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# PariSat

## EXPERIMENT REPORT

GD-2143-A-002

Revision 1.5

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| Version 0.1 | July 11, 2024 | Creation of the document |
| Version 0.2 | August 5, 2024 | Finalization of the summary |
| Version 0.3 | August 8, 2024 | Writing of the different chapters |
| Version 0.4 | September 2, 2024 | Analysis of the scientific results |
| Version 0.5 | October 12, 2024 | Proofreading of the document |
| Version 1.0 | October 24, 2024 | Distributable version |
| Version 1.1 | October 29, 2024 | Minor corrections |
| Version 1.2 | October 30, 2024 | Minor corrections |
| Version 1.3 | October 31, 2024 | Minor corrections |
| Version 1.4 | November 1, 2024 | Minor corrections |
| Version 1.5 | November 2, 2024 | Minor corrections |

# 1. INTRODUCTION

## 1.1 Project context

At the end of 2021, **GAREF** responded to a participation opportunity from ESA (European Space Agency) to embark a small payload on the inaugural launch of Ariane 6, the new European launcher. On February 4, 2022, **GAREF** received confirmation that its **PariSat** experiment had been accepted to be part of the payload of the first launch (referenced VA262) of Ariane 6, which took off from Kourou at the Guiana Space Center on July 9, 2024 at 19:00 UTC.

This is an exceptional opportunity for **GAREF**, which has been conducting numerous experiments since its creation in 1964, including 5 experimental rocket launches in Kourou and 3 in Kiruna (as part of the CNES PERSEUS project). It was in 1981 that its first satellite **Thésée** was launched on the 4th test flight (L04) of Ariane. After 3 years of work, **PariSat** is therefore a unique opportunity to put a new experiment into orbit, and it is also the first opportunity for the club to take photos from space.

What characterizes **PariSat** is above all the fact that it is entirely designed and manufactured in-house at **GAREF**, by young enthusiasts aged 15 to 25, from the overall mechanical architecture to the soldering of the cards, including electronic design and software.

## 1.2 Project objectives

The scientific objective is simple: without air in space, and under cosmic rays and those of the sun, how can we best dissipate the heat of the on-board electronics?

The experiment therefore consists of determining the material that would act as the best radiator. We have a batch of 8 miniature thermal radiators (40×40 mm plates), all different (material, surface treatment, heated or not, etc.), with a temperature sensor connected to each plate. In more technical terms, this will validate the principle of black body radiation, established in 1884 with the Stefan-Boltzmann law. These measurements will determine which material with which surface treatment would be likely to best dissipate the heat of the electronics, with a future space mission in mind (satellite or other).

Beyond the scientific aspect, the **PariSat** project turns out to be an extraordinary human adventure for a team of young amateurs aged 15 to 25, all passionate about space.

## 1.3 Technical specifications

The external structure of **PariSat** is based on the standard 6U cubesat format (30×20×10 cm), slightly modified to meet certain integration constraints; all for a total mass of 7.5 kg. In order to carry out its mission, the satellite contains different electronic modules designed by the young people of **GAREF**:

- Scientific experiment
- Shooting experiment
- Power supply
- Timecode
- On-board computer
- Telemetry system

The experiment power supply was sized to be active for the entire duration of the flight, i.e. an autonomy of approximately 2 hours. The data is stored on board throughout the flight, before being downloaded during a single pass over the Esrange satellite receiving station (near Kiruna in Sweden).

## 1.4 The PariSat team

### 1.4.1 Project management

*Nolan R.*
*20 ans*
*Project lead*

*Elias A.*
*20 ans*
*Scientific experiment lead*

### 1.4.2 Project members

*Nicolas A.*
*17 ans*
*On-board electronics*

*Atia B.*
*16 ans*
*Power supply*

*Bérenger D.*
*18 ans*
*Scientific experiment*

*Alexandra D.*
*24 ans*
*On-board electronics*

*Léon F.*
*16 ans*
*On-board software*

*Jeanne F.*
*16 ans*
*Power supply*

*Yoram F.*
*20 ans*
*Mechanical design*

*Aymeric G.*
*17 ans*
*On-board electronics*

*Chan-Ly L.*
*16 ans*
*On-board electronics*

*Ricardo M.*
*17 ans*
*Power-up sequence*

*Guillaume M.*
*16 ans*
*On-board electronics*

*Noé M.*
*17 ans*
*On-board electronics*

*Ophélie N.*
*17 ans*
*Power supply*

*Thomas R.*
*18 ans*
*On-board software*

*Joseph R.*
*17 ans*
*Mechanical integration*

*Laszlo S.*
*16 ans*
*On-board electronics*

*Philippe S.*
*18 ans*
*Photography experiment*

*Gaspard W.*
*15 ans*
*On-board software*

*Maya Y.*
*17 ans*
*Power supply*

### 1.4.3 Supporting engineers

*Axel C.*

*President of **GAREF**, On-board computer*

*Bernard S.*

*Telemetry*

*Yacine A.*

*Telemetry and transmission antenna*

*Charlie B.*

*Treasurer of **GAREF***

*Nasca F.*

*Mechanical design*

*Léo G.*

*Timecode*

*Timothée G.*

*Electronics*

*Elies H.*

*Telemetry reception*

*Noha K.*

*Mechanical design*

*Alexandre P.*

*Telemetry and transmission antenna*

### 1.4.4 Press and communication

*Matthis M.*

*Communication manager*

# 2. PRESENTATION OF THE PARISAT EXPERIMENT

## 2.1 General description

The scientific experiment consists of electronics for heating and measuring the temperature of 8 plates made of different materials such as aluminium, carbon fibre and titanium, coated with different surface treatments. An unheated plate of black anodized aluminium serves as a reference. All plates are passively heated by solar and terrestrial radiation and 2 plates are also actively heated by means of heating resistors placed behind the plates in question. A photoreceptor measures the intensity of the radiation from the Earth and the sun received by the plates.

The on-board computer (OBC) is responsible for collecting, organizing and storing all the system data, and formatting and encoding them for sending to the telemetry transmitter. Batteries provide power to the various devices. A watchdog system ensures that the experiment is automatically restarted in the event of a fatal error. A timecode module allows all measurements to be dated in a synchronized manner, to correlate them with each other and with Ariane ground measurements. A photo module containing a camera equipped with a wide-angle lens allows the acquisition of images in low orbit. A power-up module allows the start-up of **PariSat** following a signal sent by the launcher. A transmitter and two patch antennas allow the transmission of data to ground stations.

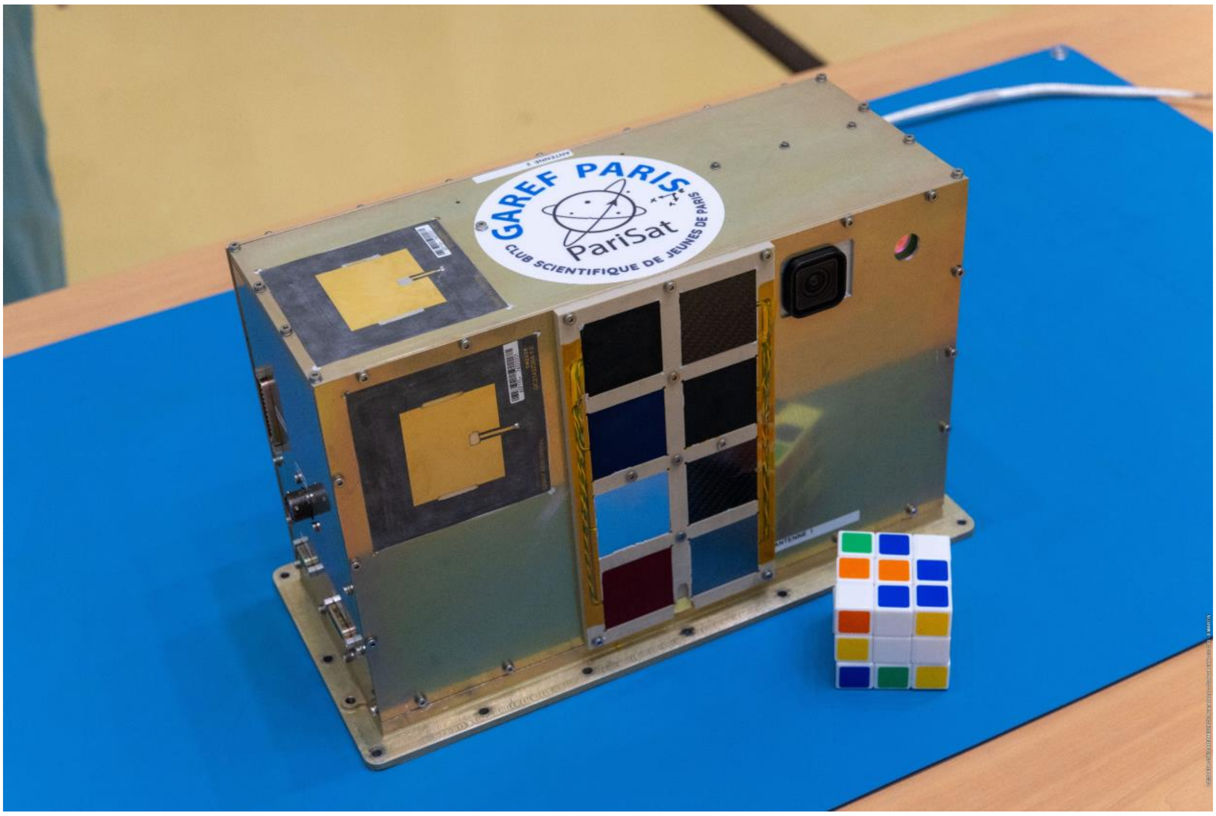


*Image of **PariSat** before its integration into Ariane 6*

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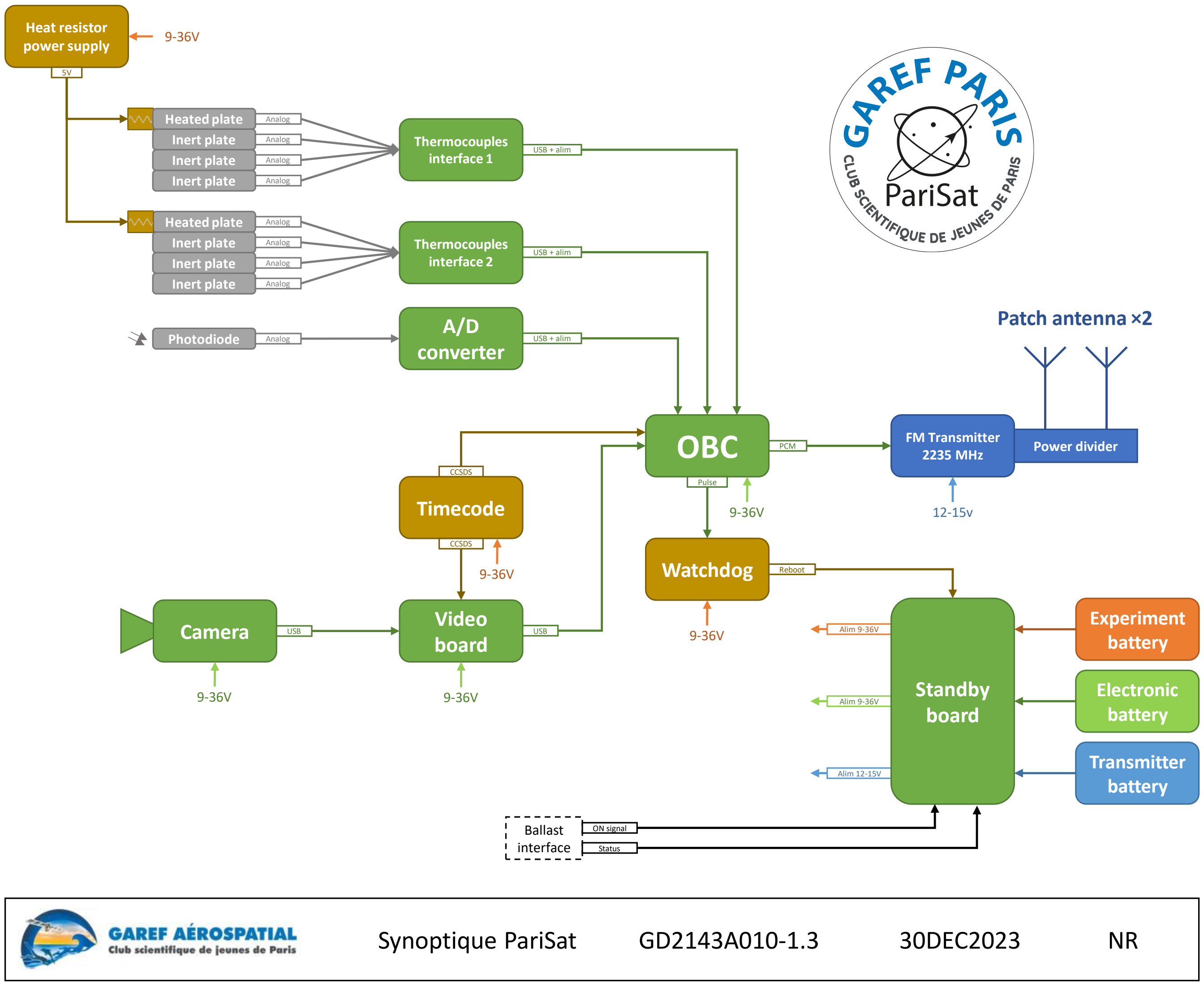
## 2.2 Synopsis of the experience



## 2.3 On-board electronics

### 2.3.1 Power-up module

The power management module integrates both the power supply board (with relays) and the watchdog board, all in a standard **GAREF** T2 housing (102×105×43.1 mm). Given the large number of electric connections between the two boards, they are connected internally using soldered cables.

#### 2.3.1.1 Power-up board

After being checked and placed on the Ariane 6 ballast (the metal block of about 2 tons allowing the launcher to simulate the mass of a satellite), the **PariSat** experiment is no longer accessible for ignition, calibrations or tests. From installation on the ballast until launch, the experiment must be turned off for an indefinite period (which can last up to 45 days according to the Ariane 6 user manual), and only turned on by order of the launcher once orbit is reached.

This order consists of opening a line on a redounded pyro-switch, so a low current must be passed continuously to detect the opening of the line, during this entire launch waiting period. The power-up board is therefore used to start the **PariSat** electronics following the launcher's order sent by the PMU-UM module (developed by Arianespace) located on the Ariane 6 ballast. The experiment then begins, and lasts until the batteries are exhausted.

