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P. L. Richards

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P. L. Richards

Physics Department
University of California
Berkeley, California

and

Materials and Molecular Research Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California

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THE COSMIC BACKGROUND RADIATION REVEALS ITS BLACKBODY SPECTRUM

The existence of cosmic background radiation with the spectrum of a 3K blackbody is an important feature of "big-bang" cosmology. Efforts to confirm the blackbody spectral character of the observed background radiation have been actively pursued. In 1975, a group under P. L. Richards at the University of California, Berkeley, measured the spectrum of this radiation in the submillimeter frequency range and showed that the flux falls with frequency in agreement with the Planck blackbody curve.

PREDICTION OF THE COSMIC BACKGROUND. In 1948 R. A. Alpher and R. Herman reported theoretical investigations of cosmological models which would explain the abundance of the chemical elements. They concluded that the universe is filled with isotropic blackbody radiation with a characteristic temperature of a few Kelvin. This radiation was emitted by the 3000K cosmic plasma and has not interacted with matter since the plasma cooled sufficiently to form hydrogen. Because of the subsequent expansion of the universe, this radiation has cooled to a present temperature of $\sim$3K.

OBSERVATIONS. The first observation of the cosmic background radiation was made in 1965 by A. A. Penzias and R. W. Wilson who used a heterodyne radiometer at a wavelength of 7.35 cm. Subsequent microwave measurements by many observers at seven different wavelengths longer than 3mm have agreed with a blackbody spectrum with a temperature of $\sim$3K. Optical measurements of the obsorption spectrum of interstellar CN fit the same theoretical curve near its peak at $\sim$2mm. These measurements are summarized in the illustration.

SUBMILLIMETER WAVELENGTHS. Measurements beyond the peak have progressed more slowly for two main reasons: the difficulty of making measurements of adequate sensitivity in the submillimeter frequency range, and interference from "earthshine" emission by the atmosphere and hot objects that might be in the field of view. The seriousness of this earthshine problem increases very rapidly with frequency. At a wavelength of 0.7 millimeter, for example, a black room temperature object radiates 30,000 times more strongly than a 3 K blackbody.

Many attempts have been made to measure the background radiation in the submillimeter region of the spectrum using rocket and balloon platforms to minimize atmospheric emission. The rocket measurements were generally limited by the short time available to test the performance of the apparatus and to obtain data. Balloon measurements give longer observing times, but the data suffer from confusion with the thermal emission from the residual atmosphere at balloon altitude. The most successful direct measurements of the submillimeter background before 1975 agreed among themselves, but it had not yet been possible to establish the shape of the spectrum beyond the peak.

That situation remained unchanged until 1975 when the Berkeley results were reported. They used a fully calibrated balloon borne spectrophotometer to measure the spectrum of the radiant emission of the night sky in the wavelength range from 0.2 to 3 millimeters. The radiation was collected in a conical metal antenna which was carefully designed and exhaustively evaluated to minimize the uncertainty in the measurement due to "sidelobe" response. The portions of the antenna which were fully illuminated with radiation that reached the detector were cooled to liquid helium temperatures to minimize their emission. The effectiveness of this cooling was tested by varying the temperature of the antenna during the flight. The window which covered the antenna during ascent was removed to avoid emission from that source. Flowing helium gas was used to prevent residual atmospheric gases from freezing onto the cooled antenna.

The spectrum of the radiation accepted by the antenna was measured using the techniques of Fourier transform spectroscopy. Interference fringes from a helium cooled two-beam polarizing interferometer were recorded during the flight and Fourier transformed later to obtain the required spectra. A bolometer made from heavily doped germanium was used for the radiation detector. The scale factor and the base line for the absolute callibration were obtained by using external ambient temperature blackbodies and an internal helium temperature blackbody, respectively.

The spectra of the night sky measured from an altitude of 40 km were dominated by the atmospheric emission lines from oxygen, ozone, and water. Since the parameters of these lines are well known, it was possible to develop a model of the line emission with only two unknown parameters, the column densities of ozone and water. Since the spectra of these molecules are very different from that expected from the cosmic background radiation, it was possible to fit the model of the atmospheric emission to the data and then subtract it to obtain the spectrum of the cosmic background radiation shown as a cross-hatched region in the illustration.

The Planck curve for a 2.9 K blackbody is clearly in good qualitative agreement with all of the available data which measure the cosmic background radiation. This agreement provides strong evidence that the expected remnant of the "big bang" is indeed being observed. The blackbody temperature which best fits the Berkeley data is $2.99^{+0.07}_{-0.14}$. This is somewhat higher than the value

2.72 ± 0.16 K which best fits the data for wavelengths longer than 3 millimeters. Although there are theoretical reasons to expect small deviations from a Planck curve which correspond to a higher temperature at shorter wavelengths, a detailed statistical analysis indicates that all of the observations are consistent with a single temperature of ∿ 2.85 K.

