# Meteorix camera tests for space-based meteor observations

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Meteorix is a Universitary CubeSat dedicated to be a demonstrator for the detection and characterisation of meteors and space debris. Its payload is an onboard camera and detection chain. Usually, cameras on CubeSat are used for daylight observations and this proceeding present some tests realized with a sensitive CMOS camera, which is also used in the martian rovers for imaging purposes. In-lab tests were conducted to measure the spectral response. First on-sky images were performed during the 2020 Geminids meteor shower from the Paris area. Follow-up tests were performed from Observatoire de Haute-Provence during the 2021 $\eta$-Aquariids meteor shower. Capabilities and needed modifications for meteor detection were identified.

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## 1 Introduction

The flux of extraterrestrial material and space debris is not yet determined with great accuracy (e.g. Zolensky et al., 2006; Rendtel & Arlt, 2014; Koschny et al., 2015). To detect meteors, and especially fireballs, large Earth-based networks are set up such as CAMS (Jenniskens et al., 2011), CILBO (Koschny et al., 2013), FRIPON (Colas et al., 2020), DFN (Devillepoix et al., 2020) or the Global Meteor Network (Vida et al., 2020).

Alternatively, mobile stations can be used to observe irregular meteor showers, such as the new 15P-Finlay shower predicted by Vaubaillon et al. (2020) and observed from Chile with MoMET (Da Fonseca et al., 2021). Complementary to these networks, space projects are beginning to emerge, including nanosatellites with the advent of Newspace, to propose meteor science missions (Ishimaru et al., 2014; Rambaux et al., 2019; Petri & Klinkner, 2020). These missions allow to overcome meteorological constraints, to cover a large sky area with a single camera and to detect meteors without the attenuation of the spectrum by the terrestrial atmosphere. Newspace also allows universities to participate in this adventure by directly involving students in these ambitious projects.

The meteor observations from space has been realised by the Meteor experiment onboard of the International Space Station (ISS) allowing to record several sequences of the meteors (Arai et al., 2018). Recently, the Chinese satellite Yangwang has also detected meteors from space.

More specifically, a few nanosatellite projects dedicated to meteor observations are currently developed in the world such as SOURCE at Stuttgart University (Petri & Klinkner, 2020) and Meteorix at Sorbonne Université and associated laboratories (Rambaux et al., 2019). The purpose of this work is to describe the advancement of the optical part of the payload. The detection chain is described in the complementary proceeding (Millet et al., 2021).

## 2 Meteorix mission

Meteorix is a 3U Universitary demonstrator CubeSat dedicated to the detection and characterisation of meteors and space debris. The main objective is to obtain a robust statistic on the entry of meteoroids and space debris into the Earth's atmosphere. These estimates allow to quantify the flux of extraterrestrial material falling on Earth and to study the interactions of high-velocity meteoroids with the atmosphere as well as the risk of collisions with artificial satellites during meteor showers. The knowledge of the space debris flux will bring an additional constraint for the space awareness models developed in the space agencies. The secondary objectives of this mission are to provide information on the ablation, fragmentation and rotation processes of these objects by measuring the photometric variations of the meteors. In addition, the trajectory of the meteoroids and their dynamical origin will be obtained precisely by combining the detections with those obtained on the ground thanks to the monitoring networks such as FRIPON (Fireball Recovery and InterPlanetary Observation Network) developed in France and which now extends to Europe (Chen et al., 2020). The technological objective of the mission is the demonstration of the feasibility of a real-time computer vision application on board a CubeSat with strong constraints in terms of power consumption and execution time (see Millet et al., 2021).

Finally, this project developed at Sorbonne Université has an important pedagogical dimension by directly involving students in the definition, design, and realisation of the nanosatellite. The scientific and technological objectives fit perfectly in the standard of a small space mission of CubeSat 3 Units developed by students. The project validated the mission definition phase in September 2015 and its feasibility phase in September 2017.

The payload is composed of a visible camera and a detection chain (Rambaux et al., 2019). The obser-

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vation is made on the night side of the Earth and the satellite points to the nadir. The nominal life-time of the mission is one year in order to observe the sporadic meteors and to record the main meteor showers. The orbit of the nanosatellite is planned at 500 km altitude on a sun-synchronous orbit.

The design of the CubeSat is based on the CNES cubesat EyeSat (Apper et al., 2020). The bus of the spacecraft is composed of four deployable solar panels in order to increase the energy available on-board and an S-band transmitter for scientific data plus a UHF/VHF transceiver. In addition, the spacecraft has all vital subsystems, a power board, thermal system, a magnetorquer board, one reaction wheel, and on-board computer (see Rambaux et al., 2019).

