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Multiwavelength view of 2024 periastron passage of PSR B1259-63 gamma-ray binary

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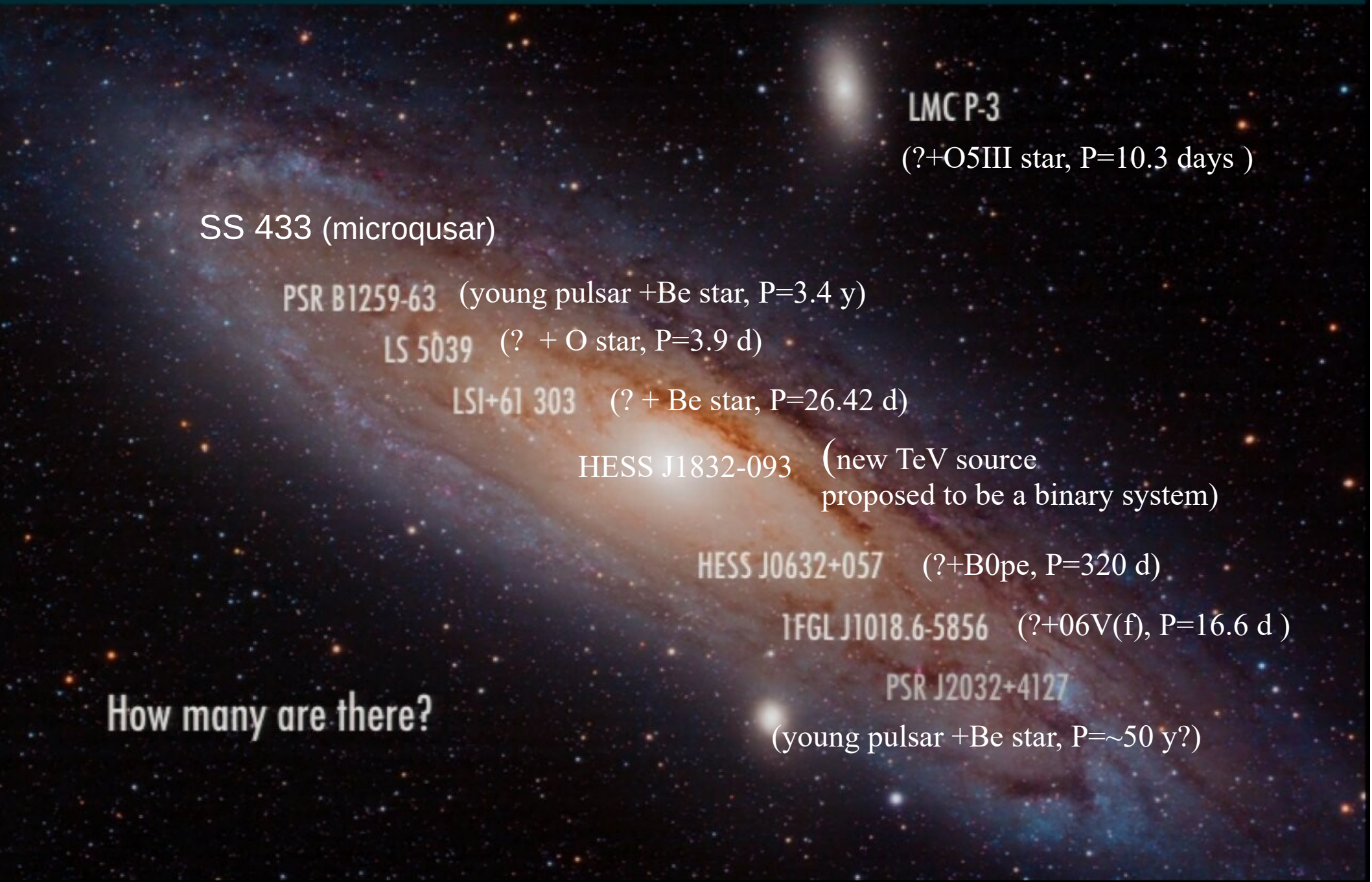
A. Kuzin (Uni Tubingen)
...

