Fermi LAT Observations of Two Be-Pulsar Binary Systems at GeV Energies

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on behalf of the *Fermi* LAT collaboration

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Be Stars

- Main sequence (B or late O type, T_{eff} near 30,000 K) with masses in the range of ~10-30 $M_{\odot}$.
  - Spectra have Balmer emission lines.
  - Observed to be rotating near critical velocity.
  - Surrounded by a disk-like outflow (decretion disk).

- Many in binary systems ($P_{orb} \gtrsim$ 20 d), disk often tilted from orbital plane.

- For a useful review, see Rivinius et al. (2013).

Be-Pulsar Binaries

- Pulsar is accretion powered –
  - Significant X-ray sources
  - Variable, often orbitally dependent
  - Many 10s of sources known

- Pulsar is rotation powered –
  - Orbitally-dependent wind-wind interactions
  - Radio to TeV gamma-ray emission.
  - Two (?) sources known

    PSR B1259-63/LS2883

    PSR J2032+4127/MT91 213

“Repeatable Experiment”

- Pulsar acts as a test particle probing the Be star outflow

- If the orbital period is long enough, outflow should “reset” before next passage

- Rotation-powered pulsar means we don't have to separate signals from accretion and wind-wind interactions

PSR B1259-63/LS 2883

- Radio pulsar discovered with Parkes – (Johnston et al. 1996 & Shannon et al. 2014)
    - 48 ms spin period
    - Spin-down power 8.2e35 erg/s
    - 3.4 year orbit with a Be star
    - High eccentricity, e = 0.87
    - Radio pulses not seen around periastron
    - No pulsations reported at any other wavelength
    - Outflow tilted 10º - 40º from orbit plane (Melatos et al. 1995)
    - Recent updated distance of 2.7 kpc (Miller-Jones et al. 2018)

B1259 System Geometry

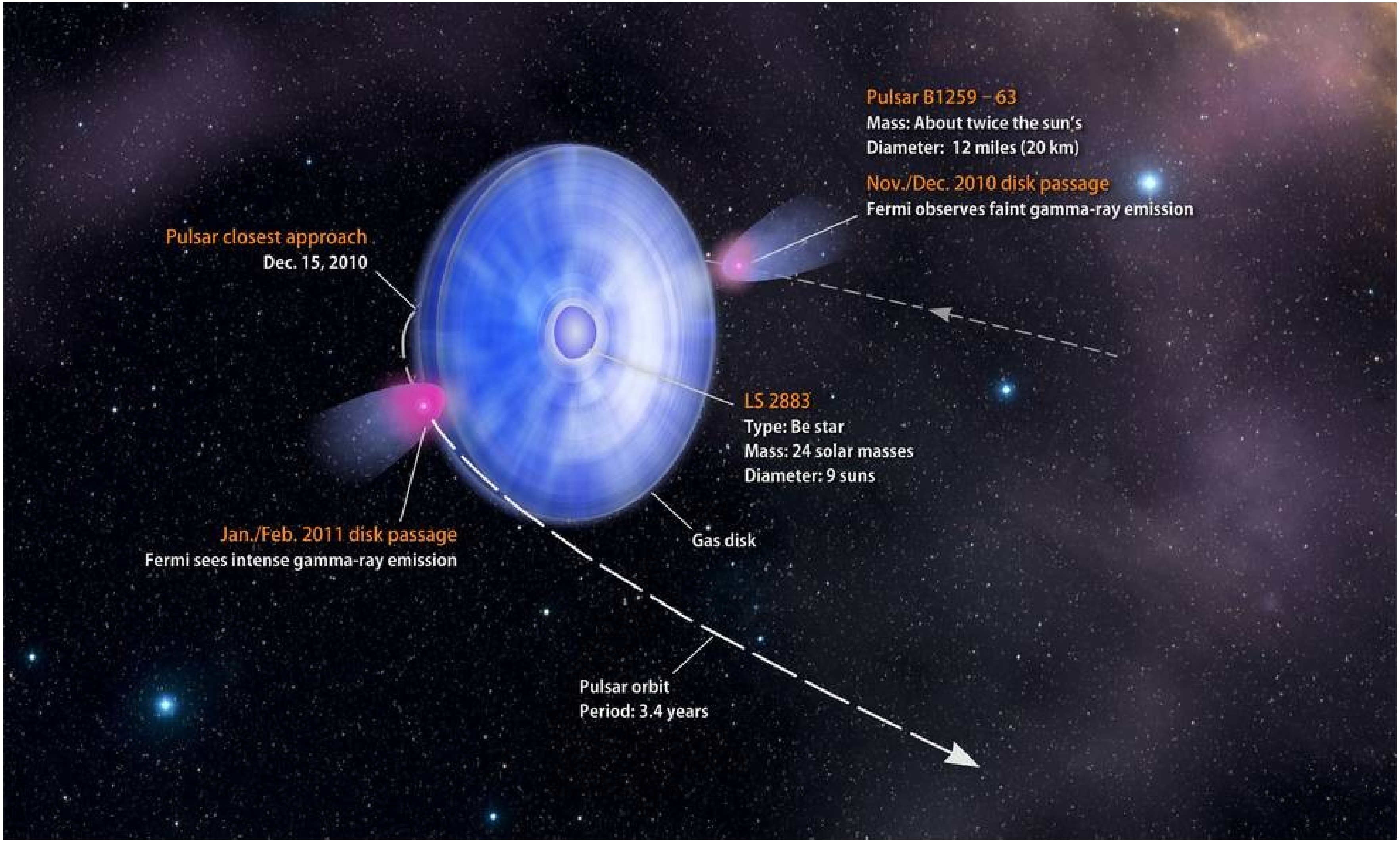


Fig. Credit: NASA

First (V)HE Detections

- Wind-wind interactions might produce X- and gamma-rays near periastron (King 1993 & Tavani et al. 1994)

- ASCA and OSSE X-ray detections (Kaspi et al. 1995 & Grove et al. 1995).
  - No pulsations, strongest just before/after periastron.

