

# LETTERS TO THE EDITOR

## ASTRONOMY

### Interpretation of Cosmic Microwave Background

THE discovery of microwave background radiation by Penzias and Wilson<sup>1</sup> is one of the most interesting events in observational astronomy in recent years. On the basis of the first observations at a single wavelength, the radiation was interpreted<sup>2</sup> as being of the black-body type, and it was concluded that this was the remnant of the primordial radiation of a big-bang universe. Later results by different observers have strengthened this interpretation. Indeed it is now claimed<sup>3,4</sup> that the black-body curve applies for a wavelength range of 1:90, and corresponds to a temperature  $T = 2.68^\circ \text{K}$ . The observers<sup>5</sup> go as far as to state that the exact black-body intensity curve

$$\mathcal{I}(\nu) \propto \frac{\nu^3}{e^{h\nu/kT} - 1} \quad (1)$$

fits the observations better than the "grey-body" approximation at long wavelengths—namely

$$\mathcal{I}(\nu) \propto \nu^2 \quad (2)$$

The purpose of this communication is to examine this interpretation in the light of available information about the universe. We begin by noting that if the observations are taken at their face value, one of the two possible conclusions can be drawn:

- (I) The entire observed cosmic background is in fact the remnant of the primordial black-body radiation.
- (II) If there are other processes operative in the universe capable of producing a microwave background of the observed magnitude, the present observations disprove (I).

It must be emphasized that for (II) to hold, it is not necessary that the microwave radiation produced by the other processes should follow the law (1) or (2). It is only necessary that the contribution be comparable with that observed in the relevant frequency range.

A few months ago one such process was indeed suggested<sup>6,7</sup>. The process consists of the absorption of optical and ultraviolet radiation from stars and its re-radiation at longer wavelengths by impurity oscillators in the interstellar dust grains of galaxies. This process could operate in all galaxies provided interstellar dust is present. It was also shown that in the steady state universe, because of the red-shift effect, radiation along a line with frequency  $\nu = \nu_0$  is smeared out in the form of a spectrum

$$\mathcal{I}(\nu) \propto \begin{cases} \nu^3 & \nu \leq \nu_0 \\ 0 & \nu > \nu_0 \end{cases} \quad (3)$$

The actual spectrum observed would be a superposition of several such spectra, arising from different  $\nu_0$ .

Although this calculation refers to the steady state universe, the process in question could equally well operate in a big-bang universe, but there are two points of difference. The red-shifts permitted in the steady state universe can be infinite; in the big-bang universe, there is an upper limit set by the epoch of galaxy formation. At present we have no definite theory of galaxy formation available to fix this epoch, but red-shifts up to  $z \approx 100$  may still be permitted. Such a factor is sufficient to bring the far infrared frequencies into the microwave range<sup>7</sup>. The second point of difference arises in that the evolutionary

cosmologies permit the use of arbitrary epoch-dependent functions—a freedom denied to the steady state theory. Such functions have been extensively used<sup>8,9</sup> to make the predictions of big-bang universes agree with observations.

On the assumption that there is no epoch-dependence, however, the function  $\mathcal{I}(\nu)$  corresponding to a single line  $\nu = \nu_0$  may be computed in a relativistic cosmological model. The calculation is particularly simple if we assume that only the matter density makes a significant contribution to  $T^{ik}$  in the Einstein equation—an assumption which seems to be justified from our present knowledge of the universe. The result can be expressed in terms of  $q$ , the deceleration parameter<sup>10</sup>. We have

$$\mathcal{I}(\nu) \propto \begin{cases} \frac{\nu^{3/2}}{\sqrt{2q\nu_0 - (2q-1)\nu}} & \text{for } \nu_1 \leq \nu \leq \nu_0 \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

Here  $\nu_1$  is the lower limit set by the epoch of galaxy formation. (This form of  $\mathcal{I}(\nu)$  can be altered almost at will by the use of arbitrary epoch-dependent functions, so that we attach no special significance to it.) For the Einstein-de Sitter universe,  $q = \frac{1}{2}$  and  $\mathcal{I}(\nu) \propto \nu^{3/2}$ . For the empty hyperbolic universe  $q = 1$  and  $\mathcal{I}(\nu) \propto \nu$ .

