The accumulation of postirons produced due to interaction of background optical and gamma photons

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The positron production due to interaction of background optical and gamma photons and its subsequent accumulation in intergalactic space is considered. The positron braking due to its interaction with cosmological microwave background phostons is taken into account.

Keywords: cosmology, background radiation, positron.

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Introduction

The space between galaxies is filled with extremely rarefied intergalactic gas. Only in the region of a galaxy cluster, where gas falls into a gravitational well and its density increases, its concentration can reach the values of $10^{-3}\,\mathrm{cm}^{-3}$ [1]. To a much greater extent, this space is filled with electromagnetic background radiation. Its main component is the cosmic microwave background (CMB), which was formed during the epoch of recombination $z \sim 10^3$ and carries information about the processes taking place at that time [2], where z is the cosmological redshift. Much later, other components of the background radiation were formed. Extragalactic background light (EBL) consists of optical and infrared background photons and is created primarily by the radiation of stars [2]. The X-ray background radiation was created primarily by the accretion of matter onto galactic nuclei [2]. There may also be a cosmic ultraviolet background (CUB) created by radiation from interstellar nebulae and hot young stars [2]. The cosmic gamma-ray background (CGB), consisting of gamma-ray photons, was born during supernova outbursts and possibly carries information about these events [2]. This radiation interacts primarily with the intergalactic and intracluster environment [3]. However, it is also possible for background photons to interact with each other to form electron-positron pairs. The optical depth in this process is many orders of magnitude lower than the optical depth due to the scattering of background photons by electrons and ions of the medium [3]. However, this process leads to the appearance of a permanent source of positrons in intergalactic and intercluster space. In this paper, we limited our consideration to the process of positron generation during the interaction of CGB photons with EBL photons. The process with these photons gives the highest rate of positron production [4]. Only the process of positron generation during the interaction of CGB photons with hypothetical CUB photons could compete with it, but only if the intensity of the CUB photon flux is close to its upper limit. The born positrons have an energy of the order of $100\,\mathrm{GeV}-1\,\mathrm{TeV}$ and therefore practically do not annihilate when propagating in an extremely sparse intergalactic and intercluster medium [5]. Their average lifetime before annihilation is $(2-3)\cdot 10^9$ year [5]. Therefore, in this paper we consider how the rate of positron generation changes over time and how they gradually accumulate in intergalactic space. This takes into account the effect on the spectrum of accumulated positrons of their Compton scattering by CMB photons. Since this scattering occurs in the non-relativistic (Thompson) regime and, consequently, the energy of the positron varies slightly with each such scattering, in this work we assume. that the result of this scattering can be described as the effect of some effective frictional force that slows down positrons.

1. Model

The rate of positron formation during the interaction of EBL photons with CGB photons, as well as the spectrum of the resulting positrons, are calculated exactly as in Ref. [4]. Its approximation from Ref. [6] was used for the rate of star formation. It was believed that the rate of CGB photon generation was proportional to the rate of star formation [7]. To simplify calculations, it was assumed that the spectrum of EBL photons does not depend on the redshift z and coincides with the currently observed spectrum [8]. The density of EBL photons was considered either proportional to the rate of star formation or corresponding to the adiabatic expansion during the expansion of the universe. The used spectra of EBL and CGB photons at $z = 0$ are shown in Fig. 1. In this paper, we limited our consideration to the redshift interval $z \sim 1-3$ only. It is taken into account that the born positrons will interact with CMB photons, which will be scattered on them. The spectrum of CMB photons is close to the blackbody [9], and their temperature $T = T_0(1+z)$, where $T_0 \approx 2.73\,\mathrm{K}$ [9], is extremely small

