High-energy emissions from pulsar/Be binaries

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References

1. Takata, J., Tam, P., Ng, C. et al., ApJ (2017) 836, 241

2. Li, K.L., Kong, A., Tam, P. ApJ, in press, arXiv:1705.09653

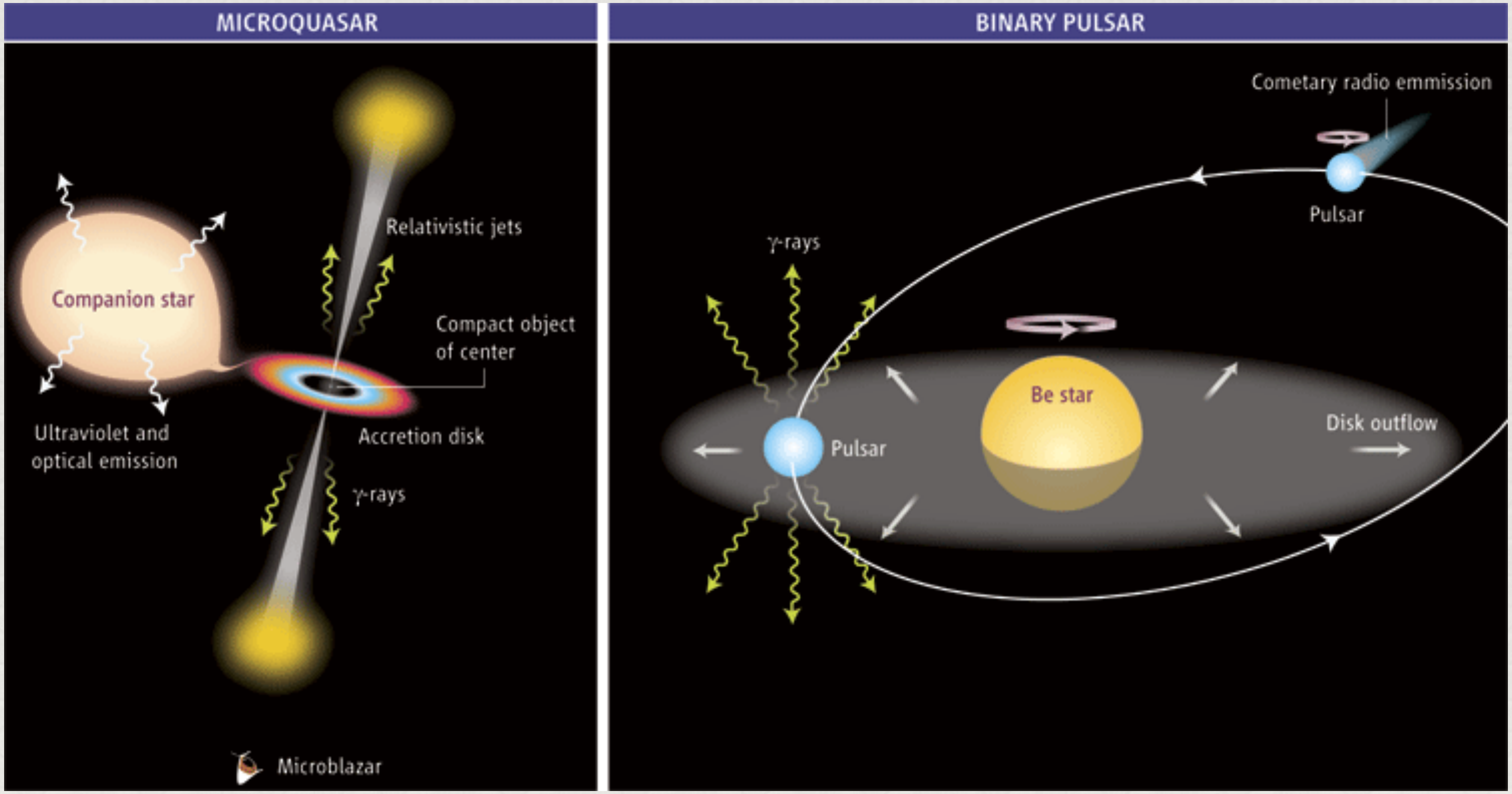
Contents

- *Probing pulsar wind with Gamma-ray binary*
- *PSR J2032+4127*
- *PSR B1259-63*

Contents

- *Probing pulsar wind with Gamma-ray binary*
- *PSR J2032+4127 (HE flares in coming periastron in 2017?)*
- *PSR B1259-63 (GeV flare?)*

Gamma-ray binaries



Currently known high-mass gamma-ray binaries

name	binary components		P_{orb} (d)	HE	VHE	refs (⋆)	notes
(high-mass) gamma-ray binaries							
PSR B1259-63	pulsar	Be	1236.7	✓	✓	[12, 13]	47.7 ms
HESS J0632+057	?	Be	315		✓	[14, 15]	
LS I +61°303	?	Be	26.5	✓	✓	[16, 17]	magnetar ?
1FGL J1018.6-5856	?	O	16.6	✓	✓	[18, 19]	
LS 5039	?	O	3.9	✓	✓	[20, 21]	

Dubus (2015)

New-comers:

- *PSR J2032+4127 (Be star, P_{orb} 50 years!)*
- *LMC P3(O star,P_{orb} 10 d)*

Long orbital period binaries

- *After ~9 years of operation, Fermi/LAT, being an all-sky monitor, has accumulated a large data base -> good time to probe these long orbital period binaries*
- *Finding more will help us understand these systems and probe the environments in the binaries and magnetization of pulsar wind*

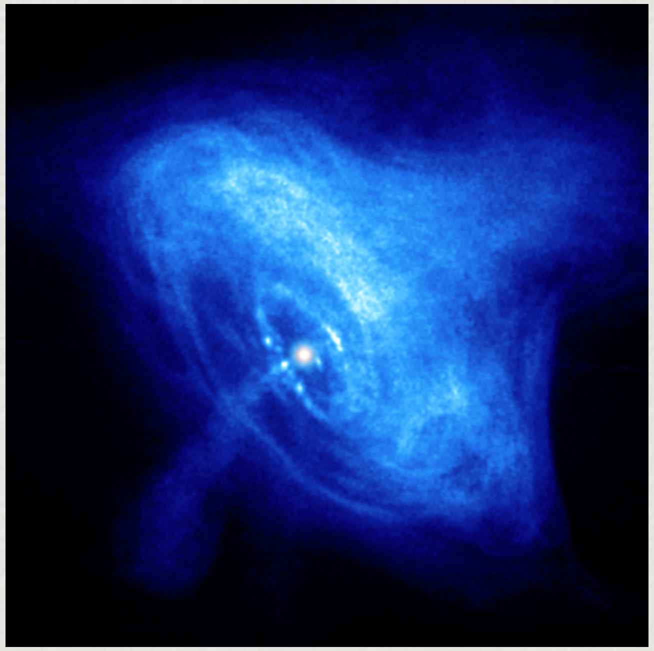
Emissions from Pulsar/Be star binary

Three emission regions normally considered modeling

1. *Magnetosphere (<10^9cm, pulsed)*
2. *Pulsar wind region (<10^{13}cm, no synchrotron, only I.C.).*
3. *Shock accelerated pulsar wind (synchrotron & I.C.).*

Probing pulsar wind

- *Pulsar wind: relativistic electrons/positrons + magnetic field.*



↔ *1pc*

- *Magnetization parameter:*

$$\sigma = \frac{\mathrm{Magnetic\ energy}}{\mathrm{Kinetic\ Energy}}$$

- *At the light cylinder,*

$$\sigma(10^{8-9}\mathrm{cm}) = 10^{2-3}$$

- *Pulsar wind nebulae*

$$\sigma(0.1\mathrm{pc}) < 10^{-2}$$

Magnetization parameter evolves with the distance. But how?

Probing P.W. with Gamma-ray binary

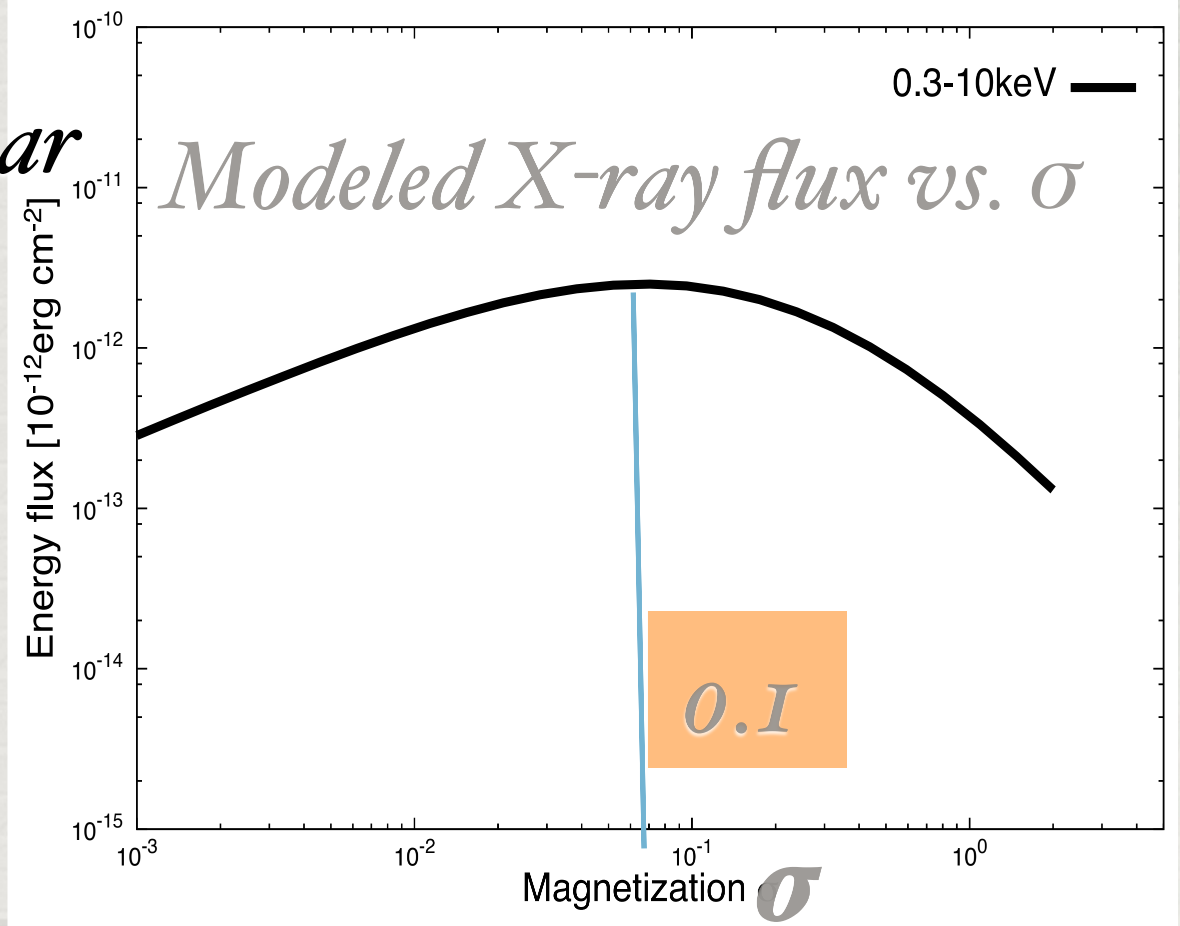
1. Magnetization parameter affects the shock emissions (synchrotron emission).

$$B_s \propto \sigma^{1/2}$$

→ *Magnetic field strength :*

$$U \propto \sigma^{-1}$$

→ *Internal energy of the shocked pulsar wind decreases with increase of σ.*



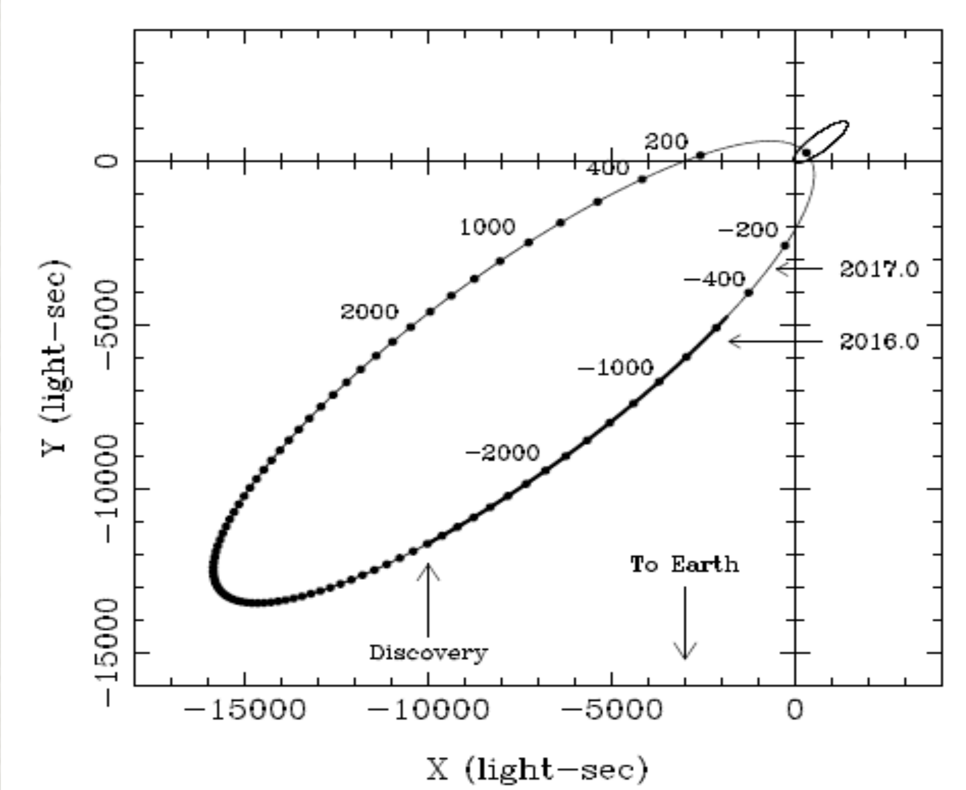
- *Observations vs. Calculations*
  - → *Probing σ at the shock*
  - *Gamma-ray binary*
  - → *Testing σ at 0.1-1AU scale.*

Probing P.W. with Gamma-ray binary

2. *Probing radial dependency of σ*

→ *Pulsar/Be orbit is extremely elongated.*

→ *Shock distance varies ~0.1-1 AU along the orbit.*



Testing radial evolution of σ.