It remains to discuss the order of magnitude of this radiation. Shakeshaft and Webster<sup>4</sup> have argued that the black-body radiation density is about 400 times greater than the energy density of star-light from all galaxies, and quote this result from a review by Davidson and Narlikar<sup>10</sup>. We wish to point out that the factor arose on the hypothesis that the radiation was of the black-body type. The radiation density corresponding to a black-body radiation temperature is

$$\sim 3.8 \times 10^{-13} \text{ erg cm}^{-3} \quad (5)$$

This energy density corresponds, however, to radiation over all frequencies. We are here concerned only with a limited wavelength range over which radiation has actually been observed, namely, from 36.6 GHz to 408 MHz, the factor of 1:90 quoted by Shakeshaft and Webster<sup>4</sup>. (In fact the process considered by us does not operate over all frequencies, as is clear from (3) and (4).) The radiation density over the observed range is less than

$$\sim 6 \times 10^{-15} \text{ erg cm}^{-3} \quad (6)$$

a figure comparable with the optical radiation density (Davidson and Narlikar, *op. cit.* page 553). Furthermore, we had allowed ourselves a factor 10–100 over and above the optical radiation density in young galaxies (not the local galaxy as quoted by Shakeshaft and Webster). We conclude therefore that there is no energy difficulty associated with this process.

Shakeshaft and Webster<sup>4</sup> have raised objections to the mechanism of thermalizing starlight. We fail to see the relevance of their arguments. While it is true that there are essential and vital differences between the electrical properties of graphite and those of alkali halides, these differences are clearly not significant for the process we consider. A weakly bound impurity atom or ion in any crystal lattice would be expected to have a localized low frequency oscillation mode, the frequency of which is determined almost entirely by the ratio of its mass to that of the host crystal atom and by the force constants of its attachment to the lattice. We cannot also follow their arguments against the possibility that all the impurities may be lodged in the outer dielectric mantles of the grains. On the basis of grain models which agree with extinction and polarization data we require the outer dielectric mantle to be about 100 times more massive than the graphite core. It would indeed seem likely that most of the impurities are lodged in the dielectric mantles, and about  $10^4$  such impurity atoms<sup>6</sup> suffice to re-radiate the absorbed starlight in the far infrared.

We therefore feel that such a process could very well operate in galaxies with interstellar dust and make a substantial contribution to the microwave background. We do not suggest that this is the only source of microwave background. It is of interest in this connexion that Partridge and Wilkinson<sup>11</sup> have recently reported a slight increase in the background radiation at the 3.2 cm wavelength from a region of the sky which is close to the galactic plane. Kurilchik and Kokin<sup>12</sup> have also detected a microwave flux at 8 cm wavelength from two individual quasi-stellar objects BSO 1 and Ton 730. Very recent infrared surveys (Low<sup>13</sup>) have actually revealed the remarkable fact that several galaxies emit ~100 times more radiation in the far infrared than in the visible spectral region. It is entirely conceivable that later and more systematic surveys of discrete sources at long wavelengths would produce further evidence of a contribution to the microwave background from such sources.

We now turn to the cosmological aspects of the problem. If the aforementioned process takes place in a big-bang universe, we fail to see how the combined curve of this process plus the primordial black-body radiation could lead to the purely black-body curve (1). Our own view is that the "black-body" explanation has been overstated and that the actual form of  $\mathcal{J}(\nu)$  may not be so simple. For this reason, it is also premature to conclude from the present observations that the steady state theory of the universe is untenable.

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## Interstellar Extinction by Quartz Grains

KNACKE<sup>1</sup> has pointed out that quartz particles possess strong absorption bands at  $\lambda \sim 10\mu$ . Although these features occur in the spectral region 3–10 $\mu$ , where Johnson<sup>2</sup> has found humps in interstellar extinction curves, by itself this cannot be taken as indicating a silica component in the interstellar grains. It has already been pointed out<sup>3</sup> that impurities in any solid with a Debye frequency close to that of graphite would give optically active lattice bands at  $\lambda \sim 10\mu^*$ . Further evidence would be necessary before quartz could be considered as a serious alternative to interstellar graphite grains.

