UNIVERSITAT DE BARCELONA

Libertas Perfundet
Omnia Luce

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Gamma-ray binaries: microquasars and binary pulsar systems

SciNeGHE 2010

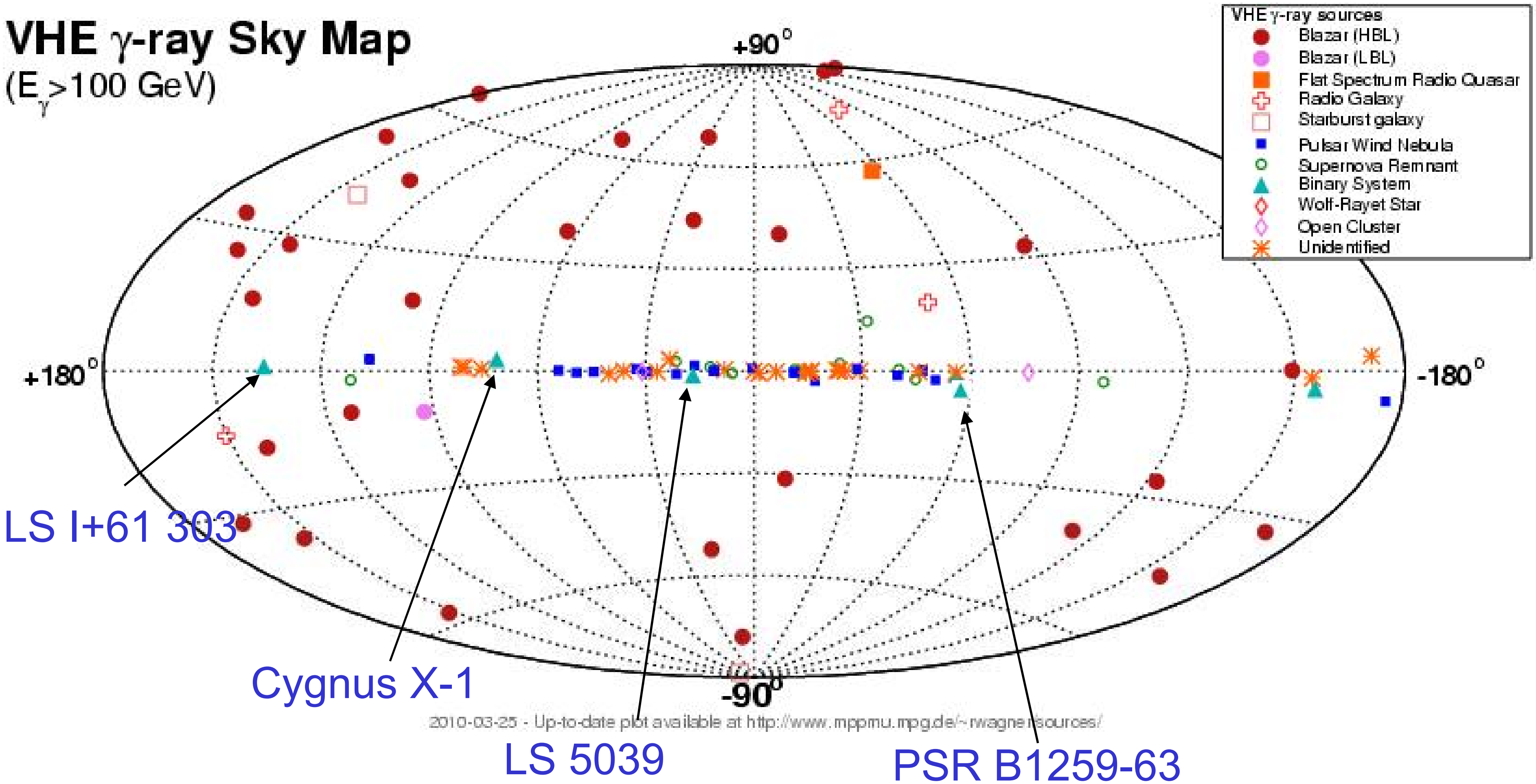
8th Workshop on Science with the New Generation of High Energy Gamma-ray Experiments

Trieste, September 8th - 10th 2010

The VHE gamma-ray Sky Map

38 extragalactic

60 galactic



At HE (E > 100 MeV)

LSI+61303, LS 5039 and Cygnus X-3: *Fermi* and *AGILE*

Cygnus X-1 and PSR B1259-63: *AGILE*

Parameters	PSR B1259-63	LS I +61 303	LS 5039	Cygnus X-1	Cygnus X-3
System Type	B2Ve+NS	B0Ve+NS?	O6.5V+BH?	O9.7I+ BH	WR+ BH?

Large luminosity
and
strong stellar wind

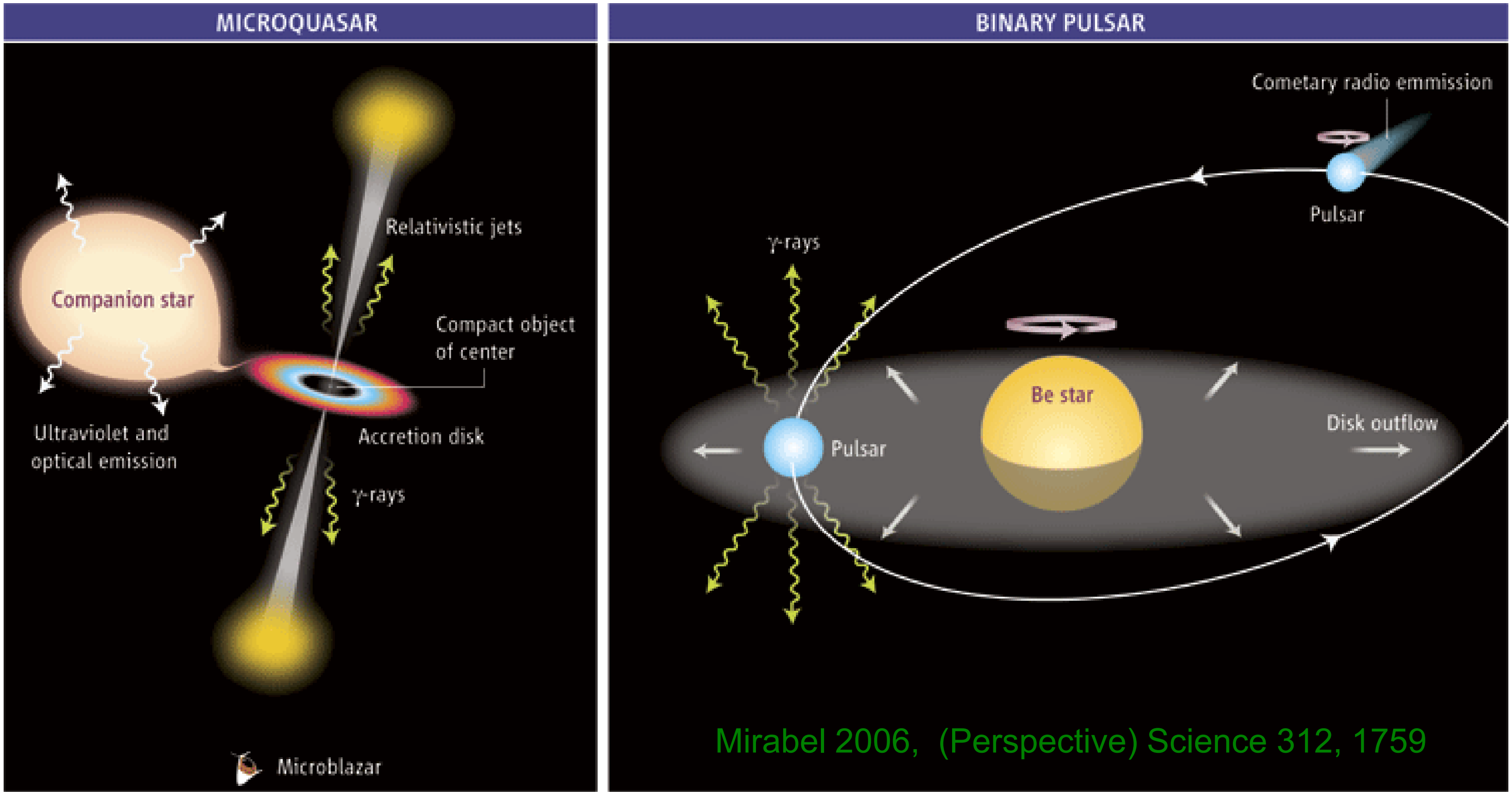
might be a BH if i<25°
(Casares et al. 2005)

Activity Radio	Periodic (48 ms and 3.4 yr)	Periodic (26.5 d and 4 yr)	Persistent	Persistent	Persistent and Bursts
Radio Structure (AU)	Jet-like ~140	Jet-like ~10-700	Jet $10 - 10^3$	Jet 40 + ring	Jet

Radio emitters
and
jet (like) radio structure

Γ_{VHE}	2.7 ± 0.2	2.6 ± 0.2	2.06 ± 0.05	3.2 ± 0.6	

GeV/TeV emitting XRBs: Accretion vs non-accretion

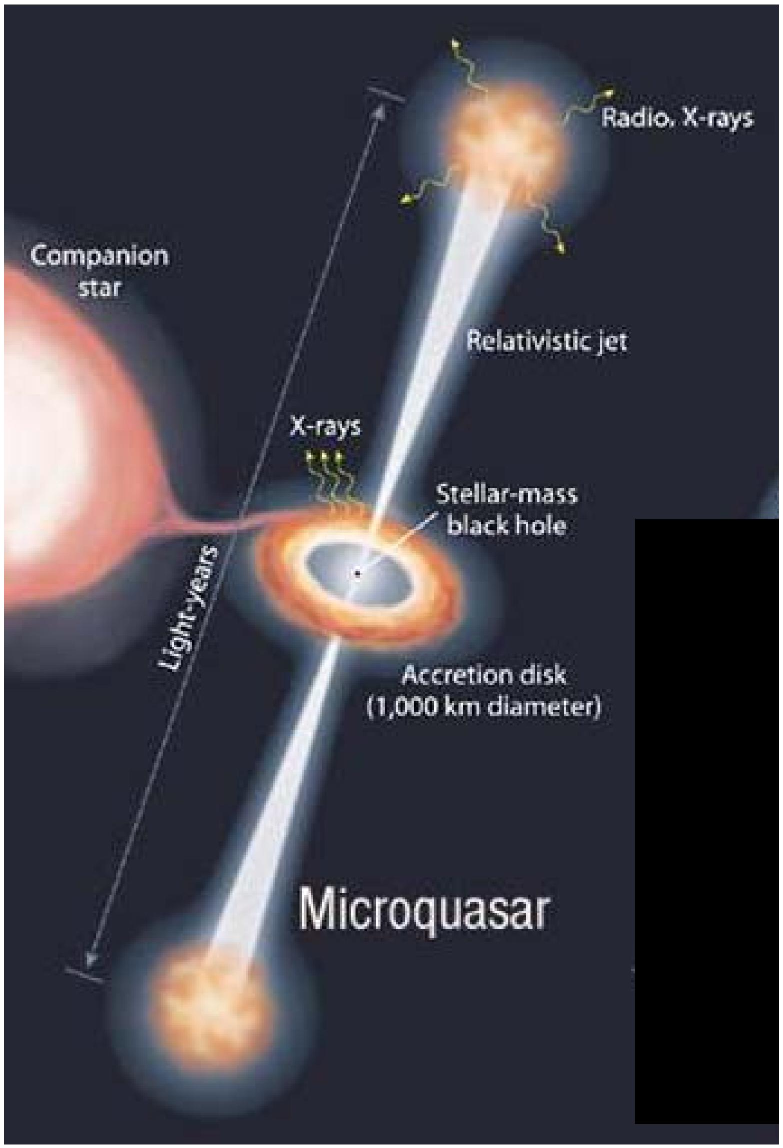


Cygnus X-3
Cygnus X-1

PSR B1259-63

LS 5039 ? LS I +61 303 ?

