Peculiarities of broadband emission of gamma-ray binaries with a radio pulsar

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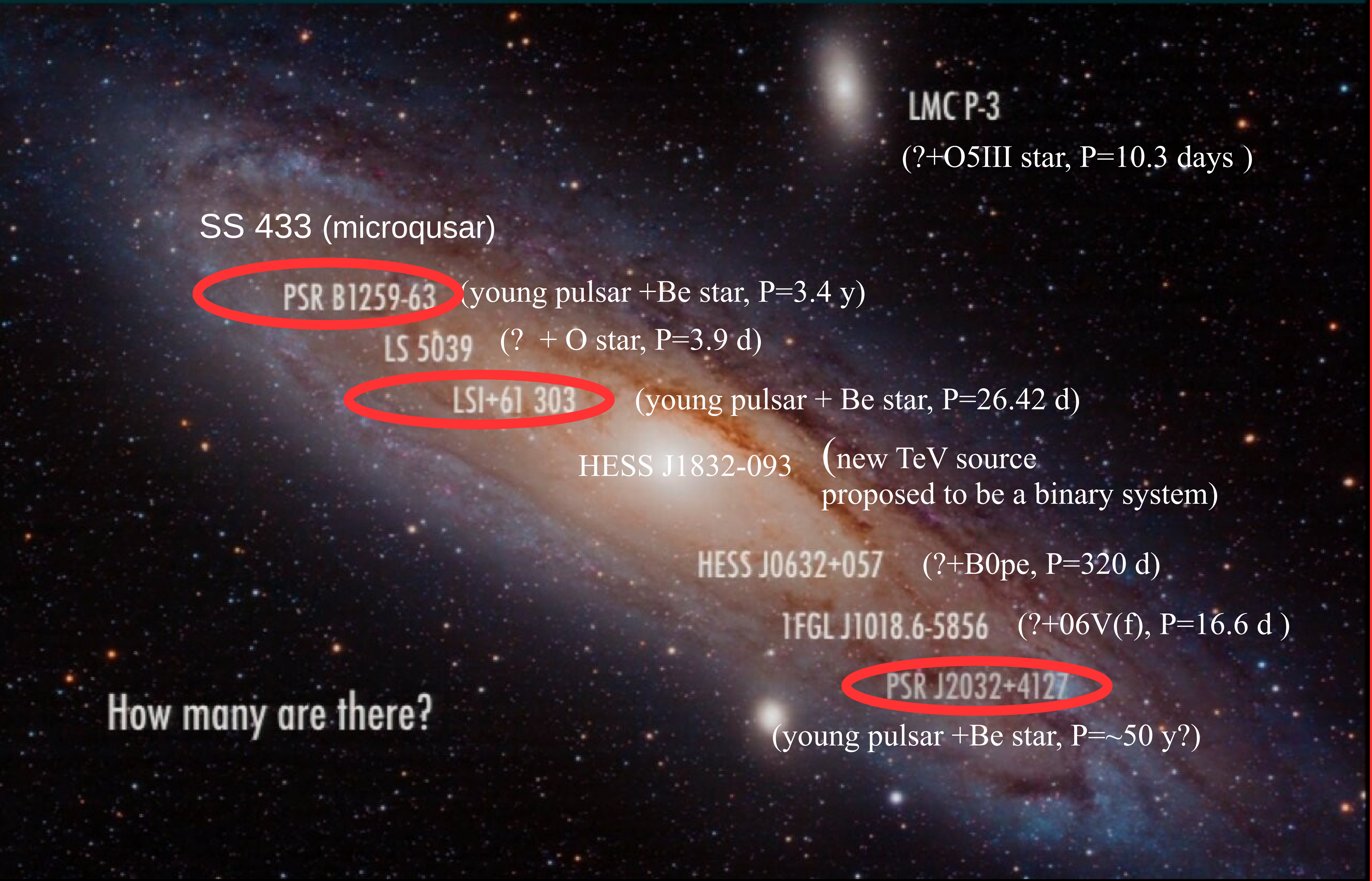
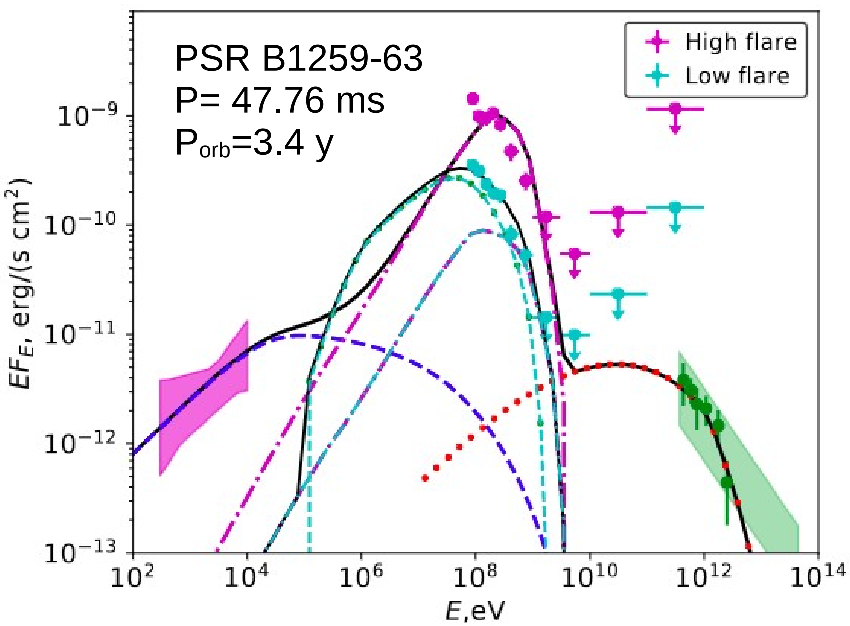
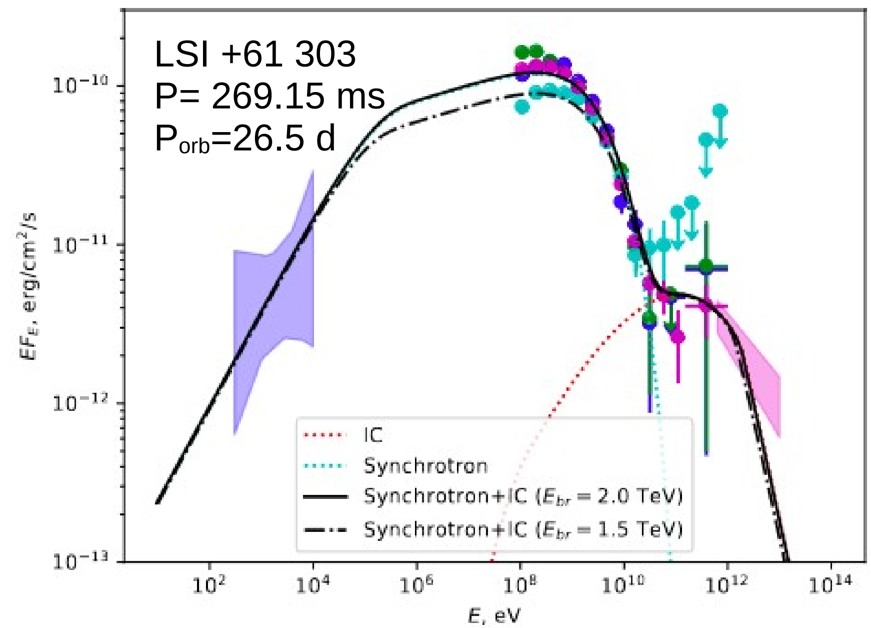
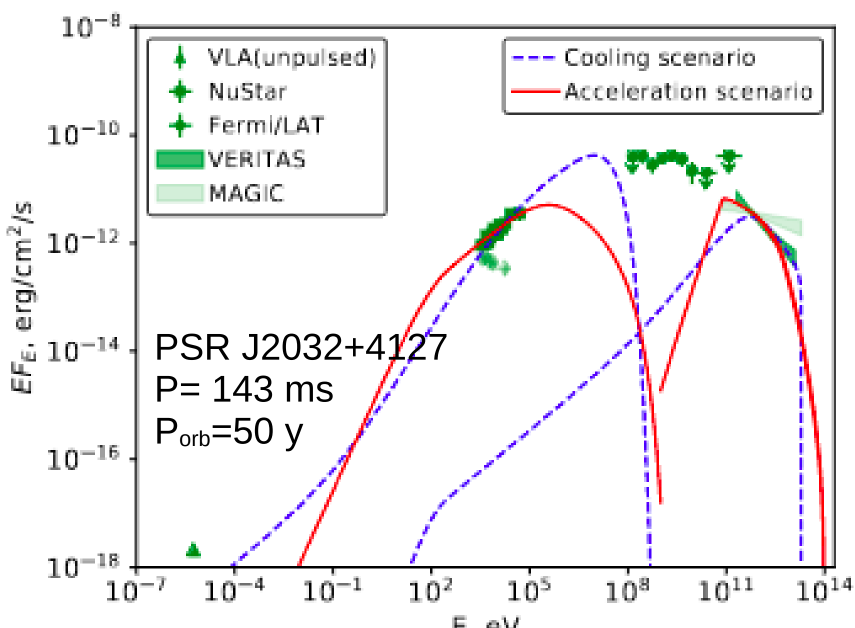
Known gamma-ray binaries



