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 and Herzberg Imaging
FUV & MUV Local Influence on Earth Climate

Luc Damé, Alain Hauchecorne, LATMOS/IPSL/CNRS/UVSQ, France

and the SUITS Team

Take Away Points

- Lyman-Alpha and Herzberg Continuum imaging is two fold science for:
  - Flares physics and forecasting of flares and CMEs;
  - True nature of the FUV, MUV sources of variability affecting ozone, stratosphere and climate
- Precise Solar Spectral Irradiance (SSI) variability measurements in the FUV, MUV and NUV are required to quantify the "top-down" mechanism amplifying UV solar forcing on the climate

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

- Envisaged for a joint opportunity CNES/NASA between Europeans and Americans partners for a possible flight in 2021-2022 (Heliophysics Explorer, Mission of Opportunity? Call next spring)
- ESA M5 Call (next spring)… with a larger P/L (microwaves, EUV, coronagraph,…)?

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

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Rationale

- Continuous Lyα 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

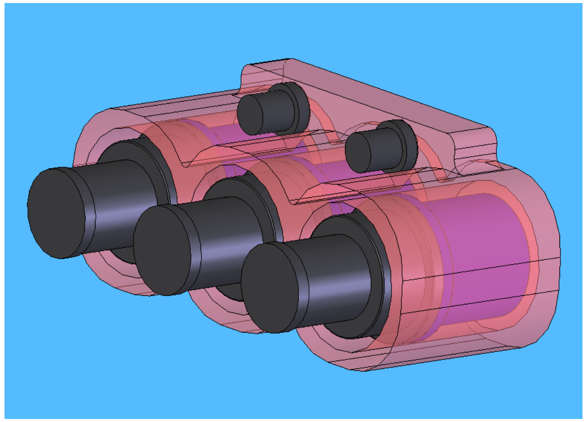
- Determine the origins of the Sun's activity; understand flaring process and CMEs onset
- Determine the dynamics and coupling of Earth's atmosphere and its response to solar (in particular UV) and terrestrial inputs
- Benefit from new activity cycle starting in 2021

Scientific Objectives

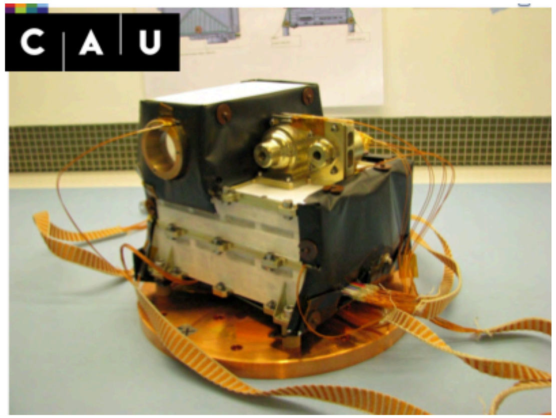
- **1** – High Energy Flare Physics
- **2** – Flares, activity & structures

  Lyman-Alpha advantages in observing and identifying flare/CMEs precursors;
  Lyα & 200–220 nm nature of structures' variability
- **3** – Ultraviolet Solar Variability (Lyα & 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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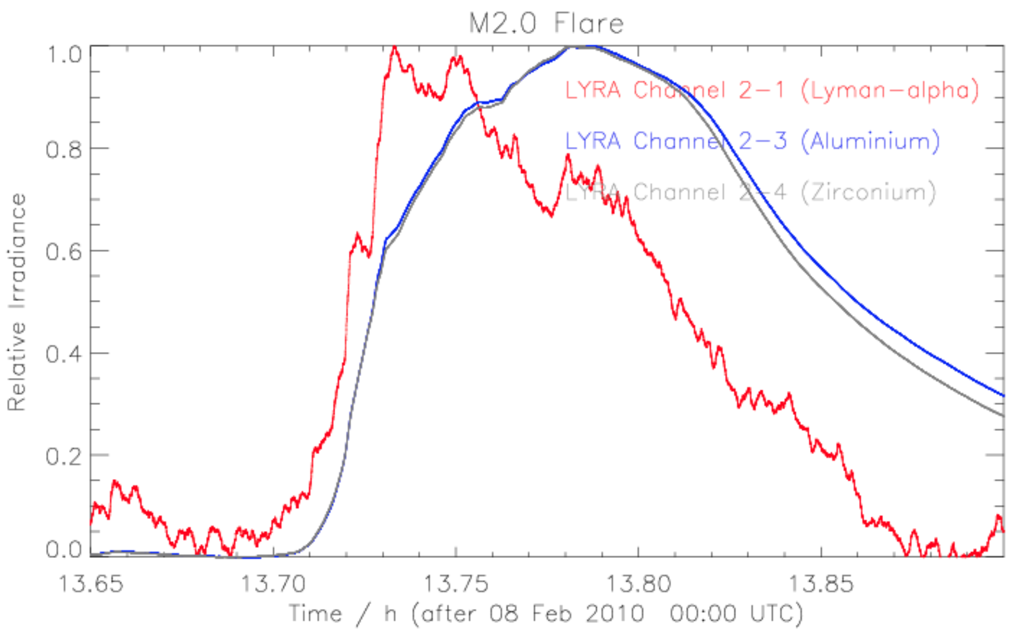
Lyα for Early Predictions and Onset Observations of Major Flares and CMEs

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 Hα for instance, visible easily on the integrated solar flux (LYRA/PROBA-2): excess of **0.5%** (M2 Flare) **to 1%** for larger flares



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

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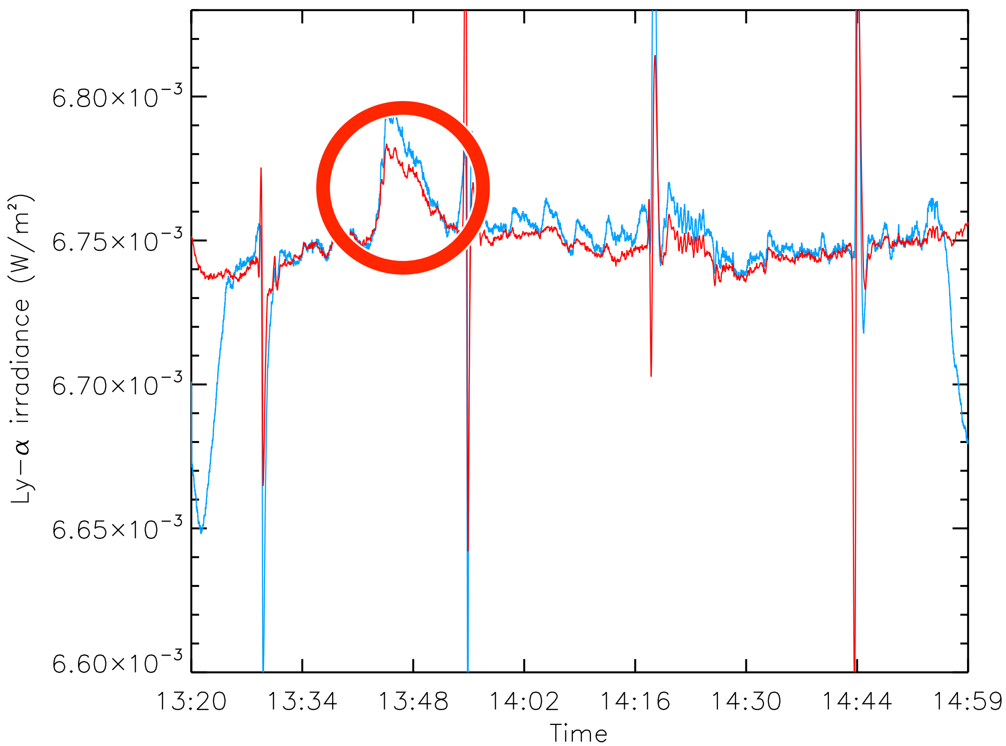


LYRA/PROBA-2 February 8 2010 M2 Flare excess (Kretzschmar et al., 2012)

Predicting and Monitoring Large Flares & CMEs: Lyα better than X-ray

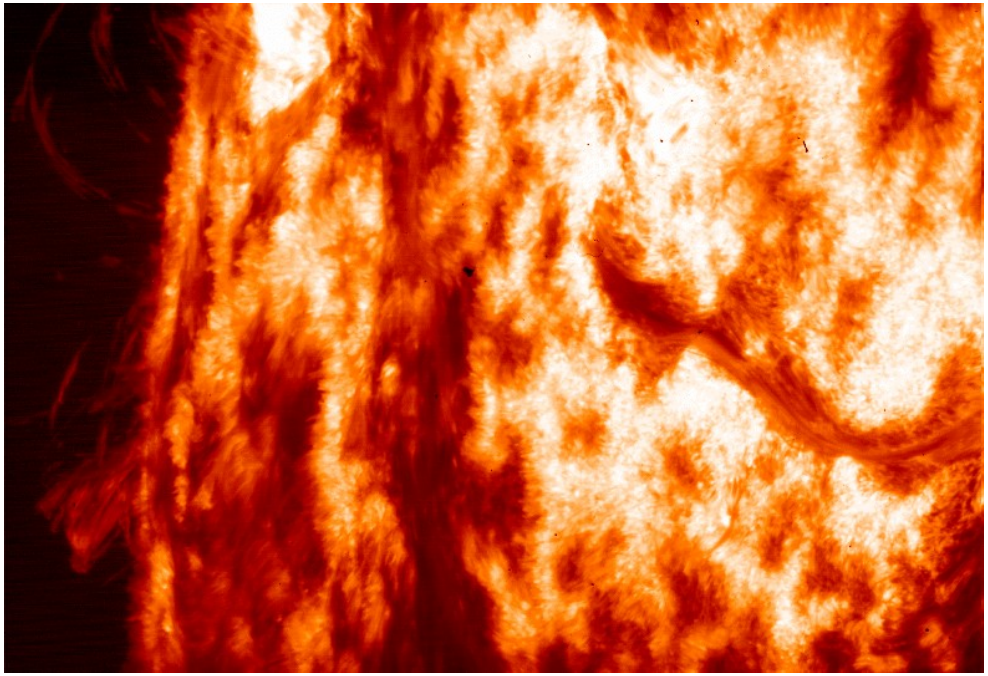
First objective is to **monitor flares** in Lyman-Alpha since as sensitive than X-ray or XUV.

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**.

Lyα Predictions of Major Flares and CMEs & Structures' Evidence

- 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

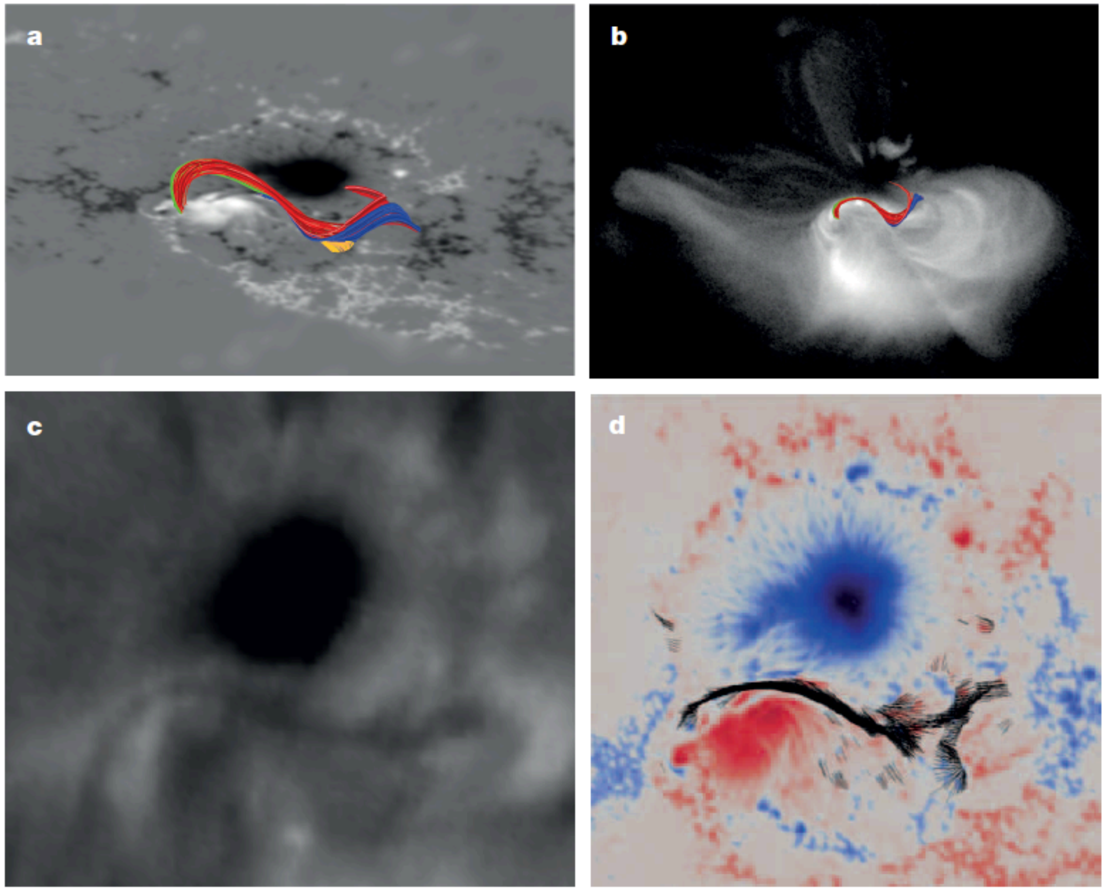
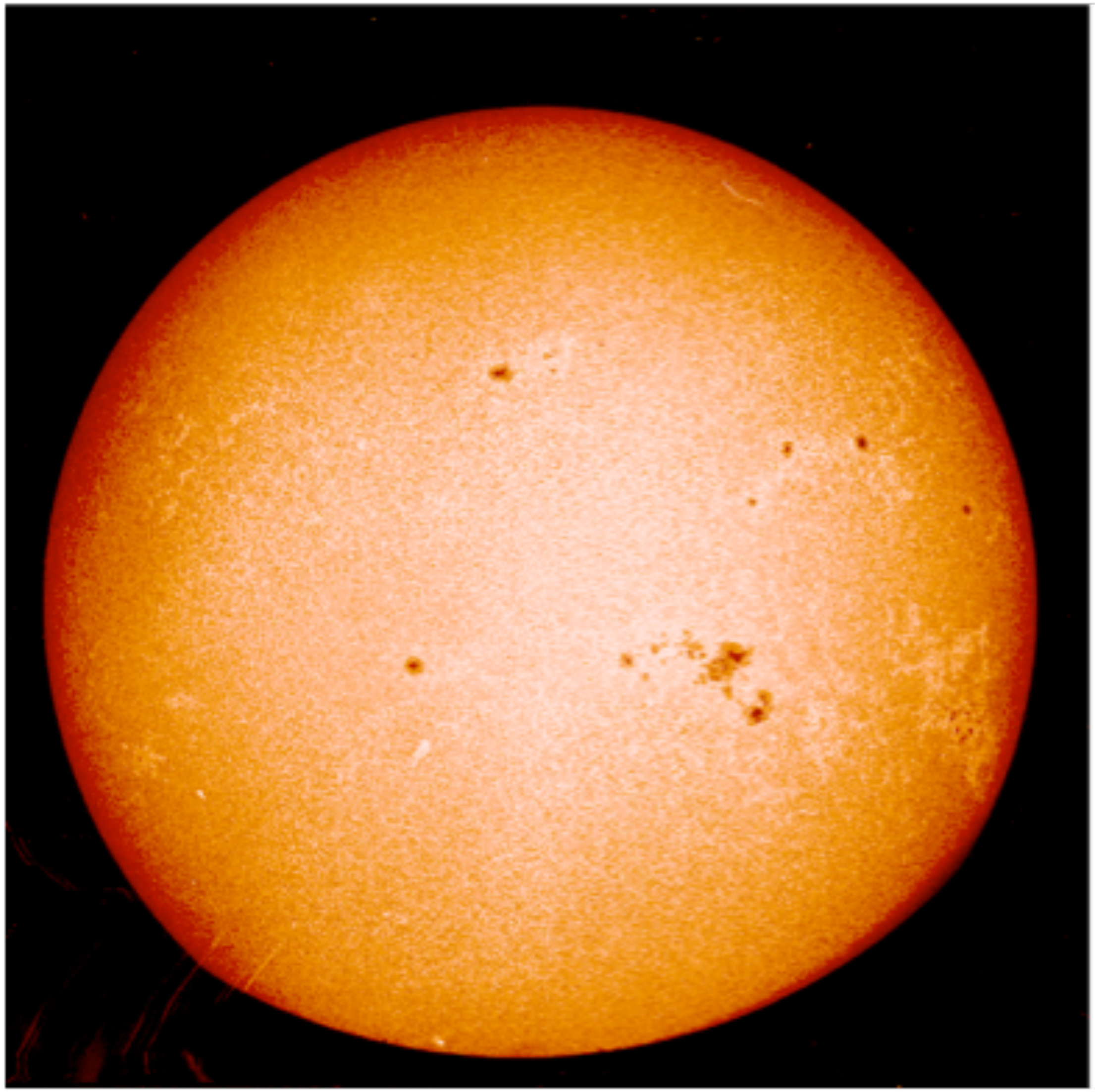


