Multiwavelength properties of gamma-ray loud binaries

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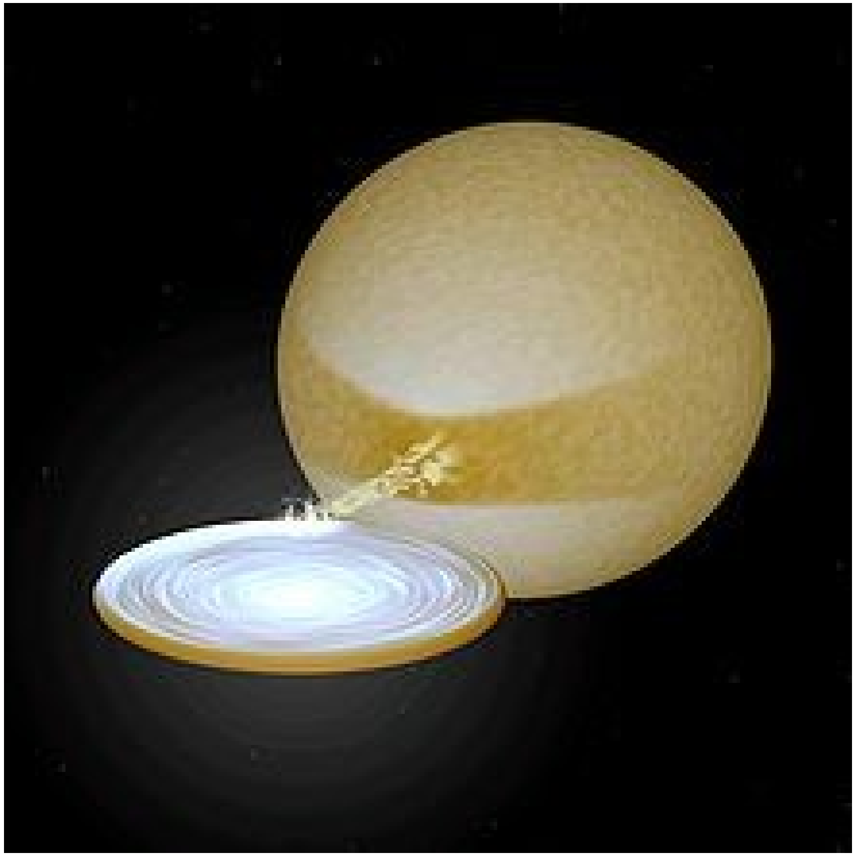
DCU

X-ray Binaries in the Milky Way

- ~180 known low-mass X-ray binaries (LMXB)
  - Contain an evolved star transferring mass onto a white dwarf, neutron star, or black hole
- 114 high mass X-ray binaries (HMXB)
  - Mass donor star is an O- or B-type star
  - 60% of HMXBs contain Be stars
- 20 black hole systems



High Energy Emission from XRBs

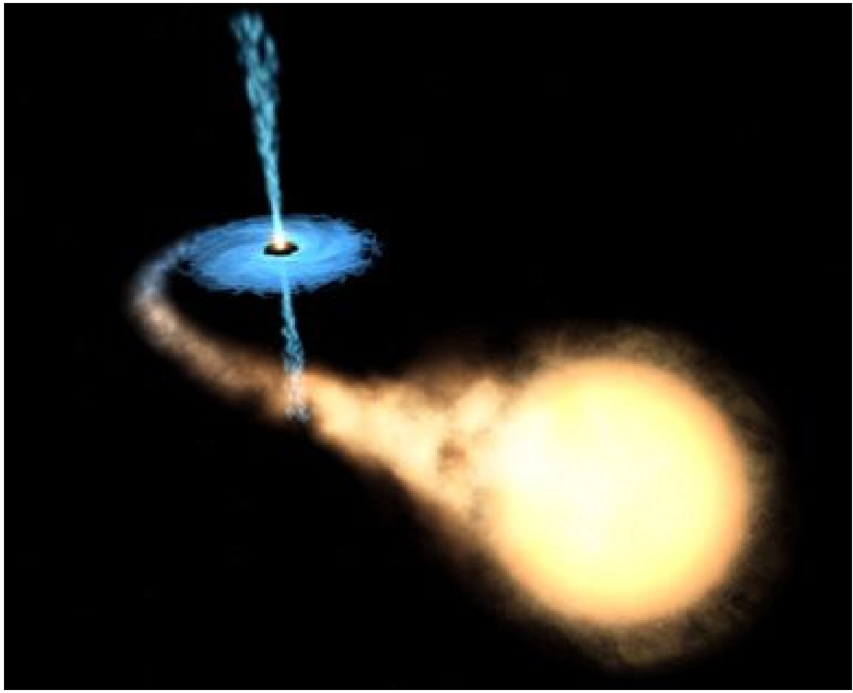
X-rays generally produced from the gravitational potential energy of accreting matter

$$L_X \sim \frac{G M_X M_Y}{R_X}$$

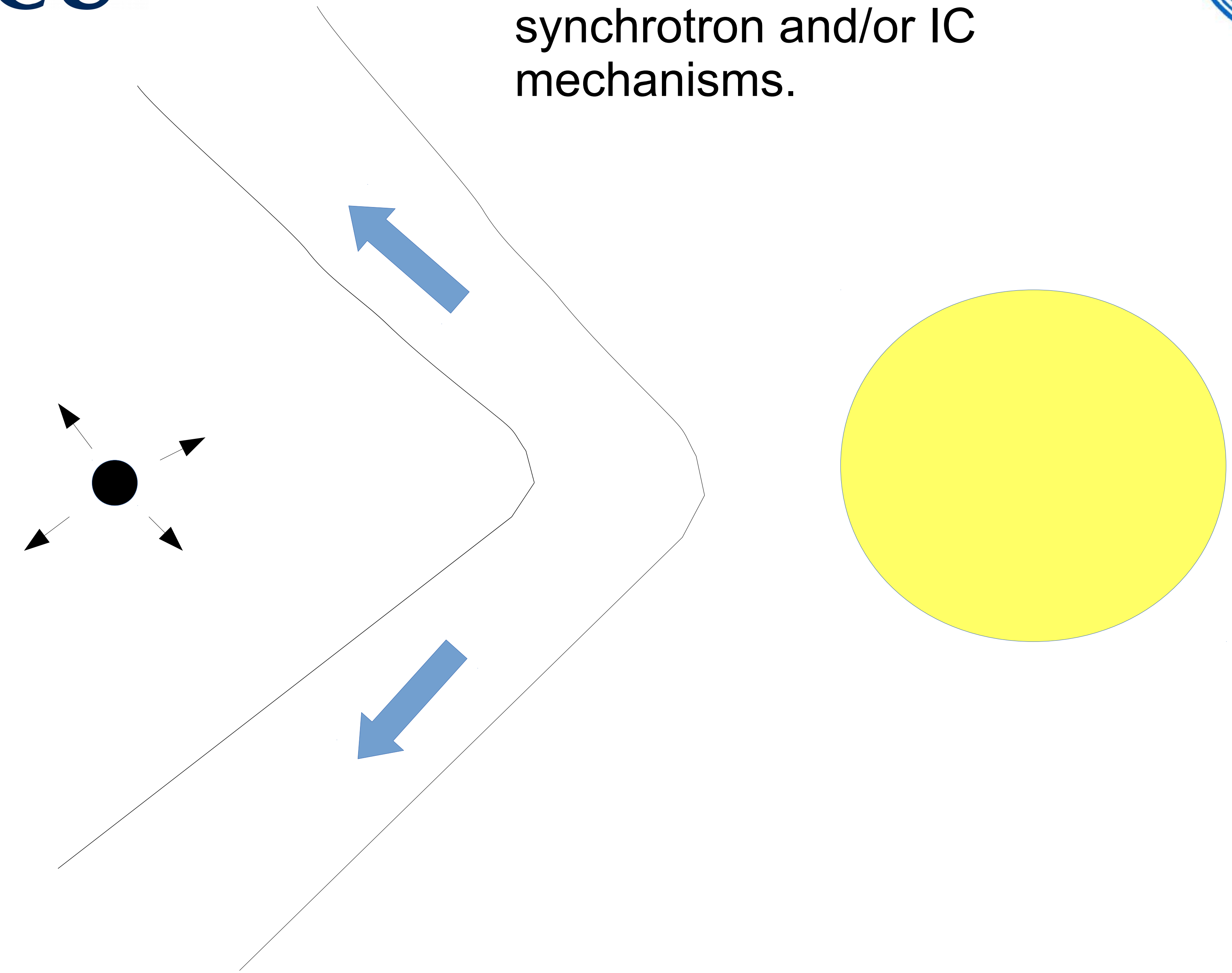
HMXBs with stellar wind accretion have $L_X \sim 10^{35}$ - 10^{36} erg/s

Roche-lobe overflow systems have ~ 10^{38} erg/s

Some accreting matter may be directed into bipolar jets (microquasars).



