# SUITS /SWUSV: A Solar - Terrestrial Space Weather & Climate Investigation

## Solar Ultraviolet Influence on Troposphere/Stratosphere
## Space Weather & Ultraviolet Solar Variability Mission

### Addressing: Flares and CMEs Studies & Forecasting
### Lyman-Alpha Imaging
### FUV & MUV Local Influence on Earth Climate

**Luc Damé, Alain Hauchecorne, LATMOS/IPSL/CNRS/UVSQ, France**
**and the SUITS Team**

# History

- First envisaged and studied in 2010
- Proposed in June 2012 at the first ESA Call for a Small Mission
- Prepared and envisaged in March 2015 for the second ESA Small Mission (S2) between ESA and China (Science Academy and CNSA) [Not submitted since of CNES lack of support]

# Future

- Could be envisaged for a joint opportunity CNES/NASA (Heliophysics Explorer Mission of Opportunity? Call next spring) between Europeans and Americans partners for a possible flight in 2021-2022
- ESA M5 Call (next spring)… with a larger P/L (microwaves, EUV, coronagraph,…)? Pre-proposal concept expected by CNES end of October…

# Large Team Built up for ESA S2 Mission (March 2015)

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# Rationale

- Continuous Ly$\alpha$ and Herzberg continuum (200-220 nm) imaging at good resolution of energy sources -> structuration/ dissipation/flare/CMEs
- High energy flare characterization to understand flaring process
- Lyman-Alpha and UV Solar Spectral Irradiance 170-400 nm inputs in Earth's atmosphere (polar regions) and simultaneous monitoring of Earth's radiative budget and ozone

- Determine the origins of the Sun's activity; understand flaring process and CMEs onset
- Determine the dynamics and coupling of Earth's atmosphere and its response to solar (in particular UV) and terrestrial inputs
- Benefit from new activity cycle starting in 2021

# Scientific Objectives

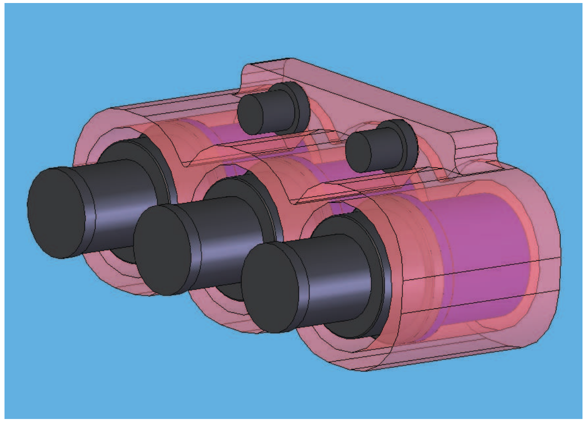
- **1 –** High Energy Flare Physics
- **2 –** Flares, activity & structures

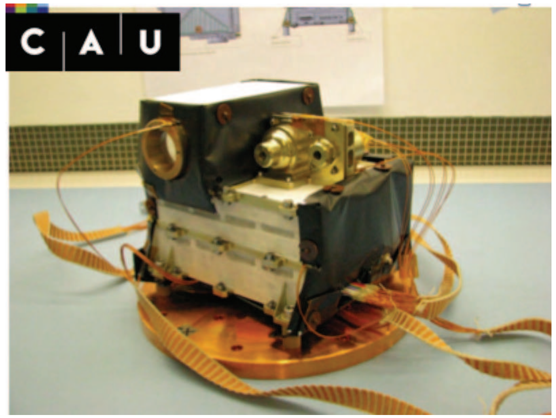
  Lyman-Alpha advantages in observing and identifying flare/CMEs precursors;

  Ly$\alpha$ & 200–220 nm structures
- **3 –** Ultraviolet Solar Variability (Ly$\alpha$ & 170–400 nm) and its influence on climate

# Model Payload
# High Energy & Particles

- **1 –** High energy flares:
  **HEBS** (*High Energy Burst Spectrometer*) hard X-rays to gamma-rays 10 keV to 600 MeV
- **2 –** Particles:
  **EPT-HET** (*Electron Proton Telescope & High-Energy Telescope*)
  electrons: 20keV to 30 MeV
  protons: 20 keV to 100 MeV
  heavy ions: 10 to 200 MeV/nuc
- **3 – Magnetometer**





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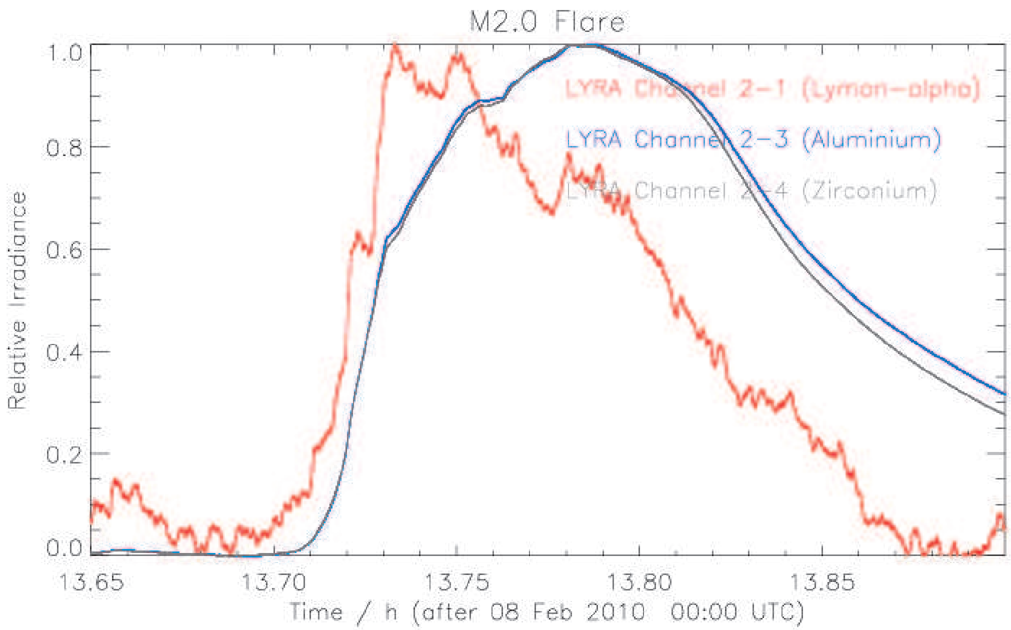
- **3** – Ultraviolet Solar Variability (Ly$\alpha$ & 180 –340 nm) and its influence on climate

# Ly$\alpha$ for Early Predictions and Onset Observations of Major Flares and CMEs

Lyman-Alpha, formed in the high chromosphere, at the most important chromosphere-corona interface, follows and localizes sources of activity /magnetic field structuring; it is the ideal tool for the detection and prediction of major flares & CMEs

- Lyman-Alpha is very sensitive to flare (rises slightly before GOES, Al or Zirconium filters of PROBA-2)
- It is also **1000 times** more powerful than H$\alpha$ for instance, visible easily on the integrated solar flux (LYRA/PROBA-2): excess of **0.5 to 0.7%** or more (M2 Flare)! Huge!




LYRA/PROBA-2 February 8 2010 M2 Flare excess (Kretzschmar et al., 2012)

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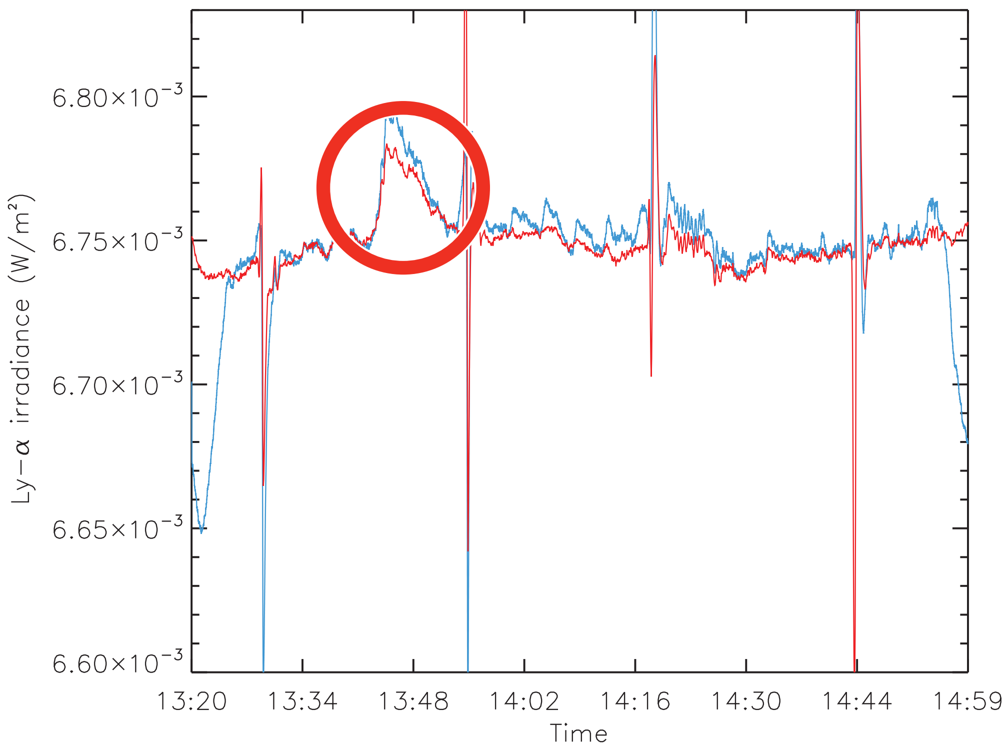



LYRA/PROBA-2 February 8 2010 M2 Flare excess (Kretzschmar et al., 2012)

# Predicting and Monitoring Large Flares & CMEs: Ly$\alpha$ better than X-ray

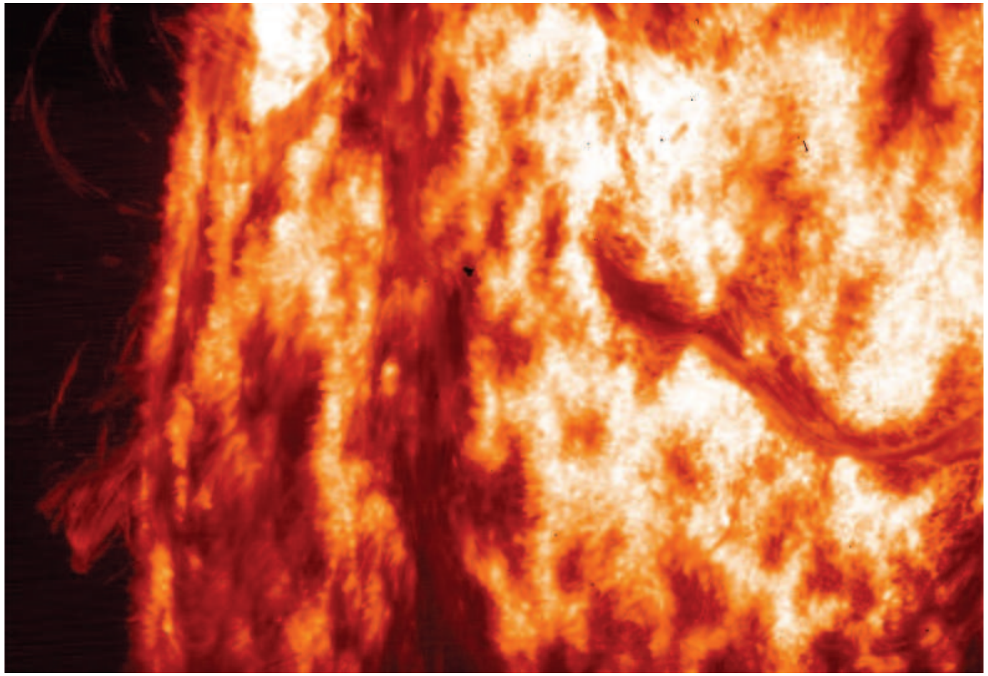
First objective is to **monitor flares** in Lyman-Alpha since as sensitive than X-ray or XUV.

Second objective, since HI Lyman-Alpha (121.6 nm), much alike H-Alpha, possesses high visibility to identify and track filaments and emerging bipolar region, is to develop excellent flares/CMEs **precursor indicators**, a space weather direct application.

Third objective is, when comparing sensitivity differences between **Lyman-Alpha and H-Alpha**, formed slightly below in the chromosphere, to develop better and **more robust flare/CME indicators** (early – several hours before – probability of major flares/CMEs) that may even restrict/allow to anticipate on the **CMEs' direction**.