MQs as high-energy γ -ray sources
Theoretical point of view



Leptonic models:

SSC Atoyan & Aharonian 1999, MNRAS 302, 253
Latham et al. 2005, AIP CP745, 323

EC Kaufman Bernadó et al. 2002, A&A 385, L10
Georganopoulos et al. 2002, A&A 388, L25

SSC+EC Bosch-Ramon et al. 2004 A&A 417, 1075

Synchrotron jet emission Markoff et al. 2003, A&A 397, 645

Hadronic models:

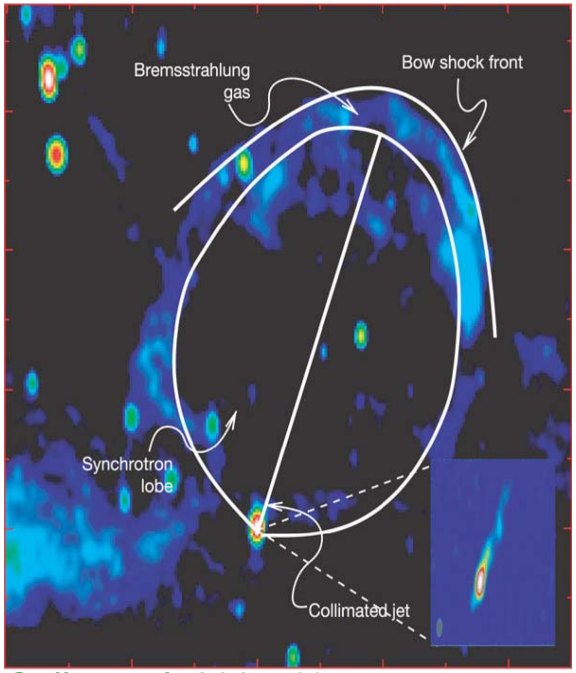
Pion decay Romero et al. 2003, A&A 410, L1
Bosch-Ramon et al. 2005, A&A 432, 609

Cygnus X-1

Stellar Mass Black Hole

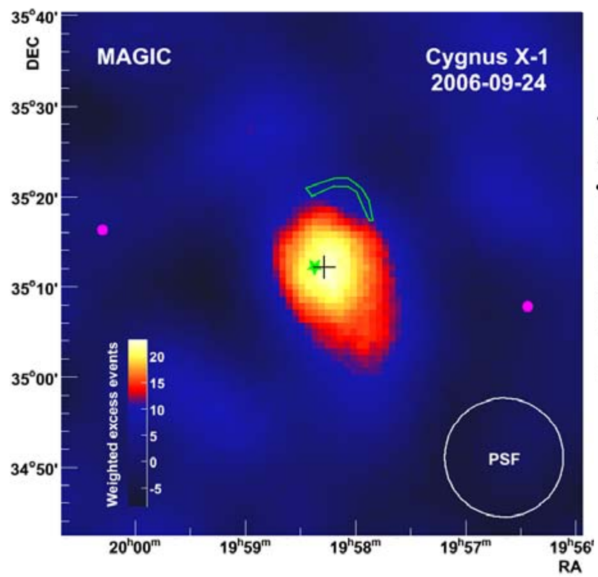
- HMXB, O9.71+BH

WSRT

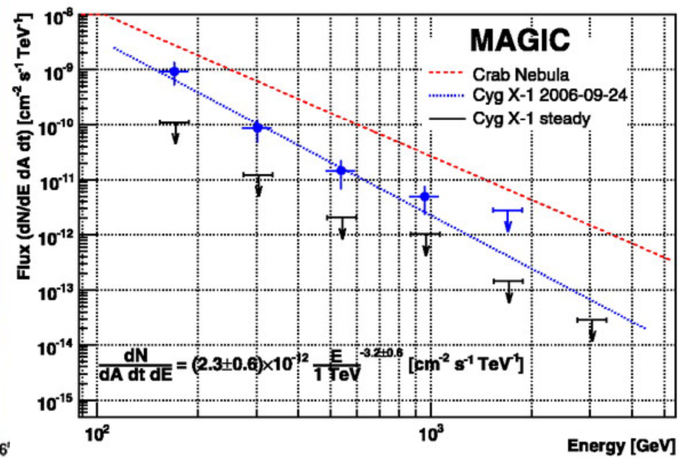


Gallo et al. 2005, Nature

5 pc (8') diameter ring-structure of bremsstrahlung emitting ionized gas at the shock between (dark) jet and ISM.



Albert et al. 2007, ApJ 665, L51



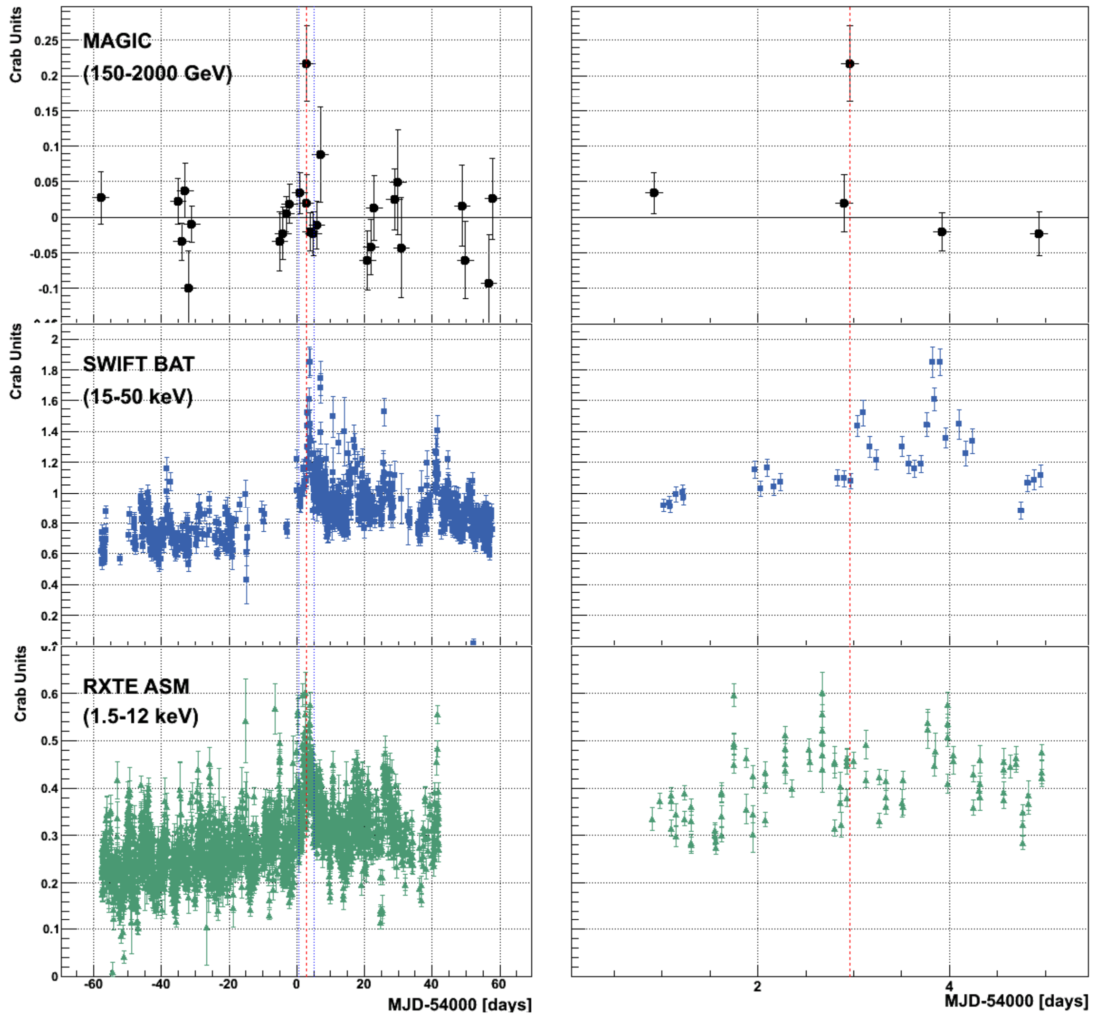
- Steady flux below ~1% Crab Nebula flux
- Strong evidence (4.1σ post trial significance) of intense short-lived flaring [1h-24h] episode discovered by MAGIC on 24-09-2006
- Soft spectrum (Γ = -3.2) between ~100 GeV and 1 TeV, with no break
- Extension below MAGIC angular resolution (~ 0.1°)
- Radio-nebula produced by the jet interaction with the ISM excluded

Detected up to 1 TeV. Orbital phase 0.9-1.0, when the BH is behind the star and photon-photon absorption should be huge: $\tau \sim 10$ at 1 TeV (Bednarek & Giovannelli 2007). Away from the BH might be the solution: flare in the jet? (Perucho & Bosch-Ramon 2008)

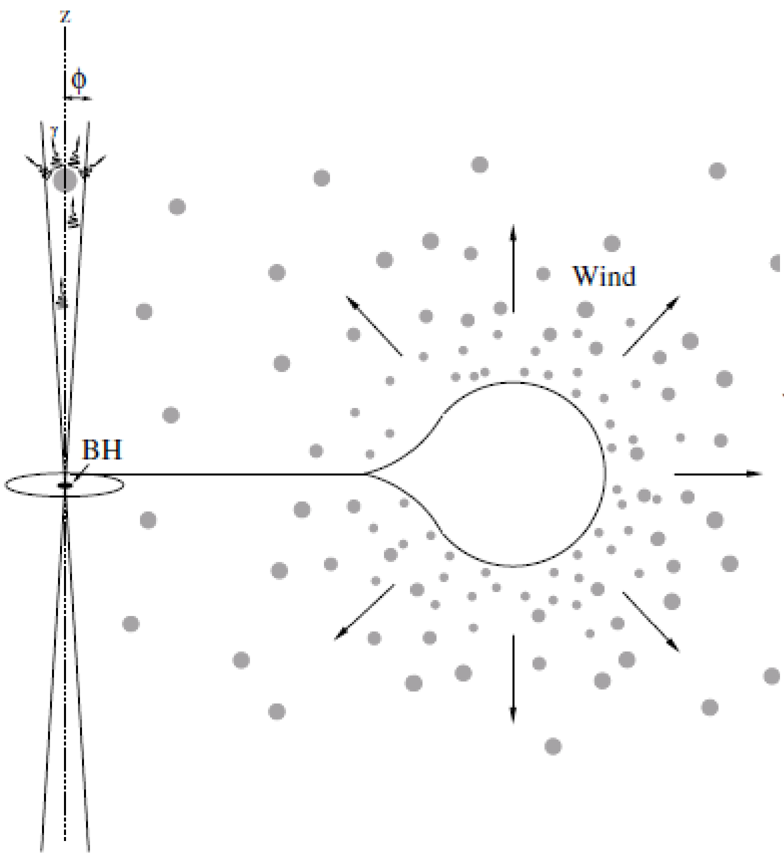
TeV excess right before the onset of a hard X-ray peak seen by *Swift*

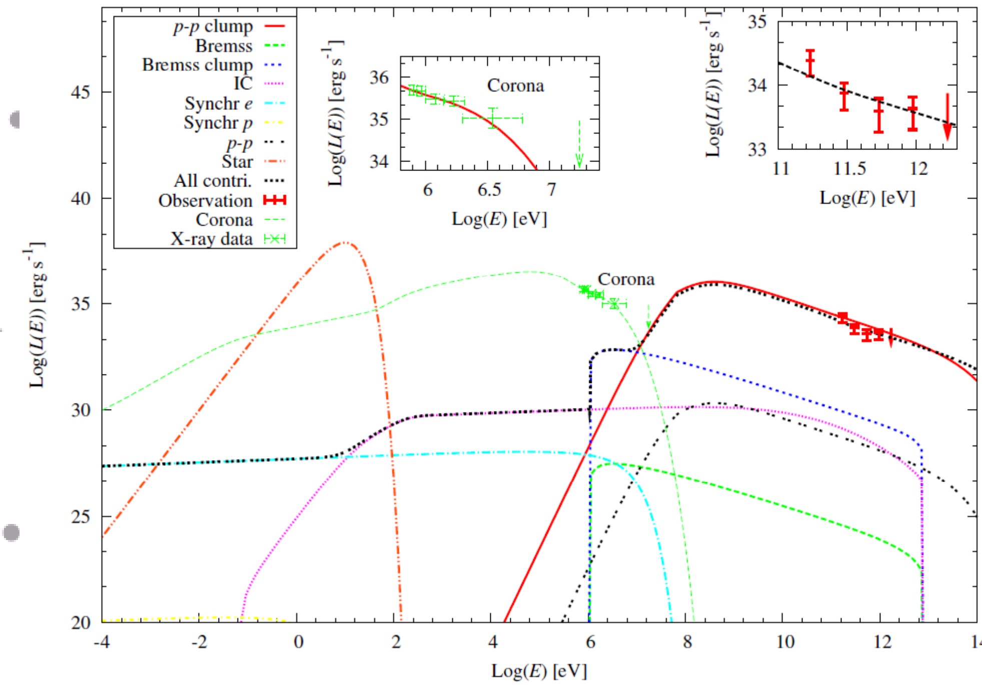
Observations one day later reveal that no TeV excess was found during the maximum and decay phase of another hard X-ray peak

