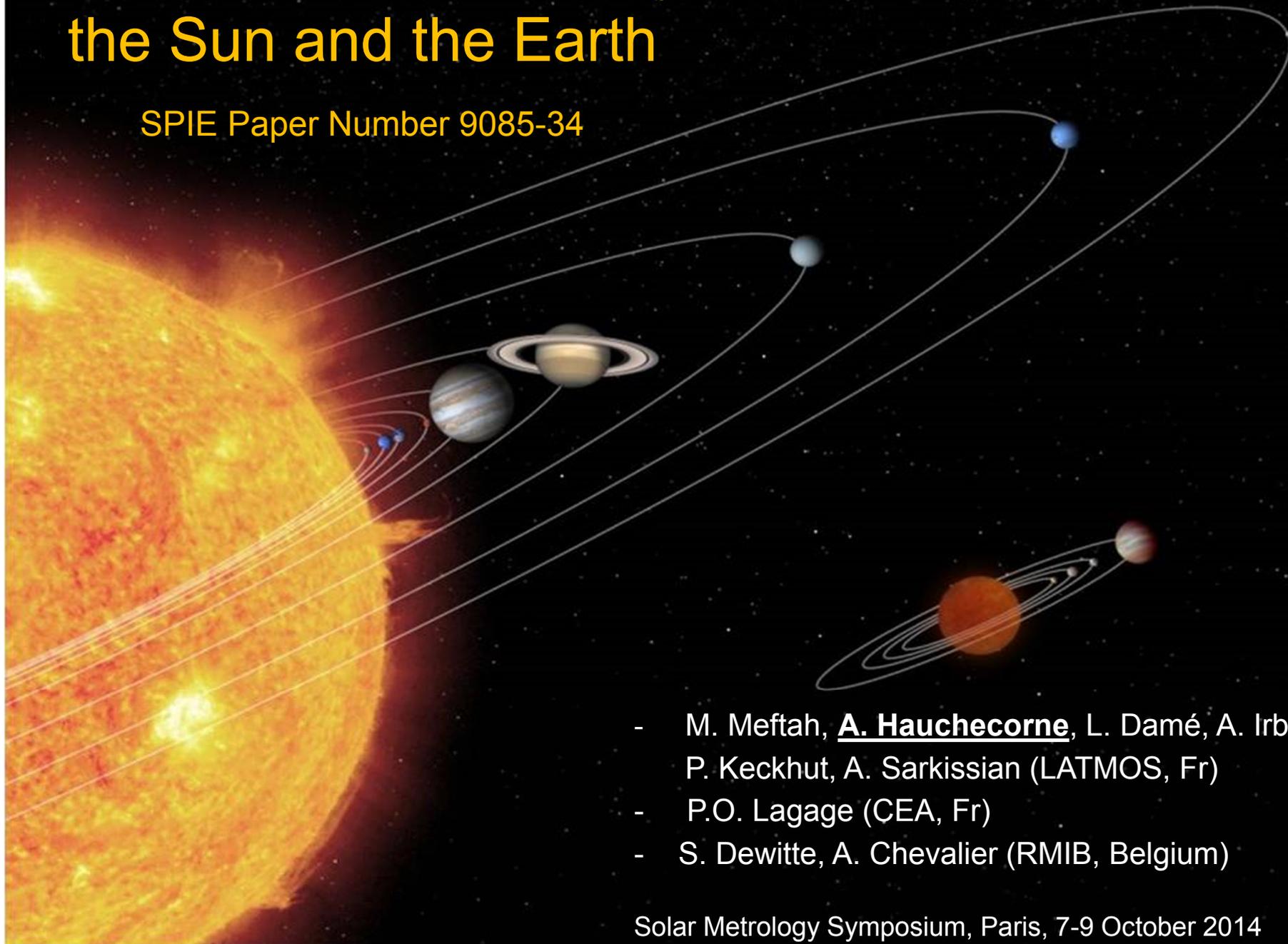


A nano-satellite to study the Sun and the Earth

SPIE Paper Number 9085-34



- M. Meftah, A. Hauchecorne, L. Damé, A. Irbah, P. Keckhut, A. Sarkissian (LATMOS, Fr)
- P.O. Lagage (CEA, Fr)
- S. Dewitte, A. Chevalier (RMIB, Belgium)

Solar Metrology Symposium, Paris, 7-9 October 2014

0 – Introduction

At the beginning of the “space age” in the late 50’s, only small satellites of a few kilograms could be launched.

The size and weight of satellites subsequently increased, and can now reach tons and meters.

However, in the 90’s, the concept of nano-satellites (1-10 kilograms) has been re-introduced, mainly for universities and government laboratories for inexpensive space testing.

Nano-satellites have a key role to play in technology maturity demonstrations.

Today, we hope through the use of nano-satellites to reduce size, costs, time of development and accordingly to increase accessibility to space for scientific objectives.

1 – Scientific objectives of the mission (1/12)

The SERB « nano-satellite to study the Sun and the Earth » is a future innovative proof-of-concept, with four ambitious science goals, to contribute to:

- *1st*: the extension of series of Total Solar Irradiance (TSI) measurement,
- *2nd*: the improvement of the knowledge of the absolute value of the TSI,
- *3rd*: the determination of the Earth radiative balance at global and regional scales
- *4th*: the understanding of the relation between solar Ultra-Violet (UV) variability and stratospheric ozone.

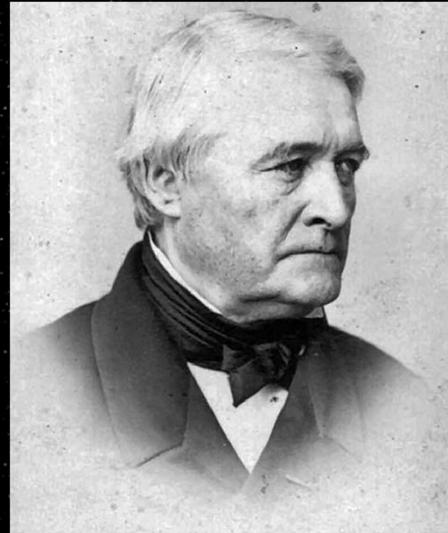
1 – Scientific objectives of the mission (2/12)

The solar irradiance (SI) is the primary source of energy reaching the Earth-atmosphere system.

The TSI is a crucial input for all climate models.
The actual TSI absolute value is still a matter of debate.

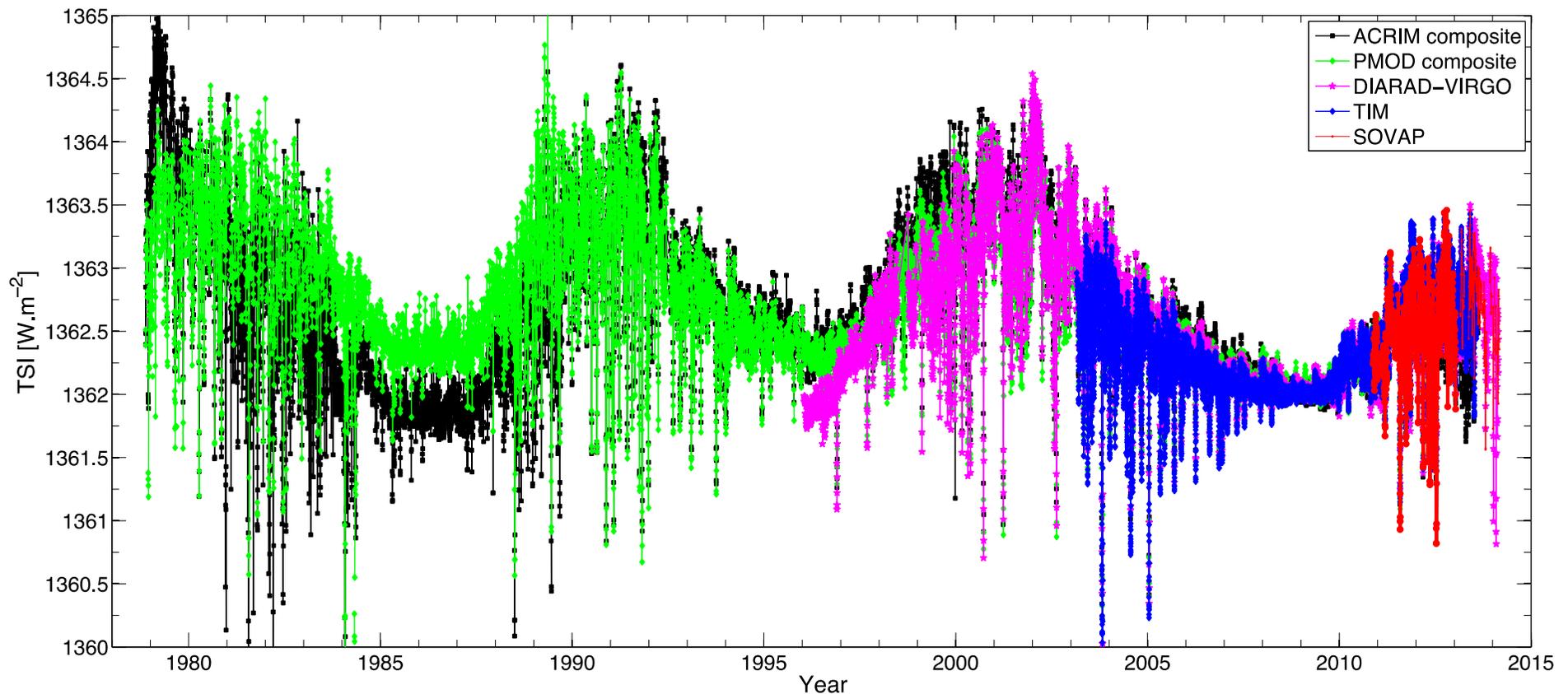
Claude Pouillet (1790-1868), a French physicist, made between 1837 and 1838, the first measurements of this fundamental astrophysical quantity.

The first estimate of The “solar constant” was 1228 W.m^{-2} (Pouillet, 1838), very close to the current estimate.



