High-energy observations of PSR B1259-63 during the 2014 periastron passage

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Contents

• PSR B1259-63/LS 2883 as a gamma-ray binary
• Multiwavelength observations over previous periastron passages
• 2014 periastron passage
• Future prospects
γ-ray binaries

- non-thermal radiations e.g., binary pulsars, micro-quasar jets
γ-ray binaries

- composed of a compact object and a massive star, distinguished by their radiative output with a peak in νFν beyond 1 MeV (Dubus 2013).

- PSR B1259-63, LS 5039, LS I +61 303, HESS J0632+057, 1FGL J1018.6-5856
### $\gamma$-ray binaries

Dubus (2013)

<table>
<thead>
<tr>
<th></th>
<th>PSR B1259-63*</th>
<th>LS 5039†</th>
<th>LS I +61°303*</th>
<th>HESS J0632+057°</th>
<th>IFGL J1018.6-5856‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{\text{orb}}$ (days)</td>
<td>1236.72432(2)</td>
<td>3.90603(8)</td>
<td>26.496(3)</td>
<td>315(5)</td>
<td>16.58(2)</td>
</tr>
<tr>
<td>$e$</td>
<td>0.8698872(9)</td>
<td>0.35(3)</td>
<td>0.54(3)</td>
<td>0.83(8)</td>
<td>-</td>
</tr>
<tr>
<td>$\omega$ (°)</td>
<td>138.6659(1)</td>
<td>212(5)</td>
<td>41(6)</td>
<td>129(17)</td>
<td>-</td>
</tr>
<tr>
<td>$i$ (°)</td>
<td>19–31</td>
<td>13–64</td>
<td>10–60</td>
<td>47–80</td>
<td>-</td>
</tr>
<tr>
<td>$d$ (kpc)</td>
<td>2.3(4)</td>
<td>2.9(8)</td>
<td>2.0(2)</td>
<td>1.6(2)</td>
<td>5.4</td>
</tr>
<tr>
<td>spectral type</td>
<td>O9.5Ve</td>
<td>O6.5V((f))</td>
<td>B0Ve</td>
<td>B0Vpe</td>
<td>O6V((f))</td>
</tr>
<tr>
<td>$M_*$ ($M_\odot$)</td>
<td>31</td>
<td>23</td>
<td>12</td>
<td>16</td>
<td>31</td>
</tr>
<tr>
<td>$R_*$ ($R_\odot$)</td>
<td>9.2</td>
<td>9.3</td>
<td>10</td>
<td>8</td>
<td>10.1</td>
</tr>
<tr>
<td>$T_*$ (K)</td>
<td>33500</td>
<td>39000</td>
<td>22500</td>
<td>30000</td>
<td>38900</td>
</tr>
<tr>
<td>$d_{\text{periastron}}$ (AU)</td>
<td>0.94</td>
<td>0.09</td>
<td>0.19</td>
<td>0.40</td>
<td>(0.41)</td>
</tr>
<tr>
<td>$d_{\text{apsastron}}$ (AU)</td>
<td>13.4</td>
<td>0.19</td>
<td>0.64</td>
<td>4.35</td>
<td>(0.41)</td>
</tr>
<tr>
<td>$\phi_{\text{periastron}}$</td>
<td>0</td>
<td>0</td>
<td>0.23</td>
<td>0.967</td>
<td>-</td>
</tr>
<tr>
<td>$\phi_{\text{apsastron}}$</td>
<td>0.995</td>
<td>0.080</td>
<td>0.036</td>
<td>0.063</td>
<td>-</td>
</tr>
<tr>
<td>$\phi_{\text{inf. conj.}}$</td>
<td>0.048</td>
<td>0.769</td>
<td>0.267</td>
<td>0.961</td>
<td>-</td>
</tr>
<tr>
<td>$\phi_{\text{sup. conj.}}$</td>
<td>0.026</td>
<td>0.009</td>
<td>0.020</td>
<td>0.014</td>
<td>-</td>
</tr>
</tbody>
</table>
PSR B1259-63 and its companion

- PSR B1259-63/LS 2883 comprises of a pulsar and an Oe star, at $d \sim 2.3$ kpc (Negueruela et al. 2011)

- Eccentricity $\sim 0.87$; orbital period $\sim 3.4$ years

- the pulsar has a spin period 47.8 ms and spin-down power $\sim 8 \times 10^{35}$ erg s$^{-1}$
A unique system

- The long orbital period means that we have to wait for years to collect data in a single orbit.
- The only gamma-ray binary in which the nature of the compact object is unambiguously known (as a pulsar).
Near the periastron

Credit: NASA
A unique system

- Non-thermal emission, radio, through X-rays, to TeV gamma-rays, is generated during the interaction between the stellar wind/disk and the pulsar wind.

