Think the way to measure the Earth Radiation Budget and the Total Solar Irradiance with a small satellites constellation

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Outlines

1 – Scientific objectives of the SERB mission

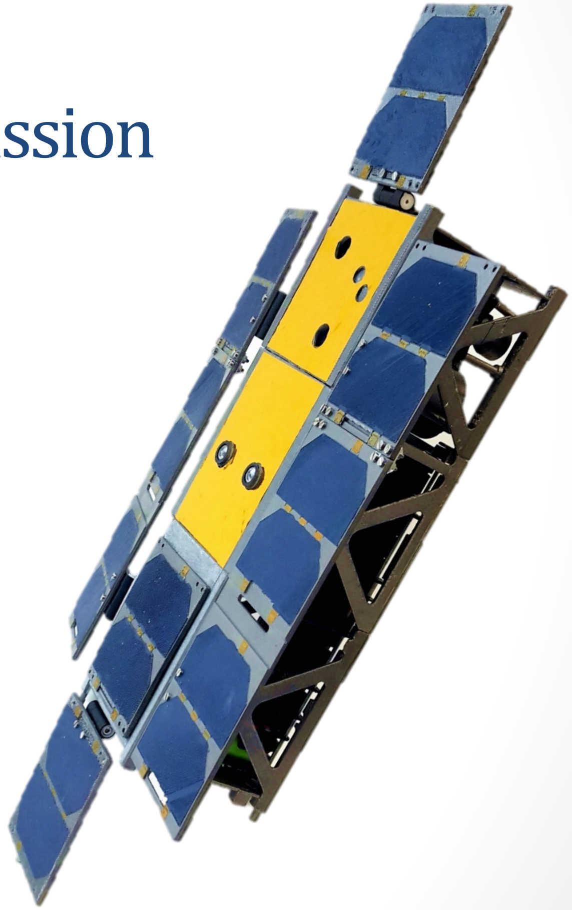
2 – Planned schedule and heritage

3 – SERB nanosatellite architecture

4 – Payload

5 – Ground segment

6 – Conclusions



1 – Scientific objectives of the mission

The « SERB nano-satellite » is a future innovative proof-of-concept, with four ambitious science goals:

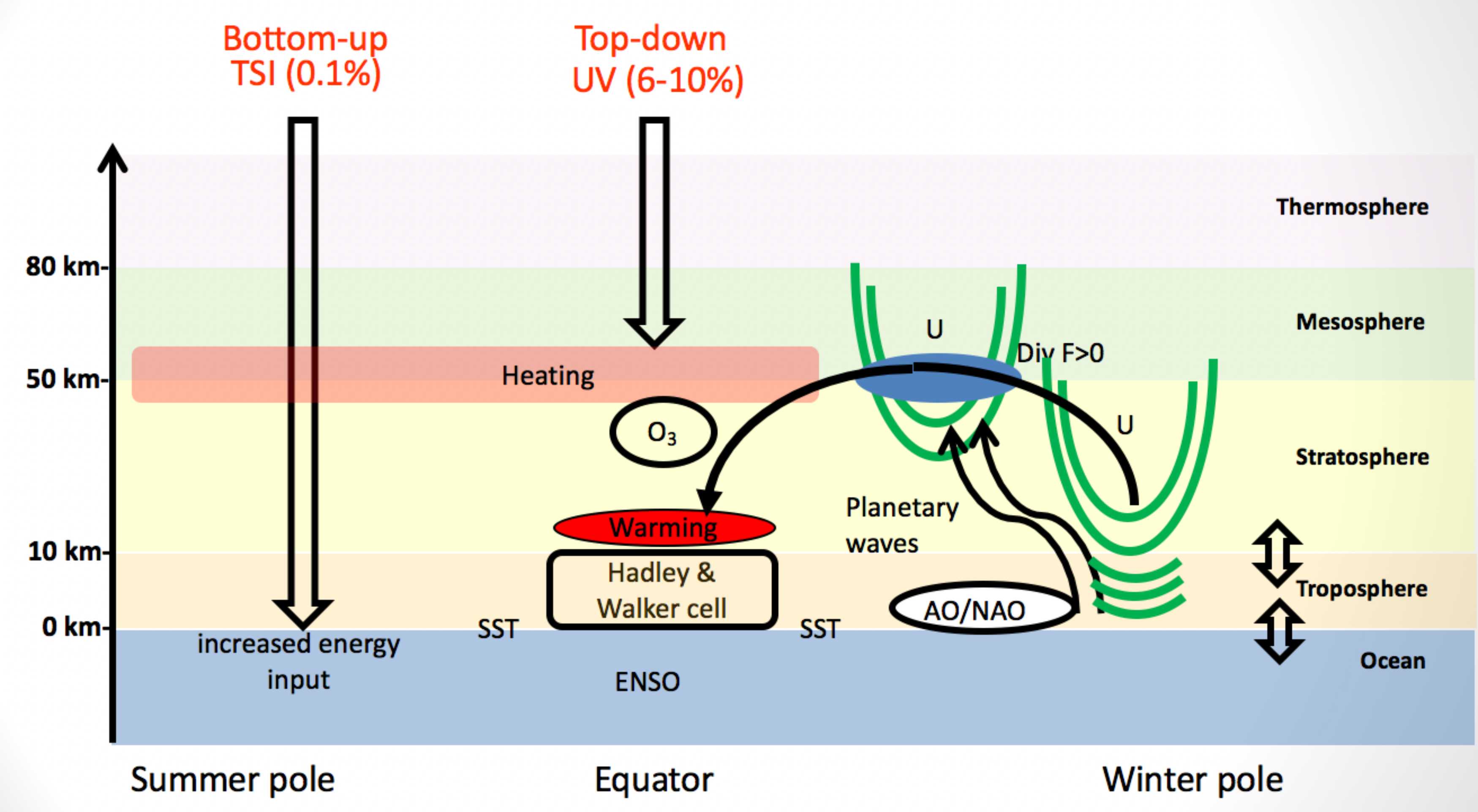
- *1st:* to improve the **knowledge of the absolute value of the Total Solar Irradiance (TSI)** with an accuracy better than 0.5 $W.m^{-2}$

- *2nd:* to **extend the TSI variability** measurement with a long-term stability (10 years) better than 0.05 $W.m^{-2}$

- *3rd:* to **monitor the Solar Spectral Irradiance (SSI) at 215 nm** (Herzberg solar continuum) with a long-term stability (10 years) better than $3.4x10^{-5}$ $W.m^{-2}.nm^{-1}$

- *4th:* to **establish a radiation balance of the Earth** with an accuracy better than 1% and link with the imbalance (between 0.5 and 1 $W.m^{-2}$)

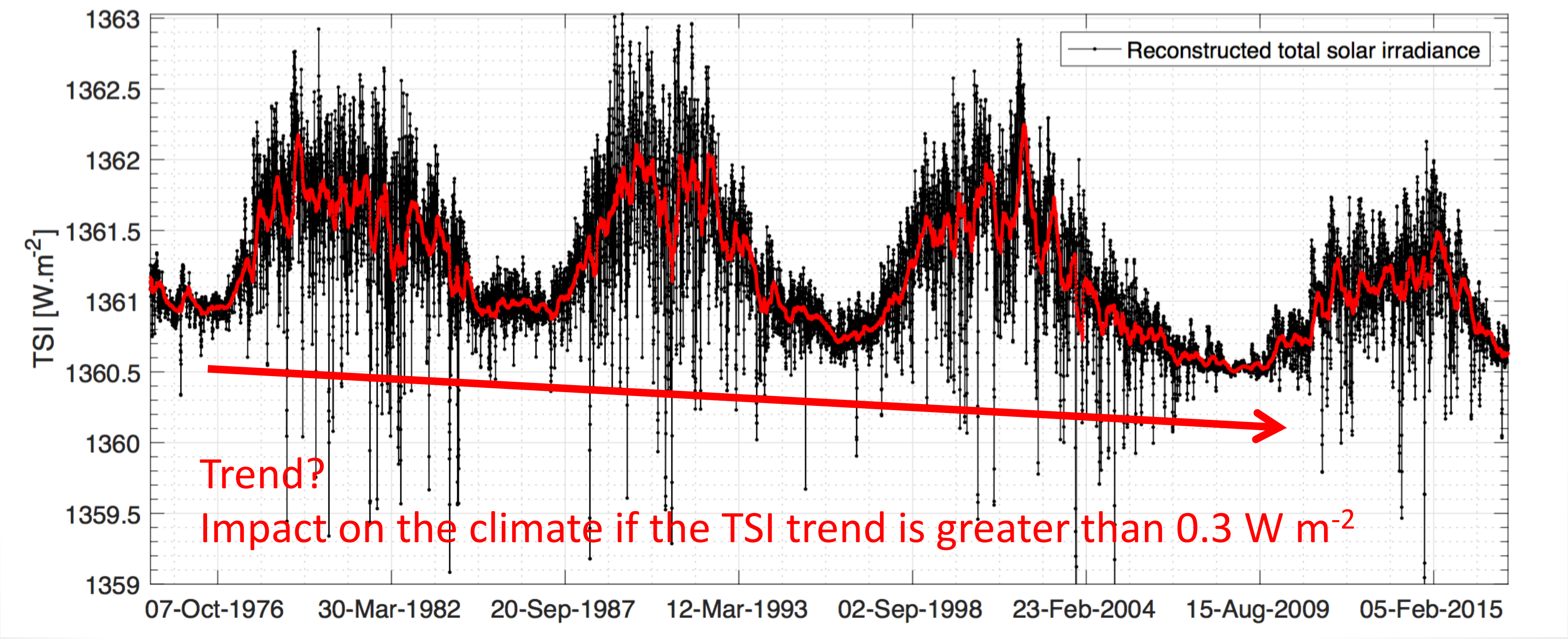
Impact on Earth climate and regional effects



- Influence of solar variability on Earth climate and regional effects.
- Dynamical amplification of the stratospheric solar response.
- Interest to develop a <u>small satellites constellation</u> to measure simultaneously all major parameters.

1st and 2nd: to extend the TSI measurements

- 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 around **1361-1362 W.m^{-2} in 2016 (IAU resolution)**.
- The total solar irradiance (TSI) is measured to vary by approximately of +/-0.05 % (over the last three 11-year cycles).
- Composite TSI time series (ACRIM, PMOD), TSI space-based radiometers, or models (SATIRE) highlight differences for the solar minima.



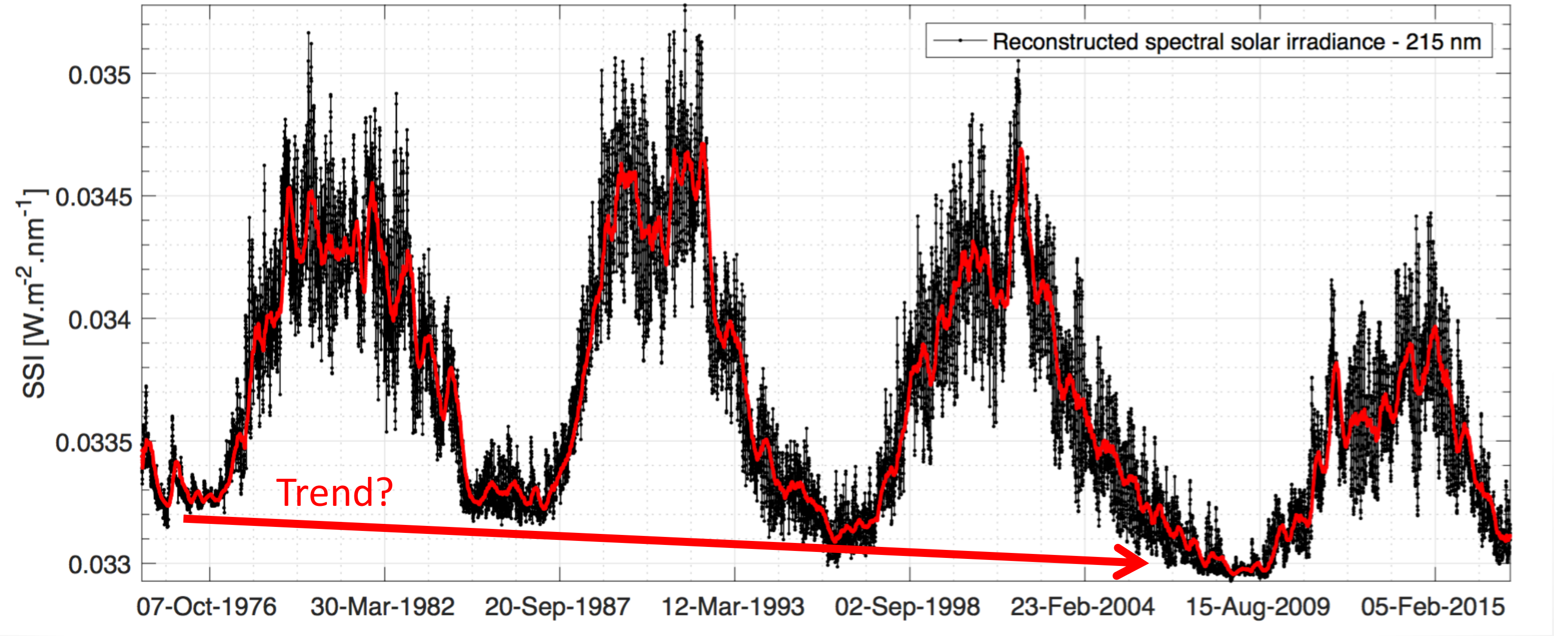
SATIRE model

3rd: to monitor the SSI at 215 nm

There is a need for a better understanding of how the Sun affects the climate, particularly for the UV radiations. **Link with stratospheric ozone and regional effects**.

This is important because the Sun has long-term and short-term variations and we need to know how these interact with anthropogenic effects.

It is also important to understand natural factors in climate variability to give a basis upon which its future state might be predicted.



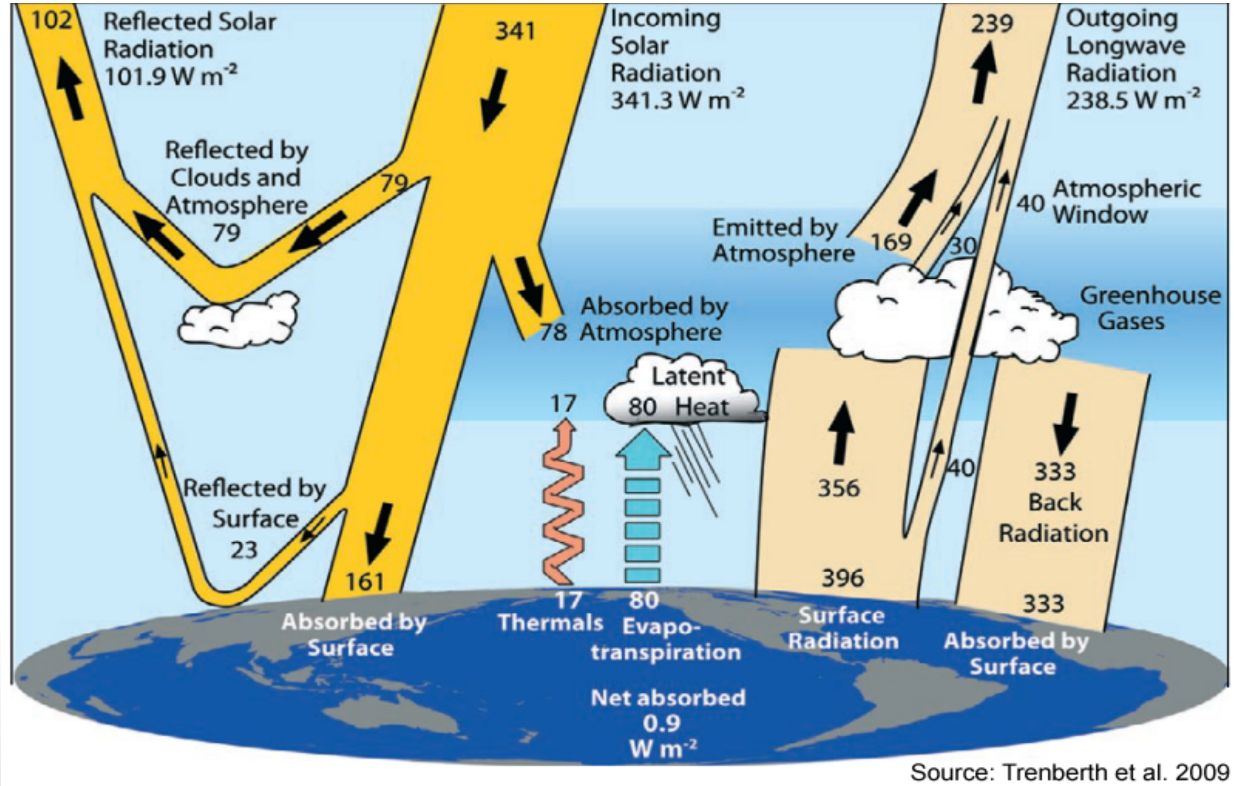
4th: to establish a Earth radiation balance

Net Flux = Incoming – Outgoing SR – Outgoing LR = 0?