3. *Probing cold-relativistic pulsar wind*

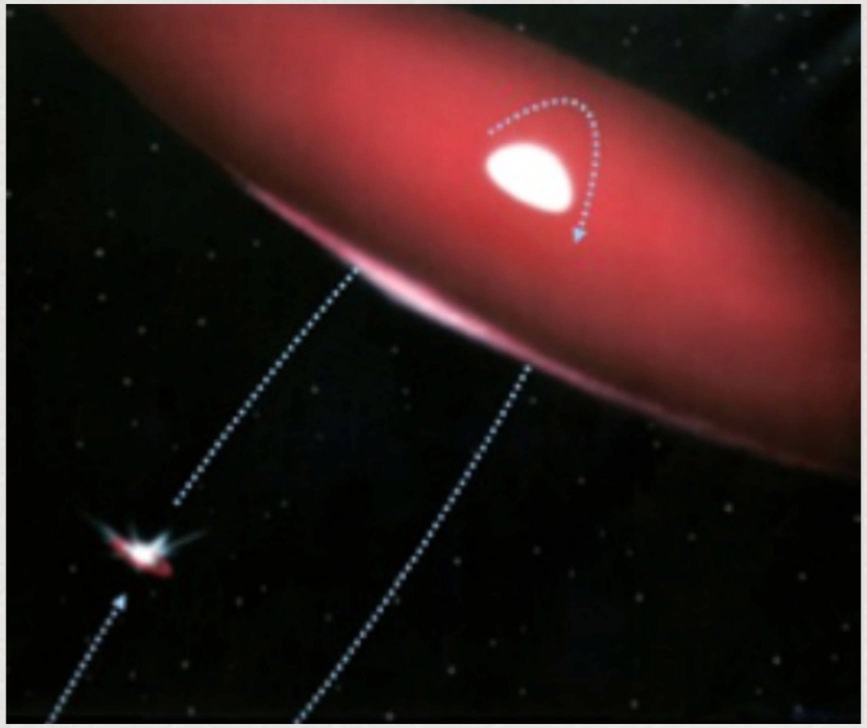
→*Stellar radiation ($L \sim 10^{4-5} L_{sun}$) illuminates the pulsar wind.*

→ *Inverse-Compton scattering process produces GeV emissions.*

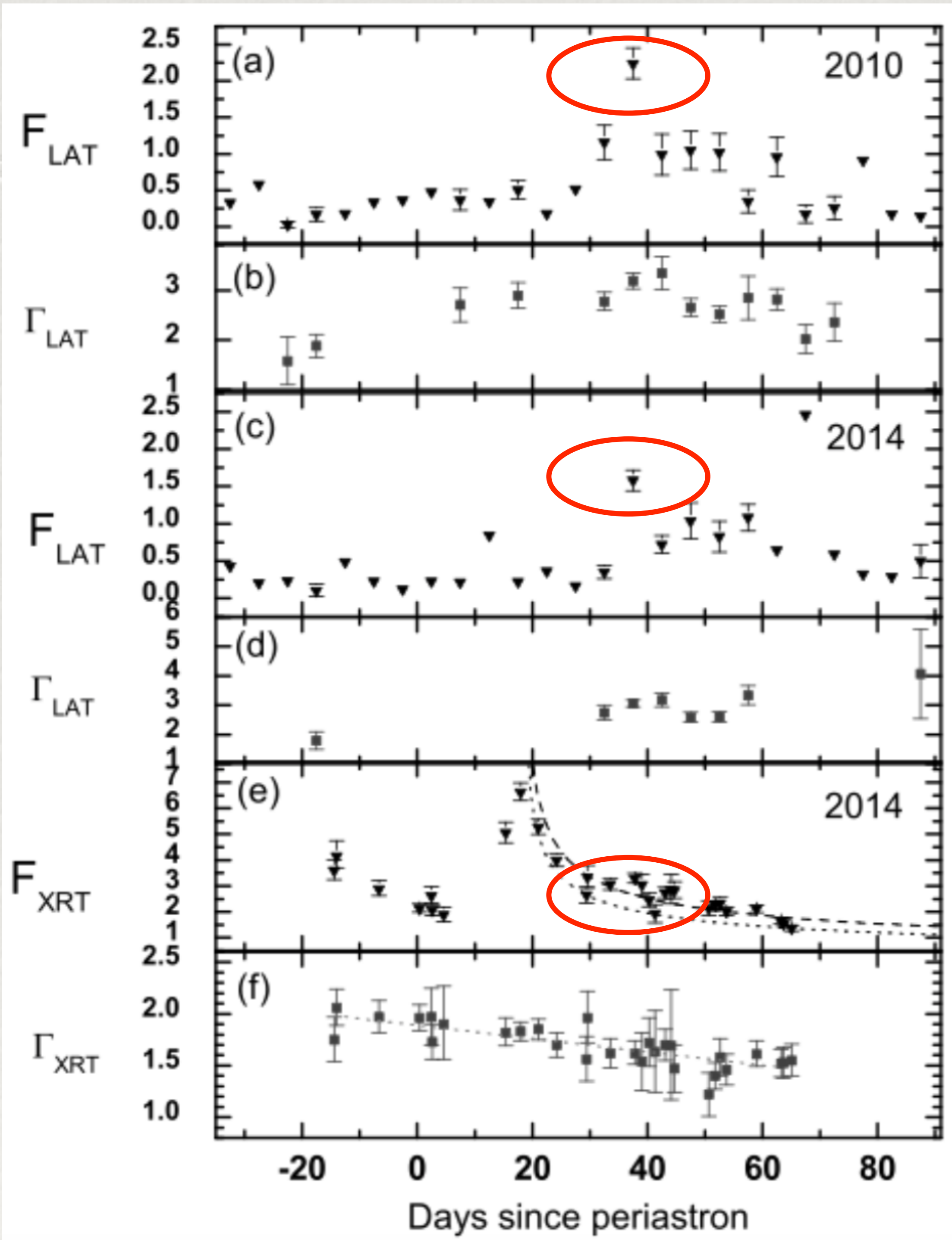
Direct measurement of cold-relativistic pulsar wind.

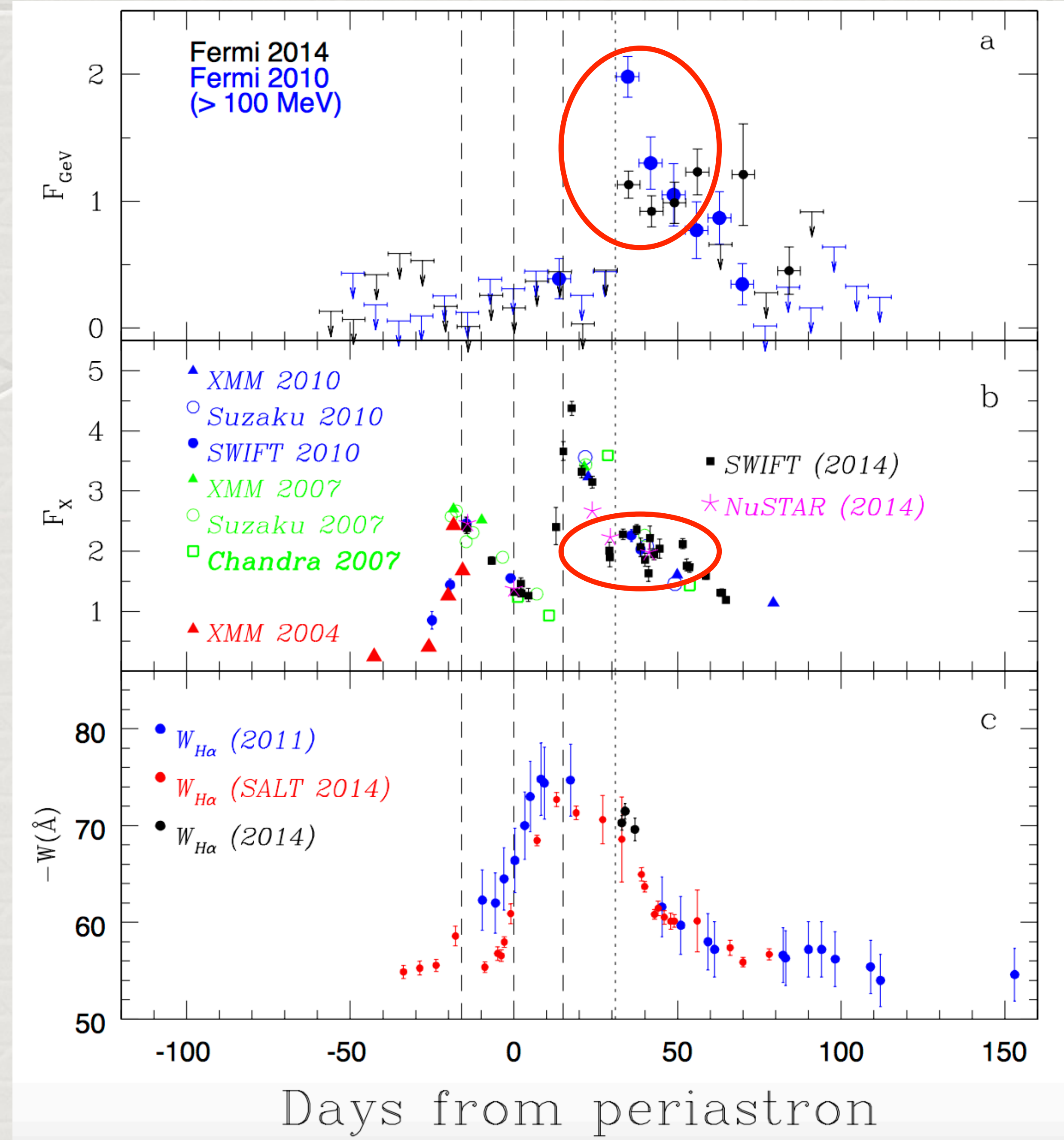
PSR B1259-63/LS 2883

- *comprising of a pulsar and an Oe star, at d~2.3 kpc*
- *orbital period: 3.4 years*
- *Interaction between the stellar wind/disk and the pulsar wind => non-thermal radiation close to periastron*



GeV flares





Tam et al. (2011, 2015)

