Gamma-ray binaries ...with a SVOM perspective

Guillaume Dubus

image credit
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IPAG
cnrs
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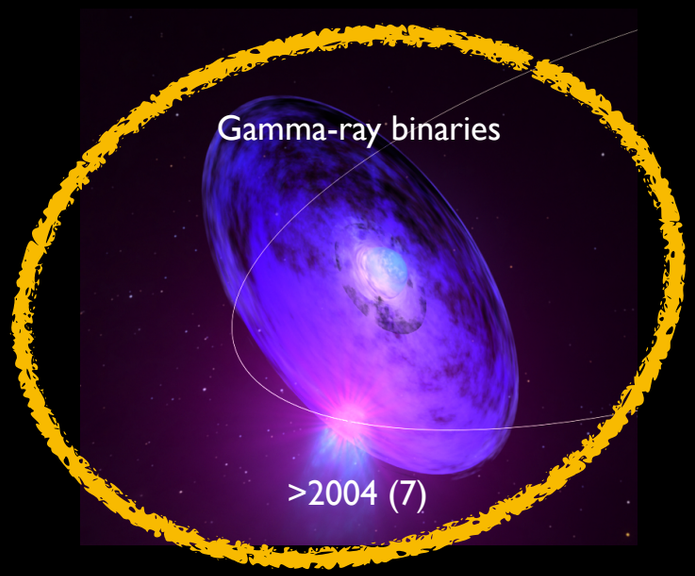
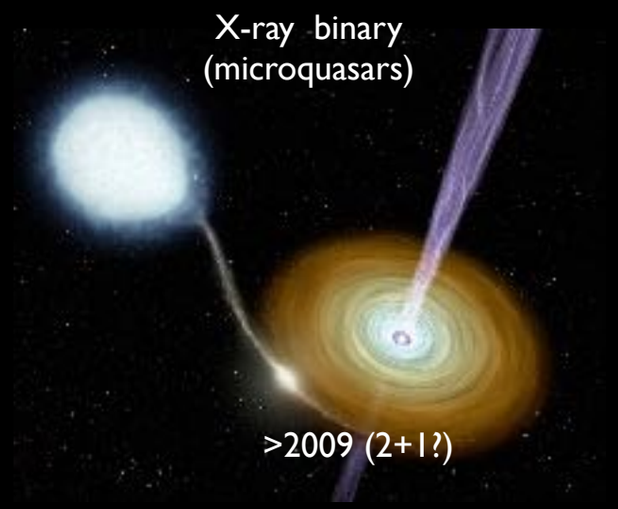
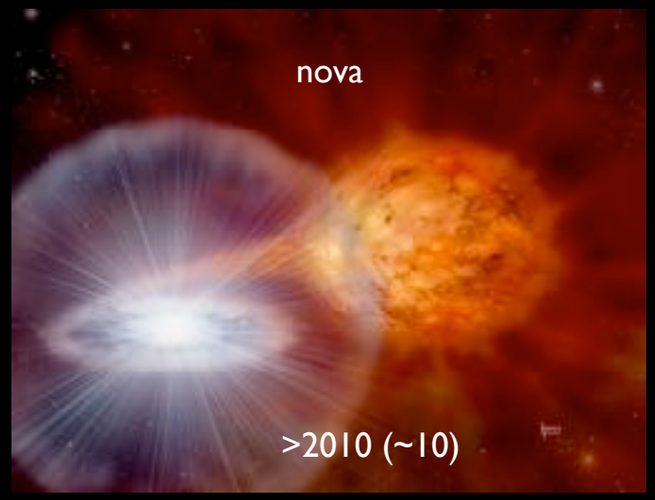
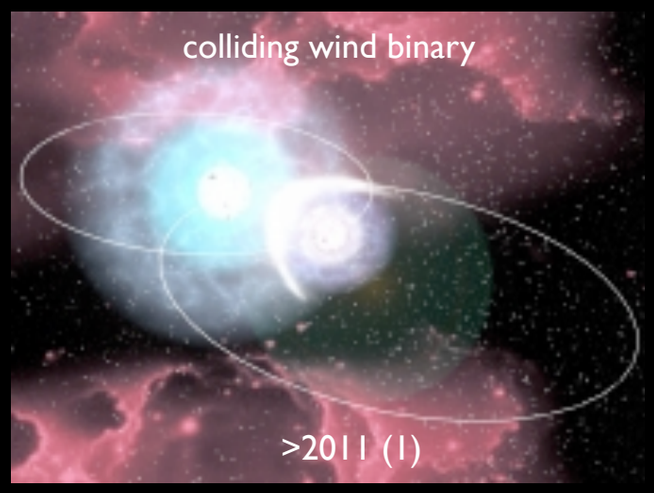
SVOM Meeting les Houches, May 15, 2018

Binaries detected > 100 MeV





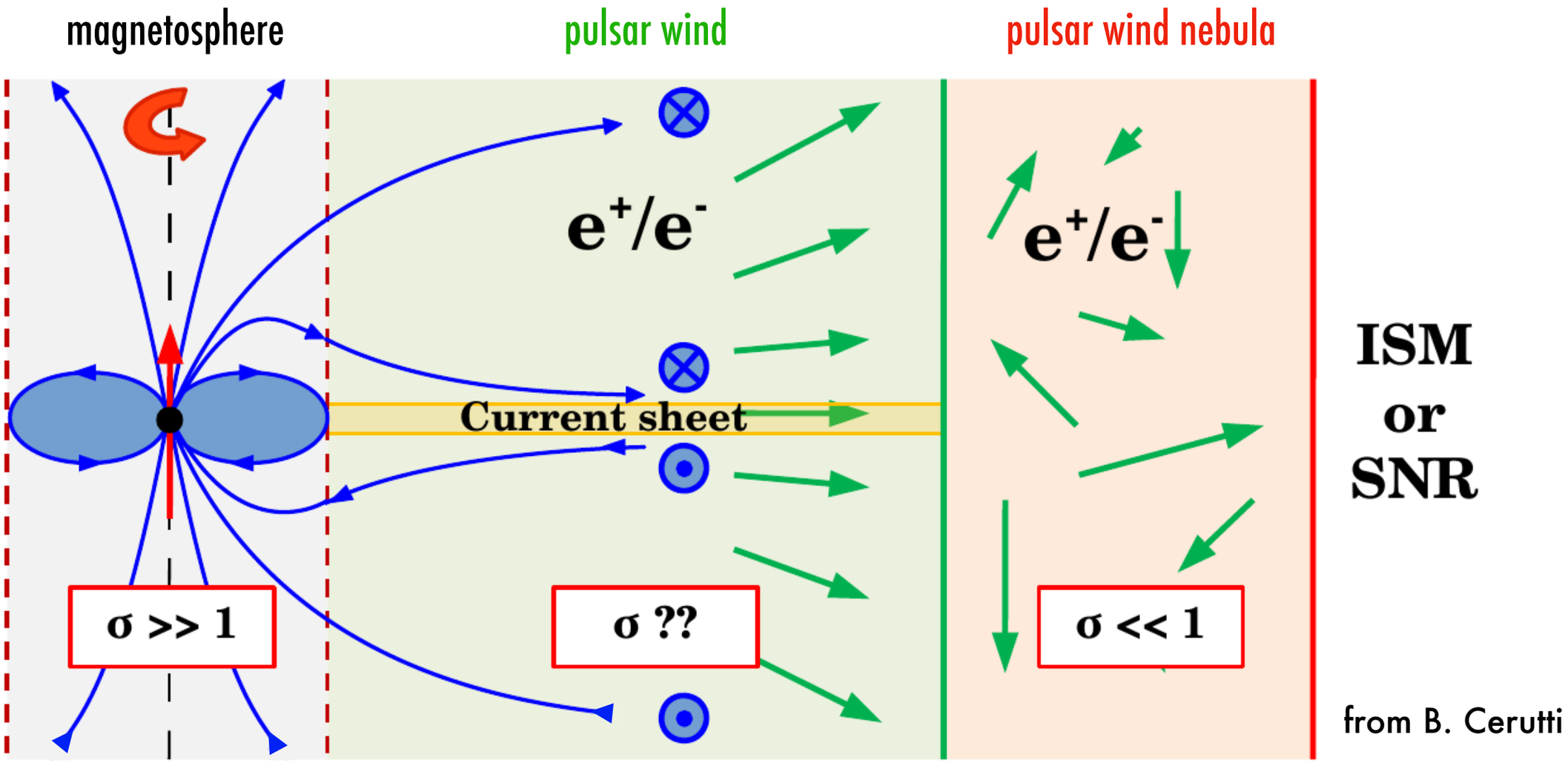




see Dubus, 2013, Astron. Astrophys. Rev.

