Multiwavelength properties of gamma-ray loud binaries

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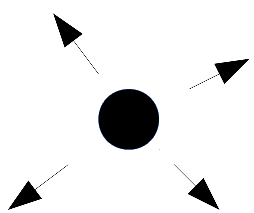
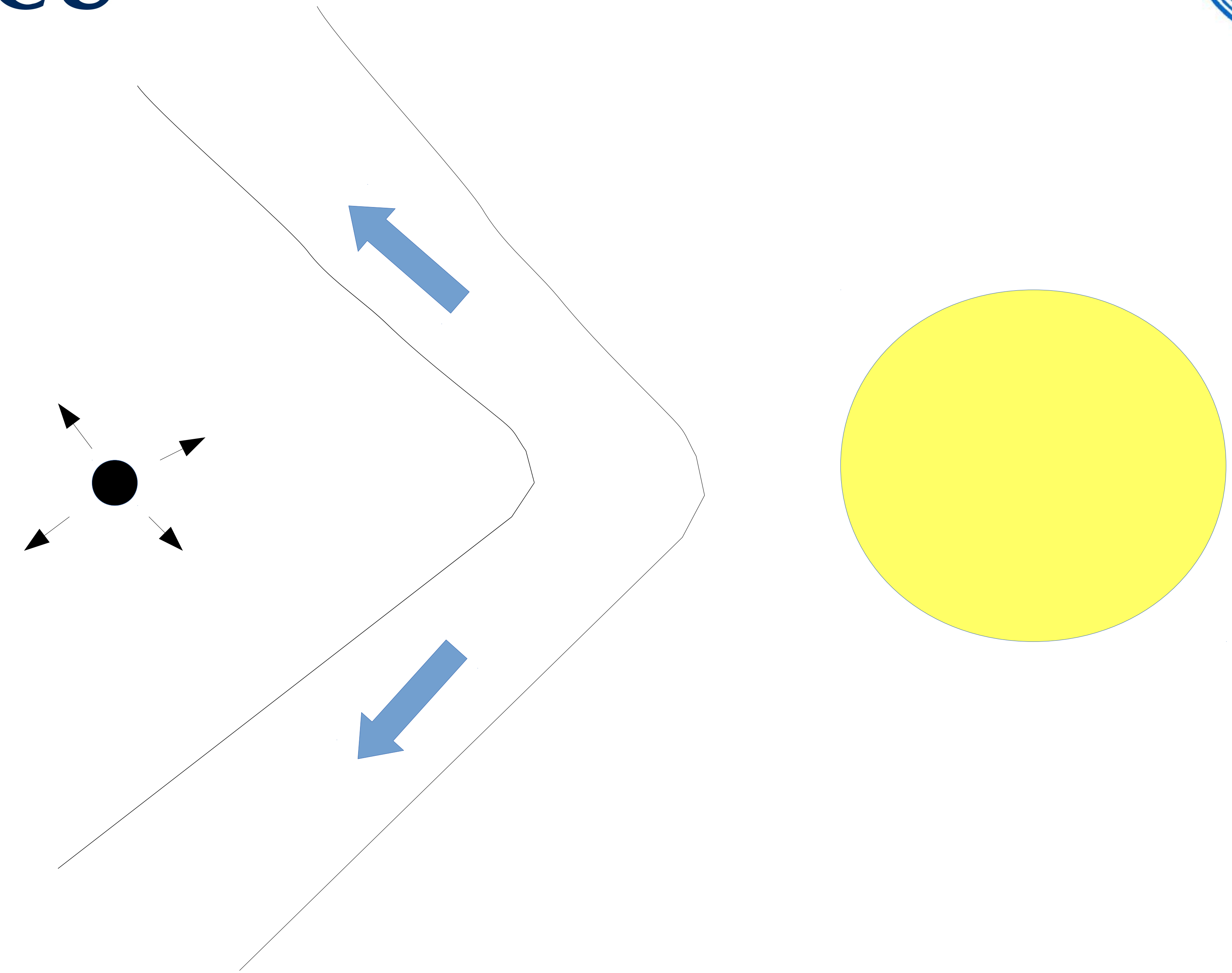
The Structure and Signals of Neutron Stars from Birth to Death
Florence, 24-28 March 2014





Known γ-ray loud binary systems.

HMXBs that also exhibit very high energy emission (MeV-TeV) are called "γ-ray binaries"

Only 4 binary systems are regularly observed in TeV:

PSR B1259-63 (young pulsar +Be star, P=3.4 y)

LSI +61 303 (comp. source + Be star, P=26.42 d)

LS 5039 (comp. source + O star, P=3.9 d)

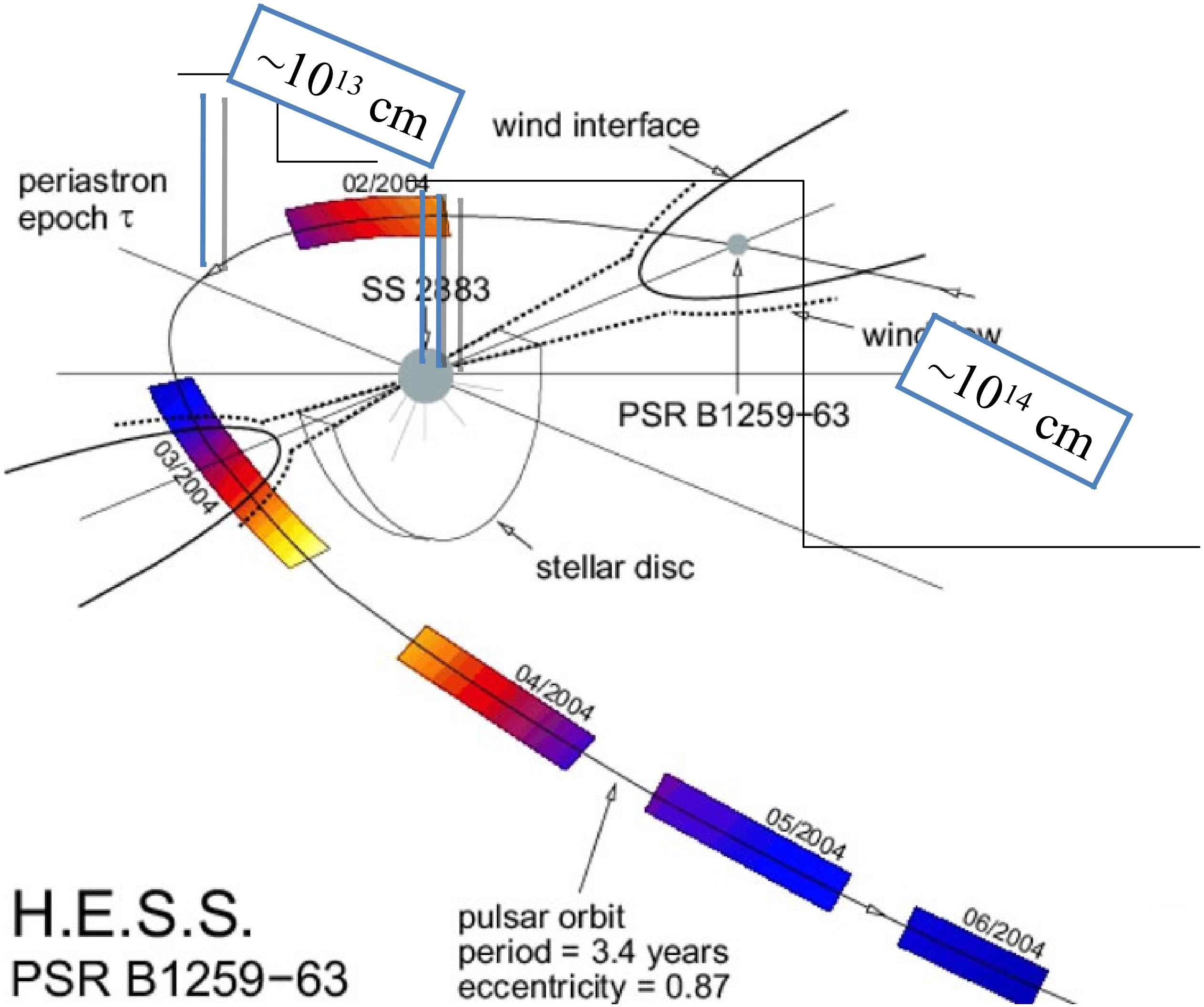
HESS J0632+57 (comp. source+B0pe, P=320 d)

Origin of the high-energy emission?

Difference from other X-ray binaries?

Powered by rotation energy rather than accretion?

PSR B1259-63 system



Aharonian et al. 2005.

Pulsar:
P=47.76 ms
L_{SD}=8.3 × 10^{35} erg s^{-1}

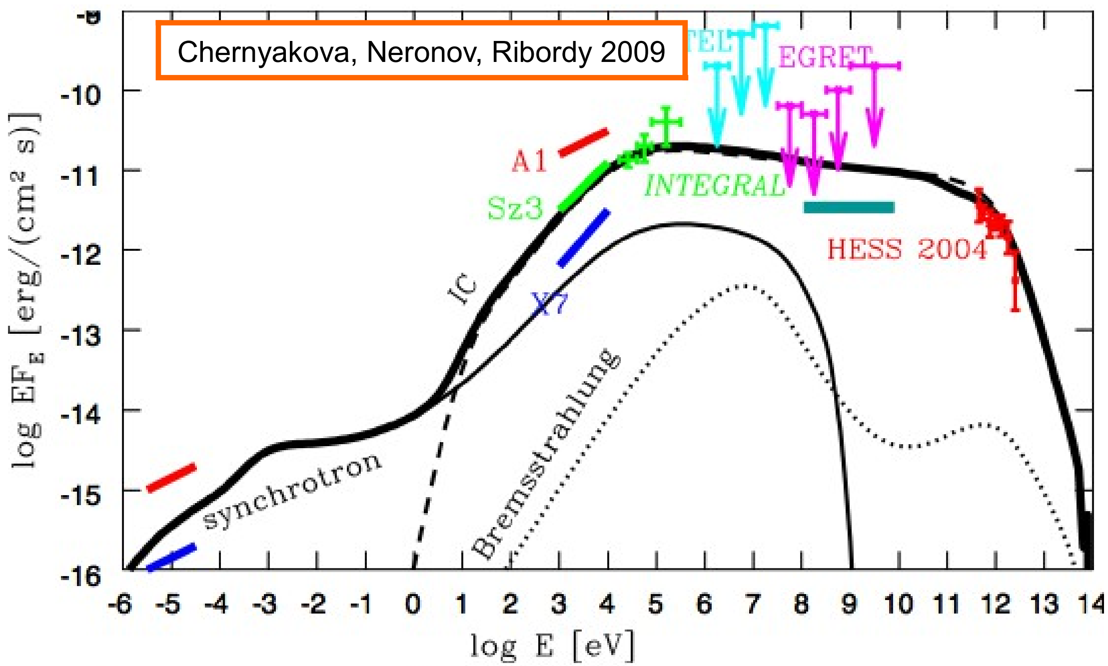
Orbit
Period ≈ 3.4 yr
Eccentricity e≈ 0.87

