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[14]The k' parameters 1 and 2π involve the feedback coefficient of the universe as calculated according to Birkhoff or Einstein, respectively (see Ref. 9).

Further Measurements of the Submillimeter Background at Balloon Altitude*

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Measurements of the far-infrared background radiation were made with a balloon-borne radiometer at an altitude of 44 km. Equivalent blackbody temperatures of $2.55^{+0.25}_{-0.45}$, $2.45^{+0.45}_{-1.05}$, and $2.75^{+0.8}_{-2.75}$°K were obtained for the background radiation in bandwidths extending from 1 to 11.5, 13.5, and 18.5 cm^{-1}. The total measured flux in the largest bandwidth is dominated by the atmospheric emission by ozone and water. The radiation of these atmospheric components was determined independently in a separate pair of radiometer spectral responses.

This Letter reports the results of a balloon flight made on 1 October 1972 from the National Center for Atmospheric Research (NCAR) Scientific Balloon Facility at Palestine, Texas. The results of earlier flights and a description of the instrument have been published.[1] There were several differences between this and previous flights.

(1) The radiometer had new filters which gave the overall system responses shown in Fig. 1. SR1 is the same as in previous flights. SR2 and SR3 are determined by sharp-cutoff low-pass capacitive-grid interference filters with cutoff frequencies chosen to reject atmospheric radiation. SR4 and SR5 are determined by two-element capacitive-grid filters with transmission peaks at the 22-cm^{-1} Q branch of ozone and the 18.6-cm^{-1} water line. The purpose of these narrow-band filters was to allow specific measurements of the ozone and water radiation, which are used to subtract the atmospheric contributions to the signals in the other spectral responses. This procedure is intended to supplement zenith scanning, which can only give a lower limit for the atmospheric contribution.

(2) The measurements were carried out at 44

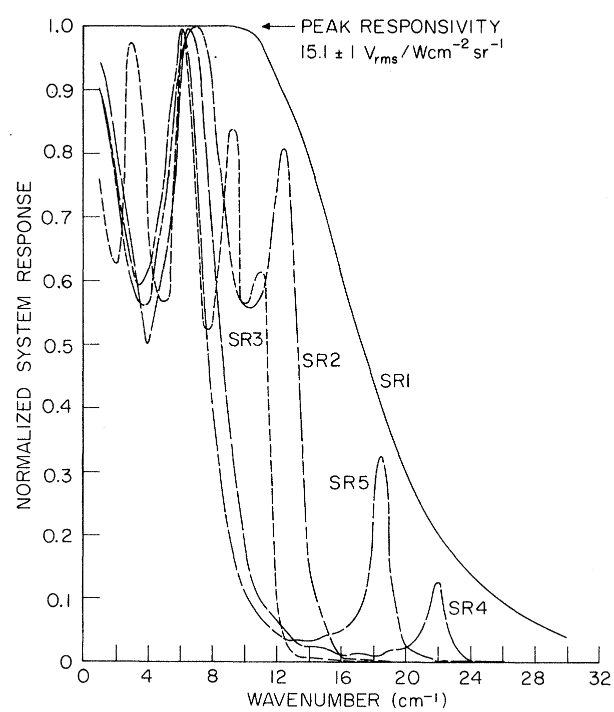

FIG. 1. Spectral responses of radiometer.

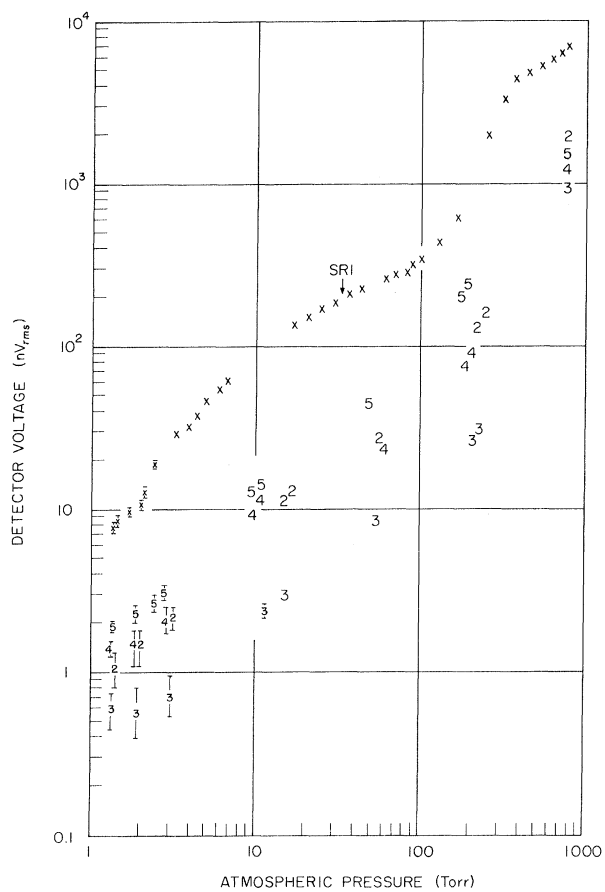

FIG. 2. Radiometer signal during ascent.