Gamma-ray binaries with a radio pulsar

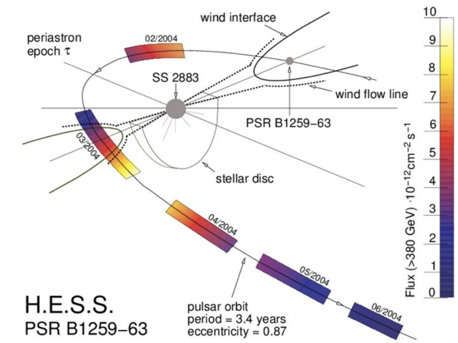


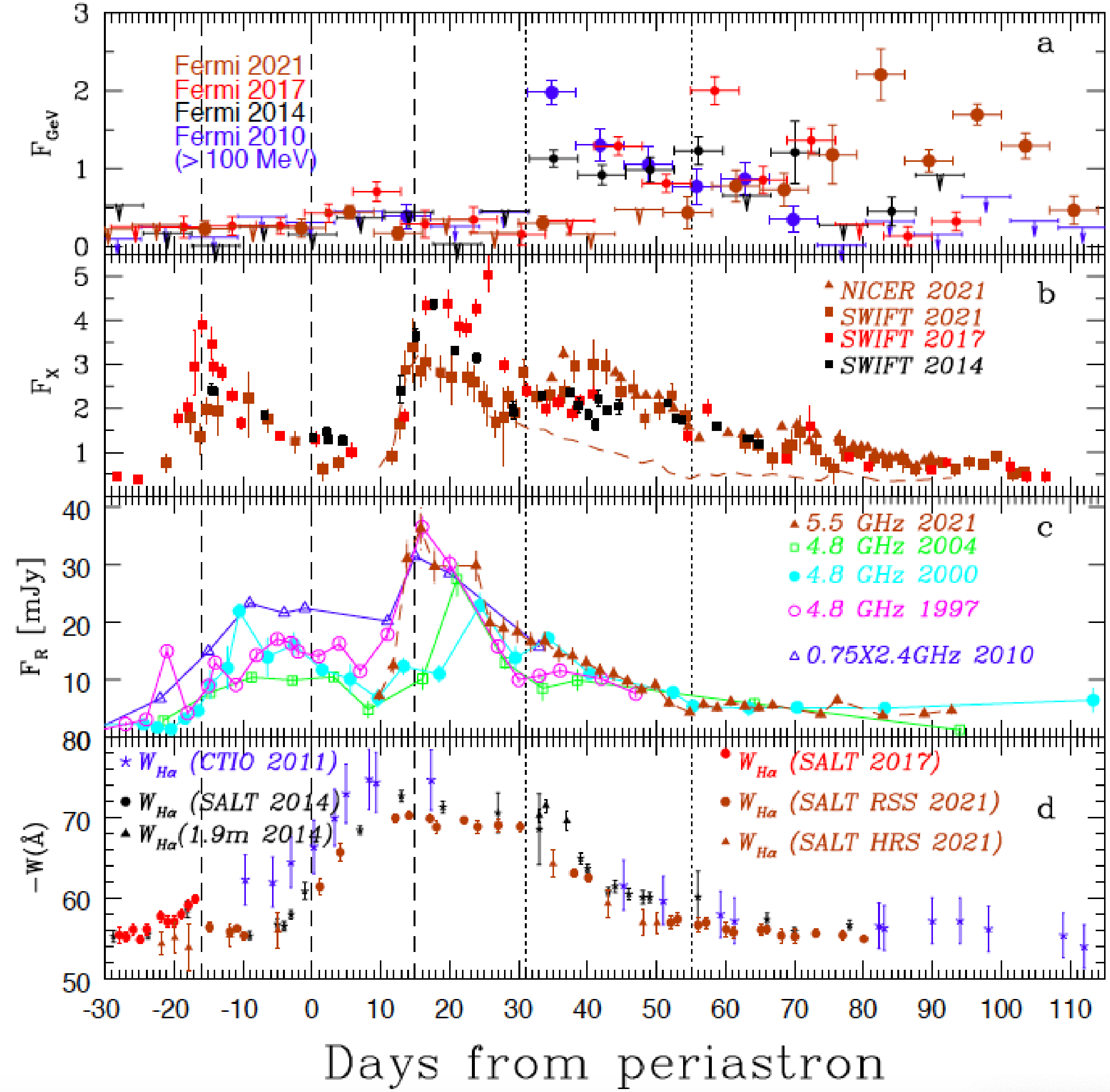




- Radio pulsar is in orbit around Be star
- Similar range of X-ray and TeV emission around periastron.
- Very different GeV appearance.
- Natural laboratories for the study of the properties of pulsar and stellar winds.

