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MICROWAVE BACKGROUND RADIATION

MICROWAVE BACKGROUND SPECTRUM - SURVEY OF RECENT RESULTS

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Introduction

For those enamoured of the primaeval fireball, the relict radiation has proved a tantalising mistress. Since the famous discovery in 1965, by Penzias and Wilson, of an excess antenna temperature consistent with cosmological expectations, many observers have succeeded in measuring a flux consistent with a thermodynamic temperature of ~3K. Until recently, however, no *direct* spectral measurements had been made at wavelengths shorter than the Planckian peak corresponding to radiation at this temperature. At such wavelengths atmospheric emission and absorption are overwhelming from even the highest mountain site and observations must be made from at least balloon platforms. The pioneering broadband rocket and balloon measurements covering this wavelength region produced consternation when excessively high fluxes were reported; successive flights gradually eliminated the excess, emphasising the practical difficulties of such observations. A review of this phase of the pursuit is given by Blair[1]. Nevertheless, it is upon direct submillimetre measurement of the spectral density I_ν that confidence in the interpretation of the longer wavelength results must reside. The outcome of the first such measurement, by Queen Mary College in 1974, seemed completely to justify such confidence. Unfortunately, the subsequent observations by Berkeley, *although leading to the same conclusion* about the value of the thermodynamic temperature, were so discrepant in detail from those of QMC as once again to raise doubts. We have since been eagerly awaiting the results of observations by independent groups but these have been frustrated by instrumental failures. We attempt here to assess the present situation. We conclude that although present measurements indicate a flux not inconsistent with a Planckian spectrum corresponding to a temperature of ~3K, they do not demand such an interpretation. Moreover, because we may not actually *expect* a Planckian curve from a fireball, very much more detailed information is needed to obtain a view of the early thermal history of the universe.

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Review of Observations

A total of 16 direct monochromatic (radiometer) measurements has been made[2-16] from the ground, mountain peaks and an aircraft platform. (A recent, quasi-monochromatic measurement at ~1.2mm[17] sets an upper limit and is discussed below). The weighted mean of these results, if interpreted in terms of a Planck spectrum, gives a thermodynamic temperature of 2.73 ± 0.08K. The value of χ^2 for these is 9, compared with an expected value of 15 ± 5. Although it is well within the 95% confidence level, the low value may reflect, as has been remarked by Peebles[18], a justifiable caution on the part of observers.

Three groups, Cornell, MIT and Los Alamos, have flown rockets or balloons to make broadband measurements of the background flux; the detailed history of these is discussed by Blair[1]. In spite of the very high submillimetre fluxes initially reported, apparently supported by observation of submillimetre line emission[19] which has certainly not been substantiated[20],[21],[22] the latest broadband measurements are mutually consistent and consistent with a temperature of 2.7K. However, as Blair points out, the Cornell and Los Alamos results are equally consistent with a temperature of zero and only MIT provides positive evidence of a 2.8 ± 0.2K equivalent flux.

Finally, a series of temperatures and upper limits have been deduced from observation of interstellar molecular absorption lines (see review by Thaddeus[23]), the most precise of which gives a temperature of 2.83 ± 0.15 K at 2.62mm. Such observations are, of course, measures of excitation and only by interpreting this excitation as being directly due to background continuum radiation does one arrive at a temperature. Although arguments against other excitation mechanisms are persuasive, the submillimetre upper limits do not impose very severe restraints upon the background. However it should be stressed that the early interstellar molecular line observations, giving upper limits to a cosmic background flux at wavelengths of 1.32mm, 0.56mm and 0.36mm were historically most important. During the same period, broadband rocket and balloon experiments were reporting extremely high fluxes in just this wavelength region. For the molecular line measurements and the broadband results to be at all consistent, one possibility was for the "excess" flux to be extremely local in origin; another featured the presence of a spectral line, leading to the 11.7 cm^{-1} emission feature saga mentioned above. The 1.32mm upper limit has now been replaced by the assignment of a definite temperature of 2.9 $^{+0.4}_{-0.5}$ K [29].

