Microquasars and binaries as e-Astrogam sources

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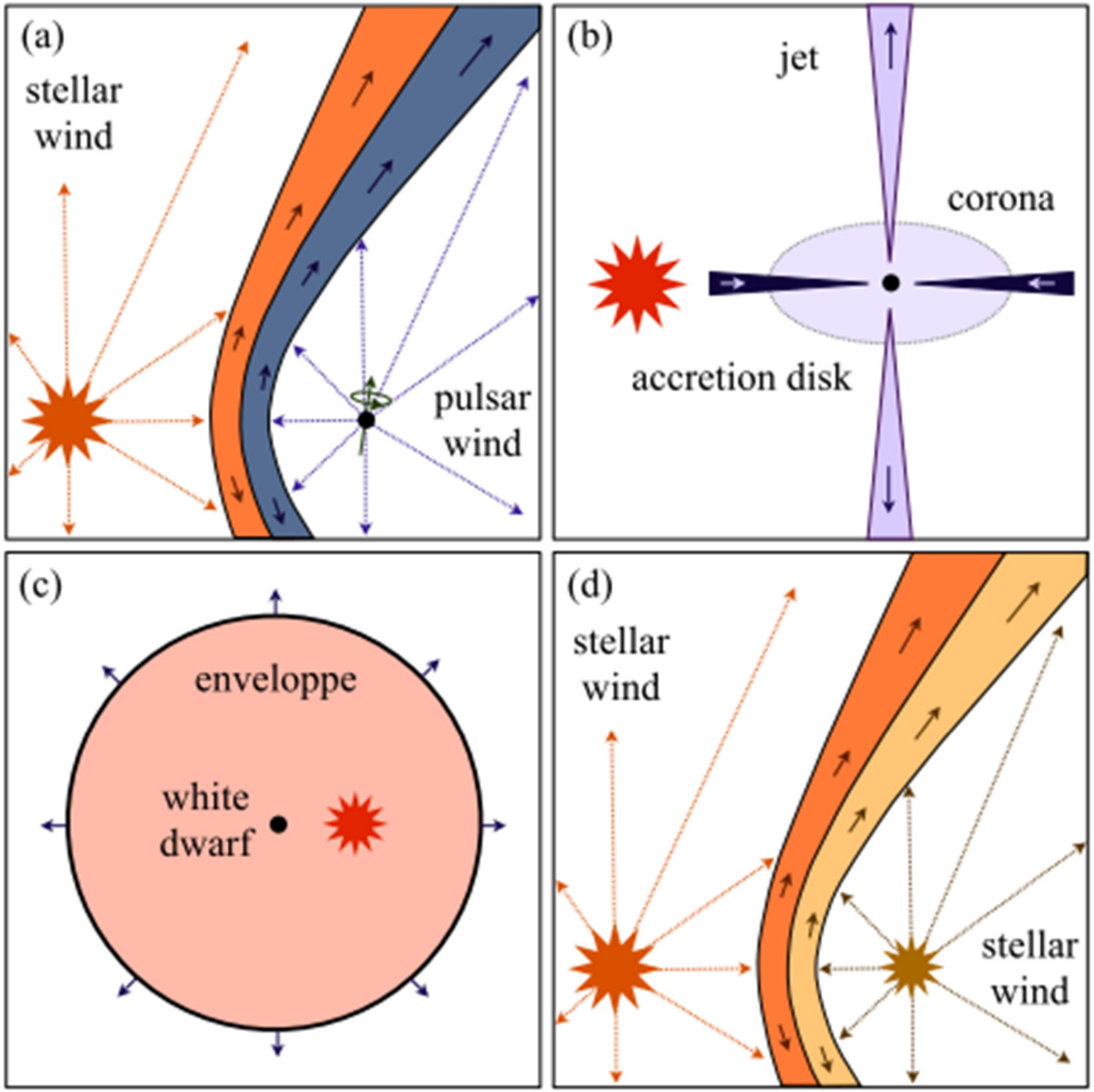
Types of γ-ray emitting binaries

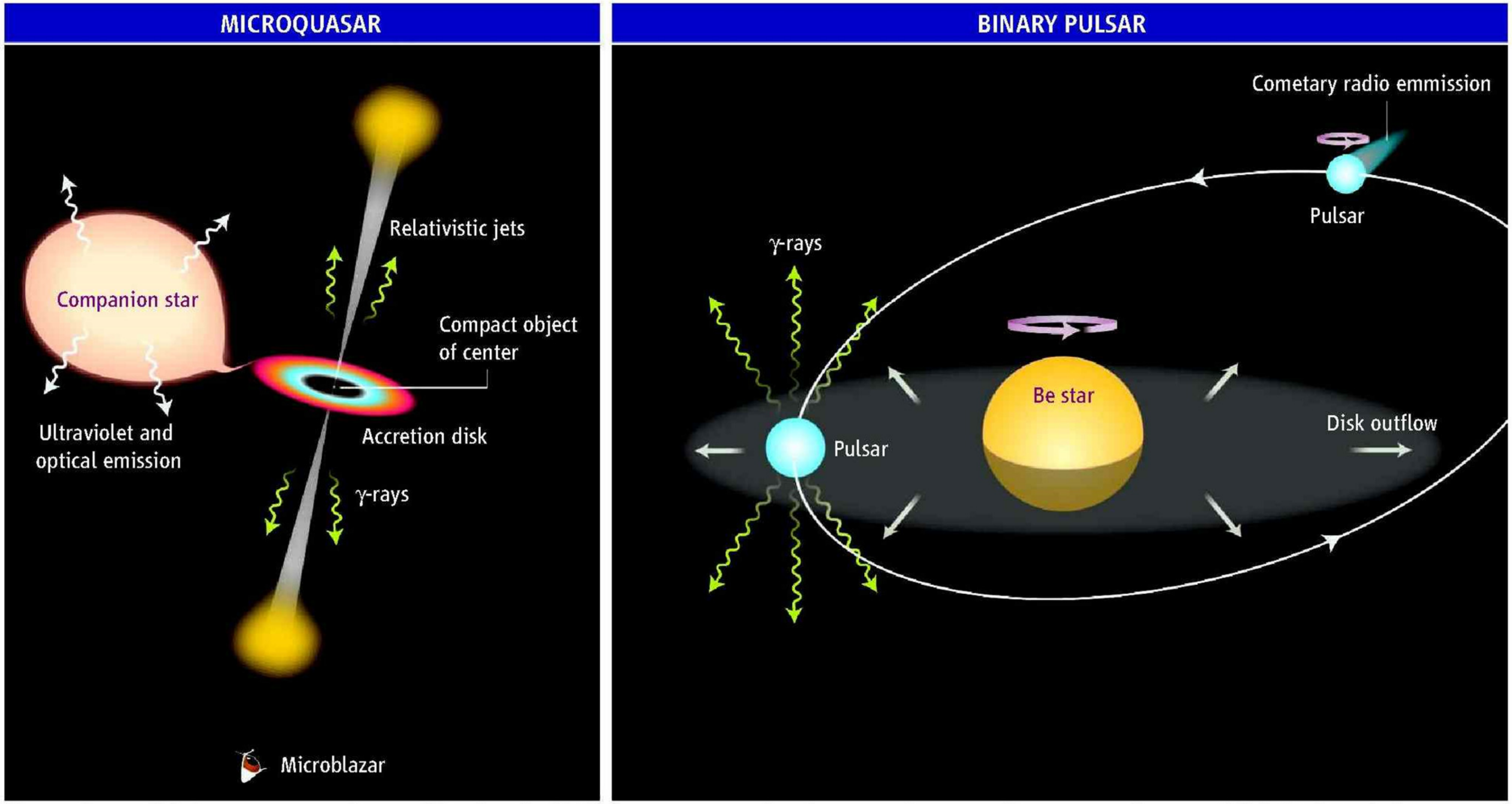
- Gamma-ray binaries: pulsar wind colliding with stellar wind from a high-mass star, powered by pulsar rotation;
- Microquasars: powered by accretion onto a black hole or neutron star, γ-ray emission of either the accretion flow or a jet;
- γ-ray emitting pulsars in binaries, in particular recycled ms pulsars spun up by accretion, but no longer accreting (powered by pulsar rotation);
  - As above, but pulsar wind ablating the low-mass companion: black widows, redbacks; some γ-ray emission from pulsar wind interacting with the companion (as in gamma-ray binaries);
- Transitional sources switching between pulsar and accretion; strong γ-ray emission during accretion stages, possibly from a jet;
- Colliding-wind binaries: collision of stellar winds from two massive stars;
- Novae: thermonuclear runaway on a white dwarf, γ-ray emission from the ejccta (covered in the talk by Margarita).

Types of γ-ray emitting binaries



Dubus 2015

A past controversy on the nature of **gamma-ray binaries**: Microquasars vs. pulsar/stellar wind collisions

