An International Constellation of Small Spacecraft

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Introduction

The Committee on Space Research (COSPAR) has had a long history of bringing the nations of the world together to undertake creative space endeavors. In 2017, COSPAR assembled a group of researchers, managers, and policy makers to examine the question of how small satellites might be used to advance technology, science research, and space applications. The two-year COSPAR study led to a summary publication (Millan et al., 2019) that laid out a compelling plan ("scientific roadmap") that gave specific guidance concerning small spacecraft utilization. These recommendations were directed to the science community, to the space industry, to various space agencies, and broadly to policy makers around the world. Ultimately, the study team recommended that COSPAR take the next logical step and lay out goals, rules, and a viable approach for international smallsat research.

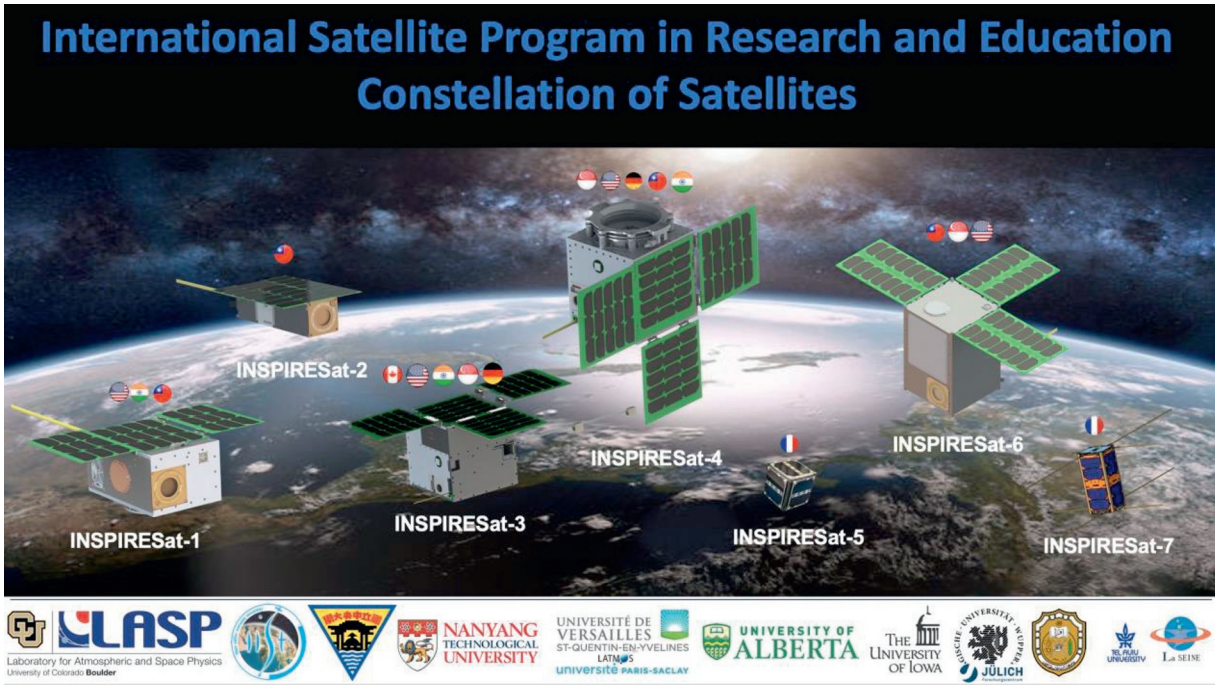
In 2019, COSPAR established a Task Group to develop an "actionable" plan for an international constellation of small satellites. As a background for taking such an approach, the COSPAR senior leadership quoted from the March 2019 COSPAR Strategic Plan:

> *"As a demonstration of COSPAR's value to its Members, and its importance in space research, COSPAR should explore the possibility of assembling an international consortium that will develop, launch, and acquire data from a constellation of small satellites. As always with COSPAR activities, participation in the consortium would be voluntary. The small satellites with instruments would need to be provided by member nations, and there will need to be a major space agency(s) that facilitates launches and data collection. It will be important that the constellation yields useful and important data, so that each contributing nation can state that it is assisting in the solution of an important scientific problem. A particularly useful constellation would be one that measures the plasma conditions in the ionosphere, with sufficient measurement density to substantially improve space weather forecasts."*

In pursuit of these objectives, the COSPAR leadership team also drew guidance from the organization's scientific roadmap (*Millan et al., 2019):*

