Observing the unique binary PSR B1259−63/LS 2883

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1 Introduction

A new class of high-mass X-ray binaries (HMXBs) have been recently discovered as γ-ray emitters. These binaries contain a compact object orbiting an OB companion star. It is commonly believed that energetic particles are either accelerated in jets or in the collision shocks between the stellar wind and pulsar wind, in turn up-scattering the optical to UV lights to GeV–TeV γ-rays. Pulsed γ-rays from pulsar magnetosphere might also contribute to the observed photons up to a few GeV. Several groups of authors have proposed phenomenological models to explain the high-energy emission behaviors of γ-ray binaries (e.g., Dubus 2006, Takata & Taam 2009, Kong et al. 2011, Zabalza et al. 2013).

Up to now, the following five systems are confirmed GeV and/or TeV γ-ray binary systems (in ascending order of the orbital periods): LS 5039 (3.9 days), 1FGL J1018.6−5856 (16.6 days), LS I +61 303 (26.5 days), HESS J0632+057 (321 days), and PSR B1259−63 (3.4 years). For LS 5039 and LS I +61 303, GeV and/or TeV γ-ray emission are modulated on the orbital period but is easily detected throughout the whole orbit. In the case of PSR B1259-63, γ-ray emission is only detected in certain parts of the orbit. Together with its long orbital period (3.4 years), it was only detected in one occasion when the pulsar approached the companion star in late 2010/early 2011. Being a transient source, it is important to capture those γ-ray signal close to its periastron once every 3.4 years. Therefore, we propose to observe PSR B1259−63, a γ-ray binary with a 3.4-year orbital periods, so as to maximize the scientific return of the Fermi/LAT instrument during its mission life.

2 A theoretical framework for γ-rays from PSR B1259−63

PSR B1259−63/LS 2883 is a highly elliptical binary with 3.4 years period containing a pulsar and a Be star companion. Asymmetric double peaks have been detected in both X-rays (Chernyakova et al. 2009) and TeV γ-rays (Aharonian et al. 2009) before and after the periastron passages. GeV-flares have also been detected shortly after the 2010 December periastron passage, albeit at a bit different orbital phase than the X-ray/TeV peaks (Tam et al. 2011, Abdo et al. 2011). Figure 1 shows the multi wavelength data of the system, including the latest periastron passage in December 2010/January 2011. Kong et al. (2012) have used a model, which includes a power-law dependent magnetization parameter, anisotropic pulsar injection and Lorentz Boosting effect, to explain the asymentric X-ray and TeV light curves and the GeV-flare. In this model the GeV-flare should occur around the Inferior Conjunction (INFC) where the Lorentz Boosting factor, which consists of the angle difference between the viewing angle and outflow angle, and the bulk Lorentz factor of the outflow, become maximum. Figure 2 depicts two proposed emission regions in the termination shock between the pulsar wind and the stellar wind. More detail observed data around the INFC can constrain the outflow detail.

Recently an orbital-dependent GeV-component has been found in the black widow system PSR B1957+20, which is interpreted as the IC component of the cold pulsar wind (Wu et al. 2012). In fact as shown in Tam et al. (2011), the detection of lower level GeV emission has been found near the Superior Conjunction (SUPC) with significant harder spectrum than the major GeV-flare occurred in INFC. The detailed monitoring around the SUPC may allow us to test the IC component of pulsar wind.

3 GeV γ-ray behavior as seen by the LAT around the 2010/2011 periastron passage

The next periastron passage will occur around May 05, 2014. Observations at the last periastron passage in December 2010 (Tam et al. 2011, Abdo et al. 2011) gave us a strong hint of what we can expect in 2014. Starting at a month before the periastron passage, a weak emission ($\sim$5-σ detection) was seen. This weak emission lasted for more than a month, but was only detectable when one uses several weeks' data just to obtain enough photons to obtain a 5-σ detection, and the source is not detectable at 5-σ level in any time spans of days or a week. The situation dramatically changed when a major GeV flare occurred on $\sim$30 days after the periastron passage, with an average flux at more than 10 times the pre-periastron flux level. This flare-like emission continues until $\sim$60 days after the periastron passage.