More simultaneous multi wavelength data is necessary to build models

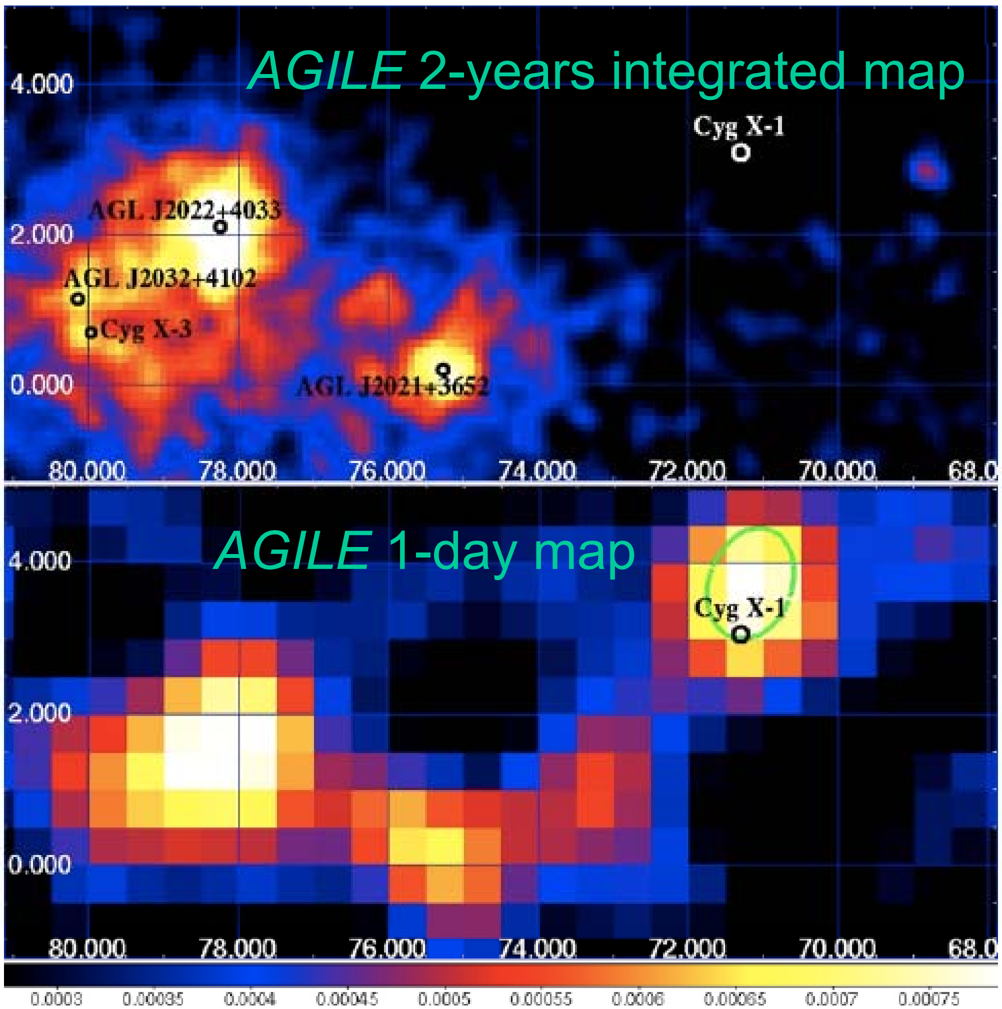


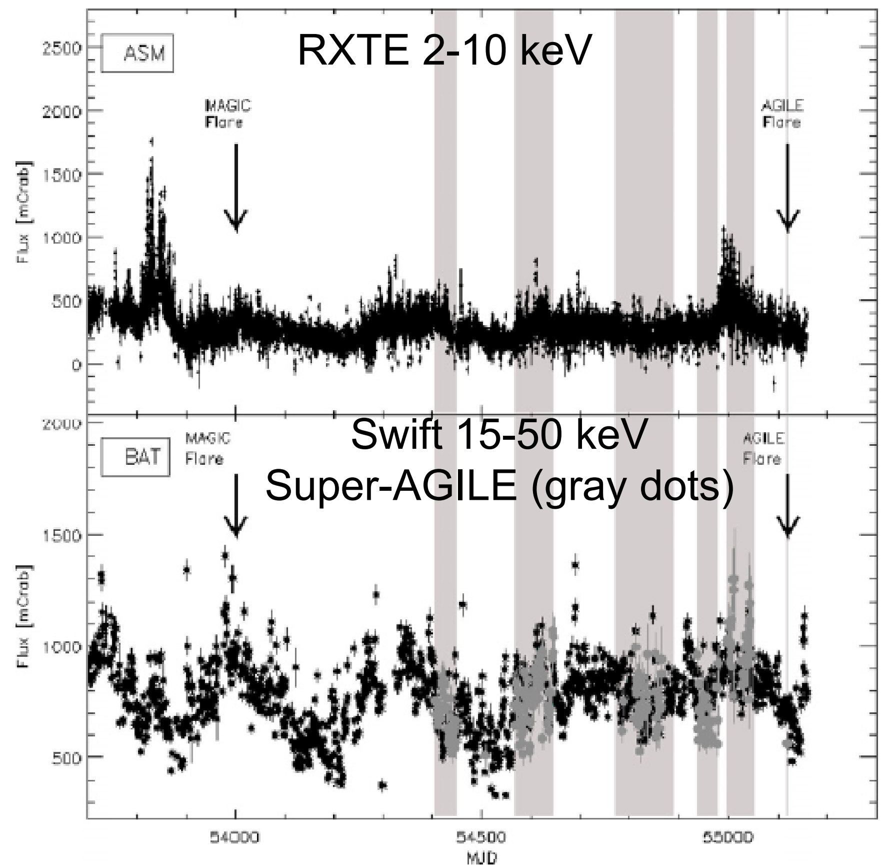
TeV flare seen by MAGIC interpreted as a jet-cloud interaction. Protons in the jet interact with ions in a cloud of a clumpy wind from the companion, producing inelastic p-p collisions and pion decay which produces a flare in TeV gamma rays (Romero et al. 2010, A&A 518, 12)





Detected >100 MeV by *AGILE* (Sabatini et al. 2010, ApJ 712, 10 and ATel #2715) but not by *Fermi*/LAT (Abdo et al. 2010, ATels and *Fermi*/LAT blog). The detection spans 1 d in about 2 years of observations, and has a 5.3σ pre-trial significance, which is 4σ post-trial. It occurred during a low luminosity low/hard state





October 16, 2009

Sabatini et al. 2010, ApJ 712, L10

Black circle: optical position   Green contour: AGILE 2sig confidence level

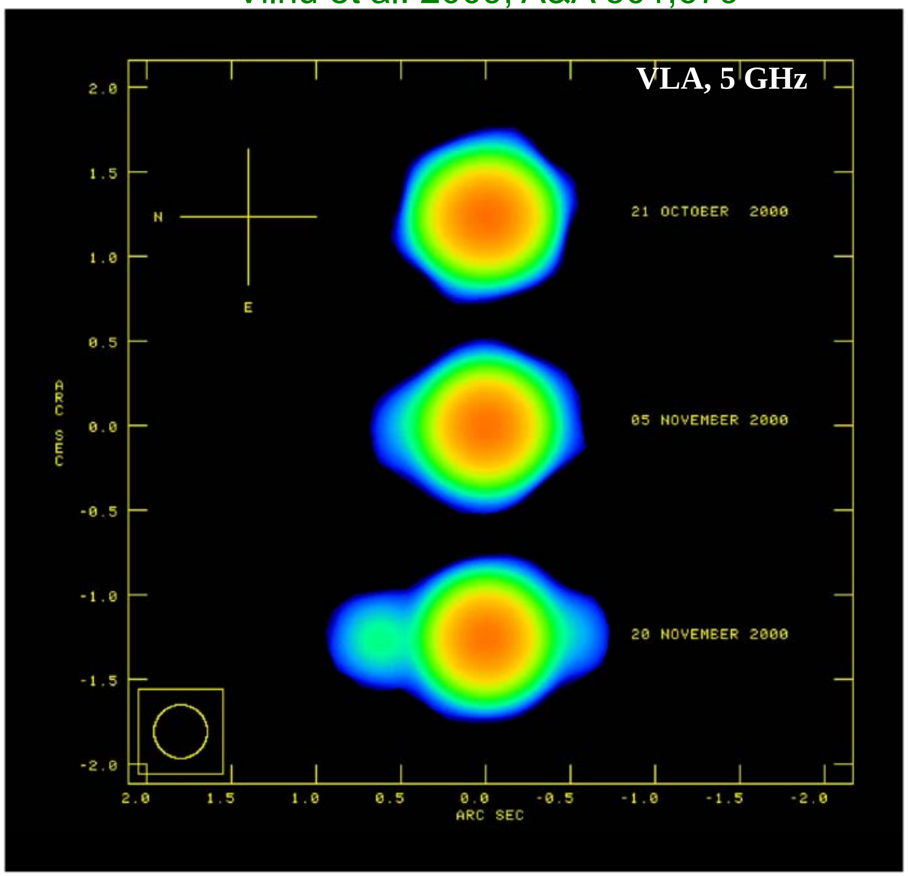
Cygnus X-3 *Strong radio outbursts*

- HMXB, WR+NS?

