0 0 0 0 4 2 0 8 3 7 0

Submitted to Physical Review Letters

LBL-3588
Preprint

A MEASUREMENT OF THE SPECTRUM OF THE SUBMILLIMETER COSMIC BACKGROUND

D. P. Woody, J. C. Mather, N. S. Nishioka,
and P. L. Richards

January 1975

Prepared for the U. S. Atomic Energy Commission
under Contract W-7405-ENG-48

For Reference

Not to be taken from this room

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY

LBL-3588

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

0 0 0 0 4 2 0 8 3 7 1

Submitted to Physical Review Letters LBL-3588

UNIVERSITY OF CALIFORNIA
Lawrence Berkeley Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

A MEASUREMENT OF THE SPECTRUM OF THE SUBMILLIMETER COSMIC BACKGROUND

D. P. Woody, J. C. Mather,* N. S. Nishioka, and P. L. Richards

JANUARY 1975

0 0 0 0 4 2 0 8 3 7 2

A Measurement of the Spectrum of the Submillimeter Cosmic Background

D. P. Woody, J. C. Mather,* N. S. Nishioka, and P. L. Richards

Department of Physics, University of California, and
Inorganic Materials Research Division,
Lawrence Berkeley Laboratory, Berkeley, California 94720

ABSTRACT

The spectrum of the night sky has been measured in the frequency range from 3 to 40 cm^{-1} using a fully calibrated helium cooled balloon based spectrophotometer at an elevation of 39 km. A model based on the known molecular parameters was used to subtract the atmospheric emission. In the frequency range from 4 to 17 cm^{-1} the spectrum of the background radiation is that of a blackbody with a temperature of $2.99^{+0.07}_{-0.14}$K.

The cosmic background radiation has been extensively measured in the Rayleigh-Jeans limit.[1] However, existing indirect measurements[2] and direct broadband measurements from balloon[3] and rocket[4,5] platforms have not established the spectral shape of this radiation beyond the peak of the blackbody curve. We report in this letter a direct measurement of this spectrum over the frequency range from 4 to 17 cm^{-1}.

A description of the apparatus used for this measurement has been published elsewhere.[6,7] The radiation was collected by a liquid helium cooled conical antenna with an apodizing horn[3] at the input to minimize diffraction sidelobes. The geometrical beam had a full width of 7.6° and the antenna pattern was measured out to 70° off-axis. A liquid helium cooled polarizing interferometer[8] was used as a Fourier spectrometer to measure the spectrum of the collected radiation. The detector was a germanium bolometer illuminated with germanium "immersion optics."[6,7] The cryostat was vented to the atmosphere and reached a temperature of 1.65K at float elevation.

The spectral flux responsivity of the apparatus was calibrated both in the laboratory and during the flight. The flight calibration obtained from a movable ambient temperature blackbody which filled 17 percent of the beam is shown in Fig. 1(a). This calibration agreed with laboratory calibrations to within a few percent.

The cryostat containing the antenna and the spectrometer was mounted in a gondola with the required telemetry and launched from Palestine, Texas by NCAR at 2008 CDT July 24, 1974. The gondola was suspended 0.6 km below the 3.3×10^5 m^3 balloon and was free to rotate about the vertical axis. Four hours of data were obtained at a float altitude of ~ 39 km.

Figure 1(b) shows the night sky spectrum measured by observing at a zenith angle of 24° with no window over the optics. The flow of helium boil-off gas from the cryostat was vented through the antenna. This was sufficient to prevent condensation of atmospheric gases into the cooled optics. Twenty-three interferograms with an (unapodized) resolution of 1.4 cm^{-1} were obtained during 69 minutes of observing as well as 2 interferograms with a resolution of 0.28 cm^{-1} during 24 minutes of observing. These data were averaged together, apodized, and Fourier transformed with linear phase correction to obtain the spectrum shown in Fig. 1(b). The spectral power can be obtained from it by dividing out the instrumental flux responsivity and adding a correction for the spectrometer temperature. The noise level shown is the rms detector noise for the high resolution interferograms alone.

