Galactic Component of the Diffuse X-ray Background

WICKRAMASINGHE's model for the galactic component of the diffuse X-ray background[1], which involves scattering of the isotropic component by dust grains, unfortunately contains a fundamental error which completely invalidates it. Particles along a line of sight may indeed scatter isotropic background radiation into the line of sight, but by the same process they will also scatter out of the line of sight the background radiation originally travelling in this direction (ref. 2, for example). If there is no absorption (that is, the albedo is unity) the two scattering effects are equal; this situation now satisfies the first and second laws of thermodynamics and ensures that the galactic disk is quite indistinguishable from the rest of the background. If the albedo is less than one, then the disk should show up in absorption, in contradiction with the observations. In no conditions can the model increase the flux from the disk relative to that of the isotropic background.

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[1] Wickramasinghe, N. C., *Nature*, **227**, 265 (1970).
[2] Lord Rayleigh, *Phil. Mag.*, **41**, 107 (1871).

Reply to Mack and Webster

As pointed out in my article[1] dust grains distributed throughout the disk of the galaxy will scatter X-ray photons from the isotropic cosmic background as well as from discrete sources. While I agree with the comments of Mack and Webster concerning the scattering of the isotropic background by dust I would like to point out that a diffuse galactic X-ray component similar to that observed[2] could arise from the scattering of X-rays from discrete sources. In discussing the contribution from discrete sources Mack neglects scattering by dust. It is likely that this effect is important for distances exceeding a few kiloparsecs. The analysis presented earlier is evidently valid for this case with two provisos: (*a*) discrete X-ray sources are distributed more or less uniformly (with respect to mean volume emissivity) throughout the hydrogen–dust layer of the galaxy, and (*b*) the intensity I (equations (6) and (7) of ref. 1) is defined as the ratio of the mean X-ray emissivity (due to sources) per unit volume to the X-ray extinction per unit distance, and this quantity is assumed comparable with the intensity of the isotropic background.

The data at present available on X-ray sources do not conflict with these requirements. A scattering model of the type considered could produce a fairly smooth galactic X-ray background with the observed concentration towards the galactic plane without requiring an excessive concentration of weak unresolved sources very near the galactic plane.

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[1] Wickramasinghe, N. C., *Nature*, **227**, 265 (1970).
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Effect of Quantum Conditions in a Friedmann Cosmology

THE observed isotropy of the microwave background and its primordial interpretation has led many to investigate the nature of particle horizons in cosmological models near the initial singularity. The standard Friedmann radiation universe

$$ds^2 = dt^2 - \lambda t[dr^2 + r^2(d\theta^2 + \sin^2\theta\, d\varphi^2)],\ \lambda = \text{constant} \quad (1)$$

has a particle horizon at

$$r = 2\left(\frac{t}{\lambda}\right)^{1/2} \quad (2)$$

at epoch t. Thus near the singularity $t=0$, very limited causal communication is possible between different parts of the universe. The observed isotropy of the microwave background cannot be understood in such a model except as arising from artificially imposed initial conditions. Misner[1] has sought to remedy the situation by looking for solutions of the classical Einstein equations very different from the Robertson-Walker form (to which that given by equation 1 above belongs). These solutions permit unlimited communication near $t=0$.

The purpose of this note is to point out that near the singularity quantum effects are important and may permit unlimited communication near $t=0$, even in the Robertson-Walker form.

There have been many different approaches to a quantum theory of gravitation. Here we adopt Feynman's path integral approach[2], for it best illustrates the difference between the classical and quantum theories. The basic concepts in relation to gravitation have been discussed by Wheeler[3] and are briefly described below. Suppose the system is specified by an action S. Classically, the transition of the system from a state I to a state II is described by a unique path Γ_c given by the principle of stationary action:

$$\delta S = 0 \quad (3)$$

In quantum theory, there is no unique path Γ_c; all paths from I to II are possible. The probability amplitude for the system to adopt a given path Γ is proportional to

$$\exp\{iS/\hbar\} \quad (4)$$

where S is computed along Γ. The classical limit (3) follows when $\hbar \to 0$ or alternatively when $S \gg \hbar$. In this case only paths close to Γ_c contribute any significant amplitude.

In Einstein's theory of gravitation, the action is

$$S = \frac{1}{16\pi G}\int R\sqrt{-g}\, d^4x - \sum_a \int m_a\, da \quad (5)$$

where radiation is temporarily omitted. R is the scalar curvature, g the determinant of the metric tensor, m_a the mass of a typical particle a. The volume integral is over the entire space time and the line integral is over the world line of a. Einstein's equations follow in the classical limit (3); but in the quantum theory this is not the case. We wish to consider equation 5 in relation to a Friedmann cosmology satisfying Einstein's equations

$$R_{ik} - \tfrac{1}{2} g_{ik} R = -8\pi G\, T_{ik} \quad (6)$$

Using the Robertson-Walker form of the metric

$$ds^2 = dt^2 - Q^2(t)\left[\frac{dr^2}{1-kr^2} + r^2(d\theta^2 + \sin^2\theta\, d\varphi^2)\right], k = 0, \pm 1 \qquad (7)$$

and specifying the 4-dimensional volume by $0 \leq t \leq t_0$, $0 \leq r \leq r_0$, we get

$$S = -\tfrac{1}{2} t_0\, \rho Q^3 \int_0^{r_0} \frac{r^2\, dr}{\sqrt{1-kr^2}} \qquad (8)$$