Orbital modulation of X-ray emission lines

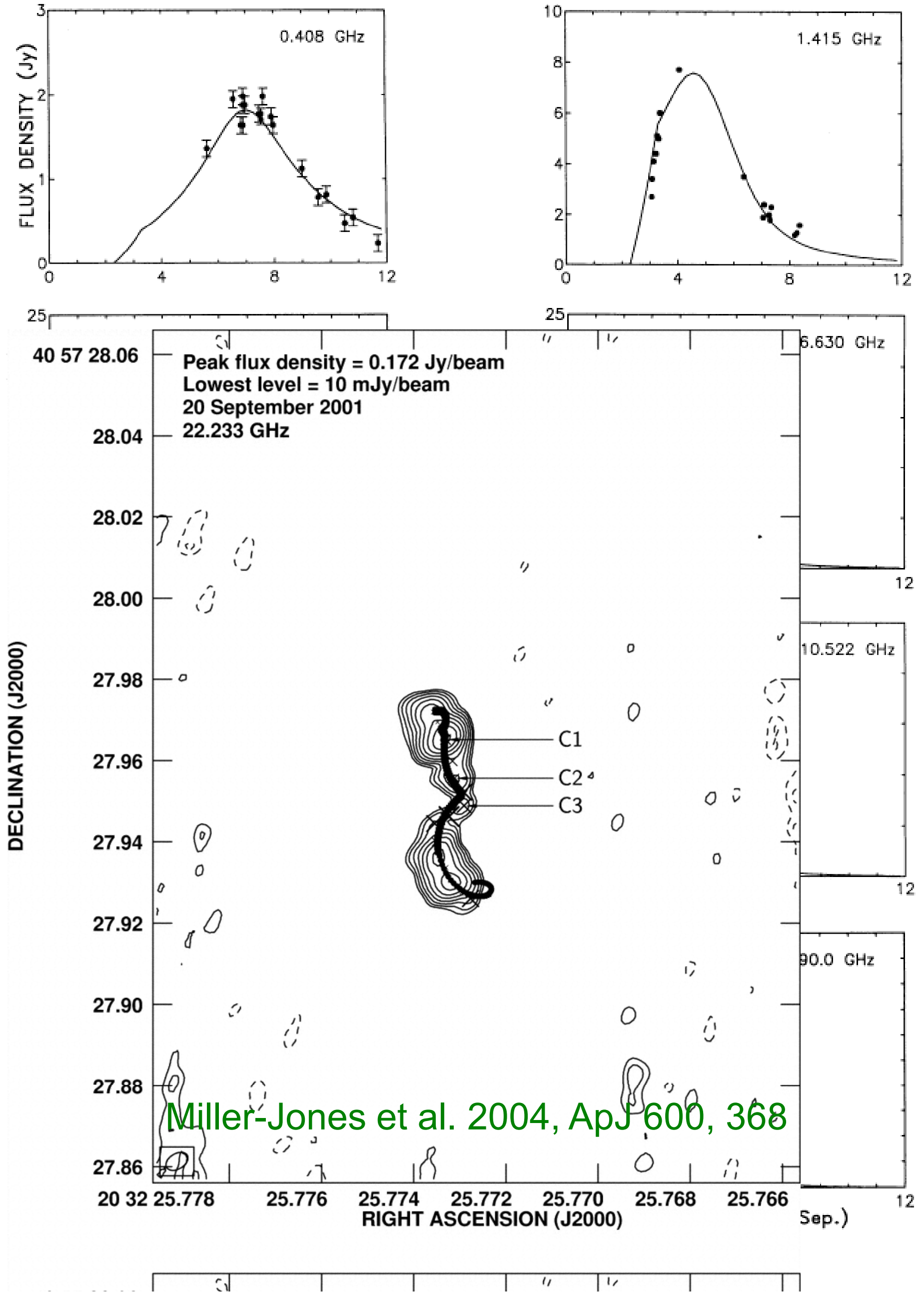
i>60 NS, i<60 BH

Vilhu et al. 2009, A&A 501,679



Development of arcsecond radio jets in CYGNUS X-3

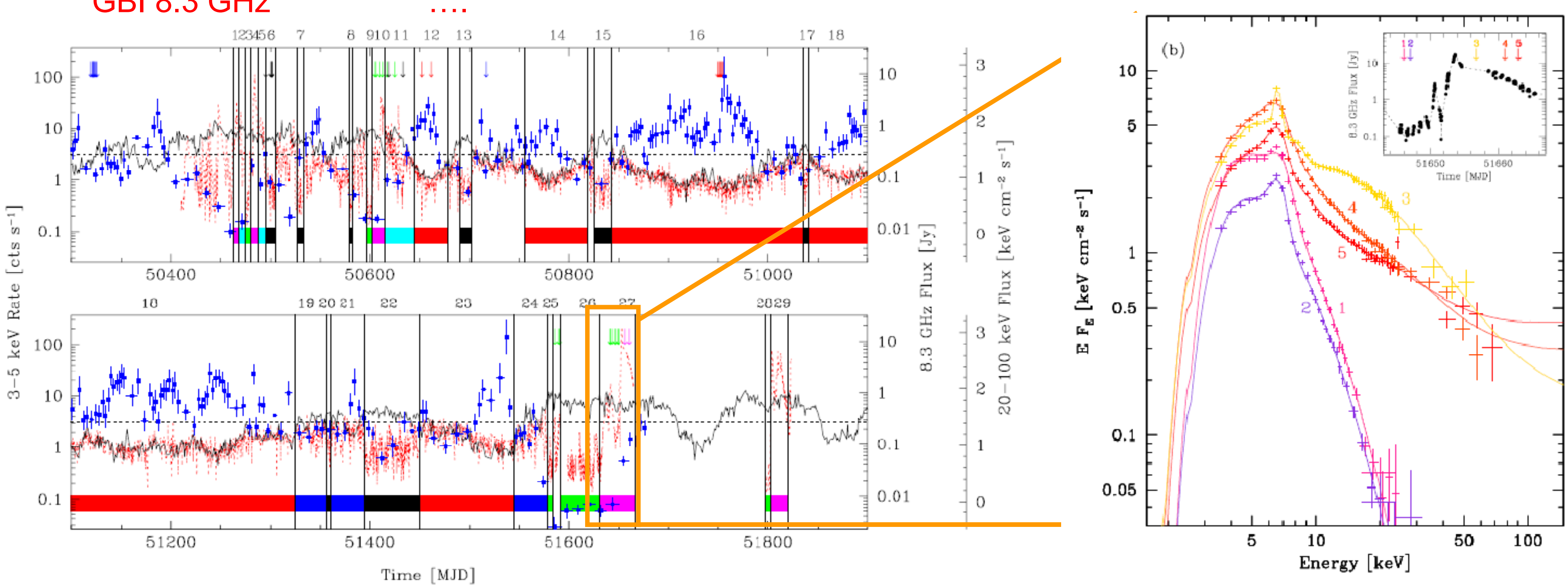
Martí et al. 2001, A&A 375, 476



Miller-Jones et al. 2004, ApJ 600, 368

RXTE ASM 3–5 keV —
BATSE 20–100 keV +
GBI 8.3 GHz ....

Szostek et al. 2008, MNRAS 388, 1001



Strong radio flares occur only when the source is in the soft state

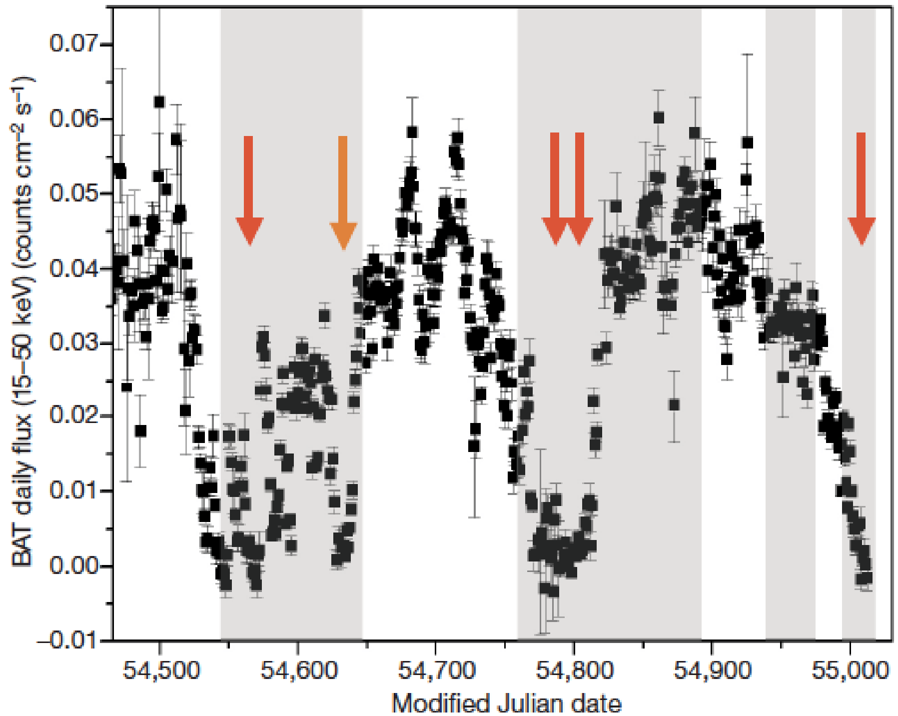
If the non-thermal electrons responsible for either

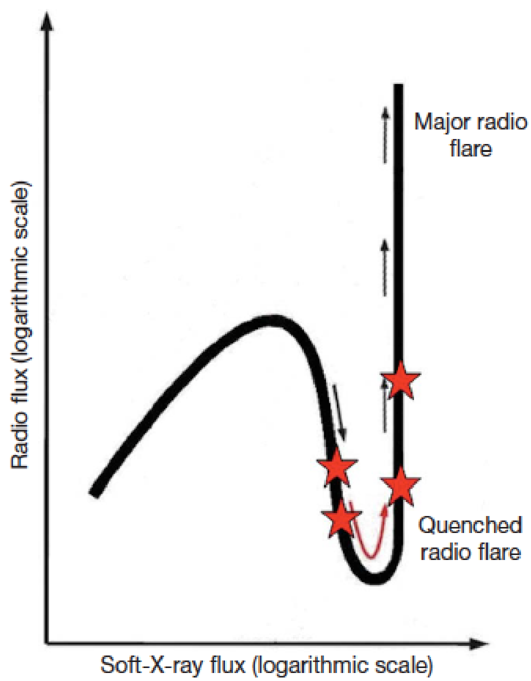
the hard X-ray tails or

the radio emission during major flares

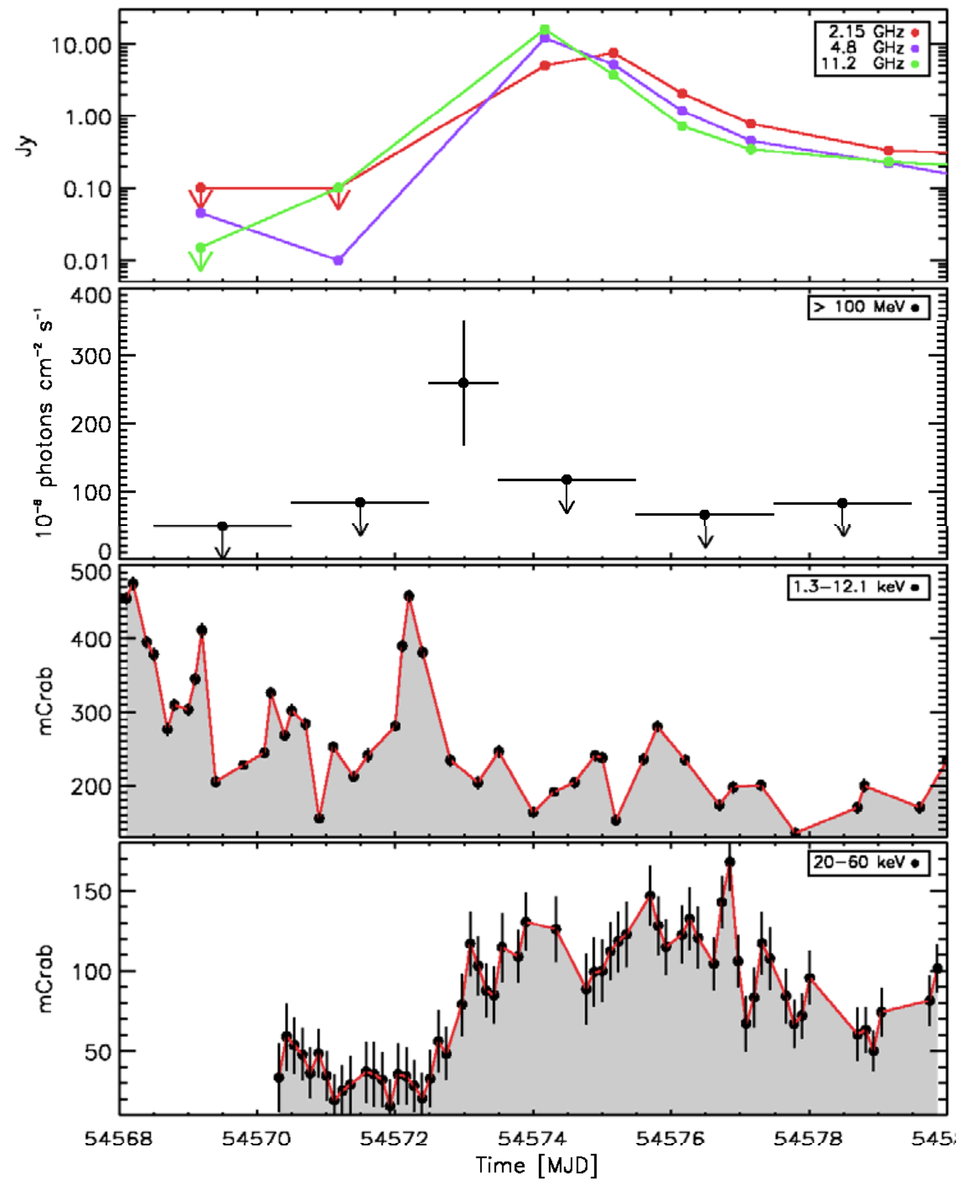
were accelerated to high enough energies then detectable emission in the γ-ray range, e.g., the GeV or TeV band, would be possible.

