DESIGN, DEVELOPMENT AND IN-FLIGHT EXPLOITATION OF IGOSAT SATELLITE PAYLOADS FOR MEASURING THE RADIATIVE CONTENT ON LOW-EARTH ORBIT AND IN THE IONOSPHERE

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1. Introduction

1.1. General introduction

Satellite technology is the symbols of a country where having highly-developed and technology-based. It is not only supports to the economic development but also builds effort to the science. The advantage of using satellites is the environment where they are working, which we cannot reach at ground. The more developed the national economic are, the more satellite application they needed. For example, satellite technology is using in the vast fields such as communication, oceanography, environmental monitoring, astronomy, and a variety of other things as well.

For each country, before starting a space mission, they always need to develop and exploitation of the instruments in order to reach the scientific objectives without any damages. For that reason, a lots of small satellite missions are started bringing the term of small satellite further than the education purposes. The development of technology is the key for the small satellites can do the same scientific work with the big ones in the past. There are a lots of scientific publications provided from the small satellite missions. Nowadays, with the development of science, the satellite – in generally – is more promising technology.

1.2. The IGOSat project [1]

With the support of the French Space Agency (CNES) and the University Paris Diderot, three laboratories (APC, IPGP and AIM), gathered within the LabEx (Laboratory of Excellence [2]) initiative, started two years ago the development of a nanosatellite: IGOSAT (Ionosphere and Gamma-ray Observations SATellite).

The selected configuration consists of two small payloads: one based on a novel kind of scintillator (presently tested at the APC) for gamma ray and electrons detection and a dual band GPS receiver for the measurement of the TEC (total electrons content) of the ionosphere. These 2 payloads will be hosted on a 3U CubeSat platform, orbiting the Earth at an altitude of about 650 km and inclination of about 97°.

1.2.1. The electrons and gamma-ray detector payload

The scintillation detector onboard IGOSat for detecting high-energy gamma-rays and electrons is based on the technology developed for the TARANIS (dedicated to the study of stormy regions), namely the XGRE sub-system(X, Gamma and Relativistic Electrons)[3].

The charged particles and photon detector consists of three parts: a cubic organic scintillator (also known as a plastic scintillator) with an inorganic scintillator ($LaBr_3$ crystal) encased in it. The pulses of light are read with a photomultiplier. The plastic scintillator will essentially be sensitive to electrons and protons, whereas the $LaBr_3$ crystal also detects gamma photons. Combining these two sets of data allows for the precise calculation of the population density for these two particle types. The photomultiplier transforms the optic signal in an electrical signal and amplifies it, making the measurement possible (see figure 1).

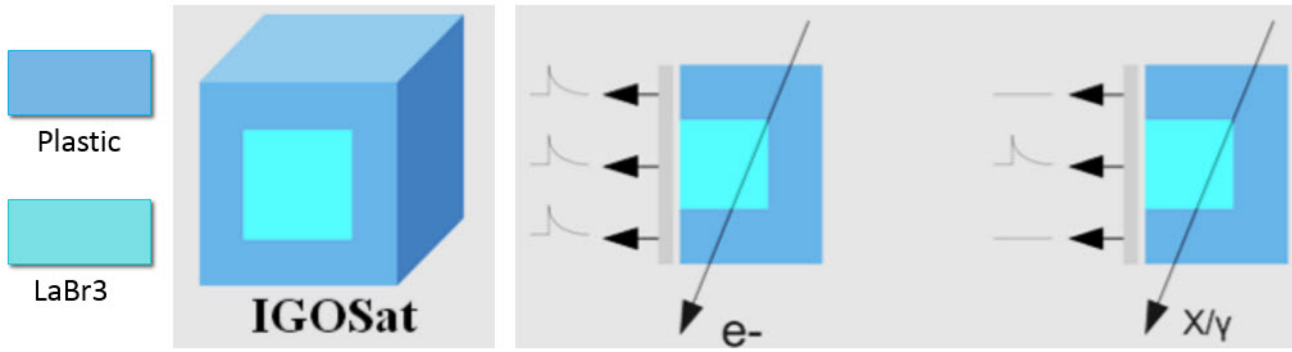

Figure 1. The $LaBr_3$ crystal detecting the electronic particles and gamma ray.

Many changes had to be done compared to the XGRE instrument for the IGOSat mission. First, the design of the scintillator has to be optimized for measurements above the magnetic poles and the SAA (South Atlantic Anomaly), at an altitude of about 600 km. The size of the detector has therefore been reduced to a cube of about 3x3x3 cm^3. Moreover, to avoid the difficulty of generating high voltage onboard IGOSat, a MPPC (multi pixel photo counters) array, constituted of a matrix of avalanche photodiodes, should be used instead of a photomultiplier tube. MPPC arrays have never been flown in space and the IGOSat flight will be a valuable qualification test for this technology.

