UNTHERMALIZED PLASMA IN BURSTS SOURCES

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ABSTRACT

We have studied the pair e^+-e^- annihilation phenomena in hot plasma in order to evaluate the photon energy spectrum. The spectra of the broadening 0.511 MeV annihilation line was calculated in the case of unthermalized plasma i.e. $T_{e^-} \neq T_{e^+}$. The energy spectra from annihilation process for unthermalized positrons are characterized by the presence of flat part for energies greater than 0.511 MeV. The flatening in the spectrum of annihilation unthermalized plasma is a strong indication that the observed features of the hard tailed spectrum of the gamma bursts can be well described by annihilation of hot positrons and cold electrons. We propose that the mechanism for the production of unthermalized positrons is associated with the charge separation in Eddington limited accretion onto a neutron star.

1. INTRODUCTION

The spectra of many bursts contain absorption (for energy $E < 100$ keV) and emission ($E = 350$-450 keV) features which have been interpreted, respectively as broad cyclotron scattering and redshifted annihilation lines (Mazets et al., 1981). One of the most important result of the gamma bursts spectral studies given by both Konus (Mazets et al., 1983) and SMM (Solar Maximum Mission, Nolan et al., 1983) experiments is fact that gamma bursts spectra can have in some phase hard tails extending to a few MeV or even higher. For example the spectrum of this type has the burst GB811231a from Konus experiment. The spectrum of another burst GB820320 has even a harder tail. This last burst was also recorded by SMM (Rieger et al., 1982), where a hard tail could be followed up to 40MeV. We can shortly summarize the experimental facts: i) there are some classes of burst with hard tail in the energy spectrum extended up to few MeV, ii) the registrated hard tail begins near the energy range of 400-500 keV i.e. in the region where the annihilation features are seen, iii) the spectral index of the photon spectrum can even aproach 1 (GB820320) in the energy range of $E > 511$ keV (one must notice that data errors are large). These may indicate that at sufficently high temperatures the plasma becomes pairs dominand, the emission processes in such a plasma acts as an additional source of hard gamma rays.

In this paper we have calculated the photons spectra from annihilation process for unthermalized positrons i. e. $T_{e^+} \neq T_{e^-}$. The spectra indicated similar features as observed in the spectrum of bursts. So we have proposed the model for the gamma bursts source with annihilation of positrons additionally heated by the charge separation in the time of matter accretion onto neutron star.

2. ANNIHILATION LINE FROM UNTHERMALIZED POSITRONS

The broadening of annihilation line 0.511 MeV can be produced by high temperatures, intense magnetic field and Doppler shifts due to bulk motion and gravitational field. We have considered only temperature effect in unthermalized pair dominant plasma i.e. $T_{e^+} \neq T_{e^-}$. In order to calculate the energy spectra from unthermalized plasma following assumption was made: i) the electrons have the temperature T_{e^-} and Maxwellian momentum distribution, ii) the positrons have temperature T_{e^+} and Maxwellian momentum distribution, iii) the angular distributions of momentum is iso-

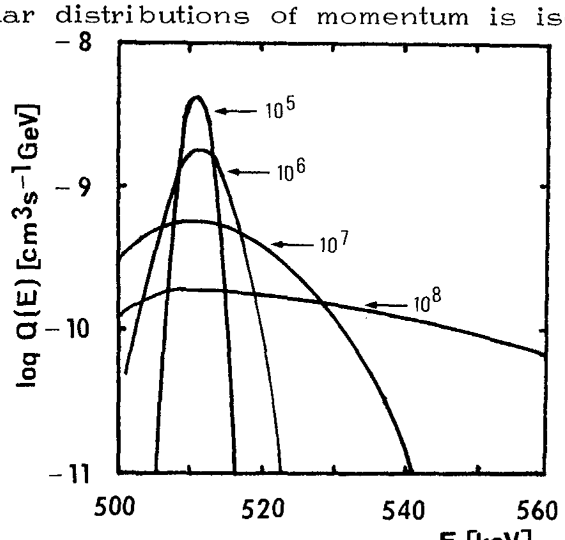

Fig. 1. The photon spectra for $T_{e^-} = 10^5$ K and $T_{e^+} = 10^5, 10^6, 10^7, 10^8$ K, respectively.

