# Gamma-ray binaries as a testbed for massive star outflows

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**–----------- Evolution and Explosion of Massive Stars –-----------**

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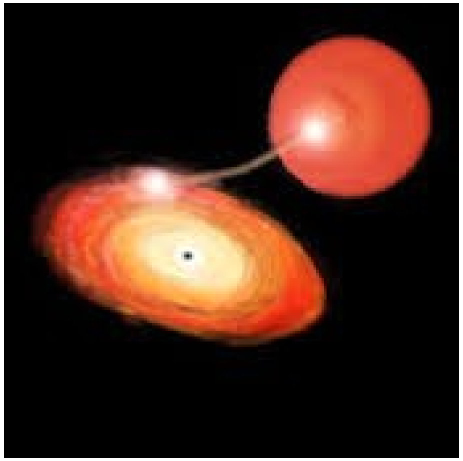
# X-ray Binaries

Galactic X-ray sky is dominated by the emission from bright X-ray binaries.

- ~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 known



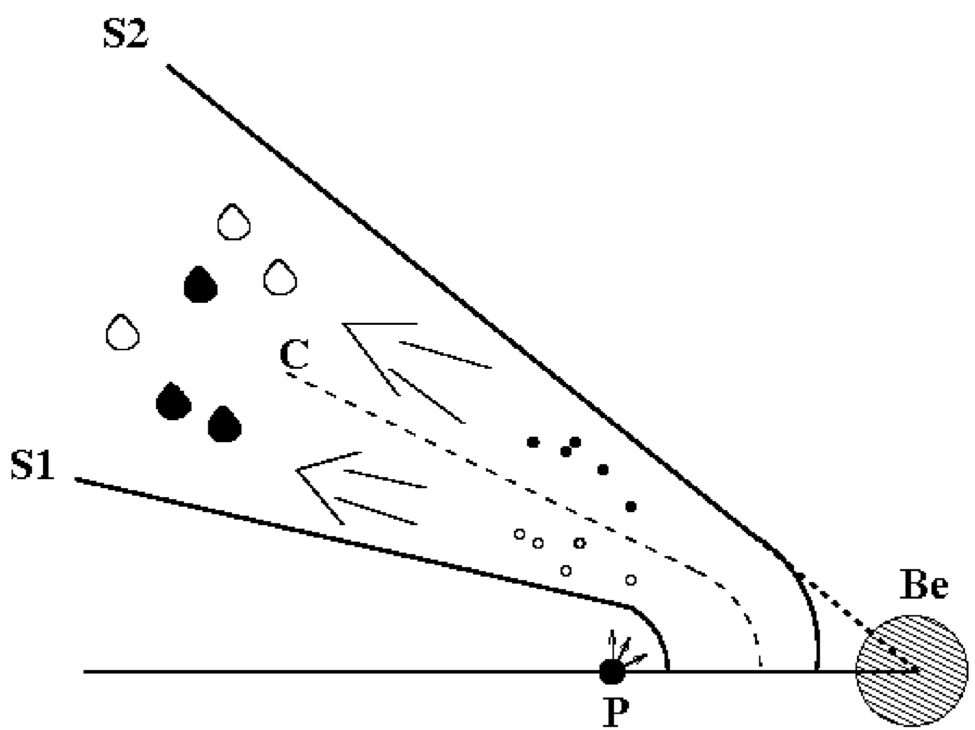
Material is accreted from the normal star onto the compact object.This releases large amounts of gravitational energy and result in the production of X-rays.

