

L. Damé<sup>1</sup>, M. Meftah<sup>1</sup>, E. Fringhian-Rupert<sup>1</sup>, P. Lacroix<sup>1</sup>, N. Rouanet<sup>1</sup>, P. Gilbert<sup>1</sup>, P. Etcheto<sup>2</sup> and J. Berthon<sup>2</sup>

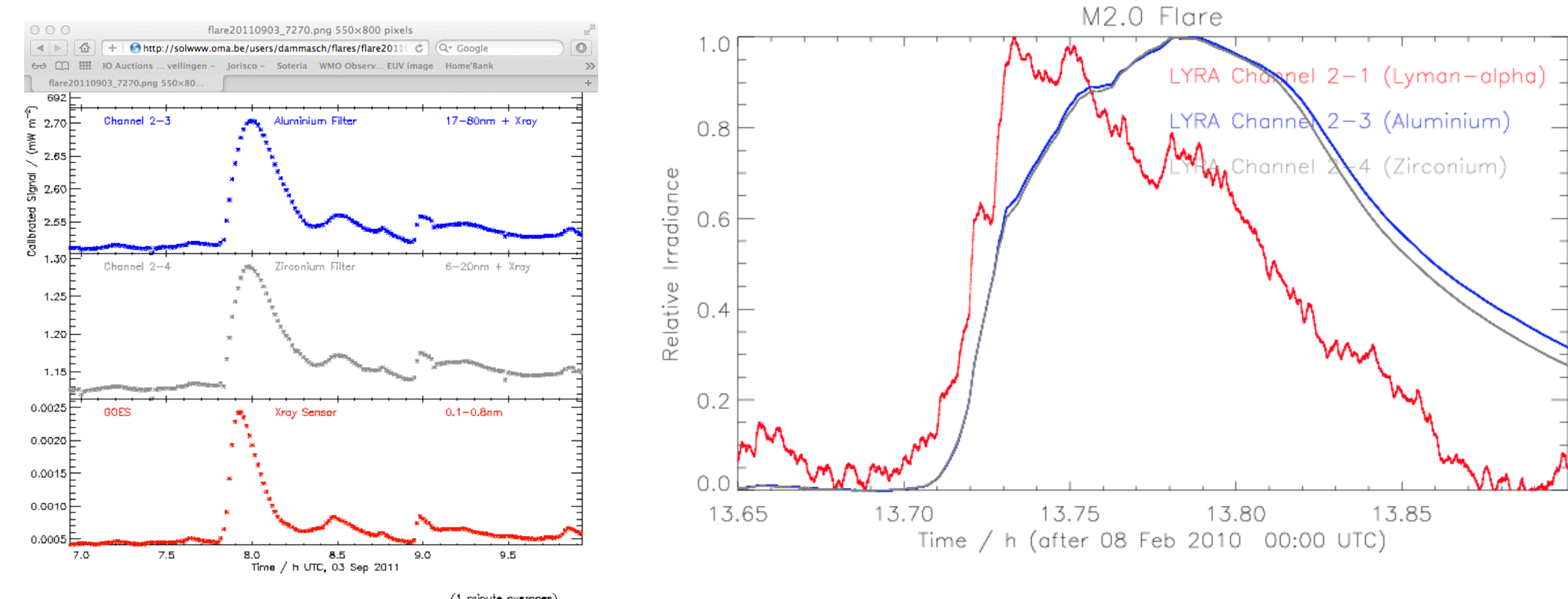
<sup>1</sup> Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS), CNRS, Paris-Saclay University, 11 boulevard d'Alembert, 78280 Guyancourt, France (luc.dame@latmos.ipsl.fr)  
<sup>2</sup> Service Optique, CNES, 18 avenue Edouard Belin, 31400 Toulouse, France

