Measurements of the Cosmic Microwave Background anisotropies with Archeops

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ABSTRACT

ARCHEOPS is a balloon–borne instrument dedicated to measuring cosmic microwave background (CMB) temperature anisotropies at high angular resolution (about 10 arcminutes) over a large fraction (30%) of the sky in the (sub)millimetre domain (from 143 to 545 GHz). Here, we describe the latest results from the instrument during the last flight that happened during the Arctic night from Kiruna (Sweden) to Russia in February 2002. Various sources of noise are discussed, including atmospheric noise, parasitic noise, photon noise, cosmic variance, . . . The white noise sensitivity for the 8 best bolometers is below $200\,\mu\mathrm{K}_{CMB}\,\mathrm{s}^{1/2}$ per bolometer. Best estimates of the angular power spectrum of the CMB anisotropies are presented, giving for the first time a continuous link between COBE scales and the first acoustic peak. The consequences in terms of cosmological parameters are outlined that reinforce the flatness of the Universe. Other results include the first measurement of polarisation and accurate maps of the galactic plane diffuse (sub)millimetre emission.

INTRODUCTION

The Cosmic Microwave Background gives many clues as to the origin of the Universe. It contains a wealth of diverse information, in contrast with the other 2 so–called pillars of Cosmology. The advent of BLIP (Background limited Performance) detectors (bolometers at 100 to 300 mK) and mostly sidelobe–free HEMT based interferometers have provided CMB maps with increasing accuracy and resolution in the last 10 years. The fluctuations that are now routinely detected in a few hours–days of integration time (*e.g.* de Bernardis et al. 2000, Netterfield et al. 2002, Hanany et al. 2000, Lee et al. 2001, Pryke et al. 2001, Sievers et al. 2002, Rubiño-Martin et al. 2002) provide vivid proof of the seeds that lead to large–scale structure formation. They are best analysed with spherical harmonic angular power spectrum C_ℓ as a function of multipole ℓ familiar to quantum physics. The generation of the power spectrum is now theoretically understood so that cosmological parameters can be deduced accurately. ARCHEOPS [1] is a CMB bolometer–based instrument with PLANCK – HFI technology that fills a niche where previous experiments were unable to provide strong constraints. Namely, 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 Earth's rotation makes the circle span a large area of the sky.

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[1] see `http://www.archeops.org`

DESCRIPTION OF THE INSTRUMENT

The instrument (Benoît et al. 2002) was designed by adapting concepts put forward for Planck – Hfi and using balloon–borne constraints. Namely, an open ^{3}He–^{4}He dilution cryostat cooling spiderweb–type bolometers at 100 mK, cold individual optics with horns at the different temperature stages (0.1, 1.6, 10 K). The Gregorian off–axis aluminum telescope, made of an effective 1.5 m aperture primary and a secondary ellipsoid mirror, provides an angular resolution of about 8 arcminutes at 143 GHz. The whole instrument is baffled so as to avoid stray radiation from the Earth and the balloon. The scan strategy imposes to observe by night. Maximising integration time means going above the Arctic circle. After a test flight in Trapani (Sicily) with four–hours integration time, the upgraded instrument was launched three times from the Esrange base near Kiruna (Sweden) by the CNES in the last 2 Winter seasons. The last and best flight on Feb. 7th, 2002 yields 12.5 hours of CMB–type data (at ceiling altitude and by night) from a 19–hours total. The balloon landed in Siberia and it was recovered (with its precious data recorded on–board) by a Franco–Russian team with –40 deg.C. weather.