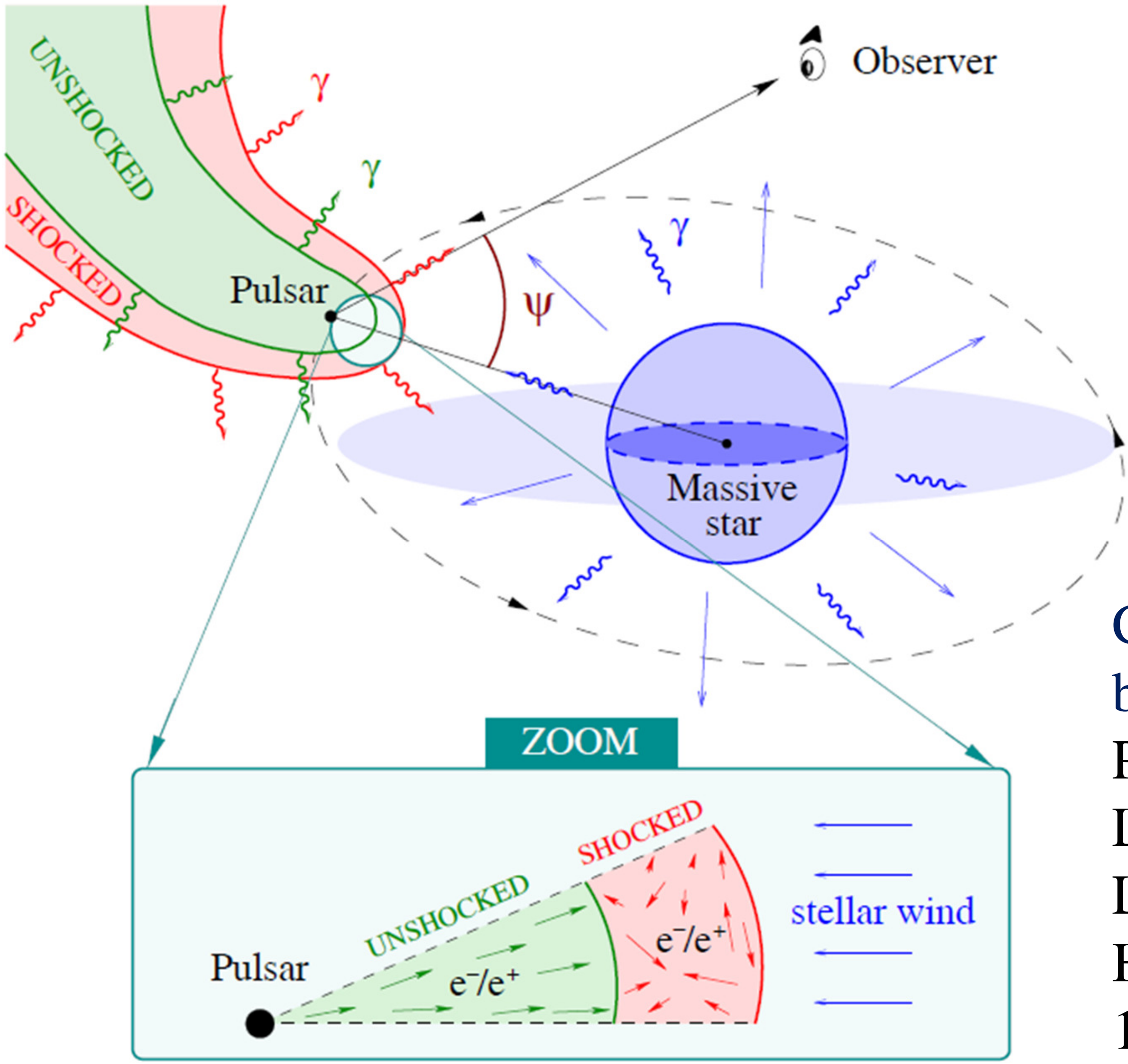


Alternative models for very energetic γ-ray binaries. (**Left**) Microquasars are powered by compact objects (neutron stars or stellar-mass black holes) via mass accretion from a companion star. This produces collimated jets that, if aligned with our line of sight, appear as microblazars. The jets boost 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

Currently, most people agree on the pulsar+stellar wind collision model.

The pulsar + massive star model; a pulsar wind nebula in a binary



Cerutti, Dubus & Henri 2009

Currently known gamma-ray binaries:

PSR B1259−63

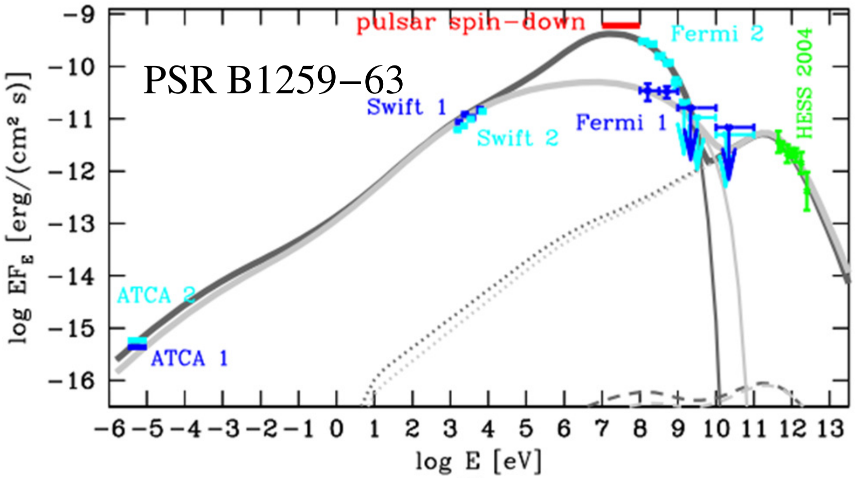
LS I +61°303

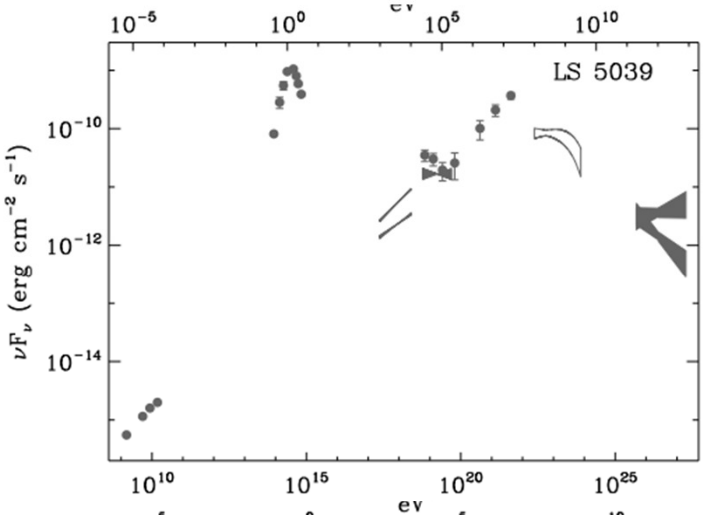
LS 5039

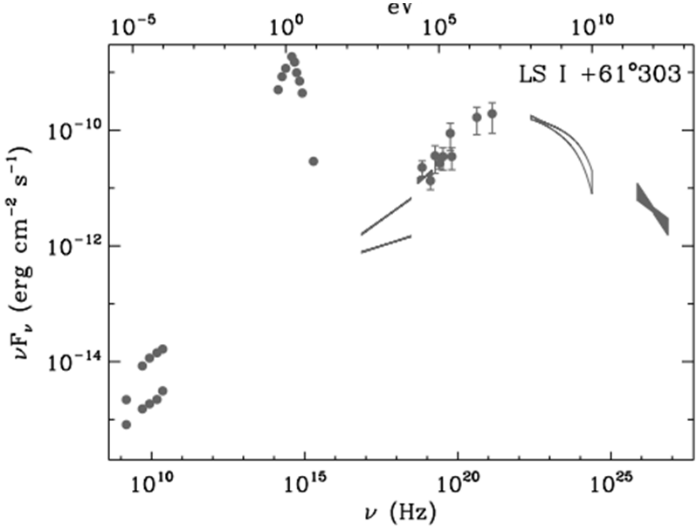
HESS J0632+057

1FGL J1018.6−5856

CXOU J053600.0−673507 (LMC)





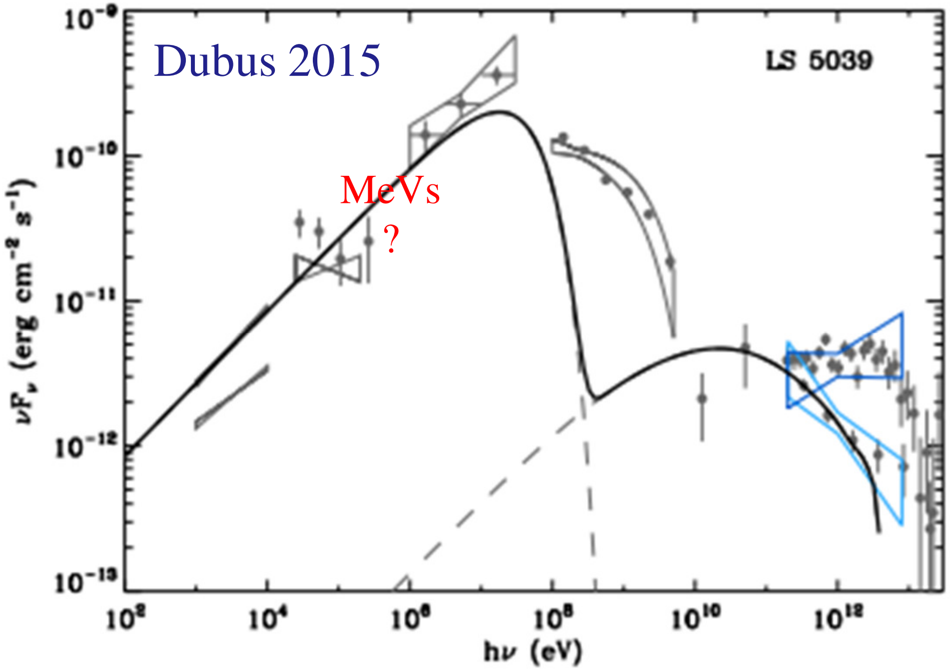


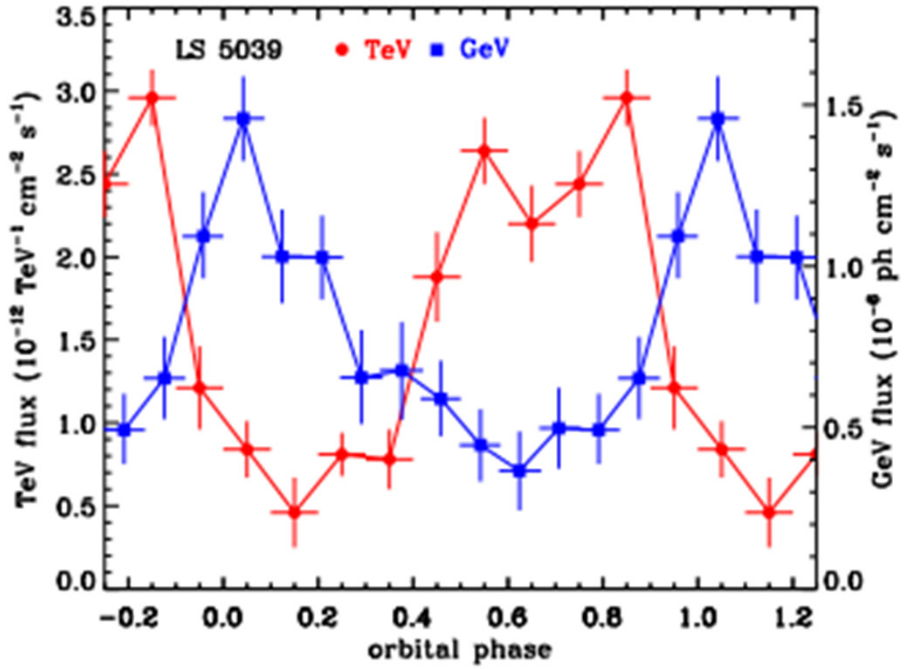
A comparison of three gamma-ray binaries:

Their spectra look very similar to each other: **peak in the MeV-GeV range**, and PSR B1259–63 is a 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 around periastron, giving rise to the broad-band emission. The radio pulsation disappear at the periastron passage.

