X-ray binaries as sources of high energy emission

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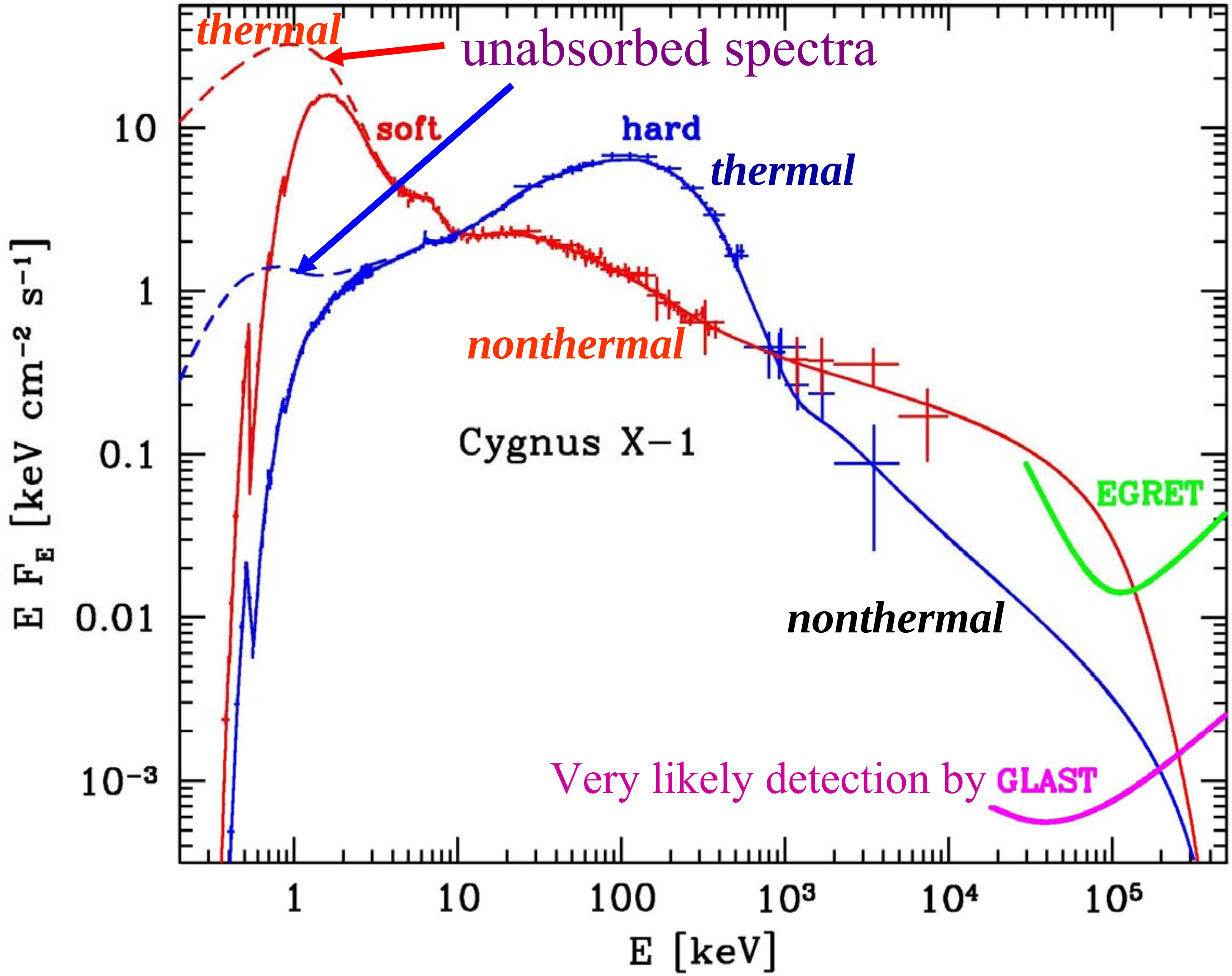
I will cover only high-mass X-ray binaries (HMXBs) since only those are confirmed sources of emission above ~1 MeV.

Classification of HMXBs:

- Compact object: a neutron star (most of HMXBs) or a black hole (Cyg X-1, LMC X-1, LMC X-3, SS 433, M33 X-7, IC 10 X-1, NGC 300 X-1, probably many of ULXs).
- Companions: O, B, supergiants, Be, WR.
- Mode of accretion: via stellar wind (e.g., Cyg X-1, Cyg X-3, M33 X-7), Roche-lobe overflow (SS 433, LMC X-4), or from a Be-star decretion disc.
- Magnetic field of the neutron star: high fields, $\sim 10^{12}$ G, in almost all cases.
- X-γ-rays from accretion or pulsar-wind/stellar-wind interaction (PSR B1259–63, LSI +61 303).

Black-hole HMXBs

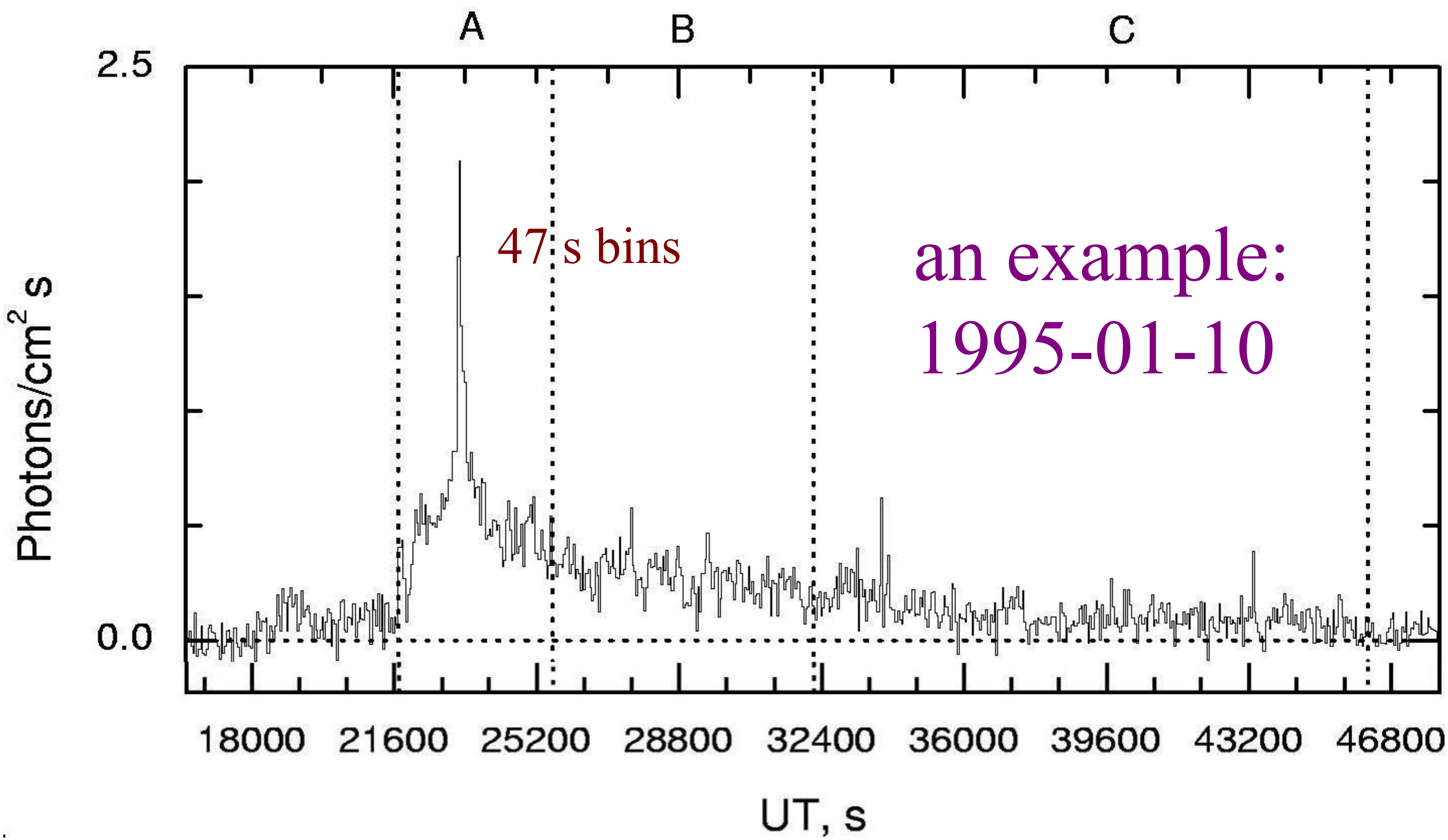
- Black-hole HMXBs: the main difference with respect to low-mass X-ray binaries (LMXB) with black holes is the persistence of emission.
- Otherwise very similar spectral and timing properties, similar spectral states, e.g. Cyg X-1 vs. GX 339–4, in spite of the different accretion mode, wind vs. Roche lobe overflow.

