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

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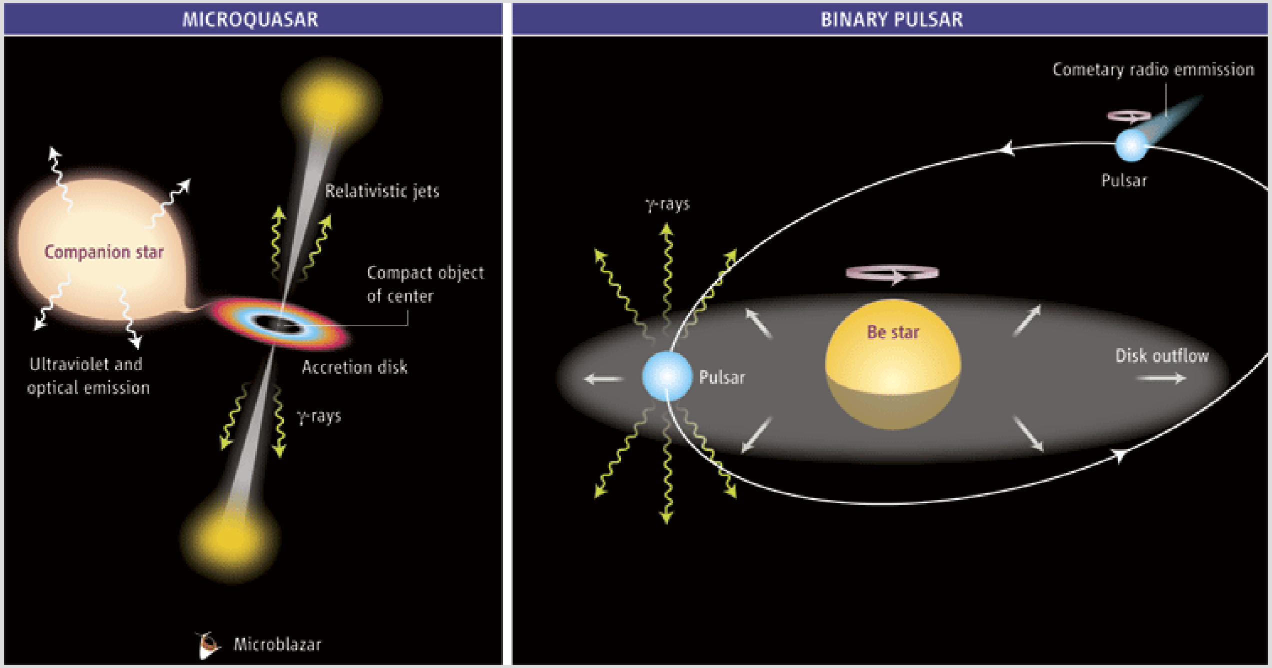
- PSR B1259-63/LS 2883 as a gamma-ray binary
- Multiwavelength observations over previous periastron passages
- 2014 periastron passage
- Future prospects

γ -ray binaries

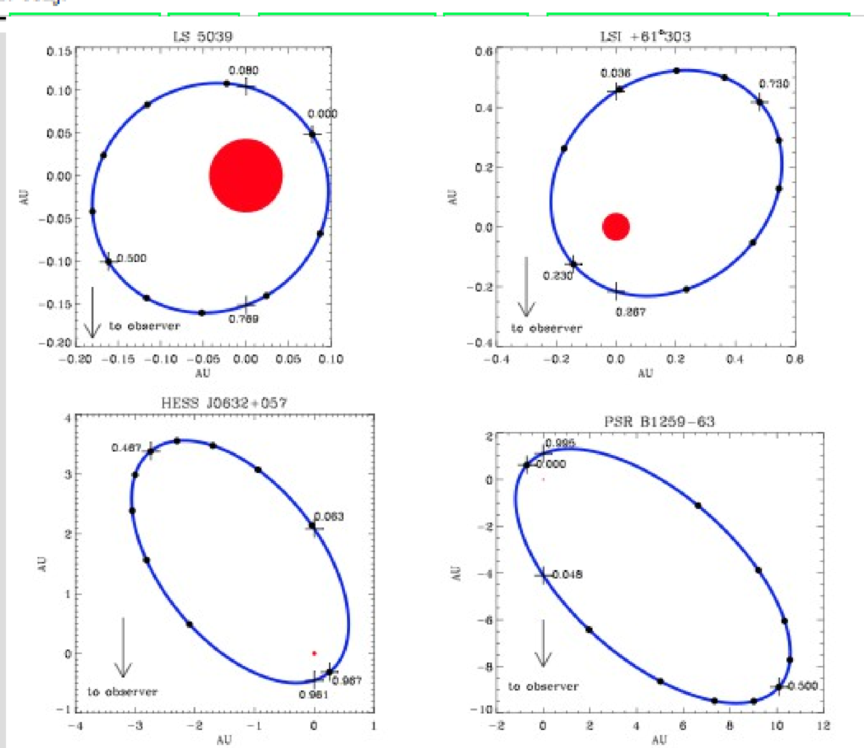
- non-thermal radiations e.g., binary pulsars, micro-quasar jets



γ -ray binaries

- composed of a compact object and a massive star, distinguished by their radiative output with a peak in $\nu F \nu$ beyond 1 MeV (Dubus 2013).
- PSR B1259-63, LS 5039, LS I +61 303, HESS J0632+057, 1FGL J1018.6-5856

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

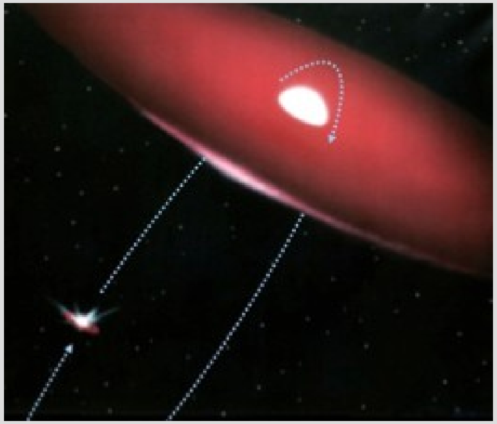


γ-ray binaries

Dubus (2013)

PSR B1259-63 and its companion

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

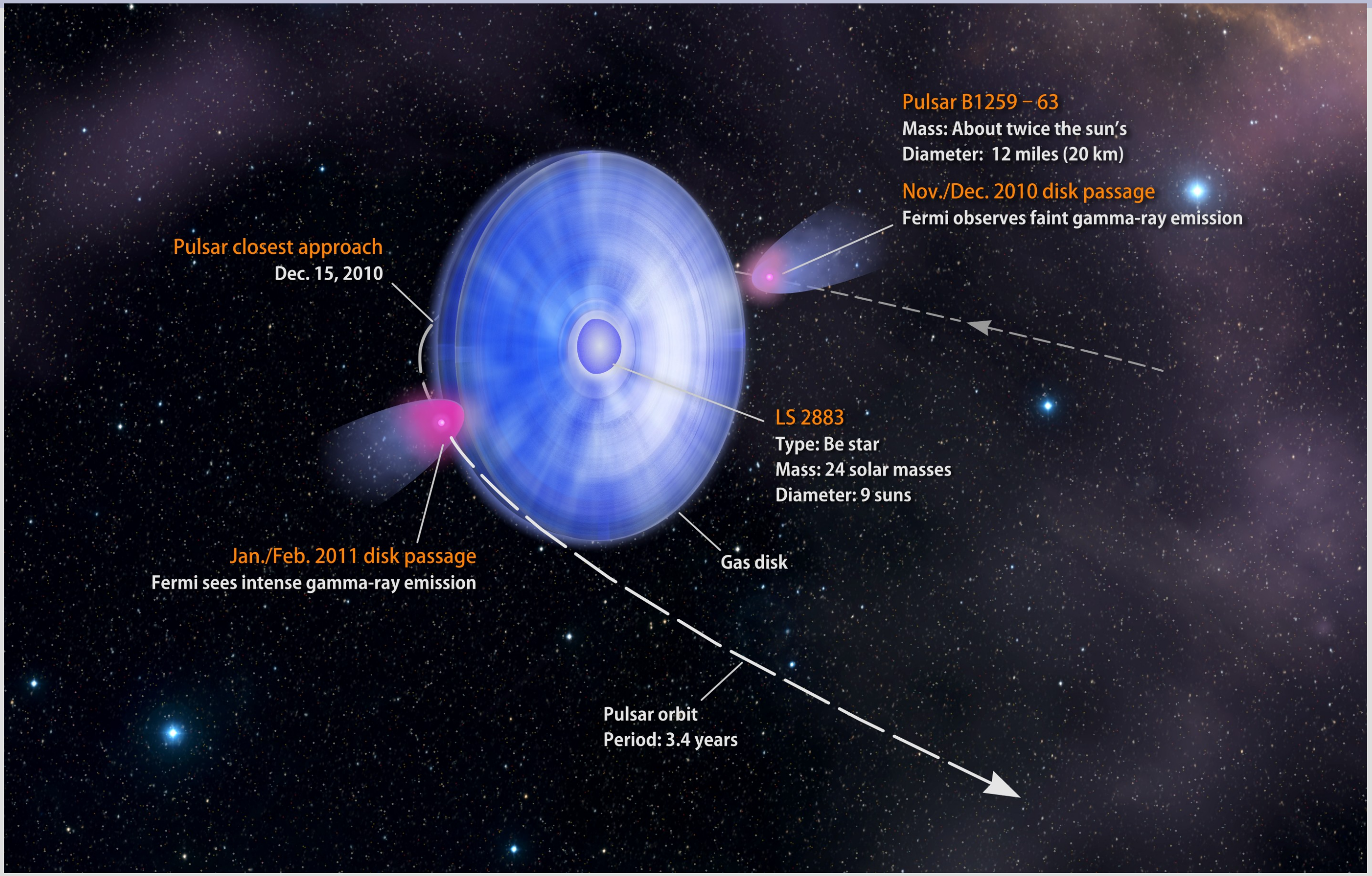


- Eccentricity ~ 0.87; orbital period ~3.4 years
- the pulsar has a spin period 47.8 ms and spin-down power ~ 8 x 10^{35} erg s^{-1}