Given that major radio flares indicates the presence of hard X-ray tails, **GeV and TeV emission should be searched for during those radio flares.**



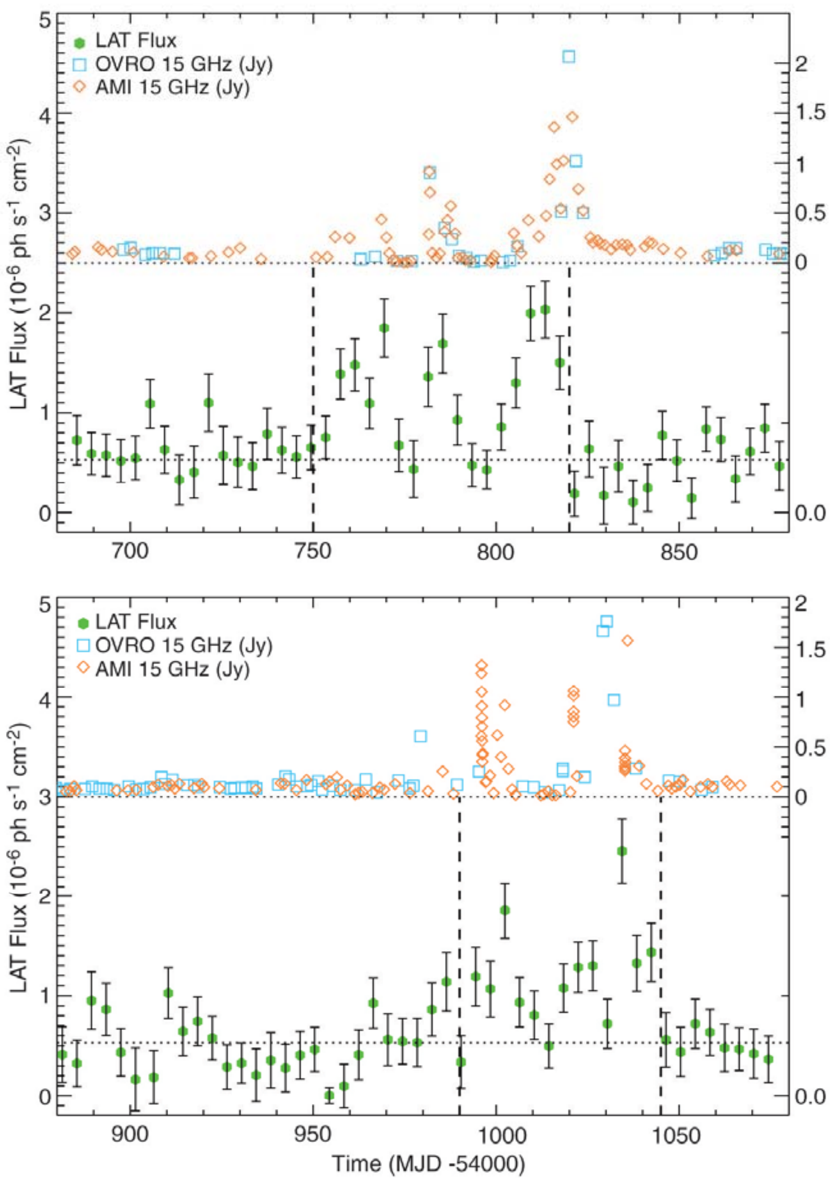


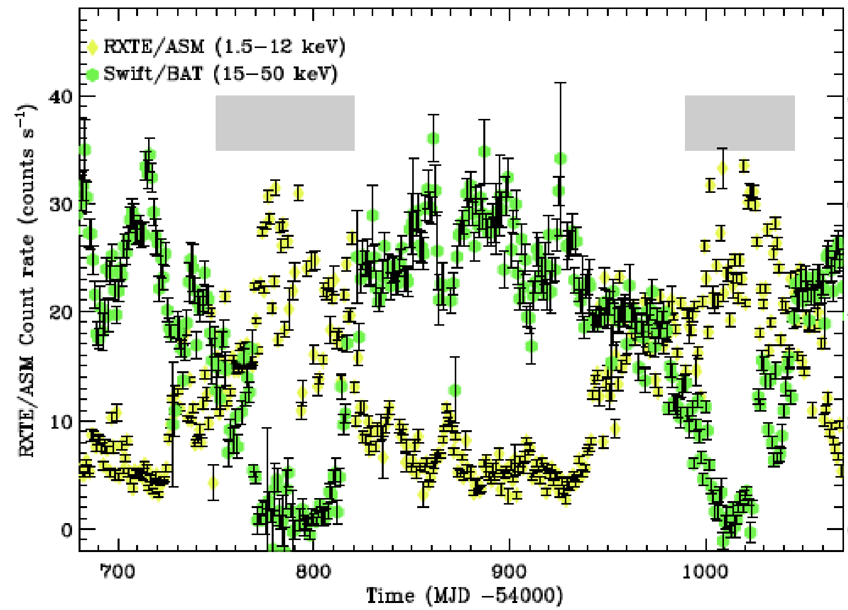
AGILE

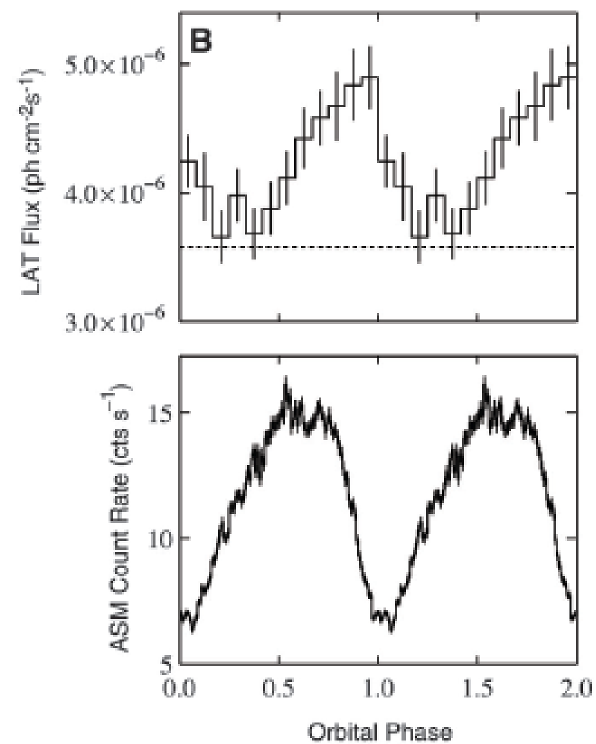


Tavani et al. 2009, Nature 462, 620

Fermi







Abdo et al. 2009, Science 326, 1512

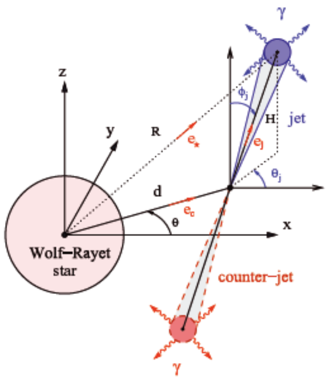
Jet IC emission

>100 MeV γ-ray modulation in Cyg X-3

Anisotropic IC by jet relat. e^- with stellar photons along the orbit produces a modulation in the gamma-ray lightcurve (Khangulyan et al. 2008, MNRAS 383, 467)

Jet launched around a BH
- moderate bulk relativistic speed
- oriented not too far from the light of sight

Dubus et al. 2010, MNRAS 404, L55



- The e^- emit synchrotron radio beyond the γ-ray emission zone on much larger scales

- A shock occurs in the wind because (Perucho et al. 2010, A&A)
  - wind mass-loss rate is very large
  - orbit very tight

Most μqs jets will interact much further away when their pressure matches that of the ISM. Any HE particles will find a much weaker radiation environment and will be less likely to produce a (modulated) IC γ-ray

Anisotropic IC $e^{\pm}$ pair cascade model. The optical depths for γ-rays created inside the binary system are huge. Escape of γ-rays with energies above a few tens of GeV is not very likely.

Bednarek, 2010, MNRAS

Young pulsar wind interacting with the companion star

PSR B1259-63 The first variable galactic source of VHE

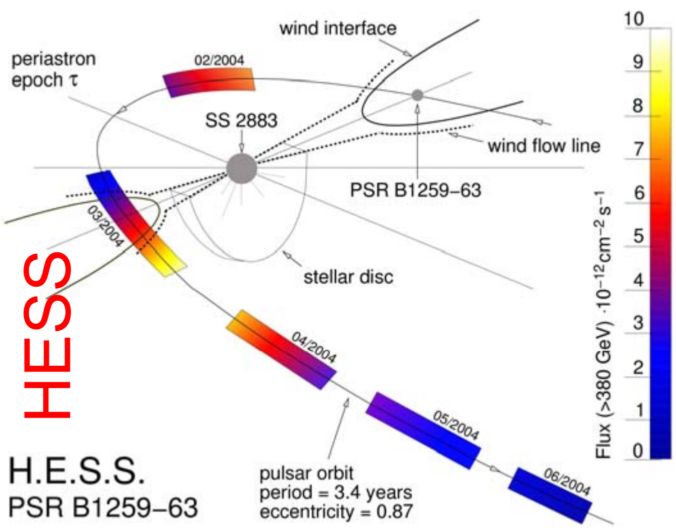
PSR B1259-63 / LS 2883: O8.5-9 Ve (Negueruela et al. 2010) (dense equatorial circumstellar disk) + 47.7 ms radio pulsar, *P*= 3.4 yr, *e*=0.87.
No radio pulses are observed when the NS is behind the circumstellar disk (free-free absorption).

Tavani & Arons 1997, ApJ 477, 439 studied the radiation mechanisms and interaction geometry in a pulsar/Be star system

The observed **X-ray/soft gamma-ray** emission was

- consistent with the shock-powered high-energy emission produced by the pulsar/outflow interaction

HESS

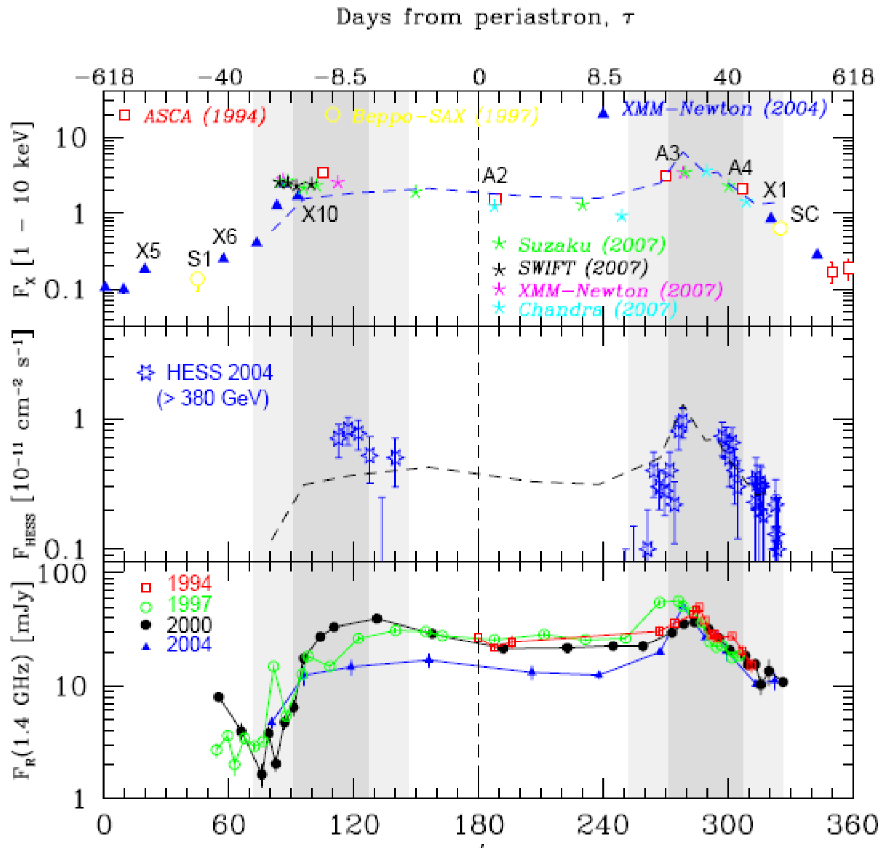


VHE gamma-rays are detected when the NS is close to periastron or crosses the disk (Aharonian et al. 2005, A&A 442, 1)

- significant variability

- power-law spectrum (Γ=2.7) explained by IC scattering processes

- the TeV, and radio/X-ray light curves, can be explained if the interaction with the circumstellar disk is considered (Chernyakova et al. 2006, MNRAS 367, 1201)