These data were analyzed by fitting them to a model which contained four adjustable parameters. The cosmic background radiation was modeled by a blackbody spectrum with adjustable temperature. The model used for the atmospheric emission was based on tabulated line parameters for water, ozone, and oxygen.[9,10] The spectrum was computed by assuming an isothermal atmosphere, an exponential pressure profile, altitude-dependent pressure broadened Lorentzian lineshapes, and a constant mixing ratio for the three gases. The pressure at float altitude varied from 3.2 to 3.4 millibars. The ambient temperature measured during the flight was 215 ± 10K. The column densities of water, ozone, and oxygen were treated as adjustable parameters. The fitting was done using the measured interferogram and the Fourier transform of the product of the model spectrum and the responsivity of the apparatus. In this

way, the experimental resolution was included correctly and problems with unresolved lines were avoided. In addition, the more precise data were automatically weighted more strongly in the fit.

The small, but finite side lobe response of the antenna meant that some earthshine could have contributed to the measured signal. An attempt was made to measure this earthshine directly by comparing spectra obtained at a zenith angle of 45° with those obtained at 24°. The column densities of atmospheric emitters computed from the 24° spectra were scaled as the secant of the zenith angle and used to subtract the atmospheric contribution from the data obtained at 45°. The residual was assumed to be earthshine and was scaled back to 24° using the measured angular dependence of the antenna pattern.[6,7] The spectrum of the residual thus obtained was less than the noise and no earthshine correction was included in the model.

Information about the radiation emitted by the warm portion of the optical system was obtained by varying its temperature during the flight. The junction between the cone and the horn was heated from 3.4 to 16K. The emission of the antenna at the lower temperature was estimated from the increase in the observed signal to be substantially less than the detector noise, so no correction was made. No other warm parts of the apparatus are expected to contribute significantly to the collected radiation.

The calculated spectrum which gave the best fit to the observed data is shown in Fig. 1(c). The spectrum of a blackbody at the best fit temperature of 2.99K is shown as a dashed line. The values for the free parameters obtained from the fit are given in Table I. The fitted

value for the column density of oxygen agrees with the value 1.54×10^{22} mol/cm^2 computed from a mixing ratio of 21 percent and an altitude of 39 km. The values for all three gases are in good agreement with the results of other measurements at the same elevation.[3] To estimate the errors in our determination of the cosmic blackbody temperature the derivatives of the fitted blackbody temperature with respect to the most sensitive fixed and free parameters were calculated. The uncertainty in these parameters and the implied errors in the blackbody temperature are shown in Table I.

Figure 1(d) shows the difference between the observed spectrum in Fig. 1(b) and the calculated spectrum in Fig. 1(c). The magnitude of the noise can be estimated from the residual above 40 cm^{-1} where there is no optical signal. Since this residual is comparable in regions with and without optical signal it is dominated by random detector noise. No significant deviations between the model and the observed night sky spectrum are apparent.

The spectrum of the cosmic background radiation is obtained by subtracting the atmospheric contribution from the measured night sky spectrum. Figure 2 shows the measured spectrum of the cosmic background radiation compared with that of a 2.99K blackbody. Both curves are plotted with a constant fractional resolution of 20 percent. The two sigma error limits were computed by assuming that the residual in Fig. 1(d) was entirely random noise. The dramatic reduction of the noise compared with Fig. 1 is due to the large amount of low resolution data. This measurement establishes that the cosmic background radiation has a thermal spectrum from 4 to ~ 17 cm^{-1}, where the curve has fallen

to ≈ 10 percent of its peak value.[11]

We have plotted our data for the thermodynamic temperature as a function of frequency in Fig. 3 along with selected narrow band results of other experiments. Over a frequency range of three and one-half decades these measurements of the cosmic background radiation (as well as those of previous high frequency broadband experiments[3-5]) are consistent with a thermal spectrum with a temperature of from 2.7 to 3.0K. The results from our experiment alone are $2.99\ ^{+.07}_{-0.14}$ (90% confidence).

The authors are greatly indebted to many persons for assistance with this experiment. Professor C. S. Bowyer suggested the project and provided a balloon for the first flight. Professor K. A. Anderson provided the gondola and a nearly ideal array of telemetry equipment. Mr. J. H. Primbsch gave invaluable assistance in all areas in the art of ballooning. Mr. B. W. Andrews helped with design calculations, and the NCAR staff at Palestine, Texas provided us with two successful balloon flights.

