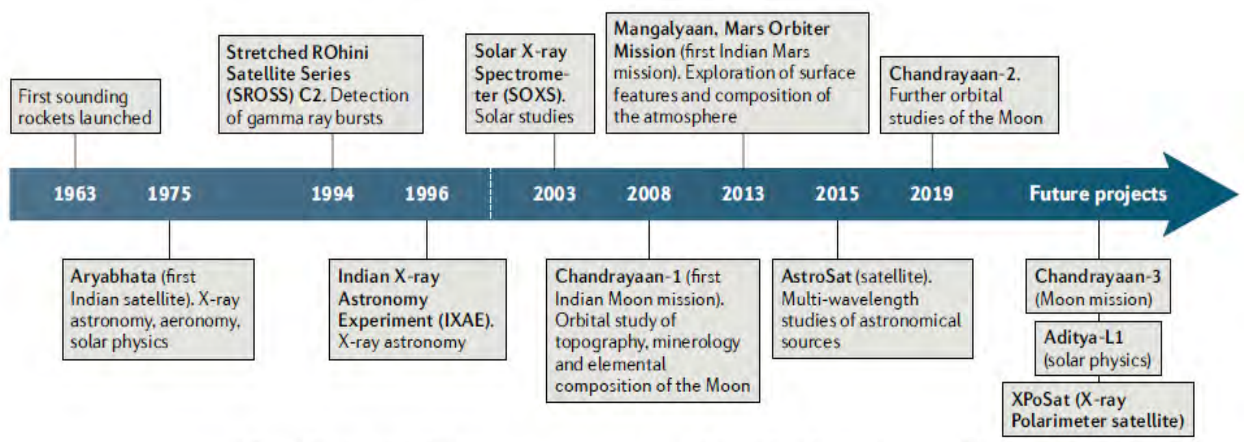

Figure 2: The timeline shows the milestones of the six decades of Indian Space Science Mission. Courtesy: Nature Review Physics, Das et. al., Nat. Rev. Phy. 3, 722-723 (2021).

The major space science missions of India are briefly mentioned below:

1.4 Achievements in Space Science Program

MARS ORBITER MISSION

Mars Orbiter Mission, the maiden interplanetary mission of ISRO, launched on November 5, 2013, completed seven years in Martian orbit as on 24th Sep, 2021 and is well beyond its designed mission life of six months. MOM data are made available at ISSDC website (https://mrbowse.issdc.gov.in/MOMLTA) to registered users.

Highlights of Science Results

- Enhanced escape of Martian atmosphere during global dust storm (for further details, see the inputs in this report as provided by National Atmospheric Research Laboratory, Gadanki)
- The solar coronal dynamics during the post-maxima phase of the solar cycle 24 using *S* -band radio signals from the MOM (For more details, see the inputs provided in this report by Space Physics Laboratory, Thiruvananthapuram)

1.5 ASTROSAT

AstroSat is India's first dedicated Space Astronomy Observatory launched into a 650-km, 6° inclination orbit on September 28, 2015, with a lift-off mass of 1515 kg, by PSLV-C30 (XL) rocket from Satish Dhawan Space Centre Sriharikota. AstroSat carries a total of five scientific payloads enabling imaging, studying temporal and spectral properties of galactic and extra-galactic cosmic sources in a wide range of wavelengths on a common platform.

The unique feature of this observatory is its capability for carrying out broad band simultaneous multi-wavelength observation going from far ultra violet to gamma rays. UVIT has the highest angular resolution of 1.5 arc sec which is 3 times better than the next best UV telescope (GALEX-Galaxy evolution explorer) operational today. LAXPC has the highest collecting area in comparison to any other X-ray detector till today. CZTI possesses a unique capability of measuring X-ray polarization and also acts as an open detector beyond 100 keV.

Some significant outcomes from the research in the various fields of Astronomy and Astrophysics are being carried out at ISRO enabled Indian academic institutions, Tata Institute of Fundamental Research (TIFR) Mumbai, Indian Institute of Astrophysics (IIA) Bengaluru, Inter University Centre for Astronomy & Astrophysics (IUCAA) Pune and Physical Research Laboratory (PRL) Ahmedabad.

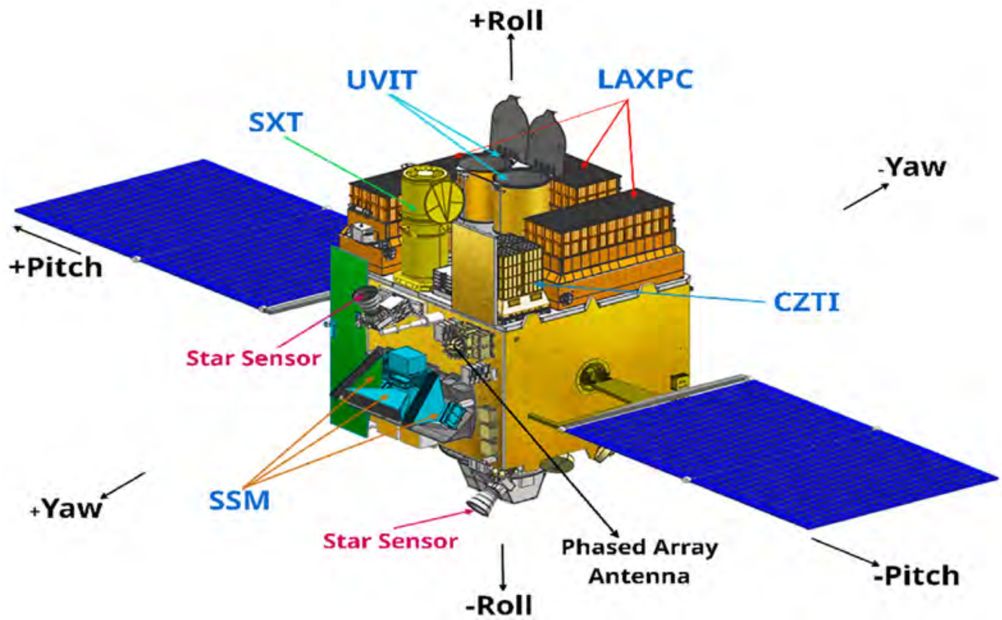

Figure 3: Image showing AstroSat spacecraft with various payloads.

AstroSat spacecraft has the following five payloads:

I. Ultra Violet Imaging Telescope (UVIT), developed by IIA, consist of two identical telescopes of aperture 380 mm. One telescope covers FUV (130–180 nm) band and the other covers NUV (200–300 nm) and visible band (320–550 nm). The hyperbolic mirrors are super polished.

II. Large Area X-ray Proportional Counter (LAXPC), developed by TIFR has three identical gas detectors. LAXPC has a total effective area of 8000 cm^2.

III. Cadmium–Zinc–Telluride Imager (CZTI), developed by TIFR works in 20–100 keV. The imaging capability is achieved with coded mask. CZTI also has the capability of making X-ray polarization measurements.

IV. Soft X-ray Telescope (SXT), developed by TIFR, uses X-ray reflecting mirrors and an X-ray CCD for imaging and spectral studies in 0.3–8 keV.

V. Scanning Sky Monitor (SSM) developed by ISRO is an all sky monitor for detecting and monitoring transient sources and for follow-up studies of known X-ray sources in 2.5–10 keV region.

AstroSat is operated as a proposal based observatory. The proposals for AstroSat data are solicited through anouncement of regular opportunity. The received proposals are reviewed by AstroSat Time Allocation Committee (ATAC) and AstroSat Target of Opportunity (TOO) supported by AstroSat Technical Committee (ATC).

Mission operations centre at ISTRAC Bengaluru manages the task of operating AstroSat, as celestial objects space observatory in a low inclination Earth orbit and provides all scientific data to user community through International Space Science Data Centre (ISSDC).

The task of optimising the spacecraft operations to enable maximum availability of observing instruments to seekers of observation is handled through mission operations team.

- o AstroSat operations consist of complex and elaborate procedures. The spacecraft is oriented to a celestial source meeting several safety and operational constraints. While pointing and shifting from one target to another avoiding Sun in field of view of sensors. Scheduling also considers other constraints like eclipse, south Atlantic anomaly (SAA), occultation, earth limb brightness to name a few. Several corrections are carried out on regular basis for attitude, on-board timer drift, gyro drift, orbit co-efficients, SAA Entry/ Exit. The spacecraft data is downloaded and the data from the five science payloads then sent to respective payload operation centre for validation and subsequently data is archived and made available to users.

  As of April 2022, AstroSat has produced 256 peer reviewed articles in national/ international refereed journals. In addition, AstroSat data has contributed to 15 theses and more than 750 conference proceedings, GCN circulars and Astronomer's telegrams. AstroSat serves 1500+ registered users from 49 countries.

Some of the major interesting discoveries from AstroSat are mentioned below:

i) "India's ASTROSAT makes rare discovery", is an exceptional and a welcome headline in the history of Indian media for the importance given in recent times to Science, particularly space science shared from PTI PUNE, on August 25, 2020. This is the first detection of a FUV photons from Lyman Alpha emitting galaxy AUDFs01 at a distance of 9.3 billion light years (redshift z=1.42). This observation is made possible due to the high sensitivity and low background of the UVIT detectors combined with the long exposure time. The importance is well recognised in the international community which has led to a growing list of scientists from all over the world joining the AstroSat Ultraviolet Deep Field project, as well as initiating a number of new collaborative projects, including the AMUSEDLy (AstroSat-MUSE Detection of Lyman continuum sources) project with the European Southern Observatory.

ii) Deep survey of M31 galaxy, popularly known as Andromeda galaxy with UVIT led to the first detection of young main-sequence stars in the bulge of M31 outside the nucleus. This survey has produced UVIT point source catalogue of 75,000+ sources in NUV/FUV.

iii) For the first time, CZTI discovered X-ray polarization from the off-pulse region of Crab pulsar. CZTI has also detected polarised prompt emission from gamma ray bursts (GRB) in about 20% of CZTI observed GRBs. The results indicate that in a fraction of cases the magnetic field in the emitting region is strongly ordered while in the rest the field is randomly distributed. These results have spawned multiple theoretical investigations worldwide in the radiative properties of GRBs and the planning of space missions dedicated to the polarimetry of GRBs.

iv) AstroSat detection and characterisation of star formation in and around Jellyfish galaxies: These galaxies are members of galaxy clusters. AstroSat UVIT observations find that new stars are being formed in the outflowing gas streams, away from the confines of the galaxies themselves. This is providing major new clues to the gas-gas interaction in galaxy clusters and the formation process of stars. Given the importance of these observations, AstroSat UVIT has been integrated into the multi-nation GASP (Gas stripping phenomena in galaxies) programme.

v) AstroSat UV/X-ray observations of OJ287 shows the importance of simultaneous broad-band observations as the FUV data from UVIT leads to strong constraints on the contribution of synchrotron component in driving the X-ray spectral changes observed in OJ287 over multiple epochs.

vi) LAXPC and SXT observations of 4U 1630-17 found that the blackhole in the binary is rotating at a speed close to the maximum possible speed of spin.

1.6 INDIAN LUNAR PROGRAM

Indian lunar program began when ISRO launched its first mission to the Moon, Chandrayaan-1 in 2008. The mission had demonstrated successful insertion into the lunar orbit and discovered the presence of water and other volatiles. The mission carried eleven payloads from India and

Major science results of Chandrayaan-1 are as follows:

- The Moon Mineralogy Mapper (M3) instrument discovered evidence of widespread surface water. This was further substantiated at the polar regions with the Mini-SAR experiment, showing evidence for sub-surface water. Mass spectrometer onboard Moon Impact Probe (MIP) showed evidence of water molecules in the lunar exosphere during its descent from 100km orbit.
- The SARA experiment provided new evidence for the presence of mini-magnetospheres by mapping energetic neutral atoms. It also revealed that solar wind protons are reflected from the lunar surface as neutral hydrogen atoms, thus providing a new dimension to solar wind – lunar surface interactions.
- Combined analysis of M3, HySI and TMC found large expanses of crystalline feldspar which validated the Lunar magma ocean hypothesis.
- Strong evidence for enhanced Na in the plagioclase of the highlands – first direct measurement of Sodium by C1XS.
- Digital Elevation Models of many craters of interest and detailed maps of lunar surface features including the potential site (buried lava tube) for future human habitability on the Moon.

Chandrayaan-2 mission was launched on 22nd July 2019 and inserted into the lunar orbit on 20th August 2019. As a followup mission to Chandrayaan-1, Chandrayaan-2 encompasses three major mission components of an Orbiter, Lander and rover. While some of the experiments on board this mission continue earlier surface and sub-surface mapping investigations providing continuity to investigations, some of the International payloads of Chandrayaan-1 have been improved and indigenised as Indian payloads on this mission. Though the soft-landing attempt of lander/ rover was not successful, the orbiter was successfully placed in the 100km lunar orbit.

Unique capabilities of Chandrayaan-2 payloads are:

- Highest resolution optical images ever (25 cm) from a lunar orbiter platform.
- First full polarimetric measurements of permanently shadowed regions.
- Largest surface composition study of Moon using X rays – elemental maps.
- High resolution DEM of the lunar surface.
- Day-night variations of Argon and other neutrals in the lunar exosphere.
- Geotail wake studies at the Moon – particle spectrum and flux.
- Mapping minerals in 0.8 to 5.0 micron with a focus on extracting clear signature of surface presence of water-ice.
- Sustained study of lunar environment using radio occultation studies.

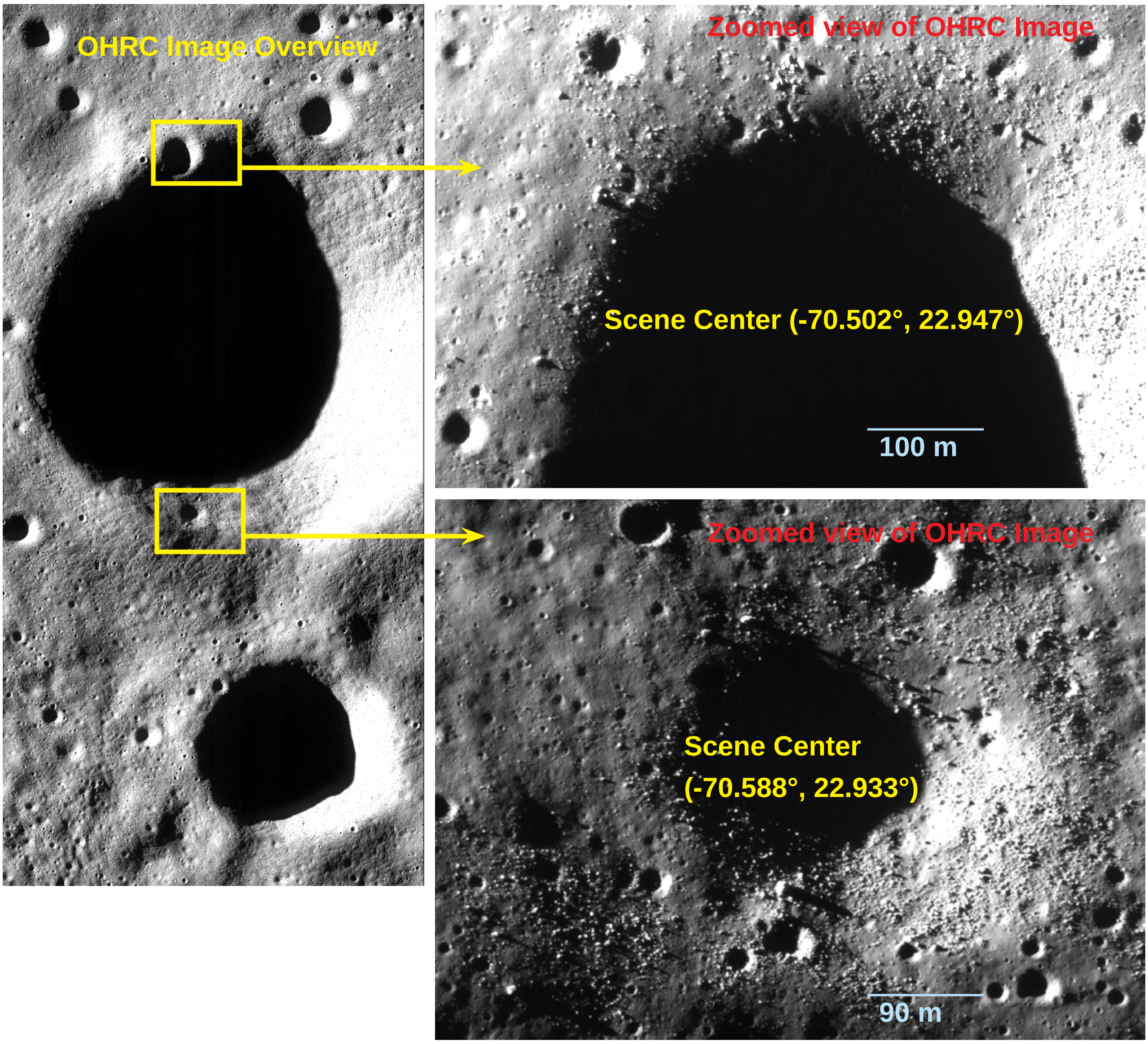

Figure 4: OHRC image covering the region between Manzinus C and Simpelius N acquired on 02nd March 2020

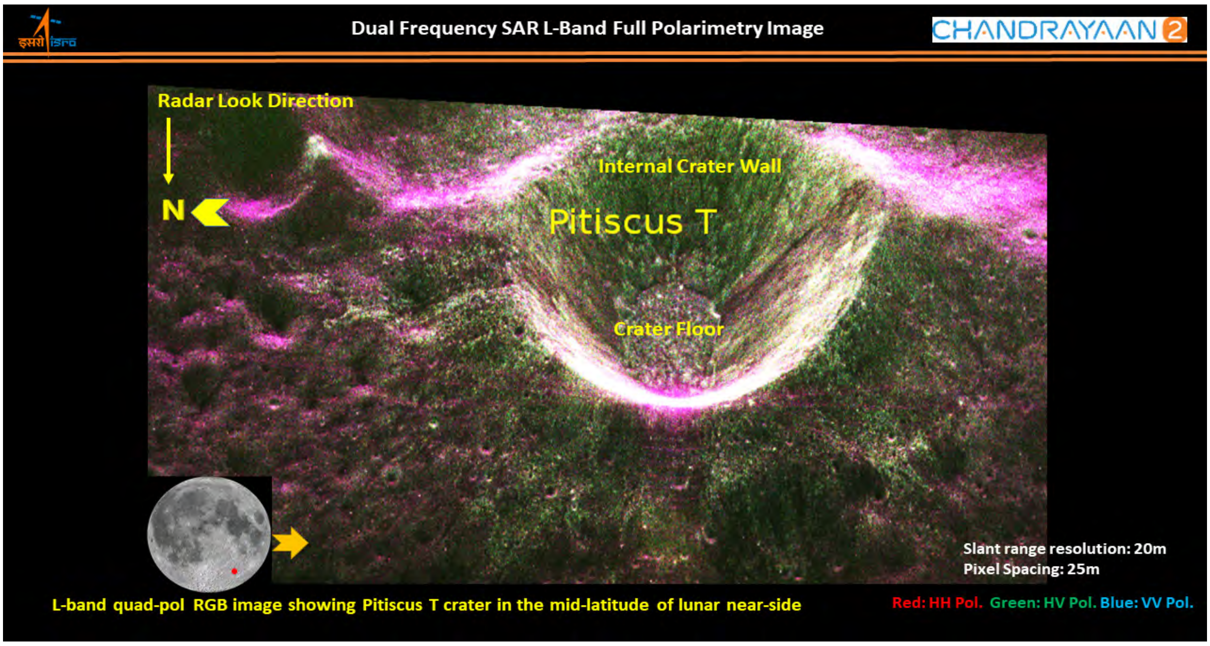

Figure 5: DFSAR L-band image showing Pitiscus T crater

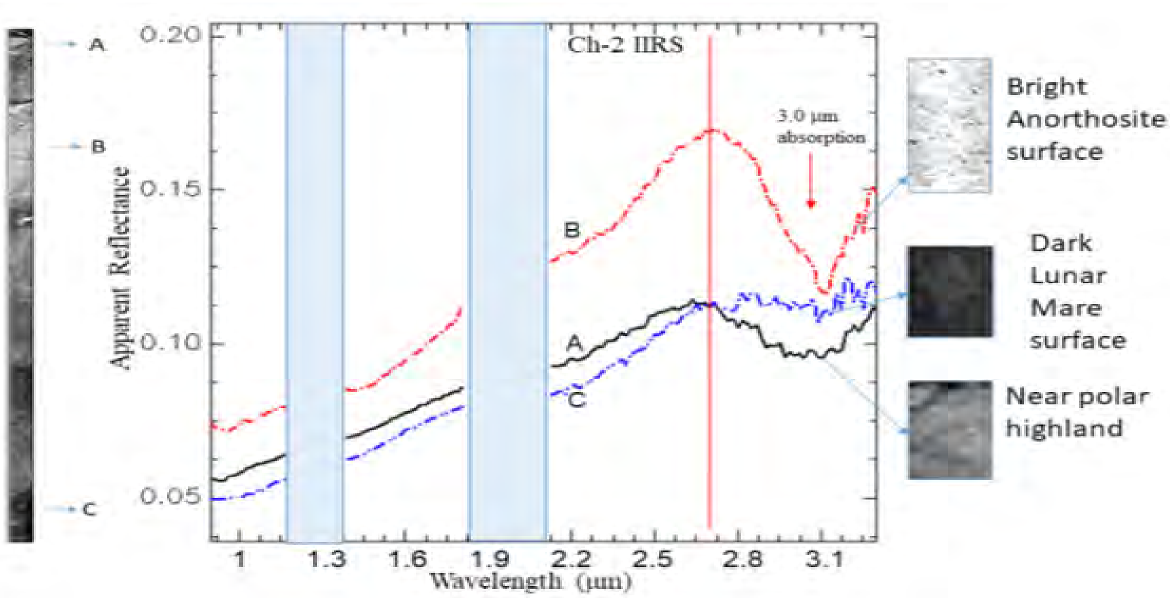

Figure 6: Lunar hydration absorption feature at 3 μm from IIRS data

Chandrayaan-2 Orbiter is continuing observations on the Moon with its eight science payloads. It has completed nearly three years in orbit and health of the spacecraft and payloads are normal. Mission maneuvers were carried out during Total lunar eclipse durations and a Collision avoidance maneuver was performed during October 2021 to mitigate Chandrayaan-2 and NASA's Lunar Reconnaissance Orbiter (LRO) conjunction.

Science results from Chandrayaan-2 payloads were documented and released to public on the occasion of two-year completion of the mission. The document is available in ISRO website (https://www.isro.gov.in/files/scienceresultsfromch-2pdf).

Chandrayaan-3 is the third Indian mission to the Moon to demonstrate safe and soft landing on the lunar surface. The configuration consists of Propulsion Module and a Lander module with Rover accommodated inside the Lander.

The propulsion module will carry the lander till lunar orbit insertion and deployment of lander. After that, the module will be utilised for science payload operations. The lander will land in the southern high latitudes on the Moon. The rover will roll out of the Lander and carryout in-situ observations.

The science payloads, which are similar to Chandrayaan-2 Lander and Rover payloads aim at studying the seismicity, thermal conductivity, plasma environment and the elemental composition in the vicinity of landing site. The propulsion module is configured to carry a science payload to observe Earth from the lunar orbit.

ISRO and JAXA are conducting a feasibility study for a joint lunar polar exploration. The aim of the mission is to characterise volatiles in the lunar south pole with suite of instruments on Rover.

1.7 ADITYA-L1 MISSION

Aditya-L1 shall be the first space based Indian mission to study the Sun. The spacecraft shall be placed in a halo orbit around the Lagrangian point 1 (L1) of the Sun-Earth system. A satellite placed in the halo orbit around the L1 point has the major advantage of continuously viewing the Sun without any occultation/eclipses. This will provide a greater advantage of observing the solar activities and its effect on space weather. The spacecraft carries seven payloads to observe the photosphere, chromosphere and the outermost layers of the Sun (the corona) using electromagnetic and particle detectors. Using the special vantage point of L1, four payloads directly view the Sun and the remaining three payloads carry out in-situ studies of particles and fields at the Lagrange point L1, thus providing important scientific studies of the propagatory effect of solar dynamics in the interplanetary medium.

The suits of Aditya-L1 payloads are expected to provide most crucial informations to understand the problems of coronal heating, coronal mass ejection, pre-flare and flare activities and their characteristics, dynamics of space weather, propagation of particle and fields etc. The payloads are at various stages of development.

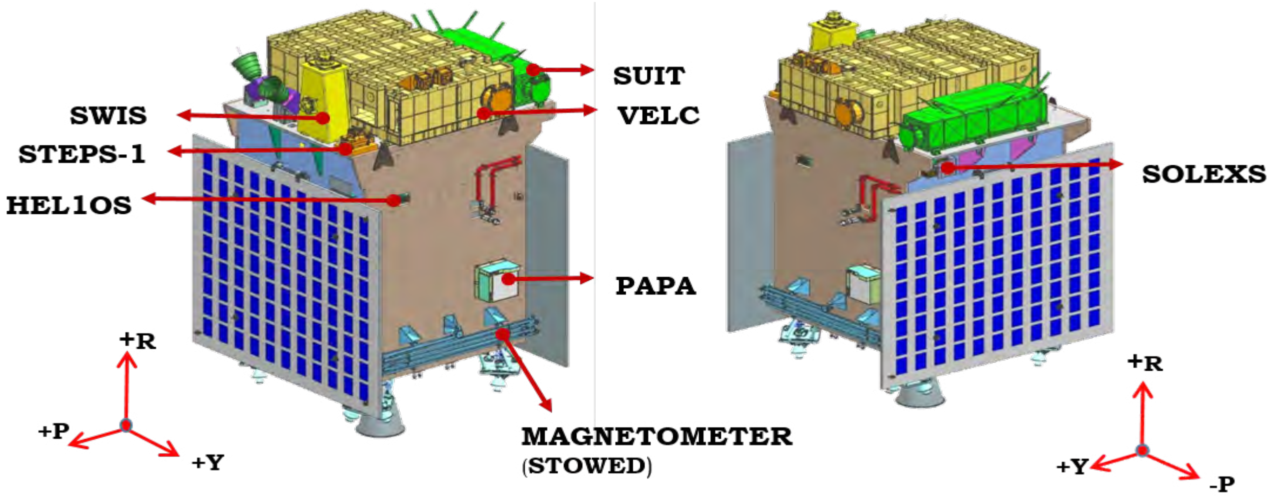

Figure 7: Aditya-L1 Payloads: Stowed view of satellite

1.8 X-RAY POLARIMETER SATELLITE (XPOSAT)

XPoSat (X-ray Polarimeter Satellite) is India's first dedicated polarimetry mission to study various dynamics of astronomical sources in extreme conditions. The spacecraft will carry two scientific payloads in a low earth orbit. The primary payload POLIX (Polarimeter Instrument in X-rays) will measure the polarimetry parameters (degree and angle of polarization) in medium X-ray energy of 8-30 keV photons of astronomical origin. The XSPECT (X-ray Spectroscopy and Timing) payload will give spectroscopic information in the energy range of 0.8-15 keV. Both these payloads are at various stages of development.

1.9 SPACE SCIENCE RELATED ACTIVITIES/ PROMOTION SCHEMES AND PROGRAMMES

SPACE SCIENCE ACTIVITIES:

Space Science research activities rocket and satellite experiments, multi-agency sponsored projects are all co-ordinated from ISRO HQ. The APEX Science Board of ISRO represented by scientists of the country and chaired by former ISRO chairman, Shri A.S. Kiran Kumar, recommends the conduct of various space science research activities and advises ISRO on the long term planning and promotion of space science research in the country. The detailed co-ordination and implementation of the space science programmes are carried out through the Science Programme Office (SPO) at ISRO HQ.

1.10 INDIAN SPACE SCIENCE DATA CENTER (ISSDC)

The Indian Space Science Data Centre (ISSDC) is the state-of-the-art facility for hosting the data received from all space science missions of ISRO. Established ahead of the Chandrayaan-1 mission in 2008, ISSDC is known for its high-end servers and processing capabilities with enterprise-class data storage. ISSDC architecture is capable of supporting multiple missions in an automated and uninterrupted manner. This data centre, located at the Indian Deep Space Network (IDSN) campus in Bengaluru, is responsible for the Ingest, Processing, Archive and Dissemination of the payload data and related ancillary data for Space Science missions. The primary users of this facility are the principal investigators of the science payloads. In addition to them, the data is made accessible to scientists from other institutions and also to the general public through registration, after the lock-in period.

Besides supporting real time operations of Chandrayaan-2, Mega-Tropiques, Mars Orbiter Mission (MOM), SARAL, AIS-SB/Resourcesat-2 & AstroSat, ISSDC has supported post mission life activities for Chandrayaan-1 and Youthsat. ISSDC is supporting India's next major Lunar Mission Chandrayaan-3, maiden solar mission Aditya-L1 and astronomical mission XPoSat.

1.11 ISRO Science Data Archive (ISDA)

ISRO Science Data Archive (ISDA) is the central repository for all scientific and engineering data acquired by different ISRO's planetary missions. ISDA makes the planetary data sets accessible to the world-wide scientific community.

ISDA was established at Indian Space Science Data Centre (ISSDC) Bengaluru (http://issdc.gov.in) during Chandrayaan-1 mission in 2008. ISDA archives data sets from following missions:

- Chandrayaan-1
- Mars Orbiter Mission
- AstroSat
- Chandrayaan-2
- Upcoming missions: Aditya-L1, XPoSat

All ISDA data are compliant with NASA's Planetary Data System (PDS) Standards for formatting and labelling files, including requirements for documentation and the structuring of data sets. ISDA provides an opportunity for international collaboration of space agencies with a mission of providing access to scientific data like other international science data centres. Chandrayaan-2 mission is the first planetary mission of ISRO to adopt the PDS4 standards.

1.12 SPACE SCIENCE SCHEMES AND PROGRAMMES

RESPOND, the Sponsored Research Programme of ISRO supports basic research and developmental projects in the focussed areas of Space Science, Space Technology and Space Applications which have linkages with the Indian Space Programme. The primary objective of the RESPOND Programme is to establish strong links with academic institutions in the country to carry out research and developmental projects which are of relevance to space programme and also to develop quality scientific / technical human resources.

ISRO has also set up Nine Space Technology Cells (STC) at premier institutions in the country like Indian Institute of Technologies (IITs) - Bombay, Kanpur, Kharagpur, Madras, Delhi, Guwahati & Roorkee; Indian Institute of Science (IISc), Bengaluru, Savitribai Phule Pune University (SPPU, Pune) to carry out advanced research in the areas of relevance to the future technological and programmatic needs of ISRO.

Also, under the Capacity Building Programme Initiatives, ISRO has set up six Regional Academic Centre for Space (RAC-S) at six geographic regions of the country. These centres are located at MNIT, Jaipur (Western region), Gauhati University, Guwahati (North-Eastern Region), NIT Kurukshetra (Northern Region), NITK Surathkal (Southern Region), IIT (BHU) Varanasi (Central Region) and NIT Patna (Eastern Region). RAC-S aims to pursue advanced research in the areas of relevance to the future technological and programmatic needs of the Indian Space Programme and act as a facilitator for the promotion of space technology activities among students in the region. This will also inculcate scientific temper in the student community and will give them an opportunity to work in the advanced field of research. RAC-S will also facilitate and engage other institutes of excellence in the region to take part in the capacity building, awareness creation and research & development activities.

In addition, to attract and nurture the young academia with innovative ideas / research aptitude for carrying out research and developing the Academia–Industry ecosystem for Space Technology, ISRO has set up of Six Space Technology Incubation Centre (S-TIC) in 6 regions of our Country at NIT Bhopal (Central), East, NIT Jalandhar (North), NIT Agartala (North-East), NIT Trichy (South) and NIT Nagpur (West). This will enable the young academia to realize their innovative ideas / research aptitude into space grade components/elements which can be utilized for space applications, and guide them towards setting-up the future start-ups.

In line with ongoing efforts to promote R& D in space technology through industry as well as academia, ISRO in collaboration with Veer Surendra Sai University of Technology (VSSUT), Burla, Sambalpur, Odisha has set up Veer Surendra Sai Space Innovation Centre (VSSSIC) within its campus at Sambalpur. The objective of this Space Innovation Research lab is to promote and encourage the students in research and development in the domain of Space Science and Technology at VSSUT and other institutes within the region.

Apart from this, the joint R & D activities have been taken up with the Centre for Nano Science and Engineering (CeNSE) at IISc caters to the requirements of ISRO in the areas of nanotechnology and nanoscience. The Centre is providing support for the R & D activities, utilization of nanofabrication and characterization facilities by the various centres of ISRO, in addition to training/capacity building.

Further, in order to enhance greater participation and contributions from academia in addition to the ongoing Respond activities, a Centre of Excellence (CoE) on Advanced Mechanics of Materials" has been set up at IISc, Bengaluru. The Centre aims at pursuing advanced research in the areas of materials especially non classical continuum mechanics and Geometric and data driven models for space applications.

In addition to this, Satish Dhawan Centre for Space Science has been set up at Central University of Jammu, Jammu to cater to the emerging Geospatial and Space technology requirements for the development of the region. The proposed centre could be considered as an extension activity of ISRO relevant to that region, managed and maintained by Central University of Jammu.

During this period (July, 2020 to Dec,2021) RESPOND has supported 141 projects from 82 Universities/colleges/National Institutes/research centres and 48 projects sponsored earlier have been successfully completed. Apart from this, under Space Technology Cell activities, 343 projects have been supported and 111 projects have been successfully completed. Under Space Technology Incubation Centre (S-TIC), 34 projects have been supported. A number of high quality scientific publications have emerged out of these projects apart from fulfilling the objectives at project level. ISRO has also supported 7 Scientific activities, which included conferences, symposia, workshops, educational and promotional activities in Space Science, application and technology areas having relevance to the Indian Space Programme.

CHAPTER-2

SPACE PHYSICS LABORATORY, VIKRAM SARABHAI SPACE CENTRE

Thiruvananthapuram

2.1 About the Laboratory

The Space Physics Laboratory (SPL) is a premier national laboratory of VSSC/ISRO focusing on atmospheric, space and planetary science research. It aims at improving the scientific understanding on the energetics, dynamics and chemistry of the terrestrial and planetary environments and its implications to the society. The genesis of SPL is closely entwined with the evolution of space sciences and space research in India and dates back to more than five decades. In 1963, Dr. Vikram Sarabhai, with the support of Dr. Homi J Bhabha, established the Thumba Equatorial Rocket Launching Station (TERLS) over the magnetic dip equator, in which SPL made a humble beginning as Space Physics Division (SPD) in 1968 to study the unique equatorial upper atmospheric phenomena. In 1984, the SPD has been elevated to SPL with the mandate to carry out advanced research in atmospheric, space and planetary sciences. Since then, SPL has traveled a long way expanding its horizon and has attained the status of a vibrant academic institution of international repute having front ranking research areas and problems covering the whole gamut of atmospheric, space and planetary sciences. Outstanding results have emerged from various ground- (laboratory and field), balloon-, rocket- and space-borne studies. SPL has a vibrant Research Fellows' Program to support the capacity building. In addition, SPL interacts/ collaborates very closely with the academia and other research institutions in India and abroad for scientific pursuits. SPL has ambitious programs for the years to come, with the extensive support from ISRO.

2.2 Keywords

Microwave and Boundary Layer Physics; Aerosols, Trace gases and Radiative Forcing; Numerical Atmosphere Modelling; Atmospheric Dynamics; Ionosphere Thermosphere Magnetosphere Physics; Planetary Science; Atmosphere Technology.

2.3 Major Research Domains

The major research activities at SPL cover the whole gamut of atmospheric, space and planetary sciences right from the surface of Earth to the ionosphere-magnetosphere and the solar system.

- **Microwave and Boundary Layer Physics (MBLP)** group focuses on the surface characteristics, structure and dynamics of the atmospheric boundary layer (ABL) and its coupling with free troposphere, clouds, convection, precipitation, and microwave remote sensing of the Earth and other planetary bodies. The main objectives are: (i) to improve the understanding of the ABL processes under distinct geographical environments, including surface-air interaction processes, diurnal evolution of ABL, and the role of ABL processes in pollutant dispersal (ii) improve the understanding on clouds, precipitation and energetics of the Earth-atmosphere system, and (iii) space-borne and ground-based microwave remote sensing of Earth's surface and atmosphere for deriving the surface properties, atmospheric water vapour, cloud characteristics and precipitation, including their potential impact on microwave propagation through the atmosphere.

- The scientific research under **Aerosols Trace gases and Radiative Forcing (ATRF)** aims at scientific understanding of the physical/chemical properties of aerosols and trace gases, involving processes that control their three-dimensional atmospheric distribution and interaction with radiation leading to climate changes. The primary objectives are (i) development of spatially and temporally resolved aerosol and trace gas database over the Indian subcontinent, adjoining oceans as well as the Himalayan and Polar environments by combining the space-borne and ground-based observations, (ii) conducting thematic multi-platform (ship, aircraft, and high altitude balloon) field experiments addressing specific problems pertinent to the climate impact of aerosols and trace gases, and (iii) assimilation of the aerosol and trace gas data with regional climate models for the assessment of potential climate impact.
- The **Numerical Atmosphere Modelling (NAM)** addresses the prediction and analysis of the weather and climate systems through a range of atmospheric models including the general circulation models, regional numerical weather prediction and climate models, atmospheric transport models, and large eddy simulations. It also aims to improve model predictions based on the observed atmospheric variations, understanding the mechanisms and physical processes responsible for various observed features, and optimizing the estimation of greenhouse gas fluxes over the Indian region using inverse modeling. Input for the short-range weather predictions for ISRO's launch vehicle missions from Sriharikota is also provided.
- The research on **Atmospheric Dynamics** focuses on atmospheric processes responsible for altering the motion of the Earth's atmosphere including the vertical coupling from troposphere to lower thermosphere. With this broad objective, the research activities are aimed at quantifying the spectrum of atmospheric waves and variabilities from gravity waves to solar cycle using ground-based and balloon- rocket and satellite-based observations. The atmospheric waves are characterized in terms of their source mechanisms, propagation characteristics, role in atmosphere coupling, short and long-term variability and their representation in global models. The research on atmospheric dynamics also focuses on stratosphere-troposphere exchange processes, wave-mean flow and wave-wave interactions as well as ray-tracing of gravity waves propagating into the upper mesosphere based on observations and modelling. The large-scale circulations and their impact on climate are also emerging areas.

- Under **Ionosphere Thermosphere Magnetosphere Physics (ITMP)**, the energetics and dynamics of terrestrial upper atmosphere are investigated, focusing on (a) the response of the magnetosphere thermosphere ionosphere system to varying space weather and geomagnetic conditions and its latitudinal differences, (b) the dynamical coupling thermosphere-ionosphere has with the atmosphere below it, and (c) in-house development and use of thermosphere-ionosphere models to represent the upper atmospheric processes and make use of these studies to provide better input for technological applications. ITMP strives to meet these research objectives through indigenous development of experiments capable of being used on ground, rocket and space-based platforms and extending the scope of its research to the magnetospheres, thermospheres, and ionospheres of other solar system bodies as well.
- As part of **Planetary Science** research, modelling and experimental exploration of the Sun, planets, moons and comets are carried out, mainly focusing on: (a) Solar wind and its interaction with solar system planets and planetary bodies, (b) Interaction of solar radiation with planetary atmospheres and the processes initiated through this interaction, and (c) Dynamics and composition of the atmospheres of planetary bodies. To realize these objectives, research activities are undertaken on the conceptualization, simulations, design and development of state-of-the-art scientific payloads for the measurement of solar wind plasma, interplanetary and planetary magnetic fields as well as the characteristics of plasma and neutrals in the planetary atmospheres.
- The technological aspects of experimental systems designed for atmospheric, space and planetary science areas are executed under **Atmosphere Technology**, which includes the design, development and testing of balloon-, rocket-, and space-borne payloads from the proof-of-concept and development of ground-based systems for in-situ probing and remote sensing of the atmosphere. The activity under Atmosphere Technology is also responsible for the augmentation and maintenance of the ongoing experimental systems, providing technical support to the scientific activities of SPL. It works in close coordination with the scientific requirements of SPL and provides technical expertise for realization of scientific ideas.

2.4 Major Scientific Applications / Results

Direct observations of the multi-year seasonal mean cloud radiative forcing over tropics using Megha-Tropiques-ScaRaB/3

Diurnal variation of cloud radiative forcing (CRF) is a major factor that controls the global radiation balance. In this study, multi-year (2012-2016) seasonal mean diurnal variations of longwave cloud radiative forcing (LWCRF) and daytime shortwave cloud radiative forcing (SWCRF) at the top of atmosphere (TOA) over tropics were derived from the broadband radiation measurements made by ScaRaB/3 onboard the low-inclination Megha-Tropiques satellite. The largest LWCRF (60 to 80 Wm^{-2}) occurs over the oceanic regions of the east equatorial Indian Ocean and the western Pacific during all seasons, as well as the South Pacific Convergence Zone, the northeast Bay of Bengal, Amazon region, central and southern Africa and north Indian landmass (monsoon trough) during the local summer (Fig.1). Diurnal variations of 15 to 25 Wm^{-2} in LWCRF (20–35% of the mean) are observed with peak values occurring at 18–21 local time (LT) over continents and 00–06 LT over oceans. The minimum LWCRF occurs at 09–12 LT throughout the tropics. Over convective regions, SWCRF maximizes at 12–15 LT (− 220 to − 300 Wm^{-2}) and has a higher magnitude over continents due to early convection occurrence, indicating the importance of diurnal phase. The net CRF and its zonal variations are found to be strikingly similar during the normal and El Nino periods because the changes in LWCRF and SWCRF are mutually compensated.

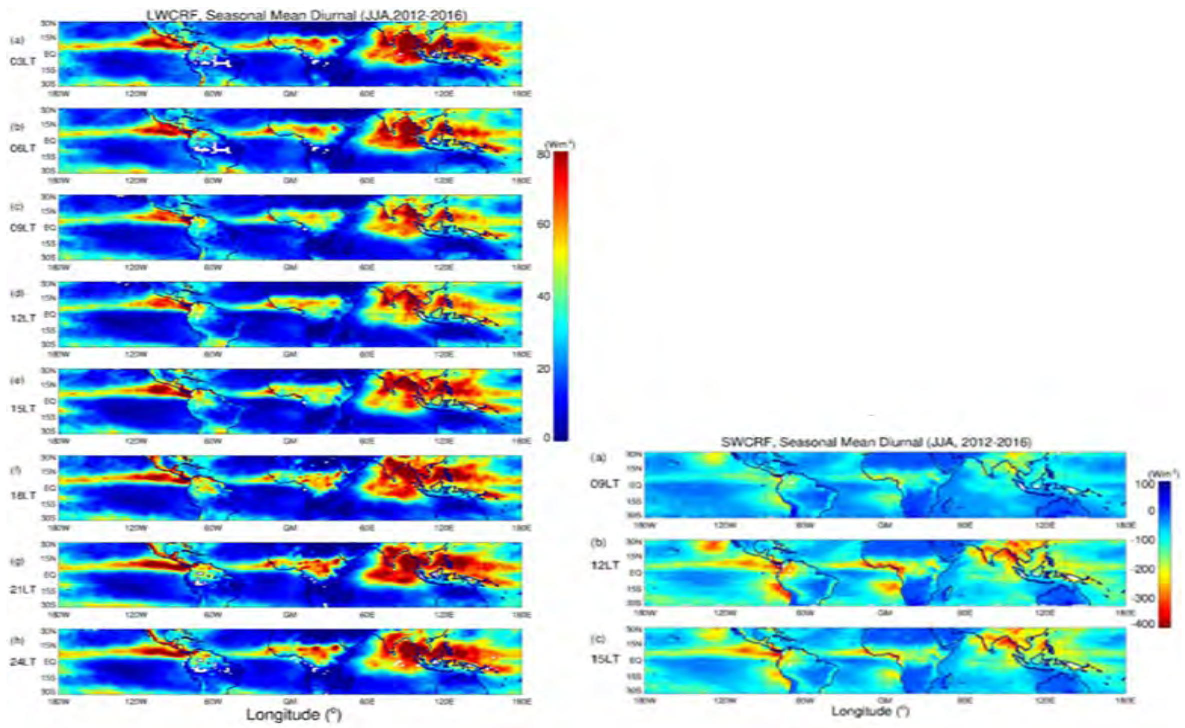

Figure 1 (Top panel): Multi-year (2012-2016) seasonal mean spatial variations of LWCRF (averaged at 3 hourly intervals) at different local times during NH summer (June–August).(Bottom panel): SWCRF averaged at 3 hourly intervals of 0800-1100 LT, 1100-1400 LT, 1400-1700 LTduring NH summer (June–August). [Gupta et al., Climate Dynamics, 2020].

Spatial and Temporal Variations of Tropical Deep Convective Clouds using Megha-Tropiques/SAPHIR Observations

The diurnal, seasonal and inter-annual cycles of Deep convective clouds (DCCs) over the tropics have been estimated using multi-year brightness temperature (TB) data obtained from SAPHIR payload, aboard the Megha-Tropiques (MT) satellite during 2011-2018. MT-SAPHIR provides the measurements at different local times over the entire tropics because of its low inclination orbit, which makes the study of the diurnal cycle of tropical DCCs possible from a single platform. The DCCs have been identified using the difference between TB measured by different channels of SAPHIR payload centred around 183.31 GHz. This methodology provides a unique opportunity to discern convective cores from the anvils. The total occurrence frequencies of DCCs are estimated for Northern Hemisphere (NH) spring (March to May), summer (June to August), autumn (September to November) and winter (December to February) seasons (Fig.2). The occurrence frequency of DCCs ranges from 0 to 4%, with the highest value occurring mostly over the ascending limbs of the Hadley and the Walker cells. Similarly, the lowest occurrence of DCC is over the descending limbs of the Hadley and the Walker cells. From the seasonal mean occurrence frequency maps, regions of large DCC occurrences are identified to study its diurnal evolution for each season (Fig.2).

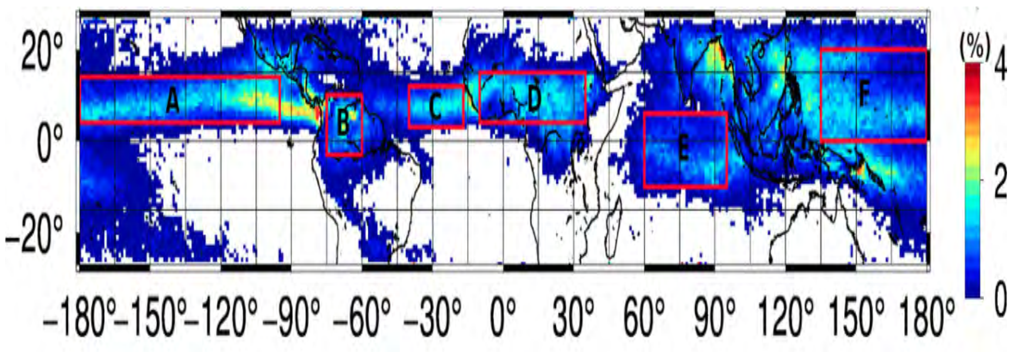

Figure 2: The frequency of occurrence of DCCs during NH summer (June-August). [Sisma et al., Int. J. Rem. Sens., 2021].

Dependence of Convective Atmospheric Boundary Layer Height on Meteorological Variables over Tropical Coastal Region

The atmospheric boundary layer height plays a crucial role in the vertical transport of energy, moisture, and pollutants from the surface. The development of convective atmospheric boundary layer (CABL) height over the tropical coastal region and its variations with the shortwave radiative flux, near-surface air temperature (Tair), soil skin temperature, soil moisture content, lower tropospheric thermal structure, and virtual potential temperature lapse rate (VPLR) during onshore and offshore-flows have been quantified based on multi-year (2012–2017) observations carried out using a microwave radiometer profiler and in situ probes at Thumba (8.5°N, 77°E), located in south-west Peninsular India. This study also shows that the growth of CABL is significantly modulated by the feedback effect of cloud radiative forcing. The maximum CABL height increases linearly with the VPLR at the rate of 140 to 200 m per °C km^{-1} (correlation coefficient of 0.82 to 0.92) during different seasons (Fig.3). When offshore-flow prevails, the CABL develops like the continental CABL, with a peak CABL height greater than that during onshore-flow by about 300 m. Early arrival of the onshore-flow leads to early development of a thermal internal boundary layer with a lower CABL height. Such quantifications for distinct flow conditions are very sparse over tropical coastal regions.

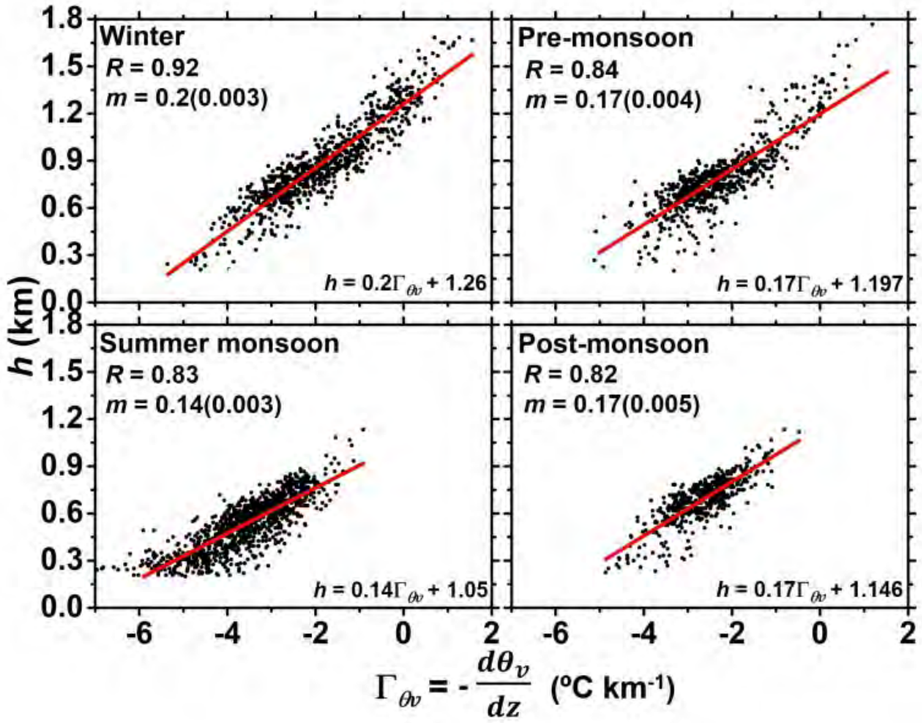

Figure 3. Scatter plots of the variations of CABL height (h) with lapse rate of virtual potential temperature below 500 m ($\Gamma\theta v = -d\theta v/dz$) during 1000–1200 LT for different seasons. The fitted empirical relations are also shown [Davis et al., Boundary-Layer Meteorology, 2021].

Anthropogenic emissions from South Asia reverses the aerosol indirect effect over the northern Indian Ocean

Atmospheric aerosols play an important role in the formation of warm clouds by acting as efficient cloud condensation nuclei (CCN) and their interactions are believed to cool the Earth-Atmosphere system ('first indirect effect or Twomey effect') in a highly uncertain manner compared to the other forcing agents. The present study using long-term (2003–2016) Aqua-MODIS satellite observations over the northern Indian Ocean shows that enhanced aerosol loading due to anthropogenic emissions can reverse the first indirect effect significantly.

In contrast to the Twomey effect, a statistically significant increase in cloud effective radius (CER, μm) is observed with respect to an increase in aerosol loading for clouds having low liquid water path (LWP < 75 g m^{-2}) and drier cloud tops. Probable physical mechanisms for this effect are the intense competition for available water vapour due to higher concentrations of anthropogenic aerosols and entrainment of dry air on cloud tops (Fig.4). For such clouds, cloud water content showed a negative response to cloud droplet number concentrations and the estimated intrinsic radiative effect suggest a warming at the TOA. Although uncertainties exist in quantifying aerosol-cloud interactions (ACI) using satellite observations, the present study indicates the physical existence of anti-Twomey effect over the northern Indian Ocean during south Asian outflow.

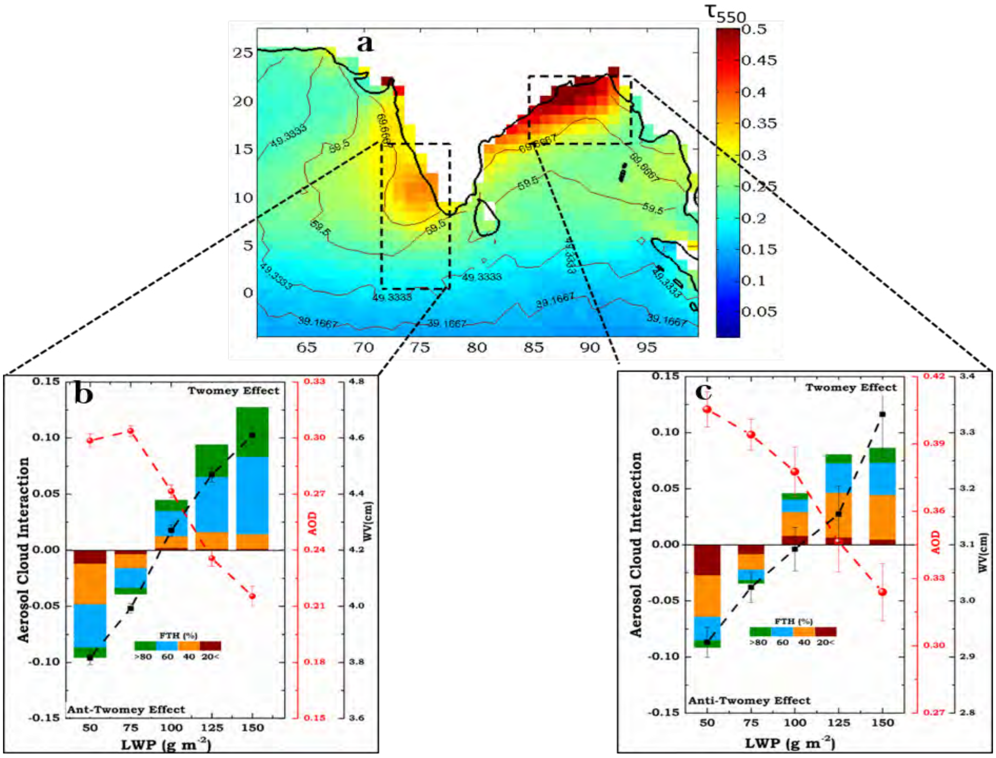

Figure 4: (a) Long-term (2003-2017) aerosol loading (AOD550) over South Asia derived from MODIS sensor onboard Aqua satellite. Contour indicates the anthropogenic fraction to total AOD(%). Rectangular boxes represent the study area SA1 and SA2 respectively. (b and c) Aerosol cloud interaction over SA1 and SA2 respectively for different cloud liquid water path (LWP) bins. Red and black curve represent AOD550 and precipitable water vapour (PWV, cm) corresponding to respective cloud LWP bin used in the estimation of ACI. Colorbars represent the percentage occurrence of free tropospheric humidity (FTH) at 700 hPa [Jose et al., Sci. Rep 2020].

Effect of aerosol-induced snow darkening on the direct radiative effect of aerosols over the Himalayan region

Regional heterogeneity in direct and snow albedo forcing of aerosols over the Himalayan cryosphere was investigated using a regional climate model coupled with the community land model having snow, ice and aerosol radiation module. Deposition of absorbing aerosols like dust (natural) and black carbon (BC) decreases the snow albedo over the Himalayas. Western Himalayas experiences a large reduction in the snow albedo (by 0.037) despite having lower BC mass concentration compared to central (by 0.014) and eastern (by 0.005) Himalayas. The contribution of BC and dust to the snow albedo reduction is comparable over the western and eastern Himalayas. The inclusion of aerosol-induced snow darkening in to the model reduces its bias with respect to the satellite derived surface albedo by 59%, 53% and 35% over western, central and eastern Himalayas respectively during the spring season (Fig. 5). The aerosol-induced decrease in snow albedo causes an early reversal in the sign of aerosol direct radiative forcing at the top of the atmosphere from warming to cooling over the western and central Himalayas, which can have implications in the radiation balance and water security over the region.

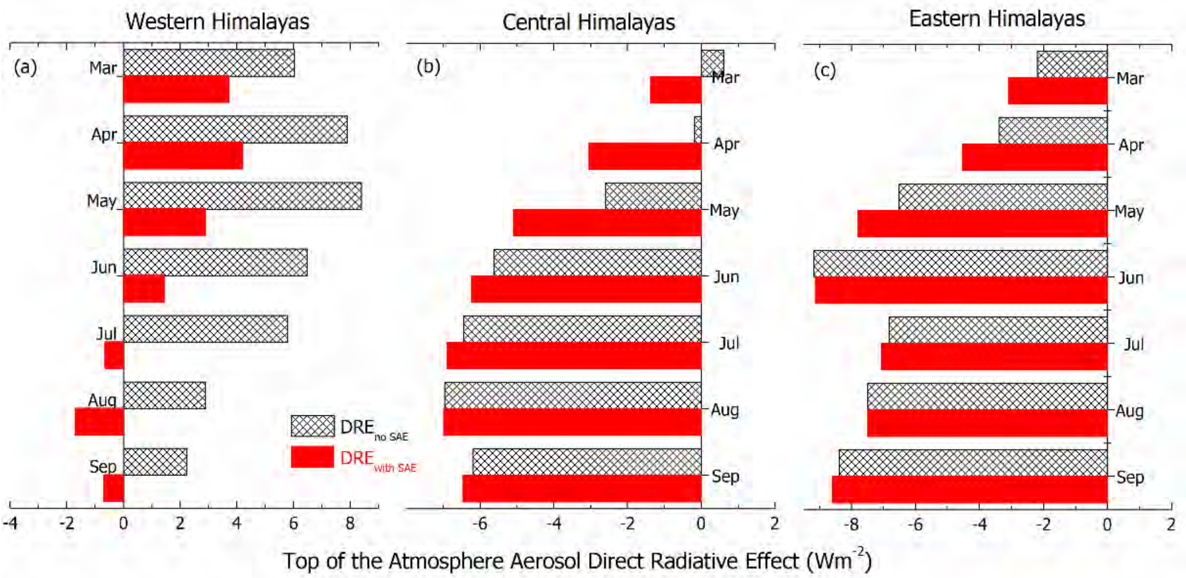

Figure 5: Aerosol direct radiative effects (DRE) at the top of the atmosphere estimated with and without aerosol snow albedo effect (SAE) (DREwith SAE and DREno SAE) for (a) western (b) central and (c) eastern Himalayas [Usha et al., Environ. Res. Lett., 2021].

Mixing State of Refractory Black Carbon Aerosol in the South Asian Outflow over the Northern Indian Ocean during Winter

The first-ever observations of the size distribution and mixing state of individual refractory black carbon particles in the South Asian outflow to South-eastern Arabian Sea (SEAS), northern (NIO) and equatorial Indian Ocean (EIO) regions were conducted using a single particle soot photometer (SP2) on-board the ship cruise of the Integrated Campaign for Aerosols, gases, and Radiation Budget (ICARB-2018) during winter-2018. The spatial variation of BC mass concentrations (Fig.6a) highlighted the transport efficiency of the BC and the widespread nature of the continental outflow. Despite widely varying BC mass concentrations, the mass median diameters (MMD, Fig.6b) were in a narrow range (0.18-0.21 μm) in all the regions. Importantly, the South Asian outflow to the adjacent oceans is characterized by thickly coated BC particles (Fig.6c), highlighting the physicochemical changes in the BC characteristics during its atmospheric aging. The BC particles over the SEAS depicted the highest aerosol coating thickness (ACT ~109 nm) due to the short-range outflow with substantial condensable vapours. The ACT values showed an east-west contrast over the northern Indian Ocean with thicker coatings over NIO-E (ACT~104 nm) than the NIO-W (ACT~86 nm). Further, high values (2.5-15) of the bulk mixing ratio of coating mass to BC mass were noticed in the outflow reflecting the thick coatings on BC (Fig.6d).

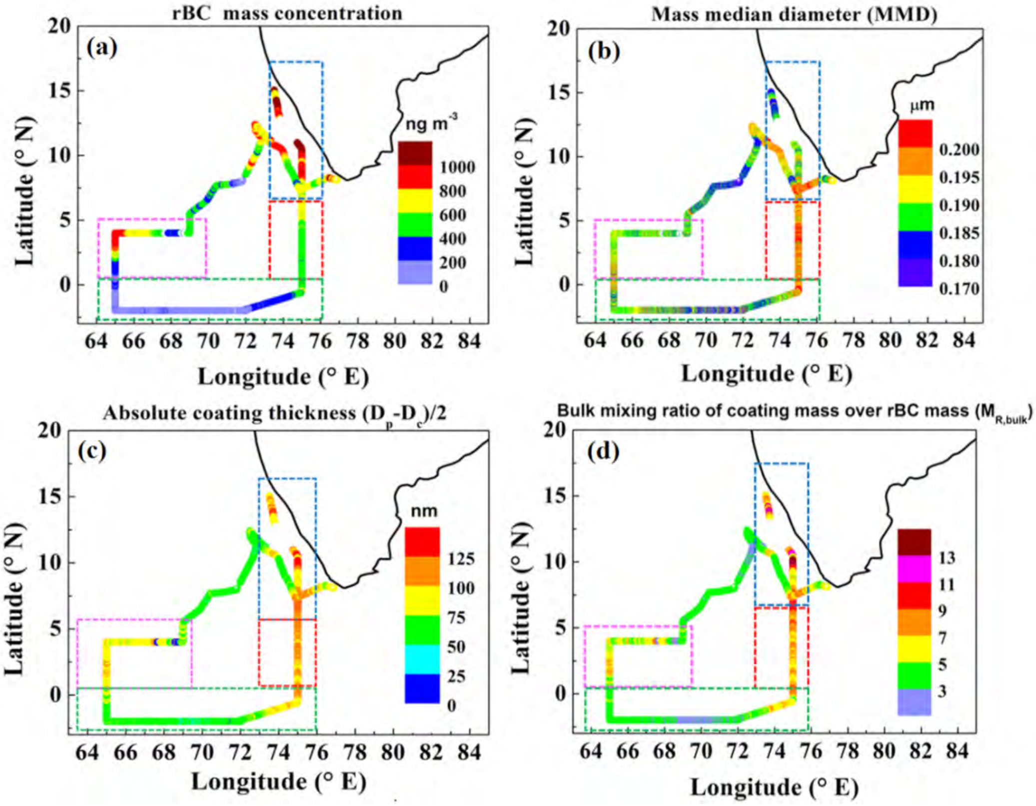

Figure 6: Spatial distribution of (a) refractory black carbon (rBC) mass concentration, (b) mass median diameter (MMD) of rBC core size distributions (c) absolute coating thickness and (d) bulk mixing ratio of coating mass to rBC mass (MR,bulk) during the ICARB-2018. Rectangles with dashed borders highlight different sub-regions [Kompalli et al., Atmos. Chem. Phys., 2021].

Chemical Characteristics of Aerosols from Distinct Environments over the Indian Region: Heterogeneity in Distribution and Sources of Carbonaceous Aerosols

A comprehensive picture of the chemical characteristics of near-surface aerosols (PM 10) from distinct geographic environments over the Indian region is presented with emphasis on carbonaceous aerosols. The regions of study were coastal, inland, coastal industrial, semiarid, coastal oceanic, and deep oceanic. The characteristics of carbonaceous species (organic carbon (OC) and elemental carbon (EC)) in terms of the seasonal variations in their mass concentration in accordance with the changing air-mass patterns, ambient meteorological conditions, and source characteristics were examined in detail. The carbonaceous components exhibited the highest concentration during the winter period over all of the study regions irrespective of the geographic distinctiveness and varied regional meteorology (Fig. 7). The chemical composition of aerosols during the winter period revealed SO_4^{2-} and OC as the major chemical species with SO_4^{2-} dominating over southern peninsular India and oceanic regions, while OC dominated over northern India. Decrease in the mass fraction of OC and increase in SO_4^{2-} were observed in the aerosol chemical composition for air-mass originating from hotspot regions such as the Indo Gangetic Plain and undergoing long-range transport to background downwind sites and oceanic environments. Progressive conversion of SO_2 to SO_4^{2-} under favorable ambient conditions during long-range transport resulted in a higher SO_4^{2-} mass fraction over background sites. The highly water-soluble nature of OC (>70%) was observed as a result of oxidative aging of organics during long-range transport over oceanic regions directly influenced by continental out flow.

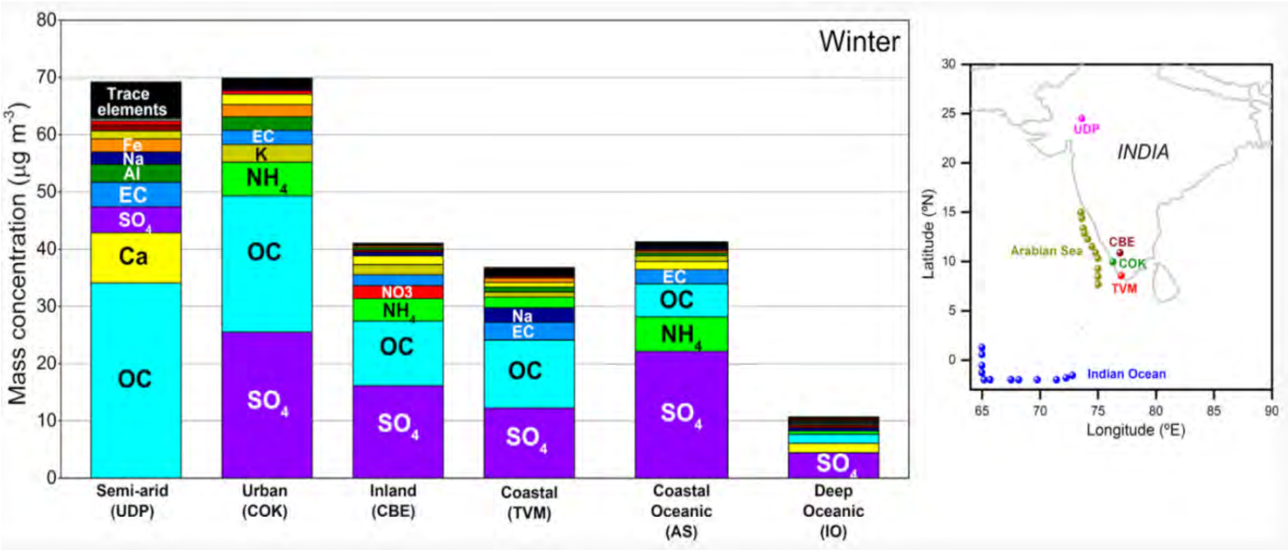

Figure 7. Mass concentrations of various chemical species over different study regions during winter.

Prediction of Tropical Cyclone Trajectories using COSMO Model

The performance of COSMO (Consortium for Small-scale Modelling) model for the prediction of tropical cyclone (TC) trajectories for varying intensities of the storm has been investigated. A total of 8 TCs over the Northern Indian Ocean from 2017 to 2019 are chosen for the evaluation. The initial and lateral boundary conditions for the COSMO model simulations are derived from the analysis and forecast fields of the ICON global model, respectively. A composite picture on the mean variations in the model-simulated trajectory as a function of forecasting lead time (Fig.8) shows a mean track error of about 50 km for the initial position of the storm, which increases to 95 km for a lead time of 24 h and to about 140 km for a lead time of 48 h. The gross features in the temporal variation of PCentral are well reflected in the model simulations. Large variations in the track error (15 – 140 km) are observed during the initial stage of a TC, when the storm is categorized as a deep depression. The track error decreases as the intensity of the storm increases, indicating improved accuracy in the identification of the storm's position when it is well established.

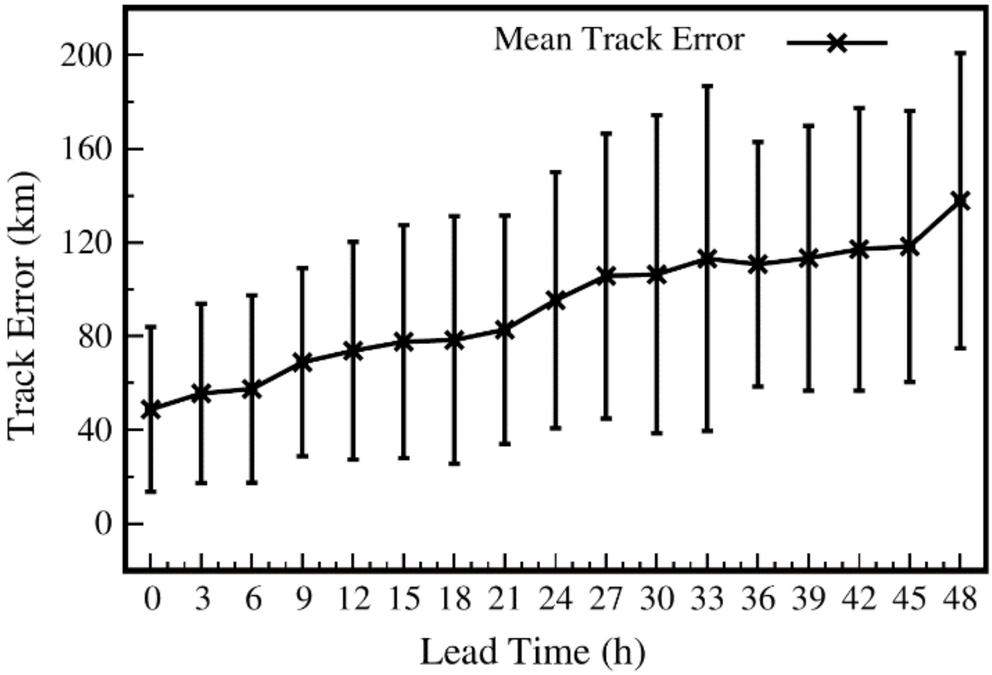

Figure 8: Mean track error in the COSMO model-simulated cyclone trajectories as a function of forecasting lead time. Vertical bars indicate standard deviations (Paul and Subrahamanyam, Meteorol. Atmos. Phys., 2021).

Is Mesospheric Quasi Biennial Oscillation Ephemeral?

The time evolution of mesospheric quasi biennial oscillation (MQBO) in the 82–98 km altitude region were investigated using long-term meteor radar observations over low and equatorial latitudes and TIMED Doppler Interferometer (TIDI) observations. The wavelet spectra of monthly mean zonal winds over Serpog (6.4°S, 106.7°E; 1993–1998), Koto Tabang (0.2°S, 100.3°E; 2003–2012) and Thumba (8.5°N, 76.9°E; 2006–2015) show the transient nature of the MQBO amplitudes, thus, questioning its perpetuity in the mesosphere-lower thermosphere (MLT). The time period of the MQBO as well as its amplitude show variability with time (Fig.9). The latitude-height structures of the MQBO at four time periods (24, 26, 28, and 30 months) are constructed using TIDI measurements, which show diverse latitudinal structure. The significance of the present study lies in bringing out the time evolution of the MQBO and addressing a few outstanding issues on its ephemerality and discrepancies in its amplitudes.

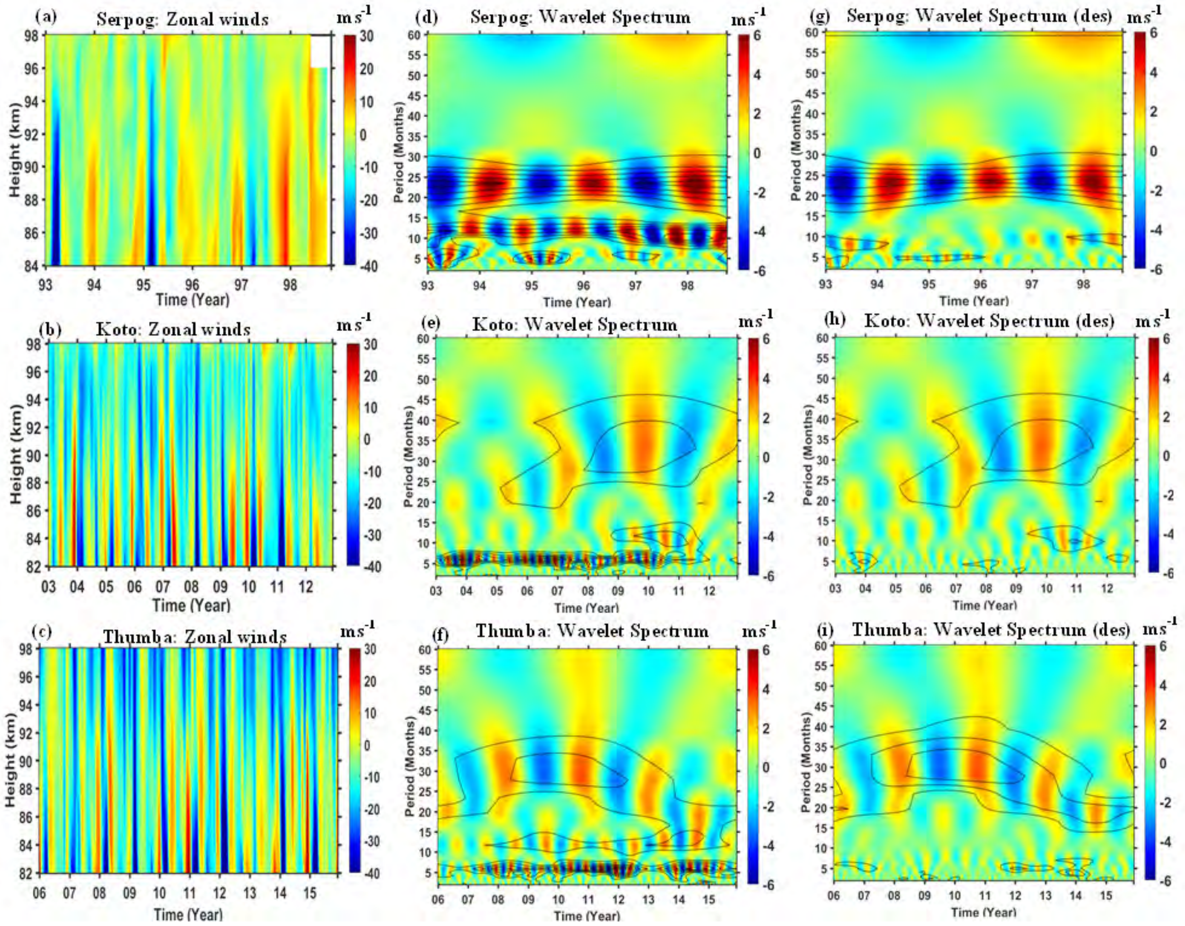

Figure 9: Time-height sections of monthly mean zonal winds over (a) Serpog, (b) Koto Tabang and (c) Thumba. Wavelet spectra of monthly mean zonal winds at 90 km altitude over (d) Serpog, (e) Koto Tabang and (f) Thumba. Wavelet spectra shown in (g), (h) and (i) are also same as (d), (e) and (f) but for deseasonalized zonal winds. Black contours in the wavelet spectra represent 95% confidence levels [Kumar, Geophys. Res. Lett., 2021].

Validation of C-band Dual-polarisation Doppler Weather Radar using Laser Precipitation Monitor and comparison with GPM observations

A C-band dual polarization Doppler weather radar (C-DWR) was installed at Thumba, a west coastal station in the southern peninsula of India, known as “Gateway of Indian Summer Monsoon”. The C-DWR operates in the frequency range of 5.6 to 5.65 GHz with a peak transmitting power of 250 kW with 0.004 duty ratio. Simultaneous observations of precipitating systems by space- and ground-based radars were used for validation of C-DWR. The dual-frequency precipitation radars operating at Ku band (13.6 GHz) and Ka-band (35.5 GHz) on-board Global Precipitation Monitor (GPM) provide the three-dimensional distribution of clouds in terms radar reflectivity. Figure 10 shows the height-longitude structure of radar reflectivity as observed by the ground-based C-DWR and space-based Ku- and Ka-band radars onboard GPM. The three radar observations were brought to common grid points for the comparison. All the three radars, in general, show similar features of the precipitating system, and the reflectivity structure agrees well.

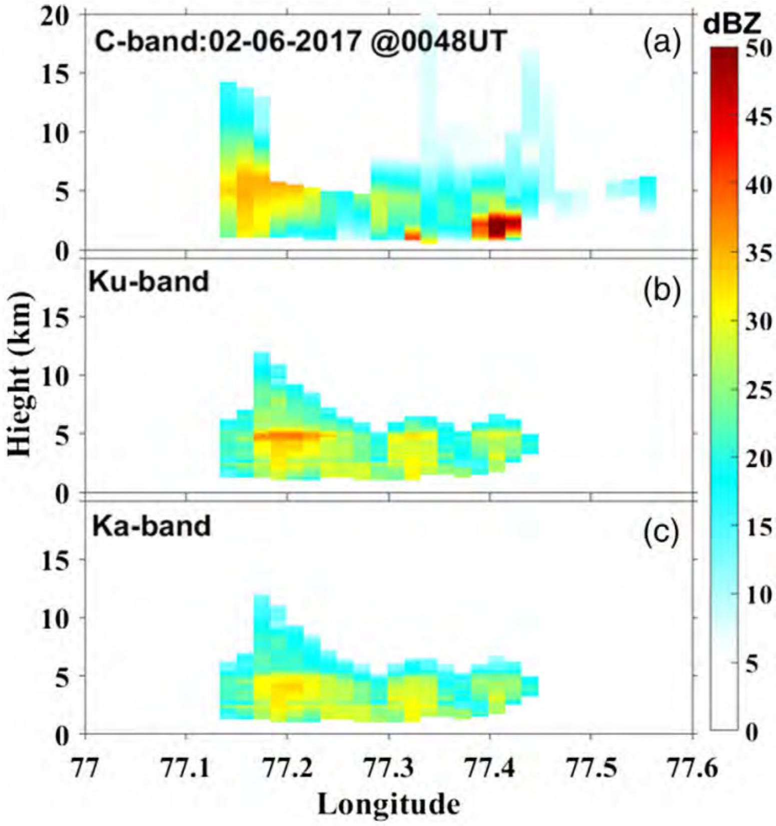

Figure 10: The height-longitude structure of radar reflectivity as observed by the ground-based C-DWR and space based Ku- and Ka-band radars [Kumar et al, J. Appl. Rem. Sens., 2021].

Multi-Platform Observations of Stratosphere-Troposphere Exchange over Bharati (69.41°S, 76°E), Antarctica during ISEA-35

During the 34th (2014-2015), 35th (2015-2016) and 36th (2016-2017) Indian Scientific Expeditions to Antarctica (ISEA), experimental campaigns were conducted by SPL at Bharati (69.41°S, 76.19°E), Antarctica. One of the objectives of this campaign was to study the stratosphere-troposphere exchange processes using balloon borne radiosonde/ ozonesonde measurements. In addition to these measurements at Bharati, there were regular radiosonde and fortnightly ozonesonde measurements along with ground-based VHF radar measurements from Davis (68.6°S, 78°E), which is about 85 km from Bharati. Intrusion of stratospheric ozone into the troposphere over Bharati during a jet stream condition is evident from these measurements (Fig.11). These observations provide evidence for the downward propagation of stratospheric O_3 into the troposphere over the Arctic associated with the polar vortices and alternating high and low pressure systems.

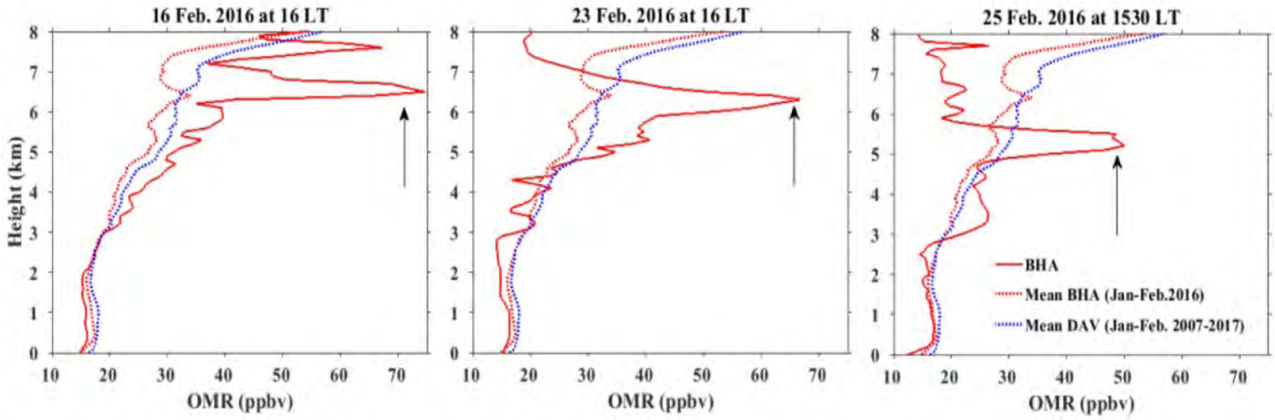

Figure 11: Height profile of ozone mixing ratio (OMR) on 16, 23 and 25 February 2016 over Bharati (BHA). Dashed lines indicate mean OMR (combination of Bharati (BHA) and Davis (DAV) profiles) during ISEA-35 (27 Jan. to 2 Mar. 2016, 12 profiles) and the long-term mean of Jan.-Feb. (2007-2017) over DAV. Vertical arrows indicate the enhancement of the upper tropospheric ozone [Das et al., J. Atmos. Solar. Terr. Phys., 2020].

Role of Equatorial Fountain for the Delayed Response of Thermosphere O1D 630.0 nm Dayglow over the Dip Equator during an X-class Flare

This study reveals, for the 'first time', a delayed response of O1D 630.0 nm dayglow emissions over Thumba, geomagnetic dip equatorial station in India, to the noontime X-class solar flare event of July 30, 2005. The dayglow measurements were made using the dayglow photometer operating at three wavelengths. The Equatorial Electrojet (EEJ) induced magnetic field, measured using a proton precession magnetometer, showed a magnetic spike having ~90 nT enhancement during this flare with a time delay of ~7.2 minutes. Unlike to the conventional understanding, the O1D 630.0 nm dayglow over the dip equator exhibited a fourfold enhancement during the noontime flare after a time delay of ~45 minutes as shown in Fig.12. Analysis of satellite measured electron density and simulations using a quasi 2D ionospheric model indicate that the thermospheric O1D 630.0 nm dayglow emission over the dip equatorial region during a solar flare is primarily driven by the electrodynamics, rather than the direct solar control. This finding is new, unique and very important for the studies related to plasma-neutral coupling and also for modelling studies on the equatorial thermosphere-ionosphere region.

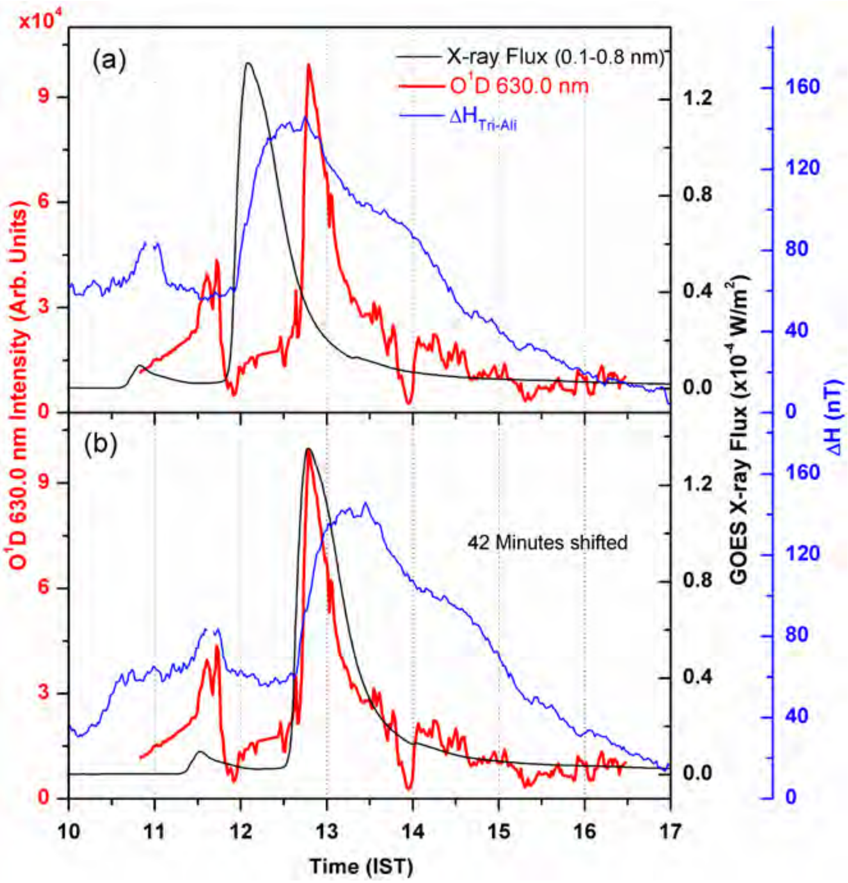

Figure 12: (a) Time variation of (a) O1D 630.0 nm dayglow emissions, X-ray flux and EEJ induced magnetic field on July 30, 2005, (b) same as (a) but for the X-ray flux and EEJ induced magnetic field forward time shifted by 42 minutes [Vineeth et al., J. Geophys. Res., 2021].

Three dimensional distribution of ions and electrons in the lunar ionosphere originated from photo chemical reactions

Using a fluid-based time-dependent numerical photochemical model, the three-dimensional distribution of ions and electrons in the lunar ionosphere, originated purely from photochemical reactions, was investigated. The photochemical model includes the production and recombination of sixteen ions, namely CO_2^+, H_2O^+, H_3O^+, OH^+, O_2^+, O^+, Ar^+, Ne^+, He^+, H^+, H_2^+, CH_3^+, CH_4^+, and CH_5^+. The model also includes the interaction of solar wind with lunar plasma and calculates electron density profiles from the surface to 200 km altitude for the entire latitudes and longitudes. Model runs suggest that the surface electron density at Moon could be as high as 1.2x105 cm^{-3} over the mid-latitudes (Fig.13) if dynamical interaction between the solar wind and lunar plasma is not accounted for. The dominant ions, in this case, would be Ar^+, Ne^+, and He^+. The absence of any intrinsic magnetic field leads the ionosphere at Moon to interact continuously with the solar wind and result in the removal of positive ions. This, in turn, leads to a negligible presence of plasma in the lunar ionosphere with maximum electron density ~1600 cm^{-3} centered around the polar region. Though solar wind acts as a strong removal agent, the electron density distribution is controlled by photochemistry, and ions are molecular in origin.

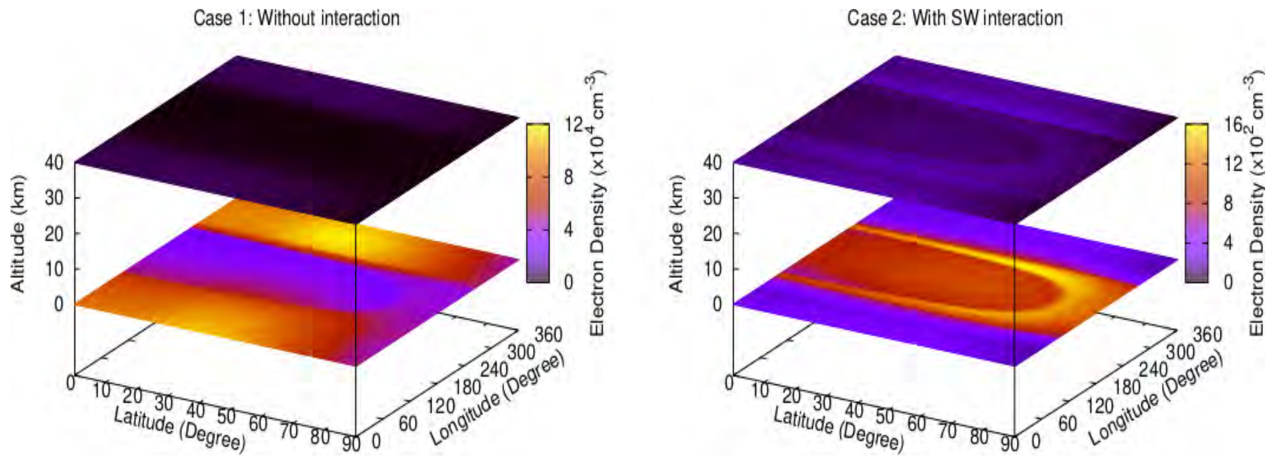

Figure 13: Three-dimensional view of electron density at the surface and 40 km for the Moon (case 1) not interacting with Solar W ind and (case 2) under the influence of Solar Wind.

First Estimations of Gravity Wave Potential Energy in the Martian thermosphere: An analysis using MAVEN NGIMS data

Precise aero-braking operations are extremely important for the safety of Mars lander missions. These operations depend on the atmospheric background conditions like wind and temperature. Gravity waves (GWs) have the potential to slow down or reverse the mean flow (wind) in the upper thermosphere through momentum exchange processes and thereby modulate the energy budget. It is therefore important to quantify the spatio temporal evolution of the longitudinal distribution of GW Potential Energy (GWPE) in the Martian thermosphere. The GWPE obtained from CO_2 density derived temperature fluctuations in the altitude region of 160-220 km corresponding to all Martian seasons during the 33rd Martian year (earth year: 2015-2017) have been analysed. Explicit diurnal evolution of GWPE (for 62° to 72° North latitude bin) with a post sunset maximum is delineated for summer (Fig.14). The higher values of GWPE, during morning hours, compared to post mid-night period in the 40°-50° latitude bin for summer, is another important observation. Further, it is seen that GWPE in autumn is 6 times higher during the night time compared to day time for the 67° to 55° latitude bin. The analysis of the latitudinal variation of GWPE for the 3-4 LT bin of summer reveals near doubling of GWPE as the latitude increases from 9.6° to 44°.

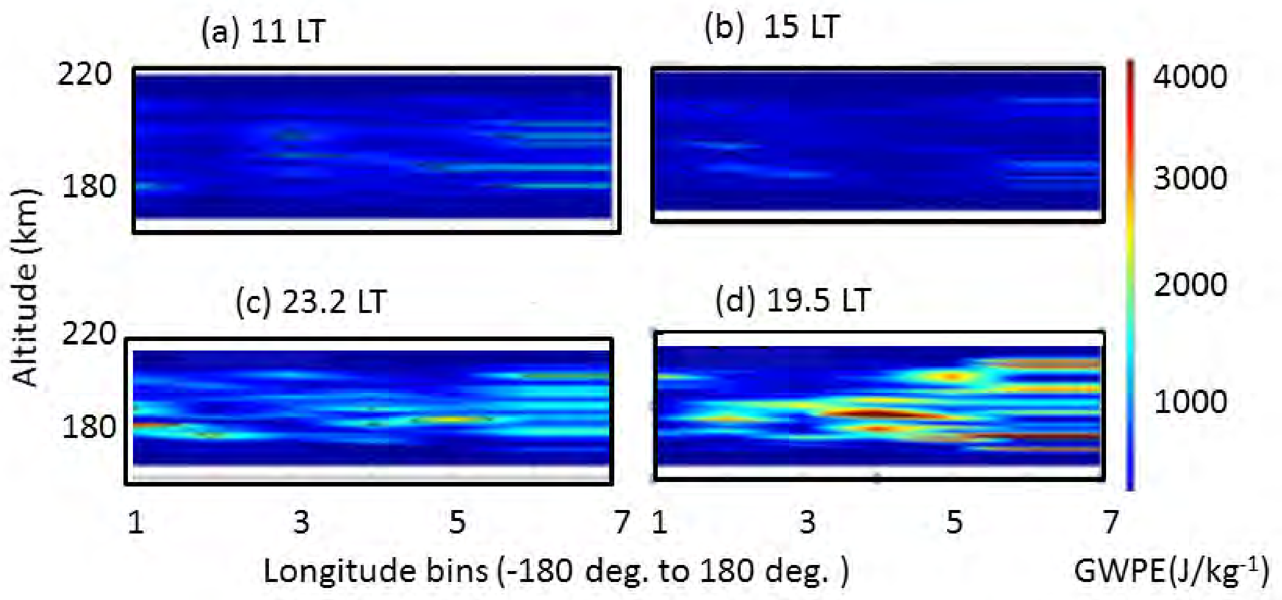

Figure 14: GWPE for four local times of the 6 longitude bins for the northern latitude bin of 52° to 73°, as a function of altitude (panels a–d) [Manju and Mridula, Monthly Notice Roy. Astrono. Soc., 2021].

A study on the solar coronal dynamics during the post-maxima phase of the solar cycle 24 using S-band radio signals from the Indian Mars Orbiter Mission

Radio signals from India's Mars Orbiter Mission (MOM) have been used to study turbulence in the solar plasma during the post-maximum phase of solar cycle 24. S-band (2.29 GHz) radio carrier downlink signals from MOM were received at the Indian Deep Space Network, Bengaluru, and frequency residuals were spectrally analysed to obtain coronal turbulence spectra at heliocentric distances ranging between 4 and 20 R⊙, corresponding to coronal regions where the solar wind is primarily accelerated. The frequency fluctuation spectrum relates to the turbulence regime in the near-Sun region. The turbulence power spectrum (the temporal spectrum of frequency fluctuations) at smaller heliocentric distances (< 10 R⊙) reveals flattening in lower-frequency regions, with a spectral index αf ~0.3 −0.5, which corresponds to the solar wind acceleration region. For larger heliocentric distances (> 10 R⊙), the curve steepens with a spectral index αf ~0.7 −0.8, a value close to 2/3 and indicative of a developed Kolmogorov-type turbulence spectrum (Fig-15). Plausible explanations to support the theory of coronal heating by magnetohydrodynamic waves and the acceleration of the solar wind are provided.

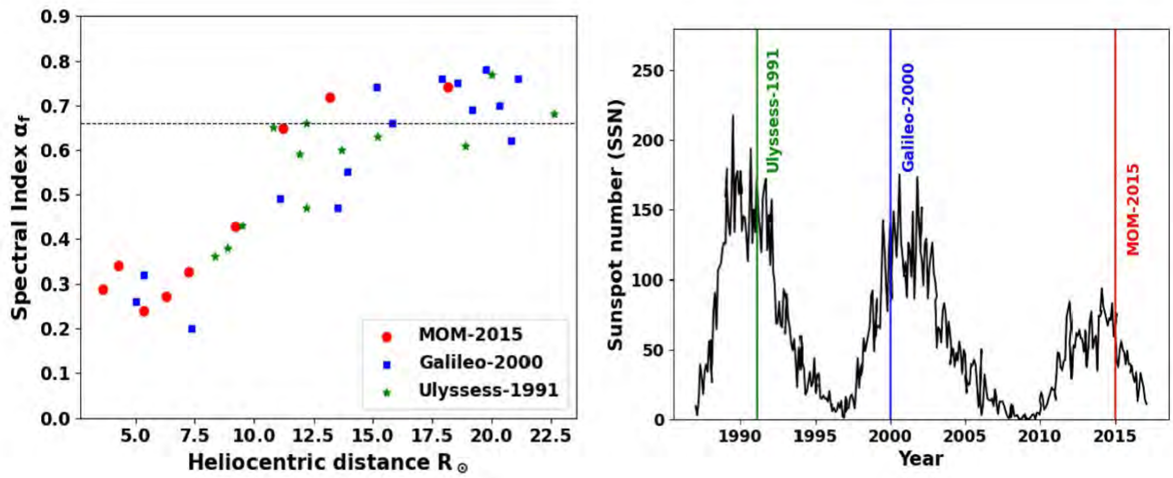

Figure 15. Left-hand panel: spectral index (αf) of the frequency fluctuation spectrum from spacecraft radio signals at various heliocentric distance Rʘ during the coronal radio sounding experiments of (a) Ulysses, (b) Galileo, and (c) MOM (Indian Mars Orbiter Mission). Data for Ulysses and Galileo missions are adapted from Efimov et al. (2005b). Right-hand panel: average sunspot numbers over the years 1987–2016, spanning three solar cycles. Vertical lines mark the period when radio-sounding experiments were conducted by the three spacecrafts.

The Impact of a Stealth CME on the Martian Topside Ionosphere

Solar cycle 24 is one of the weakest solar cycles recorded, but surprisingly the declining phase of it had a slow coronal mass ejection (CME) that evolved without any low coronal signature and is classified as a stealth CME that was responsible for an intense geomagnetic storm at Earth (Dst = −176 nT). The propagation of this CME beyond 1 au and its impact on other planetary environments have been studied using the data from the Sun–Earth L1 point and from the Martian orbit (near 1.5 au). The observations near Earth were performed using the data from the Solar Dynamics Observatory (SDO) and the Advanced Composition Explorer (ACE) satellite located at L1 point, whereas those near Mars were from the instruments for plasma and magnetic field measurements onboard Mars Atmosphere and Volatile EvolutioN (MAVEN) mission. The observations show that the stealth CME has reached 1.5 au after 7 days of its initial observations at the Sun and caused depletion in the nightside topside ionosphere of Mars, as observed during the inbound phase measurements of the Langmuir Probe and Waves (LPW) instrument onboard MAVEN (Fig.16). These observations have implications on the ion escape rates from the Martian upper atmosphere.

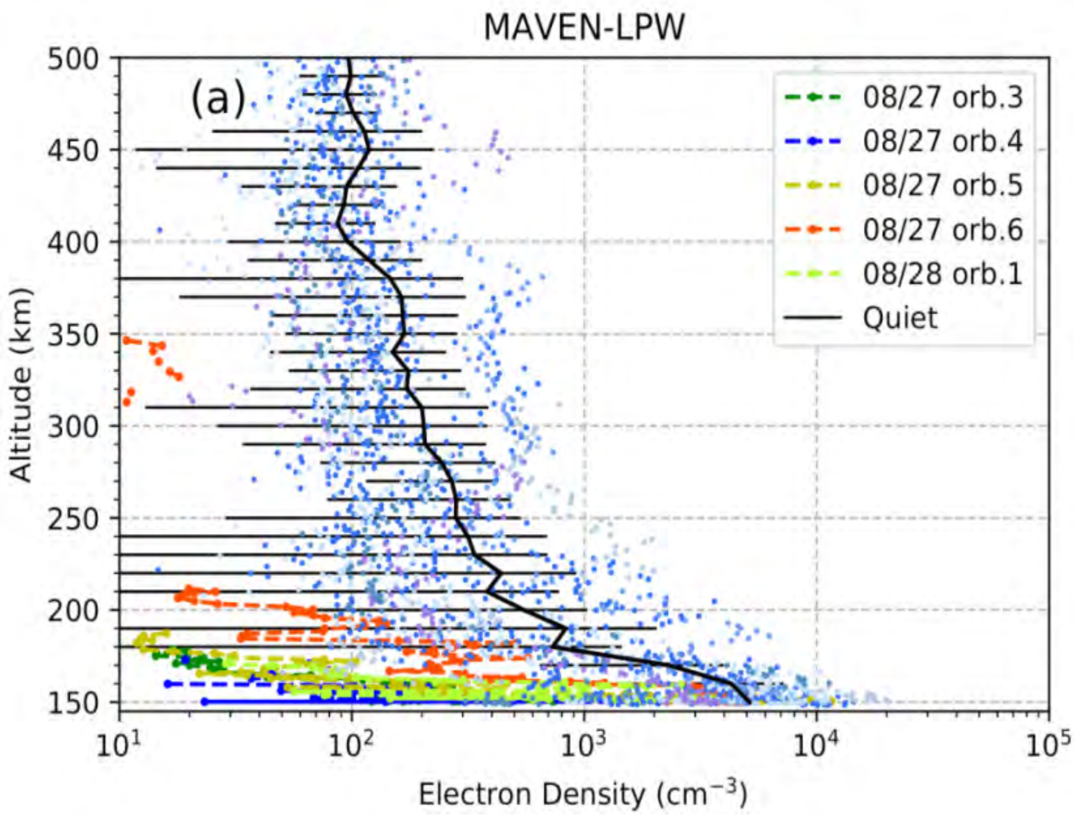

Figure 16: The Langmuir Probe and Waves (LPW) observations during 2018 August 27–28, along with the typical quiet time variation. The seven quiet orbits on 2018 August 24, 25, and 26 are shown as blue dots. The mean of the quiet time profiles is shown (black line) along with standard deviation [Smitha et.al., Monthly Notice Roy. Astrono. Soc., 2021].

Global Distribution of Argon-40 in the Lunar Exosphere from CHACE-2 aboard Chandrayaan-2 Orbiter

Ar-40 is an important noble gas in the lunar exosphere, the presence of which has been confirmed from the earlier observations in the low-latitude regions of the Moon. The distribution of Ar-40 in the higher latitude regions were not known. CHandra's Atmospheric Composition Explorer-2 (CHACE-2) experiment onboard the Chandrayaan-2 orbiter, the second Indian lunar mission, has provided for the first time the global distribution (within ±60° latitude) of Ar-40 in the lunar exosphere (Fig.17). The number densities of Ar-40 showed pre-sunrise, sunrise and sunset peaks as well as nightside minima, typical of a condensable gas. The diurnal behavior in the mid-latitude region have been found to be similar to that in the low-latitude regions. It was found that some of the regions of Ar-40 enhancements in the southern hemisphere coincide with the K-40 rich KREEP terrane and the South Pole Aitken (SPA) terrane. These observations are indicative of unknown or additional loss processes, indicate the possible role of Moon quakes or regions with lower activation energies, which need further investigation and call for a better understanding of the surface-exosphere interactions and source distributions.

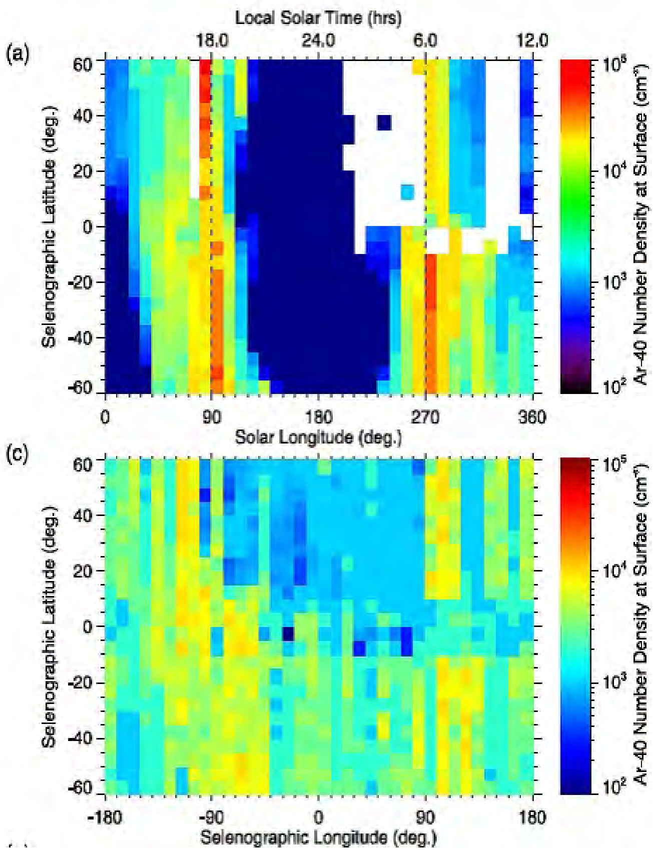

Figure 17. (Top panel) Map of relative number density of Ar-40 at the surface with respect to the solar longitude and selenographic latitude. The local solar time corresponding to the solar longitude is shown on the top x-axis. (Bottom Panel) Map of relative number density of Ar-40 at the surface with respect to the selenographic longitude and selenographic latitude. White colour represents the absence of observations in a given grid.

2.5 Instruments / Payloads / Products Developed / Sensors / Detectors

SPL has been actively involved in major space programs of the country, such as Chandrayaan-1 and -2 missions to Moon, Mars Orbiter Mission, YouthSat, Megha-Tropiques, Sounding Rocket Experiment (SOUREX), and ISRO-Geosphere Biosphere Programme. The network of observatories of SPL spreads across the length and breadth of the country including islands, as well as in Antarctic, Arctic, and the Himalayas. SPL also coordinates major experimental campaigns at national level using balloons, aircrafts, rockets, and ship cruises, and is a contributor to India's polar research programme.

Sounding Rocket Experiment (SOUREX-Phase-II)

The second phase of SOUREX campaign had been conducted successfully by launching a RH 560 MkIII rocket from SHAR on 12 March 2021, with the Electron density and neutral wind (ENWi) and Langmuir probe (LP) payloads operated in dual modes along with Trimethyl Aluminum (TMA) for the study of ion drifts, neutral winds, electron density and irregularities in the upper ionospheric region. For this purpose, the required quantity of TMA for successfully imaging using ground based cameras was estimated theoretically and the imaging locations & camera system needed for the experiment were finalized. The TMA trail, released from 96 km to 155 km altitude, was imaged successfully from four locations as seen in Fig. 18. During this experiment, the TMA measurements covered 96 to 155 km altitude region in the upleg phase, while ENWi and LP covered 75 to 512 km altitude. This activity was led by different entities of VSSC and centres of ISRO.

Analysis of the TMA data revealed large altitudinal gradient in neutral wind, which was more pronounced in the meridional wind component. The ENWi and LP instruments were operated in different modes during the mission and the electron densities were derived from the altitude of 80 km to 510 km. The electron density profiles from cylindrical and spherical modes show good correspondence in terms of the broad features while the irregular structures are more prominent in cylindrical probe. The very steep bottom side electron density gradient is a remarkable feature.The uniqueness of these observations is that the altitudinal variation of the plasma densities was revealed with good altitude resolution from around 80 km to 510 km. These profiles will help to investigate the vertical propagation characteristics of waves in the post sunset ionosphere.

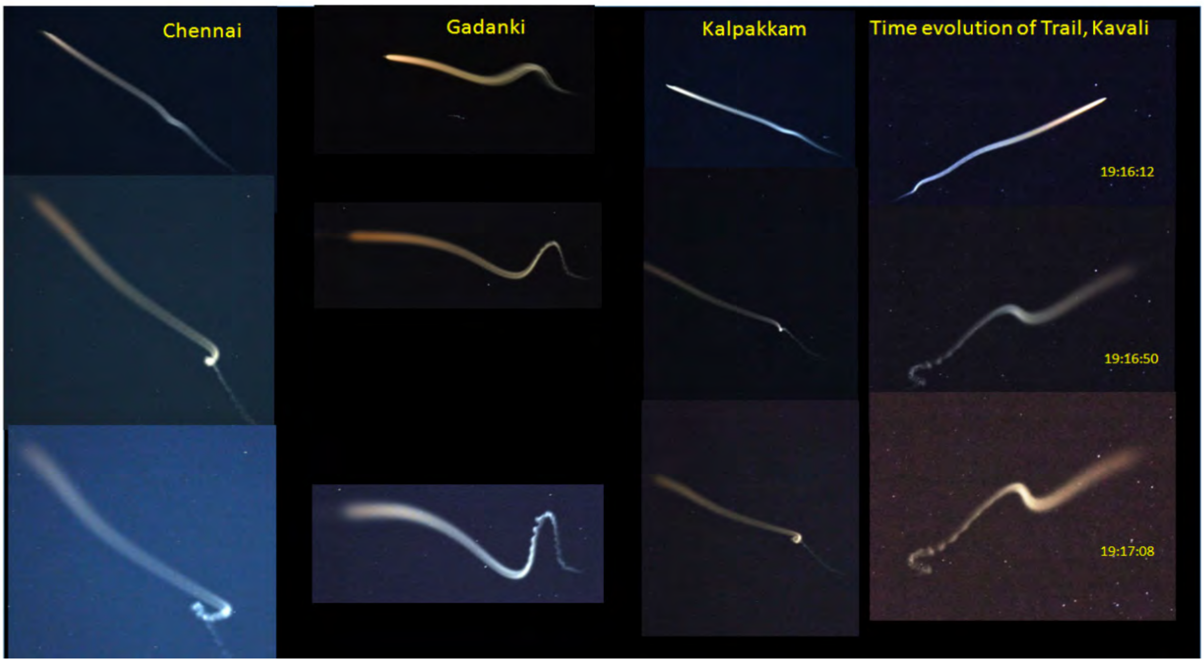

Figure 18: The TMA trail as imaged from the four ground stations are depicted above. The station name is mentioned at the top of the column.

Chandra’s Surface Thermophysical Experiment (ChaSTE)

Chandra’s Surface Thermophysical Experiment (ChaSTE) payload is intended to investigate the thermophysical properties of lunar regolith over the polar region of moon and was developed for the Chandrayaaan-3 lander, jointly by SPL in collaboration with Physical Research Laboratory (PRL) and other entities of VSSC. The objective of ChaSTE is to make insitu measurements of temperature and thermal conductivity of the lunar regolith up to 100 mm depth. The payload is basically a thermal probe, which will be inserted into the lunar regolith in a controlled manner based on the tele-commands from the Earth station. The payload consists of three major modules i.e. thermal probe, electronic module and deployment mechanism.

Radio Anatomy of Moon Bound Hypersensitive ionosphere and Atmosphere-Langmuir probe (RAMBHA-LP)

The Radio Anatomy of Moon Bound Hypersensitive ionosphere and Atmosphere-Langmuir probe (RAMBHA-LP) is a payload onboard Chandrayaan-3 Lander for in situ measurements of ambient electrons, ions, densities and their temperatures. The RAMBHA-LP payload consists of the mechanical module i.e. probe and a boom and the control electronics module. The instrument is being developed at VSSC.

Plasma Analyser Package for Aditya (PAPA)

Plasma Analyser Package for Aditya (PAPA) onboard the Aditya-L1 spacecraft is a payload for investigating the solar wind characteristics. The PAPA contains two sensors: Solar Wind Electron Energy Probe (SWEEP) to measure the solar wind electron flux, and Solar Wind Ion Composition AnalyseR (SWICAR) to measure the ion flux and composition as a function of direction and energy. Both SWEEP and SWICAR are controlled by a common PAPA Processing Unit (PPU). The instrument is under development.

2.6 Capacity Building in Space Science Research

The Research Fellow's program at SPL has evolved over the years and currently has a total strength of 25 students. Over 90 Ph.Ds were awarded so far under this program. Post-doctoral positions at SPL are open to suitable candidates. In addition to the above, SPL hosts candidates with national post-doctoral fellowships awarded by DST, Govt. of India (INSPIRE faculty, NPDF and Ramanujan Fellowships) to carry out their research activities. SPL also has a Visiting Scientist program for senior scientists who have sufficient experience and hold a permanent position elsewhere.

SPL plays an important role in creating scientific awareness and dissemination of expert knowledge to students, faculties and public at large. These are archived through various programs that include, but not limited to: (i) Lectures at schools and colleges, (ii) World Space Week program of VSSC, ISRO, (iii) Lectures at CSIR Program for Youth Leadership in Science, (iv) Lectures during National Science Day Celebrations, (v) Lectures at programs organized by Swadeshi Science Movement, (vi) Lectures to University/College teachers as a part of the UGC-Refresher course in Physics at Academic Staff Colleges, (vii) Lectures at universities and national institutions, and (viii) introductory lectures on space sciences to fresh recruits of ISRO under the ISRO Induction Training (IITP) Program. SPL also fulfills its commitment to society by imparting training to the young students, which includes: (i) B. Tech and M. Sc. Projects, (ii) M. Tech. and M. Phil Dissertation supervision. So far, more than 500 M. Sc./M.Tech. Project students have carried out their project work at SPL.

2.7 Courses offered on Space Science and Technology

SPL conducts regular Ph.D course work for the Research Fellows selected through the ISRO Research Fellowship program at SPL.

2.8 National Collaborations in Space Science and Technology

SPL collaborates very closely with the academia and other research agencies in India for scientific pursuits, which includes various centers of ISRO, Ministry of Earth Sciences (MoES), Department of Science and Technology (DST), Department of Atomic Energy (DAE), Council of Scientific and Industrial Research (CSIR), Ministry of Environment and Forest (MoEF), universities and national institutes. The long-term collaborations are listed below:\]

Sl. No.	Area of Collaboration	Collaborating Institutes
1	Regional characterization of atmospheric aerosols over Indian region through the application of ground-based measurements of aerosols and the scientific understanding of the various source and transport processes to understand the radiative and climate impacts.	Indian Institute of Science, Bengaluru
		Tamilnadu Agricultural University, Ooty
		SRM University, Chennai
		S K University, Anantapur
		Goa University, Goa
		National Remote Sensing Centre, Hyderabad
		Tata Institute of Fundamental Research, Hyderabad
		Andhra University, Visakhapatnam
		Indian Institute of Tropical Meteorology, Pune
		Institute of Minerals and Materials Technology, Bhubaneswar
		Regional Remote Sensing Centre (RRSC), Nagpur
		Saurashtra University, Rajkot
		Tripura University, Agartala
		Banaras Hindu University, Varanasi
		North Eastern Space Application Centre (NESAC), Shillong

Sl. No.	Area of Collaboration	Collaborating Institutes
		M L Sukhadia University, Udaipur and Jaisalmer
		Dibrugarh University, Dibrugarh
		Aryabhatta Research Institute of Observational Sciences, Nainital
		Punjabi University, Patiala
		Indian Institute of Remote Sensing, Dehradun
		GB Pant Institute for Himalayan Environment and Development, Kullu
		Indian Institute of Astrophysics, Bengaluru
		National Physical Laboratory, New Delhi
		Yogi Vemana University, Kadappa
		Calcutta University, Kolkata
		Dayalbagh Educational Institute, Agra
		DDU Gorakhpur University, Gorakhpur
		S V University, Vijayawada
2	Monitoring of atmospheric boundary layer (ABL) parameters, state variables, and energy fluxes at different geographical locations of India, representing typical geographical and climate conditions prevailing at distinct geographic regions of the country.	North Eastern Space Application Centre (NESAC), Shillong
		Andhra University, Visakhapatnam
		S K University, Anantapur
		Aryabhatta Research Institute of Observational Sciences, Nainital
		Goa University, Goa
		Indian Institute of Space Science and Technology, Trivandrum
		National Remote Sensing Centre, Hyderabad
		Indian Institute of Science, Bengaluru
3	Polar Research	National Centre for Polar and Ocean Research
4	Atmospheric, Space and Planetary exploration	Physical Research Laboratory (PRL), Ahmedabad
		National Atmospheric Research Laboratory (NARL), Gadanki
		Indian Institute of Geomagnetism (IIG), Mumbai
		Indian Institute of Science, Bengaluru
		Indian Institute of Astrophysics (IIA), Bengaluru
		Indian Institute of Space Science and Technology (IIST), Thiruvananthapuram

2.9 International Collaborations in Space Science and Technology

SPL interacts/ collaborates very closely with the academia and other research institutions in abroad for scientific pursuits.

Sl. No.	Area of Collaboration	Collaborating Institute/ agency and country
1	Assimilation of space-borne CAI-2 aerosol retrievals in conjunction with ground-based point measurements over south Asia for advanced quantitative information and improved understanding of the radiative implications of aerosols.	Ministry of the Environment of Japan, the Japan Aerospace Exploration Agency and the National Institute of Environmental Studies
2	Tracking and utilization of Radio Science (RS) experiment onboard Akatsuki Venus orbiter to study the atmosphere ionosphere of Venus	Japanese Aerospace Exploration Agency (JAXA)

2.10 Laboratories and Facilities Available for Space Instrumentation

High Vacuum Space Simulation Facility (HVSSF)

With SPL involvement in the development of space-borne instruments, a state-of-art High Vacuum Space SimulationFacility (HVSSF) has been set up at SPL (Fig.20a). HVSSF is a 1-m class chamber providing vacuum of the order of 10^{-7} Torr in a few hours. The HVSSF is equipped with ion and electron sources for characterization of detectors, and testing and calibration of plasma analysers and neutral mass spectrometers. The High Vacuum Space Simulation Facility (HVSSF) is maintained and augmented with sub-systems for the development, testing and calibration of scientific payloads and has been extensively utilized. A new state of the art differentially pumped fine focus ion source, featuring high current range operation over the energy range between 5 eV and 5 keV was recently added to HVSSF.

Clean Room Facility

The Clean Room facility at SPL (with class 10000 and class 100000 clean rooms equipped with work benches of class 100 and class 1000 Laminar flow tables) has been utilized for the testing and development activities for scientific payloads of SPL and for the requirements from other entities of VSSC (Fig. 20b). The Clean Room is being extensively utilized for the realization and testing of the scientific payloads.

Figure 20: (a) High Vacuum Space Simulation Facility and (b)Clean room Facility at SPL.

Payload Operation Centre at SPL

At present, the payload operation centre (POC) of SPL is handling the data from CHACE-2 and DFRS payloads on Chandrayaan-2 orbiter and MENCA on Mars Orbiter Mission. Level-0 data sets from normal phase observations of CHACE-2 have been regularly received from ISSDC via NKN-VRF link. These data sets are processed using automated software pipelines in POC; quick look plots are generated to verify the payload functionality. Also, a chain to generate the data products as per planetary data system (PDS) standard for archival and subsequent public release also runs in POC. The POC is now being geared up to serve for the payloads onboard Chandrayaan-3 and Aditya-L1.

CHAPTER-3

PHYSICAL RESEARCH LABORATORY

Ahmedabad

3.1 About the Laboratory

PRL is one of the premier science laboratories of the country conducting cutting-edge research in many domains of Astronomy and Astrophysics, Solar Physics, Space and Atmospheric Sciences, Atomic, Molecular, and Optical Physics, Geosciences, Planetary Sciences, and Theoretical Physics. PRL, formed in 1947, is also considered as the 'cradle' of space research in India as it is from PRL, conceived by Prof. Vikram Sarabhai, that the basic and applications research in space was initiated in India. PRL is broadly tasked with harnessing space technology for carrying out targeted scientific research, including instrument design, as well as payload development for scientific exploration using space-based platforms. PRL also actively contributes to capacity building and human resource development in the form of research programs/projects, including those leading towards Ph.D. degrees, in the fields of science and engineering. PRL has four campuses, the main campus at Navrangpura, Ahmedabad, and the others at Thaltej, Ahmedabad, the infrared Observatory in Mt. Abu, and the Udaipur Solar Observatory in Udaipur.

3.2 Keywords

Planetary sciences and Instrumentation, Astrochemistry, Solar physics, Space Weather, Space and Atmospheric Sciences, Geosciences, Astronomy & Astrophysics, Photonics, Quantum Communication, Theoretical Physics.

3.3 Major Research Domains

The domains of research in PRL include investigations of the sun and its variability, atmospheres of the earth and other planets, space weather effects on the atmospheres, the sun and the interplanetary medium, the study of the interiors, surfaces, and atmospheres of solar system objects and the processes governing their dynamics. This is accomplished through theoretical models (computer simulations), laboratory experiments, remote sensing, in-situ observations and experiments, development pf payloads and ground- and space-based instruments. Some of the projects are briefly described below:

- **Helioseismology**
  Acoustic waves on the solar surface interact with the magnetized regions of the Sun and can propagate along the magnetic field lines in the form of magneto-acoustic waves. These waves can contribute to the heating of solar corona. Hence, it is important to study these waves in the solar atmosphere.

- **Heating of the solar corona and transition region**
  The tenuous outer atmosphere of the Sun commonly known as 'corona', is orders of magnitude hotter (> 1 MK) than the solar surface (< 6000 K). Exact physical mechanisms behind the heating of solar corona are still unclear and is an active area of research in the field of space science.

- **Evolution of solar cycle**
  The quasi-periodic 11-year periodicity is reflected in several solar activity indices related to photospheric, chromospheric, and coronal activity. To understand the nature of solar magnetism and its link to the explosive events, is important to study evolutionary phases of solar activity cycles.

- **Onset and evolution of solar eruptive phenomena**
  Solar eruptions are complex phenomena with multiple facets right from their genesis in the solar atmosphere to subsequent consequences in the near-Sun, interplanetary, and near-Earth regions. Decades of observational and theoretical research has elucidated different aspects of it, namely, solar flares, eruptive prominences, coronal mass ejections (CMEs), coronal jets, etc., which are observationally defined as disjoint terms but occur as a result of physically coupled processes. Exploration of solar eruptive phenomena using multiwavelength, multi-instrument, and multipoint observations is key toward better understanding of the origin and prediction of space weather events.

- **Magneto-hydrodynamic (MHD) simulations of solar phenomena and space weather effects**
  Understanding the role of magnetic reconnection and the resulting dynamics at the source region of solar transients (like flares and coronal mass ejections) are essential toward the development of a physics-based space weather model. Research in this direction is carried out in USO/PRL using state of the art numerical modelling running on the Vikram-100, the High-Performance Computing facility at PRL.

- **Solar photospheric studies using Multi-Application Solar Telescope (MAST)**
  Optical instrumentation at USO has a 50 cm optical solar telescope named Multi-Application Solar Telescope (MAST) which is in operation since 2015. The MAST is equipped with instruments designed and developed in-house for making small field and high resolution observations. These observations enable a better understanding of the source regions of the active Sun leading to eruptions.

- **Ionosphere-Thermosphere system processes**
  The coupled thermosphere-ionospheric system (ITS) exhibit intriguing behaviour through the interactions of co-existing neutral species and charged particles. The energetics and dynamics of ITS are being explored through ground and space based experiments employing state of the art radio and optical techniques. A twin satellite mission (DISHA) is planned to monitor various ITS processes with adequate temporal and spatial scales.

- **Magnetosphere-ionosphere coupling processes**
  Electrodynamic coupling between terrestrial magnetosphere and ionosphere during geomagnetic storms and magnetospheric substorms is pretty strong. There are significant modifications in ionospheric electric field, currents, plasma distributions and irregularities during storm and substorm. Critical understanding on these modifications provide us important clues on the impact of space weather on terrestrial magnetosphere-ionosphere system that, in itself, is a system of systems.

- **Space Weather effects on earth's upper atmosphere**
  Disturbed space weather conditions such as coronal mass ejections, solar flares and high speed solar wind streams can severely impact the coupled ionosphere thermosphere system primarily through prompt penetration electric fields and disturbance dynamo fields. Space weather induced disturbances in ITS system adversely affect the performance and reliability of space-borne and ground-based technological systems and can endanger several facets of human life.

- **Vertical coupling of atmospheres**
  The planetary waves (period ~ 2-20 days) are an important coupling agent of various atmospheric layers. The middle atmosphere dynamics is significantly controlled by the planetary waves. The stationary planetary waves are generated in the troposphere due to orography and adiabatic heating. The traveling planetary waves are excited by irregular thermal or mechanical forcing in the lower atmosphere, instabilities in the middle atmosphere, which, in addition to other processes affect the mesosphere lower thermosphere region dynamics as well.

- **Mesosphere Lower Thermosphere (MLT) and Middle atmosphere dynamics**
  MLT region (80 – 120 km) is host to contrasting properties in earth's atmosphere. Due to its importance, the investigations are carried out using in-house developed optical instruments to study the airglow emissions at different wavelengths which originate at different altitudes.

  The low latitude middle atmosphere supports a number of waves which control the dynamical condition. Interaction of these waves with the mean wind gives rise to a number of long period seasonal scale oscillations, e.g. the semiannual oscillation (SAO), annual oscillation (AO) and quasi-biennial oscillation (QBO). The SAO and QBO are driven by breaking and dissipation of gravity waves, Rossby waves and Kelvin waves. The details of these phenomena are important to understand the various atmospheric processes.

- **Applications of Artificial Intelligence (AI) and Machine Learning (ML) for solar, terrestrial and planetary investigations**

  - Machine learning algorithm (XGBoost) was trained using the ozone observational data obtained at Graphic Era University Dehradun. Meteorology (T, RH, Wind, PBL) and precursors (CO, NOx) from a climate model were used as inputs. 50% of data are used for training and the rest for independent data validation. The results suggests that this method can be applied for more pollutants in the future.

Reference: Sci Rep 11, 22513 (2021). https://doi.org/10.1038/s41598-021-01824-z

- o Application of machine learning algorithms for automated detection of mass wasting features on the lunar surface is under development at PRL.
- o Under the aegis of DTDI (Directorate of Technology Development and Innovation)-ISRO, a scientific project named 'SALIL' was initiated for predicting groundwater levels using Machine Learning and Remote Sensing data. This project has been extended to all India level, and the work is currently in progress. This study has direct applications to Govt. of India schemes such as (i) **"Har Ghar Jal"**, Ministry of Jal Shakti, Government of India. (ii) **"SARITA"** project, SAC.

- **Instrument/Payload Development for Terrestrial/Planetary Exploration**
  One of the main research domain is the development of scientific instruments/payloads for past, current and future planetary missions. PRL has developed scientific instruments for Chandrayaan-1, Chandrayaan-2, Chandrayaan-3 and Aditya L1 missions. PRL is presently involved in the building of bread-board models for aeronomy studies of earth and Venus in ISRO's proposed twin aeronomy satellite mission, DISHA and Venus mission.
- **Investigations of Planetary Atmospheres, plasmas, and Astrochemistry**
  Research on Planetary Atmospheres and environments involves development and use of theoretical models to study the composition and structure and physical, dynamical, and electrodynamical processes in the atmospheres and plasma environments of planets. In conjunction, data from various missions are used to study various aspects of the climate, atmosphere, of Mars and Venus and astrochemistry.
- **Early Solar System Studies and Meteorites**
  The research work under this theme aims at understanding the timescales and processes in the origin and evolution of the solar system by laboratory analyses of the extraterrestrial material (meteorites or mission returned samples) and analogues. The Laboratory analyses comprise of chemical and mineralogical characterization, spectroscopy, and isotopic compositions, and are supported by theoretical calculations. In addition, research areas also include aqueous, thermal, differentiation, and impact processes in planetary bodies and the mantle and crustal evolution of Moon and Mars. Presolar grains are studied to understand the nucleosynthetic input in our Solar system. Organics from meteorites are analysed, in order to understand their origin into the evolving system.
- **Interplanetary dust studies and Planetary Lightning**
  Study of interplanetary and planetary dust for different planetary objects like Moon, Mars, Venus, Asteroid belt, etc., are carried out under this domain. Further, the effect of dust in the planetary atmosphere and near-surface environment is understood through modelling and data analysis. Study of lighting in the atmospheric clouds like that on Venus, is also carried out.

- **Planetary remote sensing geology of Moon and Mars**
  The basic aim of this domain of research is to study planetary processes, viz. impact cratering, volcanism, tectonism, space weathering, glacial, fluvial, and mass wasting, through data from remote sensing missions, and decipher their role in the geological evolution of the planetary bodies. Specifically, data from remote sensing missions to the Moon (Chandrayaan-1 & 2, LRO, Kaguya, GRAIL, and Clementine) and Mars (MOM, MRO, MGS, Mars Express, and Mars Odyssey) are analysed.

- **Studies on analogues under simulated planetary environments**
  A comprehensive understanding of surface science of a planetary body requires in-situ data from several representative and diverse locations. However, it is not practically feasible. Therefore, various experiments are carried out using analogous sample under simulated environment.

- **Impact cratering**
  Craters are natural pathways to explore planetary/satellite bodies surface and subsurface geology. Their large presence will provide crucial clues to understand and explore their evolutions. This area aims at studying impact cratering and its related processes on terrestrial planets and analogue sites.

