SWUSV: a Microsatellite Mission for Space Weather & Ultraviolet Solar Variability

Flares and CMEs Forecasting — Lyman-Alpha Imaging FUV & MUV Local Influence on Earth Climate

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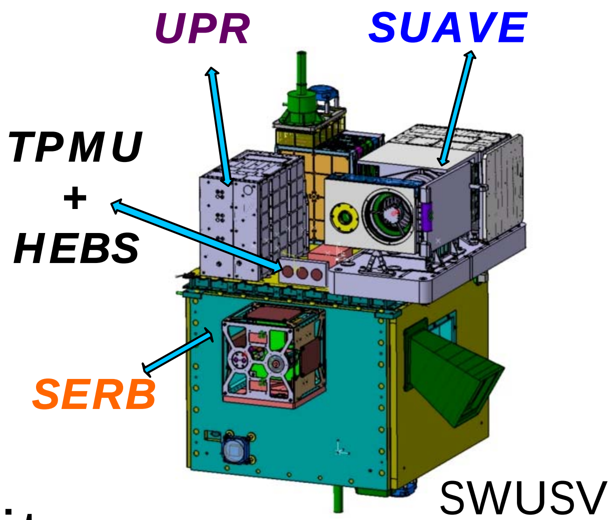
Rationale
(from Solar Physics & Space Physics talks)

- **Determine the origins of the Sun's activity**
- **Determine the dynamics and coupling of Earth's atmosphere and its response to solar and terrestrial inputs**
- **Benefit from new cycle start in 2021**

- **Continuous Lyα and Herzberg continuum (200-220 nm) imaging at good resolution of energy sources / structuration / dissipation**
- **High energy flare characterization**
- **UV Solar Spectral Irradiance 180-400 nm inputs in Earth's atmosphere (polar regions) and simultaneous monitoring of Earth's radiative budget and ozone**

Outline



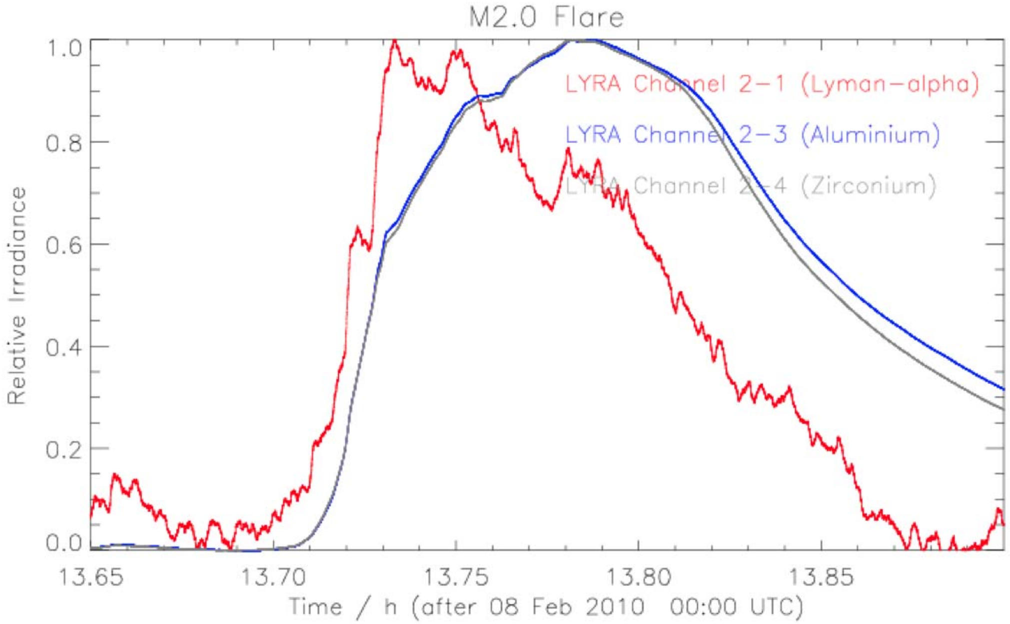
- **Part 1 –** Lyman-Alpha (and Hα) advantages to observe and identify flare/CMEs precursors
- **Part 2 –** Ultraviolet Solar Variability and its influence on climate
- **Part 3 –** The microsatellite mission SWUSV proposed to ESA and CAS

[• **Part 4 –** Technical and scientific preparation for SWUSV with the CNES SUMO (*Solar Ultraviolet Monitor and Ozone*) Nanosatellite]

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 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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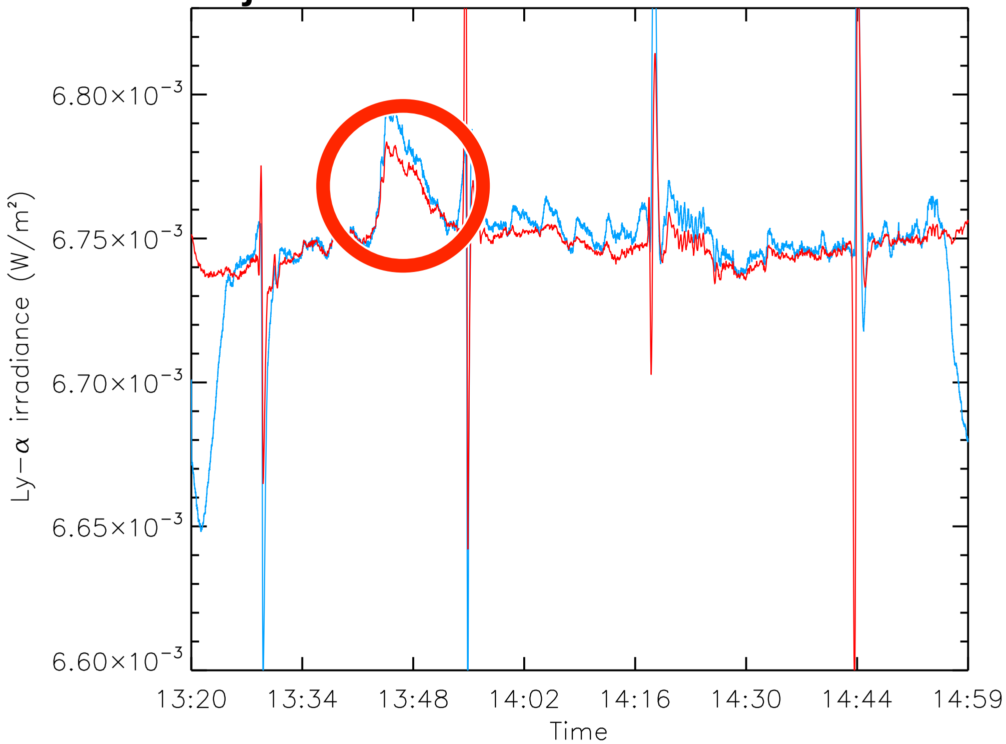

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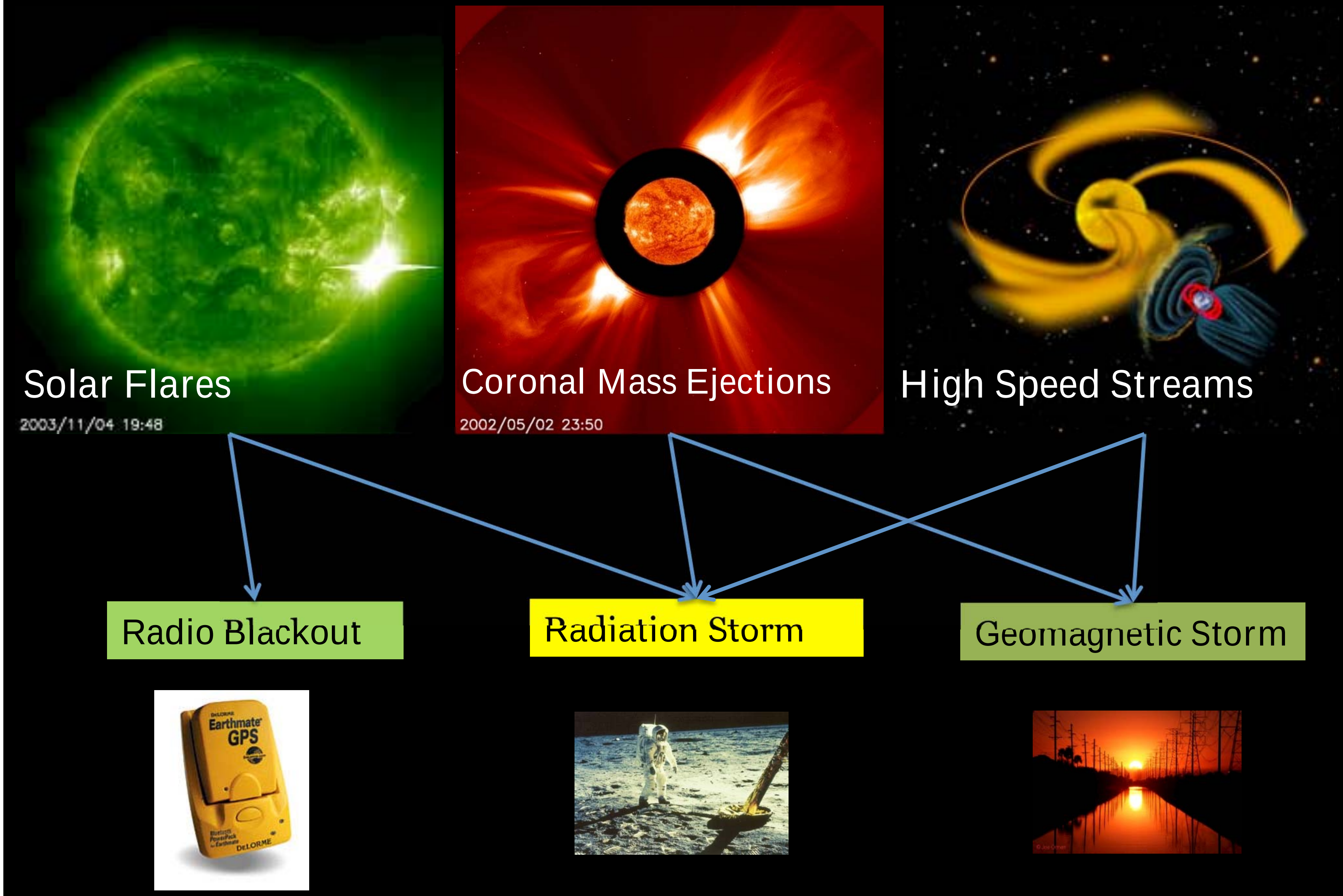

