ONERA'S ONGOING NANOSAT DEVELOPMENTS AND ROADMAP

A. Miniussi [(1)], L. Artola [(1)], F. Boust [(1)], P. Caron [(1)], C. Coudrain [(1)], G. Druart [(1)], S. Duzellier [(1)], D. Falguère [(1)], O. Gazzano [(1)], G. Gourves [(1)], K. Grossel [(1)], J. Guerard [(1)], P.-E. Haensler [(1)], F. Issac [(1)], J. Jaeck [(1)], V. Lebat [(1)], V. Maget [(1)], J.-C. Matéo-Velez [(1)], D. Packan [(1)], Y. Paichard [(1)], P. Perrault [(1)], H.-K. Phan [(1)], A. Puligny [(1)], W. Quenum [(1)], V. Rannou [(1)], B. Rosier [(1)], L. Rousset-Rouvière [(1)], J.-F. Sauvage [(1)], P. Simoneau [(1)], S. Thétas [(1)], N. Vedrenne [(1)]

[(1)] ONERA, The French Aerospace Lab, +33 1 80 38 66 75, antoine.miniussi@onera.fr

ABSTRACT

ONERA has been working for the past few years in developing space systems oriented toward Cubesat technology. In collaboration with industrials, universities and research labs, ONERA is working on several cubesat missions with scientific and technological goals. Those include ionosphere study, radiation belts monitoring, earth observation and ESD mitigation systems. To feed these activities our teams also work on technological bricks such as deployable telescope, optical freeform designs and rad-hard digital core. Finally, unique test benches to validate designs sustaining the space environment (EMC, radiation, electrical propulsion, TVAC) complete our equipment. Such range of activities requires organization and strategy to provide necessary support to our teams and partners in order to complete our missions. The ONSATLab is dedicated to this purpose.

1 ONERA's CUBESAT ROADMAP

1.1 Introduction

ONERA, a key player in applied research on orbital systems in Europe, has also a Nanosat development roadmap since 2019. This program has several major goals, including developing scientific payloads ready to be integrated in partner's platform and collaborative mission with research, academic and industrial entities. Ultimately, ONERA will cover most of the technical and administrative aspects of a Cubesat mission, such as payload design, AIT, operations, telecommunications and licensing.

1.2 Strategy and expectations

One of the core expertise of ONERA is the development of high-tech instruments dedicated to land, air and space systems. With this solid background, ONERA has started the design of several payloads (described in section 0) for earth science and observation, radar study, spacecraft charging and radiation belts monitoring. The goal is also to validate the components and systems by reaching a TRL 9.

Each ONERA technical department is specialized in a specific field, such as optical, electromagnetism, materials, or space environment effects. Thus, the several teams working on Cubesat payloads have a solid background in each of their fields, completed by a transverse Cubesat approach to support them (see §2.1). The operations of the payload and the data processing once received is the responsibility of the team which designed it to guarantee the best understanding of systematic and unexpected behaviors.

Our organization does not include for the near future the development of the Cubesat platform or its integration and tests. Instead, we prefer to rely on experienced partners working with proven subsystems with whom we can collaborate to design and launch the best platform for our payloads. However, we are seeking to operate or collaborate in the operations of our missions to fully control the commissioning and the tests of our payloads in order to understand them as well as possible.

The partnerships involved in our missions are linked with the platform as stated above as well as the development of some of the payloads. In all cases, our goal as a state funded institution is to support industry and particularly emerging startups by, for instance, collaborating in the answer to a request for proposal. ONERA experts can also team up with our partners and develop together a system ready to be ready to fly.

Finally, our strong links with many universities and their space centers as well as research labs provide us great opportunities to exchange information and share technical capacities, some of them unique in France at ONERA. This connection also allows us to train students and host some during internships.

2 ONERA's TECHNICAL SUPPORT

2.1 ONSATLab

The ONSATLab has multiple functions and purposes, but the main one is to coordinate the cubesat segment at ONERA.

The numerous ongoing missions developed at ONERA in several scientific departments require a transverse approach in order to centralize and share the scattered skills and knowledge acquired. It also intends to build a foundation of resources, standards, and best practices to ease engineers' work and lower risks. A team of Cubesat and payload experts is ready to help on future projects and a documents database is available internally.

Some equipment, such as servers, test benches or computers can be used independently of the Cubesat specific mission. Thus, the design of new ground-based facilities is oriented toward a large compatibility of Cubesat missions. This is especially true for the Mission Operation Center (MOC) and the Science Operation Center (SOC), designed to operate all missions and process the received data.

Finally, the administrative work inherent in any space project is crucial and ONSATLab intends to help our missions as well as our partners in following the best practices.

This entity is also a driving force in the creation of partnership in relation to Cubesat and payload development and the best point of contact to start a collaboration with ONERA.

2.2 Test bench

Several test facilities are available for use by our teams and partners:

- *EMI / EMC test*

Several benches are available in Toulouse to test electromagnetic susceptibility or interferences and to measure antenna radiation patterns. A reverberation room (4.9 m x 3.7m x 3.2m) can be used down to 250 MHz. An anechoic room (10 m x 7 m x 4 m) is designed for a minimum frequency of 150 MHz and includes a spinning platform. Finally, a smaller reverberation chamber (2.4 m x 1.2 m x 2.2 m) completes the experimental setup.

Figure 1 : The reverberation (left) and the anechoic (right) rooms with the 3U Cubesat test platform

- *Electric propulsion test benches*

Different test benches are available at ONERA. The ERIS facility is designed to perform a comprehensive test of an electrical propulsion system. Its large volume (5 m x 2.3 m) can host a whole nanosat and its vacuum capacity (3e-8 mbar) allows it to evaluate the ignition of the propulsion system. Other chambers have been acquired to support the design and to test small thrusters (down to micro-newton) as well as a wide range of power (> 1 kW).

