

Gamma-ray binaries as pulsars

spectral & variability behaviour

Guillaume Dubus

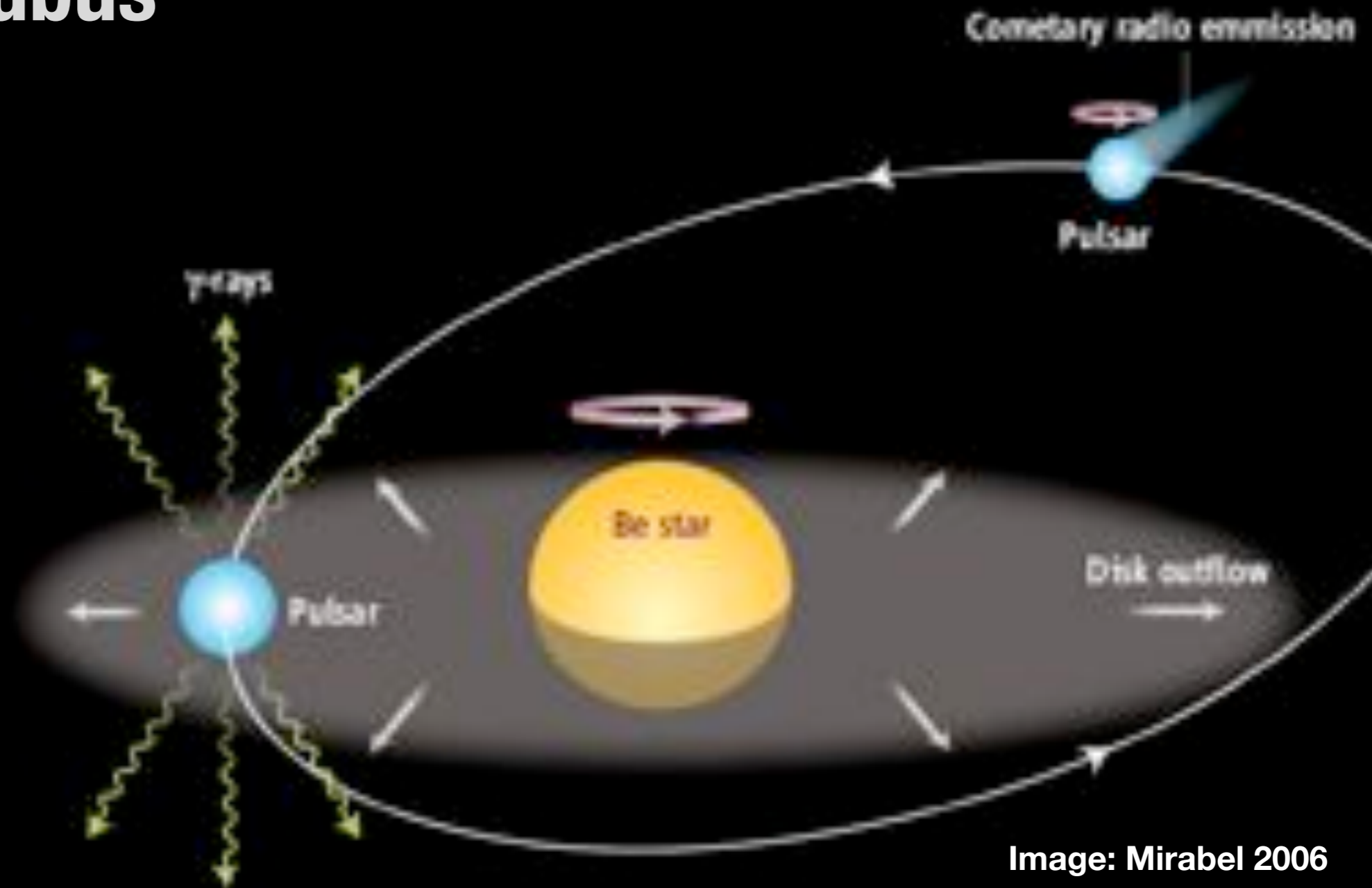


Image: Mirabel 2006

Pulsars & massive stars

- Young pulsars, magnetic fields $\sim 10^{12}$ G, ages < 1 Myr
- with massive companions

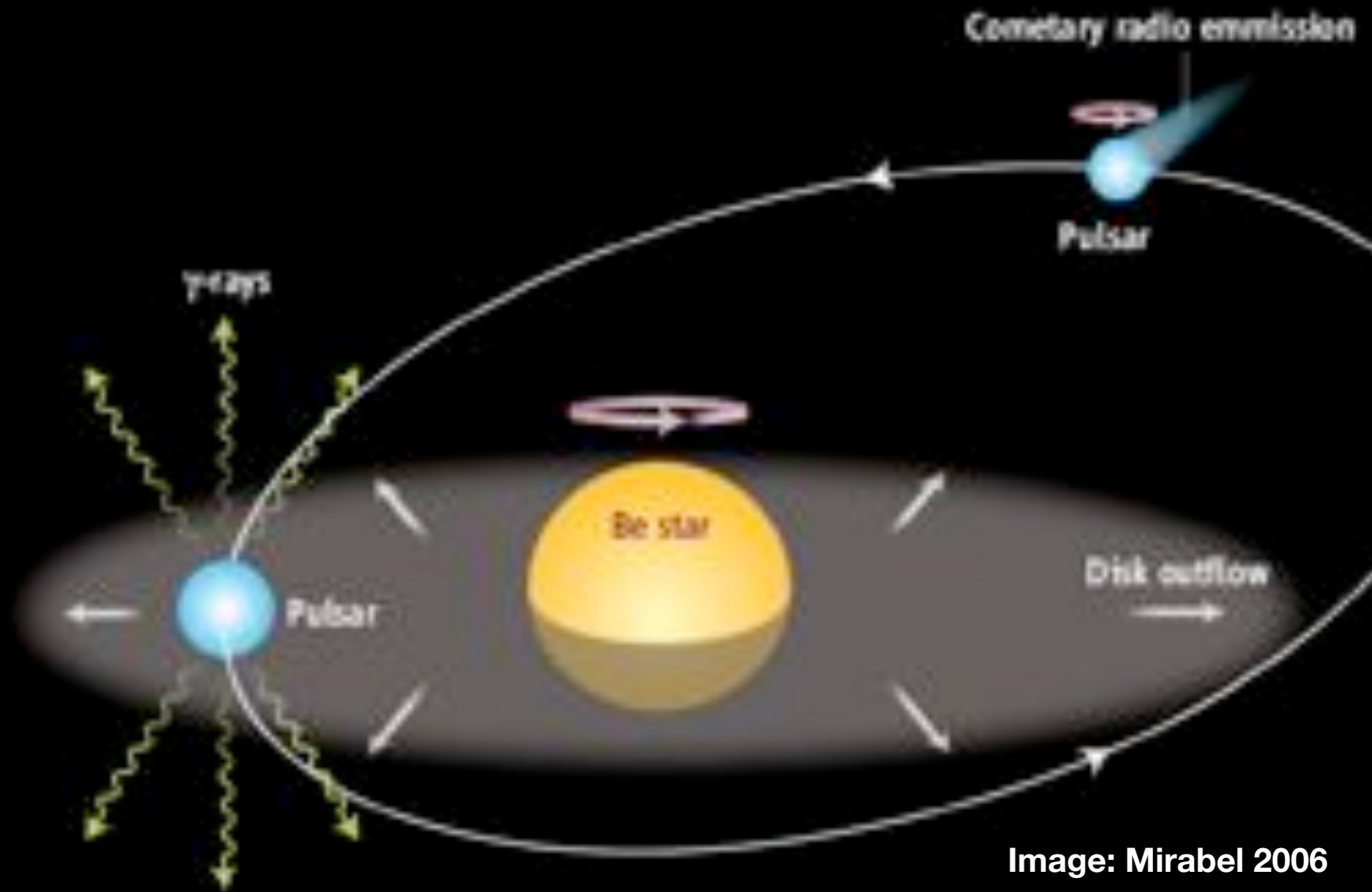


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Pulsars & massive stars

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- with massive companions are seen...

pulsar catalog

	pulse (ms)	P_{orb}	companion	dE/dt (erg/s)
PSR B1259-63	0.048	1237d	Be	$8 \cdot 10^{35}$
PSR J1740-3052	0.570	231d	$> 11 M_{\odot}$	$5 \cdot 10^{33}$
PSR J1638-4725	0.764	1941d	$> 6 M_{\odot}$	$4 \cdot 10^{32}$
PSR J0045-7319	0.926	51d	$> 4 M_{\odot}$	$2 \cdot 10^{32}$

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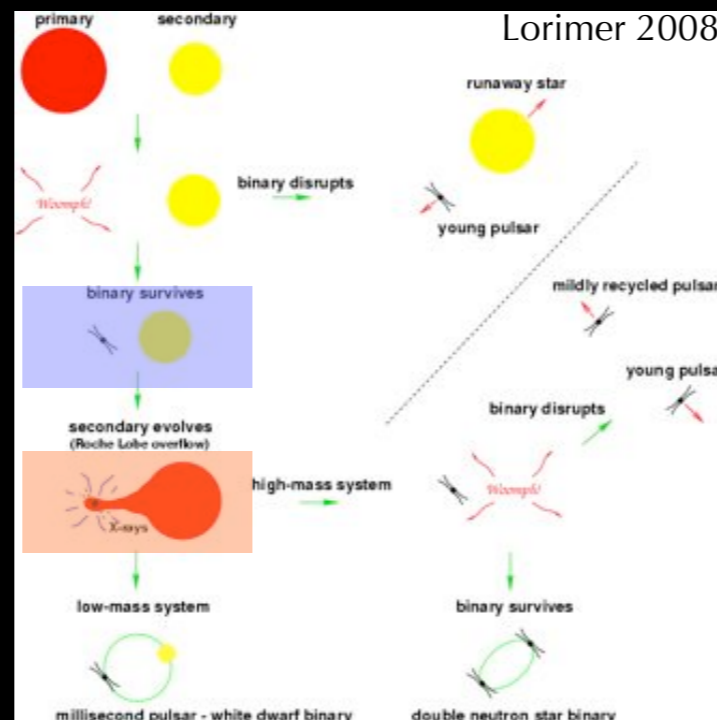
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- ...and expected in evolution models (birth rate $\sim 10^{-3}$ per year)

pulsar + massive star



accreting HMXB



Pulsars & massive stars

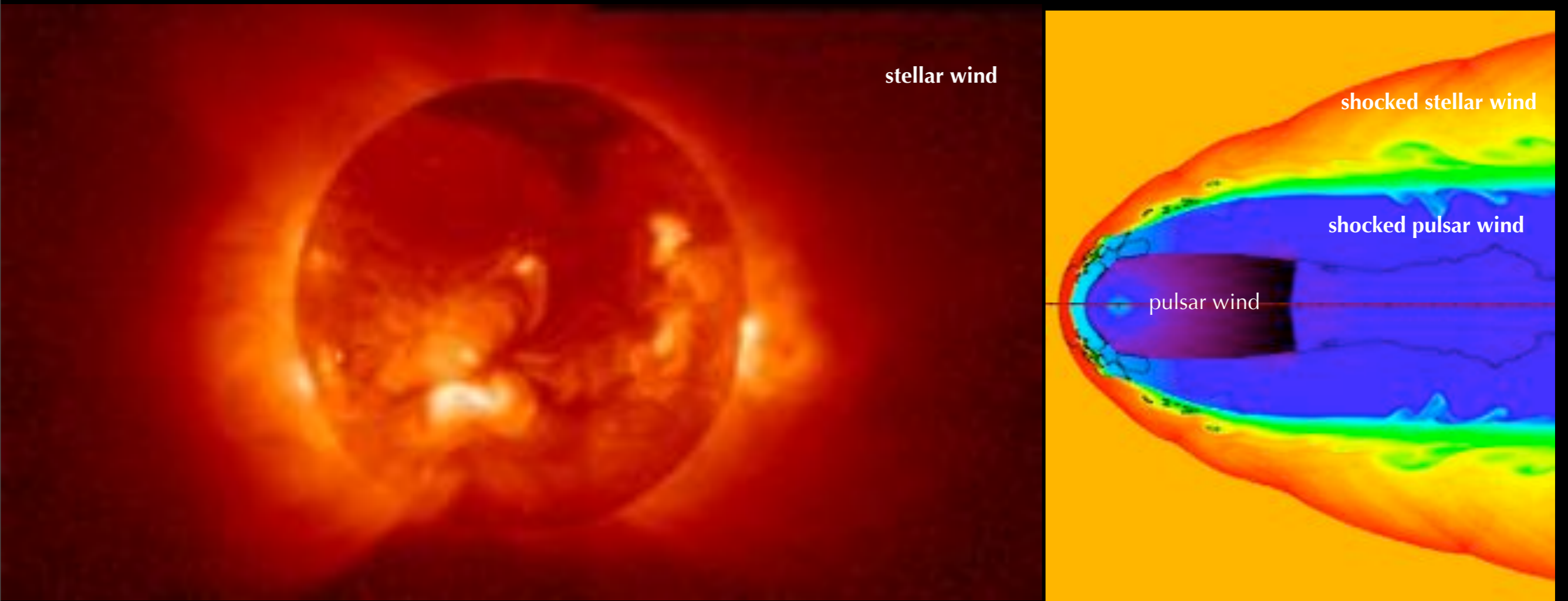
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- **(High-mass) gamma-ray binaries harbour young pulsars ?**
 - LS 5039, LS I+61°303, (HESS J0632+057) share obs. similarities with PSR B1259-63
 - radial velocity: neutron star or low-mass black hole
 - pulsation ? hard to find: absorption in radio, timing in γ -rays

