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Archeops: A CMB anisotropy balloon experiment measuring a broad range of angular scales

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Abstract

The Cosmic Microwave Background Radiation is the oldest photon radiation that can be observed, having been emitted when the Universe was about 300,000 year old. It is a blackbody at 2.73 K, and is almost perfectly isotropic, the anisotropies being about one part to 100,000. However, these anisotropies, detected by the COBE satellite in 1992, constrain the cosmological parameters such as the curvature of the Universe.

Archeops is a balloon-borne experiment designed to map these anisotropies. The instrument is composed of a 1.5 m telescope and bolometers cooled at 85 mK to detect radiation between 150 and 550 GHz. To lower parasitic signals, the instrument is borne by a stratospheric balloon during the arctic night. This instrument is also a preparation for the Planck satellite mission, as its design is similar to HFI.

We discuss here the results of the first scientific flight from Esrange (near Kiruna, Sweden) to Russia on January 29th 2001, which led to a 22% (sub)millimetre sky coverage unprecedented at this resolution. Here, we put some emphasis on interstellar dust foreground emission observations.

1 THE SCIENTIFIC OBJECTIVE

The Cosmic Microwave Background Radiation (CMBR) shows some small temperature differences of the order of one part in 100000, that were measured for the first time by the COBE satellite [8]. These so-called anisotropies trace the fluctuations of the density of matter that are thought to be the origin, by gravitational collapse, of the large-scale structure of the Universe (galaxies, clusters,...) that we observe today. Its pattern can also yield an indirect measurement of the density, age and curvature of the Universe (see *e.g.* [5]). There have been many experiments that have already measured these anisotropies with various techniques, angular resolution, noise and scanning strategy. Mosqt recent ones (e.g. TOCO, Boomerang [3,7], and Maxima [4,6]) have improved on COBE results by the wavelength coverage, the sensitivity and the angular resolution.

The Archeops experiment aims at mapping the anisotropies of the cosmic microwave background from small to large scales at the same time. For this purpose, a beam of about 8 arcminutes is swept through the sky by spinning a 1.5 m telescope pointing at 41 degree elevation around its vertical axis. A large fraction of the sky is covered when the rotation of the Earth makes the swept circle drift across the celestial sphere. This is only possible if the observations are done during the Arctic night and on a balloon where neither the Sun nor the atmosphere disturb the measurements. Ozone cloud emission and residual winds can be avoided with a high altitude strastospheric balloon. From the Swedish balloon and rocket base in Esrange near Kiruna, in cooperation with Russian scientists, the CNES balloon team can launch balloons in the polar night, with a typical trajectory ending just before the Ural mountains in Russia. Integration times can be up to 24 hours in the December-January campaigns.

2 THE INSTRUMENT

A general description of the first Archeops instrument can be found in [1] where the first gondola used during the test flight (that happened in Trapani in July 1999) is described. The present experiment uses the same concept, details of which are given in [2].

2.1 The telescope, optics and detectors

The Archeops telescope is a two mirror, off-axis, tilted Gregorian telescope consisting of a parabolic primary (1.5 m main diameter) and an elliptical secondary. The telescope was designed to provide diffraction-limited performance when coupled to single mode horns producing beams with FWHM of 8 arcminutes or less at frequencies higher than 140 GHz.

For CMB anisotropy measurements, control of spectral leaks and beam sidelobe response is critical. Archeops channels have been specifically designed to maximize the sensitivity to the desired signal, while rejecting out-of-band or out-of-beam radiation. We have chosen to use the configuration developed for Planck HFI, using a triple horn configuration for each photometric pixel. In this scheme, radiation from the telescope is focussed into the entrance of a back-to-back horn pair (10 K stage). It creates a beam-waist where wavelength selective filters can be placed (1.6 K stage). Finally, the third horn (0.1 K stage) maintains beam control and focuses the radiation onto the bolometer placed at the exit aperture. A convenient aspect of this arrangement is that the various components can be placed on different temperature stages in order to create thermal breaks and to reduce the level of background power falling onto the bolometer and fridge.

Twenty two spider-web bolometers are placed on the 100 mK low temperature plate. There are 9 bolometers at 143 GHz, 7 at 217 GHz , 6 polarised bolometers at 353 GHz and two at

545 GHz, placed at different points in the focal plane. They observe the same sky pixel at different times, from 100 msec to a few minutes. The six 353 GHz channels are devoted to the measurement of galactic polarized emission. These are assembled in three pairs, with one single back-to-back horn and a polarizer splitter (the so-called OTM configuration) for each pair. The two bolometers of each pair measure the polarized intensity of the incoming signal in two orthogonal directions. Each pair makes a different polarising angle with respect to the scan axis to enable the full determination of the Stokes parameters. Archeops will provide the first measurement of polarization in this range of frequencies with a sensitivity adequate for measuring galactic dust polarised emission, a CMB foreground as yet unmeasured for the preparation of Planck-HFI.

2.2 The gondola, the pivot and the fast star sensor

The gondola is made with welded aluminium square tubes and a careful design prevents important deformations of the optical design in the presence of strength. The two mirrors and the cryostat are fixed to the frame. The pivot connects the flight chain of the balloon to the payload through a thrust bearing, providing the necessary degree of freedom for payload spin. It includes a torque motor that acts against the flight chain to spin the payload. The rotation of the payload is controlled via a vibrating structure rate gyroscopes that can detect angular speeds as low as 0.1 deg/s.

