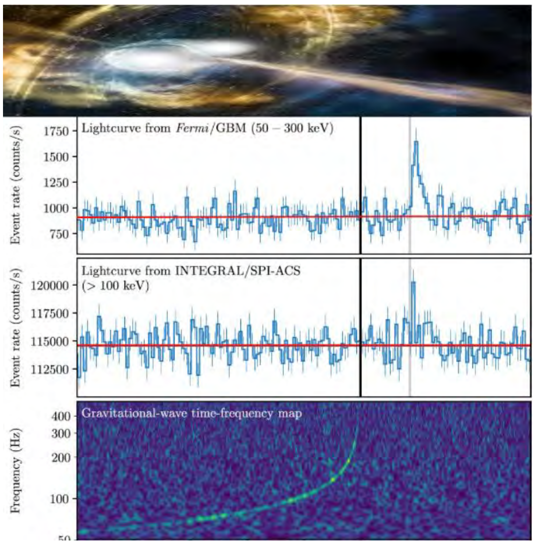
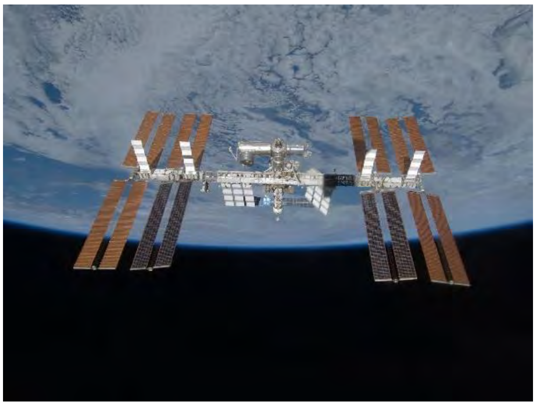
2017 REPORT ON THE STATUS OF INTERNATIONAL COOPERATION IN SPACE RESEARCH

Origins of life

The ExoMars Trace Gas Orbiter and rover



First detection of gamma-rays from the NS-NS merger GW170817



The International Space Station

Edited by Jean-Louis Fellous, COSPAR Executive Director

February 2018

2017 REPORT ON THE STATUS OF INTERNATIONAL COOPERATION IN SPACE RESEARCH

Content

I. Introduction

The primary mission of COSPAR (the Committee on Space Research) is to encourage and facilitate international cooperation in space research. We do so through our various forums – our Assemblies, Symposia, and other sponsored meetings – and through our publications and our roadmaps, all with the intent of connecting the international space research community so that they can imagine, plan, and execute space missions and research programs across all scientific disciplines that explore and use space.

In the past, as part of our efforts to encourage international cooperation in space research, the Scientific Commissions of COSPAR prepared a substantial biennial report for the UN Committee on the Peaceful Use of Outer Space (COPUOS), covering international cooperation in all space research disciplines. With the advent of information now available on the Internet, a report at this level of detail was considered to be of limited value and was discontinued.

However, the underlying purpose of a report on international cooperation in space research remains. It is an opportunity to make the COSPAR community aware of ongoing missions and research programs involving international cooperation, and in particular to be aware of opportunities for future missions and programs that COSPAR could help facilitate. Such a report does not need to be overly detailed, rather more qualitative in content, while still portraying the essential information.

The report that follows is an initial effort to create this new version of the COSPAR Report on the Status of International Cooperation in Space Research. It needs to be considered a work in progress; an effort to achieve the right balance, between completeness and only essential information and guidance, and with uniformity across the Scientific Commissions.

Each Scientific Commission Chair, working with their Vice Chairs, was asked to prepare a chapter in the Report. The Secretariat then requested some editorial changes, and in a few cases some rewrites where there were major discrepancies in the completeness of the discussion of international missions.

It is our intention to do this report biennially, but only if it is found to be useful in fulfilling COSPAR's primary mission of encouraging and facilitating international cooperation. We ask therefore that you let us know whether you find the Report to be of value; whether you consider that your scientific discipline was properly represented; whether the content is too much or too little; or any other guidance that you can offer us that will improve the Report.

Lennard A. Fisk

President of COSPAR

and Richard Bonneville

Chair, COSPAR Scientific Advisory Committee

II. International Cooperation Relating to Earth Science Data and Missions[1]

II.A. Overall assessment of the status of international cooperation in Earth Science

The task of summarizing international cooperation relating to space-based Earth Science observations is a daunting one, as there is a long history, and a vast amount of information, on this topic. Climate does not respect political boundaries, and many countries acquire and share Earth-observation data, as well as spacecraft instrument and mission responsibilities, in the service of advancing the many aspects of Earth System Science. This section attempts to review the scope of international cooperation in these areas, with the understanding that some content might be out-of-date or missing, given the magnitude of the task. Similarly, most of the underlying material is ***referenced to external sources***, where external groups collected, and in some cases assessed, information about missions and data sets. We accept the sources cited at face value, as within the current effort we could not reproduce the considerable work involved in creating these resources.

We define a satellite mission with international partners as a mission ***launched by a country with at least one satellite instrument from another country***. This definition includes all Earth-observing missions of the European Space Agency (ESA) or the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), as these organizations are international partnerships at the ministerial level. The first international partnership mission was LAGEOS-1 in 1976 (Italy and USA). Since then, about 104 missions, representing approximately 12% of the total number of successful Earth-observing spacecraft missions between 1976 and mid-2017, have involved international partners, based on the OSCAR (Observing Systems Capability Analysis and Review) database[2] maintained by the World Meteorological Organization (WMO). A separate accounting of Earth observation missions, instruments, and data sets, organized by missions, instruments, measurements, and agencies, is provided in the Committee on Earth Observation Satellites (CEOS) database[3]. Twenty-four countries and the European Union participate in this CEOS effort, involving 32 agency members and 28 associate members.

Based on these data, the maximum number of international missions launched in a year was six, which occurred in 1999, 2002, 2009, 2013, and 2015; there has been a ***general increase in satellite-mission international partnerships over time***, though the statistics are not large (Appendix 2). Based on this listing, countries involved in more than five international missions up to mid-2017 are (total number given in parentheses): ESA (42); USA (34); EUMETSAT (18); France (15); Russia-Soviet Union (15); UK (12); Canada (11); Japan (11); Ukraine (10); PRC (9); and Brazil (7). As such, the material presented in Appendices 1 and 2 indicate ***considerable cooperation in Earth observation among space-faring nations***, with certain partnerships fielding multi-mission satellite series focused on specific technologies and/or observational objectives. ***Data sharing is of course yet more widespread*** and is increasing, in part because open data policies are much easier to implement than technical collaborations, which entail greater costs, much more interpersonal interaction, as well as some technology exchange and associated risks. What is ***less clear from these statistics is the extent to which good quality, long-term data records have been and are being acquired*** for key variables; this is discussed in subsequent sections.

Overall, international partnerships in Earth-observing satellite missions are: (i) a ***relatively recent*** phenomenon; (ii) a ***small percentage*** of all such missions; and (iii) ***dominated by a few countries***. However, international cooperation has ***helped mitigate gaps*** in the data records of individual countries and offers opportunities for countries capable of building satellite instruments to contribute to global monitoring.

[1] This Report was prepared by Ralph A. Kahn (chair) with contributions by David Halpern, Jerome Benveniste, Andrey Kostianoy, Tong (Tony) Lee, Ernesto Lopez-Baeza, Jiancheng Shi, and Christian von Savigny. Grateful thanks go to the WMO OSCAR and CEOS teams for their substantial contributions to this effort, by providing freely available data summaries characterizing a vast number of satellite missions, the GEO team for offering policy guidelines for open data sharing, and all three groups for their leadership in fostering international collaboration in satellite Earth Observations.

[2] OSCAR; https://www.wmo-sat.info/oscar/satellites. See Appendix 1.

[3] http://database.eohandbook.com

COSPAR, perhaps in association with other relevant organizations, might consider fostering yet greater cooperation in filling current or likely future data gaps, and in sharing the existing and future data.

II.B. Status of Existing Co-operation for on-going Earth Observing missions

The bolded mission names in Appendix 1 indicate international collaborative satellite missions that are operating as of August 2017, based on the WMO OSCAR database. Of 104 international collaborating missions listed, 53 are currently operating, which reflects both the increase in the number of cooperative missions launched since 1999 (Appendix 2), and the great longevity of many satellite missions due to technological advances. The missions cover nearly every aspect of the Earth system, including atmospheric gases, clouds, and aerosols, as well as ocean, land, and cryosphere near-surface physical properties, and biological activity.

Appendix 3 presents a list of 32 planned international collaborative satellite missions with possible launch dates by 2023, based on the WMO OSCAR database. There are of course uncertainties in schedules and funding, but many of these missions represent the continuation of long-standing collaborations within well-established partnerships and having specific observational objectives. For example, the ESA multi-national collaborations on the Metop polar-orbiting and Meteosat geostationary series offer global meteorological observations with a long-term trajectory, complementing national efforts such as the POES and GOES series provided by the USA, and the Himawari series by Japan. The International Space Station (ISS) also serves as an effective platform for international collaboration in Earth observation from space, with eight missions in various stages of planning for near-future deployment.

The Global Earth Observation (GEO) enterprise, founded in 2005 with 61 member countries and 39 participating organizations, takes a leadership role in organizing Earth science data sharing internationally. By 2016, GEO membership had grown to 103 countries and 107 participating organizations, demonstrating the worldwide belief in the value of sharing Earth observations as a benefit for all. GEO requires all members to adopt the GEO Data Sharing Principles[4]. In brief, these state that by default, such data and associated metadata should be shared openly ***without charge or restrictions on reuse*** with ***minimum time delay***, that data sources be ***properly credited***, and that where restrictions or charges are needed, they be minimal.

Leading issues for data sharing include the need for adequate ***data validation and documentation***, which includes ***characterizing the strengths and limitations*** of the data involved. Publishing data product assessments in the ***peer-reviewed literature*** is among the most effective ways of providing assessment, especially with the advent of "***Supplemental Material***" options in published work. However, most effective data applications for advanced research seem to require ***collaboration between the data producers and users***. This is ***facilitated by international meetings***, such as the biennial COSPAR General Assemblies, and is ***sometimes limited by national or institutional policies*** regarding data sharing and/or international collaboration.

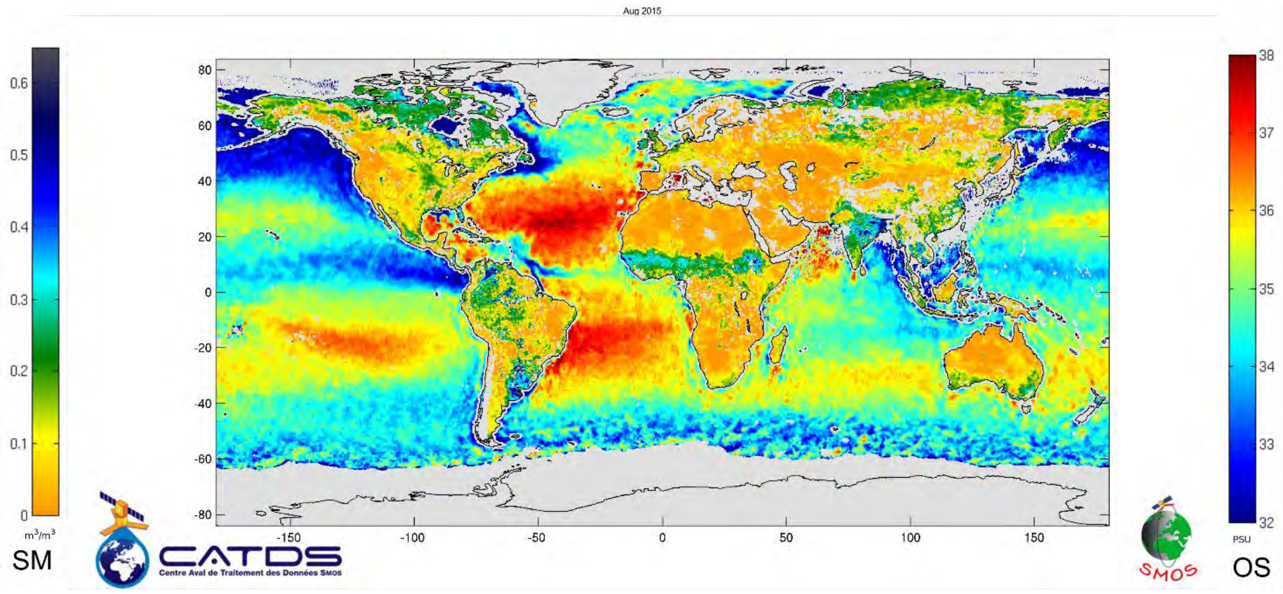
Further, some attention is yet needed to define fair practices for ***data sharing when value-added product***s or services are offered, especially by for-profit entities. Also, issues related to archiving, distributing, and in some cases analyzing ***large-volume datasets*** will have to be addressed if the data are to be used widely. COSPAR capacity building efforts might contribute to this component of data sharing. More specialized aspects of data sharing that would benefit from further consideration include the ***near-real-time requirements*** for applications such as weather and hazard forecasting, emergency response, and wind vectors for ocean circulation forecasting. Most other applications, such as climate study and health impact analysis, have less stringent dissemination, but in some cases, greater accuracy or uncertainty estimate requirements.

Another important component of data sharing concerns ***suborbital data***, which tend to be more numerous, lower volume, and considerably more diverse than satellite data, and are generally less available outside the measurement teams. In many cases, such as trans-boundary river discharge, national data is often not even shared as a matter of policy, despite strong encouragement by the WMO.

[4] GEO Data Sharing Working Group; http://www.earthobservations.org/dswg.php

II.C. Opportunities for co-operation on Future Earth Observing Missions

Clearly, not all critical Earth observations need to be acquired by international collaborative efforts. However, there are areas where observing capability gaps are looming that could benefit from stronger international cooperation. Potential data gaps in key global climate data records include scatterometer observations of ***ocean surface wind vectors*** that dominate ocean-circulation forcing, and are currently provided by the ESA/EUMETSAT Metop and ISRO Oceansat series of satellites, acquiring 6-hour coverage for ~60% of the global ocean, compared to WMO requirements for 90% coverage. The planned CFOSAT series (Appendix 3) could fill this gap, provided there is near-real-time data sharing among all parties. Among other key variables, sea-surface temperature ***(SST) in cloud-covered regions*** by passive microwave, as well as ***sea-surface salinity*** and ***soil moisture*** beyond the currently operating SMOS (Appendix 1) and NASA's SMAP and previous AQUARIUS satellites, is not assured. These variables are essential components of ocean circulation and water cycle studies, respectively. Expanding the ***radio occultation capabilities*** of the Global Navigation Satellite System (GNSS-RO) to other platforms offers many potential scientific benefits for the land, oceanic, atmospheric, and cryospheric disciplines, related to both the vertical structure of atmospheric temperature and humidity, and the precise geo-location of a wide range terrestrial measurements. The future of ***vertically resolved trace-gas and aerosol*** observations is also in question. These include essential climate variables such as GHGs and stratospheric ozone-depleting substances, tropospheric trace gases, as well as tropospheric and stratospheric aerosol amount and type, obtained with high to moderate vertical resolution from a combination of Earth-viewing and limb observations.



Soil Moisture and Ocean Salinity from SMOS, aggregated over the month of August 2015

Generally, obtaining many currently measured quantities with ***greater frequency***, ***greater spatial extent***, ***higher spatial resolution***, and/or ***greater accuracy***, would make it possible to address question that are beyond the scope of current observations. Conversely, where redundant space-based capabilities for key variables are lacking, ***single-point failures*** are possible that would ***compromise critical near-time applications***, or could ***eliminate data-record continuity*** that is required for many types of time-series and trend analysis.

There are also ***gaps in measurement concepts*** and capabilities that international collaboration could help fill. For example, new missions could be defined to obtain Earth observations that better constrain ***aerosol-cloud interactions***, two-dimensional mapping of ***atmospheric constituent vertical distributions***, or ***changes in biodiversity patterns***, atmospheric and surface observations in the ***polar regions***, and ***air-quality related observations over and downwind of urban areas***, where vertically resolved, high-spatial-resolution measurements of trace gases and species-specific aerosols are needed. There is also a strong need to pursue very accurate ***absolute and variable gravity*** measurements, which play a key role in climate, constraining mass transports in sea level budget closure, and water cycle monitoring, including seasonal ice sheet and ground water variations, especially when used along with radar altimetry.