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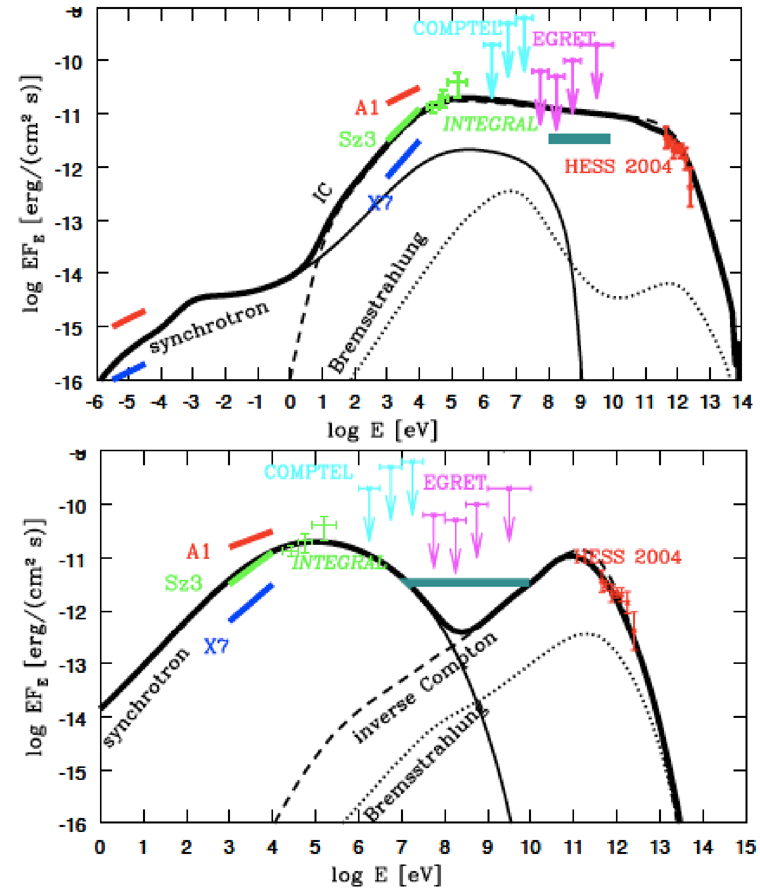
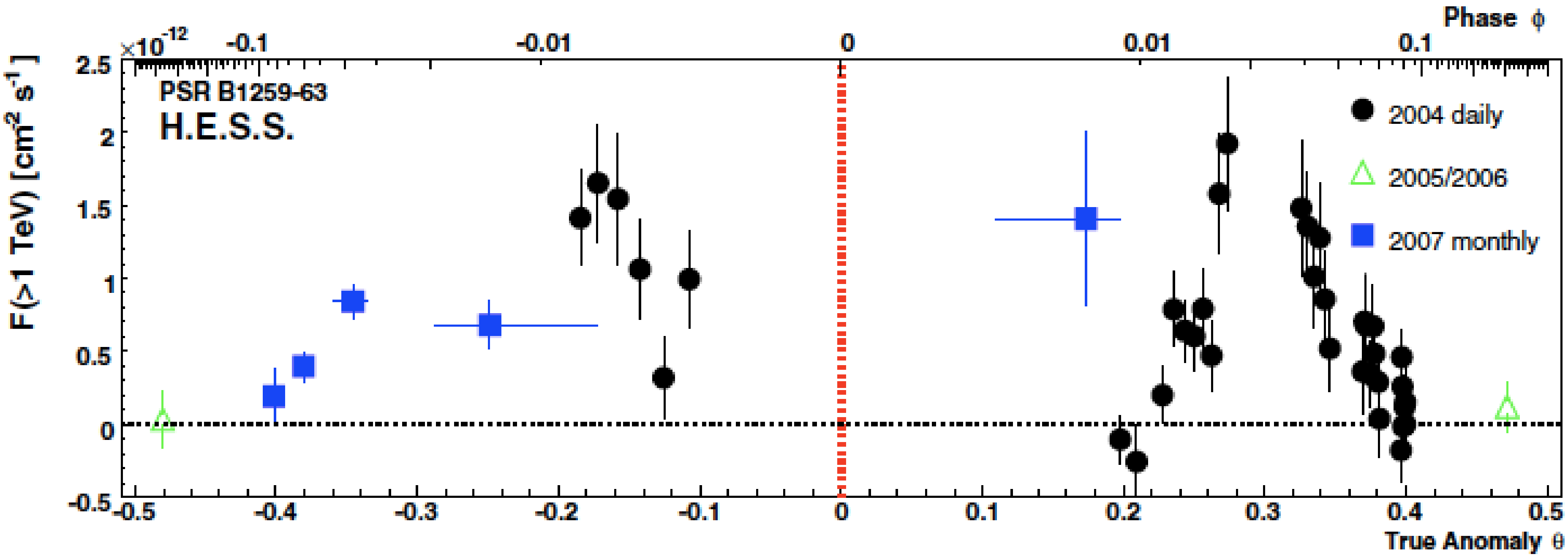
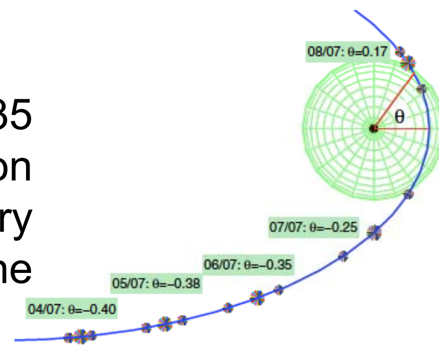


Chernyakova et al. 2009, MNRAS 397, 2123

- Need of simultaneous TeV-X ray observations



Aharonian et al. 2009, A&A 507, 389



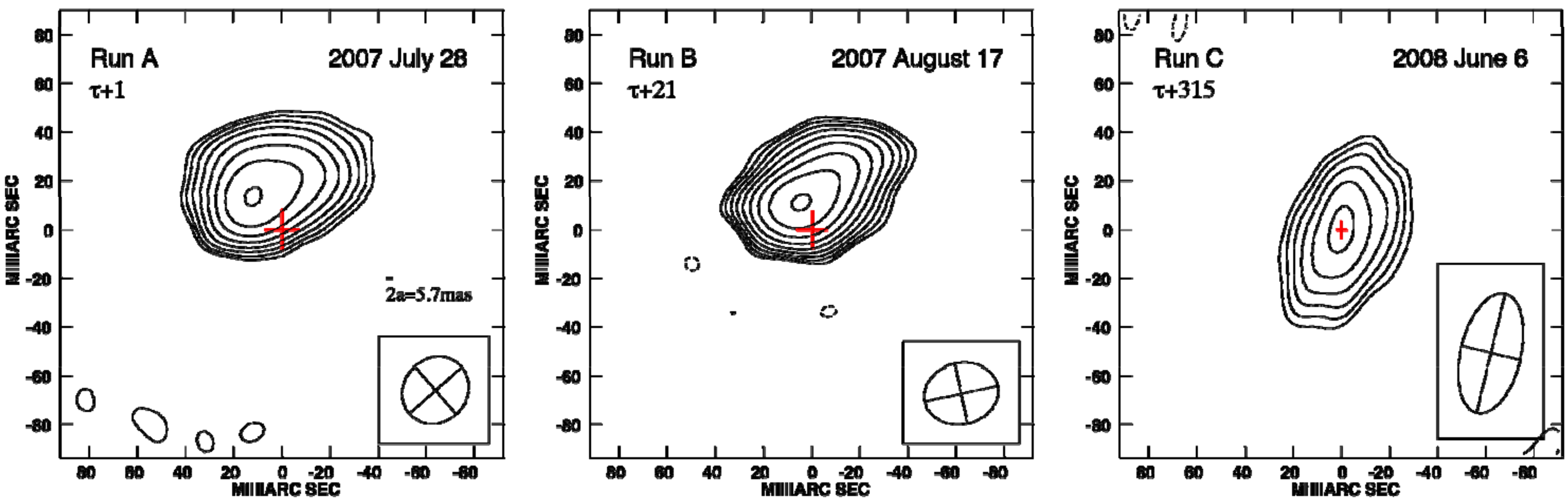
The firm detection of VHE photons emitted at a true anomaly θ ≈ −0.35 of the pulsar orbit, i.e. already ~50 days prior to the periastron passage, disfavors the stellar disk target scenario as a primary emission mechanism, based on current knowledge about the companion star's disk inclination, extension, and density profile

AGILE detected transient gamma-ray emission from the PSR B1259-63 region (Tavani et al. 2010, Atel #2772)

Not detected by *Fermi* (Abdo et al. 2010, Atel #2780)

Australian Long Baseline Array (LBA)
2.3 GHz

New



Total extension of the nebula: ~ 60 mas, or 140 ± 24 AU

The red crosses marks the region where the pulsar should be contained in each run

Moldón et al. 2010 (submitted)

Periastron passage soon!!

LS I +61 303 *Dubious case*

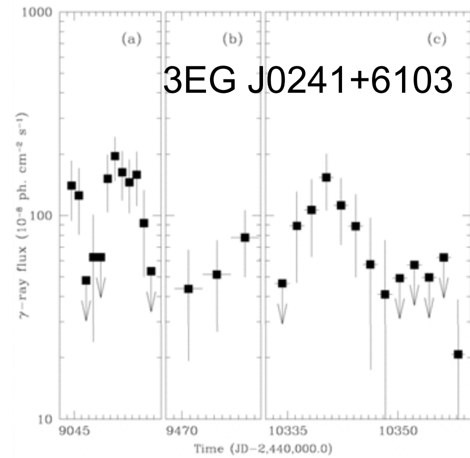
- HMXB, B0Ve+NS?

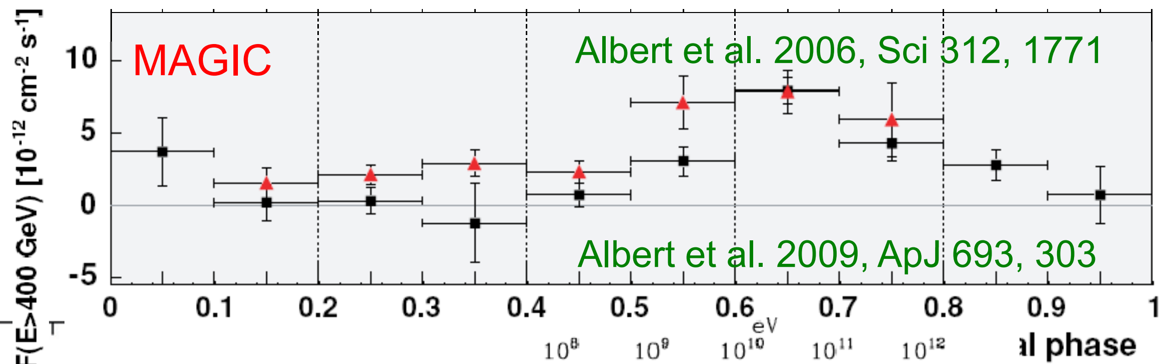
COS-B γ-ray source CG/2CG 135+01
Hermsen et al. 1977, Nature 269, 494

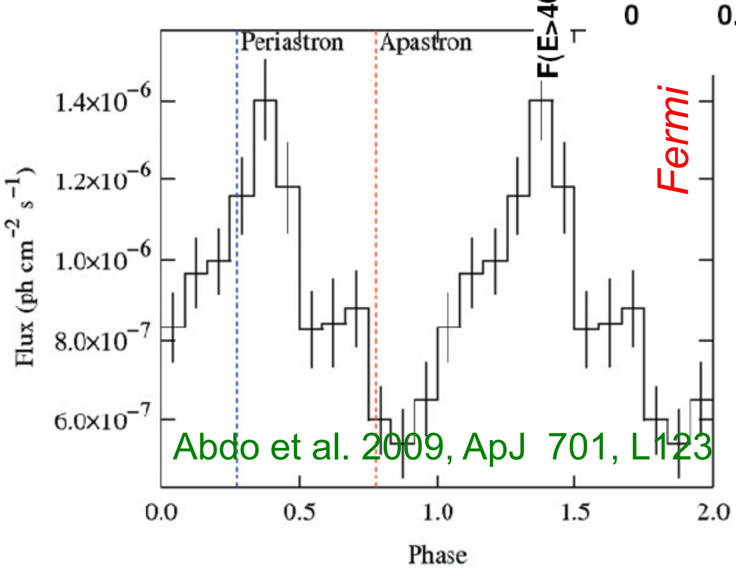
periodicity

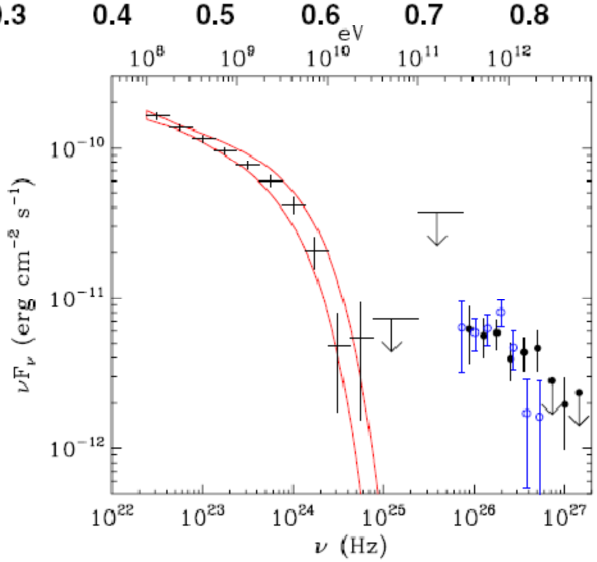
Radio (P=26.496 d) Taylor & Gregory 1982, ApJ 255, 210
Optical and IR Mendelson & Mazeh 1989, MNRAS 239, 733; Paredes et al. 1994 A&A 288, 519
X-rays rays Paredes et al. 1997 A&A 320, L25