X-rays and gamma-rays from synchrotron and/or IC mechanisms.



Known γ-ray loud binary systems.

Only 5 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) √
1 FGL J1018.6-5856 (comp. source+06V(f), P=16.6 d)

New candidates:

HESS J1832-093 – new TeV source proposed to be a binary system
LMC P3 (comp. source+O5III star, P=10.3 days)

PSR J2032+4127 (young pulsar +Be star, P=~50 y?) √

Multi-wavelength observations are crucial to understand these peculiar systems.

GeV domain

Fermi and AGILE observations reveal more binaries active in GeV domain, e.g.

Cyg X-3 (comp. source +WR star, P=4.79 h)

Cyg X-1 (black hole +blue supergiant, P=5.6 days)

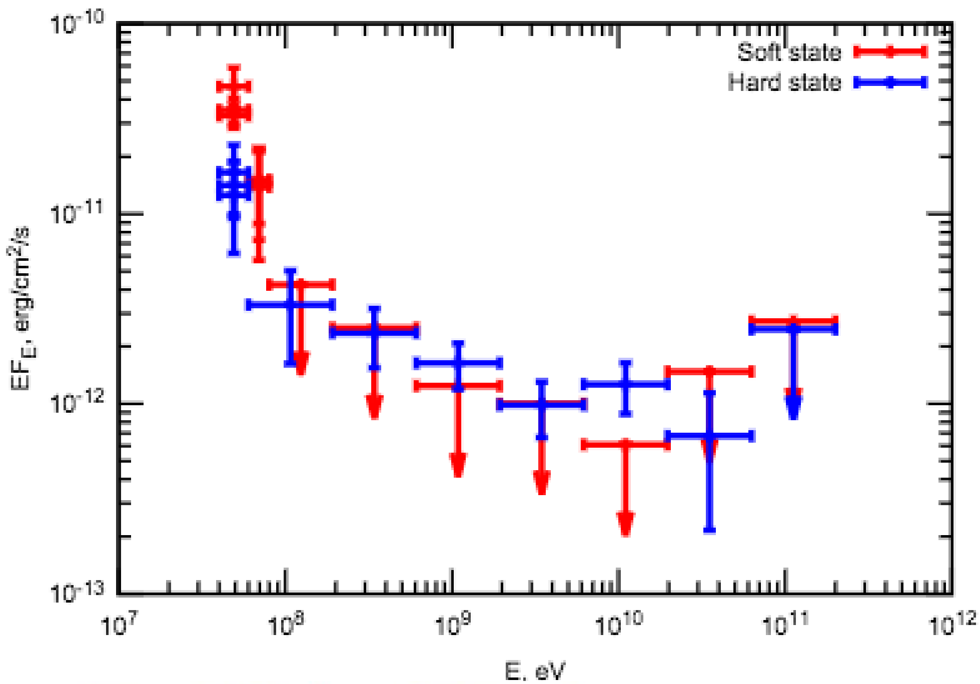
1FGL J1018.6-5856 (comp. Source + O star, P=16.6 d)

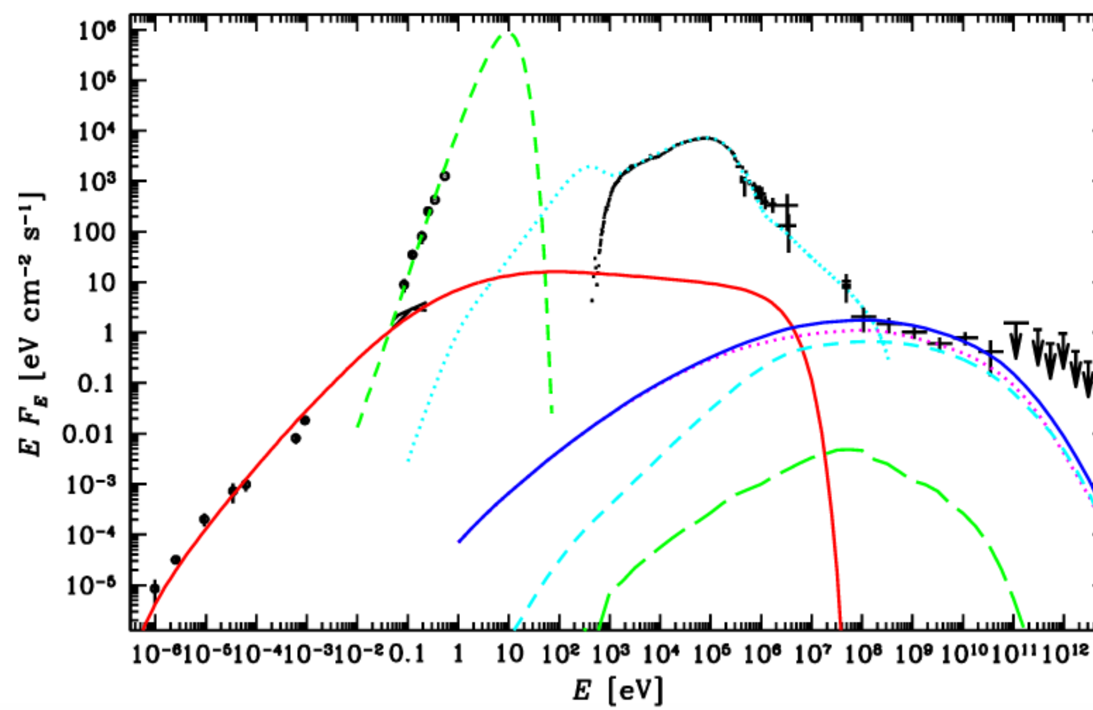
V407 Cyg (red giant +WD, P=43years (?))

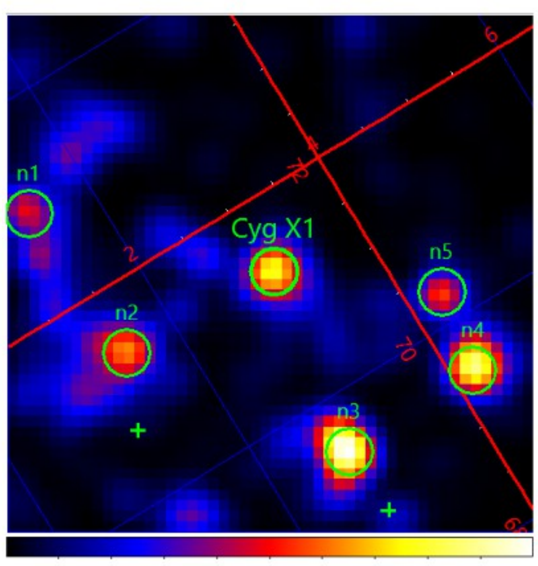
η Car (luminous blue variable star +O star, P=5.53 year)

