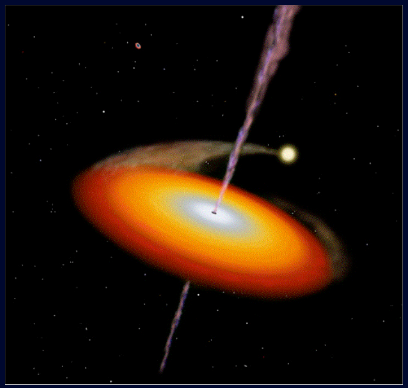


Gamma-ray binaries

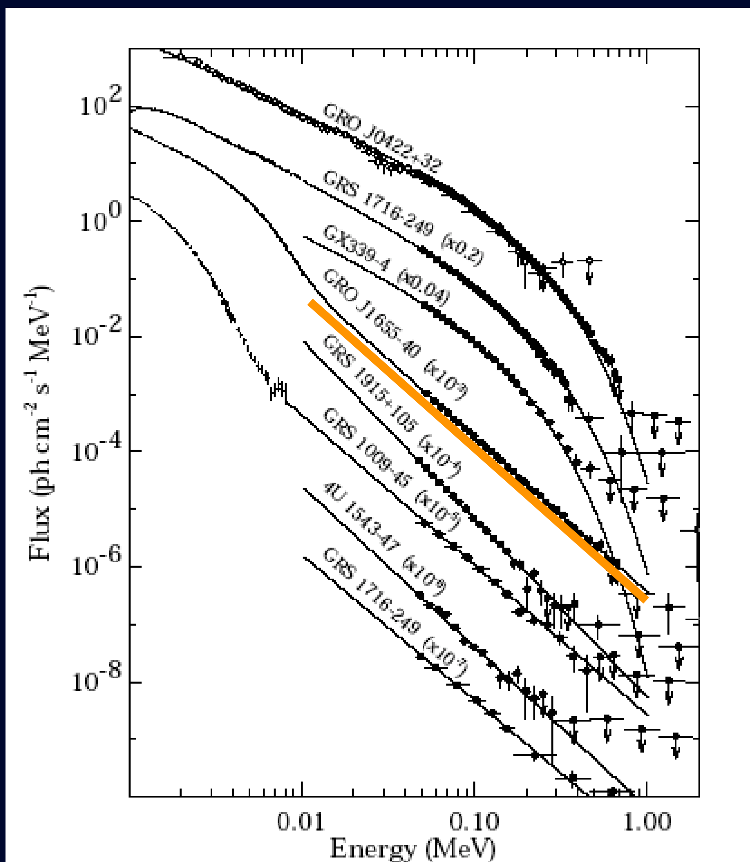
Guillaume Dubus

Laboratoire d'Astrophysique de Grenoble

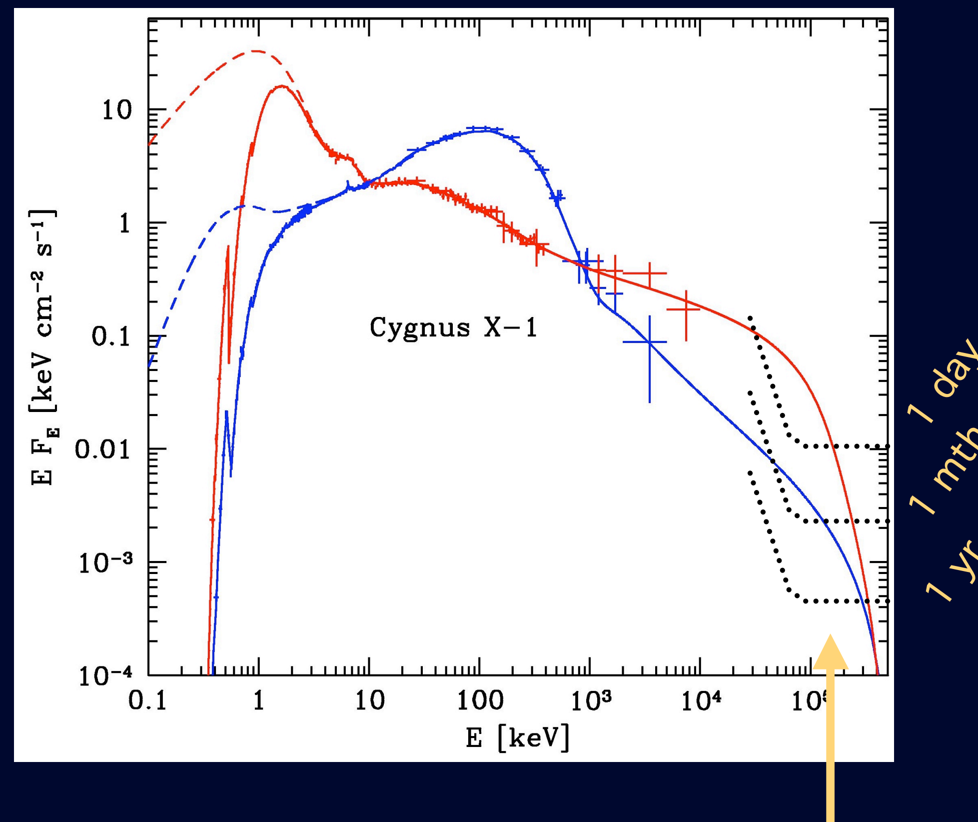
Jean-Pierre Lasota conference - October, 2007

> 1 MeV emission from binaries

Extension ≥ MeV in Steep Power Law state



Grove et al. 98

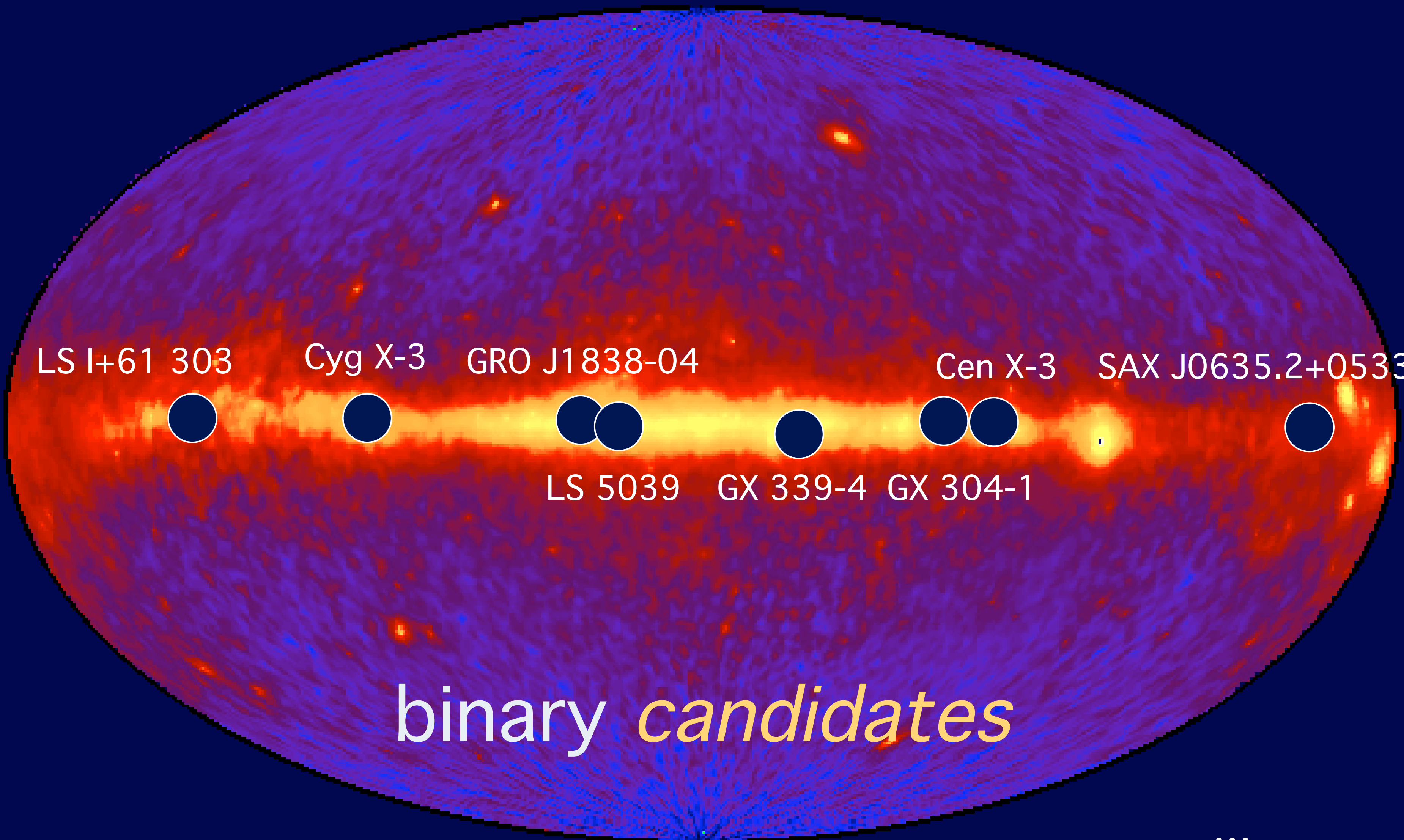


McConnell et al. 2002

Non-thermal distribution: relationship to jet formation ?

GLAST

≥ 100 MeV EGRET

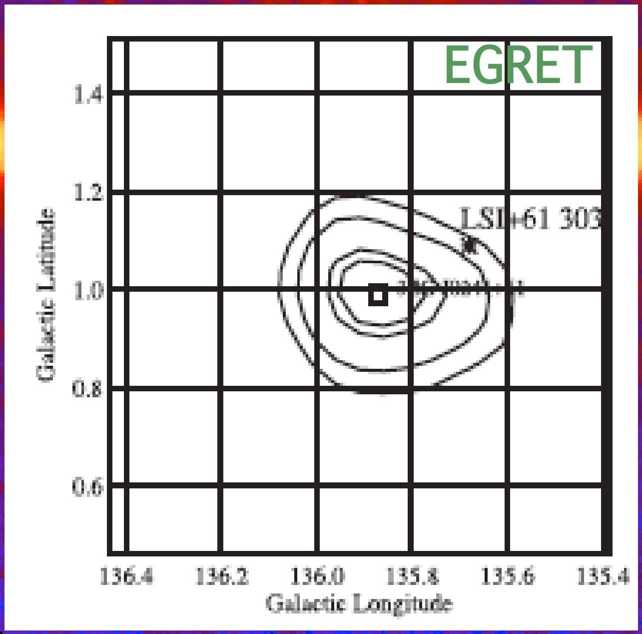


≥ 100 MeV EGRET candidates

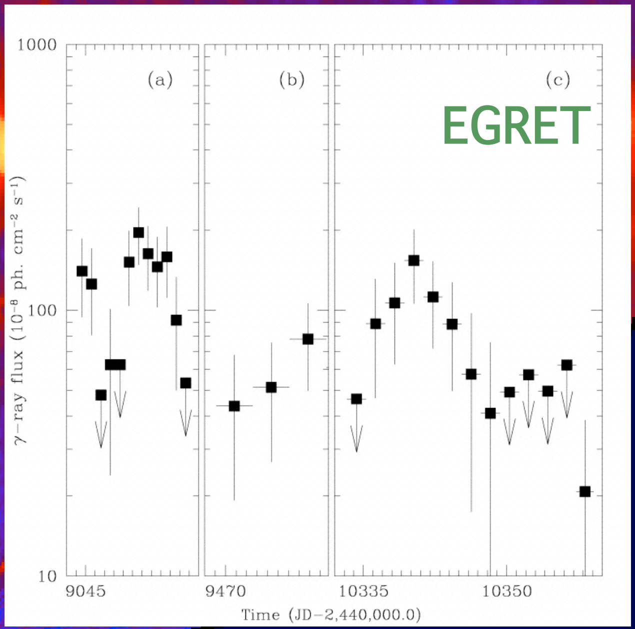
source confusion, no telltale variability (GLAST to help)

e.g. 2CG 135+01 source associated with binary LS I+61 303

LS I+61 303

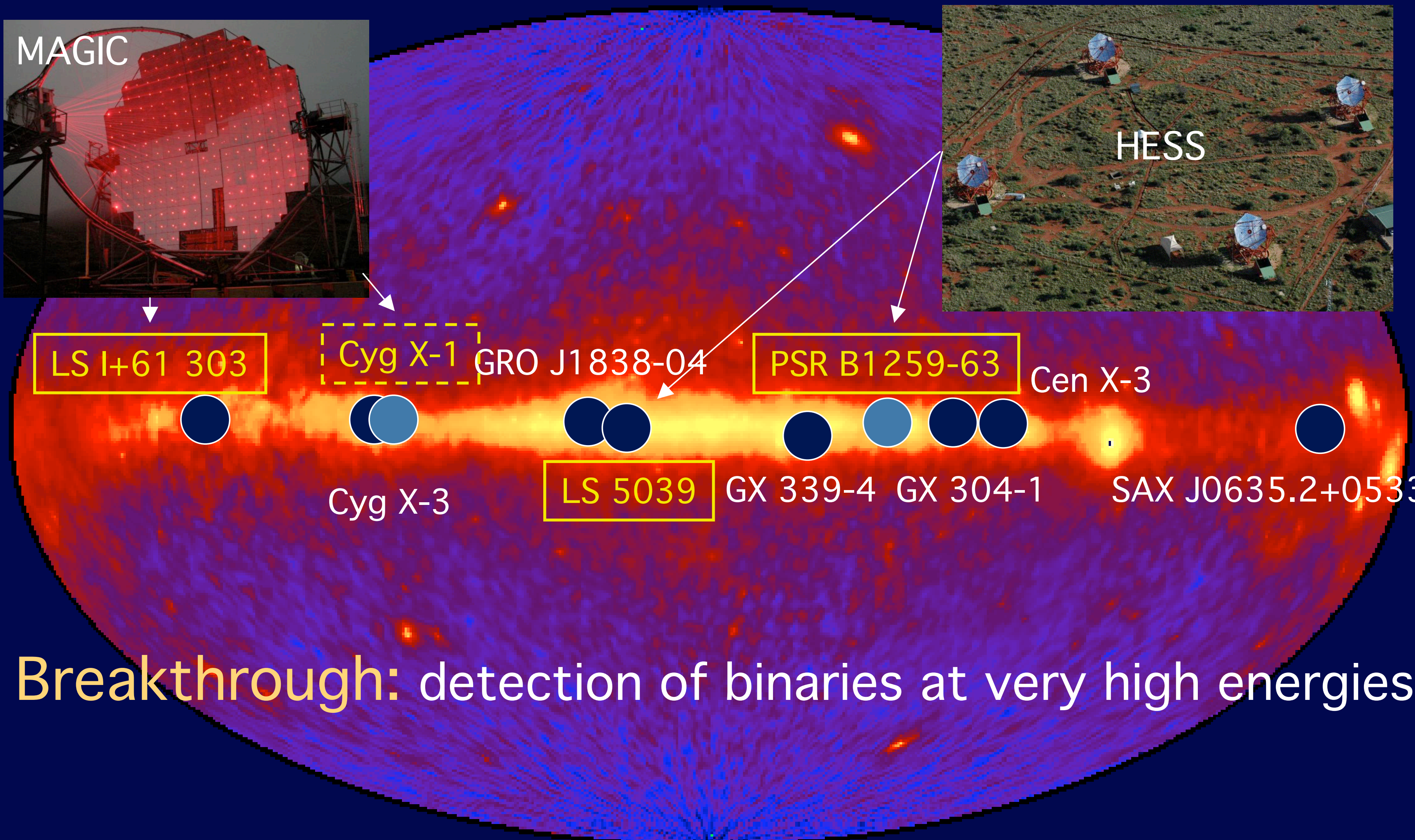


from Reimer & Iyudin 2003



Tavani et al. 1998

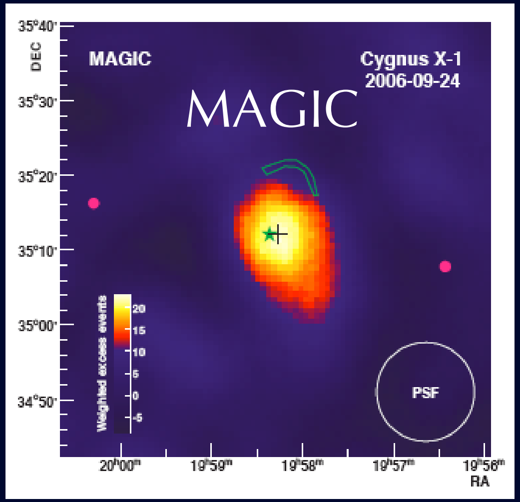
≥ 100 GeV Cherenkov (from 2004 on)