3.4 Major Scientific Applications / Results

- **Quantum Communication Experiments:** Free-space quantum communication assumes importance as it is a precursor for satellite-based quantum communication needed for secure key distribution over longer distances. Prepare and measure protocols like BB84 consider the satellite as a trusted device, which is fraught with security threat looking at the current trend for satellite-based optical communication. Therefore, entanglement-based protocols must be preferred, so that one can consider the satellite as an untrusted device too. Therefore, after implementing BB84 protocol over 200 m distance using an indigenous facility developed at PRL we went on to implement BBM92 protocol, an entanglement-based quantum key distribution (QKD) protocol in the same channel with the inhouse developed source of entangled photons. For the BB84 protocol, we observed the shift key rate of 200 Kbps with an average QBER of 4% that reduces to a secure key rate of 150 kbps after error correction and privacy amplification. For the BBM92 protocol (entanglement-based protocol) in the same channel, the sift key rate comes out to be 4.5 kbps with a QBER of 4% and a final secure key rate of 3.5 kbps.

- **An Inflated Hot-Jupiter around a Sub-Giant Star discovered by PRL Scientists:** The exoplanet search and study group at the Physical Research Laboratory (PRL), Ahmedabad has discovered a new exoplanet orbiting too close to an evolved or aging star with a mass of 1.5 times that of our Sun and located 725 light years away. This discovery is made using PRL-PARAS optical fiber-fed spectrograph on the 1.2 metre Telescope of PRL at its Mt. Abu Observatory. This newly discovered star-planet system is a very unique - the planet orbits the host star in just 3.2 days, thus placing it very-very close to the star at a distance of 0.05 AU (roughly one-tenth the distance between Sun and Mercury).

Reference: https://academic.oup.com/mnras/advancearticle/doi/10.1093/mnras/stab2970/6409152.

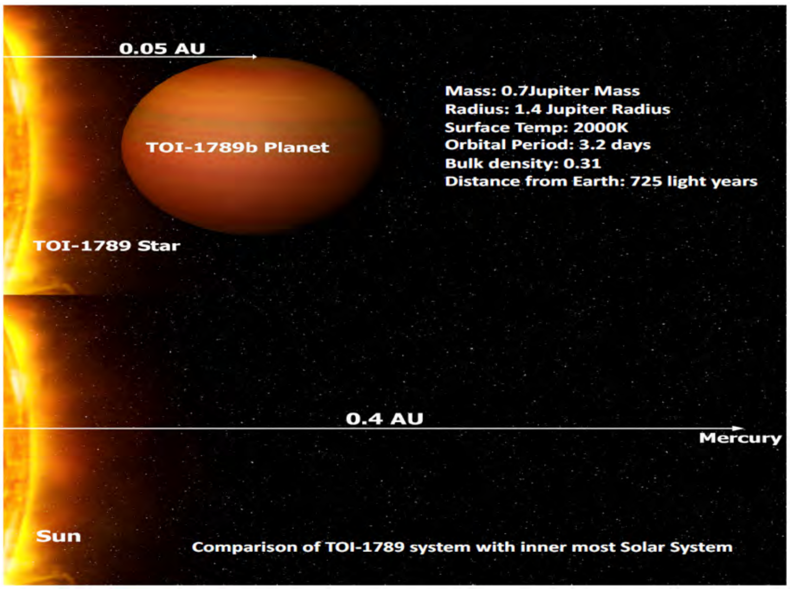

Figure 1: Artistic impression of the TOI-1789 star-planet system, along with characteristics of planet

- **Identifying igneous landforms on Mars:**

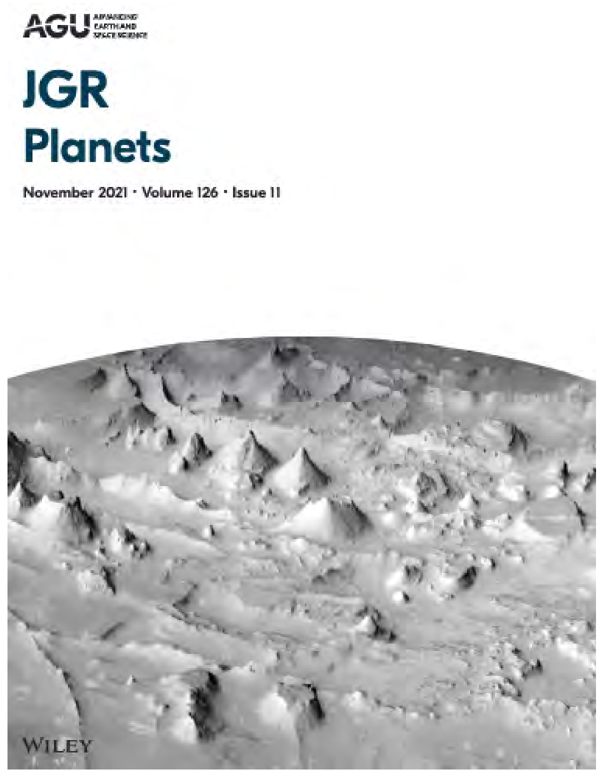

Figure 2: THEMIS day-time IR base map of the central part of the Floor Fracture Crater consisting of igneous landforms, cones and dikes. This discovery has formed the cover page of American Geophysical Union's Journal of Geophysical Research – Planets (November 2021 – Volume 126 – issue II) [https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/jgre.21394]

PRL scientists have identified structures on Mars that are igneous landforms. They have been discovered in a floor fractured crater (diameter ~85 km, centred at 28.09^{0} N, 27.87^{0} E) in Arabia Terra of Mars, which has been proposed to be named as UR Rao Crater.

Reference: https://doi.org/10.1029/2020JE006748

- **Unravelling the mysteries of the Solar Corona: New results from Chandrayaan-2 Solar X-ray Monitor:** Using Solar X-ray Monitor (XSM), a team of scientists from PRL derived the absolute abundances of elemental Mg, Al, Si in the quiet solar corona during the deepest observed solar minima. The team discovered and characterized around 100 "sub-A class" microflares in the quiet corona providing new insight into coronal heating puzzle.

Reference: https://doi.org/10.3847/2041-8213/abf35d

- **Young Glacial Landforms on Mars**: Geological investigation of glacial landforms in the Erebus Montes region (centered at 35° N, 175° W) of Mars revealed that episodic glacial flows have not happened in this region (Figure 3), which is contrary to the evidences observed elsewhere on Mars. Additionally, it has been found that Erebus Montes hosts glacial landforms as young as ~10-100 Ma.

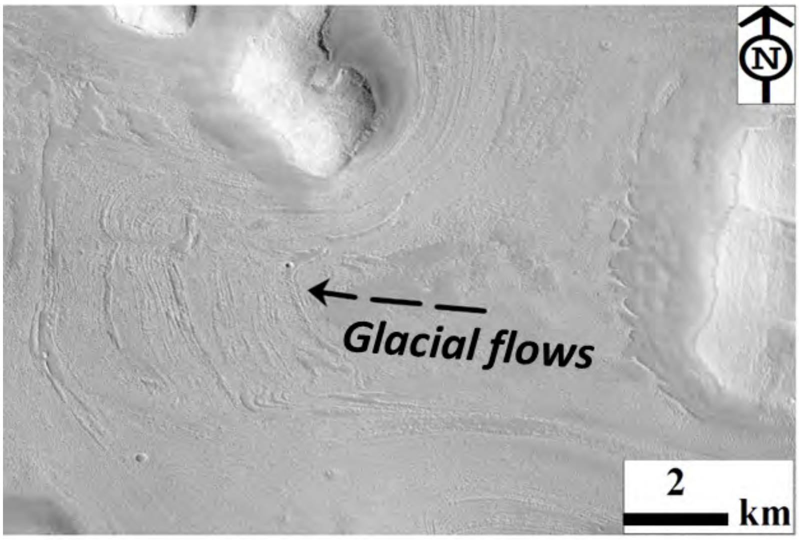

Figure 3: Glacial flows in the Erebus Montes region. Note that the superposed glacial flows from episodic glacial activities are not evident in this region.

- **Overlapping lobate debris at Mars**: For the first time, we have found morphological evidence of overlapping lobate deposits in gullies at 20 different locations on Mars. Overlapping lobate deposits are diagnostic evidence of water bearing debris flows in gullies (Figure 4).

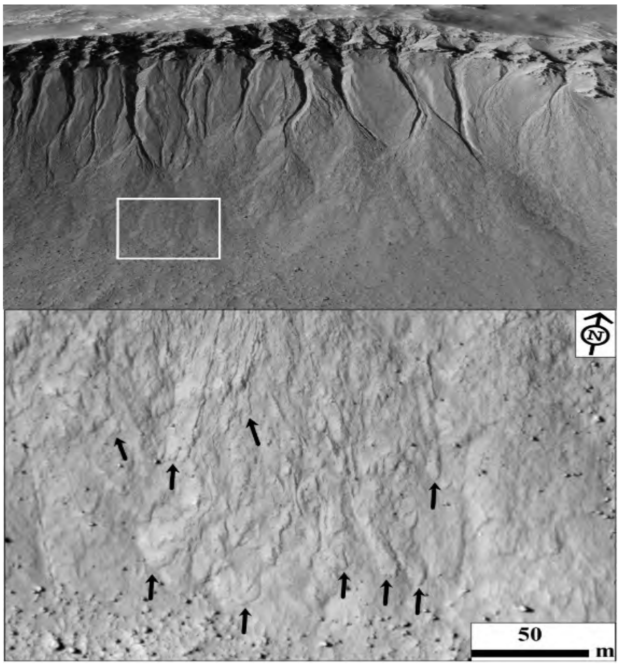

Figure 4: 3D view of gullies on the pole-facing wall of ~8 km diameter Los crater (35.08˚ S, 76.22˚ W) on Mars. Morphological evidence of overlapping lobate deposits (arrows in the bottom panel) on the gully fan at the foot of the crater wall slopes.

- **Active boulder falls at Jezero crater:** Discovery of active boulder falls in the Jezero crater (centered at 18.42°N, 77.67°E) – landing site of the Mars 2020 Perseverance rover (Figure 5). We propose that the surfaces of these freshly fallen boulders may provide an opportunity to sample material less exposed to radiation than other rocks at the Martian surface and could be ideal targets to analyze for organics.

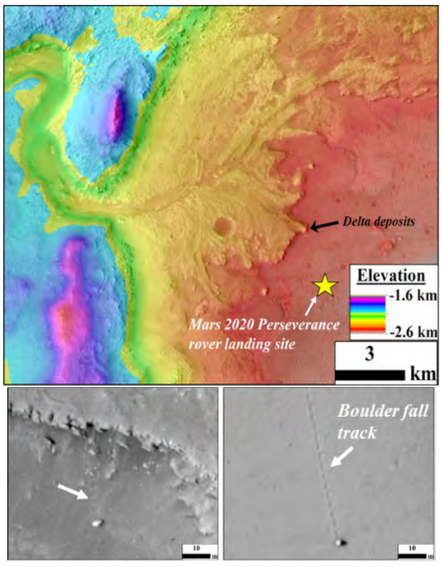

Figure 5: Active boulder falls spotted near the Mars 2020 Perseverance rover landing site. The boulder falls shown in the bottom panels could be potentially from recent seismic activity in the region.

- **Identification of new water-ice rich locations on Mars:** New exposures of water ice along the scarps wall located within craters in the northern midlatitude region of Mars.

The exposed ice is stable after one week of interval; this gives a direct proof for the stable exposed ice. Finding of shallow water ice at spatially different location reveals their widespread nature on Mars. Identification of such new water-ice-rich locations will have a vital role in identifying future landing/robotic missions on Mars and even for the in situ resource utilization (Figure 6).

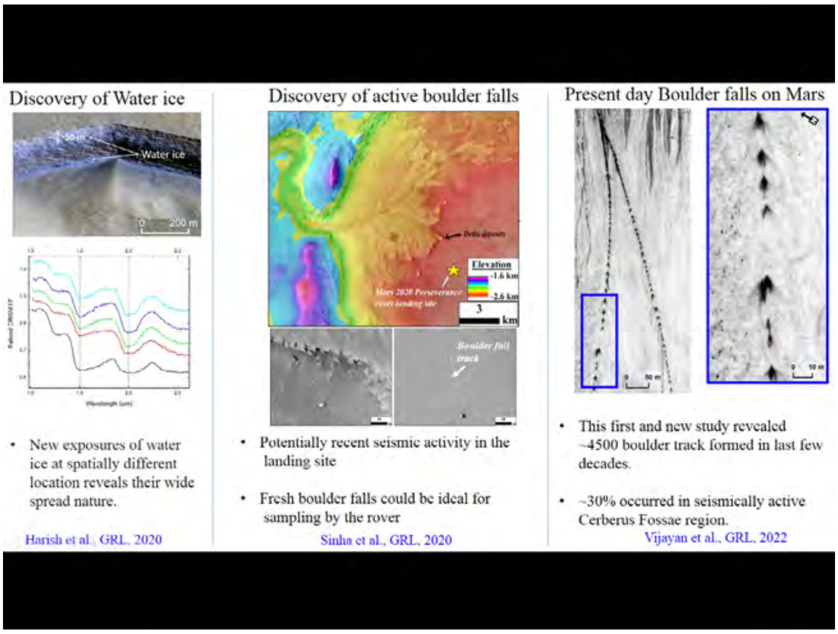

Figure 6: New exposures of water ice detected within a crater (bluish-white tone – water ice). Spectral signature derived from the ice exposures.

- **Study of seismic emission in sunspots associated with Lorentz force changes accompanying major solar flares**: Solar flares are known to generate seismic waves in the Sun. With a motivation to study seismic emission in sunspots accompanying major flares, we have used high resolution solar photospheric Dopplergrams and line-of-sight magnetograms at a cadence of 45 s, along with vector magnetograms at a cadence of 135 s obtained from Helioseismic and Magnetic Imager (HMI) instrument on-board Solar Dynamics Observatory (SDO) spacecraft. For information concerning the flare ribbons and hard X-ray footpoints location, we have used H-alpha and hard X-ray images in 12-25 keV band obtained from Global Oscillations Network Group (GONG) and Ramaty High Energy Solar Spectroscopic Imager (RHESSI) instruments, respectively. The detail investigation have provided evidence that abrupt changes in the magnetic fields and associated impulsive changes in the Lorentz force could be the driving source for the seismic emissions in the sunspots during flares. Moreover, the estimation of work done by change in Lorentz force and the observed acoustic energy over the seismic emission location reveal that change in Lorentz force of the order of 10^{21} - 10^{22} dyne is sufficient to drive the seismic waves in the sunspots.

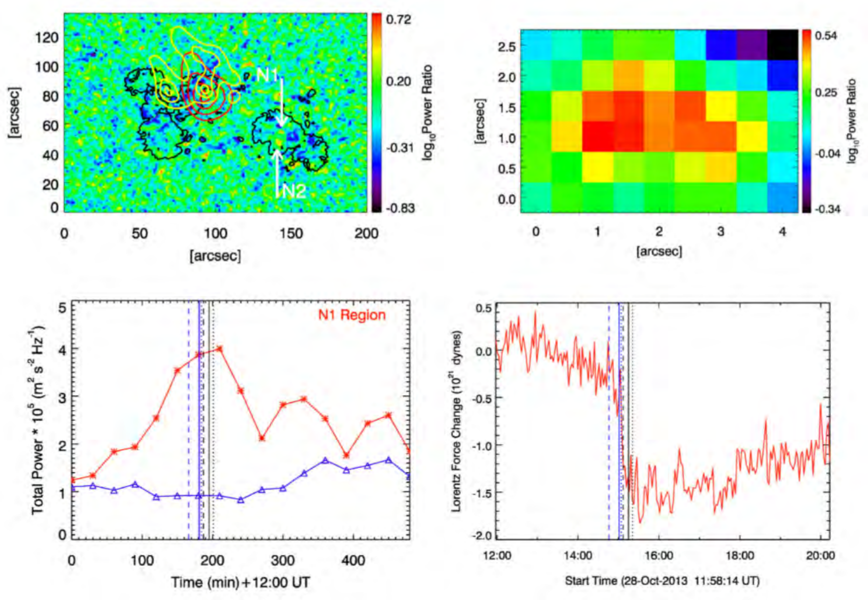

Figure 7 : A brief illustration of results obtained for the solar active region NOAA 11882. Top left panel: this illustrates the ratio of acoustic power maps estimated for spanning flare and pre-flare epochs in the 2.5–4 mHz band. Here, black contours represent the outer boundary of the sunspot penumbra, whereas the yellow contours represent flare-ribbon locations from the H-alpha observations from GONG. The red contours represent hard X-ray footpoints as observed in 12-25 keV band from RHESSI. Top right panel: illustrates the blow-up region of 'N1' enhanced location in the sunspot as indicated in the power map ratio. Bottom left panel: plots showing the temporal evolution of integrated acoustic power over the 'N1' location (red colour with asterisks) whereas that shown in blue colour with triangles represents evolution of total power in an unaffected region in the same sunspot. Bottom right panel: plot in red colour shows the temporal evolution of change in horizontal component of Lorentz force in the 'N1' location. The dashed, solid, and dotted blue and black vertical lines represent the onset, peak, and decay time of M2.7 and M4.4-class flares, respectively.

(H. Kumar et al., On the seismic emission in sunspots associated with Lorentz force changes accompanying major solar flares, *MNRAS,* **497**, 976-987)

- **Observations of solar storms in metric radio wavelengths by Udaipur-CALLISTO:** The real-time monitoring of solar storms is crucial for assessing the space weather conditions and protecting Indian space assets. The indigenously developed CALLISTO (Compound Astronomical Low frequency Low cost Instrument for Spectroscopy and Transportable Observatory) solar radio spectrometer, operating between 45 and 870 MHz with a frequency resolution of 62.5 KHz, has been operational uninterruptedly at the Udaipur Solar Observatory of the Physical Research Laboratory to observe the solar storms on real-time basis

(Joshi et al. 2021, **Two-Stage Evolution of an Extended C-Class Eruptive Flaring Activity from Sigmoid Active Region NOAA 12734: SDO and Udaipur-CALLISTO Observations**, Solar Physics, 296, 85)

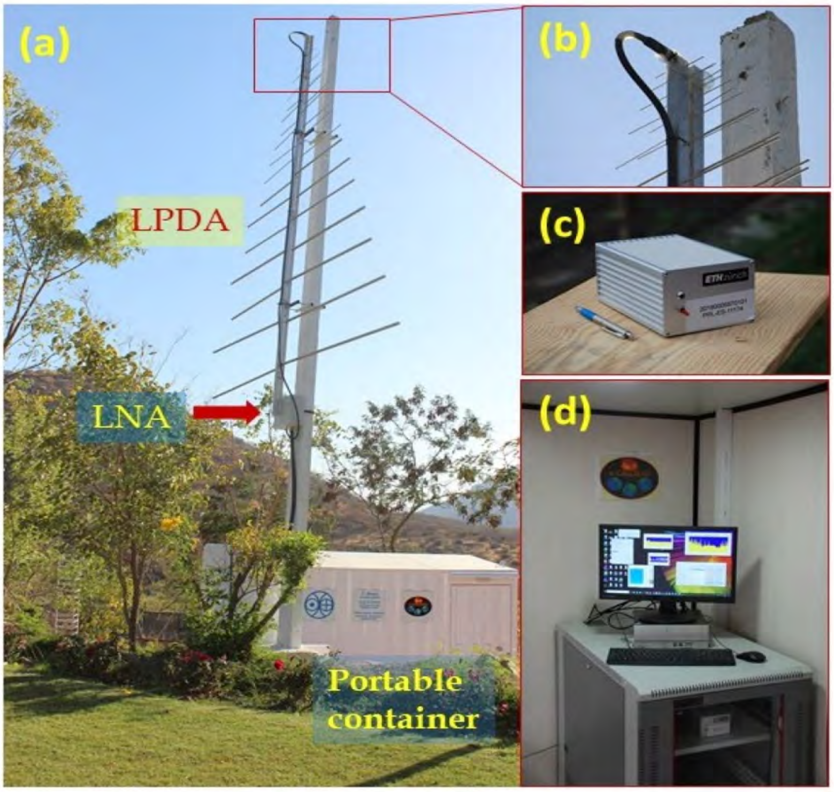

Figure 8: Various subsystem of Udaipur-CALLISTO. (a) Log Periodic Dipole Antenna (LPDA) of height 3.63 m which is mounted toward zenith. A Low Noise Amplifier (LNA), marked by red arrow, is connected between the LPDA and CALLISTO spectrograph. (b) Zoomed image of the top portion of LPDA. (c) Spectrometer. (d) Computer for data acquisition.

3.5 Instruments / Payloads / Products Developed / Sensors / Detectors

Chandrayaan-2/Chandrayaan-3: PRL has developed three scientific instruments for Chandrayaan-2 namely Alpha Particle X-ray Spectrometer (APXS) onboard Rover, Solar X-ray Monitor (XSM) onboard Orbiter and Chandra's Surface Thermophysical Experiment (ChaSTE) on-board Lander. The ChaSTE experiment is developed in collaboration with Space Physics Laboratory (SPL), VSSC.

Solar X-ray Monitor (XSM): XSM instrument provides the real time solar X-ray spectrum which is essential to interpret the quantitative elemental composition of the Moon from the orbiting satellite by the companion instrument Chandra's Large Area Soft x-ray Spectrometer (CLASS - developed at ISAC, Bengaluru). X-ray fluorescence from the Moon is critically depend on the intensity of the Solar X-ray falling on the Moon. CLASS instrument will provide the global elemental composition of the Moon using the XSM data. XSM instrument will provide high cadence (spectrum for every second) data with high energy resolution. XSM is working in the lunar orbit for more than 2 years providing many new science results.

Aditya-L1: Aditya Solar wind Particle EXperiment (ASPEX): ASPEX is a selected payload from PRL for Aditya-L1 Mission. The primary objective of ASPEX is to understand the solar and interplanetary processes (like shock effects, wave-particle interactions etc.) in the acceleration and energization of the solar wind particles from L1 point.

DISHA Dual-Aeronomy Satellite mission:

PRL is working on three payloads for this mission. They are LP (High frequency Langmuir Probe) for determination of electron densities and plasma waves, DM (Ion Drift Meter to obtain the major ion composition, ion temperature and ion-drifts which define the dynamics of the ionosphere-thermosphere regions), and AP (narrow bandwith and narrow field of view Airglow Photometer) addresses the spatio-temporal variations ion optical airglow emissions to understand the response of ionosphere thermosphere system under varying space weather conditions.

Venus Orbiter Mission:

PRL has proposed the following instruments for proposed Venus Orbiter Mission.

- Narrow band oxygen Airglow detection in Venusian Atmosphere (NAVA
- Venus Orbit Dust Experiment (VODEX)
- Lightning Instrument for Venus (LIVE)
- Venus Radiation environment monitor (VeRad)
- Venus Solar Soft x-ray Spectrometer (VS3

ISRO-JAXA LUPEX Rover:

The following instruments are proposed by PRL for ISRO-JAXA rover

Permittivity and Thermo-physical Investigation for Moon's Aquatic Scout (PRATHIMA): Objective of this instrument would be the in-situ detection and quantification of water-ice mixed with lunar surface and sub-surface soil using a rover/lander platform. The proposed experiment consists of a multipurpose probe that will be deployed into ~20-30 cm of the lunar surface to scout and quantify the presence of water-ice. This instrument is shortlisted to be flown on the LUPEX Rover and Lander.

The following instruments are under development for possibilities on lander/rover misison

- Low Energy Gamma Ray Spectrometer (LEGRS)
- Alpha Particle Spectrometer (APS)
- LUnar Micrometeorite EXperiment (LUMEX)
- Lunar Electrostatic Dust EXperiment (LEDEX)

Mars Orbiter Mission-2:

PRL has proposed and developing the following instruments for second Indian Mars Orbiter Mission under study. These instruments are at various stages of the development.

- Mars Orbit Dust Experiment (MODEX)
- Radio Occultation (RO) Experiment
- Langmuir Probe and Electric Field Experiment (LPEX)

Payloads under development for future missions:

- o **Venus Cloud Dynamics and Meteorology Experiment (VEDAM):** VEDAM is a meteorological suite with additional local imaging, wind velocity and particle size measurements.
- o **Miniature Neutral Mass spectrometer (MNMS):** This instrument would determine in-situ abundances of neutral species in the upper troposphere, Search for the presence of Sulphur and Chlorine compounds and Study of dynamics of the middle atmosphere of Venus clouds and their formation of different layers.
- o **Development Gamma-Ray Spectrometer for planetary Mission using scintillation detector:** Knowledge of elements such as Si, O, Ca, Mg, Al, Fe, Na, K, Th help in deciphering the origin and evolution of various solar system objects such as planets, satellites, and asteroids. A Gamma-ray spectrometer (GRS) is being developed to be flown on a future missions for such measurements.

Ground-based instruments:

1. **Development of a low-order Adaptive Optics system**: A low-order adaptive optics system is developed at USO for Multi-Application Solar Telescope (MAST) for compensation of atmospheric turbulence, thereby improving the resolution.
2. PAIRS: PRL Airglow InfraRed Spectrograph for OH emission measurements at 3-1 band is completed and put in operation from the Aeronomy observatory at Gurushikar, Mt. Abu.
3. A new CMAP (CCD-based Multiwavelength Airglow Photometer) is commissioned at Ahmedabad. This is in addition to the one in operation at Gurushikhar.
4. CDAP (CCD-based Daytime Airglow Photometer) has been developed to measure the OI 630.0nm daytime airglow emissions that are buried in strong solar background continuum.

Sensors/Detectors: Front-end electronics for the CMOS sensor chips have been designed and tested. Same for SCMOS chip is already designed.

3.6 Capacity Building in Space Science Research

PRL carries out several programs for capacity building and human resource development.

- PRL carries out research activities that lead to Ph.D. degree in several fields of research areas.
- PRL has a robust Post-Doctoral Fellowship program for post- Ph.D. candidates.
- In order to encourage Masters students in the fields of science PRL offers Summer internship trainings.
- For bachelors students in engineering, PRL offers Final semester project trainings.
- PRL conducts Structured Training Program for the ISRO's S&T staff.
- PRL also conducts the Space Sciences Course administered by the UNCSSTEAP in every two years wherein around 15 participants from several nations in the Asia pacific region participate. Several science and Technology staff and students are nominated for advanced training courses organized by different departments, institutes, agencies, and countries.
- PRL faculty deliver invited/solicited talks in various national/international meetings, as guest and plenary speakers.
- PRL organizers several conferences/workshop/ symposiums wherein several researchers, both from India and out of India participate. In the year 2021 the conferences/workshops relevant to the areas of space sciences that were hosted in PRL are: (a) Venus science conference 2021, (b) Meteoroids, Meteors and Meteorites - Messengers from Space (MetMeSS, 21):

In the year 2020-21 following number of students have been trained.

1) Ph.D.s: 2 completed + 3 ongoing
2) Post-Doctoral Fellows: 6 completed + 1 ongoing
3) Summer Internships in ONLINE mode: 21
4) Final Semester Projects ONLINE mode: 17
5) M.Tech. CSSTEAP: 01
6) SHE-INSPIRE (DST) Project training: 01

3.7 Courses offered on Space Science and Technology

PRL offers several course works, both at introductory and advanced level in various branches of space sciences to the students enrolled in Ph.D. program. The following PhD course work are offered in PRL

1. Introduction to near earth space
2. Dynamical, chemical and coupling processes in the Earth's atmosphere
3. Title: Solar Internal Structure and Dynamics
4. UV and X-ray Sun
5. Title: Solar Magnetohydrodynamics
6. Title: Coronal and Heliospheric Processes
7. Title: Instrumentation for Solar astronomy
8. Title: Planetary Atmospheres and Environment
9. Title: Planetary Geology
10. Cosmochemistry
11. Planetary Geochemistry
12. Planetary Remote Sensing

3.8 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	AstroSat/CZTI data analysis	TIFR- Mumbai, IUCAA-Pune
2.	Future X-ray astronomy mission	IIT-Bombay, Mumbai , RRI- Bengaluru, SAG-URSC, Bengaluru
3.	Ionospheric studies	NARL- Gadanki, India
4.	Geomagnetic storm effects on ionosphere	Andhra University, Visakhapatnam, India
5.	Ionospheric studies	IIG- Mumbai, India
6.	Space Science	IIG-Mumbai, SPL/VSSC, NARL (Gadanki), IIT-Roorkee, IIT-Indore, Dibrugarh University, Mumbai University
7.	Wave induced variability in the thermosphere	IIT, Roorkee
8.	Meteor characteristics in the lower thermosphere	University of Osmania
9.	Planetary Science	Anna University, Chennai, IIST
10.	Pulse Laser Testing Facility	IPR, Bhat, Gandhinagar
11.	High Voltage Lightning Testing Facility	CHARUSAT, Changa
12.	Scientific Research: Astrobiological and Geological investigations	School of Environmental Sciences, Jawaharlal Nehru University, New Delhi, India
13.	Scientific Research: Geological investigation of glacial landforms	Indian Institute of Space Science and Technology, Thiruvananthapuram, Kerala

Sl. No.	Area of Collaboration	Collaborating Institute
14.	Remote Sensing of Moon and Mars	Anna University, Chennai , IIST, Trivandrum
15.	Scientific Research: Reflectance spectroscopy of Martian analogues	MG Science Institute, Gujarat University
16.	Chandrayaan-1 and 2 data analysis	U R Rao Satellite Centre, ISRO
17.	Machine learning in Hyperspectral data analysis	Department of Computer Science, Gujarat University
18.	Hyperspectral data analysis	IIT Kanpur
19.	Noble gas isotopic and ratio in HED meteorites	Banasthali Vidyapith, Rajasthan
20.	Planetary Science	Allahabad university, UP
21.	Quaternary Science	Bharathidasan University, Tamil Nadu
22.	Solar Physics (Helioseismology)	IIA- Bengaluru, Kumaun University, VIT-Vellore
23.	Solar radio instrumentation	NCRA/TIFR

3.9 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1.	XSM data analysis and interpretation	Helio-physics group, DAMTP, Cambridge Uni. UK, NuSTAR Solar Physics group Solar Orbiter / STIX group NASA/GSFC Helio-physics group
2.	Ionospheric thermospheric investigations	Universidade do Vale do Paraiba (UNIVAP), Brazil
3.	Investigations on geomagnetic storm effects	Instituto Nacional de Pesquisas Espaciais, (INPE), Brazil
4.	Ionospheric modelling studies	Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy
5.	Space science	USA: Los Alamos National Laboratory, Utah State University, Laboratory for Atmospheric and Space Physics, Virginia Tech, Arecibo Observatory (Puerto Rico) Japan: Nagoya University Brazil: Instituto Nacional de Pesquisas Espaciais (INPE) Germany: GFZ German Research Center for Geosciences, Leibnitz Institute of Atmospheric Physics. Canada: University of Saskatchewan
6.	Lower thermosphere, mesophere	National Institute for Space Research, Federal University of Campina Grande, Southern Regional Space Research Center , Brazil

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
7.	Thermospheric dynamics	Leibniz Institute of Atmospheric Physics, Germany
8.	Martian Climate	Laboratoire de Météorologie Dynamique (LMD), France
9.	Venusian Lightning	UCLA, US
10.	Geological investigation of active processes on Mars	CNRS (Centre National de Recherche Scientifique), LPG (Laboratoire de Planétologie et Géodynamique), University of Nantes, France
11.	Geological investigation of Martian gullies	Department of Physical Geography, Utrecht University, Netherlands
12.	Scientific Research: Remote Sensing of the Moon	Technical University of Dortmund, Germany Max Planck Institute for Solar System Research, Germany
13.	Meteorites	Ulugh Beg Astronomical Institute, Uzbekistan Academy of Science, Astronomicheskaya 33, Tashkent, Uzbekistan Department de Geologie, Faculte des Sciences de Tunis, Universite Tunis El Manar, Campus Universitaire, 2092 Tunis, Tunisia ICATE-CONICET, Av. Espan˜a 1512 sur, 5400 San Juan, Argentina Department of Physics, University of Helsinki, Finland
14.	Quaternary Science	University of Wollongong, NSW 2522 Australia
15.	Solar Physics (Helioseismology)	National Solar Observatory, USA
16.	Solar physics, solar plasma physics	Institute of Physics, University of Graz, Graz, Austria
17.	Space weather, solar eruptions	Korea Astronomy and Space Science Institute (KASI), Daejeon, South Korea
18.	Space Weather consequences of Coronal Mass Ejections	Samarkand State University (SSU), Uzbekistan

3.10 Laboratories and Facilities Available for Space Instrumentation

Multi-layer coating facility for development of hard X-ray optics

PRL has initiated a program for the development of hard X-ray optics. The hard X-ray mirrors require alternate layers of high and low Z material, with the thickness of the orders of nano-meters, on suitable substrates. For this purpose, PRL has established a facility for multi-layer coating over a large area substrate. This facility is planned to be used for the development of the X-ray mirrors for hard X-ray telescope mission.

Payload Operation Center

PRL hosts the Payload Operation Center (POC) for the XSM payload onboard the

Chandrayaan-2 orbiter. The POC has the responsibility of the regular operation and the upkeepment of the XSM instrument.

Planetary Instrumentation Laboratory: The lab includes Electronics – Prototyping and advanced design, circuit design, Test and evaluation, Thermal chamber and clean room facilities that cater to the needs of payload development at various stages. These group of labs were involved in the development of scientific payloads for ISRO's planetary missions such as Chanddrayaan-1, 2 & 3, Aditya-L1 etc. The instrumentation is presently being carried out in the field of X-rays, gamma rays, Charged particles (protons and heavier particles), Neutral & Ion Mass spectrometer etc. The lab is also carrying out developments for the miniaturized electronics which includes hybrid components, ASIC developments etc. All necessary development facilities, test and measurement instruments are available in these labs.

Island Observatory: This laboratory/observatory has a 50 cm solar telescope with state-of-art back-end instruments developed in-house for measuring the solar magnetic fields and dynamics of the solar activity.

Adaptive Optics Laboratory: Main aim of the laboratory is to develop image restoration techniques, such as active and adaptive optics, which are also useful in on-line compensation of system induced errors in the space-based payloads. The lab is equipped with sophisticated laser interferometer for telescope (re-) alignment.

Clean Room for Payload Activity: IDSL Cleanroom: Two clean rooms of class 10,000 and Class 100 laminar flow tables are available for storage and testing of sensitive electronics, qualification and flight models of the developed payloads.

Planetary Remote Sensing Laboratory: To aid in the analysis of the remotely acquired data and assist in detector optimization for future missions, a Planetary Remote Sensing Laboratory has been established at PRL, Thaltej campus. In this laboratory, the measurements are carried out as a function of viewing geometry, grain size variations, mineral mixtures, and changes in environmental conditions.

SIMPEX Laboratory: This laboratory houses custom-developed chambers capable of simulating the environments of Moon and Mars. These chambers are facilitated with necessary test, measurement and analyzing equipment required for carrying out the target science experiments on analogue soils under simulated planetary environment.

Noble Gas Mass spectrometer : NGMS is a multi-collector mass spectrometer for isotope ratio measurement of noble gases and nitrogen. Determination of isotopic ratio and abundance of stable isotopes of Noble gases (He, Ne, Ar, Kr, Xe) and nitrogen in solid samples, mainly meteorites and returned samples from space missions.

Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS): LA-ICPMS is capable of analyzing highly accurate quantitative analysis of elemental concentrations through digestion of solid samples. The coupling of LA with the ICPMS has resulted in the development of in-situ analysis capability.

Electron Probe Micro Analyzer (EPMA): EPMA (Tungsten Filament) is principally used for the major element analysis of minerals.

Field Emission Electron Probe Micro Analyzer (HR-EPMA): HR-EPMA is principally used for the major element analysis of minerals.

X-ray Fluorescence Spectrometer (XRF): XRF is widely used for analytical technique in the determination of major and trace element chemistry of rock samples.

Nano Secondary Ion Mass Spectrometer (NanoSIMS) : NanoSIMS is a unique ion microprobe working at high lateral/Spatial resolution. It is based on a coaxial optical design of the ion beam and the secondary ion extraction along with magnetic sector mass analyser and multicollection system.

X-ray Diffraction (XRD): X-ray diffraction is used to obtain the information on the structures of crystalline materials.

Luminescence laboratory: Luminescence Laboratory is equipped with a Riso automated TL/OSL reader, and is utilized for luminescence dating of archaeological materials and sediments from various depositional environments of climatic significance.

Planetary Atmospheric Science Laboratory: Modelling, Instrumentation and Data Analysis for Planetary Lighting and Atmosphere

Interplanetary Dust Science Laboratory: Modelling, Instrumentation and Data Analysis for Interplanetary Dust Science

Spectrophotometer for spectral calibration of optical interference filters.

GPS/GNSS/IRNSS (NavIC) receivers operational in the space weather laboratory.

Laboratory Astrochemistry: The Astrochemistry laboratory in PRL has two major experimental facilities that can simulate the extreme conditions experienced in the Interstellar Medium (ISM) and the Solar System. The Simulator for Astro-Molecules at Low Temperature (SALT) is capable of recreating conditions commensurate to those experienced by the cold dust in the ISM. To understand the shock processing of dust in the ISM and impact-induced shock in the Solar System bodies, PRL has a dedicated High-Intensity Shock Tube for Astrochemistry (HISTA).

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CHAPTER-4

NATIONAL ATMOSPHERIC RESEARCH LABORATORY

Gadanki

4.1 About the Laboratory

National Atmospheric Research Laboratory (NARL), located at Gadanki near Tirupati, is an autonomous organization engaged in cutting edge research in atmospheric and space sciences with the vision of "Developing capability to predict the behavior of the earth's atmosphere through observations and modeling". Towards realizing this vision, NARL gives equal emphasis to technology development, observations, data archival and dissemination, data assimilation and modeling. The research and development activities at NARL focus on radio and optical remote sensing instruments, ionosphere and space physics, atmospheric structure and dynamics, clouds and precipitating systems, climate change, aerosols, radiation, trace gases and weather forecasting. NARL provides high-resolution upper air winds and weather forecast in support of rocket launches from SDSC, SHAR. NARL has a vibrant research program, capacity building and public outreach activity. NARL provides necessary experimental and computational facilities to atmospheric science community, both national and international, for conducting research and also disseminates the existing data.

4.2 Keywords

Atmospheric Science, Space Weather and Space Science, Climate Change, Planetary Science, Weather and climate modelling, Radar, Lidar

4.3 Major Research Domains

Research and Developmental activities at NARL are focused in the following domains.

- Clouds and Precipitation
- Aerosols, Radiation and Trace gases
- Weather and Climate modelling
- Atmospheric Dynamics and Coupling
- Ionosphere and Space Physics
- Radar Applications and Development
- Atmospheric Lidar Research and Development
- Space-borne Instrument and Development

4.4 Major Scientific Applications / Results

Studies on Ionospheric and Space Physics

- **Detection of Low-Earth-Orbiting objects using the AIR**

Space situational awareness is increasing worldwide. Also, knowledge of space objects and their signal characteristics are necessary to mitigate their effects on atmospheric signals. Currently, non-traditional instruments are also being used for enhancing the knowledge on space surveillance. For instance, phased array atmospheric radars are being used for such studies. Recently, the advanced Indian MST radar (AIR) has demonstrated its capability in detecting the low-earth orbiting objects. In order to assess the capability of detecting objects having sizes smaller than International Space Station (ISS) new experiments were conducted by configuring the AIR with different figure-of-merit by changing antenna aperture and transmitter power. To know the smallest size of object that can be detected by AIR, an experiment has been conducted on 11 November 2020 with 8x8 antenna array and a peak power of 64 kW. Strong returns from ISIS with an SNR of 22 dB (and a detectability of 30 dB) have been observed even with a small aperture. The observed SNR is nearly 25 dB weaker than that of the ISIS tracking experiment conducted on 18 February 2020 with the full antenna array. From these experiments, the smallest size of LEO object that AIR (in fully array mode) can detect is estimated as 0.05 m^2.

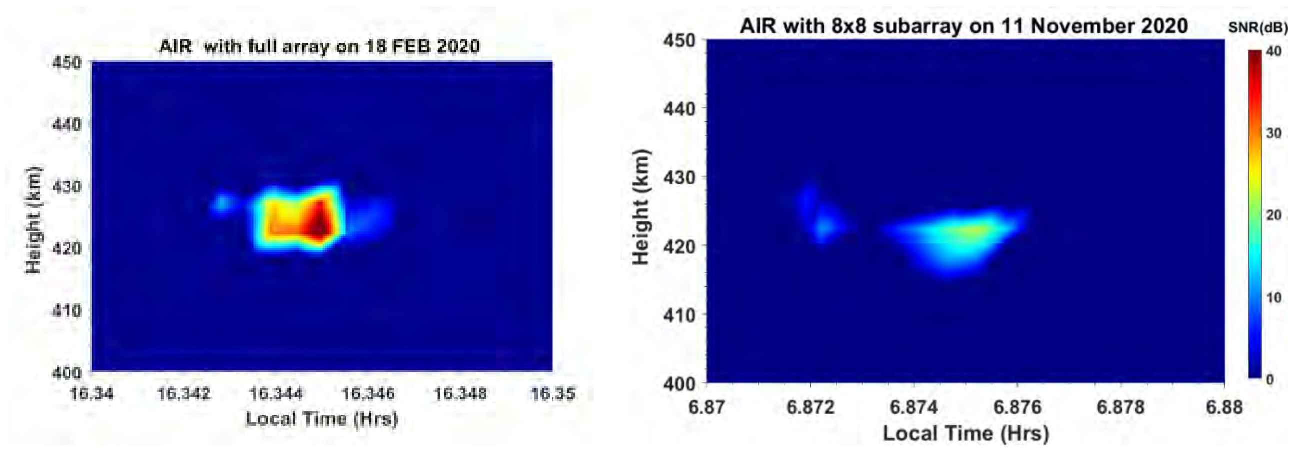

Figure-1: Time-height variation of SNR obtained from returns from ISS on 11 November 2020 and on 18 February 2020.

- **Airglow CCD imager observation of ionospheric plasma structures over Srinagar**

Under a collaboraitve research program between NARL, Gadanki and University of Kashmir, an all-sky airglow imager was installed in the University campus (34°N, 75°E, geographic). The motivation of this collaboration was to study ionospheric disturbances in the low midlatitude location over Srinagar and investigate low and mid-latitude coupling processes. It was also intended to investigate the role of underlying weather phenomena on ionospheric structures and disturbances. Figure illustrates a sequence of images observed on 6 May 2019, displaying prominent structures signifying enhancements and depletions in the airglow intensity coming from -250 km altitude. These are tell-tale of plasma density structures aligned in the north-south. Such structures are often observed in low latitudes close to the magnetic equator and are known to drift eastward. These plasma structures, however, are found to drift westward with a speed of -160 ms^{-1}, which is in contrast to their equatorial counterpart. The origin of these structures remains to be discovered.

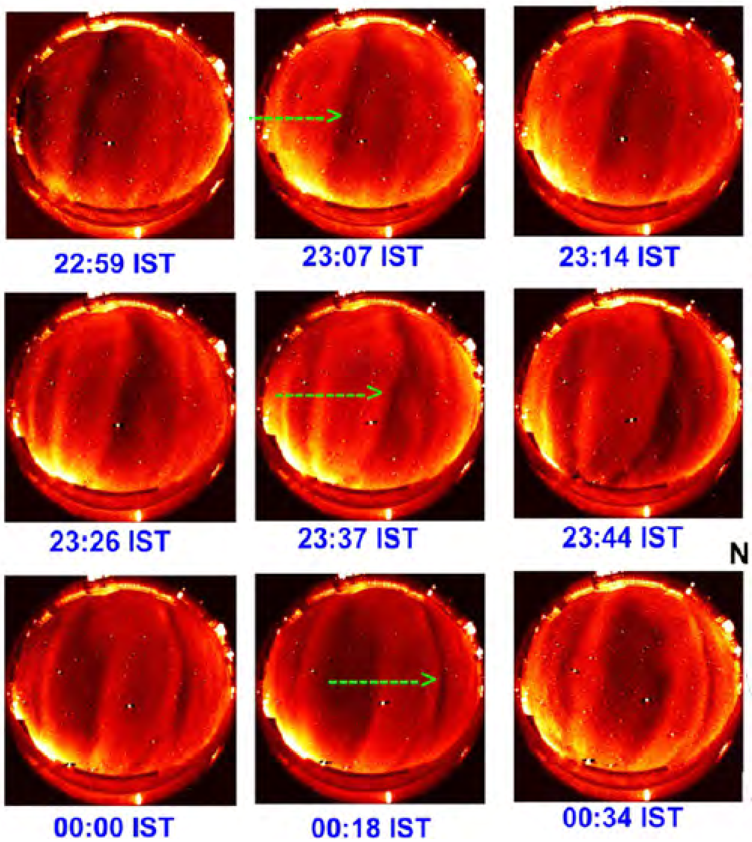

Figure-2: Plasma density structures observed with the 630 nm airglow CCD imager from University of Kashmir on 06 May, 2019. Images are obtained by subtraction of raw images from 30 min. time averaged images.

- **Ionospheric disturbances due to cyclones**

The impact of HUDHUD cyclone on ionosphere has been studied using GPS total electron content (TEC) and brightness temperature obtained from AIRS during 7-14 October 2014. The results reveal systematic propagation of wave-like short period TEC perturbations simultaneously seen from different locations. Concentric perturbations in the AIRS images provide evidences that these perturbations propagated through the stratospheric altitudes. Thus, direct linkage between cyclone generated gravity wave perturbations reaching to the ionosphere is established from this study. It is, however, puzzling to observe that such perturbations are not found on all the days and not everywhere during the passage of cyclone HUDHUD over different parts on Indian region as observed from distributed GPS receivers, underlining the role of intervening medium on the propagation of these disturbances to the ionosphere.

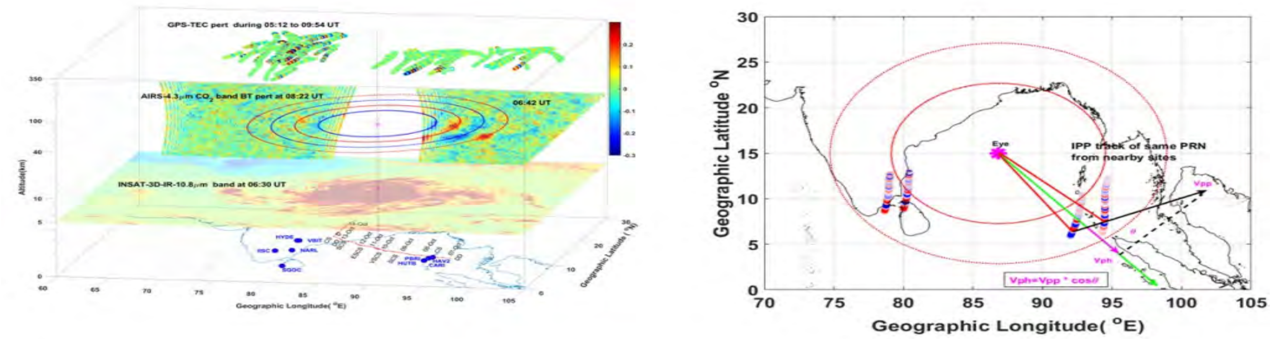

Figure-3: 3D graphics to represent altitudinal slices of observations using ground track of the cyclone, radiances from INSAT-3D at 10.8 µm at tropospheric altitude and from AIRS at 4.3 µm from stratospheric altitude; and GPS-TEC perturbations at ionospheric altitude. The concentric circles on AIRS observations are drawn to highlight the cyclone generated perturbations in radiance imagery with respect to the eye of the cyclone. Estimation of radial phase speed of ionospheric wave-like perturbations using GPS-TEC observations from different stations.

- **Frequency dependence of the mysterious 150 km echoes**

Dual-frequency observations made at 30 and 53 MHz from Gadanki showed frequency dependence of the 150 km echoes, which led to the conclusion that the electron density fluctuations responsible for the echoes are linked with some instability process. This process, however, was not identified. On the other hand, theoretical simulations suggest that the electron density fluctuations are due to photoelectron-induced enhanced incoherent scattering. Considering that incoherent scattering is frequency independent, this needs to be tested experimentally. In order to test this, coordinated observations have been conducted during June 2021 using 205 MHz radar from Cochin and 53 MHz radar from Gadanki. Initial analysis indicates that the echoes are not present at 205 MHz despite Cochin being close to the magnetic equator, while the echoes have been observed at 53 MHz radar from Gadanki. This result supports the earlier conclusion that some kind of instability must be involved. Further investigations are being carried out to elucidate the phenomena.

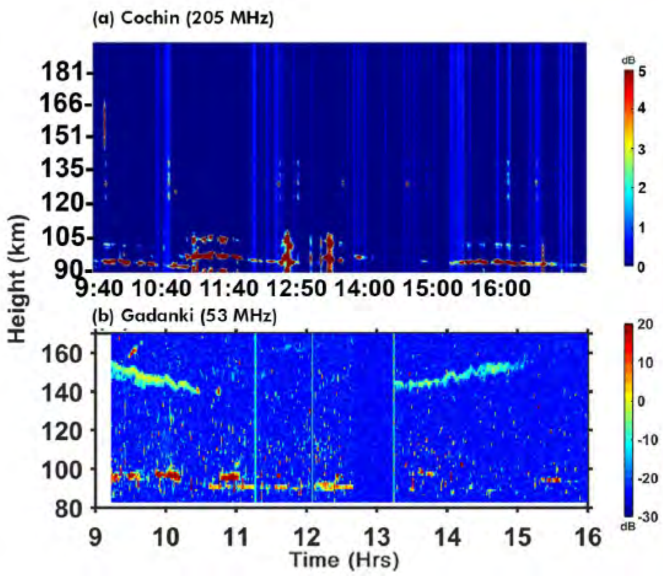

Figure-4: Height-Time variation of SNR observed on 15 June 2021 at a) Cochin (205 MHz) and b) Gadanki (53 MHz).

AI/ML Techniques for Atmospheric studies

- **Neural network based model for electron density in the Indian sector**

An artificial neural network-based model for electron density has been developed using electron density obtained from Digisonde observations located at Gadanki. A feed forward neural network with error back propagation has been used to train the network. The model output agreed well with the electron density obtained using Digisonde. Further, the model successfully reproduces the local time, day-to-day, seasonal and solar activity variations in electron density. The neural network-based model presented here is first of its kind from Indian sector, presenting local time, day-to-day, seasonal and solar activity variations of electron density during magnetically quiet conditions. As over-the-horizon radar (OTHR) uses ionospheric reflection to detect and track target, the new model is expected to play an important role in the application of OTHR.

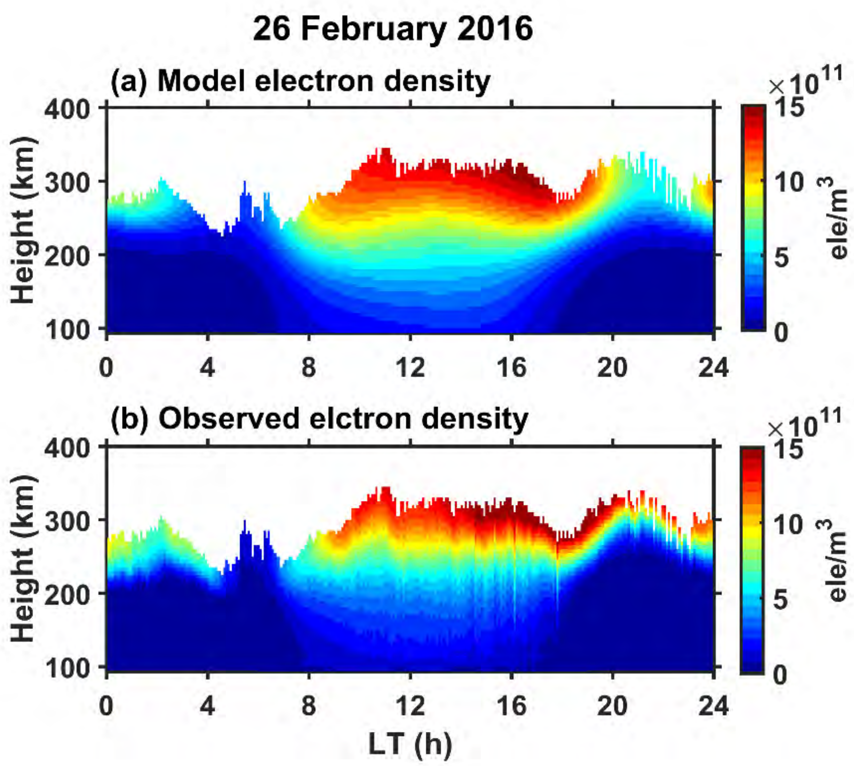

Figure-5: Electron density (a) obtained from neural network model and (b) observed using Digisonde located at Gadanki on 26 February 2016

- **Unsupervised Machine Learning Algorithm for Optimal Placement of GNSS Receivers in Indian Peninsular region**

An optimal GNSS receiver topology using the K-means clustering based unsupervised machine learning algorithm is implemented for the prediction of ionospheric structures. Different simulations are performed to use number of GNSS receivers over the Indian landmass such that the spatiotemporal coverage is maximized. The K-means clustering based approach is found successful in the optimal placement of the receivers within 300 iterations in each case. Then, the ionospheric pierce points (IPPs) are obtained for each satellite location pair considering an ionospheric layer at 350 km altitude. The optimization algorithm is tuned to adapt for maximization of grid cells which are above a threshold number of IPPs for any configuration (middle and bottom left panels in Fig.6. Then, a comparative analysis of varying size of the region boundary, the resolution of the grid cell, total number of receivers under two cases of GPS alone and multi-GNSS is performed (Fig.6). Finally, NeQuickG based ionospheric TEC is used to infer the impact of above variations in selection of final ground configuration of receivers. Results of this robust study provide a generic platform to place number of GNSS receivers (say 15 for NARL) to achieve a significant science objective in each case.

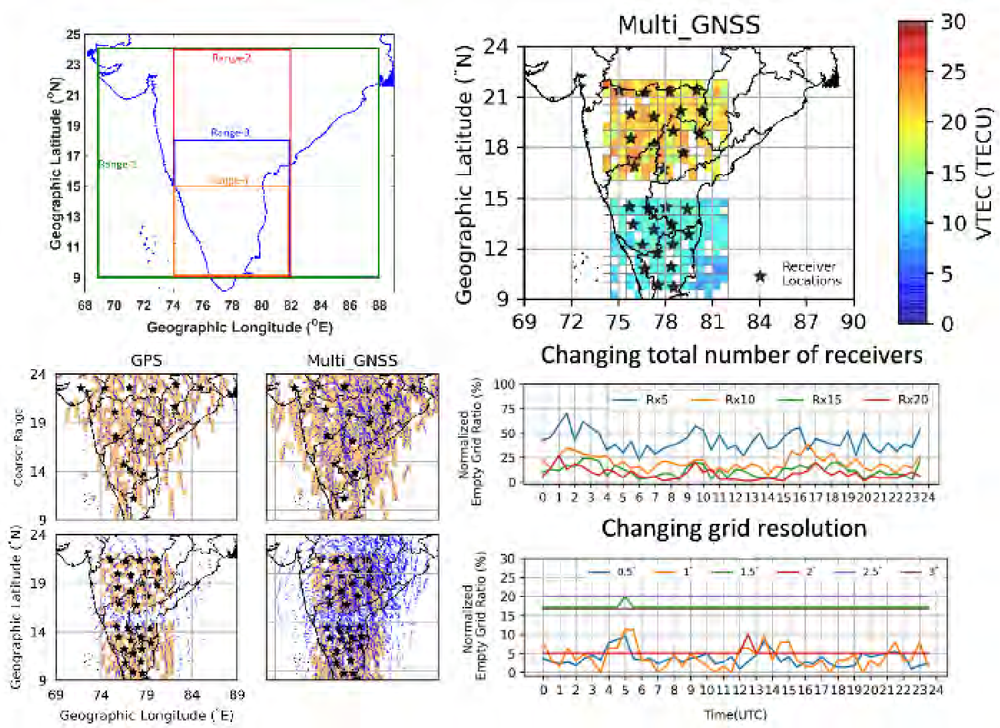

Figure-6: Different stages of Kmeans clustering algorithm for the optical placement of GNSS receivers.

Studies on the Martian Atmosphere

- **Enhanced escape of Martian atmosphere during global dust storm**

Thermosphere of Mars constitutes a reservoir of neutral and ionized species that are constantly affected by various forcings from above and below, leading to escape of some of its important constituents to outer space. During 2018 global dust storm, enhanced neutral densities below the exo-base (220 km) were simultaneously observed by MENCA onboard MOM and NGIMS onboard MAVEN spacecrafts. During this time, MOM observed the duskside, whereas MAVEN was on the dawnside. An examination of the densities measured by both NGIMS and MENCA shows that the densities, in general, decrease with an increase in altitude. Furthermore, the densities at a given height display a significant solar zenith angle (SZA) variability. Detailed analyses indicate large escape of Martian atmosphere.

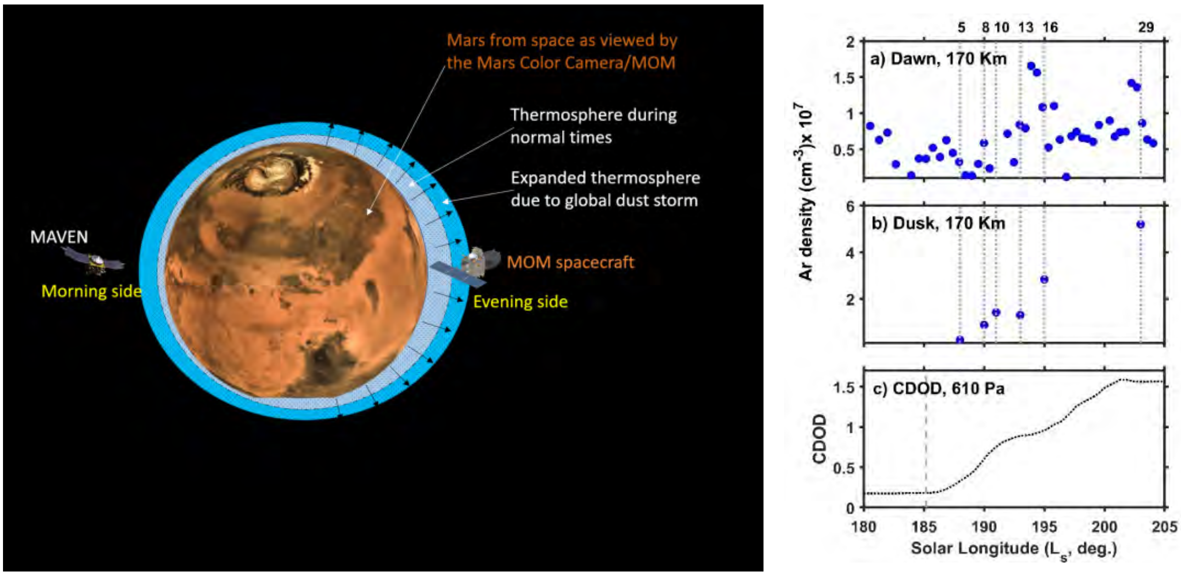

Figure-7: A schematic of Mars upper atmospheric expansion due to global dust storm. Solar longitude (Ls) variation of residual Ar densities at 170 km measured by (a) NG/MS/MAVEN on the dawn side and (b) MENCA/MOM spacecraft on the dusk side. (c) Column Dust Optical Depth (GOOD) at 9.3 µm.

- **Helium bulge anomaly in the Martian thermosphere**

Helium in the upper atmospheres of Earth, Venus, and Mars is known to accumulate on the nightside which is often referred as "He bulge." The upwelling of winds on the dayside and their downwelling on the nightside, combined with largescale circulation, is the primary driver of the bulge formation. The Mars Atmosphere and Volatile Evolution spacecraft and a general circulation model show the extension of He bulges into the southern polar region during equinoxes, which otherwise expected to occur at midlatitudes. These anomalous southern polar bulges in equinoxes are observed in regions where the observed winds point toward the southern pole (and are departed from the model winds). This indicates that the actual location of the local vertical advection is in the southern polar region which is different from that predicted by the general circulation model.

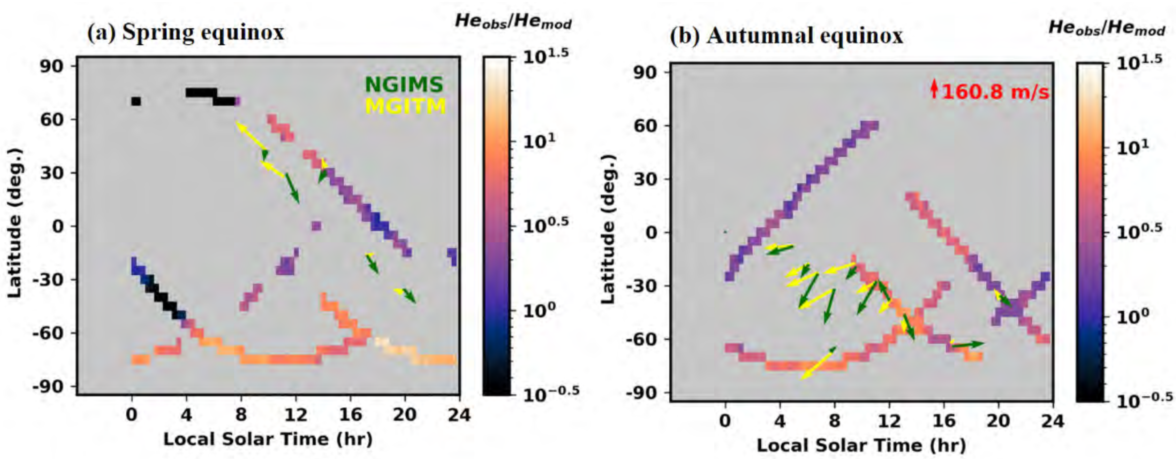

Figure- 8: Latitude versus local solar time variation of the ratios of the observed and modelled He densities (shown by color bar). The green and yellow arrows represent the winds observed by Neutral Gas and Ion Mass Spectrometer and modelled by MGITM, respectively. Tails of the arrows show the location of the winds, length of the arrows show the magnitude (reference magnitude is shown by red arrow in panel c) and heads of the arrows point to the direction of the winds.

- **Dust storm enhanced gravity waves in the Martian upper atmosphere**

Gravity Waves are ubiquitous in the Martian thermosphere with amplitudes of 10-20% of the background densities during nominal dust conditions (Ls:0-180° in Fig. 9a). Amplitudes of these waves are, in general, anti-correlated with the background temperatures (Fig.9b). During the 2018 global dust storm, however, amplitudes of the gravity waves are significantly enhanced to 30-40% (Ls: 180-360° in Fig.9a) and do not show any significant correlation with the background temperatures (Fig.9c). It is proposed that the global dust storm led to changes in the circulation of the mesosphere and lower thermosphere so that the modified circulation enhanced the upward propagation/reduced the filtering of GWs leading to their enhancement in the upper thermosphere.

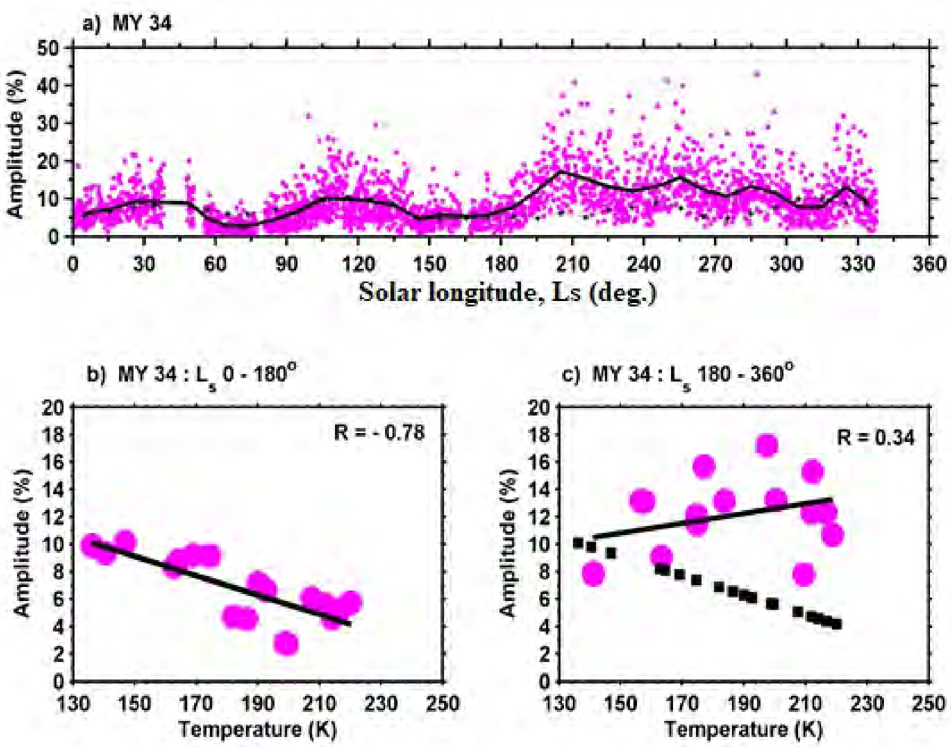

Figure- 9: a) Solar Longitude variation of the gravity wave amplitudes in Martian Year (MY) 34. The dotted line with "+" symbols in the top panel represents expected GW amplitudes and the solid line shows the average. Correlation between the gravity wave amplitudes and the background temperatures during b) Ls = 0°–180° and c) Ls = 180°–360°. Solid lines represent the fit curves. "R" represents the correlation coefficient. For comparison, the fit curve of panel "b" is again plotted in panel "c" as a dotted line.

4.5 Instruments / Payloads / Products Developed / Sensors / Detectors

- **Development of DIfferential Absorption Lidar (DIAL)**

A DIfferential Absorption Lidar (DIAL) system has been developed to measure ozone concentration in the troposphere and stratosphere for studying the role of ozone on stratosphere troposphere exchange processes. The DIAL system contains two 350 mm diameter telescopes as receivers and Excimer and Nd:YAG lasers for generating ON and OFF wavelengths. The backscattered signal is measured in photon counting mode. The system was operated and test experiments were carried out with 100 m range resolution and 8-minute time integration. The ozone concentration measured by the DIAL system compare well with mean ozone measured with ozonesonde in the month of November.

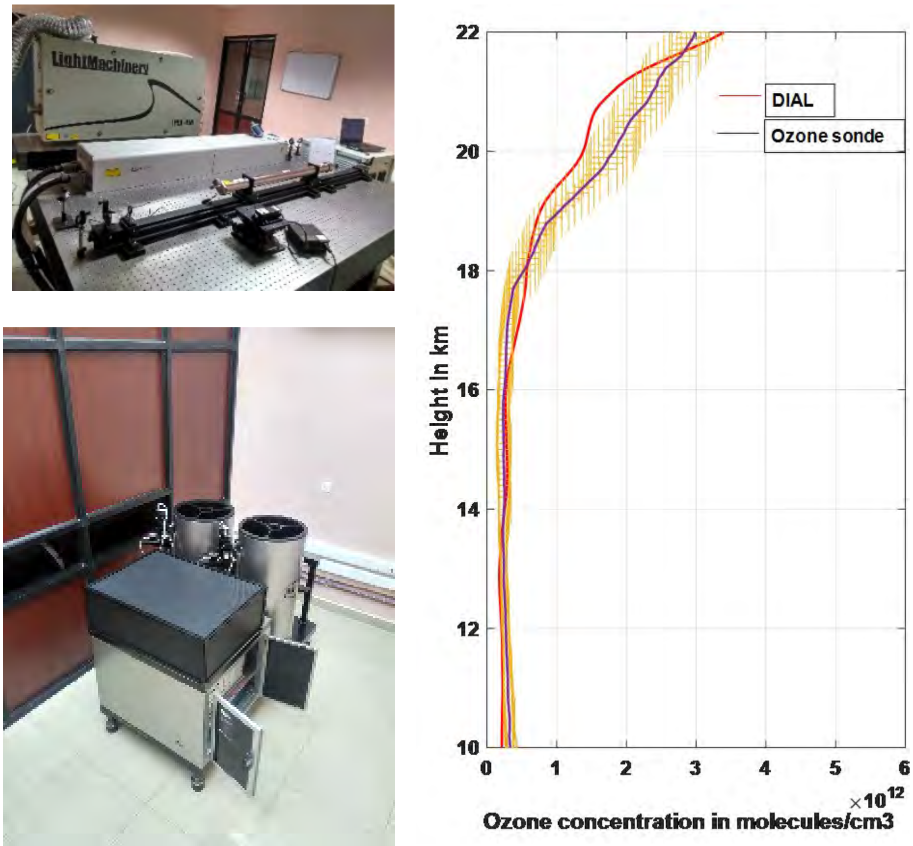

Figure-10: Newly developed DIAL system and comparison of ozone profiles obtained DIAL and Ozonesonde.

- ***Lightning mapping interferometer***

A two-dimensional, high-resolution lightning mapping system has been developed at NARL to map and study physical processes of lightning. The system operates in the frequency range of 20-80 MHz and can capture an individual lightning flash of duration up to 1 second. Generalized Cross-Correlation (GCC) and Multiple Signal Classification (MUSIC) techniques are used to generate two-dimensional maps of the lightning flash. Measured RMS errors in azimuth and elevation are 0.373° and 0.989°, respectively for source elevation of 13°. The time resolution of the generated maps is 1.2 µs. The time progression of these lightning maps made into an animation provides a detailed picture of the flash development and its progression.

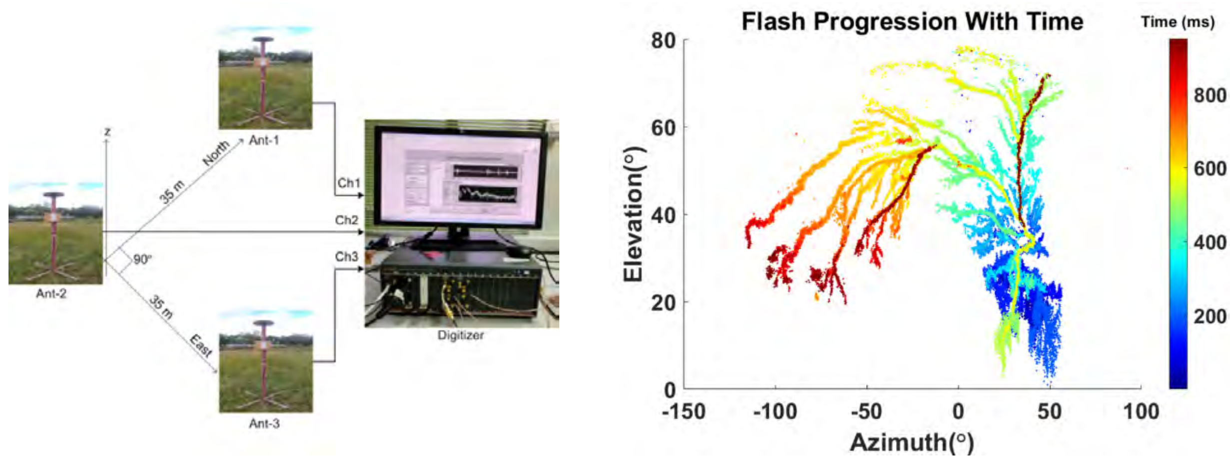

Figure-11: The time resolved two-dimensional map of lightning flash occurred on 30/07/2020 at 21:33:19 hrs.

- **Patent grant for an in-house developed lidar technology**

The technology patent for the development of Raman and Elastic backscatter lidar (CREBAL) that filed under ISRO has been with granted patent status in the year 2020. The invention was competed with a Chinese patent application bearing a no. CN200610105193 dated 20061220. The ISRO technology was found superior to the prior art in the following respects

The prior art has a limitation in the Tx-Rx configuration. It operates only in the monoaxial mode. The prior art uses multiple mirrors for directing the laser beam into the atmosphere. The prior art technology is limited to the zenith mode of operation. The prior art uses only photon counting electronics for detection.The developed CREBAL technology uses UV laser and profiles the boundary layer water vapour and aerosols during the night.

4.6 Capacity Building in Space Science Research

- NARL organised a virtual workshop on NavIC/GNSS during 3 – 5 August 2021 to impart education to stimulate interest in NavIC/GNSS applications and to strengthen collaborative research using NavIC/GNSS receivers.
- As part of the Cooperative research program using ST/MST radars, NARL conducted 5-day online tutorials on radar fundamentals.
- NARL scientists and engineers supervise student projects at bachelors' and masters' level to inculcate research culture among them. Through these projects they introduce advanced topics and instruments to the students, which also strengthen academia-institute collaboration.
- NARL has been recognized by several Universities as a prime research centre leading to Ph.D. degree in atmospheric science and technology and several of its faculties have been recognized as Ph.D. supervisor.

4.7 Courses offered on Space Science and Technology

Ph.D course work in Atmospheric Science and Technology to NARL research scholars.

4.8 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1	Anomalous Propagation	Indian Navy
2	Co-operative Research on ST/ MST radars	CUSAT, Cochin ARIES, Nainital Kolkata University and Gauhathi University
3	Microphysics of clouds	IIT Madras, Chennai
4	MLT dynamics	University of Kashmir, Kashmir

4.9 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1	Radar Remote sensing	Research Institute for Sustainable Humanosphere (RISH), Kyoto, Japan
2	GNSS/NavIC applications	CNES, France
3	Elevated Aerosol layers (BATAL)	NASA

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CHAPTER-5

U R RAO SATELLITE CENTRE

Bengaluru

5.1 About U R Rao Satellite Centre

U R Rao Satellite Centre (URSC), Bengaluru formerly known as ISRO Satellite Centre is the lead Centre for design, development, realization of communication, navigation, remote sensing, scientific and small satellite missions. The specialized teams of scientists, engineers and technicians of URSC have built more than 100 complex & advanced satellites for various applications in areas of telecommunications, television broadcasting, VSAT services, tele-medicine, tele-education, navigation, weather forecasting, disaster warning, search and rescue operations, earth observations, natural resource management, scientific and space science etc.

5.2 Keywords

Compact Objects, Sun, Space Weather, Magnetars, Moon, Planetary Atmosphere, Exo-planet, X-ray Instrumentation, UV Instrumentation, IR Instrumentation

5.3 Major Research Domains

URSC research on space experiments concentrates on the following major research area especially during the said period:

- **Physics of Compact Objects**
  - Black Hole Astrophysics – Observations, Modeling, Interpretation and Theoretical aspects of accretion dynamics.
  - LMXB-NS & Magnetars - Observations, Modeling, and Interpretation of emission mechanisms from weakly to strongly magnetized neutron stars.
- **Solar Physics & Space Weather**
  - Measurement and study of coronal magnetic fields to understand the dynamic processes occurring in the Sun.
  - Solar flare studies using X-ray observations of Sun.
  - Study of magnetospheric processes underlying space weather phenomena.
  - Measurement of energetic particles in the Earth's magnetosphere.
- **Lunar & Planetary Sciences**
  - Elemental mapping of Lunar compositions.
  - Modeling/Simulation of atmospheric composition in planetary atmospheres.

- **Exoplanet Sciences**
  - o Study of atmospheric constituents through polarimetric measurements and simulations; Concept and design optimization for Exoplanet imaging.
- **Instrumentation**
  - o End-to-end development of X-ray and NIR spectrometer payloads for space missions (Aditya-L1; XPoSat; Chandrayaan-3 Propulsion Module)
  - o Complete CCD electronics including control electronics required for mechanisms used for UV imaging payloads (Aditya-L1).
  - o Support for payload electronics, thermal design and analysis, facility and technical support with respect to polarimeters instrument (XPoSat)
  - o Development of critical hardware for Space science missions are also carried out by URSC (Mirrors and lens assemblies for Aditya-L1 & Chandrayaan-3 payloads; Advanced mechanism requirement for scientific payloads like Multiple operation entrance door mechanism, high precision linear scan mechanism, Deployable Exit Cover Mechanism, and boom mechanism for Aditya-L1; Critical thermal requirements for science payloads are also studied and implemented at URSC in close collaboration with the payload teams for all science payloads).
  - o Technical support and Clean room facilities (contamination control environment confirming to the specifications) for the integration and testing activities of UV imaging payloads for Aditya-L1 was provided.

5.4 Major Scientific Applications / Results

(A) Physics of Compact Objects

- **Black Hole and Neutron Star Systems**

  A detailed study of enigmatic black hole source GRS 1915+106 is carried out using *AstroSat* observations. Findings indicate that the source was in δ class with the detection of High Frequency QPO (HFQPO) features. Using wideband (0.7 – 50 keV) spectral modeling, source mass (12.44 − 13.09 $M_{\odot}$) and spin (0.990 − 0.997) are constrained (*Sreehari et al. 2020*) simultaneously.

  A persistent black hole source Cyg X-1 was continuously monitored by *AstroSat* during last six years. For the first time, we are able to capture the X-ray photons from the vicinity of the black hole when the source was in 'extremely' soft state. Further, wide-band spectral modeling using *AstroSat* observations confirms the similar characteristics and put a constraint on the nature of the source, which is found to be extremely rotating (*Kushwaha et al. 2021*).

Galactic black hole as well as ULX sources are dynamic (i.e., persistent, outbursting) in nature. An in-depth analysis and modeling of the sources were carried out using observations from multiple space observatories in order to understand the evolution of spectral and temporal properties of the sources indicating that the accretion processes are 'probably' controlled by two types of flow material – Keplerian and sub-Keplerian (*Das et al. 2021, Baby et al. 2021, Bhuvana et al. 2021, Katoch et al. 2021, Baby et al. 2020*).

For the first time, URSC team employed Machine Learning (ML) algorithms on classification spectral states of outbursting black hole binaries using multi-mission observations. Findings indicate that clustering algorithms club together the observations of similar characteristics more efficiently than the 'standard' method of spectral state classification (*Sreehari & Nandi 2021*).

(B) Solar Physics & Space Weather

- **Solar Physics – Spectroscopic and Spectropolarimetric observation of Corona**

  Aditya-L1 is India's first solar mission with the visible emission line coronagraph (VELC), which consists of three spectral channels taking high-resolution spectroscopic observations of the inner corona up to 1.5 RΘ at 5,303, 7,892, and 10,747 Å. In this study, optimization of the VELC using synthetic line profiles by taking into account the instrument characteristics and coronal conditions for log(T) varying from 6 to 6.5. The synthetic profiles are convolved with simulated instrumental scattered light and noise to estimate the signal-to-noise ratio (SNR), which will be crucial to designing the future observation plans.

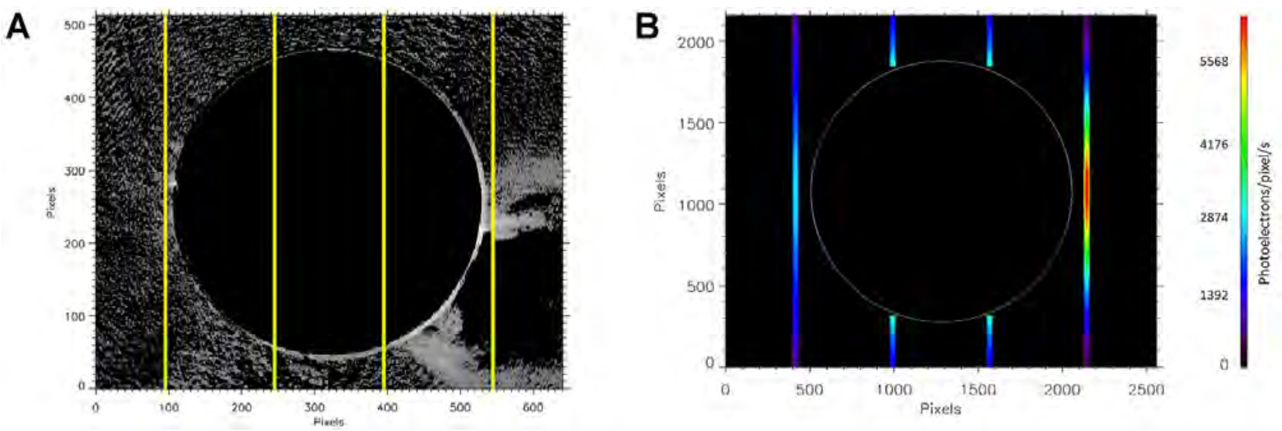

***Figure-1**: Optimisation of slit width of VELC*

An optimum slit width for VELC turns out to be 50 μm, providing sufficient SNR for observations in different solar conditions and also retaining good spectral resolution. The effect of plasma temperature on the SNR was also analysed at different heights in the VELC field of view for the optimized slit width.

- **Space weather phenomena and magnetospheric processes**

  The Earth's geomagnetic tail is a dynamic region that hosts a multitude of plasma processes governed by interactions of the magnetized solar wind with the Earth's magnetosphere. The observations of charged particle flux from CLASS instrument on-board the Chandrayaan-2 orbiter; indicate the presence of dynamical processes occurring in geomagnetic tail. Analysis of the observations indicates that there could be acceleration of electrons happening even during quiet-time of magnetospheric / solar activity in the distant geotail at lunar distance from Earth.

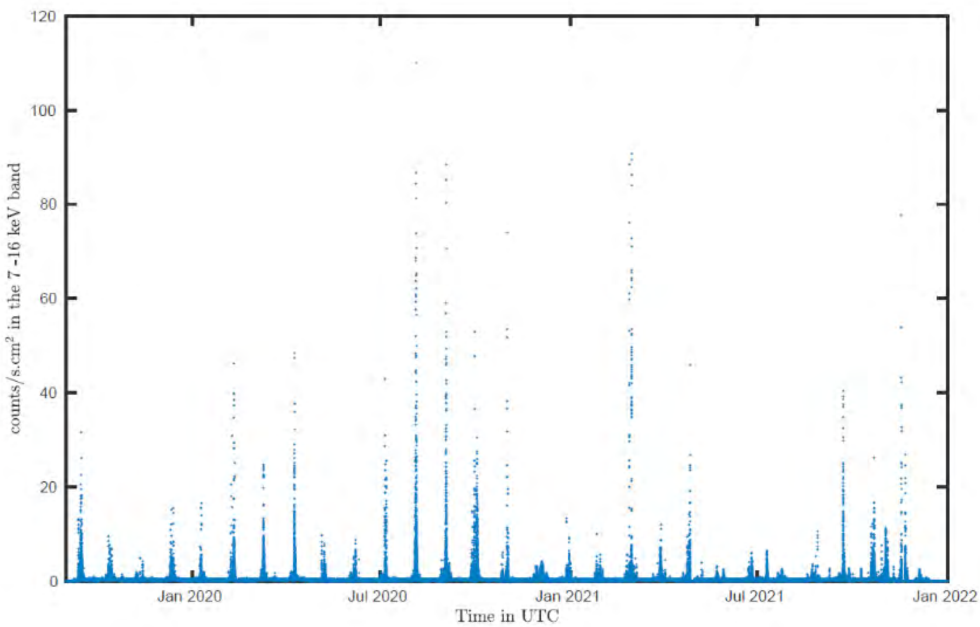

***Figure**-2: The enhancements in counts from CLASS payload onboard CH-2, as it periodically passes through the geomagnetic tail.*

(C) Lunar & Planetary Science

- **Lunar Science: Elemental mapping of Lunar composition**

  Elemental maps of the highest spatial resolution ever were generated from the X-ray fluorescence spectra measured by CLASS on Chandrayaan-2. A first result of from CLASS observation clearly indicates the detection of elemental composition from the Mare Imbrium region (*Netra et al. 2021*). Sodium, a moderately volatile element is being mapped with CLASS for the first time which gives new insights to its distribution on the lunar surface.

- **Planetary atmospheric research: spectro-polarimetric signatures of atmospheric compositions**

  Study of polarisation of sunlight scattered from planetary atmospheres can help to study the composition as well as size distribution of clouds and aerosols present in the atmosphere. A 'vector' Radiative Transfer Model is developed to study the difference in the scattered polarization from the atmosphere for various conditions on Mars (*Jaiswal et. al., 2021*). Simulation also carried out to study the variation in the 1.43 μm CO_2 absorption band in the Venus atmosphere observed due to change in the cloud top altitude of Venus Sulphuric acid clouds.

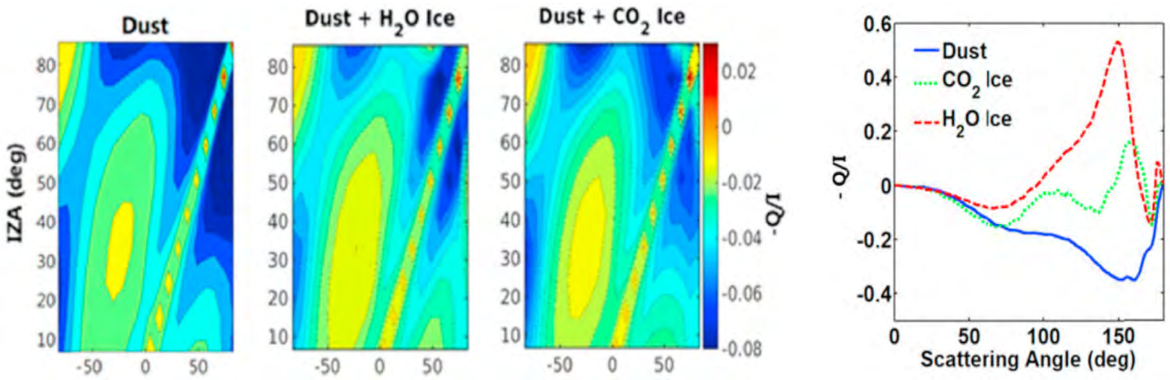

Figure-3:*Left - Multiple scattering polarization signatures of Martian compositions in Nadir observation geometry. Right – Single scattering polarization of the same.*

(D) Exoplanet Science

The study of Exoplanets helps us to explore a plethora of new worlds and allows us to probe the variety of atmospheres on these planets. Exoplanet Direct Imaging technique requires ‘nulling’ of the star-light to a very high level in order to see the faint reflected light of the planets around it. Towards this, a novel concept of a stellar coronagraph is developed with the help of polarization optics. The concept is called as Angle Sensitive Achromatic and Polarizing (ASAP) Coronagraph (*Jaiswal, 2021*). It is planned to further explore this concept, both theoretically and experimentally, in order to study its feasibility for a space mission.

5.5 Instruments / Payloads / Products Developed / Sensors / Detectors

URSC is carrying out end-to-end development of many science payloads as well as contributing towards realization of scientific instruments developed in collaboration with Institutions and other ISRO Centres. Significant progress was made in the development of scientific instruments for Aditya-L1, XPoSat and Chandrayaan-3 propulsion modules during the period from July 2020 to Dec 2021 as summarized below.

SoLEXS: Solar Low Energy X-ray Spectrometer

SoLEXS on Aditya-L1 is a soft X-ray spectrometer (1 keV to 30keV) for studying solar flares. The main science goals of SoLEXS are: (i) Flare and coronal abundance studies as a standalone spectrometer and (ii) Dynamical events studies along with other payloads. In addition to the flare & coronal abundance studies, the heating mechanism of these flares, pre-flare activities indicating the flare initiation mechanisms and the coronal abundances and hence the FIP Effects will also be studied.

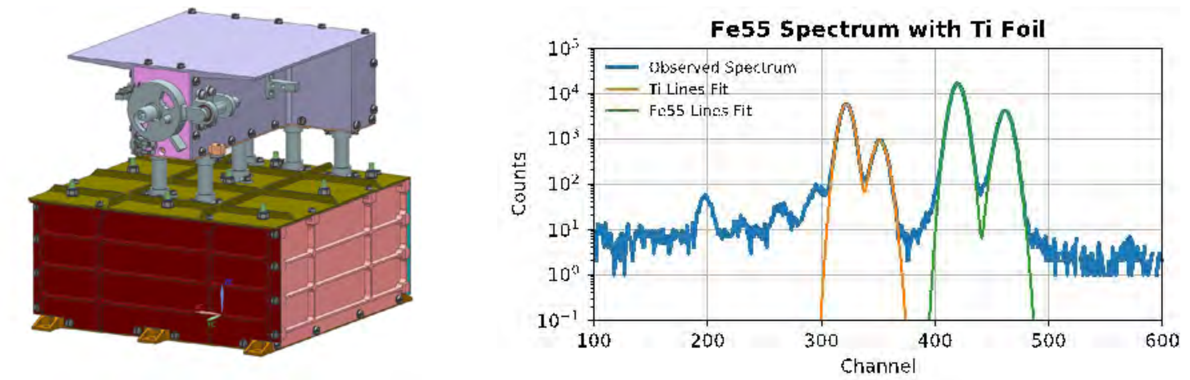

Figure-4: *SoLEXS payload model; Calibration spectrum acquired with Fe-55 radioactive source*

Silicon Drift Detectors (SDD), which have high count rate capabilities are used. The spectroscopic signal processing modules like shaper, baseline restorer, peak detector, pile-up rejecter etc. are developed in digital domain, entirely into FPGA module. Key instrument specifications are; energy range 1-30 keV, Spectral resolution: < 250 eV @ 5.9 keV keV, Flare coverage: A to X-class. The Shutter Mechanism is developed as per SoLEXS payload requirement for aperture cover during ground/launch operations and deploy in orbit for payload operations.

HEL1OS: High Energy L1 Orbiting X-ray Spectrometer

HEL1OS on Aditya-L1 is a hard X-ray spectrometer (10 keV to 150 keV) to observe Sun as a star continuously from L1 point. The main science goals of HEL1OS are to study particle acceleration processes during flares, via emission of hard X-rays (HXR) during the impulsive phase of solar flare. It is an instrument supporting multi-wavelength observations of eruptive solar phenomena.

The instrument consists of two types of detectors, Cadmium Zinc Telluride (CZT) and Cadmium Telluride (CdTe), to cover the required spectral range (10 keV – 150 keV).

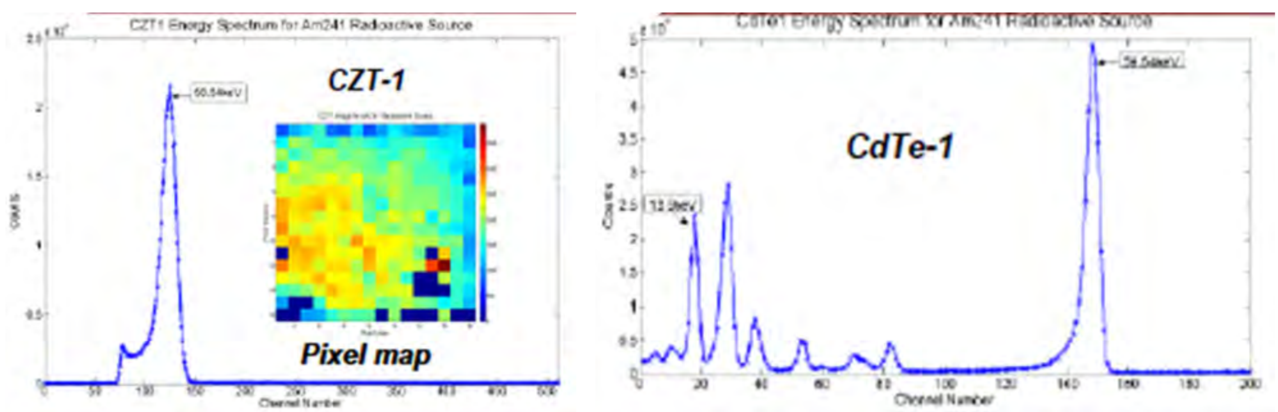

Figure-5:. *Performance of EM detectors (2 CZT and 2 CdTe) showing sample spectra of each detector.*

SUIT: Solar Ultraviolet Imaging Telescope

SUIT will observe the Sun in the 200-400 nm spectral range with 11 channels (3 Broadband & 8 Narrowband filters). SUIT is a collaborative project between Inter-University Centre for Astronomy and Astrophysics [IUCAA], Pune and URSC along with LEOS and IISU. A 4K x 4K CCD detector is used for capturing the solar disc image.

URSC is primarily responsible for the development of space qualified SUIT mirrors (M1 & M2) and also payload electronics package, which includes the CCD detector electronics, FPGA-based CCD clock and bias generation circuit, constant current based LED control circuit, SDRAM-based storage for Image formation and storage and motor electronics modules. Multiple operation Entry Aperture Cover Mechanism developed by URSC for SUIT payload covers the telescope aperture during ground and deploy in orbit, provides contamination protection and enable multiple open/close operations in orbit.

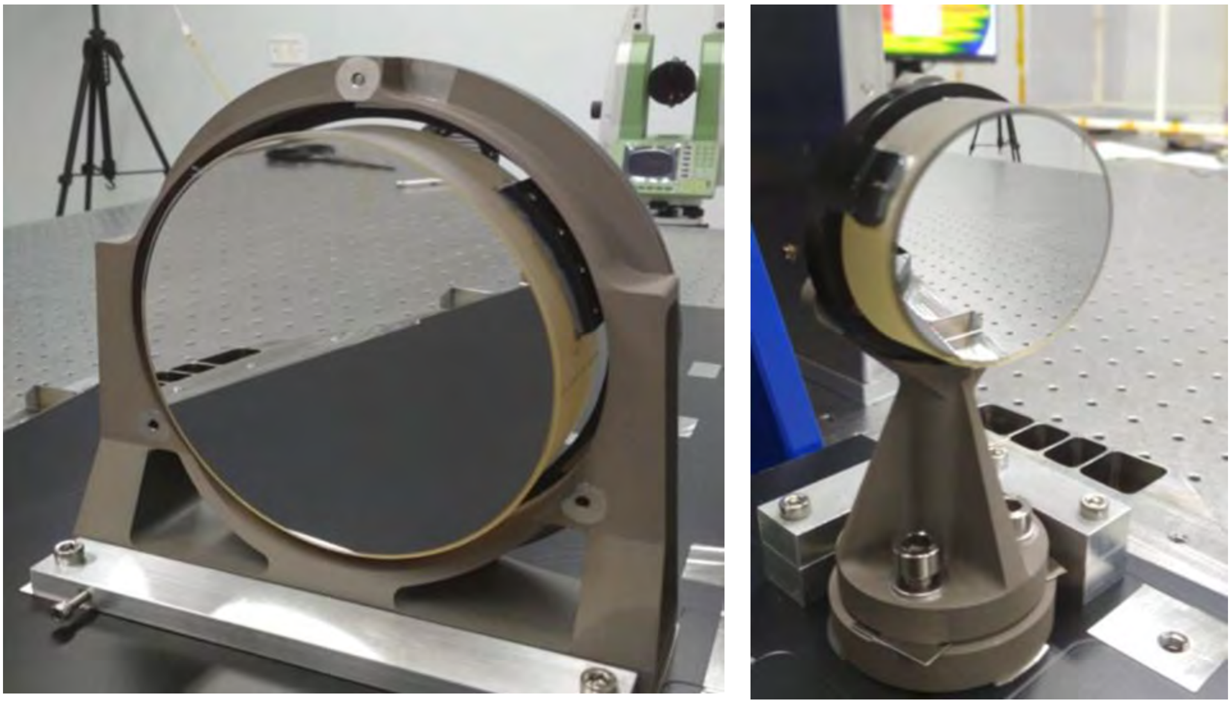

Figure-6: *SUIT primary (left) and secondary (right) mirrors along with the mounts developed by LEOS-URSC.*

FGM: Fluxgate Magnetometer

In Aditya–L1 mission, a pair of Flux Gate Magnetometers will be flown. The FGM instrument is a dual range 3-axis sets of magnetic sensors be mounted on a 6m boom (one at the tip and other at the mid-way of the boom). The design and development of the magnetic sensors, deployable 6m Magnetic Boom including the boom Testing at the Magnetic Test facility are the challenging aspects accomplished during the period.

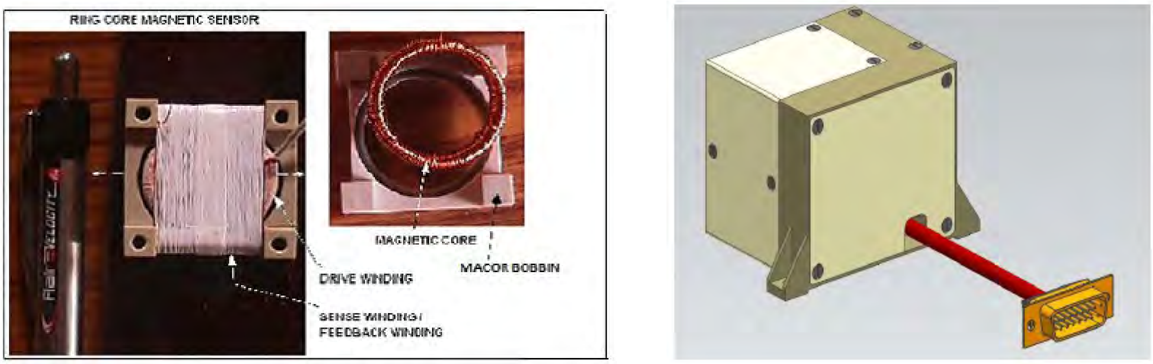

Figure-7: *One of the MAG Sensor (left) and package (right) of size 87 X 66 X56mm developed by URSC.*

VELC: Visible Emission Line Coronagraph

Visible Emission Line Coronagraph (VELC), the prime payload on-board Aditya-L1 mission is a collaborative project between Indian Institute of Astrophysics [IIA], Bengaluru and URSC. The Centre contributed in the thermal design and analysis of the VELC payload, optical design of the mirror and lens assemblies, development of Multiple operation Entry Aperture Cover Mechanism, Deployable Exit Cover Mechanism as well as Payload Drive electronics during the period.

XSPECT: X-ray spectroscopy and Timing on XPoSAT

XPoSat is India's X-ray polarimeter mission carrying POLIX (A Thomson scattering polarimeter) and XSPECT (X-ray Spectroscopy and Timing) payloads. XSPECT is large area spectrometer payload and has a unique opportunity to observe astrophysical sources for very long durations to study their spectral and temporal variability in 0.8 to 15 keV x-ray band.

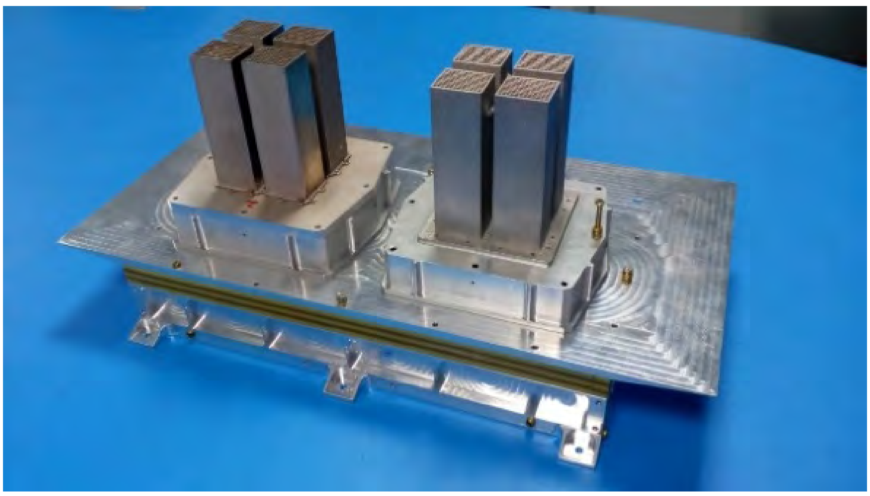

Figure-8: XSPECT detector package.

XSPECT is configured as two detector packages connected to a single electronics packages, which powers the detectors and does the necessary signal conditioning and has interface with spacecraft. Two different Field of Views (FOV) collimators, 2°X2° and 3°X3 are used enabling us to efficiently model-out the X-ray sky background. Swept Charge Device (SCD)s are used as detectors (effective area of ~35cm2 @ 6keV). These detectors enable XSPECT to have pile-up free observations at the expected count-rates with a very good energy resolution of less than ~ 200 eV @ 5.9keV. XSPECT provides a timing resolution of ~2 msec.

Polarimeter Instrument in X-rays (POLIX): The POLIX payload on-board XPOSAT aims at measuring the degree and direction of polarisation of X-ray photons from about 50 potential cosmic sources of interest in the energy band 8-30 keV. The instrument is being developed by Raman Research Institute, Bengaluru with the support of URSC.

SHAPE: Spectro-polarimetry of Habitable Planet Earth onboard Chandrayaan-3

SHAPE is an experiment on-board Chandrayaan-3 Mission for the study of spectro-polarimetric signatures of the habitable planet Earth in the near-Infrared (NIR) wavelength range (1 – 1.7 µm). The spectro-polarimeter is mounted on the Propulsion Module (PM) of Chandrayaan-3 mission. The payload will observe full-disc Earth from a distant vantage point, Moon, in order to 'mimic' Earth-like Exo-planets.

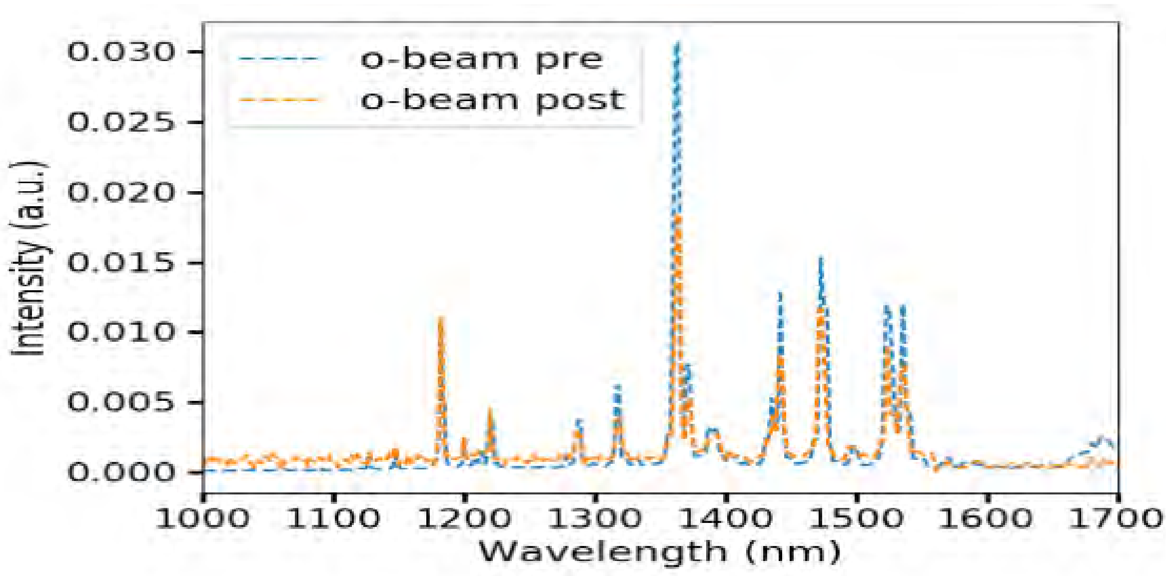

Figure-9: Performance spectra of AOTF (pre- and post-vibration).

SHAPE is being designed with two packages: (1) Electro-optical Detector System (EODS) (2) Radio Frequency Source (RFS).

Instrument for Lunar Seismic Activity Studies (ILSA)

The major objective of ILSA payloads configured in Lander Module is recording, classifying and cataloguing lunar quakes during the mission period thereby studying the seismicity at the landing site. The instrument can also record vibrations due to artificial activities helping to study the transmission characteristics of the lunar top soil.

The ground acceleration due to quakes in the lunar surface is expected to be less than a few milli-g amplitude. The overall dynamic range is covered by the fine range and coarse range sensors. The operating range for fine sensor is better than 100 nano-g Hz– ½ to 3 milli-g and that of coarse sensor is 150 µg to 500 milli-g. The instrument is communicating to Lander via 2m cable from its location of operation.

Laser Induced Breakdown Spectroscope (LIBS) Instrument for Chandrayaan-3

‘Laser Induced Breakdown Spectroscope (LIBS)’ – is a scientific payload developed at *Laboratory for Electro-Optics Systems (LEOS), ISRO* for the rover module of Chandrayaan-3 mission. The developed LIBS can perform in-situ elemental studies on any kind of planetary surface and the current version will aid in detection of 16 major elements (H, C, N, O, P, S, Na, Mg, Al, Si, K, Ca, Cr, Fe, Mn and Ti) that are commonly found in major lunar-rock forming minerals. This instrument works on the principle of ‘laser induced plasma emission spectroscopy (LIPS)’ technique that use high peak power laser pulses for the surface ablation and intense plasma plume generation. LIBS payload is capable of recording emission signatures in the spectral region of 220 nm – 800 nm with a resolution of 0.35 nm/pixel.

LIBS for Chandrayaan-3 Rover

5.6 Capacity Building in Space Science Research

URSC carries out conferences and workshops related to space science programs either through collaboration with other institutes/organizations or by their own. Conferences carried out during the last couple of years are,

- *A workshop at the ASI 2020 on “X-ray Polarisation of compact objects”. About 50+ candidates including M.Sc. Students and Ph.D. scholars participation.*
- *“Science with XSPECT” meeting in 2021. About 50+ candidates which includes M.Sc. Students and Ph.D. scholars attended this meeting.*

URSC is also active member of the Joint Astronomy Program (JAP) of Indian Institute of Science and carries out teaching as well as training students for their PhD program. Every Year URSC provides opportunity to undergraduate (BE/B.Tech) & post graduate (ME/M.Tech/M.Sc) students to carry out their project work in specific area relevant to the Centre.

5.7 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
01	WIMP - Dark Matter Study	IISc, Bengaluru
02	Probing emission mechanisms and disc dynamics of neutron star binaries	Osmaina University, Hyderabad
03	Probing the nature of transient black holes	Guru Ghasidas Vishwavidyalay, Bilaspur
04	Lunar Surface Composition	PRL, IIT-Kanpur, Pondicherry University
05	Minor elements and isotopes in lunar poles	CEas, IISc
06	Development of NIR spectro-polarimeter for planetary science	IIT-Roorkee
07	Simulation and modeling of Earth's magnetosphere for geotail studies	IISER, Kolkata
08	Observations of galactic black holes	DSU, Bengaluru
09	Observation and Theoretical aspects of accretion dynamics	IIT-G, Guwahati

5.8 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
01	Solar flare studies – by simultaneous observations of Sun	Solar Orbiter's science team of STIX payload

5.9 Laboratories and Facilities Available for Space

Space Astronomy Group (SAG) in URSC has four well equipped laboratories with several facilities established over the years to cater to space science payload developments. Different class of clean rooms as specified by ISO standard have been established for carrying out contamination sensitive experiments. Class 1000 and Class 100 clean rooms have been established to carryout assembly and testing of contamination sensitive instruments like SUIT (Solar Ultra-violet Imaging Telescope) payload on-board Aditya-L1 mission. Class 100,000 and Dark Room facilities have been established for carrying out various payload assembly and testing activities of Flight and Qualification Models.

Cleanliness levels are maintained through continuous monitoring of particle and molecular contamination levels using instruments such as Laser Airborne Particle Counter, Surface Particle Counter, and Particle Fallout Photometer. The laboratories are equipped with the following;

1. Baking chambers and Vacuum chambers - 1m dia and D-type twin chambers, for experiments on payloads and detectors.
2. Interferometer
3. High Resolution Spectrograph,
4. Cryo cool Dewar for detector cooling
5. Ultrasonic cleaning machines, Vacuum pumping and gas filling systems
6. Nuclear Instrument Modules (NIM) of different types along with BINs for standard experiments related to semiconductor, scintillator & gas filled detectors
7. N2 Gas distribution system for clean rooms and labs.
8. Standard radio-active sources, X-ray guns: 1-40 keV, X-ray generator: 1-90 keV

URSC is also equipped with large 1,00,000 class clean rooms and associated Ground Checkout systems for assembly, integration and testing of Space Science & Exploration Missions. A host of technical facilities such as electronic and mechanical computer aided design and analysis facility, PCB fabrication facility, mechanical fabrication facility, electronics fabrication facility, etc are established for the design, fabrication, testing of scientific payloads/ Instruments. The Centre also house state-of-the-art environmental facilities such as thermal-vacuum chambers, Climatic Test Chambers, vibration test facility, acoustic test facility, magnetic test facility etc. to qualify the science payloads individually or along with satellite.

List of Scientific Publications

1. Baby BE, et al., “Revealing the nature of the transient source MAXI J0637-430 through spectro-temporal analysis”, *MNRAS*, **Vol. 508(2)**, pp. 2447-2457., December, 2021.

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4. Das S, et al., “Relativistic viscous accretion flow model for ULX sources: a case study for IC 342 X-1”, *MNRAS*, **Vol. 507(2)**, pp. 2777-2781., October, 2021.

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CHAPTER-6

SPACE APPLICATIONS CENTRE

Indian Space Research Organisation
Ahmedabad

6.1 About Space Applications Centre

Space Applications Centre (SAC), is one of the major research and development Centres of the Indian Space Research Organization (ISRO). The core competence of SAC lies in development of space borne and air borne instruments/payloads and their applications for national development and societal benefits. These applications are in diverse areas of Geosciences, Agriculture, Environment and Climate Change, Physical Oceanography, Biological Oceanography, Atmosphere, Cryosphere, Hydrosphere etc., and primarily meet the communication, navigation and remote sensing needs of the country. The facilities at SAC includes highly sophisticated payload integration laboratories, electronic and mechanical fabrication facilities, environmental test facilities, systems reliability/assurance group, image processing and analysis facilities, project management support group and a well-stocked library. SAC has active collaborations with industry, academia, national and international institutes for research and development. The Centre also has state-of-art in-house and mobile exhibitions to propagate space technology and applications amongst students and public. Located at Ahmedabad, SAC is spread across three campuses having multi-disciplinary activities apart from Delhi Earth Station (DES) which is located in New Delhi.

6.2 Keywords

Moon, Mars, Venus, Mercury, Asteroids, Planetary Analogues, Planetary Instrumentation, Radio Occultation, Modeling, Simulation

6.3 Major Research Domains

➢ **Planetary Geology**

1. **Moon:**

   (i) **Characterizing the mineralogical diversity of the lunar crust and understanding the nature of lunar water cycle:** *(a)* Constraining lunar crustal composition through high-resolution hyperspectral data of the Moon obtained from recent, ongoing and upcoming lunar missions. (b) Comparative compositional studies of lunar near and far side mare and their implications in thermal and chemical evolution of the Moon. (c) Unambiguous detection of lunar hydration features (molecular water /hydroxyl ions) and characterizing their nature using hyperspectral data.

(ii) **Investigation of lunar volatiles at polar regions:** Development of new techniques and radar-based models for detection and quantitative estimation of water-ice deposits inside the permanently shadowed regions at lunar poles.

(iii) **Lunar morphological studies:** (a) Detailed investigation of global lunar geological and morphological features and preparation of seleno-morphological maps. (b) Morphometric and rheological study of lunar domes. (c) Analysis of spatial and statistical distribution of boulders from high-resolution optical datasets.

(iv) **Characterization of physical properties of lunar regolith:** (a) Inversion of global regolith thickness and physical properties of the lunar near-surface using multi-wavelength radar studies. (b) Development of physical models for dielectric constant and surface roughness estimation over lunar surface. (c) Development of empirical and semi-empirical radio-wave scattering models to address scattering from surface and subsurface heterogeneities.

(v) **Lunar crustal shortening studies:** Understanding the lunar crustal shortening through morpho- structural analysis of wrinkle ridges distributed at different regions of the Moon

(vi) **Retrieval of Photometric parameters from optical remote sensing data:** Development of algorithms and simulation of physics-based models to retrieve topographically corrected photometric parameters and comparison with lab-based BRDF measurements collected over Apollo samples.

(vii) **VNIR and thermal remote sensing simulation Studies:** (a) Visible-Near Infrared (VNIR) reflectance calculation using physics-based models and studying the effects of optical properties, viewing geometry, grain size, etc. (b) Estimation of thermal radiation from lunar regolith. (c) Development of physical retrieval algorithms for lunar surface temperature and spectral emissivity in 3–5 μm range.

(viii) **Lunar gravity studies:** (a) Detailed characterization of gravity anomalies at different regions of the Moon using a variety of interpretation techniques, integrated with observations from remote sensing data sets, and generation of crustal thickness maps.

2. Mars:

(i) Simulation of Martian subsurface for characterizing water ice layers: Shallow buried Ice detection using multi-frequency microwave radiometer and Brightness Temperature estimations.

(ii) Global albedo mapping of Mars: Using data from optical and Shortwave Infrared (SWIR) observations.

(iii) Martian geological studies: Mineralogical and morphological studies of volcanic provinces, and monitoring of Polar Ice caps on Mars using optical and hyperspectral remote sensing data.

3. **Venus:**

(i) **Venus geological studies using microwave remote sensing data:** (a) Scattering properties of Venusian geologic features, i.e., volcanic landforms and highland regions using ground-based and orbital-based radar data and development of radar scattering models. (b) Characterization of large-scale Venusian volcano-tectonic structures by integrating observations from Magellan SAR, Radiometer and Altimeter observations.

(ii) Limb darkening studies of Venus using thermal remote sensing observations.

4. **Asteroids:**

(i) **Constraining the origins of Asteroids:** Investigation of Visible and Near Infrared spectra of Main Belt and Near-Earth Asteroids obtained from spacecraft-based observations and link with those obtained from meteorites to understand their origins.

(ii) Polarimetric radar studies of Near-Earth Asteroids to characterize their near-surface physical properties.

5. **Mercury:**

Ground-based polarimetric radar studies of Mercury Poles to constrain the potential distribution and purity of water ice deposits associated with permanently shadowed regions.

➢ **Planetary Atmospheres**

1) **Radio Occultation Techniques for Atmospheric Profiling of Venus and Mars:** Development of end-to-end retrieval algorithms for deriving atmospheric profiles of temperature, pressure and sulfuric acid concentration for planetary atmospheres such as Venus and Mars using Radio Occultation (RO) techniques. In addition, research towards error propagation analyses in RO experiments for characterization of system noises feeding towards system definition for realization of future indigenous RO missions.

2) **Understanding the atmospheric circulation dynamics of the Venusian atmosphere:** Retrieval of atmospheric winds from UV channels and dynamical modelling of the Venusian Atmosphere to understand the atmospheric circulation dynamics.

3) **Understanding the diverse wave characteristics and induced angular momentum forcing in the Venusian atmosphere:** Study of atmospheric waves and oscillations of winds at different altitudes in Venusian atmosphere using retrieve winds and dynamical model to understand the diurnal, seasonal and annual periodicity.

4) **Investigating the elusive nature of Venusian lightning using synergistic observations:** Synergistic measurements from instruments aboard upcoming Venus mission of ISRO are targeted to probe unambiguous detection of Venus lightning in a more decisive manner.

5) Measurements of Venus cloud top brightness temperature statistics at different locations, emission angles, and times, and generation of cloud top temperature maps.

6) Retrieval of Venus surface emissivity and near-surface atmospheric parameters**.**

7) Investigations of dust storms and dust devils on Mars.

8) Estimation of atmospheric optical depth (AOD) as a function of altitude and scale height of aerosols on Mars.

➢ **Planetary Analogues**

1) **Terrestrial hot springs and their Astrobiological implications:** Field studies, sample collection, and characterization of mineral assemblages in the spectral range of 0.4–25 μm found in the vicinity of different hot springs located along various faults of North Western Himalayan region.

2) **Lunar and Martian Water Ice Analogues**: Permafrost deposits present in the North-western Arid Himalayan regions are analogous to the water ice deposits thought to be present on Mars and the Moon. These frozen grounds are studied using longer wavelength Synthetic Aperture Radar (SAR) observations combined with *in situ* Ground Penetrating Radar (GPR) observations.

6.4 Major Scientific Applications / Results

1) **Lunar crustal shortening across Dorsa Geikie, Mare Fecunditatis:** TMC-2 onboard Chandrayaan-2 has acquired images of an important lunar tectonic feature, which is an arcuate wrinkle ridge, called Dorsa Geikie (~1º S to 4º S and 53.25º E to 53.75º E). Morpho structural analysis of Dorsa Geikie using TMC-2 orthoimage (Figure 1a) and a DEM (Figure 1 b) has helped in estimating the crustal shrinkage and quantifying it. Some of the important results from these observations are that (i) the average crustal shortening in Dorsa Geikie is 1.89%, which is commensurable with the Lunar average (0.26-0.36%), and (ii) its age is estimated to be 3.4-3.1 Ga, which shows that this wrinkle ridge is not older than the parent basalt in Mare Fecunditatis (3.8-3.2 Ga)

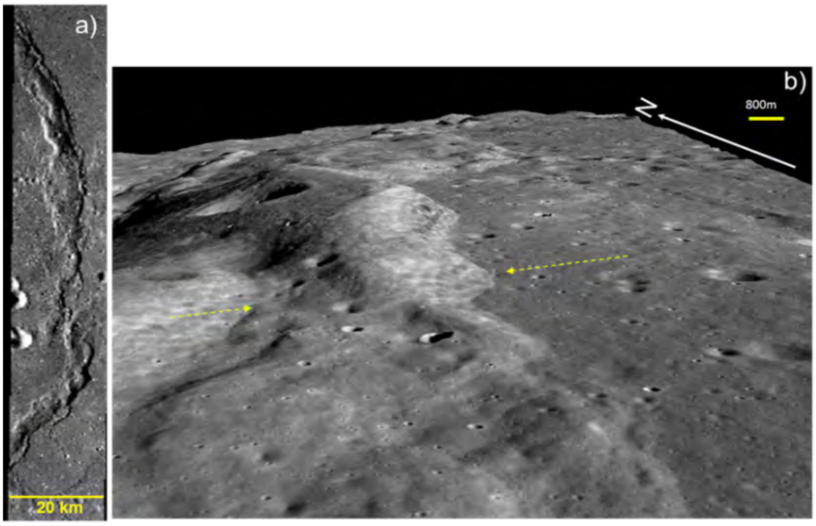

Figure 1: The topographic cross-section of wrinkle ridge Dorsa Geikie shown in a (a) TMC-2 orthoimage and (b) TMC-2 Digital Elevation Model.

2) **Analysis of boulder population of a fresh crater using high-resolution optical data from Chandrayaan-2 OHRC instrument:** A relatively small, young crater of ~340 m diameter situated near Boguslawsky E crater was selected for boulder population analysis. The boulders around this crater are distinctly seen in an OHRC image of this region because of the high spatial resolution and low sun elevation (which results in long shadows). The spatial and statistical distribution of boulders were studied systematically. A total of ~2000 boulders were identified and measured radially from the crater center, and their distribution is shown in figure 2. Heights of the boulders were estimated from the shadow length.

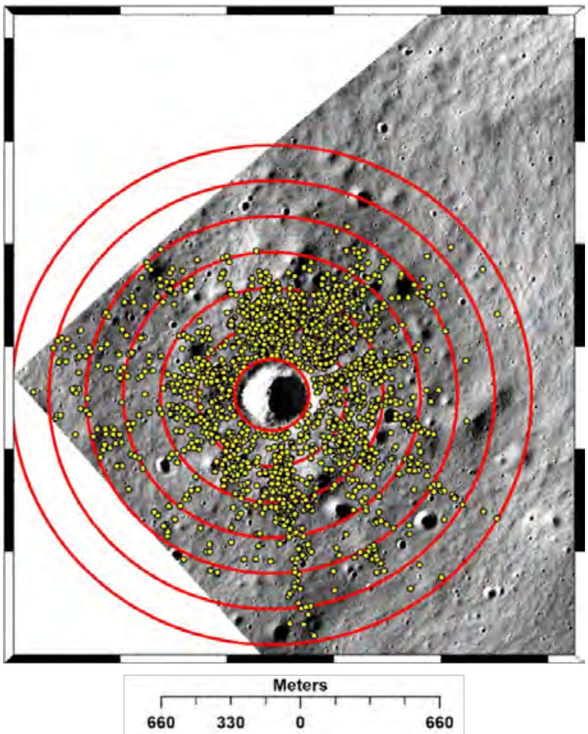

Figure 2: The distribution of boulders around the small, young crater as seen from an OHRC image of Boguslawsky E crater region. The yellow circles indicate the boulders locations and the red circles indicate the distance from the crater center in terms of crater radii.

3) **Detection and quantification of hydroxyl at Aristarchus crater using Chandrayaan-2 Imaging InfraRed Spectrometer (IIRS) measurements:** Using data from the IIRS instrument, the mineralogical diversity and enhanced hydration feature associated with crater Aristarchus (23.6°N, 47.5°W) at highest ever spatial resolution of ~80 m has been investigated for the first time ever. The water concentration is found to vary from ~15-170 ppm with an average value of ~80 ppm in the studied site (Figs. 3D and 3E).

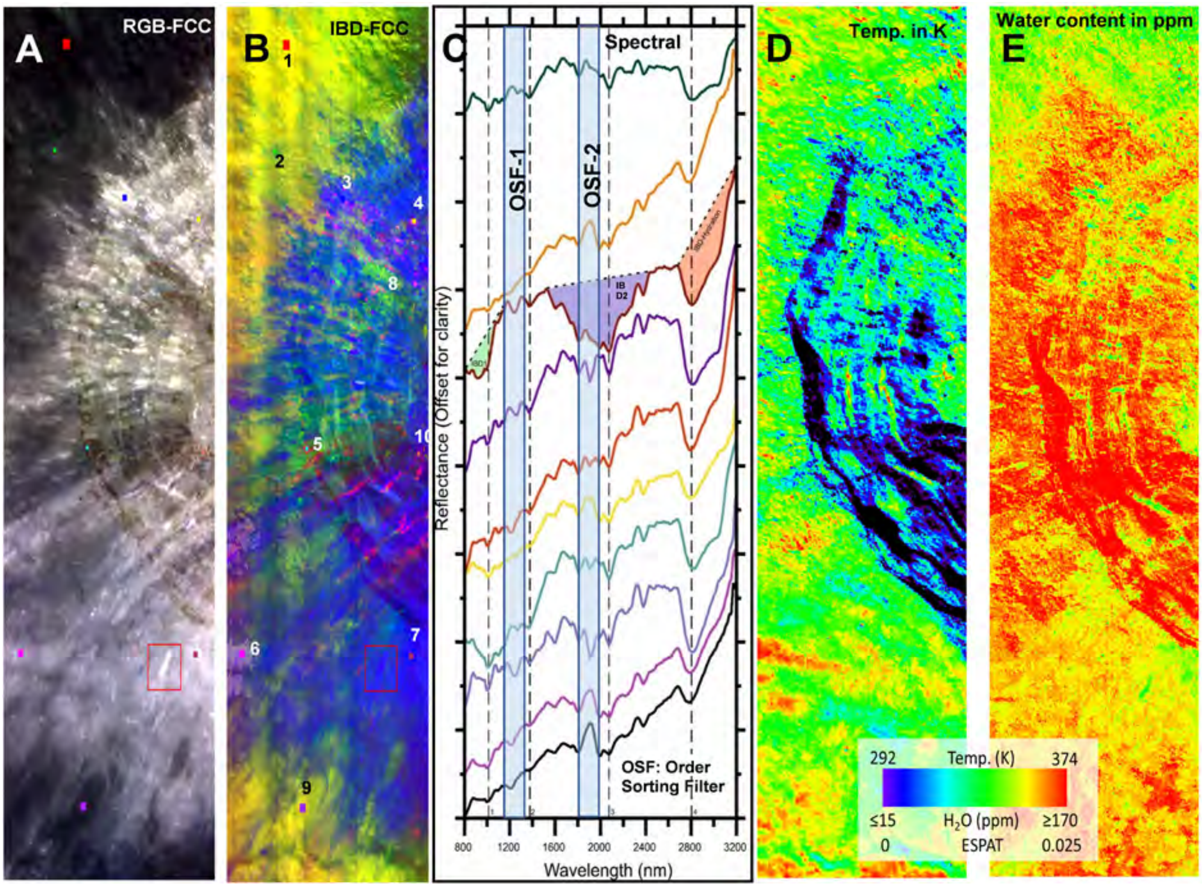

Figure 3: A. Ch-2 IIRS RGB-FCC. Colored boxes indicate regions of interests (ROIs); B. IBD-Albedo-based FCC. ROIs are marked as 1-10; C. Mean spectral plot corresponding to the ROIs; D. Temperature map; E. ESPAT vis-à-vis H_2O content map of crater Aristarchus. The nature of the hydration feature strongly suggests it to be hydroxyl (OH) and the water content is found to vary from ~15-170 ppm. The IIRS spectral range beyond 3 µm has helped in complete characterization of the lunar hydration feature for the first time.

4) **Unambiguous characterization of hydration feature in the North Polar Region on the far side of the Moon:** Preliminary analysis suggests that IIRS could successfully measure the variations in the reflected and emitted solar radiation from the lunar surface from different kinds of surface types, namely, crater central peaks (e.g., Stebbins), crater floors (e.g., Stebbins and Sommerfield), very fresh reworked ejecta associated with small craterlets within the crater floor of a large crater (e.g., Sommerfield) and the sun-illuminated inner rims of craters (e.g., Kirkwood). For the first time, OH and H_2O have been separately identified. Band center value of the 3000-nm feature is found to

vary from ~2.82 to 3.16 μm having two modes with mean band center locations near ~2.86 and 2.95 μm respectively suggesting the presence of both OH and H_2O in the north polar region on the far side of the Moon.

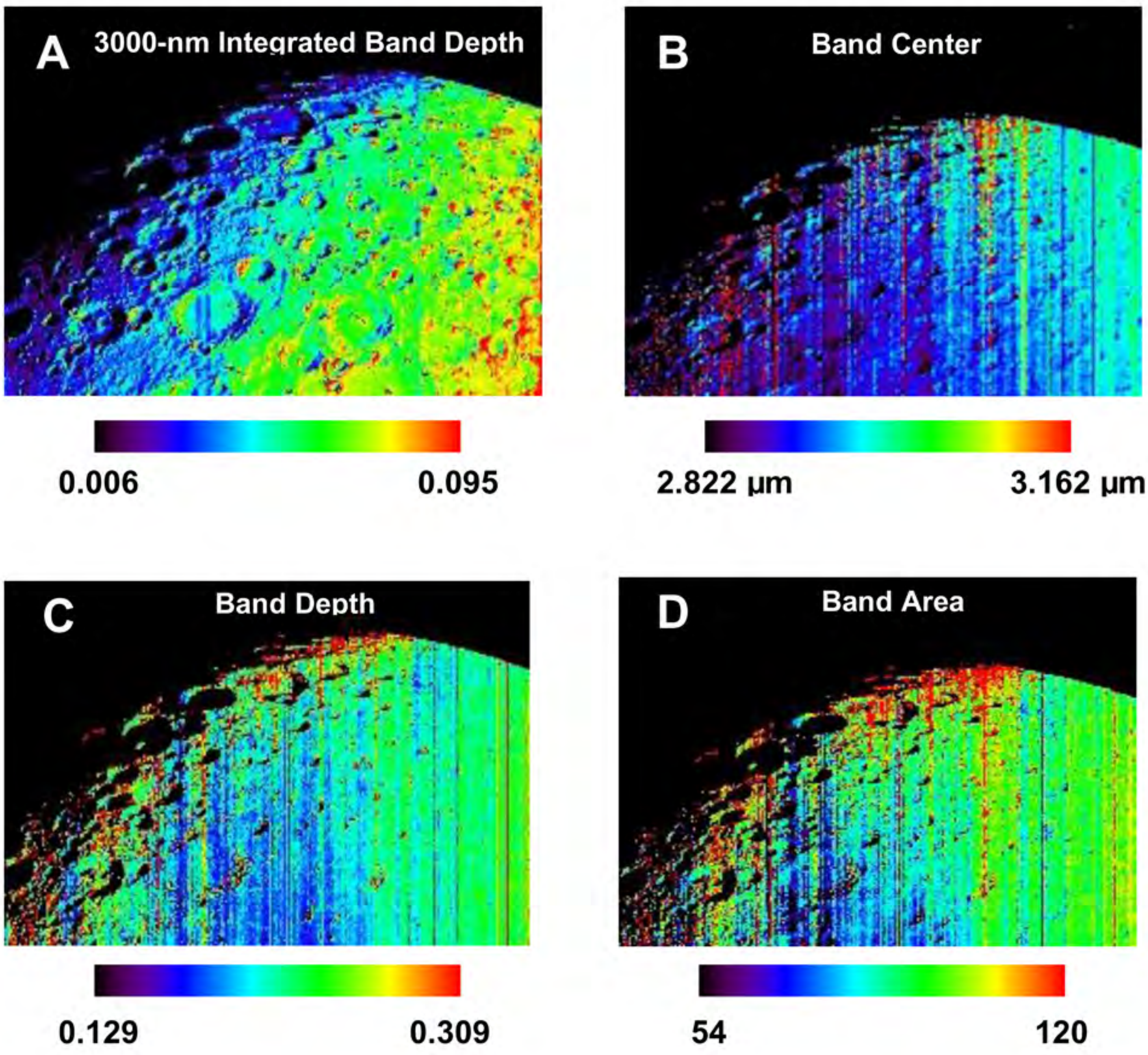

Figure 4: A. 3000-nm Integrated Band Depth (IBD) map to highlight the variations in the strength of the hydration (OH/H_2O) feature as captured by Ch-2 IIRS data over the north polar region on the far side of the Moon; B. Band Center; C. Band Depth and D. Band Area map.

