Rocket Measurement of the Submillimeter Cosmic Background Spectrum

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Abstract

The spectrum of the cosmic background radiation (CBR) has been measured using a liquid helium cooled spectrometer carried to high altitude by a rocket. The spectrum in the frequency band 2 to 30 cm⁻¹ is very well fitted by a Planck function of temperature $T=2.736\text{K}$. The estimated experimental accuracy of the mean temperature is $\pm 17\text{ mK}$.

Introduction

The cosmic background radiation (CBR), being one of the oldest quantities accessible to measurement, has been recognized as a very important observable in cosmology since its discovery in 1965.^{1,2} Substantial experimental effort has been devoted in the past 25 years to investigating the properties of this radiation. The information to be gained is very important to an understanding of the early universe but experimental difficulties have been such that definitive measurements have been obtained only recently.^{3,4}

This paper describes the principle of operation and the results of the rocket spectrometer COBRA which was used to make a successful measurement of the CBR spectrum in 1990. Further detail can be found in some other publications.^{5,6}

The apparatus

Based on experience gained in earlier attempts to measure the spectrum of the CBR from high altitude,⁷⁻⁹ a new rocket instrument was developed and tested during the 1980's.

The instrument is shown schematically in Fig.1. Radiation from the sky is directed to one

Fig. 1. A diagram showing the principle of the apparatus. **H1** and **H2** are similar horn telescopes of 6° field of view. **H1** receives radiation from the sky whereas **H2** is illuminated by a black body simulator **B**. Radiation issuing from the horns enters a two-beam interferometer **Int**, with a beamsplitter at **b**, from whence it emerges to be focussed on two bolometer detectors **D1** and **D2**. As the path difference in the interferometer is changed the signal generated by each detector (interferogram) is proportional to the difference intensity of the sky and the black body. The numbers indicate temperatures of various sections of the spectrometer.

Fig. 2. A schematic diagram of the polarization interferometer. Radiation from a source at S is split by the wire grid polarizer P into vertically and horizontally polarized beams (v and h). Flat mirrors M direct these beams through the interferometer itself, which consists of the oblique wire grid beamsplitter B , and the two dihedral mirror pairs V . Optical delay in the interferometer is varied by simultaneous displacements d of both dihedral pairs as shown. The exit beams, E and E' , are formed by directing the interferometer outputs through a vertical analysing polarizer P . The path from the second source at S' entirely overlaps the radiation path shown here, after the input analysing polarizer. The modulated signals at E and E' contain information about the brightness difference between S and S' , and are independent of source polarization.

side of a symmetric two-beam interferometer by means of a hyperbolic horn telescope. The second side of the interferometer is illuminated by an identical telescope terminated, however, with a black body simulator whose temperature can be controlled. By moving the pair of dihedral mirrors, a variable path difference is introduced in the interferometer, and the signal given by each detector is an interferogram whose Fourier transform is proportional to the spectrum of the intensity *difference* between the sky and the calibrator. If the sky spectrum

is Planckian of the same temperature as the calibrator, there is a null signal. The absolute sensitivity of the instrument is obtained by periodically changing the temperature of the calibrator by steps of 0.2K near 2.7K, the approximate expected temperature of the CBR. This procedure allows one to calculate the sky emission spectrum without achieving a null interferogram and without reference to pre or post flight calibration data.

The interferometer is of the polarizing type, the optical arrangement being shown in Fig.2. It is a modification of an early design used in mid-infrared astronomy measurements.¹⁰ The principal merit of the design in the present context, apart from uniform frequency response and good efficiency, is that the instrument is highly symmetric. This is important because one would like to obtain truly null interferograms when the sky and the calibrator have the same temperature. This ideal was closely approached. The balance was tested in the laboratory by introducing a variable temperature liquid helium cooled black body over the sky telescope, and setting its temperature equal to the internal calibrator temperature. Small offset interferograms corresponding to temperature shifts of about 50mK were measured which are subtracted from the sky interferograms before calculating final spectra.

Results

Fig. 3 shows a set of interferograms recorded during the flight, as well as the derived sky spectrum. The spectrum is very

well fitted by a Planck curve of temperature 2.736K. The error on the temperature is conservatively estimated to be $\pm 0.017\text{K}$. Our value for the temperature agrees well with the most recent value evaluated from the COBE satellite data, $2.726 \pm 0.010\text{K}$.¹¹

Fig. 3. a) Interferograms obtained late in the flight, shown as detector voltage vs. optical path difference for three different temperatures of the internal black body. The sign inversion between a) and b) indicates that the sky spectrum lies between Planck functions of 2.63K and 2.83K. Approximately one minute of data are shown here.

b) The intensity of the sky as a function of wavenumber derived from the shown interferograms. The smooth curve is a Planck function which fits the data well. The residuals are shown oscillating along the abscissa axis.

The instrument was recovered from the launch and it is currently being refurbished and modified to make CBR anisotropy measurements from balloon altitudes. In this case the internal calibrator is removed. By

means of a suitable optical system and telescope the two input channels of the interferometer are focussed on two regions of the sky separated by a few degrees. This will permit the *spectrum* of the observed anisotropy to be measured which will be of help in discriminating against foreground sources.¹²

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