**Proba-V Companion CubeSat (PVCC) mission first light and commissioning**

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## ABSTRACT

The Proba-V Companion CubeSat (PVCC) mission, initiated by VITO and supported by the Belgian Science Policy Office, has been realized by a consortium led by Aerospacelab and composed by VITO, and OIP. The mission of this 12U CubeSat to acquire images from a known payload on a smaller platform. PVCC is the complementary satellite made to Proba-V, launched in 2013, which was tasked to map land cover and vegetation growth across the entire planet every two days. PVCC therefore features the spare spectral imager from Proba-V as its main payload to provide data improving the calibration of Earth Observation imagery making use of a CubeSat platform.

This paper provides an overview of the PVCC mission, including its launch, commissioning, initial imaging activities, and ongoing developments. Additionally, it delves into key technical aspects such as payload thermal environment and AOCS commissioning.

## 1 INTRODUCTION: PVCC MISSION OVERVIEW

The PVCC mission represents a collaborative effort to advance global environmental monitoring through CubeSat technology. Initiated by VITO and supported by Aerospacelab, PVCC tests a CubeSat platform carrying the spare spectral imager of the Proba-V vegetation-monitoring instrument, aiming to enhance the calibration of Earth Observation imagery for future missions. The platform is based on the 12U product line that first gained flight heritage in June 2021 with ARTHUR-1, operated by Aerospacelab.


Figure 1 Overview of the Land-Sea mask (in light blue) and a zoom on the Mediterranean Sea

As its predecessor, the satellite embarks a large field-of-view "push-broom" payload that is made for global surveying. The payload is to image each time that the spacecraft is over land, using the so-called "land-sea-mask" presented in Figure 1.

### 1.1 Space segment

The Figure 9 presents the evolution of the platforms hosting the vegetation instrument. A significant effort has been made in the frame of the Proba-V mission for the miniaturization of the instrument. As the mission left one spare spectral imager and its read-out electronics, those equipments have been used as-is for the PVCC mission.

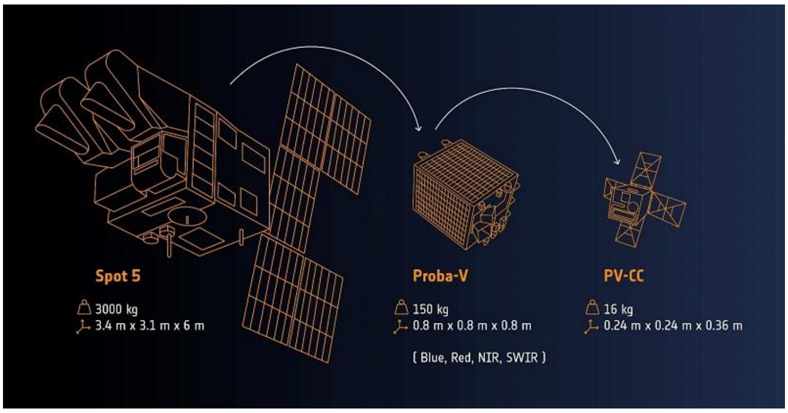

Figure 2 Platform evolution from SPOT to PVCC [1]

As shown in Figure 3, the CubeSat platform is required to emulate the Power Supply Unit as well as Data Handling Units which increases the load on the platform on-board computer, then required to packetize and compress the image data before downlinking them through the X-band datalink.