5) **Radar polarimetric properties of permanently shadowed regions (PSRs) at the lunar poles:** The Chandrayaan-2 DFSAR fully polarimetric data contains all of the scattering information for any arbitrary polarization state, thus providing better tools than the circular polarization ratio (CPR) alone to develop scattering models of the lunar terrain. Moreover, measuring the full scattering matrix provides additional information on the physical properties of the upper meter or two of the lunar surface. Preliminary results using DFSAR L- and S-band polarimetric data of selected polar and non-polar regions on the Moon indicated that: craters in both PSRs and non-PSRs that are classified as CPR–anomalous in previous S-band radar analyses appear anomalous

at the L-band also. It was also observed that the material evolution and physical properties at their interior and proximal ejecta are decoupled. Moreover, if crater age estimates are available, a comparison of their radar polarization properties at multiple wavelengths similar to that of three unnamed small south polar crater regions analyzed may provide new insights into how the rockiness of craters evolves with time.

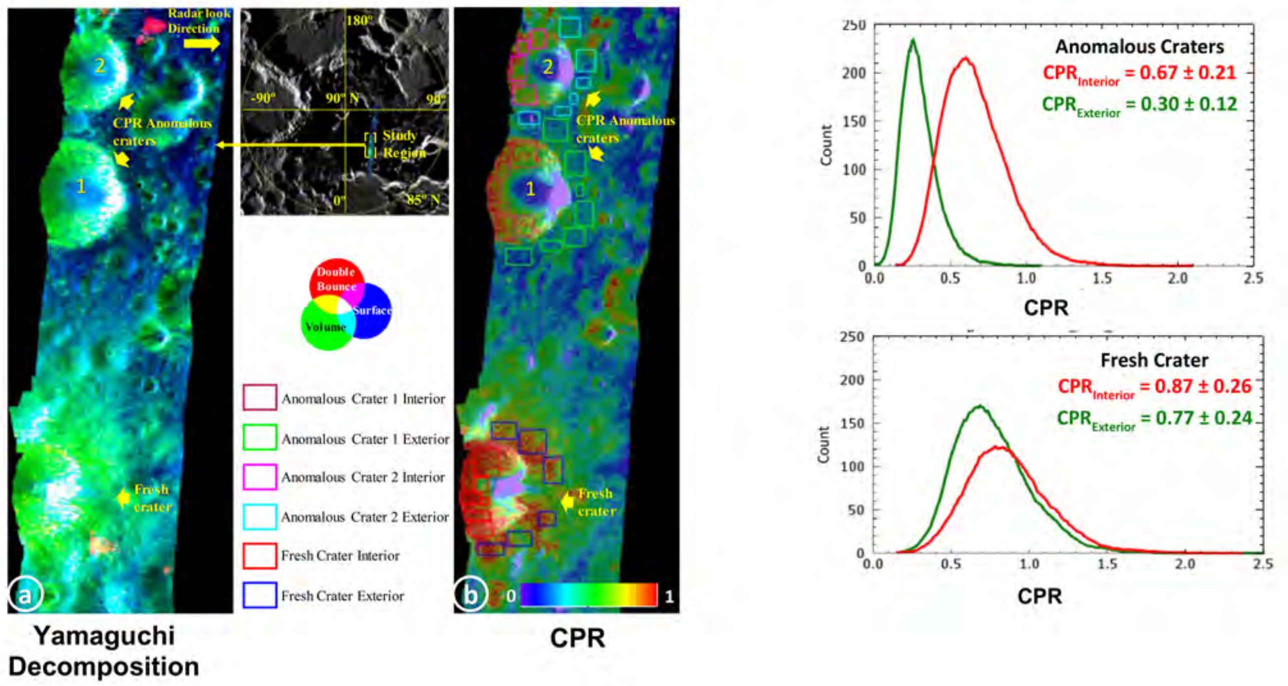

Figure 5: Qualitative comparison of secondary craters on the floor of the Peary crater from L-band DFSAR data. (a) L-band DFSAR Yamaguchi 4-component decomposition image with arrows in yellow denoting the anomalous (labeled "1", "2") and fresh craters analyzed in this work. (b) L-band DFSAR CPR image stretched to a color scale with the interior and exterior regions of interest outlined in different colored boxes as shown in the legend to its left. The polygons shown in (b) are used for the histograms shown on the right.

6) **Characterization of young, fresh lunar crater floors using radar scattering mechanisms:** The radar polarization properties of the interior regions of three of the youngest craters on the Moon that are Tycho, Jackson, and Giordano Bruno at L-band wavelength using Chandrayaan-2 DFSAR data have been analyzed and compared to the predicted behaviors of theoretical radar scattering models. The high radar circular polarization ratio (CPR) values observed from the young crater floors can be explained by a double-bounce dipole (diffuse scattering) model through scattering from and between tens of centimeter scale rock edges and cracks. Also, the highest CPR enhancements observed from the floors of these young impact craters are predicted to be caused by dihedral scattering between natural corner reflectors such as rocks many times the size of illuminating wavelength or between rock faces and the regolith.

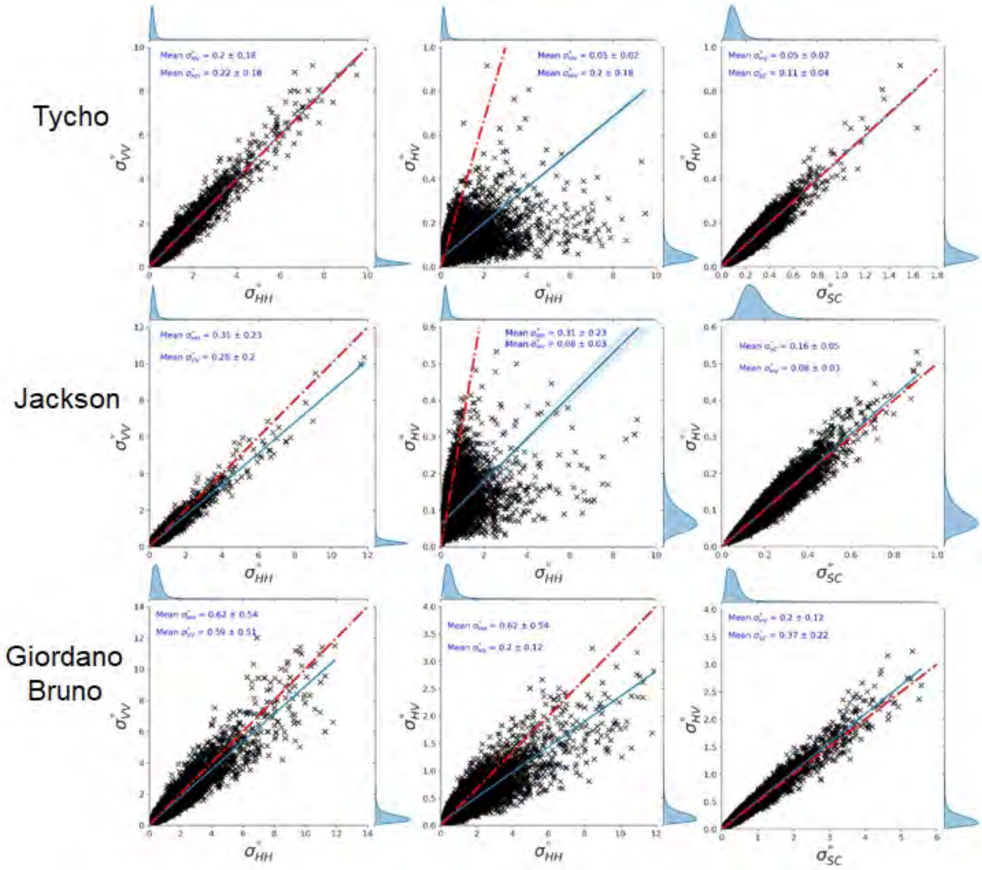

Figure 6: From left to right are the plots of HH versus VV, HV versus HH, and HV versus SC backscatter coefficients (in linear units) for L-band data of the three young crater interior regions analyzed. For each bivariate plot, a scatter plot is shown with the best fit line (linear regression) in solid blue line, with histogram of each variable at the margins. The dashed red lines show HH=VV, HH=3HV and SC=2HV trends from left to right.

7) **Estimation of Lunar Dielectric Constant and Surface Roughness using Chandrayaan-2 DFSAR data:** L-band Full Polarimetric data from Chandrayaan-2 DFSAR is being utilized for estimation of lunar dielectric constant (DC) and surface roughness parameters. An in-house physics-based model is developed to simulate lunar backscatter, and this forward model depends on multiple lunar parameters with non-linear relations among them. Direct inversion of this model is quite challenging as it encompasses ill-posed problems (number of unknowns are more than number of observations). In order to solve forward model for estimations, iterative based inversion framework was adopted and implemented using global minimization techniques which is mainly driven by cost function, relating the simulated model and satellite-based observations as non-linear constrained problems. Inversion framework consists of multiple flows with a modular approach. The values of DC, RMS height and correlation length at global minima will be the estimated values for given pixels. For validations of inversion results, dielectric properties reported from lab-based characterization of Apollo landing sites have been used. As an example, DFSAR acquisitions over Apollo-11 landing site that was used for inversion of DC and RMS height are shown in

figure 7. For this region, ranges of retrieved DC match well with those reported from lab-based results.

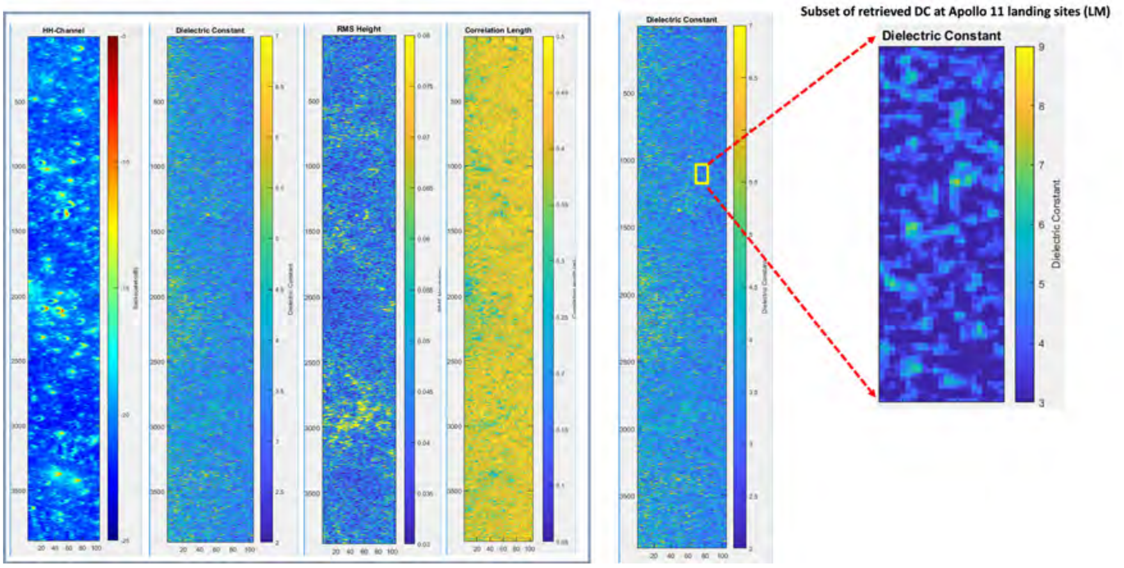

Figure 7: Model-based Dielectric Constant and RMS height estimation using Chandryaan-2 DFSAR L-band Full polarimetric data over Apollo-11 landing site

8) **Characterizing water ice deposits inside PSRs at the lunar poles:** The nature and distribution of volatiles (e.g., water ice) at the PSRs of the Moon has been a subject of considerable controversy, due to contrasting interpretations of the polarimetric behavior of the radar backscatter from these regions at near-zero phase (bistatic) angles. Unlike the Galilean satellites and Mercury poles, radar observations of lunar PSRs did not show radar-bright regions that indicate the presence of large expanses of water ice but indicated that the possible ice could be present as few wt.% in the uppermost meter of regolith or mixed as patches within the polar regolith as "dirty ice". Previous studies used elevated CPRs only as an indicator of water ice at the PSRs, and the results were found to be ambiguous as surface roughness can also greatly influence the CPR. To address this ambiguity, CPR along with physical parameters surface roughness and dielectric constant for Peary crater floor near the north pole and portion of Cabeus's crater floor near the south pole were analyzed. Preliminary results indicated the possible presence of dirty ice patches within the Cabeus' crater floor, and helped in identifying the most probable regions holding clean water ice deposits inside the PSRs on the Peary crater floor.

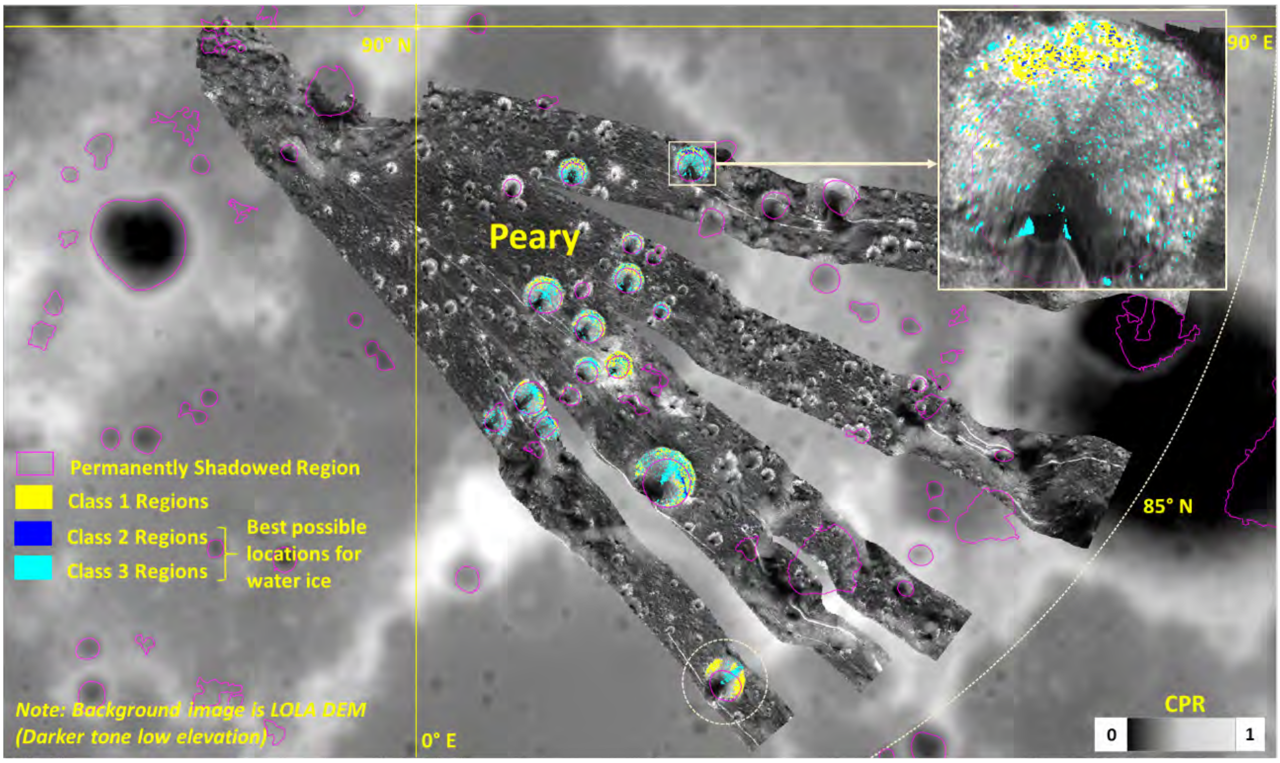

Figure 8: Initial results from a new in-house developed technique based on full polarimetric radar descriptors to identify potential regions holding water ice deposits inside the PSRs at the lunar poles. Peary crater floor with its secondary craters along with PSRs (pink polygons) and potential water ice regions (blue and cyan zones) identified with the new method are shown here, using a DFSAR L-band data mosaic overlain on a LOLA DEM of the north pole.

9) **Retrieval of geophysical profiles of Venus atmosphere from AKATSUKI RO signals:**

   i. Retrieval algorithm developed independently to retrieve profiles of neutral number density, temperature, pressure and geopotential height for Venusian atmosphere from AKATSUKI RO data. The capability can be gainfully utilized for ISRO missions to Venus and Mars.

   ii. Cross-comparison of indigenously retrieved atmospheric products against those derived by JAXA shows exceedingly good closeness of the products and thereby reflects on the performance of our indigenous algorithm to yield comparable results.

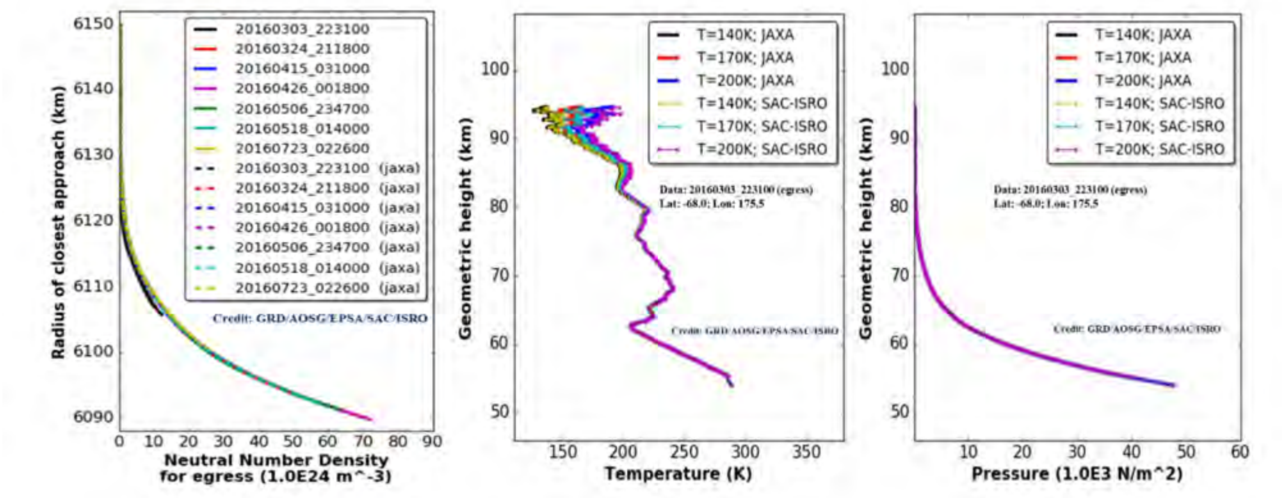

Figure 9: Neutral number density (scaled as 10^{24} m^{-3}), temperature (T in kelvin) and pressure (P in 10^3 Nm^{-2}) retrieved from SAC-ISRO algorithm and compared to JAXA derived products for all the seven profiles of AKATSUKI RO data. T & P profiles are shown for only one RO egress event for better visualization.

10) **Physical and chemical properties of Asteroids:** (a) Combined with the polarimetric radar observations of Near-Earth Asteroids (53319) 1999 JM_8, (101955) Bennu, and (33342) 1998 WT_{24} obtained by the Arecibo Observatory (AO), numerical simulations of the *m-chi* decomposition for irregular boulders indicated that significant components of their radar echoes are depolarized (random polarization) and linearly polarized. The numerical simulations confirm that depolarization is increased by single scattering from non-spherical wavelength-scale particles. The analysis also suggests that 1999 JM_8 is possibly covered in regolith and that surface scatterers dominate the scattering properties of Bennu. (b) Hydrated minerals on the surface of Main Belt Asteroid Vesta have been detected, using a narrow absorption band at 2.8 µm in VIR data. Analysis of the surface composition of the northern regions (Veneneia crater) of Vesta confirm mixtures of pyroxenes (hypersthene, pigeonite and diopside).

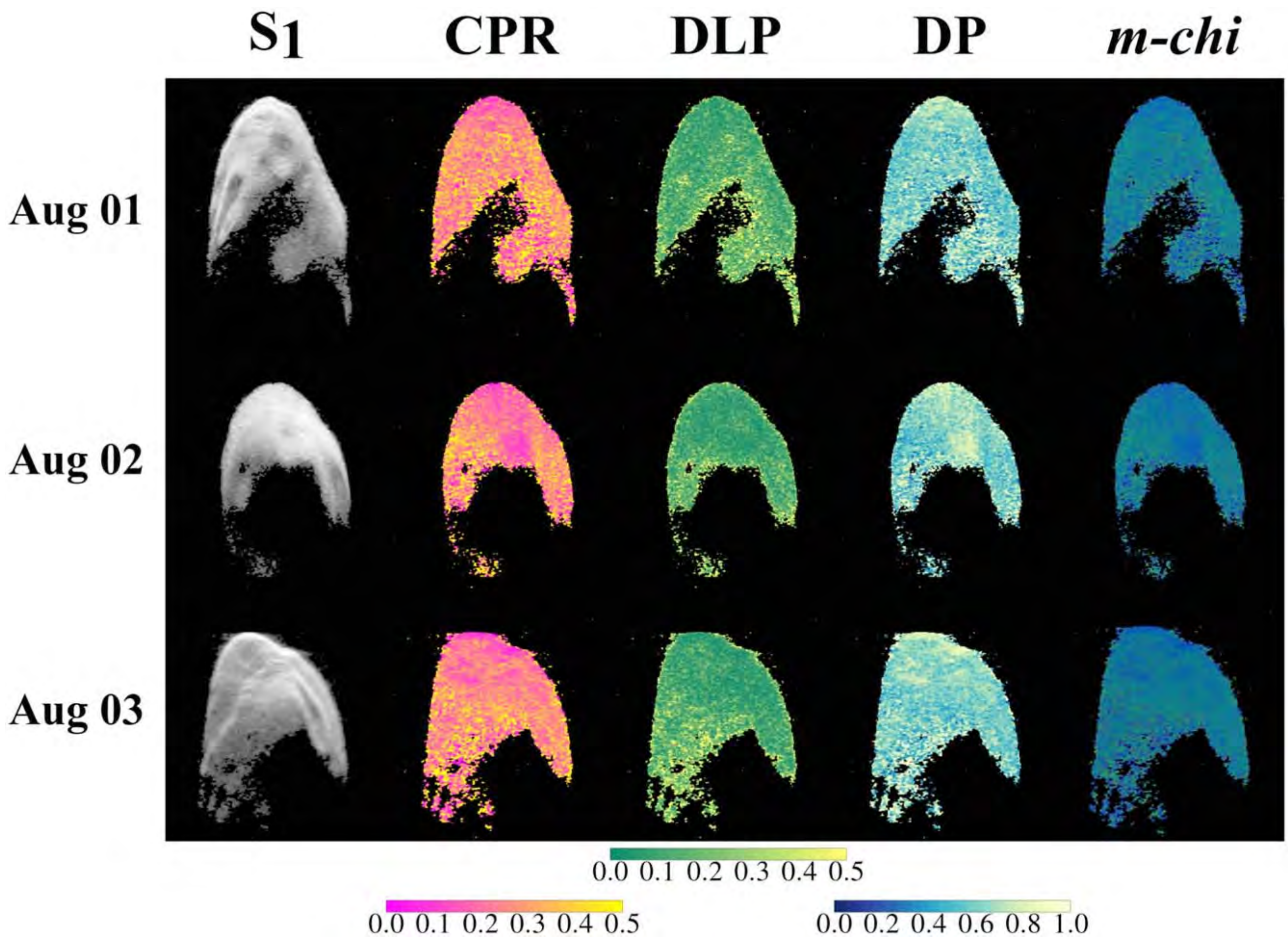

Figure 10: Delay-Doppler images (range increasing from top to bottom, frequency increasing from left to right) of total power (S1) in units of standard deviations above the rms noise (color bar excluded to reduce clutter), CPR, DLP, DP, and m-chi decomposition for AO radar data of 1999 JM8 collected on 1999 August 1–3. In these images, the vertical axis corresponds to the measured distance from the radar (range in the spatial domain and delay in the time domain) with a spatial resolution of 30 m pixel−1. The horizontal axis corresponds to the Fourier transform of all measurements at a given range bin, resulting in spectra showing the Doppler dispersion at that range resulting from the rotation of the target along the radar line of sight, with a resolution of 0.0094 Hz pixel−1.

11) **Characterizing hot springs from a Martian analogue perspective:** Terrestrial Hot Spring localities provide all the necessary components useful for existence of life and are thus considered to be the cradle for primordial life on Earth. Mineralogical characterization of mineral assemblages found in the vicinity of Tapovan Hot spring located on Malari-Joshimath Road, around 15 km south-east of the Joshimath town in the state of Uttarakhand, India has been done. It is part of numerous circum-neutral hydrothermal vents situated within Dhauliganga valley in the Garhwal Himalayas. The average altitude of the region is around 1900 m and thus lower atmospheric pressure at such high altitudes causes the water to continuously boil. The main minerals found at this area are different phyllosilicates (muscovite, biotite), clay minerals (montmorillonite,

kaolinite) and calcite. These secondary minerals are formed due to alteration of the granitic host rock caused by the hydrothermal fluid. Various spectroscopic studies already suggest the presence of these altered minerals on Mars.

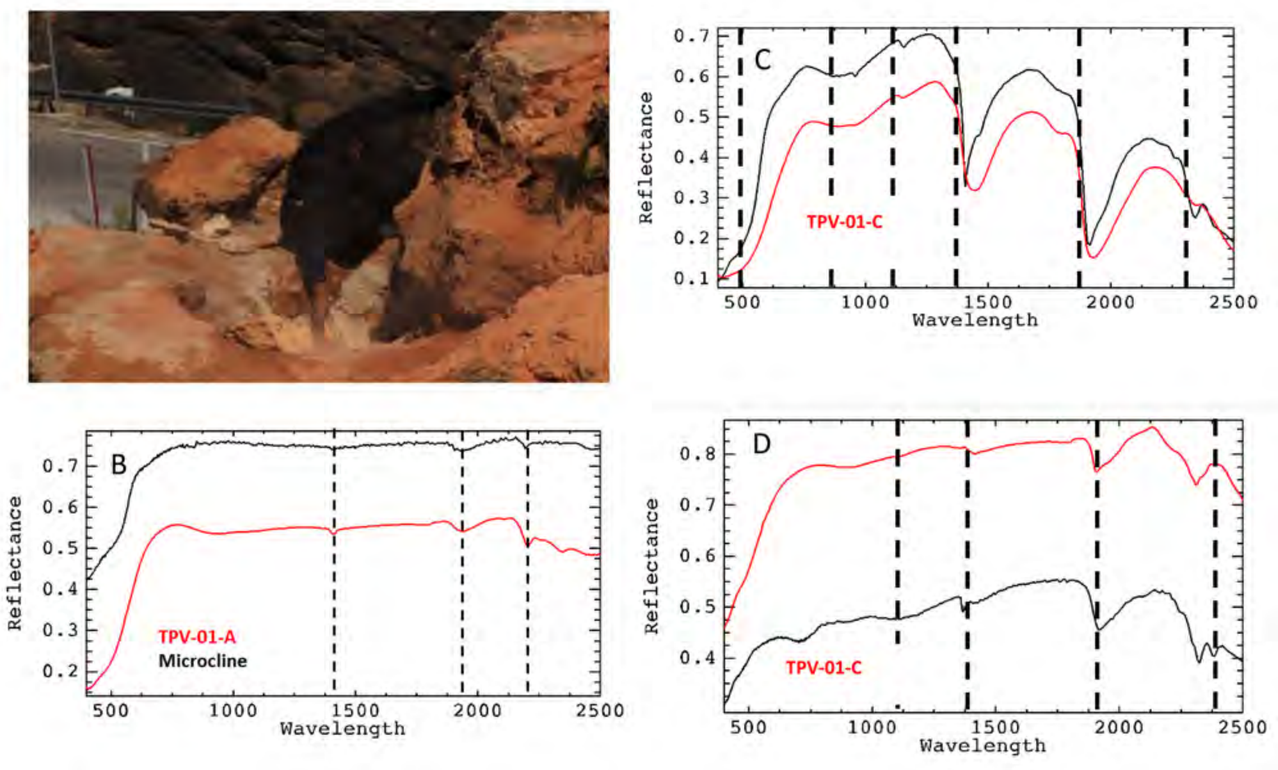

Figure 11: A. Field photograph of collection of temperature data from one of the hot spring conduits. B. C. and D. VNIR Spectra of the Samples collected from tapovan hotspring location. The samples are broadly identified as Granite gneiss, phyllosilicate, sulfate, calcite and opaline silica by comparing them with USGS Spectral Library.

12) **Planetary Water Ice Analogue studies:** Permafrost deposits present in the North-western Himalayan regions are studied using longer wavelength SAR observations combined with field GPR observations. L-band and C-band SAR data are analyzed to understand the sensitivity of SAR polarimetric parameters to permafrost layers. The study provided important insights into the development of radar-based methods for detection of water ice on Moon and Mars. Further, GPR based survey on the permafrost regions are conducted to delineate the distribution and characteristics of subsurface frozen soil layers. The study is intended to develop techniques for detection of subsurface water ice from planetary rover-based GPR instruments and spaceborne radar sounder observations.

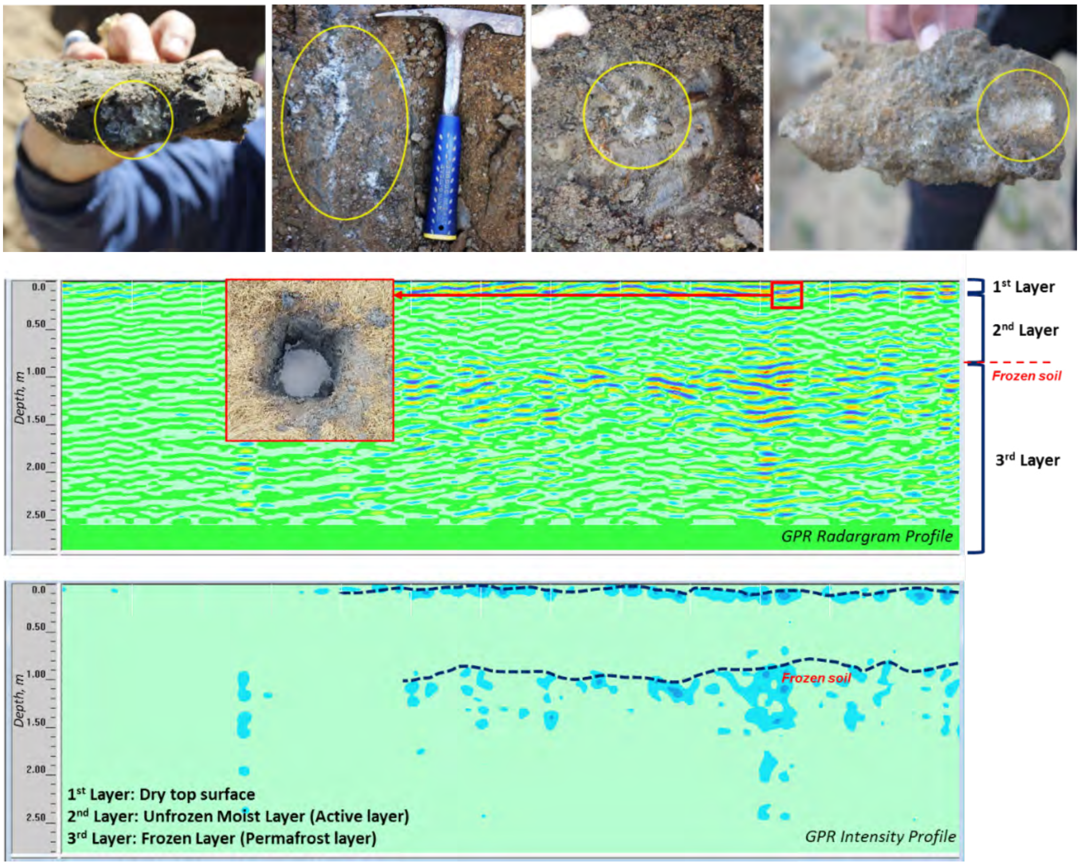

Figure 12: The ground photographs in the top row show the presence of frozen soil layer in the study area. The GPR radargram and intensity profile at the bottom reveals the disposition of unfrozen (active layer) and frozen (Permafrost layer) soil layers in depth. In the study area, during winter season the frozen soil layer is present at 1-1.5m below the surface.

6.5 Capacity Building in Space Science Research

SAC has been imparting training to students and professionals from across the country and conducting workshops/seminars on planetary science data analysis related aspects on regular basis, as part of its capacity building activities. Details of student projects/theses based on planetary science studies during this period are given below.

1) **Student projects:** Two M. Tech students have completed/ in near completion of their thesis on the following research topics: Morphological and mineralogical studies of double-layered crater ejecta on Mars; Polarimetric modeling for lunar surface characterization using Chandrayaan-2 DFSAR data

6.6 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1	Lunar morphological studies and mapping of anthropogenic features, volcanic, tectonic, and mass wasting sites	National Geophysical Research Institute (NGRI-CSIR), Hyderabad
2	Lunar morphological studies	Ashutosh College, Kolkata

Sl. No.	Area of Collaboration	Collaborating Institute
3	Mineralogical mapping of OOS suite of rocks, highly silicic volcanic constructs on the Moon, and their associations with Fe-Mg-spinel-bearing lithologies and magmatic water	IIT Kharagpur
4	Compositional vis-à-vis morphological study of lunar impact melts and its implications, mineralogy and genesis of spinel-bearing rocks on the Moon.	IIT Kanpur
5	Characterization of polarimetric radar scattering from lunar surface and algorithm development for estimation of dielectric properties of the lunar regolith	IIT Bombay
6	Development of models to estimate the complex dielectric constant of the lunar surface and the average complex dielectric constant of the lunar subsurface	IIT Roorkee
7	Developing fully polarimetric 3D electromagnetic scattering tools that are capable of simulating scattering from heterogeneous substrates such as lunar regolith mixed with water ice	IIT Madras

6.7 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1	AKATSUKI Radio Science Experiment for Venus under ISRO-JAXA MoU	JAXA, Japan
2	Ground-based Radar observations of Mercury	Lunar and Planetary Institute (LPI), Houston, USA
3	Multi-wavelength radar studies of the Moon	Johns Hopkins University (JHU) Applied Physics Laboratory (APL), USA
4	Hyperspectral data analysis for geological investigations of terrestrial and lunar surfaces; Martian analogue studies	Space Science Institute, Boulder, Colorado, USA

6.8 Laboratories and Facilities Available for Space Instrumentation

1. FT-IR Spectrometer cum FT-IR Imaging Microscope having spectral range of 0.4-25 μm at Planetary Sciences Laboratory.
2. A Software tool to process & analyze Chandrayaan-2 Polarimetric Dual-Frequency SAR (DFSAR) Data.

List of Publications

1. Arya A. S. et al., Strain/stress evaluation of Dorsa Geikie using Chandrayaan-2 Terrain Mapping Camera-2 and other data, *Current Science*, **121**, 94-102, 2021.

2. Bhiravarasu S. S. et al., Chandrayaan-2 Dual-Frequency SAR (DFSAR): Performance Characterization and Initial Results, *The Planetary Science Journal*, **2,** 134, DOI: 10.3847/PSJ/abfdbf, 2021.

3. Pathak S. et al., Geological insights into lunar floor-fractured crater Atlas, *Icarus*, **360:114374**, DOI: 10.1016/j.icarus.2021.114374, 2021.

4. Farrand W. H. et al. including Bhattacharya S., Tracking Acid Generating Minerals and Trace Metal Spread from Mines using Hyperspectral Data: Case Studies from Northwest India, *International Journal of Remote Sensing*, **42(8),** 2920-2939, DOI: 10.1080/01431161.2020.1864057, 2021.

5. Ray D. et al. including Bhattacharya S., Hematite concretions from the Late Jurassic Jhuran sandstone, Kutch, western India: Implications for sedimentary diagenesis and origin of "blueberries" on Mars, *Planetary and Space Science*, **197:105163**, DOI: 10.1016/j.pss.2021.105163, 2021.

6. Hickson D. et al. including Bhiravarasu S. S., Polarimetric Decomposition of Near-Earth Asteroids using Arecibo Radar Observations, *The Planetary Science Journal*, **2,** 30, DOI: 10.3847/PSJ/abd846, 2021.

7. Chauhan P et al., Unambiguous detection of OH & H_2O on the Moon from Chandrayaan-2 imaging infrared spectrometer (IIRS) reflectance data using 3.0 µm hydration feature, *Current Science*, **121(3)**, 391-401, 2021.

8. Paramanick S. et al. including Bhattacharya S., Spectral and chemical characterization of Copiapite and Rozenite from Padinjarathara in Wayanad, southern India: Possible implications for Mars Exploration, *Chemical Geology*, **120043**, DOI: 10.1016/j.chemgeo.3030.120043, 2020

9. Baliyan S. et al. including Bhattacharya S., Mineralogy and Spectroscopy (Visible Near Infrared and Fourier Transform Infrared) of Mukundpura CM2: Implications for asteroidal aqueous alteration, *Geochemistry*, **125729**, DOI: 10.1016/j.chemer.2020.125729, 2020

10. Roy S. et al. including Bhattacharya S., Alternating direction method-based endmember extraction for a distributed fraction cover mapping of mineralogy at Jahazpur, India, *Journal of Applied Remote Sensing,* **14(4),** 2020.

CHAPTER-7

NORTH EASTERN SPACE APPLICATIONS CENTRE

Shillong

7.1 About the Centre

North Eastern Space Applications Centre (NESAC) was established in the year 2000 as an autonomous organization under Department of Space, Government of India with an objective to cater to the needs of space technology inputs for the development of the north eastern region (NER) of India. The major objectives of the centre are (i) to provide an operational remote sensing and geographic information system aided natural resource information base to support activities on development and management of natural resources, infrastructure planning, and governance in the region, (ii) to provide operational satellite communication applications services in education, health care, disaster management support, and developmental communication, (iii) to take up research in space and atmospheric science area and establish an regional instrumentation facility and networking with various academic institutions, (v) to enable single window delivery of all possible space based support for disaster management, and (vi) to set up a regional level infrastructure for capacity building in the field of geospatial technology. The centre has successfully completed more than 200 projects covering different thematic areas during last 21 years of its existence. It has emerged as a major centre catering to the needs of space technology interventions towards holistic development of NER of India.

7.2 Keywords

Space applications, Remote sensing, GIS, Atmospheric Science, Disaster management support, Satcom applications, Capacity building.

7.3 Major Research Domains

The activities at NESAC may be divided into the following major research domains

- Satellite Remote Sensing: NESAC utilizes different types of satellite data to develop innovative methods for natural resource management, infrastructure planning, site suitability analysis, etc.
- Application of Artificial intelligence, Machine Learning, and deep learning for different applications like auto detection of features, nowcasting of weathers, etc.
- Disaster risk reduction: NESAC has developed innovative methods for early warning and management strategy for disasters like Floods, Lightning, vector borne diseases, landslides, forest fires, etc.

- Development of innovative applications using unmanned aerial vehicles.
- Research to improve short and medium range weather forecast, severe weather forecasting, characterization of aerosol and atmospheric boundary layers, aerosol-cloud interaction studies, etc under the atmospheric science area.

7.4 Major Scientific Applications / Results

The major scientific applications / results from the centre is listed below

- The first phase of the CHAMAN (coordinated horticulture assessment and management using geo-informatics) project work for NER on mapping of areas for expansion of horticultural crop in covering 16 districts of NER is being carried out. The study reveals that there is a large extent of areas suitable for expansion of commercially important horticultural crops in the selected districts ranging from 0.1% to 35% of the total geographical area of the district.
- Geotagging of Assets created under NERTPS Programme of CSB in NER: Assets created under the North Eastern Regional Textile Promotion Scheme (NERTPS) of CSB were geotagged using GAGAN based mobile app. Around 40000 assets were geotagged covering all the 8 states of NER.
- Mapping of district wise soil fertility status of Meghalaya: Prepared district wise soil fertility maps for all the 11 districts of Meghalaya. It is observed that soils of Meghalaya are non saline, acidic in nature and contains high organic carbon. Availability of phosphorus in soils varies from medium to low whereas potassium availability varies from low to medium.
- Preparation of Agro-climatic Atlas under FOCUS Project in Mizoram & Nagaland: Agro-climatic atlas for four FOCUS districts of Mizoram (Kolasib, Champhai, Mamit and Serchhip) and eight FOCUS project districts of Nagaland (Mon, Mokokchung, Longleng, Wokha, Zunheboto, Kohima, Kiphire and Phek) has been prepared.
- Mapping of Bamboo Resources for the state of Meghalaya: The project is being carried out for mapping the bamboo resources for the state of Meghalaya at the request of Soil & Water Conservation Dept. of Meghalaya. A preliminary mapping of bamboo growing areas has been completed for 7 districts of Meghalaya (Ri Bhoi, East Khasi Hills, South West Khasi Hills, North Garo Hills, West Garo, South West Garo & South Garo).
- RS and GIS input for Preparation of Forest Working Plan inputs for Arunachal Pradesh: The project has been carried for the states of Arunachal Pradesh and Mizoram. Growing stock (timber/ bamboo), phyto-sociology and carbon stock have been estimated for each division.
- Operational feasibility of additional intervention package for accelerated malaria control in areas with Jhum Cultivators in Tripura (ICMR): Under this project, the area under jhum cultivation for Dhalai district has been mapped for the year 2019 at 1:10,000 scale and

analysis of the causal factors and developing models for forecasting malaria incidence is in progress.

- In the area of hydrology & water resources, flood early warning system (FLEWS) program has been expanded to all NER states. An average success score of 75% and an average alert lead time of 24 to 36 hours could be achieved for the flood warnings under the FLEWS programme for flood-prone districts of Assam.
- Assessment and monitoring of embankment breach locations under FLEWS in Assam: Post-flood Sentinel-1 data were used to identify the embankment breaches due to the floods and 17 breach locations were identified in 9 districts of Assam. An attempt has also been made to evaluate the embankment breaches using Planet Lab archive data acquired during the month of January to April 2021 and the status of plugged or unplugged breaches have been evaluated.
- Preparation of Assam River Atlas: Preparation of River Atlas at 1:5K scale for the state of Assam has been completed and the Atlas and Geo-portal was released recently, the Assam River Atlas has a large user base comprising of line departments, individual researchers, academia etc. Due to the dynamic fluvial behavior of both Brahmaputra and Barak river systems, Assam River Atlas will need periodic updation to keep the database relevant in future.
- Feasibility Study for the construction of major bridge over the river Brahmaputra: This work was taken up at the request of Public Work Dept. of Assam. Thirty years of temporal satellite imagery were analyzed to identify suitable areas for construction of two bridges over the river Brahmaputra; one connecting Jorhat and Majuli and the other connecting Moriganon and Routa (Udalguri).
- GIS based Masterplan under AMRUT, Shillong Planning Area, Meghalaya: At the request of Urban Affairs Dept. of Meghalaya, NESAC prepared draft master plan for Shillong planning area covering sectors such as Physiography & landuse, Demography, Housing, Physical Infrastructure, Social Infrastructure, Mobility, Industry & Economy, Ecology & Environment, Governance & Institutional Arrangements and Disaster Management. Various planning proposals were suggested for the future development of the area.
- Border Area Development Plan, Meghalaya: Villages along the international Indo-Bangladesh border and inter-state Meghalaya-Assam at a buffer of 5 km, 10 km and 20 km were identified. Final report was submitted to Border Area Development Dept. Govt of Meghalaya.
- In the area of Geosciences, NESAC has carried out a number important studies including GPS based total electron content studies for earthquake precursors, Morphotectonics, Neotectonic and deformation studies, Ground water quality mapping, environmental and technological hazards assessment, river dynamics and erosions of Manas-Beki river, etc.

- RS &GIS based inputs for suitable route alignment planning for construction of Mahadev-Toloi-Pfutsero road has been carried out at the request made by NEC, Shillong. Route Alignment was carried out based on certain input parameters such as landslide susceptibility map, Digital Elevation Model, ruling & liming gradient as specified by the user. The proposed aligned route connecting the source and destination is approximately 117.50 km in length exclusive of proposed 6 bridges. Out of this total length, 27.05 km is Greenfield Alignment and 90.45 km is Brownfield Alignment.
- Geospatial Database Inputs for Planning and Restoration of Areas Affected by Coal Mining, Meghalaya: NESAC carried out this work with financial assistance from Meghalaya State Pollution Control Board under the direction of independent committee constituted by the National Green Tribunal (NGT). GF-2 satellite imageries having spatial resolution of 0.8 m (Panchromatic) and 3.2 m (multispectral) were used. Around 93 coal mines (active as well as abandoned) were found in Nongjiri village of West Khasi Hills covering an area of 120 sq.km.
- North Eastern Spatial Data Repository (NeSDR) portal was released on 11th November, 2020 with an objective to share the geospatial datasets among the User's Departments of the region to support their planning and developmental activities. The NeSDR is populated with more than 1044 datasets pertaining land and water resources, infrastructure, disaster management supports etc.
- Geotagging and Geo-monitoring of NEC/MDoNER sponsored Project Sites: This project has been taken up as per the suggestion of NEC/ Ministry of Development of North Eastern Region (MDoNER). Around 1665 projects are to be monitored and 1341 project sites have been geotagged. SRSACs of NER are engaged for geotagging and geomonitoring activity. High resolution multi-temporal satellite images have been integrated to see the progresses of the work.
- Mobile based Integrated Surveillance System for Early Diagnosis & Treatment of Malaria and Other Diseases: NESAC in collaboration with RMRC, ICMR, Dibrugarh developed an integrated surveillance graphical mobile app called 'FeverTracker' to assist the community and healthcare workers in digital surveillance and thereby contribute towards malaria control and elimination.
- Integrated WebGIS Platform for Dissemination of Real-Time Early Warnings/Alerts and Enabling Analytics in Spatial Domain for Monitoring and Management of Disaster Events: Geo-fencing based Mobile App and Dashboard Application have been developed and shared to ASDMA for feedbacks. The application is coupled with a Dashboard management system which can send alerts to the Mobile Application including the SMS text messages.
- Development of a GeoTourism Dashboard Application for planning, management and monitoring tourism activity in NE region: The project has been sponsored by NEC to

promote the tourism activity in NE region by creating a geospatial database on tourism sites and associated infrastructures along with analytical tools for taking smart decision for planning. The Mobile App for geotagging of existing sites has been developed. More than 840 tourism sites have been mapped.

- Development of Mobile and Dashboard Application for geo-spatial survey of Record of Forest Rights (RoFR) forest pattas in Tripura: The project has been taken up at the request of Directorate of land Records & Settlement, Govt. of Tripura. Tripura Banadhikar App developed under the project was released recently.
- Large Scale Survey and Mapping using UAV for various user/line departments: For various user/ line departments from the north eastern region as well as outside the region, large scale survey and mapping works were carried out such as Topographic Survey using DGPS and UAV for Dalmia Cement Lease Area at Thangskai, East Jaintia Hills, Meghalaya, generation of true orthophoto map using UAV for Sarangarh, Raigarh District, Chhattisgarh, etc.
- Crop Damage Assessment and Monitoring Service (CropDAMS): A regular assessment of crop damage due to flood is done regularly during the kharif season in Assam at different stages of growth. In 2021, 1.9 per cent Kharif crop area of Assam was severely damaged due to flood. Agricultural land lost due to Brahmaputra river bank erosion has been analyzed over the state of Assam for the period of 15 years from 2005 to 2020. It was found that 33860.68 ha of agricultural land have been lost due to Brahmaputra river bank erosion.
- Mapping of Shifting Cultivation Area at 1:10000 scale and Estimation of Jhumia Population Depending on Shifting Cultivation in the NER: At the request of NITI Aayog, NESAC executed the project with financial assistance from Dept. of Space, Govt. of India. An area of 1.4 Lakh ha and 2.7 Lakh ha have been identified under current jhum and abandoned jhum, respectively.
- Forest fire assessment in NER: Forest fire hazard alerts based on fire occurrence for each state were given from the month of February to April every year. The forest fire locations are obtained from NRSC Bhuvan. Additional information on site characteristics like forest type, forest density, elevation, slope, road connectivity, etc., is added for evaluation of the fire spread. During the 2020 time period, the entire NE region of India has witnessed around 62352 numbers of fire incidents.
- Near Real time flood inundation Mapping: A total of 16 flood events during June to September 2021 were mapped in near real time to generate village level flood inundation information which was delivered to Assam State Disaster Management Authority.
- Monitoring and Evaluation of IWMP watersheds of NE India: NESAC is carrying out the monitoring and evaluation of Integrated Watershed Management (IWMP) watersheds

of NE India with financial assistance from National Remote Sensing Centre (NRSC), Hyderabad. A total of 777 project sites have been monitored under the programme.

- Landslide susceptibility mapping in NER: In 2020, there were 141 landslides recorded during post-monsoon session in NER. NESAC has carried out the Rainfall-threshold studies for the landslide incidents in 2020 to examine the role of rainfall as a triggering mechanism for landslides in NER.
- AI based landslides detection: A study was carried out to identify landslides on satellite imagery using AI based landslides detection model which may help in rescue process when landslide occurs as a secondary event of a natural disaster like an earthquake or any other natural hazards. The current AI based landslides model is trained with 8 scenes of LISS-4 MX images of the northeast region and tested in 3 scenes.
- Analysis of Vegetation Phenology of NER using time series satellite data: The project was carried out for analysing the vegetation phenology for several natural vegetation types in North East India using 18 years time series MODIS 16 day's composite NDVI data. Seasonality parameters such as start of the season, the end of the season and seasonal amplitude have been calculated and correlated with the forest types of the region and the project is completed.
- Crustal Deformation Analysis Across Garhwal Himalaya: Part of Western Himalaya using GPS Observations: This project was a joint initiative of NESAC, Indian Institute of Remote Sensing (IIRS), Dehradun, Wadia Institute of Himalayan Geology (WIHG), Dehradun, Indian Institute of Technology Indian School of Mine (IIT-ISM) and Jammu University. The study was carried out at selected transact of Western Himalayas and Indian plate. The study suggested for continuous monitoring of deformation across major thrusts in the Himalayas with a dense network of GPS stations.
- Utilization of Artificial Intelligence/Machine Learning/Deep Learning Techniques: NESAC is utilizing a number of AI/ML/DL algorithms and tools for near real-time predictive analysis, feature extraction and pattern recognition under various operational services including R&D activities. NESAC has also successfully completed three AI/DL based projects of DTDI, ISRO Hq (Kshiti, Mausam and Nireekshan).
- Development of Thunderstorm tracking system: NESAC took up an experimental study on tracking severe storm and lightning using data from a lightning location network combined with radar or satellite-based observations. The initial developments of the thunderstorm tracking system have been completed using the DWR, Sohra data.
- ISRO-ONERA-CNES joint Ka-Band Radio Wave propagation experiment at NESAC: ISRO-ONERA-CNES joint Ka-Band propagation experiment is operational at NESAC to assess atmospheric effects (attenuation) on the propagation of the Ka-Band signal for use in satellite to earth communication. The equipment includes two high gain parabolic receiving antennas to receive the beacon signals, a Tipping Bucket Rain Gauge, a Laser

Precipitation Monitor and a Humidity Profiling Radiometer to get atmospheric humidity profile for validating satellite data.

- Aerosol Radiative Forcing over India – NER Scenario: NESAC operates three aerosol observatories in NER including two at high altitude sites. A campaign was conducted along the Brahmaputra river valley to measure the vertical profiling of absorbing aerosol. Detailed analysis of aerosol optical and chemical properties at Lachung, Sikkim revealed that carbonaceous aerosol is the dominant type over this fragile ecosystem with vehicular combustion contributing to 20% while biomass burning contributes to 25% of total aerosol loading. The impact of COVID-19 lockdown on the air quality over NER has also been studied.
- Network of Boundary Layer Experiments (NOBLE) – NER component: A campaign was conducted to understand the regional characteristics of vertical profile of black carbon over the Brahmaputra valley. Samples were collected over three sites for five days with four times a day. Sharp decrease in Black Carbon concentration with height along with east-west contrast in concentration has been observed. The climatology of planetary boundary layer height (PBLH) over the NER was also studied using data from the MERRA-2 model.
- Numerical weather prediction using the WRF Model: The WRF model is run on a daily basis with assimilation of surface and upper air data from different platforms. The impact of indirect assimilation of DWR reflectivity for simulation of thunderstorm over NER of India using WRF model was studied. The impact of INSAT-3D wind and radiance data assimilation for the simulation of tropical cyclones and heavy rainfall events have also been studied. It is observed that Hybrid data assimilation system is able to improve the severe weather forecast over NER as well as can improve the cyclone landfall forecast.
- Severe storm and Lightning nowcasting for NE region: The thunderstorm nowcasting services were continued for the pre-monsoon season of 2021. Thunderstorm potential map was prepared for three times a day with validity of four hours and was shared with the concerned. The lightning activity is also forecasted using WRF-Elec model and by assimilation of ground based lightning data. An effort is being made to develop a thunderstorm tracking system using ground based lightning data, satellite data, and DWR data. The Lightning hazard map of NER is also prepared using LIS data onboard the TRMM satellite.
- Implementation of a state of art real time hydro-meteorological monitoring system in catchment areas upstream of RHEP: A network of 17 Automatic Weather Stations has been installed within the Ranganadi catchment area in Arunachal Pradesh with funding from NEEPCO (North East Electric Power Corporation). A web based dashboard has been developed for real time visualization of AWS data and AWS health. The dashboard is web hosted for real time monitoring of the network and proposed management of the RHEP dam. The credential of the dashboard has been shared with all stakeholders.

7.5 Products Developed

NESAC develops several products for consumption by users. The major among them are listed below:

(i) Daily weather forecast (rainfall, temperature, humidity)

(ii) Precipitation estimate from Doppler Weather Radar (DWR), Sohra

(iii) Max Z (reflectivity), Max V (velocity), Vertical wind product from DWR, Sohra

(iv) Flood warning and Flood inundation maps (during summer monsoon season)

(v) Value added product for forest fire location and management

(vi) Lightning warning

7.6 Capacity Building in Space Science Research

NESAC runs regular short term training course on Remote Sensing (RS) and Geographic Information System (GIS) application in different thematic areas like Agriculture, Forestry, Geosciences, etc. Eight such course of 1-2 weeks duration are conducted every year. In addition, NESAC conducts 2 weeks course on basics of RS and GIS for Indian participants and for BIMSTEC countries separately and UAV remote sensing. More than 800 students and professionals got trained at NESAC during the reporting period.

NESAC Scientists also guide B. Tech., M.Sc., and M. Tech. students for their projects on space science, technology and applications. NESAC scientists also guide Ph D students from various subjects and areas through signing of Memorandum of Understanding between NESAC and the Ph D providing academic institute.

7.7 Courses offered on Space Science and Technology

NESAC offers the following courses

- Basic Training course on Remote Sensing & GIS Technology and Applications
- RS & GIS applications in IT and Web services
- RS & GIS applications in Agriculture and Soil
- Advanced training course on UAV Remote Sensing technological advances & applications
- RS & GIS applications in water resources
- RS & GIS applications in Forestry & Ecology
- RS & GIS applications in Urban and regional planning
- RS & GIS applications in Geosciences
- Satellite Meteorology and its Applications in Numerical Weather Prediction

- Satellite communication technology for emergency applications
- 2 Weeks basic training course on RS and GIS for the BIMSTEC countries.

In addition to the above, NESAC also provides tailor made courses for project specific requirements, 2 weeks

7.8 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1	Joint research, facility sharing, technology development, guiding Ph D students, creation of centre of excellence, and capacity building	Indian Institute of Technology, Guwahati, Assam
2	Joint research, facility sharing, guiding Ph D students and capacity building	Assam Agricultural University, Jorhat, Assam
3	Joint research, facility sharing, guiding Ph D students and capacity building	North Eastern Regional Institute of Water and Land Management, Tezpur, Assam
4	Space technology applications by various user departments and capacity building	(i) Dept. of Science and Technology, Govt of Arunachal Pradesh, (ii) Dept. of Planning, Govt. of Meghalaya (iii) Dept. of Science & Technology and Climate Change, Govt. of Assam
5	Capacity building	Assam Survey & Settlement Training Centre

7.9 Laboratories and Facilities Available for Space Instrumentation

- Laboratory with all relevant GIS and Remote Sensing tools such as high end systems and software for performing remote sensing information retrieval and data analysis, large scale mapping, etc. Latest map plotters, printers, GPS systems and cameras including GAGAN, NAVIC and DGPS for professional grade surveys
- Laboratory for development of Mobile Apps, Dashboard applications, Geo-web services, disaster management support services.
- High performance computing system including GPU servers for atmospheric modeling, hydrological modeling, Machine learning applications.
- Unmanned Aerial Vehicles for remote sensing, quick mapping support, disaster management support including drone testing, fabrication using 3D printers, drone pilot training, etc.

- Satellite communication facilities including satellite phones, to support various developmental programs and emergency communication support.
- S Band Doppler Weather Radar for management of hydro-meteorological disasters.
- Facility to launch tethered balloons and atmospheric sondes using hydrogen gas filled meteorological balloons for vertical profiling of atmosphere.

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CHAPTER-8

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY (IIST)

Thiruvananthapuram- 695 547, Kerala

8.1 About IIST

Indian Institute of Space Science and Technology (IIST), Thiruvananthapuram is a Deemed to be University under Section 3 of the UGC Act 1956, established by Department of Space (DoS), Government of India, in 2007 and functioning as an autonomous body. IIST, envisioned to be a world class educational and research institution contributing significantly to the Space endeavours, is the only institute in the country equipped to offer the whole spectrum of undergraduate, postgraduate and doctoral programmes in different branches of science and engineering with a focus towards space science & technology. Through its mission statement IIST undertakes to create a unique learning environment, imparting ethical and value-based education, enriched by the challenges of the Space Programme. The IIST-ISRO symbiotic relationships are streamlined and facilitated by Advanced Space Research Group (ASRG) through several projects, planning and review processes. Through these activities, IIST aims to provide skilled human resources and excellent technologies to address local, national and global needs. We also nurture the spirit of innovation and creativity by establishing Centres of Excellence in niche areas and a huge impetus is provided to the youth in their avant-garde ideas to grow their entrepreneurial skills through Space Technology Innovation and Incubation Centre (STIIC). We also network with several national/ international institutions and industries of repute in our journey to develop technologies and solutions to address societal needs.

8.2 Keywords

IIST, Space Science, Space Technology, Aerospace, Avionics, Earth and Space Sciences, SSPACE, ASRG, STIIC, Climate Observatory

8.3 Major Research Domains

- Advanced Propulsion and Laser Diagnostics
- Thermal and fluid flow
- Aerospace Structures and Robotics
- Small Satellites and Payloads
- Satellite Communications and Networking
- Nanoscience and Technology

- Quantum Computing and Data Security
- AI, Data Analytics & Machine Learning
- Humanoid for Crew assistance in Human space missions
- Antenna development and RF systems development
- Nano Electronics and MEMS-Optoelectronics, Sensors
- Power electronics/drives/systems
- Electrical propulsion
- Materials Science and Material Processing
- Astronomy and Astrophysics
- Atmospheric Science and Remote Sensing
- Applied and Adaptive Optics
- Atomic and Molecular Physics
- Condensed Matter Physics
- Nonlinear Dynamics and Statistical Physics
- Astrobiology, Gravitational and Space Biology
- Planetary Geosciences and Analog Research
- Climate Observatory and Balloon Launch Facility

8.4 Major Scientific Applications and Results

Being an academic institute supported by DoS, majority of the research activities at IIST are focused towards space science, space technology and space applications. The research highlights in space science and applications are reported below, with the title of the topic and a brief description.

Drug Discovery and Theranostics- towards Space Medicine Research: Small molecule drug discovery program focuses on the development of theranostics. The chemical library for screening against various disease models using Drosophila Melanogaster is being developed as part of the space biology payload for first developmental flight of Gaganyaan.

Microgravity Research: Development of Microgravity Simulating Platforms and Space Biology Payloads: Design, fabrication and validation of a Random Positioning Machine was completed (under design protection). The platform is now being used for conducting microgravity science experiments using plants and other biological samples.Space Biology Lab was initiated. Design and prototyping of spaceflight hardware for multiple experiments are in progress.

Extragalactic Astronomy: Study of the distribution of metals outsides of galaxies, in the circumgalactic and intergalactic medium was conducted. By using absorption line spectroscopy technique on UV spectra of a quasar obtained using the cosmic origins spectrograph on the Hubble Space Telescope, and visible wavelength spectra obtained using the HIRES instrument on the Keck telescope, the presence of 100,000 K warm plasma and relatively cooler gas in diffuse gas structures at five different epochs over the 5 billion-to-7.5-billion-year history of the universe was revealed.

Protocluster revealed in high-mass star-forming complex, G19.88-0.53: Detailed continuum and kinematics investigations of G19.88-0.53 unveils for the first time an interesting picture of this complex being a protocluster harboring multiple components spanning a wide evolutionary spectrum, from hot cores in accretion phase to cores driving multiple outflows to possible UC HII regions. This study utilizes radio observations taken with the Giant Meterwave Radio Telescope, Pune, India and archival data from the Atacama Large Millimeter Array (ALMA).

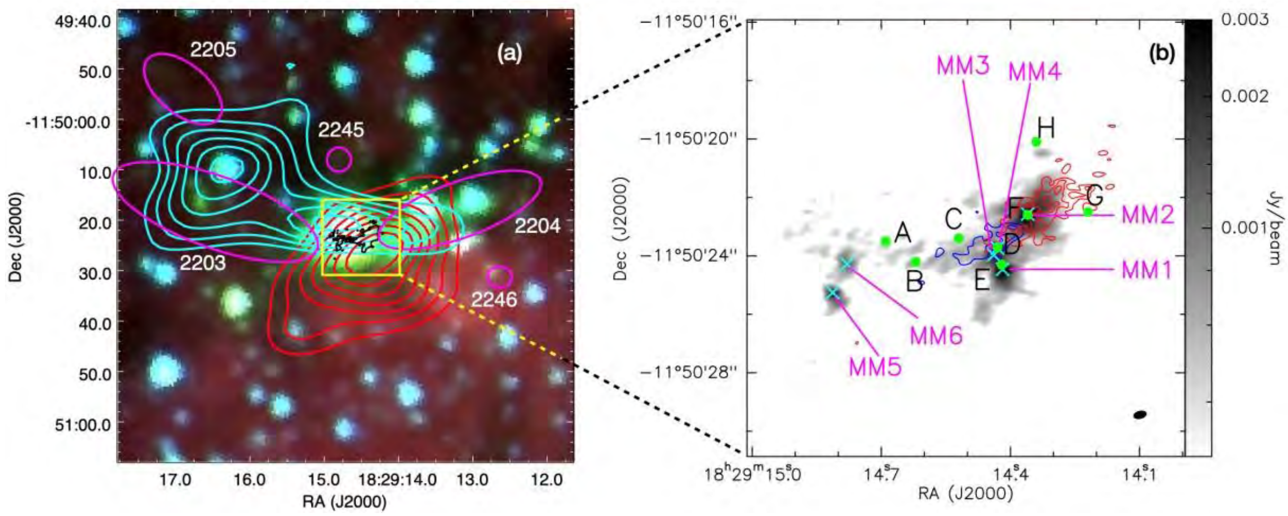

Figure1: (a) Mid-infrared view of the G19.88-0.53 complex with the protocluster at the centre. Large bipolar C18O outflow in the NE-SW direction is shown as contours. (b) A zoomed-in, high-resolution view showing the multiple radio and millimetre components of the procluster. A new bipolar outflow is seen (contours) in opposite direction and is likely driven by the source MM2.

Stellar cluster formation triggered by cloud-cloud collision in G133.50+9.01: Compelling observational evidence is presented showing G133.50+9.01 to be a bona fide cloud-cloud collision candidate with signatures of induced filament, core, and cluster formation. This study makes use of observations from the Purple Mountain Observatory 13.7-m telescope, China.

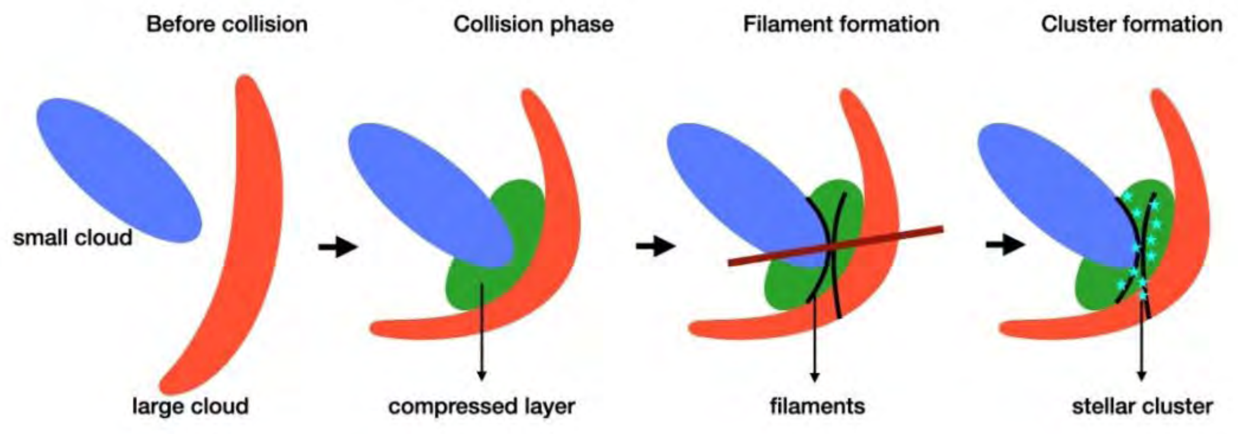

Figure 2: Schematic view of cloud-cloud collision triggered filaments and stelllar cluster formation in G133.50+9.01

Geoinformatics for vulnerability assessment: Socio-economic vulnerability of Coastal belt of Tamil Nadu was estimated using exposure and capacity related indicators to natural hazards namely cyclone, tsunami, flood etc., and man-made hazards like industrial accidents, drought, settlement collapse etc. The analysis was carried out at micro-administrative scale using the census data of 2011 pertaining to 5,235 villages/wards and household data using GIS based hot-spot analysis. The information generated in this study can be used as a baseline data to identify the micro administrative units, to be prepared locally to prevent the devastating disaster impacts, and to increase the resilience of the community.

Remote Sensing Techniques for Mineral Exploration: Texture and mineralogy of beach sediments are investigated using samples collected from Thiruvananthapuram coast, Kerala. The results indicate the dominance of medium to fine-grained sands with a high content of ilmenite mineral. The spectral indices generated using the bands of ASTER and Landsat 8OLI satellite data clearly detect the abundance of medium to fine sand area. The potential targets of mineral occurrence can be classified using hyperspectral analysis of above two data. Spectral library developed from Laboratory based data provides highly accurate information of heavy minerals, which significantly increased the accuracy of image classification.

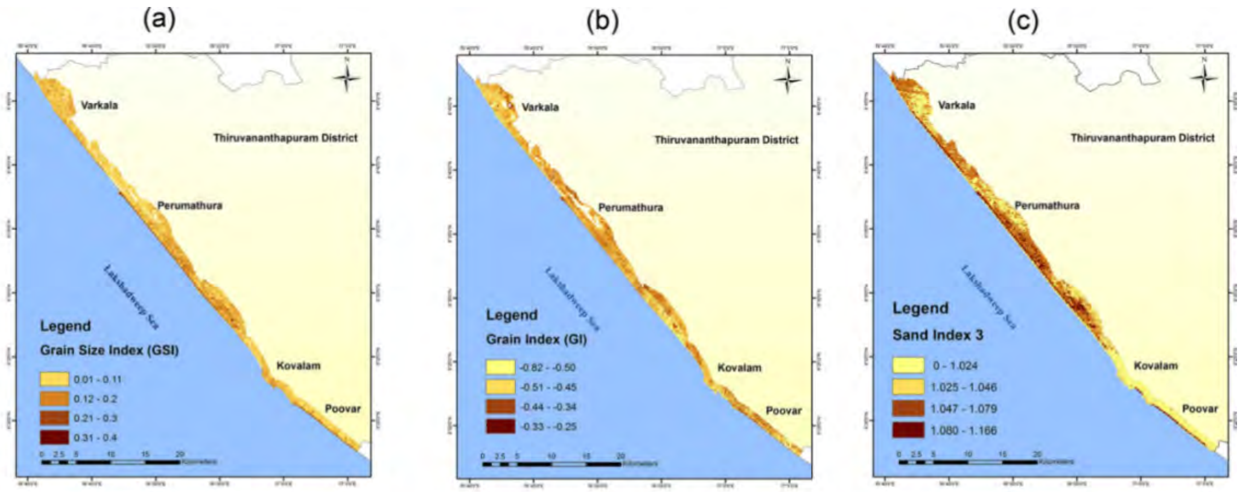

Figure 3: Satellite derived maps showing texture of beach minerals. (a) Grain size index (GSI) map; (b) Grain index map; (c) Sand index 3 map; (a1) Scatter plot corresponds to Grain size index (GSI); (b1) Scatter plot corresponds to Grain index map; (c1) Scatter plot corresponds to Sand index 3 map.

Data Assimilation and Predictability of Weather: Forecast Sensitivity of extreme rainfall events are investigated through Ensemble-based Sensitivity Analysis (ESA). ESA enables the assessment of forecast errors and its relation to the flow fields through linear regression approach. The study has far reaching consequences especially in the domain of targeted data assimilation.

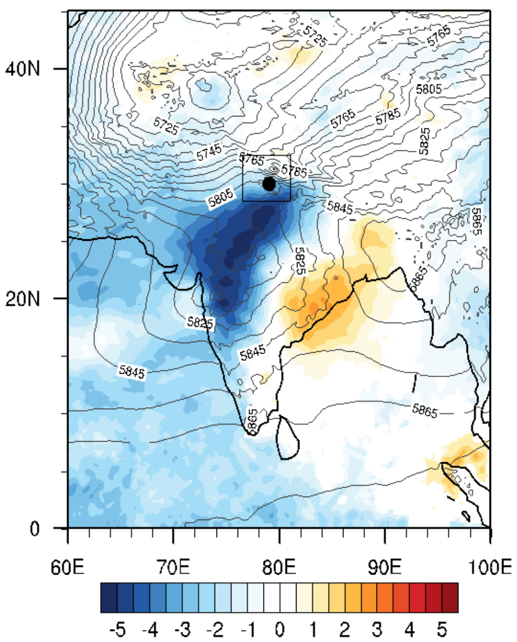

Figure :4 Ensemble sensitivity (shading) of 24-h accumulated precipitation averaged over the square box to the geopotential height at 500 hPa. The black box depicts the region of response function used in the computations

The GLOSTAR Survey: The Global View of the Star formation in the Milky Way (GLOSTAR) Project provides the most sensitive maps of the radio emission of large parts of the Northern Galactic plane so far, taken with the Karl G. Jansky Very Large Array (VLA) in New Mexico in two different configurations and the100-m Effelsberg radio telescope. While an interferometer like the VLA can produce very sharp images of the sky, the large-scale emission is often lost. However, the diffuse radio emission can be recovered by adding data from the 100-m Effelsberg telescope.

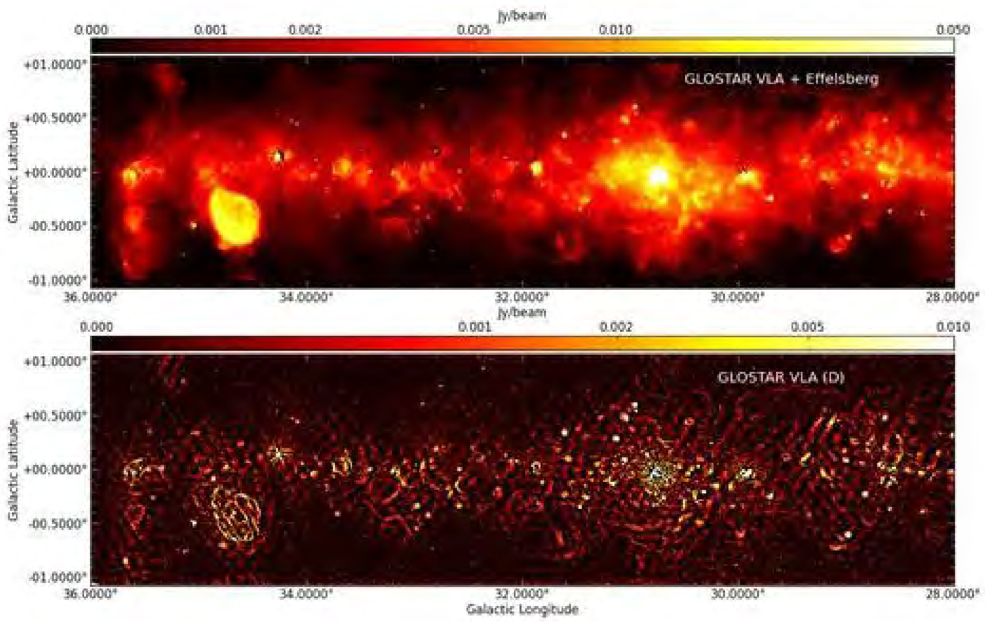

Figure 5: Top - Continuum radio image of the pilot region in the range 28° < l <36° from the combination of the VLA D-configuration & Effelsberg single dish images. Bottom- D-configuration VLA image of the full continuum of the same longitude range which was already presented in Medina et al. (2019).

CALIPSO observations of ubiquity of aerosol layers in the free troposphere over South Asia: sources and formation mechanisms: Research team analyzed cloud-free aerosol extinction coefficient (βext) and particulate depolarization ratios obtained from a space-borne lidar observations, Cloud-Aerosol Lidar with with Orthogonal Polarization (CALIOP) on-board CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) for the period of 2008-2018. Investigations also expanded to unprecedented climatology of the physical and optical characteristics of elevated aerosol particle layers (EAPL) along with their source and formation mechanism throughout its life cycle in the free troposphere.

Volcanism on the Moon: The mineralogy and chemical variations of the mare basaltic units in the Mare Humorum on the Moon's nearside using orbital remote sensing data from recent lunar exploration missions were investigated. Hyperspectral data from Moon Mineralogy Mapper on board Chandrayaan-1 mission showed pigeonites and augites as the major compositions in these basaltic units. The compositional trend between pigeonites and augites point towards the differentiation of the basaltic magma while cooling.

High-energy astrophysics on explosive transients: Research in this area was focused on three problems. In the first one GMRT observations of the persistent source associated with FRB121102 was looked at. Useful constraints on the nature of the central engine powering the FRB and the persistent source was obtained. The next problem was on the signature of galactic dust seen in late-time X-ray afterglows of Gamma-Ray Bursts (GRBs). Being the first one to consider the dust scattered emission and the original afterglow emission, the research team will be able to obtain properties of dust in GRB host galaxies which may, in turn, bring light to the origin of GRBs. The last problem is in the emerging field of multi-messenger astronomy.

High Energy Astrophysics: The research focus includes the study of accretion physics around stellar as well as supermassive black holes. The research use both theoretical and observational tools to probe the physics around compact objects.

Investigating early phases in massive star formation: A numerical model has been proposed to explain the observed radio spectral indices of protostellar jets. This model includes the effect of thermal free-free emission as well as non-thermal synchrotron emission. Observations of the star-forming region associated with RCW42 was analysed to understand the nature of the HII region and the associated star-formation activity. The feedback effects of the star formation process on the natal molecular cloud are also probed. In addition, UV observations of the globular cluster NGC5053 were carried out by the UV Imaging Telescope on Astrosat. The data was reduced and analysed to segregate and understand the hot stellar populations in the late stages of stellar evolution.

Science, Technology and Society: An ICSSR sponsored research project on the Impact of tele- medicine units in India was undertaken which studied the changes that has happened in telemedicine technology in India before and after the pandemic. A collaborative project with Jagellonian University, Poland on the perception and awareness of different sections of the society towards space programs has also been proposed to ISRO.

Technology diffusion and Economic Development: Research collaboration was established with the Centre for Development Studies for developing a methodology and measuring the Space Economy of India. Economic Analysis of Public Investments in the Indian Space Program has been initiated. A major research project under the category of ‘Novel and Path breaking Major Research Award’ has been awarded by Indian Council of Social Science Research’ for the study on the impact of tele-medicine in rural India.

Quantum Science and Technology with Bright Entangled Light: From a theoretical concept of quantum theory to applications towards quantum computing, quantum communication, and quantum sensing, quantum entanglement is critical. The research team is developing a source of bright entangled twin beams of light generated with the interaction of laser beams with hot rubidium vapour cell via a four-wave mixing process.

Optical metrology using digital holography, (Collaboration with VSSC): In collaboration with ISRO centers, applied time average digital holographic technique for Non-Destructive Testing of aerospace structures is being pursued since 2010. In continuation of that, recently developed a method to evaluate NDT of de-bond structures.

Digital holography for metrology (IISU):

In collaboration with IISU, working on a problem for testing prism element using digital holography and thin film coating. Detailed experiments are being carried out simultaneously at IISU and IIST.

Freeform optics (LEOS, Bengaluru):

Conventional two-mirror optical telescope designs are well-known, but to improve the performance of two mirror telescopic system, developed new design using freeform surface. Four variants of the optical design that make use of symmetrical and off-axis freeform surfaces for achieving superior performances in the spectral range from 400nm to 900nm, as compared to regular RC telescope design are proposed. The optical design with freeform surfaces show marked improvements compared to its counter-part comprising of conics and higher order aspherics.

Atmospheric optics (NARL, Gadanki): The vertical and spatial distribution of elevated aerosol layers obtained using long-term ground-based and space-borne LIDAR observations are developed and using this the atmospheric structural changes are being observed over various regions of India.

Development of Superconductor based quantum detectors: Superconductor based AQM using 2D material growth techniques: These AQM based sensors/devices have immense applications in space and ground based explorations including stealth navigation. We are actively working on Single Photon detectors, Transition Edge Sensor (far-infrared sensors) using SQUID based superconducting technology (extreme signal amplifiers ~10−15V/s).

Atomic and Molecular Physics: A detailed monte Carlo model was designed and tested to recreate the upper atmospheric conditions in the Titan atmosphere and obtained preliminary results. Further a plasma reactor and perform mass spectrometric measurements on the complex species formed during the discharge was built.

8.5 INSTRUMENTS/ PAYLOAD / PRODUCTS DEVELOPED / SENSORS/ DETECTORS

INSPIRESat-1

INSPIRESat-1 is a student satellite jointly developed by Small-spacecraft Systems and PAyload CEntre (SSPACE), Indian Institute of Space Science and Technology (IIST) and Laboratory of Space Physics, University of Colorado, Boulder, USA, to provide education and space science research to the students of the collaborating universities. Two other universities who contributed in this journey include NTU, Singapore and NCU, Taiwan.

The main scientific aims of the INSPIRESat-1 mission are:

1. Improve the understanding of Ionosphere dynamics through observations of ion temperature, composition, density and velocity. This effectively means characterization of plasma parameters and irregularities in the low- and mid-latitude ionosphere.

2. Improve our understanding of the sun's coronal heating processes by measuring the Soft X-Ray spectrum of the sun."

INSPIRESat-1 is a 3-axis stabilised spacecraft carrying two payloads, the CIP and the DAXSS. The spacecraft weighs 8.38Kg with stowed dimensions = 312mm x 190mm x 221mm [during launch without the ring], and deployed dimensions = 535mm x 190mm x 450mm [in space].

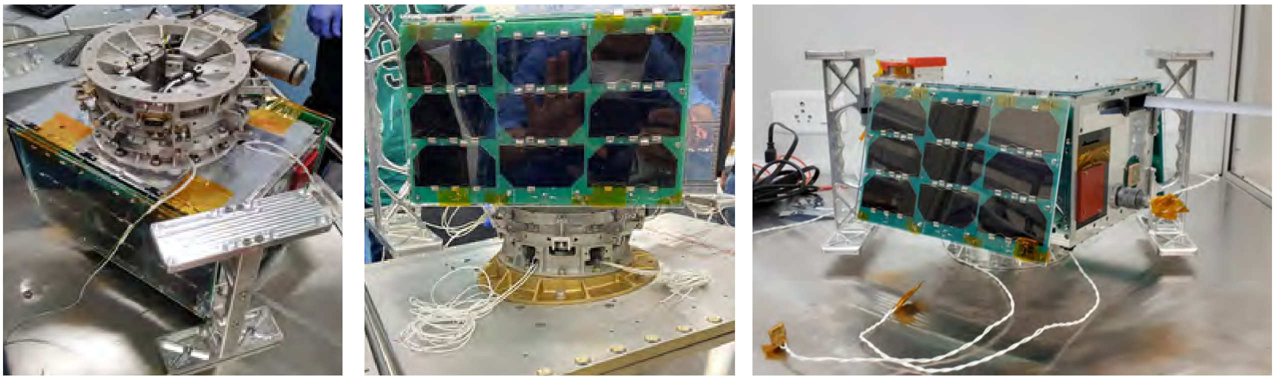

Figure 6: INSPIRESat-1, Matchmate of INSPIRESat-1 with IWL 150 V2 Deployer in SSPACE Lab in IIST, Trivandrum, India

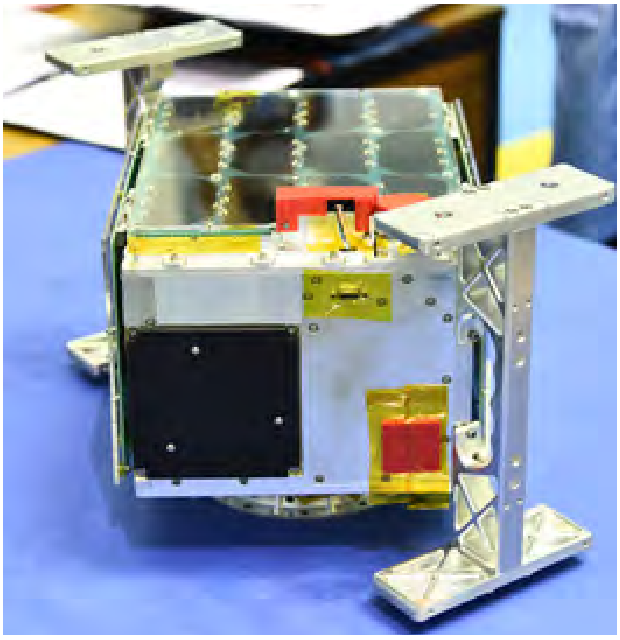

Figure 7: Spacecraft undergoing CPT at SP1B cleanroom

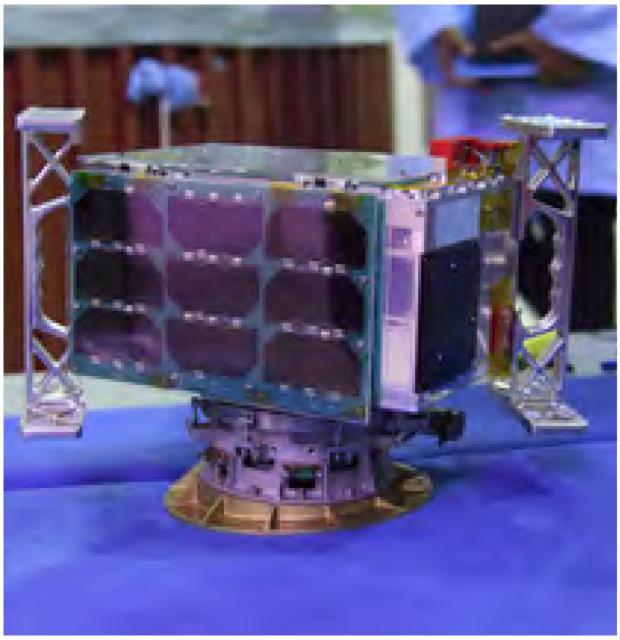

Figure 8: Satellite ready at SP3 for Integration SDSC, SHAR

ARIS Payload

A Retarding Potential Analyser has been indigenously developed for the ARIS mission.

OBC for small satellites

The onboard computer developed for the InspireSat1 mission can be used in future small satellite space missions.

EPS for small satellites

The Electrical Power System developed for the InspireSat1 mission can be used in future small satellite space missions.

Integrated Diagnostics Module (IDM) for onboard diagnostics of an electric propulsion system to be installed on a Technology demonstration satellite (TDS-1).

ARIS-2 hardware is made ready and functional testing completed at IIST. Awaiting the next opportunity on a suitable PSLV mission with a stabilised PS4 platform.

LEO plasma simulation facility is established for testing payloads and small satellites (80 cm X 80 cm X 80 cm or smaller).

A unique energy correlated mass spectrometric technique is developed at the Atomic and Molecular Physics lab using which a large family of astronomically important molecules and their interaction with stellar radiation can be studied in the laboratory

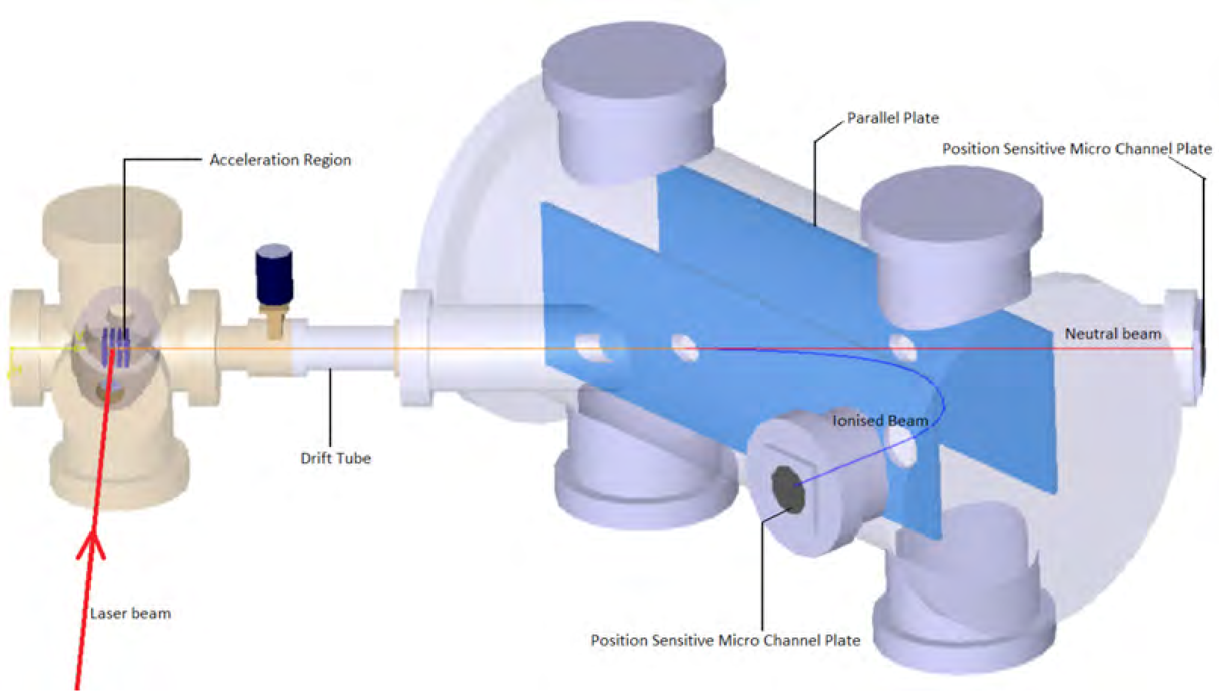

Figure 9: Schematic of the energy correlated ToF mass spectrometer developed at AMP lab, IIST

8.6 Capacity Building in Space Science Research

Being an academic institute in the country under Department of Space, all the undergraduate and postgraduate programs offered by the institute have the flavour of space science and technology. The doctoral and postdoctoral programs are also largely aligned to space program goals.

IIST organises various winter schools/ workshops and seminars in the areas of space science research to the benefit of students across the country. The incubation centre of the institute, Space Technology Innovation and Incubation Centre (STIIC), largely supports entrepreneurs with business plans in the space science and technology areas.

8.7 Courses offered on Space Science and Technology

IIST being the unique space science and technology institute in the country, all the courses offered to the students of UG and PG are directly or indirectly connected with Space Science and Technology. The institute offers B.Tech Programs in (1) Aerospace Engineering and (2) Electronics and Communication (Avionics); and a dual degree program in Engineering Physics. The list of courses includes fundamental courses and specialized courses on space science and technology. Dedicated elective courses on space science and Technology is also another highlight of the institute. Institute offers the following Masters Programs.

- M.Tech in Aerodynamics and Flight Mechanics, Structures and Design, Thermal and Propulsion, Control Systems, Digital Signal Processing, RF and Microwave Engineering, VLSI and Microsystems, Power Electronics, Materials Science & Technology, Earth System Sciences, GeoInformatics, Machine Learning and Computing, Optical Engineering, Solid State Technology
- Master of Science in Astronomy and Astrophysics
- As representative examples, three sample courses are described in detail below to demonstrate the relevance and involvement.

Course - I

i. Title : Spaceflight Mechanics for Undergraduate/ Post-graduate

ii. Intake capacity: 60 (B.Tech), 10 (M.Tech)

iii. opics covered:
Dynamics of Particles,Two Body Motion, Non-Keplerian Motion,Orbit Maneuvers. Lunar/ Interplanetary Trajectories

Iv. Total number of lectures allotted for the course : 45 lectures

Course - II

i. Title of the course: Space Mission Design and Optimization

ii. Standard of the course: Undergraduate/ Post-graduate

iii. Intake capacity: 60 (B.Tech), 10 (M.Tech)

iv. Topics covered:
Launch vehicle ascent trajectory design – reentry trajectory design – low thrust trajectory design – satellite constellation design – rendezvous mission design – ballistic

lunar and interplanetary trajectory design – basics of optimal control theory – mission design elements for various missions – space flight trajectory optimization – direct and indirect optimization techniques – restricted 3-body problem – Lagrangian points – mission design to Lagrangian point.

v. Total number of lectures allotted for the course : 45 lectures

There are a number of such courses offered in the curriculum, starting from elementary courses (for example Elements of Aerospace Engineering) to Advanced specialized courses (such as Aerospace Vehicle Design) in the curriculum. The details of all the offered courses, curricula and syllabi are available at www.iist.ac.in

Course - III

i. Title of the course: Satellite and Optical Communications

ii. Standard of the course: Undergraduate

iii. Intake capacity: Approximately 60

iv. Topics Covered:

Digital Modulation, Error control coding, Modelling the space link - frequency allocation for satellite communication, satellite orbits and link availability,Satellite link budget, Multiple access methods for satellite communication, Introduction to satellite networks. Services using satellites. Recent advances in satellite networks. Electromagnetic Interference and Compatibility.

No of lectures: 40 to 45

In addition to these courses, in response to the requirements to grow Astrobiology work force in the country, as a preliminary step, IIST initiated Institute Elective in Astrobiology (in 2018): The BTech students of all branches are offered an elective course “Basic Course on Astrobiology” as a choice-based credit system course of 2 credits (30 hours). Around 60-70 students attend the course every year.

8.8 National collaboration in Space Science

(representative ones only are listed)

Sl. No	Area of Collaboration	Collaborating Institute/ organisation
1	Space Biology	UAS Dharwad
2	Molecular dynamics in space	Interuniversity accelerator center, New Delhi

Sl. No	Area of Collaboration	Collaborating Institute/ organisation
3	Automatic labelling methods for the development of machine learning Tracking & Nowcasting of severe convective storms using deep learning (DL)/machine learning (ML) techniques Cloud physical properties under Polluted and Unpolluted conditions for Climate Studies Automatic labeling methods for development of machine learning applications for inventory of horticulture plantations DEEP CLOUD: Deep learning based system for time series Cloud detection using multi-sensor satellite Imagery	NRSC
4	Mangrove forest mapping and monitoring using multi -source remote sensing satellite data	Maharashtra Forest Department, Mangrove Cell

8.9 International Collaborations in Space Science

(representative ones listed)

Sl. No	Area of Collaboration	Collaborating institute
1	InspireSat1 Molecular dynamics in space	Laboratory of Atmosphere and Space Physics (LASP), University of Colorado, Boulder US
2	InspireSat1	Nanyang Technological University (NTU), Singapore
3	InspireSat1	National Central University (NCU), Taiwan
4	Molecular dynamics in space	Elettra Synchrotron facility, Trieste, Italy
5	Molecular dynamics in space	CMR-ISM, Rome, Italy
6	CUBESAT constellation Mission for multi-point measurements on MARS Piggyback launch for deep space exploration	ISAE SUPAERO France
7	Galastic Star formation	Max Planck Institute for Radio Astronomy

8.10 Laboratories and Facilities Available for Space Instrumentation

SPACE: Facilities for Space mission design using small satellites, design and development of small satellite subsystems, experiments to explore space science on the LEO etc are available.

GROUND STATION: capable to operate in the UHF for telecommand and telemetry of the satellite (INSPIRESat-1) at 9.6kbps. The S-band is exclusively used for receiving the data from the payload at 2Mbps.

ATOMIC AND MOLECULAR PHYSICS LAB: A unique energy correlated mass spectrometric technique is available using which a large family of astronomically important molecules and their interaction with stellar radiation can be studied in the laboratory.

GAS SENSOR LAB: The team investigates low weight, high-performance nanostructure gas sensor array on a flexible substrate at room temperature where each element of the array will be functionalized to enhance the performance of the sensor. The group is working actively with IPRC (ISRO Propulsion Complex) to develop a suitable H2 sensor for leak detection, and with SAC and SCL to develop a QM module of Gas sensors for upcoming Human Space Missions. CO sensor for human space programs was demonstrated and collaborations are established with HSFC, SAC and SCL

BALLOON LAUNCH FACILITY: IIST has a fully owned and dedicated unique research facility of Ponmudi Climate Observatory. The observatory is one of its kind in the country, with provisions for balloon-borne measurements from near-surface to stratosphere (35.0 km) of various atmospheric parameters such as chemical-physical-optical properties of aerosols and clouds and meteorological variables for climate study.

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CHAPTER-9

INDIAN INSTITUTE OF REMOTE SENSING

Dehradun

9.1 About the Institute

Indian Institute of Remote Sensing (IIRS) is a premier institute with a primary aim to build capacity in Remote Sensing and Geoinformatics and their applications through education and training programmes at postgraduate level. It is a constituent Unit of Indian Space Research Organisation (ISRO), Department of Space, Government of India. Formerly known as Indian Photo-Interpretation Institute (IPI), founded in 1966, the Institute is first of its kind in entire South-East Asia. While nurturing its primary endeavor to build capacity among the user community by training mid-career professionals since its founding in 1966, the Institute has enhanced its capability and evolved many training and education programmes that are tuned to meet the requirements of various stake-holders, ranging from fresh graduates to policy makers including academia, industry and NGOs.

The capacity building activities of the Institute are primarily grouped into the following three domains – (1) Training & Education (2) Research and (3) Outreach. The Institute also hosts and provides support to the Centre for Space Science and Technology Education in Asia and The Pacific (CSSTEAP), affiliated to the United Nations, to conduct the remote sensing and GIS training & education programmes at postgraduate level.

Vision: “Achieve excellence and remain in the forefront for capacity building in Remote Sensing & Geoinformatics and their applications.”

9.2 Keywords

The training, education and capacity building, Indian Technical and Economic Cooperation (ITEC), Remote Sensing & GIS, Earth Observation Applications Mission, Geodynamics, ISRO Geosphere Biosphere Programme, Himalayan ecosystem, Geo Ladakh, Biomass burning

9.3 Major Research Domains - Contributions in Operational & Research Projects

IIRS has played a significant role in contributing towards major operational and research programmes of ISRO, and in the process, has maintained an interface with other ISRO Centres. IIRS is recognized as a Research Centre for carrying out Ph.D. by the universities. Highlights of the major ISRO programmes/research projects in which IIRS have participated and initiated are described in below section. IIRS actively contributed the research in the areas of photogrammetry, SAR / InSAR / PolSAR remote sensing, LiDAR and image processing.

journals and conferences besides the contribution of chapters to books, contributing to the space program of the country for societal benefits. A summarized list of budgeted ongoing R&D activities may be enlisted as follows:

Earth Observation and Applications Mission

(i) Retrieving of Geophysical parameters using GNSS/IRNSS signals.

ISRO - Geosphere Biosphere Programme (Climate and Atmospheric Programme)

(ii) Soil & Vegetation Carbon Flux (SVF Forest & Agriculture)

(iii) Understanding the Impact of Climate & it's variability on hydrological fluxes vis-a-vis water availability for sustainable development

(iv) Spatio-temporal variations of gaseous air pollutants over the Indian subcontinent with a special emphasis on foothills of North Western Himalaya

(v) Carbon Dynamics Assessment in Tropical Forests of Northeast India using Multi-sensor Data.

Disaster Management Support

(vi) IIRS - Advance Studies

(vii) IIRS - Capacity Building

In-House TDPS/ R&Ds

(viii) Digital soil mapping using environmental covariates for mountainous region.

(ix) Study of fog using satellite data and geospatial techniques.

(x) Sensitivity analysis of tropical cyclone intensity and track to ocean subsurface temperature using the NWP model.

(xi) Continuation of Long Term Surface Energy Balance Studies for North-West Himalayan Agro-ecosystem using Large Aperture Scintillometry.

(xii) Estimating Soil Quality Parameters using Quantitative Colour Measurements.

(xiii) Geospatial approach for Characterization of Agro-Ecological Zones for Diversification of Horticulture Crops in Himalayan Region.

(xiv) Application of GPS for tomographic retrieval of the water vapor distribution in the troposphere

(xv) Application Potential Assessment of UAV Data for Analysing Urban Environment and Hazards.

(xvi) UAV application in characterization of soil and crop variability related to crop stress and land management

(xvii) Development of Array database based system for EO application

(xviii) Effect of tropical cyclones on physical and biological processes in the North Indian Ocean

(xix) PolSAR-based modelling for scattering characterization of different components of forest vegetation

(xx) Strain modelling and seismic vulnerability assessment in North Western Himalaya using space-based observations

(xxi) Land Deformation Detection from Space: A Persistent Scatterer Interferometry and SBAS approaches

(xxii) Development of the terrain corrections algorithms for SAR data

(xxiii) Monitoring & Assessment of Mt. Ecosystem & Services in North Western Himalaya (Phase-II)

Other Projects

(xxiv) Chandrayaan-2 Science plan for utilization of Imaging Infrared Spectrometer (IIRS) Data for lunar surface compositional mapping

(xxv) DBT Sponsored - Biodiversity Characterization at Community Level in India using Earth Observation Data

(xxvi) DBT Sponsored - Indian Bioresource Information Network (IBIN)

(xxvii) NMHS - Himalayan Alpine Biodiversity Characterisation and Information System Network

(xxviii) Geo Ladakh: Spatial Data Infrastructure (SDI) Geoportal with Allied Database Development for UT-Ladakh

9.4 Major Scientific Applications / Results

❖ **Study of Extreme Rainfall Events Based on Satellite Data sets**

- An increase of extreme rainfall/cloud burst events is noted over the North West Himalayan region in recent years.
- Owing to the sparse coverage of the observational network, it poses serious challenges to the research community for the monitoring of such events.
- The study is based on INSAT based OLR, and rainfall data sets, which demonstrates reasonable potential to capture the intensity and locations of various extreme rainfall/ cloudburst events. Satellite based OLR and rainfall data sets in association with model simulations show a promising pathway for the study, analysis and forecasting of extremely heavy rainfall/cloud burst events (Figure 1).

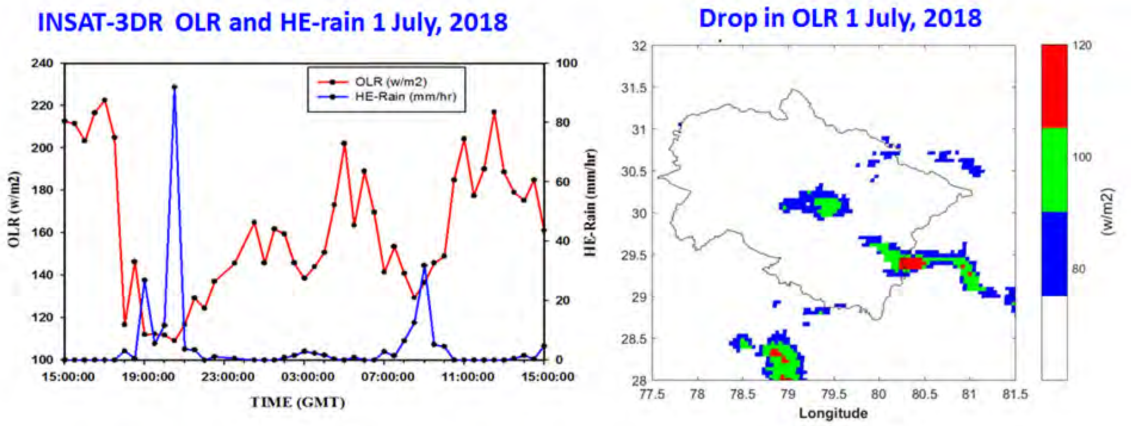

Figure. 1: Time series of the INSAT based OLR drop and corresponding rainfall on July 1, 2018 and spatial pattern of OLR drop in W/m².

❖ Effect of COVID-19 lockdown on spatio-temporal distribution of Nitrogen dioxide over India

- The nationwide lockdown was implemented in India from March 25, 2020 onwards to control the spread of deadly Coronavirus disease 2019 (COVID-19). A sudden shutdown of anthropogenic activities resulted in abrupt decrease of nitrogen dioxide (NO_2) across the Indian region. OMI (Ozone Monitoring Instrument) tropospheric column NO_2 observations show significantly decreased values during 2020 as compared to previous years during March 25 to April 19. The spatio-temporal variation of tropospheric column NO_2 difference between 2020 and average 2017-2019 showed that values decreased by more than 1 x 1015 molecules/cm2 over the Indo Gangetic Plain, eastern and southern India due to lockdown. The daily average in-situ observation of NOx (NO+NO²) also showed decrease from 65.2±18.7 ppbv to 30.3± 4.6 ppbv over Kolkata, 38.8 ± 17.5 ppbv to 11.5 ±2.9 ppbv over New Delhi, 24.4 ± 7.5 ppbv to 10.1±2.5 ppbv over Bengaluru, 14.6±3.8 ppbv to 8.9 ±1.1 ppbv over Hyderabad, 30.2±13.1 to 10.1±2.8 ppbv over Jaipur and 5.1±1.2 ppbv to 2.3 ± 0.2 ppbv over Dehradun before and during lockdown phase (Figure 2).

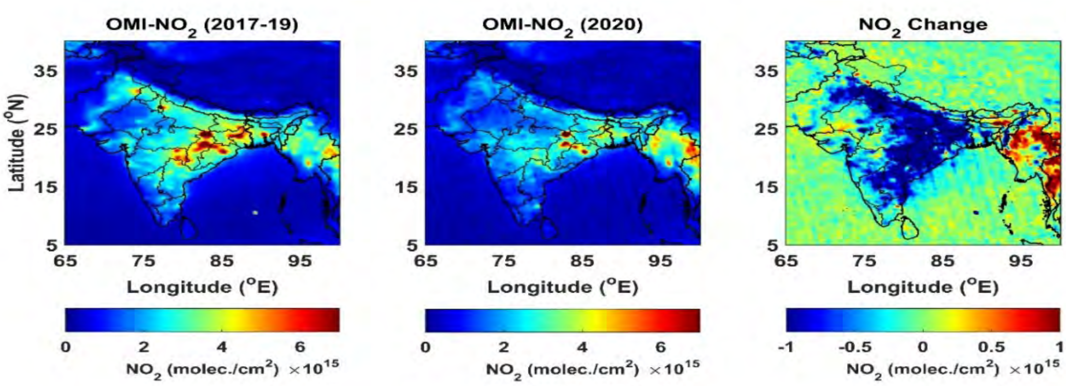

Figure 2: (Panel 1) Three year average (2017-2019) tropospheric column NO_2 *(molecules/cm2) for a period of March 25 to April 19; (Panel 2) Tropospheric column* NO_2 *for a period of March 25 to April 19, 2020; (Panel 3) Tropospheric column* NO_2 *difference (2020 minus 2017-2019 average)*

❖ Relative Contribution of different CO sources over New Delhi during stubble burning period

- Weather Research and Forecasting model coupled with chemistry (WRF-Chem) is utilized for segregation of carbon monoxide (CO) contribution from different sources over New Delhi during Parali burning period of Punjab. WRF-Chem model simulations are made during October November 2018 over the Indian region using EDGAR anthropogenic emissions, FINN biomass burning emissions, NCEP FNL data for initial and lateral meteorological boundary conditions and MOZART chemical initial and boundary conditions. Synthetic CO tracers are included in the model simulation like CO-Transport, CO-energy, CO-industry, CO-domestic, CO-biomass etc. for calculation of CO contribution from these emission source types. These tracers provide CO emitted only from specific activity without affecting the standard CO chemistry in the model simulation. 91.5% CO is contributed from anthropogenic activities and Biomass burning over New Delhi during Oct-Nov 2018. Anthropogenic activities contributed 72.7% and Biomass Burning contributed 18.8% CO (Figure). Transport is most important anthropogenic emission source of CO over New Delhi followed by domestic emissions during this period (Figure 3).

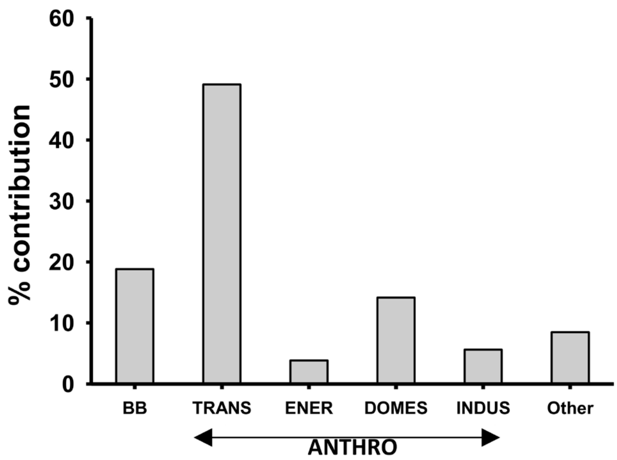

Figure 3: Percentage contribution of different emission sources in total surface CO over New Delhi during Oct-Nov 2018 simulated by WRF_Chem. BB –biomass burning emissions, TRANS-transport emissions, ENER-energy emissions, DOMES- domestic emissions, INDUS: industrial emissions, Other- chemical production and lateral boundary transport.

❖ Lunar Science: Unambiguous detection of OH/H_2O on the Moon from Chandrayaan-2 Imaging Infrared Spectrometer reflectance data using 3mm hydration feature.

- Reflectance data from Imaging Infrared Spectrometer (IIRS) on-board ISRO's Chandrayaan-2 mission for detection and completely characterize lunar hydration (2.8-3.5µm region) attributed to the presence of OH- and/or H_2O.
- The study presented initial results from IIRS reflectance data analyzed to unambiguously detect and quantify lunar 3µm absorption feature.

- Temperature maps were generated for the analyzed data strips and later on used to quantify water abundance and were utilized for understanding their spatial distribution and linkages with mineralogy and surface temperature.

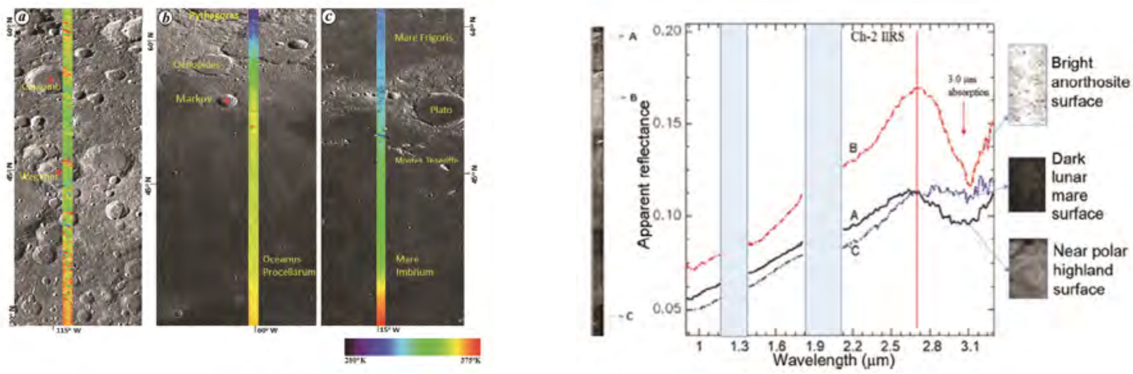

Figure 4: Temperature distribution and its variations with latitude as shown in lunar surface temperature map generated from Ch-2 IIRS radiance data. Source: Chauhan P., et al., 2021, Curr. Sci. (b) Ch-2 IIRS reflectance spectra after thermal corrections showing variability in band depth of lunar hydration associated with different surface composition. Source: Chauhan P., et al., 2021, Curr. Sci.

❖ **Lunar Science: Mineral Detection using Chandrayaan-2 IIRS reflectance data:**

- This The wavelength range of 800 nm to 2500 nm part of the spectrum was utilized for detection of common minerals from the analysed Ch-2 IIRS reflectance data strips. Almost all the dominant lunar minerals have been identified based on the location of band centres which is indicative of a particular mineral species present in VNIR region.

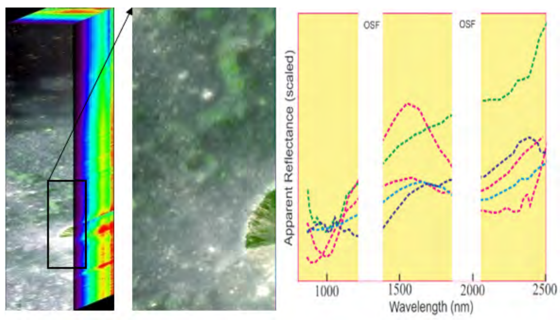

Figure 5: showing Ch-2 IIRS data cube, reflectance image and spectral reflectance of common lunar minerals (800-2500 nm). Source: Chauhan et al., 52nd LPSC 15-19 March, 2021, Houston, Texas.

❖ **Accuracy assessment of reanalysis datasets for GPS-PWV estimation using Indian IGS stations observations**

- GPS PWV (Precipitable Water Vapor) is estimated using three years ECMWF, JRA55, MERRA2, and NCEP datasets for two IGS stations HYDE and IISC in India to assess their accuracies over the Indian region. The NWP derived temperature, pressure, Zenith Hydrostatic Delay (ZHD), Zenith Wet Delay (ZWD), and PWV values are validated using AWS observations and derived products. The obtained PWV values are also compared with the total column water product from ECMWF. The results show absolute mean temperature differences of 1-2 oK and pressure differences of 1-4 hPa for HYDE and IISC. NWP models' pressure and temperature values strongly correlate with AWS values with R2 close to 0.9 in most of the cases. The estimated ZTD shows an average difference between 4 mm and 9 mm with respect to IGS ZTD. The mean differences between NWP and reference PWV values are observed from 1 mm to 2 mm. All the derived products obtained using NWP datasets are close to the reference AWS products. However, PWV derived using ECMWF, JRA55 and NCEP are very much close to AWS PWV and can be used for precise PWV computation in this region.

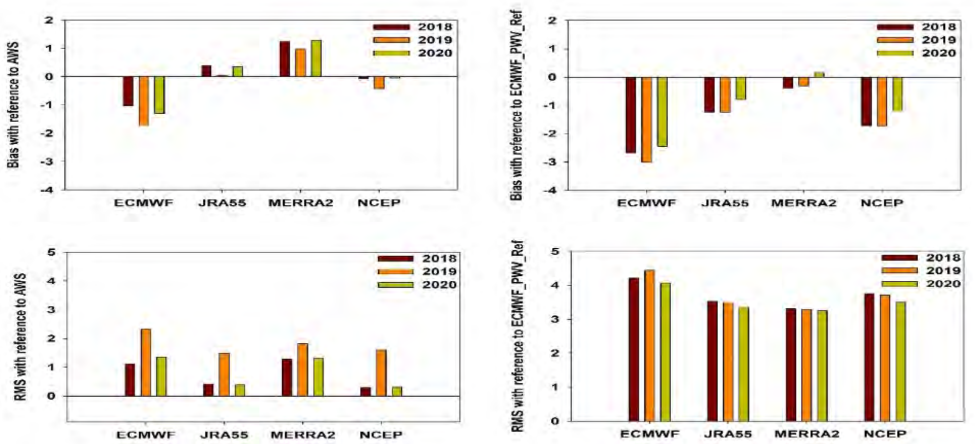

Figure 6: Bias and RMS error between NWP and reference GPS PWV

❖ **Estimation of GPS-based atmospheric precipitable water vapour over Dehradun**

- Precipitable water vapour is estimated using GPS data collected from the continuous operating reference station (CORS) located in Dehradun city, a valley in north western Himalayan region. PWV is also estimated using two well-established IGS stations observations in India to validate the retrieval process and to investigate PWV variation over these locations. Meteorological observations, required for PWV estimation, are acquired from NCEP by vertical and horizontal interpolation of grid points data for a specific station. The validation and accuracy assessment of all obtained parameters are carried out at different levels. The annual average PWV over Hyderabad (HYDE), Bengaluru (IISC), and Dehradun (DEHR) are estimated to be 35.96 mm, 31.70 mm and 22.10, mm respectively. The average PWV differences are estimated to be around 1 to 3 mm if the comparison is made among GMET, IGS and NCEP derived PWVs. Estimated PWV over Dehradun is also compared with reanalysis data from the MERRA and an average difference of about 4 mm is observed.

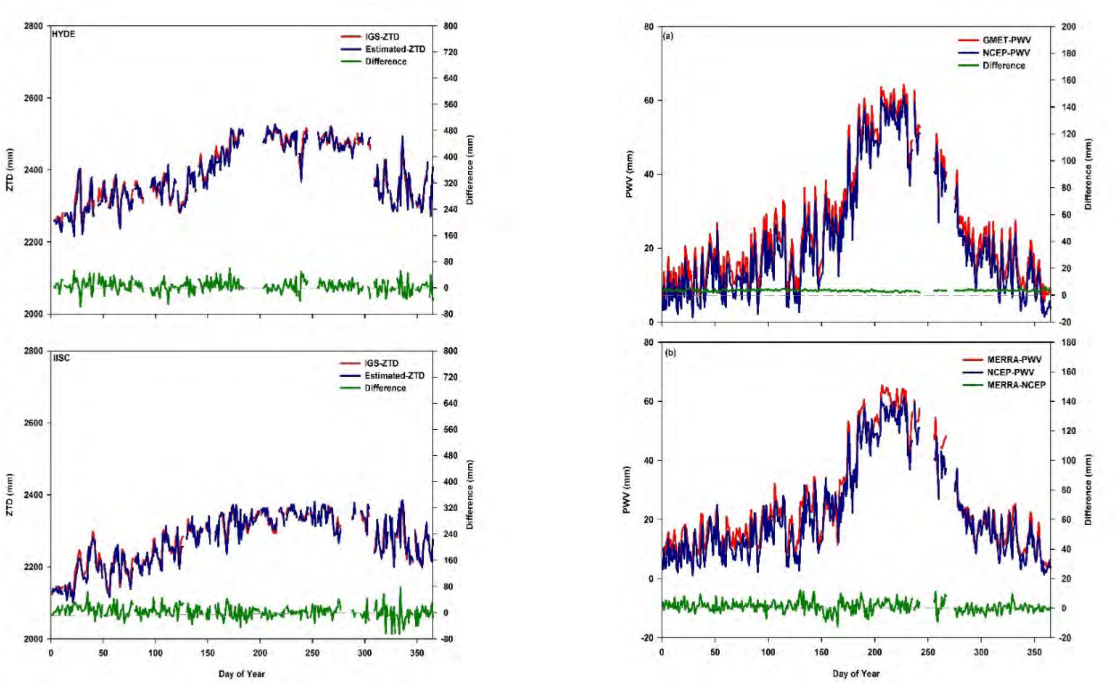

Figure 7: ZTD profile of HYDE and IISC (Left). PWV profile over Dehradun using GPS observations (Right).

❖ **Retrieval of total columnar precipitable water vapour using radio occultation technique over the Indian region**

- Total precipitable water vapour (PWV) is retrieved using radio occultation retrievals (estimated using space based GNSS observations) of water vapour from COSMIC satellites over four regions of India. This analysis is carried out to assess the accuracy of the radio occultation technique for estimating PWV and to observe the PWV variation over these regions. The impact points of radio occultation are investigated for one year to select those points which are very near to the surface for the four regions. Total column PWV is estimated using these points data and further compared to the PWV values obtained from AIRS instrument and reanalysis data from MERRA2. The findings obtained using the radio occultation technique show that the vertical profile of PWV from COSMIC provides almost similar results at different pressure levels with AIRS and MERRA2 PWVs. The PWV values obtained from COSMIC are 22 mm, 17 mm, 27 mm, and 52 mm approximately for region1, region2, region3, and region4 respectively having differences in the range of 2 mm to 7 mm with respect to PWV values estimated from AIRS and MERRA2. On the surface level, the average difference is estimated to be less than 1 mm. It is inferred that a good estimation of total column PWV is obtained using the radio occultation technique which can be further used for rainfall prediction, its impact on climate change and to study hydrological cycle more efficiently.

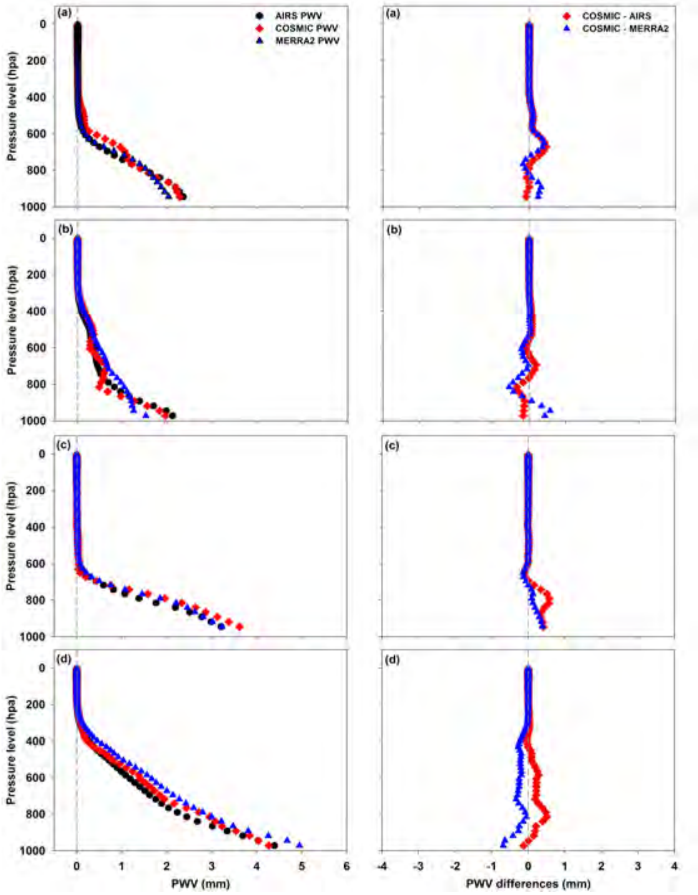

Figure 8: Vertical profile of PWV using space based GPS observations (COSMIC) and its comparison with reference datasets.

❖ **Generation of Orthorectified Polarimetric Products for Chandrayaan-2 Dual Frequency SAR (DFSAR) Imagery**

- Chandrayaan-2 Dual Frequency SAR (DFSAR) products consist of Single look complex (SLC) products, ground range products, and selenoreferenced amplitude products. Selenoreferenced products are amplitude images and no polarimetric information can be derived from these products. DFSAR provides single look complex (SLC) datasets containing the information of phase and amplitude in the slant range geometry of SAR. Polarimetric information can be derived from the SLC datasets but these products are not geometrically correct. Thus, polarimetric information of any feature cannot be compared to other sensor products. Hence, the methodology has been developed to generate the orthorectified compact and fully polarimetric products for Chandrayaan-2 DFSAR data using the SAR sensor model, orbit parameters and Digital elevation model. The figure 9(a) shows Left circular horizontal (LH) and Left circular vertical (LV) SLC image and 9(b) shows orthorectified m-delta decomposed product of orbit 127 covering area in North pole

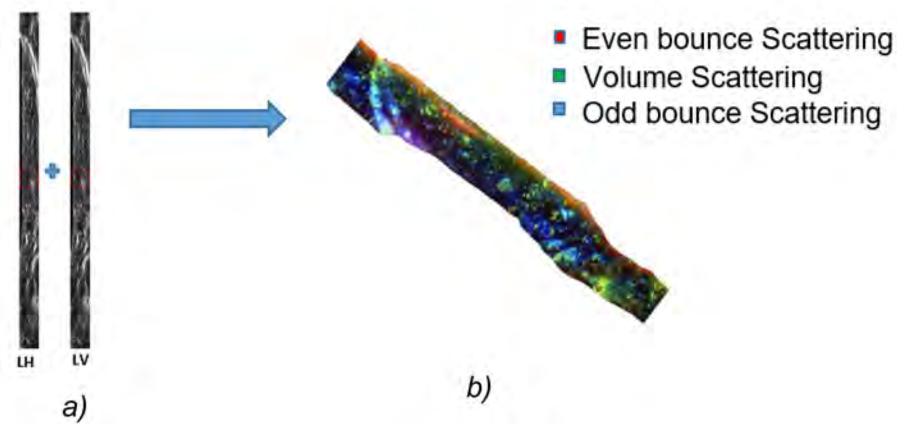

Figure 9: a) Left Circular Horizontal (LH) & Left Circular Vertical (LV) SLC images b) Orthorectified m-delta product of orbit 127 (North Pole)

- The compact Polarimetry products are generated using SLC images of DFSAR. The Compact polarimetric products are m-delta decomposed, m-chi decomposition, relative phase and compact polarization ratio (CPR) products. The geometric corrections have been done on the polarimetric products using the SAR sensor model which uses SAR processing parameters, orbit vectors, and digital elevation model (DEM) to generate the orthorectified compact polarimetric products. SAR sensor model includes the SAR forward geolocation model and the backward geolocation model. The figure 10(a) shows the orthorectified m-delta product, figure 10(b) shows orthorectified degree of polarization (DOP) product, figure 10(c) shows orthorectified relative phase product and figure 10(d) shows orthorectified circular polarization ratio (CPR) product of orbit 127.

a) b) c) d)

Figure 10: a) Orthorectified m-delta product b) Orthorectified degree of polarization (DOP) product c) Orthorectified relative phase Product d) Orthorectified circular polarization ratio (CPR) product of orbit 127

- The fully Polarimetry products are generated using Level-1 SLC images of DFSAR. Pauli decomposed products has been generated using HH, HV, and VV SLC images of DFSAR data. The Geometric corrections have been done on the Pauli decomposed image to generate the orthorectified fully polarimetric products. Figure 11 & 12 shows the different orthorectified Pauli decomposed product of different orbits.

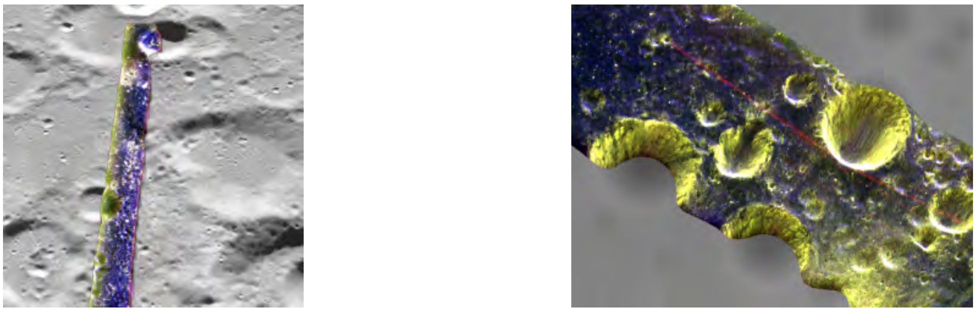

Figure 11: Orthorectified Pauli decomposed product a) Orbit 312 (South Pole) overlaid on optical data b) Orbit 617 (North Pole)

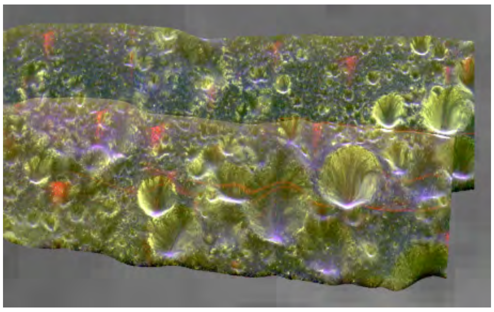

Figure 12: Mosaicking of orbit 591 and 594 orbit Orthorectified Pauli Decomposed full polarimetric Products (North Pole)

❖ Polarimetric analysis of Permanently Shadowed Regions (PSRs) of Lunar South Polar Craters using L-band DFSAR data of Chandrayaan-2 Mission

- Objective: The main objective of this study is to explore the polarimetric parameters of the L-band DFSAR data for the characterization of PSRs of the lunar South Pole craters. This study involves the scattering-based characterization of permanently shadowed regions of the lunar South Pole craters for the identification of surface ice. A compact polarimetric simulation is also performed on quad-pol SAR data to extract Stokes vector-based parameters for comparison with PolSAR roll invariant parameters.