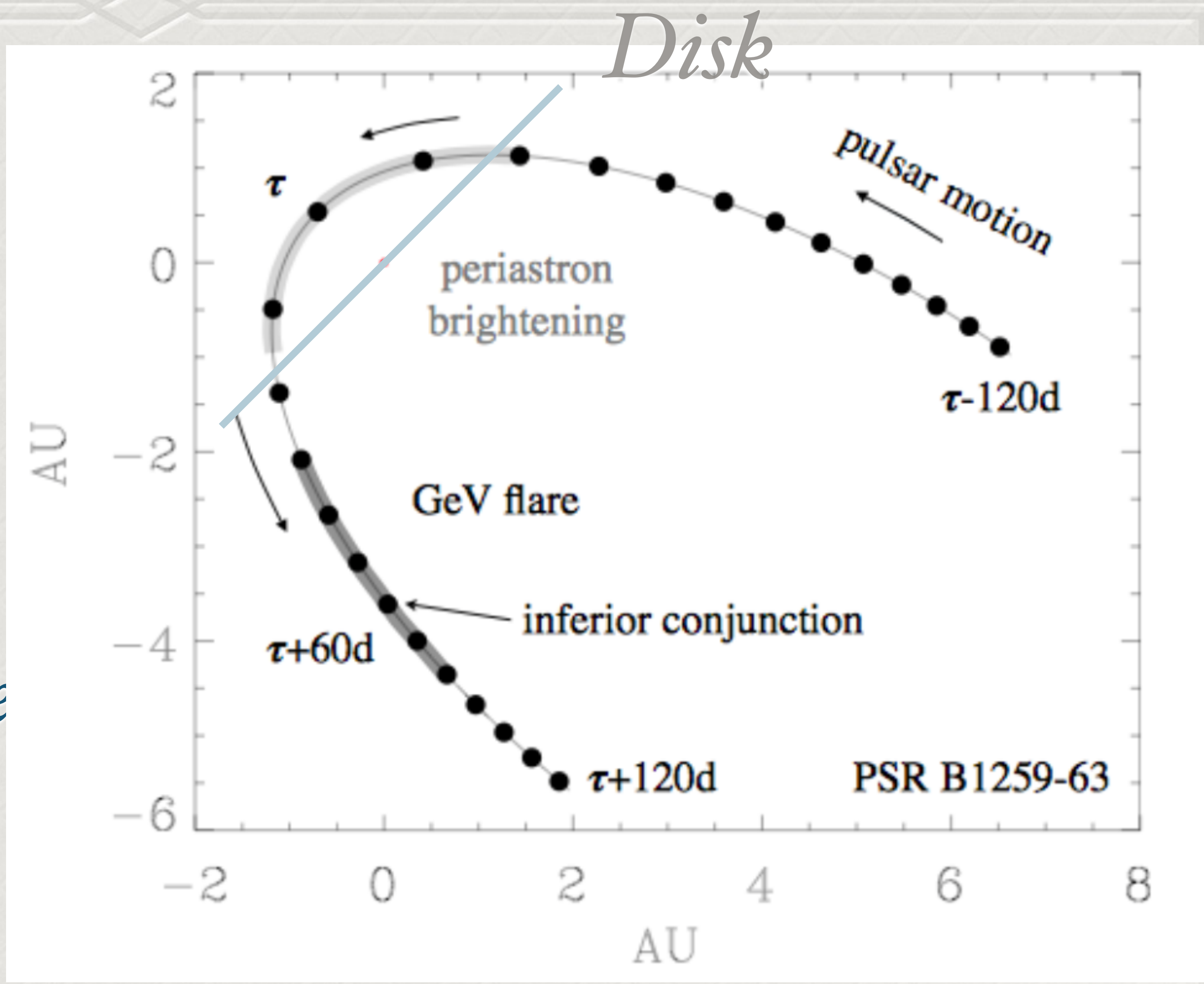
Chernyakova et al. (2015)

see also

Caliandro et al.(2015)

Mysterious GeV flares

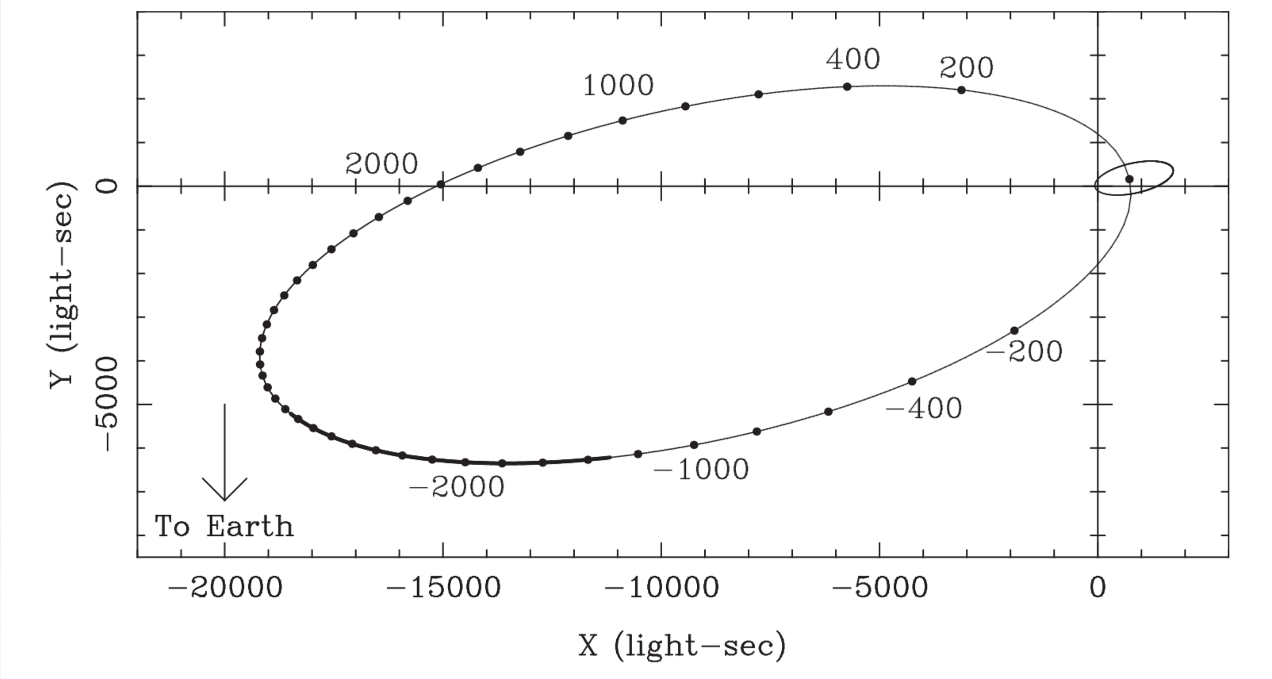
- *Delayed compared to X-ray/TeV peak*
- *Next periastron passage at 2017-09-22*

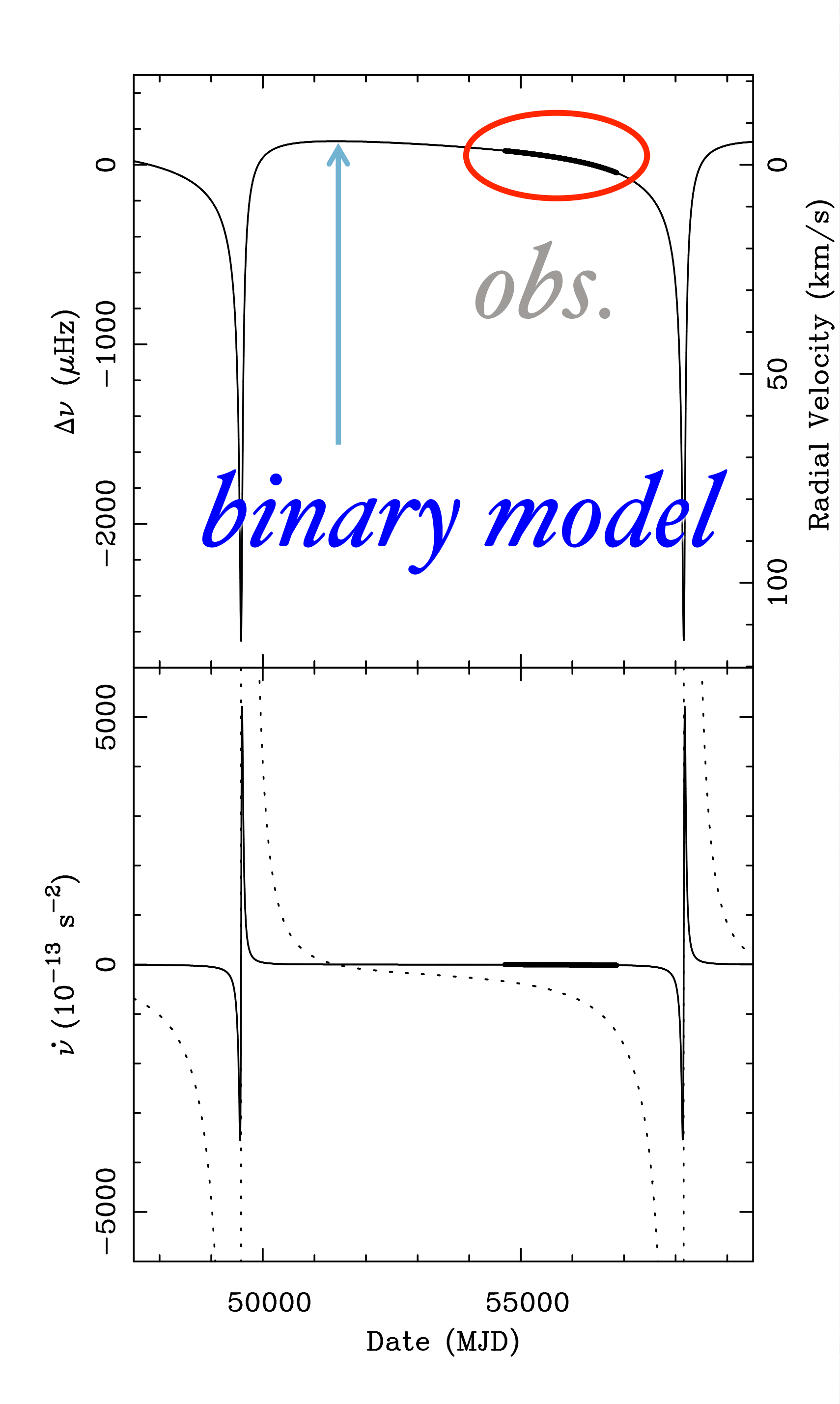


Dubus (2013)

PSR J2032+4127

- *A gamma-ray pulsar (Camilo et al.2009)*
- *pulsar in a binary orbit best explains the 'timing noise'(Lyne et al. 2015)*





PSR J2032+4127/MT91 213

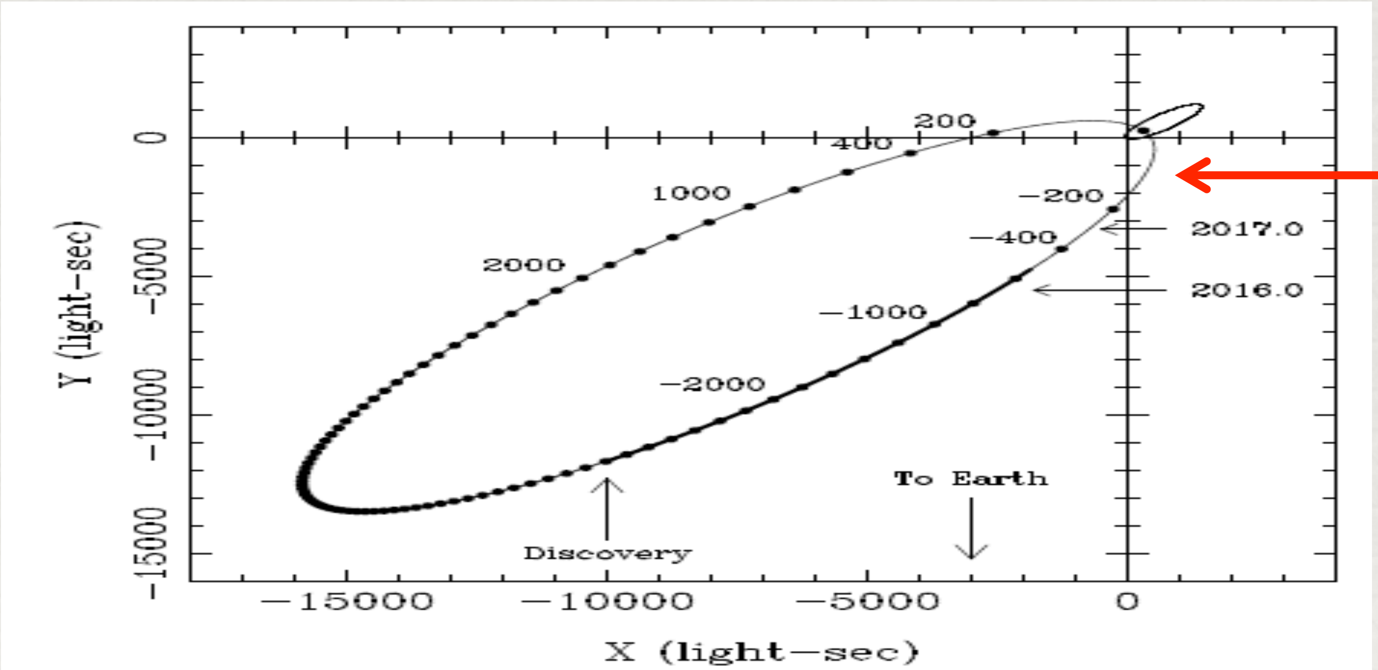
- *Pulsed emission in Radio/GeV*

  $P \simeq 143\,\text{ms} \quad L_{sd} \simeq 1.7\times10^{35}\,\text{erg/s}$

- *Very long orbit binary: P0~50 years.*

  (Ho et al. 2016)

