WAS THE BIG BANG HOT?

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ABSTRACT: I consider experiments to confirm the substantial deviations from a Planck curve in the Woody and Richards spectrum of the microwave background, and search for conducting needles in our galaxy. Spectral deviations and needle-shaped grains are expected for a cold Big Bang, but are not required by a hot Big Bang.

I. INTRODUCTION

The temperature of the Big Bang is critical to an understanding of the early Universe. One normally assumes that the 3 K background measures this temperature, but the possibility that Population III stars could have produced the background after the Big Bang must be considered (Rees 1978). Woody and Richards (1981, hereafter WR) measured a substantial deviation from a Planck curve in the 3 K background, with a large excess flux near the peak, that cannot be explained by the simplest hot Big Bang models. Negroponte, Rowan-Robinson and Silk (1981) and Wright (1981) have shown that the WR excess at 1.5 mm can be explained by hot silicate dust at a redshift of 150. Such models require that 30-40% of the total energy in the 3 K background is added well after the Big Bang, but do not significantly alter the events before decoupling. Cold Big Bang models attempting to produce 99-100% of the background after the Big Bang were tried (Layzer and Hively 1973; Carr 1981) but a mechanism to thermalize the long wavelength tail was lacking. New work (Rana 1979; Wright 1982) has shown that very small abundances of needle-shaped conducting grains can provide the required opacity, so a cold or tepid Big Bang is possible. In this paper I will consider ways of verifying the WR spectrum, which is the experimental data behind dust-distorted models; and I will see whether needles can be seen in our galaxy.

II. INDIRECT METHODS OF VERIFYING THE WOODY-RICHARDS DISTORTION

Two techniques have been proposed for obtaining information about the absolute intensity of the background without doing an absolute radiometric experiment. One is to measure the frequency dependence of

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the dipole anisotropy (Lubin and Smoot 1981; Danese and De Zotti 1981) of the background and the other is to measure the frequency dependence of the Sunyaev-Zeldovich (hereafter SZ) effect in clusters of galaxies (Rephaeli 1981). Both of these methods use the Doppler shift to convert a spectral gradient into a spatial inhomogeneity. Since a spatial variation can be measured using position switching, atmospheric effects and stray light are much easier to control. This advantage is so great that it is practical to look for 0.3 mK effects in the anisotropy in order to confirm a 300 mK distortion in the spectrum.

Since the Doppler shift produces a frequency shift proportional to the frequency, a logarithmic frequency variable is useful. Therefore I will define a variable s by $\nu = \nu_o \exp(s)$ where ν_o is an arbitrary frequency normalization. The corresponding intensity variable should be measured in photons per logarithmic frequency interval, which is proportional to I_ν. Thus I can write an unperturbed blackbody spectrum as

$$I(s) = B_\nu(T_o) \qquad \text{with } \nu = \nu_o e^s.$$

The change in I due to a Doppler shift giving a redshift z is

$$-(1+z)\partial I/\partial z = 3I - \partial I/\partial s$$

Note that $I \propto \nu^3$, a constant density in phase space, gives $\Delta I = 0$.

The SZ effect involves a random distribution of redshifts and blueshifts due to thermal motion of the scattering electrons. This leads to a diffusion in frequency plus a net increase due to an excess of blueshifts. The change in I for $h\nu << kT_e << mc^2$ is

$$\partial I/\partial y = \partial^2 I/\partial s^2 - 3\,\partial I/\partial s \qquad \text{with } y = \tau_e kT_e/mc^2 .$$

$I_\nu \propto \nu^3$ gives $\Delta I = 0$ as before, but now $I_\nu \propto \nu^0$ also gives $\Delta I = 0$. Thus the SZ effect changes sign near the peak of I_ν vs. ν.

In order to evaluate $\partial I/\partial s$ and $\partial^2 I/\partial s^2$ a smooth model flux is needed. It is not possible to numerically differentiate noisy experimental data and get reasonable results. Thus I have constructed an <u>ad hoc</u> model to fit the WR spectrum and the low frequency points. The form of this model is

$$I_\nu = [1 + a \exp(-b \ln\{\nu/\nu_1\}^2)]\, B_\nu(T_o)$$

with a = 0.252, b = 4.50, $\nu_1 = 6.158\ \mathrm{cm}^{-1}$, and $T_o = 2.792$ K. This four parameter fit to the WR plus low frequency data gives $\chi^2 = 21.9$ with 22 degrees of freedom. Given this model fit to the WR spectrum I can compute ΔI_d (for Doppler or dipole) and ΔI_{sz} for both the WR spectrum and the null hypothesis, a blackbody (BB) spectrum with T = 2.734 K. In the following Table, all intensities have been expressed as Rayleigh-Jeans brightness temperature for the convenience of radio astronomers. The dipole anisotropy columns have been normalized to

3.78 mK in the low frequency limit (Boughn, Cheng and Wilkinson 1981) while the SZ effect is normalized to -1 mK. Note that the second derivative in the SZ effect emphasizes the sharply peaked excess flux in the WR spectrum, giving an effect at 150 GHz that is 100% higher than the BB spectrum. Unfortunately the SZ effect has never been observed with enough precision at two appropriate frequencies, so there is no data available now to confirm the WR distortion using the SZ effect.