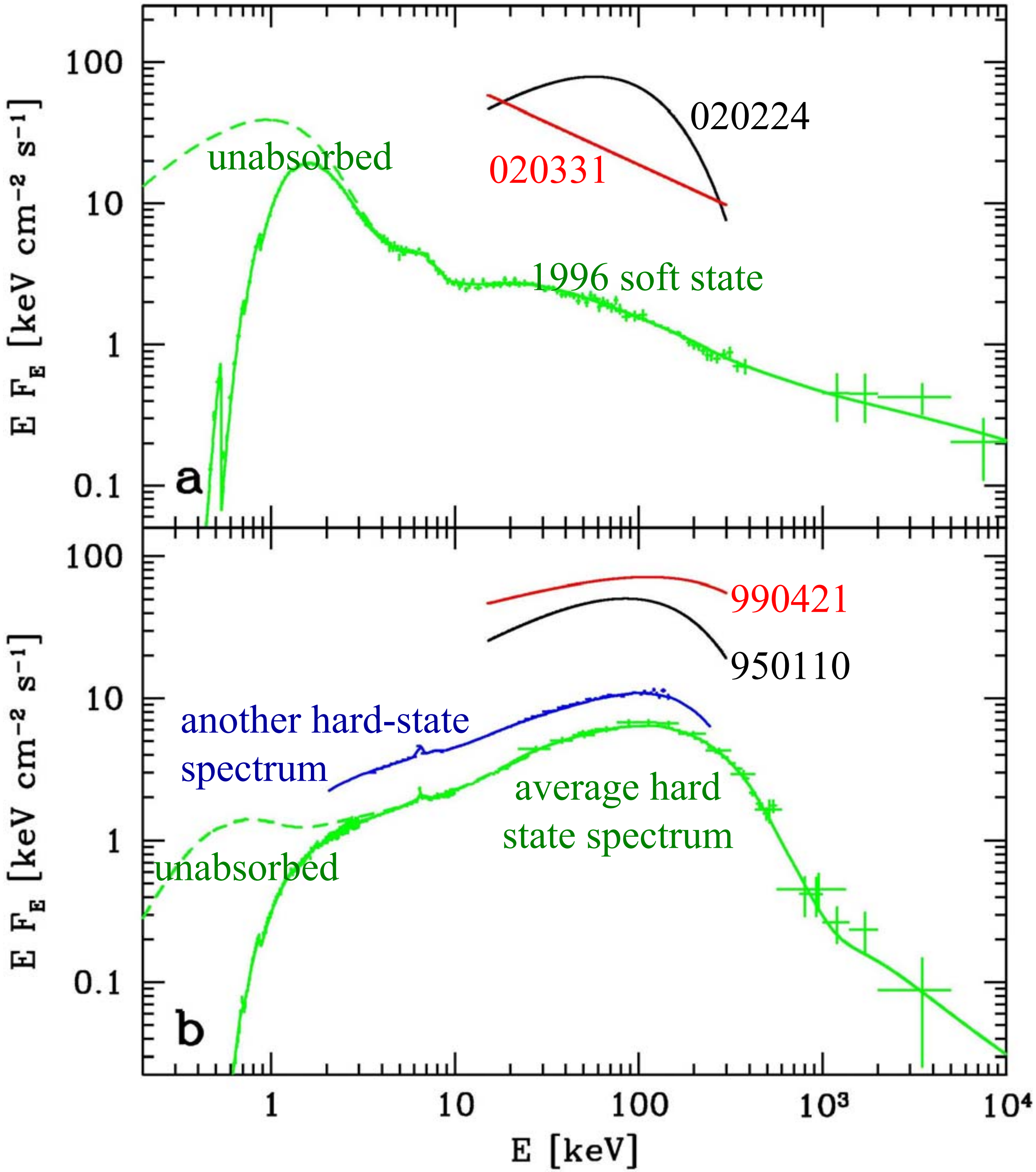


Main spectral states of accreting black holes

Z. & Gierliński (2004)

Outbursts of Cyg X-1 (Stern et al. 2001; Golenetskii et al. 2003; Türler et al. 2006)



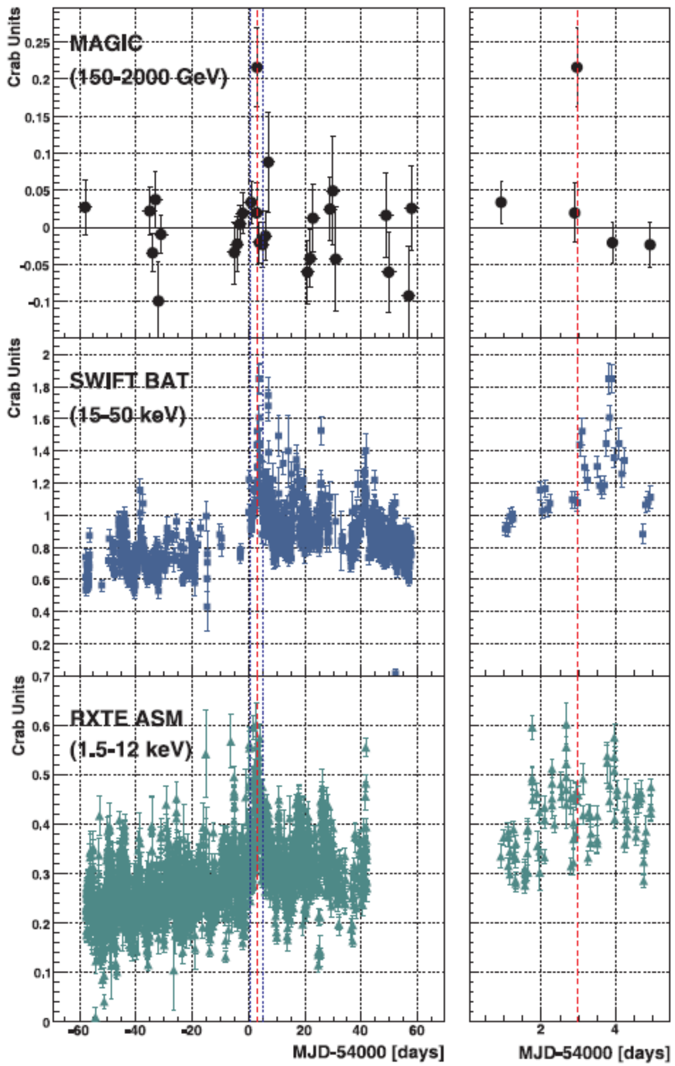


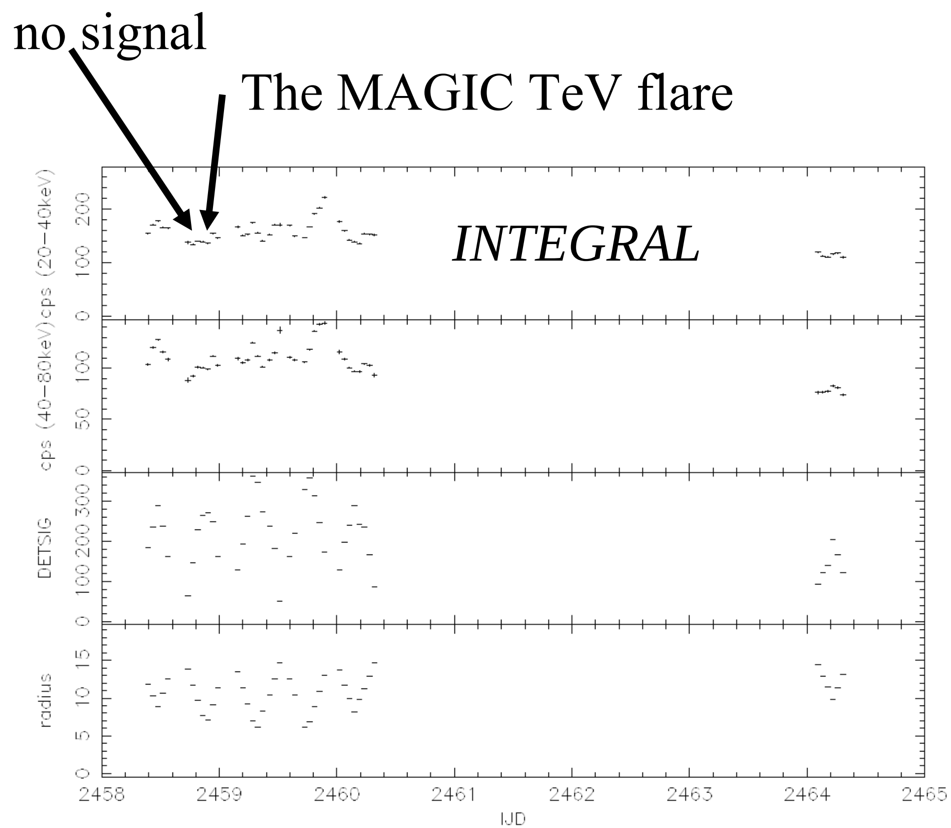
Spectra of the outbursts at their peaks

$L \leq 0.3 L_E$ at the peak

Possibly caused by large inhomogeneities in the accreting wind.

