CBR anisotropy and cold dust observations from Antarctica

CBR ANISOTROPY AND COLD DUST OBSERVATIONS FROM ANTARCTICA

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Abstract

A long-term project involving a series of ground - based experiments in Antarctica searching for Cosmic Background Radiation (C.B.R.) anisotropies at intermediate angular scale and millimetric wavelengths, has been started and some important results will be briefly discussed in this paper:

(a) Evidence for a strong contamination of the data from patchy galactic emission even at these wavelengths seems to occur. The millimetric emission is in fact highly correlated with the IRAS 100 μm data even in regions far from the galactic plane.

(b) The diffuse millimetric emission from the Magellanic Clouds and from a few galactic molecular clouds has been detected.

(c) After correction for atmospheric and galactic emission we find still evidence for statistical fluctuations of the sky at a level of $2 \cdot 10^{-4}$ at 2.5° angular scale and of $2.9 \cdot 10^{-4}$ at 5°. This result is in contrast with the strong upper limits found to the CBR anisotropies at similar angular scales by other groups (Pariiski et al., 1977; Melchiorri et al., 1981; Davies et al., 1987). We argue, therefore,

that at the moment the poor knowledge of the millimetric patchy galactic emission and its distribution does not allow a quantitative determination of the "local" disturbance to this kind of measurements.

Introduction

The millimetric range seems to offer several advantages in order to detect C.B.R. anisotropies :

(1) it has been argued that the galactic spectrum could have a minimum or *window* in this energy range (Lubin and Villela, 1985);

(2) searches for CBR anisotropies in the Wien region are more sensitive (at small changes of the temperature correspond large intensity variations);

(3) millimetric observations can be carried out from the ground in spectral bands matching the atmospheric transmission *windows*;

(4) discrete sources contribution could be negligible at these wavelengths (Franceschini et al., 1989).

However, the main limitations to this kind of measurements are:

(A) very small extraterrestrial signals, such those expected from the CBR anisotropies, are strongly hampered by the atmospheric emissivity variations due to air masses motions, which give rise to an unavoidable noise, even in very cold and dry sites, where, however, this disturbance is highly reduced.

(B) the possible presence of a diffuse and very cold component of the interstellar material can represent a strong constraint to the cosmological observations of the Cosmic Microwave Background.

Both problems have been faced as following:

(A) A way to disentangle the atmospheric signal from the astronomical one is to use two channels: one sensitive mainly to the atmospheric emission and the other matching an atmospheric transmission *window*. In principle, the correlation between the two signals is a signature of the atmospheric contribution while the residuals in the second channel are due to extraterrestrial sources. In practice, the unavoidable difference in the sampled optical paths of the two channels does not allow a fulldisentanglement of the two signals and residual atmospheric noise is always present in the second channel data.

However, the presence of the second channel has been fully exploited and different procedures to reduce the atmospheric contamination of the data have been used.

(B) Galactic thermal emission has been directly observed by the instrument during scannings of the galactic plane. A striking correlation between our measurements and the IRAS 100μm emission suggests that very likely we have detected a cold component either coexisting with the warm dust detected by the Infrared Astronomical Satellite or simply belonging to the same large-scale distribution of this interstellar material. A possible solution to partially get rid of the galactic thermal emission in the FIR can be found by using this correlation.

Furthermore, another important problem has been tackled with these observations: flux density measurements at 1 and 2 *mm* of the Magellanic Clouds have been used to estimate the total amount of dust present in the interstellar medium (see e.g., Thronson et al, 1987; Eales, Wynn-Williams and Duncan, 1989). This parameter is fundamental in estimating galactic evolution and star-formation processes. IRAS data provide evidence for strong thermal emission from late-type galaxies, originated from dust in HI clouds heated by the general interstellar radiation field, cold dust in molecular clouds and dust heated by hot stars embedded in compact HII regions. But the true dust column density cannot be properly estimated by means of the FIR measurements alone since the IRAS satellite is not sensitive to material colder than 20 K and the bulk of dust mass is expected to emit at submillimeter and millimeter wavelengths. Therefore, the presence of a diffuse and very cold component of the interstellar material can be checked only by means of millimeter data. Millimeter flux density is a good tracer of the total dust, gas and molecular mass and could represent an alternative way to estimate these parameters.

The data

The data presented in this paper have been collected during the antarctic summer 1987-88 with a double-channel instrument, suitable for measuring intensity gradients at an angular scale of 2.5° either at 350 μm and 2 *mm* or at 1 and 2 *mm*. The spectral bands are selected through interferential filters centred at 350 μm and 2 *mm* with a bandwidth of 100 and 500 μm respectively. The 1 *mm* channel was defined by an edge filter with a cut-on at 1 *mm*, while the spectral cut-off is fixed by the diffraction limit of the detector aperture ($\sim$ 5000 μm).