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

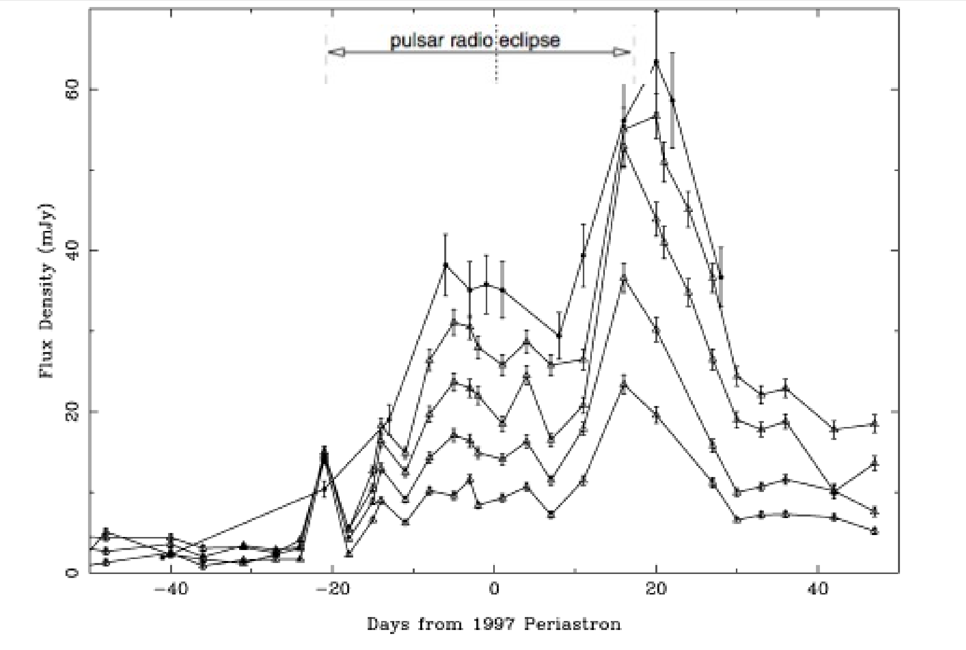


Credit: NASA

A unique system

- Non-thermal emission, radio, through X-rays, to TeV gamma-rays, is generated during the intera ction between the stelllar wind/disk and the pulsar wind
- An astrophysical laboratory to study the pulsar wind since it terminates close to the pulsar

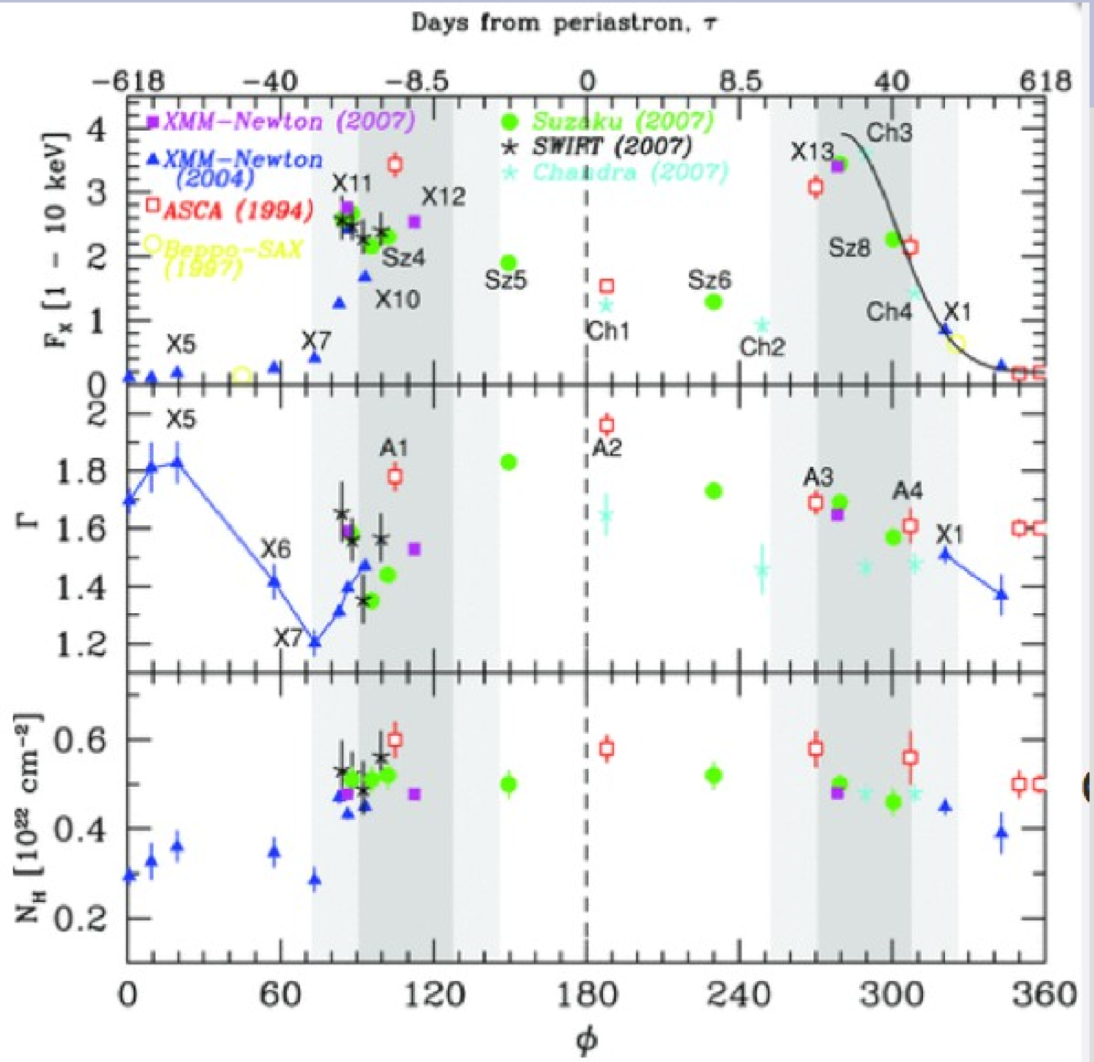
Radio observations



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

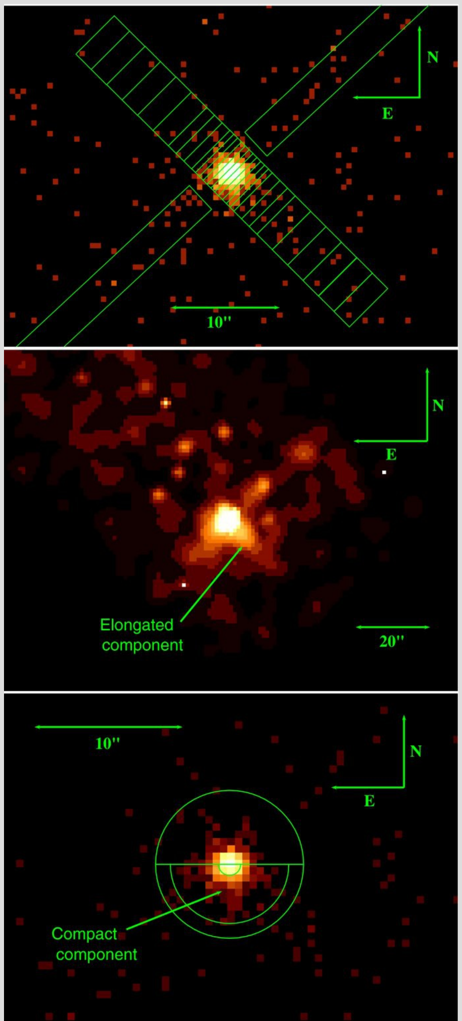
Johnston et al. (1999)

X-ray emission



Chernyakova et al. (2009)