Interacting winds

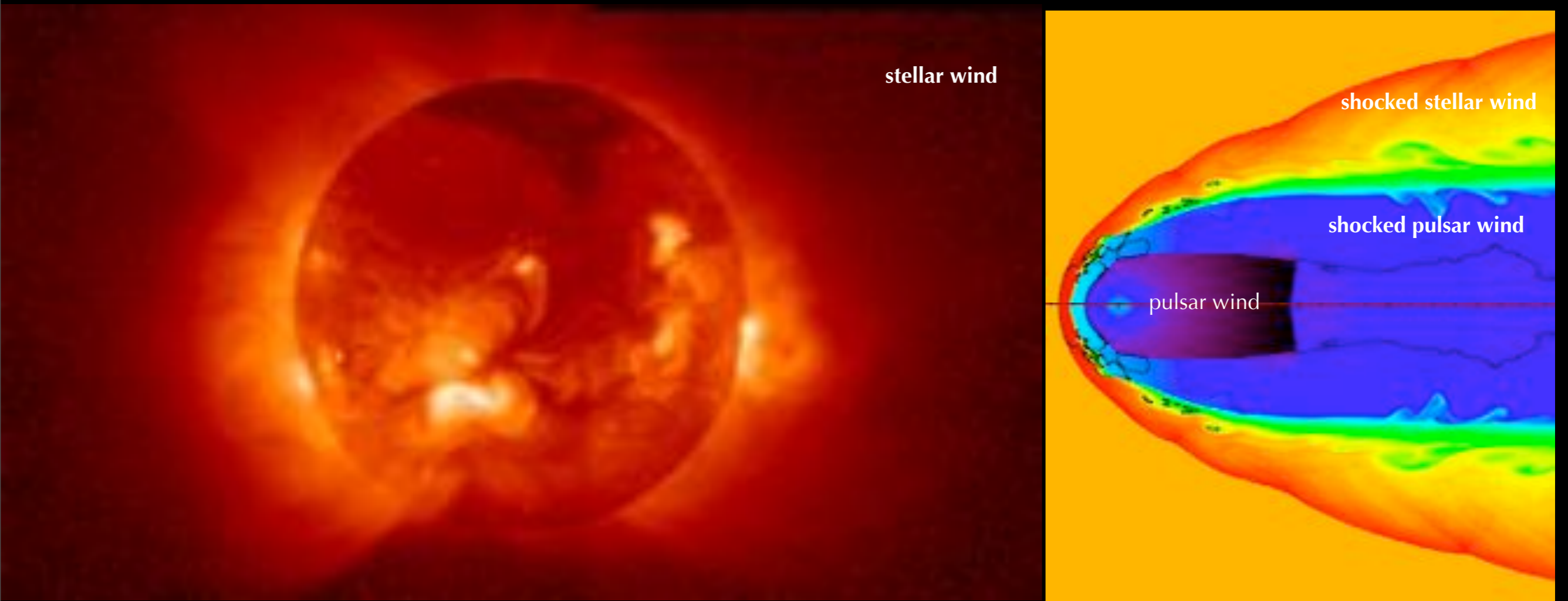


Bucciantini et al. 2005

Binary plerion, PWN

Shock close to pulsar <0.1 au or $<10^4 R_L$ in LS 5039 [0.1 pc or $10^9 R_L$ for Crab]

Interacting winds



Bucciantini et al. 2005

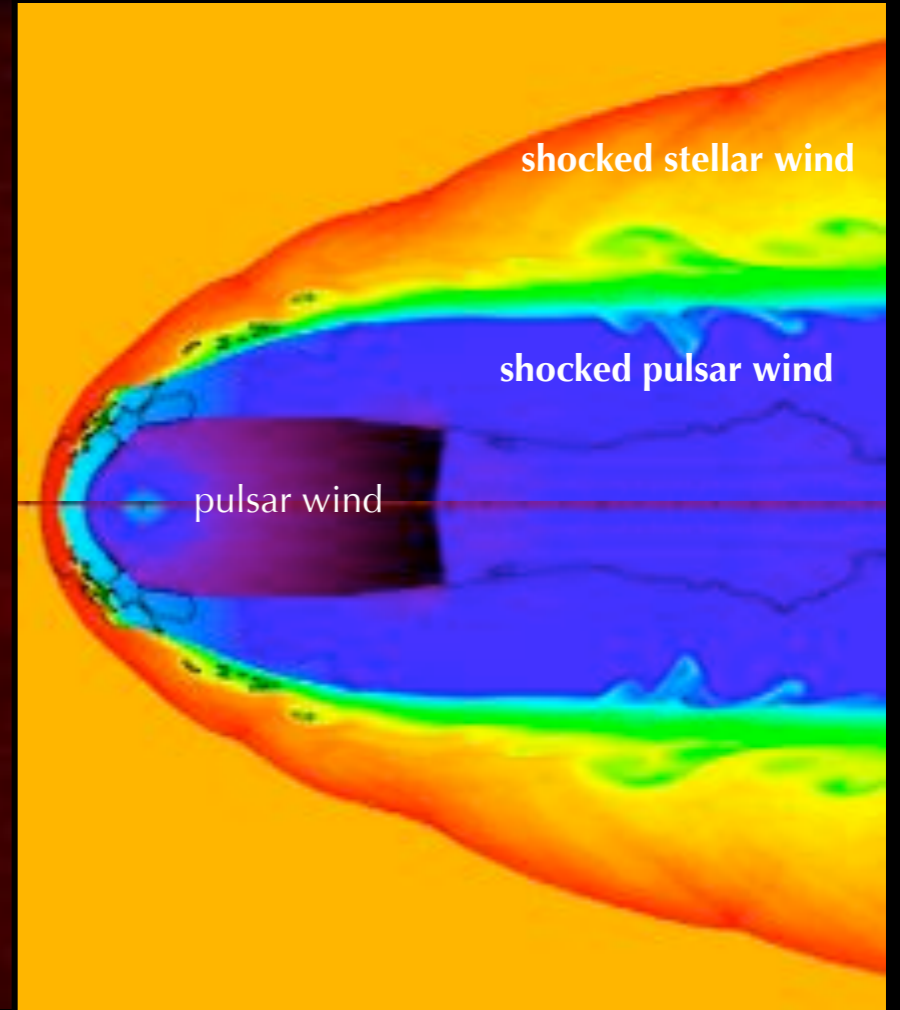
No accretion requires $p_{\text{pulsar wind}} > p_{\text{accretion}}$ at Bondi radius

$$\dot{E}_p \geq 10^{26} \rho_{-14} v_{1000}^{-3} \text{ erg/s for fast wind}$$

Interacting winds



stellar wind



shocked stellar wind

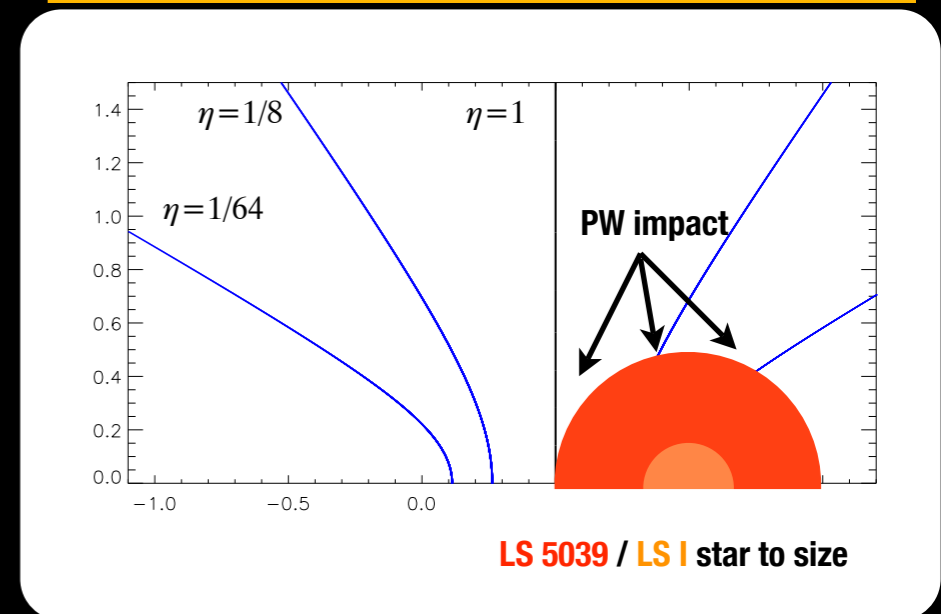
shocked pulsar wind

pulsar wind

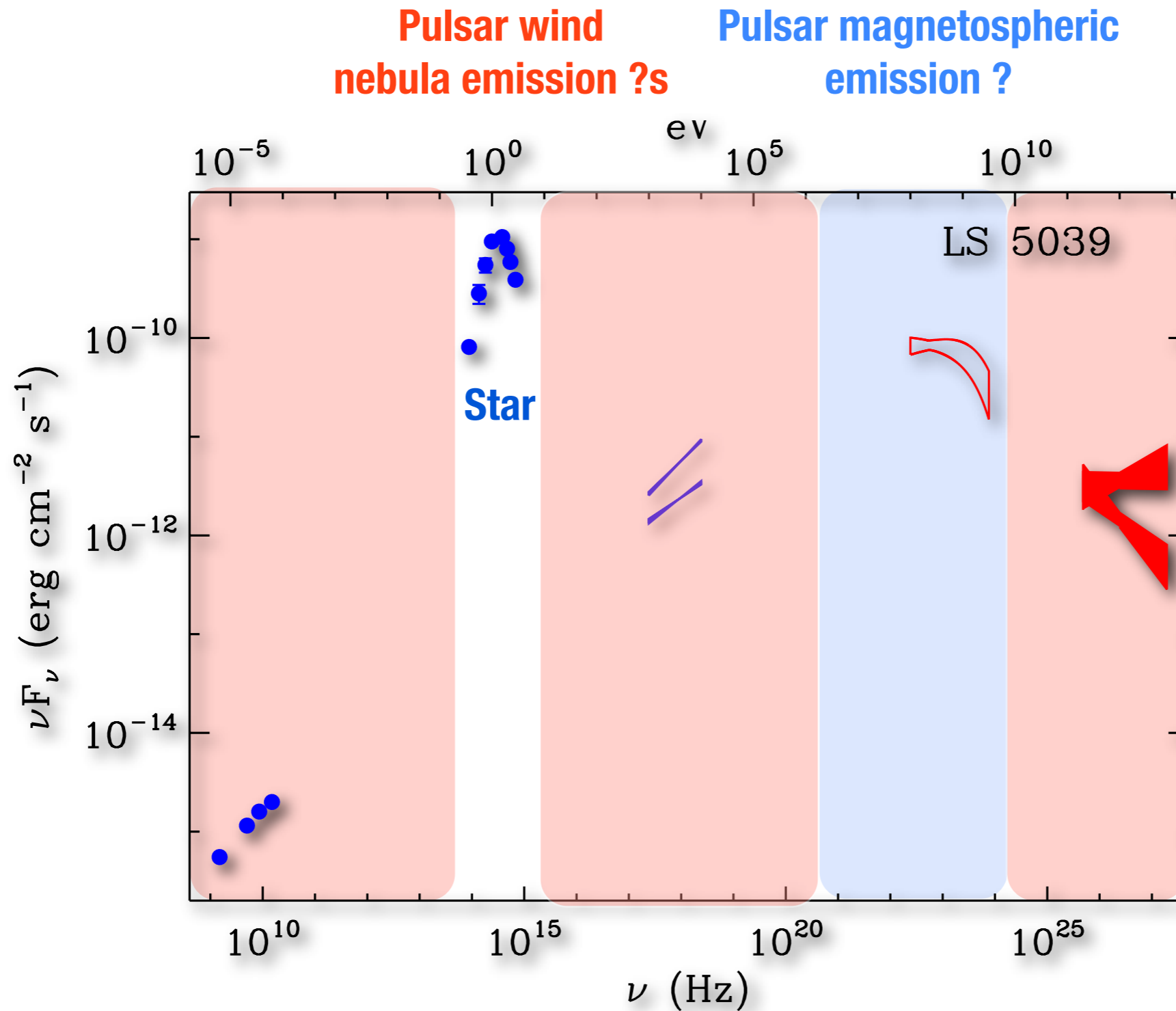
Bucciantini et al. 2005

Collimation depends on $\eta = \frac{\dot{E}_p/c}{\dot{M}_* v_*}$

$\dot{M}_* > 10^{-8} v_{1000}^{-1} \dot{E}_{36} M_\odot \text{ yr}^{-1}$ for $\eta < 1$, fast wind

