IL NUOVO CIMENTO VOL. 20 C, N. 5 Settembre-Ottobre 1997

Observations of the Cosmic Background Radiation: Search for spectral distortions and residual polarization(*)

G. BONELLI, F. CAVALIERE, G. GIARDINO, M. GERVASI, F. MONFORTI
S. MUSSIO, A. PASSERINI, G. SIRONI, F. VILLA and M. ZANNONI

Dipartimento di Fisica dell' Università - Milano, Italy
Istituto di Fisica Cosmica del CNR - Milano, Italy

(ricevuto il 5 Dicembre 1996; approvato il 25 Febbraio 1997)

Summary. — We discuss observations of the CBR presently underway in Milano. We are trying to detect polarization with a sensitivity level of $1/10^6$ and search distortions in the Rayleigh Jeans portion of the frequency spectrum.

PACS 98.70.Vc – Background radiation.
PACS 98.80 – Cosmology.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

Optimistic forecasts made by excited theoreticians immediately after the discovery of the Relic or Cosmic Background Radiation (CBR) created the illusion that easily detectable deviations from the ideal properties (equilibrium spectrum, isotropy, no polarization) of the CBR had to be expected (see for instance [1, 2] and references therein). This triggered a series of experiments with the aim of detecting spectral distortions, anisotropies and residual polarization and getting information on phenomena which marked the evolution of the Universe from the uniform early conditions to the present structured distribution of matter. The enthusiasm of the observers, however, rapidly faded when it became clear that the effects, if present, were near or below the detectability threshold set by the instrumentation and by the presence of other types of diffuse radiation: the galactic background and the blend of unresolved extragalactic sources.

The only exception was the dipole anisotropy, definitely detected more than 10 years ago [3]. The dipole effect, however, can be entirely ascribed to kinematics effects. Were not for the result obtained by COBE / DMR [4] which finally detected a level of anisotropy

(*) Paper presented at the VII Cosmic Physics National Conference, Rimini, October 26-28, 1994.

TABLE I. – *Summary of polarization measurements.*

Wavelength (cm)	Angular scale $\Delta\theta$	Polarization degree/type	Sky region	Reference
7.35	15°	$\leq 10^{-1}$ linear	–	[5]
6.0	18″–160″	$\leq (1.4 - 0.4) \cdot 10^{-4}$ linear $\leq (2.2 - 0.6) \cdot 10^{-4}$ circular	$\delta = +80$	[6]
3.2	15°	$\leq 6 \cdot 10^{-4}$ linear	$\delta = +40$	[7]
0.91	15°	$\leq 3 \cdot 10^{-4}$ linear	$\simeq +39$	[8]
0.91	15°	$\leq 6 \cdot 10^{-5}$ linear	$-37 \leq \delta \leq +63$	[8]
0.91	15°	$\leq 4 \cdot 10^{-3}$ circular	$\delta = +37$	[9]
0.05–0.3	1.5°–40°	$\leq (10 - 1) \cdot 10^{-4}$ linear	Galactic Center	[10]

of a few times 10^{-5} K on angular scale $\geq 7°$, the search would have been probably abandoned. After COBE we know, however, that the expected effects are real. They are nothing more than speckles on a uniform sea of unpolarized radiation in equilibrium, but exist, and enthusiasm sprang again among the observers.

The Milano radio group is carrying on measurements on the properties of the CBR since the early eighties. At present we are trying to detect residual polarization and looking for spectral distortions in the Rayleigh Jeans part of the CBR spectrum.

2. – Search for residual polarization

The polarization which accompanies the Thomson scattering of an electromagnetic wave impinging on a single electron disappears when averaged over uniform and isotropic distributions of matter and radiation. If, however, the distribution of the matter and the distribution of the radiation are disturbed, for instance, by a flux of gravitational waves, or are intrinsically anisotropic, residual polarization can be left over [11]. For that reason we can expect that a small degree of polarization is associated to the CBR.

Calculation shows that in our Universe i) the expected degree of polarization of the CBR is proportional to its degree of anisotropy; ii) the coefficient of proportionality, ≤ 0.1, depends on the angular scale of the observed region; iii) reionization of the Universe after recombination may have changed the ratio between polarization and anisotropy in favour of the polarization and reduced the correlation between polarization and anisotropy. We can, therefore, look for two components of the CBR polarization: one associated to the features of the anisotropy distribution and one detectable no matter where we look on the celestial sphere [12]; iv) the majority of the existing models suggests linear polarization; circular polarization can be expected only in very special conditions (*e.g.*, anisotropic expansion, rotation of the Universe, etc.).