Cyg X-1

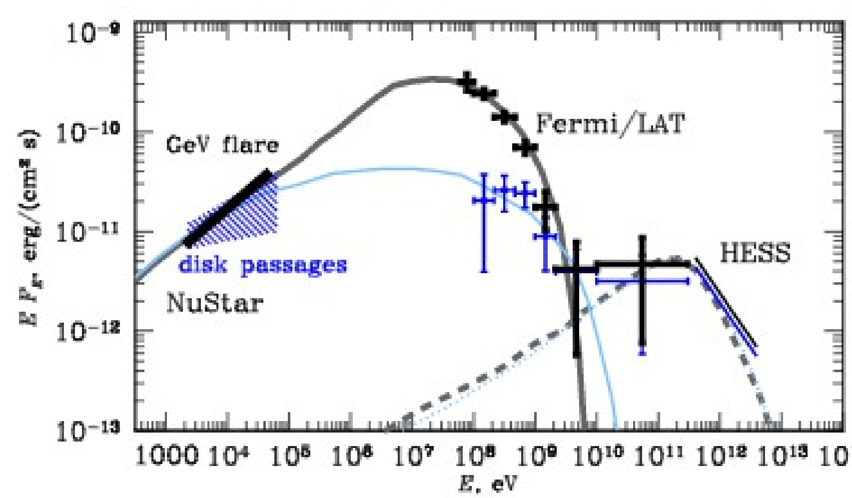
Zdziarski et al. 2017







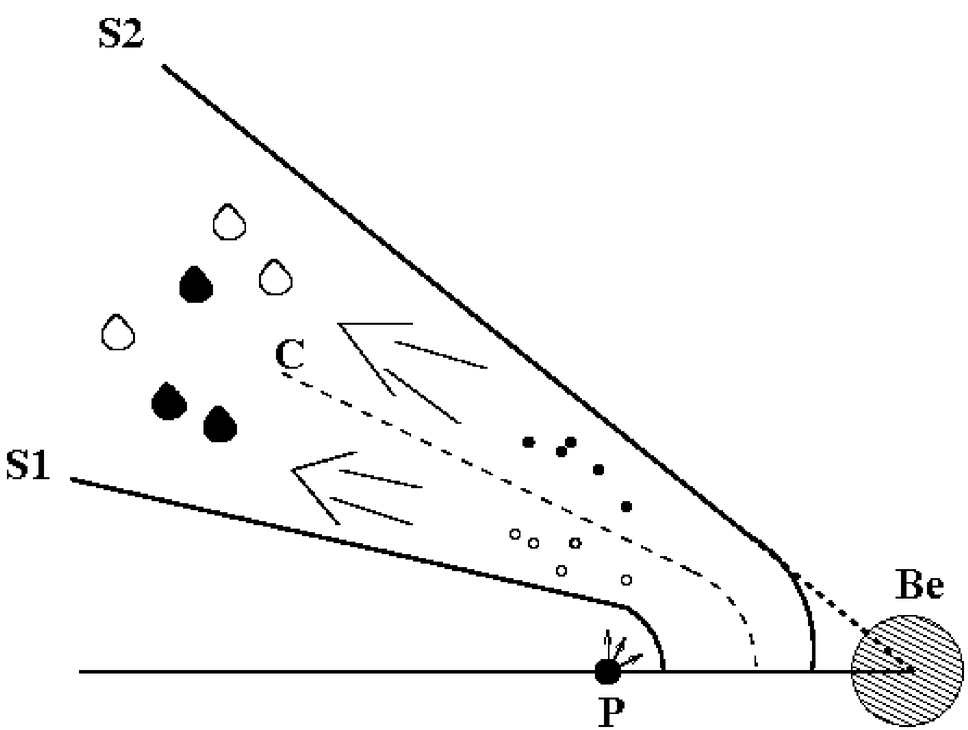
PSR B1259-63



Chernyakova et al. 2015

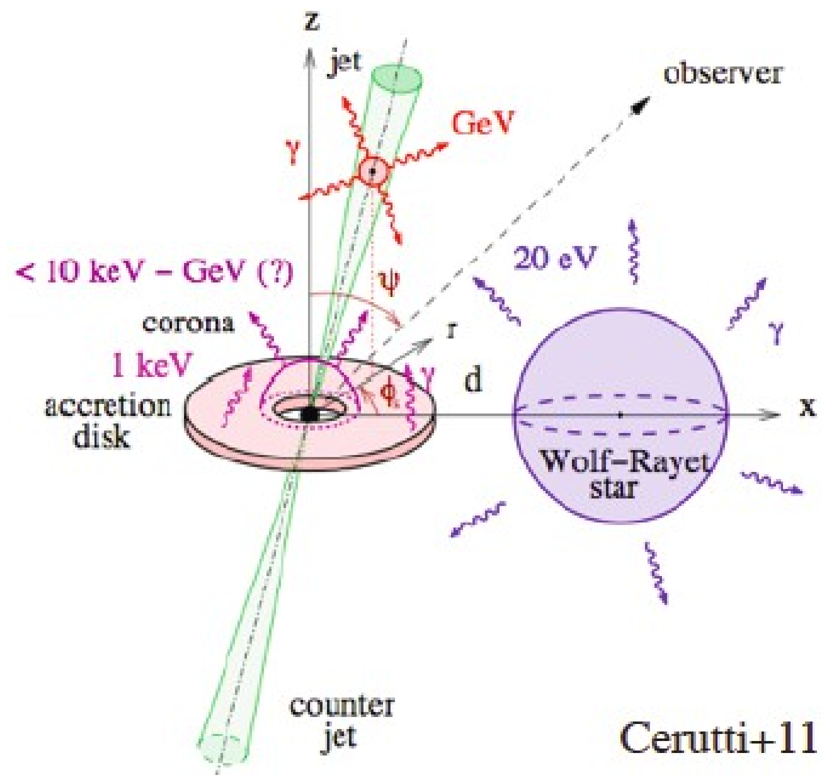
Two Theories for γ-ray Production

Colliding Winds



PSR B1259-63

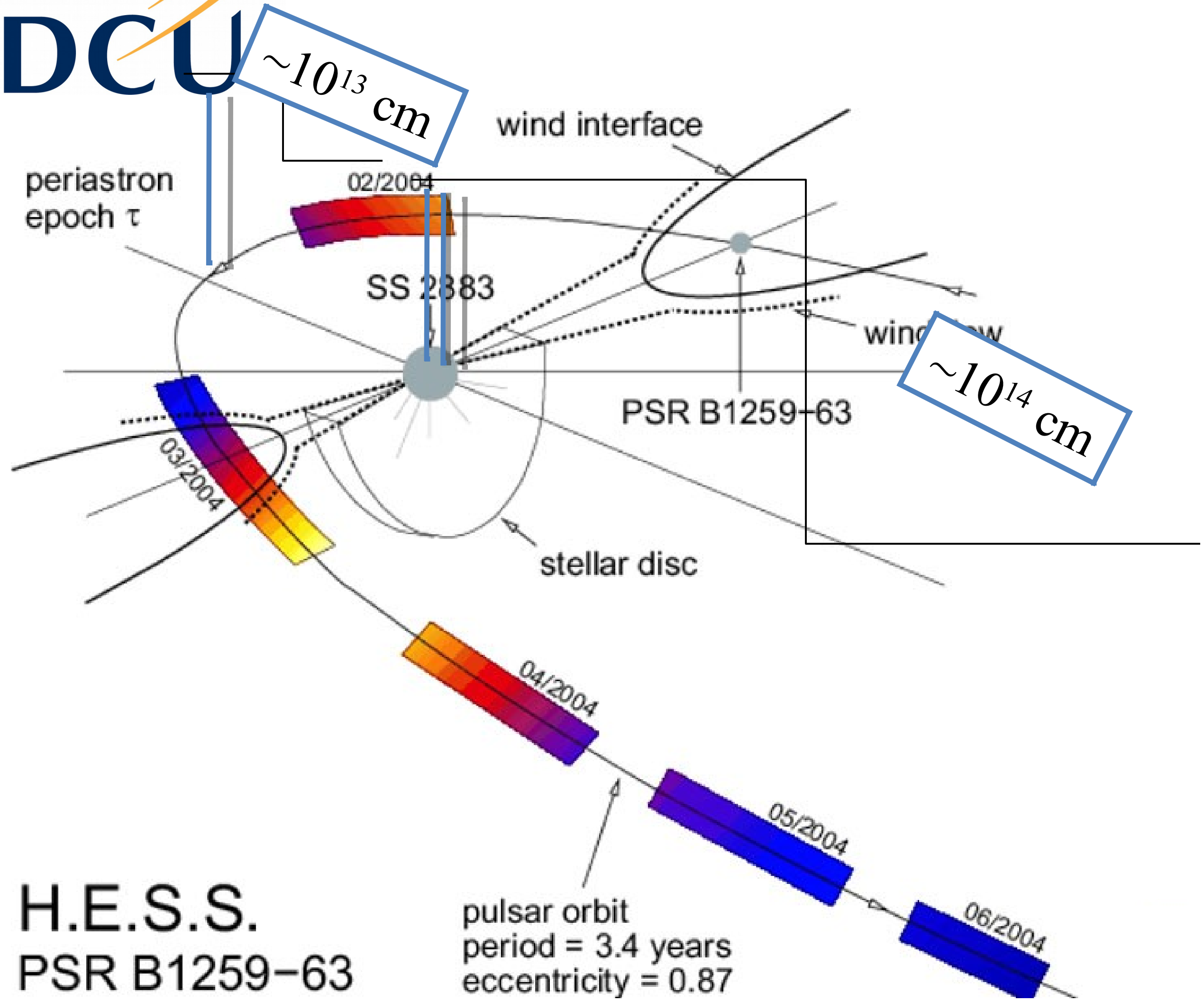
Microquasar



Cygnus X-3

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

PSR B1259-63: overview



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

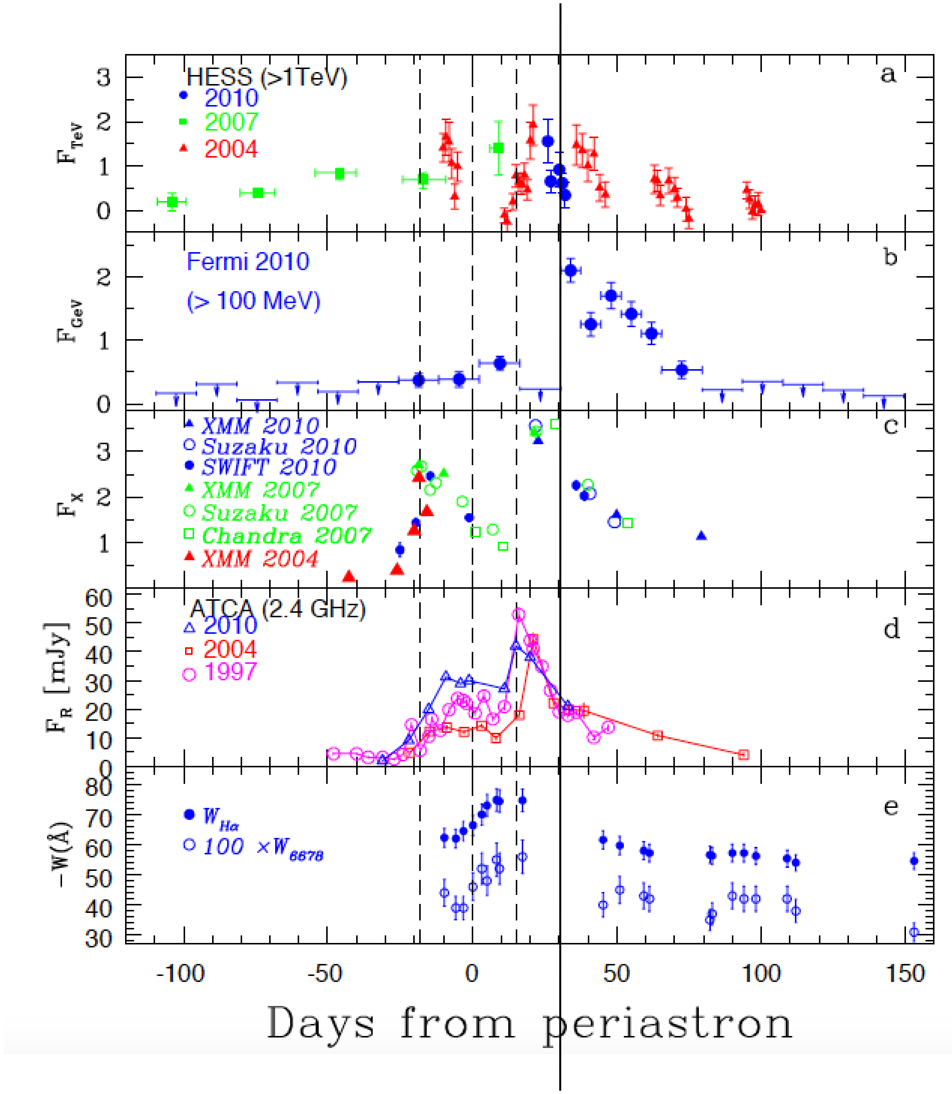
Distance 2.3 ± 0.4 kpc

SS 2883 parameters

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