Rotation-powered non-thermal emission

Magnetized neutron star with high spindown power $\dot{E} = I\Omega\dot{\Omega} \propto B^2/P^4$

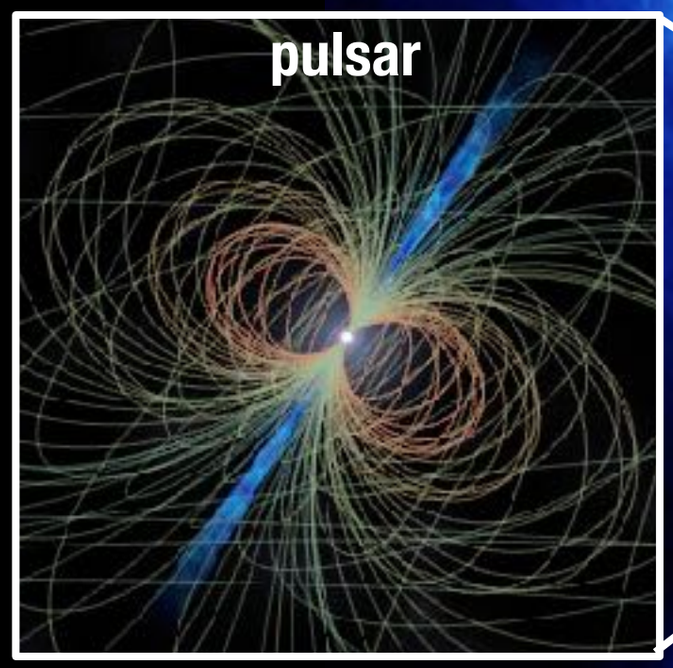


from B. Cerutti

$$\sigma = \frac{B^2}{4\pi\Gamma n m_e c^2}$$

Pulsar Wind Nebula

Pulsar wind termination shock $p_{\rm pw} = \dfrac{\dot{E}}{4\pi R_{\rm s}^2 c} = p_{\rm ext}$

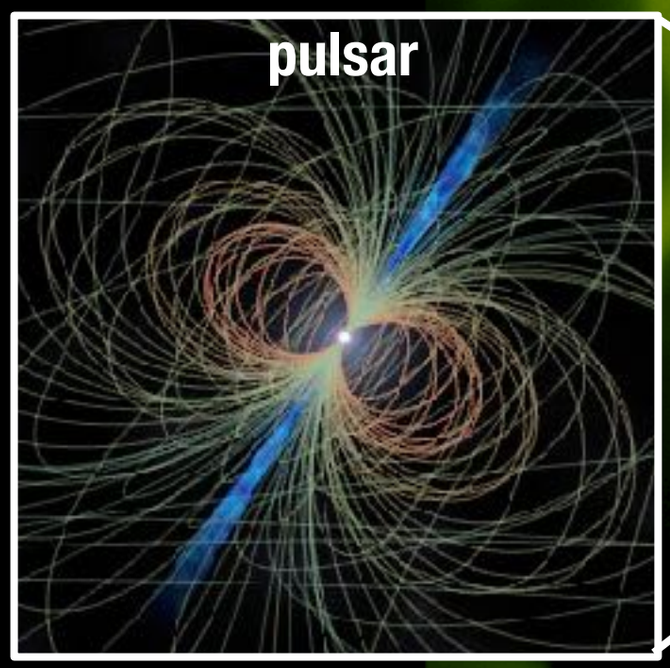


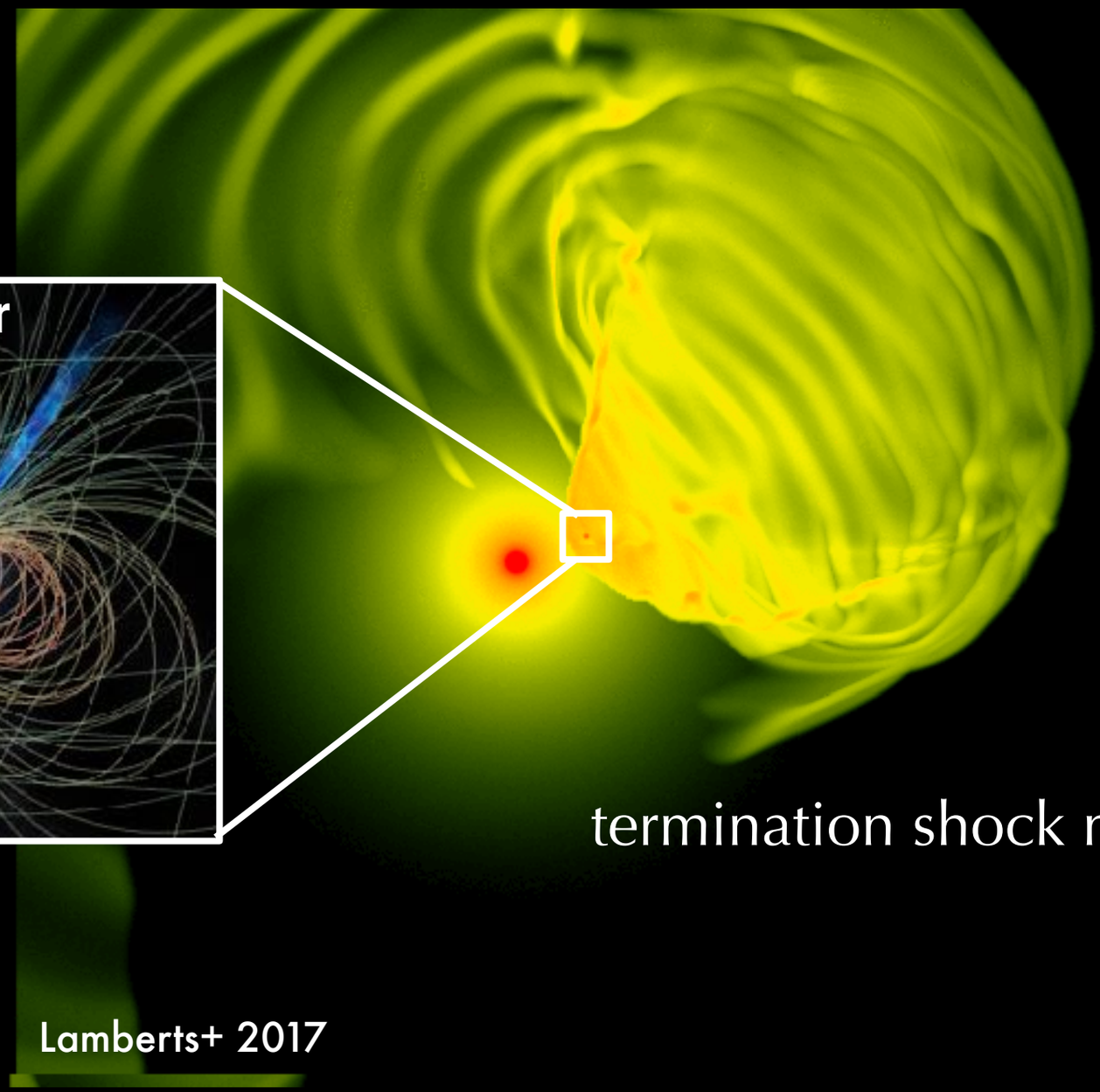
$R_s \sim 10^9 R_{lc} \sim 0.1\,\mathrm{pc}$

Crab PWN in X-rays (CXO)

A Pulsar Wind Nebula in a binary

interaction shaped by massive star wind $\quad p_{\rm ext} = \dfrac{\dot{M}_w v_w}{4\pi(d - R_s)^2}$





Lamberts+ 2017

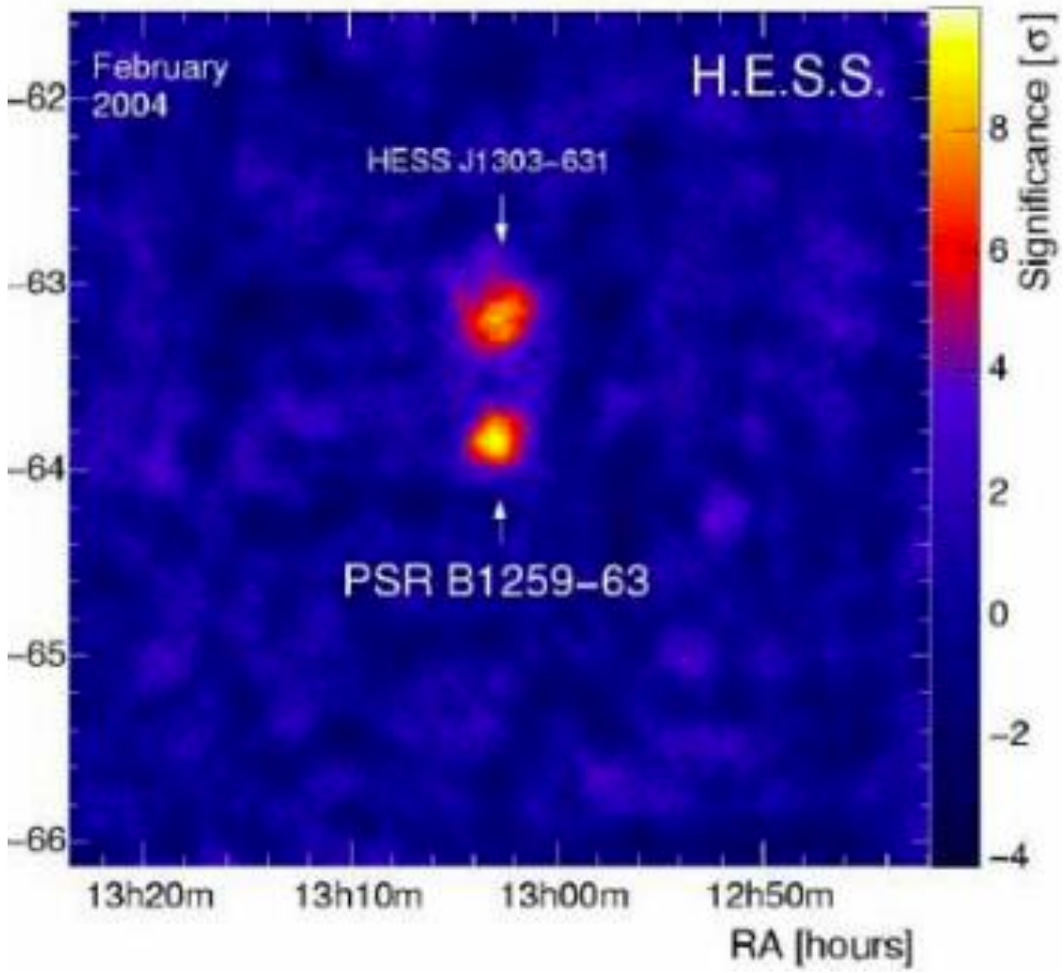
termination shock much **closer** to pulsar