# γ-ray Binaries

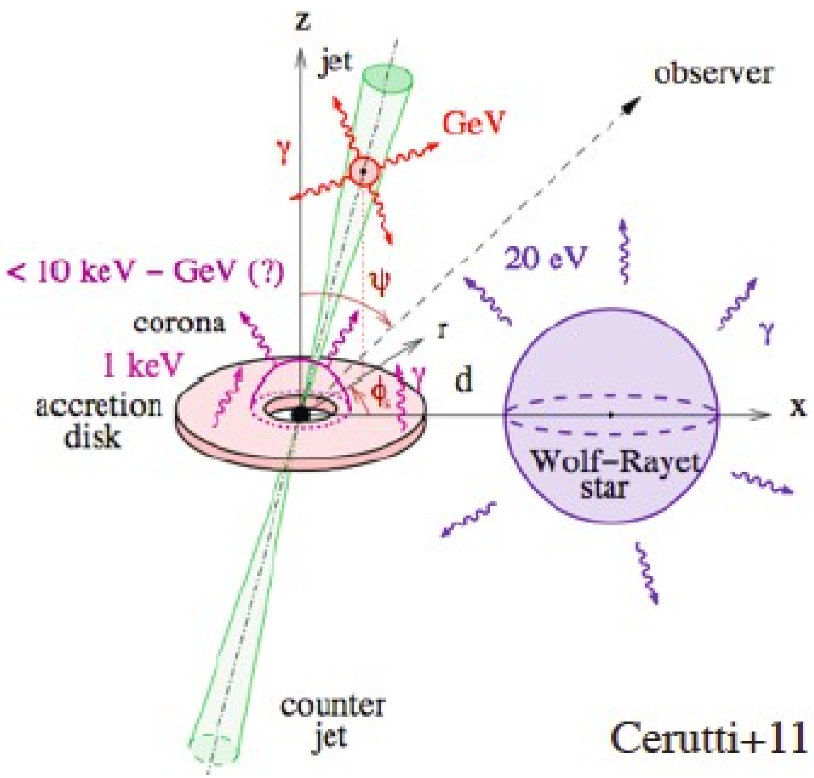
- HMXBs that also exhibit very high energy emission (MeV-TeV) are called "γ-ray binaries"
- Only 7 are regularly observed at TeV:
  - PSR B1259-63 (B2e + pulsar, P=3.4 years)
  - LS I +61 303 (B0 Ve + ?, P=26.5 days)
  - LS 5039 (ON6.5 V + ?, P=3.9 days)
  - HESS J0632+57 (B0pe + ?, P=321 days)
  - 1 FGL J1018.6-5856 (06V(f) + ?, P=16.6 days )
  - LMC P3 (O5III star +?, P=10.3 days)
  - HESS J1832-093 – new TeV source proposed to be a binary system (P. Eger et al, 2016)
- More in GeV, but still few...
  - Cygnus X-1 (O9.7 Iab + black hole)
  - Cygnus X-3 (WR + ?)
  - η Car (luminous blue variable star +O star, P=5.53 year)
  - V407 Cyg(symbiotic star, P=43years (?) )
  - Binary systems with millisecond pulsars

# Two Theories for γ-ray Production

Colliding Winds




Microquasar




## PSR B1259-63

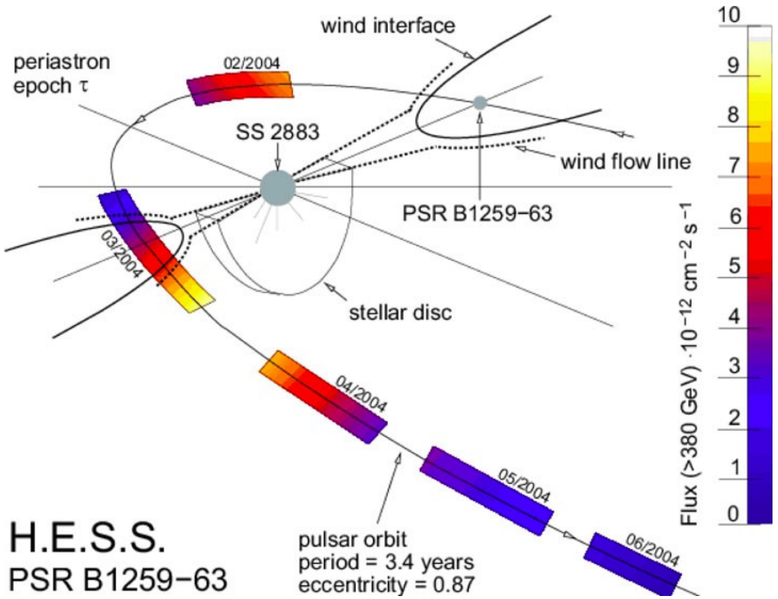
- Powered by pulsar spin down luminosity.
- Involves interaction with companion

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

## Cygnus X-3

- Accretion onto black hole (or neutron star).
- Broad band emission from jet and accretion disk.