Solar Flares
2003/11/04 19:48
Coronal Mass Ejections
2002/05/02 23:50
High Speed Streams
Radio Blackout
Radiation Storm
Geomagnetic Storm
Earthmate
GPS

Predicting and monitoring large flares & CMEs: from X-ray to Lyα & Hα

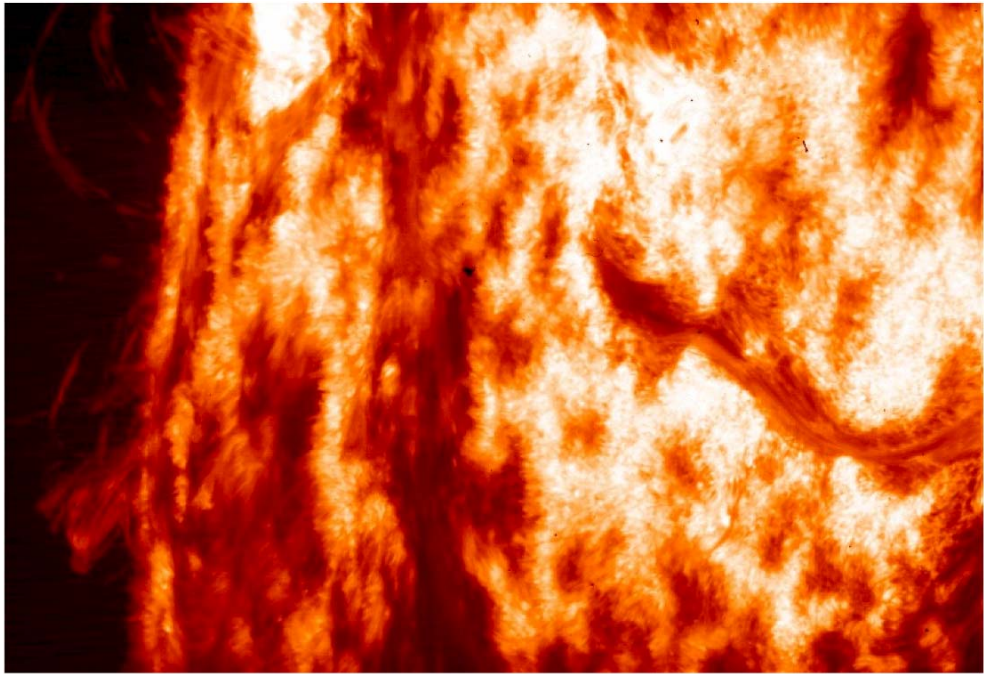
First objective is to **monitor flares** in Lyman-Alpha since as sensitive than X-ray or XUV.

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**.

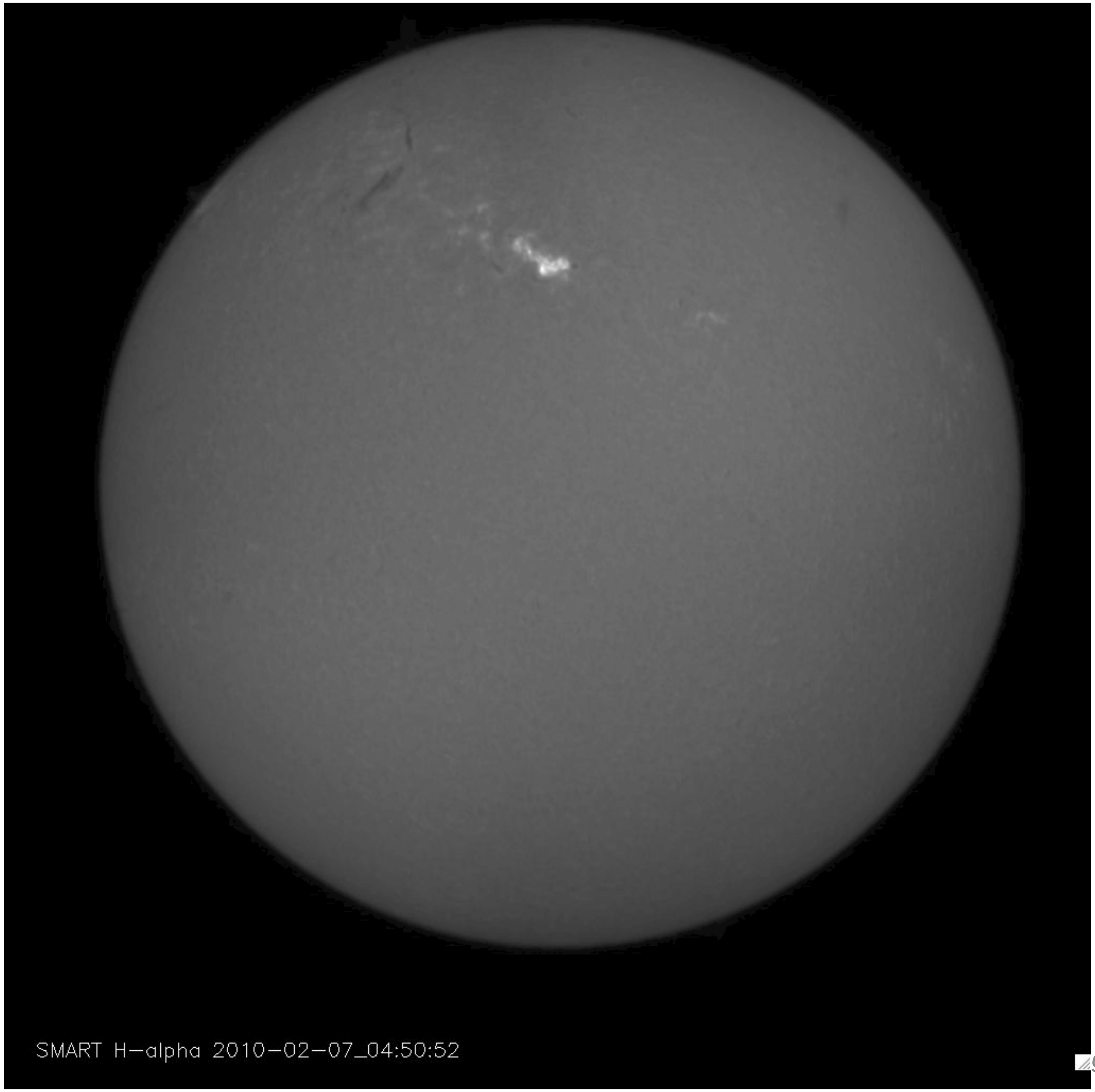
Lyα for the Early Predictions of Major Flares and CMEs

- 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)

H-Alpha Flare visible on solar disk



But **lower in atmosphere**: 1000 times less intense than in Lyman-Alpha but well visible on disk for major events

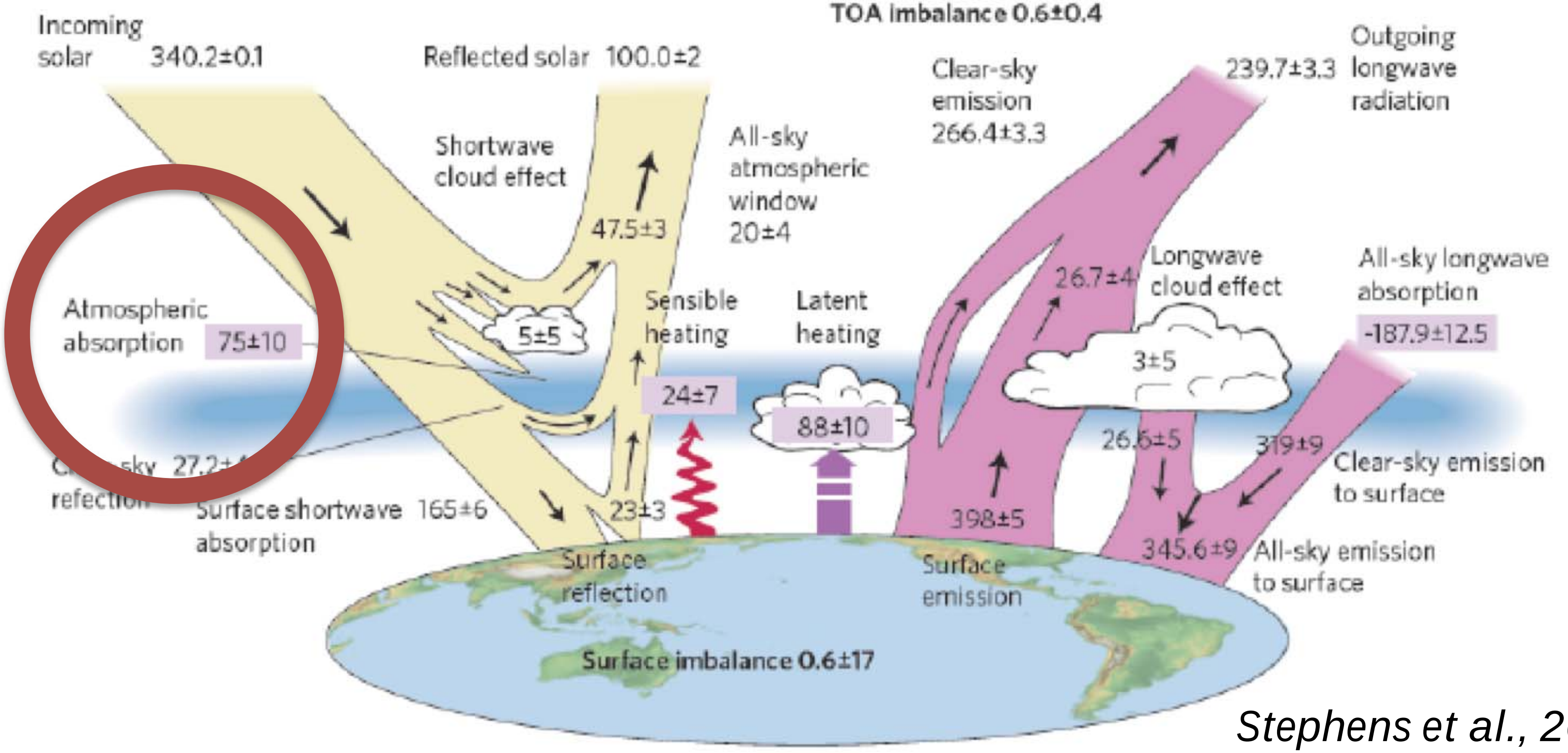
Other height -> orientation of field lines (indication of CME directivity)