# Ly$\alpha$ for the Early Predictions of Major Flares and CMEs

- Filaments and emerging bipolar region (the two major flare's precursors) are EXTREMELLY well seen in H-Alpha and in Lyman-Alpha allowing their detection, monitoring and tracking for an **earlier prediction of large flares** happening (the only ones leading to the Space Weather annoying Interplanetary Coronal Mass Ejections, ICMEs, the ones towards the Earth)
- This requires a good **imaging telescope at Lyman-Alpha** what no current satellite program has. The He II 304 Å line of SDO is not an appropriate substitute (much lower contrast)



High resolution image of the Sun in **Lyman-Alpha** taken by the VAULT rocket program of NRL and nicely showing prominences and filaments (prominences seen in absorption on the disc)

# Evidence for Twisted Flux Rope/ Filament before a Major Eruption

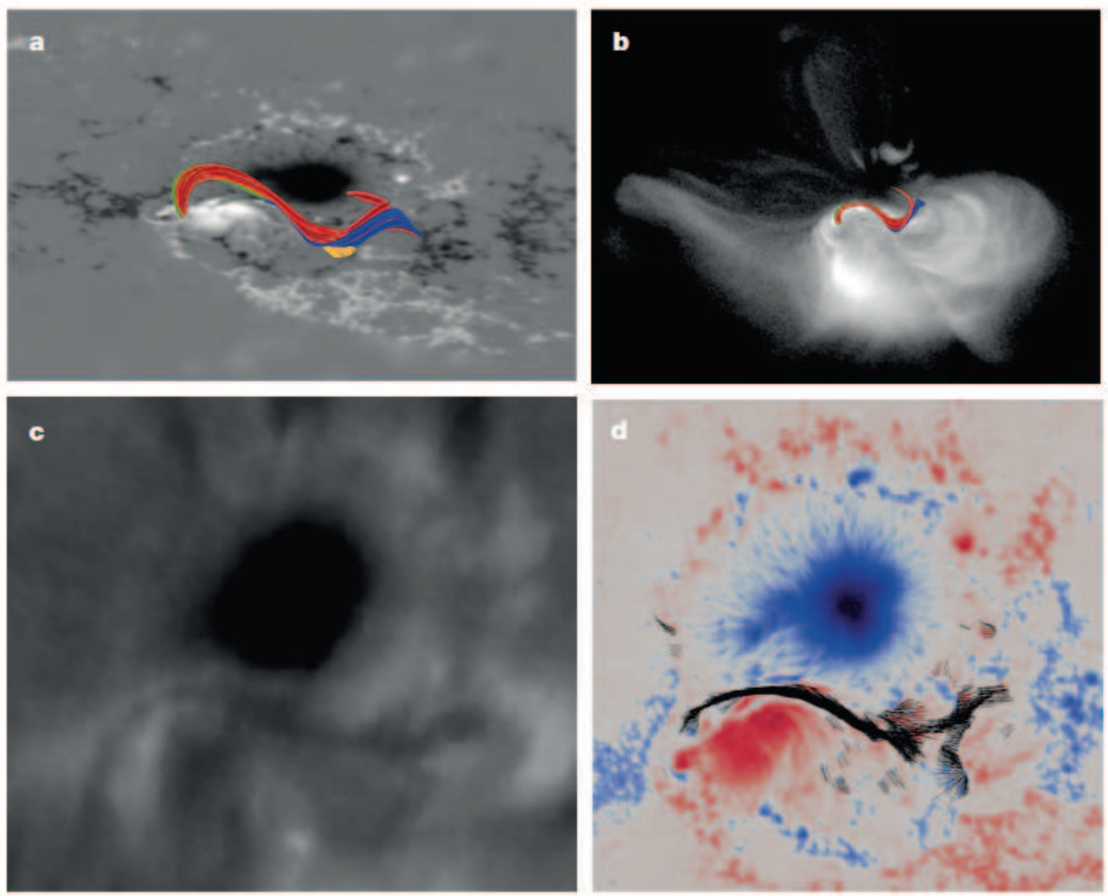
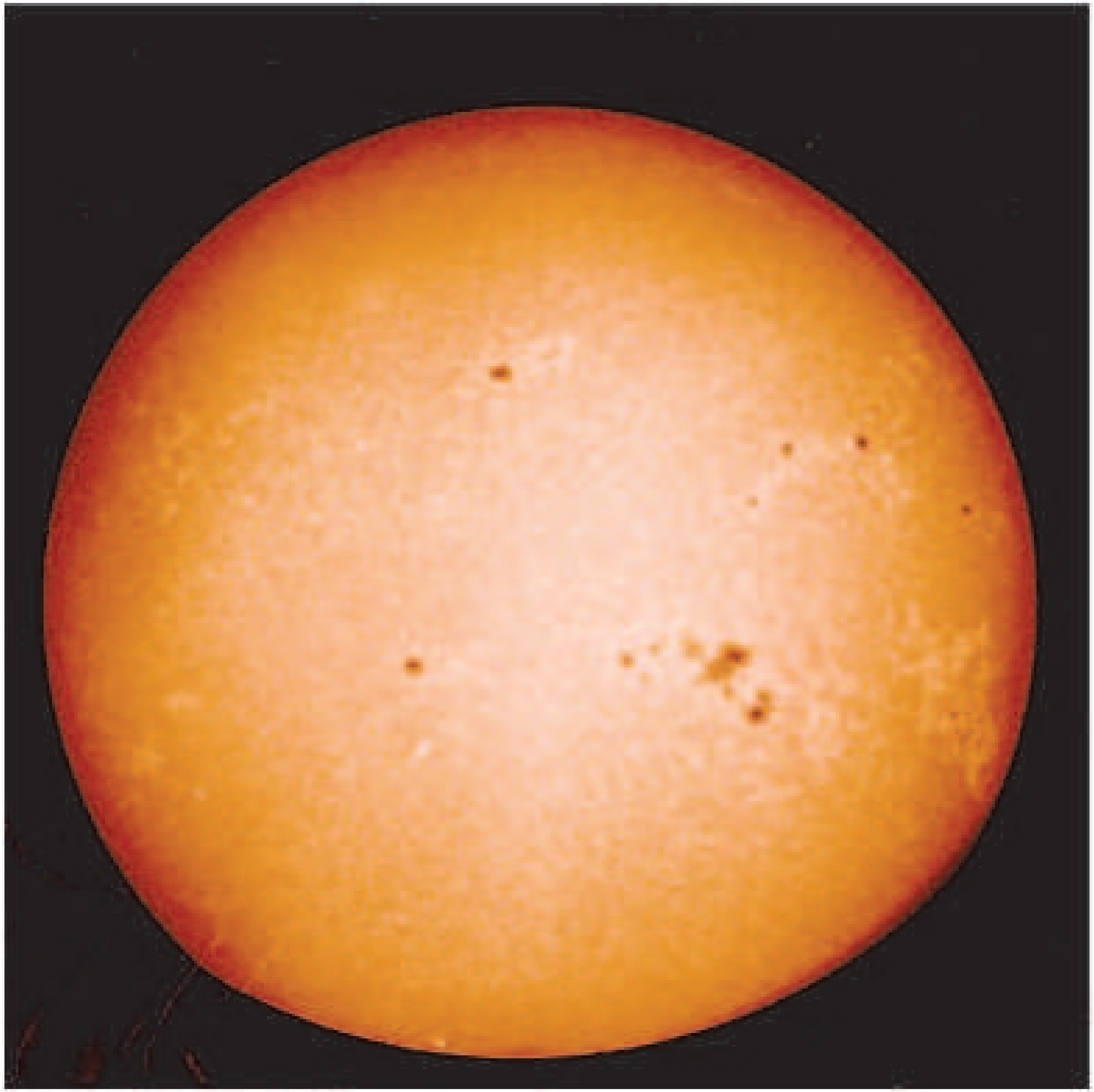



**Figure 2 | Twisted flux rope before the major eruption.** Selected field lines of the reconstructed magnetic configuration of December 12, 20:30 UT (D−1), with the same colour code as in Fig. 1. **a**, A large rope consisting of several components sits between the two spots and is seen to have accumulated a large amount of twist (about 2.25π). The hyperbolic nature of the rope (field lines bifurcating with an X-type topology) is detailed in Extended Data Fig. 2. **b**, Good agreement of the shape of some computed field lines with X-ray data from Hinode/XRT. **c**, Hα data from the spectroheliograph at the Paris-Meudon Observatory reveals that a filament (darker) extends in the atmosphere between the two spots. **d**, The filament shown in **c** coincides with the locations of the dips in the computed magnetic field (shown as black segments and seen from the same vantage point as in **c**) where cool material can sit and be supported against gravity by the magnetic force.

c) Hα data from Paris-Meudon Observatory showing filament twisted

Tahar Amari et al., Nature, Oct. 2014

# Herzberg Continuum 220 nm



TRC 3 Rocket Flight
1982 July 13

# Scientific Objectives

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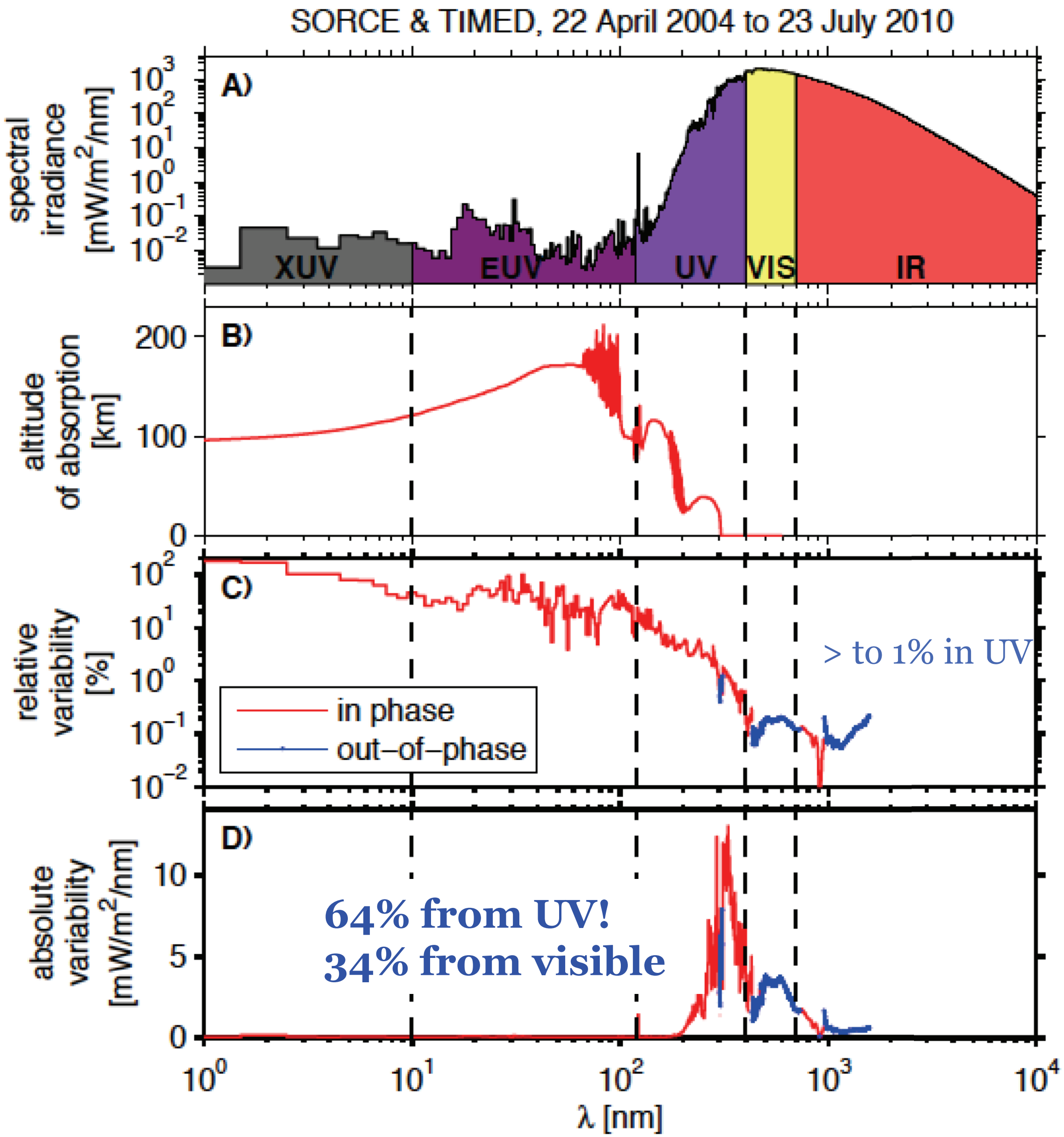
# Variability *influence* is in the UV!