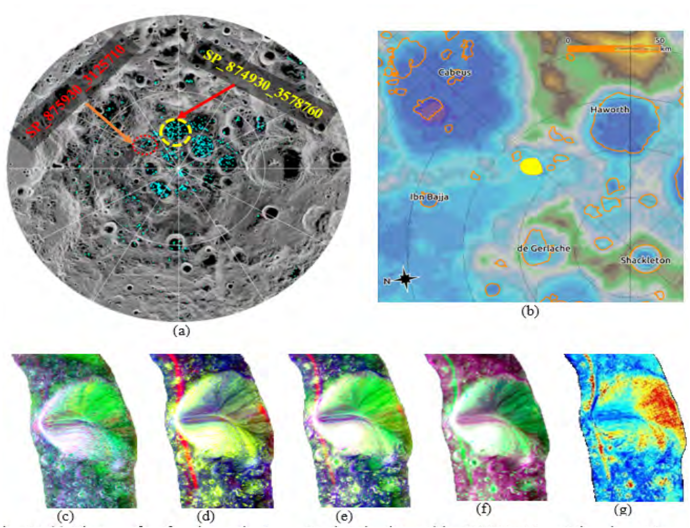

Figure 13. (a) Clusters of surface ice at the Lunar South Pole, detected by NASA's Moon Mineralogy Mapper instrument of ISRO's Chandrayaan-1 mission (Credit: NASA). The red dotted circle is the PSR ID SP_875930_3125710 and yellow circle is PSR ID SP_874930_3578760, (b) PSRIDSP_875930_3125710(inYellow) located between Ibn Bajja Crater and Haworth Crater (Credit: NASA/GSFC/ASU); Color composite representation of PSR ID SP_875930_3125710 using (c) Huynen decomposition, (d) Barnes decomposition, (e) HAα decomposition, (f) Compact decomposition, and (g) Circular Polarization Ratio (CPR).

- High volumetric scattering and CPR values were obtained from the PSR ID SP_875930_3125710. Previous studies suggested that the diffuse scattering that is received from the rock-strewn surface will have CPR near 1.0 and the 2.0 CPR value is associated with volumetric surface ice (Spudis et al., 2013). It is evident from Figure 16(a) that mapping of surface ice clusters by Li et al., 2018 using Moon Mineralogy Mapper (M3) sensor of ISRO's Chandrayaan-1 mission shows that PSR ID SP_875930_3125710 also has surface ice clusters. The high CPR (>2) and volumetric scattering from PSR ID SP_875930_3125710 indicates that these values of polarimetric parameters of the L-band DFSAR data may be due to volumetric surface ice and this is following the findings of Li et al., 2018.

- Due to the excessive CPR and volume scattering in PSR ID SP_875930_3125710, it further strengthens the possibility of getting ice according to the achievements of Li et al., 2018 and previous researchers, but due to the low amount of CPR and less volume scattering elements in PSR ID SP_874930_3578760, it is difficult to make a similar statement to confirm the presence of water ice in the PSR of the Haworth crater. Based on the scientific facts done for the Howarth crater (Berezhnoy et al., 2012; Cannon and Britt, 2020; Moores, 2016)allowing the preservation of water ice. Much has been learned about these regions from orbital measurements, but in situ access is needed to truly understand the abundance, distribution, texture, and chemistry of volatiles that might be present in the regolith. We systematically studied the accessibility of the larger cold traps to wheeled vehicles from nearby staging areas. We calculated minimum energy routes for 20 north pole cold traps and 39 south pole cold traps >50 km2 in area. At each, accessibility metrics were determined for paths into and out of the cold trap and for round trip paths that return to the same location. We found that 55 of the 59 cold traps are readily accessible without exceeding 25° slopes. Smaller cold traps are generally more accessible than larger ones, with certain exceptions. The accessibility data set is presented graphically, in tabular form, and as ArcGIS shapefiles, all of which can be used to inform site selection and mission planning for future scientific and resource-focused activities.","author":[{"dropping-particle":"","family":"Cannon","given":"Kevin M","non-dropping-particle":"","parse-names":false,"suffix":""},{"dropping-particle":"","family":"Britt","given":"Daniel T","non-dropping-particle":"","parse-names":false,"suffix":""}],"container-title":"Earth and Space Science","id":"ITEM-1","issue":"10","issued":{"date-parts":[["2020"]]},"note": "e2020EA001291 2020EA001291","page":"e2020EA001291","title":"Accessibility Data Set for Large Permanent Cold Traps at the Lunar Poles","type":"article-journal","volume":"7"},"uris":["http://www.mendeley.com/documents/?uuid=0ccc0fba-36c6-40b9-beb5-1997bce175a3"]},{"id":"ITEM-2","itemData":{"DOI":"https://doi.org/10.1002/2015JE004929","abstract":"Abstract The migration of water molecules across the lunar surface from sources sufficiently small, so as to not generate a

transient collisional atmosphere, was examined using a Monte Carlo simulation. Previous work using similar models is extended by examining a realistic distribution of large south polar Permanently Shadowed Regions (PSRs., it can be said with no doubt that there is a strong possibility of finding ice there, but it seems that in addition to CPR and volume scattering, there is a need to study more PolSAR parameters, so that the results obtained from the studies done in the past can be correlated with the future missions and the data received from them. The statement on the confirmation of the possibility of surface ice clusters needs to be further investigated by including lunar regolith's dielectric behavior and properties in the permanently shadowed regions in addition to geomorphological parameters (size of the crater, slope, etc...)

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9.5 Capacity Building in Space Science Research

The Institute has so far trained 13,263 professionals (till February, 2022), wherein total of 224 students in M.Sc. and 466 Students in M.Tech. courses have graduated since 2002. Special tailor-made/on-demand courses are conducted at the request of the User Departments from national as well as international level.

In addition to aforesaid activities, IIRS also supports activities of UN-CSSTEAP wherein 61 PG Courses (24 in RS&GIS, 12 in SATCOM, 11 in each SATMET and Space & Atmospheric Sciences and 03 in GNSS) and 60 short courses and workshops 10 online short courses have been conducted in last 26 years. These programmes have benefited 2898 participants (PG-1018, Short courses-1407 and online short courses-473) from 37 countries in the Asia-Pacific region including 48 participants from 23 countries, outside Asia Pacific region. Till date, 188 PG students (85 in RS&GIS; 50 in SATCOM; 22 in SATMET; 27 in SAS & 04 in GNSS) from 17 different countries have been awarded M. Tech. degree.

9.6 Courses offered on Space Science and Technology

Table-1: Training programmes being conducted by IIRS

Sl. No	Programme	Duration	Seats
1.	POST-GRADUATE DIPLOMA IN REMOTE SENSING and GIS 9 Specialisations –Agriculture and Soils; Forest Resources & Ecosystem Analysis; Geosciences; Urban & Regional Studies; Marine & Atmospheric Sciences; Water Resources; Natural Hazards & Disaster Risk Mgmt and Satellite Image Analysis & Photogrammetry and Spatial data science	01 year	30
2.	POST-GRADUATE DIPLOMA IN GEO-INFORMATION SCIENCE and EARTH OBSERVATION (with ITC, University of Twente, The Netherlands) 2 Specialisations– Geoinformatics; Natural Hazards and Disaster Risk Management	01 Year	10
3.	CERTIFICATE COURSE IN REMOTE SENSING Remote Sensing and Image Analysis (for Indian User participants)	8 weeks	20
4.	INTERNATIONAL PROGRAMME – CERTIFICATE COURSE IN REMOTE SENSING, GEOINFORMATICS (Sponsored by ITEC, Ministry of External Affairs, Govt. of India) Remote Sensing (with emphasis on Digital Image Processing); Geoinformatics	8 weeks	2*20 = 40
5.	NNRMS, ISRO-SPONSORED CERTIFICATE COURSE IN REMOTE SENSING and GIS FOR UNIVERSITY FACULTY 10 Specialisations - Satellite Image Analysis & Photogrammetry; GIS Technology and Advances; Agriculture and Soils; Forestry Resources and Ecosystem Analysis; Geosciences; Coastal and Ocean Sciences; Urban and Regional Planning; Water Resources; Natural Hazards and Disaster Risk Management and Geocomputation and Visualization in Web Platforms	8 weeks	64
6.	AWARENESS PROGRAMME Remote Sensing – An Overview for Decision Makers	1 week	10
7.	Tailor-made On-Demand Courses	1 to 8 weeks	Variable
8.	Online Courses / Workshops	Variable	Variable

Table- 2: M.Tech./M.Sc. courses being conducted by IIRS

Sl. No.	Title and standard of course (PG Courses)	Specializations Topics	Duration	Intake Capacity
1.	M.Tech. in Remote Sensing and GIS (with Andhra University) 09 Specialisations-	Agriculture and Soils; Forest Resources and Ecosystem Analysis; Geosciences; Urban & Regional Studies; Marine and Atmospheric Sciences; Water Resources; Natural Hazards & Disaster Risk Management and Satellite Image Analysis & Photogrammetry and Geoinformatics	2 years	60
2.	M.Sc. (with ITC, University of Twente, The Netherlands)	in Geo-information Science and Earth Observation with Specializations in-Geoinformatics(GI);	2 years	10

9.7 Instruments / Payloads / Products Developed / Sensors / Detectors

Air quality monitoring and forecast portal developed by IIRS

- In recent years an increase in episodic events of elevated air quality over the Indian region are noted (For e.g. March 2012; April 2015; November 2017; June 2018 etc.).
- Considering serious impact of such an episodic events of poor air quality on society, economy and human being; monitoring of air quality at regional scale becomes of utmost importance.
- Operational forecast of various air quality parameters is being generated at IIRS (Figure 14). Model simulated and satellite based outputs are made available on air quality web portal of IIRS www.airquality.iirs.gov.in

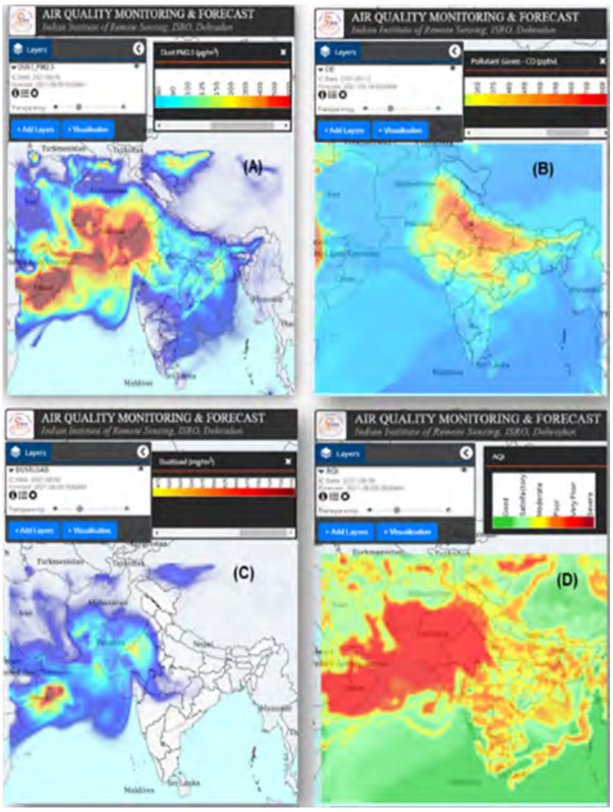

Figure 14 : Data sets available on air quality web portal. (A) Dust PM2.5 (B) CO (C) Dust load (D) AQI.

9.8 Laboratories and Facilities Available for Space Instrumentation

A trace gas laboratory is established at IIRS Dehradun in 2018. This laboratory consists of ozone, CO and NOx analysers. Ozone and CO analysers are based on photometric method whereas NOx analyser is based on chemi-luminescence method. These analysers monitor ozone, CO and NOx mixing ratio in the ambient air at every 5 minute interval. These observations are very useful in the understanding of various processes affecting the air quality over Dehradun location.

Multi wavelength solar radiometer is used for measuring Aerosol Optical Depth to understand the Aerosol loading over Dehradun region.

CHAPTER-10

SATISH DHAWAN SPACE CENTRE SHAR

Sriharikota

10.1 About the Centre

Satish Dhawan Space Centre SHAR (SDSC SHAR), the Spaceport of India, is located at Sriharikota, the spindle shaped island in SPSR Nellore district of Andhra Pradesh about 80 Km North of Chennai. The space centre, which was popularly known as SHAR (Sriharikota Range) was renamed as Satish Dhawan Space Centre SHAR on September 5, 2002, in fond memory of Prof. Satish Dhawan, former Chairman of ISRO.

Sriharikota covers an area of about 43,360 acres (175 sq.km) with a coastline of 50 km. SDSC SHAR has a unique combination of facilities such as a Solid Rocket Motor Production Plants, Solid Rocket Motor static test facilities, Launch complexes for a variety of rockets, Telemetry, Tele-command, Tracking, Data Acquisition and processing facilities & other support services. SDSC SHAR became operational on October 9, 1971 with the flight of ‘Rohini-125’, a small sounding rocket. Since then the facilities at SDSC SHAR are being expanded/upgraded to meet the growing needs of ISRO.

10.2 Keywords

Space Port of India, Solid motor production, Test facility,

10.3 Major Research Domains

- Propellants, Polymers & Chemicals,
- Liquid/Cryo Propellant Storage and Service
- Solid Motor Performance, Flight Components, Hardware & Environmental Testing
- Launch Vehicle Tracking System, Range Operation and Safety Engineering

10.4 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	Development and Fabrication of O_2, H_2, NO_2& N_2H_4 gas sensors	IISC, Bengaluru
2.	Development of Hybrid Gas Generator simulating SC200 exhaust parameters for subscale model studies.	IIT Chennai

10.5 Laboratories and Facilities Available for Space Instrumentation

I. Vibration Test Facility

In vibration test facility, an electrodynamic shaker is normally used for vibration testing of rocket motor and their subsystems. For simulating longitudinal vibration, the motor is mounted on the vertically positioned shaker and is vibrated to the specified test vibration level, frequency and duration. For simulating lateral vibration, the motor is kept on a slip table which is a magnesium plate floating on a thin film of oil. The shaker is rotated by 90º from its vertical position and connected to the slip table. In this configuration by operating the shaker, the motor can be tested for the required lateral vibration level. If the capacity of one shaker is inadequate, then 2 or 4 shakers combination is used for vibration testing.

II. Thermal Soak & Humidity Test Facility

This facility is used for simulating low temperature, high temperature, temperature cycling and different humidity conditions on the rocket motors and their subsystems. The motor is kept on a trolley which in turn is pushed inside an insulated steel test chamber. Air inside the chamber is drawn out, conditioned by passing it over heater or refrigerant coils depending on the temperature required and then this air is circulated back to the test chamber.

III. Constant Acceleration Test Facility

Constant acceleration test facility is used for simulating acceleration loads on the rocket motor. The test article is mounted on one end of the centrifuge horizontal arm and on the other end of the same arm balancing counter weights are assembled. The arm is then rotated about a vertical axis passing through the middle of this arm. Either an electric drive or a hydraulic drive is normally used.

CHAPTER-11

NATIONAL REMOTE SENSING CENTRE

Hyderabad

11.1 About the Centre

National Remote Sensing Centre is one of the major centre of Indian Space Research Organization (ISRO) has a mandate to acquire, process and disseminate remote sensing data products, undertakes research in remote sensing applications, provides disaster management support services and hosts geospatial platform for citizen centric applications as well as data visualization.

11.2 Keywords

Remote Sensing Applications, Image processing, Geospatial Technologies, Disasters Mitigation, Hydrology, Geoscience, Ground water.

11.3 Major Research Domains

The organization has specialized groups working in several thematic areas of remote sensing applications.

- **Geosciences domain** focuses on mineral exploration, groundwater, geo-environmental, geo-hazards and geodynamic studies. The major projects executed by the group consists of National Geomorphology and Lineament Mapping (NGLM), National Rural Drinking Water Program (NRDWP), Mineral exploration studies for Diamond, Iron, Phosphate Manganese, Bauxite etc., Seasonal Landslide Inventory Mapping (SLIM) and Landslide Susceptibility Zonation (LSZ). In addition to these, operational and research projects in earthquake studies, geotechnical studies, coal fire mapping, geo-environmental zonation and planetary studies are also being carried out.
- **Disaster Management Support Programme** (DMSP) is involved in monitoring of natural disasters viz. flood, cyclone, agricultural drought, landslides, earthquakes and forest fires in near real time using remote sensing based inputs.
- **Agriculture:** Satellite derived seasonal cropping pattern, experiments on yield estimation, estimation of net-sown crop area and agricultural drought assessment studies are conducted. Studies are in progress on development of new techniques and methodologies for providing space inputs for crop insurance decision support system, crop intensification, mapping of high value crops, horticulture inventory, agricultural drought vulnerability assessment.
- **Forestry and Ecology** studies are aimed at utilization of Earth observation technologies towards developing the prescriptions for sustainable management of forest resources as well as towards the fulfillment of India's commitment towards the Nationally Determined

Commitment for Carbon Sequestration at COP 21. NRSC have been focused on development on the automated processing of multi-temporal and multi sensor data, three dimensional descriptions of the forest structure and its distribution. Analysis of forest cover change, spatial biomass estimation, Community Biodiversity characterization, Forest fire alert system, inputs to working plan and wild life plan preparation, Forest carbon sequestration, Inputs to UNFCCC etc are being carried out in close collaboration with MOEF & CC, DBT, FSI and State Forest Departments.

- **Water Resources:** Remote sensing applications in water resources domain provides key inputs for planning, monitoring and management of irrigation projects, estimation of availability of surface water resources and various water balance components and addressing hydrological components of local and regional water cycle. Projects were executed by NRSC on the performance evaluation of irrigation commands and irrigation potential utilization, assessment of irrigation infrastructure across the country, space inputs for feasibility studies for Inter Linking of rivers, reassessment of water resources at river basin level, reservoir sedimentation, seasonal snow and water bodies information, and snow melt runoff. Water Resources Information Systems has been developed for organization of water resources related database, collection and integration of field data, dissemination to the stake holders for analysis and preparation of water management plans.
- **Rural development** applications are focussed on land & water conservation through systematic planning and implementation of development plans in rural sector. Land Use Land Cover (LULC) maps of an area provide information to help users to understand the current landscape. LULC information on national spatial databases enable the monitoring of temporal dynamics of agricultural ecosystems, forest conversions, surface water bodies and other features, provide estimate of net sown area and inputs to land & water resources planning. Some important projects focusing on rural India are - Mahatma Gandhi National Rural Employment Guarantee Act, Accelerated Irrigation Benefit Programme, Integrated Watershed Management, Programme, National Health Resource Repository Project, Land degradation mapping and rural connectivity. Soil resources maps help in deriving information like land capability, irrigability and suitability are assessed using supportive thematic information.
- **Urban Domain**: Space-based information & geospatial analysis tools also support host of applications viz., urban and regional planning, route alignment for road, rail, oil/ gas pipeline, site suitability analysis for hydroelectric project, new township, facility & utility planning for identification of landfill sites, schools, hospitals, etc. and also for environmental impact assessment. National Urban Information System for 142 towns were created towards regional planning. 242 cities are being mapped and thematic layers were generated using very high resolutions satellite data under national flagship program.

- **Earth and Climate Sciences**: Remote sensing applications in the domain of Earth and Climate Sciences emphasizes on studying earth as a coupled system involving land–air-ocean interactions through satellite, ground observations and modeling. Research and operational projects are being carried out in the domain of terrestrial, atmospheric and ocean sciences.
- **Web Geoportal**: Geo spatial services provided in Bhuvan portal are dissemination of tile-wise one-time satellite data of Indian Remote Sensing Satellite sensors, satellite derived products pertaining to various themes and domains. Domains and the related projects as well as theme specific databases are archived here better visualisation of the summary of information available in Bhuvan.

11.4 Major Scientific Applications / Results

Geological Mapping for Manganese Ore

- The synsedimentary deposit of manganese hosted in Sausar group of rocks occurring in four districts (Balaghat, Chhindwara, Jabalpur and Jhabua) of Madhya Pradesh, India were studied using multi sensor satellite data. The image products derived from SENTINEL VNIR sensors, complimented with microwave L band ALOS PLASAR data and satellite gravity data (EIGEN 6C4), were used to derive the structural imprints guiding the mineralization whereas the band ratios and Principal Components (PCs) of ASTER sensor were used for delineation of host rock boundary (Figure1). The derived geological themes were integrated with lab and ground based information using weighted sum method to delineate prospective zones of manganese ore, which serves as a valuable input for planning of exploration activity in the area.

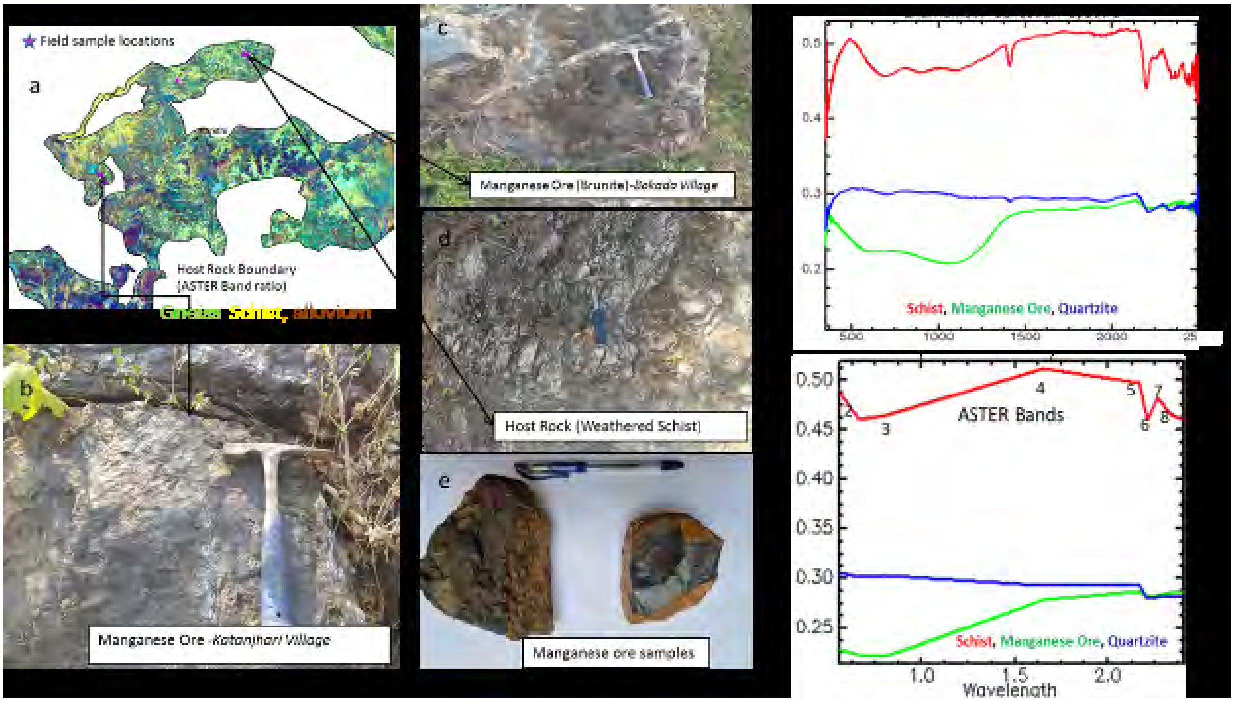

Figure 1: The band ratio of ASTER depicting the schist, tirodi gneiss. The field samples were collected from the mansar formation (b,c,d), e. The ore sample was analysed in lab under spectrometer to derive the spectra (i) which was resampled to ASTER bands (ii) for spectral mapping.

AVIRIS-NG utilization for identification of possible source of mineralization

- In a collaborative project between NRSC, ISRO and Geological Survey of India Airborne Visible InfraRed Imaging Spectrometer - Next Generation (AVIRIS-NG) data have been processed to delineate surface imprints of base metal deposit in the Pur Banera area, Bhilwara, Rajasthan. AVIRIS-NG resampled spectra of minerals like calcite, sericite and goethite were used to derive three independent relative band depth (RBD) images to delineate altered rocks and cap rocks associated with the mineralization. These RBD images are presented as FCC image. It was found that the surface imprints of gossanised encrustation and sercitised rocks are prominent in Lanpriya area where quartzite is the main host rock (Figure 2). Formation of malachite is another surface imprints of mineralization in this area.

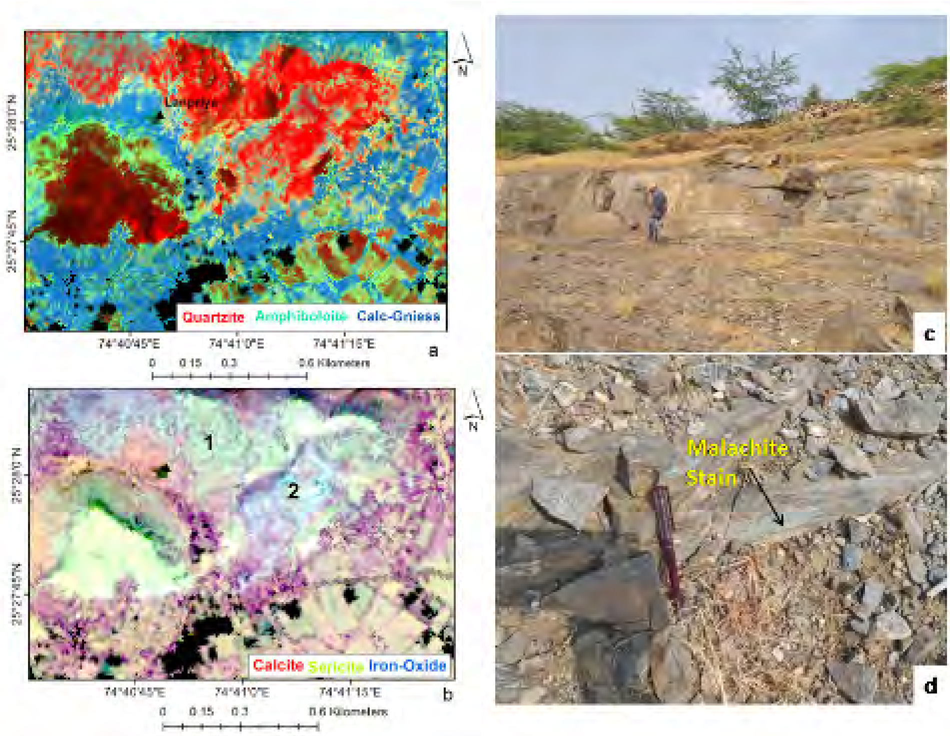

Figure 2: a. Multi-range spectral feature fitting map of each rock presented using a FCC image to spatially delineate these rock types around Lanpriya area. b. False colour composite of RBD Images delineating altered rocks (sericite bearing rocks and carbonate rocks) and cap rock (Iron oxide). c. Surface exposures of Calc.-Gneiss. d. Malachite staining is reported with quartzite.

Seasonal Landslide Inventory Mapping (SLIM)

- In India, about 0.42 million sq. km or 12.6% of land area, excluding snow covered area, is prone to landslide disaster. Preparing inventory of landslides is a primary requirement for landslide disaster mitigation. The 1st cycle of Seasonal Landslide Inventory Mapping (SLIM) project mapped 17,995 landslides triggered due to the 2014 Monsoon rainfall in 17 states in India. Further, in the 2nd cycle of the SLIM project, a total of 23,895 landslides due to 2017 monsoon rainfall, were mapped in 16 states and 02 UTs. With this NRSC has created a database of about 80,000 landslides over India since 1998. Landslides mapped are more in number in 2017 in comparison to 2014 mainly due to higher rainfall in North Eastern region (NER).

Rock Avalanche induced Flash Flood Chamoli, Uttarakhand

- A large debris flow triggered by a rock avalanche in the Raunthi glaciated valley resulted in flash floods in the Rishiganga and Dhauliganga rivers on February 07, 2021 in Uttarakhand, India. Hydel projects, houses, roads and bridges in the path of debris flow were damaged and there was loss of human life. The high resolution satellite data was used to study the source of flash floods and cause of the slope failure. The detailed geological assessment, carried out, revealed rock avalanche as the main source of slope failure (figure 3). Volume of the rock avalanche was estimated as 29 million cubic meter. The time stamping of the landslide event shows that the rock avalanche has started ~ 10.09 hrs (IST) and continued up to 50 minutes.

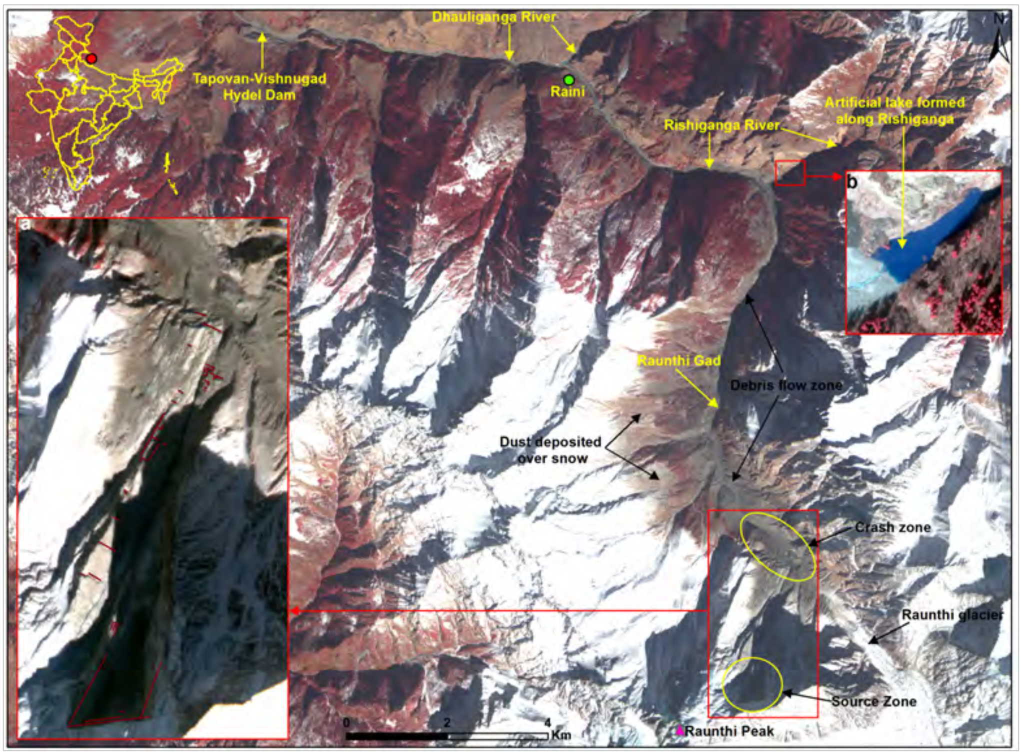

Figure 3: Synoptic view of the affected region as seen from Resourcesat-2A LISS IV image (08 February 2021) shown in FCC. Inset (a) shows enlarged view of the rock avalanche zone with joints and foliation (red lines), and SkySat-7 image (26 February 2021) in inset (b) shows lake formed due a landslide dam along at the confluence of Rishiganga river and Raunthi gad.

Monitoring of forest fires

- Forest fires in India are largely anthropogenic in origin and are predominantly ground fires which do not lead to stand mortality, however it is source of atmospheric pollution, loss of regeneration, soil erosion etc.
- Active fire products are currently being generated using data from the MODIS sensors on TERRA (from 2000) and AQUA (from 2003) satellite platforms and the VIIRS sensors

on SNPP (from 2012) and JPSS-1(from 2019) satellites on daily basis. These satellites enable eight observations daily which enable timely observations on active forest fires towards control and planning mitigation measures in India. The fire alerts are disseminated through Email, SMS and Bhuvan (https://bhuvan-app1.nrsc.gov.in/disaster/disaster.php?id=fire, Figure 4) .

Figure 4: Dissemination of near real time forest fire alerts through Bhuvan

Spatial snowmelt runoff Modelling in the Himalayan Region of Indian River Basins:

- A spatial snowmelt runoff model has been developed with integration of multi-satellite data observations (snow cover, surface temperature, aerosol optical depth, ozone, cloud cover, solar radiation & land cover) deriving energy balance. Daily snowmelt rates and 3-day (T+3 days) forecast were estimated during snowmelt season of April to June of 2021 for entire catchment area of Indian Himalayan river basins (Figure 5).

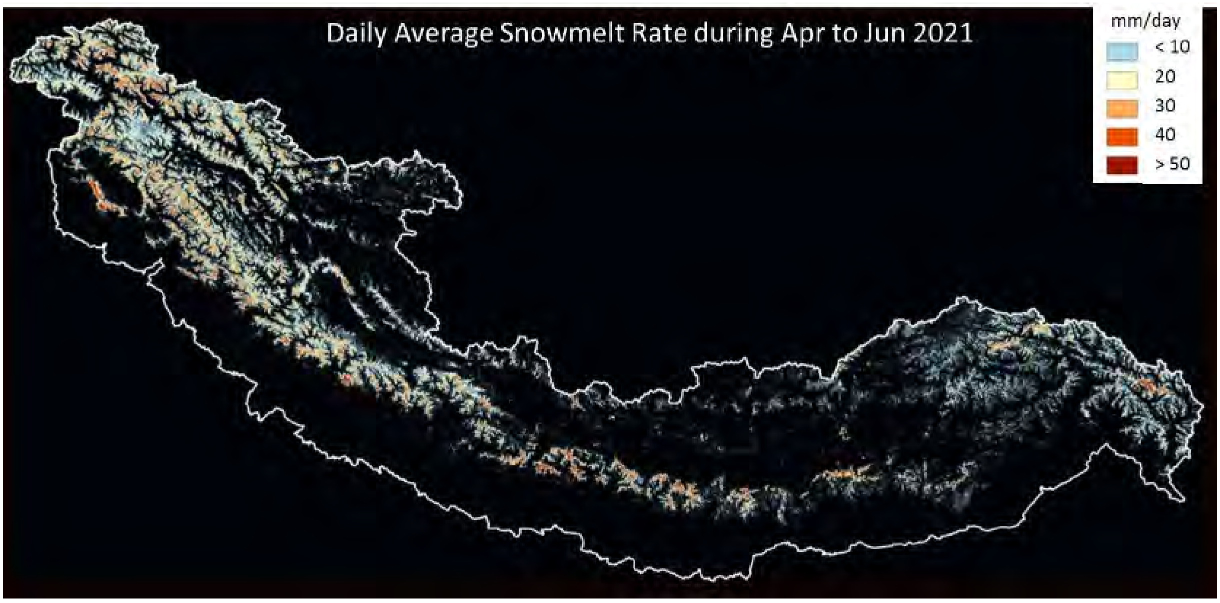

Figure 5: Daily average snowmelt rate during april to June, 2021

Glacial Lake Atlas

- Inventory of Glacial lakes of size greater than 0.25 ha (4,707 lakes) has been carried out for Ganga river basin along with 22 attributes addressing hydrological, terrain and lake characteristics using IRS LISS4 MX data of 2016-17. The Glacial Lake Atlas of Ganga River Basin was prepared and released in June, 2021.

Village level ground water prospects and sustainability mapping at 1:10K

- The main objective of the study is to develop and operationalize the methodology for village level groundwater prospects maps on 1:10,000 scale for major hydro-geological provinces in India under the Ground Water Recourses Assessment & Management (GRAM) project. Using multi resolution satellite data, detailed groundwater well observation and hydro-geological field survey, sustainable groundwater development plan has been prepared including ground water prospects and recharge zones.

Preparation of Groundwater Quality (GWQ) database

- Habitation wise Groundwater Quality (GWQ) geo-spatial database for Bihar state of India has been prepared, using groundwater quality information provided by state Public Health and Engineering Department (PHED) of Bihar state under National Rural Drinking Water Program (NRDWP). Twelve (12) geogenic groundwater quality parameters (Total Dissolved Solid, Total Hardness, Alkalinity, Calcium, Magnesium, Iron, Arsenic, Chloride, Fluoride, Nitrate, Sulphate and pH) for pre and post monsoon season has been evaluated for preparation of groundwater quality database of Bihar state following BIS 2015 standard. Iterative data mining & geo-statistical technique has been used to segregate, extract and classify unique habitation wise groundwater quality observations (Pre monsoon:8167& Post monsoon: 9575) from 2.34 lakh and 3.64 lakh native groundwater quality observations for pre and post monsoon period respectively (Figure 6).

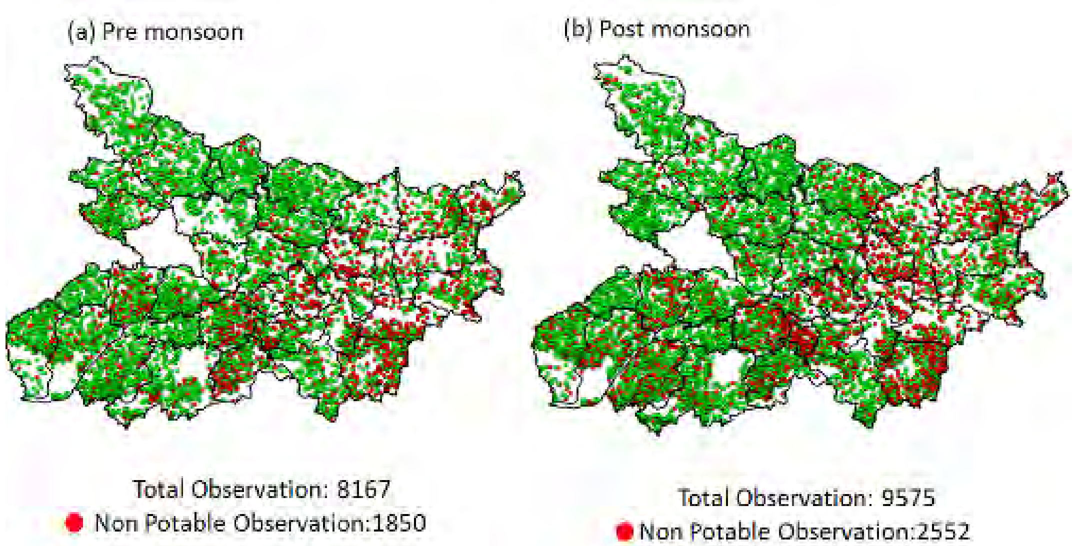

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Figure 6: Unique habitation wise groundwater quality point database for Bihar state (a): Pre monsoon; (b) Post monsoon

- Based on the groundwater quality data analysis, arsenic, fluoride and iron were found to be the major contaminants affecting groundwater quality of Bihar state.
- Due to spatio-temporal dynamicity of the groundwater quality, seasonal variation of these three elements has been estimated in 3-year cycle for 2010-2018-time period (Table 1) to understand the trend of groundwater contamination in Bihar state due to arsenic, fluoride and iron respectively.

Table 1: Temporal variation (2010-2018) of groundwater quality for Bihar state in terms of Arsenic, Fluoride & Iron for pre and post monsoon (Pre Obsn. & Post Obsn.)

Time Period	2010-12		2013-15		2016-18	
Element	Pre Obsn. (6030)	Post Obsn. (3217)	Pre Obsn. (8781)	Post Obsn. (8571)	Pre Obsn. (7004)	Post Obsn. (6789)
Arsenic (As)	175	52	1088	562	228	381
Fluoride (F)	396	81	450	1226	452	628
Iron (Fe)	507	198	619	1080	566	1202

Biodiversity Characterization at Community level in India

- Methodology was developed for spatial characterization of vegetation communities using multi-sensor data and machine learning techniques and project manual was brought out for EO based biodiversity monitoring at community level. Maps of dynamic habitat indices (DHI) were prepared using high temporal satellite data. Database on Forest / land cover and forest fragmentation were geberated for 2008 and 2018 for 9 regional landscapes. Field inventory of 640 plots (9 sites) has been completed for 0.1 ha plots. Preparation of occurrence database on endemic species and threatened species is in progress. Earth observation strategy for biodiversity monitoring would help in conservation and protection of rich biodiversity regions.

Extraction of area under Long Fallow of Brahmaputra Basin in Indian region

- To identify long fallow land available in Indian region of Brahmputra River basin consisting of areas under Arunachal Pradesh, Assam, Meghalaya, Nagaland, Sikkim and West Bengal states, multi-temporal satellite data from Resourcesat-2 LISS-III multispectral data has been analysed for 3 years (2011-12, 2015-16 and 2020-21). The common fallow land during the 10 years has been identified (Figure 7) and estimated to be 247.81 sq.kms. The study presents a gradual decrease in long term fallow land over 10 years period. This information on long fallow will be used in controlling the occurrence of flood in the region.

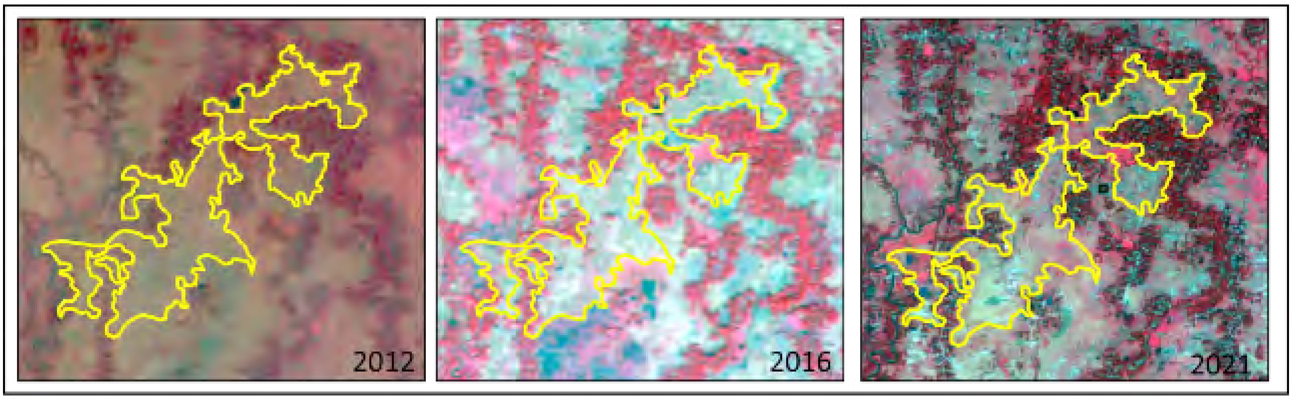

Figure 7: Long fallow land in Indian region of Brahmputra River basin

Use of Geo-Informatics in Rural Road Projects

- Creation of Geo-database by interpreting Rural Roads constructed under Pradhan Mantri Gram Sadak Yojana (PMGSY) for 13 states and 2 Union Territories of India using very High Resolution satellite data (1 m) available on Bhuvan. Interpretation were carried out for 265 thousand km of road length along with its start, mid and end point co-ordinates. In addition, a comparative analysis has been carried out to analyze the road connectivity with habitation and availability of long span bridges on these all-weather roads. This generated database is being used by National Rural Infrastructure Development Authority (NRIDA), MoRD to monitor the connectivity of roads constructed under PMGSY.

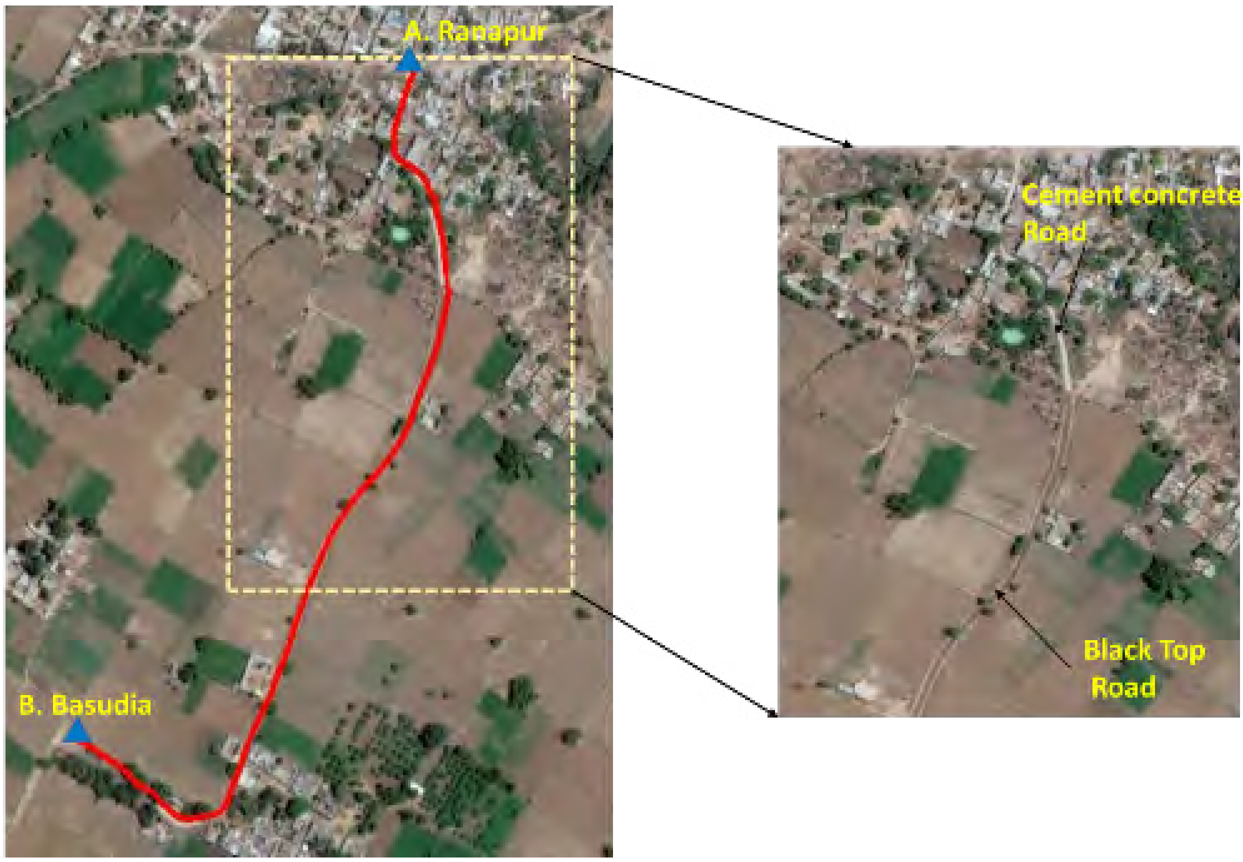

Figure 8: Delineation of Rural Road on satellite Imagery

Operational National Hydrological Modeling System

- The prime objective of the project is implementation of operational national level hydrological modelling framework towards water balance computations in near real time and establishment of comprehensive field experimentation setup for calibration and validation of model computed state variables (Soil Moisture and Evapotranspiration). Geo spatial datasets like digital elevation model, soil map of India, land use land cover, leaf area index and in-season meteorological databases were used to prepare model specified inputs. National modeling framework was developed using geospatial and hydro-meteorological data and macro-scale variable infiltration capacity (VIC) hydrological model at 3min grid level. The model outputs are grid-wise daily surface runoff, soil moisture, and evapotranspiration. These water balance components were translated into various value added products like - inflows into major reservoirs of India, drought indicators (to represent wetness or dryness, irrigation demand estimation

Regional Evaporative Flux Monitoring System for India

- A computational framework is developed using satellite data and meteorological datasets for the daily Actual Evapotranspiration (AET) product at 3′ x 3′ spatial resolution over the entire Indian sub-continent with a latency of 3 days. The near real time daily Actual Evapotranspiration(AET) product have been generated since 2019. AET database are also available at fortnightly, monthly and seasonal temporal scales. The AET products are widely used in the Irrigation management, crop stress monitoring, drought studies and climate change related studies. Figure 9 shows the AET dynamics over India during 2021.

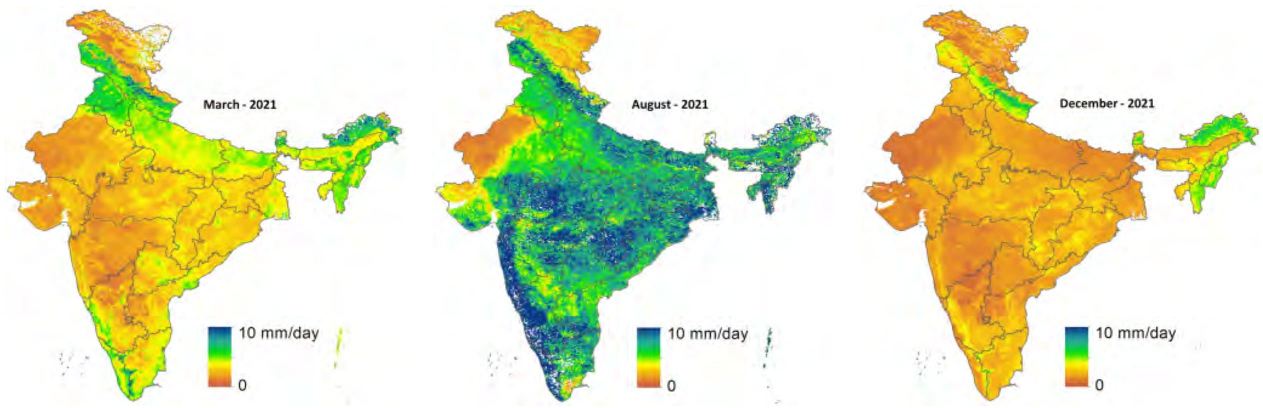

Figure 9: Distribution of AET from satellite and meteorological data for 2021 over Indian region

- Open-Path Eddy Covariance System consists of combinations of fast and slow sensors for AET measurement are installed in different agro-ecosystem for validation of the AET products using field-based instrumentation.

Large scale urban GIS database creation using very high resolution satellite data for Master Plan formulation under National AMRUT Mission for 238 cities.

- Atal Mission for Rejuvenation and Urban Transformation (AMRUT) Design & Standards on 1: 4,000 scale urban geospatial data content, classification and GIS Standards have been developed and published as a National guideline document.
- Urban databases have been created with land use maps as one of the primary input for preparing future land use proposals in the Master Plan and it also enables other applications on environment monitoring and management, facility planning, green area development, geospatial governance etc.

Spatio-temporal changes of Mangrove cover and its impact on bio-carbon flux for Indian Sundarban during 1990-2020

- A study is carried out assesses spatio-temporal variability of the greenness index of Indian mangroves of the Sundarban forest with bio-carbon flux during 1990-2020 using data from Landsat series of satellite. The analysis reveals that the mangrove stress level was very high during the years 1990, 2006, 2007, 2009 and 2011 with an average of 2011 km^2 mangroves were severely affected out of a total area of 2215 km^2. The improved and healthy condition prevailed during 1999, 2000, 2001, 2015, 2016 and 2019 and normal condition during 2002, 2005, 2008 and 2010.
- The net change in mangrove covers during the study period shows the distinct regions of loss and gain. The shoreline change analysis suggests that nearly 90 km^2 of mangroves were lost on the seaward side due to coastal erosion. Whereas, 50 km^2 of newly developed mangroves were observed in western parts of Southern Parganas due to accretion and no loss or gain was recorded in the rest of the areas. A significant positive correlation (coefficients 0.76 at p=0.01) was recorded between the increase in the extent of the mangrove region and bio-carbon fluxes for the years of normal and high-stress level condition as the dominant classes. Conversely, correlation is insignificant for the years dominated by healthy conditions. Below figure shows maps of NDVI, associated statistics, changes of mangrove area and shore line changes during the study period.

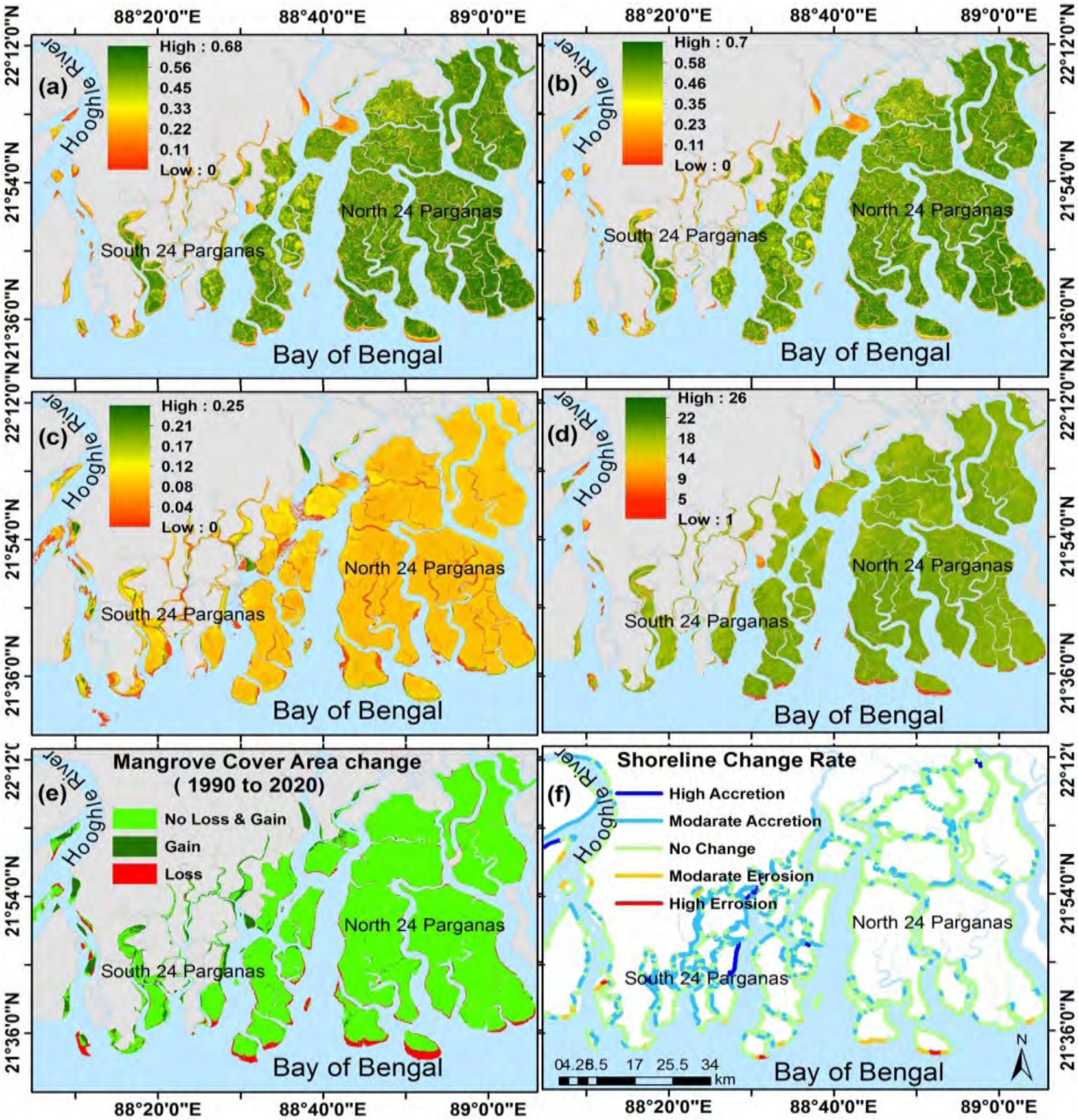

Figure 10: Spatial patterns of (a) NDVI mean climatology for spring, (b) NDVI mean for normal years, (c) NDVI Standard Deviation and (d) number- frequency of data used to calculate NDVI normal, (e) change of mangrove cover area between 1990 to 2020 & (f) shoreline change rate.

Delineation of surface coal fire and land subsidence in the Jharia coalfield

- Coal fire is a serious problem in Jharia coal field in India where high ranking coals are gradually burnt due to these fires. Delineation of coal fire and mining related land subsidence has been addressed. Thermal band of Landsat-8 (100m resolution) have been used to demarcate the coal mine fire areas from non-fire areas. Further ALOS-PALSAR 2, L band microwave data has been used to delineate zone of probable land subsidence (using differential interferometry) due to mining.

11.5 Capacity Building in Space Science Research

- Online training on Earth Observation (EO) applications on multiple thematic areas
- Training programme of specific duration on:
  - groundwater related studies using remote sensing & geo-spatial techniques,
  - modeling and spatial data analysis
  - monitoring of glacial lakes using satellite remote sensing data
  - hydrologic modelling using geospatial data inputs for water resources management

11.6 National Collaborations in Space S&T

Sl. No.	Area of Collaboration	Collaborating Institute
1	Satellite based exploration study for Manganese deposit	Manganese Ore India Ltd (MOIL)
2	Exploration of rock phosphate deposit using EO data	Atomic Mineral Directorate for Exploration and Research (AMD)
3	Hydrocarbon exploration	Oil and Natural Gas Commission(ONGC)
4	Remote sensing based Sedimentation studies	National Hydropower Power Corporation (NHPC)
5	Estimation and Tracking of Subsurface Groundwater Discharge along coastal stretches	PRIST University, Tanjavur, Tamilnadu
6	Digital Agriculture	Dept. of Agriculture, Maharashtra
7	Remote Sensing and Geophysical approach for mineral mapping.	IIT, Dhanbad, Jharkhand

11.7 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1.	Airborne Hyperspectral data processing	Michigan Tech University, USA
2	Utilization of L & S-band airborne SAR data as preparatory studies for NISAR satellite mission	NASA
3	Disaster Management	Sentinel Asia and South East Asia member countries

11.8 Laboratories and Facilities Available for Space Instrumentation

- Lab facility is available for spectral analysis of field samples using Fieldspec 3 Spectrometer (Spectral domain 350-2500 nm) and FTIR Spectrometer (Spectral domain 2000-16000 nm)
- Ground Penetrating Radar (GPR) instrument is used for characterizing subsurface aquifers as well as for detecting other subsurface features and artifacts (for archeological structures).
- Other major instruments include:
  - High Performance Liquid Chromatography- for measuring ocean chlorophyll and ocean colour satellite validation.
  - Under Water Radiometer for measuring upwelling radiance and irradiance, fluorescence and back scattering.
  - Inherent optical profiler for measurements of inherent and apparent optical properties.
  - Fast Repetition Rate Fluorometer for measurement of variable fluorescence and photosynthetic efficiency.

CHAPTER-12

ARYABHATTA RESEARCH INSTITUTE OF OBSERVATIONAL SCIENCES

Nainital

12.1 About the Institute

Aryabhatta Research Institute of Observational sciencES (ARIES) is an autonomous institute under the Department of Science & Technology, Govt. of India since March 22, 2004. It came into existence as the erstwhile Uttar Pradesh State Observatory (UPSO) at Nainital on April 20, 1954. The mandate of the institute is "Basic research in Astronomy & Astrophysics, Solar Physics and Atmospheric Science. Operating the largest optical telescope (3.6m) in the country and other telescopes/radar/lidar and associated instrumentation for Astronomy & Astrophysics and Atmospheric Sciences research by the national as well as international scientific community at large."

ARIES aims to:

- Build and operate state-of-the art observational facilities and back-end instruments to carry out frontline research in these areas, and make them accessible to the scientific community.
- Establish a strong synergy between all the facilities at ARIES and other national and international ground-based facilities and space-based programs.
- Study the effects of anthropogenic and natural activities on air-quality and regional climate change over India, particularly over the Himalayas.
- Create an engineering R&D centre to cater to in-house development, value addition and optimize performance of back-end instruments. Extend the R&D laboratories, expertise and technology to the industries and educational institutions.

12.2 Keywords

Sun, Star-formation, Supernova, Gamma-ray burst, Active-galaxies, multi-messenger-astronomy, Climate change, Air pollution, Trace species, Meteorology-dynamics.

12.3 Major Research Domains

- **The Sun and related phenomena:** Development of space-based telescope in the last three decades made some astonishing discoveries and raised some fundamental questions on our understanding of this star. ARIES is involved actively in studying solar surface features, solar dynamo, space weather which includes solar flare and CMEs, Solar atmosphere. ARIES has been maintaining a 15 inch solar telescope which takes regular observations of the Sun. ARIES is also hosting ADITYA-L1 support s cell which is a joint effort of ISRO and ARIES.

- **Galactic Astronomy:** Investigating the content of our own Milky Way galaxy forms one of the thrust research areas of the astronomy and astrophysics division at ARIES. The major astrophysical problems that this group is addressing are (i) how does a star form? (ii) Do the low and high mass stars form differently? (iii) What is the internal structure of stars, and high energy astrophysical processes occurring during the accretion of matter from one star onto the other?

- **Extragalactic Astronomy:** Investigating formation of Milky Way as well as other galaxies and galaxy clusters forms one of the thrust research areas of astronomy division at ARIES. The astrophysical problems under this category include: How does a galaxy form? What is the nature of dark matter in the galaxy? Why some galaxies are active? What is the role of black holes in formation of galaxies? What is the origin of highly energetic extra-galactic objects such as gamma rays burst and supernovae?

- **Numerical Astrophysics:** The ARIES theory group studies accretion disc models with relativistic equation of state to describe the thermodynamics of relativistic plasma that makes up the accretion disc.

- **Meteorology and Dynamics:** Nainital is considered to be the gateway to the Himalayan region dominated by intriguing dynamical/meteorological aspects such as wind structures, boundary layer characteristics, tropospheric temperature, monsoon troughs, cloud morphology, western disturbances, and short/large scale variabilities associated with atmospheric background oscillations. In this reference, ARIES ST Radar (ASTRAD) is being used to study a deep insight into synoptic processes and mesoscale systems with high vertical and temporal resolutions over the central Himalayan region.

- **Trace Gases Studies:** The Himalayan region is a natural laboratory for studying the impact of air pollution that originates from the highly polluted Indo-Gangetic Plain and/or very-long distance sources in Europe and/or Africa. Therefore, a wide range of highly sensitive instruments for surface observations for several trace gases and ozone vertical profiling using balloon-borne ozonesonde are operational at ARIES, Nainital.

- **Aerosols Studies:** Different physics, optical and chemical properties of aerosols are being studied using several instruments like, Microtop, MWR, Sun Sky Radiometer, aethalometer, nephelometer, aerodynamic particle size sizer, EC/OC analyzer, high volume samplers etc.

- **Boundary Layer Studies:** ARIES hosts a 27 m high tower (27 m) with a suite of sensors at two levels for the boundary layer studies. Recently, different sensors for for the measurement of upwelling and downwelling shortwave and longwave radiation fluxes have also been installed.

12.4 Major Scientific Applications

- **Density structure of the solar corona:** The solar corona is highly structured due to the presence of magnetic fields. Plasma is also confined to the magnetic structures thus the corona is not homogeneous in density. The inhomogeneity of the solar corona is quantified by the filling factor. A filling factor close to unity means a homogenous plasma. Using MHD simulations and forward modelling, we proposed for the first time that the MHD wave-driven turbulence increases the filling factor in the solar corona [Sen & Pant, 2021, ApJ].

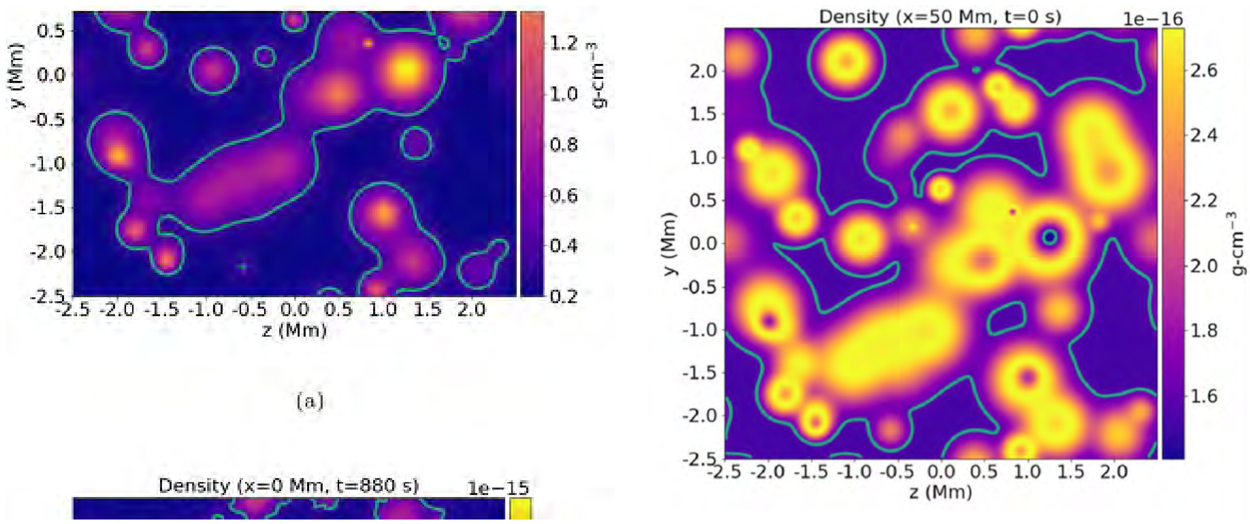

Figure -1: Left: The density structure at the start of the MHD simulation when turbulence is not developed. Green contours outline the density enhanced structures. Right: Same as left panel but at higher height and later time when turbulence is developed. Green contours outline very small area, meaning filling factor has increased.

- **Kinematics of CMEs in the inner corona:** CMEs are the drivers of the space weather. The extreme kinematics of CMEs happen in the inner corona. 3D model were used (Graduated Cylindrical Shell; GCS) to estimate the true propagation speed and expansion speed of CME using data from COR-1. It is noted that the rapid expansion and impulsive acceleration of CME happen simultaneously. This points towards the same physical mechanism responsible for the acceleration and expansion of CME [Majumdar et al, 2020, ApJ; Majumdar et al, 2021, ApJ].
- **CME initiation and propagation**: Combining the data from AIA/SDO, ARIES H-alpha telescope and coronagraph, the origin, propagation and geo-effectiveness of CMEs ejected from an active regions were studied. At the solar source region of the eruptions, circular ribbon flare were observed for both the cases, suggesting fan-spine magnetic configuration in the active region corona. [Syed et al 2021, RAA]
- **Time domain astronomy :** Studies of transients such as supernovae and gamma-ray bursts were studied in time-domain astronomy utilising the longitudinal location of ARIES observational facilities combined with data at other wavelengths. A recent

study about energetic nearby transients, observed primarily as a short-duration GRB 200826A, discovered an underlying supernova signature challenging not only the known classification of GRBs but also showed that not all massive stars produce necessarily cleaned jetted-outflows. [A.J. Castro-Tirado, et al., 2021, Nature, 600, 621-624; T. Ahumada et al, 2021, Nature Astronomy, 5, 917-927.]

- **Stellar occultation:** A stellar occultation by Pluto was observed on 2020 June 6 with the 1.3 m and 3.6 m telescopes located at Devasthal, Nainital, India, using imaging systems in the I and H bands, respectively. From this event, the surface pressure of Pluto was derived as 12.23 +0.65/-0.38 μbar. This shows that Pluto's atmosphere has been in a plateau phase since mid-2015, a result which is in excellent agreement with the Pluto volatile transport model of Meza et al. *[Pluto's Atmosphere in Plateau Phase Since 2015 from a Stellar Occultation at Devasthal by Sicardy et al, ApjL 923(2) L31, Dec. 2021.]*
- **Afterglows of gamma-ray bursts:** Optical follow-up observations of optical afterglows of gamma-ray bursts are crucial to probe the geometry of outflows, emission mechanisms, energetics, and burst environments. The follow-up observations of GRB 210205A and ZTF21aaeyldq (AT2021any) using IMAGER on 3.6m DOT around one day after the burst is able to constrain the 3-sigma upper limits (> 22.8 mag in R and > 22.6 mag inI filters, respectively). *[Revealing nature of GRB 210205A, ZTF21aaeyldq (AT2021any), and follow-up observations with the 4K×4K CCD Imager+3.6m DOT, by Gupta et al, 2021, JapA, arXiv:2111.11795]*
- **Retrieval of vertical ozone profiles from INSAT-3D Sounder:** For the first time, vertical distributions of ozone have been retrieved using data (2013-2017) from INSAT-3D over the central Himalaya and validated utilizing balloon-borne observations from a high-altitude site in Nainital. (Rawat et al., 2020)

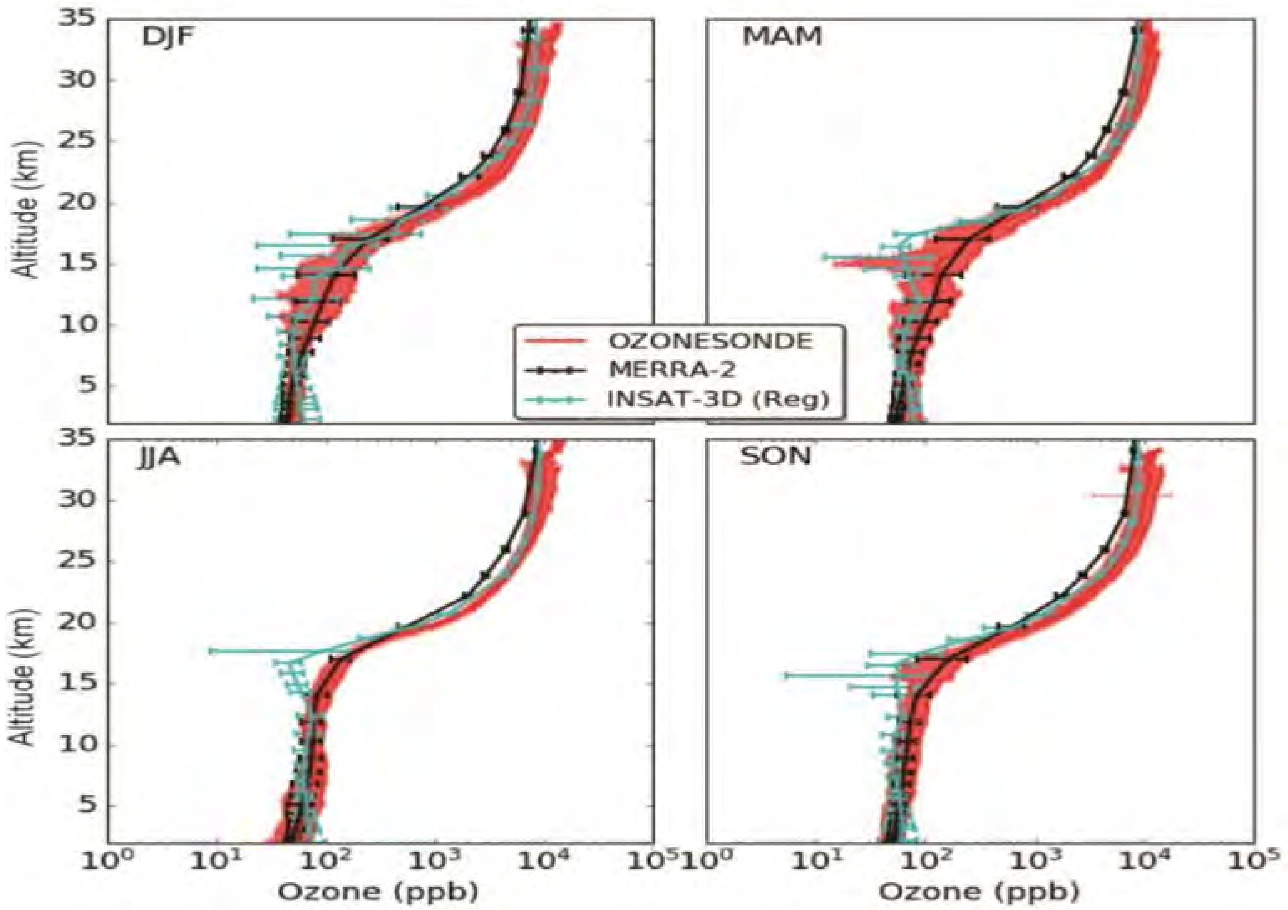

Figure-2: A comparative seasonal ozone profiles among balloon-borne ozone observations, INSAT-3D and MERRA-2 reanalysis.

- **Aerosols vertical profiling using COBALD instrument:** Extensive balloon-borne observations were carried out from ARIES, Nainital to study effect of Asian Summer Monsoon (ASM) on the upper troposphere lower stratosphere and aerosol layer near tropopause as a part of StratoClim balloon campaigns. Aerosol backscatter measurements are made by the Compact Optical Backscatter Aerosol Detector (COBALD) instrument during monsoon and post-monsoon. The analysis reveals a variety of factors contributing to the observed day-to-day variability in aerosol layer near tropopause: continental convection, tropical cyclones (maritime convection), dynamics of the anticyclone and stratospheric intrusions. (Hanumanthu et al., 2020)
- **Carbonaceous aerosols over the central Himalayas:** Online simultaneous observations of organic carbon (OC) and elemental carbon (EC) are made for the first time in the Himalayan region and provided a diurnal variations with a unimodal pattern in both OC and EC at the high-altitude site (Nainital, 29.4°N, 79.5°E, 1958 m amsl). The diurnal variations of EC are used to estimate the atmospheric radiative forcing that shows about 70% higher values in the afternoon than the forenoon.
- **Aerosols study using Lidar:** Lidar based observations from ARIES showed an aerosols layer at an altitude 4-6 km (above mean sea levels) during winter and pre-

monsoon period. Back-air trajectory analysis showed that the westerly/north-westerly winds with magnitudes of about 6–9 m/s are conducive for the generation and strengthening such aerosols layers. It is shown that these aerosols layer can warm up the atmosphere by about 1.3 K/day. (Shukla et al., 2021)

12.5 Instruments / Payloads / Products Developed / Sensors / Detectors

- **3.6 m Devasthal Optical Telescope (DOT) :** ARIES operates India's largest 3.6 m diameter optical telescope at Devasthal as a National Facility. Ninety-three percent of the time on the telescope is guaranteed for astronomers from India whereas the remaining seven percent is guaranteed for astronomers from Belgium. The DOT facility consists of a modern 3.6 m diameter optical telescope with active optics technology, a suite of complex instruments, a mirror coating plant, and a control room. The instruments can provide astronomical observations at optical and near-infrared wavelengths catering to a wide range of astronomical topics related to solar system objects, exoplanets, stars, star clusters, galaxies, and extra-galactic sources.

- **TIRCAM2:** A near-infrared imaging instrument TIRCAM2, developed jointly by TIFR and ARIES has been tested and commissioned on 3.6 m DOT. It is sensitive in the wavelength range from 1 to 3.7 microns and covers a field of view of 86.5 arcsec x 86.5 arcsec. It has broad-band J, H, K and narrow-band BrG, K-cont, PAH and nbL filters. Deep imaging observations show that the instrument has the capability to observe sources up to 19.0 mag, 18.8 mag and 18.0 mag with 10% photometric accuracy in J, H and K band respectively, with corresponding effective exposures of 550s, 550s and 1000s.

- **IMAGER:** It is an optical imaging instrument and it is indigenously designed and assembled at ARIES. It covers wavelengths ranging from 400 to 900nm. It employs a 4096 x 4096 CCD camera with a pixel scale of about 0.1 arcsec on the telescope and it covers a field of view of 6.5 x 6.5 arcmin. The available filters are Bessel U,B,V,R,I and SDSS u,g,r,i,z. Imaging observations show that the instrument has the capability to observe sources up to 24.0 mag, 25.2 mag and 24.6 mag with 10% photometric accuracy in B, g, r band respectively, with corresponding effective exposures of 1200s, 3600s, and 4320s

- **TANSPEC:** An imaging and spectroscopy instrument namely TANSPEC for the 3.6m DOT was jointly developed by TIFR and ARIES. This has been extensively tested and characterized during the reporting period on 3.6m DOT. It is a unique spectrograph providing simultaneous wavelength coverage from optical (550 nm) to nrea-infrared (2540 nm). It offers photometry for a field of view of 1 arcmin x 1 arcmin. in broad-band r, i, Y, J, H, K and narrow-band H2 and BrG filters. Stellar images with FWHM of 0.5 arcsec in K-band were recorded in best conditions and it routinely delivers sub-arcsec images in visible and near-infrared. It is possible to detect sources at J, H, K of 19.5, 18.9, 18.4 mag respectively at 10 sigma level in 10 minutes exposure. r~23 mag source is detected in 1 hour exposure.

- **ADFOSC:** The in-house designed and developed spectrograph ADFOSC was commissioned on the 3.6m DOT for the upcoming science observations. It is a low resolution slit-spectrograph and camera having sensitivity in the wavelength range 350 nm to 1050 nm. It covers a field of view of 13.6 x 13.6 arcmin. It offers broad-band SDSS u,g,r,i,z as well as narrow-band filters. Imaging observations show that the instrument has the capability to detect sources up to 24.5 magnitude with 10% photometric accuracy in r-band in effective exposure of ~2 hours in dark nights.
- **HRS :** A high-resolution spectrograph (HRS) is being built for use with the recently installed 3.6 m Devasthal Optical Telescope (DOT). This will be a second-generation instrument for DOT and will have unique specifications with first of its kind in the country. The chosen configuration of HRS is driven by the science interest of astronomical society of India and the instrument would yield two modes of the spectral resolution of 40,000 and 80,000, complete spectral coverage from 380 nm to 850 nm, and very high light efficiency. The expected time for commissioning of the HRS is three years, say by 2025.
- **ILMT:** The 4m International Liquid Mirror Telescope (ILMT) project is a joint collaboration between ARIES, India, University of Liege, Belgium and Canadian Universities. The telescope works on liquid mirror technology where the 4m primary mirror will be formed using liquid Mercury. A 4Kx4K CCD camera, operating between 4000 to 11000 Ang is mounted at the prime focus of the ILMT. The observations will be taken pointing towards the zenith in g’, r’, i’ filters in Time Delayed Integration (TDI) mode resulting in a 27 arcmin field of view. ILMT will be the first optical survey telescope in the country producing deep images of the same portion of the sky.

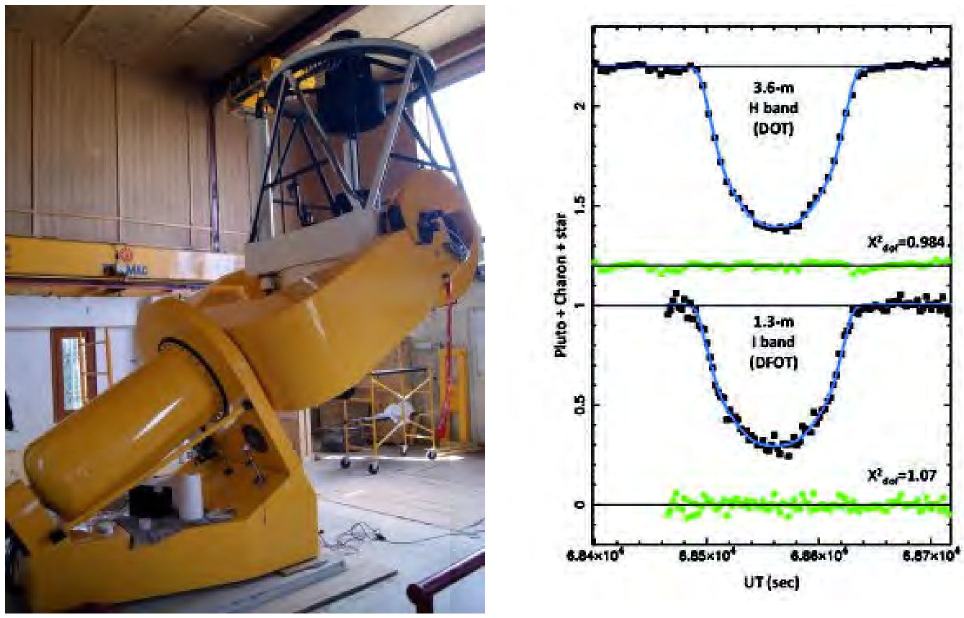

Figure-3: Left side contains view of 1.3-m DFOT and right side shows Transit light curves of Pluto taken with 1.3-m DFOT and 3.6-m DOT

- **DFOT 1.3m:** ARIES operates a 1.3-m diameter telescope at Devasthal, Nainital which was installed by the DFM Engineering Inc. USA in 2010. It is a fast F/4 telescope having a wide field of view of 18x18 arcmin and mounted with two detectors, 2kx2k CCD, and 512x512 fast read-out camera. The broad-band UBVRI, SDSS ugriz, and narrowband H-alpha, O[III], S[II] interference filters are available for multi-band imaging. Though telescope is being used for diverse scientific objectives three broad science programs are rigorously carried out with 1.3-m DFOT that includes “star clusters and star-forming regions”, “ Follow-up observation of after glow of GRBs and Supernovae”, and “optical variability in Quasars, Blazars, Active Galactic Nuclei and Seyfert galaxies”. More than 40 research papers have been published in reputed international journals using data from 1.3-m DFOT from July 2020 to December 2021.
- **ARIES ST Radar (ASTRAD) Facility:** A state of the art Stratosphere-Tropospheric (ST) Radar designed for operating at a frequency of 206.5 MHz and installed in the foothills of the Himalayan region at ARIES, Nainital (29.4°N; 79.2°E; ~1800 m amsl) to understand the intriguing aspects of lower atmospheric dynamics over the data-sparse region of the Central Himalaya. Such high altitude active aperture radar in the VHF band along with antenna elements over the rooftop has been built for the first time in the country.

Figure-4. A bird-eye view of ARIES ST Radar on the roof-top of the building.

- **TRM and Antenna Development:** A prototype of Transmit Receive Module (TRM) for its VHF active aperture ST Radar has been developed. The TRM had met the required design parameters and was successfully integrated with the existing system. In addition to TRM, folded dipoles for three-elements Yagi-Uda antenna was also fabricated and integrated into the existing antenna. Both the development works using facilities within the institute build confidence to produce two main sub-systems of an active aperture of a radar which will help in maintaining and operating a complex system like WPR with self-sufficiency.

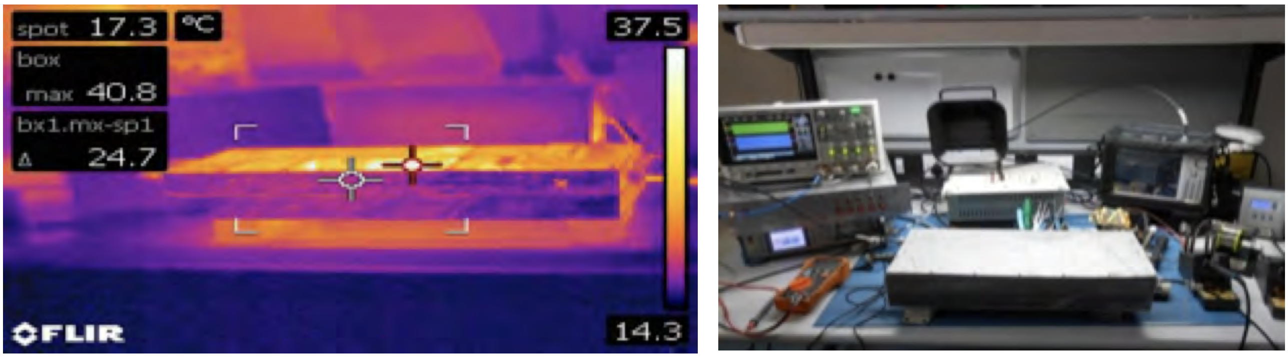

Figure-5: Testing of TRM in the ASTRAD laboratory.

- **ASTRAD Software:** To meet the need of flexibility in processing and presentation of scientific products of ASTRAD data, a machine independent customized data processing tool with user friendly interface has been developed using MATLAB. In the tool, a specially designed digital filtering technique is integrated to improve the data quality and clean the captured spectrum as per site condition. Adaptive Doppler tracking is implemented to track Doppler profile in low S/N region
- **Compact Meteorological Observational Device (CMOD):** A portable, low cost and easily deployable device has been developed for the continuous observations of

the basic meteorological parameters (temperature, pressure, relative humidity) from multiple sites. The unit has the facility to download data through a web interface on any smart mobile device. This device is being upgraded for more parameters like, winds, solar radiation, rainfall etc.

- **Solar H-alpha Telescope :** The main solar observing facility at ARIES is 15cm, f/15 Coudé Solar Tower Telescope equipped with Hα filter, and CCD camera (1Kx1K, 13 micron, 16 bit, 10 MHz read out rate, frame transfer, back illuminated). It has a spatial resolution of 0.58" per pixel. It is an automatic Hαflare patrolling system, which takes fast sequence of images in the flare mode observations. Regular observations of the solar eruptive events (e.g. solar flares, filaments and prominences eruptions, surges etc.) were routinely done with the telescope. The telescope is also equipped with FeX 6374 Å, FeXIV5303 Å, FeXI 7892 Å filters to observe the corona during total solar eclipse. The telescope is located in a reasonably good site especially during first half of the day. The total clear observing days are approximately 200 per year. Right now the telescope is undergoing a major upgrade of image acquisition software.

Figure-6: 15 cm Hα telescope solar tower mounted at ARIES

12.6 Capacity Building in Space Science Research

- ARIES offer PhD in astronomy and atmospheric sciences. Recently, ARIES started integrated MTech-PhD program from 2021. From July 2020-December 2021, 7 students have defended the theses and 6 students have submitted the thesis.

- ARIES scientists and engineers guide B.Sc./M.Sc./B.Tech./M.Tech/M.Phil students for their projects in astronomy-astrophysics, solar and atmospheric sciences. From July 2020-December 2021, about 40 students were guided by ARIES faculty.
- **Outreach/Training:** The ARIES Training School in Observational Astronomy (ATSOA) is a capacity building school aimed for post-graduate students in Physics/Astrophysics. The selected students are exposed to observational astronomy techniques in optical wavelengths with visits to the telescopes/laboratories located in ARIES. The school covers a series of lectures related to basic astrophysics followed by several hands-on data analysis sessions. ATSOA 2021 hosted and trained about 100 students. The ATSOA is being organized every year.

12.7 Courses offered on Space Science and Technology

ARIES PhD coursework: ARIES offers a diverse range of course for PhD course work. These includes basic astronomy, mathematical and statistical physics, electrodynamics and radiative processes, atmospheric sciences, fluid mechanics, evolutions of stars and their atmospheres, special and general relativity and cosmology, observational techniques, interstellar medium, aerosals etc.

ARIES MTech-PhD coursework: ARIES offers coursework for Integrated MTech-PhD students in collaboration with Department of Applied Optics and Photonics Calcutta University.

Optional Courses

In addition to the above courses, ARIES also offer optional courses in astronomical instrumentation, data handling, embedded systems, material properties, operating systems, digital systems and image processing etc.

12.8 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	Atmospheric and Space Sciences	PRL, Ahmedabad
2.		IIRS, Dehradun
3.		SPL, VSSC, Trivandrum
4.		SAC, Ahmedabad
5.		IITM, Pune
6.		NPL, Delhi
7.	Heliospheric physics and Space Sciences	ISRO, India
8.	Next generation UV payload: INSIST	IIA & ISRO
9.	TMT collaboration	IIA

12.9 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1.	Atmospheric and Space Sciences	NIES, Tsukuba, Japan NCAR, Boulder, USA IAC, ETH Zürich, Switzerland
2.	Heliospheric Physics and Space Sciences	KU Leuven and Royal Observatory of Belgium, Belgium SWRI, US Naval research lab and RAL Space, USA
3.	TMT international collaboration	International consortium including partner institutions
4	ILMT	Belgium, Canada
5	DOT	Belgium

12.10 Laboratories and Facilities Available for Space Instrumentation

Major laboratories and facilities available at ARIES are the following:

- **Optics and Aluminising workshop:** Optics section is actively involved in the instrumentation activities related to various projects in the institute. The section has various facilities and instruments for aligning, testing and integration of optical system. The details of facilities and instruments installed are as below:
    1. Clean Room Facility: Optics laboratory has a class-10,000 clean room with laminar flow unit. The clean room has a vibration isolated optical table of 12 x 9 x 9 feet dimension.
    2. Optical Profiler cum Phase Shift Interferometer: Used for the Surface roughness measurement, Shape profiles of optical elements, step height of coatings on mirror, 3D surface profile analysis.
    3. UV-VIS-NIR spectrometer: Used for fiber fed instrument used in laboratory experiments.
    4. Laser interferometer: Used for the micron level measurements (linear/angular alignments, vibrations etc.) of mechanical and opto-mechanical systems
    5. Reflectometer: Used for the reflectivity measurement of mirrors over visible wavelength range.

Figure-7: The class 10,000 clean room facility with vibration free table installed at optics lab, ARIES, Nainital

In addition to the above, ARIES also has ESD laboratory, data pipeline for astronomical observations, mechanical workshops and electronics lab for instrumentation.

Publications (July 2020 – December 2021)

There are about more than 150 publications in various peer reviewed journals from ARIES. The important publications are listed below

1. Sen, Samrat & Pant, Vaibhav. (2021), Astrophysical Jr., 923: 178 (12pp).
2. Fyfe, L. E. et al. (including Pant, V.). (2021), Astron. Astrophy., 656, A56 (11pp).
3. Paliya, Vaidehi S., Böttcher, M., Gurwell, Mark & Stalin, C. S. (2021), Astrophysical Journal Supplement Series, 257:37 (6pp).
4. Raman, Gayathri, Varun, Paul, Biswajit & Bhattacharya, Dipankar. (2021), Mon. Not. Roy. Astron. Soc., 508, 5578–5586.
5. Stern, D. et al. (including Jalan, P.). (2021), Astrophy. Jr, 921:42 (16pp).
6. Seo, J., Kang, H., Ryu, D., Ha, S. & Chattopadhyay, I. (2021), Astrophy. Jr., 920:143(16pp).
7. Majumdar, S., Patel, Ritesh, Pant, Vaibhav & Banerjee, Dipankar. (2021), Astrophy. Jr., 919: 115 (8pp).

8. Khatri, P. et al. (including Dumka, U. C.). (2021), Geophysical Research Letter, 48, e2021GL093796 (9pp).
9. Ahumada, T., et al. (including Pandey, S. B.) (2021), Nature Astronomy, 5, 917-927.
10. Sariya, D. P., et al. (including Yadav, R. K. S.) (2021), Astronomical Jr., 162:146 (11pp).
11. Banerjee, D. et al. (including Pant, V.). (2021), Space Science Reviews, 217:76 (37pp).
12. Mishra, S., Gopal-Krishna, Chand, H., Chand, Krishna, Kumar, Amit & Negi, V. (2021), Mon. Not. Roy. Astro. Soc.: Letters, 507, L46–L51.
13. Villarroel, B. et al. (including Gupta, A. C.). (2021), Nature: Scientific Reports, 11:12794.
14. Gupta, Rahul et al. (including Pandey, S. B., Kumar, Amit, Aryan, A., Kumar, B., Dimple & Misra, K.). (2021), Mon. Not. Roy. Astrn. Soc., 505, 4086–4105.
15. Rani, S., et al. (including Pandey, S.) (2021), Jr. Astrophys. Astron., 42, 47 (11pp).
16. Bisht, D., et al. (including Yadav, R. K. S.) (2021), Publ. Astron. Soc. Japan, 73, 677-691.
17. Patel, Ritesh, Megha, A., Shrivastav, Arpit Kumar, Pant, Vaibhav, Vishnu, M., Sankarasubramanian, K., Banerjee, Dipankar. (2021), Frontiers in Astronomy and Space Sciences, 8, 660992 (11 pp.)
18. Shanmugaraju, A., Syed Ibrahim, M., Suresh, K., Vijayalakshmi, P. & Dhara, S. K. (2021), Solar Phys., 296, 77 (17pp).
19. Bisht, D., et al. (including Yadav, R. K. S.). (2021), Mon. Not. Roy. Astro. Soc., 503, 5929-5947.
20. Nayak, P. K. et al. (including Bandyopadhyay, A.). (2021), Mon. Not. Roy. Astro. Soc., 503, 5291-5309.
21. Xu, Yan, et al. (including Banerjee, D.). (2021), Astrophy. Jr., 909: 86 (8pp).
22. Pattnaik, R., et al. (including Sharma, K.). (2021), Mon. Not. Roy. Astron. Soc., 501, 3457- 3471.
23. Rawat, P., et al. (including Naja, M. & Bhattacharjee, S.) (2020), Current Science, 119, 1113- 1122.
24. Ojha, N., et al. (including Singh, N.). (2020), Nature Scientific Report, 10: 5862 (11pp).
25. Dhaka, S. K., et al. (including Singh, N.). (2020), Nature Scientific Report, 10: 13442(8pp).
26. Majumdar, S., Pant, V., Patel, R. & Banerjee, D. (2020), Astrophy. Jr., 899:6 (15pp).

CHAPTER-13

THE PLANETARY GEOLOGY AND IMAGE ANALYSIS LABORATORY

Department of Geology, Asutosh College
Kolkata

13.1 About the Laboratory

Asutosh College, initially founded as the South Suburban College in 1916 by the great educationist Sir Asutosh Mukherjee, is a leading education institute in Kolkata and West Bengal. With time the College has emerged as a centre for postgraduate studies and research. Asutosh College has currently been graded as NAAC Grade A. The Planetary Geology and Image Analysis Laboratory was established in 2013 under the Department of Geology, Asutosh College. The laboratory was started in harmony with the aim of the college towards advancement of research capabilities and to conduct more quality research. The laboratory has so far housed four research projects, two completed and two on-going projects, supported by the Indian Space Research Organisation. Since the laboratory's inception, researchers have attempted to understand and explicate the geomorphic and geologic processes that have shaped the surfaces of our neighbours in the Solar System, the Mars and the Moon. The research findings from this laboratory are published in reputed journals and conference volumes.

13.2 Keywords

Polygonal Impact Craters, Rampart Craters, Ejecta Blanket, Wrinkle Ridges, Grabens, Lobate Scarps, Martian Cryosphere, Martian Channels, Lunar Mare, Geochronology of planetary surfaces.

13.3 Major Research Domains

The major domains of research that the laboratory focuses on are structural geology and geomorphology of Mars and Moon. To do that, certain specific morphological features are focused on.

- **Craters:** The geometry of craters and crater ejecta is an amazing way to study the planetary subsurface. The polygonal impact craters offer a wonderful opportunity to identify subsurface faults that do not have surface manifestations. Likewise, the ejecta blankets of ramparts craters of rampart craters provide wonderful opportunity to study the existence of a subsurface cryosphere.
- **Wrinkle Ridge, Lobate Scarps, Grabens:** These tectonic features are commonly found on the planetary surfaces. Wrinkle ridges and lobate scarps indicate to compressional tectonics while grabens hint toward extensional tectonics. All of these features help us

to understand the palaeostress conditions that prevailed in different localities in different times and also to understand the magnitude of deformation experienced in those regions.

- **Martian Channels and Fossae:** The genesis of Martian Channels and Fossae are also studied. These features help us to decipher the structural geology of a locality and impact of previous tectonic events. Channels are studied to understand the nature of paleo-fluvial activities on Mars.
- **Geochronology**: In order to explain genesis, temporal distribution of craters, wrinkle ridges, lobate scarps, grabens on the Moon and Mars and paleochannels on Mars their ages are being estimated.
- **Geological evolution:** Evolution of geomorphic and deformation structures in different regions of Moon and Mars are being explained from the studies mentioned above.

13.4 Major Scientific Results

Major scientific results are as follows:

- The study of Dorsa Geikie, a wrinkle ridge on moon reveals that an isolated, single, large thrust fault was responsible for the formation of the wrinkle ridge through upward arching of surface by fault-propagated fold mechanism. Shortening accomplished by folding causing an average 1.89% crustal contraction across the dorsa. Also, the linear relationship in maximum displacement-length scaling indicates uniform rock material. The work was done using TMC-2, Chandrayaan-2, data.
- The East Coprates Planum (ECP), Mars is ornamented with various geomorphological features that originated due to crustal deformation. Some linear structures, previously identified as strike-slip faults, which appear to be wrinkle ridges owing their origin to subsurface thrusting, are restudied based on presently available higher resolution images and digital terrain models. It can be inferred as either manifestations of wrench/tear faults due to differences in slip along the strike of thrust faults underneath, or by later thrusting along preexisting strike-slip faults. Different sets of wrinkle ridges have detachment faults at different depths. Estimates show little shortening across these wrinkle ridge sets similar to previous works on Mars and Moon. ECP was deformed by several stress regimes; compression regimes responsible for the different sets of wrinkle ridges and extensional regimes responsible for dyke emplacement and graben formation. Analyses of polygonal impact craters have revealed that the N–S and E-W trending wrinkle ridges have a major control over the formation of the polygonal impact craters. The NE-SW trending weak planes had little to no effect on the formation of the straight PIC edges. There is also of a set of weak planes trending ~ NNW-SSE which have no surface expression.
- Pyrrhae Fossae (PyFo) on Mars is a palaeo-extensional tectonic feature in the north-western Noachis Terra. The age of PyFo is found to be 3.79 Ga. The estimated age of the basement geological unit of the region is 3.98 Ga. These results indicate that the PyFo

formed in late Noachian time (~3.86– 3.74 Ga), shortly after the formation of the basement (~3.99–3.97 Ga). The orientations of PyFo do not follow the outer arc curvature of the major impact basins situated in its vicinity (within 1000 km). The evolution of Tharsis has no direct bearing on the origin of PyFo, and possibly a different tectonic event was responsible for its formation. Elastic spherical shell loading model successfully explains the present-day geoid assuming Tharsis as a massive load supported by membrane stresses in a rigid lithosphere. Therefore, in the late Noachian time flexural bending of the lithosphere induced either by loading of Tharsis or by thinning of northern lowlands possibly produced fractures in the upper crust leading to an extensional regime producing normal faults, bounding the PyFo.

- Another study tried to address the depth of excavation of rampart craters present in Thaumasia Minor (TM). It attempted to estimate the depth of excavation of each crater and their ages by conventional methods. This study reveals that the altitude of the base of the Martian cryosphere in the TM must have changed progressively with time. The study shows that the base of the Martian cryosphere which lay below 1.7 km around 1.6Ga came to lay between 2.63 km and 2.7 km above the areoid around 0.32Ga. Thinning of the cryosphere in the area must also indicate a decrease in groundwater recharge. Significantly high ejecta mobility values for craters sitting atop fault planes is possibly an indication of greater availability of meltwater due to presence of the fault planes which might have acted as water pathways.
- Analysis from another study of Polygonal Impact Craters in Margaritifer Terra, Mars unambiguously prove that within the region the orientations of the scarps do have a control on the development of Polygonal Impact Craters, but the orientations of the graben do not. The wrinkle ridges in the area, however, show contradictory behaviour when analysed. The study critically accessed the basic assumption that whether the tectonic weak planes present within the Martian crust do really contribute to the development of straight rims of Polygonal Impact Craters. The analysis showed that straight rims of Polygonal Impact Craters have developed very selectively with respect to the available tectonic structures in the area. Therefore, it was concluded that proper statistical analysis needs to be done for a critical appreciation of the control of weak plane on the development of straight rims of Polygonal Impact Craters. This study therefore can be useful to detect which of the morpho-tectonic features in a region have a proper control on crater rim geometry and the formation of complex Polygonal Impact Craters.

13.5 Capacity Building in Space Science Research

Asutosh College is an affiliated college to the University of Calcutta and therefore cannot independently offer Ph.D. to researchers. However, University of Calcutta, does provide Ph.D. opportunity to researches working in post-graduate colleges affiliated to the university.

Three researchers, working in the Planetary Geology and Image Analysis Laboratory, are enrolled for Ph.D. under the University of Calcutta.

Each year M.Sc. Applied Geology students carry out their M.Sc. theses from this laboratory. So far nine students have completed their M.Sc. thesis. In this session two students are carrying out their M.Sc. theses work here.

13.6 Courses offered on Space Science and Technology

The Department of Geography in Asutosh College provides the course of M.Sc. Geography, of the University of Calcutta.

(i) The Post-graduate course has a paper entitled 'Geomorphology & Geotectonics' in which a topic is 'Planetary geomorphology with special reference to Moon and Mars'.

(ii) The intake capacity for the course is thirty (30).

(iii) The topics covered are descriptions and origin of geomorphological features, of Mars and Moon, formed by surface processes, tectonic processes, volcanic processes and impacts.

(iv) Five lectures are allotted for this course.

13.7 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	Joint collaborative project under Chandrayaan-2 Science Plan on Terrain Mapping Camera (TMC) data utilization for understanding Lunar surface processes	Space Application Centre (ISRO)

Publications

1. Thapa, J et. al, Strain/stress evaluation of Dorsa Geikie using Chandrayaan-2 Terrain Mapping Camera-2 and other data, *Current Science*, ***121*****(1)**, 94-102, 2021.

2. Baul, S., & Dasgupta, D, An appraisal of crustal deformation of the East Coprates Planum, Mars, *Planetary and Space Science*, ***203***, 105252, 2021.

3. De, K et. al, Evolution of Pyrrhae Fossae, Mars: an explication from the age estimation using the Buffered Crater Counting technique, *Current Science*, ***121*****(7)**, 906-911, 2021.

4. Dasgupta, D et. al, An insight to the cryospheric level in Mars: Case study from the Thaumasia Minor, *Icarus*, ***372***, 114725, 2022 (Accepted in September 2021, Available online since December 2021).

CHAPTER-14

BANARAS HINDU UNIVERSITY

Varanasi

14.1 About the University

Banaras Hindu University (BHU) specially Department of Physics, Institute of Science, Varanasi has heritage in Atmospheric and Space Science Research from last few decades. Active research activities have been carried out in Atmospheric Physics, Space Physics, Astrophysics and Astrochemistry.

14.2 Keywords

Space weather studies, Ionospheric Total Electron Contents (TEC), Ionospheric Irregularities, Solar Flare, Whistlers, Lightning, VLF waves, Geomagnetic Storm, Solar Eclipse, Aerosols, Dust Storm, Cyclone, Climate change, Radiative forcing, Air pollutants, VUV detector, interstellar medium, Polycyclic Aromatic Hydrocarbon (PAH) molecules.

14.3 Major Research Domains

Ionosphere, Magnetosphere and Solar-Terrestrial Relationship:

- Space Weather Study of Ionosphere and magnetosphere.
- GPS based Total Electron Content (TEC) & Water Vapor content measurements.
- Probing of Ionosphere/Magnetosphere by VLF Whistler mode waves.
- Characteristics of Ionospheric Irregularities using VHF & GPS scintillations.
- Effect of Solar eclipses on atmosphere and ionosphere.
- Study of Ionosphreic perturbations associated with Earthquakes.

Atmosphere and Climate:

- Atmospheric studies involving Aerosols and their radiative and climate effects.
- Physical, Optical and Chemical characteristics of aerosols over Indo-Gangetic Basin (IGB).
- Characteristics of dust storms and cyclones and their climate effects.
- Air pollution and particulate matter study over Indo-Gangetic basin.

Astrophysics and Astrochemistry:

- Theoretical and Observational Spectroscopy of interstellar Polycyclic Aromatic Hydrocarbon molecules

- Understanding the reaction mechanism of the formation of carbon-based molecules in the interstellar medium
- Using the ALMA observatory to study interstellar molecular lines and abundances
- X-ray Astronomy of energetic Astrophysical sources
- Advancing towards Astrobiology

14.4 Major Scientific Applications / Results

IONOSPHERE, MAGNETOSPHERE AND SOLAR TERRESTRIAL RELATIONSHIP:

Effect of intense geomagnetic storms on low latitude TEC during the ascending phase of solar cycle 24: The study presents low latitude ionospheric Total Electron Content (TEC) variation during the chosen geomagnetic storm events happening during the solar cycle 24. We include the four intense geomagnetic storms occurred on 26 September 2011, 15 July 2012, 19 February 2014, and 20 December 2015 depending upon the availability of TEC data. For this, we have used the TEC data from low latitude station Varanasi (Geog. Lat. 25°, 16' N, Geog. Long. 82°, 59' E Geomag. Lat. 16°, 24' N) and an equatorial station Bengaluru (Geog. Lat. 13°, 02' N, Geog. Long. 77°, 34' E, Geomag. Lat. 04°, 68' N). The storm induced TEC changes at chosen stations have been discussed in terms of local time, storm wind effect, neutral wind, composition changes and variation in the dawn-dusk component of the interplanetary electric field (IEF- Ey) (For details please see Singh et al., J. of Astrophysics and Astronomy, 42, 99, 2021).

Solar flares and geomagnetic storms of September 2017: Their impacts on the TEC over 75^0 E longitude sector: This study investigates the ionospheric Total Electron Content (TEC) responses over 75^0 E longitude to the solar flares and geomagnetic storms of September 6–9, 2017. On September 6, two X class solar flares, namely X2.2 at 0857 UT and X9.3 at 1153 UT, were recorded with quiet geomagnetic conditions. The EUV/X-ray intensity of X9.3 flare was significantly greater than that of X2.2 flare, and the recovery phase of both the flares was slower than their respective impulsive phase. The overall weak TEC response to X9.3 solar flare is attributed to solar zenith angle dependency and shifting of solar flare location from disk centre to west limb. The solar flares on September 7–8 were co-occurred with geomagnetic storms and observed large increments in TEC are additionally induced by prompt penetration electric field and the enhanced level of thermospheric compositional changes (For more details please see Chakraborty et al., Advances in Space Research, 68 (4), 1825-1835, 2021).

Effect of 21 June 2020 solar eclipse on the ionosphere using VLF and GPS observations and modeling: The current work presents our outcomes from the simultaneous assessment of Tweeks (radio atmospherics) and radio signals (fixed frequency of the transmitter's signal) from multifarious VLF transmitters observed at Varanasi (Geog. Lat. 25.27^0 N, Geog. Long.

82.98^0 E, Geomag. Lat. 140 55’N). To find the presence of disturbances in the ionosphere GPS data at Hyderabad and Bengaluru is also analyzed during the solar eclipse. Tweek analysis shows the variation in the ionospheric reflection heights (~ 8-11 km) and electron density (~ 3-2 cm-3) in the D-region during the eclipse. Eclipse-imposed modifications in VLF transmitter’s signals displays an average change (decrease) of 2.8 dB and 0.8 dB in the signal strength of 18.3 kHz (HWU) and 19.8 kHz (NWC) transmitters respectively. The de-trended value of total electron content (DTEC) variations at both stations clearly shows the presence of travelling ionospheric disturbances (TIDs) having wave-like features. Such oscillation observed in the ionosphere are induced by atmospheric gravity waves (AGWs) generated during the solar eclipse (For details please see Tripathi et al., Advances in Space Research, 69, 254-264, 2021).

Predicting the maximum sunspot number and the associated geomagnetic activity indices aa and Ap for solar cycle 25: Over the last three solar cycles, the precursor method has proven to be a very reliable technique for forecasting ensuing solar cycles. In the present work, we have used the geomagnetic activity indices: aa and Ap measured

during the last 4 years of the descending phase of solar activity cycles as precursors for predicting the strength of the next solar cycle 25. From the indices aa and Ap, we estimate the maximum sunspot number (SSN) amplitude of the upcoming solar cycle i.e., solar activity cycle 25 to be 119.42 ± 28.41 and 113.70 ± 23.51, respectively. This suggests that the activity of the next solar cycle 25 is likely to be comparable to that of cycle 24. The results further suggest that the maximum solar cycle 25 is expected to be accompanied by higher geomagnetic activity levels than in cycle 24, but less than those in the previous cycles 22 and 23 (For details please see Singh et al., Astrophys Space Sci., 366, 48, 2021).

Ionospheric perturbations observed due to Indonesian Earthquake (Mw = 7.4) using GPS and VLF measurements at multi-stations: In the present study Global Positioning System (GPS) as well as Very Low Frequency (VLF) measurements at multi-stations have been used to analyze ionospheric anomalies related with major earthquake (Mw = 7.4) of South West Banten (Lampung Area), Indonesia. The analysis of the GPS-TEC data clearly supports the presence of earthquake signature in the form of anomalous perturbations in total electron content (TEC). Analysis found the presence of ionospheric perturbations 0–5 days before and after the main shock of the earthquake. VLF signal analysis using night-time fluctuation method indicates a significant increase in VLF amplitude before couple of days of EQ. Probable mechanisms behind these perturbations associated with EQ have also been discussed (For details please see Kumar et al., Acta Geodaetica et Geophysica, 56, 559-577, 2021).

ATMOSPHERE AND CLIMATE:

In recent years much interest has developed in the study of atmospheric phenomena controlling biosphere/geosphere due to large variations experienced in climate changes worldwide. There are various phenomena which are poorly understood such as formation of cloud/thunderstorm, aerosols and their role in climate control, global electric circuit and its relation with rain fall, water vapor content etc. To understand these complex phenomena, we have tried to study some of them.

Assessment of atmospheric aerosols over Varanasi: Physical, Optical and Chemical properties and meteorological implications: The present paper reports the results derived from PM2.5 and PM10 concentrations during October 2016 - May 2018 using MICROTOPS-II Sunphotometer and high-volume samplers at Varanasi. Observations showed aerosol mass loading during the post-monsoon 2016 and winter 2017 as compared to the pre-monsoon 2018 values, which typically exceed national standard. The close relationships between PM2.5 and PM10 during post-monsoon ($r = 0.571$) and winter ($r = 0.799$) suggested that both type of particulates might have originated from the same source. Further, the PM2.5/PM10 indicated that the fine particles were dominantly present during the post-monsoon and winter season whereas coarse particles were found dominant in the pre-monsoon season. In order to understand elemental and ionic composition Scanning electron microscope (SEM) coupled with energy dispersive X-ray microanalyzer (EDX) analysis were done which showed dominant presence of C, F, O, Si, N, Na, K, Al, Ca and S. The following trend $SO_4^{2-} > NO_3^- > Na^+ > Ca^{2+} > K^+ > Cl^- > F^- > Mg^{2+} > Li^+$ was observed from the Ion chromatograph (IC) analysis (For more details please see Kumar et al., J. Atmospheric-Solar & Terrestrial Physics, 209, 105424, 2020).

Predicting the rapid intensification and dynamics of pre-monsoon extremely severe cyclonic storm 'Fani' (2019) over the Bay of Bengal in a 12-km global model: The present study investigates into genesis, intensification, dynamical behavior and the prediction of Extremely Severe Cyclonic Storm (ESCS) 'Fani' over the Bay of Bengal (BoB) in the National Centre for Medium-Range Weather Forecasting (NCMRWF) global numerical weather prediction (NWP) modeling system 'NCUM.' The ESCS 'Fani' formed from 26 April–04 May 2019, over the warm waters of BoB. The TC exhibited a markedly different characteristic having genesis very near to the equator (near 2.7°N and 88.7°E) and possessing one of the longest tracks (~3030-km) over the BoB region. The NCUM global model was operationally run during the occurrence of the TC. The diagnosis of the TC's genesis and rapid intensification (RI) in the model is carried out using various metrics such as Genesis potential parameter (GPP), winds at 850-hPa, vertically integrated moisture flux, potential vorticity (PV) at isentropic level 315 K, Severe Weather Threat (SWEAT) index and daily averaged latent heat flux, etc. It is found that the early genesis, structure, RI, and movement of the TC were well captured by the model in advance (For details please see Singh et al., Atmospheric Research, 247, 105222, 2021).

Performance of water vapor retrieval from MODIS and ECMWF and their validation with ground-based GPS measurements over Varanasi: Water vapor is highly variable over tropical region and sensitive to weather condition, monsoon onset, greenhouse effect, and pollution level in Ganga River. In the present study variability in water vapor derived from Global Positioning System (GPS) over Varanasi (25º 20' N, 82º 59' E) during the period 2007-2010 has been studied. The GPS-derived water vapor (WV) has been compared with those retrieved from Moderate Resolution Imaging Spectroradiometer (MODIS) and ECMWF. The GPS-WV data concurrent to MODIS and ECMWF timing has been correlated to perform further analysis. Analysis shows an annual correlation R2 = 86%, RMSE = 9.5 mm and AE (MODIS-GPS) = 7.0 mm in MODIS retrieval and annual correlation R2 = 86%, RMSE = 6.1 mm and AE (ECMWF – GPS) = 2.4 mm in ECMWF reanalysis retrieval. Correlation of ECMWF and MODIS data sets with the GPS data sets are found to vary significantly with seasons (For more details please see Kumar et al., J. Earth System Sciences, 130, 41, 2021)

Overview of Solar eclipse of 21st June 2020 and its impact on solar irradiance, Surface Ozone and different meteorological parameters over eight cities of India: In the present study we have investigated the variation in solar radiance, surface ozone, temperature, relative humidity and wind velocity during the most recent and one of the most significant annular solar eclipses of 21st June 2020. Effects of solar eclipse have been analyzed first time at eight different cities of India located nearly perpendicular to the eclipse axis having an eclipse magnitude from 98.6 % to 77.2 %. Significant reductions in solar irradiance at different stations were found during the maximum phase of the solar eclipse due to the occultation of the Sun by the Moon. With the progression of the solar eclipse, surface ozone concentrations were also found to be decreasing and reached to its minimum value during the maximum phase of eclipse and then after the end of the eclipse started regaining their original behavior. In addition to the above, atmospheric cooling from the solar eclipse of 21st June, 2020 induced dynamical changes to the meteorological parameters (temperature, relative humidity and wind speed) with the change being most prominent during the maximum phase of the solar eclipse (For details please see Pratap et al., Advances in Space Research, 68, 4039-4049, 2021).

ASTROPHYSICS AND ASTROCHEMISTRY:

Theoretical study of infrared spectra of interstellar PAH molecules with N, NH, and NH2 incorporation: We have studied infrared spectra of nitrogen (N) – containing polycyclic aromatic hydrocarbon (PAH) molecules with the incorporation of N, NH, and NH2. It is found that neutral PAHs, when incorporated with NH2 and N (at inner positions), produce intense infrared bands at 6.2, 7.7, and 8.6 μm that have been normally attributed to ionized PAHs. The present results also suggest that strong bands at 6.2 and 11.2 μm can arise from the same charge state of some N-containing PAHs, arguing that there might be some N-abundant astronomical regions where the 6.2 to 11.2 μm band ratio is not a direct indicator of the PAHs' ionization. PAHs with NH2 and N inside the carbon structure show the UIR band features characteristic to star-forming regions as well as reflection nebulae (Class A), whereas PAHs with N at the periphery have similar spectra to the UIR bands seen in planetary nebulae and post-AGB stars (Class B). The absence of N-H stretch features near 2.9 μm constrains the contribution of NH and NH2 substituted PAHs that could be better tested with concentrated observations in this range (For details please see Vats et al., 2021, PASJ, in press)

Evidence for coronal temperature variation in Seyfert 2 ESO 103{035 using NuSTAR observations: Flux – resolved spectroscopic analysis of the active galactic nucleus (AGN) ESO 103 – 035 using NuSTAR observations is done. The spectra is fitted using a thermal Comptonization model with a relativistic reflection component to obtain estimates of the coronal temperature for two flux levels. The coronal temperature was found to increase from – 24 to 55 keV as the flux increased from 9.8 to 11.9 × 10-11 erg cm-2 s-1 in the 3 – 78 keV band. The results may be understood in a framework where AGN variability is either dominated by coronal heating variation leading to a correlated increase of temperature with flux or the opposite effect being seen when the variability is dominated by changes in the seed photon flux (For details please see Barua et al., Astrophys J., 921, 46, 2021).

Chemical complexity of phosphorous bearing species in various regions of the Interstellar medium: Phosphorus-related species are not known to be as omnipresent in space as hydrogen, carbon, nitrogen, oxygen, and sulfur-bearing species. Limited discovery of the P-bearing species imposes severe constraints in modeling the P-chemistry. Extensive chemical models have been carried out to understand the abundance of P-bearing species in diffuse clouds, photon-dominated or photodissociation regions (PDRs), and hot cores/ corinos. A strange correlation between the abundances of PO and PN and atomic nitrogen is noticed. Since N atoms are more abundant in diffuse clouds and PDRs than in the hot core/ corino region, PO/ PN is less than 1 in diffuse clouds, equal to 1 in PDRs, and greater than 1 in the late warm-up evolutionary stage of the hot core/corino regions. A radiative transfer model is used to investigate the transitions of some of the P-bearing species in diffuse cloud and hot core regions and estimate the line profiles. We find that the presence of CO2 can strongly influence the intensity of the stretching modes around ∼ 2400 cm−1 of PH3 (For details please see Sil et al., Astron. Journ., 162, 119, 2021).

14.5 Capacity Building in Space Science Research

Banaras Hindu University is actively organizing lectures and workshops in the field of Space physics, Atmospheric Physics and Astrophysics for the students of graduate, post graduate and research scholars. More than 10 lectures from different experts have been organized during 2020-21.

Various faculties of Banaras Hindu University are guiding M.Sc. students and Ph.D. students in the field of Space Physics, Atmospheric Physics and Astrophysics. More than 25 M.Sc. students have completed their dissertations/project during 2020-21 and more than 10 research students have been awarded Ph.D. degree during 2020-21 in the field of space, atmospheric and astrophysics.

14.6 Courses offered on Space Science and Technology

A course of 2 year M.Sc. Physics with Specialization in Space Physics have been introduced in the session 2009-11and currently running successfully from last 13 years.

Currently 13 students are studying in M.Sc. with specialization in Space Physics.

A “Space Physics Laboratory” for M.Sc. students with 12 experiments based on Space Physics has been setup.

14.7 National Collaborations in Space Science and Technology:

S.No	Area of Collaboration	Collaborating Institute
1	Space weather study of Ionosphere Magnetosphere	Indian Institute of Geomagnetism (IIG) Mumbai
2	Study of D-layer of Ionosphere using VLF waves	Dr. K.S.K. Geomagnetic Research Laboratory, Allahabad
3	Lightning and Global Electric Circuits	Indian Institute of Tropical Meteorology (IITM), Pune
4	VLF waves and Whistlers	Lucknow University, Lucknow
5	Aerosols, Cyclone and its climate effects	IITM, New Delhi Centre
6	Reaction mechanism and modeling of interstellar molecules	ICSP Kolkata
7	Analysis of ALMA data	NISER, Bhubaneshwar
8	UV astronomy and interstellar dust	IIA Bengaluru

14.8 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1	Balloon Remote Sensing of atmosphere	NASA Langley Research Center, USA
2	Aerosols, air pollutions and radiative forcing	Chapman University, USA
3	Ionospheric and Magnetospheric study using AWD	Etovas Univ., Budapest, Hungary
4	Ionospheric study using GNSS measurements	University of South Pacific, Suva, Fiji
5	Infrared Astronomy study	Department of Astronomy, University of Tokyo
6	Spectroscopy of PAHs and Diffuse interstellar bands	University of Nottingham, UK

14.9 Laboratories and Facilities Available for Space Instrumentation

The Atmospheric Research Laboratory, Detector Development Laboratory and Astrophysics and Astrochemistry Laboratory are three major laboratories in Department of Physics, BHU which are equipped by various space research facilities.

- **Atmospheric Research Laboratory is equipped with**: one multi-frequency GNSS receiver, two GPS receivers (One Trimble 7400 and one GSV4004B), two VLF receivers: one Automatic whistler detector (AWD); and one SoftPAL VLF receiver for ionospheric and magnetospheric studies. A solar telescope equipped with CCD camera and Solar spectrometer is installed in the laboratory to study the sunspots and solar flares. For study of atmospheric aerosol and radiative forcing in Indo-Gangatic basin, a pair of MICROTOPS-II: Sunphotometer and Ozonometer, and an Aerosol Spectrometer has been installed at BHU funded by ISRO. Recently, three High Volume Air samplers: PM10, PM2.5 and PM1.0, Aethalometer (for black carbon measurements) and NET Radiometer were also purchased and installed in the Department to study the physical, optical and chemical characteristics of aerosols.
- **Detector Development Laboratory is equipped with:** a high vacuum chamber with a base pressure of 10^{-7} Torr for production of high-quality photo-emissive materials. A VUV monochromator for photo-emission studies in the wavelength range of 150-200 nm range. R & D on Cesium Iodide (CsI) and Potasium Bromide (KBr) photocathode which is known to be the best photocathode in UV region (40% QE at 150 nm) and its

relatively good stability in air for short time. The group has been involved in developing a gaseous-based photon detector consisting of a photocathode and micro-pattern detector such as GEM (Gaseous Electron Multiplier) for High Energy Physics research and extending this technology for space science research. In this program, we have been studying a variety of detector simulation tools in order to optimize the various detector performance parameters etc.

Astrophysics and astrochemistry Laboratory is equipped with: Workstations for computational Spectroscopy (HP Z240, etc.), Software like GAUSSIAN, IDL, CASA, IRAF, PyRAF, etc. Making use of the archival data of telescopes like Spitzer, ISO, Akari, Astrosat, Chandra, etc.

Currently more than six major research projects based on Space Physics, Atmospheric Physics and Astrophysics are running in our department funded by ISRO, SERB, and DST.

LIST OF PUBLICATIONS

I In Referred Journals:

1. V. Singh, R. T. Kondur, A. K.Srivastava, I. M. Momin, S. Kumar, A. K. Singh, S. Tiwari, Predicting the rapid intensification and dynamics of pre-monsoon extremely severe cyclonic storm ‘Fani’ (2019) over the Bay of Bengal in a 12-km global model, Atmospheric Research, 247, 1 January 2021, 105222. https://doi.org/ 10.1016/j. atmosres. 2020.105222 (IF: 5.369).

2. G. Tripathi, S. B. Singh, S. Kumar, A K. Singh, R. Singh and A. K. Singh,Effect of 21 June 2020 solar eclipse on the ionosphere using VLF and GPS observations and modeling, Advances in Space Research, 69, 254-264, 2021 https://doi.org/10.1016/j. asr.2021.11.007 (IF: 2.152)

3. V. Pratap, A. Kumar, A. K. Singh, Overview of solar eclipse of 21st June 2020 and its impact on solar irradiance, surface ozone and different meteorological parameters over eight cities of India, Advances in Space Research, 68, 4039-4049, 2021 https://doi. org/10.1016/j.asr. 2021.08.014 (IF: 2.152).

4. Abha Singh, V. S. Rathore, S. Kumar, S. S. Rao, S. K. Singh, and A. K. Singh, Effect of intense geomagnetic storms on low latitude TEC during the ascending phase of solar cycle 24, J. of Astrophysics and Astronomy, 42, 99, 2021. https://doi.org/10.1007/ s12036-021-09774-8 (IF: 1.273).

5. P. R. Singh, A. I. Saad Farid, A. K. Singh, T. K. Pant, Ayman A. Aly, Predicting the Maximum Sunspot Number and the Associated Geomagnetic Activity Indices aa and Ap for the Solar Cycle 25, Astrophysics Space Sciences, 366, 48, 2021 https://doi.org/ 10.1007/s10509-021-03953-3 (IF: 1.430).

6. A. Kumar, S. Kumar, V. Pratap, and A. K. Singh, Performance of water vapor retrieval from MODIS and ECMWF and their validation with ground-based GPS measurements over Varanasi, J. Earth System Sciences, 130, 41, 2021 https://doi.org/10.1007/s12040-020-01529-3 (IF: 1.423).

7. Monti Chakraborty, A.K. Singh, S. S. Rao, Solar flares and geomagnetic storms of September 2017: Their impacts on the TEC over 750 E longitude sector, Advances in Space Research, 68 (4), 1825-1835, 2021 https://doi.org/10.1016/ j.asr.2021.04.012 (IF: 2.152).

8. S. Kumar, G. Tripathi, P. Kumar, Ashutosh K. Singh and A. K. Singh, Ionospheric perturbations observed due to Indonesian Earthquake (Mw = 7.4) using GPS and VLF measurements at multi-stations, Acta Geodaetica et Geophysica, 2021 DOI: 10.1007/ s40328-021-00345-5 (IF: 0.909).

9. P. Kumar, V. Pratap, A. Kumar, A. Choudhary, R. Prasad, A. Shukla, R. P. Singh and A. K. Singh, Assessment of atmospheric aerosols over Varanasi: Physical, Optical and Chemical properties and meteorological implications, J. Atmospheric-Solar & Terrestrial Physics, 209, 105424, 2020 https://doi.org/10.1016/ j.jastp.2020.105424 (IF: 1.735).

10. Barua et al., Evidence for coronal temperature variation in Seyfert 2 ESO 103{035 using NuSTAR observations, Astrophys J., 921, 46, 2021.

11. Sil et al., Chemical complexity of phosphorous bearing species in various regions of the Interstellar medium, Astron. Journ., 162, 119, 2021.

CHAPTER-15

BANGALORE UNIVERSITY

Atmospheric and Space Science Research Laboratory
Department of Physics, Bengaluru

15.1 About the University

In the domains of atmospheric and space science, notably planetary physics, the Department of Physics at Bangalore University in Bengaluru teaches and does research. The Department has been able to increase academic and research activity in atmospheric and space science with the support of ISRO's Space Science Promotion Scheme (ISRO-SSPS). At present, a course on Atmospheric and Space Science is offered to students doing post-graduate studies in Physics through a few electives. Atmospheric radioactivity, aerosols, electricity in the atmosphere, and connection between the troposphere, stratosphere, and mesosphere are among the key scientific interests of the Department of Physics' ASSR Lab. Researching on remote sensing, monsoon and its fluctuation, boundary layer, and atmospheric flux exchange. The Sun-Earth Relationship, variability in TEC, Lightning Activities, Martian Atmosphere Research, Moon Dynamics, and Theoretical Simulations are some of the major topics involved in frontier areas of research.

15.2 Keywords

Mars, MOM, MENCA, HZE particles, solar radiation, atmospheric constituents, solar variability

15.3 Major Research Domain

- **Atmosphere of Mars:** Mars Orbiter Mission had Mars Exospheric Neutral Composition Analyser to study the Martian atmosphere. Profiles have total and partial pressures <500 km and results were validated with Viking missions. Pressure drops by more than 2 orders of magnitude between 260-530 km and the decrease of pressure are slower with altitude compared to Viking results <200 km. In exosphere > 300 km, CO_2, N_2, O and O_2 are the dominant constituents. It is not possible to separate N_2 and CO for the same amu, the effective value of N_2 would be a fraction less as CO is a photodissociation product of CO_2.
- **Influence of solar radiation on the Martian atmosphere**: At all altitudes, total pressure decreases gradually, and decline is highly correlated with smoothed daily mean SSN decrease. Changes in solar UV/X-ray fluxes arriving at Mars due to differences in solar activity have a considerable modulating influence on exospheric pressures, and standard errors at a 95% confidence interval are found to be greater than standard errors. Because Mars lacks a magnetic field, charged particles would directly interact with neutral composition and cause photodissociation or photoionization in addition to UV/X-rays. Because of the increased temperatures, absorption of particle energy would result in changed concentrations of atmospheric species in certain height ranges.

- **Significant day-to-day changes in Argon density patterns:** In 19760, Viking landing missions took in-situ measurements of upper air density and composition, and since September 2014, MOM has been taking similar measurements. Based on near-simultaneous observations by the two orbiters, the data sets confirm significant day-to-day changes in Argon density patterns. Also made an effort to investigate how solar wind plasma velocities and fluxes affect atmospheric components. The density profiles of the constituents have been altered as a result of electron impact dissociation/ionisation. Modelling work involving the composition of the Martian exosphere and solar EUV changes owing to the Schwabe cycle should benefit significantly from these discoveries.
- **HZE particles affect space radiation and are a hazard for future Mars missions:** Manned Mars missions planned in the near future, with very low solar activity and hence higher than permissible radiation dosages due mostly to Galactic Cosmic Rays, would require the development of unique techniques and technological development to ensure the astronauts' health. HZE particle fluxes pose a serious threat to the personnel as well as the spacecraft's crucial electronic components. Due to the persisting low sunspot, data on the HZE species obtained from the ACE spacecraft shows a clear enhancement of particle fluxes during solar cycle 23 and solar cycle 24, i.e., between SSN maxima from 2002 to 2014.
- **X-ray flares and CMEs during very quiet solar activity conditions:** Solar flares SFs are massive explosions of energy that occur on the Sun's surface. Coronal Mass Ejections (CMEs) are mass ejections of electrons and ions from the solar atmosphere that usually occur after flares with bursts of X-ray emission. There is evidence that the solar magnetic field can reconnection and release energy, creating SFs and CMEs via accelerating solar plasma. The findings suggest that some changes to the existing mechanisms for generating SFs and CMEs are required in order to construct more realistic forecast models for space weather conditions.
- **Study of lightning activity:** The earth's electrical essence manifests itself through lightning, thunderstorms, and electrical conductivity. Significant lightning activity, as well as diurnal and seasonal fluctuations, are revealed by continuous monitoring. The afternoon and nighttime are the most likely times for lightning to strike. A recent rise in activity is supported by statistical variability in lightning strike density over Bengaluru. Statistics from TRMM/LIS and distribution of lightning density over Bengaluru are similar.
- **Tropopause height from upper-air data using RS-GPS:** Temperature, relative humidity, and wind are all essential meteorological elements in NWP for practical weather forecasting. Bangalore University used an indigenous GPS radiosonde for upper-air observations in collaboration with SDSC-SHAR. SDSC used this real-time data to run the NWP model to investigate air stability before each satellite launch. Over the Indian region, there exists deviation in ionospheric TEC, F-region peak ionisation, and ionospheric slab thickness. During geomagnetically quiet and undisturbed solar conditions, the findings were combined to offer comparative slab thickness of total and bottom-side ionospheric regions. Daytime thermosphere observations correspond to neutral gas scale heights of 50-80 km.