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

PSR B1259-63: lightcurves 2010



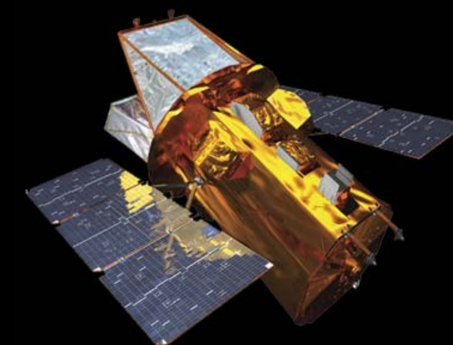
- Two peaks at X-ray and radio
- Peaks ~20 days around the periastron.
- Corresponds to the passage through the Be star disk.
- Unexpected flare at GeV emission ~30 day after the periastron. ~80% of spin-down luminosity is released.
- No obvious counterpart at other energies.
- Optics?

Chernyakova et al. 2014

2014 Multi-wavelength Campaign

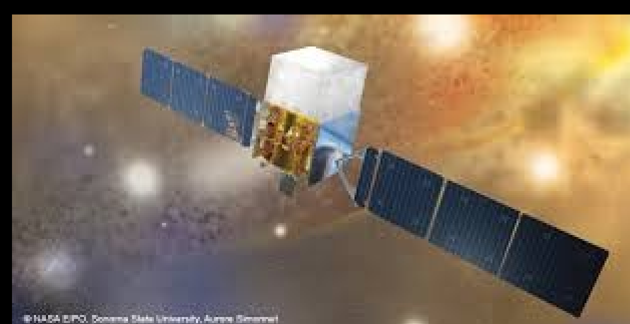
1.9 m telescope at SAAO: optical spectroscopy