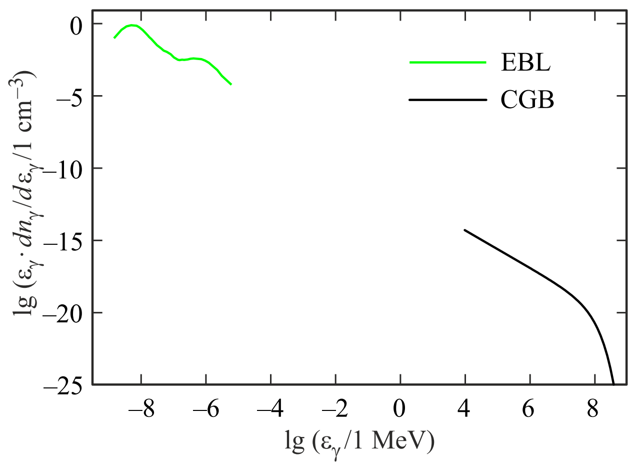

Figure 1. The spectra of EBL and CGB photons used at the redshift $z = 0$. Here ε_γ is the photon energy measured in MeV, $dn_\gamma/d\varepsilon_\gamma$ is the photon concentration, i.e. the number of photons with energy ε_γ in 1 cm^3 in a single energy range.

in the considered redshift range. The energies of positrons generated by the interaction of CGB photons with EBL photons are not too high $\varepsilon \sim 100\,\text{GeV}-1\,\text{TeV}$. And, therefore, in the positron's rest system, the energy of CMB photons is small compared to mc^2, where m is the rest mass of the electron, and, therefore, the change in the energy of the positron upon collision with CMB photons is small compared to its energy ε. Therefore, the effect of this scattering can be taken into account by considering it as the effect of a conventional frictional force reducing the energy of ε positrons

$$\frac{d\varepsilon}{dt} = -\mathscr{P}, \quad \mathscr{P} = \frac{4}{3}\sigma_T \cdot \left(\frac{\varepsilon}{mc^2}\right)^2 \cdot \epsilon_{CMB}, \tag{1}$$

σ_T is the Thompson scattering cross section, ϵ_{CMB} is the energy density of CMB photons. Then the transport equation for positrons at $\varepsilon \gg mc^2$ will take the form

$$\frac{\partial}{\partial t}\left(\frac{dn}{d\varepsilon}\right) + 2 \cdot \frac{H(z)}{1+z} \cdot \left(\frac{dn}{d\varepsilon}\right) - \frac{H(z)}{1+z} \cdot \varepsilon \cdot \frac{\partial}{\partial \varepsilon}\left(\frac{dn}{d\varepsilon}\right) = \frac{\partial}{\partial \varepsilon}\left(\mathscr{P} \cdot \frac{dn}{d\varepsilon}\right) + \frac{dq}{d\varepsilon}, \tag{2}$$

where $dn/d\varepsilon(\varepsilon, t)$ is the number of positrons in 1 cm^3 in the energy range $d\varepsilon$, and $dq/d\varepsilon(\varepsilon, t)$ is the number of positrons born in 1 cm^3 for 1 s in the energy range $d\varepsilon$. Here $H(z) = H_0 \cdot (1+z) \cdot \sqrt{\Omega_\Lambda + \Omega_m(1+z)^3}$, $\Omega_\Lambda = 0.68$, $\Omega_m = 0.32$, $H_0 = 66.9\,\text{km/(s·Mpc)}$ is the value of the Hubble constant at $z = 0$ [10]. All values are measured in a related frame of reference. The positron distribution function was considered to be isotropic. We neglected the diffusion of positrons due to their scattering by CMB photons.

2. Results

Fig. 2, *b* shows the spectrum of generated positrons at $z = 2$. Fig. 2, *a* shows the spectrum of positrons that have already accumulated and slowed down to the redshift $z = 2$. The solid curve corresponds to the case when the concentration of EBL photons is proportional to the rate of star formation, and the dashed curve — when their concentration corresponds simply to the adiabatic expansion during the expansion of the universe. Fig. 3 and 4 show similar results for $z = 1$ and 0, respectively. It can be seen that neither the spectrum of the generated positrons, nor, accordingly, the spectrum of accumulated positrons, practically depend on the chosen approximation to describe