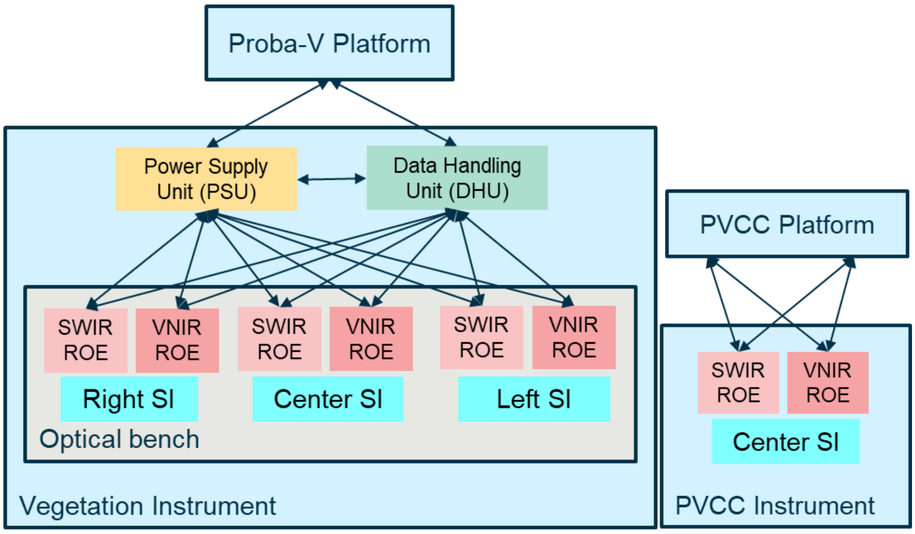

Figure 3 Proba-V and PVCC payload functional decomposition

The Figure 4 presents the different equipments composing the satellite. It can be noted that the read-out electronics, the Spectral imager and the payload baffle are taking the majority of the volume of the CubeSat. The limitation of the 12U platform prevented from implementing a propulsion unit. The impact of this aspect will be discussed in Section 2.2.

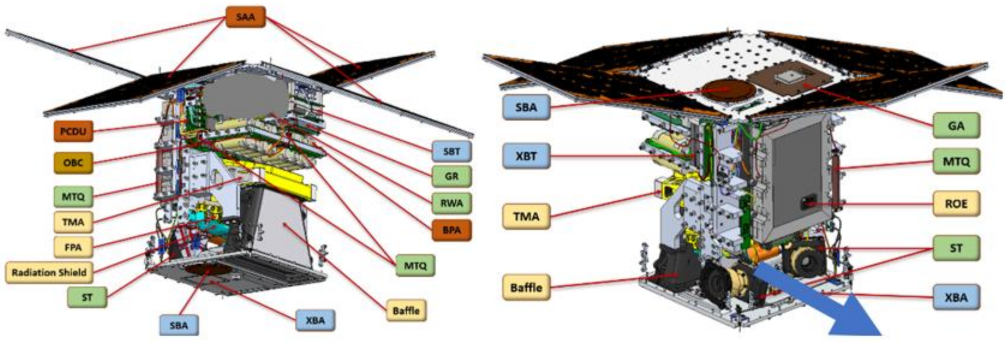


Figure 4 PVCC satellite configuration and the flight direction (-X direction in mechanical frame)

The attitude control of the satellite is using magnetometers and magnetorquers in safe mode, which is tuned to prevent sun inclusion in the payload. For the nominal mode, mostly using a nadir pointing attitude, two star trackers and four reaction wheels are baselined. The magnetorquers in the nominal mode are only used for the momentum management and wheels desaturation in the baseline design.

The images on Figure 5 present spectral imager serial number 3. A baffle in aluminum and coated internally has been developed to fit the configuration. The SI#3 is composed of a Three-Mirror Anastigmat element in Aluminium (TMA) and two Focal Plane Arrays (FPA). The TMA is fixed on what is called the TMA panel, where the star trackers are directly fixed. The TMA panel is held on the side panels of the satellite.

An effort has been made to thermally decouple the payload from the environment. This effort is materialized by a radiative decoupling with Multi-Layer Insulation (MLI) and a conductive decoupling with thermal washers, as seen on Figure 6. The TMA panel is directly connected to the "Y panels" that are coated in white.

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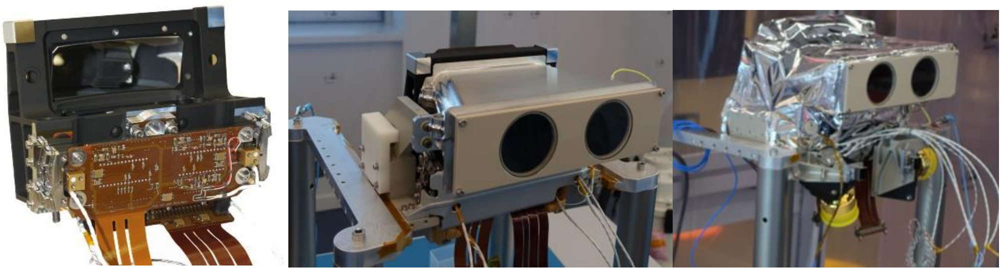

Figure 5 On the left, the Proba-V Spare spectral imager (SI#3, [2]) and its implementation on the optical bench on PVCC

