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Memorie della

OLIMPO

S. Masi,[1,2], E. Battistelli[1], D. Brienza[1], L. Conversi[1,2], A. Cruciani[1], P. de Bernardis[1,2], M. De Petris[1,2], P. Fiadino[1], A. Iacoangeli[1,2], L. Lamagna[1,2], L. Nati[1,2], F. Nati[1,2], F. Piacentini[1,2], G. Polenta[1,2], P.A.R. Ade[3], P. Hargrave[3], P. Mauskopf[3], D. Morozov[3], G. Savini[3], C. Tucker[3], A. Boscaleri[4], S. Peterzen[5], G. Di Stefano[6], G. Romeo[6], A. Delbart[7], C. Magneville[7], J.P. Pansart[7], D. Yvon[7], L. Doumoulin[8], P. Camus[9], V. Gromov[10], and I. Maslov[10]

[1] Dipartimento di Fisica, Università La Sapienza – P.le A. Moro 2, I-00185 Roma, Italy
[2] INFN Sezione di Roma 1 e-mail: `silvia.masi@roma1.infn.it`
[3] School of Physics and Astronomy, University of Cardiff, Cardiff, UK
[4] IFAC-CNR, Firenze, Italy
[5] ISTAR and Dipartimento di Fisica, Università La Sapienza
[6] Istituto Nazionale di Geofisica e Vulcanologia, Rome
[7] DAPNIA/SPP CEA-Saclay, Gif sur Yvette, France
[8] Laboratoire de Physique des Solides, Université Paris Sud, Orsay, France
[9] CNRS - Institut Néel, Dept. MCBT, Grenoble - France
[10] IKI Moscow, Russia

Abstract. The OLIMPO experiment is a balloon borne 2.6 m telescope for cosmology observations at frequencies between 140 and 450 GHz. The experiment is aimed at precision measurement of the cosmic microwave background (CMB), and in particular at the measurement of the spectral distortion of the CMB in the direction of rich clusters of galaxies (Sunyaev-Zeldovich effect). In a single long duration flight OLIMPO will be able to measure the decrement and the increment of the CMB in more than 50 carefully selected clusters. Moreover, OLIMPO will measure the power spectrum of diffuse sky radiation at multipoles up to $\ell \sim 2500$, simultaneously in four well intercalibrated frequency bands, allowing precise spectral tests of the measured anisotropy. OLIMPO can be considered a precursor for the satellite fully spectroscopic mission SAGACE, now a phase-A study of the Italian Space Agency. In this paper we describe the scientific programme of OLIMPO, the measurement method and the technical implementation.

Key words. Cosmology: Cosmic Microwave Background – Cosmology: Clusters of Galaxies – Stratospheric Balloons

1. Introduction

Millimeter waves propagate in the Universe with negligible absorption. The effect of interstellar dust is 2-3 orders of magnitude smaller than for optical radiation. In fact, the photons of the cosmic microwave background are allowed to cross half of the visible universe and