- **Space weather and ionospheric variability over low latitudes:** Ground-based observation data from a network of dual-frequency GPS receivers placed over the Indian region as part of the GAGAN project was utilized to construct grid-based Vertical Total Electron Content maps using a real-time model. This real-time model could be used to research ionosphere fluctuations at high temporal and spatial resolutions, in addition to its navigational applications. VTEC's day-to-day and latitudinal fluctuation aids in the comprehension of the system's fundamental dynamics. This is crucial in the field of geophysical phenomena and space weather.

15.4 Major Scientific Applications / Results:

The Martian exospheric studies are very limited and we proposed to utilize the observational data from ISRO's Mars Orbiter Mission (MOM) carrying a number of payloads for detailed scientific investigations through a research project from RESPOND and obtained following scientific results:

- Processed and analyzed data on the composition of the Martian neutral atmosphere based on observation from MENCA/MOM
- Observed temporal and spatial variations of atmospheric constituents of Mars
- Found the influence of Solar flares, SPEs and CMEs on atmospheric composition
- The thermosphere/exosphere models such as Direct Simulation Monte Carlo (DSMC), Mars Climate Database (MCD) and Mars Thermosphere Global Circulation Model (MT-GCM) are providing results with real-time data. MENCA-MOM data and probes like MAVEN are to be used to validate these models

15.5 Courses offered on Space Science and Technology

The Department of Physics is offering elective papers on a) Atmospheric physics, b) Space Physics, c) Atmospheric and Space Physics, d) Planetary Physics along with laboratory courses in each semester for Master Degree students in Physics since 2009 and continuing.

National Collaborations in Space S&T

Sl. No.	Area of Collaboration	Collaborating Institute
1.	Space Science	SPL, VSSC, Thiruvananthapuram
2.	Atmospheric Physics	NARL, Gadanki
3.	Space Science	SSPO, ISRO Hqs, Bengaluru
4.	Planetary Science	PRL, Ahmedabad
5.	Planetary Science	ISSDC, ISRO, Bengaluru

CHAPTER-16

DEPARTMENT OF REMOTE SENSING BIRLA INSTITUTE OF TECHNOLOGY, MESRA

Ranchi, Jharkhand

16.1 About the Department

Established in 1997 with the vision of providing best human-resources in Geospatial domain, department is steering itself to be a centre of excellence through education, research and technological services.

Vision

Be a centre of excellence in the field of Geospatial Technology education and research to match the needs of ever-increasing requirement of human resources in these fields and to cater to the larger interest of the Society and Nation.

Mission

- Impart quality education and equip the students with strong foundation that could make them capable of handling challenges of the ever-advancing geo-spatial technologies.
- Maintain state-of-the-art in research and outreach facilities in phase with the premier institutions for sustained improvement in the quality of education and research.

16.2 Keywords

Remote Sensing, Aerosol, Particulate Matter, Air Quality, GIS, Earth observatory, Vegetation dynamics, Disaster Management, Glacier Dynamics, Data Mining

16.3 Major Research Domains

- Quantifying Space-Time Dynamics of Vegetation
- Multi-Resolution Wavelet Analysis based Data Mining
- High Spatial Soil Moisture Estimation
- Multi-Sensor Integrated Crop Mapping at 10m
- Climate Change, Snow Cover, Glacier Dynamics
- Natural Hazards, Disaster Management
- Natural Resources and Basin Hydrology
- Planetary Remote Sensing, Satellite Geodesy, Geo-sciences
- Remote Sensing of Aerosols: -
- Lightning study through remote sensing (TRMM, ISS) and effect of air pollution by chemical transport model: -

16.4 Major Scientific Applications / Results

- **Photometric Correction of Images of Visible and Near-Infrared Bands from Chandrayaan-1 Hyper-Spectral Imager (HySI)**

Photometric correction is a necessary step in planetary image pre-processing since the images of planetary surfaces are acquired by orbiting spacecraft at various observational geometries. In this study, visible (748 nm) and near-infrared (948 nm) bands of Hyper Spectral Imager (HySI) onboard Chandrayaan-1 have been used to derive a preliminary photometric correction for lunar data. The purpose of the proposed photometric correction for HySI is to convert observations taken at solar incidence (i), sensor emission (e), and the solar phase angles (α) to a fixed geometry by applying $i = \alpha = 30°$ and $e = 0°$ to each image. The Lommel–Seeliger function was used to model the lunar limb darkening effect, while topography data from the merged Digital Elevation Model of Lunar Reconnaissance Orbiter—Lunar Orbiter Laser Altimeter (LRO-LOLA) and SELENE Terrain Camera (TC) was used to correct local topographic effects. Data from Moon Mineralogy Mapper (M3), SELENE Multiband Imager (MI) and Clementine Ultraviolet and Visible Camera (UV/VIS) were also used to compare radiance, reflectance and phase functions derived from HySI. Our analysis reveals that HySI is darker than M3 primarily due to low surface radiance conditions observed by HySI. The derived phase functions for the two HySI bands indicate a good correlation between the derived reflectance and phase angle as well as with the phase functions derived for the empirically corrected M3 data.

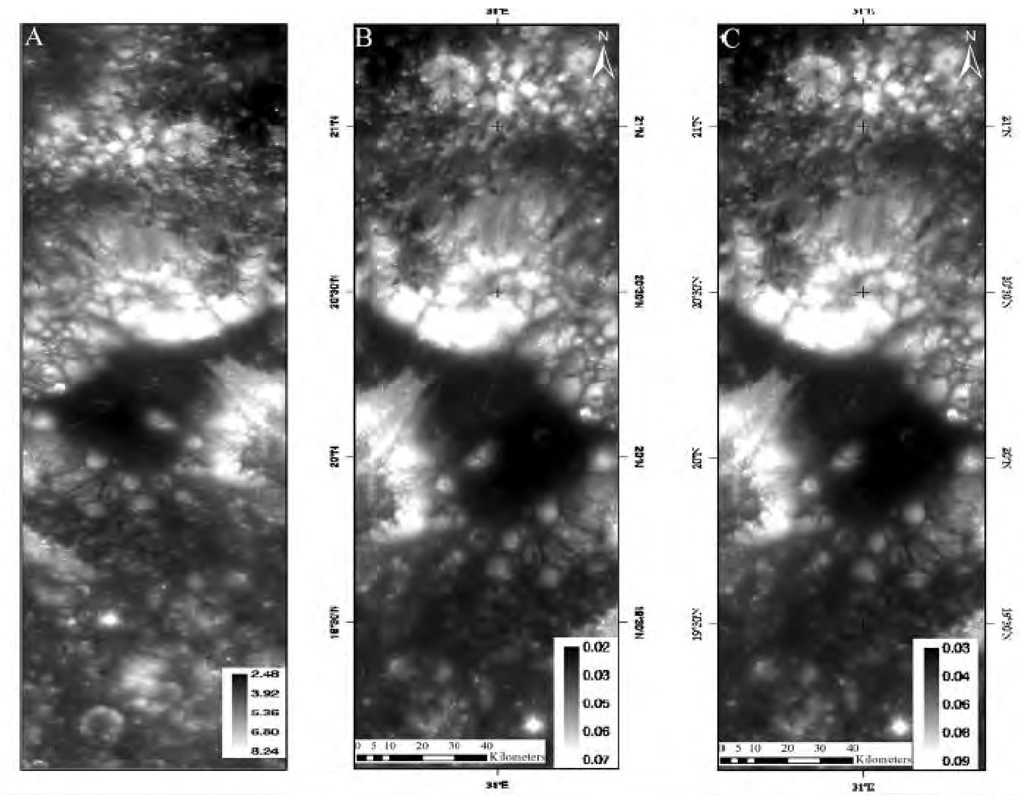

Figure 1: A Comparison between the unprocessed HySI radiance image (750 nm) on the left for the Apollo—17 landing site, B the georeferenced apparent reflectance HySI image (750 nm) in the centre and, C the spatially transformed photometrically corrected HySI reflectance image (750 nm) on the right

16.5 Capacity Building in Space Science Research

Department of Remote Sensing run three postgraduate programmes (M.Tech, M.Sc and PhD) and also organizes training workshops, seminars, symposia, conferences time to time beyond its regular curriculum. Details of these programmes are as follows:

- M.Tech (Remote Sensing)
- M.Sc.(Geoinformaticss)
- Doctoral Programmes:

Ph.D. in all branches of Remote Sensing, GIS, Earth Sciences with following research areas:

National Symposium/FDP organized by the department

16.6 Courses offered on Space Science and Technology

- Courses offered under M.Tech (Remote Sensing) Programme
- M.Tech Programme was started in the year 1997 with an intake of 15 and its current intake is 18.
- Courses offered under M.Sc (Geoinformatics) Programme

16.7 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1	Vegetation Dynamics	Regional Remote Sensing Center (RRSC, Kolkata, NRSC)
2.	Wet Land Mapping	Space Application Center
3.	Bio-Physical Process Modelling of Natural Vegetation	Space Application Center
4.	Vegetation Characterisation	Center for Ocean, Rivers, Atmosphere and Land Sciences (CORAL), IIT, Kharagput
5	Microwave Remote Sensing applications	CSRE, IIT-Bombay
6	Board of Studies (BoS)	IIT-Kharagpur
7	Board of Studies (BoS)	IIT-ISM
8	Board of Studies (BoS)	JNU, New Delhi
9	Board of Studies (BoS)	CSRE, IIT-Bombay
10	PMGSY Project	NRSC
11	Aerosol Studies and effect of gaseous (e,g :- Ozone) pollution by lightning	Institute of Environment and Sustainable Development

12	Comparison of AOD with Newly launch Indian satellite with other existing satellite like MODIS, OMI, MISR etc	SAC Ahmedabad - ISRO
13	Utilisation of SAR data under NISAR AO project	SAC Ahmedabad
14	Hyperspectral Remote sensing based application	IIST, Trivendrum

16.8 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1.	Vegetation and Climate Change Modelling	University of Lancaster, Lancaster, UK
2.	Phenology and Climate Change Modelling	University of Southampton
3	Project work - M.Tech (Remote Sensing)	Institute of Geography, Remote Sensing Group Bern, University of Bern, Switzerland
4	A global network to understand the source and sink of aerosols.	Goddard Space Flight Center (GSFC), National Aeronautics and Space Administration (NASA), USA
5	Development of Algorithm for snow/fern density estimation	Institute of Geography, Russian Academy of Sciences, Moscow 119017, Russia

16.9 Laboratories and Facilities Available for Space Instrumentation

Department has state-of-the-art laboratories equipped with advanced equipment and software essential in the field of Remote Sensing and Geoinformatics to cater the needs of postgraduate students and Research Scholars. Department has the following laboratories:

- Geographic Information System Laboratory
- Digital Image Processing Laboratory
- Digital Photogrammetry Laboratory
- GPS and Satellite Navigation Laboratory
- Cartography and Image Interpretation Laboratory
- Analog Photogrammetry Laboratory
- Map Production and Reprography Laboratory
- RS Research & Project Laboratory
- Equipments and softwares available in the department

Apart from above mentioned equipments and software, our department has specific equipment to measure aerosol concentrator in environment which are as follows:

1. Microtops – It is a portable instrument having 5 channels for measuring aerosol optical thickness, direct solar irradiance, and water vapor column easily, accurately and dependably.
2. GRIMM – Its is a spectrometer used for measuring the concentration & mass of aerosol and particulate matter (PM) i.e. (0.25 to 32 μm size) in real time.

CHAPTER-17

CENTRAL UNIVERSITY OF JAMMU SATISH DHAWAN CENTRE FOR SPACE SCIENCES

17.1 About the University

Satish Dhawan Centre for Space Sciences (SDCSS) is an advance research centre sponsored by ISRO. The Centre will be inaugurated and dedicated to nation March 12, 2022 by Dr. Jitendra Singh, MOS, Department of Space and Chairman ISRO Sh. S. Somanath. The Centre is named after Satish Dhawan, the father of experimental fluid dynamics research in India and former Chairman of ISRO (1971-84). The son of soil, Dr. Dhawan, was born in Srinagar (J&K) and played leading the successful and indigenous development of Indian space programme.

Vision Statement

To be the leading Research Centre in space sciences providing value-driven, real-world solutions, which will enable Central University of Jammu to acquire, manage, and execute educationally relevant and economically sound research programs. The Centre moves towards the achievement of four strategic goals in collaboration with ISRO and its other institutions:

- promoting the development of infrastructures for the space economy;
- promoting the development of services and applications for the space economy;
- accelerating and supporting scientific and cultural progress in a context of international collaboration (science diplomacy);
- increasing the country's international prestige (space diplomacy).

Significance

SDCSS will help in tapping the potential of Space Applications for region of J&K and provide opportunity to youth of the region to contribute to the field of space science as well as to the nation. It will also take care of the emerging Geospatial and Space Technology requirements for development of the region as its economy and habitations are affected by vegetation cover, forest area, snow, landslides, avalanches, ground water, cloud cover, atmospheric conditions etc.

17.2 Keywords

- High temperature FIR and thermometry
- Sensor and detector
- Glaciology, Seismic hazards & Lunar Geology
- GIS and Remote sensing applications in atmospheric sciences

17.3 Major Research Domains

- The Centre is engaged in high temperature non-contact mode sensing through nanophosphors through FIR and thermometry.
- The Centre is working on cost effective and easy fabrication of NIR Optoelectronic devices (Photodetectors, LEDs) by employing the thin films of various colloidal quantum dots (CQDs).
- The Centre is tapping the GIS application to evaluate the status and forecasting of air pollutants, particulate matter, identifying temperature inversions and its correlation with atmospheric stability, mesoscale modelling of weather events using meso-scale atmospheric models, improving the forecast using 3D-var data assimilation techniques
- The Centre is working on characterization of carbonaceous aerosols, organic species, metals and water-soluble ionic species.
- The Centre is actively engaged in development of a protocol to analyze non-polar organic compounds using Thermal Desorption-Gas Chromatography Mass Spectrometry (TD-GCMS).
- The Centre is playing a key role to explore the multifarious implications of bioaerosols on climate and ecosystem health in the nearby region of Jammu and Kashmir.
- The Centre is setting up high end materials characterization Lab, avionic, astronomy lab, remote sensing and GIS Lab.

17.4 Major Scientific Applications:

- The Centre is engaged to examine the temperature dependent UC luminescence properties and thermal sensitivity of the phosphor, temperature dependent studies of the material had been done. The emission spectra of the Na3Y(PO4)2:Er3+, Yb3+ phosphor under 980 excitation at different temperatures (313 K – 673 K), shown in Figure 1.

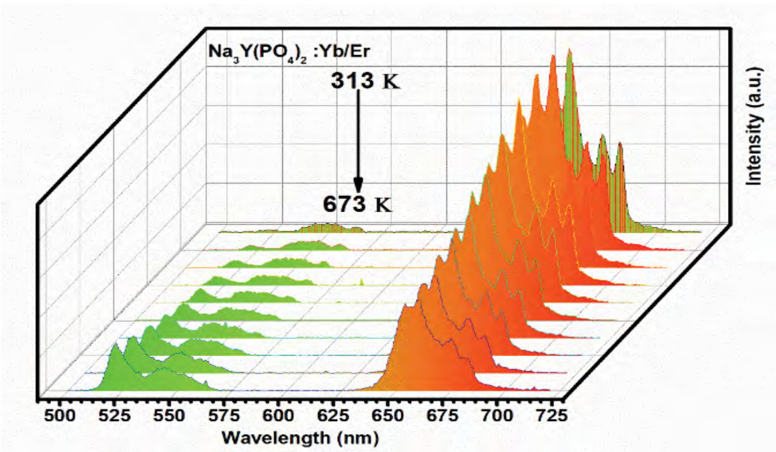

Figure 1: The emission spectra of the Na3Y(PO4)2:Er3+, Yb3+ phosphor under 980 excitation at different temperatures.

Figure 2(a) and 2(b) plots show the dependences of calculated absolute and relative sensitivity on absolute temperature for thermally coupled levels.

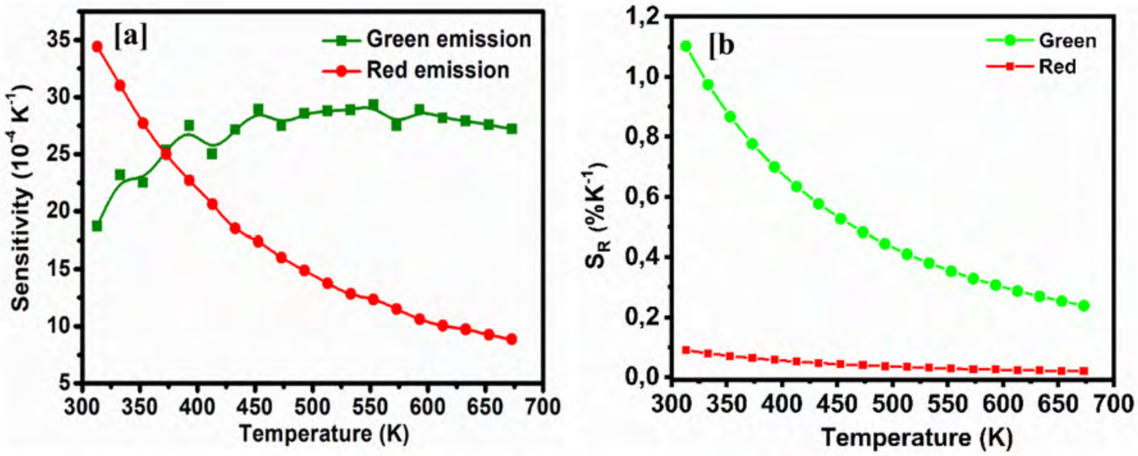

Figure 2: (a) Absolute Sensitivity (b) relative sensitivity of thermally coupled levels as a function of the temperature from 300 K to 700 K.

It can be realized that at low temperature the absolute sensitivity for the green scheme is weak as compared to the red scheme and keeps growing with an increase in temperature and reaches its highest value 0.0027 K-1 at 670 K in our experimental temperature range. The red scheme indicates a high SR value at low temperature with its highest value 0.0034 K-1 at 320 K in opposition to the green and afterward, it starts declining with raise in temperature.

- The remote sensing and GIS lab at the Centre is engaged to evaluate the status and forecasting of air pollutants, particulate matter, identifying temperature inversions and its correlation with atmospheric stability, mesoscale modelling of weather events using meso-scale atmospheric models using 3D-var data assimilation techniques. Assessing land surface parameter using HRLDAS.
- The Centre is involved in Multispectral satellite imageries analysis of the Himalayan region which reflected the fast retreat of most of the glaciers. The changing climate and glacier status has indicated an alarming rise in the number and sizes of the glacial lakes that may be potentially disastrous when converts into the glacial lake outburst flood (GLOF). Figure 3 shows the Moraine dammed lakes as delineated in Satluj basin.

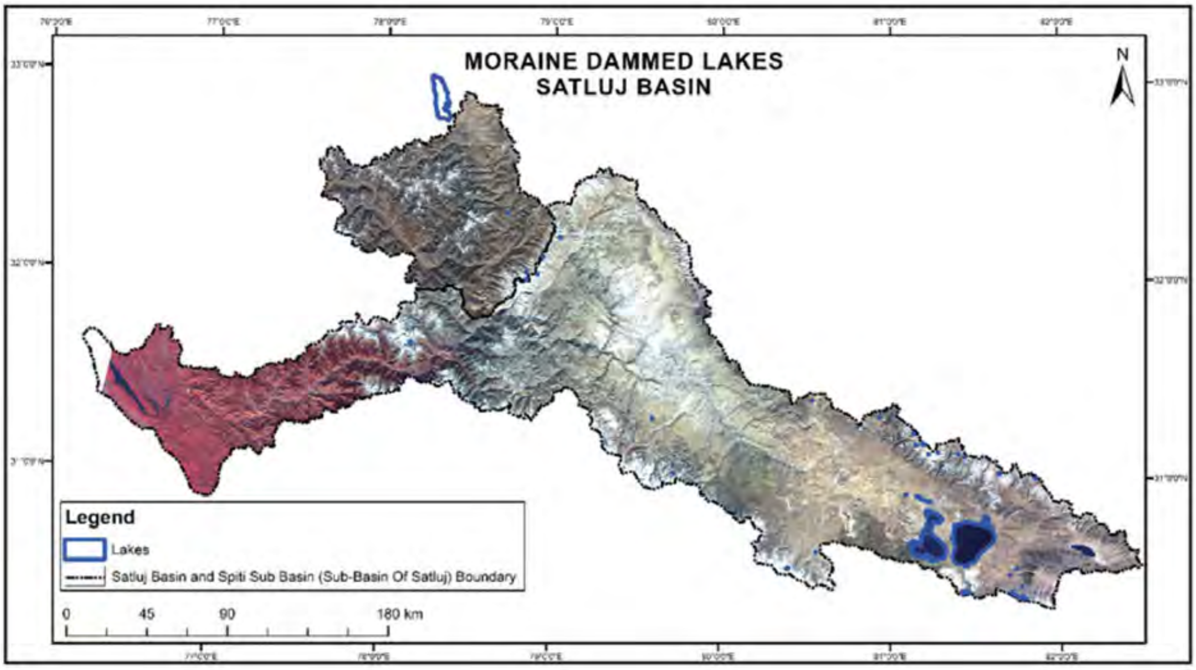

Figure 3: Moraine dammed lakes as delineated in Satluj basin (Source IRS, LISS-3).

- This study focusses on the glacial lakes mapping at the different time frame in the basins of Chenab, Ravi, Satluj and Beas of Himachal Himalaya using LISS III. The remotely sensed imageries on the GIS platform helped in preparing the moraine dammed glacial lake inventory and assessing the potentiality of becoming the GLOF in these basins. This is of prime importance for preparedness against disasters due to GLOFs. Glaciers in the Himalayas are retreating at an average rate of 15m per year, consistent with the rapid warming recorded at Himalayan climate stations since the 1970s.
- Study also reveals that there are 54,252 glaciers in the HKH region, with a total size of 60,054 sq km and predicted ice stores of 6,127 km3. Only 1.4 percent of the HKH region is glaciated. However, there is a large disparity between river basins – the biggest total glacier areas are found, by size, in the Indus, Brahmaputra, and Ganges basins respectively . Figure 4 shows the distributions of glaciers along the Himalaya.

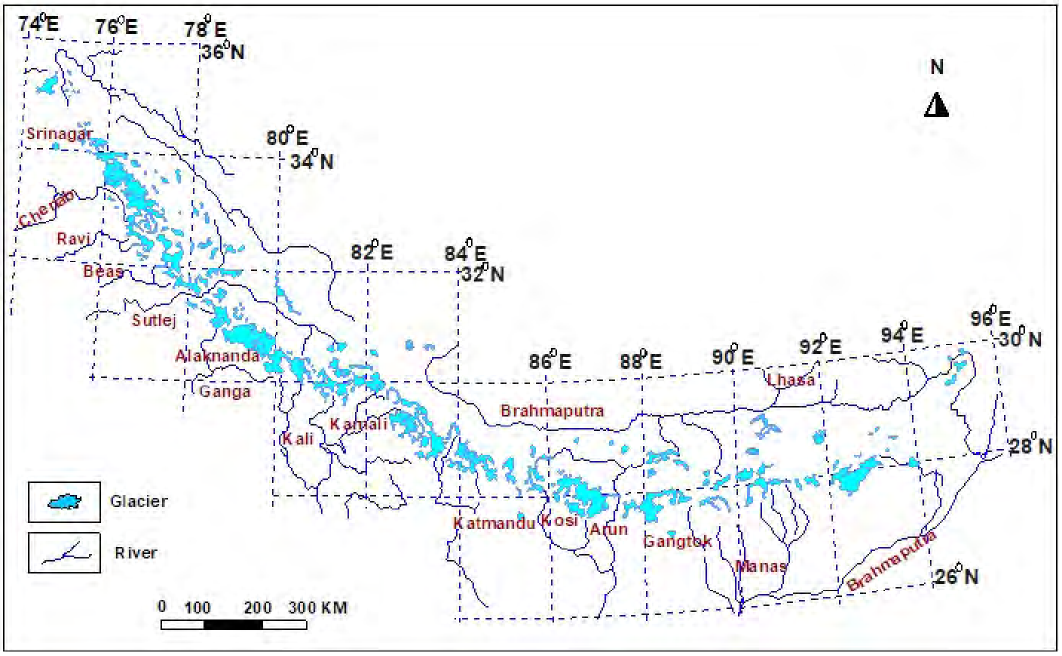

Figure 4 Distribution of glaciers along the Himalaya

- Surface Ice Velocity of the Brahma glacier has been estimated using optical remote sensing data (Landsat panchromatic Band8; 15m). COSI-Corr tools which is open-source software and a ENVI plug-in was used for this study and it was observed that the surface velocity has been significantly decreased between 2000-2020. However, the reason behind this change need further scientific investigation.
- The Centre is also working easy fabrication of NIR photodetector which can be demonstrated by employing the thin films of Cd1−xMgxS colloidal quantum dots (CQDs). The influence of doping on the transport behaviour of Cd1−xMgxS CQD films was investigated by device performance under laser light illumination at various wavelengths ranging from 405 nm to 782 nm.
- The Centre is also working on the gas sensing applicational prospects of composite mixture of rGO and Ag-nanopowders were studied via samples with varying compositions.

17.5 Capacity Building in Space Science Research

- The SDCSS is engaged in capacity building in space science research. The first National Conference “Imagining the future of Space Science and its strategic importance” was organized during October 11-12, 2018 during the foundational laying Ceremony of the Centre by Dr. Jitendra Singh, MOS, Department of Space and then Chairman Dr. K Sivan.
- The Centre is organizing International Conference on “Frontiers of Space Technology and Applications for Humanity (FSTAH-2022) on 12th-13th March, 2022 in collaboration with Indian Institute of Space Science and Technology, Thiruvananthapuram.

- The Centre is also starting B.Tech. Electronics and Communication (Avionics) from the academic session 2022-23.
- Presently, the UG and PG students from Department of Physics & Astronomical Sciences and Environment Sciences are doing their projects on remote sensing and space science and technology.
- The Centre in collaboration allied departments of University will also start offering Ph.D. in any area related to space science and technology in near future.

17.6 Courses offered on Space Science and Technology

- Central University of Jammu has a prescribed curriculum on subject(s) related to space science and technology.
- Department of Physics & Astronomical Sciences and Environment Sciences also offering courses on Astrophysics, atmospheric sciences, remote sensing and GIS.
- In B.Tech E.C.E. (avionics), the intake of the student will be 60.

17.7 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1	Bioaerosol diversity and Implications on Climate.	IIT Madras, Chennai
2	Aerosol chemistry and Isotopic analysis	Physical Research Laboratory, Ahmedabad
3	Material Sciences	Inter-University Accelerator Centre, New Delhi

17.8 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1	Materials Science	University of the Free State, South Africa
2	Bioaerosols and Ice Nucleating Particles (INPs) in the Himalayan Region	North Carolina State University, Raleigh, USA

17.9 Laboratories and Facilities Available for Space Instrumentation:

Remote sensing and GIS Laboratory: This lab is engaged in exploring the Geographic Information System coupled with remote sensing data application. The aim of this lab is to promote space applications in exploration and other mining activities for “Satellite Based

Geological Mapping and Multidisciplinary Exploration of Iron, Diamond and other mineral deposits”. It is a major step forward towards “Digital India” as Space Technology provides real – time data for generation of digital maps. This Lab is having educational licenses “ERDAS” and “ARC-GIS” software along with high end “Workstations”. It is an important area and opens up new opportunities for sustainable use of natural resources; particularly land, water and bio-diversity. Geospatial data is used to understand the land-use pattern and what changes are needed and how do you manage serious droughts and floods.

Astronomy and Astrophysics Lab: The aim of this lab is complementary theoretical calculations which are the foundations of astronomy and astrophysics. The impact of laboratory astrophysics will range from the scientific conception stage for ground-based, airborne, and space-based observatories, all the way through to the scientific return of projects and missions. ISRO data will be used to understand the under-lying physical processes and the measurements of critical physical parameters that allow us to address fundamental questions in astronomy and astrophysics.

Materials Sciences Lab for space applications: Based on the faculty expertise at Central University of Jammu in the field of radiation Dosimetry, advanced materials, nanotechnology, sensors, energy and Environmental Science, computational, laser and device Physics, the material research lab for space application has been setup at CU Jammu. Special focus of this lab will be to synthesize and design new sensors and materials for space applications

High End Material Characterization Lab: Details of equipments at the Centre is given below:

S. No.	Name of the equipment	Qty	Applications
Astronomical Laboratory			
1.	Binoculars (with tripod stands)	5	for casual sky-watching during day and night.
2.	Automated Imaging Telescope	1	To study basic parameters of stars, such as mass, radius, and luminosity come primarily from observations of binary and multiple stars
3.	Matlab (software) (Educational Licence)	1	For computation work
Remote sensing Lab			
4.	High Configuration PCs	10	For computation work

S. No.	Name of the equipment	Qty	Applications
5.	Portable GPS	2	To determine the capability of GPS to collect high quality data on the location of activities in research on the relationship between physical activity and the environment.
6.	Spectroradiometer (Handheld)	2	To measure the spectral output (energy flux density, photon flux density, or illuminance) of different radiation sources and reflectance and transmittance measurements of natural and synthetic surfaces and materials
7.	ArcGIS Software (Education server License)	10	For computation work and data acquisition
8.	ERDAS (Education server license)	10	For computation work and data acquisition
Atmospheric Sciences Lab			
9.	Automated Weather Station	1	For all current weather monitoring like Sunshine and UV intensity levels; Additional temperature and humidity levels; Parameters of interest in agriculture such as soil moisture and leaf wetness
Structural Study Lab			
10.	X-ray Diffractometer	1	To identify the structure of unknown crystalline materials (e.g. minerals, inorganic compounds). Determination of unknown solids is critical to studies in geology, environmental science, material science, engineering and biology.
Spectroscopy Lab			
11.	UV-VIS-IR	1	For material's reflection or transmission by measuring light intensity/absorbency at a specific wavelength For quantitative analysis method in fields such as chemistry, materials science, semi conductors
12.	FTIR	1	for Molecular study
13.	Atomic absorption Spectrometer (AAS)	1	To analysis elemental composition in wide variety of sample matrices including biota, soils, and water.
14.	Low temperature PL spectroscopy	1	To study the excitation and emission spectra by process of exciton (electron)-phonon interaction
Materials Research Lab for Space Applications (to be procured)			

S. No.	Name of the equipment	Qty	Applications
16.	Zetasizer	1	To measure the dimensions and stability of nanoparticles smaller than 5 nm in diameter.
17.	Ultracentrifuge	1	For synthesis of materials
18.	Ultrasonicator	1	For synthesis of materials
19.	Fuming hood	1	For synthesis of materials
20.	Laminar Flow	1	For synthesis of materials
21.	Electroluminescence set- up/ I-V measurement set- up	1	Electroluminescence finds a number of applications, such as: LEDs, Backlights Liquid crystal displays, Night lamps. Electroluminescent lighting
22.	Spin Coating Unit	1	For synthesis of materials
23.	Two zone Furnace for Vacuum Annealing	1	For synthesis of materials

CHAPTER-18

COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY

Cochin

18.1 About the University

Cochin University of Science and Technology (CUSAT) is a world-ranking university with the specific purpose of developing higher education, emphasizing post-graduate studies and research in applied science, technology, industry, humanities, and commerce.

18.2 Keywords

Laser Induced Breakdown Spectroscopy (LIBS), Remote Sensing, Radar Signal Processing, Radar Technology.

18.3 Major Research Domains

- **Applied Optics and Physics**: Main focus is on Laser-Induced Breakdown Spectroscopy (LIBS), Laser Surface Texturing (LST), and Laser Produced Plasma (LPP) characterization. In collaboration with Raman Research Institute, Bengaluru, investigates the Industrial application of LIBS. Collaboration with the Laboratory for Electro-Optics Systems (LEOS), a wing of the Indian Space Research Organization (ISRO), explores the space applications of LIBS. Fabrication of 'Black Silicon' is an ongoing activity.
- **Atmospheric Modeling and Weather Forecasting (AMF)**: Atmospheric Modeling and Weather Prediction group is focusing on incorporating our improved understanding of relevant atmospheric process in numerical models and assimilating the non-conventional observations like radars and satellites to improve the initial conditions. In order to address the forecast uncertainty arising from the inability of the physical parameterization and from inaccurate estimation of the initial state, the group is focusing on developing optimum configuration of physical and initial condition ensembles. The group is developing various model output statistics, bias correction and calibration techniques to reduce systematic biases and random errors in the model for real time operational forecast.
- **Atmospheric Process Studies (APS)**: The APS Group focusses on basic research related to the tropical atmospheric processes leading to variations in the weather and climate. The markedly non-uniform distribution of land and ocean areas together with high insolation may be expected to have a large influence on the meteorology of the tropics. Being the gateway of the Indian summer monsoon, Kerala has been

a hot spot region for monitoring the monsoonal dynamical and thermo-dynamical processes. Improved understanding of the micro and macro level processes spanning from convection to cloud formation during various seasons is the special focus of the APS group.

- **Satellite Remote sensing and Applications (SRA):** The increasing awareness of changing climate and the role played in it by water vapor and clouds has elevated the interest to undertake cloud related studies. Specifically, we look into the variability of clouds, water vapor and other trace gases in the upper troposphere/lower stratosphere (UTLS) and their transport processes and association with various climatic conditions. Another aspect of interest is the study of extreme rainfall events during monsoon season and underlying factors using high horizontal and temporal resolution geostationary satellite observations to track mesoscale convective cloud systems. We use historical satellite and model datasets to achieve the above objectives.
- **Climate Variability & Change (CVC):** The unique location of Kerala in the south west coast of India is such that it receives considerable amount of rainfall during both the southwest and northeast monsoon seasons. However, changing climate has affected the spatial and temporal variability of rainfall over Kerala during both these seasons. Recent years have seen several extremely heavy rainfall events taking place in Kerala during the southwest monsoon season. The influence of basin scale features like Indian Ocean Dipole and El Niño on the rainfall variability are explored. The spatial and temporal variability of northeast monsoon rainfall over Kerala is also explored.
- **Advanced Center for Atmospheric Radar Research (ACARR):** Provide advanced techniques to monitor the Earth's atmosphere, using highly sophisticated state-of-the art radar, LIDAR, SODAR, GPS sonde, flux measurement, integrated sounding systems, etc. Study of extreme rainfall events during monsoon season and underlying factors using horizontal and temporal resolution geostationary satellite observations track mesoscale convective cloud systems.
- **Radar Technology & Ionospheric Studies (RTI) at Atmospheric Sciences:** The group is developing low-cost radar systems in the well-equipped lab that facilitates different RF equipment types to design, implement, and test modules at different frequencies and expertise to operate and supervise the same. The final output will be a whole system including radar/instrument modules, antenna systems, and associated software. The system will sense wind components from 150 m to 6 km provide an added advantage to the existing 205 MHz wind profiler. Manpower training will be given initially in the Stratosphere Troposphere (ST) Radar system operation, maintenance, signal processing of atmospheric radar data and analysis.
- **Physical Oceanography:**

  The ongoing research domains that uses to ocean remote sensing products are

  ✓ Intra-seasonal Air-Sea Interaction

- ✓ Assessment of north Indian Ocean circulation using satellite altimetry and model simulation.
- ✓ Coastal Processes - Coastal Zone Management
- ✓ Coastal currents, tides and eddies
- ✓ Dynamical studies on coastal features and its influence on acoustic propagation
- ✓ Climate change and global warming in the Southern Ocean
- ✓ Mesoscale process and Eddies in the ocean
- ✓ Bio-physical processes in the north Indian Ocean
- ✓ Ecosystem Dynamics of the North Indian Ocean
- ✓ An investigation on the Air-Sea interaction processes over the Eastern Arabian Sea.
- ✓ Air-Sea interaction processes over the Indo-Pacific region
- ✓ Influence of Air Sea Interaction of Tropical Indian Ocean on Monsoon over Peninsular India.
- ✓ Oceanic Mesoscale features in the Bay of Bengal

18.4 Major Scientific Applications / Results

- **Observation of Stratosphere-Troposphere Exchange during a Pre-monsoon Thunderstorm Activity over Kochi**

  Though vertical velocity does not show significant changes after the deep convective activity, unusual observations have seen in SNR and in the Doppler width in the UTLS region from 0100 to 0400 Hrs LT on May 19, 2017. Doppler width from the radar is a proxy of turbulence activity in the troposphere. Enhanced turbulence is observed after deep convection. The observations reveal that the upper-tropospheric turbulence and wind shear can affect the stability of the tropopause, which can eventually aid in the vertical transport of mass from the tropopause to the lower stratosphere and vice-versa.

- **Influence of the Strongest Positive Indian Ocean Dipole and an El Niño Modoki Event on the 2019 Indian Summer Monsoon:**

  The year 2019 experienced an excess monsoon season over the Indian region, with the seasonal rainfall being 110 % of the long period average (LPA). Several zones across the country suffered multiple extreme rainfall events and flood situations resulting in a massive loss of life and property. The El Niño Modoki event that started in the boreal autumn of 2018 lasted till the beginning of the 2019 monsoon season, giving rise to the anticipation of reduced monsoon rainfall over India. Another important feature of 2019 was the strongest recorded positive Indian Ocean Dipole (IOD) that lasted approximately seven months.

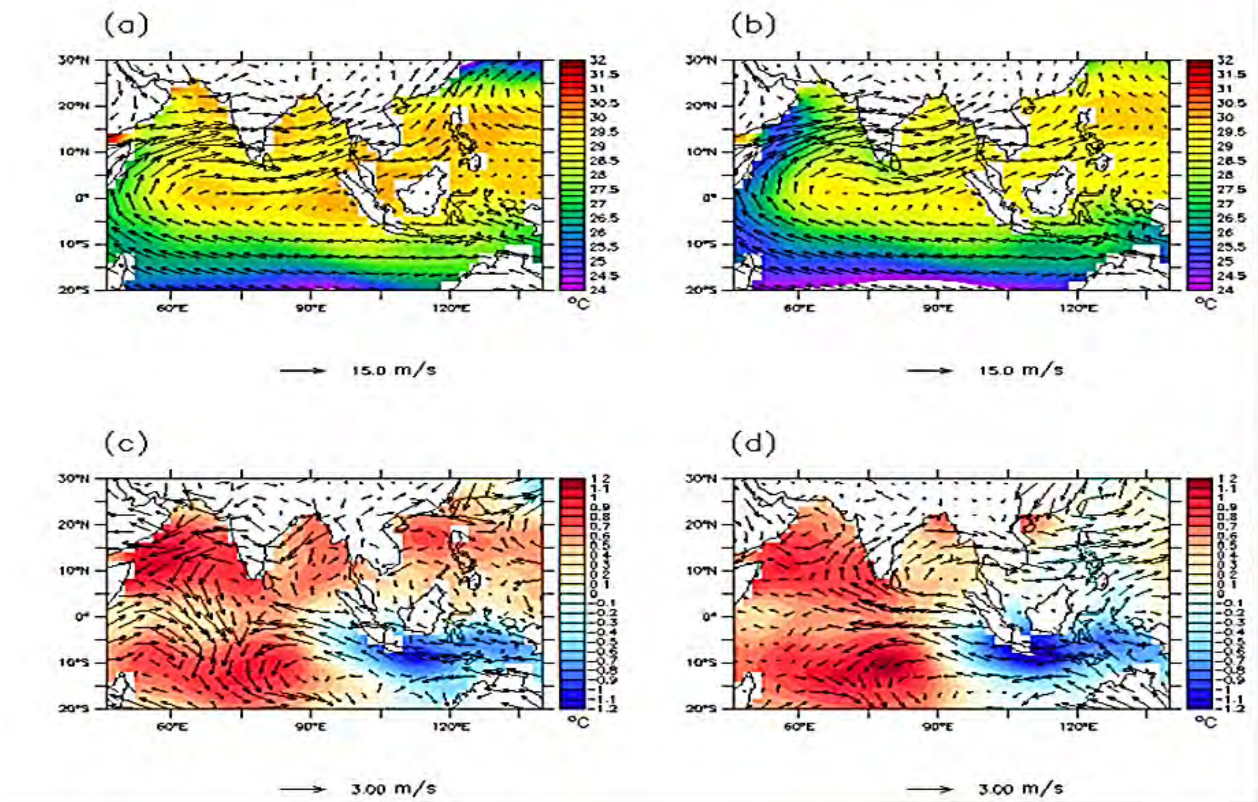

Figure 1. Zones across all-over the India

- **Influence of microphysical and boundary layer processes on stable isotopic ratios of monsoon rainfall.**

  The proposed research aspire to investigate the role of the short scale processes such as updraft/ downdraft, moisture recycling, mixing of environmental air etc on rainfall isotopic variability with the aid of isotopic analysis of rain and water vapour samples (~3 hourly) along with the atmospheric vertical profile data from Advanced Centre for Atmospheric Radar Research (ACARR) at Cochin University. This study will be highly beneficial for accurate paleo monsoon reconstruction from teak trees and cave calcite deposits from Western Ghats region also

- **Diurnal variation of deep convective clouds (DCC) over Indian monsoon region and its association with rainfall**

  DCC shows seasonal variations and amplitudes which are stronger during the northern hemispheric summer than winter and exhibits prominence over land as compared to ocean. Irrespective of seasons, deep convection peaks in the late evening hours over land whereas the peak is in the afternoon hours over the majority of the oceanic regions considered in study. Various parameters which represent the tropospheric instability are equally affected by the semi-diurnal oscillation as in deep convective clouds over the ocean. Results suggest that diurnal tides could play a key role in governing the daily cycle of deep convective clouds over oceanic regions.

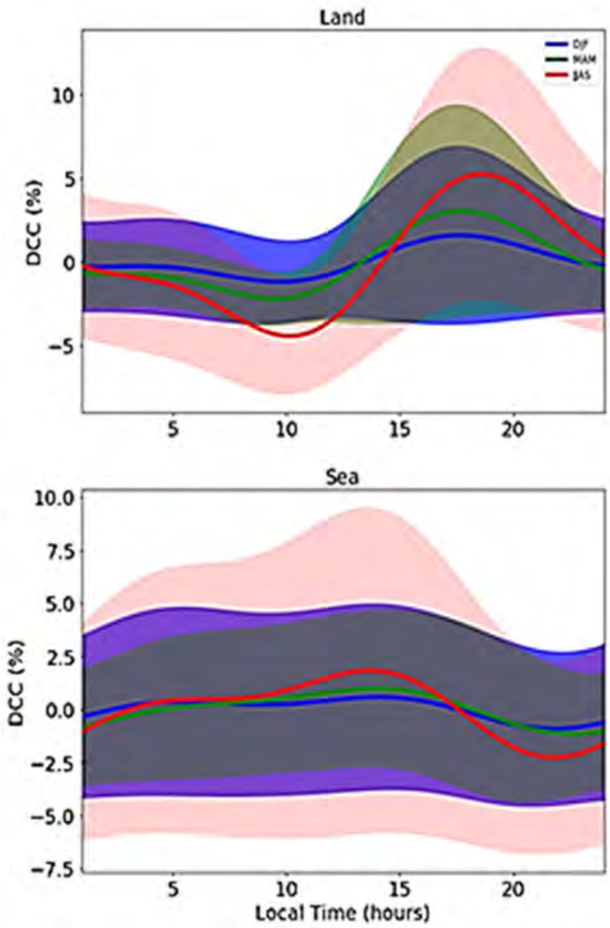

Figure 2: Diurnal cycle anomaly observed over land and ocean for different

- **Influence of High Latitude Sudden Stratospheric Warming on Tropical Weather:**

  The study illustrates the evidence of dynamical coupling between the high-latitude sudden stratospheric warming (SSW) events that occurred in three consecutive winter seasons and the concomitant changes in the wind pattern in the lower stratosphere and troposphere observed with a state-of-the-art 205 MHz stratosphere-troposphere wind profiling Radar, located at Cochin (10.03° N, 77.33° E), a tropical station in southwest peninsular India. Detailed analysis of the past 20 years of SSW events confirmed the observational evidence of unusual rainfall over the low latitude region related with the onset of SSW.

- **Evolution of Large-Scale Factors Influencing Extreme Rainfall over South Western Coast of India**

  The extreme rainfall events are linked to the development of monsoon depressions and the associated large scale dynamics. Strengthening of these parameters intensifies the monsoon low level circulation over the Arabian Sea and the west coast via steepened meridional pressure gradient. Intensification of the low level jet stream speed and its extension in the vertical causes an increase in the humidity flux in the lower and mid troposphere. The consequent ascending motion from the mid troposphere to the upper troposphere, resulting in the formation of deep convective cloud clusters over the west coast and eastern parts of the Arabian Sea.

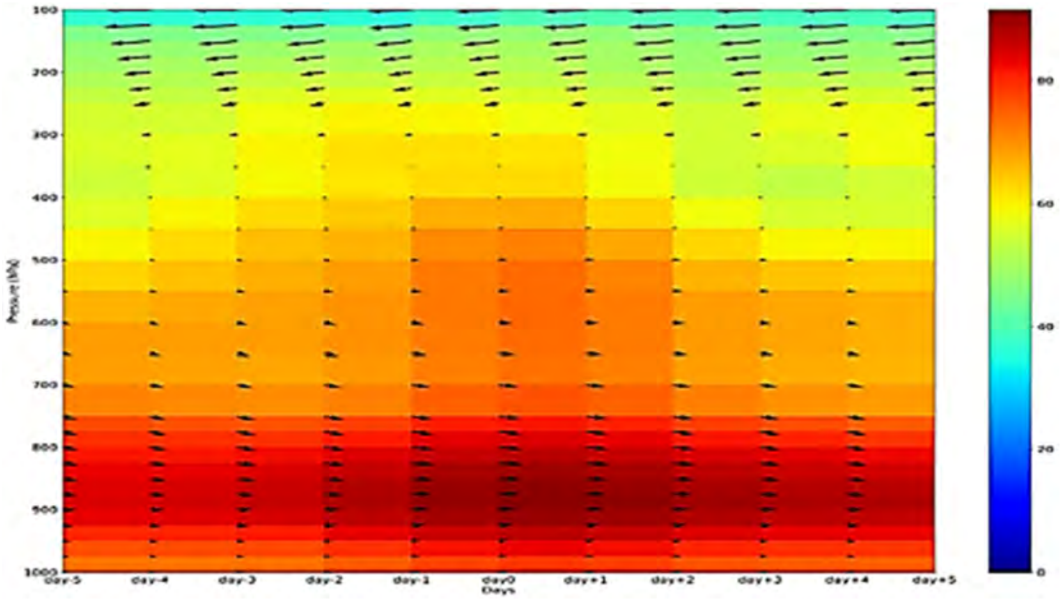

Figure 3: The evolution of relative humidity (%) and wind profiles (m/s) 5 days prior and after the extreme rainfall events (day0) over the south west coast.

- **Evaluation of global reanalysis winds and high-resolution regional model outputs**

  A stratosphere–troposphere (ST) wind profiler radar operating at a high VHF range (205 MHz) installed at Cochin (10.03°N, 76.33°E), India, provides high-resolution winds in time and altitude extending from 315 m to 20 km. ACARR, CUSAT evaluated the horizontal and vertical winds obtained from atmospheric global reanalyses (ERA5, ERA-Interim, MERRA-2 and NCEP) data and the high-resolution regional model (WRF) output winds with the ST radar (STR) wind observations at Cochin. Observed vertical winds from STR displays large fluctuations, while the estimated vertical winds in reanalysis are highly smoothed. Vertical profiles of vertical winds from the reanalysis datasets are not uniform.

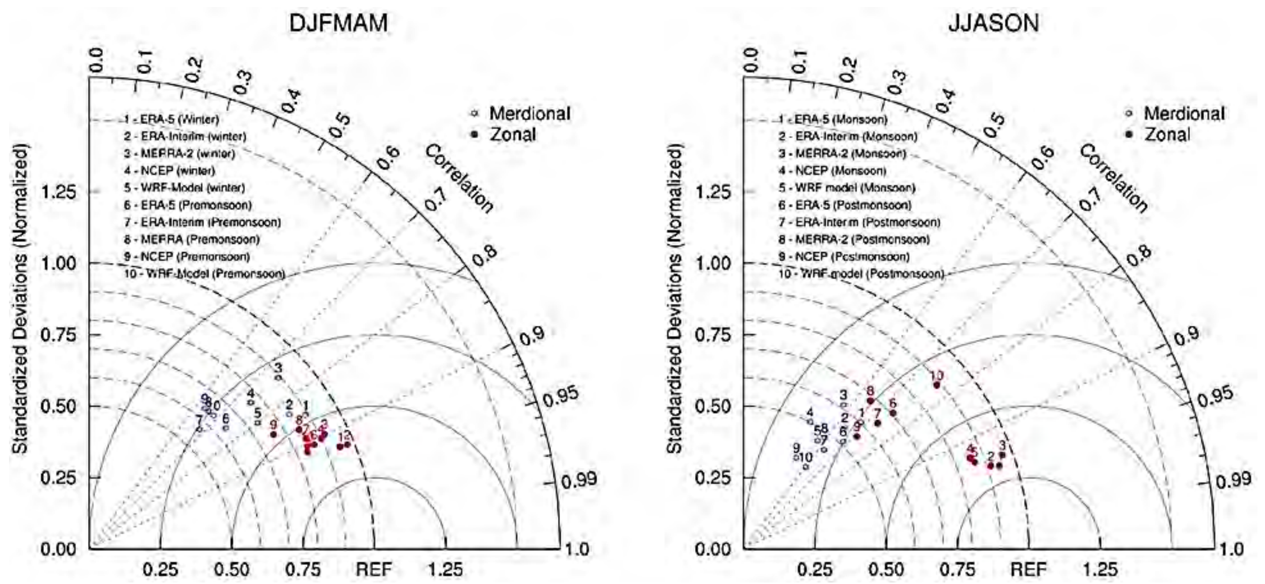

Figure 4: Taylor diagram showing the standard deviation and correlation between different reanalysis data for (a) winter and pre-monsoon, and (b) monsoon and post-monsoon.

- **A Study on the Potential Application of 205 MHz VHF Radar at Cochin in the Observation of Ionospheric Irregularities during Geomagnetic Storms**

  VHF Radar at Cochin observed no loss of plasma due to diffusion while photo production of ions continued, resulting in an increase in TEC (positive storm). The results of this case study of the moderate storm further validated the statement that the disturbance dynamo effects over the Indian equatorial/low-latitude sector dominate during the recovery phase. The increased O/N_2 ratio in the Indian sector could have caused long-term upward gradient drift instability along with upward secondary hall field associated with DDEF could have generated E-region irregularities at Cochin.

18.5 Instruments / Payloads / Products Developed / Sensors / Detectors

- **LIBS:**
  Developed a standard LIBS experimental setup for recording emission spectrum from laser-produced plasmas. Physics department developed a software package (LIBS-99) to remove all these barriers and provide fast and accurate LIBS spectra analysis.

- **205 MHz Stratosphere Troposphere (ST) Wind Profiler Radar:**
  The ST radar at Cochin (10.04°N, 76.33°E; 40 m MSL) is an active phased-array radar consisting of 619 three-element Yagi–Uda antennas arranged in an equilateral triangular grid with an inter-element spacing of 0.7λ, where λ is the operating wavelength, which is 1.43 m. It is an ideal observational facility located in the tropics for understanding the processes of the Indian summer monsoon at the region of its onset.

18.6 Capacity Building in Space Science Research

- Atmospheric Sciences have arranged a SMART Training Programme in Department with the help from Space Application Centre, Ahmedabad. Also faculty members guide the students for their PhD work.
- ACARR has been offering Summer Internship Program for the MSc/MCA/BTech/MTech students of various Universities/Colleges/Institutes for every academic year since 2015.

18.7 Courses offered on Space Science

- Department of Atmospheric Sciences and ACARR offers courses on M. Tech in Atmospheric Sciences and M.Sc.in Meteorology.
- Department of Physical Oceanography provide specialisation on remote sensing and satellite oceanography for the M.Sc. and MTech. Programs

18.8 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	Development of Green Polymer Systems as Adhesive & Coating for Space Applications' (Polymer Science and Rubber Technology)	VSSC
2.	Laser-Induced Breakdown Spectroscopy (LIBS)	Laboratory for Electro-Optics Systems (LEOS), Bengaluru
3.	Femtosecond Laser-Induced Breakdown Spectroscopy (fs-LIBS)	Raman Research Institute, Bengaluru
4.	Meteorology/ Oceanography	SAC
5.	Atmospheric Sciences	NARL
6.	Atmospheric Sciences	NCPOR
7.	Biological Oceanography	SAC-ISRO
8.	Modelling Coastal Sediment Transport and its impact on Coastal Environment	Space Application Centre-ISRO
9.	A coupled physical-ecosystem model based on MOM5-COBALT for the Indian Ocean	ESSO-Indian National Center for Ocean Information Services

18.9 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1.	Satellite Data utilization	ESA
2	Atmospheric Sciences	Swedish Institute of Space Physics

18.10 Laboratories and Facilities Available for Space Instrumentation

The following ground based instruments are available for ground based studies

- GPS Radiosonde:
- Micro Rain Radar
- Ceilometer
- Automatic Weather Station Network
- Humidity and Temperature PROfilers - (Radiometers)

Publications

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2. Martin, Max, S. et. al "Should I stay or should I go? South Indian artisanal fishers' precarious livelihoods and their engagement with categorical ocean forecasts." Weather, Climate, and Society 14, no. 1 p 113-129, 2021
3. Sreenath, et. al: Variability in lightning hazard over Indian region with respect to El Niño–Southern Oscillation (ENSO) phases." Natural Hazards and Earth System Sciences 21.8 2597-2609, 2021.
4. Sreenath, A. V. et. al, Precipitation processes over Indian region under different environmental conditions from in situ measurements." Atmospheric Research 262 105775, 2021.
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6. Kottayil, A., et. al Evolution of large-scale factors influencing extreme rainfall over south western coast of India. International Journal of Climatology, 1– 15. 2021

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15. Manoj M. G, et. al "Competing aerosol effects in triggering deep convection over the Indian region", Climate Dynamics, 56(5), 1815-1835, 2021

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18. M. Mohapatra, et. al : "Contribution of Monsoon Mission to operational advances: Short to medium range, extended range and seasonal forecasts, The CLIVAR Exchanges". DOI: 10.36071/clivar.79.2020.

19. Resmi CT, et. al "Air quality improvement during triple-lockdown in the coastal city of Kannur, Kerala to combat Covid-19 transmission", PeerJ-Environmental Science. DOI: 10.7717/peerj.9642.

20. Girish Gopinath, et. al : “Assessment of drought with a real-time web-based application for drought management in humid tropical Kerala, India, Environmental Monitoring and Assessment”. DOI:10.1007/s10661-020-08665-9.

21. Athira,U. N : et. al “Ocean-Atmosphere Coupled processes in the Tropical Indian Ocean Region prior to Indian Summer Monsoon Onset over Kerala”, Climate Dynamics. DOI: 10.1007/s00382-020-05499-6.

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25. Shinu Sheela Wilson et. al, “A New Circulation Index For The Detection Of Monsoon Intensity”, International Journal Of Climatology, Doi: 10.1002/Joc.6312, 2020.

26. Kaur M., et. al Dynamical downscaling of a multimodel ensemble prediction system: Application to tropical cyclones, Atmospheric Science Letters, DOI:10.1002/asl.971, 1-11, 2020

27. Muhsin, M., etal “Contrasting Features of Tropospheric Turbulence over the Indian Peninsula”, Journal Of Atmospheric And Solar-Terrestrial Physics, Doi.Org/10.1016/J.Jastp. 2019.105179, 2020

CHAPTER-19

DAYANANDA SAGAR UNIVERSITY

Bengaluru

19.1 About the University

Dayananda Sagar Institutions was founded in the 60s by the visionary, late Sri Dayananda Sagar. DSU is committed to take knowledge to the people and transform today's students into responsible citizens and professional leaders of tomorrow. The vision of DSU stands to be a centre of excellence in education, research & training, innovation & entrepreneurship and to produce citizens with exceptional leadership qualities to serve national and global needs. DSU strives to achieve its objectives in an environment that enhances creativity, innovation and scholarly pursuits while adhering to our vision. In the field of Basic and Applied Sciences, DSU holds a strong legacy in establishing a strong linkage between Academics, Research and Industry.

19.2 Keywords

Observational X-ray astronomy, UV imaging, UV photon detectors, X-ray detectors.

19.3 Major Research Domains

1. X-ray Astronomy

- Spectral and timing studies of extragalactic black hole binaries LMC X-1 and LMC X-3 using X-ray data observed by various X-ray missions such as AstroSat, NICER and NuSTAR to understand the physical properties of these source.
- Study of X-ray properties of GRS 1758−258 and 1E 1740.7−2942 in its different spectral states and exploring the relativistic reflection features in these sources using data observed by NuSTAR and AstroSat.
- Probing the accretion dynamics around the black hole binary GRS 1915+105 during the period of 2016−2019 by studying the evolution of these parameters during each class transition.

2. Sensor development for Space application

- Material synthesis and characterization of reduced graphene oxide for application in the development of light weight X-ray detector which can be used for space application.
- Fabrication of a miniaturized X-ray detector in the Field Effect Transistor architecture. This includes oxidation of silicon, drop casting of graphene oxide over oxidized silicon wafer, vacuum annealing at 200 degree for 6 hours and metal depositions for electrodes.

- Performance study of the fabricated device for X-rays and UV photon detection.
- Fabrication of pixelated large area device for space application and its performance analysis.

19.4 Major Scientific Applications / Results

- Bhuvana et al, Broad-band 'spectro-temporal' features of extragalactic black hole binaries LMC X-1 and LMC X-3: an AstroSat perspective MNRAS, Volume 501, 5457-5467, 2021
  - The study of MAXI light curves over a duration of 4.5 years show that LMC X-1 has a long term fractional variability of 25%, while LMC X-3 has a higher variability of 53%.
  - LMC X-1 is moderately variable from 7.4% − 16% over short time scale, while LMC X-3 has variability ranging from 9.7%−24% during the different observation epochs.
  - The weak power-law nature of PDS and evolution of fractional rms amplitude with the absence of low-frequency QPOs support that sources remained in the thermally dominated soft state.
  - We constrain the source mass in the range of 7.64 − 10.00 $M_\odot$ for LMC X-1, and 5.35− 6.22 $M_\odot$ for LMC X-3, which are in close agreement with that already reported.
  - The spin parameter is estimated to be 0.82 − 0.92 for LMC X-1 and is consistent with previous publications. In case of LMC X-3, we could obtain a better constrain of the spin as 0.22 − 0.41 in contrast with that reported earlier.

- Bhuvana et al, Multi-mission view of extragalactic black hole X-ray binaries LMC X-1 and LMC X-3: evolution of broadband spectral features, AdSR, Volume 69, 483-498, 2022
  - LMC X-1 is found to be in a steady soft state for the whole period of 2014 - 2020, whereas a state transition is seen in LMC X-3 in the following sequence: soft → intermediate → hard → intermediate → soft → intermediate → soft state during this period.
  - Spectral properties of sources during the different spectral states are similar to that of a typical BH with thermal disc dominant spectra in soft state, Comptonized flux dominant spectra in hard state and an intermediate state whose properties falls in between hard and soft state.
  - Temporal properties indicate constant low value of fractional rms in PDS of LMC X-1 whereas the rms increases in LMC X-3 as it transits from soft state towards a harder state.
  - BH spin estimation using continuum-fitting yields a = 0.85 – 0.94 for LMC X-1 and 0.16 – 0.33 for LMC X-3. Spin of LMC X-1 estimated from Fe-line fitting method is 0.93 – 0.94.

- Bhuvana et al, Broadband X-ray properties of GRS 1758−258 and 1E 1740.7−2942: AstroSat and NuSTAR results, submitted for publication, 2022
  - o GRS 1758−258 is found to occupy two different spectral states i.e. dim-soft and hard states and 1E 1740.7-2942 only the hard state.
  - o Relativistic reflection feature is found for the first time in GRS 1758−258. Fitting the reflection spectra using relxillCp+xillverCp allowed us to constrain the ionization parameter of the reflecting region to be 3.29 – 4.00 log erg cm s^{-1} with an iron abundance of 2.75(+0.22,−0.11). It also revealed the disc inclination angle to be within 62.49° – 67.69°.
  - o 1E 1740.7−2942 is also found to have relativistic reflection features in its spectra and modelling the same suggests that source has ionized accretion disc with logξ = 2.07−4.70 erg cm s^{-1}. Inclination angle of the system is revealed to be 62.53° – 75.09°.

- Athulya et al, Unraveling the foretime of GRS 1915+105: Wide-band specral and timing analysis of GRS 1915+105, MNRAS, Volume 510, 3019–3038, 2021
  - o Model independent analysis of lightcurves suggests that GRS 1915+105 displays various types of variability classes (δ,χ,ρ,κ,ω and γ). We also report possible transitions from one class to another (χ→ρ,ρ→κ via an ‹unknown› class and ω→γ→ω+γ) within a few hours duration.
  - o Detailed analysis indicates a gradual increase in the photon index (Γ) from 1.83 to 3.8, disc temperature (kT_in) from 1.33 to 2.67 keV, and Quasi-periodic Oscillation (QPO) frequency (ν) from 4 to 5.64 Hz during the rise, while the parameters decrease to Γ ~1.18, k_Tin ~1.18 keV, and ν ~1.38 Hz respectively in the decline phase.
  - o The source shows maximum bolometric luminosity (L_bol) during the peak at ~36% of Eddington luminosity (L_EDD), and a minimum of ~2.4% L_EDD during the decay phase.
  - o Further evolution of the source towards an obscured low-luminosity (Lbol of ~ 1% L_EDD) phase, with a decrease in the intrinsic bolometric luminosity of the source due to obscuration, has also been indicated from our analysis.

- Anshika, G. et al. Investigations on rGO on silicon-based UV photon detector Appl. Phys. A, 127, 863 2021
  - o The possibility of using reduced graphene oxide field effect transistor (rGOFET) on a high resistivity silicon as a photon detector in bottom gate FET architecture has been explored in this work.
  - o Highly conductive reduced graphene oxide (rGO) is synthesized from graphene oxide (GO) by a hybrid technique using hydroiodic acid (HI) fumes and thermal annealing for 6 h on the substrate itself.

- o The rGOFET device is irradiated from top and bottom at different gate-source voltages ranging between 50 mV and 5 V and a comparison of its performance is done.
- o The fabricated device has shown significant response to photons in the UV range peaking at 256 nm with a responsivity of 0.15 A/W at 5 V when irradiated from top and 0.095 A/W at 5 V when irradiated from bottom.
- o The response time of the device measured is 0.23 s, and recovery time is 0.12 s.

19.5 Instruments / Payloads / Products Developed / Sensors / Detectors

Reduced graphene oxide-based radiation detector has been developed which has shown promising results with UV photon and X-ray photons. The detector has been developed on an oxidized silicon wafer in a Field Effect Transistor architecture.

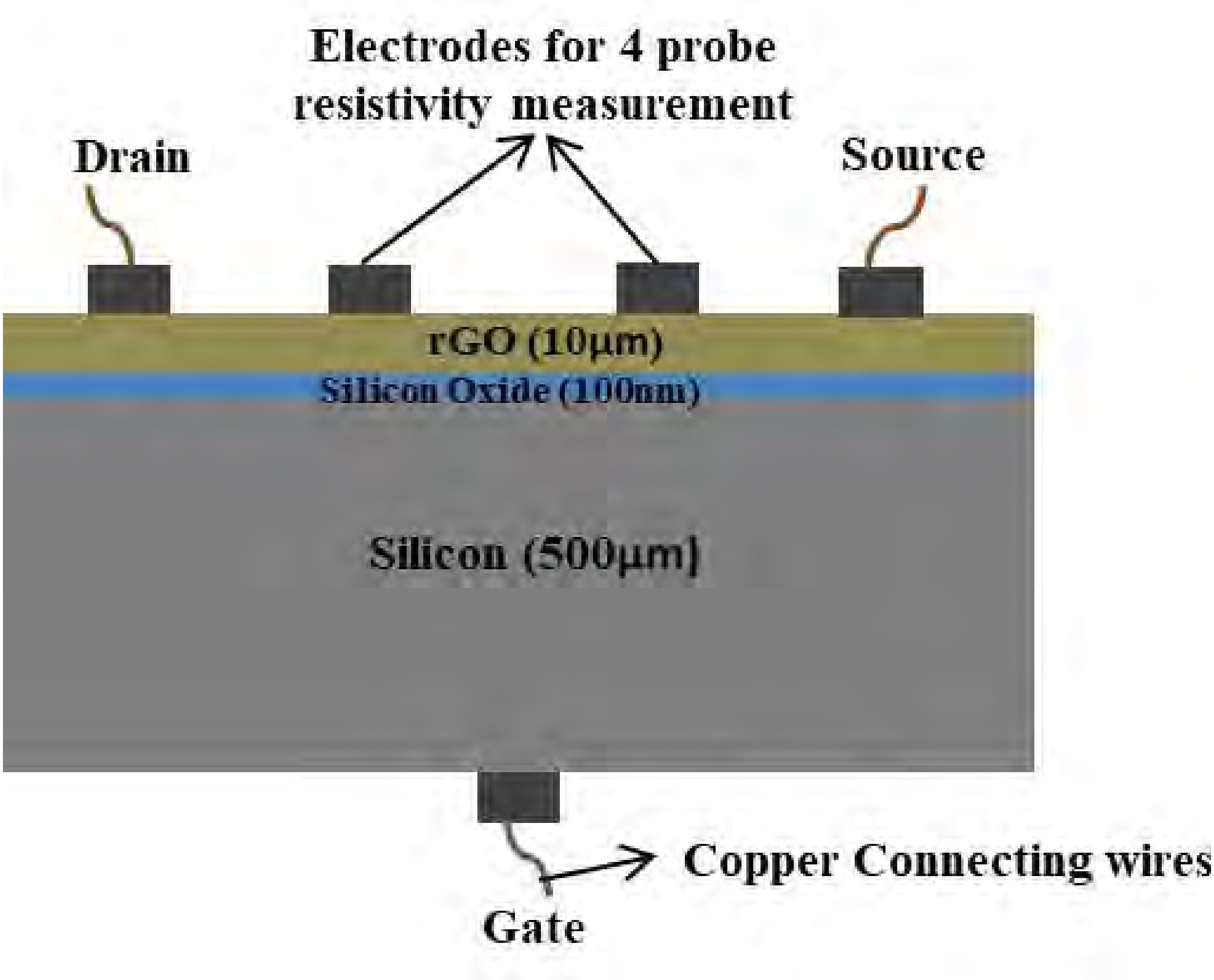

Fig1: Schematic of the Reduced Graphene oxide based radiation Detector

A pixelated device (3x3) has also been designed and developed for large area space applications

19.6 Capacity Building in Space Science Research

- Dayanada Sagar University has students' astronomy club "ASTERIA" formed in 2018.
  - o The club has organized various activities for students to learn different aspects of astronomy and astrophysics such as student visit to various observatories and laboratories
  - o Conduct of lectures by eminent scientists
- Other than these, various competitions such as logo design competition, 3D modelling competition and Astro-photography contests were arranges by the club for students.

19.7 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	Sensors	Indian Space Research Organisation (ISRO)
2.	Space instrumentation	Indian Institute of Science (IISc)
3.	Observational X-ray astronomy	Indian Space Research Organization (ISRO)

19.8 Laboratories and Facilities Available for Space Instrumentation

The Space Instrumentation laboratory in DSU is well equipped and provide the following facilities:

Wet chemical bench, Vacuum oven, Ultrasonicator, Spin coater, Chemical balance, Magnetic stirrer, Keithley source meter, Keithley electrometer, Power supply oscilloscope.

CHAPTER-20

DEPARTMENT OF PHYSICS AND ASTROPHYSICS, UNIVERSITY OF DELHI

Delhi

20.1 About the University

The Department of Physics and Astrophysics has had a tradition of research and training of students in the Area of Astronomy and Astrophysics. We have in the M.Sc. two semesters of Astronomy and Astrophysics and two semesters of General Relativity and Cosmology. In addition there is a 1 semester course in Observational Astronomy. There is also a two semester course in Plasma Physics in which there are Astronomy related topics. More recently a course in Nuclear Astrophysics as well as Fluid dynamics has been introduced. There are also specialised special elective papers in BSc. A one semester course in Astronomy and Astrophysics has been running at the Bachelor's level also from the last few years. In addition, there are about 8 PhD students currently pursuing research in Astrophysics. The Department also hosts one of IUCAA Centres for Astronomy Research and Development. We have about 12 faculty members who are pursuing research in Astronomy, Astrophysics and Allied areas in the main University and colleges.

20.2 Keywords

X-ray Astronomy (exo-planet -- neutron stars – binaries – pulsars -- bursts), Radiation Mechanism (thermal -- non-thermal), Cosmic Microwave Background Radiation, Large scale structures, Cosmic magnetic fields, Extra-Galactic Astrophysics. (Galactic Magnetic field, Faraday rotation)

20.3 Major Research Domains

X-ray Astronomy: The department is doing active research in X-ray astronomy which includes spectral and timing study of compact objects through data retrieved from various X-ray missions, such as RXTE, NICER, SWIFT, INTEGRAL, NuSTAR, Chandra and XMM-Newton. This includes broadband X-ray spectroscopy, evolution of X-ray binaries and pulse profile evolution in pulsating neutron stars. The overall perspective is to understand the radiation mechanisms, determine neutron star masses and radii in order to understand various aspects of nuclear physics that cannot be probed in laboratories. We primarily study accretion powered pulsars, wherein the physical processes manifest as pulsations, quasi-periodic oscillations, thermonuclear X-ray bursts, quiescent emission, broad relativistic iron lines and absorption line features. These are analysed to estimate the magnetic field strength of the neutron star.

20.4 Instruments/ Payloads I Products Developed I Sensors I Detectors

The Department of Physics and Astrophysics has a computational lab where students and faculty peruse various programming software for astronomical data analysis.

20.5 Capacity Building in Space Science Research

Details of lectures/ workshops/ training courses organized beyond the curriculum

- Lectures delivered
  - '*Frontiers in Astrophysics*', organized by Bishop Heber College on 12-11-2020
- Workshop Organized
  - '*A glimpse of X-ray data analysis*', organized with Nehru Planetarium, Delhi on National Science Day, 28-02-2021.
- Under-graduate Projects
  - Understanding the mysteries of X-ray pulsars (Academic Year 2020 - 2021)
  - Spectral Energy Distribution of LMC N132D (Academic Year 2021 - 2022)
  - Spectral Energy Distribution of G21.5-0.9 (Academic Year 2021 - 2022)
- Faculty Research Project
  - The faculty and students of Delhi University are currently involved in constructing an antenna to study the Universe in radio frequency. The objectives of the project are to design a radio antenna and understand the operation of front and back end instruments, to take observations from the radio antenna and calibrate the results with known radio bright sources, to measure the brightness temperature of the Sun, to determine and calibrate the main beam size through solar observations, to observe Jovian emission in radio frequencies and its evolution with time, to observe the 21 cm spectral line in the radio emission.

20.6 Courses offered on Space Science and Technology

Courses Offered

- **B.Sc**
  - Astronomy and Astrophysics: (Introduction to Astronomy and Astronomical Scales, Basic Parameters of Stars, Observational Tools and Physical Principles Sun, The Milky Way, Cosmology, Distribution of chemical compounds in the interstellar medium and astrophysical conditions necessary for the emergence and existence of life.

- **M.Sc.**
  - Astronomy and Astrophysics I : (Instruments, Magnitude scales, Stellar Physics, HR diagram)
  - Astronomy and Astrophysics II (Stellar structure, Radiative Transfer, Galactic Physics, Collapsed objects, Basics of Cosmology)
  - General Relativity and Cosmology I (Formulating of general Relativity, Blackhole Physics)
  - General Relativity and Cosmology II (Cosmology, Gravitational Waves, Relativistic Stars)
  - Observational Astronomy (Telescope based observations, CCD charecterization, Soft ware based projects using archival data)
  - Nuclear Astrophysics (Stellar Nucleosynthesis, nuclear processes in stars)
  - Fluid Dynamics: (Basic formulation, application to Astrophysics like accretion, shocks, Basics of Turbulence)

List of Scientific Publications:

1. Sharma P. et al., Broad-band spectral analysis of LMXB XTE J1710-281 with Suzaku, *MNRAS*, **496**, 197-205, 2020

2. Sharma P. et. al., Broad-band spectral study of LMXB black hole candidate 4U 1957+11 with NuSTAR, *RAA,* **21**, 214 (1-10), 2021

3. Talwar J. et. al., Stellar and Pulsar Classification using Machine Learning, *Hans Shodh Sudha*, **1**, 71-80, 2021

4. Jagannathan Sandhya, Sunil Malik, Jain Deepak and T R Seshadri, Impact of magnetic field on the gas mass fraction of galaxy clusters, *New Astronomy* **84,** 101531, 2021

5. Srivastava, P et. al., Implications of Site specific Mass Absorption Cross section (MAC) to Black Carbon Observations at a High altitude Site in the Central Himalaya, *Asia-Pacific Journal of Atmospheric Sciences, Online First,* April 2021

6. Pandey, Arun Kumar, Sun il Malik and T R Seshadri., Implications of baryon-dark matter interaction on IGM temperature and tSZ effect with magnetic field. *Monthly Notices of the Royal Astronomical Society,* **500**, 643-654, 2021

7. Jagannathan Sandhya, Ramkishor Sharma and T R Seshadri., Imprints of the post-recombination dissipation of helical magnetic field on the Cosmic Microwave Background Radiation,International Journal of Modern Physics D, 30, 2050122-120, 2021

CHAPTER-21

CENTER FOR ATMOSPHERIC STUDIES DIBRUGARH UNIVERSITY

Dibrugarh

21.1 About the University

The primary focus of the Centre for Atmospheric Studies, Dibrugarh University is to carry out research in the area of climate change and climate variability and its impact on the Environment (or Biosphere and Geosphere). We have a robust observational program of aerosol and trace gas, thanks to generous support from the Indian Space Research Organisation, the DST and the University Grants Commission.

Space weather is another area of prime focus in the Centre and we currently operate a chain of GNSS receivers in NE India and the only Ionosonde now operational since 2010 in the whole of east and northeast India. The ISRO and the DST support space research in CAS. We have also undertaken the task of the development of an Indigenous Ionosonde in collaboration with SAMEER, IIT Mumbai with financial support from DEITY.

Recently the Centre has participated in the Human and Institutional Capacity Building (HICAB) Network Programmes as part of the National Mission on Sustaining Himalayan Ecosystem (NMSHE) Strategic Programmes, Large Initiatives and Coordinated Action Enabler (SPLICE), CLIMATE CHANGE PROGRAMME (CCP), Department of Science & Technology (DST), Government of India (https://dst.gov.in/climate-change-programme).

21.2 Keywords

Climate change, space weather, aerosols, bioaerosols, trace gases, COVID 19, sulfur dioxide, metagenomic approach, Ionosphere, Ionosonde, GNSS, EIA, Space Weather, Modeling, Tomography

21.3 Major Research Domains

Earth's Atmosphere and Climate Change:

The primary focus of the research group is the measurement and modeling of the climate change drivers and their impact on the Biosphere and Geosphere over the Sub Himalayan North-East India, in particular, and the contiguous domain of South and South East Asia, in general. Dibrugarh University is the 4th oldest aerosol observatory established in the year 2000 under the ISRO GBP umbrella to which GHG measurements were added in 2008-2009. The research outcome has helped regional characterization of aerosol and trace gases in North East India with respect to the Indian subcontinent.

Space Weather:

- Centre for Atmospheric Studies carries out Ionospheric observational studies using Ionosonde, GNSS receivers and satellite measurements. The Centre has also used SCROSS satellite data, Radio Beacon TEC data and global ionosonde dataset from WDC to study the space weather and has contributed immensely to the scientific knowledge in the domain before establishing its own Ionosonde (CADI) and GPS receivers in 2009-2010 from ISRO's SSPS program.
- The department had developed a physics based low latitude model for the Indian zone by solving the continuity and momentum equations.
- The centre had demonstrated a 2D tomography based on the SVD technique.

21.4 Major Scientific Applications / Results

Earth's Atmosphere and Climate Change

Characterization of Biological Aerosols: Dibrugarh University has contributed not only in establishing the unique identity of the Northeast India (NEI) in terms of it's atmospheric composition in the past decades (e.g., Pathak et al., 2020; 2021; 2022), but has also extended the exploration to the Indian subcontinent (Ajay et al., 2021; Chutia et al., 2022) and to the globe (Subba et al., 2020). Couple of recent studies on bioaerosols over NEI,(Pathak et al., 2020; 2022),carried out through a campaign modeobservation at various locations of the region covering the four seasons of a year. The microbiological analyse carried out using culture method revealed culturable microbial populations in terms of CFU count in the range 20.83–632.45 CFU/m^3, while fluorescence microscopy revealeddominance of non-biological (non-viable) component of aerosols followed by pollens (4–20%), animal debris (1–24%), and fungal spores (1–17%). DNA-based metagenomic analysisshows a total of bacterial 184 OTUs (operational taxonomic units) with 28,028 abundance count comprising 7 major phylum, 6 classes, 10 orders, 15 families, 13 genus, and 8 species of bacteria, during pre-monsoon season. The species-level distribution identifies Gammaproteobacteria as the most abundant, followed by Bacilli, Alphaproteobacteria, Betaproteobacteria, Flavobacteria, and Sphingobacteria.

List of scientific publications

1. T Subba, MM Gogoi, B Pathak, PK Bhuyan, SS Babu (2020), Recent trend in the global distribution of aerosol direct radiative forcing from satellite measurements, Atmospheric Science Letters, https://doi.org/10.1002/asl.975 (IF:2.415).

2. PATHAK B., Borah, D., Khataniar, A., Bhuyan, P.K., Buragohain, A. K. (2020), Characterization of bioaerosols in Northeast India in terms of culturable biological entities along with inhalable, thoracic and alveolar particles, Journal of Earth System Science, J. Earth Syst. Sci. (2020) 129:141, https://doi.org/10.1007/s12040-020-01406-z (IF: 1.371).

3. PATHAK B, Pradip Kumar Bhuyan, Arshini Saikia, Kalyan Bhuyan, Ajay P., Shankar Jyoti Nath, Shyam Luchan Bora (2021), Impact of lockdown due to COVID 19 outbreak on O_3 and its precursor gases, PM and BC over North-East India, Current Science (special issue: Environmental impact of COVID-19), Vol: 120(2) (IF: 1.102).

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Space Weather:

The ionospheric response to two sudden stratospheric warming (SSW) events that occurred during low (2009) and moderate solar activity (2013) around 10°E (±10°) African-European and 95°E (±10°) Indian-East Asian sectors was investigated. The total electron content (TEC) obtained from a meridional chain of stations in the two sectors were used to understand the longitudinal and hemispheric response to these SSW events. Significant depletion of daytime TEC was observed after the onset of 2009 SSW around the equatorial ionization anomaly (EIA) crest followed by an increase during the decaying phase of SSW. The formation of an early peak in the daytime TEC and semidiurnal variation in the response of TEC in the form of morning enhancement and afternoon depletion was observed at low latitudes. The morning enhancement is prominent at northern low latitudes while afternoon depletion was more at southern low latitudes. The conspicuous TEC perturbations characterized by semidiurnal variation in mid–January of 2013 override the sudden increase in solar activity after the onset of the SSW. SSW impacted semidiurnal perturbations in F2 layer peak electron density (NmF2) and height (hmF2) noticed at Cocos Island, the southern hemisphere low latitude station. Longitudinal and interhemispheric differences in the magnitude and evolution of TEC perturbations were noticed. The longitudinal differences in SSW modulation of TEC might be attributed to the differential impact of the nonmigrating tides and differences in the geomagnetic field elements between the two sectors. The meridional wind in the mesosphere and lower thermosphere region contribute to the TEC enhancement.

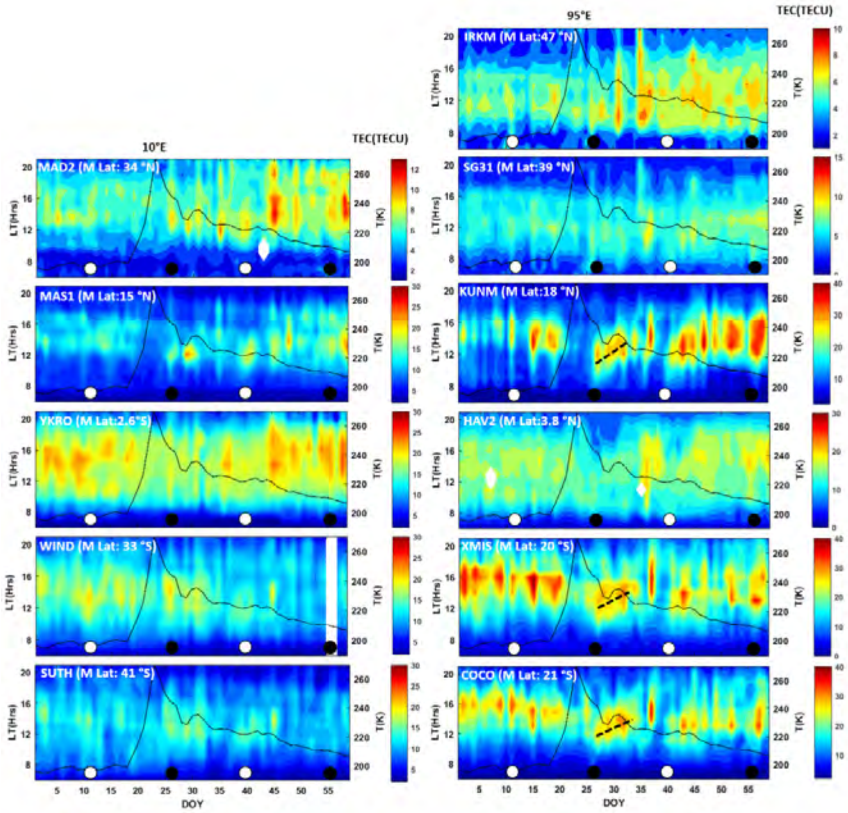

Figure 1: The longitudinal difference TEC in the two longitudes during 2009.

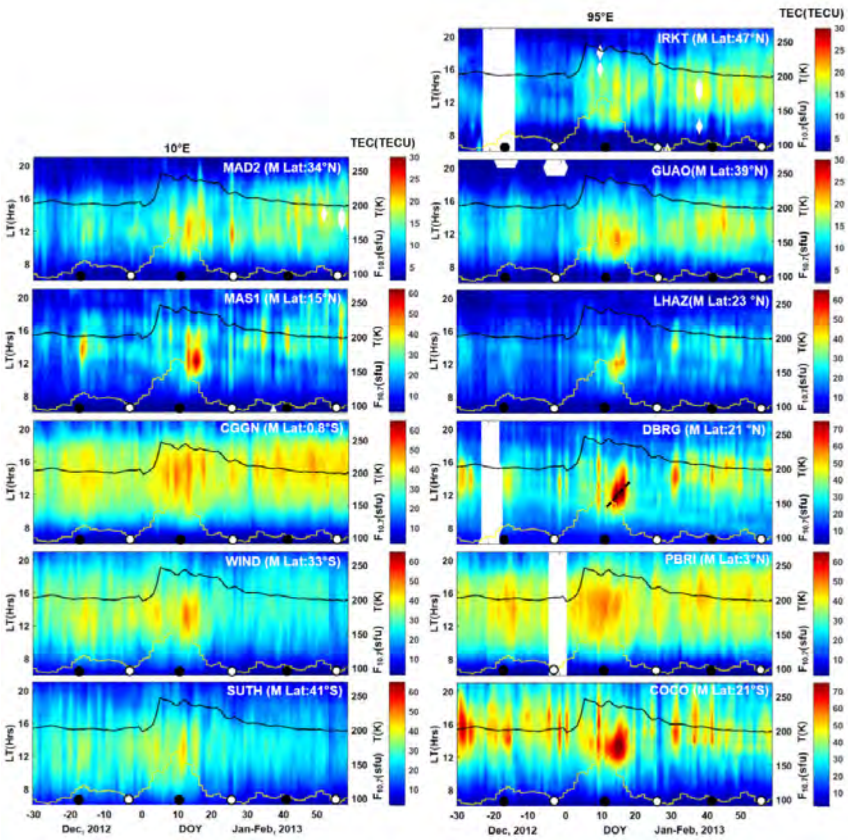

Figure 2: The longitudinal difference TEC in the two longitudes during 2013.

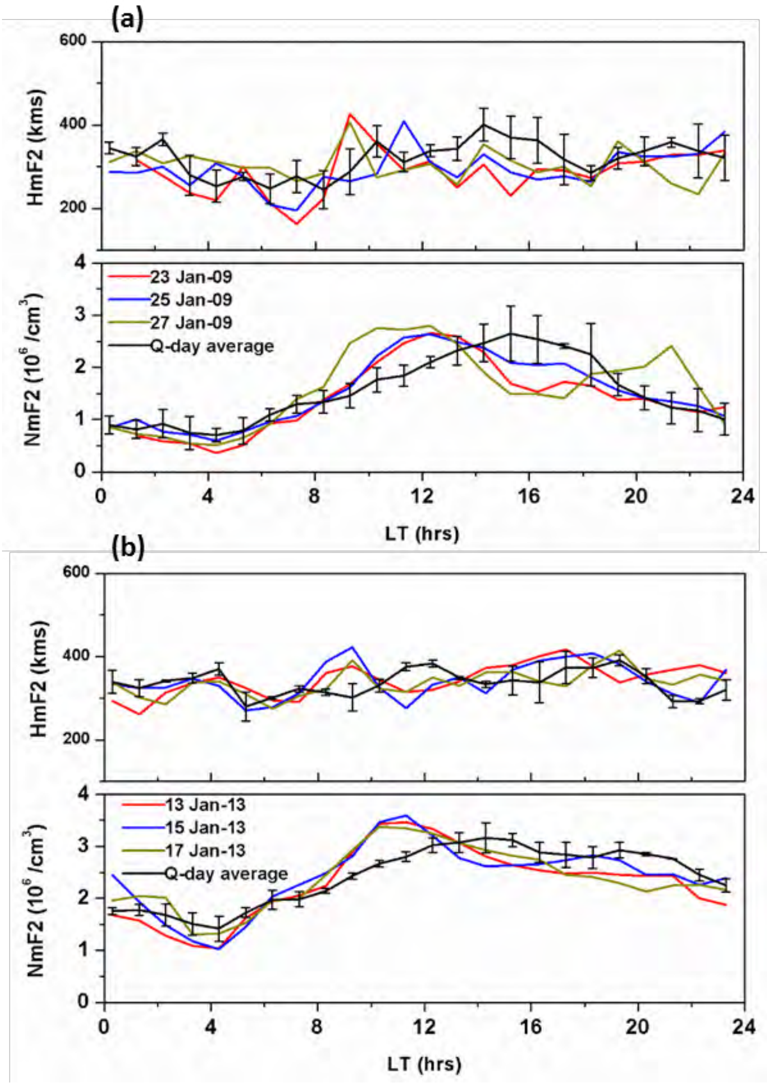

Figure 3: The variation in the hmF2 over Cocos Islands

21.5 Instruments / Payloads / Products Developed / Sensors / Detectors

1. Digital Ionosonde

   Two digital Ionosondes are available in Dibrugarh CADI and SAMEER-DU Ionospheric Radar. CADI operates in the sweep frequency range of 1-20 MHz with peak power of 700Watt. SAMEER-DU radar developed in house can operate from 2-23 MHz with peak power of 1000 Watt. Both can operate nearly concurrently.

2. Three GNSS receivers of Novatel make in Aizwal, Dimapur and Dibrugarh from 2015. One GPS receiver of Novatel make in Dibrugarh from 2009

21.6 Capacity Building in Space Science Research

International Workshop on ICTP Regional Climate Model: Applications Over South Asia CORDEX Domain, 22-28 February, 2021.

21.7 Courses offered on Space Science and Technology

A theme Based ***Multidisciplinary Course "Climate Change, Adaptation and Prediction"*** to Post Graduate students of various disciplines like Physics, Chemistry, Mathematics, Statistics, Computer Science, Engineering, Geology, Geography, Life Sciences, Sociology, Political Science, Economics etc. The course consists of 4 papers- 2 Generic Elective and 2 Ability Enhancement Course, with a total of **12 credits** (Course Co-Ordinator: Dr. B. Pathak).

Optional papers on Space Physics are offered in the regular M.Sc and Integrated M.Sc program of Physics.

21.8 National Collaborations in Space S&T

Sl. No.	Area of Collaboration	Collaborating Institute
1	Atmospheric Science	Space Physics Laboratory, VSSC, Trivandrum
2	Atmospheric Science	Physical Research Laboratory, Ahmedabad
3	Atmospheric Science	North-East Space Application Centre, Shillong
4	Atmospheric Science	Tripura University, Agartala
5	Developing Digital Ionosonde	SAMEER, Mumbai
6	GNSS receiver operation	Mizoram University
7	GNSS receiver operation	Kohima Science/Dimapur Christian College

21.9 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1	Atmospheric Science	International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal
2	Atmospheric Science	Abdus Salam International Centre of Theoretical Physics, Trieste, Italy
3	Atmospheric Science	University of Michigan
4	Atmospheric Science	Brookhaven National Laboratory
5	Sharing Ionospheric data for research	NICT Japan
6	Sharing Ionospheric data for research	Australian Bureau of Meteorology

CHAPTER-22

INDIAN INSTITUTE OF ASTROPHYSICS

Bengaluru

22.1 About the Institute

Indian Institute of Astrophysics, Bengaluru, is a premier research institute in astronomy and astrophysics. It has a rich heritage of over 250 years of research in solar and stellar astronomy. IIA developed several observatories for both stellar and solar observations over all these years. However, about 20 years ago, IIA designed and developed Ultra Violet Imaging Telescope (UVIT) for AstroSat mission. Currently IIA is developing the Visible Emission Line Coronagraph (VELC) for Aditya-L1 mission. IIA has also designed and developed few smaller UV imaging telescopes and also balloon-based payloads to meet specific focused science goals. Prof. MGK Menon Laboratory for Space Sciences at IIA is a state-of-the-art laboratory dedicated for design, develop, integration and calibration of space-based astronomy payloads (VUV to near IR).

22.2 Keywords

UVIT – Ultra Violet Imaging Telescope, AstroSat: Astronomical Satellite, VELC – Visible Emission Line Coronagraph, MGKML – Prof. MGK Menon Laboratory for Space Sciences

22.3 Major Research Domains

- Astronomy & Astrophysics: Research in Astronomy and Astrophysics carried out at the Indian Institute of Astrophysics covers a broad variety including Sun and Solar System as well as stars and galaxies. Researchers at IIA, for their research, utilize data that covers the accessible electromagnetic spectrum such as gamma rays, X-rays, ultra-violet, optical, infrared, radio and sub-mm wavelengths. The data are acquired from a wide range of instruments on both ground and space based observatories built and operated by India as well as institutes outside India.
- Optics, structures, electronics, controls, data pipe-line and processing etc
- Integrate, Test and Calibration Facilities
- Environment Test Facilities for space payloads (upto 6U)

22.4 Major Scientific Applications / Results

Ultra Violet Imaging Telescope (UVIT) for AstroSat mission: UVIT with its spatial resolution of better than 1.5 arcsec over a wide field of view of 28 arcmin diameter continues to provide important unique data at ultra-violet wavelengths since its launch in September 2015. The data from UVIT is being used both from researchers within India and abroad. The data from UVIT used in isolation on in conjunction with data from other wavelengths have lead to important scientific results. Some among them are:

- Identification and characterization of the peculiar blue straggler stars in star clusters,
- Characterization of star-forming complexes in external galaxies and constraining the physical processes,
- Characterisation of the morphological structure and evolution or planetary nebula,
- Understanding galaxy mergers,
- Constraining the physical processes in the central regions of active galaxies and
- Understanding stellar systems through ultra-violet spectroscopy.

Observations with UVIT has also lead to discoveries such as

(a) Detection of Lyman continuum emission from a distant galaxy at a redshift of z = 1.42

(b) Diffuse star forming galaxy and

(c) A triple active galaxy in a merging group of galaxies.

22.5 Instruments / Payloads / Products Developed / Sensors / Detectors

- Visible Emission Line Coronagraph on Aditya-L1 Mission (in progress)
- Lunar Ultraviolet Cosmic Imager – LUCI (completed)
- Tubingen IIA Nebular Investigator – TINI (proposed and in progress)
- Indian Spectroscopic and Imaging Space Telescope – INSIST (in progress)
- Near Ultraviolet Transient Surveyor –NUTS (in progress)

22.6 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1	Optics	LEOS, ISRO, Bengaluru
2	Detector Systems	SAC, ISRO, Ahmedabad
3.	Mechanical Structures	URSC, ISRO, Bengaluru
4.	Mechanisms	ISITE & ISU, ISRO
5	Controls, Mission, Data-pipeline etc	URSC & ISSDC, ISRO
6	Science	IUCAA, ARIES, ISRO, ISERs etc

22.7 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1.	Detector calibration	CSA
2.	Focal plane arrays and other sub-systems in INSIST-CASTOR collaboration	CSA

Laboratories and Facilities Available for Space Instrumentation

- Prof. MGK Menon Space Science Laboratory
- Environment Test Facility
- Payload Operations Center

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CHAPTER-23

INDIAN INSTITUTE OF GEOMAGNETISM

Mumbai

23.1 About the Institute

Indian Institute of Geomagnetism is an autonomous research institute under Department of Science and Technology (DST), with its headquarters at New Panvel. It operates three regional centres, namely, Dr. K.S. Krishnan geomagnetic research laboratory, Prayagraj, Equatorial Geophysical Research Laboratory, Tirunelveli and Shillong Geophysical Research Centre, with 12 magnetic observatories nationwide to monitor the geomagnetic field. IIG is a premier institute conducting basic and applied research in Geomagnetism and allied fields like Space and Atmospheric Sciences and Solid Earth Geomagnetism that covers several phenomena from the surface of the Sun to the interior of Earth. Recently, the research activities are extended to planetary ionosphere-magnetosphere systems as well. In 2022, IIG has achieved a milestone of completion of 50 years as an autonomous body. It holds the renowned Colaba-Alibag magnetic observatories that have the heritage of over 180 years of continuous geomagnetic field observations. IIG supports a World Data Centre (WDC) for Geomagnetism, which is the only International centre for geomagnetic data catering to the needs of the scientists in South Asia. IIG has a global presence by virtue of which its scientists are involved in multiple collaborations with scientists across the world.

23.2 Keywords

Magnetic observatories, Magnetometers, Space Weather, Plasma Waves and Instabilities, Atmosphere-Ionosphere Coupling and Dynamics, Polar Sciences, Solid Earth Geophysics, Environmental Geomagnetism, High Performance Computing, Instrumentation

23.3 Major Research Domains

- **Space weather research**: Space weather is an extremely important aspect of space science due to high dependence of modern society on satellite technology for navigation and communication. The solar-terrestrial interactions and associated phenomena like geomagnetic storms, sub-storms, energetic particle dynamics etc. are extensively investigated by IIG scientists using a global network of ground and satellite observations. The ultimate aim is to develop a prediction model to assess the impact of space weather phenomena on ionosphere-magnetosphere systems and on satellites. IIG proposes to utilise the science data emerging from the upcoming ADITYA-L1 mission of ISRO for this purpose.

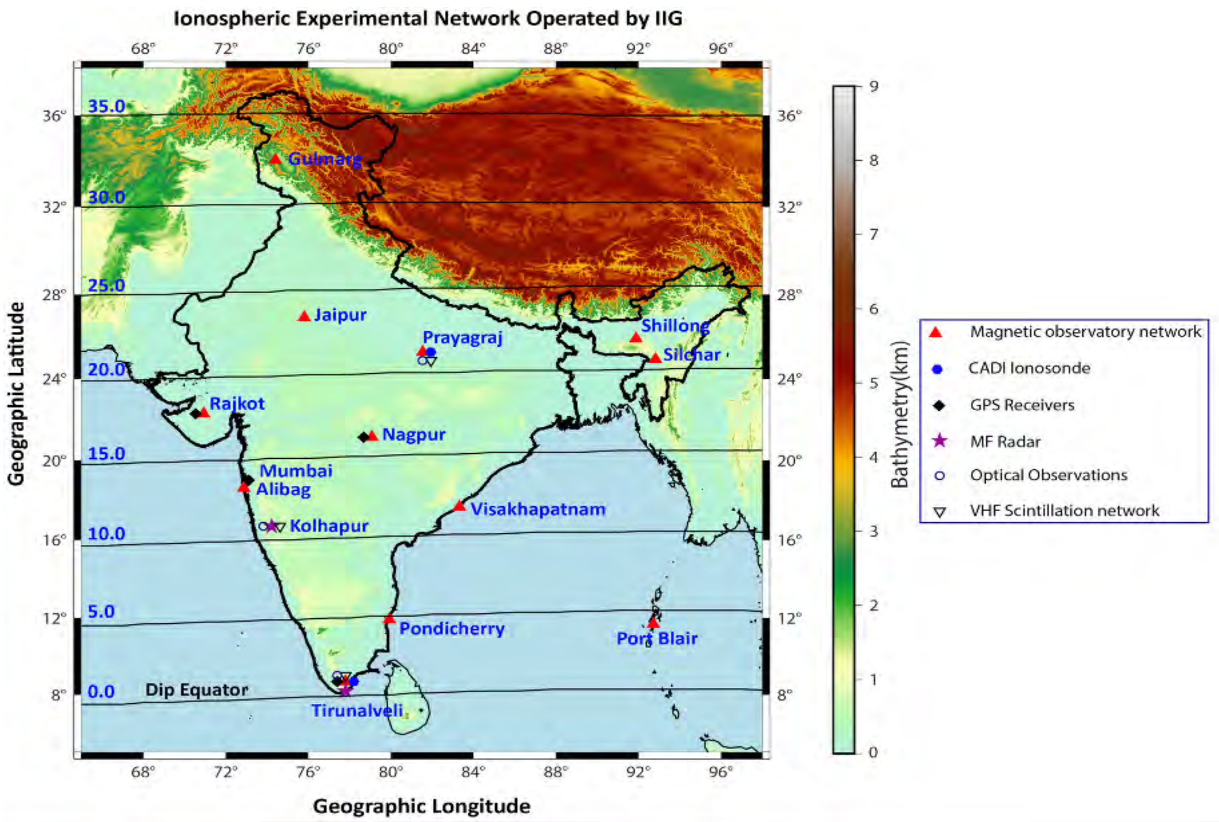

Figure 1. Map of the country showing major observational facilities of IIG.

- **Atmospheric / Ionospheric research:** IIG scientists make use of a network of radio and optical remote sensing instruments spread across the country to probe and understand a variety of ionospheric and atmospheric phenomena. The objective of this research is to understand the dynamical and electrodynamical coupling of various regions of the Earth's atmosphere-ionosphere system. One research component that has immediate practical application is the study of the dynamics of ionospheric irregularities, which are capable of causing degradation of radio signals by imposing phase and amplitude scintillations.
- **Magnetospheric research**: The magnetospheres of Earth and other planets offer a natural laboratory to study the dynamics of space plasma waves/instabilities and their role in particle acceleration/deceleration processes. At IIG, a team of modellers/theoreticians are working from the past few decades in the field of space plasmas and their work is well recognized by world scientific community. High resolution electric and magnetic field, and particle observations on the terrestrial and deep space plasmas from the upcoming ISRO missions will be extremely useful in the ongoing research conducted by IIG in these areas.
- **Polar research**: IIG has been an active participant in almost all Indian Scientific Expeditions to Antarctica since 1981. Polar research is crucial to understand the particle precipitation, high latitude and field-aligned currents, global electric circuit, secular variation of geomagnetic field, location of geomagnetic poles, crustal deformation

in the polar region etc. IIG has contributed to each of these research areas with its team of students and scientists. A number of experiments are being operated by IIG scientists at the Indian Antarctic stations, Maitri and Bharati.

- **Solid Earth Geophysics**: This division primarily focuses on understanding the Earth's surface and its interior with emphasis on the geodynamic evolution of various cratonic blocks, sedimentary basins, etc. through gravity, magnetic, magneto-telluric, geomagnetic depth-sounding techniques, etc. The near-surface geophysical and geochemical studies help to understand the groundwater potential in hard rock terrains, saline water intrusion in coastal areas, sources of geothermal springs, groundwater quality, etc. An integrated study of the coupling of the Lithosphere-Atmosphere-Ionosphere system through multi-parametric observations in the North East was initiated by IIG to detect the pre- and post-seismic signatures.
- **Palaeomagnetic and Environmental research:** IIG has modern palaeomagnetic and petrology laboratories equipped with modern instruments to study the magnetic as well as microscopic properties of rocks and minerals. The laboratory is active in the studies of Precambrian as well as Phanerozoic rock types to understand the movements of various cratonic blocs of the Indian sub-continent during different geological periods. The institute attaches great significance to the Lonar Lake in understanding its origin. Other studies include the paleoclimate from lake sediments, mineral magnetism leading to studies on pollution in different environmental setups, archaeomagnetism from archaeological artefacts etc.
- **High performance computing based research:** IIG hosts a high performance computing system supporting the studies that use computer simulations, artificial intelligence, and modelling of different nonlinear and complex phenomena occurring in the near space environment. Moreover, IIG scientists have used the simulation and neural network based models to investigate various space weather phenomena. Some of 2D/3D particle-in-cell, fluid and test particle simulation models are indigenously developed at IIG and they are used to model various magnetospheric processes in near Earth and planetary space plasma environments.
- **Instrument Development projects**: IIG has modern instrumentation labs providing technical support to run various experiments at its observatories and regional centres. One of the major achievements in the past has been the development of Proton Precession Magnetometer (PPM) with a sensitivity of 0.1 nT. The PPM is being supplied to Universities and other research organizations for field survey. Ultra-high input impedance (1015Ω) differential electrometers were developed in-house for a balloon experiment. A number of other in-house projects are currently under way. IIG provides services to the Indian defence organisations to for routine calibration of their magnetic compasses.

23.4 Major Scientific Applications / Results

- Coherent bipolar electric field structures that are found in various space and astrophysical plasmas play an important role in plasma transport and particle acceleration. A new theory has been developed incorporating electron dynamics so as to give a satisfactory explanation for the ion-hole observations by the Magnetospheric Multiscale Mission spacecraft. This new theory for ion holes can be widely applied to space and astrophysical plasmas. (Harikrishnan et al., 2020)

- The influence of east-west component of the interplanetary magnetic field (IMF-By) on ionospheric plasma convection over the polar region is well established by both observation and modelling studies. However, its influence beyond polar latitudes has rarely been addressed. To understand the effects of IMF-By at low-latitudes during geomagnetic storm times, simulation experiments using TIEGCM model have been designed. The strong IMF-By and its polarity were found to have effects on the storm-time ionosphere-thermosphere dynamics even near the equator. (Hui et al., JGR, 2021)

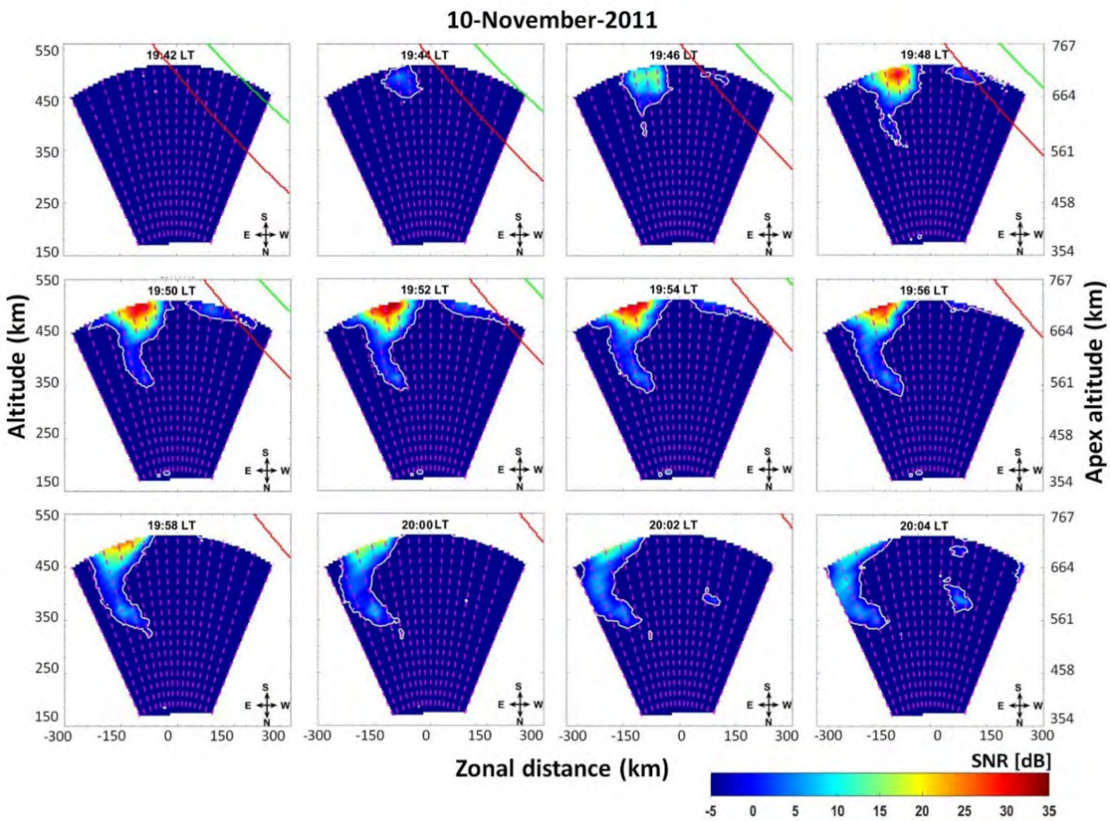

Figure 2: A unique observational evidence for the early development of 3-m scale irregularities initially at the topside region of an Equatorial Plasma Bubble and subsequently at lower altitudes.

- Study of the Equatorial Plasma Bubbles (EPBs) is important as these irregular density structures are capable of degrading the radio signal traversing through the ionosphere. Once developed, EPBs grow nonlinearly, and shorter scale irregularities are formed at the topside ionosphere. A unique EPB observation from Equatorial Atmosphere Radar that provides hitherto undisclosed evidence for the 3-meter scale irregularities initially developing at higher altitudes and subsequently developing to lower altitudes is reported, which would have significant impact on the latitudinal development of L-band scintillations. (Tulasi Ram et al., GRL, 2020)

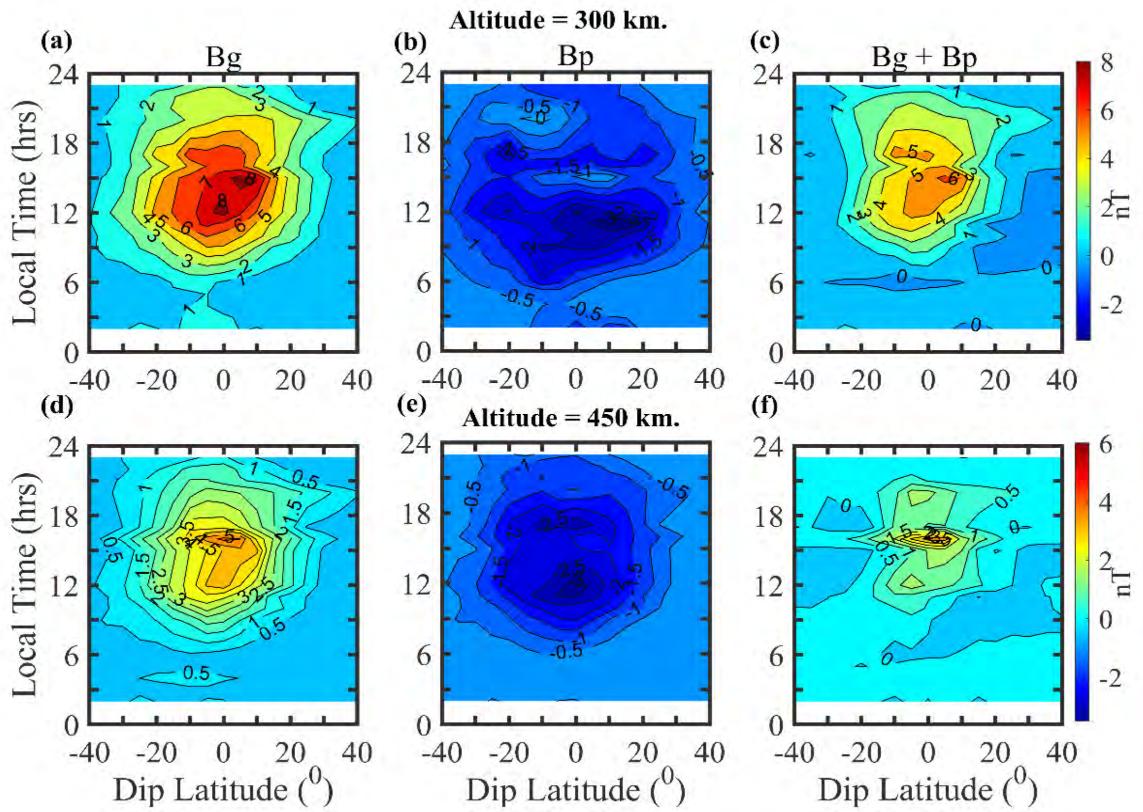

Figure 3: Local time structure of magnetic field variations due to gravity currents, pressure-gradient currents and sum of both at 300 km and 450 km in the top and bottom.

- It is well known that atmospheric pressure plays a vital role in the secondary cosmic rays (SCR) flux observed on the ground. Barometric pressure correction is a standard practice for neutron monitor data. For gamma-rays, however, being massless, their pressure dependence is not intuitive. Nevertheless, the pressure affects the particles such as electrons, positrons, muons, which produce gamma rays in the cascade. Subsequently, the indirect pressure dependence of the gamma-ray flux can be anticipated. We have examined this aspect in detail by studying the gamma-ray counts detected by the NaI (Tl) detector. (Datar et al., JCAP, 2021)
- The gravity and pressure-gradient currents have been estimated using altitude profiles of electron density obtained from the COSMIC satellite cluster. The study suggests that there is no need of correction for gravity and pressure-gradient currents in the magnetic field measurements by the LEO satellite if the satellite orbit is above 700 km, if the satellite orbit is during night to morning times, and if the satellite traverses during a period of low solar flux. (Sreelakshmi et al., JGR, 2020)

- Simulation studies revealed that the inner boundary of the radiation belt over the South Atlantic Anomaly (SAA) region is moving earthward and the earthward penetration of energetic particles has increased by ~480 km during period 1900-2020. Though the weakening of the geomagnetic field is not an impulsive phenomenon but can invoke serious concerns to our life, satellites, and climate in near future. (Soni et al., ASR 2021, Kakad et al., ASR 2021)

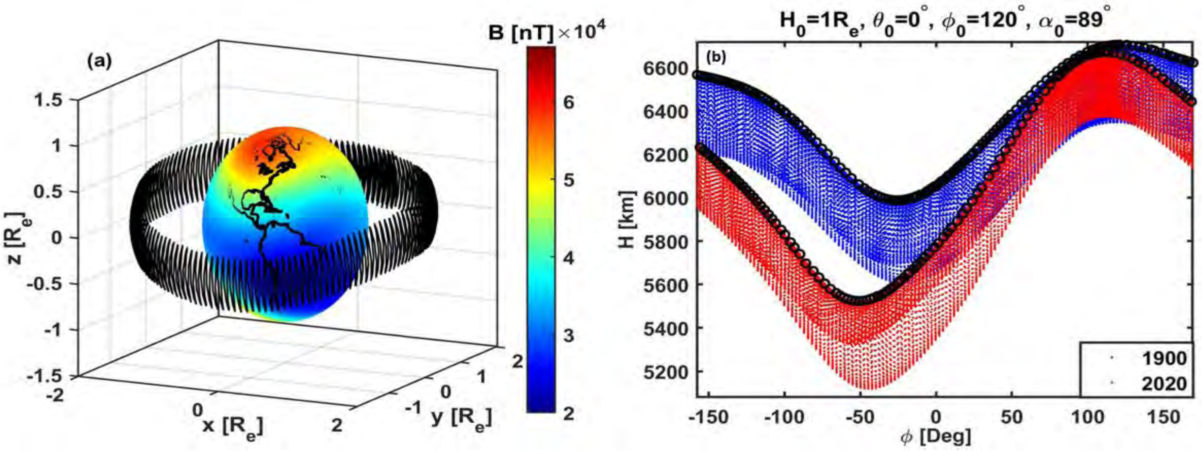

Figure 4: (a) The trajectory of a 10 MeV proton with a pitch angle of 890 initiated from [H0 =1 Re; θ = 00; ϕ =1200] in the Earth's magnetic field for 150 second. The colour bar represents the magnetic field intensity, and the proton trajectory is shown by the black ring. (b) Variation of the proton's altitude H=r-Re above the Earth's surface as a function of the geographic longitude for the years 2020 (red) and 1900 (blue). The black circles provide the upper boundary (Hu) of altitude variation and it represents the altitude of the proton associated with Bmin experienced by particles during their bounce motion.

- During a solar energetic particle (SEP) event, energetic electrons and ions flood the heliosphere causing severe damage to satellites, radio communication and humans in space. One such unique event, the largest of the solar cycle 24, was observed in September 2017 for which the energy spectra and quantification of the proton fluxes spanning from 1.5 to 433 MeV using multi-satellite observations is studied. It was found that multiple spacecraft observations are the key to quantify the temporal flux variability in terms of L-value, energy and MLT. (Pandya et al., JGR 2021)
- With the help of three THEMIS spacecraft, we simultaneously measured the nonlinear rapid evolution of the electromagnetic ion cyclotron rising tone subpackets within one wavelength, which is also comparable to the spacecraft separation. The cyclotron interaction between EMIC waves and counter-streaming protons generates these subpackets with increasing frequencies. Our study provides crucial information about the dynamics and the 3D extent of the subpackets. (Ojha et al., JGR, 2021)
- The storm induced disturbance winds and disturbance electric fields can cause the generation and evaluation of post-midnight Equatorial Plasma Bubbles (EPBs) and zonal drifts reversals even during weak magnetic disturbance. The results suggest that the cause of post-midnight EPBs could be due to manifestation of fluctuating eastward/

westward electric field due to combined under-shielding/over-shielding Electric Fields and disturbance dynamo electric fields that led to rise and fall of the F-layer over dip equator. (Gurav et al., ASR, 2021)

- It is shown that the plasma density over the EIA crest region increases in varying degrees during post-sunset hours (2000–2100 LT) in magnetically quiet periods. Comparison of average VTEC variations with global empirical model drifts reveals that the post-sunset enhancements in VTEC occurs ~1.7 h after the PRE and aresignificant only during December solstice and equinoctial months in high solar activity years similar to seasonal variations in PRE amplitudes. This time delay is almost half compared to the average response time (3–4 h) associated with the daytime fountain. (Kumar et al., JGR, 2021)
- The knowledge about future solar activity is necessary to plan our space-based missions. As yet, several prediction models have been developed to forecast the peak sunspot number. We have developed a new model to predict the peak of solar cycle 25 and sum of peak of solar cycle 26 and 27. The model suggests that the solar cycle 26 and 27 would be similar or slightly stronger than solar cycles 24 and 25. (B. Kakad et al., Solar Physics, 2020, Kakad et al., 2021)
- Another study brings out the exclusive role of solar wind density changes on the prompt equatorial electric field disturbances using the long term observations of equatorial electrojet (EEJ). In response to the sharp increases in the solar wind density, prompt increases/decreases in the EEJ indicating the eastward/westward PPEF of ~20 minute periods have been consistently observed on the day/night sides. (Nilam et al.,JGR, 2020)
- It is commonly believed that ion-acoustic solitons can only exist above the critical Mach number in a plasma system. A new class of ion-acoustic solitons that can exist below the critical Mach number is reported for the first time in a three-component plasma consisting of hot electrons, and two counter-streaming ion beams. The analysis is based on the Sagdeev pseudopotential technique, and considers a simple case of two counter-streaming proton beams with equal density and streaming velocity. (Lakhina et al., Physica scripta, 2020)
- The Earth's background free oscillations at ~3.7 and ~4.4 mHz resonantly couple with the atmospheric acoustic modes and thus energy cross-talk between the earth-atmosphere system is maximum at these frequencies. The present study proposes resonant coupling between the Earth's surface and atmosphere during the 11 April 2012 Sumatra doublet earthquake and offer a possible explanation to this occurrence. Following both these earthquakes, prolonged ionospheric oscillations centered at frequency of ~4 mHz were observed in GPS derived total electron content towards north-northeast of the epicenters. (Nayak et al., JGR 2021)

- In the Earth's inner magnetosphere, there exist regions like plasmasphere, ring current, and radiation belts, where the population of charged particles trapped along the magnetic field lines is more. These particles keep performing gyration, bounce and drift motions until they enter the loss cone and get precipitated to the neutral atmosphere. Our simulations demonstrate that the existing theoretical expression sometimes overestimates or underestimates the magnetic mirror point latitude depending on the value of L-shell, energy and gyro-phase due to underlying guiding centre approximation. (Soni et al., EPS, 2020)
- Ionospheric irregularities cause fluctuations (scintillations) in received satellite signal strength, degrading communication and navigation signals. The scintillation strength depends on the scale sizes of the irregularities and the frequency of the radio signal. The parameter S4 index describes the scintillation strength derived from the amplitude of high rate received signal sampled at 50 Hz, usually from special GNSS receivers. The correlation between occurrence percentages of S4 corresponding to ROTI are analyzed. This relation between ROTI and S4 will be beneficial in using standard GNSS receivers for the studies of ionospheric scintillations. (Kapil et al., ASR 2022)
- IIG is indigenously developing Overhauser magnetometer and proton precession magnetometer (PPM) based on the dynamic nuclear polarization. IIG has filed patent for developing low cost high precision PPM. These magnetometers have application in geomagnetic field variation studies, magnetic field surveys, detection of magnetic anomalies due to ferromagnetic objects and to calibrate low sensitivity magnetometers. IIG is also undertaking the development of a Fluxgate magnetometer. The development of a national magnetometer calibration facility is under way.

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23.5 Instruments / Payloads / Products Developed / Sensors / Detectors

- A **Proton Precession Magnetometer (PPM)** is a precision instrument that measures the scalar intensity of the local magnetic field and relies upon the proton-precession (low field Nuclear Magnetic Resonance NMR) measurement technique. PPM finds application in continuous geomagnetic field variation studies, magnetic field surveys, to detect magnetic anomalies due to ferromagnetic objects in the environment, to calibrate low sensitivity magnetometers. IIG has already been developing these magnetometers for the last three decades. The technology incorporated in this instrument is cost cutting and has been a good choice for budget conscious universities and colleges in India. Few publications are published in reputed journals and the technique is undergoing review for an Indian patent. (Patent No. 201621021949) (Mahavarkar et. al. "The low cost Proton Precession Magnetometer developed at the Indian Institute of Geomagnetism" Journal of Instrumentation, Vol-12, 2017)

Figure 5: IIG's PPM unit

- The **Overhauser Magnetometer** is a precision magnetic field measuring instrument based on the principles of dynamic Nuclear Polarization (DNP). It has the characteristics of high sensitivity and low power consumption. Compared to the traditional PPM, the Overhauser Magnetometer can achieve higher sensitivity with lower power consumption and faster sampling rate. At present, it has been widely used in geophysical exploration, mineral prospecting, volcano surveillance, weapons detection, underground buried objects, archaeological site mapping, ferromagnetic material identification, satellite magnetic survey etc. Based on the similar principle, IIG is in the process of developing India's first Overhauser magnetometer based on the Dynamic Nuclear Polarization technique. The experimental model has already been developed and the results are in good agreement with the commercial available magnetometer. Fine tuning of the experimental model to achieve the level of qualification model is in progress. It may be noted that these type of magnetometer's are only developed by two companies all over the globe.

- **National Magnetometer Calibration Facility**: A tri-axial coil system, which is a useful laboratory technique, is normally used to generate known magnetic field levels of specified volume and uniformity. These coils provide accurate means to perform numerous experiments and testing functions that require a known ambient magnetic field. The field generation can be either static, time-varying DC or AC or depending on the applications requirements. The tri-axial system along with a constant current source and data logger would complete the magnetometer calibration facility. This system generates uniform, accurate and precise magnetic fields in a volume about the center of the coil system and will serve as a calibration facility for both space and ground-borne magnetometer sensors. IIG is now upgrading the existing square Helmholtz coil system to a state-of-the-art Braunbeck circular coil system to enhance system performance by providing larger homogeneous volume and dynamic control of the magnetic field. The existing square Helmholtz coil system was used to calibrate a fluxgate sensor from VSSC and the results were published in one peer reviewed journal. In the same process windows data logger (nTlogger) developed in the institute was integrated with the Helmholtz coil system to log the data. (Mahavarkar et. al., “Tri-axial square Helmholtz coil system at the Alibag Magnetic Observatory: upgraded to a magnetic sensor calibration facility”, Geosciences Instrumentation Method Data Systems, Vol- 7,Page: 143–149, 2018)

Figure 6: Balloon payload undergoing field trial at Hyderabad

- **Electric field sensors developed for a high altitude stratospheric balloon experiment**: The primary goals of the Balloon Experiment on the Electrodynamics of Near Space (BEENS) were to probe and understand the processes that drive the various electric field sources at low latitudes and in that process generate a data base on stratospheric electric fields from a low latitude continental site. The instrument package developed and integrated for the BEENS experiment comprised of the 3-axis double probe electric field instrument, a 3-axis fluxgate magnetometer and a 3-axis search coil magnetometer (both commercially available). Though the first of the BEENS experiments was of exploratory type with the emphasis primarily on capturing the weak (1-5 mV/m) ionospheric dynamo electric fields, a surprising outcome from this experiment has been the finding of the presence of 10-15 mV/m horizontal electric fields during the post-midnight to pre-sunrise hours when the balloon was at the float altitude. With the magnetometer onboard providing useful reference, the direction and the magnitude of the observed electric fields were not representative of the ionospheric fields but appear to be of local origin, similar to the findings of earlier experiments conducted by Holzworth and his colleagues. (Gurubaran et al., 2017)

Figure 7. The BEENS payload to be flown on a balloon was ready for launch

- **Windows data logger for Magnetometers (nTLogger)**: IIG has 12 magnetic observatories running all over India and each observatory has 2 DFM's (Digital Fluxgate magnetometer) and PPM (or Overhauser). Earlier, the data logging system had to be procured as a bundle of hardware and software at the approximate price of Rs. 3 lakh per unit. Thus the institute had to depend on a particular vendor or hardware. To overcome this dependability, project was undertaken to develop a windows based data logger in house to record DFM's data and PPM data simultaneously. This project was completed successfully. Post completion, the data logger were installed in all observatories of the institute. Furthermore, the data logger can be custom-designed to be used with other sensors or instruments.
- **Automated Geomagnetic Absolute Measurement System**: AutoGAMS measures Absolute Inclination (I), Absolute Declination (D) and Absolute Total magnetic field (F). The horizontal field H and the vertical field Z are computed in real time from the above values. The sampling rate of the geomagnetic components D, H, Z, F and I is 2 samples per minute. The AutoGAMS system is being developed to function as an unmanned geomagnetic observatory system, which can take absolute observations, record geomagnetic data and transmit the data from the remote location, where it operates, to the control room.

23.6 Capacity Building in Space Science Research

- IIG conducts basic and applied research in Geomagnetism and allied fields like Solid Earth Geomagnetism/Geophysics, Magnetosphere, Space and Atmospheric Sciences. IIG has a number of active research groups involved in theoretical, experimental, and observational work. The Institute has a modern laboratory for design and fabrication of instruments used in Geomagnetism and allied fields. In collaboration with various

Universities along the length and breadth of the country, IIG offers Doctoral Programme in Geomagnetism and Allied Fields pertinent to studies of Space and Atmospheric sciences and Solid Earth.

- IIG has been engaged in capacity building activity for many years in space science and research. Currently more than forty students are engaged as Research Scholar and Research Associate in the institute. IIG also offers a post-doctoral programme besides the reputed **Nanabhai Moos Research Fellowship (NMRF)** programme.
- Apart from the regular course work, to attract, motivate and train young talent to undertake research in geomagnetism and allied fields, the institute has conceived the **Inspiring the Minds of Post-graduates for Research in Earth and Space Science (IMPRESS)** programme with an in-take of 25-30 post-graduate students from Indian universities every year. It is believed that IMPRESS will bridge the gap between universities and research institute and may provide knowledge resource covering a wide spectrum of topics with adequate field training and hands on experience.
- IIG has been actively involved in training international students under the SCOSTEP Visiting Scholar (SVS) programme. Similarly, students from IIG are visiting various other countries under the SVS program to get exposed to international research and laboratory experience, particularly in the developed countries.

23.7 Courses offered on Space Science and Technology

- Essentially, they are the Pre-Ph.D. courses offered by IIG for its Research Scholars, which are recognised by the Universities wherein IIG students register for their Ph.D. The Pre-Ph.D. courses cover a range of topics like Statistics & Signal Processing, Electrodynamics and Plasma Physics, Atmospheric & Ionospheric Physics, Geomagnetism, Applied Geology, Geophysical Prospecting, Geopotential Mapping, Environmental Geomagnetism, Earthquake Seismology, Lithosphere-Atmosphere-Ionosphere Coupling & Ionospheric Seismology, etc. The duration of the Ph.D. course work is typically six months, which will be divided into four months of theory followed by two months of project work. The in-take capacity of Ph.D. students by IIG is ~10.

23.8 National Collaborations in Space Science and Technology

Only those collaborations during the recent years are included here.