~ 1/3 of incoming solar reflected back to space

Incoming solar = TSI(1362W/m²)/4

Longwave Radiation (LR) budget: → measure Outgoing LR



Source: Trenberth et al. 2009

Earth's energy balance at the top of atmosphere

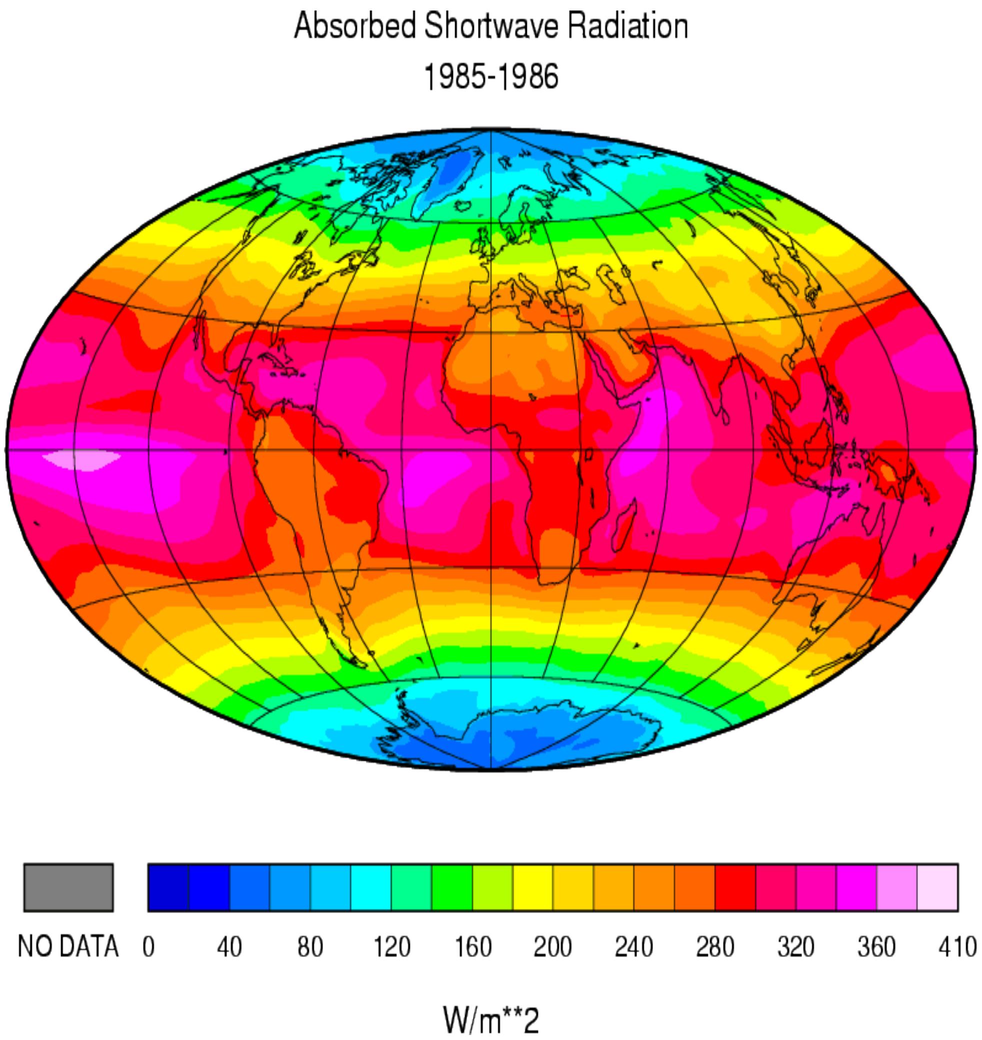
- Determination of the Outgoing Longwave Radiation (OLR) – Earth infrared flux
- Determination of the Reflected Solar Radiation – albedo flux

Global distribution of Absorbed SR

Absorbed SR = Incoming – Outgoing SR (satellite data)

Annual mean for 1985-1986 period

Satellites constellation for resolution and revisit time

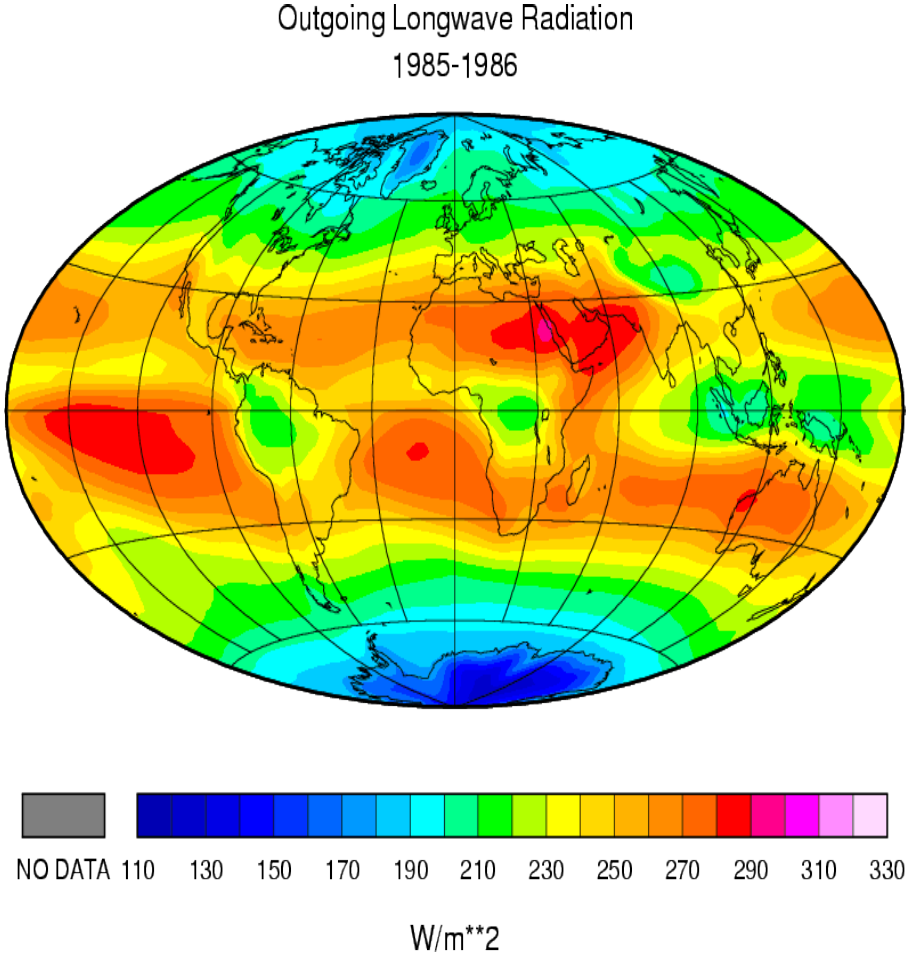


Global distribution of Outgoing LR

Satellite data

Annual mean for 1985-1986 period

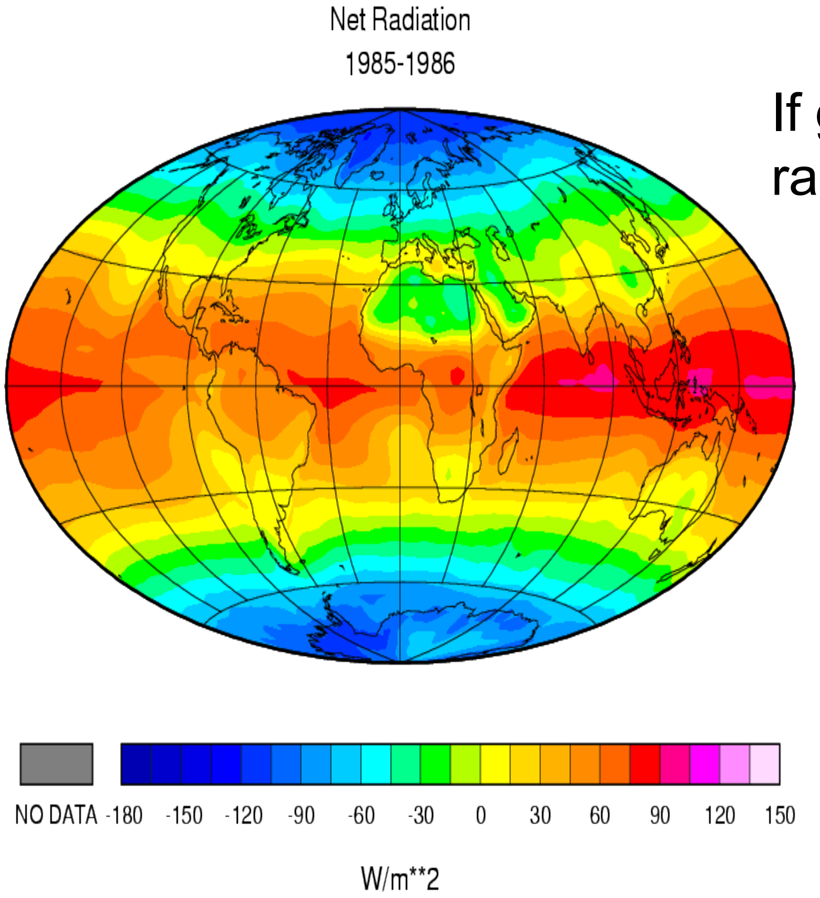
Satellites constellation for resolution and revisit time



Global distribution of Net Flux
(Energy absorbed by system =Absorbed SR – OLR)

Satellite data

Annual mean for 1985-1986 period



If globally averaged Net Flux = 0, radiative equilibrium

Satellites constellation for resolution and revisit time

No closure and only estimations.

Globally averaged Net Flux of the order of half of W/m^2

Scientific requirements

Essential Climate Variable	Required measurement uncertainty at 1σ	Stability (per decade) at 1σ
TSI	**+/-0.04%** (+/-0.5 $W.m^{-2}$)	**+/-0.004% per decade** (+/-0.05 $W.m^{-2}$)
SSI (215 nm)	**+/-0.5%** (+/-1.7 10^{-4} $W.m^{-2}.nm^{-1}$)	**+/-0.1% per decade** (+/-3.40 10^{-5} $W.m^{-2}.nm^{-1}$)
Top of atmosphere Outgoing longwave radiations (infrared)	**+/-0.4%** (+/-1 $W.m^{-2}$)	**+/-0.04% per decade** (+/-0.1 $W.m^{-2}$)
Top of atmosphere Shortwave radiations (reflected)	**+/-0.9%** (+/-1 $W.m^{-2}$)	**+/-0.09% per decade** (+/-0.1 $W.m^{-2}$)

- **Top of the atmosphere measurements of radiation from space** can track changes over time but **lack absolute accuracy**.
- **All estimates (ocean heat content and TOA) show that over the past decade the energy imbalance ranges between 0.5 and 1.0 $W.m^{-2}$.**
- **The imbalance at TOA is too small to measure directly from spacecraft?**
  → **Challenging measurements** that requires simultaneous measurements, revisit time, resolution, …
  → Constellation with pre-flight and flight calibrations.

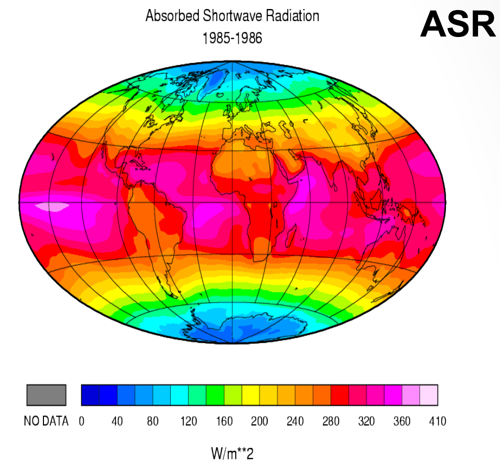
Radiative budget and Earth's Energy imbalance

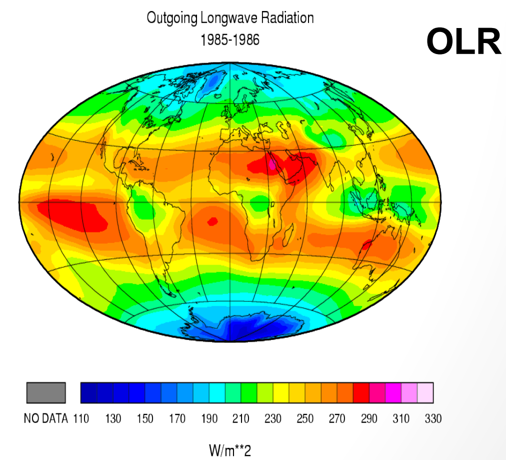
- Earth's Energy Imbalance characterizes how close the climate system to equilibrium.
- **Earth's Energy Imbalance reveals the future direction of the climate change and necessary measures to prevent excessive global warming.**
- **Earth's Energy Imbalance helps to constrain poorly known forcing (e.g., aerosol, aerosol-cloud interactions or solar irradiance).**
- Directly measured three components of Earth's Energy Imbalance can help to improve climate models.

How to measure it:

- **Direct satellite measurements of SW and LW radiation at the top of the atmosphere → Use of Satellites observations (constellation).**
- Retrieval of ocean heat content (Ho) tendencies from the subsurface observations → Not accurate.

