SERB, a nano-satellite dedicated to observe the Sun and the Earth

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Outlines

1 – Scientific objectives of the SERB mission
2 – Planned schedule
3 – SERB nanosatellite architecture
4 – Payload
5 – Ground segment
6 – Conclusions
The « nano-satellite to study the Sun and the Earth » is a future innovative proof-of-concept, with four ambitious science goals:

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

• 2\textsuperscript{nd}: to extend the TSI variability measurement with a long-term stability (10 years) better than 0.05 W.m\textsuperscript{-2},

• 3\textsuperscript{rd}: to monitor the Solar Spectral Irradiance (SSI) at 215 nm (Herzberg solar continuum) with a relative accuracy better than 0.5\% per year,

• 4\textsuperscript{th}: to establish a radiation balance of the Earth with an accuracy better than 5\%. 
Impact on Earth climate

Influence of solar variability on Earth climate. Coupling the 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 +/-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.

Impact on the climate if the TSI trend is greater than 0.3 W m\(^{-2}\)
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.

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.

![Graphs showing SSI measurements and model predictions]

SOLAR/SOLSPEC onboard ISS
4th: to establish a radiation balance of the Earth

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

- 2022-2023: Satellite In Orbit Commissioning Review
- December 2021: Ready for flight

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- January-October 2021: Satellite Assembling Integration & Test phase (AIT)
- January 2021: Payload delivery
- September 2020: Satellite Critical Design Review
- April 2019: Payload Critical Design Review
- October 2017: Payload Preliminary Design Review
- June 2017: Satellite Preliminary Design Review

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- 2015-2017: Satellite and Payload preliminary design (Phase 0/A) → SERB is a Student program (X-CubeSat II)
**SERB (launch vehicle and orbit)**

- **Launch schedule:** 2022-2023

- **Launch Vehicle:** To be define

- **Target Orbit:**
  - Helio-synchronous Orbit
  - Altitude: 680 +/- 30 km
  - Local time at ascending node: 06H00 +/- 00H30
  - Orbital inclination: 98.21 +/- 0.

Life time: ~ 12 months

**Objectives:** constellation

Debris mitigation guidelines and the preservation of the space environment

LOS : Loi relative aux Opérations Spatiales
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.
SERB Nano-satellite (Front view)

- **Payload (solar radiometer)**
- **Payload (solar photometer)**
- **S-band antenna**
- **Payload (camera)**
- **CubeADCS 3-Axis bundle (AOCS)**

SERB Nano-satellite (Rear view)

- **S-band antenna**

→ Sun View
SERB electronics

On Board Computer (OBC)

Payload board

CubeADCS 3-Axis bundle (AOCS)

Electronic power supply board

S-band board

Batteries

S-band antenna

GPS board

With radiation shielding.
## SERB (main characteristics)

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

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

« P-Nadir » → **Direct observation of the Earth**
Design of the solar panel deployable system

The goal of the following deployable system is to create an innovative system that can be used on any CubeSat with high cleanliness requirements. It can be split into three subsystems:

- The solar panel,
- The wire mechanism with its hook,
- And the hinge mechanism.

The wire mechanism keep the solar panel closed during takeoff while the hinge mechanism open the solar panel during the deployment in space.
Design of the solar panel deployable system

Wire

Hook

Solar panel

Hinge mechanism

Opening time of the solar panel
On-board computer and power boards

- On-board computer: use of the NINANO board (Steel, France)
  - 1 Gbyte DDR3 or 512 Mbyte EDAC protected
  - 8 Kbyte FRAM
  - 16 Mbyte QSPI Flash for boot-loader and PL configuration
  - 128 Gbyte NAND flash for data storage
  - Ultrastable Crystal Oscillator XO

- Power (Steel Electronique, France):
  - 1 electronic board for Battery Charge Regulator (BCR) & 1 electronic board for Power Control and Distribution Unit (PCDU)
  - Different inputs to connect the Solar Generators
  - Battery charge management (Li-ion 4 cellules)
  - Thermal control management (heaters, temperature, etc.) & satellite deployment control
  - 3 regulated outputs 3V3/4W, 5V/13W, 12V/8W
  - 9 lines which can be controlled
  - TM / TC Management (temperature, voltage, current, power switch)
S band transmitter/receiver: RF characteristics

For the satellite transmitter
- Frequency band: within the band 2200-2290 MHz
- RF Power from 27 to 33 dBm
- Data Rate: One fixed rate from 10 kbps to 3 Mbps
- Modulation: QPSK/OQPSK
- Convolutionnal Coding (7;1/2)
- Consumption: around 9.0 W for 2W RF output

