COSMIC BACKGROUND MEASUREMENT AT A WAVELENGTH OF 9.24 mm*

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The cosmic background temperature measured at 9.24 mm is 3.16 ±0.26°K, which is consistent with measurements at longer wavelengths.

Observations of the cosmic microwave background[1-3] at a wavelength of 9.24 mm (32.5 GHz) were made between 28 June and 11 July 1967, at the Barcroft Laboratory of the White Mountain Research Station of the University of California, located near Bishop, California. The radiometer configuration is shown in Fig. 1. A standard Dicke radiometer was mechanically switched at 30-sec intervals between the sky horn and a liquid-helium reference source. The receiver gain was calibrated every 5 min by a 50°K signal from an argon discharge tube. The discharge tube was calibrated daily against a 300°K absorber placed over the sky antenna. The radiometer output had an rms fluctuation of ±0.1°K for a 1-h integration time. The secondary and "cold-load" antennas were small horns aimed at arbitrary regions of sky to provide conveniently cold and stable sources of radiation.

The helium reference load was a crossed array of Fiberglas spikes clad with Nichrome film, filling the lower 8 cm of a 6.3-cm-diam cylinder 40 cm long. In operation, the spikes were submerged in liquid helium, boiling at the ambient atmospheric pressure. The presence of the cylinder, which has a high thermal mass, and the small heat leak to the top of the Dewar assured that the absorber spikes were held close to the boiling temperature of helium at the ambient pressure. The can, made of gold-flashed copper and copper-plated stainless steel, formed an oversize waveguide at the operating wavelength and assured low loss. Temperature of the upper wall was measured by means of a thermocouple.

The zenith brightness temperature was measured by using identical 20-dB standard gain horns (20° half-power beamwidth) placed symmetrically on either side of the mechanical

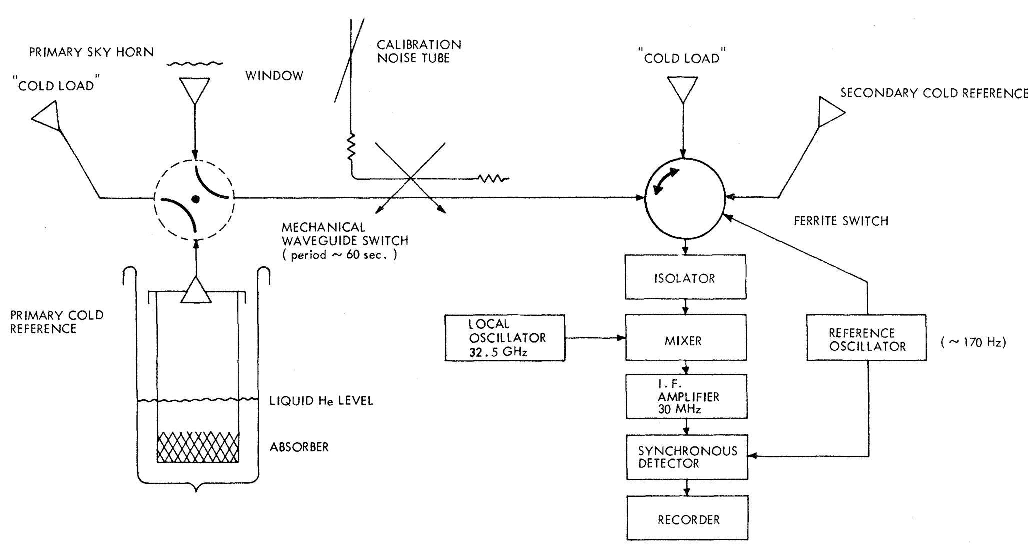

FIG. 1. Radiometer block diagram for absolute measurements.

switch. One horn looked down into the helium load while the other looked up at the zenith as indicated in Fig. 1. Temperatures at various points on the horns were measured by thermocouples. The electrical symmetry of the switch-horn assembly was directly measured by the radiometric procedure described below and was confirmed every few days by inverting the assembly with respect to the reference load. A pyramidal shield placed directly around the upper horn reduced the effect of sidelobes.

The contribution to the observed brightness by the earth's atmosphere was determined by tipping the radiometer and Dewar to various zenith angles (z) and measuring differences in antenna temperature. A 26-dB horn (10° beamwidth) and 30-deg bend replaced the upper 20-dB horn in a manner that allowed the larger horn to sweep from $z=0°$ to $z=60°$ in its H plane, while the Dewar was tilted, at most, 30° from vertical. Plots of atmospheric brightness versus $\sec z$ were fitted well by a straight line.

In either operating mode, moist air was kept from the system by a window of "Saran Wrap" at the upper horn. A slight flow of warm helium gas was introduced into the waveguide system to prevent water vapor or cold helium from entering the switch or horns. The helium Dewar was vented directly to air.

A large system of shields was erected around the radiometer to further shield the radiometer from the lower sky and the earth.

