Gamma-ray binaries as pulsars

spectral & variability behaviour

Guillaume Dubus

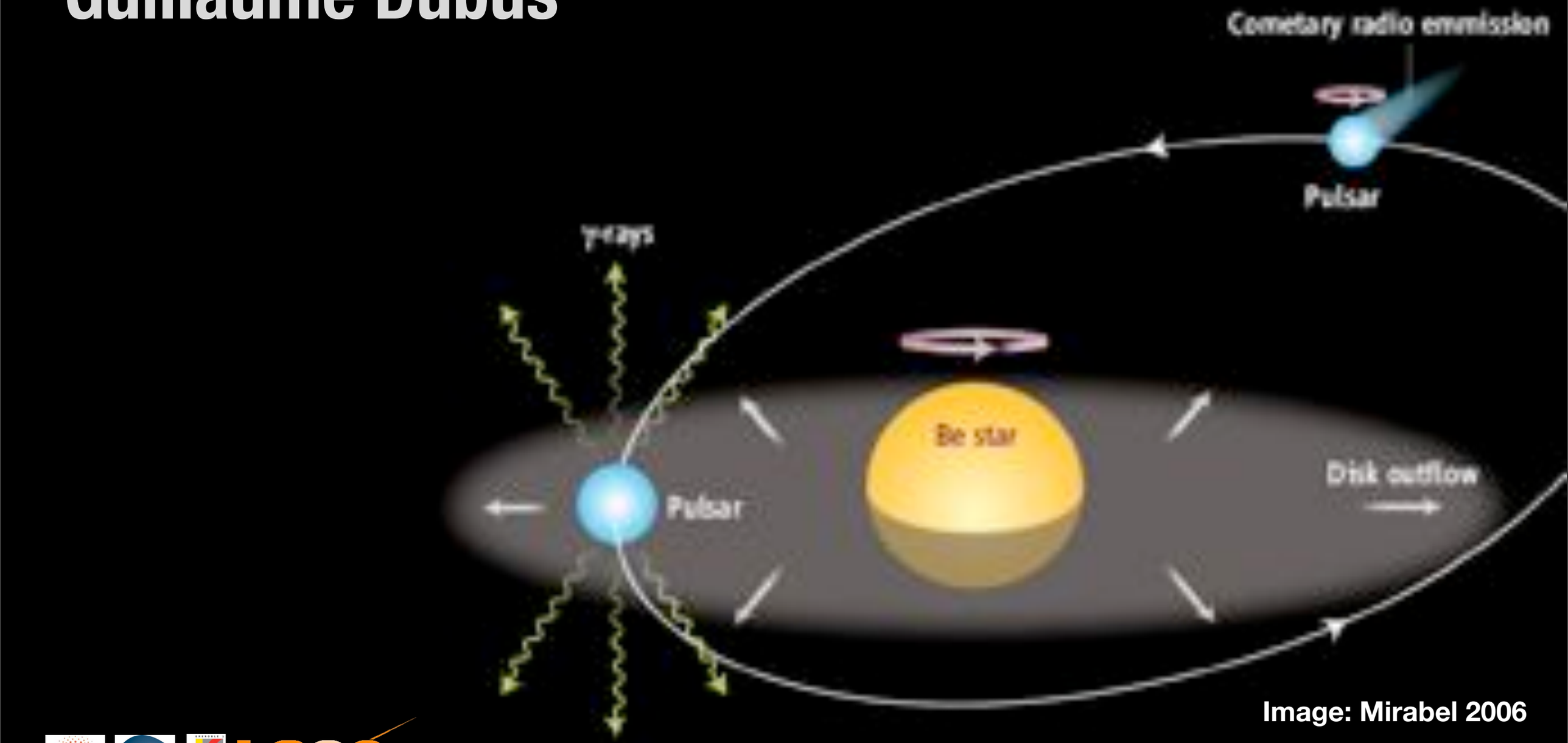


Image: Mirabel 2006

Laboratoire d'Astrophysique de Grenoble UMR 5571 UJF / CNRS

Pulsars & massive stars

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

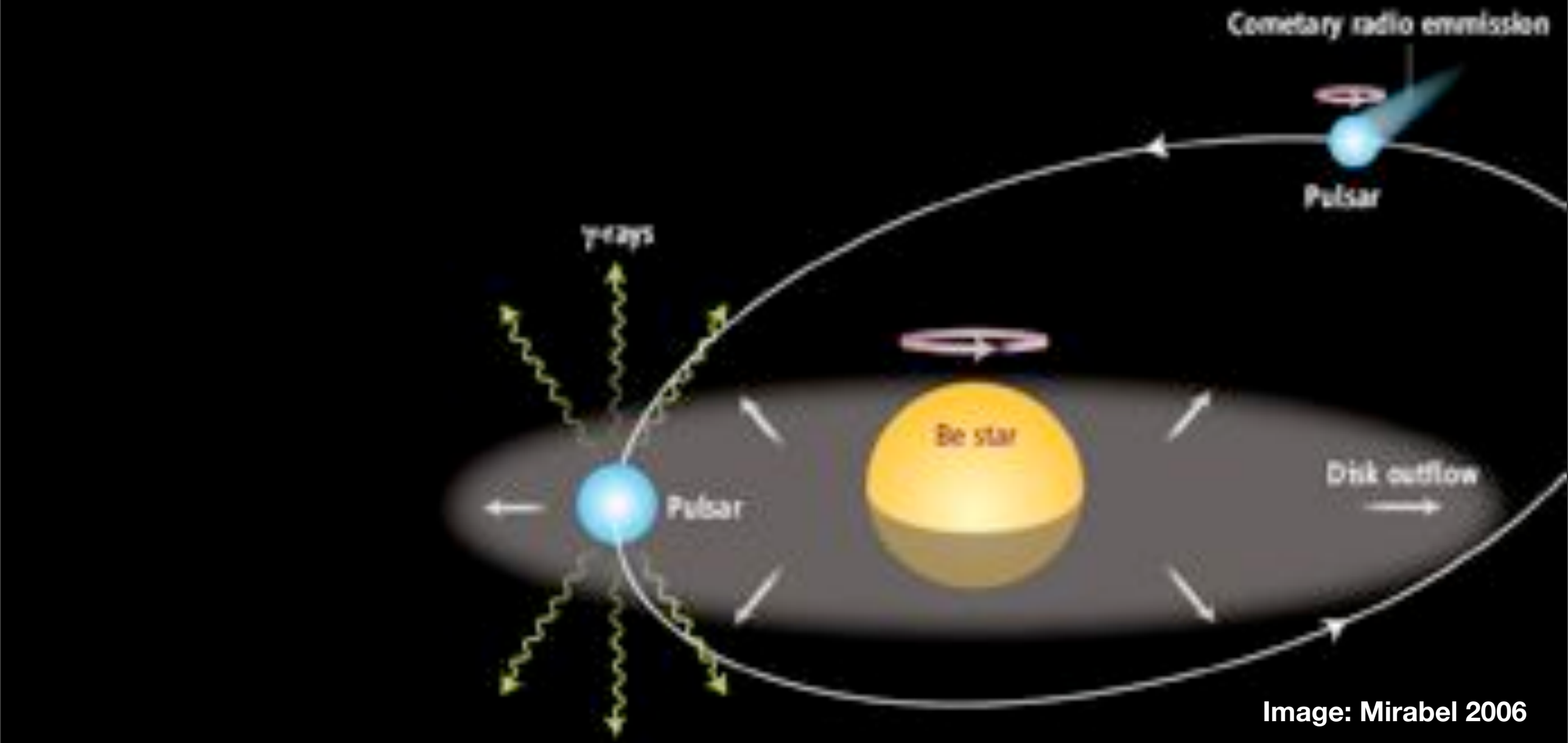


Image: Mirabel 2006

Pulsars & massive stars

- Young pulsars, magnetic fields ~ 10^{12} G, ages < 1 Myr
- with massive companions are seen...

pulsar catalog

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

Pulsars & massive stars

- Young pulsars, magnetic fields ~ 10^{12} G, ages < 1 Myr
- with massive companions are seen...

pulsar catalog

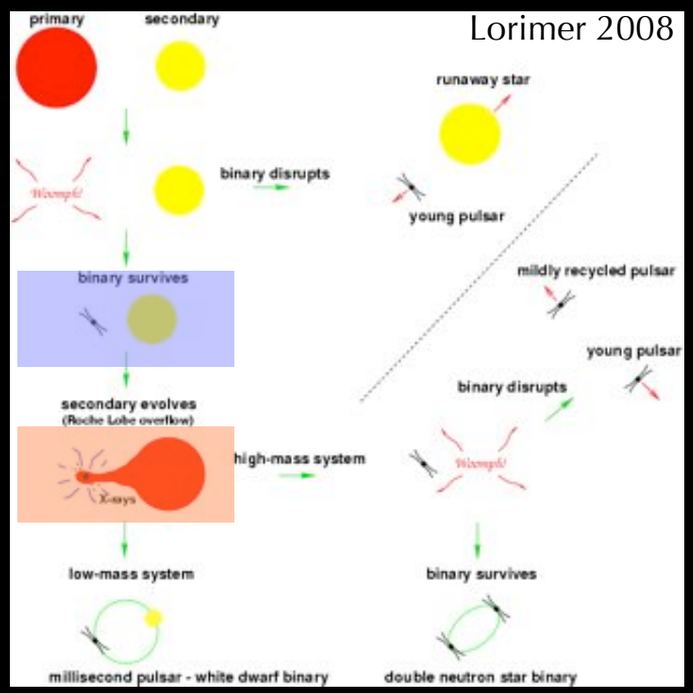
	pulse (ms)	P_{orb}	companion	dE/dt (erg/s)
PSR B1259-63	0.048	1237d	Be	8 10^{35}
PSR J1740-3052	0.570	231d	> 11 $M_\odot$	5 10^{33}
PSR J1638-4725	0.764	1941d	> 6 $M_\odot$	4 10^{32}
PSR J0045-7319	0.926	51d	> 4 $M_\odot$	2 10^{32}

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

pulsar + massive star

↓

accreting HMXB



Pulsars & massive stars

- Young pulsars, magnetic fields ~ 10^{12} G, ages < 1 Myr
- with massive companions are seen...