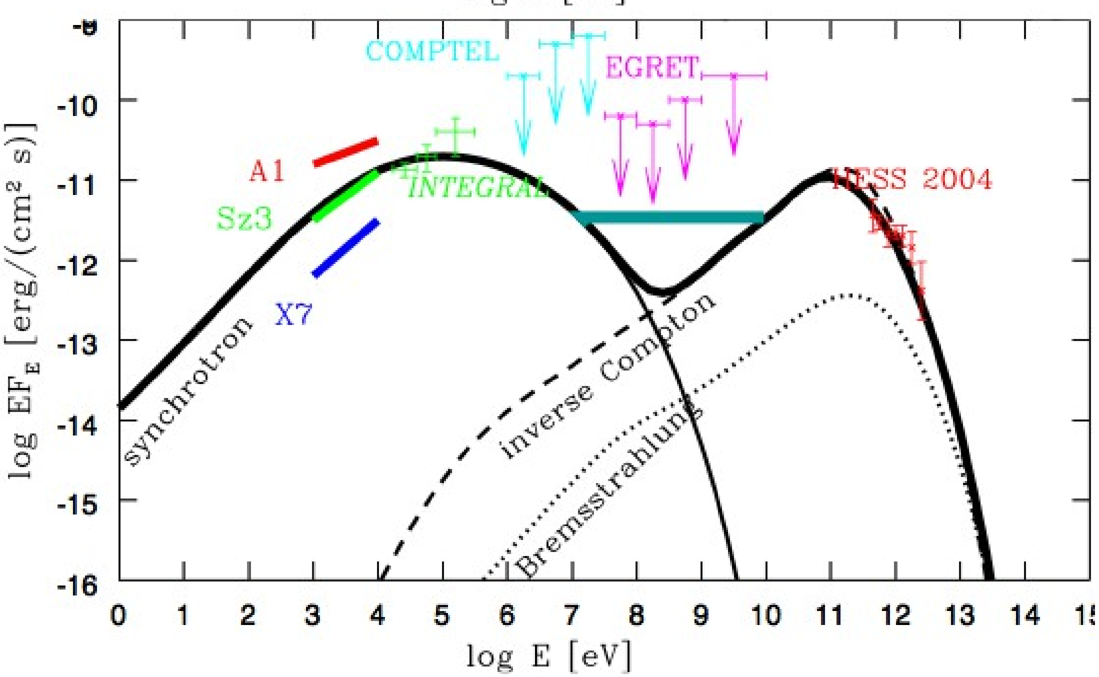
Distance 2.3 ± 0.4 kpc

SS 2883 parameters
- L_*=2.2E+38 erg/s
- M~10M_{sun}
- T~27000 K

"Laboratory" for the study of the properties of pulsar winds

PSR B1259-63: before Fermi observations





Gamma-ray emission from the system was observed in 2004 and 2007 by HESS in the TeV energy range.

Similarly to large scale Pulsar Wind Nebulae (PWN), commonly considered contributions to the spectrum are

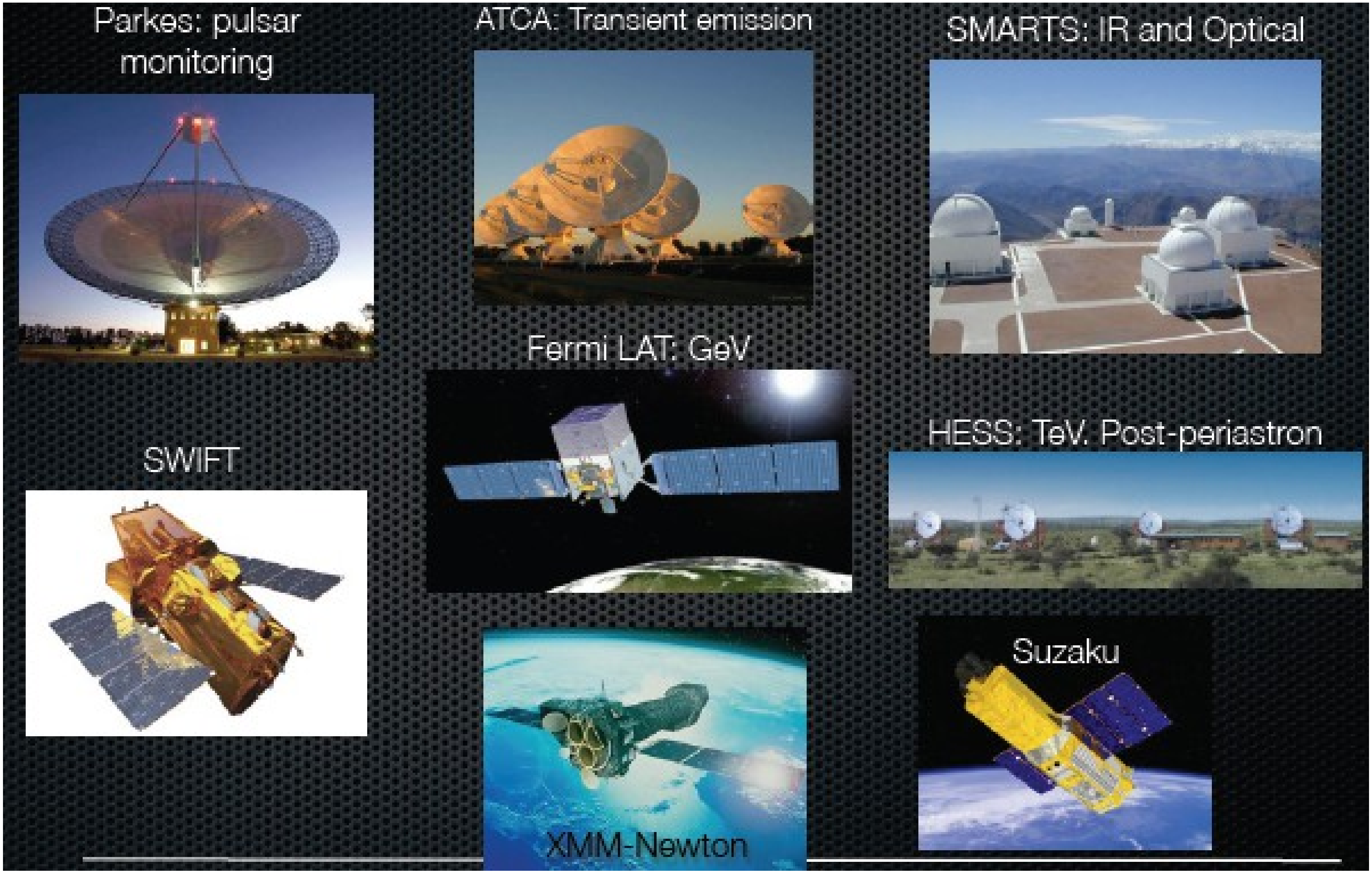
- synchrotron emission
- inverse Compton emission
- Bremsstrahlung

by high-energy electrons.

