Institut Supérieur de l'Aéronautique et de l'Espace
SUPAERO

# PhD Position

**Thesis Title**: Space Radiation Effects on Optical Detectors for Space LiDARs used for wind speed measurement of the Earth's atmosphere.

PhD Thesis Advisors: Vincent Goiffon and Olivier Marcelot (ISAE-SUPAERO)
Funding partners: Airbus Defence and Space, and Teledyne e2v
Main location: ISAE-SUPAERO, Toulouse, France

**Thesis subject description**:

## 1) Context

After the considerable success of the Aeolus / Aladin space mission developed by Airbus on behalf of ESA and launched in July 2018 (see: https://earth.esa.int/eogateway/missions/aeolus, the first European space LiDAR, first space LiDAR dedicated to wind speed measurement, first UV space LiDAR), the development of an operational mission is now required by Eumetsat, in order to improve the revisit time for data acquisition feeding European agencies of meteorology. This mission called Aeolus Follow-On (AFO) will be based on the use of 2-3 satellites with a lifespan of 7 years each.

Figure 1: Artist drawing of the Aeolus mission

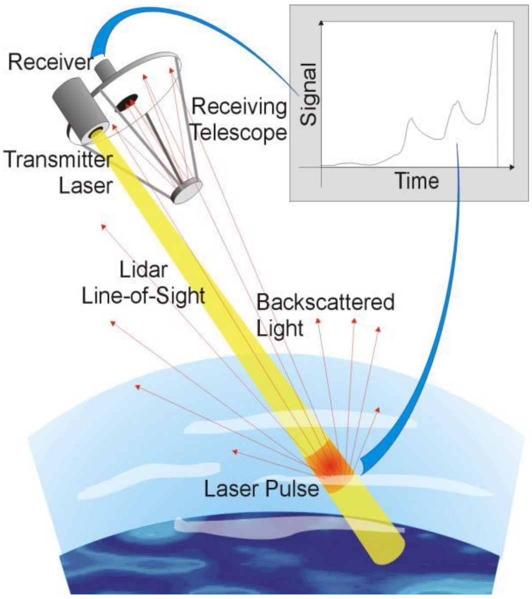


Figure 2: Working principle of the LIDAR Aladin

ESA started in 2020 pre-development activities for the two most critical elements of the AFO mission, namely the UV power laser and the detector. The latter is based on the development of a new generation image sensor (ACCD NG) largely reusing the principle of ACCD (Accumulation CCD) designed by Airbus and manufactured by Teledyne-e2v for the Aeolus mission. Compared to other alternatives like MCP PMT, Avalanche Photodiode, SiPM, the CCD technology offers a high quantum efficiency (80%) at 350nm, a 1D/2D imaging capability, and a linear dynamic of 100 dB.

The architecture of the ACCD makes it possible to circumvent two intrinsic limitations of the technology in order to make it compatible with an atmospheric LiDAR mission: the use of a dedicated memory structure makes it possible to store and sum a large number of LiDAR echoes (typically 20 for Aeolus), consequently minimizing the degradation of the useful information during its readings.
While the ACCD perfectly meets the needs of the Aeolus mission, raw data acquired in flight has demonstrated the presence of an anomaly that affects an increasing number of detector pixels. Despite extensive investigations carried out in 2020, the root cause of this anomaly (called “Hot Pixels”) has not been fully explained to date, and in particular the potential role of the space radiation environment and of the emission of Beta radiation from the detector window are not solved. However, it has been shown that the phenomenon of Clock Induced Charges was involved, although it is known not to generate permanent faults (see for example "Measurement and optimization of clock-induced charge in electron multiplying charge-coupled devices", N. Bush et al., J. Astron. Telesc. Instrum. Syst., 01-03 / 2021, Vol. 7).
As shown by the following figure, the artifact signature looks similar to RTS pixels due to displacement effect induced by protons. However, it has been established that this is not the case.