Variable Galactic Gamma-Ray Sources (VGGRS) VII,
Barcelona, May 7th 2025

Known gamma-ray binaries



LMC P-3

(?+O5III star, P=10.3 days)

SS 433 (microqusar)

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

LS 5039 (? + O star, P=3.9 d)

LSI+61 303 (? + Be star, P=26.42 d)

HESS J1832-093 (new TeV source proposed to be a binary system)

HESS J0632+057 (?+B0pe, P=320 d)

1FGL J1018.6-5856 (?+O6V(f), P=16.6 d)

PSR J2032+4127

(young pulsar +Be star, P=~50 y?)

How many are there?

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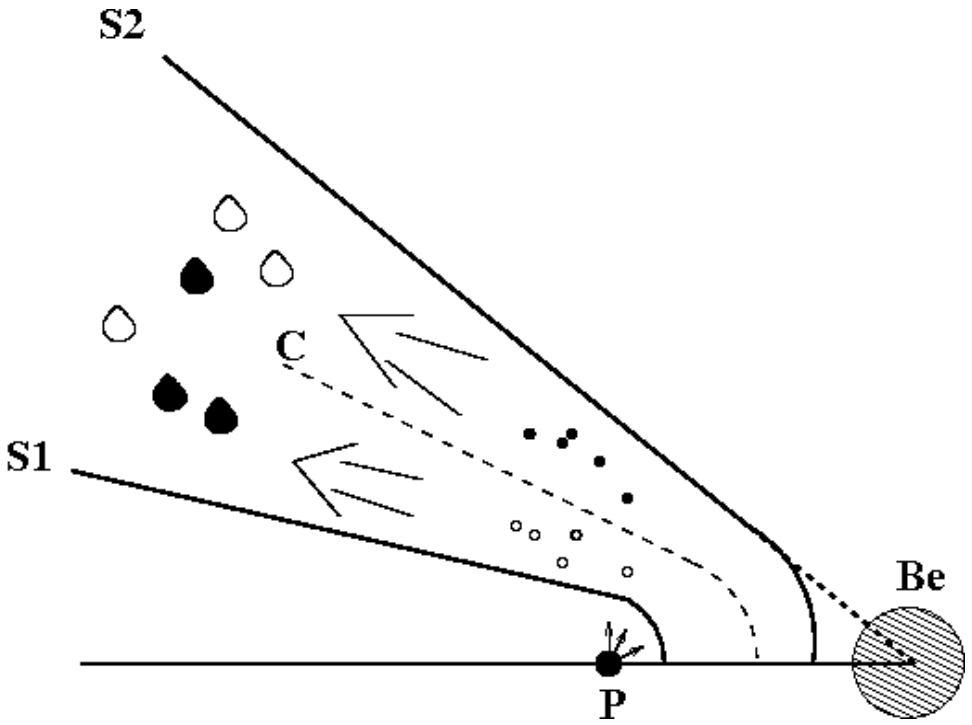
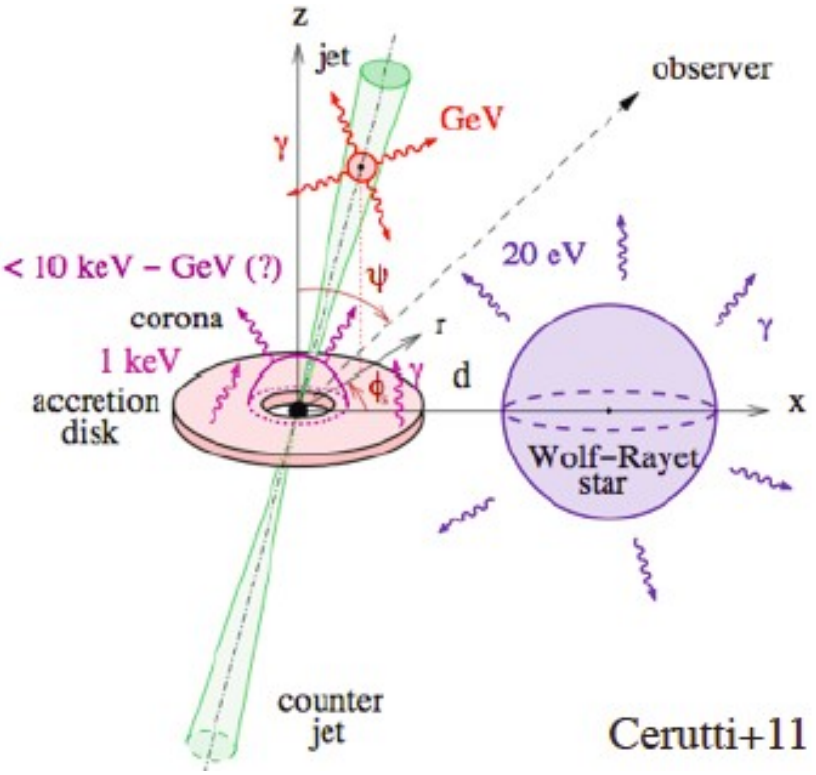
Two Paradigms of γ-ray Production