The power-up board is located between the batteries and the rest of the satellite, and is made up of space-qualified "EL 415 122 E" latchable relays, used to control the power supply of the electronic modules following the order from the launcher. Diodes also make it possible to use an external power supply without discharging the batteries, during ground integration tests. Three relays are used, one for each battery pack. They will switch successively:

- The launcher command controls relay 1 which activates the power supply of the systems on battery pack 1, including the watchdog card. We therefore guarantee that the watchdog cannot by itself cause the experiment to turn on before the launcher command. The status of this first relay is sent back to the launcher so that it can insert it into its telemetry, indicating the initialization of the experiment.

- The watchdog, when initialized, causes a first reset which activates relay 2, activating the power supply of the systems on battery pack 2, including the OBC.

- Once the OBC has finished starting and the flight program is running, the OBC controls relay 3, activating the power supply of the telemetry transmitter. The status of this third relay is also sent back to the launcher so that it can insert it into its telemetry, indicating that **PariSat** has started its data transmission to the ground.

A status signal is present on each relay to know its current state, which will be sent back to the ground equipment to validate the sequence during ground integration tests.

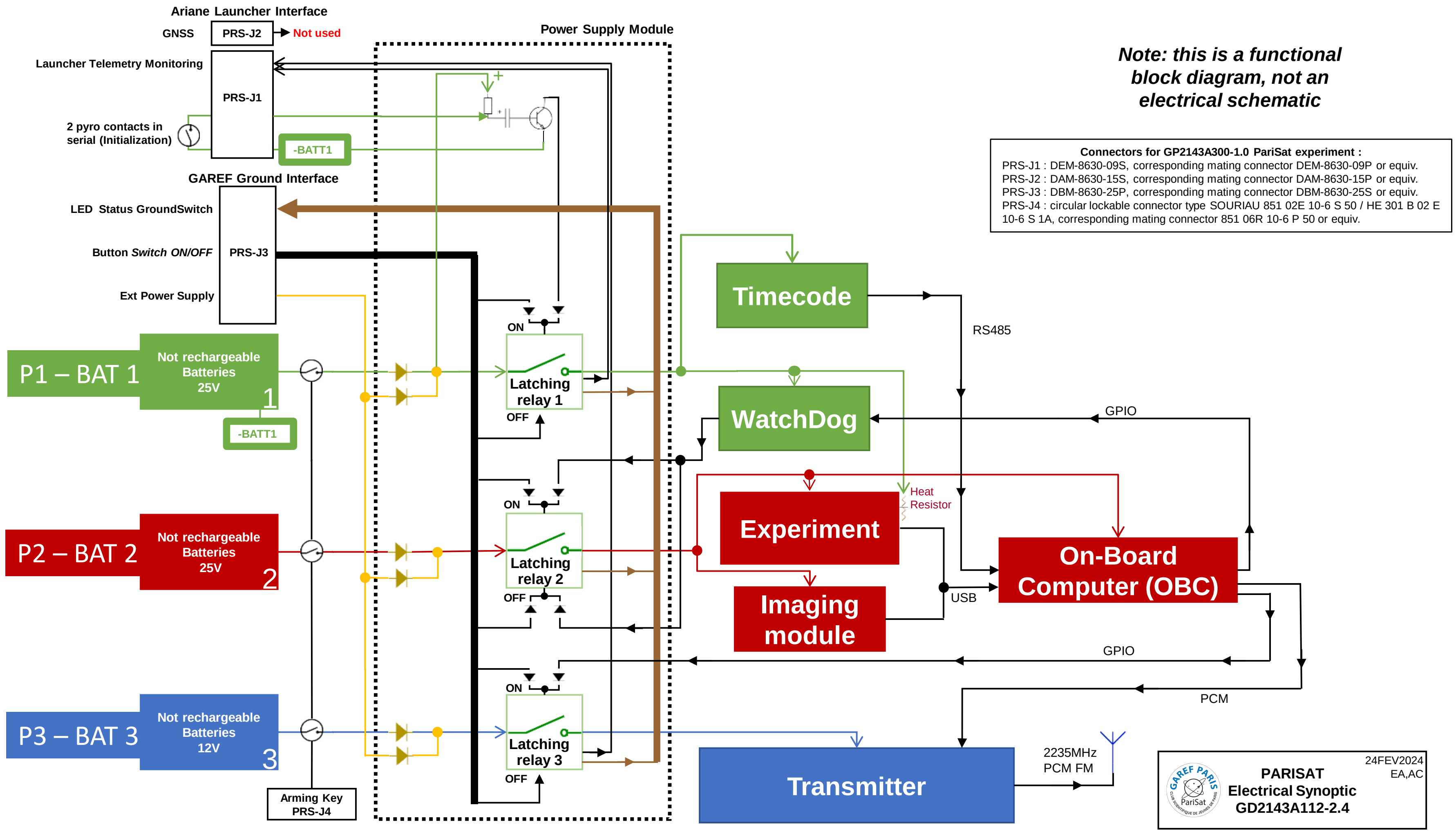
#### 2.3.1.2 Watchdog

The role of the watchdog is to restart the electronic modules which contain software, which could potentially "crash", in the event the reset signal sent by the OBC stops being received.

Simply containing an oscillator using passive components and logic counters, the watchdog contains only simple components to ensure its robustness (no software).

The OBC sends a "reset" signal to the watchdog every 500ms. If the expected reset signal is not received after a time of about 60 seconds (to account for the OBC startup time), then the watchdog acts on the power management board by opening for 1 second then closing the relay of the battery pack 2, which cuts the power supply to the associated modules and allows all the satellite software to be restarted.

### 2.3.1.3 Electrical synoptic (initialization stage)



### 2.3.2 Power supply system

To optimize the autonomy and mass of our power supply system, various tests lead to the choice of the following solution: 3 blocks of non-rechargeable lithium batteries, which power the modules that accept an input voltage over a 9-36 V range. The first two blocks (respectively standby and electronic) deliver a nominal voltage of approximately 25 V, and the third block dedicated to the transmitter delivers a voltage of approximately 15 V. Each module has an internal DC/DC converter to have a constant voltage despite the progressive discharge of the batteries. The efficiency of these regulators is included in the powers estimation. An arming key, a connector placed at the last moment of the integration of **PariSat** on the Ariane 6 ballast, guarantees that the batteries are not consumed during the testing and assembly stages.

There are 2 phases where the experiment consumes on the batteries:

- one between the end of the integration on the ballast corresponding to the putting of the arming key, and the ignition order sent by the launcher in orbit (this so-called "standby" phase can last from 2 days to 45 days, depending on the launch postponements), and
- the other until the end of the mission (this so-called "flight" phase is planned to last about 7000 seconds).

During the standby phase, only the power-up board consumes on the battery blocks, with a low current that monitors the ignition order (in the form of a pyro-switch, which opens). After a quick consumption peak at the transition to switch on the relays, it stops consuming during the flight phase.

### 2.3.3 OBC (On Board Computer)

The OBC designed and manufactured by **GAREF** is composed of three functional elements: a processor board, an FPGA managing the different interfaces and a USB hub board.

The processor board is the heart of the on-board electronics. It plays the role of an on-board computer thanks to software programmed by **GAREF**. It receives data from the different modules connected by the USB hub and digital inputs, constructs frames out of it, saves them on a flash memory and transmits them to the FPGA which puts them in PCM format, so that they can be transmitted to the telemetry transmitter.

The image stream coming from the photo module via USB is also split into frames to be sent. The OBC will be responsible for managing data coming from the thermocouple interface cards, the photoreceiver and the camera.

The OBC sends a signal to the watchdog module every 500ms to signal its proper operation. The OBC stops sending this signal if it detects a malfunction of a critical module or if it malfunctions itself. All the modules powered on block 2 are then restarted: OBC, thermocouple interface cards, photo module.

This OBC has been used for about ten years (date of its last major evolution) on **GAREF** experiments and is perfectly validated and robust for an aerospace on-board experiment.

### 2.3.4 Timecode

The function of the timecode module is to provide a common precise time (in Universal Time) to all modules requiring it (OBC and photo module).

This allows to time, with an accuracy of 10 ms, the different measurements acquired and the events occurring during the flight in a synchronized manner. It is therefore possible to compare these measurements and events with each other and with the ground equipment. The timecode is broadcast to the different **PariSat** modules (see **Synopsis of the experience**) in BCD format on an RS485 bus.

Since the experiment is switched off while on the ground, it is not possible to synchronize the module before the flight. The module will thus start the time at EPOCH (January 1, 1970 0h00:00.000) and allow a later resynchronization from the precise UT (Universal Time) date and time of initialization of the experiment which will be given by ESA.

## 2.4 Mechanical structure

The **PariSat** structure is composed of a main chassis made of 6061 aluminium (with Alodine 1200 surface treatment), a metal that is both light and strong and which allows the heat emitted by the on-board electronics to be dissipated by conduction towards the Ariane 6 ballast.

All the electronic modules are placed in standard **GAREF** T1 and T2 housings, with the exception of the thermal measurement plates and the photography experiment module.

This module (which contains the camera and the processing circuit) is integrated into a standard **GAREF** T2 housing, slightly modified for easier heat dissipation.

**PariSat** is not directly connected to the ballast but is screwed to the PIP (Passenger Interface Plate, cf. **Significant events**), an interface plate made of aluminium treated with Alodine 1200. A ground braid between **PariSat** and this plate is installed, in order to allow efficient electrical conduction that meets Arianespace's electrical requirements. To secure **PariSat** to the PIP, 16 CHC M5 screws and M5 nuts are used.


*CAD view of **PariSat** (front and back)*

The measuring plates are inserted on the side of **PariSat** in a machined PEEK (polyetheretherketone) support.

The photo module is screwed into the upper right corner of the satellite to maximize visibility of Earth. It promotes thermal conduction through the structure to the ballast. The on-board electronics are screwed into the bottom of the structure to lower the satellite's centre of gravity and optimize the volume. In addition, this promotes thermal dissipation of the electronics through the ballast interface plate.

## 2.5 Scientific experiment

Heat dissipation is a challenge faced by many engineers. In the space sector, this constraint is of capital importance because the space environment (extra-atmospheric) does not allow convection but only radiation as a means of heat transfer to the ambient environment. The various achievements of **GAREF** have already demonstrated that the problem of heat dissipation arises for the heat generated by electronics, particularly in weather balloons operating in the upper atmosphere for several hours. The solution implemented was the dissipation of energy by black body radiation, using a black anodized aluminium plate.

The possibility of designing a satellite-based experiment during the first launch of Ariane 6 allows us to study the emissivity of different radiating materials in low Earth orbit. **PariSat** therefore carries 8 plates of different materials coated with different surface treatments, 2 of which are heated to measure and compare their radiation in a space environment according to the laws of black body radiation. Thus, heating on two plates makes it possible to simulate the energy dissipated by electronic systems at constant speed and to reach thermal equilibrium more quickly.

In summary, the scientific objective of **PariSat** is to find, thanks to the measurement of the temperature of plates made of different materials heated by heating resistors and/or by solar radiation, the model of black body radiation.

## 2.6 Photography experience

The photography experience consists of capturing and processing images using a GoPro HERO10 camera specially modified to adapt to space conditions and a photo module processing the images before sending them to the OBC. Photos are taken at regular intervals (one per minute) before being transmitted to the OBC via a Raspberry Pi 4B card (specially adapted to control the camera). It is responsible for controlling the photo taking as well as the photo parameters, but also other elements such as turning the camera on or off. Since our telemetry rate does not allow for a continuous flow, sorting is carried out in flight by an algorithm developed by **GAREF**, in order to determine the best images to send back to Earth (thanks to an analysis of the weight and therefore the visual details of each image). The data is sent to the OBC every 4 minutes, which corresponds to approximately a cycle of 4 images.

For the camera, it is necessary to deal with various thermal and mechanical constraints for its proper functioning. First, it is essential to mechanically maintain the lens to obtain usable images, a special mechanical housing is therefore designed to bring together the GoPro and its Raspberry Pi control board. Concerning the temperature, the camera overheats by itself after a certain time. To overcome this problem, the camera is placed on the upper part of the structure, thus allowing efficient heat dissipation by conduction, and alternates periods where it is on and off.

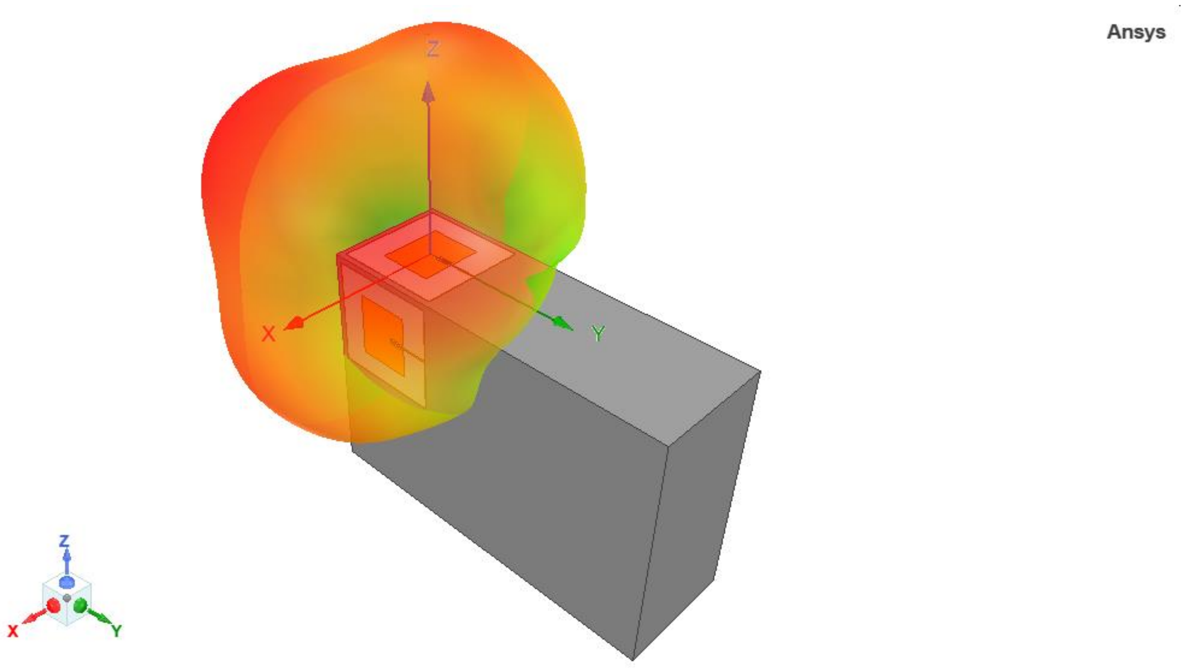
If this module is mainly designed for communication purposes, it is no less interesting to obtain information on the photo parameters (white balance, ISO, aperture, etc.). The camera is programmed to select the best parameters automatically, and a program then allows this information to be retrieved in EXIF format. This data, associated with each photo, is transmitted at the same time as the image and allows a much more detailed analysis for a future experiment.