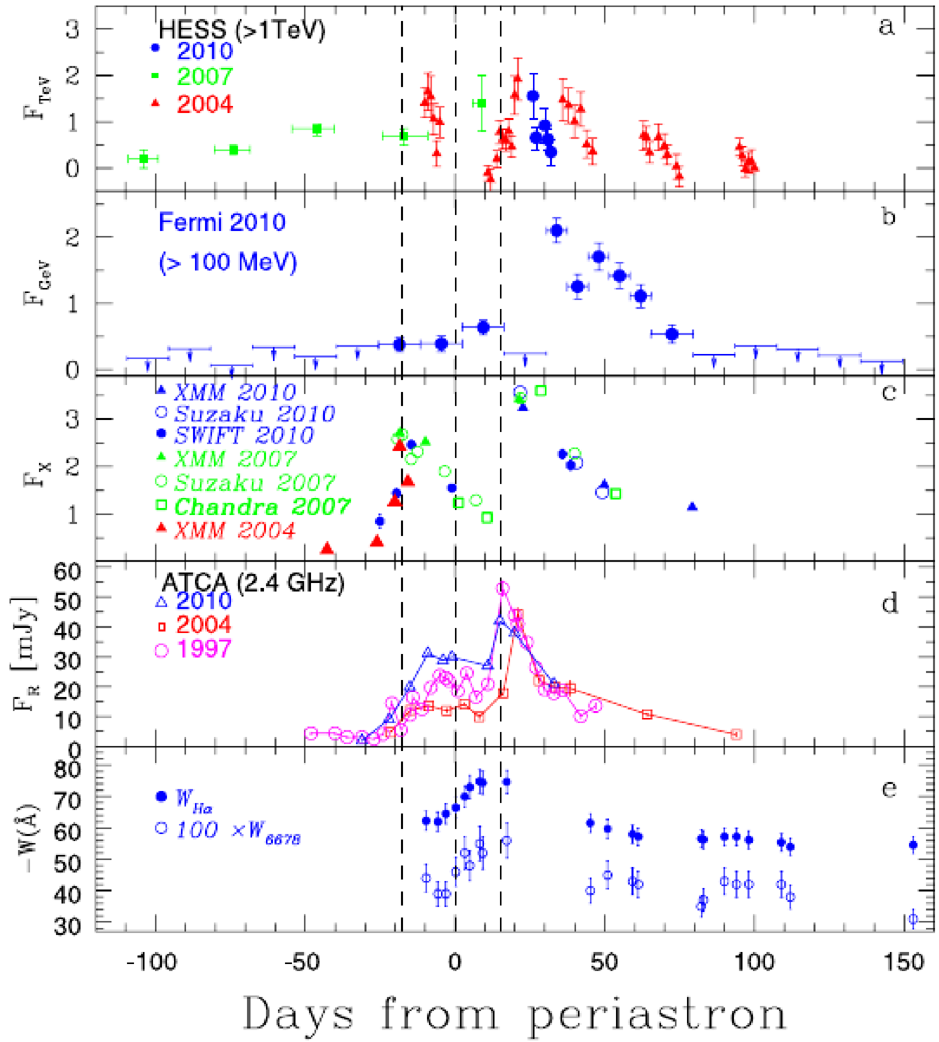
- No >100 MeV gamma-rays detected with EGRET (Tavani et al. 1996).
  - Observations from -6 d to +14 d from periastron.

- IC might lead to >100 GeV emission (Kirk et al. 1999).
  - VHE detection by HESS (Aharonian, et al. 2005).

B1259 in the Era of *Fermi*

- First periastron passage *Fermi* observed was late 2010.
- Detections near periastron.
  - Low-significance.
- Unexpected flare ~30 days after periastron.
  - Unmatched at other wavelengths.
  - Benefit of a survey instrument.
  - Hints of curvature, not confirmed

Chernyakova et al. (2014)