### Introduction

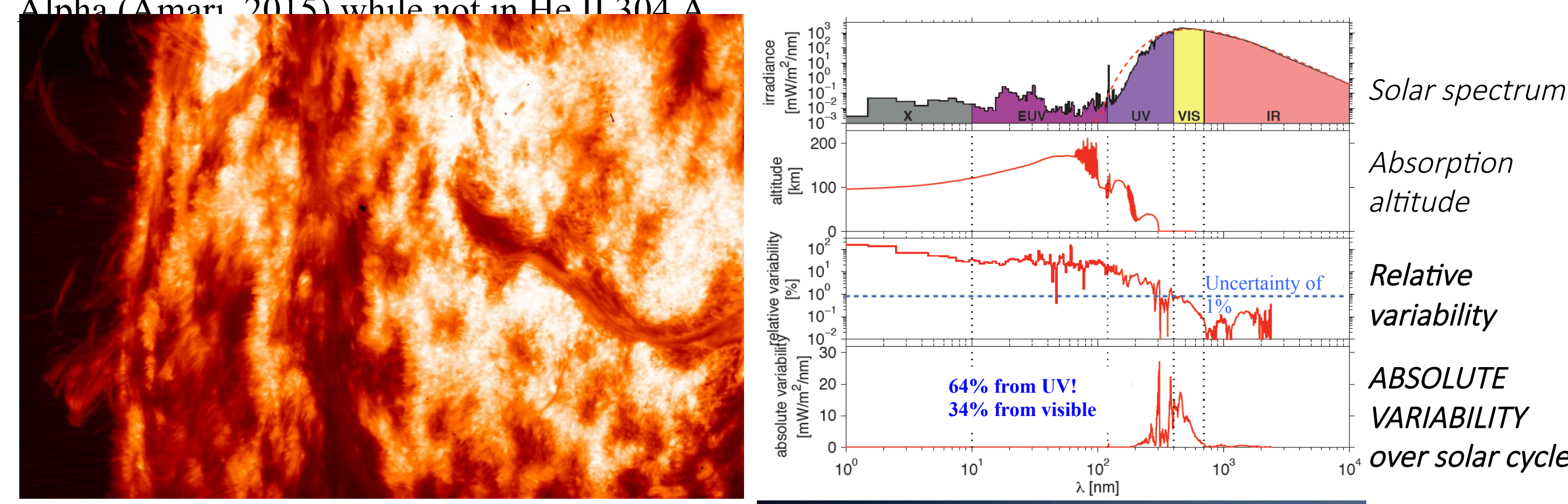
SUAVE (Solar Ultraviolet Advanced Variability Experiment) is a far UV imaging solar telescope (Lyman Alpha, 121.6 nm, Herzberg continuum, 200-242 nm, etc.) of novel design (off-axis telescope with "mushroom type" SiC mirrors) for ultimate thermal stability and long lasting performances over years instead of, often, a few weeks or months in this wavelength range. SUAVE has no entrance window for long and uncompromising observations in the UV (no coatings of mirrors, flux limited to less than 2 solar constants on filters to avoid their degradation), associated with an ultimate thermal control (no central obscuration resulting in limited thermal gradients and easier heat evacuation, focus control, stabilization). Design and performances will be detailed as well as results of thermal/optical tests performed on the SiC primary mirror and regulated support plate (in SiC also). SUAVE is the main instrument of the Solar/Space Weather/Climate SoSWEET (Solar ultraviolet variability & Space Weather Extreme EvenTs) microsatellite mission.

### Predicting and monitoring large flares & CMEs: from X-ray to Lyman-Alpha

- Objective is to monitor flares in Lyman-Alpha rather than X-ray or XUV. Lyman-Alpha, much like H-Alpha, is an excellent flares/CMEs precursor indicator since of filaments and emerging bipolar region high visibility (space weather direct application). Furthermore, comparing sensitivity difference with H-Alpha, formed lower in the chromosphere, might lead to directivity (geoeffectiveness) and better and more robust flare/CME predictions.
- Lyman-Alpha is EXCELLENT at detecting flares (cf. LYRA/PROBA-2) with an important raise in global integrated light curve (1000 times H-Alpha), and this even before GOES X-ray (1-8 Å) or the LYRA channel 2-3, Aluminium 17-80 nm, or 2-4, Zirconium 6-20 nm.



- Filaments and emerging bipolar region (the two major flare's precursors) are EXTREMEL-LY well seen in Lyman-Alpha allowing their detection and tracking, and their configuration changes to anticipate/predict large flare happenings. Coupled with H-Alpha, some direct-ivity could be predicted hours in advance (geoeffective CME). Modelling the disruption of the flux rope is possible in Lyman-Alpha (Amari 2015) while not in He II 304 Å.