## 2.7 Telemetry transmission system

The on-board telemetry, compliant with the PCM-FM / IRIG 106 standard, consists of a transmitter, a power divider and two transmission antennas. **PariSat** transmits at a frequency of 2235 MHz and at a power of +33 dBm (approximately 2W) for a flow rate of 1 Mbit/s. The transmission begins as soon as it is switched on, and keeps going continuously until its batteries are exhausted approximately 2 hours later. The two antennas transmit respectively in a transverse direction and a longitudinal direction, so as to radiate as much time as possible towards the Earth.

Since the upper stage of Ariane 6 rotates on its roll axis at a speed of 1°/s, the transmission antennas are not oriented towards the ground reception station during the entire pass window (see **Esrange reception station**).

The antennas are designed in partnership with ENSEA (National School of Electronics and its Applications), below is their radiation pattern observed in an anechoic chamber.




*Radiation pattern of **PariSat** antennas*

## 2.8 Qualification tests

In order to be able to rely on scientific expertise in the realization of space projects, **GAREF** contacts various research laboratories specialized in the space field: IAS (Spatial Astrophysics Institute), LESIA (Laboratory of Space Studies and Instrumentation in Astrophysics), and OVSQ (Observatory of Versailles Saint-Quentin-en-Yvelines). Independently of this scientific support, OVSQ allows us to carry out qualification tests in vibrations and thermal vacuum using their resources.

### 2.8.1 Mechanical qualification

In December 2023, **GAREF** qualified **PariSat** in vibrations at the Integration and Test Platform (PIT) of the Versailles Saint-Quentin-en-Yvelines Observatory (OVSQ). **PariSat** first underwent a search for resonance frequencies, before successfully verifying the qualification levels specified by Arianespace. Sensors installed on the satellite collect data on its vibration behaviour, which allows OVSQ to certify that **PariSat** complies with the requirements to be able to embark on Ariane 6.

### 2.8.2 Electrical qualification

A "fit-check" is conducted with Arianespace in October 2023 to validate the electrical and mechanical interfaces. In particular, it validates that the initialization stage is working and that the initialization order is correctly detected. Various ground tests are conducted to guarantee the reliability of the flight software and verify that everything works, even with active telemetry.

Battery discharge tests are also carried out with the complete satellite powered up, which allows us to guarantee an operating time of approximately 4.5 hours (after the standby phase which concerns the first battery pack).

### 2.8.3 Transmission test

An anechoic chamber test carried out with ENSEA students in January 2024 validates the antenna radiation patterns, as theorized during the design. In addition, this confirms our transmission power of around 2W and, more generally, the proper functioning of the entire transmission system.

# 3. DETAILED DESCRIPTION OF THE SCIENTIFIC EXPERIMENT

## 3.1 Thermodynamic contextualization

Below is a brief summary of the thermodynamic concepts used in the **PariSat** scientific experiment.

The evolution of temperature is described by the evolution of the quantity of heat contained in the object considered. The densest materials will generally have a greater heat capacity at a given volume. For a given material, the quantity of heat is all the greater as the object is voluminous. It is similar to a thermal inertia of the object considered: thus, the greater a material's heat capacity, the more heat (energy) must be supplied to raise its overall temperature by 1K (i.e. 1°C). Let us note the quantity of heat: C (in $J.K^{-1}$).

Concerning the heat flow, a first intuitive image would be to materialize it as a flow that transfers heat between two objects, from the hottest to the coldest. The nature of the interaction (the way in which the two bodies interact) between the two bodies is essential to describe the heat flow considered. The associated physical quantity is the Watt, noted here: $\Phi_{indice}$.

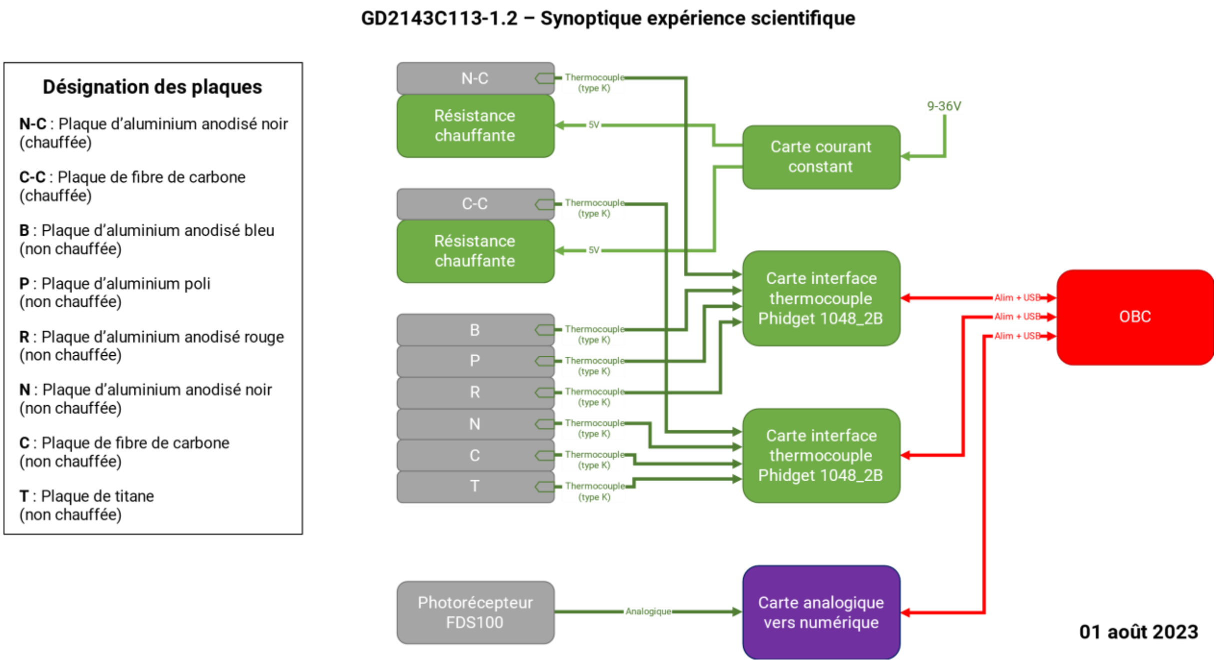
- Conduction: Consider two objects in direct contact and imagine their contact surface through which the heat will diffuse. The heat transferred is all the greater as the temperature difference of the objects is greater. Materials also have an intrinsic characteristic: thermal conductivity. The greater this quantity, the more easily the heat can propagate by contact in the material.

- Convection: Consider an object in contact with a fluid (any liquid or gas), and it is by contact of the fluid that the heat will be able to propagate. Here again the temperature difference between the fluid and the object increases the value of the heat transfer. In addition, depending on the overall movement of the fluid, the transfer will be facilitated or not. A static fluid at rest will transport heat worse than a fluid in motion. For example, it is easier to cool down in a draft or wind than in a room without air movement.

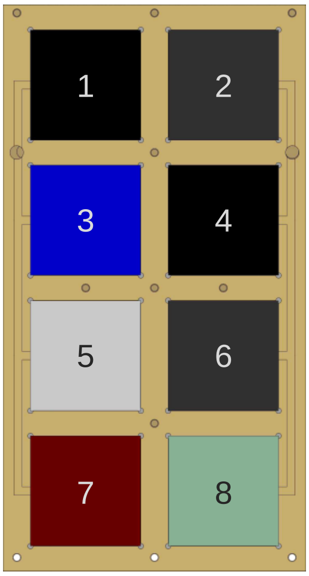
- Thermal radiation: Any exposed object receives electromagnetic radiation. Similarly, any object that is not at absolute zero 0K (-273.15°C) emits thermal radiation depending on its temperature; but at "low" temperatures (down to -100°C) it remains negligible. The electromagnetic radiation emitted by the hot gases of our star, the Sun, also propagates through the vacuum of space.

## 3.2 Technical description

### 3.2.1 Synopsis of the scientific experiment




### 3.2.2 Radiative plates




| N° | Material | Surface finishing | Heated | Weight | Thermal capacity |
|---|---|---|---|---|---|
| **1** | Aluminium (6061) | Matte black anodized (20 µm) | Yes (3.2W) | 7.35g | 6.6 J·K$^{-1}$ |
| **2** | Carbon Fiber | None | Yes (3.2W) | 5.3g | 3.6 J·K$^{-1}$ |
| **3** | Aluminium (6061) | Matte blue anodized (20 µm) | No | 7.35g | 6.6 J·K$^{-1}$ |
| **4** | Aluminium (6061) | Matte black anodized (20 µm) | No | 7.35 g | 6.6 J·K$^{-1}$ |
| **5** | Aluminium (6061) | Polished | No | 7.35g | 6.6 J·K$^{-1}$ |
| **6** | Carbon Fiber | None | No | 5.3g | 3.6 J·K$^{-1}$ |
| **7** | Aluminium (6061) | Matte red anodized (20 µm) | No | 7.35g | 6.6 J·K$^{-1}$ |
| **8** | Titanium | None | No | 12.27g | 6.4 J·K$^{-1}$ |

### 3.3 Forecast study

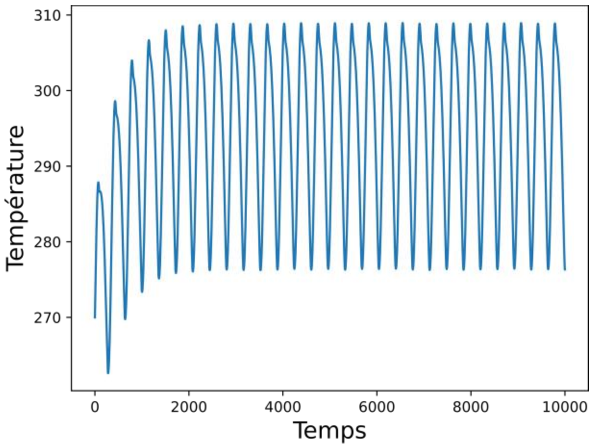
To model the experiment, we rely on the black body radiation model. We therefore define the different parameters such as the specific heat capacity of the plates studied as a function of the density and dimensions of the plates, the heating power, the emissivity of the system, the angular velocity of the stage. We therefore model the appearance of the temperature of different plates as a function of time, using a program in python programming language.

We take as solar surface power in low Earth orbit 1361 W/m$^2$. In addition, we consider a surface power emitted by the terrestrial thermal radiation towards space in low orbit of 400 W/m$^2$. We therefore obtain the following results: for an initial temperature of 273.15K (0°C), the curve obtained has a negative exponential appearance with a negative exponent.

| ***Matte black anodized*** | **Equilibrium temperature** | **Time to reach 90% equilibrium** | **Time to reach equilibrium over total flight time** |
|---|---|---|---|
| *Plate facing the Sun, unheated* | 390K | 700s | 16% |
| *Plate facing the Earth, unheated* | 290K | 1100s | 25% |
| *Plate facing the Sun, heated at 1W* | 436K | 400s | 10% |
| *Plate facing the Earth, heated at 1W* | 370K | 600s | 13% |

These values only take into account the emission and absorption of the face facing space. Since other surface treatments have lower absorption and emissivity, the back face of the plate is considered non-radiative.

Taking into account the angular velocity of the ballast (1°/s) and visibility of the Earth 50% of the time on a rotation as well as solar illumination on an unheated plate, we obtain the following graph (on the x-ordinate the time in seconds and on the y-ordinate the temperature in Kelvin):



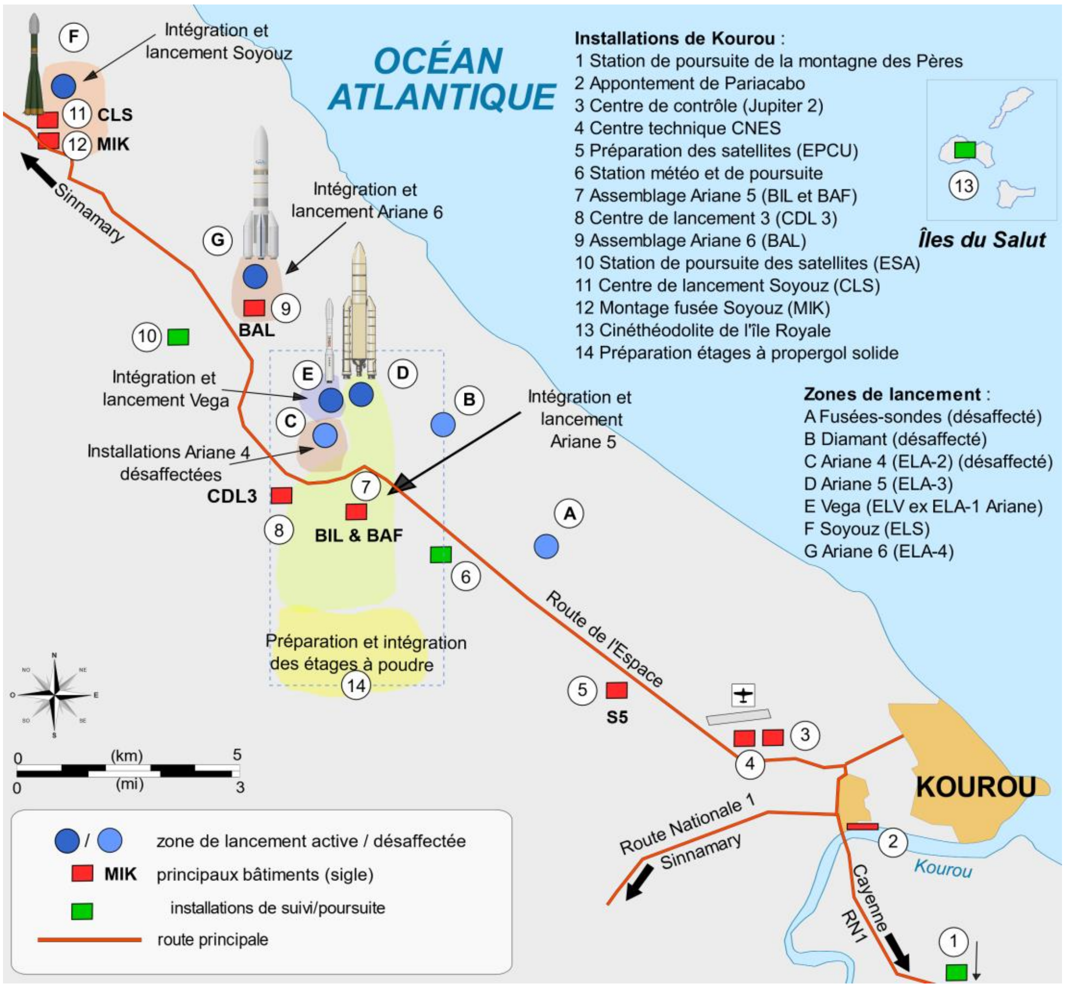
# 4. LAUNCH

## 4.1 Integration campaign

### 4.1.1 Technical operations

The **PariSat** project needs to be integrated on the ballast located under the fairing at the top of Ariane 6. Arianespace, the Ariane 6 launch services operator, is planning a campaign to integrate the various payloads for this purpose. This mission, which is taking place at the Guiana Space Centre, aims to carry out the final operating tests and assembly operations on the ballast.