Breakthrough: detection of binaries at very high energies

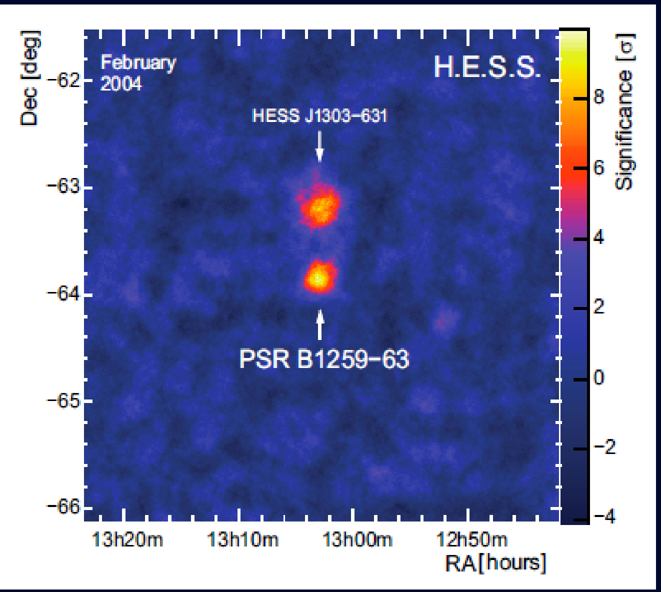
positions < arcmin + variability =
binaries emit VHE γ-rays.

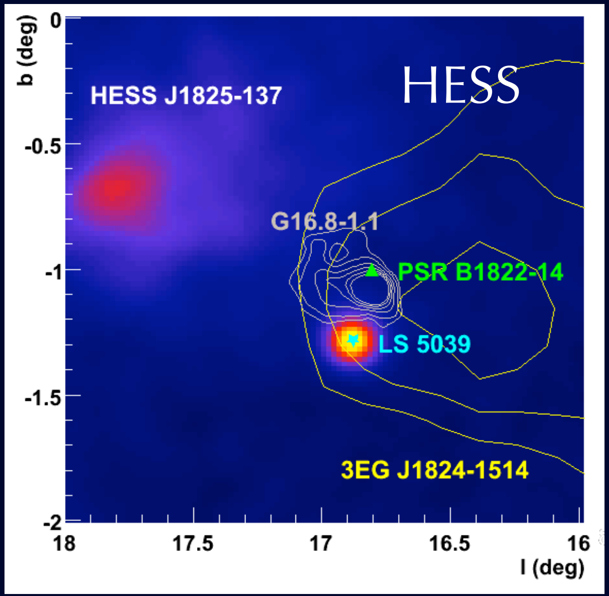
[Cyg X-1 VHE emission tbc because low significance]

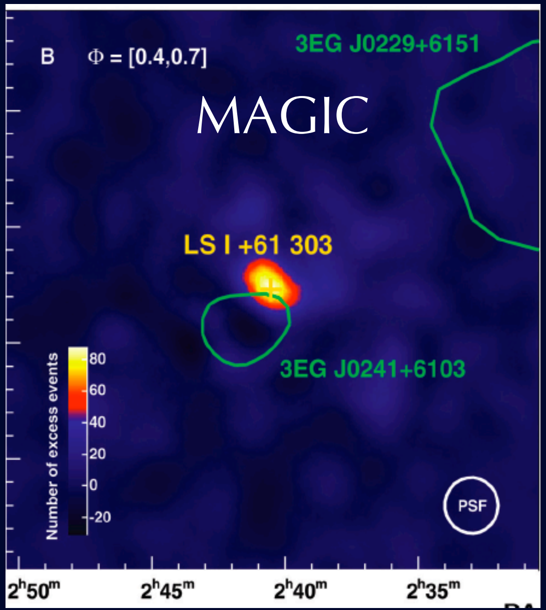


Albert et al. 2007 ApJ 665 L51

TeV ~ 10^{33} erg/s ~ X-ray luminosity
Gamma-ray binaries





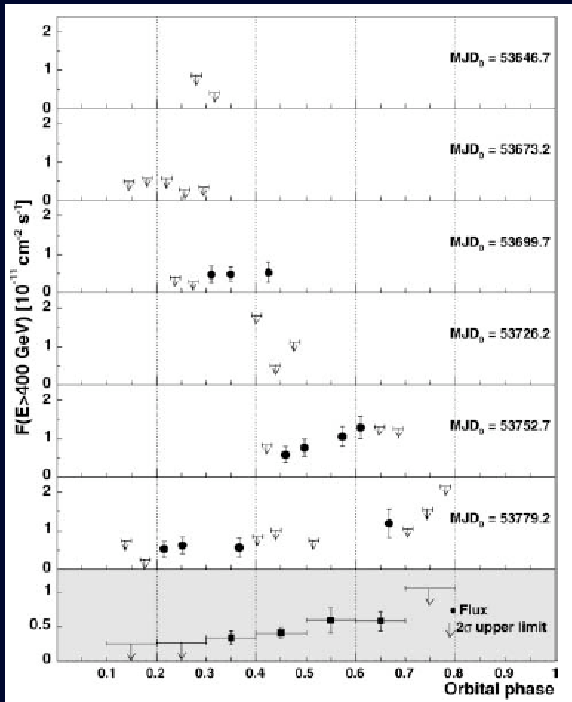


Aharonian et al. 2005, A&A, 442, 1

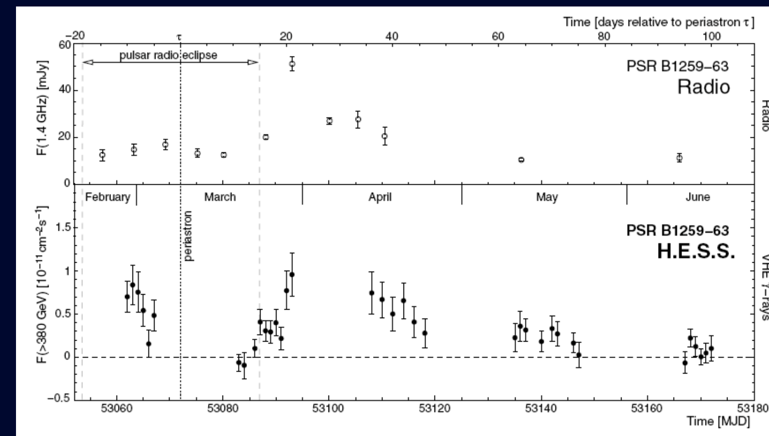
Aharonian et al., 2005, Science, 309, 746

Albert et al., 2006, Science

Variability

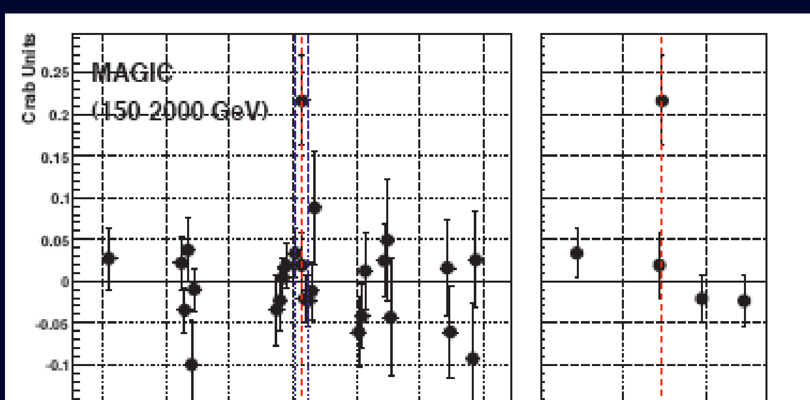


LS I +61 303

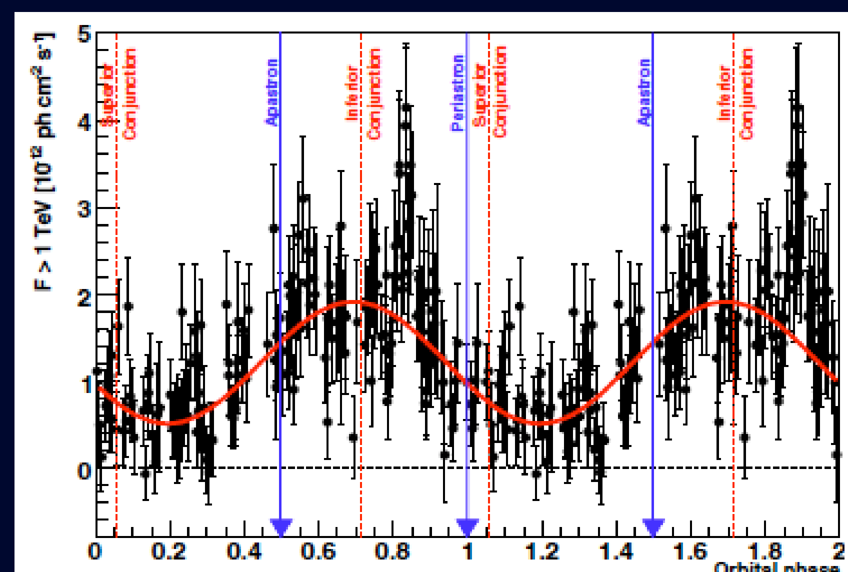


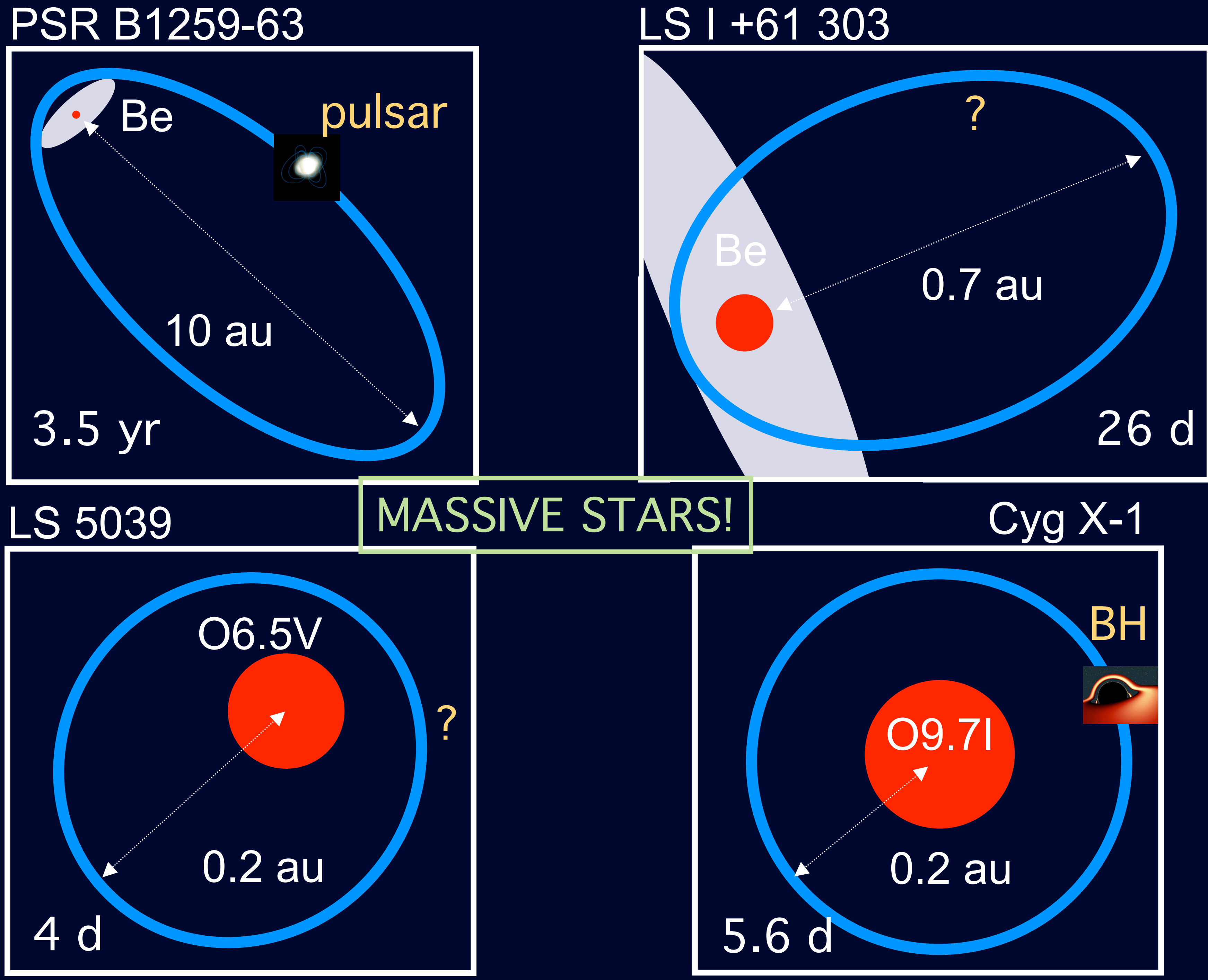
PSR B1259-63

LS 5039: proven orbital modulation



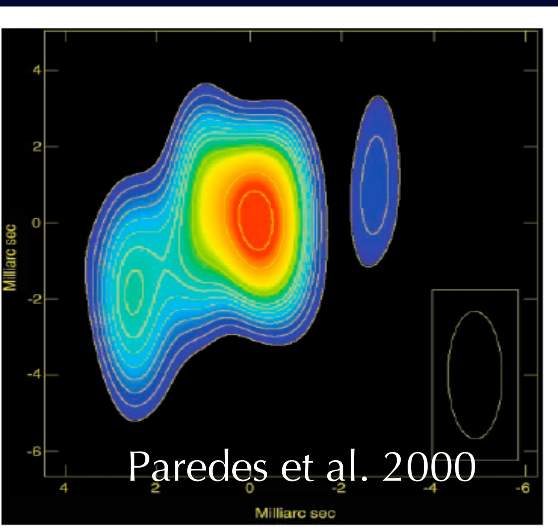
Cyg X-1



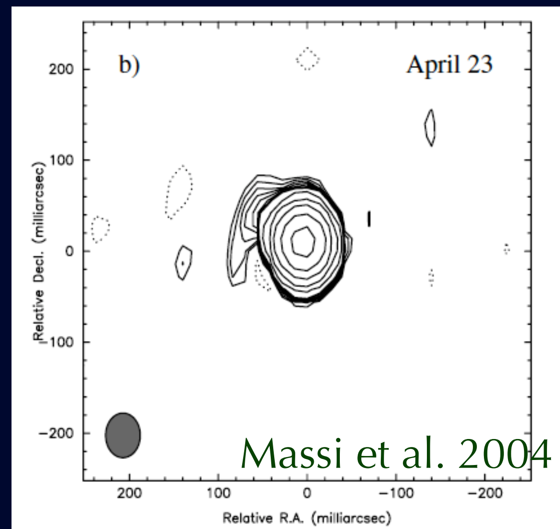

PSR B1259-63
Be
pulsar
10 au
3.5 yr
LS I +61 303
?
Be
0.7 au
26 d
MASSIVE STARS!
LS 5039
O6.5V
?
0.2 au
4 d
Cyg X-1
BH
O9.7I
0.2 au
5.6 d

