OLIMPO: a balloon-borne, arcminute-resolution survey of the sky at mm and sub-mm wavelengths

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ABSTRACT

We describe OLIMPO, a balloon-borne telescope devoted to cosmological and astrophysical surveys in the mm and sub-mm range.We summarize the relevant science (principally surveys of SZ clusters, of the sub-mm cosmic background and observations of galactic and cirrus dust) and the innovative sub-systems we have developed. The test flight of the telescope is planned for July 2004; the long duration flight is planned for the end of 2005.

1. INTRODUCTION

The development of new detectors, like the extremely sensitive micromachined bolometers [1], and the availability of long duration balloon flights [2] are opening the possibility to carry out surveys of the sky in the last unexpolred range of the electromagnetic spectrum: the mm / sub-mm range. The BOOMERanG experiment [3] has provided sensitive maps of 3% of the sky in the range 90 to 400 GHz, with a resolution of ~ 12'. Other balloon experiments, like Pronaos (see e.g. [4]), have provided high angular resolution maps of smaller selected targets. The BLAST experiment will cover the spectral range 600-3000 GHz with arcmin resolution [5]. The OLIMPO payolad, described here, is a 2.6 meter on-axis millimeter-wave Cassegrain telescope, mounted on an attitude controlled stratospheric balloon payload. This telescope is designed to be flown with a >10 days Long Duration CircumPolar flight. The system contains 4 arrays of bolometers in the wavelength bands centered at 150, 240, 410, 600 GHz. The instrument will be diffraction limited at 150 GHz (3.5 arcminutes FWHM), and will map significant parts of the sky. All the experiments listed above are preliminary and complementary to the surveys of the SIRTF , Herschel and Planck satellites, coming later this decade. The science drivers for these mm and sub-mm continuum surveys are compelling for cosmology, for the interstellar medium and for the study of the star formation process.

2. MM/sub-MM COSMOLOGY

The Universe is very transparent in this wavelength range. The Cosmic Background Radiation is prominent in the microwaves (the CMB from the Early Universe) and in the far IR (the FIRB, Far IR Background from Primeval Galaxies). The extra-galactic sky has three main sources of diffuse emission: the CMB and its primary anisotropy, the emission from Cluster of Galaxies (Sunyaev-Zeldovich effect) and the FIRB. The "cosmological window" extends roughly from 3000 to 500 μm: at lower frequencies interstellar emission of spinning dust grains, free-free and synchrotron dominates the cosmological background; at higher frequencies the clumpy cirrus dust foreground dominates the sky brightness even at high Galactic latitudes. Reference [6] describes mm/sub-mm cosmological observables in deeper detail. Any experiment seriously attempting the detection of these diffuse emission components has to be multi-band (see e.g. [7]).

2.1 SZ Effect in Cluster of Galaxies

A survey of Clusters of Galaxies, visible via the Sunyaev-Zeldovich effect, can provide crucial information about the background cosmology and about the Hubble Constant (see e.g. [8,9]). Clusters can be seen against the CMB background at high redshift, much deeper than in the complementary optical and X-ray surveys, thus providing a unique tool to investigate the early evolution of structures. The OLIMPO bands are ideally suited to measure the Sunyaev-Zeldovich effect in clusters of galaxies and distinguish it from competing foregrounds. Moreover, the simultaneous

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observation of the positive effect at 0.5mm and at 0.85 mm in addition to the "zero effect" measurement at 1.35 mm will allow us to measure the relativistic corrections and the temperature of the gas even in the absence of X-ray data.

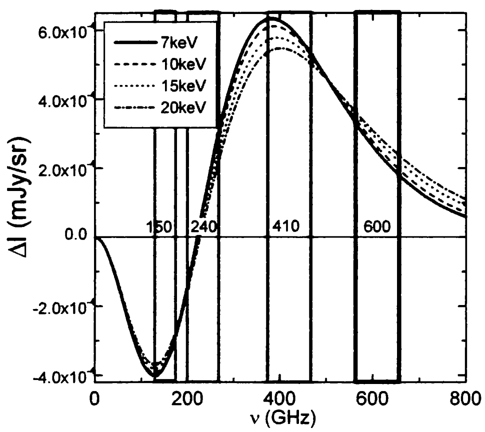

Fig. 1: Spectrum of the Sunyaev-Zeldovich effect in a rich cluster of galaxies, for different temperatures of the intracluster electrons (7 to 20 keV) [10]. The spectrum is compared to the OLIMPO bands at 150, 240, 410 and 600 GHz. Notice that the relativistic correction for high temperatures has opposite effects in the two high frequency bands of OLIMPO, thus breaking a degeneracy in the determination of the cluster Temperature.