Figure 2 | Twisted flux rope before the major eruption. Selected field lines of the reconstructed magnetic configuration of December 12, 20:30 UT (D−1), with the same colour code as in Fig. 1. **a,** A large rope consisting of several components sits between the two spots and is seen to have accumulated 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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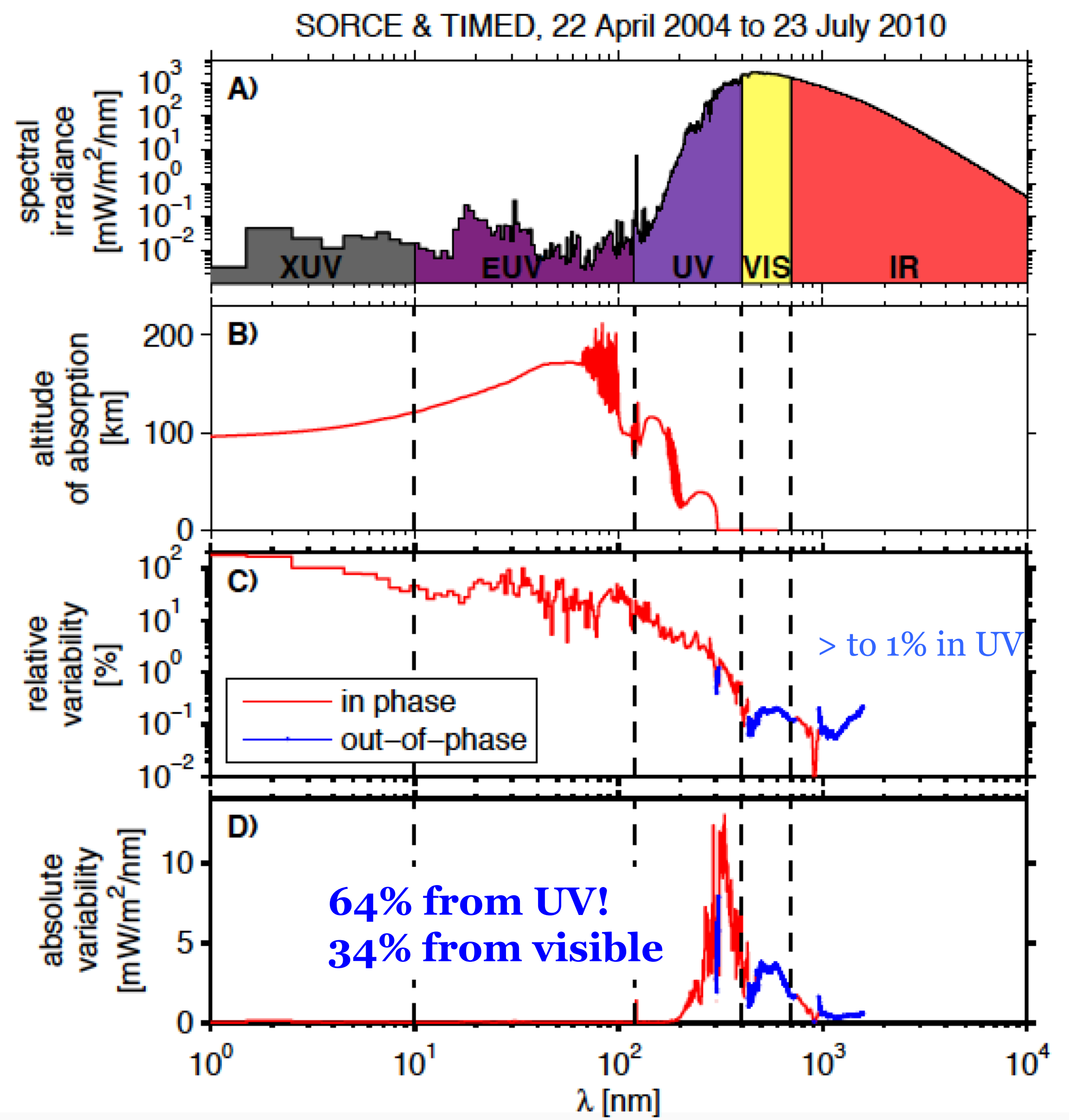
Variability *influence* is in the UV!



Solar spectrum

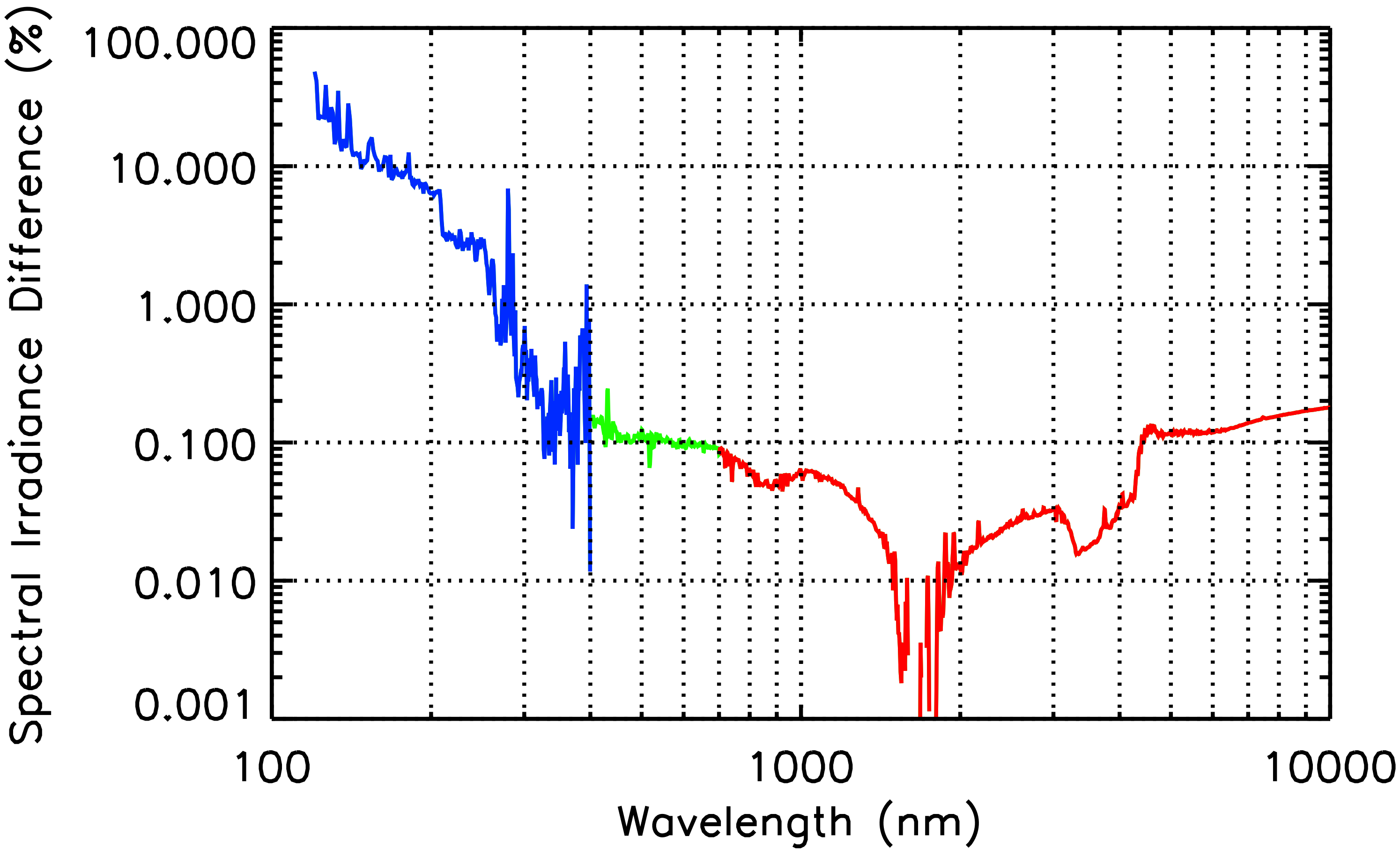
Absorption altitude

Relative variability

ABSOLUTE VARIABILITY over solar cycle

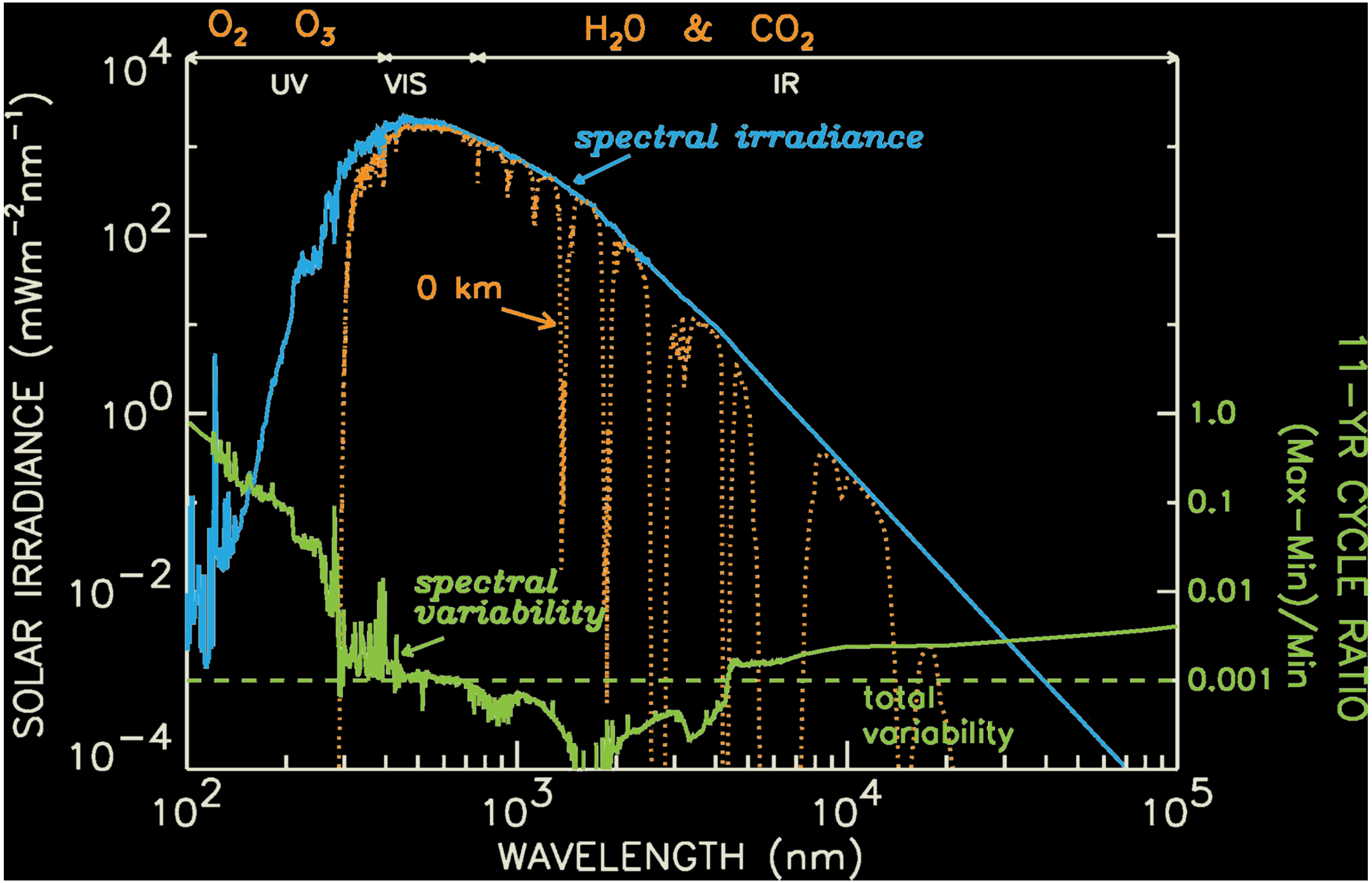
Ermolli, et al. (2013)