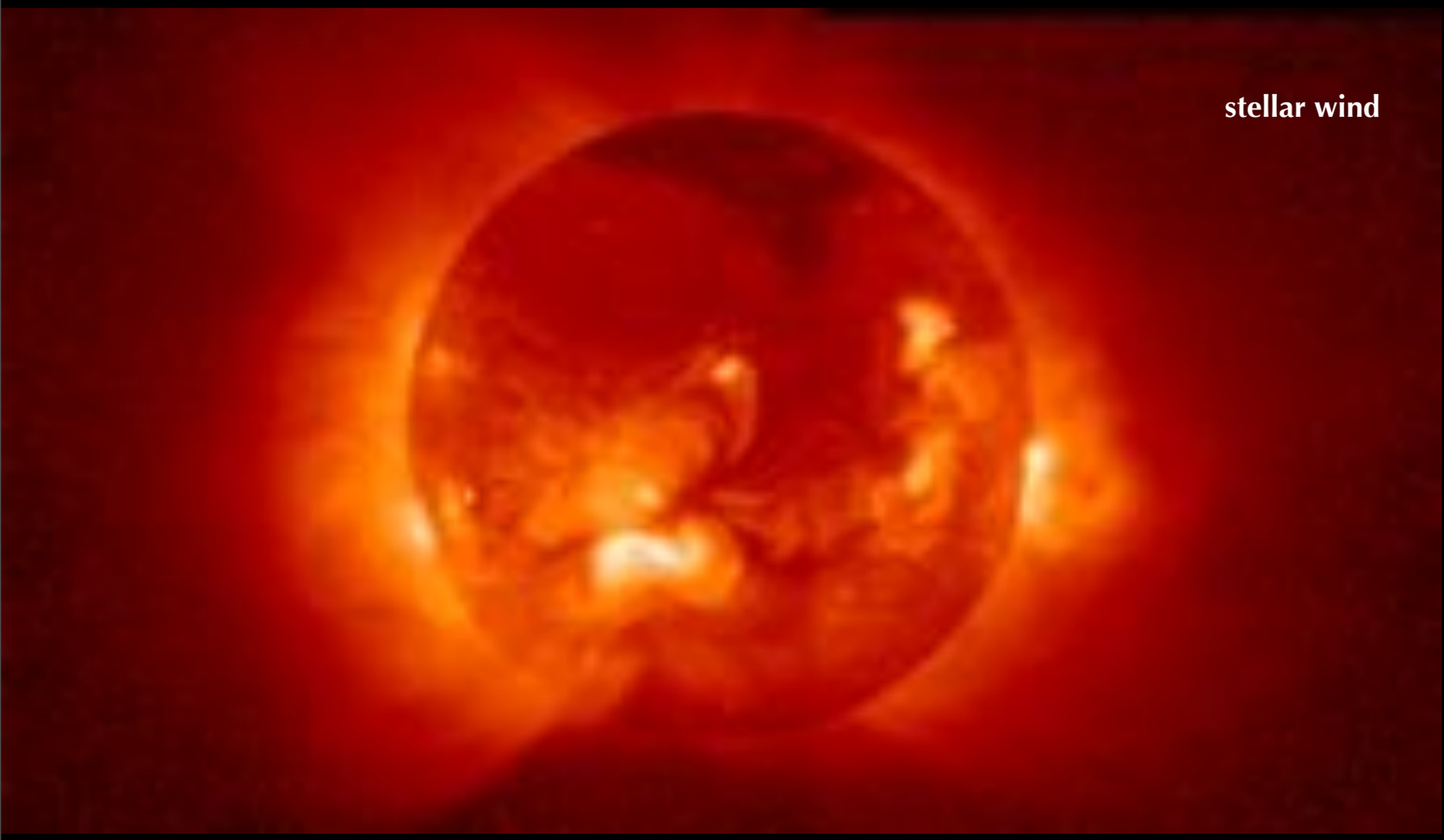
pulsar catalog

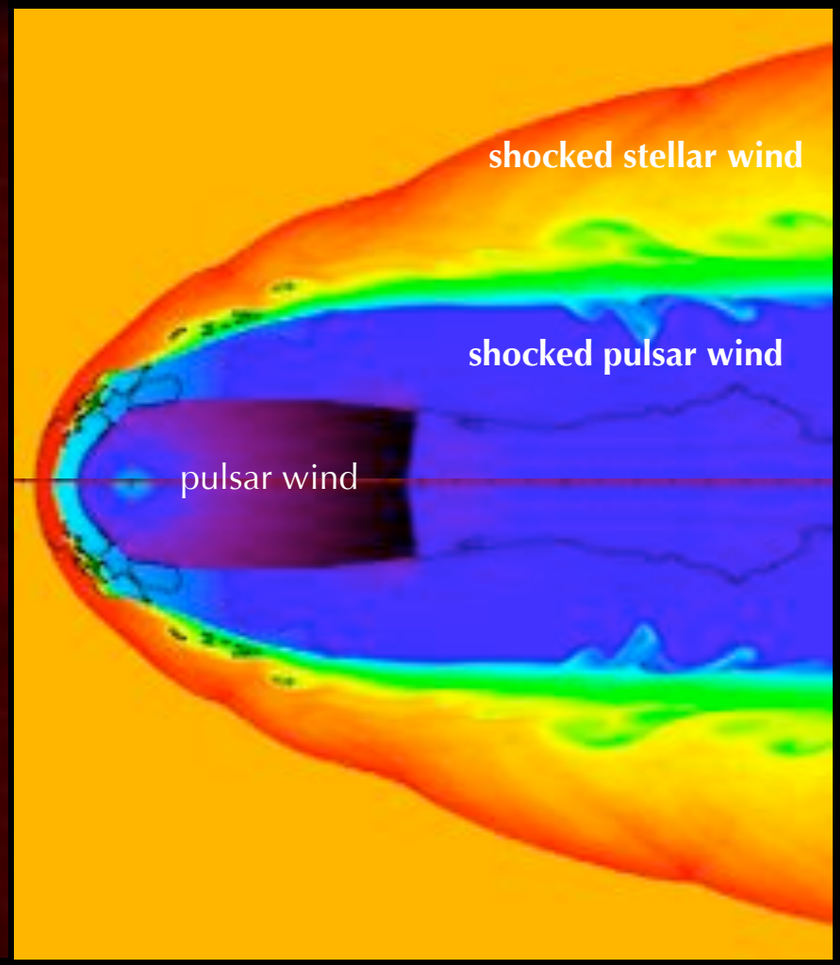
	pulse (ms)	P_{orb}	companion	dE/dt (erg/s)
PSR B1259-63	0.048	1237d	Be	8 10^{35}
PSR J1740-3052	0.570	231d	> 11 $M_\odot$	5 10^{33}
PSR J1638-4725	0.764	1941d	> 6 $M_\odot$	4 10^{32}
PSR J0045-7319	0.926	51d	> 4 $M_\odot$	2 10^{32}

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

- (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





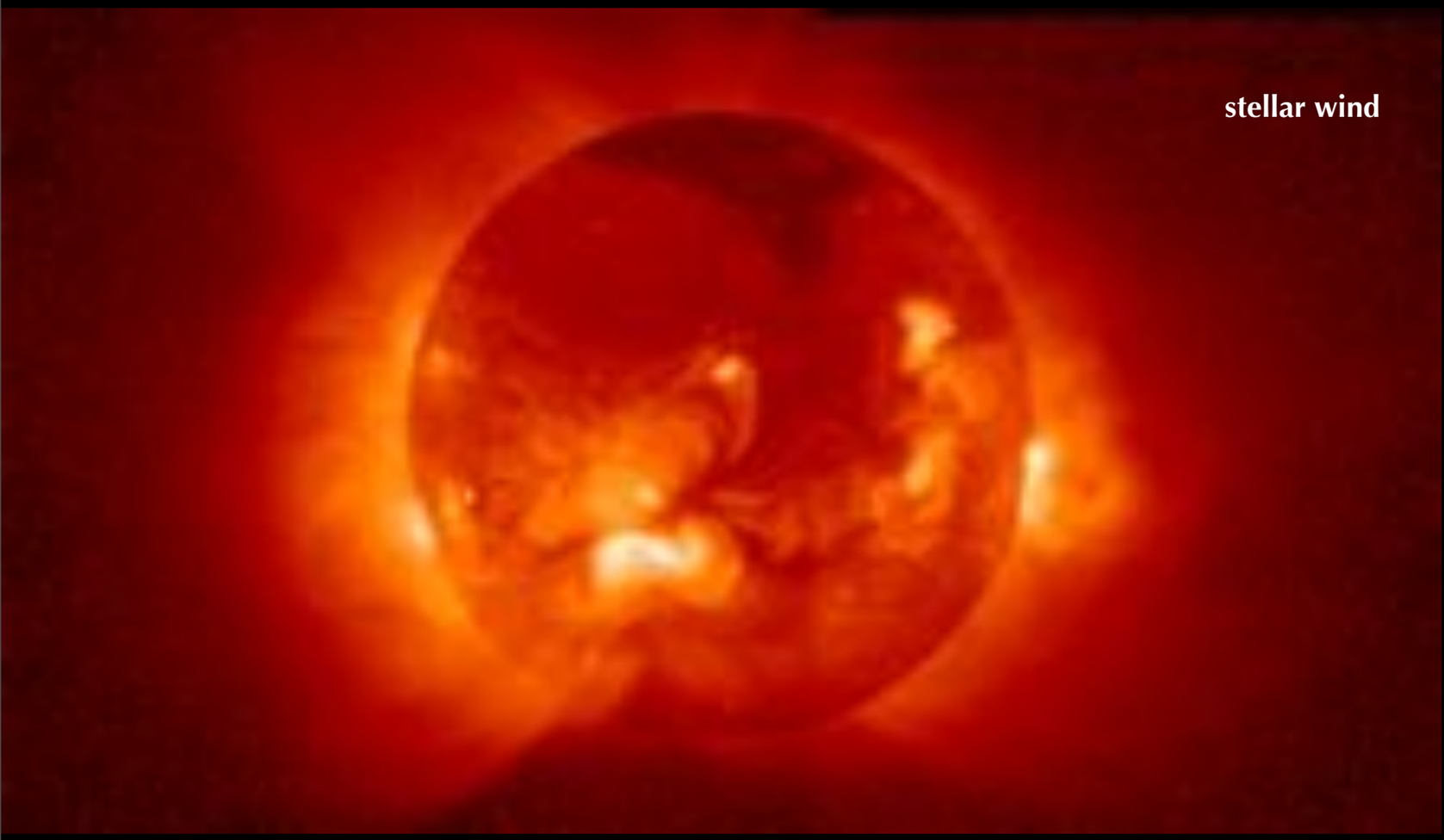
Bucciantini et al. 2005

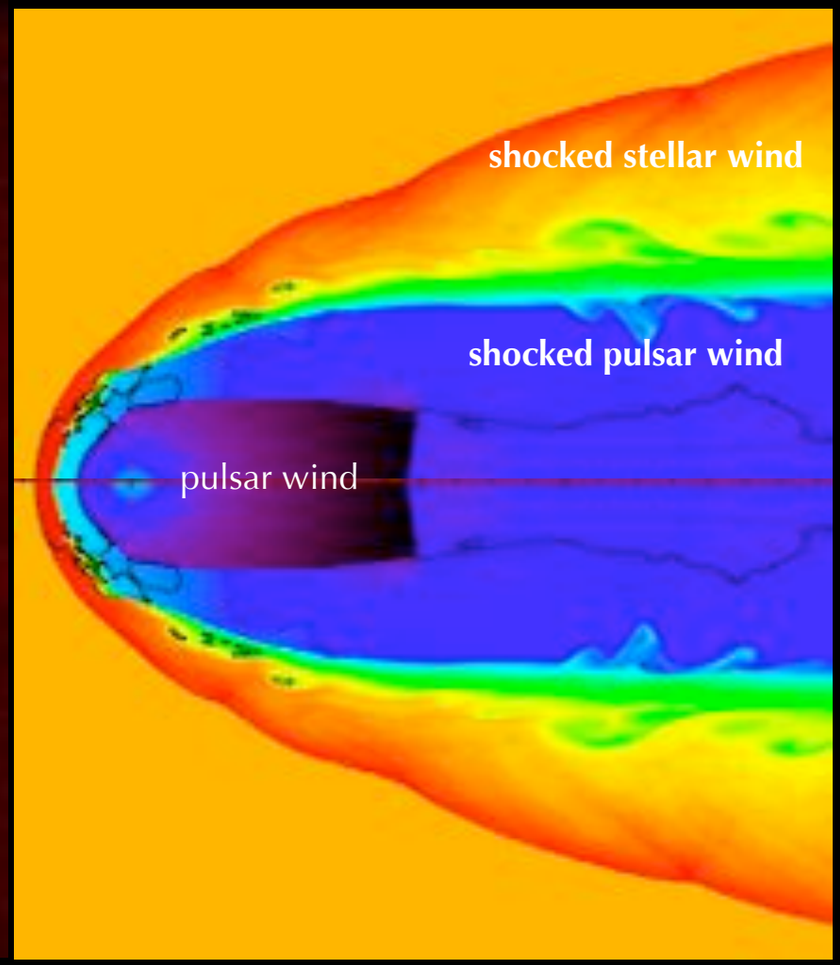
Binary plerion, PWN

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]