Tavani et al. 1998, ApJ 497, L89





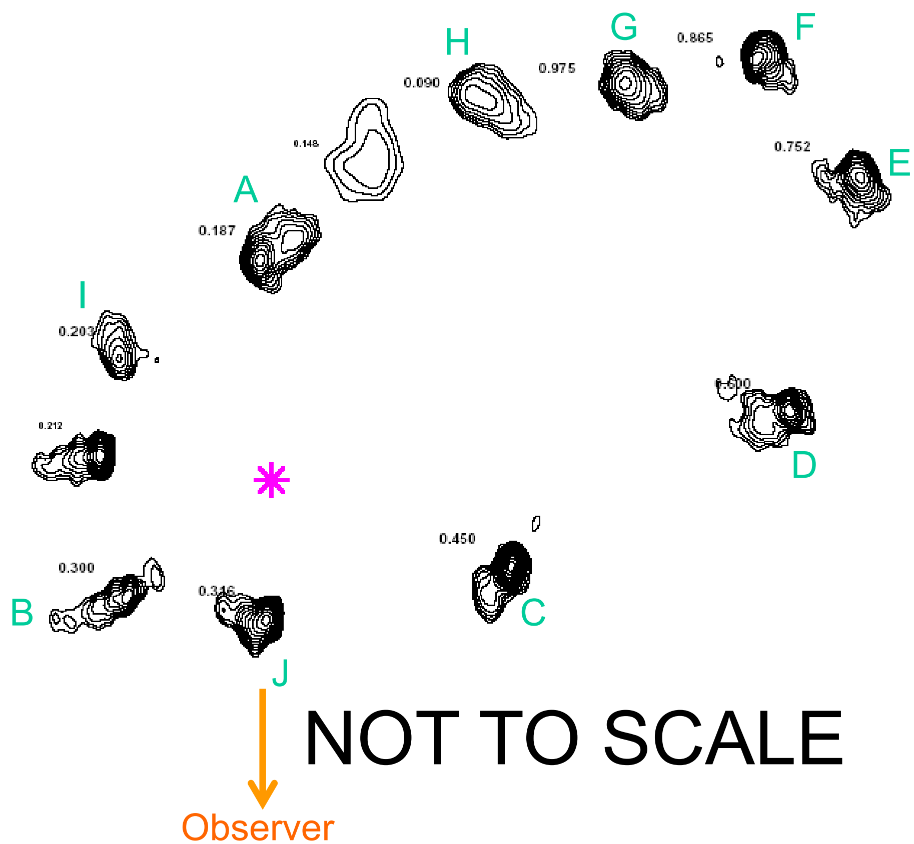


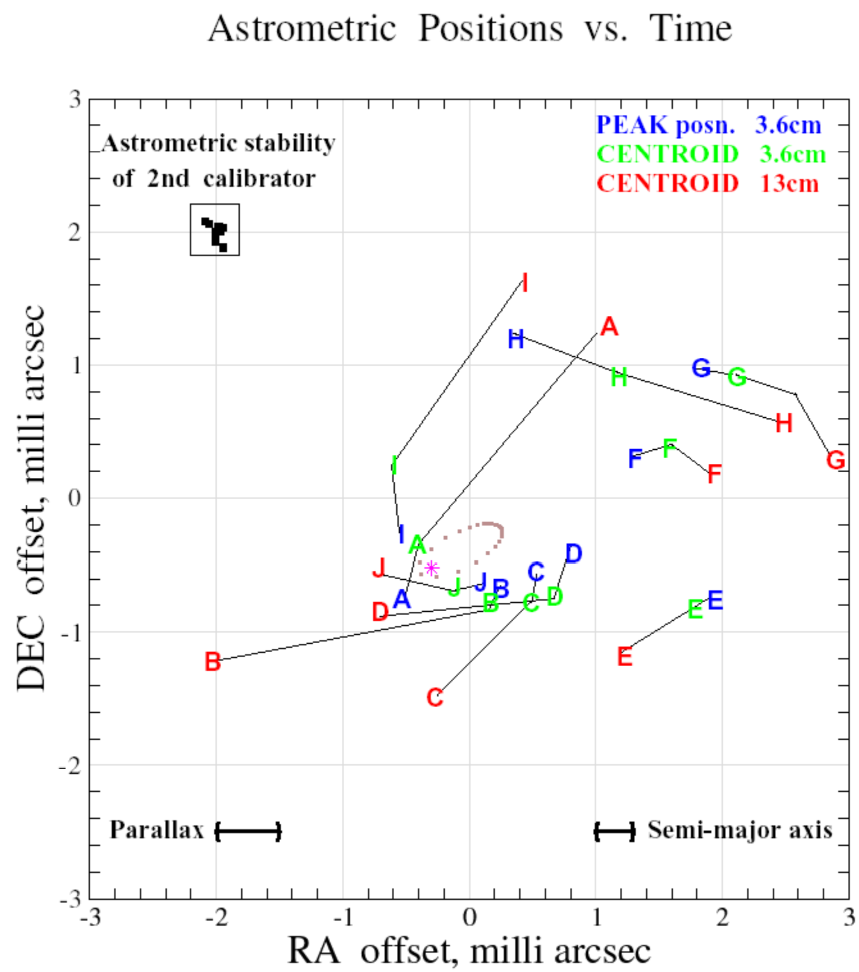


Fermi
MAGIC blue, 0.5-0.7
VERITAS black, 0.5-0.8

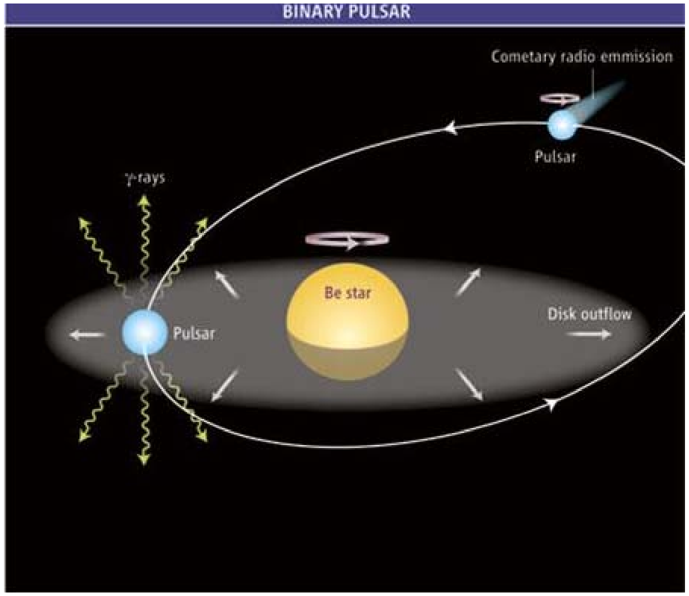
VLBA

Jet-like features have been reported several times, but show a puzzling behavior (Massi et al. 2001, 2004). VLBI observations show a rotating jet-like structure (Dhawan et al. 2006, VI Microquasars Workshop, Como, Setember 2006)



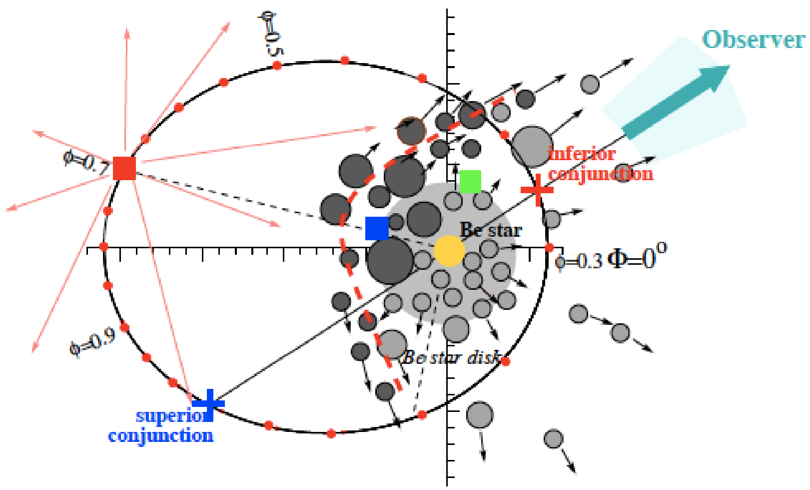


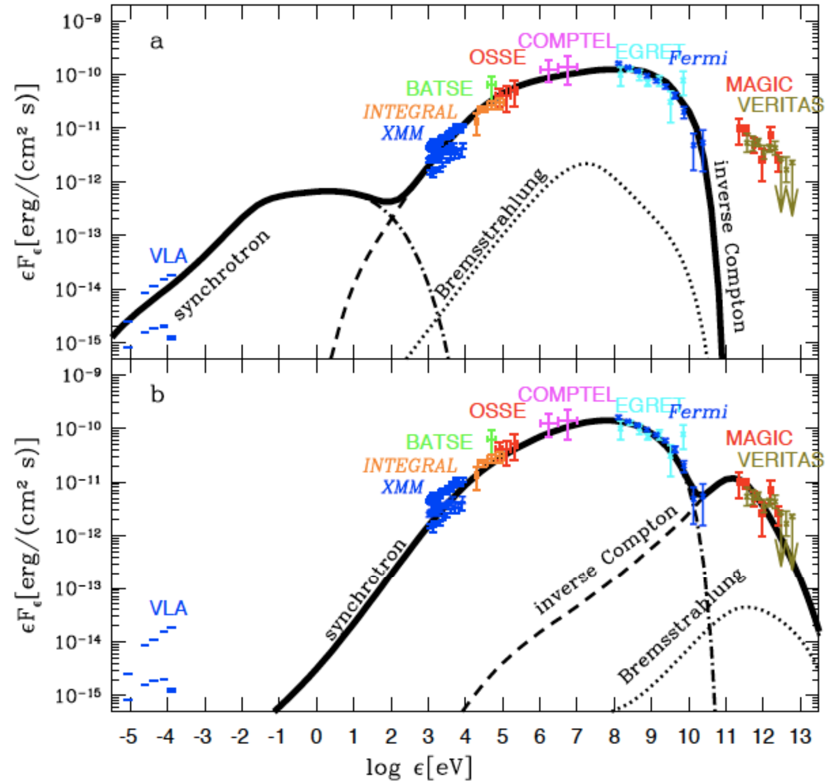
3.6cm images, ~3d apart, beam 1.5x1.1mas or 3x2.2 AU.
Semi-major axis: 0.5 AU



Pulsar scenario: Interaction of the relativistic wind from a young pulsar with the wind from its stellar companion. A comet-shape tail of radio emitting particles is formed rotating with the orbital period. We see this nebula projected (Dubus 2006, A&A 456, 801). UV photons from the companion star suffer IC scattering by the same population of non-thermal particles, leading to emission in the GeV-TeV energy range

Zdziarski et al. 2010, MNRAS 403, 1873



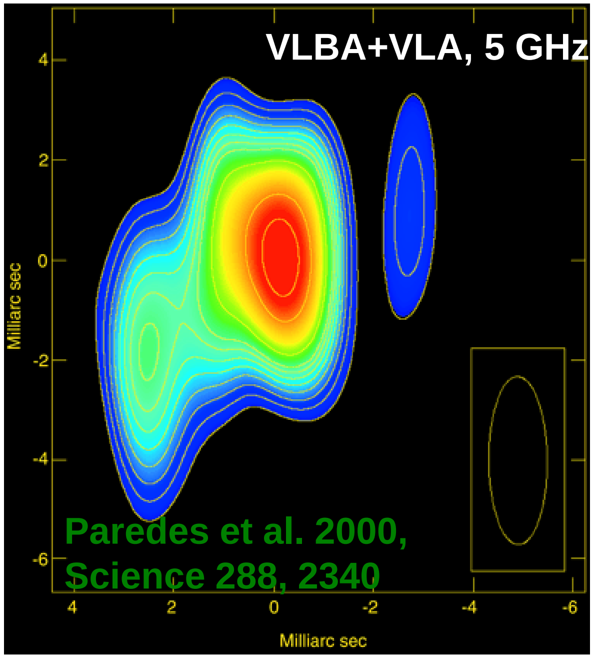


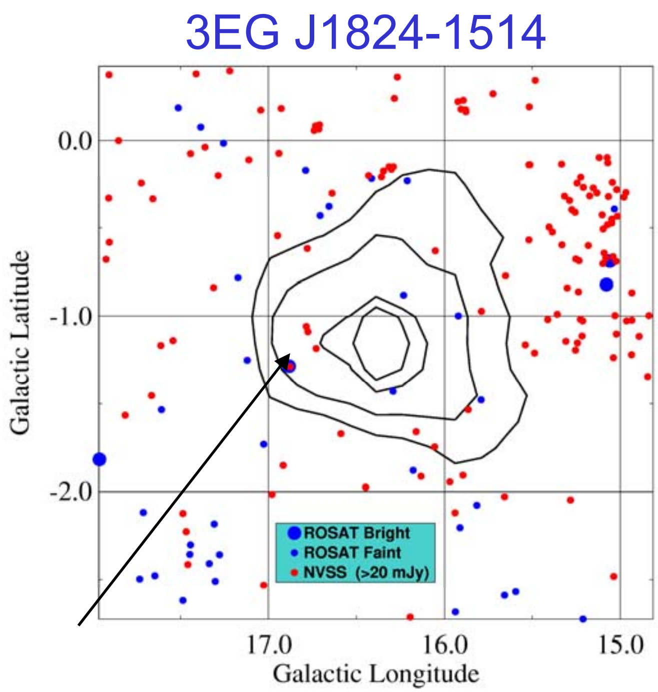
Not resolved yet the issue of the momentum flux of the pulsar wind being significantly higher than that of the Be wind, which presents a problem for interpretation of the observed radio structures (as pointed out by Romero et al 2007, A&A 474, 15)

