A FEASIBILITY STUDY OF COSMIC MICROWAVE RADIATION VIA GRAPHITE NEEDLES

(Letter to the Editor)

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Abstract. It is pointed out that the total amount of microwave radiation that could possibly be generated by all the graphite needles in space would be considerably smaller than the observed total energy of the cosmic microwave background radiation. The question of relevant optical depth of the cloud containing the needles has been examined. It is found that the optical depth is not sufficiently large for the cloud to radiate like a black body.

1. Introduction

The discovery of the cosmic microwave background radiation (hereafter referred to as MBR) by Penzias and Wilson (1965, 1969) led to its popular interpretation in terms of the relic radiation from the early hot dense phase of the big bang. Subsequently, a distortion of the spectrum shortward of its blackbody peak wavelength was observed by Woody and Richards (1979). There have been many suggestions regarding alternative ways of producing the microwave background ranging from pregalactic supermassive stars (Rees, 1978) to the presence of long slender graphite whiskers in intergalactic clouds acting as thermalizers of the ambient radiation (Rana, 1980; Wright, 1982). However, these call for very special situations (such as, for example, too high an abundance of graphite) for which observational evidence is meagre unlike the natural explanation provided by the big bang model which, moreover, simultaneously accounts for the helium and deuterium abundance.

In yet another attempt recently, Hoyle *et al.* (1984, hereafter referred to as HNW) have suggested that the needle shaped graphite grains could be expected to form in certain astrophysical conditions and for needles with sufficiently large length to diameter ratio, adequate dipole emission can be produced over wavelengths throughout the whole of the cosmic infrared and microwave background spectrum. They have stated that the observed existence of MBR would have been taken as strong evidence for radiation from such particles if the overwhelming view, that this MBR is a relic of the big bang, was not prevalent. In other words they admit the possibility that the entire MBR could have been generated by electromagnetic radiation (not thermal) from the supposedly wide-spread occurrence of graphite needles in the Universe.

In Section 2 of this paper we have derived an expression for the expected power radiated under the mechanism proposed by HNW. It is shown that the calculated upper bound is much smaller than the observed MBR. We have estimated the optical thickness

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(depth) of the radiating discrete cloud in the galaxy (Section 3). It is found that the optical depth is not quite adequate for the cloud to radiate like a black body. In Section 4 we have considered intergalactic optical depth in the steady state cosmological model; the resulting upper bound on the optical depth in this case also is not sufficiently large. A discussion follows in Section 5 with a conclusion in Section 6.

2. Power Radiation by Cosmic Graphite Needles as Dipoles

HNW suppose that the grphite needles act as 'resistors' and sustain dipole oscillations in the sense of antennae in wireless telgraphy (Abraham and Becker, 1948). They use the well-known Johnson formula for the rms noise voltage across it, i.e., $\sqrt{4kTR\Delta\nu}$, and suggest that, as pointed out by Dicke, kT must be replaced by $h\nu/\{\exp(h\nu/kT) - 1\}$. Here k is Boltzmann constant; T, the temperature; R, the resistance of the needle; and $\Delta\nu$ the effective bandwidth of the voltage measuring instrument. Then the power radiated by a needle of length l, radius a, and electrical conductivity σ assumes the Planckian form

$$p_\nu \, d\nu = \frac{32\pi^2\sigma}{3c^3} (\pi a^2 l) \frac{h\nu^3 \, d\nu}{\exp(h\nu/kT) - 1} , \tag{1}$$

where h and c are the Planck constant and the velocity of light, respectively. The following typical values have been used throughout:

$$\sigma = 10^{15} \text{ s}^{-1} , \qquad a = 0.1 \text{ }\mu m , \qquad l = 10^4 a .$$

However, even if the Planck form of the microwave background spectrum can be manipulated for radiation emitted by the needles, one has to verify whether the total radiation emitted by all the needles can mimic the observed total energy in the MBR.

