Discovery of GeV γ-ray emission from PSR B1259−63/LS 2883

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Abstract: The binary system PSR B1259−63/LS 2883 consists of a 47.8 ms radio pulsar that orbits the companion Be star with a period of 3.4 years in a highly eccentric orbit. In this contribution we report on the discovery of >100 MeV gamma-rays from PSR B1259−63/LS 2883 through the 2010 pariastron passage. This makes PSR B1259−63/LS 2883 the third known GeV gamma-ray binary after LS I +61 303 and LS 5039. Two major flares that occur after the pariastron passage were observed from PSR B1259−63/LS 2883. The fact that the GeV orbital light curve is different from that of the X-ray and TeV light curves strongly suggests that GeV γ-ray emission originates from a different component. We speculate that the observed GeV flares may be resulting from Doppler boosting effects.

Keywords: gamma rays: stars — gamma rays: observations — Pulsars: individual (PSR B1259−63) — X-rays: binaries

1 Introduction

The binary system PSR B1259−63/LS 2883 comprises a young radio pulsar with a period 47.8 ms and a Be star LS 2883. With an eccentric (e$\sim$0.87) orbit, the pulsar approaches the periastron every 3.4 years. The system is highly variable over an orbital period in radio [1], X-rays [2, 3], and TeV γ-rays [4, 5]. The broadband electromagnetic spectrum is believed to result from the interaction of the pulsar wind of PSR B1259−63 and the stellar wind of LS 2883. The stellar disk is inclined with respect to the orbital plane [6] such that the pulsar passes through the disk shortly before and shortly after the periastron passage.

The first detection of PSR B1259−63/LS 2883 in γ-rays was made by the H.E.S.S. Cherenkov array through the 2004 periastron passage [4], and subsequently in 2007 [5]. The 2004 and 2007 data show that the TeV emission peaks $\sim$10 days before and $\sim$20 days after the periastron passages and the possible dips seen in the TeV light curves before and after the periastron seem to coincide with the stellar disk passage (see [7]).

The first time since the launch of Fermi/Large Area Telescope (LAT), PSR B1259−63 approached the periastron around mid-December 2010. It had been expected that GeV γ-rays would be detected close to the periastron passage [8].

In November 2010, we reported the first evidence ($\sim 4\sigma$) for γ-ray emission from PSR B1259−63/LS 2883 during a 3-day time interval [9]. The discovery was later confirmed by [10]. In this proceeding, we present the major results. More detailed γ-ray analysis of PSR B1259−63/LS 2883 are given elsewhere [11, 12]. The γ-ray data used in this work were obtained using the Fermi/LAT between 2008 August 4 and 2011 February 28.

2 Light curve

PSR B1259−63/LS 2883 remained undetected by LAT between August 2008 and October 2010, apart from a putative detection claimed by the AGILE collaboration in a 2-day period in August 2010 [13] that has not been confirmed by LAT data during the same period [14]. It became active only in November 2010, roughly when PSR B1259−63 entered the stellar disk [9, 10].

As shown in Fig. 1, the 0.2–100 GeV γ-ray light curve is highly variable through the 2010 periastron passage: (1) The source started to be active in γ-rays about a month before 2010 periastron passage (P1); (2) It remains undetected for about one month since mid-December (Q1); (3) Subsequently, a major flaring period was identified; it peaks at $\sim$35 days after periastron. Having an average flux higher than that in P1 by an order of magnitude, this flare lasted for only $\sim$7 days (P2); (4) A second flare that peaks at $\sim$46 days after periastron, however, lasted longer, so that the source was detected until end of February (P3 and P4). There are also signs of shorter time-scale variability during the flaring period down to $\sim$1 day (see Fig. 2 of [11]).

