SUITS: a Microsatellite Mission for Space Weather & Ultraviolet Solar Variability Studies

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

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Presentation Plan

- Introduction — Luc Damé
- Science rationale, objectives:
  - Flares & activity — Siming Liu
  - Space Weather, variability, UV & Climate — Luc Damé
- Model Payload
  - High energy flares & particles — Siming Liu
  - Space Weather and flares-CMEs imaging, variability, possible extras — Luc Damé
- Mission Profile
  - Orbit, platform, launcher, heritage — Luc Damé
- Cooperation
- Conclusion

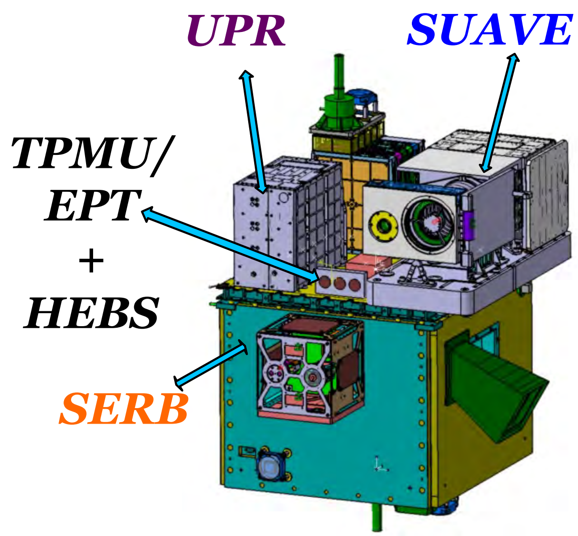
Rationale

(Solar Physics & Space Physics issues)

- **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**
- **UV Solar Spectral Irradiance 120-400 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 start in 2021**

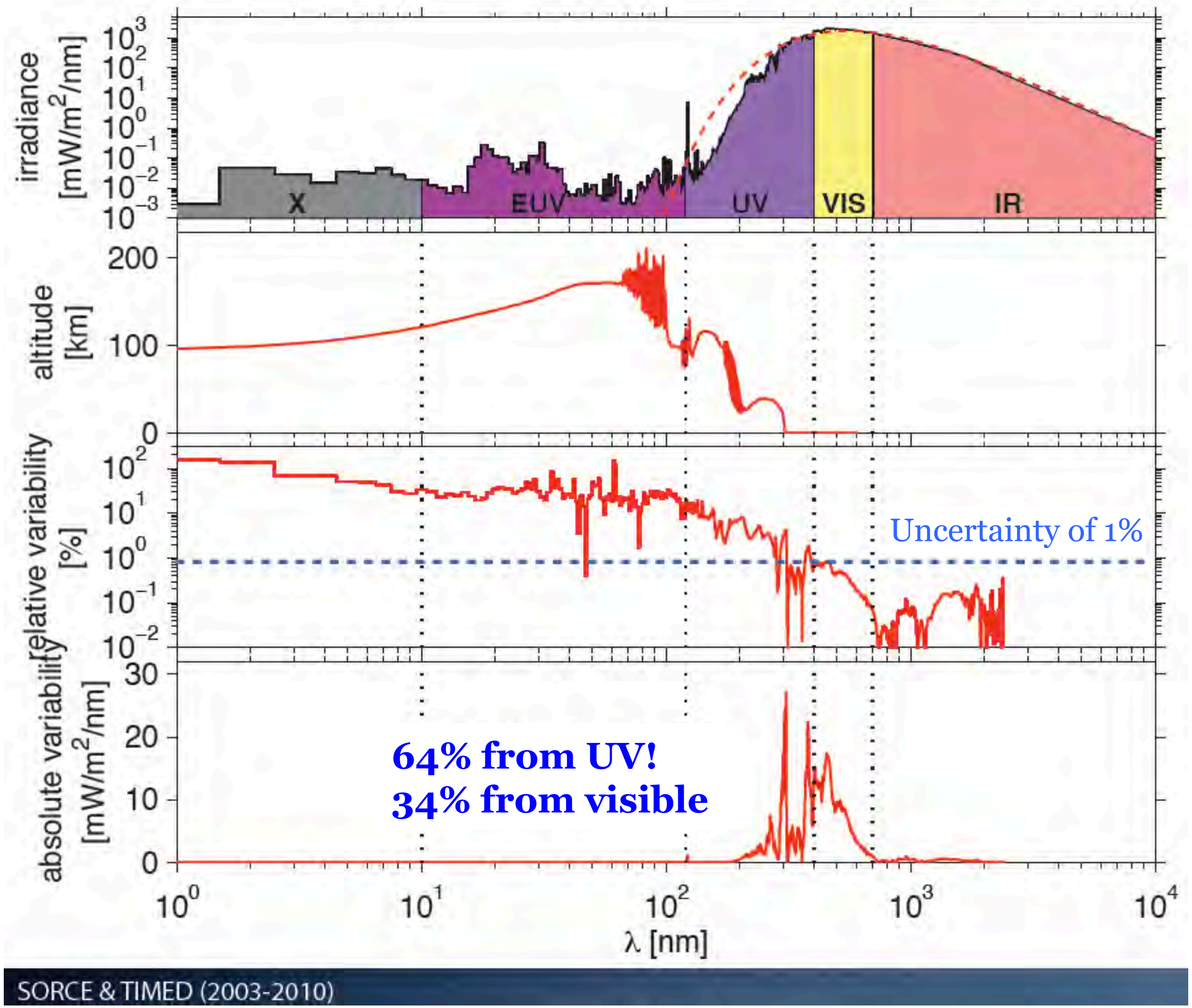
Scientific Rationale

- **1** – High energy flare physics
- **2** – Lyman-Alpha advantages in observing and identifying flare/CMEs precursors
- **3** – Ultraviolet Solar Variability and its influence on climate



SUITS (Myriade)

Variability of Solar Spectrum



Solar spectrum

Absorption altitude

Relative variability

ABSOLUTE VARIABILITY over solar cycle

Timing and shape of TSI flare signal

TSI observations of three >X10 flares:

(Woods et al. 2006)

peak of TSI signal coincident with peak of GOES derivative

profile of TSI signal similar to GOES derivative in rising phase

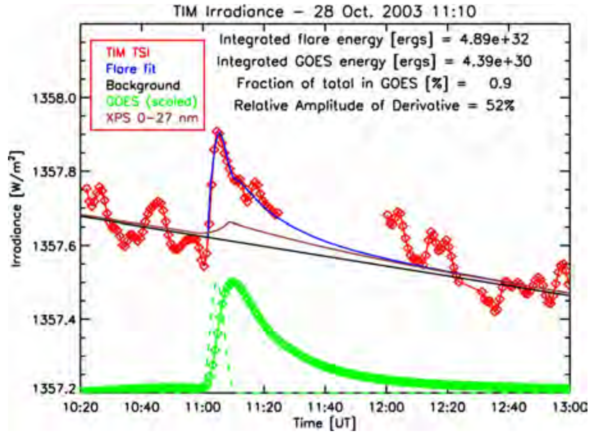
TSI profile has more extended tail in decaying phase

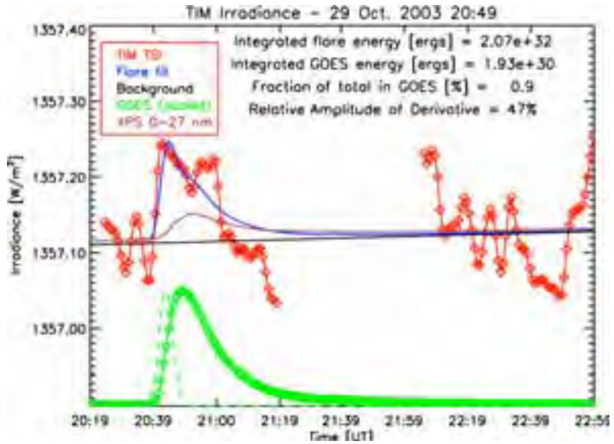
Epoch analysis of 2100 flares:

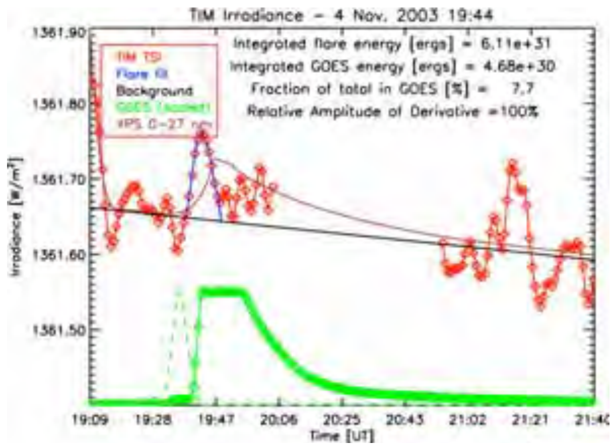
(Kretzschmar 2011)

TSI & WL peak at GOES derivative max.

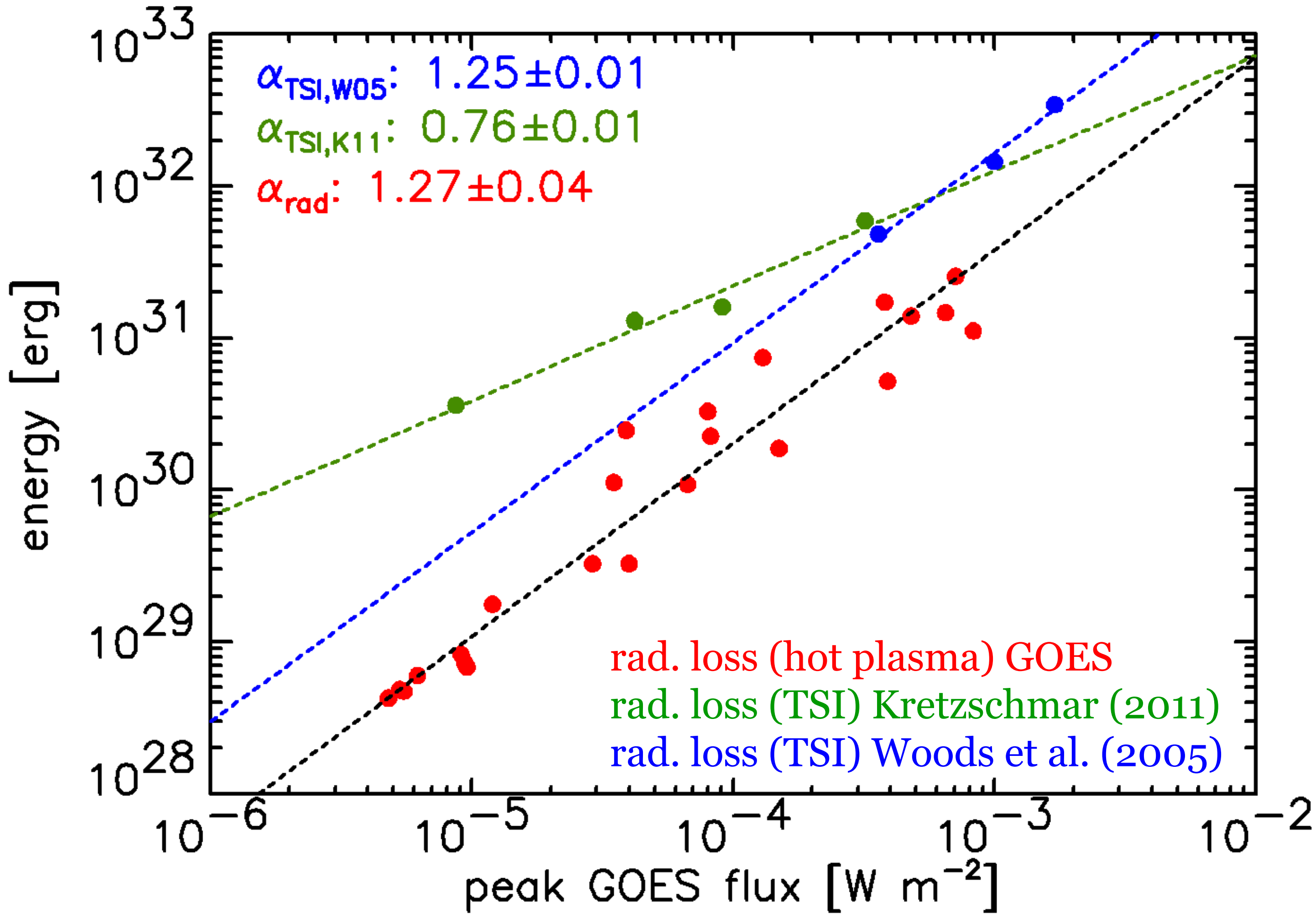
no gradual phase for TSI (below noise?)





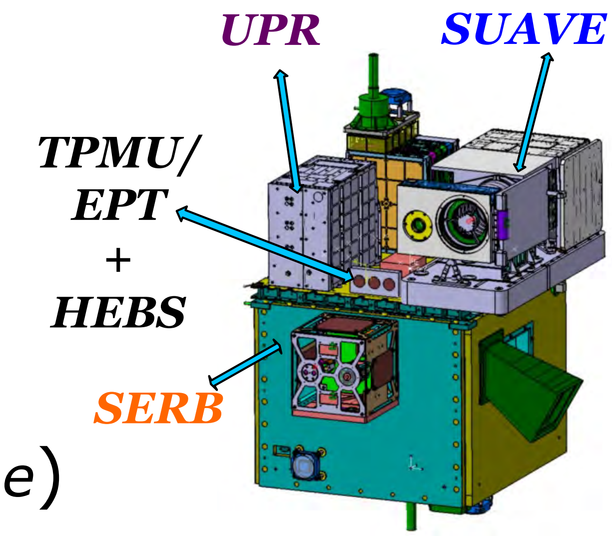


Total radiative losses and radiative losses of hot plasma



Model Payload
High Energy & Particles

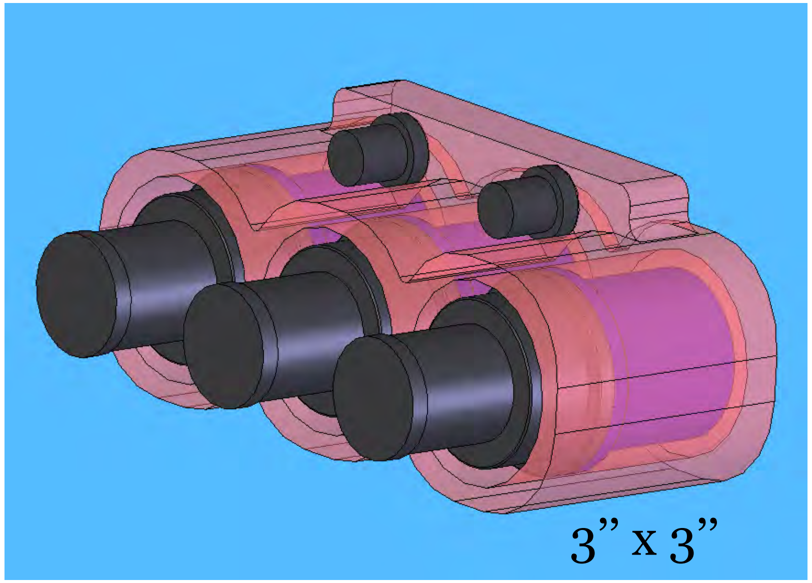
- **1** – High energy flares:
  HEBS (*High Energy Burst Spectrometer*)
- **2** – Particles:
  EPT-HET (*Electron Proton Telescope & High-Energy Telescope*)
- **3** – Magnetometer



