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Authors

Friedman, S.D.
Smoot, G.F.
De Amici, G.
et al.

Publication Date

1983-06-01

LBL-16182
Preprint

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Physics, Computer Science & Mathematics Division

Submitted to Physical Review Letters

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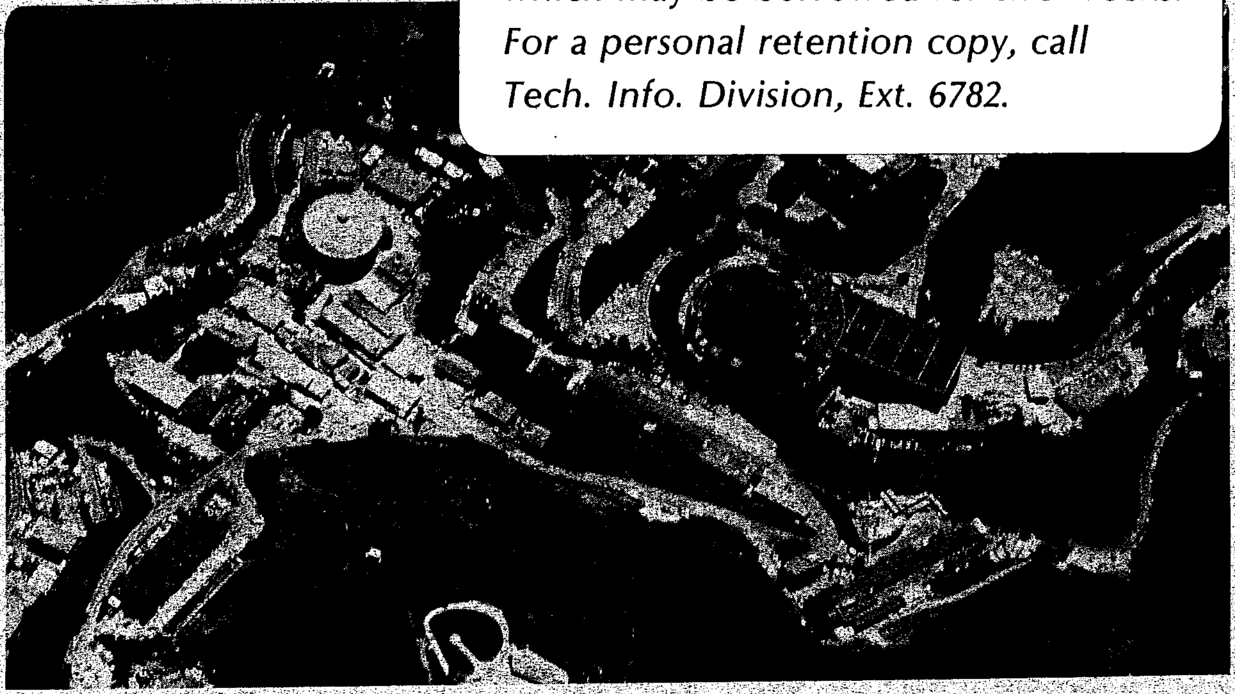
June 1983



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

A Measurement of the Cosmic Background Radiation Temperature at 3.0 cm

Scott D. Friedman, George F. Smoot
Giovanni De Amici, Chris Witebsky

Space Sciences Laboratory and Lawrence Berkeley Laboratory
University of California, Berkeley, California 94720

ABSTRACT

We describe a measurement of the cosmic background radiation temperature at a wavelength of 3.0 cm. The experiment was made in conjunction with measurements at four other wavelengths in an effort to measure the long wavelength spectrum to high accuracy. The result at 3 cm, $T_{CBR} = 2.91 \pm 0.19$ K, is in good agreement with the values at neighboring wavelengths, and consistent with previous results.

PACS numbers: 98.70.Vc, 98.80.Bp

Previous measurements of the cosmic background radiation (CBR) temperature at long wavelengths have not been sufficiently accurate to detect the small distortions from a blackbody distribution that may result from a release of energy in the early universe[1]. This paper describes a measurement of the intensity of the CBR at 3.0 cm (10 GHz). This was part of an experiment[2] to search for distortions by making measurements at five wavelengths in the Rayleigh-Jeans region.

The Dicke-switched superheterodyne radiometer used to make the measurement is shown schematically in Figure 1. The receiver has a noise temperature of 470 K, and an RF bandwidth of 910 MHz. The rms noise fluctuations were measured to be 50 mK $\mathrm{Hz}^{-1/2}$. The Dicke switch is driven at 100 Hz. The radiometer is mounted on bearings so that it can rotate in a vertical plane. It has two low-sidelobe corrugated horn antennas, with 12.5° HPBW beams, which are perpendicular to each other. The primary antenna can swing through 360° to view any desired zenith angle. The rotation axis is coincident with the axis of the secondary antenna whose beam is reflected by a fixed mirror toward the vertical sky.