# PSR B1259-63




## Orbital parameters

$e=0.87$

$P_{orb}=1236.8$ days

$a=10^{13}$ cm

D ~ 2kpc

## Pulsar parameters

P=47.762 ms

dP/dt=2.28E-15

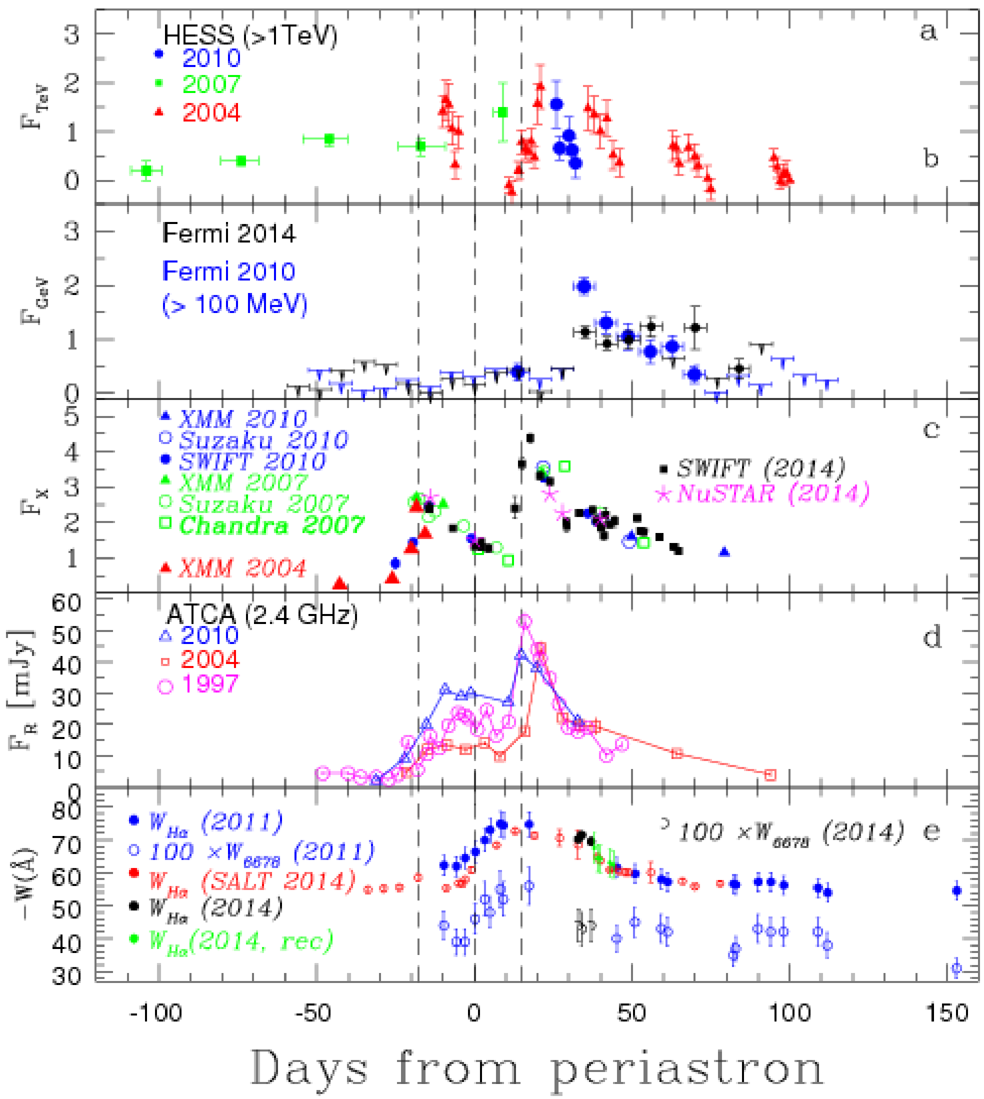
$L_p$=9E+35erg/s

## SS 2883 parameters

$L_*$=2.2E+38 erg/s

$M \sim 10 M_{sun}$ T~27000 K

# PSR B1259-63

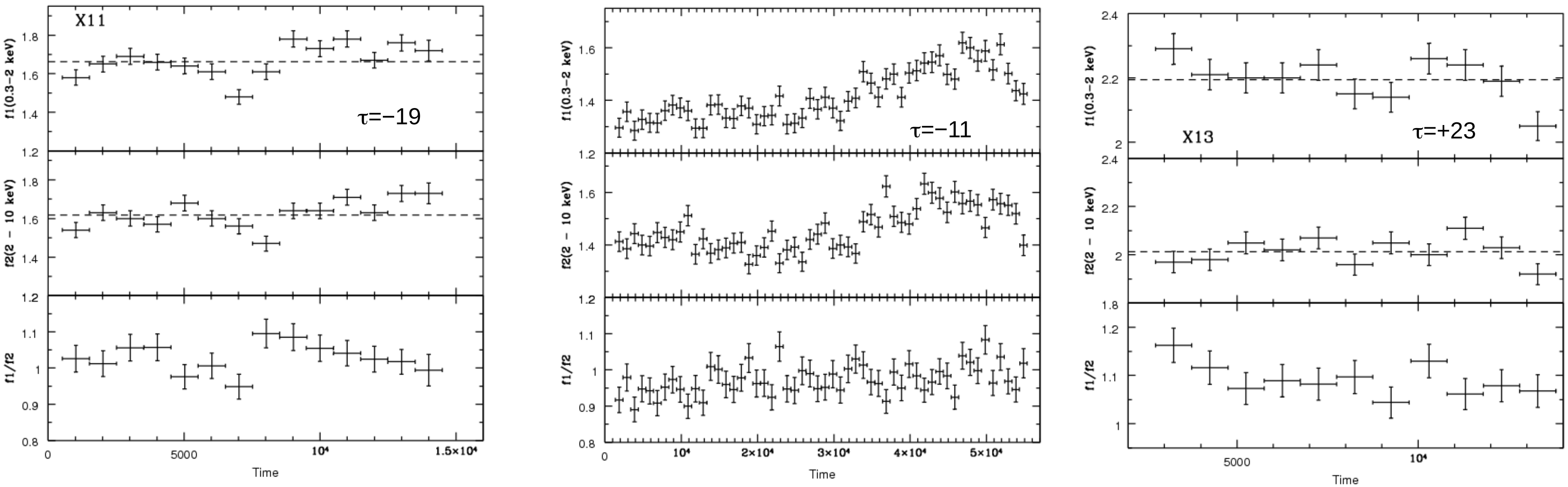



M. Chernyakova et al., 2015

- Double-peaked light-curve in X-rays and radio due to the passage through the disk.
- Huge GeV flare (>50% of spin-down luminosity is released) 30 days after the periastron.
- Increase of the H$\alpha$ equivalent width around periastron due to the tidal interactions with the pulsar.
- Disruption of the disk at the time of GeV flare.

