Multiwavelength properties of gamma-ray loud binaries

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–----------- Variable Galactic Gamma-Ray Sources (V) –-----------
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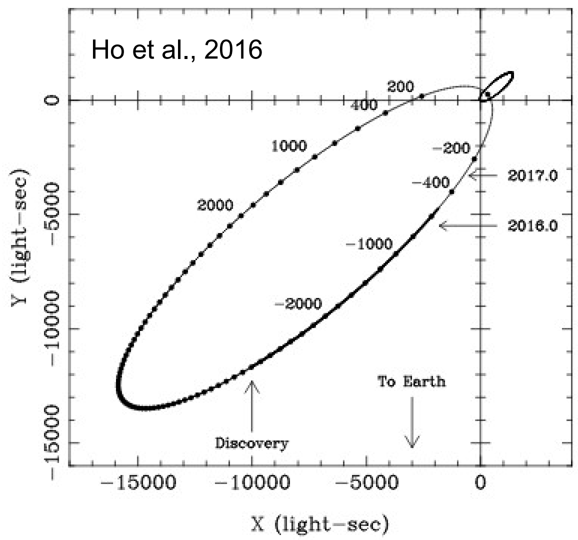
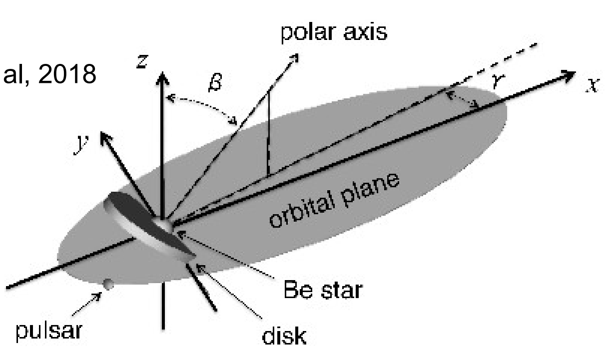
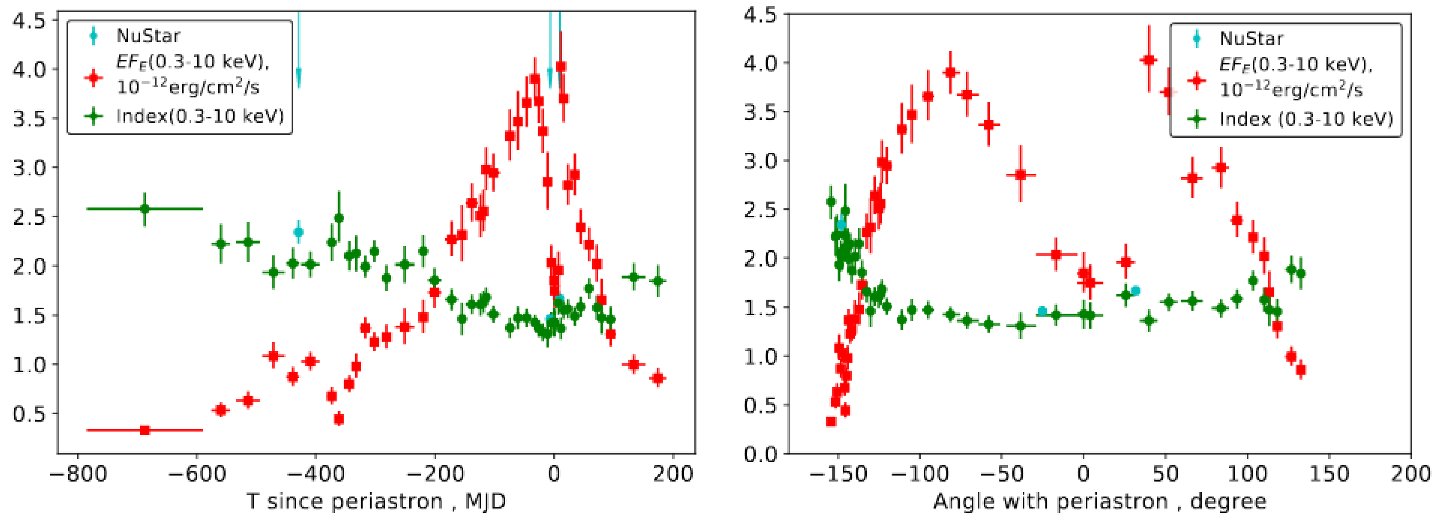
PSR J2032+4127 / MT91 213