The shorter wavelength monochromatic, and the latest broadband and interstellar excitation measurements are summarised in figure 1, which emphasises the need for the subsequent short-wavelength spectral measurements.

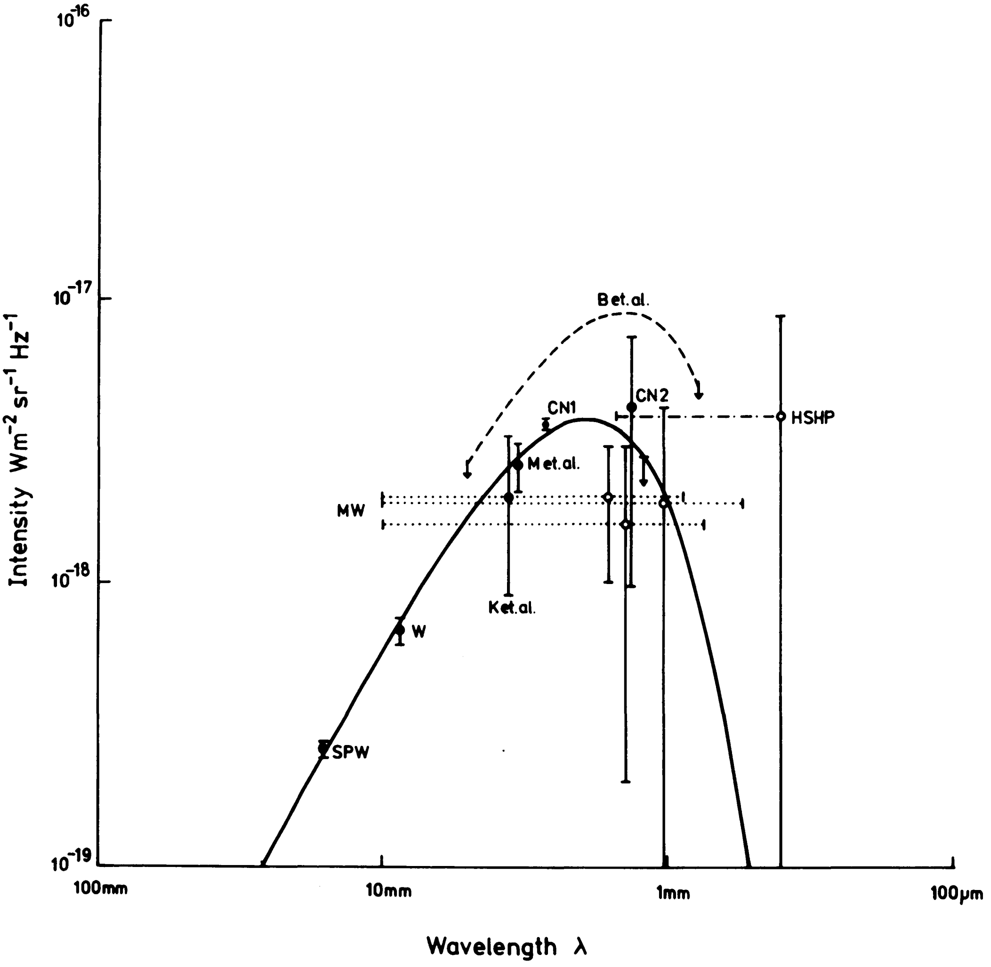

Figure 1 Short-wavelength monochromatic, broadband and interstellar excitation observations of the background flux. References as follows: SPW (8); W (11); K et al. (13); M et al. (15); MW (23); B et al. (25); HSHP (26); CN1 (27); CN2 (28).

Balloon-borne Spectrometric Observations

In spite of having been made over two years ago, the balloon-borne spectrophotometric observations of QMC[30] and Berkeley[31] remain, unfortunately, the only such measurements. A recent re-flight by Berkeley had instrumental difficulties and added little new data. The long-awaited announcement of results by an independent group has not appeared, at least one experiment having suffered mechanical failure under the severe conditions experienced in the stratosphere.