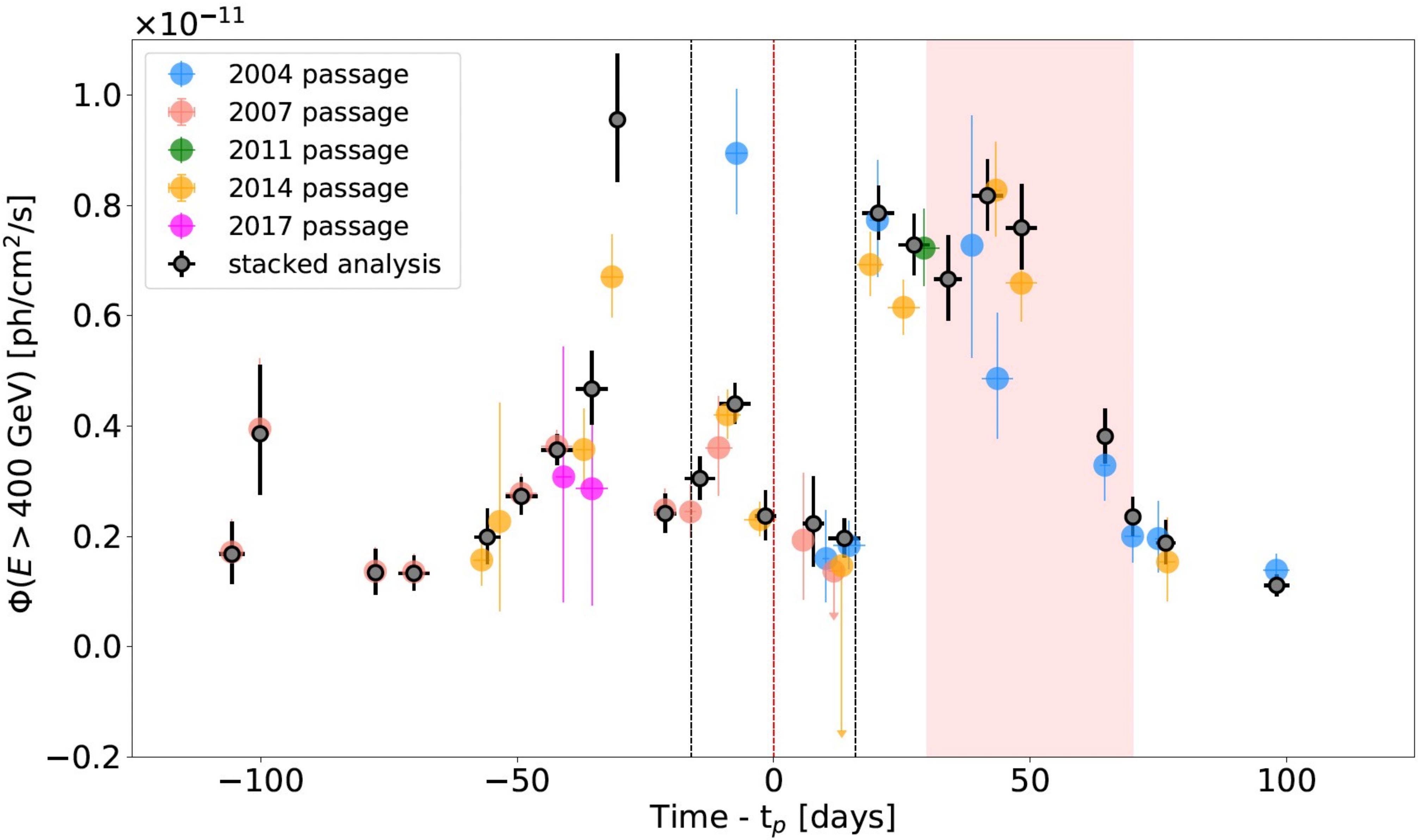
PSR B1259-63: light curves





- Two peaks at X-ray and radio ~20 days around the periastron.
- Corresponds to the passage through the Be star disk.
- Break of the Radio - X-ray correlation at the beginning of the 3rd peak.
- Huge GeV flare with energy release close to spin-down luminosity on a weekly scale ~30/40/60 days after the periastron.
- No obvious counterpart at other energies.