So far all the attempts at detecting residual polarization of the CBR failed. In the

TABLE II. – *Characteristics of the Milano Polarimeter.*

Frequency	(33 ± 0.75) GHz
Antenna: corrugated horn	
Half-power beam width	7°–15°
First side lobes	< -30 dB
Backlobes	< -40 dB
Polarization	circular/linear
Output	orthomode transition
Isolation beetween polarised components	> 40 dB
Return loss	≤ -25 dB
Receiver: 2 channel correlator	
Intermediate frequency	3 GHz
Bandwidth	3 GHz
Effective noise temperature	100 K

literature we find only upper limits (see table I) which after the measurements of COBE appear very poor. Assuming in fact a 0.1 upper limit for the ratio between polarization and anisotropy and excluding reionization, the expected temperature of the polarized signal cannot be greater than few times 10^{-6} K.

With the aim of detecting it and getting information about reionization, we recently completed a polarimeter for ground-based observations of the CBR (see table II). It allows to measure both linear and circular polarization at 33 GHz on angular scales of 7° and 15°. The system noise and bandwith are sufficient to reach a sensitivity of 10^{-6} K with an integration time of 20 days. The instrument has been shipped to Antarctica where it will be used for observation from Deception Plateau, a high and dry site near the Italian base of Terra Nova Bay. Observation will begin in November 1994 (see the *Note added in proofs*) and will last three months. During that first observing campaign we will take advantage of the fact that the properties of the fraction of the polarization which is not correlated with the anisotropy are independent of the place where we look and the antenna will be aimed to a fix point, the South Celestial Pole. In future campaignes we will look for polarization associated to the spots suggested by the distribution of the anisotropy COBE is now providing [4].

3. – Search for spectral distortions

The FIRAS experiment [13] on COBE set very stringent upper limits ($\leq$ 0.01%) on possible deviations from a Planckian frequency distribution of the CBR between 30 and 600 GHz. At lower frequencies, however, where large deviations can be expected, the data in the literature are definitely worse (see table III and references therein). In spite of the efforts made in the past by the White Mt. collaboration and by the Milano and Berkeley groups, we are unable to exclude that very large distortions exist below 2.5 GHz. Particularly intriguing is the situation between 1 and 2 GHz: here the error bars are very large and nobody can say if a distortion exists, but the regular trend of the distribution *vs.* frequency of the measured values of temperature suggests the existence of a dip of a few hundred mK around 1.4 GHz. Were this distortion confirmed, an estimate of Ω_b, the barionic density of the Universe, would be possible [14].

We are, therefore, trying to gain a factor 10 on the accuracies of the measured values of the CBR temperature at $\nu \leq 2$ GHz through: i) measurements of the temperature of the diffuse radiation at 0.6, 0.82 and 2.5 GHz with an angular resolution of 15° around $\delta = +41°$ (experiment TRIS at Campo Imperatore (Italy)) [15]; ii) preparing a set of radiometers and a parabola which will map the southern sky ($-90° \leq \delta \leq -45°$) at six frequencies (0.4, 0.6, 0.8, 1.4, 2.5, 4.8 GHz), with an angular resolution of 5°. They will measure the absolute temperature of the sky and the Stokes parameters Q and U (experiment MEGA at Terra Nova Bay, Antarctica); iii) studying the possibility of mapping the whole sky from space (project LOBO).

All these projects use multifrequency observations to disentangle the different components (synchrotron and thermal background from our Galaxy, blend of unresolved extragalactic sources, CBR) of the diffuse radiation in a frequency region where none of them is negligible. Old measurements of the diffuse background one can find in the literature are, in fact, insufficiently accurate (for a discussion see, for instance, [16]). For instance the widely used whole sky map of the diffuse radiation prepared by Haslam *et al.* [17] at 408 MHz, has an error bar associated to the zero level of the scale of temperature of ± 3 K, comparable to the temperature of the CBR. Moreover, the existing surveys of the total background polarization (see, for instance, [18]) leave large regions of sky unexplored.

Our program for improving the quality of the data requires long observations and major technological efforts. We built new reference sources at the temperature of the liquid helium [19] and developed three channel correlation receivers which allow to measure the total intensity I and the Stokes parameters U and Q.

4. – Conclusion

Our observations program is underway. By spring 1995 we expect preliminary results on polarization of the CBR at 33 GHz and a series of accurate data on the temperature of the total background at 0.6, 0.82 and 2.5 GHz. Mapping the southern sky will begin at the

TABLE III. – *Summary of measurements of the CBR temperature at low frequencies* ($\nu \leq 3$ GHz).