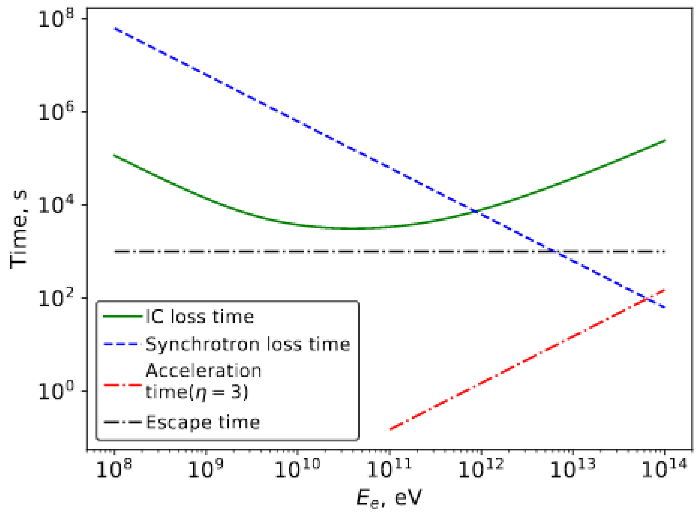
- 143 ms radio pulsar, first discovered by the Fermi (Abdo et al. 2009).
- The pulsar is rotating around the 15-solar-mass B0Ve star MT 91-213 in a very eccentric orbit.
- Ho et al. (2016) confirmed the binary nature and an orbital period of 45-50 years with a periastron in November 2017.
- Periastron passage occurred on 13 November 2017.
- Unpulsed radio, X-ray and TeV emission are detected around the periastron.

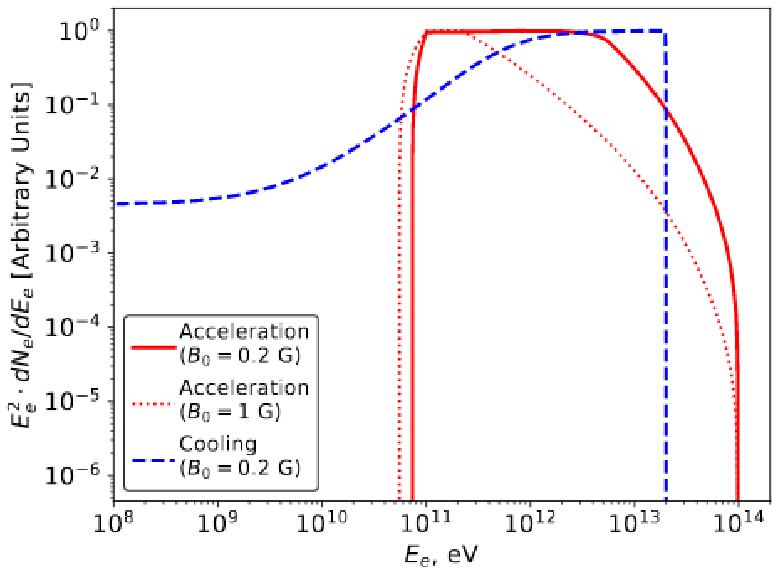
PSR J2032+4127: X-rays



- Similar to PSR B1259-63 and HESS J0632+057 two peak X-ray lightcurve.
- Slope of X-ray band spectrum hardens as the pulsar approaches the Be star, reaching Γ~1.5.
- No significant variations of hydrogen column density (n_H~ 0.9x10^{22}cm^{-2}).
- Li et al. (2018) suggested that the strong X-ray dip close to the periastron is explained by an increase of the magnetization parameter of star–pulsar colliding winds shock. The model predicts the overall shape of the orbital X-ray lightcurve, but neither the details of the double-peak flux structure around the periastron, nor the hardening of the X-ray spectrum around periastron.
- Coe et al. (2019) report on optical and X-ray flux measurements of PSR J2032+4127 accompanied with SPH modeling of this system. Authors assumed that the disk of the Be star is inclined to the orbital plane. The modeling failed to describe the details of the observed X-ray lightcurve of the system, and lacks the spectral variability studies.