High resolution image of the Sun in Lyman-Alpha taken by the VAULT rocket of NRL and nicely showing details of prominences and filaments (prominences seen in absorption on the disk). [Vourlidis et al., 2010]

Solar spectrum, its absorption altitude, relative (%) and absolute variability over solar cycle (data from *SORCE & TIMED*, 2003-2010). [Ermolli et al., 2013]

UV affects stratospheric dynamics and temperatures, altering weather patterns

### SUAVE Rationale

- SUAVE is a **Space Weather** watch-dog for potentially harmful extreme events with a **unique Lyman-Alpha imaging telescope (1 arcsec resolution)**; it also monitors UV variability influence on climate (ozone creation) through Herzberg continuum (200-242 nm) observations.
- Need of long duty cycle (> 6 years, 1/2 solar cycle) => **SiC mirrors of "mushroom" type** since: no coating -> no degradation, thermal conductivity and homogeneity -> heat evacuation preserving the filters (SiC reflect 40% in UV and only 20% in visible).
- High resolution imaging implies stability and a **thermally optimized configuration: an off-axis telescope is the solution** => no central obscuration of primary mirror, flux homogeneity minimizes thermal gradients, M2 protected inside structure (no back illumination)
- SUAVE is the main instrument of the **SoSWEET (Solar ultraviolet variability & Space Weather Extreme EvenTs) small satellite mission** using a solar observing satellite on a polar Sun-synchronous orbit) at 720 km.
- Low cost small platforms** (< 150 kg; 60-70 kg P/L) are a new reality (OneWeb, Blue Canyon, etc.), not compromising on performances, pointing and telemetry, allowing more ambitious missions in same project envelope.



OneWeb small satellite (<150 kg) ARROW platform was developed by Airbus Defence and Space (ADS): 428 satellites out of a total of the 648-satellite constellation have already been launched as of spring 2022. Courtesy ADS.

### Conclusion

SUAVE is a novel **disruptive** far UV imaging solar telescope for Lyman Alpha (121.6 nm) and Herzberg continuum (200-242 nm) using SiC mirrors for long duty cycle (> 6 years) since:

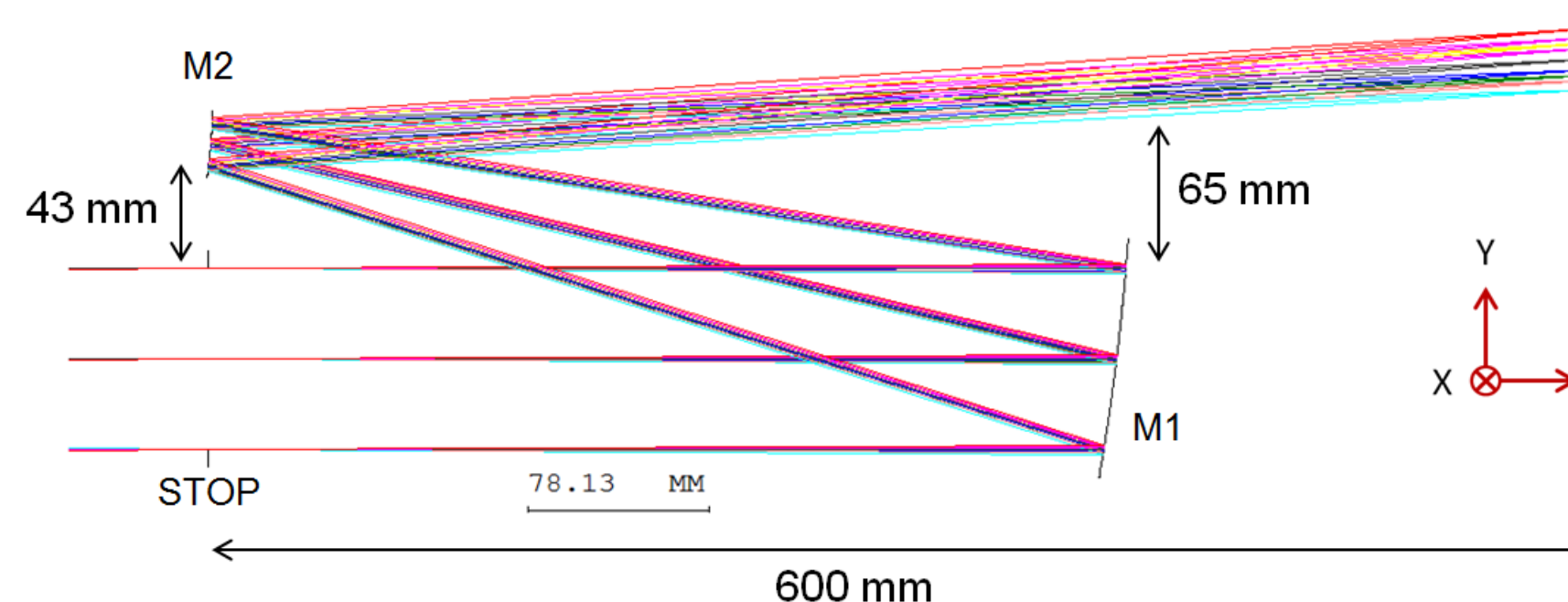
- no coating (no degradation of coatings)
- thermal conductivity and homogeneous -> heat evacuation
- reflect 40% in UV and 20% in visible -> filters are preserved