RESULTS

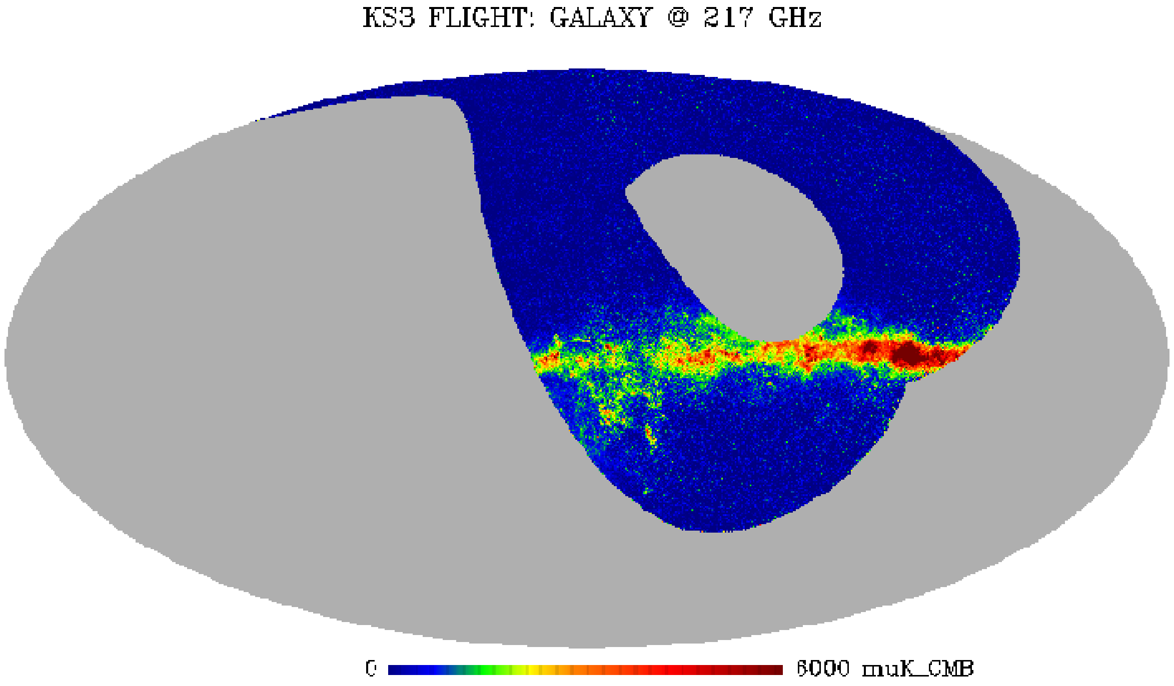

Fig. 1. 217 GHz map obtained during the last Archeops flight. This is an all–sky Mollweide projection with the Galactic anticentre in the middle. This preliminary map is a combination of several detector outputs. To avoid 1/f noise in Archeops data, scales larger than 30 degrees were extrapolated from Iras (Schlegel et al. 1998).

After being calibrated with the CMB dipole (Smoot et al. 1992), the FIRAS Galaxy or Jupiter emission,