All display radio emission

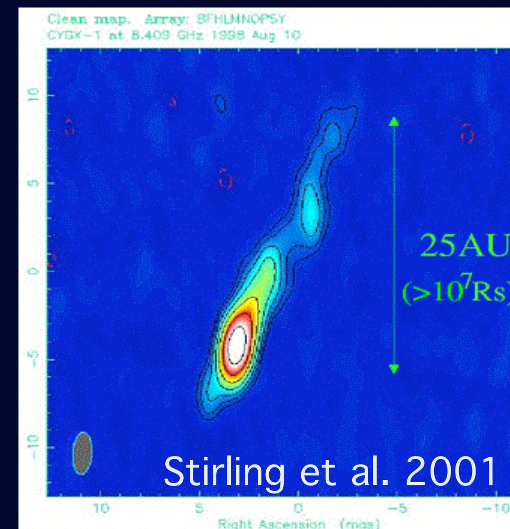
LS 5039



LS I+61 303



Cyg X-1



Resolved on scales of au+ in LS 5039, LS I+61 303 and Cyg X-1.

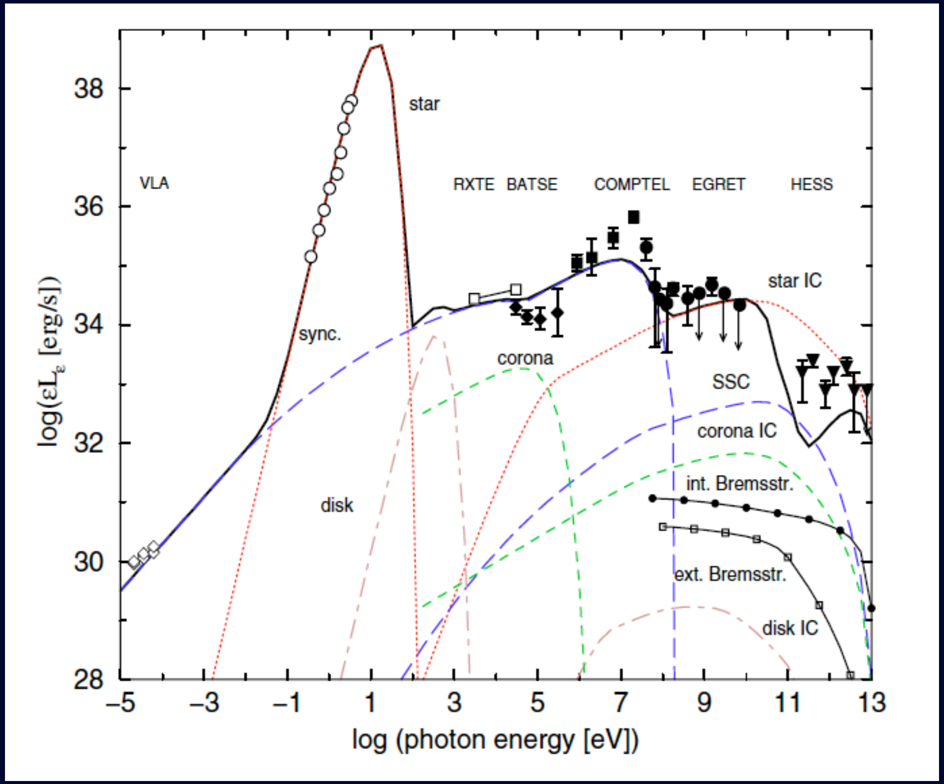
LS 5039 and LS I+61 303: emission from a relativistic jet ?

- Jet natural interpretation for resolved radio.
- Radio ~ compact jet typical of hard/low state.
- Hard X-ray spectrum also suggests hard/low state.
- Black hole ⇔ low inclination (with measured mass function) ⇔ jet close to line of sight which may help to have gamma-rays.

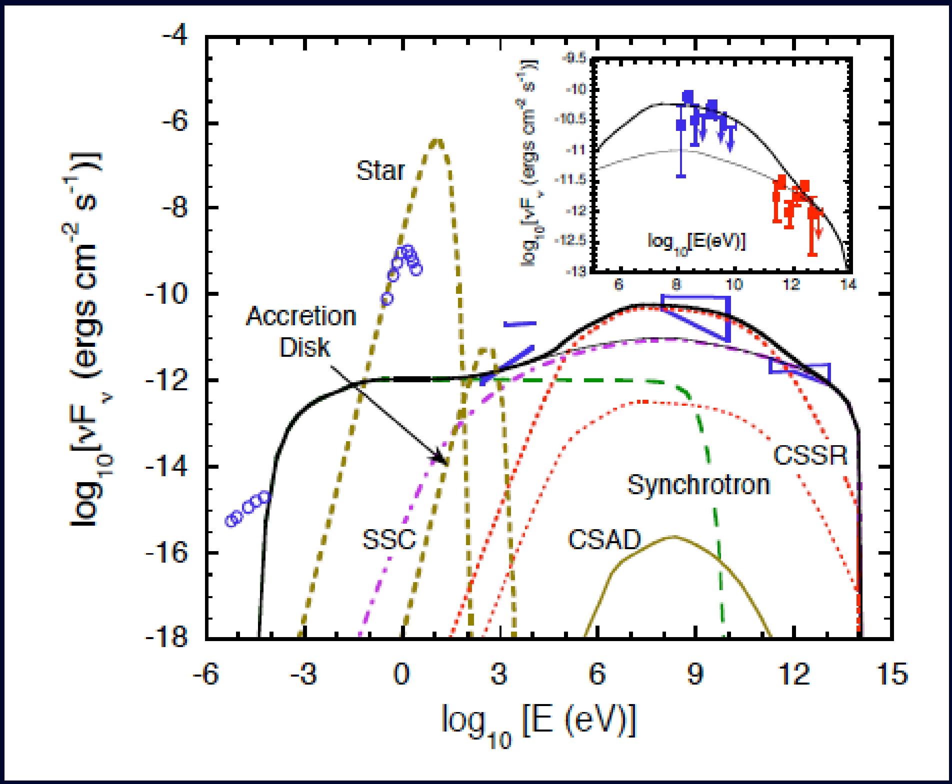
Jet models

LS 5039

Paredes et al. 2006



Dermer & Bottcher 2006

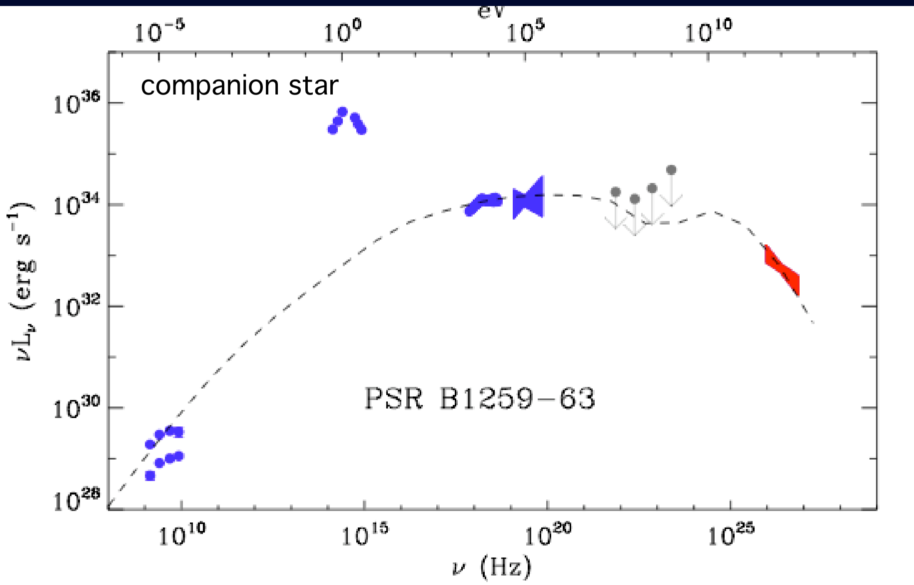


Radio and X-ray properties

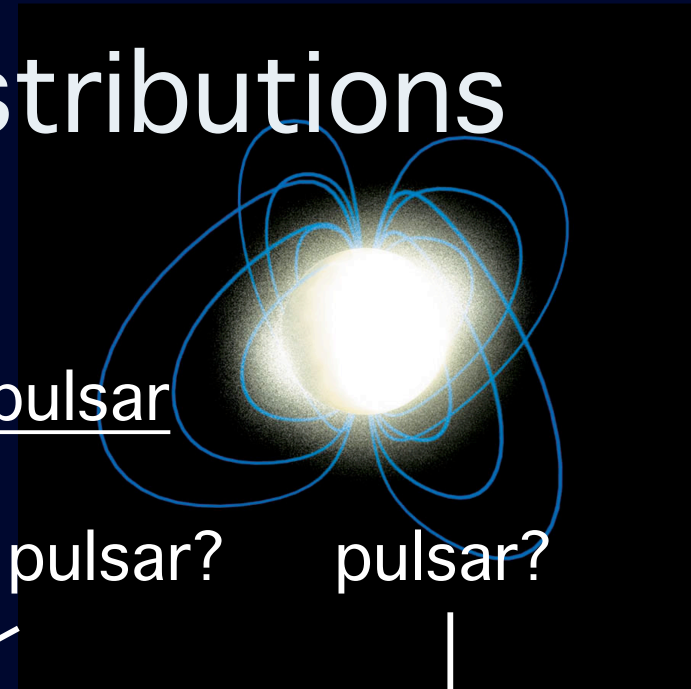
- X-ray spectrum suggests hard/low state of “microquasars” but
  - No broad band noise / QPO
  - No flux variability on long timescales
  - Low X-ray luminosity
- In the low/hard state there is radio emission associated with compact jet
  - but $F_\nu \sim \nu^{-0.5}$ while compact jets usually have flat spectra
  - No resolved motion, low bulk Lorentz factor

Martocchia et al. 2005; GD 2006, A&A, 456, 801

Spectral Energy Distributions

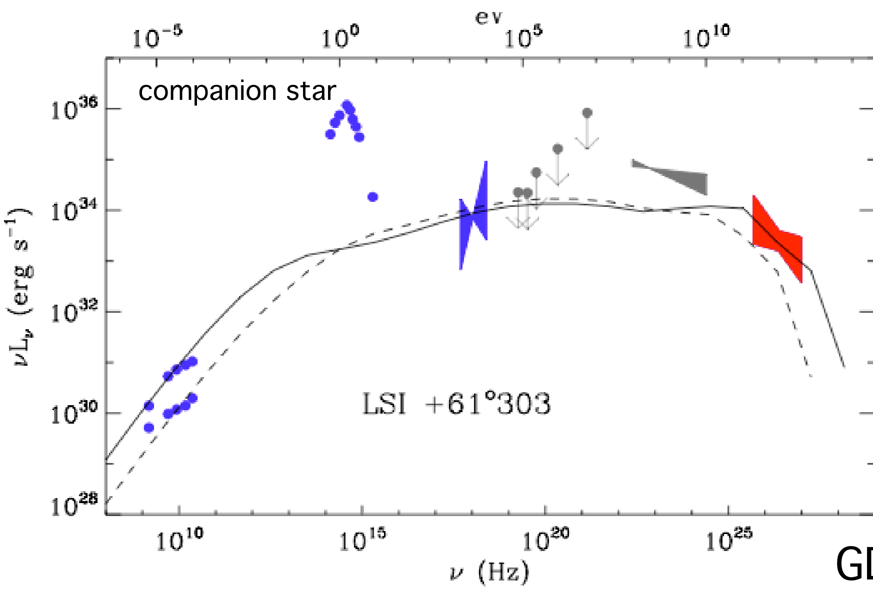


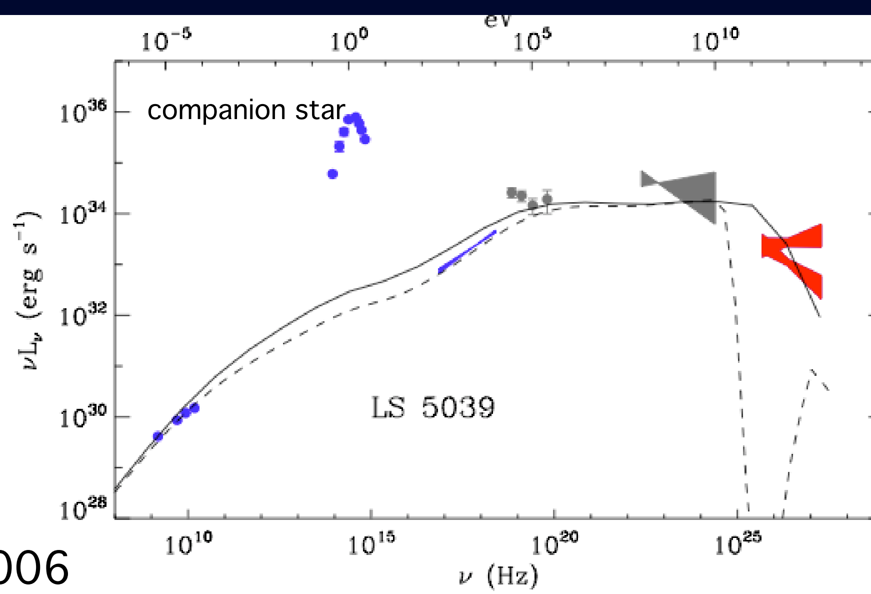
pulsar



pulsar?