> *"COSPAR should facilitate a process whereby international teams can come together to define science goals and rules for a modular, international small satellite constellation. The role of COSPAR is one of an honest broker, coordinating not funding. The results of an international effort to build small satellite constellations would be valuable for all participants and would be more valuable than the individual parts. COSPAR is in a position to help foster this international collaboration, creating a precedent for setting up community science in a very open way."*

Sidebar 1: INSPIRE



The INSPIRE constellation of satellites with the flags of each mission's participating nations on top. The INSPIRE partner University logos are below the graphic

The International Satellite Program in Research and Education (INSPIRE) started off in 2015 as an international consortium of space-faring universities for developing space science missions. The participating universities intend to develop academic programs to teach space science and engineering to develop capacity building in spacecraft development, instrumentation and data analysis. The first INSPIRE satellite mission was funded internally by participating universities in 2017 and is currently undergoing environmental testing for a 2020 launch. INSPIRE currently has 6 missions funded from various participating universities and national space agencies and aims to provide a constellation of Earth and space weather-observing satellites. INSPIRE runs a 10-week summer program at the Laboratory for Atmospheric and Space Physics at the University of Boulder campus from May to July. Students from INSPIRE partner universities come to CU-LASP facilities to work on current and future INSPIRE missions.

The work broadly involves:

1. Participating in preliminary design of missions
2. Hardware prototyping
3. Flight hardware development
4. Testing and Integration
5. Mission Operations

Task Group Charter

In accord with previously mentioned recommendations, a Task Group was established in late 2019 for the purpose of developing an actionable plan for implementing the recommendations of the COSPAR *Strategic Action Plan* and the COSPAR Scientific Roadmap on *Small Satellites for Space Science*. The Task Group charter is intended to be an ongoing effort focusing on a series of small satellite constellations addressing many outstanding problems important to humanity. The Task Group members agreed that initially, at least, the driving theme for the first effort should be "Space Weather and Space Situational Awareness".

Specifically, the Task Group was directed to:

- Design, in reasonable detail, a constellation of small satellites that could measure the plasma conditions in the ionosphere, with sufficient measurement density to substantially improve space weather forecasts;
- Specify the measurements required and likely instruments that must be carried on each spacecraft;
- Specify the data rates and possible means for acquiring and analyzing the data, and making it available to improve space weather forecasts;
- Determine which national space programs, or organizations would be willing and able to contribute a capable small satellite to the constellation;
- Determine whether a major space agency or agencies would be willing and able to assist in the development, launch, and operations of the constellation;
- Specify the permanent organization structure that would coordinate the development and operations of the constellation.

The Task Group was also asked to coordinate its activities with the INSPIRE program (See Sidebar 1), which aims to provide a constellation of Earth and space weather-observing satellites through international collaboration between university and industry partners. INSPIRE is a consortium of global space universities formed to advance space science and engineering, and can be a source of small satellites for the constellation while providing capacity building opportunities for participants. The Task Group has had membership drawn from the international community committed to—and knowledgeable on—the use of small satellites. The purpose of the TG included both encouraging international cooperation and making a meaningful contribution to solutions of problems that are important to humanity. The authors of this article constitute the present Task Group membership.

Task Group Progress

The COSPAR team, known formally as the Task Group on establishing a Constellation of Small Satellites (TGCSS) began its formal deliberation work in early March of 2020. The effort to date has been carried out via email exchanges and biweekly videoconferences. In addition to deliberations about what COSPAR should–and should not–do as part of its action plan, the TG has also examined many present and prior smallsat programs such as QB50 (see Sidebar 2) to learn lessons and to understand what most is needed going forward.

The Task Group members also agreed to begin addressing several key issues and concerns:

- Smallsat design/system engineering
- Spacecraft bus standards
- Access to space
- Ground systems/communications
- Data archiving/sharing/standards

The Task Group members quickly recognized two quite important and distinct aspects of the COSPAR Action Plan. One branch of activity should be geared toward harnessing and taking good advantage of what international COSPAR adherents

already are doing in the smallsat realm (see Sidebar 3). By identifying and orchestrating such efforts, COSPAR is able to perform an immensely worthwhile service to the space community and the nations of the world.

The other aspect of this plan is to build capacity amongst nations and institutions that presently have little (or no) space involvement or experience.