We plan to map about 40 clusters per flight with sensitivity better than 10^{-5} in the componization parameter. We will combine these measurements with X-ray measurements to build a "Hubble diagram" for the determination of H_o. Deep surveys of SZ clusters can give independent estimates of Ω_Λ and Ω_m through the evaluation of clusters counts and the shape of the power spectrum.

2.2 CMB Anisotropy

CMB anisotropy at high multipoles ($\ell > 400$) can be detected in the lower frequency bands of OLIMPO, providing estimates of the dark matter density in the Universe through the measurement of the damping tail of the power spectrum [11]. Taking advantage of its high angular resolution, and concentrating on a limited area of the sky, OLIMPO will be able to measure the angular power spectrum of the CMB up to multipoles ℓ about 3000, significantly higher than BOOMERanG, MAP and Planck. This measurement will complement those of the low-frequency (30 - 90 GHz) ground based interferometers, with orthogonal systematics. Due to the higher frequency this measurement will provide a mandatory cross-check for potential foregrounds. Also, the high multipoles tail of the power spectrum of the sky includes contributions from any point sources population, like SZ clusters or early galaxies. Only multiband observations can discriminate between them: the bands of OLIMPO have been optimized for optimal components separation by means of extensive simulations of the mm/sub-mm sky.

2.3 FIRB

The Extragalactic Far Infrared Background has been measured by the COBE satellite [12] and is believed to result from an early generation of Galaxies, still unresolved. Resolving the FIR background and studying the unresolved component is important in order to investigate the cosmic "middle ages" at z = 1-10, where light starts to shine again in the Universe. High Star Formation Rate is expected at these redshifts [13]. Cosmic star formation history can thus be investigated in a way completely orthogonal to the deep visible and NIR surveys; the very significant (negative) K-correction present at these wavelengths makes sub-mm observations quite sensitive [14].

3. GALACTIC STUDIES IN THE MM/SUB-MM

mm/sub-mm observations are very effective in measuring the mass and temperature of cold dust clouds, either in the cirrus at high galactic latitudes or in the molecular clouds in the Galactic plane. We plan to use OLIMPO to make a survey of selected regions in the Galactic plane and to map high latitude cirrus at higher resolution than done with BOOMERanG [15]: this will be important in view of the forthcoming precision surveys of the CMB, like Planck, where the Galactic foreground will be the main factor limiting the precision of the cosmology observations.

4. THE OLIMPO PAYLOAD

OLIMPO is implementing a number of advanced technical solutions.

The main frame (see fig.2) is made out of aluminum alloys, and has been optimized to withstand 10g shocks (vertical) and 5g shocks (horizontal, any azimuth) at parachute opening. The telescope and detector system are monted on a tiltable inner frame. Its elevation can be set from 0° to 60°. Reaching low elevations is very important for ground based calibrations of the telescope (the far field is about 20 km away!).

The Cardiff group is in charge of developing the four arrays of bolometers and the dichroics for the multiband focal plane. These detectors are an evolution of the highly successful devices used in the BOOMERanG and Planck-HFI instruments [1]. In order to easy manufacturing, a fully photolitographic process producing TES (transition edge superconductor) sensors on silicon nitride islands on a Si wafer has been developed. Filters and antennas are integrated on the same wafer. We will mount 4 arrays at 2.0, 1.4, 0.75, 0.50 mm of central wavelength, with 19, 37, 37, 37 detectors respectively. Multimode detectors (in the higher frequency bands) are obtained by combining the signals from several adjacent antennas. Each array will fill the optically correct area of the focal plane (about 0.5° in diameter projected in the sky).

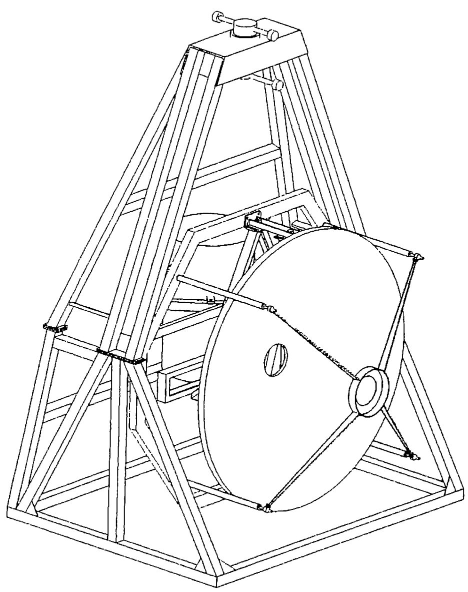

Fig. 2: The OLIMPO payload (shields removed)

The cryogenic reimaging optics is being developed in Rome. It is mounted in the experiment section of the cryostat, at 2K, while the bolometers are cooled at 0.3K. Extensive baffling and a cold Lyot stop reduce significantly straylight and sidelobes. The optics has been optimized to permit diffraction-limited operation with significant tilt of the primary mirror during sky scans.