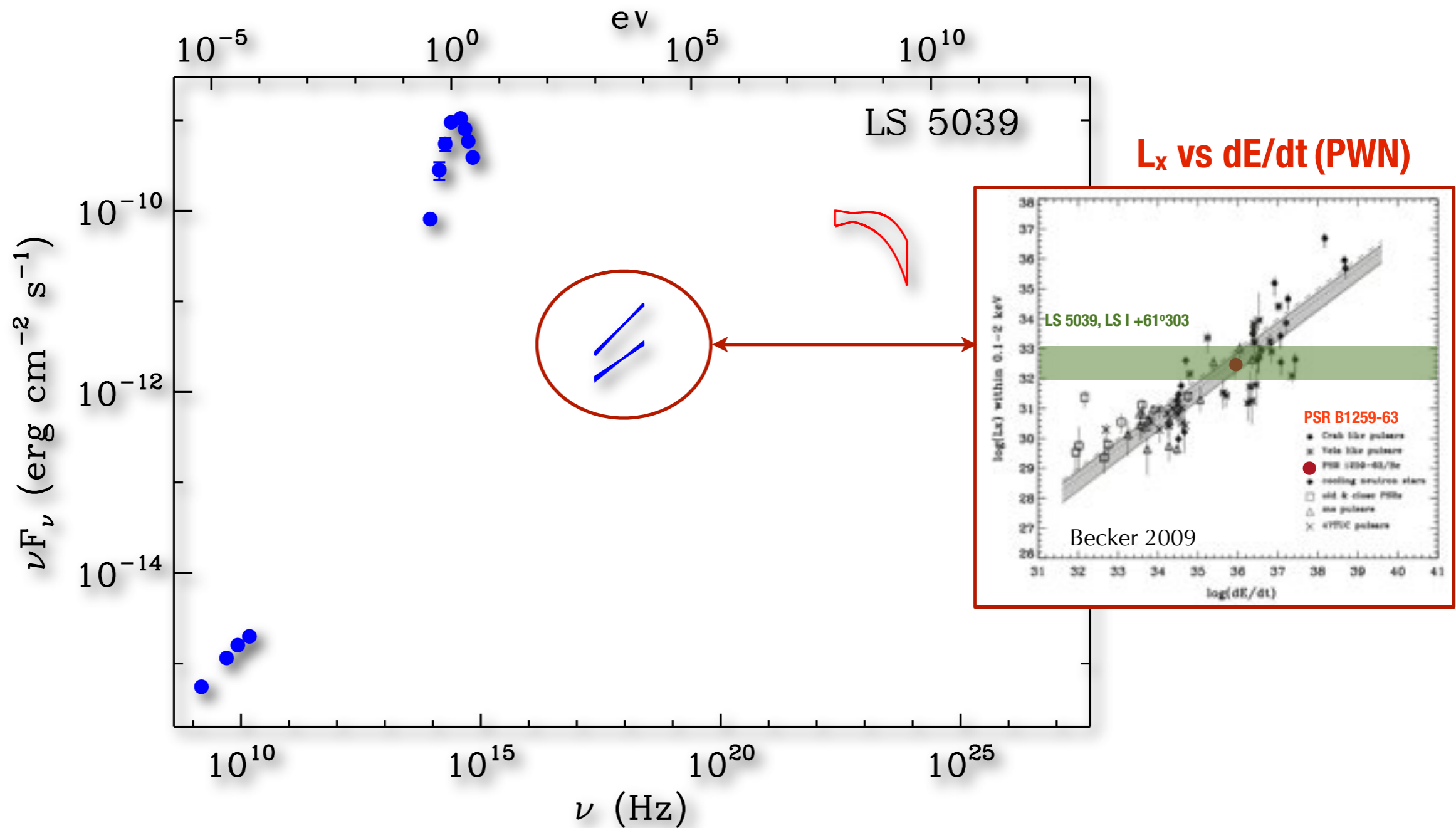


Emission from system



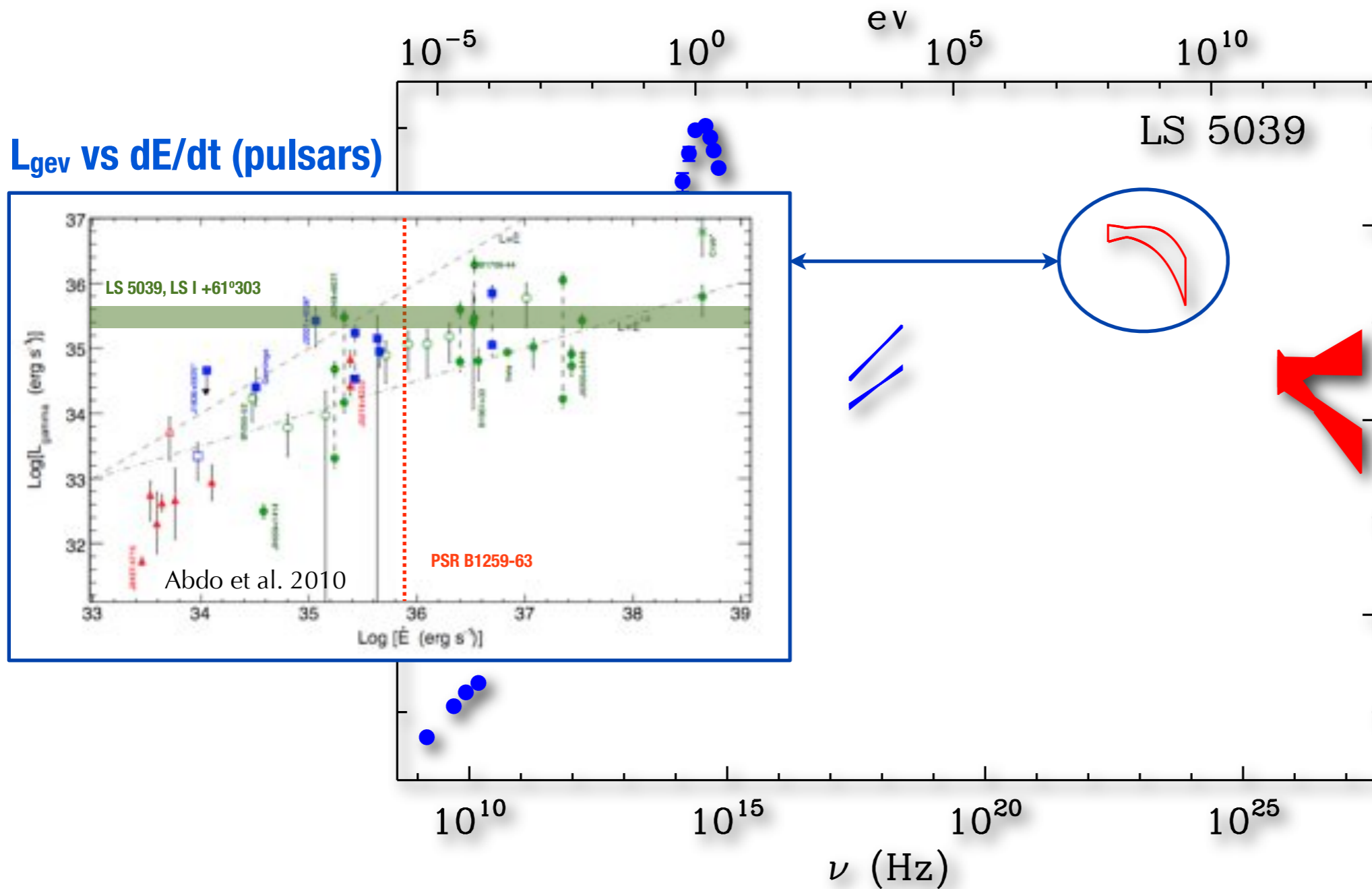
Emission from system

X-ray spectral shape and luminosity similar to young pulsar with $dE/dt \sim 10^{36}$ erg/s



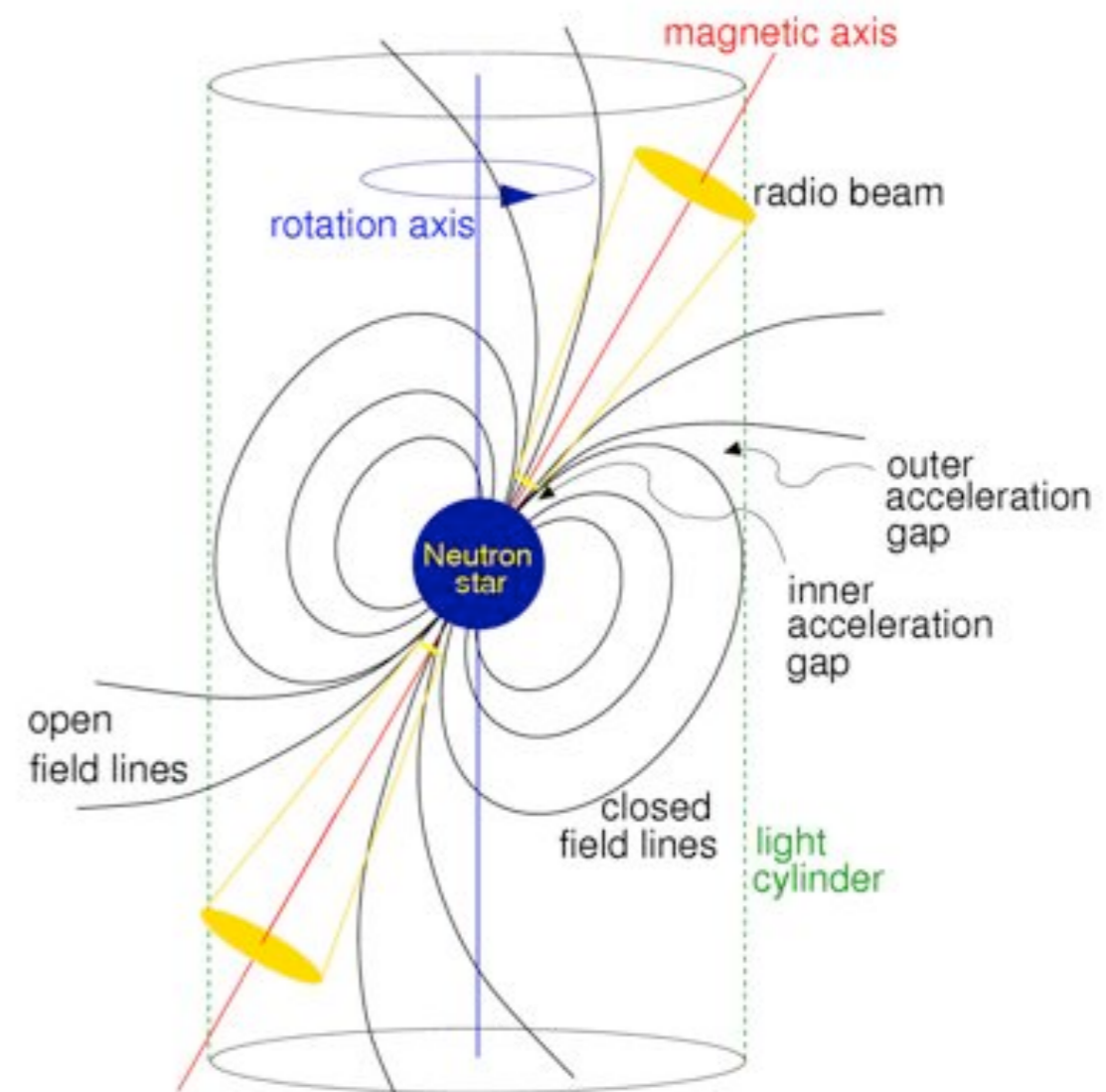
Emission from system

GeV spectral shape and luminosity similar to young pulsar with $dE/dt \sim 10^{36}$ erg/s