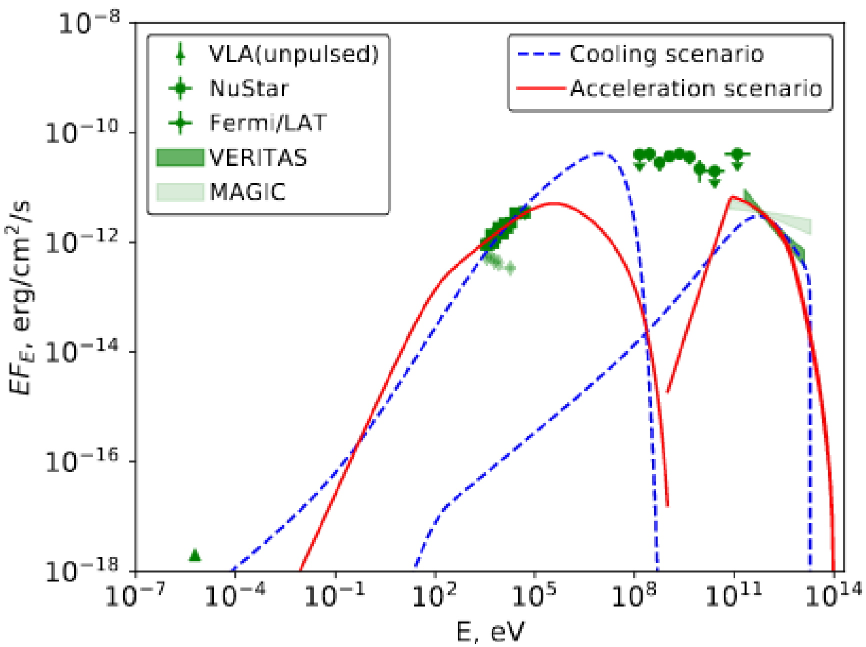
PSR J2032+4127: cooling and acceleration





- Disk of the Be star is inclined to the orbital plane.
- X-ray and TeV emission are of synchrotron and IC origin correspondingly. The electron spectrum has slope ~2 with a low-energy feature (break or a cut-off) as it follows from radio data.
- **Cooling scenario:** close to monochromatic electrons (~20 TeV) are constantly injected by a pulsar to interaction region. Continuous radiation losses modify spectrum and form X-ray and TeV emission.
- **Acceleration scenario:** injected monochromatic electrons has energy ~0.1 TeV). Injected electrons accelerate at shock with characteristic timescale $t_{acc} \approx 0.1\ (Ee/1TeV)\ \eta B^{-1}$. This scale is much shorter than synchrotron and IC-loss times for the electrons with energies ~100 TeV, leading to the fast formation of a cut-off powerlaw spectrum of electrons with a slope of ~2 (Fermi acceleration) and a cut-off at ~30 TeV. On longer times electrons' spectrum is modified by synchrotron and IC losses, leading to the observed X-ray/TeV emission.