Extended radio/X-ray emission



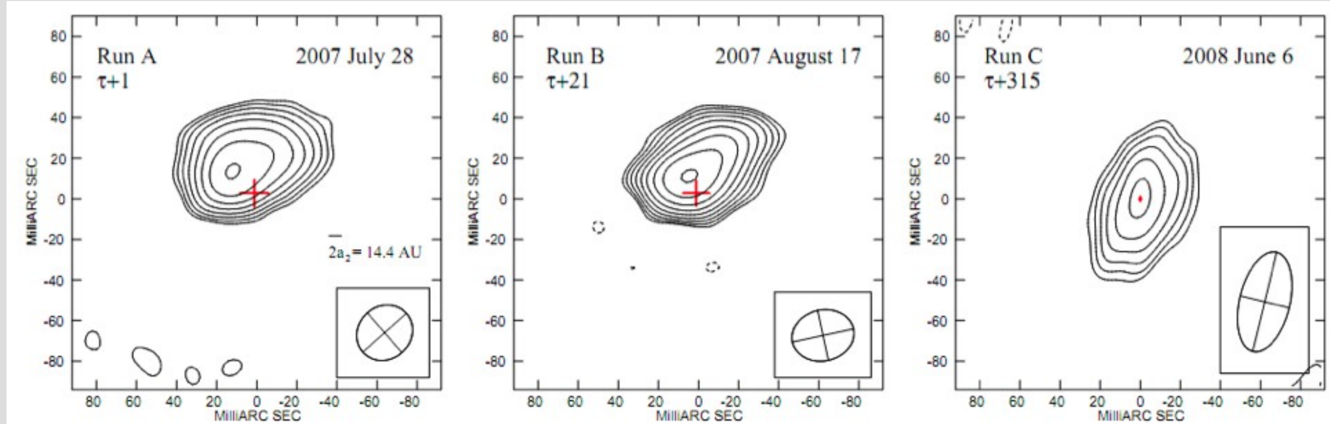


FIG. 1.— LBA images of PSR B1259−63 at 2.3 GHz. North is up and east is to the left. The dates and the days after the periastron passage (τ) are quoted at the top of each panel. The synthesized beam is displayed in the rectangle on the bottom-right corner of each image. The red crosses mark the region where the pulsar should be contained in each run (see the text). As a reference, the size of the major axis of the orbit of PSR B1259−63/LS 2883 is shown in the first panel. For each image, the displayed contours start at 3σ and increase by factors of $2^{1/2}$; the 1σ rms close to the source in each image from left to right is 0.30, 0.66, and 0.15 mJy beam^{-1}.

Moldon et al. (2012)

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

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)

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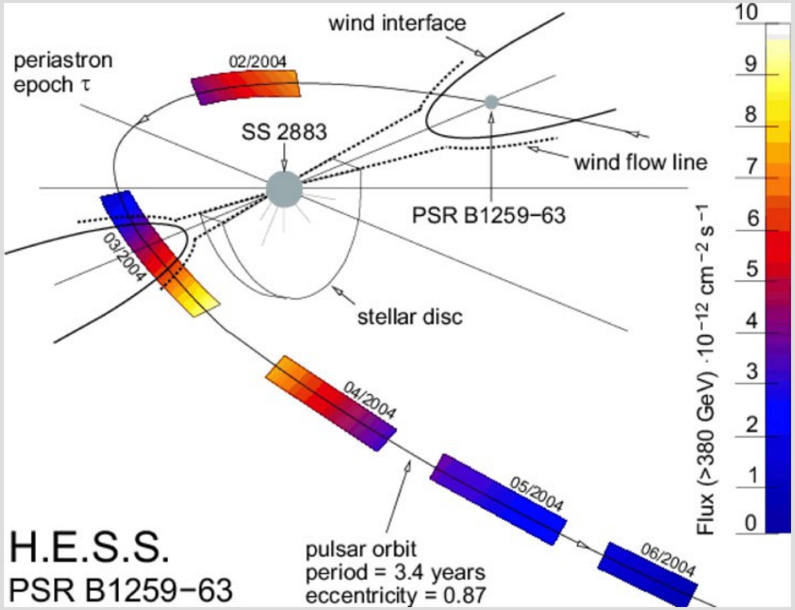
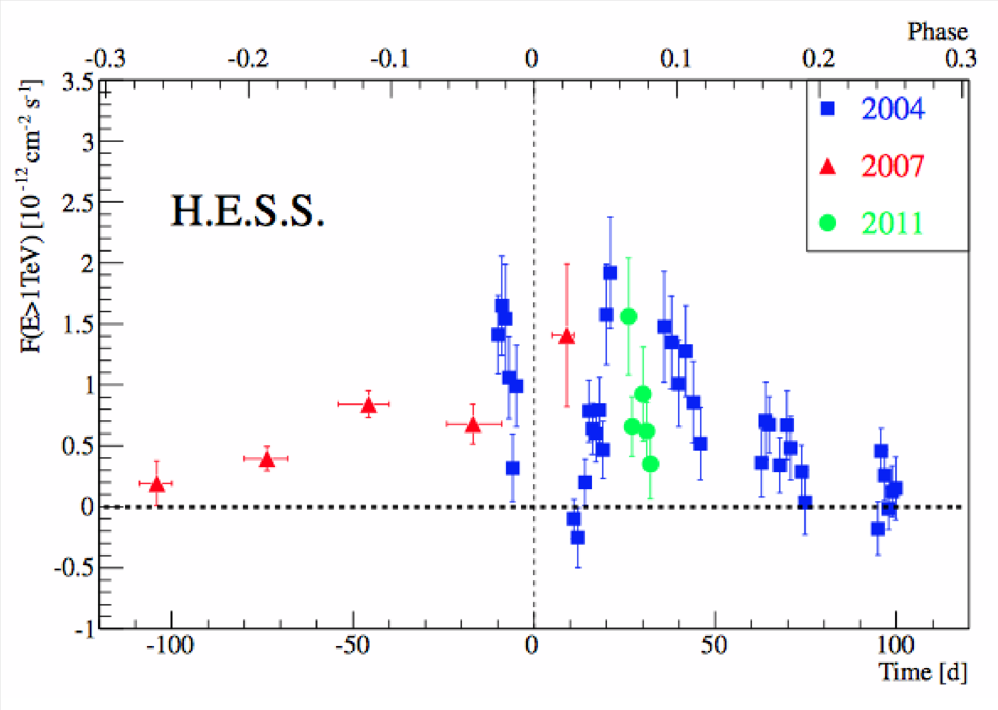


H.E.S.S. Collaboration (2005)

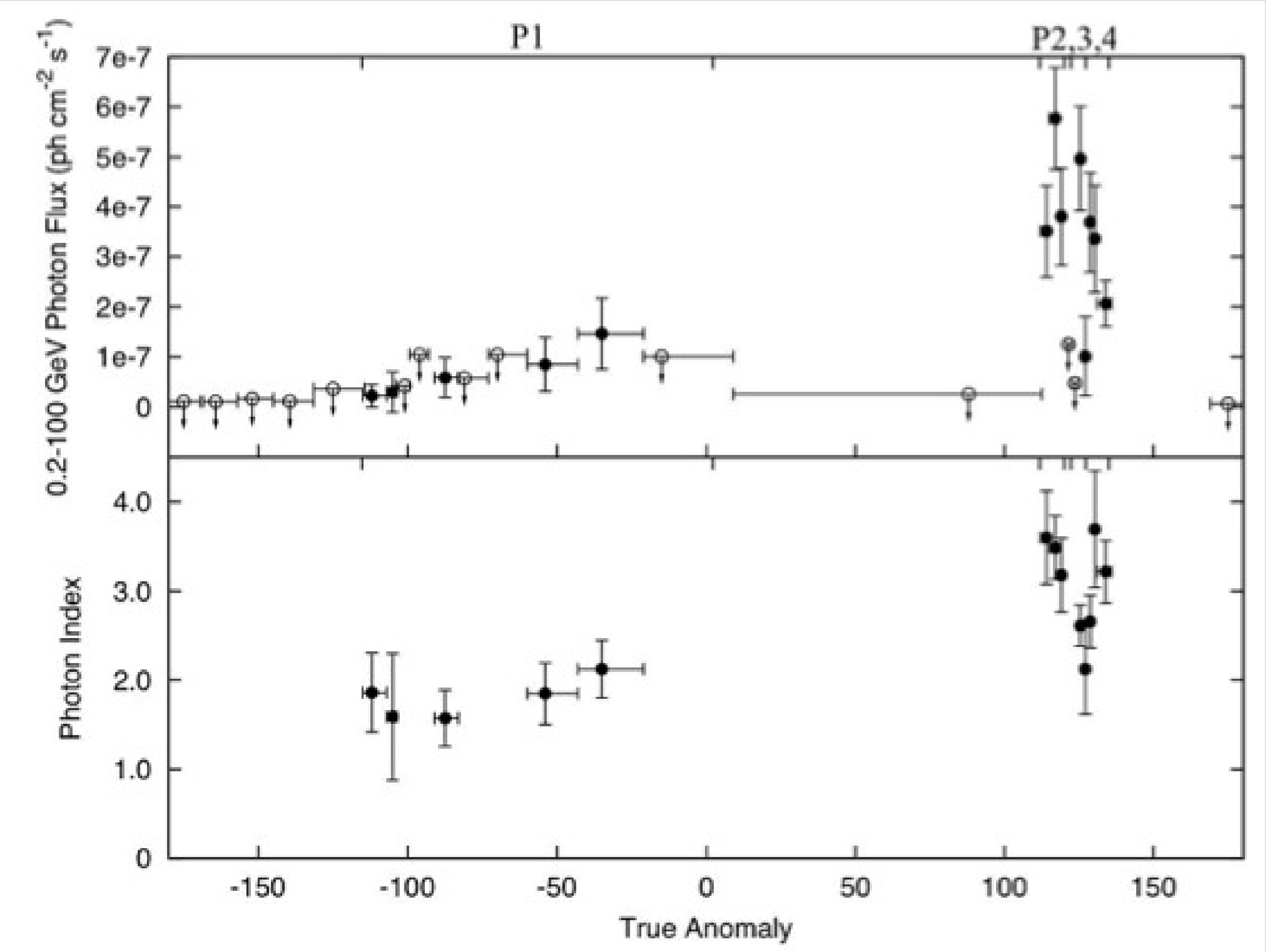


H.E.S.S. Collaboration (2013)