Spectral Solar Irradiance (SSI): SMax vs. SMin

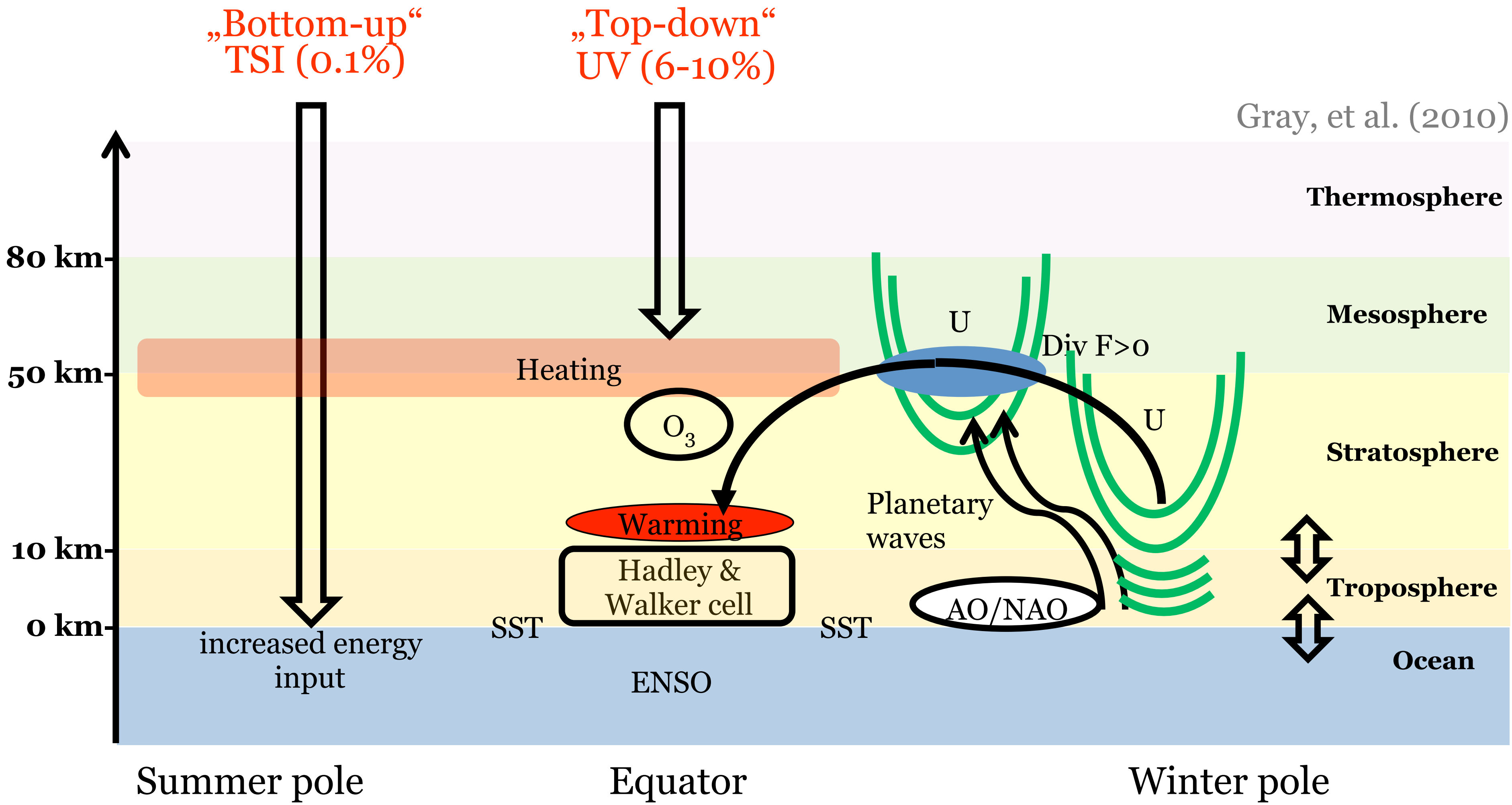


Very small variations in the visible (0.1%) or IR, but big changes in the MUV & FUV (5 to 60%)

Solar Variability (Activity Sources) Drives Spectral Irradiance Variations

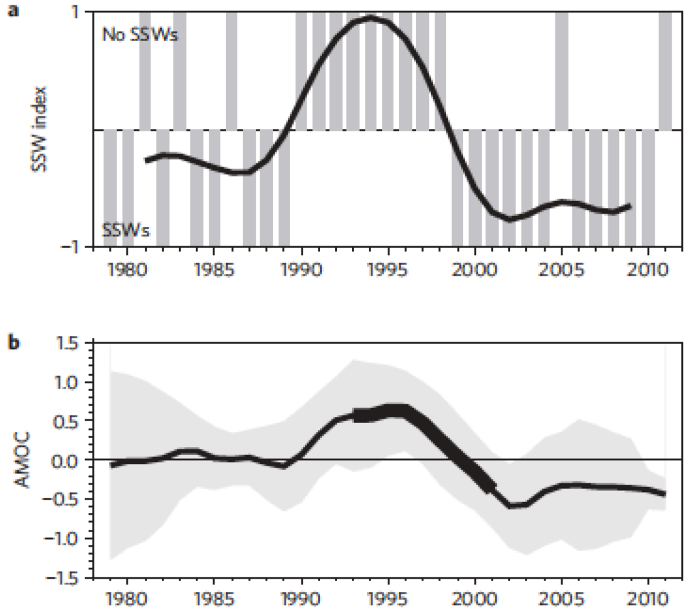


Influences of Solar Variability on Climate: the “Top-down” mechanism



Evidence of "Top-Down" mechanism influence on Climate

- Ineson et al., Ngeo, 2011 — Evidence of "top-down" mechanism: solar forcing of winter climate variability in the Northern Hemisphere
- Martin-Puertas et al., Ngeo, 2012 — Changes in atmospheric circulation amplified by grand solar minimum 2800 years ago
- Reichler et al., Ngeo, 2012 — SSW correlated circulation evidencing stratosphere-troposphere coupling
- Maliniemi et al., JGR, 2014 — Correlation between northern hemisphere temperatures and solar cycle
- Thiéblemont et al., Ncomm, 2015 — Solar forcing synchronizing the decadal North Atlantic climate variability



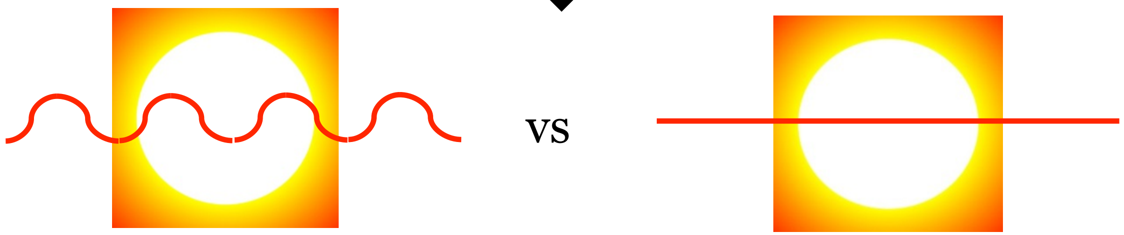
Reichler et al., 2012

Thiéblemont et al., Nature Comm., 2015

1. Can we reproduce the Solar/NAO relationship with a realistic (transient) multi-decadal climate simulation?

2. Which mechanisms are implied?

<u>2 experiments</u>
(145 years)

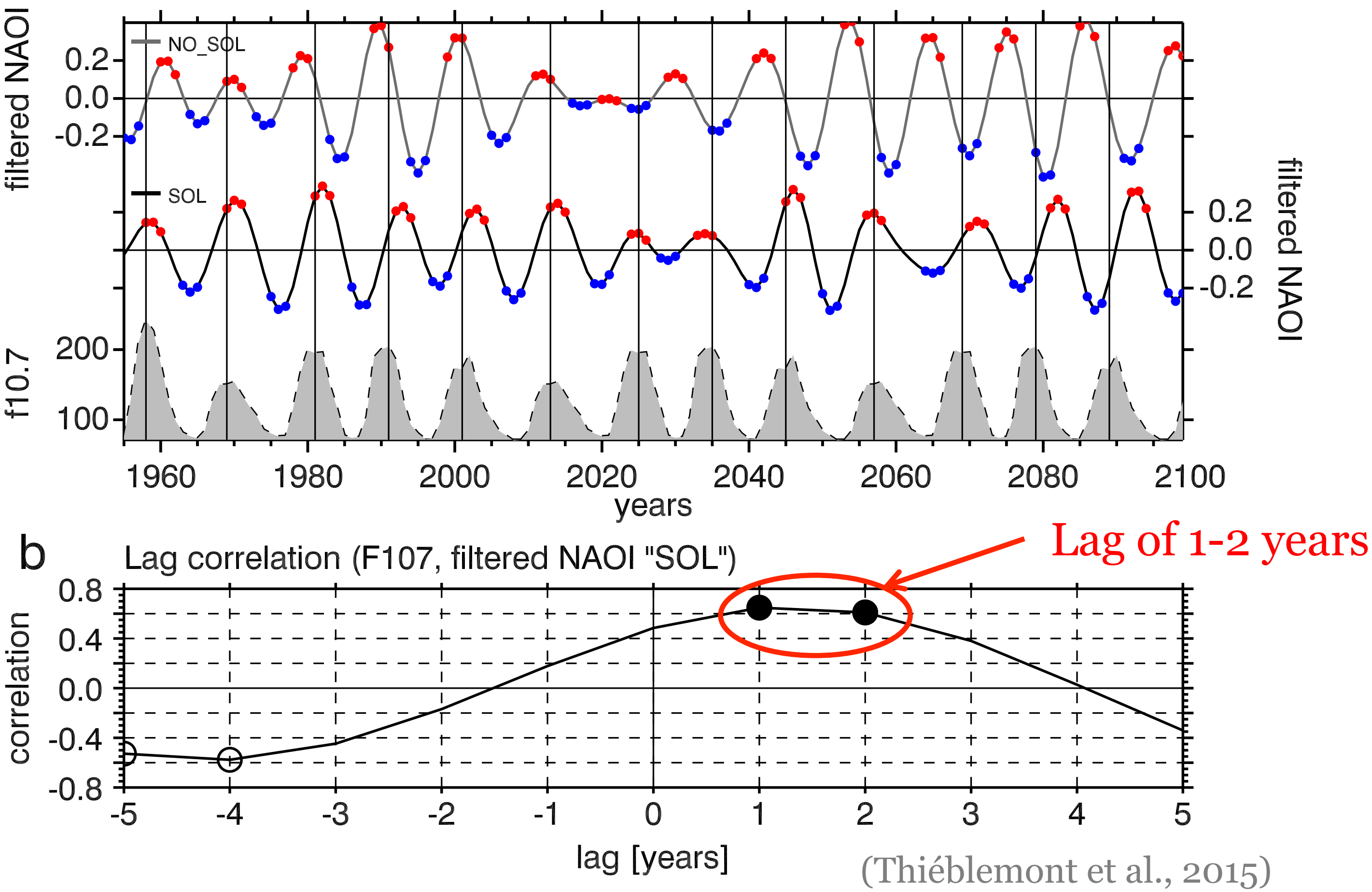


<u>Model</u>

<u>CESM-WACCM3.5</u> (*Marsh et al.*, J. Clim., 2013):

- atmosphere (WACCM3.5): 2.5x1.9 (lon x lat), 66 levels up to 140 km, interactive chemistry & and high spectral resolution in UV band
- ocean (POP): 1°x1° triangular horizontal grid, 60 levels.
- GHG/ODSs kept constant at 1960‘s level

Synchronization of the NAO by the solar cycle



(Thiéblemont et al., 2015)

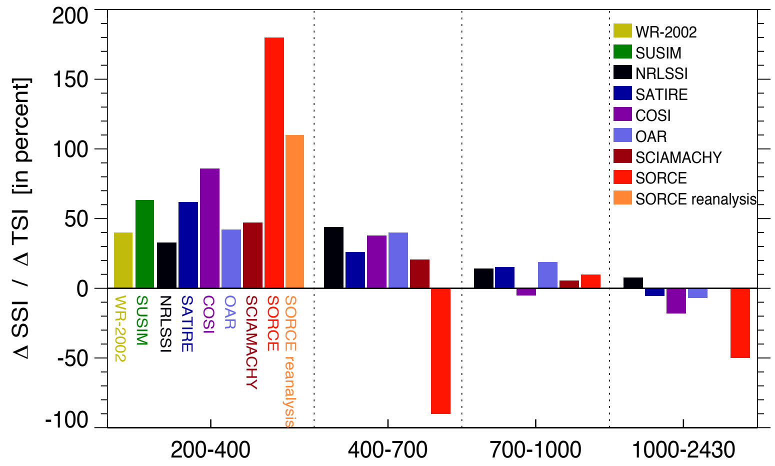
The solar cycle synchronizes the NAO quasi-decadal fluctuations

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?

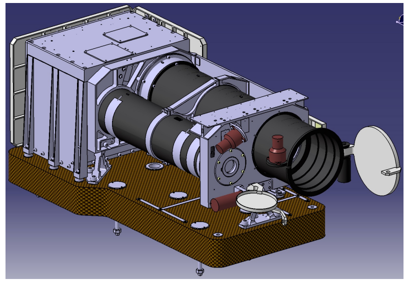
- **Sufficiently high resolution** of the radiative scheme in the UV range (Nissen et al., 2007, Foster et al., 2011)
- **Interactive ozone chemistry** (or a good stratospheric ozone parameterization)
- **Reduce SSI uncertainty**



Ermolli, et al. (2013)

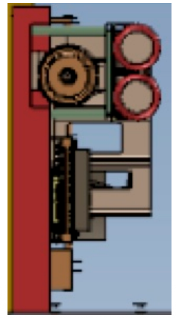
➢ next step: proper input for climate modelling, CCMI, CMIP6 (new SolarMIP initiative, K. Matthes, B. Funke), etc.