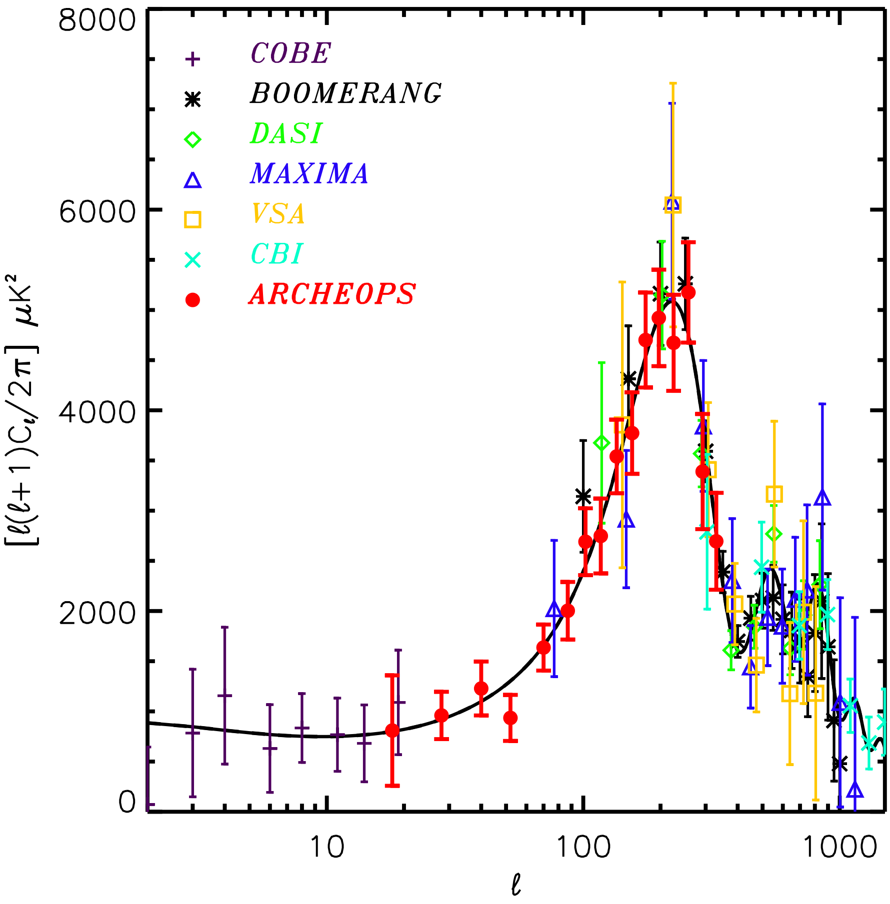

Fig. 2. ARCHEOPS power spectrum in 16 bins along with some other recent experiments. A best model fit (continuous line) is obtained. The fitting allowed the gain of each experiment to vary within their quoted absolute uncertainties. Recalibration factors, in temperature, which are applied in this figure, are 1.00, 0.96, 0.99, 1.00, 0.99, 1.00, and 1.01, for COBE (Tegmark et al. 1996), BOOMERANG (Netterfield et al. 2002), DASI (Halverson et al. 2002), MAXIMA (Lee et al. 2001), VSA (Scott et al. 2002), CBI (Pearson et al. 2002) and ARCHEOPS (Benoît et al. 2003a) resp., well within 1 σ of the quoted absolute uncertainties ($<$ 1, 10, 4, 4, 3.5, 5 and 7%).

eight detectors at 143 and 217 GHz are found to have a sensitivity better than 200 μK_{CMB} in one second of integration corresponding to the stationary part of the noise. For a square pixel of 20 arcmin the average 1 σ sensitivity with all detectors combined per channel is 100 and 150 μK_{CMB} (0.04 and 0.06 MJy/sr) at resp. 143 and 217 GHz. It is 0.4 and 0.8 MJy/sr at 353 and 545 GHz. A large part of the data reduction was devoted to removing additional noises which come from the various thermal stages (at frequencies $f \leq 0.03\,\mathrm{Hz}$), atmospheric effects (an elevation systematic effect is seen below 0.1 Hz and the four frequencies are correlated between 0.1 and 1 Hz).

Fig. 1 shows an example of the unprecedented millimetre maps that are currently being produced. Benoît et al. (2003a) and (2003b) show the results of a first reduction of the data, which are summarized below. Only the best bolometer of each CMB channel (143 and 217 GHz) is used here. The data are cleaned and calibrated, and the pointing is reconstructed from stellar sensor data. Maps are produced along many Monte–Carlo simulated maps to account for the exact power spectrum of the various noises. The sky power spectrum above a galactic latitude of 30 °(safe of foreground contamination) is deduced after subtracting the noise power spectrum with a MASTER–like approach (Hivon et al. 2002). The spectrum is shown in 16 bins ranging from $\ell = 15$ to $\ell = 350$ in Fig. 2 in comparison with a selection of other recent experiments and a best–fit theoretical model. 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 error bars. 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. 2. One of the main goals of the experiment, *i.e.* to provide an accurate link between the large angular scales from COBE and the first acoustic peak as measured by degree–scale experiments like BOOMERANG, CBI, DASI, MAXIMA, VSA, has been achieved. Cosmological constraints can be placed on adiabatic cold dark matter models with passive power-law initial fluctuations. Because ARCHEOPS power spectrum has small bins in ℓ and large ℓ coverage down to COBE scales, it provides a precise determination of the first acoustic peak in terms of position at the multipole $l_{\rm peak} = 220 \pm 6$, height and width. Using a large grid of 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, with 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. 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 is flat. An excellent absolute calibration consistency is found between ARCHEOPS and other CMB experiments (Fig. 2). All these measurements are fully compatible with inflation–motivated cosmological models, and in particular, with the best fit model obtained with $\Omega_{\rm tot} = 1.00$, $\Omega_\Lambda = 0.7$, $\Omega_{\rm b} h^2 = 0.02$, $h = 0.665$, $n = 0.945$, $Q = 19.2\,\mu$K, $\tau = 0$.

CONCLUSIONS

Constraints on various cosmological parameters (Benoît et al. 2003b) have been derived by using the ARCHEOPS data alone and in combination with other measurements. 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, because of the large sky coverage that greatly reduces the sample variance. The measured spectrum is in good agreement with that predicted by simple inflation models of scale–free adiabatic peturbations and a flat Universe assumption. Finally let us note that these results were obtained with only half a day worth of data.

Work is in progress to measure galactic dust emission polarization with the ARCHEOPS last flight 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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