The MPPC channels will be read thanks to the EASIROC (Extended Analogue Silicon pm Integrated Read Out Chip) ASIC, developed by Omega Micro. As for the MPPC array, the IGOSat mission will be the first qualification test in space for this ASIC (primarily developed for particles detectors used on ground).

1.2.2. The GNSS payload

The dual-frequency GPS receiver will measure the Total Electronic Content of the ionosphere. To achieve this goal, IGOSat will observe the radio occultation of GPS satellites through the ionosphere and will be able to deduce the TEC from the relative phase of the two signals (see figure 2).

The GPS receiver will measure phase differences between two GNSS carrier signals at 1.2 GHz (L1) and 1.6 GHz (L2). The ionosphere is a dispersive medium which introduces a propagation delay in a signal of a defined frequency. The phase difference between the two carrier signals will give us information about the cumulative electronic density on the aiming line between one of the 31 GNSS satellites on the MEO (Medium Earth Orbit), at about 20 000 kilometers of altitude, and the nanosatellite's receiver, on the near-polar LEO. The relative motions of these two satellites regularly cause an occultation. During this occultation, the aiming line crosses the ionosphere and an estimate of the total electron content in this area can be computed.

The dual frequency (L1 and L2 carrier frequencies) receiver is connected to a patch antenna, specifically designed for IGOSat. The antenna will be fixed on one of the small side of the satellite. A modest accuracy attitude control system (using magneto-torquers) is needed to point GPS satellites through the ionosphere, i.e. a pointing direction towards the limb, opposite to the satellite's velocity and with an accuracy of a few degrees. The OEM615 dual frequency GNSS receiver from Novatel was selected and is currently undergoing characterization tests. The raw data recorded by the GNSS receiver will be processed and compressed by the onboard computer before being sent to the ground station using the UHF emitter.

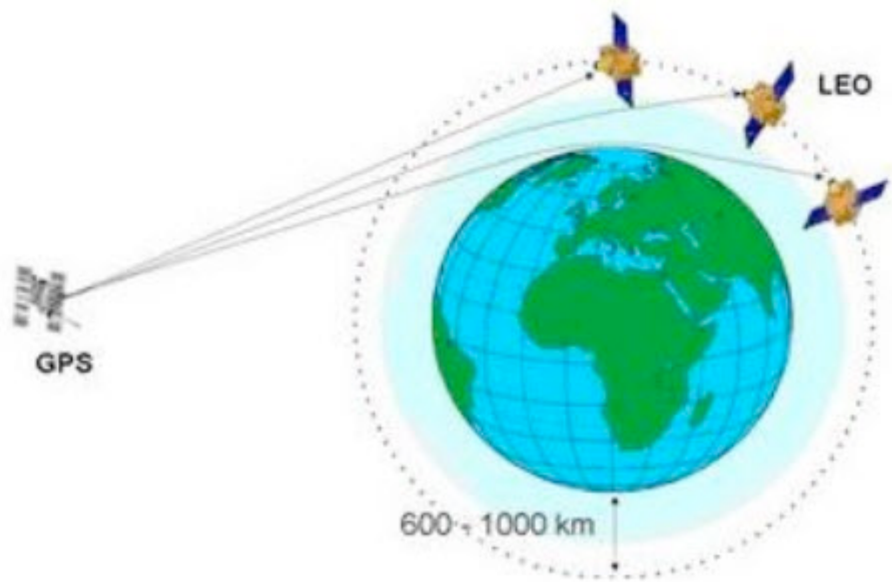

Figure 2. Radio-occultation of a GNSS signal by the ionosphere

2. Scientific objectives

The technological and scientific objectives of this spacecraft mission are the following :

- Characterization and space qualification of a novel readout system for scintillating detectors (Silicon Photomultipliers + dedicated processing ASIC).
- Measurements of the high energy photons and electrons on polar, low-Earth orbit.
- Validation of the measurement of the ionospheric Total Electronic Content (TEC) with a dual frequency GPS card in space (occultation method)
- In-flight characterization of the TEC acquisition pipeline : Earth coverage, noise level, comparison with ground-based measurements, variability with Sun activity
- Correlation studies between the radiation belt particles density (measured by the scintillation detector) and the ionization level of the upper atmosphere (TEC). The role of the PhD student will be to accompany the development, both technically and scientifically, of this project, from the current design status to the in-flight commissioning and data processing.

3. Timeline of the PhD thesis (03 years 100% in France)

During this thesis, the student will focus on the development, characterization and data processing of the IGOSat payloads. The IGOSat project begun in Sept. 2012 and is expected for launch in 2017 or 2018. IGOSat is presently in phase B and the PhD student should start his work while IGOSat will be entering phase C (construction of the engineering model).

