PRODUCTION OF METAGALACTIC X-RAYS BY
RELATIVISTIC DUST GRAINS

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Abstract. The relativistic dust grains which may be responsible for ultra-high energy cosmic rays, as suggested by the present author, interact with the cosmic black-body radiation. This results in the energy loss of the relativistic dust grains, so that their energy spectrum is cut-off at the Lorentz factor as large as $2 \times 10^8$ (0.1$\mu/m$), where $a$ is the grain radius. The black-body radiation is scattered and absorbed by the dust grains. The photons scattered and reemitted contribute to metagalactic X-rays. The X-ray intensity estimated is comparable to the observed one in the soft X-ray region.

1. Introduction

In order to explain huge extensive showers of cosmic rays, the author (Hayakawa 1972a, which will hereafter be referred to as I) has suggested that dust grains of relativistic energies may be responsible for their origin. This is motivated by the fact that protons which are supposed to produce such extensive air showers strongly attenuate by meson producing collisions with universal black-body radiation of 3 K if their energies exceed $10^{19}$ eV. Although the dust grains are unable to produce mesons by such collisions, since the Lorentz factors required for the dust grains to have energies as large as $10^{20}$ eV are of the order of $10^5$, they may also lose their energies due to the collisions with the universal black-body photons, analogous to the inverse Compton effect of relativistic electrons.

In the rest system of a dust grain whose Lorentz factor is $\gamma$, energy of a universal photon with energy $\varepsilon$ is of the order of $\gamma \varepsilon$. Such a photon is either scattered or absorbed by the grain. If $\gamma \varepsilon$ lies in the visible or ultraviolet range, both the scattering and absorption cross-sections are of the same order of magnitude as the geometrical cross-section of the grain, and consequently the mean free path for the processes under consideration is as short as $10^2$ km in the metagalactic space. If the scattering is nearly isotropic, the average energy of scattered photons is of the order of $\gamma^2 \varepsilon$. This lies in the X-ray range and the scattering processes are responsible both for the energy loss of the relativistic dust gains and for the generation of metagalactic X-rays. The photons absorbed heat up the grains to a temperature $T_g$. The thermal emission from the grains produces photons of energies about $\gamma k T_g$, where $k$ is the Boltzmann constant, and is also responsible for the energy loss and the generation of XUV radiation.

Since the energy loss rate is proportional to high power of $\gamma$, the energy spectrum of the dust grains changes its shape at about $\gamma_e$, so that the flux at $\gamma > \gamma_e$ should be smaller than that would be expected without taking the photon interaction processes
into account. The interpretation of the huge extensive air showers in terms of the relativistic dust grains would, therefore, have to be re-examined. The spectrum of the metagalactic X-rays thus generated reflects the spectrum of the dust grains. In view of that the spectrum of metagalactic X-rays seems to consist of several components of different origins (Kellogg, 1972; Hayakawa, 1972b) and that its interpretation in terms of currently accepted mechanisms, such as the inverse Compton process of metagalactic electrons (Felten and Morrison, 1966), seems to be difficult (Hayakawa and Sugimoto, 1971), it would make sense to speculate that the relativistic dust grains are responsible, at least in part, for the metagalactic X-rays.

The present paper gives a semi-quantitative description of the interactions of the relativistic dust grains with photons, thus supplementing a qualitative discussion given by the author (Hayakawa 1972c). The result is not free from ambiguity, since the optical properties of dust grains are not sufficiently known.

2. Interactions of Relativistic Dust Grains with Thermal Photons

A thermal photon of energy $\varepsilon$ propagating at an angle $\theta$ with respect to the direction of motion of a relativistic dust grain with velocity $c\beta$ has the energy

$$\varepsilon^* = (1 - \beta \cos \theta)\gamma \varepsilon$$

in the rest system of the grain, where $\gamma = (1 - \beta^2)^{-1/2}$. In this system the direction of the incident photon is preferentially head-on and the photon coming from other directions has a small cross-section since it has an infrared energy. The incident photon in the rest system may, therefore, be assumed to be in the head-on direction. Then the average energy of the scattered photon is given by

$$\varepsilon' = (1 - \beta g)\gamma \varepsilon^*,$$

where $g$ is the forward asymmetry factor in the scattering. Substituting Equation (2.1) in Equation (2.2) and averaging it over the incident angle, we obtain the average energy of the scattered photon

$$E_s = (1 - \beta g)\gamma^2 \bar{\varepsilon}.$$

Here $\bar{\varepsilon}$ is the average energy of the incident photons in the laboratory system, $\bar{\varepsilon} = 2.7 kT_b$, where $T_b = 2.7$ K is the temperature of the universal black-body photons.

The relativistic dust grain is heated by the collisions with thermal photons and ambient intergalactic matter. The energy dissipated in the grain by the absorption of a photon is $\varepsilon^*$, whereas that by the collision with an electron or a proton is about $2 \times 10^6 \rho a$ eV, where $\rho$ is the density of the grain and $a$ is the grain radius. Although the latter is greater than the former, the frequency of collisions with the photons is greater by a factor of $10^8$ or so than that with ambient electrons and protons. We have, therefore, only to take the photon absorption precesses into account for the grain heating.