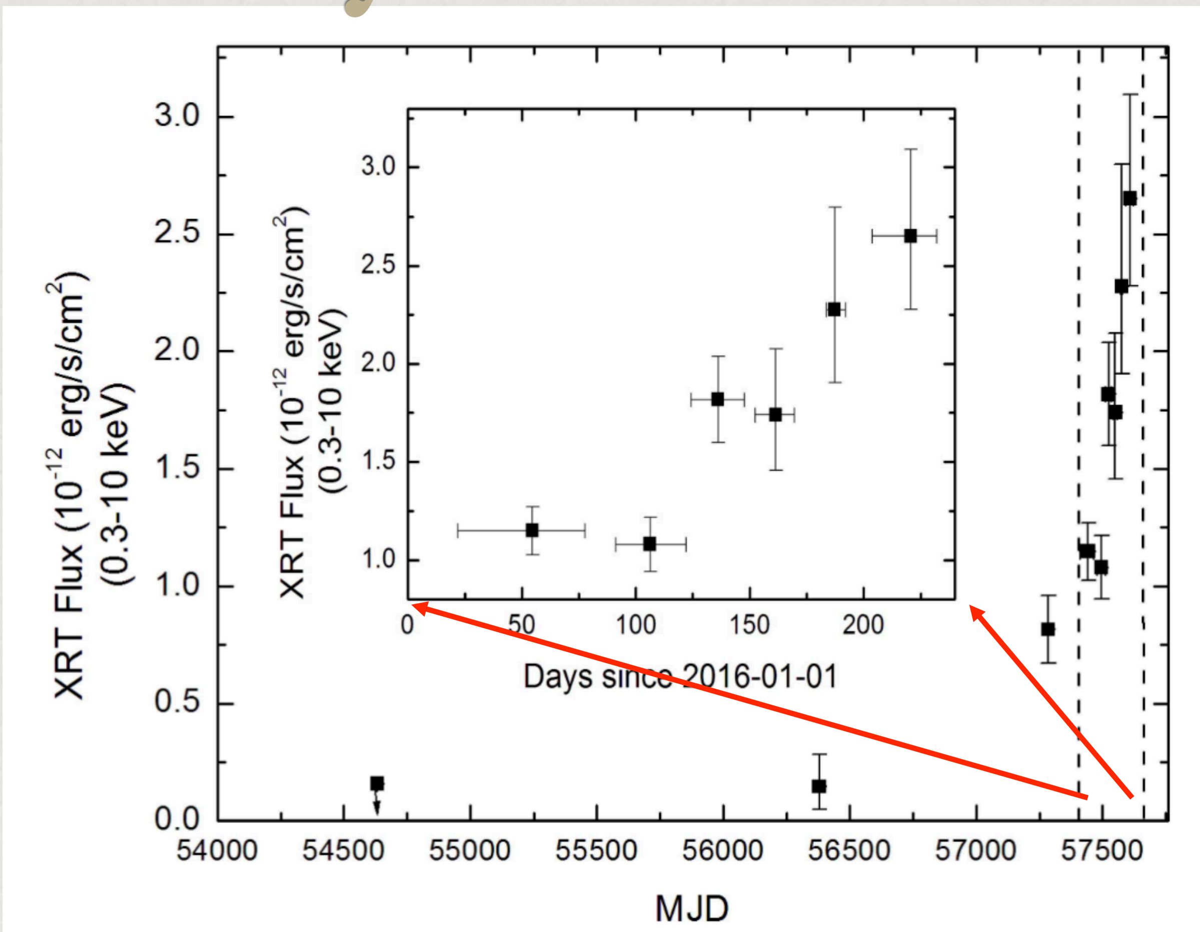
- *Next periastron passage in late 2017.*

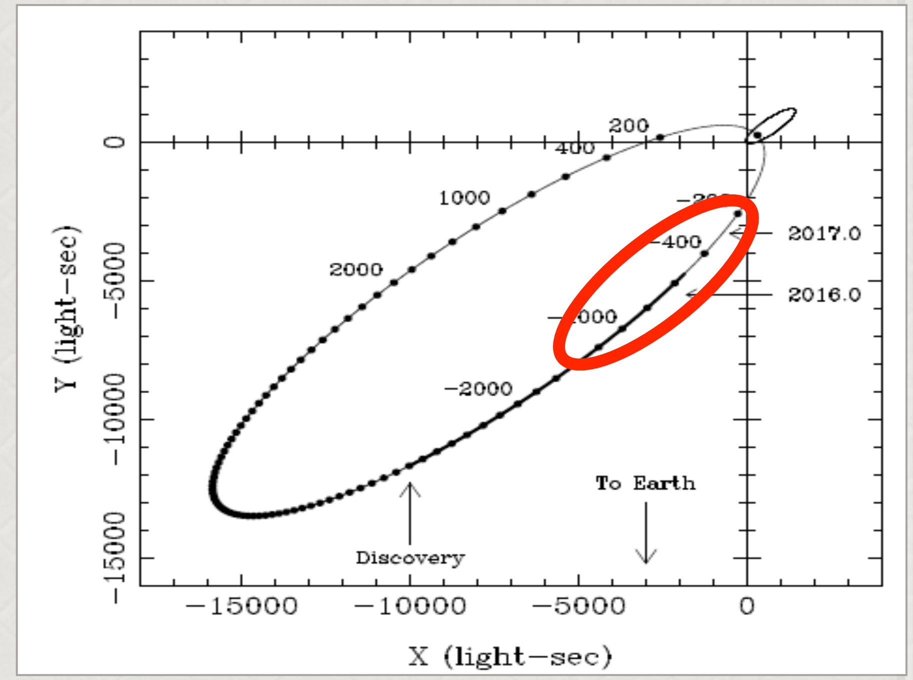


Pulsar now!

X-ray/GeV data

Takata, Tam et al. (2017)

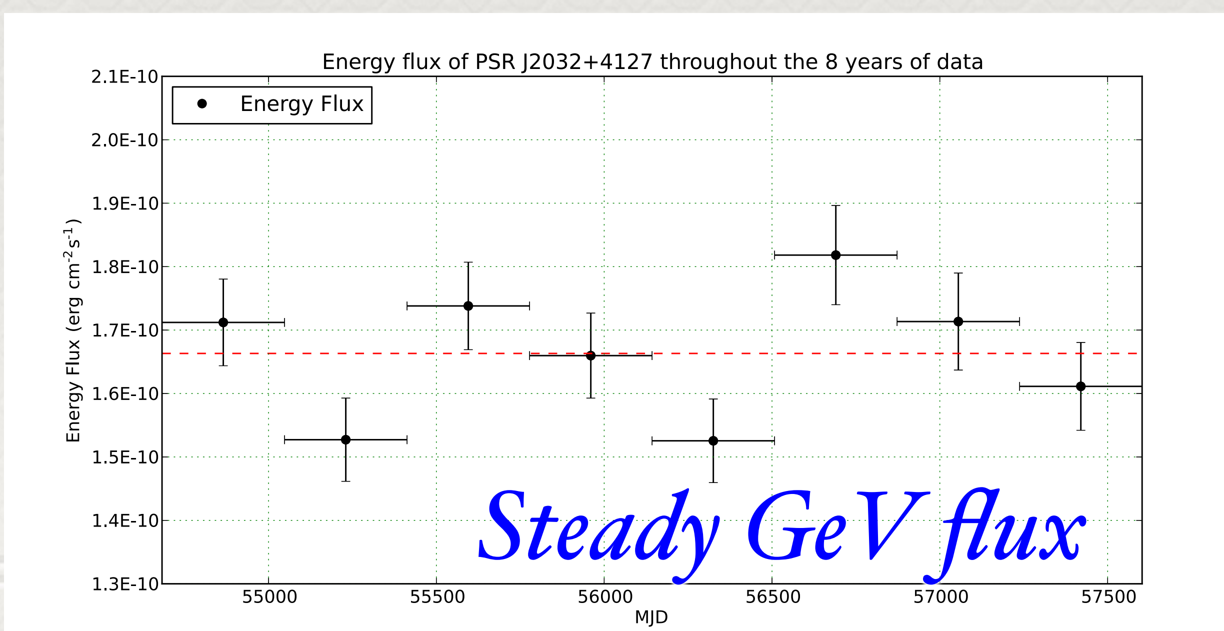




- *X-ray flux has increased for a factor of ten in last ~3 years*

(see also Ho et al 2016)

- *What cause the increase of X-rays? Shock?*



Model calculation

- *Emissions from pulsar wind/stellar wind interaction.*
- *Isotropic pulsar wind and stellar wind.*
- *Magnetization parameter:*

$$\sigma(r) \propto r^{-\alpha}.$$

α *and normalization are model's free parameters*

Stellar wind parameter

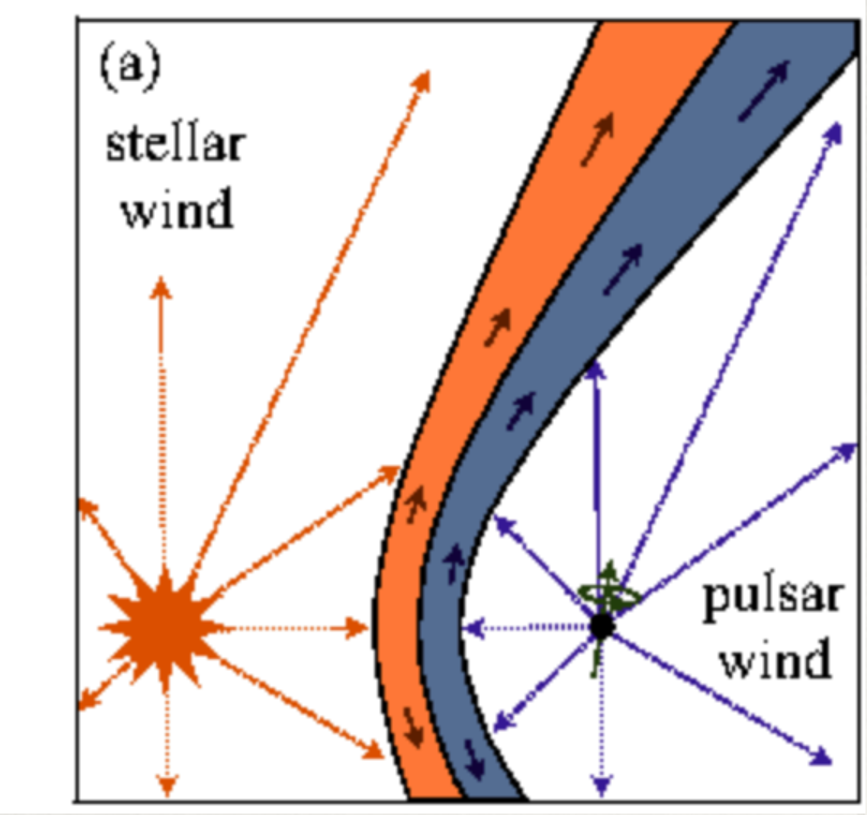
$$v_w = 10^8 \mathrm{cm/s}$$

$$\dot{M}_w \sim 10^{-9} - 10^{-7} M_\odot \mathrm{yr}^{-1}$$

- *Power law distribution of the shocked particles*

$$f_0(\gamma) = K_0 \gamma^{-p}, \quad \Gamma_{PW,0} \le \gamma \le \gamma_{max},$$

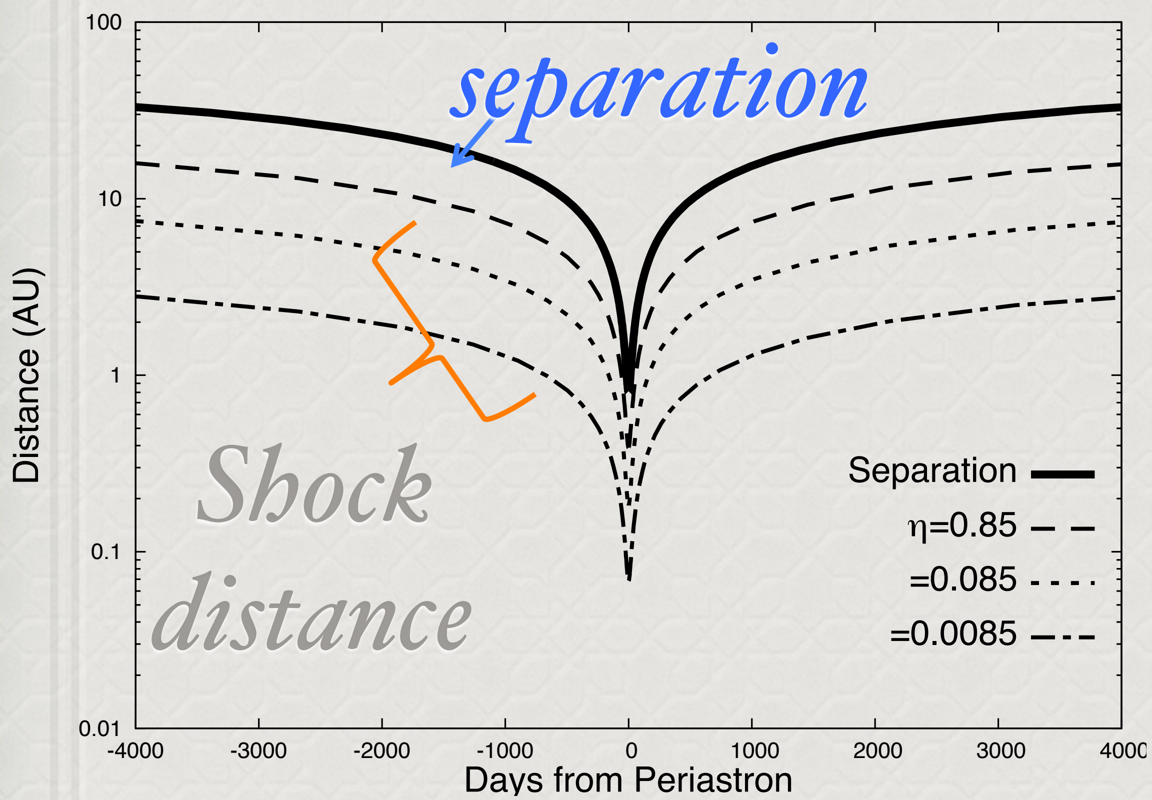
$$m_e c^2 \int_{\gamma_{min}}^{\gamma_{max}} \gamma f_0(\gamma) d\gamma = \varepsilon_2(\sigma)$$