G. Dubus, Workshop “Variable Galactic Gamma-ray Sources”, Dec. 2010, Heidelberg

Interacting winds



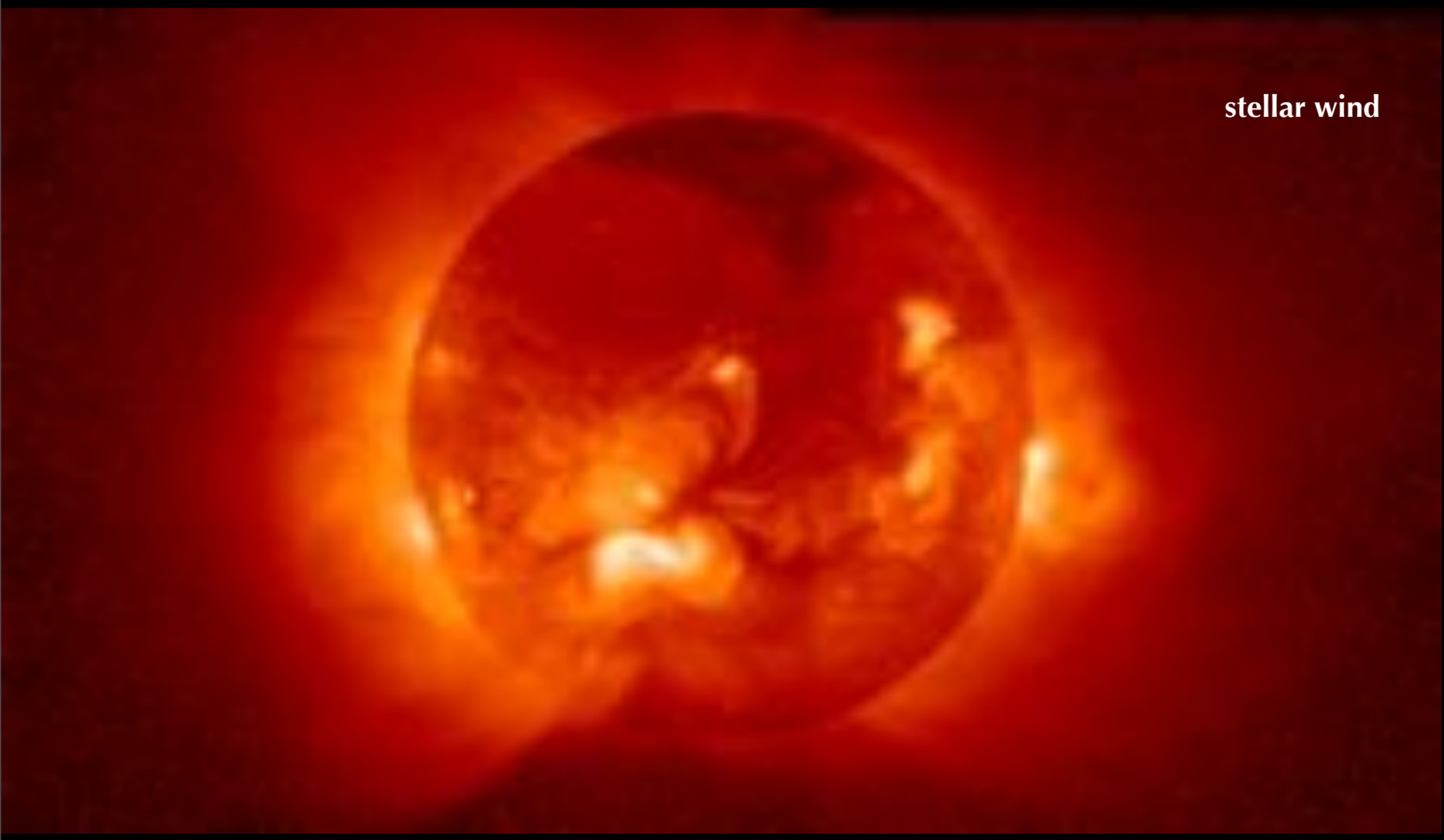


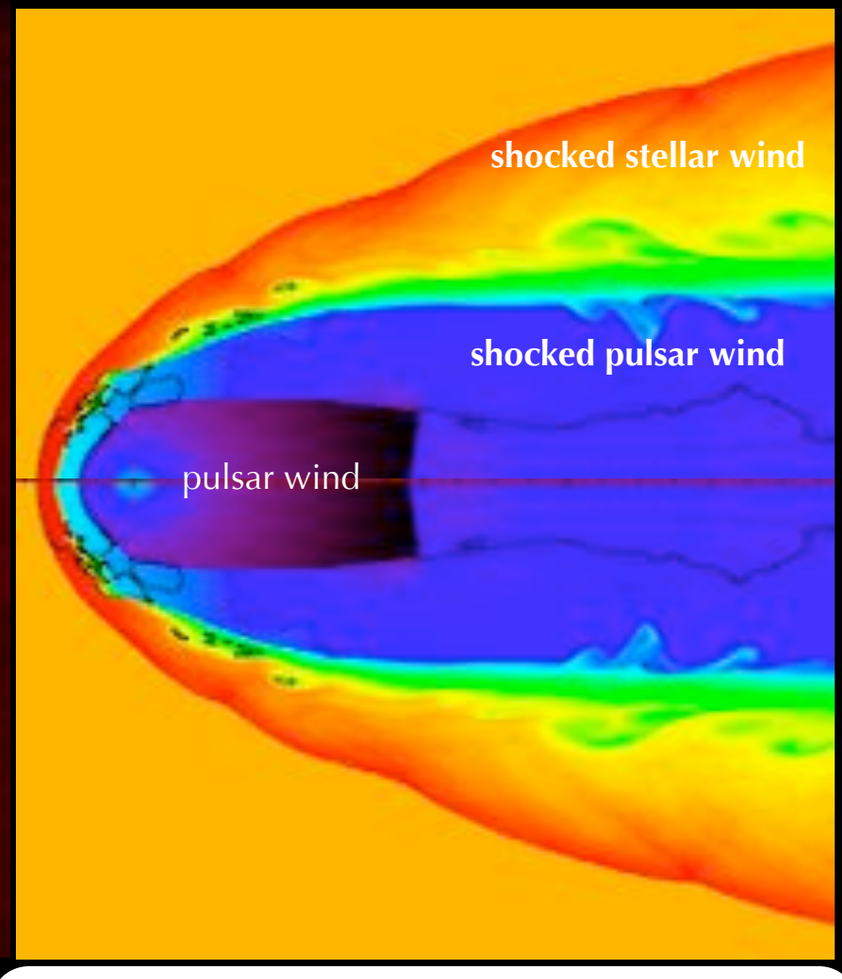
Bucciantini et al. 2005

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

$$\dot{E}_{\rm p} \geq 10^{26}\ \rho_{-14} v_{1000}^{-3}\ {\rm erg/s} \quad \textbf{for fast wind}$$

Interacting winds

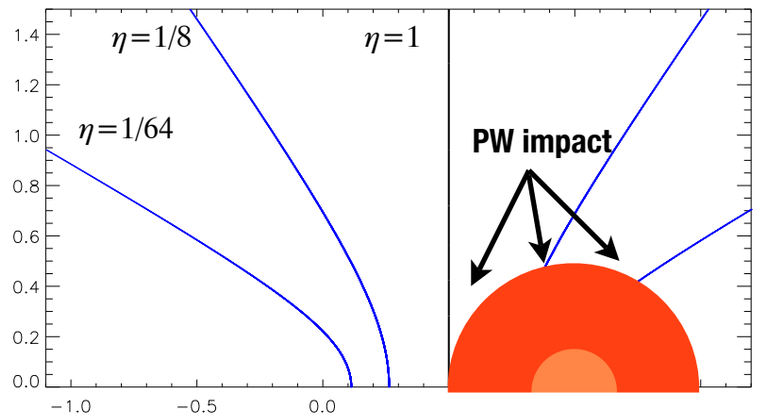




Bucciantini et al. 2005

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

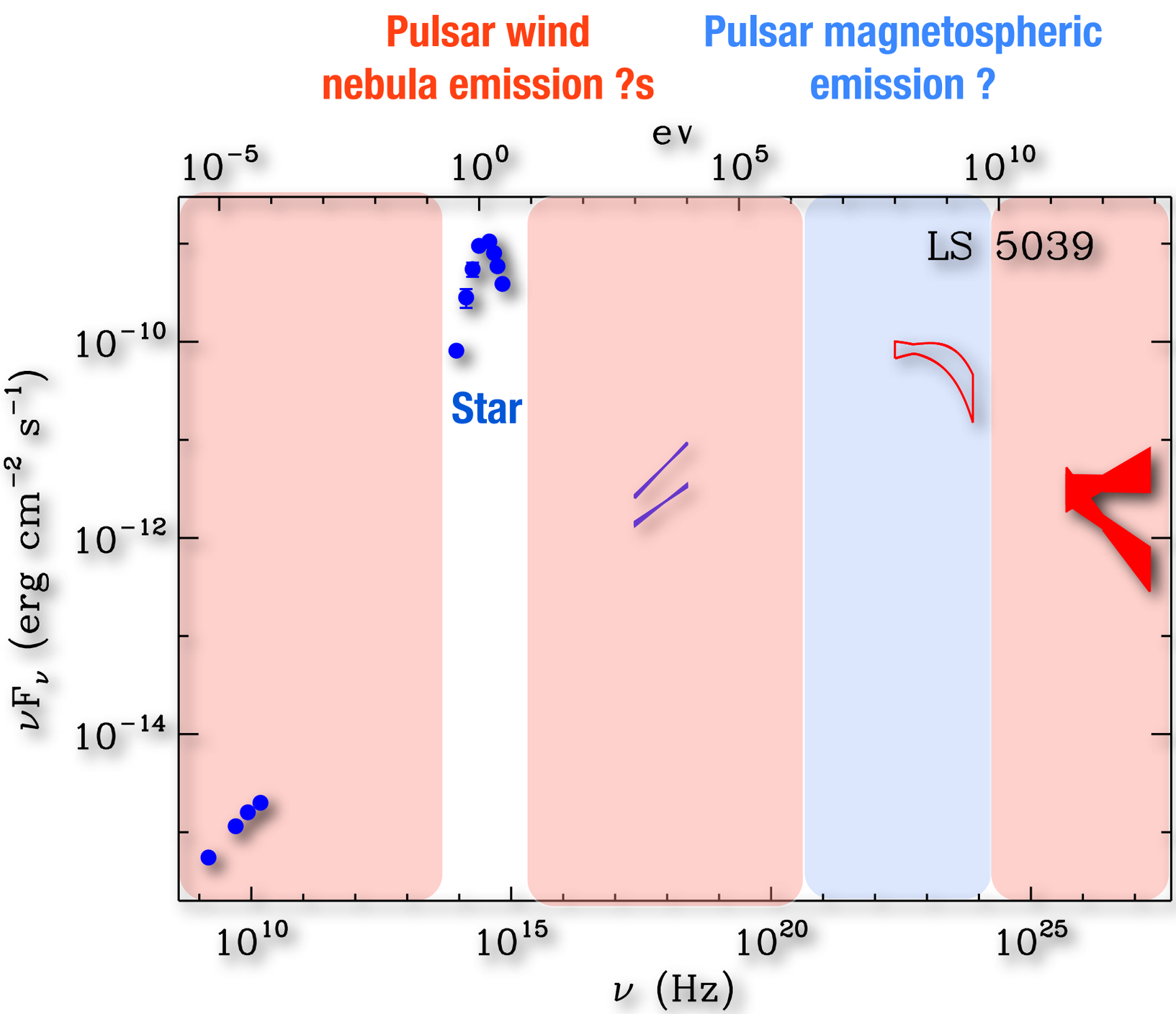
$\dot{M}_\star > 10^{-8}\ v_{1000}^{-1} \dot{E}_{36}\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}$ **for η<1, fast wind**



