Discovery of High-Energy Gamma-Ray Emission from the Binary System PSR B1259–63/LS 2883 Around Periastron with Fermi

Aous A. Abdo (GMU/NRL), for the Fermi LAT Collaboration, S. Johnston (CSIRO), M. Chernyakova (DIAS), A. Neronov (DIAS), and Fermi Pulsar Timing Consortium

Fermi Gamma-ray Space Telescope

GEORGE MASON UNIVERSITY

Abstract: We report on the discovery of ≥ 100 MeV γ rays from the binary system PSR B1259–63/LS 2883 using the Large Area Telescope (LAT) on board Fermi. The system comprises a radio pulsar in orbit around a Be star. We report on LAT observations from near apastron to ~ 60 days after the time of periastron, tp, on 2010 December 15. No γ-ray emission was detected from this source when it was far from periastron. Faint γ-ray emission appeared as pulsar approached periastron. At ~ tp + 30d, the ≥ 100 MeV γ-ray flux increased over a period of a few days to a peak flux 20–30 times that seen during the pre-periastron period,but with a softer spectrum. For the following month, it was seen to be variable on daily time scales, but remained at ~ 1 − 4 × 10−6 photons cm−2 s−1 before starting to fade at ~ tp + 57d. The total γ-ray luminosity observed during this period is comparable to the spin-down power of the pulsar. Simultaneous radio and X-ray observations of the source showed no corresponding dramatic changes in radio and X-ray flux between the pre-periastron and post-periastron flares. We discuss possible explanations for the observed gamma-ray-only flaring of the source.

System Overview

The binary system PSR B1259-63/LS 2883 consists of a 47.76 ms pulsar (PSR B1259-63) orbiting a massive Be star (LS 2883) in a highly elliptical orbit (e = 0.87) with an orbital period of 3.4 years. The companion shows evidence for an equatorial disk in its optical spectrum, and has generally been classified as a Be star [1]. The pulsar comes within ~ 0.67 AU of its companion star at periastron [2]. The orbital plane of the pulsar is believed to be highly inclined with respect to this disk and so the pulsar crosses the disk plane twice each orbit, just before and just after periastron [3]. Shock interaction between the relativistic pulsar wind and the wind and photon field of the Be star is believed to give rise to the variable unpulsed X-ray emission observed throughout the orbit [4,5] and the unpulsed radio and TeV γ-rays observed within a few months of periastron [6].

At energies around 1 GeV, EGRET provided only an upper limit for the 1994 periastron passage ($F_\gamma \leq 9.4 \times 10^{-8}$ photons cm^{-2} s^{-1} for E ≥ 300 MeV [7]). In TeV γ-rays the system was detected during the 2004 and 2007 periastron passages and flux variations on daily timescales were seen for energies > 0.38 TeV in 2004 [8,9].