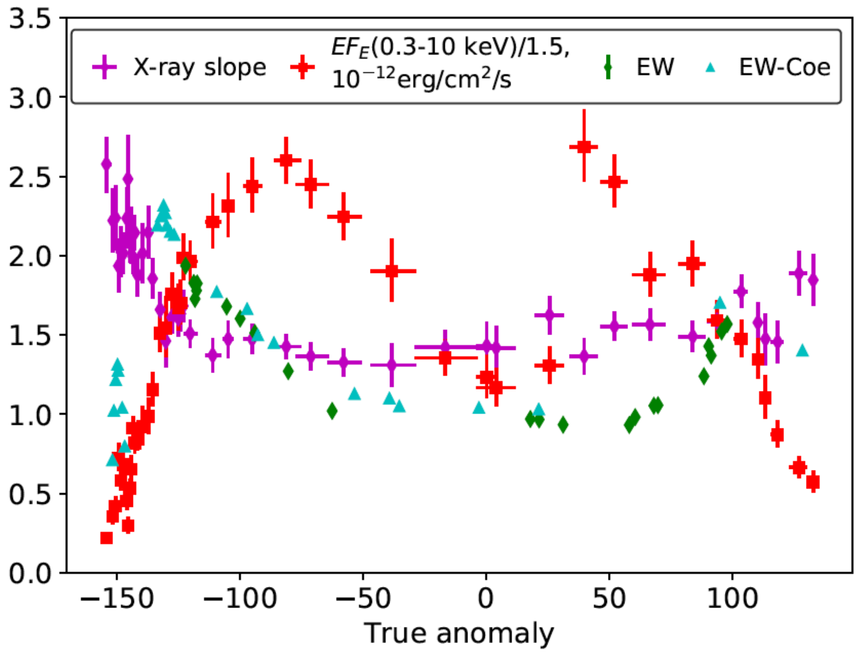
PSR J2032+4127: broadband spectra

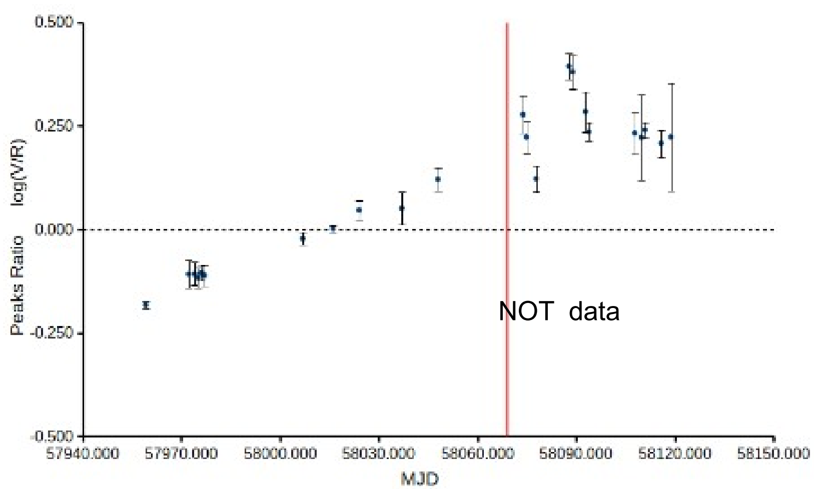


- X-ray flux increases as the pulsar enters dense regions of the stellar wind and wind-wind interaction region shifts towards the pulsar.
- The dip close to periastron happens when pulsar enters sparser regions of Be-star disk. The wind-wind interaction region shifts further from the surface of the pulsar and decreases magnetic field in this region.
- Shift of the emission region closer to the star at periastron orbital phases is also inline with the observed increase of TeV emission –> density of the soft photons increases and TeV raise up as reported by Abeysekara et al. (2018).

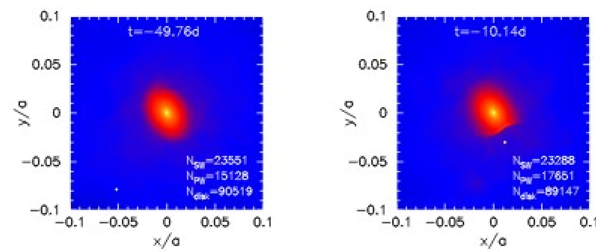
- GeV emission is dominated by the magnetospheric emission from the pulsar and thus is stable along the orbit.