$R_s \sim (10^4 \,\text{to}\, 10^6) R_{lc}$

The first gamma-ray binary

PSR B1259-63, a 48 ms radio pulsar in a 3.5 yr orbit around a 30 $M_\odot$ Oe star

GeV+TeV emission at periastron when orbital separation ~15 R_{star})



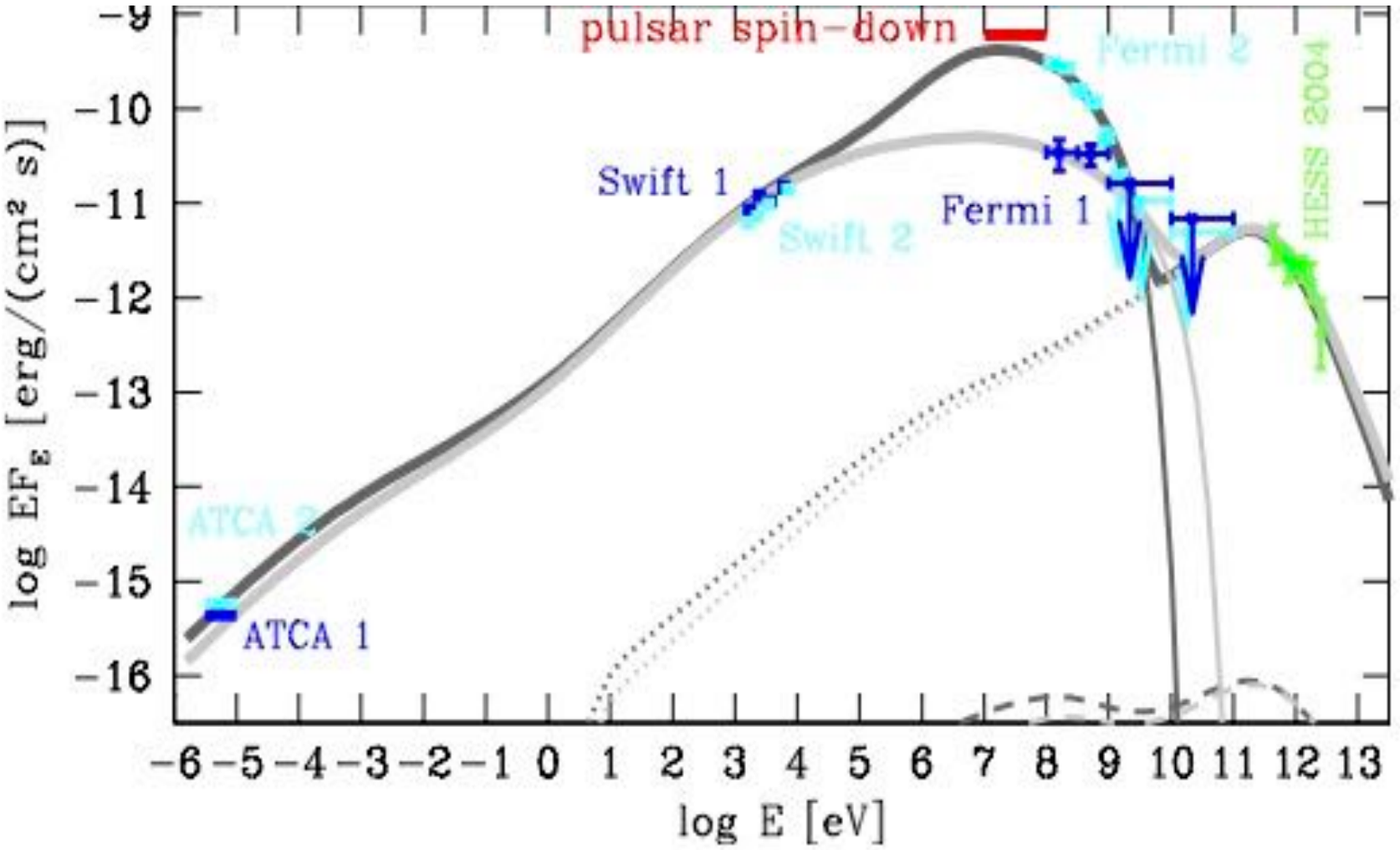
H.E.S.S. 2005

pulsar spinning down on timescale $\tau \approx 3 \times 10^5\,\mathrm{yr}$

spindown power $\dot{E} \approx 8 \times 10^{35}\,\mathrm{erg\,s^{-1}}$

The GeV flares of PSR B1259-63

GeV flares with luminosity = spindown power ~ 40 days after periastron !



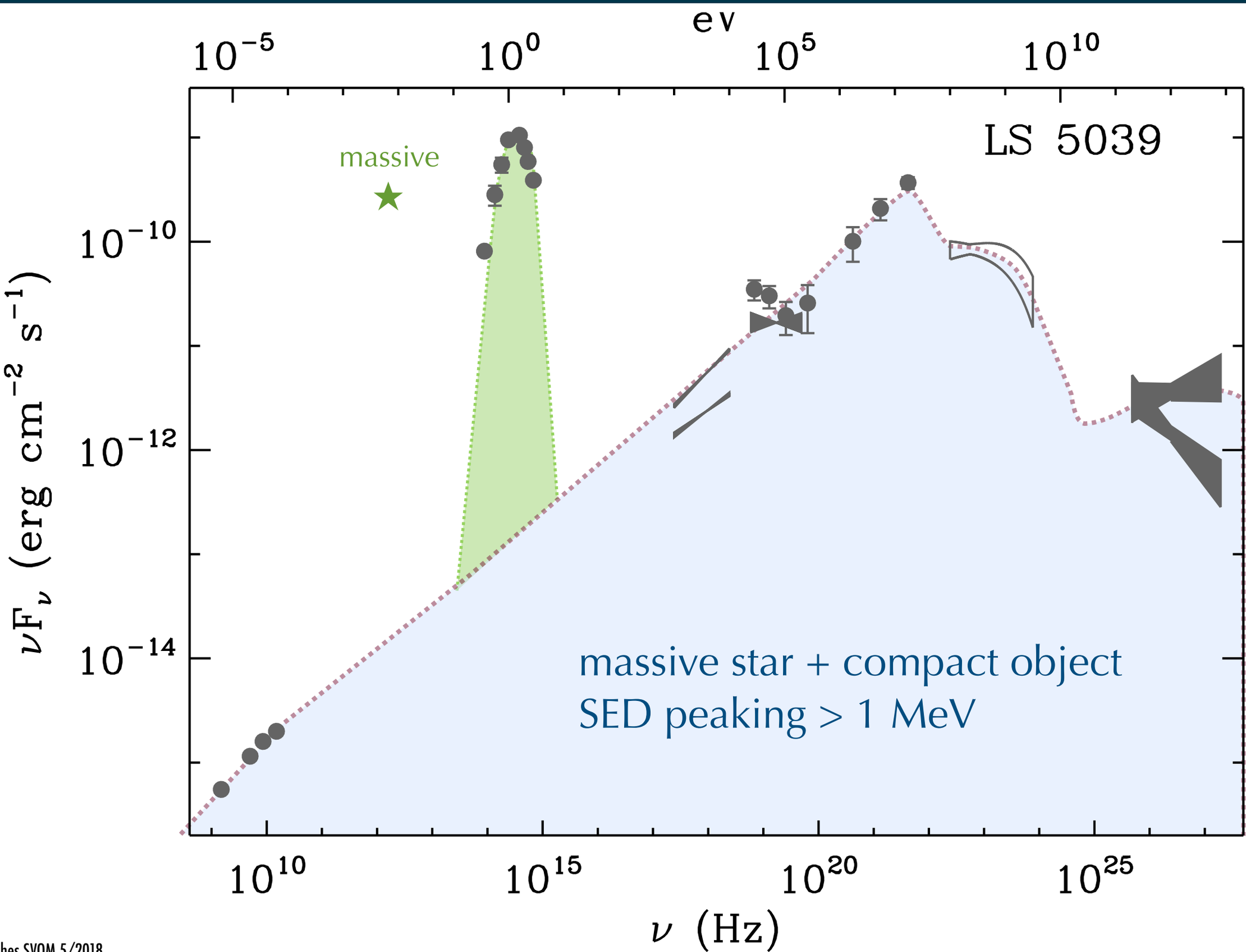
Abdo et al. (Fermi-LAT) 2011

A window into pulsar wind physics

- Gamma-ray binaries = neutron stars with a high spindown power interacting with O or Be massive star companion