SUITS Model Payload
Space Weather, FUV, MUV & Climate



1 – FUV imaging Lyα & 200-220 nm: **SUAVE** (*Solar Ultraviolet Advanced Variability Experiment*)

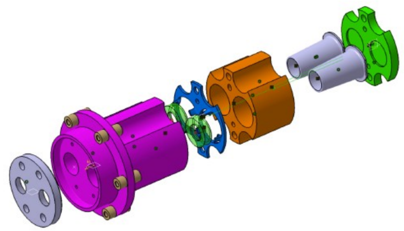
2 – Solar Spectral Irradiance 170-340 nm (Atm. modeling – res. ~0.65 nm): **SOLSIM** (*SOLar Spectral Irradiance Monitor*)



3 – Solar radiometers at Lyα, 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



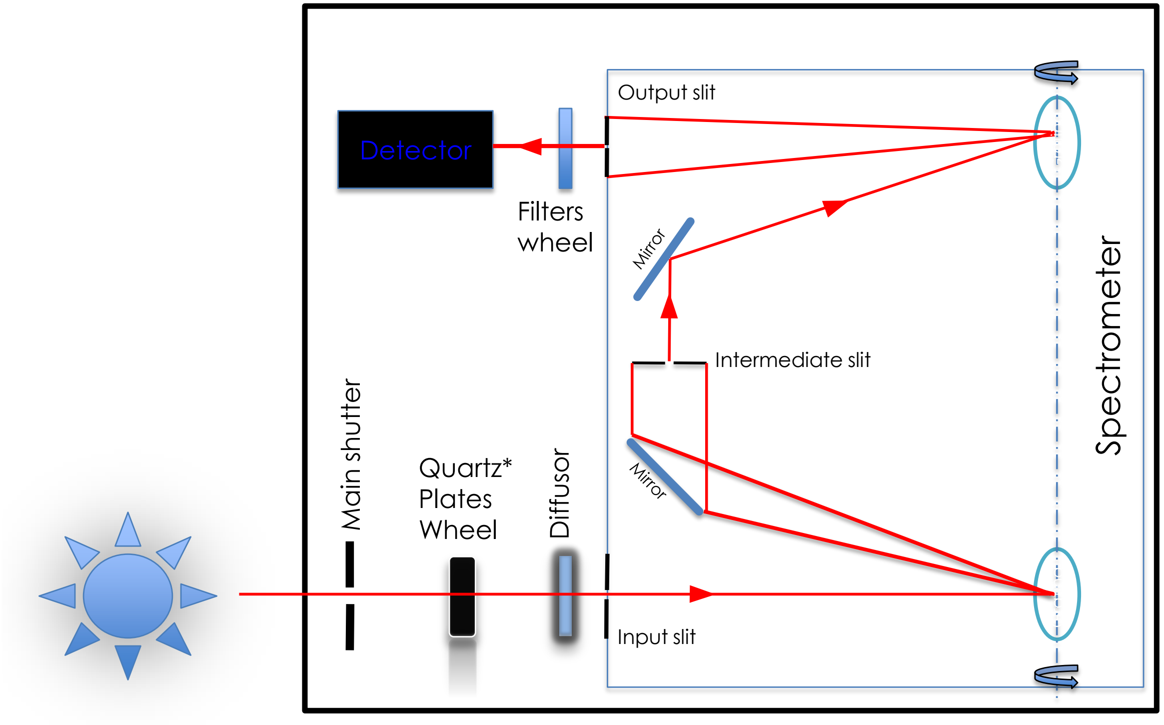
SOLSIM (***SOLar Spectral Irradiance Monitor***)

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

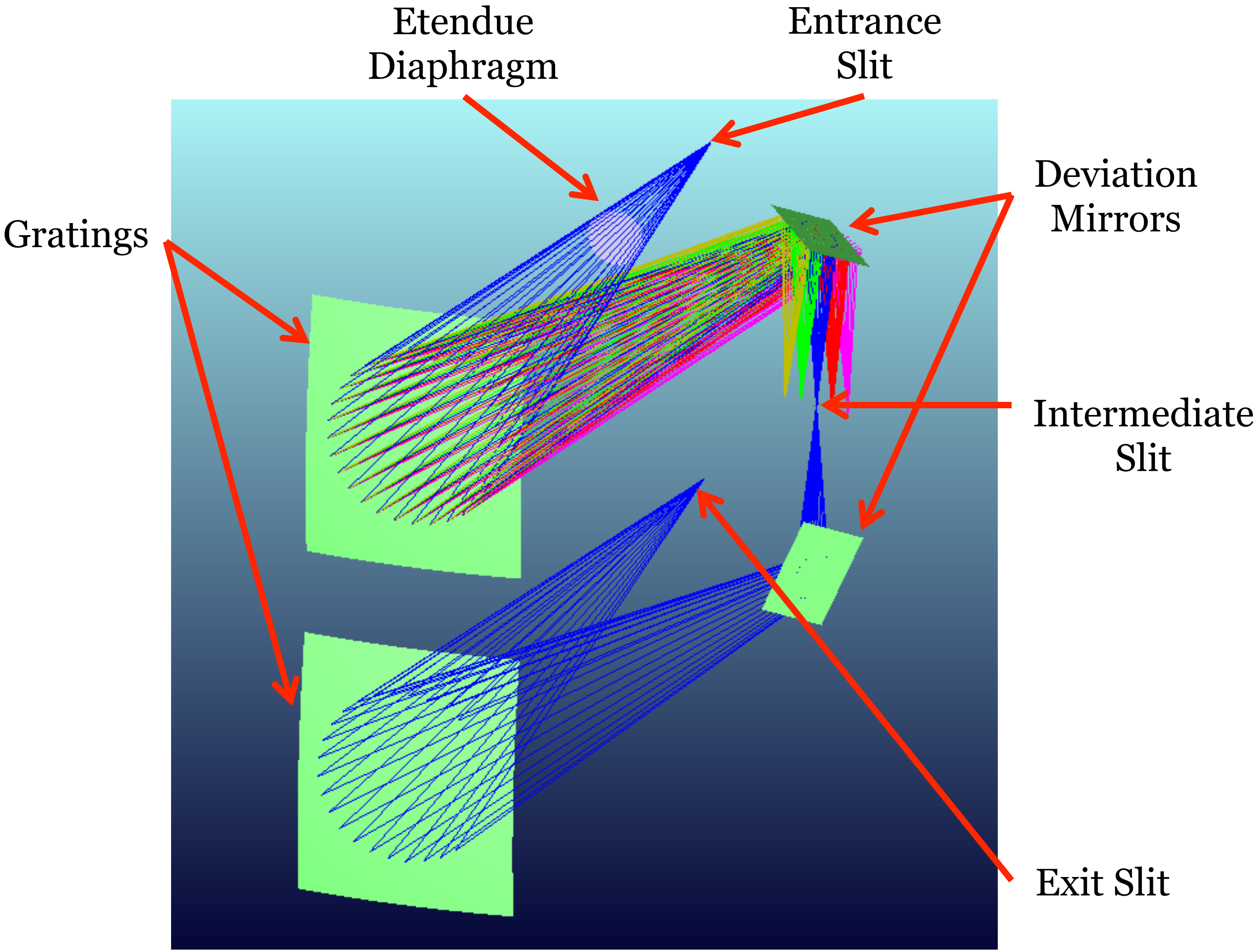
Experience at LATMOS and IASB (SOLSPEC experiment)

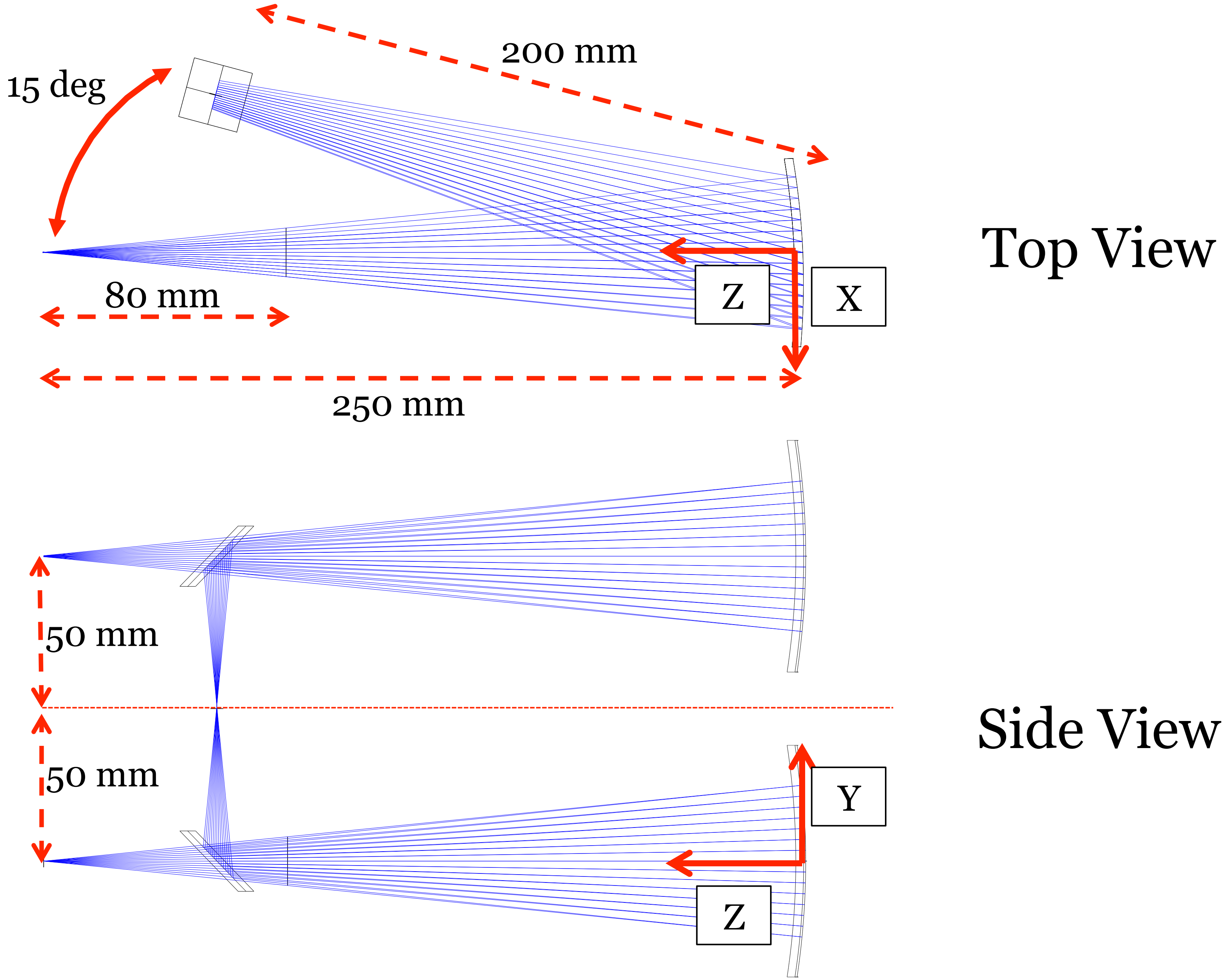
Expertise also of LPC2E Orléans

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
Top View
Z
X
80 mm
250 mm
50 mm
Side View
50 mm
Y
Z

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

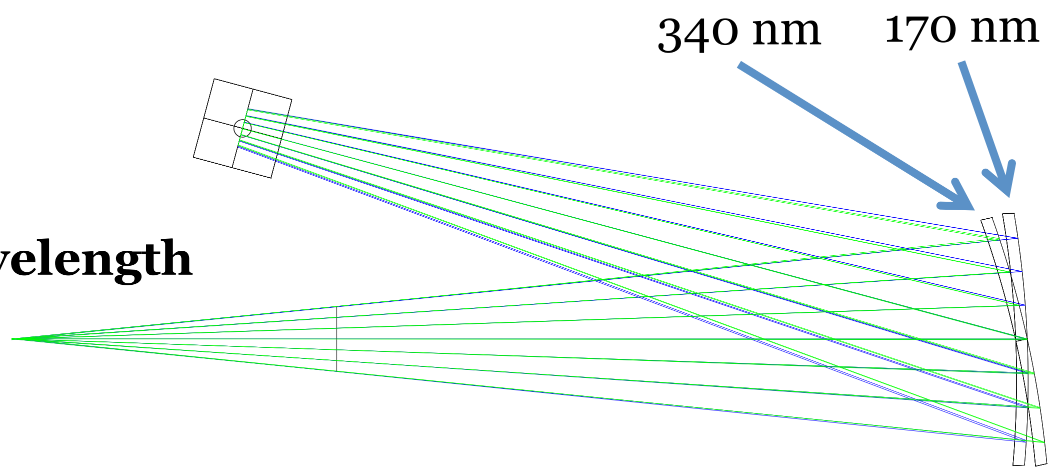
2 Gratings G1 & G2

- 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) :

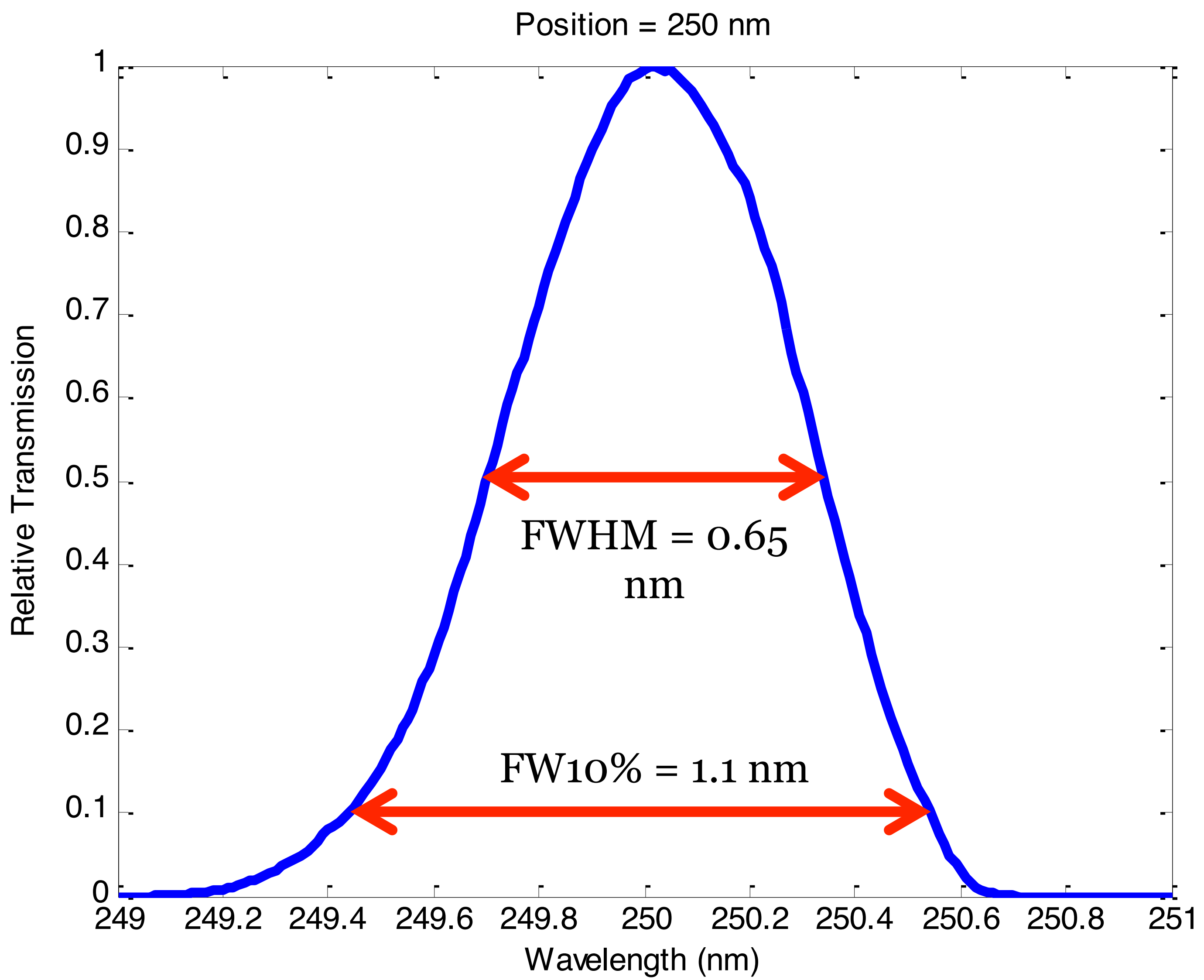
  X1 = -30.417 mm
  Z1 = +274.971 mm
  X2 = +324.100 mm
  Z2 = +187.095 mm