# PSR B1259-63

M. Chernyakova et al., 2009

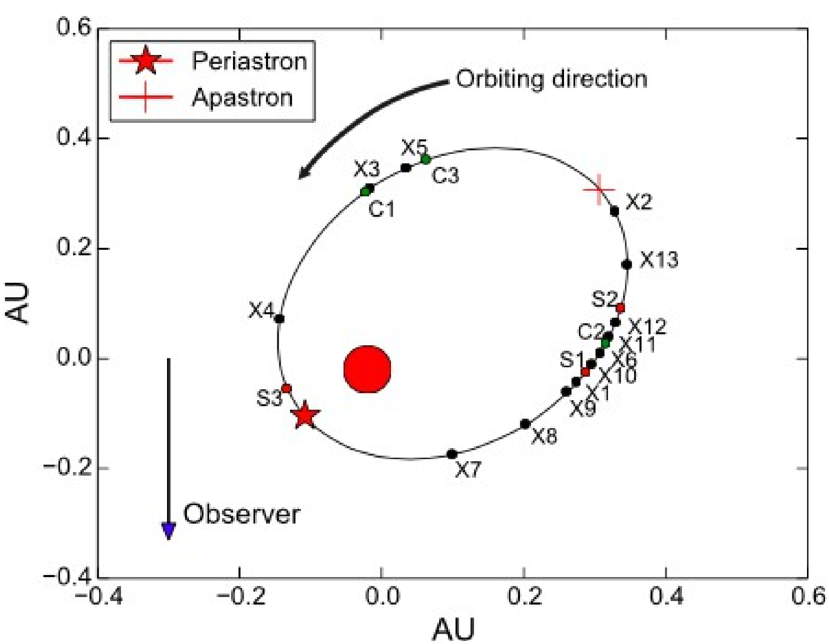


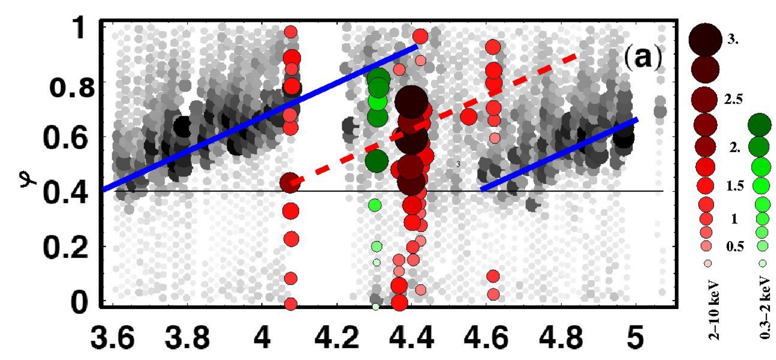

Moderate variability at a level of 6 $\sigma$ is seen on an hour time scale near the disk entrance (x11).
Evidence of more clumpier structure at the edge?

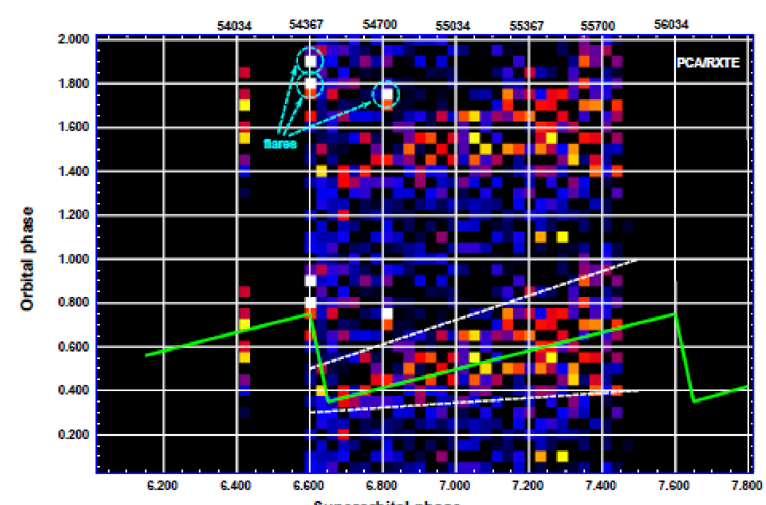
# LSI +61 303

- Emission is modulated throughout the 26.5-day orbit.
- In radio, X-ray and GeV the source is known to exhibit one flare per orbit.
- The orbital phase of the periodic flares drifts with P=4.6 year.
- Possible explanation of the 4.6 yr time scale is the build up and decay of the equatorial disk around the Be star (Zamanov et al. 1999).