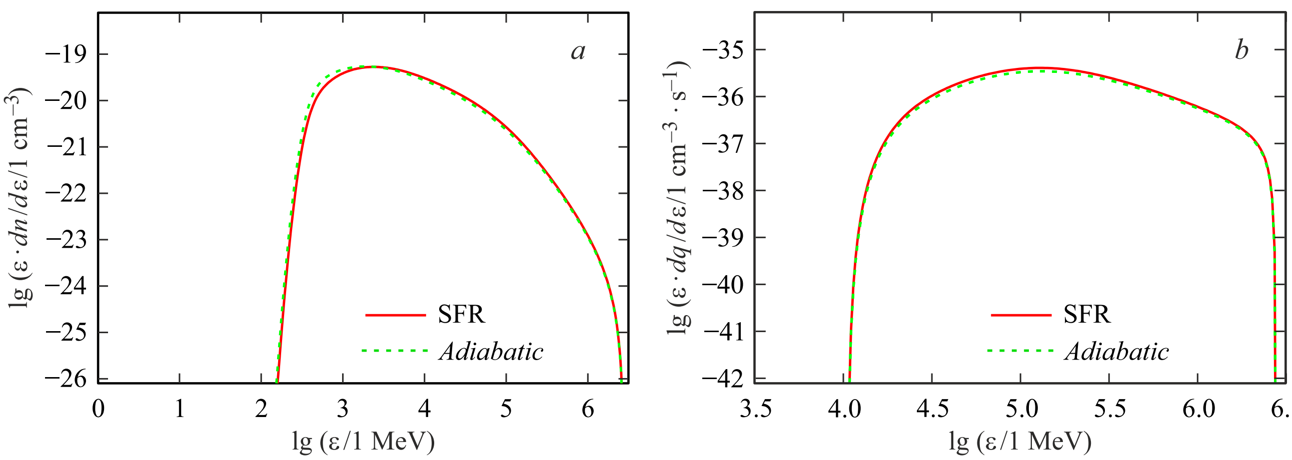

Figure 2. *b* is the spectrum of emerging positrons at redshift $z = 2$. *a* corresponds to the spectrum of positrons accumulated and managed to slow down to the redshift $z = 2$. The solid curves correspond to the case when the concentration of EBL photons is proportional to the rate of star formation, and the dashed curves correspond to the case when the concentration corresponds to adiabatic expansion. Here ε is the energy of positrons, measured in MeV, $dq/d\varepsilon$ is the rate of positron birth, i.e. the number of positrons with energy ε, born in 1 s in 1 cm^3 in the unit energy range, $dn/d\varepsilon$ is the concentration of positrons, i.e. the number of positrons with energy ε in 1 cm^3 in the unit energy range. All values are calculated in the accompanying reference frame.

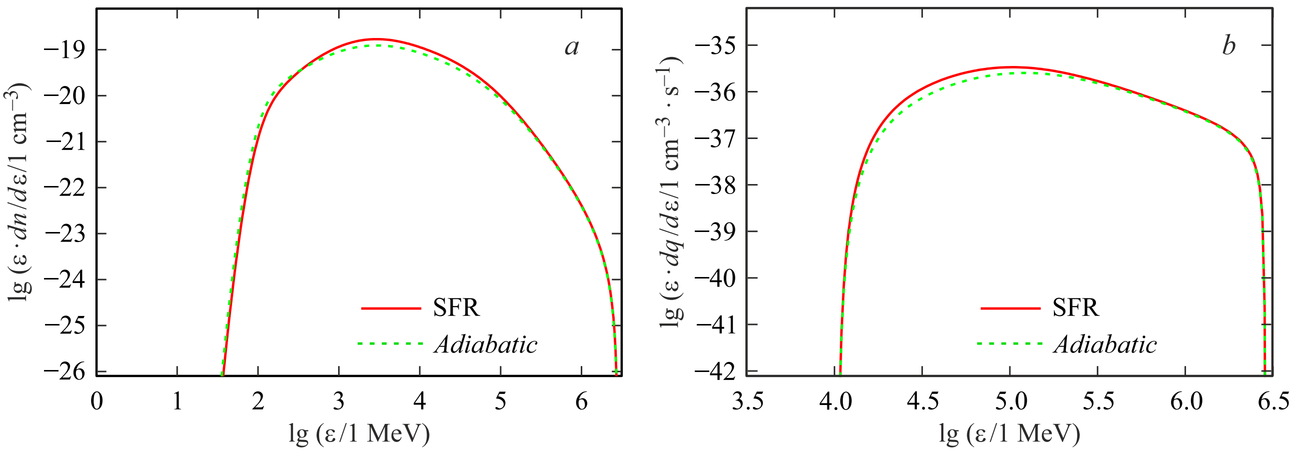

Figure 3. Same as in Fig. 2, but for the case $z = 1$.

