Focus over absolute Polarization Angle and Beam Patterns (Two main benefits from CalSat):

- The new generation of CMB telescopes presents unprecedented levels of sensitivity. However, the primordial polarization B-mode remains undetected.
- Systematic effects, previously only partially considered due to higher statistical uncertainties, are now the most significant limitation.
- Instruments on-board satellites are in excellent environmental conditions, but accurate calibration processes are needed.
- Celestial sources are often used as external calibrators after launch, but they are not characterized with the accuracy required in ultra-sensitive CMB polarization experiments:
  - Tau-A → about 0.5 deg, Pol. Ang. error
  - Jupiter → about -50 dB (100 GHz) un-polarized Noise Floor (NF) for the beam characterization.

Study of a novel calibration system: A calibration satellite (CalSat) flying in formation with a CMB telescope (CMBSat), in an orbit located at L2

- During calibration, the sources on-board CalSat emit purely polarized microwave radiation from the far field towards the CMB satellite.
- Baseline option: CalSat is based on the CubeSat standard. Preliminary design follows the main characteristics of an small aperture (30 cm, FWHM=30 arcmin) space mission (similar to LiteBIRD).
- CalSat conceived to travel as a piggyback integrated on the service platform of CMBSat. Deployed once in the L2 orbit
- CalSat: Independent experimental calibration method: Control over intensity, polarization and radiation pattern systematics among others.

2- Impact on CMB polarization Missions

- BB signals of two non-ideal beam models (140 GHz) FSL: At more than 20 degrees (red) and 10 degrees (blue) from the beam center.

3- Calibration Satellite Description and Operation

Thermal Control and Power Budget:

<table>
<thead>
<tr>
<th>Flat (GHz)</th>
<th>CalSat (Cal.)</th>
<th>CalSat (Th.)</th>
<th>Jupiter</th>
<th>CMB Pow</th>
<th>Flat-Pow</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>40.8</td>
<td>3e-4</td>
<td>2.17</td>
<td>0.16</td>
<td>0.5</td>
</tr>
<tr>
<td>100</td>
<td>5.1</td>
<td>4.7e-3</td>
<td>2.3e-4</td>
<td>0.21</td>
<td>0.8</td>
</tr>
<tr>
<td>200</td>
<td>5.1</td>
<td>37.5e-3</td>
<td>0.27</td>
<td>0.12</td>
<td>0.9</td>
</tr>
<tr>
<td>400</td>
<td>5.1</td>
<td>0.3</td>
<td>2.17</td>
<td>15e-3</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Calibration strategy:

- Formation Flying Phase (FFP): present 3 sub-phases: Stand-by orbit (FFP-SBO), calibration phase (FFP-CAL) and positioning (FFP-POS). Maneuvers for calibration positioning from FFP-SBO to FFP-CAL and viceversa. 4 impulses are required.
- Safe Escape Maneuver (SEM) and a Disposal phase (to ensure reaching a final orbit diverging from the one of CalSat) will be also available.

Requirements:

- CalSat at L2 during 3 years: minimum on-ground distance of 300,000 km from CMBSat and within 5.6 km for calibration (at least 6 hours). N=300 calibration per year: Maximum of 30 hours to move away from CalSat FwV (CalSat direction knowledge error < 10 arcmin), CalSat orientation knowledge error < 1 arcmin; Pointing error < 3 arcmin; accuracy in the distance between satellites < 0.3 m. Displacement error (propulsion system) < 3.3 m.
- Critical subsystems: AOCS, Fine Sun Sensors (CubeSpace) and star trackers (CalStar (CubeSpace): Metrology and communications, RF ranging technology (Telhers Unlimited); Propulsion Nanoprop (GOMSPACE))

4- Access Time and Viewed Detectors

- For a FwV of 30 degrees the best option to place CalSat is about 10-15 degrees from the anti-Sun axis.
- Percentage of Viewed Detectors (PVD) approaches 100% in that region for a cal. session of 12 hours (a). In positions with maximum PVD, around 1 hour (total time inside FwV) available to calibrate pointing, polar angle, etc. (b). During FwV crossings, in order to avoid detector saturation, the power of the calibration signal would be attenuated.
- Very good S/N ratios can be achieved in the calibration measurements within this period of time.
- Expanded FwV of 120 degrees considered to calculate the Access Time (AT) for the characterization of the Near- and Far-Side Lobes (FSL) of beams. AT > 5 hours available for that task (c).
- Most of detectors characterised simultaneously thanks to the large angular values of the FSL. Much lower required time.
- Power values of the Table above: About 90 minutes of AT (6 hours session) to characterise FSL of all detectors. NF better than -72 dB (40-400 GHz).