Figure 2 : The ERIS test bench at ONERA's facility in Palaiseau, France.

- *Radiation effects in electronics components and materials*

Several radiation facilities and test benches, as well as software, have been developed at ONERA, Toulouse. This expertise allows us and our partners to assess, anticipate and qualify the reliability of embedded electronics and materials in harsh environment conditions including radiation, extreme temperatures, and high vacuum.

Electronic systems require to be tested under radiation to anticipate Single Event Effects (SEE) and the impact of the Total-Ionizing-Dose (TiD), based on standards [1] and [2]. For instance, TiD in CMOS are tested in our gamma ray facility (MEGA, depicted Figure 3) with a flux of 36–360 rad(Si)/h. The emergence of deep sub-100 nm technologies requires adapting SEE test process, particularly for single event latch-up (SEL) issued for nano and small satellites. Thus, microcontroller, FPGA, SoC can be evaluated at ONERA in a dedicated vacuum chamber (CIRIL) allowing the mounting of a small radiation source, for instance Californium emitting alphas [3].

In addition to experimental activities, ONERA developed radiation-engineering software dedicated to the estimation of soft error rates of embedded avionics (SEE-U) in orbits. See [4] for further details.

Figure 3 : MEGA facility for Total Ionizing Dose tests and analysis at ONERA in Toulouse, France.

For materials, the complexity and wide diversity of mechanisms at play in the diverse organic or inorganic materials forbid generic approach. Thus, testing of radiation damage (charged particles and/or UV, combined or not) in varied materials requires specific test conditions for each. Susceptible materials include polymers, thermal control paints or external surface of structural materials used for thermal control applications, Second Surface Mirror (SSM) or glasses. ONERA has developed the ALEX laboratory to provide a comprehensive test facility for material. It includes two Van De Graff accelerators (electrons and protons with energies up to 2 MeV) and three target chambers:

SEMIRAMIS (surface material such as space painting and coverglass), MIRAGE (optoelectronics and solar cells) and GEODUR (for bulk charging in dielectrics). See [5] for further details.

- *Vacuum chambers*

Several test platforms, of different sizes and including different features can be used in our facilities to test subsystems, Cubesat instruments or the whole platform. A TVAC setup (1 m high x 60 cm diameter) including thermally regulated plates can simulate heat load or sink. Another one with similar features is dedicated to infrared camera calibration.

- *ESD tests*

The JONAS bench (3.4 long x 1.85 m diameter) is dedicated to test electrostatic discharge (ESD) by exposing the system to a plasma, electron beam and ultra-violet light.

2.3 Technological bricks

One of ONERA's core activities is to imagine and design technological bricks ready to be implemented in larger systems. These technological bricks are advanced and necessary bits to push forward innovation, internally or from our partners. They are present in every field covered by ONERA and only a few dedicated to Cubesat are listed below.

- *Electrical propulsion*

ONERA has been involved in the development and tests of electrical propulsion systems since the 60's. Several technological bricks are being studied, including new concept of thruster technologies, intrusive and non-intrusive diagnostics, or numerical tools specific to the physics involved in electrical thrusters to ease the development of key technologies.

The ECRA propulsion system, under patent, has been developed in the 2010's at ONERA and during the H2020 MINOTOR project in collaboration with seven other partners. Using microwaves, several test campaigns have shown great efficiency for a 30 W and 200 W versions of the thruster. Currently at TRL 4, the development of a prototype is still ongoing.

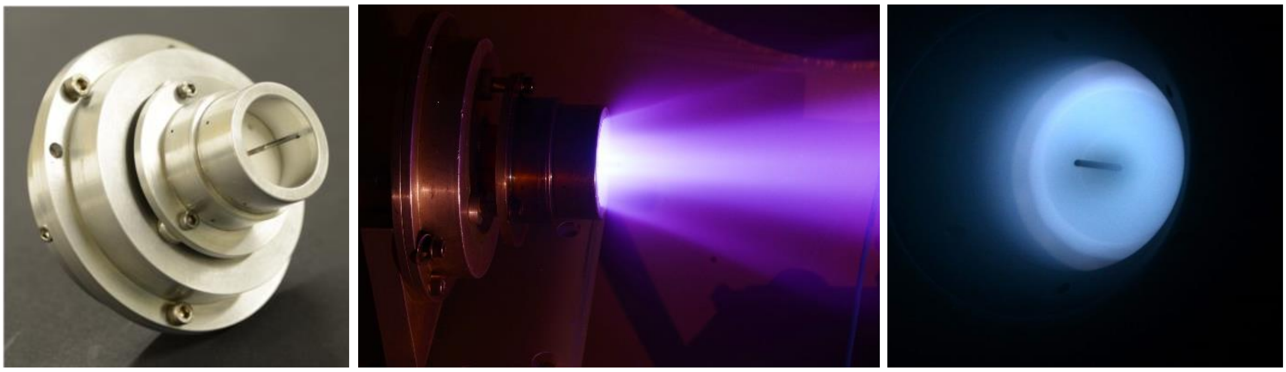


Figure 4 : Left, the microwave electrical thruster, ECRA. Middle, the 30 W version. Right, the 200 W version

- *Deployable telescope: AZIMOV (AutomatiZatIon of MOVable optics for high resolution observations)*

One of the advantages of CubeSat technology is its low cost, allowing designing large constellations of satellites. These constellations used from Low Earth Orbit increase naturally the revisit rate. However, one of the remaining technical limitations of Cubesat technology in high-resolution observation is the ability to use large telescopes. To deliver jointly high revisit rate and high angular resolution, ONERA proposes the concept of a deployable 30 cm diameter telescope fitting into a 1.5 U volume.

The primary mirror is composed of four petals controlled by Artificial Intelligence (AI)-driven Active Optics (AO) system for high spatial resolution. The secondary mirror is deployed from the same initial volume. AZIMOV [6] targets an image resolution under 1 meter at 500 km altitude for a gain of mass of a factor 10 compare with satellites of similar resolution and swath.