For the satellite receiver
- Frequency band: within the band 2025-2110 MHz
- Modulation: PCM/SP-L/PM
- Data Rate: One fixed rate selectable between at least 8, 16, 32, 64, 128, 256 kbps
- Maximum Doppler shift: +/-66kHz

- Mass: less than 400 g
- Dimensions without diplexer: 96 x 90 x 22.8 mm³
- Consumption : 10 W for 33 dBm RF output

Views of the S band TT&C transponder with 2 diplexer configurations (credits: CNES).
Pointing system electronic boards

The Stellenbosh/Surrey Space Centre ADCS (Attitude Determination and Control system) will provide attitude sensing and control capabilities to 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
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.
4 – SERB payload

The 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;

- 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;

- A camera to take pictures of the Earth.
SERB payload (2D representation)

Solar radiometer
A solar radiometer covers the spectral range from 0.2 to 3µm.

UV photometer
A UV photometer covers the spectral range between 200 and 220 nm using a typical interferential filter.
SERB solar radiometer (focus)

- Without thermal control of the solar radiometer, there are high variations of temperature during the mission.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case A</th>
<th>Case B</th>
<th>Case C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar flux [W m$^{-2}$]</td>
<td>1412</td>
<td>1408</td>
<td>1324</td>
</tr>
<tr>
<td>OLR [W m$^{-2}$]</td>
<td>237</td>
<td>237</td>
<td>237</td>
</tr>
<tr>
<td>Albedo</td>
<td>0.35</td>
<td>0.35</td>
<td>0.27</td>
</tr>
</tbody>
</table>

- TSI determination from temperatures or power with a voltage loop:

$$ TSI = \frac{GL \times (T_t - T_{SD}) + P_{SD} + \epsilon}{\langle \alpha \rangle \times S_{SD}} \times \frac{z^2}{(1 \text{ au})^2} $$

$$ TSI = \frac{P_{SD}(\text{cl}) - P_{SD}(\text{c}) + \epsilon_0}{\langle \alpha \rangle \times S_{SD}} \times \frac{z^2}{(1 \text{ au})^2} $$
**SERB solar radiometer (focus)**

- A method was developed to determine the main parameters of the Proportional Integral thermal control algorithm (Kp and Ki).

\[
S_e = -K_p \times (T - T_s) - K_i \times \int_0^{\Delta t} (T - T_s) \, dt
\]

\[
C_e \times \frac{\partial T}{\partial t} = \frac{1}{R_e} \times (T_I - T) + S_e
\]

- One can achieve the general solution of the system in the Laplace domain, and then in the time domain. When the input is a step function, the resolution of the closed-loop system equation gives:

\[
Ratio = \frac{T - T_S}{T_I - T_S} = \frac{1}{\cos(\alpha)} \times \cos(w_0 \times t + \alpha)
\]

\[
K_p = -\frac{1}{R_e} + \frac{4\pi \times \xi_0}{R_e \times \sqrt{1 - \xi_0^2}}
\]

\[
K_i = \frac{4\pi^2}{R_e^2 \times C_e \times (1 - \xi_0^2)}
\]
SERB solar radiometer (focus)
SERB solar radiometer (focus)

- Tests in laboratory of the solar radiometer (experimental model)
- Work in progress
5 – Ground segment: S band antenna

→ Main characteristics of the antenna
- Antenna of 2.4 m diameter
- Frequency (Rx): 2200-2300 MHz
- Frequency (Tx): 2015-2120 MHz
- Efficiency: 55%
- Gain (back-lobe gain): -30 dB
- Debit: around 5 Mbit per second

Station visibility: Palaiseau or Toulouse (France) vs. SERB
Conclusions

The SERB nano-satellite aims three scientific objectives in connection with the observations of the Earth and the Sun.

The deployment system of the solar panels designed for this nano-satellite is suitable for any CubeSat and cleaner than classic systems.

Parts of the solar 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, and it must be exact during the whole mission. Two options are available in order to measure the TSI (from a thermal control of the solar detector or from a heat flux sensor loop system).

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.
Conclusions

• Impact of the degradation of space-based instruments (UV measurements).
• Interest for a halo orbit at Lagrangian point L1 like Solar and Heliospheric Observatory (SOHO) \(\rightarrow\) solar measurements.
• Interest for long-term measurements.
• Interest for a constellation.

On-orbit performance degradation of SOLAR/SOLSPEC onboard ISS.

Thank you for your attention