From an approximate calculation, Knacke<sup>1</sup> has claimed that silica grains of radii  $\sim 0.2\mu$  would fit the observed interstellar extinction curve in the wavelength range 0.3–1.5 $\mu$  to within about 15 per cent, but the extension of the observed extinction curve into the far ultraviolet region<sup>4,5</sup> has greatly enhanced the sensitivity of this test<sup>6</sup>. It is therefore of interest to compute accurate extinction cross-sections for quartz particles and particles with a quartz core and ice mantle for the entire wavelength range

\* The phonon spectrum of reactor grade graphite shows the strongest pile up of phonon states at  $\sim 7\mu$  (ref. 9).

of the observations. We have performed such calculations for single-sized quartz particles, quartz particles with an Oort-van de Hulst<sup>7</sup> distribution of radii and for quartz particles covered with ice mantles.

Calculations of the cross-sections for homogeneous quartz particles were done using the Mie theory and those for the composite particles using the Gütler theory (see, for example, ref. 8). The results of our calculations are shown in Figs. 1–3. We have adopted a normalized extinction  $F_\lambda$  defined by

$$F_\lambda = \frac{0.5 [Q(\lambda) - Q(0.5556\mu)]}{Q(0.4464\mu) - Q(0.5556\mu)}$$

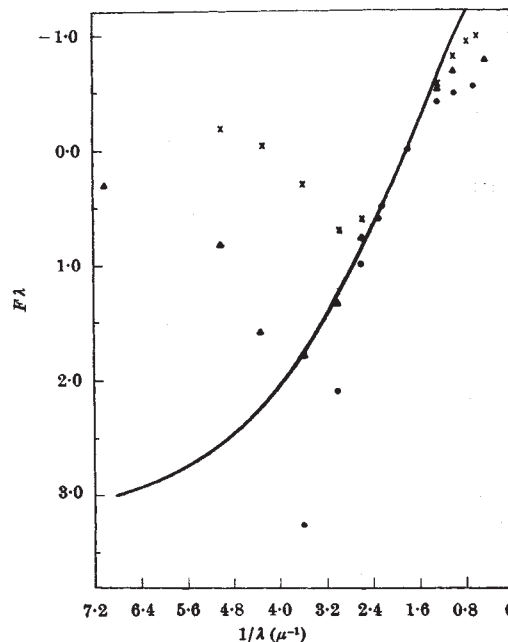


Fig. 1. Comparison of the theoretical extinction curve for single homogeneous quartz grains with observations. The solid line denotes the smoothed curve drawn through the observations. ●,  $r = 0.10\mu$ ; ▲,  $r = 0.15\mu$ ; ×,  $r = 0.20\mu$ .

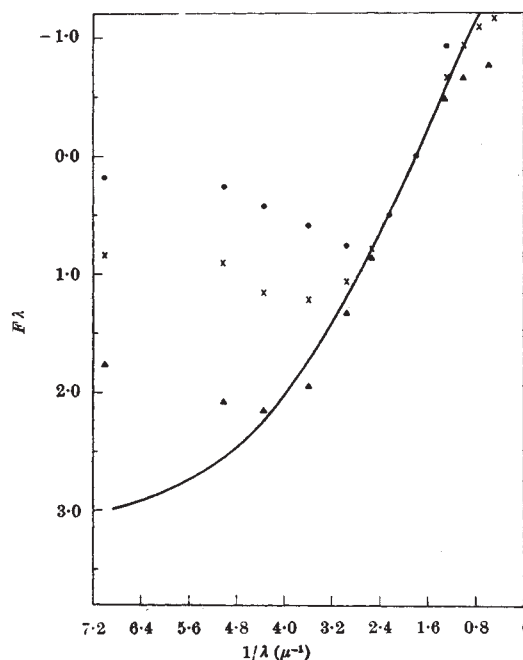


Fig. 2. Comparison of the theoretical extinction curve (for quartz particles integrated over Oort-van de Hulst size distribution) with observations. The solid line denotes the smoothed curve drawn through the observations. ●,  $\gamma_1 = 0.10\mu$ ; ×,  $\gamma_1 = 0.08\mu$ ; ▲,  $\gamma_1 = 0.06\mu$ .