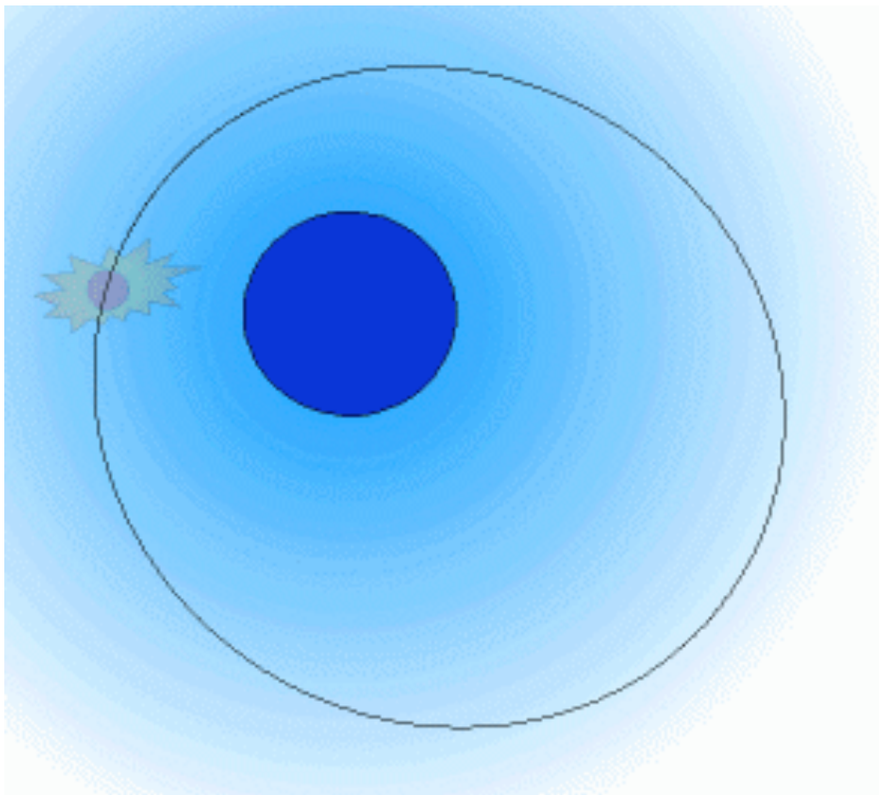
- Access to pulsar wind on smaller scales
  - how to convert magnetic energy into kinetic energy in relativistic outflows