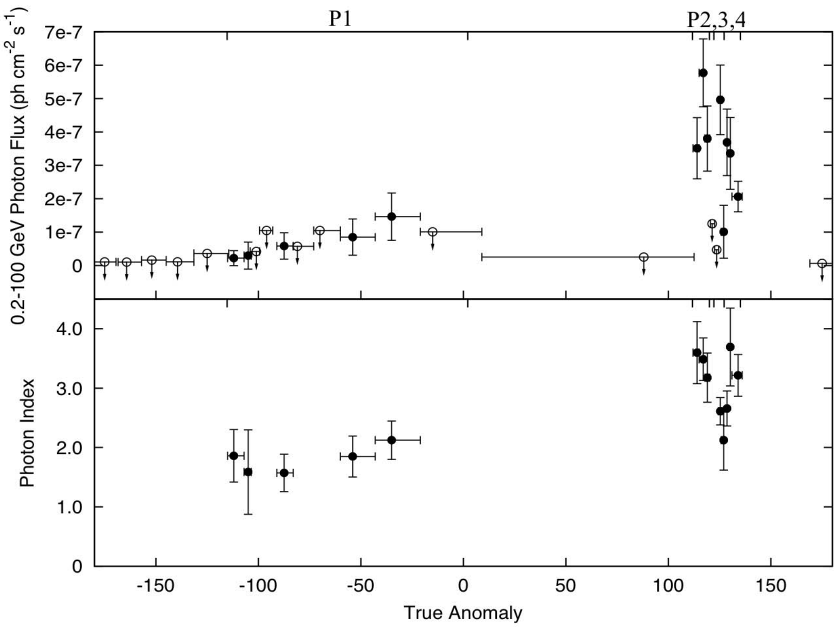

Figure 1: *Upper panel*: Orbital light curve from PSR B1259−63/LS 2883, using data taken from 2008 August 4 to 2011 February 21. This covers 90% of the orbital phase. Power law is assumed in deriving the photon flux. For periods without significant detection (i.e., TS<5), 2 confidence-level upper limits were calculated assuming a photon index of 2.1. *Lower panel*: Photon index variation over time.

3 Time-varying Spectra

As seen in Fig. 1, the photon indices change significantly with time. We show the 0.1–3 TeV γ-ray spectra for P1–P4 in Fig. 2. While the emission is detected, i.e., Test-statistics (TS)>5, from 1.4 GeV to 20 GeV for P1, no γ-ray source was detected at the PSR B1259−63 position above 1.4 GeV (the derived TS values <5) for P2, P3, and P4, indicating a cut-off at energy ∼1 GeV during the flaring period. We therefore attempted to fit the 0.1–100 GeV spectrum with a power law with an exponential cut-off (PLE). We found that PLE describes the spectrum even better than the power law model during the periods P2, P3, and P4, by ΔTS>8, i.e., $>3\sigma$ in significance levels. The cut-off energies were found to be 310±160 MeV, 550±330 MeV, and 250±95 MeV during the periods P2, P3, and P4, respectively.

As shown in Fig. 2, the GeV emission evolves differently compared to the TeV emission, assuming that the TeV behavior does not change dramatically between 2004 and 2010 periastron passages.

At a distance 2.3 kpc [15], the average energy flux during the flares of $\sim 3\times10^{-10}$ erg cm^{-2} s^{-1} corresponds to the γ-ray luminosity 1.9×10^{35} erg s^{-1}. Given the pulsar spin-down luminosity $\sim 8\times10^{35}$ erg s^{-1}, the average γ-ray efficiency is about 25% during the flares.

3.1 Discussion

PSR B1259−63/LS 2883 is the third known binaries with significant detection in GeV, after LS I+61°303 [16] and LS 5039 [17]. It is also the only system among these three for which the nature of the compact object is certain. However, the observed GeV emission from PSR B1259−63/LS 2883 has challenged existing models, leptonic and hadronic alike. We briefly introduce a possible scenario (in the context of a leptonic model) in this section.

In leptonic models (e.g., [18, 19, 20]), pulsar wind particles are accelerated at the shock where the dynamical pressure of the pulsar wind and that of the stellar wind are in balance. These particles in turn emit non-thermal photons over a wide range of energies via synchrotron radiation (for radio waves to GeV γ-rays) and inverse-Compton (IC) upscattering off star light (for >10 GeV γ-rays), resulting in two peaks in the broadband spectrum.