1 – Scientific objectives of the mission (3/12)

- First objective: the extension of series of Total Solar Irradiance (TSI) measurement
It's very important to continue to measure this essential climate variable with overlapping periods between instruments

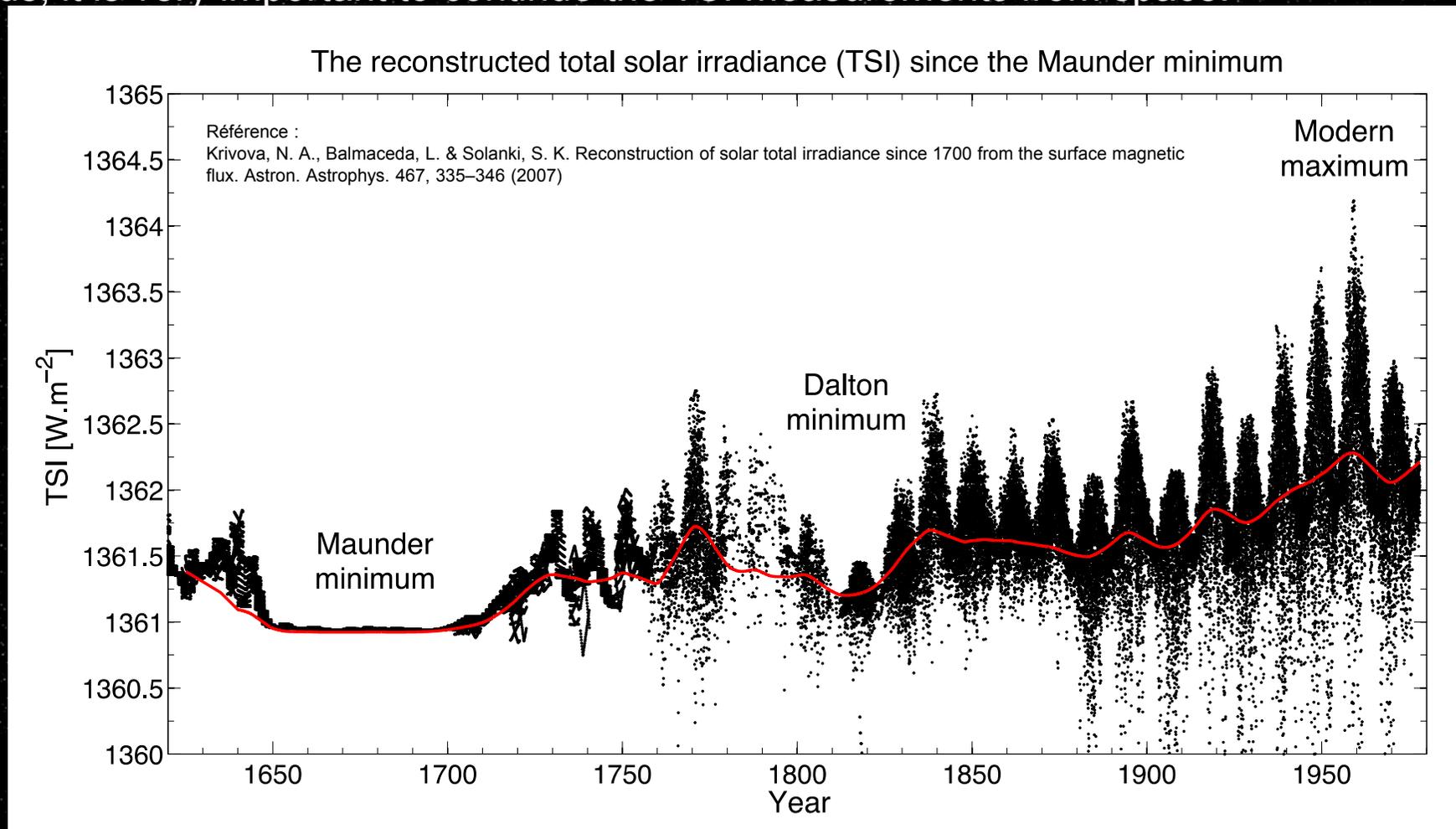


The TSI is measured to vary by approximately $\pm 0.05\%$ (over the last three 11-year sunspot cycles). Composite TSI time series (ACRIM and PMOD) or TSI space instruments highlighting differences for some solar minima.

1 – Scientific objectives of the mission (4/12)

The TSI is correlated with Earth climate (Lean, Beer, and Bradley, 1995; Fröhlich and Lean, 2002; Foukal, 2003; Soon and Legates, 2013) and temperature.

However, solar irradiance measurements are only available since the last four decades (Satellite era), which calls for the use of models over longer time scales. Thus, it is very important to continue the TSI measurements from space.



1 – Scientific objectives of the mission (5/12)

- Second objective: the improvement of the knowledge of the absolute value of the TSI

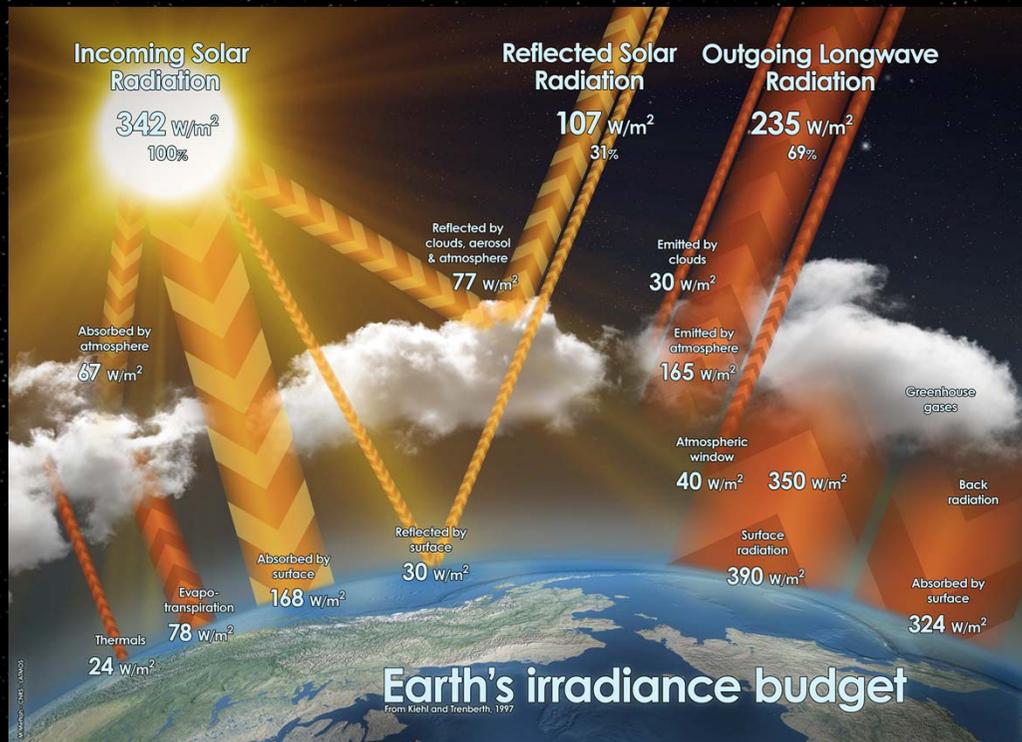
Instrument	Years	TSI	References
ERB/NIMBUS 7	1978-1993	TSI ~ 1371 W.m⁻²	Hickey et al., 1980 Hickey et al., 1988 Kyle et al., 1994
ACRIM 1/SMM	1980-1989	TSI ~ 1367 W.m ⁻²	Willson et al., 1981 (1368.31 W/m ²)
ERBE/ERBS	1984-2003	TSI ~ 1365 W.m ⁻²	Lee et al., 1987
ERBE/NOAA 9	1985-1989	TSI ~ 1364 W.m ⁻²	Barkstrom et al., 1990
ERBE/NOAA 10	1986-1987	TSI ~ 1364 W.m ⁻²	Barkstrom et al., 1990
ACRIM2/UARS	1991-2001	TSI ~ 1365 W.m ⁻²	Willson & Mordvinov, 2001
SOVA 1/EURECA	1992-1993	TSI ~ 1365 W.m ⁻²	Crommelynck et al., 1993
DIARAD/VIRGO on SOHO	1996-present	TSI ~ 1365 W.m ⁻²	Dewitte et al., 2004
PMO6V/VIRGO on SOHO	1996-present	TSI ~ 1365 W.m ⁻²	Finsterle et al., 2006 Fröhlich et al., 1997
ACRIM3/ACRIMSAT	2000-present	TSI ~ 1365 W.m ⁻²	Willson & Helizon, 1999
TIM/SORCE	2003-2013	TSI ~ 1361 W.m ⁻²	Kopp et al., 2005
PREMOS/PICARD	2010-present	TSI ~ 1361 W.m ⁻²	Schmutz et al., 2013
SOVAP/PICARD	2010-present	TSI ~ 1362 W.m⁻²	Meftah et al., 2014 (Solar Phys.)

Based on measurements collected from various spacecraft instruments over the last 35 years, the TSI has incrementally declined from 1371 W.m⁻² in 1978, to 1365 in the 1990's, and to around **1362 W.m⁻² in 2014** (Meftah, Dewitte, Irbah et al.).

1 – Scientific objectives of the mission (6/12)

- Third objective: the determination of the Earth radiative balance at global and regional scales

The total solar irradiance is the main external heat input into the Earth's climate system. The annual mean global energy balance for the Earth-atmosphere system is also very important to understand.



Irbah, Meftah, 2012 (SPIE)

Importance of the Earth radiative budget :

Radiation at "visible" and "NIR" wavelengths warms the lower atmosphere and the surface of the Earth. The TSI is a good proxy for solar energy reaching the ground.