Now the total energy in the MBR is given by integrating the energy over all wavelengths, over the entire Robertson–Walker or Hubble volume, and over the Hubble age. Thus integration of Equation (1) with respect to frequency from zero to infinity leads to the power radiated by one needle as given by

$$p = \int_0^\infty p_\nu \, d\nu = \left\{\frac{32\pi^7 k^4}{45c^3h^3}\right\} \sigma a^2 l T^4 . \tag{2a}$$

Note that σ represents conductivity. Inserting typical values of a, l and the constants in Equation (2a), one obtains a simple relation

$$p \simeq 9.90 \times 10^{-10} \, T^4 \text{ erg s}^{-1} . \tag{2b}$$

Incidentally, if the needle temperature $T = 3$ K, then during the Hubble age, it will radiate about 4×10^{10} ergs which is roughly the rest mass energy of the needle itself!

To generate microwaves with high efficiency (and for applicability of the resistor formula to minimize the surface effects), HNW require very slender graphite needles with length to radius ratio $\simeq 10^4$. The mass of a typical graphite needle with $a = 0.1$ μm would then be 7.8×10^{-11} g. Now the total number of needles in space would of course be constrained by the total amount of carbon in the Universe. Various observational constraints (such as the deceleration parameter, deuterium abundance, etc.) would suggest an average mass density of the universe of about $10^{-2} \rho_c$, where $\rho_c = 10^{-29}$ g cm^{-3} is the closure density, i.e., the density required to have a closed universe. The Hubble volume of the universe is $2\pi^2 R_H^3$, where R_H the Hubble radius $= c/H_0 \simeq 10^{28}$ cm, H_0 being the Hubble constant. Thus the total mass of matter in the Universe is $\simeq 2 \times 10^{54}$ g. We assume that the observed abundance of carbon by number is $\simeq 3.7 \times 10^{-4}$. Note that the abundance is obtained from stellar spectroscopy and is independent of the model of the Universe. Therefore, the total mass of carbon in the Universe is $\simeq 8.9 \times 10^{51}$ g. This implies that we can have at most $N \simeq 1.14 \times 10^{62}$ graphite needles even in the very unlikely assumption that all of the carbon goes to form the slender graphite needles. Thus, over a Hubble age ($t_0 \simeq 4.73 \times 10^{17}$ s), the total energy radiated by all the needles in the Universe would lead to a theoretical value of E_{th} to be given by

$$E_{\text{th}} = pNt_0 \lesssim 4.37 \times 10^{72} \text{ ergs} . \tag{3}$$

The estimate in Equation (3) may be treated as a sort of upper bound on the total power of the MBR because, from the observational point of view, we have ignored the effects of the attenuation along the intervening path, the variation due to the cosmological redshift parameter, and the interactions of the radiation with matter in general.

The observed energy density of the MBR (Allen, 1973) is $u \simeq 6.3 \times 10^{-13}$ erg cm^{-3}. Therefore, the total energy observed in the MBR in the whole universe is about 1.26×10^{73} ergs, which is much larger than the above theoretical estimate. The latter was based on the assumption that all the carbon atoms in the Universe are locked up in the graphite needles. However, a sizable amount of carbon must be discounted in the form of atoms, molecules and non-cylindrical grains. There would also be non-graphitic grains in all kinds of shapes and compositions. Above all, most of the carbon atoms would be in residence within the stars. Because of these constraints, only a small fraction of the carbon atoms should contribute to the formation of the graphite needles. Therefore, the above theoretical estimate in Equation (3) would be drastically reduced, conservatively, by at least two orders of magnitude, as compared to the observational value. The deficit must be supplied by other sources probably without prejudice to the relic big-bang radiation.

3. Optical Thickness of the Radiating Cloud

We have some reservations also about the optical thickness of the assumed uniform spherical cloud containing the needle-shaped graphite grains (see section 3 of HNW). Here we consider a discrete cloud in the galaxy. An upper bound on the relevant optical depth at the wavelength ($\lambda \simeq 1000$ μm) of the peak emission of the 3 K spectral energy distribution can be estimated by considering perfect (Picket fence) alignment of the cylindrical needles. Following HNW, we choose the radius and the length of the needles (all identical) to be a = 0.1 μm and $l = 10^4$ a, respectively. The index of refraction of graphite at λ = 1000 μm is $m = 18.988 - i\,152.94$. It is based on the data of Taft and Philipp (1965). The extinction efficiencies of an absorbing needle for two orthogonal states of polarization of the incident radiation can be calculated by approximate formulas (see, for example, van de Hulst, 1957; Shah, 1971) because the parameter $x = 2\pi a/\lambda = 6.28 \times 10^{-4} \ll 1$ and also, $mx \ll 1$. However, in view of the unusual index of refraction, we have used the computer code (Shah, 1967) for the exact theory of scattering by infinite cylinders (Lind and Greenberg, 1966). The resulting extinction efficiencies are $Q_{\text{ext}}^E \simeq 5.489$ and $Q_{\text{ext}}^H \simeq 3.3 \times 10^{-7}$ for E (electric) and H (magnetic) vectors, respectively, parallel to certain reference plane. Let the number density of similarly radiating needles be n and the diameter of the cloud be $2r$. Using Equation (7) of HNW, one obtains the column density of the needles along a diameter of the cloud:

$$2nr = \frac{9c}{8\pi\sigma}\,\frac{1}{\pi a^2 l} = 3.42 \times 10^5\ \text{cm}^{-2}\,. \tag{4}$$

Since we are interested in the local optical depth within the cloud and not along the line of sight, the redshift parameter does not come in the picture. The optical depth (τ_{1000}) at λ = 1000 μm along a radius of the cloud is given by

$$\tau_{1000} = \langle C_{\text{ext}} \rangle\, nr\,, \tag{5a}$$

where $\langle C_{\text{ext}} \rangle$ = the cross-section of the cylindrical grain defined (van de Hulst, 1957) by

$$\langle C_{\text{ext}} \rangle = 2al \langle Q_{\text{ext}} \rangle\,. \tag{5b}$$

The symbol $\langle\ \rangle$ denotes average taken with respect to the states of polarization E and H. The resulting optical depth works out to be $\tau_{1000} \simeq 1.88$. This value is far too low for the cloud to radiate like a black body. A black body means that the entire cloud must attain a thermal equilibrium; this implies $\tau \gg 1$. In fact, ideally, one should have $\tau = \infty$. Further calculations reveal that even for infrared (IR), visual (V), and ultraviolet (UV) wavelength regions, the optical depth along a radius of the cloud is $\tau_{(\text{IR, V, or UV})} \lesssim 1$. For $\lambda > 1000$ μm, the following trends may be noted: The optical depth would be (i) a slowly varying function of m, (ii) independent of the size a, provided $a/\lambda \ll 1$, and (iii) varying inversely as the wavelength. Thus it is clear that the assumption about the 'optically thick' cloud made by HNW is fundamentally inconsistent. Besides, another aspect relating to polarization needs attention. In general, for perfectly aligned cylindrical grains, the forward scattered electromagnetic radiation from a distant source towards the observer would be highly polarized; the polarization is 100% at $\lambda \simeq 1000$ μm in the present context. However, in real situation in space, the grains would be spinning with their axes randomly oriented. So only a small amount of polarization would be observed. It may be noted that simply the presence of extinction in interstellar space or elsewhere does not necessarily guarantee the occurrence of polarization.

4. Intergalactic Optical Depth

The intergalactic optical depth, $\tau_{\text{ext}}^{ss}(\lambda_0, z_0)$, due to extinction by dust grains at the peak wavelength of the MBR in the steady state cosmological model is given by (Weinberg, 1972; Chitre and Narlikar, 1976; Rana, 1981)

$$\tau_{\text{ext}}^{ss}(\lambda_0, z_0) = \frac{c\rho_0}{H_0 V s} \int_0^{z_0} \langle C_{\text{ext}}(a, \lambda)\rangle \frac{\mathrm{d}z}{(1+z)}, \tag{6a}$$

where

λ_0 = the observational wavelength = 1000 μm,
z_0 = the redshift parameter for a distant source,
ρ_0 = the dust grain density in the Universe = $10^{-34}\,\text{g}\,\text{cm}^{-3}$,
H_0 = the Hubble constant = $100\ \text{km}\ \text{s}^{-1}\ \text{mpc}^{-1}$,
s = the specific density of the grains = $2.5\ \text{g}\ \text{cm}^{-3}$ for graphite,
V = the volume of the grain, and
$C_{\text{ext}}(a, \lambda)$ = the extinction cross section at wavelength λ for a grain with radius a.