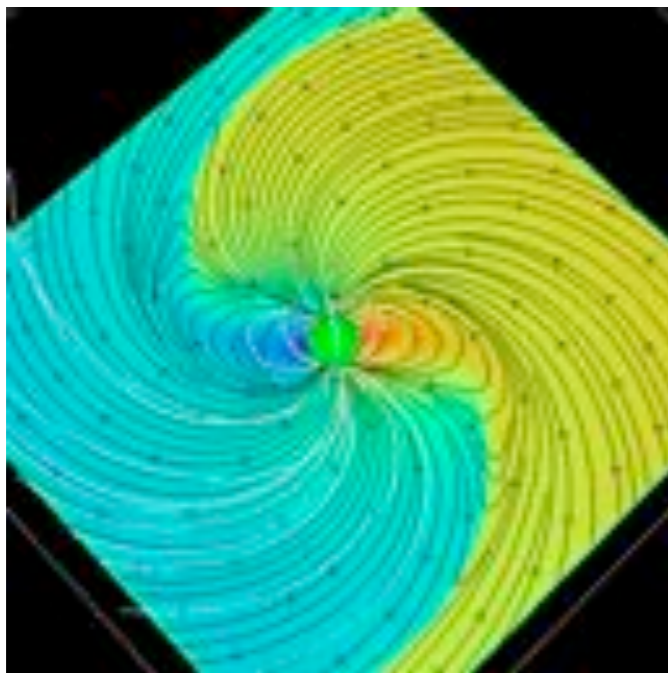
GeV emission

- Fermi finds GeV emission is **modulated** on orbit.
- GeV pulsar emission usually attributed to curvature radiation in outer gap
 - no modulation expected

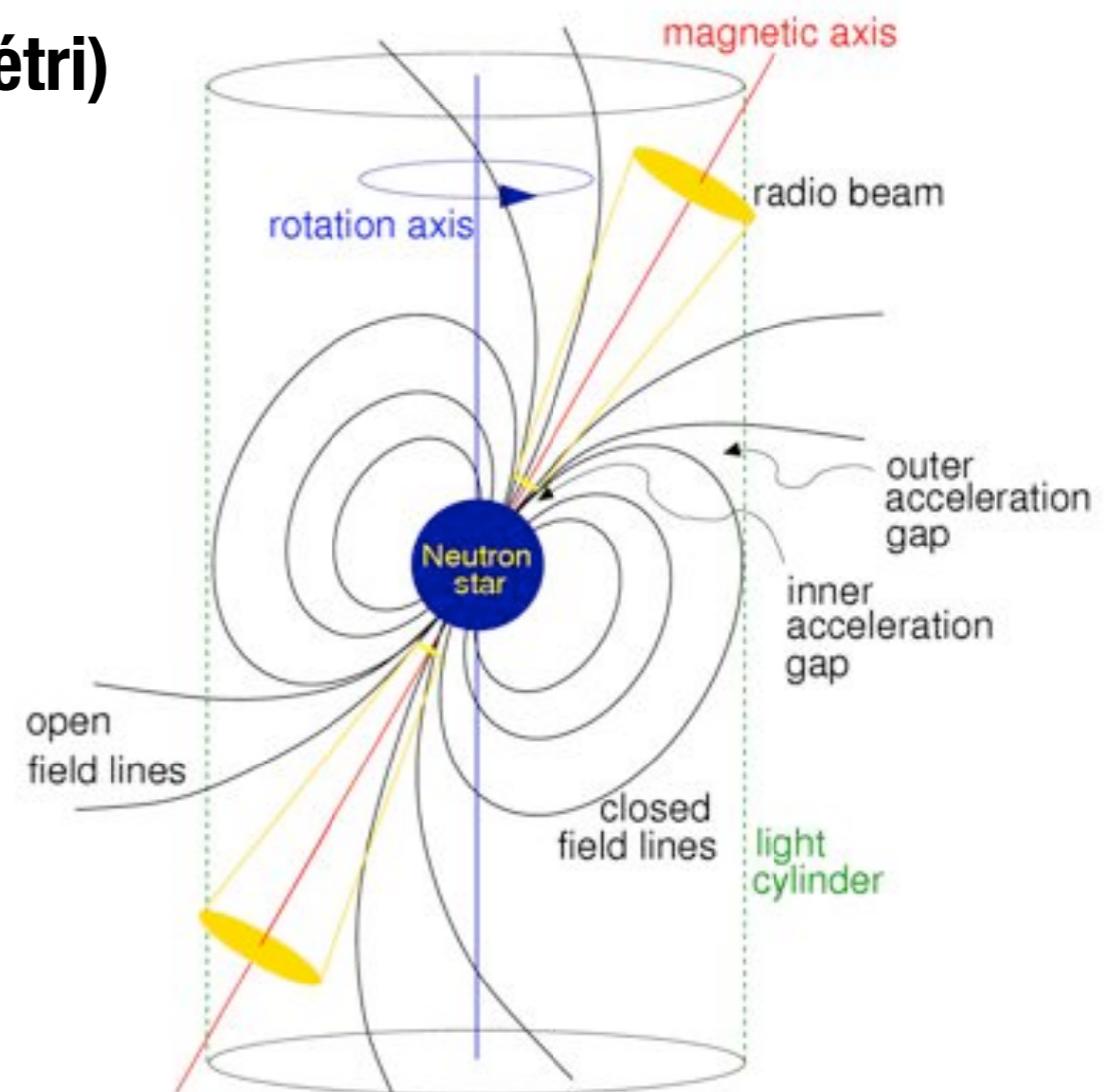


GeV emission

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- In **striped wind**, GeV emission from IC (→ J. Pétri)
 - **orbital modulation (stellar photons)**



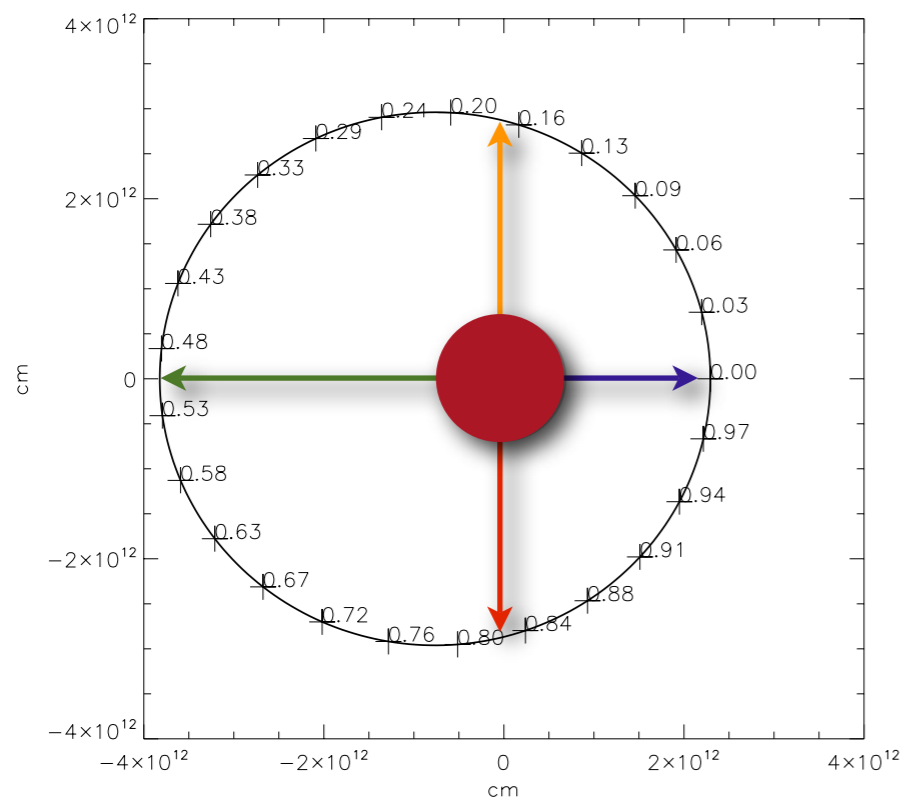
Spitkovsky



Orbital modulations

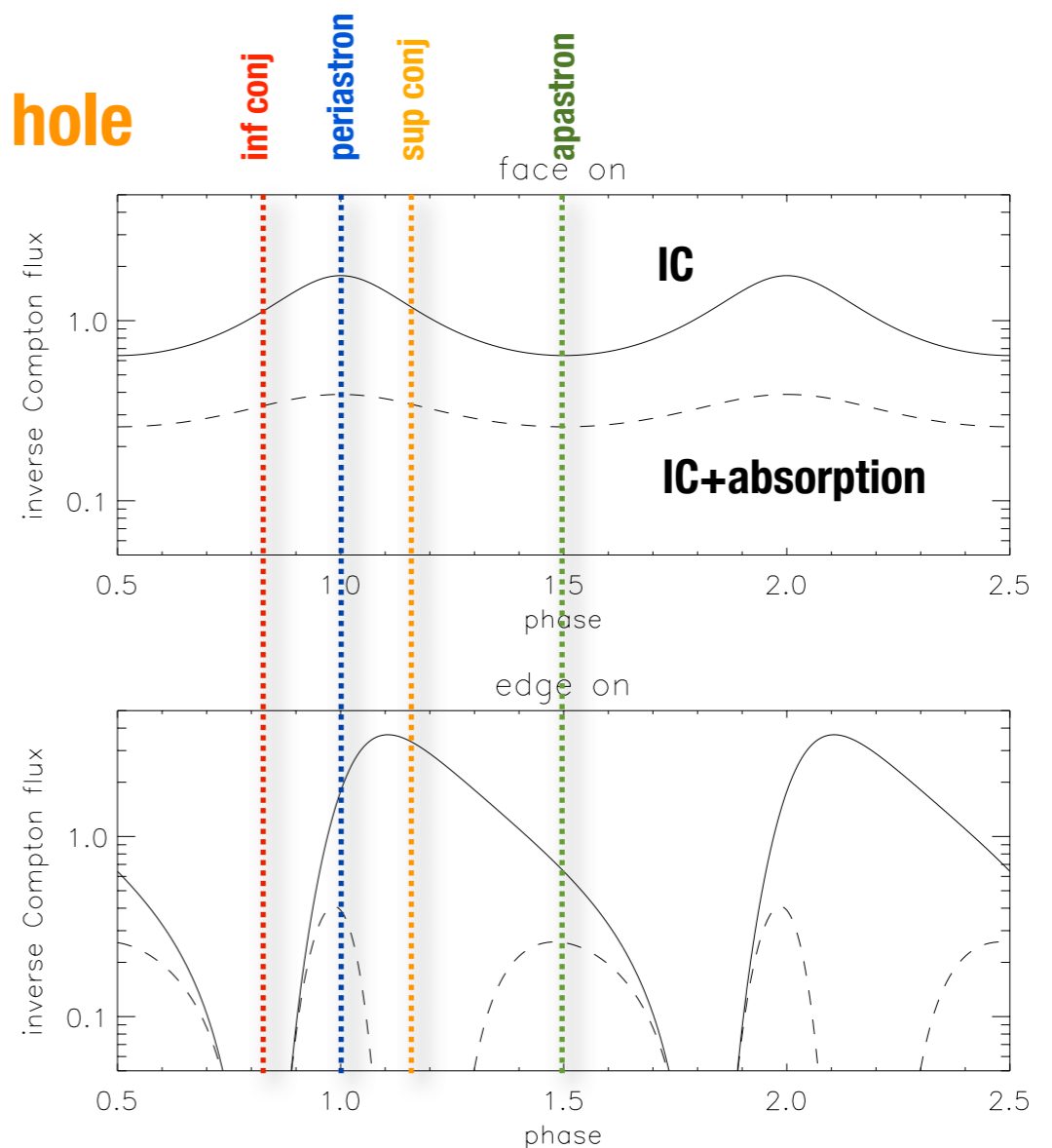
- Leptonic, usual processes: synchrotron, inverse Compton, pairs
- very high energy electrons in vicinity of pulsar
- LS 5039 and LS I+61°303:

if pulsar then higher inclination than black hole



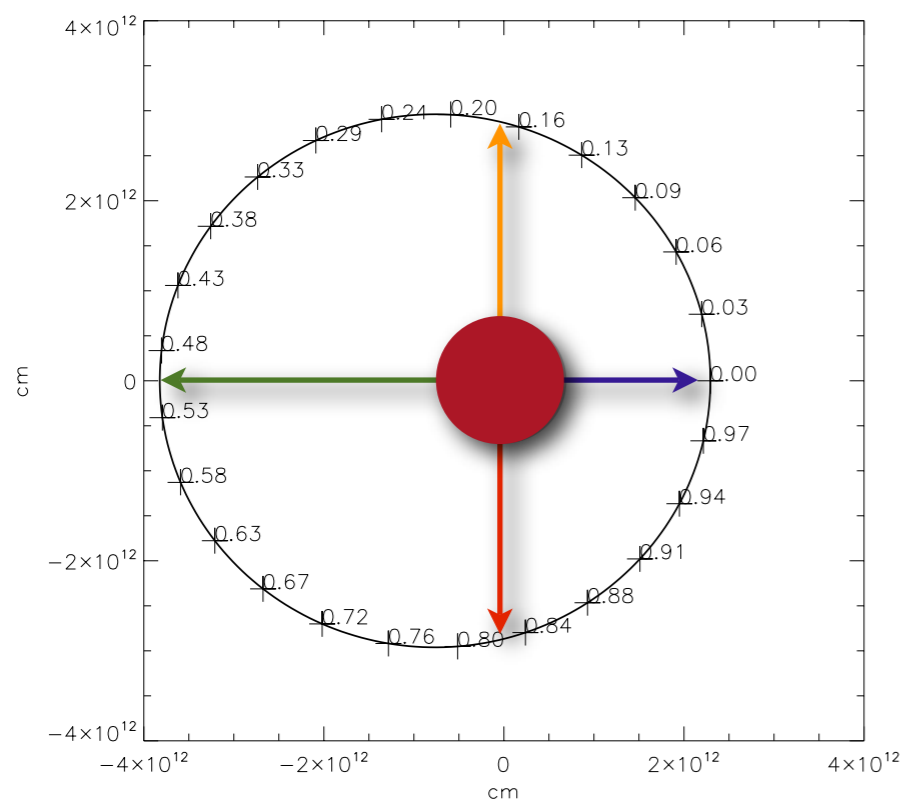
face on

edge on



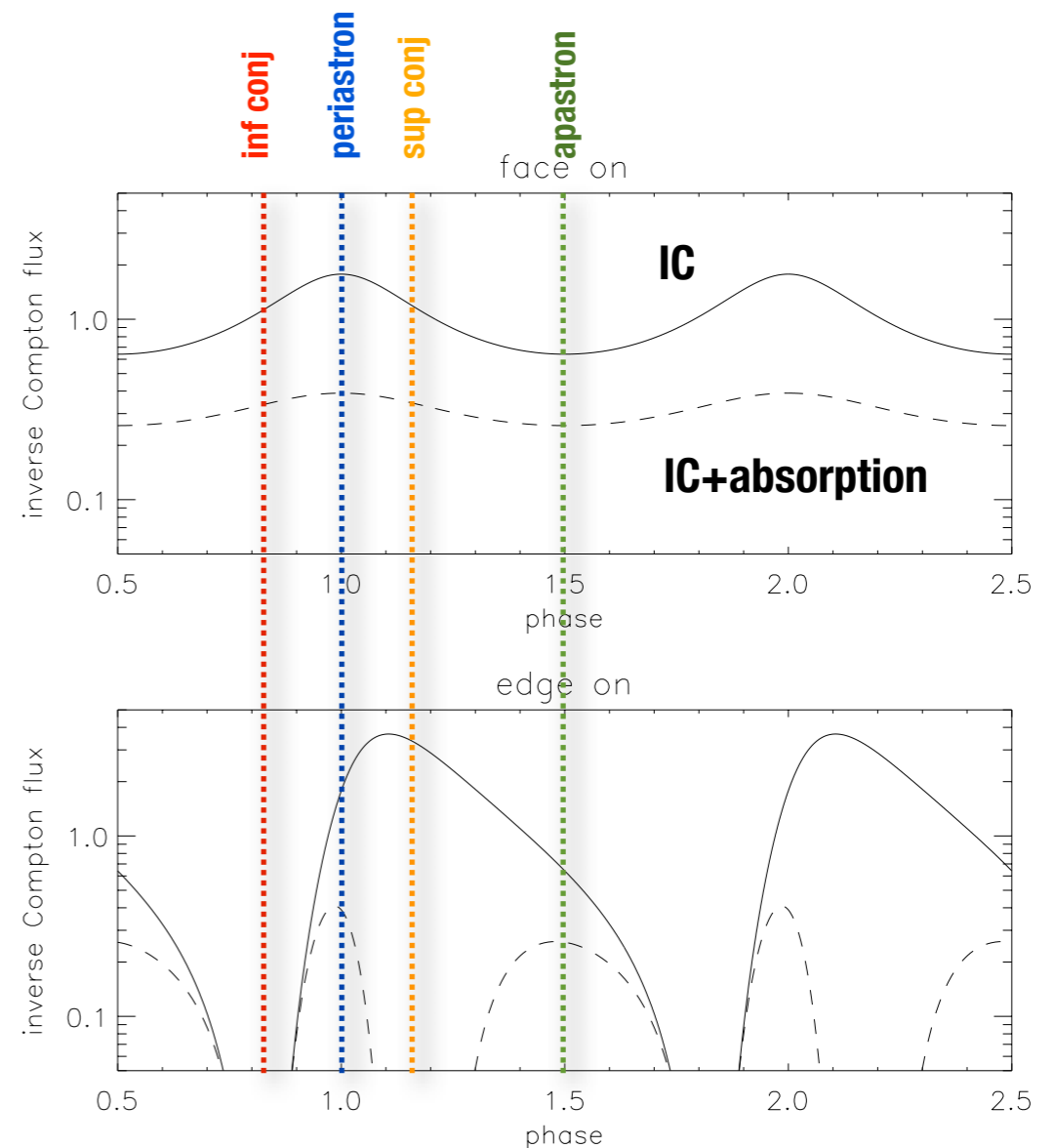
Orbital modulations

- **LS 5039 and LS I+61°303: if pulsar then higher inclination than black hole**
 - **conjunctions important**
 - **larger amplitude modulation**
 - **strong absorption at sup. conjunction**



face on

edge on

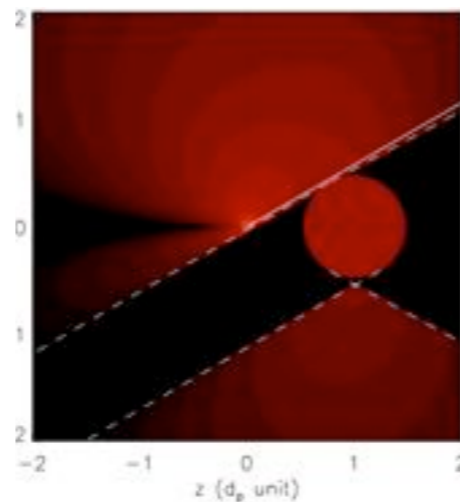
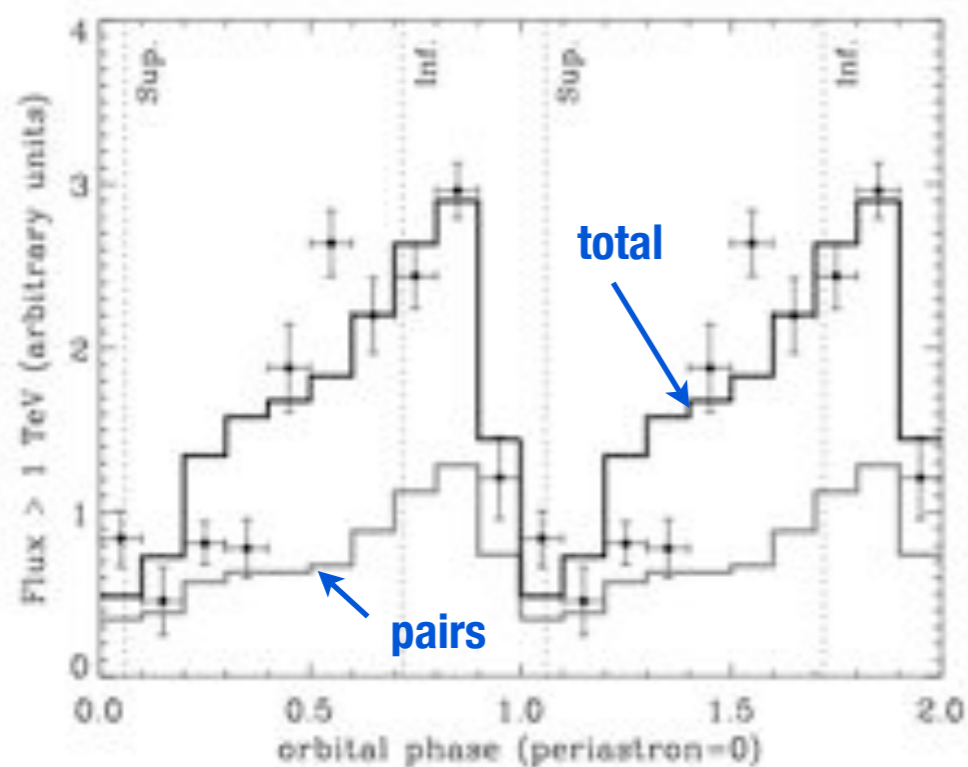


Pair cascade LS 5039

- Significant pair cascade emission to account for HESS detection at sup conj.
- Limits magnetic field $\langle B \rangle \sim$ a few G, compatible with pulsar.

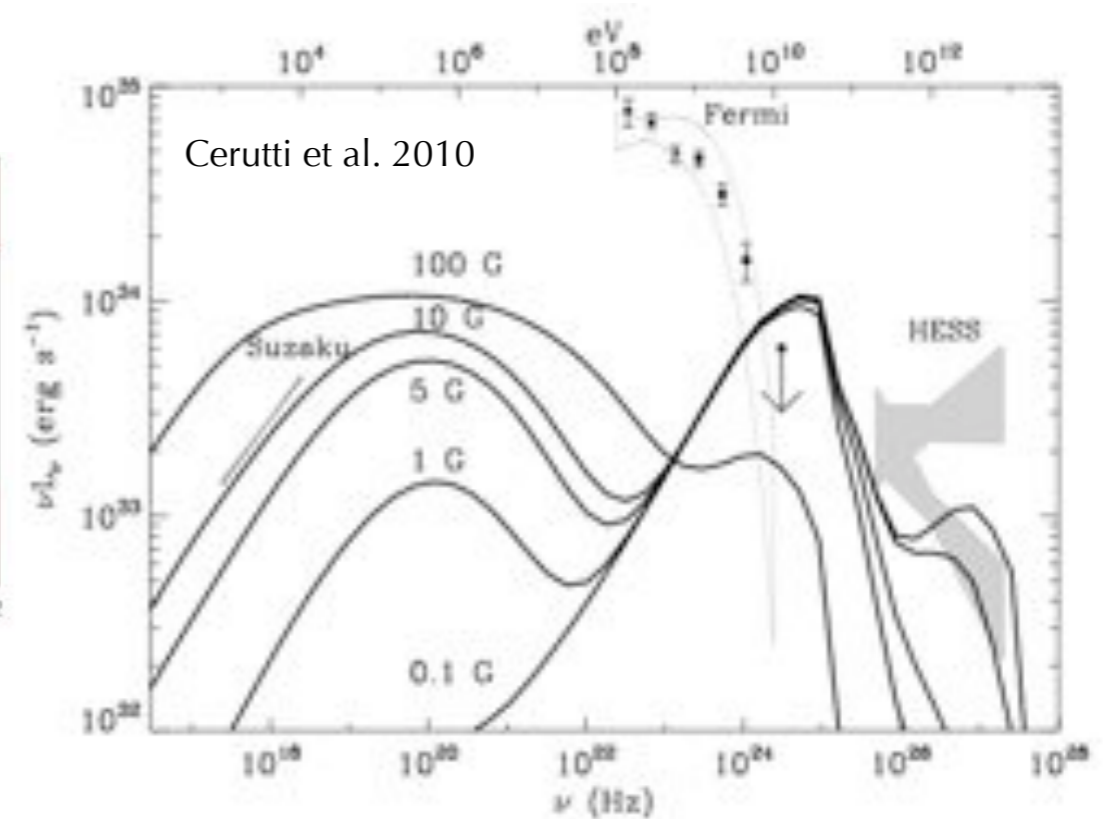
VHE lightcurve & model (3d monte-carlo)