The 2010 periastron passage

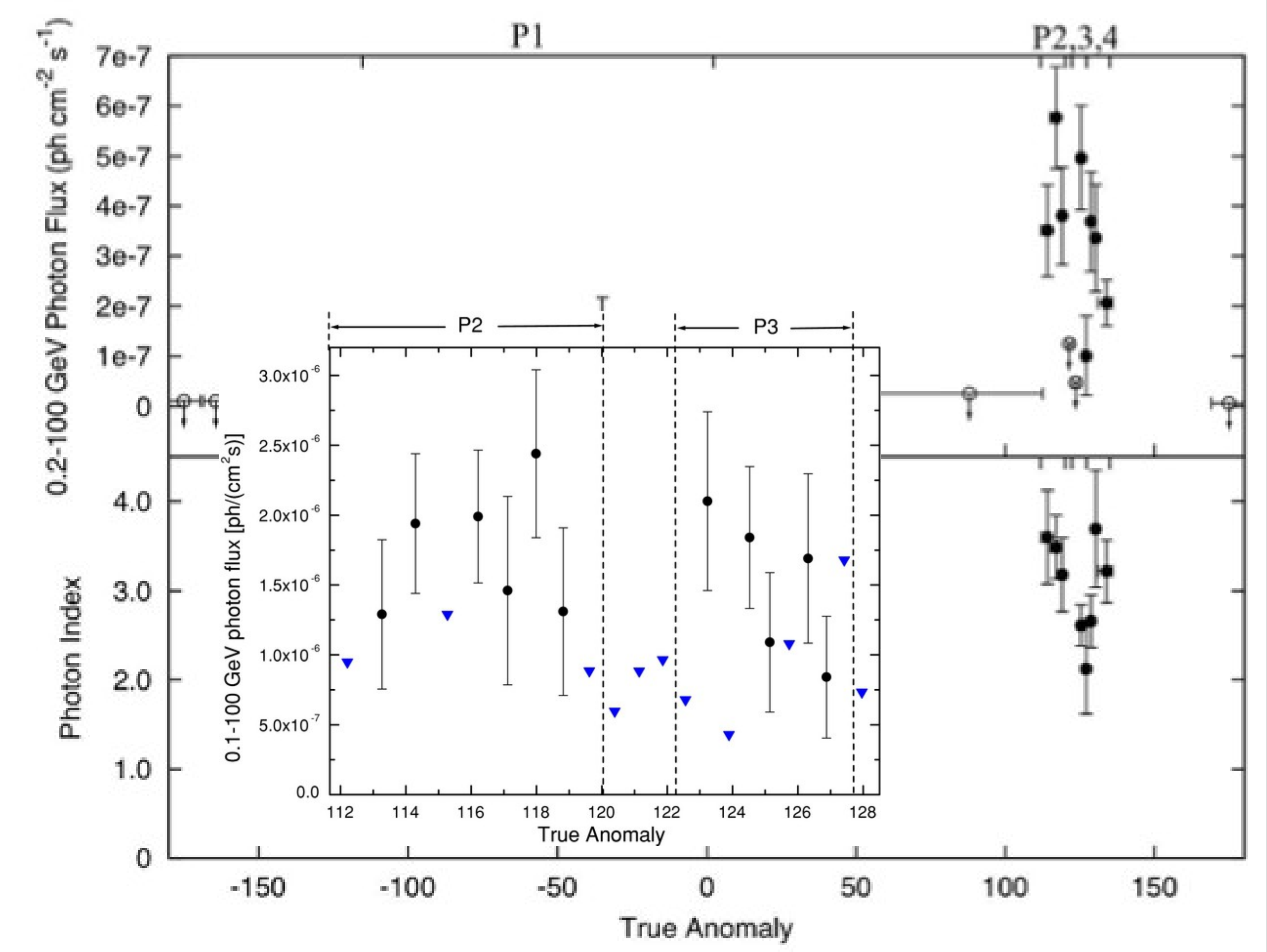
- No detection before end of 2010
- First periastron passage since Fermi launch @ December 14, 2010
- Will any GeV light curve be similar to X-ray/TeV light curve?

GeV emission was first seen



Tam et al. (2011)

The GeV surpise!
Post-periastron flares



Tam et al. (2011)

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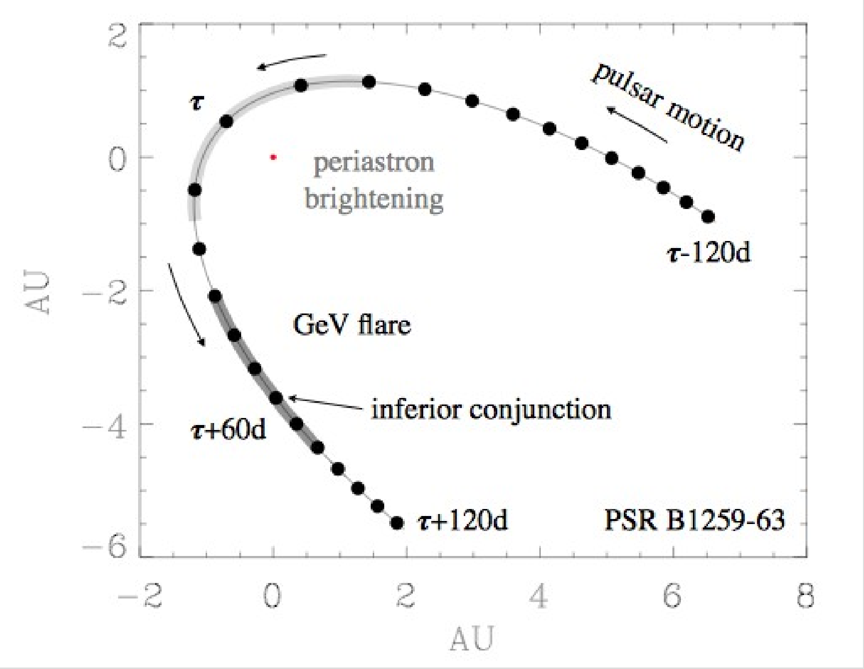
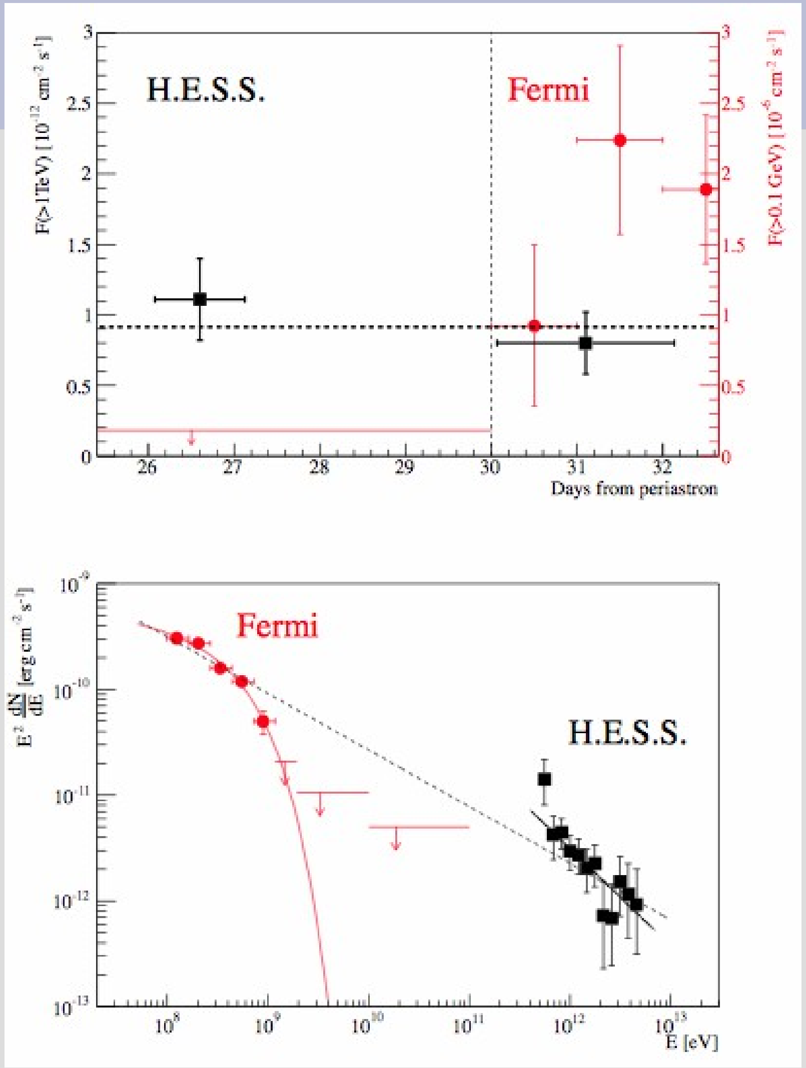


