IS THE '8° K' BACKGROUND RADIATION UNIVERSAL?

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ABSTRACT

The high energy gamma-ray flux (energy greater than $10^{12}$ eV) resulting from high energy protons interacting with photons of the recently observed sub-millimeter microwave radiation in metagalactic space is calculated. Comparison of the flux of these gamma-rays with experimental observations indicate that the observed sub-millimeter radiation may not be universal.

The presence of a microwave background radiation in space with wavelengths above 2.7 mm. has now been established; its energy spectrum and observed isotropy suggest a universal black body radiation of temperature 2.7° K. More recently Shivanandan et al., by sending instruments to great heights on rockets, have detected the existence of sub-millimeter wavelength radiation with an intensity of $5 \times 10^{-9}$ watts cm.$^{-2}$ sr$^{-1}$ (We use this value in our calculations below). The existence of this radiation is confirmed by Houck and Harwit. If this radiation is interpreted as a black body radiation, the temperature is about 8° K. However, it is not established yet whether the radiation is galactic, or universal. In this paper we present evidence against the universality of the 8° K radiation. We calculate the high energy gamma-ray flux produced in the interaction of high energy protons with the '8° K' photons and compare it with experimental upper limits. For this purpose we assume that the intensity of high energy protons (energy greater than $10^{17}$ eV) in metagalactic space is the same as measured near the earth. This is thought to be correct since the galactic magnetic fields are not large enough to contain the high energy protons (energy greater than $10^{17}$ eV) within the galaxy. The observed isotropy of these protons is also consistent with the intensity in metagalactic space to be the same as that near the earth.

Greisen has summarised the various production and absorption processes due to the interaction of the background microwave radiation with
high energy electrons, protons and heavier nuclei. In this paper we shall use the formulae given by him.

The absorption of high energy protons in collisions with microwave photons producing electron pairs is studied by Jelley⁶ and by Gould and Schreder.⁷ The corresponding mean free path for absorption of photons is about 0.4 kpc. at $10^{15}$ eV gradually increasing to the dimension of the universe at $4 \times 10^{13}$ eV; the universe becomes transparent for photons below this energy.

The interaction of the microwave photons ($\epsilon$), with high energy protons $p$, yields high energy electrons, positrons and $\pi^\circ$-mesons:

$$\epsilon + p \rightarrow p + e^+ + e^-$$
$$\rightarrow p + \pi^0$$
$$\rightarrow \gamma + \gamma$$
$$\rightarrow n + \pi^+$$
$$\rightarrow \mu^+ \rightarrow e^+$$

The pair production sets in at proton energies more than a hundred times lower than that for pion production and has a larger cross-section; hence it is sufficient to consider the first reaction to calculate the gamma-ray flux.

The proton differential energy spectrum in the energy region $10^{17}$ eV is given by $F'(E_p) \frac{dE_p}{dp} = 1.7 \times 10^4 E_p^{-16/5} dE_p \text{cm}^{-2} \text{sec}^{-1} \text{sr}^{-1}$, where $E_p$ is the energy of the proton in units of GeV. The electron energy (equipartition of pair energy between electron and positron is assumed) $E$ is given by the approximate form⁶

$$E = \frac{m}{M} \frac{\nu_0}{\nu} E_p$$

where $\nu$ is the frequency of the background photon in the reference frame of the proton, $\nu_0$ is the threshold frequency $2 mc^2/h$, and $m$ and $M$ are the masses of electron and proton respectively. Let $F(E) dE$ be the total production of electrons in the interval $dE$ per unit area, time and solid angle along a line extending to a distance $c/(2H)$, where $H$ is the Hubble constant and $c$ is the velocity of light.

$$F(E) dE = \frac{1}{H} \int \frac{dE}{I} d \nu (\nu) F'(E_p) dE_p$$

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where $\sigma$ is the pair production cross-section, approximated by $1.8 \times 10^{-27}$ \( [1 + \frac{v}{v_0} - 1 + \frac{v_0}{v}] \) cm$^2$, $d\rho (\nu)$ is the black body spectrum in the reference frame of the proton, and \( I = \frac{E_p}{M c^2} \). The electron spectrum can be evaluated and is given in Fig. 1; here $E_0 = (mc^2)/kT = 3.2 \times 10^{14}$ eV. The total production is obtained by integrating $F(E)dE$ and is $3 \times 10^{-10}$ particles cm.$^{-2}$ sr$^{-1}$ sec$^{-1}$ at a mean energy of $1.4 \times 10^{14}$ eV; practically all of it is above $4 \times 10^{13}$ eV.

The high energy electrons produce gamma-rays by Compton scattering of the microwave photons. The mean free path for this scattering is about $3 \times 10^{20}$ cm. and the gamma-ray receives most of the energy of the electron. The produced gamma-rays in turn are absorbed to give rise to high energy electrons through the reaction $\gamma + e \rightarrow e^+ + e^-$. The cascade due to successive Compton and pair production reactions continues until the energy of the photons reaches $4 \times 10^{13}$ eV when the universe becomes transparent.
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The electrons below $4 \times 10^{13}$ eV lose energy rapidly to produce gamma-rays. Thus photons will accumulate in the interval $10^{13}$ and $4 \times 10^{13}$ eV with a mean energy of $2 \times 10^{13}$ eV. The gamma-ray flux due to the cascade is obtained by multiplying the electron intensity by the ratio of the mean energy of the electrons and the mean energy of the gamma-rays. This flux is $2 \times 10^{-9}$ photons cm.$^{-2}$ sec.$^{-1}$ sr.$^{-1}$ at a mean energy of $2 \times 10^{13}$ eV and are distributed isotropically. The uncertainty in the predicted flux arises from the approximate equation used for the relation between $E$ and $E_p$. By considering the electron energy distribution in pair production, we estimate that the error in the gamma-ray flux calculated above is less than a factor of two.

Experimental observation of high energy gamma radiation above $10^{12}$ eV has been attempted by Malhotra et al. They give an upper limit for the gamma-ray flux at energies greater than $10^{13}$ eV of $4.5 \times 10^{-10}$ photons cm.$^{-2}$ sec.$^{-1}$ sr.$^{-1}$. This upper limit corresponds to the flux in the atmosphere at a residual depth of 22 g. cm.$^{-2}$ and is also the upper limit for cosmic gamma-rays. This upper limit is significantly lower than the predicted flux, implying that the ‘8° K’ radiation may not be universal.

We wish to point out that doubt about the universality of the ‘8° K’ radiation is also cast by the difficulties it produces with respect to cosmic ray lifetimes and energy spectra.

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REFERENCES


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