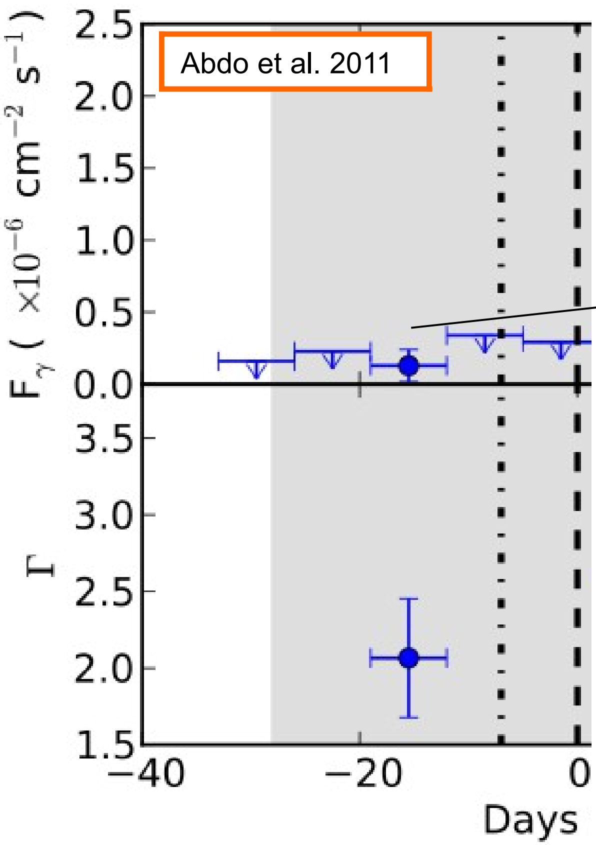
Electrons/positrons could be

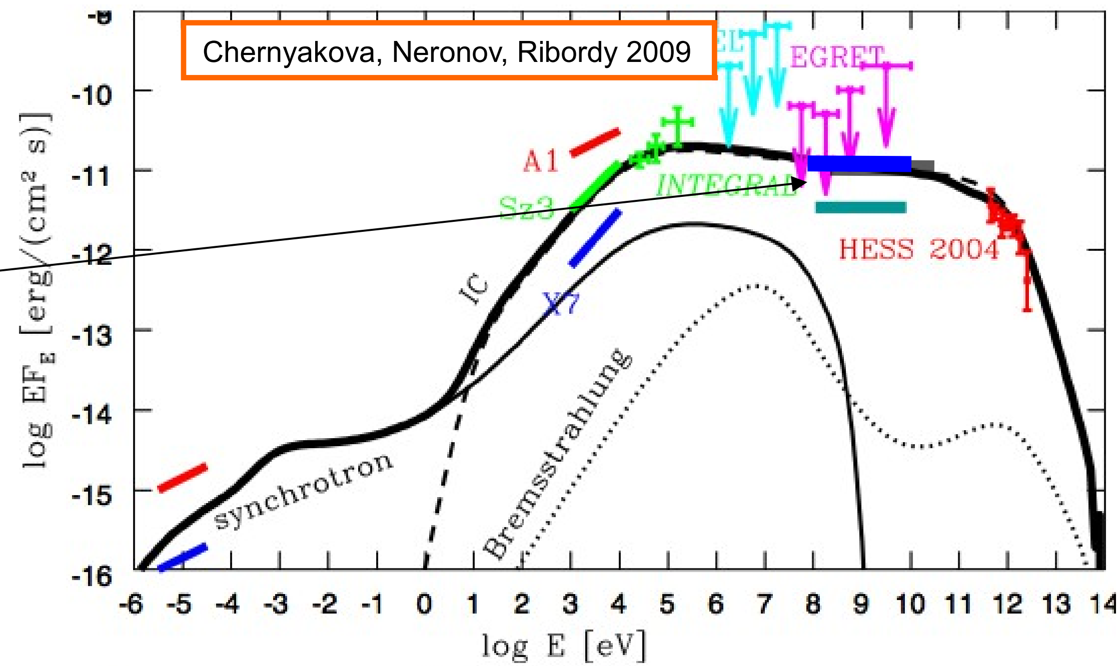
- accelerated at the bow-shock (similarly to the termination shock of the pulsar wind in PWNe)
- injected directly from the pulsar wind

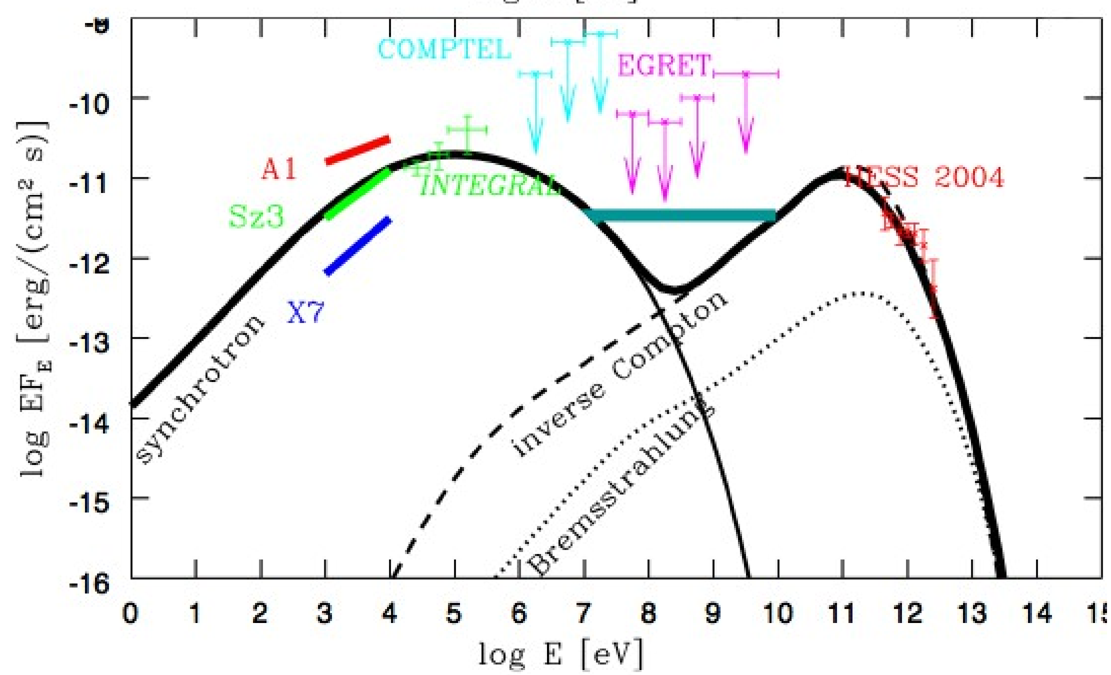
2010 Multi-wavelength Campaign



PSR B1259-63 2010-2011 pre-periastron emission



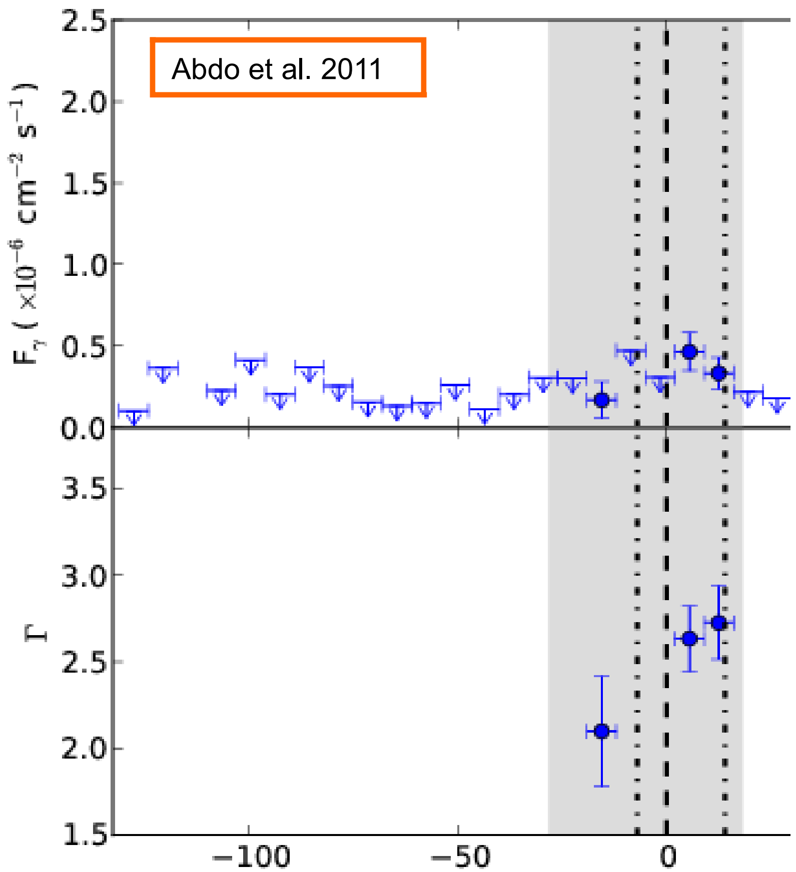


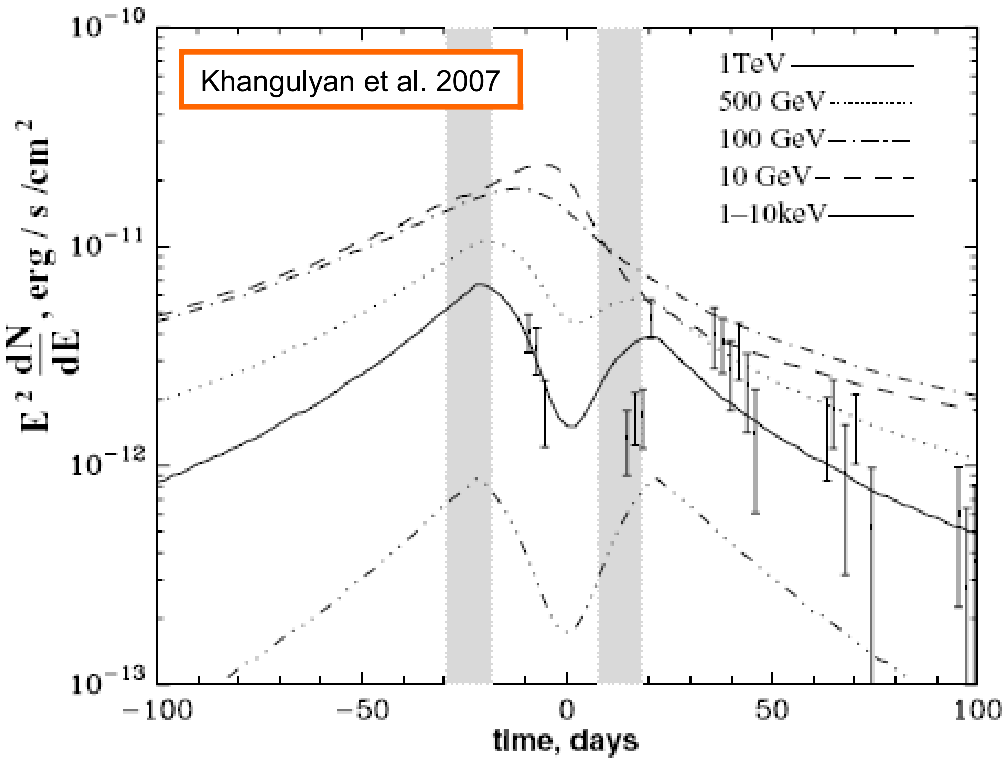


- The source was first detected ~20d before the periastron, during the first passage through the Be star disk.
- Spectrum was relatively hard, with photon index $\Gamma \approx 2$.

Source characteristics are consistent with the IC model.