A custom star sensor has been developed for pointing reconstruction in order to be fast enough to work on a payload rotating at 2-3 rpm. We have developed a simple night sensor, based on a telescope with photodiodes along the boresight of the mm-wave telescope. Thus, like the millimeter telescope, the star sensor scans the sky along a circle at an elevation of 41 deg. A linear array of 46 sensitive photodiodes were placed in the focal plane of a 40 cm diameter, 1.8 m focal length parabolic optical mirror. The line of photodiodes is perpendicular to the scan and covers 1.4 degrees in elevation on the sky. We can observe during one rotation of the payload stars up to magnitude 7 *i.e.* between 50 and 100 stars per turn during night time. An optical filter allows this star sensor to yield at least a few detected stars even in the presence of low elevation Sun. Pointing reconstruction is done a posteriori by comparing star candidates and a dedicated star catalog. The precision of the pointing solution is better than 1 arcminute rms for the Trapani test flight and 2 arcmin. for the Kiruna 2001 flight.

2.3 The cryogenics, the electronics and the telemetry

The focal plane is cooled to 100 mK by means of an open cycle dilution refrigerator. This type of refrigerator has been designed for satellite applications (it will be used on Planck HFI) and Archeops is the first balloon-borne experiment using a dilution refrigerator. The bolometers are placed on the 100 mK stage supported by Kevlar cords. The bolometers are biased using AC square waves by a capacitive current source. Their output is measured with a differential preamplifier (the first stage uses JFET working at about 120 K) and digitized before demodulation, with boxes already designed in preparation for Planck HFI. Data ampled at 152 Hz are compressed and stored in a 2 Gbyte on-board flash-eprom memory. A telemetry channel using the Inmarsat satellite is used to control the experiment during the whole flight.

3 ARCHEOPS FLIGHTS AND FIRST RESULTS

A first flight of the instrument took place in Trapani on July 17th 1999. This test flight used only a few detectors (5) and we got only 4 hours of data during the night. Nevertheless, this flight allowed us to check all the fonctionnalities of the instrument [1]. Preliminary results concerning the Galactic Plane emission are shown by Boulanger et al. (this conference).

One flight was successful at the end of the Dec 2000-Jan 2001 campaign in Kiruna (Sweden), on the 29th January 2001; it lasted 7h30 at a 32 km altitude. Very high stratospheric winds limited both the flight duration and the altitude. The (sub)millimetre beams could be measured during the flight when the telescope crossed Jupiter twice and are as expected (optical beam of 8 arcmin. at 143, 217 and 545 GHz and 6 arcmin. at 353 GHz). The 143 and 217 GHz signals are dominated by the cosmic dipole and the 10 K back-to-back horn emission (sinusoidal shape). At 353 and 545 GHz, the emission from the Galaxy is dominant as well as some atmospheric signal. A significant fraction of the sky could be observed (22%) albeit with a small zone covered twice. The galactic plane is well observed at all frequencies from the anticenter to the Cygnus regions. Some clouds much below the Galactic plane can easily be identified with their CO and infrared counterparts (Perseus, Taurus, Pleiades). In-flight calibrations with the CMB dipole and the Galaxy as measured by COBE-FIRAS agree within 10% of each other. Sensitivity to cirrus HI clouds is estimated at 545 GHz as $2 \times 10^{20}\,\mathrm{H\,cm^{-2}}\,(\theta/1\,\mathrm{deg})^{-1}$ $(1\ \sigma)$ for square areas with an angular side of θ and standard dust emissivities.

With the 353 GHz channels, Archeops will provide the first measurement of galactic polarized emission in this type of frequencies. It is an important topic in the prospect of foreground removal for Planck-HFI, and is also of great interest to constrain the physics of galactic dust and molecular clouds. The sensitivity for the current flight is a degree of 5% polarisation $(1\ \sigma)$ for $A_V = 15$ in a one-square degree patch. Sensitivities are typically between 50 and $100\,\mu\mathrm{K_{RJ}}$ for one second of integration and for one photometric pixel at 143 and 217 GHz. There are about 8 pixels with a CMB sensitivity between 120 and $200\,\mu\mathrm{K_{CMB}}$ for one second of integration and for one photometric pixel.

Good detections of the CMB anisotropy spectrum can be expected from large angular scales to beyond the first so-called acoustic peak. This work is currently in progress. Archeops should also be able to constrain dust emissivity laws in the many galactic regions that were not resolved by FIRAS (a hotly debated issue in this conference). Another specific benefit from Archeops is to connect, in the spherical harmonic l-space sense, the calibration of the FIRAS low resolution all-sky (sub)millimetre survey up to the high resolution small area observations from ground telescopes.

The development of this current Archeops project owes a lot to the pionneering work and enthusiasm of Guy Serra in the domain of submillimetre astronomy. We also wish to thank the CNES and Esrange Swedish Facility for their continued support for this project and the flights (technical and scientific) that were realised very smoothly.

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