Two Events, Two Light Curves

Inclusive Pre /Post Periastron

Post-periastron, expanded

2010, Flux

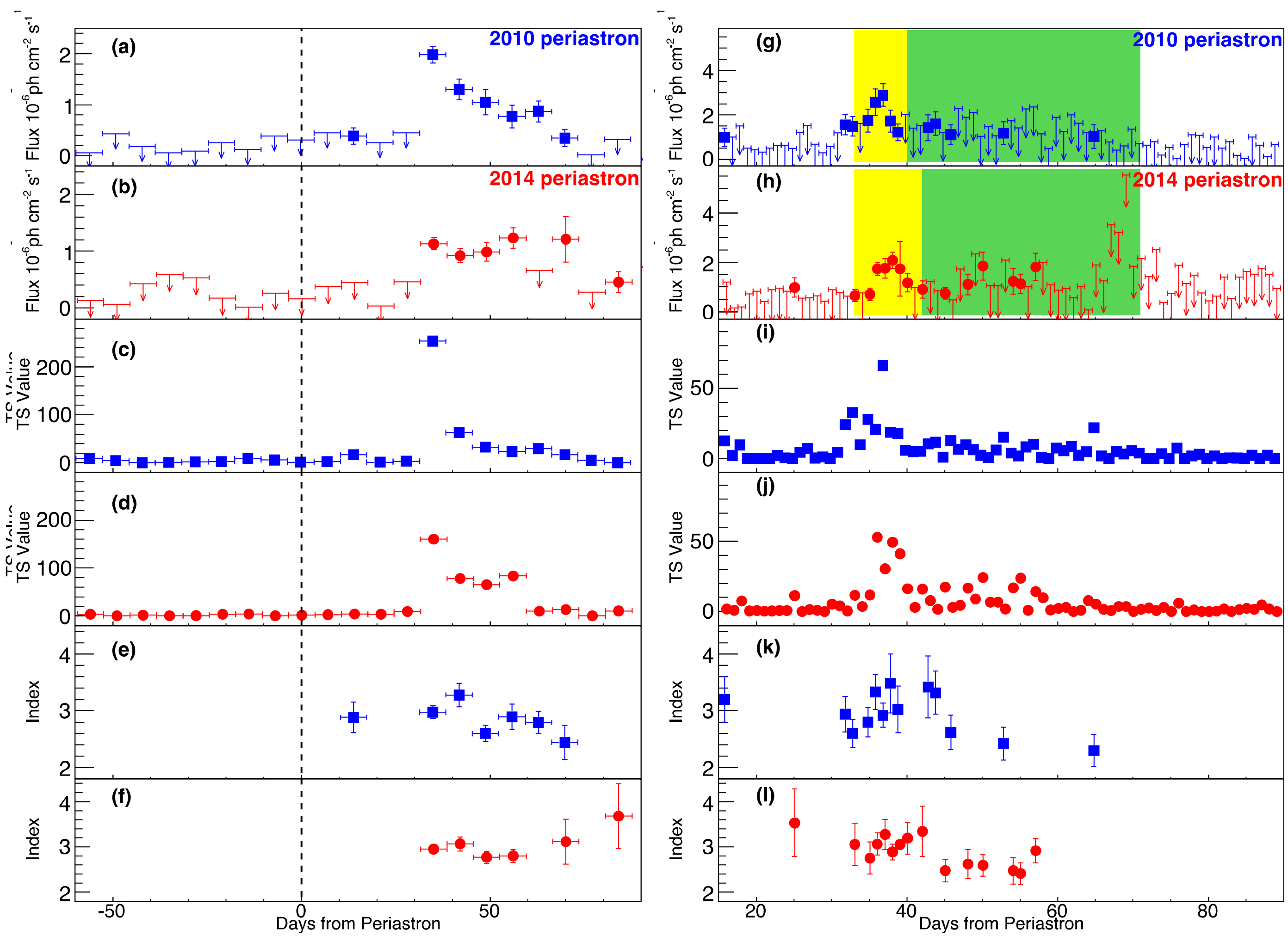
2014, Flux

2010, TS

2014,TS

2010, Index

2014, Index

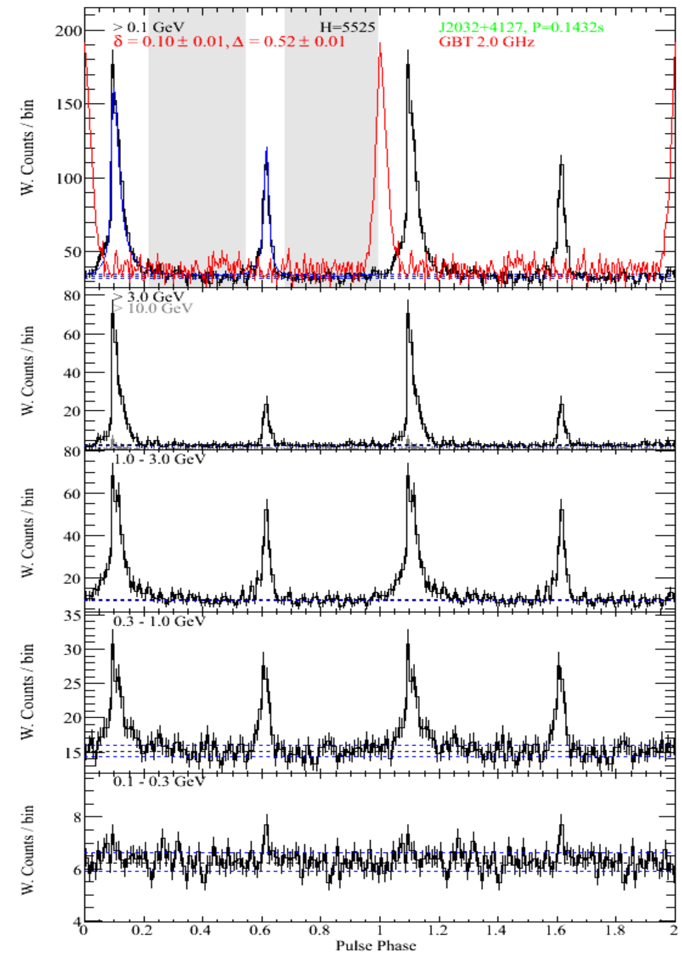


Caliandro et al. (2015)

PSR J2032+4127

- Discovered in gamma rays, quickly followed up in radio (Abdo et al. 2009 & Camilo et al. 2009).
  - P = 140 ms
  - Pdot = 1.2e-14 s/s
  - spin-down power 1.6e35 erg/s

- Positional coincidence with Be star MT91 213 noted, but no evidence for binary orbit in timing, unless P_orb $\gtrsim$ 100 yr.