LS 5039 / LS I star to size

G. Dubus, Workshop “Variable Galactic Gamma-ray Sources”, Dec. 2010, Heidelberg

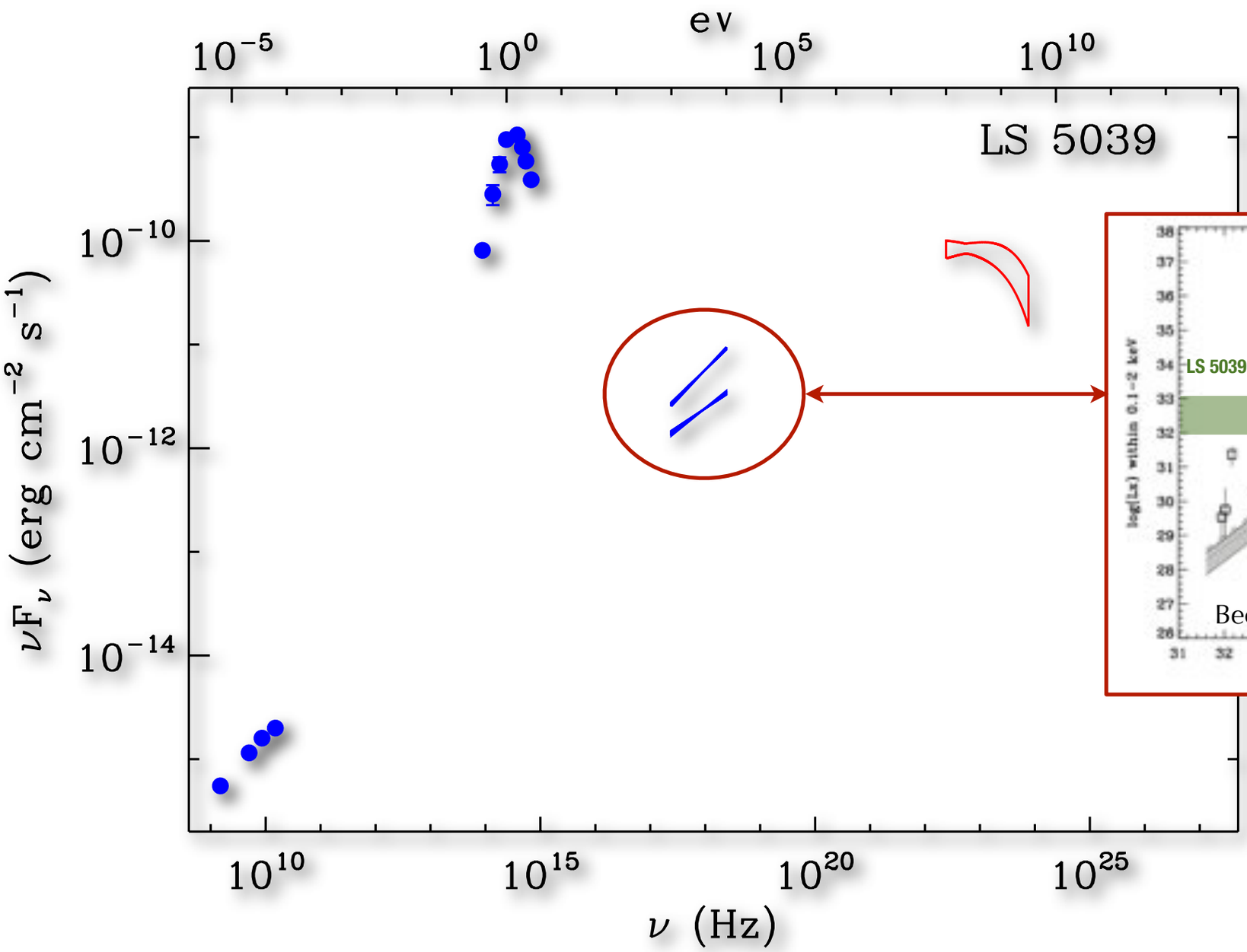
Emission from system



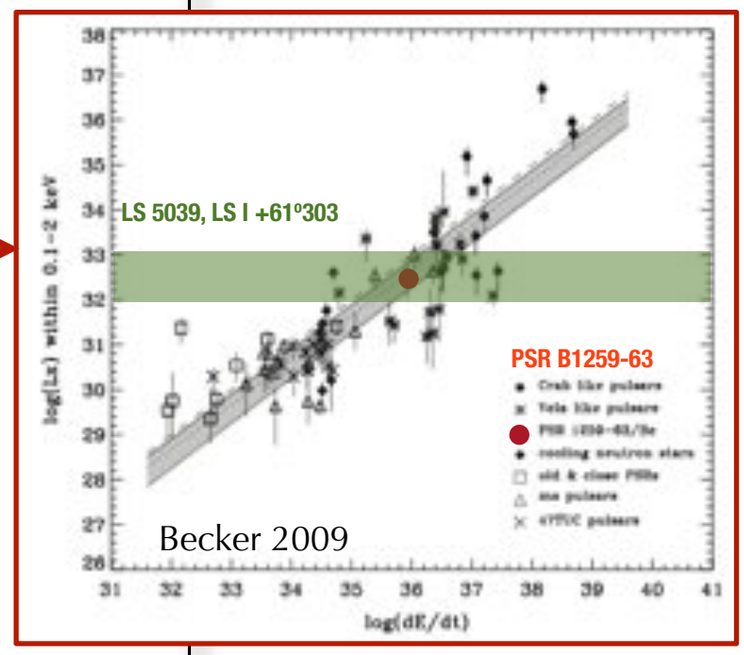
G. Dubus, Workshop “Variable Galactic Gamma-ray Sources”, Dec. 2010, Heidelberg

Emission from system

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



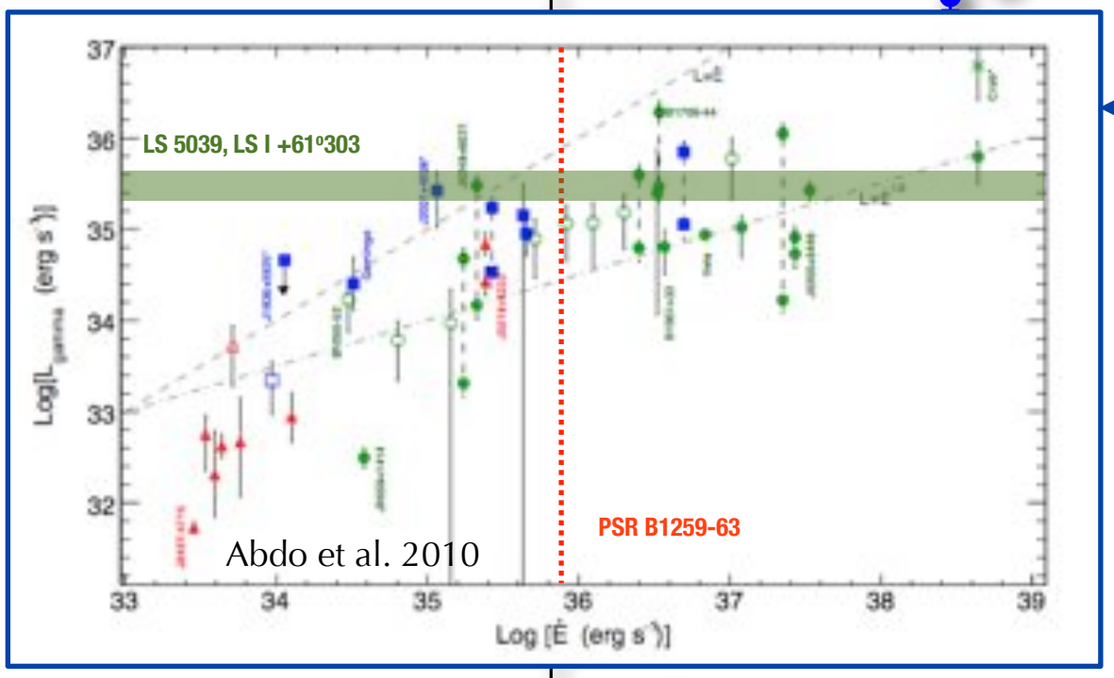
L_x vs dE/dt (PWN)



Emission from system

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

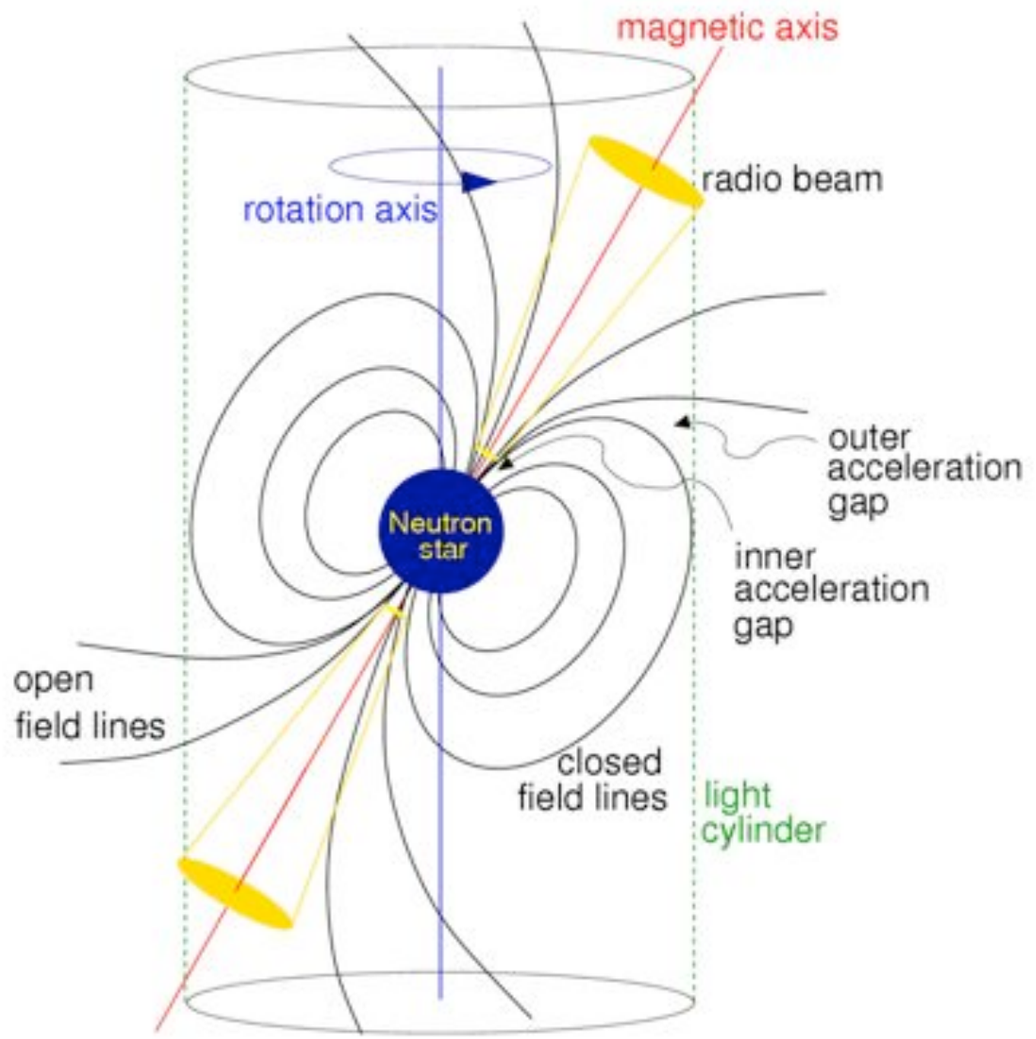
L_{gev} vs dE/dt (pulsars)



G. Dubus, Workshop “Variable Galactic Gamma-ray Sources”, Dec. 2010, Heidelberg

GeV emission

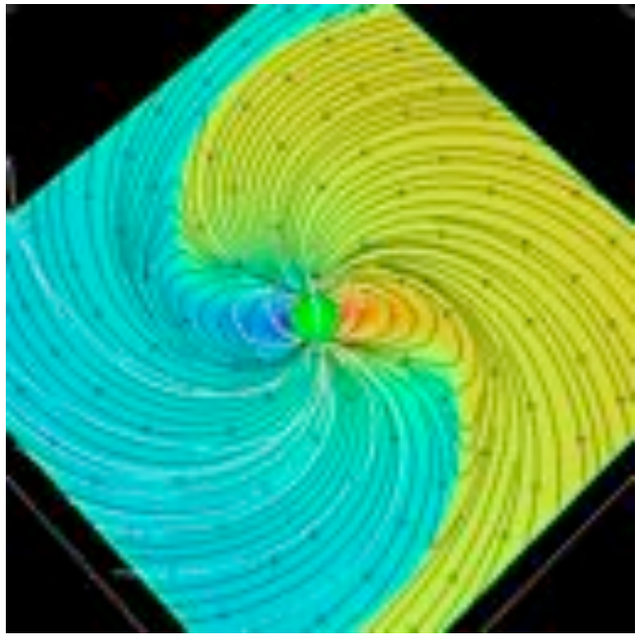
- Fermi finds GeV emission is modulated on orbit.
- GeV pulsar emission usually attributed to curvature radiation in outer gap
  - ➡ no modulation expected



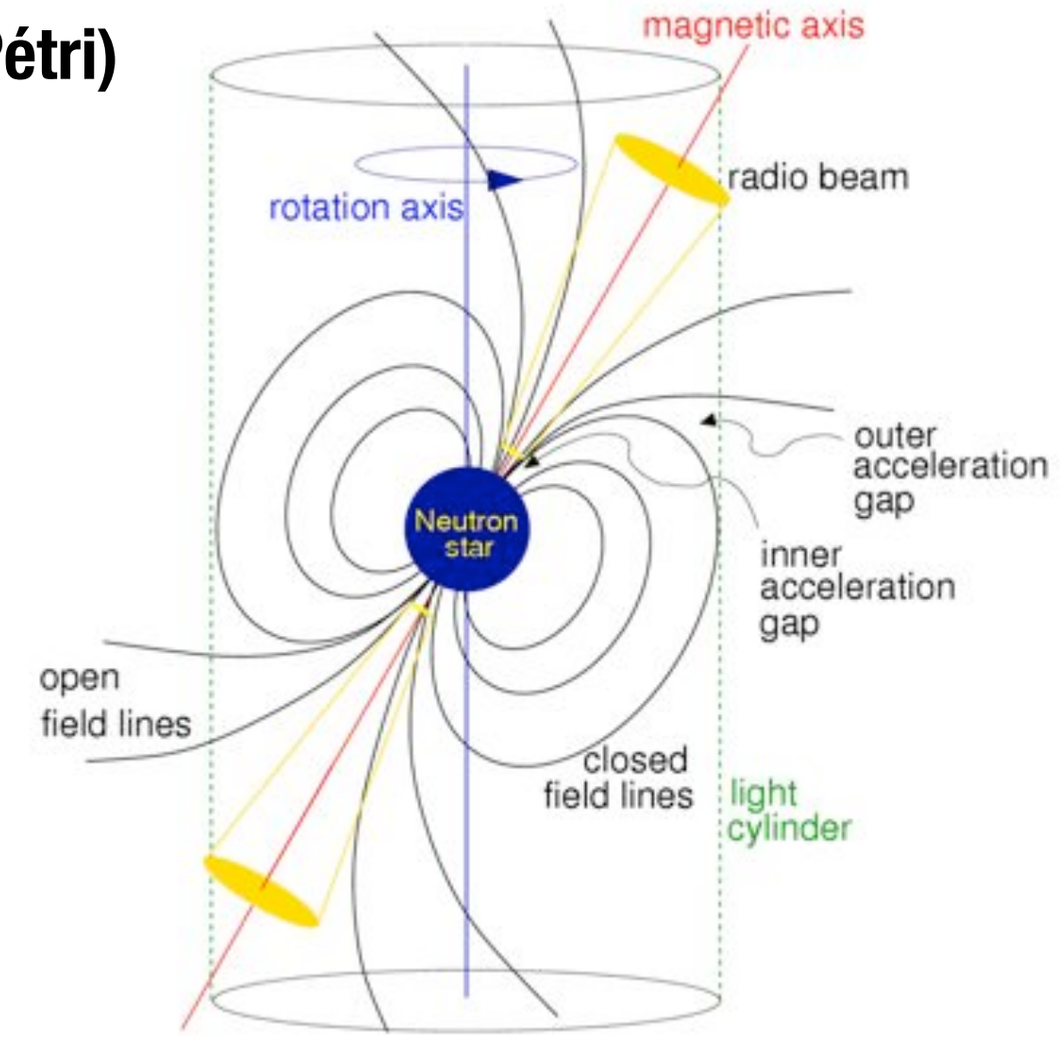
G. Dubus, Workshop “Variable Galactic Gamma-ray Sources”, Dec. 2010, Heidelberg