When considering new mission concepts to support space-based Earth observation, international collaboration could also help in obtaining ***suborbital data*** required to ***calibrate*** and ***validate*** the space-based observations, and to acquire ***measurements unobtainable from remote sensing*** alone. The AERONET surface-based sun and sky scanning photometers represent a federated, international collaboration providing aerosol optical depth and some column-effective particle properties at hundreds of globally distributed stations. Similarly, the WMO's Global Atmosphere Watch[5] includes 31 core stations and several hundred affiliates that collect column-effective trace-gas, aerosol, and UV radiation measurements, and the World Radiation Monitoring Center (WRMC) supports the 59 Baseline Surface Radiation Network[6] stations, making high quality short and long-wave radiative flux measurements. The CEOS Working Group on Calibration and Validation[7], the Copernicus marine validation activities[8] address some of these needs on an international basis. For example, the space4environment effort supported under the Copernicus framework[9] is validating the organization's global land cover and land cover change mapping products, and ESA's Climate Change Initiative[10] is evaluating that organization's aerosol products.

However, in other cases, the required *in situ* data are not yet acquired, such as key ***microphysical properties of major aerosol air mass types***, needed for direct climate forcing, indirect effects of aerosol on clouds, and air quality assessment (e.g., particle mass density and hygroscopicity, that are unobtainable from remote-sensing, and spectral light absorption, that can be constrained adequately for climate forcing only from *in situ* measurements). These represent examples of further international-collaboration opportunities in service of COSPAR's global scientific objectives.

Participants and lecturers of the COSPAR-WASCAL Capacity Building Workshop on "Interdisciplinary Remote Sensing, Modeling, and Validation of Environmental Processes", 12-23 June 2017, Kumasi, Ghana

Other opportunities for international collaboration using space-based observations in the future could include ***early warning systems***, e.g., for drought, flooding, severe storms, landslides, avalanches, wildfires, air pollution, earthquakes, pasture, livestock, and other agriculture-related conditions, especially for less developed countries and in mountainous terrain. Elements of each of these exist (e.g., the International Charter on Disasters), but primarily for developed countries, which reflects the likely value of major ***additional capacity building efforts***, such as those spearheaded by COSPAR.

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[5] GAW; https://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html
[6] BSRN; http://bsrn.awi.de
[7] WGCV; http://ceos.org/ourwork/workinggroups/wgcv/
[8] https://ec.europa.eu/jrc/en/science-update/copernicus-marine-validation-activities-jrc
[9] Copernicus is the European Programme for the establishment of a European capacity for Earth Observation. Copernicus encompasses a set of systems which collect data from multiple sources: earth observation satellites and *in situ* sensors such as ground stations, airborne and sea-borne sensors. space4environment is active in one of the six thematic areas of Copernicus – the land domain – supporting applications including urban areas, environmental planning, forestry, climate change, sustainable development and tourism.
[10] CCI; http://www.esa-aerosol-cci.org

Appendix 1. International Satellite and Satellite-Instrument Missions*[11]

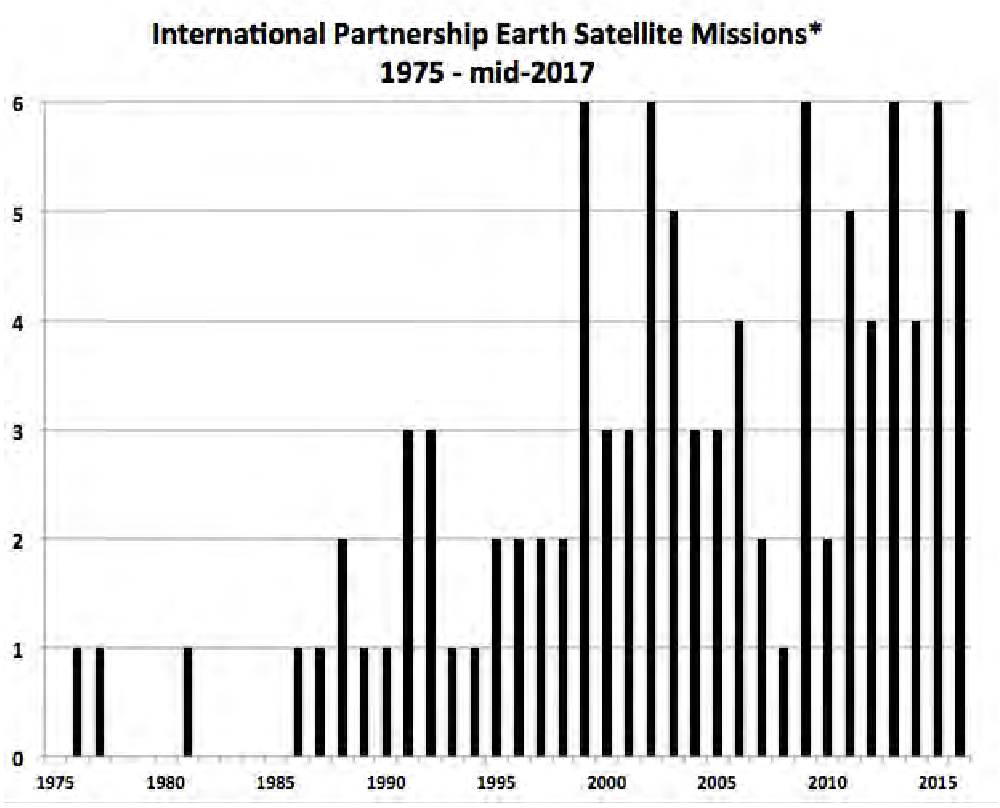
OSCAR ID	Satellite Mission	Launch Date	Countries
2	ADEOS	17 Aug 1996	Japan, USA
3	ADEOS-2	14 Dec 2002	France, Japan, USA
8	AlSAT-1 (DMC)	28 Nov 2002	Algeria UK (DMC Consortium)
708	***AlSat-1B** (DMC)	26 Sep 2016	Algeria UK (DMC Consortium)
9	AlSat-2 (DMC)	12 Jul 2010	Algeria UK (DMC Consortium)
10	***AlSat-2B** (DMC)	26 Sep 2016	Algeria UK (DMC Consortium)
79	***Aqua**	4 May 2002	Brazil Japan USA
80	***Aura**	15 Jul 2004	Finland Netherlands UK USA
18	Beijing-1 (China-DMC+4) (DMC)	27 Oct 2005	China UK (DMC Consortium)
16	BILSAT-1 (DMC)	27 Sep 2003	Turkey UK (DMC Consortium)
19	***CALIPSO**	28 Apr 2006	France USA
25	CBERS-1	14 Oct 1999	Brazil PRC
26	CBERS-2	21 Oct 2003	Brazil PRC
27	CBERS-2B	19 Sep 2007	Brazil PRC
28	CBERS-3	9 Dec 2013	Brazil PRC
29	***CBERS-4**	7 Dec 2014	Brazil PRC
32	**Cloudsat**	28 Apr 2006	USA (part of the A-Train)
37	***COSMIC-1**	14 Apr 2006	Taiwan USA
38	CryoSat-1	8 Oct 2005	ESA
39	***CryoSat-2**	8 Apr 2010	ESA
46	Deimos-1 (DMC)	29 Jul 2009	Spain (DMC Consortium)
668	***DMC-3A**	10 Jul 2015	PRC UK
669	***DMC-3B**	10 Jul 2015	PRC UK
670	***DMC-3C**	10 Jul 2015	PRC UK
78	Envisat	1 Mar 2002	ESA
89	ERS-1	17 Jul 1991	ESA
90	ERS-2	21 Apr 1995	ESA
733	FORMOSAT-1	26 Jan 1999	Taiwan USA
100	FORMOSAT-2	21 May 2004	Taiwan USA
734	FORMOSAT-5	24 Aug 2017	Taiwan USA
711	***Galileo**	21 Oct 2011	EC ESA
475	***GEOTAIL**	2 Jul 1992	Japan USA
136	GOCE	17 Mar 2009	ESA
156	***GPM Core Observatory**	27 Feb 2014	Brazil Japan USA
158	***GRACE**	17 Mar 2002	Germany USA
622	***ISS CATS**	10 Jun 2015	Canada ESA Japan Russia USA
625	ISS HICO	25 Sep 2009	Canada ESA Japan Russia USA
623	***ISS LIS**	19 Feb 2017	Canada ESA Japan Russia USA
621	ISS RapidScat	21 Sep 2014	Canada ESA Japan Russia USA
478	***ISS SAGE-III**	19 Feb 2017	Canada ESA Japan Russia USA
204	JASON-1	7 Dec 2001	France USA

[11] From WMO OSCAR database (extracted 18 July 2017), with additional coauthor contributions. Mission names in bold, with leading asterisks, are operational as of August 2017, based on the OSCAR database.

208	***JASON-2**	20 Jun 2008	EUMETSAT France USA
206	***JASON-3**	17 Jan 2016	EUMETSAT France USA
217	***LAGEOS-1**	4 May 1976	Italy USA
218	***LAGEOS-2**	22 Oct 1992	Italy USA
226	***LARES**	13 Feb 2012	Italy USA
228	***Megha-Tropiques**	12 Oct 2011	France India
295	Meteosat-1	23 Nov 1977	ESA EUMETSAT
296	Meteosat-2	19 Jun 1981	ESA EUMETSAT
297	Meteosat-3	15 Jun 1988	ESA EUMETSAT
532	Meteosat-3 (ADC)	1 Aug 1991	ESA EUMETSAT
533	Meteosat-5 (IODC)	1 Jun 1998	ESA EUMETSAT
300	Meteosat-6	20 Nov 1993	ESA EUMETSAT
534	Meteosat-6 (IODC)	27 Apr 2007	ESA EUMETSAT
535	Meteosat-7	2 Sep 1997	ESA EUMETSAT
301	Meteosat-7 (IODC)	5 Dec 2006	ESA EUMETSAT
302	***Meteosat-8**	28 Aug 2002	ESA EUMETSAT
303	***Meteosat-9**	21 Dec 2005	ESA EUMETSAT
304	***Meteosat-10**	5 Jul 2012	ESA EUMETSAT
305	***Meteosat-11**	15 Jul 2015	ESA EUMETSAT
306	***Metop-A**	19 Oct 2006	ESA EUMETSAT
307	***Metop-B**	17 Sep 2012	ESA EUMETSAT
313	NigeriaSat-1 (DMC)	27 Sep 2003	Nigeria UK (DMC Consortium)
314	***NigeriaSat-2** (DMC)	17 Aug 2011	Nigeria UK (DMC Consortium)
564	***NigeriaSat-X** (DMC)	17 Aug 2011	Nigeria UK (DMC Consortium)
348	***Odin**	20 Feb 2001	Canada Finland France Sweden
349	Okean-O-1	17 Jul 1999	Russia Ukraine
350	Okean-O1-1	29 Jul 1986	Soviet Union Ukraine
351	Okean-O1-2	16 July 1987	Soviet Union Ukraine
352	Okean-O1-3	5 Jul 1988	Soviet Union Ukraine
353	Okean-O1-4	9 Jun 1989	Soviet Union Ukraine
354	Okean-O1-5	28 Feb 1990	Soviet Union Ukraine
355	Okean-O1-6	4 Jun 1991	Soviet Union Ukraine
356	Okean-O1-7	11 Oct 1994	Russia Ukraine
357	Ørsted	23 Feb 1999	Denmark France USA
359	Parasol	18 Dec 2004	France (part of the A-Train)
364	***PROBA-1**	22 Oct 2001	ESA
490	***PROBA-2**	2 Nov 2009	ESA
562	***PROBA-V**	7 May 2013	ESA
382	SAC-A	4 Dec 1998	Argentina USA
383	SAC-B	4 Nov 1996	Argentina USA
384	SAC-C	21 Nov 2000	Argentina USA
385	SAC-D / Aquarius	10 Jun 2011	Argentina USA
390	***SARAL**	25 Feb 2013	France India
393	SCISAT-1	13 Aug 2003	Canada USA
396	***Sentinel-1A**	3 Apr 2014	EC ESA

397	***Sentinel-1B**	25 Apr 2016	EC ESA
398	***Sentinel-2A**	23 Jun 2015	EC ESA
399	***Sentinel-2B**	7 Mar 2017	EC ESA
400	***Sentinel-3A**	16 Feb 2016	EC ESA
402	***Sentinel-5P**	13-Oct 2017	ESA Netherlands
403	SICH-1	31 Aug 1995	Russia Ukraine
404	SICH-1M	24 Dec 2004	Russia Ukraine
408	***SMOS**	2 Nov 2009	ESA France Spain
658	***SWARM-A**	22 Nov 2013	Canada ESA France
422	***SWARM-B**	22 Nov 2013	Canada ESA France
423	***SWARM-C**	22 Nov 2013	Canada ESA France
81	***Terra**	18 Dec 1999	Canada Japan USA
443	TOPEX/Poseidon	10 Aug 1992	France USA
445	TRMM	27 Nov 1997	Japan USA
447	UK-DMC-1 (DMC)	27 Sep 2003	UK (DMC Consortium)
448	***UK-DMC-2** (DMC)	29 Jul 2009	UK (DMC Consortium)
449	***VENμS**	1 Aug 2017	France Israel
540	***VRSS-1**	29 Sep 2012	PRC Venezuela

Appendix 2. Approximate annual number of Earth satellite missions with international partnerships



*Derived from the WMO *OSCAR* database with coauthor additions. Mission names are given in Appendix 1.

Appendix 3. ***Planned*** International Satellite and Satellite-Instrument Missions with possible launch before 2023[12]

OSCAR ID	Satellite Mission	Planned Launch	Countries
004	ADM-Aeolus (global wind)	2018	ESA
508	BIOMASS (forest biomass)	2022	ESA
545	CFOSAT Oceanography	2018	PRC France
688	CFOSAT follow-on	2022+	PRC France
450	COSMIC-2a (T, RH, space weather)	2017	Taiwan USA
451	COSMIC-2b (T, RH)	2020+	Taiwan USA
71	EARTHCARE	2019+	ESA Japan
511	FLEX (vegetation fluorescence)	2022+	ESA
159	GRACE Follow-On	2020	Germany USA
689	ISS-CLARREO (energy balance)	2020+	Canada ESA Japan Russia USA
628	ISS-DESIS (hosted Earth-views)	TBD	Canada ESA Japan Russia USA
634	ISS-ECOSTRESS	2018+	Canada ESA Japan Russia USA
633	ISS-GEDI (3-D forest laser)	2019+	Canada ESA Japan Russia USA
623	ISS-LIS (lightning monitor)	TBD	Canada ESA Japan Russia USA
624	ISS-OCO-3 (CO_2)	TBD	Canada ESA Japan Russia USA
478	ISS-SAGE-III (strat. gas, aerosol)	2022+	Canada ESA Japan Russia USA
478	ISS-TSIS (solar irradiance)	2018+	Canada ESA Japan Russia USA
479	JASON-CS/Sentinel-6	2020	ESA EUMETSAT USA
592	MERLIN (CH_4)	2021+	France Germany
308	Metop-C (polar orbit met.)	2018+	ESA EUMETSAT
082	Metop-SG-A1 (polar orbit met.)	2021+	ESA EUMETSAT
085	Metop-SG-B1 (polar orbit met.)	2022+	ESA EUMETSAT
-	Microcarb (CO_2)	2020+	France UK
289	MTG-I1 (geostat. imaging met.)	2021+	ESA EC EUMETSAT
293	MTG-S1 (geostat. sounding met.)	2021+	ESA EC EUMETSAT
639	NI-SAR (hydrology-biomass)	2020+	India USA
358	PACE (ocean color/productivity)	2022+	France USA
626	SAC-E/SABIA-MAR A (food, water)	2020+	Argentina Brazil USA
627	SAC-E/SABIA-MAR B (food, water)	2021+	Argentina Brazil USA
396	Sentinel-3B	2018	ESA EC EUMETSAT
402	Sentinel-5P (tr. gas sndng, imgng)	2017	ESA Netherlands
360	SEOSAR/Paz (T, RH sndng. precip)	2017+	ESA Spain
360	SEOSat/Ingenio (high-res imag, UV)	2019+	ESA Spain
424	SWOT (ocean topography)	2021+	France USA

[12] From the WMO OSCAR database (https://www.wmo-sat.info/oscar/satellites) and the EO Portal directory (https://directory.eoportal.org/web/eoportal/satellite-missions), with coauthor additions. 'Plus' signs ("+") represent uncertainties in mission readiness and launch dates, where indicated in the data source.