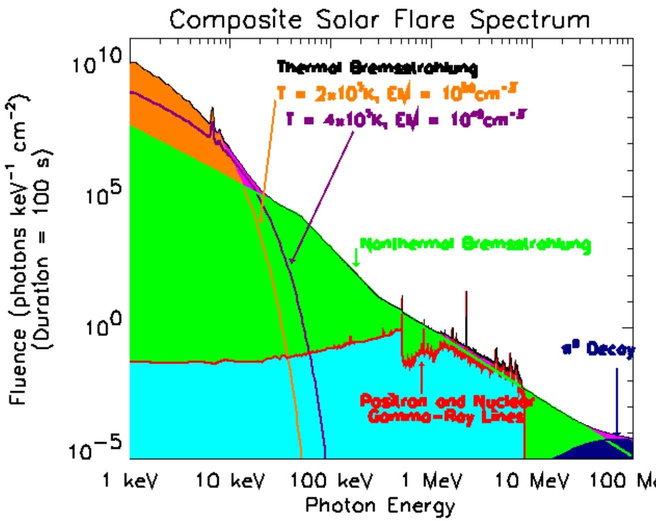
SUITS (Myriade)

Model Payload

High Energy Burst Spectrometer (HEBS)

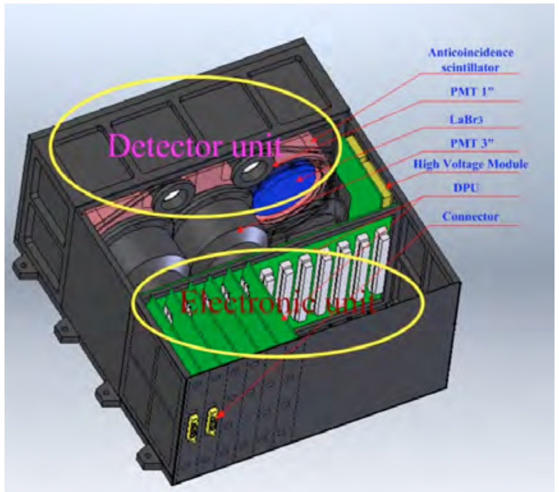


Size	362×349×172.5mm
Weight	20.5 kg
Power	20 W
Energy Range	10keV - 600MeV
Energy Resolution	3%@662keV
Temporal Resolution	1s (quiescent), 32ms (flare-mode)



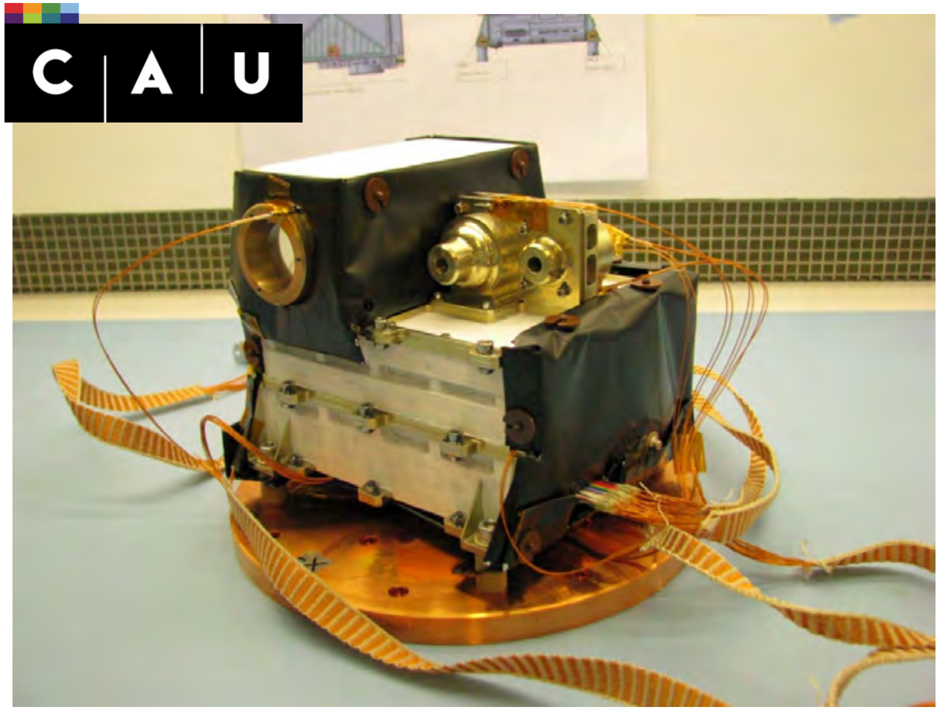
High Energy Burst Spectrometers (HEBS)
[Inheritated from SMESE CNES/CNSA Phase A+ Study]

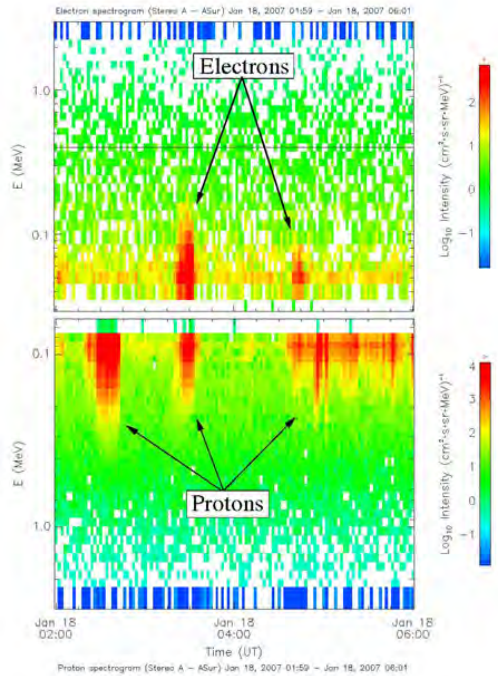
- Evaluate the electron to ion ratio and its time evolution during a Flare
- Provide estimates of the input of energy by particle beams at the top of the chromosphere
- 2 observing instruments:
  - hard X-rays from 10 keV to 500 keV
  - gamma-rays from 300 keV to 600 MeV (new)



- 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



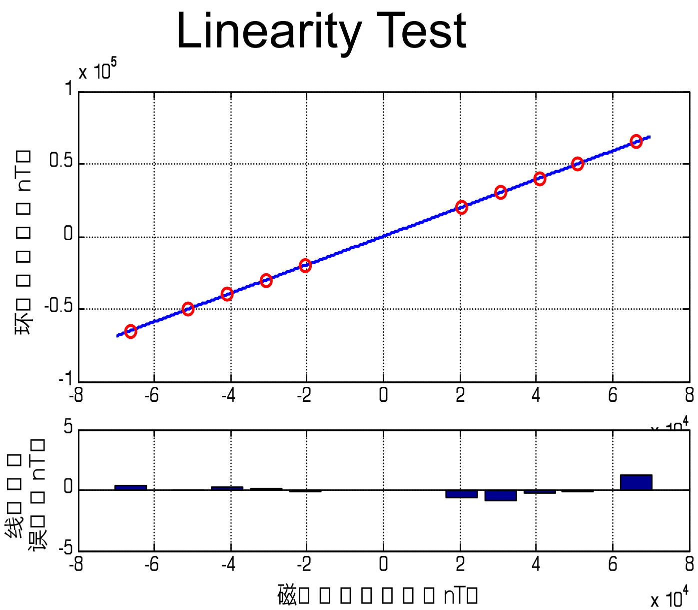


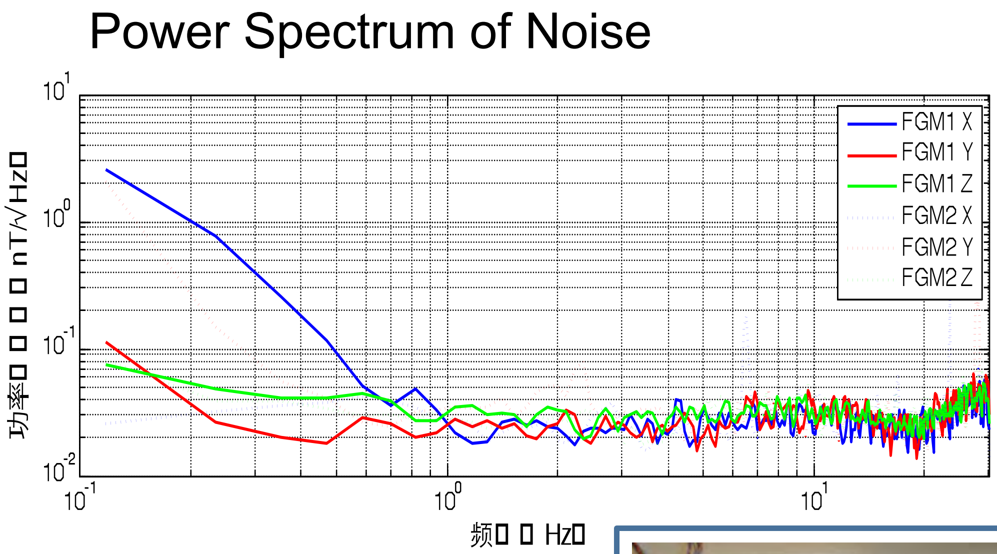
Electron-Proton and High-Energy Telescopes (EPT-HET)

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)**

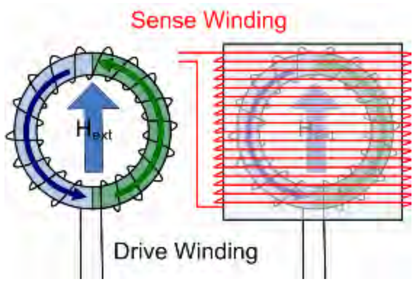
Heritage from STEREO/SEPT & MSL/RAD

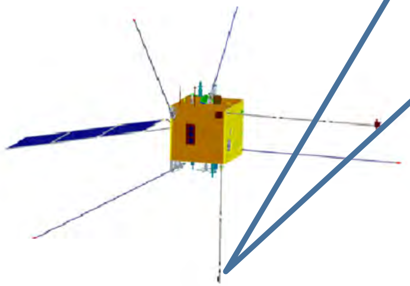
Magnetometer





Magnetic Field Range	Better than ±65000nT
noise	< 30pT/ √ Hz @1Hz
mass	1kg
power	< 1.5W/detector





High Energy & Particles Instruments

High Energy Burst Spectrometer (HEBS)	
Size	362×349×172.5mm
Weight	20.5 kg
Power	20 W
Telemetry	2 Gbits/day
Energy Range	10keV - 600MeV
Energy Resolution	3%@662keV
Temporal Resolution	1s (quiescent), 32ms (flare-mode)
Effective Area	>60cm^2@1MeV
Sensitivity (300keV-10MeV)	Better than 3X10^{-3}photos/cm^2/s

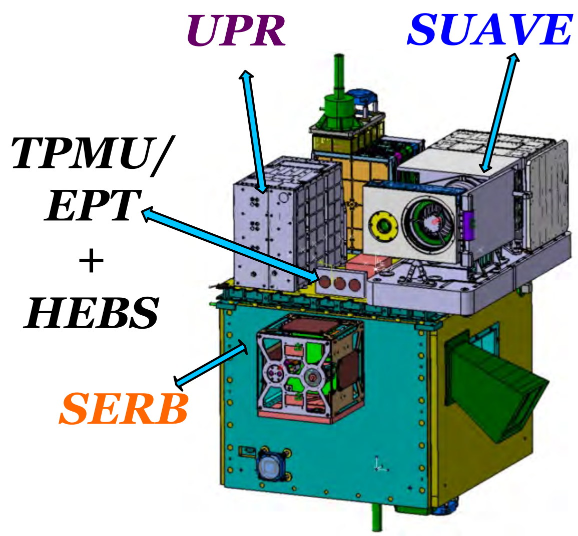
Electron and Ion Detectors	
	EPT-HET
Mass	2.5 kg
Power	5 W
Telemetry	1.5 kbps
Energy Range	Electrons: 20 keV – 30 MeV Protons: 20 keV – 100 MeV Heavy ions: ~10 MeV/nuc – ~200 MeV/nuc (species dependent)
Time Resolution	10s (species dependent)
Geometry Factor [cm^2 sr]	EPT: 2 x 0.01 HET: 3 x 0.21 (protons) HET: 2 x 0.26 (heavy ions)

Magnetometer		
1kg	1.5W/detector	±65000nT

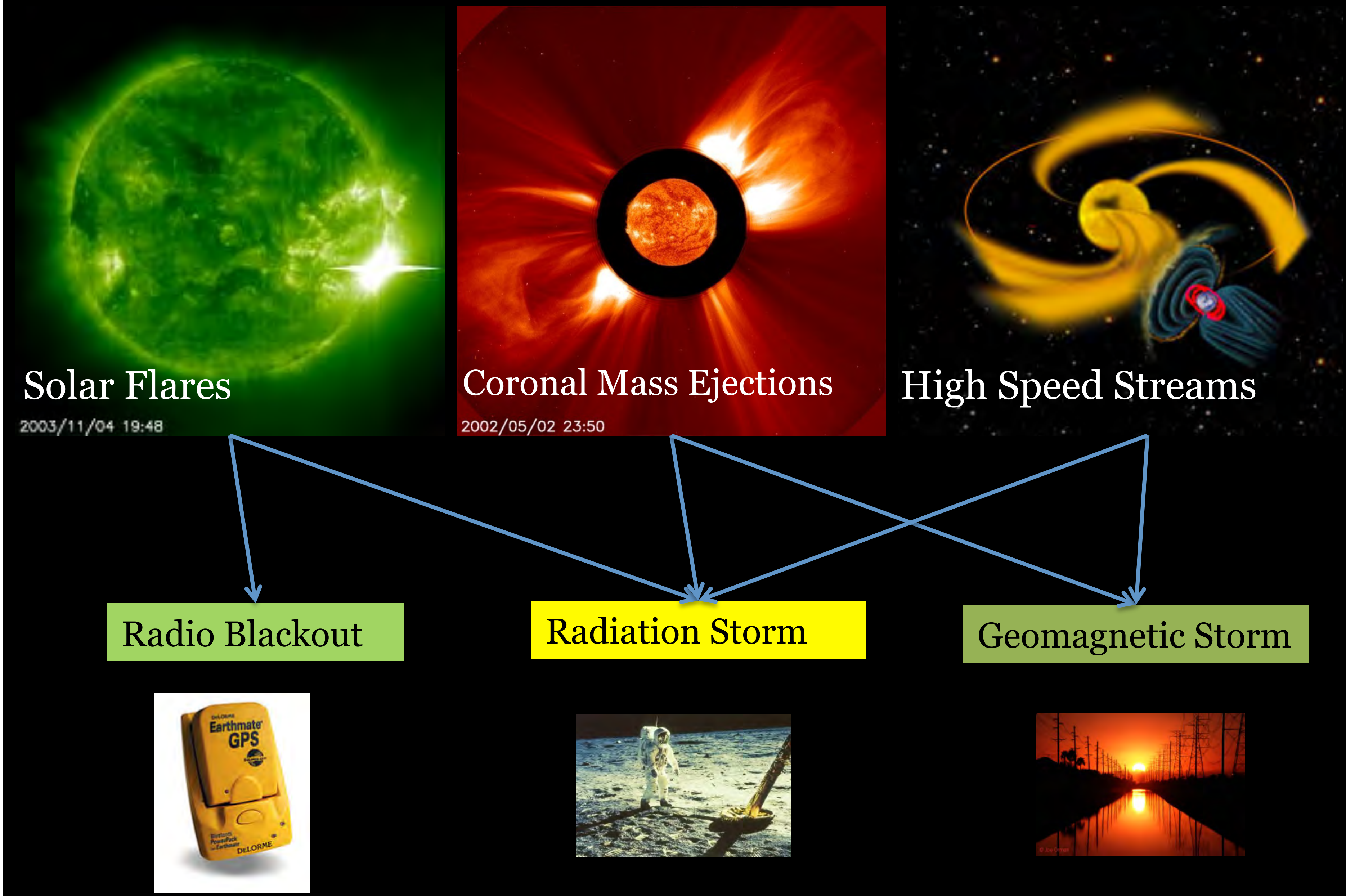
Total:
24 kg
27.5 W

Scientific Rationale

- **1** – High energy flare physics
- **2** – Lyman-Alpha advantages in observing and identifying flare/CMEs precursors
- **3** – Ultraviolet Solar Variability and its influence on climate