GeV emission

- Fermi finds GeV emission is modulated on orbit.
- GeV pulsar emission usually attributed to curvature radiation in outer gap
  - ➡ no modulation expected
- In striped wind, GeV emission from IC (→J. Pétri)
  - ➡ orbital modulation (stellar photons)



Spitkovsky

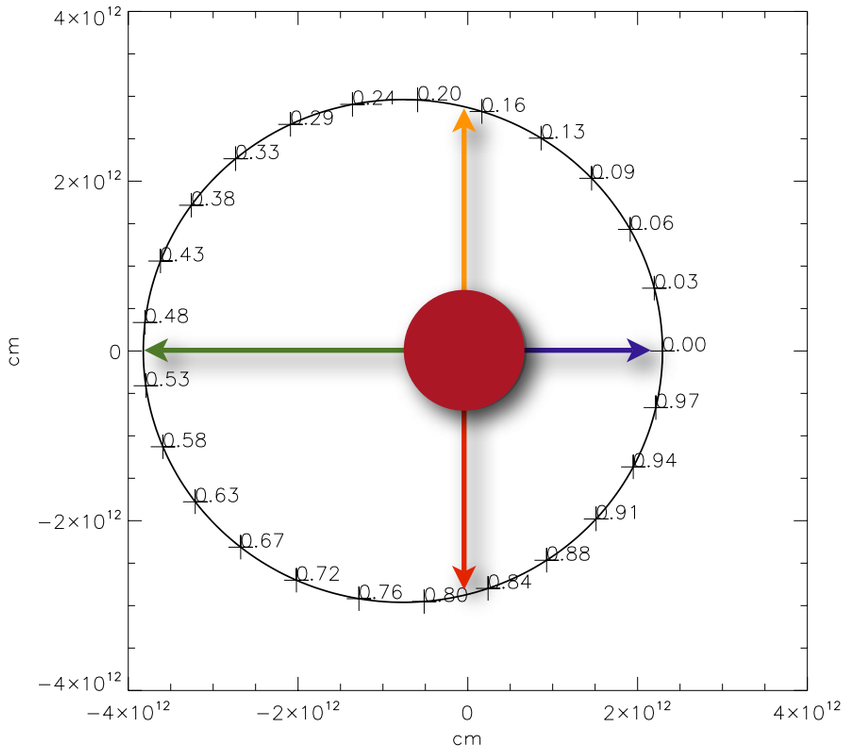


G. Dubus, Workshop “Variable Galactic Gamma-ray Sources”, Dec. 2010, Heidelberg

Orbital modulations

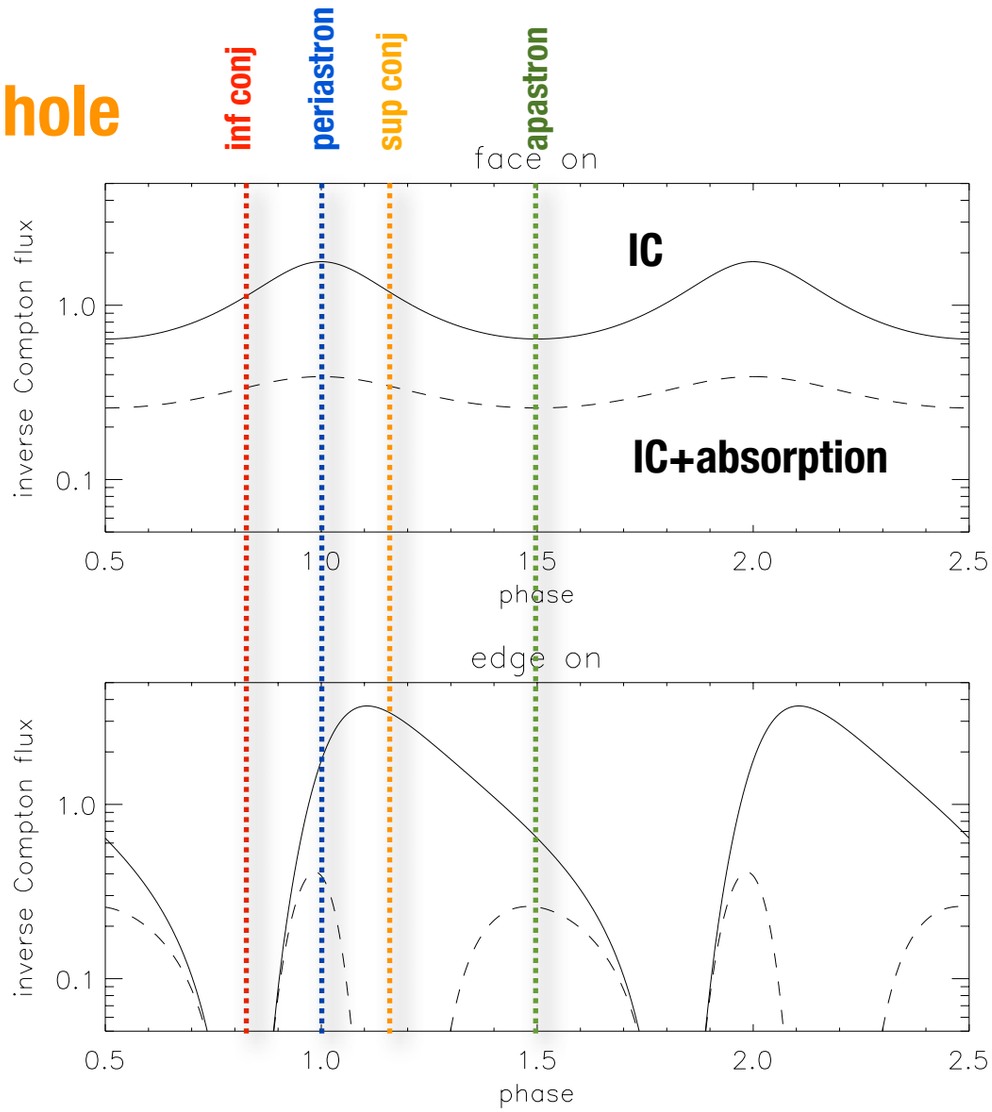
- **Leptonic, usual processes: synchrotron, inverse Compton, pairs**
- **very high energy electrons in vicinity of pulsar**
- **LS 5039 and LS I+61°303:**

  if pulsar then higher inclination than black hole



face on

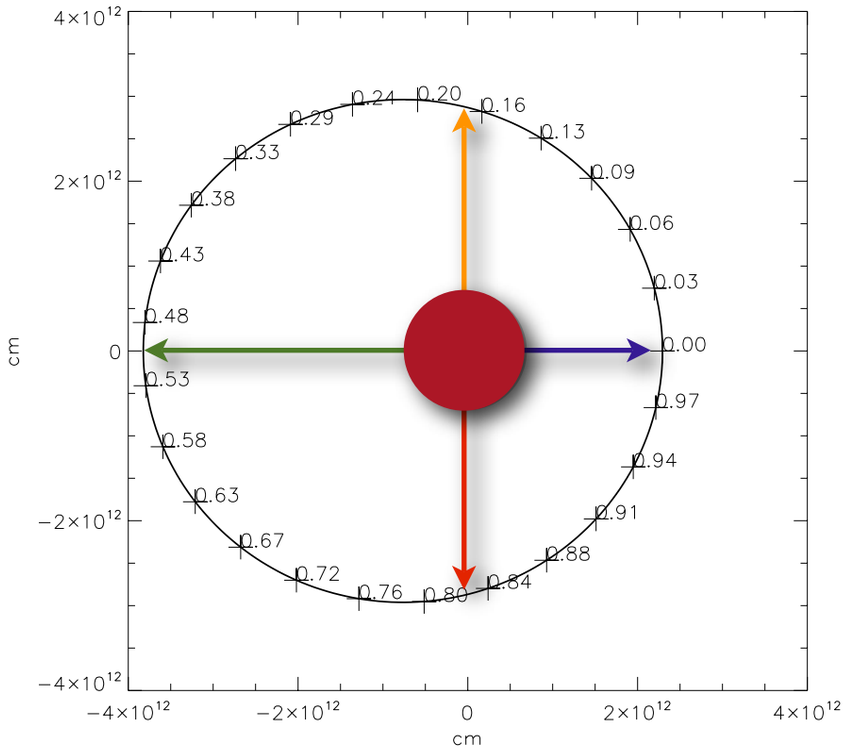
edge on



G. Dubus, Workshop “Variable Galactic Gamma-ray Sources”, Dec. 2010, Heidelberg

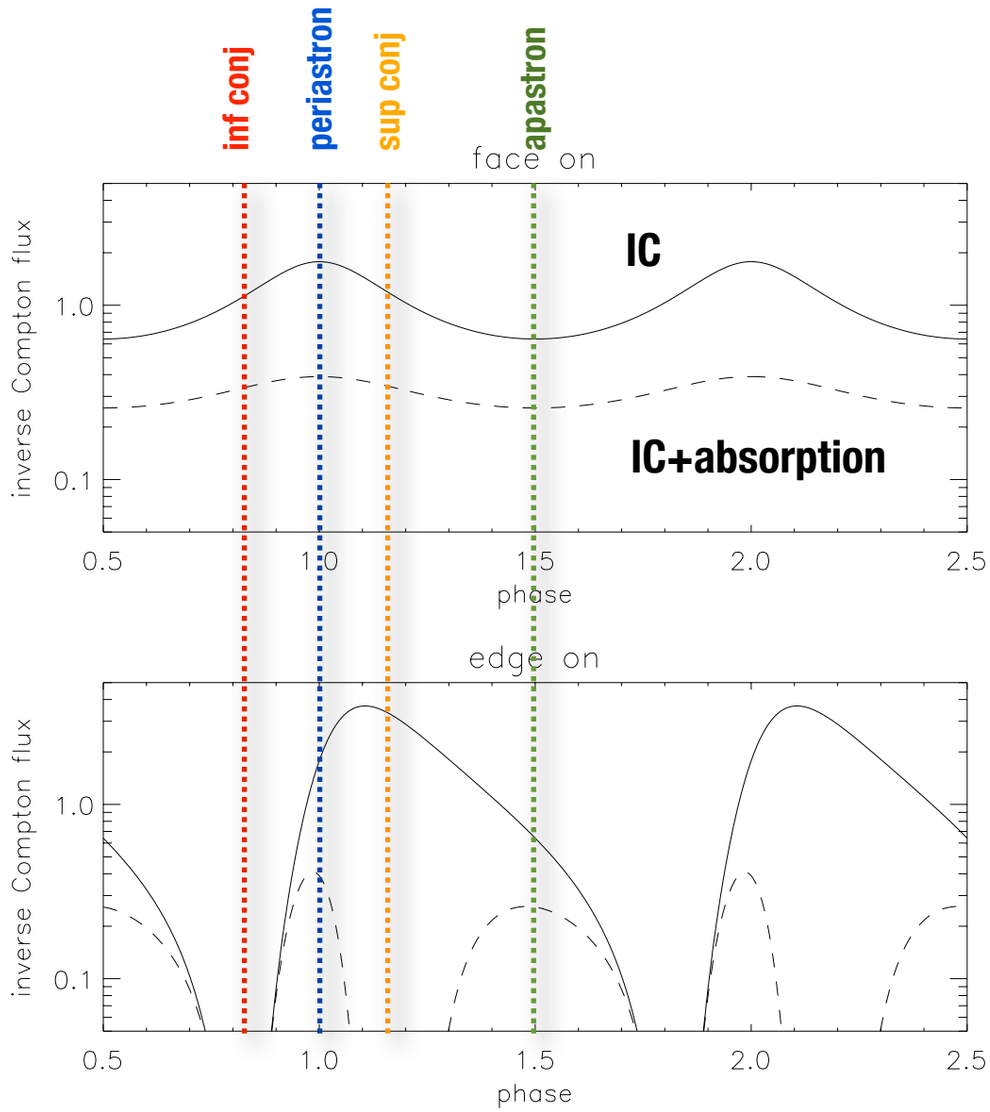
Orbital modulations

- **LS 5039 and LS I+61º303: if pulsar then higher inclination than black hole**
  - **conjunctions important**
  - **larger amplitude modulation**
  - **strong absorption at sup. conjunction**