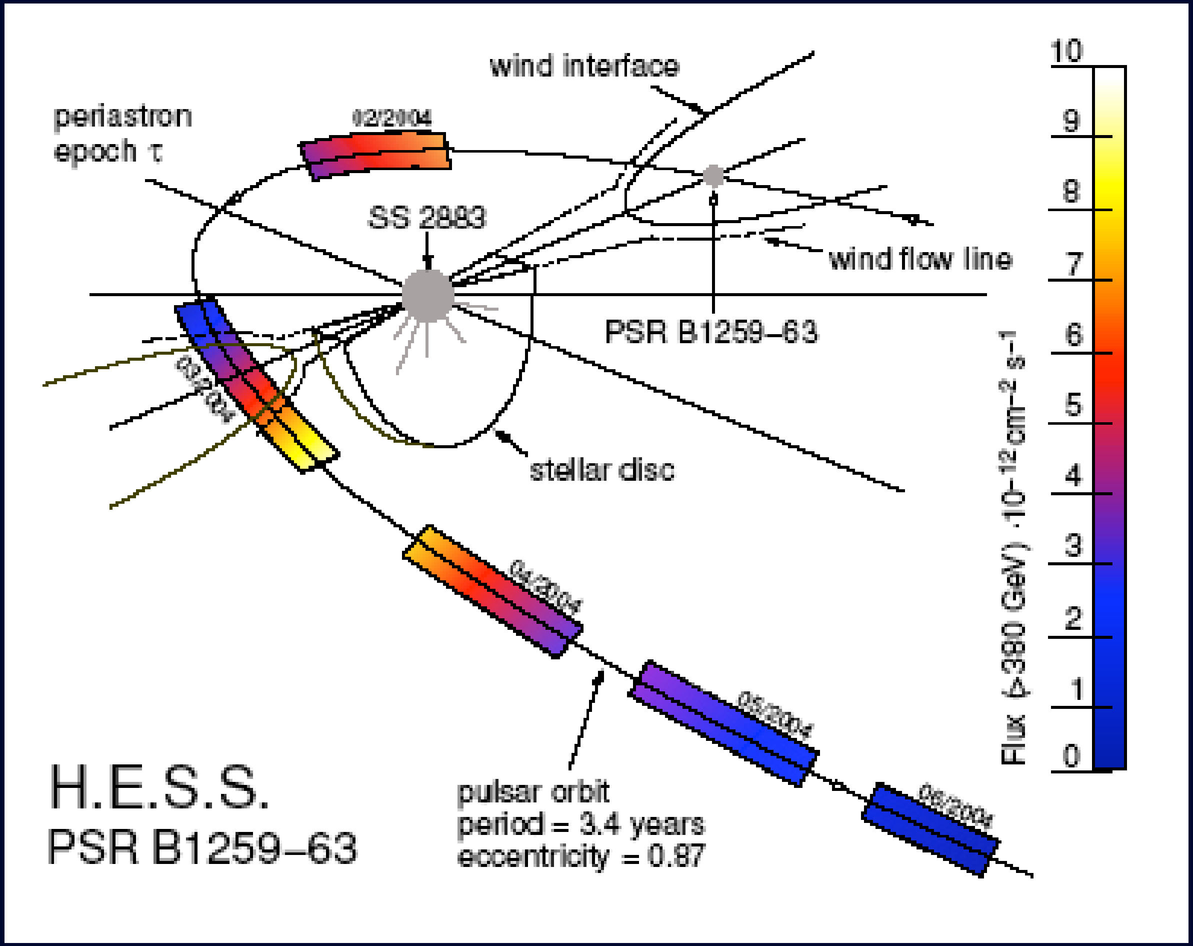
pulsar?





GD 2006

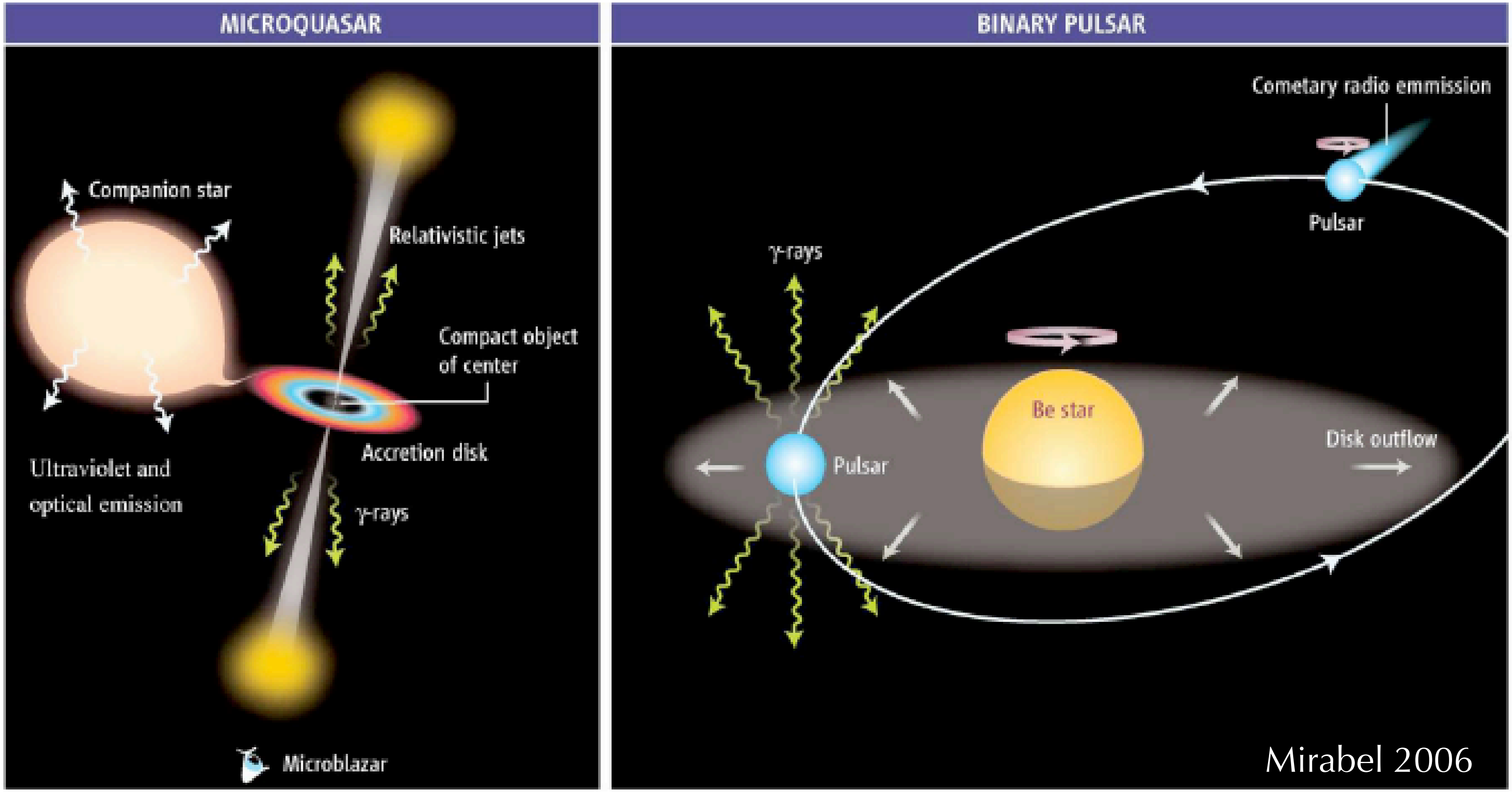
In PSR B1259-63, VHE emission due to particle acceleration at pulsar wind termination shock



48 ms pulsar, spindown power 10^{36} erg/s, no accretion

Tavani & Arons 97; proposed for LS I+61 303 by Maraschi & Treves 81

Controversy: origin of VHE emission in LS 5039 / LS I +61 303 ?



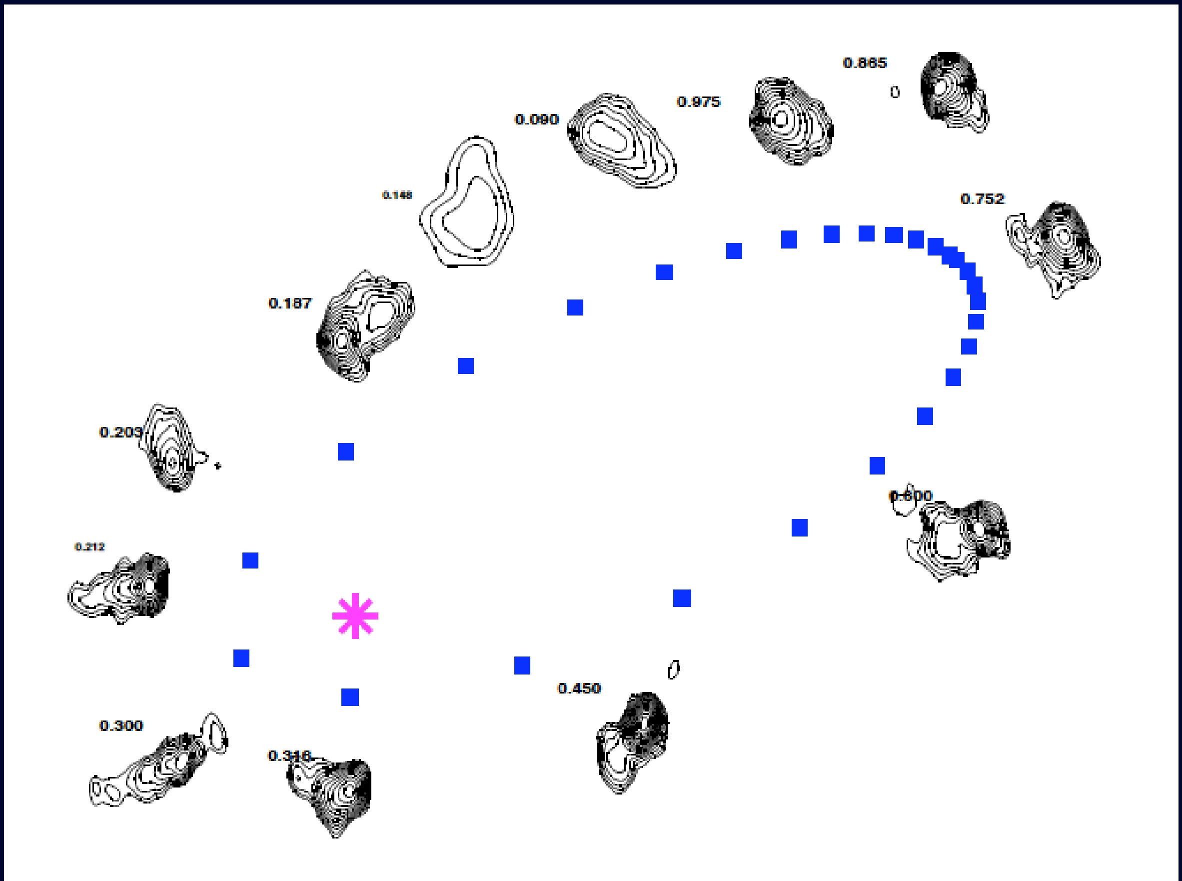
Accretion power

Rotation power

LS I+61 303 is a pulsar not a microquasar

Radio VLBI observations of LS I +61 303 by Dhawan & collaborators.

Dhawan et al. 2006, PoS (MQW6) 52



- No bulk relativistic motion
- Lower frequency further away
- Morphology varies along orbit
- Tail points away from star

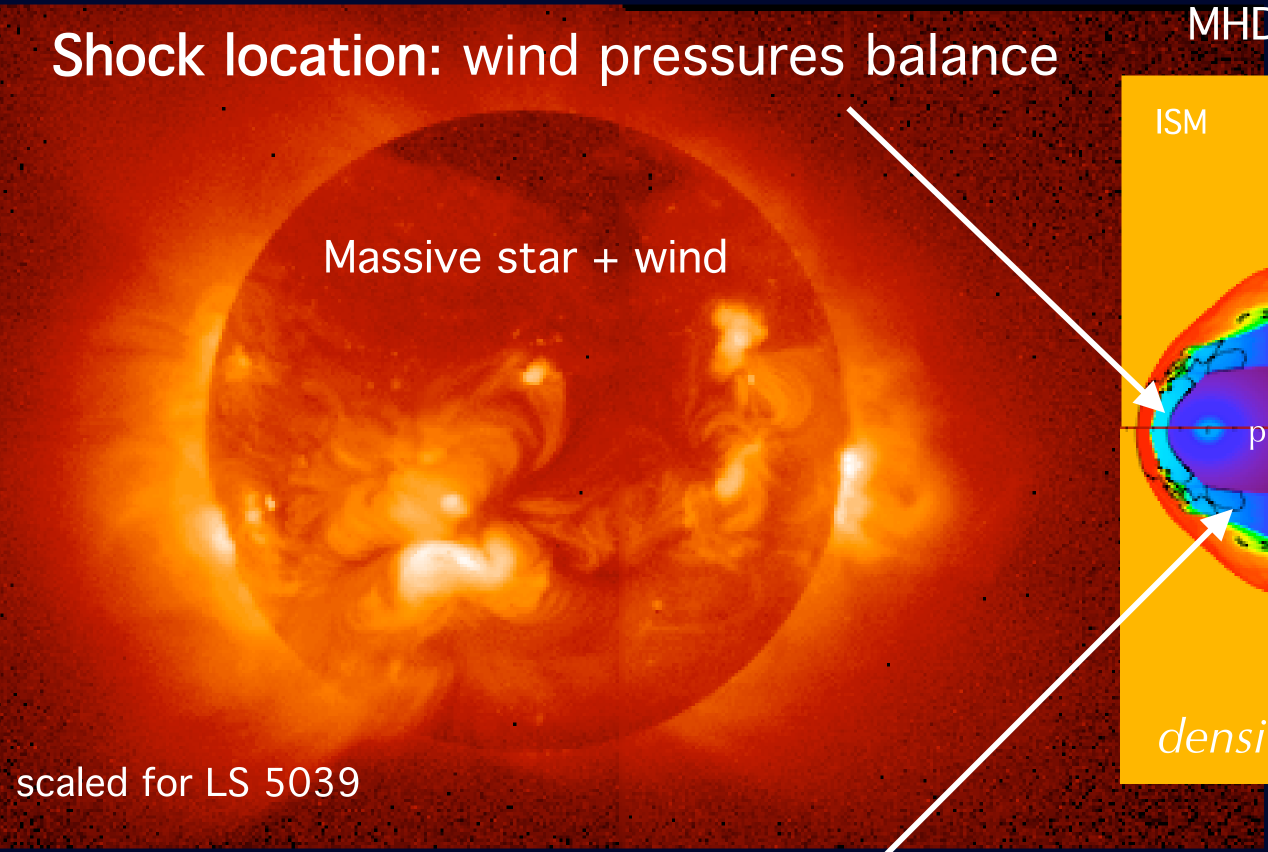
[Radio pulse (not seen) is absorbed in stellar wind.]

We conclude that the pulsar model is strongly supported, i.e., the radio synchrotron emission arises not in a jet, but from particles shock-accelerated in the interaction of the pulsar wind with the dense equatorial wind from the Be star.