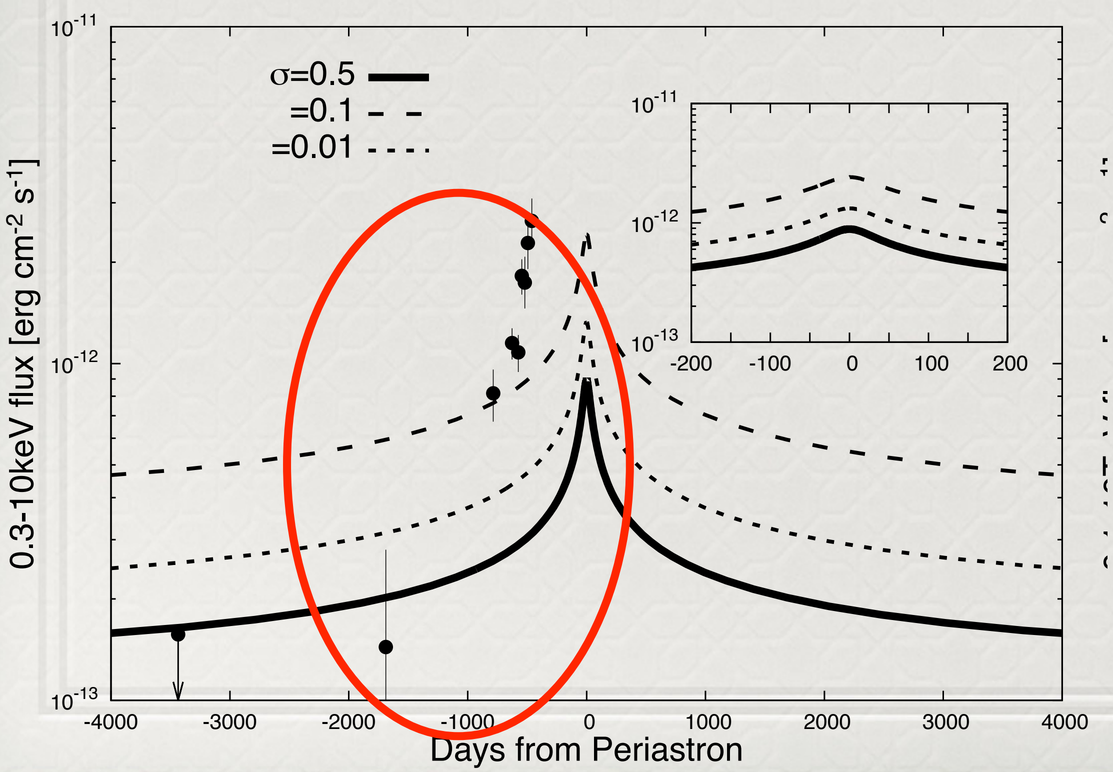


- *Evolution of particle distribution.*

$$\frac{d\gamma_e}{dr} = \frac{1}{v_{pw}} \left[\left(\frac{d\gamma}{dt}\right)_{ad} + \left(\frac{d\gamma}{dt}\right)_{syn} + \left(\frac{d\gamma}{dt}\right)_{ICS} \right].$$

Model Results





- *Size of system*

-- *Separation ~ 1AU-30AU*

-- *Shock distance from pulsar*

~0.1AU-5AU

- *Case for σ(r)=constant*

-- *Pulsar → periastron.*

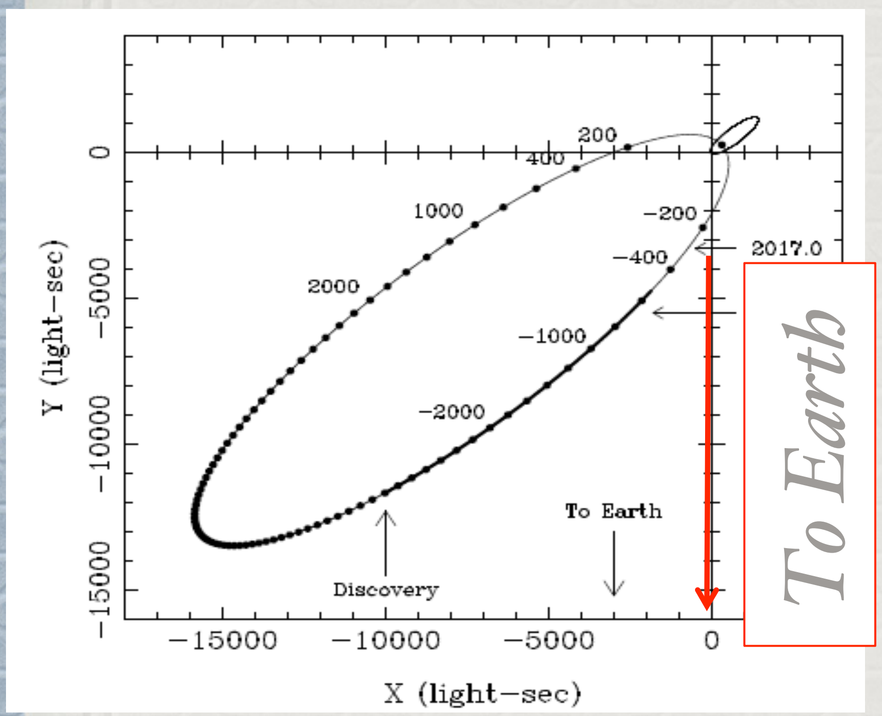
→ *shock distance from the pulsar decreases*

→ *Increase X-ray emissions*

-- *In the model*

$$F_X \propto B^2(r_s) \times \text{Volume} \propto 1/r_s$$

Effect of Doppler boost

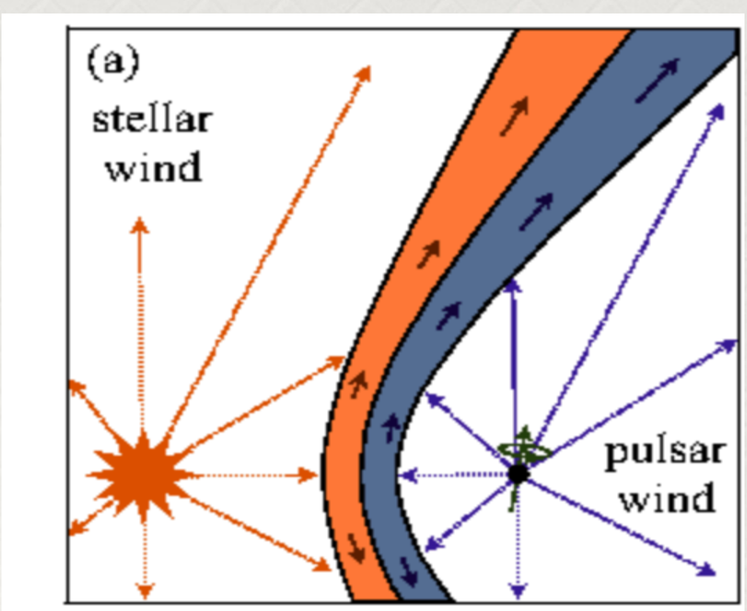


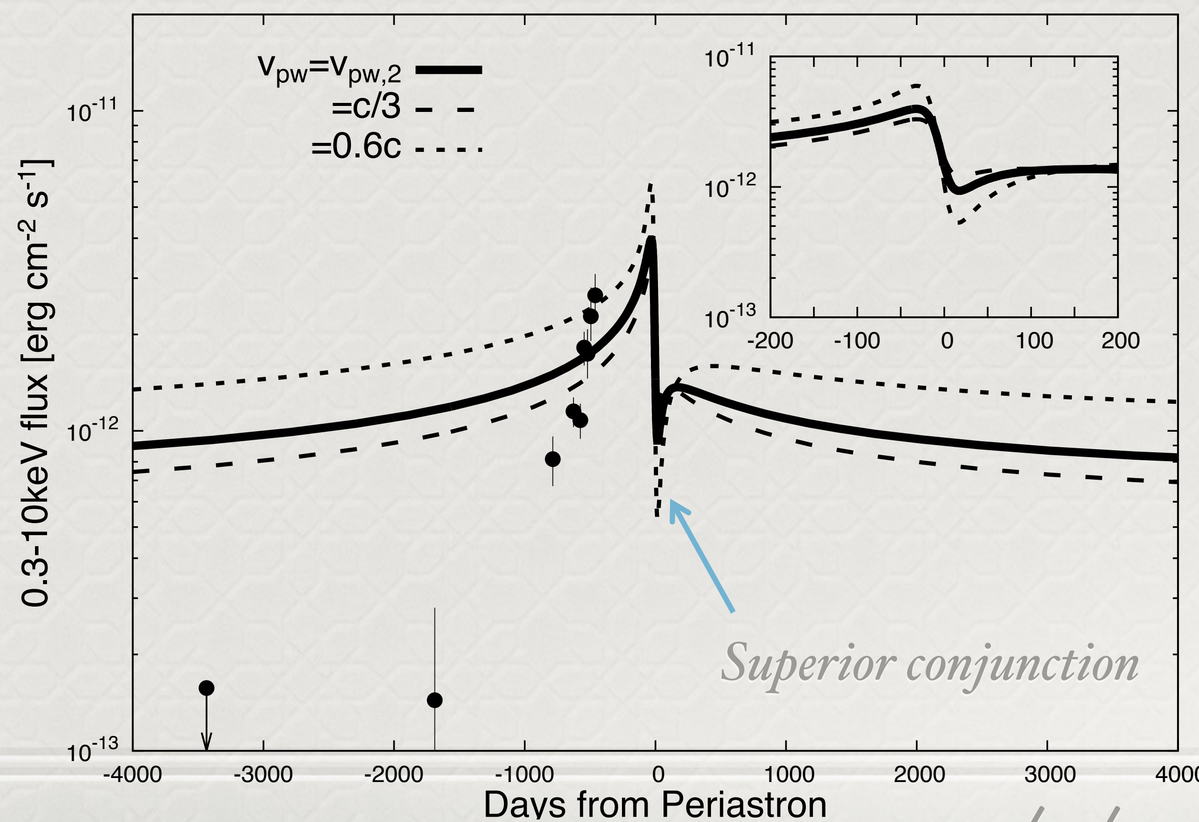
-- *The pulsar is close to inferior conjunction.*