*Solar spectrum*

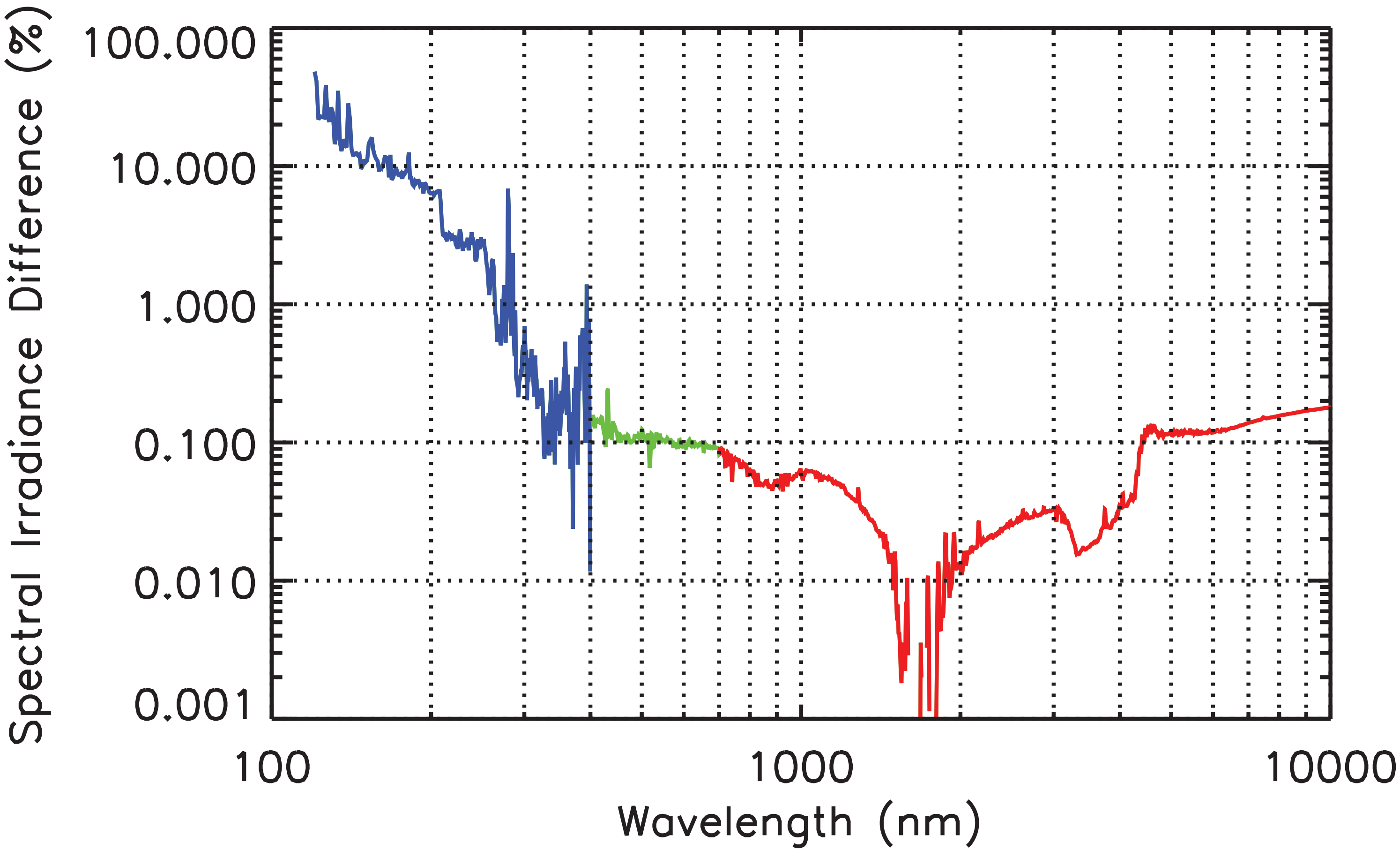
*Absorption altitude*

***Relative variability***

***ABSOLUTE VARIABILITY over solar cycle***

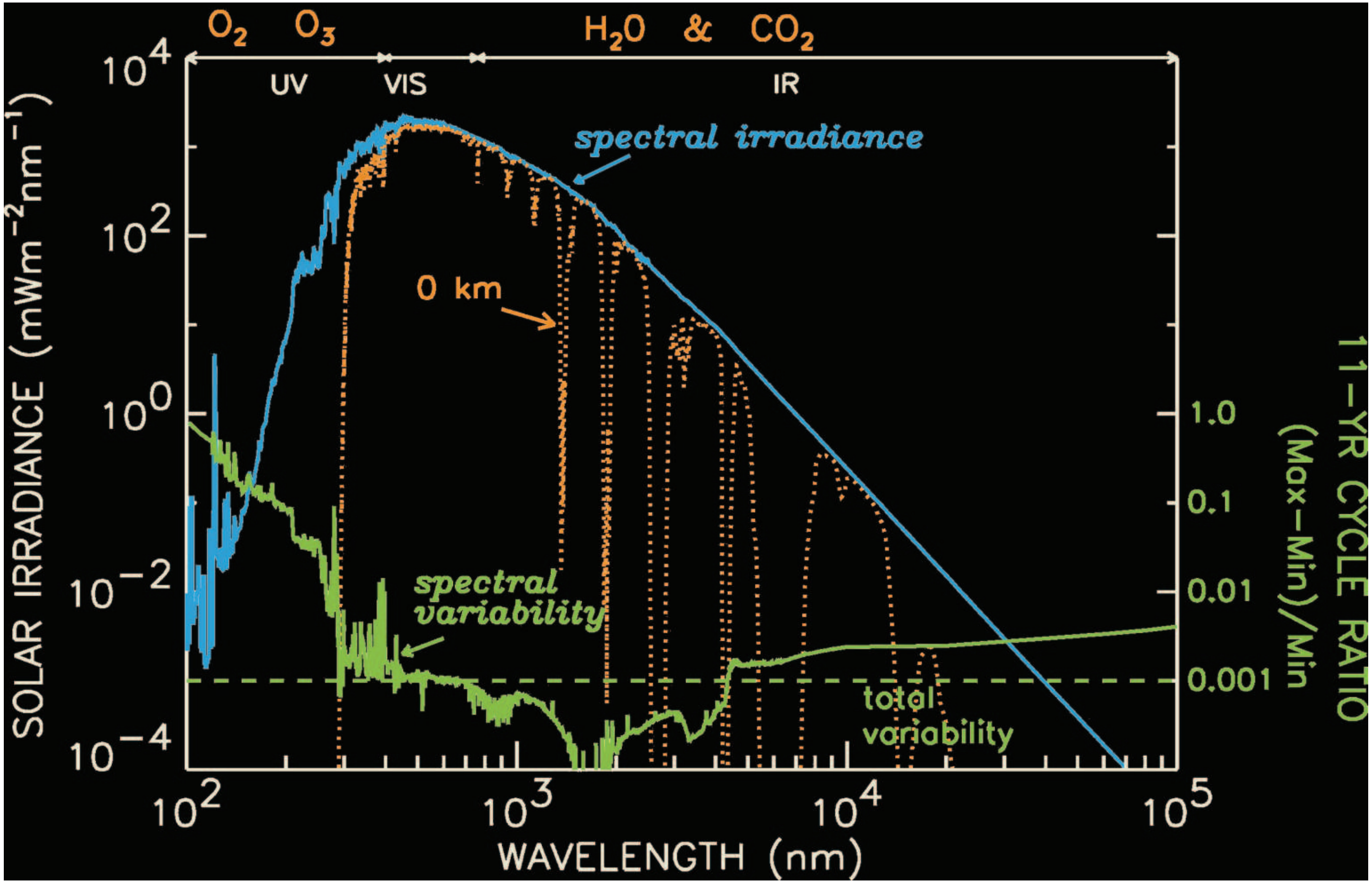
***Ermolli, et al. (2013)***

# Spectral Solar Irradiance (SSI): SMax vs. SMin

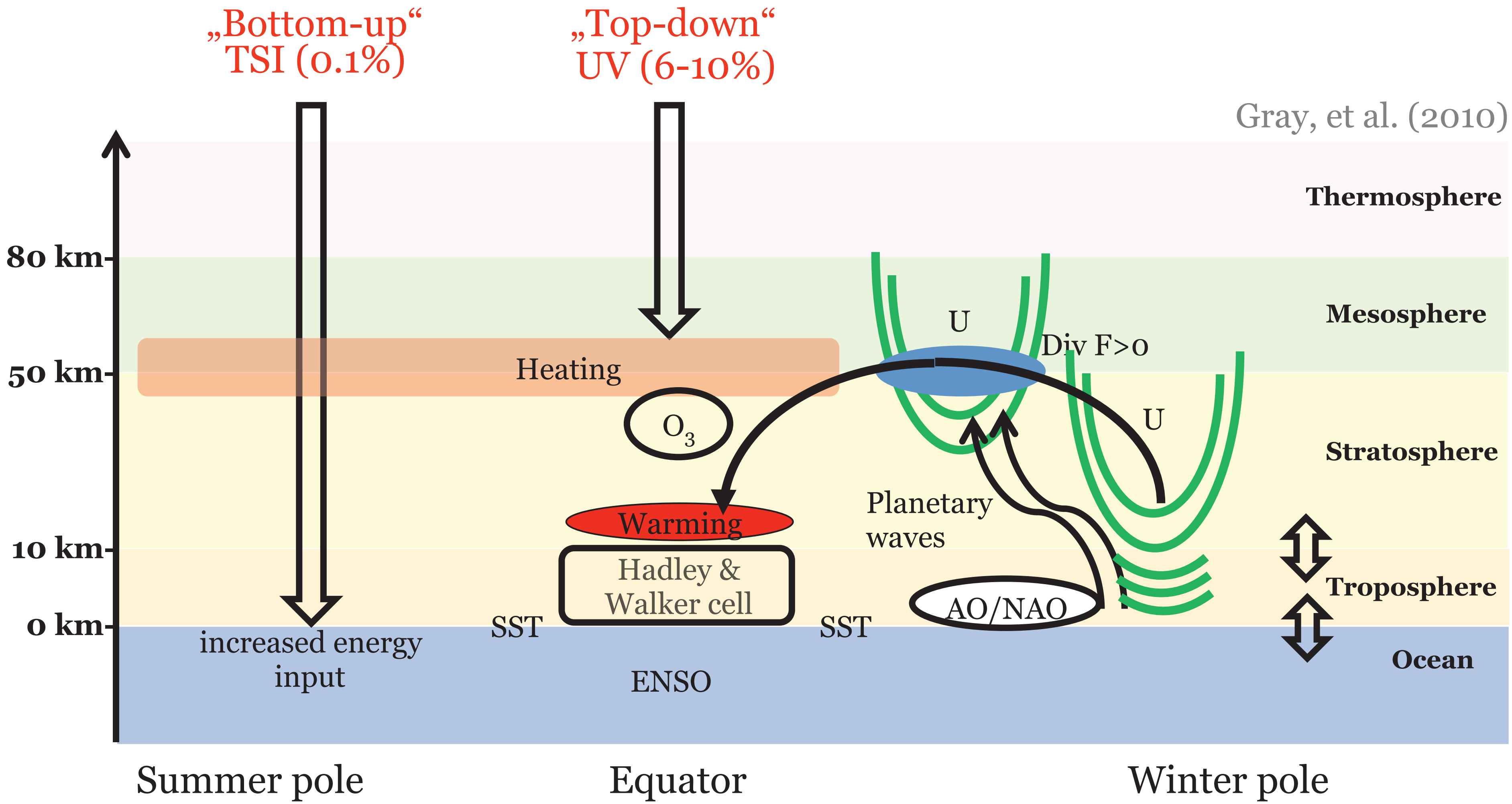



**Very small variations in the visible (0.1%) or IR,**
**but big changes in the MUV & FUV (5 to 60%)**

# Solar Variability (Activity Sources) Drives Spectral Irradiance Variations



# Influences of Solar Variability on Climate: the "Top-down" mechanism

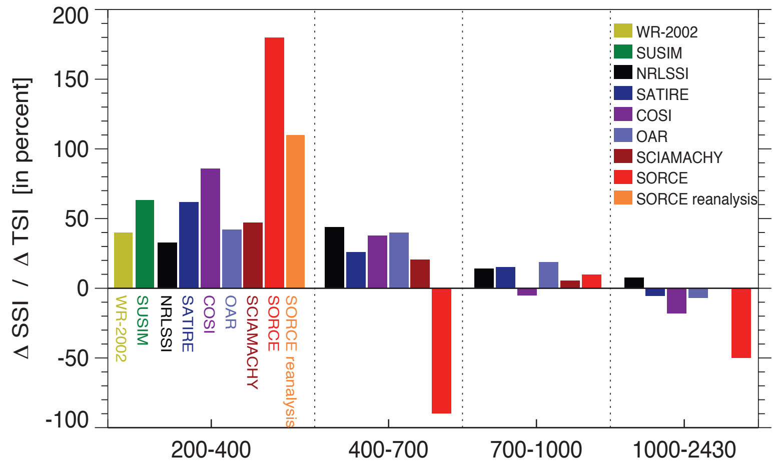


# Measurement Needs

Increasing evidences that solar variability influences the regional climate decadal variability through stratospheric pathway

What do we need to capture the solar signal?

- **Sufficiently high resolution** of the radiative scheme in the UV range (Nissen et al., 2007, Foster et al., 2011)
- **Interactive ozone chemistry** (or a good stratospheric ozone parameterization)
- **Reduce SSI uncertainty**

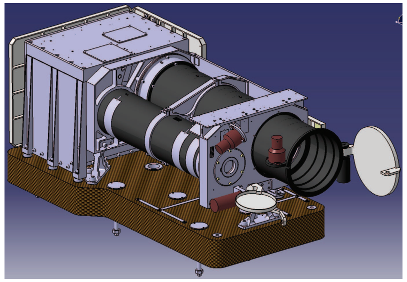



*Ermolli, et al. (2013)*

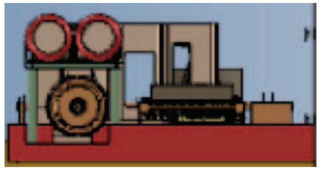
➢ next step: proper input for climate modelling, CCMI, CMIP6 (new SolarMIP initiative, K. Matthes, B. Funke), etc.

LATMOS · Institut Pierre Simon Laplace · cnrs · Université de Versailles St-Quentin-en-Yvelines

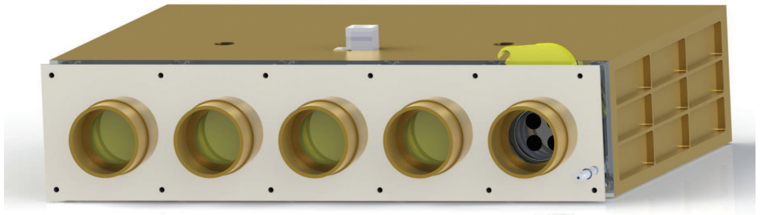
# SUITS Model Payload
# Space Weather, FUV, MUV & Climate



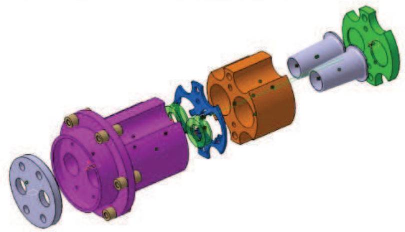
**1 –** FUV imaging Ly$\alpha$ & 200-220 nm: **SUAVE** (*Solar Ultraviolet Advanced Variability Experiment*)



**2 –** Solar Spectral Irradiance 170-340 nm (Atm. modeling – res. ~0.65 nm): **SOLSIM** (*SOLar Spectral Irradiance Monitor*)



**3 –** Solar radiometers at Ly$\alpha$, Herzberg 200-220 nm, CN, MgII, 340-400 nm by Δ20nm: **SUPR** (*Solar Ultraviolet Passband Radiometer*)