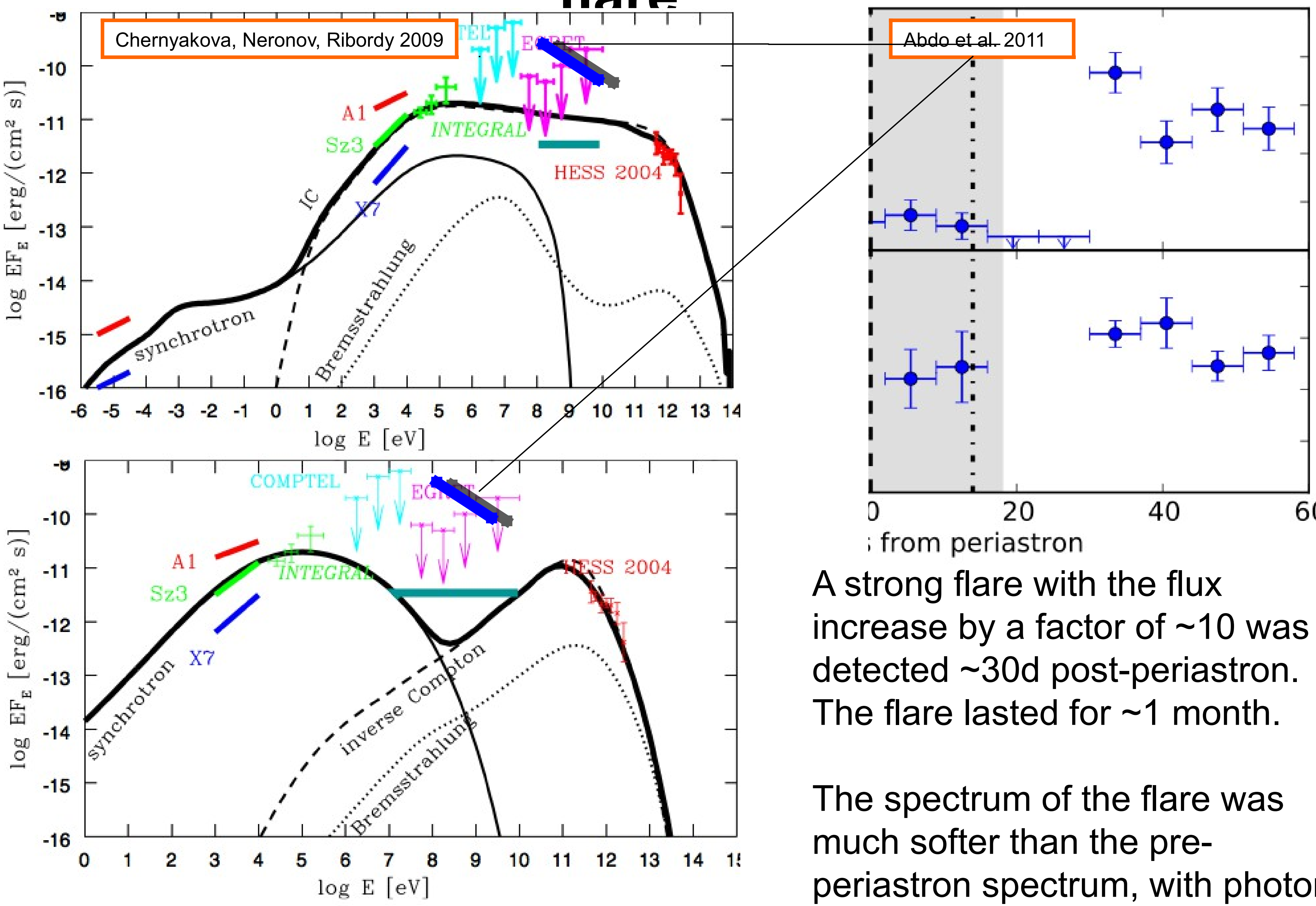
PSR B1259-63 2010-2011 periastron emission





Maximum of GeV lightcurve near the periastron was first predicted by Khangulyan et al. 2007.

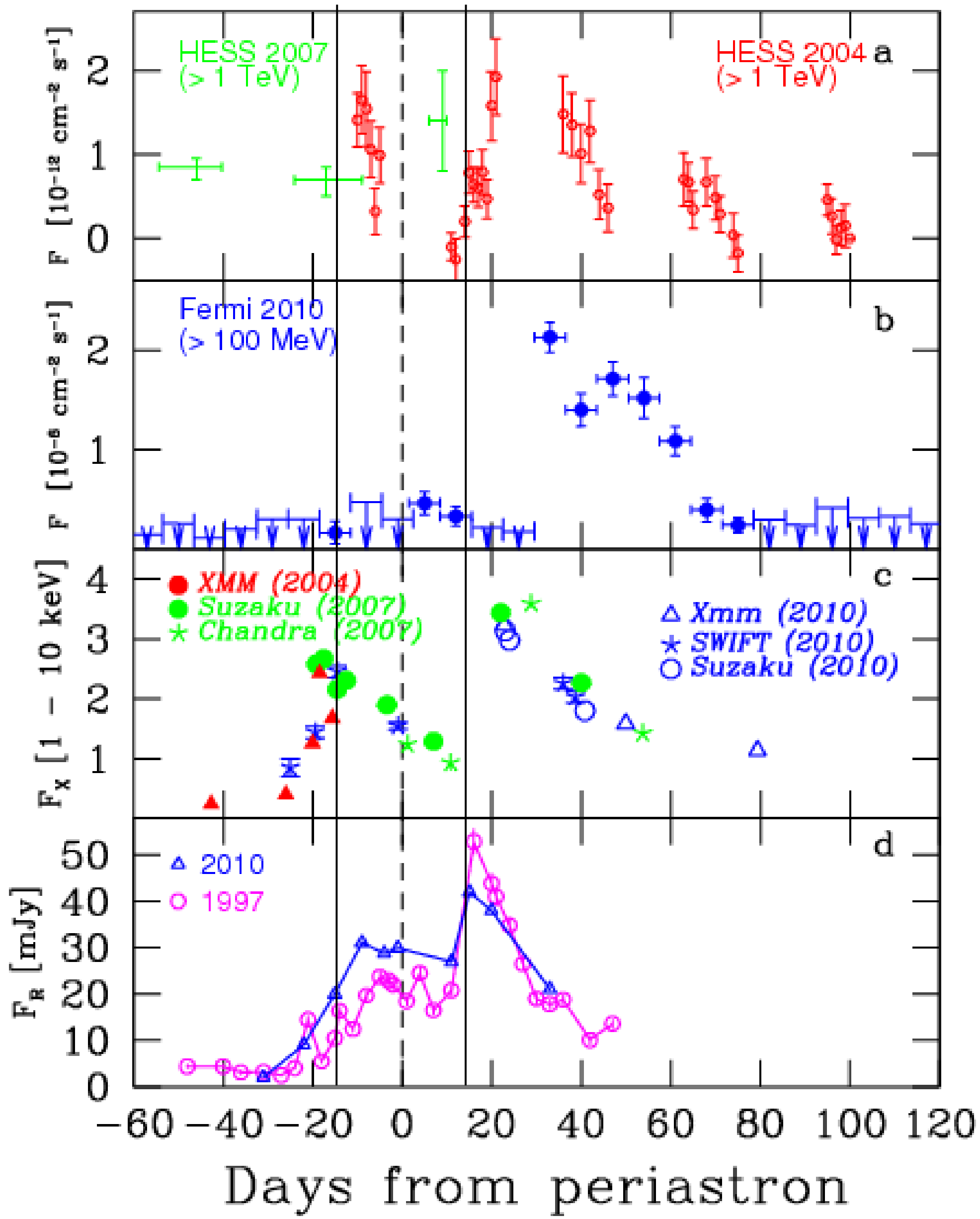
PSR B1259-63 2010-2011 post-periastron flare



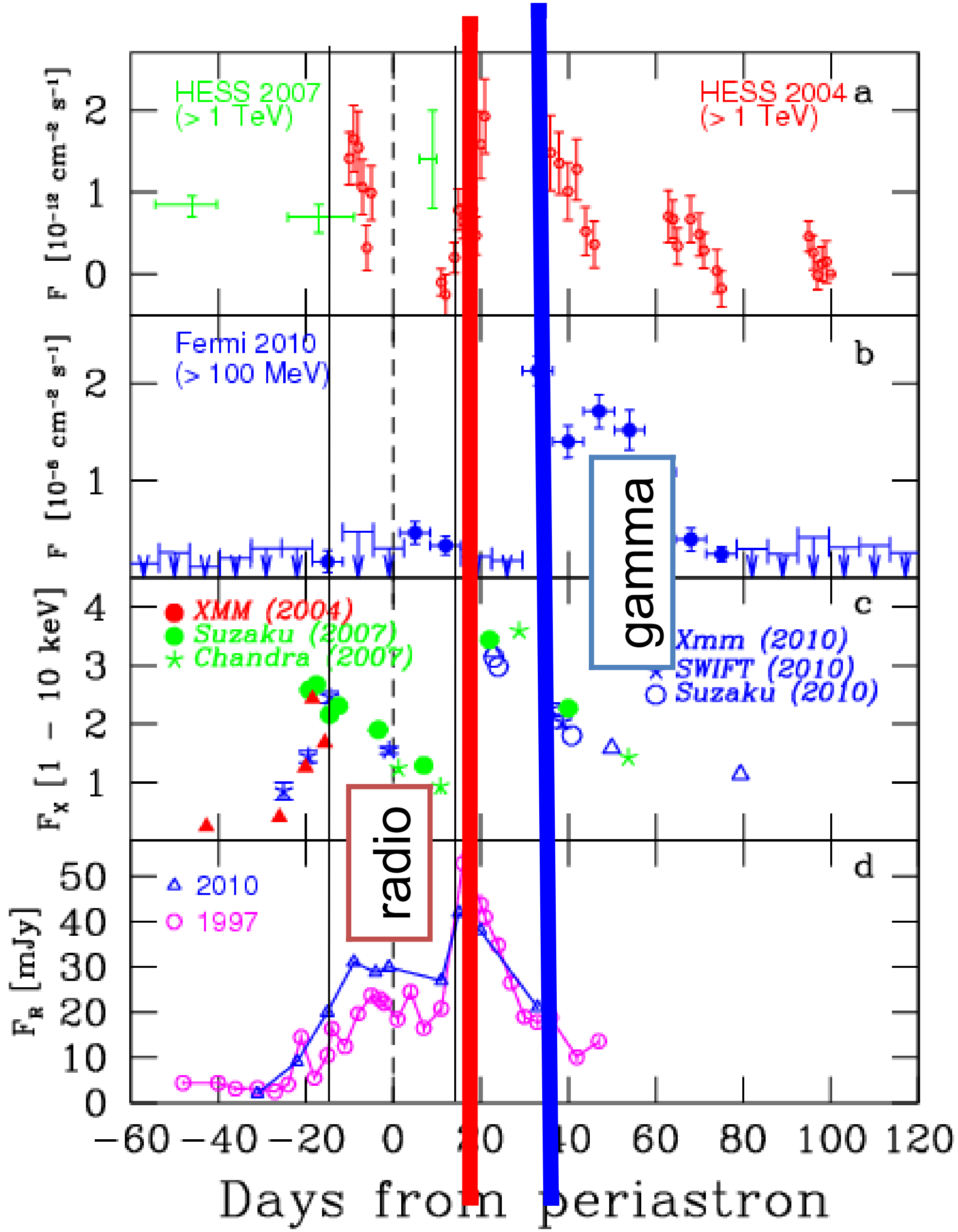
A strong flare with the flux increase by a factor of ~10 was detected ~30d post-periastron. The flare lasted for ~1 month.