The consortium includes UK-ATC (developing the opto-mechanical design), ONERA (developing the Active Optics system), INESCTEC (Porto University, working on the AI algorithm), and "Laboratoire d'Astrophysique de Marseille" (for the environmental tests).

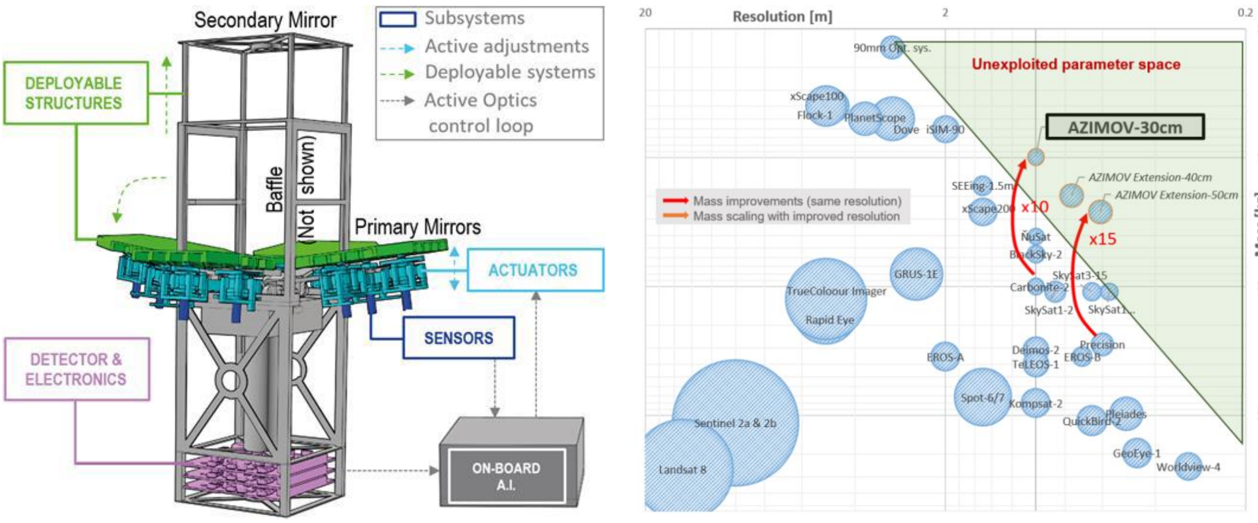


Figure 5 : Left, a 3 U Cubesat carrying the deployable and active AZIMOV telescope. Right, the resolution image versus satellite mass and swath for several missions. The aim is to reach high ground resolution with a low-cost satellite.

- RESISTACK - Atomic Oxygen measurement

Atomic oxygen (AO) is the main component of the residual atmosphere present at low earth orbit. The main consequence is erosion of surface materials. Some classes of materials are stable under AO attack (oxides for instance) and incoming flux is then re-emitted with specific angular and energy distributions. In case of sensitive materials, typically 90% of the incoming flux is also re-emitted. Then multiple reflections can locally enhance or lower erosion rate in complex geometry.

With the needs for "super low" and EOR orbits, flight data and detectors are of great interest to evaluate actual erosion yield and fluence in operational conditions. The concept of a light, low power, small size and low-cost detector is proposed by ONERA.

RESISTACK is an active AO detector based on a stacking of metallized polymer films acts a set of resistances in parallel. Kapton is chosen for its well-known erosion rate under AO flux, the absence of UV synergy, and energy-dependence linear law on erosion rate. The equivalent resistance gradually increases each time a layer is fully eroded (opened "switch"). The number and thickness of kapton layers define the range of fluence and accuracy of the detector. RESISTACK operation consists in continuous and automatic 2-pin or 4-pin measure of resistance to detect complete erosion of each layer, further correlated to fluence.

Manufacturing of prototypes is based on standard space-qualified flexible circuit process. RESISTACK device has been tested and validated in APTC and TVAC chambers (air-pressure and thermal vacuum testing), at CNES facilities. The calibration has been done at University of Montana under an AO flux facility.

The RESISTACK is planned to fly on the ISS in 2022 with the SESAME experiment and later on with the IONSat mission, developed at CSEP (Centre Spatial Etudiant Polytechnique).

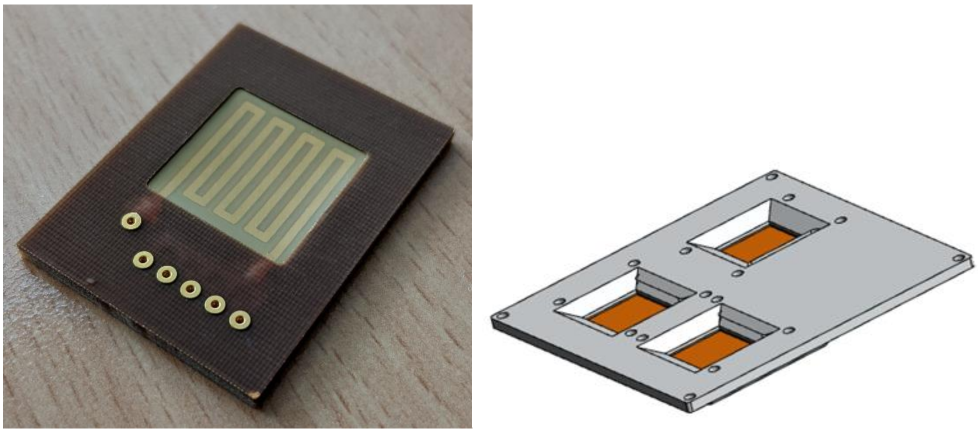


Figure 6 – Left: RESISTACK device, dimensions 4 x 3 cm², detection zone is 1.6 x 1.6 cm² for a mass of 4g. Right: Three RESISTACK embedded in 2D module of SESAME (ISS, 2023).