Part 2

Ultraviolet Solar Variability Influence on Climate

The impacts of undulating UV (~1% of the TSI solar radiation) may be substantial. Since UV radiation creates ozone in the stratosphere, the oscillation in UV levels can affect the size of the ozone hole. Absorption of UV radiation by the ozone also heats up the stratosphere. Several recent studies (Ineson *et al.*, 2011 and Martin-Puertas *et al.*, 2012) indicate that changes in stratospheric temperatures alter weather patterns in the troposphere.

Energy (im)balance

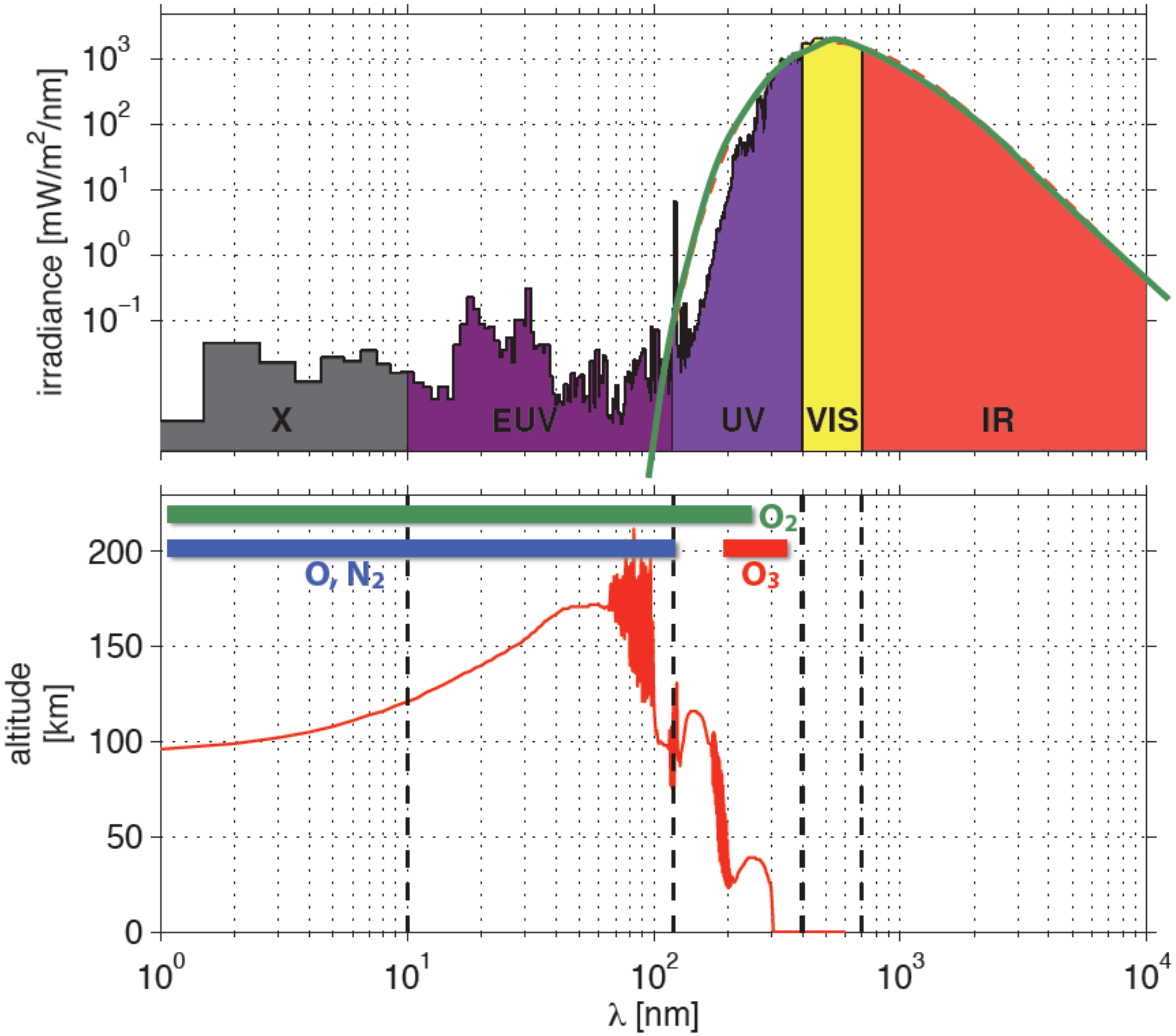


Stephens et al., 2012

Representation of the energy system of the Earth

It well illustrates inputs/outputs solar fluxes in the atmosphere and in particular the fact that the ultraviolet below 300 nm (**direct solar input to atmosphere**), representing a 1% contribution of the solar irradiance, is absorbed in the stratosphere and higher and has a significant influence on climate through its large variability (5-10%) and the temperature anomalies affecting the stratospheric and tropospheric dynamics

Incoming solar flux and atmospheric absorption

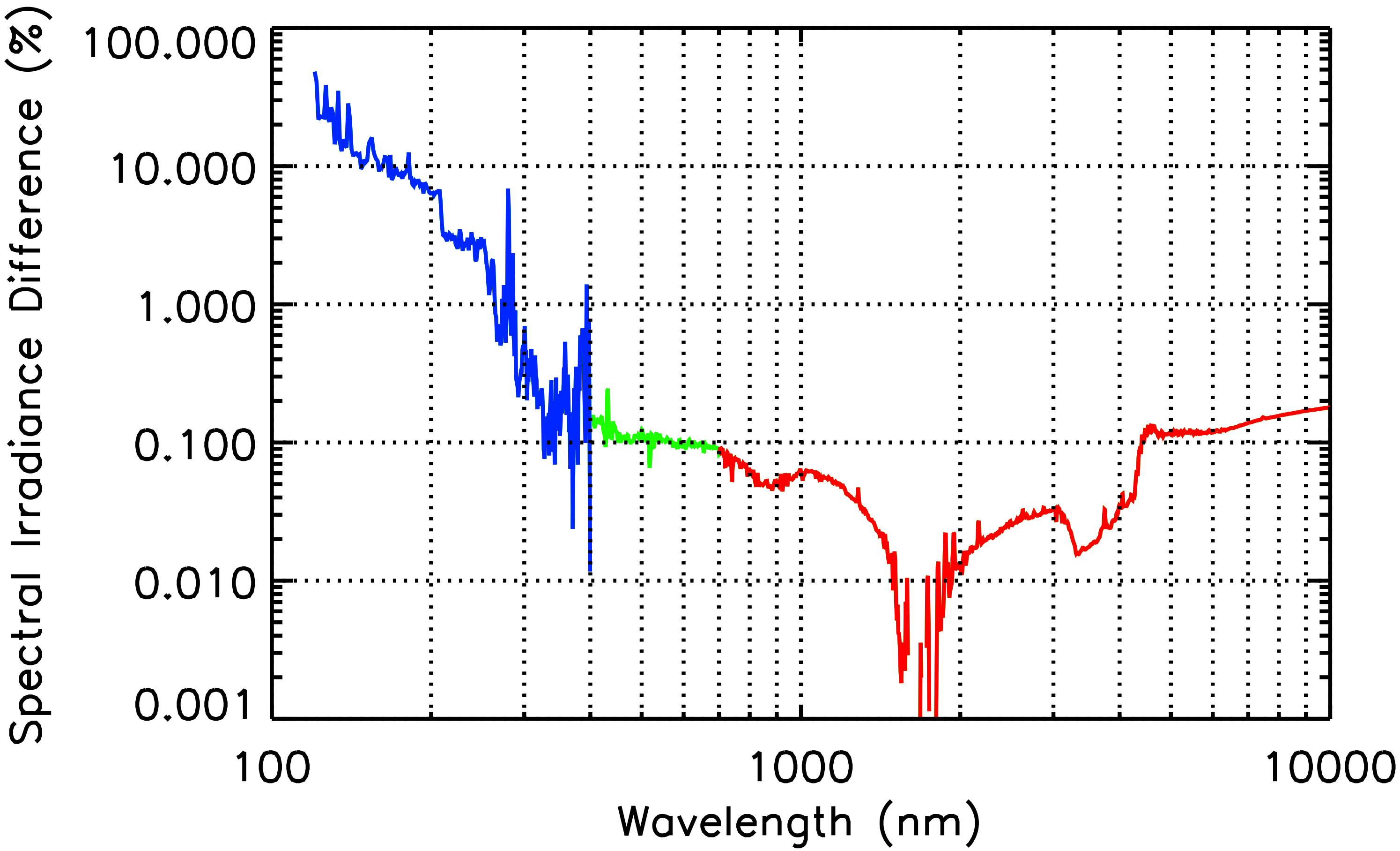


SORCE & TIMED (2003-2010)