Beam incidence angles vs wavelength

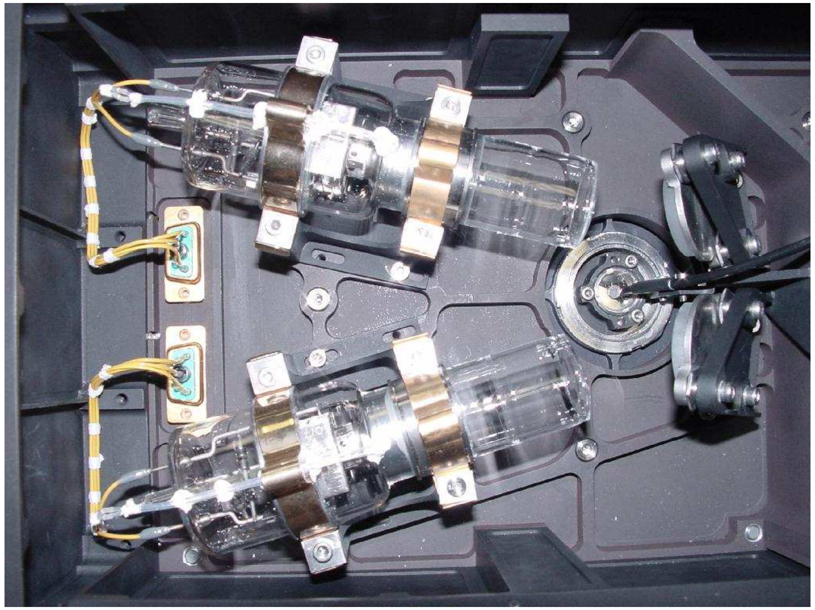
- λ = 170 nm ⇒ θ = 2.379 deg
- λ = 340 nm ⇒ θ = 12.566 deg

Spectral Resolution

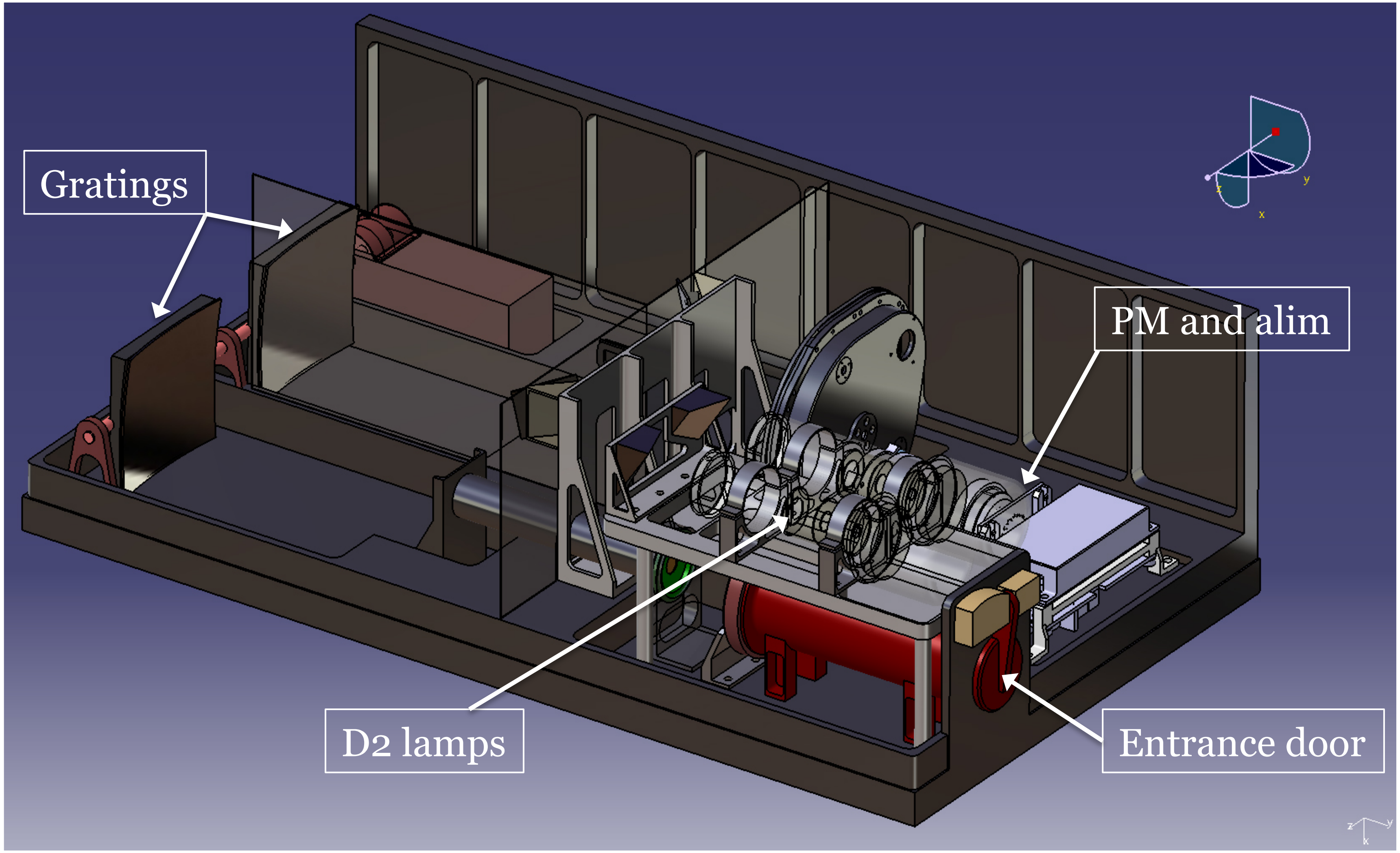


Design Heritage

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

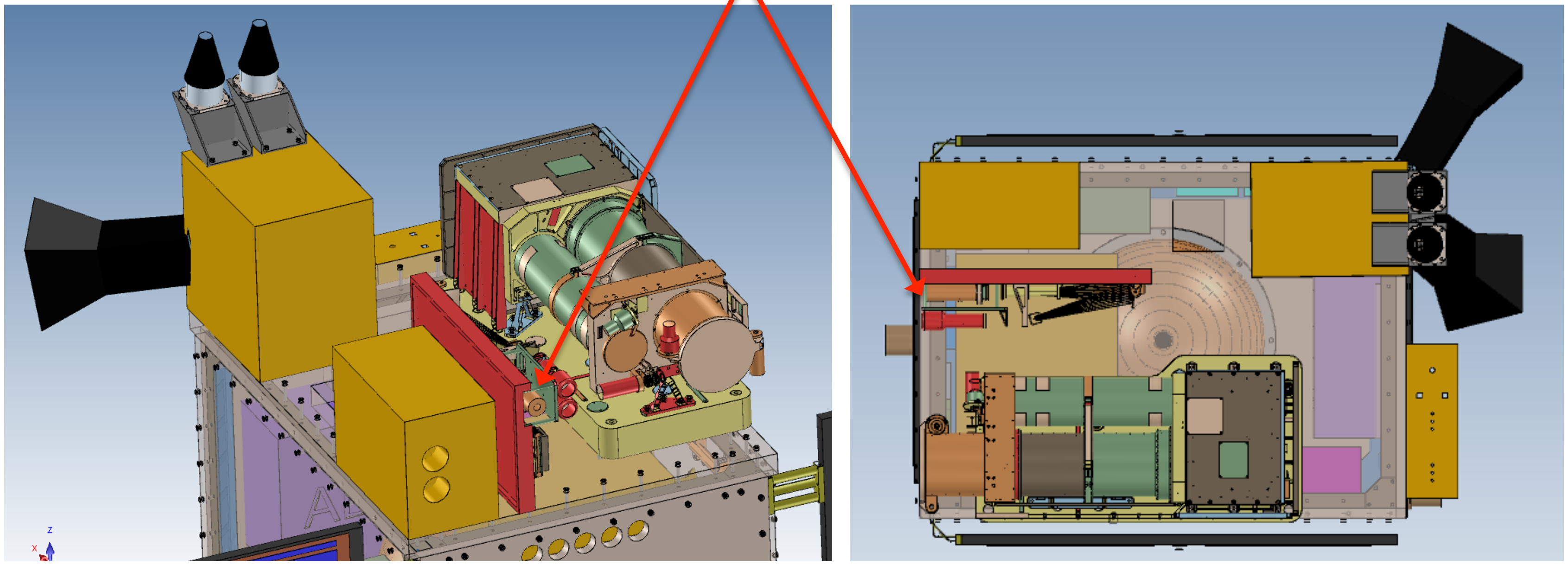


Preliminary Mechanical Implementation



Preliminary Mechanical Implementation on SUITS

Vertical accommodation (entrance on top)



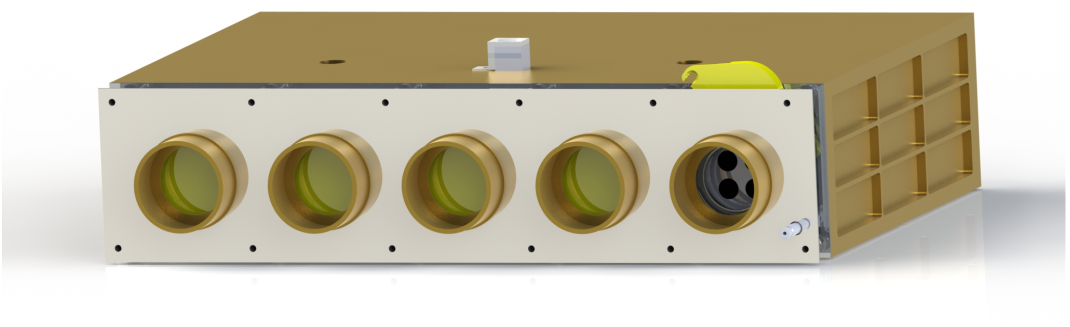
SUPR Filter Radiometers FUV, MUV & UV: "extending LYRA"

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

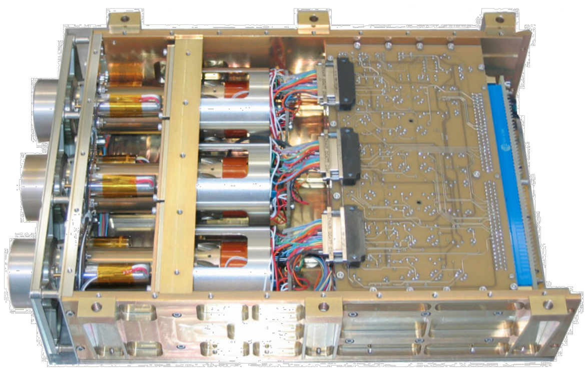
- 5 at Lyman Alpha 121.6 nm (3 at different rates)
- 5 at Herzberg continuum 200–220 nm
- CN bandhead 385–390 nm; Mg II; 340-400 nm by 20 nm