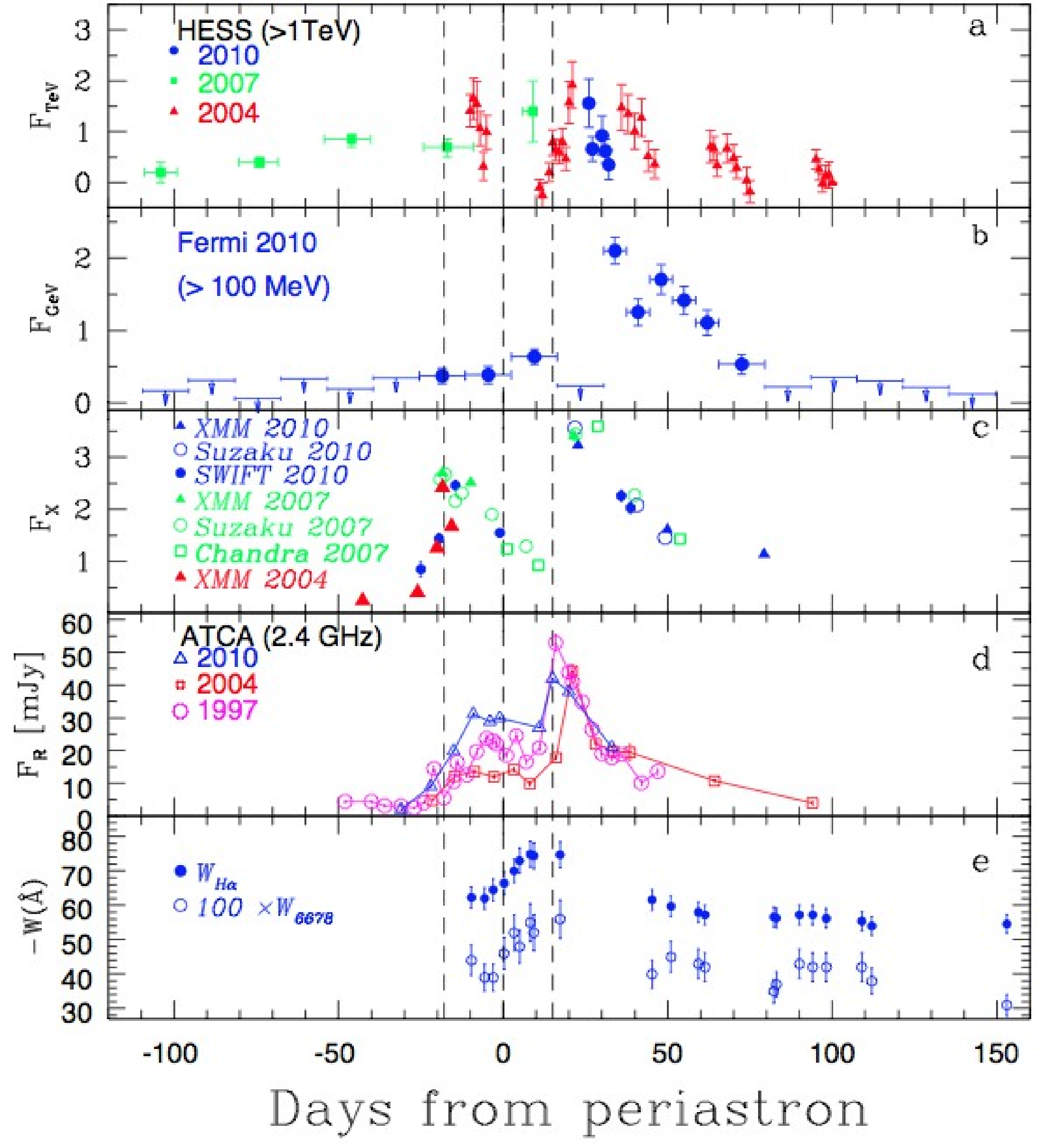
Dubus & Cerutti (2013)

No contemporaneous TeV flare



H.E.S.S. Collaboration (2013)

Multi-wavelength lightcurves



Chernyakova et al. (2014)

Press conference in Taiwan

發現「γ射線瞬變」清大領先全球

【記者蔡永彬／台北報導】去年11月20日，清華大學天文研究所一個6人小團隊在位於南十字座旁的雙星系統發現「γ（讀作gamma、伽瑪）射線瞬變現象」，這項發現領先全球。研究成果登在昨天的《The Astrophysical Journal Letters》（天文物理期刊通訊）上。

清大校長陳力俊指出，他們發現了一個人類並不十分理解的「奇異現象」，未來人類對「中子星」的了解可能要修正了。

清大天文所博士後研究員譚栢軒是第1位發現此現象的天文學家。從去年10月起，他觀察位於南十字座附近的一顆中子星「PSR B1259-63」和一顆質量是太陽24倍的大質量恆星「LS 2883」組成的雙星系統，中子星以傾斜橢圓軌道繞大恆星運行，周期3.4 年。

譚栢軒表示，一般的雙星系統大多放出X光，放出γ射線的系統非常罕見；有天文學家預期，這兩星距離很近時，就可能會放出γ射線。去年11月20日前，譚栢軒沒任何收穫，當天卻突然探測到微弱γ射線，「很高興！」今年1月中旬，研究團隊又觀測到γ射線，而且強度增加好幾倍。

團隊的博士後高田順平推測，γ射線可能起因於這兩顆星的粒子互動，目前無法完全解釋成因。清大天文所副教授江國興說，雖然有理論解釋中子星經過大恆星會是什麼狀況，不過以前也沒人真的看過。

清大團隊在位於南十字座的雙星系統發現「γ射線瞬變現象」。圖中人物爲清大天文研究所副教授江國興。
記者蔡永彬／攝影

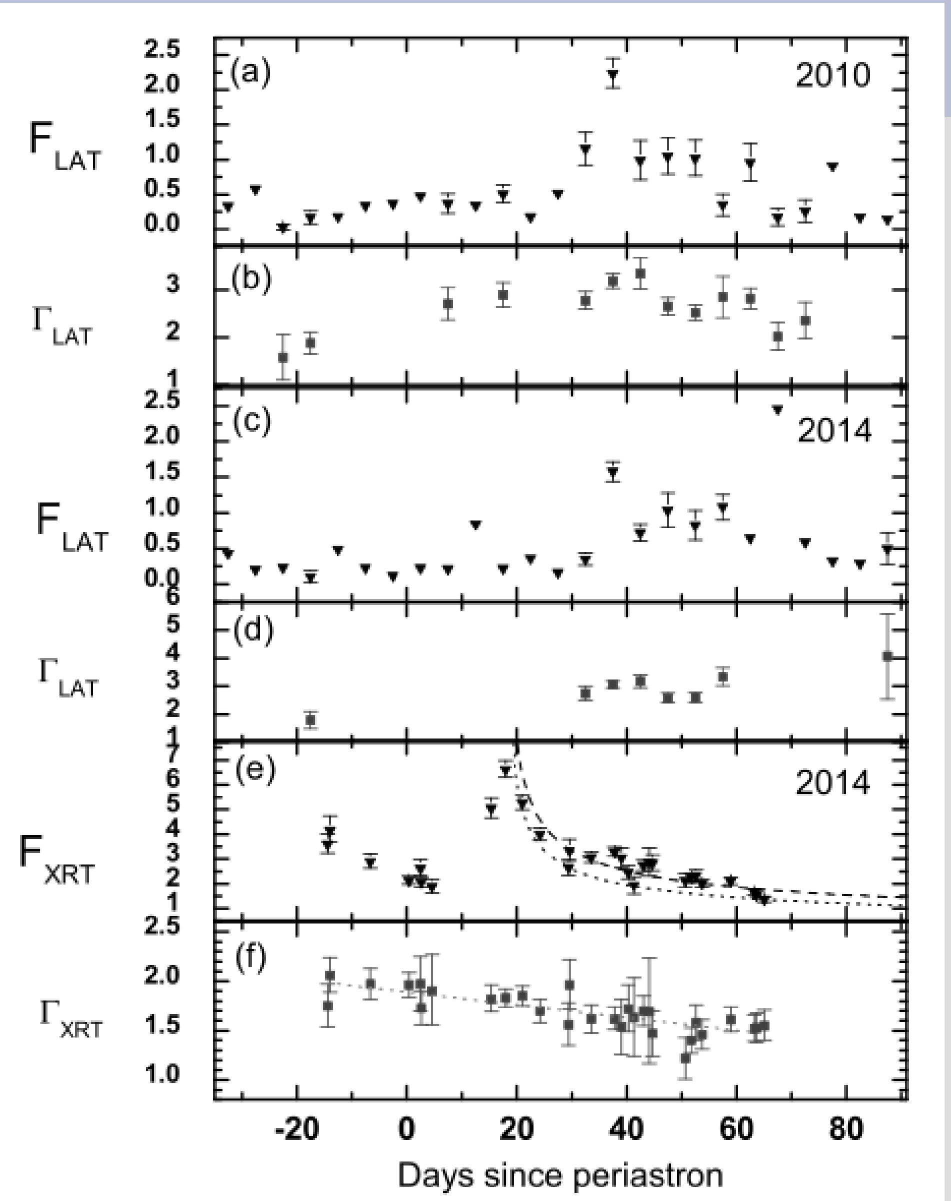
Questions before 2014 May

- 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 contemperanous 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 pasage, even on daily basis during June 10 to 18
- NuSTAR observed PSR B1259-63 five times over the passage, good converage for different phases