Sl. No.	Area of Collaboration	Collaborating Institute
1	Polar studies at Maitri and Bharati	National Centre for Polar and Ocean Research (NCPOR), Goa
2	High altitude balloon experiment	TIFR Balloon Facility, Hyderabad
3	Cosmic Ray studies	Mumbai University

Sl. No.	Area of Collaboration	Collaborating Institute
4	Solar-terrestrial physics	IISER, Pune
5	VLF studies	Tripura University, Tripura
6	Study of atmospheric electric field.	Indian Institute of Tropical Meteorology, Pune

23.9 International Collaborations in Space Science and Technology

Only recent collaborations are included below

Sl. No.	Area of Collaboration	Collaborating Institute
1	Cosmic noise absorption	Lancaster University, England
2	VLF studies	British Antarctic Survey, England
3	Auroral imaging at Maitri, Antarctica	National Institute of Polar Research (NIPR), Tokyo, Japan
4	Radiation belt dynamics and polar studies	RISH, Kyoto University, Japan
5	Lithosphere – ionosphere coupling mechanism	Institut de Physique du Globe de (IPGP), Paris
6	Atmospheric electricity and lightning	Massachusetts Institute of Technology, Cambridge, USA

23.10 Laboratories and Facilities Available for Space Instrumentation

- **National Magnetometer Calibration Facility at Alibag**: IIG is now upgrading the existing square Helmholtz coil system located at Alibag to a state-of-the-art Braunbeck circular coil system to enhance system performance by providing larger homogeneous volume and dynamic control of magnetic field.

Figure 8. Induction Coil Magnetometer Calibration Facility deployed at EGRL, Tirunelveli

- **High resolution magnetometer calibration system at EGRL, Tirunelveli**: The AC Magnetometer (Induction coil magnetometer/Search coil magnetometer) calibration facility was established during the year 2011 at Equatorial Geophysical Research Laboratory, Tirunelveli. The entire calibration facility is housed in an EMI/EMC compatible nonmagnetic hut (Faraday cage). This facility is utilised for calibration of induction / search coil magnetometers used for geomagnetic field survey and can be exploited for future space-borne missions such as high altitude balloon payloads, sounding rockets and small satellites.

CHAPTER-24

CENTER OF EXCELLENCE IN SPACE SCIENCES

Indian Institute of Science Education and Research (IISER), Kolkata

24.1 About the Institute

The Center of Excellence in Space Sciences India (CESSI) is a multi-institutional Center of Excellence hosted by the Indian Institute of Science Education and Research (IISER) Kolkata and has been established through funding from the Ministry of Human Resource Development. CESSI aims to explore the Sun's activity, generate the understanding necessary for space weather forecasting, hunt for gravitational waves, support national space science initiatives, participate in international capacity building activities and pursue public-private partnerships in space science research. The Center will take advantage of high-performance computing facilities, cloud computing and the high-speed National Knowledge Network grid to achieve its goals.

Head of the center: Prof. Dibyendu Nandi, email: dnandi@iiserkol.ac.in

24.2 Keywords

solar physics, star-planet interactions, space weather, space optics instrumentation, gravitational waves

24.3 Major Research Domains

1. **Solar physics**: CESSI has been involved in developing numerical models to study the effects of plasma flows on the evolution of magnetic field deep within the solar convection zone and on the solar surface.

2. **Star-planet interactions**: CESSI has developed a numerical model first time in India for studying the interaction between solar wind and planetary magnetospheres which is important for predicting environments of solar system planets and planning space missions.

3. **Space weather**: We at CESSI direct our efforts towards both predicting and analyzing the impact of space weather events through numerical simulations and multi-spacecraft observations. We use numerical models combined with observational data to study the large scale magnetic field of the solar corona, the dynamics of which is thought to be the main driver of space weather events.

4. **Space instrumentation**: One of CESSI's space optics instrumentation projects involves the development of a payload, the SUIT (Solar UltraViolet Imaging Telescope) onboard the Aditya-L1 mission, in collaboration with other institutes/organizations.

5. **Space mission support**: Using in-house numerical models, CESSI is providing support to missions such as Aditya-L1, Chandrayaan-2 and upcoming ones to Venus and Mars.

6. **Gravitational waves**: At CESSI, we are also working on gravitational wave data analysis where we use statistical techniques to extract and analyze the signals detected by instruments like LIGO. We also provide support to the LIGO-India mega project for deploying a third LIGO detector in Indian soil.

24.4 Major Scientific Applications / Results

- First century scale, data driven simulation of solar magnetic cycle and a model-based ensemble prediction of sunspot cycle 25 indicating that space radiation environment and upper atmospheric forcing over next 10 years is going to be similar to that observed during solar cycle 24. No Maunder-like grand minima expected in solar activity.
- Development of the first magnetohydrodynamic star planet interaction module in India which has the capability to model and simulate the solar forcing of the Earth's magnetosphere and the magnetosphere and atmosphere of other solar system planets
- Development of an unique model with the solar wind, Earth and moon in the same system to simulate the lunar space environment during its orbit around the Earth.
- Development of Machine Learning and Artificial Intelligence based operational solar flare forecasting techniques.
- Development of the first comprehensive space weather assessment and prediction Center in India
- Involvement in the detection of the first binary black hole merger event from LIGO
- Involvement in the first detection of a black hole neutron star merger event with LIGO-VIRGO network.

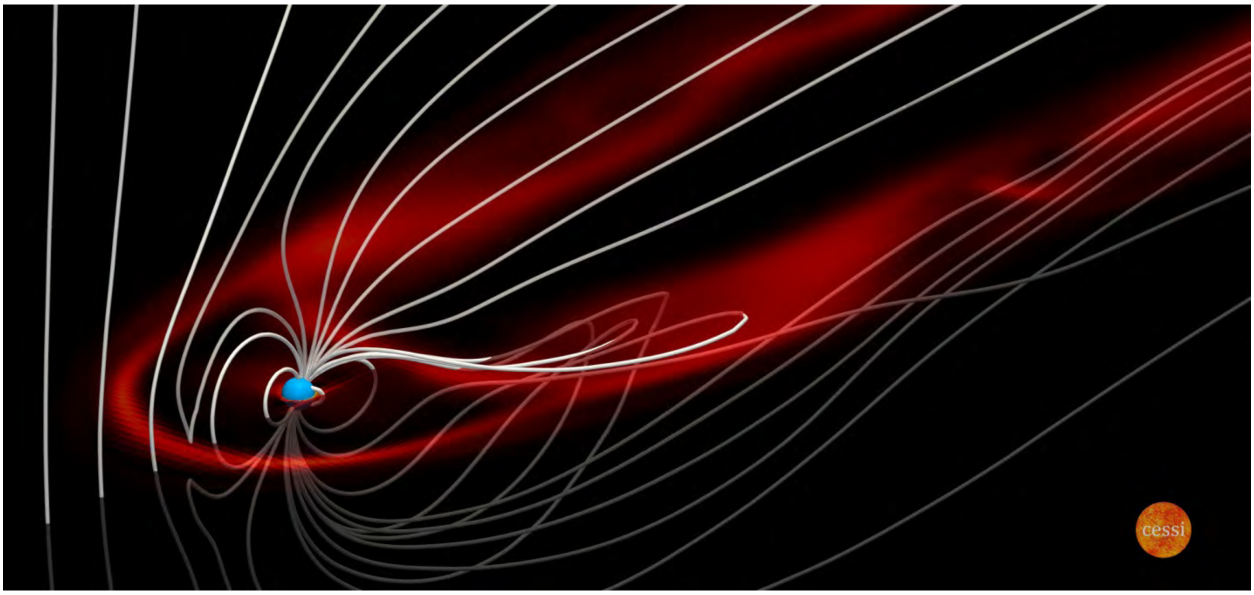

Figure 1: A numerical simulation showing a 3D view of the Earth's magnetosphere (white field lines) shaped by the solar wind. The red color depicts regions of high current formed due to the interaction. The Earth is marked using a blue sphere. Credits: CESSI.

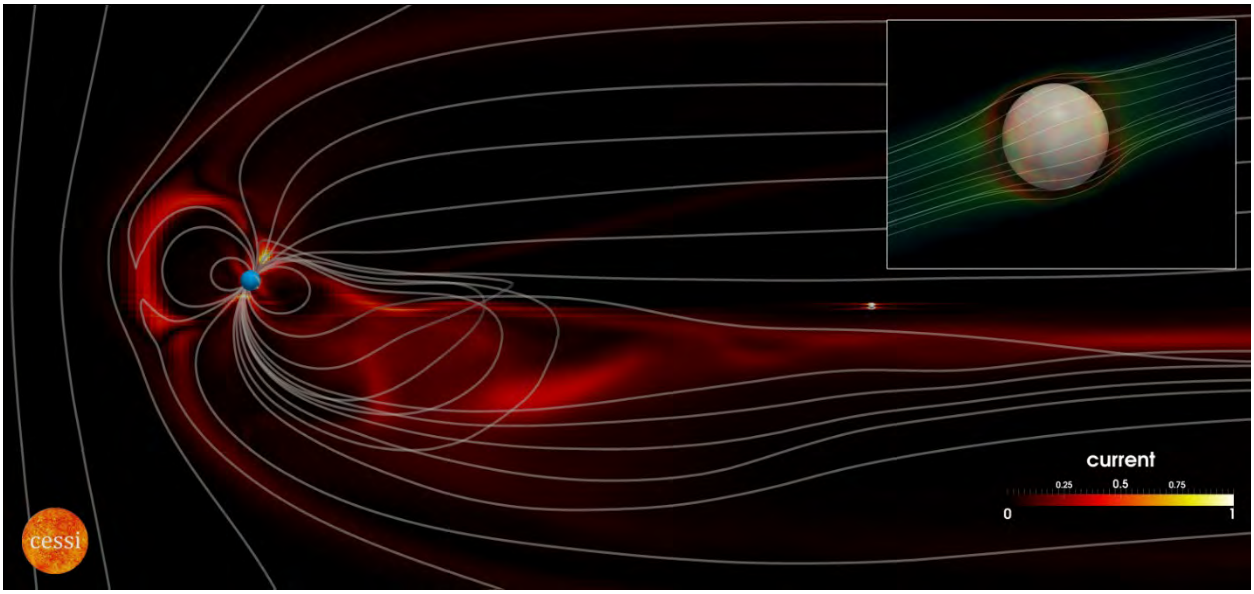

Figure 2: A 3D simulation of solar wind interaction with the combined Earth-Moon system during a full moon event. The field lines are plotted in white while the colormap represents current density. The Earth and Moon are depicted using blue and white spheres respectively. The inset shows the configuration of magnetic field lines in the lunar vicinity. Credits: CESSI.

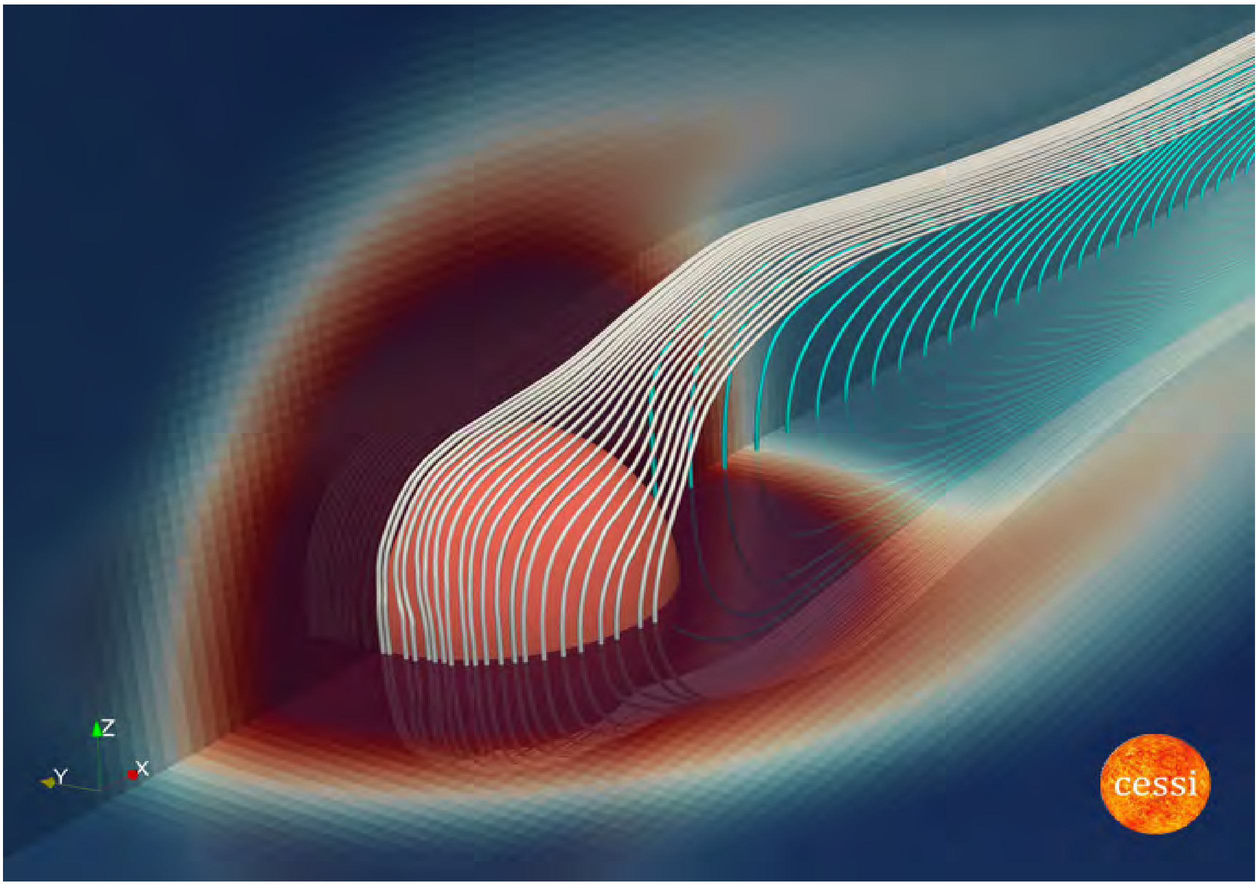

Figure 3: A 3D simulation showing the formation of an imposed magnetosphere around Mars (marked using red sphere) due to interaction with the solar wind. The colormap depicts loss of the planetary atmosphere. The white and blue field lines are at the day and night sides respectively. Credits: CESSI.

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24.5 Instruments / Payloads / Products Developed / Sensors / Detectors

1. At CESSI, we are developing a space optics instrumentation laboratory. CESSI personnel are also involved in the development of a payload, the SUIT (Solar Ultra Violet Imaging Telescope) onboard the Aditya-L1 mission, in collaboration with other institutes/organizations which is being led by IUCAA
2. CESSI has developed numerical models for studying plasma flows in the solar convection zone and solar corona.
3. The machine learning (ML) algorithm of CESSI is able to forecast flares and coronal mass ejections from the Sun which is important for space weather.
4. For the first time in India, CESSI has developed a star-planet interaction module which is essential for understanding planetary environments and planning space missions.

24.6 Capacity Building in Space Science Research

Programs offered by CESSI are as follows.

PhD in space physics: The goal of the doctoral program is to train future generations of space scientists who are equipped with the necessary skills to lead national and international endeavours in the astrophysical space sciences. Students interested in pursuing research in space science and allied fields of interest to CESSI can apply for PhD positions.

MS in space physics: The program aims to attract highly motivated B.Tech. and B.E. students with an engineering background who are desirous of contributing to fundamental research and mission-development in space sciences. The courses in this degree are aimed towards equipping students with the basic knowledge for tackling research problems in astrophysics.

Scientists from reputed institutes within India and abroad visit CESSI year round to deliver lectures and explore research collaborations. CESSI cultivates an open academic atmosphere wherein students are encouraged to take advantage of the ensuing interactions to forge scientific collaborations across institutional borders.

Statistics of students are given below.

Current PhD: 11

Current BS-MS: 5

CESSI alumni (including PhD, MS, BS-MS and Postdoc): 46

24.7 Courses offered on Space Science and Technology

1. Courses taught by CESSI faculty at IISER Kolkata:
2. Introductory Astrophysics (PH4102)
3. Space Astronomy (SS4101)
4. Fluid and Magneto-hydrodynamics (SS4201)
5. General Theory of Relativity and Cosmology (PH4205)
6. Computational Physics (PH3205)
7. Advanced Electricity, Magnetism, and Optics (PH4107)
8. Advanced Optics Laboratory (PH4201)
9. Atomic and Optical Physics (PH4212)
10. Mathematical Methods of Physics (PH3103)

24.8 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	Space weather	ISRO URSC
2.	Space weather	USO-PRL Udaipur
3.	Space weather	IUCAA Pune
4.	Space weather	IISER Pune
5.	Space weather	ARIES Nainital
6.	Space weather	IIT Indore
7.	Space weather	IIA Bengaluru

CHAPTER-25

INDIAN INSTITUTE OF TECHNOLOGY (BHU)

Varanasi

25.1 About the Institute

IIT (BHU) Varanasi has a rich history of space science research since last several decades in various sub-fields of Astrophysics, Space science and application (e.g. Solar Physics; Space and Atmospheric Plasma Physics; Planetary Magnetospheric Research, Image processing etc). The inherited research culture is now cultivated and strengthened to form a globally visible group in the field of Astrophysics and Space science covering a diverse range of research topics starting from solar and heliospheric physics to galactic/extragalactic astronomy and cosmology, and remote sensing application in the field of water resources and agriculture. The group members pursue front-line research problems in their respective fields, and are also involved in various ongoing national and international research programmes. They are also involved in extensive teaching and training of adept researchers that may further serve the ongoing/upcoming national & international programmes (e.g. science and technological developments related to space and ground-based observational facilities spread across our country).

Regional Academic Centre for Space (RAC-S) at IIT(BHU) has been established with collaboration of ISRO. The RAC-S shall pursue advanced research in the areas of relevance to the future technological and programmatic needs of the Indian Space Programme and act as a facilitator for the promotion of space technology activities in the central region comprising the states of Chattisgarh, Madhya Pradesh, and Uttar Pradesh.

25.2 Keywords

Physics of the Sun's Atmosphere, Dynamo Theory, Solar Cycle and Extended Solar Cycle, Solar Transients And Magnetohydrodynamic (MHD) Wave, Coronal And Stellar Seismology, Stellar Physics, Galactic/Extragalactic Astronomy, Radio Interferometric Technique, Cosmology-Cosmic Microwave Background (CMB), Liquid Propulsion, Hyperspectral Imaging, Water Resources Management, Radiative Transfer Models, Land Surface Temperature, Machine Learning, Mobile Robot, Microwave Engineering, Antenna, Transceiver Designs, Image Processing, VLSI Techniques

25.3 Major Research Domains

Astrophysics and Space Science

- Origin of the solar magnetism through dynamo modeling;
- Solar and stellar cycles, their variability and prediction of solar cycle;

- Understand the dynamics of convective flows inside the sun.
- On solving the paradox of Sun's coronal heating;
- Magnetohydrodynamic (MHD) waves and oscillations and Solar Magneto Seismology (SMS)
- Solar Eruptive Phenomena and Transients
- On forecasting the space weather events; Solar-Stellar connection: Towards establishing an analogy in understanding the stellar flares and magnetic activities.
- To isolate this cosmic signal buried in the plethora of astrophysical and cosmological signals that are registered by a detector.
- Extraction of its power spectrum reliably for its use in estimating cosmological parameters that describe our universe.
- Studying the statistical properties of the CMB thus extracted.
- Studying and addressing the fundamental questions of the structure formation in the universe, to the dynamics and structure of the galaxies and its relation to star formation.
- Radio Astronomy

Remote Sensing & Geo-spatial science

- Application of machine learning techniques on multi-sensor onboard satellite dataset.
- Understanding the scattering mechanisms of microwaves.
- Analysis of river thermal pattern and characteristics of surface water bodies.
- UAV based photogrammetry for development of DEMs and their accuracy assessments.
- Application of Remote Sensing in surface and groundwater modelling.

Space related instrumentation and technologies

- Design, modeling and characterization of frequency selective devices
- Design and implementation of antennas and receiver systems for space related applications
- Metamaterial absorbers for multi-frequency applications
- To develop the high specific strength PH-stainless steels used in liquid propulsion applications (LPSC). This class of material can be used for numerous critical components and sub-systems in launch vehicles.
- Development of thermomechanical processing route to improve strength and sub-zero impact toughness in the precipitation hardenable stainless steels,

- Development of a low cost-efficient, and lightweight catalytic reactor system that can work in moderate temperature and pressure conditions and can be used for efficient methane fuel production on Mars surface using its atmospheric CO2.
- Development of a data-driven free-will algorithms to execute precision tasks in unstructured environments and visual Simultaneous Localization and Mapping (SLAM) algorithms for autonomous mobile robotic manipulator control.
- Study on structure-property-processing correlations for precipitation hardenable stainless steels used in liquid propulsion applications (LPSC)

25.4 Major Scientific Applications / Results

- At IIT (BHU), there exists a globally visible Astrophysics and Space Science Group. The group is extensively involved in the solar physics, stellar physics, star formation, radio astronomy, and cosmological studies.
- The group has devised new science regarding dynamo modelling; solar cycle and extended solar cycle. It has also put forward a multitude of novel scientific results about the discovery of high-frequency torsional Alfven waves, pseudoshocks, Alfven pulse driven spicules, magnetic instabilities, forced reconnection, as well as certain aspects of solar eruptive phenomena and jet formation, etc.
- Many of these newly derived science are having wide acceptance and utilization in the national and international community, and act as a ready reference for the science aimed by different ground (e.g., 4m-DKIST, 1m-SST, ROSA, upcoming 2m-NLST, 4m-EST, etc) and space (Hinode, SDO, IRIS, upcoming Solar-C, Aditya-L1, etc) based observatories.
- Monitoring of land use/land cover, landscape dynamics and land surface temperature based on machine learning techniques using multi-sensor onboard satellite dataset.
- Understanding the scattering mechanisms (both monostatic and bistatic modes) of microwaves (L, C and X bands) with crop growth variables and soil surface parameters using ground based scatterometer and multiple orbiting satellites.
- Effect of incoming polluted waters on the river thermal regime along with effect of the geomorphological controls and River-Aquifer exchanges over the river thermal characteristics.
- Application of Remote Sensing as an input data source in surface and groundwater modelling.
- Antenna, Polarization Converters, Filters, Phase Shifters. The structures are extremely useful for the microwave and higher band communication systems.
- SAR antennas or communication terminals

- Flat panel beam steerable reflect array antenna system.
- Ceramic matrix composites (CMCs)
- FPGA implementation of Algorithms

25.5 Instruments / Payloads / Products Developed / Sensors / Detectors

- Various antennas, polarization converters, absorbers have been developed and characterized in the Microwave Metasurface Lab. Multiple frequency selective surfaces have also been reported in mm-wave and terahertz domain.
- Developed a customized wearable prototype with a photoplethysmographic sensor to acquire pulse signals from the fingertip. The data-acquisition process follows the recording set-up of the Physionet MIMIC standard. The real-time signal processing of biosignals is performed on a single-board computer.
- Designed and developed a wearable internet of medical things (IoMT) device for fetal ECG monitoring.
- Prototype sensor and sensor array
- Software models of sensors developed using COMSOL and Verilog-A.
- Sensor readout circuit: design and topology
- Developed a Technology for Defence Avionics Research Establishment (DARE), DRDO, Bengaluru
- The astrophysicists from IIT (BHU) are taking part in the science teams/scientific works related to various upcoming/existing missions, e.g., Aditya-L1, 2m-NLST, CMB Bharat, GMRT, SKA, etc.
- They are extensively engaged in large-scale data analysis and computer modeling. The high-specification servers, data analysis and modelling facilities are in place in the group to facilitate the research and development.
- Optimization of CVD reactor at VSSC
- FPGA implementation of OTFS algorithm

25.6 Capacity Building in Space Science Research

- IIT(BHU) systematically executing capacity enhancement program in space science research concerning new research infrastructure, human resources, intellectual property rights, and collaborative research.
- Regional academic centers for space play a key role to strengthen the involvement of academia in various ISRO programs. It would support the overall space-related activities of our institute.

- The astrophysicists from IIT (BHU) are involved in the front-line research, teaching and training in the field of solar physics, astrophysics, and cosmology, solar coronal heating, origin of magnetic field in sun, probing the H-I region in the universe, star formation, CMB theory, etc.
- To sustain and grow the research in the astrophysics and space science, the Astrophysics & Space Science group perform a multitude of academic activities including publishing the research in high impact peer-reviewed journals.
- The faculties working in this area of research are involved in teaching and training of the Ph.D. and Master students. The various courses are specifically designed in the curriculum of the institute where the various aspects of astrophysics and space science are being taught.
- The various projects are offered to the under-graduate and master students to teach them basics of Astrophysics & Space Science, and to develop different skills among them.
- The outstanding contributions of the group in various academic, research, and capacity/ skill building fetched in various national awards in the group, e.g., INSA Young Scientist Award; Best Teacher Award; Laxminarayana & Nagalaxmi Modali Award, etc.
- The workshop, conferences (e.g., Dynamic Sun: I), teaching courses (e..g, GIAN) are being organized to develop and popularize the scientific components, and inherit the collaborative aspects.

25.7 Courses offered on Space Science and Technology

Intake capacity in each UG course is Capacity 100 in PG around 15. Total Lectures around 36 in each course.

- Microwave Communication,
- Microwave Measurements
- Fault-Tolerant Digital System Design, Advanced Digital Image Processing,
- Digital Communications, and Telecommunication Networks.
- LSI/VLSI Design course: Design of sensor readout electronics
- Microwave Communication System: LOS and Troposcatter Systems
- Solar and Space Plasma Physics
- Magnetohydrodynamics
- Space and Solar Physics
- Physics of the Sun and Its Atmosphere
- Fluids and Plasmas

- Remote Sensing, GIS and Application of Geoinformatics
- Astronomy and Astrophysics
- General Relativity and Cosmology
- Space Weather
- Modeling and simulation of material processing

25.8 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1	Design and Manufacturing	IIITDM, Jabalpur
2	Inference of Solar Variability across Scales	Indian Institute of Astrophysics (IIA), Bengaluru Udaipur Solar Observatory (USO), PRL.

25.9 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1.	Space Application-Remote Sening	The Ecole Normale Superieure De Lyon (ENSL), France

The scientists at IIT (BHU) are participating in a variety of international collaborations across the globe and leading different prestigious scientific networks (e.g., IUSSTF, UKIERI, etc). They are involved in many bi-lateral/multi-lateral international research cooperation (e.g., Indo-US, Indo-UK, Indo-Russian, Indo-Austrian, Indo-Bugarian, Indo-German, etc).

25.10 Laboratories and Facilities Available for Space Instrumentation

- Metasurface Lab in IIT (BHU) is available for simulation and prototype characterization of various frequency selective surfaces developed inhouse. A handheld Vector Network Analyzer is available operating till 44 GHz. The lab is now focused to extend its utility up to mm-wave band.
- Geoinformatics lab established to work on the challenges related to GIS, Remote Sensing, Mathematical Modeling, WebGIS, Machine Learning and Data processing.
- Sensors and systems lab facility and PCB prototyping machines are available with the Department of Electronics and Communication Engineering, and central instrument facility IIT(BHU), respectively. This lab is focused on the design of the sensors-based system using digital techniques and instrumentation. A variety of tools and development boards are available for implementing various experiments based on sensors, sensor networks, Internet of Things (IoT), and smart systems for efficient systems for Cyber-Physical Systems (CPS) and Robotics.

- Anechoic Chamber 700-25 GHz, Portable VNA, Spectrum Analyser, and Milling machine
- High-specification computational servers in Astrophysics and Space Science Research group to perform the large-scale data analysis and modeling of solar data, CMB data, radio astronomical data, as well as MHD simulations and computer modeling.
- Microelectronics lab for sensor fabrication and measurement
- SEM/TEM for sensor characterization in the central instrument facility (CIF) IIT BHU
- VLSI lab for design of devices and circuits which has tools like, Synopsys EDA and TCAD, Cadence EDA etc.

List of Publications

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CHAPTER-26

Department of Aerospace Engineering

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

This document summarizes various research areas in which the faculty of Aerospace Engineering department has contributed in recent past as well as potential topics related to space research where the faculties can contribute in the future.

26.1 Aerodynamics group

Aerodynamics faculties can contribute in the following topics relevant to ISRO's future missions:

Aeroacoustics: The study of flow-generated noise, as relevant for understanding and mitigating the extremely high-amplitude pressure oscillations during rocket launch.

Thermoacoustics: The study of large-amplitude oscillations in pressure/thrust that arise due to the coupling of the heat release rate fluctuations with or more of the acoustic modes of the rocket combustion chamber (also called combustion instability). Specific areas of expertise

1. Modelling: L* instability, azimuthal mode instability, vortex driven instability.
2. Damping estimation: From pressure/thrust measurements.
3. Modal analysis: Identifying natural mode shapes and frequencies of complex combustor geometries
4. Impedance measurement: Using impedance tube technique

Supercritical flows: Numerical simulation (LES/RANS) of jet flows through injectors at supercritical/transcritical conditions taking into account real gas effects in OpenFOAM. Mixing studies and reaction of supercritical/transcritical CH_4/O_2 and H_2/O_2

26.2 Propulsion group:

Recent contributions to ISRO's programs from Propulsion group:

Demonstration and feasibility studies on Pulse Detonation Rocket Engine (PDRE) technology – A detonation tube is developed and the pressure profiles in the detonation chamber were obtained. Deflagration to detonation was also successfully demonstrated.

Work on arc heated wind tunnel – Development of flow solver to simulate arc in tunnel and study of heat transfer to the flow for high enthalpy hypersonic flow experiments.

Spray-acoustics interactions – Experimental work on the acoustically excited swirl coaxial atomizer in the context of combustion instabilities in semi-cryogenic engine. Provided important guidelines on the frequency response of the spray, analysis of nonlinear interactions, and measurement of spray statistics in the presence of acoustics.

Possible future research themes in the context of ISRO:

Propulsion faculties can contribute in the following topics relevant to ISRO's future missions:

1. Development of particle in cell (PIC) codes to study the instabilities observed in hall thrusters
2. Atomization, droplet spray combustion studies on metallized gel propellants
3. Spray combustion – acoustics with cryogenic propellants
4. Development of new atomizers, testing and analysis for deep throttling engines
5. Simulation methodologies for super/trans-critical fluids injection, mixing and combustion studies using open source CFD packages
6. Novel propellant development, Combustion and instabilities studies on solid rocket motors
7. Simulation of hypersonic internal/external flows with in-house solvers
8. Aerothermal analysis, thermal protection system analysis for reusable hypersonic vehicles

26.3 Structures group:

Past contributions to ISRO's programs from Structures group:

High strain rate materials testing

Possible future research themes in the context of ISRO:

Structures group faculty could contribute in the following topics relevant to ISRO's future missions:

1. Erosion modeling in thrusters
2. Structural mechanics of space frame helical structures
3. Impact modeling and crater formation
4. Fracture and failure modeling of advanced composite materials
5. High strain rate material characterization

26.4 Dynamics and Control group:

Thousands of satellites are getting launched and all have limited lifetime. After the active life, these objects become a threat for the existing satellites. These dead satellites may also have angular speed. There is a need to track, capture and deorbit these objects. To capture precise position and estimation is required. Environment of planets is not well modelled and this poses a challenge when landing missions are envisaged. Using multiple sensors reliable information about satellite motion can be estimated, in turn leading to controlled successful landing.

In the area of dynamics and control related to space applications, the following topics can be investigated:

1. Constrained spacecraft/satellite attitude control
2. Attitude control and synchronization of spacecrafts, including fault tolerance with respect to actuator failures
3. Rendezvous and docking of satellites
4. Trajectory optimization of reusable launch vehicle
5. Tracking of space debris and removal.
6. Fusion of Imaging, RADAR and LIDAR Sensors for Landing Application on other planets
7. Fusion of Imaging, RADAR and LIDAR Sensors to estimate position velocity and attitude states for Space Docking.
8. Autonomous Formation Flying.
9. Landing of Space Flight Vehicle in Unknown Terrain with Demonstration using UAV
10. Loosely/Tightly Coupled NavIC/IRNSS with IMU
11. Safe Landing of Impaired RLV
12. Integrated Control of Airbreathing Hypersonic Vehicle and Scramjet Engine with Vehicle Guidance

CHAPTER-27

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

KANPUR, UTTAR PRADESH

27.1 About the Institute

Indian Institute of Technology Kanpur, established in 1959, is one of the premier institutions established by the Government of India. The aim of the Institute is to provide meaningful education, to conduct original research of the highest standard and to provide leadership in technological innovation.

ISRO-IITK Space Technology Cell was established on March 02, 2001 to enhance Research & Development efforts towards a truly self-reliant and self-generating Space Programmes for our nation. The recently established Department of Space Science and Astronomy will be devoted to the broad field of Space, Planetary, Astronomical Sciences and Engineering.

Apart from this, various faculties and research students associated with different Centers and departments also conducting research on frontier areas of space technology.

27.2 Keywords

Remote sensing, GaN HEMT, Thermal design, Planetary atmosphere, Aerosol optical depth, Black carbon, Cloud Condensation Nuclei, QPO.

27.3 Major Research Domains

Space Science: Physics of the ionosphere and magnetosphere, meteorology, dynamics of the atmosphere, geophysics, geology; astronomy, cosmology, astrophysics, planetary and interplanetary space physics and climatology.

Space Technology: Rocket and satellite technology, propulsion systems design and optimization, aerodynamics and heat transfer problems related to space vehicles, guidance and control systems for launch vehicles and spacecraft; polymer chemistry, propellant technology, ultra-light-weight structure, satellite energy systems, space electronics, Space communication systems, orbital mechanics, computer sciences and new material development.

Space Application: Remote sensing of the earth's resources, space communication, satellite geodesy image processing, satellite meteorology including weather forecasting, Space Education and Ecology.

- **Studies on Planetary atmosphere:** Aerosol characteristics, calculation of ion–aerosol attachment coefficient, aerosol charging, and consequences of aerosol charging in planetary atmospheres is important.
- **Aircraft measurement:** Black carbon (BC) aerosols are strong absorber of the solar radiation in the visible and near-infrared wavelengths contributing significantly to positive radiative forcing. During an extensive aerosol field campaign as part of ISRO-GBP program, aircraft measurements of vertical profiles of aerosol black carbon (BC) were made during winter, for the first time, at Kanpur, an urban industrial location in Northern India.
- **New particle formation:** Ultrafine particles are ubiquitous in the Earth's atmosphere and have received increasing attention because of their possible impacts on global climate and health.
- **Surface measurement:** Collocated measurements of particle mass, particle number size distributions, aerosol optical properties, e.g., aerosol optical depth (AOD), Angstrom exponent a, single-scattering albedo (SSA) measured by sun/sky Space Science Exploration and Research in India radiometer, were carried out at Kanpur. Direct measurements of all the aerosol parameters reduce the uncertainties in the regional aerosol model, and hence are important to further the state of the art on role of aerosols in influencing atmospheric conditions.
- **Aerosol behavior in primary heat transfer system:** The Nuclear Aerosol Facility (NAF) is well equipped with all the instrumentations to perform the experiments to observe the aerosol behavior like aerosol growth, deposition, resuspension etc.
- **Numerical simulation:** Studies on the transport, evolution and deposition of aerosol particles in PHT and in containment are supplemented by the understanding of aerosol dynamics and complex processes. Not only the interaction is two phase, particle-particle collision for a multi-size aerosol spectrum requires advanced simulation methods and codes. The uncertainty of such computer simulations can be reduced by experimental validations only. This approach augments the analysis of thermal hydraulics, structural designing, safety system evaluation and finally the estimation of environmental source term in an event of severe accident. Experiments in test piping section is used to estimation retention factors which were validated with simulations performed with ASTEC code.

27.4 Major Scientific Applications / Results

Major results and scientific applications of various research work relevant to space research are detailed below:

❖ Planetary Atmosphere

The generation of dust in the atmosphere of Mars and some of the interesting characteristics about the dust activities on Mars have been analyzed. The presence of CO, and water ice clouds on Mars has also been mentioned. Despite being different in a number of ways, the atmosphere of Titan is very similar to that of the Earth mainly due to the presence of N_2. The haze formation in the atmosphere of Titan at various altitudes have also been analyzed. Recent spacecraft observations were able to point out the presence of methane clouds in the atmosphere of Titan. The dust storms on Mars can be classified into three types according to their sizes. The largest type is the planet-encircling storm, which engulfs all longitudes of the planet. These storms are also known as global or planet-wide storms. The second type is the regional storm with an affected area of more than 2000 km, and the third type is the local storm with an affected area of less than 2000 km. Titan possesses an atmosphere that is often compared to that of the Earth as it is composed mainly of N_2. It also possesses CH_4, and a wealth of organic materials. A well-defined haze structure has been observed on the Titan since the Voyager era.

❖ Aircraft measurement Black Carbon (BC)

Two vertical profiling from the same day (morning and afternoon) of BC showed that BC decreases with height up to 600 m and then increases up to 900 m before becoming more or less constant with height. Potential temperature profile, derived from concurrent measurements of temperature, shows a stable layer at the same altitude where BC shows increased concentration. This vertical structure of boundary layer was further confirmed by separate temperature and relative humidity profiles obtained from balloon sondes during December. The increased BC at 900 m suggests the presence of enhanced BC layer, which will have significant implications to BC radiative forcing and modifying cloud properties.

❖ CCN Measurements

In-situ aircraft measurements of cloud condensation nuclei (CCN) and aerosol size distribution were carried out over the region spanning from 24.78 °N to 29.5 °N and 78.1 °E to 85.0 °E from June 29 to July 3, 2009 during the Indian Continental Tropical Convergence Zone (CTCZ) campaign, consisting of total 9 flight sorties. CCN measurements were conducted at a constant supersaturation (SS) of 0.84%. It was found that at higher altitudes (4.7–6.7 km), 30 nm sized particles were dominating while at lower altitudes (0.6–3.7 km), 50 nm particles. Overall, CCN closure ratio (CCNpredicted/CCNmeasured) at different altitudes using Köhler theory and assuming pure ammonium sulfate was 1.375 (R2 = 0.80). For each sortie, the closure ratio varied with height and depended greatly on measured CN concentrations

❖ New Particle Formation

Various in situ measurements show evidence of new particle formation over a wide range of latitudes in the middle to upper troposphere and lower stratosphere. However, the exact mechanism of new particle formation is still uncertain. Using a combination of satellite-derived brightness temperature, air parcel backward trajectory information, in situ measurements of aerosol and precursor gases and an aerosol microphysical model driven by parameterized ion-induced nucleation, we investigate the mechanism responsible for, and factors leading to, new particle formation in the middle to upper troposphere during the Tropospheric Ozone Production about the Spring Equinox (TOPSE) experiment.

❖ **Aerosol physical, optical and chemical properties**

Aerosol optical and physical properties show marked differences during foggy/hazy and clear conditions; aerosol mass and number concentration are significantly higher during the foggy/hazy days because of the existence of stable shallow boundary layer and plausible contribution to pollutant loads due to anthropogenic activities. Collocated measurements of a number of atmospheric and aerosol parameters along with simultaneous sampling of near surface aerosols of size less than 10 mm (PM10) were made as part of an intense field campaign launched under the Indian Space Research Organization Geosphere Biosphere Program (ISRO-GBP).

❖ **Astrosat**

Using the unique capabilities of AstroSat, it is found that the Quasi Periodic Oscillations (QPO) seen in the source GRS 1915 + 105 can be identified with stationary modes of the accretion disk. This result is very exciting since the data is able to probe the physics of the source very close to the central black hole and hence provide unique opportunity to test the general theory of relativity in the strong gravity regime.

27.5 Instruments / Payloads / Products Developed / Sensors / Detectors

- Microstrip patch antennas are fabricated for single-band, dual-band and multi-band operation, along with fabrication of frequency-selective surfaces (stand-alone and integrated with antenna)
- Heat Flux sensor – E and K type thermocouples for convective heat transfer measurement in hypersonic flows was developed in house
- Small coupons of ultra-high temperature ZrB2-HfB2-bsed ceramics were fabricated
- Joining technology of the ultra-high temperature ceramics is developed (with Ni-based fillers and filler-less sintering)
- UAVs – fixed wing, rotary wing, VTOL
- Camerasandsensors:Optical,multispectral,thermal,hyperspectral,spectroradiometers, water quality sensors
- Surveys: Total station, DGPS, Terrestrial laser scanners, inflatable boats, ADCP
- Software: Agisoft, Lastools, Topotools, QGIS, ArcGIS.
- Industry standard SPICE model and PDK for GaN HEMTs

- Industry standard SPICE model and PDK for bulk and High voltage MOSFETs
- Power Amplifier, Low Noise Amplifier and RF Switch for Space Electronics
- Load Pull Characterization
- Fluid flow and thermal solvers has been developed for ISRO: The name of the code is "Non-equilibrium Flow Solver (NFS)". The NFS code was transferred to ISRO.
- The other solver developed is a thermal response solver, Charring Ablator Thermal response Solver (CATS), which can be employed for TPS design and reentry thermal analysis. The coupled solver is transferred to ISRO.
- Coupling DSMC code with in-house Discrete Element Method (DEM) based code for modeling dusty-gas flows is also being studied. This DSMC-DEM coupled solver will be employed for planetary landing applications.
- The Aethalometer (AE–42) for measuring the Black Carbon (BC) continuously from the atmosphere in online mode.
- Aerodynamic Particle Sizer measure aerodynamic particle size from 0.5 to 20 micrometers with the only sizer of its kind on the market.
- The 3 wavelength Photo Acoustic Soot Spectrometer (PASS) manufactured by Droplet Measurement Technologies (Boulder, Colorado) measures the optical absorption coefficient of suspended aerosol particles using a variation of the photo acoustic technique which is also used to measure optical absorption by gases.

27.6 Capacity Building in Space Science Research

IIT Kanpur has recently established a new department – Department of Space Science & Astronomy. It will admit the first batch of students in the M.Tech. and Ph.D. programs starting from July 2022. It will admit 10 students in M.Tech. and 5 in Ph.D. in the first year. The two M.Tech. streams named Radio Astronomy and Planetary Science & Technology will be offered in the first year:

Apart from this large number of Ph.D. and M.Tech students from various disciplines conduct their research work in the vital areas of Space science and Technology.

27.7 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	Flood risk assessment using remote sensing	IIT Gandhinagar
2	River management	IISER Bhopal

Sl. No.	Area of Collaboration	Collaborating Institute
3	Optical characterization of wetlands from space observations	SAC Ahmedabad
4.	LST and soil moisture estimation from UAV remote sensing	SAC Ahmedabad
5	Airborne remote sensing for water quality mapping, wetland health assessment	WWF-India
6	Aerosol Charging and Electrical Conductivity in the Lower Atmosphere of Mars (ISRO-PLANEX)	PRL
7	Integrated Campaign for Aerosols, Gases and Radiation Budget (ICARB) (ISRO-GBP)	National Remote Sensing Agency, Balanagar, Hyderbad, IISA, VSCC
8	Effects of Ionization Rate Variation on Aerosol and Cloud Microphysical properties (ISRORESPOND Program)	IITs, IISc etc.
9	Impact of anthropogenic aerosols on cloud microphysics.	IISC, SPL
10	Cosmic Rays-CloudClimate Conundrum: Can Ion-Aerosol NearCloud Mechanism Explain the Observed Correlations?	IITM, Delhi Branch
11	Measurement of aerosol and liquid droplet size distribution and validation of aerosol and droplet microphysical models	BARC
12	Manufacturing	Mishra Dattu Nigam Limited, Hyderabad
13	Reconfigurable meta-surface antenna	SAC-ISRO

27.8 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1.	Hyperspectral remote sensing for water quality assessment	University of Glasgow, UK University of Stirling, UK
2	Thermal remote sensing for soil moisture assessment	University of Leicester, UK University College, London
3	Microwave data analysis and integration with ground-based sensors for soil moisture assessment	University of Potsdam, Germany

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
4	Corona data processing, river health assessment from remote sensing, flood risk assessment	University of Durham, UK
5	Modeling of dusty-gas flows	University of Illinois at Urbana-Champaign
6	Nano cube-sat: modeling and analysis	Purdue University

27.9 Laboratories and Facilities Available for Space Instrumentation

The laboratories and facilities available for space research in IIT Kanpur is listed below:

- The PCB lab (for fabrication) and Antenna lab (for measurement)
- Possess spark plasma sintering for fabrication of small coupons (~15-20 mm diameter) of ultra-high temperature ceramic pellets.
- Furnaces and thermos-gravimetric analyzer for assessing oxidation behavior of ultra-high temperature ceramics.
- Instrumented indentation for elastic modulus and hardness measurements.
- Tribological assessment (fretting, scratch and pin-on-disk tests) of materials.
- UAV laboratory equipped with a fleet of drones and sensors including multispectral, thermal and hyperspectral cameras.
- Spectroscopy lab including state of the art spectroradiometer.
- Modern facilities for terrain surveys including GNSS receivers, RTK enabled DGPS, and Total Station.
- Soil moisture sensors, field installation and integration.
- Semiconductor device characterization laboratory.
- Conventional Hypersonic Shock/ Ludwieg Tunnel: Mach 6 tunnel .
- Free Piston Driven Expansion Tunnel: ~ 40 MJ/kg (commissioning in progress).
- Calibration and testing facility for temperature sensitive paints.
- Instrumented test rigs for combustion-acoustic interaction.
- Cleanroom infrastructure for fabrication of TFT arrays and circuits:
- Circuit design, lay-out and mask-writing:
- Device characterization:

- Femtosecond Laser Lab with state-of-the-art technology.
- Three laboratories are under development for the Department of Space Science and Astronomy.
    - o Space Instrumentation laboratory
    - o Radio Astronomy laboratory
    - o Space Science data analysis laboratory

Journal Publications:

1. R. Sinha et al., Channel morphodynamics and sediment budgeting of the Lower Ganga River using a hydro-geomorphological approach. *Earth Surface Processes and Landforms* (2022)

2. M. Singh and R. Sinha, Basin-scale inventory and hydrodynamics of floodplain wetlands using time-series remote sensing dataset. *Remote Sensing Letters*, **13** (1), 1-13, (2022).

3. D. Rawat et al, Time-resolved spectroscopy on the heartbeat state of GRS 1915+105 using *AstroSat Monthly Notices of the Royal Astronomical Society* **511-2,** 1841-1847 (2022)

4. K. P. Singh and S. Bhattacharjee , Optical Parameters of Atomically Heterogeneous Systems Created by Plasma Based Low Energy Ion Beams: Wavelength Dependence and Effective Medium Model, *Frontiers in Physics*, **9**, 671137, (2021).

5. A. Laha et al., Application of Earth Observation (EO) dataset and multi-criteria decision-making technique for forest fire risk assessment in Sikkim. *Current Science*, **121**, 1021-1031, (2021).

6. M. Singh, and R. Sinha, Hydrogeomorphic indicators of wetland health using multi-temporal remote sensing data and their application at a new Ramsar site (Kaabar Tal), India. *Ecological Indicators*, **127**, 107739 (2021).

7. S. Sinha and R. Sinha Active tectonics, landscape evolution and sediment dynamics in Dehra Dun, Northwest Himalaya inferred from geomorphic indices and GIS tools. *Quaternary International*, **505**, 55-69 (2021).

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9. M. Singh et al., Geomorphic connectivity and its application in understanding the complexities of hydro-geomorphic systems in tropical regions. *Earth Surface Processes and landforms*, **46**, 110-130 (2021)..

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12. S. K. Rout et al, Multi-wavelength view of the galactic black-hole binary GRS 1716–249, *J.Astrophys.Astron*. **42-2**, 39 (2021)

13. P. Dasgupta et al General Treatment of Reflection of Spherical Electromagnetic Waves from a Spherical Surface and its Implications for the ANITA Anomalous Polarity Events, *Astroparticle Physics*, **128**, 102530 (2021)

14. S. Swarnkar, et al, Morphometric diversity of supply-limited and transport-limited systems in the Himalaya foreland. *Geomorphology*, **348**, 106882, 1-14 (2020).

15. K.. Mishra, and R. Sinha, Flood risk assessment in the Kosi alluvial plains (megafan) using multi-criteria decision analysis: a hydro-geomorphic approach. *Geomorphology*, **350**, 106861, 1-19, (2020).

16. R.K. Kaushal,et al. Spatio-temporal variability in stream power distribution in the Upper Kosi River basin, Central Himalaya: controls and geomorphic implications. *Geomorphology*, **350,** 106888, 1-16 (2020)

17. M. Singh and R. Sinha, Distribution, diversity, and geomorphic evolution of floodplain wetlands and wetland complexes in the Ganga plains of north Bihar, India. *Geomorphology*, **351**, 1-18 (2020).

18. R. Misra et al Identification of QPO frequency of GRS 1915+105 as the relativistic dynamic frequency of a truncated accretion disk, *Astrophys J. Lett*. **889-2**, L36 (2020)

19. B. Hariharan et al Energy sensitivity of the GRAPES-3 EAS array for primary cosmic ray protons *Exper.Astron*. **50,** 185-198 (2020)

20. M. Zuberi et al Simulation of atmospheric pressure dependence on GRAPES-3 particle density *Exper.Astron*. **49**, 61-71 (2020)

21. V. B. Jhansi et al The angular resolution of GRAPES-3 EAS array after improved timing and shower front curvature correction based on age and size *JCAP* **07**, 024 (2020)

22. Yang, Y., *et al.,* "Effect of Argon Gas in Oxygen Catalytic Recombination on a Silica Surface: A Reactive Molecular Dynamics Study", *Acta Astronautica*, **175**, 531 (2020).

23. S. Singhal and D. Goswami, Unravelling the molecular dependence of femtosecond laser-induced thermal lens spectroscopy in fluids, Analyst **145(3),** 929—938 (2020).

CHAPTER-28

INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

Kharagpur

28.1 About the Institute

Indian Institute of Technology (IIT) Kharagpur is deeply engaged in contributing to Space Science Education and Research of India by (1) performing collaborative research through ISRO - RESPOND program (2) teaching many important undergraduate (UG) and postgraduate (PG) courses (syllabi of which are formulated to cater to Indian space science education), (3) developing instruments and laboratories which are relevant for space science research. Faculty members and researchers at IIT participate in joint research and development activities with scientists of various ISRO laboratories in order to give a fillip to self-sustaining Indian space program. A total of 140 projects have been completed successfully, till date, while more than 40 projects are running currently. Outputs of several projects have been utilized in various activities of ISRO. ISRO and IIT Kharagpur have identified some specific areas where more emphasis can be laid in the field of space technology and further targeted research works can be carried out. Kalpana Chawla Space Technology Cell (KCSTC) (located in the premises of IIT Kharagpur) serves to coordinate and foster the cooperative research activities jointly undertaken by the two organizations. Rest of this document indicates research domains explored, significant products developed, courses offered and manpower trained towards boosting Indian space program.

28.2 Keywords

Waveguide based Antenna, RF beamforming networks, Doppler Radars, Millimeter-Wave Six-Port Receiver, Chill-down Operation in a Cryogenic Feed line, LOX Booster Turbo-pump for Semi-Cryogenic Rocket Engine, Compact Heat Exchangers, Prediction of Rocket Engine Performance, Processing-Microstructure-Property correlation in materials, Formability of sheet metals

28.3 Major Research Domains

- **Waveguide based Antennas**: Accurate spatial alignment is not required for the circularly polarized antennas. Thus, they avoid polarization mismatch. Also, change in polarization due to ionosphere propagation does not create any problem. Several circularly polarized antennas are developed for SAR and Retro-directive array applications.
- **RF beamforming networks**: They provide electronically controllable phase distributions at the antenna ports. A new form of traditional $2^n \times 2^n$ Butler matrix is developed for continuous scanning. It requires half of the phase range compared to the traditional

phase shifter approach. It also reduces the number of phase shifters to half. Several other electronically controllable delay lines and phase shifters are developed using PIN diodes, and varactor diodes. A modified form of the Nolen matrix is also developed for compactness and better control of phase. Research is also going on electronic switches for the minimization of power consumption and isolation improvement.

- **Doppler Radars**: stand-alone multi-mode Doppler radars at microwave and millimeter wave frequencies are becoming popular for various short range applications like automotive radars, biomedical applications, imaging, mining applications, police guns, security applications, as sensors, and sports industries. They can work in CW and FMCW modes and determine target's range, velocity and vibration. They can also track any target. However, available radars are application specific, one radar for one application cannot be used for another. Recently, a multi-purpose generic radar system is developed and implemented. It can operate in CW and FMCW mode with full software control. The modulation scheme is selectable, frequency range is tunable, transmitted power can be varied.
- **Millimeter-Wave Six-Port Receiver**: A six-port receiver mostly uses passive networks and detector arrays to decode the I- and Q-channel signals. It does not use any mixer like a traditional homodyne or superheterodyne receiver. Instead, it uses vector addition of LO and incoming RF signals. It is claimed to provide better accuracy than a superheterodyne receiver. The heart of a six-port receiver is a six-port network. Recently, a novel wideband six-port network is developed for UWB communications. A new fast and accurate calibration technique is also developed.
- **Chill-down Operation in a Cryogenic Feed line**: it requires an accurate prediction model to capture the complex phase change flow and conjugate heat transfer. Chill-down numerical models play a critical role in the efficient design of the cool-down operation and thereby reducing the fuel consumption and time taken. Moreover, these models also play a crucial role in analyzing the peak pressure transients and thermal stresses generated during chill-down, which can critically damage the supply line due to bowing and cold shock etc.
- **Thermo-hydraulic simulation of LOX Booster Turbo-pump for Semi-Cryogenic Rocket Engine**: SC-2000, India's indigenous semi-cryogenic rocket engine, is being developed at ISRO's LPSC. This project helped to develop the Low-Pressure Oxidiser Turbopump (LPOT), which is part of the SC-2000's staged combustion cycle. In this project, the axial pump in LPOT is powered by a partial admission impulse turbine, which is run by the oxidizer-rich combustion products (hot gas) from the pre-burner. The hot gas at the turbine exit mixes with LOX from the pump exit, forming a multi-component multiphase flow with phase change, leading to solidification of CO_2 and H_2O.

- **Compact Heat Exchanger**: A set of compact heat exchanger, made of perforated plates, have been designed and numerically demonstrated. The objective is to cool the command helium gas to about 25K by using liquid hydrogen. Being compact, the heat exchanger would require much less space envelop compared with the existing tube-in-tube heat exchanger in ISRO. Prototype heat exchangers have been successfully fabricated and demonstrated experimentally.
- **Prediction of Rocket Engine Performance through Data Fusion Technique**: In this work, a computer software is being developed to predict the performance of a rocket engine through data fusion technique. Using one or more set of test data, the computer program can be trained to predict the performance of the engine under different operating conditions. This way, with limited number of experiments we can predict the behavior of the engine when one or more operating parameters are changed.
- **Processing-Microstructure-Property Correlation in Materials**: The first-ever indigenous development of an ultra-high strength (~1700 MPa), high fracture toughness (~80 SI units) steel with excellent stress corrosion cracking resistance (K1SCC >70 MPa.√m) on an industrial scale for space application is achieved. The extensive microstructural studies and failure analyses provide academic insight to scientists while correlating microstructure with formability performance.
- **Formability of Sheet Metals**: The forming process map developed through the project will provide guidelines to VSSC/LPSC, ISRO for the successful fabrication of thrust chamber liner of cryogenic and semi-cryogenic engines of satellite launch vehicles, outer casing of Ni-H_2 battery and high-pressure oxygen gas bottles components. These process maps can be utilized as diagnostic tools while designing dies, punches and draw beads, and selecting process parameters for successful fabrication of various light weight and high performance sheet metal components.

28.4 Major Scientific Applications / Results

Anechoic Chamber in the **Department of Electronics and Electrical Communication Engineering** is the only laboratory in IIT Kharagpur that provides the facility for antenna measurement. In addition to the basic chamber, it is well equipped with other instruments for the characterization of different types of microwave circuits and components till 30 GHz.

PROCESS EQUIPMENT AND DESIGN LABORATORY is one of the research labs of **Cryogenic Engineering Centre**, IIT Kharagpur that is engaged in research in the following domains: modeling and simulation of cryogenic refrigeration and liquefaction systems, large scale helium cryogenics, Cryogenic rotating turbo-expander, pump, and other rotating equipment, design and development of low-temperature processes and equipment, reverse Brayton Cryo-cooler, two-phase flow in cryogenic systems and cavitation and bubble dynamics.

Department of Metallurgical and Materials Engineering in IIT Kharagpur conducts research on Processing-Structure-Texture-Property correlations in structural materials for aerospace, space and energy generation applications. Faculty members work on material systems include Ti alloys, TiAl based intermetallic alloys, Ni-based super-alloys, and advanced steels. Our interests also include materials for high-temperature applications like Nb-Si based alloys, Mo-Ti-Zr-C system, Mo-W-Si-C system, etc.

28.5 Instruments / Payloads / Products Developed/ Sensors/ Detectors

Cryogenics Engineering Centre in IIT Kharagpur has been instrumental in setting up the following:

- Experimental facility to predict pressure transients during Source changeover: Cryogenic Propellant feed system in the form of Source changeover test facility is developed to predict the pressure transients due to sudden valve operation. Instruments like Piezoelectric sensors, RTD sensors and Coriolis Mass Flowmeter are mounted in the system with a suitable mounting system. Globe Control valves are used to control fluid supply. DAQ system of make Qbrixx Controller is used for configuring data from sensors.

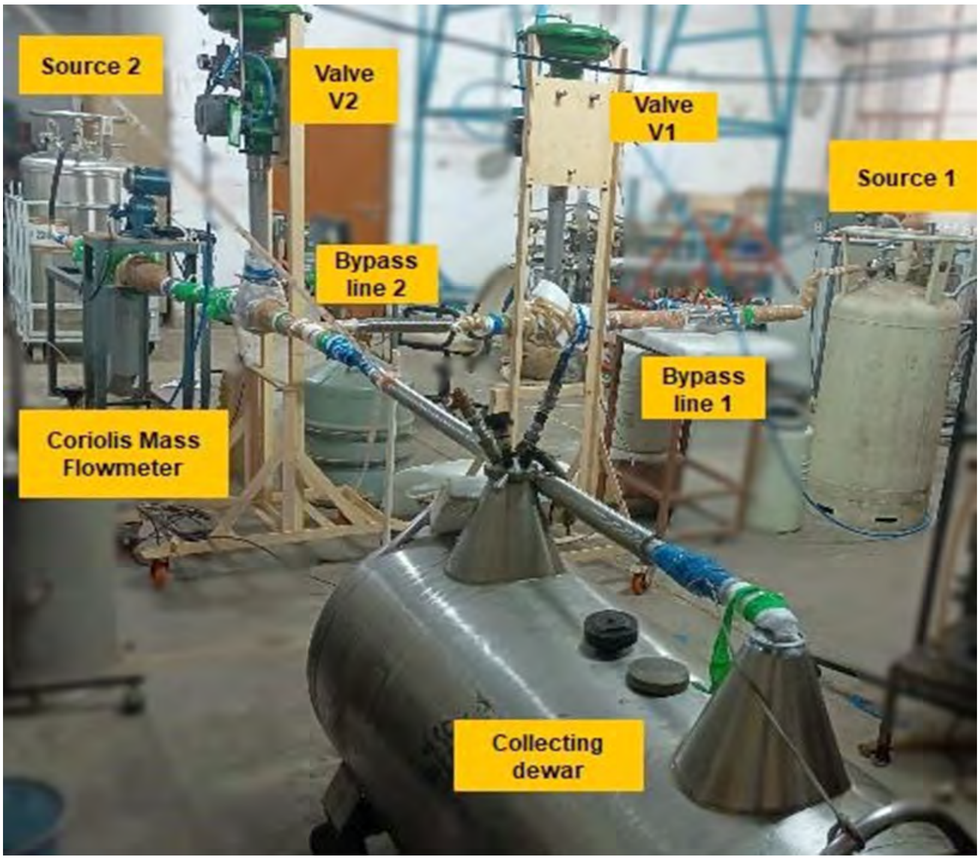


Figure 1: Cryogenic source changeover experimental test facility developed in Cryogenic Engineering Centre.

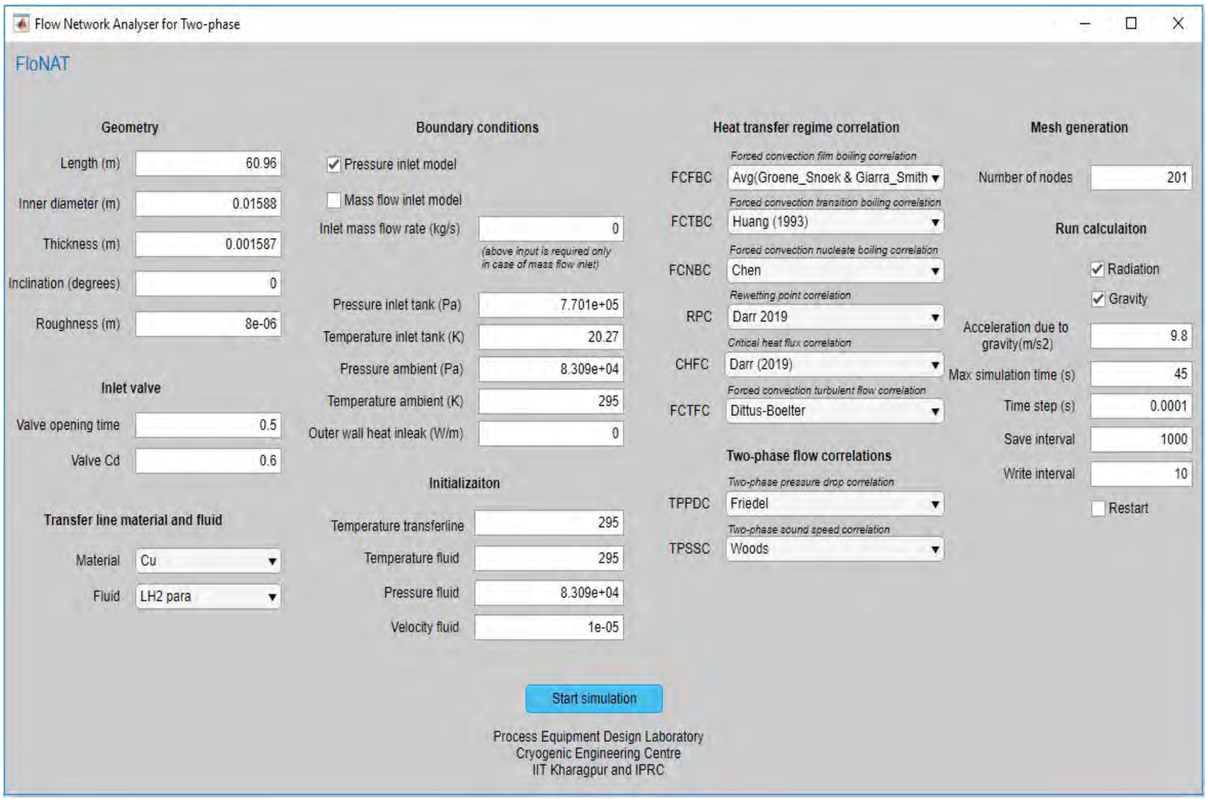


Figure 2: user interface of the chill-down software code.

- Software code for cryogenic feed line chill-down modeling: Understanding the flow boiling phenomenon during cryogenic transfer line cool-down as well as developing a reliable mathematical model of the same have critical industrial applications. For instance, the optimization of the transfer line cool-down operation is essential for propellant loading as well as thermal management in space flights. To aid the cryogenic transfer line development activities and to facilitate optimum cool down operations of transfer lines at ISRO Propulsion Complex, IIT Kharagpur has developed a two-phase simulation program. A one-dimensional transfer line cool-down simulation program (FloNAT) is developed for the above purpose. Here, the Crank-Nicolson scheme with a tridiagonal system solver is used for the transfer line wall whereas, a homogeneous equilibrium mixture model having various constitutive relations for heat transfer and pressure drop estimation and solved based on the inverse method of characteristic using a hybrid solver is employed for two-phase flow modeling.

Department of Electronics and Electrical Communication Engineering in IIT Kharagpur has built the following which are pertinent to Space Education and Research

- RF beamforming networks.
- Electronically controllable delay lines.
- Sub-harmonic mixers and detectors using Schottky diodes at millimeter-wave frequencies, power amplifiers using discrete HEMT.

- Microwave systems: Multi-mode Doppler radars (2.4 GHz and 24 GHz) with full software control, millimeter-wave six-port receivers for high data throughput, retro-directive arrays.

Figure 3: X-band array antenna.

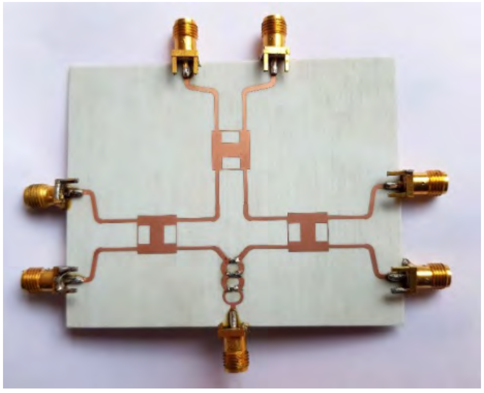


Figure 4: Six-port network (part of six-port receiver system).

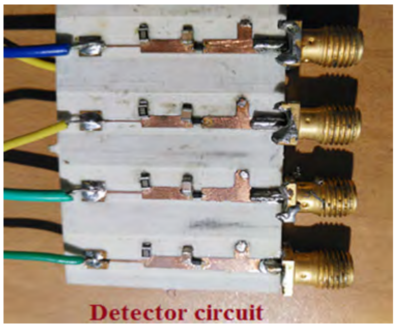


Figure 5: Detector array.

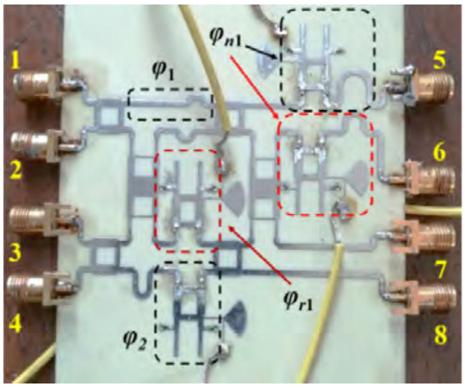


Figure 6: X-band electronically controllable beamforming network.

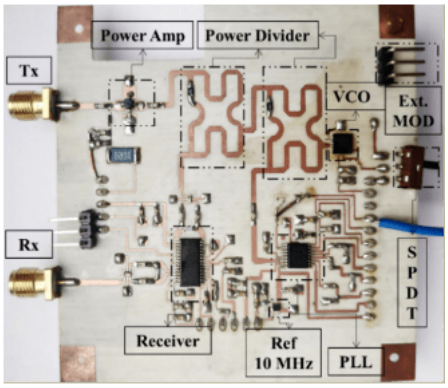
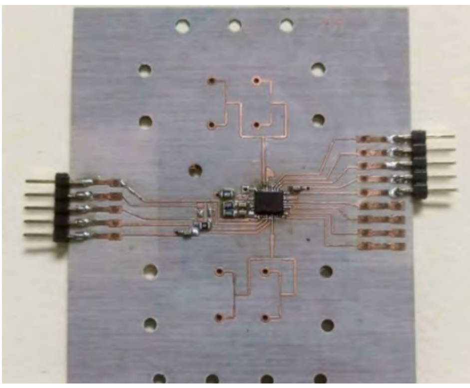
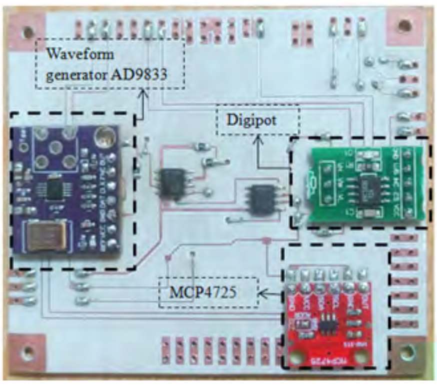


Figure 7: Top RF layer of the 2.4 GHz Doppler radar.

(a)



(b)



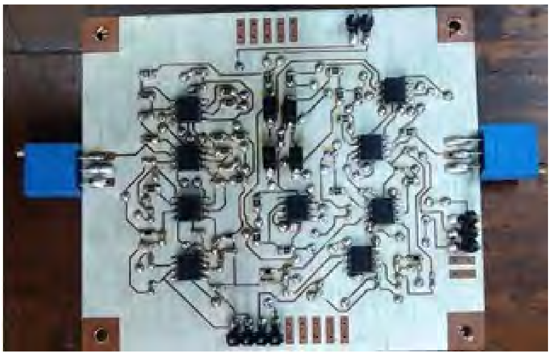
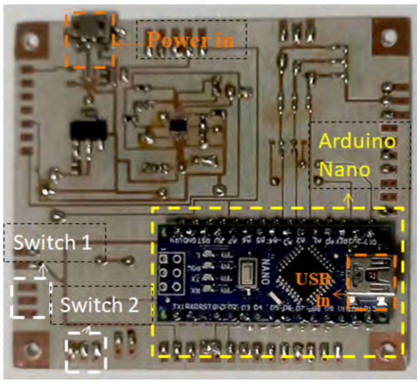
(C)  (D) 

Figure 8: Different layer of the 24 GHz multi-mode FMCW radar circuit, (a) top RF layer, (b) waveform generator, (c) baseband unit, and (d) DC power distribution and control circuit (antenna is a 3-layer structure sitting back to RF layer, not shown here).

In **Department of Metallurgical and Materials Engineering**, IIT Kharagpur, indigenous Custom 465 stainless steel has been developed. This indigenously developed ultra-high strength, high fracture toughness corrosion resistant steel will replace the existing maraging steel for potential space and aerospace applications. This material will be used for high-strength fasteners and merman bands in satellite launching vehicles. Pictures of fasteners made by this material are given in Figure 9.

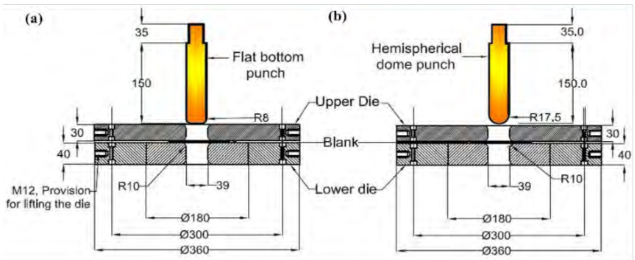
Figure 9: High strength fasteners fabricated using newly developed indigenous Custom 465.

Working jointly, faculty members from **Department of Mechanical Engineering** and **Department of Metallurgical and Materials Engineering**, IIT Kharagpur have developed the following:

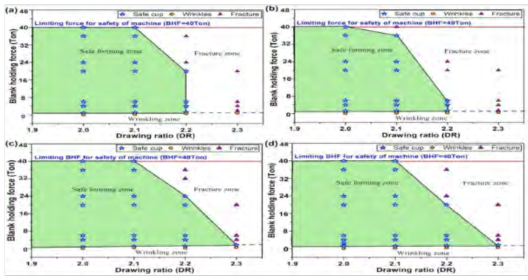
- IN718 is used in the fabrication of outer casing of $Ni\text{-}H_2$ battery used in low earth orbit (LEO) and geosynchronous equatorial orbit (GEO) satellites, and high-pressure oxygen gas bottles carried by astronauts to meet the emergency oxygen supply.
- Cu-Cr-Zr-Ti alloy is used in the thrust chamber liner of the cryogenic and semi cryogenic engine of the satellite launch vehicle.

- Nb-10Hf-1Ti alloy is mostly used in the divergent portions of the nozzles of upper stage liquid engines as well as the satellite thrusters used in Altitude Orbiter Control Systems (AOCS).

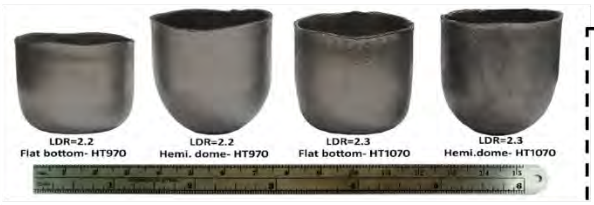
Deep drawing of Inconel 718 sheets



Schematic of deep drawing setup used: (a) flat bottom punch, and (b) hemispherical dome punch



Deep drawing process windows of (a) HT970 using flat bottom, (b) HT970 using hemispherical dome, (c) HT1070 using flat bottom, and (d) HT1070 using hemispherical dome punch



Successful cups corresponding to LDR cases from the deep drawing process window

Key findings:

- ❑ Process window for IN718 was evaluated for an acceptable range of blank holding force for fabrication of successful cup for two solution treated materials using both flat bottom and hemispherical dome punch.
- ❑ The limiting draw ratio (LDR) for HT1070 material (LDR=2.3) was found to be marginally higher than HT970 material (LDR=2.2) irrespective of punch geometries.

The forming process map developed through the project will provide guidelines to VSSC/LPSC, ISRO for the successful fabrication of thrust chamber liner of cryogenic and semi-cryogenic engines of satellite launch vehicles, outer casing of Ni-H_2 battery and high-pressure oxygen gas bottles components. These process maps can be utilized as diagnostic tools while designing dies, punches and draw beads, and selecting process parameters for successful fabrication of various light weight and high performance sheet metal components. The extensive microstructural studies and failure analyses provide academic insight to scientists while correlating microstructure with formability performance. Also, the outcome of this work will be useful for analytical modeling of the formability of IN718 and Cu-Cr-Zr-Ti alloy sheet components used in various sheet metal formed components. Another approved project will start on 1st Feb 2022 for the development of technology for forming tailor welded blanks of C-103 sheets. The outcome of this project will provide guideline for the fabrication of tailor welded C-103 sheet space components.

28.6 Capacity Building in Space Science Research

In **Cryogenic Engineering Centre** of IIT Kharagpur, many M. Tech, MS and PhD thesis related to space science and technology have been produced

28.7 Courses offered on Space Science and Technology

Following courses related to **satellite payload design** are offered to PG and UG students:

1. Millimeter Wave technology

(i) Title of the course: Millimeter Wave technology

(ii) standard of the course: post-graduate and PhD coursework,

(iii) intake capacity: max 60,

(iv) topics covered:

- Introduction to Millimeter-wave technology
- Material properties at millimeter wave frequencies.
- Guiding structures at millimeter-wave frequencies
- Resonators
- Fabrication technologies.
- Circuit components
- Antennas
- Packaging and interconnects
- Millimeter-wave systems

(v) number of lectures allotted for the course: 35 hours

2. Microwave Design Laboratory

(i) Title of the course: Microwave Design Laboratory

(ii) standard of the course: post-graduate and PhD coursework,

(iii) intake capacity: max 30,

(iv) topics covered:

- Studies on microstrip lines
- Design of a bias tee.
- Design of a two element array antenna
- Design of a power divider and a coupler
- Design of an amplifier.
- Design of a detector.
- Design of a sub-harmonic mixer.

(v) number of lectures allotted for the course: 36 hours (12 weeks).

3. Microwave Engineering

(i) Title of the course: Microwave Engineering

(ii) standard of the course: under-graduate course,

(iii) intake capacity: 150,

(iv) topics covered:

- Transmission lines
- Guiding structures.
- Network analysis
- Impedance matching
- Resonators.
- Power dividers and couplers.
- Filters
- Noise and non-linearities
- Amplifiers
- Detectors and mixers
- Microwave propagation
- Microwave systems.

(v) number of lectures allotted for the course: 45 hours.

4. Microwave Laboratory

(i) Title of the course: Microwave Laboratory

(ii) standard of the course: under-graduate course,

(iii) intake capacity: 30,

(iv) topics covered:

- Experiments based on waveguide bench: introduction to microwave system, concept of guided wavelength, dispersion, impedance matching and modulation.
- Studies on Gunn source.
- Studies on the characteristics of a Schottky diode based detector.
- Studies on antenna characteristics
- Concept of calibration and measurement of S-parameters of passive components.
- Studies on amplifiers.
- Introduction to full wave simulations.

(v) number of lectures allotted for the course: 36 hours (12 weeks).

28.8 National Collaborations in Space Science and Technology

Some of the projects undertaken by faculty members of IIT Kharagpur in collaboration with various agencies including ISRO are given as follows:

Sl. No.	Area of Collaboration	Collaborating Institute
1	Substrate integrated waveguide based components	URR-SC
2	Retro-directive array	SAC, ISRO
3	LTCC based microwave components	ISRO
4	Material's research	VSSC, and LPSC, ISRO
5	Material's research	MIDHANI
6	Material's research	DMRL
7	Material's research	CSIR-NML
8	Material's research	IGCAR/BARC
9	Formability study of various sheet metals, failure analysis and microstructure evaluation of various space alloys.	VSSC/LPSC ISRO

28.9 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1	Cryogenic Fluid Transients	University of Alabama in Huntsville and NASA Marshall Space Flight Center
2	Material's research	The Ohio State University
3	Material's research	University of Michigan

28.10 Laboratories and Facilities Available for Space Instrumentation

Department of Electronics and ECE, IIT Kharagpur has the following facilities:

- Anechoic chamber (450 MHz to 26 GHz)
- RF source: 30 GHz
- Spectrum analyzer: 32 GHz.
- VNA: 32 GHz

Department of Metallurgical and Materials Engineering, IIT Kharagpur provides the following facilities:

- o PANDAT.
- o MIPAR (Microstructure processing software)

- Optical Microscope
- Dual disc polishing machine
- Microprocessor controlled electropolisher
- Jet polisher (For TEM sample preparation)
- Disk punch (For TEM sample preparation)
- Precision cutting low speed saw
- Ultrasonic cleaner (Revotek)
- Hot plate
- Fume hood for electrolyte and etching purpose
- Muffle furnace (1700º C)

Figure 10: Facilities available for research in Department of Metallurgical and Materials Engineering laboratory.

Department of Mechanical Engineering, IIT Kharagpur houses the following facilities:

- Universal Tensile testing machine

  Tensile and anisotropic properties of materials were evaluated both at room and high temperatures.

- 100-ton double action hydraulic press

  Formability of material was evaluated using limiting dome height (LDH), limiting drawing ratio (LDR), forming limit diagram (FLD), V-bending and springback experiments.

- Vertical machining center with CNC control

  Single point incremental forming (SPIF) process was implemented to fabricate any complex shape space component by moving the tool through computer numerical control technique.

- Optical microscope, Stereo zoom microscope
- Advanced Microstructural characterization (SEM, EDS, EBSD and TEM)
- Micro-hardness and nano-hardness
- FE simulation software (LSdyna)

Publications

1. N. Yancy, M K Mandal, and R. Shaw, "Circularly polarized high gain coaxial line leaky wave antenna with backfire radiation", *IEEE trans. on Antennas and Propagation*, **vol. 70, pp. 1 – 4**, online, 2022.

2. M. Kahar and M.K. Mandal, "A wide-band tightly coupled slot antenna for 360° full azimuthal beam steering applications", *IEEE trans. on Antennas and Propagation*, **vol. 69**, issue 6, **pp. 3538 – 3542**, Jun 2021.

3. A.K. Singh and M.K. Mandal, "Parasitic compensation and hence isolation improvement of PIN diode based switches", *IEEE trans on Circuits and Systems II*, **vol 68**, issue 1, **pp. 97-101**, Jan. 2021.

4. P. Kumar, S Dwari, M. K Mandal, S Singh, J Kumar, A Kumar, "Electronically controlled beam steerable dual band star-shape DRA for UAS and Wi-Fi data link applications", *IEEE trans. on Antennas and Propagation,* **vol. 68**, issue 10, **pp. 7214 – 7218**, Oct. 2020.

5. Bhuvana R G et.al, A Scaling Procedure for Predicting Pressure Fluctuations caused by Fluid Transient in Cryogenic Systems, *Recent Advances in Computational and Experimental Solid/Fluid Mechanics, Springer Nature*, 2020.

6. Bhuvana.R G et.al, Numerical analysis of Fluid Transient during ground testing of cryogenic propellant feed system, *Indian Journal of Cryogenics,* 2020.

CHAPTER-29

INDIAN INSTITUTE OF TECHNOLOGY-GANDHINAGAR

29.1 About the Institute

Since its establishment, IIT Gandhinagar (IITGN) has been steadily crossing milestones in teaching, research, innovation, and institute building. With a strong emphasis on interdisciplinarity, the Institute is a blended hub of different disciplines from the areas of Science, Technology, Engineering, Arts, and Mathematics (STEAM) that collaborate to produce innovative research with the potential to solve real-world problems.

Since its establishment in 2008, IITGN has been gradually building its research and development repertoire by hiring enthusiastic faculty members, visiting scholars, post-doctoral fellows and selecting passionate undergraduate, postgraduate, and PhD scholars. The growth of the Institute has been accompanied by collaboration with various prominent organisation, both national and global, one of which is ISRO. Over the years, faculty members at IITGN have worked with ISRO on multiple projects and the Institute hopes to continue strengthening this partnership in the years to come.

The Institute's collaborative and inclusive culture promotes multi-disciplinary research successes, and provides a holistic environment to be at the forefront of cutting-edge research and innovation. IITGN hopes to continue treading on its path of pursuing research with immense real-world applications and will build a unique brand in the years to come.

29.2 Keywords

Remote Sensing & GIS applications, Open Quantum Systems and Sensors, Gravitational Wave Astronomy and Black Hole physics, Water and Climate

29.3 Major Research Domains

1) **Space Technology and hardware development**

a) Antenna and Optical Communication Technology

i) Digital beamforming Techniques for reconfigurable Antennas.

ii) Metasurfaces and electromagnetic bandgap based antenna design.

iii) Metasurface based compact filters, polarizers and lenses from terahertz to ultraviolet bands.

iv) Inter satellite free space optical links with machine learning based error correction.

b) Electronic and Mechanical Support Services

i) Thermochromic material as low emissivity coating for spacecraft application.

ii) Technology development of high voltage and high power semiconductor devices for space applications.

iii) Development of Fast Computational Electromagnetics Method for the transient analysis of space-craft bodies embedded in the space-plasma environment.

c) Electronic Devices and Sensors

i) Precision tunable laser diode-based spectroscopy for trace gas sensing for air quality monitoring and industrial hazard monitoring.

ii) Fiber Bragg grating-based temperature, strain and vibration sensing for industrial and biomedical applications.

iii) ZnO and TiO2-based transparent conductors for optical devices.

d) Circuit Design and Signal Processing

i) Design of different analog and mixed-signal circuits.

ii) Design of Electrostatic Discharge (ESD) protection circuits and Power management integrated circuits.

iii) Source localisation algorithms using array signal processing.

e) Radiation hardened systems

i) Radiation hardened processor design (focused on RISC-V processor)

ii) Radiation hardened memory design.

2) Space Sciences

a) Gravitational Wave Astronomy

i) Development of search pipelines for the detection of gravitational wave signals from LIGO and Virgo detectors and from space-based GW detectors like LISA.

ii) Exquisite reconstruction and measurement of black hole/neutron star masses and spins using gravitational wave observations.

iii) Deploying deep searches for gravitational wave signals from exotic astrophysical objects allowing for departures from Einstein's theory of general relativity.

iv) Measurement of the Hubble constant using gravitational wave observation of binary neutron stars followed by prompt multi-wavelength observation of gamma ray bursts.

v) Understanding the physics of compact objects using gravitational wave observations.

b) Black Hole Physics

i) Constraining various modified gravity models using astrophysical observations like black hole shadow.

c) Quantum Thermodynamics

i) Study of collective dissipative open quantum systems.

ii) Engineering collective dissipation in solid-state quantum technology platforms to make better quantum sensors

iii) Study of Bose-Einstein Condensates as ultra-precise force sensors

d) Lunar Surface Science

i) Analysis and interpretation of lunar surface processes through study of craters. New algorithms have been generated to identify and quantify the craters and its shape have been used to assess the degradation pattern.

3) Earth Observations including Meteorology

a) Computer Vision and Image Processing

i) Coded Aperture Photography for Image Restoration and Depth Estimation

ii) Image Restoration with Training Data Independent Deep Networks

iii) HDR Image and Video Synthesis for Dynamic Scenes from LDR Data

b) River Science

i) It includes the study of river hydrology, morphological dynamics, and analysis of the river's future in reference to climate change and anthropogenic disturbances.

ii) Watershed modeling and flood hazard analysis based on DEM data is one of the important components.

c) Resilience of networked systems subjected to hydrometeorological extremes

i) Understanding impact of extreme precipitation and extreme precipitation induced secondary hazards on spatial networked systems

ii) Physics Guided Machine learning for enhancing predictability and interpretability of hydrological processes

iii) Designing optimal recovery strategies for national and regional infrastructure systems subject to natural and man-made hazards by leveraging open-source datasets including Land-use/Land-Cover datasets, Digital Elevation Maps, remotely sensed and in-situ observations, and multiple models-multiple-initial condition ensembles of climate change projections.

29.4 Major Scientific Applications / Results

1) Space Science

a) Detection and study of gravitational waves

i) Soumen Roy, et al., Unveiling the spectrum of inspiralling binary black holes, Phys. Rev. D, 103, 064012, 2021.

b) Understanding Black Hole physics

i) Rajes Ghosh, et al., Light rings of stationary spacetimes, Phys. Rev. D, 104, 044019, 2021.

ii) Kabir Chakravarti, et al., Signature of Non-uniform Area Quantization on Gravitational Waves, Phys. Rev. D, 104, 084049, 2021.

iii) Kabir Chakravarti, et al., Signature of nonuniform area quantization on black hole echoes, Phys. Rev. D, 105, 044046, 2021.

2) Earth Observations including Meteorology

a) River Science

i) V. Kumar, et al., Incorporation of Slope and Rainfall Variability in Channel Network Extraction from DEM Data at Basin Scale, Geocarto International, 8, 1-16, 2021.

ii) R. Sahoo, et al., Process inference from topographic fractal characteristics in the tectonically active Northwest Himalaya, India, Earth Surface Processes and Landforms, 45, 2020.

iii) B. Borgohain, et al., Evidence of episodically accelerated denudation on the Namche Barwa massif by megafloods, Quaternary Science Reviews, 245, 106410, 2020.

iv) R.K. Kaushal, et al., Spatio-temporal variability in stream power distribution in the Upper Kosi River basin, Central Himalaya: controls and geomorphic implications, Geomorphology, 350, 106888, 2020.

v) V. Jain, et al., Riverine Flood Hazard (Part A): types, processes and causative factors, Proceedings of the Indian National Science Academy (PINSA), 85, 43-64, 2020.

3) Space Technology and Hardware Development

a) Electronic devices and sensors

i) **Role and application of thin films and interfaces in engineering and spaces science**

(1) Krishna Manwani, et al., Thickness induced modifications in the valence, conduction bands and optoelectronic properties of undoped and Nb-doped anatase TiO_2 thin films, Materials Science in Semiconductor Processing, 134, 106048, 2021.

(2) Ravi Teja Mittireddi, et al., Non-stoichiometric amorphous TiOx as a highly reactive, transparent anti-viral surface coating. Journal of Alloys and Compounds, 881, 160610, 2021.

(3) Rohit Dahule, et al., Surface Study of Cu2SnS3 Using First-Principles Density Functional Theory, Advanced theory and simulations, 4, 2000315, 2021.

(4) Krishna Manwani, et al., Annealing effected Nb dopant activation and optoelectronic properties in anatase thin films, Journal of Materials Science: Materials in Electronics, 32, 3273-3285, 2021.

(5) Abhishek Raghav, et al., Intrinsic electronic defect states of anatase using density functional theory, Computational Materials Science, 184, 109925, 2020.

(6) Narendra Bandaru, et al., Reduced doping efficiency of aluminium in Al-doped ZnO film: role of excess aluminium and deposition rate, Applied Physics A, 126, 526 2020.

29.5 Capacity Building in Space Science Research

As an institute pursuing interdisciplinary research, IITGN has undergraduate, postgraduate, and PhD programs in fields that are directly related to space research or have an intersection with the same. Data some IITGN has been listed below:

1. **Lunar Morphology:** On project fellow (JRF) joined PhD overseas. Currently, one PhD student is working on an algorithm to automate crate identification and density assessment.
2. **River Science**: Five PhD students are working on different aspects of river science. One PhD student graduated in the area of river science.
3. **Open Quantum Systems**: Two Ph.D. students, one JRF, and one post-doctoral fellow are working in this research field.
4. **Space Science**: The institute offers PhD on various aspects of gravitational wave physics and black hole physics. MSc Students from Physics dept at IIT Gandhinagar have won prestigious international fellowships for PhD studies (Ronald Drever prize fellowship). Two recently graduated PhD students, who trained at the IITGn Gravitational Wave group, have joined as postdoctoral fellows at NIKHEF, Netherlands and at the University of Utrecht with the Virgo gravitational wave group. Present students in the gravitational-wave group have won the prestigious TCS Fellowship for carrying out doctoral research. The student is involved in an ambitious project for fast source reconstruction of binary black holes in LIGO and Virgo data. Another student has started work on finding exotic GW sources that go beyond Einstein's theory of gravitation.

29.6 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1	Space Science	IIT Bhilai
2	River Science	IISER Bhopal
3	Gravitational wave astronomy, cosmology and tests of general relativity.	LIGO-India Scientific Collaboration: IIT Gandhinagar CGCRI, Chennai Mathematical Institute, DCSCEM, ICTS-TIFR, IISER-Pune, IISER-Kolkata, IIT, Bombay, IIT Madras, IIT, Hyderabad, IPR, Bhatt, IUCAA,RRCAT,SINP,TIFR
4	Ultra-high sensitivity tunable laser-based spectroscopic gas detection system for the Human Spaceflight Programme	IITGN and Space Applications Centre, Ahmedabad

29.7 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1	River Science	Prof Gary Brierley , Auckland University, NZ
2	River Science	Prof Kirstie Fryirs , Macquarie Univ, Australia
3	River Science	Prof Herve Piegay , University of Lyon, France
4	Gravitational wave astronomy	LIGO Scientific Collaboration, Caltech and MIT, USA

29.8 Laboratories and Facilities Available for Space Instrumentation

1. Photonic Sensors Lab

The lab's core expertise is in laser-based physical and chemical sensing. The major focus is on near-infrared and mid-infrared tunable diode laser absorption spectroscopy (TDLAS) and photoacoustic absorption spectroscopy (PAS) for detection of gases such as CO, CO2, NO, N2O, NH3, C2H2) with sensitivities down to ppb levels. These techniques are usable in harsh industrial process monitoring and safety, microbiological growth studies, environmental monitoring, biomedical sensing and plasmonic nano-bio-sensing. The research group develops compact and portable high-sensitivity detection platforms that can be configured for plant-wide industrial safety applications using fiber optic beam delivery as well as for ambient air quality monitoring. We also work on fiber Bragg grating-based sensing of temperature, strain and minute vibrations that find use in biomedical diagnostic applications such as stroke rehabilitation.

2. Laboratory of Thin Films and Interfaces:

The main research focus of the group is to fundamentally understand, optimize and fabricate industrial grade films for optical, and electrical applications. Additionally, the laboratory aims to understand the role of the interfaces in developing the microstructure of these coatings. This work can find applications in designing variable emittance coating in spacecraft as well as in optical solar reflectors for radiative cooling of spacecraft.

3. Semiconductor Device Characterization Facility

The semiconductor device characterization facility has been established for detailed wafer-level characterization (I-V, C-V, pulse, noise, and reliability measurements). This facility has the following equipment: a 6-inch wafer probe station with thermo chuck (Semiprobe), semiconductor parametric analyzer B1500 with 4 SMUs, 1 LCR meter, 1 pulse unit (Agilent), dynamic signal analyzer 35670A (Agilent), low-noise current preamplifier (Stanford Research Systems), ICCAP modeling software (Agilent), manual diamond scriber (ATV). This facility is being extensively used for semiconductor device/circuit research, semiconductor device modelling and electrical characterization of nanostructures.

4. Wind Tunnel Testing Facility

IITGN houses a low speed, open-loop wind tunnel, which has a test section of 330mm X 330mm. The speed can be varied from 0 to 40 m/s. The facility is capable of performing measurements in boundary layers, open jets, and mixing layers. The facility is equipped with Hotwire anemometer, surface pressure transducers with state-of-art data acquisition system.

5. In addition to the above, IITGN also hosts research facilities such as the Remote Sensing and GIS Lab, Flume Lab, and a Survey Lab. These are attached to the Earth Sciences discipline. The Institute has a well-equipped Central Instrumentation Facility (CIF) which boasts numerous high-end state-of-the-art equipment such as Transmission Electron Microscope (TEM), Field Emission Scanning Electron Microscope (FE-SEM), Advanced analytical FE-SEM, Inductively Coupled Plasma (ICP-MS/OES), X-Ray Diffractometer (XRD), Multipurpose XRD, and more. IITGN also houses instruments such as an Optical Lithography system, UHV Organic/Metal Physical Vapor Deposition, Mass Spectrometer, FT-IR Spectroscopy, RF Spectrum Analyzer, I-Speed 221 High Speed Camera & Accessory, and more.

CHAPTER-30

INDIAN INSTITUTE OF TECHNOLOGY
Roorkee

30.1 About the Institute

Indian Institute of Technology Roorkee (IIT Roorkee) is one of the foremost technological institutions in India. It is also considered a trend-setter in education and research in the field of Science, Technology, and Engineering. IIT Roorkee has its main campus at Roorkee, Uttarakhand, and two other Campuses at Saharanpur and Greater Noida.

The institute has a rich legacy of being the one of the First Engineering Colleges in Asia in the British Empire as The Thomason College of Civil Engineering. It became the University of Roorkee in 1948. In 2001, the University was declared an institute of national importance by a bill in the parliament, changing its status from University of Roorkee to Indian Institute of Technology Roorkee.

Vision: To attain global level of excellence in education and to create a sustainable and equitable society through innovative research in science and technology.

Mission: To create an environment that shall foster the growth of intellectually capable, innovative and entrepreneurial professionals, who shall contribute to the growth of Science and Technology in partnership with industry and develop and harness it for the welfare of the nation and humankind.

30.2 Keywords

1. Space Science & Space Technology
2. Mechanical and Chemical Engineering
3. Electronics and Communication Engineering, and AI and Data Science
4. Metallurgical and Materials Engineering
5. Natural Science (Physics, Chemistry, Mathematics, BioScience, Earth Science)

30.3 Major Research Domains

- **Self-Deployable Antenna, Mesh Antenna, Wrinkling Analysis & Shape Control**
  - **Wrinkling Analysis & Shape Control, Crease-wrinkle Interaction:** Being prized for their small mass and space mission costs, mechanical and thermal disturbances in the space environment becomes more critical. These results in corrupting the pointing accuracy, increasing the jitter. Hence, the successful operation of any inflatable antenna

system requires an understanding of system response, structural behaviour, and dynamics. Our primary research focuses on a couple of the following research domains to achieve that: crease formation, compact packaging with different folding techniques, controlled deployment/inflation, wrinkle formation due to non-uniform loading, crease-wrinkle interaction, shape control by implementing wrinkle minimization strategies. All these concentrated on a common goal of maintaining the desired surface accuracy of the inflated membrane reflector throughout its lifespan. Post-deployment, structural rigidity is essential to get the designed output.

- **Rigidization**: It is a process to enhance the structural stiffness of inflatable structures. Several rigidization techniques are available in the literature. SMSL (Smart Materials and Structures Lab) provides the resources to find the best-suited techniques and testing facilities to get meaningful output with precision and accuracy. The results will be useful to many ongoing and future space programs.
- **Tensioning and Connecting Mechanism:** Tensioning system is a vital part of space-borne membrane structures; therefore, the research aims to design and develop a novel tensioning device. The canister is the connecting part of the satellite used to deploy the reflector into a predefined position once the satellite reaches orbit. Attention is given to the development of a passive mechanism, which can work without an onboard power supply.
- **Deployment Mechanism for Mesh Antenna:** Nowadays, mesh antennas are majorly used for large aperture foldable space antennas. Conventional deployable mesh antennas are deployed with the actuators that need an onboard power source. In SMSL, research is going on designing and developing a self-deployable mesh antenna that will eliminate the need for an onboard power source. Conventional actuators will be replaced with flexure-based joints to make the structure self-deployable.

❖ MEMs, Vibration Sensor, Energy harvester

Design and fabrication of MEMs structure for vibration sensing and energy harvesting.

- Design of MEMs vibration sensors /accelerometer and tunable frequency high power density piezoelectric energy harvester with proof mass.
- Aluminum Nitride (AlN) as piezoelectric material
    - Compatibility with other manufacturing steps.
    - AlN's piezoelectric coefficient is about ten times lower than PZT. It's roughly 100 times lower dielectric constant results in a comparable or higher figure of merit for energy harvesting and sensing.
- Design Specification of MEMs accelerometer and harvester.

- Frequency range 10Hz - 2kHz,
- Sensitivity > 10mV/g,
- Measurement range: 20g

❖ **High surface area nanoporous materials, carbon dioxide capture and utilization, hydrogen storage, catalysis, electrode materials for supercapacitors, removal of heavy metals and organic dyes, nanostructures immobilization in cellulose matrices, deactivation of microbes, cellulose based flexible super-capacitor devices**

➢ Synthesis of electrode materials: Several hetero-atoms enriched electrode materials are synthesized by simple condensation reactions between less expensive and commercially available building blocks. Due to the presence of multivalent precursors, the formation of the porous framework having voids, cavities and channel inside is feasible. Further condensation of these voids, cavities, and channels directed rigid, three-dimensional frameworks with high surface area and tuned pore architecture.

➢ Best performance of electrode and electrolyte designing: The synthesized heteroatoms-rich framework materials with hierarchical pore structure where the large pores will assist in the transportation of the electrolytes and small pores would contribute in the formation of double layers for a greater specific capacitance. The recyclability of the devices is highly desirable and in a non-aqueous electrolyte, this can be expected to show an excellent recyclability performance.

➢ Electrochemical characterization: The electrochemical supercapacitor performance of the synthesized materials is evaluated by fabricating the electrodes. Several binders and charge carriers that are commonly used in supercapacitor devices are already added to the synthesized materials. The performance of the three electrodes system is already evaluated by cyclic voltammetry (CV) and galvanostatic charge discharge (GCD) while will be evaluated for two electrode system. The device performance will further be evaluated by the electrochemical impedance spectroscopy (EIS). Moreover, the fabrication of the solid-state devices will be the ultimate goal.

➢ Linkage to space science and technology programme: High surface area materials enriched with heteroatoms such as N, P, S, B etc. are shown to exhibit superior supercapacitor efficiency. This research would be very much useful for space technology as the light weight storage system with high power and energy densities are highly sought for space missions.

❖ **Advanced metallic materials, Superalloys, vacuum arc melting, High entropy superalloys, Aluminum matrix composites, bainitic steels, Thermomechanical simulation, Electron microscopy, EBSD, Fatigue strength.**

- Superalloys
- High entropy alloys
- Advanced steels
- Nanostructured metallic materials, amorphous materials and nanocomposites
- Mechanical properties of advanced metallic materials
- Mechanical alloying
- Cryo-deformation, rolling, forging. Severe plastic deformation
- Thermomechanical simulation

❖ **High Efficiency Solar Cells Characterization, Intensity Modulated Impedance Spectroscopy**

- Complete understanding of impedance parameters in multi junction solar cells and CIGS solar cells for characterization of high efficiency solar cells for space application.
- Probing charge carrier dynamics and device stability by intensity modulated impedance spectroscopy for emergent space PV application.

❖ **Dynamic modelling, Vibration, Impact, Biomechanical Analysis, Injury Biomechanics**

- Developing a computationally efficient human full body FE model to study the effect of spacecraft environment on human body.
- Evaluation of performance of human body under accelerative and other mechanical loading during a spaceflight.

Acquisition of full body MRI and CT images of human.

❖ **Sub-millimeter/THz Components, Microwave Studio, RF system-on-chip solution, CMOS/BiCMOS process**

- developing low cost and low loss basic building blocks used in the sub-millimeter wave/THz transceiver such as transition and couplers or hybrid for astronomy applications
- rigorous electromagnetic analysis of the subsystems such as transition and couplers are being done using commercial e. m. solver such as HFSS and CST
- The RF receiver front-end has two basic electronic components: the low noise amplifiers (LNA) and the mixer. For wideband systems, the LNA design must provide input matching in the wide frequency band. In order to improve the sensitivity of the receiver, the LNA design should provide high gain as well as introduce low noise. Research is going on the studies of LNA and mixers circuit topologies for Tri-band (L1/L5/S) wireless receivers, designing of combination of the LNA and mixer topologies for Tri-band which includes frequency range starting from 1 GHz to 3 GHz.

30.4 Major Scientific Applications / Results

❖ **Smart materials and Deployable Antenna**

Analysis and prediction of crease(s) arrangement to minimize the wrinkles Analytical approach for one-dimensional Z-folded membrane is developed and implemented in numerical simulations. It is valid and applicable for any number of creases that follow this approach (irrespective of membrane size). The technique is successfully tested and validated for membrane sizes up to 1 m × 1 m. For wrinkle alleviation, various combinations of crease positioning (Crease orientation angle + No. of creases) are analyzed. Couple of them are suggested, which keeps the surface accuracy within the desired limit. These combinations can be implemented to any upscaled membrane size. After successful experimental verification, the membrane is connected with the torus. Membrane reflector deploys the way torus deploys. To start deployment, the gas process is found to be 0.6 and 0.8 kPa for both cases of 900 and 450 crease orientation fold arrangements. Among these, the later one deployed in more controlled manner. The maximum gas pressure that the torus can handle is equivalent to the force required for 10 mm membrane displacement, 7 MPa. However, for creased membrane, the number of creases and the location of crease are of more concern. From analysis, it is clear that crease location and orientation vary from shape to shape.

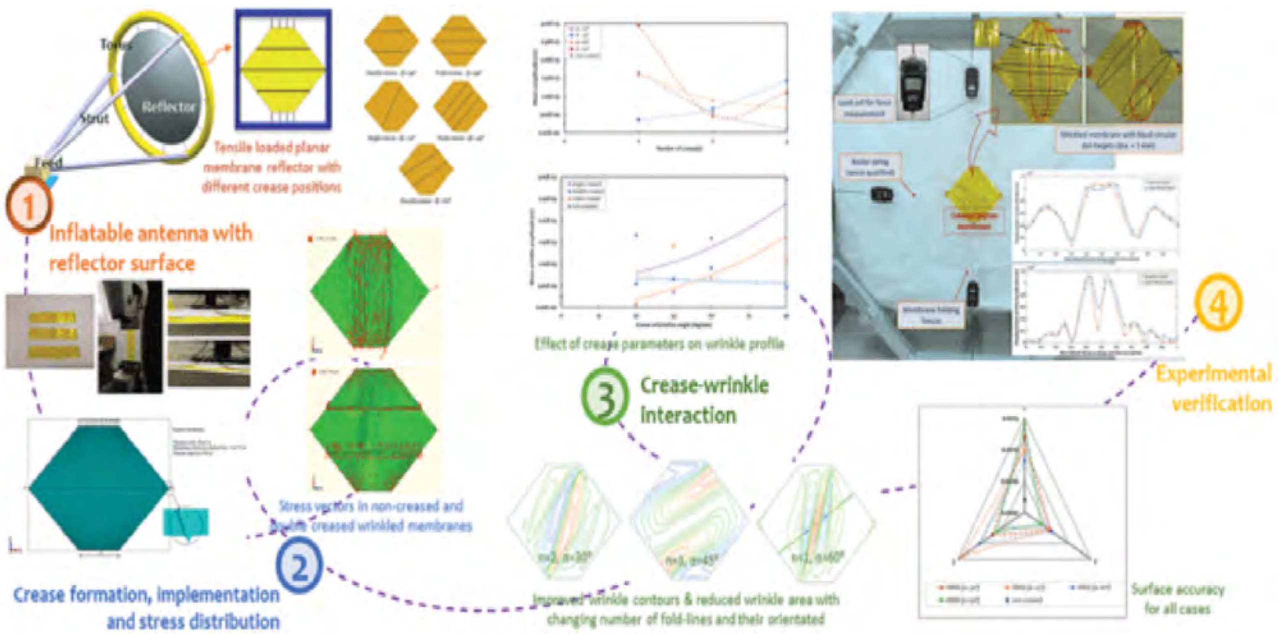


Figure 1. Crease characterization and z-fold arrangement is followed by wrinkle and crease wrinkle interaction analysis for varied fold-lines and their positions. The results from numerical analysis are successfully validated with experimental outcomes.

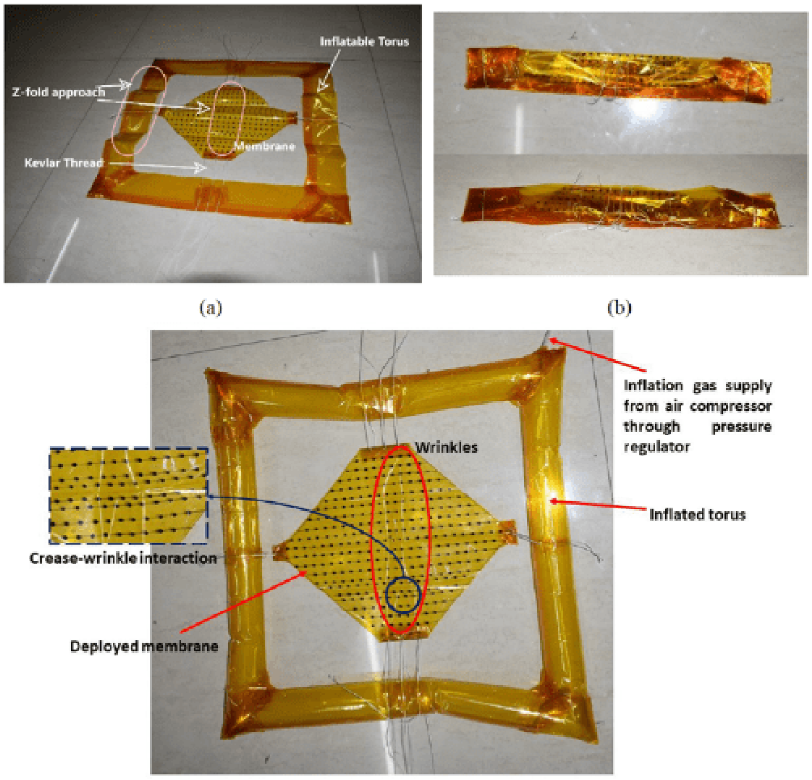


Figure 2. Deployment sequence for Z-fold membrane (with torus) where fold-lines are at 900 to the tensile loading direction, keeping the two side edges fixed

Rigidization of Structure: Inflatable antenna is the assembly of mainly three major parts: torus, reflector, and strut. Strut provides transverse and longitudinal loading support to the entire assembly. Out of many rigidization techniques, most potential techniques, the strain hardening method is chosen to rigidize the strut. FEM and experimental analysis have been performed to measure the generated structural rigidity in the strut after rigidization.

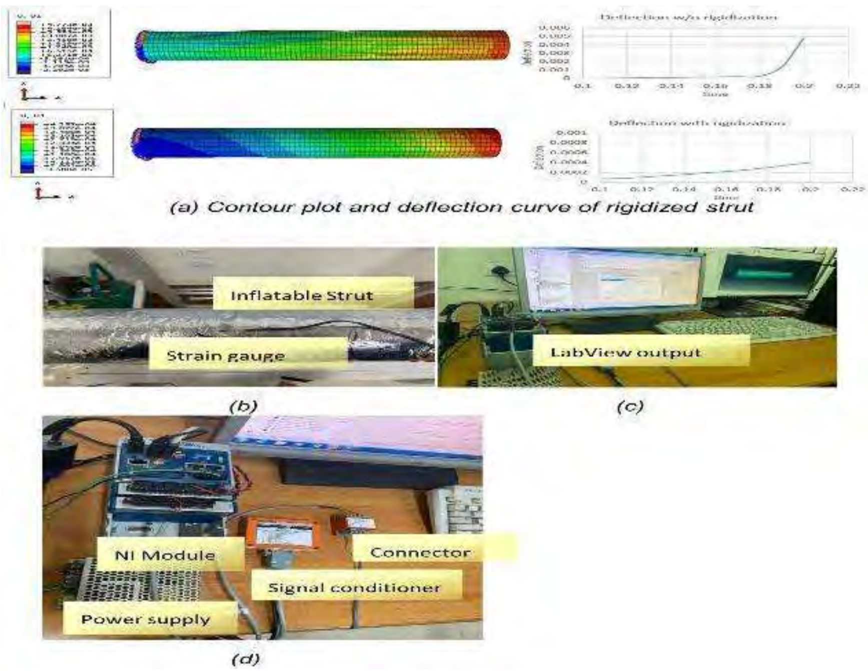


Figure 3. Rigidization sequence of laminated strut

Figure 3 exhibits numerical and experimental sequences to rigidize the inflatable boom through strain hardening. Figure 3 (a) shows the deflection pre and post rigidization while figure 3 (b), (c) and (d) are showing equipment used to rigidize the strut experimentally. Strain gauge pasted on the strut surface senses the alteration in dimensions during inflation beyond the yield strength of the strut wall.

Tensioning and Connecting Mechanism

The developed tensioning mechanism produces the predefined state of stresses in the membrane reflector and can work without an onboard power supply. The antenna canister also acts as a connecting part between the satellite and reflector. The novel flexural-based canister mechanism is developed for the space-borne planar membrane reflector antenna. The proposed system uses as flexural linkages so that very less actuation power source is required to perform the required motion. The deployable canister required very little storage space and easily accommodated on a satellite platform. The mechanism will work on the principle of storing bending potential energy and releasing it, once it reaches the required orbit.

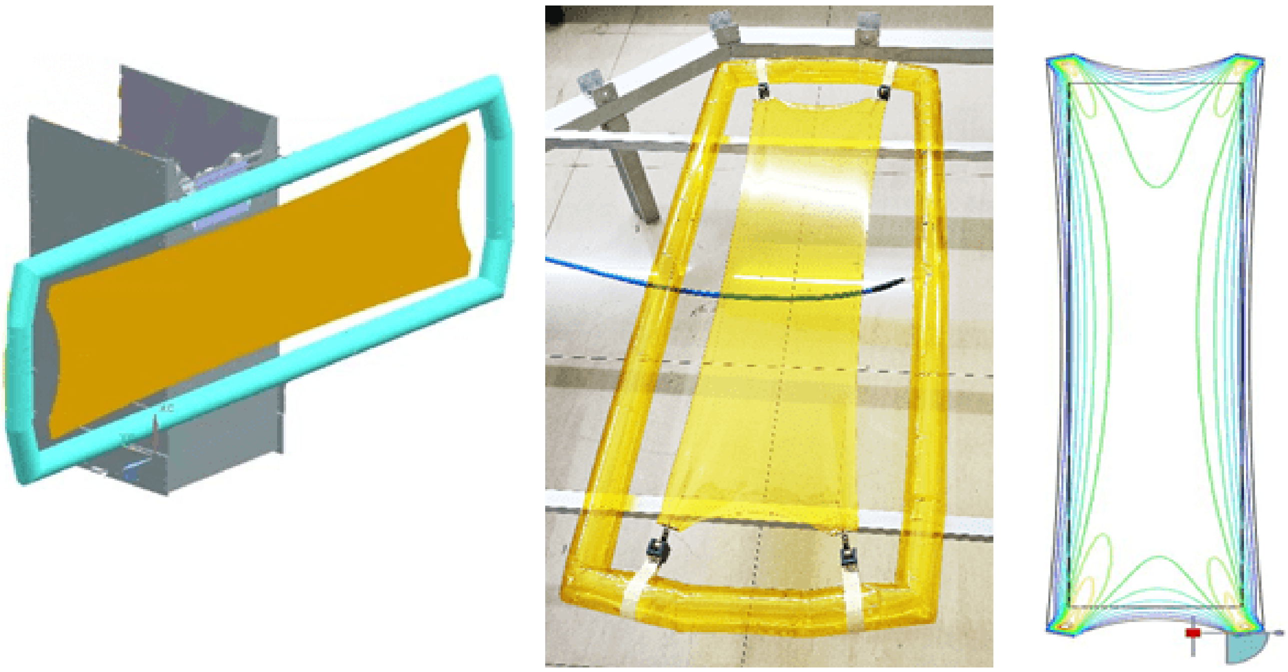


Figure 4. Rectangular planar membrane reflector

Design & Development of a self-deployable mechanism for mesh antenna

The self-deployable ring structure of the mesh antenna is being developed with the help of flexural hinges. Different design configurations are being explored based on flexure rolling and bending phenomena. Using the flexure hinges, the structure can be self-deployed by the stored energy of the flexural hinge during the fold. The following figures show the stowed and deployed condition of the ring structure of the mesh antenna for the proposed flexure-based approach. This approach will eliminate the need for an onboard power source.

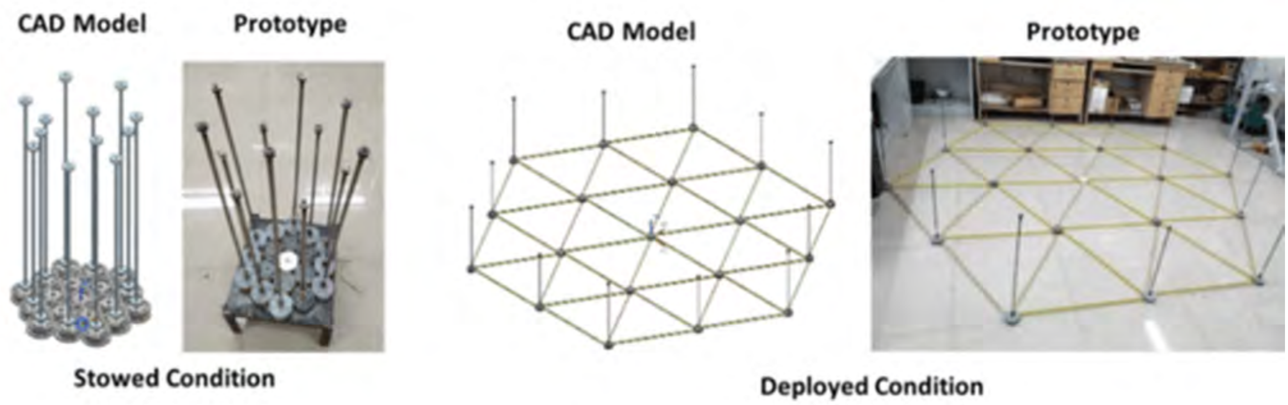


Figure 5. Stowed and deployed condition of a ring structure with flexural rolling phenomena

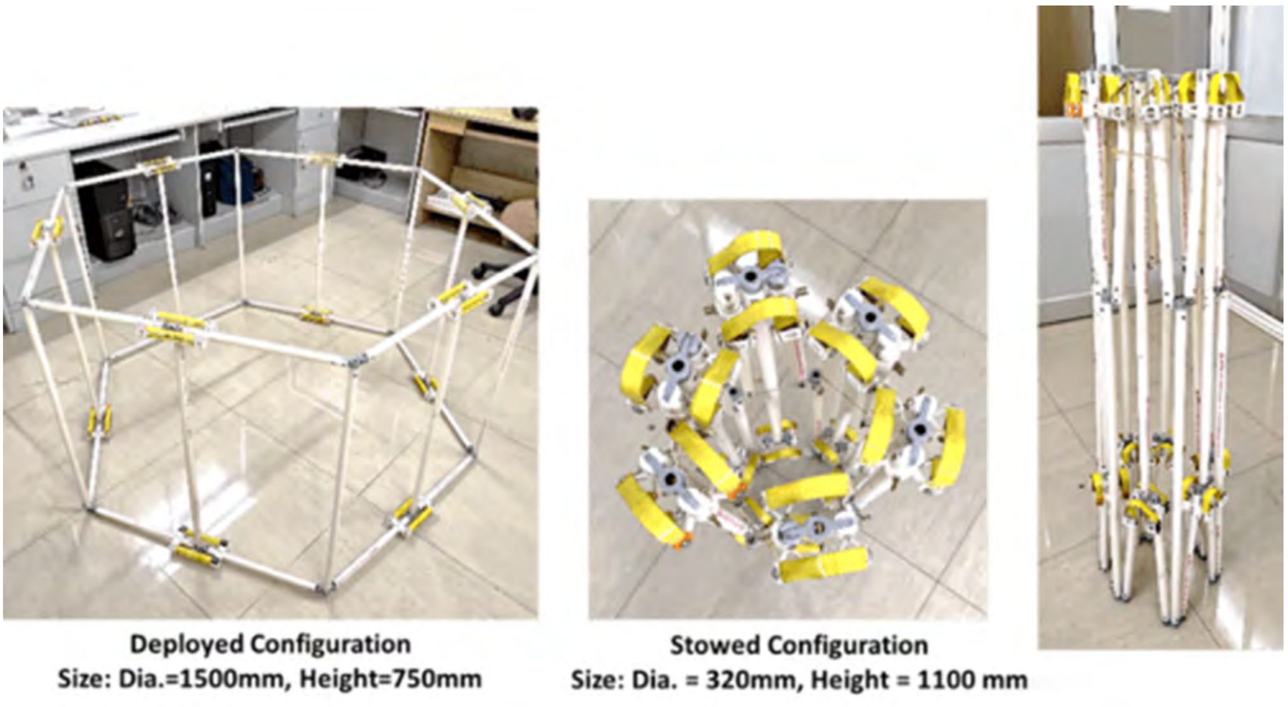
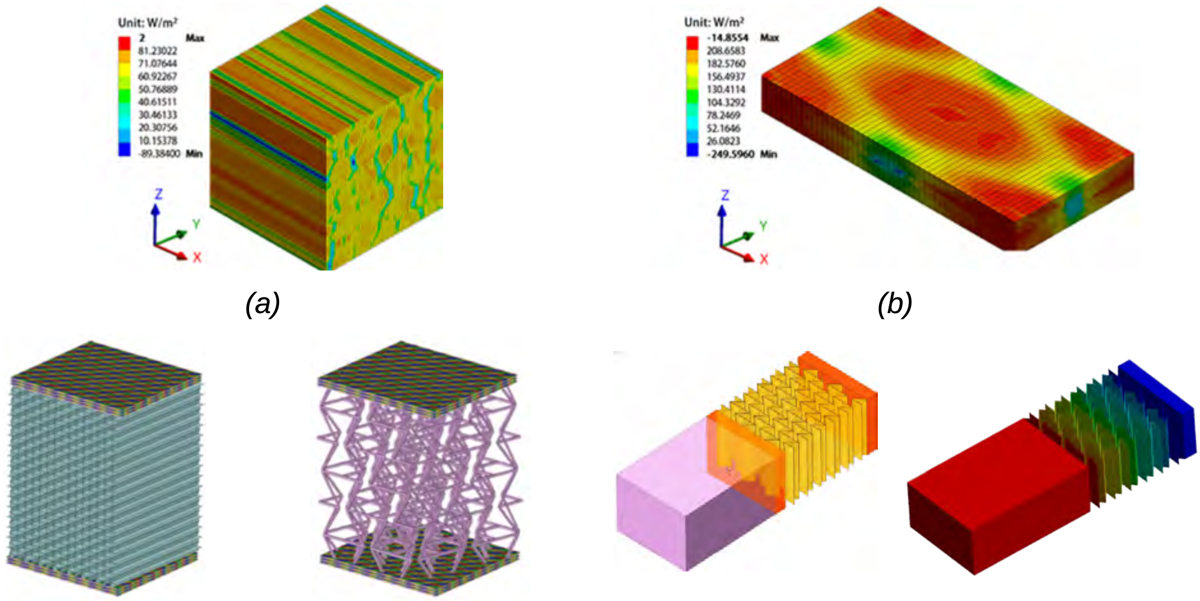


Figure 6. Stowed and deployed condition of a ring structure with flexural bending

- **Applications of the Finite element method, textile composite, auxetic metamaterial, phase-field fracture, in-house coding, parallelization, high performance computing, topology optimization**

Design of heat resistant meta-sandwich structure for thermal shield in space structure



(a) (b) (c) (d)

Figure 7. (a) Microscale analysis at fiber matrix level, (b) Mesoscale analysis at fabric level, (c) Proposed meta-sandwich structures, (d) Steady-state thermal analyses of the proposed meta-sandwich structure.

This work aims to develop a textile based auxetic meta-sandwich structure that can resist high temperature (1650◦ C) deformation, fracture and fatigue. Auxetic are of great interest due to the usefulness of the novel property itself: Counter-intuitive (‘opposite’) response and high-volume change. They provide a route to achieving unusual or extreme values of other material properties not easily achievable in conventional materials. They have enhanced properties including increased shear modulus, higher indentation resistance, synclastic curvature and thermal shock resistance. The micro and mesoscale RVEs are considered for modelling the textile where the microscale RVE consists of fibers, matrix, interphase between them. Thermal effective core characteristics, including coefficient of thermal expansion, thermal conductivity, and specific heat capacity, have been predicted and compared using the computational homogenization technique. Results show that the proposed structural configurations show 70% and 93% temperature reduction than conventional materials. Further, we performed numerical analysis of selected configurations via mode-I standard compact tension (CT) specimens performed Using our in-house codes and validated them with experimental and FE package ABAQUS results.

❖ Applications of Biomechanics studies:

- Acquisition of full body MRI and CT images of human volunteer (age 31 years and body mass index 23.6 kg/m2).
- Geometric and FE modeling of human tissues from acquired images

- Geometric models of human skull, thorax, pelvis, femur, tibia and foot have been generated.
- High quality hexahedral meshes of femur have been generated.

❖ **List of Patents (July 2020 – December 2021)**

1. Shinde Swapnil, and Upadhyay, S. H., "A Tensioning and Connecting Device for the Space-Borne Membrane Reflector Antenna" (*Indian Patent filed, application no. 202011017218 dated. 22.04.2020)*
2. Shinde Swapnil, Upadhyay, S. H., Sammir Sakhare, and K.S Singh, "Deployable canister mechanism for an inflatable planar membrane reflector antenna" (*Indian Patent published, application no. 202011055864 dated. 22.12.2020)*
3. Shinde Swapnil, Upadhyay, S. H., Sammir Sakhare, and K.S Singh, "Deployable canister mechanism for an inflatable planar membrane reflector antenna-Design" (I*ndian Patent published, application no. 337084-001, dated. 01.01.2021)*

30.5 Instruments / Payloads / Products Developed / Sensors / Detectors

❖ **Accelerometer**

❖ **Vibration actuator setup**

It is meant for analyzing the effect of vibration generation under actual conditions. Actuation unit generates the vibration in the membrane through the piezo patches. Photogrammetry tool provides different positions of membrane under vibration effect.

❖ **Small scale isothermal chamber**

It is for generating the isothermal environment for heat actuated deployment structures. Inflation source provides the capability to inflate the gossamer structures at various pressure ranges. The SMSL has capacity to inflate the structure upto 8 bar pressure.

30.6 Capacity Building in Space Science Research

❖ IIT Roorkee has established a Space Technology Cell (STC) in association with ISRO and currently, thirteen Research projects are being executed through the STC. Several B.Tech, M.Tech, and PhD students are working under the projects and many project staffs are being trained through the programs.

❖ Total number of students engaged in various Space Technology related projects are:

- Ph.D : 18
- Research Associate : 1
- M. Tech : 8
- B.Tech : 11

- Two B.Tech students have chosen space science as a career by joining ISRO as scientists.

❖ A TEQIP online faculty development programme was conducted on "MULTIFUNCTIONAL CHARACTERISTICS OF ADVANCED MATERIALS," providing observations, insights, and strategic opportunities in the field of modeling, simulation, and manufacturing of multifunctional metamaterials and their applications in defense and space. It involved talks and discussion from IIT professors and director and scientists of DRDO labs including, Terminal Ballistics Research Laboratory (TBRL) Chandigarh.

❖ Following workshops, lectures and talks have been organized for students and faculty members to create awareness about advancement in space research. Events organized in last few years are as follows:

- World Space Week 2020: 6th October to 10th October 2020
- World Space Week 2021: 6th October to 10th October 2021

30.7 Courses offered on Space Science and Technology

No specific courses on Space technology is currently offered. However, the core areas of research relevant to Space technology are covered in various courses given by the following departments

- Metallurgical & Materials Engineering
- Electronics & Communication Engineering,
- Mechanical & Industrial Engineering
- Chemistry
- Physics
- Civil Engineering
- Computer Science & Engineering

30.8 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	Development of new materials, Powder Metallurgy, High ductility of metals,	VSSC, Thiruvananthapuram
2.	Biomechanics, Safety aspects in spaceflight	VSSC, Thiruvananthapuram
3.	Energy Storage device, Supercapacitor	VSSC, Thiruvananthapuram
4.	Structural Engineering of composites	VSSC, Thiruvananthapuram

Sl. No.	Area of Collaboration	Collaborating Institute
5.	MEM, Sensors, Microelectronics, CMOS process,	SCL, Chandigarh
6.	RF, CMOS, THz Technology	SAC, Ahmedabad
7.	Deployment mechanisms, Inflatable Antenna	SAC, Ahmedabad
8.	Solar Cells, Energy resource	URSC, Bengaluru

30.9 Laboratories and Facilities Available for Space Instrumentation

❖ **Membrane testing facility**

Multipurpose experimental test setup for planar membrane reflectors subjected to edge-tension, shear, and corner loading [With laser displacement sensor and piezo-patches connection to Data Acquisition System (DAQ)].

❖ **Tension force analysis facility**

The tension force analysis setup consists of the digital load cell, strain gauge, and data acquisition system. The setup is used to perform the strain analysis to accurately design the required tension forces.

❖ **Experimental setup for deployment speed test of rolled flexural spring**

An experimental setup is developed for the deployment study of the rolled flexural spring. An approach is being investigated to reduce the deployment speed and end-deployment shock by introducing an external spring force. Initial results show a 50% speed reduction with the approach. Further, spring type and parameter optimization are under process.

❖ **Membrane Inflation Test setup**

The experimental set up is used to study the inflection dynamics of the prototype of the deployable boom, torus and parabolic reflector. The displacements, membrane stresses and the inflation pressure can be investigated for different geometric configurations of the membrane structures.

❖ **Vacuum Bagging Facility**

Vacuum bagging has the capability of producing small-scale composite materials like flexural tape springs. Sample preparation for composite spring is under process. The following figure shows the vacuum bagging setup & composite spring sample prepared.

❖ SMSL is developing thermal test capability from room temperature to 200 degC. This capability may be used to test the space structures under actual thermal conditions. Different sensors like load cell, thermocouples, vibration actuators can be linked with setup to get relevant readings.

❖ **Rotatory evaporator**

It is mainly used for the process of evaporation, concentration, crystallization, drying, separation, and solvent recovery, and especially used for the continuous distillation of large amounts of volatile solvents under the vacuum condition. The solvent steam is recycled in the receiving flask after being cooled by the high efficiency glass condenser.

❖ **Automatic film coating machine with cover heater, film applicator and vacuum pump:** It is designed to produce films with consistent thickness by using micrometer adjustable applicators or fixed thickness applicators.

❖ **Compact vacuum mixer & hot roll press:** It designed to produce coating slurry by mixing the small batch of chemicals (solvents) and compounds (binders and additives) under vacuum to remove gas bubble and protect the sample from oxidation. It is good for preparing battery and supercapacitor electrodes.

❖ **Heat pressing machine:** It is designed to adjusting thickness and increase active material density in of the electrode in supercapacitor and battery research after coating and drying. It is also helpful for making small electrodes in rolling process which is suitable for experimental line.

❖ **HPC facility**

❖ **Elegoo Saturn resin 3D printer** 50µm xy resolution, 19.2cm × 12cm × 20cm build volume capacity for prototyping designed metamaterials and topologically optimized complex architectures.

❖ Mechanical alloying/milling instruments, Spark plasma sintering facility, Vacuum arc melting facility, Gleeble thermomechanical simulator, EDM wire-cut facility, Microhardness testing facility, Tensile Testing -room temperature and high temperature setup, Wear-room temperature and high temperature setup, Fatigue testing - room temperature and high temperature setup, HR-TEM/ SEM/EBSD/XRD/XRF facilities are available at the Department of Metallurgical & Materials Engineering and the Institute Instrumentation center.