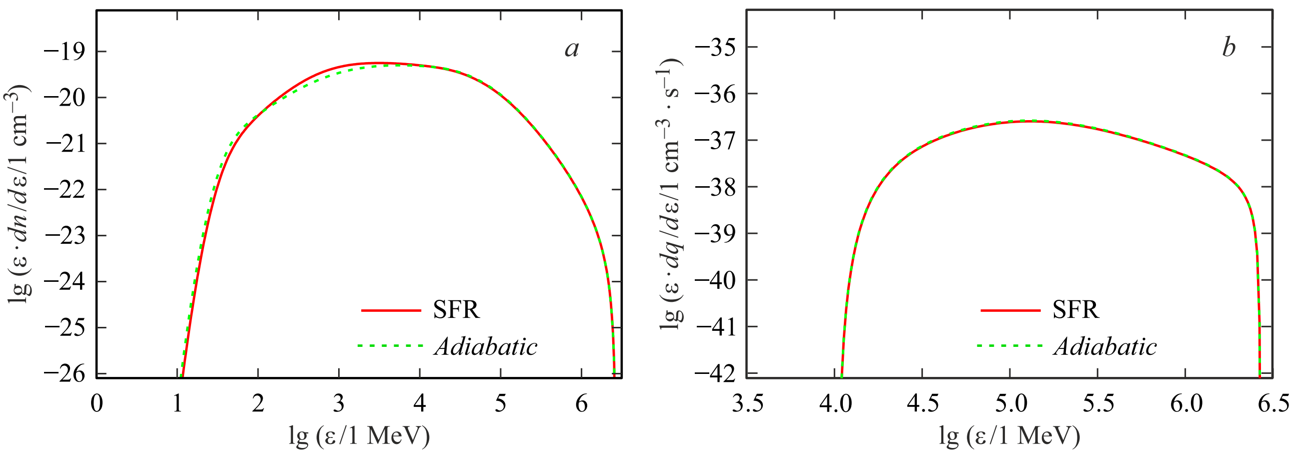

Figure 4. Same as in Fig. 2, but for the case $z = 0$.

the evolution of the EBL photon concentration. At the same time, it can be seen that although positrons are born with energies $\varepsilon \sim 10\,\text{GeV}-1\,\text{TeV}$, but due to interaction with CMB photons, they are very noticeably slowed down, slowing down by $z = 2$ to energies $\varepsilon \sim 300\,\text{MeV}$, and by now, $z = 0$ their energy may drop to the values of $\varepsilon \sim 10-30\,\text{MeV}$. The latter, of course, simplifies their annihilation in collisions with electrons of intergalactic and intercluster gas. However, even for such energies, the lifetime of such positrons remains very long $\sim (1-3) \cdot 10^9$ year [5]. It should also be noted that even the total number of positrons born in the process under consideration is very small. For example, it is significantly less than the number of low-energy (with energies $\varepsilon \sim 10\,\text{MeV}$) positrons produced by old pulsars [11], and much orders of magnitude less than the number of positrons that emit jets from active galactic nuclei [5]. However, it is worth noting that the considered positrons represent a more or less homogeneous background. Whereas the low-energy positrons produced by old pulsars are rather concentrated near the parent galaxies [11]. Giant jets, in principle, can hurl positrons far into the inter-cluster environment, but firstly, there are not very many such jets anymore, and secondly, due to the presence of a magnetic field in the jet's ejection, low-energy positrons most likely do not stray far from the jet remnant.

Conflict of interest

The authors declare that they have no conflict of interest.

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