Abdo et al. (2013)

A Binary After All

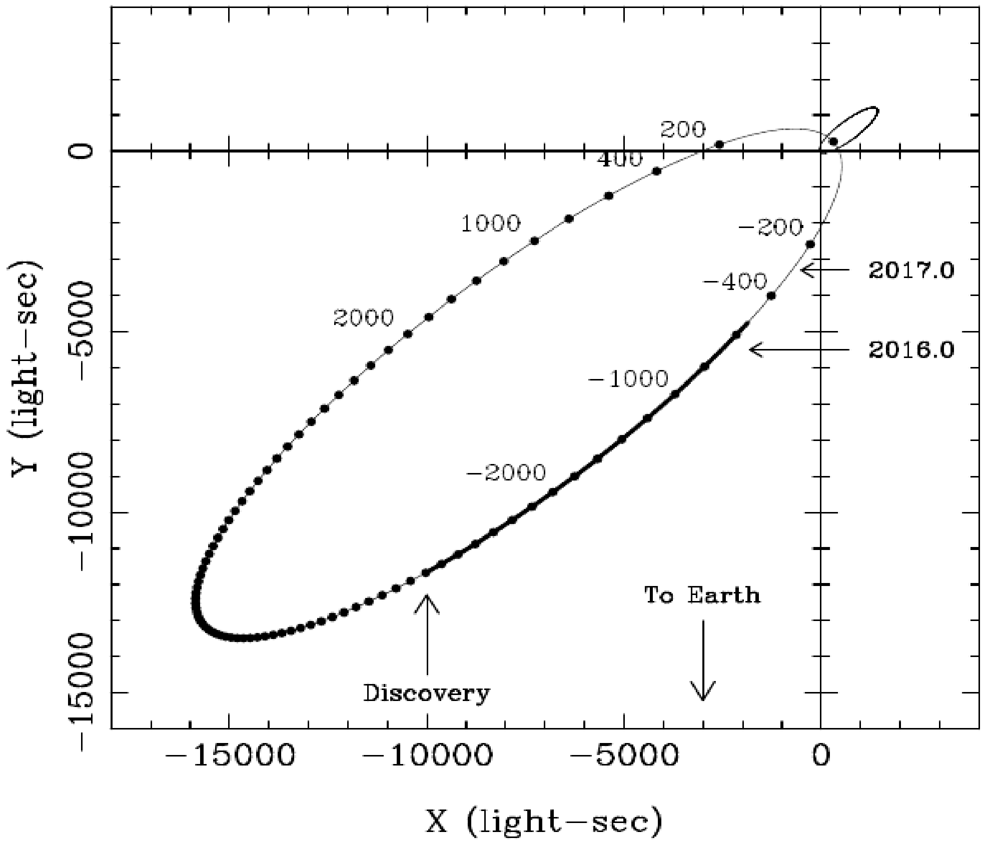


Figure 1. Schematic diagram illustrating the approximate orbital motion of PSR J2032+4127 and its Be-star companion MT91 213 about their common

Ho et al. (2017)

- Continued timing revealed binary orbit (Lyne et al. 2015 & Ho et al. 2017).
  - Orbital period ~50 years
  - Eccentricity ~ 0.96
  - Periastron 13 November 2017
- Another B1259?
  - Spin-down power of J2032 is 20% that of B1259
  - J2032 is closer at 1.4 kpc

Lead up to Periastron

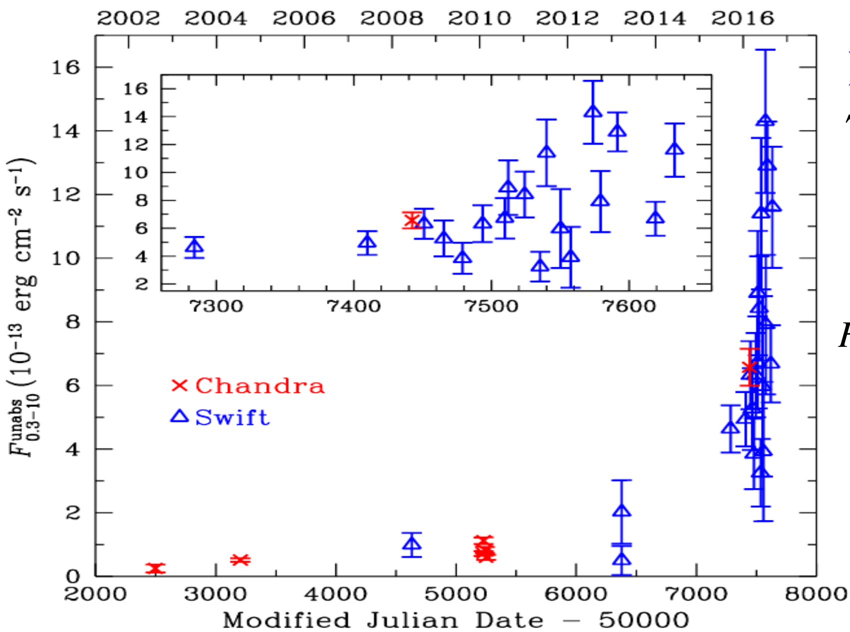


Figure 6. X-ray light curve of PSR J2032+4127/MT91 213 from 2002 to 2016. Points (and 1σ error bars) are *Chandra* (crosses) and *Swift* (triangles) unabsorbed 0.3–10 keV flux (see Table 2). Inset: closer view of the data covering the period from 2015 September to 2016 September.

- X-ray flux increase by a factor of 70 since 2002, 10 since 2010.