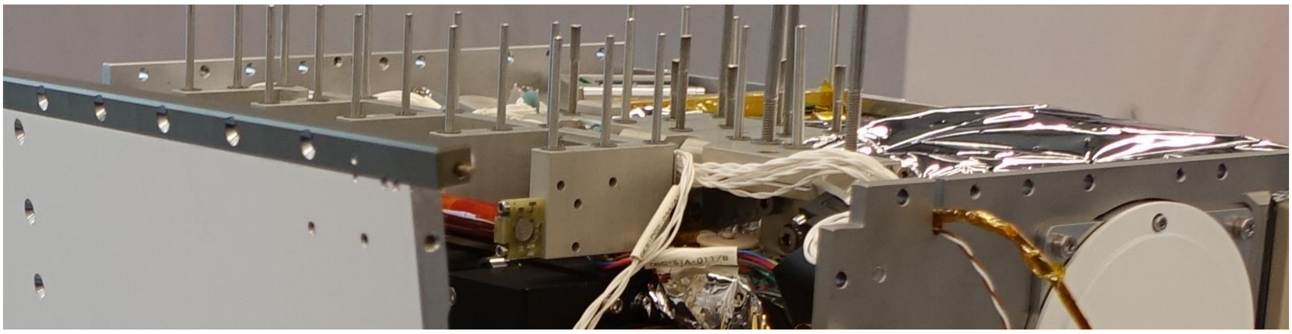

Figure 6 Assembly of the side panel in contact with the TMA panel, with the thermal washers visible

### 1.2 Ground segment

The PVCC uses ESEC in Redu as main ground station for telemetry and telecommand (TM/TC) in S-band. Swedish Space Corporation (SSC) is providing support with Kiruna and Inuvik as secondary TM/TC ground station and primary payload data ground station for data reception in X-band. The data is then directly delivered to the Payload Data Ground Segment (PDGS) operated and maintained by VITO, in a similar manner to the Proba-V mission.

The ground stations are connected to the Mission Control Center (MCC) which receives the requests from the user and prepares the planning to be uploaded to the space segment. The MCC is developed and implemented by Aerospacelab.

## 2 LAUNCH AND COMMISSIONING

PVCC was successfully launched aboard the VV23 mission on Vega-C from Kourou, French Guiana, on October 9$^{th}$ 2023. Following launch, the satellite underwent commissioning procedures to ensure proper functionality. This phase included system checkouts, power system verification, communication tests, and payload instrument initialization.

### 2.1 Initial Imaging Activities

The thorough testing realized on the ground allowed to bring the different subsystem in nominal conditions in a rapid fashion. This allowed to get to the step of turning on the payload for the first time on October 12$^{th}$, 3 days after launch. The acquisition was made by a manual telecommand while connected to the satellite through the ESEC/Redu ESA ground station. The location was selected due to cloud coverage over northern Europe and to the fact that acquiring coastlines would facilitate a preliminary geometric assessment. The first light is presented in Figure 7.

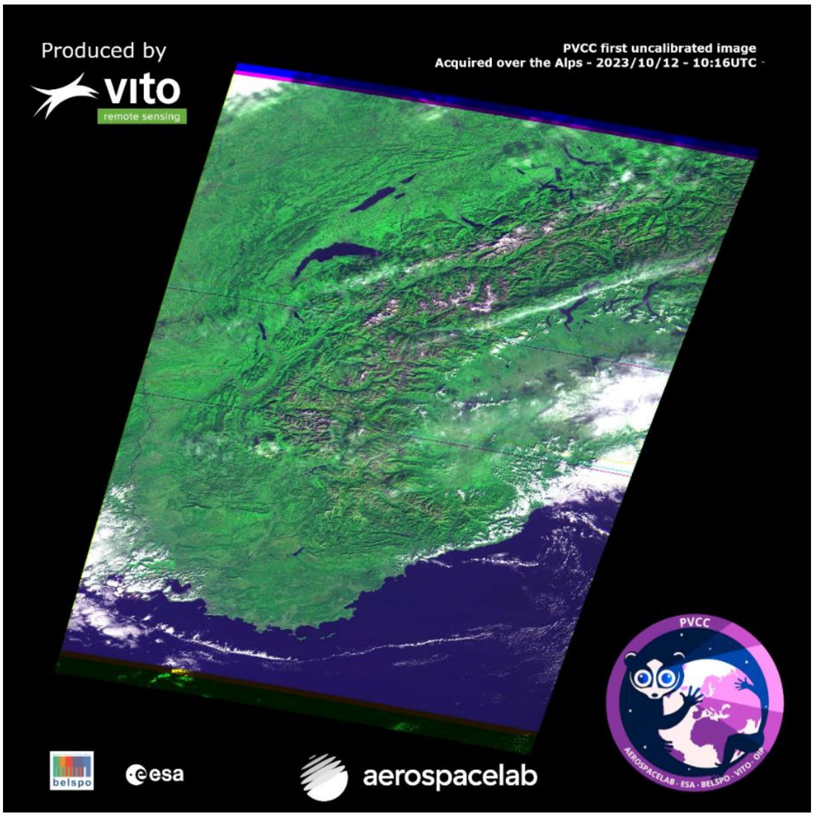

Figure 7 First light acquired by PVCC on 12/10/2023 over the Alps

PVCC initiated imaging activities using its spectral imager, capturing valuable data for Earth observation. Early images demonstrate the satellite's capability to acquire data from its payload on the CubeSat platform. The swath of this image is about 350km. Preliminary geometric assessment indicated that the geolocation error on this first image was below 8km based on position and attitude knowledge.