### SUAVE Off-axis SiC Telescope Design

Evolution & optimization of SODISM: off-axis, no window, SiC mirrors & new "thermal" door and radiators

SUAVE is a **disruptive** evolution of the SODISM telescope flown on the CNES PICARD small satellite mission (2010-2014) with a new **optical design limiting thermal gradients**:

- no window, **SiC mirrors ("Mushroom")**, new "thermal" door and radiators
- thermally optimized off-axis configuration** (homogeneity, no central hole, no back flux on M2)



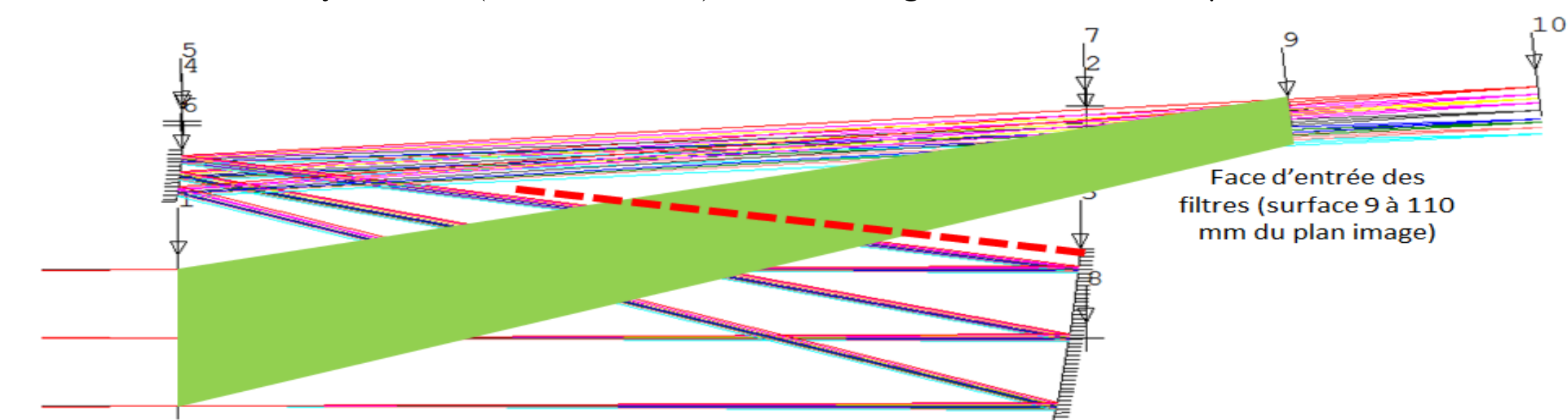
#### Scattered light

The large distance between the M1 and M2 mirrors and between the M1 mirror border and the beam out of the M2 gives an easy scattered light control by a simple baffle. Filters (in plan 9) are protected by flux elimination of the M1 & M2 mirrors: they receive less than 2 solar constants => **no degradation since flux concentration is not sufficient to polarize contaminants.**