Due to the marginal detection of the pre-periastron emission, the spectrum and variability during this emission period, is poorly constrained. A modified rocking mode was indeed triggered for 10 days in 2010/2011, which provided a 30% increase

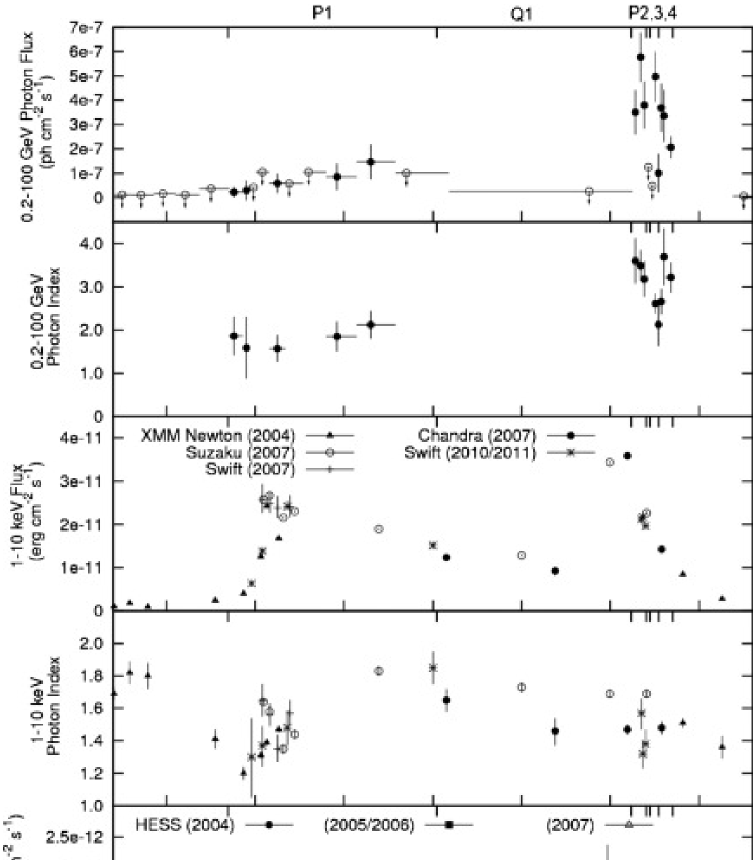

Figure 1: Observations of PSR B1259−63/LS 2883 at GeV γ-rays (upper two panels), X-rays (the third and fourth panels), and TeV γ-rays (lower panel). Symbols represent data taken in the 2010/2011 periastron passage, unless otherwise specified (Tam et al., 2011).