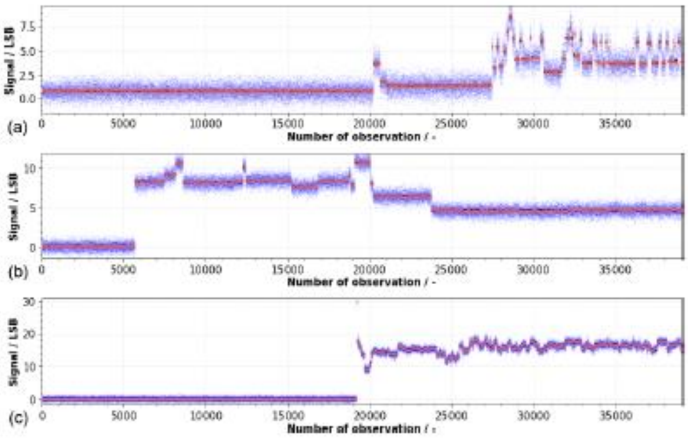


Figure 3: example of temporal behavior of hot pixels from ACCD Aeolus in dark condition.

Some corrections and compensations have been developed in order to minimize the hot pixel effects at the expense of an increased complexity of data treatment and flight operations. Furthermore, these corrections will reach a limitation when a consequent amount of ACCD pixels will present a hot pixel behavior.
In addition to the hot pixel anomaly, the feedback from the ground segment of the Aeolus mission shows a high sensibility of the final product to artifacts introduced on each pixel offset.
While the processing of the data generated during the ACCD proton tests in the early 2000s did not allow the detection of RTS pixel transitions with an amplitude lower than 5 - 10 electrons, this feedback demonstrates that it will be necessary to develop methods to characterize amplitudes significantly lower than 1 electron after proton irradiation (first campaign planned for the end of 2022-beginning of 2023). This is an important topic as the altitude and duration of the AFO mission will be higher than those of the Aeolus mission (respectively 420 km/7 years and 320 km/3 years) and the solar activity will be significantly higher.

Besides, the ACCD and ACCD NG detectors are produced by the company Teledyne-e2v on the basis of their CCD processes. If the sustainability of this process seems certain for the next few years, it remains hypothetical in the medium term. Given the advantages offered by ACCD-type architectures, it is now important to work on a port of the principle of these detectors for more recent technologies based on a CMOS processes, in particular the CCD on CMOS and CDTI (Capacitor Deep Trench Isolation).

## 2) Objectives of the thesis

The main objectives proposed for this PhD thesis work are as follows:
- After a bibliographic review covering the physical phenomena potentially related to the Hot Pixel anomaly of the ACCDs of Aeolus (Clock-Induced-Charge, the space radiation environment, window radiation, timing diagrams and applied voltage…), the PhD student will help in determining the root cause of the "Hot Pixel" anomaly by comparing in-orbit and on-ground measurements. To do this, ACCD and ACCD NG components are available to carry out laboratory investigations by using using the bench developed to operate new prototypes of these detectors. The PhD student will also have access to data from the detection chains of the Atlid LiDAR which uses a Memory CCD (MCCD) derived from the ACCD
- Based on the requirements of the AFO mission, the doctoral student will participate in the definition of the irradiation and test plans of the new ACCD components (flight models) and will develop the data processing methodology making it possible to characterize the amplitudes of pixels affected by the Hot Pixel anomaly and by proton atomic displacement effects to sub-electronic amplitudes. He will participate in the irradiation and characterization campaigns of these detectors. From the interpretation of the results obtained, he will help define their optimum operating conditions in flight (choice of timing diagrams, operating temperature, etc.) to mitigate the hot pixel anomaly.
- Starting from the definition of ACCDs and MCCDs developed for the Aeolus, AFO and Atlid missions and after having appropriated the capabilities of alternative technologies to Teledyne -e2v CCD technology, the doctoral student will study the possibility of transferring the principle of such CCDs dedicated to atmospheric LiDAR applications to technologies based on emerging CMOS technologies. Physical modeling will be carried out in order to improve the maturity of the most promising concepts. Technological vehicle architectures intended to validate these concepts will be proposed.

The doctoral student will have to promote her/his results in the form of scientific publications and communications in international conferences.

Applicant Profile:

Master Degree (or equivalent) in one or more of the following field:
- nano/microelectronics (design, characterization, technology, manufacturing process…)
- optoelectronics
- detectors/instrumentation
- semiconductor device physics
- solid state physics
- particle physics
- particle matter interactions
- space radiation environment and its effects on electronics