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

Mass < 5.7 kg; 0.16 Gbit/day

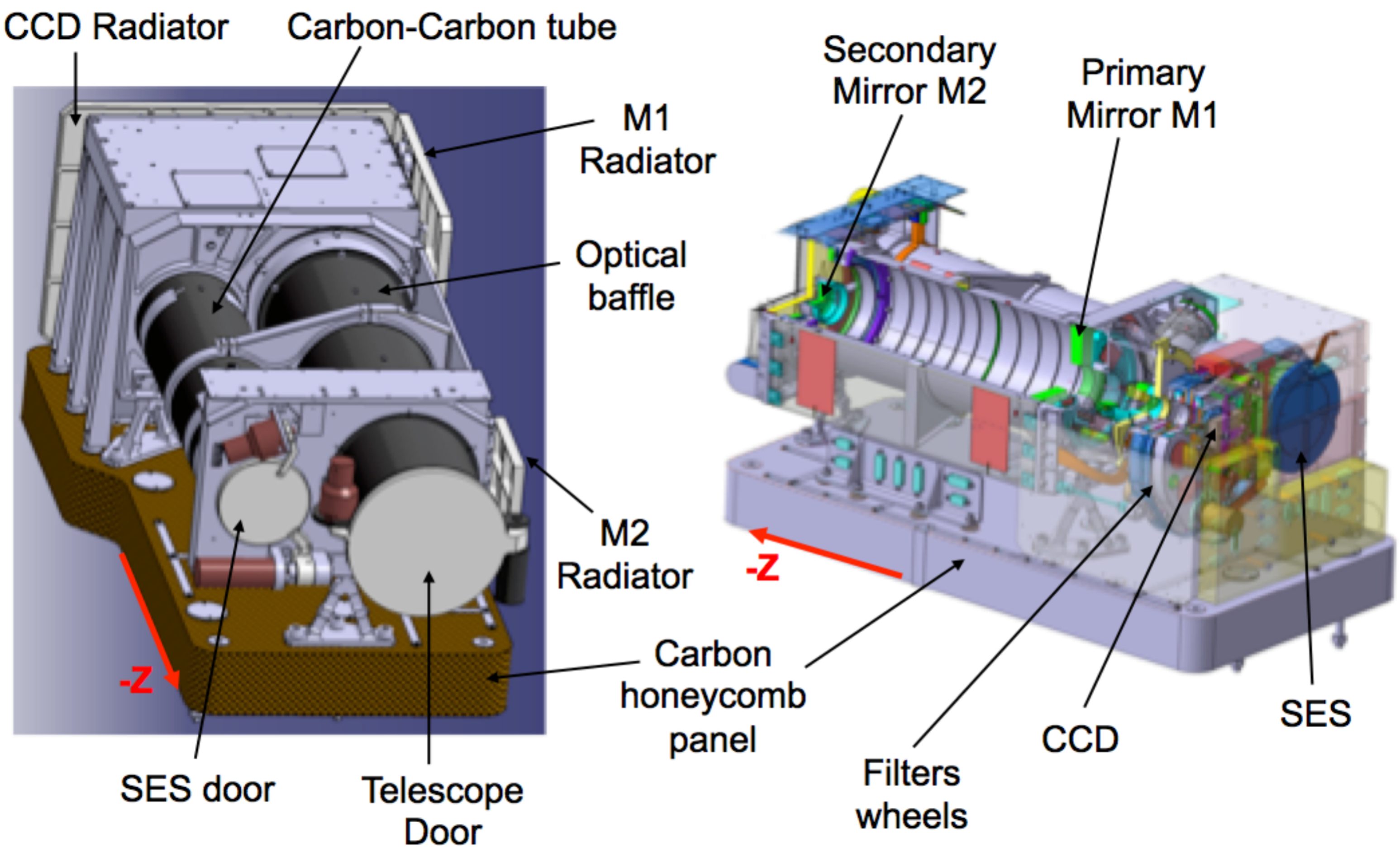


5 heads of reduced length compared to LYRA (see below)



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

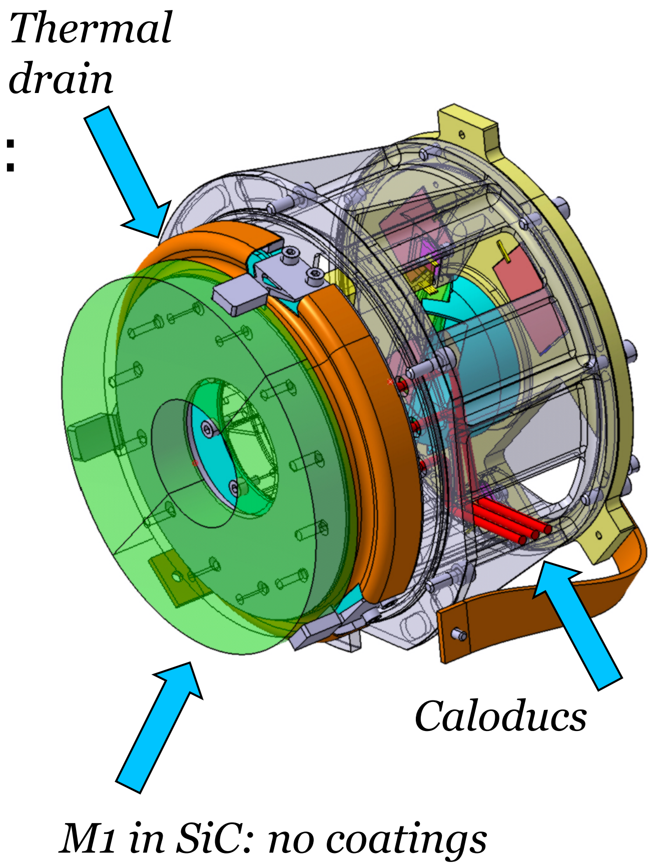


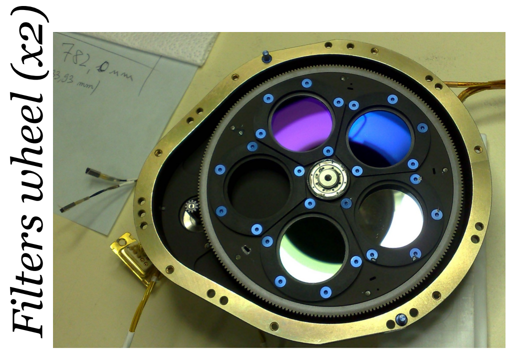
New design thermally optimized of the SUAVE telescope (left) compared to the SODISM/PICARD one (right)

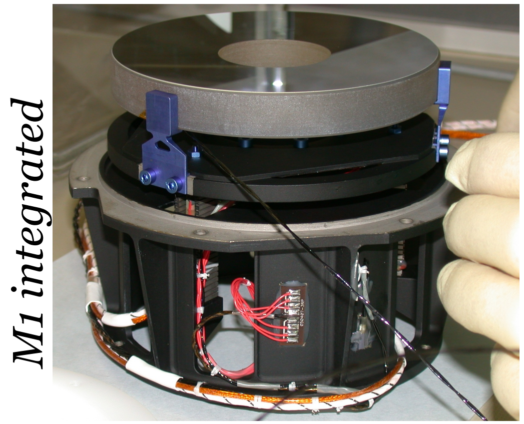
New SiC Mirrors: FUV duty cycle

Unique properties:

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







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

SiC Mirrors Heat Flux Extraction

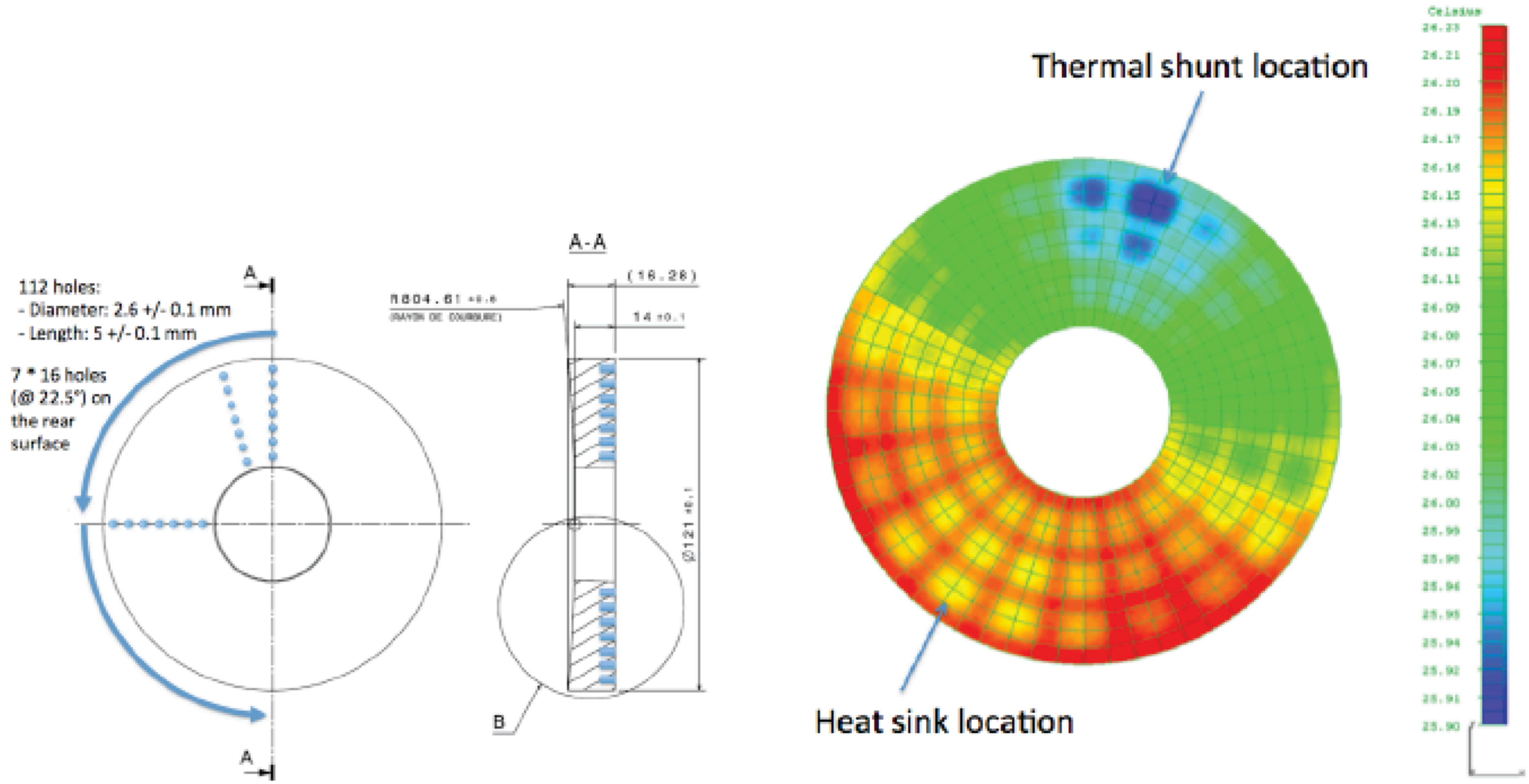


Figure 6. Thermal analysis of the SiC primary mirror of SUAVE in its nominal configuration with 112 holes on the rear surface of the mirror used as heat sinks between the mirror and the mirror's support. (Left) Design of the 112 holes in the SiC mirror; (right) the resulting temperature gradients appear acceptable (limited to ±0.16°C).

Damé et al., 2014

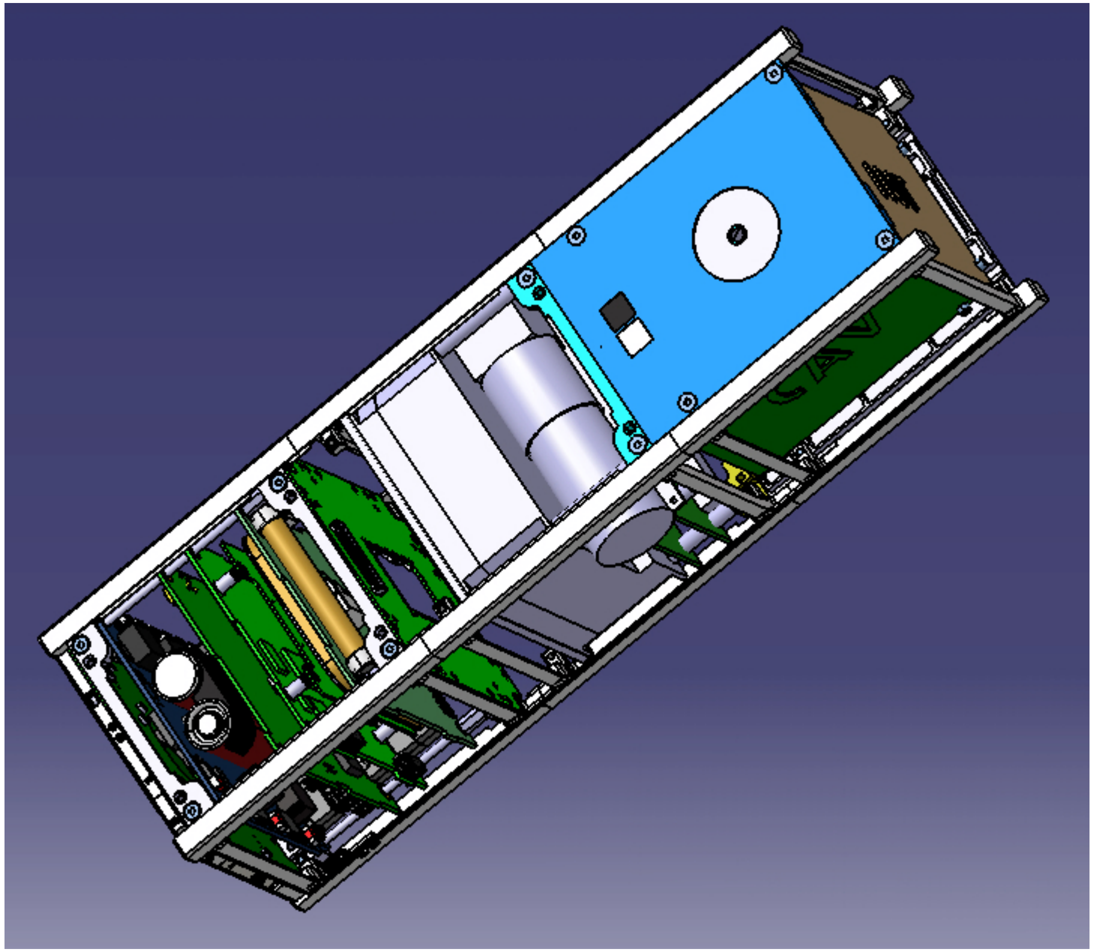
ERBO (Earth Radiative Budget & Ozone)

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)