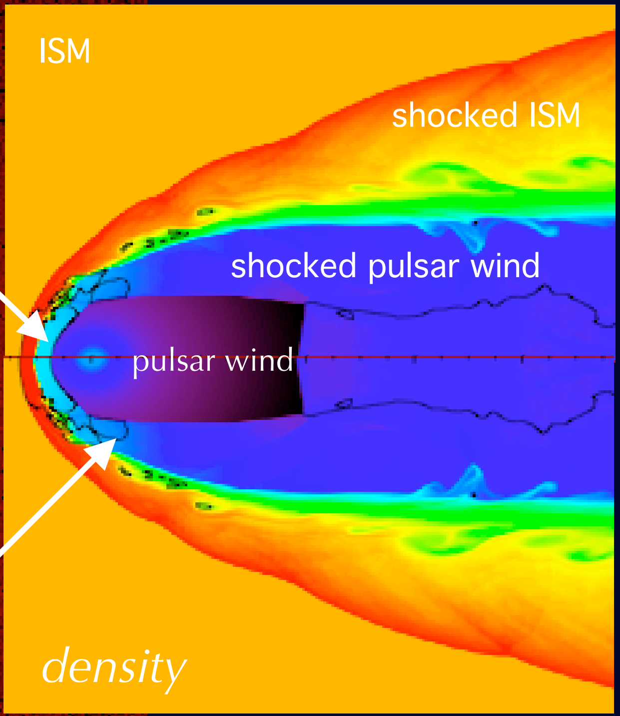
1. Some binaries emit HE and VHE photons, can be due compact PWN nebula in binary system.

2. What can we learn?
Modeling the PWN emission.

Modeling the pulsar wind nebula



MHD simulation PW+ISM



Bucciantini et al. 2005

Particle acceleration and **high energy** emission occur in a small zone very close to pulsar, where stellar radiation is intense.

Radiative timescales at work

Assume efficient acceleration of e^+e^- (*purely leptonic*),
+ radiative timescales < escape timescale from emission zone.

Inverse Compton cooling on star photons (Klein Nishina regime)

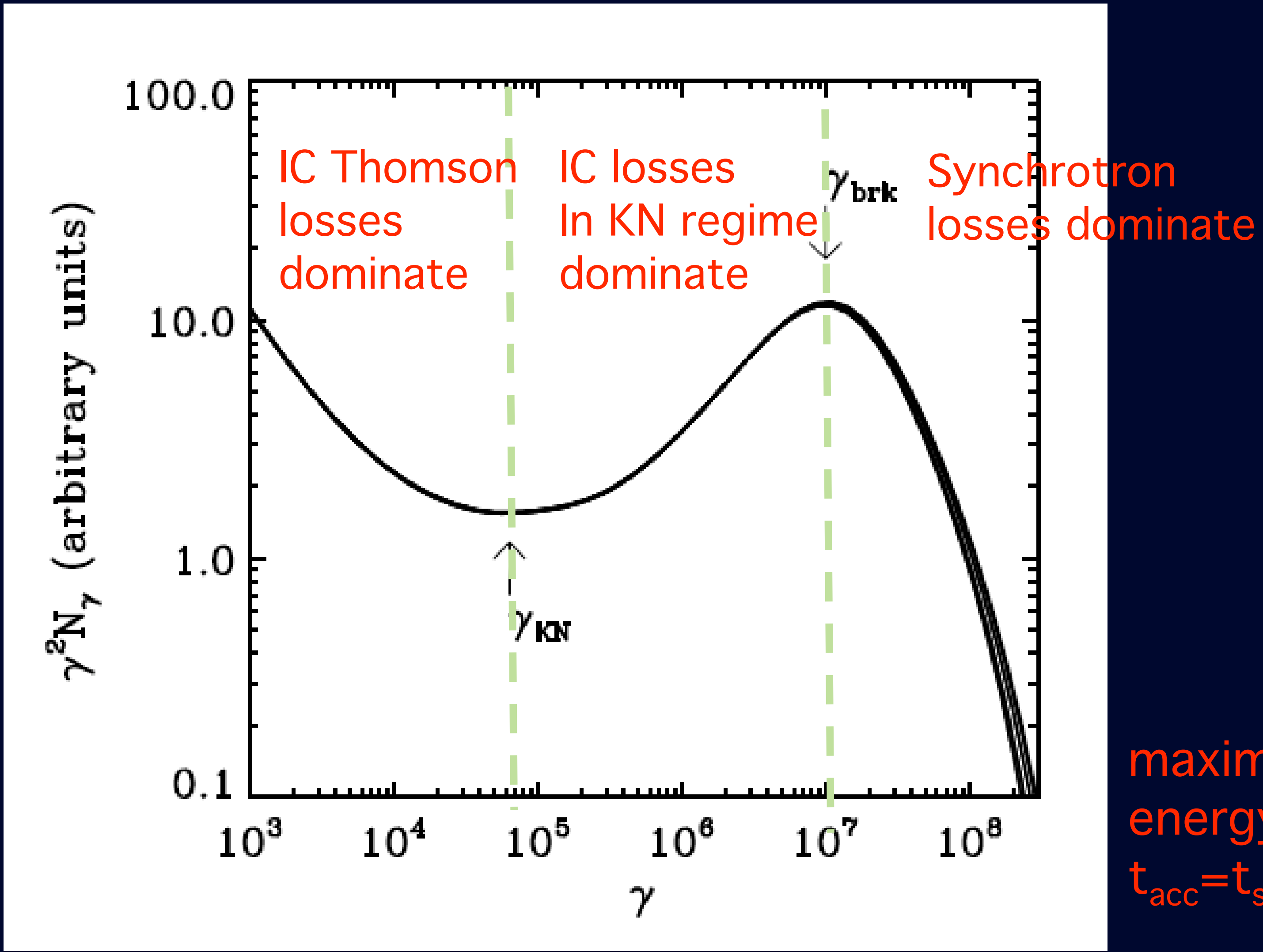
$$t_{IC} \approx 20\ \gamma_6 d_{0.1}^2\ /\ \left[\ln\gamma_6 + 1.3\right]\left(T_{*,4\mathrm{e}4} R_{*,10}\right)\ \mathrm{s}$$

Synchrotron cooling

$$t_S \approx 770\ /\ B_1^2 \gamma_6\ \mathrm{s}$$

[note: pulsar wind or jet model only comes in via estimate of B]

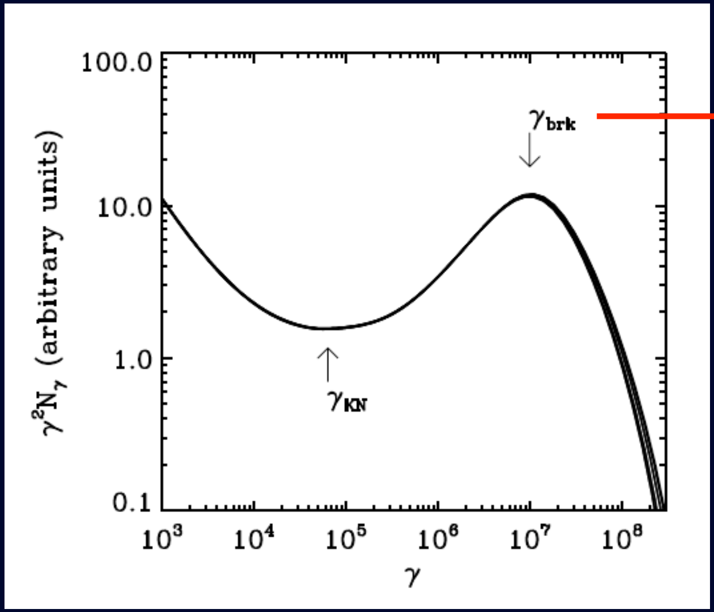
Steady-state electron distribution



B=0.8G
Injection: power-law $dN=E^{-2}dE$

maximum energy
$t_{acc}=t_{sync}$

Steady-state electron distribution



$$\gamma_{brk} \approx 6 \cdot 10^6 \left(T_{*,4} R_{*,10} / d_{0.1} B_1 \right)$$

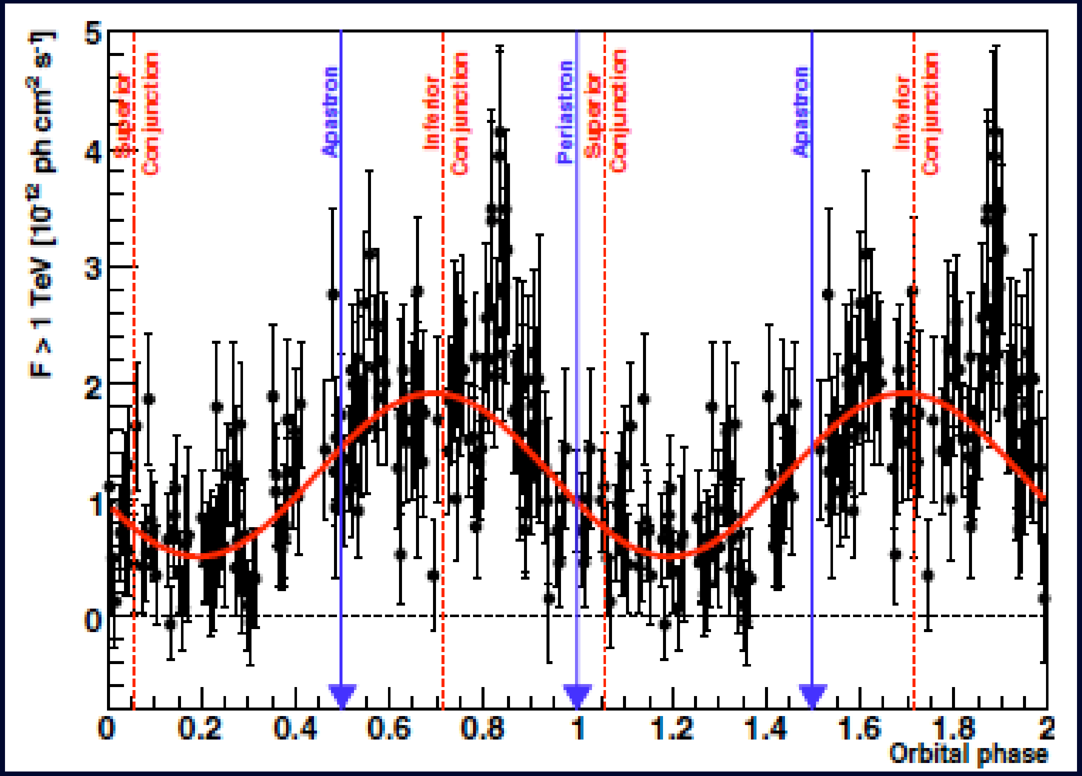
Cutoff in spectrum at

$$h\nu_{IC} \approx 3 \left(T_{*,4} R_{*,10} / d_{0.1} B_1 \right) \text{ TeV}$$

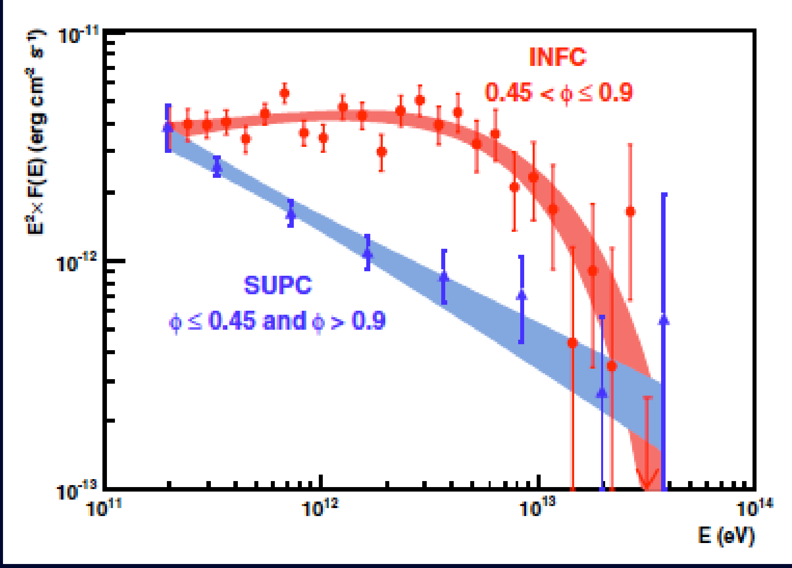
Compact PWN: B~1/d

Massive star radiation field sets everything but B.

Orbital modulation of VHE flux in LS 5039

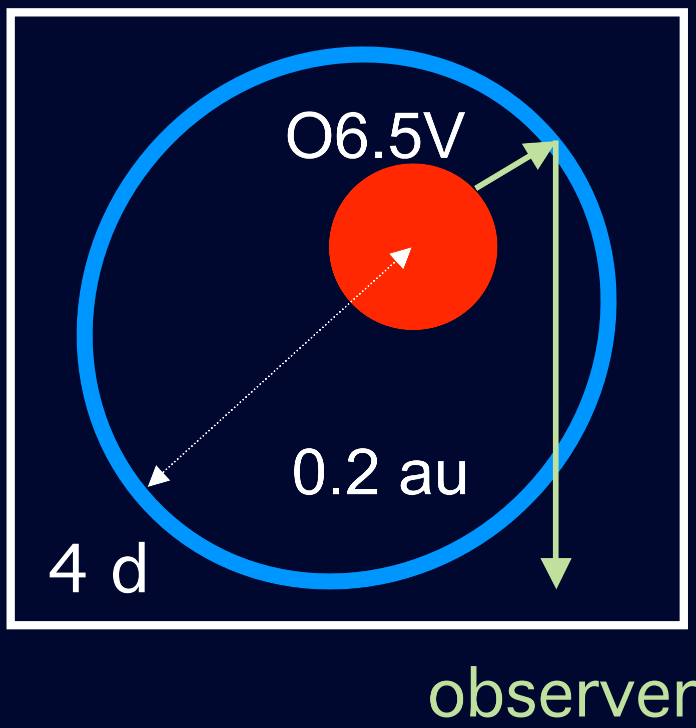


Aharonian et al. (HESS) 2006



Infer B from spectral break ?