PSR J2032+4127: disk evolution



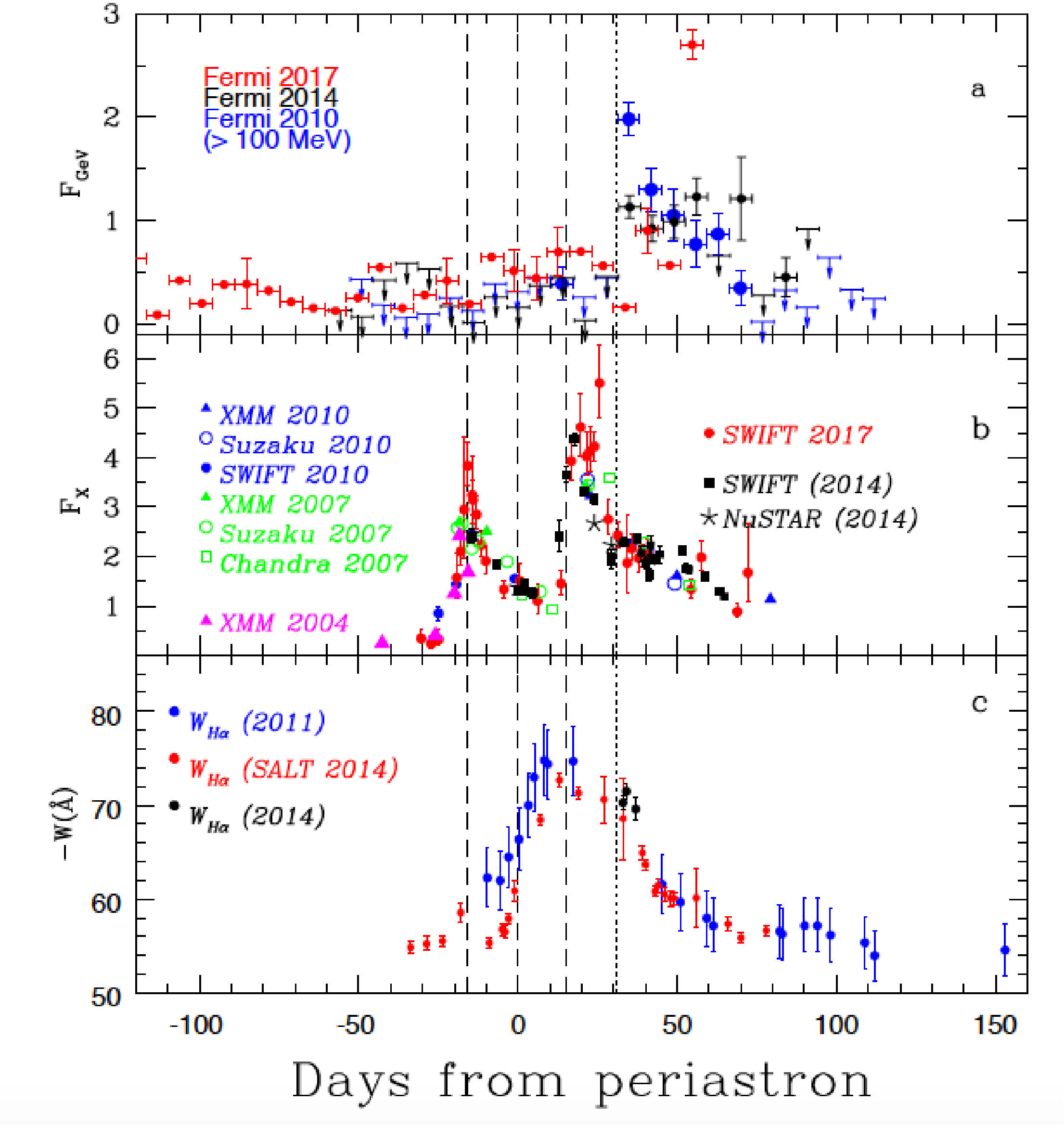


Coe et al. (2019)



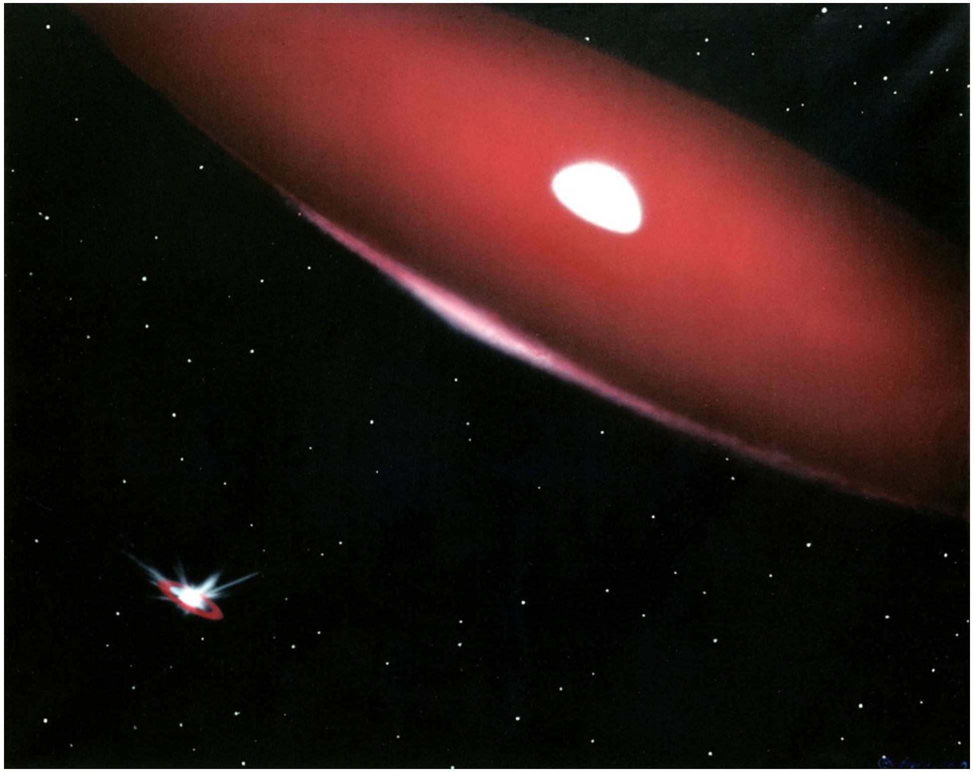
- Interaction of the pulsar and stellar wind can be traced by the evolution of Hα emission line.
- Tidal interactions increase the size of the disk (rise of the Hα EW) until the pulsar enters the stellar wind deep enough.
- Max of the EW roughly corresponds to the moment when X-rays hardens to −1.5 (start effective particle acceleration).
- After that external layers of the disk are destroyed, leading to the decrease of the EW.
- Cut-off of the external layers of the disk also lead to the change of the V/R ratio, removing part of the disk moving away from observer.
- Gradual increase of the disk size after periastron, again due to tidal interactions.
- Gradual decay of the disk as the pulsar moves away