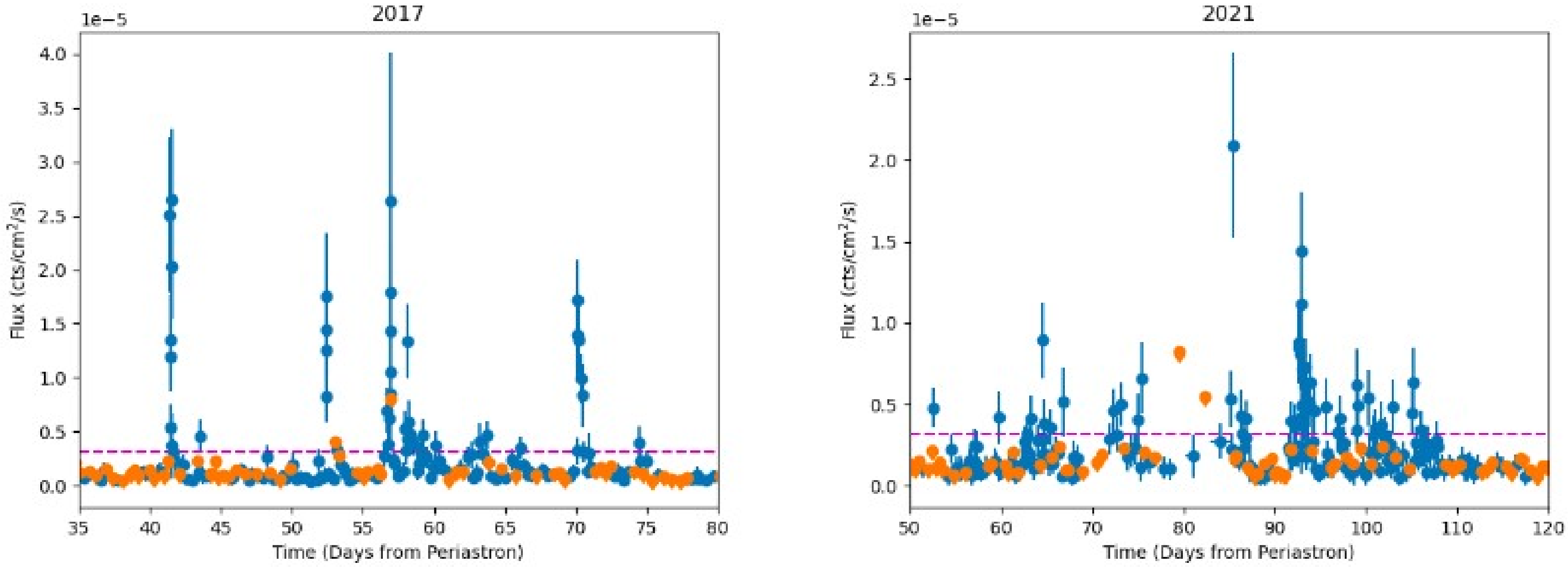
Chernyakova et al. 2021



H.E.S.S. Collaboration 2020

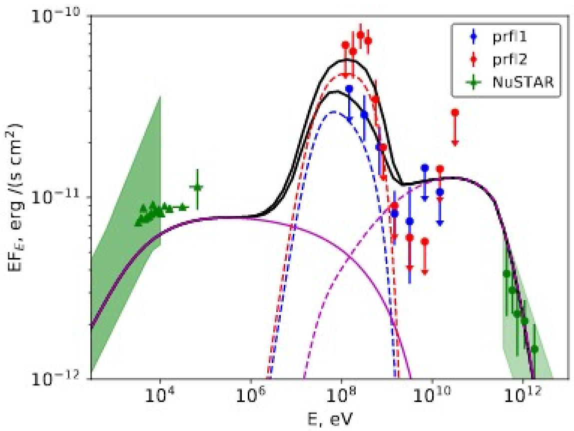
PSR B1259-63: light curves 2017

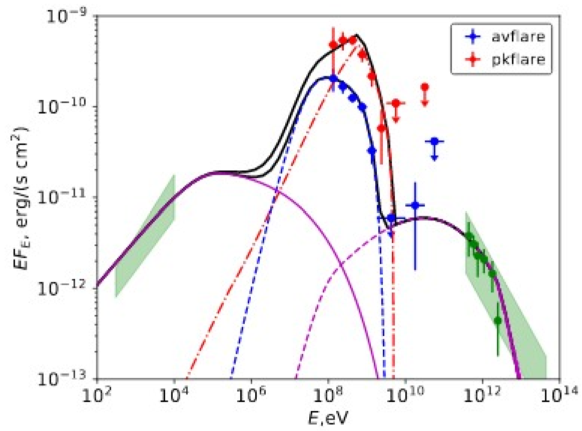
Chernyakova et al. 2024

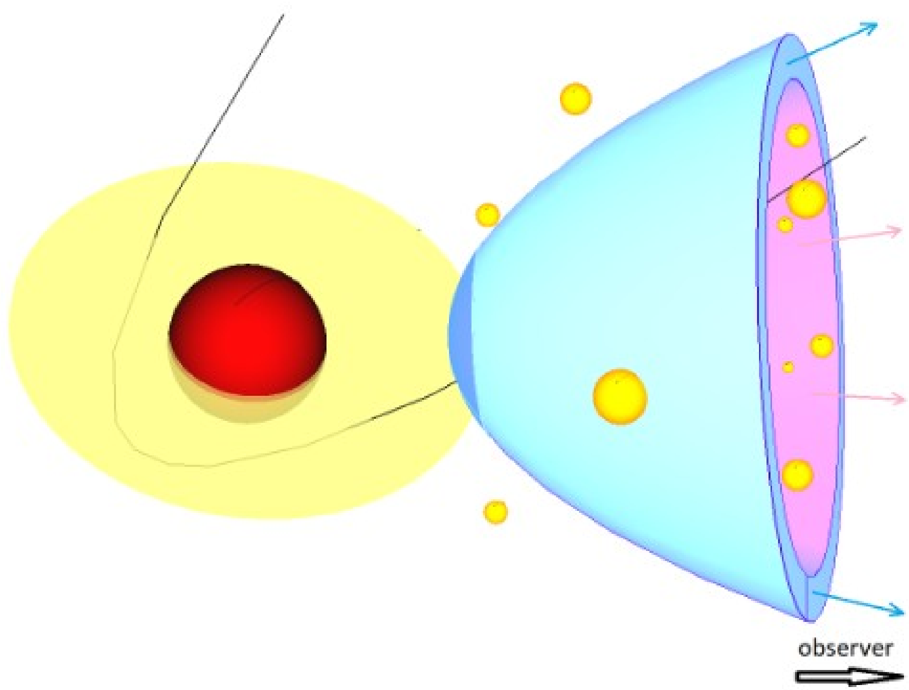


- Evidence of very fast (~15 min) gamma flares
- The isotropic gamma-ray luminosity corresponding to the short flares greatly exceeds the pulsar spin-down luminosity!
- Various models to explain GeV, e.g. Khangulyan et al. 2012, Dubus & Cerutti 2013, Yi & Cheng 2017, Chernyakova et al. 2020

PSR B1259-63: model



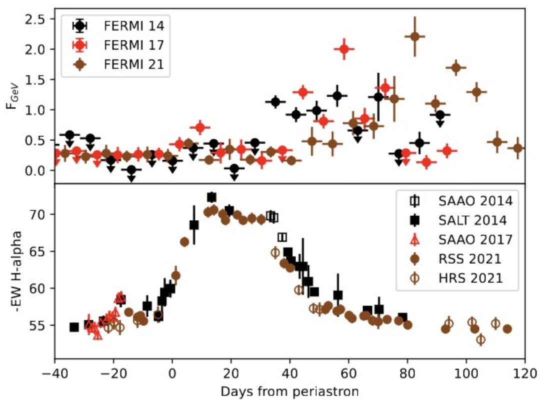




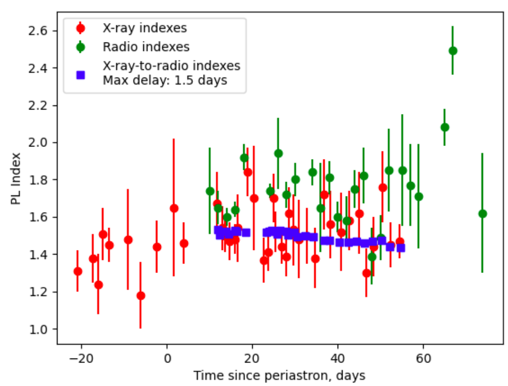
- Observed X-ray and TeV emission can be explained as a synchrotron and IC emission of the strongly shocked electrons of the pulsar wind.
- GeV component is a combination of the IC emission of unshocked / weakly shocked electrons and bremsstrahlung emission.
- Luminosity of the GeV flares can be understood if it is assumed that the initially isotropic pulsar wind after the shock is reversed and confined within a cone looking, during the flare, in the direction of the observer.