The PhD student will therefore have the opportunity to contribute to the mission development, prepare the data analysis, characterize the instrument's performance, study the science topics related to the measurements and process the in-flight data.

The following section describe the expected work for each year of the PhD thesis.

3.1. First year - 2015 / 2016

During the first year, the PhD student is expected to work mainly on the technological development of the payloads. The electrons and gamma-ray detector is not an 'off-the-shelf' component and its construction and testing will require an important effort. Based on the previous works and current design, the PhD will be responsible of the realization of an engineering model of the scintillation detector in 2016. This work consists of:

- a extensive bibliography on detection techniques for high energy electrons and gamma-rays, with their associated performance noise levels and constraints.
- a review of existing measurements and models of the radiative environment on low-Earth orbits and its effect on satellite and gamma-ray astrophysics.
- validating the design (mechanics, electronics, data acquisition, observation strategy, etc.) of the detector in order to fulfill the science objectives
- supervising the construction of the payload and define test procedures and set-up test benches.
- characterizing the performance of the instrument through dedicated Monte Carlo simulations and ground measurements (e.g. with radioactive sources).

A similar work shall be done on the other payload : a dual-frequency GPS card for measuring the Total Electronic Content (TEC) of the ionosphere thanks to the occultation technique. The GPS card is an 'off-the-shelf' component (which has already been used in space) and will be much easier to implement on the satellite. The student will however have to validate the design in view of the scientific objective : a similar sensitivity (0.1 TECU) as what is done from groundbased stations [4]. The performance estimation of the TEC measurements will require a review of the different phenomena leading to a change in the TEC of the upper atmosphere.

Once the final design of the satellite and performance of its payloads have been assessed (by the end of 2016), these results shall be published in a peer-review journal and presented in conferences.

3.2. Second year - 2016 / 2017

Once the engineering model has been completed and validated, qualification and flight models of IGOSat will be constructed (phase D). During this phase, the PhD student will supervise the integration of the payloads, based on his previous work. He will also be in charge of the final performance tests.

His main activity during this year will however be focused on the preparation of the flight and data analysis :

- Detailed review of the physical processes correlating the TEC in the ionosphere and high energy particles density on low Earth orbits (such as the solar activity)
- Design of data processing algorithms (filtering, compression, physical values extraction, etc.) on-board and on ground.
- Implementation of a data analysis pipeline to extract the relevant information form the data stream from the satellite.
- End-to-end simulation of the recorded data (to be compared with in-flight data)

This work can also be subject to publication in a peer-review journal, especially the correlation mechanisms between the radiation belts contents and the TEC of the ionosphere (which is poorly documented up to now) and the measurement predictions on that topics with IGOSat.

Being full time on the IGOSat project, the PhD student will have a crucial role in the progress of the project, especially by transmitting his experience (and knowledge) to the numerous students working on the IGOSat every year.

3.3. Third year - 2017 / 2018

IGOSat is expected to be launched late 2017 or in the beginning of 2018 (the exact date will depend on the launch opportunities). If the launch is successful, the main activity of the PhD student during this year will be about the in-flight commissioning of the satellite (especially the payloads) and the scientific exploitation of the recorded data. This work will be done in close collaboration with the APC and IPGP laboratories, which are experts in high energy detectors and planetary sciences.

It is important for the analysis pipelines to be fully operational during the second year of the PhD thesis (and, of course, before the flight) : the third year should be entirely dedicated to the science operations and the writing of the PhD manuscript.

The PhD thesis might not cover the entire mission duration but will allow scientific publications based on the processing of the first in-flight data. These publications will assess the performance of the satellite instruments in orbit and the potential of the payload technologies (scintillation detector and dual frequency GPS card) for future (bigger) space-based observations.

3.4. Transverse activities

During the entire duration of the thesis, the PhD student will also actively participate to the development of the satellite platform (especially the interfaces with the payload) and co-supervise some of the bachelor and master students working on the project.

Finally, collaborations are foreseen with the VNSC and USTH, e.g. on the ground station and GPUs developments. the PhD student will be the obvious person to develop these collaborations and to make a link between the French and Vietnamese teams.

4. References

[1] IGOSat website, http://www.igosat.fr

[2] LabEx UnivEarthS website, http://www.univearths.fr

[3] J.-L. Pinon, E. Blanc, P-L Blelly, M. Parrot, J-L Rauch, J-A Savaud, E. Sran, *TARANIS - scientific payload and mission strategy*, General Assembly and Scientific Symposium, 30th URSI, Orleans, France, Aug. 13-21, (2011)

[4] Liu, J.Y., Y. H. Chu, M. Q. Chen, L. C. Tsai and C. M. Huang, Modeling and Ground Observations of the Ionosphere Related to the COSMIC project, Terrestrial, Atmospheric and Oceanic Sciences, vol 11, pp. 349-364 (2000)