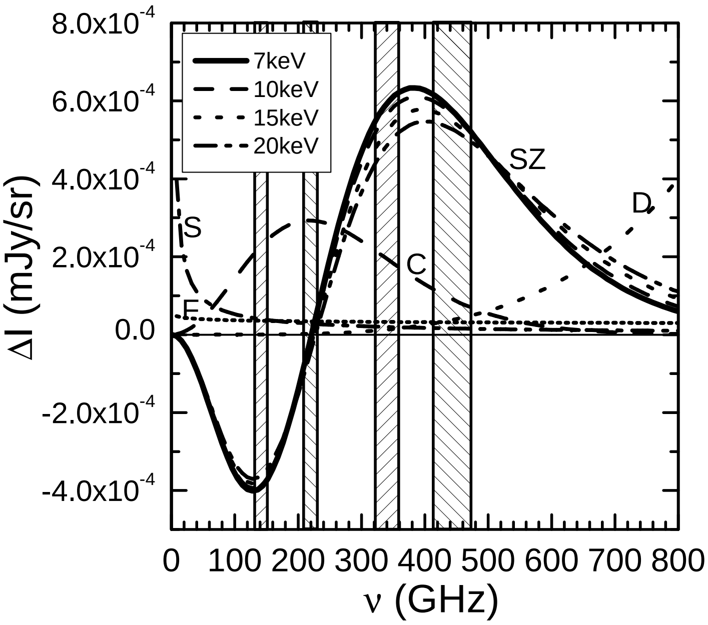

Fig. 1. Spectrum of the S-Z effect compared to the observation bands of OLIMPO and to other foregrounds. The S-Z spectrum for a differential observation (cluster - reference) is computed for different temperatures of the electrons as specified in the box. The other lines correspond to generic (arbitrary normalization) spectra of CMB anisotropy (C, long dashes), of synchrotron (S, dash-dots), free-free (F, dots) and dust (D, short dashes) from the interstellar medium. None of them can mimic a S-Z spectrum. The four observation bands of OLIMPO at 140, 220, 340 and 450 GHz are shown as vertical dashed stripes.

reach us without interacting significantly with matter.

However, when crossing rich clusters of galaxies there is a small likelihood of inverse Compton scattering against the hot electrons of the intercluster plasma. This is the so-called Sunyaev-Zeldovich (S-Z) effect (Sunyaev and Zeldovich 1970; Birkinshaw 1999). The optical depth through the cluster is $\tau \sim n\sigma\ell \sim 0.01$ for rich clusters, while the energy gained from a 5 keV electron is of the order of $\Delta E/E \sim kT_e/m_e c^2 \sim 0.01$. The resulting CMB temperature anisotropy in the direction of the cluster is $\Delta T/T \sim \tau\Delta E/E \sim 10^{-4}$. This is a significant signal: maps of the CMB with sensitivity per pixel of 10^{-5} of the background are now routinely obtained by CMB anisotropy experiments. The process is such that all the involved photons are shifted to higher energies. This results in a deficit of photons at frequencies lower than 217 GHz (the frequency of maximum brightness fluctuation for the CMB), and in an excess of photons at energies higher than 217 GHz: a very distinctive spectral feature. Experiments aimed at measuring the S-Z effect, separating it from other brightness fluctuations, should take simultaneously measurements below and above this zero-effect frequency.

High-energy plasmas produce relativistic distortions to the spectrum of the S-Z effect (the most important being a shift of the zero-effect frequency). These could be used to estimate the temperature of the plasma (Itoh et al. 1998).