The atmospheric emission is measured with zenith scans, by directing the primary antenna 30° away from vertical in the east and west directions. The vertical sky emission is found by direct comparison with a liquid-helium cooled load. The measured atmospheric emission, and contributions from the galaxy and other small sources, are subtracted from the vertical sky. The residual is the CBR signal.

The function of the secondary antenna is to provide a constant, low temperature reference signal; the sky serves as a convenient source. Radiation reflected from the mirror is partially linearly polarized. However, this antenna is sensitive to circular polarization, which ensures that the rotation of the radiometer does not introduce a significant systematic error.

When the two antennas viewed identical cold loads, asymmetry in the apparatus produced an output equivalent to a 1.1 K temperature difference between the loads.

Tests were made to ensure that this offset did not change excessively as the radiometer was rotated from one orientation to another. Mechanical stress changed the offset by less than 32 mK when the primary antenna was directed horizontally, and by less than 27 mK when directed vertically. Rotation of the instrument relative to the earth's magnetic field changed the offset by less than 4 mK. Twisting of the power signal and sensing cables introduced no measurable effect.

There was a degradation in performance of the equipment after movement to the observing site at White Mountain, California. Although the vertical offset did not change, there was an additional offset introduced at the zenith angles of $\pm 30^{\circ}$ due to a combination of mechanical stress on the radiometer, and misalignment of the ground shield-reflector system. This offset increases by about 100 mK the error of the atmospheric temperature, up to a value of 160 mK, and causes a corresponding increase in the error of the cosmic background radiation temperature. This represents the single largest source of error. Measurements now planned for the summer of 1983 should not be subject to this problem.

The gain of the radiometer was measured by using two blackbody calibration loads at widely different temperatures. The first was an ambient temperature calibrator consisting of a 7.6 cm thick piece of Emerson & Cuming Eccosorb CV-3, a microwave absorber, enclosed in a thermally insulating styrofoam box. The emissivity of the Eccosorb is greater than 0.999. The temperature of the Eccosorb was automatically recorded every 16 seconds. During these ambient temperature calibrations, when there was a large input power difference between the two antennas, the radiometer was found to saturate slightly. For a temperature difference of 275 K, there is $6 \pm 2\%$ saturation. The calibration is corrected for this effect. The gain of the radiometer varied by less than 0.4% during any measurement period (approximately one hour).

The second calibrator was a liquid-helium cooled load, and is described in the first paper[2] in this series. The physical temperature of the liquid helium was 3.77 ± 0.01 K, and the additional contribution due to insertion loss and reflection was 0.03 ± 0.02 K at 3 cm. Hence, the effective radiometric temperature of the load was 3.80 ± 0.02 K.

A complete set of data for the 3 cm radiometer was taken every 160 seconds. Each set consists of five 32 second periods with a different target observed during each period. The targets were always viewed in the same order: cold calibrator, vertical sky, sky 30° west of zenith, sky 30° east of zenith, and ambient temperature calibrator. This sequence of measurements was repeated continuously during the observing runs.

All data were automatically recorded on magnetic tape and by hand for later analysis. The lockin amplifier output was integrated for two seconds and recorded. The basic cycle time for the data recorder was 16 seconds, and 2 cycles transpired for each target. Output values taken while the radiometer was rotating from one position to the next were removed from the raw data.

Screens were erected around both antennas to reduce sidelobe reception of ground radiation. At tilt angles of ±30° the measured sidelobe pickup contributed an additional 5 mK to the primary antenna. The data were corrected for this.

The galactic background, due to synchrotron and HII thermal emission, contributes a significant signal only within about 20° of the galactic plane. The correction for the synchrotron flux is estimated by scaling the data of Haslam et al.[3], using a spectral index of -2.8. An estimate of the HII emission comes from a source list[4] scaled with a spectral index of -2.1. The maximum correction at 3 cm due to emission from galactic sources is 28 mK; however, most of the data require correction of less than 10 mK. This scaling model agrees to better than 20% with the galactic background emission values that were measured during this experiment at 6.3 cm, and to better than 10% at 12 cm.

The measured value of the vertical atmosphere antenna temperature is $T_{ATM} = 0.93 \pm 0.16$ K. This was determined by using the zenith scan data and assuming a spherical, uniform density atmosphere convolved with the antenna beam pattern. Assuming an exponential instead of a uniform atmosphere changes T_{ATM} by less than

2 mK. This value of T_{ATM} is 0.1 K lower than the value determined at the same time by Partridge et al.[5] at 3.2 cm.