The light curves



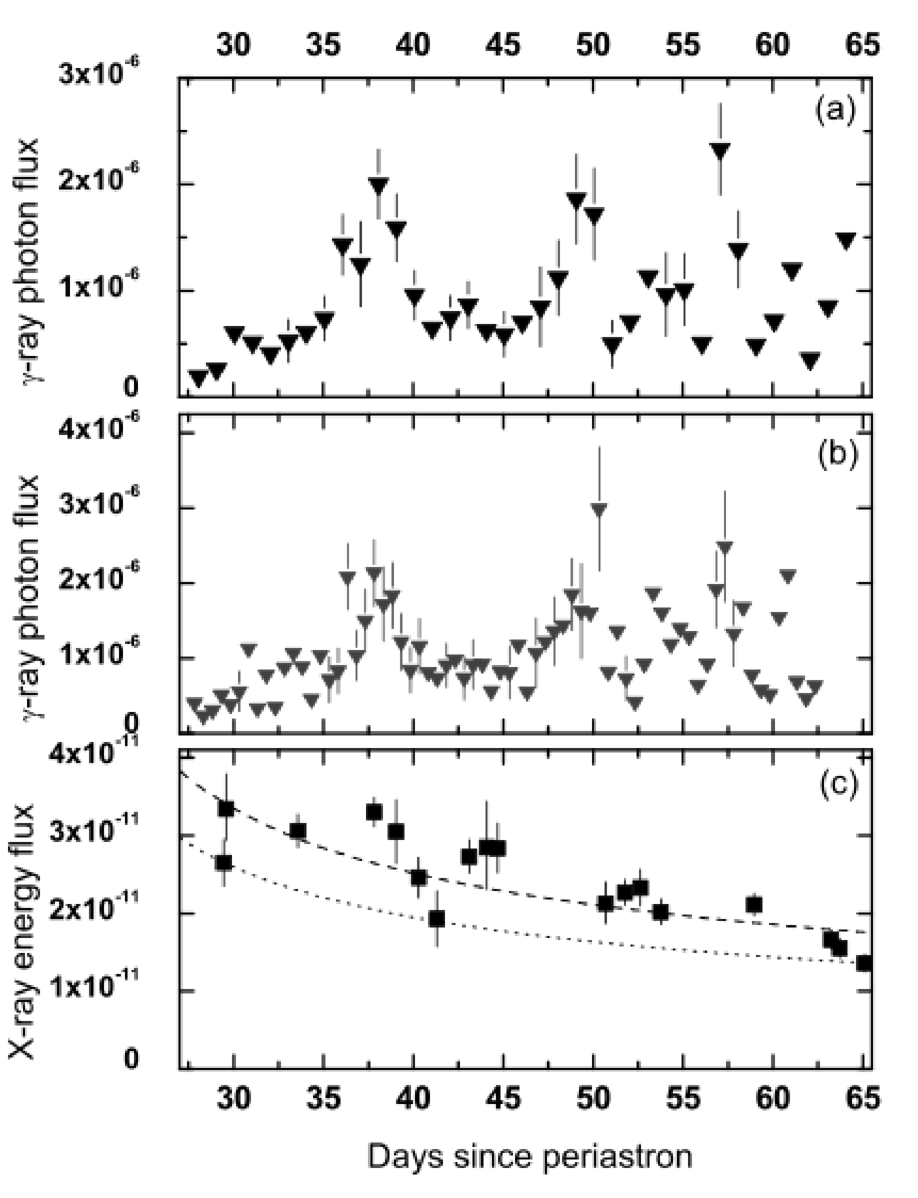
5-day bins

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)