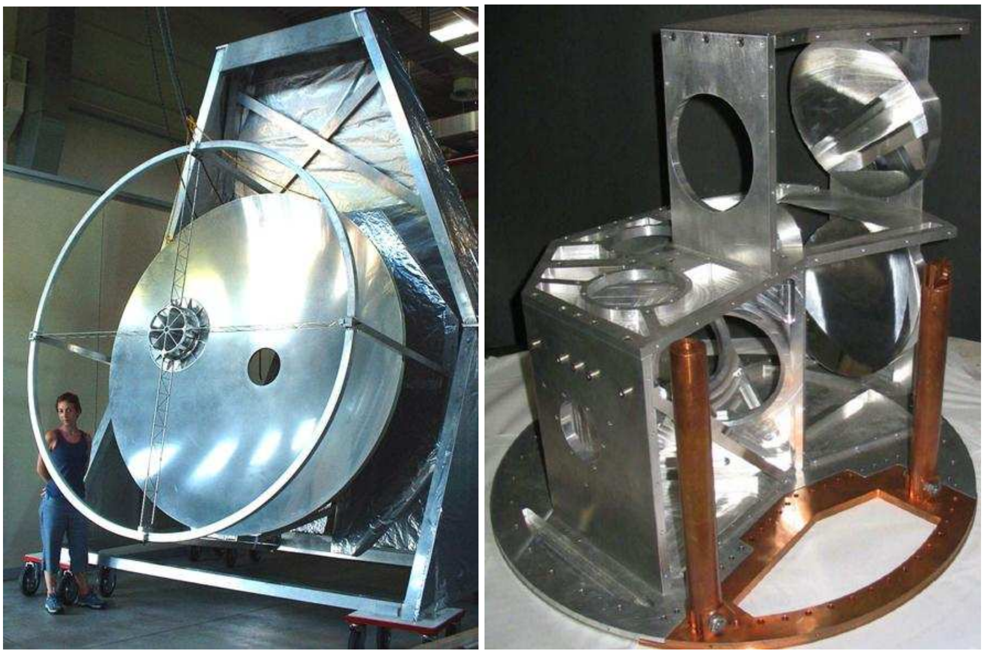

Fig. 2. The OLIMPO telescope and gondola (left, all shields removed). The Cassegrain telescope has aluminum mirrors; the 2.6m primary can be tilted in cross-elevation to perform sky scans while the gondola is staring at the target. On the right a picture of the cryogenic reimaging optics, splitting the image on the sky on the four detector arrays.

The amplitude of the S-Z effect is proportional to the density of electrons in the cluster, and is independent of the redshift of the cluster: for this reason it is in principle possible, using S-Z observations, to study very distant clusters, not observable at visible and X-ray wavelengths. These studies can provide fundamental insight on the process of formation of cosmic structures and on the large-scale structure of the Universe Juin et al. (2007) .

Detailed studies of single, resolved clusters, can provide important information on the external regions of the plasma (where X-ray emission, proportional to n^2, is negligible), on internal substructures and cavities, possible cooling flows, magnetic structures (Colafrancesco 2005; Colafrancesco and Giordano 2006).

In addition to the thermal S-Z, a kinematic S-Z is also present: photons scattered by electrons in motion with velocity v (relative to the Hubble flow) will exhibit a temperature fluctuation at a level $\Delta T/T \sim v/c \sim 10^{-5}$. The spectral behavior of the kinematic effect is exactly the same as for the primary CMB anisotropy, thus making this effect much more difficult to measure and separate from the intrinsic anisotropy of the CMB in the direction of the cluster. However, statistical surveys of a large number of clusters could provide significant information on the velocity fields in the universe Bhattacharya and Kosowsky (2008).

Research on the S-Z effect is extremely active and competitive today. Ground based telescopes will perform deep, high resolution surveys at 90, 150, 220 GHz (SPT, ACT, VSA, AMI, MITO ...). Higher frequency measurements will be performed from space. Planck will perform a shallow, full-sky survey of 1000-10000 clusters, limited by angular resolution and integration time. OLIMPO will focus on a selected set of key clusters (about 100) to measure their positive SZ in detail.

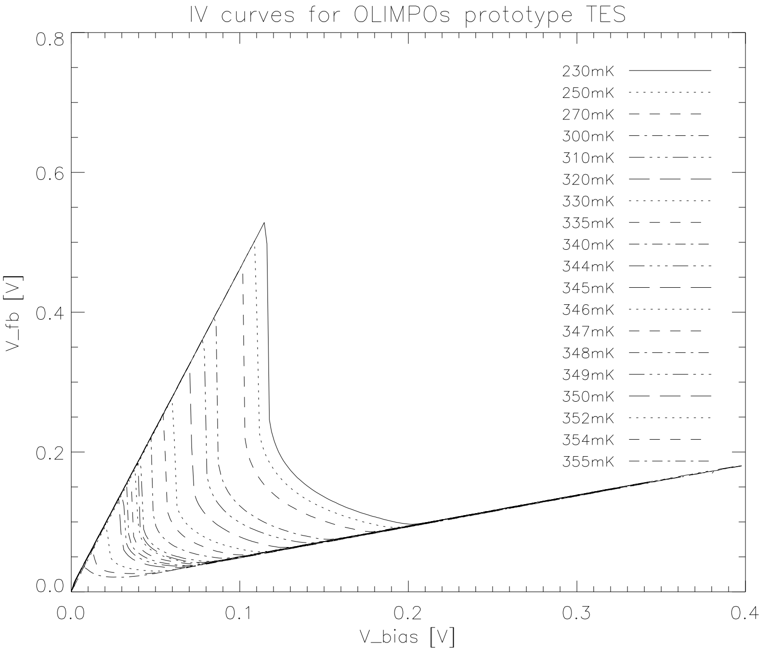

Fig. 3. Typical load (I-V) curves acquired during OLIMPO TES development. The curves are acquired for different temperatures of the thermal stage they are linked to. The normal branch is evident in the right hand side of the figure as a straight line. The superconducting transition is the curved part in the center while the superconducting branch is the steep straight line on the left hand side of the figure.