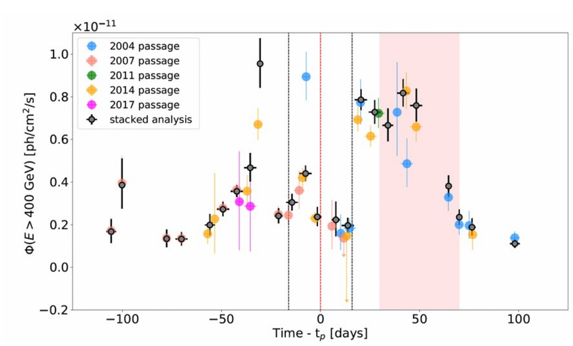
Chernyakova et al. 2020

PSR B1259-63: open questions



Chernyakova + 2024





H.E.S.S. Collaboration 2020

- Relation of the GeV flare to the state of the disc? IR studies are crucial to study the disk closer to the edge. ALMA observations in 2024 can shed a light on it.

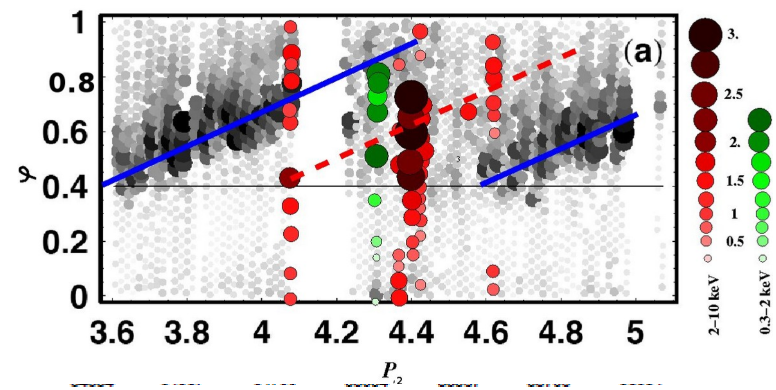
- Origin of radio emission? Disappearance of the X-ray/radio correlation? The radio spectrum is inconsistent with a single population of electrons explaining both X-ray and radio emission. To explain observed radio variability on a day scale one needs either high magnetic field (~20 G) or ineffective cooling.

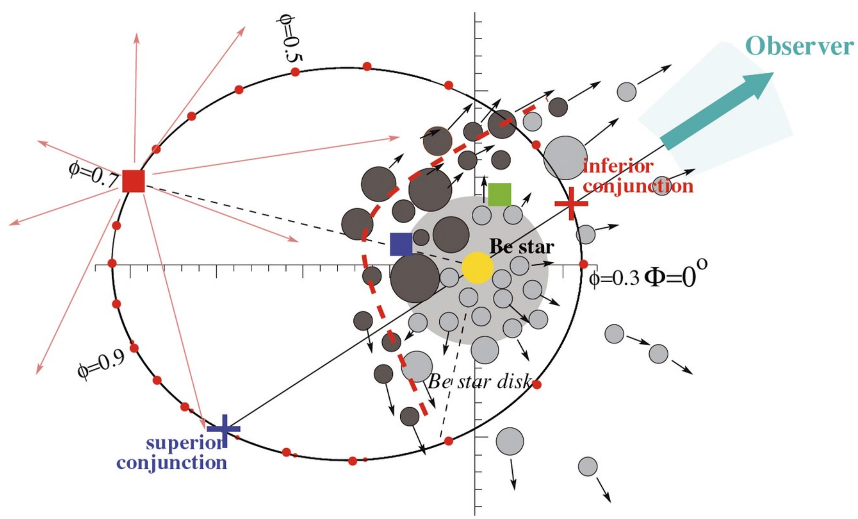
- Origin of TeV emission far from periastron? Possible X-ray/TeV correlation if magnetic field in periastron is dominated by the Be star? TeV variability at short timescale?

LSI +61 303

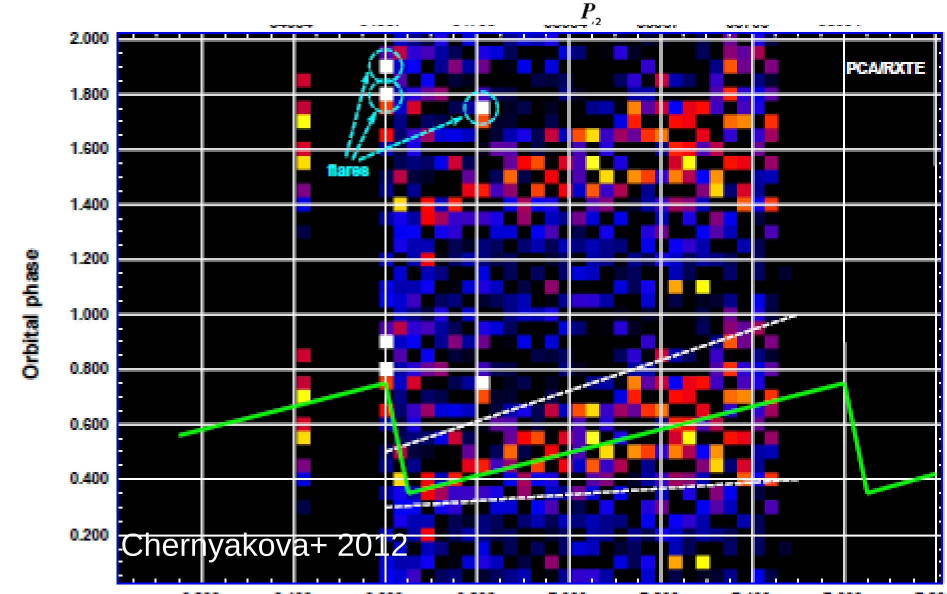
- Radio pulsar (P=269ms, Weng+ 2022) in an orbit with Be star.
- Emission is modulated throughout the 26.5-day orbit.
- The orbital phases of X-ray and radio flux maxima "drift" with superorbital (SO) period P=4.6 year.
- Evidence of superorbital modulation at GeV and TeV energies.