The MAGIC TeV flare of Cyg X-1





Only 3.2σ significance. No clear theoretical explanation. It took place during a relatively minor X-ray outburst, but only a day after its start.

Neutron-star HMXBs

- All confirmed neutron stars in high-mass X-ray binaries (HMXB) have high magnetic fields. Accretion, if present, is onto the polar caps, causing X-ray pulsations.
- Almost all NS LMXBs have weak fields, implying decay of the magnetic field.

Some exceptions:

- The X-ray burster Cir X-1 claimed to have a supergiant companion. Also the non-recycled ms pulsar PSR J1903+0327 with $B \sim 10^8$ G recently discovered. Probably neutron stars can be born with a weak field.
- Three known non-recycled X-ray pulsars with low-mass companions, Her X-1, GX 1+4 and X1626–67. $B > 10^{12}$ G measured in Her X-1, from a 40-keV cyclotron line.

LMC X-4

Boroson et al. 2001

The disc is tilted with respect to the binary plane and precessing.

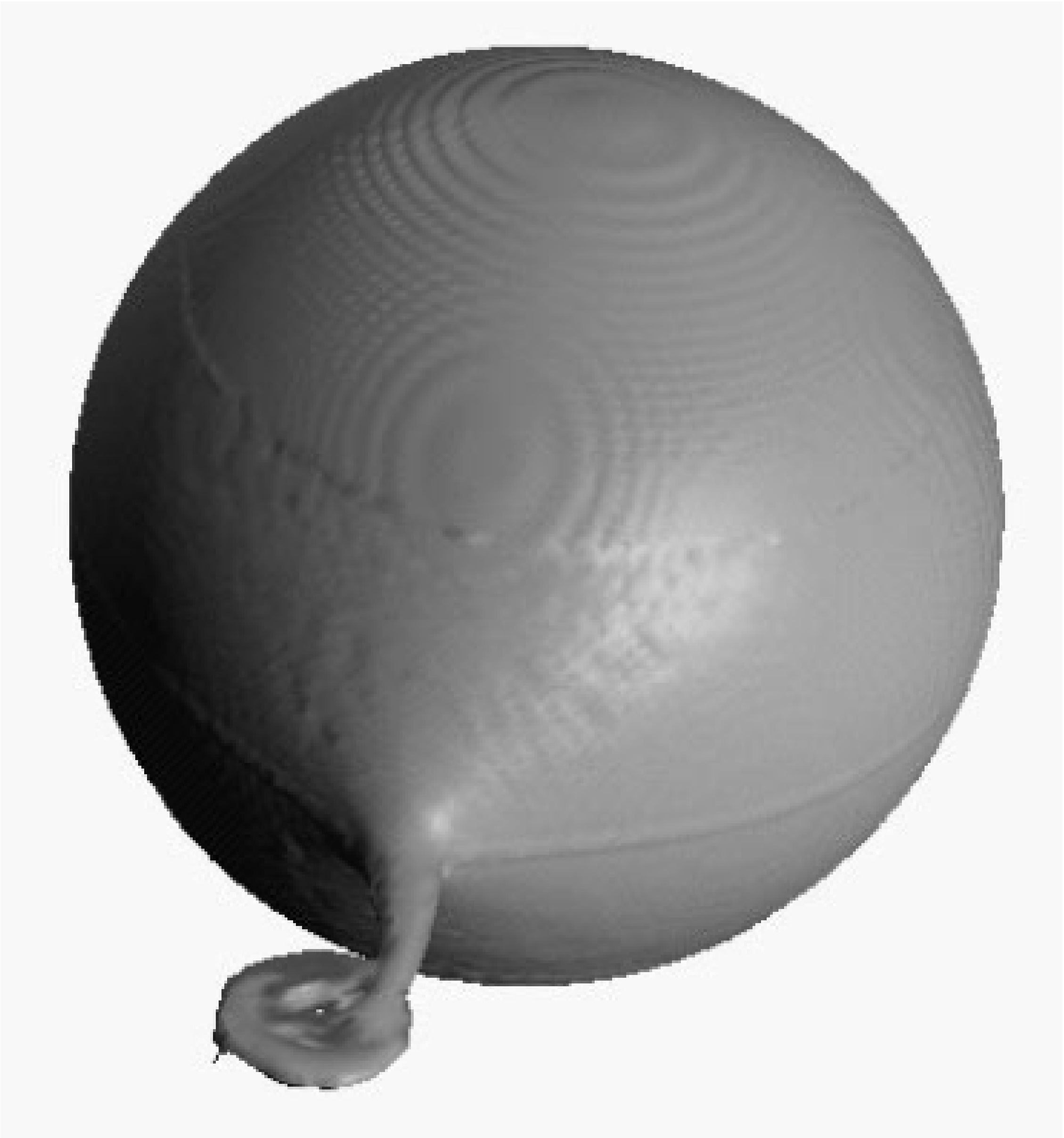


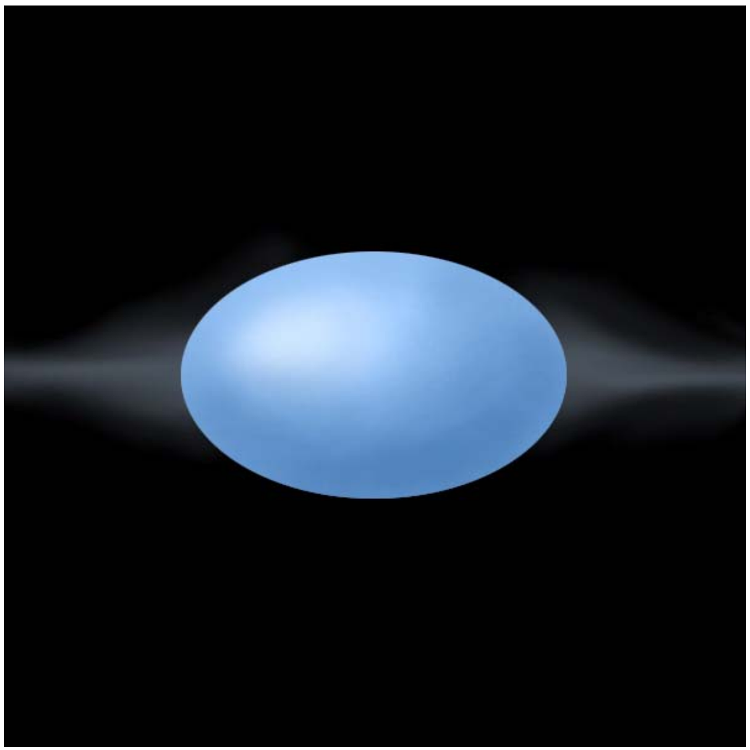
FIG. 1.—Isodensity surface of the hydrodynamic model at the end of the numerical simulation, illustrating the relative scales of the accretion disk, tidal stream, and primary star.

X-ray binaries with Be stars

- Be stars are B stars rotating close (0.8–0.9) to breakup.
- All known Be binaries contain neutron stars (although white-dwarf and helium-star probably exist but are difficult to detect).
- The stars have equatorial decretion discs, which are probably viscous and similar to accretion discs, except for the sign of the flow rate.
- All have substantial eccentricity, and accretion can proceed via tidal removal of angular momentum .
- Often accretion only around the periastron, when the neutron star interacts with the decretion disc.

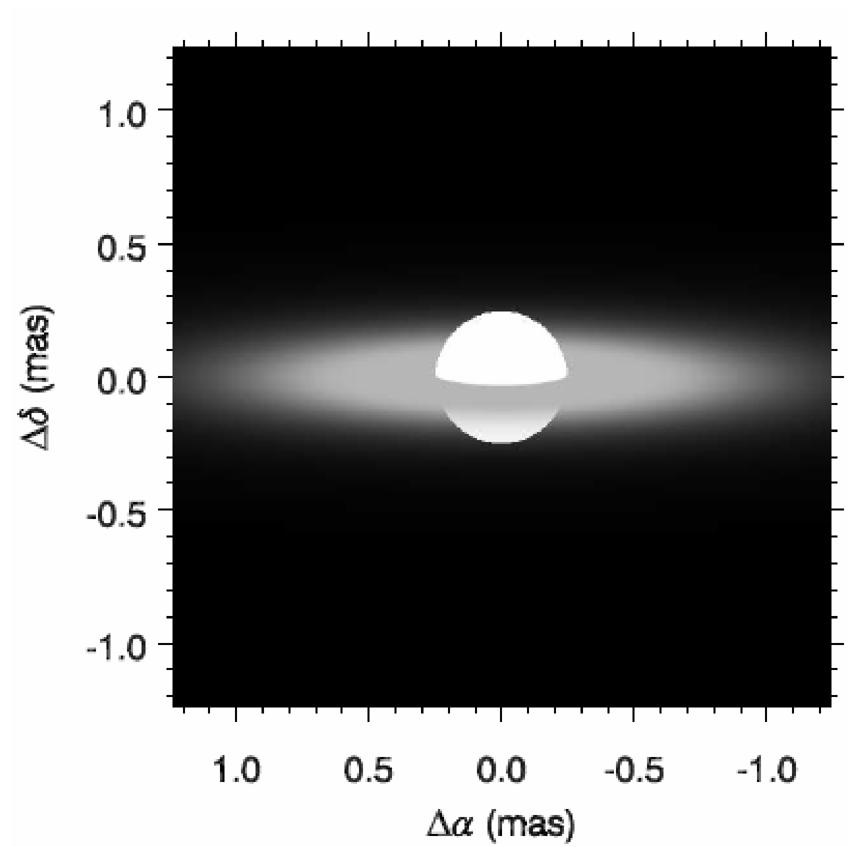
Interferometry of Be stars and their discs