III. Status of International Cooperation in Space Studies of the Earth-Moon System, Planets, and Small Bodies of the Solar System[13]

III.A. Overall assessment of the status of international cooperation in the field under consideration

In the field of planetary space science and exploration the international cooperation is of particular importance given the technical complexity and cost of the missions, but also the extreme public interest generated by such investigations. Partnerships in the planetary science offer therefore the best grounds for peaceful cooperation in space, being less demanding then human exploration projects. The most notable in the past are a set of coordinated missions by four international parties on the occasion of the 1984 apparition of Comet P-Halley, and a major joint mission by NASA and ESA to study the Saturn system Cassini-Huygens (1997-2017). As of 2016/2017 out of 23 completed, operating, or ready to set off during the period planetary missions 16 are of international character (see appendix 4 below). For five of these missions, the cooperation might be qualified as major: a joint development, mission element provision, or major contribution. Out of these five, two new missions, BepiColombo (ESA-JAXA) and ExoMars (ESA-ROS) are large-scale. Major cooperation missions always have a bi-lateral core; no example of three- or more partnership survived. The remaining eleven missions benefit from cooperation at the level of science experiments. Even if hardware exchange is not the case, most of the present planetary missions include international science cooperation, involving co-investigators and collaborators from different countries.

The major players in planetary exploration are NASA, ESA, JAXA, Roscosmos (ROS) and rapidly accelerating Chinese and Indian agencies. Dedicated groups for Moon and Mars (International Lunar and Mars Exploration Working Groups, ILEWG and IMEWG) aim to facilitate the international cooperation in exploration of these bodies.

NASA has recently brought to completion the major Cassini-Huygens mission, which studied the Saturn system in cooperation with ESA. More recent major cooperative projects, such as the Europa-Jupiter mission (EJSM) with ESA and ROS, or ExoMars with ESA were not as successful. For the Jupiter system, ESA maintained a stand-alone JUICE mission, and ExoMars cooperation was re-established with ROS. Meanwhile, NASA encourages contribution to their smaller-scale projects at the level of science experiments, often allowing such missions to fit under the cost cap. NASA-funded experiments and contributions take part in numerous interplanetary missions. In most cases, NASA also provides ground support (spacecraft tracking, enhanced data downlink, etc.) to the interplanetary missions.

By its nature, ESA is an example of international cooperation between its member-states. At present the major external partners within the planetary program are ROS and JAXA. ESA programs fall into two categories. The ‘mandatory programs’, i.e., those carried out under the Space Science program budget where all member-states participate, are more difficult for external cooperation. ‘Optional programs’, such as ExoMars, funded by some member states only, are more open. This sector bears large potential, in particular for enhancement of the technical capabilities (JAXA), or for multiplied opportunities (China and India). Numerous European instrument-level contributions on planetary missions of NASA and other agencies proved extremely successful. They are mostly decided and funded by ESA member states, agencies, space offices, etc.

JAXA planetary missions, purely national in the past, are progressively becoming more open. Starting from Hayabusa-2, all levels of cooperation are supported.

As of 2016-2017 ROS has been facing some difficulties to handle its overcommitted space science program. International partnerships are therefore the viable means to bring selected missions to the completion, as per the ExoMars cooperation with ESA. ROS has also demonstrated successful instrument-level contributions.

CNSA (China) adopted a weighted approach to cooperation: the first mission of a kind is purely national, and if successful, its duplicate becomes open to cooperation, as it happened with the Chang’e-4 lunar mission.

[13] This report was contributed by Oleg Korablev, Chair of COSPAR Scientific Commission B.

One limiting factor of such approach is a short time allocated for partners to step-in. It would be similarly beneficial to find a way for an earlier-stage international discussion and possibly involvement for the case of Mars. Science benefits would be multiplied.

The first mission of ISRO (India) to the Moon, Chandrayaan-1 brought highly important science results, in large owing to internationally provided instruments. The following Mangalyaan or Mars Orbiter Mission even if declared as technology demonstrator, carries a number of instruments, and operates in orbit of Mars since 2013. Unfortunately, its science return is less important. Chandrayaan-2 ambitious lunar mission is also developed as purely national. A balanced international involvement would be a way to strengthen the science base of the future lunar and planetary ISRO missions.

III.B. Status of existing co-operations on on-going missions

The ESA-JAXA BepiColombo mission will be ready for launch in 2018 or early 2019. It is dedicated to diversified studies of Mercury by means of two satellites. ESA bears responsibility for the launch, transfer vehicle, and one Mercury remote sensing orbiter (MPO) focused on the planet itself. JAXA built a smaller orbiter (MMO) to be put on higher orbit and aimed to study the magnetospheric environment of Mercury. Both satellites include science instruments from both parties, and ROS-contributed instruments.

ExoMars is a major cooperation effort of ESA and ROS. The first part of the mission, ExoMars 2016 TGO science and relay orbiter is in flight. Its final science orbit is to be achieved by aero-braking in April 2018. The main goal of TGO is the sensitive measurements of the Mars atmosphere, in particular to detect minor gases of biogenic or geothermal origin. ESA provided the TGO spacecraft, and the Schiaparelli demonstration lander (failed to land in 2016). ROS provided the launch and 50% of the science payload (two out of four instruments) of TGO. The second part of the mission is in development, targeting the launch in 2020. It consists of a rover (ESA) and a surface platform (ROS-led) to assess the habitability and conditions at the surface of Mars. The Rover is equipped with a 2-m drill to reach for soil unaltered by cosmic radiation, where the signs of possible past life might be preserved. The launch is by ROS, and the cruise spacecraft is by ESA. Within the landing element ESA and ROS are sharing tasks at sub-system level. Science instruments are mostly European on the Rover and mostly Russian on the fixed lander, but there are reciprocal exceptions, and profound science cooperation. The ground segment is shared between ESA and ROS, allowing for enhanced data downlink. NASA provides orbiter-surface radio link, and contributes to the ground segment.

The JAXA Hayabusa-2 mission was launched in 2014 to reach asteroid Ryugu in July 2018, and to return samples to the Earth in 2020. The mission will allow the pristine Solar system material to be thoroughly analyzed in the terrestrial laboratories. The mission includes MASCOT (Mobile Asteroid Surface Scout), a small lander with *in-situ* instruments built by DLR in cooperation with CNES.

The InSight NASA Mars lander is in preparation for launch in 2018. The goal of the mission is to study the internal structure of Mars, by means of a seismometer, and a heat probe. Both science instruments are internationally provided, by CNES and DLR respectively. This cooperation, in particular the very expensive seismometer can be considered as major. It allowed reducing the costs for NASA, and in fact enabled this long-awaited science mission.

Also many on-going missions benefit from cooperation at the level of science experiments, when one or few instruments out of many are contributed. Such projects are Mars Odyssey, NASA satellite operating since 2002 with one ROS instrument, Mars Express, ESA satellite, operating since 2004 with one US and few ROS instruments, LRO, lunar orbiter by NASA since 2009 with one ROS instrument, Opportunity, one of NASA Mars rovers still operating since 2003 with two European instruments, Curiosity NASA rover working at the surface of Mars since 2011 with two European and one ROS contributions, and planned for launch CNSA's Chang'e 4 lunar lander/rover with European contributions.

One important factor limiting the international collaboration is related to sanctions and International Traffic in Arms Regulations (ITAR). Many of the developed scientific instruments include components from the ITAR lists. A re-flight of such instrument on, e.g., a Chinese mission involves serious delays, re-design, or might preclude the collaboration. More relaxed ITAR rules regarding space science projects would favor wider international co-operation.

In planetary exploration there is no particular issue of data sharing. This sector has a long history of rapid dissemination of mission data. All cooperation partners are expected to archive data in public domain after a proprietary period, which is generally shorter than 6 months. The partners share all the data of the mission between them as they arrive. Major data release venues include the ESA Planetary Science Archive[14] and the NASA Planetary Data System[15].

III.C. Opportunities for co-operation on future missions

The ROS Lunar robotic exploration program includes three approved missions, one technology demonstration polar lander (Luna 25), an orbiter (Luna 26), and a larger polar lander (Luna 27). The overarching science goal is to assess the hydration of the lunar surface in particular of its polar areas, as discovered by Chandrayaan-2 and earlier missions. The launch dates are uncertain, owing to budget and technical difficulties, and in present are 2020, 2022, and 2023 respectively. All three missions include European contributions; in particular, significant ESA input is planned for the full-scale science lander (hazard-avoidance landing; drilling device with associated payloads). For the orbiter (Luna-26) on top of ESA-members contributed instruments, one NASA-funded remote instrument is under consideration. This cooperation is expected to enhance technical capabilities, and allows for cost savings.

The CNSA Lunar program, an ambitious initiative to be implemented after Chang'e 5 sample return (2018), includes a number of missions including polar landing, mobility and sample return, supported by orbital relay. Little is known about the program, but some of these missions, as, e.g., the duplicate of Chang'e 5 sample return, would be presumably more open to international cooperation. The main goal of the cooperation is to strengthen the science base of the program. There is also a potential to enhance the technical capabilities of the mission elements. These missions are also expected to be coordinated with the program of human exploration of the Moon, and a circumlunar manned station. A similar approach would be beneficial for the CNSA Mars program, aiming to deliver a lander/rover to the surface of Mars, and to provide the radio relay with a single launch. COSPAR encourages the openness of such program. Even if the involvement of the leading agencies is unlikely, there is a large number of smaller agencies and countries eager to support it, on bi-lateral or multi-lateral basis.

The JAXA MMX mission is dedicated to a sample return from Phobos, the satellite of Mars. The origin of Phobos is uncertain, and a detailed analysis of a sample in terrestrial laboratories would either allow to assess a pristine material of the Solar system (an asteroid capture scenario), or to obtain a sample of early Mars (since Phobos may have formed from debris of Mars after a large impact, like the Moon). To a large extent this project is based on Hayabusa-2 heritage. Another example is Phobos-Grunt by ROS, which failed at launch in 2011. In 2017 the MMX launch has been delayed until 2024. Contributed instruments are expected, funded by CNES and by NASA. Also a contributed mission element (surface mobile platform) is under consideration between JAXA and CNES. The cooperation relies on successful Hayabusa-2 partnership, and JAXA declares willingness to enlarge the international involvement with a general goal to strengthen the science base of the program.

The ROS-NASA Venera-D, a mission to Venus, is essentially a lander similar to those accomplished by the USSR 25-30 years ago, equipped with modern instrumentation. The mission targets precise measurements at the surface and in the lower atmosphere, including noble gases and their isotopes, in order to constrain cosmogony scenarios, which led Venus, otherwise so close to the Earth, to the present catastrophic climatic state. Initially conceived as a ROS mission it did not survive budget cuts and fell out of the ROS program. Since 2015 a Joint science definition team (JSDT) by ROS and NASA is considering the architecture of the mission with considerable NASA contributions on the mission element level (small long-living stations, aerial platform). The proposed core mission consists of the lander (ROS) including small long-living station (NASA), and a relay and science orbiter. NASA might also provide an optional element (e.g., aerial platform). The cooperation would be open for third parties. The Venera-D joint initiative is a notable example of potentially major cooperation in spite of political tensions. It targets to strengthen the science, enhance technical capabilities, and allow for cost savings.

[14] http://www.rssd.int
[15] http://pds.nasa.gov/

The Venera-D Probe (*Credit: Roscosmos*).

The International Mars Sample return (MSR) is a large-scale mission considered as a necessary precursor for a human exploration of Mars. Science benefits of returning Mars samples are manifold. It includes assessing the habitability, in the past and at present, searching signs of extinct or extant life, obtaining a geologic evidence of early epochs, not available on the Earth, assessing hazards for human exploration, etc. Technically MSR would require multiple launches, and significant investments on the ground. It is therefore intended to be a worldwide endeavor. Plans to exercise some MSR technologies were drafted in the early 2000's (Mars Premier CNES-NASA initiative). In 2007, IMEWG chartered the international Mars Architecture for the Return of Samples Working Group (iMARS WG). The iMars WG issued a report in 2008, and reconvened in 2014 for a second phase. The Phase 2 WG issued a final report in June 2016. The preferred mission architecture is made of three flight elements and one ground element (3+1). The elements are 1) Sample cashing rover, 2) Sample return orbiter, 3) Sample retrieval and launch element, and the +1) Sample receiving facility on Earth. Two very important aspects are: it is internationally-tasked and includes an accepted planetary protection protocol having technical and programmatic implications for the mission architecture. The MSR partners should establish an international Science Institute as part of the campaign's governance structure upon approval to return samples from Mars. Two key enabling technologies, the Mars ascent vehicle and the sample containment are identified. The precursor element of the MSR, a rover to collect and cash samples is at present in preparation by NASA. If its launch schedule (2020) is respected, the return of Mars samples to the Earth might be completed by 2031 or 2033. The iMars Phase 2 activities were completed mostly by NASA and ESA, with a limited ROS participation. The initiative is open to the wider international community.

Appendix 4. The list of completed, operating, or ready to set off planetary missions as of 2016-2017.

	Name	Agency	Status	Target	Mission	Cooperation
1	BepiColombo	ESA-JAXA	set off in 2018-2019	Mercury	2 Orbiters	Major; +instruments from ROS
2	Akatsuki	JAXA	Launch 2010 operating since 2015	Venus	Orbiter	No
3	LRO	NASA	operating since 2009	Moon	Orbiter	Instrument level (ROS)
4	Chang'e 3	CNSA	Launch 2013 Lander alive in 2017	Moon	Lander/Rover	No
5	Chang'e 4	CNSA	Set off in 2018	Moon	Lander/Rover	Instrument level (EMS*)
6	Chang'e 5	CNSA	Set off in 2019 pending launcher	Moon	Sample return	No
7	Chandrayaan-2	ISRO	Set off in 2018	Moon	Orbiter/Lander/Rover	No
8	Rosetta	ESA	Launched 2004 landing 2015 EoM 2016	comet Churyumov–Gerasimenko	Orbiter/Lander	Instrument level (NASA)
9	Dawn	NASA	Launch 2007 In orbit	Asteroids Vesta, Ceres	Orbiter	Instrument level (ESM)
10	Hayabusa-2	JAXA	Launch 2014, rendezvous 2018	Asteroid Ryugu	Sample return	Small lander contributed by DLR/CNES
11	OSIRIS/Rex	NASA	Launch 2016, rendezvous 2018	NEO Bennu	Sample return	Instrument level (CSA)
12	Mars Odyssey	NASA	Launch 2001 operational	Mars	Orbiter	Instrument level (ROS)
13	MER*	NASA	Launch 2003, Opportunity alive	Mars	2 Rovers	Instrument level (EMS)
14	Mars Express	ESA	Launch 2003 operational	Mars	Orbiter	Instrument level (ROS, NASA)
15	Mars Reconnaissance Orbiter	NASA	Launch 2003 operational	Mars	Orbiter	Instrument level (ASI)
16	Curiosity	NASA	Launch 2011 operational	Mars	Rover	Instrument level (EMS)
17	MAVEN	NASA	Launch 2013 operational	Mars	Orbiter	No

18	Mangalyaan	ISRO	Launch 2013 operational	Mars	Orbiter	No
19	ExoMars	ESA-ROS	One launch 2016, second 2020	Mars	Orbiter/Lander/Rover	Major; +NASA contribution
20	InSight	NASA	2018	Mars	Lander	Major instrument contribution (CNES, DLR)
21	JUNO	NASA	Launch 2011 in orbit 2016	Jupiter	Orbiter	Instrument level (ASI)
22	Cassini/Huygens	NASA-ESA	Launch 1997, landing 2005; EoM 2017	Saturn system	Orbiter/Lander	Major
23	New Horizons	NASA	Launch 2005, flyby 2014, dormant	Pluto, KBO*	Fly-by	No

Color Code:

Major cooperation (joint development, mission element provision, major contribution)
Science instrument(s) provision
Science cooperation, or no international involvement

Notes: *EMS=ESA Member States; NEO=Near-Earth Object; MER=Mars Exploration Rovers; KBO= Kuiper Belt Object. The two Voyager spacecraft, still communicating, are not included.