face on

edge on



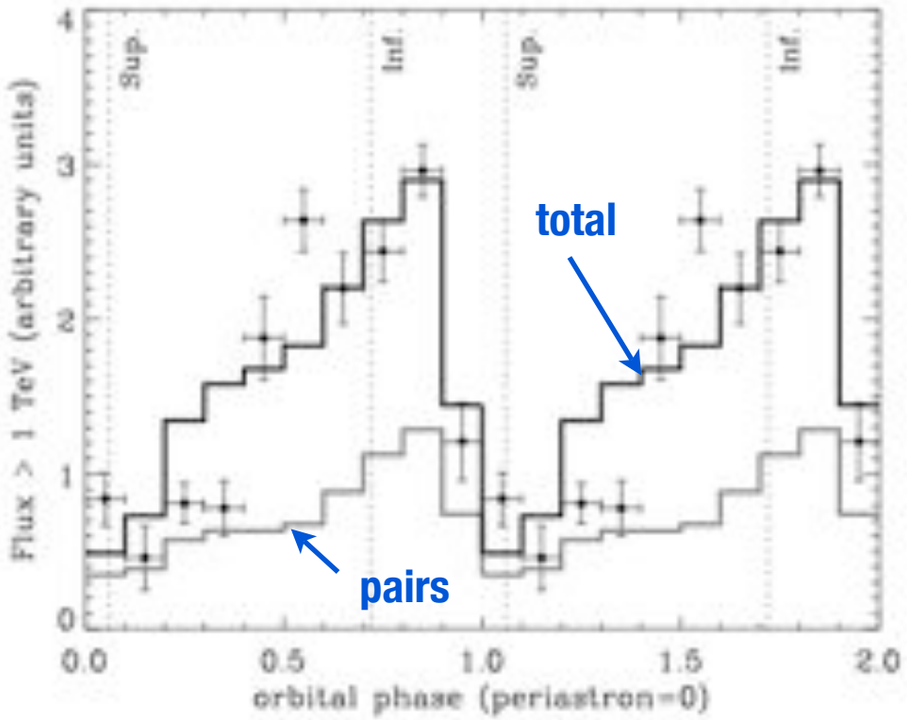
G. Dubus, Workshop “Variable Galactic Gamma-ray Sources”, Dec. 2010, Heidelberg

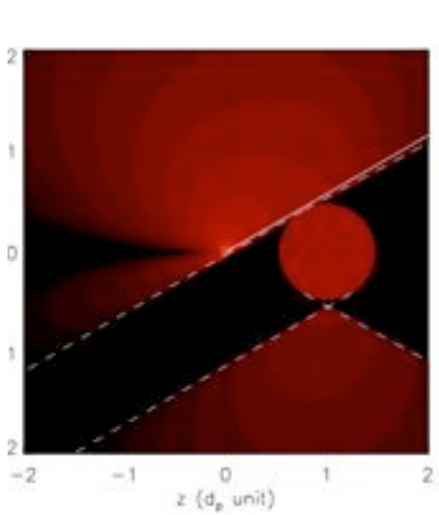
Pair cascade LS 5039

- **Significant pair cascade emission to account for HESS detection at sup conj.**
- **Limits magnetic field <B>~a few G, compatible with pulsar.**

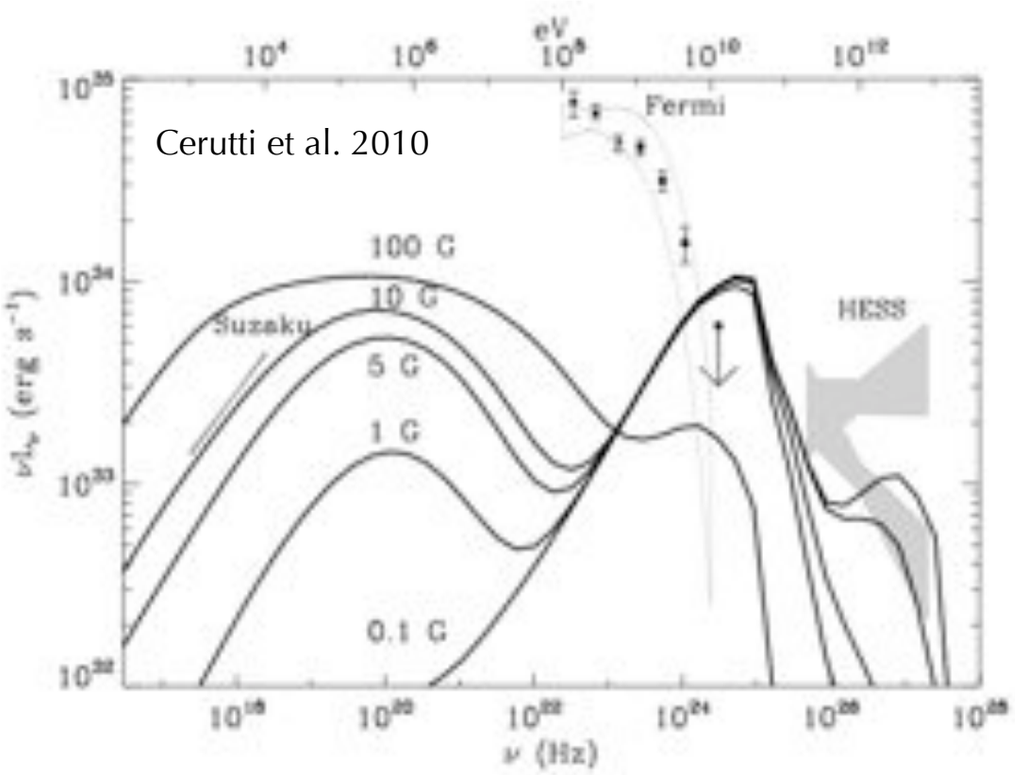
VHE lightcurve & model (3d monte-carlo)

Cerutti et al. 2010



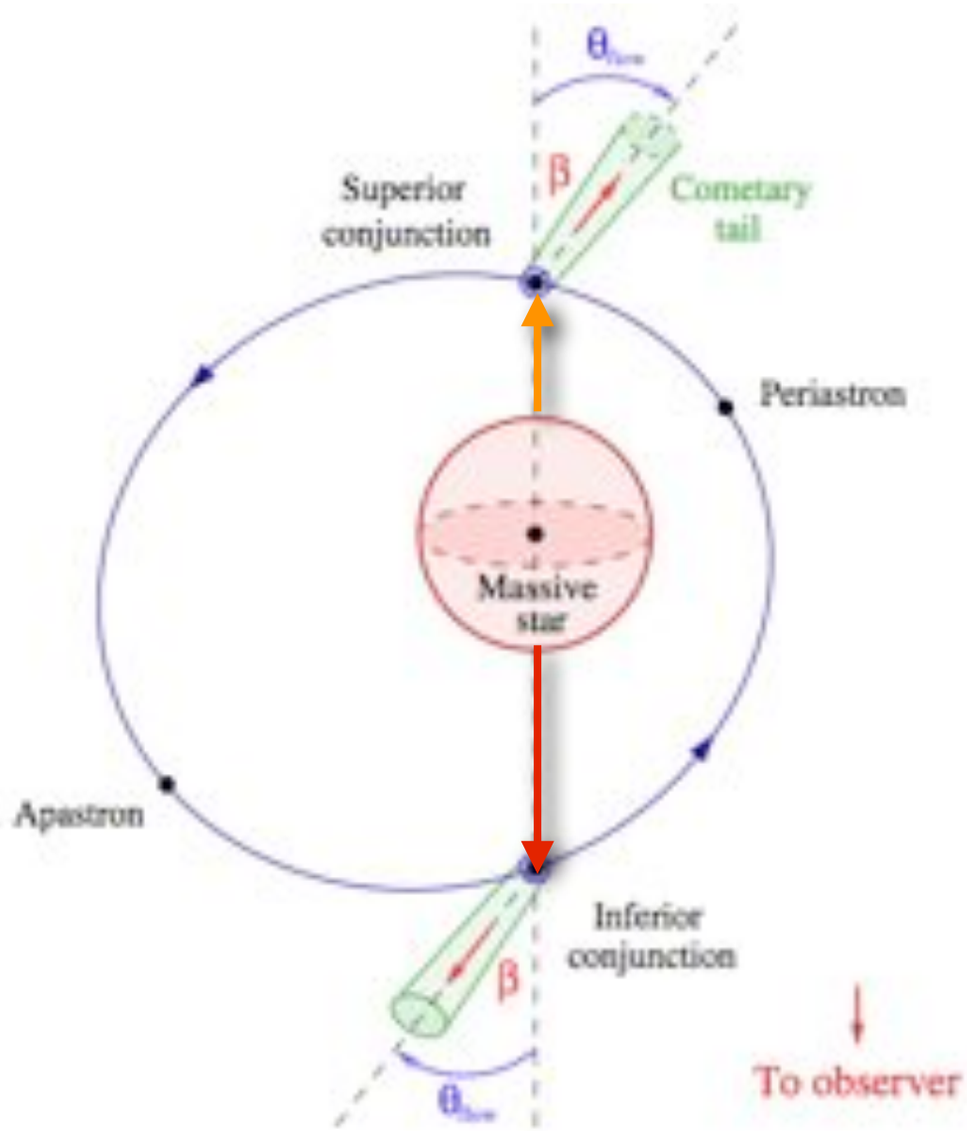


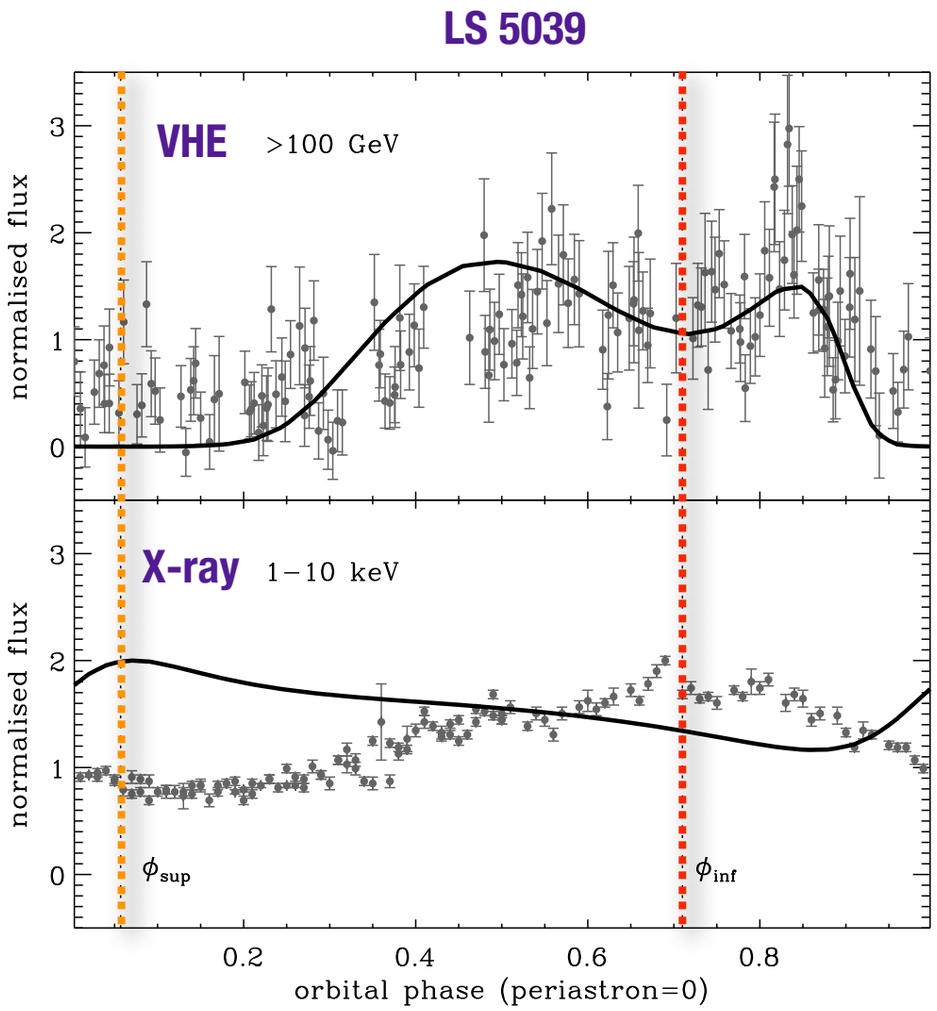
cascade emission (only) @ sup. conjunction