Achernar (α Eridani)



Domiciano de Souza et al. 2003

γ Cas



Gies et al. 2007

Be/X-ray binaries

- The decretion disc is tidally truncated, usually close to the periastron distance.
- In highly eccentric Be binaries, the neutron star interacts with the disc around periastron, giving rise to X-ray outbursts periodic with the orbital period (so called type I outbursts).
- In weakly eccentric binaries, the matter accumulates in the truncated disc. After its mass exceeds some critical value, there is a rapid transfer onto the neutron star, which represents type II outbursts, occuring with intervals much longer than the orbital period.

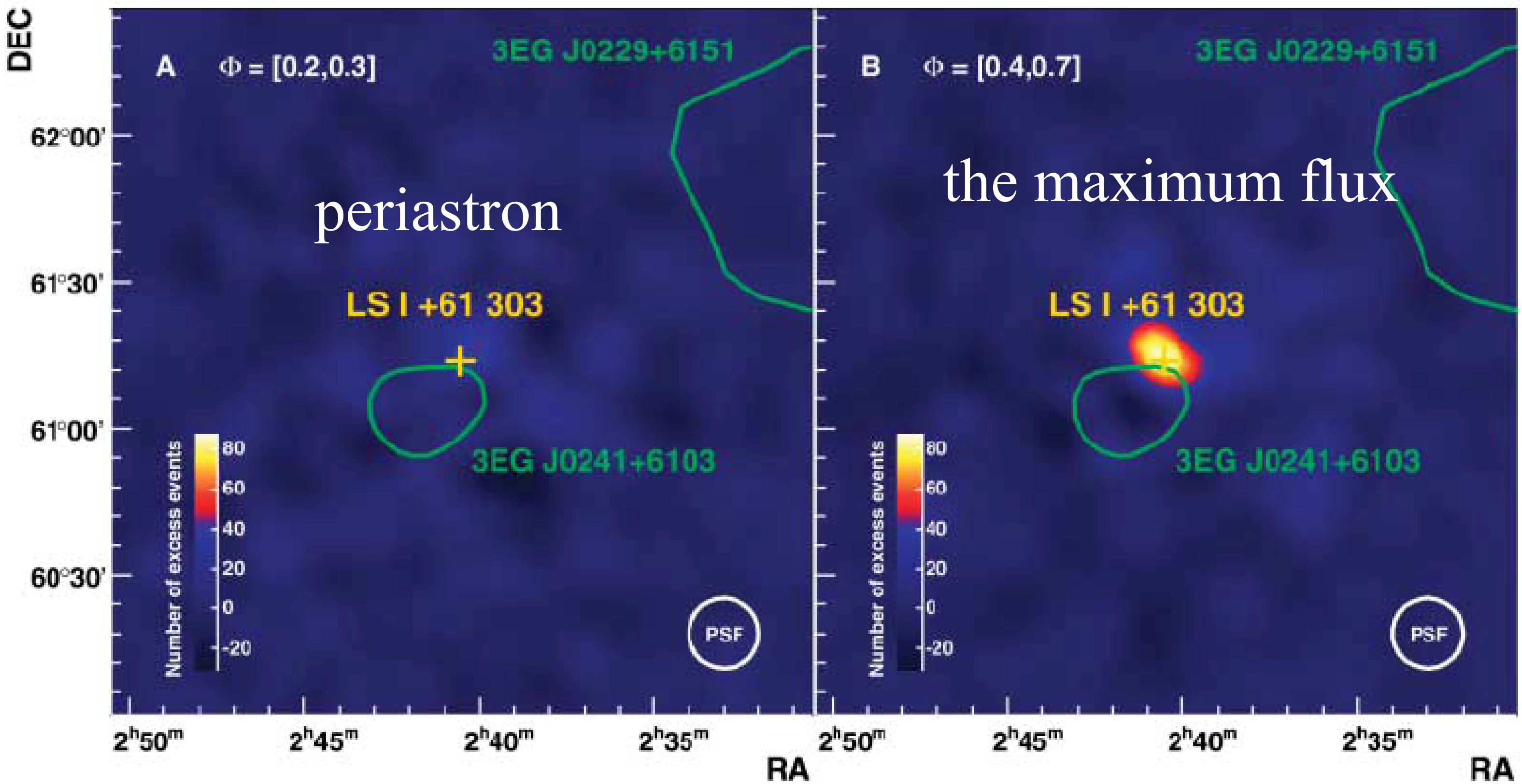
HMXBs with neutron stars in which accretion is inhibited by a pulsar wind

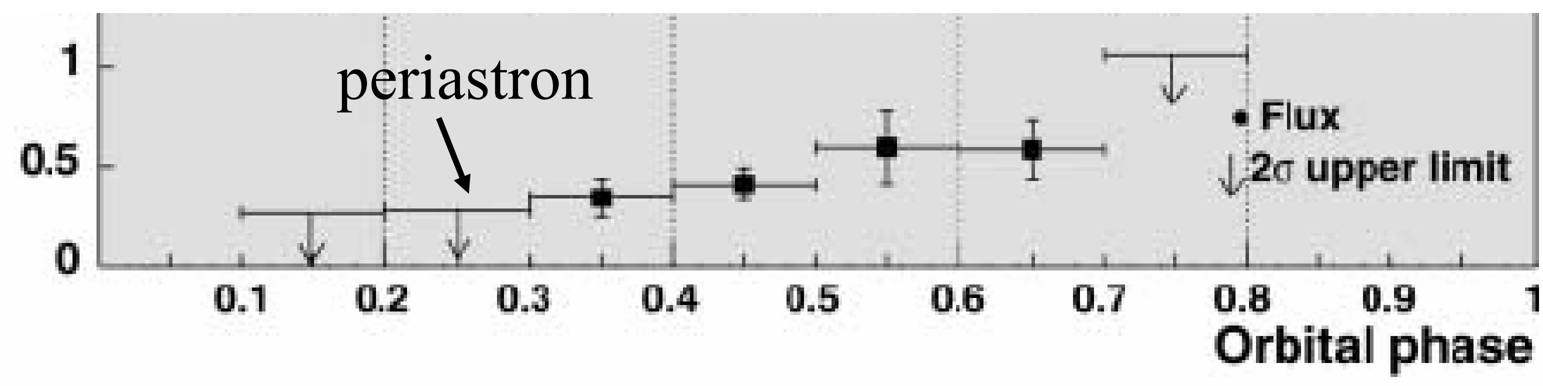
- The period has to be approximately <0.1 s for the wind to be strong enough.
- Binary analogs of pulsar-wind nebulae.
- One 100% confirmed case, PSR B1259–63.
- Two suspected cases, LSI +61 303, and LS 5039.
- Those three systems coincide with the confirmed cases of GeV–TeV emission from binaries.