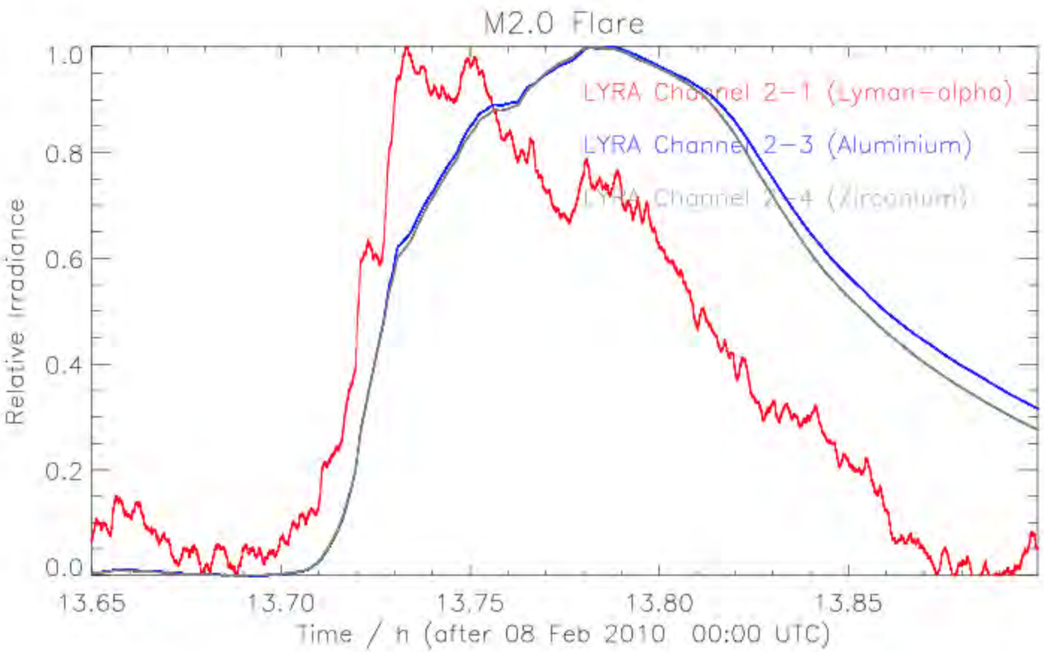
SUITS (Myriade)


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
DeLORME

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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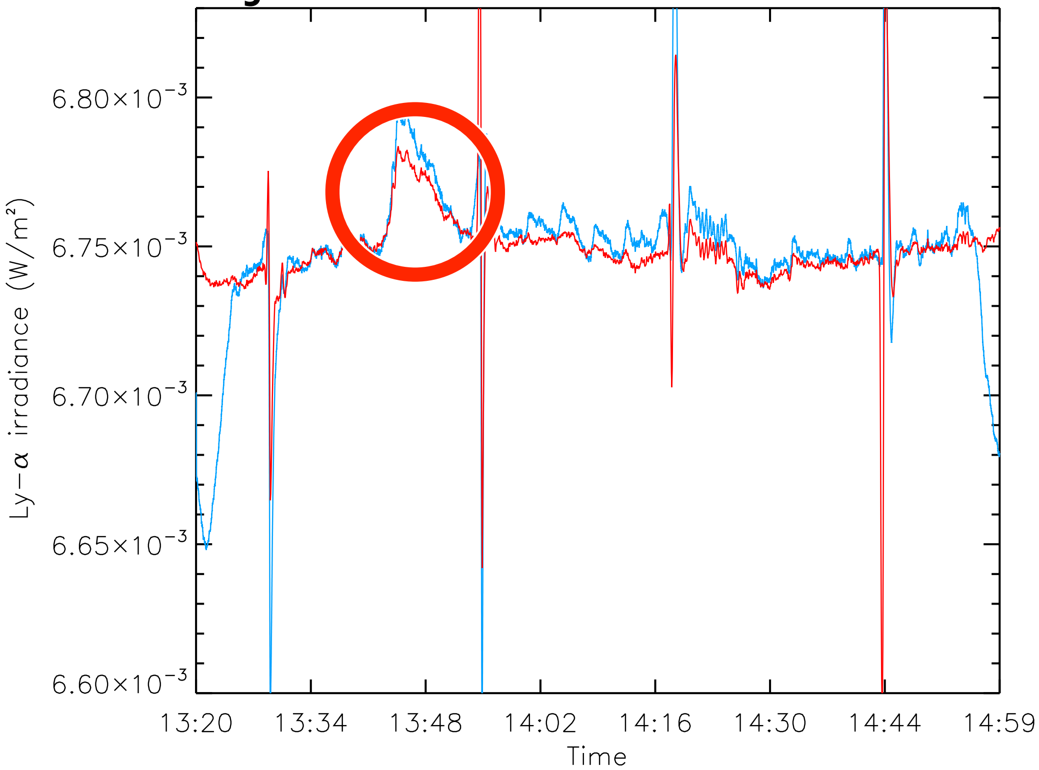


LYRA/PROBA-2 February 8 2010 M2 Flare excess (Kretzschmar et al., 2012)

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

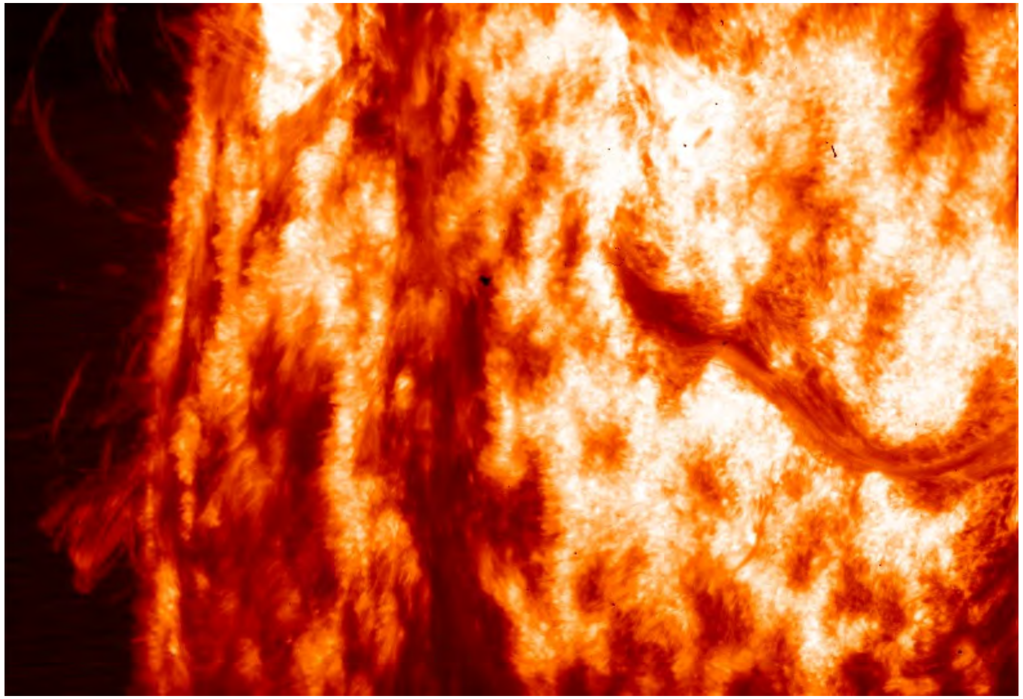
First objective is to **monitor flares** in Lyman-Alpha since as sensitive than X-ray or XUV.

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 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)



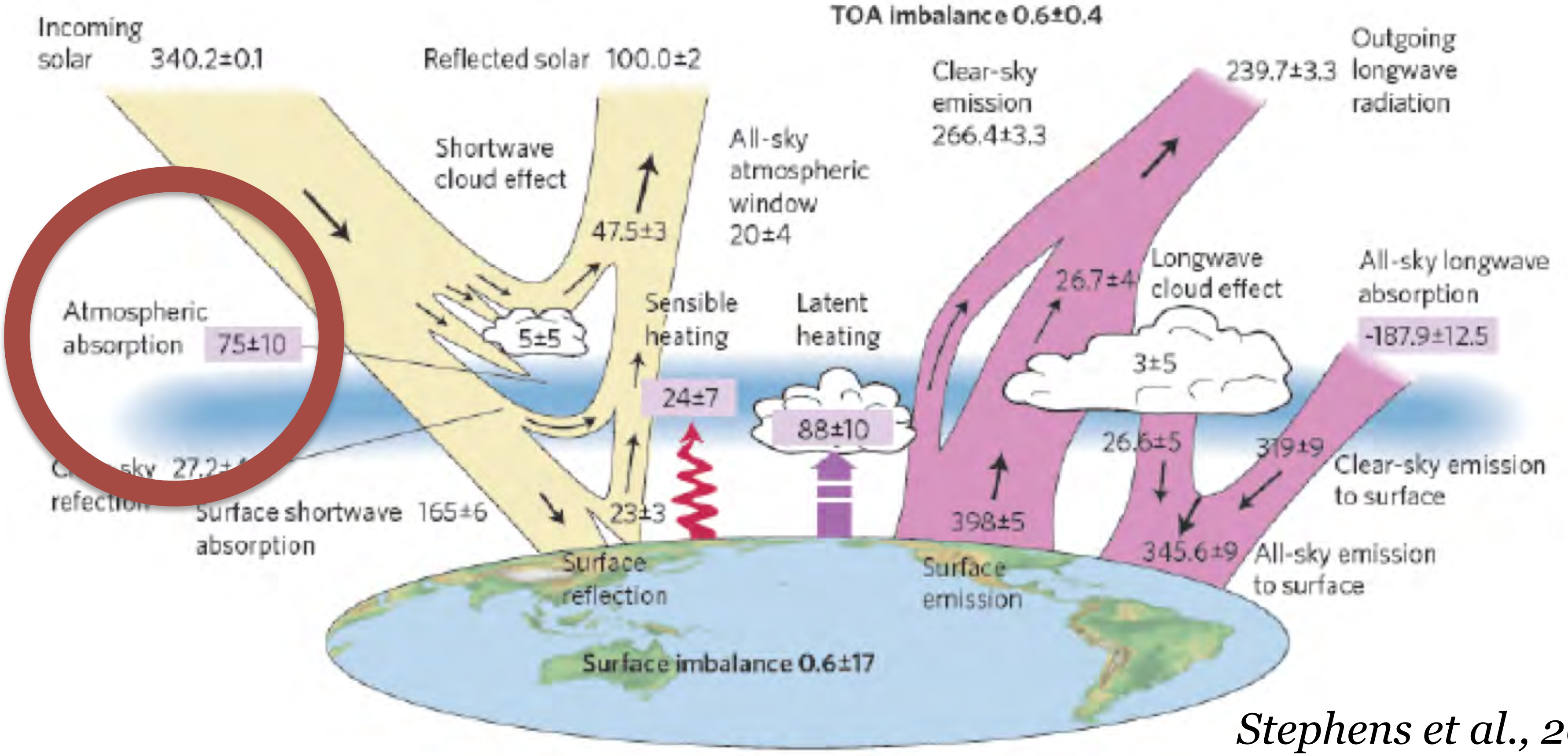
High resolution image of the Sun in **Lyman-Alpha** taken by the VAULT rocket program of NRL and nicely showing prominences and filaments (prominences seen in absorption on the disc)

3

Ultraviolet Solar Variability Influence on Climate

The impacts of undulating UV (<300 nm; ~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, Martin-Puertas *et al.*, 2012,…) indicate that changes in stratospheric temperatures alter weather patterns in the troposphere.