At first sight, the temperatures deduced by QMC and Berkeley, $2.7^{+0.2}_{-0.3}$ K and $2.99^{+0.07}_{-0.14}$ respectively, are in remarkable and encouraging agreement. Detailed comparison of the observed spectra (cf. discussion in Rowan-Robinson[32]) quickly cools enthusiasm. In spite of similarities of instrumentation and flight conditions, the observed spectra differ considerably in the contribution of the residual atmosphere, this appearing to be much more significant in Berkeley's result. While QMC believed that they could distinguish directly the turnover of a 2.7 K Planck spectrum at ~1mm wavelength, Berkeley obtained their temperature by fitting an emission model to their spectrum. Their model atmosphere is isothermal, has an exponential pressure profile and constant mixing ratio and uses tabulated line parameters, some of which (Oxygen lines:- Gebbie, private communication) are somewhat uncertain. As free parameters, they used the column densities of oxygen, ozone and water vapour and the temperature of a Planck spectrum.

Assessment of Present Position

All the present direct observations of the background flux are summarised in figure 2, where the logarithm of antenna temperature, T_A, is plotted against the logarithm of the wavelength λ. Antenna temperature, defined by

$$I_\nu \equiv \frac{2\nu^2}{c^2} kT_A ,$$

where I_ν is the specific intensity at frequency ν, has been chosen as a direct measure of I_ν, avoiding the prejudice of deducing a thermodynamic temperature. Filled circles are results of references 2-16. The bounded region above 2.5mm represents the 2σ limits of the Berkeley group *when they fit a Planck spectrum*; the error bars on the open circles (QMC) are 1σ. The solid line corresponds to a Planck spectrum of 2.82 ± 0.06 K, the weighted mean of all results shown. ($\chi^2 = 12.6$, compared with an expected 16 ± 6). You will see that the curve does not fit entirely within either the QMC 1σ or Berkeley 2σ limits; *neither does a 2.99 K* curve, corresponding to Berkeley's best estimate of the temperature. In fact, although one can claim that present results indicate a dramatic drop of antenna temperature at short wavelengths, they cannot be said to be strong evidence for a *Planck* spectrum. Also, the upper limit of 2.7 K at 1.2mm imposed by the recent Italian mountain based observation[17] is rather embarrassingly low. Although this measurement is extremely difficult and should therefore be treated with some caution, it well indicates the uncertainty in this spectral region.

Finally, the dotted line shows a fairly extreme Compton-distorted[33] spectrum (adapted from Chan and Jones[34]). It is clear that the precision of present measurements is completely inadequate to determine such distortions with any confidence; we believe that this