Gregory 2002



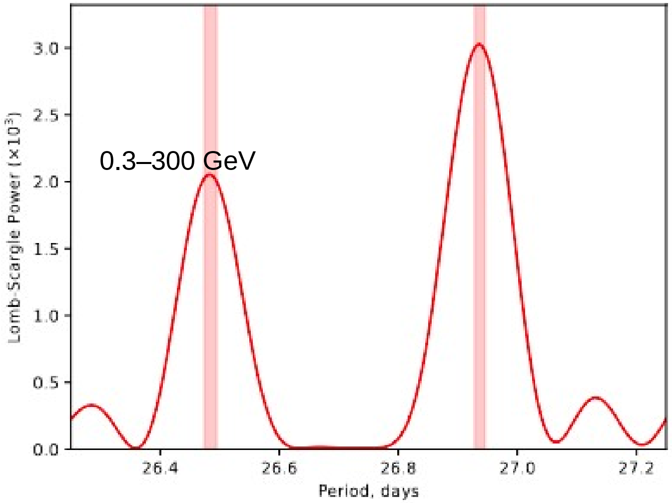


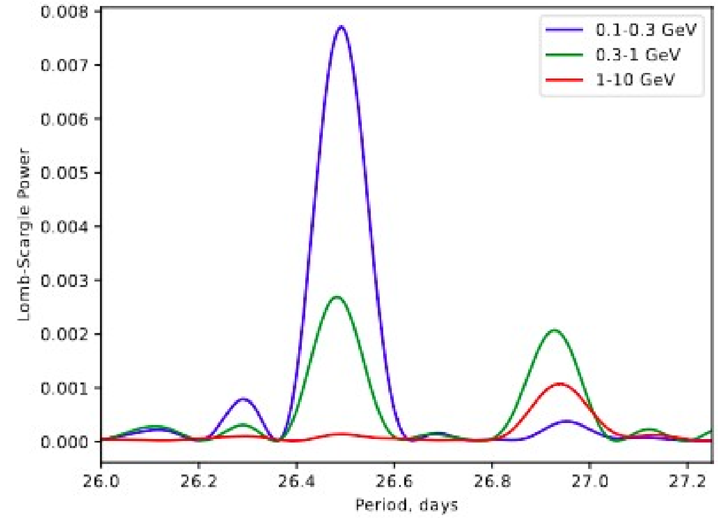
Zdziarski+ 2010



Chernyakova+ 2012

LSI +61 303

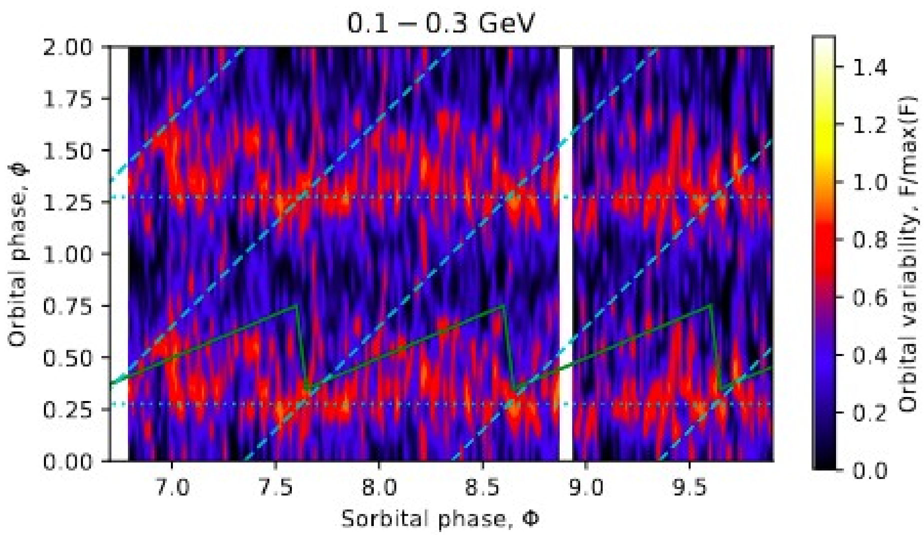


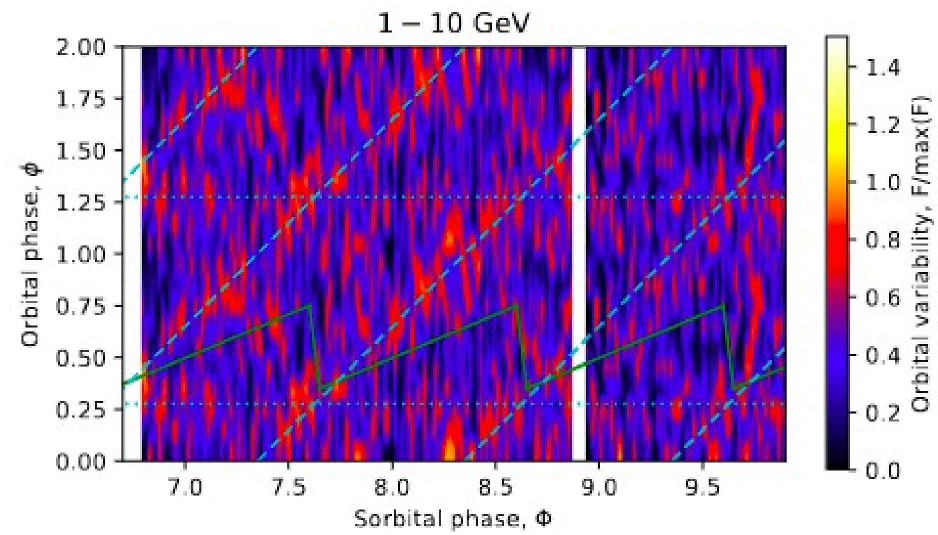


Chernyakova + 2023

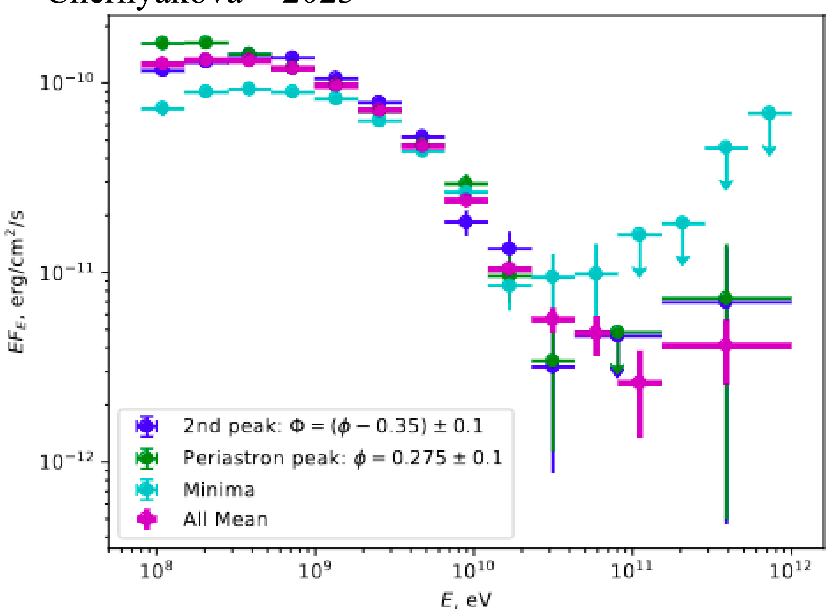
- Analysis of more than 14 years of the Fermi/LAT data.
- Similar to previous findings of Massi et al. (2013) Lomb-Scargle analysis of 0.3–300 GeV light curve reveal 2 peaks
- $P_1 = 26.485 \pm 0.012$ and $P_2 = 26.932 \pm 0.012$.
- These periods are consistent (1σ) with the orbital period $P_{orb} = 26.496$ and orbital-superorbital beat-period $P_{beat} = \frac{P_{orb} P_{so}}{P_{so} - P_{orb}} = 26.924\,d$
- More detailed analysis demonstrates energy dependence of the peak's height.