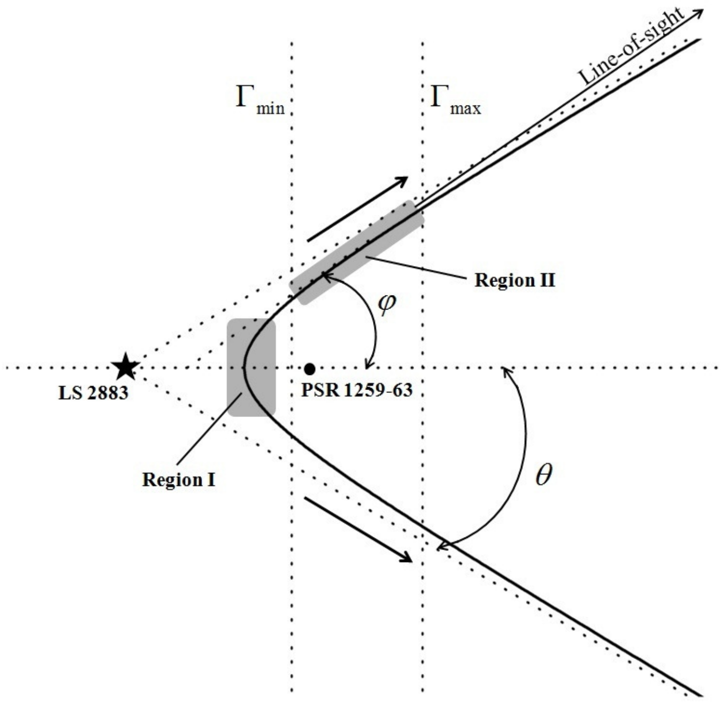

Figure 2: Two proposed emission regions in the termination shock between the pulsar wind and the stellar wind. In this model, the 2011 January GeV flare results from Doppler boosted emission from the shock tail (Region II) while PSR B1259−63 is close to the INFC. The model can also reproduce the symmetric double peaks around the periastron passage seen in both X-rays and TeV γ-rays (Kong et al., 2012).

in exposure during this period. But the main emission periods, including the pre-periastron low-level emission and the post-periastron flares, were outside these 10 days. Thus, in order to advance our knowledge of this unique GeV source, further increasing the photon statistics over the whole periastron passage period in 2014 is essential. We argue that given the rare occasion of a periastron passage of this system (i.e., only once every 3.4 years), a modified survey mode observation at or near the position of PSR B1259-63 in 2014 for >10 days can be justified. Assuming Fermi/LAT will have a total life time of ten years (i.e., mission ends at mid-2018), the 2014 passage will be the second last chance that the LAT can obtain data from this unique binary system at its periastron passage. The last chance will be in September 2017.

Concerning the synergy between GeV and TeV instruments, it is important to note that PSR B1259−63 is visible for the only operating TeV instruments in the southern hemisphere, the H.E.S.S. II telescopes (with an energy threshold of ∼30 GeV now), over the three-month period (April, May, and June) of the 2014 periastron passage, *but not* over the 2017 September passage. The Cherenkov Telescope Array (CTA) is planned but it is not clear whether it will be operational by 2017 and the site of the CTA is also not yet settled.

4 Feasibility Study and Observing Proposal in 2014

First, we study the exposure maps for some observing strategies of interest. A modified survey mode which emphasize the southern hemisphere sources and in particular PSR B1259−63 was performed between Dec 27, 2010 and Jan 5, 2011 (10 days; Figure 3). Under this mode, the LAT spends one orbit rocking to the north (50 degrees) for every two orbits rocking to the south. Also shown is a simulated exposure map for a 60-day period, whereas the above modified survey mode is used. It can be seen that the exposure for all southern hemisphere locations is increased (at about 30%) while not sacrificing too much the exposure for other parts of the sky. For comparison, the lower left panel in Figure 3 shows the exposure map for a 60-day observation during mid-2010, a typical survey mode observation. Pointed mode observations (lower right panel) can also be considered but the decrease in exposure in other parts of the sky is more severe, and should only be employed for a short period of time, e.g., less than a week.

Given the observed GeV emission in 2010/2011, we suggest to observe PSR B1259-63 once X-ray emission starts to rise, i.e., April 01, 2014, around 30 days before the periastron passage. The duration of the pre-periastron emission is not very clear and ranges from ∼30–45 days (Tam et al., 2011 and Abdo et al., 2011). If modified survey mode is employed for one or two months, the detection of the pre-periastron emission from PSR B1259−63 should be more secure. More accurate measurements of the spectral and temporal behaviors of the source over the whole pre-periastron period than before are also expected. We further suggest to continue the observations at least until the periastron passage, in order that we can see when and how the spectrum changes between the pre-periastron and post-periastron emission, as reported in both Tam et al. (2011) and Abdo et al. (2011). This will also enable a more thorough investigation from theoretical side, as outline in Section 2. We suggest to switch back to normal sky survey mode from June 01, 2014, i.e., a month after the periastron passage, since the flux level during the post-periastron flares is much higher. Another possibility is to keep the normal survey mode, but consider a ToO pointed mode observations that lasted only a few days once we see post-periastron flares at level above 3×10^{-7} ph cm^{-2} s^{-1} above 200 MeV (see Tam et al., 2011 and Abdo et al., 2011). Such ToO will help to probe the short-time (daily, even hourly scale) variability during the flares. The caveat for any pointed mode observations for this source is that exposure for other parts of the sky is largely reduced. We are ready to receive comments from the LAT collaboration on such a critical ToO possibility.