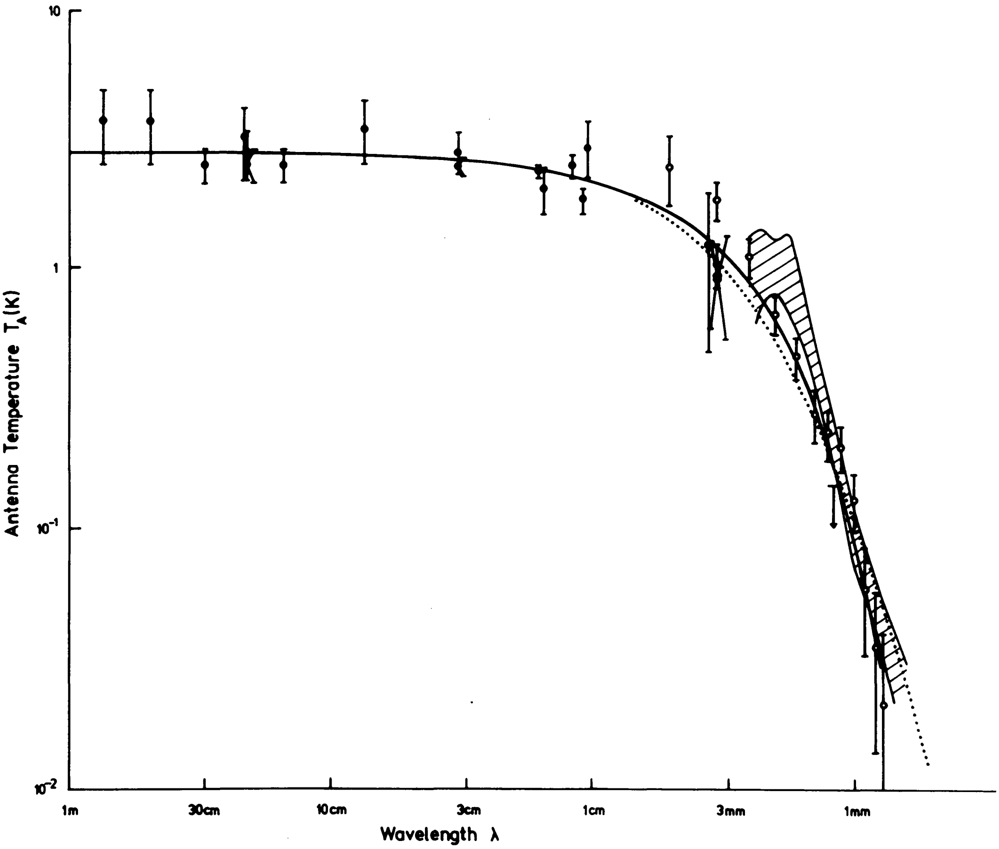

Figure 2 Monochromatic and spectral measurements of the background antenna temperature. References: Filled circles (2-16); open circles (QMC, 30); hatched region, Berkeley 2σ limits (31); upper limit (17); Solid curve, 2.82 K Planck spectrum; dotted curve, Compton-distorted spectrum (see text).

will remain true for observations at balloon altitudes.

Conclusions

The considerable effort devoted to observing the microwave to submillimetre background flux has not, in my opinion, unambiguously demonstrated the Planckian nature of its spectrum. Indeed, because of the discrepancy between the two submillimetre spectral observations, even the point of turnover of the spectrum is open to question, although this matter should be settled by future balloon observations.

Even further are we from investigating thermal events in the early universe by measuring departures from a Planck curve. We are convinced that only by making observations from space platforms, clear of the contamination by atmospheric radiation, may we hope to obtain this information.

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DISCUSSION

Partridge: Would you comment further on the apparent differences between your results and those of the Berkeley group? In particular, could you say why your atmospheric spectrum differs from theirs?

Robson: The crucial points are that in the QMC spectra the atmosphere does not dominate the cosmic background spectrum, whereas in the Berkeley results the atmosphere appears as a continuum spectrum which must first be subtracted before the cosmic background spectrum can be measured.

COSMIC BACKGROUND EXPERIMENT FROM SPACE

S. Gulkis

The United States space agency, NASA, has recently appointed a team of six scientists to study high sensitivity measurements of the diffuse infrared and microwave background radiation from a dedicated satellite in space. The study will last for one year and produce a preliminary plan for a spacecraft experiment. Presently, three groups of instruments are being considered which will measure the diffuse infrared and microwave background over the broad range from 5 microns to 2 cm wavelengths. The three groups of instruments consist of a cryogenic far infrared spectrometer which covers the frequency range from 3 to 30 $^{-1}$, to measure the spectrum of the 3 K background; a group of differential radiometers using microwave and infrared techniques to cover the frequency range 0.5 to 20 cm^{-1} (15 to 600 GHz), to measure anisotropy of the 3 K background; and finally a large beam absolute radiometer which covers the range from 100 to 2000 cm^{-1}, to measure zodiacal dust emission, galactic dust, and extragalactic diffuse light. The spatial resolution of the anisotropy measurements will be ~ 10° and be able to measure temperature differences of approximately 0.0001 K on that scale. The spectrum experiment is planned to be able to detect a spectral intensity which departs from a best-fitting blackbody by one part in 10^{4} with a resolution of 1 cm^{-1}.