- Optical sensors, telescope design and freeform

The emergence of optical thermal sensors widely used in automotive and security systems has made this technology very affordable, less energy consuming and more compact. Based on this recent evolution, ONERA has been working for the past few years on innovative designs of infrared and multispectral cameras, cooled and uncooled, fitting small volume. For Cubesat applications, ONERA also develops calibration setup for infrared payloads.

Finally, ONERA contributes to the payload downsizing development adapted to Cubesat by designing new telescopes based on freeform reflective surfaces [7]. As an example, this type of design allows a common fore optics for a bi-spectral instrument (Figure 7) with a reduced mass and volume.

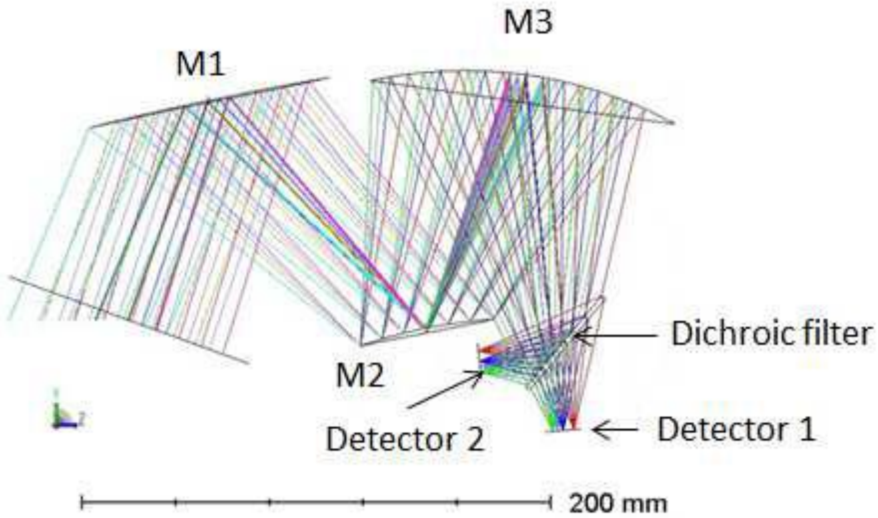


Figure 7 : Layout of a multi spectral band solution with a dichroic filter

- Optical ground station, optical channel models and emulator

To match the growing need for data throughput between the ground and space, driven by the development of upcoming mega communication constellations [8] including nanosats [9] optical links are an increasingly credible alternative to radiofrequency links. Offering a favourable SWAP, frequency allocation free and intrinsically secured very high data rate transmission, the implementation of high-speed optical communication functions between space and the ground is the subject of sustained developments that might lead to commercial exploitation in the medium term if the effects of atmospheric turbulence on the optical link can be mitigated.

ONERA has been developing methods and models to mitigate the detrimental effects of optical propagation through the atmosphere for more than 30 years. The TURANDOT code [10] simulates the complex amplitude disruptions encountered by the beam along the path and different types of correction strategies including multi-emission and adaptive optics. The PICOLO hardware bench [11] (see Figure 8) emulates atmospheric turbulences. These two projects are open to ONERAS's partners. Finally, LISA is a compact adaptive optics (AO) system dedicated to downlink LEO optical link

All these developments among others are gathered into the FEELINGS [12] (Figure 8) ground station, a technical validation platform for optical link telecommunication with satellites. The main objective is to flight test the channel mitigation mechanisms necessary to match the required high reliability. The FEELINGS ground station offers a monostatic configuration with a 600 mm full aperture, LEO tracking ability, a high performance ONERA built AO system for bidirectional links, a fine pointing capacity compatible with beaconless optical links and dedicated atmospheric channel characterizations.

With the FEELINGS access, ONERA also provides the joint capacity to emulate the encountered optical channel almost instantaneously (within a few seconds) thanks to the coupling of real-time turbulence channel assessment on the data and to a built-in high performance simulation process based on ONERA's code SAOST [13].

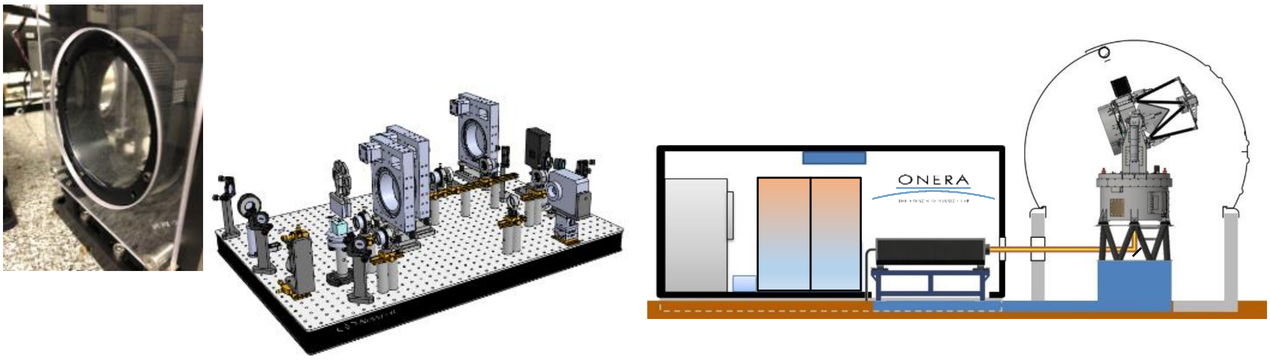


Figure 8 : Left: turbulence emulator PICOLO, top left: one of the three phase screens on the bench. Right: FEELINGS ground station 60 cm telescope and dedicated adaptive optics bench.

2.4 SpaceLab

SpaceLab is a space mission simulation environment developed by ONERA in order to provide our engineering teams with in-house validated software.