After making these corrections we find that the value of the thermodynamic temperature of the cosmic background radiation is

$$T_{CBR} = 2.91 \pm 0.19 \text{ K.}$$

This is the mean of 82 independent measurements. The total error is the quadrature sum of the individual errors, and is dominated by the rotation offset described previously. A histogram of the results is shown in Figure 2.

There have been two previous measurements of T_{CBR} at the nearby wavelength of 3.2 cm. In 1965, shortly after the discovery of the cosmic background radiation, Roll and Wilkinson[6] found $T_{CBR} = 3.0 \pm 0.5$ K from data taken at Princeton, New Jersey. Stokes et al.[7] made measurements from White Mountain in 1967 with the result $T_{ATM} = 1.37 \pm 0.1$ K and $T_{CBR} = 2.69^{+0.16}_{-0.21}$ K. This value of T_{CBR} is compatible with our result, differing by less than 1.4 standard deviations. However, their value of T_{ATM} is inconsistent both with our result and that of Partridge et al.[5] A reduction in their atmospheric temperature would increase their cosmic background temperature, giving even closer agreement with our result.

We thank the staff of the White Mountain Research Station for their valuable assistance during our visit. Hal Dougherty and John Gibson provided expert technical support. Jerry Epstein and Alan Benner contributed needed help and encouragement.

This work was supported by NSF grant PHY80-15694, and by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Division of High Energy Physics at the US Department of Energy under contract DE-AC03-76SF00098.

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FIGURE CAPTIONS

Figure 1. Schematic of the 3.0 cm radiometer.

Figure 2. Histogram showing the results of measurements of the CBR. 82 individual measurements were made over the course of two nights of observations.

