ARCHEOPS: AN INSTRUMENT FOR PRESENT AND FUTURE COSMOLOGY

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Abstract ARCHEOPS is a balloon-borne instrument dedicated to measure the cosmic microwave background (CMB) temperature anisotropies. It has, in the millimetre domain (from 143 to 545 GHz), a high angular resolution (about 10 arcminutes) in order to constrain high ℓ multipoles, as well as a large sky coverage fraction (30%) in order to minimize the cosmic variance. It has linked, before WMAP, COBE large angular scales to the first acoustic peak region. From its results, inflation motivated cosmologies are reinforced with a flat Universe ($\Omega_{\rm tot} = 1$ within 3 %). The dark energy density and the baryonic density are in very good agreement with other independent estimations based on supernovae measurements and big bang nucleosynthesis. Important results on galactic dust emission polarization and their implications for PLANCK-HFI are also addressed.

Introduction

ARCHEOPS is a CMB bolometer-based instrument using PLANCK-HFI technology that fills a niche where previous experiments were unable to provide strong constraints. Namely, ARCHEOPS seeks to join the gap in ℓ between the large angular scales as measured by COBE/DMR and degree-scale experiments, typically for ℓ between 10 and 200. For that purpose, a large sky coverage is needed. The solution was to adopt a spinning payload mostly above the atmosphere, scanning the sky in circles with an elevation of around 41 degrees. The gondola, at a float altitude above 32 km, spins across the sky at a rate of 2 rpm which, combined with the Earth rotation, produces well sampled sky map at 143, 217, 353 and 545 GHz.

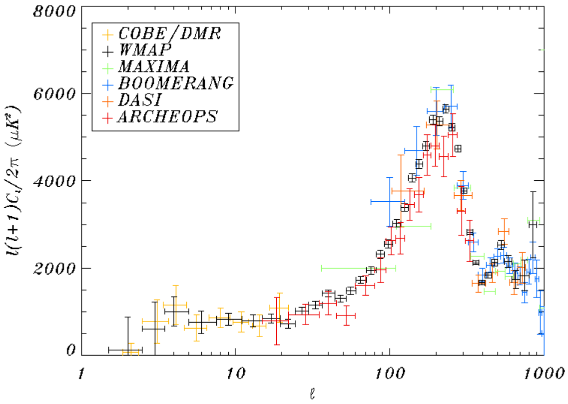

Figure 1. ARCHEOPS CMB power spectrum (Benoît et al. 2003a) in 16 bins along with other recent experiments COBE (Tegmark et al. 1996), WMAP (Bennett et al. 2003), MAXIMA (Lee et al. 2001), BOOMERANG (Netterfield et al. 2002) and DASI (Halverson et al. 2002).

Description of the instrument

The instrument was designed by adapting concepts put forward for PLANCK-HFI and using balloon-borne constraints (Benoît et al. 2002) : namely, an open ^{3}He-^{4}He dilution cryostat cooling spiderweb-type bolometers at 100 mK, cold individual optics with horns at different temperature stages (0.1, 1.6, 10 K) and an off-axis Gregorian telescope. The CMB signal is measured by the 143 and 217 GHz detectors while interstellar dust emission and atmospheric emission are monitored with the 353 (polarized) and 545 GHz detectors. The whole instrument is baffled so as to avoid stray radiation from the Earth and the balloon. We report on the first results obtained from the last flight (12.5 night hours) that was performed from Kiruna (Sweden) to Russia in February 2002.

Results

After being calibrated with the CMB dipole – in agreement with the FIRAS Galaxy or Jupiter emission – eight detectors (yielding effective beams of typically 12 arcminute FWHM) at 143 and 217 GHz are found to have a sensitivity better than 200 $\mu\mathrm{K}_{CMB}.s^{1/2}$. A large part of the data reduction was devoted to removing systematic effects coming from temperature variations on the various thermal stages and atmospheric effects.