Energy absorbed by system = Absorbed SR – OLR



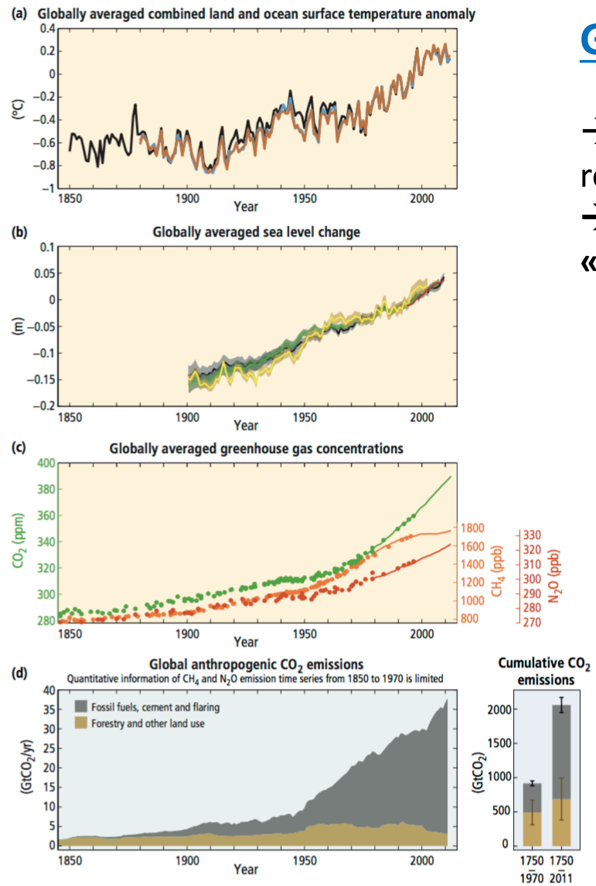


Climate change: a need to observe from space

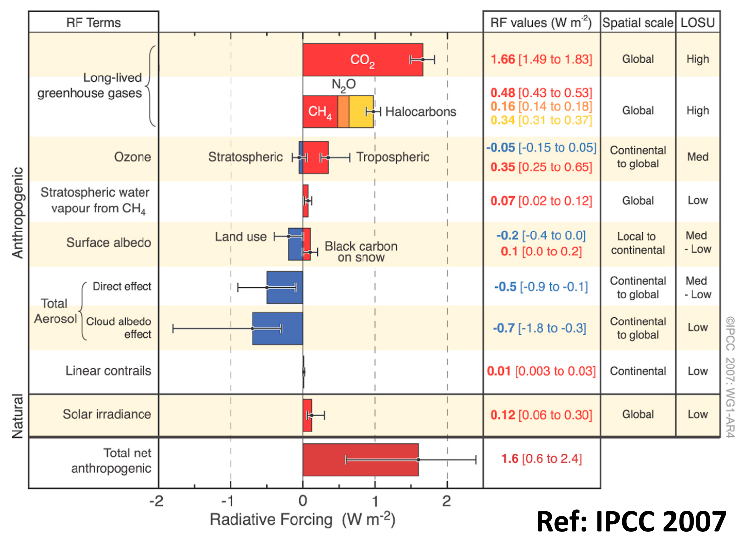
Global warming caused by human activities is indisputable.

→ It is very important to better understand the mechanisms determining the response of the Earth's climate system.

→ **Earth's energy imbalance, if measured accurately, provides one way to resolve « the aerosol » ambiguity.**



Climate Change 2014: Synthesis Report



Ref: IPCC 2007

Most climate models employed aerosol forcings and achieved good agreement with observed global warming over the past century, **suggesting that the aerosol forcing is only moderate**.

2 – Schedule for a demonstrator in orbit

- Launch schedule:
2022 ?

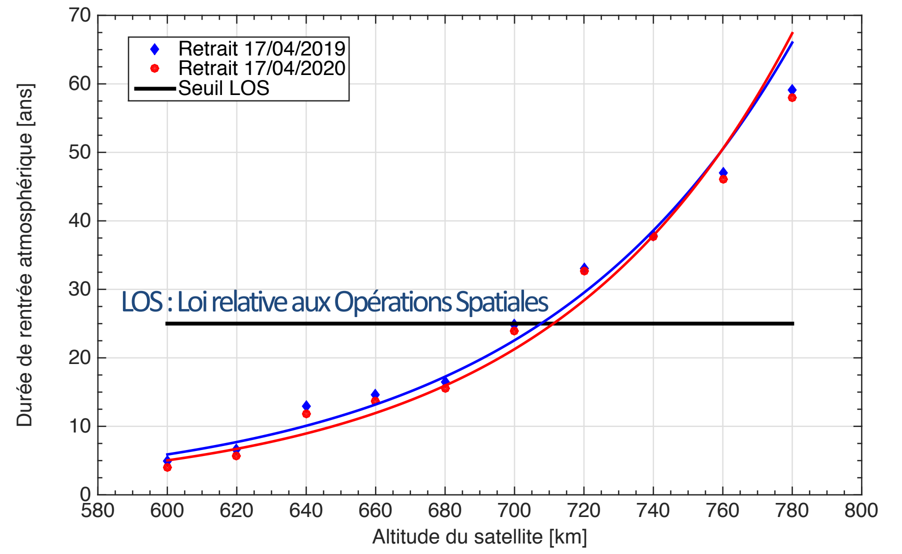
- Launch Vehicle:
To be define (PSLV, …)

- Target Orbit:
- Helio-synchronous Orbit
- Altitude: 680 +/-30 km
- Local time at ascending node:
06H00 +/-00H30
- Orbital inclination: 98.21 +/-0.2°

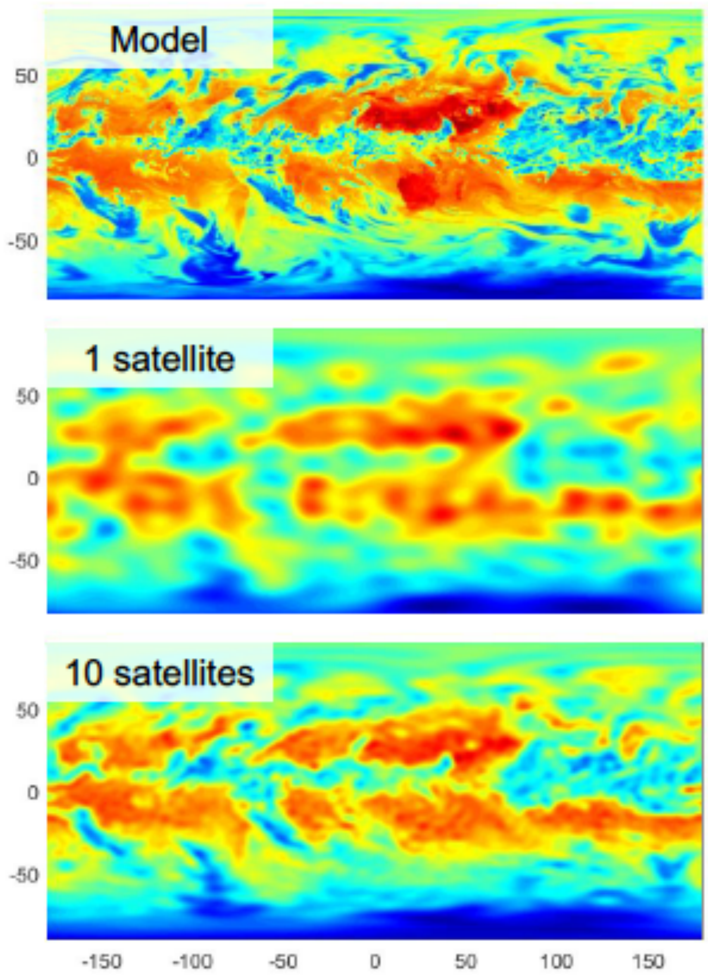
Life time: ~ 12 months

Final Objectives:
constellation with 10 nanosatellites.

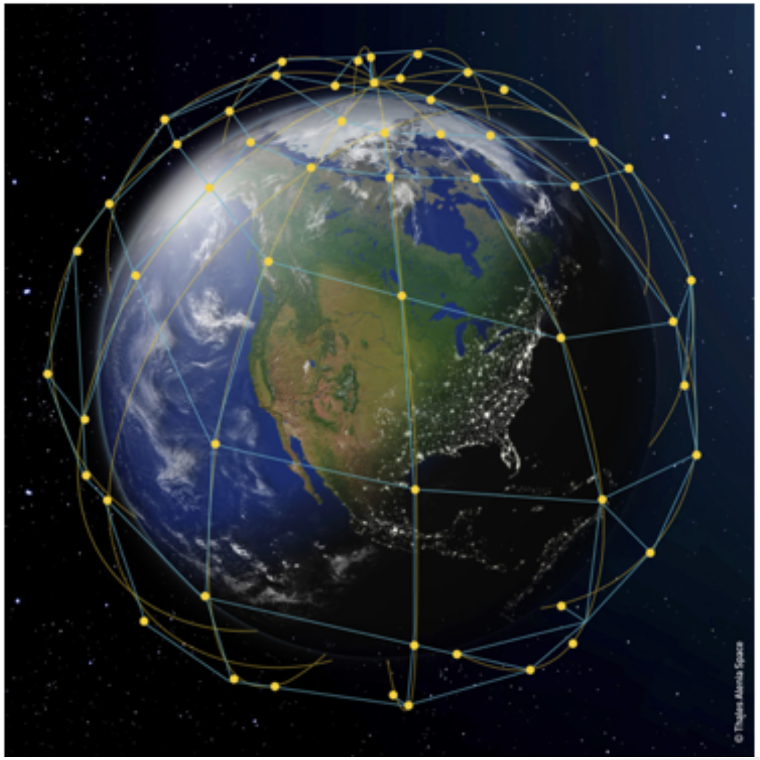
Debris mitigation guidelines and the preservation of the space environment



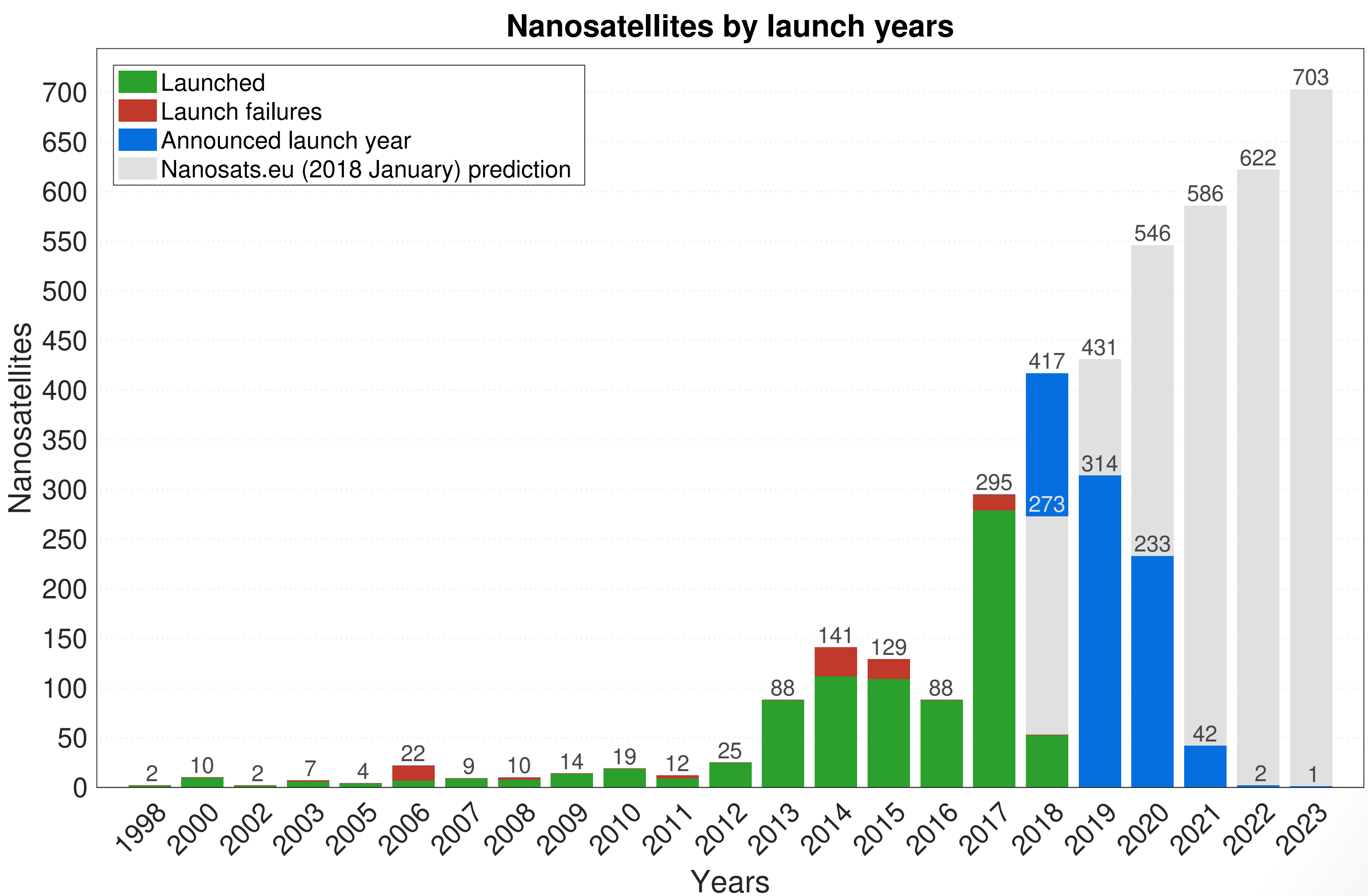
Why we need a constellation?



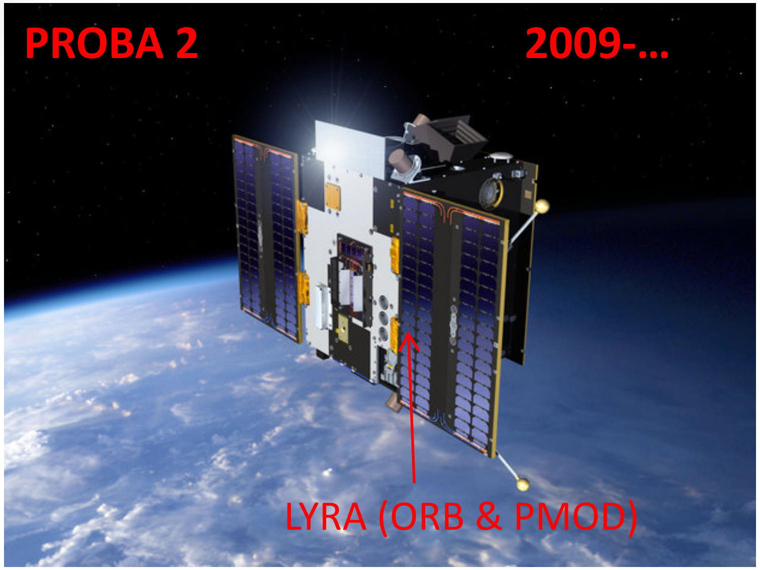
More satellites provide greater spatial (and temporal) resolution and less error



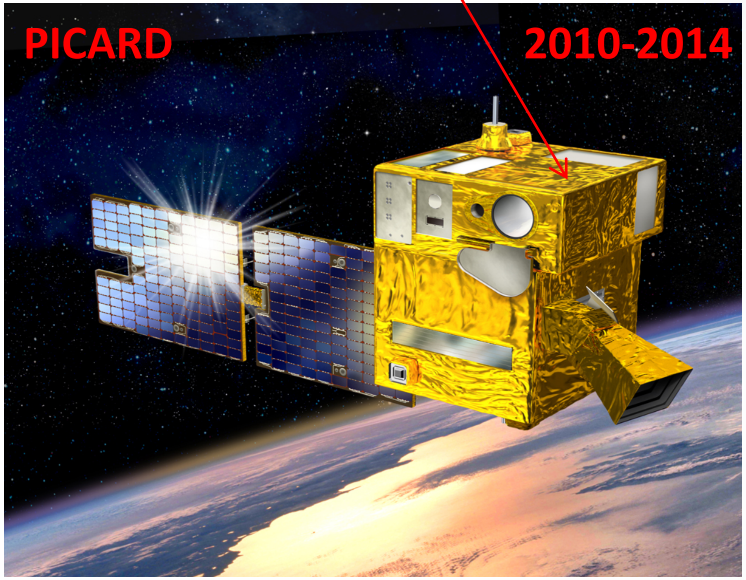
2 – Schedule for a demonstrator in orbit