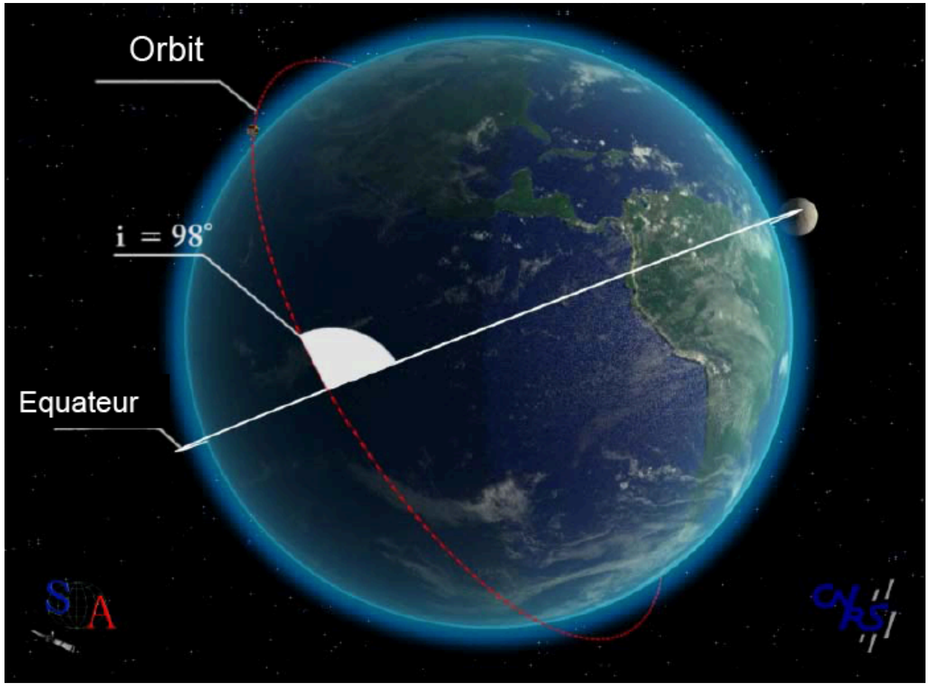
Instruments' Characteristics

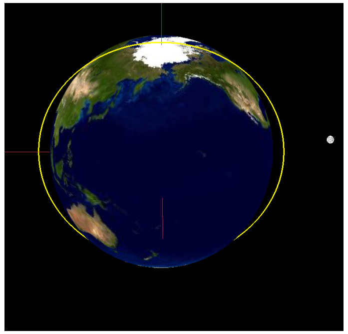
Instrument	Mass (kg)	Power (W)	Dimensions (L W H, mm)	Telemetry (Gbits/day)
SUAVE Electronics Box	20 10	26	750 x 308 x 300 223 x 306 x 304	3
HEBS	14	16	310 x 170 x 230	2
SOLSIM	8	8	450 x 140 x 250	0.1
SUPR	5.7	6	315 x 350 x 92.5	0.16
EPT-HET	2	5	130 x 170 x 140	kbps
ERBO	2	2	100 x 100 x 200	kbps
Magnetometer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

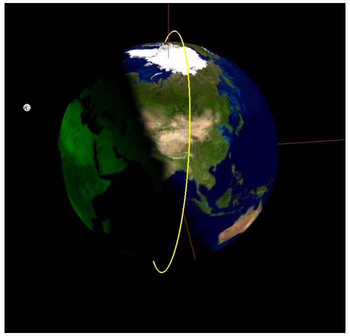
A simple orbit choice for thermal stability

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: $1.04x10^{-3}$
- Argument of periapsis: 90°

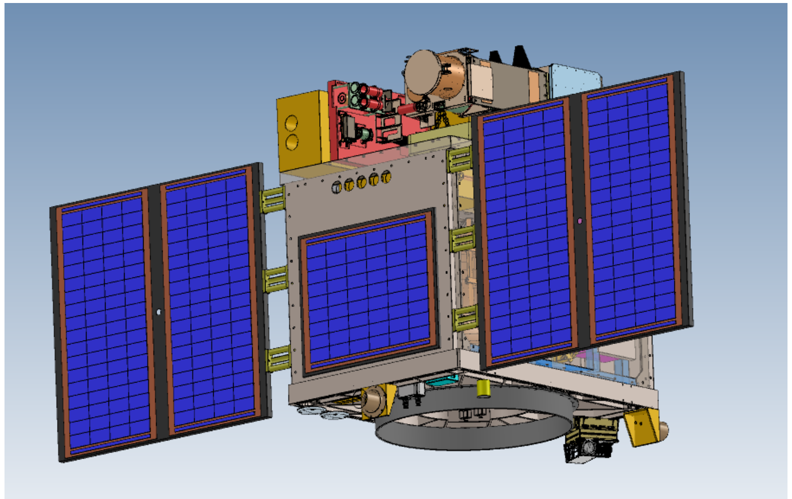


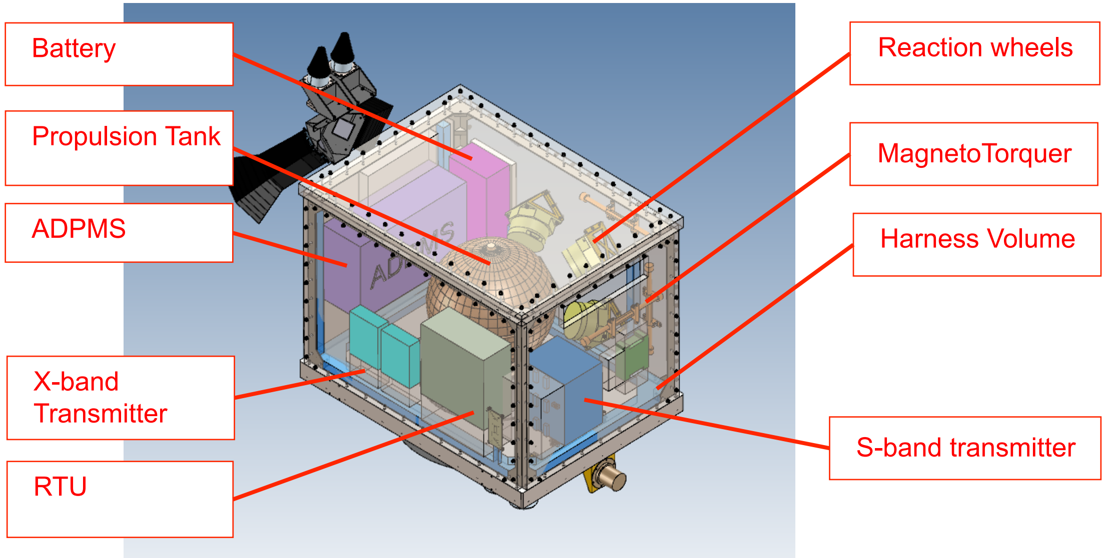




New PROBA Platform from QinetiQ

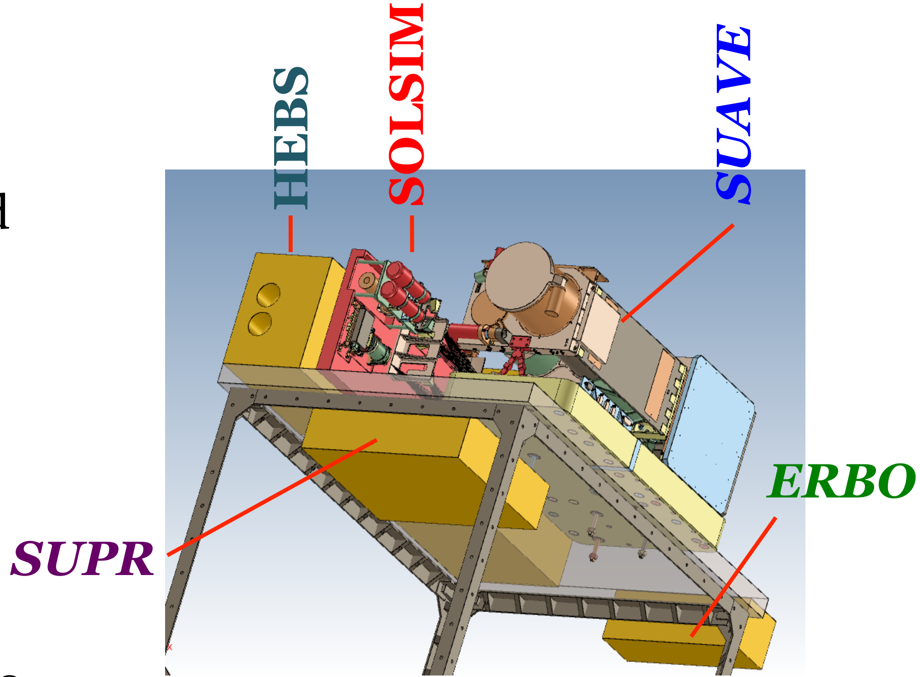
- ITAR Free
- Deorbiting compatible
- < 200 kg
- 694 x 946 mm top plate

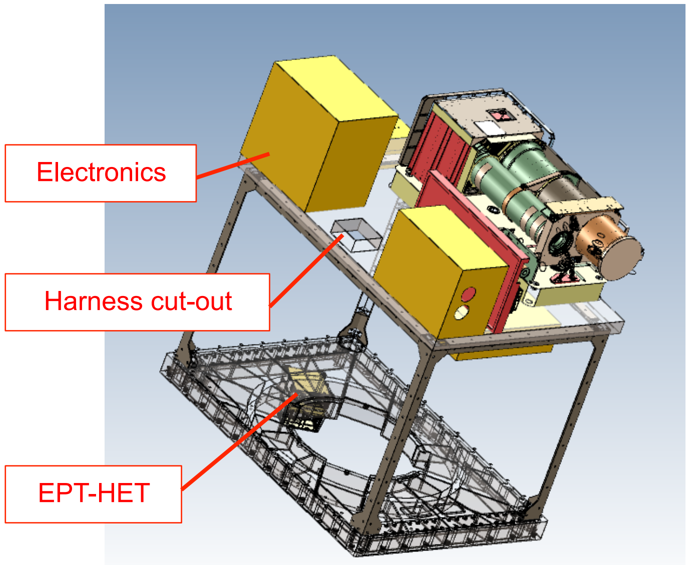




SUITS/SWUSV PROBA Accommodation

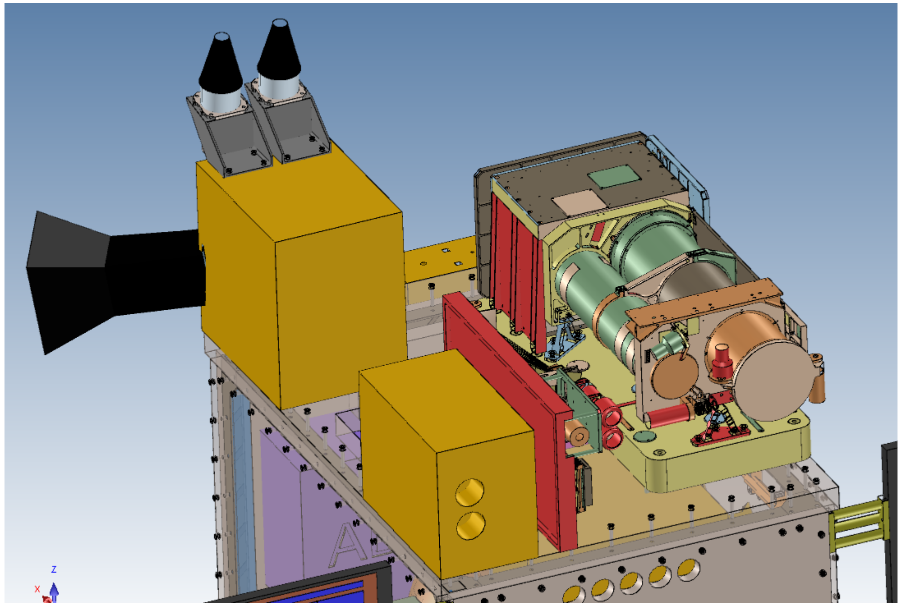
- **SUAVE** (*Solar Ultraviolet Advanced Variability Experiment*), Lyman-Alpha and 200-220 nm Herzberg continuum imaging with 3 redundant set of filters to preserve long-term sensitivity
- **SOLSIM** (*SOLar Spectral Irradiance Monitor*) 170-340 nm, spectral resolution 0.65 nm
- **HEBS** (*High Energy 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

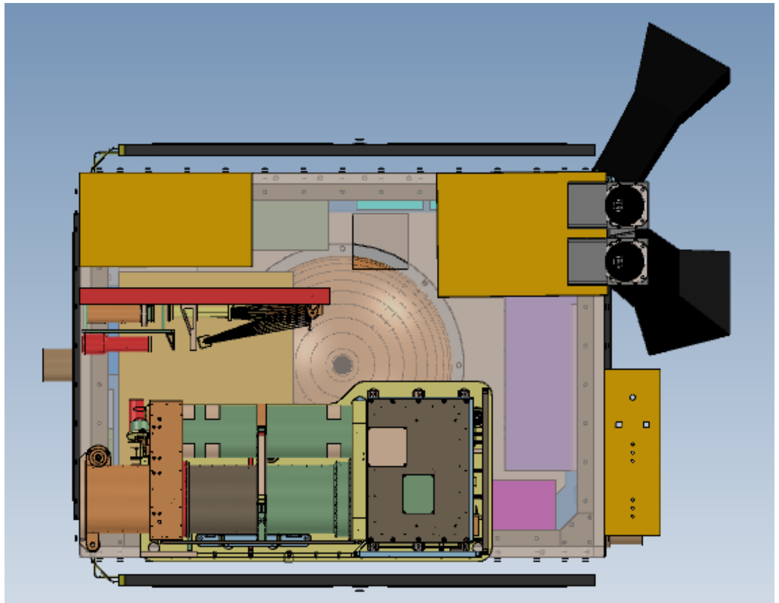




SUITS Payload Accommodation

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



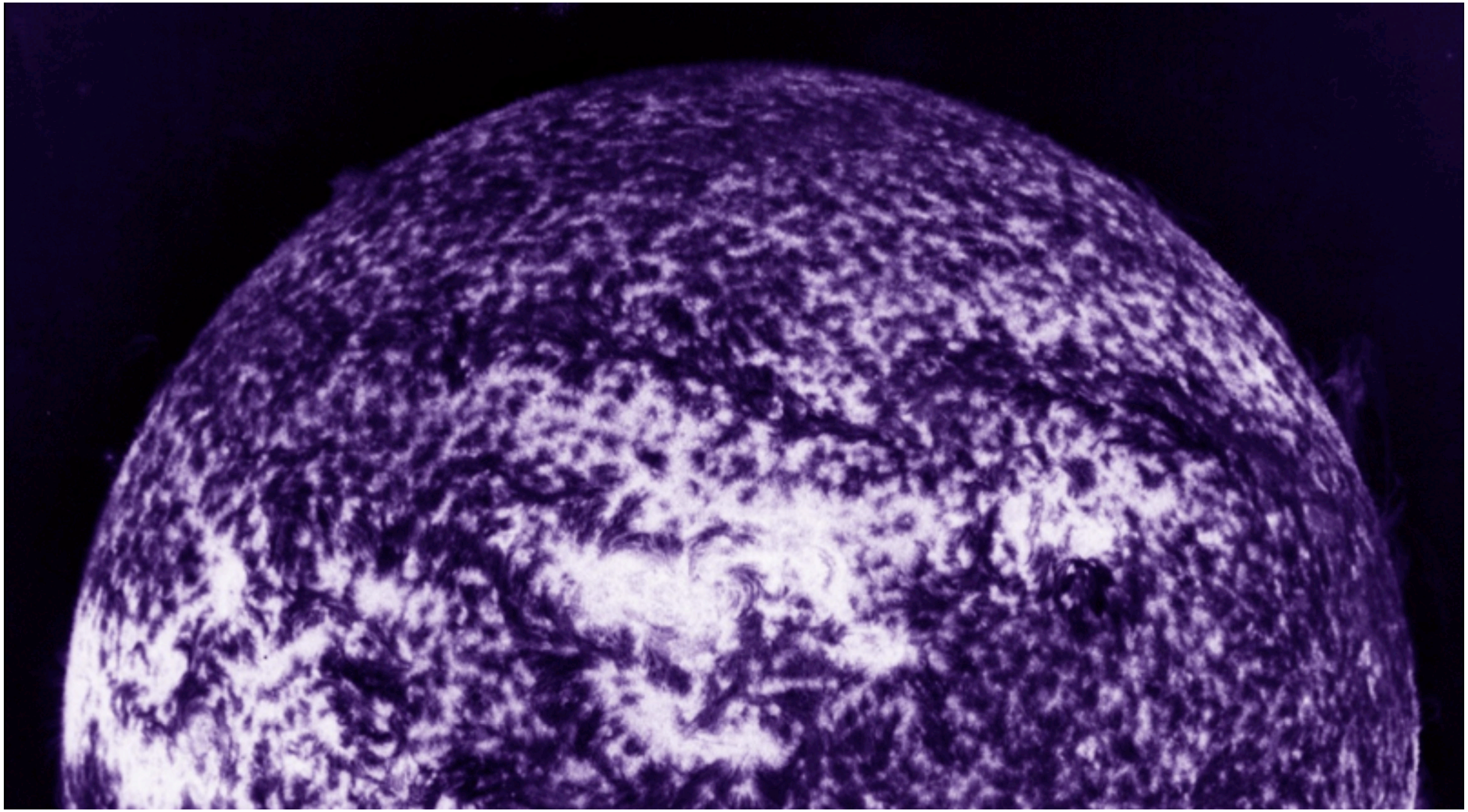


In stowed position, the SUITS/SWUSV (accounting antennae and star tracker) is 1183 (L) x 968 (W) x 1273 (H) mm^3