Benoît et al. 2003a and Benoît et al. 2003b show the results of a first analysis of the data, which are summarized below. Only the best bolometer of each CMB channel (143 and 217 GHz) was used. The data are cleaned and calibrated, and the pointing is reconstructed from the stellar sensor data. The sky power spectrum above a galactic latitude of 30 °(free of foreground contamination) is deduced using a MASTER-like approach (Hivon et al. 2002). The observed spectrum is shown in Fig. 1 and compared to a selection of other recent experiments. Much attention was paid to the possible systematic effects that could affect the results. At low ℓ, dust contamination and at large ℓ, bolometer time constant and beam uncertainties are all found to be negligible with respect to statistical errors. The sample variance at low ℓ and the photon noise at high ℓ are found to be a large fraction of the final ARCHEOPS error bars in Fig. 1.

Cosmological constraints

ARCHEOPS provides a precise determination of the first acoustic peak in terms of position at the multipole $\ell_{\rm peak} = 220 \pm 6$, height and width. Using a large grid of cosmological models with 7 parameters, one can compute their likelihood with respect to the datasets. An analysis of Archeops data in combination with other CMB datasets constrains the baryon content of the Universe to a value $\Omega_{\rm b} h^2 = 0.022^{+0.003}_{-0.004}$ which is compatible with Big-Bang nucleosynthesis (O'Meara et al. 2001) and with a similar accuracy (Fig. 2). Using the recent HST determination of the Hubble constant (Freedman et al. 2001) leads to tight constraints on the total density, *e.g.* $\Omega_{\rm tot} = 1.00^{+0.03}_{-0.02}$, *i.e.* the Universe would be flat. An excellent absolute calibration consistency is found between COBE, ARCHEOPS and other CMB experiments (Fig. 1). All these measurements are fully compatible with inflation-motivated cosmological models. The constraints shown on Fig. 2 (right), leading to a value of $\Omega_\Lambda = 0.73^{+0.09}_{-0.07}$ for the dark energy content, are independent from and in good agreement with supernovae measurements (Perlmutter et al. 1999) if a flat Universe is assumed.

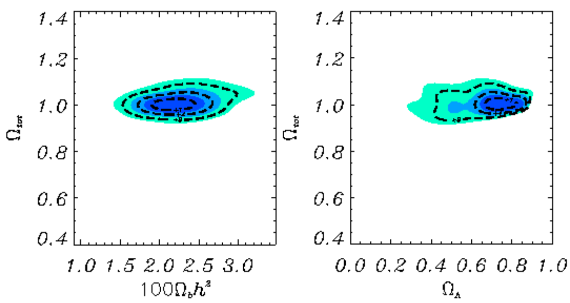

Figure 2. Likelihood contours for 3 of the cosmological parameters: total density versus baryonic density and cosmological constant. Greyscale corresponds to 2-D limits and dashed line to 1-D contours equivalent to 1, 2, and $3\,\sigma$ thresholds. A Prior on the Hubble constant $H_0 = 72 \pm 8\,{\rm km/s/Mpc}$ (68% CL, Freedman et al. 2001) has been added.

Polarized Foregrounds

The polarized channel at 353GHz gives important results on the polarization of the emission of the dust in the galactic plane. Concerning the large scales, we find a diffuse emission polarized at 4-5% with an orientation mainly perpendicular to the galactic plane. We found also several clouds of a few square degrees polarized at more than 10% in the Gemini and the Cepheus regions. It is interesting to note that the brightest region, Cygnus, is not polarized. These results suggest a powerful grain alignment mechanism throughout interstellar medium. All the interpretations are developed in Benoît et al. 2003c. Interstellar dust polarization emission will be a major foreground for the detection of the polarized CMB for PLANCK-HFI.

Conclusions

The measured power spectrum (Benoît et al. 2003a) matches the COBE data and provides for the first time a direct link between the Sachs-Wolfe plateau and the first acoustic peak. The measured spectrum is in good agreement with that predicted by inflation models producing scale-free adiabatic peturbations and a flat Universe. Finally note that these results were obtained with only half a day of data.

Use of all available bolometers and of a larger sky fraction should yield an even more accurate and broader CMB power spectrum in the near future. The large experience gained on this balloon-borne experiment is providing a large feedback to the PLANCK-HFI data processing community.

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