Energy (im)balance

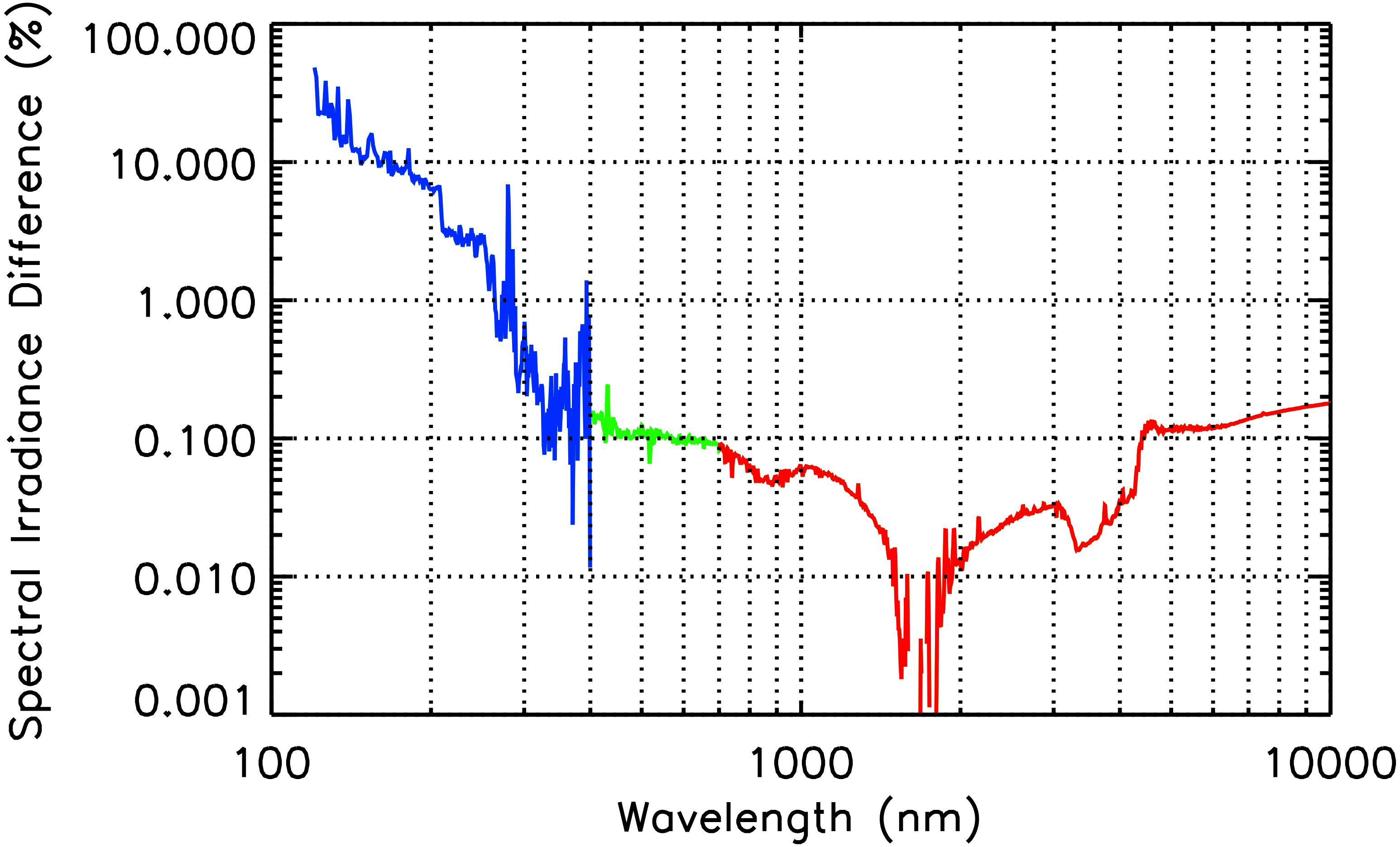


Stephens et al., 2012

Representation of the energy system of the Earth

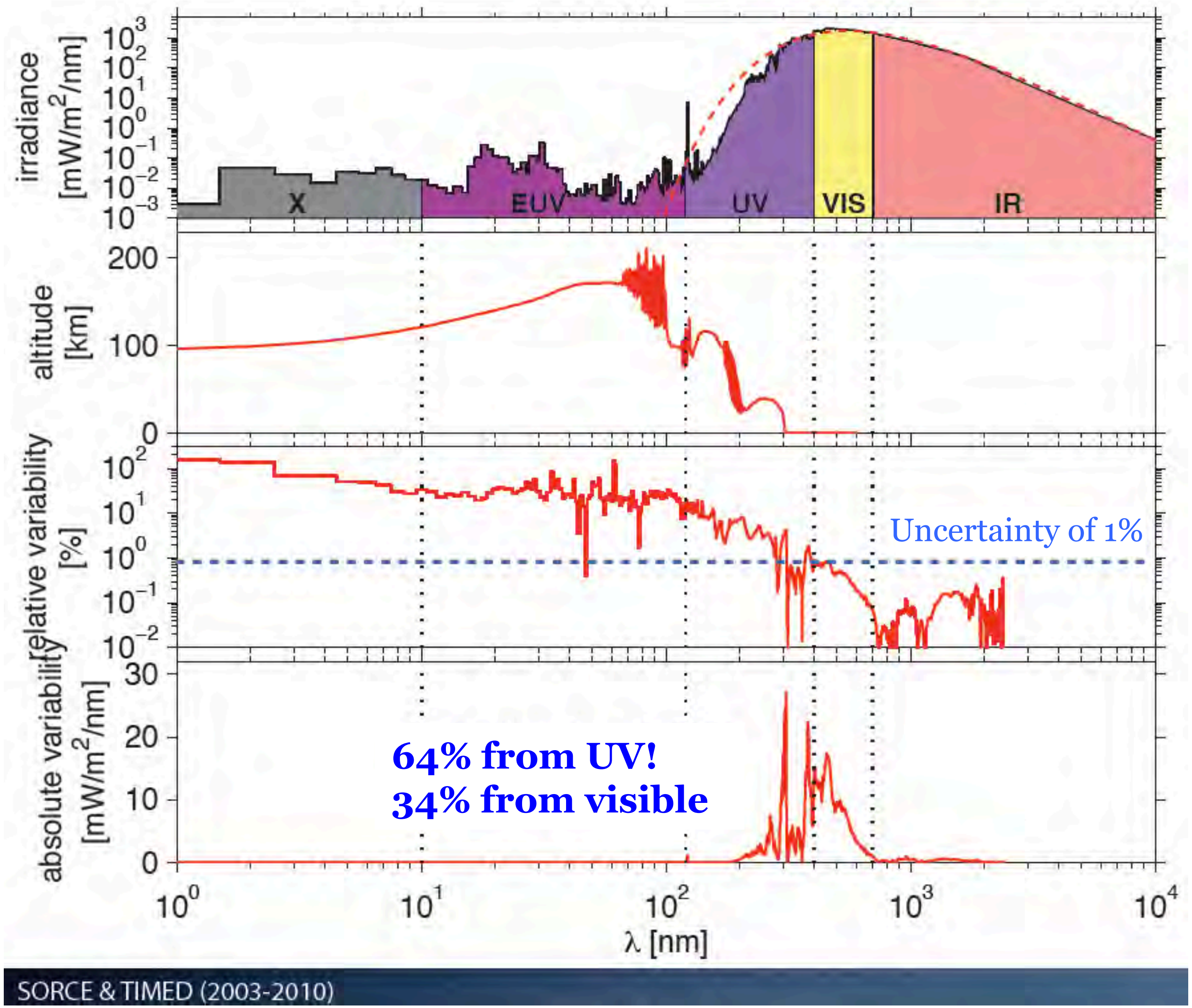
It well illustrates inputs/outputs solar fluxes in the atmosphere and in particular the fact that the ultraviolet below 300 nm (**direct solar input to atmosphere**), representing a 1% contribution of the solar irradiance, is absorbed in the stratosphere and higher and has a significant influence on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

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

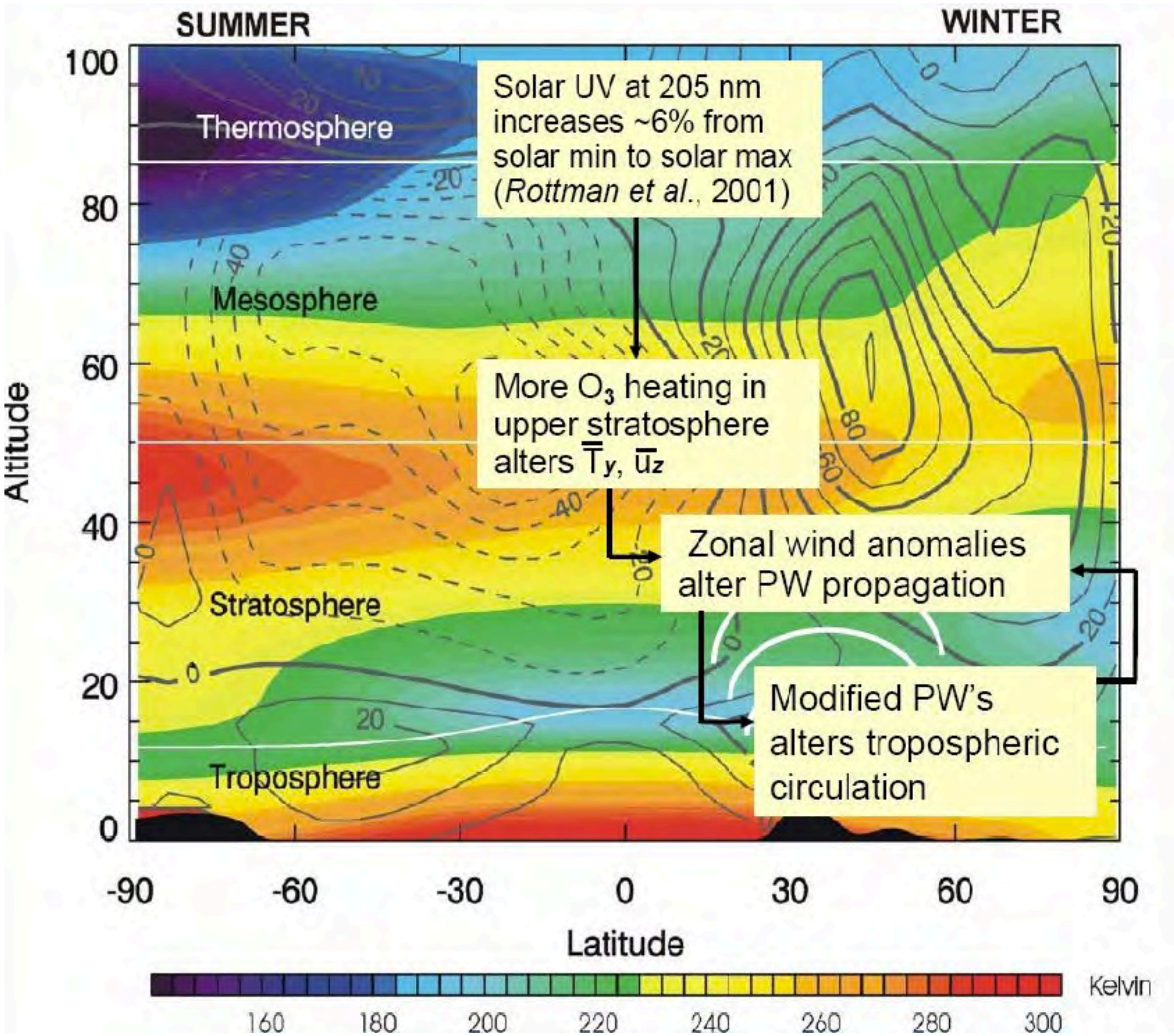


Illustration of the possible Sun-climate connection through the variability of solar UV that heats the ozone locally and create defects/ anomalies on the propagation of the zonal planetary wave that will, in turn, affect the tropospheric circulation.

[Courtesy, J. P. McCormack].

Evidence for MUV influence on stratospheric dynamics

The Spectral Irradiance Monitor (SIM) instrument on SORCE (since April 2004), has 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.

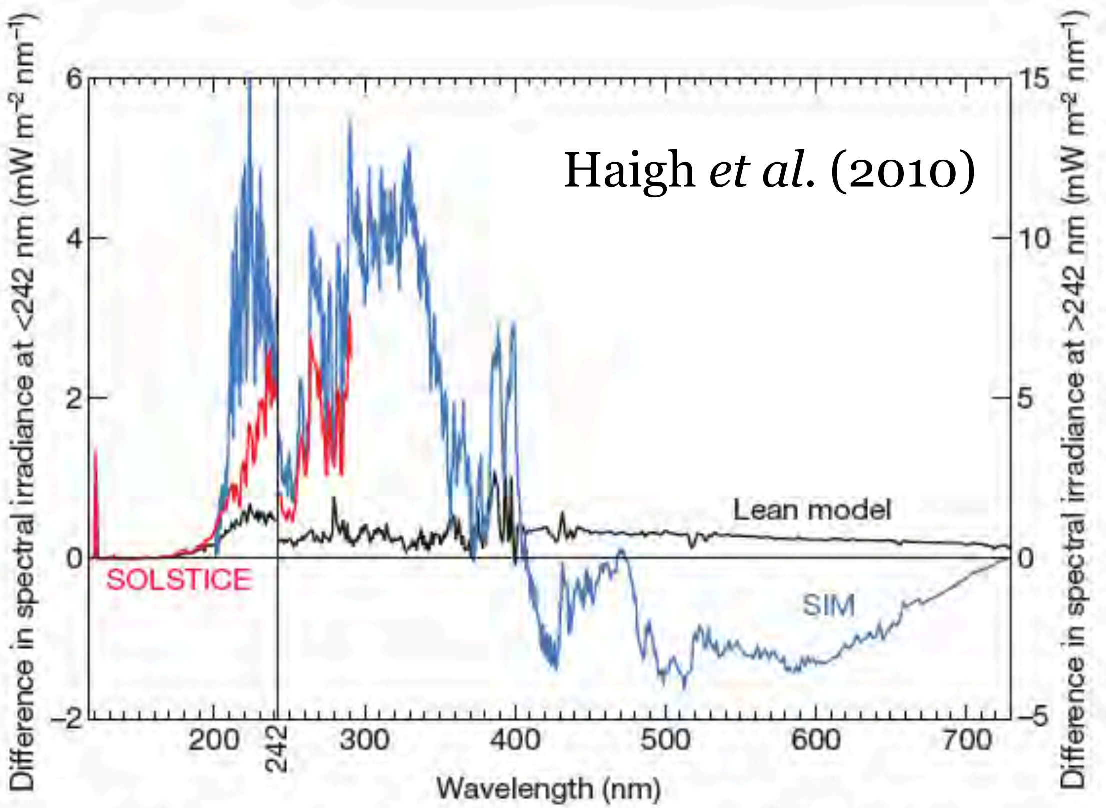
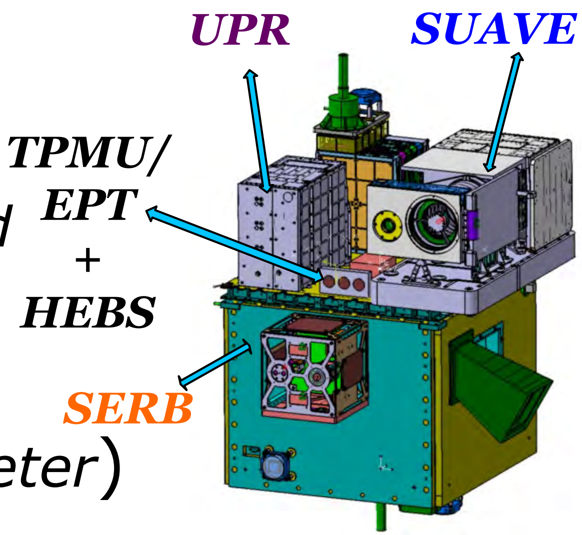


Figure 1 | Difference in solar spectrum between April 2004 and November 2007. The difference (2004–2007) in solar spectral irradiance (W m^{-2} nm^{-1}) derived from SIM data[4] (in blue), SOLSTICE data[8] (in red) and from the Lean model[5] (in black). Different scales are used for values at wavelengths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

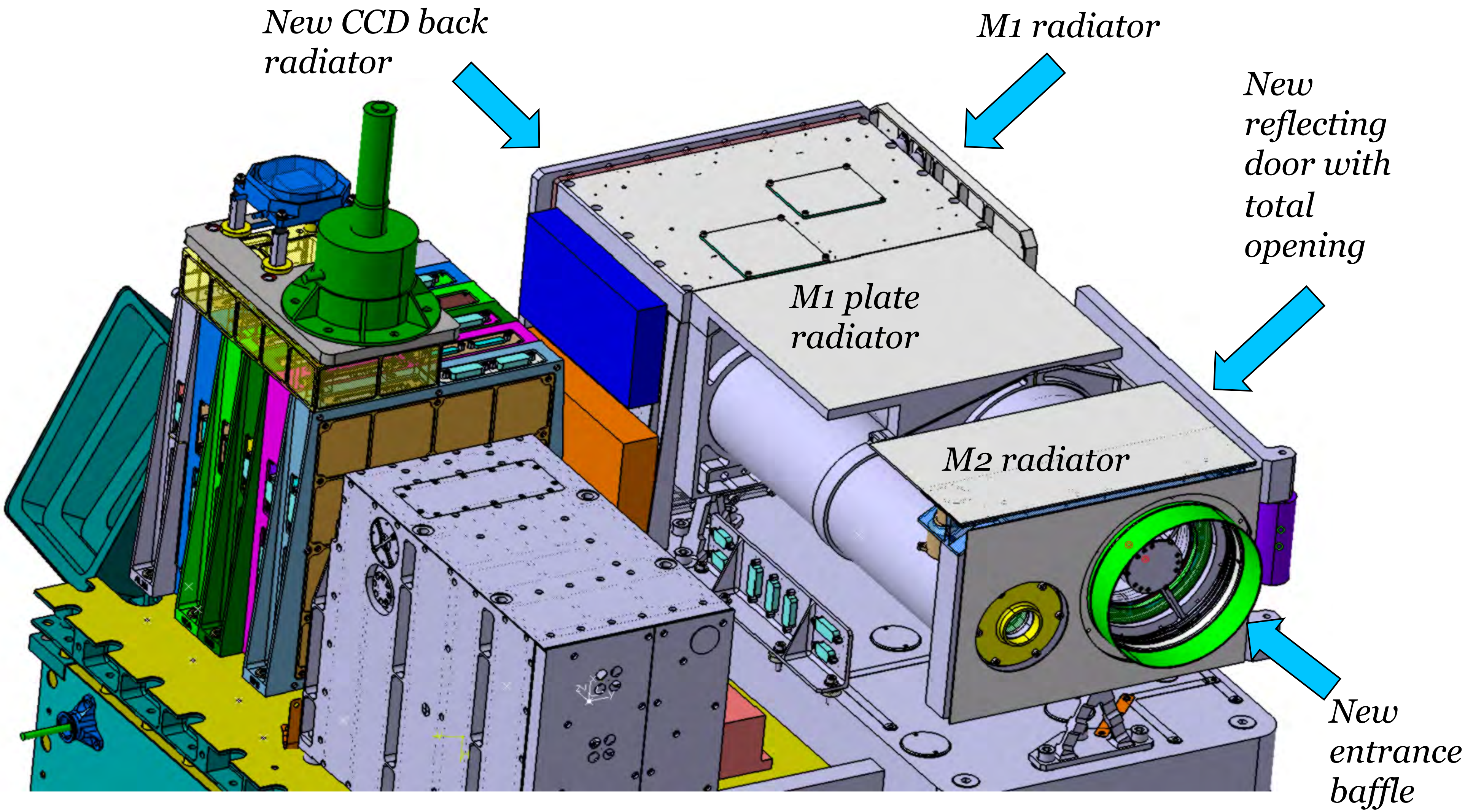
Model Payload
Space Weather, (F)UV & Climate