### 2.2 Altitude evolution

Due to CubeSat limitations and lack of propulsion, it was not possible to inject PVCC in a similar altitude to Proba-V. Moreover its orbital parameters are evolving quicker than Proba-V, namely on the altitude. This has a significant on the data product as the resolution and revisit will evolve during the mission. It is to be noted that the local time of descending node is well within the requirements for the mission at 10h14 (requirement. 09h30-11h30, goal 10h00 – 10h30) and is expected to remain during the duration of the mission.

The Figure 8 presents the evolution of the mean altitude, perigee and apogee of PVCC.

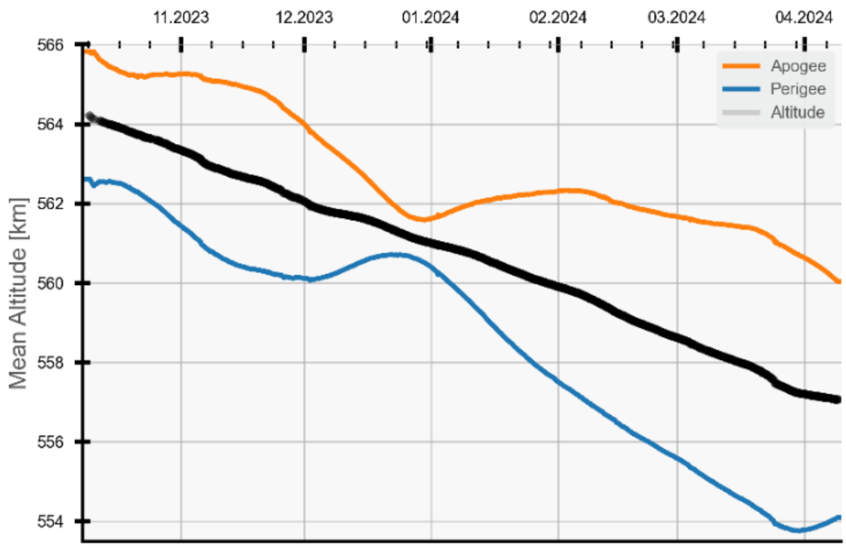

Figure 8 PVCC altitude evolution from launch until April 2024

The lower altitude has also an impact on the shape of the pixels. Indeed, if the nominal Proba-V line rate is used, the pixels will be rectangular. Some tests during the commissioning will assess whether a faster line rate can be achieved with the payload, and what impacts it will have on its thermal stability.

### 2.3 Challenges during commissioning

During platform commissioning, the satellite experienced issues with two of the four reaction wheels. The gravity of the issues increased with time, ultimately resulting in a partial loss of use of the reaction wheels in question, required for the nominal nadir pointing attitude. The AOCS was reconfigured to retain functionality with the remaining subset of functioning units with minor losses in pointing performances and reduced agility. AOCS aspects of this degraded mode are discussed in the Section 3.4.

Since the identification of this issue in October 2023, investigations on the root cause were initiated, while potential alternative strategies were developed. Unfortunately, experience on ARTHUR-1, which has a virtually identical configuration for the impacted units, could not be leveraged, as the issue was not encountered in more than two years of operations

Investigations indicated in February that alternative strategies were to be favoured over a recovery. Since then, Aerospacelab implemented different feature upgrades, namely an automatic reconfiguration algorithm, as well as nadir pointing attitude controller using less than three reaction wheels by making use of the magnetorquers. Such controller allowed to reach nadir pointing and remain in nominal mode for more than 10 days in early April with two reaction wheels and the three magnetorquers.

## 3 PRELIMINARY OBSERVATIONS WITH RESPECT TO DESIGN

The period in nominal nadir pointing allowed to gather critical data that can assess the environment seen by the payload, as understanding the impact of a CubeSat environment on a payload made for a MicroSat is the main objective of the mission.

Unfortunately, at time of writing this paper, the status of imaging activities does not allow to present image-based data results. This section is therefore solely based on the telemetry received from the satellite.

### 3.1 Thermal aspects

The initial observation is that the observed temperatures on PVCC are within the predicted ranges. As revealed in the thermal analysis, some temperature variations across different parts of the satellite are mitigated by physical decoupling. Electronic Units and their respective structures exhibits orbital variations around 10 to 15°C, while the Focal Plane Array (FPA) demonstrates an efficient decoupling from the rest of the platform and space environment, with an orbital temperature variation below 4.6°C. These temperature profiles serve as critical inputs for ensuring the satellite's thermal stability and performance for delivery imagery.