km, corresponding to an atmospheric pressure of 1.4 mm. This was 5 km higher than the altitude obtained in previous flights of the instrument. Figure 2 shows the variation in detected signal with atmospheric pressure on ascent in each spectral response. The curve for SR1 is in agreement with earlier measurements for pressures higher than 2.5 mm and continues to decrease at lower pressures.

(3) The instrument was equipped with a large reflector which shielded the radiometer from radiation by the earth and lower atmosphere. The principal purpose of this shield was to determine if the increase of signal with zenith angle observed in this and earlier flights might have been caused in part by radiation from the ground entering the radiometer at large angles to the optic axis. By removing the shield during the flight, we established that the shield made less than a 2% change in the signal in SR1 at the maximum zenith angle of 46.5°. This confirmed that the zenith-angle dependence is due to the atmosphere.

The results of the flight are summarized in Table I. The estimates of the atmospheric contributions to the total signals are based on both calculations and measurements. The oxygen contribution is calculated from the spectral response curves of Fig. 1 and the known fine-structure and rotational spectra of oxygen, as well as its column density above 44 km (8.4×10^{21} mol/cm^2). The water and ozone contributions are calculated by using the signals in SR4 and SR5. The relative intensities of ozone and water radiation in the different spectral responses were determined by measuring the thermal emission of these gases at room temperature in a low background emissivity cell placed over the radiometer. We separate the ozone and water contributions in SR4 and SR5 in flight by assuming that the background radiation in the low-pass parts of these spectral responses is that of a 2.7 ± 0.2°K blackbody. This procedure is justified by the results of earlier measurements of the background radiation at these frequencies.[1] The ozone and water contributions in SR1, SR2, and SR3 are calculated by using the measured ratios. The increase of the SR1 signal with zenith angle is consistent with the results of these calculations.

The minor atmospheric constituents such as N_2O, NO_2, NO, CO, HNO_3, and OH contribute at worst 1% of the total atmospheric emission.

The cone correction is an estimate of the emission by the low-emissivity cone that shields the radiometer from stray radiation at large angles to the optic axis. The cone and the method by which the cone correction is calculated have been described.[1]

The "detector radiation" correction comes from an effect in InSb which we considered only recently. The carrier electrons in the detector are at a higher temperature than the crystal lattice since they are heated by the bias current and transfer energy to the lattice slowly. By direct measurement of the radiation emitted by the detector, we have established that the carrier electrons are at ~3.8°K when the bath and the lattice are at 1.5°K, as at float altitude. These measurements will be described in a separate paper.

Emission by the detector affects the radiometer signal because, in the flight, we refer the signals measured in the various spectral responses to the signal seen with an opaque reflector in the beam. This procedure eliminates instrumental offsets, but also reflects about 10% of the detector radiation back to the detector. In

TABLE I. Results of 1 October 1972 flight. Signals are given in nanovolts at the detector.

	SR1	SR2	SR3	SR4	SR5
Tot. Sig. at 44Km altitude (nV) Zenith Angle 20.5°	6.86±.36	1.18±.36	0.73 ± .22	1.32±.22	1.86±.15
46.5°	8.14±.36				
Total Signal	4.55±.15	$3.0^{+.25}_{-.3}$	2.6 ± .2	3.29±.2	3.9 ± .15
Equiv. Black Body T[a] (°K)	4.85±.15				
Atmospheric Radiation O_2(nV) 8.4×10^{21} mol/cm^2	0.63	0.095	0.048	0.051	0.073
H_2O(nV) $(1.8\pm1.7)\times10^{17}$ mol/cm^2	1.68±1.46	0.107±.093	0.0094±0.0082	0.094±.082	0.63±0.55
O_3(nV) $(2.1\pm2)\times10^{17}$ mol/cm^2	3.12±3.06	0.352±.346	0.101 ± 0.099	0.455±.445	0.515±.505
Cone Radiation (nV)	0.19	0.014	0.007	.01	.01
Corrected Detector Sig.(nV)	$1.24^{+2.2}_{-3.3}$[b]	.612 ± .5	.565 ± .23		
Equivalent Corrected Black Body T[a] (°K)	$2.75^{+.8}_{-2.75}$[b]	$2.45^{+.45}_{-1.05}$	$2.5^{+.25}_{-.45}$		
Normal. Box Bandwidth (cm^{-1})	1 → 18.5	1 → 13.5	1 → 11.5		
Spectral Density 10^{-12} Watts/cm^2 sr cm^{-1}	$5.8^{+10}_{-5.8}$[b]	4.9±4.3	6.0 ± 3.0		
Corr. due to Detector Rad. Added to Total Signal (nV)	.43 ± .2	.3 ± .15	.24 ± .12	.22 ± .1	.19 ± .1

[a]Determined by absolute calibration. [b]Limit determined to be consistent with zenith scanning data.

the absolute calibration, the signals are not referred to the opaque reflector, but rather to a blackbody source at the temperature of the liquid-helium bath which does not reflect the detector radiation. As a result the flight measurements have to be corrected.