TABLE 1: Blackbody (BB) vs. Woody-Richards (WR)

ν	Dipole			SZ		
(GHz)	BB	WR	Ratio	BB	WR	Ratio
30	3.693	3.696	1.001	-0.954	-0.956	1.002
60	3.449	3.446	0.999	-0.832	-0.815	0.980
90	3.083	2.933	0.951	-0.654	-0.544	0.832
120	2.646	2.495	0.943	-0.459	-0.544	1.185
150	2.187	2.386	1.091	-0.277	-0.581	2.097
180	1.748	2.220	1.270	-0.129	-0.356	2.760
210	1.356	1.842	1.358	-0.022	-0.071	3.227
240	1.024	1.386	1.354	+0.046	+0.101	2.197
270	0.757	0.985	1.266	+0.082	+0.159	1.939
300	0.548	0.681	1.243	+0.095	+0.157	1.653

The dipole anisotropy has recently been measured at 90 GHz and 184 GHz by two different, highly sensitive balloon experiments. The 90 GHz experiment (Lubin 1982) measured a dipole magnitude of 2.95 ± 0.1 mK, while a preliminary analysis of the MIT 184 GHz channel gives 1.6 ± 0.3 mK (Wright, Halpern and Weiss 1982). The ratio of 184 to 90 GHz dipoles is 0.54 ± 0.10, while the predicted ratio is 0.55 for BB and 0.67 for WR, so neither spectrum can be ruled out. Current experiments have adequate sensitivity for a definitive result, but careful cross-calibration will be essential.

III. DO CONDUCTING NEEDLE-SHAPED GRAINS EXIST?

One byproduct of measurements of the anisotropy of the microwave background is an estimate of the emission from our galaxy. The MIT experiment used 4 frequencies in order to determine the spectrum of the galactic emission. This offers a chance to look for emission from conducting needle-shaped grains that could thermalize the long wavelength tail of the microwave background.

An anisotropy experiment cannot measure the absolute intensity of the galactic emission, but only its spatial gradient. Thus, in order to determine T_p, the brightness temperature at the galactic pole, one has to compare the difference between the galactic plane and the pole with a model. For the MIT data with a 16^o beam I have used a csc(b) model with a smooth cutoff at the galactic plane that approximates the FWHM of the beam. In addition I have included a galactic plane term with longitude variation. The high frequency channels have strong galactic emission but very little dipole signal, so I have used these signals to define the shape of the galactic model. Then I use a four

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parameter fit of dipole plus galaxy to find the emission spectrum of the galactic dust. The results are given in Table 2, along with lower frequency data from Lubin (1982) and Wilkinson (1982). Remember that these numbers are quoted at the pole, but are really measured close to the galactic plane. The average brightness of the galactic plane over the observed range of $75^{\circ} < \ell < 240^{\circ}$ is 14 times the value given for T_p in the four MIT channels.

TABLE 2: Galactic Emission

ν(GHz)	25	90	184	429	729	925
T_p(μK)	250 ± 70	45 ± 23	58 ± 19	69 ± 16	93 ± 20	116 ± 25

There is an excess emission in the 90-184 GHz data, but the excess is only slightly significant. Also, comparing different experiments is difficult unless they have identical sky coverage; but the MIT data is only from the outer galaxy while the low frequency experiments have better coverage.

If the excess galactic emission at 90-184 GHz is real, a fit to a sum of ordinary dust with emissivity $\propto \nu^2$ plus long needles with constant emissivity gives an optical depth of $(6 \pm 3) \times 10^{-5}$ due to needles with T = 3.8 K and an optical depth of $(4.5 \pm 0.8) \times 10^{-6}$ at 1 mm due to normal dust with T = 15 K. In this model the needles radiate 0.21% of the total galactic power. Since needles emitting just 0.1% of the total power could be cosmologically significant, it is very important that better 30-300 GHz spectra of the emission of cold galactic dust be obtained. Measurements of small, visually opaque dark clouds using large ground-based telescopes should give better data on dust emission than all-sky, large beam measurements of the entire galaxy.

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DISCUSSION

(The discussion of the papers by Professors Rowan-Robinson and Wright was deferred until after Wright's paper. The following question, from Dr. Segal, was directed to Rowan-Robinson, but answered by Wright; Rowan-Robinson has waived the offer to submit a written response to Dr. Segal, thereby yielding to Wright's reply to Segal. Ed.*)*

Segal: The cosmic background radiation is, of course, not uniquely indicative of a Big Bang, but a Planck law for the background photons is implied by any temporally homogeneous theory in which the energy is modelled, as usual, by the infinitesimal time evolution generator. A very simply quasiphenomenological explanation of the Woody-Richards anomaly is a postulated non-vanishing isotropic angular momentum for the CBR in, for example, the vicinity of the Local Group. This provides a very good fit to their data, depends only on a single contemporary parameter rather than by hypothetical events at redshifts such as 200 or 1000, and automatically displaces the pure black-body law in the observed direction, rather than the opposite direction, as early discussions of perturbations of a Big Bang predicted. Therefore, isn't this scientifically more economical and in principle empirically accessible explanation for the Woody-Richards anomaly more natural than those presented that require a complete scenario hardly capable, in principle, of independent substantiation?