Working definition of a gamma-ray binary

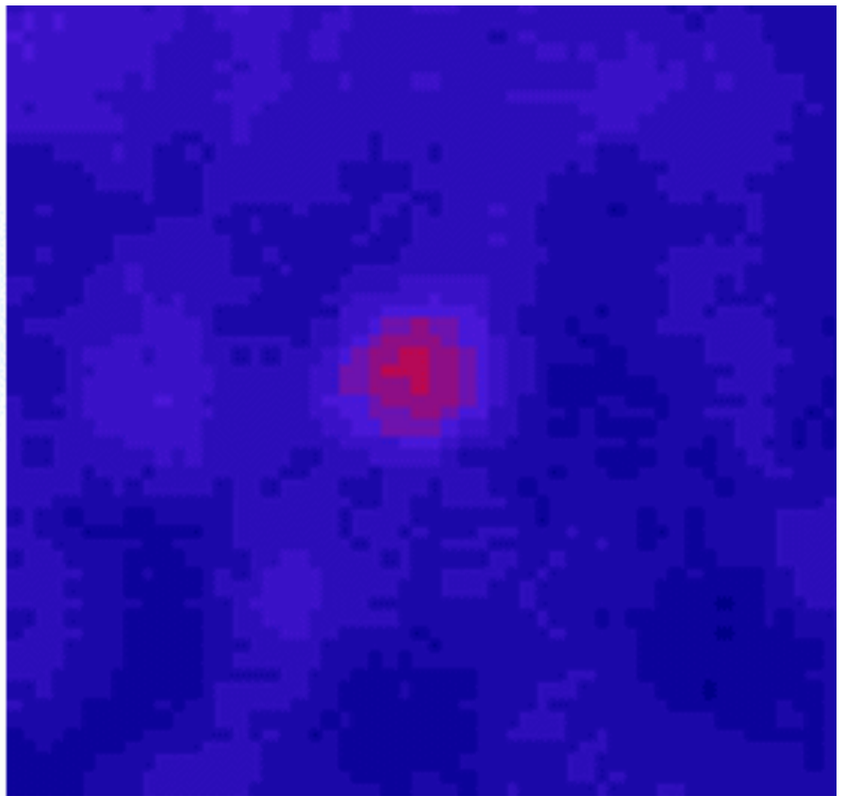


Gamma rays modulated on orbital period

LS 5039, a compact object in a 3.9 day orbit around a massive O star



orbit

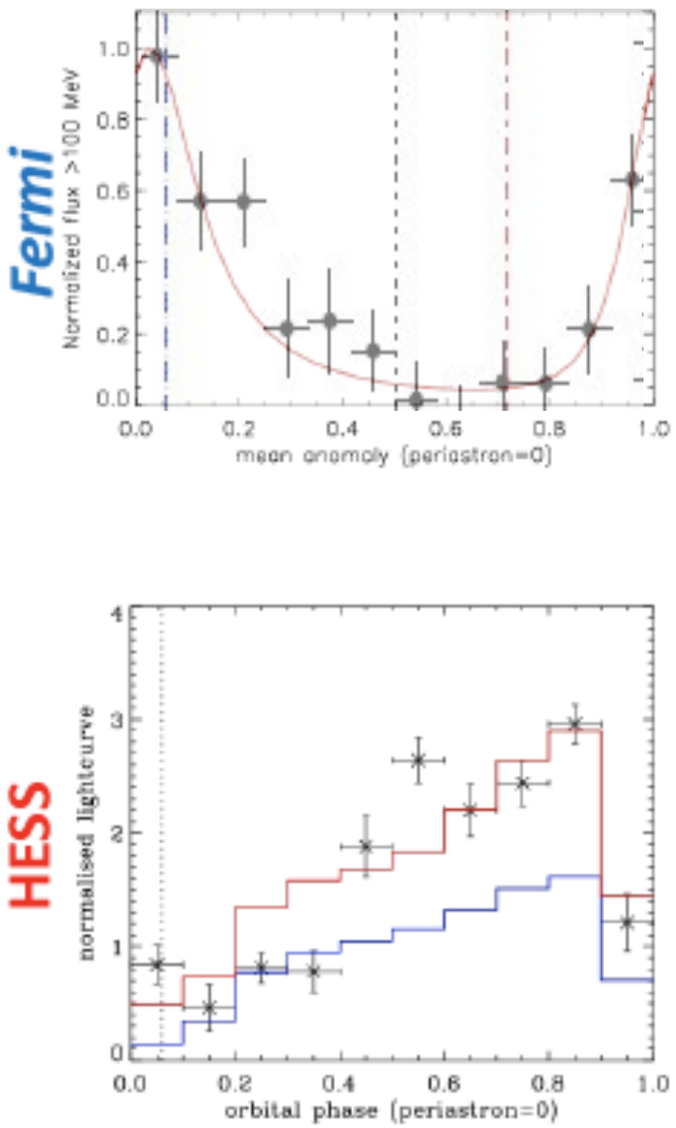


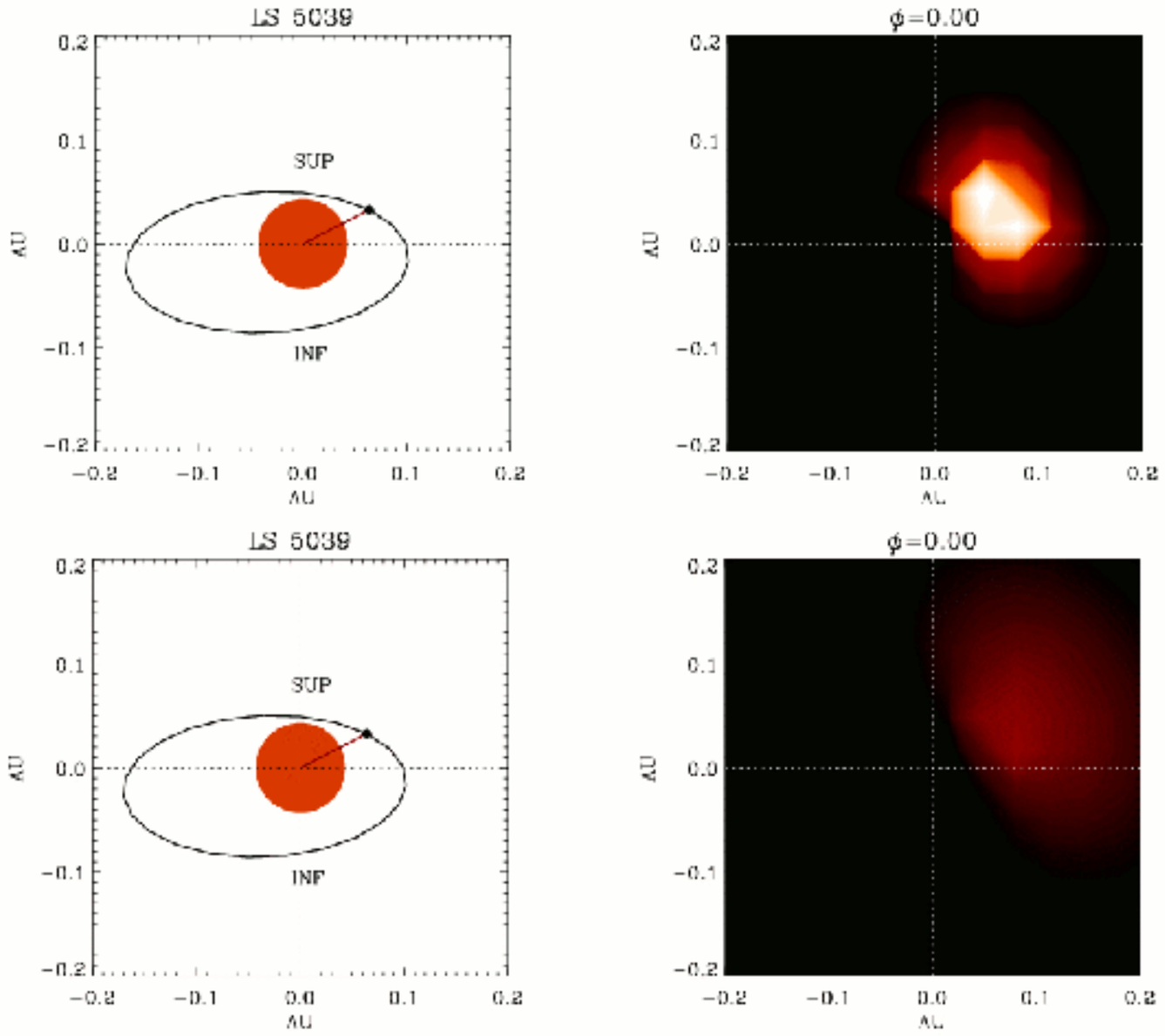
VHE γ-ray emission

H.E.S.S. 2005, 2006

« Geometric » orbital modulations

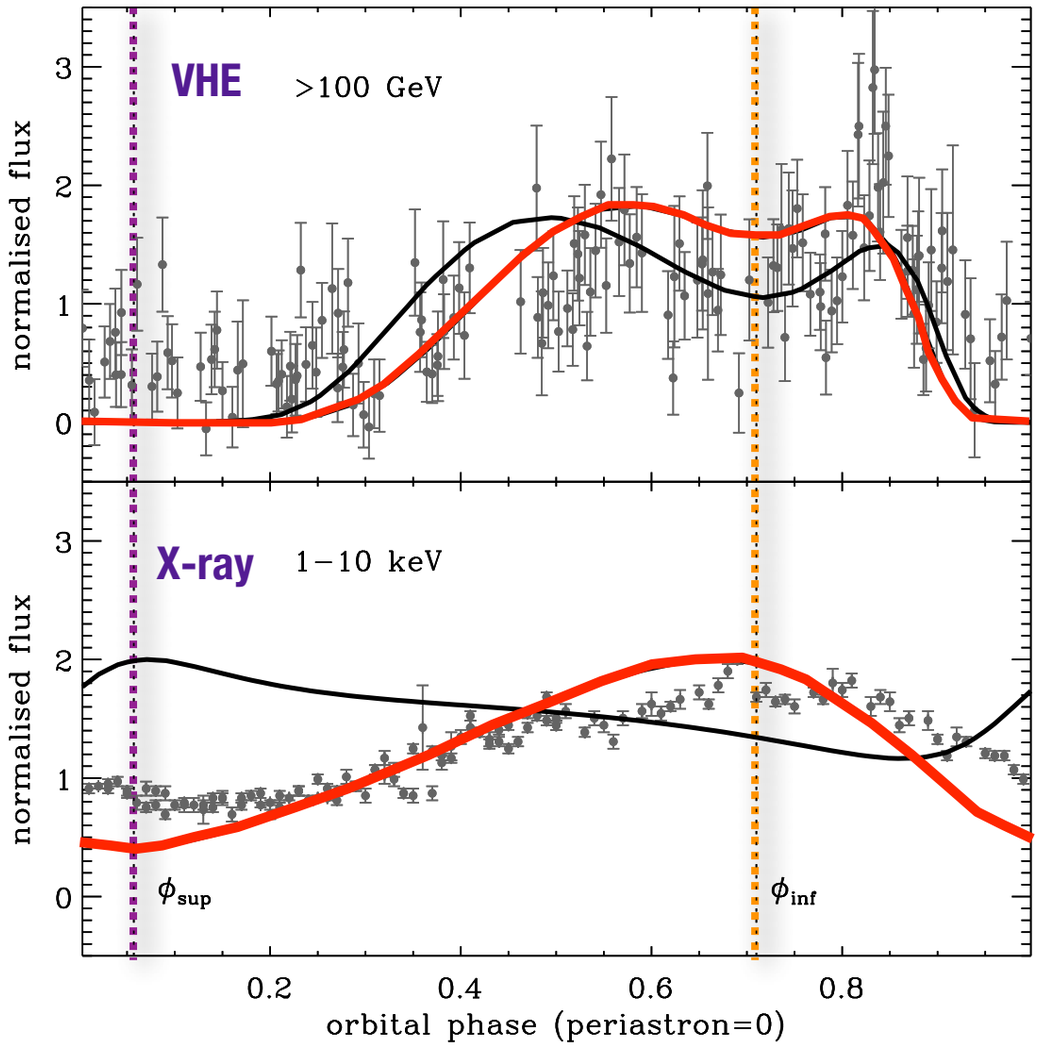
anisotropic inv. Compton scattering + pair production on stellar photons