To summarize, we propose to carry out a modified survey mode observation of the binary system PSR B1259-63/LS 2883 from April 01, 2014 to May 31, 2014. We also consider a ToO pointed mode observation once flares of Jan-2011-type are seen in the post-periastron period.

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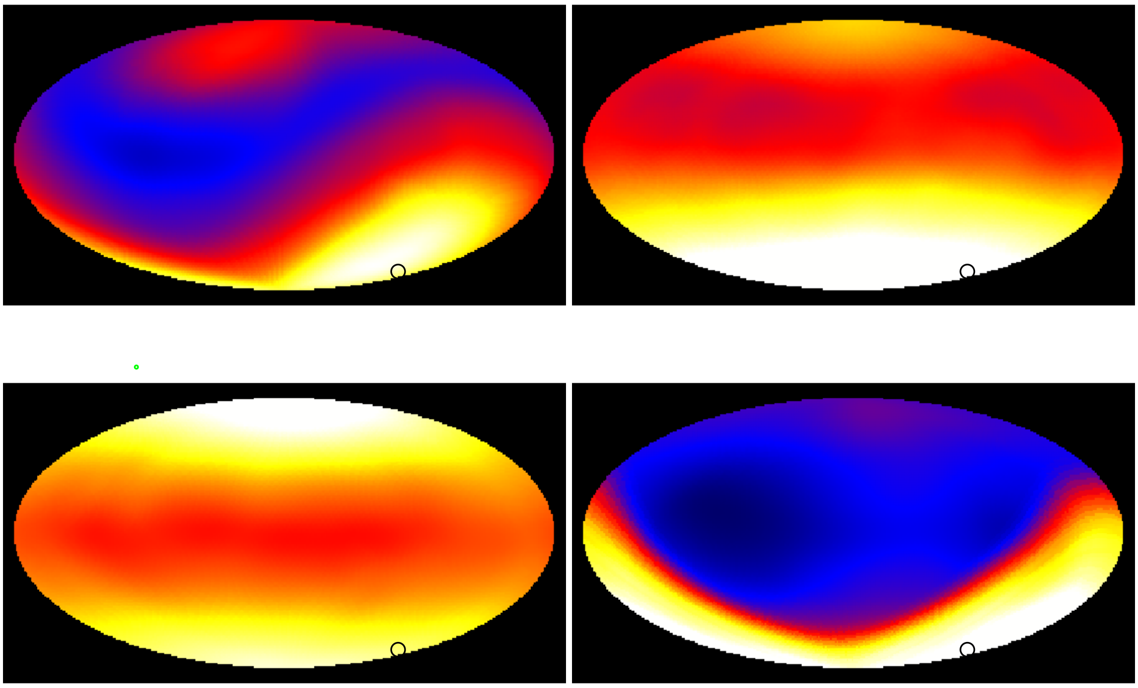

Figure 3: All-sky exposure maps for several observing strategies (at 3 GeV). Color scales are normalized to the 60-day normal survey mode (±50 deg rocking mode), except for the 10-day observations performed in 2010/2011. EAA of 30 degrees is used for simulated modes. The solid circles located the PSR 1259−63 position. Upper left panel: modified survey mode performed between Dec 27, 2010 and Jan 5, 2011. In this mode, the LAT spends one orbit rocking to the north (50 degrees) for every two orbits rocking to the south. Upper right panel: simulated exposure map for a 60-day period, using such modified survey mode. Lower left panel: exposure map for a 60-day observation during mid-2010, a typical survey mode observation, shown for comparison. Lower right panel: simulated pointed mode observations at (R.A., Decl.) = (195.70, −43.84) deg, i.e., 20 degrees to the north of the PSR B1259−63 position, switching to survey mode if the source is Earth-occulted.