In addition to S-Z measurements, OLIMPO will measure the spectrum of the CMB at multipoles up to $\ell \sim 2500$, and measure the power spectrum of the background generated by unresolved galaxies Masi et al. (2005).

2. OLIMPO: general design

Driven by the science case summarized above, we have designed the OLIMPO stratospheric balloon payload.

The experiment is sensitive in four spectral bands centered at 140, 220, 340, 450 GHz, with 16,10,10,12% FWHM bandwidths, respectively. The filter bands are compared to the spectra of the S-Z effect and to competing foregrounds in fig.1. The selected bands of OLIMPO sample simultaneously the negative, null and positive part of the S-Z effect, thus allowing efficient separation of competing foregrounds, and possibly detection of spectral distortions.

The angular resolution of a mm-wave telescope depends on the size of the primary mirror, and on the collecting area of the detectors. We have used a fast primary mirror (2.6 m in diameter), in a compact Cassegrain configuration (De Petris et al. 1989), very similar to the configuration used in the ground based telescopes MITO, COCHISE, QUAD. A telescope of this size is - to our knowledge - the largest one ever flown on a stratospheric balloon. By comparison, PRONAOS (Lamarre et al. 1998) and BLAST (Pascale et al. 2008) both had 2m primary mirrors. In fact, even without shields and solar panels the size of the gondola is quite impressive (see fig.2).

To reduce spillover, sidelobes, and scan-synchronous offsets, the entrance pupil of the telescope is kept ∼ 15% smaller than the diameter of the primary. The resulting diffraction-limited angular resolution is 4.3, 2.7, 1.8 and