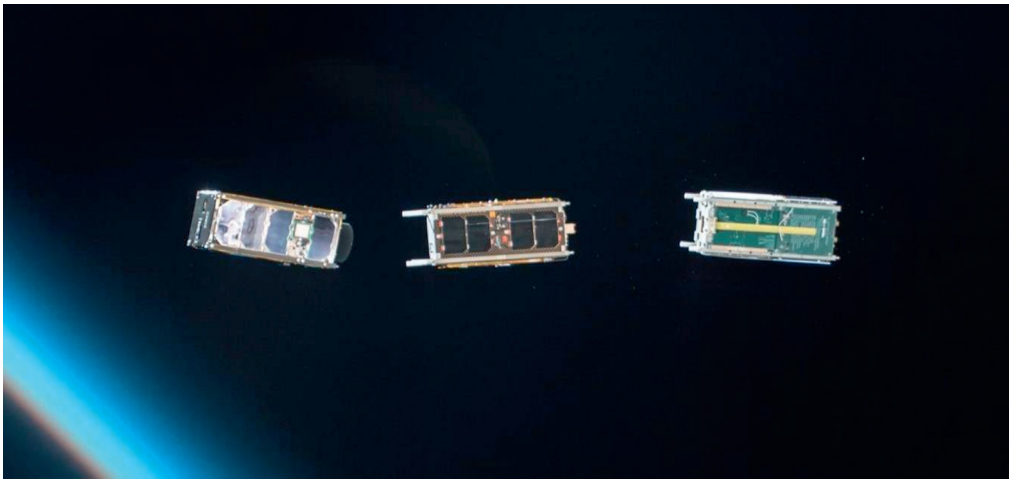
Sidebar 2: QB50

The QB50 project (www.qb50.eu) was an ambitious CubeSat-based scientific mission with the goal of flying nearly 50 spacecraft in the lower thermosphere (90-350 km), a region traditionally inaccessible due to high atmospheric drag.

The project was funded by the European Commission via a FP7 grant. The spacecraft were developed by over 40 institutions worldwide, with many providing their first spacecraft ever. Each spacecraft development team chose one of three scientific instruments (Langmuir probe; ion and neutral mass spectrometer; oxygen sensor) provided by the project, and committed to downloading data for 60 days. Beyond this, institutions could carry their own payloads in 2U or 3U form factors.

The QB50 constellation of 36 spacecraft was launched in two instances in April and June 2017. QB50 was extremely successful as an educational project which was its primary objective, although only 16 spacecraft were producing valuable science data on a daily basis. One CubeSat (InflateSail) successfully completed its mission within 2 months, the others took a large number of measurements using a widely-distributed network of sensors in the hitherto poorly studied lower thermosphere; the last one re-entered the atmosphere in December 2018.

The QB50 mission demonstrated the potential of international university collaboration supported by the "new space" industry (start-up companies that grew up in academia), by launching a network of CubeSats built by university teams from 23 different countries around the world. Such a model provides enormous potential for science.

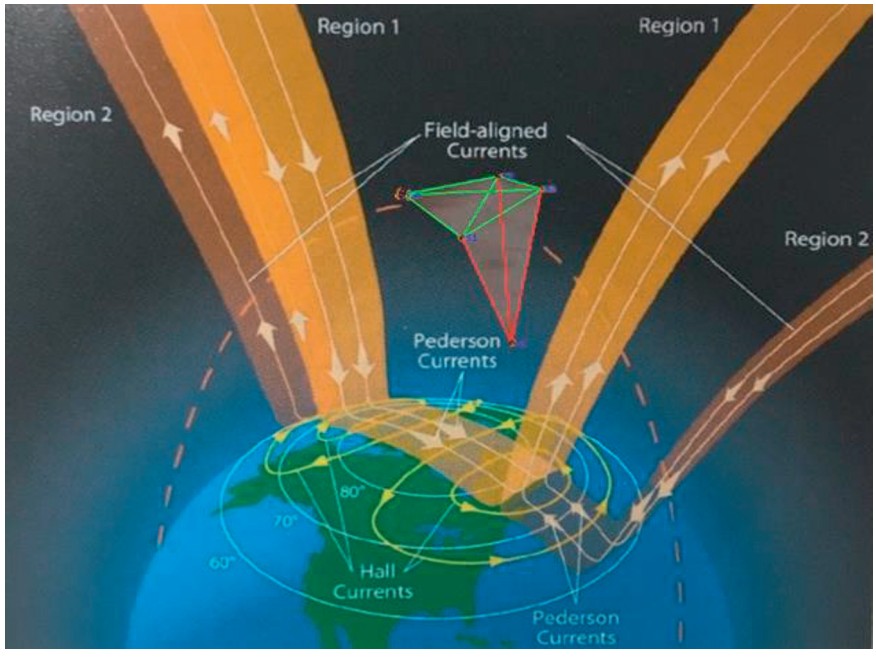


Three QB50 satellites after deployment from the *International Space Station* (Image Credit: The QB50 Consortium, von Karman Institute)

Sidebar 3: MUSE

MUSE ***M***ultiscale c***U***rrents density and magnetic field ***S***tructure ***E***xplorer, a 5-CubeSats formation mission for space weather research.