IV. Report on the status of international cooperation in space research on upper atmospheres of the Earth and planets[16]

IV.A. Overall assessment of the status of international cooperation in the field of upper atmospheres

Scientific Commission C of COSPAR is devoted to space studies of the upper atmospheres of the Earth and planets including reference atmospheres. For both terrestrial and planetary atmospheres significant progress has been achieved in understanding the structure and dynamical, chemical, and electromagnetic characteristics of the atmosphere. Especially in the Earth's atmosphere and ionosphere vertical, regional and global couplings have been revealed in detail, and the idea of considering 'the whole atmosphere' extending from the ground to the upper atmosphere as a unified system has become very important. The whole atmosphere is a comprehensive system comprising a multitude of waves with various temporal and spatial scales, requiring observations covering a wide spectrum in time and space.

Recent satellite missions on the middle and upper atmosphere have used smaller satellites with generally less opportunities for international collaborations with many countries, compared with prior larger satellites such as UARS (Upper Atmosphere Research Satellite) launched in 1991. However, the scientific targets are becoming more comprehensive, and various key dynamical phenomena, such as atmospheric tides and gravity waves, are now understood to be closely linked and frequently attain very large amplitudes in the mesosphere and above. Therefore, observations of many different local times have become very important. This means that single satellite missions, which often observe at a fixed local time, as in case of the polar orbiters, cannot cover all the variations with different time and spatial scales. Hence, international collaborations with many countries are becoming essential in order to observe the atmosphere and ionosphere using coordinated satellites and ground-based network observations to achieve new scientific goals. Also, collaborations with various numerical models developed in different countries and with standard model atmospheres/ionospheres developed by international working groups are increasingly important. It should be noted that such international collaborations are not limited to the developed countries, and worldwide coverage incorporating the developing countries is becoming very important. COSPAR's Capacity Building Workshop program is playing a highly significant role in this process.

Very recently, Cubesat technology is revolutionizing space exploration with close to 100 of these miniature satellites being put into orbit each year. These are forming observation networks in space, and becoming complementary to the ground-based observation networks. Such new instrumentation also stimulates new international collaboration.

IV.B. Status of existing co-operations on on-going missions

Regarding the Earth's middle atmosphere and lower ionosphere, several satellite missions and ground-based campaigns have been conducted. Major satellite missions and instruments directed by NASA, such as TIMED/SABER, TIMED/TIDI (Launched in December, 2001), Aqua/AIRS (launched in May, 2002), Aura/MLS and Aura/HIRDLS (launched in July, 2004), continue to provide essential global observations of temperatures, winds, constituents and wave activity such as planetary waves, atmospheric tides and gravity waves in the middle atmosphere and lower ionosphere. In particular, the TIMED (Thermosphere Ionosphere Mesosphere Energetics and Dynamics) mission studies the influences of the Sun, and anthropogenic effects, on the Mesosphere-Lower-Thermosphere-Ionosphere (MLTI) which is a critical gateway between Earth's environment and space, where the Sun's energy is first deposited into Earth's environment. The TIMED mission is the current terrestrial anchor of the NASA Heliophysics System Observatory and researchers worldwide use temperature data from the SABER instrument for reference MLT measurements. To date, 1,600 papers have been published including 600 from non-US scientists[17].

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[16] This report was prepared by Takuji Nakamura, Chair of COSPAR Scientific Commission C, with contributions by Michael J. Taylor, Dmitri Titov, Andrew Yau (vice-chairs), Kazuo Shiokawa (C1 chair), Duggirala Pallamraju (C1 vice-chair), Michael Gerding (C2 chair), David Altadill (IRI-TG chair), Dieter Bilitza, Amal Chandran, Vladimir Kalegaev and Jan Lastovicka.

[17] These publications are openly available at http://www.timed.jhuapl.edu/WWW/index.php

The NASA AIM (Aeronomy of Ice in the Mesosphere) is a small explorer satellite launched on April 25, 2007. This unique mission was developed to study the structure and dynamics of Polar Mesospheric ice Clouds (PMC), which occur at high-latitudes in the summer mesosphere. It also provides temperature and constituent measurements over the high latitude regions. Most recently, this mission has been extended to include a new lower mesosphere gravity wave measurement capability for further studying global dynamics of the middle atmosphere. AIM has developed several cooperative research ties with international institutions in Germany, Sweden and Japan and the AIM data and publications are openly available[18].

The Enhanced Polar Outflow Probe (e-POP) is a LEO mission to investigate plasma outflow and neutral escape in the polar ionosphere and thermosphere and the associated auroral dynamic and wave-particle interaction processes. Launched in September 2013, this mission is led by Canada, with instrument contributions from Japan and the USA, and is currently in its 5th year of science operations. The research co-operations between institutes from these three nations is continuing. In addition, coordinated observation campaigns with various international ground observatories and facilities such as SuperDARN, EISCAT, HIPAS, and Sura are an integral part of the continuing e-POP science operation. Starting in late 2017, e-POP operations will be in close coordination (and effectively integrated) with the ESA Swarm operations.

The SWARM mission, an Earth-observing satellite mission developed by ESA, continues to stimulate new international collaborations. The three SWARM satellites were launched on 22 November 2013 into near-Earth orbit to provide precise measurements of magnetic field variations that stem from the Earth's core, mantle, crust and oceans, as well as from the ionosphere and magnetosphere. The SWARM mission data are openly available through the mission website, and are widely used by international scientists[19].

The Lomonosov satellite developed by Moscow State University and Roscosmos was successfully launched in April, 2016. The main goal of this mission is to study extreme processes in space, such as Ultra High Energy Cosmic Rays, Transient Luminous Events (TLE), Gamma Ray Bursts, variations in the radiation belts, and to test optical monitoring of potentially dangerous space objects. The scientific program was developed in close association with universities from USA, Korea, Denmark, Spain, and Mexico[20].

In the framework of the EU's QB50 program 36 CubeSats were launched into orbit in 2017. QB50 is an international network of CubeSats for multi-point, in-situ measurements in the lower thermosphere and re-entry research. Cubesat programs are funded by NASA, ESA, EU, ISRO, JAXA and many other agencies.

For all the above mentioned missions, ground-based multi-instrument, multi-national campaigns are especially important for studies of dynamics of the atmosphere and ionosphere, because the research targets include variabilities of various spatial (km to tens of thousands km) and temporal scales (ranging from minutes to hours, days, months and years), under conditions where multiple phenomena are interacting comprehensively. Recent challenging programs combining satellite and ground-based international networks include DEEPWAVE and GW-LCYCLE which enabled in-depth studies of gravity wave propagation from the troposphere to the MLT, ANGWIN with a special focus on Antarctic and Arctic region dynamics, ICSOM with simultaneous runs of large ground-based radars etc. Various science networks have fostered international co-operations between scientists investigating the middle atmosphere and the exchange of data, e.g., NDMC, and MERIDIAN. Climate research in the middle atmosphere continues to be successfully coordinated under the umbrella of SCOSTEP (Science Committee of Solar Terrestrial Physics) of ICSU. SCOSTEP is operating a five-year program called "Variability of the Sun and Its Terrestrial Impact (VarSITI)[21]" covering the period 2014-2018. More than 900 scientists from 67 countries have joined this program. COSPAR cooperates with SCOSTEP on this program.

The effort of creating sophisticated models of the atmosphere and ionosphere is one of the most important goals of satellite missions for Commission C. The IRI (International Reference Ionosphere) Task Group of COSPAR Commission C, working jointly with URSI, is a very active and successful on-going international collaborative project. IRI is an empirical standard model of the ionosphere compiled with data from many

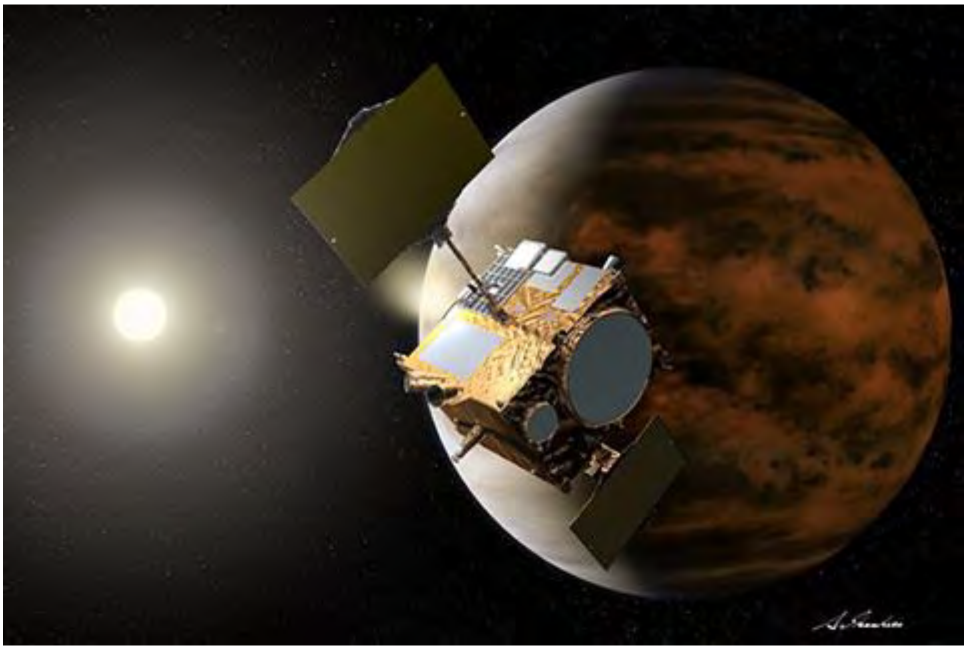
[18] See website at aim.hamptonu.edu
[19] The SWARM website is at http://www.esa.int/Our_Activities/Observing_the_Earth/Swarm
[20] The website is at http://lomonosov.sinp.msu.ru/en/project/collaboration.
[21] The website of the VarSITI program is at http://www.varsiti.org/

satellites, rockets, ionosondes and incoherent scatter radars, etc.[22] The IRI team is also active in Capacity Building. Workshops with over 100 participants in Bangkok in 2015 (with 35 students) and Taipei in 2017 (27 countries incl. 37 students) focused on introduction of the updated (real-time) version of IRI utilizing real-time ionosonde and GNSS measurements.

One of the activities related to the United Nations is a nine-month Post-Graduate Diploma Course in Space and Atmospheric Science that is conducted every alternate year at the Physical Research Laboratory (PRL), Ahmedabad, India, under the auspices of the Center for Space Science and Technology Education in Asia and the Pacific (CSSTEAP), affiliated with the UN. So far, ten courses have been conducted and 109 participants from 16 countries have benefited[23].

International collaboration at Mars is progressing very well. ESA's Mars Express and NASA's MAVEN missions focus on the upper atmosphere and aeronomy revealing processes of atmospheric escape that shed a light on evolution of the Mars atmosphere and its habitability. The first element of the ESA-Roscosmos ExoMars program, Trace Gas Orbiter (TGO), was inserted in orbit around the Red Planet in October 2016. Since then the spacecraft has been performing aero-braking to reach its operational orbit and begin science observations in April 2018. TGO will focus on detailed investigations of minor species and chemistry of the Martian atmosphere.

The International Venus Exploration Working Group (IVEWG) is fostering international collaboration and cooperation in the exploration of Venus. In the recent Venus Express mission, ESA, NASA and JAXA collaborated on data collection, archiving and access to Venus data. At present JAXA's Akatsuki orbiter mission is one example of a collaboration between JAXA, NASA and ISRO. Also, at present Roscosmos and NASA have a Joint Science Definition Team for Russia's Venera-D mission.



JAXA's Venus Climate Orbiter "AKATSUKI" (PLANET-C) (*Courtesy of Akihiro Ikeshita*)

IV.C. Opportunities for co-operation on future missions

NASA is preparing to launch two new satellite missions to investigate the Earth's upper atmosphere. One is ICON (Ionospheric Connection Explorer) that will investigate the environment and coupling of neutral and ionized particles in the upper atmosphere where many spacecrafts, including the International Space Station, orbit[24]. The other is GOLD (Global-scale Observations of the Limb and Disk) that will investigate densities and temperatures in the thermosphere and ionosphere using an ultraviolet (UV) imaging spectrograph observing

[22] The latest version, IRI-2016, includes significant improvements and is available from the IRI homepage at http://irimodel.org

[23] The details can be found at http://www.cssteap.org

[24] https://www.nasa.gov/mission_pages/sunearth/missions/mission_icon.html

from geostationary orbit over the American longitude sector[25]. Both missions will promote and enhance significant international collaborations on research of the Earth’s atmosphere and geospace environment around the Earth.

MATS (Mesospheric Airglow/Aerosol Tomography and Spectroscopy), launch date 2019, is a new Swedish satellite mission that will apply tomographic retrievals to determine wave properties and interactions in the mesosphere. Tomography will provide horizontally and vertically resolved data, while spectroscopy will analyze mesospheric composition, temperature and cloud properties. MATS international team includes scientists from Europe, Canada, USA and Japan.

The Moscow State University space project “UNIVERSAT-SOCRAT” is devoted to mitigating risks related to space factors. This project aims to develop satellites groups for real-time monitoring in near-Earth space including radiation conditions, potential dangerous natural and man-made objects (asteroids, meteoroids and space debris), and electromagnetic transients. The scientific program is being developed in collaboration with French and Korean universities.

The Russian Mini-EUSO project aims to study the chemistry of the mesosphere, in particular airglow emissions, transient atmospheric phenomena, like TGF and LTE, and the detection of cosmic ray showers. K-EUSO is devoted to study ultra-high energy cosmic rays based on improved KLPVE device developed at Moscow State University. It observes transient luminous phenomena in the Earth's atmosphere caused by incoming particles from space. The sensor is a super wide-field telescope that detects extreme energy particles. The scientific program for both experiments is being developed by the international JEM-EUSO collaboration.

The International Satellite Program in Research and Education (INSPIRE) is a global consortium spearheaded by the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado at Boulder. A series of INSPIRE CubeSats for ionosphere measurement will be launched after 2019 under collaboration of USA, India, Singapore, Taiwan and Oman.

In summary, simultaneous and co-located wind and temperature measurements are essential to quantify the most important dynamical features of the Earth’s middle and upper atmosphere. Global coverage is essential for improved understanding of the general circulation. Only by a combination of space and ground-based multi-instrument campaigns, can the drawbacks of, e.g., “instrumental filters” and limited altitude coverage, be successfully balanced. Due to the global nature of these measurements, such topics are best handled by combining expertise from different institutions and nations. Current obstacles are a future lack of continued global measurements of temperatures and winds as well as challenging funding conditions for multi-national measurement campaigns.

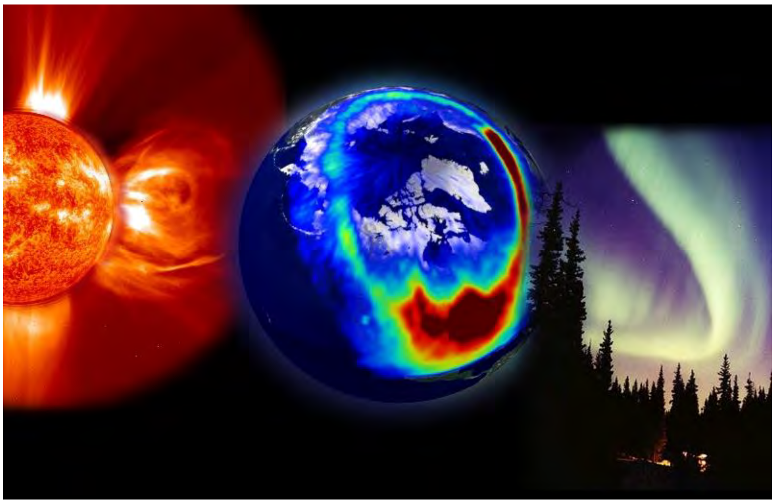
[25] http://gold.cs.ucf.edu/

V. Status of international cooperation in space research on Space Plasmas in the Solar System, Including Planetary Magnetospheres[26]

V.A. Overall assessment of the status of international cooperation on space plasmas

COSPAR's Scientific Commission D is dedicated to processes of the solar atmosphere, its extension into the interplanetary space as well as its interaction between planetary bodies and the interstellar medium. This concerns thermal and non-thermal plasma physics as well as the transport of energetic particles.