The spectrum of the flare was much softer than the pre-periastron spectrum, with photon index $\Gamma \approx 3$.

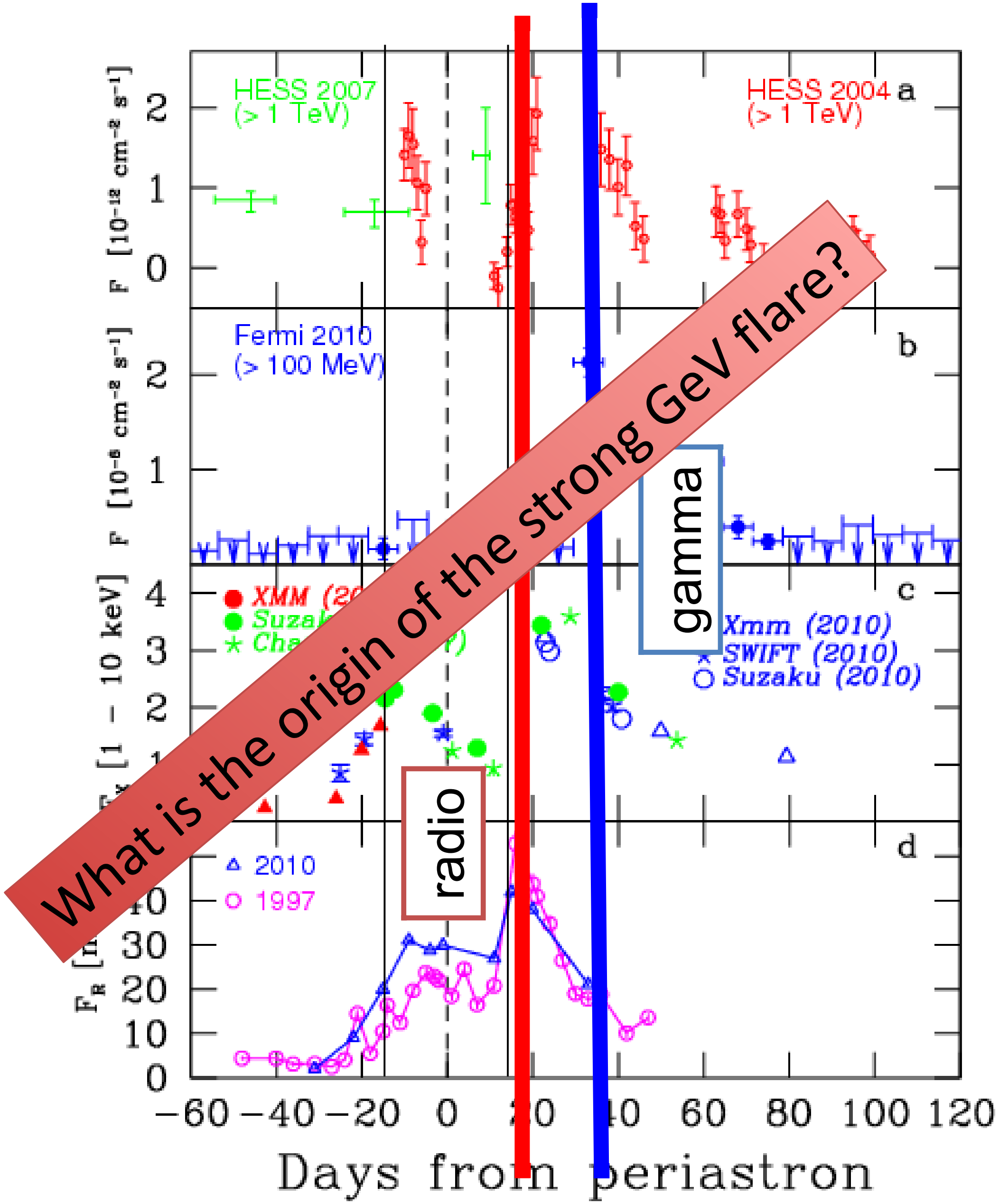
PSR B1259-63 2010-2011 post-periastron flare



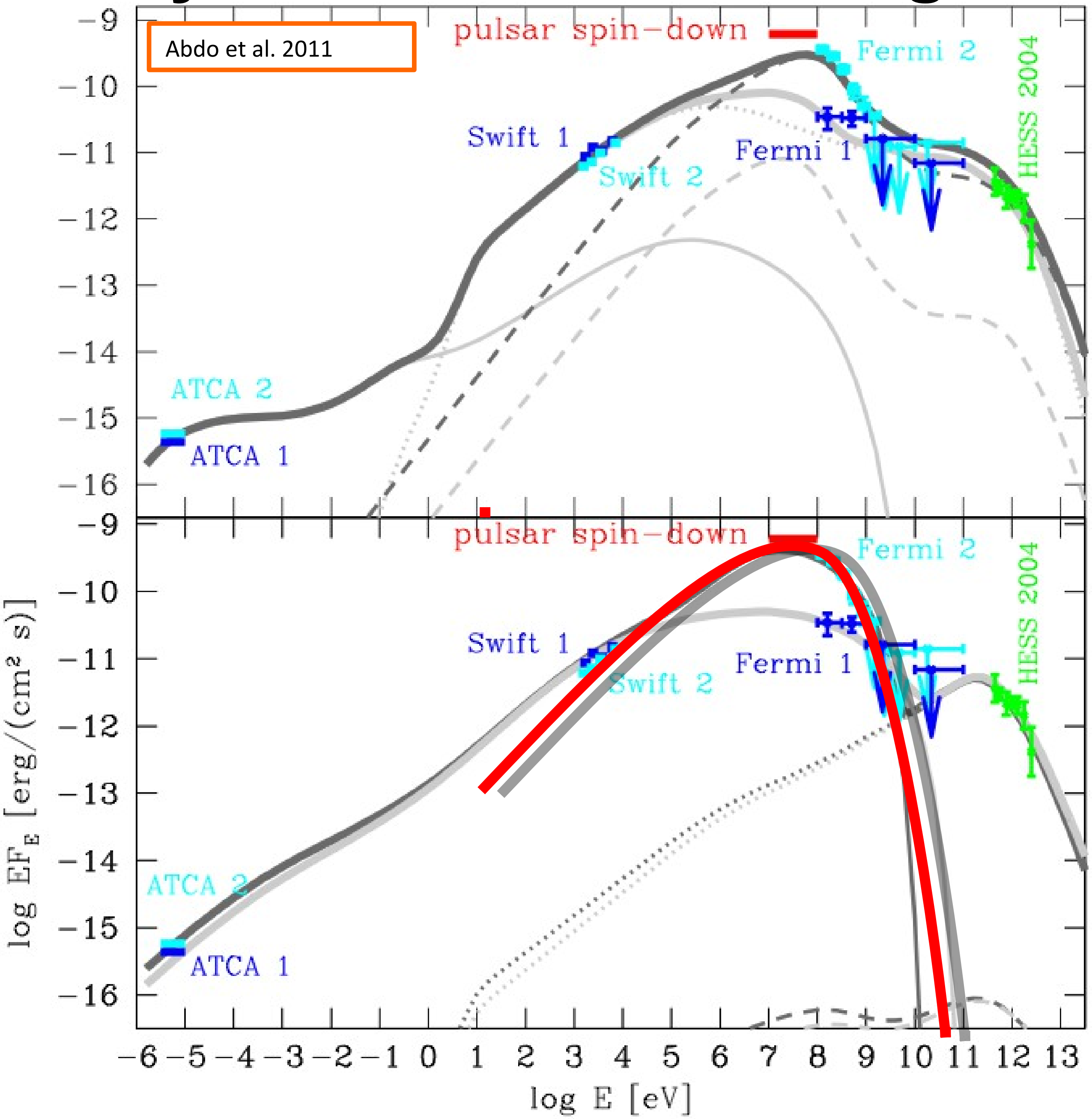
PSR B1259-63 2010-2011 post-periastron flare



PSR B1259-63 2010-2011 post-periastron flare



Physical mechanism of gamma-ray emisison



Inverse Compton emission from a sharply peaked electron distribution? $E_e \approx 1$ GeV?

Unshocked pulsar wind with bulk Lorentz factor 10^3?

Khangulyan et al. 2011
G. Dubus & B. Cerutt I 2013

Disk disruption give a chance to see synchrotron emission from a sharply peaked electron distribution? $E_e \approx 10^{15}$eV?

Similarity to Crab GeV flares?

Chernyakova et al. 2014

Enhanced Bremmstrahlung emission from the pulsar passage through the "debris" of the Be star disk?

Abdo et al. 2011

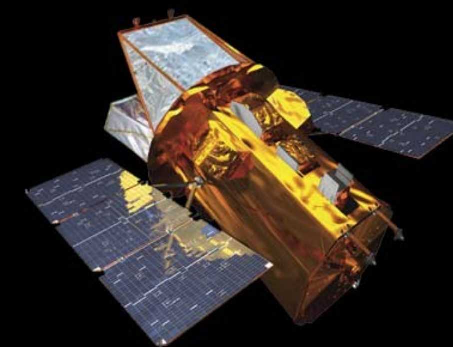
More observations are needed!