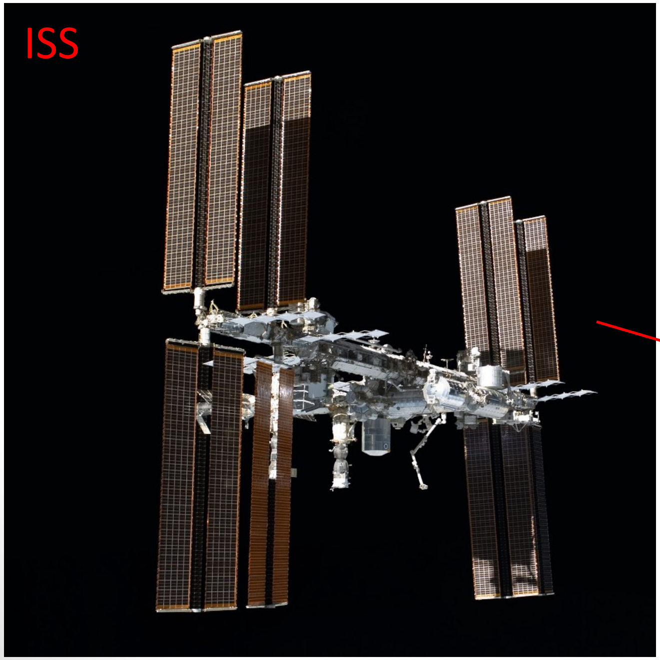


2 – Heritage



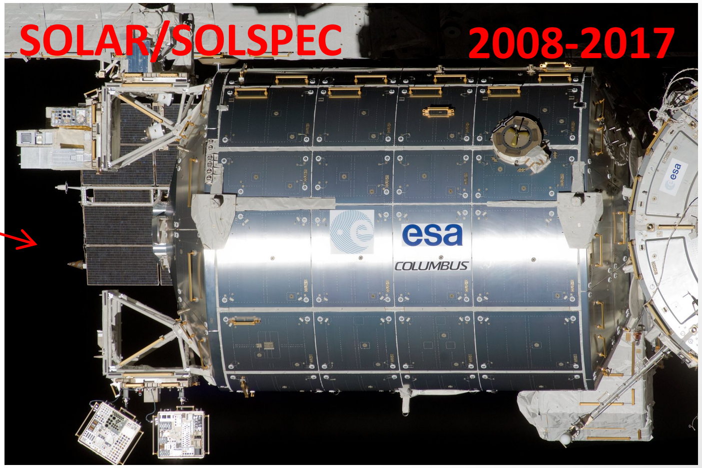
SODISM (LATMOS)
→ With stars calibration



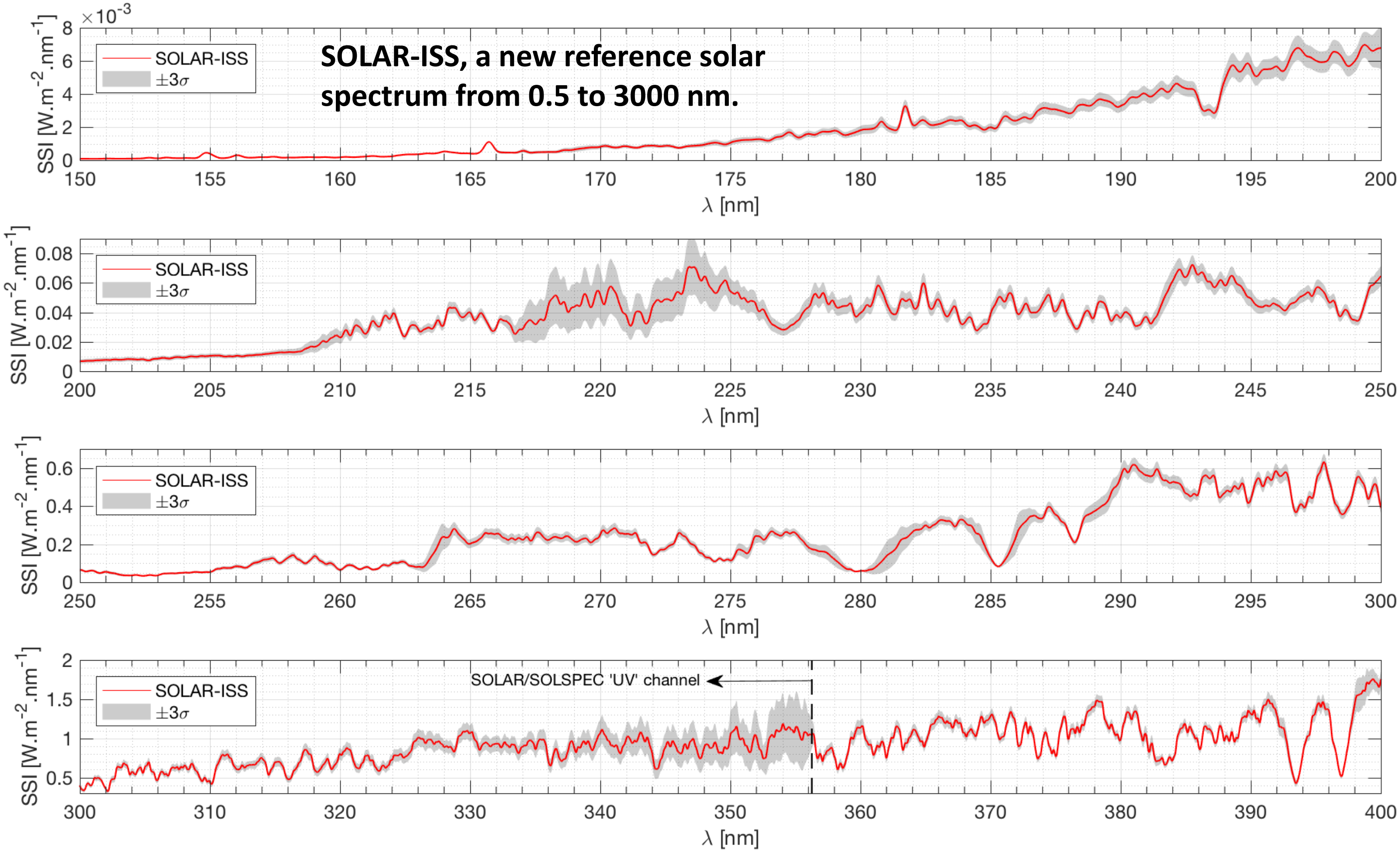


COLOMBUS Module

SOLSPEC (LATMOS & IASB)
→ With lamps calibration (aging control)



A new solar spectrum and its variability

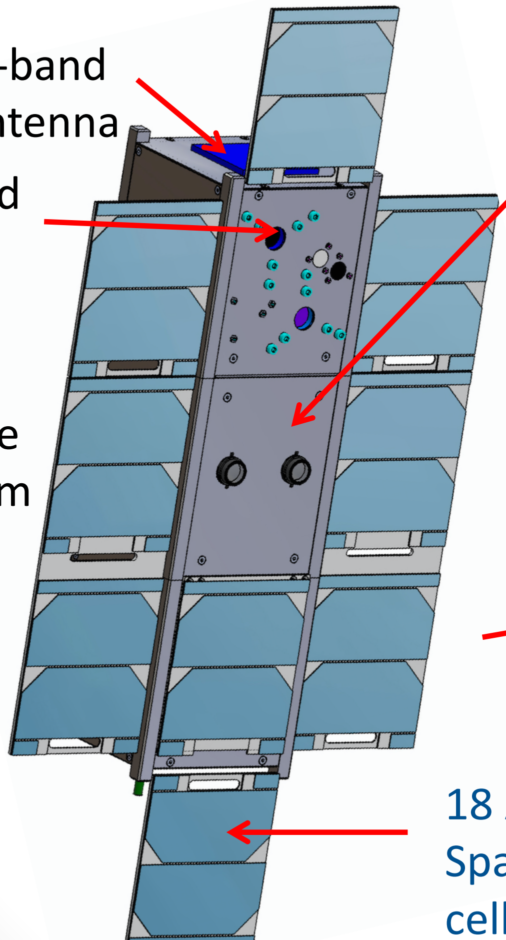


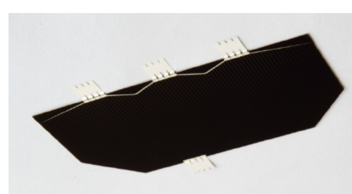
Meftah, Damé et al., 2018, A&A

Today, we have +/-2.5% uncertainty at 215 nm with SOLAR-ISS spectrum.
→ Target: SSI measurement (215 nm) of +/-0.5% uncertainty at 1σ.

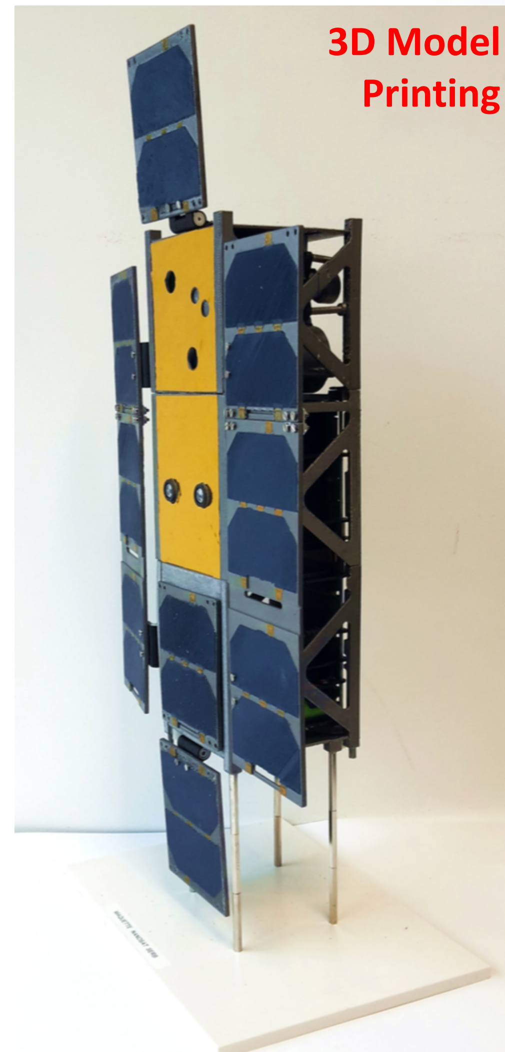
3 – SERB nano-satellite

The 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 with the deployable solar panels.



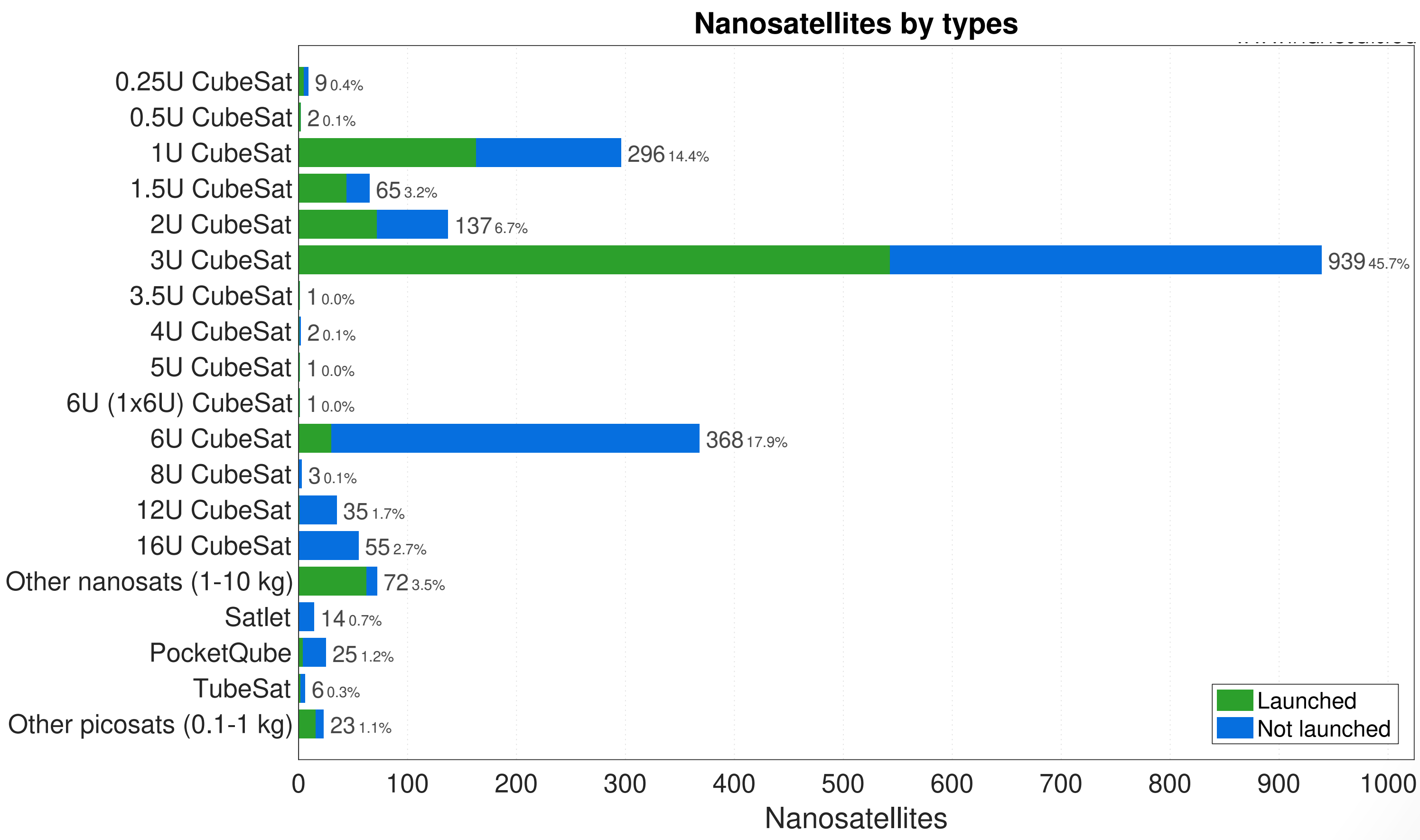


From the CAD design to the model produced with a 3D printing



3 – SERB nano-satellite

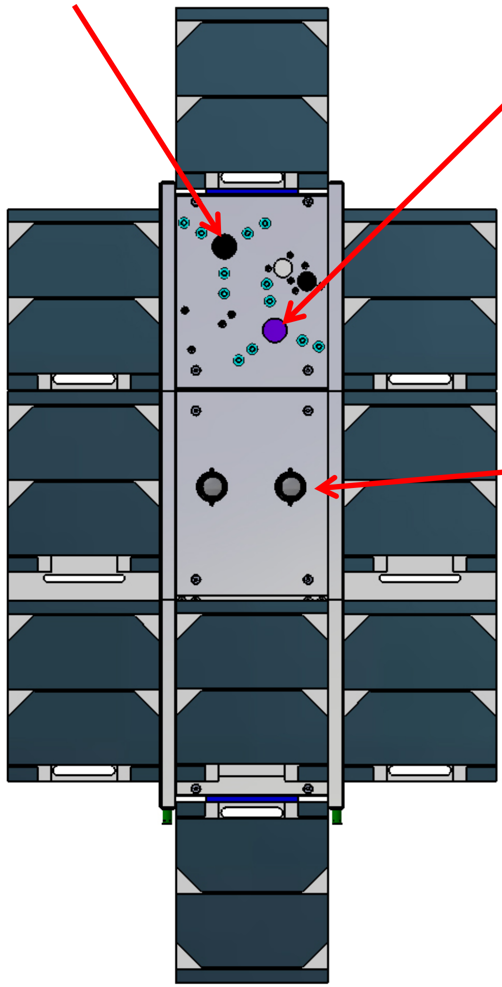
The 3U CubeSat represents the most popular configuration in the world.