Cerutti et al. 2010

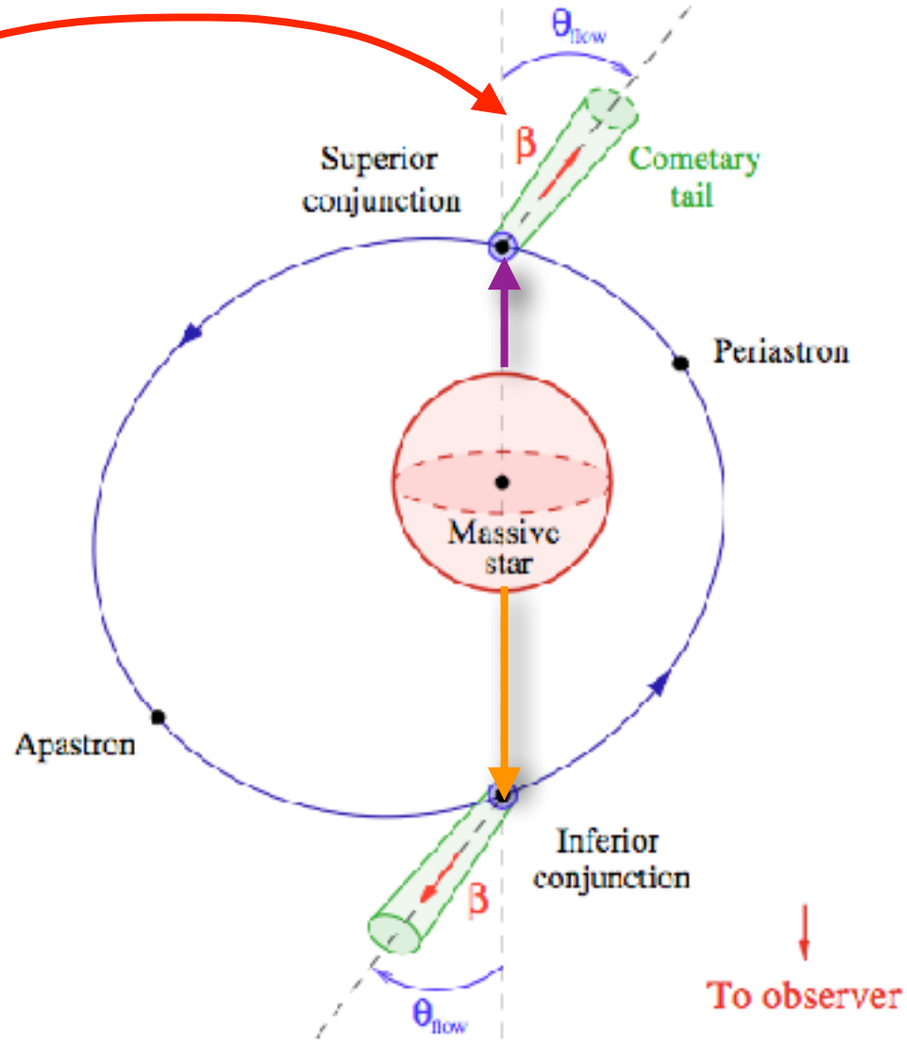
X-rays reflect bulk relativistic motion



Dubus+ 2010, 2015

β=0

β=c/3



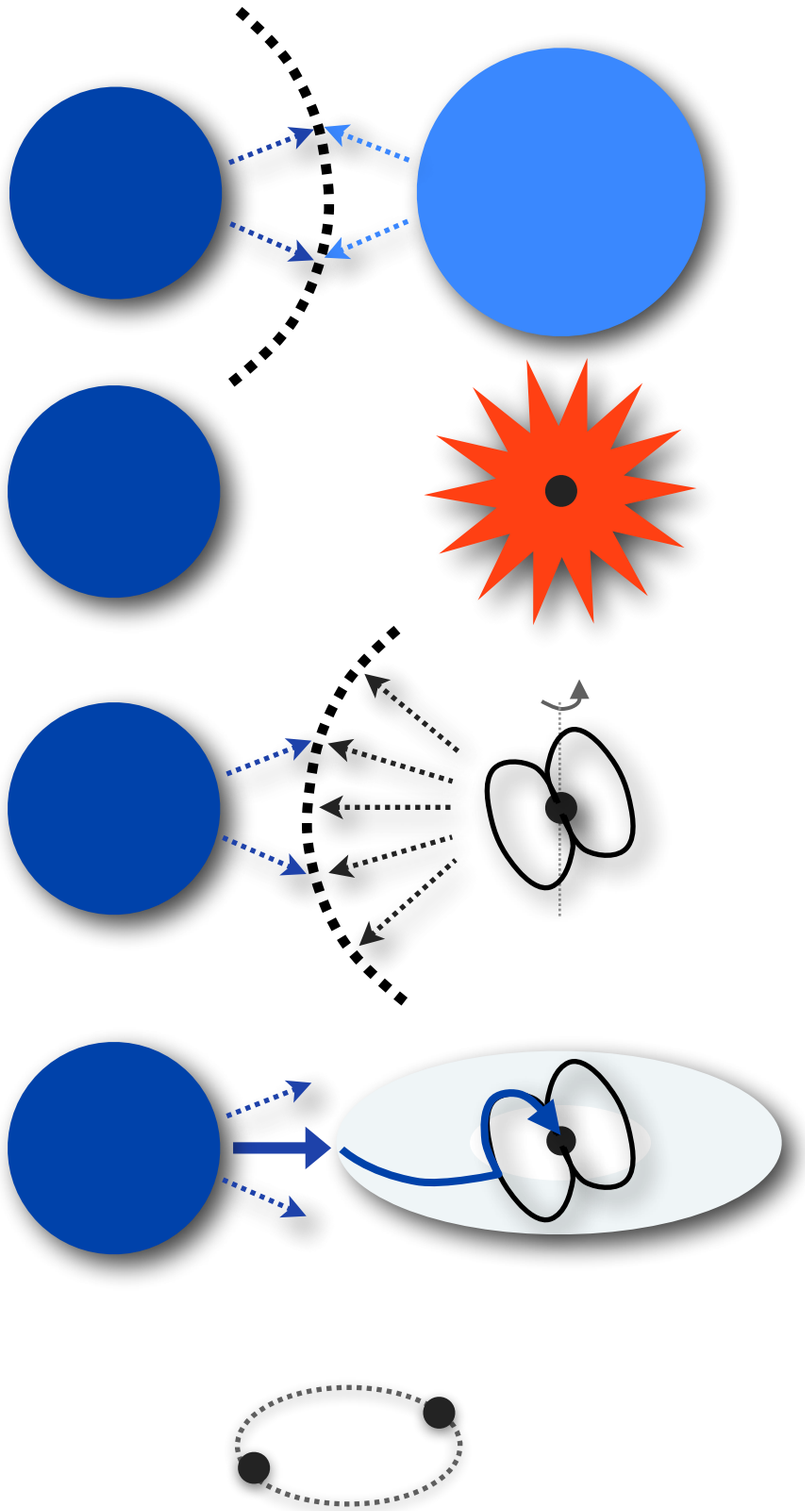
Emission properties of gamma-ray binaries

- Hard X-ray sources with flux ~ (1 to 10) x 10^{-12} erg cm^2 s^{-1}

- Powerful non-thermal emitters up to TeV energies
  - very efficient particle accelerators

- Emission is modulated on orbital period
  - probes different lines of sights into pulsar wind

Gamma-ray binary evolutionary phase



massive stars

colliding wind binary

supernova → neutron star

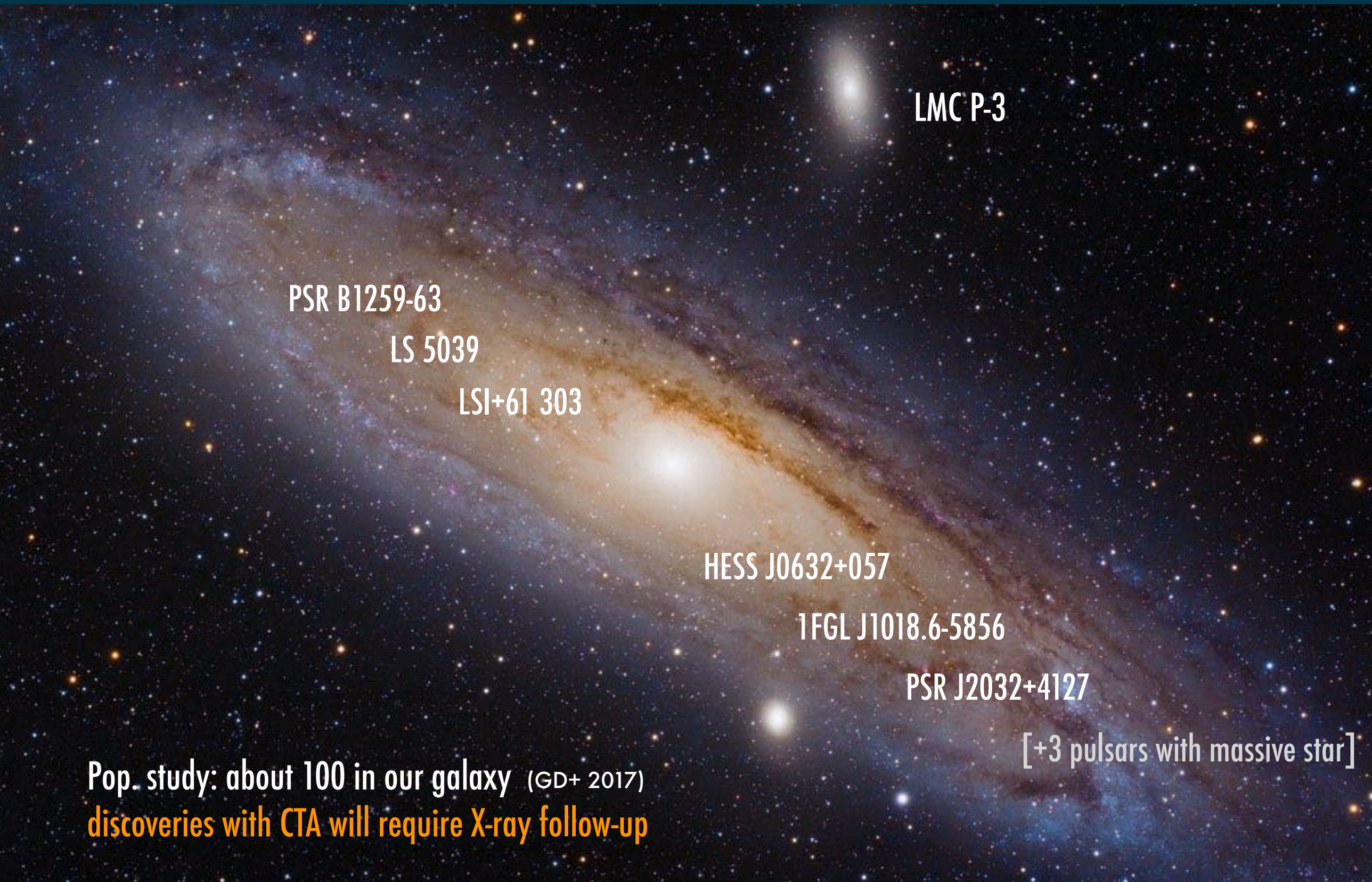
high spindown pulsar → pulsar wind

gamma-ray binaries

pulsar slows down → accretion high mass X-ray binaries

supernova → binary neutron star → sGRB?