Ho et al. (2017)

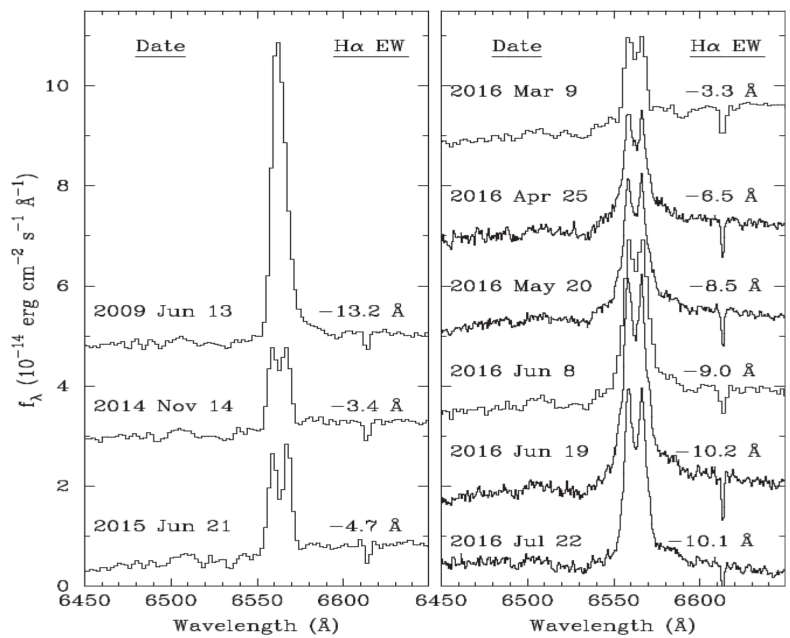
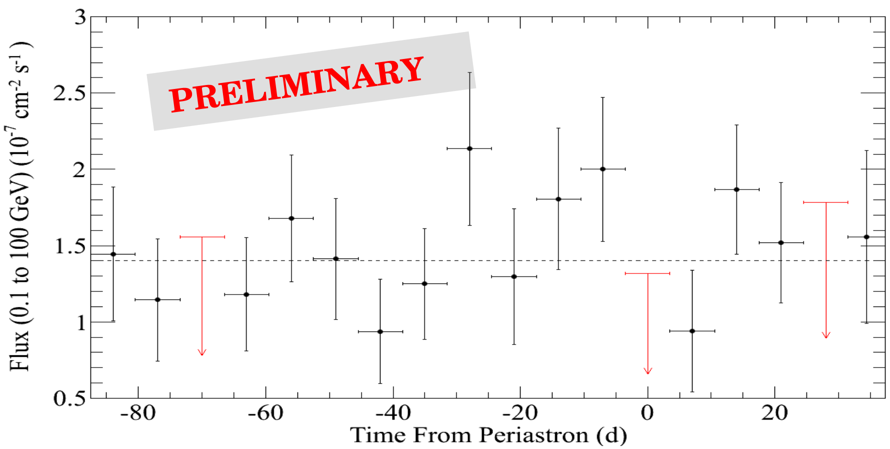


Figure 7. Hα region of spectra of MT91 213 (see Table 5). Spectra have been shifted vertically for clarity. The 2009 spectrum is the same as appears in Camilo et al. (2009). Absolute flux densities for MDM spectra are not reliable due to the narrow (1 arcsec) slit width used.

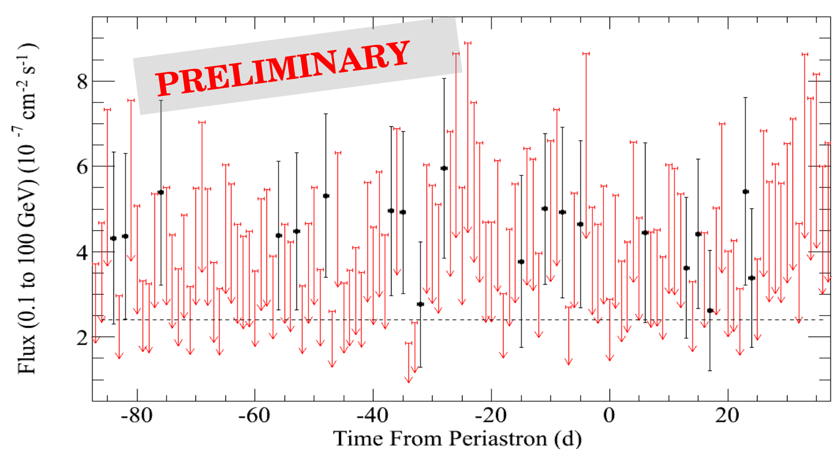
- H-α variations suggest changes in size of outflow by a factor of ~2.

J2032 Periastron

PSR J2032+4127, one-week bins



PSR J2032+4127, one-day bins



- GeV Gamma rays...not much (see also Li et al. 2018)
- Other wavelengths...a lot

TeV gamma-ray emission from PSR J2032+4127/ MT91 213

ATel #10810; ***The VERITAS and MAGIC Collaborations***
*on **3 Oct 2017; 17:52 UT***
Credential Certification: Jamie Holder (jholder@physics.udel.edu)

Subjects: Gamma Ray, TeV, VHE, Request for Observations, Binary, Neutron Star, Transient, Pulsar

Referred to by ATel #: 10851, 10971

Tweet | Recommend 65

The VERITAS and MAGIC collaborations report the detection of an enhanced TeV gamma-ray flux from the pulsar/ Be-star binary system PSR J2032+4127/ MT91 213 (RA 20h32m13.13s, Dec +41d27m24.4s, J2000.0). The binary nature of this system was identified in 2015 through radio and gamma-ray timing observations (Lyne et al., MNRAS, 451, 581, 2015). The orbital period is estimated at 45-50 years, with periastron expected to occur around November 2017. The X-ray flux has been steadily increasing as the system

