Gamma-rays from the massive binary LSI 61°+303

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Abstract

We investigate the model for gamma-ray emission from massive binary LSI 61°+303 in which a young Vela type pulsar injects relativistic $e^{\pm}$ pairs into the radiation field of a massive Be type star. The gamma-rays are produced by $e^{\pm}$ pairs in the inverse Compton scattering (ICS) occurring in the pulsar wind zone confined by the shock formated in the collisions of the stellar and pulsar winds. We calculate these gamma-ray spectra as a function of the phase of the pulsar on its eccentric orbit around the massive star.

1. Introduction

The binary system LSI 61°+303 contains the massive Be star, with the radius of $R_{\rm Be} = 10 \times R_{\odot}$, where $R_{\odot}$ is the Solar radius, the surface temperature of $T_{\rm Be} = 1.55 \times 10^4$ K, and a compact object on a highly eccentric orbit, $e \cong 0.8$, the semimajor axis of 5×10^{12} cm, and the phase of the periastron passage $\omega = 39^{\rm o}$ (the system is probably eclipsing) [4]. LSI 61°+303 is within the error box of the γ-ray source 2CG 135+01 [1]. It has a flat spectrum > 100 MeV and shows a day scale variability [6]. The high energy emission from this binary has been interpreted as due to particles accelerated by the shock, created in the interaction of the pulsar and massive star winds [3], or as a result of the super-Eddington accretion onto a neutron star [7]. Here we investigate the scenario of a young non-accreating pulsar inside LSI 61°+303.

2. Propagation of $e^{\pm}$ pairs and gamma-rays

Following Maraschi & Treves [3] it is assumed that LSI 61°+303 contains a Vela type pulsar, with typical period of 50 ms and the surface magnetic field of 10^{12} G. We investigate the propagation of $e^{\pm}$ pairs, injected by such pulsar, in the strong radiation field of the massive companion. The models of high energy processes in the pulsar magnetospheres suggest that $e^{\pm}$ pairs can be injected with the monoenergetic or the power law spectra. If the pulsar in LSI 61°+303 is close enough to the massive star, $e^{\pm}$ pairs can efficiently comptonize its anisotropic thermal radiation. The pulsar wind is confined by the wind termination shock

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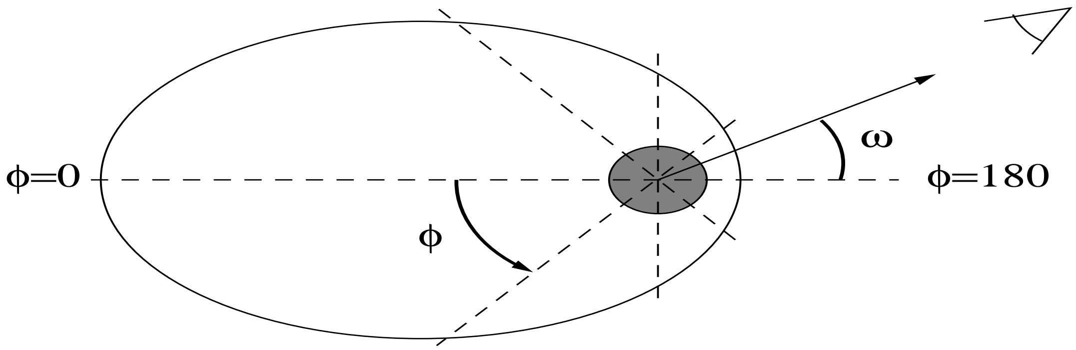

Fig. 1. The schematic picture of the massive binary system LSI 61°+303. The location of the pulsar is defined by the orbital phase Φ, measured from the apoastron. The observer is located in the plane of the system in the direction marked by the thin line.