As anticipated in the analysis, there is a minor thermal link between the star trackers ST2 and the FPA, both located on the TMA secondary structure.

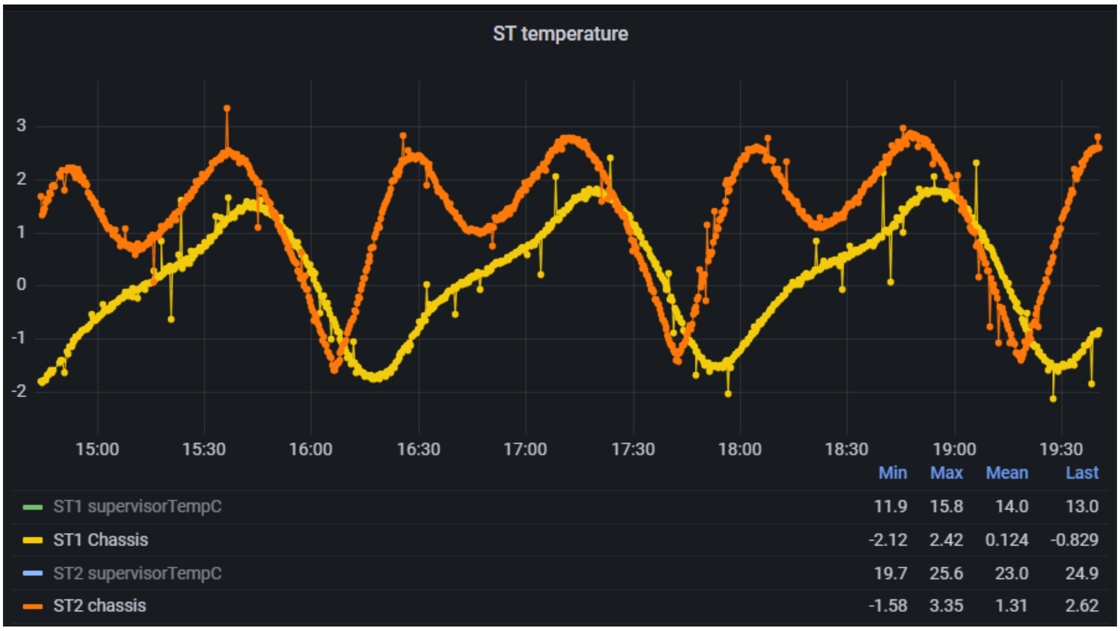

Figure 9 Star trackers chassis temperature variation

Figure 9 shows that the Star tracker 2, located on the Y+ side of the TMA secondary structure experiences solar heating at the start of daylight for a few minutes. This is also the reason why a gradient can be observed on the TMA between Y+ and Y- on Figure 10. This can be observed with a lower impact on the FPA on Figure 11.