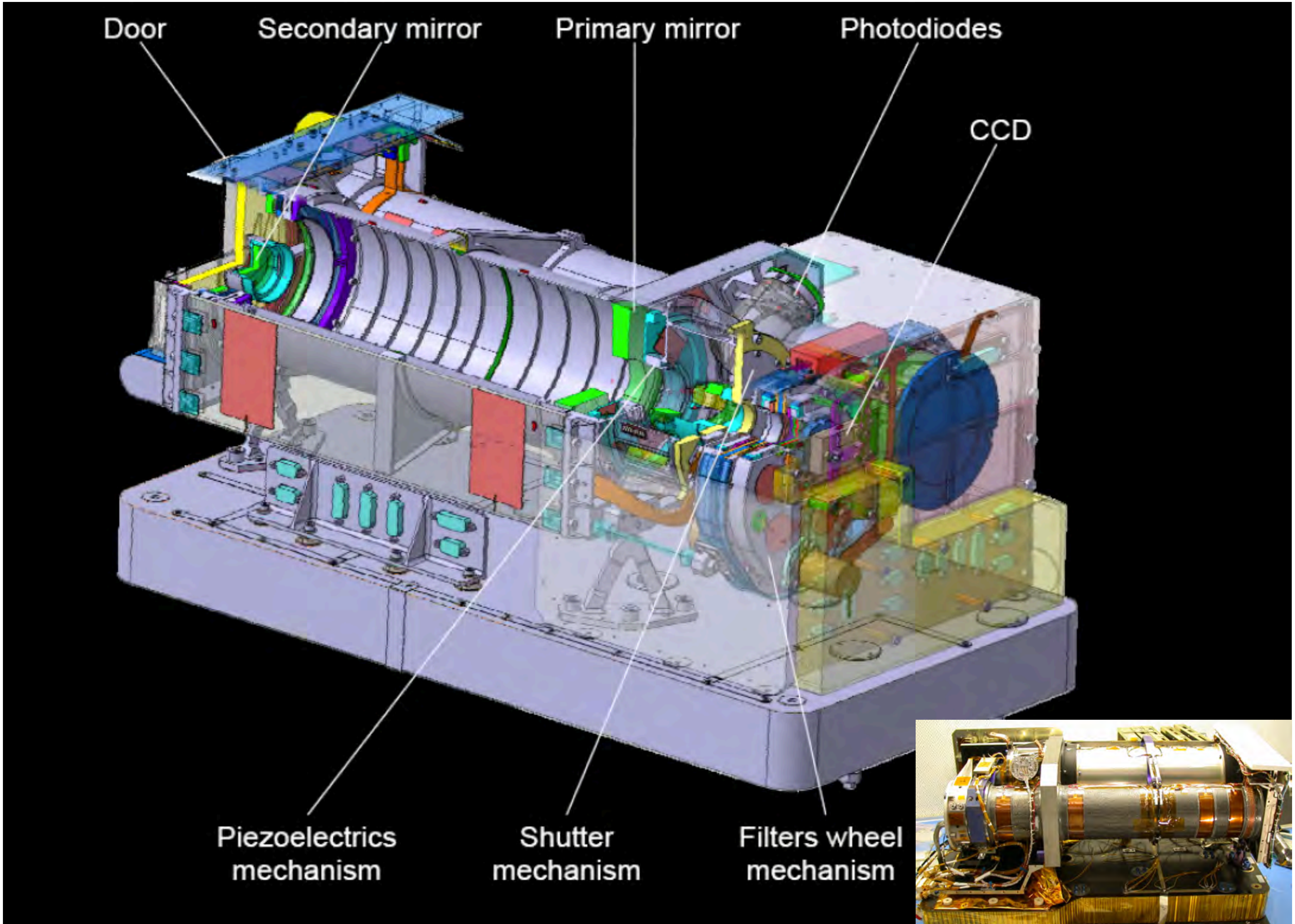
- **1** – FUV imaging for flares pre-cursors and Space Weather: SUAVE (*Solar Ultraviolet Advanced Variability Experiment*)
- **2** – Solar spectral irradiance: UPR (*Ultraviolet Passband Radiometer*)
- **3** – Solar Spectral Irradiance (Atm. modeling – res. 1 nm): DSSIM (Dual Solar Spectral Irradiance Monitor)*
- **4** – SERB (Solar irradiance & Earth Radiative Budget)
- **5** – Other Space Weather instrumentation



SUITS (Myriade)

SUAVE (*Solar Ultraviolet Advanced Variability Experiment*)
FUV Imaging Telescope (evolution & optimization of SODISM):
no window, SiC mirrors & new "thermal" door and radiators

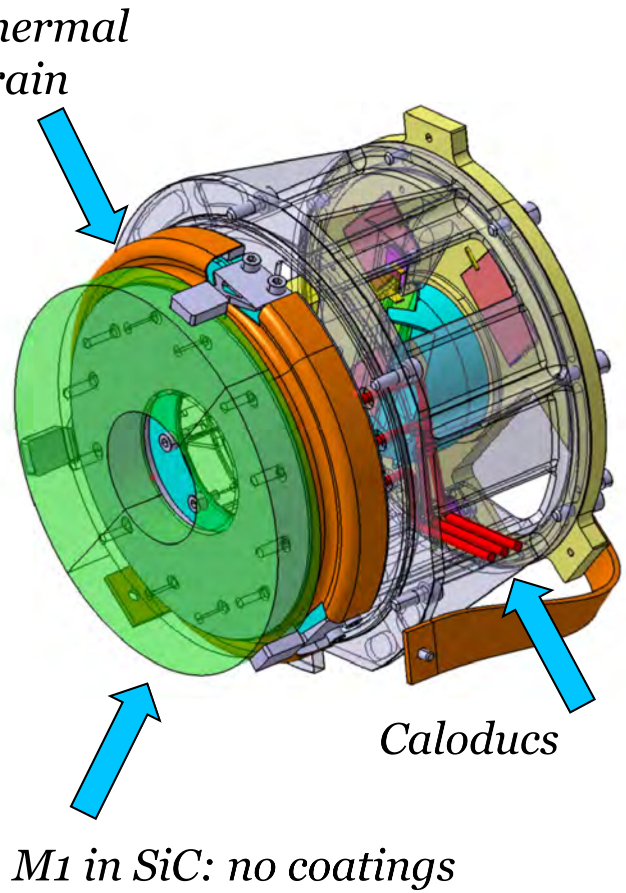



Door
Secondary mirror
Primary mirror
Photodiodes
CCD
Piezoelectrics mechanism
Shutter mechanism
Filters wheel mechanism

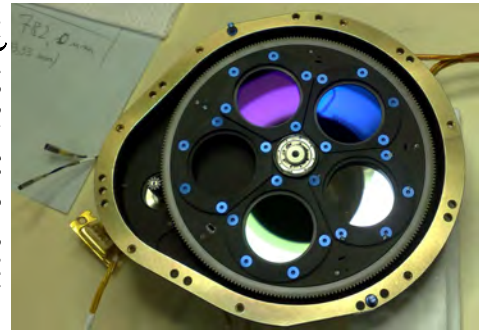
New SiC Mirrors: FUV duty cycle

Unique properties:

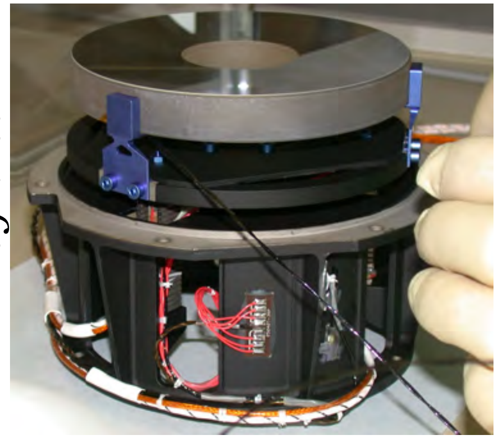
- conducting
- homogeneous
- heat evacuation
- no coating (no degradation)
- 40% R in UV
- 20% R in visible



Filters wheel (x2)



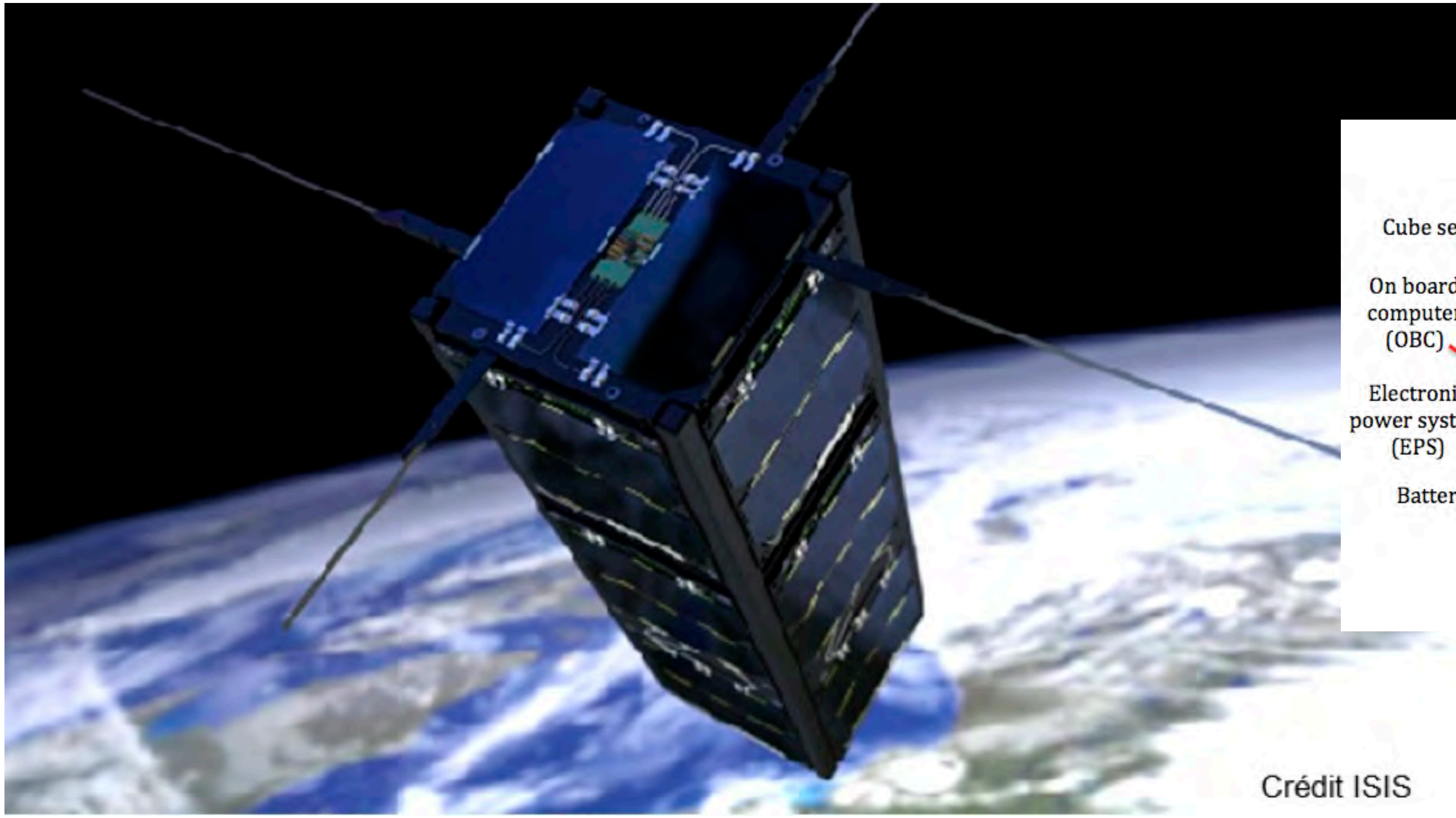
M1 integrated

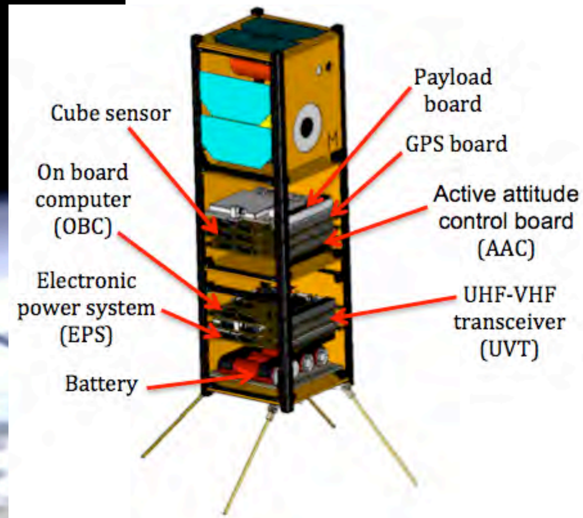


➡ ***R&T CNES 2014–2015: realization of a representative optical and thermal breadboard of SUAVE SiC mirrors and supports (primary and secondary)***

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

Xnano 2018 (X&CNES n°2)





L. Damé, M. Meftah, A. Hauchecorne, P. Keckhut, A. Sarkissian, A. Irbah, S. Godin-Beekmann (LATMOS/IPSL/CNRS/UVSQ)
(+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

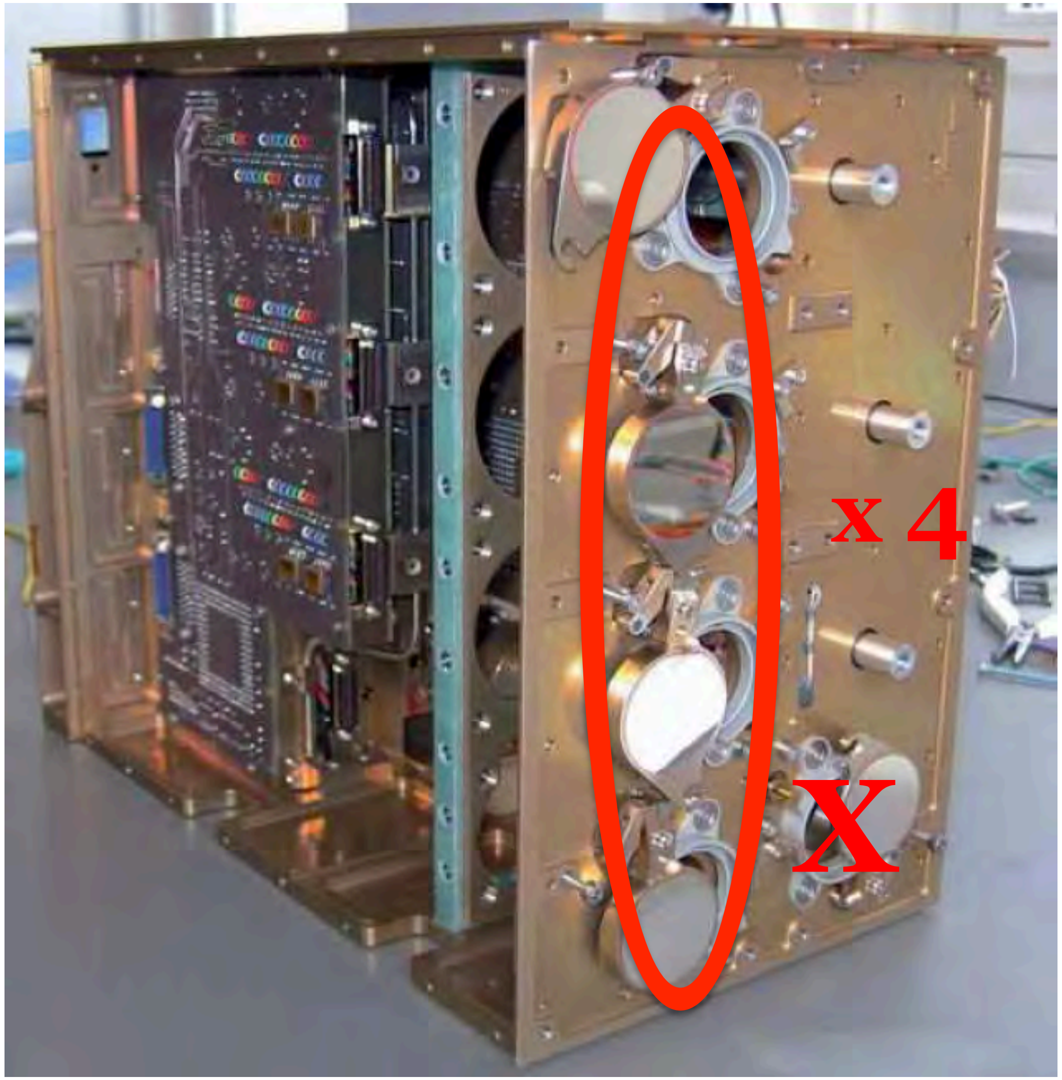
Filter Radiometers FUV, MUV & UV: "extending PREMOS & LYRA"