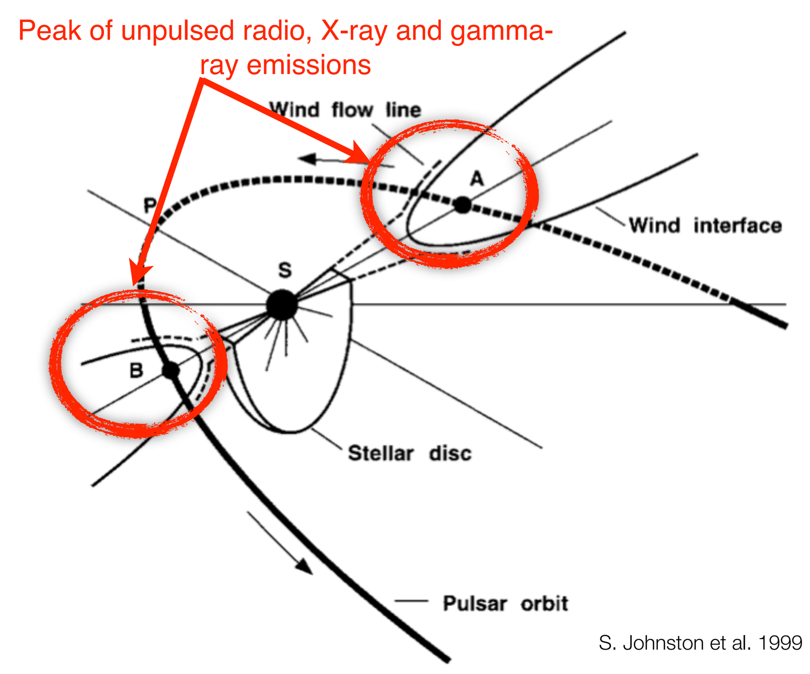


Fig. 1. Schematic diagram of the binary system

2010/2011 Multi-Wavelength Campaign

For the 2010/2011 passage the time of periastron $\mathbf{t_p}$ was on 2010 December 15. By comparison to previous passages, the unpulsed radio and X-ray emission was expected to start rising in mid 2010 November peaking around $\mathbf{t_p}$ − 10d in the pre-periastron phase and reaching another peak around $\mathbf{t_p}$ + 15d in the post-periastron phase.

For this periastron passage we assembled a campaign to observe this system over ~15 decades of energy, from radio to TeV γ-rays. One of the main questions we are trying to answer regarding this system is: What are the emission mechanism(s) responsible for non-thermal emission from this system. Previous attempts to answer this question has failed due to the lack of detection of the system in the GeV band.

Here we describe results from our MW campaign with emphasis on the Fermi LAT detection of PSR B1259–63 in the E ≥ 100 MeV range around the 2010/2011 periastron passage. We have analyzed LAT data over the entire time period from the beginning of the Fermi mission (2008 August 4; at which time the pulsar was nearing apastron) through periastron up until the middle of the second disk passage of the pulsar into the disk at 2011 February 8.

Participating instruments:

1. Parkes radio telescope: Monitor pulsed radio emission as well as changes in the dispersion measure (DM) and rotation measure (RM)
2. ATCA telescope array: Monitor unpulsed radio emission around periastron (1.1 and 10 GHz)
3. VLBI: Imaging in radio
4. 1.5 m SMARTS telescope: IR and optical monitoring around periastron
5. Monitor X-rays around periastron with: I) Swift II) Suzaku III) XMM-Newton IV) INTEGRAL
6. Fermi-LAT: Look for GeV γ-ray emission from the system and for any possible temporal and spectral variability
7. H.E.S.S telescope: Monitor the system in TeV γ-rays

Radio & X-ray Results

Our radio observations of the system for this periastron passages showed behavior that is similar to that seen in previous passages. Mainly:

- Pulsed emission eclipsed for 30 days starting 16 days before the time of periastron ($\mathbf{t_p}$ − 16d). The eclipse of the pulsar during this period is likely due to absorption and severe pulse scattering in the Be star's disk.
- During the two weeks preceding the eclipse the system showed significant changes in the DM with an increase of ΔDM ~ 10 cm^{-3} pc
- Unpulsed transient radio emission was detected throughout the periastron passage with a behavior similar to that seen in previous observations. The emission can be characterized by a double peak features at $\mathbf{t_p}$ − 10d and $\mathbf{t_p}$ +15d with a local minimum around the time of periastron as can be seen in Figure 2. The transient radio emission started rising some 30 days before periastron and is expected to decay to near-apastron levels some time in April ($\mathbf{t_p}$ + 100d).

X-ray observations of the system during this periastron passage demonstrated the repeatability of the 1-10 keV light curve as shown in Figure 2.

- Similar to the characteristics of the unpulsed radio emission, the X-ray light curve shows a double peak feature with a minimum around the time of periastron. The location of the two peaks in orbital phase are also similar to those seen in radio, $\mathbf{t_p}$ − 15d and $\mathbf{t_p}$ +15d.
- Our X-ray observations confirmed the spectral hardening preceding the pre-periastron flux rise.