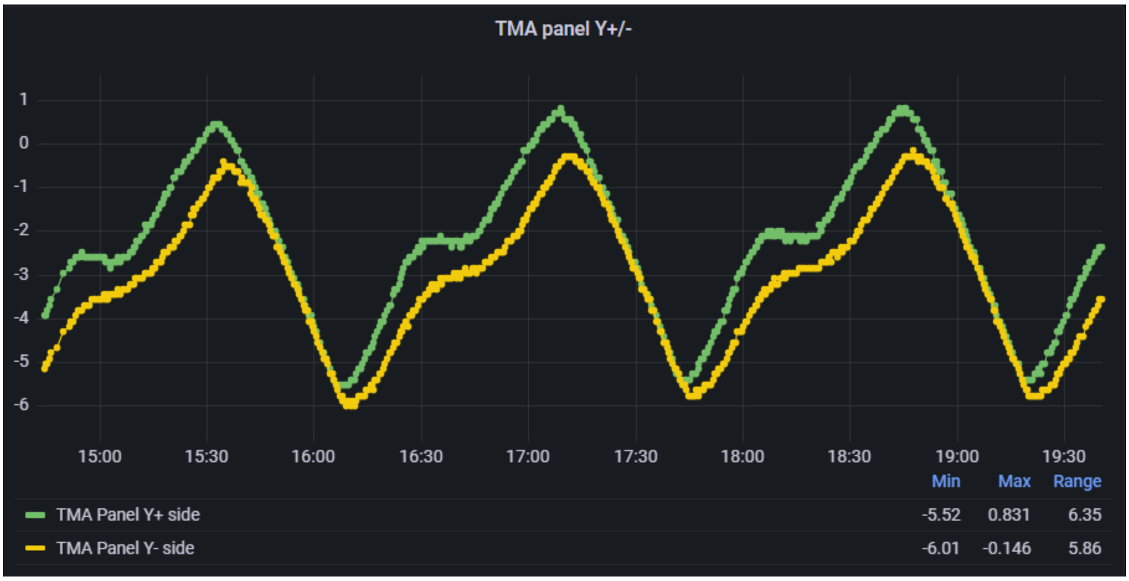

Figure 10 TMA secondary structure temperature variation

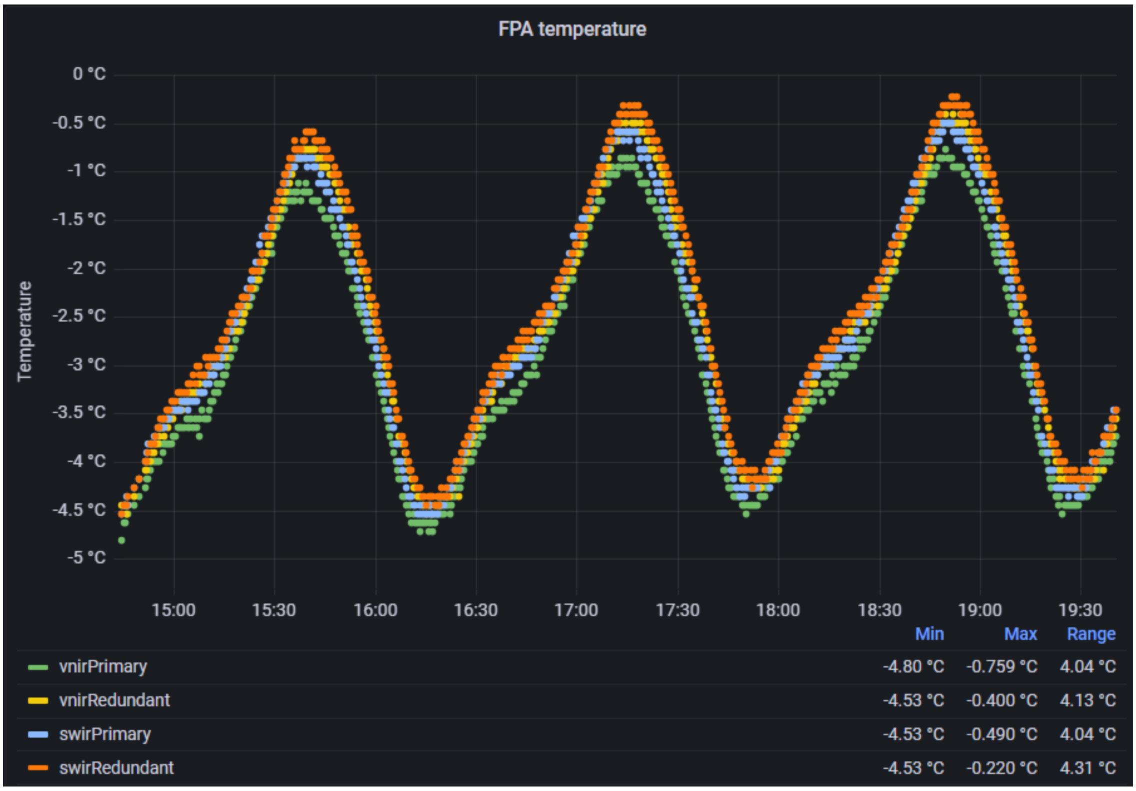

Figure 11 FPA temperature variation

### 3.2 Temperature Stability

The temperature stability is a key point for the calibration of the data products. Due to its low mass and compactness, there are only limited margins for implementation. In addition to the physical decoupling discussed in Section 1.1, the payload FPA incorporates heaters to dissipate the equivalent power used by the detectors while the payload is not imaging.

Ongoing monitoring and analysis indicate that the temperature variations of the payload at FPA level during an orbit averages between 4° and 5°. over a full day. As presented on Figure 12, orbit-to orbit variations can be estimated on the processed telemetry, which could indicate a stability below 1.2°. This number will have to be consolidated with the increased imagery duty cycle which will allow the one-to-one comparison of imagery of the same locations. It is however encouraging for latitude-based calibration.