Cerutti et al. 2010



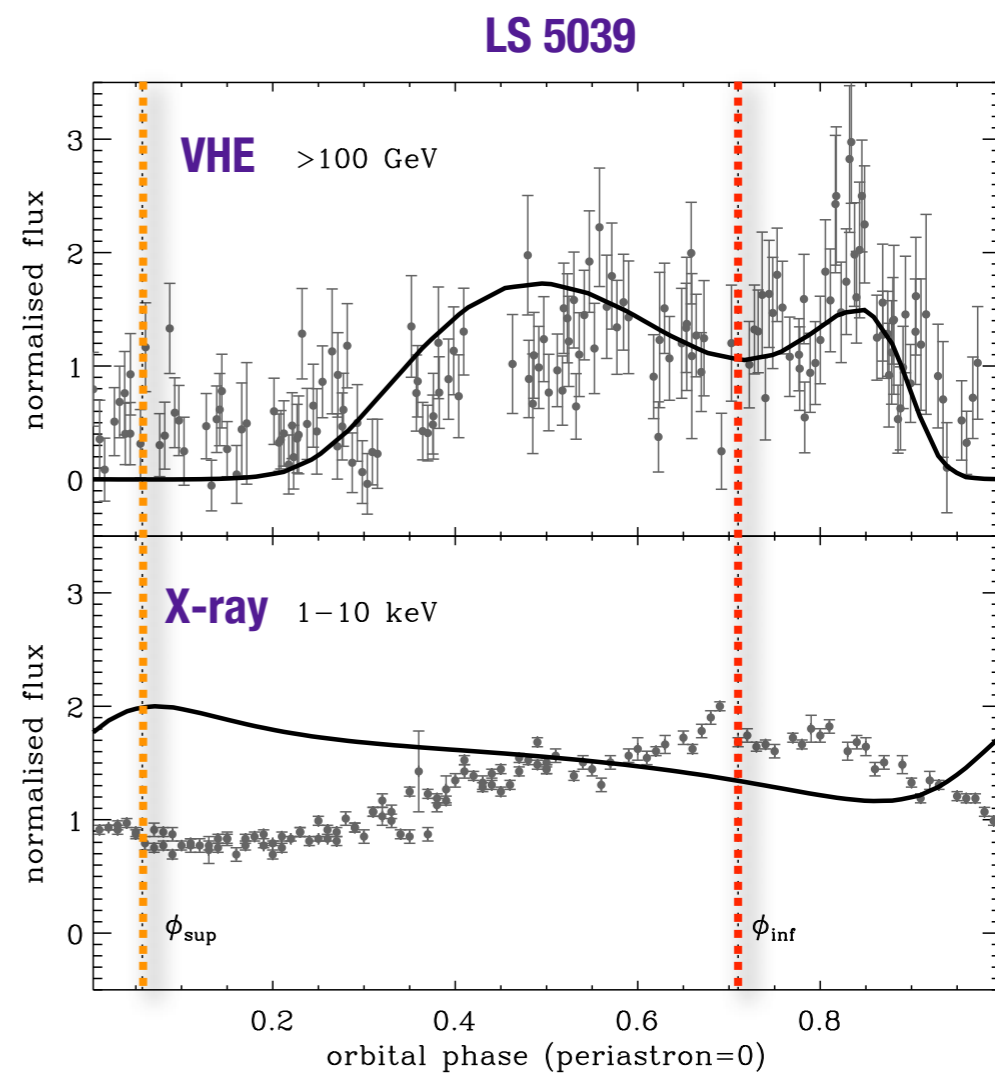
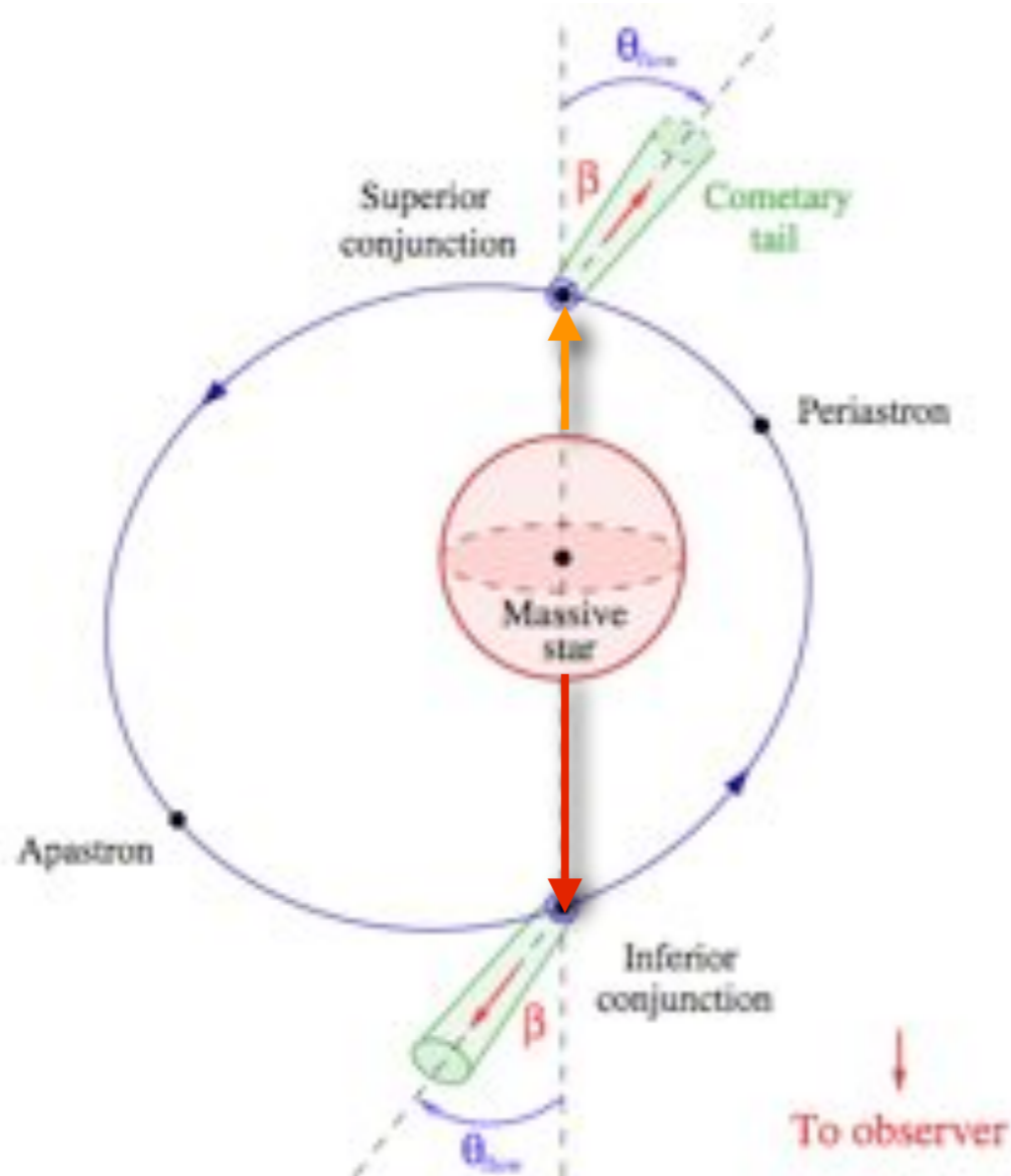
cascade emission (only) @ sup. conjunction

Cerutti et al. 2010



Modulated Doppler boost

- Shocked pulsar wind mildly relativistic, orientation changes along orbit
- Doppler boost changes synchrotron and IC lightcurve

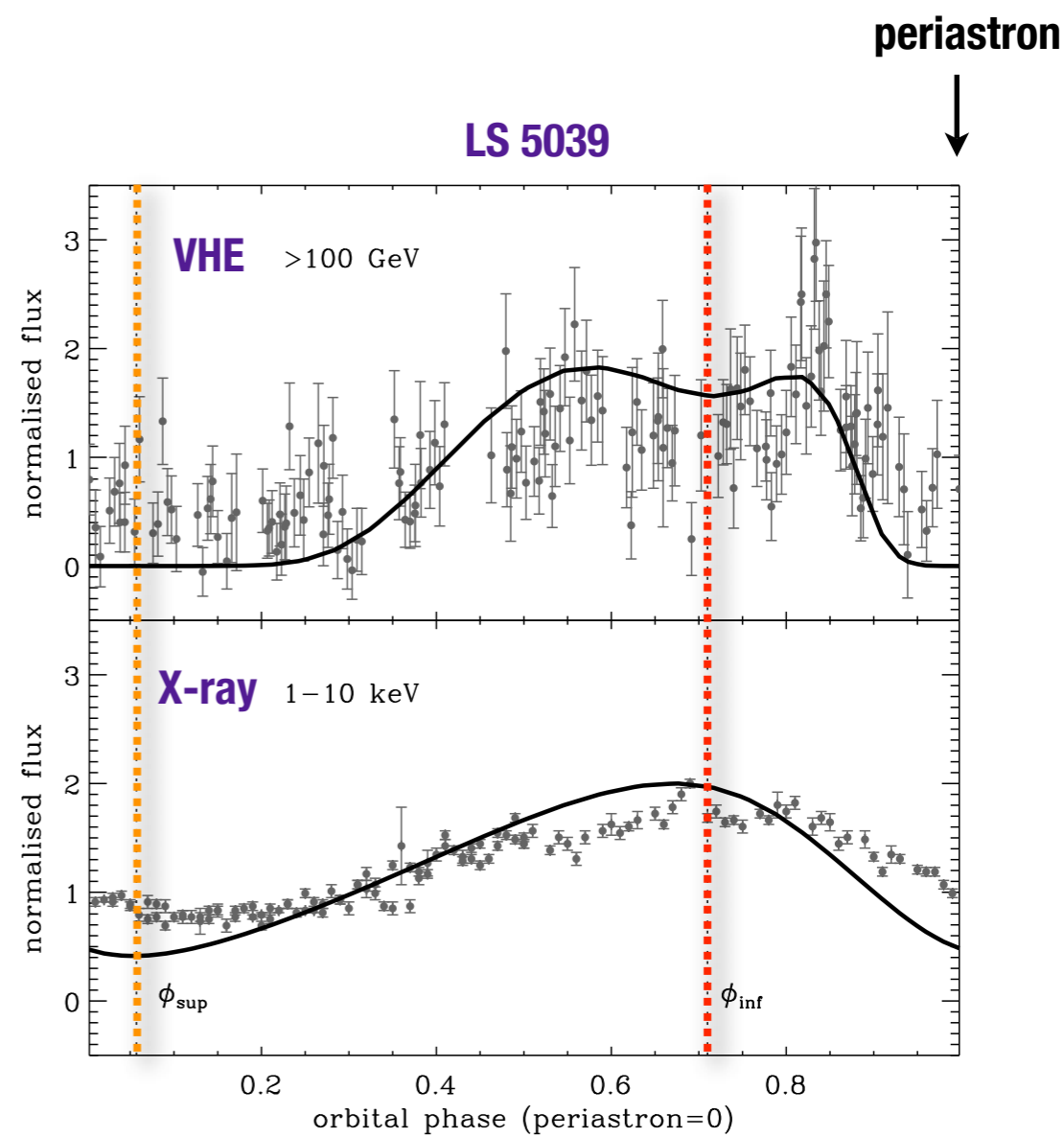
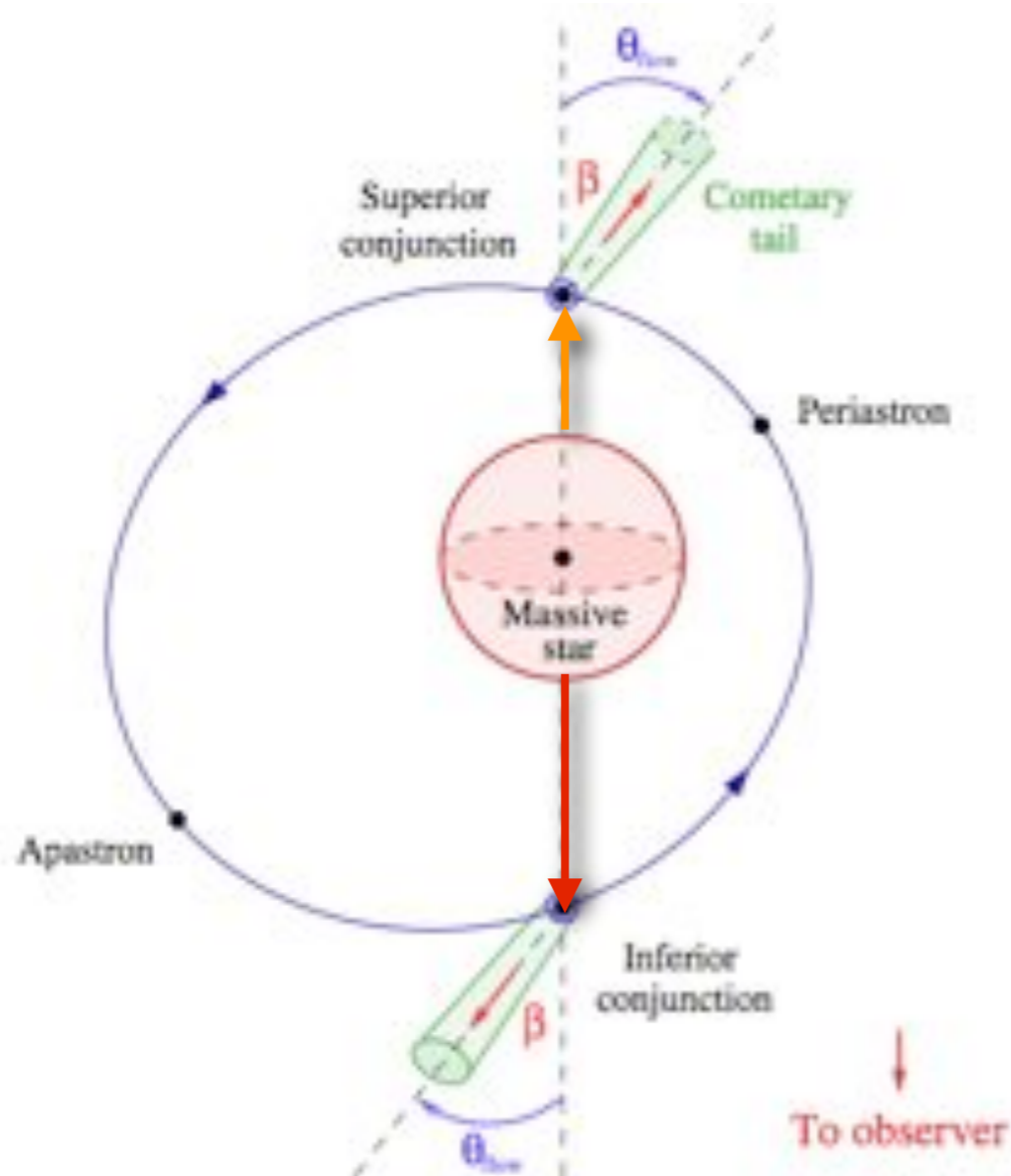