This work was supported in part by the U.S. Energy Research and Development Administration, and in part by the Space Sciences Laboratory, University of California, Berkeley under NASA Grant NGL05-003-497.

REFERENCES

* Present address: Goddard Institute for Space Studies, 2880 Broadway, New York, N.Y. 10025.

1. P. J. E. Peebles, Physical Cosmology (Princeton University Press, 1971).
2. D. J. Hegyi, W. A. Traub, and N. P. Carleton, Astrophys. J. 190, 543 (1974).
3. D. J. Muehlner and R. Weiss, Phys. Rev. Letters 30, 757 (1973).
4. K. D. Williamson, et al., Nature Phys. Sci. 241, 79 (1973).
5. J. R. Houck, B. T. Solfer, and M. Harwit, Ap. J. 178, L29 (1972).
6. J. C. Mather, P. L. Richards, and D. P. Woody, IEEE Trans. Microwave Theory Tech., 22, 1046 (1974).
7. J. C. Mather, Far Infrared Spectrometry of the Cosmic Background Radiation, Ph.D. thesis, University of California, Berkeley, Jan. 1974.
8. D. H. Martin and F. Puplett, Infrared Phys. 10, 105 (1969).
9. R. A. McClatchey, et al. AFCRL Atmospheric Absorption Line Parameters Compilation, AFCRL-TR-73-0096, Environmental Research Papers No. 434, January 1973.
10. H. A. Gebbie, et al. Proc. Roy. Soc. A 310, 579 (1969).
11. No significant bias is introduced by assuming a blackbody background when fitting the atmospheric parameters. If we assume no background radiation in the fit, or if we assume it has no sharp features and fit the atmospheric model to the data with large path difference, the estimate of the amount of O_2 is increased and the derived spectra fall below that in Fig. 2 (between 12 and 17 cm^{-1}), but within the error limit. The procedure used for Fig. 2 is preferable because the rms residual is smaller and the O_2 density agrees with the

accurate value known from the pressure and the mixing ratio.

12. P. Thaddeus, Annual Review of Astron. and Astrophys. 10, 305 (1972).

0 0 0 0 4 2 0 8 3 7 6

FIGURE CAPTIONS

Fig. 1(a). Instrumental flux responsivity as a function of frequency. (b) Observed instrumental response to the night sky. (c) The fitted model spectrum. The origins of some of the stronger atmospheric emission lines are shown. (d) The difference between curves (b) and (c).

Fig. 2. The present measurement of the cosmic background radiation compared with a 2.99K blackbody curve. Both curves are plotted with a constant fractional resolution of 20 percent.

Fig. 3. The present measurement ($\pm 2\sigma$) of the thermodynamic temperature of the cosmic background radiation compared with selected results of other experiments. The data for frequencies $\leqslant 3\ cm^{-1}$ were obtained using ground based microwave radiometers (see Ref. 1). The data at 3.8 and 7.6 cm^{-1} were obtained from optical measurements of cyanogen (see Ref. 2 and 12).

TABLE I. Model parameters and errors

	Value with 90% confidence limits	Error in blackbody temperature[a]
Fixed Parameters:		
Atmospheric temperature	215^{+35}_{-10} K	$^{+.05}_{-.02}$ K
Calibration factor[b]	$33.2^{+3.3}_{-3.3}$ K	$^{+.05}_{-.06}$ K
Earthshine	$0^{+6}_{-0} \times 10^{-13} \nu^{1/2} \frac{W}{cm^2 sr\ cm^{-1}}$	$^{-.13}_{+.00}$ K
Fitted Parameters:		
H_2O vertical column density	$3.92^{+.20}_{-.20} \times 10^{17} \frac{molecules}{cm^2}$	$^{-.001}_{+.001}$ K
O_3 vertical column density	$3.50^{+.18}_{-.18} \times 10^{17} \frac{molecules}{cm^2}$	$^{-.02}_{+.02}$ K
O_2 vertical column density	$1.67^{+.17}_{-.17} \times 10^{22} \frac{molecules}{cm^2}$	$^{-.01}_{+.01}$ K
Blackbody temperature[c]	$2.99^{+.07}_{-.14}$ K	

[a]Error induced in fitted blackbody temperature by parameter errors quoted in column two.