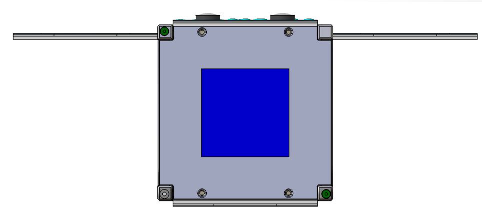
Main technical objectives:

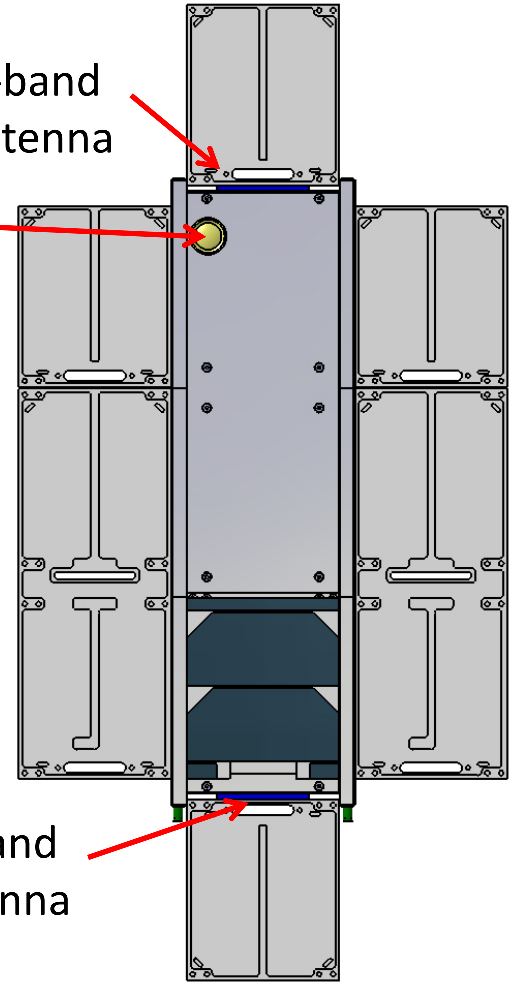
- **Miniaturization**
- **Performances**
- **In orbit demonstration satellite for a future constellation**

SERB



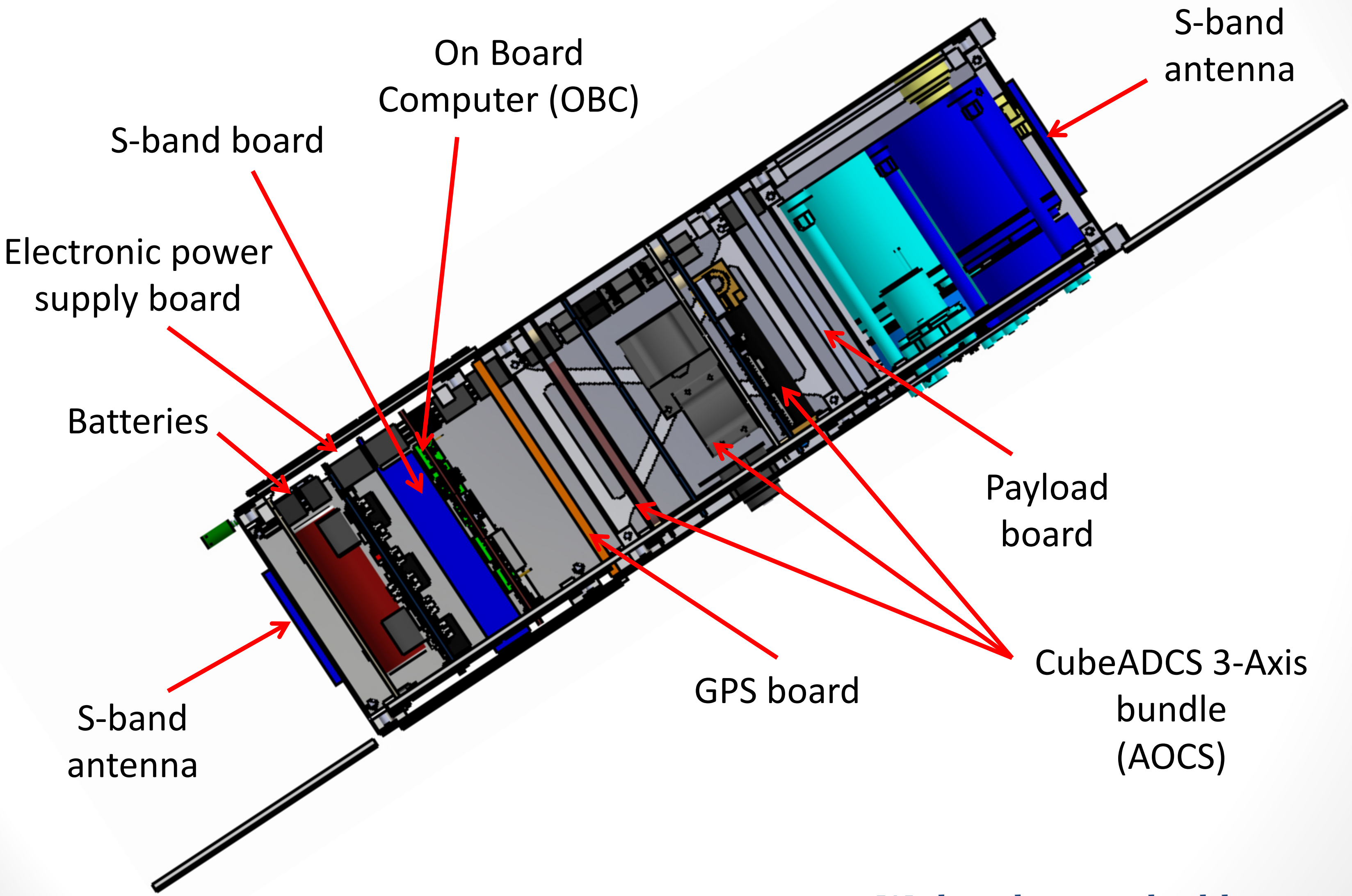
SERB Nano-satellite (Front view)
→ Sun View





SERB Nano-satellite (Rear view)

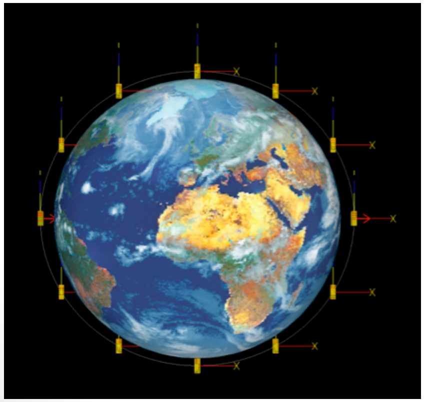
SERB electronics



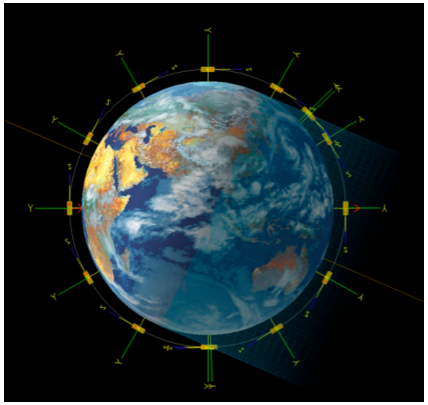
With radiation shielding.

SERB (main characteristics)

Parameter	Value (note)
Volume (stowed position)	10 (X) × 30 (Y) × 10 (Z) cm
Volume (deployed configuration)	30 (X) × 50 (Y) × 10 (Z) cm
Mass	4.5 kg (maximum with margin)
Orbit average power generated	18.9 W (without eclipse)
Orbit average power generated	15.0 W (with eclipse duration ∼20 mn)
Electrical power consumption (all instruments)	13.8 W (case EPC 1)
Electrical power consumption (without camera)	11.9 W (case EPC 2)
Field of view (payload)	180°
Data storage	1 Gbyte
Downlink speed (S-band)	From 10 kbps to 1 Mbps (megabits per second)
Uplink speed	8 kbps to 256 kbps
Ground station contact time	∼ 10 minutes per passage (∼ 6 passages per day)
Downlink volume (S-band)	∼ 400 Mbyte per day
Uplink volume	∼ 0.3 Mbyte per day
Mission modes	Sun pointing, Nadir pointing, and stars pointing
Mission lifetime	One year required and three years expected



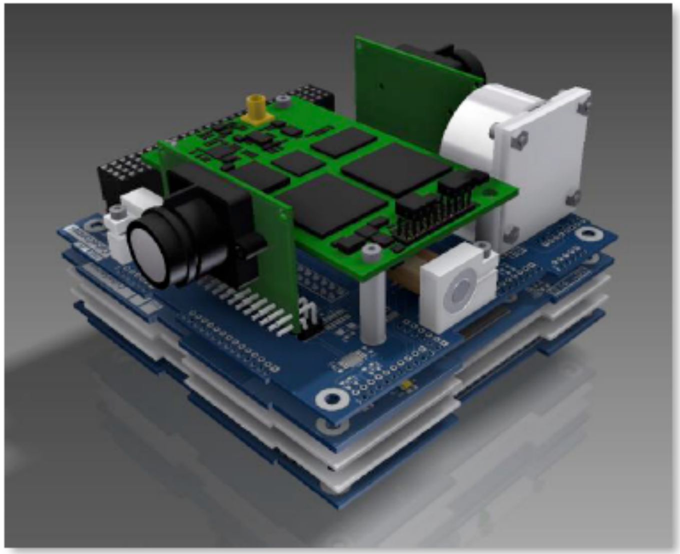
« P-Sun » → **Observation of the Sun**

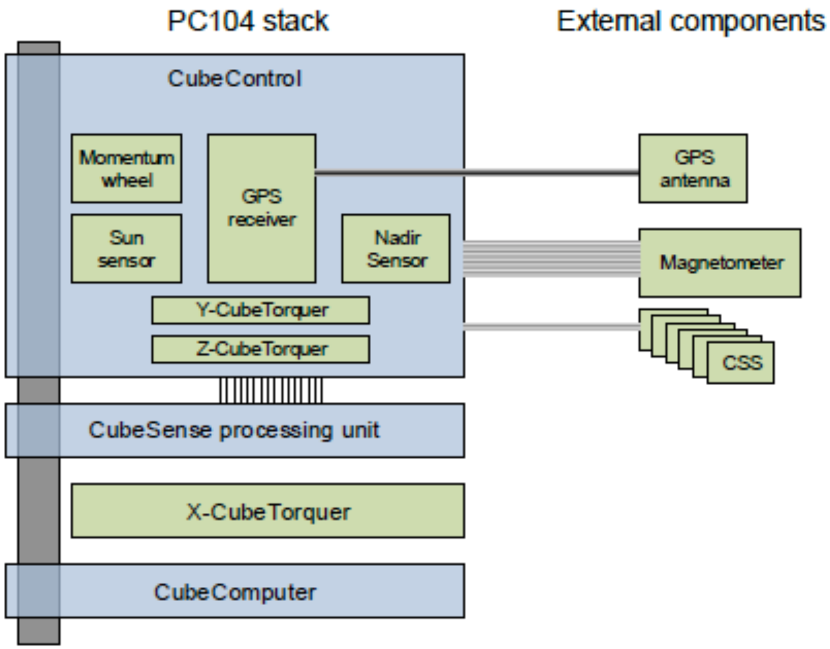


« P-Nadir » → **Direct observation of the Earth**

Pointing system electronic boards

The Stellenbosh/Surrey Space Centre ADCS (**Attitude Determination and Control system**) will provide attitude sensing and control capabilities to the SERB nanosatellite in order to meet the system requirements and science unit requirements.

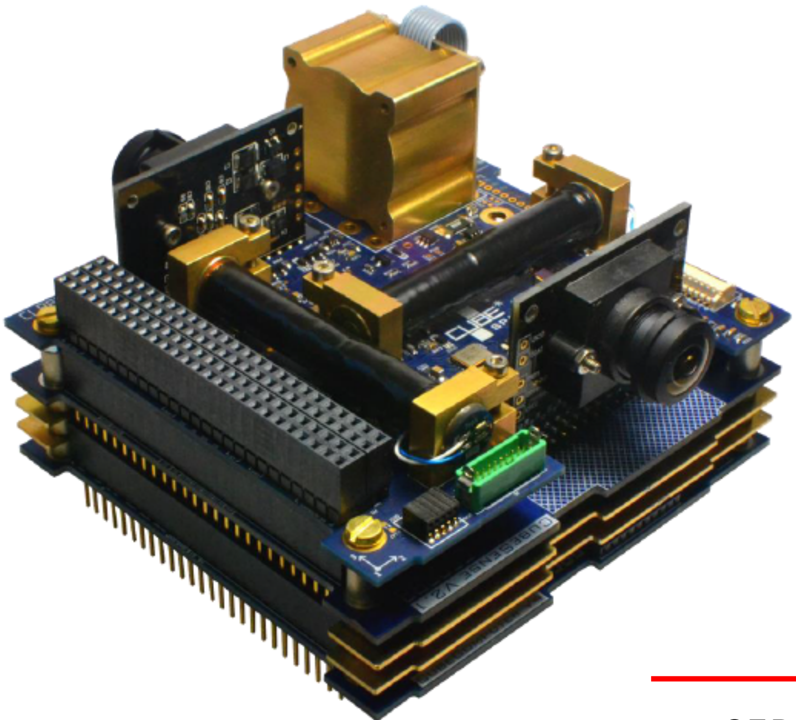


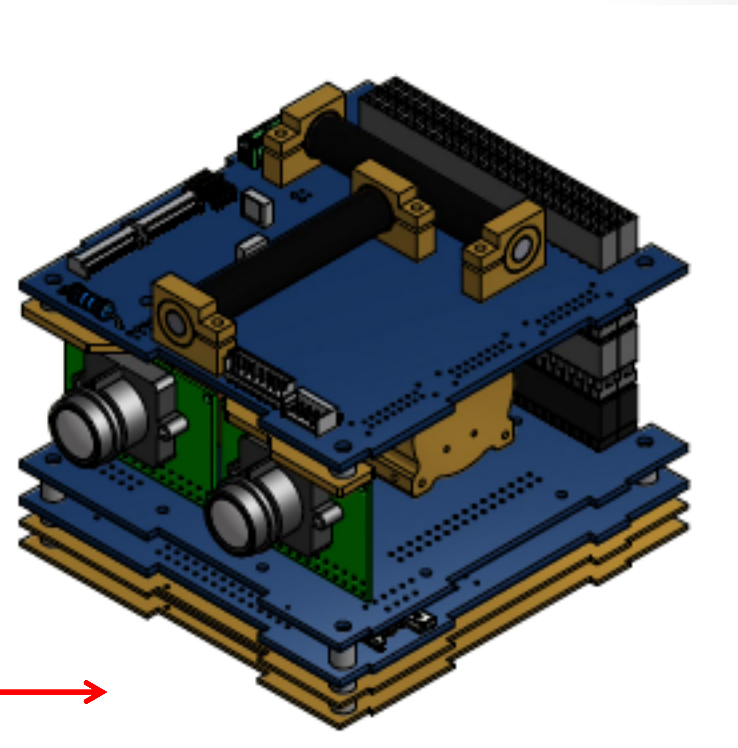


The desired performances are:

- **Sun pointing: the platform is three-axes stabilized. The attitude and orbit control subsystem (AOCS) is required to provide a pointing accuracy of 0.2°.**
- **Nadir pointing**: the satellite is pointed towards the Earth (payload line of sight) **with accuracy better than 1°.** There is also a GPS (time and position are required).

Pointing system electronic boards





SERB ADCS

Sun and Earth pointing in the same face.