PSR B1259-63: light curves 2017



- 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...*
- Main puzzle is detection of very fast (~15 min) gamma flares during which ~30 times more energy than spin down luminosity is released (Fermi collaboration, 2018)

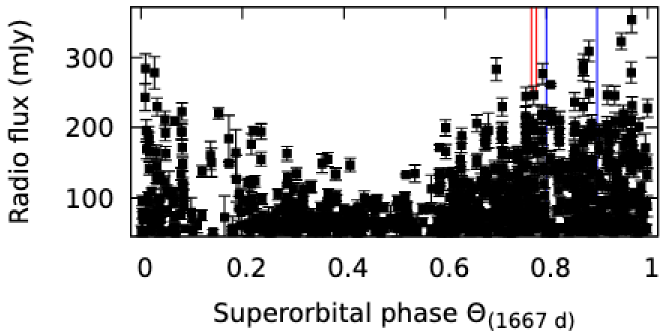
LS I 61º 303



- 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 (SO) period P=4.6 year.
- 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).

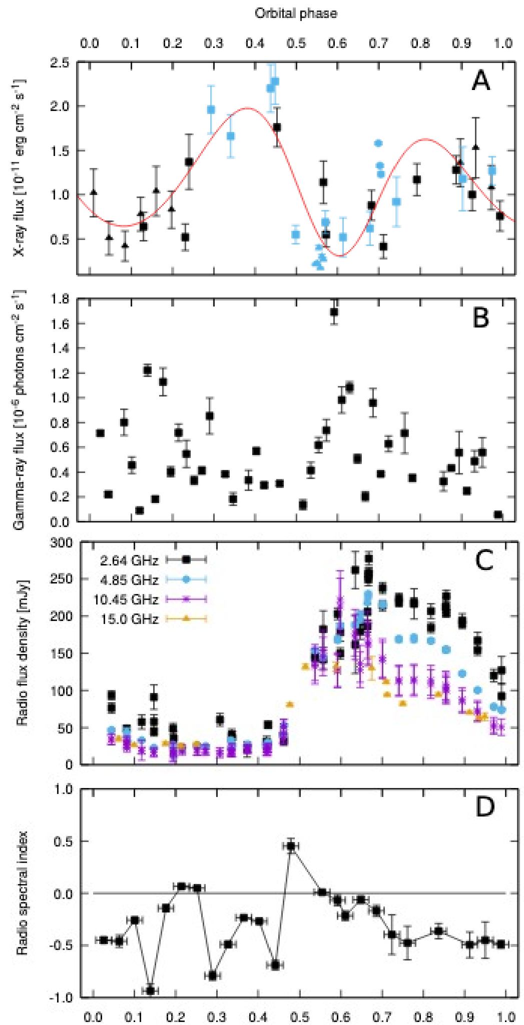
LS I 61º 303: microqusar model

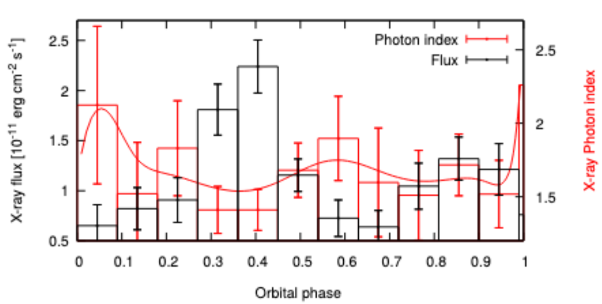
- Various groups (e.g. Marti & Paredes 1995; Bosch-Ramon et al. 2006; Romero et al. 2007) studied possibility that LSI 61+303 is a microqusar and predict that the accretion rate might have two peaks along the orbit.
- In this scenario, each peak in accretion rate is followed by an ejection of particles radiating gamma-rays (IC) and radio emission (synchrotron) (e.g. Bosch-Ramon et al. 2006;Jaron et al. 2016), with the most significant radio outburst happening further from periastron passage.
- These predictions seems to be supported by radio and GeV observations. The radio spectral index α is negative most of the orbit, but rises towards zero, or even to positive values twice along the orbit (Massi & Kaufman Bernado 2009), in agreement with the behaviour of compact jets (Fender 2001), revealing the moments of generation of a compact jet.