Dubus 2013

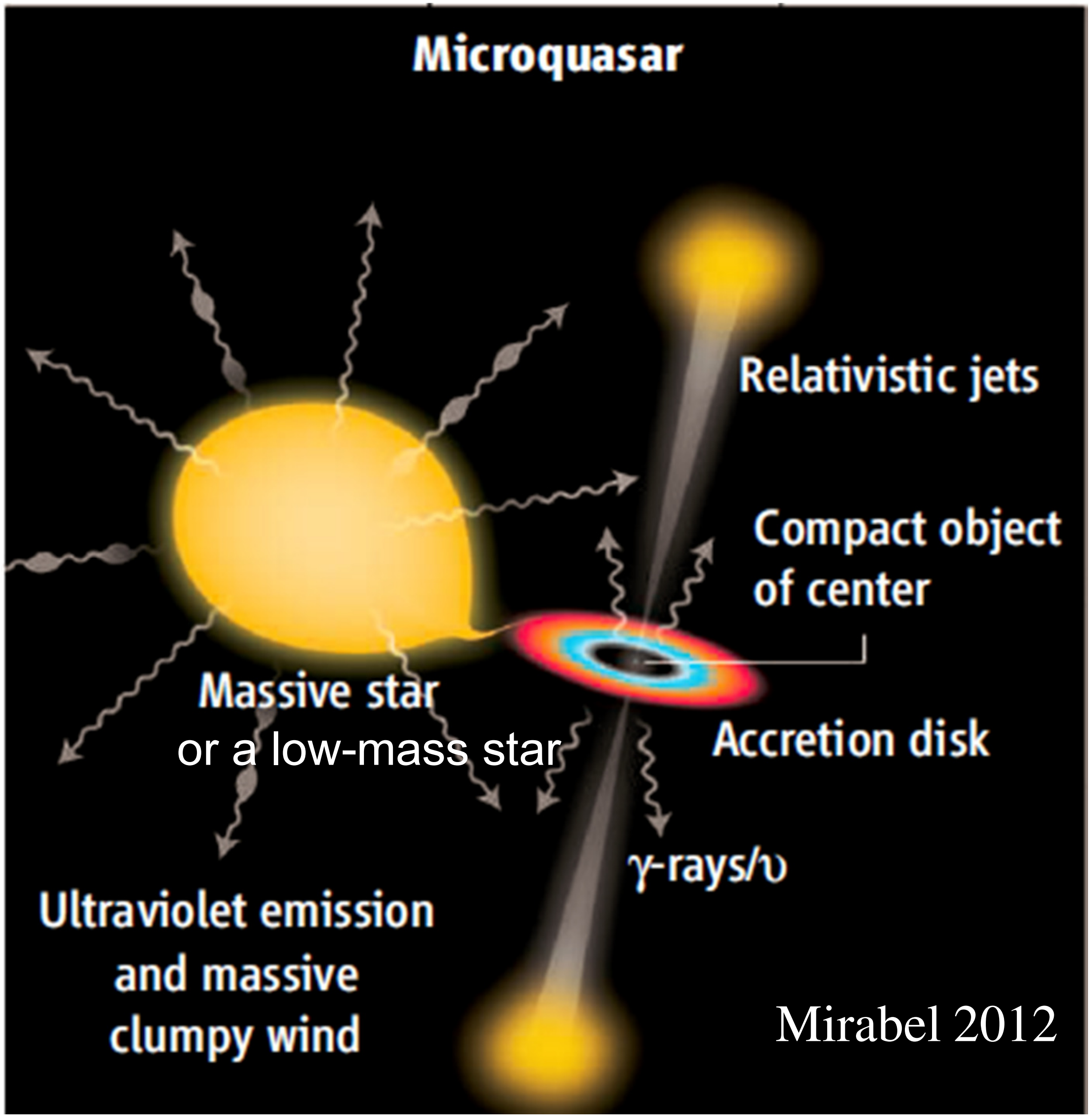
Some outstanding issues for gamma-ray binaries





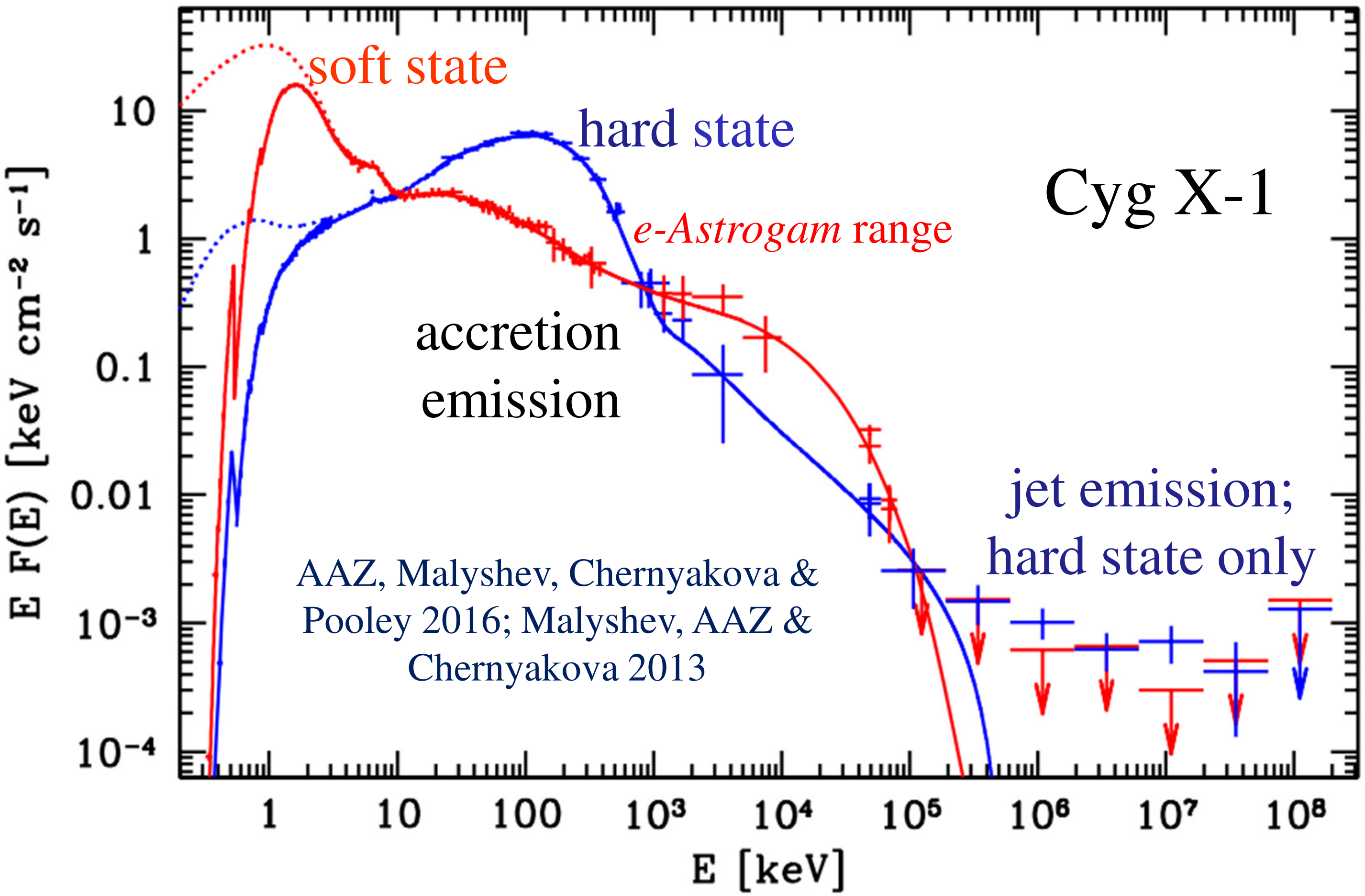
- Complex phenomenology requiring complex, multi-component models.
- Different electron populations for GeVs and TeVs; location?
- The peak in GeVs in PSR B1259–63 a month *after* the periastron passage.
- MeV spectra known only from COMPTEL; e.g., a mismatch with the *Fermi* spectrum in LS 5039.
- The virtually unknown MeV range: to be studied by *e-Astrogam*.

Microquasars



The accretion flow can emit soft γ-rays, and the jet, high and very high energy γ-rays. So far, unambiguous high-energy γ-ray detections of only Cyg X-3 and Cyg X-1 (high-mass donors).

