A laboratory as tested bed for novel space technologies: from blueprint to orbit

We want to use space-based astronomy with CubeSats as a driver to consolidate an agile development cycle of space technologies for scientific and application space missions.

Since the dawn of the space era, the development of space technologies has been restricted to economically developed countries. This is the case for geoscience and astronomy missions, which have always been the domain of big space agencies. Space telescopes are usually designed, built, launched, and managed by government space agencies such as NASA, ESA, and JAXA. The costs of such types of endeavors typically range from hundreds of millions to a few billion dollars and can take decades to complete. However, the recent technological concept of CubeSat has opened an opportunity for the participation of smaller actors. CubeSats are a subset of miniaturized satellites which are built in standard units of 10 cm × 10 cm × 10 cm cubes, called 1U, and typically weigh less than 2 kg. Such standardization of satellites' size has made their components more readily available and has dramatically lowered the development costs, thereby causing the recent spike in CubeSat's popularity. The same drive towards miniaturization and component standardization is evident in our everyday lives and has pushed technological development globally in the past two decades. Small, embedded cameras, for example, began as expensive gadgets. But thanks largely to smartphones they became progressively cheaper, smaller, and better, and are now found in all sorts of devices, from cars to drones and even CubeSats. The same virtuous cycle of commerce and innovation is actively driving the CubeSat surge today.

Satellite scientific missions, devoted to geosciences or astronomy, have the potential to advance technological developments that can be relevant to other, more applied fields such as Earth remote sensing or communications.

Chile is decades and several billions of dollars in investment behind the leading countries in space exploration. On the other hand, Chile is only a few years behind the same countries in the case of development of CubeSats technologies for scientific research. The Space and Planetary Exploration Laboratory (SPEL) from the Faculty of Physical and Mathematical Sciences (FCFM) at the University of Chile (UCH) has been leading the study and development of CubeSat-based space missions in the country with four missions: the SUCHAI-1 (1U CubeSat), SUCHAI-2 (3U), SUCHAI-3 (3U) and PlantSat (3U). The last three 3U missions were launched into space recently (April 1st, 2022) and are designed to operate in a coordinated manner. Telescope-term, these capabilities developed for space-based optical and radio telescope missions would serve as a tested bed for further missions for geophysical research and space applications.

Chile is at a pivotal moment since it is developing a space program to execute a national plan. In this plan, universities and research centers could play a relevant role by developing knowledge and technology as pathfinders that can be used for large national missions once they have been tested in smaller missions. We propose to consolidate the process used in SPEL for developing and testing novel (but risky) space technologies. The process includes laboratory and balloon testing on Earth, as well as space testing and experiments aboard the International Space Station (ISS) and in 1U to 3U CubeSat missions with the aim to reinforce the skills needed to perform space-based astronomy. Thus, we propose a mission to perform photometric studies from space over one of the closest astronomical objects to Earth: the Moon. Although the Moon does not seem very exciting as an astronomy target, photometry measurements of the moon, by using the earthshine method, could provide precise estimates of the Earth's albedo, a key parameter in the radiative balance of the Earth, which is important for the modelling of the global climate change. Furthermore, knowing the irradiance at different points of the orbit on its dark sides could be a relevant parameter for estimating aerosols using ground-based moon-photometers at night. The envisioned mission will use a 6U or 12U CubeSat platform. During the design phase we will have to overcome some technical challenges for the telescope and for the attitude determination and control (ADC). The technology for the mission will be tested in the thermal vacuum chamber and shakers available at SPEL. At the Chilean Nuclear Energy Commission (CCHEN), we will perform radiation tests on the subsystems. We propose to test the systems in space at the ISS for one to three months before bringing them back for in-situ component evaluation. We will evaluate the system before and after the radiation exposure in CCHEN. The telescope will be tested in PUCV facilities and potentially in AURA facilities. The optical system will be evaluated by pointing it at the Earth during the night-time to calibrate it with city-lights during its stay at the ISS. The ADC system will be tested with a 1U CubeSat mission that will picture the moon with a small camera. The ADC system will include hardware and software for the operation, but the platform will be reprogrammable to facilitate the evaluation of the pointing algorithms with time and for training purposes (education and outreach). The telescope and the ADC system will be based on the refined technology developed for the current CubeSat missions in SPEL, with the practical knowledge of potential issues and their solutions. The evaluation of the systems in space will require sensors that monitor the space environment to look for relations between the space conditions and the system performance. Taking advantage of these sensors, we will pursue two other secondary objectives. The first one is to test new graphene-based sensors, while the second is to conduct space weather studies, the efficiency of which have been proven in a number of CubeSat missions like ELFIN [Zhang et al., 2022]. The second objective will require a higher cadence of the sensors than is required to evaluate the performance of the systems. It will impose energy and communication requirements on the missions. During the first year, the ISS and 1U CubeSat missions will be designed and developed, with the goal of deploying the instruments to the ISS early in the second year. The 1U CubeSat is expected to be launched into orbit in the third year. We will complete the 6U CubeSat mission in the third year based on the previous on-ground and in-space experiments. This mission will be designed so that it can also be integrated into one of the 12U CubeSats acquired by the national space program. The final choice will depend on the amount of funds available for the launch of the 6U mission we will apply for funding during the third year and the opportunity to go into one of those 12U CubeSats.

Through this project, we expect to train at least three postdocs, six PhD students, and six MSc or undergraduate students. We also expect the knowledge developed during this project to serve as a complementary guide to the new national space program. We can also finish with a low-cost space methodology and platform for future space missions that could be used within the country and abroad. In addition to classical outreach activities (talks, seminars, presentations, YouTube channel, etc.), we will spread out the work of the project in collaboration with the Explora RM Sur Poniente center, by providing summer courses for teachers, where they will acquire material and obtain training for demonstration activities during the year with their students, not only in STEM subjects but also in other areas such as science fiction writing, science communication, documentary, space art, etc. We will also run three national school campaigns: one to name the 1U CubeSat, a second one to name the final mission (the 6U or 12U mission), and a third one to carry a small study to the ISS. Thus far, we are planning to carry a bio-sample proposed by a school community in small containers like those used in the PlantSat mission (http:/.spel.cl). Through the project, we will strengthen the international collaboration with ERAU, ANL, TU Delft, University of Tokyo, and Chalmers University, and the national collaborations with CCHEN, USACH, PUCV, Biociencia Foundation, and CATA and CMM centers. In addition, we expect to establish collaborations with the Millennium Nucleus for Planet Formation (NPF), in particular to evaluate the use in space of the carbon fiber mirrors they are fabricating. We also plan to consolidate the collaboration with AURA and with the national space program through the collaboration agreement that University of Chile has with the Chilean Air Force.