**4 –** **ERBO** (*Earth Radiative Budget & Ozone*)

**5 –** Other Space Weather instrumentation

# **SOLSIM** (***SOLar Spectral Irradiance Monitor***)

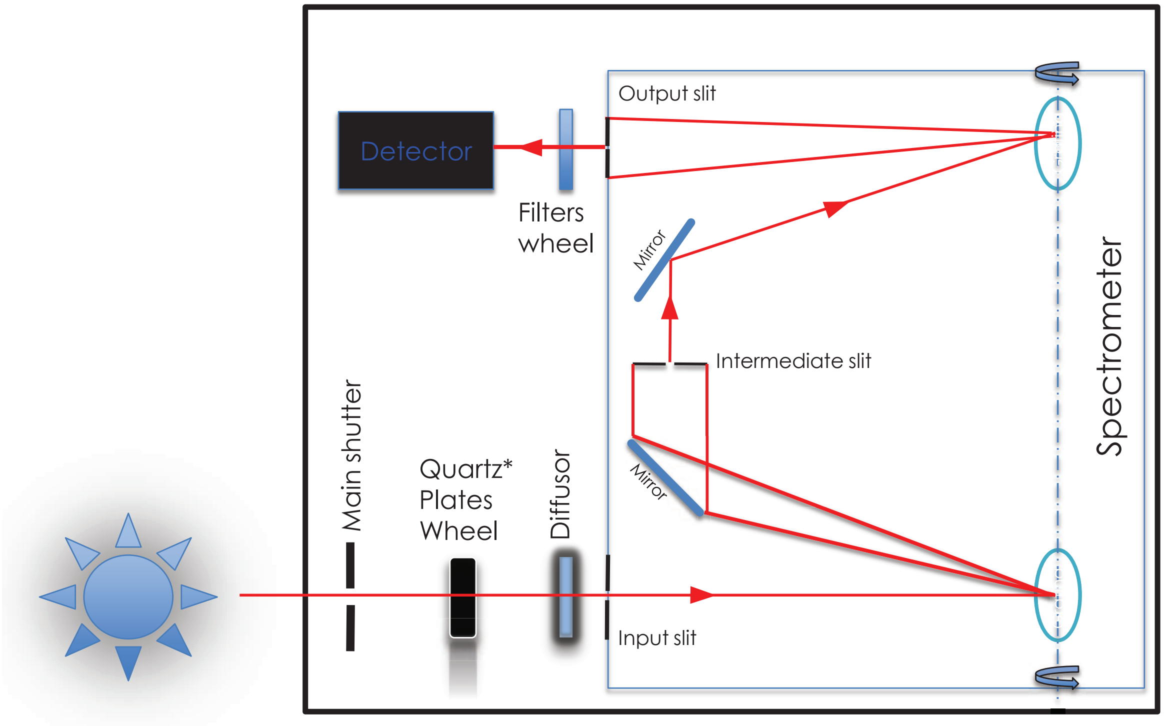
*A UV spectrometer (in the ozone production bands) with a reasonable spectral resolution is essential for the chemistry modeling of the Earth atmosphere*

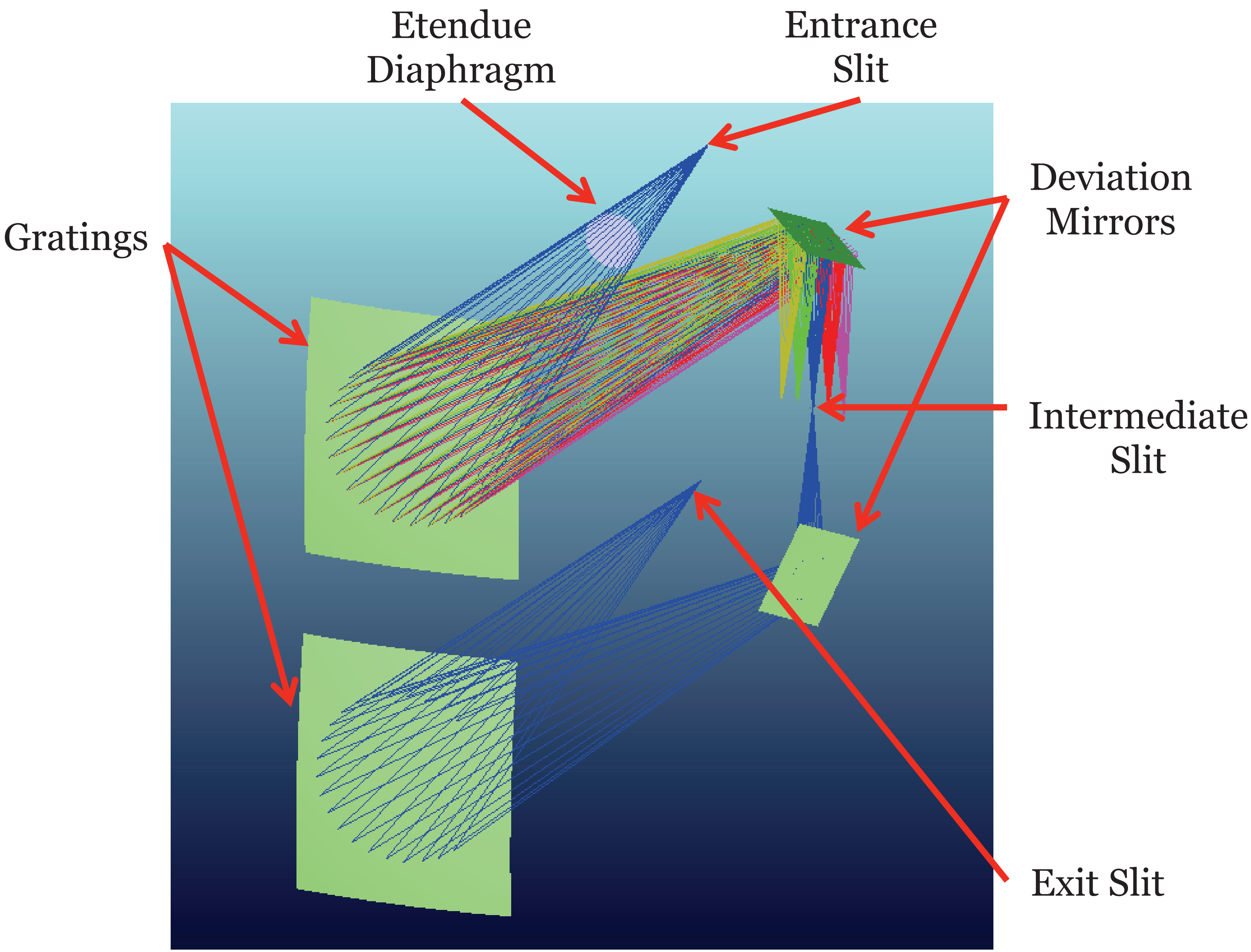
Experience at LATMOS and IASB (SOLSPEC experiment)

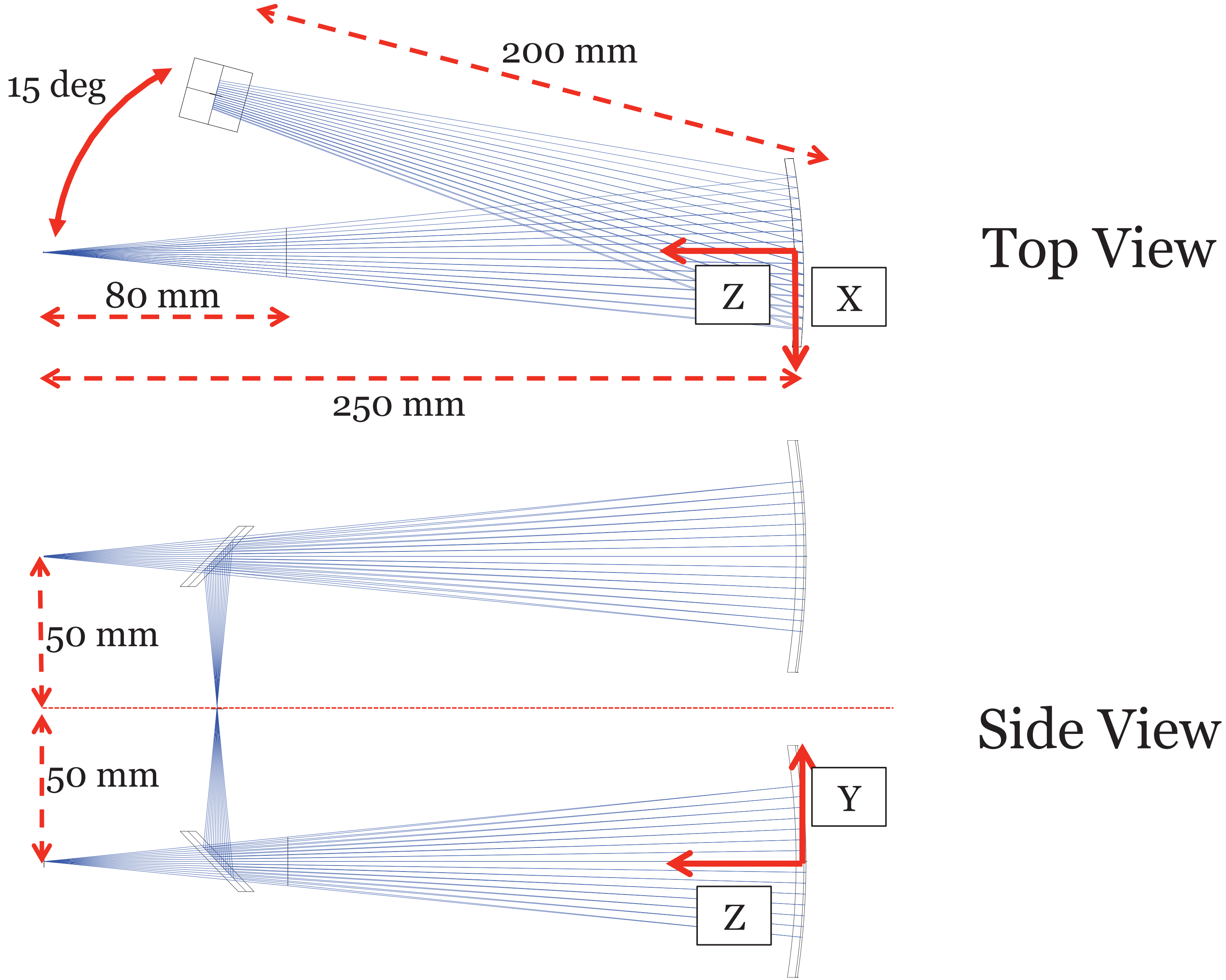
Expertise also of LPC2E Orléans

Design along **SOLSPEC** (UV channel only: 2 gratings)

| | |
|---|---|
| Weight | < 8 kg |
| Wavelength Range | 170-340 nm |
| Spectral Resolution | ~0.65 nm |




Etendue Diaphragm
Entrance Slit
Deviation Mirrors
Gratings
Intermediate Slit
Exit Slit


200 mm
15 deg
80 mm
Z
X
250 mm
Top View
50 mm
50 mm
Y
Z
Side View

**3 Slits**

- Entrance Slit : 4 mm × 0.2 mm
- Intermediate Slit : 4.2 mm × 0.21 mm
- Exit Slit : 4.4 mm × 0.3 mm

**Diaphragm**

- F/5 beam
- Diameter : 16 mm
- Position : 80 mm form Entrance Slit

**2 Deviation Mirrors M1 & M2**

- Flat Mirrors
- 90 degrees deviation
- Dimension : 20 mm × 28 mm
- Position M1 : 200 mm from Grating G1
- Position M2 : 50 mm from Intermediate Slit

**2 Gratings G1 & G2**

- Strictly identical gratings
- Toroidal holographic gratings
- 2000 gr/mm
- Curvatures : 255.676 mm & 245.403 mm
- Position G1 : 250 mm from Entrance Slit
- Position G2 : 200 mm from Deviation Mirror M2
- Dimensions : (X) 62 mm × (Y) 76 mm

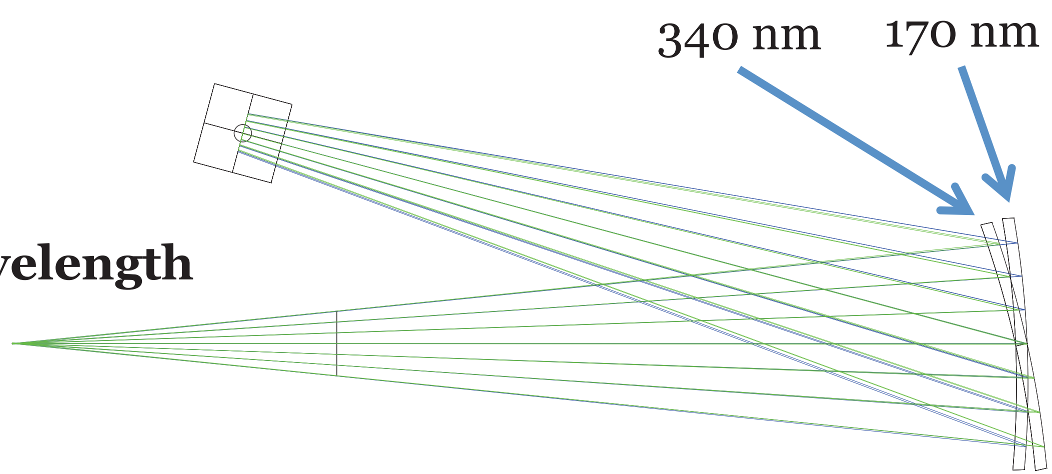
**Holographic parameters**

- Construction wavelength = 488 nm
- Construction Points Coordinates (relative to Grating reference frame) :