X-ray emission in this model is generated in accretion flow around the stellar mass black hole (e.g. Yang et al. 2015). To investigate simultaneous orbital evolution of radio and X-ray emission we performed in 2017 a one-month multiwavelength campaign, scheduled towards the maximum of the modulation.

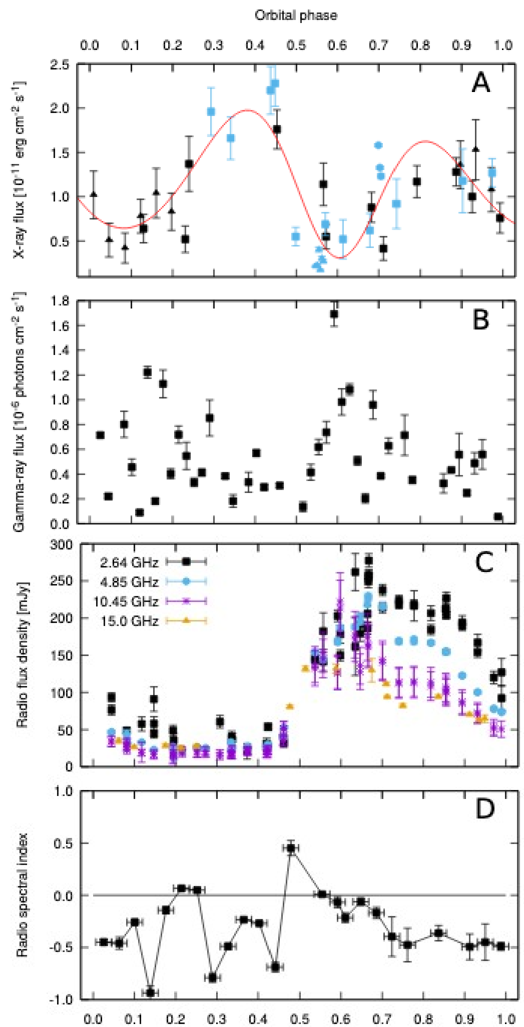
LS I 61° 303: results of the campaign

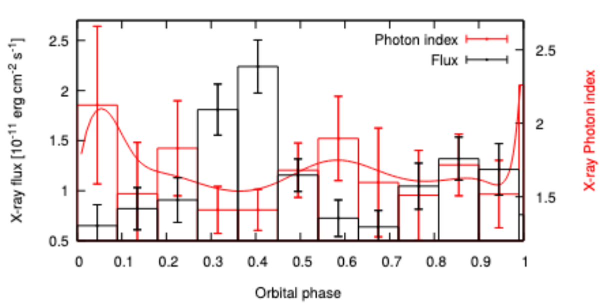




- The X-ray data have a peak (Φ=0.43) and a dip (Φ = 0.5−0.6).
- Position of X-ray dip corresponds to the onset of the radio and gamma-ray outbursts.
- X-ray dips associated to radio emission peaks were observed in the stellar massblack hole system GRS 1915+105 (Mirabel & Rodrıguez1999; Klein-Wolt et al. 2002).
- The X-ray dip is explained as disappearance of matter from the accretion flow, part of it passing the event horizon and part of it ejected into a radio emitting jet (the radio peak).
- Gamma-rays peak similar to radio. X-ray spectrum softens during the dip and the jet is self-absorbed until Φ~0.55. Then the radio spectral index after an oscillation stabilizes to $\alpha = -0.5$ for an optically thin outburst forming a bump in the decay of the radio light curve.