The bolometer arrays and the reimaging optics will be mounted in a modified version of the long duration cryostat developed for BOOMERanG [16,17]. The main difference here is the use of fiberglass cylinders to replace the kevlar cords suspending the LN and LHe tanks. With fiberglass cylinders we get a higher stiffness of the system, necessary to keep the detectors arrays precisely centered on the optical axis during operation at different elevations. Moreover, the window has been moved to a side of the cryostat, to permit operation of the system with the telescope axis horizontal or at low elevation, during ground based calibrations and during in-flght calibrations on planets.

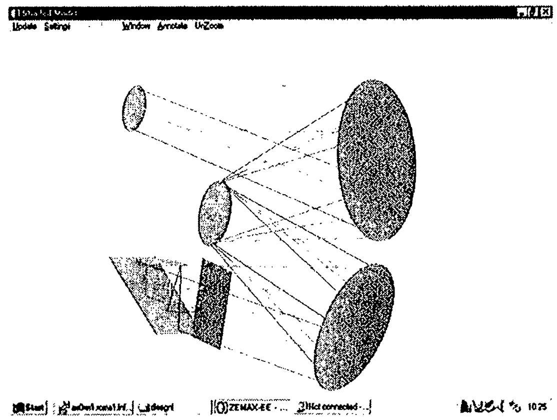

Fig. 3: Ray Tracing of the cryogenic section of the optics. From top to bottom are shown the vacuum window of the cryostat, the tertiary mirror, the Lyot Stop, the fifth mirror and the two dichroics splitting the beam on the four detectors arrays.

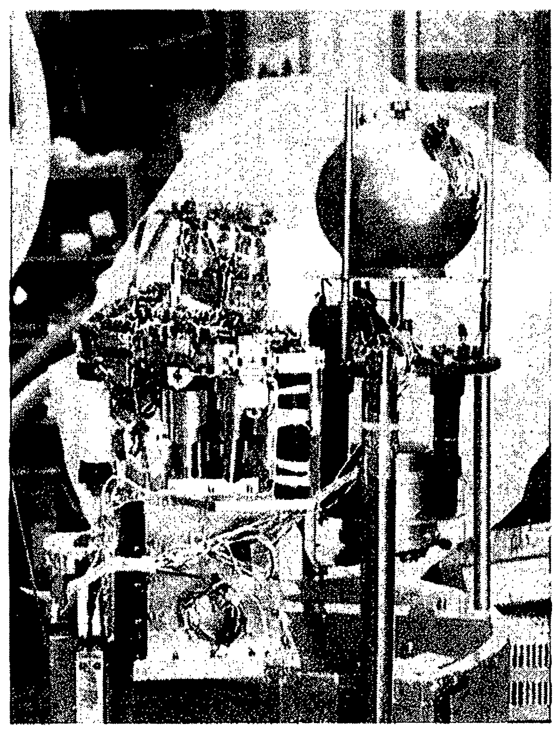

Fig. 4: The 0.3K refligerator used for the BOOMERanG experiment will be used for OLIMPO as well.

The telescope is also being developed in Rome. It is a classical Cassegrain with a 2.6m aluminum primary [18] The secondary mirror is suspended by means of kevlar cords. Sky scans are obtained by slowly scanning the primary mirror in the cross-elevation direction. The chopper design is similar to the ones in [19] and [20], but allows a substantial reduction of the scan-syncronous offset by tilting the primary instead of subreflector. Up to 3° wide, 1° /s cross-elevation scans are possible with this system.

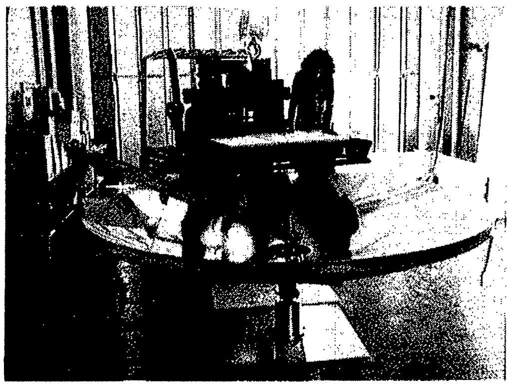

Fig. 5: The primary mirror for OLIMPO (2.6m diameter) during testing.

The rest of the payload (on-board data conversion and acquisition, Attitude Control System, Telemetry, Thermal Shields and Housekeeping) is similar to the BOOMERanG experiment [21,22]. The Attitude Control System is derived from the BOOMERanG one and completed with day and night-time attitude sensors: laser gyroscopes, sun sensors, star camera.

The test flight will be a trans-mediterranean flight from Sicily to Spain, to be done in 2004 as a joint venture between the ASI and the NSBF.

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