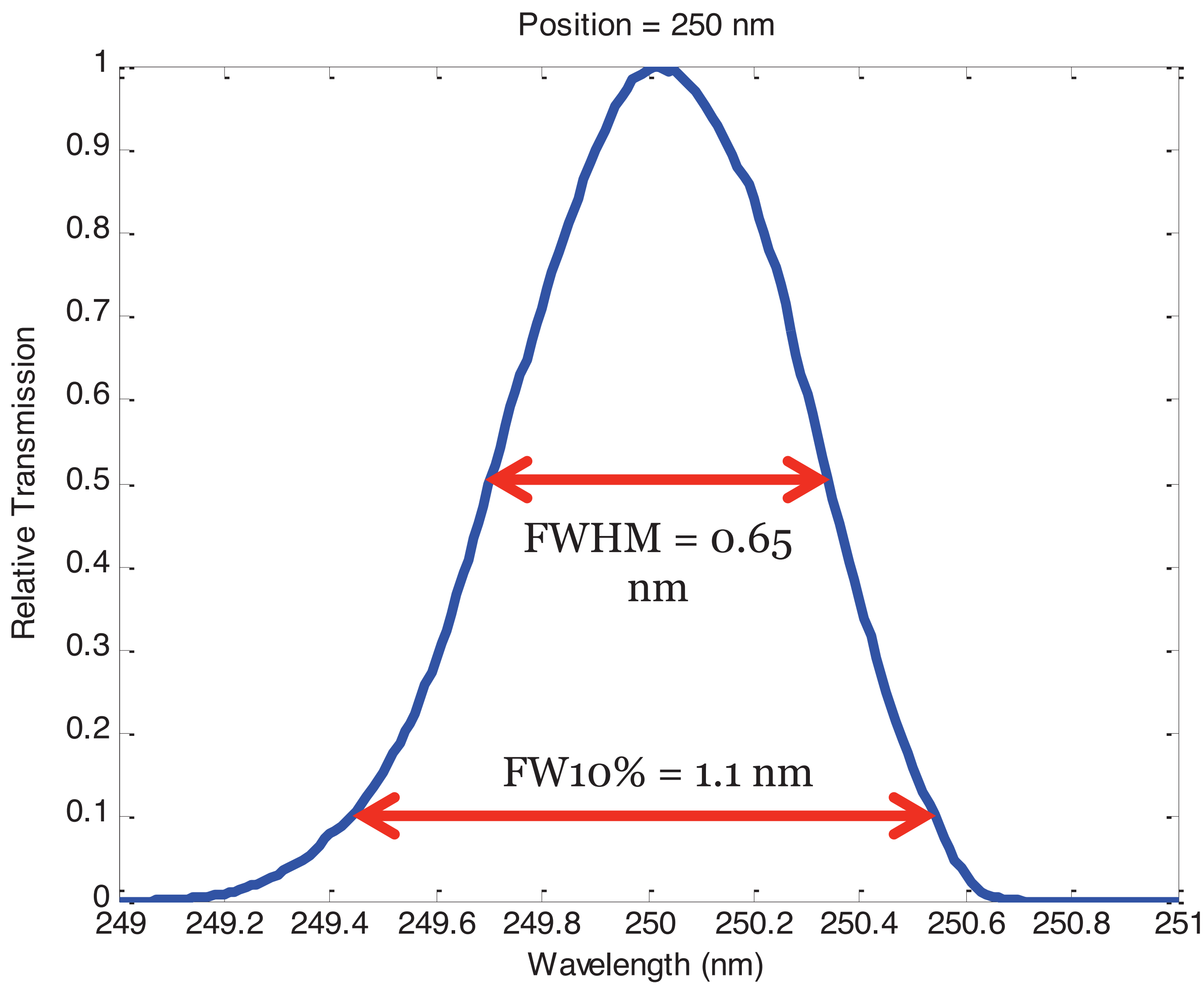
  X1 = -30.417 mm
  Z1 = +274.971 mm
  X2 = +324.100 mm
  Z2 = +187.095 mm

**Beam incidence angles vs wavelength**

- $\lambda$ = 170 nm ⇒ $\theta$ = 2.379 deg
- $\lambda$ = 340 nm ⇒ $\theta$ = 12.566 deg



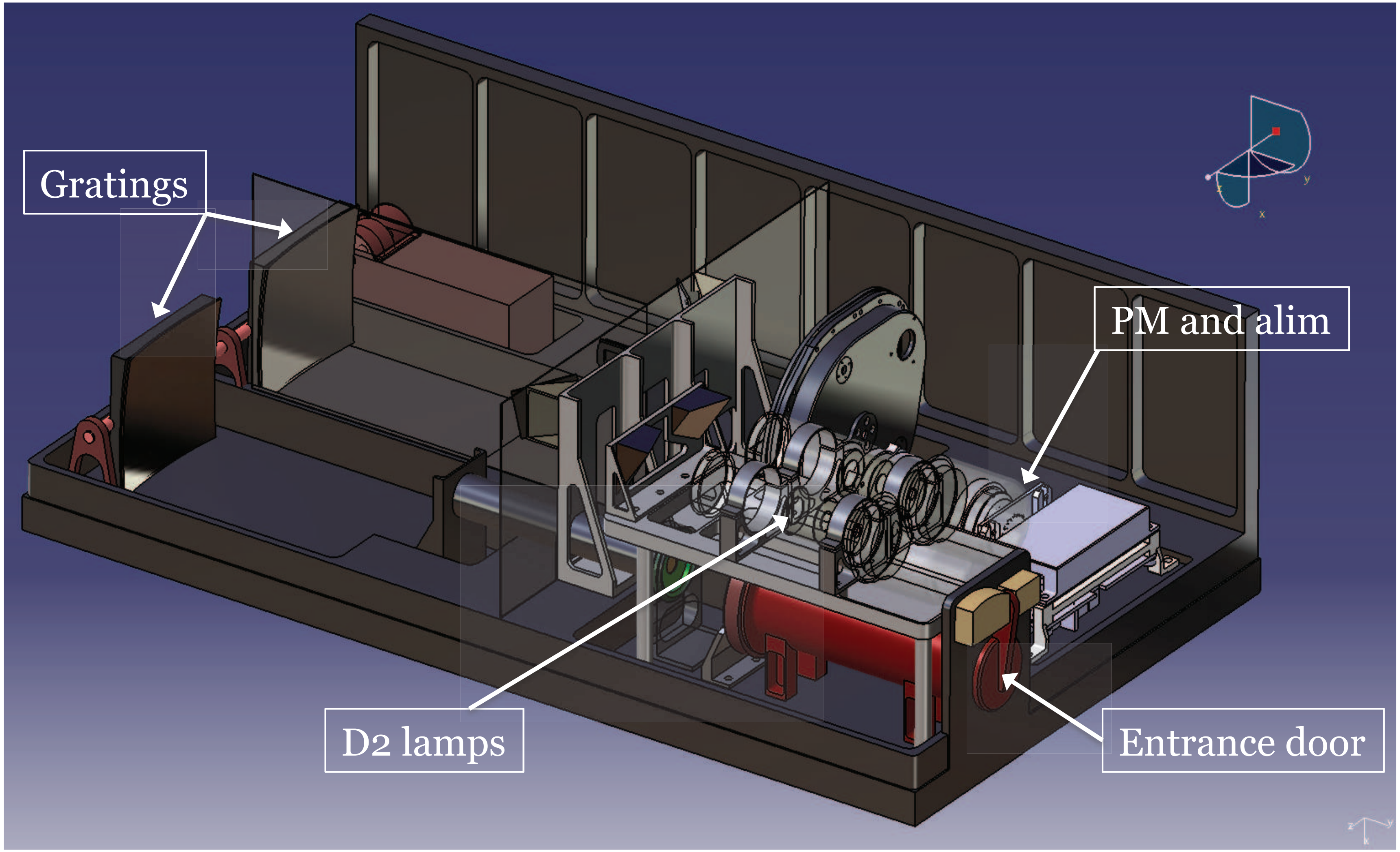
# Spectral Resolution



# Design Heritage

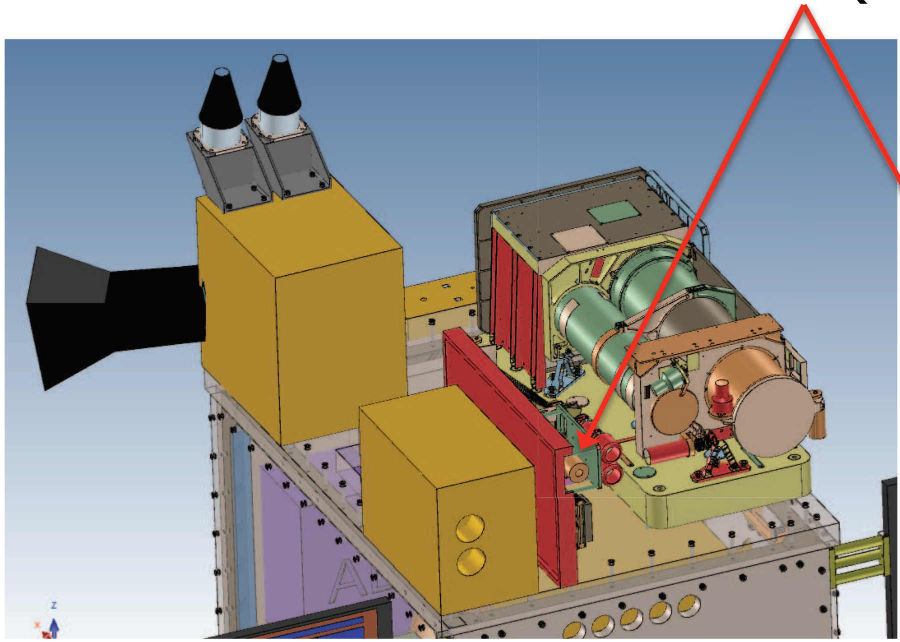
SOLSIM will use the same D2 lamps (left) than the SOLAR/SOLSPEC experiment, and also with relay mirrors (right). Disposition will be slightly different (lamps aligned) in new set-up

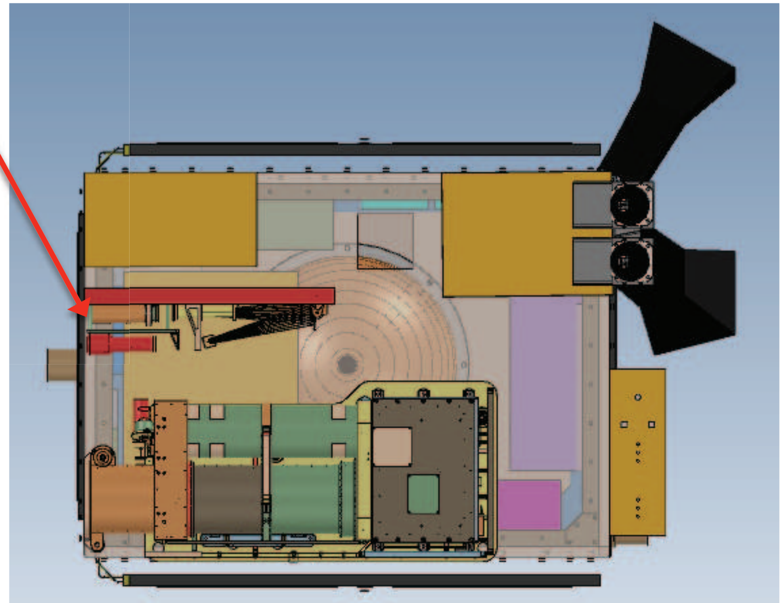
# Preliminary Mechanical Implementation



# Preliminary Mechanical Implementation on SUITS

Vertical accommodation (entrance on top)





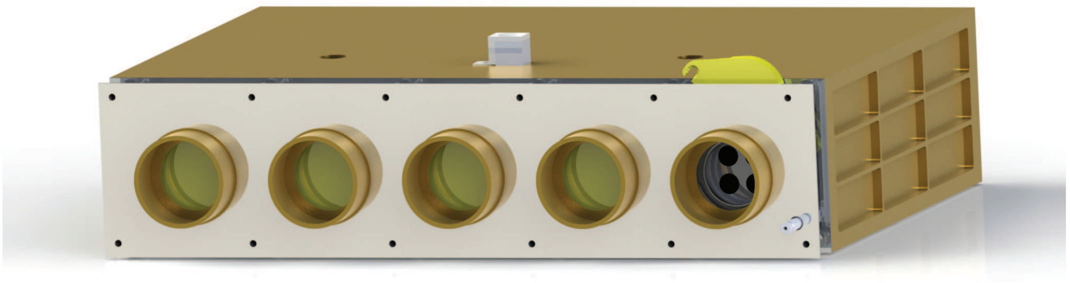
# SUPR Filter Radiometers FUV, MUV & UV: "extending LYRA"

Absolute variability is measured at Lyman-Alpha, Herzberg continuum and CN bandhead; we implement 20 channels (5 heads) with large redundancy:

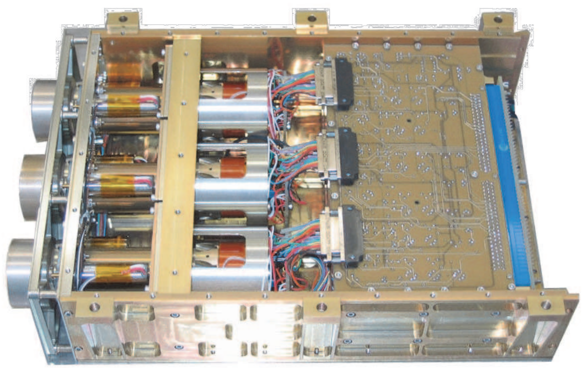
- 5 at Lyman Alpha 121.6 nm (3 at different rates)
- 5 at Herzberg continuum 200–220 nm
- CN bandhead 385–390 nm; Mg II; 340-400 nm by 20 nm

The 121.6 and 200–220 nm channels support imaging modes of SUAVE.