The objective of this integration campaign is therefore for **GAREF** to test and attach **PariSat** on the PIP (Passenger Interface Plate) which is itself assembled on the Ariane 6 ballast. Some members of **GAREF** who worked on **PariSat** will go to the Guiana Space Center between Tuesday, May 21 and Sunday, June 3, 2024. The main technical operations to be carried out are the replacement of the battery packs for the flight, a general operating test, the assembly of **PariSat** on the PIP, and finally the installation of the arming key to put the experiment in its standby state. All these operations are carried out at the EPCU in the HN hall of the S3B building, dedicated to the final assembly of the satellites.




*Map of the Guiana Space Center*

*Source : Wikipédia*

#### 4.1.2 Significant events

Among the highlights of this campaign, members of the **GAREF** team had the chance to sign the Ariane 6 fairing before its integration onto the launcher.


*Signing of the fairing by the **GAREF** team*

*©2024 ESA-CNES-ARIANESPACE-ArianeGroup / Optique vidéo du CSG – T LEDUC*

Before being placed under the fairing, the PIP that hosts **PariSat** must be integrated into the ballast. These operations, carried out by Arianespace, take place in the HR hall of the S3B building.


*Integration of **PariSat** on Ariane 6 ballast*

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### 4.1.3 Other payloads

While this inaugural flight of Ariane 6 allows **GAREF** to carry out a new experiment in orbit, some other payloads are also passengers. The mission allows the launch of several satellites, deployers and experiments; carried out by space agencies, companies, research institutes, universities and young professionals, from France and Europe. During the **PariSat** project, several connections are established with the different teams, in particular for the reception of telemetry. This integration campaign is therefore also an opportunity for meetings with future collaborations in mind.


*Ariane 6 maiden flight payloads*

*Source: ESA*

## 4.2 Flight progress

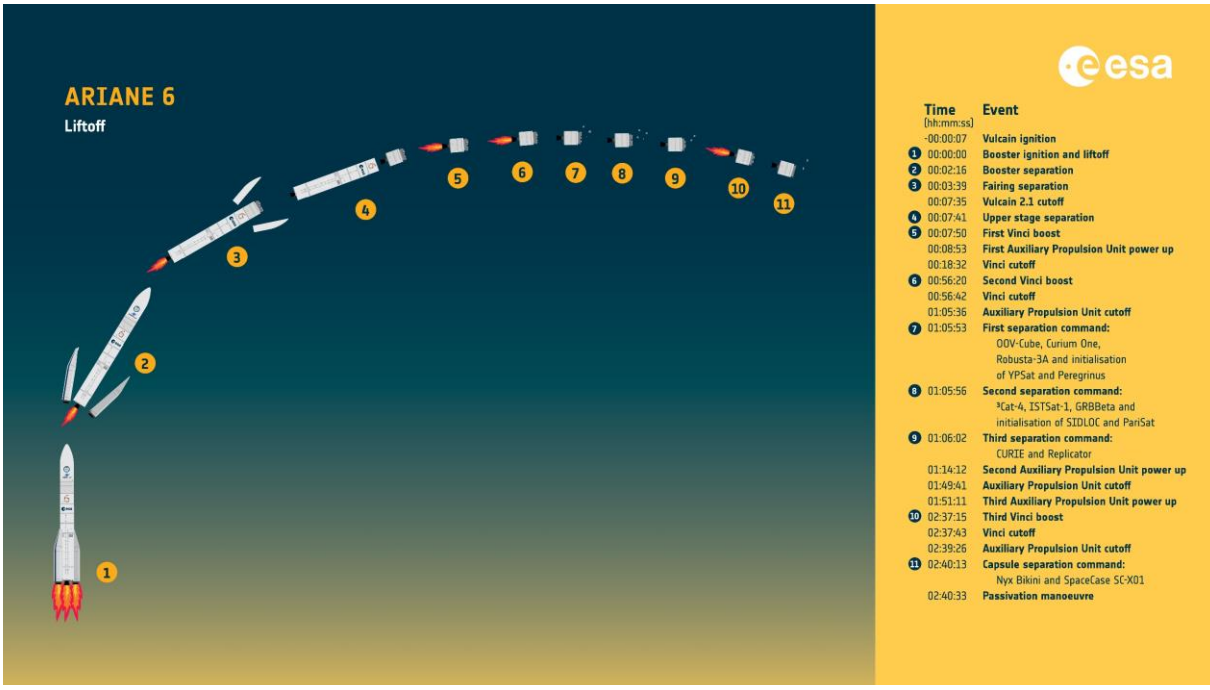
The first Ariane 6 rocket successfully lifts off on July 9, 2024 at 19:00:00.000 UTC (16:00 local time in French Guiana, 21:00 Paris time) from the ELA4 launch pad (4th Ariane Launch Complex, Guiana Space Center), restoring Europe's independent access to space. This inaugural flight, designated VA262, is a great success, paving the way for future Ariane 6 flights and demonstrating the ability of the new heavy launcher to reach its target orbit.

The launcher thus propels itself towards space, separating its two boosters 137 seconds after lift-off and its main stage approximately 5 minutes later. The upper stage engine is then ignited for the first time to place the Ariane 6 upper stage and its payloads into an elliptical orbit of 300 to 600 km above the Earth. This achieves the first major result: in-flight cooling, as well as the first ignition of the Vinci engine and the Auxiliary Propulsion Unit (APU). After a 35-minute ballistic phase, the engine is ignited for the second time, demonstrating its ability to modify the launcher's orbit. It is this second boost of the Vinci engine that circularizes the Ariane 6 orbit at 580 km, now ready to release its eight satellites and activate the five on-board experiments, including **PariSat**.

It is therefore at T0+3965.530s (i.e. 20:06:02.530 UTC) that **PariSat** receives its initialization order and begins its experiment. The scientific measurements and images then begin to be transmitted to Earth by telemetry, and are recovered during the passage over Kiruna approximately 1 hour after ignition.

The final phase of the Ariane 6 launch was a technical demonstration, verifying for the first time the behaviour of the upper stage in microgravity. The APU was ignited for the second time, before being quickly shut down due to technical problems. This means that the third and final boost of the Vinci engine cannot take place. It would have allowed the upper stage to deorbit and safely re-enter the Earth's atmosphere. As the upper stage then behaved nominally, the on-board software triggered "passivation" which removes all energy on board to avoid possible explosions. As a result, the launcher does not release the two atmospheric re-entry capsules.

This unforeseen event is an opportunity for a second pass over Kiruna to unload data from a new orbit, but **PariSat** no longer has battery power and no signal is detected in this degraded mission scenario.



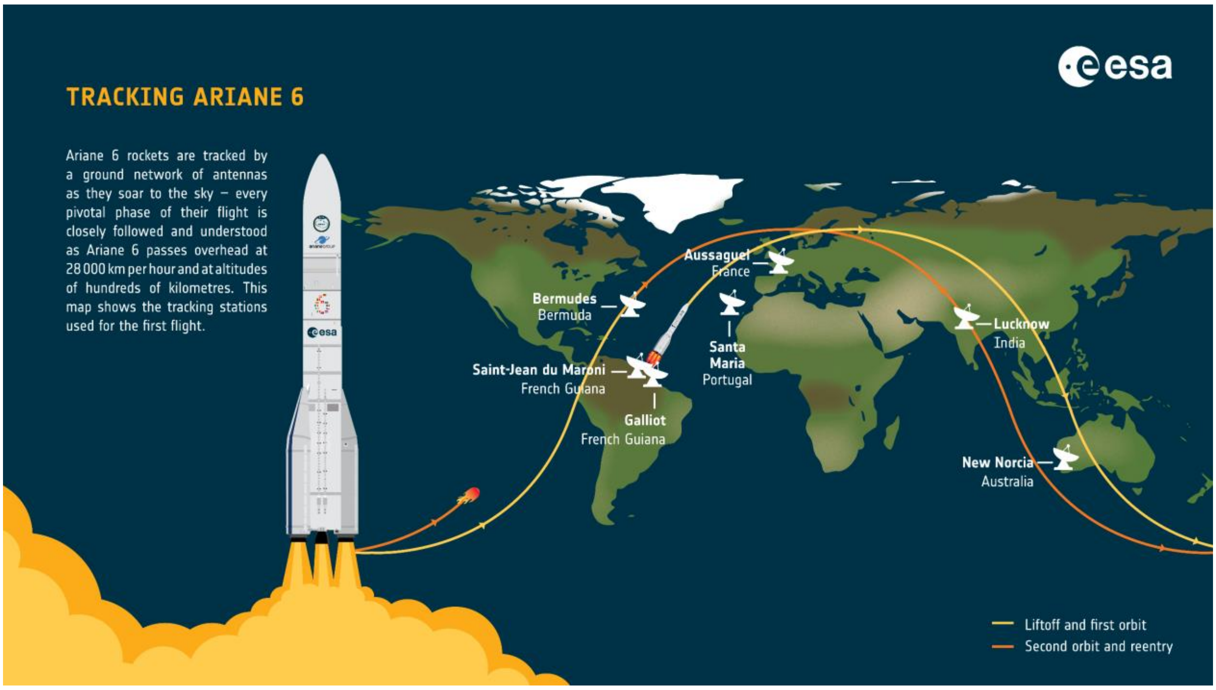

*Ariane 6 maiden flight planned timeline*

*Source: ESA*

## 4.3 Flight trajectory

### 4.3.1 Planned trajectory

The target orbit is a low Earth orbit, approximately 580 km in altitude and with an inclination of 62°. Various trajectory predictions allow us to simulate it faithfully, in particular to optimize telemetry reception in Kiruna. These are the predicted orbital parameters that allow us to create a file in TLE (Two-Line Elements) format, readable by the receiving equipment of the reception station.




*Planned trajectory of the maiden flight of Ariane 6*

*Source: ESA*

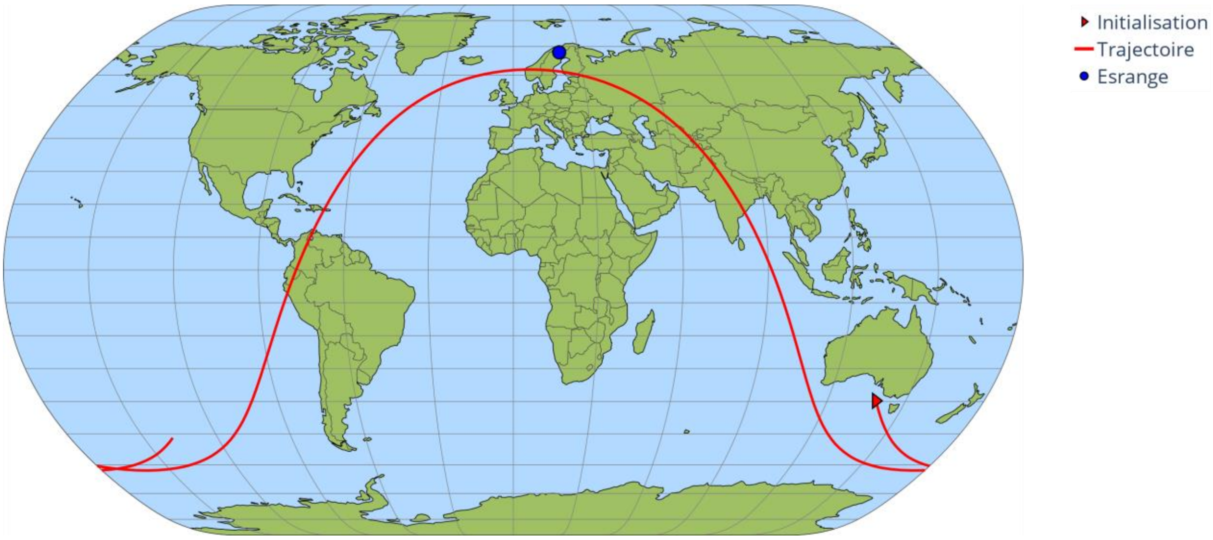
### 4.3.2 Two-line orbital parameters (TLE)

Two-Line Elements are a standardized representation of the orbital parameters of objects in Earth orbit. From data provided by ESA, it is possible to create a TLE faithful to the parameters measured during the flight, and therefore to verify the actual trajectory of the launcher (as of July 9, 2024):

```
PARISAT
1 60235U 24128A   24191.83752928  .00000000  00000-0  00000-0 0    18
2 60235  61.9940 161.6170 0002691 303.0960 283.4570 14.96533815    13
```

### 4.3.3 Actual trajectory

The simulation based on the predicted orbital parameters allows us to check the passage of **PariSat** over Kiruna before calibrating the reception equipment. The various orbital parameters measured during the flight were subsequently transmitted to us, and allowed us to verify that the actual trajectory of the upper stage had followed the predicted trajectory, which allowed us to ensure nominal reception at the Esrange station (near Kiruna).




*Actual trajectory of the maiden flight of Ariane 6*

## 4.4 Esrange reception station

### 4.4.1 Collaboration with SSC (Swedish Space Corporation)

Since the beginning of the **PariSat** project, one of the major technical challenges has been to successfully transmit all our data from space via a telemetry system. Various internships focusing on telemetry have allowed us to study the possibilities available to us in terms of reception. Given the planned flight trajectory, the SSC station in Esrange in northern Sweden (40 km from Kiruna) appears to be an ideal solution.

In addition to having a large fleet of reception antennas, this complex hosts a sounding rocket launch pad that **GAREF** has already used several times in the past to launch experimental rockets. It was therefore natural that contact was made with the teams at the reception station, and the idea of collaborating with students from the University of Lulea (neighbouring Kiruna) for **PariSat** telemetry quickly emerged.