This covers a wide range of observational and theoretical requirements from microphysics, like particle acceleration on the Sun, at interplanetary shocks and at the termination shock of the solar wind, to macrophysics, like the large-scale structures of the heliospheric interaction with the interstellar medium or the propagation of Coronal Mass Ejections (CMEs).



From Sun to Earth: The connection between the activity at the Sun through interplanetary space to the Earth's magnetosphere and atmosphere (*Credit: NASA*).

To study the microphysics a high resolution in time and space is required. This is achieved in the Earth magnetosphere, where multiple (international) space missions like Cluster, Themis or MMS provide the required data. These coordinated observations allow to study the microphysics of planetary bow shocks as well as the generated plasma waves and turbulence. In the interplanetary space, the time resolution is still high and coordinated observations of particle transport allows to uncover the microphysics of acceleration processes and turbulence.

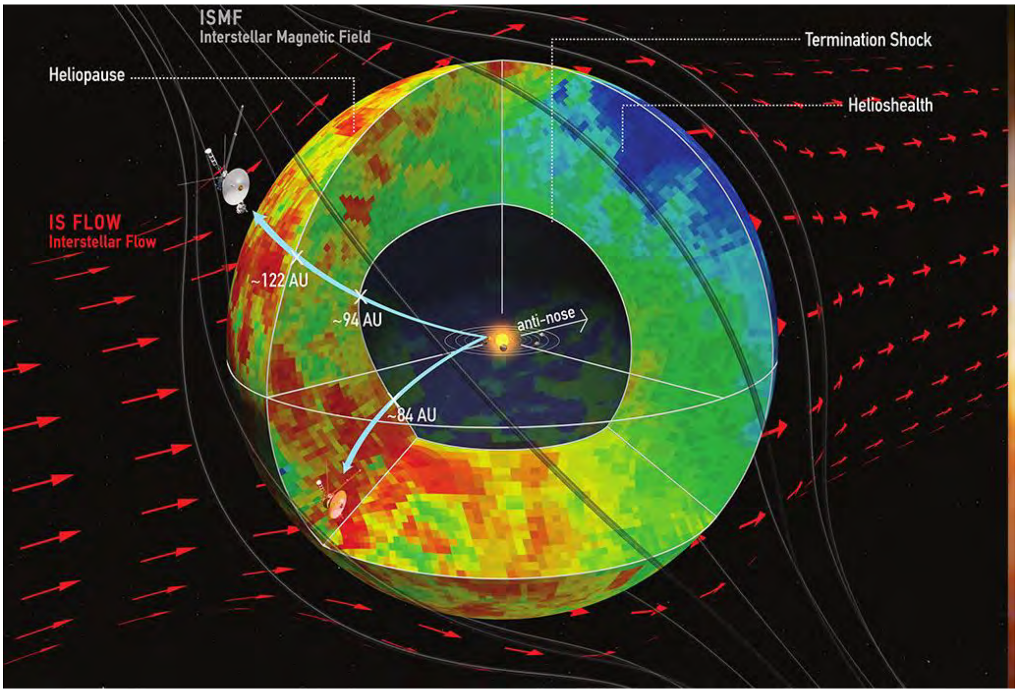
While the particle instruments onboard of the SoHo, ACE, Pamela, and Voyager missions provide a detailed understanding of the transport of energetic particles from the Sun and the interstellar medium in the ecliptic, the out-of-ecliptic Ulysses spacecraft adds the three-dimensional component.

The above mentioned spacecraft have also plasma instruments onboard which allow a description of the macrophysics. In addition, with the Stereo spacecraft, this gives a tomographic view of the propagation of CMEs, as well the particle propagation connects with them. Especially, the SoHo, Stereo and SDO spacecraft also observe the long term behavior of the Sun (solar cycle) and the evolution of the magnetic field in the heliosphere. The Hinode and IRIS spacecraft provide high resolution spectroscopic and imaging information of plasma and magnetic processes that drive the solar wind and eruptive events. RHESSI provides information on acceleration processes during flares.

The Voyager spacecraft are the only ones which provide *in situ* data from the outer edge of the solar system. An international effort is carried out to understand the physical processes in that region and in the interstellar medium. These observations are supported by the IBEX spacecraft (Interstellar Boundary EXplorer) which

[26] This report was contributed by Klaus Scherer, Chair of COSPAR Scientific Commission D, with the help of his co-chairs Louise Harra, Gurbax Lakhina and Ming Zhang.

provides images of Energetic Neutral Atoms from the outer edge of the solar system. The latter are the messengers from the outer heliosphere and with the IBEX observations the three-dimensional structure shall be revealed. The most prominent feature of the latter is the so-called Ribbon, which physics is not yet completely understood. In addition to IBEX, the Cassini spacecraft also offered occasionally ENA data.



The interaction region between the solar wind and the interstellar medium (*Credit: NASA*).

Most of the above mentioned space missions featured international cooperation on the instruments or launchers, and because most of the data are available for all scientist a huge progress in understanding space physics has been achieved.

While for the magnetospheric and solar observations the situation concerning missions and cooperation is quite good, the situation for *in situ* measurements in the outer heliosphere is mainly based on the Voyager and IBEX spacecraft.

In addition to the space missions, ground-based observations complete the physical environment, especially the long-term observations and anisotropies of energetic particles by neutron monitors and large area observatories like ICECUBE or HAWK.

With increasing physical understanding and computational power, lots of achieved spacecraft data from old missions, like Helios, Ulysses, Themis, and others are still used to support models.

V.B. Status of existing co-operations on on-going missions

The scientific objectives of most of the missions below are described above in more detail. Here a short alphabetical overview is given. Because most of the data of the missions below are publicly available and used in coordinated observations, national missions are also cited.

ACE: The Advanced Composition Explorer collects and analyses particles of solar, interplanetary, interstellar and galactic origins. It was launched in 1997.

Cluster is investigating the Earth's magnetic environment and its interaction with the solar wind in three dimensions. It was launched in 2000.

The JAXA **Hinode** mission launched in 2006 is about to celebrate eleven years of successful operations. There are three instruments – the Solar Optical Telescope, the X-ray telescope and the EUV Imaging Spectrometer. The instruments are all performing nominally. There are no issues with the spacecraft that would prevent Hinode from continuing for many more years. The operations are funded by JAXA, NASA, UKSA and ESA. There have been over 1,100 refereed publications from the mission data, and around 100 PhD theses from around the world.

The **IBEX** (Interstellar Boundary Explorer) mission remotely observes neutral energetic particles from the heliospheric boundary. It was launched in 2008 in a hugely eccentric Earth orbit with two instruments for ENAs.

The **IRIS** (Interface region imaging spectrograph) mission was launched in June 2013. It is a NASA SMEX mission that studies the complex and dynamic chromospheric region of the Sun with high spatial and spectral resolution.

The Magnetospheric Multiscale Mission **MMS** investigates how the Sun's and Earth's magnetic fields connect and disconnect, known as magnetic reconnection. Four identically instrumented spacecraft measure plasmas, fields, and particles in a near-equatorial orbit that will frequently encounter reconnection in action. It was launched in 2015.

RHESSI (Reuven Ramaty High Energy Solar Spectroscopic Imager) explores the physics of particle acceleration and explosive energy release in solar flares. This is achieved through imaging spectroscopy in X-rays and gamma-rays with fine angular and energy resolution to reveal the locations and spectra of the accelerated electrons and ions and of the hottest plasma. It was launched in 2002.

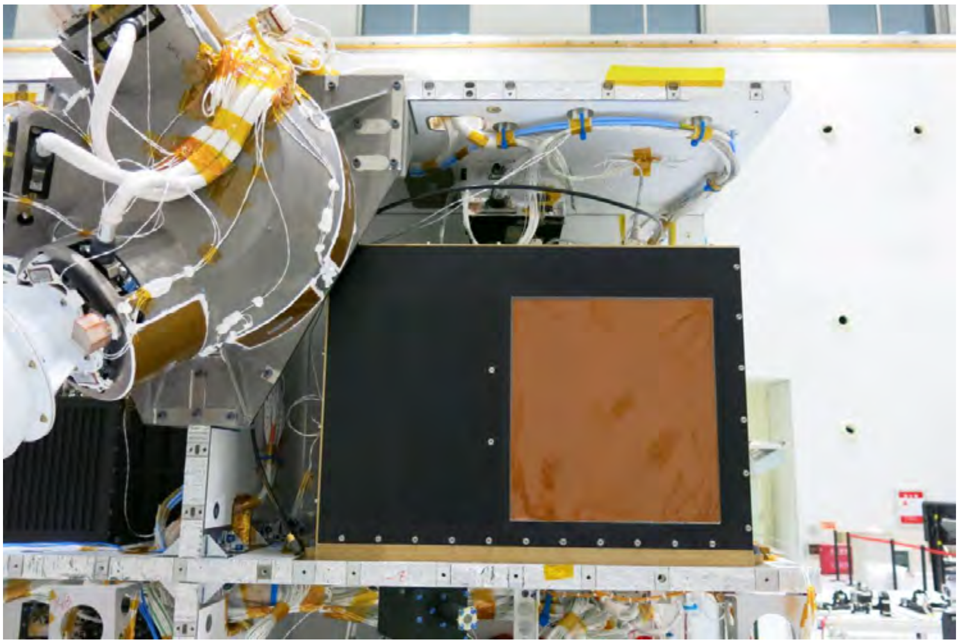
SDO (Solar Dynamic Observatory) provides ultra-high-definition images from the Sun as well as spectral information and magnetic field data. It was launched in 2010.

Stereo (Solar TErrestrial RElations Observatory) studies the cause and mechanism of CMEs and their propagation through the interplanetary space as well as the corresponding particle acceleration. It was launched in 2006.

Van-Allen-Probes: The two spacecraft are measuring the particles, magnetic and electric fields, and waves that fill geospace. They were launched in 2012.

The two **Voyager** spacecraft launched in 1977 are about to celebrate 40 years of successful operations. These are the only spacecraft which provide *in situ* information on the plasma state and energetic particles at the edge of the solar system and beyond. These spacecraft are still operated by NASA.

Finally, it is worth mentioning **CSES**, the China Seismo-Electromagnetic Satellite. CSES is a partnership scientific mission of China National Space Administration and the Italian Space Agency, dedicated to i) monitoring electromagnetic field and waves, ii) plasma and particles perturbations of the atmosphere, iii) ionosphere and magnetosphere induced by natural sources and iv) anthropocentric emitters. Launched 2 February 2018, CSES is entirely dedicated to study the above-mentioned magnetospheric perturbation and their correlations with the (unfortunate) occurrence of seismic events.



The HEPD-FM instrument on the CSES satellite (*Credit: INFN*).

V.C. Opportunities for co-operation on future missions

Solar Orbiter is the first medium-class mission in the ESA's Cosmic Vision 2015-2025. It has a unique payload of ten instruments with a tuned mix of remote sensing and *in situ* instruments. It will be launched into an orbit that will reach a perihelion of 0.28 A.U., and will slowly move out of the ecliptic plane providing the first view of the polar regions. The main goal of the mission is linking the understanding of the processes that create the solar wind measured by the remote sensing instruments to the actual measurements of the solar wind itself from the *in situ* instruments. The launch, provided by NASA, is currently planned for February 2020 from Cape Canaveral. The **Parker Solar Probe** mission was dedicated to Eugene Parker, the pioneer who predicted the solar wind. It will explore regions close to the Sun – never probed before. It will be launched in the summer of 2018.

NGSPM (Next Generation Solar Physics Mission): JAXA, NASA and ESA formed a Science Objective Team to develop and document the scientific priorities of a mission within resources specified by the agencies. This would be for a post-2024 mission. All three agencies appointed members to the team. A call for white papers was sent to the solar community, and 34 white papers were received. There are three main categories: coronal heating, solar wind and dynamic heating; flares and space weather research for prediction; and, solar cycle and irradiance variations that influence climate on Earth.

As regards space sustainability, an important role is played by the effect of the Sun-Earth interaction, an essential part of the Space Astrophysics investigations, boosted by the launch of the Chinese-Italian CSES Satellite, planned in February 2018. This interaction drives the space weather-related events and their effect on human activities for different societies and for different economic sectors. The 'space weather' is now formally recognized as an area of relevance to World Meteorological Organization activities.

VI. Status of international cooperation in research on astrophysics from space[27]

VI.A. Overall assessment of the status of international cooperation in Astronomy and Astrophysics from space

This Report summarizes two years (2015-2017) of space science activity. The aim is to provide the relevant information in a snapshot, giving at the same time a full overview of the current space research programs that revolve around the observation of the Universe with all the available tools, from space and ground.

The use of space techniques continues to play a key role in the advance of astrophysics by providing access to the entire electromagnetic spectrum from the radio to gamma rays. The increasing size and complexity of large space-based observatory missions places a growing emphasis on international collaboration. This is particularly marked by the increasing range of joint missions involving the large space agencies in Europe (ESA), Japan (JAXA), the Russian Federation (RKA) and the United States (NASA), with a major contribution recently given by the Chinese and Indian space agencies.

It is important to iterate that the world's space agencies coordinate their mission plans for both large and smaller scale enterprises. In addition, the coordination of existing and future datasets from space-based and ground-based observatories is an emerging mode of powerful and relatively inexpensive collaboration to address problems that can only be tackled by the application of large multi-wavelength datasets.

This Report outlines the main operative and planned space missions, and the achievement in the field of Astronomy, Astrophysics, Astroparticles and, more recently, in the so called ***"Multimessenger"*** physics. This new field of front-line research, includes observations of electromagnetic counterparts of cosmic phenomena observed/detected in different "windows": Gravitational Waves, Neutrinos, Fast Radio Bursts and high energy cosmic rays, observed in parallel in the classic electromagnetic band.

In conclusion it is important to maintain the rate of fundamental scientific discoveries in space science that has been achieved in recent decades. This success will continue to derive from the ability to use space to access the full electromagnetic spectrum.

Large and powerful space astronomy missions have an outstanding track record of technical success, new discoveries, and long-lasting legacy science. In the future, such missions will continue to be essential to address key questions in astrophysics including the properties of dark matter and dark energy, gravitational wave astrophysics, the formation of the first stars, the evolution of galaxies like the Milky Way, the development of planetary systems, the characteristics of exoplanets and the associated evidence for emerging of life.

VI.B. Status of existing co-operations on on-going missions

The following paragraphs provide an updated summary of world-wide space programs in astronomy and astrophysics.

X-rays and Gamma rays

NASA's Chandra observatory and ESA's X-ray Multimirror Mission (XMM/Newton) have been operating successfully in space since 1999. The combination of CHANDRA high resolution, large collecting area, and sensitivity to higher energy X-rays will make it possible for Chandra to study extremely faint sources, sometimes strongly absorbed, in crowded fields. Chandra was boosted into an elliptical high-earth orbit that allows long-duration uninterrupted exposures of celestial objects. XMM-Newton observatory is ESA's second 'Cornerstone' mission and was launched on 10 December 1999 from Kourou on the first commercial Ariane-5 into a highly elliptical 48-hr orbit. The mission provides high-quality X-ray and optical/UV data from the European Photon Imaging Camera (EPIC), the Reflection Grating Spectrometer (RGS) and the Optical Monitor (OM). With their complementary emphasis on high angular resolution and high throughput spectroscopy, these observatory missions continue to generate major advances in astrophysics. The two missions have

[27] This report was prepared by Pietro Ubertini, Chair of COSPAR Scientific Commission E.

been particularly effective in studying distant galaxies, including galactic mergers, the massive black holes at their centers, and the billion-degree gas that permeates the medium in clusters of galaxies.