Mass < 5.7 kg; 0.16 Gbit/day



*5 heads of reduced length compared to LYRA (see below)*

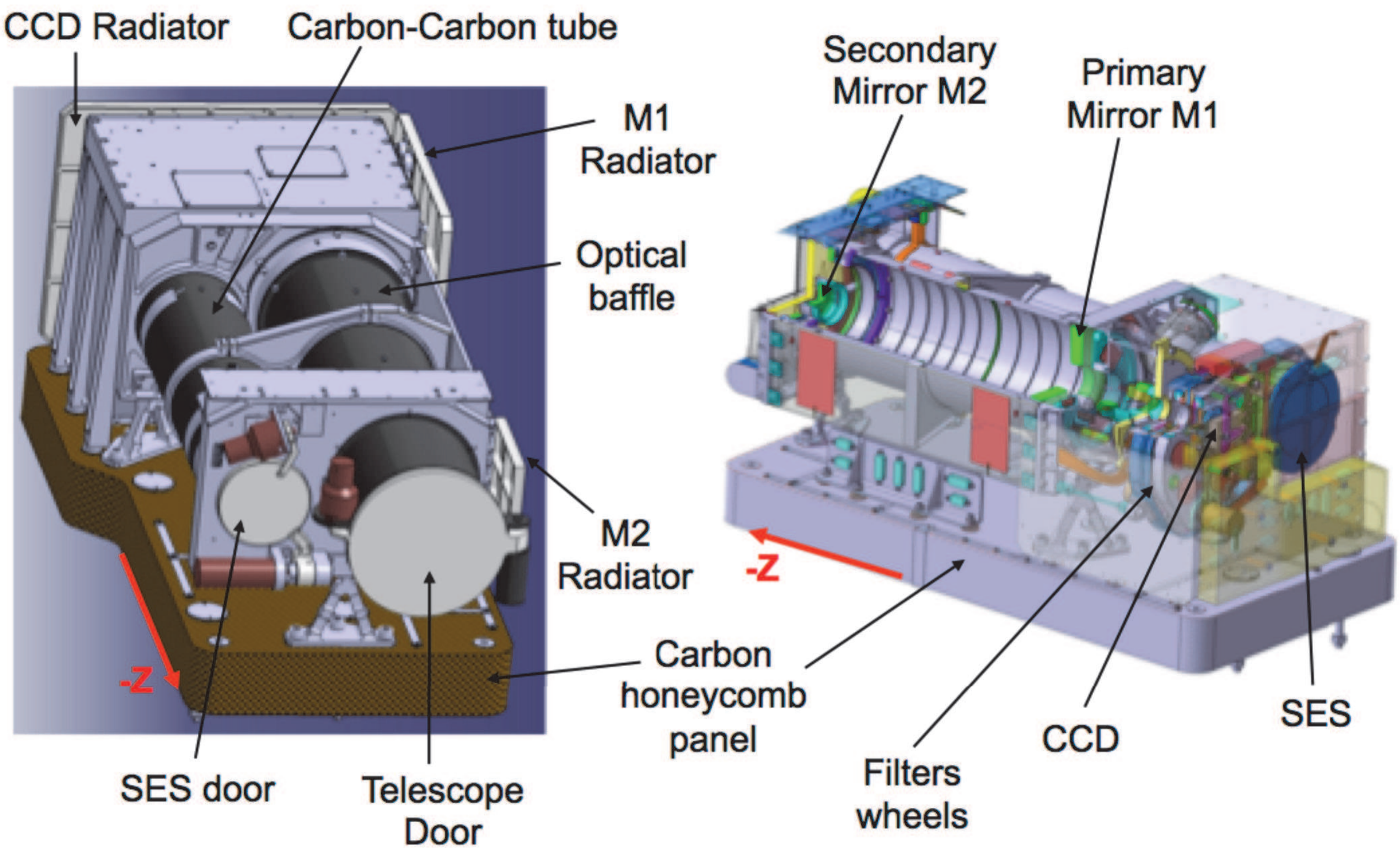


*LYRA on PROBA-2*

# SUAVE (*Solar Ultraviolet Advanced Variability Experiment*)

# FUV Imaging Telescope (evolution & optimization of SODISM):

## no window, SiC mirrors & new "thermal" door and radiators

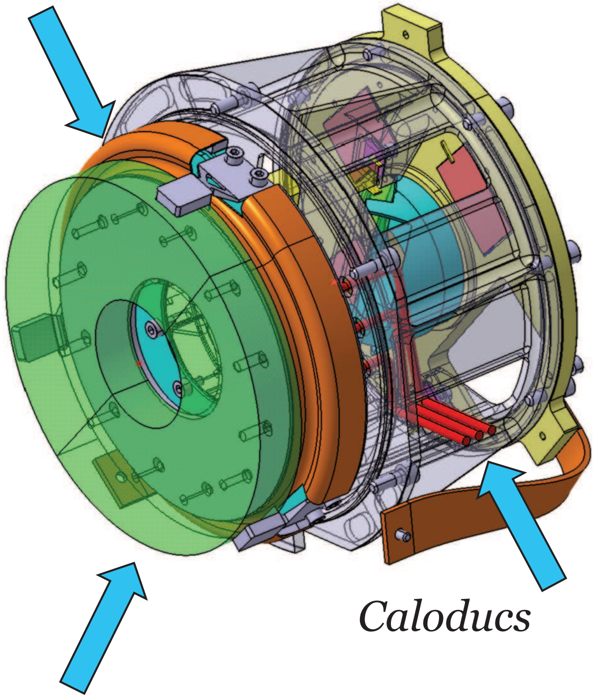


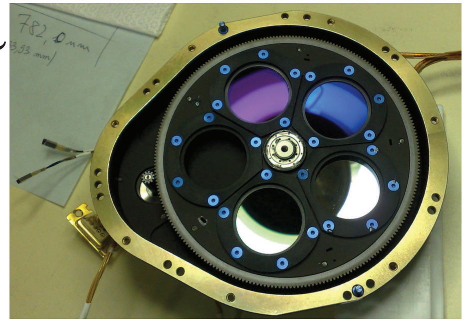

New design thermally optimized of the SUAVE telescope (left) compared to the SODISM/PICARD one (right)

# New SiC Mirrors: FUV duty cycle

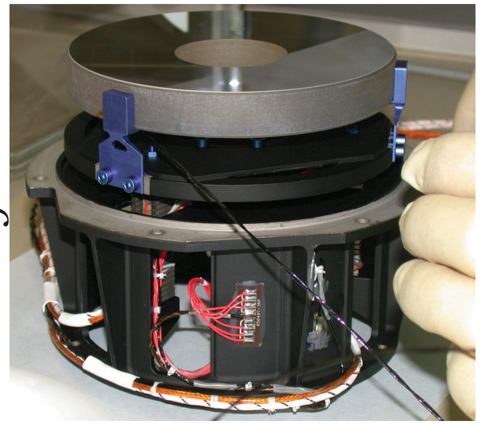
**Unique properties**:

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



*Filters wheel (x2)*



*M1 integrated*

***R&T CNES 2014-16: realization of a representative optical and thermal breadboard of SUAVE SiC mirrors and supports (primary and secondary)***

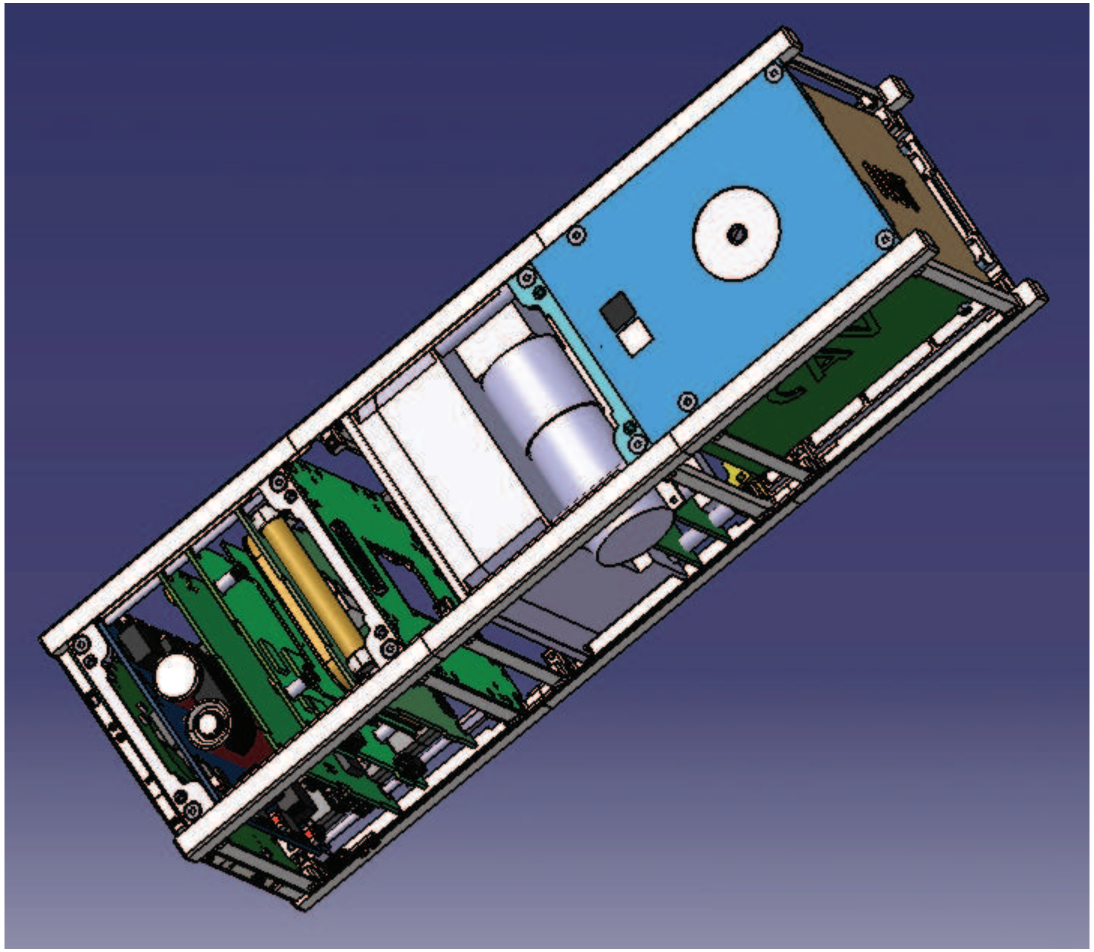
# ERBO (Earth Radiative Budget & Ozone)

*To evidence the direct link between the solar UV variability and the Earth consequences*

**ERBO is two-fold:**

- **SERB-OS reduced to 6 wavelengths:** 273, 283, 292, 302, 312, 331 nm
- **SERB-ER using SIMBA** (Sun-Earth IMBAlance radio-meter) 0.1-100 µm (ESA Nanosat demonstration launch in 2016)

2U or 3U instrument NADIR pointed (2 kg; 2 W maximum)



Artist view of the SIMBA/ESA nanosatellite soon to be launched (2016)

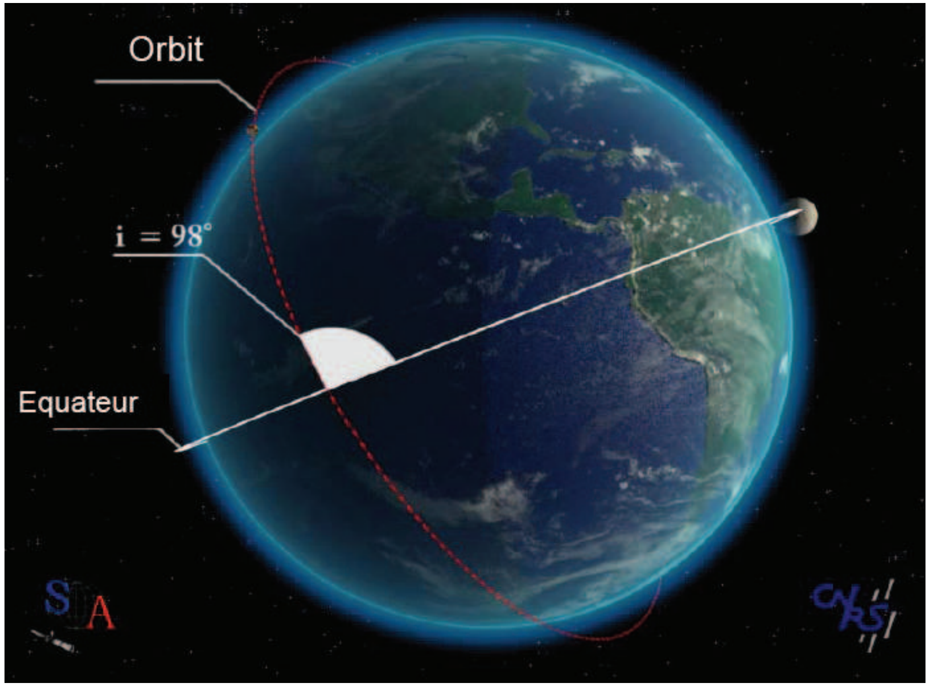
# Instruments’ Characteristics

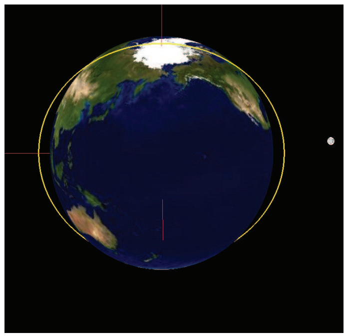
| Instrument | Mass (kg) | Power (W) | Dimensions (L W H, mm) | Telemetry (Gbits/day) |
|---|---|---|---|---|
| SUAVE<br>Electronics Box | 20<br>10 | 26 | 750 x 308 x 300<br>223 x 306 x 304 | 3 |
| HEBS | 14 | 16 | 310 x 170 x 230 | 2 |
| SOLSIM | 8 | 8 | 450 x 140 x 250 | 0.1 |
| SUPR | 5.7 | 6 | 315 x 350 x 92.5 | 0.16 |
| EPT-HET | 2 | 5 | 130 x 170 x 140 | kbps |
| ERBO | 2 | 2 | 100 x 100 x 200 | kbps |
| Magnetometer | 1 | 1.5 | (Electronics box?) | kbps |
| **TOTAL** | **62.7** | **64.5** | **~750 x 760 x 305** | **< 5.5** |

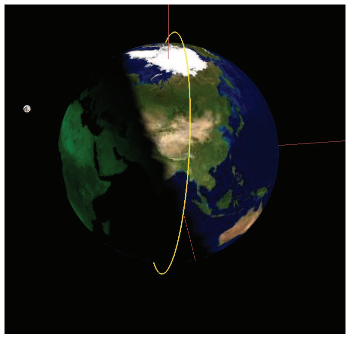
# A simple orbit choice for thermal stability

Orbit with "almost" permanent Sun viewing (much alike PICARD but 18h-06h):

- Sun synchronous orbit
- Ascending node: 18h00
- Altitude: **> 725 km**
- inclination:98.29°
- Eccentricity: $1.04 \times 10^{-3}$
- Argument of periapsis: 90°