The purpose of this software is to federate our various experts in the domain around a common tool for the conception, simulation and control of space missions. It can host conception and performances analyses scripts shared across the office in order to enable long-term knowledge management in the domain and facilitate further studies.

Among other possibilities, the software provides toolboxes for inter-visibility and observation analysis, orbital mechanics and manoeuver design as well as sensor performance analysis. Possible objects in the simulation include satellite, launchers, ground or embedded sensors and constellations. A future evolution of the software is meant to interact with a mission control service in order to generate operational scenarios and analyze mission data throughout a nanosat operation phases.

The SpaceLab suite runs on ONERA's simulation engine "RGINE" and includes a set of technical models as well as a graphical interface used for scenario definition and visualization.

The code is managed via an internal Git and any engineering department can contribute to the software by adding models, and use it either as a standalone installation or via web-service through an URL on the office's network redirecting towards the SpaceLab's server.

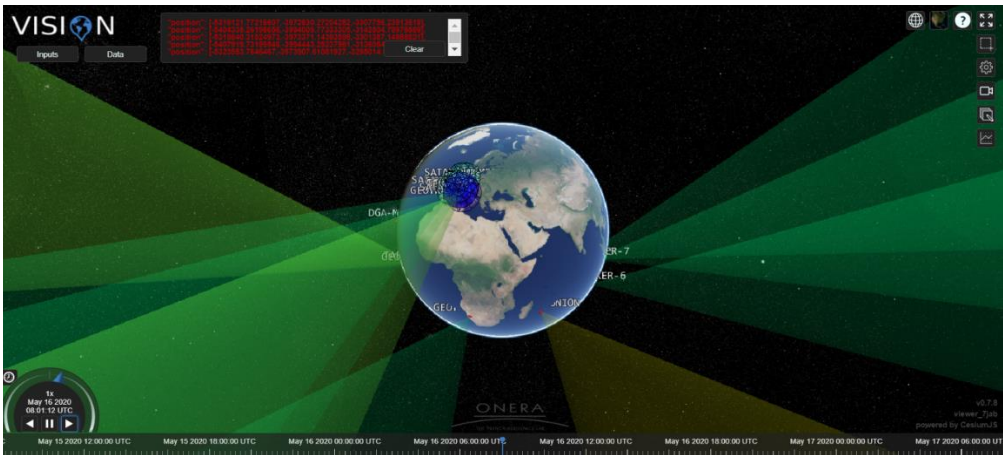


Figure 9 : Visualization tool for the SPACELAB software

3 ON GOING AND FUTURE MISSIONS

3.1 CREME

Energetic charged particles such as electrons (keV to 10’s MeV) and protons (keV to 100’s GeVs) are trapped by the Earth’s magnetic field in the so-called Van Allen or radiation belts (Figure 10). Such particles are mostly produced by solar activity and the dynamics observed in the radiation belts may be extreme, enhancing the radiation level (in terms of charged particles fluxes) of several orders of magnitude in a few hours. All the satellites orbiting the Earth as well as our ground systems are subject to these ionizing particles and induced effects. For instance, the radiations belts are spread out between an altitude of 400 and 50 000 km where most of the satellites operate. In such an environment, the ionizing particles interacting with the electronic components can generate punctual events caused by a single particle or cumulative long-term radiation effect. These effects can lead to malfunctioning or even complete failure of spacecraft systems and/or subsystems.

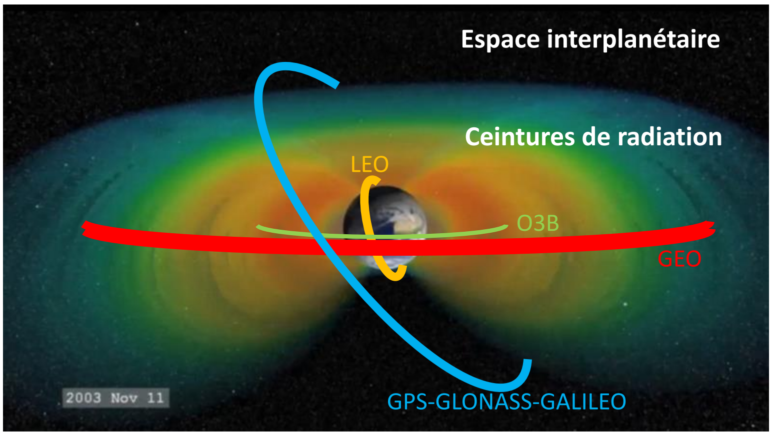
To get a better understanding and mapping of these energetic particles, ONERA and ISAE-SUPAERO partners of the Toulouse University Space Center (CSUT) [14] collaborate to the CREME (Cubesat Radiation Environment Monitoring Experiment) mission. ONERA is responsible for the ONERAD instrument, designed to monitor the highly energetic electrons and protons trapped in the radiation belts. This instrument is based on the proven designs of typical solid-state detection head such as NGRM (ESA) and ICARE-NG (CNES) [15]. Developed for large missions and with an industrial philosophy they can cover a wide energy range of particles. ONERAD, on the other hand, intends to provide complementary results with a gain in compactness (1.25 U), mass (1.4 kg) and power consumption (< 4 W) by focusing its measurements on chosen sections of the energy spectrum.

ONERAD is a first step in a new area of radiation monitors and is expected to demonstrate how it can be complementary to instruments currently acquiring data. With a set of tools already developed at ONERA, such as data assimilation [16], the measurements from these different sources are combined together to provide a more accurate picture of the dynamics of the radiation belts for Space Weather applications.

The ONERAD instrument (Figure 10) is designed with two detection heads composed of different shielding layers and sensors sensitivity. The variation of materials and thickness provides ONERAD the ability to measure protons in the range 2.5-150 MeV and electrons in the range 700 keV–2 MeV. The current objective is to reach and achieve the Engineering Model by the end of 2022.