#### SUAVE optical design

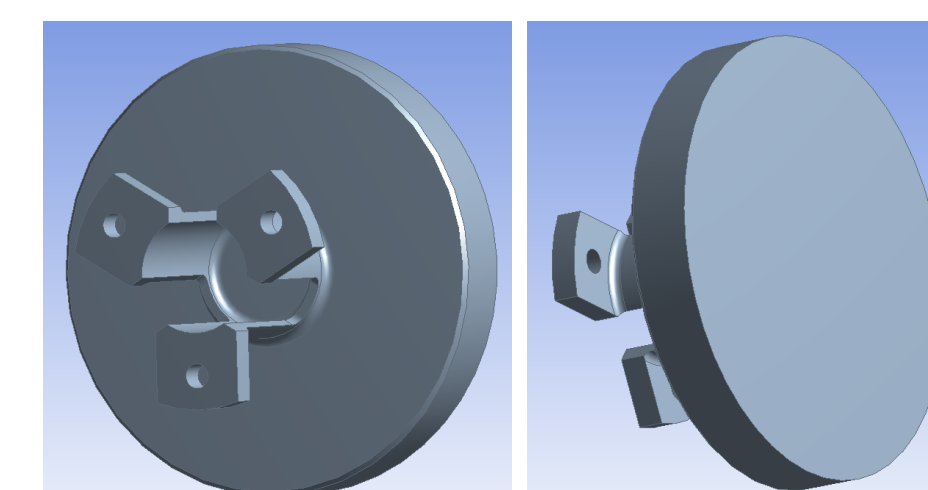
- Pupil 80 mm; Focal 2630 mm
- M1 100 mm vertex inclined 0.15° (useful 84 mm)
- M2 28 mm vertex inclined 1.26° (useful 23.5 mm)
- Dimensions: 100x200x600 mm<sup>3</sup> (200x300x750 mm<sup>3</sup> with mechanics)

Diffraction limited (10 μm pixels) in FUV. Defocus and astigmatism compensated by refocus (MTF min: 0.3). Decentering/Tilts M1/M2: ±10 μm - ±10 arcsec.



SUAVE is a FUV optimized version of SODISM (**diffraction limited**), flown on the CNES PICARD mission, with **SiC mirrors in an off-axis configuration** for long observations and ultimate thermal control (heat evacuation, focus control). SUAVE has no entrance window and hosts a main entrance baffle and a new implementation of the door to avoid Earth albedo returns. The radiator of the secondary mirror is increased to improve its cooling. Two radiators are added: for the CCD and for the primary mirror M1. Using SiC (or CVD SiC) mirrors avoids the degradation of coatings (SiC "naked" reflects 40% in the FUV and 20% in the visible), limits the thermal load (SiC is homogeneous and conducting) and the flux on the filters (less than 2 solar constants: no or limited polymerization possibilities) to preserve their lifetime. SiC has also the advantage of being sensitive to temperature what allows to control the radius of curvature of the mirror (focal length control) by setting working temperature.

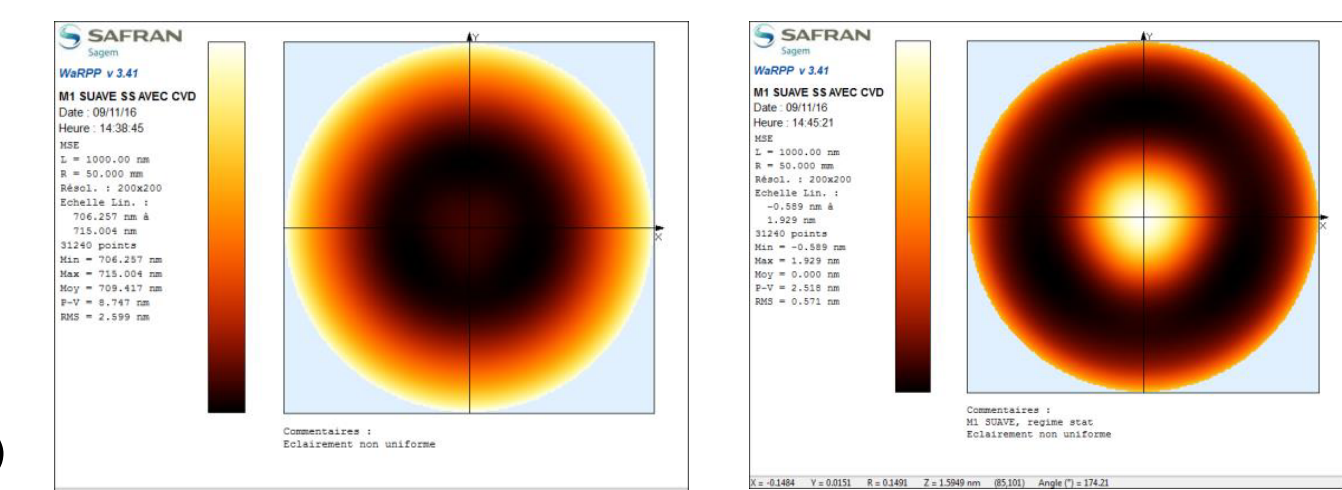
M1 SiC mirror of SUAVE  
 Diameter 100 mm (84 used)  
 R 1029.85 mm  
 Conicity -0.9657 mm