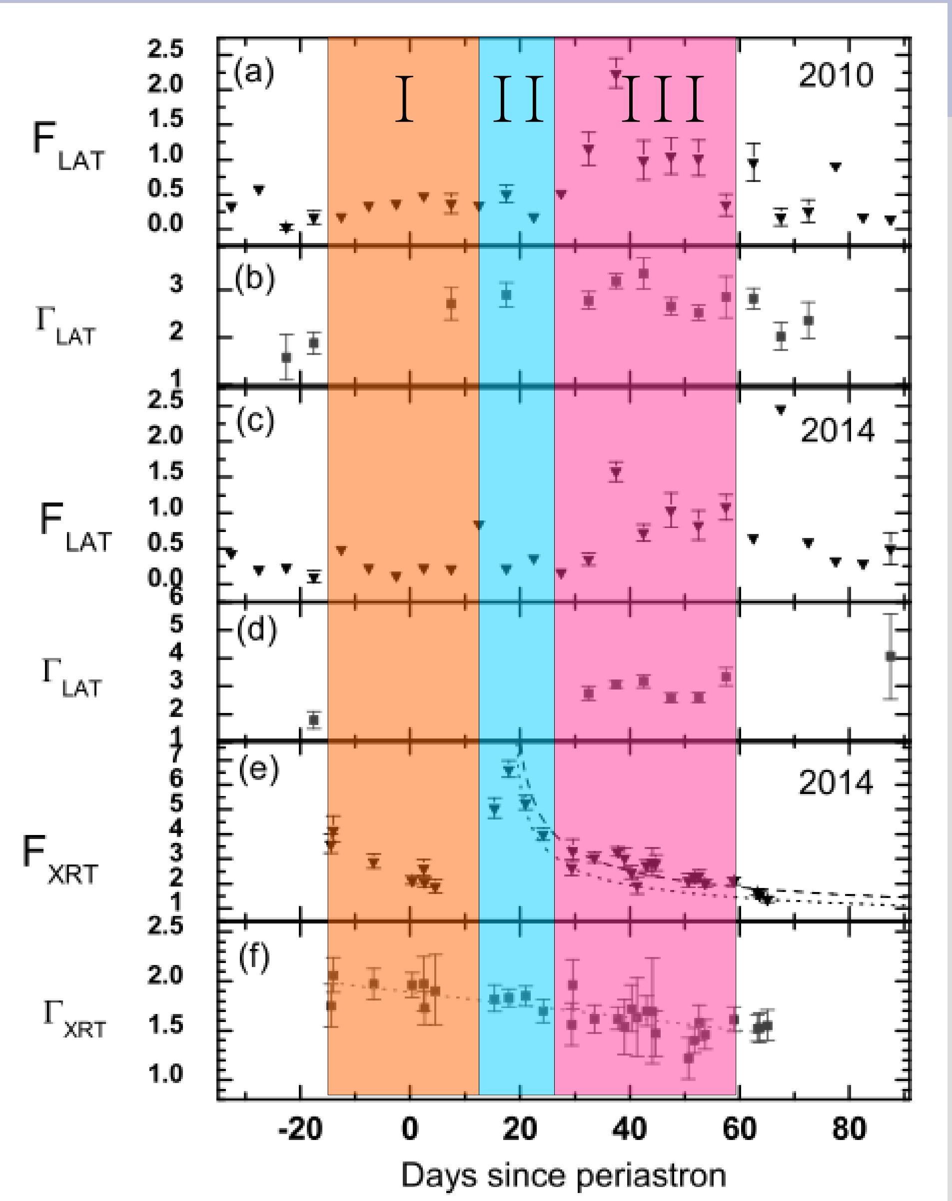


Daily bins

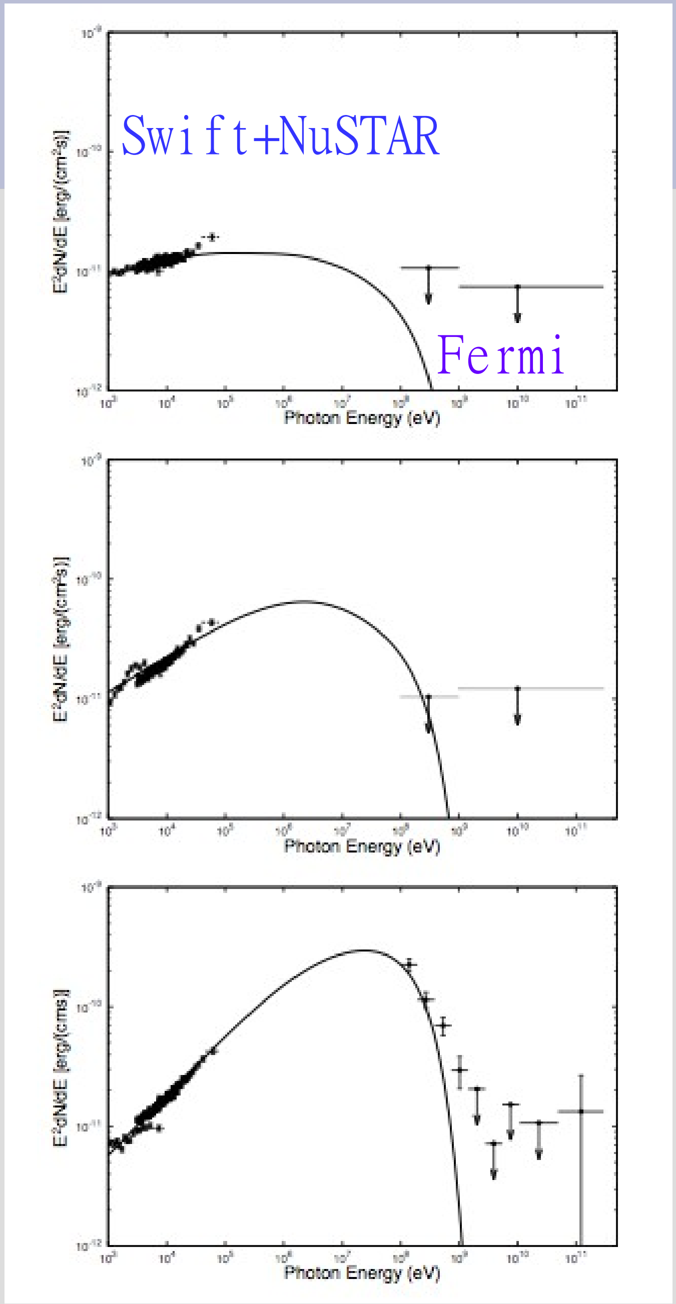
½-day bins

Swift/XRT

The light curves



The spectra



I

April 20 – May 14
(periastron passage)

II

May 15 – June 1
(X-ray peak)

III

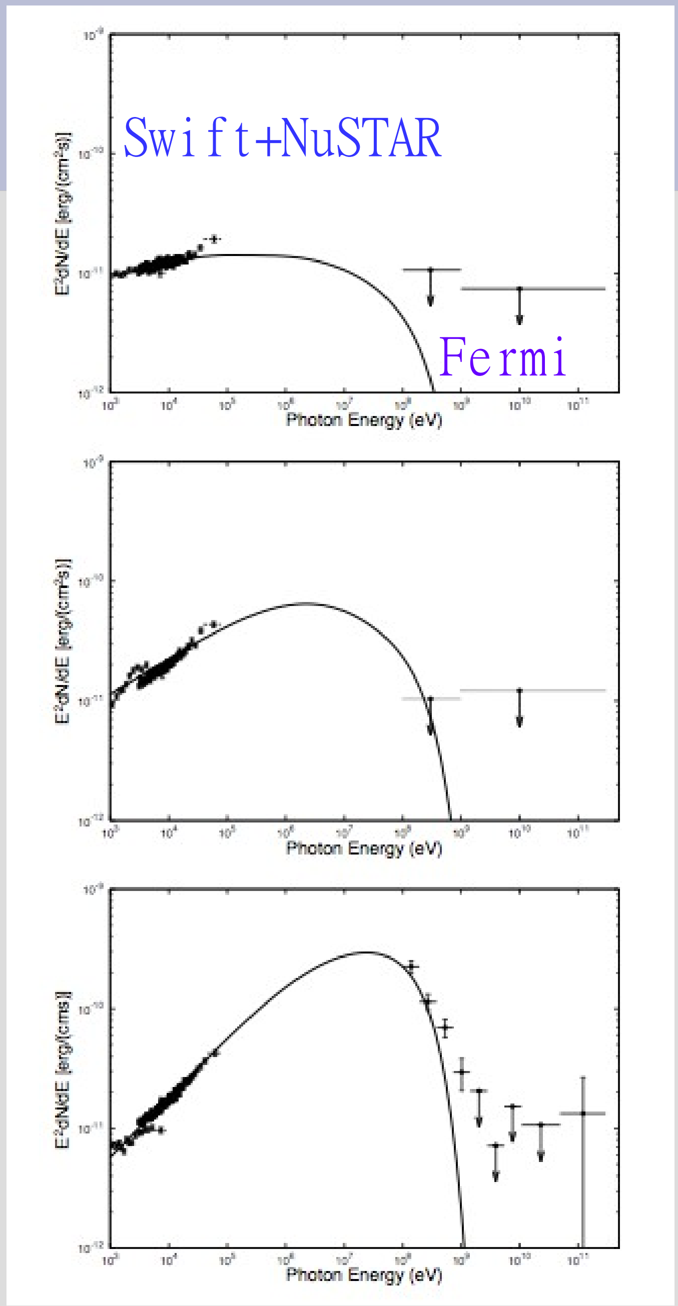
June 2 – July 2
(flaring state)

The spectra

I

II

III

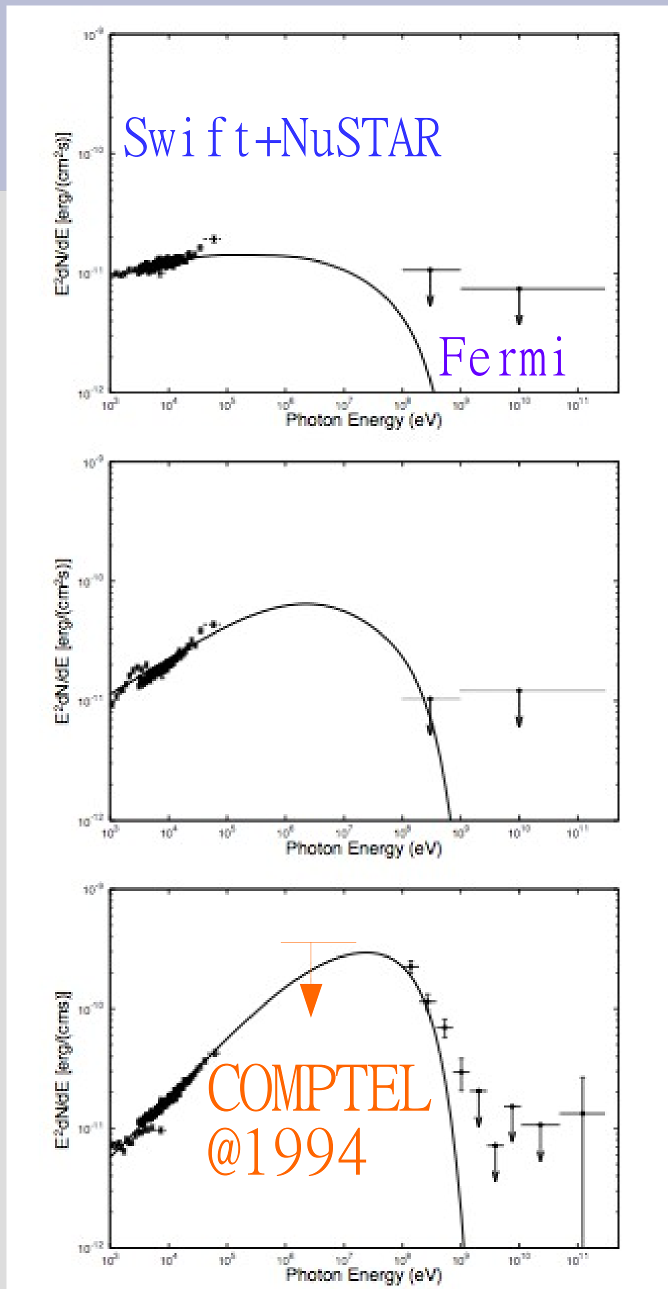


April 20 – May 14
(periastron passage)
p=2.7, p(electron index)
synchrotron emission