Gregory 2002



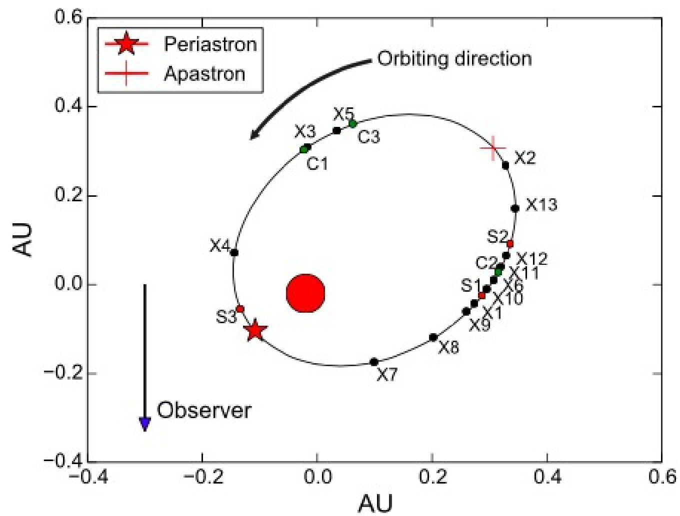




Chernyakova et al. 2012

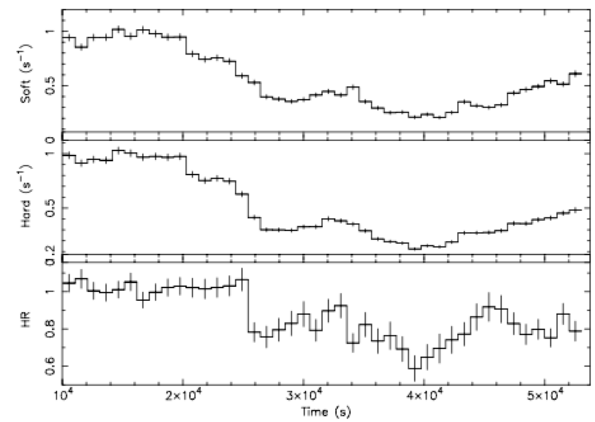
# LS I 61 303

Short (~1000s) time scale variability is more evident at the edge of the disk rather than in the center.