The development has been made possible thanks to industrial partnerships (3D-PLUS, EREMS and TRAD), as well as strong internal support from ONERA itself. FEDER and “Région Occitanie” are funding this project as well as ONERA and ISAE-SUPAERO themselves.

The 3U Cubesat platform is developed, built and tested in collaboration with ISAE-SUPAERO and U-Space, a French startup based in Toulouse.



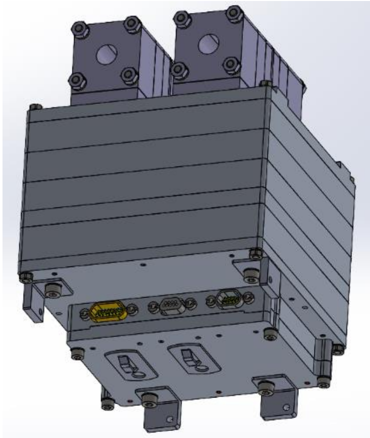


Figure 10 : Radiation belts illustration (left), and ONERAD mechanical design (right). Credits: NASA (left) and ONERA (right).

3.2 CROCUS

Space is filled with plasma from many different sources, including low energy charged particles in the range of 10 eV to 100's keV. Its density varies over time and location due to many mechanisms including solar activity and magnetosphere shape. In this environment, all space systems interact with this plasma, inducing a static charge of its external surfaces as well as its inner components. Eventually, during geomagnetic substorms, the deposited charges produce high potential difference that leads to ESDs on the satellite surface. These discharges can then damage electronic components and materials, up to the total failure of the system. Tens of percent of abnormal configurations (called *anomalies*) reported during flight are still attributed to ESD [17] [18]. Thus, the spacecraft and subsystems design shall include ways to mitigate ESD and processes to recover quickly from it. While the effect is understood, the multi-physics involved and multi time scale of the sources are extremely hard to simulate accurately. The advent of cheap access to space with nanosatellites provides an excellent opportunity to validate mitigation techniques for instruments particularly sensitive to ESD.

The *ChaRging On CUbeSat* (CROCUS) mission, led by ONERA in collaboration with the Ecole Polytechnique space center (CSEP, [19]) wishes to demonstrate a new generation of instruments dedicated to charging, discharging and mitigation assessment. Several instruments are integrated into the CubeSIM payload as listed in Table 1. The scientific objectives are to detect the occurrence of ESDs, identify and simulate the charging conditions, identify the space weather and geomagnetic indices and reduce the charge levels. More details are provided in [20]-[21]-[22].

The design of the platform has been initiated with the CSEP and is an ongoing development with scientific and industrial partners.

Instrument name	**Functionality**
TWIST	Detect ESD transient in the 0.1 to 10 µs scale
SPARK	Calibrate TWIST by generating artificial electrical transient representative of ESDs
SCAPEE	Mitigate charging
MISTEEC and BEC	Improve the statistics of spacecraft charging events

Table 1 : List of all the instruments and their description, included in the CubeSIM payload

3.3 CUIONO

The electromagnetic radiation from the sun interacting with the upper atmosphere generates ions distributed over different density and energy layers, forming the ionosphere (50 to 500 km). The variation over time and space of the electronic density of the ionosphere, directly linked with solar activity, affects the telecommunication and observation services. Thus, understanding and monitoring the ionosphere is the best way to keep ground and space-based systems operating.

The CUIONO instrument, developed at ONERA, is mainly composed of a RF antenna and a software defined radio (SDR) card on board a Cubesat. Together with a ground-based sounder emitting RF signal between 8 and 23 MHz, the full setup can characterize the ionosphere.

A first model of this instrument is being developed for integration to the INSPIRE-Sat 7 mission in collaboration with LATMOS [23]. The 2U satellite, planned for launch early 2023, carries multiple instruments to measure the Earth's energy budget for climate change studies.

A second model, with advanced features, is planned to be part of the Flylab-2 satellite described in this publication in chapter 3.4.

Finally, a third one is planned to fly onboard the ASTERIX mission, still under definition.

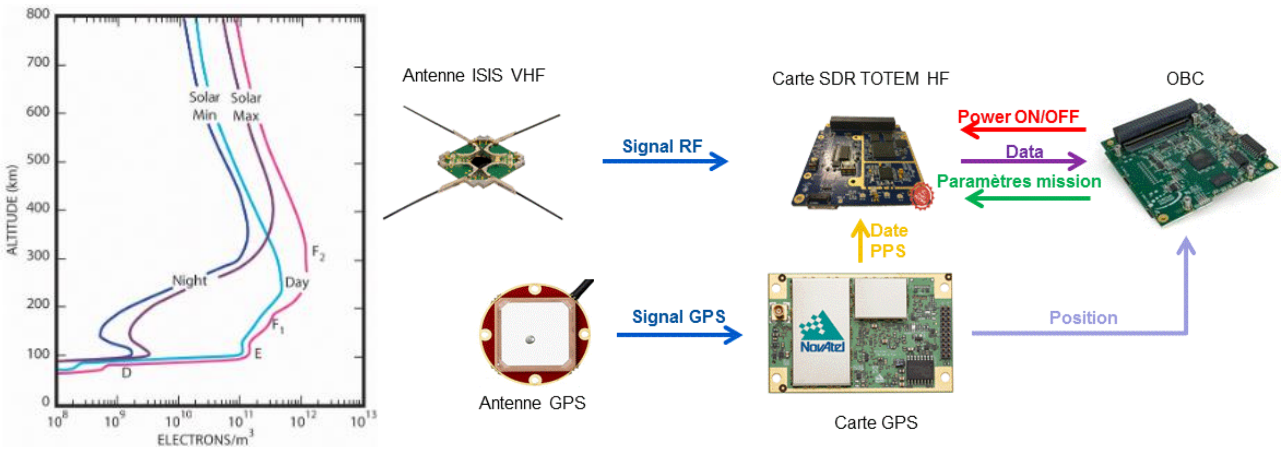


Figure 11 : Left, variation of the electronic density with the altitude, measured by an experimental setup such as CUIONO. Right, components and functions included in CUIONO model developed for the Flylab mission. The first model dedicated to INSPIRE-Sat 7 does not include the GPS signal and PPS function.