Conclusion

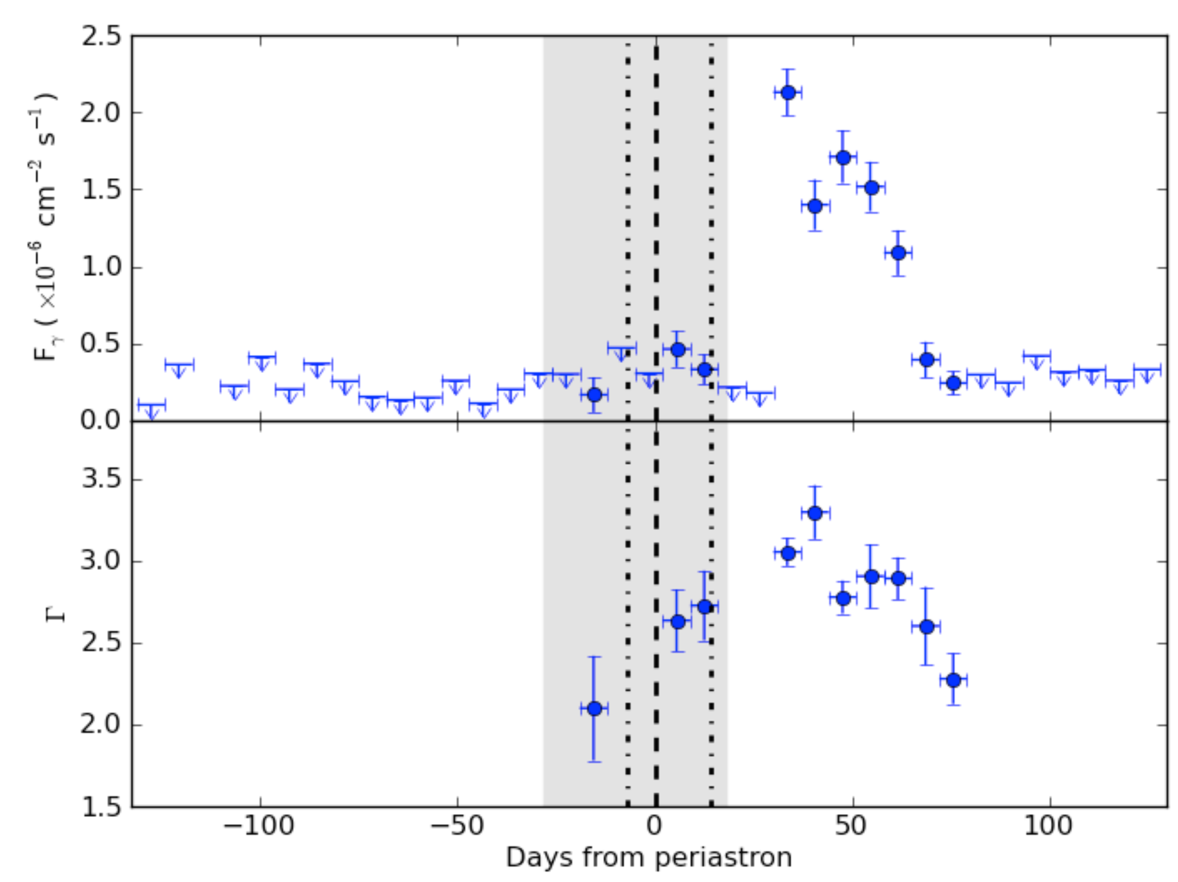
Our multi-wavelength campaign for the monitoring of the PSR B1259-63/LS 2883 binary revealed remarkable results. For the first time GeV γ-ray emission has been detected from this system. The behavior of the system in GeV γ-rays around periastron is quite different for the pre- and post-periastron passage. Faint hard emission with no sign of a cutoff was seen in the pre-periastron passage while softer exponentially cutoff emission that is 20-30 times brighter was seen in the post-periastron passage. This is contrary to what is seen in radio and X-rays. These seems to be a time lag between the flare in the GeV energy range compared to the second peak seen in radio and X-rays. The large difference in flux seen by the LAT between the two disk passages can be explained by either by anisotropy of the γ-ray emission, or by the difference between physical conditions during the first and second disk passages.