Hitomi was a joint JAXA/NASA mission designed to perform high-resolution spectroscopy of X-ray sources that failed, due to a SW problem, soon after the launch in 2016. An X-ray Astronomy Recovery Mission (XARM) is a JAXA/NASA collaborative mission, with ESA participation, planned with the objective to investigate X-ray celestial objects in the Universe with high-throughput, high-resolution spectroscopy. XARM is expected to be launched in 2021 on a JAXA H-2A rocket. The XARM payload consists of two instruments: Resolve, a soft X-ray spectrometer, which combines a lightweight Soft X-ray Telescope paired with an X-ray Calorimeter Spectrometer, and provides non-dispersive 5-7 eV energy resolution in the 0.3-12 keV bandpass with a field of view of about 3 arc-min; Xtend, a soft X-ray Imager, is a CCD detector with a larger field, at the focus of the second lightweights Soft X-ray Telescope in the energy range of 0.4-13 keV. The XARM satellite is designed to recover the science capability lost with the Hitomi incident. The characteristics of its instruments are similar to those of the SXS and SXI flown on Hitomi.

At the relatively low gamma-ray energies are operative the ESA INTEGRAL Observatory and the NASA SWIFT Mission, both based on the “coded mask” technology to provide high energy images of the sky. INTEGRAL was successfully launched from Baikonur (Kazakhstan, 2002) as the 2nd medium size project of the Horizon 2000 scientific program. It is led by ESA and realized with the instrument complement and the Scientific Data Centre provided by five different European consortia, with a contribution from Russia, for the Proton launcher, and from USA that made available the NASA ground station of Goldstone. The Observatory is devoted to the observation of the gamma-ray Universe in the energy range from 15 keV to 10 MeV with substantial monitoring capability X-ray and optical. The mission has recently demonstrated the capability to study counterparts of Gravitational Wave (GW) emitted by collapsing binaries. Very recently discovered, together with the NASA FERMI-GBM satellite, is the first short Gamma-ray Burst GRB170817A emitted contemporary to the GW emission from a binary NS-NS inspiral. This is considered the start of the new “Multimessenger” astrophysics[28]. Swift is part of NASA’s medium explorer (MIDEX) program, launched into a low Earth orbit on a Delta 7320 rocket on 2004. With international participation, scientists have a tool dedicated solve the gamma-ray burst mystery. Its three instruments give scientists the ability to scrutinize gamma-ray bursts like never before. Within seconds of detecting a burst, Swift relays its location to ground stations, allowing both ground-based and space-based telescopes around the world the opportunity to observe the burst’s afterglow.

The NuSTAR mission, launched in 2012, has deployed the first orbiting telescopes to focus light in the high energy X-ray (6-79 keV) region of the electromagnetic spectrum. Our view of the universe in this spectral window has been limited because previous orbiting telescopes have not employed true focusing optics, but rather have used coded apertures that have intrinsically high backgrounds and limited sensitivity, even if over a much larger field of view. Among the more interesting discoveries are the detailed studies of stellar and supermassive black holes, neutron stars, cyclotron line features from galactic binaries, and cosmic background observations with unprecedented sensitivity.

The Indian ASTROSAT mission is a multi-wavelength astronomy mission on an IRS-class satellite in a 650-km, near-equatorial orbit. It was launched by the Indian launch vehicle PSLV from Sriharikota on September 28, 2015: worth to mention is the polarization measures of the Crab Pulsar. Among other capabilities, provide an all-sky monitor that is complementing, MAXI (JAXA): an all-sky X-ray Image Monitor with featuring a highly sensitive X-ray slit camera over an energy range of 0.5 to 30 keV, in orbit on the ISS since 2009.

NICER, the Neutron star Interior Composition Explorer (NICER), is an International Space Station (ISS) payload devoted to the study of neutron stars through soft X-ray timing, that was launched aboard a SpaceX Falcon 9 rocket on June 3, 2017 and is fully operative.

On June 15, 2017, HXMT (Hard X-ray Modulation Telescope), China's first astronomy satellite, was launched to observe black holes, NSs, active galactic nuclei and other phenomena based on their X-ray and gamma-ray

[28] Goldstein *et al.* 2017 ApJL 848 L14, Abbott *et al*. 2017 ApJL 848 L12, Abbott *et al*. 2017 ApJL 848 L13, and Savchenko *et al*. 2017 ApJL 848 L15.

emissions. The project, a joint collaboration of the Ministry of Science and Technology of China, the Chinese Academy of Sciences, and Tsinghua University.

At the higher energies that will facilitate investigation of the highest energy processes in the universe, Italy's AGILE was launched in 2007 and the major Fermi Gamma-ray Space Telescope developed by NASA and the US Department of Energy together with Universities and Agencies in France, Germany, Italy, Japan and Sweden, was launched in 2008. Both spacecraft are generating discoveries every month.

Other operative instruments are RESOURSE-P #2 satellite with NUCLEON instrument chemical composition of high-energy galactic cosmic rays (Russia, Dec 2014), LOMONOSOV, Multiwavelength, GRBs and Ultra High Energy Cosmic Rays (Russia, April 2016), CALET (installed at ISS August 2015), JAXA, CALorimetric Electron Telescope, DAMPE, DArk Matter Particle Explorer, (China, December 2015), and other smaller missions, difficult to enumerate in this short report.

Among the international mission under development: Spectrum RG (launch 2018), Russia led in collaboration with MPE-Germany to observe in the X-ray (eROSITA) and hard X-Ray (ART X-C), SVOM, a gamma-ray bursts mission, bilateral collaboration between France (CNES) and China (CAS, CNSA), with the contribution of the University of Leicester and the Max Planck Institut für Extraterrestische Physik (launch 2021) and the recent NASA-ASI IXPE: The Imaging X-ray Polarimetry Explorer, a NASA Small Explorers mission devoted to provide imaging X-ray polarimetry of celestial sources (Launch late 2020).

UV/Extreme UV and Visible

The Hubble Space Telescope (HST), launched in 1990, continues to operate successfully producing spectacular images. In 2009, the fourth servicing mission replaced key subsystems. In addition, two new instruments were installed (COS and WFC3) and two instruments were repaired (STIS and ACS). NASA's GALEX (Galaxy Evolution Explorer), is conducting the first deep all-sky survey in the ultraviolet, and has detected more than one million hot stars and galactic cores since being launched in 2003. ESA's Gaia, launched in 2013, is an ambitious mission to chart a three-dimensional map of our Galaxy, the Milky Way, in the process revealing the composition, formation and evolution of the Galaxy. Gaia will provide unprecedented positional and radial velocity measurements with the accuracies needed to produce a stereoscopic and kinematic census of about one billion stars in our Galaxy and throughout the Local Group.

Infrared

NASA's Spitzer Observatory has ended its cryogenic phase, and is currently still operational at short infrared wavelengths. JAXA's AKARI satellite has finalized its all-sky IR survey in six bands from 9 to 160 µm and performed pointed observations of a wide variety of astronomical sources. A more sensitive all-sky IR survey in the 3-25 µm range is being performed by the WISE NASA SMEX mission launched in 2009.

The JWST (James Webb Space Telescope), launch planned in 2019 (NASA-ESA mission), is a large infrared-optimized space telescope with IR 6.5m mirror telescope sensitive from 0.6 to 27 micrometer. Webb will find the first galaxies that formed in the early Universe, connecting the Big Bang to our own Milky Way Galaxy. Webb will peer through dusty clouds to see stars forming planetary systems, connecting the Milky Way to our own Solar System. Webb's instruments will be designed to work primarily in the infrared range of the electromagnetic spectrum, with some capability in the visible range Webb will have a large mirror, 6.5 meters (21.3 feet) in diameter. JWST will be a milestone in the space exploration and its science capability will be fully complementary to large ground based projects such as ALMA, SKA, etc.

Under development is worth to mention EUCLID, an ESA mission, planned to be launched in 2020, to map the geometry of the dark Universe. The mission will investigate the distance-redshift relationship and the evolution of cosmic structures by measuring shapes and redshifts of galaxies and clusters of galaxies out to redshifts ~2, or equivalently to a look-back time of 10 billion years. In this way, Euclid will cover the entire period over which dark energy played a significant role in accelerating the expansion. WFIRST, the Wide Field InfraRed Survey Telescope, is a NASA observatory designed to settle essential questions in the areas of dark energy, exoplanets, and infrared astrophysics. The telescope has a primary mirror that is 2.4 meters in diameter (7.9 feet), and is the same size as the Hubble Space Telescope's primary mirror. WFIRST will have two instruments, the Wide Field Instrument, and the Coronagraph Instrument.

Radio

RadioAstron is an international space VLBI project led by the Astro Space Center of the Lebedev Physical Institute in Moscow, Russia. The payload, a space 10 m-Radio Telescope, is based on spacecraft Spektr-R, that have been designed by the Lavochkin Association. The organizations which are participated in the development of the project and now support the RadioAstron mission are NRAO, USA, Helsinki University of Technology, Finland, European Space Agency (ESA), Observatory of Neuchatel, Switzerland, Tata Institute for Fundamental Research (TIFR), India, CSIRO, Australia. It was launched on 18 July 2011, by a Zenit-3F launcher, from Baikonur Cosmodrome to perform research on the structure and dynamics of radio sources within and beyond our galaxy. Together with some of the largest ground-based radio telescopes, this telescope forms interferometric baselines extending up to 350,000 km.

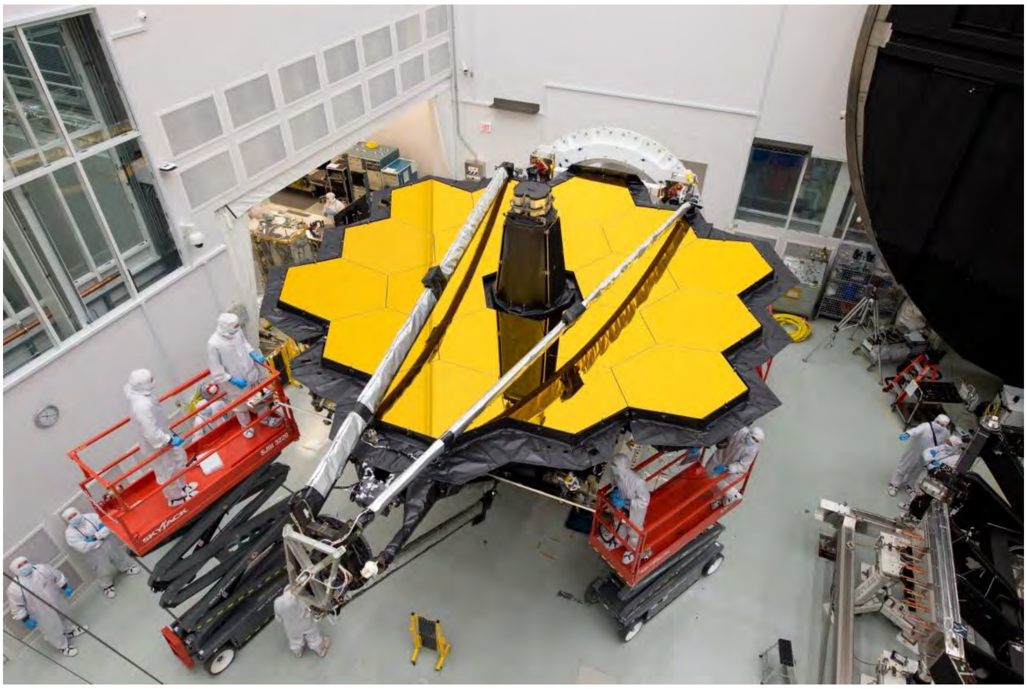
Interdisciplinary

Future major space observatories that will foster “transformational” astronomy are **Athena**, the ESA-NASA-JAXA large X-ray Observatory ever built (launch 2028) and **eLisa**, the Gravitational Wave space explorer to come along in 2034.

Finally, worth to mention that there is an increasing number of nations active in space astrophysics and planetary science. International cooperation is key to future missions (large and small) to maintain a FULL ACCESS to the whole electromagnetic spectrum in synergy with large ground-based observatories.

VI.C. Opportunities for co-operation on future missions

As depicted briefly in the above section, Space Astronomy has been since the beginning of the 1960s a common effort among the major faring space countries. “Astronomy is a difficult observational science requiring continuous and simultaneous access to the full electromagnetic spectrum to explore our complex Universe and to pursue answers to fundamental scientific questions. The history of space astronomy, especially the past three decades, has demonstrated clearly the importance and benefits of access to the gamma-ray, X-ray, UV-optical, near IR and far- IR spectrum from space. To build on this success, continuing technical and scientific advances and commitment to space science on the part of the world’s space agencies are going to be needed. It will be essential to complement with the space segment the powerful “ground based” facilities that will soon be available, and to ensure that the next generation of astronomers has access to the whole spectrum” (Excerpt from COSPAR Working Group report on the *Future of Space Astronomy*, Ubertini *et al*., Advances in Space Research, 50, 1–55, 2012).



The JWST folded up in the cleanroom outside of Chamber A at NASA’s Johnson Space Center, Houston, Texas (*Credit: Desiree Stover/NASA*).

The increasing size, complexity and cost of large space observatories places a growing emphasis on international collaboration. Furthermore, combining existing and future datasets from space and “ground based” observatories is an emerging mode of powerful and relatively inexpensive research to address problems that can only be tackled by the application of large multi-wavelength observations. While the present set of astronomical facilities is impressive and covers the entire electromagnetic spectrum, with complementary space and “ground based” telescopes, the situation in the next 10-20 years is of critical concern. The James Webb Space Telescope (JWST), to be launched in 2019, is the only ready future major space astronomy mission, to be followed by Athena (ESA-NASA) in 2028 and eLisa (2034). Other major highly recommended space astronomy missions have yet to be approved for development.

Conclusions

Astronomy from space is a model for international scientific cooperation. Most missions have some international hardware collaboration, and virtually all feature extensive data sharing. International astronomical databases now include ground-based as well as space-based archival data in standard formats, so that astronomers anywhere in the world can access all results after brief proprietorial periods. They can perform extensive multi-wavelength investigations of large data samples from their desktops: this minimize investment and travelling and make amenable high scientific investigations with a sustainable effort to low-middle developed countries scientific community.

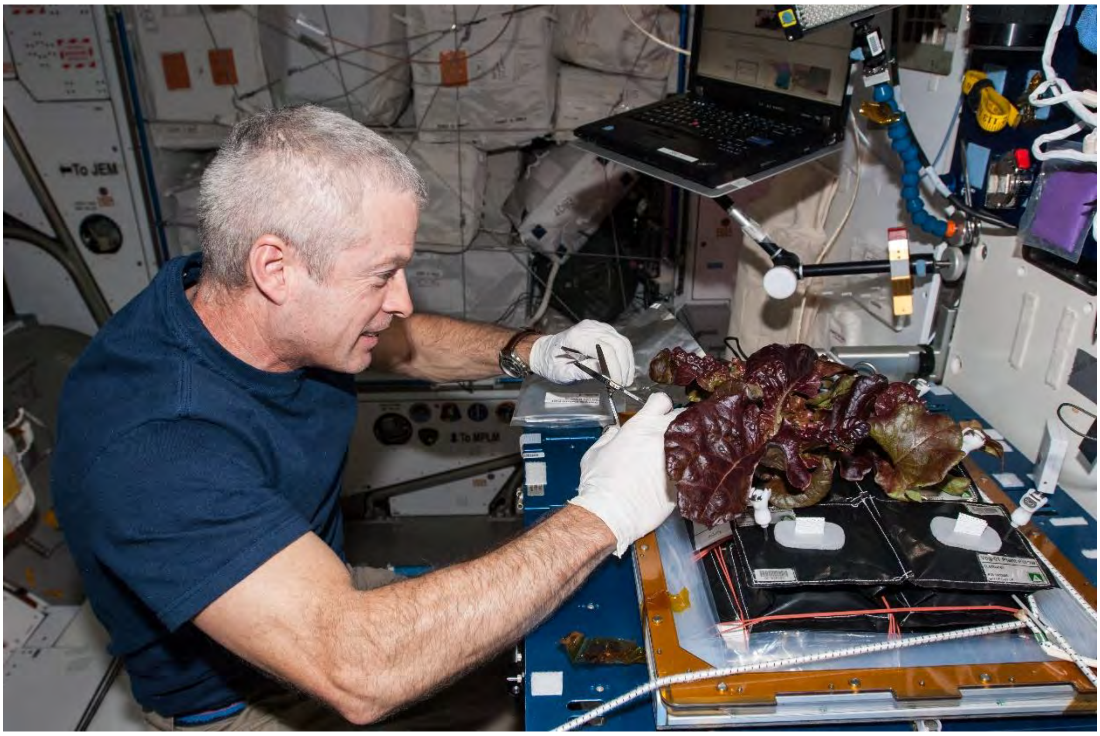
Furthermore, the last August discovery of the electromagnetic counterpart of the GW170817 event, with the GRB detection 1.8 s after the GW signal and the Hypernova discovery in the galaxy NGC4993, has started the new “Multimessenger” Astrophysics era.