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

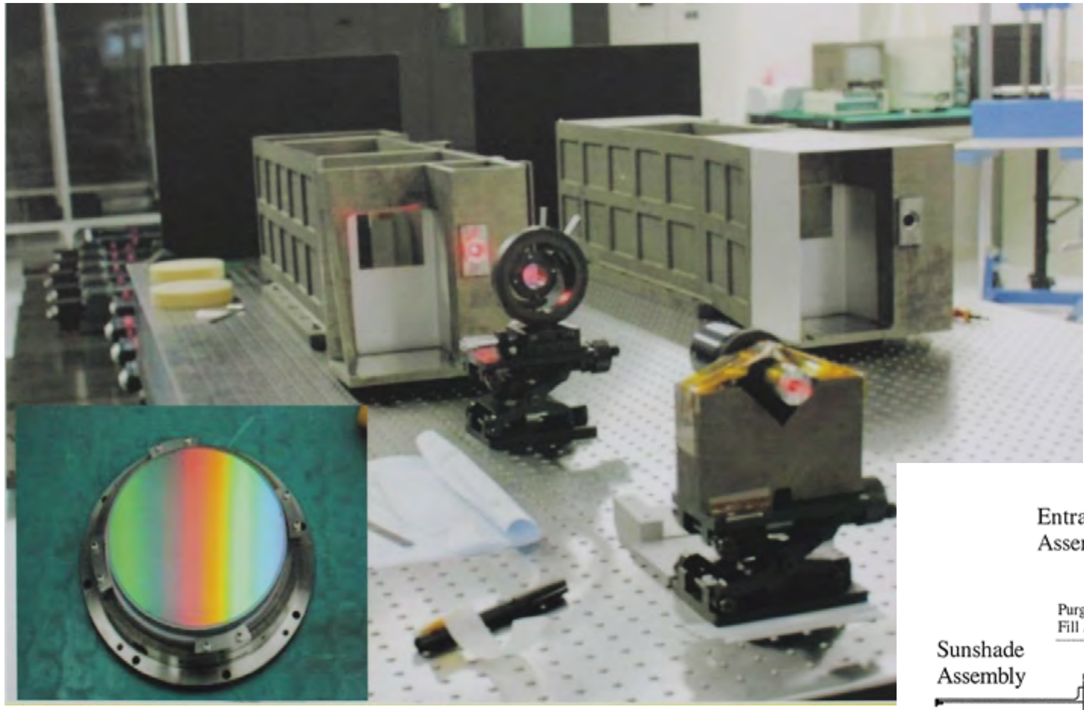
The 121.6 and 200–220 nm channels support the imaging mode of SUAVE.

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



DSSIM (*Dual Solar Spectral Irradiance Monitor*)

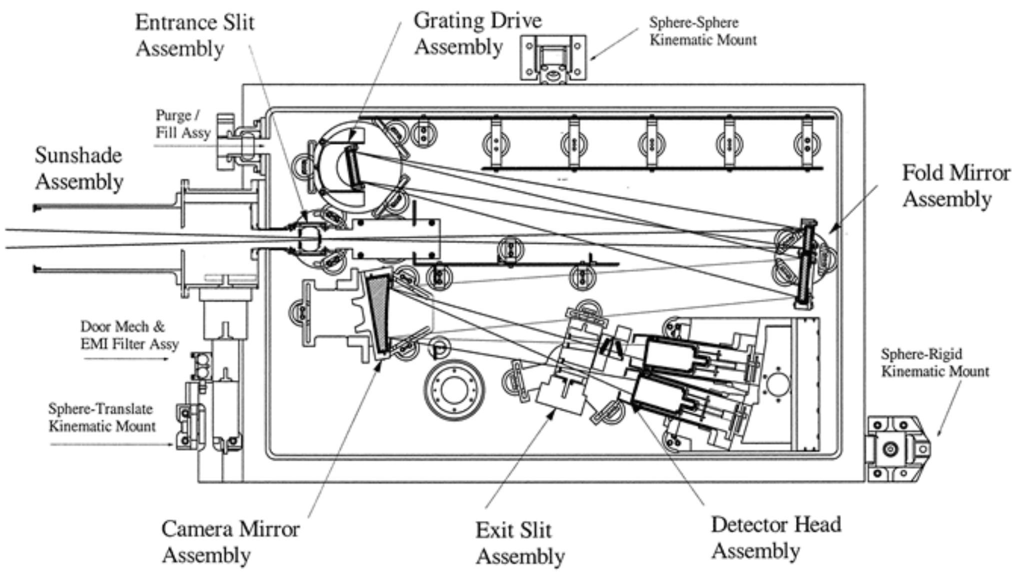
A UV spectrometer (in the ozone production bands) with a reasonable spectral resolution is essential for the chemistry modeling of the Earth atmosphere



Experience at NAOC, Beijing (WSO program)
& LATMOS: SOLSPEC on Space Station

Expertise also of LPC2E Orléans

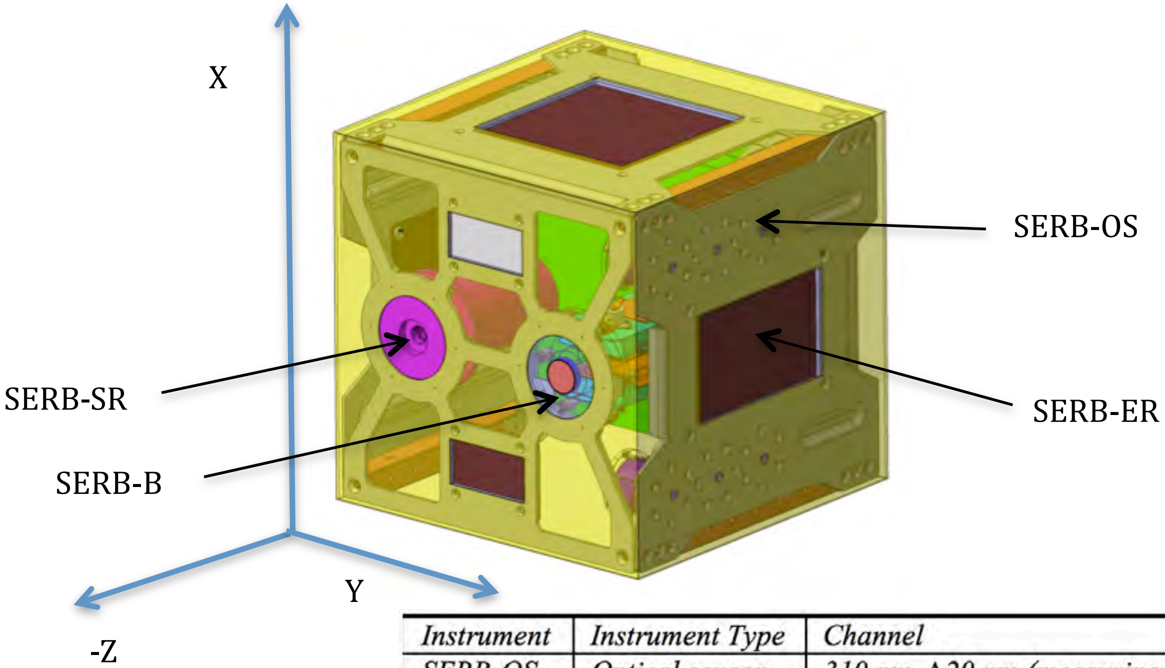
Design along SOLSTICE II
(one chanel only: F)



Weight	<20 kg
Wavelength Range	180-340 nm
Spectral Resolution	0.2 nm

Simultaneous Radiative Budget Experiment: SERB

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

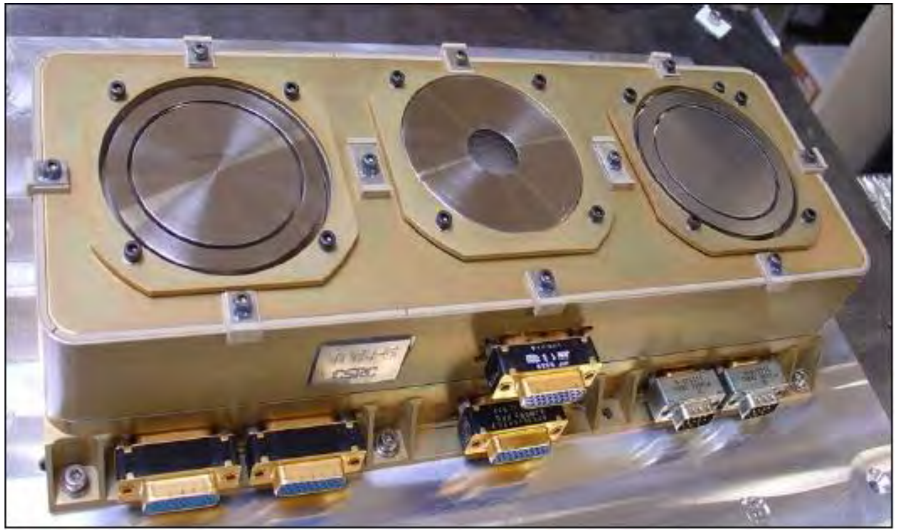


***SERB**: Solar irradiance and Earth Radiative Budget (4 instruments in a 20x20x20 cm^3 cube of 3 kg)*

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)*

Space Weather Specific Instrumentation

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

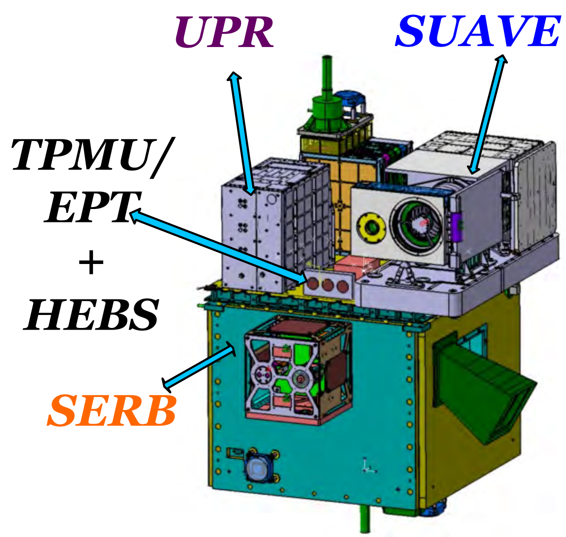


Instruments' Summary

Instrument	Mass (kg)	Power (W)	Telemetry (Gbits/day)
HEBS	20.5	20	2
EPT-HET	2.5	5	kbps
Magnetometer	1	1.5	kbps
SUAVE	25	30	3
UPR	18	12	kbps
SERB	3	3	kbps
*DSSIM**	*20*	*15*	*kbps*
*Extra**	*26*	*20*	*1*
TOTAL	**70**	**71.5**	**5**
*TOTAL**	*116*	*106.5*	*6*

Mission Profile

- **1** – Orbit
- **2** – Platform and payload
- **3** – Launcher
- **4** – Heritage

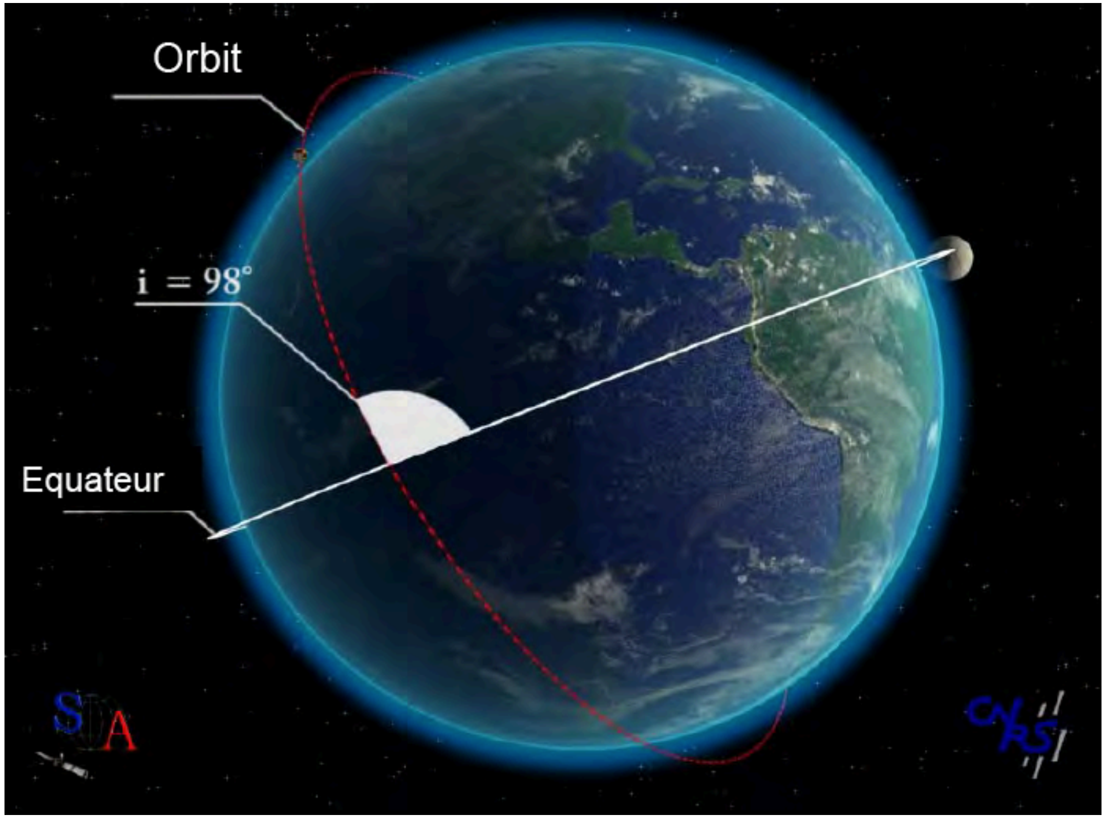


SUITS (Myriade)