Detection of GeV Gamma-Rays with the LAT

We monitored the system with the Fermi Large Area Telescope (LAT) in two epochs. First we looked for γ-ray emission from the system when the pulsar was away from periastron. Analyzing two years of LAT data which covers the phase when the system was nearing apastron up until 4 months before periastron, no γ-ray signal was detected and we place an upper limit of $F_\gamma \leq 9 \times 10^{-9}$photons cm^{-2} s^{-1} for E ≥ 100 MeV.

Starting in November 2010 we started monitoring the system in daily and weekly time bins. This was done since this time marks the typical start of enhanced X-ray and unpulsed radio flux. Although no detection of γ-ray emission was observed on these time scales, we did notice higher-than-average test statistic (TS) values (compared to integrations at the same time scales but when the pulsar was far from periastron.) Integrating from $\mathbf{t_p}$ −28d to periastron yielded a clear detection of excess γ-ray flux from the source with a TS of ~ 24 which corresponds to a detection significance of ~5σ. The system continued to show faint γ-ray emission up until the end of the eclipse of the pulsed radio signal which also marks the start of the second disk passage. During this faint γ-ray brightening period the source flux above 100 MeV was $F_\gamma = (2.0 \pm 0.5_{stat} \pm 0.3_{sys}) \times 10^{-7}$photons cm^{-2} s^{-1} with a power law spectrum with photon index $\Gamma = 2.4 \pm 0.2_{stat} \pm 0.4_{sys}$. For the following two weeks the system went into quiescent state in GeV γ-rays before showing a rapid brightening with fluxes that were ~20 - 30 times higher than those seen during the faint-flux period. In addition to this unexpected flare the spectrum of GeV γ-rays during this flare is softer than that seen during the faint-flux period as can be seen in the bottom panel of Figure 3.

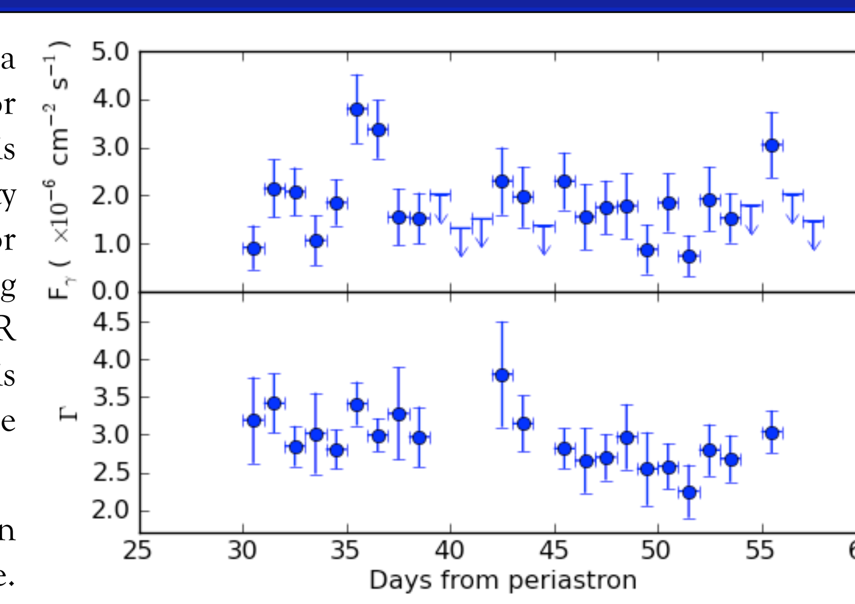
Integrating over the flare period we get a γ-ray flux of $F_\gamma = (1.9 \pm 0.2_{stat} \pm 0.35_{sys}) \times 10^{-6}$ photons cm^{-2} s^{-1} and is best fitted by a power law with an exponential cutoff with a power law index of Γ = 1.99 ± 0.2$_{stat}$ and a cutoff E_c = 398 ± 100 MeV.



Gamma-ray Spectral Variability During the Flare

The top panel of the figure on the right shows γ-ray flux as a function of time in 1-day time bins during the flare. To look for flux variability from the source on daily time scales during this flaring period we adopt the method for defining the variability index V outlined in [11]. At the 99.9% confidence level and for 27 degrees of freedom the light curve is inconsistent with being flat if V > 54.05. This variability condition is met by PSR B1259–63 for which V = 65 on daily time scales during this flare. During this strong-variability flaring period the source flux varied by a factor of 2–3 on daily time scales.

