# THE SPOrt RADIOMETERS


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## ABSTRACT

The Sky Polarization Observatory (SPOrt) is an instrument to be operating onboard the International Space Station during Early Operation Phase, aimed to measure the linear diffuse sky polarization in the frequency range 22-90 GHz. The SPOrt payload is presented with particular emphasys to the radiometer architecture, designed for very high sensitivity polarization measurements requiring careful optimization of systematics.


## INTRODUCTION

The last decade of the 20th century has seen great advances in observational cosmology due to the NASA-COBE DMR (Smoot et al, 1991) space mission in the first place. More recently BOOMEranG (de Bernardis et al, 2000) and MAXIMA (Lee A.T. et al, 2001) balloon experiments as well as DASI (Halverson et al, 2001) from ground have definitely confirmed that the early Universe was not completely homogeneous. All these experiments have collected significant data on the Cosmic Microwave Background Radiation (CMBR), a radiation filling up the Universe and representing the relic of the Big Bang. An important feature of the CMBR is that it is really almost isotropic but not quite, as proved by the tiny temperature fluctuations ($\Delta T/T \sim 10^{-5}$) that have been observed by several experiments at different angular scales. Fundamental information is encoded in the angular power spectrum of these CMBR anisotropies, thought to be the seeds of the present cosmological structures.
The detailed structure of this spectrum allows to test different cosmological models and to increase the precision in the determination of the Universe parameters. In addition, the CMBR can be (linearly) polarized. However, while further anisotropy information with greater sensitivity is expected shortly from present and future experiments, polarization signals are expected to be at least one order of magnitude weaker than the anisotropy. But the polarization of CMBR is essential to remove degeneracies between important cosmological parameters and it represents today's challenge for experimenters (Figure 1).

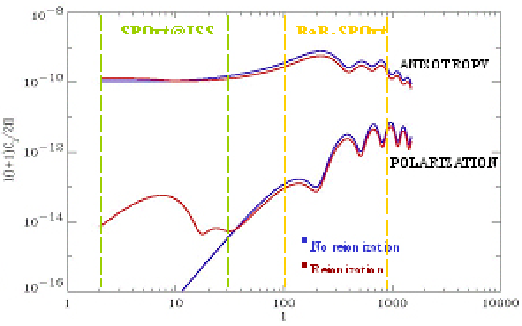


Fig. 1:The expected polarization signal respect with the anisotropy

The current available technology seems to be already suitable to attain the first detection of the low polarization signals when combined with proper observing strategies. The problem of foreground subtraction, in fact, plays a fundamental role: the galactic polarized emission (mainly synchrotron) must be known with great precision to single out genuine CMBR polarization (Cortiglioni & Spoelstra, 1995). The SPOrt (Sky Polarization Observatory) Program (Cortiglioni et al, 2002) is facing the problem by preparing two experiments: SPOrt@ISS (Carretti et al, 2002) and BaR-SPOrt (Zannoni et al, 2002). The first one has the task to provide full-sky accurate measurements of the microwave sky (foregrounds and CMBR polarization) at large angular scale, onboard the International Space Station. The latter is an experiment to be flown onboard stratospheric balloons for observing sub-degree angular scales. The SPOrt Program also includes "low frequency" ground observations of some sky regions for complementary investigations and calibrations. Furthermore, such an approach is fundamental to design the best strategy for future forth generation experiments on CMBR.

**THE MICROWAVE SKY**

The microwave sky is really unknown at frequencies higher than few GHz, especially in its linearly polarized component, which has been properly mapped only in regions close to the galactic plane. High Galactic latitudes have been surveyed extensively - but undersampled - at frequencies not higher than 1411 MHz (Figure 2). Angular Power Spectra (APS) of the Galactic synchrotron polarized radiation have been given an increasing attention in these years, because of the need for an angular-scale-dependent separation between the CMBR and the polarized foreground.