GD et al. 2010

(c/3 with Kennel Coroniti)

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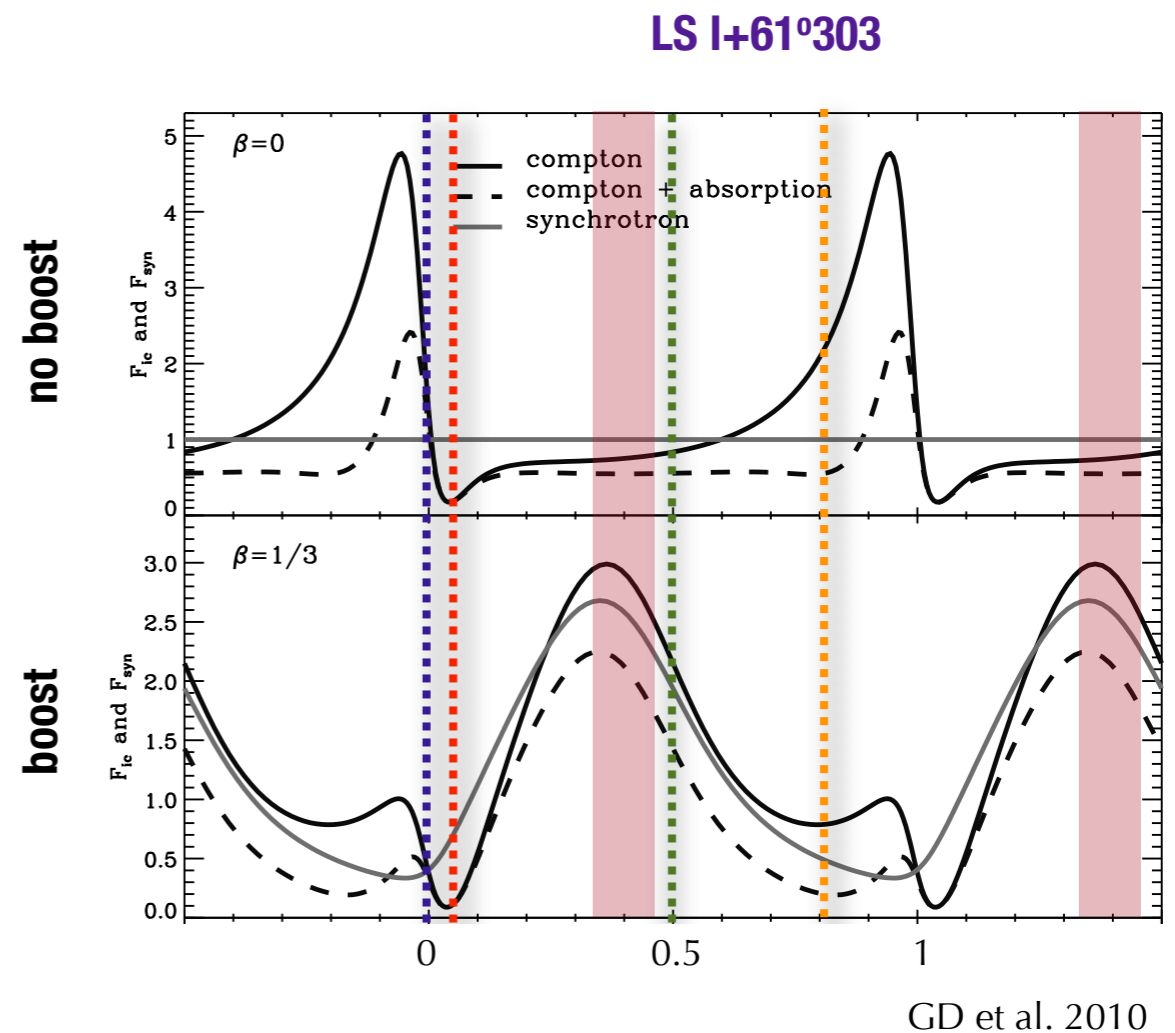
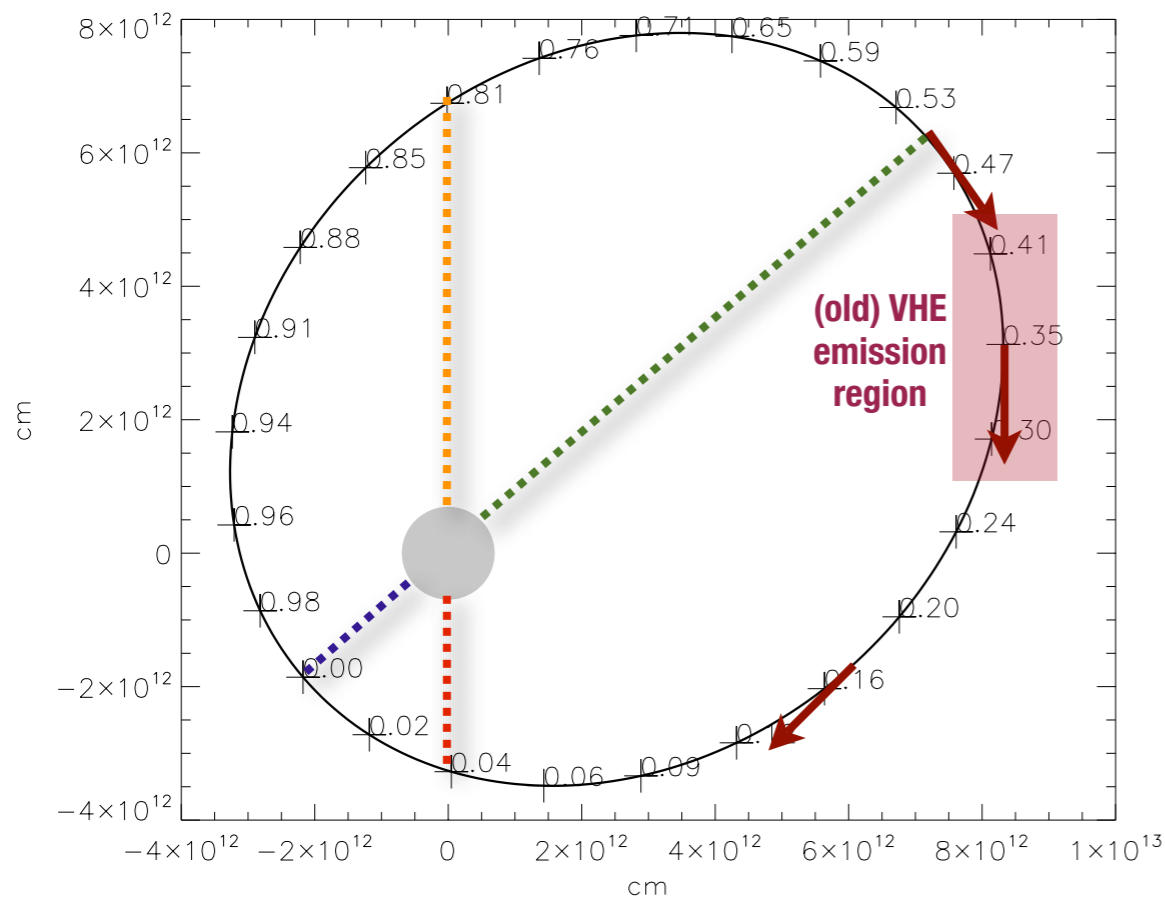


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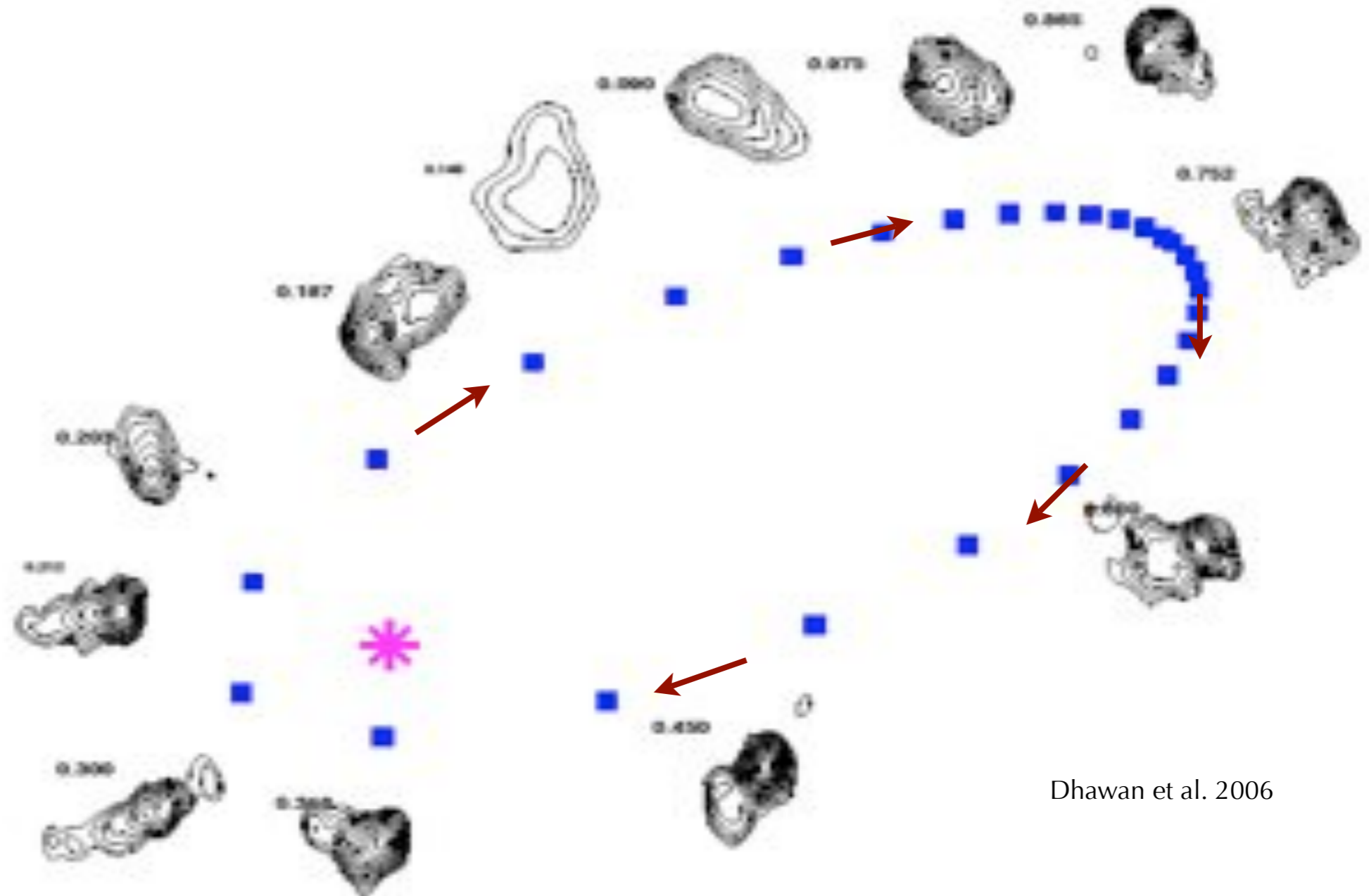
- Shocked pulsar wind mildly relativistic, orientation changes along orbit
- Doppler boost changes synchrotron and IC lightcurve
- **LS I+61°303: VHE peak linked to variations in flow direction or velocity ?**