❖ Thermal and Vibration testing facility for Structural Engineering

❖ **List of Recent Publications (Relevant to Space Technology Research)**

1. Parth K. Kamaliya, S H Upadhyay, H M Y C Mallikarachchi, "Investigation of wrinkling behaviour in the creased thin-film laminates", International Journal of Mechanics & Materials in Design, Vol. 17, 899–913, 2021

2. Shinde Swapnil and Upadhyay S H, “The novel design concept for the tensioning system of an inflatable planar membrane reflector”, Archive of Applied Mechanics, Vol. 91, 1233-1246, 2021

3. Shinde Swapnil, Satish Kumar, Upadhyay S H, “Investigation on material combination technique to enhance the anti-wrinkle and anti-vibration characteristics of the planar membrane reflector”, Proc IMechE Part C: J Mechanical Engineering Science, IMechE, Vol. 235(21), 5675-5683, 2021.

4. Sharma H. and Upadhyay S H, “Folding pattern design and deformation behavior of origami based conical structures”, Advances in Space Research, Vol. 67(7), 2058-2076, 2021

5. Sharma H. and Upadhyay S H, “Geometric design and deployment behavior of origami inspired conical structures”, Mechanics Based Design of Structures and Machines, 2020. DOI: 10.1080/15397734.2020.1833738

6. Saxena K.K., Pancholi V., Zr-Nb Alloys and its Hot Deformation Analysis Approaches: A Review, Journal of Metals and Materials International https://doi.org/10.1007/s12540-020-00812-8.

7. Naveen Kumar Tailor, Satyaprasad P. Senanayak, Mojtaba Abdi-Jalebi, Soumitra Satapathi, “Low-Frequency Carrier Kinetics in Triple Cation Perovskite Solar Cells Probed by Impedance and Modulus Spectroscopy”, Electrochemia Acta, doi.org/10.1016/j.electacta.2021.138430, 2021.

CHAPTER-31

INDIAN INSTITUTE OF TROPICAL METEOROLOGY

Pune

31.1 Keywords

Microwave satellite data, Pacific SST, snow-monsoon relationship Microwave satellite data, Antarctic sea ice, Pacific SST, ISMR, El Niño Modoki, ENSO, Eurasian snow, Greenland sea ice, Indian summer monsoon, Kalpana 1, VHRR, OLR, Arctic Oscillation, Southern Annular Mode; Clouds and precipitating systems, Forecast evaluation, Kalpana VHRR, INSAT-3D and 3DR.

31.2 Major Research Domain: Satellite Meteorology

Objectives

1) Investigation of large scale cloud characteristics over the Indo-Pacific Ocean basin and the driving mechanisms for the same.
2) Satellite passive microwave remote sensing for understanding the role polar sea ice processes in driving SST's over Indo-Pacific basin having direct implication on ISMR.
3) Understanding diverse characteristics of South (in-particular India) and East (in-particular Japan-Korea) Asian summer monsoon rainfall using satellite and reanalysis data products
4) Performing sensitivity experiments for investigating the relationship of polar sea ice processes with ensuing South and East Asian summer monsoon having useful implications in long range forecasting of rainfall.
5) ISMR-Teleconnection based studies involving evaluation of large-scale northern and southern annular modes using satellite data products.
6) Institute utilizes various datasets which contain vital information on earth systems obtained from space-borne platforms of both National and international missions. These datasets help in the understanding of the underlying physical processes of the earth's atmosphere and climates. This wealth of data is also getting utilized in the evaluation of model simulations and regional hydrological parameters. Emphasized is also given to retrieval of geophysical physical parameters from the satellite observed basic quantities.
7) Institute also participates in the validation of retried geophysical products through dedicated field campaigns and surface-based specialized measurements. The ongoing atmospheric test-bed facilities site at Bhopal is further steps towards this.

8) A suite of payloads such as cloud and rain radars, hyper-spectral sounders, microwave sensors for soil moisture, and high resolution unambiguous sea-surface winds and LEO missions has been suggested for future ISRO scientific missions as a part of the ISRO-ADCOS study teams on advance payloads for future missions. Similarly, for the Fourth Generation of INSATs advanced operational Imagers, Sounders channels along with lighting imager proposed as a part of atmosphere research to enhance observational capabilities and advancing forecasting capabilities and to face future challenges in the backdrop of rapidly changing climate.

31.3 Major Scientific Applications / Results

Found some new perspectives with respect to Indian summer monsoon using Satellite inputs

1) **Regional perspectives of snow-monsoon** - Eurasian snow association with spatial distribution of rainfall over India features a tri-polar pattern of significant negative-positive-negative correlations over the northern, east-central and south-western regions of India respectively. The physical mechanism for this snow-monsoon link is envisaged through two pathways. One of the channels is Eurasian winter snow directly affecting the ensuing summer monsoon rainfall through large scale circulation, while the other way is winter snow affecting monsoon indirectly through Tropical Eastern Pacific (TEP) Sea Surface Temperatures (SSTs). Enhanced Eurasian wintertime snow is found to be associated with warm TEP SSTs from preceding winter through to the following summer, leading to anomalous large scale zonal circulation during summer monsoon season, thereby affecting rainfall over India (Study published in Polar Science, 2021).

2) **Antarctic Sea ice, ENSO** - Microwave satellite based study during the period 1983-2015 demonstrated an in-phase significant relationship between sea ice over the Western Pacific Ocean (WPO) sector and the ISMR, while for the same period, an out-of-phase relationship has been observed between Bellingshausen and Amundsen Sea (BAS) sector with that of ISMR. The physical mechanism proposed that relay the southern polar variability signal towards the Indian monsoon is through the Pacific Ocean channel associated with El Niño Southern Oscillation (ENSO), wherein the sea ice variability over the BAS (WPO) sector affects the equatorial central (western) Pacific. The anomalous meridional circulations caused by BAS (WPO) sea ice variability is associated with anomalous warming over the central (western) equatorial Pacific, which con-currently impacts the summer monsoon rainfall over the Indian continent adversely (favourably) (Study published in Polar Science, 2021).

3) **Combined impacts of Greenland sea ice, Eurasian Snow, and ENSO on out-of-phase relationship between Indian Summer Monsoon (ISM) and Korean Summer**

Monsoon (KSM) - have been investigated through numerical experiments. Results reveal that non-linear responses of Indian and Korean summer rainfall to ENSO and Greenland sea ice forcing prevail when both the events co-occur. The physical mechanism for this snow-monsoon link is envisaged through two pathways. One of the channels is Eurasian winter snow directly affecting the ensuing summer monsoon rainfall through large scale circulation, while the other way is winter snow affecting monsoon indirectly through Tropical Eastern Pacific (TEP) Sea Surface Temperatures (SSTs). Enhanced Eurasian wintertime snow is found to be associated with warm TEP SSTs from preceding winter through to the following summer, leading to anomalous large scale zonal circulation during summer monsoon season, thereby affecting rainfall over India (Numerical study published in International Journal of Climatology, 2020;Observational study published in Climate Dynamics, 2016).

4) **ISCCP observed large-scale cloud features over the Indo-Pacific, Southern Annular Mode and Indian Summer Monsoon** - The International Satellite Cloud Climatology Project's (ISCCP) data demonstrated the spatial distribution of High-level clouds, specifically the deep convective clouds, as compared to Low-level and Mid-level clouds, over the central Pacific as a manifestation of ocean-atmosphere coupled interactions associated with Southern Annular Mode (SAM). This study has a potential application in understanding the cloud dynamics over the Indo-Pacific basin, which is associated with SAM phenomenon, having an implication on the performance of Indian summer monsoon. (Study published in Polar Science, 2018).

5) **Generation of high resolution 3-hourly OLR climatology over the Indian region using Kalpana-1 VHRR data** - This project produced OLR data products and its climatology at 25 km - spatial and 3 hourly - temporal resolution from May 2004 onwards. Archival of raw data files of IR and WV channels obtained through VHRR onboard Kalpana-1 satellite from IMD, New-Delhi. In-house software was developed for computing OLR using Genetic Algorithm (GA) that uses both IR and WV radiances and the final product has been uploaded on the IITM web portal. The end product i.e. the 3-hourly OLR Climatology generated for above mentioned spatial and temporal resolution will be highly useful to the scientific community to study the mesoscale processes occurring over the Indian region. (Study published in Current Science, 2013).

6) **Annular Modes and Indian Summer Monsoon Teleconnections** - Both the Southern Annular Modes (SAM) and Northern Annular Modes (also known as Arctic Oscillation (AO)) have been investigated for its potential implications on presaging the contradictory nature of summer monsoon rainfall over the Indian mainland (ISMR) and the North East (NE) Indian region (NEISMR) respectively. In essence, while the summer monsoon rainfall over major parts of India (excluding the NE region) appears to be related with events in the Southern Hemisphere, namely the SAM episodes through the Pacific sea

surface temperatures (SSTs), the variation of summer monsoon rainfall over the NE region appears to be related with events in the Northern Hemisphere associated with the AO, Eurasian snow and Atlantic SSTs. A schematic representation of hypothesis linking NEISMR, tropical north Atlantic SST and Eurasian snow is shown in Figure 1. (Study related to AO and ISM published in Climate Dynamics, 2017; Study related to SAM and ISM published in Climate Dynamics, 2016)

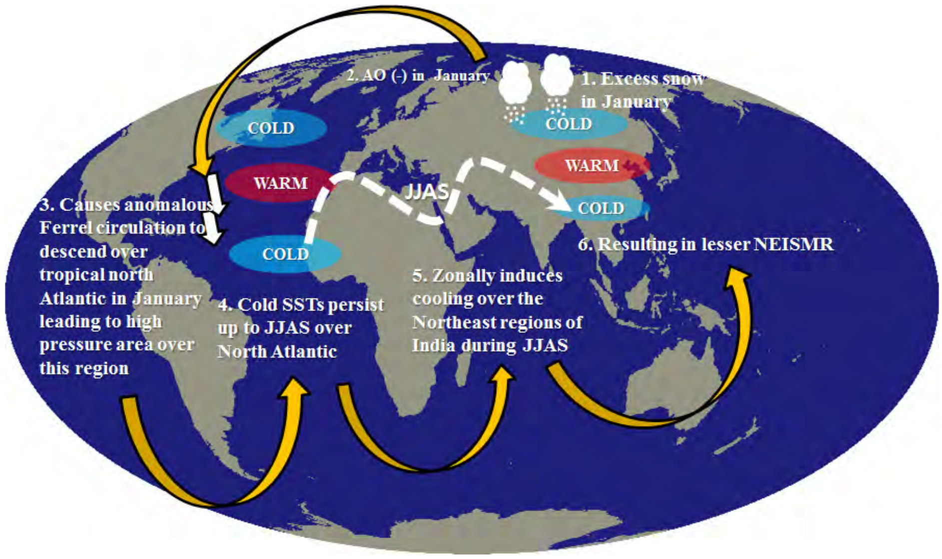


Figure 1: A schematic representation of hypothesis linking NEISMR, tropical north Atlantic SST and Eurasian snow (Source: Figure 3 of Prabhu et al. 2017, Climate Dynamics)

- Collocated and contiguous TRMM PR and VIRS data were used to detect cumulus congestus clouds population during Indian summer monsoon i.e. precipitating clouds with negligible ice process. These clouds produce rain through the warm rain process and yield light rain, few of them later transform into deep convections. To assess the model fidelity in simulating the diurnal signature of precipitating clouds and deep convection precursors these data were analysed.
- A pronounced and fine-scale diurnal variation in outgoing longwave radiation retrieved from Kalpana VHRR is observed over the Indian sub-continental landmasses in contrast to the surrounding Oceans. This data is further utlised to evaluate cloud types and radiation budget components obtained through model simulations. However, large navigational errors were noticed in the VHRR images during the course of the work. It can also be noticed in recent INSAT imagers this hinders combined usage of INSAT-3D and 3DR.
- Cloud's microphysical quantities not only control precipitation initiations and intensities it alters the vertical distribution of radiative heating. However, due to the lack of polarized and Doppler capabilities cloud radar in space, such quantities are not readily available yet. The CPR hydrometeor retrievals onboard CloudSat data along with other available information was used to derive the above parameters. Analysis showed that

CFS models find it difficult to reproduce even the mean vertical structures due to simplified cloud microphysical representations. Even, state of the art models has large biases in radiative fluxes due to improper considerations of cloud ice and water in the radiative transfer parameterizations.

- INSAT-3D infrared brightness temperatures and imageries of other channel information were used to attribute the Kerala floods during 2018 and 2019 due to extremely heavy rain episodes and to further assess a suite of short and extended range forecast models. It was found that the precipitation occurrence was mostly from prolonged shallow convective systems. [Mukhopadhyay et.al, Unravelling the mechanism of extreme (more than 30 sigma) precipitation during August 2018 and 2019 over Kerala, India, Weather and Forecasting, 36, DOI:10.1175/WAF-D-20-0162.1, 1253-1273, 2021.]

List of Scientific publications:

1) Prabhu A., et al., Regional perspectives in Eurasian snow - Indian monsoon relationship: An observational study, Polar Science, 30, 1-15, 2021

2) Prabhu A., et al., Association between Antarctic Sea ice, Pacific SST and the Indian summer monsoon: An observational study, Polar Science, 30, 1-11, 2021

3) Kim I., Prabhu A., et al., Combined impact of Greenland sea ice, Eurasian snow, and El Niño-Southern Oscillation on Indian and Korean summer monsoons, International Journal of Climatology, 40, 1375-1395, 2020

4) Prabhu A. and Pandithurai G., ISCCP observed large-scale cloud features over the Indo-Pacific, Southern Annular Mode and Indian summer monsoon. Polar Science, 18, 167-175, 2018

5) Prabhu A., et al., SMMR-SSM/I derived Greenland Sea ice Variability: Links with Indian and Korean Monsoons, Climate Dynamics, 50, 1023-1043, 2018

6) Amita Prabhu, et al., Summer monsoon rainfall variability over North East regions of India and its association with Eurasian snow, Atlantic Sea Surface temperature and Arctic Oscillation, Climate Dynamics, 49, 2545-2556, 2017

7) Prabhu A., et. al., Can the Southern Annular Mode influence the Korean Summer Monsoon Rainfall?, Asia-Pacific Journal of Atmospheric Sciences, 53, 217-228, 2017

8) Prabhu A., et al., Potential role of the February-March Southern Annular Mode on the Indian summer monsoon rainfall: a new perspective, Climate Dynamics, 47, 1161-1179, 2016

9) Prabhu A. et al., Association of the Indian summer monsoon rainfall variability with the geophysical parameters over the Arctic region, International Journal of Climatology, 32, 2042-2050, 2012

10) Prabhu A. et al., Role of Antarctic circumpolar wave in modulating the extremes of Indian summer monsoon rainfall, Geophysical Research Letters, 37, 1-5, 2010

31.4 Instruments / Payloads / Products Developed / Sensors / Detectors

- Developed a high-resolution ¼ degree gridded Outgoing Longwave Radiation datasets from Kalpana (formerly METSAT) VHRR images, in collaborations with India Meteorological Department and SAC(ISRO). The data almost for the entire span of the satellite (i.e. years 2004-2017) can be accessed or interactively viewed through the Institute Live Access Server. More than 40 peer-reviewed publications have appeared utilising this dataset. [Mahakur et. al, A high-resolution outgoing longwave radiation dataset from Kalpana-1 satellite during 2004–2012, Current Science, 105, 1124-1133, 2013.]
- Prepared gridded cloud water and ice datasets from retrieved total cloud hydrometeors of CloudSat and CALIPSO missions for assessment of model simulations and understanding cloud physical processes under the National Monsoon Mission program. [Abhik et. al, Revised cloud processes to improve the mean and intraseasonal variability of Indian summer monsoon in climate forecast system: Part 1, Journal of Advances in Modeling Earth Systems, 9, DOI:10.1002/2016MS000819, 1-28, 2017]

Data Used from the following Sensors:

1) Scanning Multichannel Microwave Radiometer (SMMR) and Special Sensor Microwave Imager (SSM/I) derived sea ice data over the Arctic region, provided by National Snow and Ice Data Centre (NSIDC) from October 1978 onwards, has been utilized in this study.
2) International Satellite Cloud Climatology Project (ISCCP) D2 data has been used for observing the distribution of large-scale cloud features.

31.5 Capacity Building in Space Science:

3. Research guidance

(1) IITM scientists guided several summer internships, Masters and Ph.D. students in Atmospheric, space sciences and meteorology who used satellite data sets.

31.6 Courses offered on Space Science and Technology

IITM has in house training facilities for teaching Atmospheric and Climate Sciences for its newly recruited Scientists and Research fellows. Satellite Meteorology is taught as a part of this curriculum. Institute Scientists are also involved in teaching Satellite Meteorology to students of various Indian universities as guest faculty. Only the major programs are mentioned below.

Title of the course	Standard of the course	Intake capacity	Topics covered	Total numbers of lecture allotted
In house training (1 year duration)	Course work for Scientists recruited after BTech/Post Graduations through CAT	20	Satellite Meteorology	30
Training for JRFs	Ph.D course work (1 year duration)	10-20	Satellite Meteorology as an Elective subject	25
M.Sc(Space and Atmos. Sciences), SP Pune University under MoU	Post Graduation		Satellite Meteorology as an Elective subject	30

31.7 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	Kalpana and INSATs geophysical products	SAC (ISRO)
2.	GSICS and preparation of Climate quality geophysical products from INSATs	SAC (ISRO)

31.8 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1.	Preparation of CloudSat-CALIPSO cloud hydrometeors data towards evaluation of model simulations	JIFRESSE (UCLA) & NASA-JPL, USA

CHAPTER-32

INSTITUTE OF RADIO PHYSICS AND ELECTRONICS

University of Calcutta, Kolkata

32.1 About the Institute

Institute of Radio Physics and Electronics, University of Calcutta was established in 1949 by Late Professor Sisir Kumar Mitra. This Department was one of the first in the country to start post-graduate teaching in Electronics. Ionospheric studies conducted from University of Calcutta since early 1930s spearheaded by Late Professor Sisir Kumar Mitra, have made seminal contribution in advancement of the subject. The first experimental evidence of E layer, predicted by Heaviside and Kennely, was obtained by Mitra and Rakshit in 1930. His seminal book 'The Upper Atmosphere' has been considered a Bible for researchers in the field. Ionosphere Field Station, Haringhata hosted the first Ionospheric Sounding System in Asia in 1956, manually assembled by Late Professor Sisir Kumar Mitra. Using indigenously fabricated equipment, Prof Mitra's group determined the properties of the ionospheric layers, namely, the electron density, electron temperature and the magnetic field at this location. This was a remarkable achievement, the data being later verified by rockets and satellites. Apart from frontier-level research, Prof. Mitra was instrumental in promoting broadcasting in India, Calcutta being at the centre of such activities. In 1966, the Satellite Beacon Group was established and tracking of beacons from Low Earth Orbiting satellites, namely, Explorer-22 and -27 started at 20, 40 and 41MHz respectively. During 1972-1973, 136MHz telemetry transmissions from the near-synchronous satellite, INTELSAT-2F2 was recorded which was the first geostationary satellite observation in India. Signals from the geostationary satellite ATS-6 were recorded at this station at 140MHz in 1975-1976.The first long-term (1977-1990) measurement from this station with a VHF beacon was performed with the Japanese geostationary satellite ETS-2 at 136MHz. Amplitude recordings from VHF beacon of another satellite, FLEETSATCOM-2 at 244MHz were started in 1981. Recording of the amplitude of the 1537MHz signal from INMARSAT-2F1 was started in 1990. One of the first GPS receivers in India became operational at this Institute in 1994.

32.2 Keywords

Ionospheric Total Electron Content, Ionospheric Scintillation, Space Weather Impact on technological systems, Ionosonde observations, ST Radar, Rain DSD, Water Vapor, Aerosol, Lightning, EM Signal Propagation

32.3 Major Research Domains

- Characterization of equatorial and low-latitude ionospheric propagation effects

- Space Weather impact on Signal-in-Space performance of Satellite-based Communication Navigation System
- Stratosphere-Troposphere exchange process using ST Radar
- Radiometer and propagation studies of the Atmosphere
- Earth-space path propagation study in the Tropical and Temperate region at Ka and Ku-band
- Atmospheric Electric Field
- Convective processes in the boundary layer
- Aerosols studies at an urban location
- Gravity wave studies related to tropical cyclones and intense convective phenomena

32.4 Instruments / Payloads / Products Developed / Sensors / Detectors

i). Wideband Satellite Beacon Receiver

ii). VHF Phased Array Radar

iii). Dual-frequency GPS Receiver

iv). Multi-frequency multi-constellation GNSS Receiver

v). Software Defined GPS Receiver

vi). Small-form Low-Power GNSS Module

vii). Tri-band IRNSS Receiver

viii). Optical Rain Gauge

ix). Disdrometer

x). Micro Rain radar

xi). Laser Precipitation Monitor

xii). Automatic Weather Station

xiii). Aethalometer

xiv). Multi-wave length Radio Meter

xv). Electric Field Mill

32.5 Courses offered on Space Science and Technology

- Institute of Radio Physics and Electronics offers papers on **Radiowave Propagation**, **Satellite Communication** and **Radar** under the **Bachelor of Technology** (B.Tech.) course in **Electronics and Communication Engineering**. This course has an intake of 42. Typically 30-35 contact hours are allotted to each of these subjects.

- This Institute also offers **Master of Technology** (M.Tech.) course in **Radio Physics and Electronics** with specialization in **Microwave and Space Science**. Under this course, there are elective papers offered on **Global Navigation Satellite System (GNSS): Aids and Applications**, **Radio Astronomy Techniques**, **Space Climatology and Weather** and **Space-borne and Terrestrial Remote Sensing**. In these courses, 30-35 lecture hours are allotted for each paper.

32.6 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	Indian Regional Navigation Satellite System (IRNSS)	Space Application Centre (SAC), ISRO, Ahmedabad
2.	VHF Phased Array Stratosphere Troposphere (ST) Radar	National Atmospheric Research Laboratory, Gadanki
3.	Coherent RAdioBEacon Experiment (CRABEX)	Space Physics Laboratory (SPL), Thiruvananthapuram
4.	GNSS Observations	Indian Institute of Technology, Indore
5.	Characterization of transitional low-to-mid latitude ionospheric irregularities	Department of Physics, North Bengal University

32.7 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1.	SCIntillation Network Decision Aid (SCINDA) station of the global GPS and GNU VHF spaced-aerial receiver network	Institute for Scientific Research, Boston College, USA
2.	COSMIC-2 Radio Occultation ground network station	University Corporation for Atmospheric Research (UCAR), Boulder, USA
3.	Ionospheric effects and VHF Radar	Institute of Solar Terrestrial Physics, German Aerospace Centre (DLR/SO), Germany
4.	Global features of ionospheric irregularities as observed across a spectrum of frequencies	International Centre for Theoretical Physics (ICTP), Italy
5.	Space Weather studies from the low and polar latitudes	National Institute of Geophysics and Volcanology (INGV), Italy
6.	GNSS and Ionosonde observations from the low and transitional mid-latitudes	Frederick University, Cyprus

Laboratories and Facilities Available for Space Instrumentation

i). Satellite Technology Application Laboratory

ii). Radio Remote Sensing Laboratory

iii). Satellite Beacon Laboratory at Ionosphere Field Station, Haringhata

iv). ST Radar Facility at Ionosphere Field Station, Haringhata

32.8 Major Scientific Applications / Results

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CHAPTER-33

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS (IUCAA)

Pune

33.1 About the Centre

The Inter-University Centre for Astronomy and Astrophysics (IUCAA) has been established in 1988 by the University Grants Commission (UGC), under Section 12 (CCC) of the UGC Act No. 3 of 1956, as an autonomous centre of excellence. The main objectives are:

- To conduct vigorous research programme of its own in Astronomy and Astrophysics (A & A), and to provide a centre of excellence within the Indian University sector.
- To promote nucleation and growth of active groups in A & A in Indian Universities/ Colleges.
- To function as a field station and resource centre, and to provide general guidance and help for A & A activities in India and neighbouring countries.

33.2 Keywords

Astronomy and Astrophysics, Cosmology, Gravitation and Gravitational Waves, Structure Formation, Astronomical Observation, Instrumentation, Computing and Data Analysis, Associateship and Visitor Programmes, and Public Outreach.

33.3 Major Research Domains

- Black Holes: Very massive stars at the end of their lives would undergo core collapse to generate a black hole. This is usually accompanied by a most spectacular explosion, known as a Gamma Ray Bursts. Extensive research is going on at IUCAA on the study of black holes and the matter around them. At the centre of this activity is the Indian X-ray/UV astronomy satellite AstroSat. IUCAA in collaboration with ISRO, operates the Science Support Cell for this mission, and interacts with a wide cross section of researchers across India, especially from the university sector.
- Cosmology and Structure Formation: IUCAA scientists have demonstrated that formation of primordial black holes may result from small bumps or dips in the inflation potential of the early universe. A new cosmological estimator, called the Voronoi Volume Function, has been proposed, and shown to be a sensitive probe of galaxy evolution physics, dark matter and dark energy. In an exploration of the nature of dark energy, it was found that phantom brane could reproduce the observed expansion history of the universe well, but predicted a different rate of growth of perturbations than in the conventional description using a cosmological constant.

- Dark Matter and Brane World: The standard hypothesis is that dark matter consists of weakly interacting massive particles, but despite long-running experiments, no evidence for such particles has yet been found. Researchers at IUCAA have explored other possibilities, one of them being the Primordial Black Holes. Such black holes may have been formed in the early universe and would not be directly visible today.
- Observational Cosmology: In clusters of galaxies, it was found that satellite galaxies with earlier infall tend to be red and quiescent, while the later ones were blue and star forming. From the analysis of an imaging survey carried out by IUCAA scientists, using the Hyper Suprime Camera (HSC) on Subaru telescope, have identified over 550 new cases of strong gravitational lensing. One of these lensed systems was used to estimate the Hubble constant, and in another case X-ray observations were used to estimate the mass of the lensing structure. Study of weak lensing in the HSC survey yielded a new high precision estimate of density fluctuations in the universe. Gravitational lensing was also used to estimate the mass distribution of stars in very distant galaxies.
- Gravitational Wave Data Analysis Algorithms: IUCAA scientists have constructed an optimal Chi squared test for glitches in the data, which can be modelled as Sine Gaussian, and which is ubiquitous.
- High Energy Astrophysics: Very rapid millisecond correlations between X-ray and optical emission have been studied by IUCAA researchers. Radio observations of pulsars have been used to study glitches, and X-ray observations were used to put constrain on any pulsed emission from a ultra-luminous X-ray source in the galaxy M81. Gamma-ray and X-ray studies have revealed that a binary is a milli-second pulsar, while pulse phase resolved spectroscopy study using AstroSat data has been undertaken. Low frequency variability in a pulsar has been discovered by AstroSat.
- Physics of Compact Objects: Detailed long term spectral evolution studies have been undertaken on Active Galactic Nuclei (AGN) to determine differences in broad and narrow line AGN and the relativistically blurred reflection has been studied for several sources. Time delays between the X-ray and UV emission from AGN were measured and interpreted.
- Discovery of Very Large Radio Structures in Radio Maps: A supercluster is a chain of galaxies and galaxy clusters, bound by gravity, often stretching to several hundred times the size of clusters of galaxies, consisting of tens of thousands of galaxies. Scientists from IUCAA and three Indian universities have identified a previously unknown, extremely large supercluster of galaxies located in the direction of constellation Pisces. This supercluster is the first major discovery of its kind made in India involving Indian universities. This supercluster is given the name *'Saraswati'*.
- Magnetic Field and Turbulent Dynamos: Galaxies consist of dark matter and gas, where some of the gas condenses to form stars. One ubiquitous entity that threads through all this gas is a magnetic field, which is present everywhere in the universe at

varying strengths. The origin of these magnetic fields continues to remain an unsolved mystery. Scientists at IUCAA, while exploring a popular mechanism called the Dynamo, have discovered that this operates on two different scales.

- Galaxy Morphology: Galaxies present themselves in a wide variety of shapes – some resulting from the original assembly of material, some due to the merger of multiple early galaxies, and yet others due to the stripping of gas as the galaxy moves through a dense surrounding medium. IUCAA scientists have suggested a new mechanism for the formation of a type of galaxy called Lenticular, distinguished by a dominant, spherical stellar bulge. This is shown through numerical simulations that certain spiral galaxies with prominent disks can become unstable, causing the disk to break up, clump and contribute to the bulge formation.
- High Redshift Galaxies: Using the Hubble Deep Field observation, IUCAA scientists have studied the evolution of disk galaxies without any bulge components. It was discovered that significant fraction (~ 15 – 18%) of disk galaxies in the HDF and in the local universe are such disk galaxies without bulge.
- Astronomical Instrumentation: Wide Area Linear Optical Polarimeter (WALOP) instruments are being developed in IUCAA to survey the polarization of around a million stars in the galactic polar regions.
- Solar Astrophysics: The problem of solar coronal heating has been one of the most stubborn in the field of astrophysics. IUCAA scientists have for the first time shown the presence of chromospheric evaporation related to small transient brightenings that leads to the formation of coronal loops.
- AstroSat Research: IUCAA's major contribution to AstroSat research are: (ii) X-ray Binaries, (iii) Finding of Multiple Stellar Population in NGC 1851, (iv) Imaging of Ram-Pressure Stripping in Action, (v) UV/X-ray Variability of Active Galactic Nuclei, (vi) Discovery of Lyman-alpha Leaking Galaxy in "Redshift Desert", (vii) Measurement of Polarized Prompt Emission in Gamma Ray Bursts, and (viii) Spectro-timing Studies of Multiple Compact Star in X-ray Binaries.
- LIGO – India: IUCAA is leading the Indian initiative in Gravitational Wave observations, which is for the construction and operation of an advanced interferometric gravitational wave detector in India, called 'LIGO-India' under an international collaboration with Laser Interferometer Gravitational-wave Observatory (LIGO) Laboratory, USA.
- Thirty Metre Telescope: The Thirty Metre Telescope (TMT) project is a major international undertaking to build one of the world's largest telescopes. IUCAA is playing a lead role in this project along with the Indian Institute of Astrophysics (IIA), Bengaluru; and Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, India.

33.4 Major Scientific Applications/Results

1. Discovery of a new supercluster, a chain of galaxies and galaxy clusters, bound by gravity and consisting of tens of thousands of galaxies. The supercluster is given the name 'Saraswati'.
2. Discovery of Lyman-alpha Leaking Galaxy in "Redshift Desert"
3. Measurement of polarized prompt emission from Gamma Ray Bursts (GRB)

For details on science results published by IUCAA, please refer the publications as listed in the end of this chapter.

33.5 Instruments/Payloads/Products/ Developed /Sensors / Detectors

- Solar Ultraviolet Imaging Telescope for the Aditya L1: Solar Ultraviolet Imaging Telescope (SUIT) is an instrument onboard the Aditya-L1 spacecraft, the first dedicated solar mission of the Indian Space Research Organization (ISRO), which will be put in a halo orbit at the Sun-Earth Langrage point (L1). SUIT has an off-axis Ritchey–Chrétien configuration with a combination of 11 narrow and broad bandpass filters, which will be used for full-disk solar imaging in the Ultravoilet (UV) wavelength range 200-400 nm. It will provide near simultaneous observations of lower and middle layers of the solar atmosphere, namely the Photosphere and Chromosphere. These observations will help to improve our understanding of coupling and dynamics of various layers of the solar atmosphere, mechanisms responsible for stability, dynamics and eruption of solar prominences and Coronal Mass ejections, and possible causes of solar irradiance variability in the near and middle UV regions, which are of central interest for assessing the Sun's influence on climate.

33.6 Capacity Building in Space Science Research

- Graduate School: One year Graduate School is conducted for the first year PhD students with prescribed syllabus and course structures. Averagely, 5 graduate students per year defend their PhD theses.
- Workshops and Schools: IUCAA has been conducting workshops and schools in A & A and related areas, from introductory level to advanced research level, in IUCAA as well as outside IUCAA in various Indian university/college campuses.
- Lecture Courses: IUCAA faculty members give lecture courses in A & A to BSc/MSc/BE/BTech students in various universities and colleges. Under the initiatives of the MHRD, IUCAA has been coordinating all activities in A & A in university and college teachers. The first of these activities has been the production of the very first online courses of 55 lectures on introductory A & A for the Swayam Portal, which had an enrolment of over thousand teachers.

- A & A Courses to MSc Students: In the Department of Physics, and Space Science, Savitribai Phule Pune University (SPPU), every year IUCAA offers optional courses in A & A.
- Vacation Students' Programme: Every year, during summer for seven weeks, IUCAA has been conducting this programme in A & A for pre-final year students of MSc/BE/BTech, and very talented students of final year BSc.
- Summer School: Every alternate year, during summer for four weeks, IUCAA has been conducting Introductory Summer School in A & A, for second/third year BSc/MSc/BE/BTech students. They attend well planned lectures from introductory level to advanced level, and complete practicals and projects.
- Refresher Course: Every other alternate year, during summer for four/five weeks, Refresher Course in A & A for university/college teachers has been conducted. This course is recognised by the UGC for such teachers to get enhancement in their career.
- Guiding Project Students: Students from various universities/colleges complete their final year projects in A & A, with guidance from IUCAA faculty members.
- Public Outreach Programme: This is a major popular programme among the public, school and university/college students. This programme consists of National Science Day events, Public/Popular Lectures, Second Saturday Lecture/Demonstrations, School Students' Summer Programme, Night Sky Observations, etc. More than 15,000 attend these events every year.
- AstroSat Science Support Cell: The ISRO sponsored AstroSat Science Support Cell (ASSC) is hosted at IUCAA. The Cell has a help desk, where queries regarding AstroSat data analysis techniques are answered. AstroSat data users visit the Cell and are taught analysis details. The Cell organizes workshops at IUCAA and at different parts of the country, where young faculty members and MSc/PhD students are given hands-on experience in handling AstroSat data. Advanced software are developed, which help users to do sophisticated analysis in a user friendly manner.

33.7 Courses Offered on Space Science and Technology

- IUCAA offers Graduate School for the first year PhD students in A & A with prescribed curriculum and course structures. The intake is through an entrance test and interviews in every year, and capacity is limited and not fixed.
- A & A Courses to MSc Students: In the Department of Physics, and Space Science, Savitribai Phule Pune University (SPPU), every year IUCAA offers optional courses in A & A.
- Apart from this, recently an MSc programme in Physics and Astrophysics has been started, in collaboration with the Department of Physics, and Statistics of the SPPU.

33.8 National Collaborations in Space Science and Technology

Sl. No.	Area of collaboration	Collaborating Institute
1	Solar Flares: Physics and forecasting for better understanding of space weather	Physical Research Laboratory, Ahmedabad; and Indian Institute of Technology, Banaras Hindu University, Varanasi

33.9 International Collaborations in Space Science and Technology

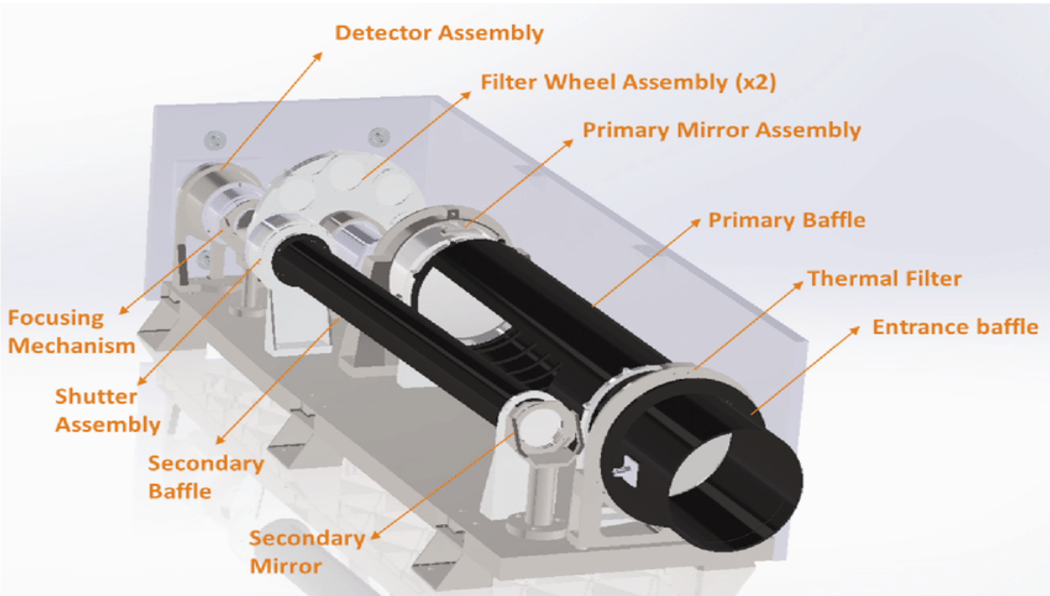
Sl. No.	Area of collaboration	Collaborating Institute/ Agency and Country
1	Wide Area Linear Optical Polarimeter	ASSO Telescope, South Africa; and Skinakes Observatory Telescope, Greece
2	Robo-AO	Caltech Optical Observatory, USA; University of Hawaii; University of North Carolina, USA; and National Central University, Taiwan
3	Laser Interferometer Gravitational-wave Observatory	Laser Interferometer Gravitational-wave Observatory Lab, USA

33.10 Laboratories and Facilities Available for Space Instrumentation

- Optical Instrumentation Laboratory: In partnership with the California Institute of Technology, USA, the Optical Instrumentation Laboratory has developed a laser guide star Adaptive Optics system, called RoBoAO, which has been demonstrated on the Palomar 60 inch telescope as well as at IUCAA Giravali Observatory. Under separate agreements with the University of Wisconsin-Madison (UW), and the University of Florida (UF), controllers have been developed for handling the operation and data acquisition from near-IR Hawaii detectors using a special ASIC, called SIDECAR. The first of these has been used in the near-IR arm of the Robert-Stobie Spectrograph, built by UW for the Southern African Large Telescope (SALT). The second controller has been used in the Canarias InfraRed Camera Experiment (CIRCE), built by UF for the 10.4 m Gran Telescopio Canarias (GTC) on La Palma. The laboratory is at present developing a Solar Ultraviolet Imaging Telescope for the Aditya-L1 mission of ISRO. In addition, an integral field spectrograph is being built for the 3.6 m Devasthal Optical Telescope at the Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital. It has also established a collaborative programme with Caltech (USA), MPIfR (Germany), University of Crete (Greece), and NCU (Poland), as a part of which a novel, four-channel polarimeter is being designed and developed, and the same will be installed at the Skinakas Observatory (Greece).
- Precision Quantum Measurement (PQM) Laboratory: PQM Laboratory is being established in IUCAA, and it will be useful for mega-science projects, such as Laser

Interferometric Gravitational-wave Observatory (LIGO – India), advanced astronomical instrumentation, quantum communications, Thirty Metre Telescope, and in fundamental science research. This lab will build India's first optical atomic clock, and also train human resources, so that when the age of quantum technology comes, India is not short of skilled manpower.

- AstroSat CZTI Payload Operation Centre: The ability to detect and localize Gamma Ray Bursts (GRB) by the AstroSat CZTI payload was developed in collaboration with the AstroSat CZTI team. Three bright GRBs have been detected by this instrument during the period October 2015 – Januaru 2016, confirming this capability. Calibration and characterization of AstroSat CZTI payload, and running the Payload Operation Centre have been the key developmental/technical service activities performed.
- Aditya L1 SUIT Payload Operation Centre: The Solar Ultraviolet Imaging Telescope (SUIT), on-board the Aditya L1 mission is aimed to study the radiation emitted by the Sun in the wavelength range 200 – 400 nm. The telescope is being developed at the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune in collaboration with the Centre of Excellence in Space Sciences (CESSI), Indian Institute of Science Education and Research (IISER), Kolkata; Indian Institute of Astrophysics (IIA), Bengaluru, and various agencies of ISRO. The payload will be operated by the processing electronics according to predefined sequences and operational modes. For each exposure, the two filter wheel mechanisms will independently move a desired combination of science and neutral density filters into the beam path. While the filter wheels are being moved, the beam will be blocked by the shutter mechanism. Once the desired filters are in position, the shutter will open for a pre-programmed duration to expose the CCD detector. After exposure, the shutter will remain closed while the detector is read and the filter wheels are moved into the position for the next exposure according to the operational mode.



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CHAPTER-34

MILLIYA ARTS, SCIENCE AND MANAGEMENT SCIENCE COLLEGE

Beed

34.1 About the College

Milliya Arts, Science and Management Science College, is run by Anjuman Ishat-e-Taleem, Beed. Beed is a gradual developing district in Marathwada region (Maharashtra, India. The College was incepted in 1991. The objectives of the college aim at producing graduates fit for various purposes: social, cultural, political, economical, etc.

The vision statement of the college is 'to mold the students into good human beings as well as globally competent'. Since its inception the college has immensely grown as a educational institution, and today it is offering post graduate and research courses to its students.

34.2 Keywords

Space Science, Hyperspectral Remote Sensing, Microwave Remote Sensing, Chandrayaan-1, Chandrayaan-2, NISAR, Modeling and Simulation, Mineral Mapping, Soil Moisture

34.3 Major Research Domains

1) Hyperspectral Remote Sensing
2) Microwave Remote Sensing

34.4 Major Scientific Applications / Results

1) Modeling and Simulation of Hyperspectral Imager (HySI) Sensor Chandrayaan-1 Image for Lunar Mineral Mixing Analysis.
   - The hyperspectral data has the potential to discriminate among the type of object and material identification for earth and planetary bodies. taking the advantage of data in continuous bands specifically for mineral identification is a challenge. Using the mathematical model for spectral deconvolution is efficient for the spectral interpretation as presented in this work.
   - The radiative transfer model has been implemented for spectra derived from hyperspectral images to model and quantify the lunar surface mineralogy
2) Modelling and Assimilation of NISAR, L & S Airborne Synthetic Aperture Radar Land Images for Geophysical Parameter Retrieval.
   - With the help of physical scattering mechanisms of SAR images, the geophysical parameters like soil moisture, dielectric constant (ε), backscattering signal (σ0) will

be retrieved by using respective data sets as well as ground truth study. We have developed geophysical parameter retrieval models for SAR data using a statistical model. The result has been assimilated with ground truth study.

Scientific Findings:

1) Chndrayaan-1 Project:

- The Chandrayaan-1 Hyperspectral HySI data for the first time have been modeled for spectral deconvolution using the Bi-directional reflectance function.
- Data from low land areas were used and the active spectra from fresh areas were derived for modeling.
- The radiative transfer model has been implemented for spectra derived from hyperspectral images to model and quantify the lunar surface mineralogy.
- The modeling results from the Crisium basin shows the high mass fraction of clinopyroxne and low agglutinates for small fresh craters spread across the Mare areas for both datasets.
- In case of South Pole region, the results obtained from modeling process shows the high mass fraction of clinopyroxne and low Orthopyroxene content for small fresh craters spread across the study area.
- At south pole region there are strong chances of getting hydroxyl absorptions

2) NISAR Project: Hybrid Approach of (Oh, MDB) models:

- We have Developed the Hybrid Approach of (Oh, MDB) models with Interactive data language (IDL) simulation tools,
- The main focus on the parametric values (surface roughness (s), soil moisture mv, incidence angle θ). Using these IDL codes we develop a user-friendly graphical user interface using the Visual Basic package this will help quick understanding of the relation between backscattering coefficient with surface soil parameter.
- The geophysical parameter is obtained from the image and the ground truth is used as a known parameter to simulate (σ0) in VH and VV polarizations.
- After those simulated values are compared with the (σ0) values calculated from the image corresponding to the field area. Then the accuracy of the simulated and calculated (σ0) values is computed using root mean square error (RMSE) and correlation coefficient (R2).
- After calculating RMSE and R2 for hybrid models, it was observed that these models are very useful to make a way for future studies and developments of algorithms.

Publications:

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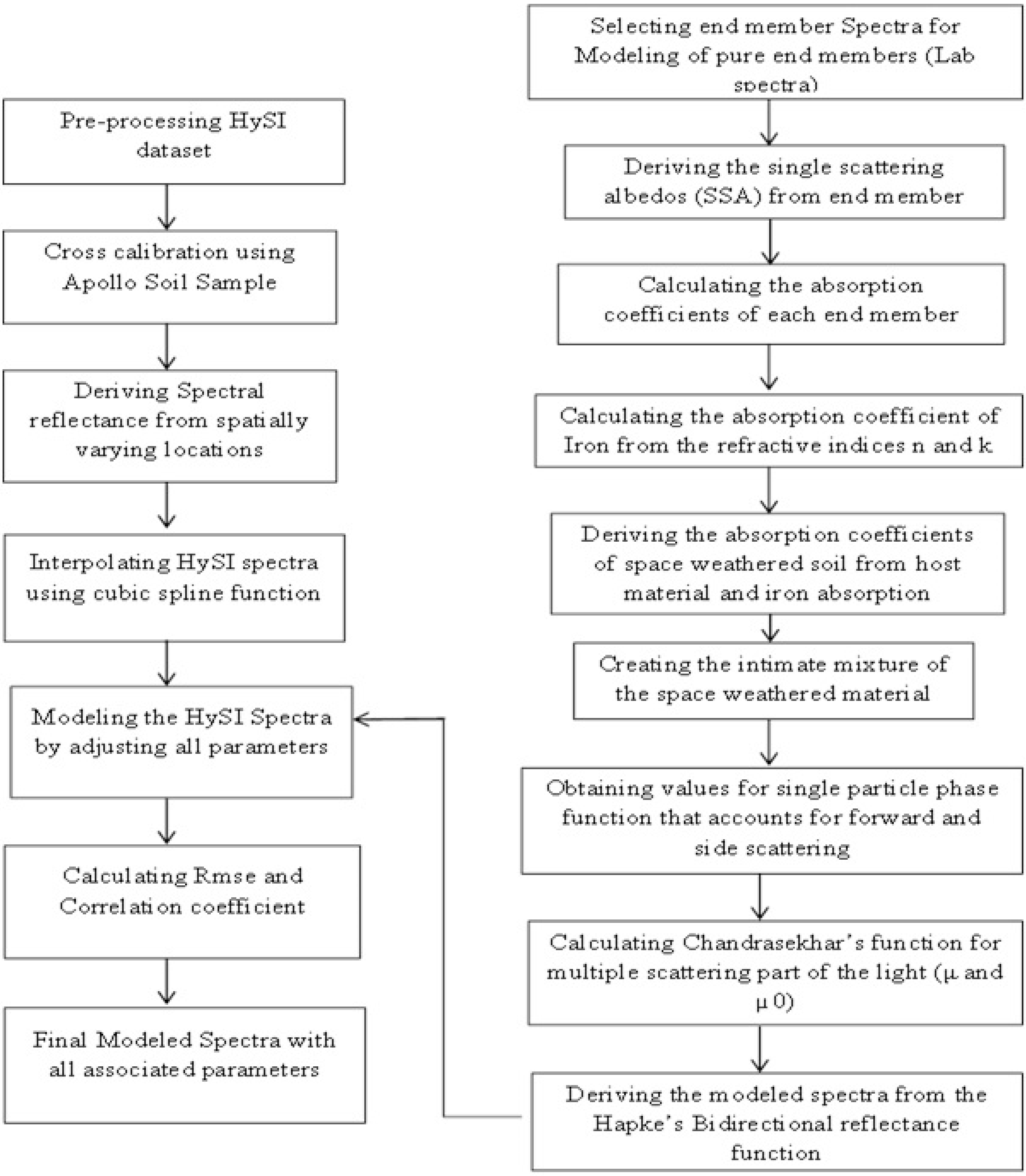
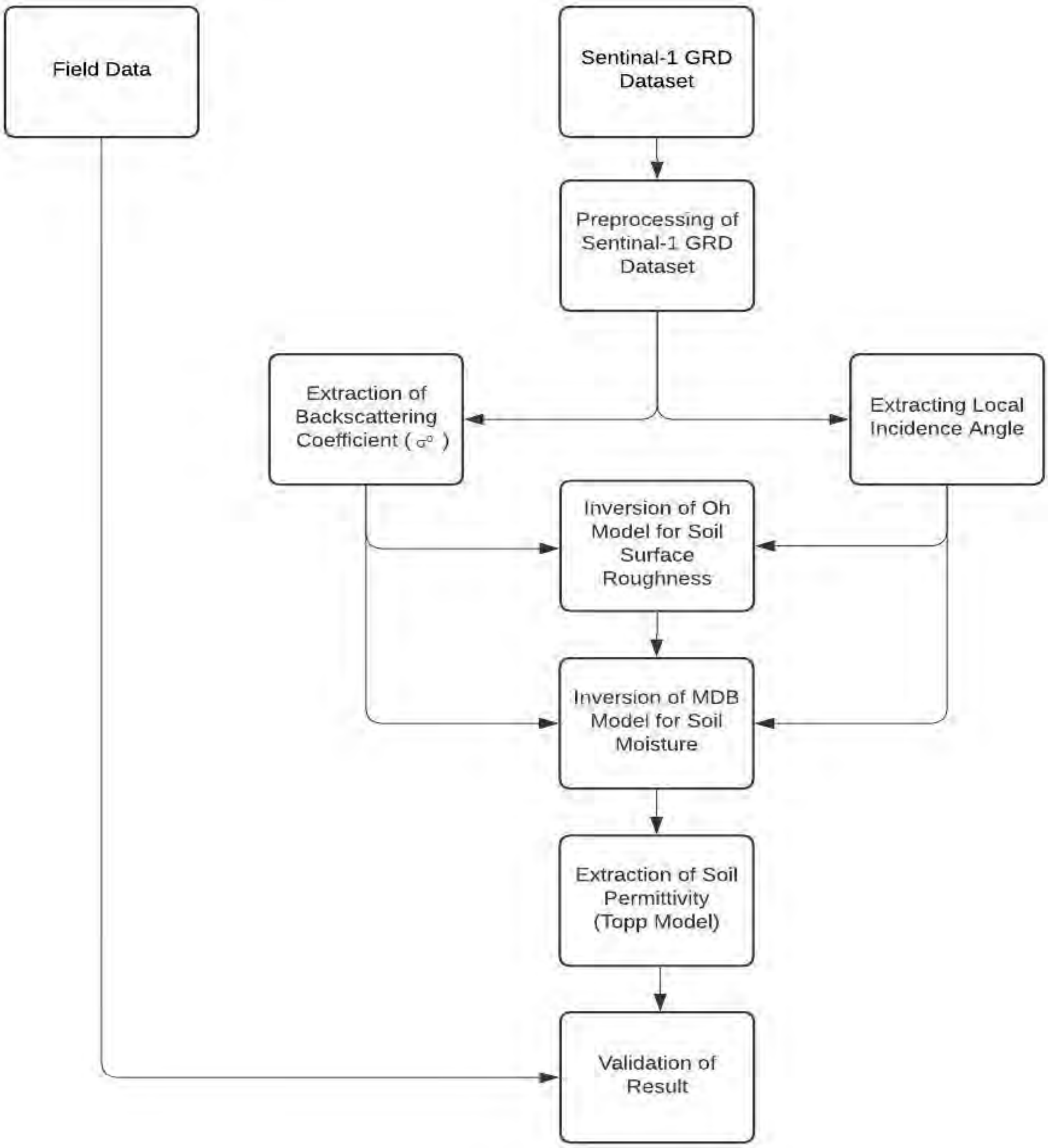
34.5 Instruments / Payloads / Products Developed / Sensors / Detectors

Chandrayaan-1 Project: Typical workflow for creating artificial spectra and modeling with the measured HySI spectra

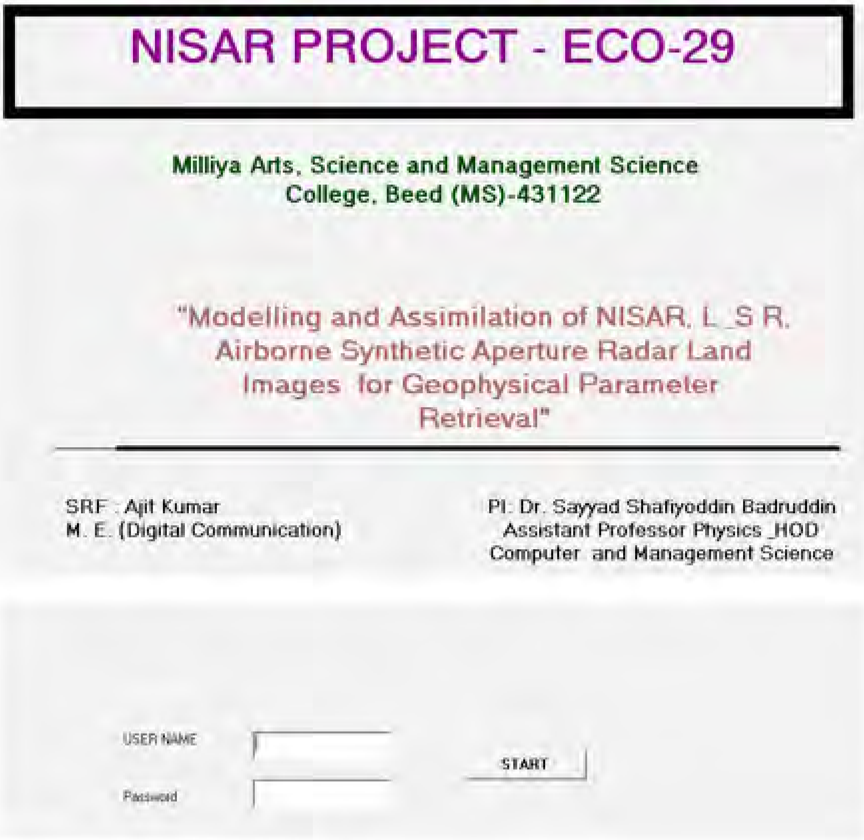


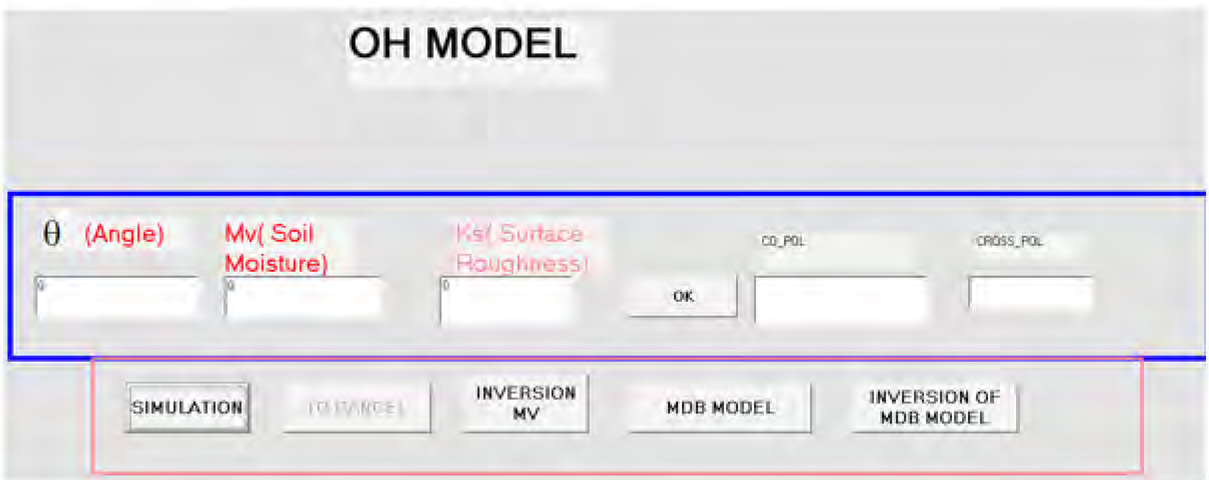
NISAR Project: Typical workflow for Modeling and Assimilations

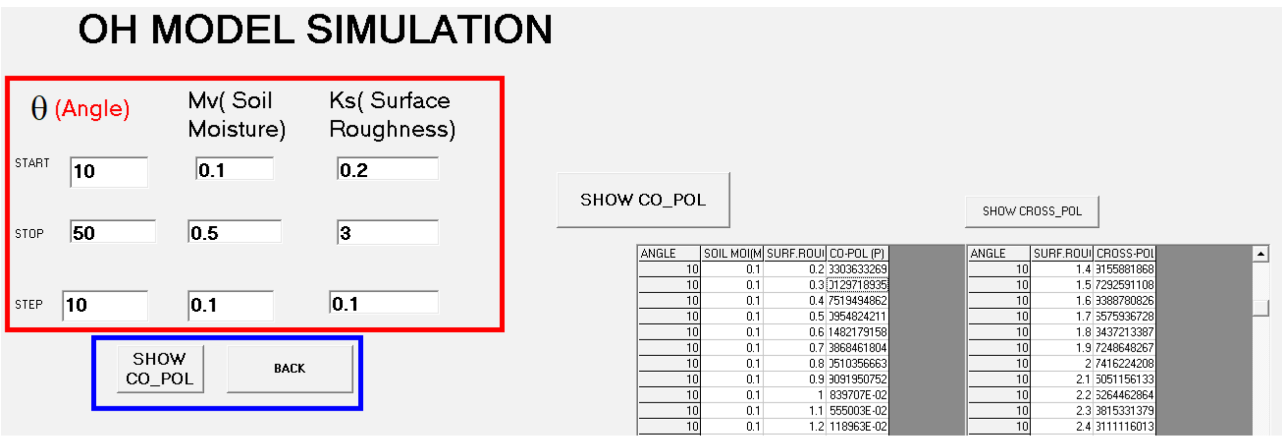


Development of GUI simulation and retrieval of soil moisture

The graphical user interface is developed using the Visual Basic package.to develops the empirical model. GUI will help quick understanding of the relation between backscattering coefficient with surface soil parameter.

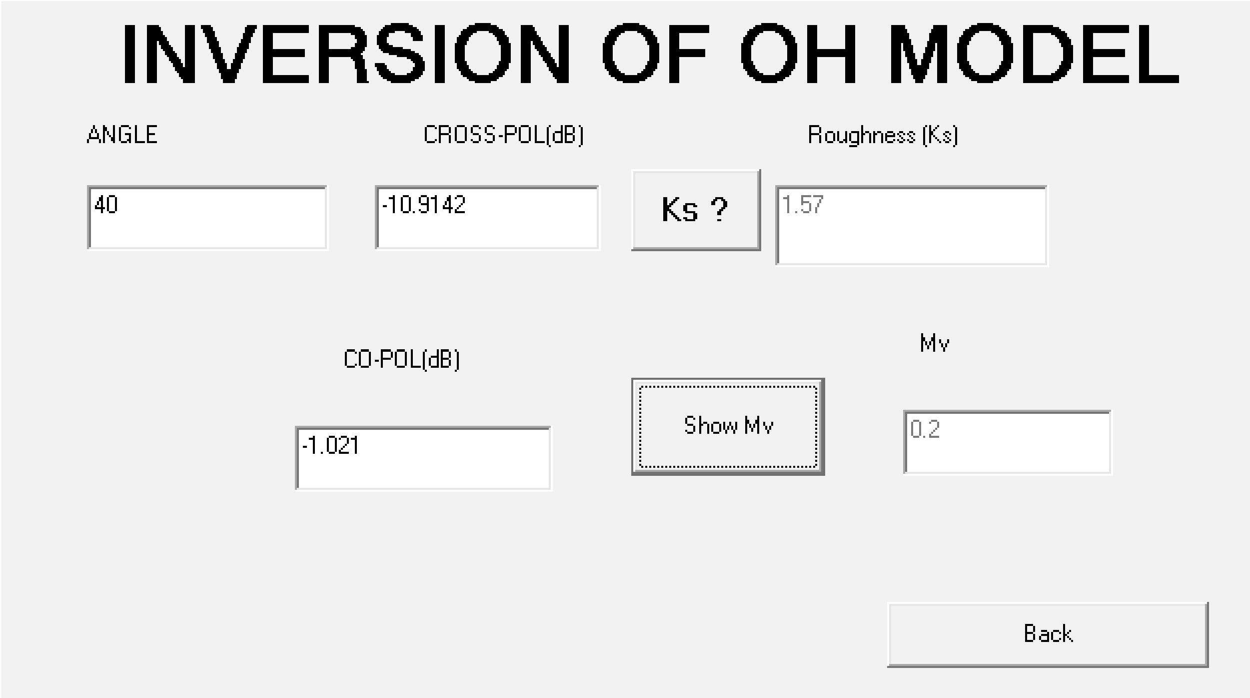


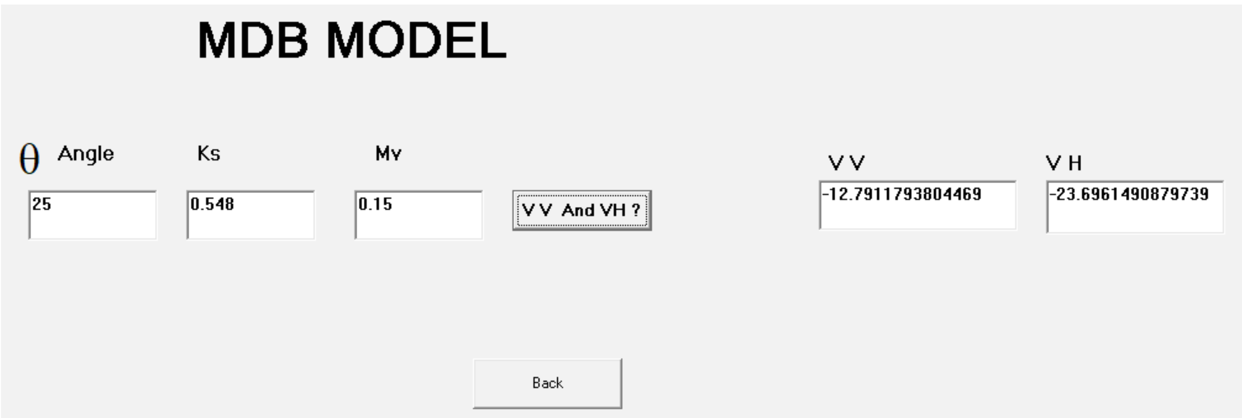


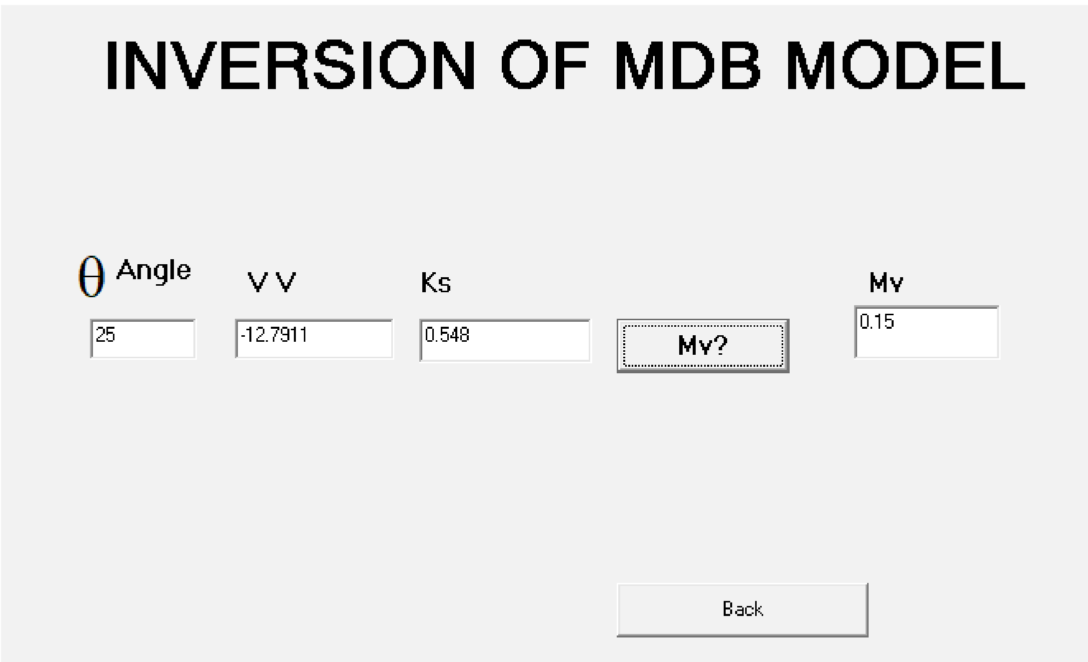


ANGLE	SOIL MOI(M	SURF.ROU	CO-POL (P)
10	0.1	0.2	3303633269
10	0.1	0.3	3129718935
10	0.1	0.4	7519494862
10	0.1	0.5	3954824211
10	0.1	0.6	1482179158
10	0.1	0.7	3868461804
10	0.1	0.8	3510356663
10	0.1	0.9	3091950752
10	0.1	1	839707E-02
10	0.1	1.1	555003E-02
10	0.1	1.2	118963E-02

ANGLE	SURF.ROU	CROSS-POL
10	1.4	3155881868
10	1.5	7292591108
10	1.6	3388780826
10	1.7	3575936728
10	1.8	3437213387
10	1.9	7248648267
10	2	7416224208
10	2.1	5051156133
10	2.2	5264462864
10	2.3	3815331379
10	2.4	3111116013


INVERSION OF OH MODEL
ANGLE
CROSS-POL(dB)
Roughness (Ks)
40
-10.9142
Ks ?
1.57
CO-POL(dB)
Mv
-1.021
Show Mv
0.2
Back


MDB MODEL
θ Angle
Ks
Mv
V V
V H
25
0.548
0.15
V V And VH ?
-12.7911793804469
-23.6961490879739
Back


INVERSION OF MDB MODEL
θ Angle
V V
Ks
Mv
25
-12.7911
0.548
Mv?
0.15
Back

34.6 Capacity Building in Space Science Research

- We are planning to start various capacity building programs in future.
- With collaboration of IEEE-GRSS Bombay chapter we organize various workshops/ webinars.
- Two Ph. D. students awarded Ph.D. in Space science related topics. Also 4 students working for Ph. D. in this field

34.7 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	Remote Sensing	Dr. Babasaheb Ambedkar Marathwada University, Aurangabad

34.8 Laboratories and Facilities Available for Space Instrumentation

- Milliya College establishes State of the art Microwave and Imaging Spectroscopy Research Laboratory with the help of grant received from two major research projects from ISRO.
- In Imaging Spectroscopy Research Laboratory, we have Two High Performance Workstations with ENVI Software. The scope of this laboratory is to extracts information from remote sensing images and integrates it for several applications.
- In Microwave Imaging Laboratory we establish C- band microwave bench, SHOOL Soil parameter sensor (developed by ISRO-SAC, Soil testing kit, surface roughness apparatus. The scope of this laboratory is to collect real time ground truth data of soil surface.

CHAPTER-35

NATIONAL INSTITUTE OF SCIENCE EDUCATION AND RESEARCH

Odisha

35.1 About the Institute

National Institute of Science Education and Research (NISER), Bhubaneshwar, is a unique institution in India for pursuing undergraduate and postgraduate education in basic sciences combined with frontline research. Space science exploration and research at NISER is mainly carried out in the School of Earth and Planetary Sciences (SEPS) and School of Physical Sciences (SPS).

SEPS is the youngest and an interdisciplinary department of the institute bridging the gap between planetary scientists, astrophysicists, astrobiologists, cosmo-chemists, earth scientists, and atmospheric physicists. Current faculty members at SEPS are involved in various areas of space science research such as solar system exploration (comets, asteroids, meteorites, and dusts), star and planetary formation using ground and space- based telescopes, astrobiology, exoplanets (atmospheres, interiors, and formation mechanisms), future planetary/sample return/exoplanetary missions, instrumentations, and state-of-the-art laboratory techniques.

Faculty members at SPS are involved in various areas of space science research such as observational cosmology, galaxy formation and evolution, cosmological N-body (and hydrodynamical) simulations, search for primordial gravitational waves, data pipeline development for the wide-field optical polarimeter and state-of-the-art data analysis techniques in simulations and observations.

35.2 Keywords

Planetary Atmospheres, Planetary Surfaces, Planetary Interiors, Cosmochemistry, Planetary Astronomy & Astrophysics, Star and Planetary Formation, Extrasolar Planets, Observational Cosmology, Galaxy formation and evolution, Epoch of reionization, Structure Formation, Primordial gravitational waves

35.3 Major Research Domains

SEPS space science group is focused in addressing following fundamental questions:

How did our solar system form and evolve?

Explore the origin and evolution of our solar system, the terrestrial planets, the Moon and the Earth, the environment and the material from which our solar system formed and how the physical, chemical and geological processes in our solar system operate, interact and evolve, by studying isotope and mineral composition of extraterrestrial materials using most advanced instrumentation, and observing planetary bodies in the solar system and beyond.

How to probe early Earth evolution from planetary bodies and meteorites?

Solve some of the major questions about the early evolution of Earth and the Moon and the origin of water and organics by studying natural laboratories of planetary bodies and extraterrestrial materials of solar and interstellar origin.

How did we get here?

Explore the origin and evolution of the stars and planets that make up our Universe, by investigating the key processes that were essential for the formation of fundamental chemical elements (C, N, O, and H) in the interior of the stars, physical and chemical processes that regulates the planet formation around new stars, the formation and evolution of complex organic molecules in interstellar space, or the search of new extrasolar planets.

What is the diversity in exoplanets out there?

The discovery of exoplanets has opened an entire new paradigm to explore the Universe. a large diversity of exoplanets such as hot Jupiter's, warm Neptune's, super Earths and Earth-size planets are discovered by international space missions. However, with current techniques we have only been able to constrain either their size or mass with detailed characterization for just a few of them. Therefore, there is a great opportunity to characterize a large number of exoplanets including their atmospheres. This also allow to assess the habitability potential of exoplanets.

Are we alone?

Discover and study the habitability of the solar system's planets and moons, in particular on Jupiter's moon Europa, Saturn's moons Enceladus and Titan, and Neptune's moon Triton, primitive asteroids and comets, including planets around other stars by observing potential bio-signatures using modern observatories.

SPS space science group is focused in addressing following fundamental questions:

Primordial gravitational waves:

The discovery of the primordial gravitational waves generated during inflation is the next frontier in the field of Cosmology. One of the ways to detect primordial gravitational waves is through the measurement of CMB B-mode polarization at very large angular scales.

Reionization history:

The epoch of reionization is very important in cosmic history to understand the transformation of the post recombination neutral Universe into the present state of the ionized Universe.

Missing baryon problem:

According to the standard model of Cosmology, our Universe is composed of approximately 5% baryonic matter and the rest 95% of the total energy in the form of dark matter and dark energy. Through observation spanning the electromagnetic spectrum from radio to X-rays, one can account for 70% of the total baryon density predicted by the standard cosmological model. This apparent discrepancy is famously known as “the missing baryon problem”. The remaining baryons may be present in the warm hot intergalactic medium that are hard to detect using direct observations.

Magnetic field of the Milky way:

The wide frequency coverage of the CMB experiments allow us to measure the synchrotron and dust polarization map of our galaxy. Combining the CMB frequency maps with starlight polarization measurement as a function of distance, it is possible to map out the three-dimensional magnetic field of our own Milky way galaxy.

Large Scale Structure in the Universe:

Large scale structures in the Universe form due to gravitational instability and is inherently a non-linear problem. Using Cosmological N-body simulations the growth of perturbations in different cosmological models can be studied. Open questions to study are: (a) is the non-linear regime of perturbations sensitive to cosmology (b) how do structures collapse in different models (c) can we construct new variables and their correlations to probe cosmology?

Galaxy Formation and Evolution

The formation and evolution of galaxies is a, relatively, poorly understood subject due to the interplay of physical processes with large dynamic range. Observations have led the field and have provided inputs for theoretical models of galaxy formation. With the advent of multiwavelength observations it has become even more important for theoretical models to not only reproduce them but also to interpret these observations.

With the aid of cosmological hydrodynamical simulations, halo models and observations various aspects galaxy formation and evolution are studied.

Research Groups:

Star and Planetary Formation Group: Understanding the physical and chemical origins of planetary systems such as our own

The group is working at the interfaces of astrochemistry/cosmochemistry, Solar-system planetary science, and exoplanetary science—mostly focused on understanding the physical and chemical origins of planetary systems such as our own. an interdisciplinary approach is taken to study various aspects of formation and evolution of planetary systems. State-of-the-art numerical models and techniques, together with single dish telescope observations at (sub-) millimeter/centimeter wavelengths, interferometric observations at (sub-) millimeter wavelengths, space telescope observations at near, mid and far-infrared wavelengths are used for research.

Currently, some of the unique fundamental questions about star formation, planetary formation and exoplanetsare being worked out:

1. How do planets and planetary systems form?
2. What is the chemical evolution of interstellar material on its voyage from clouds to forming stars and ultimately to newborn planets?
3. How can we watch other solar systems form? What does the composition of the Earth and other Solar System objects tell us about how they formed?
4. How do planets and their atmospheres evolve over time? What are exoplanets made of?
5. How many Earth-like planets exist? Do they have atmospheres? In other words, is Earth unique?

Planetary composition: Understanding the planetary processes in the early solar system

Understanding planetary formation and evolution, including our unique home - the planet Earth's, is one of the prime science objectives of Planetary Science. In this context, information of planetary surface composition plays an important role to reveal not only the surface characterization but also the sub-surface and interior composition and their formation mechanism allowing to construct the overall evolutionary history. Therefore, study of surface composition and the geology of various planetary bodies are being carried out along with participation and collaboration at national and international platform (i.e., active participation in NASA Dawn mission to the largest asteroids Vesta and Ceres; ISRO Chandrayaan-2 mission to the Moon, etc.). Besides, study of planetary analogue samples and the meteorites or space rocks are also one of the major activities to decipher

Planetary and Exoplanetary Atmospheres: Characterizing the atmospheres of exoplanets as well as the planets in our solar system.

The atmospheres of exoplanets are characterized using observations from various telescopes. Similarly, the atmospheres of solar system planets are either studied using orbiters such as the ISRO's Mars orbiter or using telescopes. For both exoplanets and solar system planets, understanding these observations and converting them to useful physical information about the planet's atmosphere requires a theoretical model of the planetary atmosphere. Therefore, in our research group theoretical models of the planetary atmospheres are developed and applied. These models include detailed radiative transfer computations, atomic and molecular opacity, convective parameterization and various chemistry schemes to simulate the planetary atmospheres in detail. These theoretical models provide us a tool to understand different physical and chemical processes that shape the planetary atmosphere. In addition, simulated observations from these models are used to understand the data from various instruments and observational geometries, which ultimately helps in constraining various dominant processes and properties of the planetary atmosphere. We also propose and plan observations of exoplanet atmospheres using our theoretical models for various telescopes such as Hubble Space Telescope, Very Large Telescope and the recently launched James Webb space telescope.

Regional Hydroclimatology

Research in this group focuses on identifying regional drivers of climate modulation and change as compared to synoptic and larger scale climate dynamics. Anthropogenic modifications to climate are increasingly and rapidly becoming a policy issue because unlike climate change over eons, humans and ecosystems are not adapted to sudden climate change. Research interests focus on the regional impacts of the following anthropogenic drivers of climate -

1. Climate modulation by large swaths of forests and deforestation in the Amazon rainforest and Himalayan forests.
2. Regional climatic impacts and modulation by atmospheric water vapor and its role specifically in near surface heat stress.
3. Impacts of global warming in mountainous regions.

The following process-based studies are conducted to study the above research objectives.

1. Boundary layer dynamics and vegetation-climate coupling through numerical modeling and direct field observations.
2. Convective processes and their coupling with the larger scale dynamics.

Crustal Deformation and Earthquake Physics

Research in this group focuses on theoretical and experimental analysis of the physics of deformation and shear failure across scales in earth sciences. Over the last year, the group has worked on a variety of problems spanning cm-scale deformation data gathered in the laboratory to the 10s-of-km scale data accessed through observations of earthquake related deformation in nature. :

A. Characterization of the 'correct' constitutive phenomenology of fault friction in response to extreme changes in shear and normal loading conditions.

B. Development of analytical and numerical models of fluid-induced aseismic slip in the context of injection-induced fault deformation.

C. Combining high spatial resolution InSAR data with physics-based models of earthquake ruptures to understand the role of aseismic slip in triggering earthquake swarms in continental interiors.

D. Examining the extent to which observed time delays between rainfall- induced landslide occurrence and peak precipitation can be explained by assuming laboratory-derived, time-dependent variations in the shear strength of soil columns.

In addition to these immediate projects, we are in the process of developing a state-of- the-art tribology laboratory at NISER capable of characterizing frictional properties of geomaterials across many orders-of-magnitude variations in slip rate.

Galactic Astrophysics and Cosmology: Search for CMB B-modes and measurements of starlight polarization

The next frontier of Cosmology research is to extract the wealth of cosmological information available from its polarization measurements, in particular the divergence free B-mode CMB signal induced by inflationary gravitational waves from the cosmic inflation. The current limit on the amplitude of the CMB B-mode signal, $r < 0.07$ (95% confidence interval) comes from the BICEP2/Keck experiment. One of the major challenges in the CMB B-mode detection is the removal of Galactic foregrounds at the level of 99% or more (or 1% or less of residual foregrounds) in the component separated CMB B-mode map. In this context, we test the existing component separation algorithms for a proposed mission, develop new statistical tools to extract information about the Galactic foregrounds and study the decorrelation of dust B-modes by mapping the three- dimensional magnetic field through the measurements of starlight polarization at high Galactic latitude using the proposed PASIPHAE survey. The group here at NISER is part of the PASIPHAE collaboration, SKA

1cm line as a probe of large-scale structure and galaxy formation in the post-reionization Universe

Investigating how the neutral HI gas, via the 21 cm line emission, is distributed in galaxies in the local Universe and demonstrate how model dependent predictions at high redshifts could be distinguished in upcoming surveys like the Square Kilometer Array (SKA) in which India is a member and the upgraded GMRT at NCRA, Pune. This will allow us to use HI as a useful probe of large-scale structure and constrain the galaxy formation models and cosmology in the post reionization Universe.

Multiwavelength observations of galaxies are used in the high-redshift Universe ($z>0.2$) and cosmological hydrodynamical simulations to understand the relation between halos and the different phases of baryons in galaxies, e.g., hot and cold gas, stellar populations, dust and metals, to name a few. Understanding the role of feedback in galaxies on galaxy formation is to be done. One aspect is to use metal lines in the intergalactic medium to probe feedback processes and efficiencies in self-regulating the growth of galaxies.

Halo shapes and halo collapse may depend on the primordial spectrum of perturbations. We are using N-body simulations to look at the dependence of halo properties on the primordial index. A related question is to use the velocity (or redshift) field of galaxies to probe cosmology. We are constructing mock galaxy catalogs from simulations to study this question. galaxy catalogs from observations are used to constrain cosmology.

35.4 Major Scientific Applications / Results

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35.5 Capacity Building in Space Science Research

I. Academic activities in Space Sciences:

1. Ph.D. program in various different aspects of space sciences from SEPS and SPS
2. Integrated MS program (Major and Minor) in Earth and Planetary Sciences is being developed by SEPS
3. MS/MTech Thesis and Internship program in Space Sciences from SEPS and SPS

II. Present and past outreach and student's activities in Space Sciences:

1. Regular astronomy related activities organized by NISER astronomy club with the help of SEPS and SPS faculties. These events are open to school and college students.
2. Public event on Chandrayaan-2 lunar landing, 7th Sept 2020, with the help of NISER students (Astronomy club, Robotics club, Zaariya club, and Art club). This event was attended by the school and college students.

35.6 Courses offered on Space Science and Technology

Ph.D. program of SEPS:

List of courses:

(i) Planetary Sciences

(ii) Astrochemistry and Astrobiology

(iii) Formation and evolution of planetary system

(iv) Exoplanets

(v) Planetary atmosphere and space weather

(vi) Planetary surface processes

(vii) Planetary Geophysics

(viii) Planetary Geochemistry and Geochronology

Integrated M.Sc. program of SEPS (To be started):

List of courses:

(i) Fundamentals of Astronomy

(ii) Formation and evolution of planetary system

(iii) Astrobiology, Origins and Early Evolution of Life

(iv) Planetary Surface process

(v) Advanced Cosmochemistry

(vi) Planetary and Exoplanetary Atmospheres,

(vii) Extrasolar Planets: Physics and Detection Techniques

(viii) Stellar and Planetary Magnetosphere

(ix) Analysis of Planetary materials and space instrumentation

(x) Multi-wavelength Observational Astronomy

(xi) Advance Space Science and Technology

Integrated M.Sc. and PhD program of SPS:

(i) Astronomy and Astrophysics

(ii) Introduction to Cosmology

(iii) Experimental Techniques

(iv) General Relativity and Cosmology

35.7 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	'Cradle of Life' science using future Indian cm and sub- mm facilities-	SKA-India consortium and Indian Sub-mm- wave Astronomy Alliance (ISAA)
2.	PASIPHAE survey (measurement of a million stars polarization)	IUCAA, Caltech, University of Crete, Oslo University, South African Astronomical Observatory
3.	Post Reionisation and EoR SKA-India Consortium -	SKA-India consortium

35.8 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1.	Planetary surface composition and geology in Max Planck India Partner Group -	Max Planck Institute for Solar System Research, Germany
2.	Study physics and chemistry of protostellar binaries in Perseus using JWST GTO program	NASA JPL, USA
3.	Interpreting the observations of Exoplanet atmospheres using JWST ERS and GTO programs.	Space Telescope Science Institute and multiple universities
4.	Understanding The role of metals in the Intergalactic Medium	IUCAA

35.9 Laboratories and Facilities Available for Space Instrumentation

1. Laboratory for simulation of impact of dust particles and solar wind on planetary surface

The changes in surface properties of asteroids and airless planetary bodies with time due to impact of dust particles and solar wind is simulated using a femtosecond and nanosecond (to be installed in the future) pulsed laser facility and an ion implanter (to be installed soon) present in SPS and SEPS. The nanosecond pulsed laser laboratory in SEPS will be installed in 2022-2023 and will be dedicated for this study along with preparing a large spectrum of planetary analog materials that will be characterized using IR-spectroscopy and advanced electron microscopes. The library of data will support any missions of ISRO to terrestrial planets, asteroids and comets.

2. Electron microscopy laboratory for study of extraterrestrial materials

The center of interdisciplinary science (CIS) in NISER and SPS houses advanced electron microscopes (e.g., focused ion beam-scanning electron microscopes, transmission electron microscope) and these will be used for studying extraterrestrial materials (e.g., meteorites, IDPs, primitive micrometeorites, pre- solar grains, samples returned from asteroids and comets, etc.) and also for capacity building by training PhD students. This facility could act as an important infrastructure for study of any future sample-return mission by ISRO.

3. Clean room facility for curation of meteorites and extraterrestrial materials

A clean room facility will be set up in SEPS in the future that will be dedicated to curation and preparation of extraterrestrial materials. The facility will include an advanced storage facility for rare meteorites and extraterrestrial materials under controlled conditions, facility for extraction of rare pre-solar grains from meteorites, manipulation of small grains using advanced micromanipulators and preparation of small grains for isotope and electron microscope studies. The facility will also be dedicated to building future manpower by training PhD researchers in preparation and study of extraterrestrial materials. Such a facility will support any future sample-return mission by ISRO.

4. Planetary cryogenic reflectance spectroscopy laboratory:

A lab (with an FTIR spectrometer (Bruker Vertex 80V) along with an Oxford cryostat is planned to be set up in 2024-2025. The lab is expected to cover the spectral ranges from UV to VIS and NIR parts (i.e., ~0.3 to 25 microns) with various spectral resolutions (~5 - 50 nm, etc.). The cryostat (with liquid N2) is expected to cover temperatures down to 60-70 K in vacuum conditions. The lab is expected to simulate the cold planetary environment up to the asteroid belt (~upto 3.3 AU). The main objective of the lab set up is to measure the reflectance signals of planetary analogue particulate samples or mixtures in various grain sizes and physical conditions in different geometries. Such studies form the basis for understanding the chemical and physical properties of planetary surfaces under different illumination and observation conditions.

5. Earth and Planetary remote sensing and Image processing laboratory

A lab with image processing and analysis software and packages along with high end computers is set up. The remote sensing softwares (ENVI and ArcGIS) are being used for the satellite data processing and analysis. Open source softwares (like QGIS) are also used. The Planetary Image Processing Software (ISIS, developed by United States Geological Survey) image processing package required for NASA and ESA planetary missions is also being used. The Spacecraft Planet Instrument C-matrix Events (SPICE) package/routines developed by JPL/NASA is also used not only for NASA/ESA planetary missions but also deriving required ephemeris/geometry informations for other planetary missions including ISRO's Chandrayaan mission. The laboratory facility is also used for Earth and atmospheric applications and computing.

6. Meteorological observatory in the Middle Himalayas

Under this facility infrastructure for observing meteorological variables and variables related with forest-atmosphere interactions in the forested regions of middle Himalayas is developed. Through these observations it is invisioned to study forest-triggered convective processes and their interactions with hydrology and climate. Some satellite based meteorological data products, specifically related with clouds and precipitation, generated by ISRO are also being used in the project. The data being generated under this project can also be utilized for ground truthing of ISRO's meteorological data. The observatory can also serve to put up more meteorological sensors for evaluating and constraining ISRO's satellite based meteorological products.

7. Crustal Deformation and Friction Physics laboratory

This laboratory will combine state-of-the-art modeling techniques with a dedicated laboratory designed to measure the shear strength of geomaterials to characterize a wide range of processes from large scale fault deformation to rainfall-induced landslides. Among other interests, the laboratory is developing in-house computational models and data inversion frameworks for interpreting data generated by ISRO's ground- and space-based geodetic observations including IIRS and SAC maintained GPS networks and high- resolution InSAR data anticipated from the NASA-ISRO SAR (NISAR) mission

The laboratory will also work to characterize frictional properties of geomaterials across earthquake and landslide shear zones to complement ISRO's efforts in the area of Disaster

Management Support by providing physics-based inputs for the estimation of shear-failure related geohazards. Among the instruments planned over the next 2-3 years are a biaxial shear press capable of driving rock samples at slip rates spanning a substantial fraction of the earthquake cycle under crustal normal loads and a ring shear tester with a pore-pressure control box to simulate rainfall-induced landslides in the laboratory. These instruments will be complemented with high-end computational infrastructure to provide a complete, in-house, experiment-to-model framework for analyzing the physical processes controlling shear-failure induced geohazards like earthquakes and landslides.

CHAPTER-36

INSTITUTE OF TECHNOLOGY, NIRMA UNIVERSITY

Ahmedabad

36.1 About the Institute

Institute of Technology, Nirma University was established in the year 1995 by the Nirma Education and Research Foundation (NERF). The Institute is the first self-financed engineering college of the State of Gujarat. All the BTech Programmes are accredited by the National Board of Accreditation (NBA) under the Tier-I category. It is one of the most sought after institutes and has been recognised as a leading centre of education in the country. The Institute offers multidisciplinary undergraduate, postgraduate and doctoral programmes in Engineering and Technology. It has been consistently ranked among the top self-financed engineering colleges of India.

36.2 Keywords

VLSI Design and Test, Signal Processing, Communication Engineering, Embedded Systems, RF and Microwaves.

36.3 Major Research Domains

- VLSI Design and Test: Analog, Mixed-Signal, and RF VLSI Design, System on Chip Design, Testing and Verification of VLSI Design
- Signal Processing and Communication Engineering: Next Generation Communications, Antennas and RF Communication, Signal Processing: Systems, Algorithms, and Applications
- Embedded Systems: Machine Learning for Embedded Systems, Cyber-Physical Systems, Embedded Vision
- Development of Low-Cost Methodology for Surveying and Mapping Using IRNSS
- Identification of Existing Road Material, Condition and Potential Parking Area of Ahmedabad City Using AVIRIS Data and Updation Plan of Undeveloped Road
- Identification of Perched Water Table Areas in Irrigated Tracts and Seepage through Irrigation Canal using Air-Borne SAR data
- Identification of Material and Distress for Road Network of Ahmedabad City using L and S Band Airborne SAR Data
- Calibration and Validation of SAR sensors

36.4 Major Scientific Applications / Results

- Development of Low-Cost Methodology for Surveying and Mapping Using IRNSS - In this project, attempt is made to establish IRNSS reference station at Nirma University campus, develop low cost method to collect terrain data with IRNSS receiver and prepare maps of Gandhinagar city with reasonable accuracy
- Identification of Existing Road Material, Condition and Potential Parking Area of Ahmedabad City Using AVIRIS Data and Updation Plan of Undeveloped Road - In this project, hyperspectral data (AVIRIS) was used for identification of existing road materials (Bitumen & Concrete) in some roads of Ahmedabad city. Spectral analysis is carried out for road distress using field spectrometer and compared the results of road material & Distress spectra obtained with satellite - Identification of Perched Water Table Areas in Irrigated Tracts and Seepage through Irrigation Canal using Air-Borne SAR data - In this study, attempt has been made to identify the canal seepage, perched water and salinity in the command area of Indira Gandhi canal in Hanumangarh district of Rajasthan using Air borne L- and S-band Synthetic Aperture Radar (SAR) data. Sentinel 1 A, Sentinel 2 and ALOS PALSAR data processed and back scatter values of different stations are extracted to understand the soil moisture, seepage through canal and perched water. Two extensive field visits were carried out to understand the study area, canal seepage through irrigation canal, degraded fields, identify vulnerable areas for water logging in January 2019 and February 2021.
- Identification of Material and Distress for Road Network of Ahmedabad City using L and S Band Airborne SAR Data - In this project, attempt has been made to apply decomposition methods to extract road material and establish the suitability of L and S band airborne data for identification of road material and distress of major roads.
- Calibration and Validation of SAR sensors - Radiometric calibration of SAR data is essential component for all the applications that requires quantitative analysis. It allows us to go for temporal or multi-sensor analysis for various applications as it provides a reference to evaluate the change in SAR-backscatter due to temporal changes or changes in SAR-sensor parameters. Calibration method establishes a relationship between SAR-sensor output and radar-cross-section (RCS) of a known standard-target or distributed-target of known-RCS. In this study, attempt has been made to compute RCS of corner reflectors, determine quality parameters of SAR sensors and compared with the specified values.

36.5 Instruments / Payloads / Products Developed / Sensors / Detectors

[1] Project Title: Development and Testing of NavICSuite: Processing Software Tool for NavIC Receiver

- Duration: 2 Years

- Scope of Project: The proposed research proposal aims to develop NavICSuite: a precise, scientific, multipurpose, data processing software suite for processing NavIC receiver data. NavICSuite will be a multipurpose software that can be used for: (i) identifying and extracting relevant data from raw NavIC files, (ii) pre-processing the data to apply necessary corrections and compensations for drags and atmospheric loading etc., (iii) deriving and analyzing ionospheric and tropospheric content variations, scintillation strength, multipath components, etc.NavICSuite with its Graphical User Interface (GUI) will be easy to explore and will allow the user to easily explore the functionalities of the software.

[2] Project Title: Design and Development of Fabry Perot Cavity based Feed Cluster

- Duration: 2 Years
- Scope of Project: Horn antennas are extensively used as feed to reflector antennas for various space applications such as global coverage, telemetry, tracking and control, and as feed clusters for Multiple Beam Antennas (MBAs). One of the prime requirements for all such applications is to have high gain from the feed horn. The conventional way to increase the gain of the antenna is by increasing the aperture of the horn. However, in the case of space applications, there is always a space constraint and it may not be possible to increase the gain by increasing the aperture dimensions of the horn. In such situations, some innovative technique may be thought of to increase the gain of the horn antenna without increasing the aperture diameter and compromising with the RF performance. The proposed research includes design, analysis and realization of a PRS based feed cluster (septet) with high gain.

[3] Project Title: Growth and Characterization of Nano-Structured thin Films of Magnetic Materials for High Speed Computer Memory Cell

- Duration: 3 Years
- Scope of Project: Ferromagnetic materials exhibits a spontaneous magnetization at room temperature. Their spontaneous magnetization disappears above Curie temperature also called as critical temperature. The most important ferromagnetic substances consist of double oxides of iron and other oxides called ferrites. These ferrites are ceramic ferromagnetic materials, which are composed of ferric oxide, (α-Fe_2O_3, hematite) and have been considered as highly important electronic materials for more than half century. Their crystal structure is cubic in shape and belongs to that of mineral spinel ($MgAl_2O_4$). The crystal structure of hexagonal materials allows the substitution of various metallic ions which affects the magnetic properties of the hexagonal ferrites like, the coercive field, the magnetic anisotropy, the saturation magnetization and changes the magnetic property of the materials. In addition, due to their excellent dielectric properties, ferrites have the advantage of low loss and

high power handling capacity as compared to that of semiconductors. Ferrites are the magnetic dielectric materials that absorbs the electromagnetic waves, thereby initiating electromagnetic interaction between the wave and the magnetization within the material. This interaction has been used for the manufacturing of useful devices. In the present suggested project, highly pure barium hexaferrites and strontium hexaferrites will be synthesized by wet chemical methods like heat treatment and co precipitation techniques. The main objective of the proposed project is thin film deposition of hexaferrite/composite material to have negative value of K (Magnetocrystalline anisotropy constant) and low tangent loss.

36.6 Capacity Building in Space Science Research

Lectures/Workshops/Training Programmes for the Students/Researchers

Sl. No.	Date	Topic of Lectures/Workshops/Training Programme
1	November 28-29, 2020	National Webinar on "Micro-Electro Mechanical System (MEMS) Design"
2	September 5, 2020	Webinar on "Why 5G matters for your career?"
3	October 2-4, 2021.	Online Workshop on "Fundamentals of Artificial Intelligence and Machine Learning"
4	September 13-17, 2021	A five-day National Webinar on "Rietveld Refinement of XRD Data"
5	August 6-7, 2021	A Two-Day National Webinar on "Optical Wireless Communication: Challenges and Opportunities"
6	July 19-23, 2021	A one-week online Faculty Development Programme on "Internet of Things for Agriculture"

36.7 Courses offered on Space Science and Technology

- 05 Junior Research Fellows were trained to collect and process the data
- 01 Ph D student carried out his research work
- 8 to 10 UG students trained to collect and process the data

Student Projects on Space Science and Technology

- July 2021 - Simulation of Precise Point Positioning (PPP) Techniques for Navic Receiver, guided by Dr Sachin Gajjar
- July 2021 - Hyperspectral imaging in remote sensing, guided by Dr Yogesh Trivedi
- July 2021 - GPS based field area calculation system, guided by Prof Jayesh Patel
- July 2020 - Software Development for IRNSS receiver, guided by Dr Sachin Gajjar

36.8 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	Electronics and Communication Engineering, Computer Science and Engineering, Remote Sensing and GIS	Space Applications Centre, ISRO, Ahmedabad
2	calibration and validation of RISAT-1	M. G. Science

36.9 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1.	Electronics and Communication Engineering	Public University of Navarra, Spain

36.10 Laboratories and Facilities Available for Space Instrumentation

- The Department of Electronics and Communication Engineering has the following key laboratories and facilities that can be used for space science and technology: VLSI Design and Testing, Embedded System Design, Communication Engineering, RF and Antenna Engineering.

Publications

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2. Dharambhai Shah et al., "Convex geometry and K-medoids based noise-robust endmember extraction algorithm.", *Journal of Applied Remote Sensing*, **14,** 034521, 2020.

3. Dharambhai Shah et al., "Convex Polygon Maximization-Based Hyperspectral Endmember Extraction Algorithm.", *Journal of the Indian Society of Remote Sensing*, **49**, 1-14, 2020.

4. Jay Gupta et al., "Profiled Horn Antenna with Wideband Capability Targeting Sub-THz Applications.", *Electronics*, 10, 412, 2021.

5. Rohit B. Patel et al., "Design and evaluation of 2.3 Tb/s (23 ch.× 100 Gb/s) multi-carrier WDM optical transmission systems.», *Optical and Quantum Electronics*, **53**, 1-13, 2021.

6. Ankur Pandya et al., “Investigation of Recycling and Impurities Influxes in ADITYA-U Tokamak Plasmas.”, *Plasma and Fusion Research*, **16**, 2402055-2402055, 2021.

7. Rhea Biji et al., “Performance Analysis of Vedic Mathematics Algorithms on Re-configurable Hardware Platform”, *Sādhanā*, **46**, 1-5, 2021.

8. Khushbu Sinha et al., “Modified Correlation Detector Based Spectrum Sensing with Laplacian Noise in Cognitive Radio.”, *Radioelectronics and Communications Systems*, **64**, 390-402, 2021.

9. Khushbu R. Joshi et al., “Satellite Image Classification: from Handcrafted Features to Deep Learning Features”, *Indian Journal of Computer Science and Engineering,* **12***,* 1494-1502*.*

CHAPTER-37

NSS COLLEGE OF ENGINEERING

Palakkad, Kerala

37.1 About the College

NSS College of Engineering (NSSCE), Palakkad is one of the most reputed, premier engineering educational institution in Kerala affiliated to APJ Abdul Kalam Technological University. It was established in 1960 by Nair Service Society under the leadership of late Bharatha Kesari Mannathu Padmanabhan, during the second five year plan with the assistance of the Central and State Government under the grant-in-aid scheme. The college has an enviable heritage and legacy of grooming brilliant engineering professionals who later made their mark in industrial and other sectors of the country and abroad.

37.2 Keywords

NIRAMM, Indigenous satellite sub systems for Nano-Satellites,

37.3 Major Research Domains

Gagan Aerospace is a space oriented startup with 28 members incubated under the Innovation & Entrepreneurship Development Cell of NSS College of Engineering, Palakkad. The project on the development of indigenous satellite sub systems for Nano-Satellites is undertaken by Gagan Aerospace. The project named NIRAMM (NSSCE Ionising Radiations & Magnetic Field Analysis Mission) was initiated on 2020 April to develop a student nano-satellite payload to take part in ISRO's opportunity for utilizing the fourth stage (PS4) of PSLV as an orbital platform for conducting space experiments. The team is gearing up for project proposal submission to ISRO.

37.4 Capacity Building in Space Science Research

The activities carried out during the period is listed below.

- 'Asteroid Hunt' workshop was conducted on May 23, 2021 via online platform, exclusively for the students of our college. The workshop consisted of teaching the basics of asteroid observation by analyzing the datasets received from Pan-STARRS observatory with the help of a software.
- A lecture on 'The search of Habitable Worlds' by Dr. Anand Narayanan, Professor at Indian Institute of Space Science and Technology, Thiruvananthapuram was conducted on June 30, 2021 for the student space enthusiasts across Kerala. Celestial bodies and the observations on habitable planets beyond our solar system were the topics lectured in detail.

- Online workshop series on Nano-Satellite payload development were conducted during the month of April, May, June, 2021 for the students of the college. Basics on satellite subsystems, its functioning and detailed study on Nano-satellites launched were conveyed. Prototype of a Pico Satellite named 'GAGANSAT' was also developed.
- Space awareness classes and competitions were carried out at our college for nearby school students as a part of the World Space Week 2021.
- A workshop on 'Hydro Rocket Development', conducted during the month of November, 2021 covered the technical details on the design of a rocket, its propulsion elements, how to use 'OpenRocket' software for designing rockets, setting up of a launch pad.
- 'Amateur Radio' workshop was conducted on December 18, 2021. The workshop detailed the technical aspects of using Ham radio.
- There are two BTech fourth year projects titled 'Structural design and analysis on Nano-Satellite payload' and 'Thermal control and analysis of a Nano-Satellite' in Department of Mechanical Engineering
- The collection of space clubs in Kerala under the name of Pioneers in association with AASTRO Kerala and SSERD, NSSCE space club CELESTIA lead the world space week celebrations in 2020, October 4-10 and conducted a series of lectures and contests.
- In 2021 December NSSCE space club CELESTIA participated in NOVA with a workshop on Amateur Radio
- NSSCE space club CELESTIA had a webinar on astro photography by Surendran Punnassery, Amateur Astronomer and Astrocolumnist.

37.5 Courses offered on Space Science and Technology

1. Course 1
   i. Title of the course: Propulsion Engineering (KTU ME462)
   ii. Standard of the course: Undergraduate
   iii. Intake capacity: 60
   iv. Topics covered: Fundamentals of propulsion, theory of propulsion, Jet propulsion, rocket propulsion, flight performance
   v. Total number of lectures allotted for the course: 42

2. Course 2
   i. Title of the course: Cryogenic Engineering (KTU ME467)
   ii. Standard of the course: Undergraduate

iii. Intake capacity: 60

iv. Topics covered: Introduction to cryogenic systems, applications of cryogenics, gas liquefaction systems, cryogenic refrigeration systems, cryogenic fluid storage and transfer systems, cryogenic instrumentation, cryo pumping applications.

v. Total number of lectures allotted for the course: 42

CHAPTER-38

CENTRE FOR GEOINFORMATICS AND PLANETARY STUDIES

Periyar University, Salem

38.1 About the Centre

Centre for Geoinformatics and Planetary Studies (CGIPS) was established in Periyar University on 30.3.2010. Periyar University is a state university established in 17th September, 1997 as per the provision of the Periyar University act,1997. The University recently reaccredited with NAAC A++ grade and secured 73rd position among Indian Universities in NIRF. The main objective of centre is conducting an advanced research and promote higher education in the field of Remote Sensing, GIS and Planetary Studies. The centre was formerly inaugurated by former president Dr.APJ. Abdul Kalam on 12.1.2013. The centre has basic infrastructure and computational facilities for Remote Sensing, Digital Image processing, GIS and planetary remote sensing studies. The major research activities in the centre are planetary remote sensing, hyperspectral remote sensing, mineral exploration, GIS applications, disaster mapping and mitigation, sustainable ground water development and impact of climate change studies in water resource. The centre regularly coordinating ISRO-IIRS outreach programmes. The centre has handled Rs.1.27 crore worth of research projects in remote sensing & GIS applications, disaster mapping and planetary studies. The centre major achievement is production and supply of Lunar soil simulant to ISRO Satellite Centre for Chandrayan2 Mission programme.

38.2 Keywords

Hyperspectral, Planetary, Remote Sensing, Lunar analog, soil simulant, Mars, fluvial, geomorphology.

38.3 Major Research Domains

Lunar Soil Simulant:

- The Centre for Geoinformatics and Planetary studies has produced an indigenous lunar soil simulant namely ‘LSS ISAC-1’ for ISRO’s lunar exploration programme in coordination with scientists from ISRO Satellite Centre and National Institute of Technology, Tiruchirappalli. In absence of original lunar soil sample in the country, the bulk quantity of lunar soil simulant produced and supplied to ISRO for conducting major experimental work and mission testing. The Lunar soil simulant was used for creation of Lunar Terrain Testing Facility at ISITE, Bengaluru for testing lander and rover of Chandrayaan2 mission. LSS ISAC-1 soil simulant was produced from the rock samples collected from the Sittampundi Anorthosite Complex, located in the central Tamil Nadu, India.

Lunar lithology and Geomorphological mapping:

- The lithology and geomorphological mapping of Baade vallis on lunar surface were carried out using Chandrayaan1 HySI and TMC data Analysis. TMC and HySI data were downloaded from ISSDC website from ISRO. Moon Mineralogy Mapper (M3) data is downloaded from Lunar Orbiter Explorer site. Geomorphology of Vallis Baade region was interpreted using LROC WAC data and TMC DEM. Crater Size Frequency Distribution (CSFD) Method was adopted to estimate the age of Vallis Baade Region using the IDL Module Crater Stat software. Elemental mapping for Vallis Baade was carried out using HySI and M3 data.

Fluvial Morphological study on Martian surface:

- Fluvial morphological studies of Cusus and Columbia Valles were conducted with help of Mars Odyssey THEMIS IR day image, MGS MOLA data and MOM MCC data. The ArcGIS 10.4, ENVI 5.2 and JMARS software were used for extracting the morphological features and profiles of the channels. The geology, structure, geomorphology and morphometric parameters of Cusus Valles were studied. The increase of hydrostatic pressure and subsequent development of cryosphere rupturing are the main causes for catastrophic flooding in Columbia Valles.

38.4 Major Scientific Applications / Results

- LSS ISAC-1 soil simulant produced by the CGIPS along with ISRO and NIT team has its uniqueness, quality and scientific fidelity with reference to original lunar soil. The chemistry and mineralogy of the simulant clearly demonstrated that its analogue nature with original soils collected from lunar highland terrain through Apollo missions. The grain size distribution, physical and geo-mechanical properties of LSS-ISAC-1 simulant are at par with Apollo 16 return soil samples and proved its credibility for using as lunar highland soil simulant.

Figure 1. CGIPS and ISAC task team at Lunar soil simulant production site.

- The fluvial morphological study of Cusus and Columbia Valles on Martian surface has indicated that two different theory of origin for development of fluvial basin. Cusus Valles developed through precipitation induced valley network, whereas Columbia

Valles evolved through fractured and fragment of pressurized aquifer system and subsequent catastrophic flooding event. In this study, the volume of flooded water in the valles was estimated.

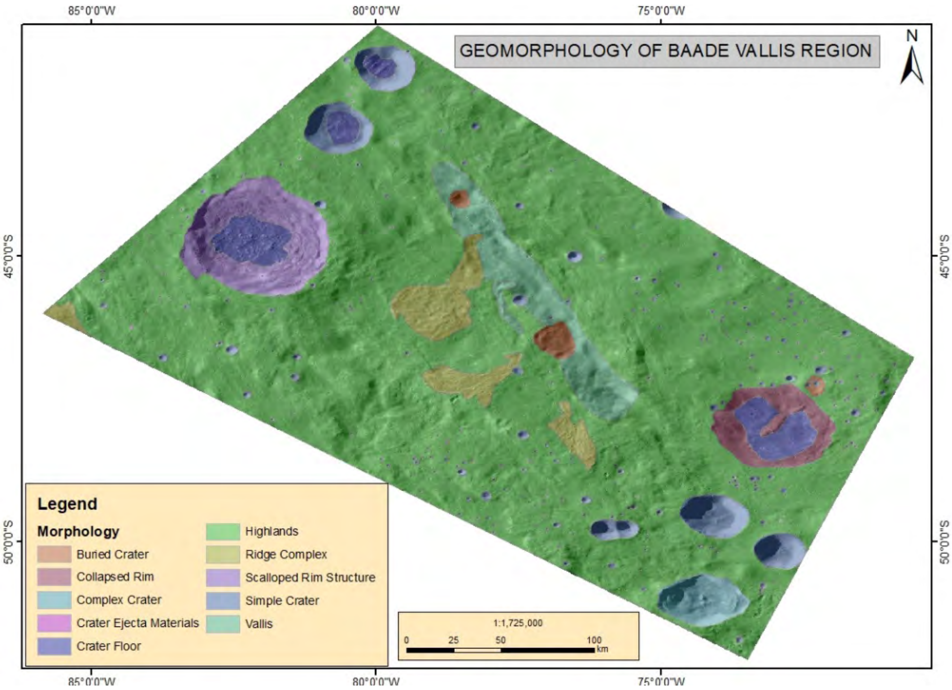

Figure 2. Geomorphology of Vallis Baade region interpreted from LROC and TMC data.

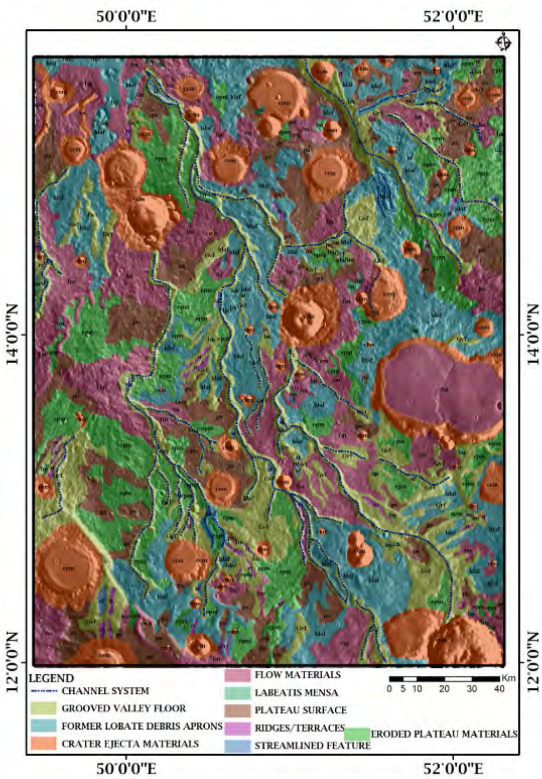

Figure 3. The Cusus Valles interpreted from Mars Odyssey THEMIS image. The Valles associated with several geomorphic processed features such as channel system, grooved valley floor, Lobate debris, crater ejecta, flow materials, mensa, plateau, ridges/terraces.

38.5 Instruments / Payloads / Products Developed / Sensors / Detectors

Product Developed: The centre has developed Lunar Soil Simulant for creation of Lunar terrain testing facilities at ISRO, Bengaluru. The facilities being utilized for Chandrayaan mission programme.

38.6 Capacity Building in Space Science Research

The Centre for Geoinformatics and Planetary studies is regularly conducting and coordinating capacity building programme in space science research, which include Workshops, special lectures and training programmes. In the last 10 years, around 700 students/ researchers / nodal officers were benefited from the programme. During 2020-2021, there are 17 outreach programmes coordinated from the Centre and trained 94 students. Out of which, at least 10 students/ researchers were chosen space science in their career.

Ph.D., Programme:

- The centre offering Ph.D., programme in space science applications, which include hyperspectral remote sensing, mineral exploration, Lunar and Martian geological studies, reflectance spectral studies, planetary analog studies, disaster mapping, sustainable groundwater management studies.

38.7 Courses offered on Space Science and Technology

Centre for Geoinformatics and Planetary studies offering Ph.D., programme in space science applications. The following course works are offered as guide paper and part of their research programme.

- Hyperspectral remote sensing
- Planetary Remote Sensing in Geology
- Remote sensing in Natural disaster studies
- Remote sensing in Groundwater exploration

38.8 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	Lunar soil simulant	UR Rao Satellite Centre (formerly ISAC), Bengaluru
2.	Hyperspectral Remote sensing	Department of Earth Sciences, IIT Bombay
3.	AVIRIS-NG Hyperspectral Remote sensing	Space Application Centre, Ahmedabad

4.	Hyperspectral Remote sensing	Department of Earth and Space Sciences, IIST Trivandram
5.	Hyperspectral Remote sensing	Department of Earth Sciences, Pondicherry University
6.	Planetary remote sensing	Space Science Programme, ISRO Bengaluru.

38.9 Laboratories and Facilities Available for Space Instrumentation

- Computing facilities for image processing and GIS work
- ENVI and ArcGIS software
- LCD projections for hands on training and teaching
- Satellite data (soft copy) for planetary remote sensing studies.
- Microscope facilities for petrological and ore study

Scientific Publications

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CHAPTER-39

RAMAN RESEARCH INSTITUTE

Bengaluru

39.1 About the Institute

Raman Research Institute (RRI) is primarily engaged in research in fundamental sciences in physics spanning sub-atomic to cosmological length scales, overlapping with some areas of chemistry and biology. Research carried out at RRI broadly covers four themes, namely Astronomy and Astrophysics, Light and Matter Physics, Soft Condensed Matter and Theoretical Physics. RRI is strongly invested in experimental research with major emphasis on instrument development for cutting edge research. Along with stand alone experiments, RRI also takes part in national and international collaborations for major instrument developments in ground and space based astronomy.

Research carried out at RRI in Soft Condensed Matter include Mechanical Properties of Soft Materials, Nanoscale biophysics of biological systems, Biophysics of Axons, Physics of Lipid Membranes and Polyelectrolytes and Liquid Crystals. Under the theme of Light and Matter Physics, the following topics are pursued: Ultra-cold Atoms, Molecules and Ions, Precision Atom-Light Interaction and Spectroscopy, Intense Light - Matter Interactions, Quantum Communications, Quantum Optics, and Quantum Information Science. Theoretical physics pursued at RRI covers Non-equilibrium statistical physics and stochastic processes, Non-equilibrium Quantum Dynamics, Loop Quantum Gravity, Causal Set Theory etc. Astrophysics research pursued at RRI include Interstellar and circum-galactic Medium, Galactic Structure and Stellar Dynamics, High Energy Astrophysics, Cosmology, X-ray Astronomy and Radio Astronomy.

39.2 Keywords

X-ray Astronomy, Radio Astronomy, High Energy Astrophysics, Cosmic Microwave Background, Epoch of Re-ionisation, Gravitational Wave, Space Sciences, Quantum

Communications, Quantum Information Science, Ultra-cold atoms

39.3 Major Research Domains

Major domains of research in the institute, relevant to the space science and technology programme.

- **Theoretical Astrophysics and Cosmology**

Work carried out at RRI in theoretical astrophysics and cosmology involves development of analytical models and numerical simulations describing the dynamics, physical properties and underlying physical phenomena in celestial objects like stars, planets, galaxies, interstellar medium etc. Theorists also work on answering fundamental cosmological questions on the formation and evolution of the Universe. Specifically, the following areas of theoretical astrophysics are currently pursued at RRI: Optical and IR signatures of high redshift host galaxies of supermassive black holes, Constraints on cosmic rays in the Milky Way circum-galactic medium, Diffuse gamma-rays from star clusters, Precipitation limited hot-haloes from massive galaxies to clusters, Spiral structure of disc galaxies, Dust Attenuation Curves and Structure of Galaxies, Involvement of host galaxies in AGN jet origin, Modelling of two-component molecular discs in spiral galaxies, HI scale height in dwarf galaxies and spiral galaxies, Thick disk molecular gas fraction in galaxies, Post reionization era and the large scale structure of the universe, probe of dark matter models, post-reionization HI 21-cm signal etc.

- **Observational Astronomy**

Observational astronomy at RRI mainly includes radio and X-ray observations using a wide range of telescopes world wide, both ground and space based. The topics covered are: PeV-EeV neutrinos from gamma-ray blazars, multi-wavelength Temporal and Spectral variability of blazars and AGNs, Orphan Gamma Ray Flares, Detection of signals from the Epoch of Re-ionisation with various experiments, Observational cosmology using 21-cm line, Background Radio Spectrum, Gas mass of star-forming galaxies, star forming disc galaxies, SZ effect from radio galaxy cocoons, star forming complexes in spiral galaxies, UV and HI Properties of disk galaxies, accretion powered pulsars, cyclotron lines, thermonuclear X-ray bursts, Cataclysmic Variable systems and ultra-luminous X-ray sources etc.

- **Experimental Astronomy**

RRI astronomers built specialized telescopes designed to focus on specific unsolved problems. Instrument developemet activities at RRI are in the area of X-ray and Radio Astronomy. Details of experiments under development at RRI are given in the next section.

39.4 Major Scientific Applications / Results

Research and developmental activities at RRI are primarily in fundamental sciences. Usually there are no direct applications of these developments. A list of publications in Space Sciences is given below.

Application oriented development activities at RRI:

- **Quantum Key Distribution**

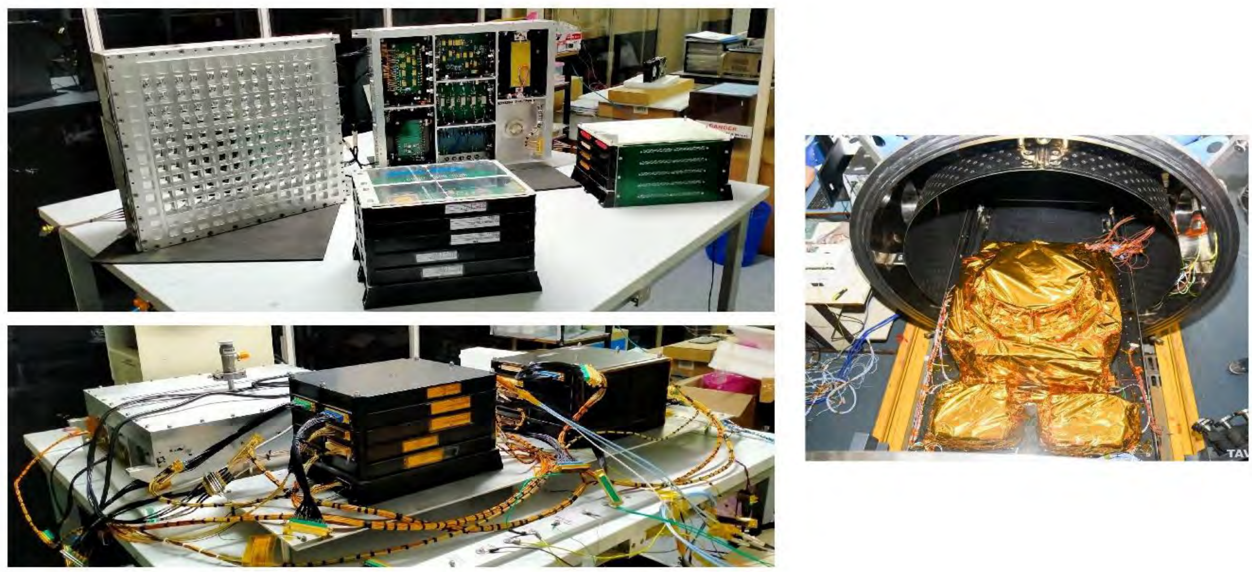
RRI has an ongoing collaboration with ISRO on a satellite based quantum key distribution (QKD) experiment. The free space QKD in-lab experiment performed by the lab was chosen by the Department of Science and Technology as one of its top 20 innovations and also by

India Science - The Nation's Science channel as one of its top 10 science achievements for the year 2020. RRI has conducted an end-to-end free space quantum key distribution in-lab experiment, and also performed an inter-building free space quantum communications experiment connecting two buildings at RRI through the atmosphere. This is the first such demonstration performed in India.

X-ray Pulsar based Deep Space Navigation

RRI has carried out preliminary design studies for development of an X-ray pulsar based navigation system. A proposal for development of a prototype was submitted to ISRO.

39.5 Instruments / Payloads / Products Developed / Sensors / Detectors



X-ray Polarimeter (POLIX)

Figure 1: Qualification Model of POLIX: On laboratory test bench and in Thermo-vacuum Chamber

During the past few years, RRI has been designing and building an X- ray polarimeter (POLIX) instrument for astronomical observations. POLIX is the main payload onboard the small satellite mission of ISRO called XPoSat dedicated for X-ray polarization measurement from cosmic sources. X-ray polarimetry is an unexplored area in high energy astrophysics. X-ray polarization measurements can give valuable insights into (i) the strength and the distribution of magnetic field in the sources (ii) geometric anisotropies in the sources (iii) their alignment with respect to the line of sight and (iv) the nature of the accelerator responsible for energizing the electrons taking part in radiation and scattering. Development of the Qualification Model (QM) of the X-ray Polarimeter instrument POLIX has been completed and assembly and tests of the Flight Model (FM) is ongoing.

X-ray Optics

Focusing capability for hard X-rays (beyond 10 keV) has tremendous potential to open a new discovery window in high energy astronomy. Fabrication of such hard X-ray telescope is a very ambitious project and hence requires active collaboration with several national institutions. A collaborative effort has been initiated between RRI, PRL Ahmedabad and URSC, ISRO to develop technology for hard X-ray telescope. RRI is engaged in development of a novel technique for the precise assembly of segmented X-ray mirrors. A proposal has been submitted to ISRO (in collaboration with PRL and ISRO) for hard X-ray optics technology development to use with future X-ray missions.

- **PRATUSH : Epoch of Reionization**

PRATUSH -- Probing ReionizATion of the Universe using Signal from Hydrogen -- is a proposed cosmology experiment to detect the global red-shifted 21-cm signal from the Cosmic Dawn and Epoch of Reionization (CD/EoR). PRATUSH will seek to precisely measure the low-frequency radio sky-spectrum over the frequency range of 40 to 250 MHz in an orbit around the moon. In September 2021, an ISRO appointed review committee recommended that PRATUSH move to project mode. Phase-I of PRATUSH will seek to fly in a low earth orbit for technology demonstration, early risk mitigation, and preliminary science measurements. This will be followed by the PRATUSH phase-II in lunar orbit in the future. The PRATUSH baseline design has been realised and it operates over the crucial frequency range of 55-110 MHz and a ground-based concept model is under development. Individual hardware subsystems of the concept model using ground based components are ready and under testing. The system integration and field testing to demonstrate the concept with sky measurements and their comparison to simulations are planned.

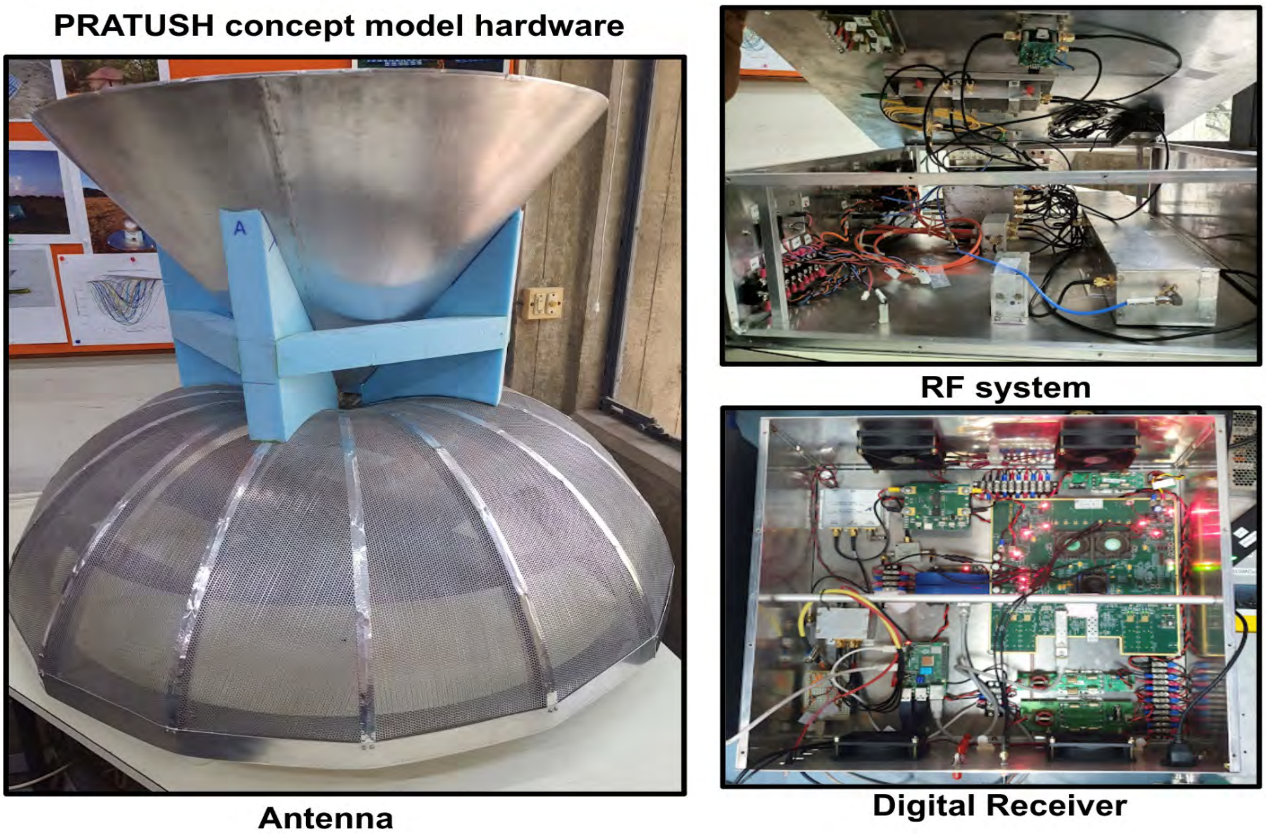


Figure 2: PRATUSH concept model antenna, RF system, and digital receiver

- **SARAS**

The SARAS experiment aims to detect global 21-cm signal from cosmic dawn and epoch of reionization. The experiment, operating in 50-200 MHz frequency range, has undergone a series of editions. Its first version provided an improved absolute calibration for the 150-MHz all-sky map. SARAS 2 rejected 10% of theoretically predicted models of reionization. It became the first experiment worldwide to constrain astrophysical parameters of the first stars and galaxies through 21-cm observations. SARAS 3, observing on lakes in 50-100 MHz, has recently conclusively refuted the detection of 21-cm signal that was claimed by the EDGES experiment. It is the first experiment to reach the required sensitivity and cross-examine the claim. Currently, SARAS 3 receiver is being upgraded to be deployed in radio-quiet locations to increase observing time and constrain standard cosmological models. In parallel, SARAS 4 antenna, observing between 100-200 MHz, is being designed and is scheduled to be tested soon.

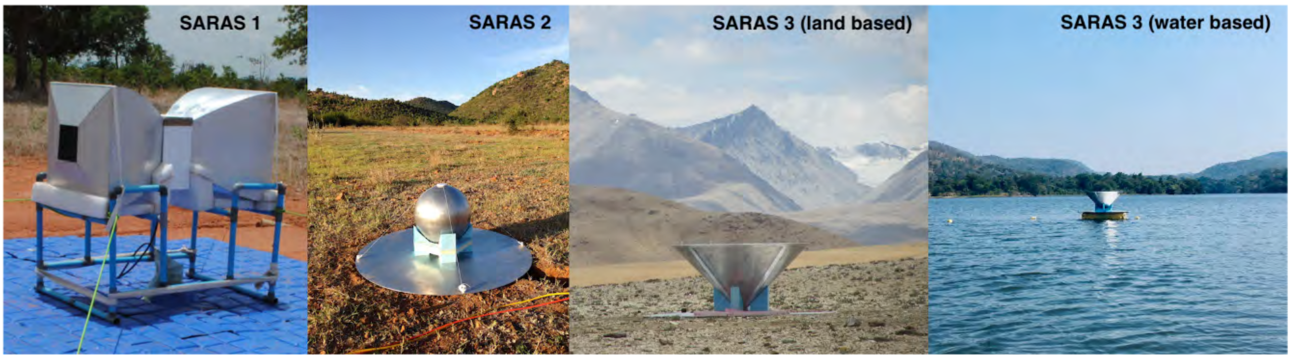


Figure 3: Different stages of the SARAS experiment

- **Square Kilometer Array**

The Square Kilometre Array (SKA) is an international radio telescope project to be built in Australia and South Africa. For SKA, RRI is involved in development of i) state-of-the-art and generic digital hardware (Integrated Prototype – IP) platform for digitization and real-time signal processing of broadband radio astronomy signals, ii) broadband frequency independent antennas and analog beam formers, iii) firmware for the Tile Processing Module (TPM) of SKA to produce multiple (48) beams in the sky, and iv) evaluation of Field Programmable Gate Array (FPGA) based accelerated pulsar search sub-module (PSS). In addition, a two element interferometer will be built along with an analog beamformer in the frequency range 30-360 MHz. The frequency independent characteristics of this two element interferometer will be used to i) demonstrate the possibility of simplifying calibration procedure of Low frequency aperture array (LFAA) of SKA and ii) test the digital platform being developed in the laboratory both for its functionality and beam forming action.

- **Quantum Experiments with satellite technology**

Goal of this project is to establish theoretically secure quantum communications between two Indian ground stations using an Indian satellite as a trusted node.

Milestones achieved so far include: i) In-lab prototype for prepare and measure based QKD, ii) In-lab prototype for entanglement based QKD in free space: BBM92 protocol established in-lab, iii) Free-space QKD between two buildings through an atmospheric channel: Demonstrated first time in India in January 2021 between two buildings at RRI Bengaluru, iv) Novel simulation tool kit for QKD with process and device imperfections: 1st two iterations ready, v) Automated compensation for input beam displacement using control feedback mechanism both for fixed as well as moving source. In Future, development of payload as well as ground stations for demonstration of satellite based QKD are planned.