-- *Shock pulsar wind moves toward the Earth.*

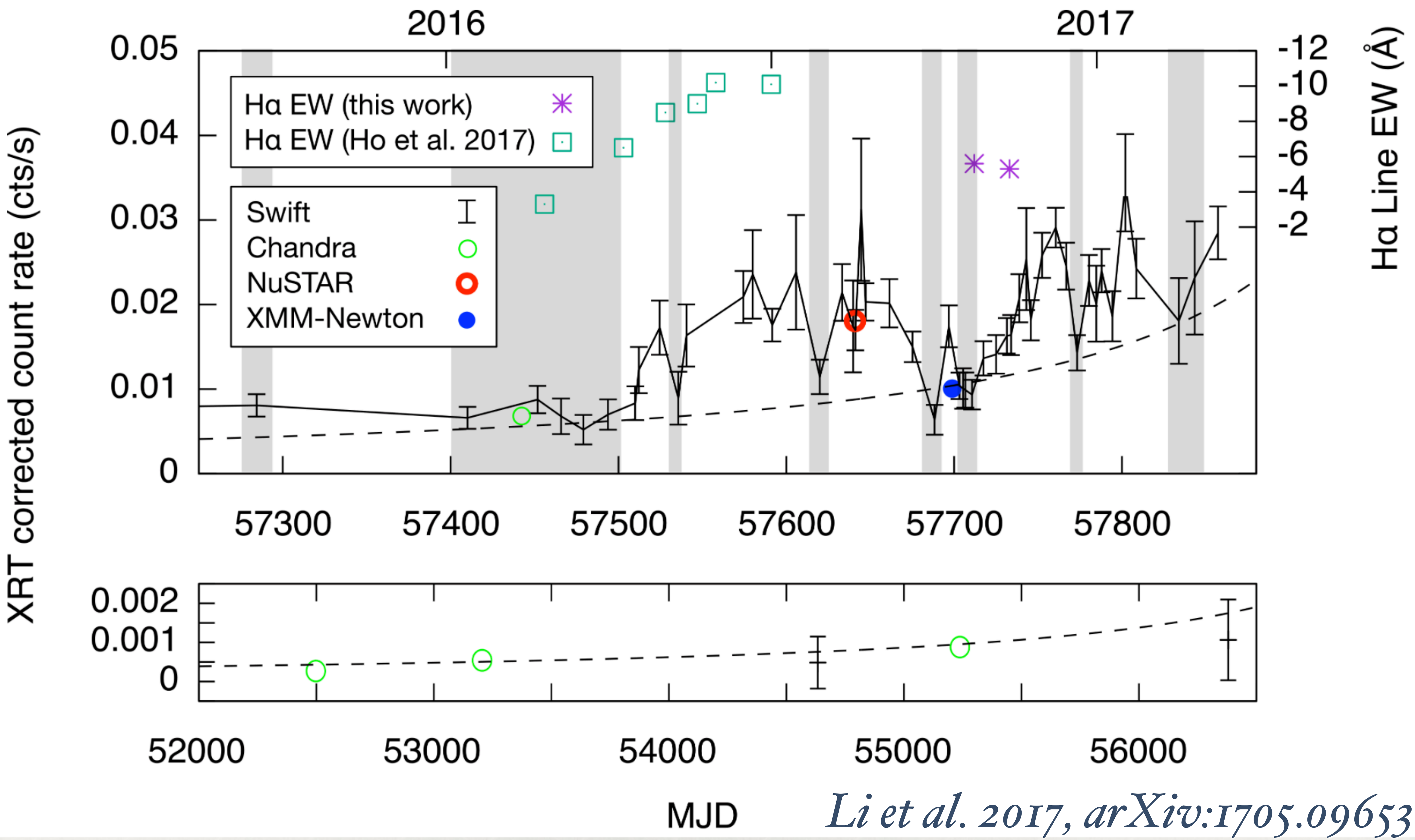
--*Doppler boost:*

$$\mathcal{D} = \frac{1}{\Gamma_{pw}\sqrt{1-(v_{pw}/c)\cos\theta_{pw}}},$$





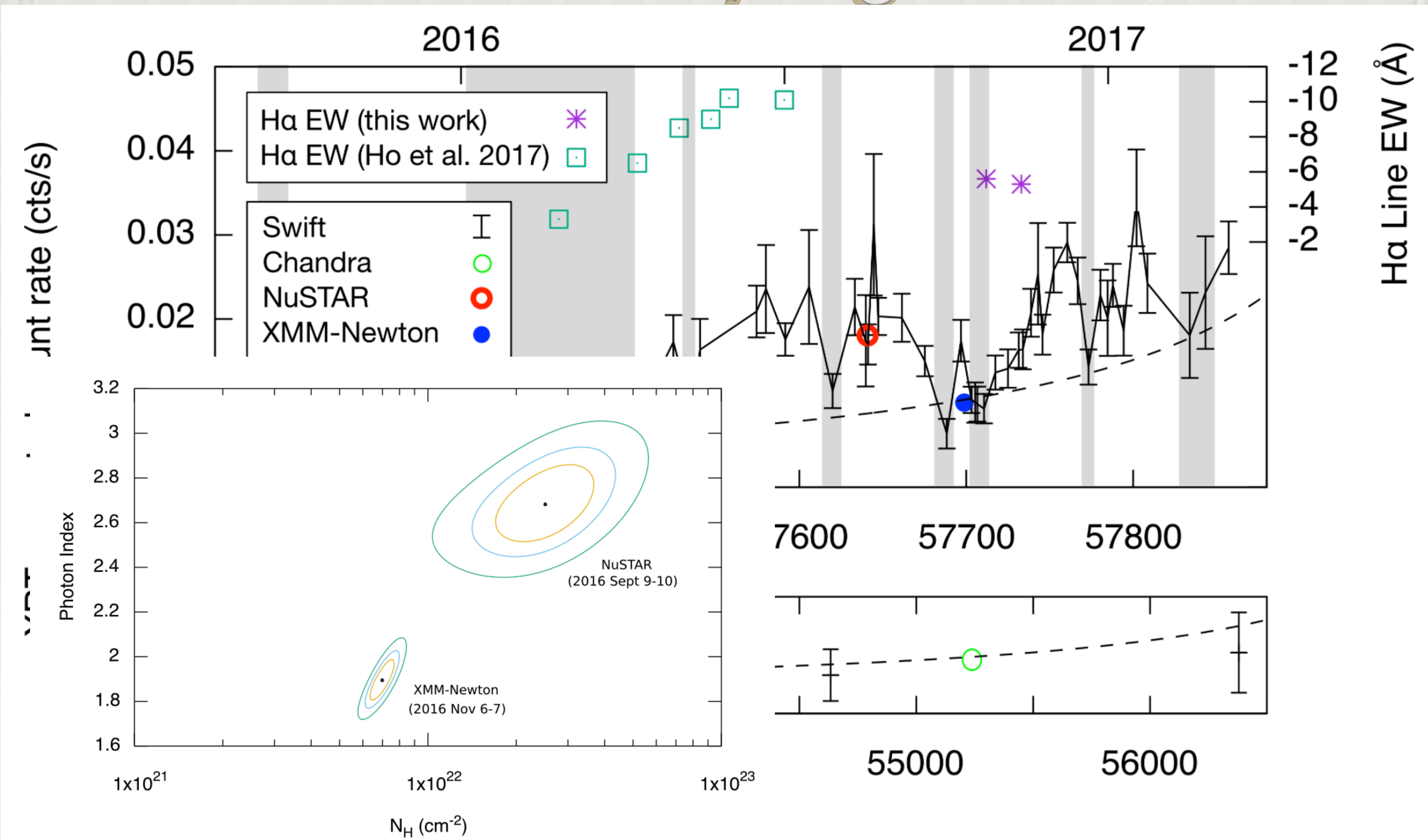
Recent X-ray light curve



Li et al. 2017, arXiv:1705.09653

- Instead of a monotonically increase in X-ray flux, the light curve may be characterized by:
1) a long-term increase trend from 2013-2015: the low state
2) short-term (weeks-months) flares: the flaring state

Recent X-ray light curve



- Instead of a monotonically increase in X-ray flux, the light curve may be characterized by:
1) a long-term increase trend from 2013-2015: the low state=> lower nH
2) short-term (weeks-months) flares: the flaring state=> higher nH

Some thoughts

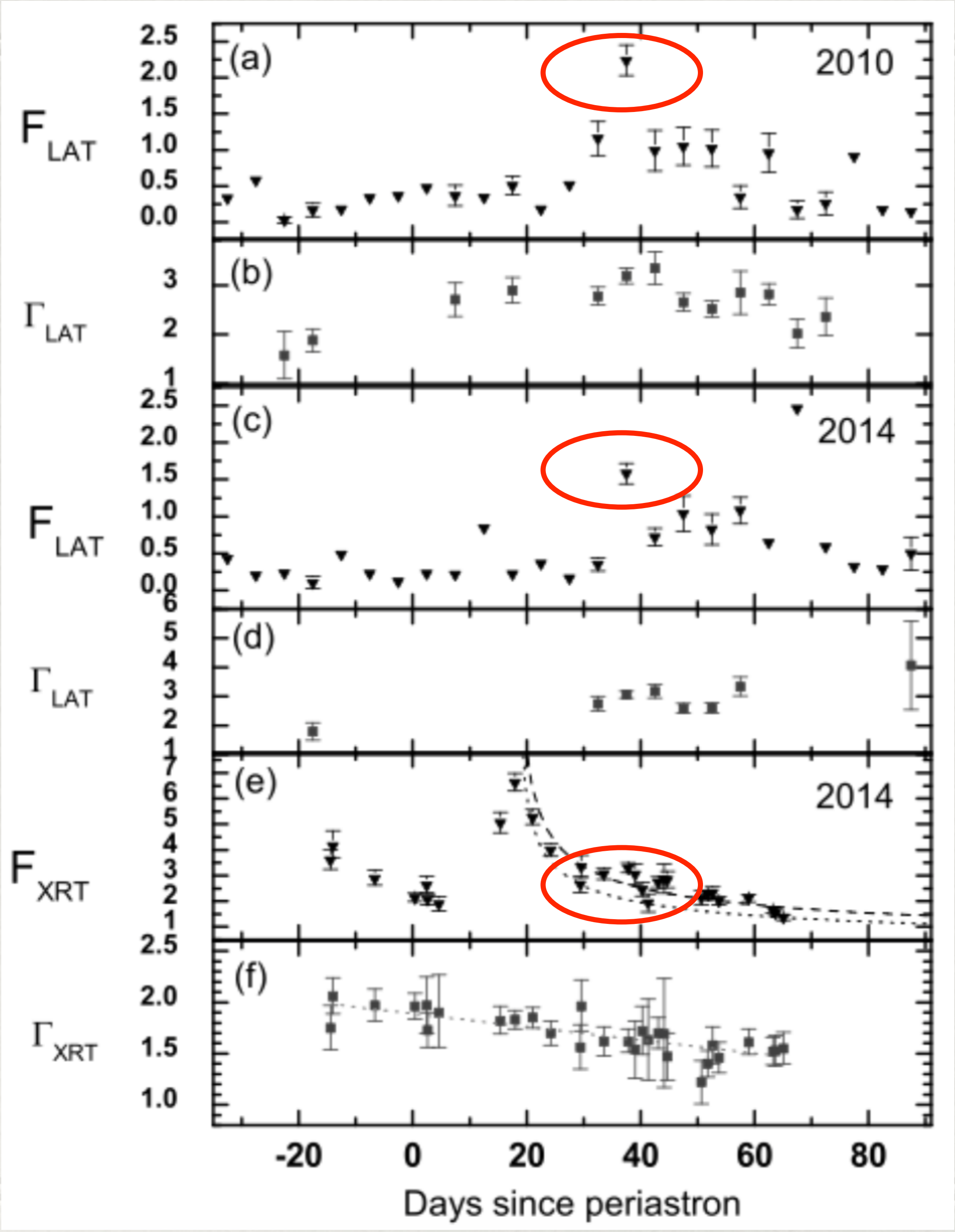
- *It would ease the difficulties faced by too rapid increase of magnetic field at the shock (proportional to binary separation)*
- *Local clump(s) of clouds from stellar wind, consistent with high nH required*

PSR J2032+4127
&
PSR B1259-63
are two similar systems

PSR/Companion	P (s)	L_{35}	P_o (yrs)	e	a (lt-s)	T_*	R_*
J2032+4127/MT91 213	0.143	1.7	25-50	0.96	9022	30000K	$10R_\odot$
B1259-63/LS2883	0.048	8	3.4	0.83	1296	~30000K	$\sim 9R_\odot$

TABLE 1

GeV flares in 2011 & 2014!