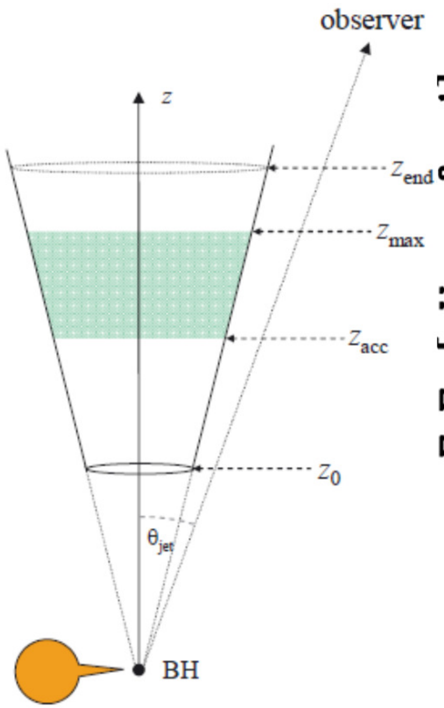
Cyg X-1, a black hole+OB supergiant binary

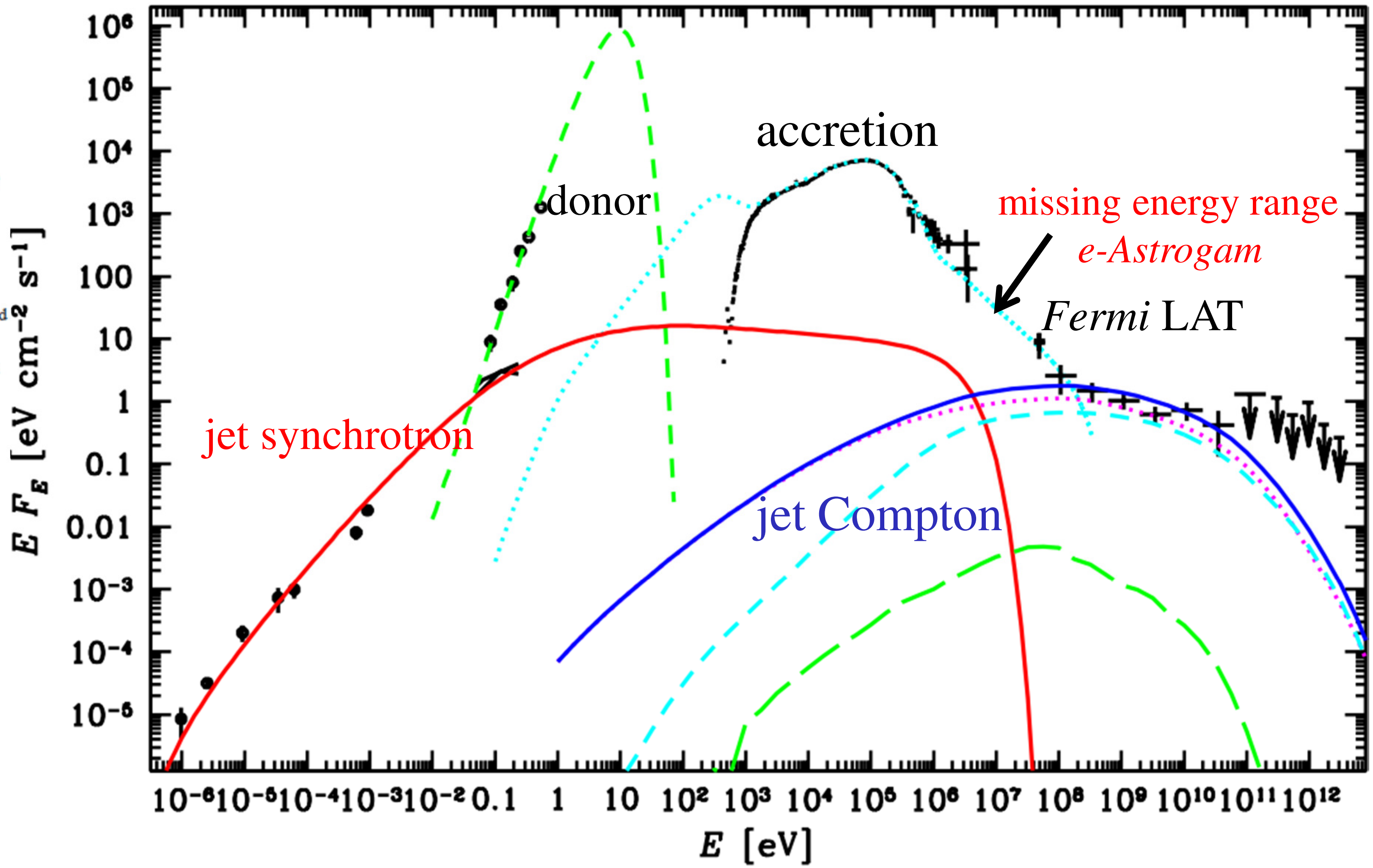


- High-energy tails extending to several MeVs in both the hard and soft states.
- High-energy γ-rays in the hard state only (Malyshev+2013, Zanin+2016, AAZ+2016); emitted by the jet seen in the radio to mm.
- AAZ+2016 found soft spectral components at <100 MeV, with the flux in the soft state being higher than that in the hard state at a 5σ significance. They match well the extrapolations of the accretion models. To be tested by *e-Astrogam*.

The jet contribution to the hard-state broad-band spectrum in the hard state of Cyg X-1

The shown broad-band spectrum is reproduced by a model with electron acceleration, cooling, electron transport, all radiative processes. Compton scattering of stellar blackbody and SSC dominate the γ-ray emission.



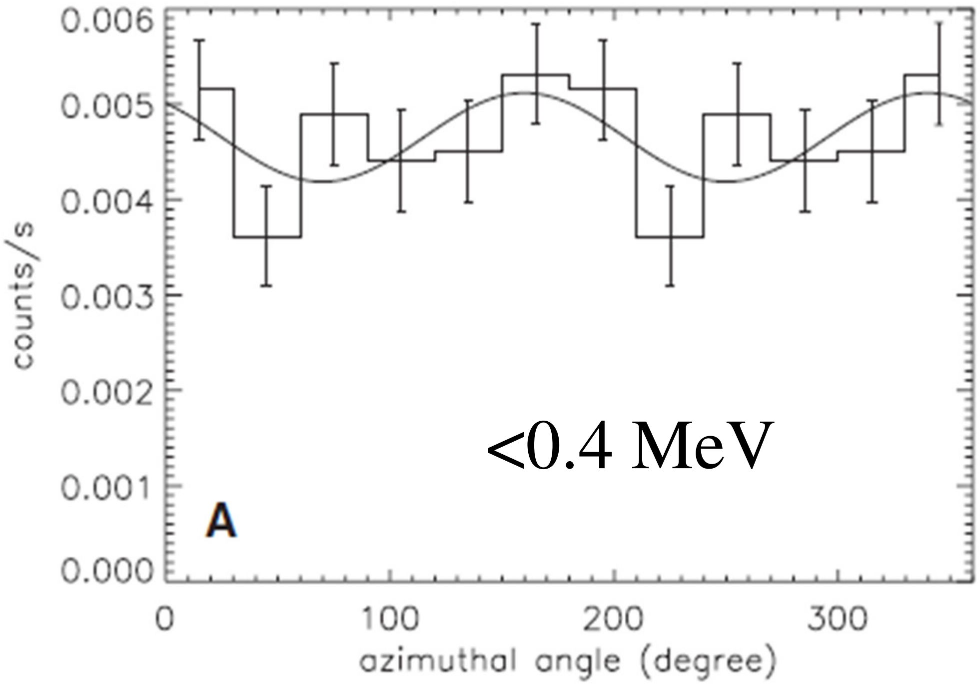


AAZ+ 2014a,b, 2016

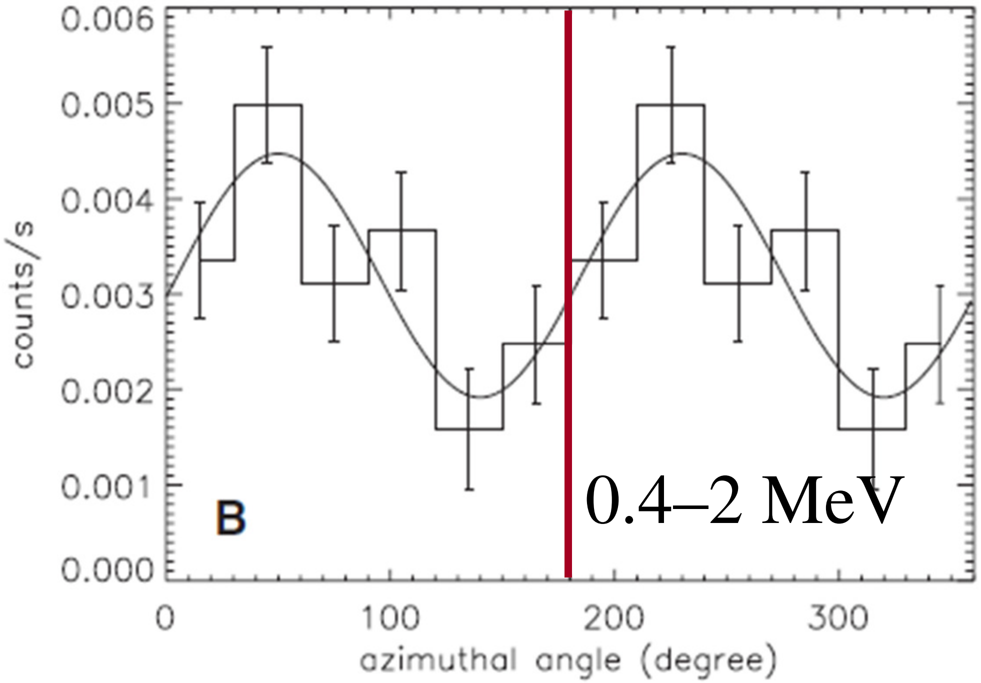
Very strong 0.2–2 MeV polarization claimed from *INTEGRAL* Compton-mode data in the hard state of Cyg X-1

- Laurent+ 2011 (*Science*) and Rodriguez+ 2015 (*ApJ*) claim linear polarization of ~70% above 400 keV.
- If it is real, it is likely to be synchrotron jet emission.
- A revision of the results of Laurent+ 2011 given by Laurent (2016, *INTEGRAL* conference presentation), no publication as yet. In particular, the strong high-energy tails claimed before appear to be spurious.

Polarization at the level of 67±30% in the hard state in the 0.4–2 MeV band of Cyg X-1– Laurent+ (2011), *Science*.