Wavelength (cm)	Frequency (GHz)	Temperature (K)	Reference
73.5–49.5	0.41–0.61	3.7±1.2	[20]
50	0.6	3.0±1.2	[21]
47.2	0.635	3.0±0.5	[22]
36.6	0.82	2.7±1.6	[23]
30–21–15	1–1.43–2	2.5±0.3	[24]
21.26	1.41	2.22±0.55	[25]
21.26	1.41	2.11±0.38	[26]
21.2	1.415	3.2±1.0	[27]
21.05	1.425	2.2–2.9	[28]
20.7	1.45	2.8±0.6	[29]
20.4	1.47	2.27±0.19	[30]
13.05	2.297	2.66±0.77	[31]
12	12.5	2.62±0.25	[32]
12	2.5	2.79±0.15	[33]
12	2.5	2.50±0.34	[23]

end of 1995. Mapping the whole sky from space is a project whose future depends on the decisions the Italian Space Agency.

Note added in proofs. – This paper was written as a status report presented at the VII Cosmic Physics National Conference, Rimini, October 26-28, 1994. No content revision has been made. The delayed submission to *Il Nuovo Cimento* does not depend on the authors.

* * *

This work has been supported by the Italian Program for Antarctic Research (PNRA), the CNR and MURST (40% program).

REFERENCES

[1] DANESE L. and DE ZOTTI G. F., *Rivista Nuovo Cimento*, **7** (1977) 277.
[2] PEEBLES P. J., *Principles of Physical Cosmology* (Princeton University Press) 1993.
[3] SMOOT G. F., GORENSTEIN M. V. and MULLER R., *Phys. Rev. Lett.*, **39** (1977) 898.
[4] SMOOT G. F. *et al.*, *Astrophys. J. Lett.*, **291** (1995) 123.
[5] PENZIAS A. A. and WILSON R. W., *Astrophys. J.*, **142** (1965) 419.
[6] PARTRIDGE R. B. *et al.*, *Nature*, **331** (1988) 146.
[7] NANOS G. P., *Astrophys. J.*, **232** (1979) 341.
[8] LUBIN P. M. *et al.*, *Astrophys. J.*, **245** (1981) 1.
[9] LUBIN P. M. *et al.*, *Astrophys. J.*, **273** (1983) L511.
[10] CADERNI N. *et al.*, *Phys. Rev. D.*, **17** (1978) 8.
[11] REES M. J., *Astrophys. J.*, **153** (1968) L1.
[12] CRITTENDEN R., preprint PUPT-94-1487 (1994).
[13] MATHER J. C. *et al.*, *Astrophys. J.*, **420** (1994) 439.
[14] BURIGANA C., DANESE L. and DE ZOTTI G., *Astron. Astrophys.*, **246** (1991) 49.
[15] BONELLI G. *et al.*, *Astro. Lett. & Commun.*, **32** (1995) 15.
[16] SIRONI G., BONELLI G. and GERVASI M., *PASP Conf. Series*, **51** (1993) 541.
[17] HASLAM C. T. G. *et al.*, *Astron. Astrophys. Suppl.*, **47** (1982) 1.
[18] BROUW W. N. and SPOELSTRA T. A. T., *Astron. Astrophys. Suppl.*, **26** (1976) 129.
[19] GERVASI M., BONELLI G., SIRONI G., CASANI F., CAVALIERE F. and PASSERINI A., *Rev. Sci. Instrum.*, **66** (1995) 4789.
[20] HOWELL T. F. *et al.*, *Nature*, **216** (1967) 753.
[21] SIRONI G. *et al.*, *Astrophys. J.*, **357** (1990) 301.
[22] STANKEVICH K. S. *et al.*, *Australian J. Phys.*, **23** (1970) 529.
[23] SIRONI G. *et al.*, *Astrophys. J.*, **378** (1991) 550.
[24] PELYUSHENKO S. A. *et al.*, *Sov. Astron.*, **13** (1969) 223.
[25] SMOOT G. F. *et al.*, *Astrophys. J.*, **331** (1988) 653.
[26] LEVIN S. *et al.*, *Astrophys. J.*, **334** (1988) 14.
[27] PENZIAS A. A. *et al.*, *Astron. J.*, **72** (1967) 315.
[28] STAGGS S., *PASP Conf. Series*, **51** (1993) 512.
[29] HOWELL T. F. *et al.*, *Nature*, **210** (1966) 1318.
[30] BENSADOUN M. *et al.*, *Astrophys. J.*, **409** (1993) 1.
[31] OTOSHI T. Y. *et al.*, *IEEE Trans. Instr. Meas.*, **24** (1975) 174.
[32] SIRONI G. *et al.*, *Phys. Rev. D*, **29** (1984) 2686.
[33] SIRONI G. *et al.*, *Astrophys. J.*, **311** (1986) 418.