[b]Product of calibrator temperature and filling factor

[c]Error determined by the rms sum of the detector noise plus the errors shown in column three.

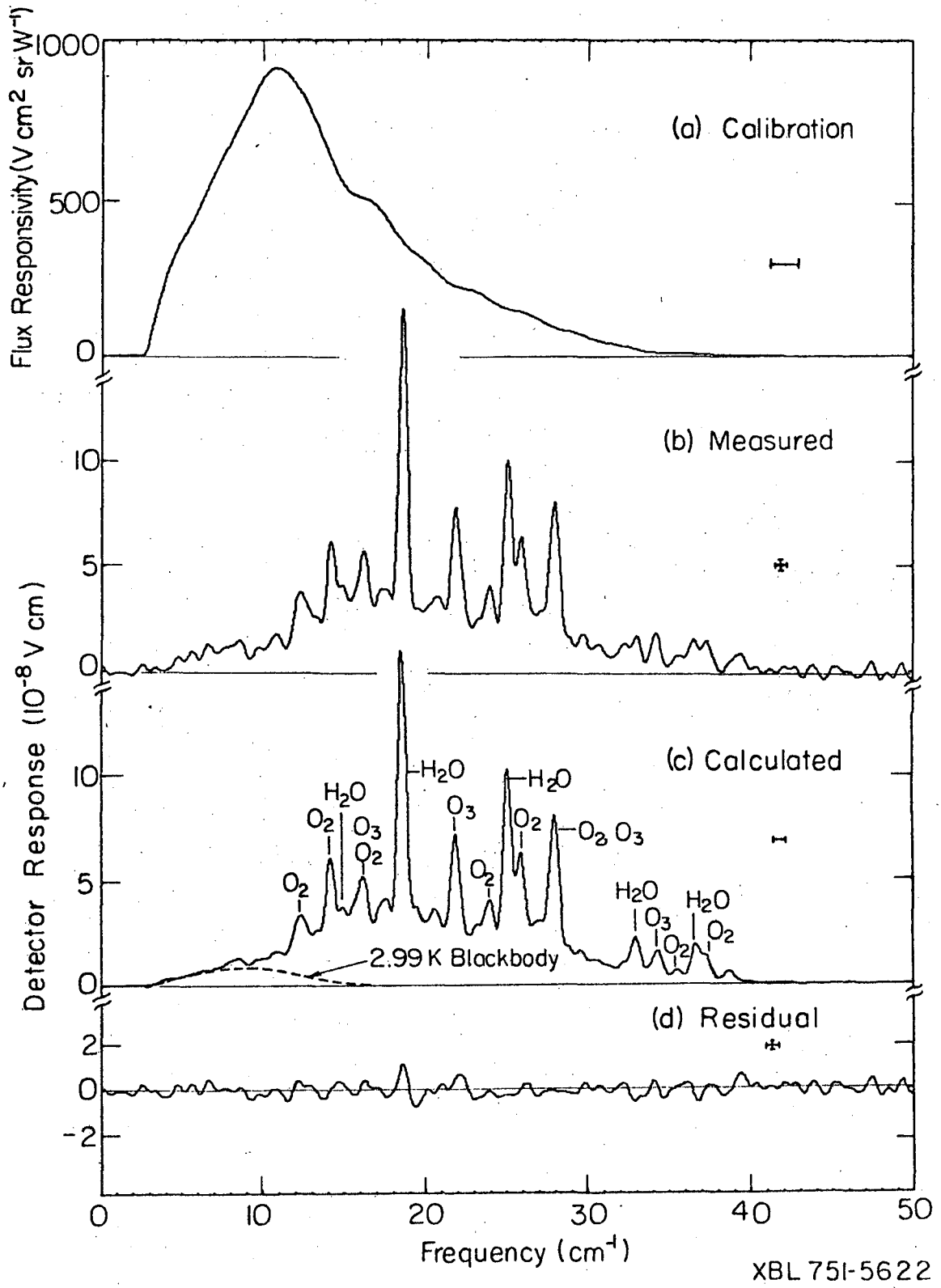

Flux Responsivity (V cm² sr W⁻¹)
1000
500
0
(a) Calibration
(b) Measured
10
5
0
Detector Response (10⁻⁸ V cm)
(c) Calculated
H₂O
O₂
O₃
2.99 K Blackbody
(d) Residual
2
0
-2
0
10
20
30
40
50
Frequency (cm⁻¹)
XBL 751-5622