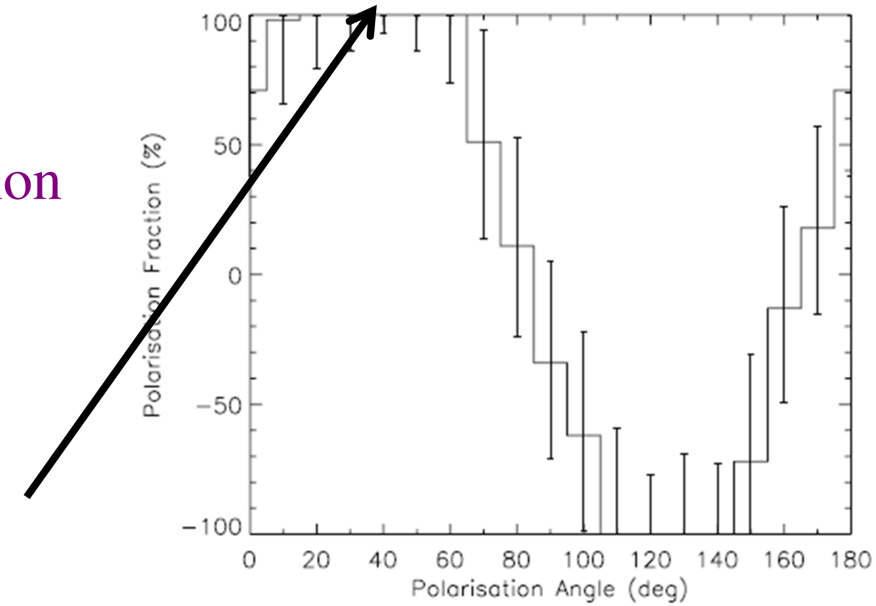
Polarization fraction <20%

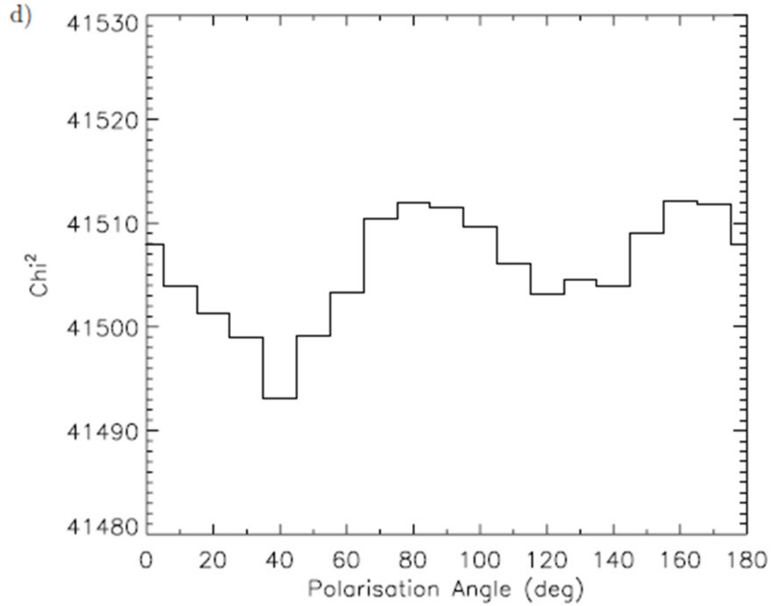


Polarization fraction claimed 67±30%, but note that only the 0°–180° bins are independent. It appears that the statistical significance is not very strong.

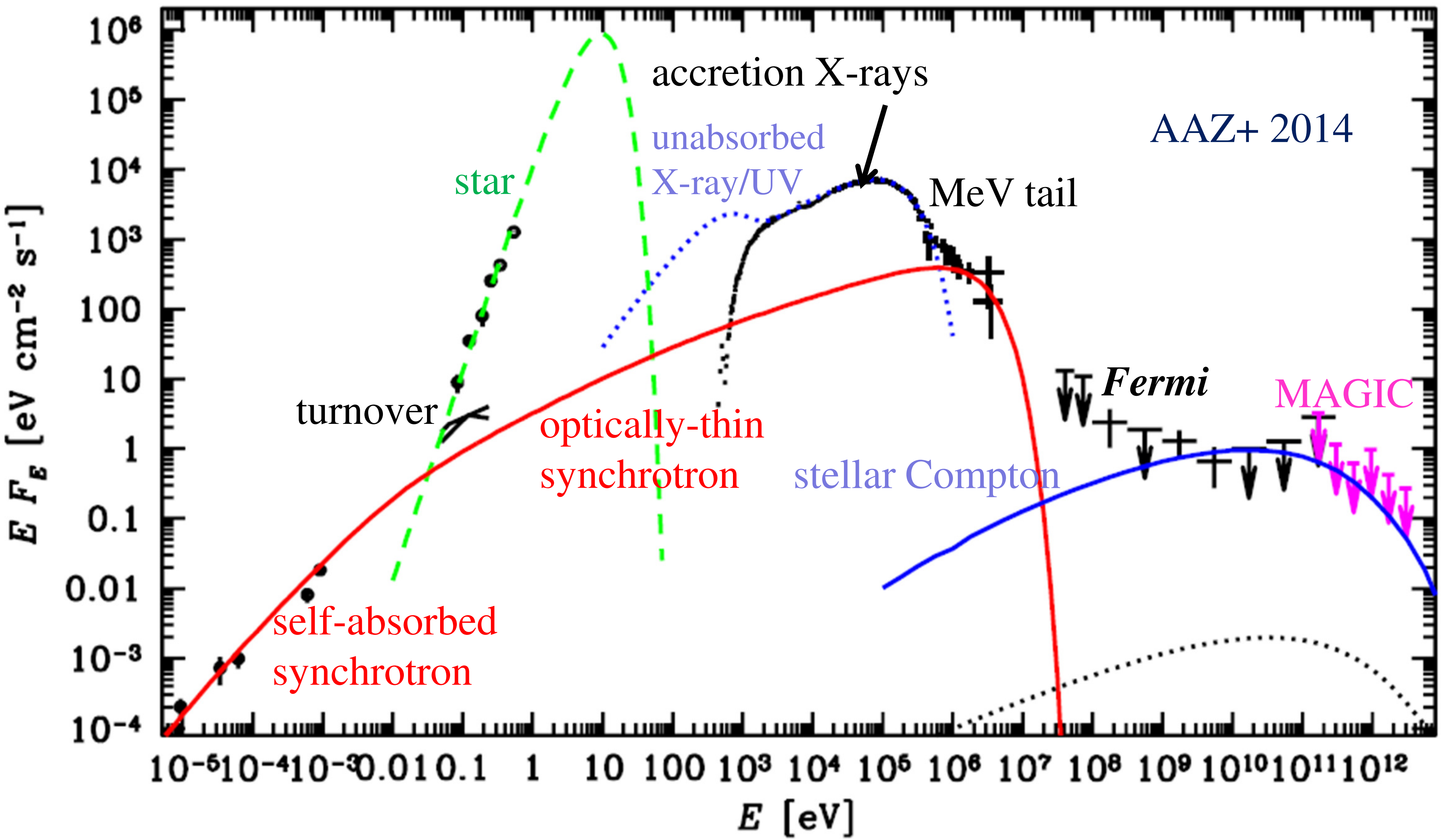
Strong polarization in the hard state at $E \geq$ 230 keV claimed by Jourdain+ 2012

- From the *INTEGRAL* SPI data.
- Average over 230–850 keV: linear polarization fraction 76±15%, position angle 42±3°.
- This polarization level agreed with Laurent+2011 but it is higher than that of Laurent 2016.
- No polarization at $E < 230$ keV.
- The 370–850 keV data best-fitted with the polarization fraction >100%.
- $\Delta\chi^2 \approx 15$ at $\chi^2 \approx 41500$. PF>100% is unphysical, and $\Delta\chi^2$ at PF ≈ 70% is ≈ 0.
- Is it real?
- This issue was to be tested by the SGR detector onboard *Hitomi*.
- Should be studied by *e-Astrogam*.





A jet model reproducing the MeV tail.

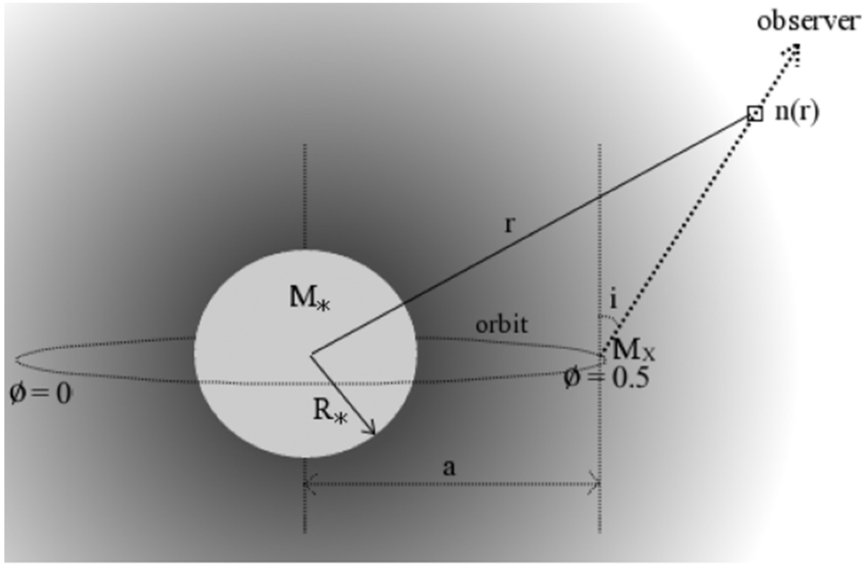


The acceleration index $p = 1.5$ (very hard), $B_0 = 5\times10^5$ G at the jet base of $z_0 = 240R_g$, extreme $(B^2/8\pi)/u_{gas} \sim 10^5$. Given the substantial variability of both the accretion flow and the jet, strong fine-tuning is required. ***e-Astrogam* observations crucial.**

