ISOTROPY AND HOMOGENEITY OF THE UNIVERSE FROM MEASUREMENTS OF THE COSMIC MICROWAVE BACKGROUND*

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A Dicke radiometer (3.2-cm wavelength) was used to make daily scans near the celestial equator to look for possible anisotropy in the cosmic blackbody radiation. After about one year of intermittent operation we find no 24-h asymmetry with an amplitude greater than ±0.1% (of 3°K). There is, however, a possibly significant 12-h anisotropy with an amplitude of about 0.2%.

Measurements[1] of the intensity of the cosmic background radiation at several wavelengths support the suggestion[2] that this radiation has a blackbody spectrum. If further measurements, particularly at short wavelengths, continue to fit a blackbody spectrum, then we must take seriously the idea[3] that the universe is filled with blackbody radiation which is a relic of a hot, highly contracted phase of the universe. A measurement of the isotropy of this radiation is of considerable cosmological interest, for the radiation serves as a probe to study the isotropy of the expansion of the universe. Thorne[4] has shown that an anisotropy in the expansion subsequent to the last interaction of the radiation with matter can contribute to the anisotropy of the background radiation. This last scattering occurs at a redshift of at least $\Delta\lambda/\lambda = 7$, and may occur at a much earlier time if the density of the intergalactic plasma is low.[5] Another effect has recently been suggested by Sachs and Wolfe.[6] They show that a large-scale ($\sim 3 \times 10^9$ light yr) density inhomogeneity, of magnitude $\delta\rho/\rho \sim 10\%$, could produce inhomogeneity and anisotropy in the background-radiation temperature as large as $\frac{1}{2}\%$. For the last year, we have looked for anisotropy in the microwave background along the celestial equator.

The instrument used in this work is shown schematically in Fig. 1. The Dicke radiometer is a modified version of the one[7] used to make an absolute intensity measurement of the background radiation. The principal modifications were these: (1) The cold reference termination was replaced by a small horn antenna pointed to the zenith, and (2) the radiometer was tipped to an elevation of 42° above the southern horizon. As the earth rotates, the antenna beam (width ~10° to −10 dB) scans a region running parallel to the celestial equator at a declination of about −8°. If the intensity of the background radiation is varying along this region, we would expect a sidereal periodicity in the recorder output.

To provide a reference for the instrument, a large aluminum reflecting sheet was raised to the vertical to deflect the antenna beam toward the celestial pole (near Polaris). This point served as a fixed reference source of background radiation. The reflector was raised for 15 min every half-hour to subtract out the effects of solar heating of the apparatus and diurnal variations in the atmospheric radiation temperature (~5°K). Both the measuring beam (near the celestial equator) and the reference beam (near Polaris) can have the same zenith angle. Thus the two beams pass through the same thickness of the atmosphere, and atmo-

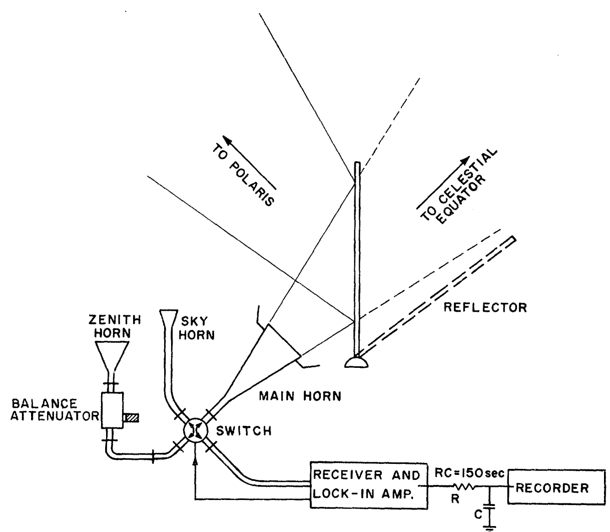

FIG. 1. The isotropometer. The zenith horn and attenuator provide a convenient means of balancing the radiometer inputs, and the sky horn is merely a cold termination. The undeflected beam actually is pointed 8° S of the equator and the reflected beam misses Polaris by 2°.

Table I. The results of averaging ~55 runs. Each error is the standard error of the mean. Because of the relatively large error associated with the mean 24-h amplitude, very little weight should be attached to the hour angle.

Sidereal period (h)	Mean amplitude (10^{-3} °K)	Anisotropy (percent of 3°K)	Right ascension of maximum temperature
12	4.9 ± 2.0	0.16 ± 0.07	7^h30^m and 19^h30^m
24	1.0 ± 2.2	0.03 ± 0.07	15^h30^m

spheric temperature drifts largely cancel out.

The differences between the equatorial and polar radiation temperatures, $T_E - T_P$, were read from the recorder chart at 15-min intervals for each 24-h run. The differences were then analyzed for 24- and 12-h components by least-squares fitting the functions $[A_{24}\cos(2\pi t/24+\varphi_{24})+C_{24}]$ and $[A_{12}\cos(2\pi t/12+\varphi_{12})+C_{12}]$ to $T_E - T_P$ (t = sidereal time in h). The best-fit amplitudes and phases of each of ~55 runs were found and a weighted average was made. These results are listed in Table I, and Fig. 2 is a polar diagram of the 12-h results.