Importance of the UV solar variability:

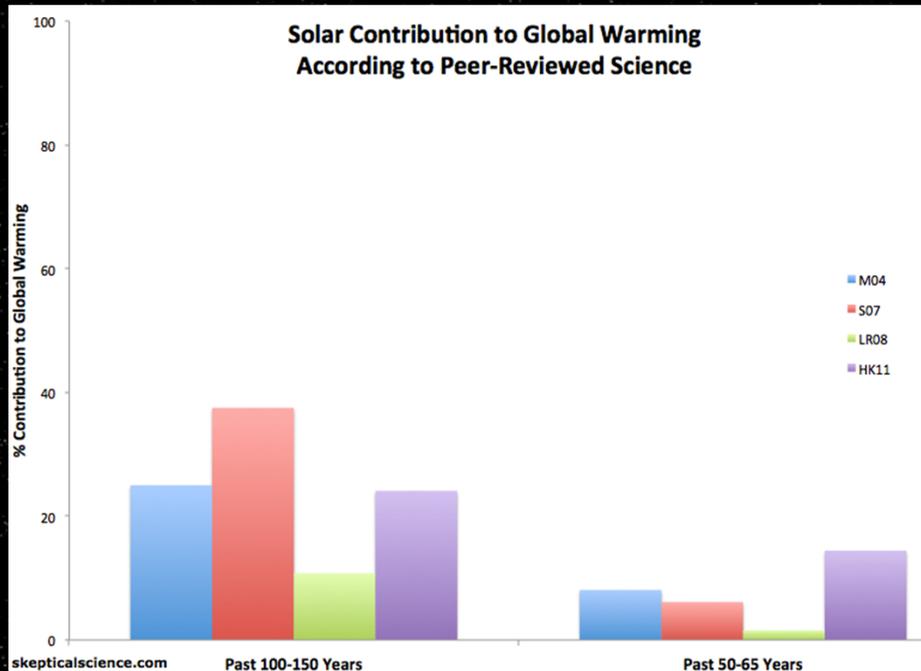
UV radiation photodissociates atmospheric molecules (including production of stratospheric ozone) and is the main source of heating in the stratosphere.

Atmospheric layers are dynamically and radiatively coupled

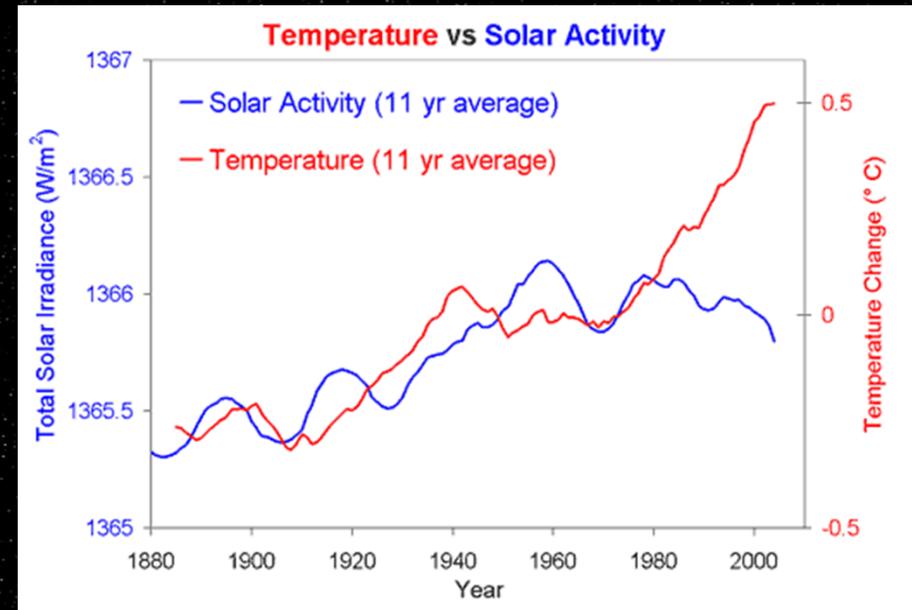
1 – Scientific objectives of the mission (8/12)

Contributions of different forcing agents to the total observed temperature change:

- Greenhouse gases, tropospheric O₃, solar, volcanic, stratospheric H₂O, direct aerosols, indirect aerosol



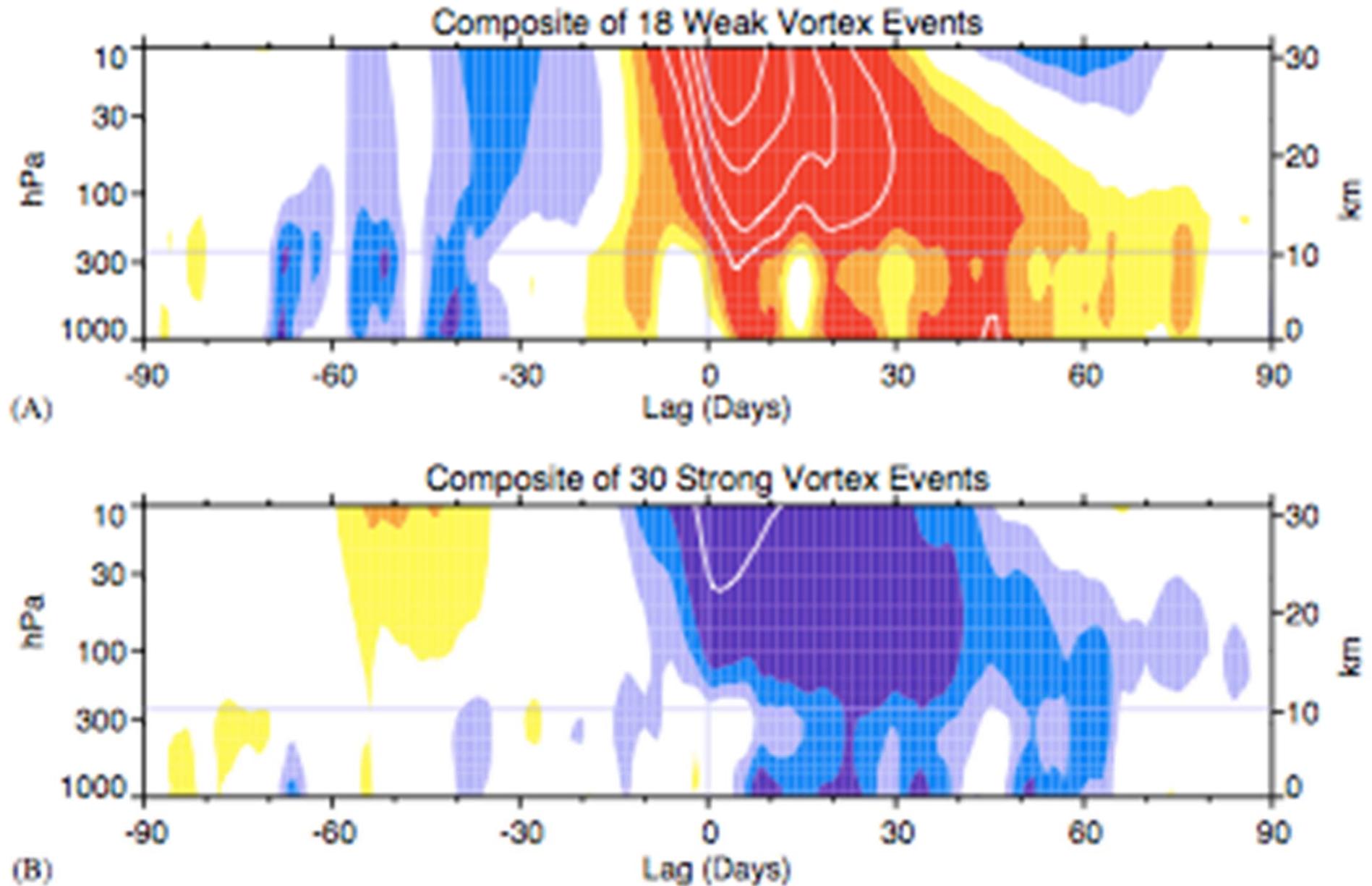
Solar contribution to global warming according to Meehl et al. 2004 (M04, blue), Stone et al. 2007 (S07, red), Lean and Rind 2008 (LR08, green), and Huber and Knutti 2012 (HK11, purple).



In the last 35 years of global warming, sun and climate have been going in opposite directions.

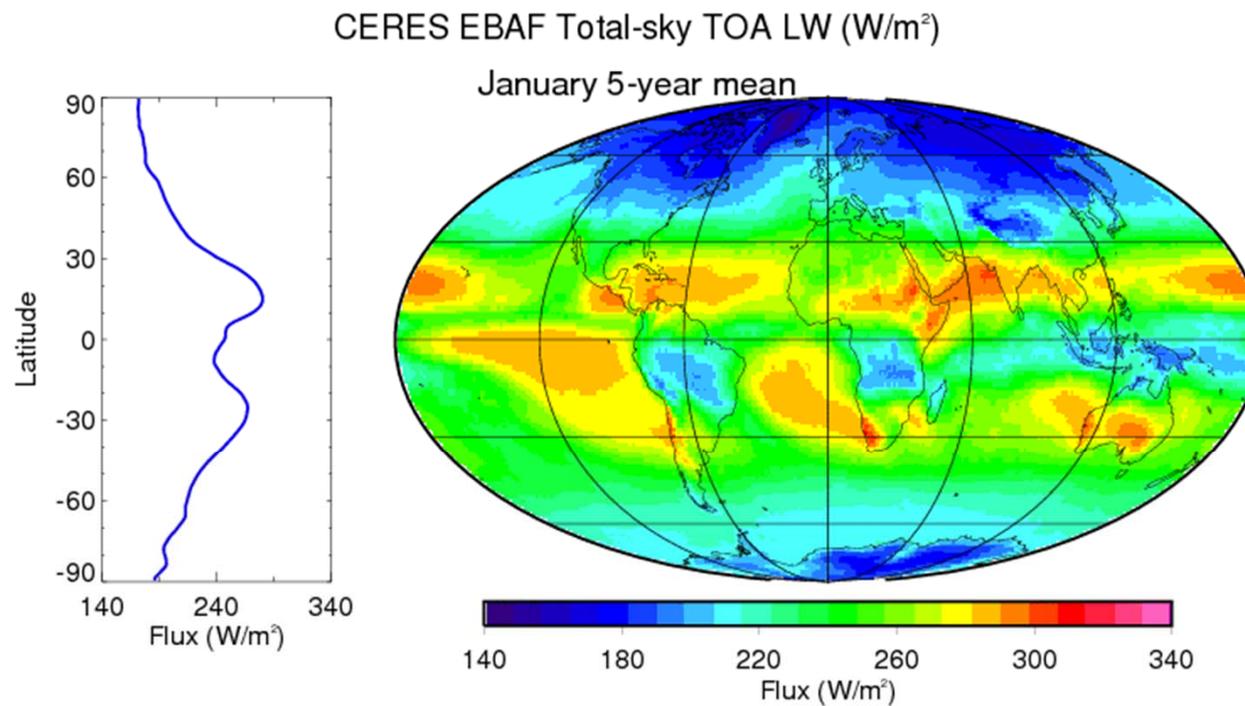
There is a relatively small solar contribution to global warming, particularly in recent decades.