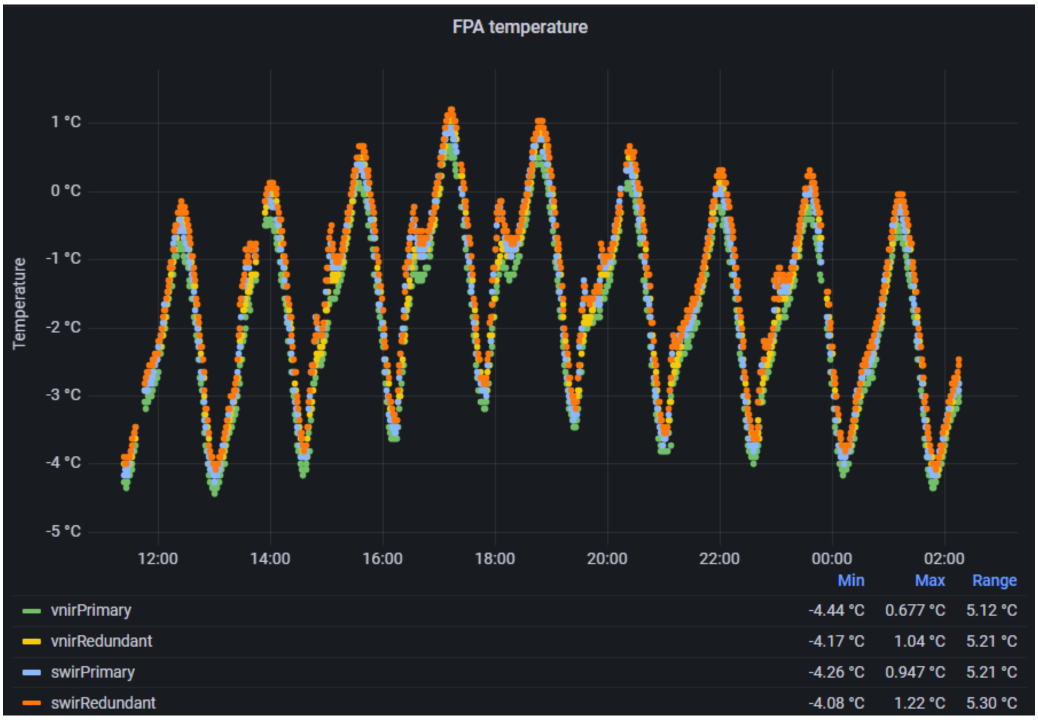


Figure 12 FPA temperature variation over different orbits (no imaging)

Figure 13 presents one of the longest imagery use case, with almost 20 minutes of continuous imaging. The peak before 7:00 at -1.5°C is below the similar peaks seen on Figure 12. This indicates that the strategy with payload heaters is supporting the payload thermal stability.

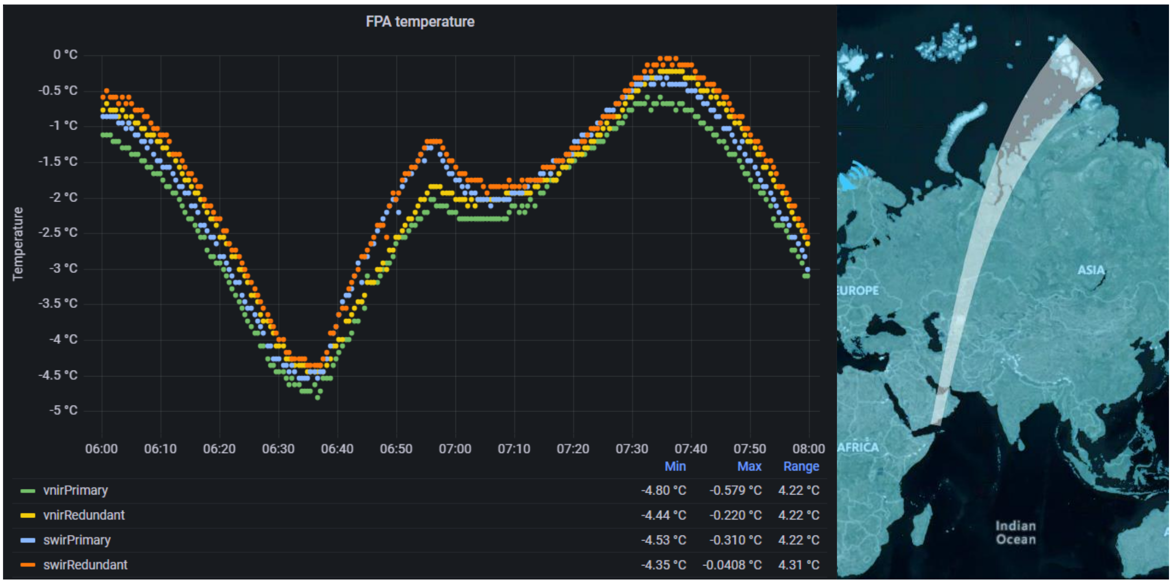


Figure 13 FPA temperature variation during an orbit with 7700km of imaging (6:37 to 6:56)

### 3.3 Thermal stabilisation

The data shown in Figure 14 demonstrated a stable transition from safe to nominal mode. It can be observed that the transient phase takes about 5-6 orbits or about 8-10 hours.