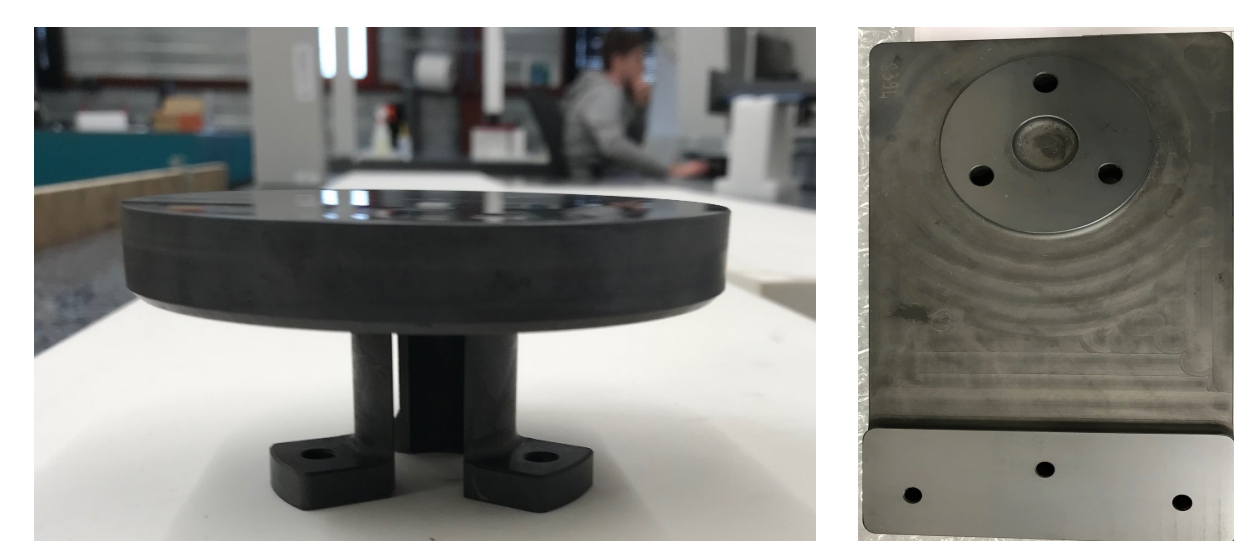
M1 and its cold support/interface plate (photos) have been realized by MERSEN BOOSTEC, and coated with CVD (M1 only).

- conducting
- homogeneous
- heat evacuation
- no coating (no degradation)
- 40% R in UV; 20% R in visible

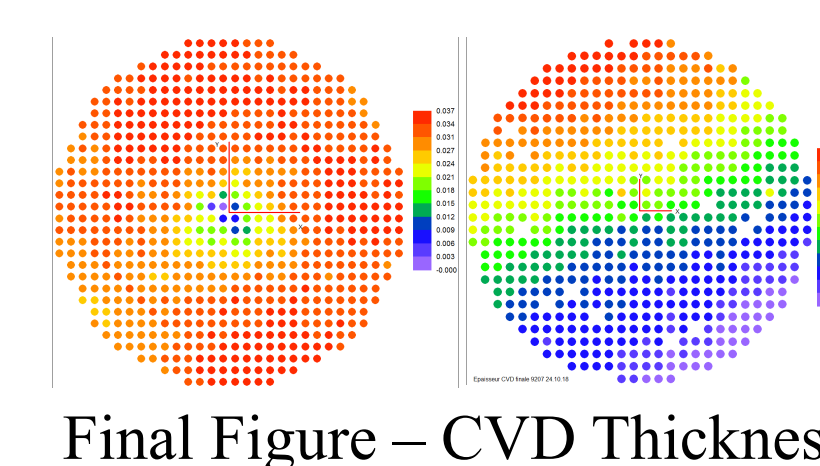
Example of SUAVE mirror  
 Thermal behavior (0.6 nm peak to peak surface error)



Opto-thermo-mechanical analysis of the SiC primary mirror of SUAVE (M1) in its nominal orbit and solar flux lightning configuration was carried by REOSC and showed that even in extreme conditions peak-to-peak surface error of the mirror stays in within prescriptions. Nominal interface plate (also in SiC) is controlled to 22°C. A representative breadboard of the M1 mirror and its support plate has been realized (BOOSTEC SiC) and is now ready for optothermal testing.