(c/3 with Kennel Coroniti)

LS I+61°303 radio morphology

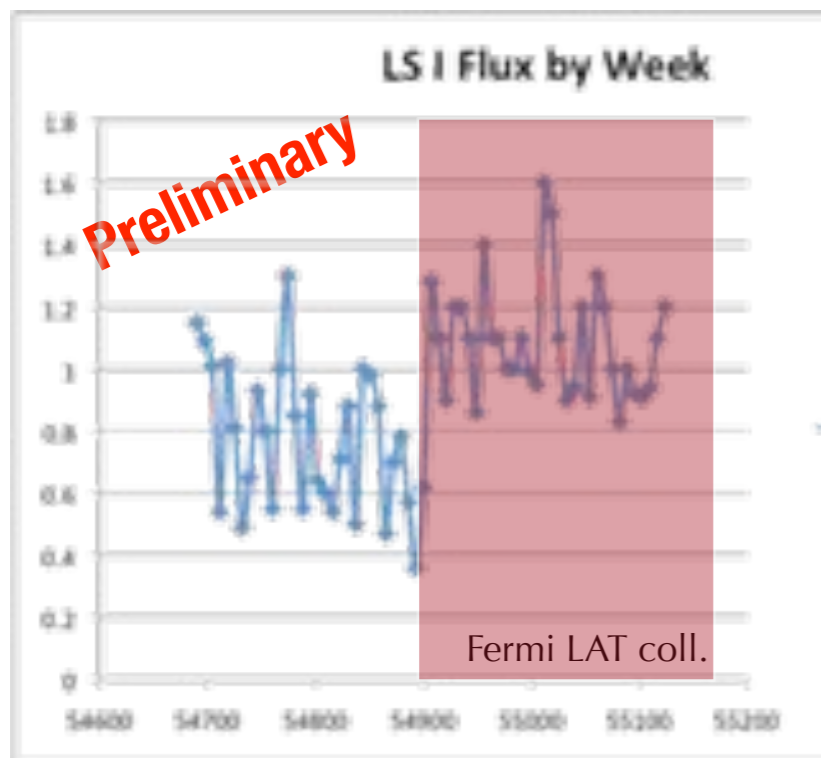
- Radio VLBI observations calls for PWN
- Collimation ? stability ? Be disc ? radio outbursts ? clumping ? mixing ?
- Compare to relativistic MHD simulations



Dhawan et al. 2006

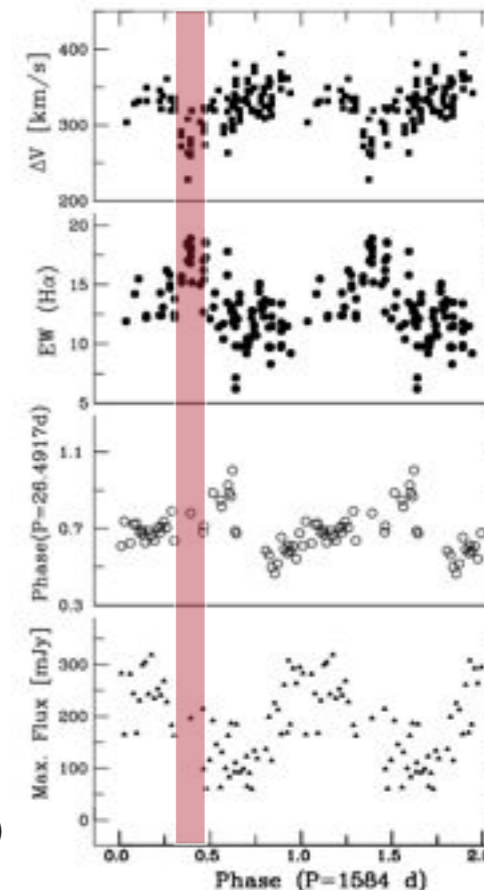
Non-orbital variability

- long-term variability linked to stellar wind ?

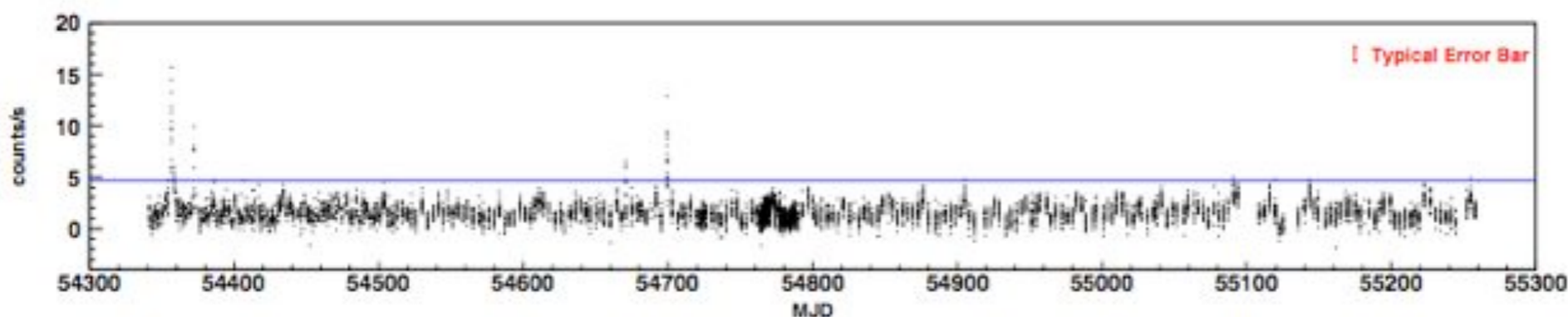


HE γ -ray

Zamanov et al. 1999, long ~ 4 year period (Be disc precession?)



- shorter term variability: processes at termination shock ? (e.g. Crab flare)

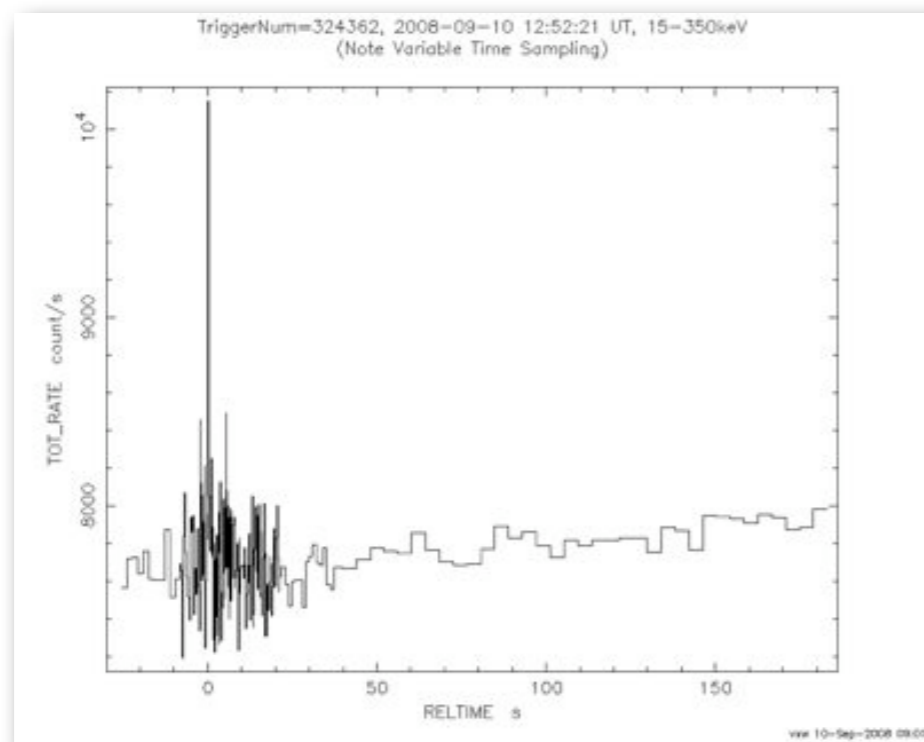


Torres et al. 2010

LS I+61°303: magnetar burst ?

- SGR/AXP short duration burst within 2' of LS I+61°303

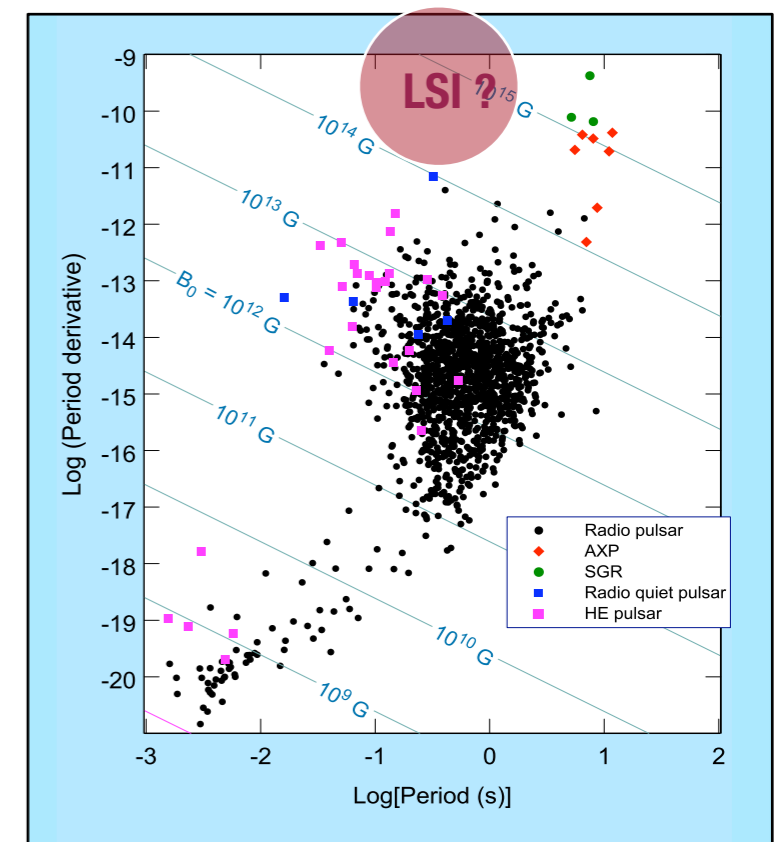
GCN 8215



Burst lasted 230ms, $E=10^{37}$ erg

blackbody $kT=7.5$ keV, $R=100$ m

- Magnetar-like activity in HMXB ?



Conclusions

- **Gamma-ray binaries fit within pulsar & PWN population**
- **Orbital modulations expected due to usual processes (IC, pairs)**
 - stronger γ -ray modulations when inclination is higher
 - significant pair cascade emission at sup. conjunction in LS 5039
 - magnetic field in γ -ray emission zone ~ 1 G in LS 5039
- **Pulsar wind nebula flow**
 - additional modulation due to relativistic boost in PWN, explains LSI ?
 - **need numerical simulations**
- **Non-orbital variability**
 - stellar wind, need input from **optical observations**
 - fast variability in pulsars