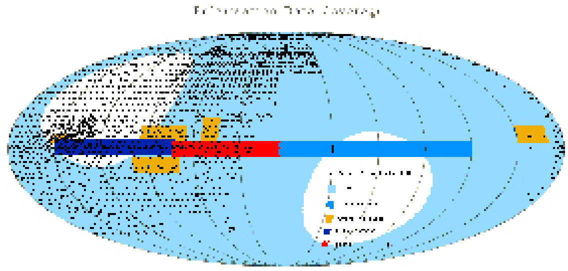

Figure 2: The available polarization data up to 2.7 GHz

Unfortunately, good polarization maps are necessary to calculate APS, at different frequencies and with sub-degree angular resolution.
The major problem is that at a frequency as high as few GHz the Galactic polarized emission gets in the order of mK, in terms of antenna temperature, rapidly decreasing to tens of μK due to its steep spectrum. Most common Radiotelescope receivers do not have the long-term sensitivity required for appreciating such low polarized signals as those generated by galactic synchrotron, free-free and dust emission in the microwave and sub-millimeter domain. Moreover, the angular resolution of most modern Radiotelescopes is too high to allow large-scale surveys extending at high Galactic latitudes, as required by the very careful foreground subtraction in CMBR polarization measurements. Additional restrictions come from the limited availability of polarimetric facilities and from the atmospheric emission fluctuations. For these reasons each experiment aimed at investigating the CMBR polarization must provide its own strategy for foreground removal, which is usually based on multifrequency observations.

**SPOrt@ISS**

The International Space Station (ISS) is the largest manned structure to be built in space. Five space agencies (USA, Russia, Canada, Japan and Europe) are contributing to the realization of this huge laboratory flying around the Earth for more than 10 years with a permanent crew. Its low polar orbit (350-450 km of altitude, 51.2° of inclination) with a 90 min. period will allow SPOrt@ISS to cover more than 80% of the sky every 70 days by observing the zenith (at least 7 complete surveys in 1.5 years of minimum lifetime). Beside pressurized laboratory, ISS will accommodate several external payloads aiming at both Earth and sky observations. In 1998 the European Space Agency selected 5 experiments (out of 21 proposed for space science, over a total of about 100) for the Early Utilization Phase starting in 2004. One of them, SPOrt@ISS, has been
entirely designed and funded by the Italian Space Agency to be the first microwave scientific polarimeter for space astrophysics. The SPOrt@ISS goals are:

- the construction of very precise maps of the Galactic polarized emission at 22 and 32 GHz, where synchrotron dominates;
- the attempt to measure the large scale polarization of the Cosmic Microwave Background Radiation at 60 and 90 GHz, where the so called "cosmological window" (in the frequency-angular scale plane) should allow us to investigate the deep sky.

Due to the ISS constraints SPOrt shall use a 7° beam (HPBW) at all frequencies. However, degree angular scales bring the most important information on the optical depth at re-ionization epochs even though the expected polarization signal is lower. On the other hand, low signals require more sensitivity as well as long term stability and low systematics. SPOrt@ISS represents the synthesis between simplicity and a new receiver architecture applied to space microwave astrophysics. A bottom-up study of a 4$^{th}$ generation CMBR space mission devoted specifically to polarization would greatly benefit from the accumulated experience within the SPOrt@ISS project. The SPOrt payload is realized by a consortium of industries led by ALENIA Spazio, under contract with the Italian Space Agency.

## THE SPOrt@ISS INSTRUMENT

Since the beginning it has been realized that such ambitious goals cannot be reached using "standard" technology, the one available from telecommunication applications representing the only one commercially available. Another baseline is that a real polarization measurement needs the direct evaluation of the Stokes parameters Q and U representing the (linear) polarization.

The SPOrt Team has developed a phase-switched receiver architecture (Fig. 3) where the two circular components are correlated onboard by a correlation unit based on a Hybrid Phase Discriminator. Because of these really severe requirements all the passive waveguide components have been customized by the Team, aiming at the minimization of systematics (offset <50 mK). The total rejection to the unpolarized component (3K) is ≈70 dB. An internal calibrator provides full amplitude and phase calibration pixel by pixel, every 105 sec. The front-ends (Polarizer+OMT+LNAs) are actively cooled at ≈ (80±0.1) K by a closed-loop mechanical cooler.

Tab. 1. General specifications of SPOrt@ISS radiometer

| | |
|---|---|
| Frequency | 22, 32, 60, 90 GHz |
| Angular resolution | HPBW =7° |
| Pixel sensitivity (antenna temperature) | 3.4-6.3 □K |
| P(rms) sensitivity | <0.3 □K |
| Sky coverage | >80% (every 70 days) |
| Lifetime | 1.5 year (extendible to 3) |
| Mass/size | 62 Kg/450 mm x 450 mm x 1170 mm |

The SPOrt receivers provide the Stokes parameters Q and U, representing the linear polarization, by analog correlation of the two circularly polarized components of the incident electric field (A, B). After their separation by the Ortho-mode Transducer (OMT), amplification and filtering, they enter the Analog Correlation Unit (ACU), which is based on the Hybrid Phase Discriminator (HPD). The combination of the four primary outputs of the HPD, after detection, demodulation and integration provide Q and U simultaneously (100% of efficiency).