2014 Multi-wavelength Campaign

ATCA: radio continuum

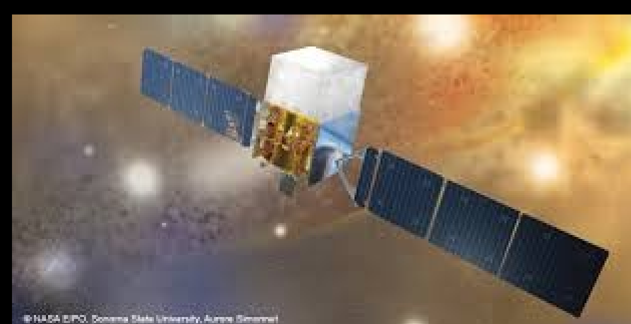
1.9 m telescope at SAAO: optical spectroscopy

SWIFT: X-ray monitoring



NuSTAR: 4 observations

Fermi: GeV monitoring



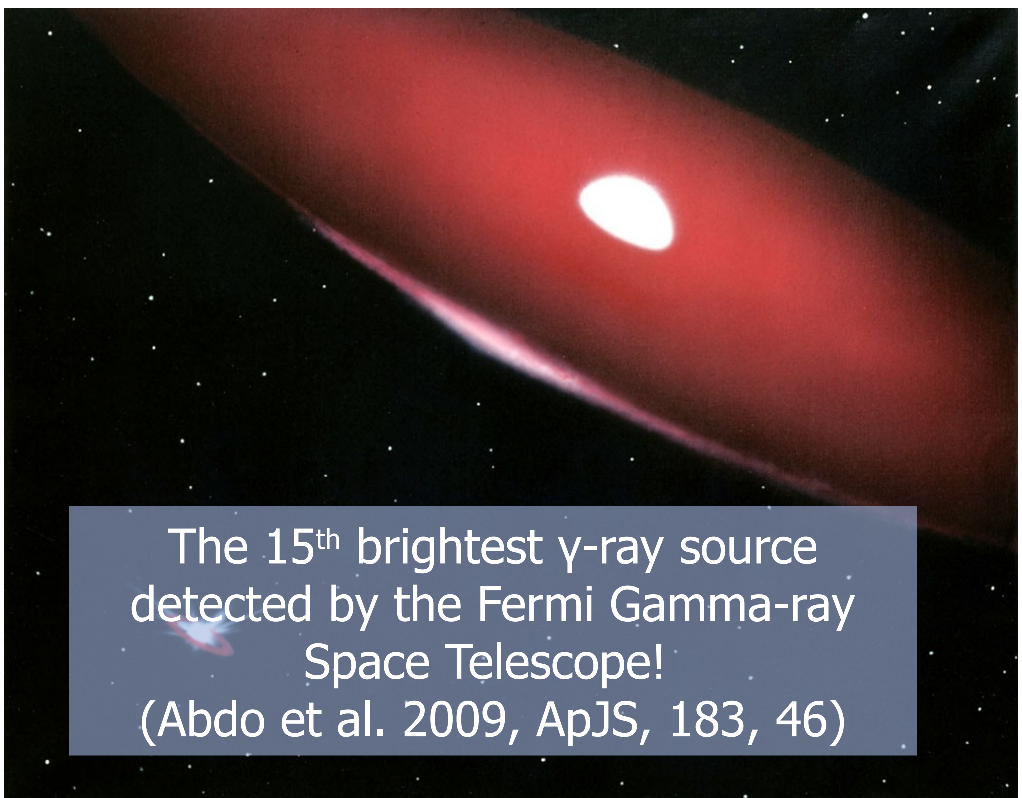
HESS: TeV monitoring

LSI +61 303

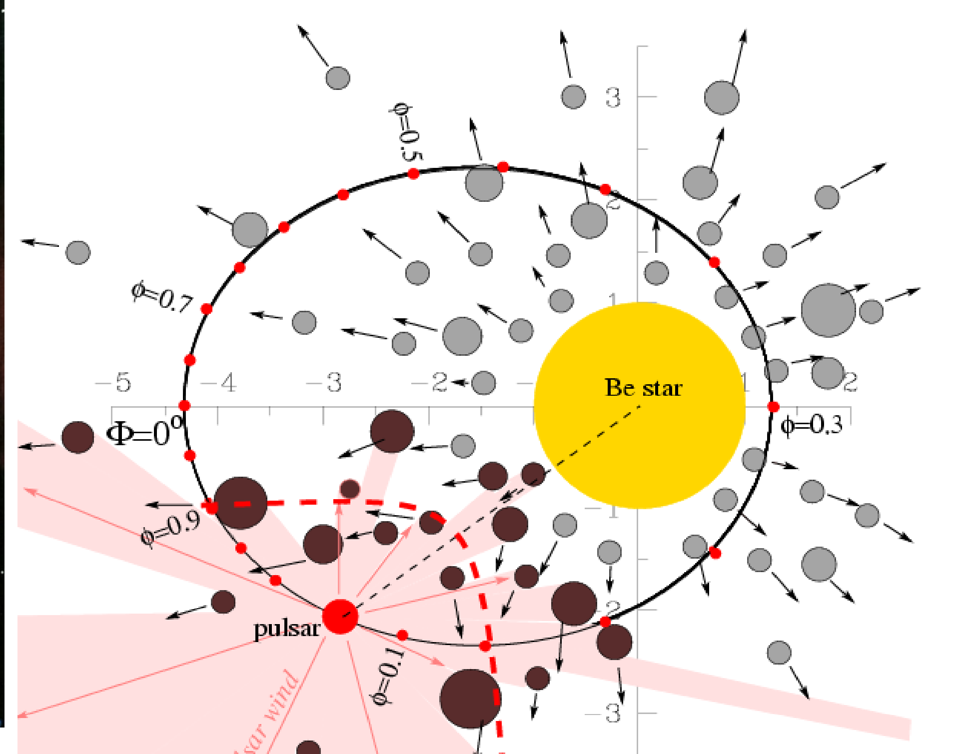
A rapidly rotating “Be” star surrounded by a dense, circumstellar disk and an unknown compact companion

Be disk interacts with the companion to produce emission across the electromagnetic spectrum

Emission is modulated throughout the 26.5-day orbit.

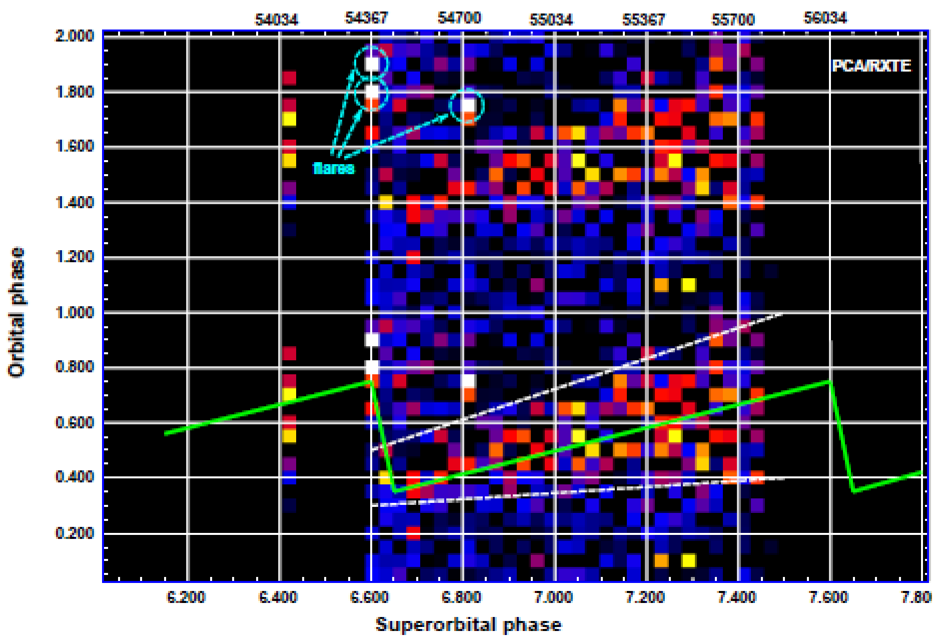


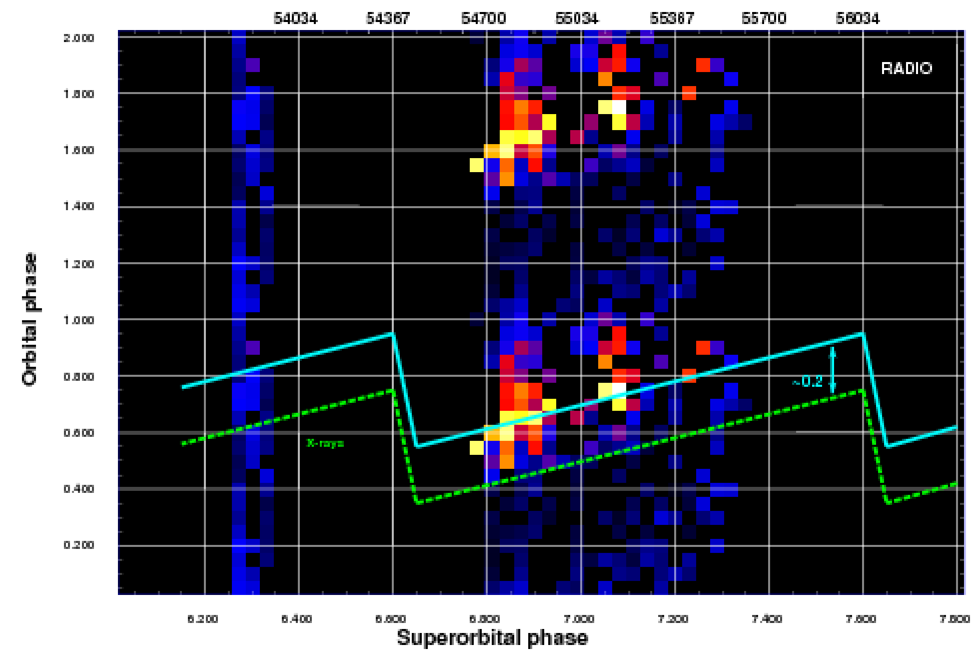
Eccentricity e~0.7



Superorbital Variability

Chernyakova et al. 2012





- The orbital phases of X-ray and radio flux maxima "drift" with superorbital period P=4.6 year.
- Phase of the X-ray activity period always precedes the phase of the radio outburst by $\Delta\phi_{X-R}=0.2\sim5.3$ days.
- 4.6 yr superorbital cycle is interpreted as the cycle of gradual buildup and decay of the equatorial disk of the Be star. At the superorbital phase $\Phi_X \simeq 0.5$ the equatorial disk is weak, i.e. has relatively small density and/or size. Gradual buildup of the equatorial disk due to ejection of matter from the Be star leads to the increase of the disk density and/or disk size.