Solar spectrum: black body at 5777 K; EUV/XUV: 4 order of magnitude less energy than UV/Vis

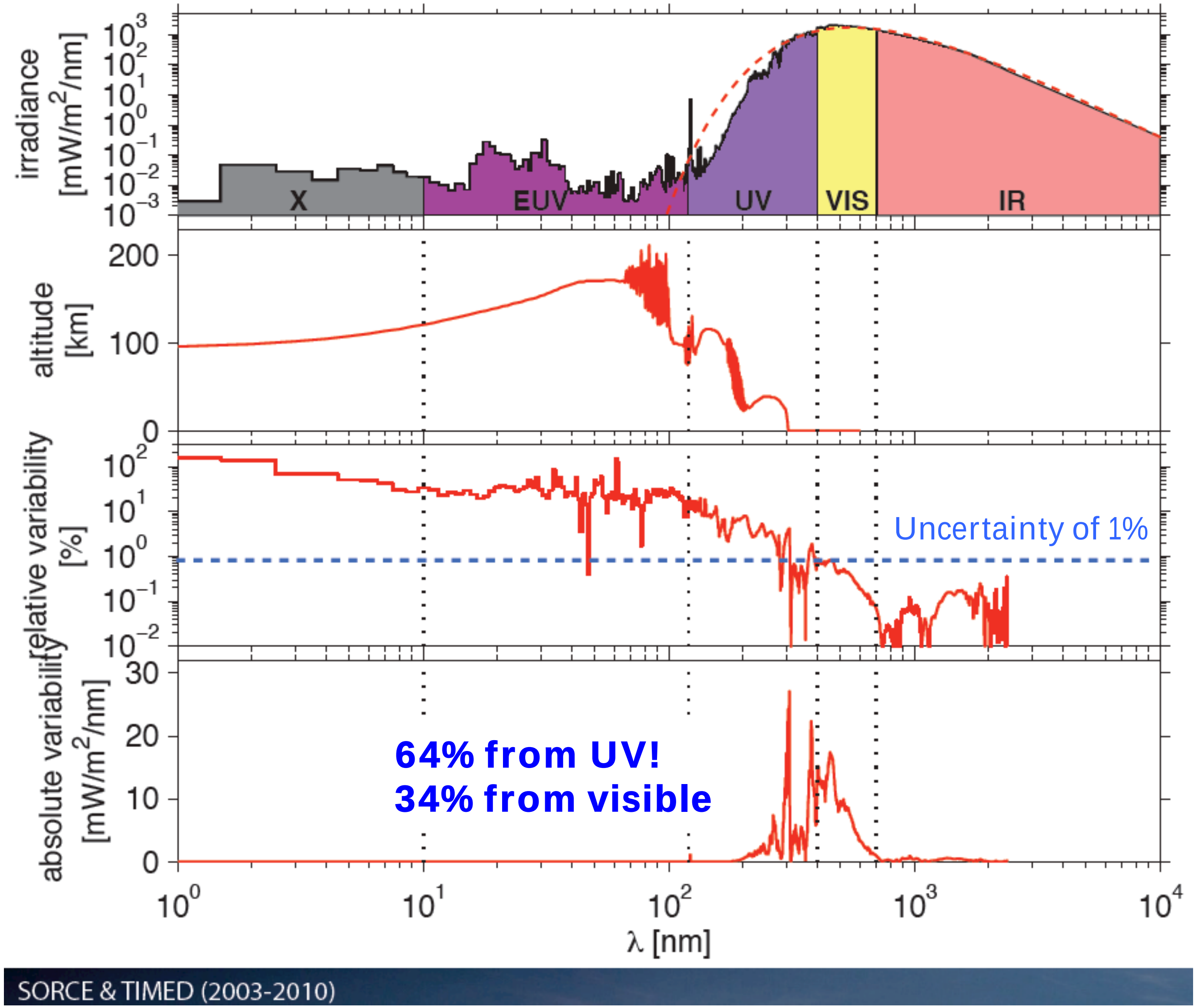
FUV-MUV: oxygen absorption (photodissocia-tion) and ozone layer

Spectral Solar Irradiance (SSI): SMax vs. SMin



Very small variations in the visible (0.1%) or IR,
but big changes in the UV (5 to 20%)

Variability *influence* is in the UV!



Solar spectrum

Absorption altitude

Relative variability

ABSOLUTE VARIABILITY over solar cycle

Climatic influence: an amplifying mechanism

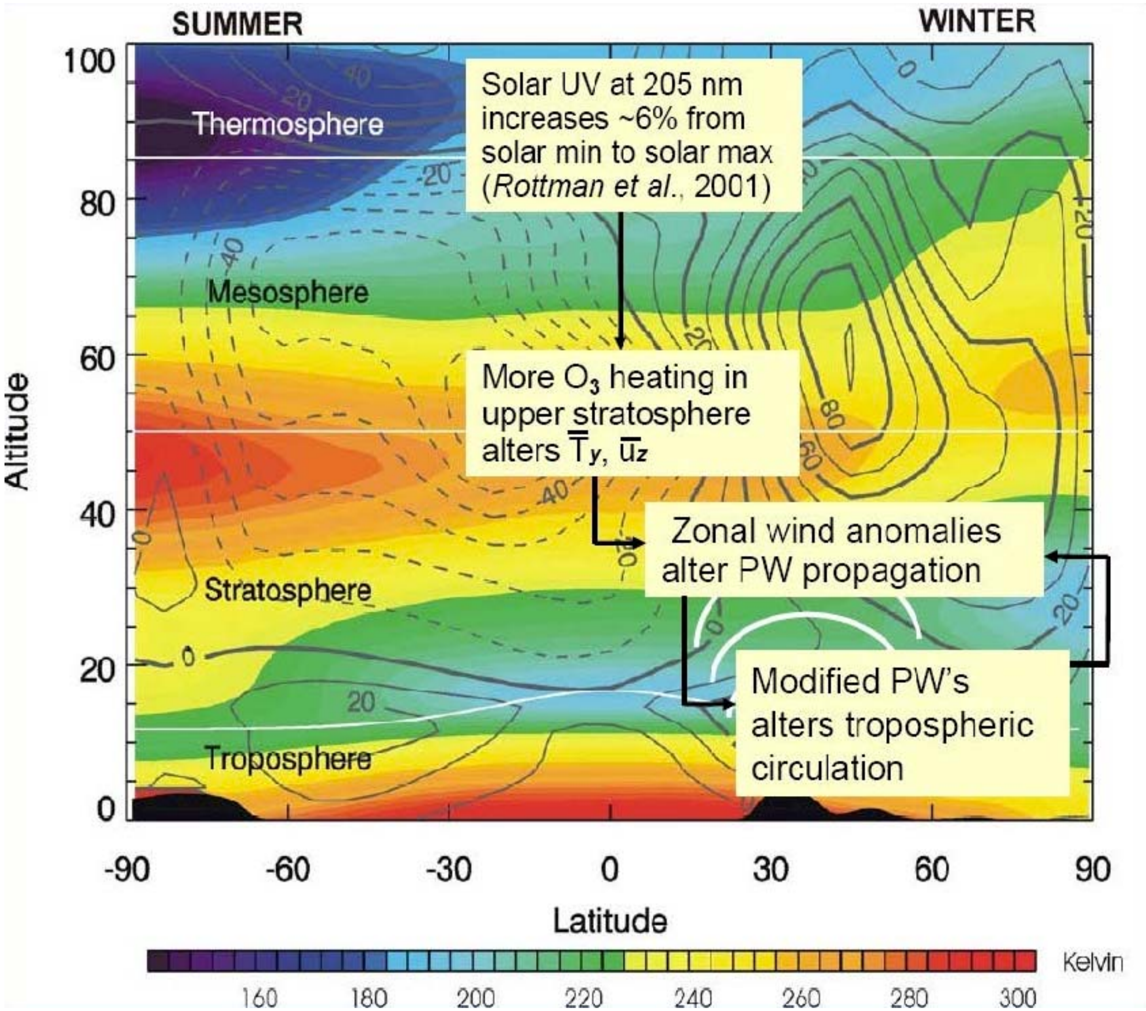


Illustration of the possible Sun-climate connection through the variability of solar UV that heats the ozone locally and create defects/ anomalies on the propagation of the zonal planetary wave that will, in turn, affect the tropospheric circulation.

[Courtesy, J. P. McCormack].

Evidence for MUV influence on stratospheric dynamics

The Spectral Irradiance Monitor (SIM) instrument on SORCE (since April 2004), have revealed that over this declining phase of the solar cycle there was a ***four to six times larger decline in ultraviolet*** than would have been predicted on the basis of our previous understanding. This reduction was partially compensated in the total solar output by an increase in radiation at visible wavelengths. **Haigh *et al.* (2010)** showed that these spectral changes appear to have led to a significant *decline from 2004 to 2007 in stratospheric ozone below an altitude of 45 km, with an increase above this altitude*. Stratospheric dynamics of ozone and oxygen is definitively affected! Confirmed by Ineson *et al.*, 2011 and Martin-Puertas *et al.*, 2012 studies.