The MUSE mission is proposed to measure the multiscale magnetic field structure and in-situ current density in the polar region, by multi-CubeSats with formation flight over the Earth polar region. The mission consists of one mother small-sat and four daughter CubeSats, with a set of precision AMR magnetometer and deployable boom onboard each of them. Thanks to the technology of the magnetometers and spacecraft formation, MUSE would uniquely measure the multiscale magnetic field structure from 1 km to 100 km scale and in-situ current density distribution, tracking the multiscale coupling process during substorm. It represents a typical utilization of small satellite for space science according the guidelines of the COSPAR small satellites roadmap for space sciences.



By bringing more developing nations to the "space exploration table", COSPAR will greatly increase and benefit the entire space enterprise.

Task Group Points of Consensus

As the TGCSS has met and discussed the elements of an actionable plan, several areas of strong consensus have been reached. The TG members have reaffirmed the notion that COSPAR should be the "honest broker" in getting the smallsat effort organized and initiated. But, the smallsat program should be a bottom-up effort in most respects, not a top down enterprise. Everything possible should be done to encourage "grass roots" involvement and development. The TG members agree that COSPAR as an organization should emphatically not design spacecraft or dictate engineering approaches but rather provide overall coordination and best practices for engineering efforts as required. More experienced COSPAR adherent bodies might offer mentoring and guidance to less seasoned players, but there should be great flexibility for teams that wish to join in the efforts.

The TGCSS members are in strong agreement that COSPAR can—and should—help to solicit contributions to the CSS effort. COSPAR can

also help seek launches and launch services through its member nations. Certainly, COSPAR could readily help in defining data standards and data sharing protocols. But all of this should be done with a light hand.

In all of this, it is envisioned that COSPAR (perhaps through a successor body to the TGCSS) would provide a framework and a set of rules for active participation. The task is not to build forcefully a constellation so much as it is to allow an effective constellation to self-organize and come together. COSPAR can act as a facilitator bringing together institutes contributing instruments with organizations providing spacecraft and agencies making available launches. By learning from earlier efforts, COSPAR can help to share best practices and give sound advice.

Present Steps and Future Vision

Right now–under the aegis of the TGCSS—we have been polling nations and various COSPAR adherent bodies around the world. The question being posed is whether COSPAR entities are interested in this program and what elements such COSPAR adherents might wish to "lay on the table" now or in the near future. We are also seeking ideas on what nations might do to help support the CSS infrastructure. Of course, our next step is to collect and analyze the responses from this COSPAR letter of inquiry sent out some weeks ago. This will help to inform and guide the next phases of the program.

We also note our interest and intention of involving industry in meaningful ways. Finding industry partners through the good offices of COSPAR could help jump start programs for many aspiring nations and institutions. If industry partners wished to contribute expertise, hardware, or data support, this would be welcome in a program such as envisioned.

The TGCSS also likes the idea that we would—under our own auspices with COSPAR support—organize regional "town hall" virtual meetings to solicit more ideas and engage with developing nations. With such meetings we could understand better the interests and capabilities in the Asian, African, European, and American sectors.

Finally, Task Group respectfully suggests that we have "planned" long enough—it is time for more action. This leads to us urging that we move forward toward an implementation phase even before the 2021 COSPAR meeting. It is envisioned that our TGCSS might now evolve more towards a "steering committee" that will advise and guide future subcommittees and groups working on various aspects of the implementation phase of the COSPAR program.

Summary and Conclusions

The TGCSS envisions that this first Space Weather constellation effort will serve as a demonstration mission, establishing a framework for carrying out future international constellation programs that tackle key science questions in all of the space science disciplines. We believe that the TG has validated many of the points raised in the COSPAR Roadmap. We further believe that a grass roots, bottom-up approach under the guiding hand of COSPAR can be immensely successful in coordinating efforts from established nations as well as providing great opportunity for developing nations.

The Task Group members and senior COSPAR leadership welcome questions, comments, and suggestions for advancing the CSS program. We also welcome active participation from interested members of the science community, from policy makers, and representatives from the aerospace industry.

Reference

R.M. Millan et al. *Advances in Space Research,* **64** (2019), 1466–1517.