From summer 2023, videoconferences will therefore continue with the Esrange team in charge of receiving **PariSat** data, and mainly with Erik Öskog (who coordinates the team on the Esrange side), Elena Battistello (who is doing her master's thesis to **PariSat** telemetry reception) and Emil Söderman (who gives technical support on the usage of the antennas).

#### 4.4.2 Link budget

Signal to noise ratio:

$$SNR = \frac{EIRP \cdot \left(\frac{G}{T}\right) \cdot \left(\frac{\lambda}{4\pi D}\right)^2}{k \cdot B_{fi}}$$

$$SNR_{dB} = EIRP_{dBm} + \left(\frac{G}{T}\right)_{dB} + \left[\left(\frac{\lambda}{4\pi D}\right)^2\right]_{dB} - k_{dB} - {B_{fi}}_{dB}$$

$$EIRP_{dBm} = {G_{antenne\ d'émission}}_{dB} + {P_{émission}}_{dBm}$$
$$P_{émission} = 33\ dBm$$
$$P_{émission} = 0\ dB$$

$\left(\frac{G}{T}\right)$ : Station merit factor in dB/K

$\left(\frac{\lambda}{4\pi D}\right)^2$ : Free space propagation losses

$D = 1500\ km$ : Satellite – antenna distance

$k = 1.38 \cdot 10^{-23}\ m^2.kg.s^{-2}.K^{-1}$ : Boltzmann constant

$B_{fi} = 2.2\ MHz$ : Bandwidth at 1 Mbit/s

$\lambda = \frac{c}{f} = 0.13413m$ : Wavelength

Antenna gain (with antenna efficiency factor k = 0.37) :

$$G = 10 \cdot \log\left(k \cdot \left(\frac{\pi \cdot D}{\lambda}\right)^2\right)$$

| | |
|---|---|
| Transmit power | 33.00 dBm |
| Free space propagation loss (for 1500km) | -162.96 dB |
| Transmitting antenna gain | 0.00 dB |
| Receiving antenna gain | 40.00 dB |
| Received power | -89.96 dBm |
| Receiver bandwidth | 2.400 MHz |
| Noise power | -110.13 dBm |
| Signal to noise ratio | 20.2 dB |

A $SNR_{dB}$ greater than 20dB is necessary to take into account the different noises (Gaussian white noise, atmospheric noise, noise temperature, etc.). To obtain a signal-to-noise ratio greater than 20dB, the antenna must have a gain greater than or equal to 40dB.

### 4.4.3 Preliminary mission to Esrange

As **PariSat** only plans to make a single pass over Sweden, the antennas must be perfectly calibrated before the flight. A simulator of the **PariSat** telemetry system is sent to the Esrange team several months before the flight, in order to reproduce a radio signal identical in every way to that emitted by the satellite. It is mainly to optimize the calibration of the reception equipment that a **GAREF** team is going to the Esrange base between Sunday 7 and Tuesday 10 April 2024. Several technical points of telemetry are therefore addressed, and this mission makes it possible to establish direct contact with the Esrange team, which helps to perpetuate our relations with SSC.

*Part of the **GAREF** team at the foot of a reception antenna in Esrange, under the snow*

### 4.4.4 Data reception

To ensure nominal reception of **PariSat**, three antennas operate in parallel on the day of the flight. A "small antenna" of diameter 7.3m, with therefore a wider reception cone, is used to locate the launcher in the sky. The other two, of diameter 11m and 13m respectively, are slaved to this first antenna to point in the right direction and receive the signal with maximum gain. The main antenna used to receive data from **PariSat**, the 11m one, is called Freya; while the smallest one which will ensure the tracking of the satellite, the 7.3m one, is called Fenix.

In order to ensure effective communication on the launch day, a Microsoft Teams discussion is opened between the SSC team (in Esrange) and the **GAREF** team (in Paris). As **PariSat** passes over Sweden, the raw data is recorded by the receiving equipment. It is transmitted later in the evening to the **GAREF** team for a first quick analysis of the frames received (see **Data transmission logic**).

# 5. EXPERIMENT CONCLUSIONS

## 5.1 Data processing

### 5.1.1 Ground Software

Once the raw data has been transmitted and decoded, ground software is used to extract the scientific data and photos. It is largely based on the DDP software, entirely developed by **GAREF**, with some modifications for **PariSat** specific data. This software was developed for the reception of previous **GAREF** projects.

### 5.1.2 Data transmission logic

In order to ensure that all generated data is transmitted, it will be accumulated in a buffer that is sent continuously: as soon as the current buffer is completely sent, we start sending it again from the beginning. All frames, composed of 78 bytes and equipped with a CRC to identify those that are corrupted, have the same structure (h=hexadecimal notation):

- a fixed 24-bit synchronization word (FAF320h) = 3 bytes
- a 4-byte frame number
- a 1-byte identifier (which indicates the frame type and the arrangement of the data inside)
- 64 bytes of module data
- 6 bytes of checksum

A buffer accumulates the data of the scientific experiment, a second buffer accumulates the data of the photo experiment. These buffers are kept if a restart occurs because the watchdog module has detected a failure.

During the flight, we switch successively from a "sending scientific experiment data" mode for 2 seconds to a "sending photo experiment data" mode for 10 seconds, and this is repeated in a loop for the entire duration of the mission. This ensures that the scientific data, more critical but less data intensive than the photo data, are transmitted a greater number of times.

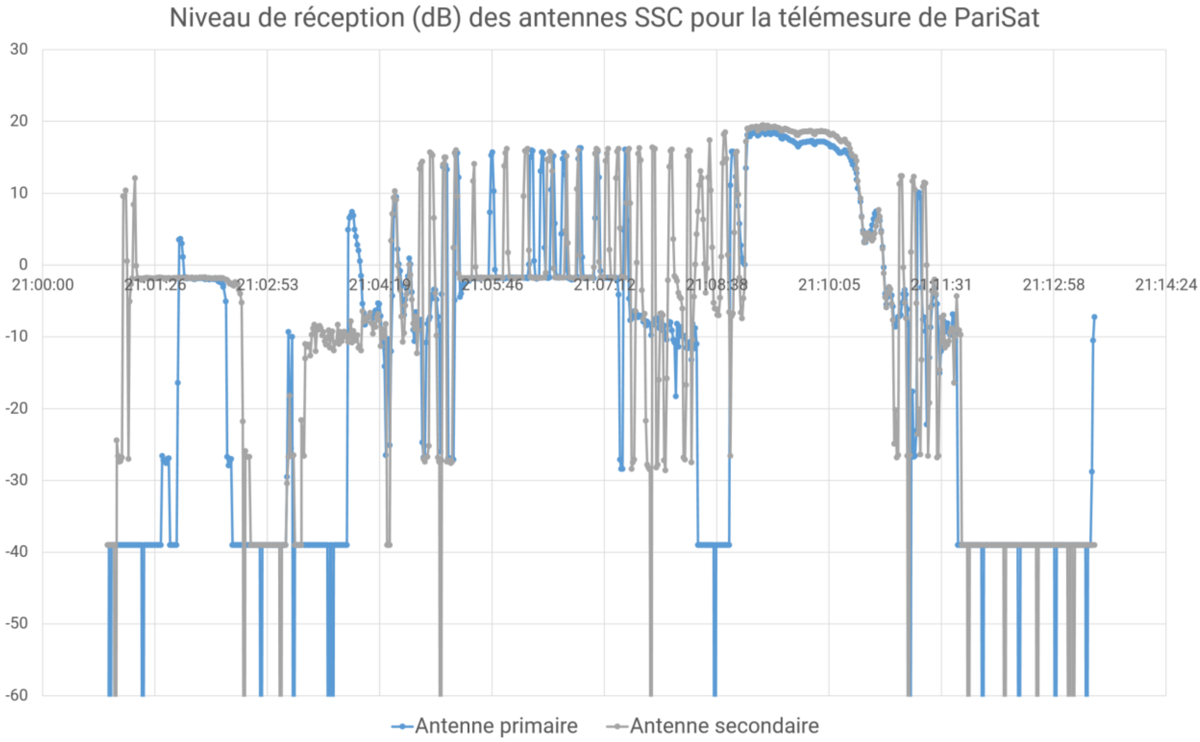
The frames are numbered to allow a posteriori reconstruction and error correction by comparing multiple receptions. The identifier separates the scientific experiment data and the images.

The frames containing scientific experiment data consist of: 64 bits of timecode, 8×16 bits of thermocouple data, 1×16 bits of photoreceptor data, and all in duplicate (to store 2 data points in a 64-byte frame).

The frames containing the photo experiment data consist of: 1 byte of photo number, 2 bytes indicating the fragment number within the photo, then 61 bytes of a fragment of the image file (which are about 8Mbit per frame, with additional data to indicate the time the image was taken). The photo and fragment numbers are used to facilitate the reconstruction of the images later, to glue together frames received during a different repeat loop, or in a period with reception gaps.

### 5.1.3 Processing of raw data

As described above, two antennas are used to receive **PariSat** data. We therefore obtain two sets of reception data, which we then decode separately. We then match the extracted data, to obtain the cumulative data. Below, the curve indicating the reception level of the two antennas over time. The SSC reception equipment only succeeds in extracting digital data when the signal-to-noise ratio exceeds 0dB.




T0 (Ariane 6 flight VA262 take-off time): 19h00m00.000s TU(UTC)
The first data is received at T0+7262s (21h01:02 UTC).
The last data is received at T0+7879s (21h11:19 UTC).
The reception pass thus has a total duration of 617s.

We were then able to analyse this digital data to extract the scientific experiment measurements and the photos. Among the data received by the primary antenna: 242 711 frames can be decoded (equivalent to 151.5s of continuous reception), including 8 494 (3.5%) with a bit correction by CRC. Among the data received by the secondary antenna: 189 565 frames can be decoded (equivalent to 118.3s of continuous reception), including 4 739 (2.5%) with a bit correction by CRC. Once the data coming from these two antennas are combined, we obtain 279 593 distinct frames decoded (equivalent to 174.5s of continuous reception).

The observation of the data shows that a failure of the USB access to the thermocouple sensors by the OBC occurred at T0+5634s (20:33:54 UTC), which is correctly detected and which causes a restart of the OBC by the watchdog module. The experiment can thus work correctly again from T0+5741s (20:35:41 UTC). These data allow us to extract the entire scientific experiment data, of which we receive repetitions between 19 and 21 times depending on the measurement points; we can thus guarantee that all these points are correct.

The photo experiment data is much more complex to exploit, because several images contained transmission errors that must be corrected by gluing together the pieces coming from the reception of other repetitions or from the other antenna (on the total reception pass, the buffer containing all the images is sent about 6 times).

Once all these treatments are done, we obtain 12 different photos that are sent by **PariSat** during its flight, including:

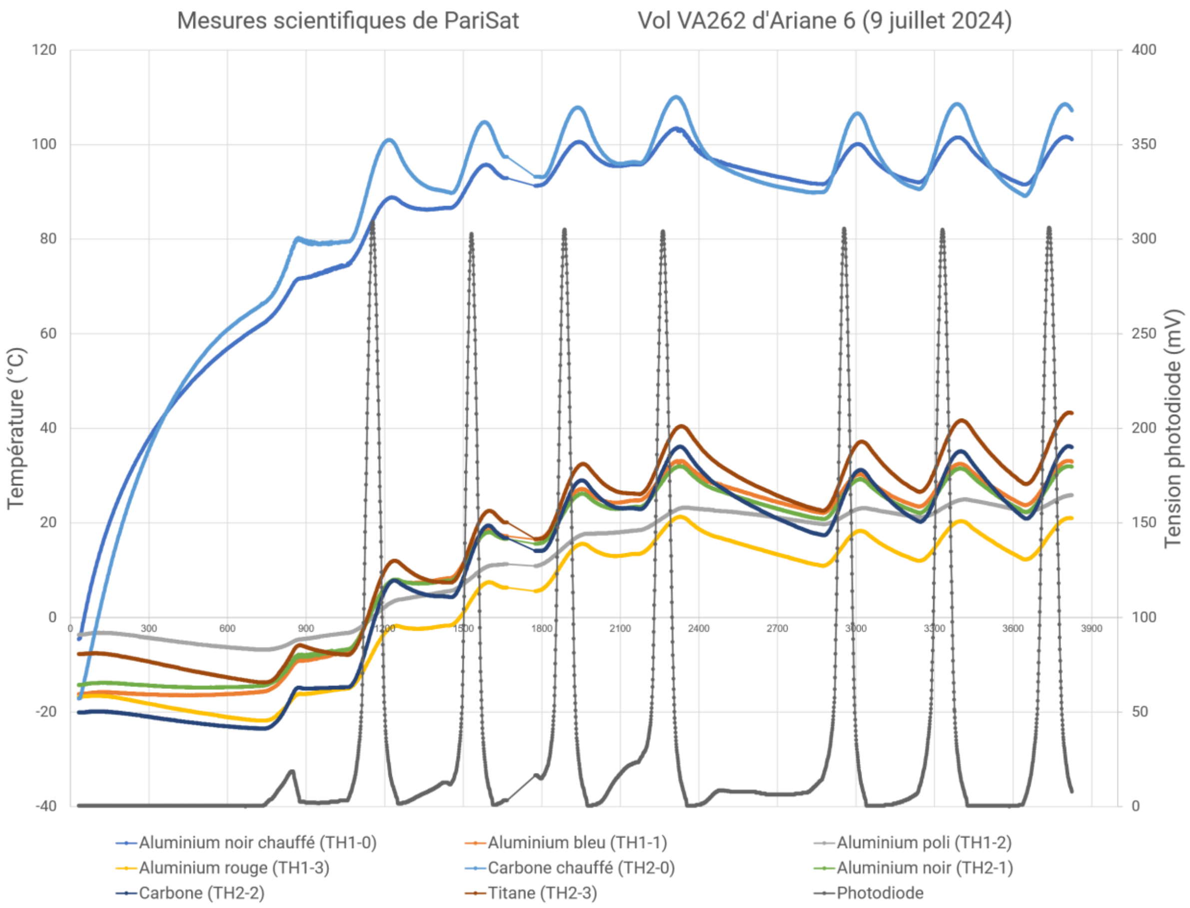
- 5 are received whole, reconstructed without error.

- 5 are received partially, therefore are truncated or have a gap, but can still be opened and visually usable.

- Only 2 were received too scrambled to be usable (as a reminder, these images are in JPEG compressed format to reduce their size, which prevents the interpretation of any sequence if a certain number of previous data have not been received).