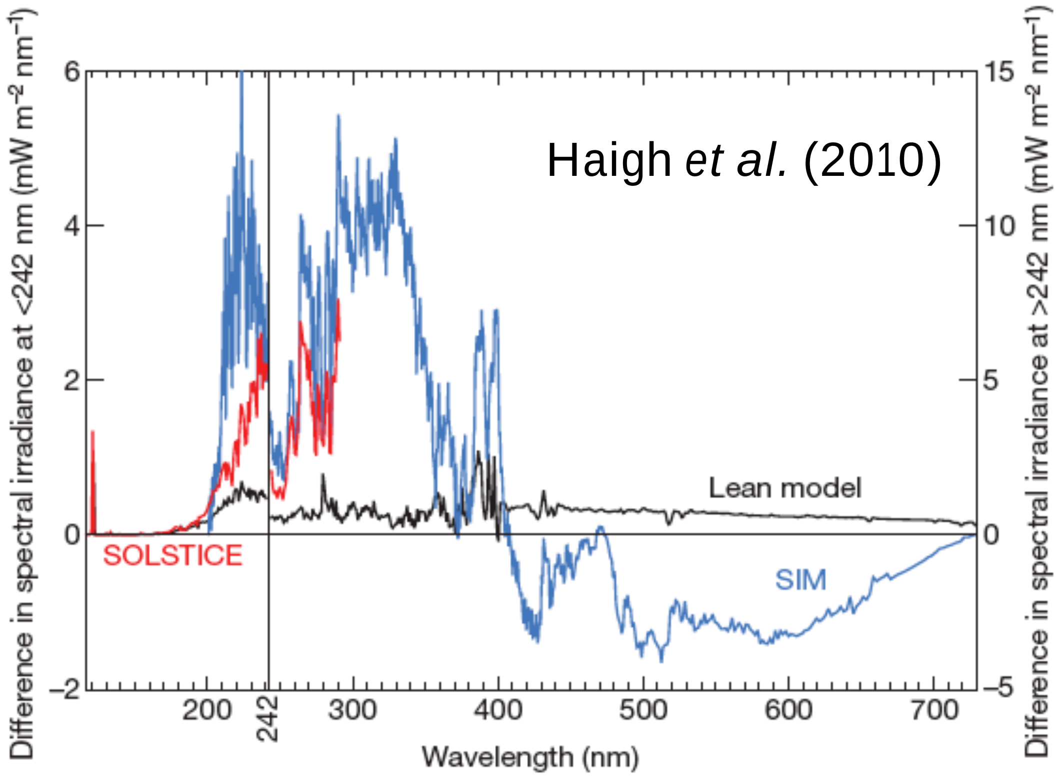
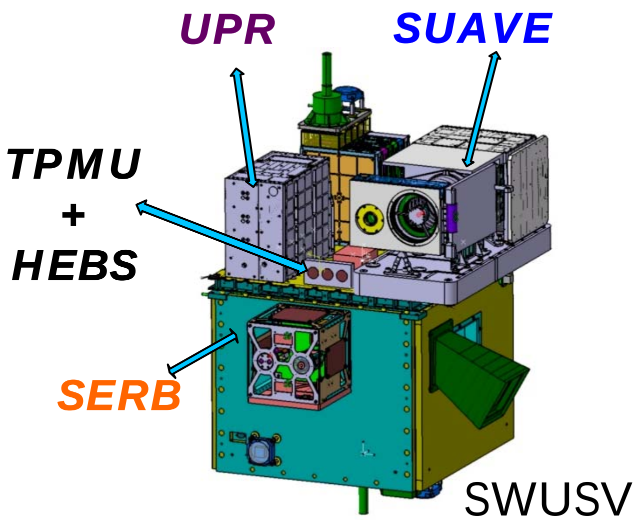


Figure 1 | Difference in solar spectrum between April 2004 and November 2007. The difference (2004–2007) in solar spectral irradiance ($W\,m^{-2}\,nm^{-1}$) derived from SIM data[4] (in blue), SOLSTICE data[8] (in red) and from the Lean model[5] (in black). Different scales are used for values at wavelengths less and more than 242 nm (see left and right axes respectively).

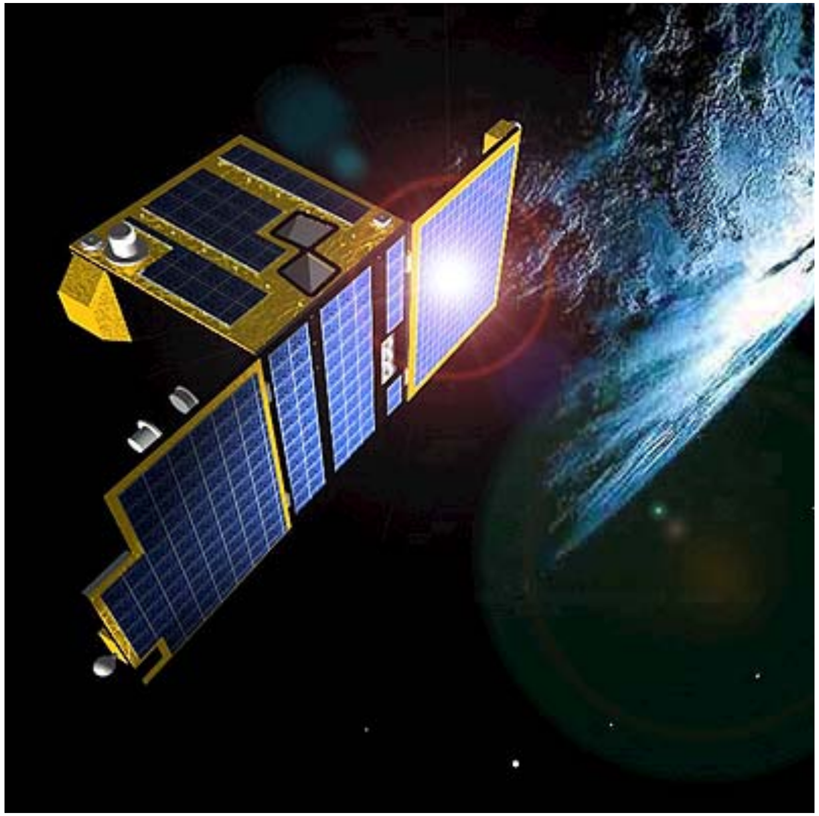
Part 3

A New Microsatellite Mission for **Space Weather & Ultraviolet Solar Variability** (**SWUSV**)

Model Payload and Rationale



New Microsatellite for UV & FUV Variability and Space Weather *building on PROBA-2 and PICARD*

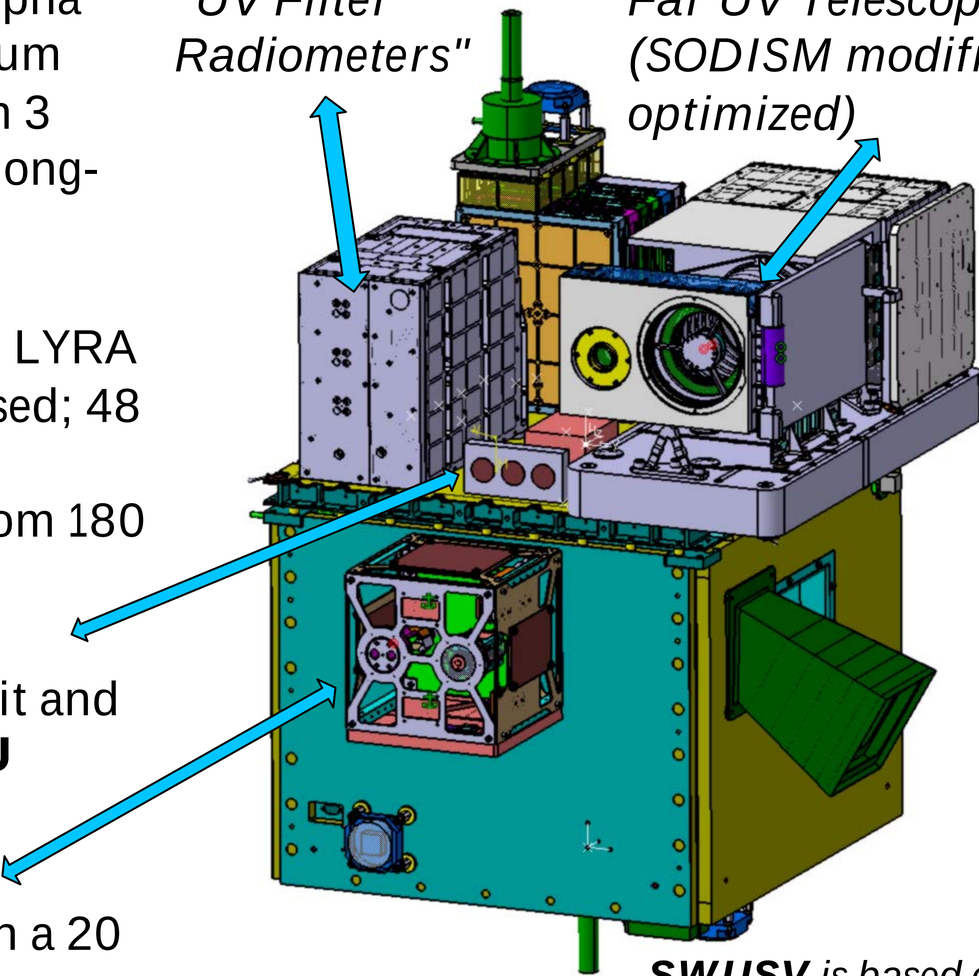


PROBA-2: LYRA, SWAP, Magnetometer and Ionosphere

PICARD: SODISM, PREMOS, SOVAP

SWUSV: Space Weather & Ultraviolet Solar Variability Microsatellite

- **SUAVE** (*Solar Ultraviolet Advanced Variability Experiment*), Lyman-Alpha and 200-220 nm Herzberg continuum imaging (sources of variability) with 3 redundant set of filters to preserve long-term sensitivity
- **UPR** (*Ultraviolet Passband Radiometers*) based on PREMOS & LYRA with 64 UV filter radiometers (16 used; 48 redundant) for Lyman-Alpha, CN bandhead (385-390 nm) and UV from 180 to 400 nm by 20 nm banpasses
- Scientific Vector Magnetometer & Thermal Plasma Measurements Unit and Langmuir Probes (**SGVM** & **TPMU +DSLP** from ESA/PROBA-2)
- **SERB** (*Solar irradiance & Earth Radiative Budget*): 4 instruments in a 20 cm cube of 3 kg (including TSI)