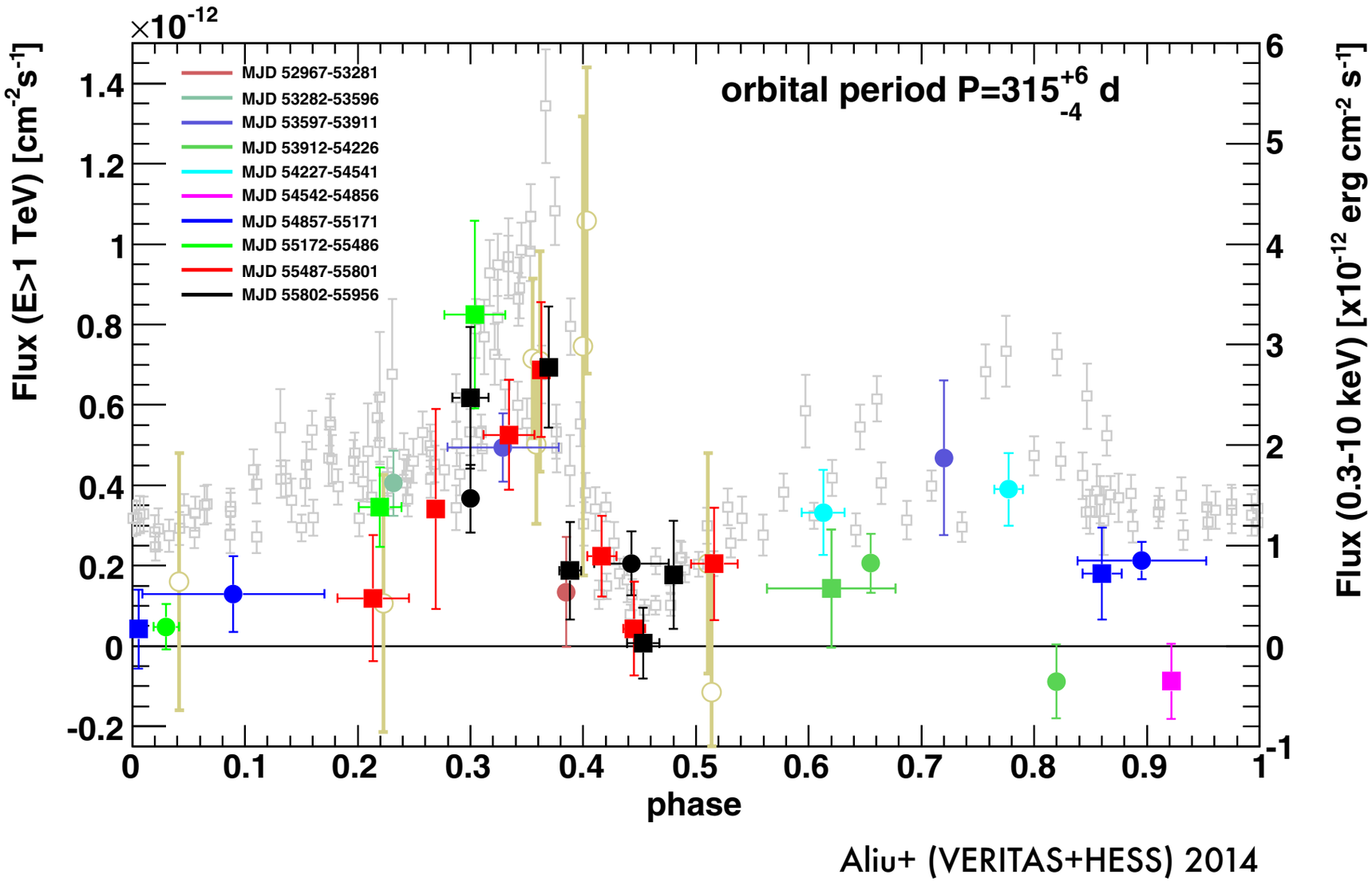
Known gamma-ray binaries



X-ray monitoring is critical

Detection of the orbital period in HESS J0632+57 thanks to *Swift*

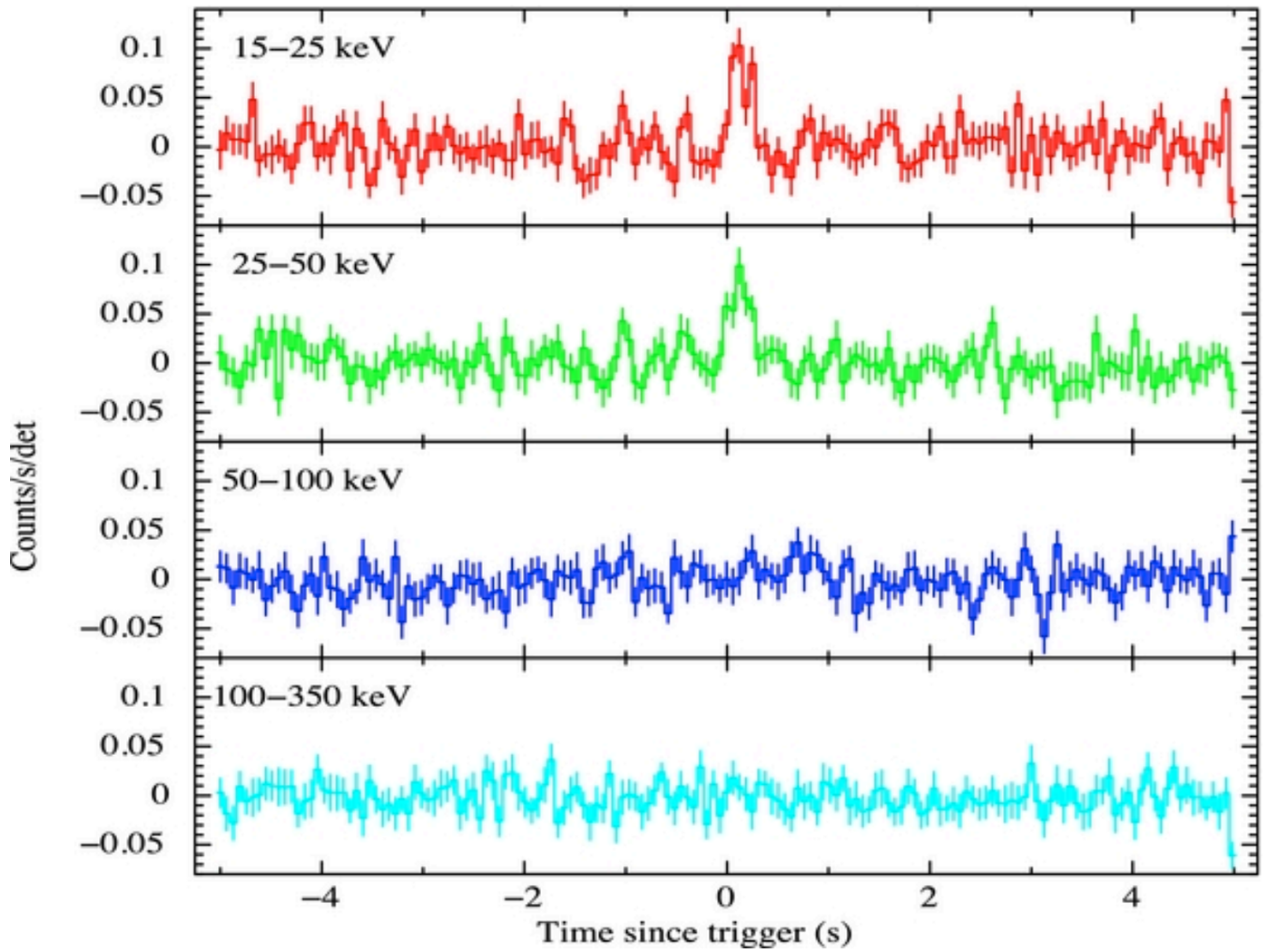
(there could be dozens of such GeV faint systems uncovered by CTA)



Magnetar-like bursts from LS I+61 303

Swift BAT bursts consistent with gamma-ray binary position !

Barthelmy+ 2008, GCN 8215, Burrows+ 2012, GCN 12914



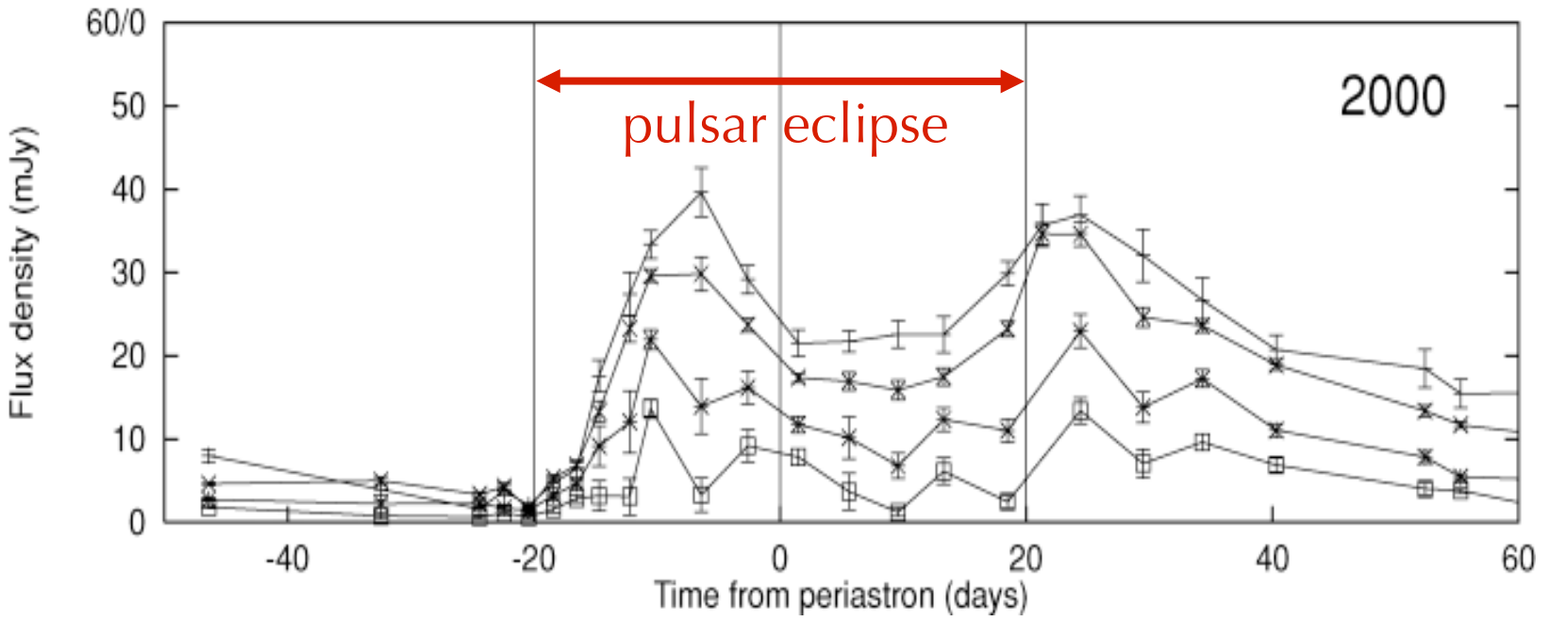
Torres+2012

duration < 0.3 s ; L ~ (3-10) x 10^{37} erg/s
7.5 keV blackbody R ~ 200 m (at 2.6 kpc)