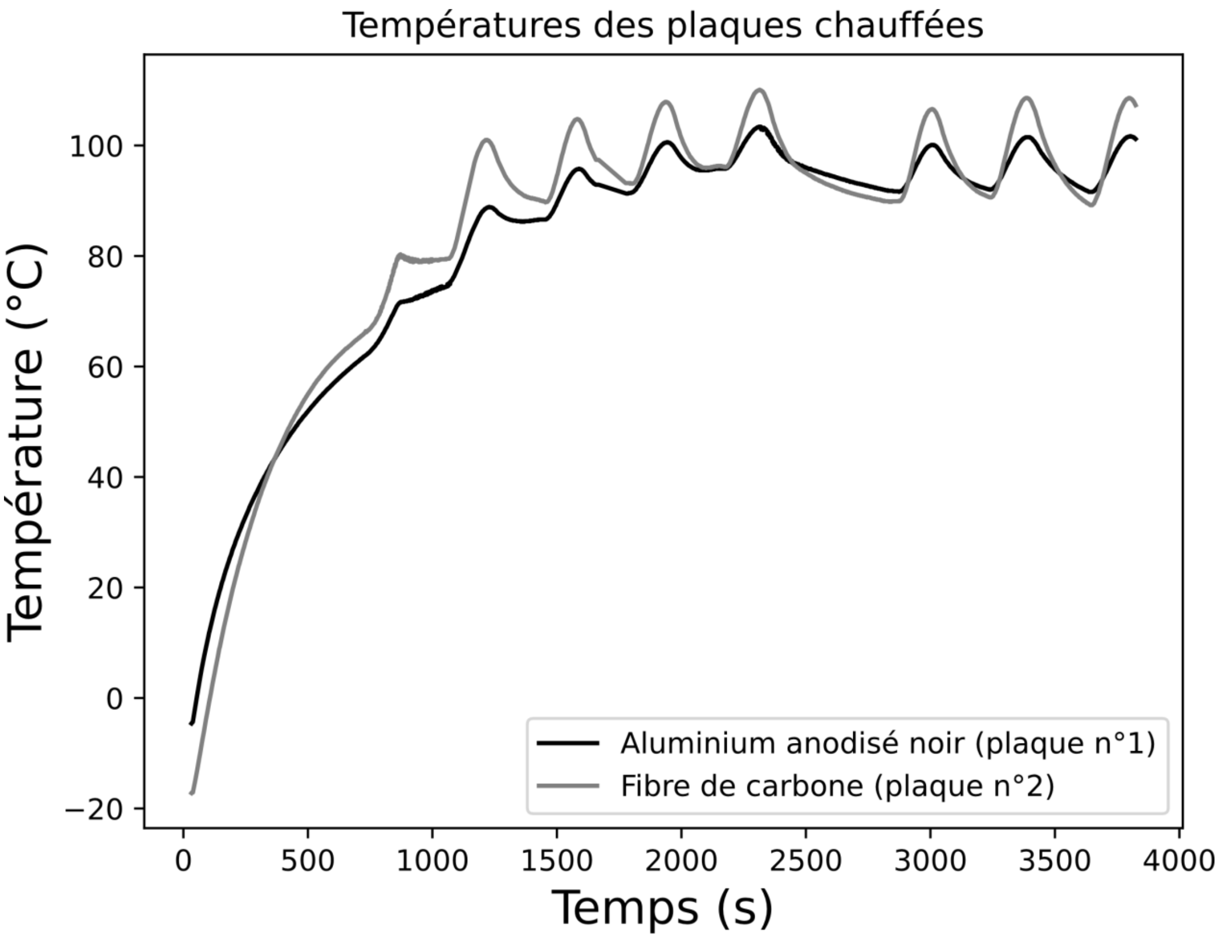
## 5.2 Analysis of temperature data

### 5.2.1 Visual chronology




- From 32s to 730s: Orbital night period (no or little incident radiation)
- From 731s to 1668s: Cruise period with roll along the φ axis (Euler angles)
- From 1669s to 1774s: Data loss for 105s (OBC restart)
- From 2400s to 2880s: Second stage roll stop manoeuvre
- From 2880s to 3825s: Cruise period with roll

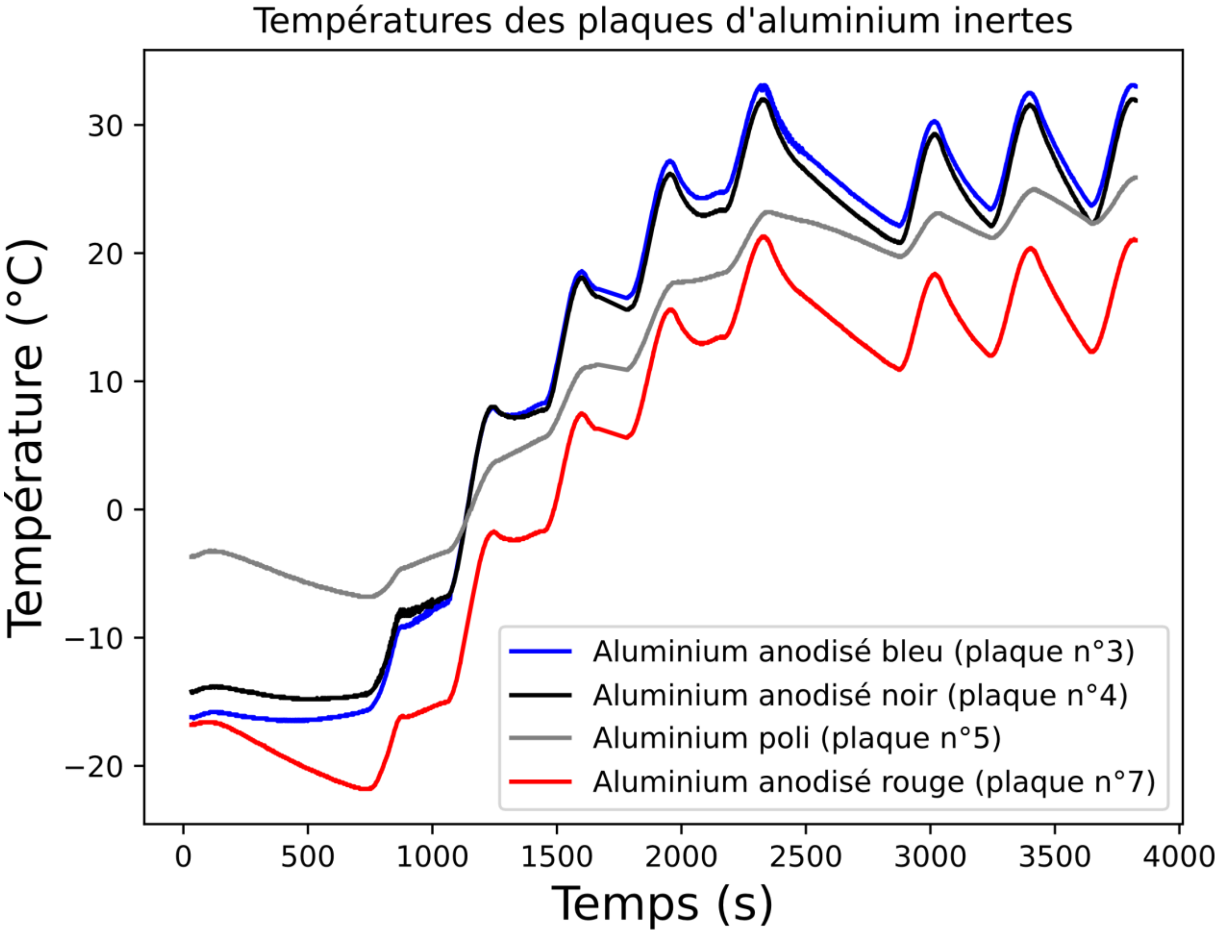
#### 5.2.2 Heated plates (plates n°1 and n°2)




We observe the sudden increase in temperature as soon as the experiment is switched on, because the heating resistors provide a thermal flux to these plates. However, the curve tends to increase less quickly as time passes. When **PariSat** is switched on (T0+3966s), the carbon fibre plate (no. 2) has an initial temperature of -17.2°C, while the heated aluminium plate (no. 1) has an initial temperature of -4.5°C; this is due to the lower thermal capacity of carbon fibre at constant volume. Although the lighting conditions are the same between aluminium and carbon fibre, the latter has cooled more quickly. This observation is found in the intersection of the temperature curves: for equal heating, carbon fibre heats up more quickly than aluminium.

Finally, we observe in the oscillating part an increase in temperature and a greater cooling of the carbon fibre than aluminium. Carbon fibre reaches higher top temperatures and lower bottom temperatures than black aluminium. The average temperature in the oscillatory part for carbon fibre and aluminium appears to be +90°C.

### 5.2.3 Inert aluminium plates (plates n°3, n°4, n°5 and n°7)

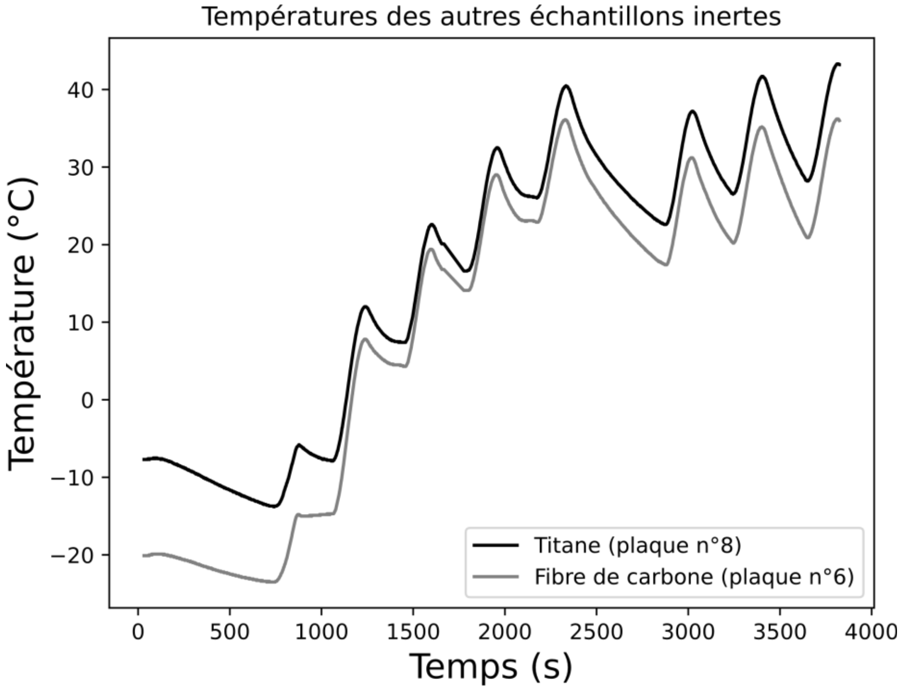



The temperatures of the inert plates start with a "bounce". It is noted that the blue anodized and black anodized aluminium plates have a very similar behaviour. On the other hand, the polished aluminium and the red anodized aluminium stand out from the others. The initial temperatures of the blue anodized and black anodized aluminium plates are respectively: -16.2°C and -14.2°C.

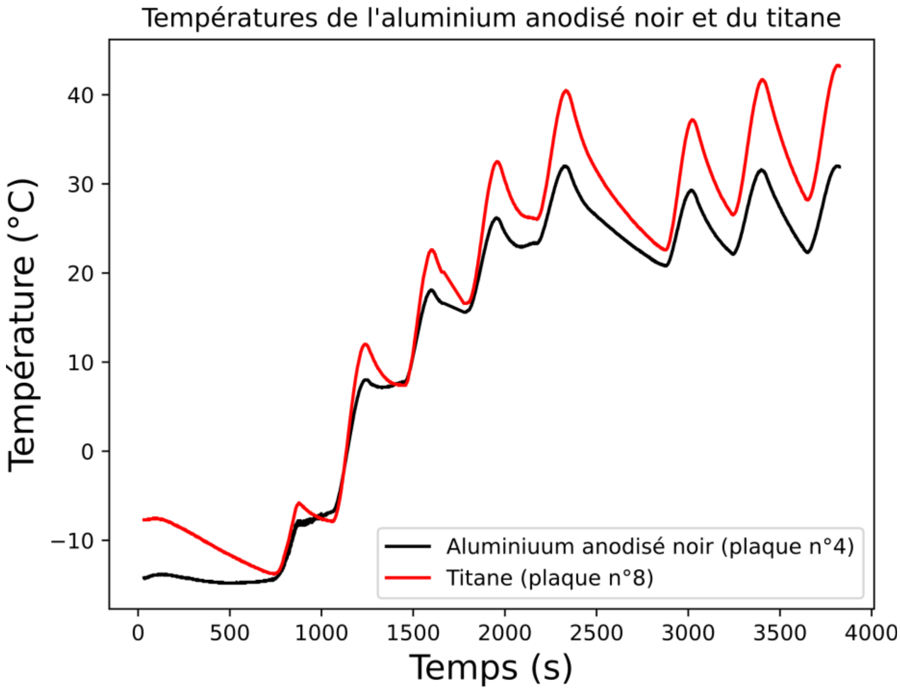
The temperature of the blue anodized aluminium exceeds that of the black anodized aluminium after about 1200 seconds, then the distinction is clear and the temperature of the blue anodized aluminium remains above that of the black anodized aluminium. Their average values after 2000s are about +27°C. The blue anodized and black anodized aluminium plates seem to be impacted by their heating neighbours: up to T0+750s, the temperatures of the polished (n°5) and red anodized (n°7) plates continue to drop, the temperature of the blue anodized (n°3) and black anodized (n°4) aluminium plates begin to increase slightly.

The initial temperature of the polished aluminium plate (n°5) is -3.7°C. We note that it is this plate whose temperature varies the least throughout the experiment. It finally oscillates around +21°C with a very slight residual increase. The initial temperature of the red anodized aluminium is -16.8°C. The temperature drop is clear, then the red anodized aluminium maintains the same appearance as the black anodized and blue anodized aluminium plates, with a constant temperature difference of approximately 10°C.

### 5.2.4 Carbon fibre and titanium plates (plates n°6 and n°8)




The initial temperatures of the carbon fibre plate (#6) and the titanium plate (#8) are -20.1°C and -7.7°C, respectively. This large initial temperature difference, due to the lower heat capacity of the carbon fibre, is quickly compensated; the plates eventually have a roughly constant difference of about 6°C, which tends to increase.




Although the black anodized aluminium plate is impacted by heated neighbours, it turns out that titanium is more prone to heating.