The absorption optical depth can be obtained by substituting $C_{\text{abs}}(a, \lambda)$ instead of $C_{\text{ext}}(a, \lambda)$. We can express Equation (6a) in terms of the extinction efficiency $Q_{\text{ext}}(a, \lambda)$ of the cylindrical grains with uniform radius a and length l in the form

$$\tau_{\text{ext}}^{ss}(\lambda_0, z_0) = \frac{2c\rho_0}{\pi a s H_0} \int_0^{z_0} \langle Q_{\text{ext}}(a, \lambda)\rangle \frac{\mathrm{d}z}{1+z}. \tag{6b}$$

The wavelength λ_0 is sufficiently large compared to the radius ($a = 0.1\ \mu\text{m}$) of the cylindrical grains so that the Rayleigh approximation for perfect alignment (van de Hulst, 1957) can be used in the form

$$\langle Q_{\text{ext}}(a, \lambda)\rangle \simeq -\frac{\pi x}{2}\ \text{Im}(m^2 - 1), \tag{7}$$

where x and $m = m(\lambda)$ are the size parameter $2\pi a/\lambda$ and the complex index of refraction at wavelength λ, respectively. We have adopted this expression in the present section in order to illustrate the dependence of the optical depth explicitly on m, z_0, and λ_0. Normally under this approximation absorption efficiency $\langle Q_{\text{abs}}(a, \lambda)\rangle$ is nearly equal to the extinction efficiency $\langle Q_{\text{ext}}(a, \lambda)\rangle$. Therefore, the absorption optical depth

$$\tau_{\text{abs}}(\lambda_0, z_0) \simeq \tau_{\text{ext}}(\lambda_0, z_0).$$

Thus

$$\tau_{\text{ext}}^{ss}(\lambda_0, z_0) \simeq \frac{2\pi c\rho_0}{s H_0} \int_0^{z_0} \frac{\{-\text{Im}(m^2 - 1)\}\,\mathrm{d}z}{\lambda(1+z)}. \tag{8}$$

Noting that $m^2 - 1$ is a slowly-varying function at very long wavelengths and $\lambda_0 = \lambda(1 + z)$, the integral in Equation (8) can be simplified to give

$$\tau_{\text{ext}}^{ss}(\lambda_0, z_0) \lesssim \frac{2\pi c \rho_0}{s H_0} \{-\text{Im}(m^2 - 1)\} \frac{z_0}{\lambda_0} . \tag{9}$$

The inequality sign is introduced due to the fact that we have used $m(\lambda) = m(1000\ \mu\text{m})$. Using the above quoted values of various quantities, one obtains

$$\tau_{\text{ext}}^{ss}(1000\ \mu\text{m}, z_0) \lesssim 0.0135\, z_0 . \tag{10}$$

Usually z_0 is chosen to be 1 or 2. Therefore, $\tau_{\text{ext}}(1000\ \mu\text{m}) \lesssim 1$. Once again such a situation will not permit the cloud to radiate like a blackbody in the steady state cosmology as envisaged by HNW. It may be mentioned that $\tau_{\text{ext}} > 1$ is not precluded in other cosmological models such as the standard big bang cosmology (Rana, 1981). In an expanding universe, the density of the graphite needles could be much higher at an earlier epoch, which may lead to sufficiently large optical depth at high redshifts. However, as concluded by Wright (1982), so far it is not possible to decide whether the MBR was produced by the process of thermalization of starlight in a hot big-bang. The question remains: can one admit the possibility of generating MBR electromagnetically from the radiating dipole needles in big-bang cosmological models?

5. Discussion

In order to maintain the power radiated by a graphite needle at a level of $\simeq 8.02 \times 10^{-8}$ erg s^{-1} according to Equation (2b), there must be some input source of energy which can drive the noise current within the needle. One can imagine that the intergalactic radiation field in the optical region provides the driving mechanism for the needles to radiate like dipoles. Assume that the ambient radiation density is 1.26×10^{-14} erg cm^{-3} (Allen, 1973) in the optical region. Then it turns out that the amount of radiation energy incident on a graphite needle (radius = 0.1 μm, length = 0.1 cm) would be $\simeq 5 \times 10^{-11}$ erg s^{-1}. This implies that, in equilibrium condition, the output exceeds the input by three orders of magnitude!

6. Conclusions

In conclusion, it may be stated that the microwave energy, that can possibly be generated by graphite needles under the mechanism proposed by HNW, will considerably fall short of the observed energy in the cosmic microwave background radiation. The cloud containing such needles cannot radiate like a black body in steady state cosmological model because the optical depth is not sufficiently large.

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