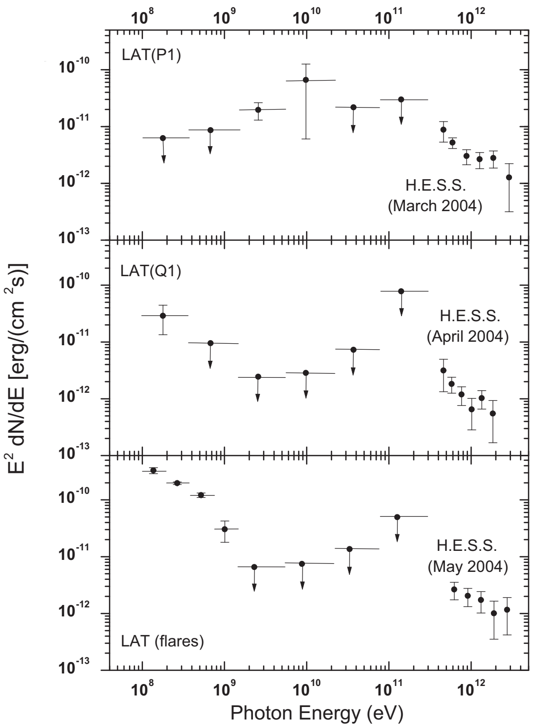

Figure 2: 100 MeV to ∼3 TeV γ-ray spectra in $E^2\, dN/dE$ representation during different orbital phase periods. Data between 100 MeV and 300 GeV were obtained by Fermi/LAT through the 2010 periastron passage. Data above 300 GeV were obtained by the H.E.S.S. telescopes through the 2004 periastron passage [4]. The observations were carried out in the periods shown in each panel which are chosen to be in the similar orbital phases for the two energy bands in the same panel. Two confidence-level upper limits were calculated for those bins with TS<5.

During the pre-periastron epoch, GeV emission at a flux level $\sim 6 \times 10^{-11}$ erg cm^{-2} s^{-1} is detected from mid-November through mid-December. The fitted spectrum during this period (P1) is relatively hard ($\Gamma_\gamma \sim 2$). The emission during this period may be related to emission originating just behind the shock where the bulk Lorentz factor is ∼1.

During the post-periastron epoch, Doppler boosting may provide a plausible mechanism to produce the GeV flares during January 14 – February 3, 2011 (see also [21]). Numerical simulations in the hydrodynamic limit imply that the post shock bulk flow for the binary system can be accelerated into relativistic regime due to the rapid expansion of the flow in the downstream region [22]. For example, Dubus et al. [23] discussed the effects of Doppler boosting on the orbital modulations of the X-ray and TeV emission. If the bulk flow is relativistic and oriented radially away from the star, the Doppler effect may be at work close to the true anomaly corresponding to the direction of the Earth ($\sim 130°$). This is approximately the time when the GeV flares were observed (i.e., $110° - 130°$). The Doppler effect increases the photon energy as $E = \mathcal{D}E'$ and the intensity as $I_\nu \propto \mathcal{D}^{3+\alpha} I'_\nu$, where $\mathcal{D}$ is the Doppler factor, and $\alpha = \Gamma - 1$ the spectral index. Non-prime and prime notations represent quantities in the observer and co-moving frames, respectively.

In γ-rays, $\alpha_\gamma \sim 1-2$ is expected from synchrotron radiation models, which is consistent with the Fermi results. An enhancement factor of 5–10 in flux during flares (P2 and P3) compared to the emission before periastron (P1) suggests $\mathcal{D}$ ∼1.5–2.

In X-rays, Suzaku observations indicate a low energy break, i.e., around 10 keV [24]. Because the photon index of the synchrotron spectrum below the break is $\alpha = -1/3$, the enhancement factor becomes $D^{3-1/3} \sim 3$. Thus, the enhancement in X-rays is suppressed compared to γ-rays. It is important to obtain simultaneous observations in X-rays and gamma-rays during the flaring period to test the boosting model.

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