## 3 Camera payload

The payload of Meteorix consists in two parts: a camera in the visible domain and an on-board detection chain. The camera is used to record the meteors under the satellite and it is composed of a detector and an optic. The meteors are observed on the night side of the Earth and their detection requires a high sensitivity detector. An off-the-shelf camera is not an optimal solution because most of the Earth CubeSat cameras are dedicated to recorded images during the day. The choice is currently made on the detector 3DCM734 detector of 3Dplus that allows to reach a high enough sensitivity with a quantum efficiency close to 60%. Such detector has a high space-heritage because it flew with the Mars Science Laboratory (Maurice et al., 2021) and on the CNES CubeSat EyeSat (Apper et al., 2020).

A first test phase consisted in verifying the spectral response of the detector. Figure 1 shows the result of a laboratory test campaign of the detector response without optics. This Figure shows the very good agreement between specifications and measurements, confirming the good sensitivity of the detector.

The choice of the optics is not yet confirmed. It has to correspond to the scientific requirements of the detection of a hundred meteors per year requiring a field of view of at least 40 deg (Rambaux et al., 2019).

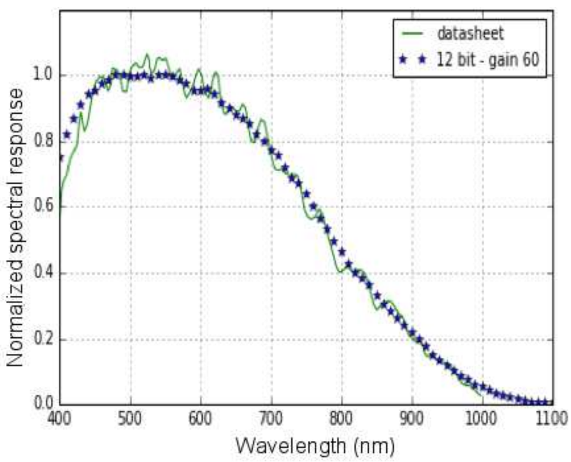


*Figure 1* – In-lab measurement of the normalized spectral response of the CMOS monochrome detector 3DCM734 (blue points) compared to manufacturer's data (green curve).

There are commercially available optics with a 6-mm focal length and a 1.4 aperture giving large field of view. Such optics have to be reworked to be compatible with the space environment.

A test campaign was carried out during the meteor shower of $\eta$-Aquariids in May 2021. The Figure 2 shows a sequence of a meteor built on image difference. The integration time is 100 ms, the lens used is 6 mm $f/1.4$. The images in the analysis are centered on the meteor so the real field-of-view was larger than displayed here.

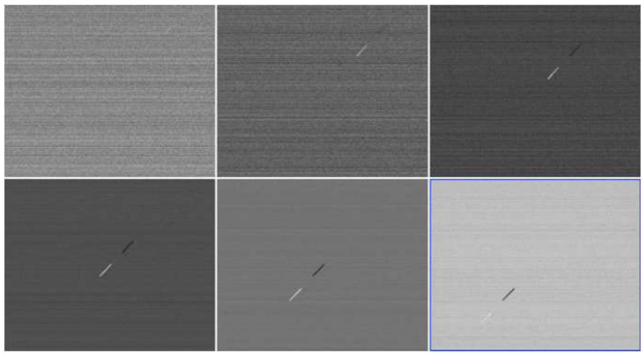

*Figure 2* – Sequence of meteor images acquired at the Observatoire de Haute-Provence during the 2021 $\eta$-Aquariids with the 3DCM734 detector. The images are differences in order to highlight the meteor. The integration time is 100 ms with cadence of 100 ms.

## 4 Discussion

These first tests on the selected detector allow to validate its very good sensitivity but two limitations appeared during this phase test. First, the data flow of the full-images ($2048 \times 2048$) of the detector is limited to a rate of 7 fps due to the use of a space-wire used to communicate with the detector. This data rate is lower than the 10–30 fps required for meteor science objectives and the detection chain algorithms. The current mitigation is to reduce the size of the image ($512 \times 512$) allowing to accelerate the transfer. A second way of mitigation will be to access directly to the detector registers. Secondly, the detector is used at its sensitivity limit and horizontal lines appear differently for each image. The improvement of these lines is still on working and a back pixel column will be used to clean up the images. In addition, the astrometry of the meteor and the photometry reduction are still in progress.

## 5 Conclusion

The Meteorix mission is a demonstrator CubeSat mission dedicated to the meteor and space debris science and with technological objectives on the innovative detection chain on-board. This project is developed in laboratories and at the Sorbonne University implying a large number of students that developed new skills around development of a space mission. So this mission is a great source of motivation and inspiration for young people, as the meteor science is challenging and fascinating domain. Currently, the project focused on the payload and the detector has been tested in laboratory and on the ground. The sensitivity of the detector is confirmed and limitations have been identified. The development of a prototype with a full test-bed meteor simulations and detection chain is on progress.

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