May 15 – June 1
(X-ray peak)
p=2.4

June 2 – July 2
(flaring state)
p=2.0

The spectra



I

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

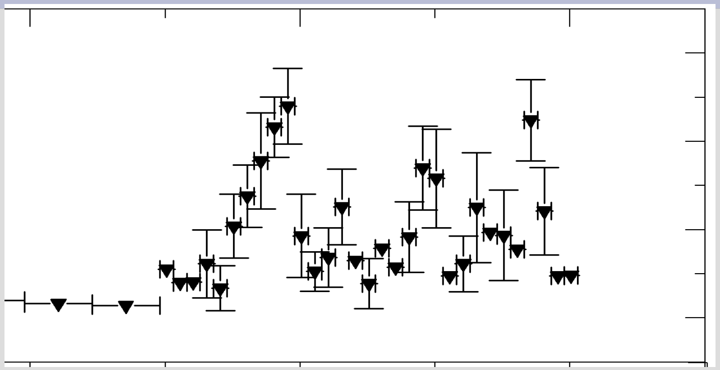
II

May 15 – June 1
(X-ray peak)
p=2.4

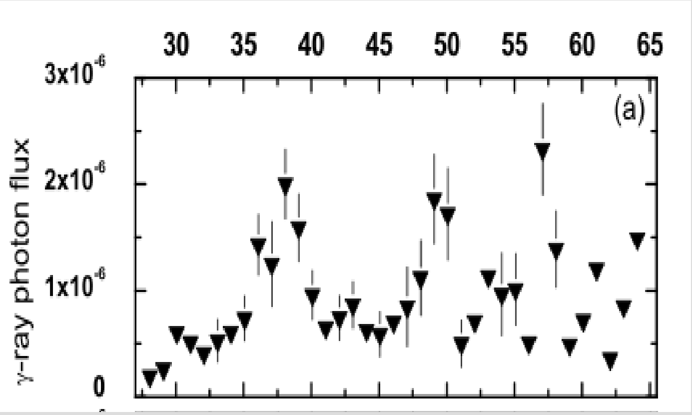
III

June 2 – July 2
(flaring state)
p=2.0

Does dedicated pointing really help?



With rocking angle < 52^0 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 contemperanous 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)

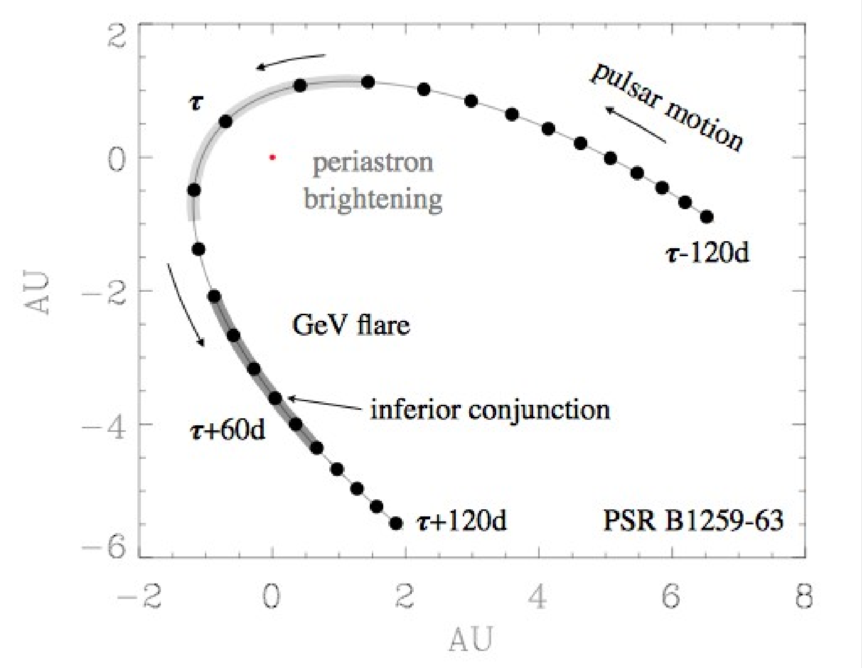
- Future

  CTA @ 50 GeV

  Soft gamma-rays 0.1-10 MeV

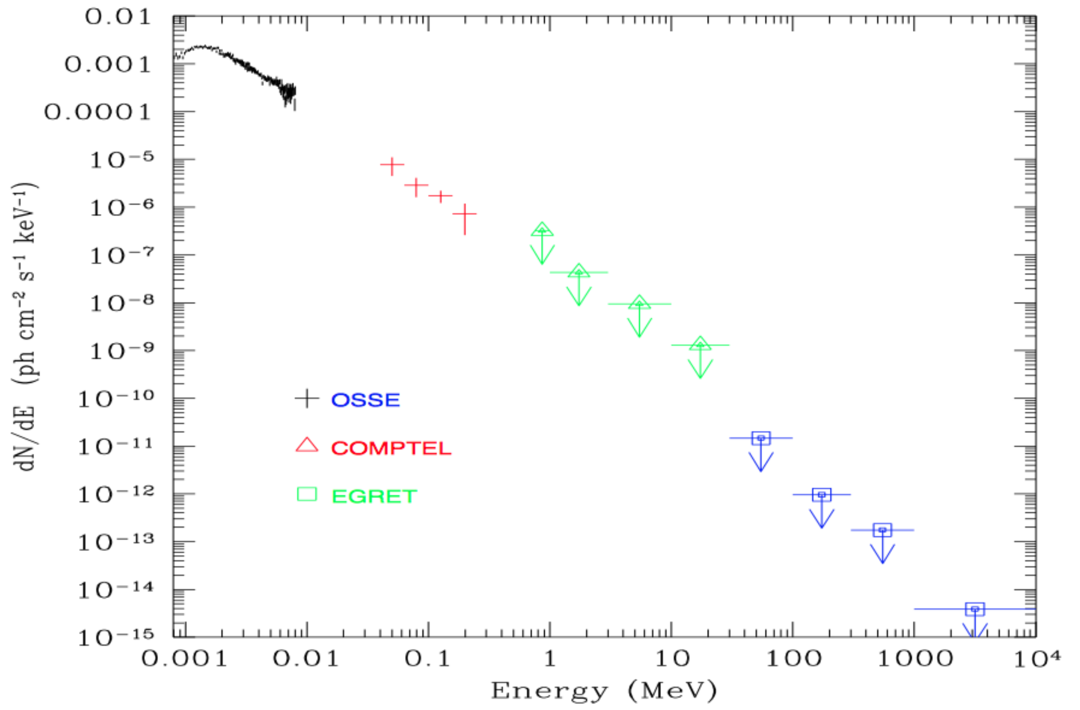
Questions

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

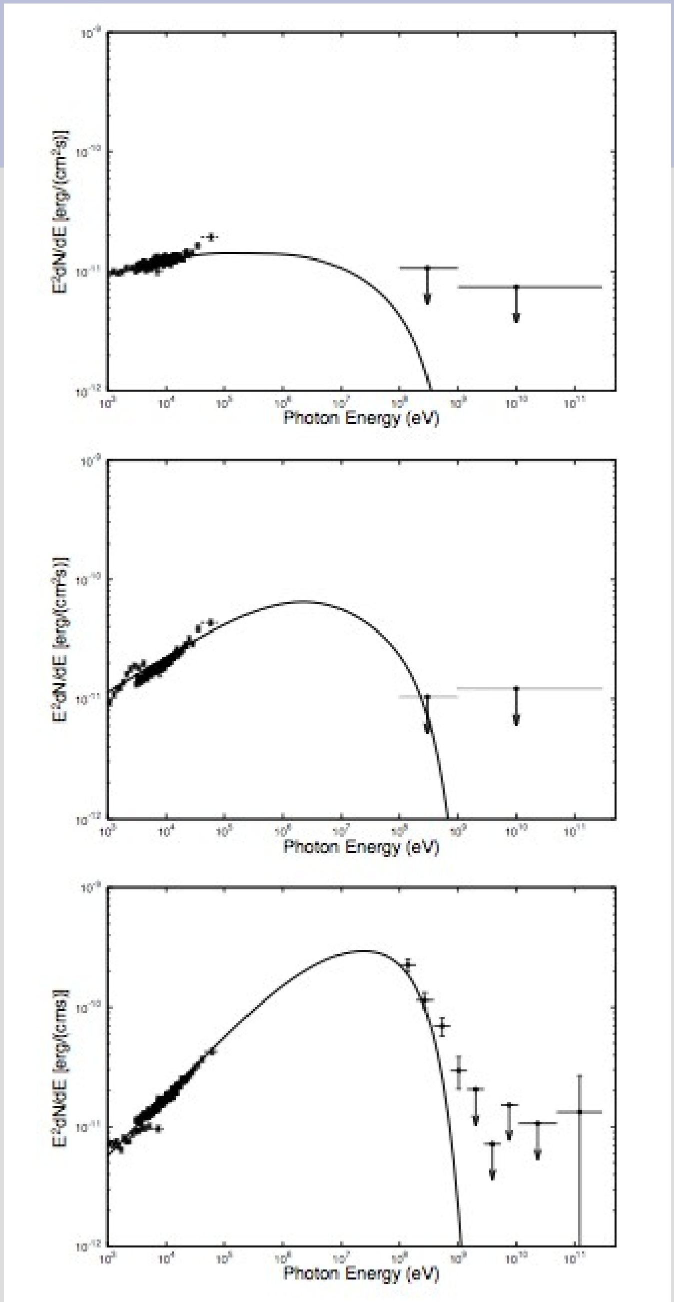


Dubus & Cerutti (2013)

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 simiar to gamma-ray flux (durin g the 'flare epoch'), with a lesser extent
- Pre-periastron GeV emission situation unclear (increased LAT exposure certainly needed 2017)
- Establishing keV – GeV spectral connection