The instrumentation together with the calibration and the observational procedures are reported elsewhere (Andreani et al., 1989). A sketch of the instrument is shown in fig.1.

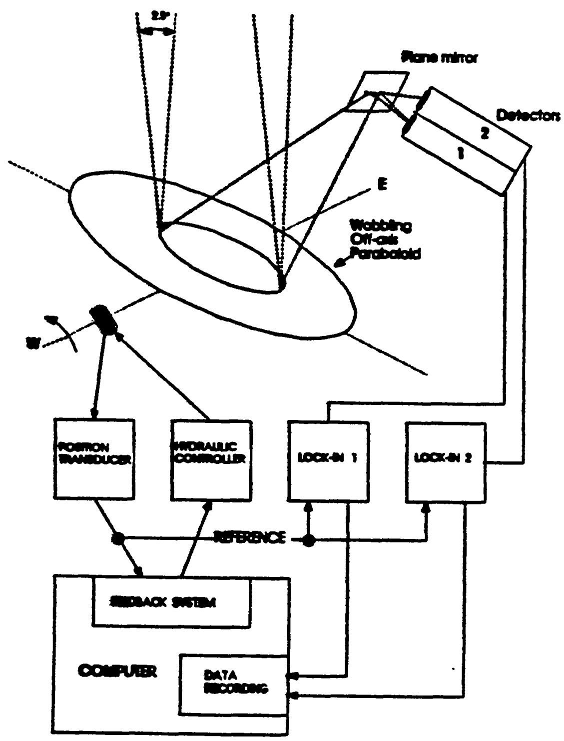

fig.1 A f/2 off-axis paraboloid, 1 meter in diameter, defining a geometrical field of view of about 1°, collects sky radiation modulated at a frequency of 8 cps with an amplitude of 2.5° in the sky. At its focus a ^{3}He Ge-bolometer and a ^{4}He Si-bolometer

Here we emphasize that the photometers are sensitive to small temperature variations down to about 1.5 mK$/\sqrt{Hz}$ and their intrinsic noise turns out negligible when compared with the sky signal. Their photometric sensitivity is then primarly limited by the excess noise from the sky.

Observations have been carried out with the *drift scans* techniques, i.e. by keeping the telescope fixed. This configuration eliminates the effects of different diffraction patterns surrounding the observing beam and provides a scanning of the sky following the Earth's rotation.

Each independent field of view was observed for about 16 minutes ($\sim 1°$) and the real-time data were sampled every 10 s and integrated for 30 s.

Furthermore, atmospheric conditions are determined by evaluating the transmission and the precipitable water vapour during the observations. A simple experimental procedure, described in Dall'Oglio et al. (1988), allows us to infer the atmospheric transmission at 350 μm and 2 mm and a hydrometer and radiosoundings (kindly supplied by Giudici and Serao) have been used to continuously monitor the precipitable water vapour.

The results

The detailed description of the data analysis has been published elsewhere (Andreani et al., 1989; Andreani et al., 1990a). Here we briefly discuss the results.

Observation of the Magellanic Clouds

The spectra of the Magellanic Clouds (see fig.2) show that a conspicous cold component seems to be present in the interstellar material. As clear from the figure the IRAS 60 and 100 μm data and the millimetric (1 and 2 mm) data cannot be accounted for from the same thermal curve.

Estimation of the parameters of the thermal curves fitting the spectra leads :

(a) by considering only the 100 μm 1 and 2 mm points we obtain as parameters of the modified Planck spectrum: $\lambda^{-\alpha} B_\lambda(T_d)$ (where α is the spectral index of the dust) : $\alpha \sim 1.0 \div 1.2$ with $T_d \sim 15 \div 18$ K.

(b) On the other hand, if we consider separately the IRAS measurements at 60 and 100 μm and the millimetric points we can fit the data with two thermal components. In this case we infer rough values for the temperature and the spectral indices of the two components. The temperatures are evaluated once the spectral index is fixed to a value between 1 and 2, as most of the models for dust grains predict (e.g. Draine and Lee, 1984). In this case we obtain : $\alpha \sim 1.0 \div 1.2$ with $T_d \sim 6 \div 15$ K.