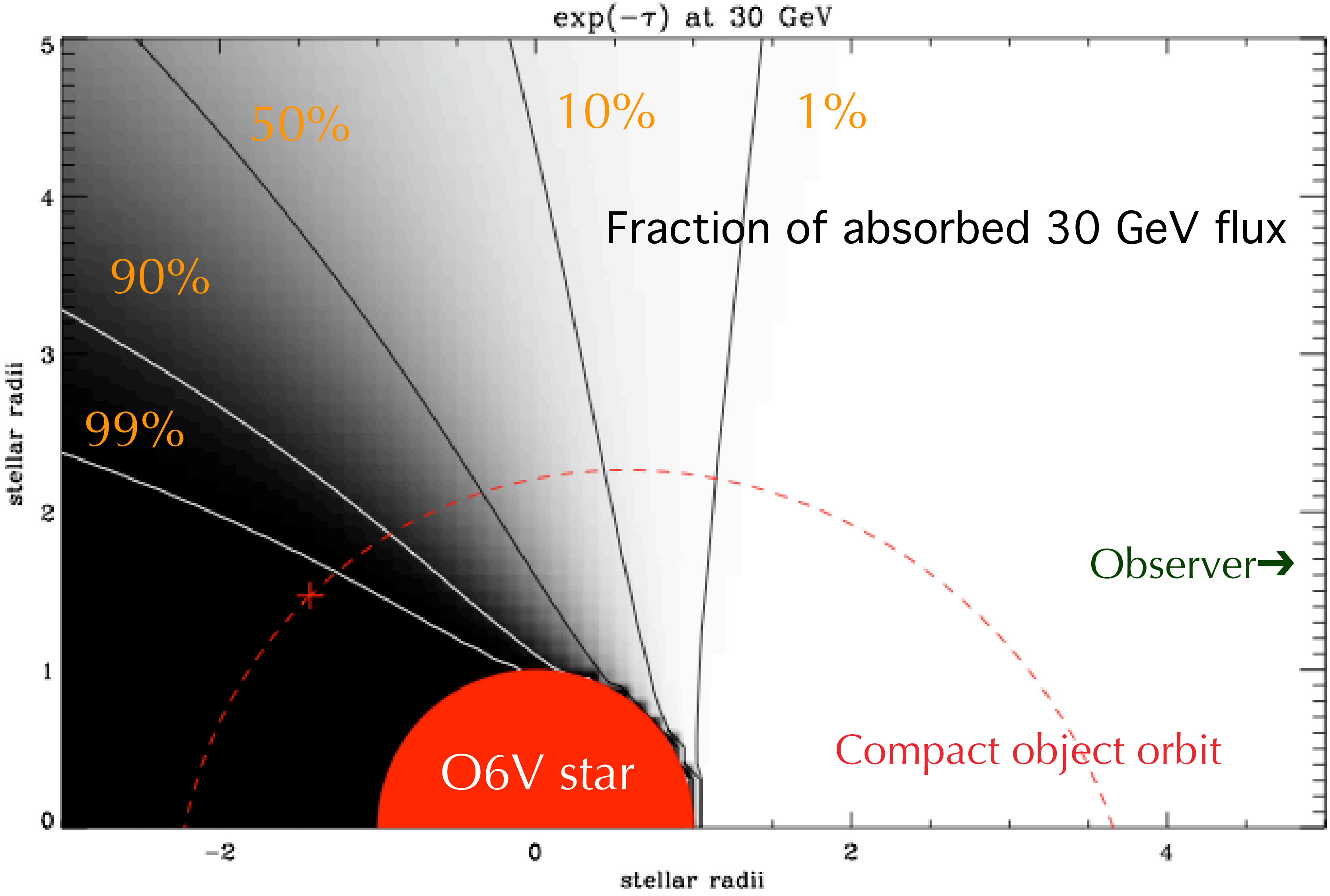
VHE emission in a binary star



photon field anisotropy:

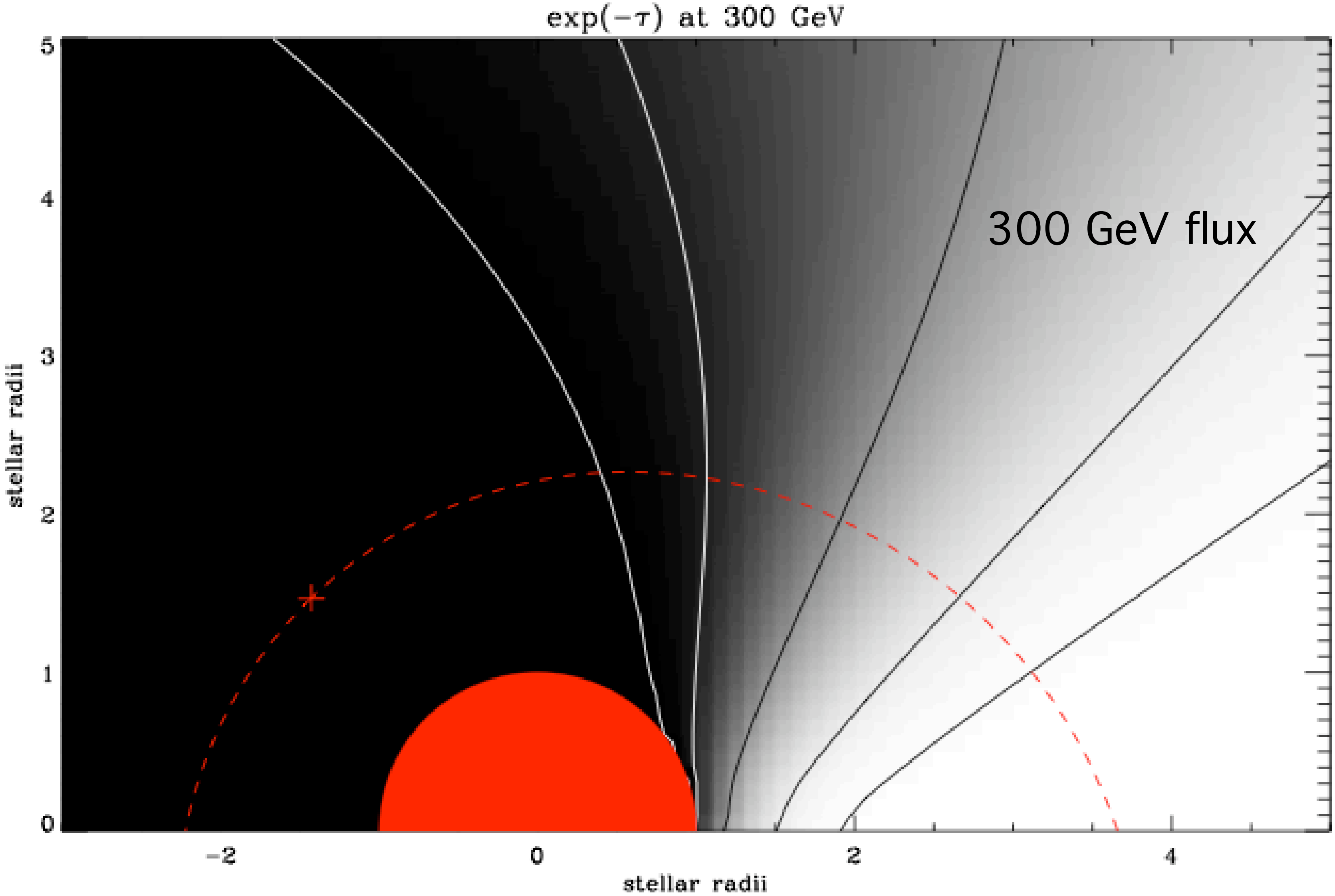
phase dependence of
(1) gamma-ray absorption due to pair production,
(2) the inverse Compton emission.

Gamma-ray absorption



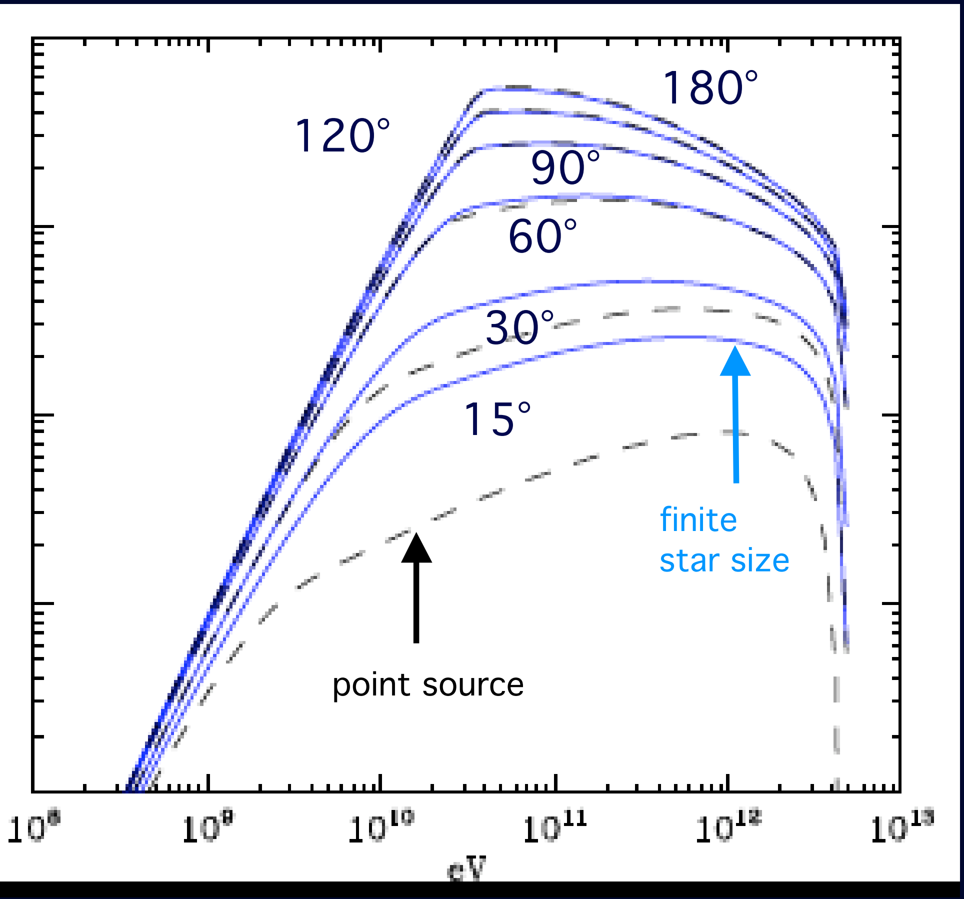
GD 2006 A&A 451, 9

Gamma-ray absorption



GD 2006

Anisotropic Compton emission



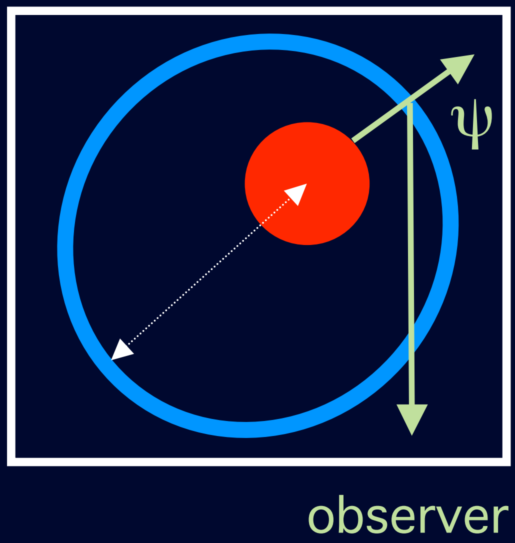
Electrons: power-law γ^{-2}

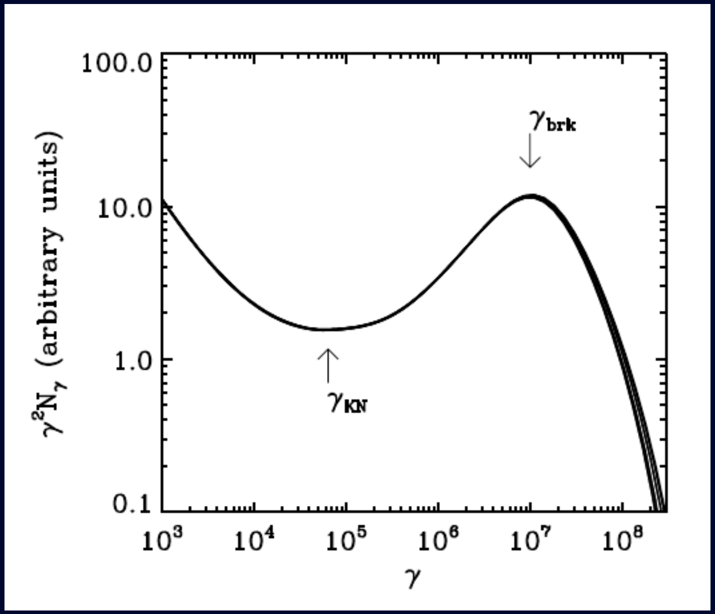
- Scattering more likely when electron moves toward source.

- Hardening of spectrum at small viewing angle

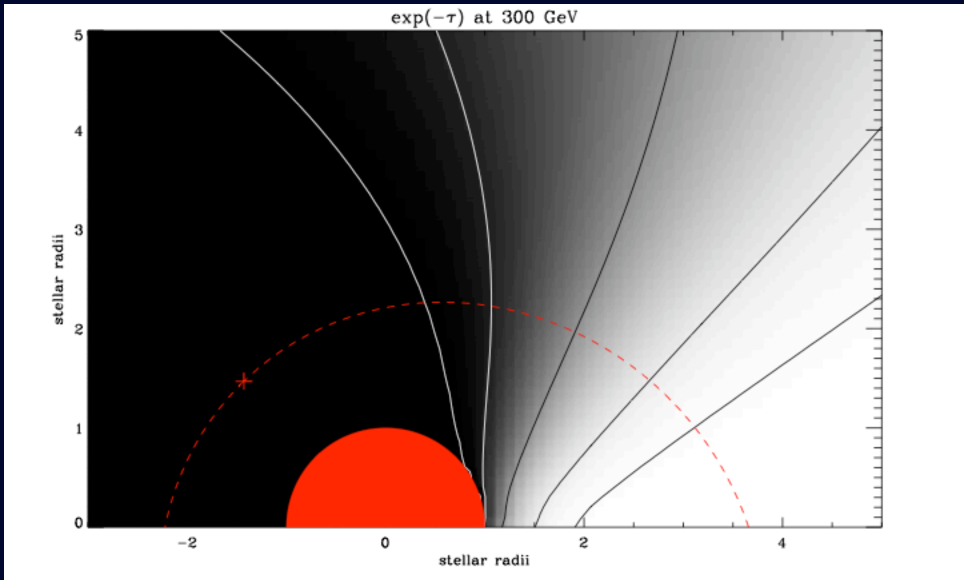
limit between Thomson and KN regime:

$$\varepsilon_i \gamma (1 - \beta \cos\psi) \approx mc^2$$

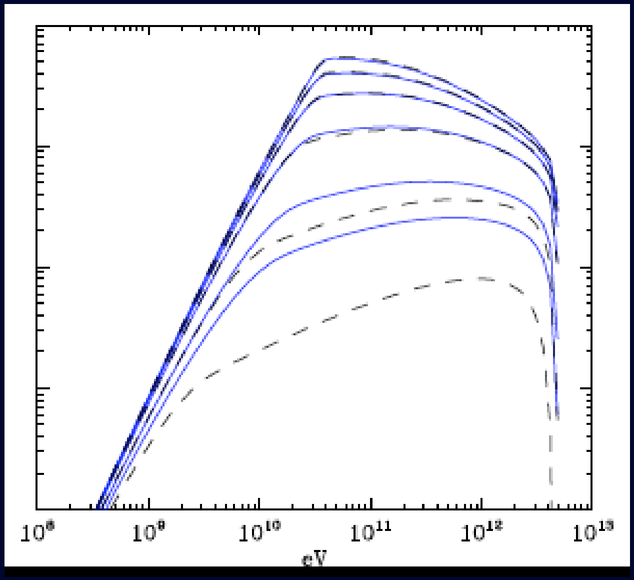



100.0
10.0
1.0
0.1
$\gamma^2 N_\gamma$ (arbitrary units)
γ_{brk}
γ_{KN}
10^3 10^4 10^5 10^6 10^7 10^8
γ

