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N90-19959

THE COBE COSMIC 3 K ANISOTROPY EXPERIMENT: A GRAVITY WAVE AND COSMIC STRING PROBE

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ABSTRACT

Among the experiments to be carried into orbit next year, by the COBE satellite, are differential microwave radiometers. They will make sensitive all-sky maps of the temperature of the cosmic microwave background radiation at three frequencies, giving dipole, quadrupole, and higher order multipole measurements of the background radiation. The experiment will either detect, or place significant constraints on, the existence of cosmic strings and long wavelength gravity waves.

I. INTRODUCTION

The microwave radiometer experiment on the Cosmic Background Explorer (COBE) satellite will be a sensitive probe of long wavelength gravity waves and cosmic strings. This anisotropy experiment will make full sky maps of the temperature of the cosmic microwave background radiation (CMBR) at three frequencies to a sensitivity of $\Delta T/T \sim 3 \cdot 10^{-5}$ for each of 1,000 independent pixels on the sky, where T = 2.7 K is the temperature of the CMBR. The sensitivity to a quadrupole term will be $\Delta T/T \sim 5 \cdot 10^{-6}$, approximately an order of magnitude more sensitive than previous experiments which give limits of $3 \cdot 10^{-5}$ (Klypin *et al.* 1988) and $7 \cdot 10^{-5}$ (Lubin *et al.* 1985, Fixen *et al.* 1983, and Cheng *et al.* 1979). This increased sensitivity will result in stringent limits on density perturbations at decoupling, anisotropic expansion, and the energy density in the Universe due to long wavelength gravity waves, and with a field of view of ~7°, CMBR anisotropies due to large cosmic string loops and horizon length cosmic strings.

The COBE satellite is to be launched by NASA in May 1989 on a Delta rocket. COBE carries three experiments:

(1) an absolute radiometer, to measure the cumulative emission from the earliest galaxies being formed;
(2) a spectrophotometer, to measure the spectrum of the CMBR and map it over the whole sky; and
(3) differential microwave radiometers, to measure the large angular scale anisotropy of the CMBR over the entire sky.

The focus here, the differential microwave radiometer experiment, is a three-frequency experiment designed to measure sensitively small temperature differences in the sky. The radiometers at 31 GHz, 53 GHz, and 90 GHz each have a pair of horns with fixed 60° separation. The radiometers are mounted on a spacecraft which spins at 0.8 rpm while in polar orbit. With these motions, the experiment rapidly measures temperature differences over large areas of the sky.

The largest expected source of systematic errors is Galactic emission, including thermal radiation from dust, free-free radiation from electrons, and synchrotron radiation from the relativistic electrons spiraling around the magnetic field lines. Observing at the three frequencies separates the Galactic and CMBR emission since each source of radiation has a fairly well-defined spectrum which is distinguishable given the three frequency operation.

II. GRAVITY WAVES

If there is a significant background of gravity waves in the universe, then at least one such wave might be passing through the earth (and the observer, COBE) at the present time. Consider a single, weak, linearly polarized plane wave with a sufficiently long wavelength to appear static to us. The wave perturbs the metric and thereby stretches the wavelenghts of the CMBR photons. Burke (1975) calculated the effect of such a gravity wave and showed that the expression for the observed frequency shift, as a function of the Θ between the source of emission and the propagation direction of a wave with polarization angle Φ, is given by
$z(\Theta,\Phi) = 1/2(A_1 - A_0)\ (1-\cos\Theta)\ \cos 2\Phi$, where A is the proper strain ($\delta l/l = h/2$ where g_{ik} $g_{ik}^{(\circ)} + h_{ik}$) observed between freely falling observers, A_0 is the amplitude at emission (or last scattering), and A_1 is the amplitude at the receiver. The change in frequency appears as a Doppler shift of the spectrum, which is equivalent to a temperature shift by the same factor.

The energy density of such a gravity wave is $\varepsilon_{GW} = \omega^2 c^2 h^2/32\pi G$. Expressed in terms of the critical density, $\rho c = 3H_o^2/8\pi G$, and measured anisotropy amplitude, ΔT, one finds $\Omega_{GW} = \varepsilon_{GW}/\rho_{crit}c^2 = \pi 2 c^2 h^2/e\lambda^2 H_o^2$, or

$$\Omega_{GW} = 1.6 \cdot 10^{-3} \frac{[(\Delta T/T)/(0.1\mathrm{mK}/2700\mathrm{mK})]^2}{(\lambda/10\ \mathrm{Mpc})^2\ (H_o/100\ \mathrm{km \cdot s^{-1} \cdot Mpc^{-1}})^2} .$$