The data are best presented as the temperature of a blackbody that gives an equivalent signal in each spectral response, since this offers the most direct comparison between the primary calibration of the instrument and the measurements.

In order to estimate the spectral density of the background flux, it is necessary to assign equivalent bandwidths to the spectral responses. The effective bandwidths given for the spectral responses are necessarily somewhat arbitrary, especially in the case of SR1. The low-frequency cutoff at about 1 cm^{-1} for all spectral responses is an effect of the lower aperture of the collimating cone. The effective high-frequency cutoff given for SR1 is the cutoff frequency of an ideal square band-pass response which, below its cutoff frequency, has the same sensitivity as SR1 in its maximum region, and which would give the same signal as SR1 for a flat input spectrum. The cutoff frequencies shown for SR2 and SR3 are those at which their response is ~50% of their average low-frequency response.

Figure 3 presents the spectral density of the background radiation measured in this flight superposed on the spectrum of a 2.7°K blackbody. The data are consistent with the hypothesis that the background radiation is that of a blackbody at 2.7°K. The uncertainty in the data, however, allows us only to set limits on the background radiation above 13 cm^{-1} comparable to those of previous flights. Part of the trouble in this flight was the short time at float altitude, only $1\frac{1}{2}$ h, because the instrument was swept into high and unfavorably directed winds which forced an early termination. A more fundamental difficulty is that the atmosphere contributes approximately 30 times more power than a 2.7°K blackbody in SR1 in the region above 13 cm^{-1}. The uncertainty in the background flux in SR1 is caused primarily by the noise in the SR4 and SR5 signals, which is propagated through the subtraction of the atmospheric contribution.

In conclusion, the new data confirm the results of prior flights, in particular, that a substantial

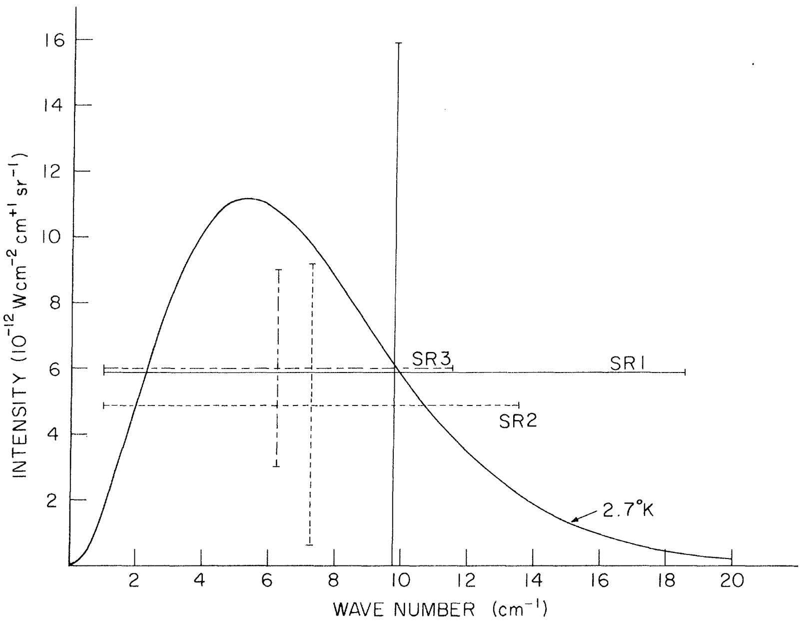

FIG. 3. Spectral flux from 1 October 1972 flight compared with 2.7°K blackbody.

amount, and perhaps all, of the radiation above 13 cm^{-1} is due to the atmosphere. At present, all direct measurements of the submillimeter background, including this new result, are in agreement but it has not been possible to establish the spectrum above 12 cm^{-1}.[2,3] Further measurements with broad-band radiometers at balloon altitudes to determine the spectrum of the background radiation at these high frequencies do not now seem promising. High-resolution spectrometers that can look between the ozone lines are another possible approach if far-infrared technology, particularly that of detectors, is improved. Better still, the experiment is an excellent candidate for a spacecraft platform, possibly the space shuttle.

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