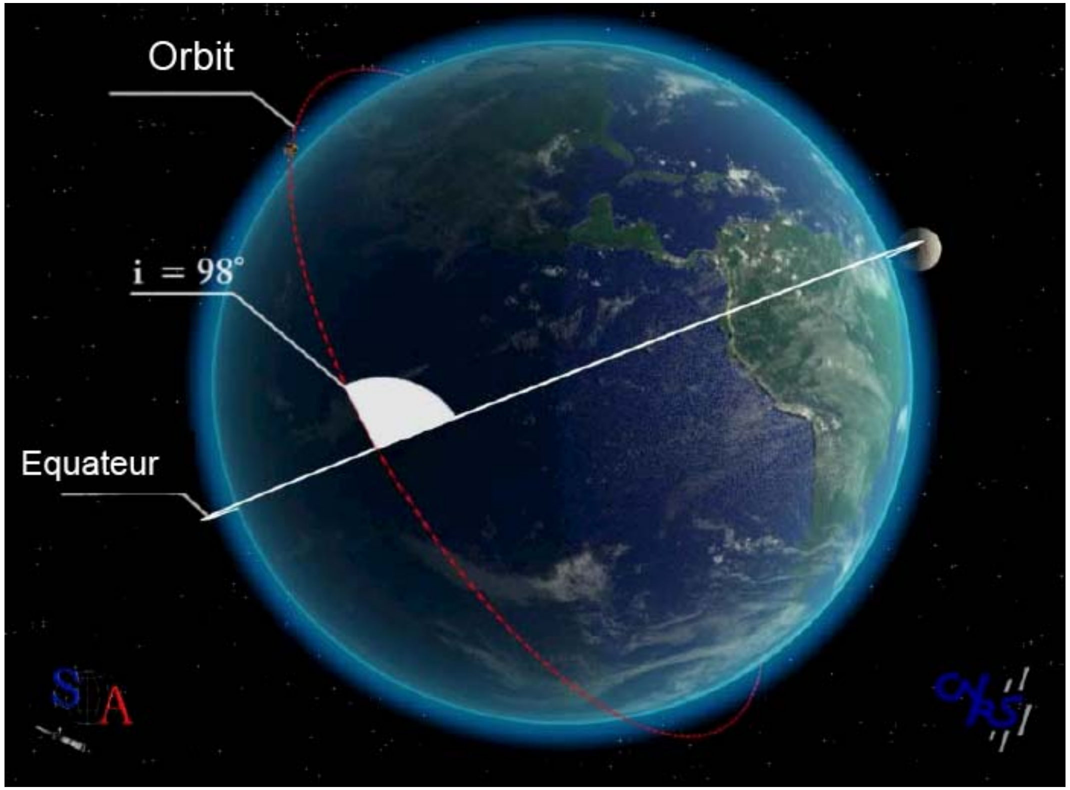


***SWUSV** is based on the same CNES/Myriade platform than PICARD*

Thermal stability starts with the right orbit choice

Orbit with "almost" permanent Sun viewing (alike PICARD):

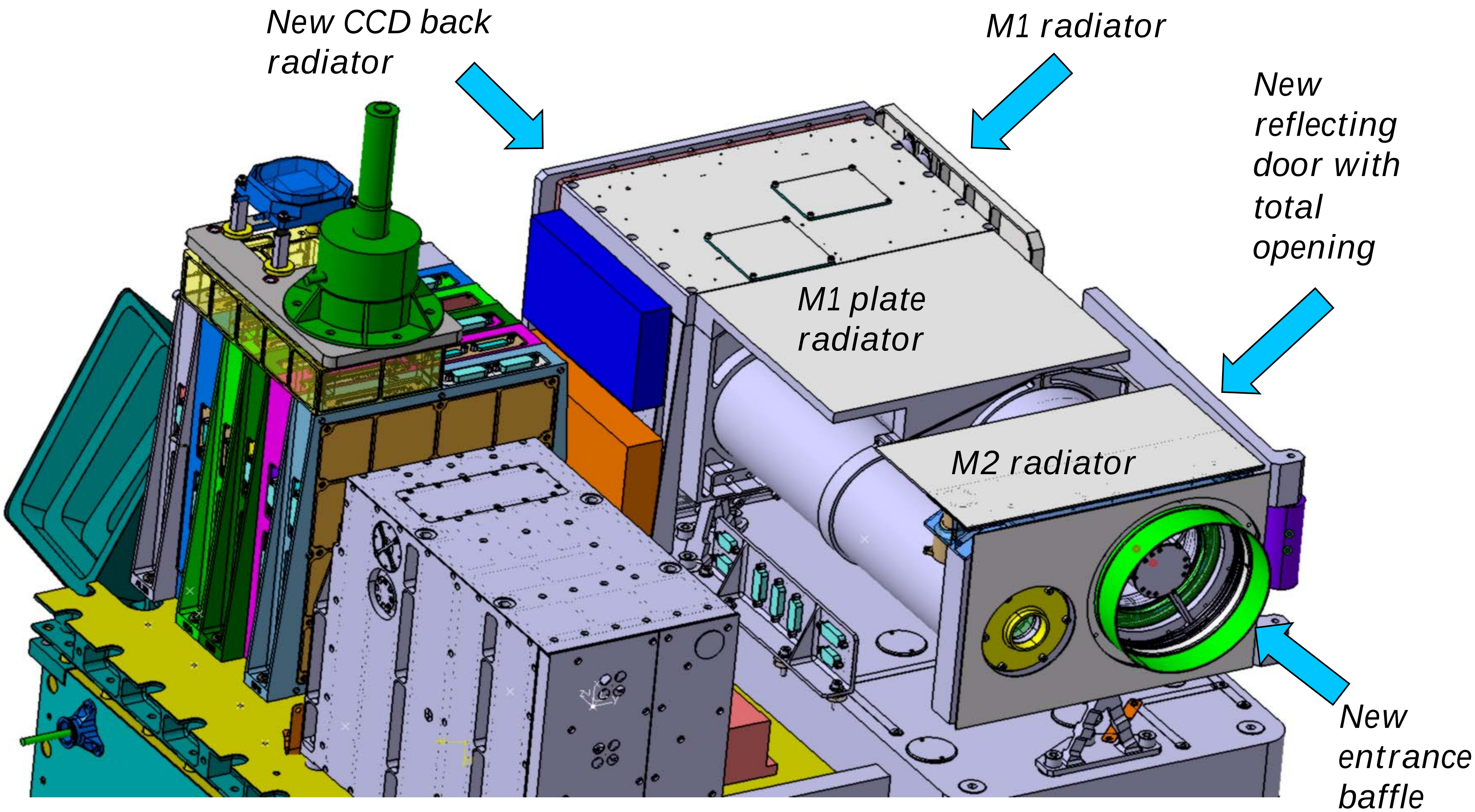
- Sun synchronous orbit
- Ascending node: 06h00
- Altitude: **> 725 km**
- inclination:98.29°
- Eccentricity: 1.04×10^{-3}
- Argument of periapsis: 90°