Finally, it is worth noting that there is now an agreement (at least followed by ESA) to develop an advance plan for deorbiting satellites at the end of operational life in a safe mode.

VII. Status of International Cooperation in research relating to Life Science in Space[29]

VII.A. Overall assessment of the status of international cooperation in Life Sciences

International cooperation is the key to achieve the exploration of the solar system by humans. The members of Commission F represent a science community covering all spacefaring countries as well as membership from both developed and developing nations which is clearly seen also on the national distribution of Commission and sub-Commission officers. The five sub-Commissions cover all facets of life sciences in space research including investigation towards the origin and evolution of life on Earth and elsewhere; covering the basic mechanisms of the effects of spaceflight environment on molecular, cellular, tissue and whole system effects from plants to animals to humans; developing measures that allow humans to stay in space and on planetary surfaces during extended periods and finally performing studies on their life support. The research activities are closely connected to the activities of Commission B and E and to the Panels of Planetary Exploration (PEX), Planetary Protection (PPP), Space Weather (PSW) and Radiation Belt Environment Monitoring (PRBEM).



Red romaine lettuce grown in NASA's Veggie plant growth system on the International Space Station (*Credit: NASA*)

For the preparation of human missions in Space, a strong ground based research program should be in place to mitigate risks to crew health, thereby trying to ensure long-term crew health. Several major studies are on-going to define such a research program including roadmaps. The main tasks are to prevent behavioral conditions and psychiatric disorders as well physiological changes due to environmental factors. Two factors that have been shown to steadily increasing with mission duration are bone loss and the risk of late radiation effects. Basic research tackling the understanding of biological effects of microgravity and radiation are well covered in the program of Commission F. Provision of life support systems (LSS) is a precondition for human missions; this science is well presented in Commission F as well. There is also a strong interaction with

[29] This report was prepared by Guenther Reitz, Nuclear Physics Institute of the CAS (NPI), Prague, Czech Republic, Chair of COSPAR Scientific Commission F, with contributions by Tom Hei, Columbia University Medical Center, New York, USA, John Kiss, UNCG, Greensboro, USA, Dieter Blottner, Charite Universitätsmedizin, Berlin, Germany, Christophe Lasseur, ESA-Estec, Noordwijk, The Netherlands, Rafael Navarro-Gonzalez, Universidad Nacional Autonoma de Mexico, Ciudad de Mexico, Mexico, and Maria M. Kuznetsova, NASA GSFC, Washington, USA, chair of the COSPAR Panel on Space Weather.

Astrobiology research, since LSS uses different kind of biological systems, the behavior of such systems in extreme environments, namely the question on adaptability and survival strategies is one of the burning questions to be resolved in Astrobiology research. Astrobiology is also one of the core research fields in Commission F. The evolution and search for life in the universe is a basic question of mankind as well as the adaption of terrestrial life beyond its birthplace. Planetary protection programs to prevent contamination of visited solar bodies are of outmost importance for the search of life.

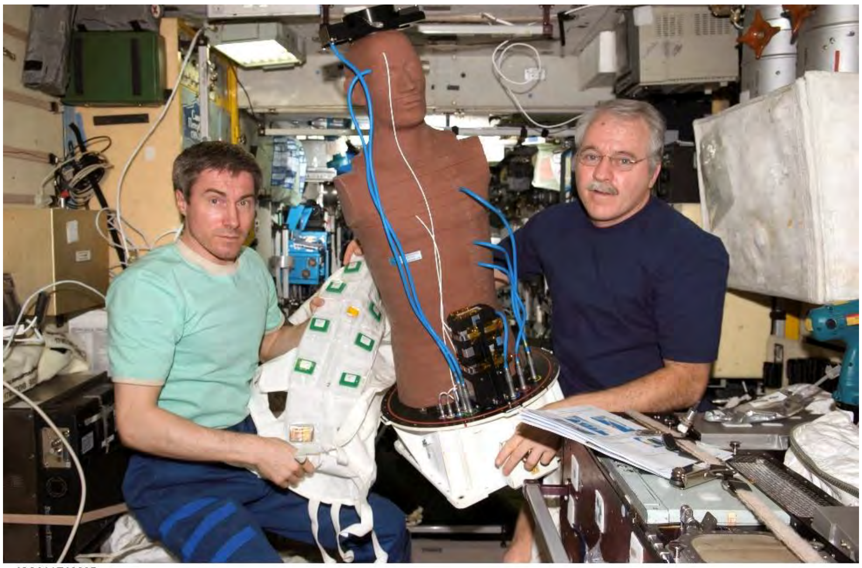
For isolation studies facilities such as the Human Exploration Research Analog (HERA) at NASA-Johnson Space Center (JSC), the *:envihab* at the German Aerospace Center (DLR), the Ground-Based Experimental Complex (NEK) at the Russian Academy of Sciences 'Institute of Biomedical Problems (IBMP) and Antarctica stations are major tools to prepare humans for long-duration missions. Our researchers make use of microgravity simulators such as clinostats, random positioning machines and magnetic levitation, as well as parabolic flights and drop towers. Radiation facilities, in particular heavy ion accelerators are the major simulation tool for cosmic radiation and are used for radiobiological studies. Balloon missions are used frequently for atmospheric radiation studies. Astrobiological research makes use of extreme environments on Earth to search for potential extraterrestrial habitable environments.

Besides the intense use of the ground facilities, experiments in space play a major role in all areas of research. Sounding rockets, e.g., TEXUS and MAXUS, and research satellites are used to get answers on basic effects of radiation and microgravity. But the major tool for life science research in space is the International Space Station (ISS). The use of centrifuges is essential to differentiate between microgravity and other space environmental effects. Meanwhile, the science community supports the ISS as the platform to fully simulate a Mars journey.

The community also participates in unmanned missions to other solar bodies, carefully interpreting results towards the questions to past and present occurrence of life forms, e.g., the Cassini mission, Mars Science Laboratory (MSL), ExoMars, and Mars 2020.

VII.B. Status of existing co-operations on on-going missions

The European Space Agency (ESA) has established since 2009 the special Ground-Based Facility (GBF) element which has been providing the scientific user community with the ability to access a large variety of European research laboratories and institutions that simulate some of the conditions that can be found in the space environment. NASA also recently has established a ground-based facility with microgravity simulators in the Kennedy Space Center. These programs yield further scientific knowledge of the basic influence of gravity or other space or planetary conditions on life, physical, and interdisciplinary processes in general and significantly improves the preparation of space experiments.



Disassembly of the ESA 'Human Phantom MATROSHKA' Experiment in the International Space Station (*Credit: ESA*)

For the reduction of uncertainties in radiation risk assessment, a comprehensive amount of radiation facilities is used, of which the major ones are the NASA Space Radiation Laboratory (NSRL) at Brookhaven National Laboratory on Long Island (NY), followed by the Heavy Ion Medical Accelerator in Chiba (HIMAC), Japan. The NASA Space Radiation Health Program is by far the most intense undertaking towards mitigating the radiobiological risk in explorative missions. The NASA Radiation Health program and the ESA IBER (Investigation of Biological Effects of Space Radiation) program are good examples of international collaboration. Similar programs are performed in Russia at the Dubna Heavy Ion facility and on the HIMAC Facility at NIRS in Chiba, Japan. There is a strong international cooperation between NASA, IMBP, Japan Aerospace Exploration Agency (JAXA) and ESA and international universities to continuously monitoring the radiation dose on the ISS (DOSIS3D, MATROSHKA, PADDLES, US and Russian Operational Radiation Monitoring Systems).

Astrobiology addresses questions on the origins of life, detection of biosignatures in the solar system such as Earth, Mars and Icy worlds as well as on ExoPlanets. The NASA Astrobiology Institute and the European Astrobiology Network Association provide up-to-date and comprehensive information on activities, accomplishments, and plans involved in the astrobiology enterprise worldwide. Studies are performed in extreme environments on Earth in field trips and in space using external exposure facilities on the ISS, Russian Biosatellites and CubeSats. In ESA's external exposure Facility EXPOSE that accommodates biochemical and biological samples various groups investigated the response of the samples to space environment and especially effects of the solar ultra-violet radiation in combination with vacuum.

Retrieval of the ESA EXPOSE Facility (*Credit: ESA*)

Protecting the environment for the detection of life on other planets constitutes one major part of the work and follows the COSPAR planetary protection policies. The community also participates in unmanned missions to other solar bodies carefully interpreting results towards the questions to past and present habitability of life forms, e.g., the Cassini program is an international cooperative effort involving NASA, ESA and the Italian space agency (ASI), as well as several separate European academic and industrial contributors with the central mission to gain a better understanding of Saturn, its stunning rings, its magnetosphere, Titan and its other icy moons.

Validation of plant cultivation technologies are performed at multiple analogue test sides to support bio-regenerative Life Support Systems (LSSS) for future human exploration. For example, MELiSSA (Micro-Ecological Life Support System Alternative) is a European Project. The MELiSSA consortium is a partnership of independent organizations including universities, research centers, Small to Medium Enterprises (SME's), and industrial world leaders. The flight experiment NITRIMEL, devoted to nitrifying bacteria in space, was successfully performed in collaboration between the MELiSSA project and IBMP. There is a continued exchange with the Russian colleagues at the Institute of Biophysics (IBP) in Krasnoyarsk and IBMP in Moscow. Ground demonstration of plant cultivation is further addressed in the COMPET 7 Program of Horizon 2020 with the EDEN ISS project. Of interest is NASA's testing of the VEGGIE plant growth unit on the ISS; plants are already being harvested. There have been similar demonstrations with the Russian Svet plant growth chamber on Russian Space Station Mir, and the Russian Lada vegetation chamber on the ISS.

NASA and ESA collaborate on the utilization of the Pulmonary Function System, MARES, and exercise research. NASA and JAXA collaborate on research to study bone-related risks, auscultation capabilities, and utilization of environmental sampling. Since 2016, the NASA Human Research Program (HRP) has begun discussions with DLR for multi-lateral human physiology and bed rest studies as well as human short-arm centrifuge studies to be conducted in their new facility—called "DLR :envihab"—located in Cologne, Germany. The first study will place 12 subjects in Head-Down Tilt (HDT) bed rest study for 30 days, in an atmosphere enriched in carbon dioxide. The study seeks to better understand and characterize the vision impairment and intracranial pressure syndrome observed in some ISS astronauts and determines whether a ground-based analog can be used to develop countermeasures. Another objective is to investigate neurostructural, neurofunctional, and cognitive function changes during bedrest—with and without the presence of CO_2 — a significant risk factor for the use of behavioral medicine in the clinical management of adverse behavioral or cognitive and psychiatric disorders.

A second multilateral HDT bed rest study related to a countermeasure trial such as reactive jumps (RSL-Study 2015-2016) has been conducted at the DLR's *:envihab*. In addition to this study in Cologne, ESA supported a 60-day bed rest study (COCKTAIL 2016-2017) Space Clinics from the CNES in Toulouse, France, mainly focusing on a special diet defending oxidative stress. Five HRP-funded and one DLR-funded research investigations have been conducted in the latter half of 2017.

Ongoing cooperative missions included existing flight missions (Bion-M1), unloading models (rats, mice) and simulated microgravity (clinostats) using cell lines. Bion Missions (biosatellite missions of 30 days' duration on orbit with mice) are used as cooperative missions between Russia, US, France and Germany. The main scientific objectives include muscle and bone research, immunology, brain and spinal cord, but also other body systems in small rodents and mice, as well as research in plant biology. The benefit of cooperation is certainly found first of all in sample sharing from space-flown animals, organizational support from the Russian Space Agency (RSA) and Institutions such as the IMBP, Moscow.

VII.C. Opportunities for co-operation on Future Missions

Isolation and bedrest studies have to be continued to ensure the best preparation for explorative missions. Besides such studies using analogues, the ISS is the main tool for Life Sciences research in space. Cooperation with the Chinese Space Agency using satellites and later on the Chinese space station will be enhanced in the future. Cooperation in the Russian Biosatellite program such as Bion will be continued to investigate basic effects of microgravity and radiation. Monitoring of the radiation environment will be continued on the ISS and also initiated in the Orion spacecraft.

The ISS is the best available platform that can mimic the impact of microgravity, radiation, living and psychological conditions that astronauts will face during a cruise to Mars. NASA has suggested a "full-up deep space simulation on last available ISS Mission: 6/7 crew for one-year duration; full simulation of time delays and autonomous operations". The most challenging venture for humanity asks for a final, real 'dry-run', a mission which is as close as reasonably possible to what will be the real voyage, lasting 400-800 days, mimicking most of the challenges which will be undertaken during a deep space mission: length, isolation, food provision, decision making, time delays, health monitoring diagnostic and therapeutic actions and more. In future, when a cis-lunar hab is in place, this will significantly enlarge the performance of dry runs in preparation for Mars.

NASA is planning a collaborative study with the Russian IBMP Ground-Based Experimental Complex (NEK) isolation facility to investigate multilateral isolation missions of 4-, 8-, and 12-months. The aim is to gather operational knowledge for long-duration missions, including a Russian-sponsored 520-day mission that was part of the campaign called Mars 500.

For promoting cooperation between divisions of JAXA and ESA relevant to the human planetary habitation in space information about concepts, achievements, and future plans of the MELiSSA project and Japanese relevant projects was exchanged in recent meetings. Members of the Science Union of Human Planetary Habitation in Space launched in 2016 as a cooperative organization of five space-related scientific communities in Japan mainly attended the Symposium. The controlled ecological life support system (CELSS) is an important step for the development of China's manned space program. The first 180-day campaign with four astronauts growing 25 different kinds of plants was successfully completed and includes a dozen institutions from China and other countries.

Scientists are looking forward to future missions like the second part of ExoMars, Juice to Jupiter and sample return missions to asteroids and Mars. This is especially so regarding the latter one, which will allow a deeper insight in the chemistry of the bodies and to improve the potential search for traces of life.

Another opportunity of international cooperation is encouraging formation and creating coordinated funding opportunities for dynamic international action teams focusing on specific tasks and emerging needs identified in Roadmaps. These teams can also be also a resource for periodic Roadmaps updates, maintaining website consolidating all relevant information and building a network of interconnected web-based resources. This will address the need to move from cooperation in writing reports, plans and roadmaps to collaborative, innovative and cost-effective approaches.

VIII. International Cooperation Relating to Microgravity Research in Physical and Material Science[30]

VIII.A. Overall assessment of the status of international cooperation in Microgravity Physical Science

In the physical sciences research, the aim is improving our knowledge in areas such as materials, fluids and novel states of matter such as complex dusty plasmas by enabling studies of phenomena that are masked on Earth by the influence of gravity. The results of this research will improve fundamental knowledge and may be used to optimize chemical industrial processes or combustion processes in power plants or automobile engines, and improve industrial casting models to help in the development of new alloys.

International cooperation relating to physical science did comprise a few large missions in past. Since the early 1980’s, the launch of the first Space Shuttle has initiated a new era in access to space for microgravity science. The first European-built and NASA operated Spacelab-1 was launched on board Space Shuttle Columbia in November 1983. The 71 microgravity experiments, conducted using instruments from the European Space Agency, produced many interesting and provocative results. During the mission, scientific experiments were conducted in a variety of fields including Astronomy, Solar Physics, Space Plasma Physics, Earth Observation, Material Science, Technology and Life Sciences.

In October-November 1985 was a scientific D-1 Spacelab mission, funded and directed by Germany. The mission carried the NASA/ESA Spacelab module into orbit with 76 scientific experiments on board, and was declared a success. Payload operations were controlled from the German Space Operations Center near Munich, instead of from the regular NASA control centers. The experiments included investigations into fluid physics, with experiments in capillarity, Marangoni convection, diffusion phenomena, and critical points; solidification experiments; single crystal growth; composites; biological studies, including cell functions, developmental processes, and the ability of plants to perceive gravity; medical experiments, including the gravitational perceptions of humans, and their adaptation processes in space; and speed-time interaction studies of people working in space.