UNIVERSITEIT STELLENBOSCH UNIVERSITY

Work in progress
Other solutions are analysed

Pointing system

Reaction wheel: Max angular momentum = 0.0017 Nms, Max wheel torque = 0.23 milli-Nm

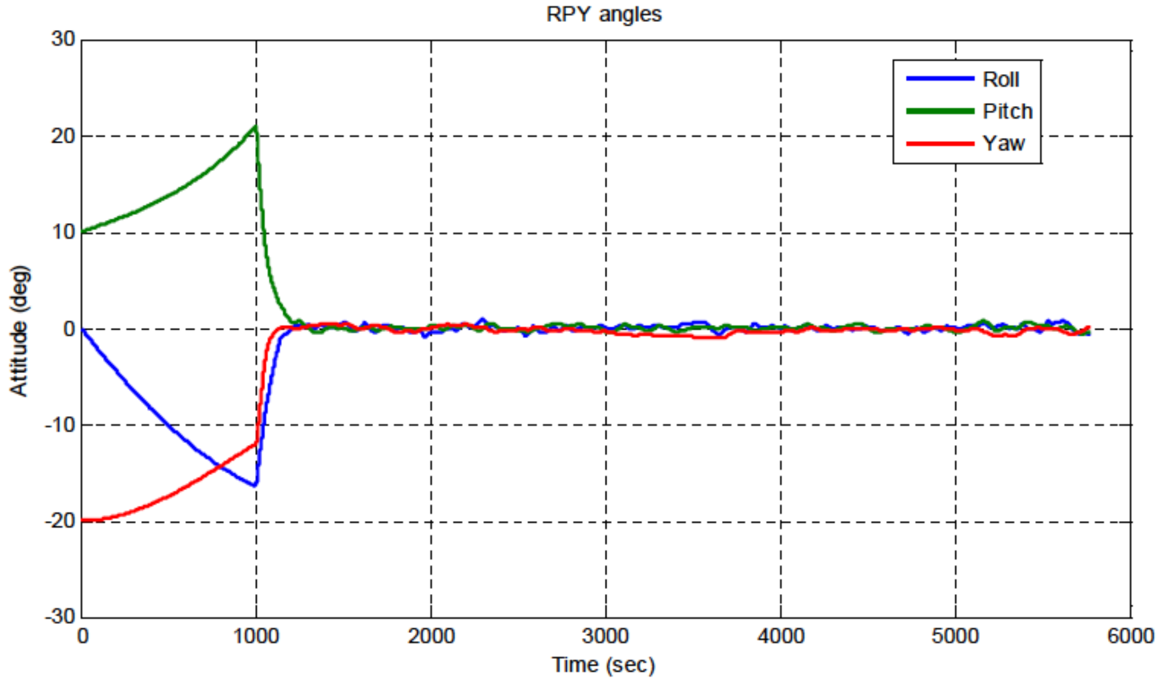
Torquer coil & rods: Max magnetic moment = 0.2 Am^2

Attitude/Rate sensors: 3-axis Magnetometer, 6 x coarse sun sensors, 180 deg FOV sun sensor, 180 deg FOV nadir sensor, 3-axis MEMS rate sensors

Initial RPY attitude: Roll = 0°, Pitch = 10°, Yaw = 20°

Initial ORC rates: ω_{xo} = 0.0°/s, ω_{yo} = -62.4 milli°/s, ω_{zo} = 0.0°/s

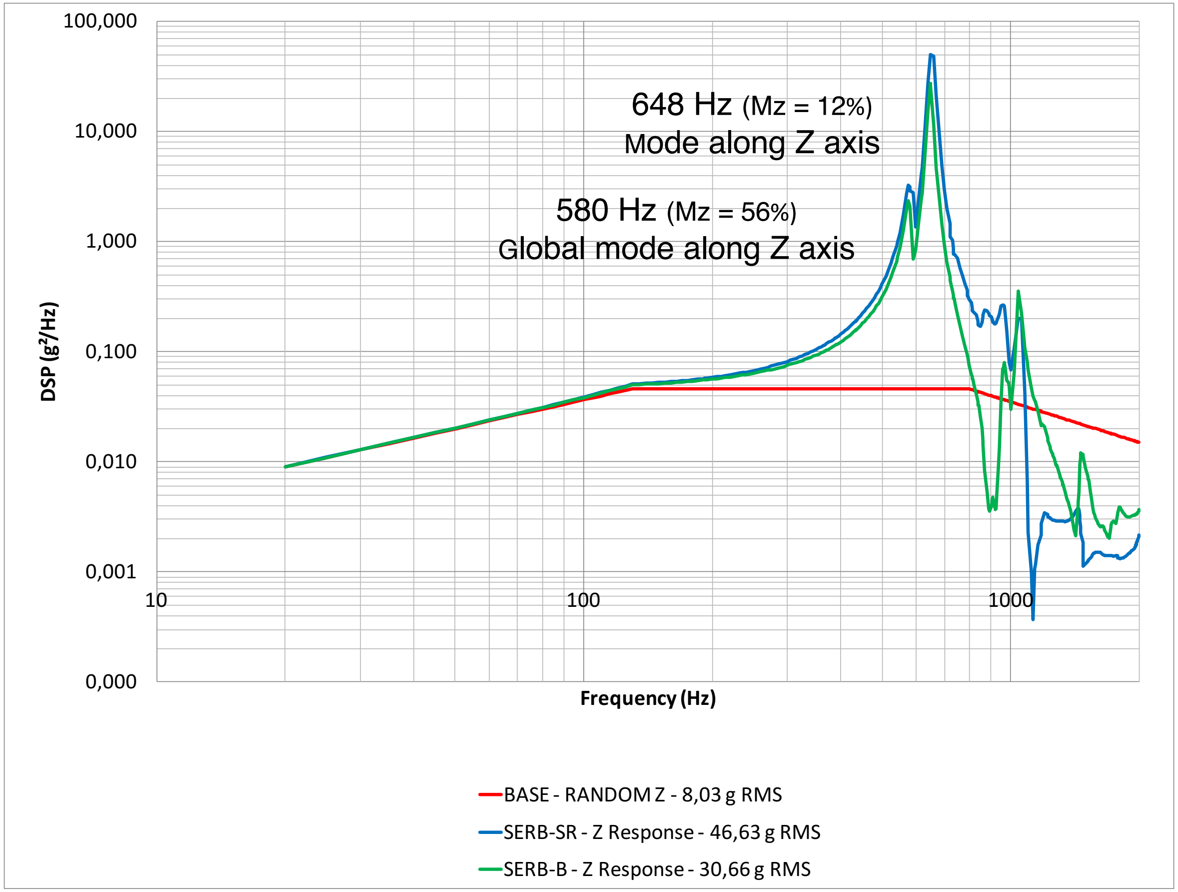
Sensor noise P-P: Magnetometer = 2 µT, Coarse SS = 10°, Fine SS = 0.2°, Nadir = 0.2°

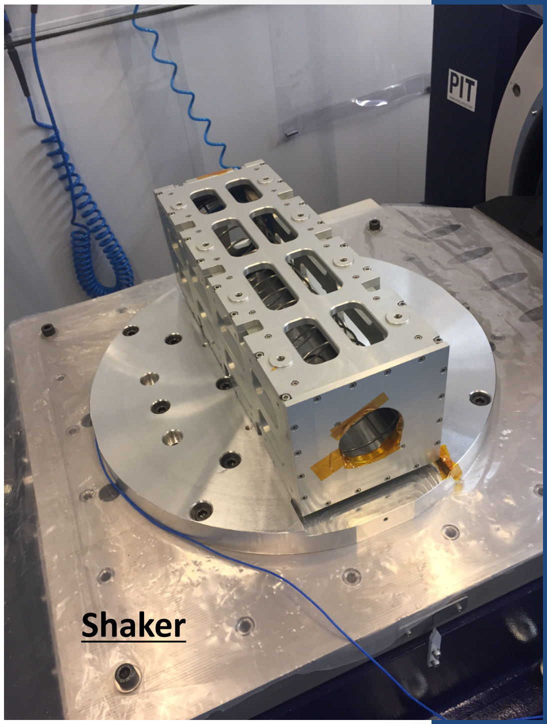


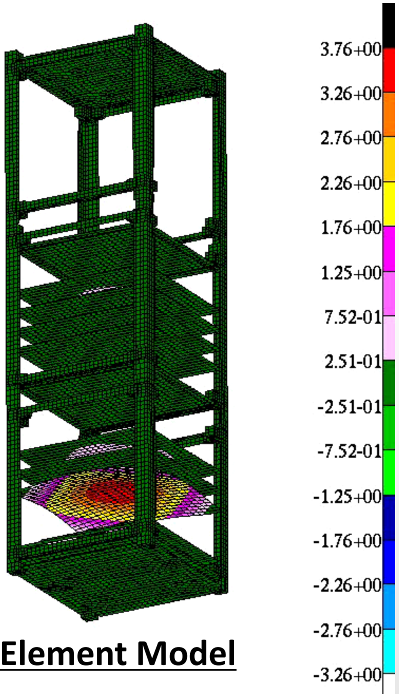
The first 1000 seconds no control was active. At 1000 seconds a 3-axis reaction wheel Q-feedback controller was enabled with a magnetic controller for wheel momentum maintenance.

The addition of a star tracker, especially for the eclipse period, will definitely improve the estimation performance

Mechanical environment







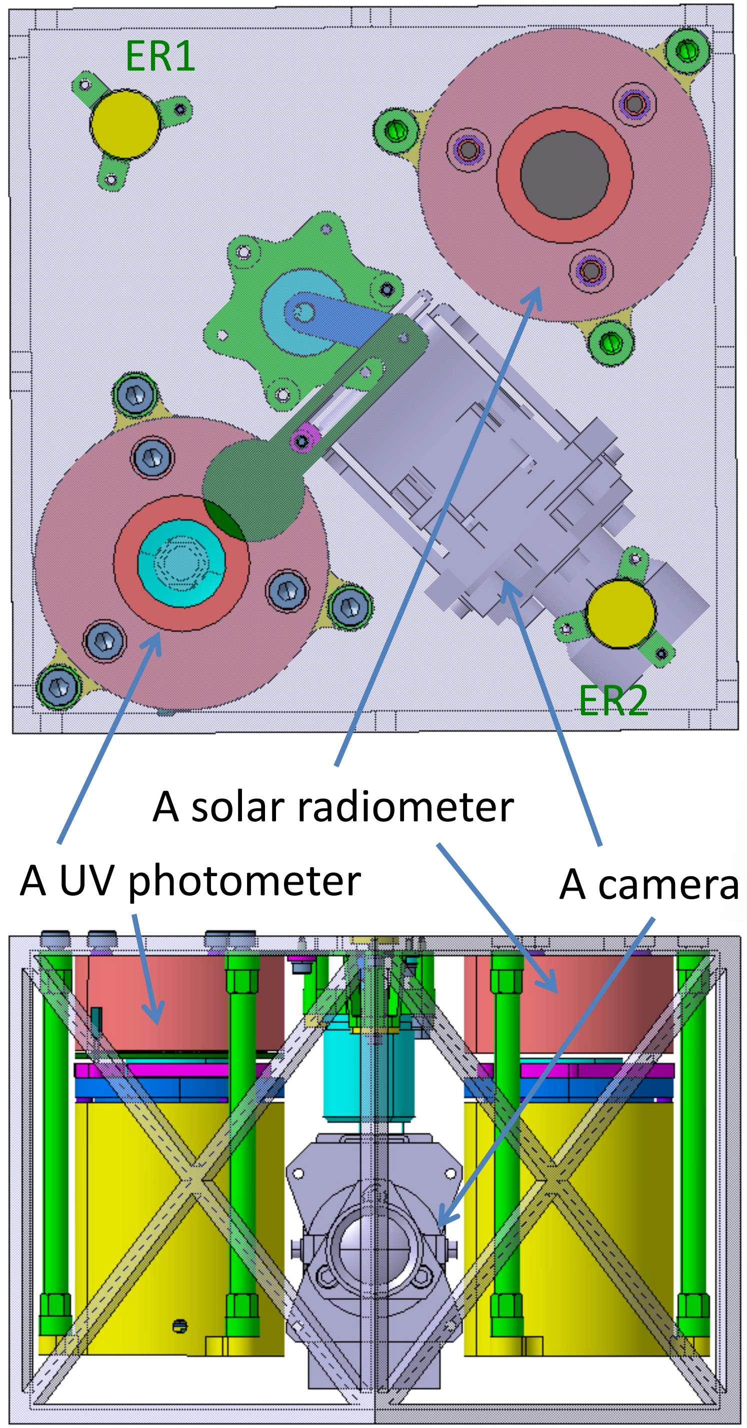
SERB Finite Element Model

High mechanical environment on the payload.

4 – SERB payload

The payload encompasses four instruments in a 1 kg, 10x10x10 cm^3 space, and requires 1W of power. Instruments are:

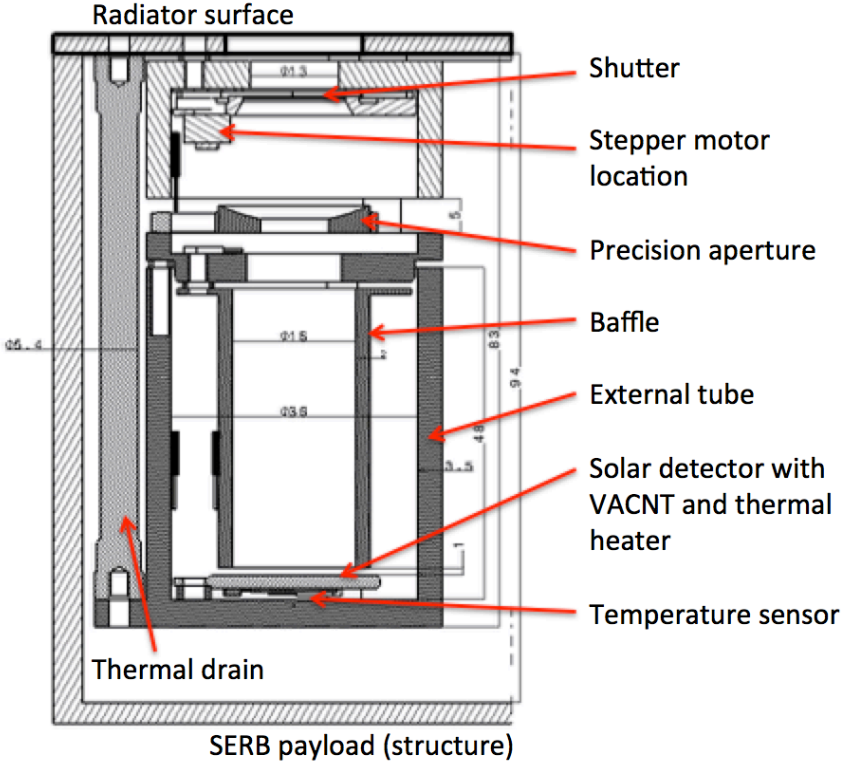
- **A solar radiometer (SR)** of new instrumental design, used for the measurement of the total solar irradiance;
- **A UV sensor (UVS)** detector for the solar radiations Herzberg continuum between 200 and 220 nm;
- **Two Earth radiometers (ER1 and ER2)** which measure the IR radiation and the albedo;

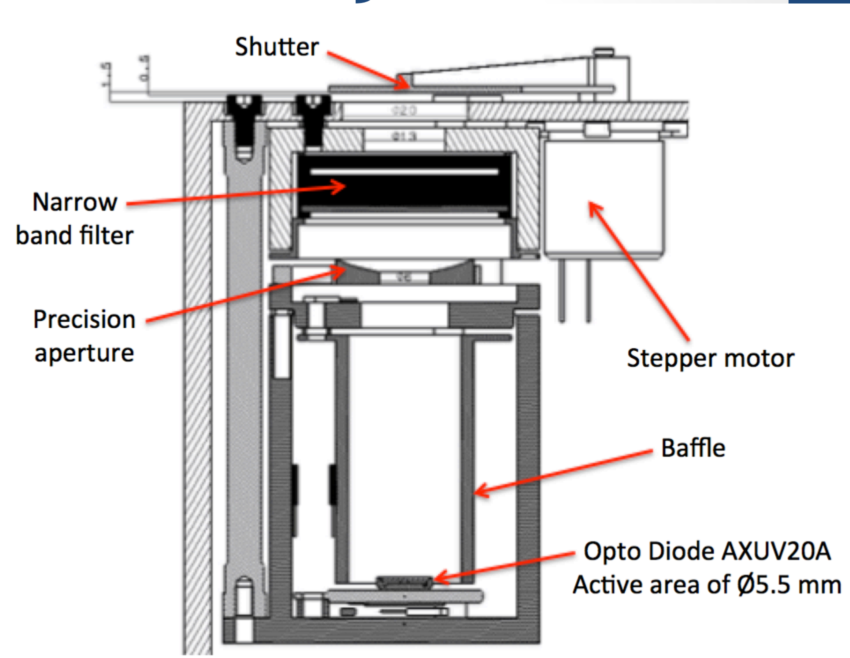


SERB payload (2D representation)

Solar radiometer

- A solar radiometer covers the spectral range from 0^+ to 10 µm (redundancy?).