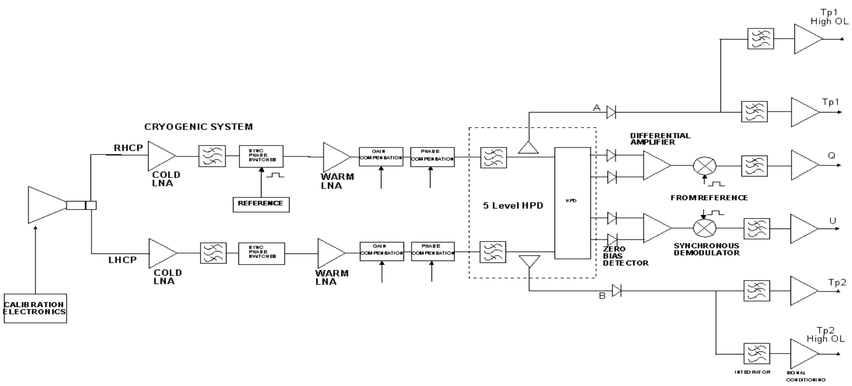


Figure 3: The architecture of SPOrt@ISS / BAR-SPOrt radiometer

The phase modulation improves offset cancellation and 1/f noise. The most stringent requirements of such configuration are those related to the parts where the two components (A, B) interact generating cross-talk (Carretti et al, 2001) and spurious polarization: the antenna system (feed, polarizer, OMT) and the HPD (Tab. 2). Other severe requirements are those aimed at the minimization of the insertion loss, of the return loss and of the phase distortion as well as the onboard calibrator. Also, since part of the front end is cooled, some devices must be suitable for operating at cryogenics temperatures (<70K). Since CMBR polarization measurements always require long integration times for reaching the proper sensitivity, most of the technological efforts both by industrial and scientific side have been devoted to privilege long-term stability rather than noise temperature. Following this concept most of the "standard" commercially available waveguide components were not considered suitable and it was necessary to proceed with new custom designs.

Tab. 2. Main parameters for spurius rejection

| | |
|---|---|
| Feed cross-polarization | <-35 dB |
| OMT insulation | >60 dB |
| HPD rejection to Unpolarized component | >30 dB |
| Total rejection to the Unpolarized component | >70 dB |
| Total spurious polarization | <0.2 μK |

**THE BaR-SPOrt INSTRUMENT**

The BaR-SPOrt project foresees the realization of two phase-switched correlation polarimeters, at 32 and 90 GHz, each of them housed in a cryostat, which allows the cold parts (Polarizer, OMT and Low Noise Amplifiers) to be taken at temperature <(70±0.1) K. Also, the cryostat has a warm room for temperature stabilization of other critical parts (feed, Correlation Unit, detectors, etc.). The polarimeter design has been developed to minimize instrumental effects and to increase long-term stability in order to reduce 1/f noise effects. The main instrumental characteristics are:

- low cross-polarisation optics (< -40 dB) providing beam-width of ~30' and ~10' at 32 and 90 GHz, respectively; on-axis telescope with primary mirror of Ø=120 cm;
- a cryostat to cool (< 70 K) LNAs, circulators, polarizer and OMT by a closed loop cryocooler providing a temperature stability better than ±0.1K during operations. The feed might be cooled as well. A thermal shield, temperature regulated, is located inside the cryostat to increase the thermal stability;
- custom design internal calibrator for full polarization calibrations
- custom design waveguide Hybrid Phase Discriminator for analog correlation. It provides a rejection >30 dB to the unpolairsed component (3K); this value grows up to ~70 dB by using phase modulation;
- custom design OMT with high isolation between channels (> 60 dB) to limit the unpolarised component contamination and the offset generation.

Tab. 1. General specifications of BaR-SPOrt radiometer

| Frequency | 32 GHz | 90 GHz |
|---|---|---|
| BW | 10% | 20% |
| Primary mirror Ø | 120 cm | 120 cm |
| HPBW | 30arcmin | 10 arcmin |
| Sky coverage | 6°x6° | 2°x2° |
| Sensitivity | 0.5 mKs$^{1/2}$ | 0.5 mKs$^{1/2}$ |
| $\sigma_{pix}$ | 4.5 μK | 4.5 μK |
| $P_{rms}$ | 1.6 μK | 3.7 μK |
| $\sigma$ $P_{rms}$ (68% C.L.) | 0.7 μK | 0.7 μK |

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