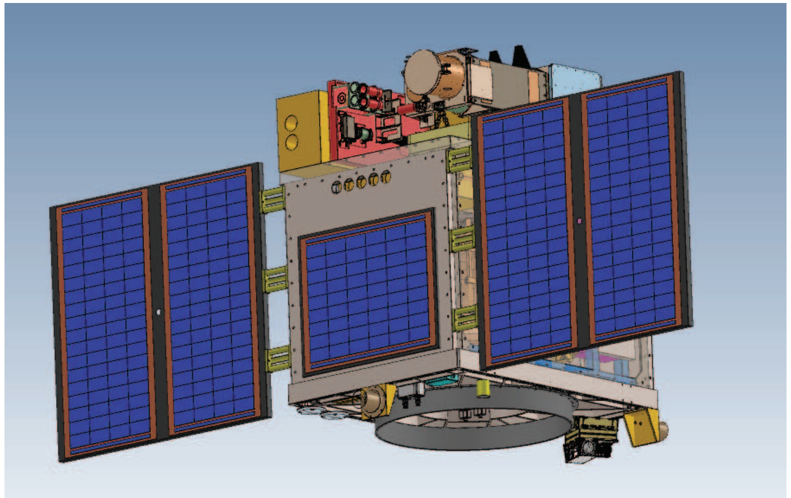


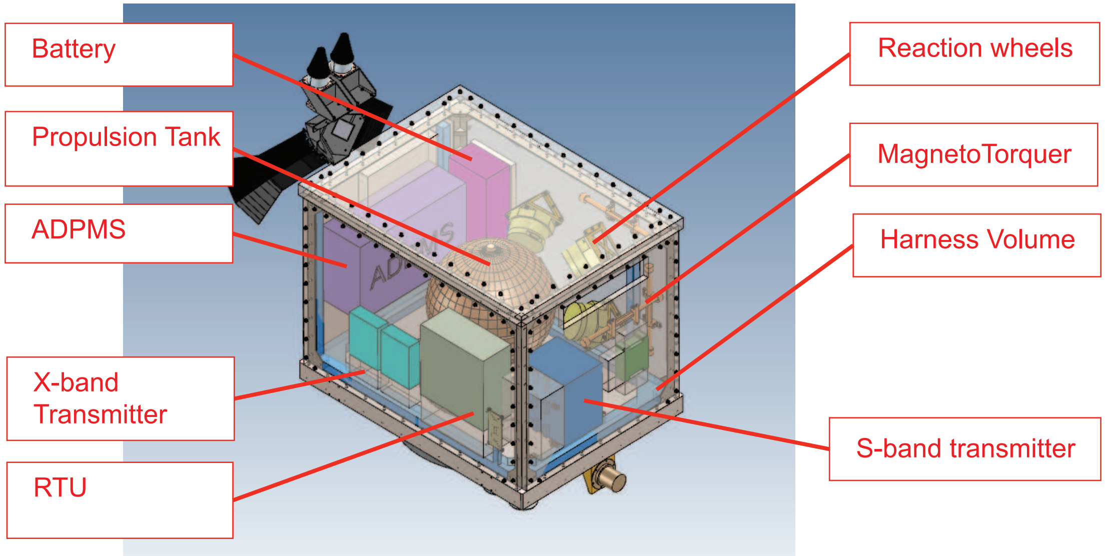





# New PROBA Platform from QinetiQ

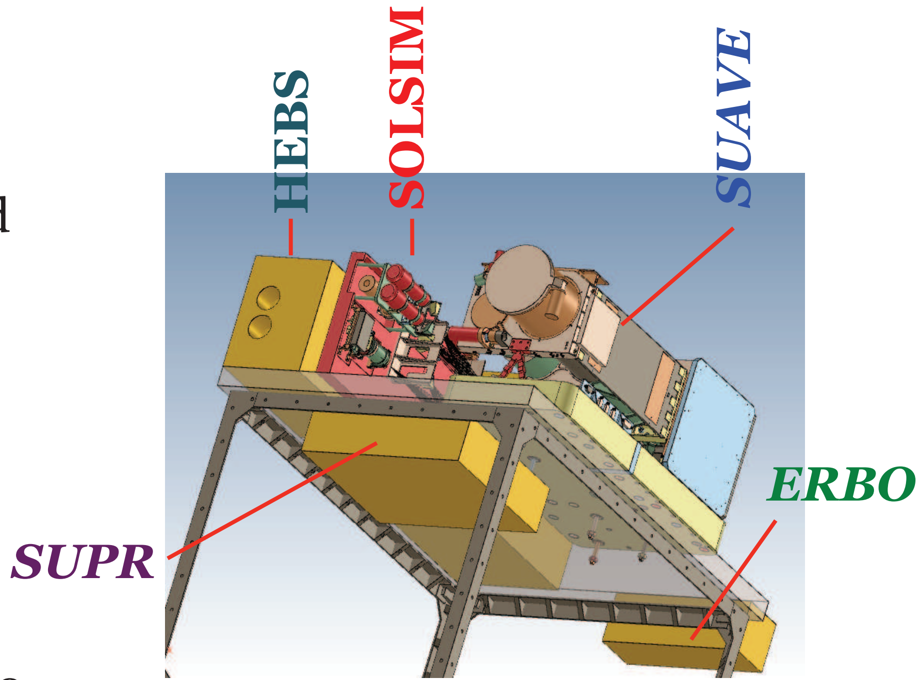
- ITAR Free
- Deorbiting compatible
- < 200 kg
- 694 x 946 mm top plate

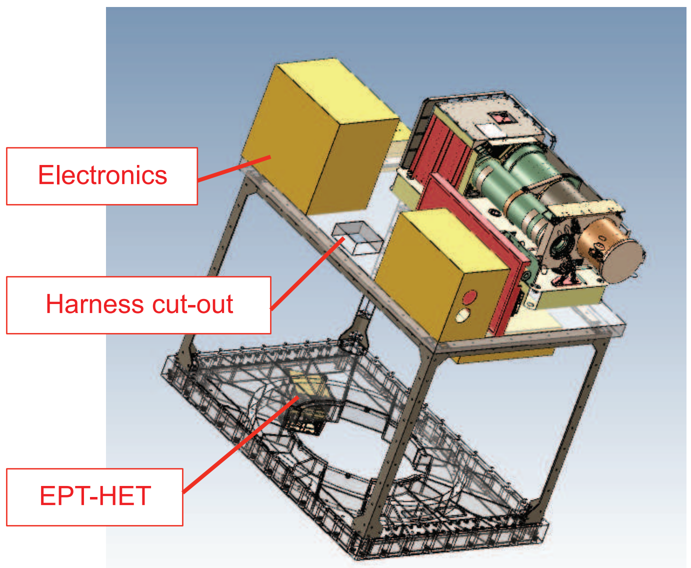




# SUITS/SWUSV PROBA Accommodation

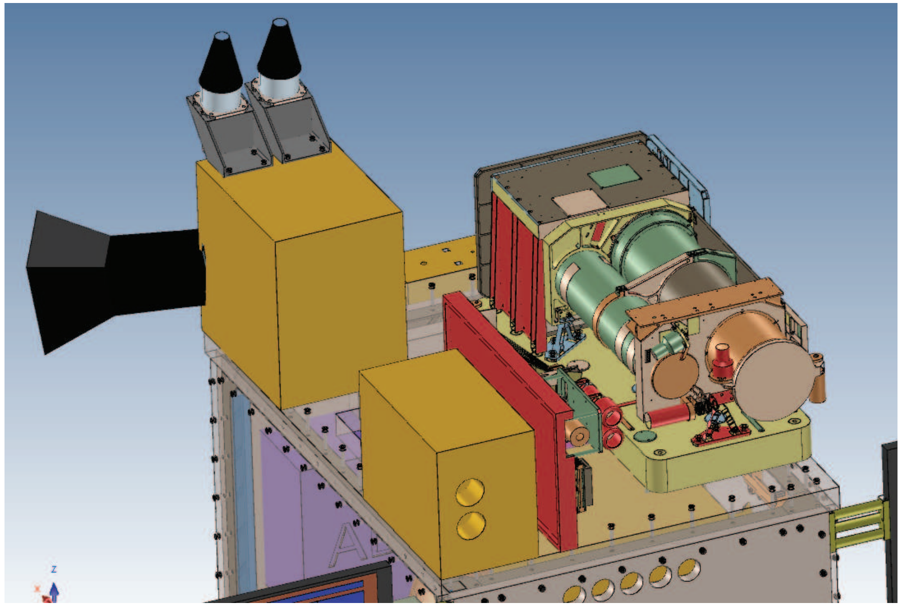
- **SUAVE** (*Solar Ultraviolet Advanced Variability Experiment*), Lyman-Alpha and 200-220 nm Herzberg continuum imaging with 3 redundant set of filters to preserve long-term sensitivity
- **SOLSIM** (*SOLar Spectral Irradiance Monitor*) 170-340 nm, spectral resolution 0.65 nm
- **HEBS** (*High Energy Burst Spectrometer*) hard X-rays & gamma-rays from 10 keV 600 MeV
- **SUPR** (*Solar Ultraviolet Passband Radiometers*) based on PREMOS & LYRA with 20 UV filter radiometers for Lyman-Alpha, Herzberg, CN bandhead (385-390 nm) and UV from 180 to 340 nm by 20 nm bandpasses

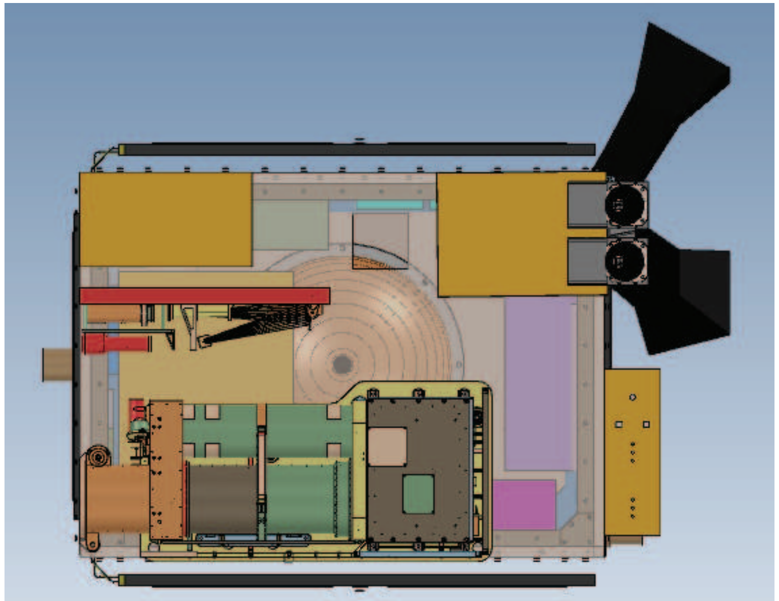


# SUITS Payload Accommodation

SUITS spacecraft payload panel (3D view and top view)



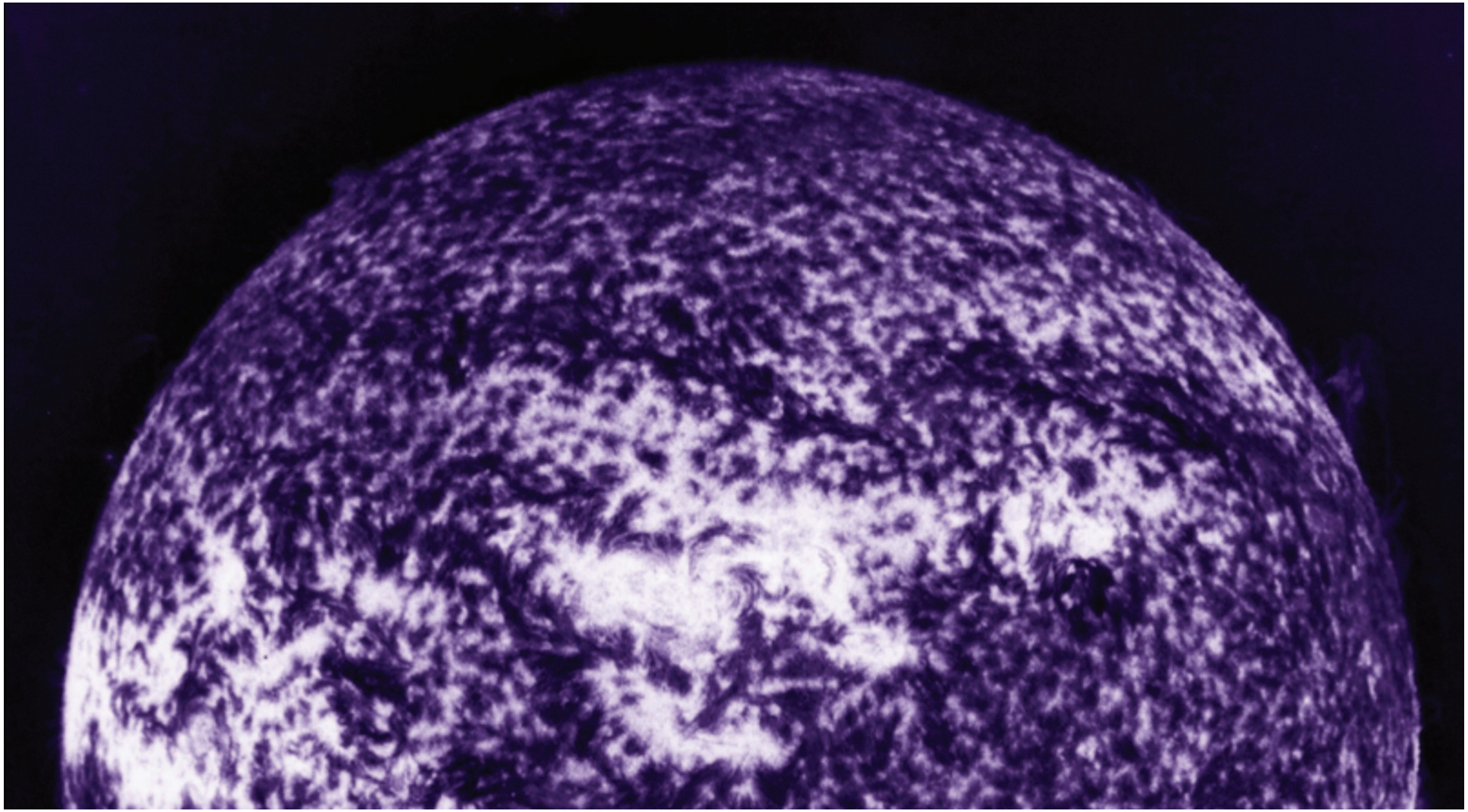


In stowed position, the SUITS/SWUSV (accounting antennae and star tracker) is 1183 (L) x 968 (W) x 1273 (H) $mm^3$