SWIFT: X-ray monitoring



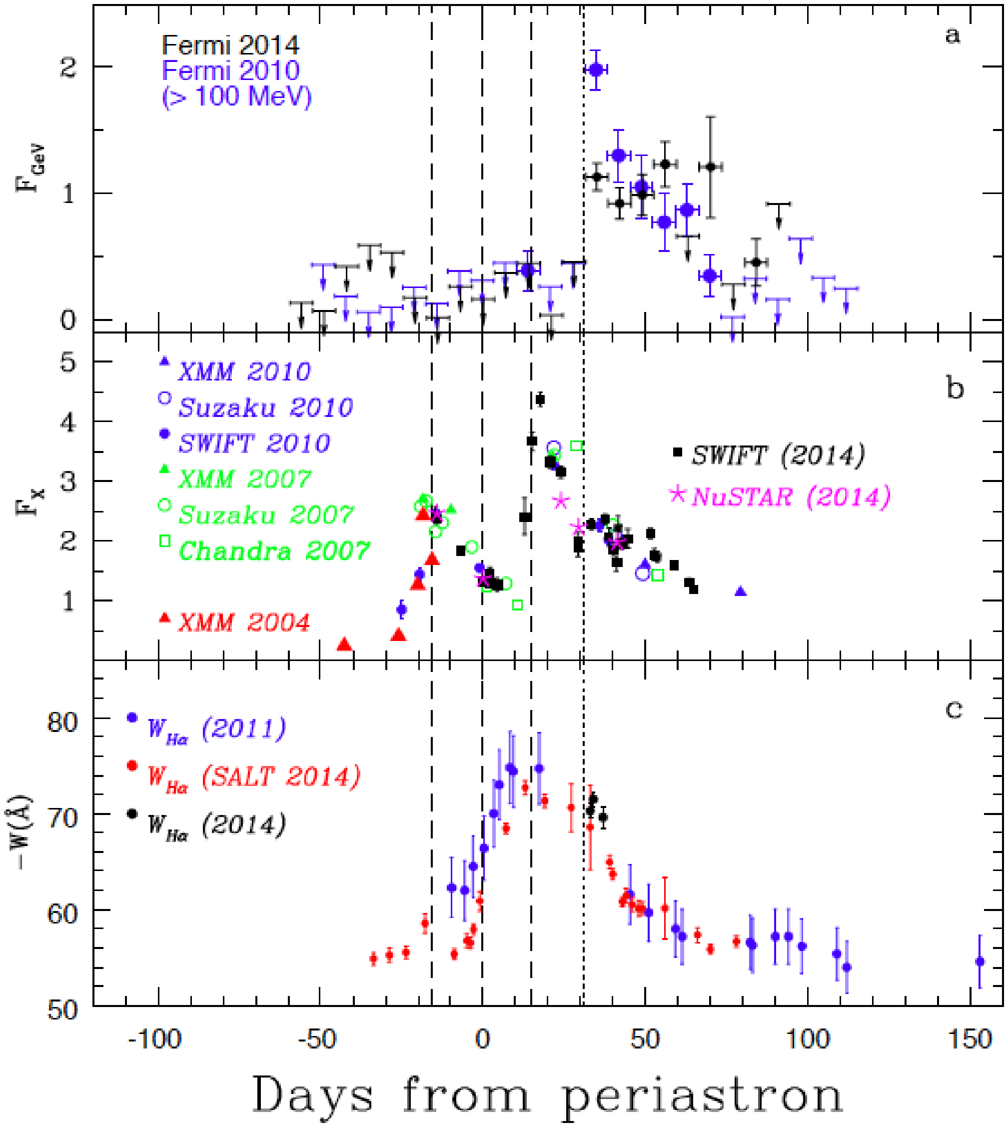
NuSTAR: 4 observations

Fermi: GeV monitoring



HESS: TeV monitoring

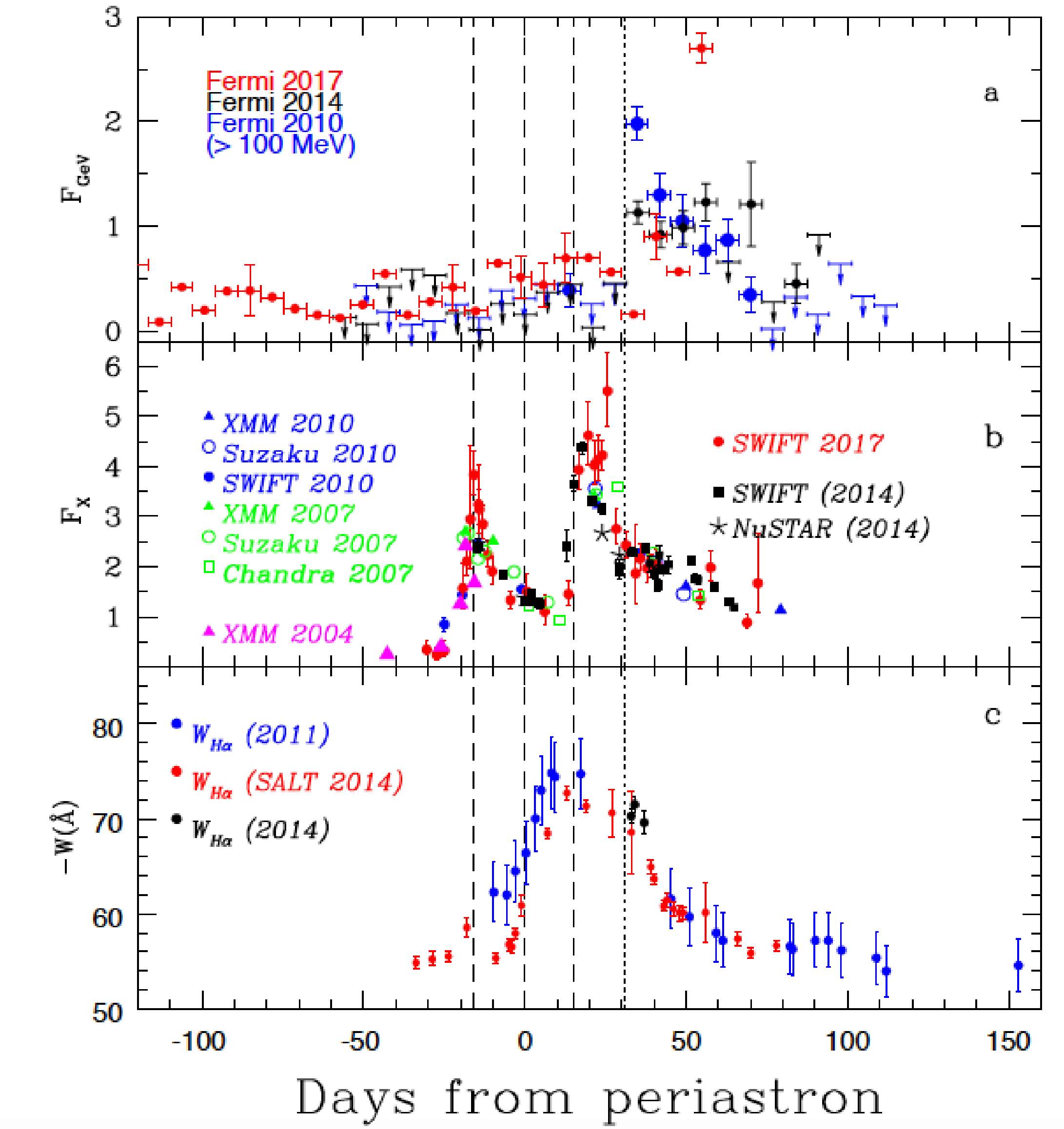
PSR B1259-63: light curves 2014



- Similar flare at GeV
- Clear relation between GeV flare and disruption of the disk
- Change of the X-ray decay during the flare

Chernyakova et al. 2015

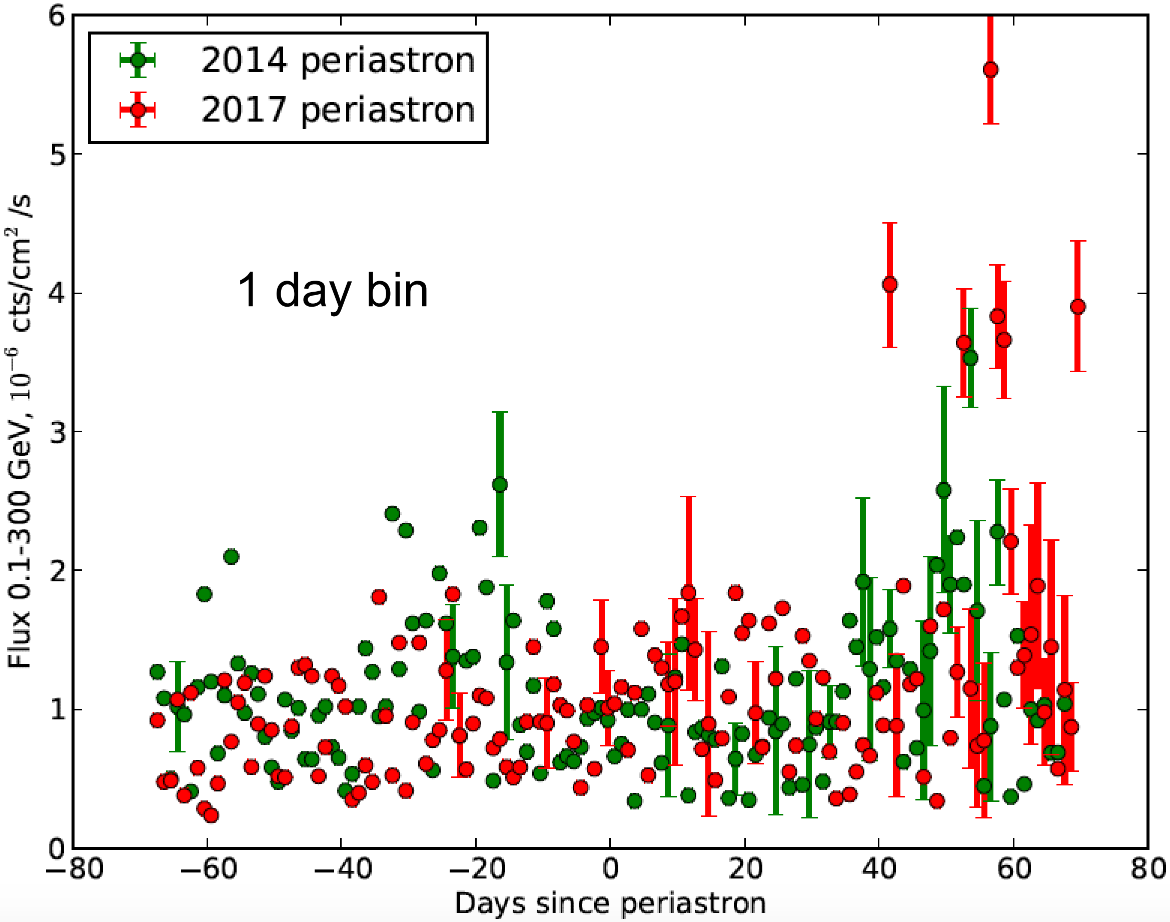
PSR B1259-63: light curves 2017



- Delay of GeV flare
- Very different structure of the GeV flare

Preliminary results!