The high-mass X-ray binaries LS I +61 303 and LS 5039

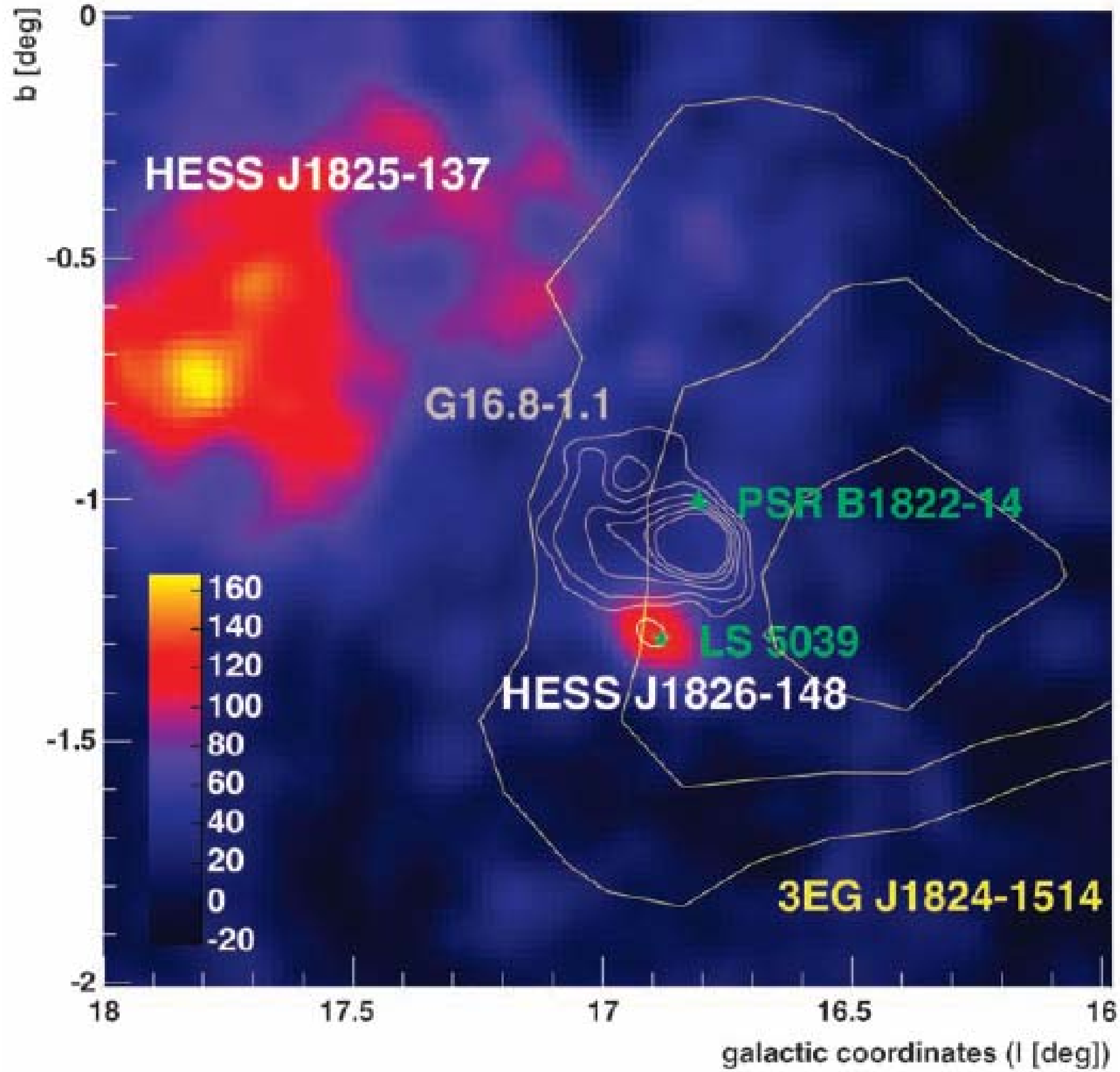
- They have been almost universally be considered accreting binaries and called *microquasars*.
- But the problem is the sources do not look *at all* like any X-ray binary accreting at a low rate ($L \approx 5\times10^{35}$ erg s^{-1}), e.g., the spectra show no high-energy cutoff up to >1 MeV.

The MAGIC detection of LS I +61 303

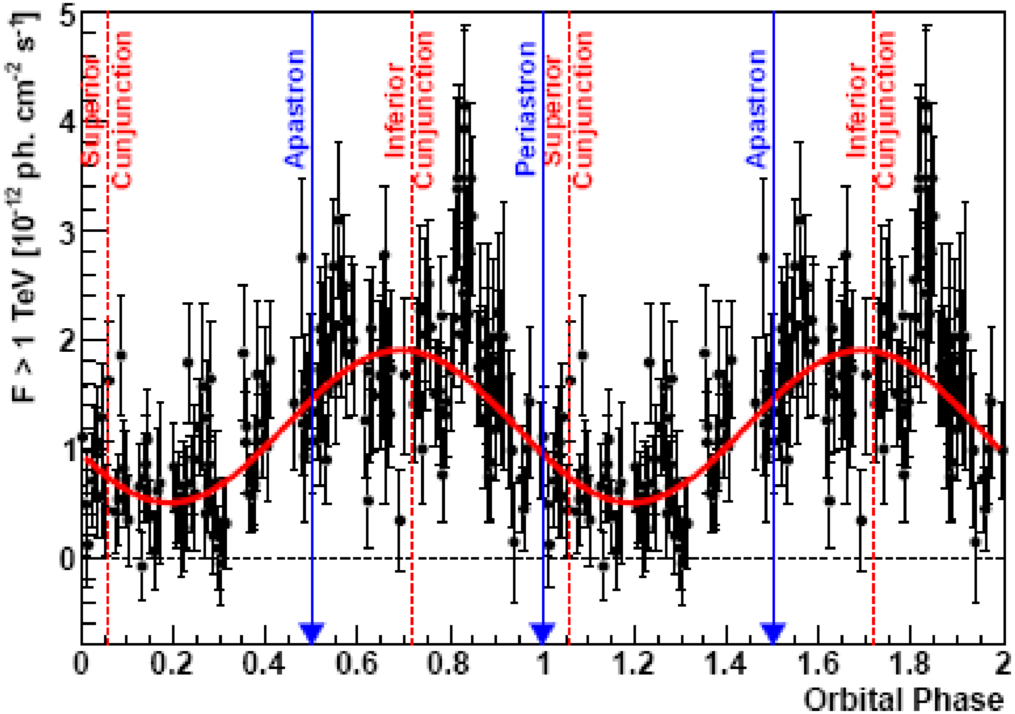




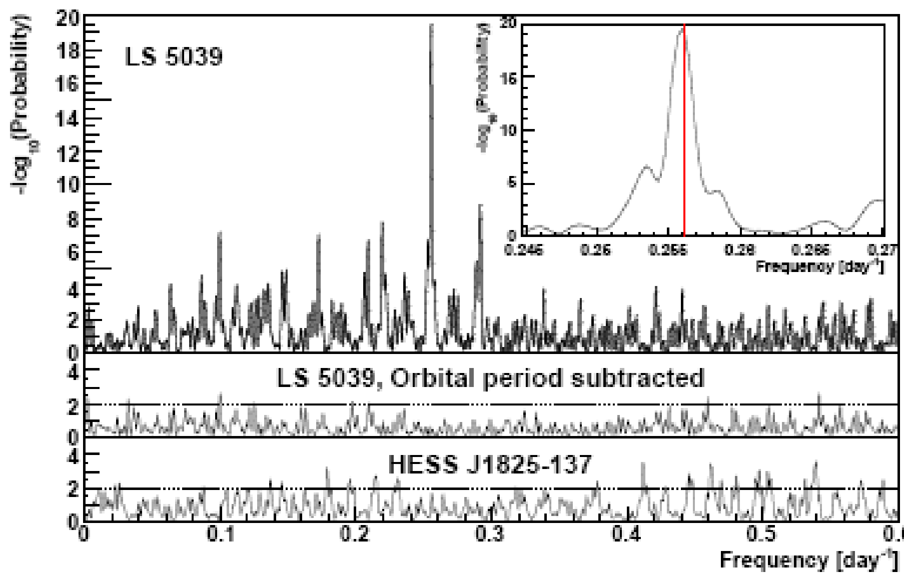
The HESS detection of LS 5039



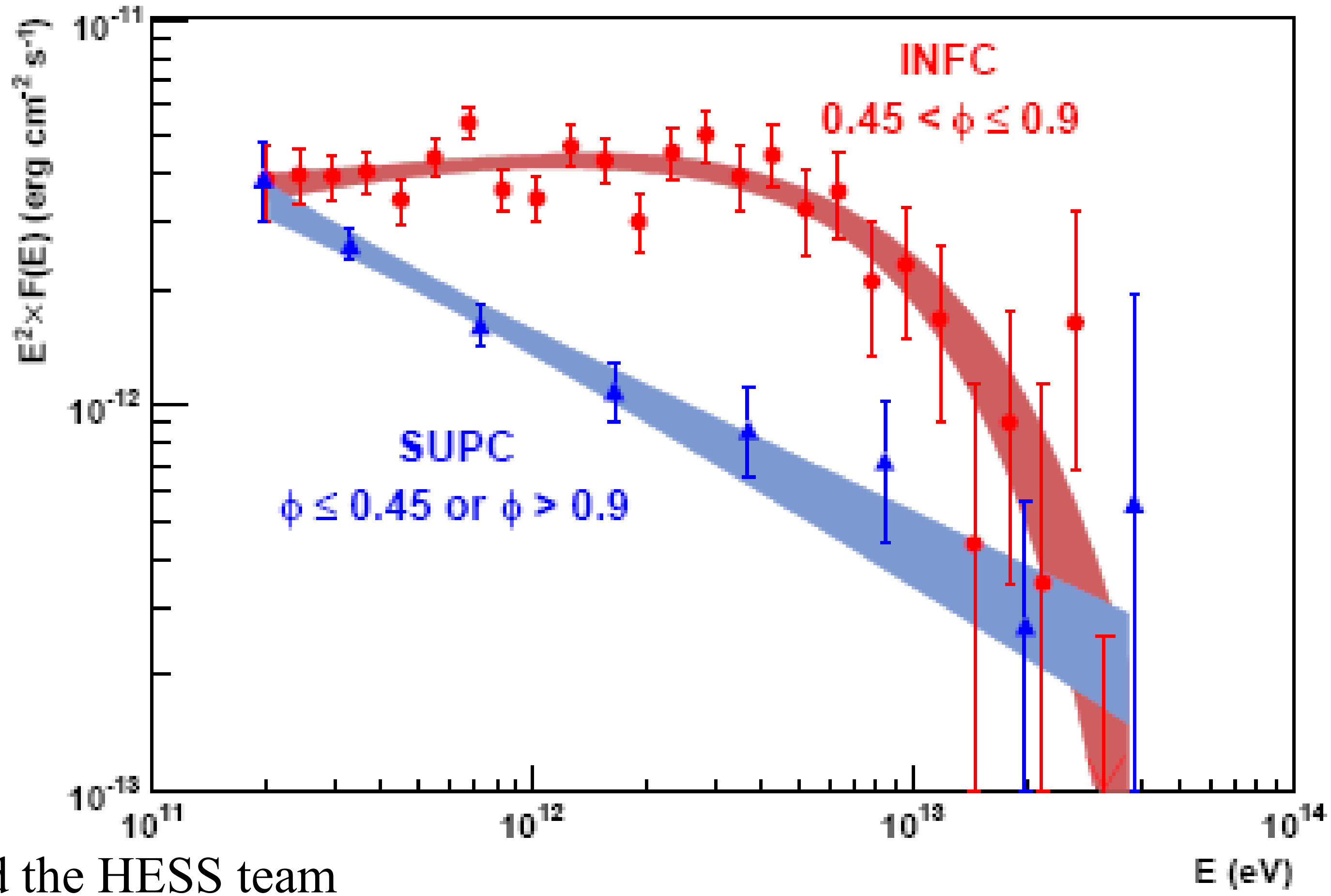
TeV orbital modulation in LS 5039:



de Naurois and the HESS team



TeV spectral variability in LS 5039, partly caused by phase-dependent pair absorption



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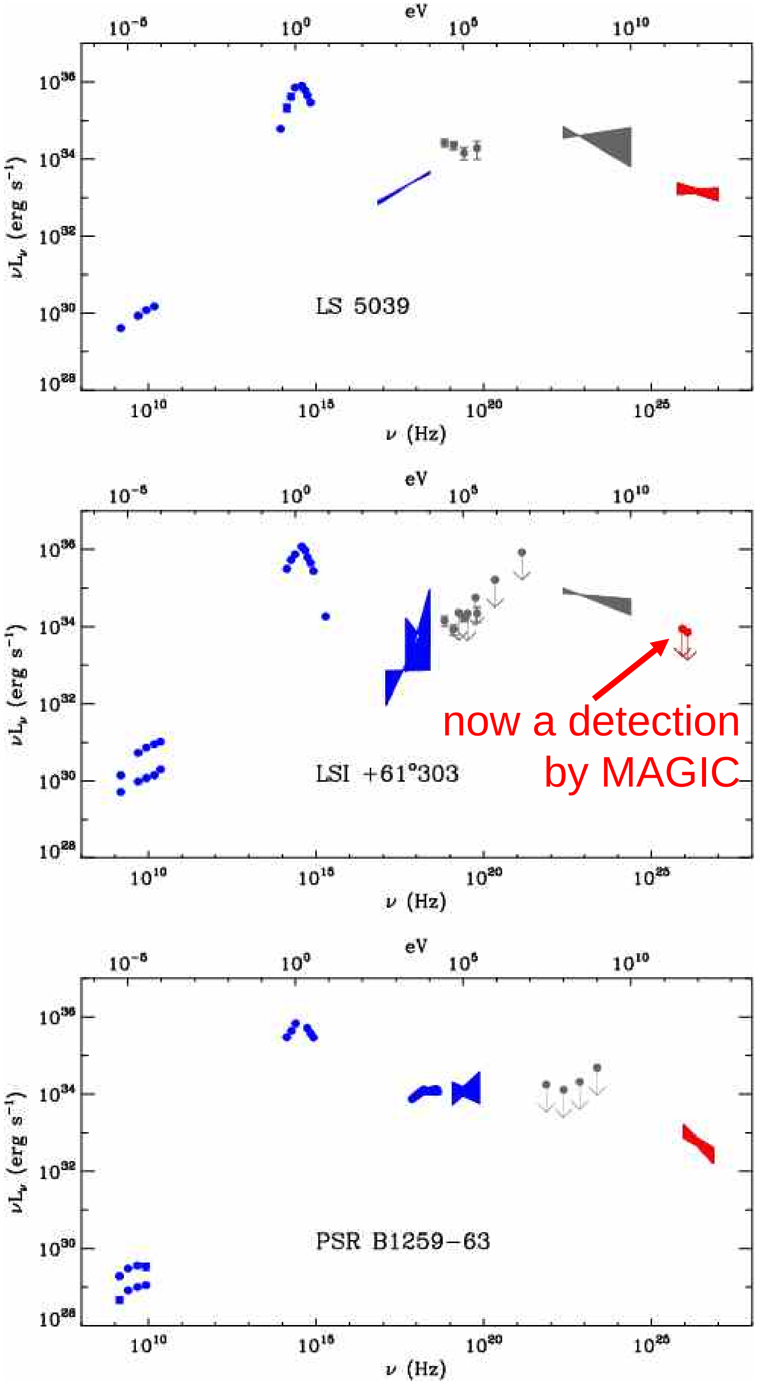
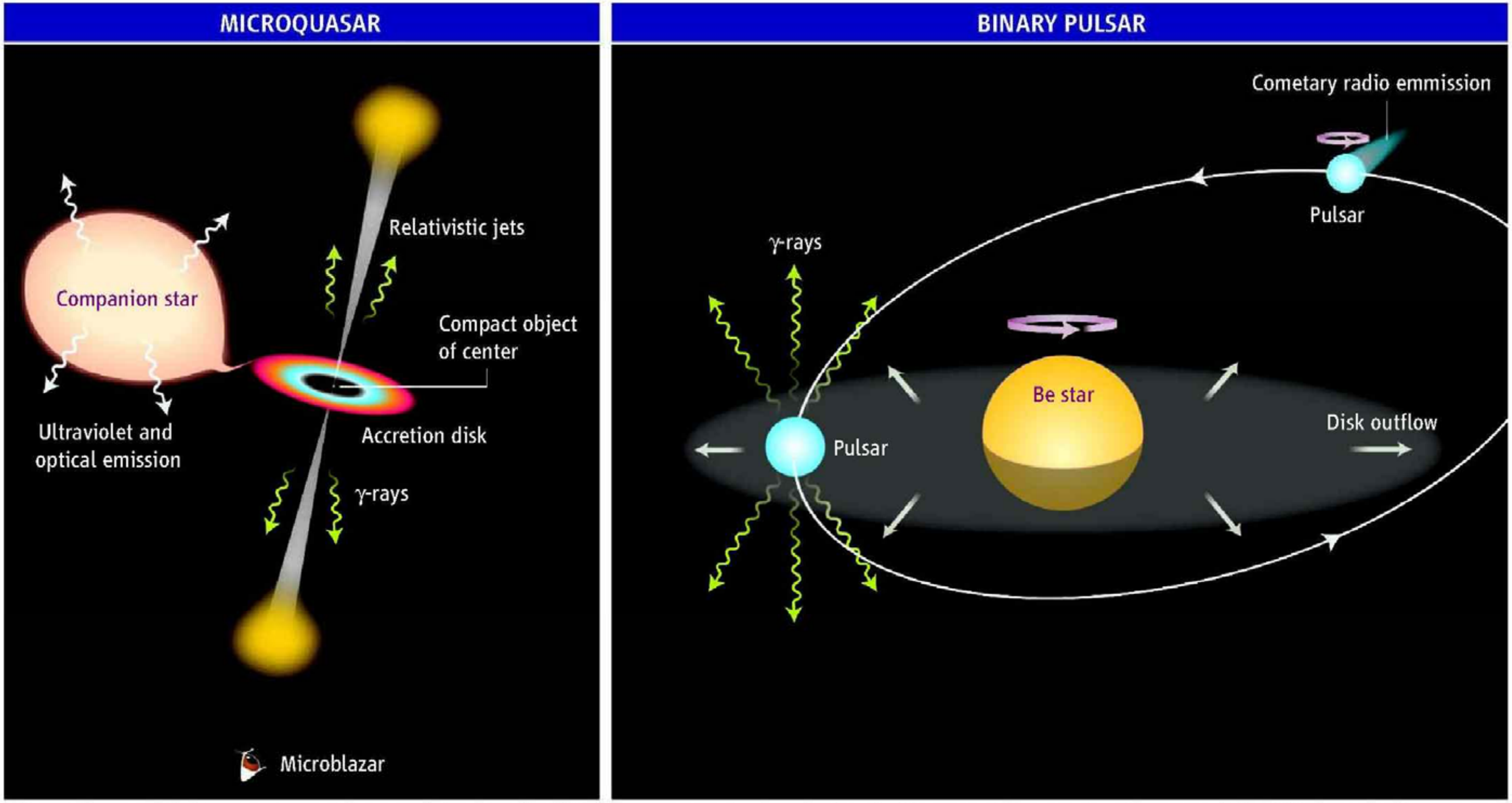


The three TeV-emitting binaries disovered so far:

Dubus 2006, A&A, 456, 801:
„Gamma-ray binaries: pulsars in disguise"

They all look very similar to each other, but PSR B1259–63 is a well-known 48-ms radio pulsar with a Be companion (3.4 yr orbit), in which the wind of the pulsar interacts with the wind of the Be star, giving rise to the broad-band emission.