1 - Dynamical stratospher-tropospher coupling (7/12)



1 – Scientific objectives of the mission (9/12)

- Determination of the Outgoing Longwave Radiation (OLR)
- Determination of the Reflected Solar Radiation or albedo flux



Evolution of the IR flux of the Earth during the year
(« Outgoing Longwave Radiation » or OLR)

1 – Scientific objectives of the mission (10/12)

- 4th objective: the understanding of the relation between solar Ultra-Violet (UV) variability and stratospheric ozone

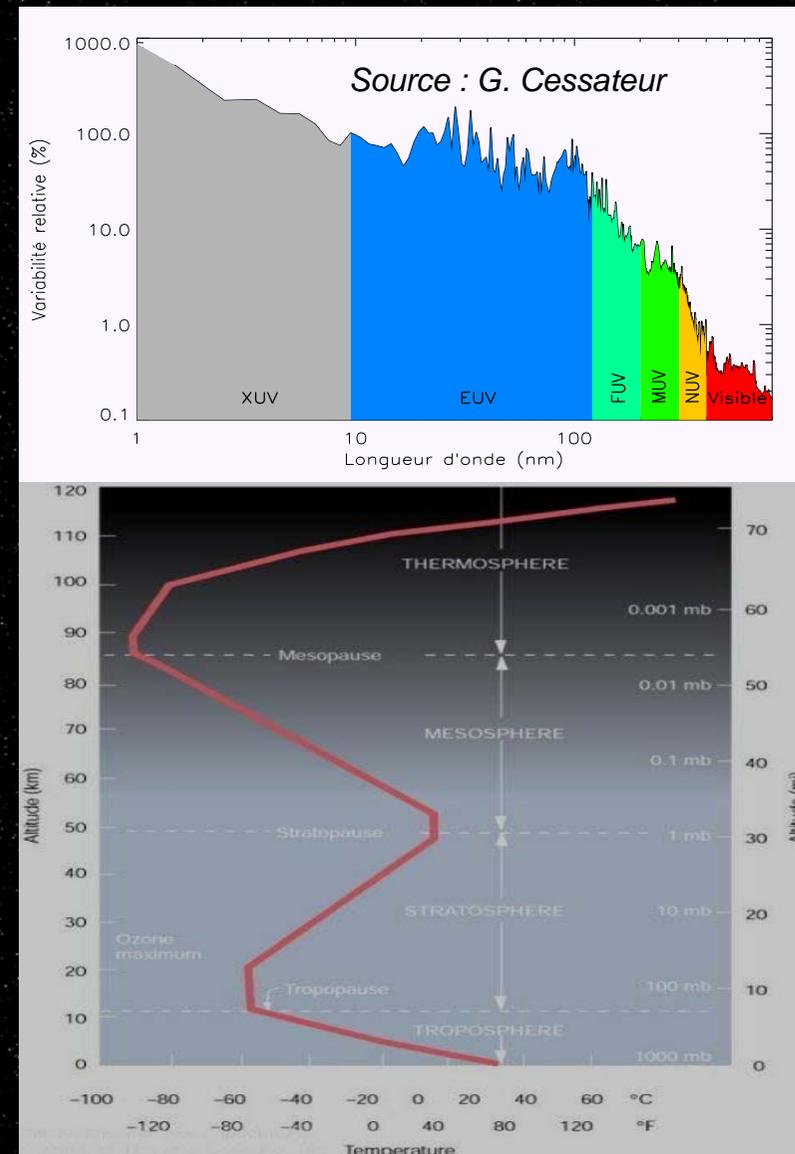
Solar UV:

In the UV, the variations of the solar spectral irradiance is more important: 1 to 20% of variability over a solar cycle (Cebula and Deland, 2012).

Stratospheric Ozone:

The measurement of the vertical column of ozone is very important.

It will be performed using a differential absorption method at two wavelengths (310 nm and 340 nm).



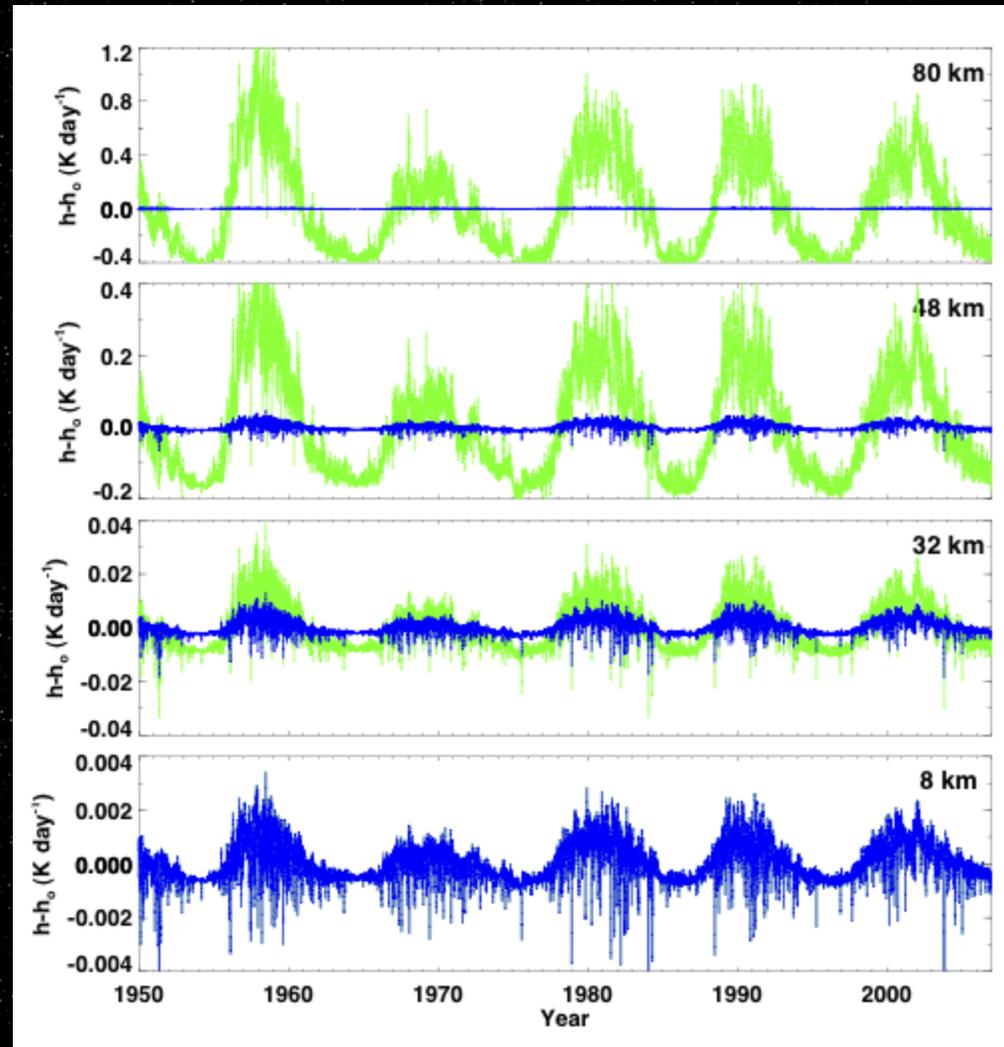
1 - Estimation of the variation of the atmospheric heating along the 11-year Solar cycle (11/12)

80 km

48 km

32 km

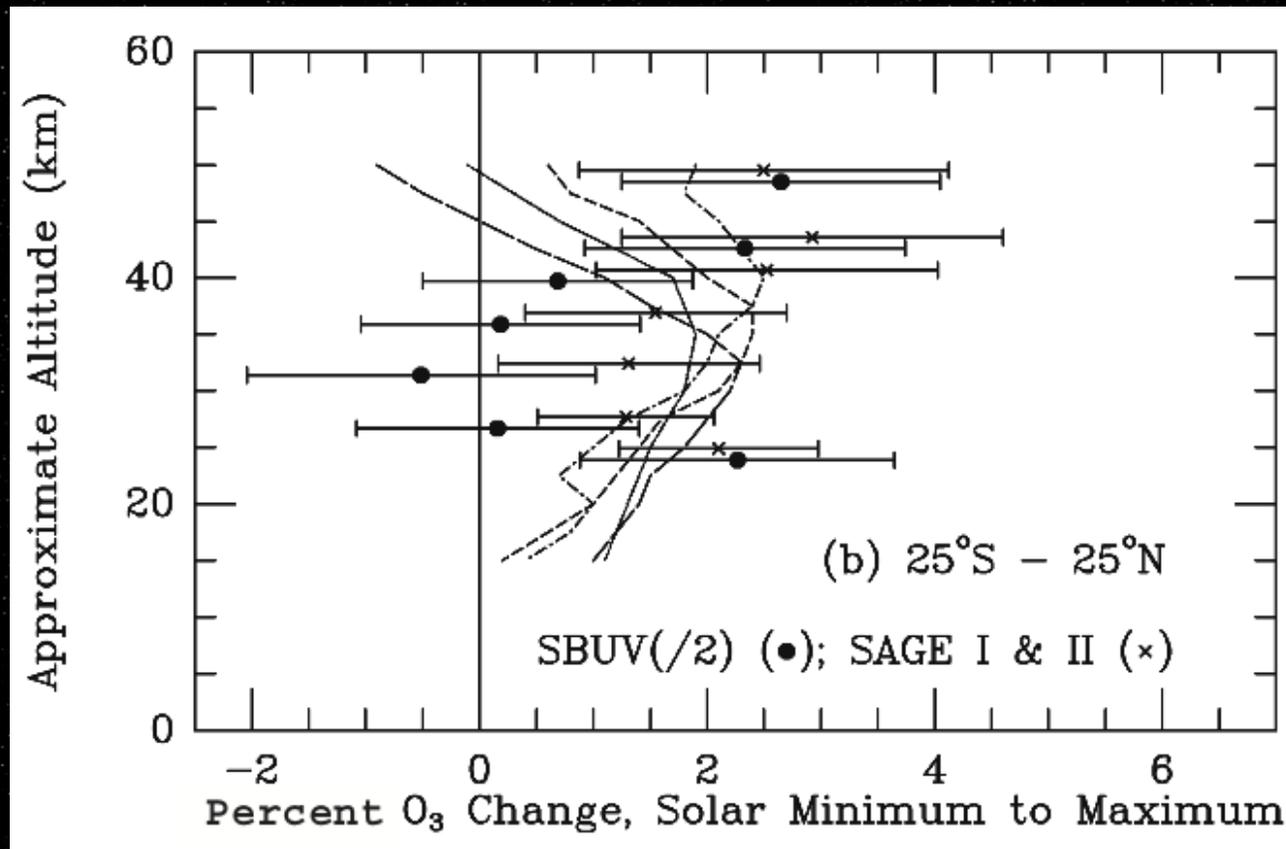
8 km



Semeniuk et al., 2011

1 –Response of stratospheric ozone to the 11-year solar cycle (12/12)

- Models underestimate this response and do not match very well its altitude profile
- What are the physical and photochemical mechanisms really involved ?