Conclusion: Small Mission Readiness

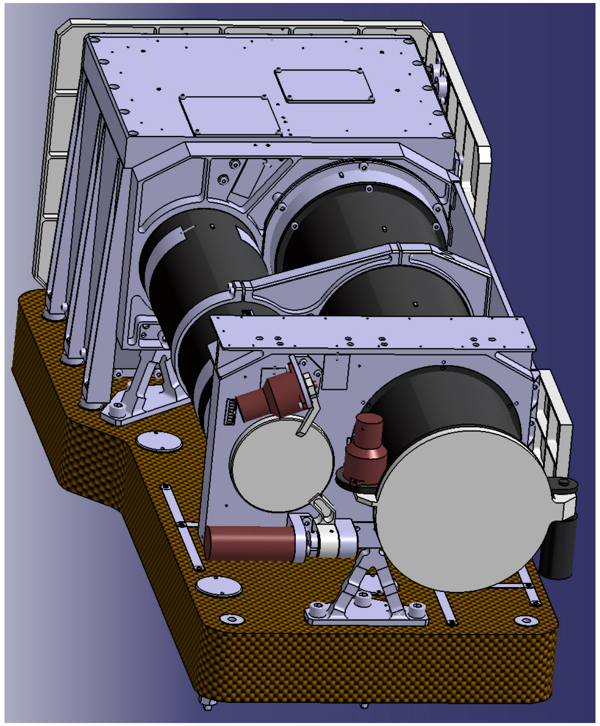
- Altogether, the SUITS P/L has:
  - a very complete science case with **4 unique assets** complementing (not addressed by) larger missions:
    - **Flare** physics at **high energy** and in **Lyman-Alpha**
    - **Prediction** and detection of **majors eruptions** and **CMEs**
    - **UV** (FUV, MUV, NUV) spectral measurements to determine local stratospheric **influence** mechanisms **on climate**
    - **Simultaneous ozone** & **radiative budget** (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 (Pegasus…)
- Suited for a Small-size (or more?) mission

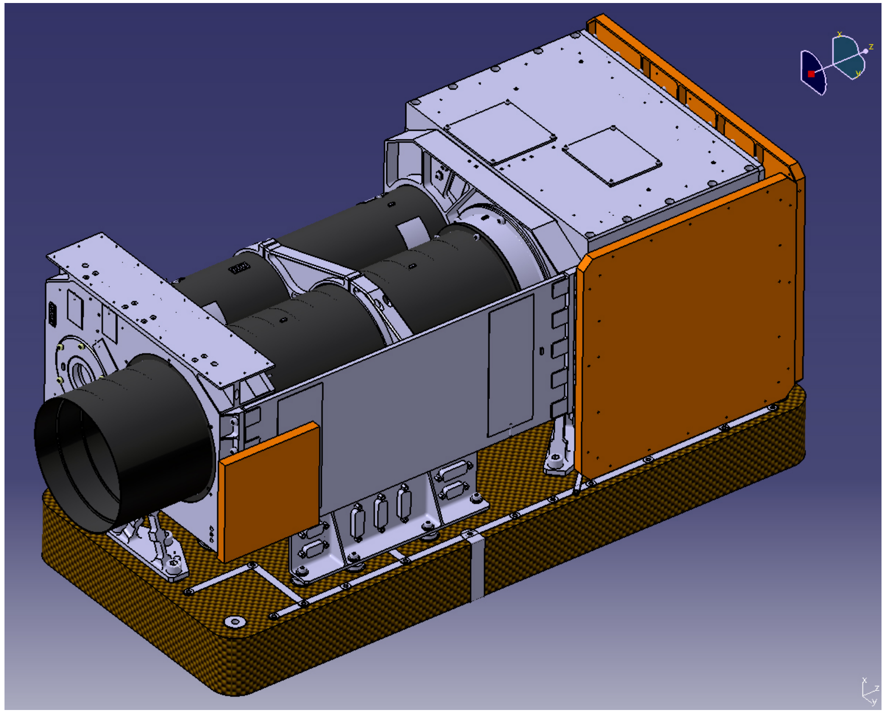
Thank you!!

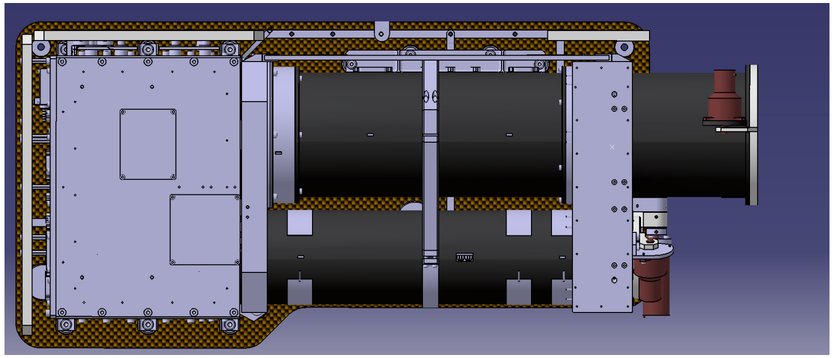


*Lyman-Alpha filtregram obtained in **1979** during the first rocket flight of the Transition Region Camera (**TRC**) and yet the best resolution (**1 arcsec**) full disc Lyman-Alpha image of the Sun. SUAVE/SUITS will reach the same resolution.*

SUAVE New Design

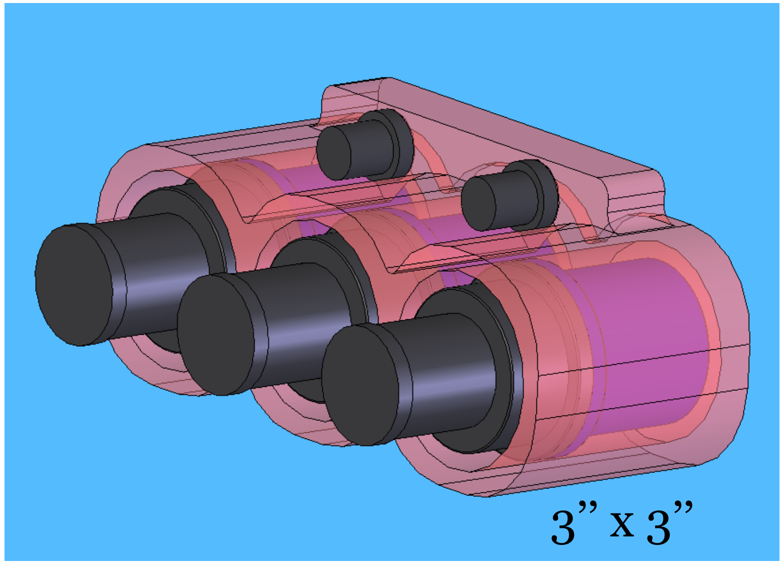




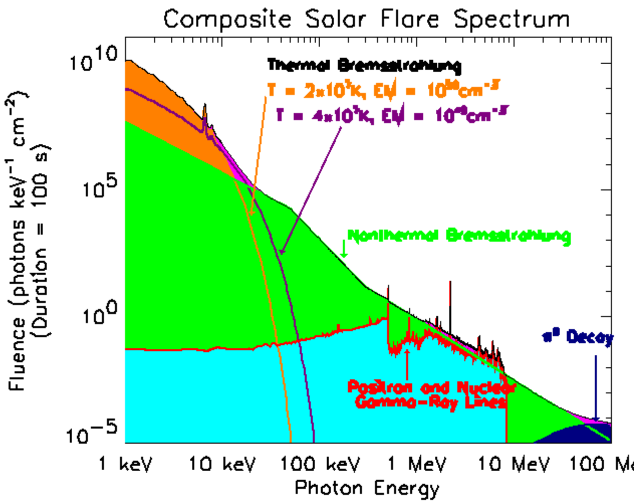


Model Payload

High Energy Burst Spectrometer (HEBS)

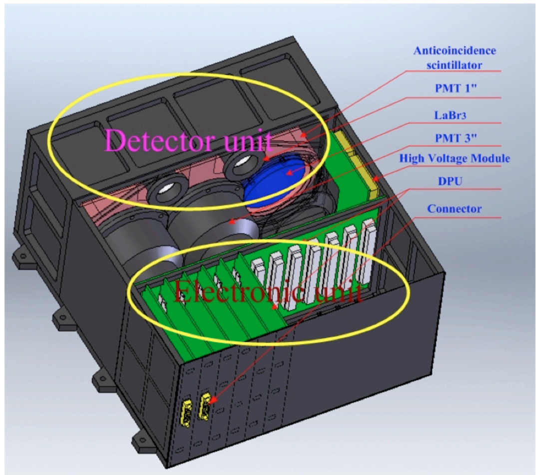


Size	310 x 170 x 230 (mm)
Weight	14 kg (2 heads)
Power	16 W (2 heads)
Energy Range	10keV - 600MeV
Energy Resolution	3%@662keV
Temporal Resolution	1s (quiescent), 32ms (flare-mode)



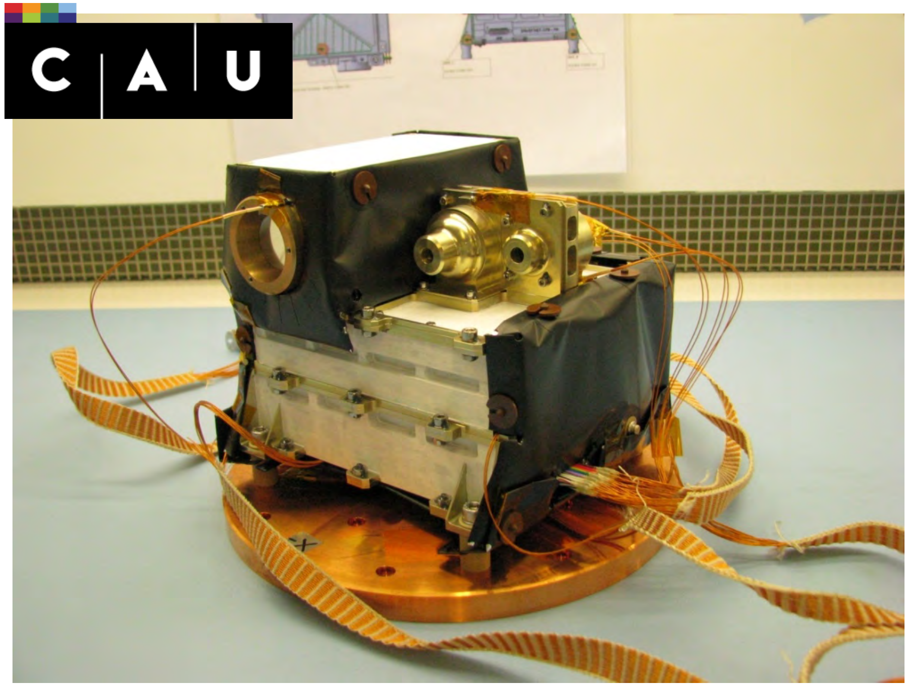
High Energy Burst Spectrometers (HEBS)
[Inheritated from SMESE CNES/CNSA Phase A+ Study]

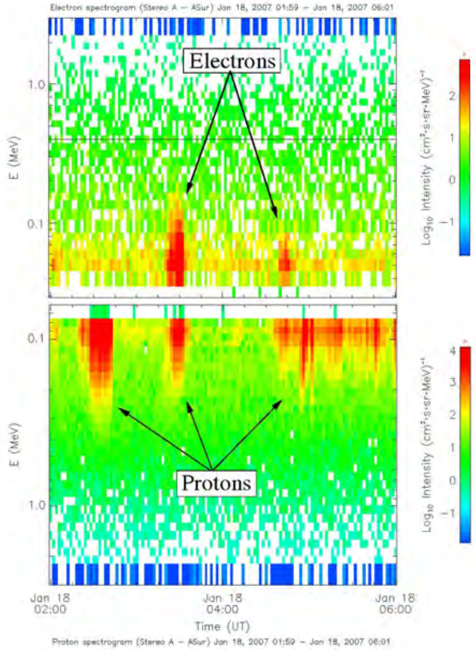
- Evaluate the electron to ion ratio and its time evolution during a Flare
- Provide estimates of the input of energy by particle beams at the top of the chromosphere
- 2 observing instruments:
  - hard X-rays from 10 keV to 500 keV
  - gamma-rays from 300 keV to 600 MeV (new)



- 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** **Protons: 20 keV – 100 MeV** **Heavy ions: ~10 MeV/nuc – ~200 MeV/nuc (species dependent)**
Time Resolution	**10s (species dependent)**

Heritage from STEREO/SEPT & MSL/RAD