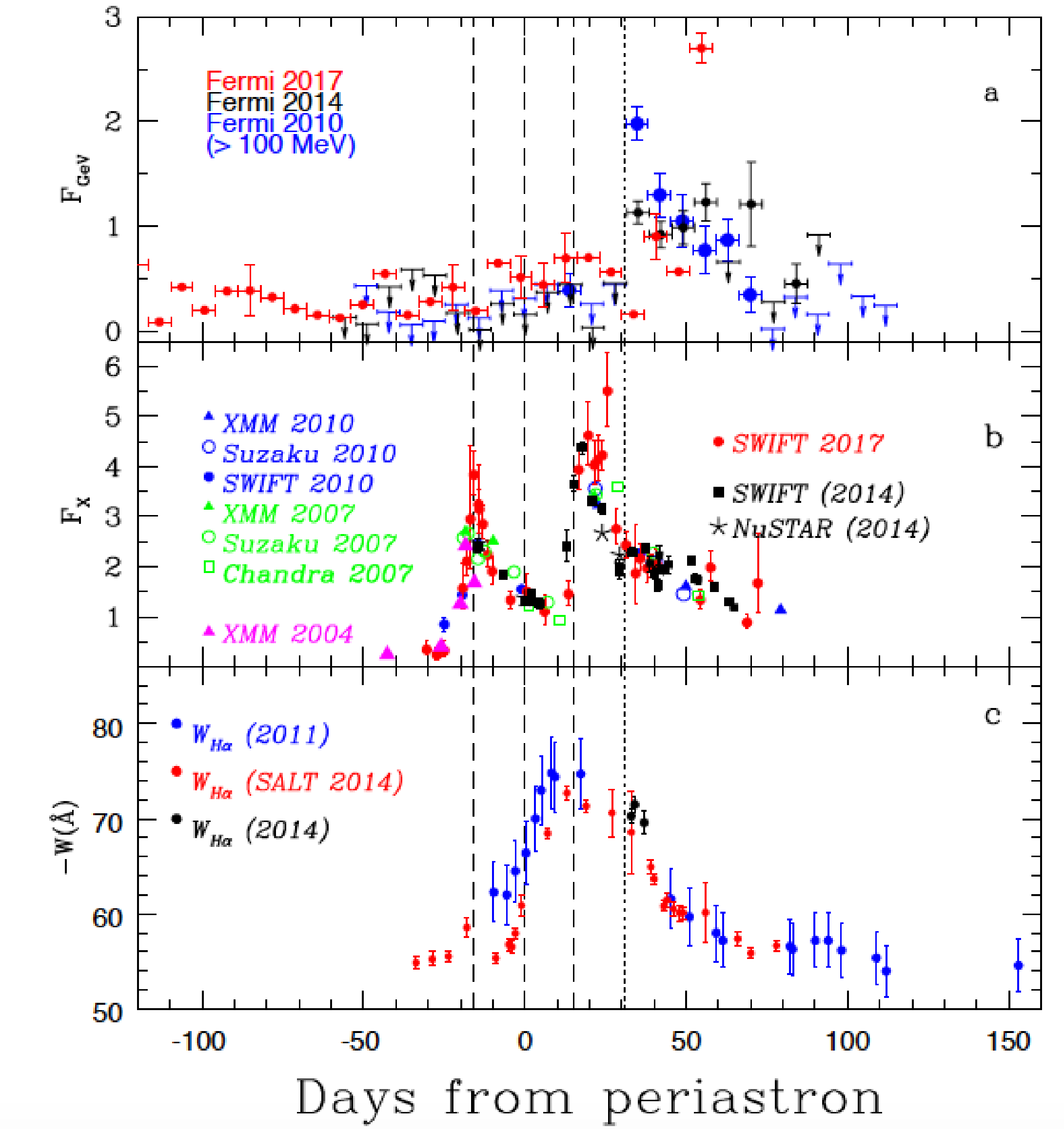
PSR B1259-63: light curves 2017



- Delay of GeV flare
- Very different structure of the GeV flare
- The isotropic gamma-ray luminosity corresponding to the highest day-average flux is almost exceeding the pulsar spin-down luminosity.

Preliminary results!

PSR B1259-63: light curves 2017

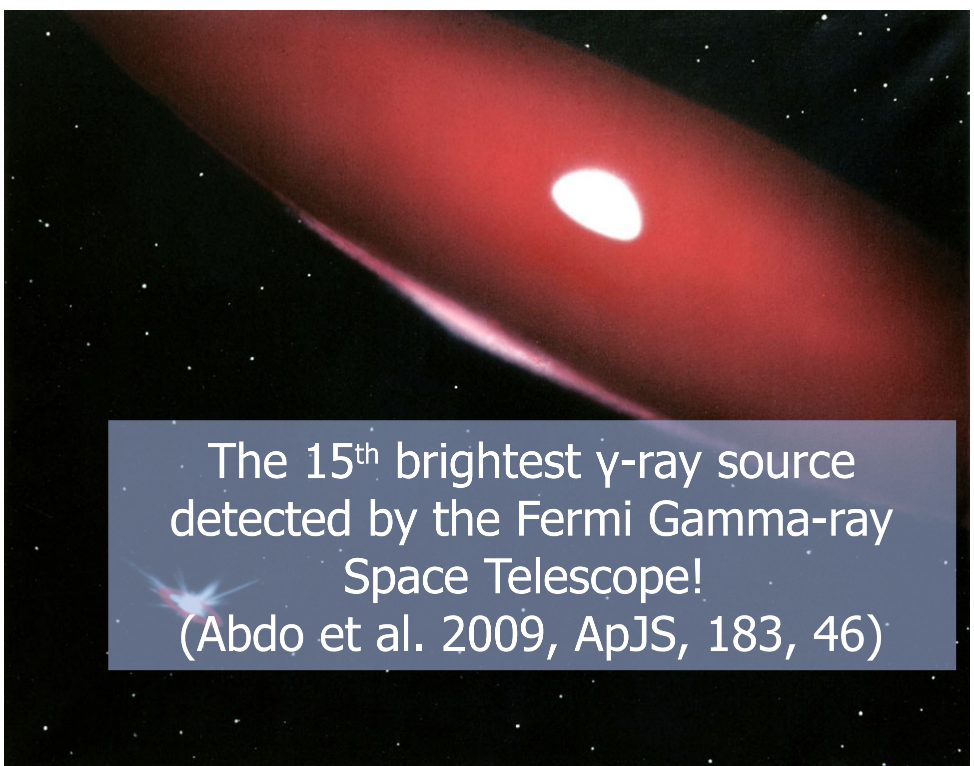


Preliminary results!

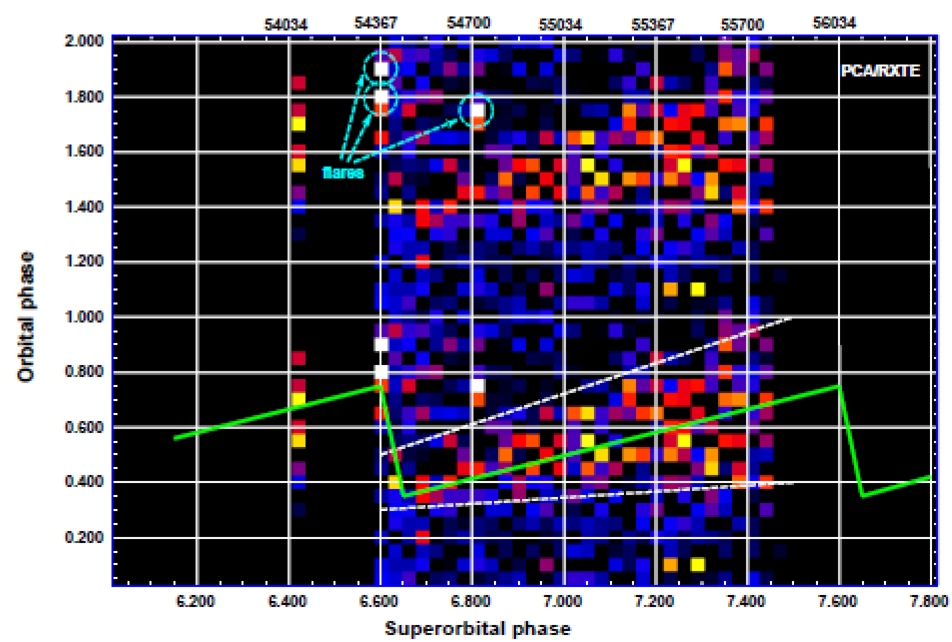
- Delay of GeV flare
- Very different structure of the GeV flare
- Clear structure of the second X-ray peak
- Clear relation between GeV flare and change of the X-ray decay –- *not that clear this time…*
- Optical data are available only before periastron: good agreement with previous years (Van Soelen, private communications)

LSI +61 303

- Rapidly rotating “Be” star surrounded by a dense, circumstellar disk and an unknown compact companion
- Emission is modulated throughout the 26.5-day orbit.
- The orbital phases of X-ray and radio flux maxima “drift” with superorbital period P=4.6 year.