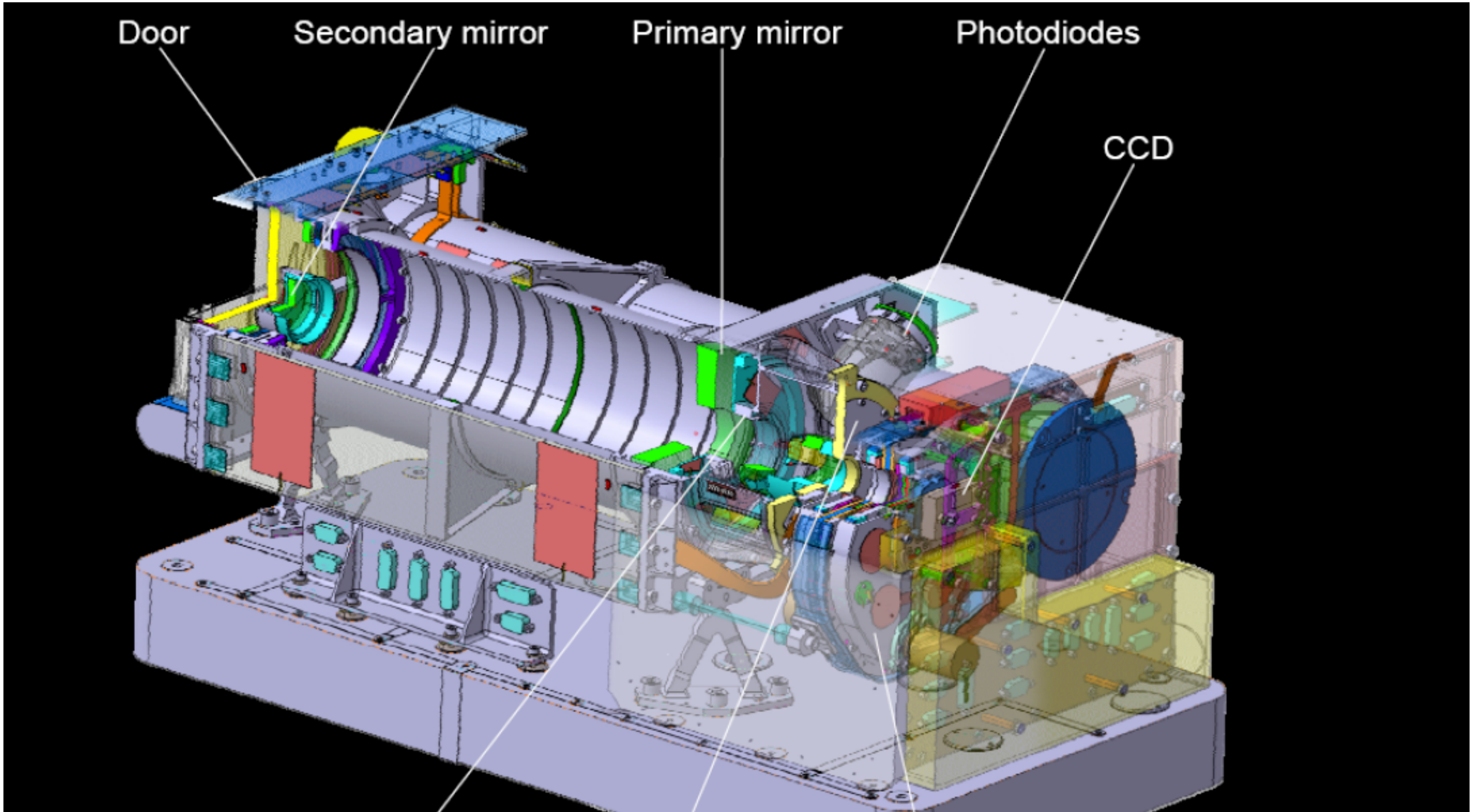


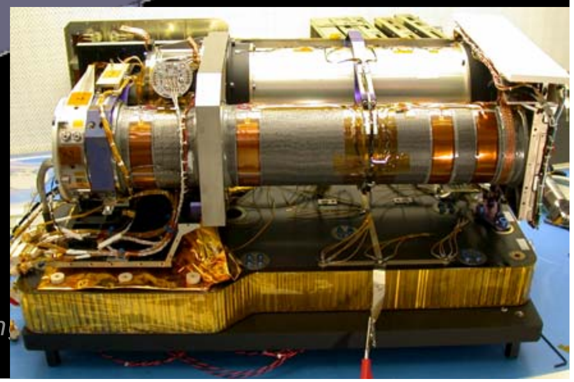
SUAVE (*Solar Ultraviolet Advanced Variability Experiment*)

FUV Imaging Telescope (evolution & optimization of SODISM):

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



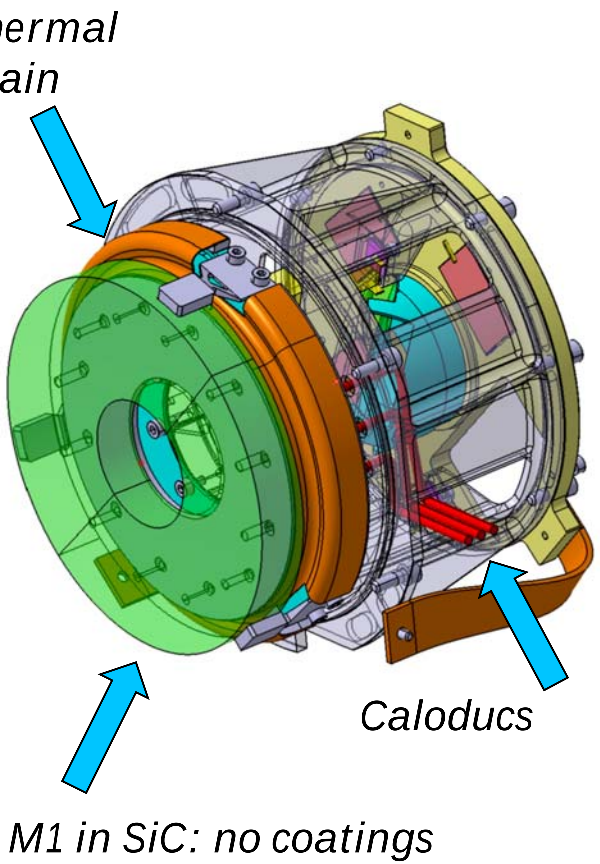

Door
Secondary mirror
Primary mirror
Photodiodes
CCD
Piezoelectrics mechanism
Shutter mechanism
Filters wheel mechanism

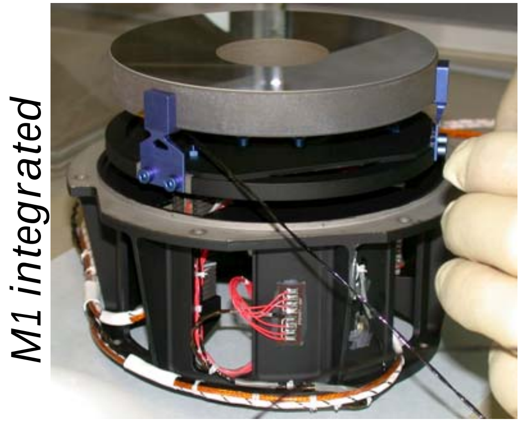


New SiC Mirrors: FUV duty cycle

Unique properties:

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





R&T CNES 2014–2015: realization of a representative optical and thermal breadboard of SUAVE SiC mirrors and supports (primary and secondary)

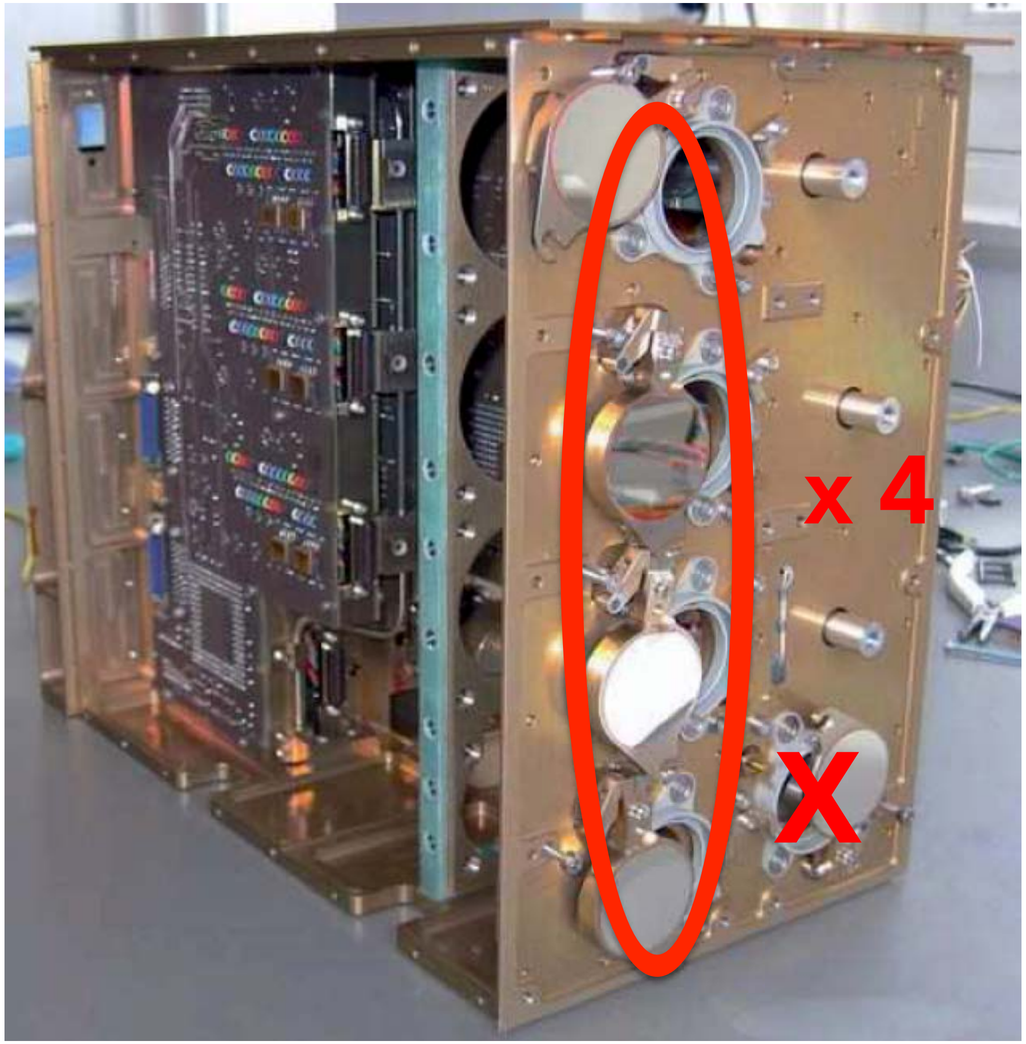
Filter Radiometers FUV, MUV & UV: "extending PREMOS & LYRA"

Absolute variability is mainly at Lyman-Alpha and between 180–400 nm; then we implement 64 channels (16 used; 48 redundant):

- Lyman Alpha 121.6 nm (4 at different rates)
- CN bandhead at 385–390 nm
- 11 radiometers of Δ20 nm from 180 to 400 nm

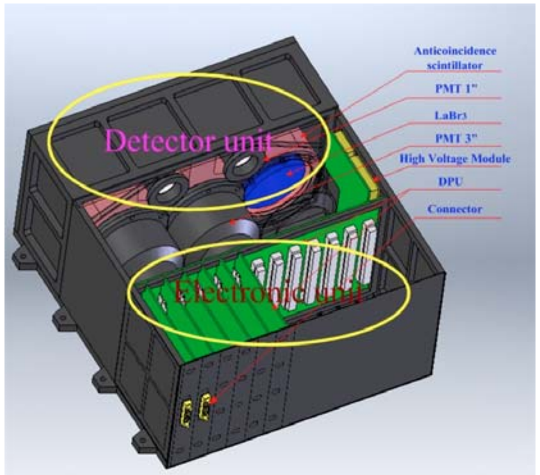
The 121.6 and 200–220 nm channels support the imaging mode of SUAVE.