# Conclusion: Small Mission Readiness

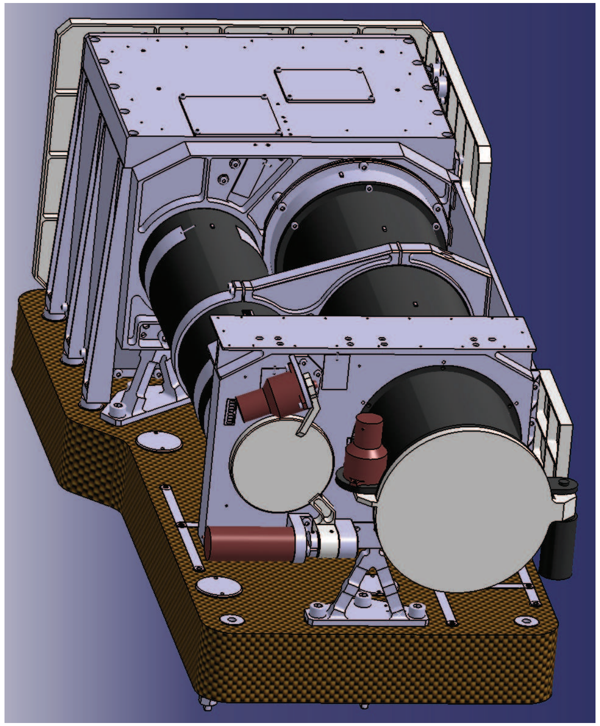
- Altogether, the SUITS P/L has:
  - a very complete science case with **4 unique assets** complementing (not addressed by) larger missions:
    - **Flare** physics at **high energy** and in **Lyman-Alpha**
    - **Prediction** and detection of **majors eruptions** and **CMEs**
    - **(F)UV** spectral measurements to determine local stratospheric **influence** mechanisms **on climate**
    - **Simultaneous** radiative budget with 1% in differential
  - a novel, innovating and yet very mature P/L with **TRL 6 to 9** based on optimized instruments of PICARD, PROBA-2 & SOLAR/ISS, allowing development on 3-4 years (2021-22 launch compatible)
  - a sound mission profile since of recurrent use of the ESA PROBA platform, 5.5 Gbits/day of telemetry allowance, and a piggy-back low cost VEGA or else (LM-2C or D launch…)
- Suited for a Small-size (or more?) mission

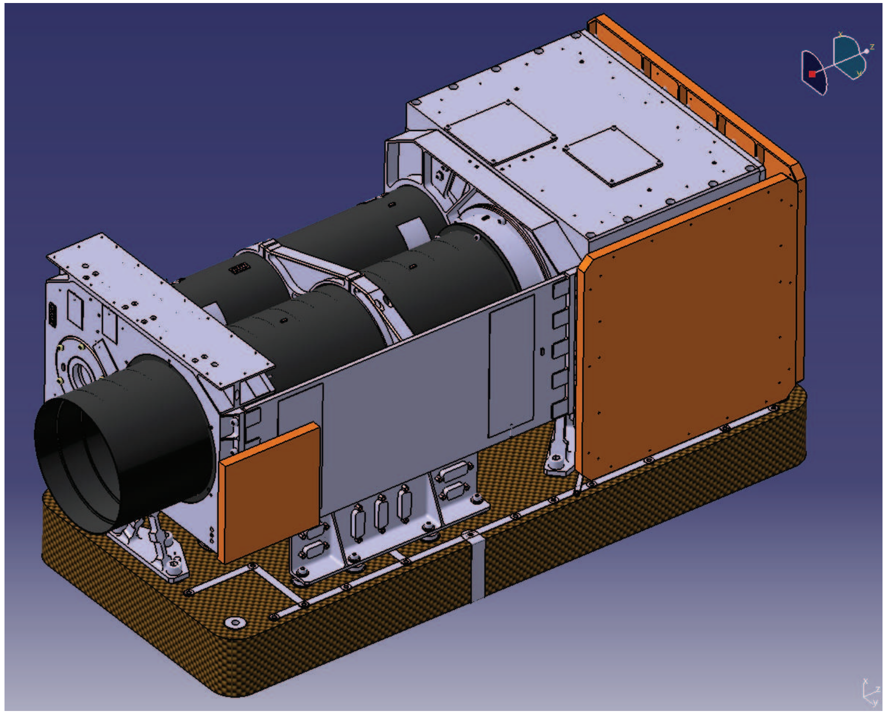
# Thank you!!

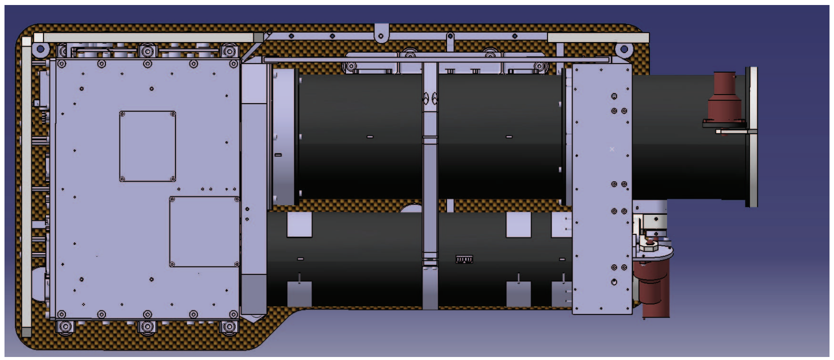


*Lyman-Alpha filtregram obtained in **1979** during the first rocket flight of the Transition Region Camera (**TRC**) and yet the best resolution (**1 arcsec**) full disc Lyman-Alpha image of the Sun. SUAVE/SUITS will reach the same resolution.*

# SUAVE New Design

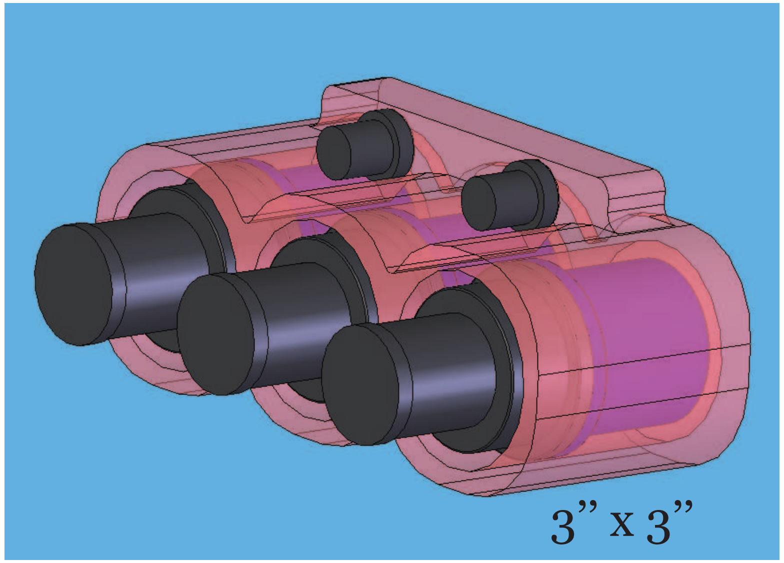




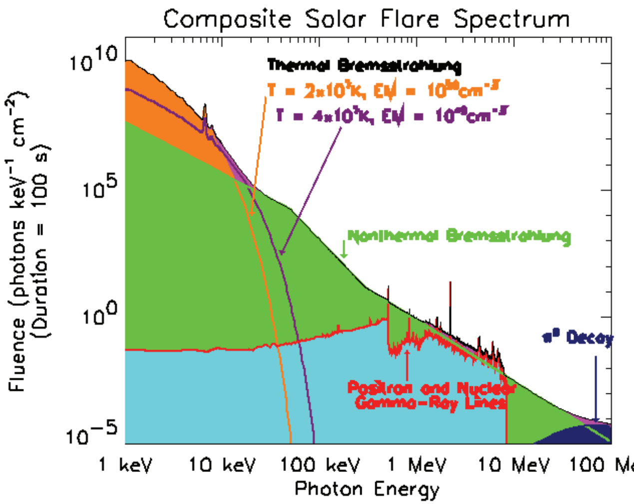


# Model Payload

## High Energy Burst Spectrometer (HEBS)

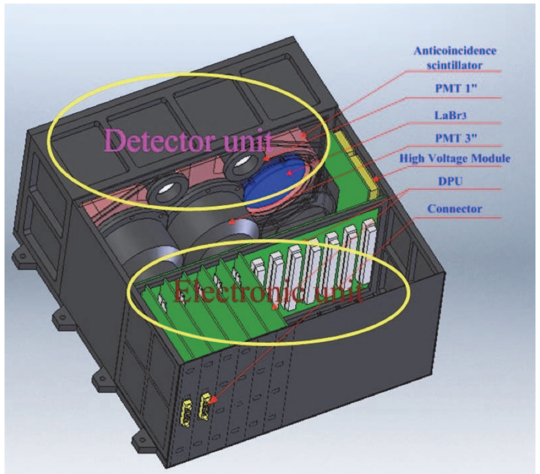



| | |
|---|---|
| Size | 310 x 170 x 230 (mm) |
| Weight | 14 kg (2 heads) |
| Power | 16 W (2 heads) |
| Energy Range | 10keV - 600MeV |
| Energy Resolution | 3%@662keV |
| Temporal Resolution | 1s (quiescent), 32ms (flare-mode) |



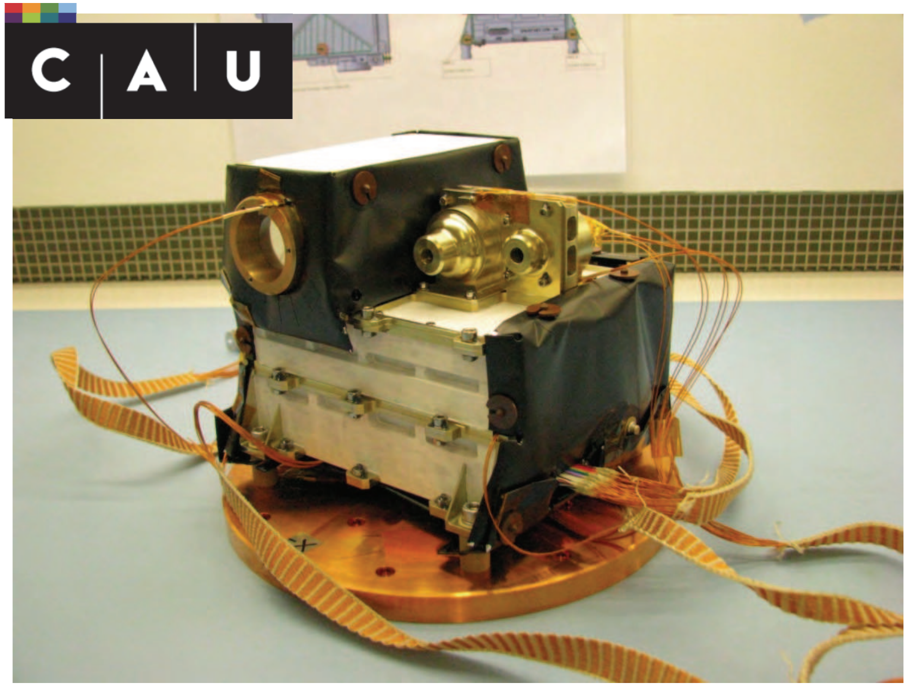
# High Energy Burst Spectrometers (HEBS)
## [Inheritated from SMESE CNES/CNSA Phase A+ Study]

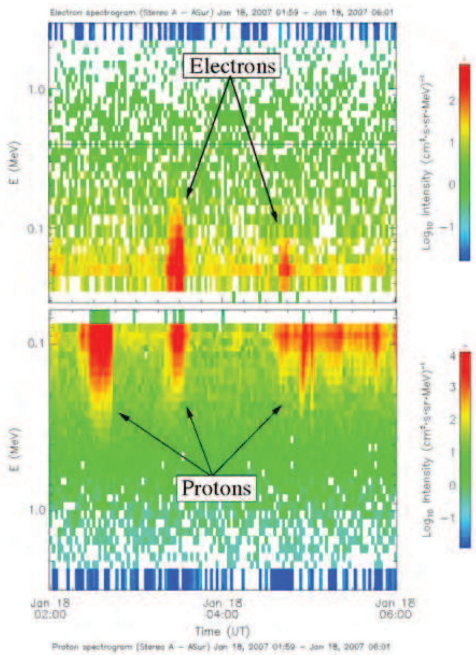
- Evaluate the electron to ion ratio and its time evolution during a Flare
- Provide estimates of the input of energy by particle beams at the top of the chromosphere
- 2 observing instruments:
  - hard X-rays from 10 keV to 500 keV
  - gamma-rays from 300 keV to 600 MeV (new)




- HEBS will provide the first systematic measurements of the photon spectrum from a few tens of keV to a few hundreds of MeV
- HEBS has carried a Phase A+ study in the framework of the CNES/CNSA microsatellite SMESE that confirmed feasibility and readiness. Instrument is to be realized by Purple Mountain Observatory and Nanjing University, China

# Electrons, Protons and Ions Detectors




## Electron-Proton and High-Energy Telescopes (EPT-HET)

| | |
|---|---|
| Mass | 2.5 kg |
| Power | 5 W |
| Energy Range | Electrons: 20 keV – 30 MeV<br>Protons: 20 keV – 100 MeV<br>Heavy ions: ~10 MeV/nuc – ~200 MeV/nuc (species dependent) |
| Time Resolution | 10s (species dependent) |

Heritage from STEREO/SEPT & MSL/RAD