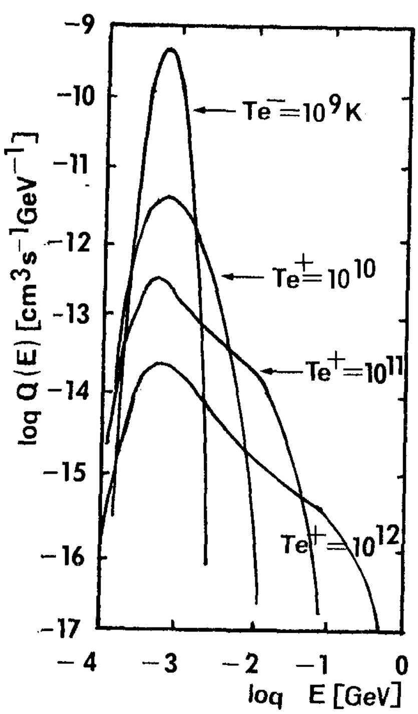

Fig. 2. The photon spectra for $T_{e^-} = 10^9$K and $T_{e^+} = 10^9, 10^{10}, 10^{11}, 10^{12}$ K, respectively.

tropic for both electrons and positrons. The kinematics of annihilation and numerical calculation of spectra for above conditions should be analyzed in most general case, as it was shown for thermalized plasma (Svensson, 1982: Karakuła and Tkaczyk, 1984). As example we present on the Fig. 1 the photon spectra (in detail scale) from annihilation of electrons with temperature $T_{e^-} = 10^5$ K and positrons with temperature: 10^5, 10^6, 10^7, 10^8 K. Figure 2 shows the spectra for higher temperatures (see also Fig. 1 in paper OG 2.7-11). The curves on this Figures are labeled by temperatures of positrons. We can notice that the spectra have a flatening tendency for energy $E > 0.511$ MeV. For the large difference of electrons and positrons temperatures the spectra are of the invers power low type with power index = 1. We have analyzed relations between annihilation time and attenuation energy time for bremsstrahlung and we can conclude that for temperature of plasma $T_{e^-} = T_{e^+} = 3 \cdot 10^{11}$ K the annihilation process is more efficient than bremsstrahlung. So taking in the consideration the shape of spectrum and efficiency of the process, the observed features in the spectrum of the gamma bursts with hard tail can be well described by annihilation of unthermalized positrons. We have proposed that the charge separation in the matter of Eddington limited accretion onto a neutron star can produce unthermalized positrons (Colgate and Petschek, 1983). The scenario can be shortly described as: the layer of the thickness ($\tau = 1$) falls onto the neutron star. The electrons will be pushed away from the star by the photons flux outgoing from the surface. This produces a charge separation and consequently and electric field. The electrons are heated by interaction with the photons. Photons are produced by annihilation of positrons and by the compression caused by the matter falling onto the star surface. The pair production processes caused by photons or other particles are the source of the positrons which are accelerated not only by photons interactions, as electrons, but also by the electric field.

3. DISCUSSION AND CONCLUSIONS

The calculated spectra from annihilation process of the unthermalized positrons ($T_{e^-} \neq T_{e^+}$) are characterized by the presence of flat part for energies greater than 0.511 MeV. The annihilation process is sufficiently effective for generaly acceptable parameters of the gamma bursts sources and can describe the obseved spectrum with hard tail. The temperatures of electrons $T_{e^-} = 10^8$ K and positrons $T_{e^+} = 10^{10}$ K and concentration of order magnitude $n_{e^-} = n_{e^+} = 10^{18}$ cm^{-3} secures the observing high energy ($E > 0.511$ MeV) flux in burst GB811231a located at typical galactic distance. Validity of our result is guaranteed by using the same procedures of calculations as we have used in the thermalized case, results of which are in compliance with Svensson (1982). Our model has a common part with the model recently proposed by Colgate and Petschek (1983), it is the charge separation as the source of additional heating of positrons. We show that the positrons can effectively annihilate. Colgate and Petschek proposed that the positrons can additionaly heat photons producing hard tail in the spectrum.

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