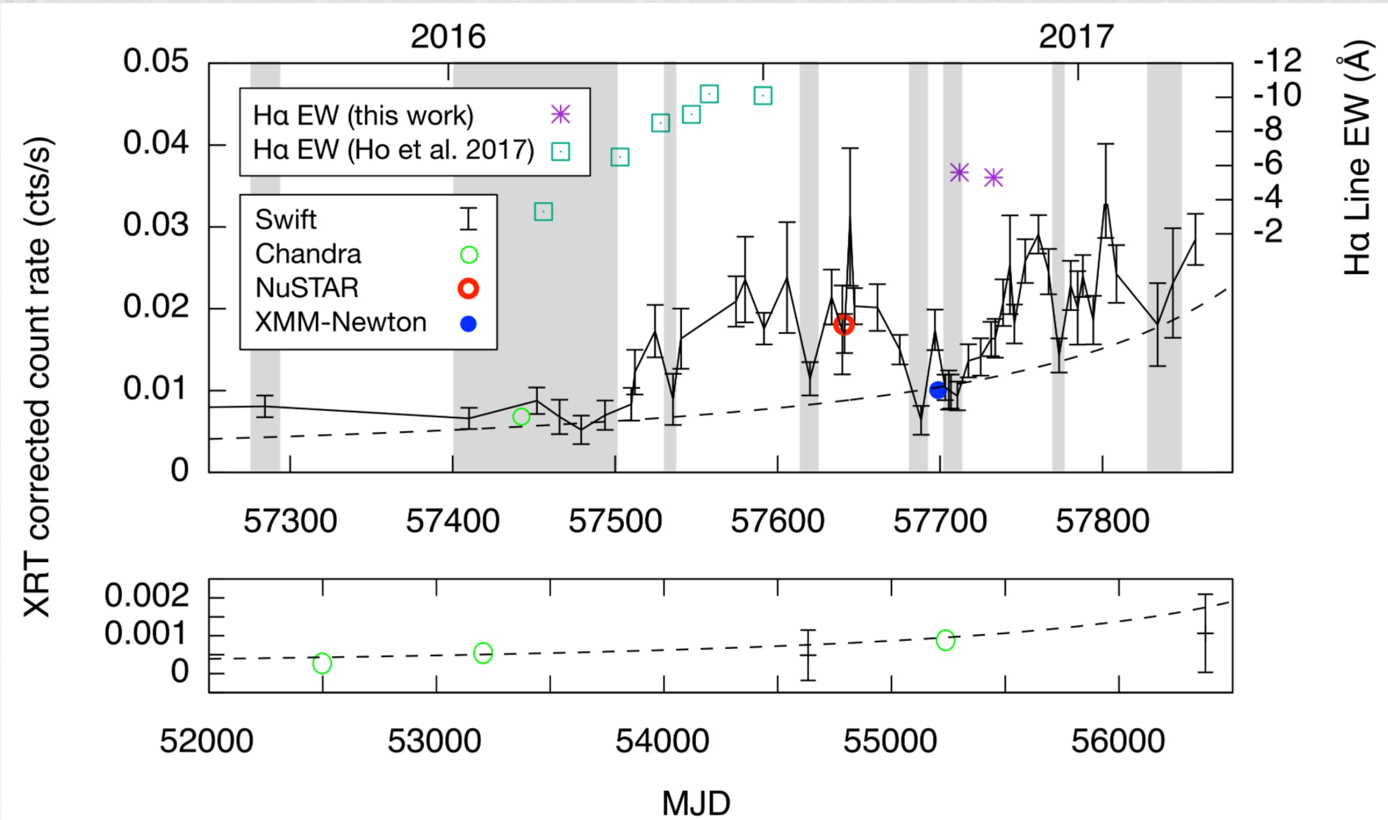
Tam et al. (2011, 2015)

see also

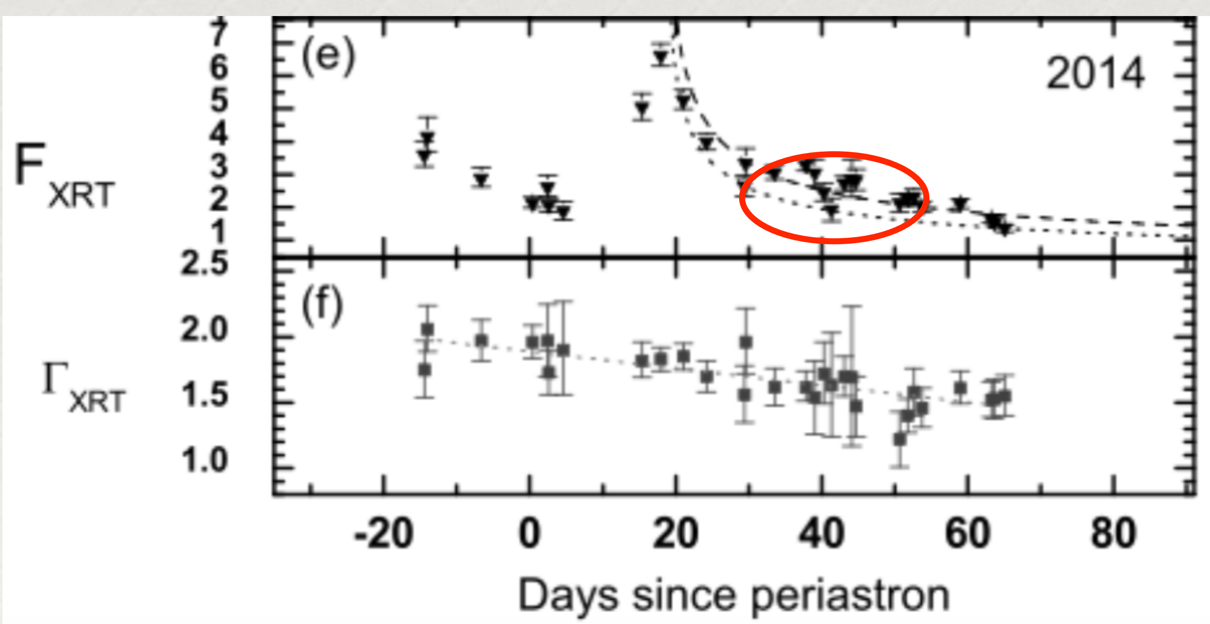
Caliandro et al.(2015)

Chernyakova et al. (2015)

X-ray light curves

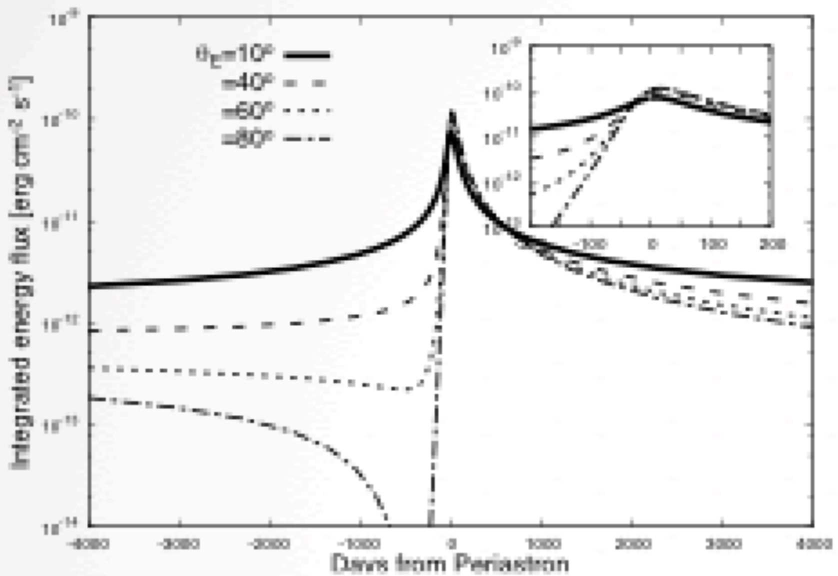


Li et al. (2017)
PSR 2032+4127



Tam et al. (2015)
PSR B1259-63

Future perspective



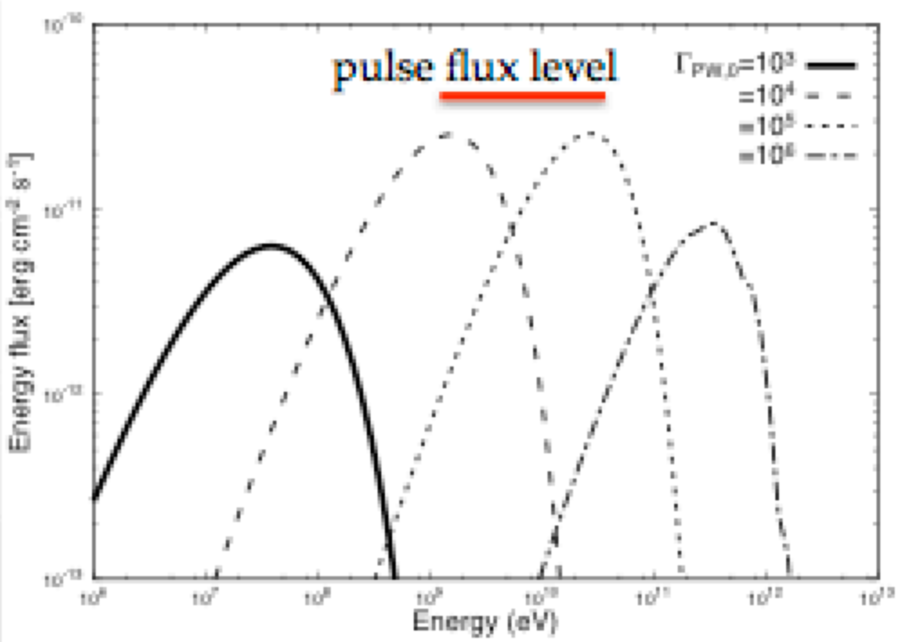
- Relativistic pulsar wind

--I.C. scattering off the stellar photons.

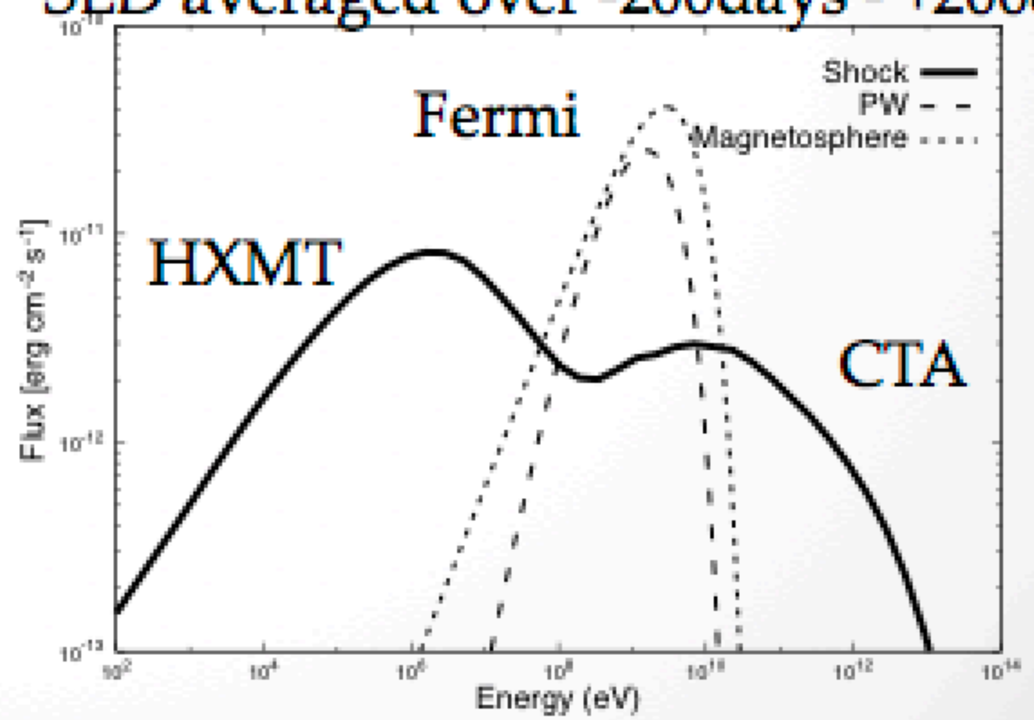
-- Predicted flux ~10^{-10} erg $cm^{-2}s^{-1}$ at periastron.

-- Good target for Fermi.

Spectrum of I.C. from pulsar wind



SED averaged over -200days - +200days



Summary(1): general

- *It's now a good time to study gamma-ray binaries with orbital period of years*
- *Pulsar/Be binary : laboratory of the pulsar wind, studying magnetosphere/Pulsar wind/Shock emissions.*
- *Prototype: PSR B1259-63/LS2883, origin of GeV flare still not solved*

Summary(2): PSR J2032+4127

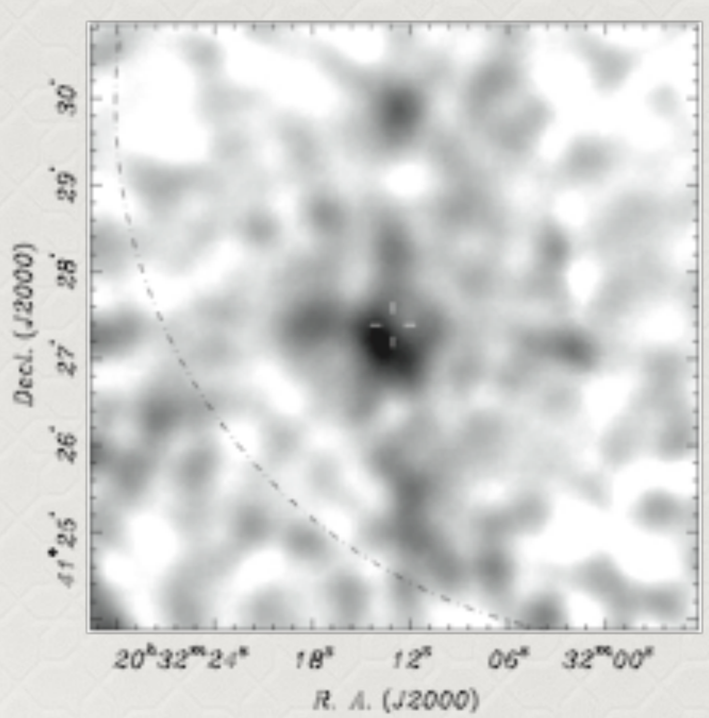
- *PSR J2032+4127/MT91 213 : what causes the X-ray flares?*
- *Prediction from the shock model: Orbital modulating GeV/TeV emissions in the next periastron passage (late 2017, Takata, Tam et al., 2017).*
- *The first and last chance for us.*