### 5.2.5 Comments and temperature evolution

| Material | T0+32s Initial state | T0+730s Orbital day | T0+1668s Data loss | T0+1775s Data resuming | T0+2400s Stop of roll | T0+2880s Roll resuming |
|---|---|---|---|---|---|---|
| **Black Alu (heated) TH1-0** | -4.5°C | +63.2°C | +92.9°C | +91.2 °C | +98.9°C | +91.7°C |
| **Blue Alu TH1-1** | -16.2°C | -15.3°C | +17.2°C | +16.5°C | +30.3°C | +22.2°C |
| **Polished Alu TH1-2** | -3.7°C | -6.8°C | +11.3°C | +10.9°C | +22.9°C | +19.7°C |
| **Red Alu TH1-3** | -16.8°C | -21.7°C | +6.3°C | +5.6°C | +18.7°C | +11.0°C |
| **Carbon (heated) TH2-0** | -17.2°C | +67.4°C | +97.4°C | +93.2°C | +100.5°C | +90.0°C |
| **Black Alu TH2-1** | -14.2°C | -14.1°C | +16.6°C | +15.6°C | +29.0°C | +20.8°C |
| **Carbon TH2-2** | -20.1°C | -23.3°C | +16.8°C | +14.1°C | +31.6°C | +17.4°C |
| **Titanium TH2-3** | -7.7°C | -13.6°C | +20.1°C | +16.6°C | +36.4°C | +22.6°C |

Before take-off, thermal conditions are controlled by active ventilation at +20°C, and this during the entire period under the fairing.

### 5.2.6 Setting up the thermal model

Let us consider a material plate of dimensions 40×40×1.8 mm that we assume to be non-deformable. We apply the first thermodynamic principle to it and neglect any type of work related to pressure forces. It is mainly exposed to incident thermal radiation from the Sun and the Earth. The outgoing flux is considered to be thermal radiation described according to the black body emission model. The material plates are held in a PEEK (polyetheretherketone) support with a thermal conductivity of 0.25 $W.m^{-1}.K^{-1}$.

We have the flux transmitted by conduction: $\Phi = \frac{\lambda \cdot S}{e} \cdot (T_1 - T_2)$.

With $\varphi$ The flux transmitted by conduction, λ the thermal conductivity of the material considered, S the conduction surface, and e the material thickness. Thus for a difference of 50 degrees, considering the surfaces in contact (1.8×40mm) with a thickness of 3mm and the thermal conductivity of PEEK, we obtain the flux transmitted: $\Phi = \frac{0.25 \cdot 1.8 \cdot 10^{-3} \cdot 40 \cdot 50}{2} = 0.45W$.

At high temperatures, the flux transmitted by conduction is low but not negligible; initially we neglect conduction. Since the material plates are in low Earth orbit at an altitude of 580 km during the experiment, any convection due to a possible residual atmosphere is neglected.

According to the first principle of thermodynamics and Joule's law, we have: $dT \cdot C = d\Phi$. With C the thermal capacity of the plate considered.

The incoming and outgoing thermal fluxes are expressed as:

- $\Phi_{entrant} = \alpha \cdot S \cdot \cos(\varphi) \cdot R$
  With *α* the absorbance, *S* the surface exposed to the incident flux, *φ* the inclination of the surface to the incident radiation, and *R* the surface incident radiation (in particular the direct solar flux but also the solar flux reflected on the Earth's atmosphere).
- $\Phi_{sortant} = -\varepsilon \cdot S \cdot \sigma \cdot T^4$
  With *ε* the emissivity, *S* the emitting surface, *σ* the Stephan-Boltzmann constant, and *T* the temperature of the plate.

We end up with a differential equation that we can solve numerically to compare our experimental results to our model to refine it.

$$\frac{dT}{dt} \cdot C = d\Phi_{entrant} + d\Phi_{sortant}$$

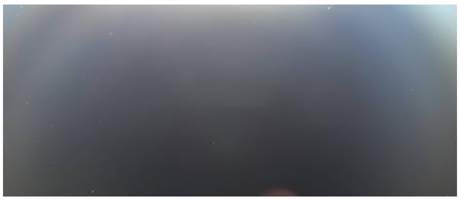
$$\frac{dT}{dt} \cdot C = \alpha \cdot S \cdot \cos(\varphi) \cdot R - \varepsilon \cdot S \cdot \sigma \cdot T^4$$

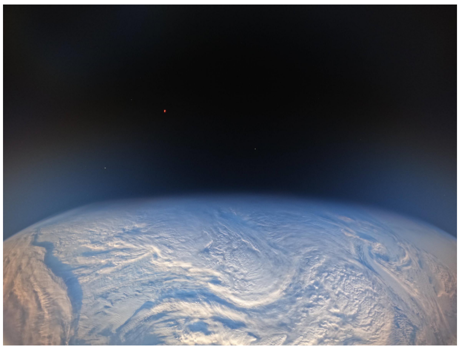
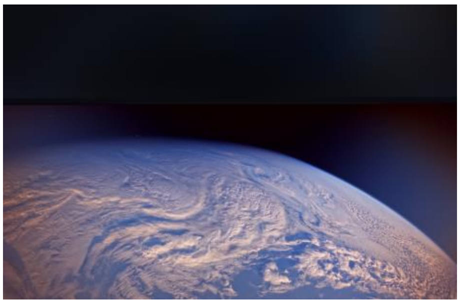
### 5.2.7 Scientific conclusion

The orbital temperature measurement experiment allowed us to reveal and recover the thermal behaviours of materials. It was found that polished surfaces allow the best thermal stability useful for preserving sensitive equipment that may be exposed to solar radiation. Otherwise, black and blue-violet anodized aluminium had almost similar behaviours. Then red anodized aluminium through its lower stabilization temperature allows better dissipation than darker shades. Titanium is not a better dissipative than black aluminium.

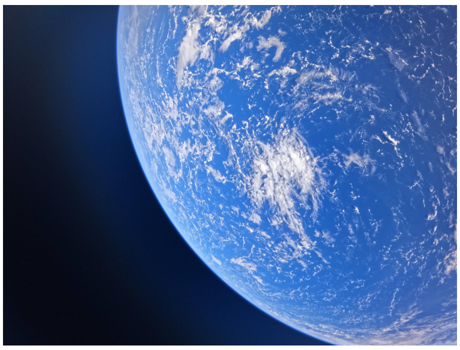
In general, all behaviours were found in accordance with theoretical models, some thermal influence phenomena between plates reduce the ideal nature of the experiment. An in-depth study with minimization of deviation from the model will allow us to recover the emissivity and absorption parameters of the materials.

## 5.3 Analysis of received images



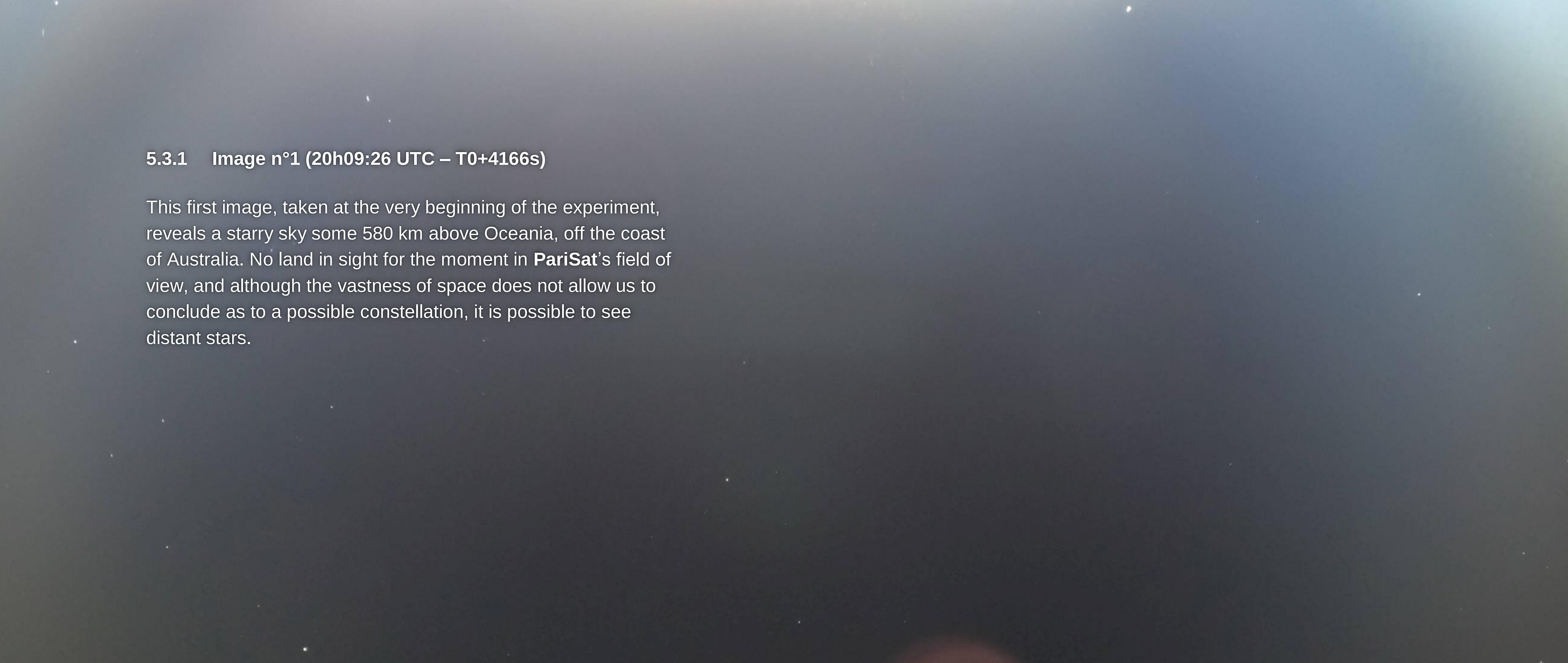






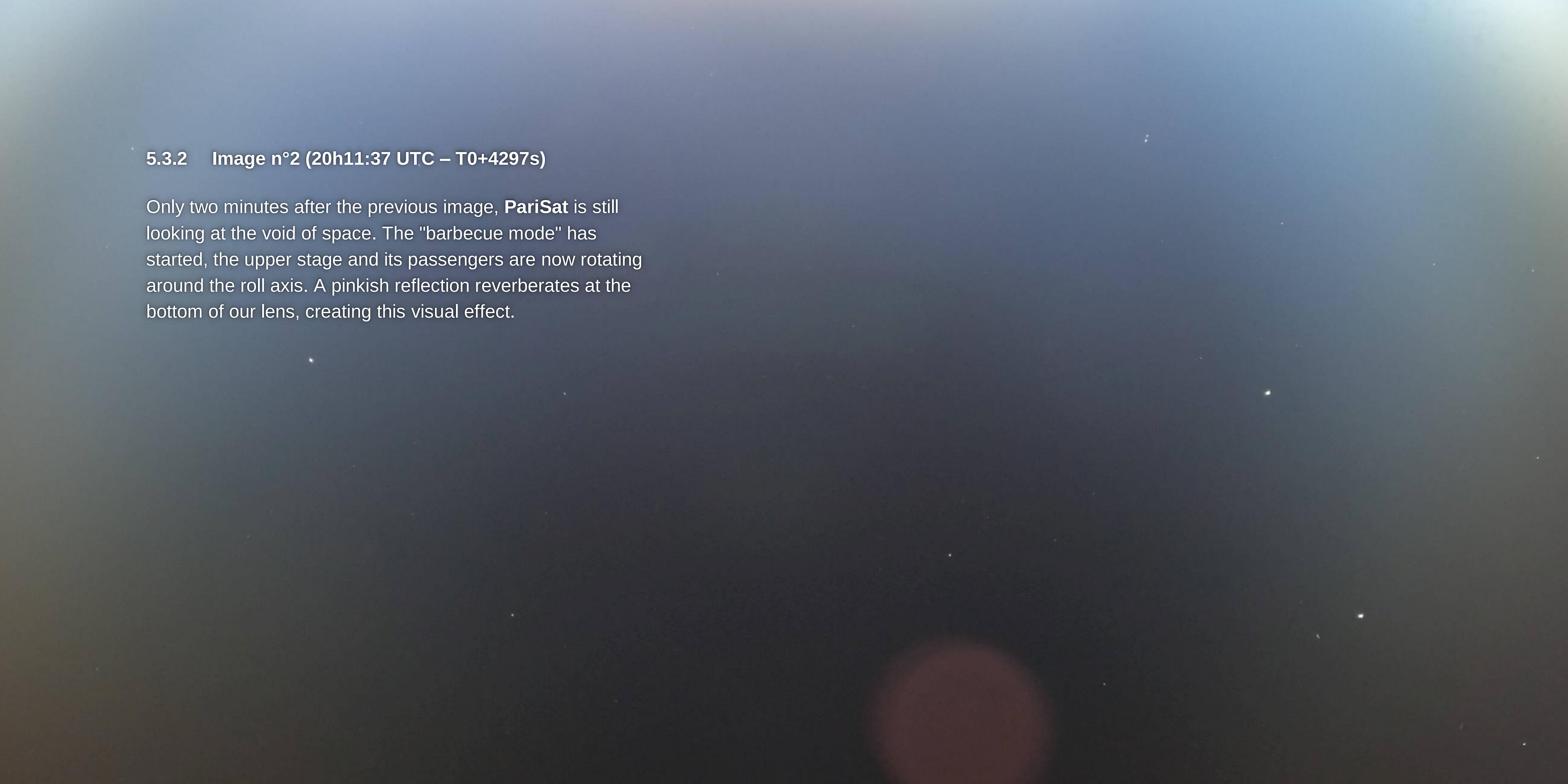
### 5.3.1 Image n°1 (20h09:26 UTC – T0+4166s)