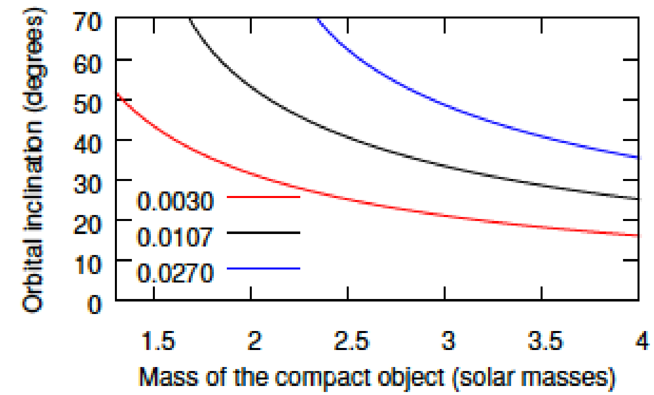


The 15th brightest γ-ray source detected by the Fermi Gamma-ray Space Telescope!
(Abdo et al. 2009, ApJS, 183, 46)

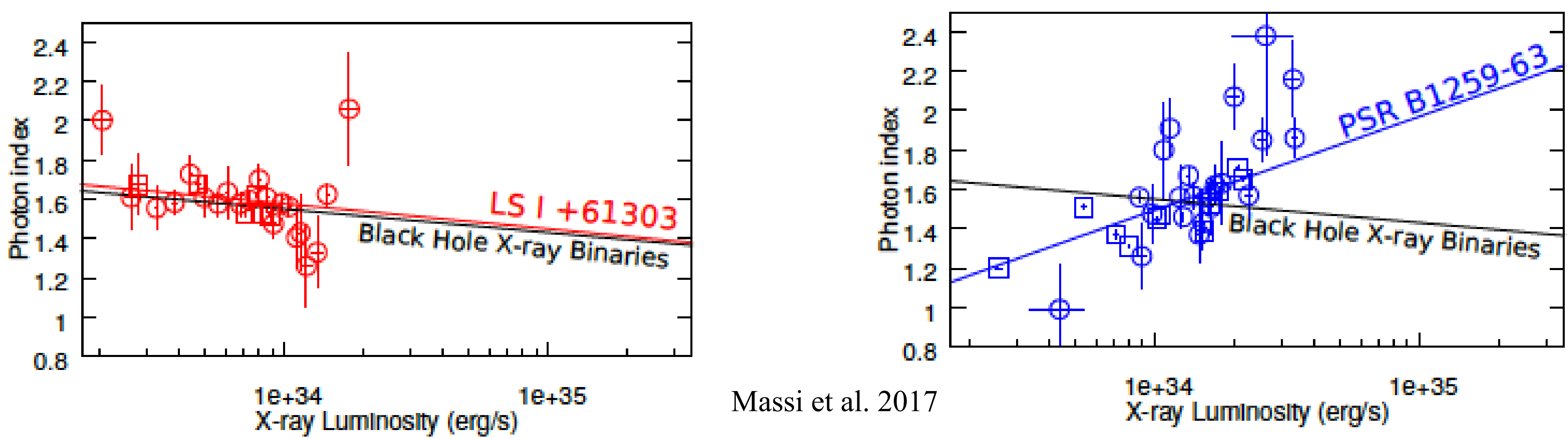


LSI +61 303: nature of the compact source

Uncertainty in the mass function and orbital inclination doesn't allow to determine the mass of the compact source.



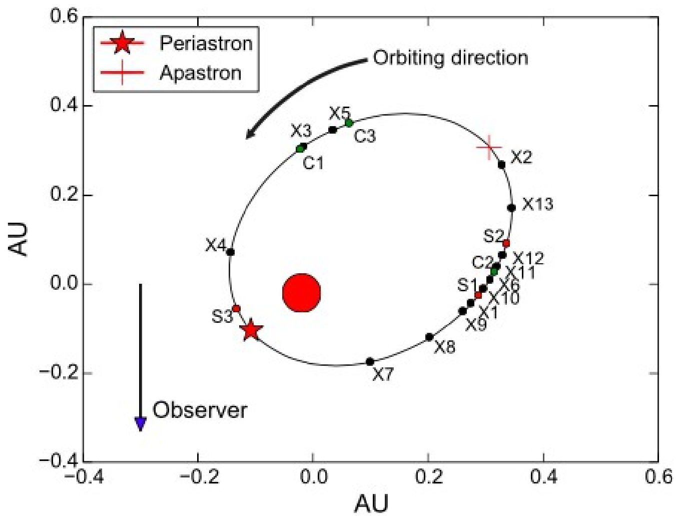
Statistical study of black hole X-ray binaries (Yang et al. 2015) shows that there is an anti-correlation between photon index Γ and the 2-10 keV luminosity, L_X



Massi et al. 2017

LS I 61º 303

Emission from LSI +61° 303 is modulated on timescales of ~ 26.5 d and ~ 1667 d in the radio (Gregory 2002), optical (Paredes-Fortuny et al. 2015), X-ray (Chernyakova et al. 2012, Li, Torres & Zhang 2014) and VHE (Jaron & Massi 2014) domains. The superorbital variability could be either due to the cyclic change of the Be star disk size (e.g. Chernyakova et al. 2012, Paredes-Fortuny et al. 2015), or precession of a jet associated with the compact object (Massi & Torricelli-Ciamponi 2014).



+ 164 SWIFT observations between 2010 and 2014.

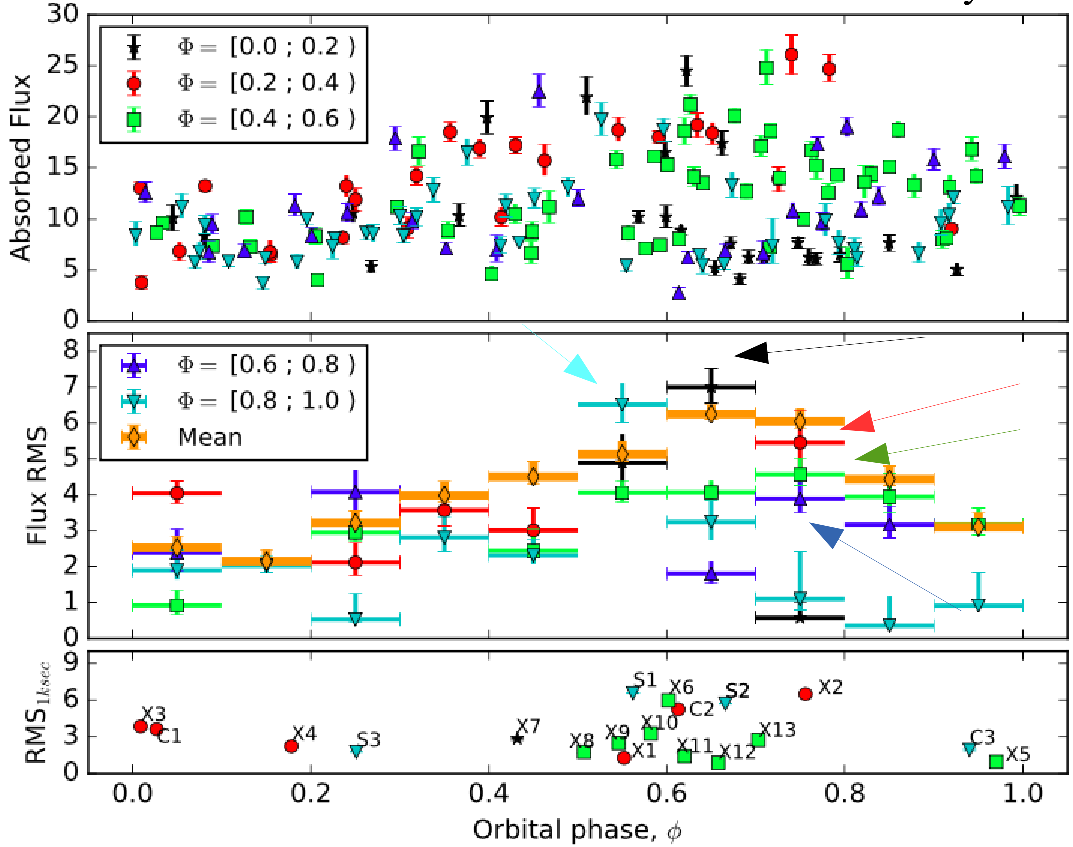
If the superorbital variability in the system is linked with the disk build-up process one can expect the gradual increase of the absorption, as the compact object moves on its orbit. We have systematically reviewed all publicly available data from Suzaku, XMM-Newton, Chandra and Swift observatories in order to

- measure the absorption profile of the circumstellar Be disk as a function of orbital and superorbital phases
- study short-term variability of the system as a function of orbital and superorbital phases
- test the stability of the superorbital period.