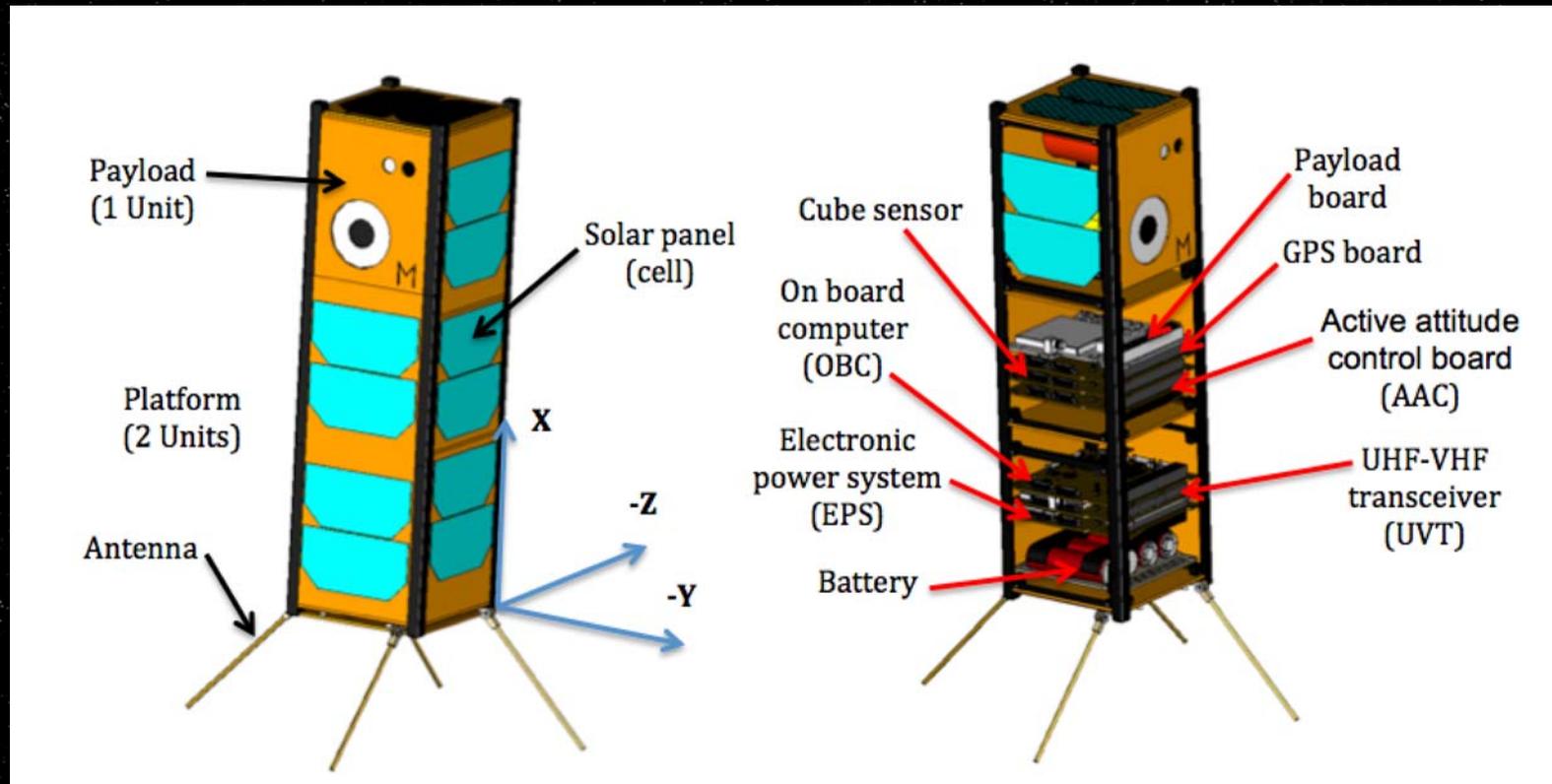


2 – The nano-satellite (1/10)

The SERB nano-satellite « to study the Sun and the Earth » is a three-unit CubeSat. A preliminary configuration of the nano-satellite system can be seen below.

SERB has been selected to be built at the Ecole Polytechnique Student Space Center with help of CNES

The key element of the mission is the space segment, containing the nano-satellite ($10 \times 10 \times 30 \text{ cm}^3$, 3.6 kg maximum and 3.0 W nominal consumption) that includes the payload and the avionics.



2 – The nano-satellite (2/10)

Parameter	Values (remarks)
Volume	10 (d) × 10 (w) × 30 (h) cm ³
Mass	3.6 kg (maximum with a margin of 20%)
Orbit average power generated	4.2 W (without eclipses)
Electrical power consumption	3.0 W (minimum power allowed during eclipses)
Field of view (payload)	180°
Data storage	2 Gbyte
Downlink speed	9.6 kbps (telemetry and tele-commands or TM/TC)
Downlink speed (S-band option)	115.0 kbps (large amount of payload data)
Uplink speed	1.2 kbps
Ground station contact time	30 minutes (hypothesis)
Downlink volume	~ 2.2 Mbyte per day
Downlink volume (S-band option)	~ 25.9 Mbyte per day
Uplink volume	~ 0.3 Mbyte per day
Mission modes	Sun pointing, Nadir pointing and stars pointing
Mission lifetime	One year

2 – The nano-satellite (3/10)

Artist view of the nano-satellite « to study the Sun and the Earth »



Source : ISIS

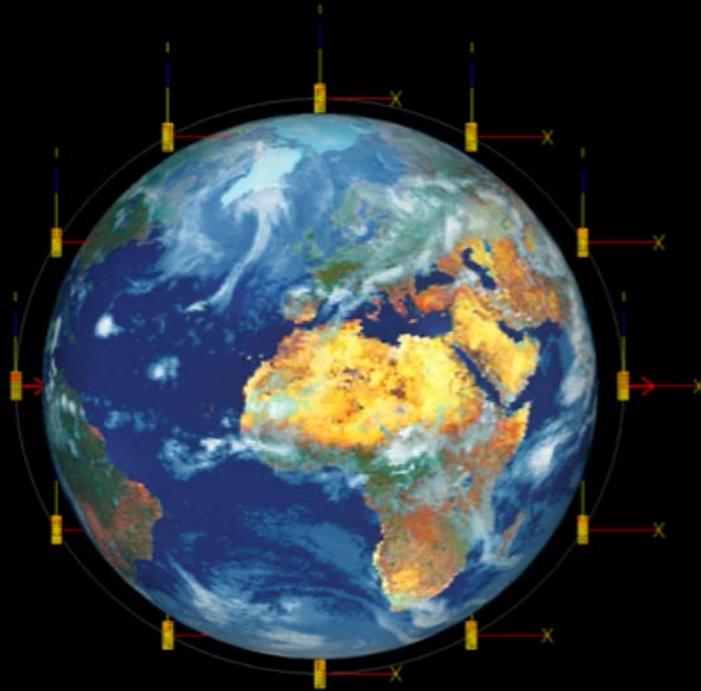
2 – The nano-satellite (4/10)

Orbit and active attitude control

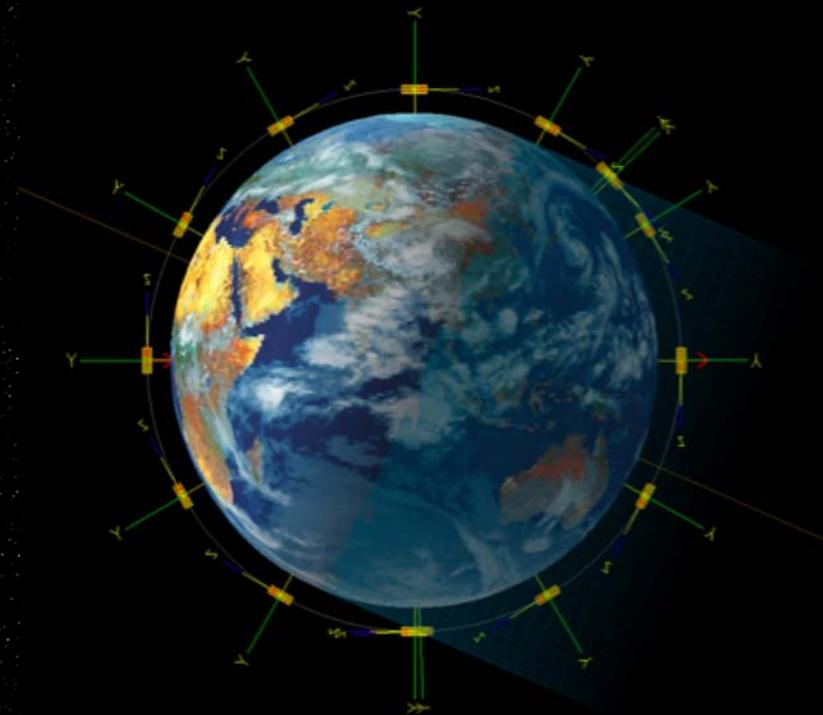
- Altitude: 600 km
- Local time at ascending node: 06H00
- Orbital inclination: 98°