A chaotic sea of gravity waves will produce distortions in the CMBR intensity. Calculations by Lindner (1988) show the finite thickness of the last scattering surface can cause dilution of the anisotropy produced by gravity waves with wavelengths less than 100 Mpc. He estimated that the anisotropy power spectrum will peak at ~1°, but extend out to large angles. For the COBE anisotropy experiment, which measures the difference between 7°-wide patches on the sky 60° apart, there would be a measurable anisotropy for a significant field of gravity waves. While the COBE microwave anisotropy experiment is not ideally designed to look for a chaotic gravity wave field, it will be able to set cosmologically significant limits on the energy density of long-wavelength gravity waves.

It is possible that there are some very long wavelength gravity waves. We might expect that any primordial gravitons existing from around the Planck time ($\sim 10^{-43}$ secs) would be thermalized; however, Grishchuk (1977) showed that that might not be the case and that there is a mechanism that could produce a nonthermal spectrum.

Grishchuk and Zel'dovich (1978) showed that gravity waves with wavelengths larger than the horizon of the universe can be observed through the resulting anisotropy in the CMBR, making the assumption that the phases of the gravity waves do not conspire to make our location uniquely privileged to have a flat background inside our horizon. The effect of a superhorizon length gravity wave on the CMBR isotropy depends both upon its amplitude and time dependence.

III. COSMIC STRINGS

Cosmic strings are line-like topological defects in the universe that are produced naturally in many particle physics gauge theories as the universe undergoes a phase transition from very high temperatures to very low temperatures (Vilenkin 1985). Strings are characterized by a mass per unit length, μ, which deforms flat space to conical space. This makes cosmic strings unusual in that they act as gravitational lenses whose bending angle, $\Delta\Theta = 8\pi G\mu/c^2$, is independent of impact parameter. This, by itself, does not produce an anisotropy in the CMBR, since the CMBR has highly uniform surface brightness. However, the string also has tension, μ, so that the string tries to straighten itself at relativistic speeds. Due to the motion of the string, photons passing on one side are boosted to higher frequencies and on the other side pulled back to lower frequencies. The maximal discontinuity occurs when the velocity of the string is perpendicular to the line of sight where one finds a step in the brightness of the CMBR across the string to be $\Delta T/T = 8\pi G\mu\beta\gamma/c^2$, where β and γ are the usual relativistic parameters.

Not all strings are long strings stretching from horizon to horizon. Some strings form closed loops which are oscillating and radiating gravity waves at an enormous rate (Vilenkin 1981). These closed loops also produce temperature anisotropies and several examples have been calculated (Stebbins 1988).

An example of a candidate string is presented by Turner *et al.* (1986). Turner *et al.* (1986) suggested the possibility of a 2.6 arcminute linear gravitational lens. Such a string would produce an anisotropy step across the string of about 2 mK. Stark *et al.* (1987) searched for this effect and they did not see it at the 1 mK level, and later Lawrence *et al.* (1986) set a 0.1 mK limit, so alternate explanations for the object have been advanced.

For questions of energy density and galaxy formation the natural mass per unit length, $G\mu/c^2$, is the 10^{-6} to 10^{-4} giving anisotropy levels resulting in anisotropies in the range of 0.03 to 3 mK. Stebbins (1988) calculates examples of distortions of the CMBR for sample closed loops. Veeraraghavan *et al.* (1988) consider the effects of horizon-length strings.

IV. CONCLUSION

The microwave anisotropy experiment on the COBE satellite should detect, or provide a stringent limit on, long wavelength gravitational radiation. It will also be a sensitive probe of the perturbation to the cosmic background photons caused by cosmic strings.

ACKNOWLEDGEMENTS

This work was supported by the NASA COBE Project.

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DISCUSSION

SHAPIRO: You mentioned that the Berkeley, Princeton, and USSR results on the microwave background anisotropies were discrepant. Could you elaborate on the details of these discrepancies?

BENNET: The Soviet data was contaminated by radiation from the Earth, picked up by the sidelobes of the horn. They did extensive work to attempt to eliminate this source of systematic error, but to my eye, these remain features in the map due to Earth radiation. The dipole results are:

	USSR	Berkeley	Princeton
ΔT(mk)	3.16 ± 0.12	3.44 ± 0.21	3.18 ± 0.21
α(hrs)	11.3 ± 1.6	11.2 ± 0.1	11.2 ± 0.1
δ(degrees)	-7.5 ± 2.5	-6.0 ± 1.5	-8 ± 2