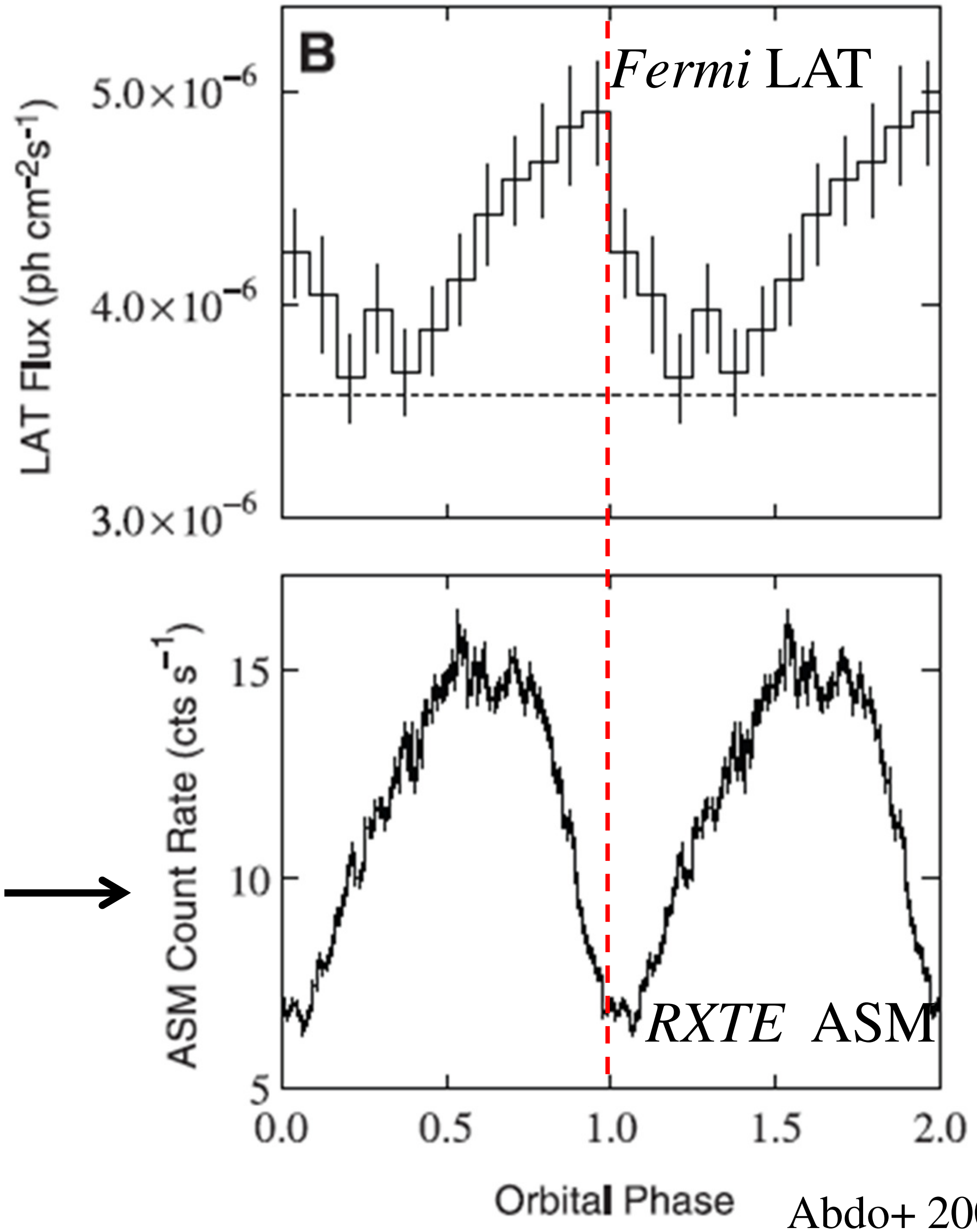
Cyg X-3: γ-ray detection by *Fermi* in the soft state

Orbital modulation of γ-rays during the active periods. The γ-rays have the ***maximum*** close to the superior conjunction.

The X-rays undergo wind absorption, thus their ***minimum F*** is at the superior conjunction (black hole behind the donor).



Folded lightcurves



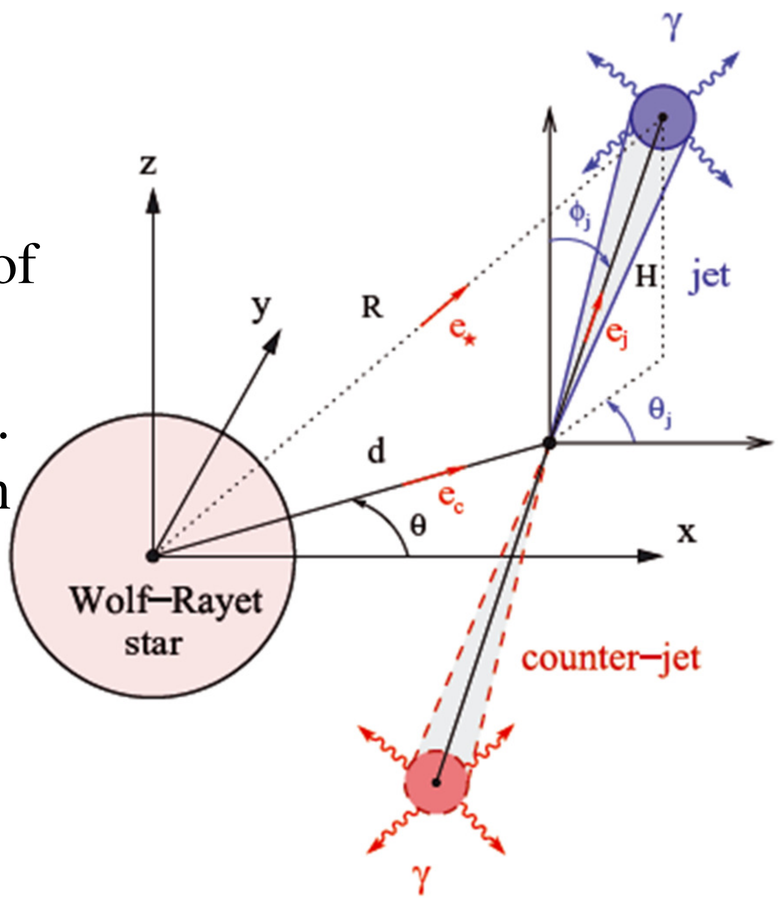
Abdo+ 2009

Also detections by *AGILE*

A model for the modulated GeV emission

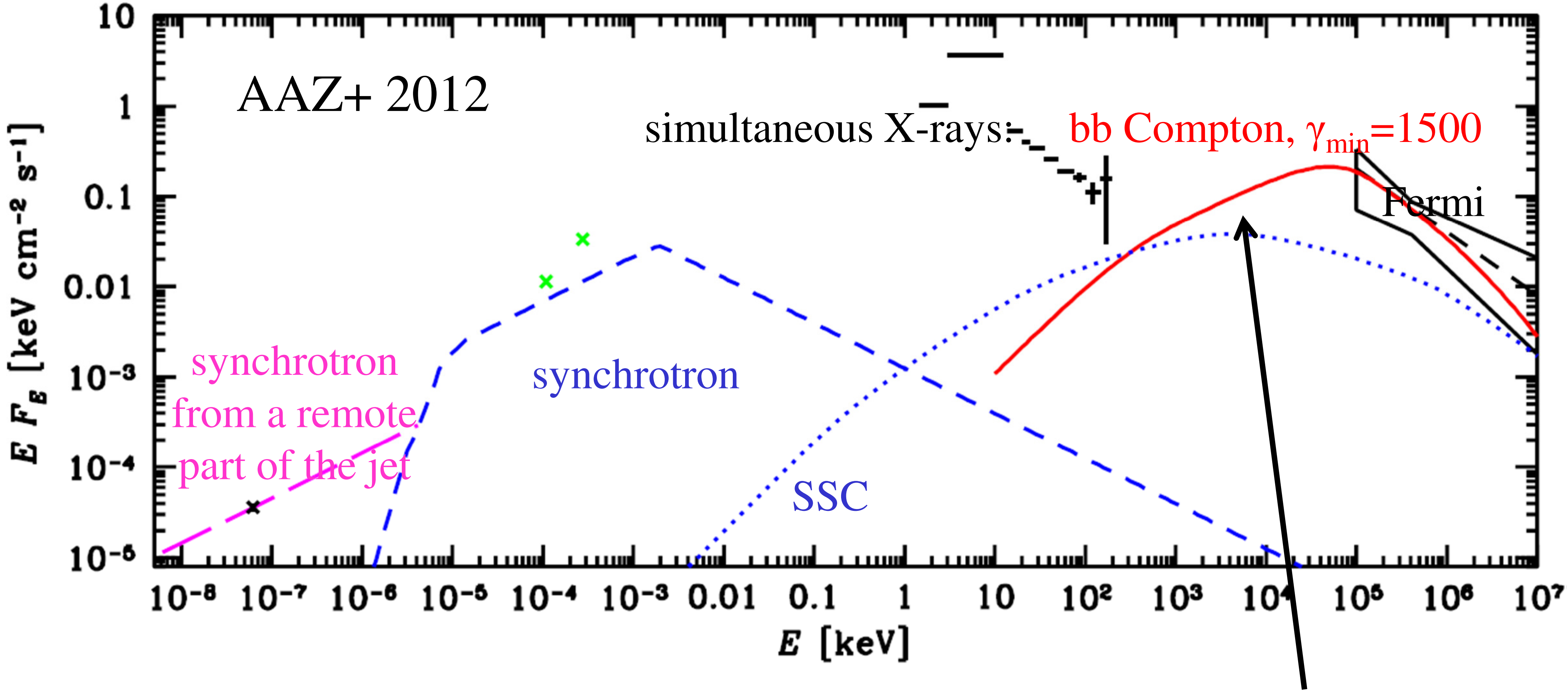
Compton anisotropy:

- The relativistic electrons in the jet Compton upscatter stellar photons to GeV energies.
- Highest scattering probability for electrons moving towards the stellar photons.
- Relativistic electrons emit along their direction of motion.
- Thus, most of the all emission is toward the star. The maximum of the observed emission is when the jet is behind the star.
- Fits of the model determine the γ-ray source location, ~the binary separation.