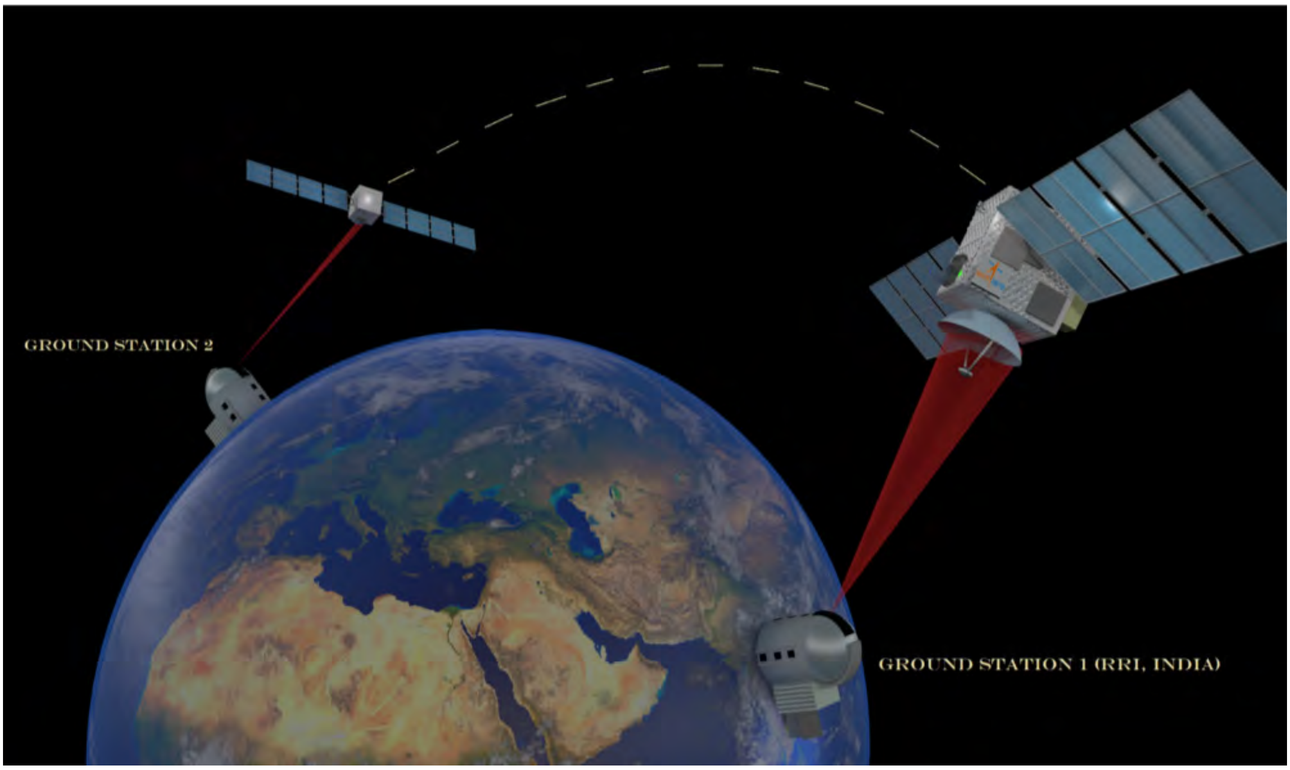


Figure 4: Quantum Experiments with satellite technology at RRI

39.6 Capacity Building in Space Science Research

- RRI is heavily engaged in capacity building in space science research. RRI has a flexible Visiting Students Program (VSP) in which science and engineering undergraduate/ postgraduate students are given research training in advanced research laboratories. Many of the VSP students have subsequently chosen space science / astronomy research career.

- RRI has a PhD program of its own and it is also a member of the Joint Astronomy Program (JAP) in collaboration with Indian Institute of Science, Indian Institute of Astrophysics, and Indian Space Research Organisation. RRI staff members regularly teach the graduate course in the PhD program.
- Members of the Astronomy and Astrophysics group often deliver lectures/demonstrations in workshops related to their research areas. Radio Astronomy training workshops were held frequently.

39.7 Courses offered on Space Science and Technology

RRI has a PhD program with a student strength of about 20 in the area of Astronomy and Astrophysics. RRI is also a member of the Joint Astronomy Programme (JAP) which is a collaborative program with IISc, IIA and ISRO.

39.8 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	X-ray Astronomy	URSC
2.	Radio Astronomy	ISRO
3.	Satellite based secure quantum communications.	URSC and LEOS

39.9 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1.	Radio Astronomy	SKA and SKA India consortium

39.10 Laboratories and Facilities Available for Space Instrumentation

- **Radio Astronomy Laboratory**

This laboratory is equipped for development of analog and digital electronics, antenna design etc. This laboratory has contributed to several national and international radio telescope projects, most notable being the The Murchison Widefield Array (MWA) and Square Kilometer Array (SKA). The SARAS and PRATUSH experiments described elsewhere in this document are entirely designed and built in this laboratory.

- **X-ray Astronomy Laboratory**

This laboratory is equipped for design and development of gas filled X-ray detectors, analog and digital signal processing electronics etc. The X-ray detectors and all associated electronics of the X-ray polarimeter instrument POLIX to be flown on XPoSat are designed and developed here. Cleanrooms for detector and electronics assembly work are available. However, there are no facilities for vibration tests, thermal tests or thermo-vacuum tests. The Payload Operations Centre (POC) for the POLIX payload will also be at RRI.

- **Quantum Information and Computing lab (QuIC lab):**

This laboratory is equipped for design and development of single and entangled photon sources that are the main workhorse for satellite based secure quantum communications. The laboratory has a clean room environment. Dedicated spaces for development of analog and digital processing electronics as well as small scale PAT systems are available. The lab model, engineering model as well as the space compatible payload for the QuEST-ISRO project will be developed at RRI. The laboratory also hosts domain specific capabilities in post processing requirements for quantum cryptography.

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CHAPTER-40

ISRO SPPU STC CELL PUNE, SAVITRIBAI PHULE PUNE UNIVERSITY

(formerly University of Pune)
Pune

40.1 About the Centre / Laboratory / Institute:

Initiating Joint Research Programme (JRP) between ISRO and Savitribai Phule Pune University (SPPU), a Memorandum of Understanding (MoU) was signed on 21 January 1998. Initially five broad disciplines were identified for carrying out research study under this JRP. Co-operation between the two organizations was found beneficial and as a result these areas were enlarged by identifying additional disciplines where more emphasis could be laid on. The areas currently recognized for development are:

- Space Radiation
- Wind measurements and modeling
- Optical coatings and sensors
- Rural development and developmental communication
- Geo-informatics
- Remote sensing applications
- Material Sciences
- Biodiversity
- Instrumentation
- Image processing

With a view to ensure that the research studies are relevant to ISRO programme, prospective investigators are being advised to go through the ISRO's document Research Areas in Space giving details of the research areas of interest to ISRO. At the time of formulating their proposal, it will be advisable to interact with the concerned ISRO Scientists and take their suggestions to ensure that the studies are useful in ISRO program. The document Research Areas in Space is available in the University website as well as in ISRO website.

40.2 Keywords:

Development of sensors, Original of life & Biodiversity, Nano Sciences, Microgravity, Metallurgy & Space Applications.

40.3 Major Research Domains:

Sensors, Original of life & Biodiversity, Nano Sciences, Microgravity, Metallurgy & Space Applications.

40.4 Major Scientific Applications / Results:

1. Title: "Development of Low energy (~20 KeV) electron beam facility"

The electron beam facility was designed to provide electrons of different energy in the range of 1 keV to 20 keV. The beam current can also be varied from 100 nA/cm2 to 100 μA/cm2. Over this range the perveance of the electron gun varies from 0.01 μperv to 0.4 μperv. The components such as Experimental chamber, electron gun with its mounting, sample holder cum Faraday cup, High voltage power supply, isolation transformer, etc. The electron gun includes cathode, focusing electrode, Control electrode and Anode electrode. The beam diameter can be varied from 5 mm to 150 mm. The electron density over the beam spot is better than 10%. This electron irradiation system is being used for studying the irradiation effects of 1 keV to 20 keV energy electrons on space quality insulating materials, as well as sensitive detectors and sensors.

2. Title: "Study of Single event effects on short channel and highly packed memory devices using heavy ion irradiation"

Single event upsets (SEU) or soft errors are mainly logic upset errors that almost always occur in high density integrated circuits such as LSI(Large scale Integration) and VLSI(Very Large Scale Integrated) devices. These transitory errors are called Single Event Upsets. When ionizing radiation coming from natural sources such as galactic cosmic rays, solar wind flux, heavy particles trapped in Van Allen belts etc is passing through the sensitive area can corrupt the information in an integrated circuits. A single energetic ionizing particle penetrating a semiconductor device can produce a track of ionization, in its wake a narrow plasma cylinder with a radius of around 1 micrometer or even less can produce.

The circuit for the measurement of SEU based on Field Programmable Gate Arrays (FPGA) is successfully designed, developed and incorporated in to irradiation experiments. The SEU measuring electronic circuit consists of FPGA (2S100PQ206) Xilinx, RS232 port, RAM, EPROMs etc. The memory device under test is connected to the FPGA of 20 MHz through a 1 MB RAM. This FPGA is electrically connected to the PC through the RS 232 port to read and store the digital data of the device under test (EPROM). The initial data of the device is kept in RAM for the reference. When the programmed device will go under the irradiation (Ions or electrons) then because of the deposition of the charge in the memory location, the respective states will lead to change from 1 to 0 or 0 to 1 states respectively and affects the programmed data. Therefore, in this case, the particular location of the device which has gone under transition will simultaneously be interrogated and compared with the initial programmed data. It will store the information with the memory address and data in the PC. This FPGA circuit will provide the total time scan for UV-EPROM around 2 msec. Therefore, this fast measuring electronic circuit will certainly help us to measure the precise SEU effects due to high energy radiation in space. The results for the UV-EPROM irradiated with heavy ions such as Nickel, Iodine, Silver etc shows sufficiently higher SEU cross-section as compared to the high energy electron and low energy alpha particles.

3. Title: “Irradiation effects of electron, proton, UV on optical coatings and thin films”

A simultaneous UV radiation, protons and electrons radiation exposing system is developed at Department of Physics, S P Pune University and the combined irradiation effects of UV radiation, protons and electrons on the space materials is studied.

Such a radiation environment is close to the space environment seen by a satellite on a typical geosynchronous mission.

The results of these studies used in predicting the behavior of the materials in the space environment during the mission period of a satellite.

4. Title: “Development of Nuclear Batteries using Radioactive sources”

Nuclear Batteries can supply low power, around a few μW over a period of ten to fifty years without any need of charging or maintenance. Under this project, using Radioactive Beta-sources with high activity, we have successfully designed and fabricated three kinds of Nuclear Batteries for providing ~ μW power. These included

I. Direct Charge Collection based on charging semispherical and hemispherical capacitor by beta particles,

II. Beta-Voltaic based on Schottky Junction type batteries using microcrystalline as well as nanocrystalline SiC and nanotubes of TiO2 and

III. Photovoltaic Nuclear Batteries using light from Tritium radioactive source and photovoltaic solar cells. All these low-power nuclear batteries were designed, developed and successfully tested in the Department of Physics and the required radioactive sources were purchased commercially from the BRIT, Government of India, Mumbai.

Ongoing Projects

1. Title: “Development of anti-erosion coatings on polymers for Low Earth Orbit Space applications”

Atomic oxygen exposure to the outer layer of spacecraft which is made up of polymers is a serious threat to its durability. To prevent or reduce the atomic oxygen erosion and oxidation of these polymer layers, anti-erosion coatings are being developed with varied degrees of success. The films should also withstand the temperature variation ranging from -40 0C to

+120 0C. The developed coatings on polymers should be tested in the atomic oxygen and UV radiation environment to prove its capability and sustainability during the space mission period.

The objectives of the project is i) To develop 5 to 10 eV atomic oxygen irradiation system ii) To develop anti-erosion coatings on polymers for Low Earth Orbit Space applications.

The components in the complete system involved are Ion source, Deceleration column, Mass analyzer, Experimental Chamber, Power Supplies and Vacuum system, etc. The combined assembly becomes whole as a system. Out of the above said components, Ion source is tested and characterized for various energies and optimized to get the maximum current focused ion beam. The deceleration column is simulated and tested to decelerate the ion beam. Experimental chamber is designed and fabricated. Its vacuum testing is under progress. Mass analyzer testing is to be done in upcoming days. After testing of mass analyzer, the complete installation of the system will be done and the atomic oxygen facility will be ready for the irradiation purpose.

We have synthesized MoS2 using single step hydrothermal method. The synthesized MoS2 is coated on Polyimide substrate using Doctor Blade Method. The film is also exposed to the ECR plasma oxygen ions to check the effects of low energy oxygen ions on the developed coatings. Further experiments are going on in order to enhance the adhesion between the coating and substrate.

40.5 Instruments / Payloads / Products Developed / Sensors / Detectors:

Scientific Rationale

Available observations from space have indicated a large diversity of radio sources in planetary magnetospheres, depending on the plasma conditions, the possible generation mechanisms, and the available free energy sources. SEAMS" Space payload will attempt to study the electromagnetic interactions between the solar wind plasma, the Moon, Earth's magnetosphere and geo-tail which are still not fully understood and much remains to be explored. With the birth of a new class of low frequency radio telescopes like LOFAR, MWA and LWA, low frequency radio astronomy is pushing the limits of the observable universe. However, at the very lowest of frequencies, these telescopes will become severely limited by near opacity of the ionosphere at frequencies ≤ 15 MHz. While arrays like LOFAR will be able to push the observable limit to about 10 MHz using various mitigation techniques, it is not possible to observe at frequencies lower than 10 MHz since the ionosphere reflects all frequencies less than the plasma frequency back to earth. In addition, during periods of high solar activity, this opacity may rise to 16 MHz. The SEAMS instrument will be designed to address these problems by providing a space-based solution to these impediments, at lower frequencies. While this is being done one of the major barriers is the Radio Frequency Interference coming from earth. The strong intensities of RFI make the astronomical observations impossible even in lunar orbit. It was demonstrated by RAE2 that the one of the radio quiet sites to perform low frequency observations is Far side of the moon. In the Moon mission, the payload will be placed on the far side of the Moon or at the Moon-Earth L2 to avoid the RFI from Earth. Figure 1 shows the range of expected flux densities in Lunar orbit from various sources.

40.6 Capacity Building in Space Science Research:

Does it organize lectures/workshops/training courses for the students/researchers beyond its curriculum?

1. Refresher Course on "Earth Science and Exo-Meteorology" for University and College Professors from 4-17January 2021.
2. Workshop on "Space Meteorology", for officers of the Indian Air Force from 1-14 March 2006.

40.7 Courses offered on Space Science and Technology

(i) title of the course offered : Space weather and Satellite Technology

(ii) standard of the course (undergraduate / post-graduate / PhD coursework, etc.), : Post graduate

(iii) intake capacity : 15 for M.Sc and 10 for MTech

40.8 Laboratories and Facilities Available for Space Instrumentation:

Space Electric And Magnetic Sensor) payload for low frequency Radio astronomy (SEAMS)

Overview of SEAMS

Space Electric and Magnetic Sensor (SEAMS) is a Radio telescope which is currently being designed to operate from 300kHz to 15MHz. Low frequency ionospheric cut off hinders the radio astronomical observations below 15 MHz. The payload will be placed on the 4th stage of a PSLV to study the RFI from Earth and to understand the nuances of data acquisition and analysis. Considering the effect of man-made RFI and its consequences on astronomical data, it is mainly targeted towards measuring the RFI in low earth orbit. The system will be designed with COTs components which would considerably reduce the cost and further it would test the utility of COTs components in Low Earth Orbit (LEO)

All the possible sources of radio frequency at low frequency (< 15MHz) are severely hindered by the manmade RFI emitting from Earth. Moreover, the received RFI is a function of location of payload in orbit and the time at which the data is being captured. In order to mitigate these sources of interference it is crucial to know the characteristics of the emissions and their relative intensities as a function of location and time. Considering the effect of manmade RFI and its consequences on the experiments, the SEAMS payload is targeted towards measuring the RFI in low earth orbit with the help of two monopole antennas placed orthogonal to each other. This is an experiment not reported to date and would provide an important as well as valuable information for all groups working on low frequency radio astronomy payloads. This is proposed to be done by deploying SEAMS as a payload on the PS4 orbital platform to get data regarding the RFI levels which would be be analysed to map the RFI and study effect of variations in ionosphere on the measurements.

List of Publications

- Atharva Kulkarni, Aditee Nagulpeli, Rasika Sali, Nikhil Navale, D.C. Gharpure,Avinash Deshpande, S. Anathakrishnan, “Instrumentation for SEAMS Phase I presented at URSI GASS 2021, Rome.
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- Kulkarni, A., Pingale, S., Gharpure, D. and Ananthakrishnan, S., 2019, March. RF Front-End for SEAMS. In 2019 URSI Asia-Pacific Radio Science Conference (AP-RASC) (pp. 1-1). IEEE.

CHAPTER-41

SAHA INSTITUTE OF NUCLEAR PHYSICS

Kolkata

41.1 About the Institute

The Institute grew out of the Palit Research Laboratory in Physics of the University of Calcutta (CU) as Professor Meghnad Saha (then Palit Professor of Physics, CU) saw immense potential of nuclear science for betterment of the country. Experiments in Nuclear Physics and instrumentation started in his laboratory. A small-scale cyclotron was felt necessary for gaining knowledge in this virgin field that was decided to build here. With the help of Jawaharlal Nehru and Dorabji Tata, fund to procure its parts became available. CU constructed a new building to house the Cyclotron. The Institute of Nuclear Physics was founded which was renamed as Saha Institute of Nuclear Physics (SINP).

SINP is engaged in basic scientific research on four broad subject areas, namely; (a) Theoretical Physics, (b) Nuclear Science, (c) Material Physics and (d) Biophysics. The Institute is also engaged in several large international collaborations like CMS, ALICE, MAGIC etc., the activities of teaching and training as well as the ventures like Vigyan Pratibha Program.

The Institute has presently 64 faculty members, 140 research fellows and 20 Postdocs, who are actively engaged in various research and teaching programmes.

41.2 Keywords

Astroparticle Physics & Cosmology, Applied Nuclear Physics, High Energy Nuclear & Particle Physics, Nuclear Physics, Plasma Physics, Condensed Matter & Surface Physics and Material Science, Biophysics and Structural Genomics, Crystallography & Molecular Biology, Chemical Sciences Theoretical Physics

41.3 Major Research Domains

- Theoretical and Experimental Physics
- Biophysics and Structural Genomics (Biophysics)

41.4 Major Scientific Applications / Results

Space Biology

- **A micro gravity cellular biosensor**

  Bio-engineering solutions to human space travel must consider micro-gravity as an important component. Thus, one of the fundamental challenges of space bio-engineering is to create cellular micro-gravity responsive device, which integrate micro gravity as a signal within biochemical and cellular processes. Researchers from Saha Institute of Nuclear Physics, Kolkata designed, fabricated and characterized the first biochemical and cellular micro-gravity responsive device using an engineered genetic circuit in E Coli, which responded to micro-gravity by changing the expression of a target enhanced green fluorescent gene (EGFP). We demonstrated that the basic design of the device is universal in nature for E Coli, by creating multiple successful devices. Further, we applied this device to control the cell division process by micro-gravity. Here we targeted the cell division regulator FtsZ, which resulted an elongated cell shape in normal gravity and this deformed cell shape got rescued to normal one by applying micro-gravity. The work showed for the first time, a way to integrate micro-gravity as a physical signal within biochemical processes of a living cell in a human designed way and thus, may have significance in space bio-engineering.

- **Effect of micro-gravity on bacteria**

  Bacteria are important organisms for space missions due to their increased pathogenesis in micro-gravity that poses risks to the health of astronauts and for projected synthetic biology applications at the space station. We understand little about the effect, at the molecular systems level, of micro-gravity on bacteria, despite their significant incidence. In this study, we proposed a systems biology pipeline and performed an analysis on published gene expression data sets from multiple seminal studies on Pseudomonas aeruginosa and Salmonella enterica serovar Typhimurium under spaceflight and simulated micro-gravity conditions. By applying gene set enrichment analysis on the global gene expression data, we directly identified a large number of new, statistically significant cellular and metabolic pathways involved in response to micro-gravity. Alteration of metabolic pathways in micro-gravity has rarely been reported before, whereas in this analysis metabolic pathways are prevalent. Several of those pathways were found to be common across studies and species,indicating a common cellular response in micro-gravity. We clustered genes based on their expression patterns using consensus non-negative matrix factorization. The genes from different mathematically stable clusters showed protein-protein association networks with distinct biological functions, suggesting the plausible functional or regulatory network motifs in response to micro-gravity. The newly identified pathways and networks showed connection with increased survival of pathogens within macrophages, virulence, and antibiotic resistance in micro-gravity. Our work establishes a systems biology pipeline and provides an integrated insight into the effect of micro-gravity at the molecular systems level.

- **Effect of micro-gravity on human cells**

  Micro-gravity is a prominent health hazard for astronauts, yet we understand little about its effect at the molecular systems level. In this study, we have integrated a set of systems-biology tools and databases and have analyzed more than 8000 molecular pathways on published global gene expression data sets of human cells in micro-gravity. Hundreds of new pathways have been identified with statistical confidence for each data set and despite the difference in cell types and experiments, around 100 of the new pathways are appeared common across the data sets. They are related to reduced inflammation, autoimmunity, diabetes and asthma. We have identified down regulation of NfκB pathway via Notch1 signaling as new pathway for reduced immunity in micro gravity. Induction of few cancer types including liver cancer and leukaemia and increased drug response to cancer in micro gravity are also found. Increase in olfactory signal transduction is also identified. Genes, based on their expression pattern, are clustered and mathematically stable clusters are identified. The network mapping of genes within a cluster indicates the plausible functional connections in micro gravity. This pipeline gives a new systems level picture of human cells under micro gravity, generates testable hypothesis and may help estimating risk and developing medicine for space missions.

41.5 Instruments / Payloads / Products Developed / Sensors / Detectors

Space Biology

Established a micro gravity simulator reactor for culturing cells and related facility.

41.6 Capacity Building in Space Science Research

Space Biology

- 1 student completed his PhD in space synthetic and systems biology
- 5 undergraduate students were strained in space systems biology

41.7 Courses offered on Space Science and Technology

- A PhD level full course on Space Bio-engineering (Title : Introduction to Space Bio-engineering and Medicine) has been offered to the PhD students.
- Around 20 lectures were offered.

41.8 Laboratories and Facilities Available for Space Instrumentation

- A micro gravity simulator reactor for culturing cells and related facility
- Synthetic Biology facility

List of scientific publications in Space Biology

1. Sayak Mukhopadhyay, and Sangram Bagh* (2020). “A Microgravity ResponsiveSynthetic Genetic Device in Escherichia Coli.” Biosensors and Bioelectronics, vol. 167, Nov. 2020, p. 112462. , IF: 10.257

Astronomy and Astrophysics

List of Scientific Publications related to space science and technology :

1. R. Prince et al, Multi-wavelength Analysis and Modeling of OJ 287 During 2017-2020, Astronomy & Astrophysics, 654, A38, (2021)

2. R. Prince at al, A comprehensive study of 2019-2020 flare of OJ 287 using AstroSat, Swift, and NuSTAR, MNRAS, 508, 315-325, (2021)

3. V. A. Acciari et al, Multi-wavelength variability and correlation studies of Mrk 421 during historical low X-ray and gamma-ray activity in 2015/2016, MNRAS, 504, 1, 1427-1451 (2021) (Corresponding authors : B.Banerjee, T.Terzic, D.Paneque and P.Majumdar)

4. P.Bhattacharjee et al, Multiwavelength analysis of low surface brightness galaxies to study possible dark matter signature, MNRAS, 501, 3, 4238-4254 (2021) (Corresponding authors : P.Bhattacharjee and P.Majumdar)

CHAPTER-42

UGC-SVU CENTRE FOR MST RADAR APPLICATIONS

SV University, Tirupati

42.1 Historical Backdrop

To create scientific awareness about the potential use of the sophisticated radar and other instrumentation facilities for advanced research in the area of atmospheric sciences and to attract bright and young researchers to utilise the MST Radar, Lidar and other co-located Facilities available at NARL, Gadanki; University Grants Commission (UGC) has established an UGC-SVU Centre at S.V. University, Tirupati, to serves as a common platform for the University system in India for the exchange of scientific knowledge and the centre is accessible to scientist and researcher from Indian Universities working in the area of Atmospheric Sciences.

42.2 Keywords

Atmospheric Science, Space Science, Soil moisture, QBO, Gravity waves, Martian Atmosphere, Tropical cyclones.

42.3 Major Research Domains

- Disrupted Stratospheric QBO Signatures in the Diurnal Tides Over the Low-Latitude MLT Region
- Variability of temperatures and gravity wave activity in the Martian thermosphere during low solar irradiance

42.4 Major Scientific Applications / Results

- **Disrupted Stratospheric QBO Signatures in the Diurnal Tides Over the Low-Latitude MLT Region**

  Meteor radar measurements of winds in the mesosphere and lower thermosphere (MLT)over Tirupati (13.63°N, 79.4°E; 2013–2020) and Microwave Limb Sounder (MLS) observations of ozone are used for investigating the effect of the disrupted stratospheric quasi-biennial oscillation (SQBO) during the year 2016 on the diurnal tides. The positive tidal perturbations are observed during positive perturbations of ozone and eastward phase of the SQBO and vice versa. These observations are well captured by the Specified Dynamics Whole Atmosphere Community Climate Model (SD-WACCM) simulations. The results suggest that the ozone and wind perturbations in the stratosphere induced by the sudden phase transition in the SQBO winds are the potential candidates for the observed abrupt changes in the diurnal tide amplitudes in the MLT region. The SQBO disruption thus provided an opportunity to seek further insights into the pathways through which the lower atmosphere influences the middle and upper atmosphere.

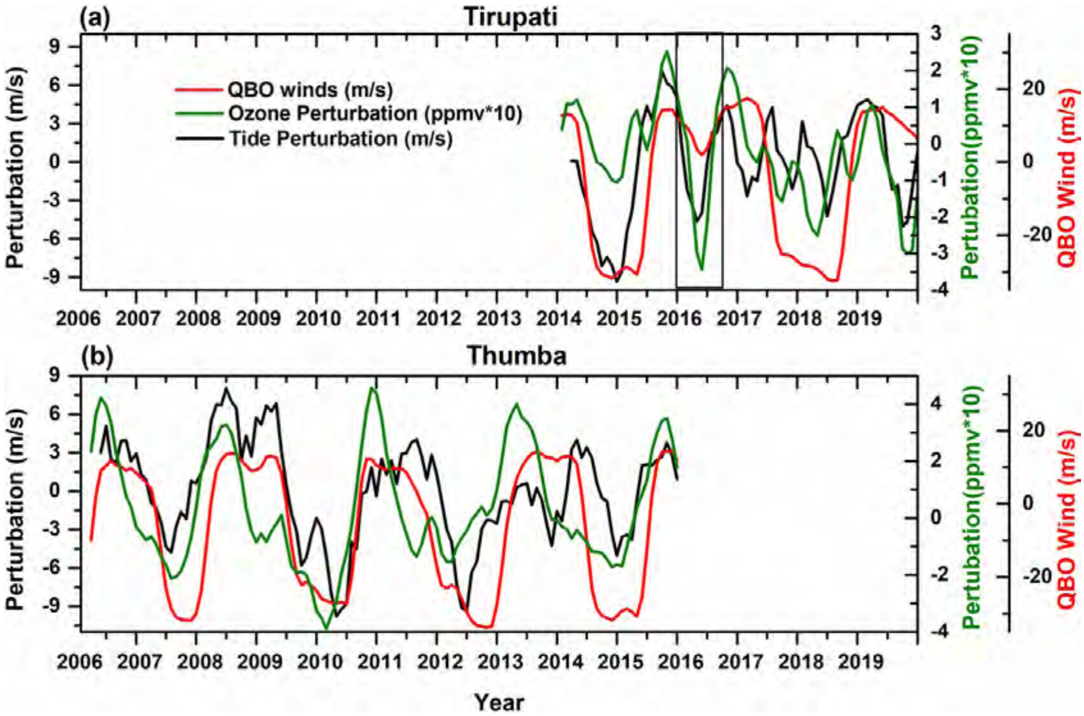

Figure 1: Interannual variability of deseasonalized diurnal tide perturbations in the meridional winds at 88 kmaltitude derived from meteor radar observations (black), SQBO winds (red) at 30 hPa level and deseasonalized ozoneperturbations (green) at 26 hPa over (a) Tirupati and (b) Thumba.

During the year 2016, for the first time the SQBO disruption took place. The present study investigates the effect of the SQBO disruption on the amplitudes of the diurnal tides in the MLT region using meteor radar observations over a low-latitude station. Stratospheric ozone measurements obtained from Microwave Limb Sounder (MLS) as well as simulations from Specified Dynamics Whole Atmosphere Community Climate Model (SD-WACCM) are also employed to shed light on the relation among diurnal tides, SQBO winds and ozone shown in Figure 1. The results suggest a positive correlation between diurnal tide perturbations and ozone perturbations as well as SQBO winds. During the SQBO disruption, there is a negative anomaly in the ozone perturbations and westward winds below 20 hPa, which are thought to be the prime candidates inreducing the observed diurnal tide amplitudes in the MLT.Atmospheric tides are global scale oscillations with periods that are sub-harmonics of a solar day (24, 12, 8 h etc.). Among these, diurnal tides (24 h) are very prominent over low latitudes and play a major role in shaping the structure and dynamics of the middle atmosphere. Stratospheric quasi-biennial oscillation (SQBO) is a long period oscillation with a mean time period of ~28 months in the stratosphere and is believed to modulate diurnal tides at interannual time scales.

- **Variability of temperatures and gravity wave activity in the Martian thermosphere during low solar irradiance**

  This present work deals with temperatures and gravity wave (GW) activity in the Martian thermosphere during low solar activity. For this purpose, we extracted the

GW amplitudes and thermosphere temperatures from CO2 densities measured in situ by the Neutral Gas and Ion Mass Spectrometer (NGIMS) aboard the Mars Atmosphere and Volatile Evolution (MAVEN) mission. These observations were obtained during the declining phase of solar activity between solar longitude (Ls) =294° in Mars year (MY) 32 and Ls = 242° in MY 35. The observations of the present study show that the temperatures are lower and GW amplitudes are higher at low solar activity. The response of the thermospheric temperatures to solar irradiance is local time dependent such that the noontime and duskside temperatures show significant correlation (correlation coefficient, R > 0.8) with the solar irradiance whereas the temperatures on the dawnside show moderate correlation (R = 0.55) shown in Figure 2. Furthermore, the nominal negative correlation between the gravity wave amplitudes and thermospheric temperatures, which was disturbed during the 2018 global dust event, was restored after the subsidence of the event. Interestingly, the correlation between the thermospheric temperatures and GW activity is also local time dependent with moderate correlation at noon (R = -0.65) and weak correlation at other local times shown in Figure 3.

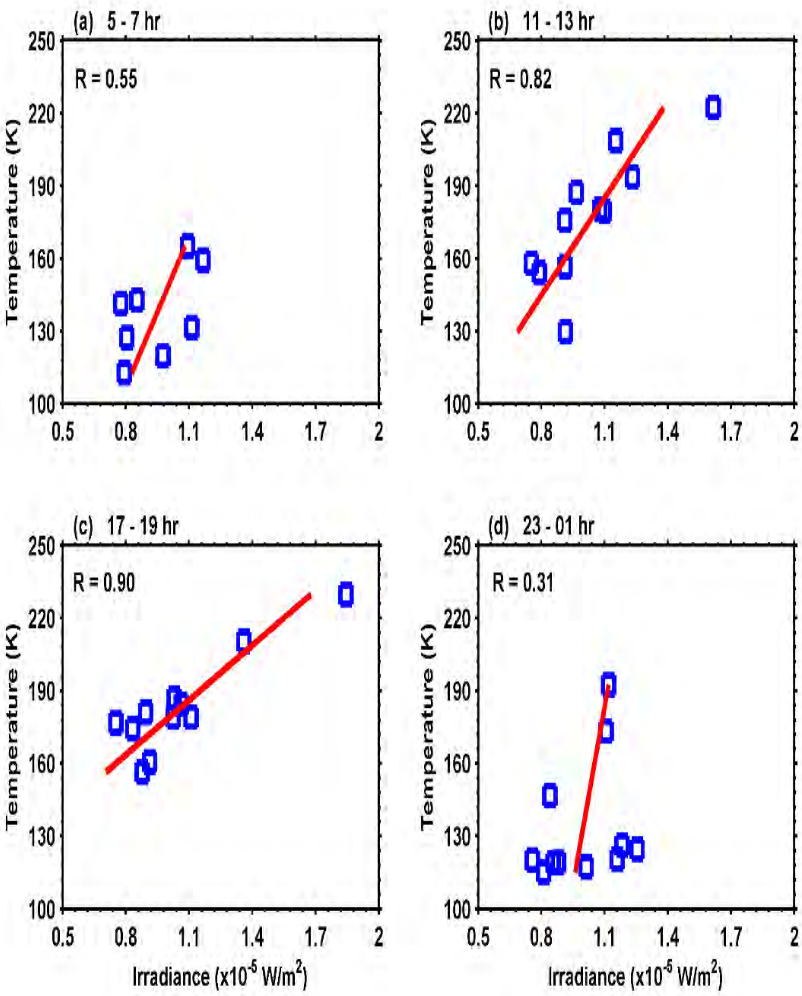

Figure 2: Scatter plot between solar irradiance and thermosphericltemperarture depicting the correlation coefficient (a) 5 – 7 h (b) 11 – 13 h (c) 17 – 19 h (d) 23 – 01 h. The solid red line shown the best fit for each dataset.

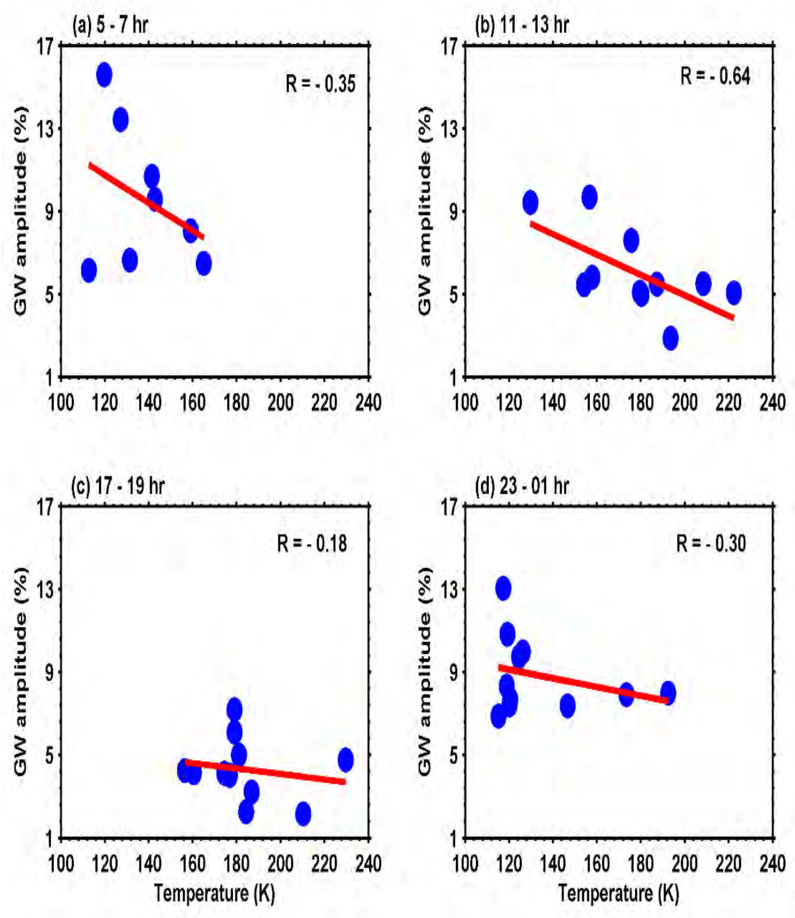

Figure 3: Same as Figure 2, but shows the correlation analysis between the thermosphere temperature and GW activity.

From the results of the present study, it is inferred that the variability of GW amplitudes in the Martian thermosphere are not necessarily controlled by the temperatures of the underlying atmosphere alone. Other factors, such as the variation of GW amplitudes at the source region and/or changes in the circulation of the underlying atmosphere, are also likely to play a significant role, particularly at the terminator and on the nightside.

42.5 Instruments / Payloads / Products Developed / Sensors / Detectors

- Meteor Radar
- Micro Pulse Lidar
- Micro Rain Radar
- Optical disdrometer
- Air Samplers
- HPC
- GIS Software

42.6 Capacity Building in Space Science Research

- The centre organizes training and conference/workshops in the area of Atmospheric Sciences.(Due COVID-19 No program was organized during the reported period)
- The Centre is guiding PhD and M.Sc project works in the area of atmospheric sciences.

42.7 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	Research Collaboration	NARL, Gadanki
2.	Research	University of PUNE

Publications

1. Pramitha M, Kumar KK, Ratnam MV, Praveen M, BhaskaraRao SV (2021) Stratospheric Quasi Biennial Oscillation Modulations of Migrating Diurnal Tide in the Mesosphere and Lower Thermosphere Over the Low and Equatorial Latitudes. Journal of Geophysical Research: Space Physics. 2021 Jul; 126(7):e2020JA028970.

2. He M, Chau JL, Forbes JM, Zhang X, Englert CR, Harding BJ, Immel TJ, Lima LM, BhaskarRao SV, Ratnam MV, Li G. (2021) Quasi-2-day wave in low-latitude atmospheric winds as viewed from the ground and space during January–March, 2020. Geophysical Research Letters. 2021 Apr 5:e2021GL093466.

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CHAPTER-43

ST. JOSEPH'S COLLEGE

Bengaluru

43.1 About the College:

St. Joseph's College (Autonomous) is one of the premier institutions of higher education in India. Established in the year 1882, the College strives for a just, secular, democratic and economically equitable society, by caring for the poor, the oppressed and the marginalized through the formation of its students as agents of change in the society - "men and women for others" and "Fide et Labore" (translated from Latin as faith and toil) being the vision and mission for the college. In 2017, the College was accredited by the NAAC in its 4th Accreditation Cycle by a grade of A++ (with a score of 3.79/4) - placing it among the top.

The Physics department at St. Joseph's College had its humble beginnings in the year 1923. At present, the Department has 14 faculty members and teaches around 500 and 60 students in the UG and PG sections respectively. A recent approval of the department as a Research Center under Bangalore University will see more advances in the unique features of this department. The following are the Vision and Mission statements of the department:

Vision: Striving to prepare the students for higher educational and career challenges by fostering scientific temper and human values

Mission: Dedication to inculcating in its students a deep commitment to the pursuit of knowledge and understanding in the Physical Sciences through promoting a spirit of open-ended intellectual curiosity. We encourage our students to be innovative and adaptable to new developments in society through an emphasis on quality in teaching, learning and research.

43.2 Keywords

Galaxies: spiral; structure; Stars: neutron; Physical data and processes: dense matter; gravitation; solid state: refractory; Astronomical Instrumentation, Methods and Techniques:

43.3 Major Research Domains

- Astronomy and Astrophysics
    - Observational Astrophysics: We have been involved in studying the distribution (MOM 0) and motion (MOM 1) of Atomic hydrogen [HI] in spiral galaxies using GMRT, WSRT and VLA Radio Telescopes. Using the MOM 0 and MOM 1 data, we studied the rotation curves of galaxies belonging to the Ursa Major and Eridanus groups of galaxies as well as evolved a technique to quantify the asymmetries,

both in the distribution and motion of [HI] in spiral galaxies. If the asymmetries are caused by dark matter halo potential, we were also able to estimate the asymmetry in the dark matter halo potential. To further our study, we shall be studying dwarf galaxies, isolated spiral galaxies as well as compact group of galaxies.

- Theoretical Astrophysics: Research related to Neutron stars:
  - using numerical relativity to construct and solve relativistic structure equations with inputs of high density matter equations of state,
  - magnetohydrodynamics simulations relevant to the interiors of proto neutron stars; these are also applicable to systems with axial symmetry - like galaxies) with collaborations in India and Italy.
  - with significant experience in numerical techniques and use of python, and having access to the student community (who are also trained in numerical techniques using python), have initiated collaborations with several groups

43.4 Capacity Building in Space Science Research

- Space-Science Course at SJC: The Department of Physics, St. Joseph's College (Autonomous) has been conducting an intercollegiate certificated course titled "Space and Rocket Dynamics" in collaboration with ISRO for B.Sc.,M.Sc. and B.Tech. students. The course was initiated in the year 2000 and the objective of the course was to kindle interest in space sciences and astronomy in the young minds of our country and to give them an exposure to the great work ISRO is doing in the field of space sciences. The overwhelming response (detailed in the section Courses Offered), enthusiasm and interest we received from the students of various B.Sc. and B.Tech. colleges in and around the Bengaluru city gives us a clear indication of the effectiveness of this course. The course continued without break for 18 years from 2000 to 2018. The course was also supported by other premier research institutions like IIA, Bengaluru, Gauribidanur Observatory (IIA and RRI) for the successful conduct of the course in terms of providing resource persons and organizing exposure visits to ISAC Bengaluru,Gauribidanur and Vainu Bappu Observatory, Kavalur and SDSC at Sriharikota etc.
- The most recent workshop (during the reporting period is): "Renewed Interest in Venus", a webinar by Dr. P Sreekumar, former Director of SSPO, ISROHQ) and is now a Satish Dhawan professor in ISRO HQ, on the 17th of July 2020
- B.Sc/M.Sc.: The faculties guide students from B.Sc/M.Sc. for internships. Ph.D.: The HRD has conferred a University status to the college, this was further ratified by the Karnataka Government and the college is slated to start functioning as a university from next academic year.

- Night Sky Watch and Special Astronomical Events: The college holds Night Sky Watch and Special Astronomical Events whenever possible. The most recent sky-watch program was held on 12 Feb. 2022:

About 200 students completed the certificate course Typically 200-300 students graduate from the BSc course with physics and 30 students complete the MSc physics course every year (each of these courses have a small component of Astrophysics for all).

Several students who have attended the certificate course (more than 10) in the past 5 years, have gone on to do a masters and then take up Ph.D. courses in the country and abroad. A part of them do their masters at St. Joseph's College (Autonomous) - so the numbers are partially shared.

43.5 Courses offered on Space Science and Technology:

- BSc Astronomy and Astrophysics:

  (i) Title: Astronomy and Astrophysics

  (ii) Standard of the Course: Undergraduate

- BSc (Open Elective - Open to students of all departments - including humanities and commerce):

  (i) Title: The Universe and Me

  (ii) Standard of the Course: Undergraduate

  (iii) Intake capacity: 160

(iv) Space and Rocket dynamics (A certificate course open to B.Sc. and B.Tech. students in and around Bengaluru - course was started in 2000):

Certificate Course Details: The details of the course conducted for the past 5 years are given above.

(i) Title: Space and Rocket dynamics

(ii) Standard of the Course: Undergraduate

(iii) Intake capacity: 50

- MSc Physics (Department Elective):

(i) Title: Astrophysics

(ii) Standard of the Course: Post-graduate

(iii) Intake capacity: 15-18

- MSc Physics (softcore):

(i) Title: Astrophysics

(ii) Standard of the Course: Post-graduate

(iii) Intake capacity: 30

(iv) MSc Physics (Open Elective - Open to students of all departments - including humanities and commerce):

(i) Title: Astrophysics Open Elective

(ii) Standard of the Course: Post-graduate

(iii) Intake capacity: 30

43.6 Laboratories and Facilities Available for Space Instrumentation:

Considering that we are primarily an educational institution, our facilities tend to focus on the educational part. Some equipment help take the topics to a research level. In this light, the following facilities are available (in addition to standard equipment making up a typical physics laboratory):

- A Departmental Library with more than 300 books on astronomy and astrophysics
- Four telescopes:

A new 12 Inch telescope with a drive developed by the PG students is due to be housed in the Science block dome in the coming months.

An existing 8 inch telescope will be moved to a new dome currently under construction in the PG Block

A radio telescope exclusively for studying the sun.

In addition, the PG department has its own 6 inch telescope used for daytime activities (solar observations and resolving power calculations).

Technologies

Research domains

- Materials Science
  - Manganites and Spintronic Materials: Doped rare earth manganite belong to the class of strongly correlated systems and exhibit wide range of properties like colossal magnetoresistance, charge order, phase separation due to which has potential application in spintronics, IR sensors, spin valves, magnetic refrigeration, magnetic sensors etc. Our study includes preparation of monodispersed nanoparticles of doped rare-earth manganite using bottom-up techniques. Study of size induced transport and magnetic properties using dynamic probes, electron paramagnetic resonance and squid magnetometer. Temperature induced phase transition. Relevant for positioning systems in space-physics. The work is done in collaboration with the Indian Institute of Science.
  - Material Science and Batteries: In the power sub-system of a small satellite, two power sources are normally used- solar cells or photovoltaic cells, which act as primary source of energy and batteries like Nickel-metal hydride and Li-ion which act as the secondary source. We also focus on potential materials for use in rechargeable batteries with better charge storage capabilities.
  - Semiconductor Materials, Thin Films, Materials for Solar Cells and Batteries: Reducing the cost as well as increasing the efficiency of devices represents the important challenges in the solar cells industry. We propose novel and unique concepts to increase the efficiency of solar cells by better utilization of the full solar spectrum through multilayer or multiband structured solar cells. Multilayer structures have attracted attention in emerging devices - particularly in optoelectronics. It can provide information to study quantum size effects and confinement effects. We focus on Quantum dot solar cells and nanostructures for future development using our in house equipment like: spin coater, box furnace and our own automated SILAR instrument.
  - Semiconductor Heterostructures: Semiconductor heterostructures are an integral part of modern energy devices that harness the utilization of solar energy. Hence

this domain promises a lot of potential towards applications. Most of the space mission power demand is fulfilled by solar cells; there is a huge surge in their performance due to inclusion of heterostructures. Homojunction and multijunction solar cells, both seem good, but multijunction cells are more efficient in converting solar energy into useful electrical energy. In this line, various theoretical and experimental activities have been carried out in the department.

- o Exciton in Heterostructures and Excitonics: Exciton is a bound electron-hole pair coupled through Coulomb interaction. A tight bound Frenkel exciton (F-Ex) is usually seen in organic molecules and a loosely bound Mott-Wannier (MW-Ex) exciton in semiconductors. Our interest is on MW-type in nanostructures that offer extended lifetime to these neutral bosonic quasi-particles. We are working on Exciton-Mott Transition in heterostructures. Similarly, both F-Ex and MW-Ex are the most promising elements in solar energy harvesting devices. So, the studies based on excitons is also one of our major research areas in the department.
- o Graphene based research: The success of graphene has given rise to two-dimensional materials (2D) as a new resource for various applications. However, the lack of bandgap in graphene limits its use. Other 2D materials, with intrinsically semiconducting nature like transition metal dichalcogenides (TMDs) have been considered as an alternative. These TMDs exhibit a wide variety of polymorphs and the controlled synthesis of TMDs has been a matter of intense research, expected to be beneficial in several fields, including in space sciences. TMD materials withstand relatively high doses of environmental radiation. These applications require extremely high quality films with a controlled number of layers. Molecular beam epitaxy (MBE) growth method provides a route to synthesize films matching these requirements. We have developed a method to synthesize atomically thin molybdenum ditelluride (MoTe2) and have presented and characterized it. This topic too, is an integral part of the research carried out at St. Joseph's College (Autonomous).

Publications

1. Substrate temperature dependence of the crystalline quality for the synthesis of pure-phase MoTe2 on graphene/6H-SiC(0001): Phase controlled synthesis and characterization, Roshan Castelino, Nanotechnology(IOP), 31, 115702-115705, 2020

2. Hartree-Fock Approximation for Exciton Mott Transition in Double Quantum Well: Direct and Indirect Exciton Diamagnetism, G Vignesh, Physica E: Low-dimensional Systems and Nanostructures, 119, 114008, (2020).

3. Exciton Mott transition through diamagnetic susceptibility in a quantum well, G Vignesh, AIP Conference Proceedings, 2265, 030082, 2020.

4. Stability of indirect and direct excitons through diamagnetic susceptibility in a concentric double quantum ring structure, G Vignesh, AIP Conference Proceedings, 2265, 030064 (2020).

5. Analysis of elastic properties of lithium substituted barium vanadate glasses to understand the structural changes, Parul Goel, Materials Today: Proceedings,44, 2309-2312, (2021).

6. Temperature effect on CuO nanoparticles via facile hydrothermal approach to effective utilization of UV–visible region for photocatalytic activity, E. Bruno, A. Mohan, Appl. Phys. A 127, 925 (2021)

7. Formation of self-assembled hierarchical structure on Zn doped in CuO nanoparticles using a microwave-assisted chemical precipitation approach., E. Bruno, A. Mohan J Mater Sci: Mater Electron, 32, 19339–19351 (2021)

CHAPTER-44

ST. XAVIER'S COLLEGE

Kolkata

44.1 About the College

St. Xavier's College (Autonomous), Kolkata (SXC) has a rich legacy of Studies and Research related to Astrophysics. The initial initiative was taken by Fr. Eugène Lafont, S.J, then Rector and Principal, SXC, considered widely to be a pioneer of modern science teaching in Bengal, who built an astronomical observatory in 1875 for spectroscopic studies of the sun and planetary atmosphere in conjugation with other European laboratories. Currently, it has a twin observatory (christened ELFO), consisting of a stellar observatory with a motorized dome and a separate sliding roof observatory meant for solar observations. The observatory serves as a center for a P.G. Course with specialization in astrophysics and also research and outreach activities.

44.2 Keywords

Astrophysics, Compact Objects, Black Holes, Dark Matter, Dark Energy, MACHO, 21 cm Astronomy, Dynamical Astronomy, Chaos and Non-linear Dynamics, Galactic and Extragalactic Modelling, Particle Dynamics.

44.3 Major Research Domains

The major thrust areas of work, indicated below, are based on publications in prominent research journals and relates well to present day observations.

- High Energy Astro Particle Physics:
    - General Relativity and Modified Gravity
    - Higher dimensional gravity and Geodesic motions
    - Gravitational Waves and Gravitational Collapse
    - Observational Astrophysics
    - Galactic and Particle Dynamics around Compact Objects, Accretion
    - Nonlinear Dynamics and Biological Systems
    - Solid State Physics

44.4 Major Scientific Applications / Results

Title	Authors	Journal Reference and DOI	Abstract
Exploring multimessenger signals from heavy dark matter decay with EDGES 21-cm result and IceCube	Ashadul Halder et al.,	*JCAP* **10** (2021) 033 DOI: 10.1088/1475-7516/2021/10/033	Possible multimessenger analysis of heavy dark matter decay has been carried out. One of which could be the source of ultra high energy neutrino signals whereas the other signal attributes to the fluctuation of the global 21-cm signal.
Bounds on abundance of primordial black hole and dark matter from EDGES 21-cm signal	Ashadul Halder et al.,	*Phys.Rev.D* **103** (2021) 6, 063044 DOI: 10.1103/ PhysRevD.103.063044	The combined effect of primordial black hole (PBH) evaporation and baryon-dark matter (DM) interaction in the 21cm scenario is explored in this analysis. The upper and lower bounds on the initial mass fraction of PBHs, dark matter mass and baryon-DM cross-section are also investigated by incorporating the observational excess of EDGES's experimental result.
Bounds on dark matter annihilation cross-sections from inert doublet model in the context of 21-cm cosmology of dark ages	Rupa Basu et al.,	*Int.J.Mod.Phys.A* **36** (2021) 23, 2150163 DOI: 10.1142/ S0217751X21501633	We study the fluctuations in the brightness temperature of 21-cm signal at the dark ages with a dark matter candidate in Inter Doublet Model (IDM). A lower bound on annihilation cross-section for this dark matter is also obtained analyzing the signal using EDGES observational result.
Chandrasekhar limit for rotating quark stars	Ashadul Halder et al.,	*Phys.Rev.C* **103** (2021) 3, 035806 DOI: 10.1103/ PhysRevC.103.035806	The maximum mass of a rotating quark star essentially depends on the rotational frequency apart from other fundamental parameters and bag constant.

Title	Authors	Journal Reference and DOI	Abstract
Addressing -ray emissions from dark matter annihilations in 45 milky way satellite galaxies and in extragalactic sources with particle dark matter models	Ashadul Halder et al.,	*Mon.Not.Roy.Astron. Soc.* **500** (2020) 4, 5589-5602 DOI: 10.1093/mnras/staa3481	We compare the computed results using particle dark matter models with the observational upper bounds for -ray flux reported by Fermi-LAT and Dark Energy Survey (DES) for 45 dSphs by adopting different dark matter density profiles. We then extend similar analysis for the observational upper bounds of -ray fluxes from extragalactic sources.
Probing the effects of primordial black holes on 21-cm EDGES signal along with interacting dark energy and dark matter–baryon scattering	Ashadul Halder et al.,	*Mon.Not.Roy.Astron. Soc.* **508** (2021) 3, 3446-3454 DOI: 10.1093/mnras/stab2795	We explore the combined effects of primordial black holes (PBH), dark matter (DM) - baryon collisions and interaction of dark matter - dark energy (DE) fluid on the 21-cm brightness temperature. We therefore estimate bounds on IDE parameters as well as PBH and DM parameters using the observed excess EDGES experiment.
Beyond-Newtonian dynamics of a planar circular restricted three-body problem with Kerr-like primaries	Shounak De et al.,	*Mon.Not.Roy.Astron. Soc.* **501** (2021) 713-129 DOI:10.1093/mnras/staa3733	The dynamics of the planar circular restricted three-body problem with Kerr-like primaries in the context of a beyond-Newtonian approximation is studied. The amount of chaos in the system remains higher than the Newtonian system as well as for the planar circular restricted three-body problem with Schwarzschild-like primaries for all non-zero values of ϵ.

Title	Authors	Journal Reference and DOI	Abstract
On the gravitational entropy of accelerating black holes	Sarbari Guha and Samarjit Chakraborty	*International Journal of Modern Physics D*, **29** (2020) pp. 2050034. DOI: 10.1142/ S0218271820500340	We have examined the validity of a proposed definition of gravitational entropy in the context of accelerating black hole solutions of the Einstein field equations. We have adopted a phenomenological approach proposed in Rudjord *et al.* [*Phys. Scr.* **77**, 055901 (2008)] and expanded by Romero *et al.* [*Int. J. Theor. Phys.* **51**, 925 (2012)]. Considering the C-metric for the accelerating black holes, we have evaluated the gravitational entropy and the corresponding entropy density for non-rotating, non-rotating charged, rotating and rotating charged blackhole. We discuss the merits of the analysis and the possible reason of failure in the case of rotating charged black hole and comment on the possible resolution.

44.5 Instruments

Stellar observatory with a motorized dome and a separate sliding roof observatory meant for solar observations

44.6 Capacity Building in Space Science Research

Workshops have been organized in the areas of observational astronomy in remote areas, experimental physics, computational aspects of physics/astrophysics, radio-astronomy, Astro-particle physics, science of interfacing involving participation and resourcing from an wide array of scientific institutes like ARIES, IISC, IUCAA, IIA, SNBNCBS, Bose Institute, Inter-university consortium for nuclear physics, Presidency University, WBSU, St. Joseph Bengaluru as part of the Jesuit Collaboration, as well as from inside the organization.

The number of total beneficiaries over the last 14 years have been about 1600 students and 250 faculty members. As many as 1000 students have chosen science-based careers. CU has sanctioned the department of Physics to award Ph.D. degree and the first of them would be graduating this year in the field of Astro-particle physics.

44.7 Courses offered on Space Science and Technology

- Specialization on Astro-Particle Physics offered at the P.G level (From 2007 onwards)
  - (i) Title: Specialization in Astro-Particle Physics
  - (ii) PG final year
  - (iii) Intake Capacity: 20 Students
  - (iv) Topics Covered: Foundations of Astrophysics, General Relativity, Cosmology, Solar, Galactic and Extragalactic Astrophysics, Standard Model of Particle Physics, Astro-particle Physics, Astrophysics Lab, Computational Astrophysics.
  - (v) 350 Lecture hours
- PhD Level courses: Currently seven students are working in related areas. Standard coursework offered to PhD Students included: Course on Computation, Non-linear Dynamics, Fluid Dynamics, Quantum Mechanics, General Relativity, Gravitational Waves, Gravitational Collapse.

44.8 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1.	Astro-Particle Physics and Space Science (PAST: 2006 – 2015)	Bose Institute (CAPSS)
2.	Observational Astronomy (Planned)	SNBNCBS

44.9 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1.	Relativistic Astrophysics	Astrophysics and Cosmology Research Unit, University of KwaZulu-Natal, Durban, South Africa

44.10 Laboratories and Facilities Available for Space Instrumentation

The functional observatory which can be used for observations and follow-up programs (particularly with reference to ASTROSAT).

CHAPTER-45

TATA INSTITUTE OF FUNDAMENTAL RESEARCH (TIFR)

Mumbai

45.1 About the Institute

TIFR is a premier research institute carrying out fundamental research in natural sciences. In the aera of space science, its activities are carried out at its various centres namely, (1) TIFR Balloon Facility, Hyderabad (2) Department of Astronomy and Astrophysics, TIFR, Mumbai, and (3) National Centre for Radio Astrophysics (NCRA), Pune.

TIFR Balloon Facility (TIFR-BF) was established in 1969 as a field station to carry out scientific ballooning activities in the fields of space astronomy and atmospheric sciences. It has become a unique centre of technology which offers complete solutions in scientific ballooning for high altitude studies. The centre has an in-house balloon production facility as well as ground facilities for balloon launching and recovery operations.Balloon flights carrying payloads of scientific experiments in Cosmic ray, X-ray, Gamma Ray and Infrared Astronomy, Astrobiology as well as Atmospheric sciences have been launched from this facility with several important and interesting results being obtained.

The Department of Astronomy and Astrophysics-TIFR is Located in the scenic Mumbai campus. The department carries out cutting edge research in theoretical and observational astrophysics with an active interest in instrumentation. The observations are carried out using ground-based facilities as well as balloon-borne and satellite-borne instruments. This is supplemented by the work done in Radio Astronomy and High Energy Cosmic Rays by other groups in the Institute.

The National Centre for Radio Astrophysics (NCRA) has built and runs, in India, some of the most sensitive radio observatories in the world, such as the Ooty Radio Telescope (ORT, commissioned in 1970 and still functional) and the Giant Metrewave Radio Telescope (GMRT, commissioned in 2001 and recently upgraded in 2019). The scientists at NCRA carry out cutting edge research in a wide range of topics in astrophysics, using both the in-house facilities, as well as other international facilities. The engineering team, that has built the in-house facilities and supports their operations, also carries out technology innovations for future developments. Today, NCRA also leads India's participation in the Square Kilometre Array project – a large, international collaboration to design and build the next generation radio astronomy observatory.

45.2 Keywords

Zero pressure balloon, Aerostat, X-ray astronomy, infrared astronomy, sub mm astronomy, theoretical astrophysics, astronomical instrumentation, radio astronomy, radio telescope, GMRT,ORT, pulsars, radio galaxies, cosmology, the early universe, Milky Way galaxy

45.3 Major Research Domains

- Scientific ballooning: Design and fabrication of zero pressure balloons, tethered balloons (natural shaped and aerostats), special balloons, sounding balloons and launching and operating them from TIFR-BF. X-ray Astronomy: AstroSat satellite has performed many scientific observations of a wide variety of sources, and scientific research papers are being published.
- Infrared Astronomy: Currently, infrared astronomers at TIFR are developing a payload for spectroscopic and imaging survey for a future Indian satellite. The Infrared Spectroscopic Imaging Survey (IRSIS) has been proposed as a payload for the small satellite program of ISRO. It is a two band near infrared spectrometer (1.7 – 3.4 μm and 3.2 – 6.4 μm) having an optic fibre IFU.
- Instrumentation for Radio Astronomy: NCRA develops cutting-edge hardware and software instrumentation to detect and process weak radio signals from celestial sources. These include wideband antenna feed elements, sensitive front-end analog electronics with high dynamic range, new signal transport systems, and back-end receiver systems combining hardware and software technologies. In particular, development of flexible software- and hardware-based back-ends is an area where NCRA has played a pioneering role. New modes include flexible post-processing of voltage signals, mitigation of terrestrial interference, detection of transients, new correlation modes for interferometry etc, which greatly enhance capabilities of the GMRT and the ORT.
- The Sun and heliosphere: Radio waves provide a view of the Sun that is complementary to other wavelengths. Besides using the GMRT, NCRA researchers are involved in mapping the Sun with the Murchison Widefield Array (MWA) radio telescope in Australia for high fidelity imaging over short time intervals and narrow frequency widths. NCRA astronomers also use the ORT facility for probing the Sun's heliosphere via the technique Interplanetary Scintillation (IPS) of distant radio sources. This is used to provide insight into solar activity, including solar bursts, coronal mass ejections, and solar-wind driven magnetic storms that affect the near-Earth environment.
- Studies of the Milky Way galaxy: Besides start, the Milky Way galaxy consists of various gas phases, including neutral atomic, ionized, and molecular gas, at different temperatures, pressures, and densities. NCRA astronomers use the hyperfine spectral line of neutral atomic hydrogen (HI) at a rest frequency of 1420.40575 MHz (21cm) to study physical conditions in the neutral gas in the Milky Way. They also use deep radio

continuum imaging studies to trace ionized gas structures arising from supernova remnants and ionized hydrogen regions in the Milky Way, and to derive densities, temperatures, and energetics therein.

- Magnetic stars, neutron stars, and transients: Neutron stars or pulsars are an active area of research, ranging from searches for new and interesting pulsars to studies aimed at understanding the origin of pulsar radio emission, its interaction with the interstellar medium, as well as precision pulsar timing studies aimed at detection of gravitational waves. Magnetic stars are highly magnetised main sequence stars which exhibit recently discovered interesting phenomena in the radio window. Detailed studies of transient sources which suddenly appear and last for short periods from seconds to few days are also an active area of work, with particular focus on Fast Radio Bursts.
- Studies of the radio galaxies and distant galaxies: NCRA astronomers focus on the detailed studies of the properties of radio galaxies, or galaxies with active galactic nuclei, using sensitive radio imaging techniques. Research is also carried out on studies of giant radio sources, recurrent activity in radio galaxies, the interaction between radio plasma and the inter-cluster and intra-group media, radio halos and relics. Clusters of galaxies, which are gravitationally bound collections of hundreds to thousands of galaxies, are also an active area of research. Understanding the nature of high-redshift galaxies, as well as galaxy evolution, is also an important area of work.
- Cosmology and the early Universe: The Epoch of Reionization (EoR) when the early Universe transitioned from neutral to ionised and the first stars and galaxies formed, provides an outstanding probe of cosmology. Detecting redshifted HI 21cm emission from neutral hydrogen in the EoR is an area of research at NCRA. Work is also being done on theoretical modeling of the EoR, to understand the formation of the first stars in the early Universe. Simulations of the HI 21cm emission signal from neutral hydrogen at different cosmic times are also being carried out.

45.4 Major Scientific Applications / Results

- A zero pressure balloon was designed and fabricated with a volume of 5885 cubic meters for carrying a payload of 240 kg which is able to reach an altitude of 21.5 km. The balloon has a provision to fix an apex valve at the top portion to release the gas from the balloon for controlling the altitude. Two such balloons were fabricated with linear low-density polyethylene (LLDPE) as an envelope material with a film thickness of 20 μm for space research.
- A zero pressure balloon was designed fabricated with a volume of 5647 cubic meters for carrying a payload of 160 kg which is able to reach an altitude of 24.8 km. The balloon has a provision to fix an apex valve at the top portion to release the gas from the balloon for controlling the altitude. One balloon was fabricated with linear

low-density polyethylene as an envelope material with a film thickness of 20 μm for collecting carbon particles from atmosphere.

- Tethered Balloon Design and Fabrication: A natural shaped tethered balloon with a volume of 34.1 cubic meters was designed and fabricated with linear low density polyethylene film with 38 μm film thickness. The balloon can be tethered up to 150 m by carrying 10 kg science payload for measuring various atmospheric parameters.
- Aerostat Design and Fabrication: A 103 cubic meters aerostat was designed to carry a payload of 35 kg and can be tethered up to 300 m altitude. This aerostat can be used for providing mobile communication and internet facility over the rural areas.
- Mukerjee et al., AstroSat Observations of GRO J2058+42 during the 2019 Outburst, ApJ, 897, 73, 2020. The X-ray pulsar in a Be-binary system GRO J2058+42 was observed by AstroSat during a rare giant outburst in April 2019. The data from both SXT and LAXPC instruments were used for the study. The pulsation period of 194.2201\ pm 0.0016 s and a spin-up rate of (1.65±0.06) x 10-11 Hz/s were obtained from the light curve. The pulse profile showed strong dependence on energy. A QPO with a frequency of 0.09 Hz along with the first harmonic was observed for the first time in this source. The spectral study also revealed the presence of cyclotron lines around energies of 10 keV, 20 keV and 38 keV. A magnetic field of about 1.4 x 1012 G was inferred from the cyclotron line.
- Baby et al., AstroSat and MAXI view of the Black Hole Binary 4U 1630-472 during 2016 and 2018 Outbursts, MNRAS, 497, 1197, 2020. A spectral and timing analysis of the black hole binary 4U 1630-472 during 2016 and 2018 outbursts was performed. No Keplerian disc signature was observed at the beginning of the 2016 outburst, but a few hours later the disc appeared and remained prominent with temperature of 1.3 keV and the photon index increased from 1.8 to 2.0. While the source was in a disc dominant state throughout the AstroSat observation during 2018 outburst. Mass of the black hole was estimated to be 3--9 solar mass, using inner disc radius, bolometric luminosity and two component flow model.
- Katoch et al., AstroSat view of IGR J17091-3624 and GRS 1915+105: Decoding the ‘Pulse’ in the ‘Heartbeat State’, MNRAS, 501, 6123, 2021. IGR J17091-3624 is a transient black hole source which shows a characteristic quasi-periodic variability known as ‘heartbeat’ state, similar to that observed in the well-studied source GRS 1915+105. The properties of the two sources during the heartbeat state were compared. During the 2016 outburst, IGR J17091-3624 showed a double peaked QPO in some time segments. Using dynamic power spectrum, it was demonstrated that the double peak is due to change in frequency of QPO during the observation.
- Banerjee et al., Accretion Flow Properties of GRS 1915+105 During its theta-Class using AstroSat Data, ApJ, 916, 68, 2021. The galactic microquasar GRS 1915+105

shows rich variability that is categorised into different classes. Spectral and timing analysis of the source in theta-class was performed using LAXPC data obtained during March 2016. The theta-class is marked by the recurrent appearance of U-shaped segments in the light curve. A QPO with a frequency of 4-5 Hz was found, with its frequency increasing with time. Spectral study was used to study the evolution of the accretion flow during the observation. A gradual increase in the power-law photon index with intensity was observed, suggesting the progressive softening of the source.

- Mukerjee et al., Studies of Cepheus X-4 during the 2018 Outburst with AstroSat, ApJ, 920, 139, 2021. The X-ray pulsar in a Be-binary system, CepX-4 was observed by AstroSat in July 2018 during an outburst. The timing analysis was used to determine the pulsation frequency and its spin-down rate during the two observations by AstroSat. Apart from the variations during outbursts the pulsar shows a long-term spin down rate which was attributed to the propeller effect in a subsonic phase. The spectrum between 0.7 keV and 55 keV was studied using the SXT and LAXPC instruments. A prominent cyclotron line around energy of 30.5 keV was detected, which is consistent with other observations of the source.

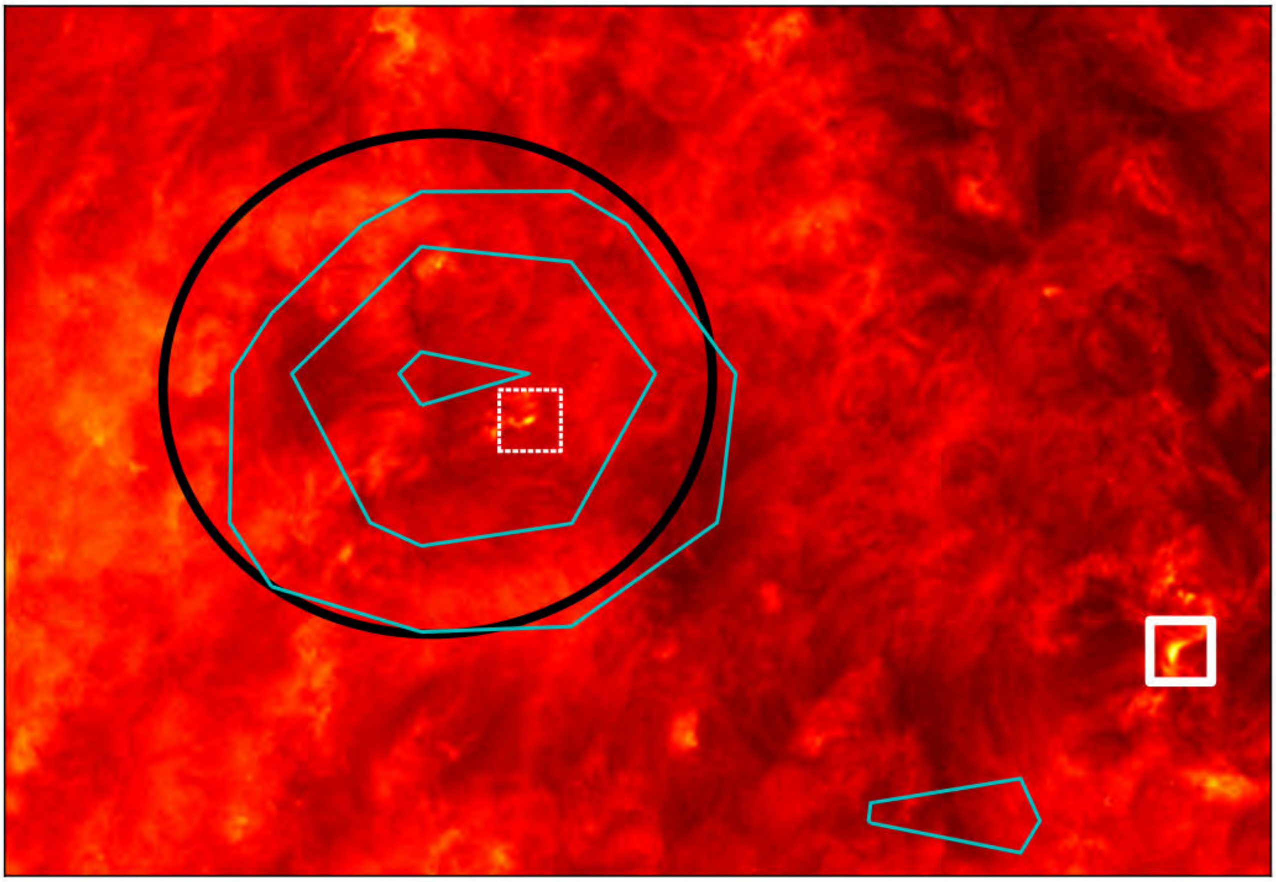
- Antia et al., Large Area X-ray Proportional Counter (LAXPC) in orbit performance: Calibration, background, analysis software, JoAA, 42, 32, 2021. The performance of LAXPC detectors during the five years after launch was analysed. Currently, only one detector, LAXPC20 is working nominally. The temporal variation in detector gain, resolution and background was studied. A prominent quasi-diurnal variation in the background was found apart from a long-term increase in the detector background by about 10%. The capabilities and limitations of the instrument were pointed out.

- Suzuki et al., [C II] emission properties of the massive star-forming region RCW 36 in a filamentary molecular cloud, A&A, 651, A30, 2021. The properties of [C II] 158 **μm** emission of RCW 36 in a dense filamentary cloud were investigated. [C II] observations of RCW 36, covering an area of ~30’ × 30’, were carried out with a Fabry-Pérot spectrometer on board a TIFR 100-cm balloon-borne far-infrared telescope with an angular resolution of 90 arcsec. It was found that RCW 36 is formed in a filamentary molecular cloud and is then dominated by far-UV illuminated cloud surfaces. The difference in large-scale gas structures is shown to be the cause of the enhanced brightness ratio of [C II]/160 **μm**.

- Kumar et al., Ultraviolet Imaging Telescope (UVIT) observation of the Galactic globular cluster NGC 7492, MNRAS, 502, 313, 2021. Detailed photometric observations of the Galactic globular cluster NGC 7492 using the data obtained with two far-ultraviolet (FUV; 1300-1800 Å) and three near-ultraviolet (NUV; 2000-3000 Å) filters of Ultraviolet Imaging Telescope (UVIT) onboard the AstroSat satellite were carried out. 176 sources in NUV and 41 sources in FUV were found as cluster members and classified as extremely blue horizontal branch stars (EHBs), blue horizontal branch stars (BHBs), red giant branch stars (RGBs), variable stars, and blue straggler stars (BSs) based upon their positions in UV- optical and optical color-magnitude diagrams (CMDs). A new EHB star at the core of the cluster was identified using UV and UV-optical CMDs.

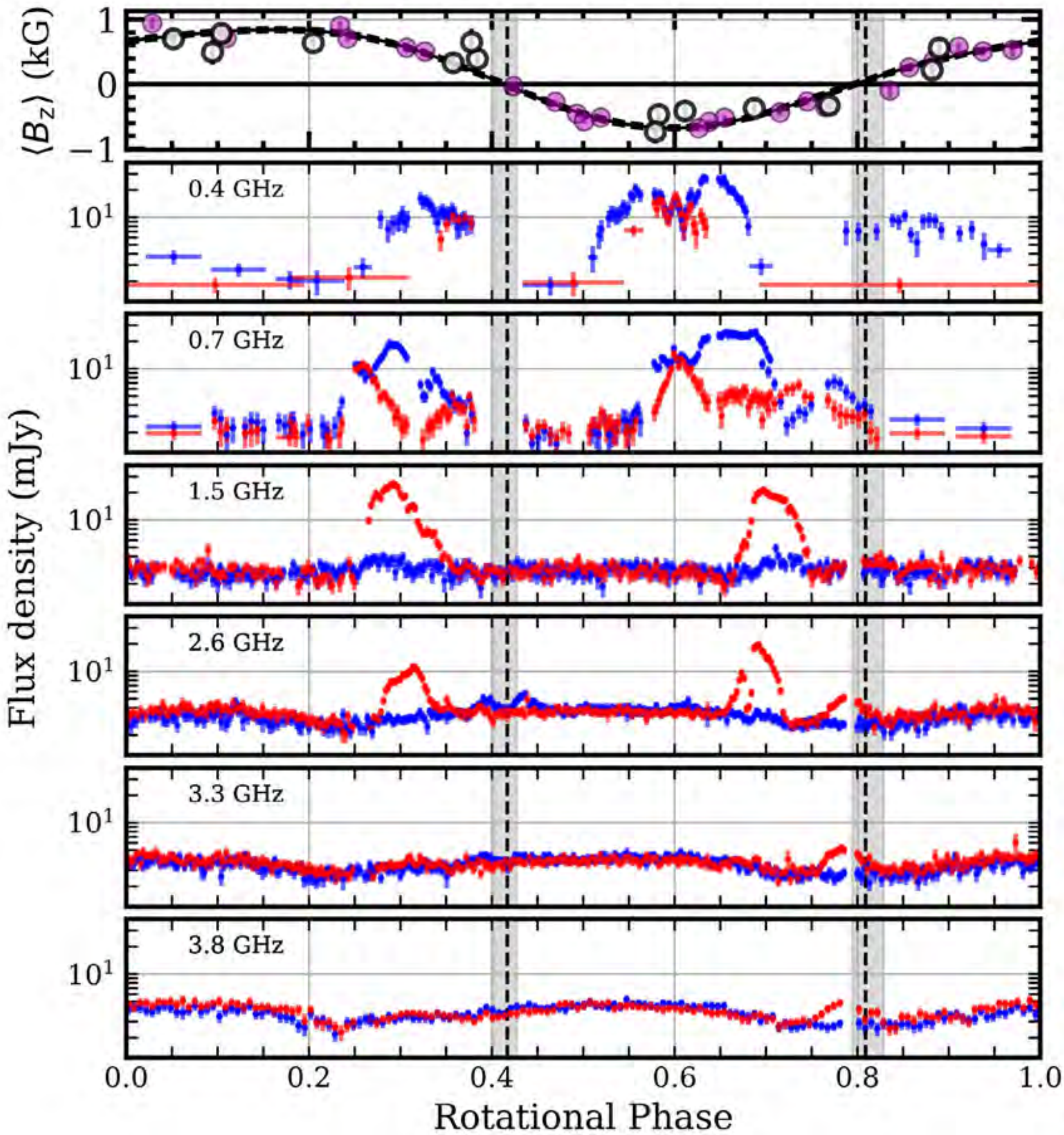
- Kumar et al., Study of Galactic structure using UVIT/AstroSat star counts, JoAA, 42, 42, 2021. The structure of our Galaxy has been studied from ultraviolet (UV) star counts obtained with the Ultra-Violet Imaging Telescope (UVIT) on board the AstroSat satellite. The scale length and scale height of the thick disc and the scale height of the thin disc using the space density function and the exponential density law for the stars of intermediate galactic latitudes have been estimated using UV star counts. The scale length of the thick disc ranges from 3.11 to 5.40 kpc whereas the scale height ranges from 530±32 pc to 630±29 pc. The scale height of the thin disc comes out to be in the range of 230±20 pc to 330±11 pc.
- Kumar et al., UVIT study of UV bright stars in the globular cluster NGC 4147, JoAA, 42, 36, 2021. Far-UV observations of globular cluster NGC 4147 were carried out using Ultra-Violet Imaging Telescope (UVIT) on-board the AstroSat satellite. 37 blue horizontal branch stars (BHBs), one blue straggler star (BSS) and 15 variable stars using UV-optical color-magnitude diagrams (CMDs) were identified. It was found that all the FUV bright BHBs are second generation population stars. Using UV-optical CMDs, two sub-populations, BHB1 and BHB2, among the UV-bright BHBs in the cluster were identified with stars count ratio of 24:13 for BHB1 and BHB2.
- **Understanding the solar corona:** NCRA solar physics group has presented the first firm observational evidence for the presence of ubiquitous impulsive nonthermal radio emissions from the quiet solar corona (Mondal et al., 2020). These have since been christened WINQSEs – Weak Impulsive Narrow-band Quiet Sun Emissions - and are the smoking guns for the weak underlying magnetic reconnection processes or `nanoflares' which were hypothesised to explain the many decades-old coronal heating problem. They have estimated the energy that must be dumped in the corona to generate these impulsive emissions and find it to be consistent with the coronal heating requirements. The figure shows the radio contours at 132 MHz overlaid on an AIA 171 A map in Extreme UltraViolet (EUV). The two possible EUV brightening candidates are shown in white boxes, with the likely one shown in the solid white box. This is the weakest EUV transient event for which a radio counterpart has been identified.

  Reference: Surajit Mondal, 2021, Solar Physics, 296, 8



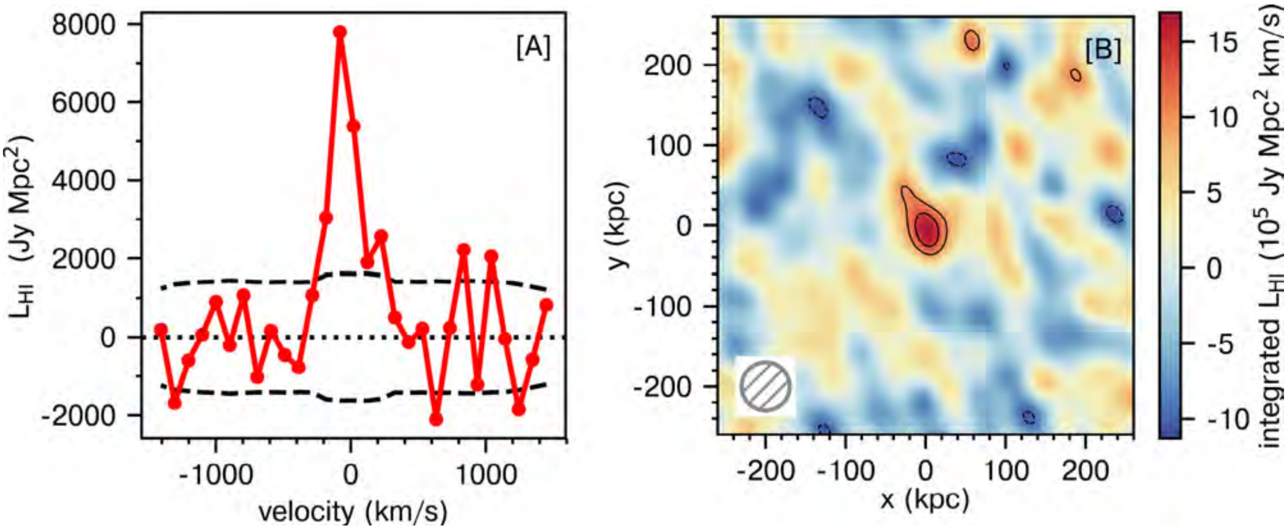
- **Decoding the exotic Main-sequence Radio Pulse emitter stars :** These are main-sequence stars that emit coherent radio pulses periodically by the process of electron cyclotron maser emission (ECME). NCRA scientists and collaborators, using the powerful capabilities of the GMRT and other facilities, have made landmark progress in finding more of these objects and decoding their properties. In particular, Das and Chandra (2021), for the first time, have carried out extensive observation of the star CU Virginies for one full rotation cycle, over the frequency range 400 MHz to 4.0 GHz, using the upgraded GMRT (uGMRT) and the Karl G. Jansky Very Large Array (VLA). They have reported very interesting results of the polarised radiation which gives information about the magnetospheric properties of such stars. The figure shows the light curves of the star at different frequencies (red and blue represent RCP and LCP, respectively) along with the stellar longitudinal magnetic field (top panel).

  Reference: B. Das and P. Chandra 2021, ApJ, 921, 9



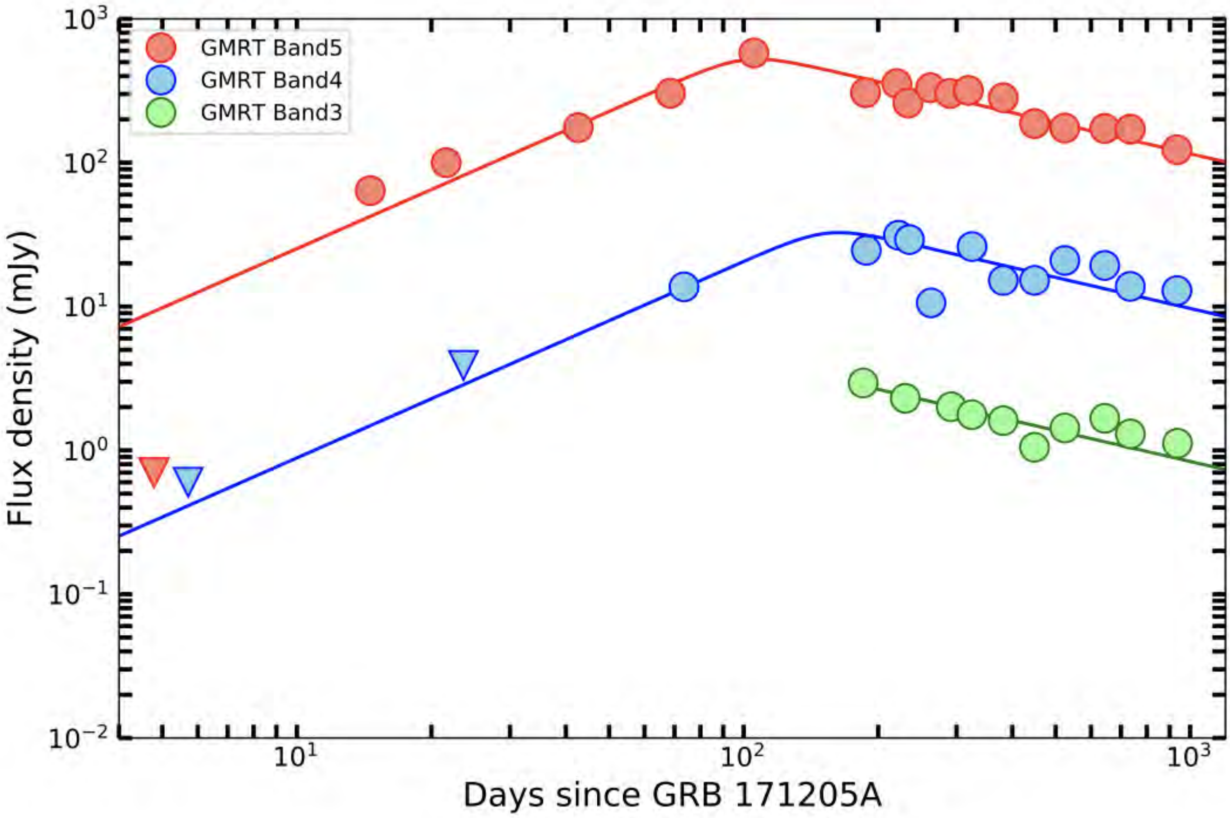
- **GMRT Detection of HI 21 cm emission from star-forming galaxies at z ~ 1.3 :** NCRA astronomers (Chowdhury et al, 2021) have used approximately 400 hrs of GMRT observations to obtain a detection of the average HI 21cm emission signal from ~2800 star-forming galaxies at z~1.3. Panels [A] and [B] of the figure show the average HI 21cm emission spectrum and the average HI 21cm image, respectively; a detection can be clearly seen in both panels. This is the highest redshift at which the HI 21cm signal has so far been detected, coming from galaxies 9 billion years ago. The authors used the detection of the average HI 21cm emission to estimate the average HI mass of star-forming galaxies at z~1.3: they find that the average HI mass of galaxies at this epoch is roughly 2.5 times higher than the average mass in stars. The new results extend to higher redshifts the group's earlier detection of the average HI 21cm signal, from galaxies at z~1.0. This result has important implications for understanding the evolution of galaxies during this stage of the evolution of the Universe.

  Reference: A. Chowdhury, N. Kanekar, B. Das et al. 2021, ApJL, 913, L24



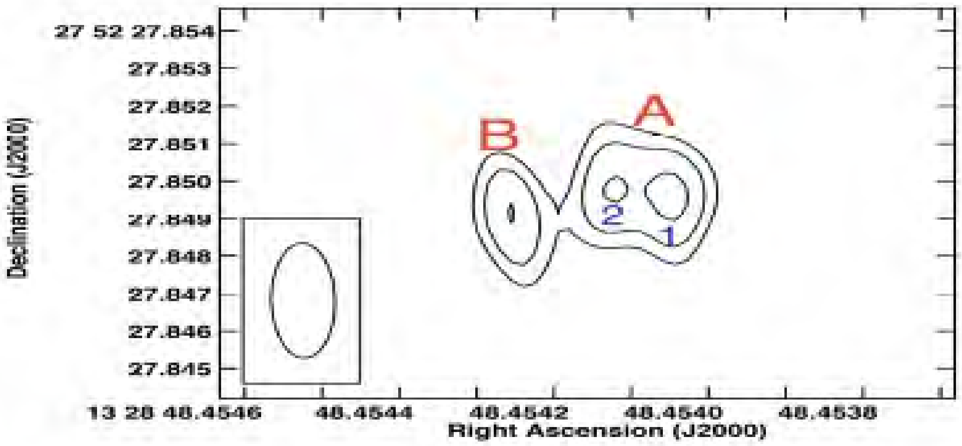
- **Three years of observations of low luminosity GRB 171205A :** NCRA astronomers (Maity & Chandra, 2001) have carried out the lowest-frequency measurements of gamma-ray burst (GRB) 171205A with the upgraded GMRT, covering a frequency range of 250-1450 MHz and a period of upto 1000 days. This is the first GRB afterglow detected in the 250-500 MHz frequency range and the second brightest GRB detected with the uGMRT. Even though the GRB was observed for nearly 1000 days, there is no evidence of a transition to the non-relativistic regime. The data are fit with a synchrotron afterglow emission arising from a relativistic, isotropic, self-similar deceleration as well as from a shock breakout of a wide-angle cocoon. The figure shows the uGMRT Band-5, Band-4 and Band-3 radio light curves, with the Band-4 and Band-5 values scaled by factors of 10 and 100, respectively. The data are best fit with pre- and post peak spectral indices of 1.37 +/- 0.20 and -0.72 +/- 0.06.

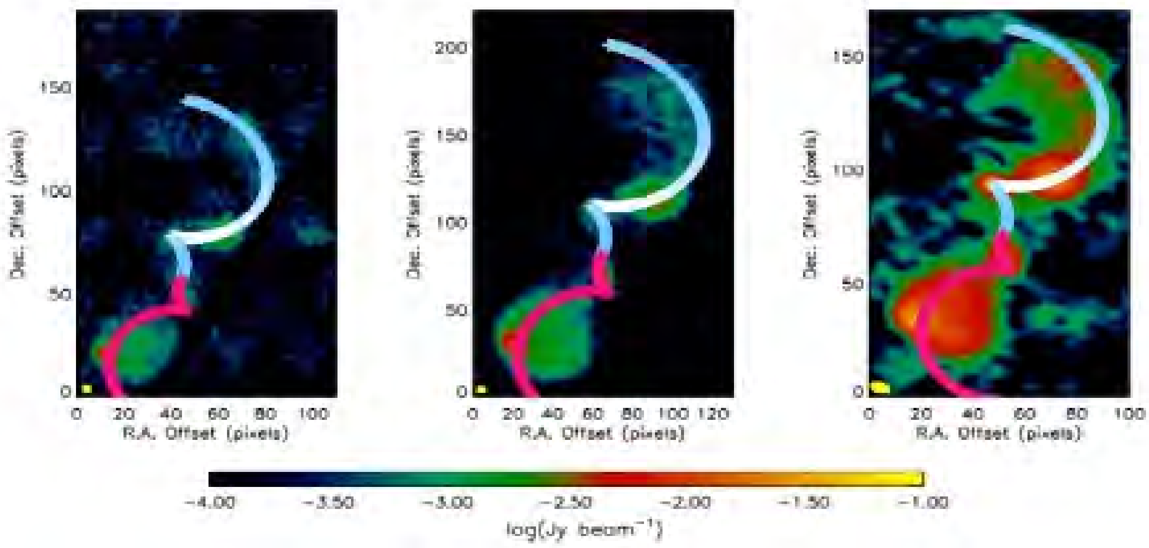
  Reference: B. Maity & P. Chandra 2021, ApJ, 907, 60



- **Double-peaked Lines, Dual VLBI Components & Precessing Jets in J1328+2752 :** NCRA astronomers and collaborators (Nandi et al. 2021) have used observations with the GMRT and Very Large Array Faint Images of the Radio Sky at Twenty centimeters (FIRST) images for a detailed study of the radio galaxy, J1328+2752, with symmetric helical jets that was known to have double peaked line profiles for the central component. The authors carried out very long baseline interferometry (VLBI) 5 GHz imaging and kinematic precession modeling of this radio galaxy. The VLBI image reveals a core-jet structure (component A with sub-components 1 and 2 in the upper panel of the figure) and another single component (B) separated in projection by ~ 6 parsec. The estimated binary separation obtained from the double-peaked lines matched exactly with the VLBI data. The precession helices generated by the kinematic model match well with the GMRT and FIRST images at 325, 610 and 1400 M Hz (lower panel of the figure). The model indicates that either the jet precession is induced by torques in the primary accretion disc due to the secondary black hole in a non-coplanar orbit around the primary, or the jet may forced to precess under the Bardeen-Petterson effect.

S. Nandi, A. Caproni, P. Kharb, et al. 2021, ApJ, 908, 178





Publications:

Anand et al., TIFR zero-pressure balloon programme crosses a milestone, *Current Science*, **120**, 1672, 2021.

45.5 Instruments / Payloads / Products Developed / Sensors / Detectors

- Developed a 6 stage Quartz Crystal Microbalances (QCM) balloon-borne impactor for measuring the mass concentration of composite aerosol in the size ranges between 0.15 µm and 5 µm in free troposphere. As a part of NARL-ISRO and TIFR-BF collaboration, TIFR-BF conducted balloon experiments using 6 stages QCM along with the NARL payloads to study the vertical profile of aerosol mass concentration and also to find out the different chemical species of aerosols.

6-stage Quartz crystal microbalances

- Developed a field programmable gate array (FPGA) board to include most of the balloon flight control on board digital electronics.
- Developed Spartan-6 FPGA board for telemetry encoder with programmable bit rates of 25 kbps, 50 kbps and 250 kbps.
- Materials and vendors for micro-lenses and fibres for the longer wavelength channel of IRSIS payload have been identified and efforts are on to check out the performance.
- In-house IRSIS detector control and readout electronics being designed. Basic prototype has been tested.
- Passive cooling systems are under study for designing appropriate passive cooling for IRSIS optics.
- **Upgrade of the Ooty Radio Telescope :** In collaboration with the Raman Research Institute, the ORT's analog and digital electronics are being upgraded, to provide a wide field of view and improved sensitivity. In addition, a new pulsar backend has been installed. The versatile upgraded ORT will allow a number of studies requiring high sensitivity, such as accurate pulsar observations, searches for neutral hydrogen at high redshifts, searches for transients, solar and space weather studies, etc.
- **Upgrade of the GMRT:** A major upgrade of the GMRT has recently been completed and the upgraded GMRT has been made available to the global user community, roughly coinciding with 20 years of operations of the original GMRT systems. This upgrade provides almost seamless frequency coverage from 110 to 1460 MHz with increased sensitivity and upto 400 MHz of instantaneous bandwidth with many other improvements. Further refinements to the upgraded GMRT are also being carried out, including new observing modes such as Very Long Baseline Interferometry (VLBI), even as a wave of exciting new science results have been triggered by the upgrade. Recently, in 2021, the GMRT was awarded a special international recognition: the IEEE Milestone status.

- **Participation in the SKA:** The SKA (Square Kilometre Array) observatory is an international project to design and build the next generation radio astronomy facility. India, via the leadership of NCRA, is a participant in this project. Significant contributions have been made to the development and early prototyping of a next generation telescope monitor and control software system for the SKA observatory, with India playing the lead role.

45.6 Capacity Building in Space Science Research

- For familiarizing about scientific ballooning activities amongst the youngsters, TIFR-BF invites enthusiastic students from local schools, colleges and universities for one day outreach program and give lectures and also briefly explains about scientific ballooning activities with flight control instrumentation for ballooning. Laboratory visits, demonstration of aerostat hoisting, etc. along with field experiments where scientific balloons are used are part of this outreach activities.
- TIFR-BF Offers students' projects at the levels of graduate and post graduate.
- The Payload Operation Centre (POC) for two of the payloads for the first Indian astronomy satellite, AstroSat, i.e., the Large Area X-ray Proportional Counter (LAXPC) and the Soft X-ray Telescope (SXT) were established to process and distribute data from these instruments.
- DAA members presented many AstroSat related lectures in India and outside India, and contributed to the organization of several AstroSat-related conferences.
- A number of publications in international refereed journals have shown that LAXPC and SXT data from a variety of cosmic sources (e.g., stars, accreting black holes, neutron stars, white dwarfs) are being used by a wide scientific community (including PhD students and postdocs).
- NCRA is actively involved in the following capacity building activities:
  - (a) in-house research and training program leading to a PhD in astrophysics for selected students: typically, 6-10 students are admitted to this program each year.
  - (b) summer and winter training program in different aspects of radio astronomy for visiting undergraduate and graduate students.
  - (c) guiding of BTech and MTech projects of students from different institutions in topics related to radio astronomy and space science.

45.7 Courses offered on Space Science and Technology:

Details of the graduate school level courses offered at NCRA are as follows:

- **Methods of Mathematical Physics I** *(21 lectures; of 1 hour each)*

  Scope: The emphasis will be on practical aspects of using mathematics to solve problems rather than on formal mathematical proofs. Emphasize on Green functions, and Fourier analysis.

Topics: Sturm-Liouville problem and its connection with special functions - Partial differential equations (inhomogeneous and homogeneous wave equations, diffusion equation, Green functions) - WKB and other approximation methods, series expansions, saddle-point, etc. - Fourier analysis.

- **Introduction to Astronomy and Astrophysics I** *(14 lectures; of 1 hour each)*

  Scope : All these topics will come up for detailed study later; the aim of this course will be to connect physics with astrophysics at an order-of-magnitude level and to introduce conventions and jargons of A & A to a physics student.

  Topics : Earth-solar system - The Sun as a star - Stellar structure and evolution - The HR diagram - Colours, magnitudes, Spectral classification - White dwarfs, neutron stars, black holes - Binaries - ISM - Structure of Milky Way - Stellar population and galactic structure - Cosmology - Brief description of Galaxy morphology and evolution - Active Galaxies - Clusters of Galaxies.

- **Electrodynamics and Radiative Processes I** *(14 lectures; of 1 hour each)*

  Topics : Review of Maxwell's equations, and M.Sc level electrodynamics - Motion of charged particle in E, B fields - Electromagnetic waves - Polarization and geometrical optics - Radiation of electromagnetic waves - Scattering of radiation (Thomson and Compton) - Bremsstrahlung and synchrotron radiation.

- **Quantum and Statistical Mechanics I** *(14 lectures; of 1 hour each)*

  Scope: The Course will emphasize the functionality of QM rather than its mathematical or conceptual structure.

  Topics : Overview of M.Sc. level quantum mechanics - Solution of Schrodinger equation in 1 d and potential motion - Quasi classical case, WKB - Hydrogen atom and the structure of periodic table - Perturbation theory - Fine structure and hyperfine structure (21 cm) - Quantum theory of radiation - Energy levels of atoms, and molecules and selection rules.

- **Methods of Mathematical Physics II** *(14 lectures; of 1 hour each)*

  Topics : Physical basis for GR - Tensor analysis - Geodesics, connection and curvature - Einstein equations - Schwarzschild metric (orbits and classical tests of GR) - Black holes - Gravitational waves - FRW spacetime.

- **Introduction to Astronomy and Astrophysics II** (14 lectures; of 1 hour each)

  Observational data on stars (types of stars, spectral classification, regions of HR diagram) - Basics of nuclear energy generation - Sources of opacity - Steady state stellar models (homologous models and multilayered configurations) - Stellar evolution (simple analytical estimates and summary of numerical results) - Supernova and SNR - End stages of stellar evolution (white dwarfs, neutron stars and black holes) - Pulsars

- Evolution of binary star systems - Star formation (including brown dwarfs) - Star cluster.

- **Electrodynamics and Radiative Processes II** *(14 lectures; of 1 hour each)*

  Topics : Basics of fluid dynamics - Hydrostatic equilibrium, with applications to self gravitating bodies - Instabilities - Accretion and winds - Shocks - Turbulence - Basics of plasma physics - MHD - Dynamos - Radiative processes in astrophysical systems : Bremsstrahlung, synchrotron radiation, Compton and inverse Compton processes - Macroscopic description of radiation field - Moments of radiative transfer equations and simple approximate solutions - Ionisation and recombination processes.

- **Quantum and Statistical Mechanics II** *(14 lectures; of 1 hour each)*

  Topics : Overview of M.Sc.level statistical physics - Basics of statistical mechanics and thermodynamics - Boltzmann, Bose,Fermi distributions - Applications to classical gases,electron degeneracy in white dwarfs - Photons - Bose condensation and superfluidity - Ionisation and pair creation equilibria - Phase transitions - Elementary introduction to stochastic processes.

- **Astronomical Techniques I** *(14 lectures; of 1 hour each)*

  Topics : Time and coordinate measurements - Atmospheric effects (absorption, seeing, ...) - Basics of telescopes - Noise and statistics - Photon detectors - Basics of photometry - Spectroscopy and polarimetry.

- **Galaxies : Structure, Dynamics and Evolution** *(21 lectures; of 1 hour each)*

  Topics: Galaxies as self gravitating objects, virial equilibrium - Estimates of collision times - Collisionless Boltzmann equation and some steady state solutions - Globular clusters - stability - Spiral structure, bars and disc dynamics - Ellipticals - Galaxy morphology - Chemical evolution - Galaxy formation and evolution.

- **Extragalactic Astronomy I** *(21 lectures; of 1 hour each)*

  Topics : Friedmann models (geometrical and physical aspects) - Thermal history of the universe from T = 1 GeV to T = 900 K - Linear growth of perturbations - Anisotropies in CMBR and comparison with observations - Nonlinear evolution of perturbations (Zeldovich approximation, spherical top hat, basic idea of simulation results) - Segregation of baryons and dark matter - Very early universe and inflation - Clusters and superclusters - Overall structure of IGM - Gunn-Peterson effect - Quasar absorption systems - High reshift galaxies.

- **Astronomical Techniques II** *(14 lectures; of 1 hour each)*

  Topics: Partial coherence - Aperture synthesis and image reconstruction - High angular resolution techniques and astrometry - Databases in astronomy.

- **Interstellar Medium** *(14 lectures; of 1 hour each)*

  Topics : Extinction and reddening of star light, dust - 21 cm, galaxy rotation curves, HI distribution - Ionised gas, pulsar DM - HII regions - Cooling and heating - Shocks - Supernovae remnants - Phases of the ISM - Magnetic field and Faraday rotation - Cosmic rays - Molecular clouds and star formation.

- **Extragalactic Astronomy II** *(14 lectures; of 1 hour each)*

  Topics : Phenomenology of AGNs (Seyferts, Quasars, Radio Galaxies, LINERS, BL Lacs) with a survey of continuum, emission and absorption features of spectra - Black hole and accretion disc models for AGNs - Emission line regions (BLR, NLR) - Physics of jets and hot spots.

- **Project Work**

  Scope: This lasts for two months, and the student is expected to submit a report and give a seminar.

- **Topical Course (for earlier batch of students)** *(< 21 lectures; of 1 hour each)*

  Scope: Topical courses will be given by IUCAA/NCRA members and visiting faculty which graduate students can take for credit. Each of the topical courses will credit as half course and will involve a maximum of 12 lectures on a focused topic. Students will be graded pass/fail by the lecturer. Thesis supervisors will ensure that their students pass at least two of these topical courses before they submit the thesis.

45.8 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1	Atmospheric Science - Aerosol Radiative Forcing over India (ARFI)	SPL-VSSC
2	Trace gases Analysis – Atmospheric Trace Gases – Chemistry, Transport and Modelling (ATCTM) - IICT Hyderabad	IICT
3	Balloon Campaign to Study the Asian Tropopause Aerosol Layer (BATAL)	NARL - ISRO
4	Atmospheric Gravity Waves	SPL - VSSC
5	Aerosol studies	Divecha Centre for Climate Change, IIST, Bengaluru
6.	SKA India Consortium for coordinating all SKA related activities in the country (see http://www.ncra.tifr.res.in/ncra/skaindia for more details)	More than 20 institutions in the country covering major astronomy and space science research institutes, IITs, universities and some colleges

45.9 International Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute/agency and country
1	Far-infrared [C II] observations with a 100-cm balloon-borne telescope to study interaction of massive stars with the star-forming environments.	Nagoya University. Japan. ISAS-JAXA, Japan Tokushima University, Japan.
2.	Square Kilometre Array (SKA) observatory (see https://www.skatelescope.org/ for more details)	SKA Organisation and 10 other member countries : Australia, South Africa, UK, Canada, Italy, Portugal, The Netherlands, China, Sweden, Switzerland.

45.10 Laboratories and Facilities Available for Space Instrumentation

1) At TIFR Balloon Facility

- Thermovac Chamber: A thermovac chamber with a size of 1 m dia x 1.5 m length capable of attaining a vacuum level of 3.3 x 10^{-5} hpa and temperature control in the range of -40^{o} C to +80^{o} C.
- Vibration Chamber Facility: A vibration chamber in the frequency range of 5 to 2000 Hz and is capable of producing a force of 35.6 kN sine and random mode of operation and maximum acceleration of 1080 m/s in sine wave and random rms of 735.5 m/s. The diameter of armature is 440 mm and it has an amplifier for air cooling system with 40 kva power generator.
- Clean Room Facility: Class 10,000 clean room facilities are available with a room size of 8.3 m x 5.1 m x 2.6 m (2 rooms). Another class 100 laminar air flow benches are also available (4 nos)

2) AT DAA. Mumbai

- A 1.5 meter thermovac chamber with capacity to test payloads up to 1400 mm (L) x 600 mm (W) x 850 mm (H) and up to 150 kg weight.
- Class 10000 clean room (3 meter x 4 meter) at DAA, TIFR with 3 Laminar Flow benches that provide class 1000 work area of about 1200 mm x 1000 mm.
- Two small 10000 Class cleanrooms (Size approx. 9 feet x 7 feet) with 100 Class laminar flow filters suspended over the optical bench.
- Well equipped department workshop with precision lathe machine. Support from TIFR

Central workshop with well-equipped lathe and CNC milling machines (including 5 axis milling machine).

3) At NCRA

- **RF electronics laboratory:** This laboratory carries out cutting edge work in radio frequency electronics, primarily aimed for the GMRT, but also for other applications in radio astronomy. These include wideband antenna feed elements, sensitive, low-noise front-end analog electronics, high quality filters, techniques for packaging of sensitive electronics for use in outdoor, rugged environments, mitigating the leakage of unwanted radio frequency signals etc. The laboratory is well equipped with the latest radio frequency measurement instruments and software simulation tools.
- **Optical fibre technology laboratory:** This laboratory specialises in the development of novel methods of transmissions of signals over optical fibres, as well as practices for long-term maintenance of the optical fibre network of the GMRT. Strengths include analog transmission schemes, digital transmission schemes, long distance transmission of signals with high fidelity and noise reduction and next-generation practices for quality optical fibre transmission systems. The laboratory is well equipped with the latest optical fibre measurement instruments and diagnostic kits.
- **Digital electronics and signal processing laboratory:** This laboratory specialises in the development of quality high speed digital hardware that is needed for next generation signal processing applications, and other related topics. Strengths include FPGA technologies, CPU and GPU technologies, high speed data and computer networks for real-time applications, hardware as well as software based systems, special signal processing algorithms, and precision time and frequency standards. The laboratory is well equipped with the latest tools and software suites. fibre measurement instruments and diagnostic kits.
- **Monitor and control software development laboratory:** This laboratory focuses on the development of next generation monitor and control systems, both hardware and software. Strengths include microprocessor based as well as CPU based hardware systems, signal transmissions for monitor and control applications etc. The laboratory is well equipped with all the latest software tools needed for this area of work.
- **Servo systems laboratory:** This laboratory specialises in the development of modern servo systems that are essential for the GMRT antennas. Strengths include motor and drive controls, BLDC technology, servo control loops, real-time systems, and microprocessor based systems. The laboratory is well equipped with all the latest equipment and software tools needed for this area of work.

- **Mechanical engineering laboratory and workshop:** This laboratory is concerned with all aspects of mechanical systems and the GMRT, and also runs the central mechanical workshop that caters to all the in-house needs for all the engineering groups and activities at NCRA. Strengths include mechanical design and development, corrosion prevention, surface coating and protection techniques, as well as running diverse tools and jobs in the workshop. The laboratory has a well-equipped central workshop and other hardware and software tools.

CHAPTER-46

TEZPUR UNIVERSITY

Tezpur

46.1 About the University

VISION: To develop human excellence and inculcate leadership through hard work and creativity.

MISSION: To render Tezpur University one of the most preferred destinations of students, faculty and employees.

HERITAGE & LEGACY: Tezpur University came into existence on 21st January 1994 by an Act of Parliament of India, The Tezpur University Act, 1993 (Act No. 45). It is a unitary and residential Central University. The University is located at Napaam, near Tezpur town in Sonitpur District of Assam, India. The University has a campus area of about 262 acres. The academic programmes offered in the University have a distinct focus on Science, Technology, and Humanities and Social Sciences, reflecting the objective of the University. Currently the University is offering Doctor of Philosophy programmes (Ph.D.) in 17 disciplines, Masters programmes in 23 disciplines, Post Graduate Diploma in 3 disciplines and B. Tech. in 6 disciplines besides many other diploma and certificate programmes.

46.2 Keywords

Physics, Astrophysics, Image-processing, Nanoscience, Sensor

46.3 Major Research Domains

- Astrophysics
  - o Observational Astrophysics
  - o Astrophysical Data processing

46.4 Major Scientific Applications / Results

Applications

- o Collaborative work with Inter University Centre for Astronomy and Astrophysics (IUCAA) on observational astrophysics using data analysis tools, ASTROSAT data, solar observation data. Research on X-ray binaries, galaxy morphology, inter-stellar dust are being currently carried out by Tezpur University research scholars Ms.Kabita Deka, Mr. Olag Pratim Bordoloi and Mr. Anshuman Borgohain in collaboration with IUCAA, Pune.

- The Solar Ultraviolet Imaging Telescope (SUIT) onboard Aditya-L1 is intended to image the Sun in the 200-400nm wavelength range from the Lagrange 1 point of the Sun-Earth system. Tezpur University research scholar, Janmejoy Sarkar, is presently working on SUIT in Class 100 Clean Room facility at Space Science Instrumentation Facility (SSIF), ISRO Satellite Integration and Test Establishment (ISITE). Presently, he is involved in optical alignment and testing flight model SUIT payload. Furthermore, he is carrying out the characterization of flight model science filter and assembly of flight model filter wheel. He is working closely with ISRO Space Astronomy Group members in matters pertaining to both science and instrumentation.

46.5 Capacity Building in Space Science Research

The Department of Physics, Tezpur University, regularly holds workshops and conferences on Astrophysical Data Processing, Image Processing and Astrophysics Research in collaboration with IUCAA. Moreover, through an ISRO sponsored scheme which is part of its Space Science Promotion Scheme, Tezpur University has benefited by being able to bring top researchers in the area of Astrophysics and Space Science to the Department for extended durations and deliver talks and lectures.

46.6 Courses offered on Space Science and Technology

- Title of the course offered: Astrophysics
- Standard of the course: This course is for M.Sc (Physics) and Integrated M.Sc (Physics) in their final year as specialization and as PhD course work for PhD students.
- Intake capacity: Out of the total intake capacity in the M.Sc (Physics) / Integrated M.Sc (Physics) course of 60 students per year, 5-10 students per year are selected for Astrophysics specialization.
- The topics covered are: Introductory Astrophysics , Celestial coordinate systems, Observational characteristics, Stellar structure and evolution, Solar System, Exoplanets, Galaxies, Elements of GTR and Cosmology, etc.
- Lecture hours: There are three lectures of one hour each week for two semesters.

46.7 National Collaboration in Space Science and Technology

Sl.No.	Area of Collaboration	Collaborating Institute
1.	Astrophysics Research	IUCAA, Pune, India.
2.	Astrophysics related research and technology	ISRO, Bengaluru, India

46.8 Laboratories and Facilities Available for Space Instruentation

The Department of Physics, Tezpur university has the required high end computing facilities and advanced software for Astrophysical data analysis and research.

Publications

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CHAPTER-47

UNIVERSITY OF AGRICULTURAL SCIENCES

Bengaluru

47.1 About the University

The University of Agricultural Sciences, Bengaluru was established in 1963. To expand Agricultural Education, the UAS, Bengaluru has ensured a broad geographic spread of its teaching, research and extension campuses in different regions covering 10 districts of Karnataka.

Vision: Transforming University of Agricultural Sciences, Bengaluru into world-class Farm University. The University has built a sound knowledge base through its unique programmes in basic, strategic and translational research. This strong foundation of knowledge drives the research programmes of the University to enhance the productivity of agriculture in the State.

Mission: Generating quality human resource in the area of agriculture and allied disciplines, cutting-edge competitive technologies and evolve efficient disseminating mechanism to serve the farming community of the State and the Country. The University of Agricultural Sciences, Bengaluru has grown into an institution of national and international repute. More importantly, it has carried out its mission in agricultural education, research and extension to transform agriculture in the state bringing smiles to farmers.

The University stood at 3rd Place among State Agricultural Universities in the Country and 1st Place in South India, achieved many laurels. The University has contributed for developing quality human resource, developed over 200 varieties / hybrids and 550 crop management technologies besides innovative approach for outreach activities.

47.2 Keywords

Agriculture, UASB

47.3 Major Research Domains

- ❖ Crop improvement: Development of varieties suiting to different agro-ecological situations
- ❖ Crop production: Agronomic approaches for different production systems. AI application in crop management
- ❖ Remote sensing and GIS application: for soil characterization, monitoring crop health and identifying management zones

47.4 Major Scientific Applications / Results

- Crop improvement: Attempts were jointly made with ISRO for evaluating genotypes for cultivation
- Crop production: Remote sensing, AI and IoT based technologies were standardized for crop management under precision farming
- Remote sensing and GIS application: Used for soil characterization.

47.5 National Collaborations in Space Science and Technology

Sl. No.	Area of Collaboration	Collaborating Institute
1	Soil Survey and land use planning	ICAR-NBSS&LUP

47.6 Courses offered on Space Science and Technology

1) Title of the course offered:

   a. SAC 311: Problematic Soils and Their Management , Geoinformatics (1+1)

      1. undergraduate degree programme during 3rd year first semester
      2. Intake of around 340 students.
      3. Topics covered: Definition, concepts, tool and techniques; their use in Precision Agriculture. Crop discrimination and Yield monitoring, soil mapping; fertilizer recommendation using geospatial technologies; Spatial data and their management in GIS; Remote sensing concepts and application in agriculture; Image processing and interpretation; Global positioning system (GPS), components and its functions; Introduction to crop Simulation Models and their uses for optimization of Agricultural Inputs. Remote sensing and GIS in the diagnosis and management of problem soils.
      4. Total number of lectures allotted for the course: 9

2) Title of the course offered:

   b. SAC 603, Remote sensing and GIS techniques for Natural Resource Management (2+1)

      1. Masters and Doctoral degree programme
      2. Intake of around 40-45 students.
      3. Topics covered: Introduction and history of remote sensing. Basic principles of remote sensing, Electromagnetic Spectrum, physics of remote sensing, atmospheric interactions with electromagnetic radiation, Energy interactions with earth's surface materials. Remote sensing platforms and sensors; optical, thermal and microwave. Spectral signatures of earth surface features, spectral

characteristics of vegetation, soil and water. Different types of data products and their characteristic. Satellite data acquisitions, storage and retrieval. Fundamentals of aerial photographs. Advantages and disadvantages of remote sensing, latest trends in remote sensing. Aerial photo and Satellite image processing. Visual and Digital image interpretation. GPS- Introduction, basic principles and its utility. Data base management and Relevance to agricultural research. Geographic information system (GIS) - Introduction, development, basic elements, components and benefits. Raster and vector data analysis. Spatial and non spatial data. Digital Elevation Models. Spatial interpolation techniques. Classical and Geostatistical techniques of evaluation of variability. GIS classification methods – multivariate analysis and classification. Application of remote sensing, GPS and GIS techniques - land use, soil survey, soil moisture studies, crop stress and yield forecasting, prioritization, management and monitoring of watershed, drought and flood assessment and management, wasteland identification and management.

CHAPTER-48

UNIVERSITY OF KERALA

Thiruvananthapuram, Kerala

48.1 About the University

One of the first 16 Universities in India, University of Kerala was founded as Travancore University in 1937 by Maharaja, Sri ChithiraThirunal Balarama Varma. Crafted by a legacy of excellence and nurtured by illustrious line of alumni, University currently stands tall as a Centre of Excellence in Higher Education and Research, with 43 teaching and research departments, School of Distance Education, UGC-HRDC, Publications Division, Lexicon, several Multidisciplinary research centres, replete with state-of-the-art Laboratories, grand Libraries with mammoth digital repertoire, unique Manuscript Library, sophisticated Computer/Instrumentation Centres. The Royal Travancore Observatory, which was founded in 1837, is also augmented with the University (Department of Physics). From the very first day of its inception, the observatory is supporting science popularization programs, observational astronomy and astrophysics research.

48.2 Keywords

Energy conversion and storage, space age materials and technologies, functional materials/ thin films for optical and electronic applications, space physics, meteorites, Remote sensing, weather and climate change, artificial intelligence and robotics, neurobiology, cancer and nanobiology.

48.3 Major Research Domains

(i) Bio regenerative life science support systems: Development of self-sustained zero energy demanding systems for bio-regenerative life support systems in manned space missions are critical.

(ii) Systematic study on the landslides on Martian surface with special emphasis on Valles Marineris using data of varying resolution and scale:

(iii) Meteorite impact craters as hotspots for mineral resources and energy fuels

(iv) Deriving a denudation index for terrestrial meteorite impact craters using drainages as proxies.

(v) Spectral and Chemical Characterization of Copiapite and Rozenite from Padinjarathara in Wayanad, Southern India: Implications for Mars Exploration

(vi) The impact of Sudden Stratospheric Warming episodes in the equatorial and low latitude ionosphere thermosphere system.

(vii) Interaction of Solar wind with planetary environments. Quiet and disturbed time plasma distribution over the terrestrial upper atmosphere

48.4 Major Scientific Applications/Results

(i) Bio regenerative life science support systems: Development of self-sustained zero energy demanding systems for bio-regenerative life support systems in manned space missions are critical. In the work the group reported on the feasibility of using two direct sunlight powered processes sequentially for the recovery of water and nutrients from urine. The work presented experimental evidence on nutrient and water recovery achievable using the proto-type designed and developed in lab. The design and testing of the solar still which would serve on the nutrient recovery front was reported in the manuscript. The cooled condensate from the solar still serves as the feedstock to a solar powered electrolysis unit where nano-structured Indium Sulphide (In_2S_3) thin films coated over fluorine doped Tin Oxide (SnO_2:F) substrate serve as one of the working electrodes. The developed proto-type demonstrates the feasibility of water and nutrient recovery without the use of a membrane which manifests as a technical achievement. The results show that the COD level in the recycled water is very low.

(ii) Spectral and Chemical Characterization of Copiapite and Rozenite from Padinjarathara in Wayanad, Southern India: Implications for Mars Exploration:Copiapite ($Fe^{2+}Fe^{3+}{}_4(SO_4)_6(OH)_2 \cdot 2(H_2O)$) and rozenite ($Fe^{2+}(SO_4) \cdot 4H_2O$) are secondary hydrous sulfate minerals, mostly formed because of oxygenation and weathering events of primary sulfides on Earth. Acidophiles, mainly archaea and bacteria, and specifically anaerobic methanogens (methane-producing microorganisms) have been detected in regions where alteration of primary sulfide phases to secondary sulfates are predominant. These secondary sulfate minerals are significant in defining past geological environments on Earth and other rocky planets such as Mars.

(iii) Deriving a denudation index for terrestrial meteorite impact craters using drainages as proxies: Meteorite impact craters are morphologic features that can develop characteristic radial, centripetal, and concentric drainage patterns. With age, fluvial activity denudes this morphologic feature, thereby erasing the evidence of a prominent geologic event. Apart from morphology and age, the target lithology and climate also influence crater denudation. In this study, an index, called the Denudation Index (DI), which is a measure of rim degradation caused by fluvial activity is derived.

(iv) Meteorite impact craters as hotspots for mineral resources and energy fuels: A global review: The ever-increasing recovery rate of natural resources from terrestrial impact craters over the last few decades across the globe offers new avenues for further exploration of mineral and hydrocarbon resources in such settings. As of today, 60 of the 208 terrestrial craters have been identified to host diverse resources such as hydrocarbons, metals and construction materials. The potential of craters as plausible resource contributors to the energy sector is therefore, worthy of consideration, as 42 (70%) of the 60 craters host energy resources such as oil, gas, coal, uranium, mercury, critical and major minerals as well as hydropower resources.

(v) Martian landslides have been extensively analyzed using the data from different satellites like images from Mars Reconnaissance Orbiter (MRO) Context Camera (CTX), Mars Orbiter Mission (MOM) Mars Colour Camera (MCC), and high-resolution Google Mars. Digital Elevation Model (DEM) from the Mars Express (MEX) High-Resolution Stereo Camera (HRSC), Thermal Inertia (TI) from Thermal Emission Imaging System (THEMIS). Martian landslides were mapped with the aid of and available geological map were used to define 15 critical parameters of the landslide inventory. Different models that provided the best results are used in machine learning algorithms to better understand the actual scenario like, simple logistic, logistic regression, meta-classifier, multi-layer perceptron, and Sequential Minimal Optimization (SMO). Of these, simple logistics has the maximum classification accuracy of 81.09%. The study demonstrates the potential of using machine learning models to classify extra-terrestrial landslides, especially the long-runout landslides that are characteristics of other planets and satellites.

(vi) Traditionally, dam monitoring is performed by a combination of visual surveillance and instrumentation. Monitoring dams is critical for identifying vulnerabilities affecting its performance and managing the risk of failure. This study presents the satellite based interferometric Synthetic Aperture Radar (InSAR) application for monitoring deformations at dam sites to understand its vulnerability. The Sentinel-1 and ENVISAT Advanced Synthetic Aperture Radar (ASAR) images were processed using Persistent Scatterers Interferometry (PSI). Results indicate that, combined with traditional methods, remote sensing using radar offers an opportunity for long-term dam monitoring and the development of a deformation-based early warning system.

48.5 Instruments / Payloads / Products Developed / Sensors / Detectors

University has an Astronomical Observatory in which a 14 inch and 8-inch telescopes are installed. This facility is open to public for sky watching.

Other Major Instruments (Including at the central instrumentation facility at Central Laboratory for Instrumentation and Facilitation (CLIF)

1. X-ray Photoelectron spectrometer (XPS)
2. Nuclear Magnetic Resonance spectrometer (NMR)
3. Raman Microscope (2 Nos)
4. Fourier Transform Infrared Spectrometer (FTIR 3Nos)
5. Sophisticated Photoluminescence Spectrometer (4 Nos)
6. X-Ray Diffractometer (Powder XRD)
7. Inductively Coupled Plasma Mass Spectrometry (ICPMS)

8. Gas Chromatography
9. High-performance Liquid Chromatography
10. Ion chromatography
11. Laser Scanning Spectral Confocal Microscope
12. Scanning Probe Microscopy
13. Field Emission Scanning Electron Microscopy with EDX
14. Atomic Force Microscope
15. X-ray Fluorescence Spectrometer
16. DNA Sequencer
17. Confocal Microscope
18. BET Surface Area Analyser
19. High Performance Computing System
20. Automatic Weather Station (2 Nos)

48.6 Capacity Building in Space Science Research

MSc Physics (with specialization in Space Physics) program started in 2020, 9 students are doing their masters on the topic.

Topics covered:

- Introduction to Physics of the Atmosphere
- Space Physics
- Earth's Upper Atmosphere and Space Weather
- Introduction to Astrophysics
- Lab- Space Physics

Foundations of Astronomy

✓ Course offered to the Postgraduate students of any stream to get a flavour of the astronomy and astrophysics.

✓ Intake capacity of 50 students

Topics covered:

- Specially formulated curriculum for postgraduate course which helps to Identify and arrange different celestial objects by exploring the sky from moon to star clusters, describe the formation and structure of stars, describe the origin of solar system, explain origin of life and possibility of life on other worlds, and basics of Astrophysics.

Science popularization and Star watching programs are being organized regularly at the Observatory.

48.7 Courses offered on Space Science and Technology

1. MSc Physics (specialization in Space Physics) program
2 LMS Course- Space age Materials and Technologies
3 Observational Astronomy, Postgraduate level research is actively perused at the Observatory.
4 Foundations of astronomy course are being offered to the postgraduate students from other departments. 50 students are currently enrolled into the program.

48.8 National Collaborations in Space Science and Technology

Sl No	Area of Collaboration	Collaborating Institute
1.	Space and Atmospheric Sciences	Space Physics Laboratory, VSSC, Thiruvananthapuram
2.	Space Science and Atmospheric Sciences	National Centre for Earth Science Studies, Thiruvananthapuram
3.	Space and Atmospheric Sciences	Indian Institute of Space Science and Technology, Thiruvananthapuram

48.9 Laboratories and Facilities Available for Space Instrumentation

- 14 inch Telescope at Observatory
- Nano materials synthesis and coating facilities.

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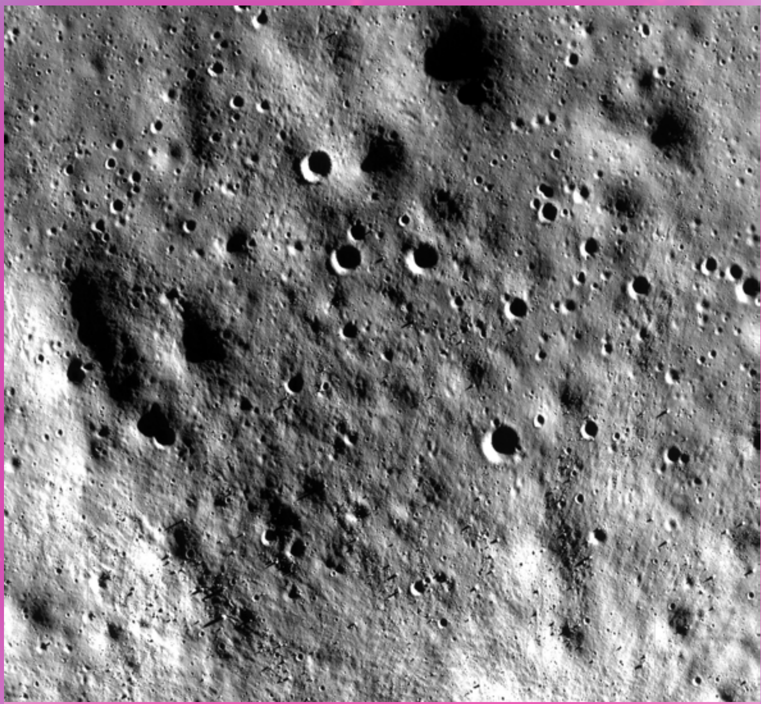
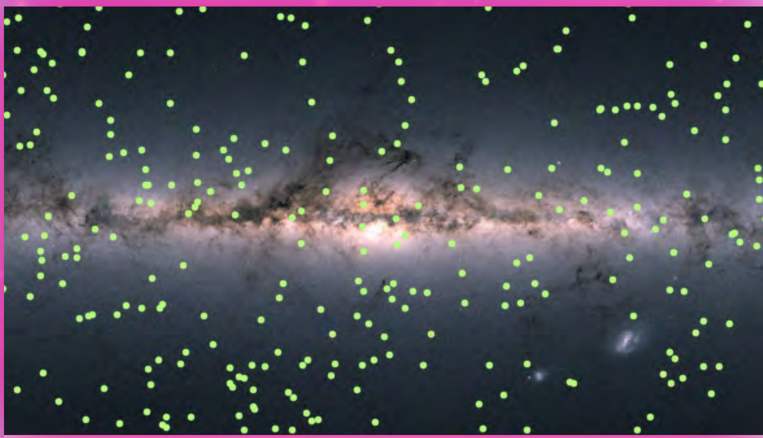


Region near the Boguslawsky E crater on the Moon Surface viewed by OHRC onboard Chandrayaan-2



“The distribution of 500 GRBs seen by AstroSat CZTI”

Indian Space Research Organisation
Bengaluru

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