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ANNIHILATION OF MATTER AND
ANTIMATTER AND THE COSMIC
X-RAY BACKGROUND

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ABSTRACT

A model for the cosmic X-ray background is suggested being based on inverse Compton scattering of galactic light on annihilation electrons.

ANNIHILATION OF MATTER AND ANTIMATTER AND THE COSMIC X-RAY BACKGROUND

In cosmologic models which suggest that matter and anti-matter exist in a symmetric way in the universe^{1 - 5} annihilation of particles and antiparticles is likely to occur also at the present time. At the annihilation of a proton and an antiproton 1.6 negative electrons and an equal number of positive electrons (positrons), each with an energy of about 10 - 100 MeV are produced together with gamma rays and neutrinos⁶. The electrons thus formed have an energy spectrum as shown in Figure 1 (solid curve) with a maximum close to 30 MeV. After the annihilation the initial energies of the electrons can be expected to decrease gradually due to the interaction of the electrons with cosmic magnetic fields, plasmas, and electromagnetic radiation. As a result of these interactions synchrotron radiation, bremsstrahlung, and inverse Compton radiation are emitted.

Of particular interest is that when photons in the optical part of the spectrum are scattered against the relativistic electrons, X-rays are produced due to the inverse Compton effect. This mechanism may be an important source of cosmic X-rays. It is the purpose of the present note to study how efficient this X-ray mechanism can be in intergalactic space (where most of the annihilation electrons are expected to occur) and to see whether it can offer an explanation to the cosmic X-ray background observed (see refs 7 - 9 for example). For the sake of clarity we shall restrict ourselves to consider a simplified model of the X-ray mechanism by assuming

- 1/ that the annihilation of protons and antiprotons occurs at a constant rate giving rise to relativistic electrons with a production spectrum according to Figure 1.
- 2/ that the energy of the electrons created decreases continuously, primarily due to synchrotron losses, so that a stationary energy spectrum is obtained for the electrons.

3/ that the primary optical radiation in intergalactic space (with which the annihilation electrons interact and produce X-rays) consists mainly of galactic light having an intensity of $S_{10} = 1.4(m_V = 10)$ star deg^{-2} ¹⁰ and a spectrum of the same shape as a black-body spectrum of the temperature $T_{ph} = 6 \times 10^3$ °K.

Under the general assumptions 1/ and 2/ Ekspong et al.⁶ have estimated the stationary energy spectrum of the annihilation electrons. Their result is shown in Figure 1 (dashed curve). A considerable concentration of electrons towards small energies can be noticed in this spectrum.

Korshak¹¹ has calculated the spectrum of the inverse Compton radiation produced by one electron of energy E_e interacting with black-body photons of the temperature T_{ph} and the density n_{ph} . He finds

$$P_C(\nu) = 1.24 \sigma_T c h n_{ph} F\left(\frac{\nu}{\nu_C}\right) \text{ erg s}^{-1} \text{ Hz}^{-1} \quad (1)$$

provided $E_e \gg m_e c^2$, $\beta E_e \gg h\nu \gg kT_{ph}/\beta$, ($\beta = v/c \approx 1$).

$\sigma_T = 6.65 \times 10^{-25} \text{ cm}^2$ is the Thomson cross-section, ν is the frequency of the scattered photons, and $\nu_C = (4kT_{ph}/h)(E_e/m_e c^2)^2$.

The function $F(\nu/\nu_C)$ reaches its maximum value 0.254 at $\nu = \nu_C$ and is $\approx 1.65 \nu/\nu_C$ for $\nu/\nu_C \ll 1$ and $\approx (\nu/\nu_C) \exp(-\nu/\nu_C)$ for $\nu/\nu_C \gg 1$.

By integrating numerically the spectrum defined by equation (1) over the stationary energy distribution of the relativistic electrons (dashed curve in Figure 1) we can estimate the spectrum of the inverse Compton radiation in our model. The shape of the spectrum is shown in Figure 2 together with the measured intensities of the cosmic X-ray background in the interval $h\nu \approx 1-10^2 \text{ keV}$ ⁹. As is clear from the Figure the inverse Compton spectrum agrees well with the observed spectrum in the interval shown.

It should be noted that except for the total intensity there is no adjustable parameter in the derivation. For photon energies above 1 MeV the inverse Compton spectrum starts to deviate appreciably from observational data⁷. The maximum photon energy of the inverse Compton radiation that can be produced by the mechanism considered is well above 10 MeV.

The intensity of the inverse Compton radiation is proportional to the density of the primary photons and to the density of the relativistic electrons. Furthermore the intensity depends also on the size of the volume which the electrons occupy. With the radius of the volume being $R = 10^{10}$ LY = 10^{28} cm and the primary radiation consisting of galactic light as assumed in 2/, the intensity shown in Figure 2 is obtained for a mean density of the electrons of the order $n_e \approx 10^{-9}$ cm⁻³ in the energy interval $E_e = 10 - 10^2$ MeV. This electron density is about two orders of magnitudes smaller than the mean atom density of the galactic material throughout the universe.

The electrons which are necessary to produce the cosmic X-ray background will of course also give rise to other types of electromagnetic radiation. One of these is the synchrotron radiation whose intensity and frequency is influenced by the magnetic field B. To obtain a stationary spectrum for the electron energies of interest, $E_e \geq 1$ MeV, (as assumed in 2/) we must require that the magnetic field is so strong that the decay time due to synchrotron losses

$$\tau_s = \frac{5.1 \cdot 10^8}{B^2} \frac{1}{1 + E_e/m_e c^2} \quad \text{s} \quad (2)$$

(B in gauss) is smaller than at least the age of the universe being of the order 10^{10} years = 3×10^{17} s. Hence, the magnetic field must be $\geq 2 \times 10^{-5}$ gauss.

With a magnetic field of this strength the intensity of the synchrotron radiation in the radio band, being produced by the annihilation electrons necessary for the X-ray generation, would be too high compared with measurements^{12 - 14}. The solution of this problem may be that the annihilation electrons are created locally in quasars and galactic nuclei¹⁵ where the magnetic field is sufficiently strong to cause a rapid energy decay of the electrons. These electrons then escape into intergalactic space which they fill uniformly and where they produce the X-ray background by interacting with optical photons.

There are a number of other important questions in this context which, however, can be clarified only by a general development of the symmetric cosmology.

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FIGURE CAPTIONS

Fig. 1. Solid curve: Energy spectrum of electrons (negative and positive) directly produced by annihilations of protons and antiprotons. The spectrum is normalized by means of the total number of electrons N_0 formed. Dashed curve: Stationary energy spectrum of annihilation electrons dN/dE_e multiplied by B^2/ϕ_A . The spectrum is obtained for a constant rate of annihilation ϕ_A when the electrons created decrease in energy due to synchrotron radiation in a magnetic field B .

Fig. 2. Spectrum of inverse Compton radiation resulting from scattering of galactic light on annihilation electrons which decrease in energy because of synchrotron radiation (solid curve). The inverse Compton spectrum is compared with measured intensities of the cosmic X-ray background in the energy interval $h\nu \approx 1-10^2 \text{ keV}$ ⁹.

Fig. 1

Fig. 2

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Key words: Cosmic X-ray background, Inverse Compton radiation, Matter and antimatter, Annihilation, Cosmology.