In arriving at equation 8 we have assumed ρ to be the mean density of matter so that ρQ^3 is constant, and used the fact that from 6

$$R = 8\pi G\rho \qquad (9)$$

Evidently, for a specified r_0, we can choose t_0 smal enough to make $S \sim \hbar$. If, for example, we fix r_0 so as to include the part of the universe that we observe at the present day (and which is known to be isotropic from the microwave background observation), $t_0 \lesssim 10^{-102}$ s ! At or before this epoch, classical conditions are no longer valid, and we are no longer limited to solutions of Einstein's equations. Any space time metric can be chosen provided the magnitude of S computed for it is comparable with $\hbar$. It is possible, for example, to take the metric

$$ds^2 = dt^2 - \alpha^2 t^2\left[\frac{dr^2}{1+r^2} + r^2(d\theta^2 + \sin^2\theta\, d\varphi^2)\right] \qquad (10)$$

$$\alpha = \text{constant},$$

for this gives $R = 0$. Such a universe with trace free T_{ik} would therefore have $S = 0$.

This metric has the desired property of unlimited communication near $t = 0$. A light signal emitted at $t = t_1$ from $r = 0$ reaches $r = r_0$ at time $t = t_2$, where

$$r_0 = \sinh\left\{\alpha^{-1} \ln \frac{t_2}{t_1}\right\} \qquad (11)$$

Thus for any t_2, r_0 can be made arbitrarily large by taking t_1 near enough to $t = 0$. Because the restriction of Einstein's equations is removed, many more Robertson-Walker type models with unlimited communication and $S \sim \hbar$ are possible. The quantum universe could have taken any one of these possible paths.

The question now arises of whether the above argument would be seriously changed by an electromagnetic field, such as the microwave background, assumed primaeval. The action is changed by

$$\frac{1}{8\pi} \int (E^2 - H^2) d^4x \qquad (12)$$

where (E, H) is the electromagnetic field. This is zero for a transverse field, so such a field has no action contribution that would affect the argument directly. Nor does the gravitational action change, for T_{ik} is traceless. It follows that a transverse field would have no effect on the argument if it were uncoupled from matter. Near $t = 0$, however, the background would have a very high temperature and a profusion of particle pairs would be created. But such particles would not be comoving with respect to the coordinate system. For pairs produced by very high energy quanta $da \sim 0$ instead of $da = dt$ assumed in arriving at equation 8. In so far as particles move at speeds close to that of light they behave essentially as quanta, in which case the situation is not changed. There would seem therefore to be a strong *prima facie* case that quantum effects are important in establishing communication near the singularity of a Friedmann cosmology.

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Is Ball Lightning a Nuclear Phenomenon?

Ball lightning is characterized by the presence of a luminous mobile globe of high energy density produced in regions of considerable electrical activity. The properties of ball lightning have been outlined in recent surveys[1–4]. We are interested here in the few but significant cases of high energy ball lightning.

In one incident a lightning ball fell into a rain barrel and boiled 18 l. of water for a few minutes[5]. The energy of the ball was estimated as 8×10^6 J with an energy density between 2×10^9 and 5×10^9 J m^{-3} (refs. 4, 6, 7).

Another report[8], brought to our attention by C. M. Botley, describes a red lightning ball about 60 cm in diameter which dug a trench 100 m long and 1·2 m deep in soft soil near a stream, and then tore away another 25 m of stream bank. If the trench was about 1 m wide, the energy expended by the ball must have been at least 3×10^6 J and very likely more than 10^7 J, with an energy density in the ball exceeding 10^8 J m^{-3}. On the other hand, if this ball had an energy density of 4×10^9 J m^{-3}, as in the rain barrel case, the total energy would have been 4×10^8 J.

There are reports of ball lightning exploding or shattering wooden logs[9], cutting metal cables and wires[10], or doing damage requiring surprisingly large amounts of power.

In both of the cases cited, and in several other cases also indicative of high energy ball lightning, an energy density significantly higher than 10^8 J m^{-3} is indicated. This means that if the energy were stored by chemical means, the ball would have to consist of air or gas which is at least singly ionized. Experimental results, however, indicate that an ionized ball of air, ozone or any of the nitrogen oxides could not remain ionized in the atmosphere for longer than a few tenths of a second without an external supply of power[11]. The decay of an ionized ball of air would most likely be explosive. According to the rain barrel report, however, the water boiled for a few minutes, and remained hot even after 20 min. We conclude that the ball lightning supplied at least 5×10^4 W of power to the water in the rain barrel for a few minutes at a relatively steady rate (in other words, not explosively). The case of the trench-digging ball also indicated a large but continuous power release.

Another difficulty with the idea that all the energy of ball lightning is stored in the form of ionized air is the absence of any indications of intense heat. Ball lightning does not rise like hot air nor is it disrupted by convection into a thermal plume as are hot fireballs. Magnetic containment of a hot plasma under normal atmospheric conditions is not possible at the required energy density[12] and in any case would be subject to convective disruption as well. A cold degenerate plasma ball[13] held together by exchange forces or collective plasma modes would not emit enough light to make the ball visible.