LS 5039

- Orbital period P_{orb}~3.9 days.

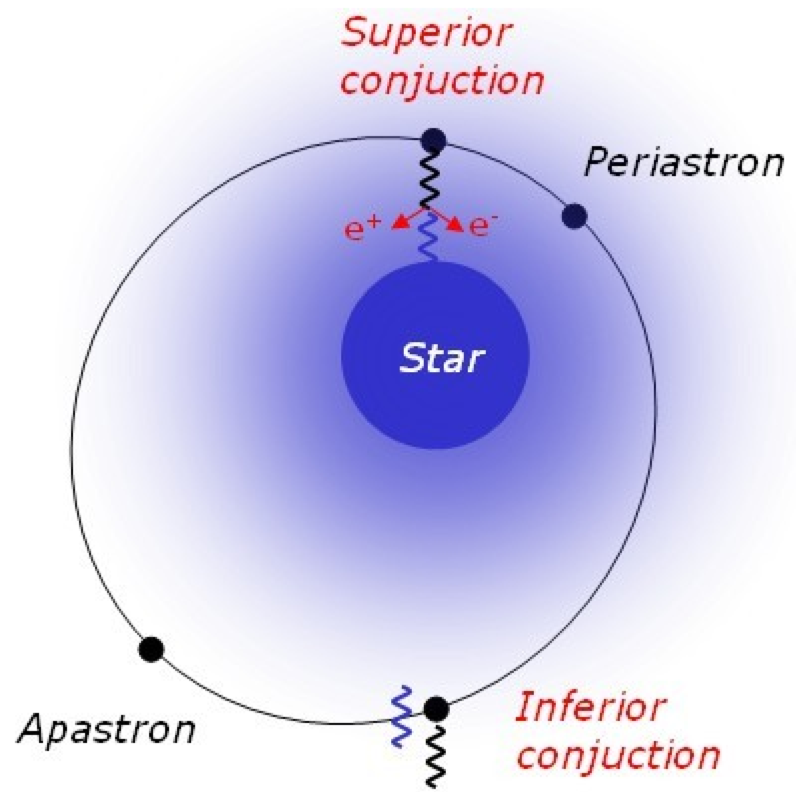
  Eccentricity e = 0.35±0.04

  Optical companion O6.5V(f) V=11.2

  Distance d=2.5±0.1 kpc

  Orbital separation at the periastron ~10^{12}cm

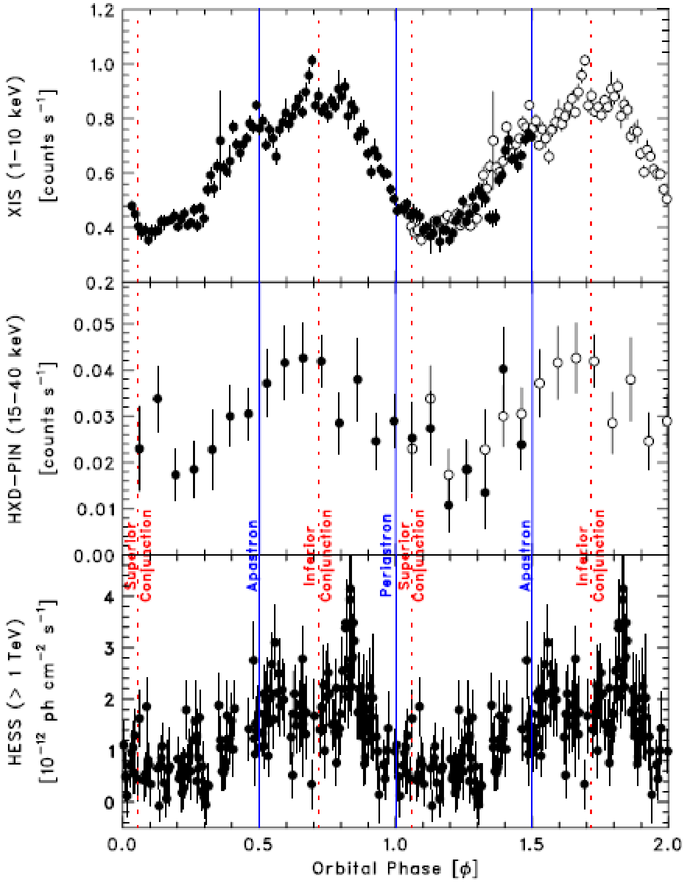
(Casares et. al. 2005)

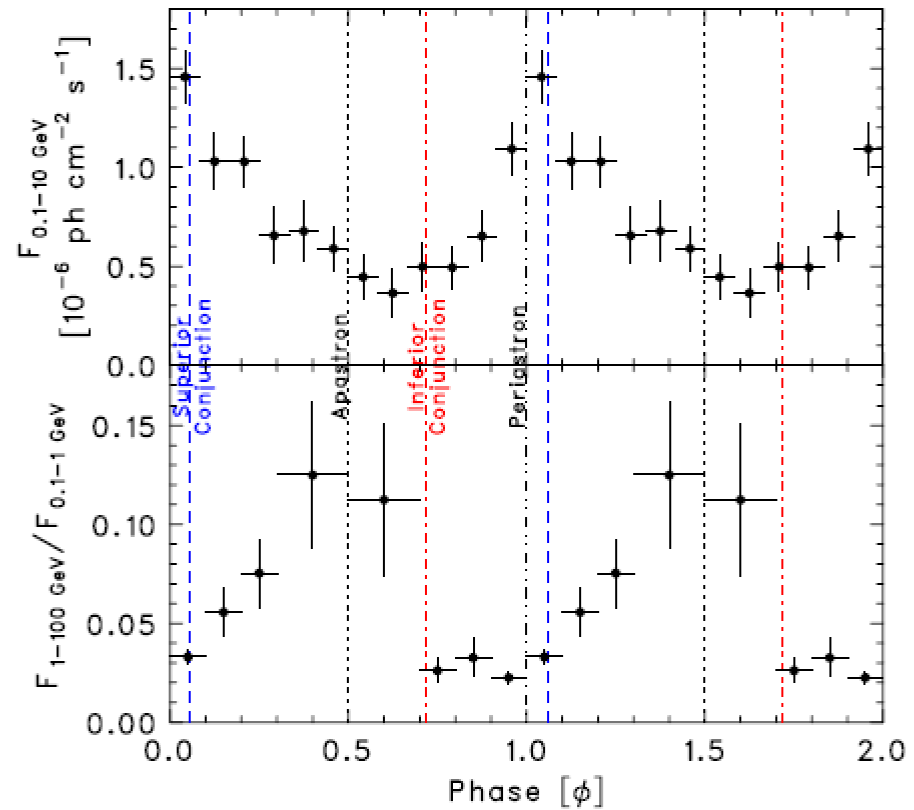


Compact object moves close to the surface of the massive star
Orbital separation at the periastron ~2 R_*, and 4 R_* at the apastron.

Stable X-ray emission assumes stability of the wind from the massive companion (Kishishita et al. 2009; Hadasch et al. 2012).

Orbital variability at different energy bands

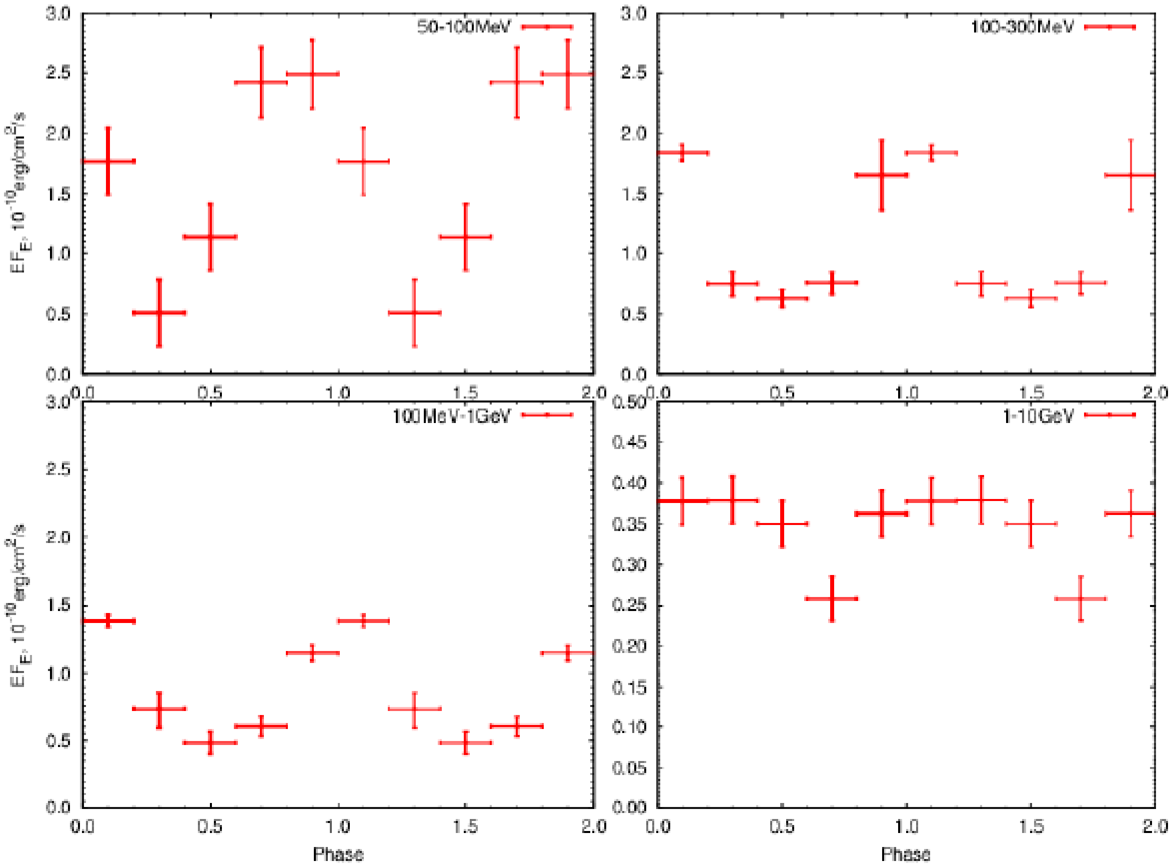




- Similar orbital behaviour of the TeV and X-ray emission (Takahashi et al. 2009).
- GeV has a maximum at the periastron and a suppression of the flux at the inferior conjunction (Abdo et al. 2009).