+


exp(−τ) at 300 GeV
stellar radii
stellar radii

+

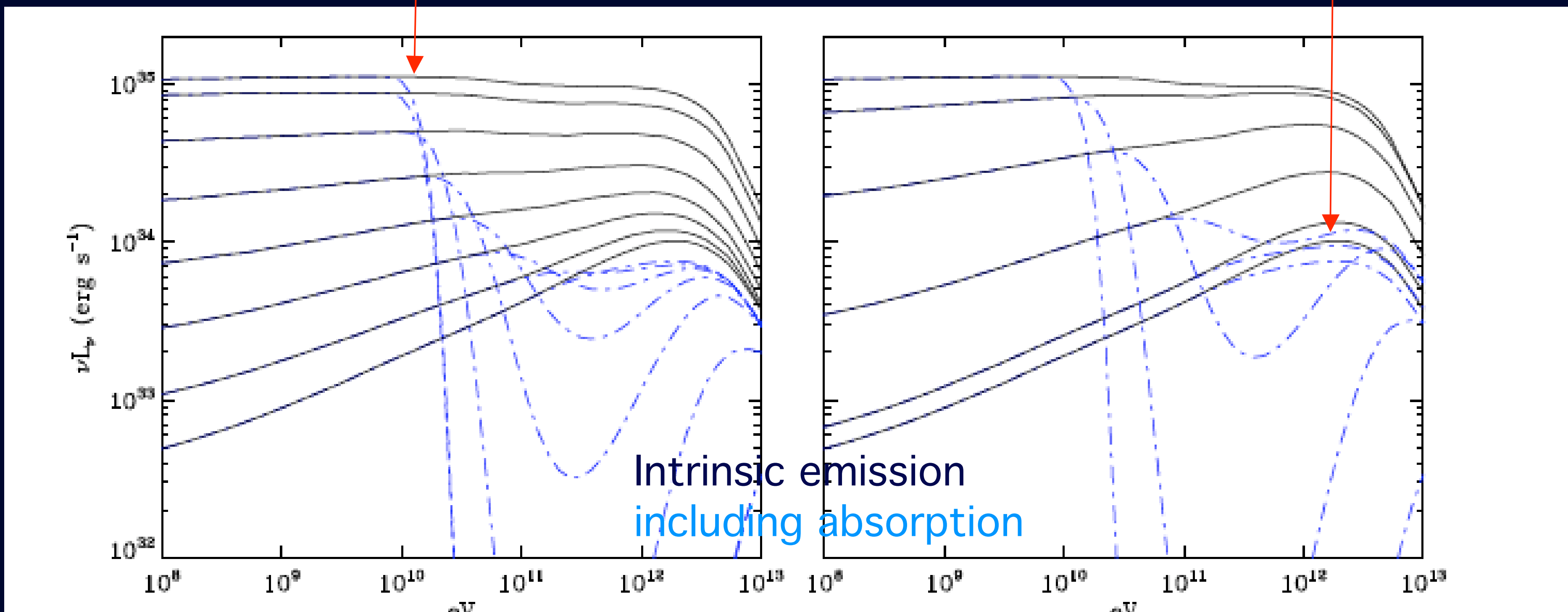

10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
eV

= ...

Spectral evolution

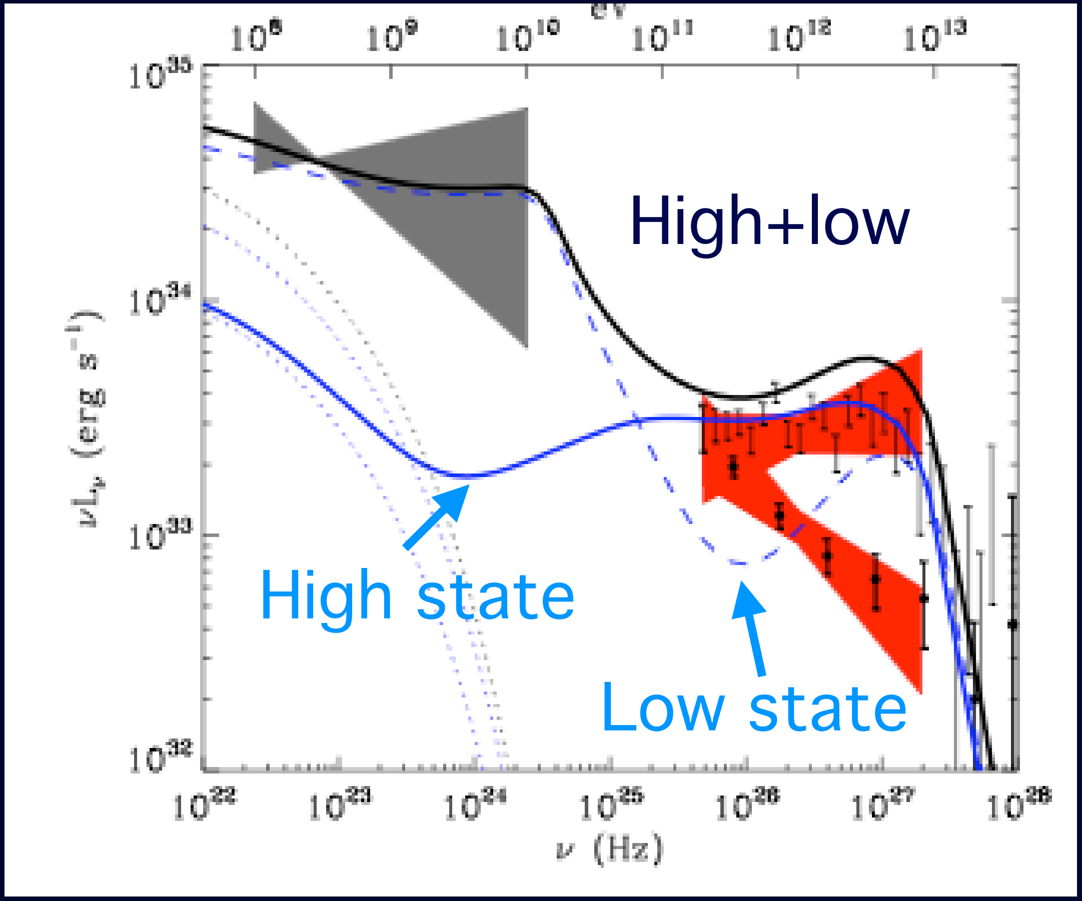
Source behind star

Source in front of star



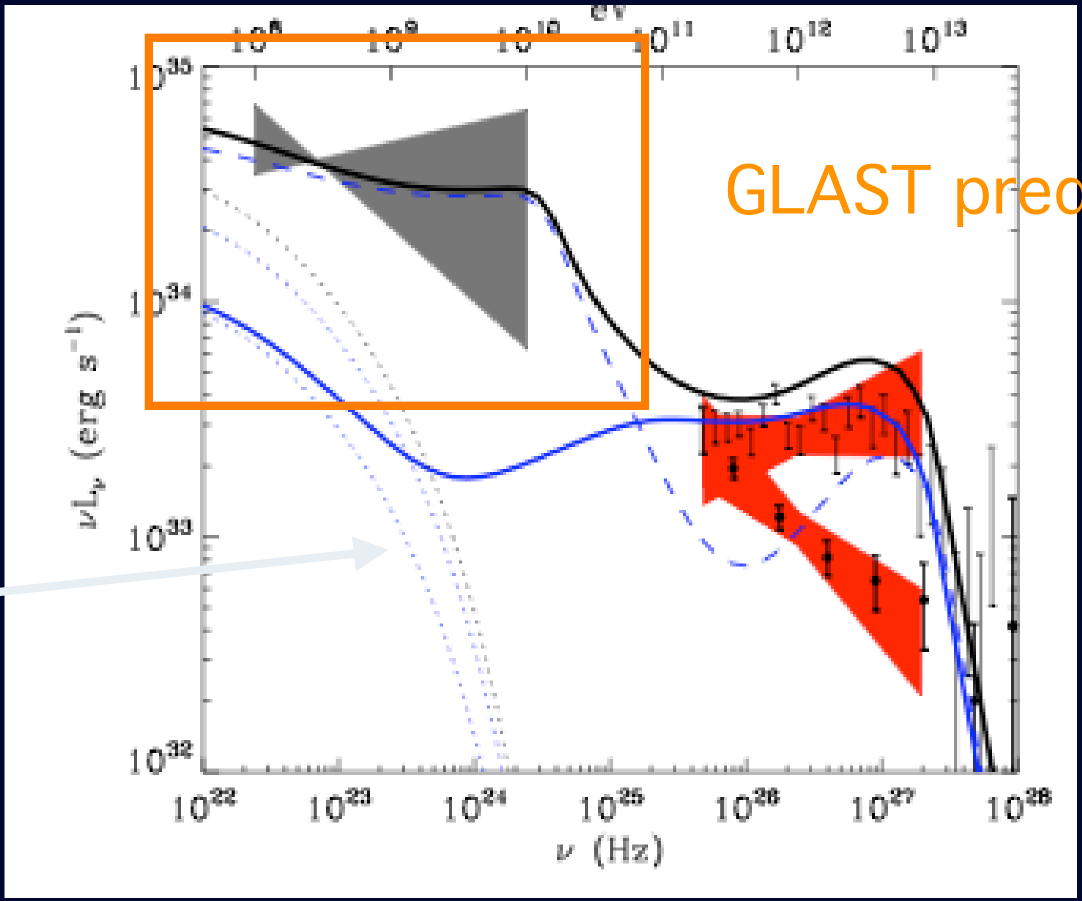
Inverse Compton spectrum for various orbital phases
in LS 5039 assuming electron distribution discussed previously.

LS 5039: anisotropic absorption & emission



Fit high state spectrum by varying B, index, normalization.
(Low state and EGRET are by-products!)

LS 5039: anisotropic absorption & emission



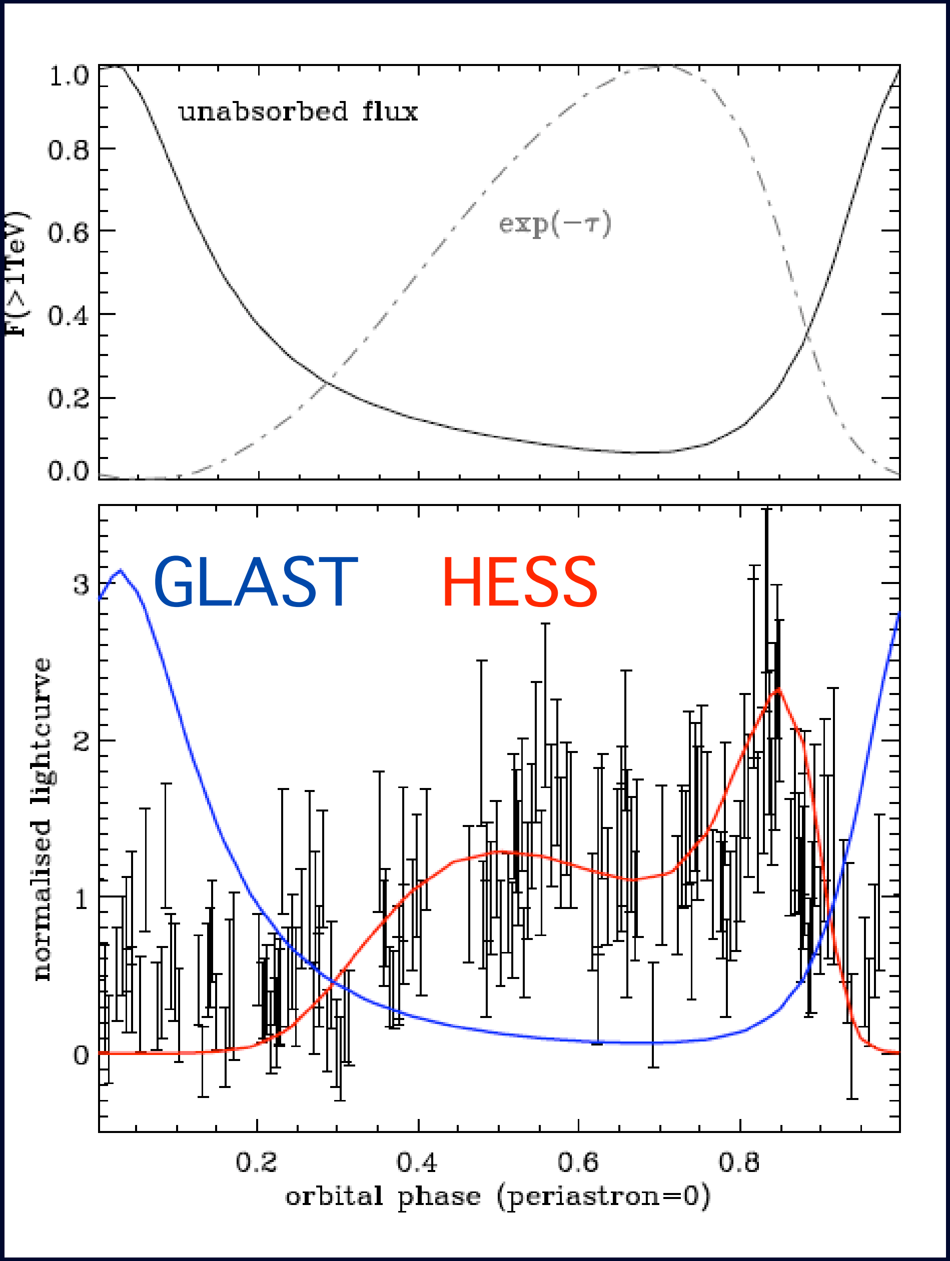
GD, Cerutti, Henri 2007

electron energy	3 10^{37} ergs
injection slope	-2±0.3
magnetic field	0.8±0.2 G (d_p/d)

LS 5039
orbital variations

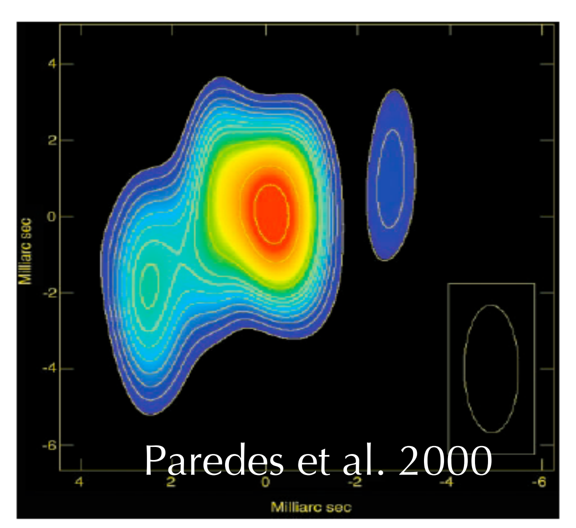
Anisotropies predict a small peak in HESS lightcurve.