The thermal emission from dust at these wavelengths is optically thin, therefore one samples the entire line of sight and determines the total dust column density; at *mm* and *submm* wavelengths the flux density, F_λ, depends linearly on the dust mass and its temperature (Draine 1989; Mathis and Whiffen, 1989):

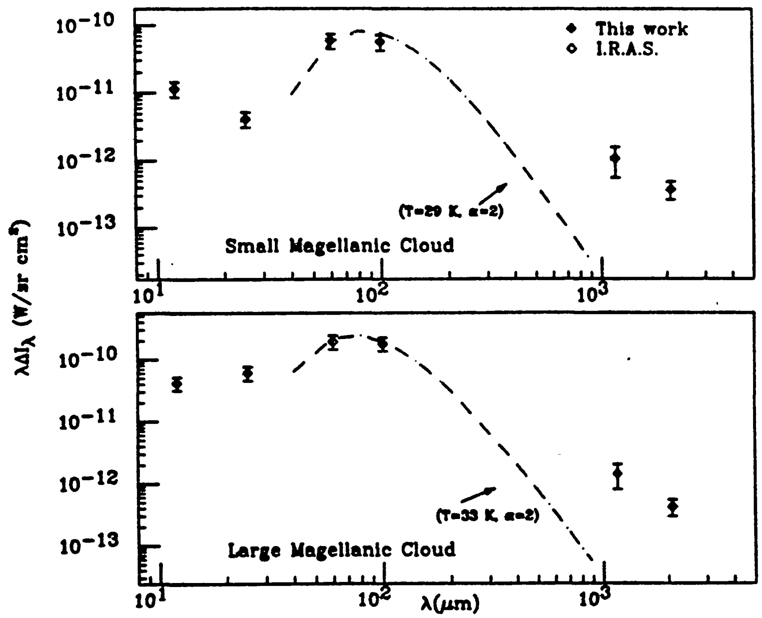

fig.2 IR/mm spectrum of the Small Magellanic Cloud (upper panel) and of the Large Magellanic Cloud (lower panel). The 12, 25, 60 and 100 μm have been obtained by IRAS sky maps. The black points are from this work. The greybody curves fitting the IRAS 60 and 100 μm points are shown. (from Andreani et al., 1990a)

$$F_\lambda \simeq \frac{2kc \sum_i \chi_i(\lambda) < T_i > M_d}{\lambda^4} \tag{1}$$

where $\chi_i(\lambda)$ are the Planck-average grain opacities due to component i; $< T_i >$ is the average temperature (at these wavelengths it is possible to approximate the temperature distribution of the grains with a single temperature) and M_d is the dust column density (in $\frac{g}{cm^2}$).

We estimated the dust masses of the clouds by using two different models of interstellar dust (Draine and Lee, 1984; Mathis and Whiffen, 1989). These models provide values for the grain opacities at 1 mm using different composition and dimensions of dust grains. Draine and Lee assume that dust grains consist of a mixture of silicate and graphite with size distribution : $f(a)da \propto a^{-3.5}da$ for a varying between 50 Å and 0.1 μm. Mathis and Whiffen consider that the shapes of dust grains are irregular since they can be a result of a composite collection of very small particles loosely attached to one another. Therefore, grains can attain greater dimensions (up to $\sim 0.9\ \mu m$).

By using eq. (1) we find:

Table 1. Estimated dust mass (in $M_\odot$)

Galaxy	Draine - Lee	Mathis - Whiffen	IRAS
LMC	$(5.1 \pm 2.2)10^6$	$(2.0 \pm 0.9)10^5$	$5.5\ 10^5$
SMC	$(1.4 \pm 0.7)10^6$	$(5.6 \pm 2.8)10^4$	$2.4\ 10^4$

For comparison the masses evaluated from IRAS measurements are also shown (Schwering, 1987).

Determination of the sky fluctuations

In order to extract an extraterrestrial signal from the atmospheric noise, we used two different procedures:
(a) by using those measurements carried out simultaneously with two channels, one mainly sensitive to the atmospheric emission (350 μm) and the other matching an atmospheric transmission *window* (2 mm);
(b) by comparing the signals, taken simultaneously, from the first channel centred at 1 mm with those from the second channel centred at 2 mm. This procedure has been suggested by Boynton (Boynton, Lombardini and Melchiorri, 1975; Melchiorri and Melchiorri, 1982). One can get rid of the atmospheric contributions by fitting sums and differences of the two channels signals:

$$S = \Delta I_{\lambda_1} + \Delta I_{\lambda_2} = 2\Delta I_{astr} + \alpha_{\lambda_1}(1+k)(\Delta I_{atm} - \Delta I_{astr})$$

$$D = \Delta I_{\lambda_1} - \Delta I_{\lambda_2} = \alpha_{\lambda_1}(1-k)(\Delta I_{atm} - \Delta I_{astr})$$

and then:

$$S = 2\Delta I_{astr} + \frac{(1+k)}{(1-k)} \cdot D \qquad (3)$$

where we have put $\alpha_{\lambda_2} = k\alpha_{\lambda_1}$. A linear fit between S and D gives a value for ΔI_{astr}.