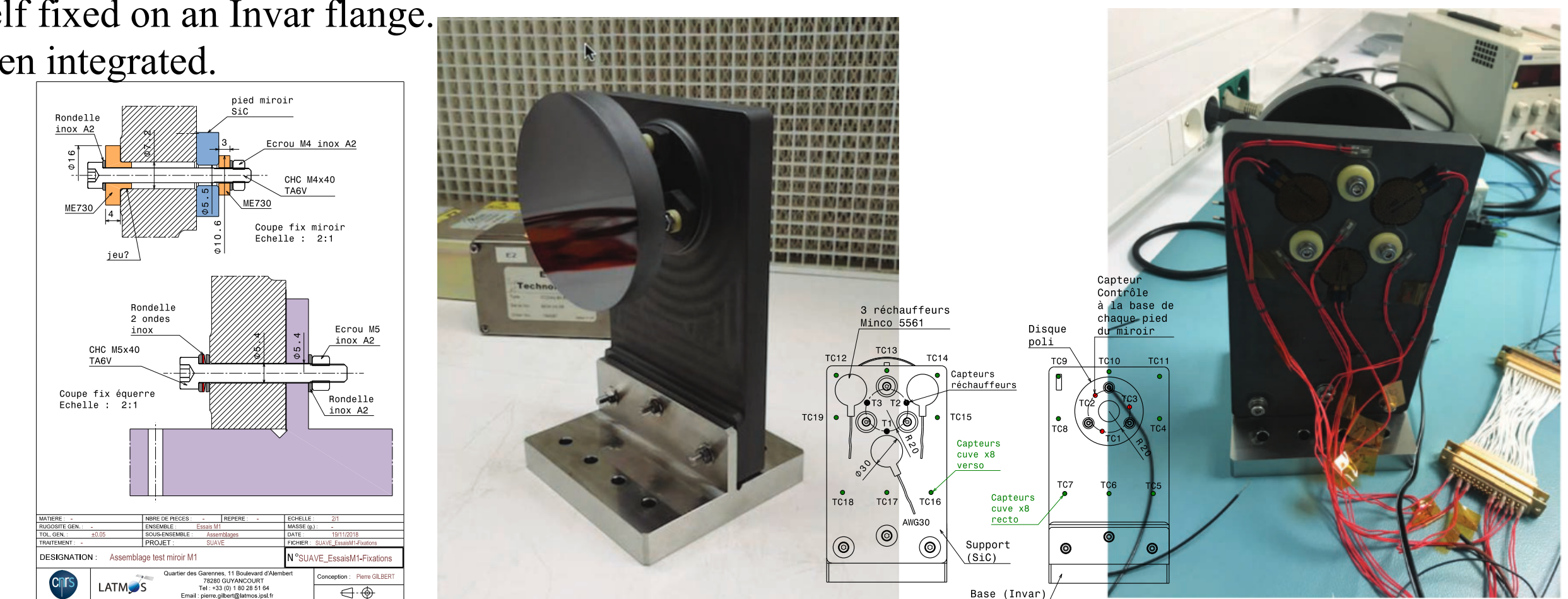
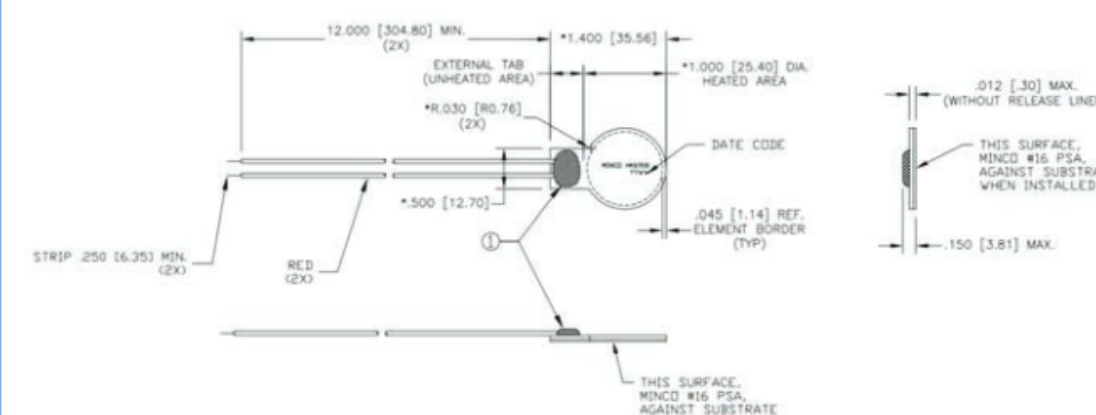
Polishing by OPA-OPTICAD:  
 Rugosity < 0.7 nm  
 Planicity < 0.1 fringe.