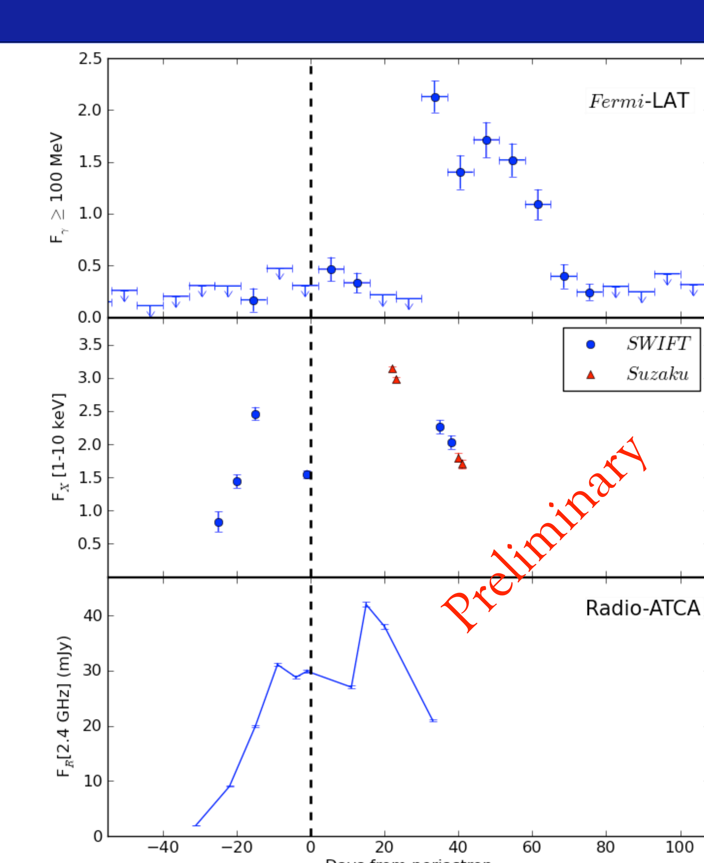
The figure on the right shows the gamma-ray flux and photon index of PSR B1259–63 in daily time bins during the flare. Upper panel: ≥ 100 MeV flux, bottom panel: spectral index of a power law spectrum.



The Multi-wavelength Picture

The figure on the right shows the source behavior in GeV gamma-rays (top), X-rays (middle), and unpulsed radio (bottom) as a function of time from the 2010/2011 periastron passage. The double peak feature seen in both the X-ray and radio light curves is clear. In both cases the second peak is a factor of 2 or so higher than that seen for the first peak. This is believed to be due to the build of emission from the second disk passage over the decaying emission from the first disk passage.

The flare seen by the LAT is not coincident with the second peak in radio and X-ray and is much brighter in comparison to the faint brightening during the fist disk passage.



References

[1] Johnston, S., et al. 1994, MNRAS, 268, 430
[2] Johnston, S., et al. 1992, ApJ, 387, L37
[3] Melatos, A., et al. 1995, MNRAS, 275, 381
[4] Cominsky, L., et al. 1994, ApJ, 427, 978
[5] Chernyakova, M., et al. 2009, MN- RAS, 397, 2123
[6] Chernyakova, M., et al. 2006, MNRAS, 367, 1201
[7] Tavani, M. et al. 1996, A&AS, 120, C221+
[8] Aharonian, et al. 2005, A&A, 442
[9] Aharonian, F., et al. 2009, A&A, 507, 389
[10] Johnston, S., et al. 1999, MNRAS, 302, 277
[11] Abdo, A. A. et al. 2010a, ApJS, 188, 405
[12] Edwards, R. et al. 2006, MNRAS, 372, 1549
[13] Abdo, A. A. et al. 2010b, ApJS, 187, 460
[14] Tavani, M., & Arons, J. 1997, ApJ, 477, 439