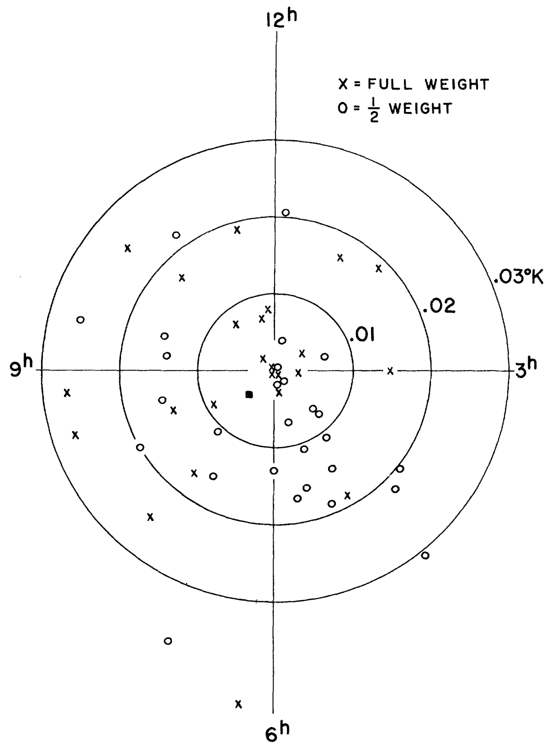

FIG. 2. The results of analyzing ~55 isotropy runs for 12-h components. Half-weighted runs were interrupted by weather or instrument failure so that a complete 24-h series was not obtained. Note that the outer circle represents an amplitude of 1% of the background radiation temperature of 3°K. The average of all results is indicated by the solid square.

The 24-h asymmetry has an average amplitude of less than 0.1% (of 3°K). This places an upper limit of about 300 km/sec on the equatorial component of the velocity of the sun with respect to the comoving frame of the distant matter which last scattered the background radiation. A 24-h component would also be expected from the daily passage through the antenna beam of the central region of the galaxy. To estimate the size of this effect, we have extrapolated long-wavelength measurements[8] of galactic radiation to our wavelength (3.2 cm) and convoluted this temperature distribution with our antenna pattern. The resulting galactic pulse should contribute 12- and 24-h amplitudes of only about 0.01%.

The average amplitude of the 12-h component is about $2\frac{1}{2}$ standard deviations greater than 0 and is possibly a real anisotropy. One possible spurious source of a 12-h sidereal component is the noon-time passage of the sun through our antenna beam, which occurs only during two seasons of the year. The result is a semiannual modulation of a series of spikes separated by 24 h in solar time. Such a series contains a 12-h sidereal time component. To check for this effect we removed all data taken within $1\frac{1}{2}$ h of solar noon and reanalyzed all the runs. The average amplitudes of the 12- and 24-h sidereal components did not change significantly.

As a further check for possible systematic errors due to solar heating of the apparatus, including the reflector itself, the daily runs were averaged over the year in solar time. Thus solar heating effects are not averaged out. The 12- and 24-h solar components have amplitudes of less than or about 5×10^{-3} °K. Since our data were averaged over most of a year, the solar-heating effects in the sidereal averages are at least 10 times smaller. We feel confident that the 12-h sidereal result is not caused by solar-time effects.

Finally, all the data in hourly (sidereal) bins were averaged, and the results examined for hot and cold spots. No local irregularities greater than $\pm\frac{1}{2}\%$ were found along the directions scanned. This result places an upper limit of $\pm 10\%$ on density inhomogeneities of the type considered in Ref. 6.

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QUANTUM THEORY OF LINEWIDTHS IN BRILLOUIN SCATTERING FROM PURE SOUND FIELDS IN THE LOW-DAMPING LIMIT*

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Linearized classical hydrodynamic and heat-transport equations describing the collective behavior of density and temperature fluctuations in liquids have in the past been the subject of intensive study. For example, Mountain[1] recently examined these equations and from his solutions deduced the spectral distribution of light scattered from liquids (spontaneous Brillouin scattering). Among other classical predictions is the following: If the sound field is nondispersive and if the thermal coefficient of expansion is 0 (in which case the sound excitations are independent of the thermal fluctuations—i.e., we have a "pure" sound field), the half-width (angular frequency) of the Brillouin lines is equal to the inverse lifetime of the sound wave,

$$\Gamma_B(\text{class.}) = \tfrac{1}{2}(\tfrac{4}{3}\eta_s + \eta_v)(k^2/\rho_0), \tag{1}$$

η_s and η_v being the shear and bulk viscosities, ρ_0 being the ambient fluid density, and k being the wave vector of the excitation which scatters the light, whose magnitude is related to the scattering angle θ and the wave number k_i of the incident light in vacuum through the equation

$$k = 2nk_i \sin\tfrac{1}{2}\theta, \tag{2}$$

n being the index of refraction for the liquid.

It is the purpose of the present paper to show that quantum mechanically, Eq. (1) is decidedly not valid in low-damping situations; instead, quantum mechanics leads to the startling result

$$\Gamma_B(\text{Q.M.}) = 0 \tag{3}$$

in this limit. Accordingly, it is not clear that classical calculations of line shapes in light scattering by thermal sound excitations are valid under any conditions.

We begin by writing the quantum mechanical expression for the intensity of scattered radiation as a function of the frequency difference between the incident and scattered light ω, and the point of observation $\vec{R}$,

$$I_{sc}(\vec{R},\omega) = I_{inc}\left(\frac{Nk_i^4}{16\pi^2 R^2}\right)\left(\frac{\partial\epsilon}{\partial\rho}\right)_T^2 P_{\vec{k}}(\omega)\sin^2\varphi, \tag{4}$$

I_{inc} representing the incident-light intensity (assumed to be monochromatic), N being the number of molecules in the scattering volume, and φ being the angle between the polarization axis and the direction of observation. $P_{\vec{k}}(\omega)$