Alternative models for very energetic γ-ray binaries. **(Left)** Microquasars are powered by compact objects (neutron stars or stellar-mass black holes) via mass accretion from a companion star. This produces collimated jets that, if aligned with our line of sight, appear as microblazars. The jets boost the energy of stellar photons to the range of very energetic γ-rays. **(Right)** Pulsar winds are powered by the rotation of neutron stars; the wind flows away to large distances in a comet-shaped tail. Interaction of this wind with the companion-star outflow may produce very energetic γ-rays.

Mirabel 2006, Science, 312, 1759

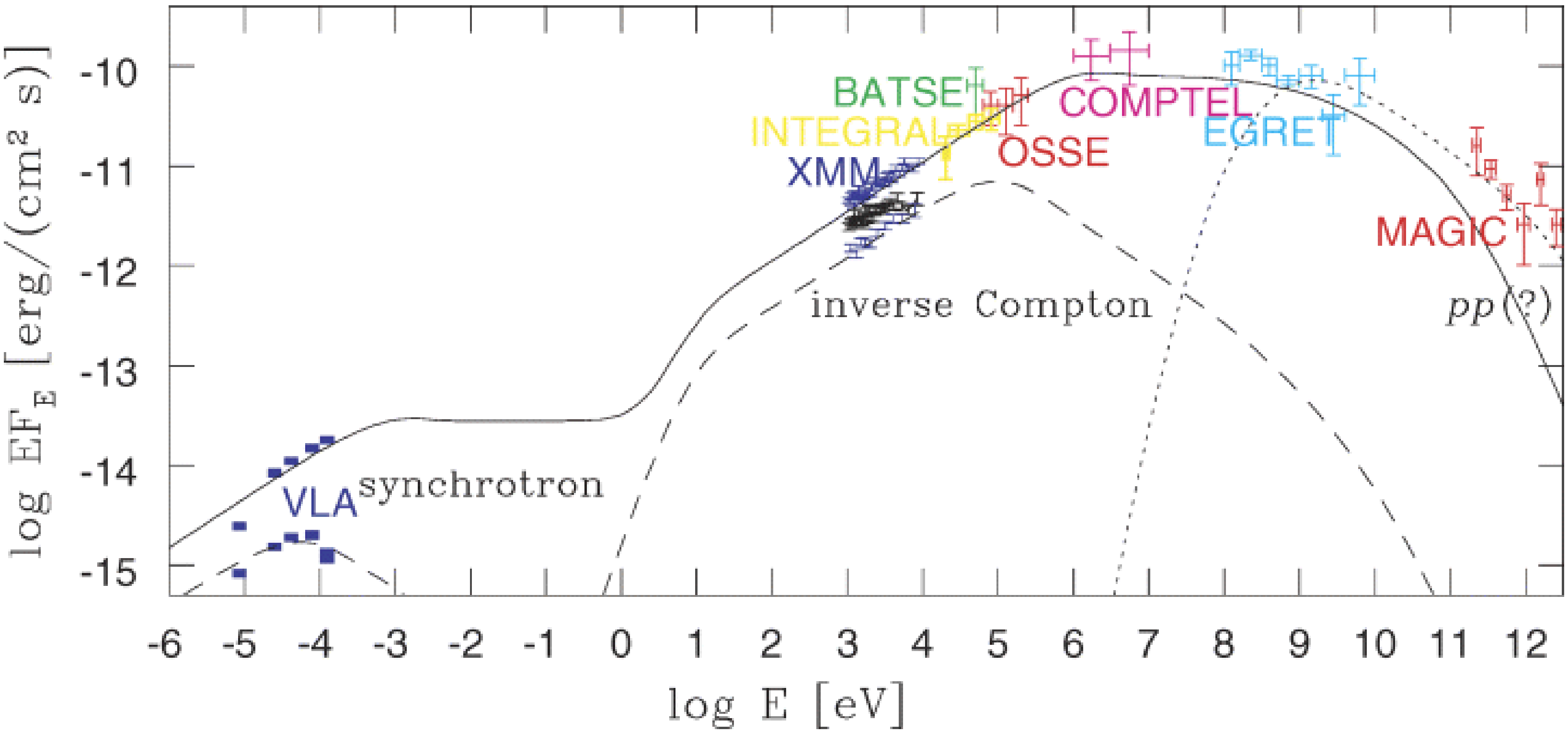
The radio-pulsar model

- In fact, a pulsar-wind model for LS I +61 303 was proposed long time ago, by Maraschi & Treves (1981), soon after the discovery of ~100-MeV γ-rays from the object.
- In this model, accretion is inhibited by the pressure of the pulsar wind, and the emission is due to interaction between the pulsar wind and the stellar wind.

- In the pulsar model-wind, the neutron star loses its rotational energy energy at a rate of $\sim 10^{36}$ erg s^{-1} and generates pair plasma at $\gamma \sim 10^{(5-6)}$ moving away from the pulsar and colliding with the wind from the Be star. This results in a shock, which further accelerates the pairs.
- The relativistic pairs lose energy and emit radio synchrotron radiation and inverse Compton emission off the stellar optical photons.

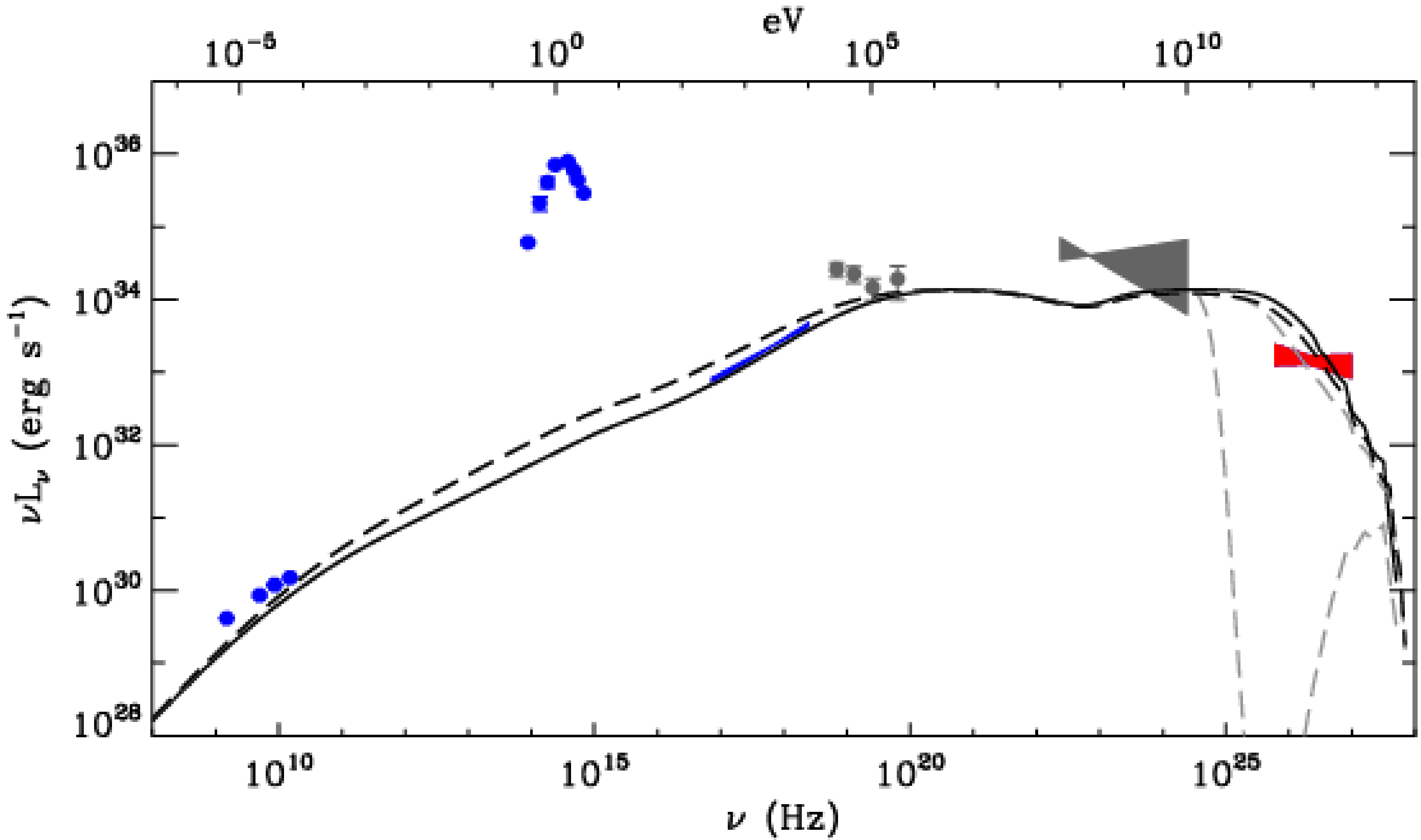
- The model predicts the spin period of <0.1 s. The lack of observed radio pulsations is fully explained by free-free absorption in the stellar wind. These two systems are much more compact than PSR B1259–63 (P = 26.5 d, 3.9 d vs. 3.4 yr), but even in that system radio pulsation is not observed near the periastron, at which the separation is similar to the separation of LS I +61 303 at the apastron.