LS 5039

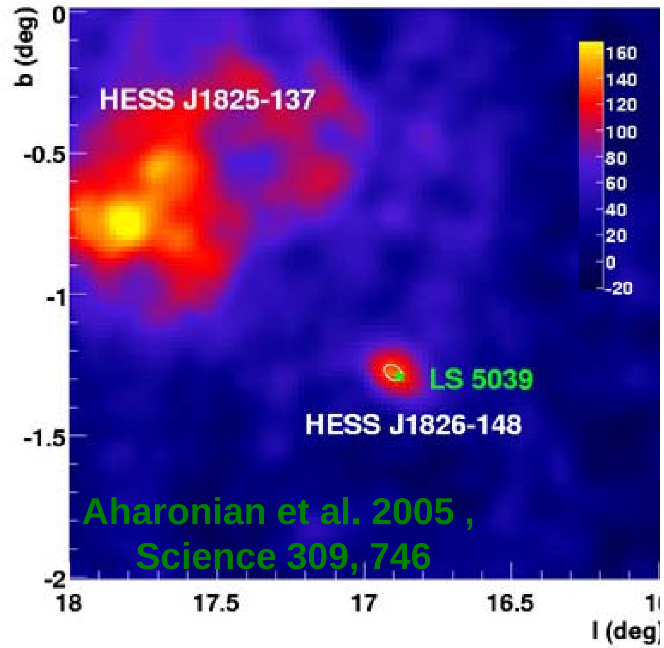
- HMXB, O6.5V+NS?

EGRET



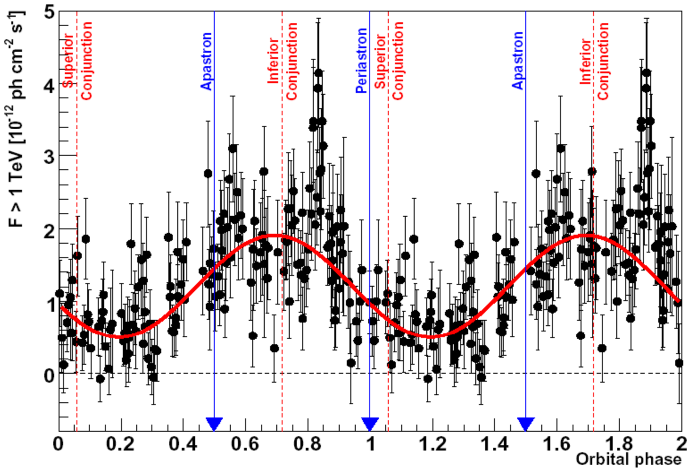


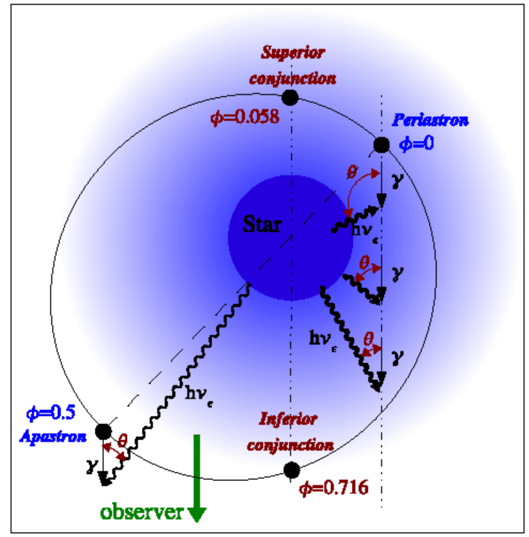
HESS



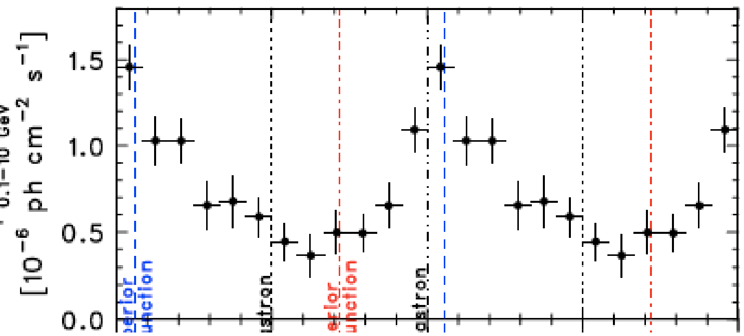
Aharonian et al. 2006, A&A 460, 743

H.E.S.S.

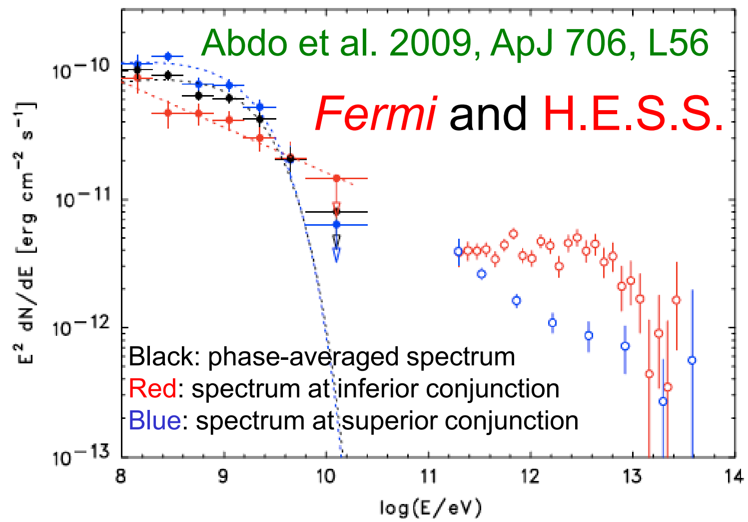




Fermi



Abdo et al. 2009, ApJ 706, L56

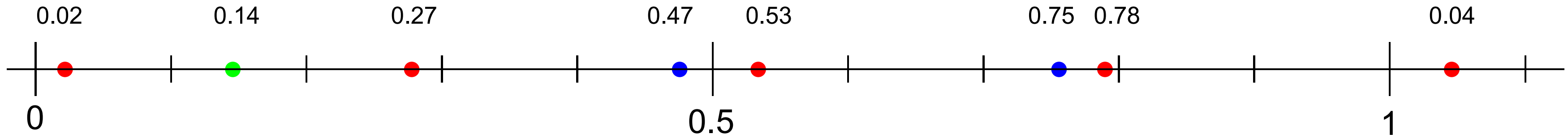


(Khangulyan et al. 2008; Sierpowska-Bartosik&Torres 2008b)

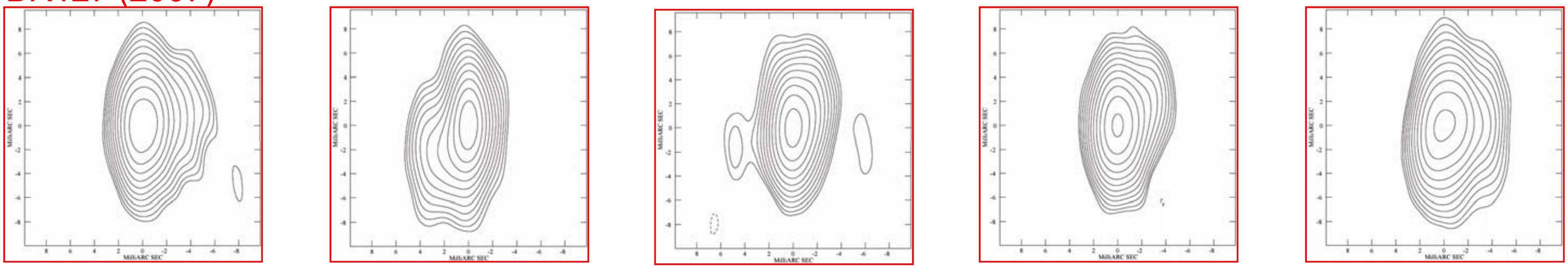
- The emission is enhanced (reduced) when the highly relativistic electrons seen by the observer encounter the seed photons head-on (rear-on), i.e., at superior (inferior) conjunction
- VHE absorption due to pair production will be maximum (minimum) at superior (inferior) conjunction

The γ-ray data require a location of the production region at the periphery of the binary system at ~10^{12} cm (Khangulyan et al. 2008, MNRAS 383, 467; Bosch-Ramon et al. 2008, A&A 489, L21)

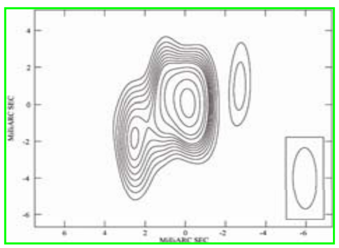
Phase

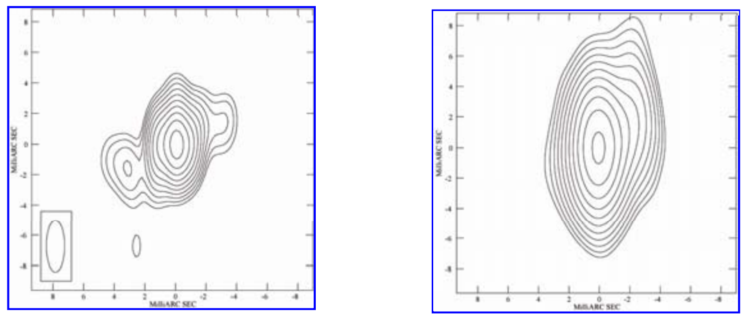


BR127 (2007)



BP051
(1999)

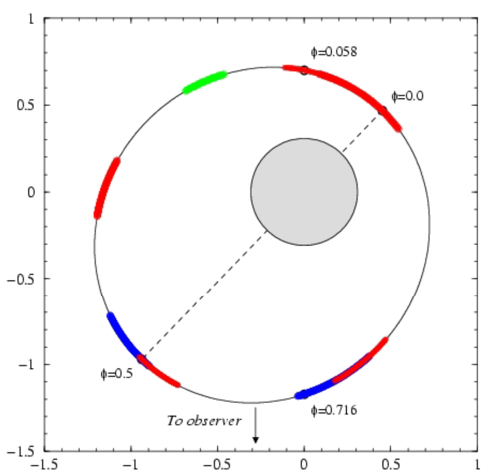




GR021 (2000)

Preliminary!

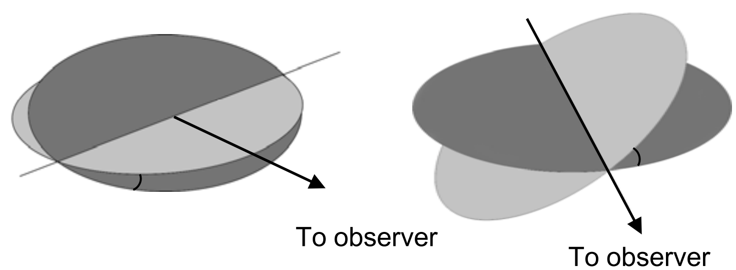
[Moldón et al., in preparation]



The orbital plane has two degrees of freedom:

Inclination of the orbit

Longitude of the ascending node



Summary

Instrument	PSR B1259-63	LS I +61 303	LS 5039	Cygnus X-1	Cygnus X-3
EGRET >100 MeV	—	3EG J0241+6103	3EG J1824-1514	—	—
AGILE 30 MeV-50 GeV	yes	yes	yes	yes	yes
FERMI 30 MeV-300 GeV	—	yes Periodic	yes Periodic	—	yes Periodic
HESS >100 GeV	yes	not visible	yes Periodic	—	—
MAGIC >60 GeV	not visible	yes Periodic	—	yes	—
VERITAS >100 GeV	not visible	yes	—	—	—

All of them are HMXBs

- All of them are radio emitters + jet (jet-like) structure
- All of them have a bright companion (O or B star) → source of seed photons for the IC emission and target nuclei for hadronic interactions

- NS and BH are among these detected XRBs
- VLBI monitoring of the jets along the orbit is crucial to understand some of these systems
- Multi-wavelength (multi-particle) campaigns are of primary importance