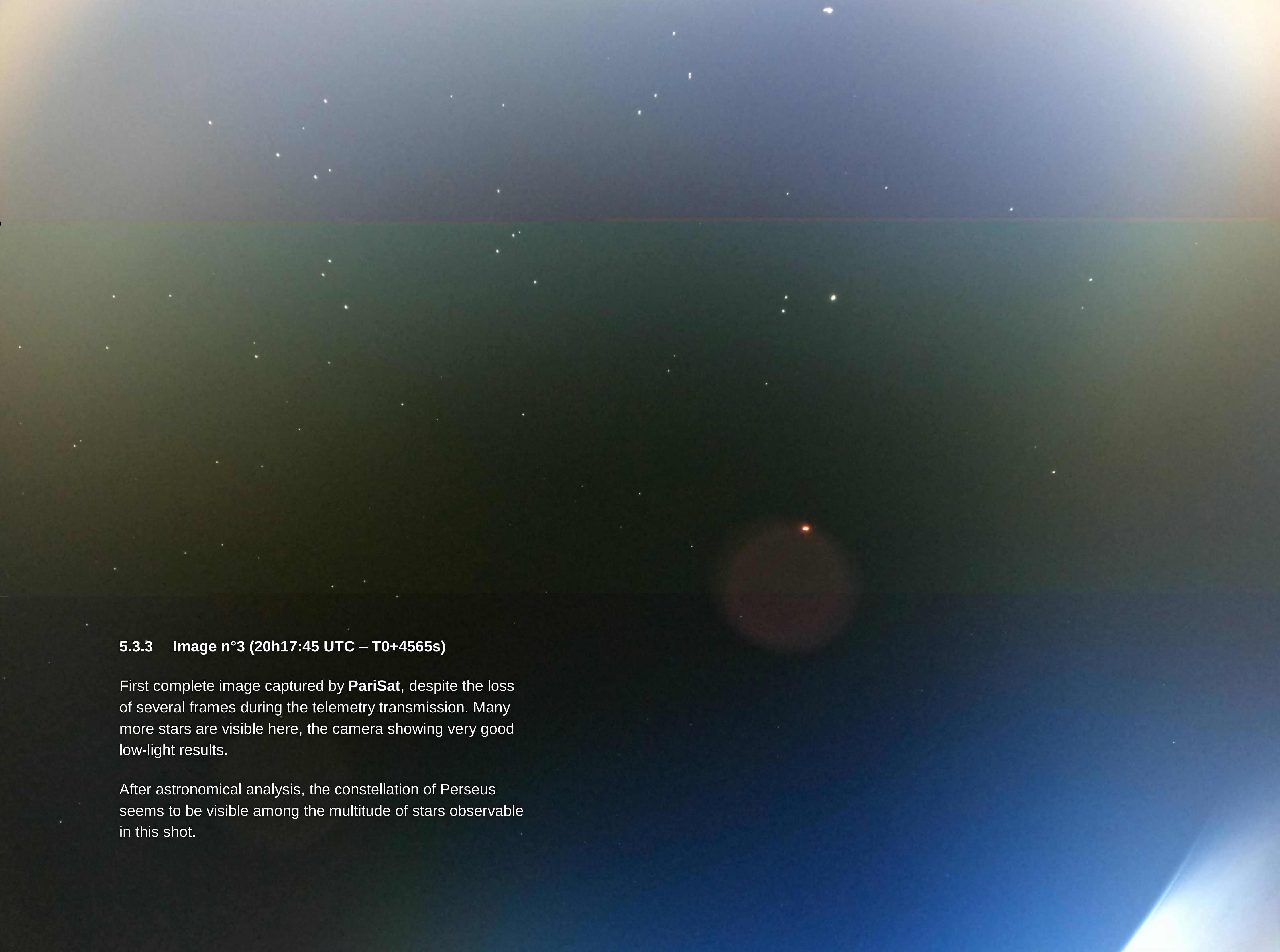
This first image, taken at the very beginning of the experiment, reveals a starry sky some 580 km above Oceania, off the coast of Australia. No land in sight for the moment in **PariSat**'s field of view, and although the vastness of space does not allow us to conclude as to a possible constellation, it is possible to see distant stars.



### 5.3.2 Image n°2 (20h11:37 UTC – T0+4297s)

Only two minutes after the previous image, **PariSat** is still looking at the void of space. The "barbecue mode" has started, the upper stage and its passengers are now rotating around the roll axis. A pinkish reflection reverberates at the bottom of our lens, creating this visual effect.





### 5.3.3 Image n°3 (20h17:45 UTC – T0+4565s)

First complete image captured by **PariSat**, despite the loss of several frames during the telemetry transmission. Many more stars are visible here, the camera showing very good low-light results.

After astronomical analysis, the constellation of Perseus seems to be visible among the multitude of stars observable in this shot.

### 5.3.4 Image n°4 (20h22:05 UTC – T0+4925s)

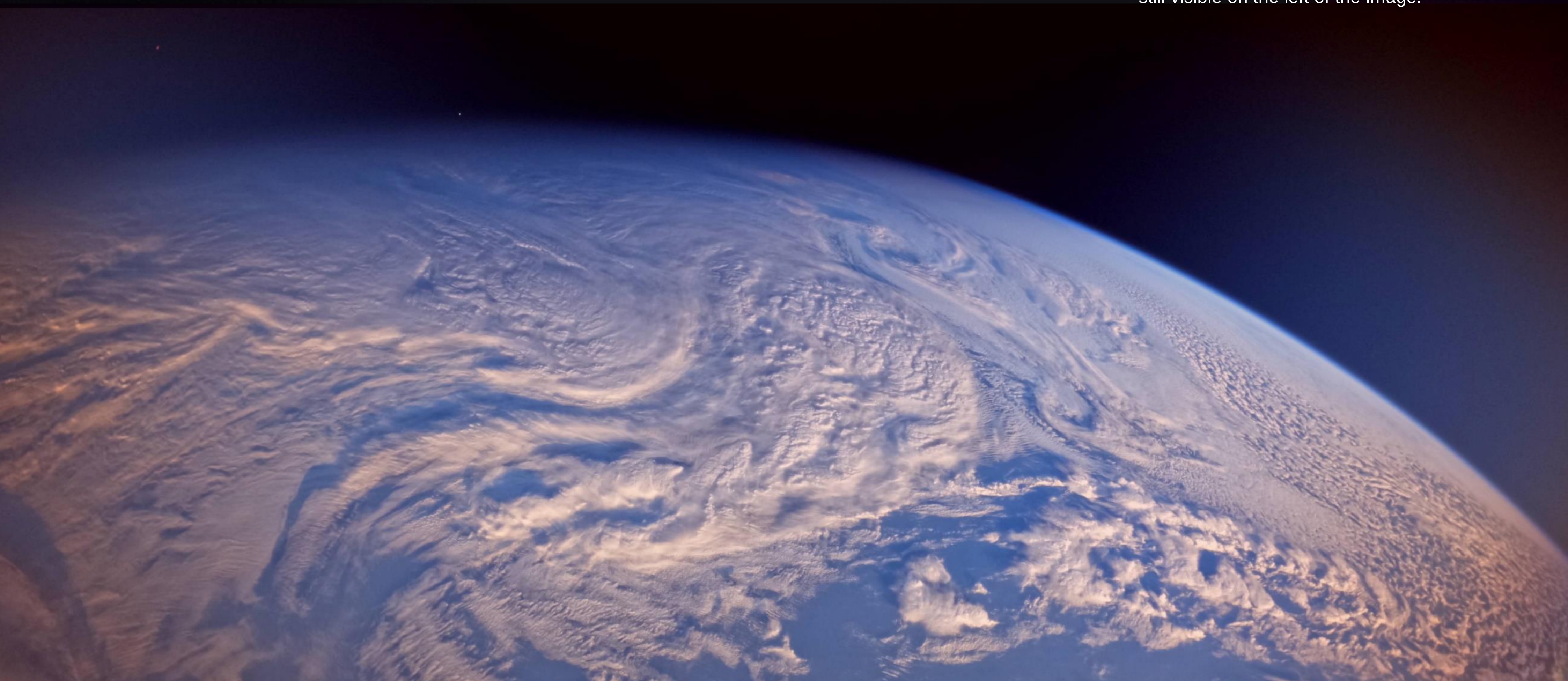
This image is the only one where we see a surface at night, Antarctica hidden in its winter. The Ariane 6 stage is upside down and **PariSat** has its back to the Sun. No land in sight, although the clouds show us their very varied relief, thanks to a Sun at the extreme horizon and therefore strongly projected shadows. The dark areas are indeed the shadows of the high layers on the low ones.

In the sky we are centred on the constellation of Scorpius, but few stars are visible. The dynamic range of the camera seems to treat the brightness of each of the stars differently. One star is nevertheless visible, which would correspond to Antares (α Scorpii), a red supergiant located 550 million light-years from Earth, 668 million times larger than the Sun.

### 5.3.5 Image n°5 (20h22:43 UTC – T0+4963s)

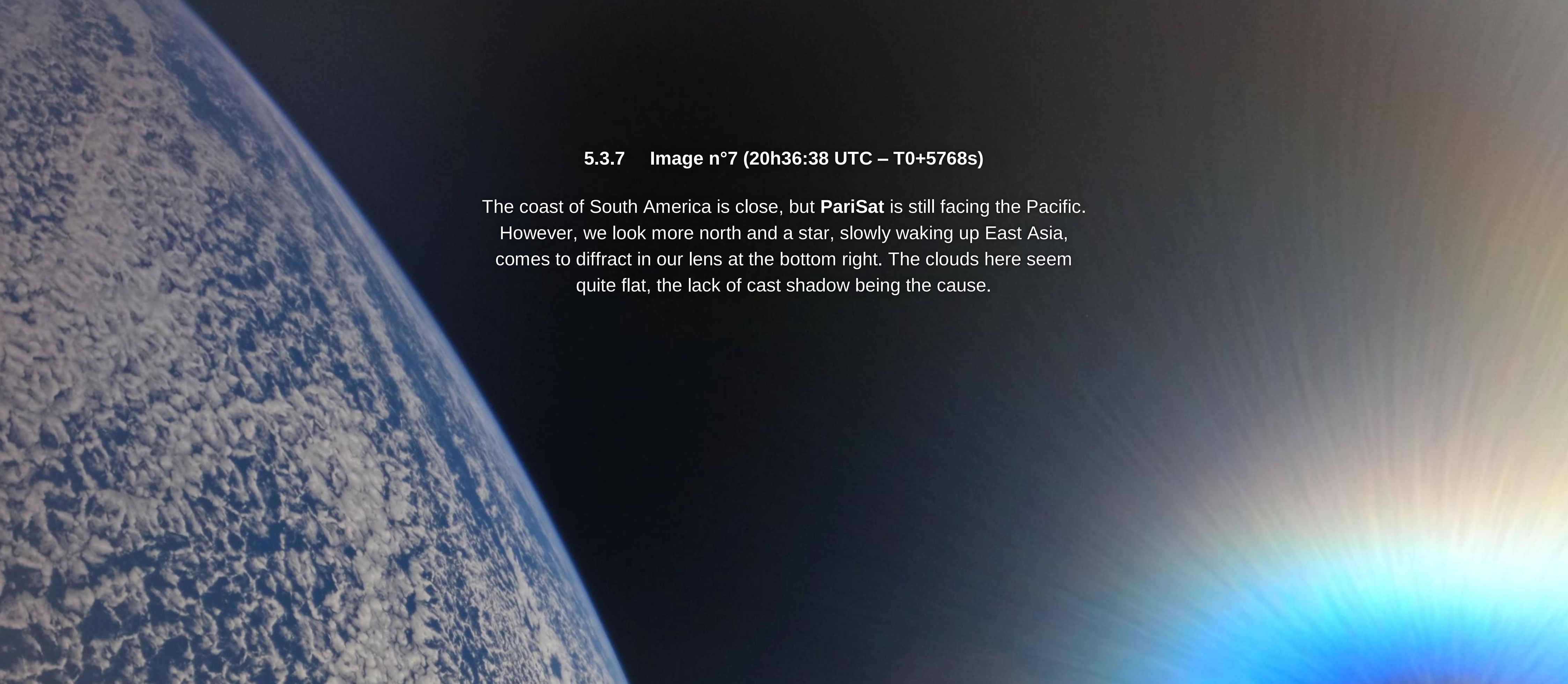
In this shot taken only a few dozen seconds after the previous one, the same cloud mass shows us particularly defined shapes above Antarctica.

The terminator, the limit between day and night, is still visible on the left of the image.



### 5.3.6 Image n°6 (20h23:26 UTC – T0+5006s)

A few minutes later, in the middle of the Pacific with still many clouds, the launcher is in a straightening maneuver (puts its "head" in the direction of the trajectory).



### 5.3.7 Image n°7 (20h36:38 UTC – T0+5768s)

The coast of South America is close, but **PariSat** is still facing the Pacific. However, we look more north and a star, slowly waking up East Asia, comes to diffract in our lens at the bottom right. The clouds here seem quite flat, the lack of cast shadow being the cause.

### 5.3.8 Image n°8 (20h41:58 UTC – T0+6118s)

**PariSat** is here above Central America. We can see very well the Peruvian tip of Paita at the top right. On the left the large natural national park of Río Puré, the border between Brazil and Colombia. The clouds strongly hide Colombia and Panama but the Andes mountain range points very well through.

**5.3.9 Image n°9**
**(20h48:42 UTC – T0+6522s)**

This image is our penultimate one. While the Ariane APU attempts a final start, and the launcher's camera looks at the sky, we finally change oceans, with a magnificent blue spreading.

### 5.3.10 Image n°10
### (20h49:20 UTC – T0+6560s)

It is 1h49 after the launch, Kiruna will be in sight in a few minutes. And most of the time **PariSat** will actually look towards space (unlike the launcher camera), images that will therefore be rejected by the on-board sorting algorithm.

# 6. PROJECT CONCLUSIONS AND ACKNOWLEDGEMENTS

After 3 years of effort, the **PariSat** experiment took off on Tuesday, July 9, 2024 at 7:00 p.m. UTC, before turning on at 8:06 p.m. UTC. Embarked on the inaugural flight of Ariane 6, it nominally carried out its scientific and photo experiments from a low orbit at an altitude of 580 km. The integration and launch from the Guiana Space Center went perfectly.

The design of a satellite, and particularly for a team of young people (17 years old at the start of the project), is ambitious and requires a lot of rigor. All the simulations and theoretical analyses carried out before the flight made it possible to effectively analyse our data. It is this preparatory work that also made it possible to qualify **PariSat** to the standards of the European Space Agency to embark on Ariane 6.

As previously said, **PariSat** was designed and optimized for a 2-hour mission. But that was without taking into account the minor malfunction of the upper stage of Ariane 6 (at the APU level, see **Flight progress**) which prevented the engine from re-igniting. **PariSat** was therefore not de-orbited and will continue to orbit at 580km above our planet for the next few decades.

It is possible to track its actual location via the SatNOGS network:

https://db.satnogs.org/satellite/LRPR-7984-5193-0374-6707#mapcontent

As in any project, in addition to the technical part, there is also a very important human aspect. Its success was based on good organization of teamwork, with a clear distribution of tasks and regular meetings. The large number of people involved and the duration of the project led us to write many documents. Finally, it is essential to emphasize that these activities, carried out in parallel with everyone's studies, are part of leisure activities.

The entire **GAREF** team would like to once again warmly thank all the partners who helped and supported us, without whom this unique project could not have succeeded: ESA, SCC, Arianespace, CNES-CSG, LESIA, IAS, PIT, IPSA, ENSEA, Polytech, Aéroclub de France, the City of Paris and the Mairie du 13ème.