Modulated Doppler boost

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



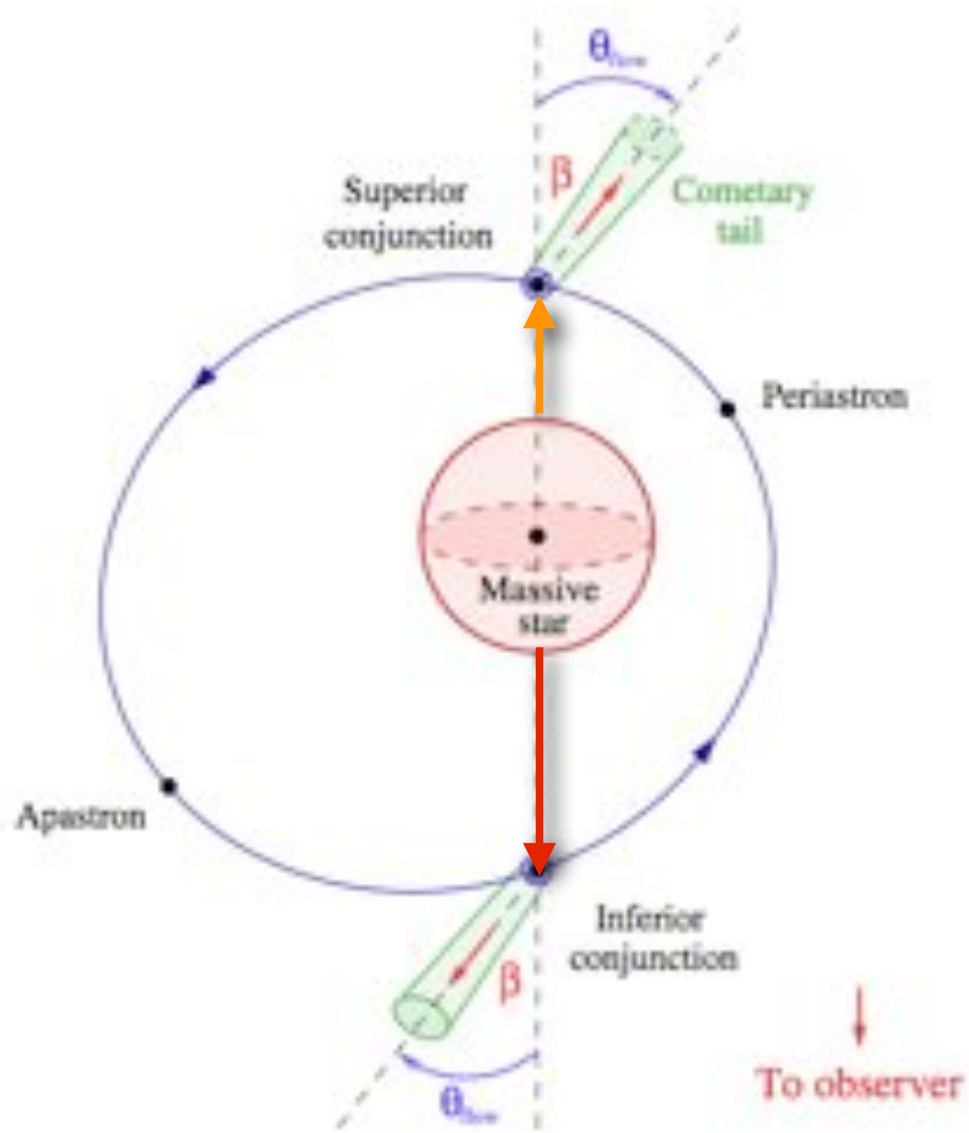


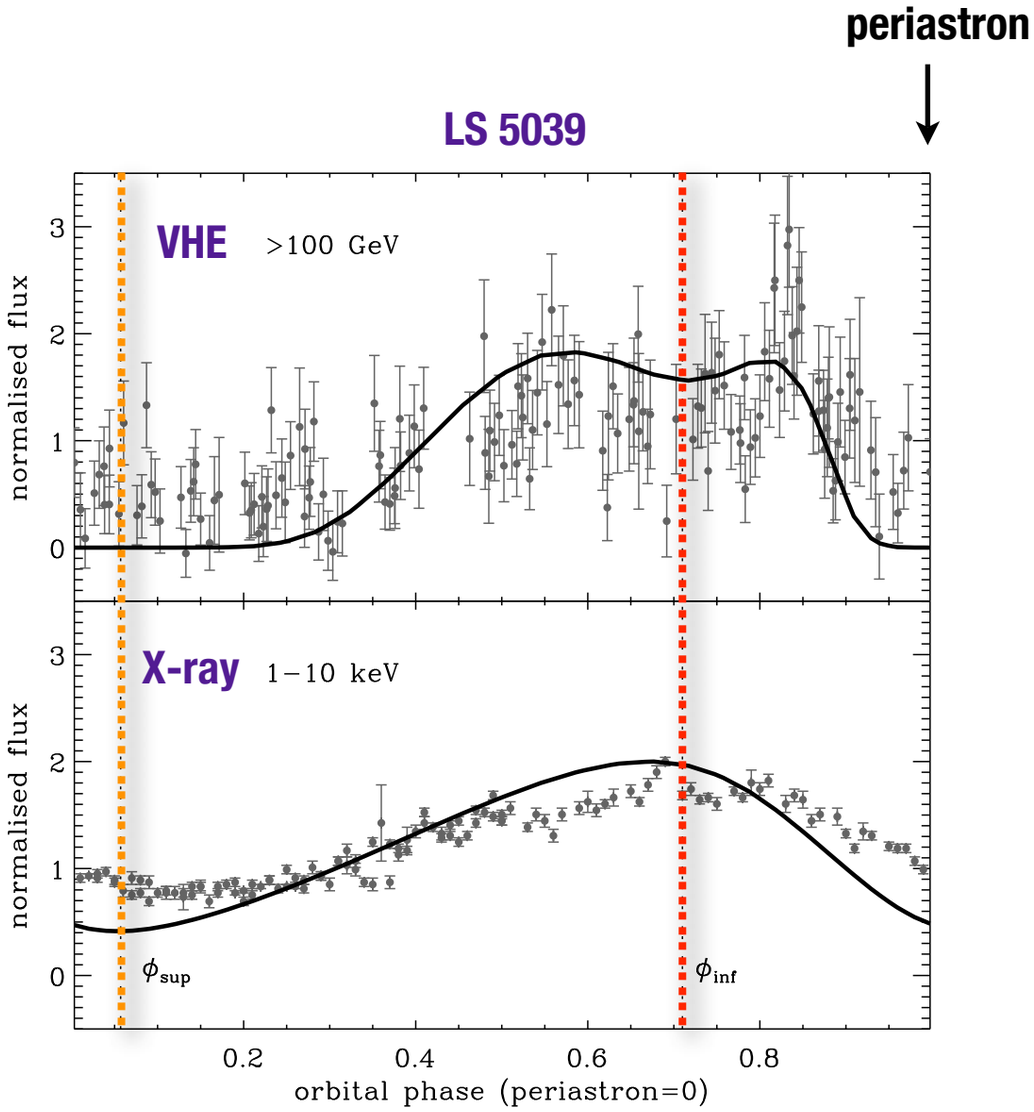
GD et al. 2010

(c/3 with Kennel Coroniti)

Modulated Doppler boost

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



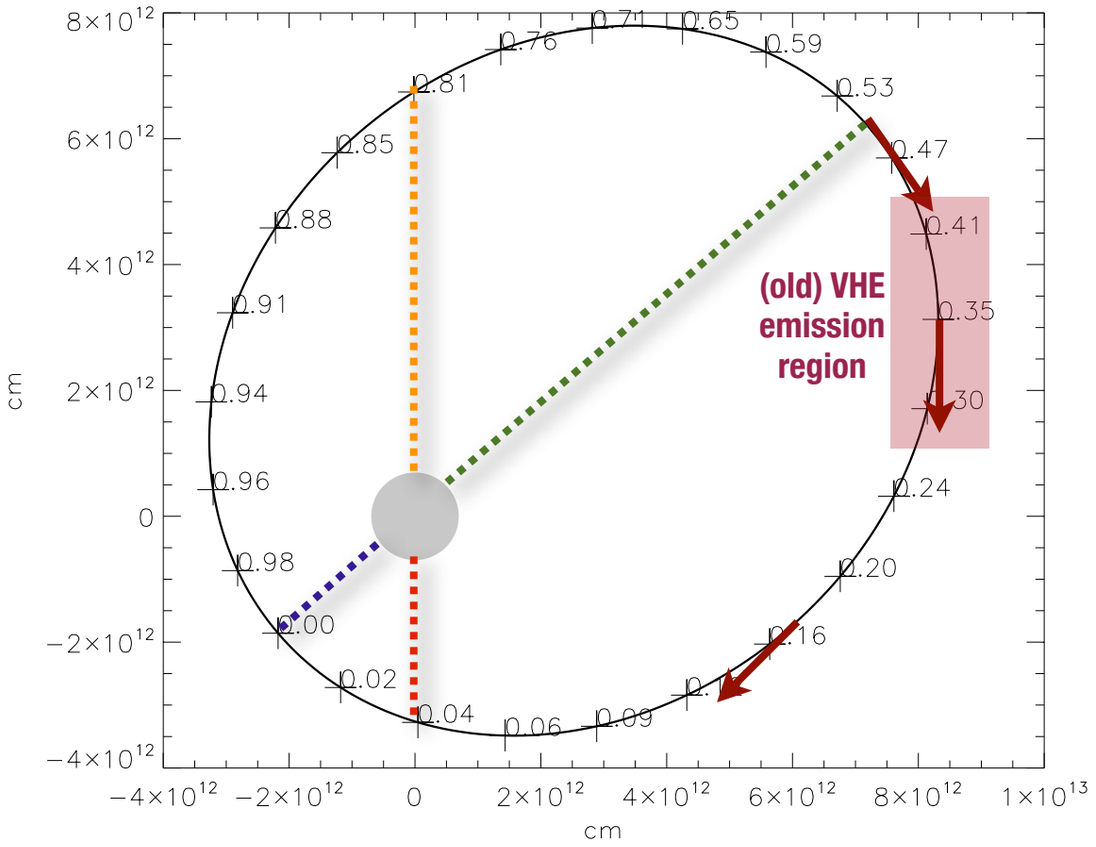


GD et al. 2010

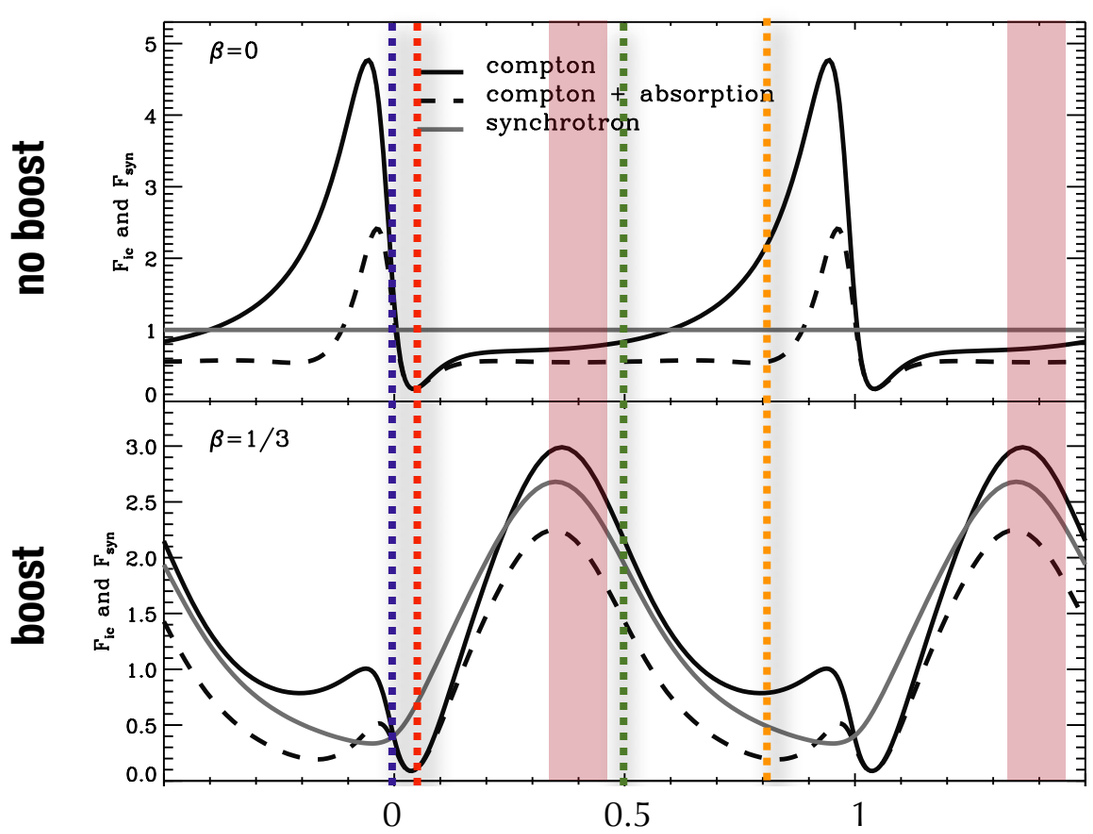
(c/3 with Kennel Coroniti)

Modulated Doppler boost

- Shocked pulsar wind mildy 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 ?