PSR J2032+4127/MT91 213 on approach to periastron: X-ray & optical monitoring

Tel #10920; ***Coe M. J. (Southampton University), Steele IA (LJMU), Ho VCG (Southampton University), Stappers B (Manchester University), Lyne AG (Manchester University), Halpern JP (Columbia University), Ray PS (NRL), Johnson TL (GMU), Ng C-Y (Hong Kong University), Kerr M (NRL)***
*on **2 Nov 2017; 08:53 UT***
Distributed as an Instant Email Notice Transients
Credential Certification: Malcolm Coe (mjcoe@soton.ac.uk)

ubjects: Optical, X-ray, Gamma Ray, Binary, Neutron Star, Pulsar

eferred to by ATel #: 10971, 10993

Tweet | Recommend 3

Swift XRT monitoring of the ~50 year binary system PSR J2032+4127/MT91 213 shows a dramatic decrease in the X-ray flux as the system is in the final stages of approach to periastron (13 November 2017). The X-ray flux from this gamma-ray binary system has fallen sharply by a factor of two in the last few days in complete contrast to the steady X-ray flux rise seen over the past 150

TeV gamma-ray emission from PSR J2032+4127/ MT91 213 at periastron

ATel #10971; ***Razmik Mirzoyan for the MAGIC Collaboration and Reshmi Mukherjee for the VERITAS Collaboration***
*on **14 Nov 2017; 20:01 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: >GeV, TeV, VHE, Binary, Pulsar

Tweet | Recommend 52

The MAGIC and VERITAS collaborations report a continuing increase in TeV gamma-ray emission from the 50-year period pulsar/ Be-star binary system PSR J2032+4127/ MT91 213 (RA 20h32m13.13s, Dec +41d27m24.4s, J2000.0) The system reached periastron on 13 November 2017. The Swift X-ray flux has dropped dramatically over the past two weeks (see ATEL #10920 and the

A rapid X-ray brightening of PSR J2032+4127/MT91 213

ATel #10993; ***K. L. Li (MSU), A. K.H. Kong (NTHU), J. Takata (HUST), P. H.T. Tam (SYSU), K. S. Cheng (HKU), X. He (SYSU), C. Y. Hui (CNU), C. W. Ng (HKU), Partha Sarathi Pal (SYSU)***
*on **22 Nov 2017; 11:31 UT***
Credential Certification: Albert Kong (akong@phys.nthu.edu.tw)

Subjects: Optical, Ultra-Violet, X-ray, Request for Observations, Binary, Variables, Pulsar

Tweet | Recommend 0

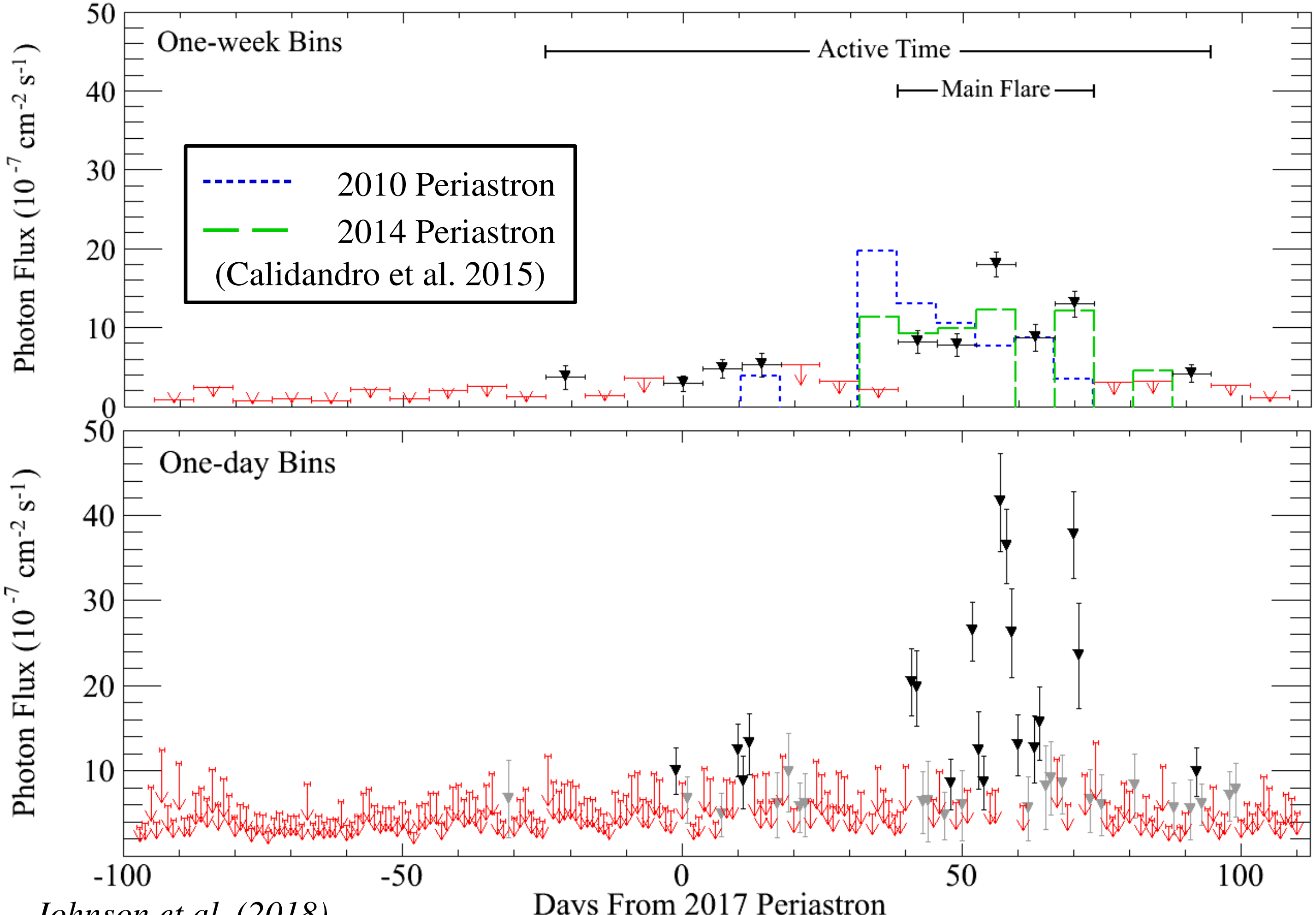
After showing an X-ray decline around the periastron (2017-11-13 or MJD 58070; ATel #10920), the gamma-ray binary candidate PSR J2032+4127/MT91 213 has exhibited a dramatic return in X-rays, witnessed by the three Swift/XRT observations taken in 2017-11-20/21 (see also the light curve at the

