A Calibration Satellite Study for CMB Polarization Missions

Francisco J. Casas[1], Enrique Martínez-González[1], Juan Bermejo-Ballesteros[2], Sergio García-González[2], Javier Cubas[2], R.Belén Barreiro[1], Patricio Vielva[1]
Angel Sanz Andrés[2]

1 EXCELENCIA MARÍA DE MAEZTU · IFCA Instituto de Física de Cantabria · CSIC Consejo Superior de Investigaciones Científicas · UC Universidad de Cantabria

2 idr Instituto Universitario de Microgravedad "Ignacio Da Riva" · POLITÉCNICA

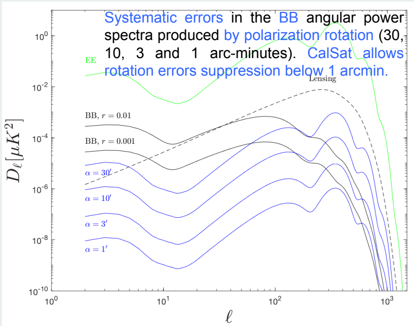
1- Calibration Requirements

- 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.

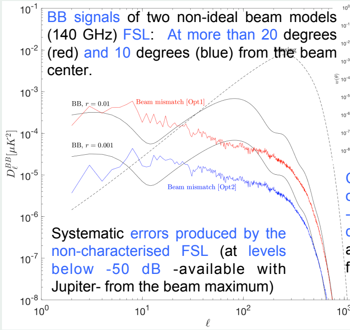
- Study of a novel calibration system: A calibration satellite (CalSat) flying in formation with a CMB telescope (CMBSat), in an orbit located at L2
- During calibration, the sources on-board CalSat emit purely polarized microwave radiation from the far field towards the CMB satellite.
- Baseline option: 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

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

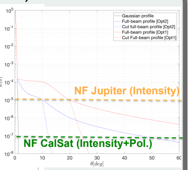


Systematic errors in the BB angular power spectra produced by polarization rotation (30, 10, 3 and 1 arc-minutes). CalSat allows rotation errors suppression below 1 arcmin.



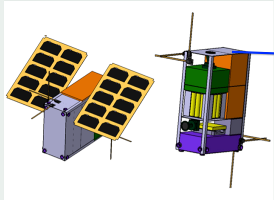
BB signals of two non-ideal beam models (140 GHz) FSL: At more than 20 degrees (red) and 10 degrees (blue) from the beam center.

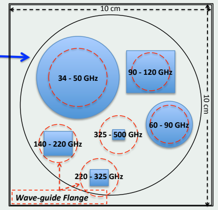
Systematic errors produced by the non-characterised FSL (at levels below -50 dB -available with Jupiter- from the beam maximum)

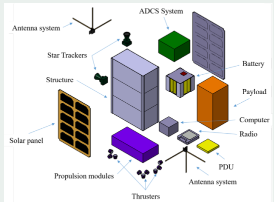


CalSat: Characterization of FSL at levels below -70 dB, covering until 50 degrees (blue) and until about 80 degrees (red) from the beam center.

3- Calibration Satellite Description and Operation







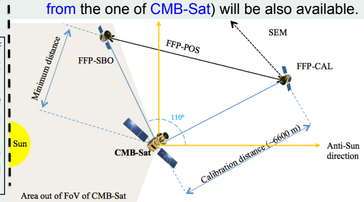
-Narrow- and wide-band microwave sources of linearly polarized signals (34 - 500 GHz).
-Limited power generation at highest frequencies ➔ conical horns (less gain) for two lower frequency bands; rectangular horns (more gain) for the rest.
-Mass: 1.3 Kg; Power consumption (calibration): 50 W; Cal. signal: -60 dB of cross-polarization (WGP).

Requirements: 6U CubeSat at L2 during 3 years; minimum-security distance of 4620 m from CMBSat and 6600 ± 66 m for calibration (at least, 6 hours); 2 calibrations per year; maximum of 20 hours to move away from CMBSat FoV; CMBSat direction knowledge error < 10 arcmin; CalSat orientation knowledge error < 1 arcmin; Pointing error < 3 arcmin; accuracy in the distance between satellites < 3.3 m; Displacement error (propulsion system) < 3.3 m;
Critical subsystems: AOCS, Fine Sun Sensors (GomSpace) and star trackers CubeStar (CubeSpace); Metrology and communications, RF ranging technology (Tethers Unlimited); Propulsion Nanoprop (GOMSPACE)

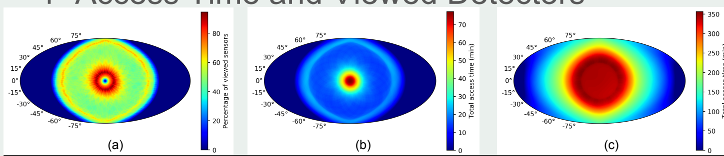
Thermal Control and Power Budget:
Power in pW from Jupiter and CalSat arriving at a 30 cm diameter aperture for fractional band-widths of 0.25; CMB and detectors saturation powers are shown in the last two columns.

Freq (GHz)	CalSat (Cal.)	CalSat (Th.)	Jupiter	CMB-Pow	Sat-Pow
40	40.8	3e-4	2.2e-3	0.16	0.5
100	5.1	4.7e-3	34e-3	0.21	0.8
200	5.1	37.5e-3	0.27	0.12	0.9
400	5.1	0.3	2.17	15e-3	1.2

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



4- Access Time and Viewed Detectors



No technical show-stopper found for a CalSat accomplishing the requirements of a small aperture CMB polarization mission.

- For a FoV 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 FoV) available to calibrate pointing, polar angle, etc. (b). During FoV 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 FoV 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).

CMB Systematics and Calibration focus Workshop - Nov. 30 to Dec. 2, 2020