The D-2 (STS-55, April 1993) mission augmented the German microgravity research program started by the D-1 mission. Eleven nations participated in the experiments. This flight was a multinational Spacelab flight involving 88 experiments from eleven different nations. The experiments ranged from biological sciences to simple earth observations. DLR, NASA, the European Space Agency (ESA), and agencies in France and Japan contributed to D-2's scientific program. Of the 88 experiments conducted on the D-2 mission, four were sponsored by NASA.

Neurolab (STS-90 in 1998) was a joint venture of six space agencies of Canada, France, Germany, and Japan, the European Space Agency and NASA. Investigator teams from nine countries have conducted 31 studies was focused on the effects of microgravity on the nervous system. This was the 16th and last scheduled flight of the ESA-developed Spacelab module although Spacelab pallets would continue to be used on the International Space Station.

MIR Space Station was circling the Earth on low orbit from 1986 to 2001, operated by the Soviet Union and later by Russia. The international collaborations were done through dedicated program such as the Intercosmos, Euromir and Shuttle-Mir programs, which made the station accessible for several Asian, European and North American nations. The station served as a microgravity research laboratory in which crews conducted experiments in biology, human biology, physics, astronomy, meteorology and spacecraft systems with a goal of developing technologies required for permanent occupation of space. A Canadian-built system used magnetic levitation to isolate sensitive experiments from very small movements.

A modular Space Station MIR was precursor of the International Space Station (ISS) launched into orbit in 1998.

[30] This report was prepared by Valentina Shevtsova, Chair of COSPAR Scientific Commission G.

VIII.B. Status of existing co-operations on on-going missions

The International Space Station (1998 to present) provides the highly desired condition of long-duration microgravity, allowing continuous and interactive research similar to Earth-based laboratories. The program has benefited from research collaborations among the International Space Station partners (NASA, Russia, Europe, Japan, and Canada) and individual foreign governments with space programs, such as France, Germany, and Italy. The phase of active scientific experiments has been started in 2007 and continued until now.

In fluid physics experiments, the scientists examine capillary flows, Marangoni convection, colloids, evaporation, miscible fluids, crystallization, foams, combustion, and, as the ISS offers long duration microgravity time, there is a series of experiment on diffusion and thermo-diffusion in liquid mixtures.

Material science is another area in which the lack of gravity is a key. The Microgravity Materials Science Program conducts experiments on the International Space Station designed to improve our understanding of materials processing and properties in order to achieve better and/or less expensive materials. The ISS provides a simplified environment to study materials since there is nearly negligible sedimentation- and buoyancy-driven convection affecting the observations. This helps scientists clarify the role of different effects on materials processes. The series of the ISS experiments investigate binary colloidal alloys, the structure of paramagnetic aggregates from colloidal emulsions, magnetically controlled convective conditions, etc.

The astronaut Mike Hopkins installs the DCMIX-2 cell array into the Selectable Optical Diagnostic Instrument (SODI) on-board the ISS on 30 November 2013 (*Credit: NASA*).

Another recent mission is the Chinese mission SJ-10 with 20 scientific experiments which was launched in April 2016. In the SJ-10 program, there were 6 experiments of fluid physics, 4 of combustion, 8 of material science, 3 of radiation biology, 3 of gravitational biology and 4 of biotechnology. One of the scientific experiments (Soret Coefficient in Crude Oil) was jointly developed with ESA (European Space Agency). The scientific objectives of SJ-10 experiments may be summarized as follows:

- To promote the basic research of fluid physics and biology experiments.
- To support the manned space flight for fire safety research.
- To improve human health topics in biotechnology studies.
- To develop high-technology experiments of coal combustion, materials processing, and biotechnology.

VIII.C. Opportunities for co-operation on future missions

The experiments on the International Space Station will continue until 2024.

Currently, there is no announced future mission in the frame of which can be conducted experiments in microgravity physical and material science. The future of the European microgravity science is partly possible in cooperation with China.

Another program under discussion between the International Space Station partners is the “Deep Space Gateway”. Some microgravity experiments can be conducted in frame of this program.

IX. International Cooperation regarding Fundamental Physics in Space[31]

IX.A. Overall assessment of the status of international cooperation in Fundamental Physics in Space

Fundamental Physics in Space is about the exploration of the basic laws governing our universe, ranging from the microscopic domain to the largest dimensions. It covers the generally valid laws of quantum mechanics, statistics, and gravity and explores the basic interactions described today through the standard model. One main issue is to explore the fundamental laws underlying Quantum Theory and General Relativity with better precision and finally to resolve the inconsistency between these two universal theories. Furthermore, the properties of many particle systems and the laws of structure formation need to be better understood. Finally, the structure of the Universe including galaxy clusters, galaxies, stars and solar systems, Neutron Stars and Black Holes, has to be investigated. Major tools for that will be high energy astroparticle astronomy and gravitational wave astronomy, together with conventional optical and radio astronomy. Besides the understanding of the physics of Neutron Stars and Black Holes, one has to resolve the mysteries of Dark Energy and Dark Matter. Fundamental Physics in Space is about how space can help to answer these important scientific questions and whether the technology required for that is ready.

At the moment Fundamental Physics in Space is very active and exciting: LISA Pathfinder has been just shut down after very successful technology tests, we have the running missions MICROSCOPE testing the Equivalence Principle in Space, the LARES mission for a better test of the general relativistic Lense-Thirring effect, data analysis of the clock data of the Galileo 5 and 6 satellites being on an elliptical orbit around the Earth for a better test of the general relativistic gravitational redshift, GAIA which makes high precision astrometric measurements also testing General Relativity, AMS on the ISS which delivers data on the antimatter content of the universe, the MAIUS mission with the first Bose-Einstein Condensate in space, and the Quantum Key Distribution mission QUESS. The number of Fundamental physics missions operating at once has never before been realized.

The LISA Pathfinder spacecraft (*Credit: ESA*)

[31] This report was prepared by Claus Lämmerzahl, ZARM, University of Bremen, Germany, with contributions by Alexander S. Zakharov, New York University, USA and CERN, Switzerland, and Paul MacNamara, LISA Pathfinder project scientist, ESA, The Netherlands.

The first Fundamental Physics experiment in Space was and still is Lunar Laser Ranging LLR. Further earlier missions were GP-A launched in the late seventies to perform the up-to-date best test of the gravitational redshift, LAGEOS which made the best test of the Lense-Thirring effect presently being improved by LARES, the Saturn mission Cassini which also tested the gravitational time delay and provided the presently best Solar system test of General Relativity, and GP-B which for the first time measured the Schiff effect, i.e., the precession of a gyroscope due to the general relativistic frame dragging.

In any case, the missions benefit or require the space conditions which are given by: (i) extreme long distances, (ii) large velocities, (iii) large gravitational potential differences, (iv) much increased free fall time, (v) quiet environment without seismic noise, and (vi) all degrees of freedom without boundary conditions or restrictions. The extreme large distances are needed for gravitational wave detection at low frequencies and for the exploration of the large scale structure of the gravitational field. Long distances are also used in LLR and the tests of the Lense-Thirring effect. Large velocities are required for tests of Special Relativity (or Lorentz invariance), and large gravitational potential differences lead to large gravitational redshift experienced by clocks. The measurement of tiny forces requires a long time of free fall for an accumulation of these small forces. This is important in tests of the Equivalence Principle as is just being done with MICROSCOPE. This mission also takes advantage of the fact that a satellite can accelerate in all directions and rotate around all axes, that is, of all motional degrees of freedom.

An artist rendition of the MICROSCOPE satellite (*Credit: CNES*)

The earlier Fundamental Physics missions are:

- **LLR** (Lunar Laser Ranging): The NASA Apollo missions brought laser reflectors to the Moon. By means of laser pulses sent to the Moon, being reflected, and registered again on Earth, the relative distance between the Moon and the Earth can be measured in the cm range. This gives new results for tests of the Weak Equivalence Principle, the Strong Equivalence Principle, as well as for Earth sciences as, e.g., Earth rotation, tectonics, etc.
- **GP-A** (Gravity Probe A): A Hydrogen maser has been brought to a parabolic flight of 10,000 km height over ground using a Scout rocket. The maser has been continuously compared in a two-way scheme with a similar maser on ground. This NASA mission gave the currently best test of the gravitational redshift and also new results on the special relativistic Doppler effect.

- **LAGEOS** (Laser Geodynamics Satellite): This mission consists of two high-density ball-shaped satellites equipped with passive laser reflectors. While this US-Italian mission was designed for geodesy and measuring plate tectonics it has also been used for a first confirmation of the Lense-Thirring effect.
- **Cassini**: Cassini-Huygens is a very successful NASA/ESA/ASI Saturn mission launched in 1997. One part of the payload was a transponder in order to exchange signals with the Earth. The time of flight of these signals depends on the gravitational field (of the Sun) the signals traverse. If the Sun is near to the signals, then the time of flight is larger (gravitational time delay or Shapiro effect). Cassini carried through the best test of this effect and therewith also the best estimate of the Post Newtonian Parameter gamma.
- **GP-B** (Gravity Probe B): This is a mission measuring the tiny precession of a spinning top during its flight around the Earth. The spinning top is a Niobium coated silicon sphere the rotation axis of which could be extremely precisely measured using SQUIDs. With that the geodetic precession of 6.6 arc-seconds per year has been measured with an accuracy of 0.3% and the Schiff effect (the precession due to the gravitomagnetic field of the Earth) of 37 milliarc-seconds per year has been confirmed for the first time with 20% accuracy.

IX.B. Status of existing co-operations on on-going missions

Running missions (including terminated missions where data analysis is still ongoing) are:

- **LISA Pathfinder**: This is a mission dedicated to test the basic technologies for the gravitational wave mission eLISA. These were the laser interferometry, the inertial sensors, and the drag free control. All systems exceeded their target performance. Together with the recently direct detection of gravitational waves from Black Hole and Neutron Star mergers, the selection of LISA as the third Large class mission in the ESA science program was advanced.
- **LARES** (Laser Relativity Satellite): Like LAGEOS this is a metallic ball equipped with laser reflectors. It complements LAGEOS in terms of its inclination which had be chosen in such a way so that LAGEOS and LARES data can be combined so that the largest disturbing effect due to J2 can be eliminated. This then will give a confirmation of the Lense-Thirring effect at the 1% level within a few years of measurement time.
- **AMS-02** (Alpha Magnetic Spectrometer): This is an astroparticle instrument mounted on the ISS in 2011. It detects and counts antiparticles. One major result is the excess of cosmic positrons over electrons, with a possible explanation for the excess using a Dark Matter model with a particle mass around 1 TeV.
- **PK-4** (Plasma Krystall-4): In collaboration between ESA and Roscosmos, this experiment carried through on board of the ISS studies complex plasmas with low temperature gaseous mixtures composed of ionized gas, neutral gas, and micron-sized particles.
- **MICROSCOPE** (Micro-Satellite à traînée Compensée pour l'Observation du Principe d'Equivalence): With this satellite launched on April 25, 2016, the first test of the Weak Equivalence Principle in space is being performed. The mission is still running but the first data have already been analyzed and published reporting an improvement of the best Earth bound test by one order of magnitude. MICROSCOPE is a CNES mission with contributions from ESA and the DLR.
- **MAIUS** (Matter Wave Interferometry in weightlessness): After many years of developments of the technologies in the Bremen drop tower, in January 2017 the first Bose Einstein Condensate has been created in space on board on a sounding rocket. This is a major technological step in bringing quantum technologies to space. More experiments on this type are planned within this DLR funded space project.
- **QUESS** (Quantum Experiments at Space Scale): This is another dedicated mission for bringing quantum technology to space. This Chinese mission has been launched in September 2016 and carried through a quantum key distribution experiment (QKD) where entangled quantum states on the satellite and on the Earth have been created.
- **Galileo**: This "mission" just takes advantage of the failure of the Fregat module on a Soyuz rocket with the consequence that the satellites Galileo 5 and 6 were brought to an elliptic orbit only. With clocks on the Galileo satellites one is able to measure the gravitational redshift, i.e., the change of the observed ticking rate of the clocks according the altitude of the satellites. The eccentricity of about 0.15 implies that the height variation is about 8700 km twice per day. It could be shown that orbit modelling taking into account the influence of Solar radiation is necessary for a consistent data interpretation. The results are at the level of GP-A.

IX.C. Opportunities for co-operation on future missions

There are two missions which are well defined and on the way to become realized. The first one is ACES/PHARAO, the other is eLISA:

- **ACES/PHARAO** (Atomic Clock Ensemble in Space / Projet d'horloge atomique par refroidissement d'atomes en orbite): This project brings two clocks, a Hydrogen maser and a Cesium laser cooled atomic fountain clock to the ISS. They will be the best clocks in space with a stability of the order 10-16. They will perform fundamental tests of Lorentz invariance, redshift, the constancy of the fine structure constant, and more, but also technological tests by doing clock synchronization on Earth.
- **eLISA** (Laser Interferometer Space Antenna): eLISA will detect gravitational waves in the low frequency range between 0.1 and 100 mHz. This corresponds to binary systems in their early stage before merger and to the merger of supermassive Black Hole binaries.

There are of course plans and developments for possible future missions, experiments and technologies. This has been discussed on a recent conference on Fundamental Physics in Space, held in Bremen in late October 2017. There are several developments for the future:

- (1) Development of quantum technologies: This is a general task as can be seen by the huge financial investment by the European Union, the UK, China and the US in the development of corresponding technologies. Regarding space, this will concern the further development of clocks, of laser interferometers, of cold atom interferometry, entanglement, and others. Possible applications in space are space quantum metrology, TAI from space, geodesy, fundamental physics tests (tests of General Relativity, quantum theory), satellite control, communication, and others.
- (2) Clocks in space: Clocks in space are important for the definition of time from space, possibly for clock based geodesy from space, and for improved and new tests of General Relativity. Regarding the latter there are proposals to test the gravitomagnetic clock effect, the clock analogue of the Lense-Thirring and Schiff effect. Clocks also help in searching for generalized theories of gravity.
- (3) Optical technologies: These technologies are important for communication as well as for new tests of General Relativity.
- (4) Many particle physics: This concerns the properties of fluids, plasmas, quantum fluids and other collective phenomena. For these phenomena gravity on Earth is always destroying the symmetry and leads to unwanted effects. Investigations of undisturbed many particle systems will allow for a better confirmation of e.g. the universality nature of critical phenomena, scaling properties, quantum phenomena.

X. Concluding Remarks

The goal of the COSPAR Report on the Status of International Cooperation in Space Research, as described in the Introduction, is to provide a concise report that increases the awareness of the COSPAR community of ongoing missions and research programs involving international cooperation, and in particular awareness of opportunities for future missions and programs that COSPAR could help facilitate. We hope we have succeeded in this goal and that the COSPAR community will assist by evaluating the impact of the Report, and in improving future reports.

Some concluding remarks are in order:

- The Report confirms a basic tenet: space research, in all disciplines, is a truly international endeavor, as it must be. The only limitation on our capability to explore and to utilize space, to create knowledge and profound discoveries, is the resources that we can apply. And so we must maximize the effective use of available resources by sharing the burden across all space programs with the technical capability to contribute.
- In the world today, with its frightening geopolitical challenges, international cooperation in space research stands as a beacon of hope that we can replace parochial needs with pursuit of the common good. Space is the domain of all nations who will use it for peaceful purposes and so we should pursue the exploration and utilization of this global commons in cooperation.
- In the world today, with the future of our civilization threatened by the human impact on our climate, international cooperation in space is ever more important: actions and solutions must be pursued based on knowledge acquired and accepted by all nations.
- In the world today, where nations throughout the world seek to benefit from the opportunities in space, but lack the technical workforce and resources to do so, international cooperation in space research spreads the benefits widely, and improves the lives of many.
- COSPAR is on a mission to encourage and facilitate international cooperation in space research: to maximize available resources, to assist in the pursuit of world peace, to assist in protecting our planet from ourselves, and to share the benefits of space research with all humankind.

Please join us in this effort.

Lennard A. Fisk

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