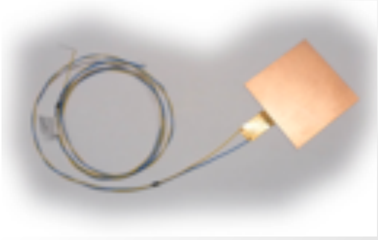


UV photometer

- A UV photometer covers the spectral range between 200 and 220 nm using an interferential filter (preflight and flight calibrations, aging control?).

Earth radiometer

- A channel (all wavelengths) with VACNT and a blackbody for calibration.
- A shortwave channel, which uses a sapphire filter dome to transmit only the shortwave radiation from 0.2 to 5 µm.



SERB solar radiometer (focus)

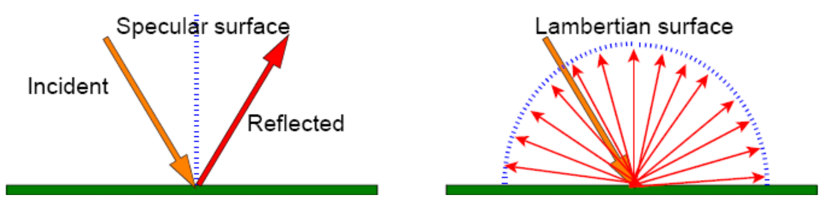
❑ **Characterizations of the black coatings**

- Solar absorption (0.5 to 3000 nm)
- Normal emittance (around 10 µm)
- Bidirectional Reflectance Distribution Function (BRDF) measurements

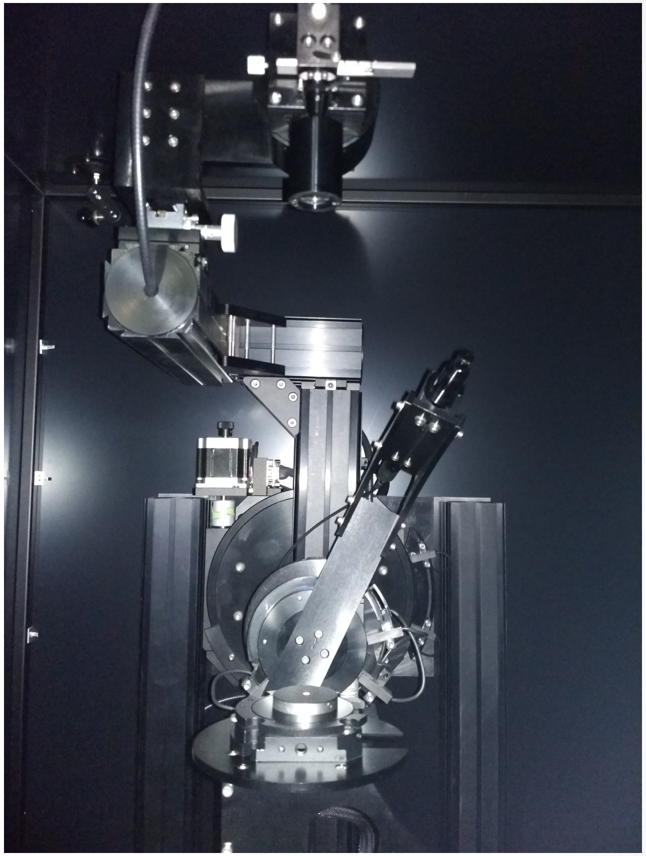
→ This data tells about how much a surface behaves like a glossy surface a matte surface or somewhere in-between.

→ Impact on TSI measurements (accuracy of the pointing (angle of incidence) and aging (nature of the contaminants))

Ideal surfaces



Real surfaces



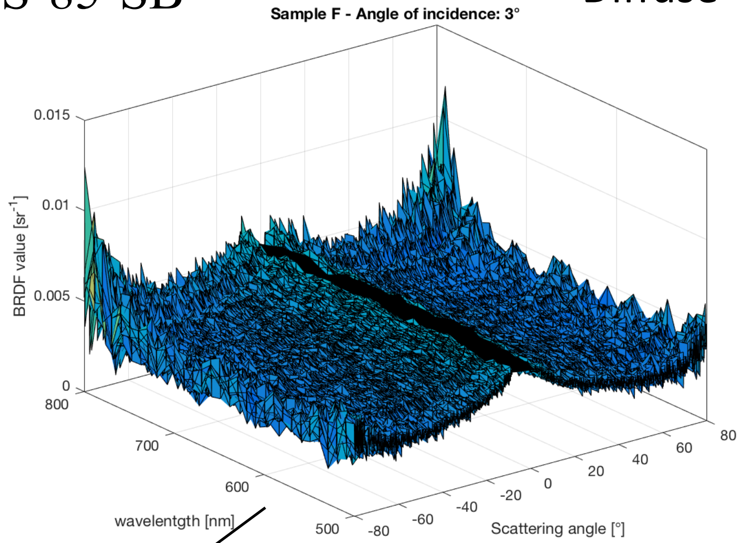
REFLET 180S goniophotometer:

A goniophotometer is an instrument for measuring light scattering in the visible spectral band.

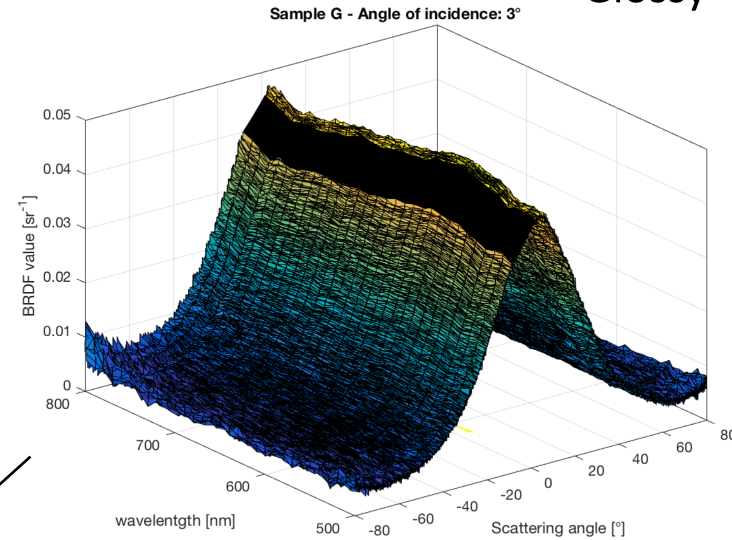
SERB solar radiometer (focus)

- MLS-85-SB

Diffuse



Glossy

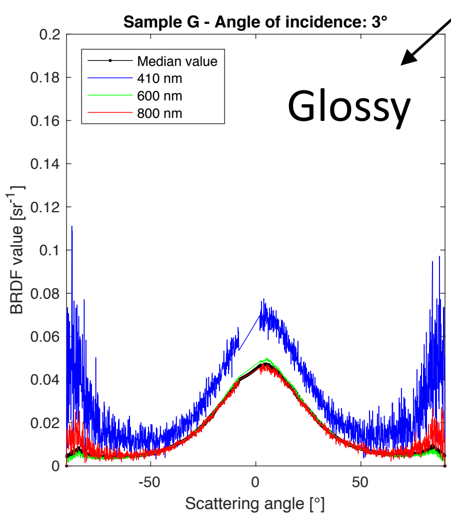


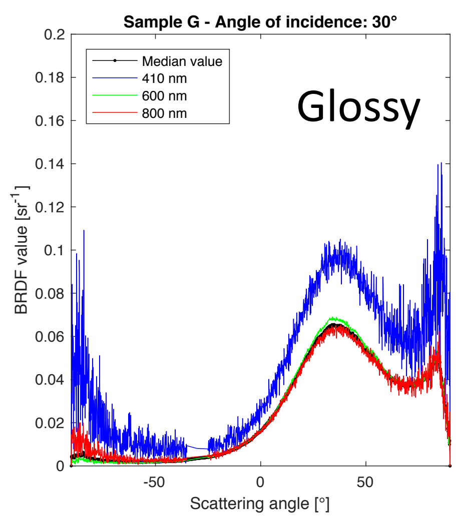
Diffuse

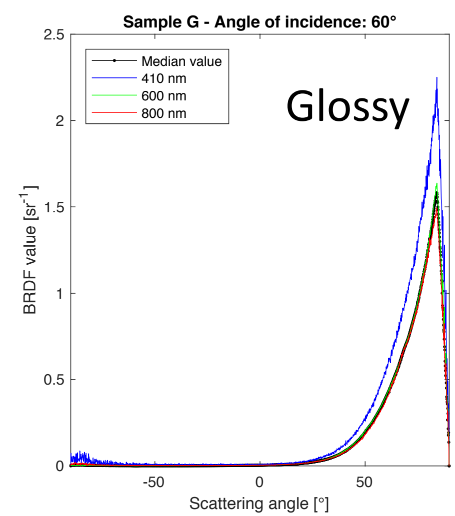
- Solar absorption α =0.979 (AOI=3°)

- Solar absorption α =0.978 (AOI=30°)

- $\Delta\alpha$=4x10^{-5} /°

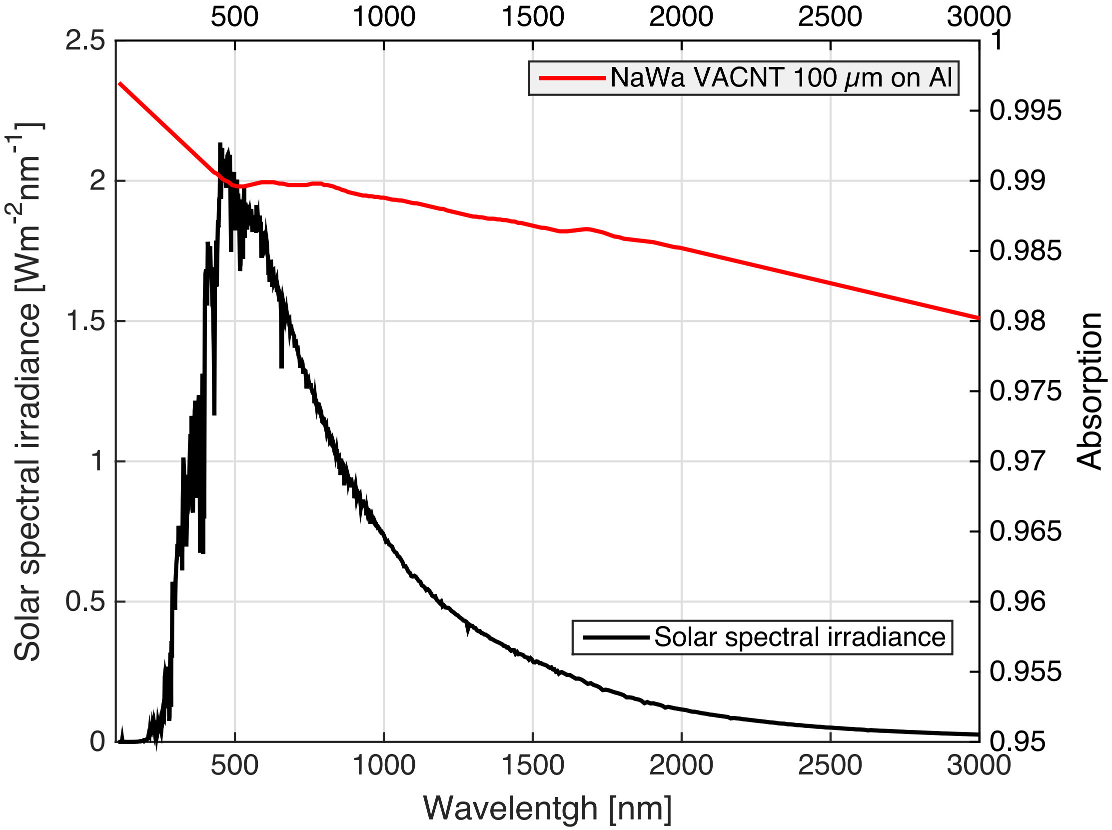






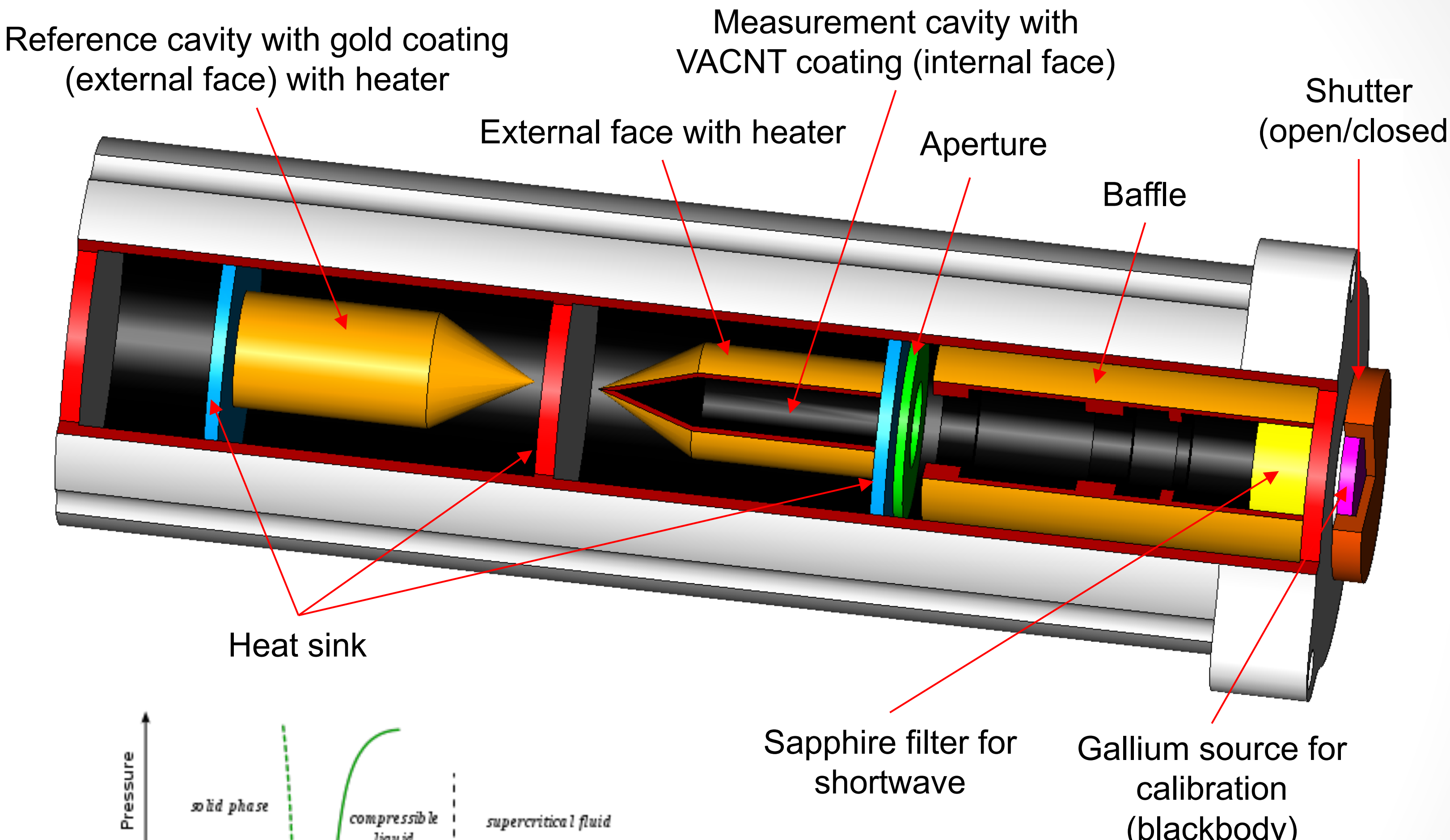
SERB solar radiometer (focus)