3.4 Flylab

The Cubesat technology is reshaping many sides of space activities: in science, from earth observations and monitoring to deep astrophysical studies, Cubesats are performing measurements grouped in constellation or fly in formation; as well as in development of new technologies such as hardware bits or algorithms, easily validated in space. These two major aspects are gathered into the FlyLab mission, designed and operated by ONERA and composed of two 6U satellites flying on a Sun-Synchronous Orbit (SSO) at around 550 km. The platforms are designed and manufactured by an industrial partner.

Both satellites are deployed almost simultaneously, ready to proceed with one of the main objectives of the mission: orbital manoeuvers and formation flying. One satellite includes an electrical propulsion system, the second one a cold gas or chemical propulsion system. To complete this setup the platforms carry a fine attitude control system (star tracker, magnetorquer and reaction wheel) to perform precise pointing for earth observation and telecommunication. This full Attitude and Orbit Control System (AOCS) allows ONERA to test new attitude control algorithms and validate complex manoeuvers in orbit, a first step toward a formation flight.

The other objectives involve several payloads distributed over the two satellites. FlyLab1 carries two optical instruments developed with industrial partners. CATFly is a 1.5 U megapixel infrared thermal camera with a resolution of about 80 m / pixel at 550 km. Its primary objective is to validate the developed technology and optical models by comparing in-flight data with ground-based calibration. The second payload, CAVFly, is a 1 U visible camera with a resolution of about 60 m / pixel at 550 km, used for periodic Earth observations. Both cameras are also used to characterize the companion satellite, FlyLab2.

The second set of payloads, carried by FlyLab2, is composed of CUIONO2 and RepSat, both developed by ONERA. CUIONO2 is composed of VHF antennas and a software defined radio (SDR) card. A ground-based emitter completes the setup to allow the characterization of the ionosphere. More information is available in chapter 3.3 of this publication. RepSat is composed of an L-band antenna and another SDR card designed for radar analysis.

3.5 ASTERIX

The rapid change of our planet's atmosphere requires a frequent and precise monitoring of the Earth's radiative budget. The ASTERIX mission responds to this challenge by measuring several atmospheric parameters (temperature, OH layer altitude, aerosols, TEC) with the MARTIC and NIGHTCAP 1U payloads. This first satellite paves the way to a constellation that will further provide a fine spatiotemporal coverage of these measurements [24].

The MARTIC camera is designed to measure the evolution of the Earth's limb temperature profile from 30 to 90 km of altitude during its flight. The Engineering Model (EM) of MARTIC, optically designed by ONERA and built by LATMOS, is already available for laboratory tests.

The NIGHTCAP camera is designed to observe the "Nightglow" radiation emitted by the OH layer located around 87 km of altitude. The EM of NIGHTCAP, fully developed by ONERA, is currently manufactured at Winlight System facilities, and soon be assembled at ONERA.

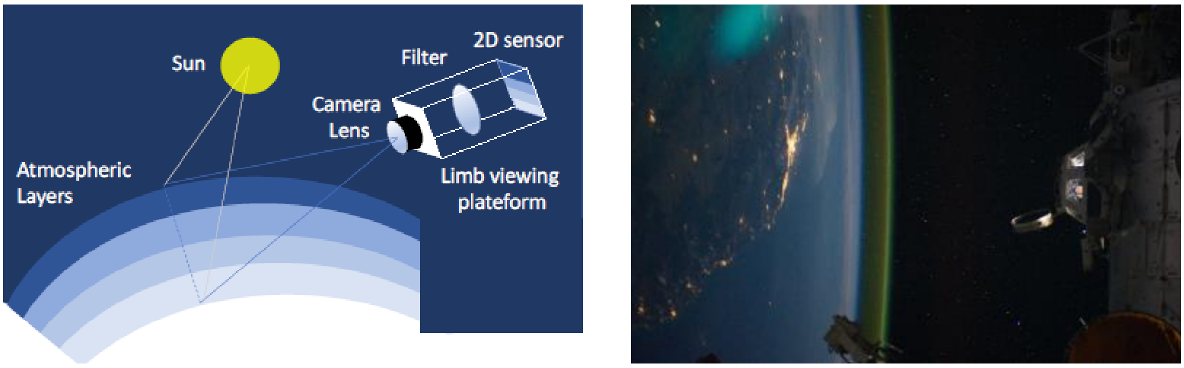


Figure 12 : Left, schematic setup for limb viewing from space (courtesy LATMOS) – Right, view of Nightglow emission layer from the ISS (courtesy NASA)

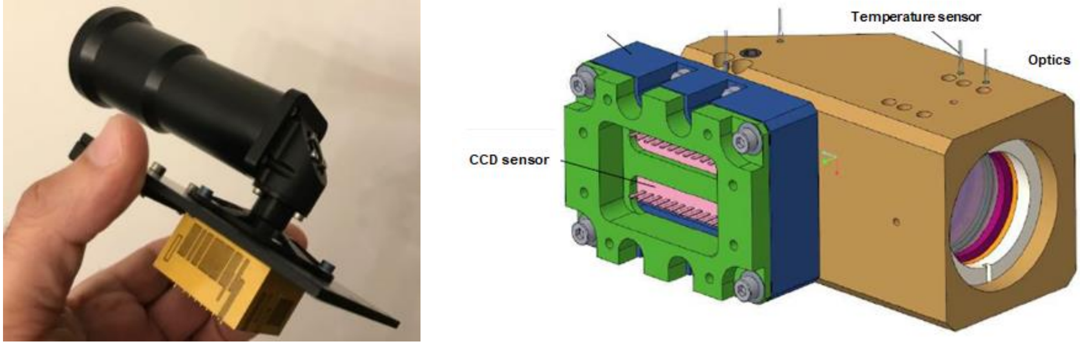


Figure 13 : Left, photography of MARTIC EM (courtesy M. Meftah and P. Keckhut) – Right, CAD view of NIGHTCAP EM

4 CONCLUSION

In the past 3 years, ONERA has been, and keeps consolidating, its nanosat segment to support the scientific and industrial enthusiasm toward this newspace approach. Over this period, four Cubesats and payloads have been initiated with different partners for launch dates planned between 2023 and 2025.