Strong constrains on particle acceleration and magnetic field on small scales in the vicinity of pulsars.

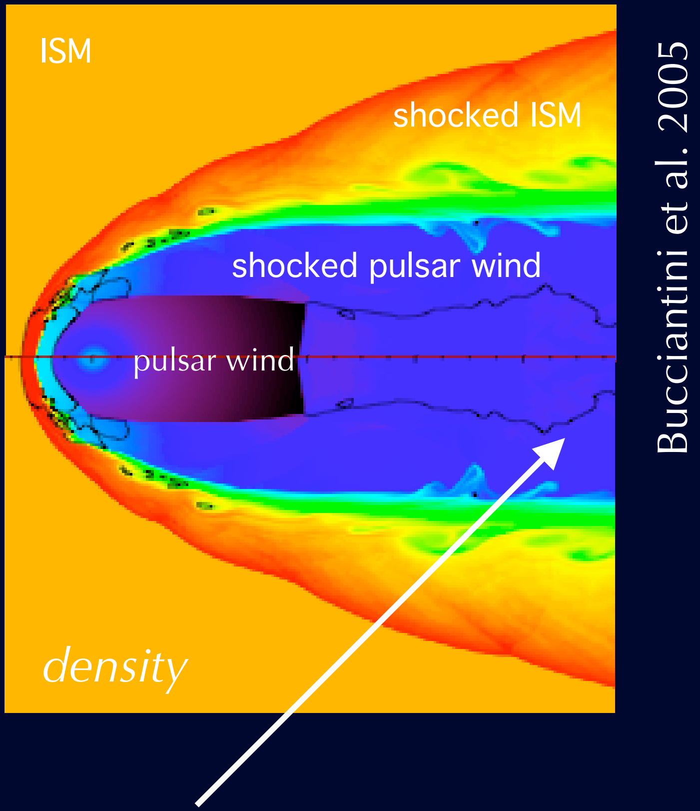


GD, Cerutti, Henri 2007

Modeling the radio emission



MHD simulation PW+ISM



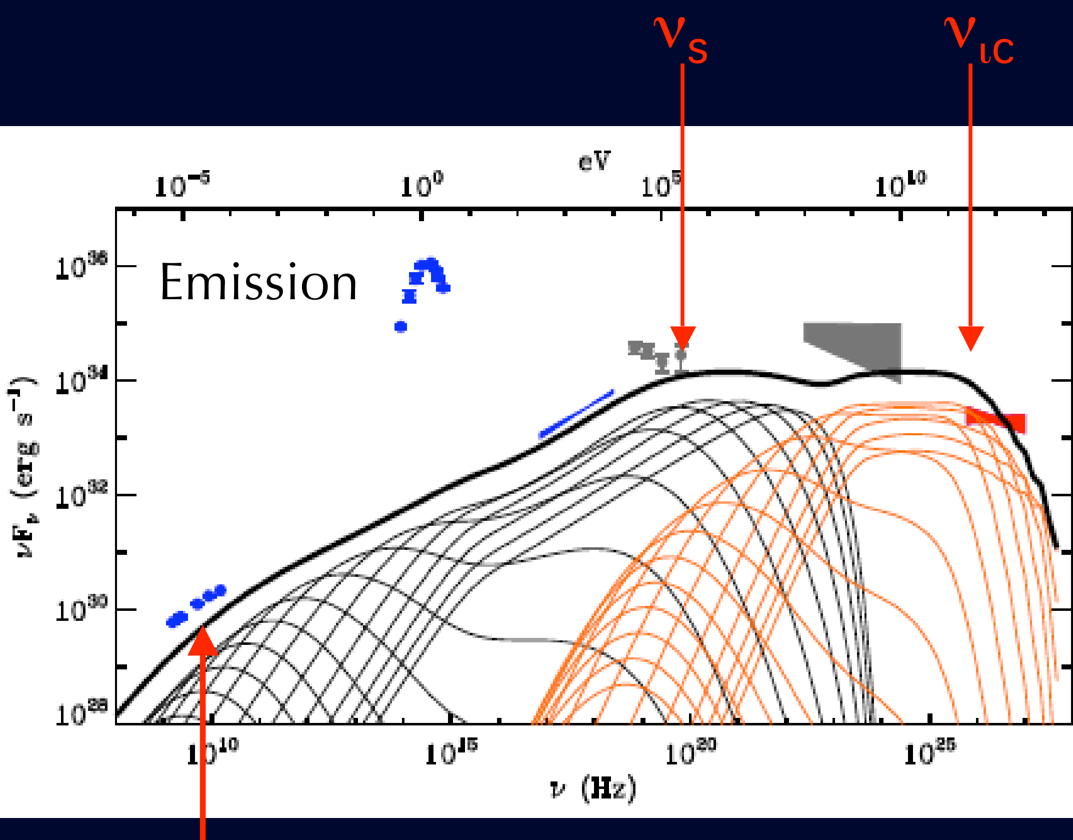
low energy emission occurs (very) far from pulsar.

Need to take into account variation along flow.

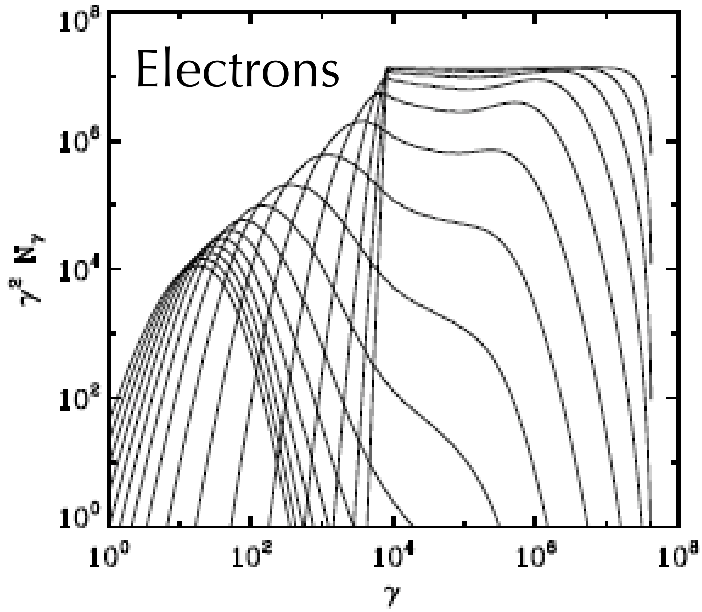
Lower energy radiation:

take evolution of particles in flow into account

(no anisotropy in seed photons here)



10^{36} erg/s, σ=0.01, γ=10^5

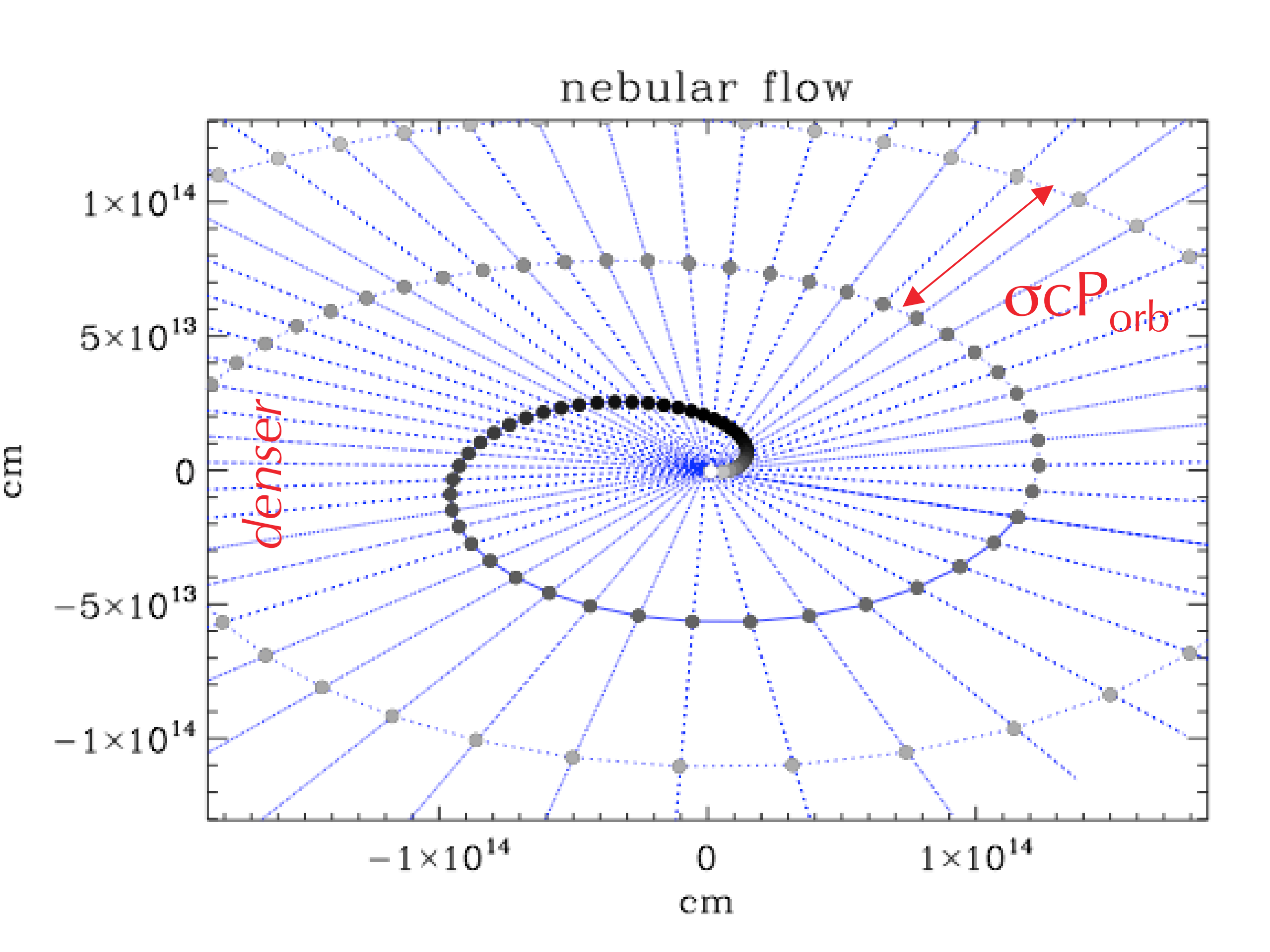


Radio cometary emission

GD 2006 A&A 456 801

Pulsar garden sprinkler

Radio outflow changes position angle with ϕ_{orb}.

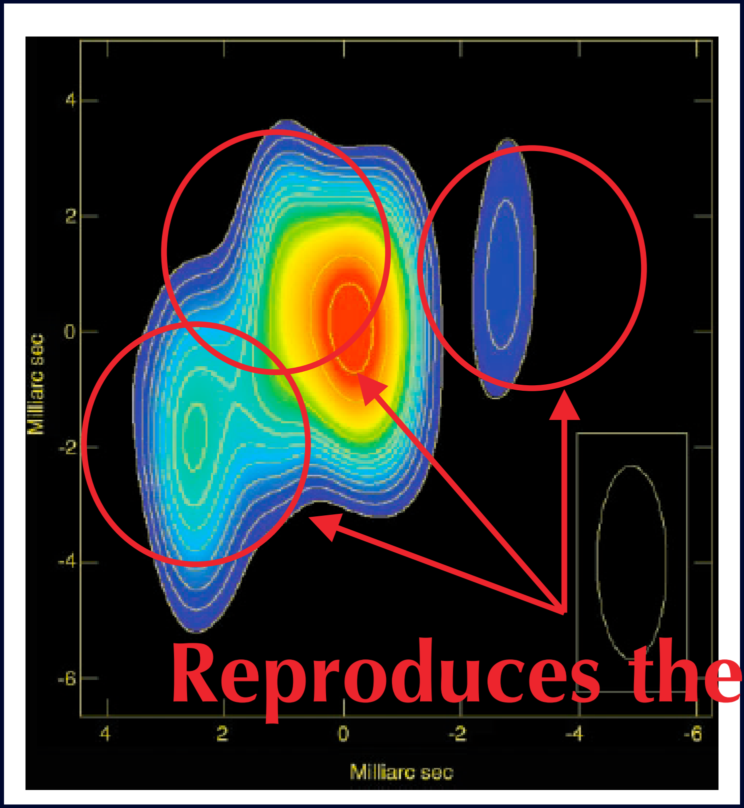


Inclination of system 60°

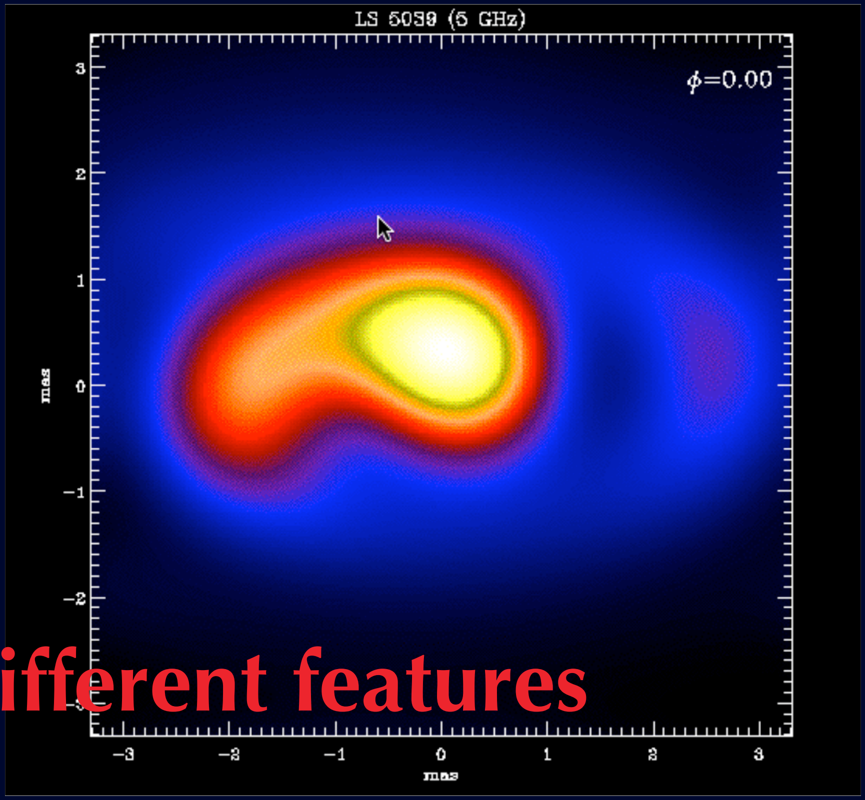
Radio emission from comet tail

VLBI observation

Paredes et al. 2000



Model 5 GHz emission



Reproduces the different features

GD 2006

Gamma-ray binaries:

- Three sources with emission dominated by HE/VHE gamma-rays.
- High mass companions; orbital VHE modulation.
- Binary plerions, new window for pulsar wind physics.

- Emission from *accretion-powered* binaries:
  MAGIC may have seen it with Cyg X-1. Prospects good with GLAST.