Three type of pointing:

- Stellar pointing → « P-Star »
- Solar pointing → « P-Sun »
- Nadir pointing → « P-Nadir »



« P-Sun »
Nominal mode

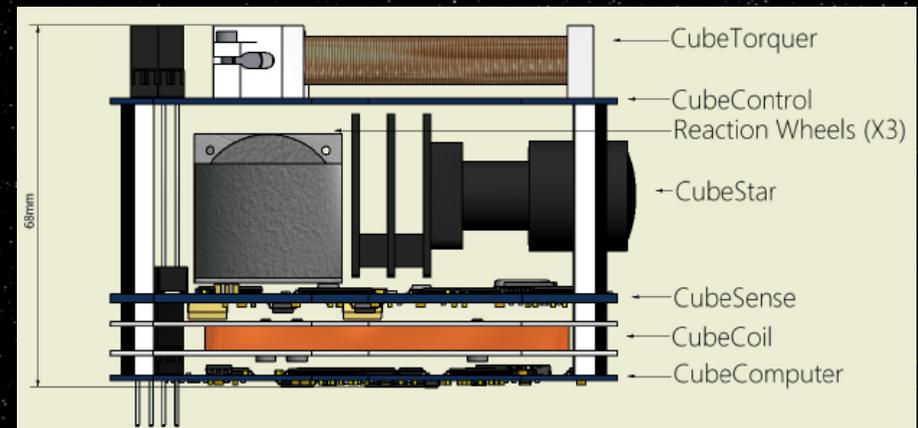
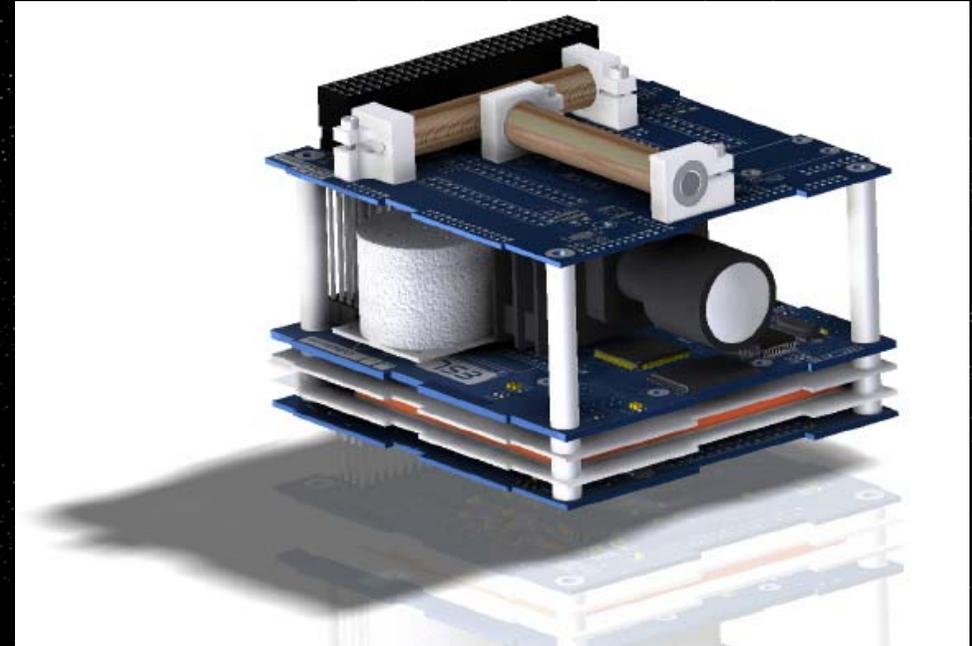


« P-Nadir »
Direct observation of the Earth (activity
of the O3)

2 – The nano-satellite (5/10)

The attitude and orbit control subsystem (AOCS) is required to provide a pointing accuracy of ± 30 arc-seconds for the -Z-axis of the nano-satellite (along the payload line of sight).

« P-Sun » $\rightarrow \sim 0.01^\circ$
« P-Nadir » $\rightarrow 0.4^\circ$

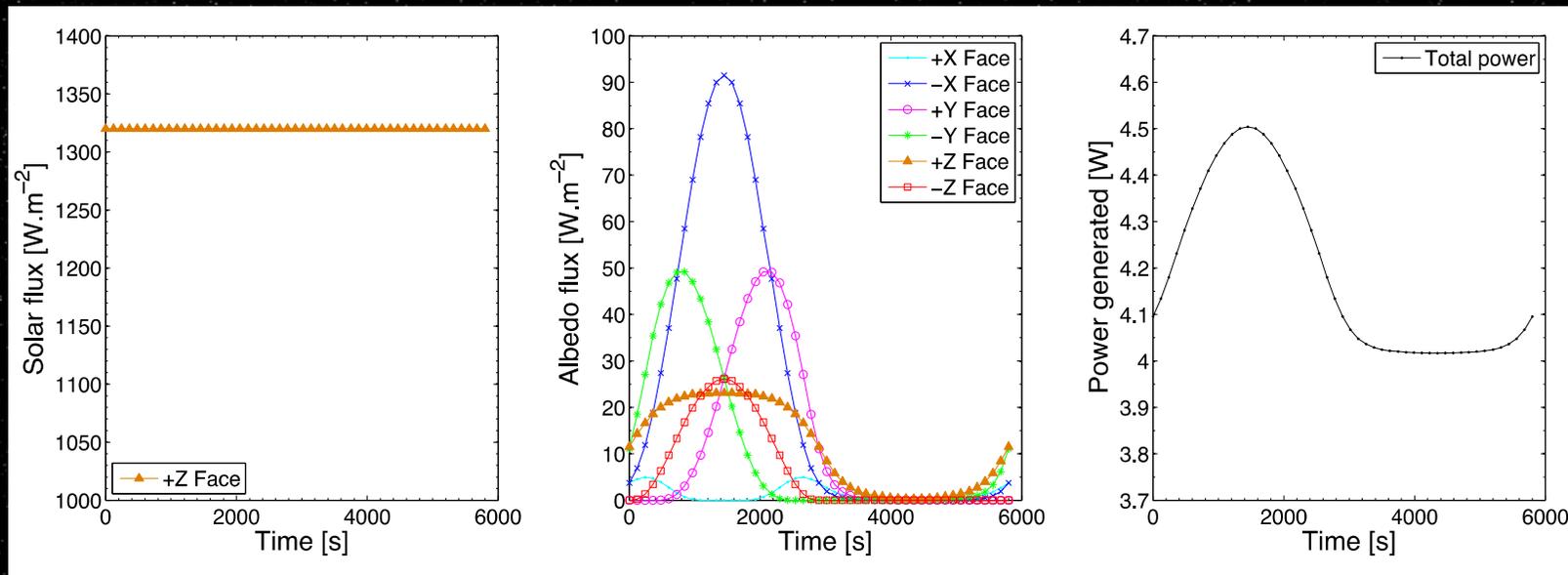


Crédits: ISIS

2 – The nano-satellite (6/10)

Power profile and power buses distribution

A typical orbital power profile for the mission has been analyzed (incident solar fluxes and albedo incident solar fluxes on the solar panels). The nano-satellite uses a minimum of 11 solar panels pairs (22 cells). During the Sun pointing mode (June solstice), the average power generated is near 4.2W.



(Left) Incident solar flux on the solar panel surfaces.

(Center) Incident albedo fluxes on the solar panel surfaces.

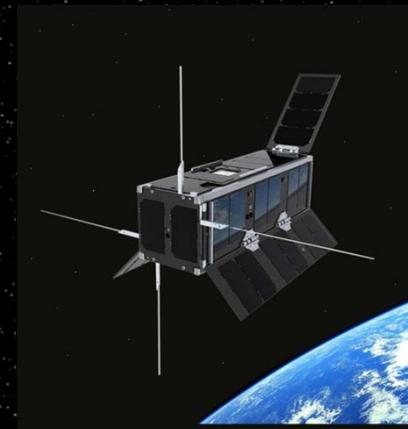
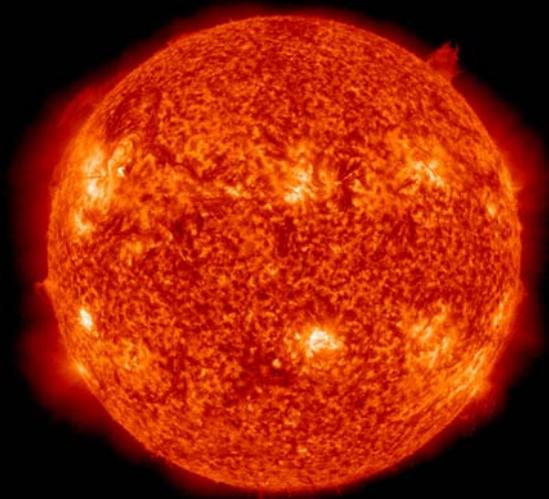
(Right) Power generated during an orbit of 5799 seconds.

2 – The nano-satellite (7/10)

The electronic power supply (EPS) shall distribute power through the interface in groups of 3.3 volts, 5 volts and power of the battery around 9 volts.