Thermal stability starts with the right orbit choice

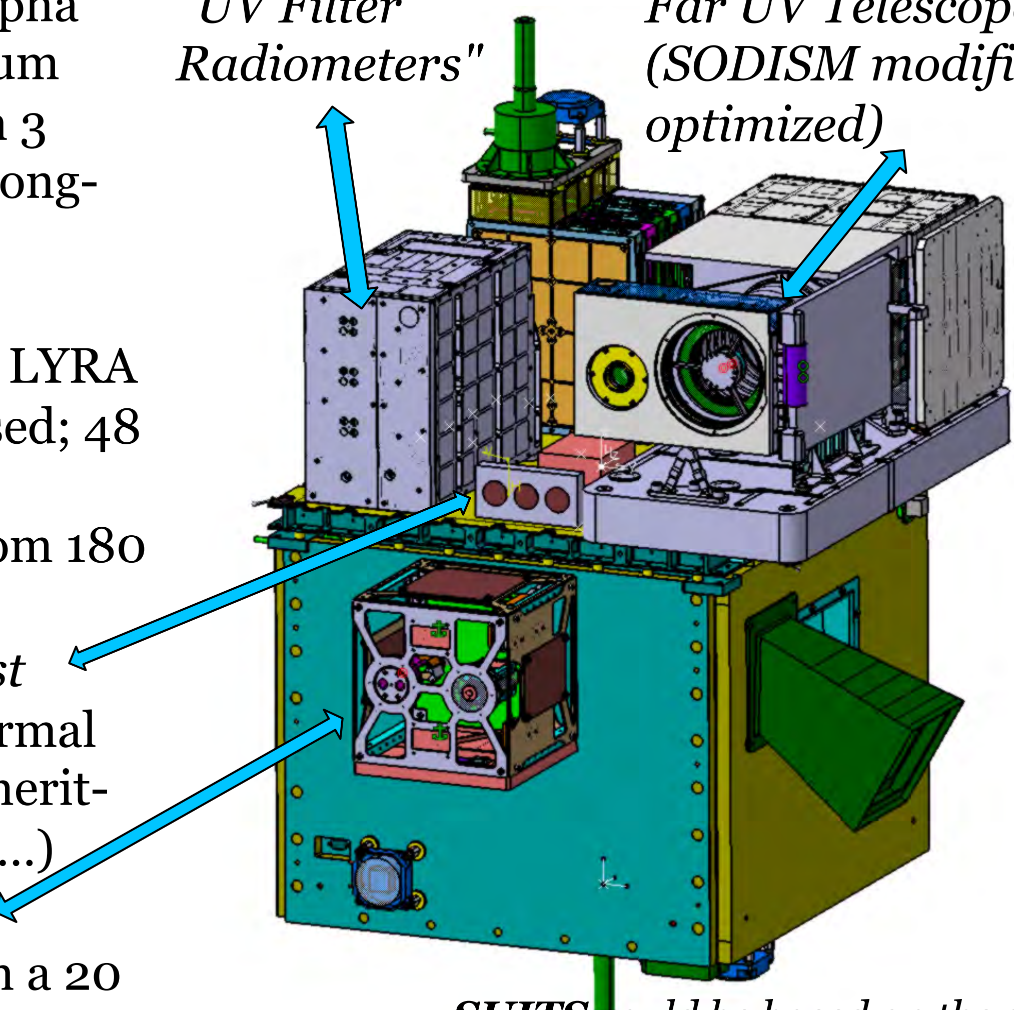
Orbit with "almost" permanent Sun viewing (alike PICARD):

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



SUITS (ex-SWUSV): Space Weather & Ultraviolet Solar Variability Microsatellite

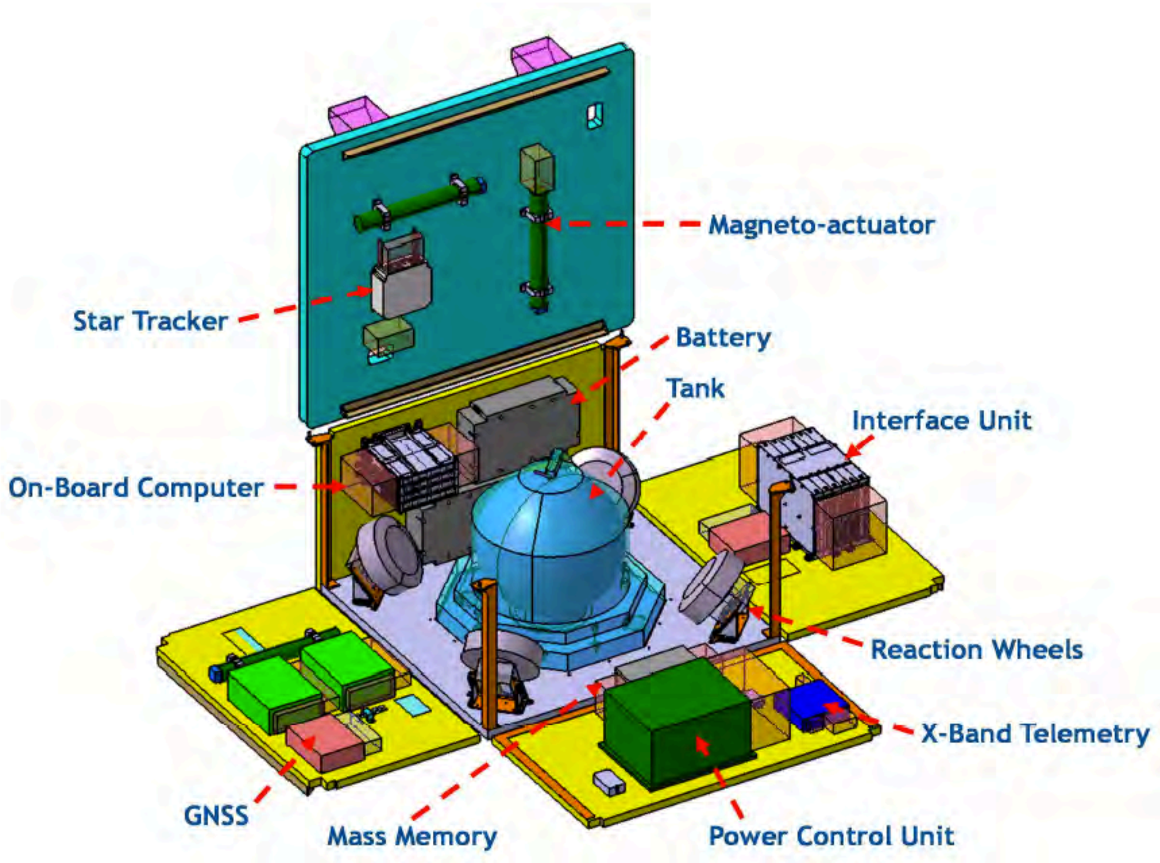
- **SUAVE** (*Solar Ultraviolet Advanced Variability Experiment*), Lyman-Alpha and 200-220 nm Herzberg continuum imaging (sources of variability) with 3 redundant set of filters to preserve long-term sensitivity
- **UPR** (*Ultraviolet Passband Radiometers*) based on PREMOS & LYRA with 64 UV filter radiometers (16 used; 48 redundant) for Lyman-Alpha, CN bandhead (385-390 nm) and UV from 180 to 400 nm by 20 nm banpasses
- Place for **HEBS** (*High Energy Burst Spectrometer*), Magnetometer, Thermal Plasma Units & Particles (multiple heritage: CNES/SMESE, ESA/PROBA-2...)
- **SERB** (*Solar irradiance & Earth Radiative Budget*): 4 instruments in a 20 cm cube of 3 kg (including TSI)



***SUITS** could be based on the same CNES/Myriade platform than PICARD or, better, on Myriade +*

Platform: from Myriade to Myriade Evolutions

- CNES/DLR MERLIN mission (2019)
- 320 kg satellite (up to 400 kg possible):
  - 250 S/C; 70 kg P/L
- 7 years lifetime (half solar cycle)
- Compliant space debris regulations
- Further instrumental possibilities:
  - better/simpler accommodations
  - DSSIM included
  - small coronagraph
  - microwave monitor…



Internal accommodation of Myriade Evolutions platform (Millet et al., 2014)

Launcher LM-2C or 2D

Myriade Evolutions 350/400 kg satellite on a 725/730 km Sun synchronous orbit is perfectly adapted for a piggy-back/passenger LM-2C or -2D (~1200 kg @ SSO 700 km) launch or, alternatively, to a "low cost" VEGA launch

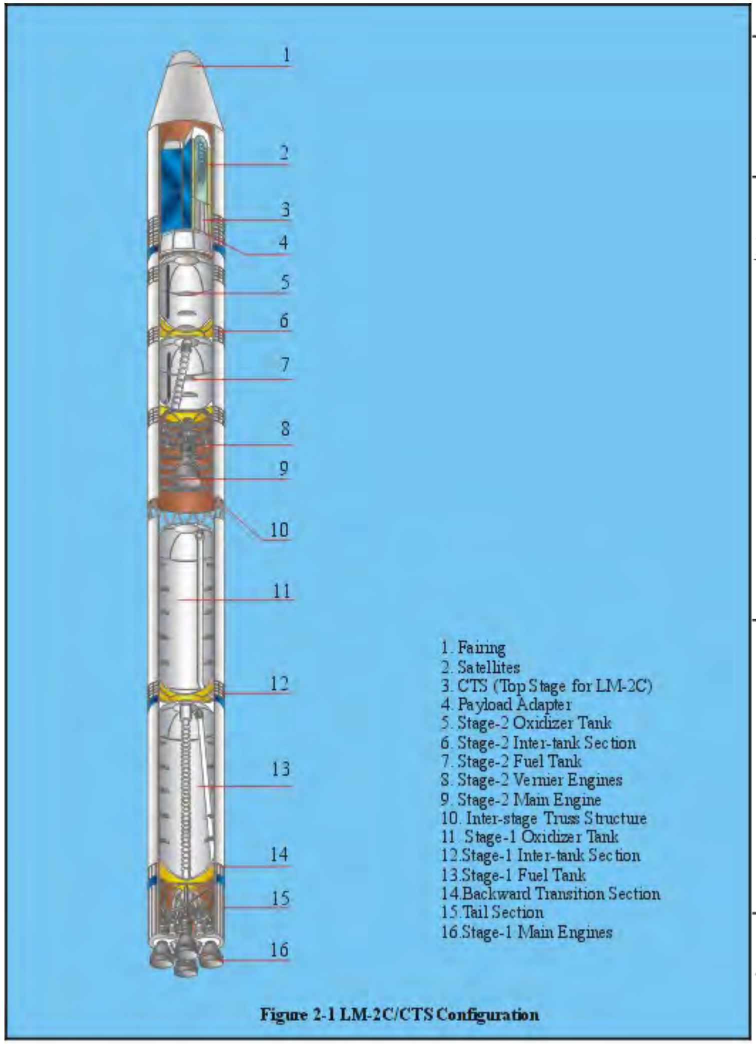
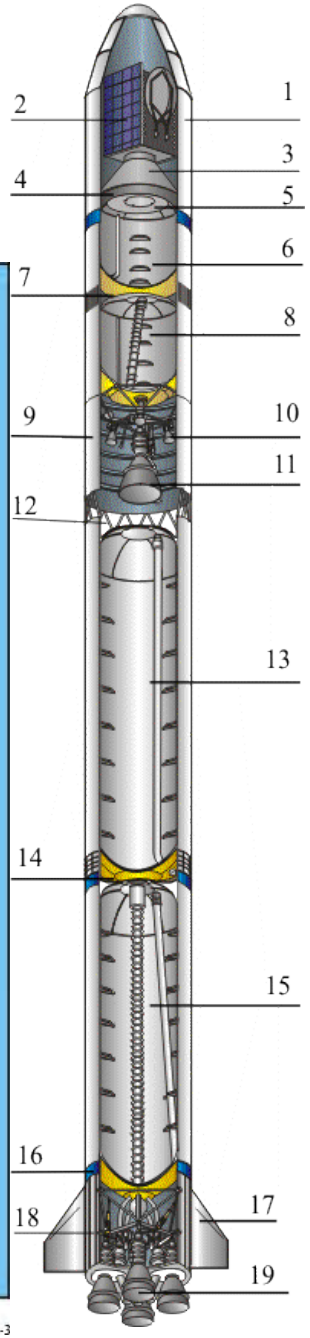
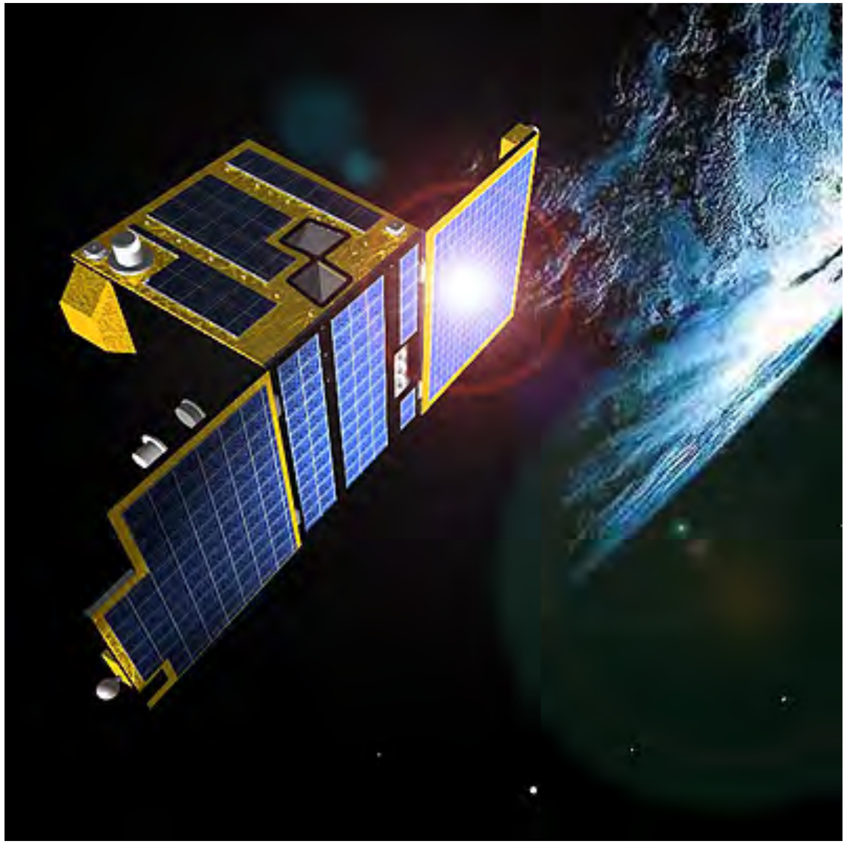


Figure 2-1 LM-2C/CTS Configuration



2-3

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



PROBA-2: LYRA, SWAP, Magnetometer and Ionosphere

PICARD: SODISM, PREMOS, SOVAP

Cooperation (China)

Science and Data Analysis:
Siming Liu, Youping Li, Weiqun Gan (PMO, CAS), Linghua Wang (PKU), Gang Qin (NSSC), Chuan Li (NJU), China

HEBS (*High Energy Band Spectrometer*):
Jian Wu, Jin Chang, Purple Mountain Observatory, China

DSSIM UV Spectrometer (*Dual Solar Spectral Irradiance Monitor*):
Sen Wang, Yuanyong Deng National Astronomical Observatories, CAS, China

Magnetometer*:
Yong Liu, National Space Science Center, CAS, China

Cooperation (Europe)

Science and Data Analysis:
Luc Damé, Alain Hauchecorne, Philippe Kechkut, Alain Sarkissian, Eric Quémerais, Marion Marchand, Slimane Bekki, *LATMOS, FRANCE*
Robert Erdélyi von Fay-Siebenburgen, V. Fedun, *SP2RC, Sheffield, UK*
Nathalie Huret, Matthieu Kretzschmar, *LPC2E, Université d'Orléans, FRANCE*
Valentina Zharkova, *Northumbria University, Newcatle, UK*

SUAVE (*Solar Ultraviolet Advanced Variability Experiment*):
Luc Damé, Mustapha Meftah, Abdenour Irbah, *LATMOS, FRANCE*
Kanaris Tsinganos, *University of Athens, GREECE*

UPR (*Ultraviolet Passband Radiometers*):
Werner Schmutz, Alexander Shapiro, Gaël Cessateur, *PMOD, SWITZERLAND*

SERB *(Solar irradiance and Earth Radiative Budget)*
Mustapha Meftah, Alain Sarkissian, *LATMOS, FRANCE*
Steven Dewitte, *Royal Observatory of Belgium, BELGIUM*