Orbital lightcurve at different energies

Neronov, Mayshev, Chernyakova 2014



- Search for the orbital modulation of LS 5039 in Fermi/LAT data reveals different dependences of the flux on orbital phase for different energy bands.
- At low (<100 MeV) energies flux demonstrates strong variability with the minimum at orbital phase 0.3, close to one observed in X-rays and TeVs.

- With increase of the energy, the minimum shifts toward the orbital phase 0.5–0.7, observed previously in GeV range.
- Simultaneously with the increase of energy the significance of the variability decreases.

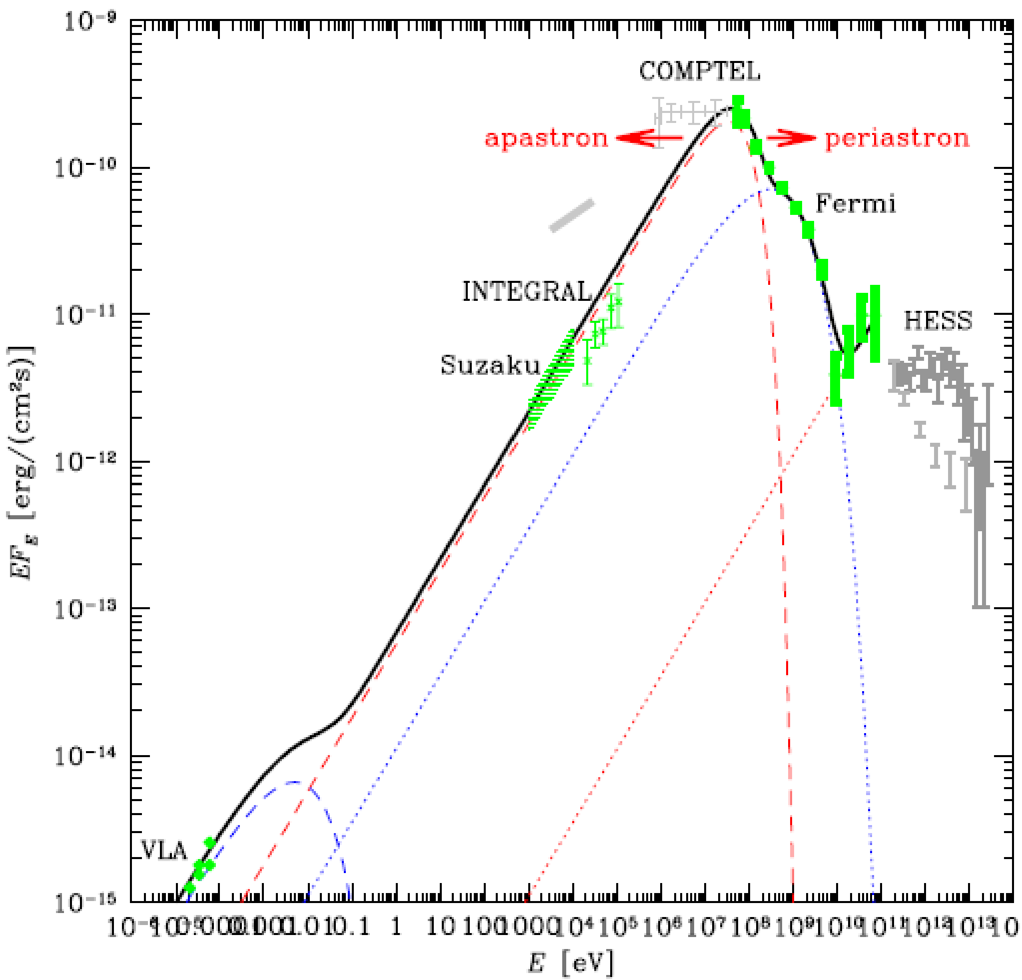
Phase-averaged spectrum

- The observed orbital folded lightcurves can be interpreted as a sum of steady (dominant at GeV energies) and significantly variable (dominant at lower energy) components.

- These components are readily explained in terms of two-component model, where variable component is explained by synchrotron emission from the interior part of the binary.

- Around the periastron magnetic field is the strongest and the maximum of synchrotron emission moves to high energies, leading to a decrease in X-rays and a suppress of IC component, leading to a decrease of TeV .

- Steady component is the IC counterpart of extended radio synchrotron emission from a much larger than the binary system size region.



Neronov, Mayshev, Chernyakova 2014

Conclusions

γ-ray loud binaries apparently form a separate class of sources powered by interaction of relativistic wind from the compact object with the stellar wind.

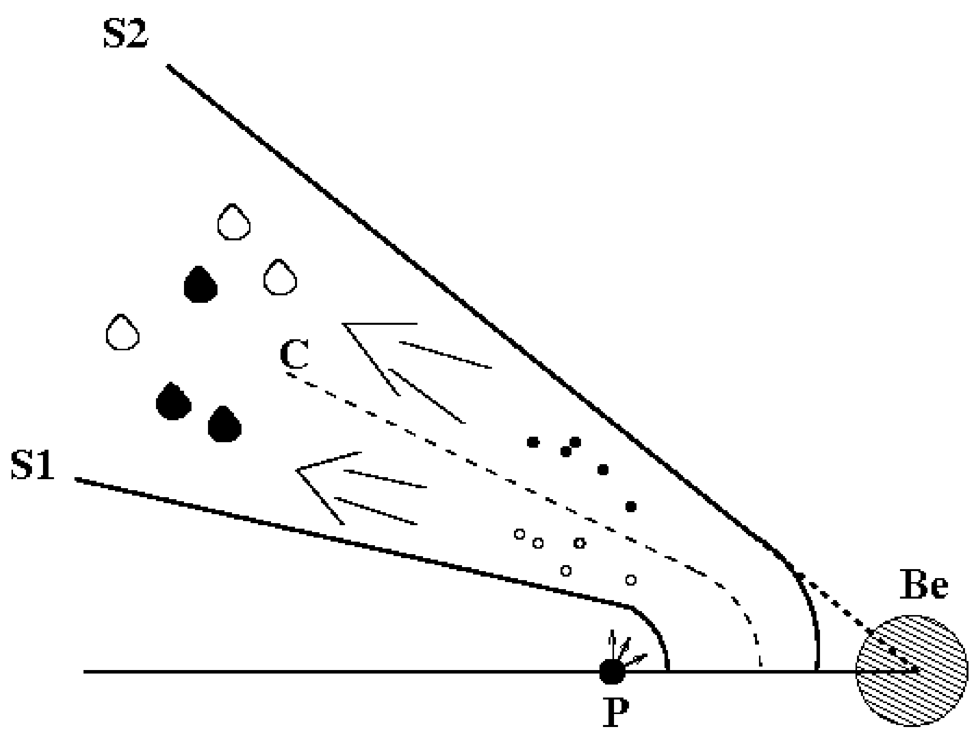
The emission from such a system is highly variable along the orbit.

Non-thermal radio, X-ray, γ-ray, and very high-energy γ-ray emission during the periods of pulsar passing through the dense regions of the companion wind.

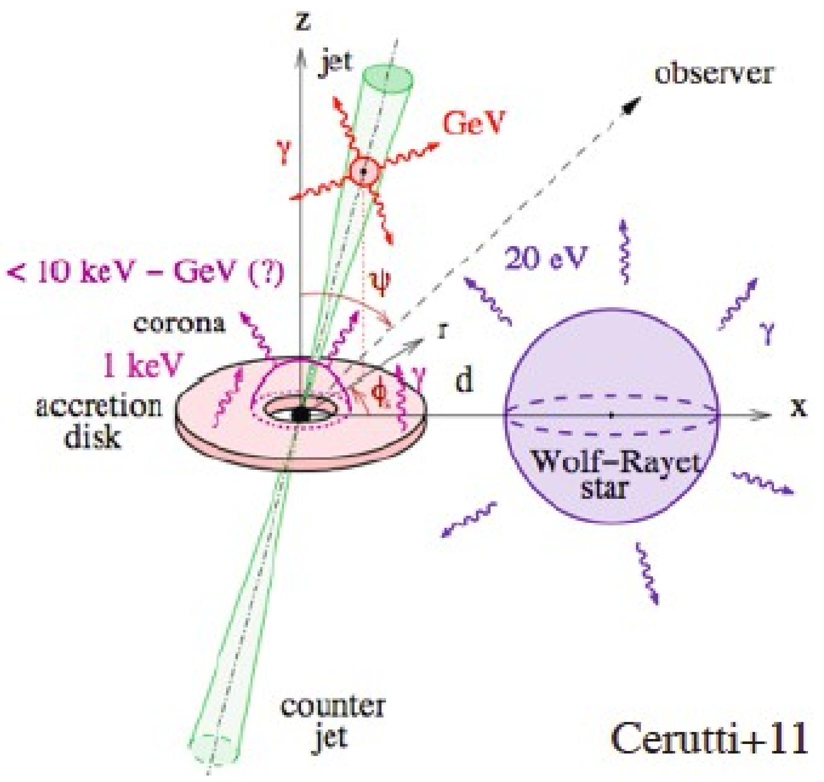
Perfect laboratory to study the properties of the pulsar wind and details of its interaction with the stellar wind and ISM.

Two Theories for γ-ray Production

Colliding Winds



Microquasar



PSR B1259-63

Cygnus X-3

LS 5039
LS I +61°303
HESS J0632+057
1FGL 1018.6-5856