LSI +61 303





Chernyakova + 2023

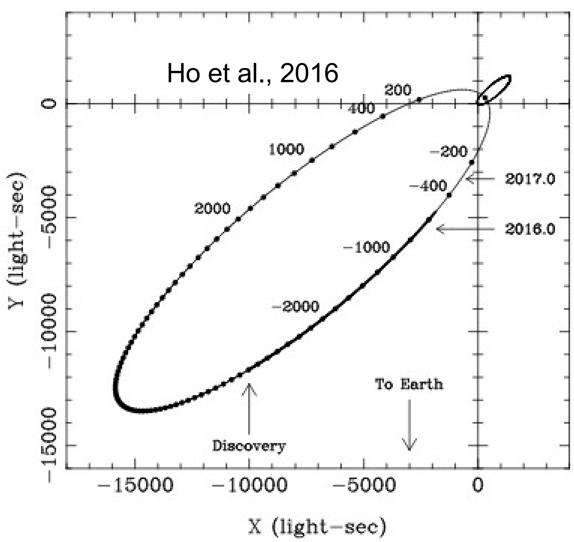


- "All Mean": all time-averaged data.

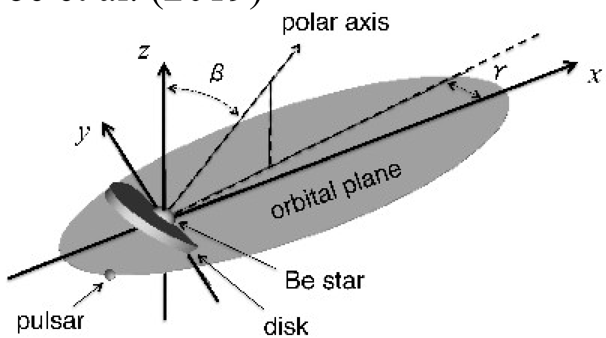
Orbital/ SO behaviour identifies distinct periods :

- periastron max (φ = 0.275 ± 0.1); **0.1 - 0.3 GeV**;
- beat-period maximum (Φ = (φ − 0.35) ±0.1); dashed diagonal lines, clearly seen **above 1 GeV.** Drift of the emission peak due to the precession of the pulsar or Be-star disk? Periodic growth and decay of the Be star disk?
- γ-ray emission from bow and tail of the shock?
- "minima": periods of low GeV emission **< 0.3 GeV** (Φ > 0.4 AND φ > 0.75);

PSR J2032+4127 / MT91 213

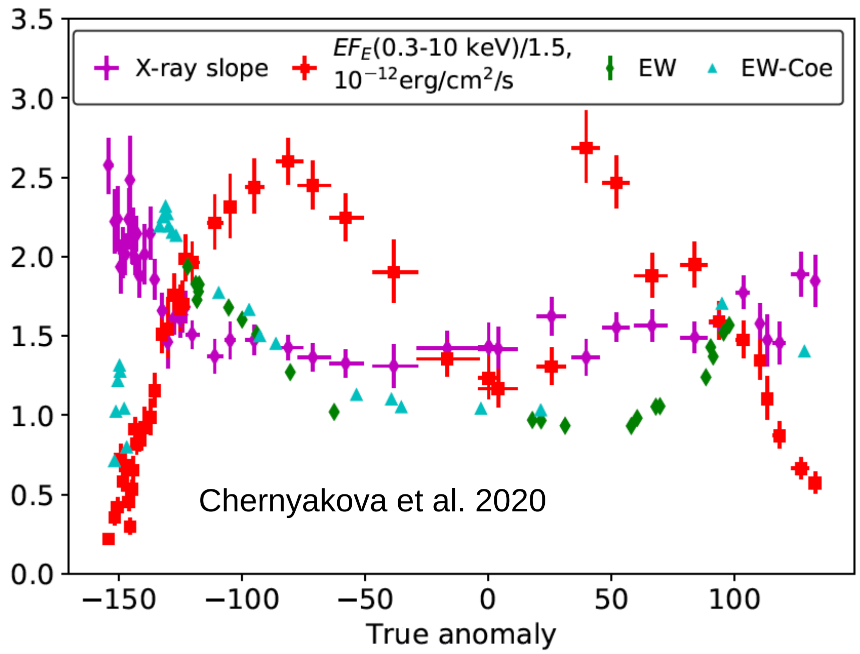


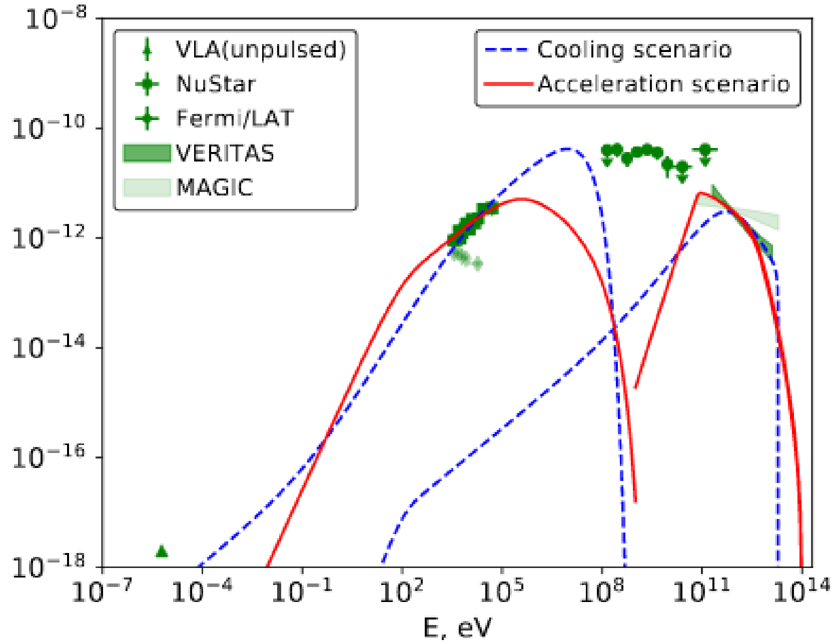
Coe et al. (2019)



- 143 ms radio pulsar, discovered by Fermi (Abdo et al. 2009).
- The pulsar is rotating around the 15-solar-mass B0Ve star MT 91-213 in a very eccentric orbit, orbital period of 45-50 years (Ho et al., 2016).
- Periastron passage occurred on 13/11/ 2017.
- Unpulsed radio, X-ray and TeV emission are detected around the periastron.
- Stable GeV emission from the pulsar's magnetosphere.
- Disk of the Be star is inclined to the orbital plane.
- Extensively studied by Takata et al. (2017), Li et al. (2018), Coe et al. (2019), Ng et al. (2019), Chernyakova et al. (2020) ...