B1259 2017 Periastron

- Most recent periastron on 22 September 2017
  - Several ATels – #10775, 10818, 10924, 10925, 10972, 10973
  - Talk by Pak Hin Tam earlier in this conference

- Strikingly different behavior
  - Weak signal leading up to periastron
  - Small flare ~9-11 days after periastron
  - **More-intense flaring** ~40-70 days after periastron
    Variability on timescales < 6 hours
  - Significant spectral curvature

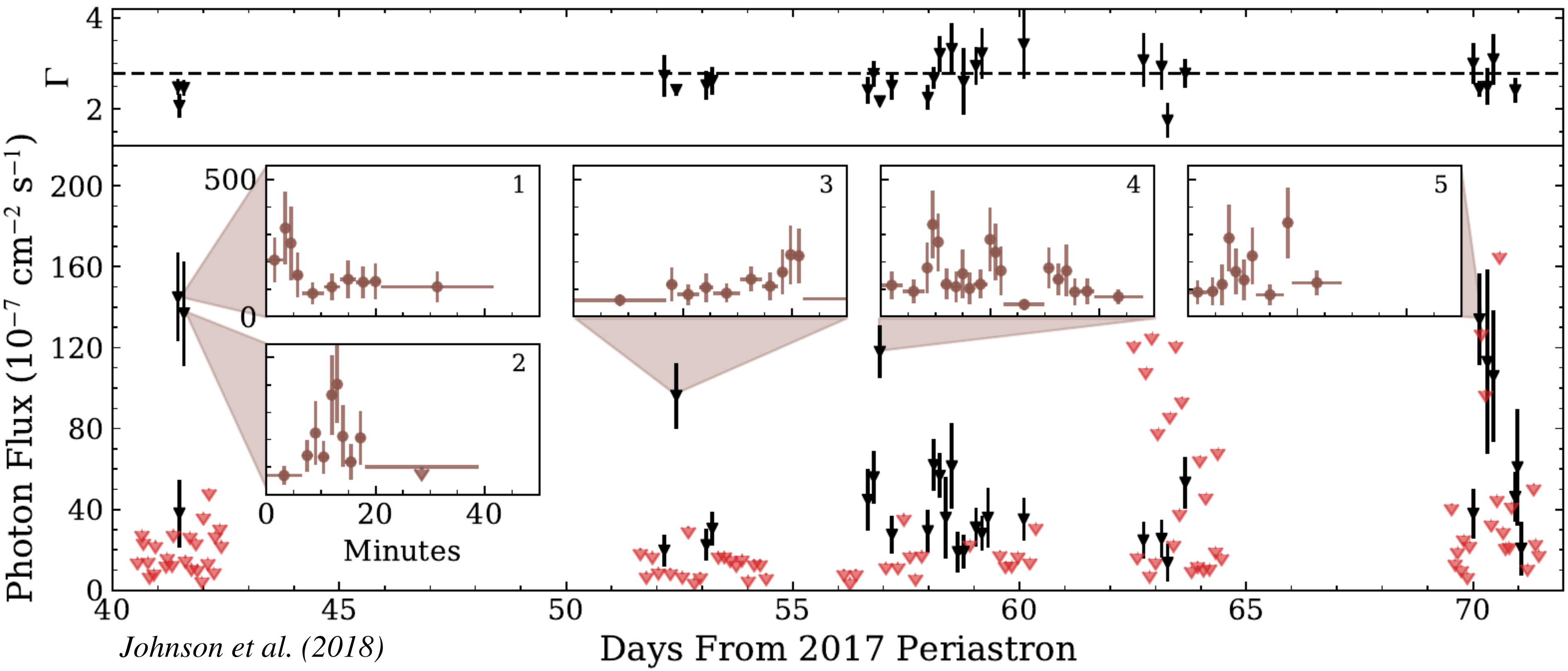
B1259 2017 Periastron



Johnson et al. (2018)

See also Chang et al (2018) and Tam et al. (2018)

B1259 2017 Periastron



Johnson et al. (2018)

- Flux variability on spacecraft orbit, and sub-orbit, timescales
  - Photon index not clearly variable
- Rise and fall times suggest factor of 2 changes in 1-1.5 minutes
  - Insets show 5 highest TS orbits