Fig. 1

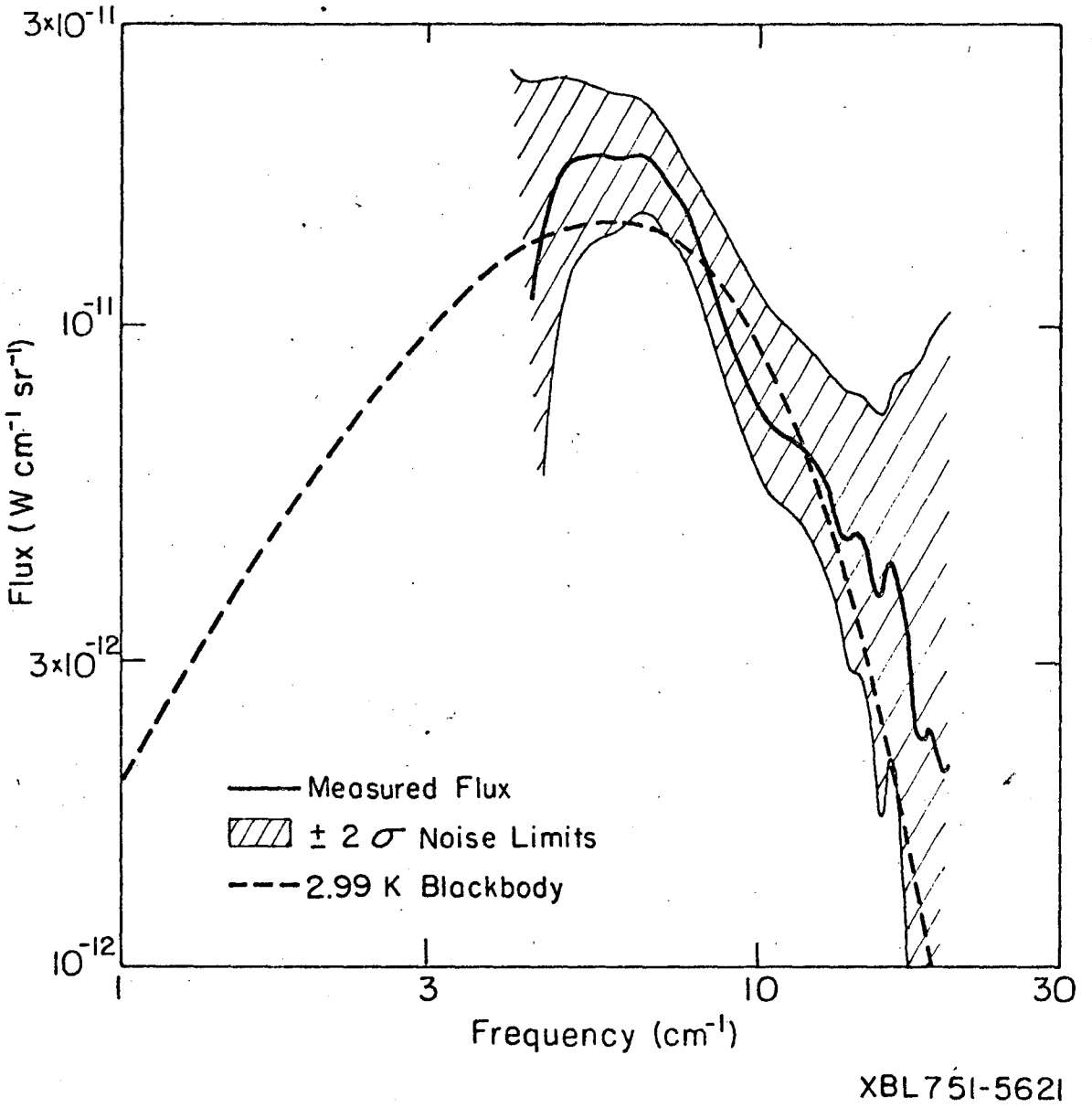
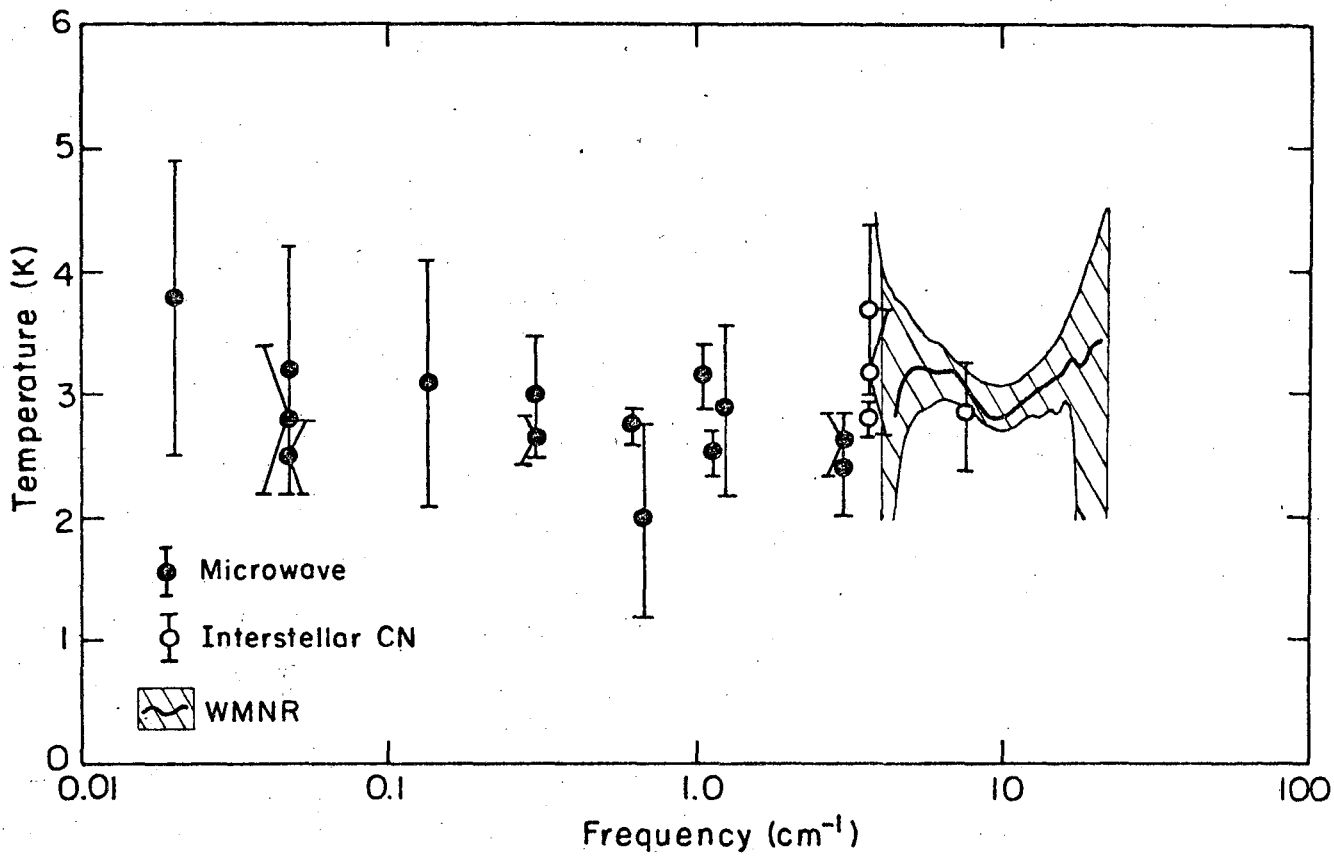

3×10⁻¹¹
10⁻¹¹
3×10⁻¹²
10⁻¹²
Flux (W cm⁻¹ sr⁻¹)
1
3
10
30
Frequency (cm⁻¹)
Measured Flux
± 2 σ Noise Limits
2.99 K Blackbody
XBL751-5621

Fig. 2



XBL751-5620

Fig. 3

0 0 0 5 4 2 0 8 3 7 9

LEGAL NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720