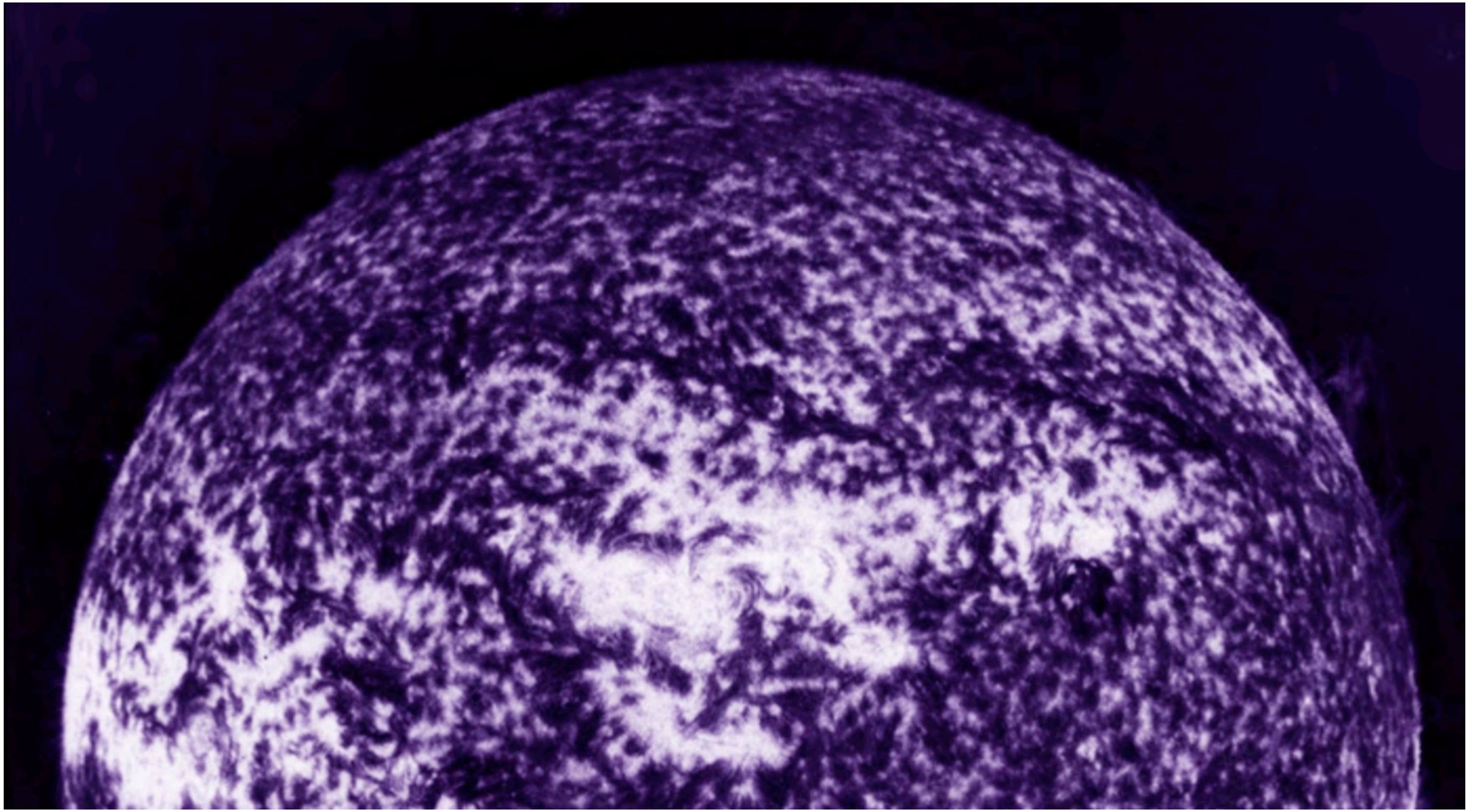
EPT (*Electron-Proton Telescope*):
Robert Wimmer-Schweingruber, *CAU, University of Kiel, GERMANY*

Magnetometer*:
José Merayo, *Technical University of Denmark, Lyngby, DENMARK*

Conclusion: Small Mission Readiness

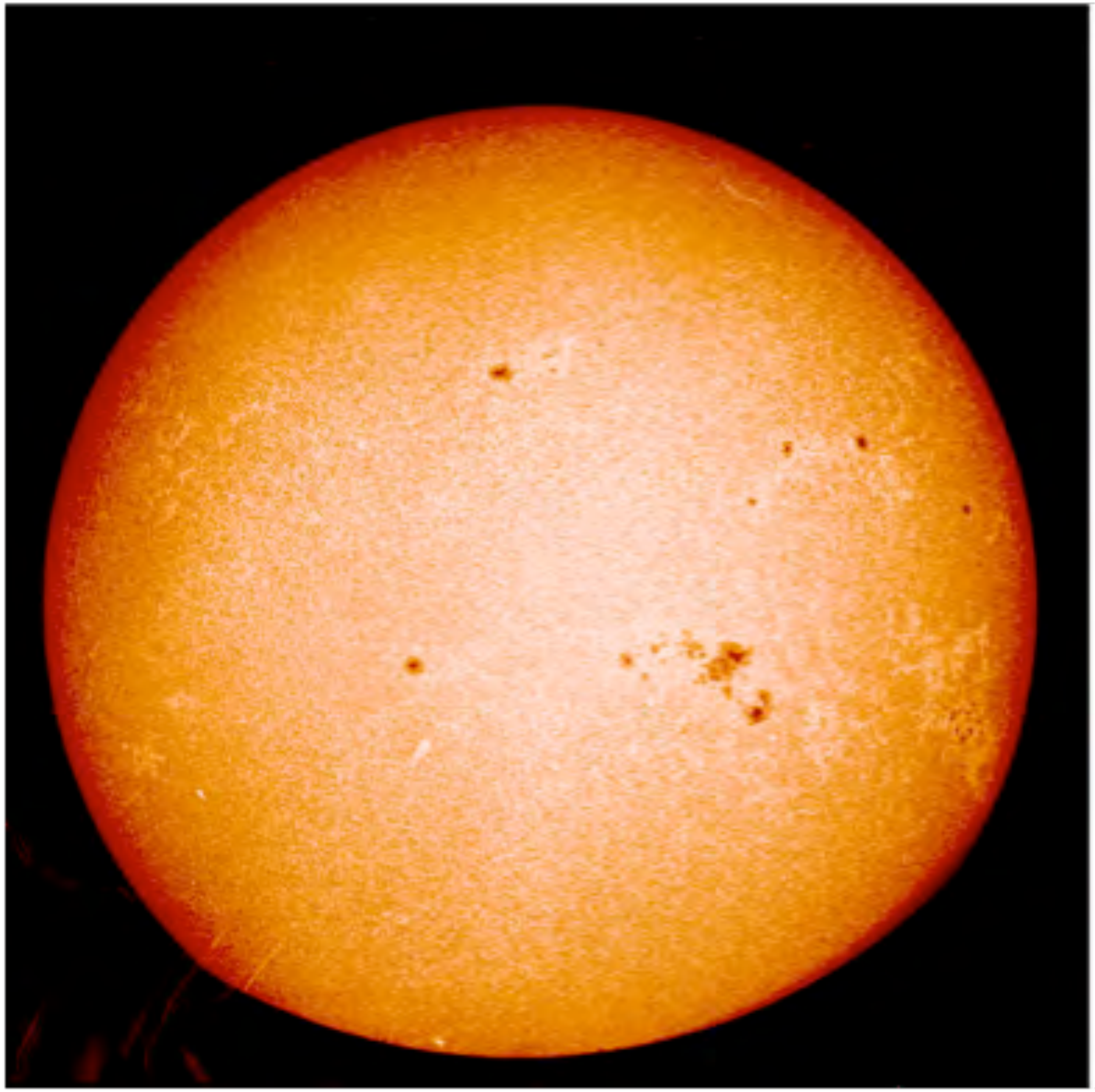
- Altogether, the SUITS P/L has:
  - a very complete science case with **4 unique assets** complementing (not addressed by) larger missions:
    - **Flare** physics at **high energy** and in **Lyman-Alpha**
    - **Prediction** and detection of **majors eruptions** and **CMEs**
    - **(F)UV** spectral 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 and PROBA-2, allowing development on 3-4 years (2021 launch compatible)
  - a sound mission profile since of recurrent use of the CNES/ Myriade (=> Myriade Evolutions) platform, 6 Gbits/day of telemetry allowance, and a piggy-back low cost VEGA or LM-2C or D launch
- Suited for ESA-CAS Small-size mission & a possible & valuable contribution to ESA/SSA

Thank you!!



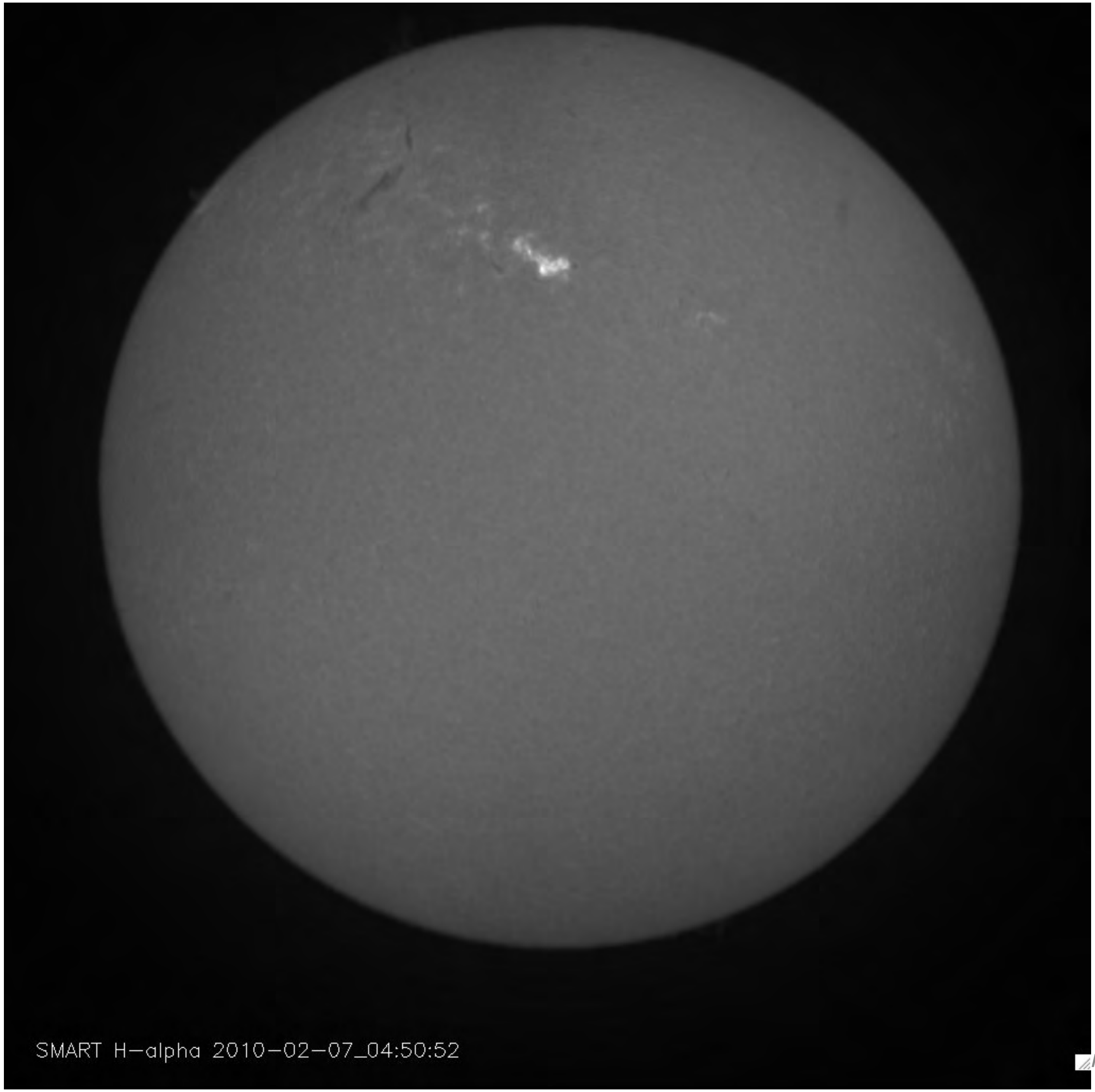
*Lyman-Alpha filtregram obtained in **1979** during the first rocket flight of the Transition Region Camera (**TRC**) and yet the best resolution (**1 arcsec**) full disc Lyman-Alpha image of the Sun. SUITS will have the same resolution.*

Herzberg Continuum 220 nm



TRC 3 Rocket Flight
1982 July 13

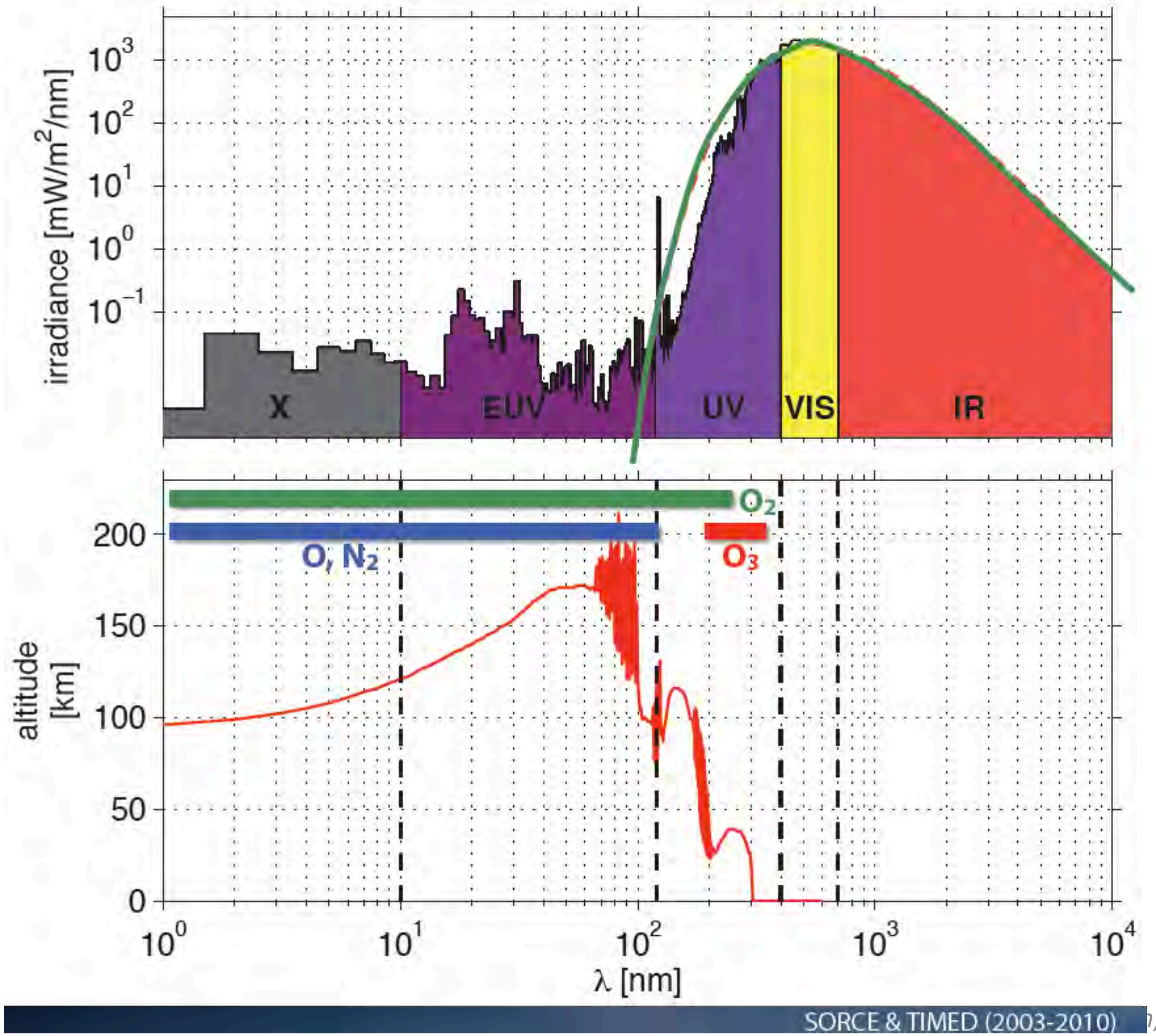
H-Alpha Flare visible on solar disk



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

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

Incoming solar flux and atmospheric absorption



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