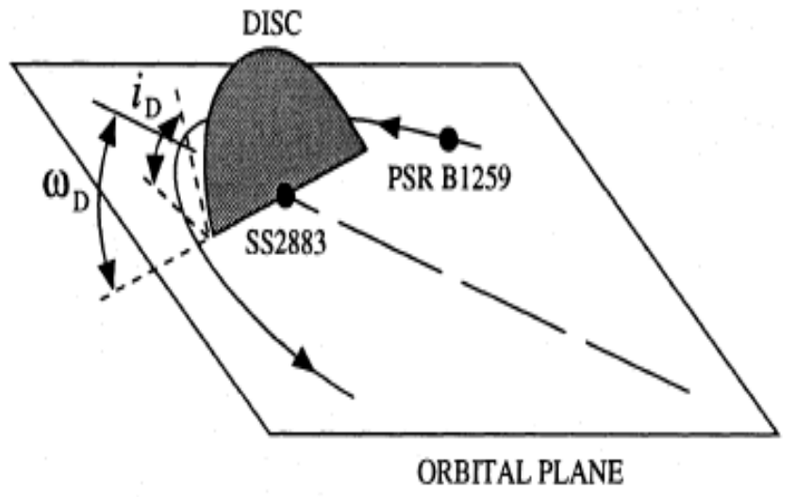
Pulsar is hidden in most gamma-ray binaries

No detection because radio pulses are absorbed by massive star wind

e.g. PSR B1259-63: large scale shock radio emission at periastron but pulsed emission eclipsed



Connors et al. 2002



Melatos et al. 1995

Searching for new gamma-ray binaries

- Rare population of sources, every system counts
  - on the evolutionary path to double NS, NS+BH systems

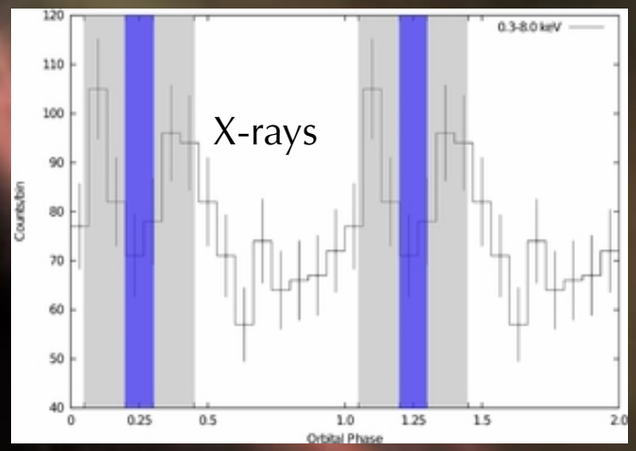
- X-ray follow-up critical to identify gamma-ray source

- Possible sources of **magnetar bursts**
  - implies B~10^{13} G, P~1s or less to have enough power
  - very young system < 10 000 years ?

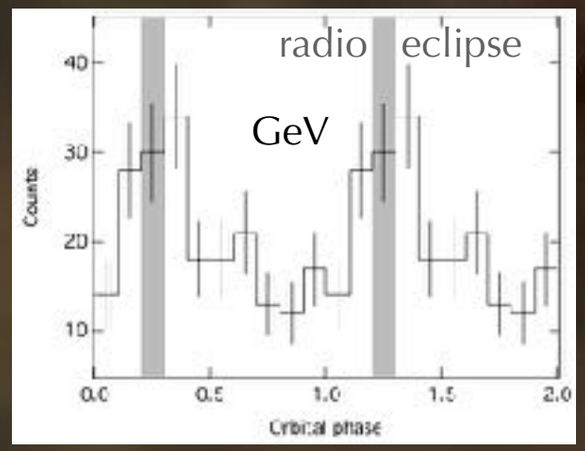
« Low-mass » gamma-ray binaries

- old pulsar spun-up by accretion in LMXB (recycled ms pulsar)
- pulsar wind pressure ends up quenching accretion
- non-pulsed high-energy γ-ray emission in some systems

« black widow » PSR B1957+20



Huang+ 2012



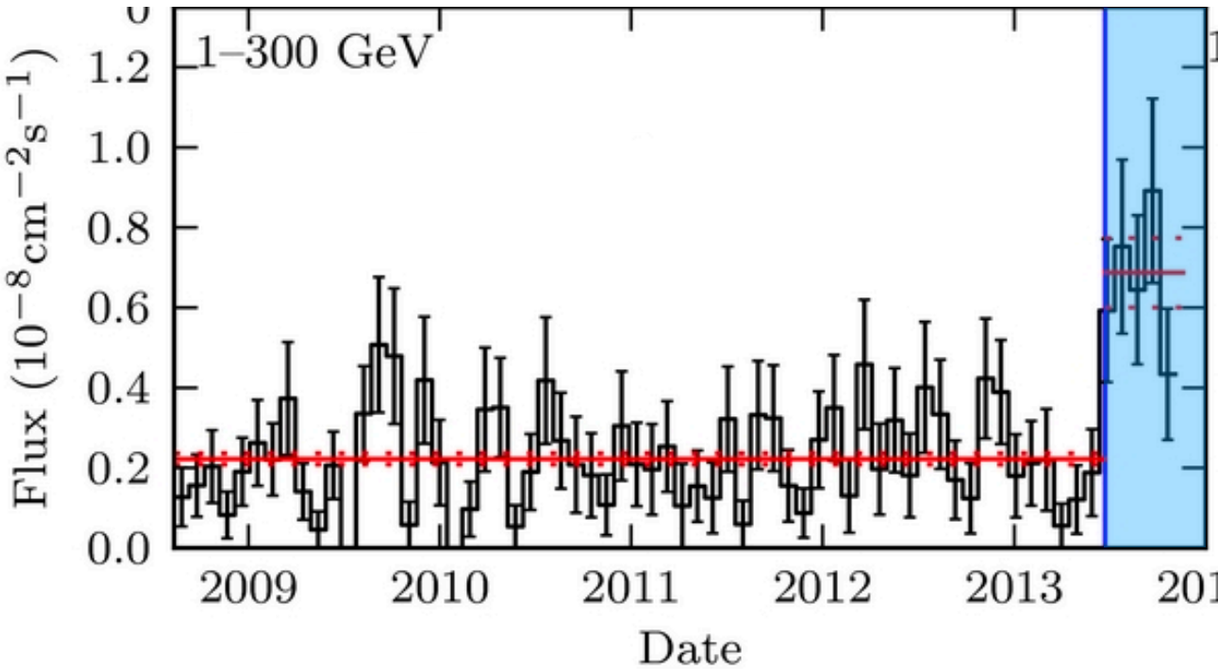
Wu+ 2012

Transitional millisecond pulsars

3(+3?) systems transition between rotation and accretion-powered states

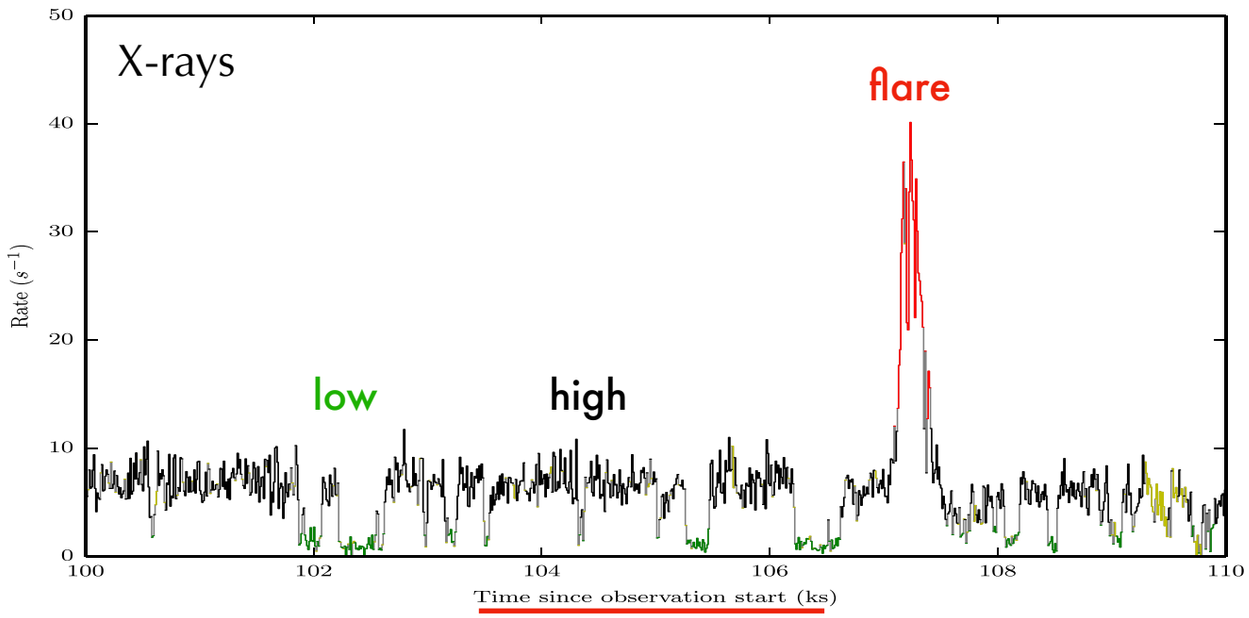
links recycled ms pulsars and accreting ms pulsars !

radio pulsar state — disk state



Stappers+ 2014

fast variability in **disk state**: « mode » switching



PSR J1023+0028

Archibald+ 2015

Summary

- **Gamma-ray binaries** are powered by spindown of a neutron star
- Powerful non-thermal emitters from radio to TeV
- Window into pulsar wind physics

- Follow-up of candidate systems
  - e.g. search (super)orbital modulations
- Long-term monitoring
  - e.g. state changes of transitional millisecond pulsars
- **Watch for magnetar bursts associated with binaries**