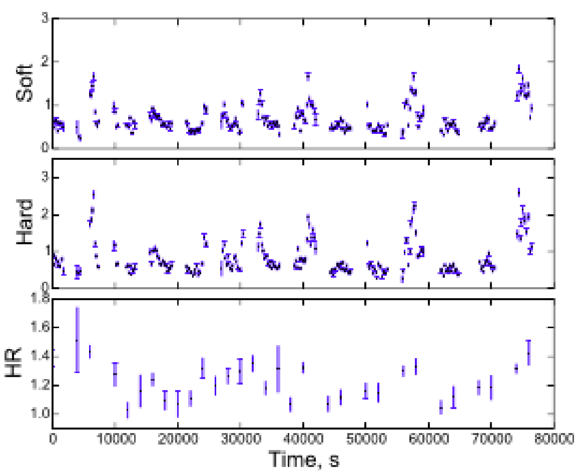

Sidoli et al. 2006

X6

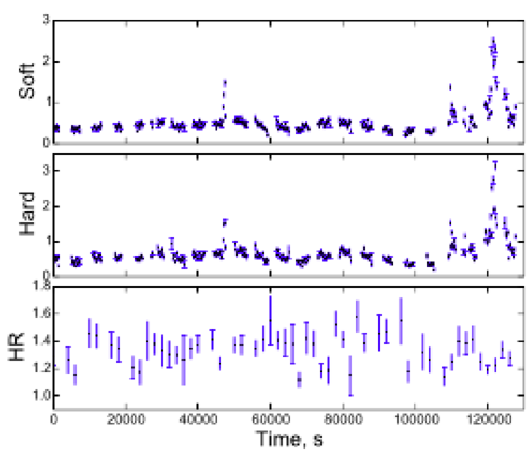



Chernyakova et al. 2017

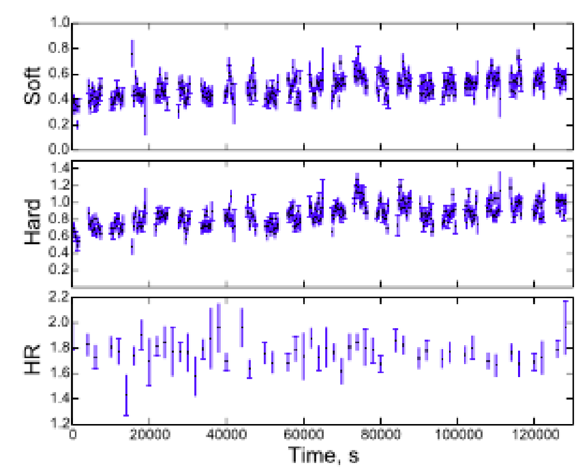
S1




S2

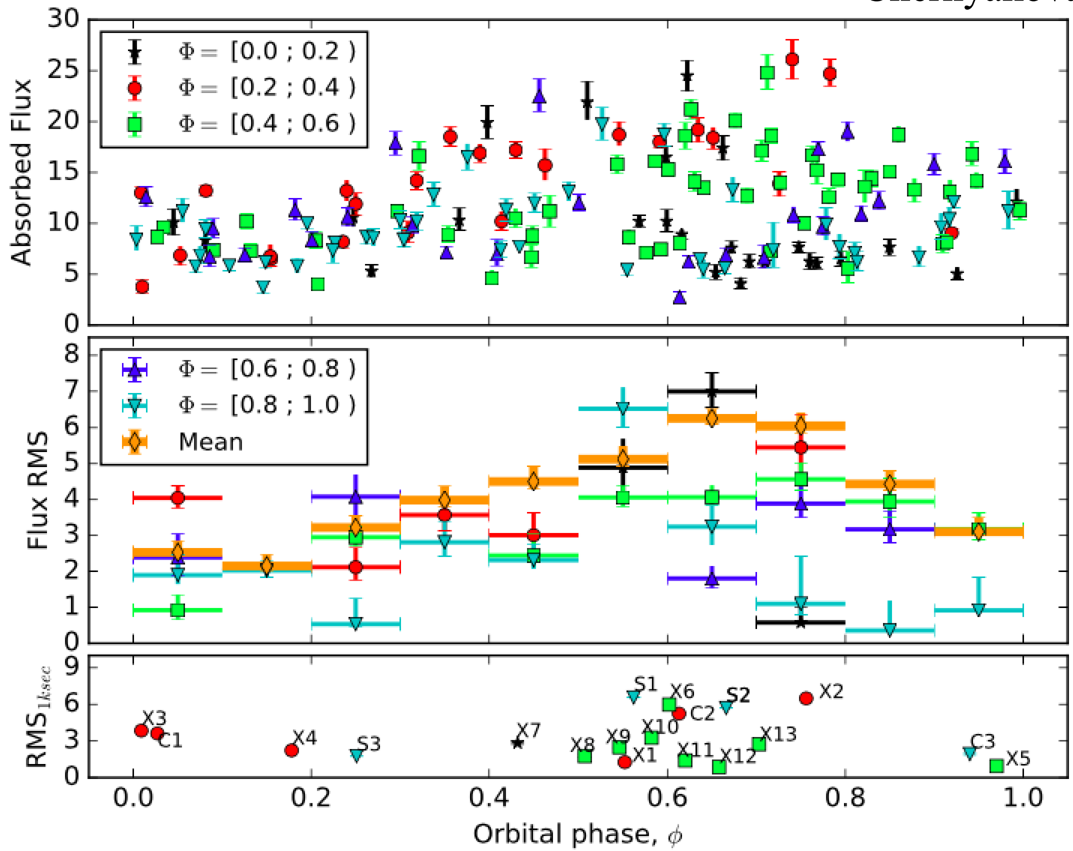



S3



# LS I 61 303

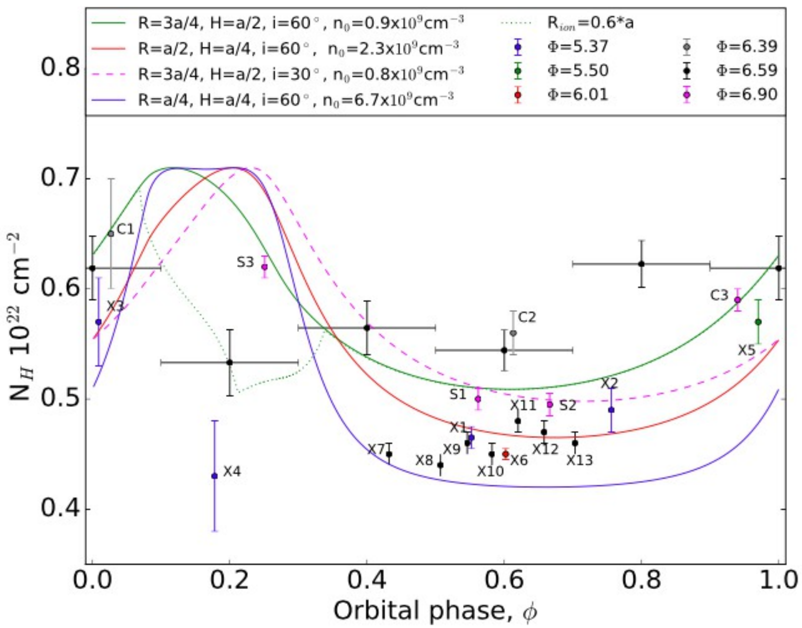
Chernyakova et al. 2017

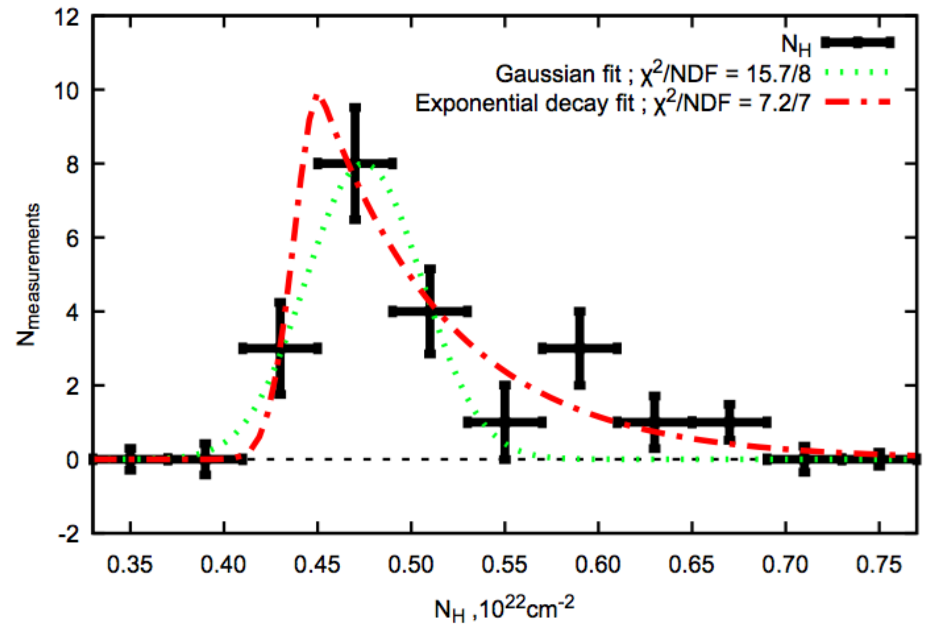



Shift of the max RMS φ = 0.55 [Φ = 0.8−1] → φ = 0.65 [Φ = 0.0−0.2] → φ = 0.75 [Φ = 0.2−0.4] due to a gradual increase of the disk size at superorbital time scales. No shift if the compact object spend the whole orbit inside the dense regions of the near-to-maximum size disk [Φ=0.4 – 0.8] .

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




- Variability of $N_H$ is another tool to study the geometry and structure of the disk. Disagreement of the simple model with observations can be due to the ionization of the central region of the disk.

- Alternatively, the observed distribution of $N_H$ can originate from the constant $N_H$ level modified by the presence of dense clumps that intersect the line of sight and effectively increase the $N_H$ on short time scales. Observed “fast rise – exponential decay” behavior corresponds to the presence of the disk clumps with a certain distribution of densities/sizes

.

# Conclusions

- $\gamma$-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 variable along the orbit, non-thermal X-ray, $\gamma$-ray, and very high-energy $\gamma$-ray emission during the periods of pulsar passing through the dense regions of the companion wind.
- Interaction of the compact source with a massive star outflow gives a chance to measure various parameters of the stellar wind (e.g. geometry, density, clumpiness).