Wright: The Jakobsen, Kon, and Segal model (1979, Physical Review Letters, 42, 1788, hereafter JKS) of the Woody and Richards (WR) spectrum has two basic flaws. The first flaw is that it does not fit the data if the low frequency results are included. The Planck brightness temperature of the JKS model is a nonincreasing function of frequency, while the observed data rises from 2.7 K at low frequencies to 3.0 K at the peak, then falls to 2.8 K on the high frequency side of the peak. The JKS model matches the WR spectrum at the peak and higher frequencies, but predicts 3.4 K at low frequencies (see accompanying figure).

The second flaw in the JKS model is that the predicted background is inhomogeneous and anisotropic (Wright, 1980, Physical Review D, 22, 2361). The local perturbation just proposed by Segal is also manifestly inhomogeneous. An inhomogeneous background violates the cosmological principle, and is thus incompatible with all modern cosmological models, including the chronometric cosmology of Segal.

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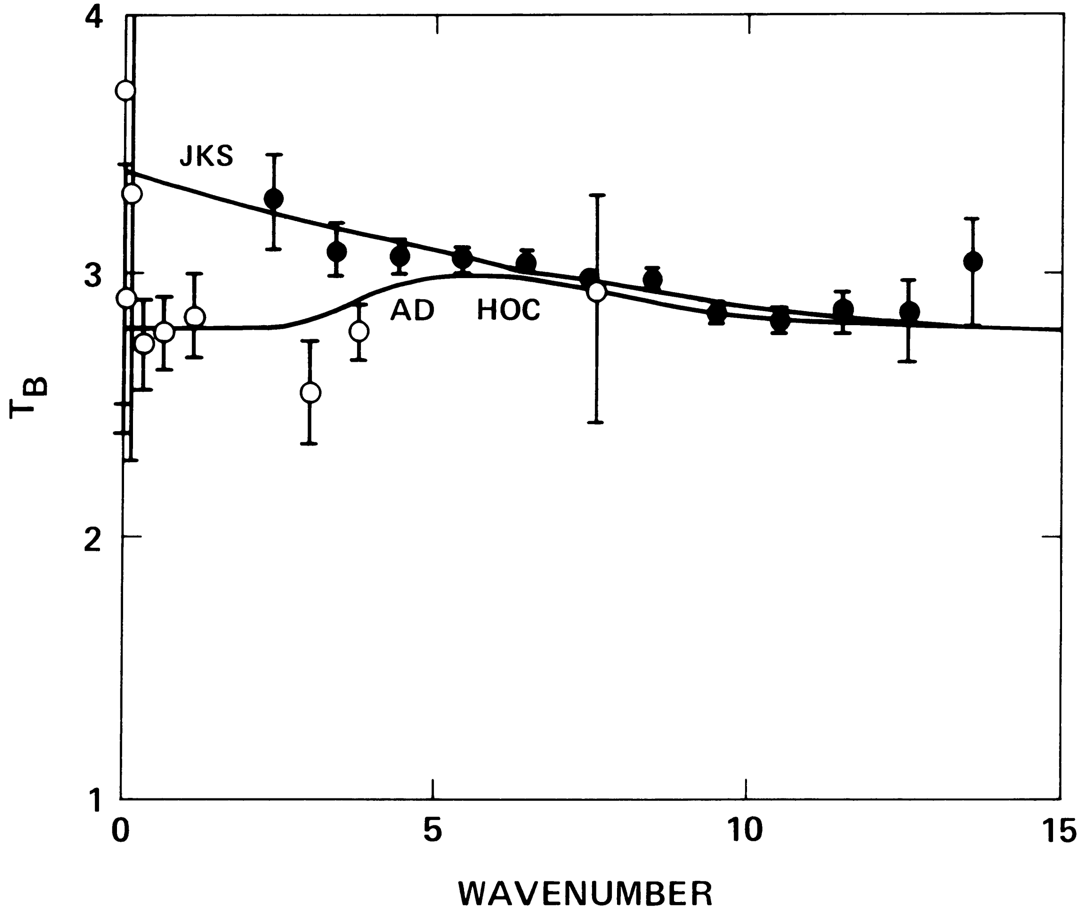

Comparison of the Jakobson, Kon and Segal model (dashed curve) and Wright's *ad hoc* fit (solid curve) to the Woody and Richards data (filled symbols) and the ground-based and CN data (open symbols. While the JKS model fits the W-R data, it is not consistent with the ground-based low-frequency data.