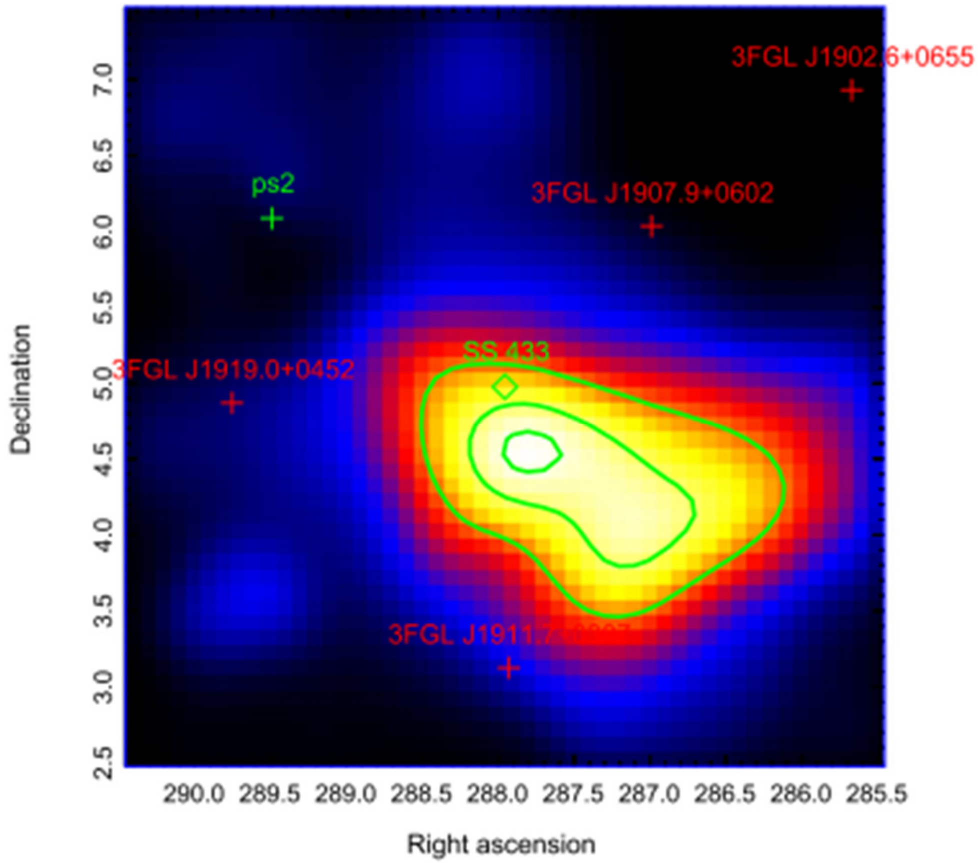
Dubus+ 2010

A spectral model of the broad-band spectrum:



The MeV-range spectrum: transition from the spectrum dominated by accretion to that jet-dominated; to be investigated by *e-Astrogam*

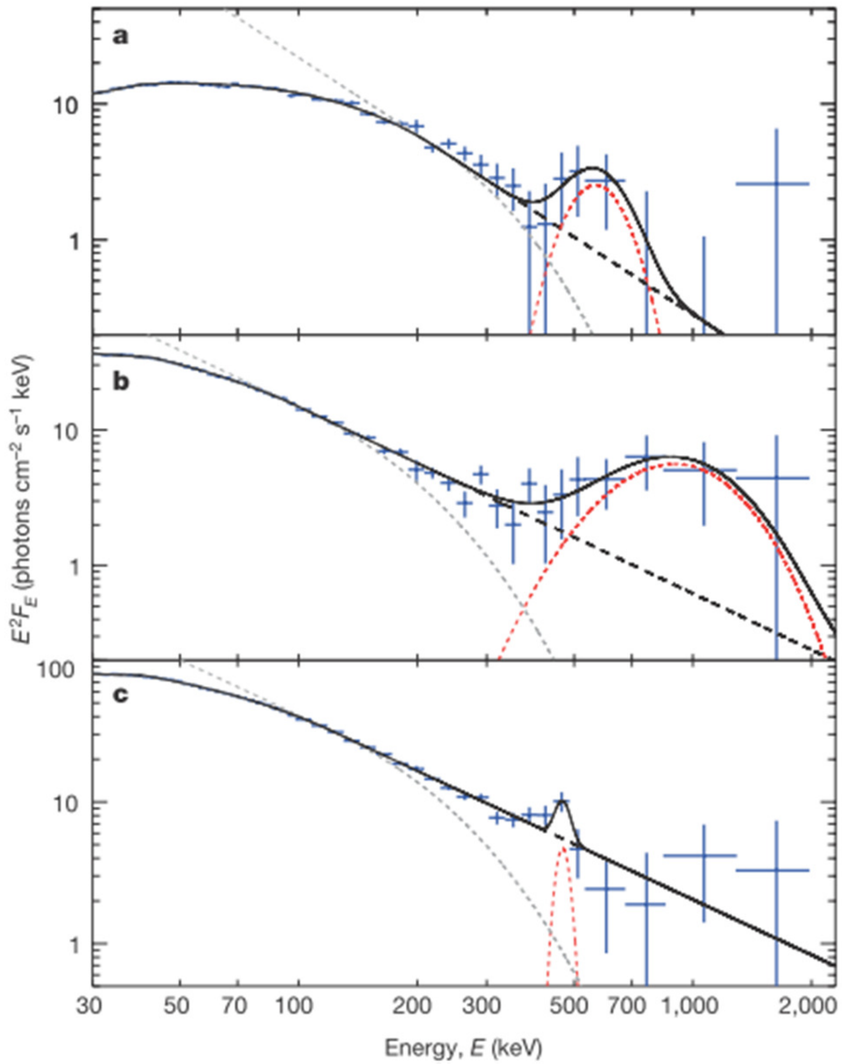
γ-rays from SS 433?



Fermi LAT;
Bordas+2015

- High-energy γ-rays are emitted from the direction of the microquasar SS 433, but it is difficult to distinguish them from those from the SNR W49.

Strong e± pair annihilation spectra claimed from V404 Cyg



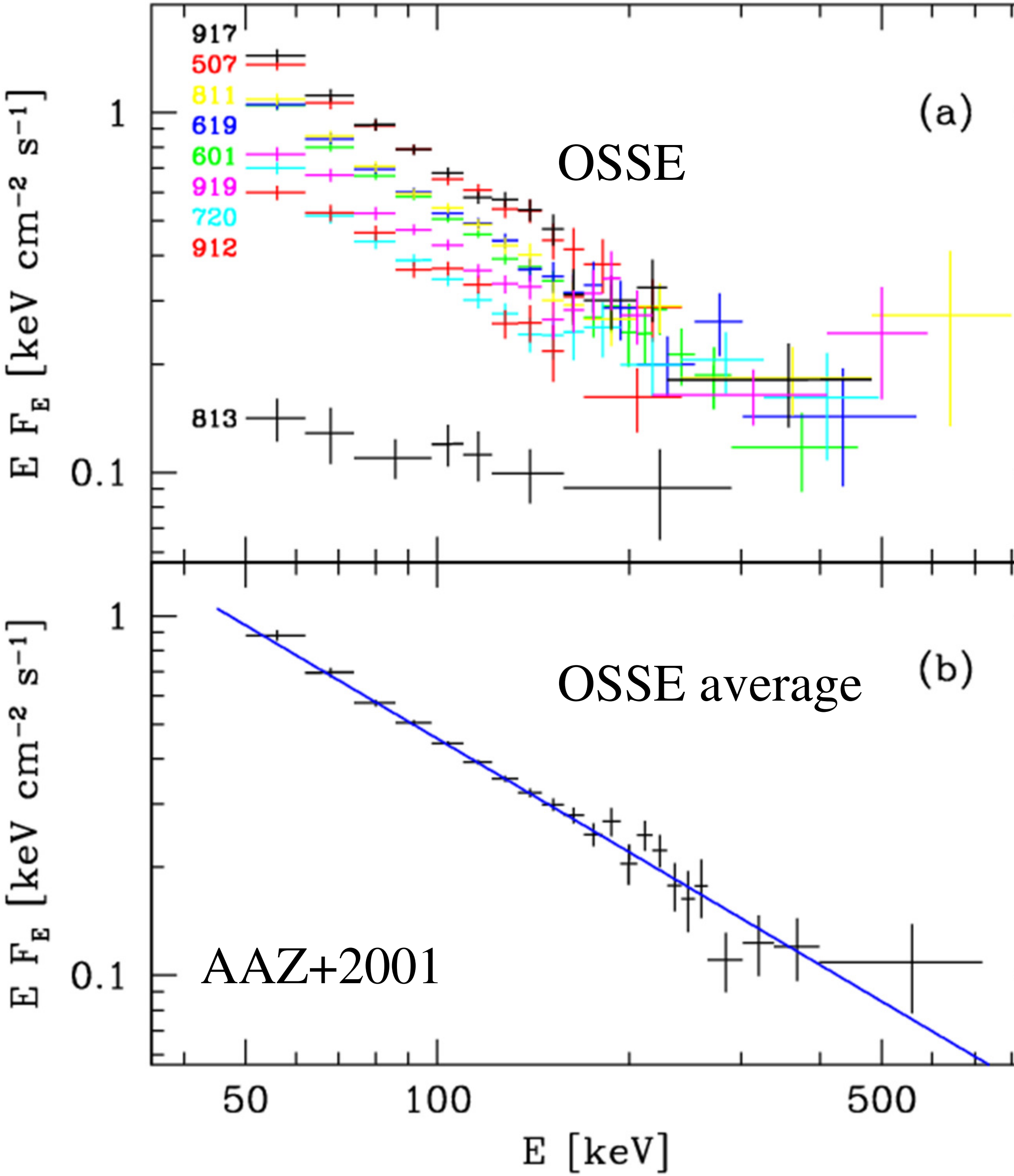
Siebert, Diehl+ 2016, *Nature*

No detailed theoretical model as yet.

e-Astrogam will measure e± pair annihilation features in microquasars in much more detail.

Luminous BH LMXBs, e.g., GRS 1915+105

- No high-energy cutoff seen in observations by the *CGRO* OSSE; the spectrum at higher energies to be measured by *e-Astrogam*.