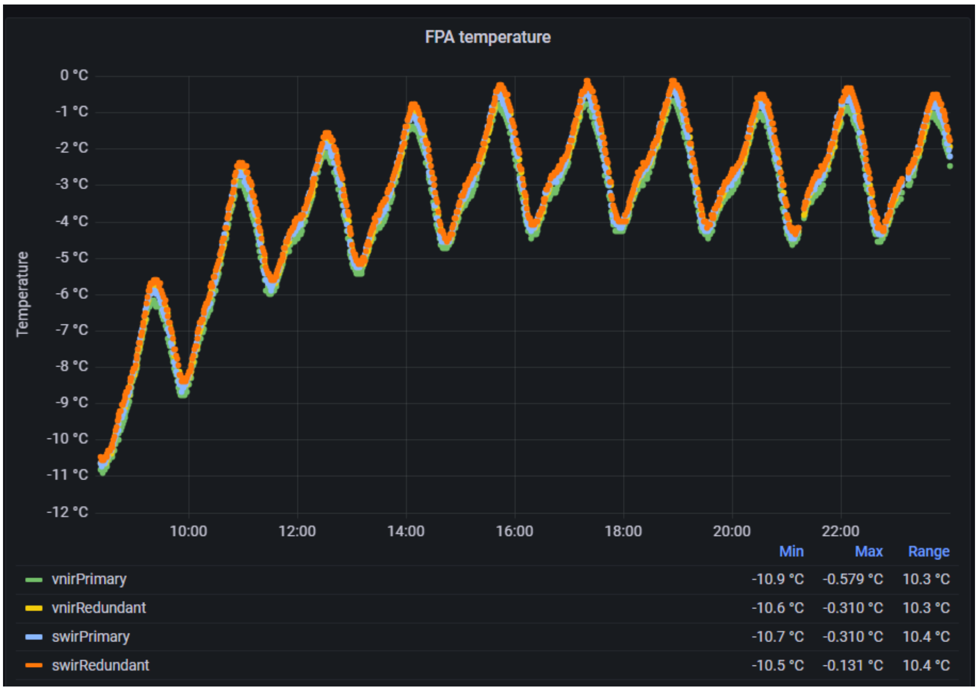


Figure 14 FPA stabilisation from safe to nominal mode

Temperature variations over days and seasons will be further analysed, as well as the impact of turning off the payload heaters to reduce the temperature on the FPA and improve the dark current behaviour.

### 3.4 AOCS Performances

The AOCS subsystem of PVCC was designed originally for operations using a cluster of four reaction wheels and three orthogonal magnetorquers. The concept of operations includes stable nadir pointing for imaging, multiple ground-station pointing maneuvers each day, and periodic calibration maneuvers including imaging spectral calibration using the moon.

Following the degradation of functioning of two reaction wheels, the AOCS was re-worked to include autonomous reconfiguration functionalities as a function of healthy and available actuators. In degraded mode scenarios the AOCS performance may be compromised. Ongoing evaluations and simulations validate AOCS performances under various operational conditions.

The objective was set to being able to run the nadir pointing and low agility parts of the mission using the reliable set of actuators, and reserving the use of the remaining ones for maneuvers where more authority and agility are needed.

## 4 CONCLUSION

The PVCC mission allows to push the design of a payload made for a MicroSat in the limits that a 12U CubeSat allows. Initial operations after launch were encouraging, however the degradation of some actuators that cannot be compensated by a software update forced the operators to find innovative strategies to maximize the mission returns.

With the support of a goal-oriented team, a degraded attitude control mode could be designed and implemented. The in-orbit results will allow to refine the final update of the attitude control subsystem before allowing the resuming of payload commissioning.

In the meantime, the thermal stability of the satellite will be further put to the test with the increase of imagery duty cycles and configurations.

The extra developments required by the challenges encountered during the commissioning will provide valuable perspectives for future missions, emphasizing the importance of robust design and operational resilience in space exploration.

## 5 REFERENCES

[1] ESA, https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Big_Earth_imager_to_be_tested_on_small_Vega_CubeSat, retrieved on 15/04/2024

[2] OIP, https://oipspace.be/solutions/spectrometers/planetary-observation/proba-v/ retrieved on 15/40/2024