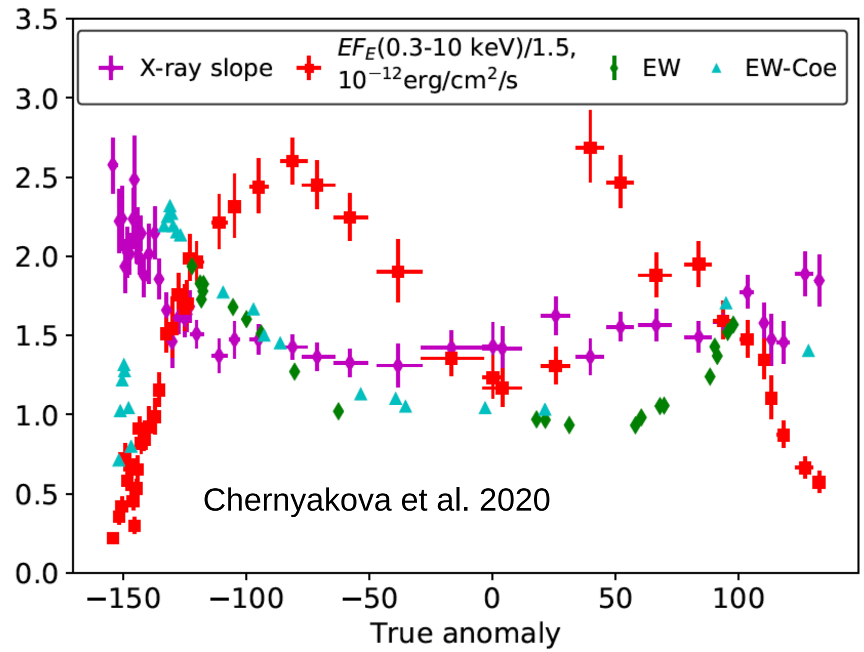
PSR J2032+4127: X-rays

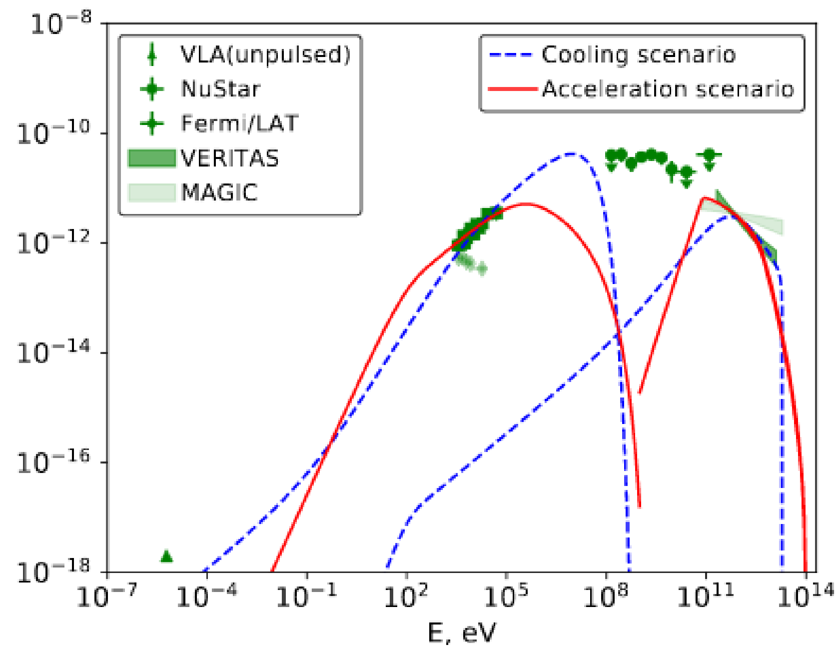




- **Similar** to PSR B1259-63 two peak X-ray light curve.
- X-ray and TeV emission are of synchrotron and IC origin correspondingly.
- GeV emission is dominated by the magnetospheric emission from the pulsar and thus is stable along the orbit.
- Peak and dips in the X-ray curve can be explained due to the shift of the emission region further from /closer to the star as the pulsar enters / leave the disk.
- Evolution of Hα emission line con4firms this picture, tracing the enlargement of the disk due to tidal interactions and destruction of the disk due to the pulsar passage nearby.

PSR J2032+4127: X-rays





PSR J2032+4127 (weak disk):

- X-ray index soft (-2) far from and hard (-1.5) close to periastron.
- emission region far from the pulsar → lower magnetic field → not effective cooling via synchrotron losses → hard keV index
- no cone-like specific effects (GeV flare)
- TeV maximum at periastron – increased level of soft photons

PSR B1259-63 (strong disk):

- X-ray index hard (-1.5) far from and soft (-2) close to periastron
- emission region close to the pulsar → higher magnetic field → effective cooling via synchrotron losses → soft keV index
- cone-like specific effects (GeV flare)

Conclusions

- Gamma-ray binaries with radio pulsar provide a chance to study the properties of the winds and details of their interaction. CTA observations being able to study spectral variability on short time scales will help to reconstruct the details of physical processes in these systems.
- Unique features of 2021 periastron passage of **PSR B1259-63**:
  - Presence of a third X-ray flux peak starting ~30 days after the periastron.
  - Correlation between the X-ray and radio fluxes during the 2^{nd} X-ray peak, and an absence of such a correlation with the 3^{rd} rise of the X-ray flux.
  - Indication that radio emission is either coming from accelerated stellar wind or highly magnetized region.
  - Intensive observational campaign of periastron 2024 is coming, stay tuned!
- Energy dependence of the periodicity pattern in **LSI +61° 303**.
  - $P_1 = 26.485 \pm 0.012$ at 0.1 – 0.3 GeV
  - $P_2 = 26.932 \pm 0.012$ at 1 – 10 GeV
- Broad band emission from **PSR J2032+4127** demonstrates both similarities and differences to PSR B1259-63.