Energetics

Table 2. Maximum Gamma-ray Energetics on Different Time Scales

Time Scale	G (10^{-10} erg cm^{-2} s^{-1})	L_γ (10^{35} erg s^{-1})	$L_\gamma/\dot{E}$
One-week	7.3 ± 0.6	$6.4^{+2.0}_{-1.6}$	0.8 ± 0.2
One-day	14 ± 2	12^{+4}_{-3}	$1.5^{+0.5}_{-0.4}$
One-orbit	70 ± 16	61^{+18}_{-14}	$7.4^{+2.2}_{-1.7}$
Intra-orbit	280 ± 100	244^{+74}_{-56}	$29.8^{+9.0}_{-6.8}$

NOTE—For the time scales listed during the 2017 periastron passage, this table provides the maximum energy flux (G), gamma-ray luminosity (L_γ), and luminosity as a fraction of the spin-down power $\dot{E} = 8.2\times10^{35}$ erg s^{-1} ($L_\gamma/\dot{E}$). For the uncertainty on L_γ, we incorporate both the energy flux and distance uncertainties.

Johnson et al. (2018)

- Previous periastrons already pushed the spin-down power limit
- 2017 exceeds even on 1-day timescales, need boosted/beamed emission

Conclusions

- PSR B1259-63 continues to provide surprises
  - Three periastron passages, three different light curve
  - 2017 event showed the fastest variability seen in LAT data (excluding GRBs and solar flares)

- Gamma-ray luminosity suggests Doppler boosted emission
  - Disfavors inverse Compton emission
  - Estimate a maximum Doppler factor D ~ 3
  - ~1.5 minute variability $\rightarrow$ emission region radius $\lesssim$ 8e7 km (~30 - 40% of the distance to the Be star)

- No flare from PSR J2032+4127 near periastron
  - Geometry? Energetics?

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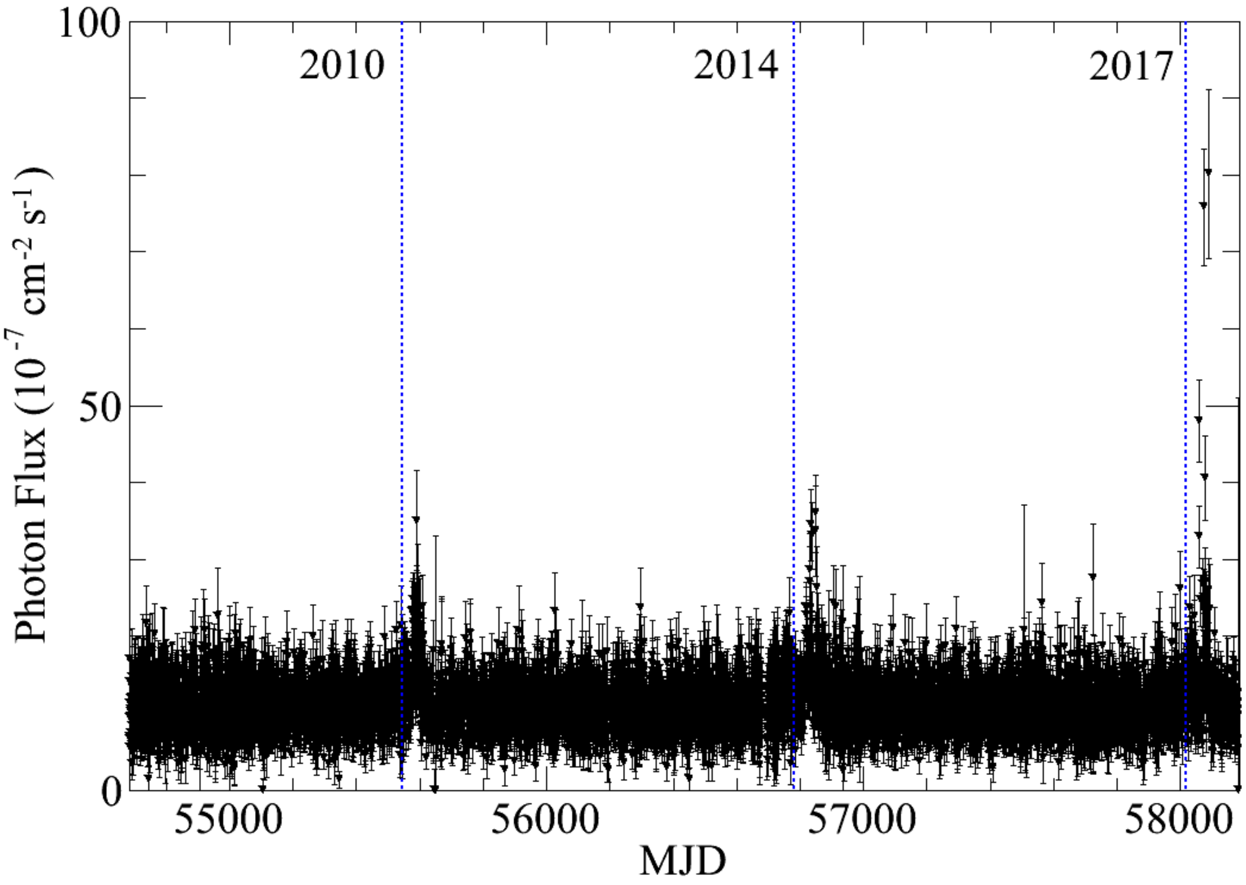
Backup

Previous Periastrons



- Aperture photometry, 12 h bins
- No evidence for similar rapid variability in previous periastrons