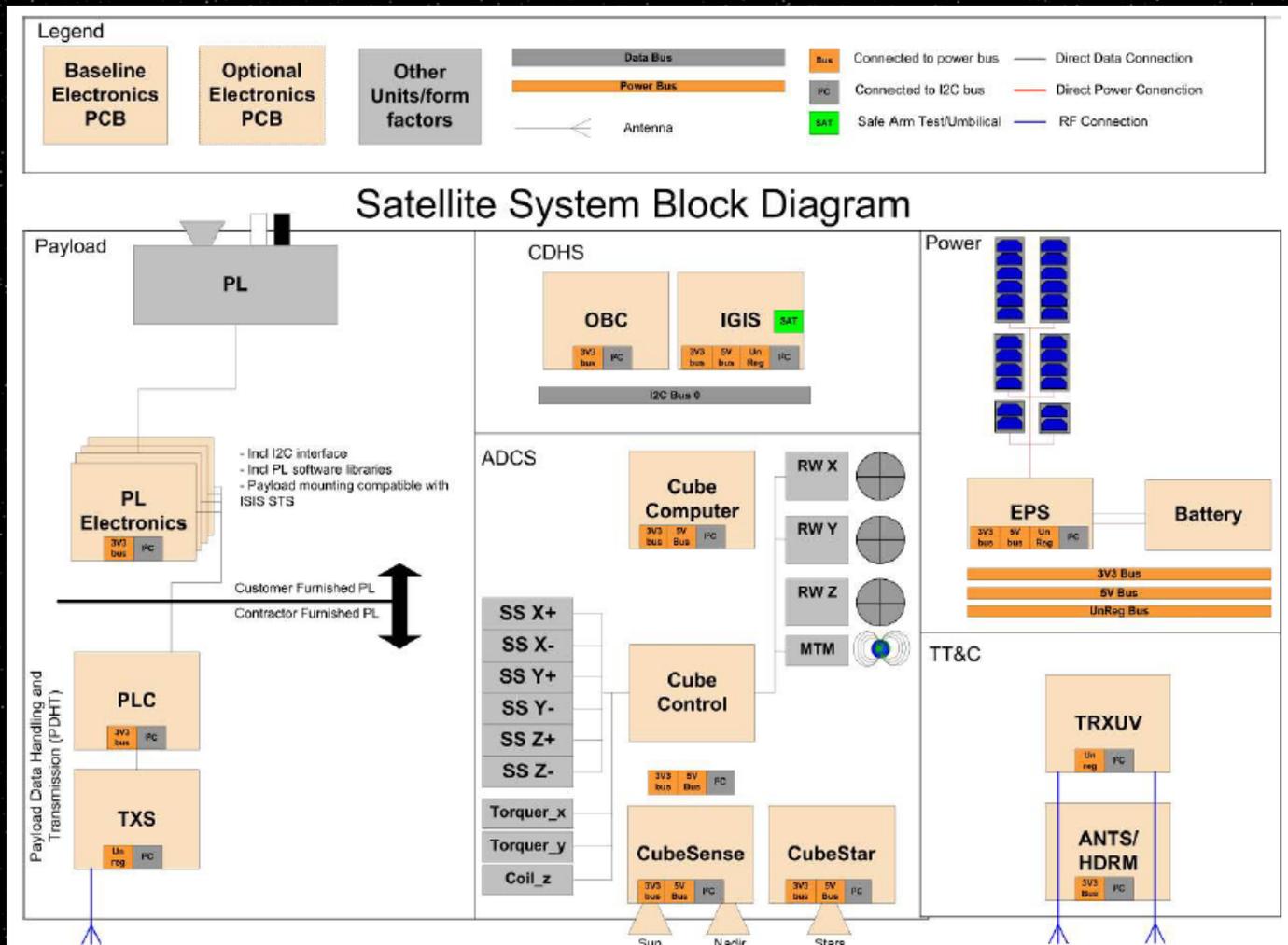
Thus, it is possible to have a view of the power consumption of the nano-satellite for each element of the nano-satellite.

Element	Consumption
Payload board	1.00 W
GPS board, Cube sensor board and AAC board	0.29 W
OBC (on-board computer)	0.41 W
UHF-VHF transceiver and S-band	0.83 W
EPS	0.36 W
Battery (loss)	0.11 W
Total electrical power consumption (nominal)	3.00 W



2 – The nano-satellite (8/10)

Satellite system block diagram



2 – The nano-satellite (9/10)

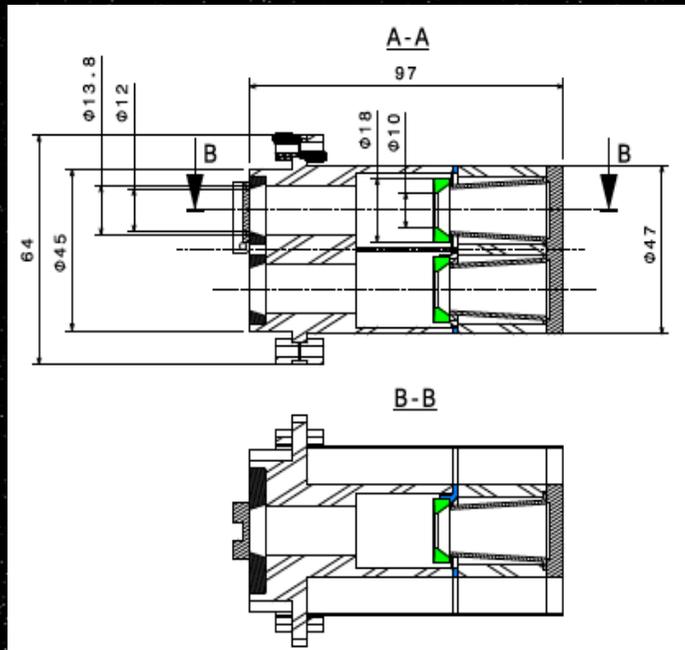
The payload

The model payload encompasses four instruments in a 1 kg, 10 10 10 cm³ space, and requires 1W of power. Instruments are:

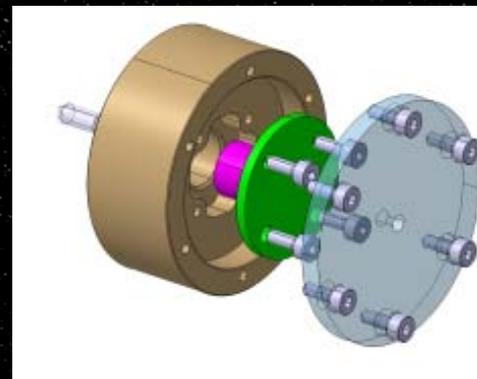
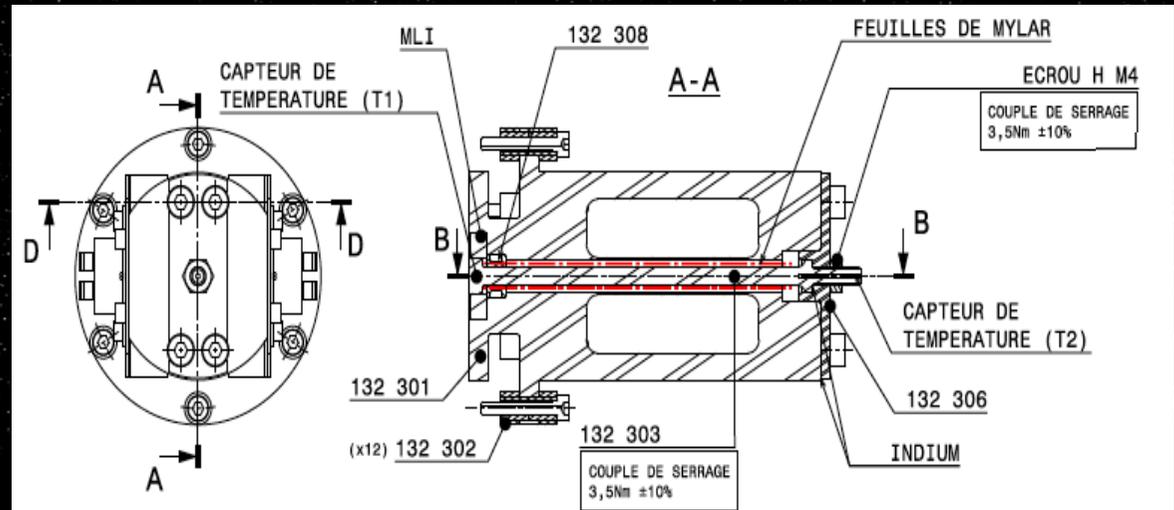
- a solar radiometer (SR) of new instrumental design, used for the measurement of the total solar irradiance. It covers the spectral range 0.2 to 3 μ m, with a mass of 0.15 kg and with dimensions of 47mm diameter by 95mm length;
- an Earth radiometer (ER): a simple two-radiation plate system (structure element with white paint and black paint) of 0.05 kg, covering 3 to 100 μ m spectral range and with dimensions of 40 40 1mm³, which measures the OLR radiation;
- an O3 sensor (O3S): a two-channels ozone detector (310nm and 340nm);
- a UV sensor (UVS) detector for the solar radiations Herzberg continuum between 200 and 220 nm.

2 – The nano-satellite (10/10)