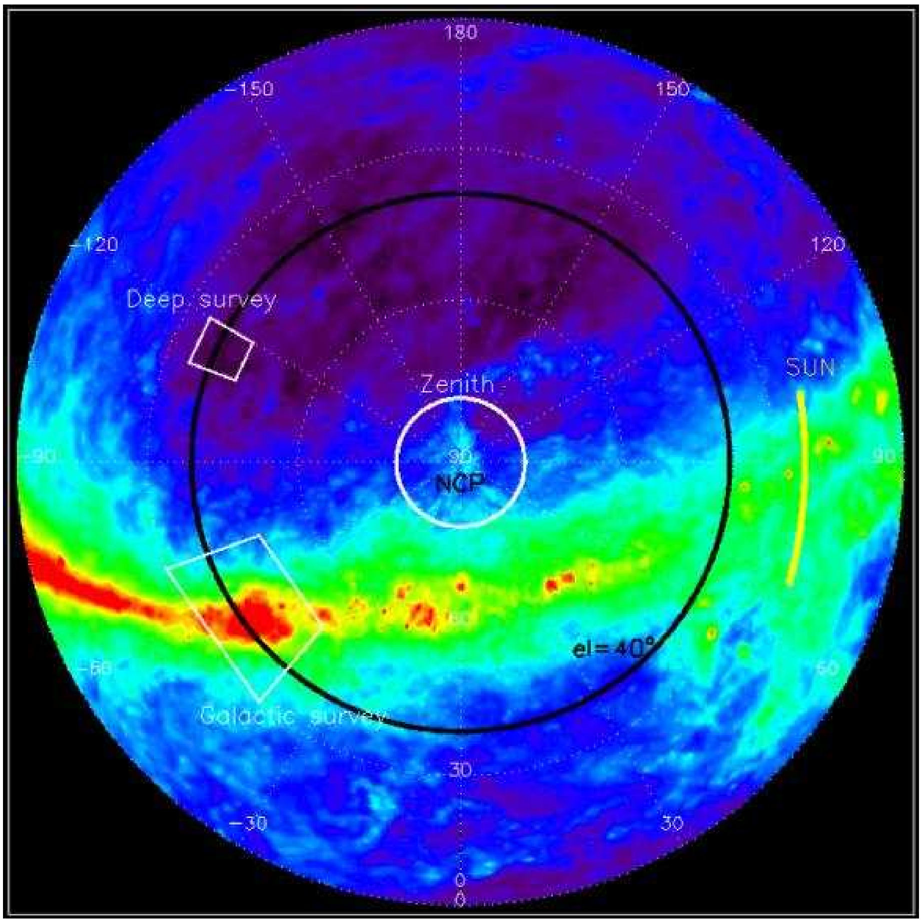

Fig. 4. The sky observable during a long duration balloon flight from Svalbard islands. The false color map represents the emission of interstellar dust as monitored by IRAS at 3000 GHz. The white line represents the local zenith of the payload during the flight. The yellow line represents the position of the sun during the flight season (june-july): the payload must observe directions opposite to these position. The tentative locations of a deep survey and of a Galactic survey are also shown: both are visible with an optimal elevation of the telescope of about 40^o.

1.3 arcmin respectively at 140, 220, 340 and 450 GHz. This resolution is already a factor ~ 2 better than the one achievable with Planck, and enough to study a few hundred nearby clusters, and even to resolve a few of them to investigate their internal and peripheral structure.

The detector arrays use two different technologies: low impedance TES bolometers (Mauskopf et al. 2006) for the 150 and 220 GHz channels (see fig.3), and high impedance Si:Nb for the 340 and 450 GHz channels (Ukibe et al. 2006). Each array will fill the optically corrected area of the focal plane (about 0.25^o in diameter projected on the sky). The bolometer are coupled to the input radiation by means of aluminum feedhorns. For the diffraction-limited arrays at 140 and 220 GHz, the two hexagonal arrays have 19 and 37 pixels respectively. The two high-frequency arrays (340 and 450 GHz) will not be diffraction-limited, and will be composed of 37 pixels matching the positions of the 220 GHz channel.

OLIMPO will map the clusters by staring the telescope at the cluster center, and tilting the primary mirror in cross-elevation, periodically, with a triangle waveform with an amplitude of 30-60 arcmin. In this way each detector of the arrays will scan the cluster region at constant speed: detector signals can be AC-coupled removing the constant background signal from the datastream. Observing the cluster at different elevations will produce strongly cross-linked scans, the key to obtain clean maps of the differential S-Z effect.

Both the pointing system and the cryogenic system of OLIMPO are built on the experience gained with the BOOMERanG experiment (Masi et al. 2006). The OLIMPO cryogenic system, able to cool down at 300 mK the arrays and at 2K the optics box, is described in L. Nati et al. (2008). The pointing system is described in F. Nati et al. (2008); Boscaleri (2008).

3. OLIMPO: the mission

OLIMPO will fly for the first time on a long-duration balloon launched from the Svalbards by the Italian Space Agency and Andoya Rocket Range Peterzen et al. (2007). The forecast duration of these flights is more than 2 weeks, at an approximately constant latitude of 80^oN and an altitude of 38-40 km . From this advantage location OLIMPO will be able to observe about 40 clusters per flight, plus a long deep survey on a foregrounds-clean region for a blind survey of distant clusters. The sky observable with OLIMPO during the first flight is a large fraction of the northern hemisphere, as shown in fig.4. Thanks to the possibility to tilt the telescope elevation down to $\sim 10^o$, the experiment can be calibrated on Mars, for responsivity, beam and sidelobes (de Bernardis et al. 1999). A second flight from the southern hemisphere will allow us to complete a survey of about 100 selected clusters. Simulations show that, for each of them, the Comptonization parameter can be measured by OLIMPO down to $\Delta Y \sim 10^{-5}$ (taking into account confusion and separation of the foregrounds) thus producing a significant, well calibrated sample of S-Z clusters useful even for statistical studies. The potential of the deep survey has been analyzed in depth in Juin et al. (2007). The first flight is scheduled for June 2009.

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