created in the interaction of the massive stellar and pulsar winds. The geometry of the pulsar wind shock is described by the parameter $\eta = L_d/\dot{M}Vc$, which is determined by the parameters of the winds of these two stars, i.e. the period and the surface magnetic field of the pulsar, the mass loss rate of Be star $\dot{M} = 10^{-7}$ $M_\odot$ yr^{-1}, and its wind velocity at the infinity $V_\infty = 10^3$ km s^{-1}. The velocity of the stellar wind increases according to $V = V_\infty(1 - R_{\rm Be}/D)^{1.5}$. D is the distance between the stars which depends on the orbital phase of the pulsar. The shock is located at the distance $\rho = \sqrt{\eta}D/(1+\sqrt{\eta})$ from the pulsar. In order to determine the efficiency of scattering process, we calculate the optical depths for the $e^\pm$ pairs and γ-rays in the radiation field of the star from their injection at the pulsar light cylinder up to the infinity, applying the above mentioned parameters of the Be star and the binary system (see Fig. 1a). The optical depths for $e^\pm$ pairs during their propagation in the pulsar wind region are shown in Fig. 1b. Note that the optical depths for $e^\pm$ pairs and γ-rays are typically much lower than in the case of the Cyg X-3 binary system [5]. Therefore, the cascading effects during propagation in the pulsar wind zone do not play an important role in the case of LSI 61°+303.

3. Gamma-ray spectra from LSI 61°+303

The γ-ray spectra, produced in the ICS of the anisotropic radiation field are calculated for two different models for injection of $e^\pm$ pairs by the pulsar: (1) monoenergetic injection from the inner magnetosphere into the wind zone with energies 10^6 MeV; (2) injection from the inner pulsar magnetosphere with the power law spectrum between 100 MeV and 500 GeV and the spectral index -1.2. Such power law spectra are expected in the pulsar polar cap acceleration model [2]. $e^\pm$ pairs injected from the inner pulsar magnetosphere move radially through

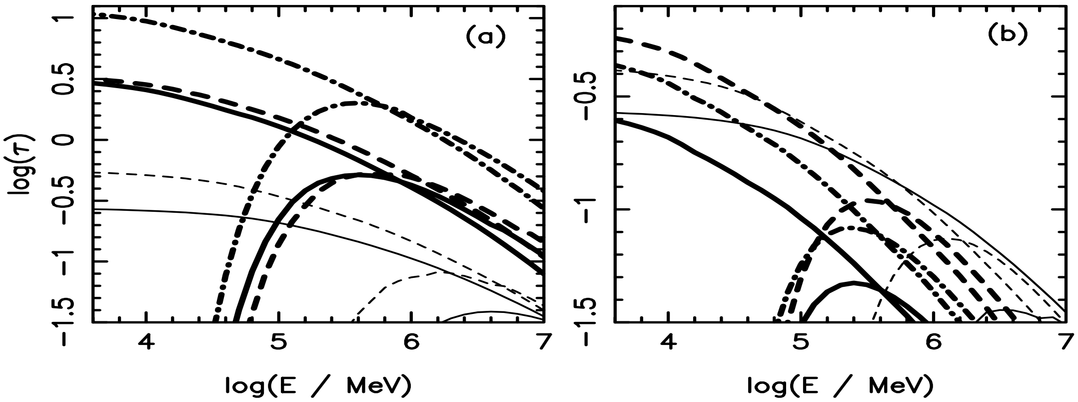

Fig. 2. (a) Optical depths for $e^{\pm}$ pairs on ICS and for absorption of γ-ray photons in the unterminated propagation through the anisotropic radiation of the Be massive companion as a function of the phase of the pulsar (see Fig. 1), $\Phi = 0^o$ (thick full curve), 45^o (thick dot-dashed), 90^o (thick dashed), 180^o (thin full), and 270^o (thin dashed). (b) as in (a) but in the case of particle propagation inside the pulsar wind termination shock determined by the parameters of the stars mentioned in the text.

the pulsar wind zone almost at rest in respect to the pulsar wind. Therefore, we neglect their synchrotron losses. We calculate the γ-ray spectra produced by $e^{\pm}$ pairs propagating in the pulsar wind zone including their further absorption during propagation above the shock in the wind of the massive star. The secondary $e^{\pm}$ pairs, from absorption of γ-rays in this region, do not contribute significantly to the escaping spectrum of γ-ray spectrum since in this region the magnetic field energy density is likely to dominate over the radiation energy density and energy of secondary $e^{\pm}$ pairs is radiated in synchrotron process.