Note that the TSI (Total Solar Irradiance) is now measured by SERB-SR



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)



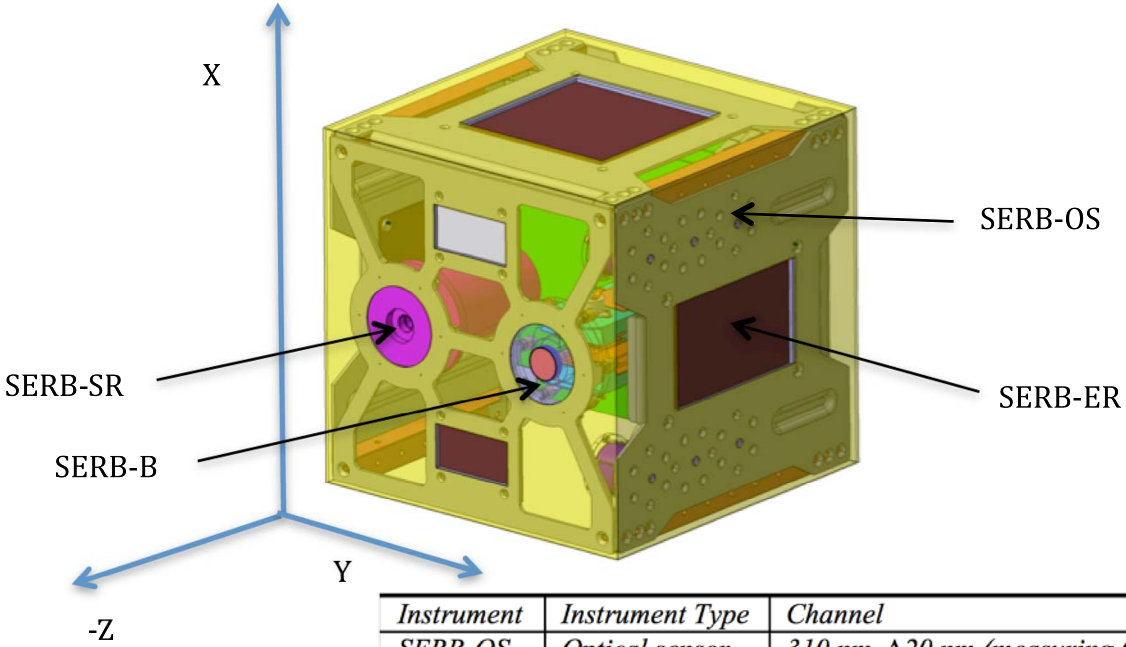
- HEBS will provide the first systematic measurements of the photon spectrum from a few tens of keV to a few hundreds of MeV
- HEBS has carried a Phase A study in the framework of the CNES/CNSA microsatellite SMESE that confirmed feasibility and readiness. Instrument is to be realized by Purple Mountain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

Space Weather Instrumentation

- Science Grade Vector Magnetometer (**SGVM**, alike ESA/PROBA-2)
- Dual Spherical Langmuir Probes (**DSLP**) for plasma density and temperature
- Thermal Plasma Measurement Unit (**TPMU**) for ionosphere characterization: electron temperature, floating potential, ion temperature, concentration and composition

Simultaneous Radiative Budget Experiment: SERB

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

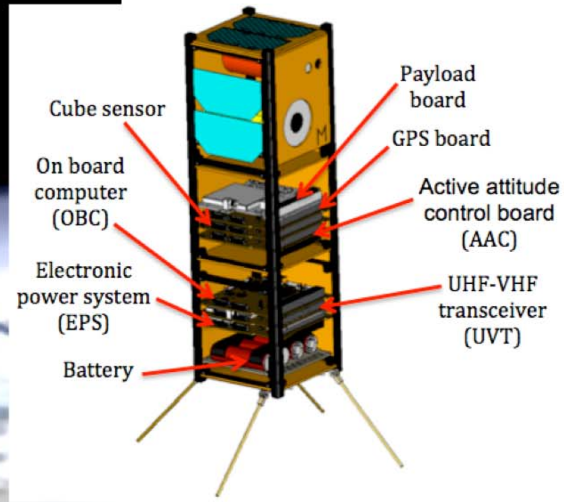


***SERB**: Solar irradiance and Earth Radiative Budget (4 instruments in a 20 cm^3 cube of 3 kg)*

Instrument	*Instrument Type*	*Channel*
SERB-OS	*Optical sensor*	*310 nm, Δ20 nm (measuring O3)* *350 - 450 nm (polar albedo, particle size)* *535 nm, Δ20 nm (ref. for differential measures)* *760 nm, Δ20 nm (measuring altitude of cloud top)* *880 nm, Δ50 nm (particle size)* *940 nm, Δ20 nm (water vapor H20)*
SERB-ER	*Radiometer*	*2.5 μm - 40 μm*
SERB-B	*Bolometer*	*0.2 μm - 40 μm*
SERB-SR	*Radiometer*	*0.2 μm - 3 μm (TSI: PMO6 type)*

SUMO, a nano-satellite to study solar UV variability influence on ozone

Part 4



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(+Belgium and industrial participations: IRMB, ORB, Nanovation)

- Demonstration of contamination control (ZnO nanostructures on SP)
- Demonstration of nanostructured anti-reflection coatings
- Demonstration of solar-blind (λ<280 nm) MgZnO detectors

Context & Perspectives

Context:

- CNES is looking now for "opportunities" (no National Initiative stand-alone microsatellite missions are likely in the future)
- Expertise acquired with PICARD & PROBA-2, solar & plasma databases (MEDOC, CDPP), filaments' tracking (grd, SDO, etc.)
- Following ESA Small-size Mission proposal in June 2012, SWUSV is ready, properly sized and yet with high scientific return for the ESA-CAS Small-size Mission possibility

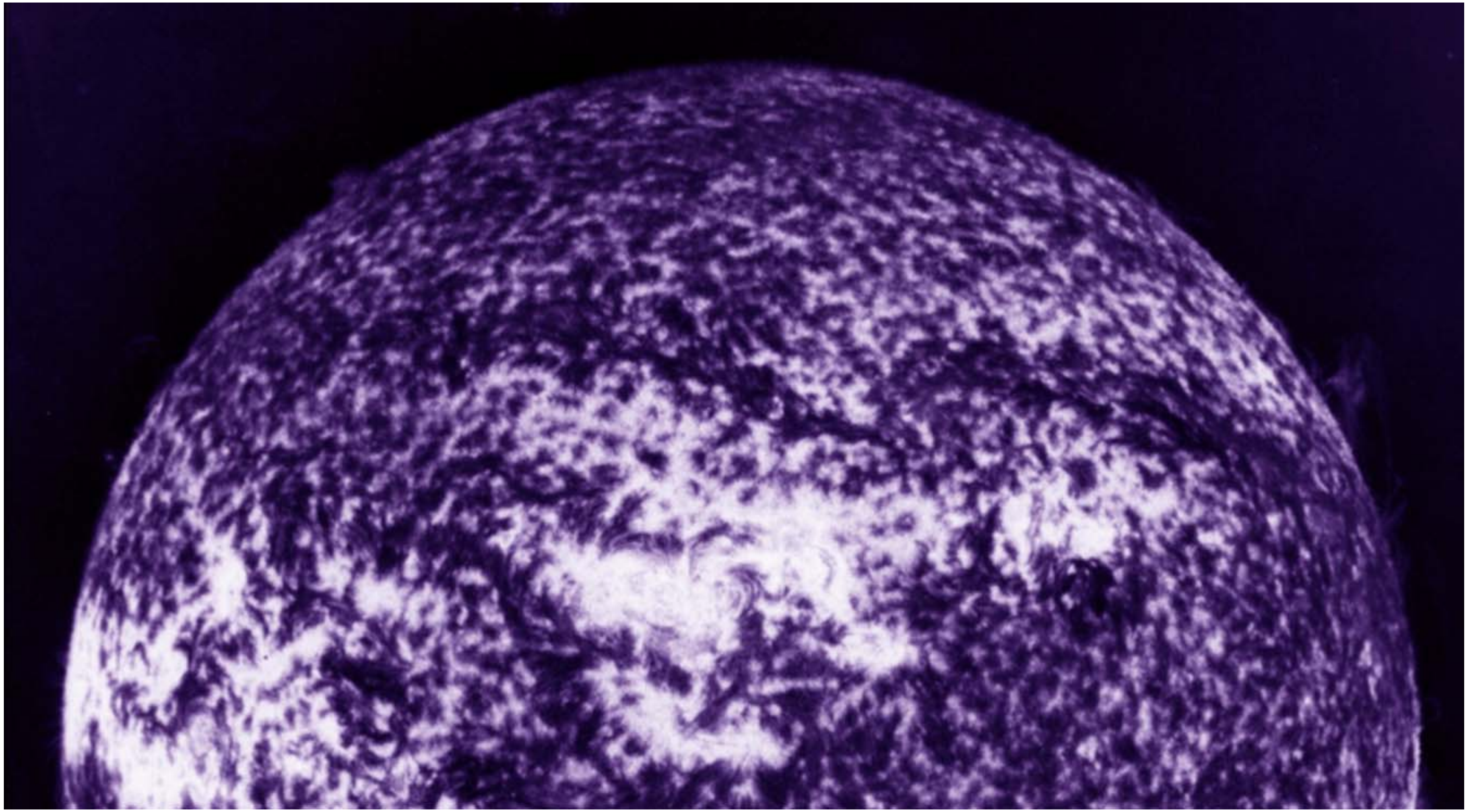
Perspectives:

- Need to further organize collaboration at European level for this mission (in particular Belgium, German participations) to proceed with an even stronger candidate for the ESA-CAS Small-size Mission
- French participation in SWUSV could be envisaged as the French/CNES contribution to ESA SSA (*Space Situational Awareness*) Space Weather program now in Phase II

Conclusion: Small-size Mission Readiness

- Altogether, the SWUSV P/L has:
  - a very complete science case with **3 unique assets** complementing larger missions (like RHESSI or TRACE):
    - Prediction and detection of majors eruptions and CMEs
    - UV spectral measurements to determine local stratospheric influence mechanisms on climate
    - Simultaneous radiative budget with 1% in differential
  - a novel and very mature P/L with TRL 6 to 9 since based on optimized instruments of PICARD and PROBA-2, allowing development on 3-4 years (2021 launch compatible)
  - a sound mission profile since of recurrent use of the CNES/ Myriade (or Myriade+) platform, 6 Gbits/day of telemetry allowance, and a piggy-back low cost VEGA or LM-2 launch
- Suited for ESA-CAS Small-size mission and a possible, valuable, contribution to ESA/SSA

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. SWUSV will have the same resolution.*