- An astrophysical laboratory to study the pulsar wind since it terminates close to the pulsar.
Radio observations

From top to bottom flux densities are at 0.84, 1.4, 2.4, 4.8, 8.4 GHz

Johnston et al. (1999)
X-ray emission

Chernyakova et al. (2009)
Extended radio/X-ray emission

Chandra observations taken in 2009, near apastron (Pavlov et al. 2011)

Moldon et al. (2012)
Gamma-ray emission

- Not detected by COMPTEL & EGRET over 1994 periastron passage
- Predicted to be γ-ray source by Tavani & Arons (1997), Kirk et al. (1999)
Gamma-ray emission

- Not detected by COMPTEL & EGRET over 1994 periastron passage
- Predicted to be γ-ray source by Tavani & Arons (1997), Kirk et al. (1999)

The 2010 periastron passage

- No detection before end of 2010
- First periastron passage since Fermi launch @ December 14, 2010
- Will any GeV light curve be similar to X-ray/TeV light curve?
GeV emission was first seen

Tam et al. (2011)
The GeV surprise!
Post-periastron flares

Tam et al. (2011)
The GeV surprise!
Post-periastron flares

Dubus & Cerutti (2013)
No contemporaneous TeV flare

H.E.S.S. Collaboration (2013)
Multi-wavelength lightcurves

Chernyakova et al. (2014)
Press conference in Taiwan
Questions before 2014 May

- Will the gamma-ray flare repeat?
- If so, will it happen at a similar orbital phase?
- How many flares are there?
- Is there pre-periastron emission? How we characterize it?
- Is there contemporaneous X-ray flare?
Fermi, Swift & NuSTAR campaign

- Periastron occurred on May 4, 2014
- Pointed-mode observations (with increased exposure towards PSR B1259-63) were taken during May 31 to June 26, 2014 (c.f. Julie)
- Swift/XRT observed PSR B1259-63 more intensively over the passage, even on daily basis during June 10 to 18
- NuSTAR observed PSR B1259-63 five times over the passage, good coverage for different phases
The light curves

5-day bins

X-ray spectrum becomes harder over time
Atels: when did the GeV emission start?

- Atel 6198 (Tam & Kong): no GeV emission before periastron; highest-ever X-ray flux at $t_p +18$ days
- Atel 6204 (Malyshev+): GeV flare@June 3-5
- Atel 6216 (Tam, Kong & Leung): did not confirm Atel 6204, instead the flare started@June 6-8
- Atel 6225 (Wood & LAT team): confirm Atel 6216
- Atel 6231 (AGILE team): GeV detection@June 11-13
- Also Atel 6248 (Bordas+): Short-term X-ray/ gamma-ray variability from PSR B1259-63
The light curves (flare)

Daily bins

½-day bins

Swift/XRT
The light curves
The spectra

April 20 – May 14
(periastron passage)

May 15 – June 1
(X-ray peak)

June 2 – July 2
(flaring state)
The spectra

April 20 – May 14
(periastron passage)
p=2.7, p(electron index)
synchrotron emission

May 15 – June 1
(X-ray peak)
p=2.4

June 2 – July 2
(flaring state)
p=2.0
The spectra

April 20 – May 14
(periastron passage)
p=2.7, p(electron index)
synchrotron emission

May 15 – June 1
(X-ray peak)
p=2.4

June 2 – July 2
(flaring state)
p=2.0

I

Swift+NuSTAR

Fermi

II

III

COMPTEL

@1994
Does dedicated pointing really help?

With rocking angle < 52° constraint

No cut on rocking angle
Questions before 2014 May

- Will the gamma-ray flare repeat? Yes.
- If so, will it happen at a similar orbital phase? Yes.
- How many flares are there? More than One.
- Is there pre-periastron emission? Probably. How we characterize it? ...
- Is there contemporaneous X-ray flare? Yes.
Synergy with other instruments

- Current
  - X-rays (Swift, Chandra, XMM, Suzaku)
  - hard X-rays (NuSTAR)
  - Hα emission (probe disk size, c.f. Chernyakova+ 2014)

- Future
  - CTA @ 50 GeV
  - Soft gamma-rays 0.1-10 MeV
Questions

- What caused the GeV flares?
- Why it happen at orbital phase when there seems to be nothing happening?

Dubus & Cerutti (2013)
20 years on ..

Tavani+ (1994)

Tam+ (2014)
Summary

- PSR B1259-63 has brought surprises over every periastron passage
- The GeV flare did repeat, at a similar orbital phase as 3.4 years ago
- X-ray flux varies similar to gamma-ray flux (during the 'flare epoch'), with a lesser extent
- Pre-periastron GeV emission situation unclear (increased LAT exposure certainly needed 2017)
- Establishing keV – GeV spectral connection