Fig. 2 shows the spectra of γ-rays which escape from the binary system as a function of the pulsar orbital phase for different injection spectra of primary $e^{\pm}$ pairs: monoenergetic injection (a) and (b), power law injection (c) and (d). Due to relatively low optical depth, the monoenergetic $e^{\pm}$ pairs do not develop efficient cascade in the radiation field of the massive star. As a result, the escaping γ-ray spectrum is strongly peaked at TeV energies (Figs. 2a and b). The γ-ray spectra, produced by $e^{\pm}$ pairs with the power law spectrum are much broader, showing the differential spectrum with the spectral index $\sim 1.5 - 2$, in the energy range 100 MeV - 10 GeV. This case seems to consistent with the spectral features of the EGRET γ-ray source 2CG 135+01. The model with the power law spectrum of primary $e^{\pm}$ pairs predicts time variable γ-ray spectrum according to the period of the binary with the lowest γ-ray flux near the periastron of the pulsar. This feature should help to distinguish discussed here scenario from the other radiation models proposed for LSI 61^o+303.

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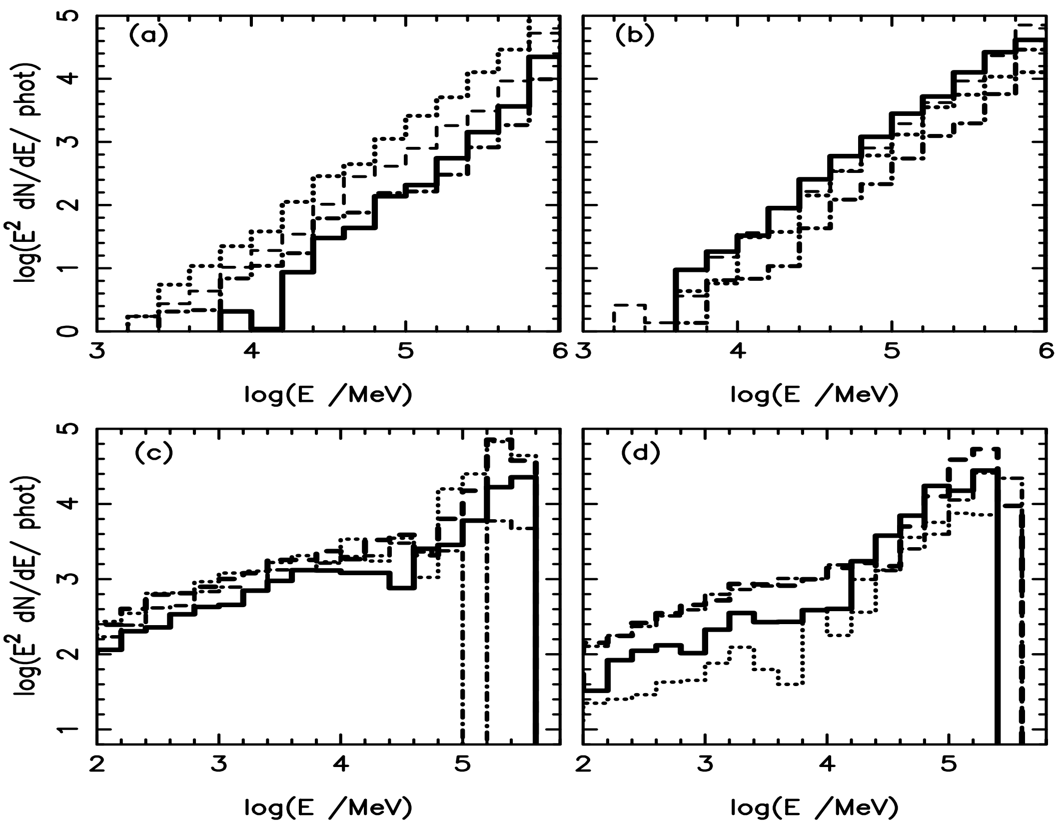

Fig. 3. The photon spectra produced by monoenergetic $e^{\pm}$ pairs with the Lorentz factor $\gamma = 10^6$ as a function of the orbital phase of the pulsar: figure (a) $\Phi = 0^o$ (full histogram), 45^o (dot-dashed), 90^o (dashed), 135^o (dotted), and figure (b) 180^o (full), 225^o (dotted), 270^o (dashed), and 315^o (dot-dashed). (c) and (d) as in (a) and (b) but for $e^{\pm}$ pairs with the power law spectrum and the spectral index -1.2. The spectra are normalized to one injected primary $e^{\pm}$ particle. The parameters of the binary system LSI 61^o+303 are given in the text.

4. References

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