The two methods are fully described in Andreani et al. (1990b).

Correction for atmospheric noise leads to an estimate of the residual sky (galactic + extragalactic) fluctuations of $\frac{\Delta T}{T} < 2\ 10^{-4}$. However, since both procedures are not sensitive to galactic backgrounds this upper limit may contain contamination from patchy galactic emission.

Moreover, a tentative quatification of the galactic contamination to the sky fluctuations has been estimated by comparing the millimetric data with the those of IRAS.
As already shown elsewhere (Andreani et al., 1989 and 1990a) the millimetric sources detected by the instrument can be identified as IRAS 100 μm objects on the basis of the strong spatial correlation between the IRAS and the millimetric data.
Fig.3 shows an example of this comparison between one of the 2 mm scans at $\delta \sim -75°$ and $\alpha \sim 7^h \div 11^h$ and the IRAS 100 μm gradients of the same sky region. From the striking agreement between the 2 mm signals and the 100 μm ones, we can reasonably assume that the detected cold dust is spatially distributed as the warm one.

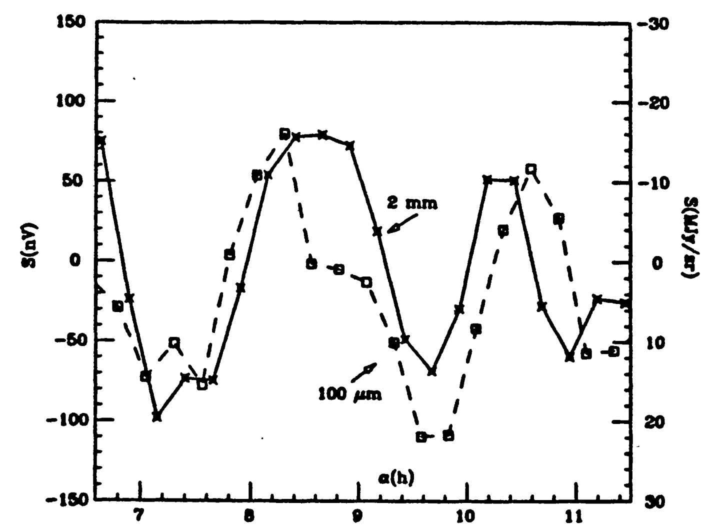

fig.3 Scan of the sky region at $\delta \sim -75°$ and $\alpha \sim 7^h \div 11^h$. The 2 mm signal (solid line) is superposed on the IRAS 100 μm gradient of the same sky region (from Andreani et al., 1990b)

In this case a correction for galactic emission can be made by assuming that the galactic FIR/mm spectrum deduced from these observations does not depend on the angular coordinates of the sky but its intensity does. We have then corrected

those data correlated with the IRAS dust by extrapolating the 100 μm value to 2 mm using the cirrus IR/mm spectrum reported in Andreani et al. (1989). This procedure gives rise to a set of data whose variance is a factor of two smaller than that from the uncorrected data and the determination of the sky fluctuations provides an upper limit for the $\frac{\Delta T}{T}$ of 3.3 $\cdot 10^{-4}$.
This correction is limited not by the spatial correlation between the IRAS emission and the millimetric signals but by the extrapolation assumed of the $\frac{S_{2mm}}{S_{100\mu}}$ ratio. A detailed model of the cold dust emission and its relation to the warm dust is needed in order to check the reliability of this result.

Conclusions

Results on detection of thermal emission from a very cold component of the interstellar material both in the Galaxy and in the Magellanic Clouds have been reported. The estimated total dust column densities in these galaxies are an order of magnitude greater than those found by using IRAS data (Schwering, 1987), in agreement with the hypothesis that most of the dust mass (90 %) is expected to have a temperature < 20 K and to radiate 10 % of the energy (Pajot et al., 1986b).

Searches for intermediate angular scale anisotropies of the 3 K background in the peak region of the spectrum are limited by the atmospheric noise and the galactic thermal emission. While the former can be reduced by using a second channel and/or by averaging different scans of the same sky regions the contamination of the latter can be hardly defined because of the poor knowledge of the galactic millimetric emission. In any case, the 100 μm IRAS data have been successfully used to get rid of most of such background. In this analysis, it is difficult, however, to disentangle an eventual extragalactic component from the observed fluctuations.
Further improvements of the experimental conditions (observations at 2000 meters on the Tourmaline Plateau in Antarctica and with more wavelength channels) are in progress and will help to distinguish the nature of these results.

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