LS I 61º 303

T_{min} ~100 − 1000 s. Short time scale variability is more evident at the edge of the disk rather than in the center

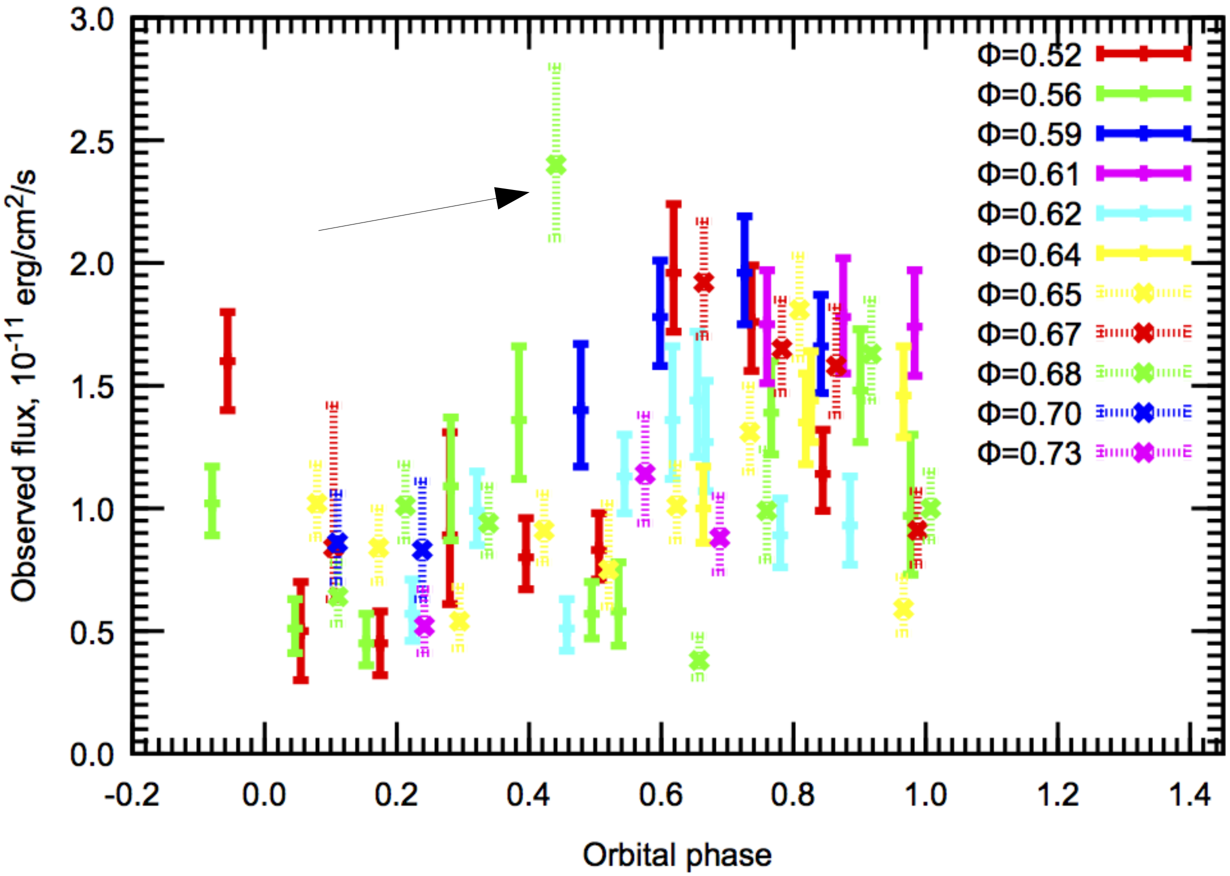
Chernyakova et al. 2017



Shift of the max RMS $\varphi = 0.55$ [$\Phi = 0.8$–1] → $\varphi = 0.65$ [$\Phi = 0.0$–0.2] → $\varphi = 0.75$ [$\Phi = 0.2$–0.4] due to a gradual increase of the disk size at superorbital time scales. No shift if the compact object spend the whole orbit inside the dense regions of the near-to-maximum size disk [Φ=0.4 – 0.8] .

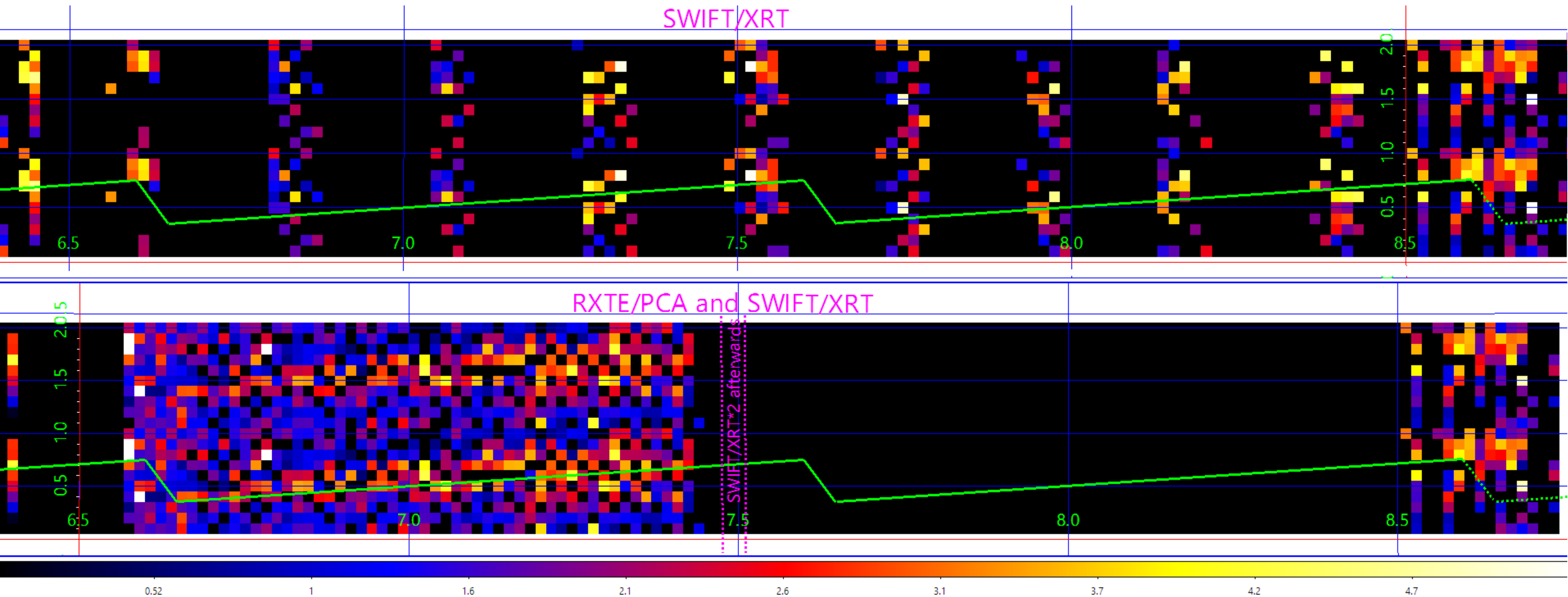
Averaged over superorbital phase RMS also indicates that close to periastron the compact object is embedded into the smooth dense region of the Be star disk (most stable with respect to superorbital changes), while closer to the apastron the compact object moves in clumpy outskirts of the disk.

LS I 61° 303



Observed flux, 10^{-11} erg/cm^2/s
Orbital phase
Φ=0.52
Φ=0.56
Φ=0.59
Φ=0.61
Φ=0.62
Φ=0.64
Φ=0.65
Φ=0.67
Φ=0.68
Φ=0.70
Φ=0.73
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

LS I 61º 303



New observations disagree with $P_{so} = 1667 \pm 8$ days orbital period of Gregory 2002.

New analyses of a longer radio data set by Massi et al. 2016 give different value with larger errors $P_{so} = 1628 \pm 48$, FERMI data analyses gives $P_{so} = 1610 \pm 58$ (Ahnen et al. 2016)

Evidence of variability of this period?

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 the compact object passing through the dense regions of the companion wind.

Perfect laboratory to study the details of particle acceleration and interaction of the relativistic outflow with the stellar wind and ISM.

Work in progress. More data are needed to clarify open questions.