LS I 61º 303: results of the campaign





- This is consistent with the unified model of black hole X-ray binary jets (Fender, Belloni & Gallo 2004) where during the rising phase of an outburst the self-absorbed jet persists while the X-ray spectrum softens. Subsequently, the jet becomes unstable and an optically thin radio outburst occurs, associated to shocks.

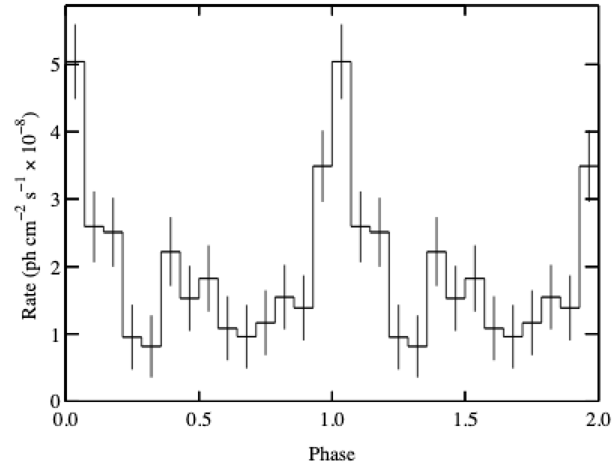
- The accretion theory in LS I +61 303 predicts another accretion peak and a subsequent gamma-ray emitting ejection.

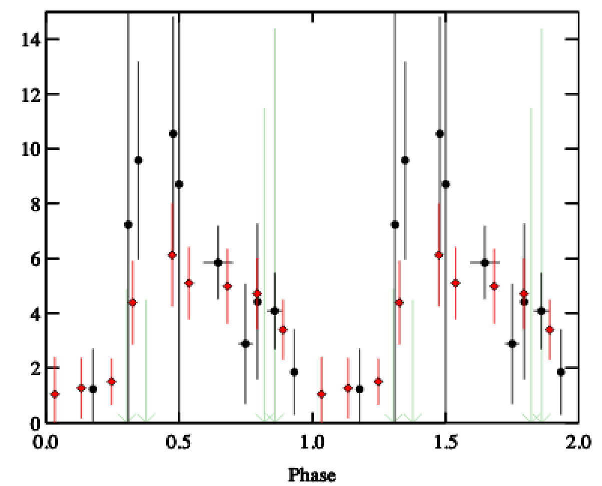
- In agreement with this X-ray emission rises again and drops at Φ~0.0−0.2 with a gamma-ray peak occurring at Φ~0.2. Also in this case the dip is a soft one and (Φ~0.2) the jet is self-absorbed.

New Gamma-Ray Binary 4FGL J1405.1-6119

http://arxiv.org/abs/1908.10764v1

- Corbet et al. (2019) report the identification from multi-wavelength observations of the Fermi source 4FGL J1405.1-6119 as a high-mass gamma-ray binary.
- Observations with the LAT show that gamma-ray emission from the systemis modulated at a period of13.7135±0.0019 days, with the presence of two maxima per orbit with different spectral properties.
- X-ray observations using the Swift-XRT show that X-ray emission is also modulated at this period, but with a single maximum that is closer to the secondary lower-energy gamma-ray maximum.
- A radio source, coincident with the X-ray source is also found from ATCA observations, and the radio emission is modulated on the gamma-ray period with similar phasing to the X-ray emission.





Conclusions

- Since our last meeting in Tokyo PSR B1259-63 and PSR J2032+4127 passed their periastra providing new results and new puzzles.
- Next periastron of PSR B1259-63 is ahead in February 2021.
- Nature of compact object in LSI +61 303 is still debated.
- New gamma-ray binary system has been detected.