### Assembly, Integration & Thermal Tests

The mirror is fixed on a SiC support, itself fixed on an Invar flange. Heaters and temperature sensors have been integrated.

- Use of MINCO heaters (120.62 Ohms) with MINCO #1 PSA adhesives.
- 22 sensors and 3 heaters (on support plate)
- Harnesses are manufactured.
- Use of EC2216 glue to fix the harnesses.



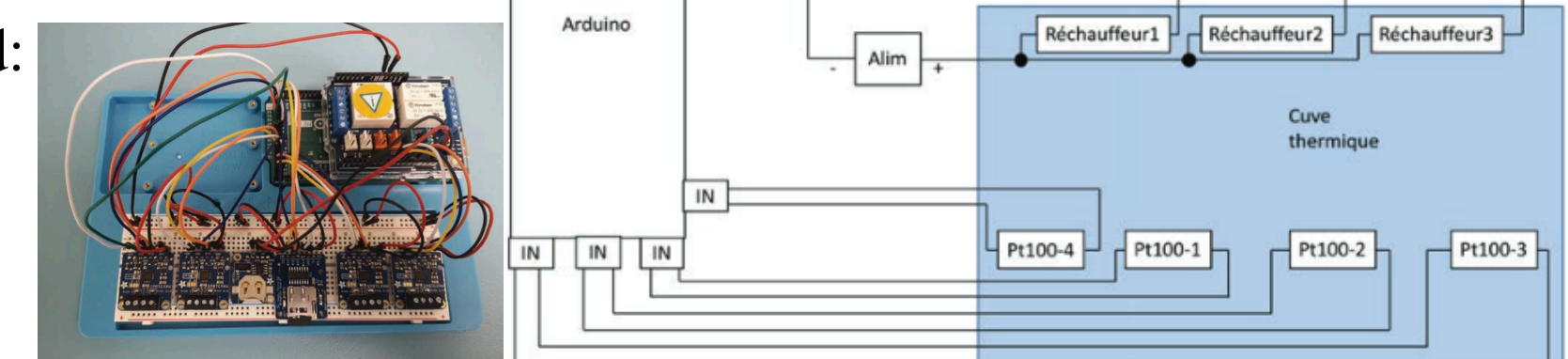
Software solution: implementation of an Arduino board for the thermal control of the primary mirror.

Upcoming test: the mirror is mounted on the support plate regulated at 22°C, and fixed on the interface plate (ITF) controlled in a thermal vacuum tank.

3 types of tests (temperature and optics; flux transmission) are performed:

- hot case: T<sub>ITF</sub> = 10°C, T<sub>reg</sub> = 22°C, T<sub>i-rad</sub> = 20°C, F<sub>sol</sub> = 1420 W/m<sup>2</sup>
- cold case: T<sub>ITF</sub> = 0°C, T<sub>reg</sub> = 22°C, T<sub>i-rad</sub> = 20°C, F<sub>sol</sub> = 1300 W/m<sup>2</sup>
- transitory case: F<sub>sol</sub> = ON = 1420 W/m<sup>2</sup> and F<sub>sol</sub> = OFF = 0 W/m<sup>2</sup>

Performance to be verified at M1:  
 • measurement of mirror WFE, including PTF;  
 • MSE < 10 nm rms.



SUAVE has a thermally optimized configuration:

- off-axis mirrors (no central obscuration, flux homogeneity minimizing thermal gradients, secondary preserved from direct light: easier heat extraction)
- no insert on mirrors => no distortion & better figure since of "mushroom" type