ANISOTROPY. Attempts to observe any anisotropy in the cosmic background radiation are in progress at microwave and submillimeter wavelengths in several laboratories. The sensitivity required to observe a predicted anisotropy due to the motion of the observer relative to the center of mass of the universe will be achieved in some of these experiments. Other possible sources of anisotropy include a non-uniform matter distribution in the early universe.

(P. L. RICHARDS)

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Figure Caption: Present status of measurements of the spectral flux of the isotropic cosmic background radiation compared with the Planck curve for a temperature of 2.9K. The spectral flux is plotted as a function of inverse wavelength, and the error limits correspond to ∿ 90 percent confidence.

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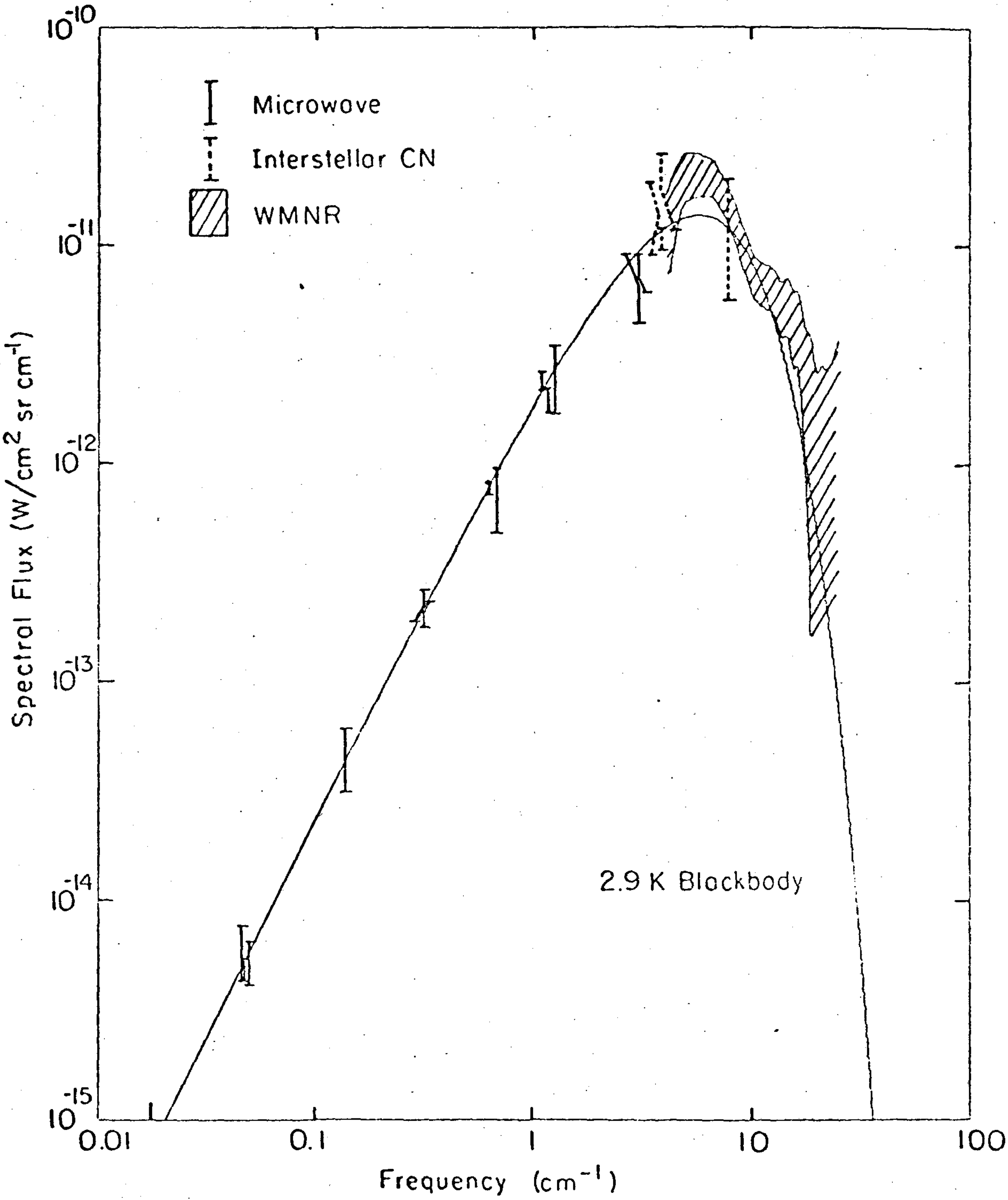

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LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720