an Earth radiometer



a solar radiometer



an O₃ sensor

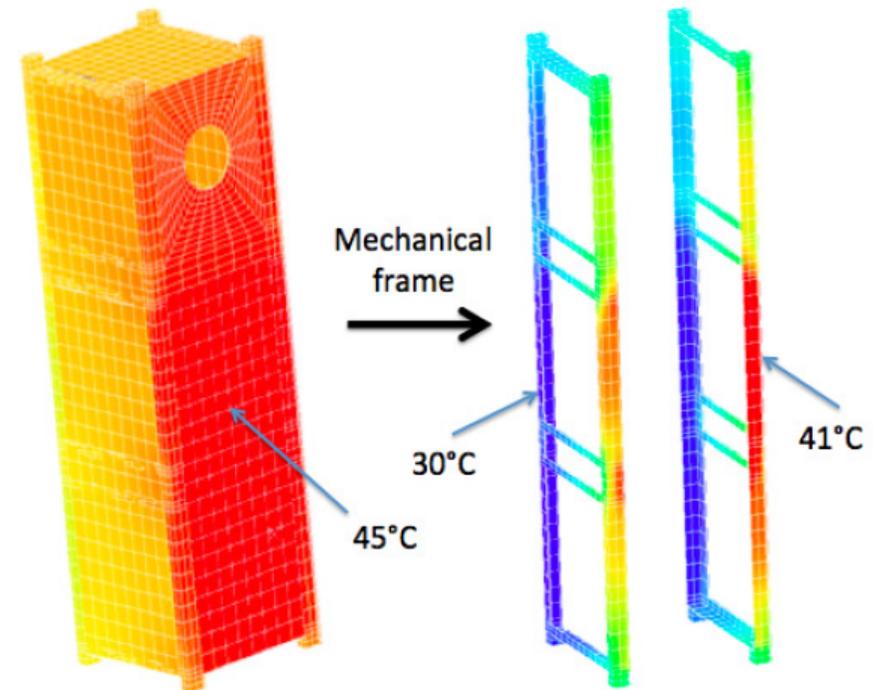
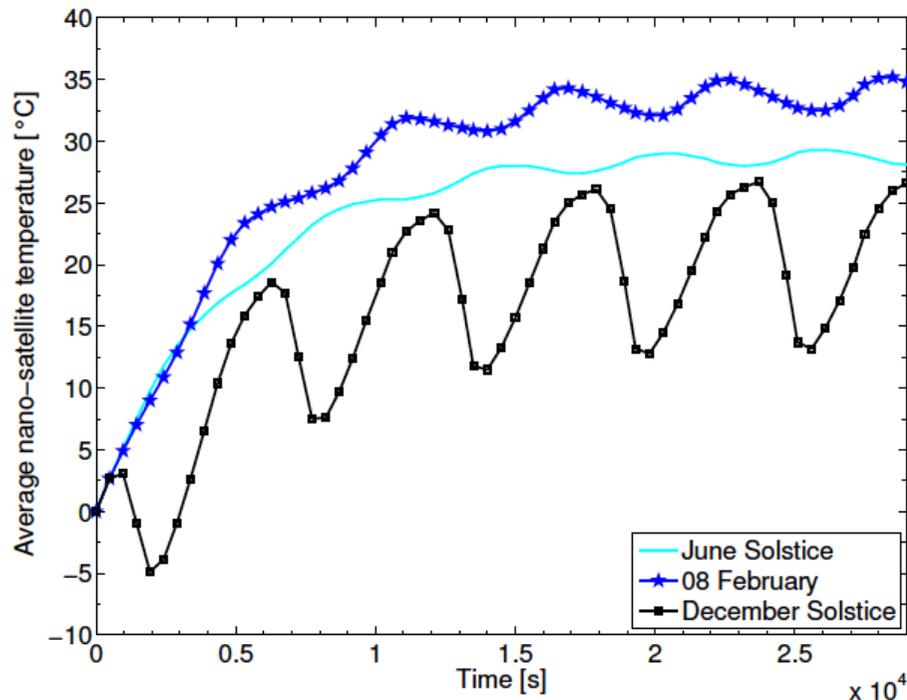


a UV sensor

3 – Models and qualification (1/3)

A preliminary thermal mathematical model was developed to study temperature variations and thermal gradients affecting the nano-satellite in different typical cases in orbit (summer solstice, hot case in February and winter solstice).

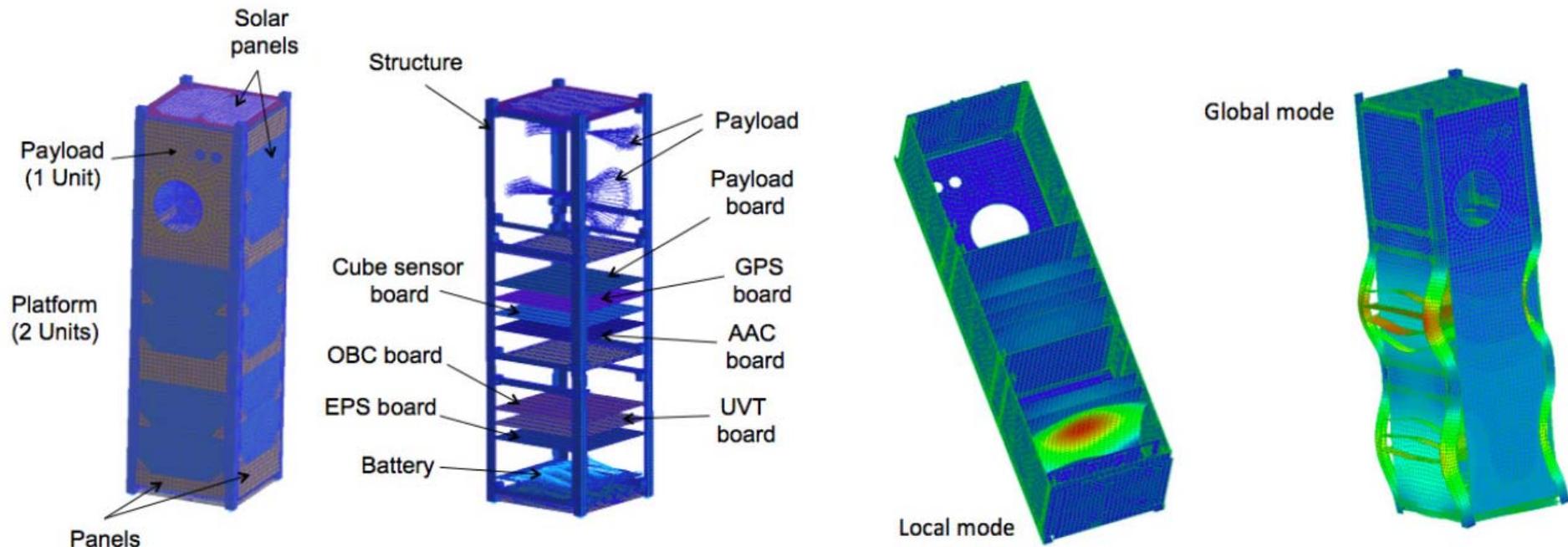
The ultimate goal of this thermal analysis is to ensure that all the components of the nano-satellite will be functioning in their safe range of temperatures and with a proper heat rejection.



3 – Models and qualification (2/3)

Some preliminary mechanical analyses have been carried out on the nano-satellite. Indeed, models were needed to design the nano-satellite and to give the accelerations' envelope on the payload instruments interfaces.

The first Eigen frequency of the structure is at 191.7 Hz (local board mode along X-axis). The first global mode of the structure is at 499.8 Hz (see the Figure).



3 – Models and qualification (3/3)

Mechanical test

Model	Qualification	Acceptance
Direction	X, Y and Z	X, Y and Z
Rms acceleration	8.0 g rms	6.5 g rms
Duration	120 s	60 s
Profile	20 Hz - 0.009 g ² .Hz ⁻¹ 130 Hz - 0.046 g ² .Hz ⁻¹ 800 Hz - 0.046 g ² .Hz ⁻¹ 2000 Hz - 0.015 g ² .Hz ⁻¹	20 Hz - 0.007 g ² .Hz ⁻¹ 50 Hz - 0.007 g ² .Hz ⁻¹ 200 Hz - 0.035 g ² .Hz ⁻¹ 640 Hz - 0.035 g ² .Hz ⁻¹ 2000 Hz - 0.010 g ² .Hz ⁻¹

Thermal test

Model	Qualification	Acceptance
Maximum non operational temperature	+65°C	+60°C
Maximum Switch-On Temperature	Not applicable	Not applicable
Maximum operational temperature	+60°C	+50°C
Minimum operational temperature	-35°C	-25°C
Minimum Switch-On Temperature	-40°C	-40°C
Minimum non operational temperature	-50°C	-50°C
Number of cycles	8	4
Dwell time	3 hours	3 hours
Temperature Rate of Change	>2°C per minute	>2°C per minute
Pressure	<10 ⁻⁵ mbar	<10 ⁻⁵ mbar

4 – Space facility in Guyancourt



Cleanroom for integration (particularly for UV filters)



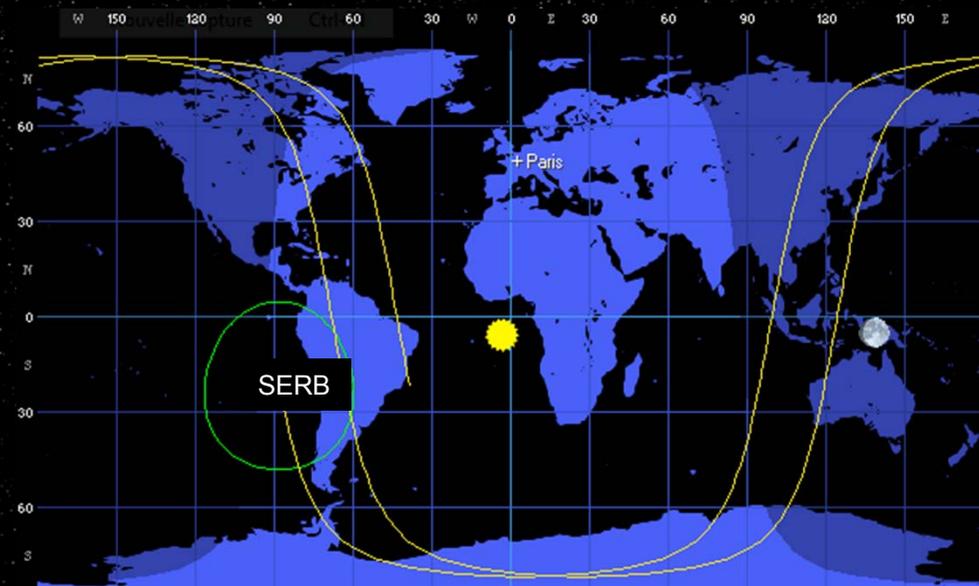
Mechanical tests (random)



5 – The antenna (1/1)

Antenna network

(UHF/VHF antenna in the first time and after, use of a band S antenna)



Conclusion

The role of nano-satellites for education is well established. Space sciences remain very attractive for young people interested in new technologies.

Nano-satellites provide an appealing way for training students to space activities and more generally to complex technological projects, from fundamental and engineering sciences to project management and communication.

Critical components of instrumental payloads of future large missions can acquire the technical maturity by flying in a CubeSat (coatings, UV filters, etc.).

Nano-satellites represent also an excellent alternative of instrumentation testing, providing longer flights than rockets.

Even now, targeted science can be performed by nano-satellites.

In summary, we are promoting the development of one or several nano-satellites, to contribute to the extension of TSI series and improvement the TSI absolute value, the determination of the Earth radiative and the understanding of the relation between solar ultraviolet variability and stratospheric ozone.