The broad-band spectrum of LS I +61 303 fitted by the pulsar-wind model



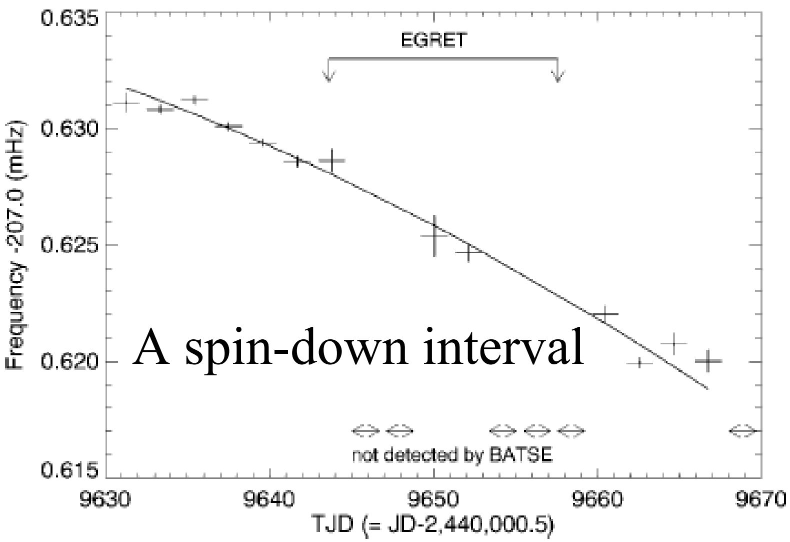
Chernyakova et al., 2006, MNRAS, 372, 1585

LS 5039 fitted by Dubus (2006) with the pulsar-wind model:

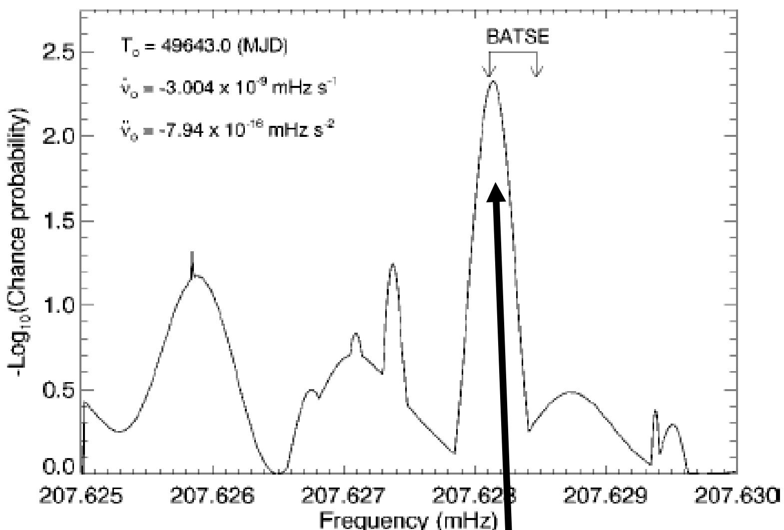


Possible X-ray binary sources of high energy γ-rays:

An outburst from Cen X-3 detected by EGRET



A spin-down interval



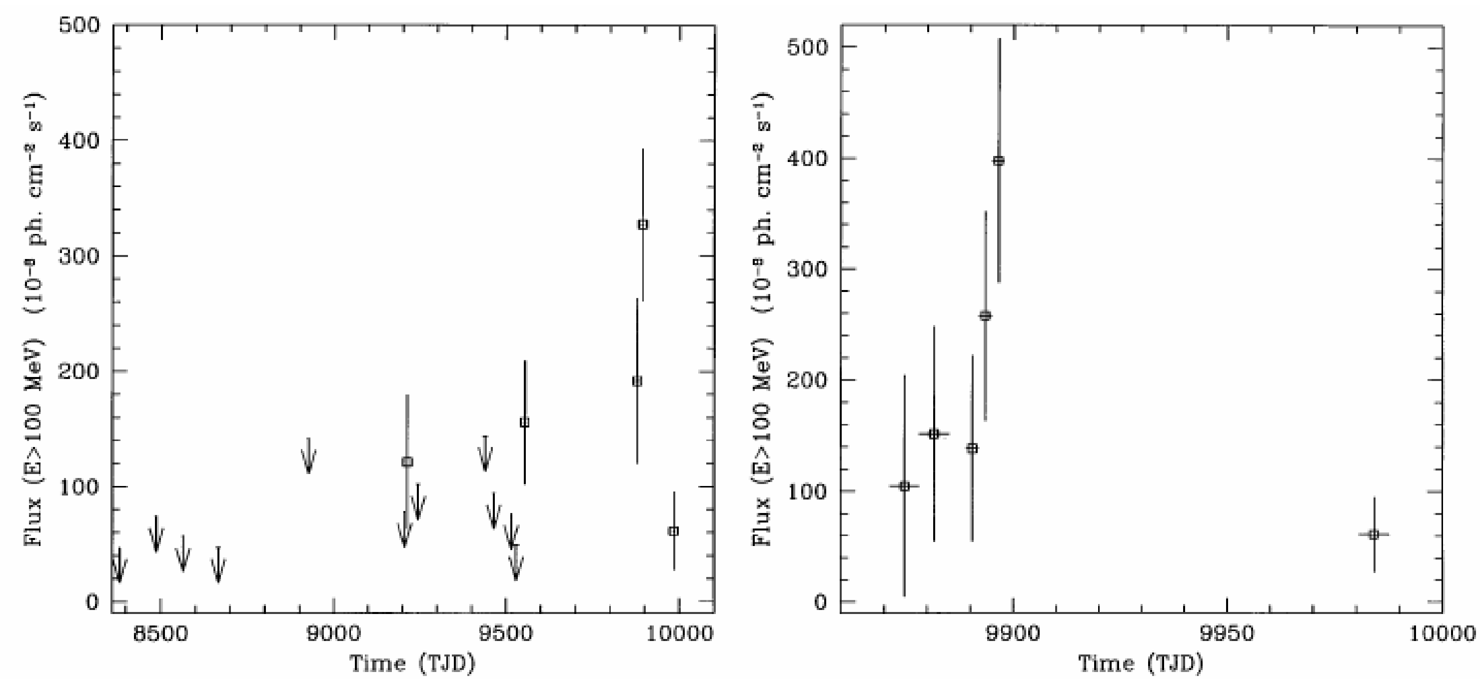
Relatively low detection significance, but the Cen X-3 spin period detected in the EGRET signal

Vestrand et al. 1997

Not detected by HESS, an upper limit.

Previous claims of TeV emission.

A bright transient GRO J1838–04 detected by EGRET near the Galactic Plane



One of the most intense γ-ray transients ever detected, the 2nd brightest EGRET source in the sky at the time of the detection. No identification, in particular no blazar counterpart. No HESS upper limit.

Tavani et al. 1997

A new HMXB class discovered by *INTEGRAL*:

- Supergiant Fast X-ray Transients.
- Duration of hours, increase of a persistent very low luminosity by $\sim 10^4$.
- The probable mechanism is accretion of inhomogeneities of the stellar wind.
- No high energy emission detected so far, **can they emit TeVs?**

A new HMXB class discovered by *INTEGRAL*:

- Strongly absorbed supergiant X-ray binaries.
- Flares.
- Very weak emission below 10 keV because of the strong absorption.
- Localization in the Norma i Scutum/Sagittarius regions.
- Speculations that proton-proton interactions at $N_H > 10^{23}$ cm^{-2} can produce TeV photons.
- IGR J1632–4751 detected as HESS J1632–478, but the HESS emission is extended, ruling out the association.
- **Can they emit TeVs?**

Conclusions

- No *unambiguous* detection of TeV photons from any accreting binary yet.
- Three similarly looking TeV sources, PSR B1259–63, LSI +61 303 and LS 5039. One of them is a pulsar, which wind interacts with the stellar wind. Are they all of the similar nature? More studies needed.
- Given the record of previous uncorfirmed TeV detection claims, the TeV detection of Cyg X-1 needs to be confirmed at a higher significance.
- *GLAST* is likely to provide a lot of data on binaries. Then TeV counterparts should be promptly searched for.