The fast pace of ONERA in this field shows once more that nanosat technology is a great vector to push for technologies development up to TRL 9 with validation in orbit within a few years.

Endorsing its role, ONERA has been and will keep creating collaborations with many private and public entities. From startups or small businesses to the universities and the research labs ONERA is always looking for new partnerships to develop future joint missions.

5 REFERENCES

[1] ESCC 25100 – *Single event effects test method and guidelines*

[2] ESCC 22900 – *Total dose steady-state irradiation test method*

[3] G. Hubert and L. Artola, "Experimental Evidence of Ground Albedo Neutron Impact on Soft Error Rate for Nanoscale Devices," in IEEE Transactions on Nuclear Science, vol. 66, no. 1, pp. 262-269, Jan. 2019, doi: 10.1109/TNS.2018.2877263.

[4] J.-C Matéo-Velez, L. Artola et al. “Assessment of Space Environment Effects on ESD Cubesat through new Spacesuite Code” 70th International Astronautical Congress (IAC), 2019

[5] S. Duzellier et al., "AXEL lab.: Representative Ground Simulation for Investigating Radiation effects in Materials and Electronics," 2017 17th European Conference on Radiation and Its Effects on Components and Systems (RADECS), 2017, pp. 1-7, doi: 10.1109/RADECS.2017.8696228

[6] *AZIMOV - AutomatiZatIon of MOVable optics for high resolution observations*, HORIZON-EIC-2021-PATHFINDEROPEN-01- AZIMOV

[7] L. Duveau et al., *Design strategies of an unobscured three mirror telescope with freeform surfaces for infrared nanosatellite imagery*, ICSO 2020, Proc. of SPIE Vol. 11852, 118520C

[8] M. Toyoshima, « Recent Trends in Space Laser Communications for Small Satellites and Constellations », *J. Lightwave Technol.*, vol. 39, nº 3, p. 693-699, févr. 2021, doi: 10.1109/JLT.2020.3009505.

[9] https://www.newspace.im/

[10] N. Vedrenne *et al.*, « Turbulence effects on bi-directional ground-to-satellite laser communication systems », Proc. Of ICSOS conference, 2012.

[11] M.-T. Velluet *et al.*, « PICOLO: turbulence simulator for adaptive optics systems assessment in the context of ground-satellite optical links », in *Environmental Effects on Light Propagation and Adaptive Systems III*, oct. 2020, vol. 11532, p. 1153207. doi: 10.1117/12.2573954.

[12] P. Cyril *et al.*, « FEELINGS : the ONERA's optical ground station for Geo Feeder links demonstration », in *2022 IEEE International Conference on Space Optical Systems and Applications (ICSOS)*, mars 2022, p. 255-260. doi: 10.1109/ICSOS53063.2022.9749705.

[13] C. Lucien, L. Jerome, V. Nicolas, R. Angelique, et G. Artaud, « Performance evaluation of coded transmission for adaptive-optics corrected satellite-to-ground laser links », in *2017 IEEE International Conference on Space Optical Systems and Applications (ICSOS)*, Naha, nov. 2017, p. 71-76. doi: 10.1109/ICSOS.2017.8357214.

[14] CSUT website : https://www.csut.cnrs.fr/en/

[15] D. Boscher et al., *In Flight Measurements of Radiation Environment on Board the French Satellite JASON-2 A Proton Sensor for Energies From 2 to 20 MeV*, IEEE Transactions on Nuclear Science, vol. 58, no. 3, pp. 916-922, June 2011, doi: 10.1109/TNS.2011.2106513.

[16] Bourdarie, S. A., & Maget, V. F. (2012). *Electron radiation belt data assimilation with an ensemble Kalman filter relying on the Salammbô code*. Annales Geophysicae-Atmospheres Hydrospheresand Space Sciences, 30(6), 929, https://doi.org/10.5194/angeo-30-929-2012

[17] J. Minow, *Spacecraft Charging: Anomaly and Failure Mechanisms*, Spacecraft Anomalies and Failures Workshop, Chantilly, Virginia, June 2014

[18] N. Ahmad et al., *Diagnosing low earth orbit satellite anomalies using NOAA-15 electron data associated with geomagnetic perturbations*, Earth, Planets and Space (2018) 70:91

[19] CSEP website : https://centrespatial-polytechnique.fr/en/

[20] Y. Bernard-Gardy et al., *Innovative technique for electrostatic discharges characteristisation on a floating nanosat mockup*, submitted

[21] J.-C. Matéo-Vélez et al., *ESD Cubesat Payload Definition and Mission Analysis,* Applied Space Environments Conference 2019, 12 - 17 May 2019, Los Angeles, CA.

[22] J.-C. Matéo-Vélez et al., *Detection of ESDs with CubeSIM*, Spacemon Workshop, dec 2020

[23] Meftah, M. et al., INSPIRE-SAT 7, a Second CubeSat to Measure the Earth's Energy Budget and to Probe the Ionosphere. Remote Sens. 2022, 14, 186. https://doi.org/10.3390/rs14010186

[24] Keckhut P. et al., Middle-Atmosphere Temperature Monitoring Addressed with a Constellation of Cube-Sats dedicated to Climate issues, AMS Journal of Atmospheric and Oceanic Technology, February 2021