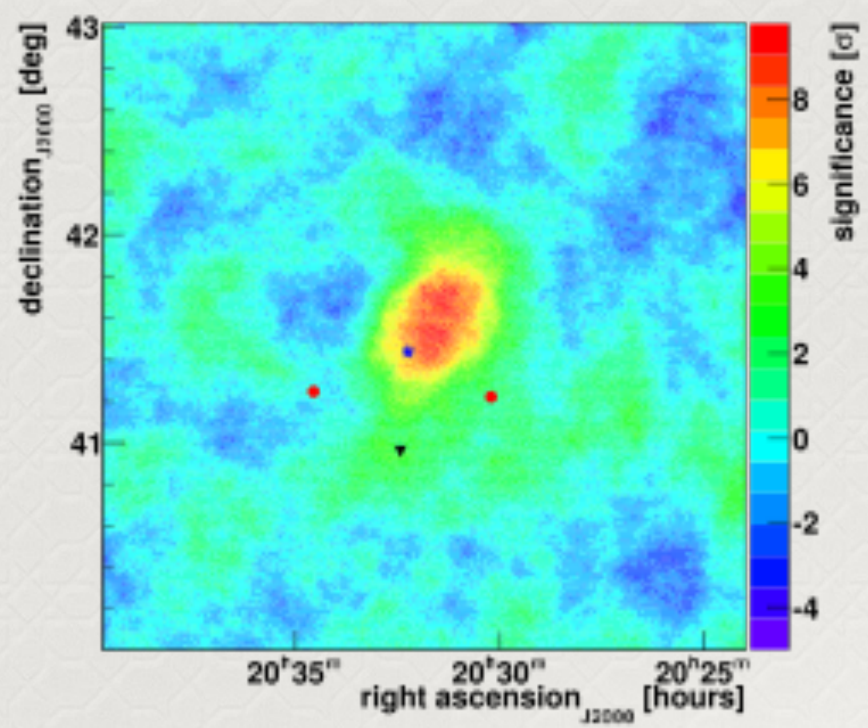
Thank you!

PSR J2032+4127

- *Gamma-ray pulsars with radio timing solutions (Camilo+ 2009)*
- *It has TeV and X-ray counterparts (PWN?)*

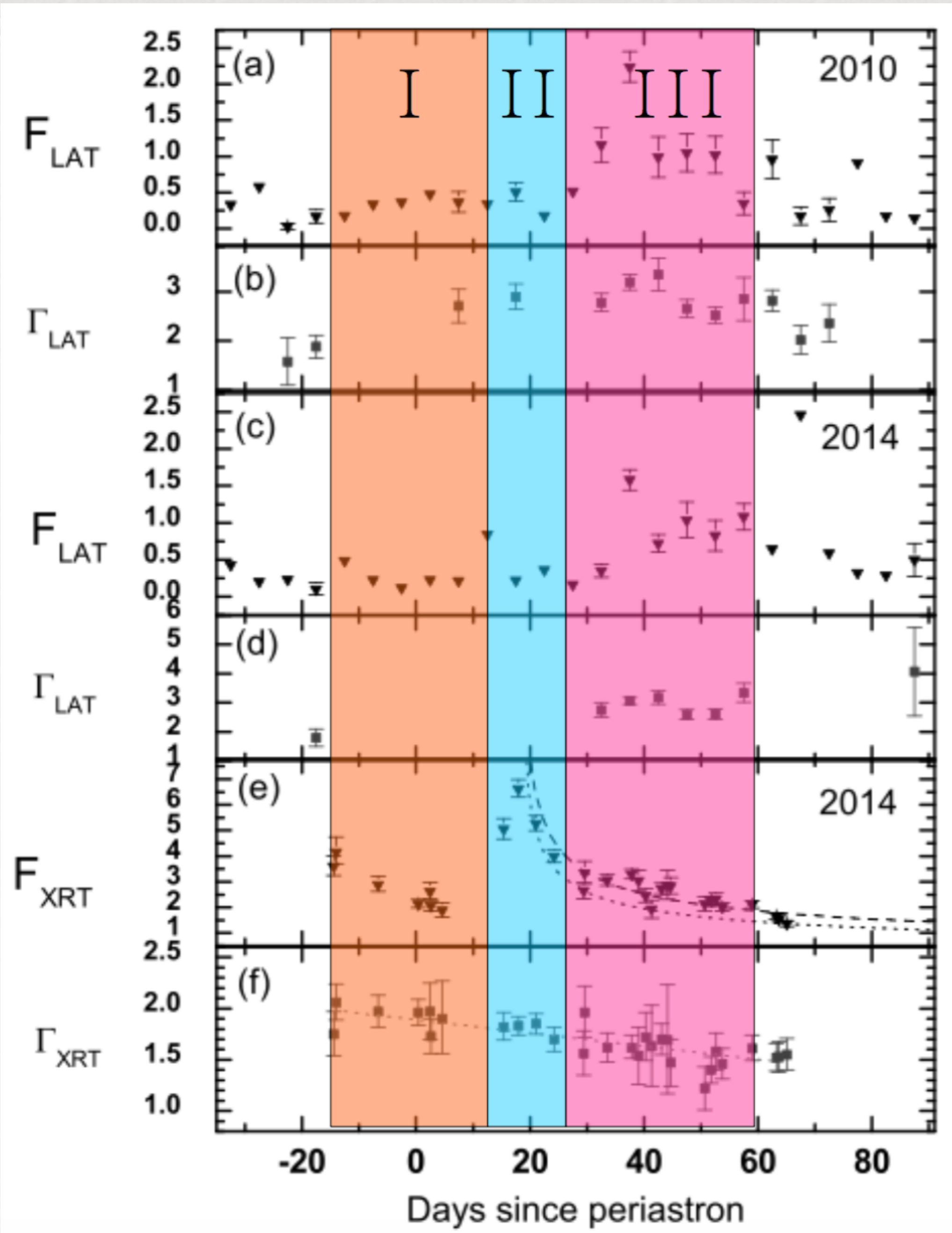
7 arcmin

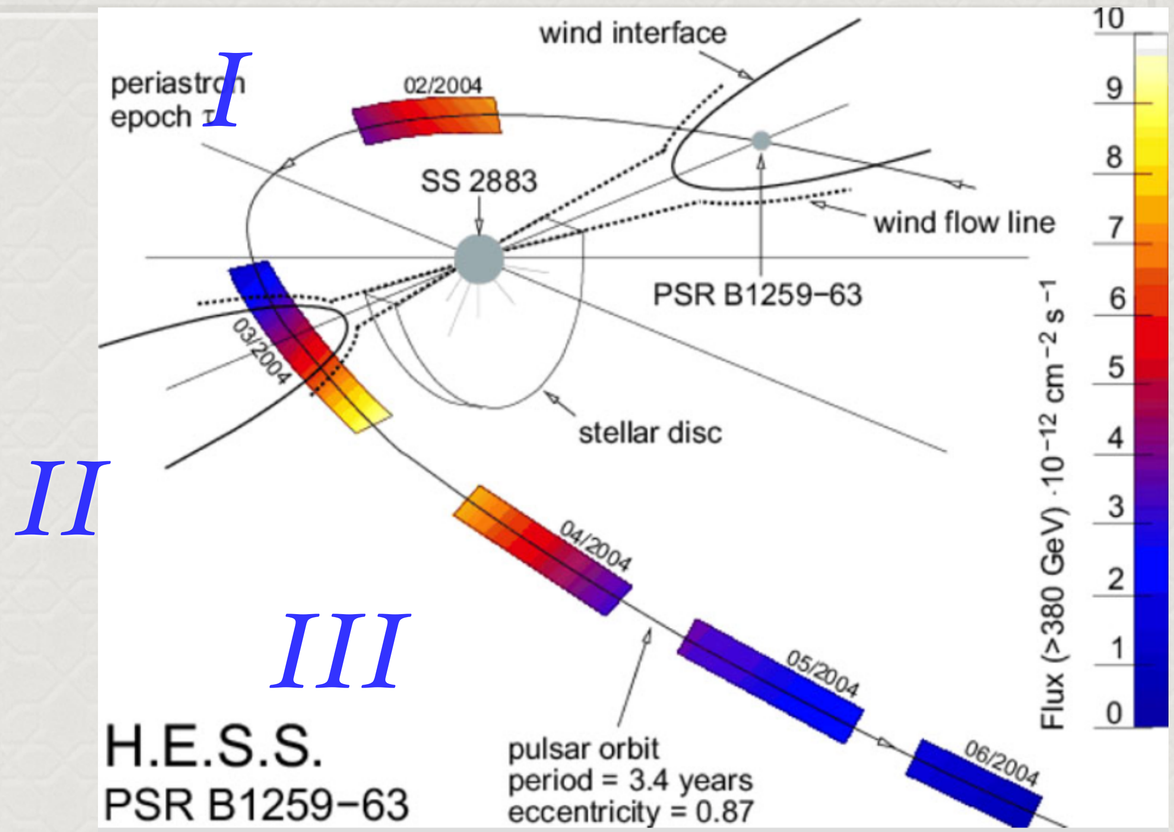




3 degrees

X-ray/GeV connection?





Tam et al. (2015)

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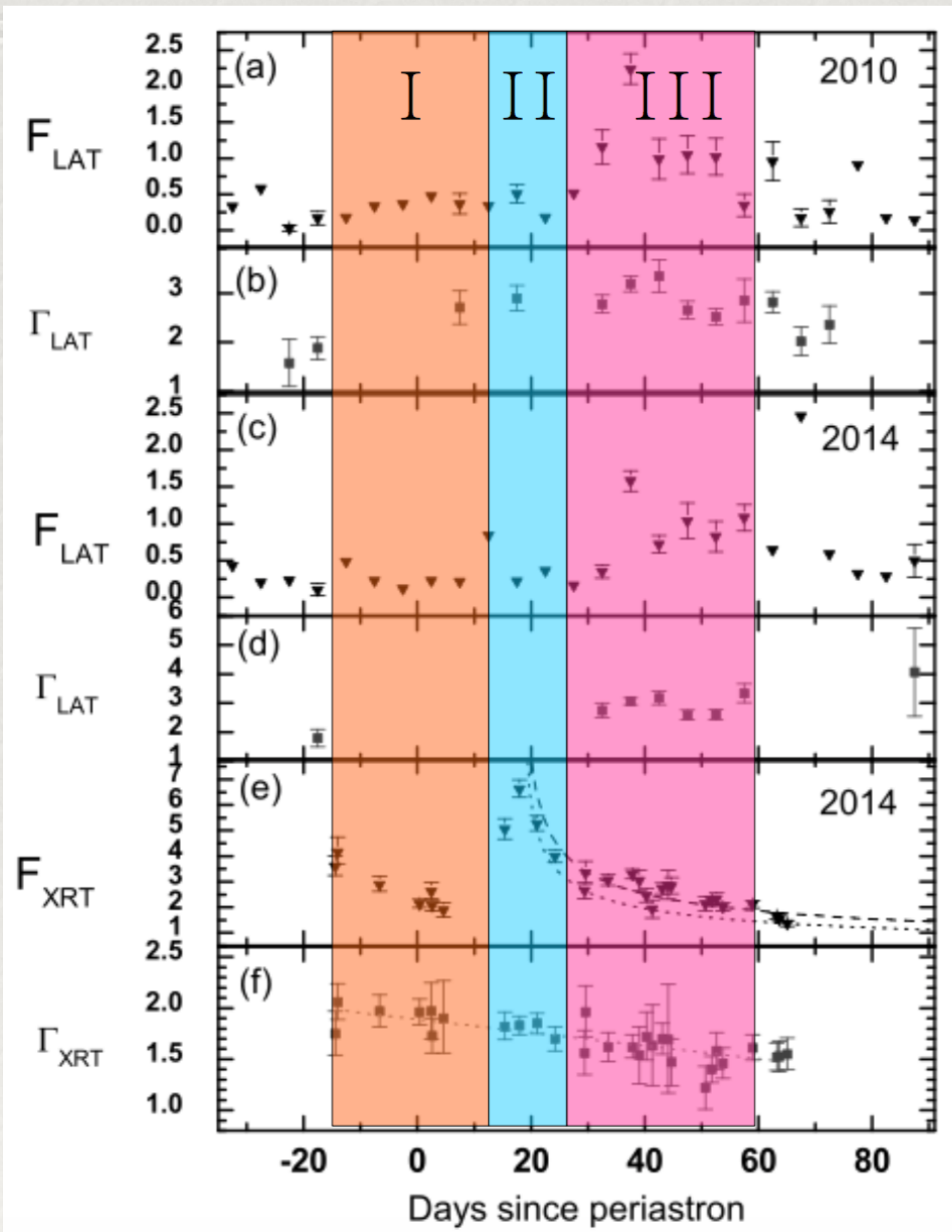

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