LS I+61°303

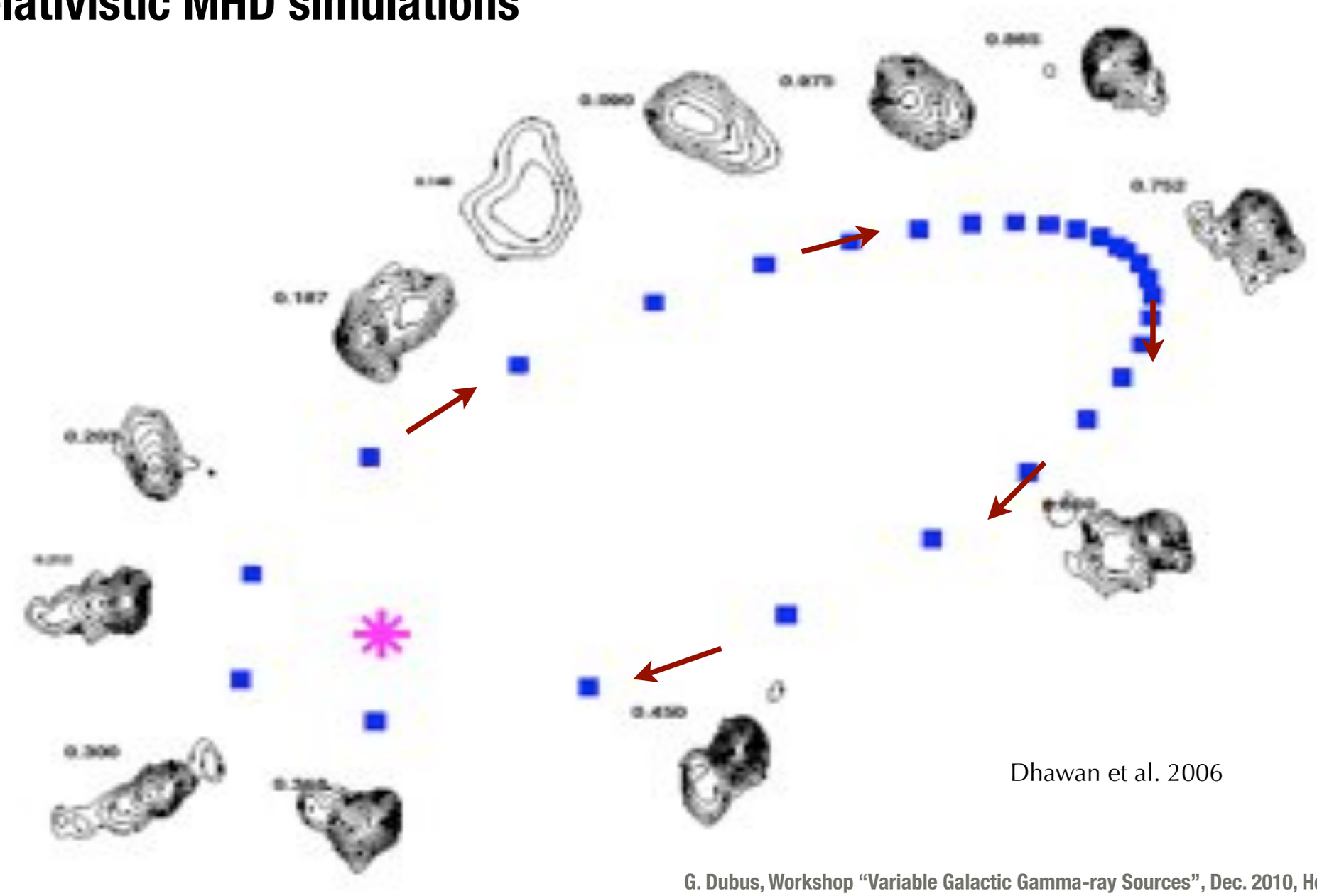


GD et al. 2010

(c/3 with Kennel Coroniti)

LS I+61º303 radio morphology

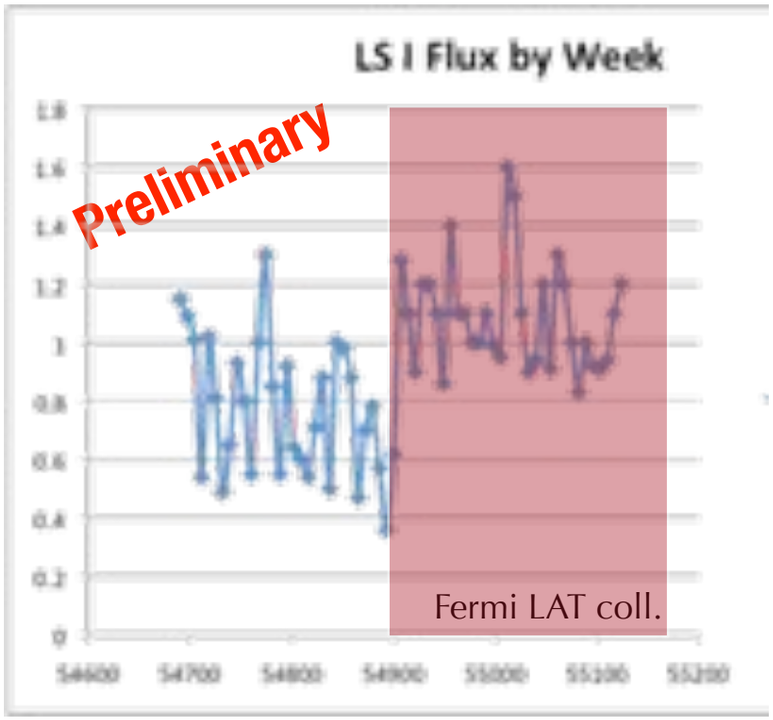
- Radio VLBI observations calls for PWN
- Collimation ? stability ? Be disc ? radio outbursts ? clumping ? mixing ?
- Compare to relativistic MHD simulations



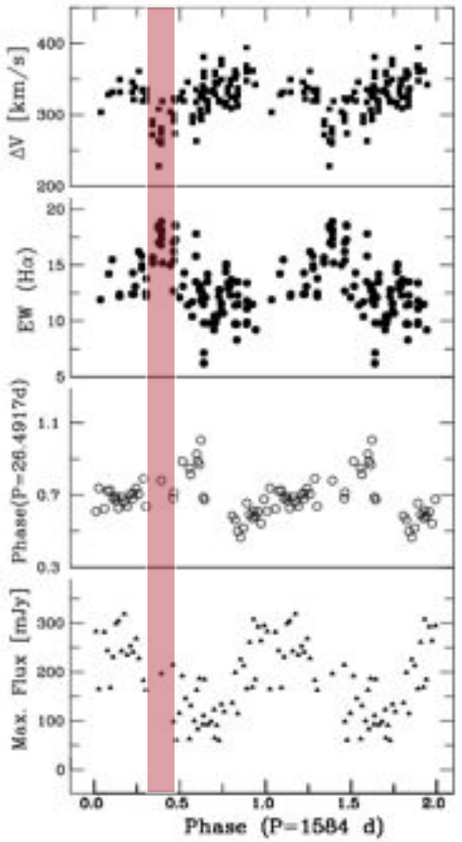
Dhawan et al. 2006

Non-orbital variability

- **long-term variability linked to stellar wind ?**

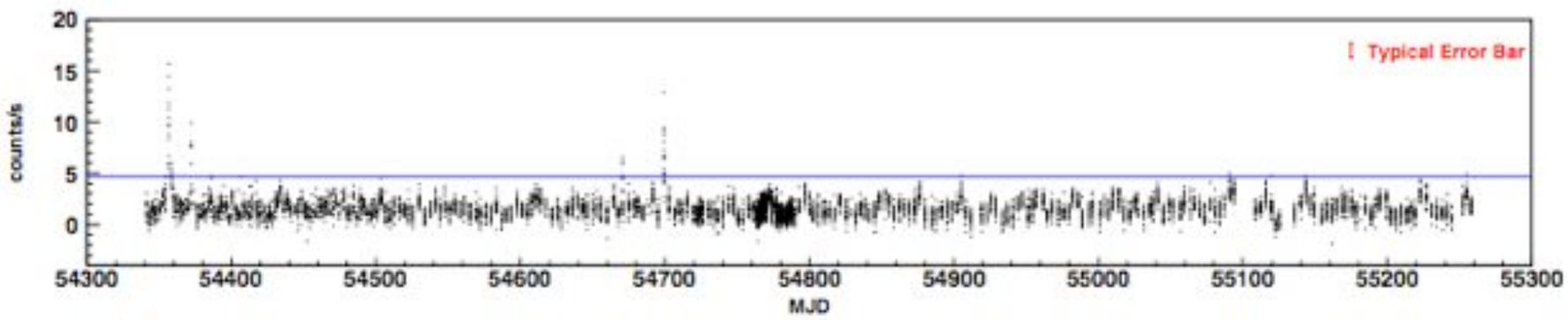


HE γ-ray



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

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

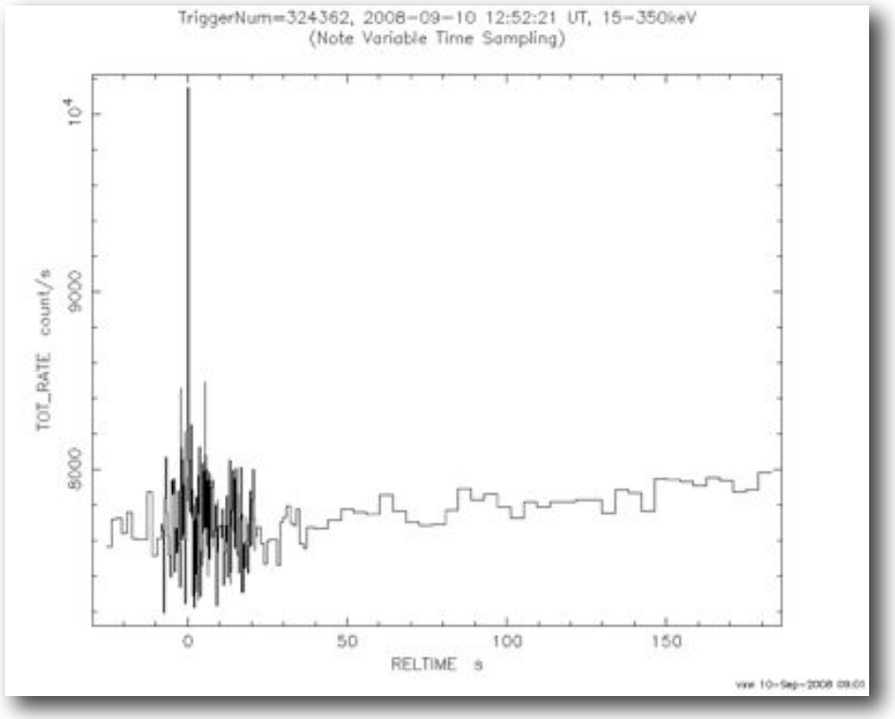


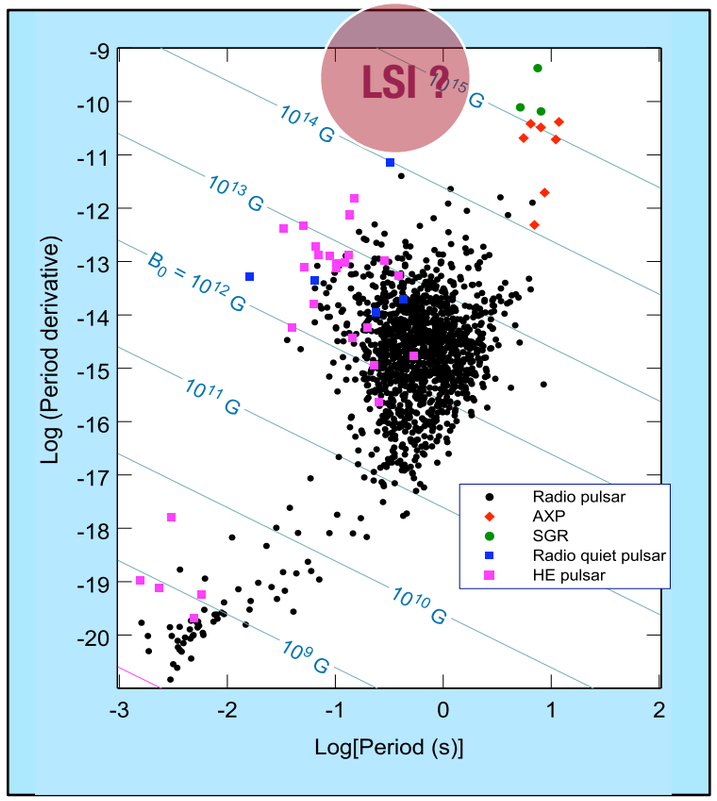
Torres et al. 2010

LS I+61º303: magnetar burst ?

- **SGR/AXP short duration burst within 2’ of LS I+61º303**

GCN 8215





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

blackbody kT=7.5 keV, R=100m

- **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