A typical experiment consisted of a helium Dewar fill, noise-tube calibration, an absolute-zenith measurement for 1 h, a $\frac{1}{2}$-h atmospheric measurement, Dewar refill, and $1\frac{1}{2}$ h of atmospheric measurement. Observations were allowed only when the sun was more than 30° removed from the antenna beam and during times of few or no clouds.

Corrections made to the measurement are summarized in Table I.

The first three entries of Table I were measured radiometrically in a reflector assembly which allowed the 20-dB horns on either side of the mechanical switch to view the same area of sky. Heater coils on the horns allowed the effect of a temperature differential between the horns to be measured.

Radiometric measurement of the loss of the wall of the helium-load cylinder indicated an attenuation of 0.26 ± 0.02 dB/m at 300°K. The effective helium-load temperature was calculated utilizing the measured temperature distribution of the wall, which depends on the helium level; allowance was made for the change of conductivity and skin depth with temperature.

The effect of side and back lobes of the antenna was computed by numerical integration of the antenna pattern over the sky and earth, taking into account the presence of the large shield.

Reflectivity of the helium reference load and leakage into the load were measured, and produce a negligible increase in load temperature.

The cosmic background temperature may be expressed as

$$T_{\mathrm{BG}} = \alpha^{-1}[T_{\mathrm{OBS}} + T_{\mathrm{He}} - 1.03T_{\mathrm{ATM}} + T_{\mathrm{C}} - T_{\mathrm{SW}} + T_{\mathrm{W}}],$$

where α, the attenuation coefficient of the atmosphere for $T_{\mathrm{ATM}} \sim 4°\mathrm{K}$, is 0.984; T_{OBS} is the observed brightness temperature difference between the two switch ports; T_{He} is $3.79 \pm 0.01°\mathrm{K}$, the boiling point of helium at 490 mm Hg (the ambient barometric pressure); T_{ATM} is the measured zenith atmosphere contribution; T_{C} is $-0.16°\mathrm{K}$, the sum of the nonvarying contributions of Table I; T_{SW} is the switch asymmetry; and T_{W} is the helium-load wall loss.

All the background measurements taken at the Barcroft Laboratory are presented in Ta-

Table I. Systematic errors in absolute measurements.

Source	Temperature correction	rms error
Switch asymmetry (varies from day to day)	$\pm(0.4$ to $0.9)°\mathrm{K}$	$\pm0.10°\mathrm{K}$
Window loss	-0.06	±0.02
Cooling of lower horn by helium vapor	-0.21	±0.06
Loss in helium-load wall (depends upon helium level)	$+0.7$ to $+1.2$	±0.15
Convolution of 20-dB antenna pattern with sky	$-0.03T_{\mathrm{ATM}}$	±0.003
Backlobes of 20-dB horn on ground	-0.03	±0.01

Table II. Summary of observations. Asterisks denote data used for final evaluation of background temperature.

Date	Length of observation	T_{OBS}	T_{ATM}	T_{SW}	T_W	T_{BG}
6/28/67	4.0 hours	3.17°K	3.29°K	0.44°K	1.20°K	4.24 a
6/29/67	4.2	4.51	5.08	0.44	0.84	3.36 b
6/30/67	2.0	5.80	4.74	0.44	0.76	4.95 c
7/1/67	3.0	4.52	5.59	0.44	0.88	2.88*
7/3/67	4.0	3.58	3.84	0.44	0.90	3.77*
7/4/67	3.8	5.28	5.49	0.44	1.17	4.05 c
7/7/67	4.3	7.14	4.90	0.44	0.80	6.18 d
7/7/67	1.3	3.01	4.60	-0.44	0.84	3.23 c
7/8/67	4.3	3.29	4.52	-0.44	0.84	3.60 d
7/8/67	4.0	2.10	4.16	-0.44	0.74	2.67 d
7/9/67	4.0	2.19	3.68	-0.44	0.84	3.36 d
7/10/67	2.0	1.07	4.12	-2.10	0.98	3.60 e
7/10/67	4.7	2.46	4.51	-0.51	0.88	2.88*
7/11/67	4.3	2.43	4.53	-0.70	0.98	3.12*

[a]Experiment performed without sidelobe shields.
[b]Apparatus improperly assembled.
[c]Clouds formed overhead during experiment.
[d]Drifts in radiometer.
[e]Anomalous switch asymmetry.
*Data used to compute final result.

ble II. The starred values of T_{BG} are those which are used in our final result. The remaining measurements were rejected on a priori grounds as indicated in footnotes; they are presented to indicate the relative insensitivity of the experiment to such difficulties.

The standard data of Table II yield the background temperature 3.16 ± 0.26°K. The error indication represents the geometric sum of the rms deviations of the corrections of Table I and of the mean of the starred data of Table II. The latter rms deviation is estimated to be ±0.15°K. An average of both "good" and "bad" background measurements gives 3.71°K.

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