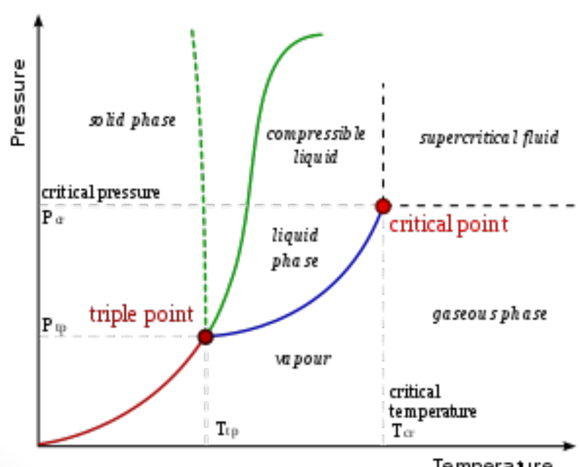
- Interest for Vertically Aligned Carbon Nanotube (VACNT)



- VACNT Solar absorption: <α> = 0.989
- Black paint (diffuse MLS-85-SB) solar absorption: <α> = 0.979
- CHEMGLAZE black paint <α> = 0.960
- MAP-PU1 black paint <α> = 0.960

SERB Earth radiometer (focus)



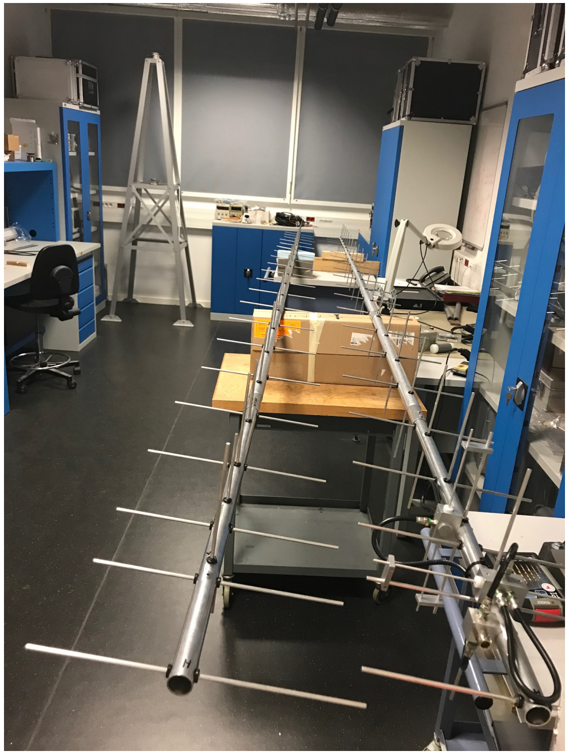


Cylindrical body in suprasil

5 – Ground segment: UHF/VHF antenna

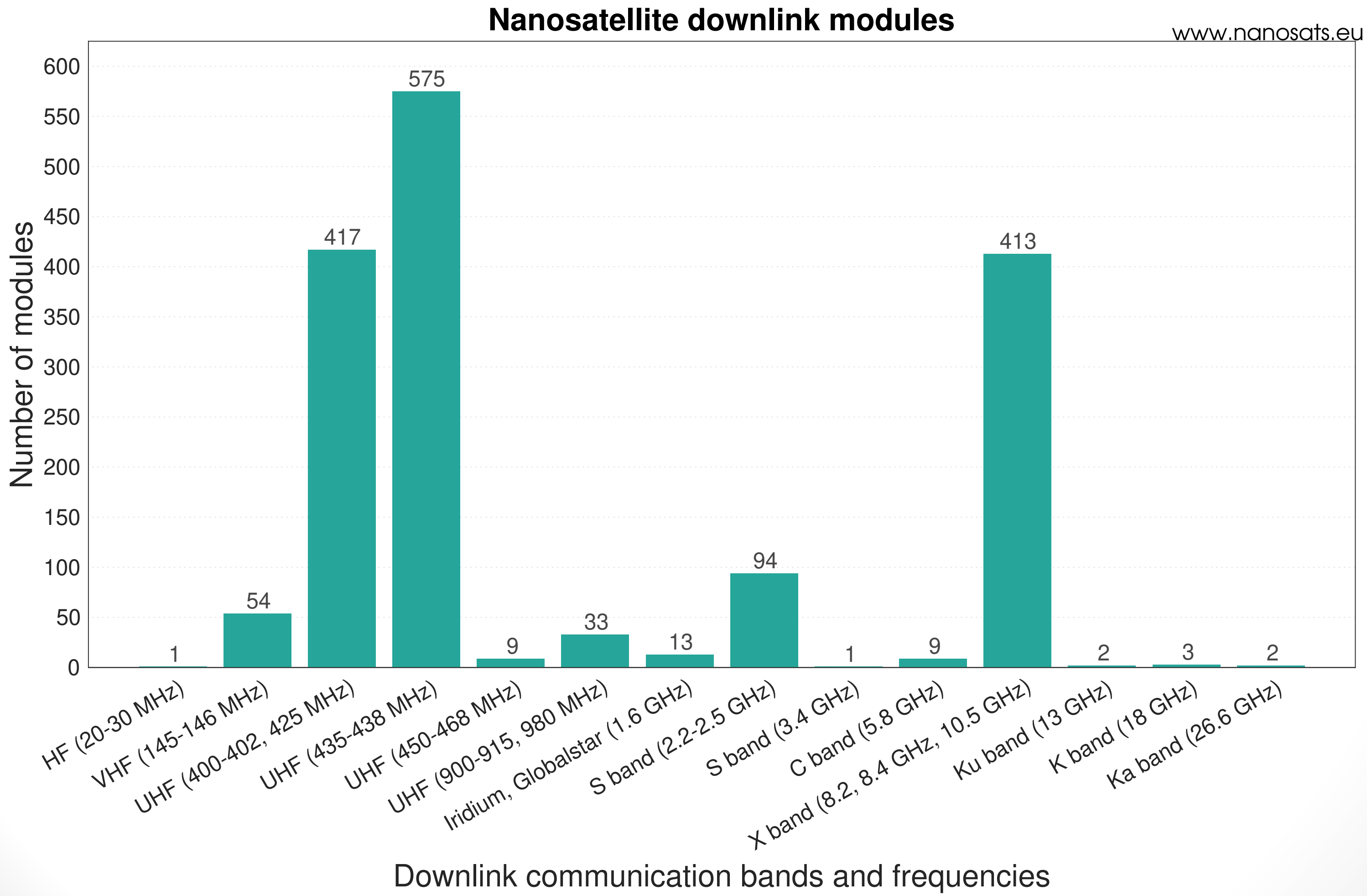
The INSPIRE-LATMOS antenna is designed for UHF at a frequency of 437.250MHz (with FWHM of 1 kHz). There is another frequency at 450MHz.

We start the integration of the antenna in 2018.



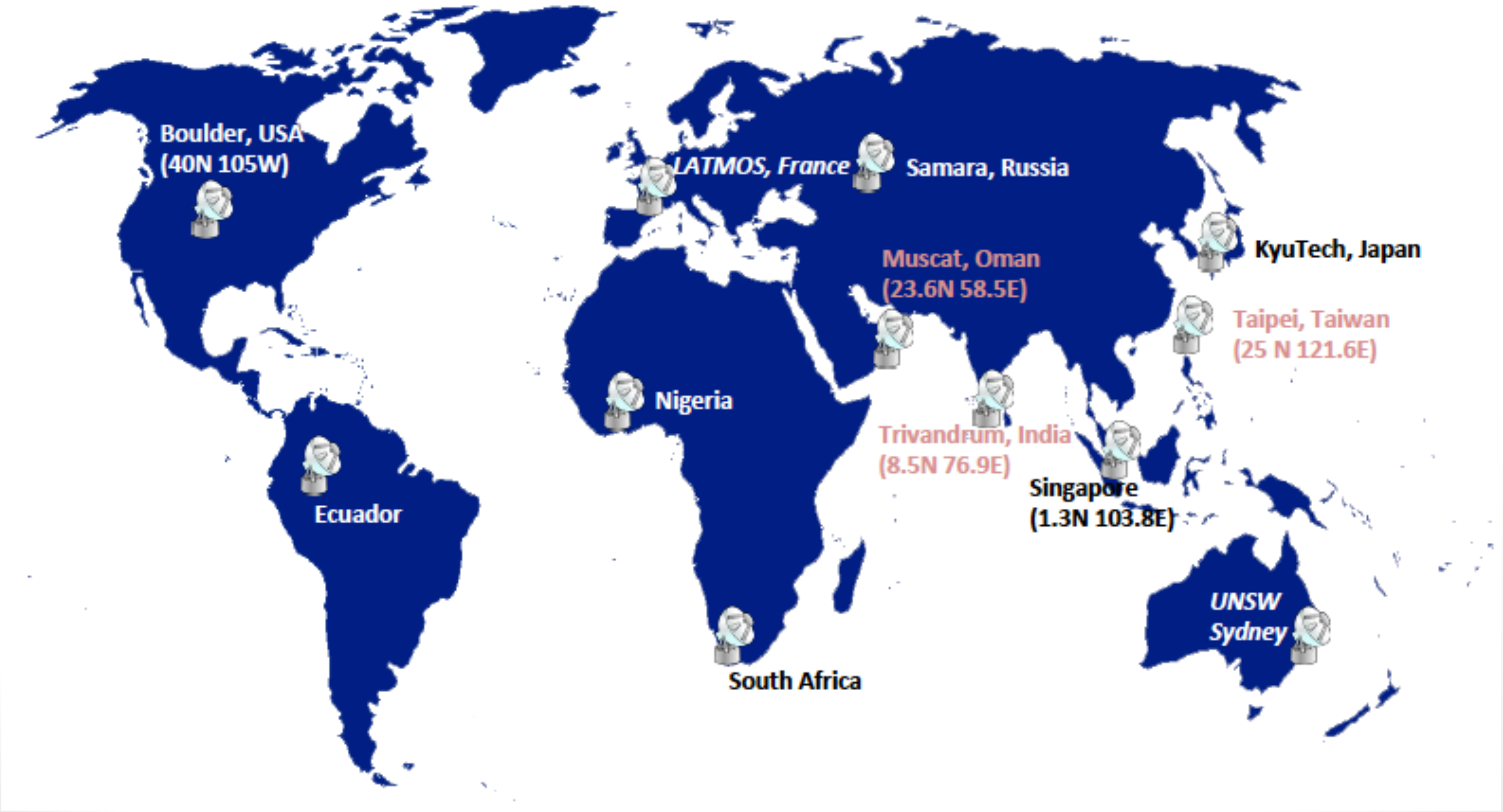
5 – Ground segment: UHF/VHF antenna

The 437.250MHz frequency is the most used.



- **SERB is in an international Satellite Program**

Link with the INSPIRE program of the LASP (USA).



Conclusions

The SERB nano-satellite aims four scientific objectives in connection with the observations of the Earth and the Sun. Scientific requirements are established.

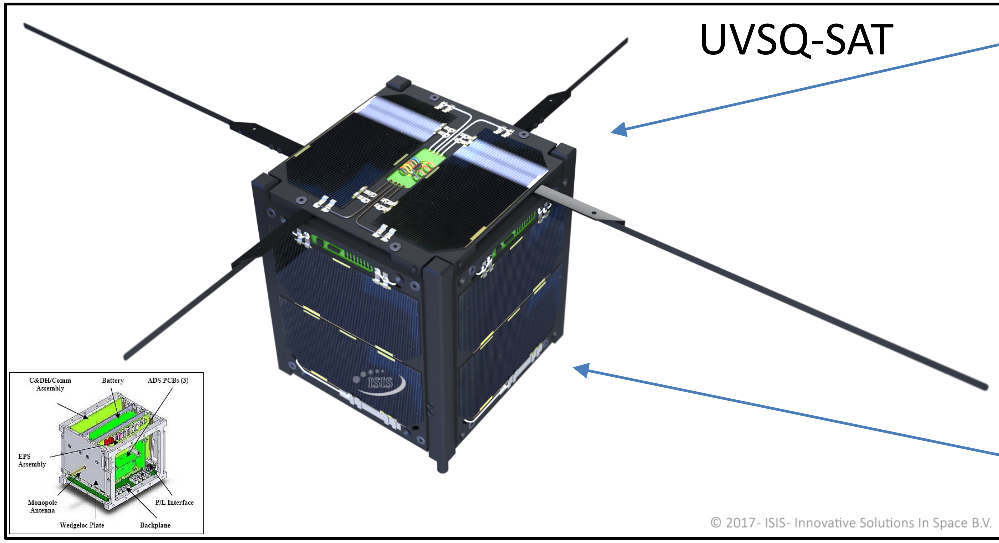
The first step of our program is to develop an innovative proof-of-concept nano-satellite. The second step is to launch a minimum of 10 nano-satellites to obtain a global distribution of Earth fluxes.

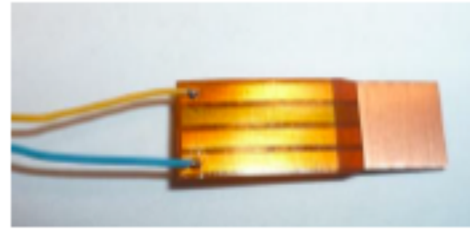
We need to determine the Earth energy imbalance through measuring both total solar radiation and fluxes from the Earth (infrared and reflected solar radiation) simultaneously and ideally with the same instrument type. We will use radiometers.
Parts of the solar radiometer and the Earth radiometer are made with advanced technologies like VACNT, which have proved its ability to absorb the solar flux (solar absorption close to 0.99).

To obtain high accuracy of measurements, a sleek design of the solar radiometer has been established.

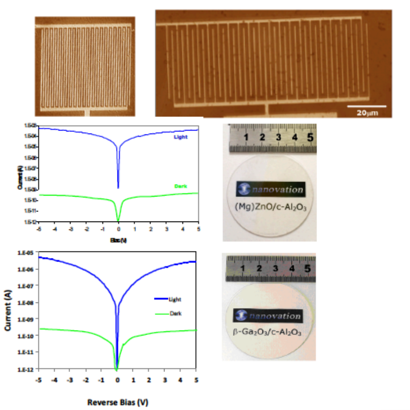
At the end of life, the nano-satellite will become a debris. At an altitude of 680 km, the orbit would naturally decay within the allotted 25 years. Thus, the rule of the 25 years to avoid space debris is respected.

Why we go to UVSQ-SAT?





** Use of small Flux sensors → for the radiative budget of the Earth
- Use of White paint and nanotube of Carbon



** Use of UV nanovation sensors
→ ANR DEVINS

	Launch option 1	Launch option 2	Launch option 3
Launch country:	India	Europe	Russia/Europe
Launch vehicle:	PSLV	VEGA	Soyuz
Launch period:	From Q4 2020	Q1-Q2 2021	From Q3 2020
Orbit parameters:	500-720 km SSO, 12:00 LTAN	500-600 km SSO, LTAN 10:30	500-750 km SSO, LTAN 15:05
Launch adapter options:	QuadPack / DuoPack	QuadPack / DuoPack	QuadPack / DuoPack