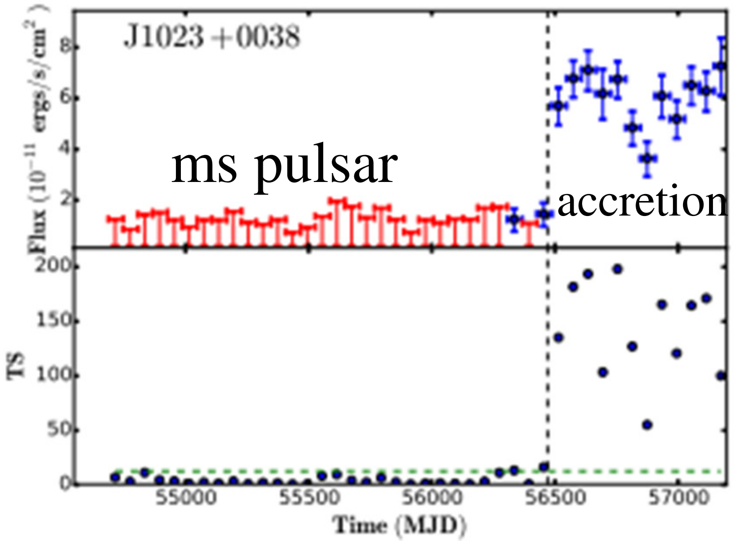


Transitional ms pulsars during accretion states

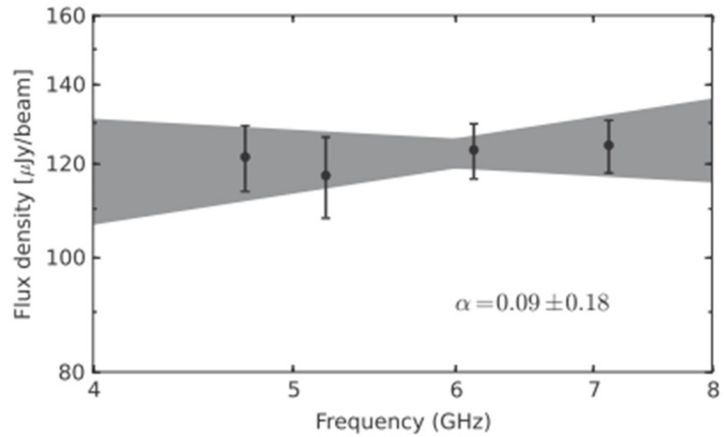
- A few ms pulsars have recently been discovered to change between rotation-powered pulsar states and accretion-powered X-ray pulsar states (e.g., Archibald+2009; Papitto+2013; De Martino+2010,2013,2015; Bassa+2014).
- During their rotation-powered states, they show the usual pulsed magnetospheric emission from radio to high-energy γ-rays.
- Two cases of transitions into sub-luminous states with accretion discs, with $L_X \sim 10^{33}$ erg/s: PSR J1023+0038 (Stappers+2014) and PSR J1227−4853 (De Martino+2010,2013).
- Unexpectedly, these sources during the weak accretion states show large increases of the high-energy γ-ray luminosity, up to a factor of several.
- Initially, the enhanced γ-ray emission was attributed to the pulsar wind interacting with the accretion disc.
- However, a strong radio emission with the spectral index of $\alpha \approx 0$ was then found in PSR J1023+0038 (Deller+2015). Such emission is characteristic to radio jets in accreting systems.
- This makes likely that the γ-ray emission is from the jet, thus being the first such case in an LMXB.

The ms pulsar transitions in γ-rays

Torres+ 2017

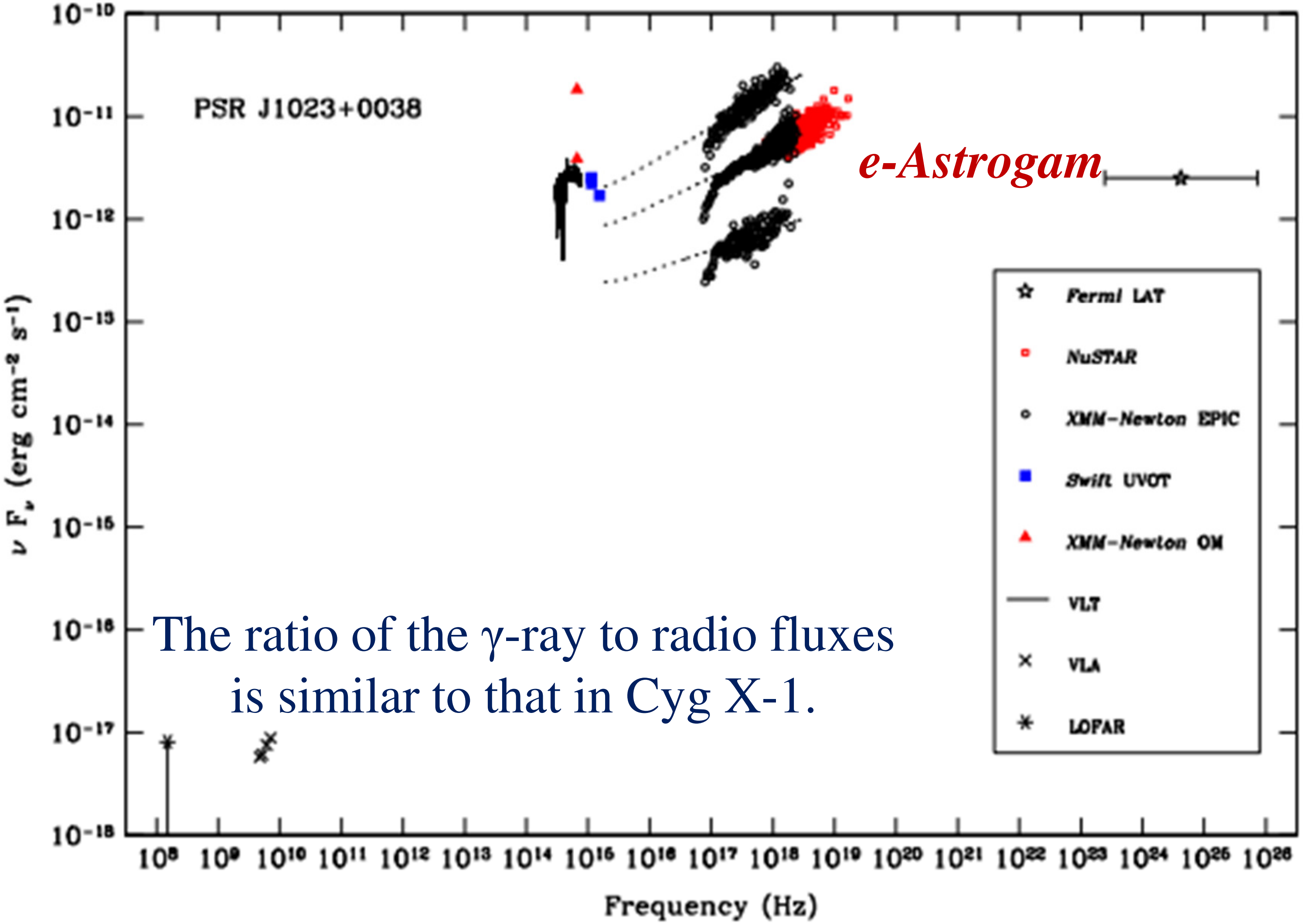


An example of the radio spectrum, $\alpha \approx 0$.



Is this a manifestation of the low-luminosity accretion states being dominated by jet emission?

The broad-band spectrum of PSR J1023+0038



The ratio of the γ-ray to radio fluxes is similar to that in Cyg X-1.

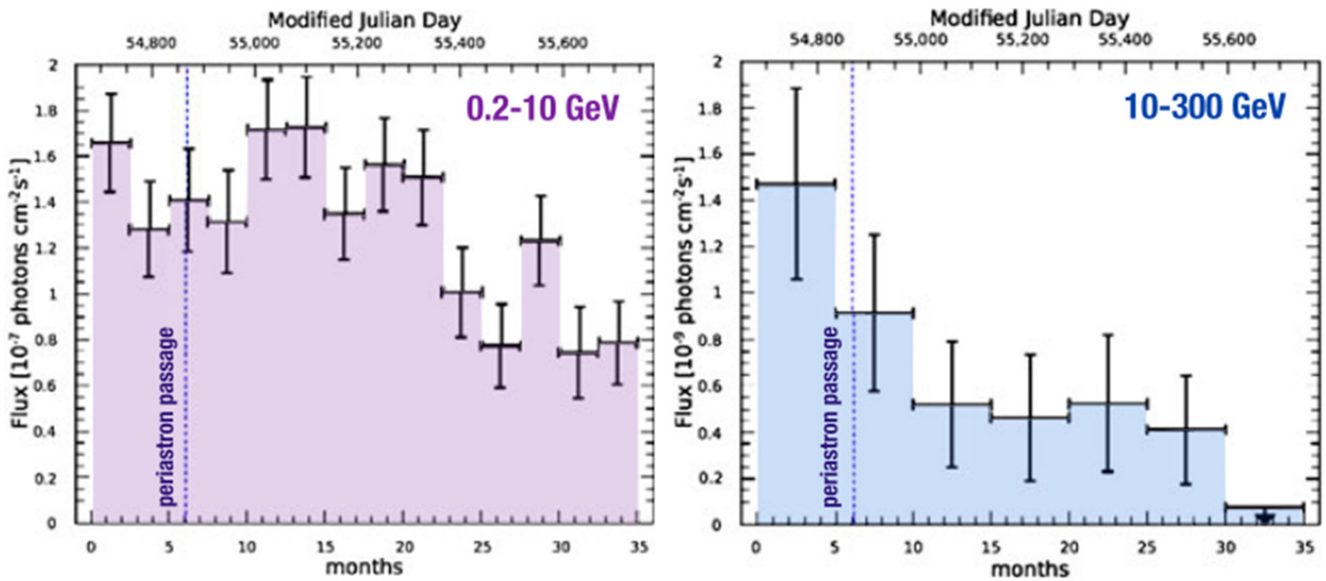
e-Astrogam will be able to study the transitionary region from X-rays to the MeV range, and unambiguously determine the nature of the γ-rays.

γ-ray emission of low-mass vs. high-mass X-ray binaries

- Cyg X-1 and Cyg X-3 are high-mass X-ray binaries, and their γ-ray emission appears to be dominated by Compton up-scattering of stellar blackbody by relativistic electrons.
- Also, interaction of the stellar wind with the jet can enhance the γ-ray emission (Yoon, AAZ, Heinz 2016).
- LMXBs lack these factors.
- Still, relativistic electrons in the jets of LMXBs will emit SSC and up-scattering of disc photons.
- Low accretion-rate states may be jet-dominated and can have substantial γ-ray emission (see PSR J1023+0038).
- ***ASTROGAM*** will, most likely, detect many LMXBs in γ-rays.

Colliding-wind high-mass binaries

- Only one colliding-wind binary has been detected in high-energy γ-rays (by *AGILE* and *Fermi*), Eta Car, a binary with a ~100$M_\odot$ LBV and an O or WR star in a 5.5 year orbit. The γ-ray luminosity ≈ 0.2% of the available wind kinetic power.
- Why so few? Why is acceleration so inefficient?
- *e-Astrogam* will be able to detect more sources in the range <100 MeV.



Reitberger+2012

Final remarks

- Intersection of the accretion and jet components in the MeV region in microquasars. *e-ASTROGAM* will disentangle those contributions in particular in Cyg X-1, Cyg X-3 and PSR J1023+0038, already detected in γ-rays.
- It will resolve the issue of the origin of MeV tails, either from non-thermal Comptonization or jet synchrotron emission.
- It will measure the MeV polarization in Cyg X-1.
- It will measure orbital modulation in γ-rays in both microquasars and gamma-ray binaries.
- It will likely detect many LMXBs and collidign-wind binaries in γ-rays.