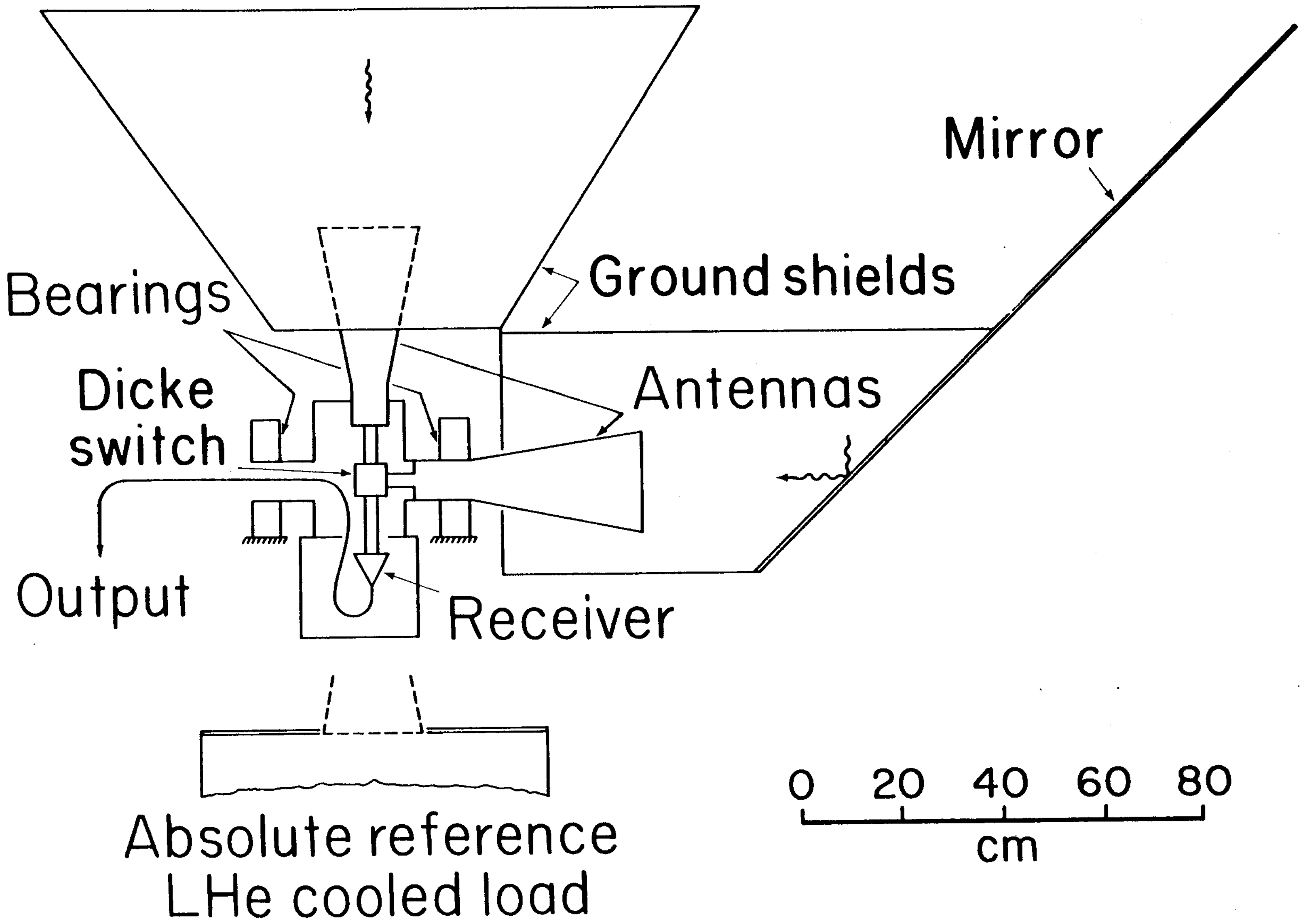

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Fig. 1

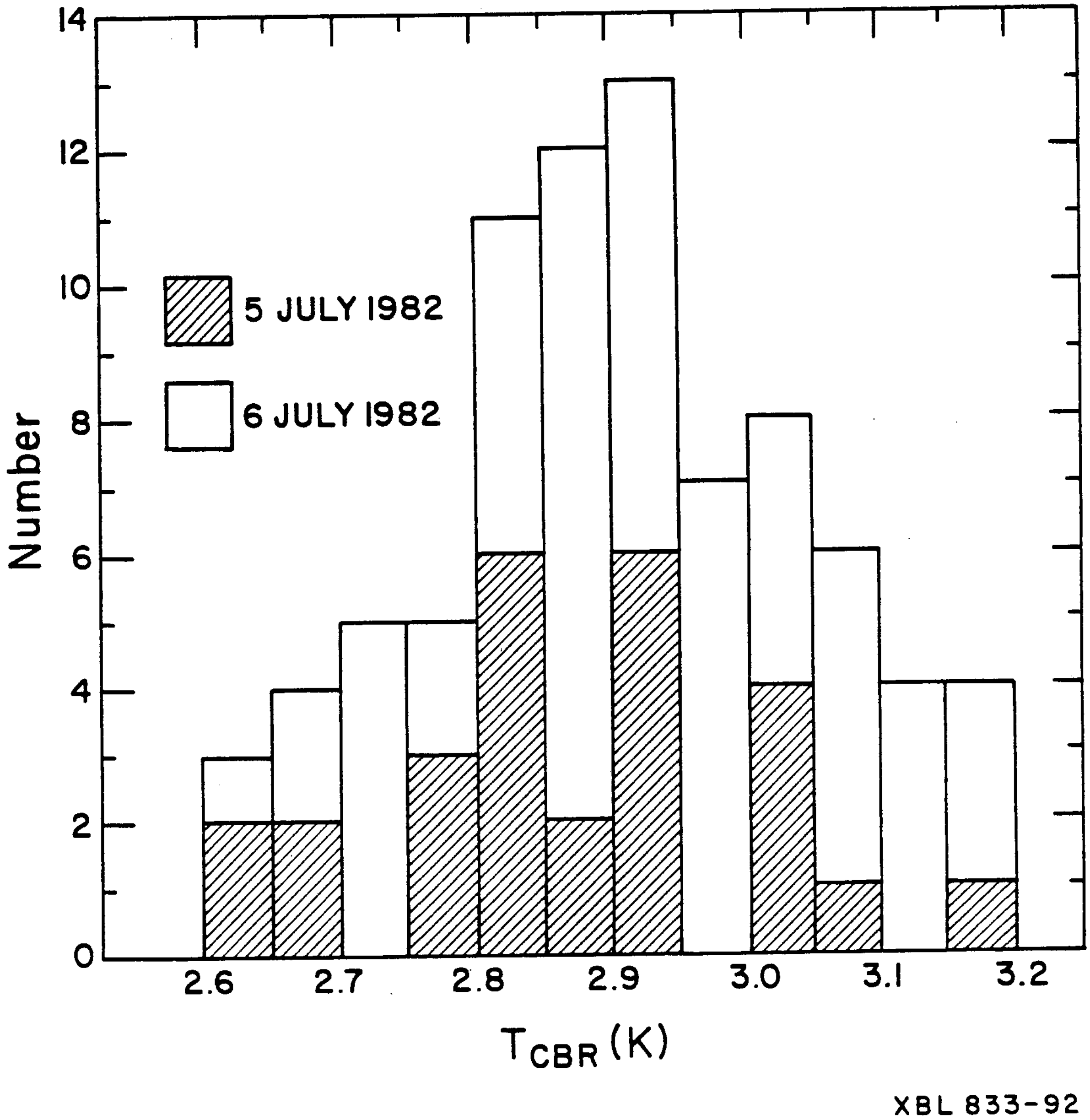
14
12
10
8
6
4
2
0
Number
5 JULY 1982
6 JULY 1982
2.6
2.7
2.8
2.9
3.0
3.1
3.2
T_CBR (K)
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Fig. 2