Colliding Winds



PSR B1259-63
PSR J2032+4127
LS I +61°303

Microquasar



LS 5039 (PSR ??)
HESS J0632+057
HESS J1832-093
1FGL 1018.6-5856
...

Cygnus X-3
Cygnus X-1
SS 433

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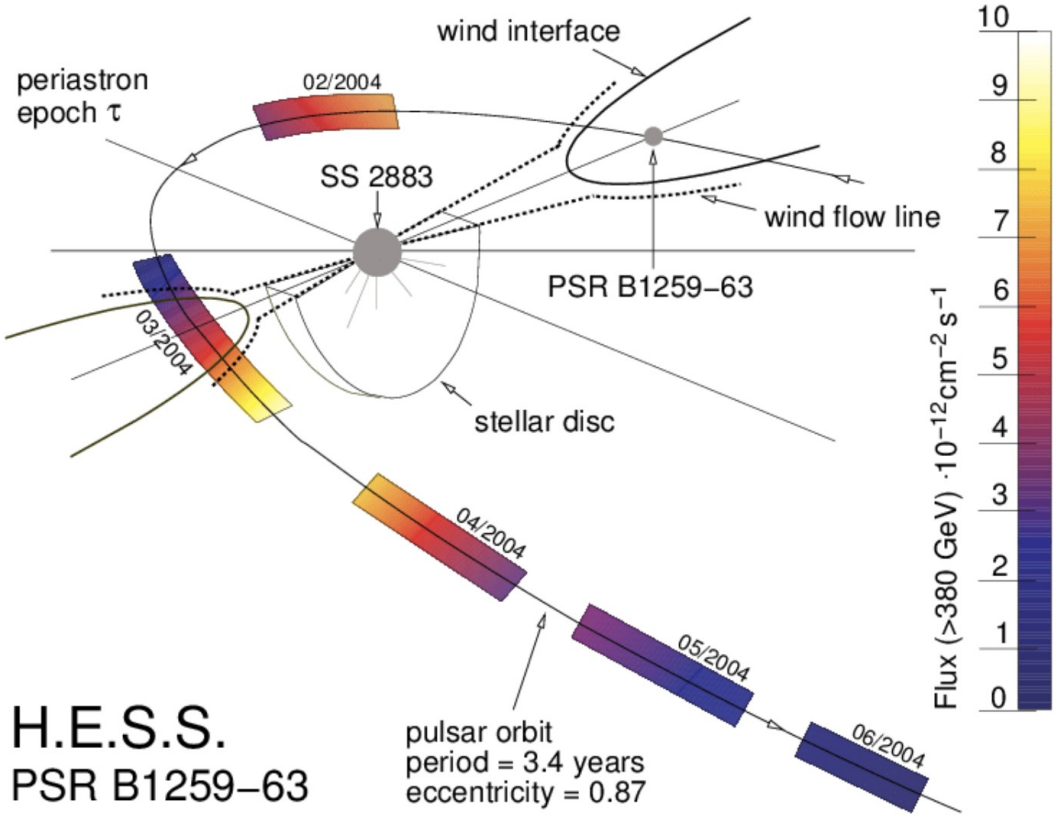
PSR B1259-63: highlights



Aharonian+ 2005

- A pulsar on ~3.4 yr orbit around Be star
- Decretion disk of Be star is inclined to the orbit of the pulsar
- Pulsar intersects the disk twice around the periastron
- A lot of non-thermal emission close to periastron: from radio to TeVs
- Most probable origin – interaction of the pulsar wind with Be star decretion disk
- Still a lot of open questions:
  -- role of *geometry/orientation* of the interaction surface
  -- role of *clumps*
  -- exact *mechanism of production* and *population(s) of particles* responsible for the emission at different wavelengths

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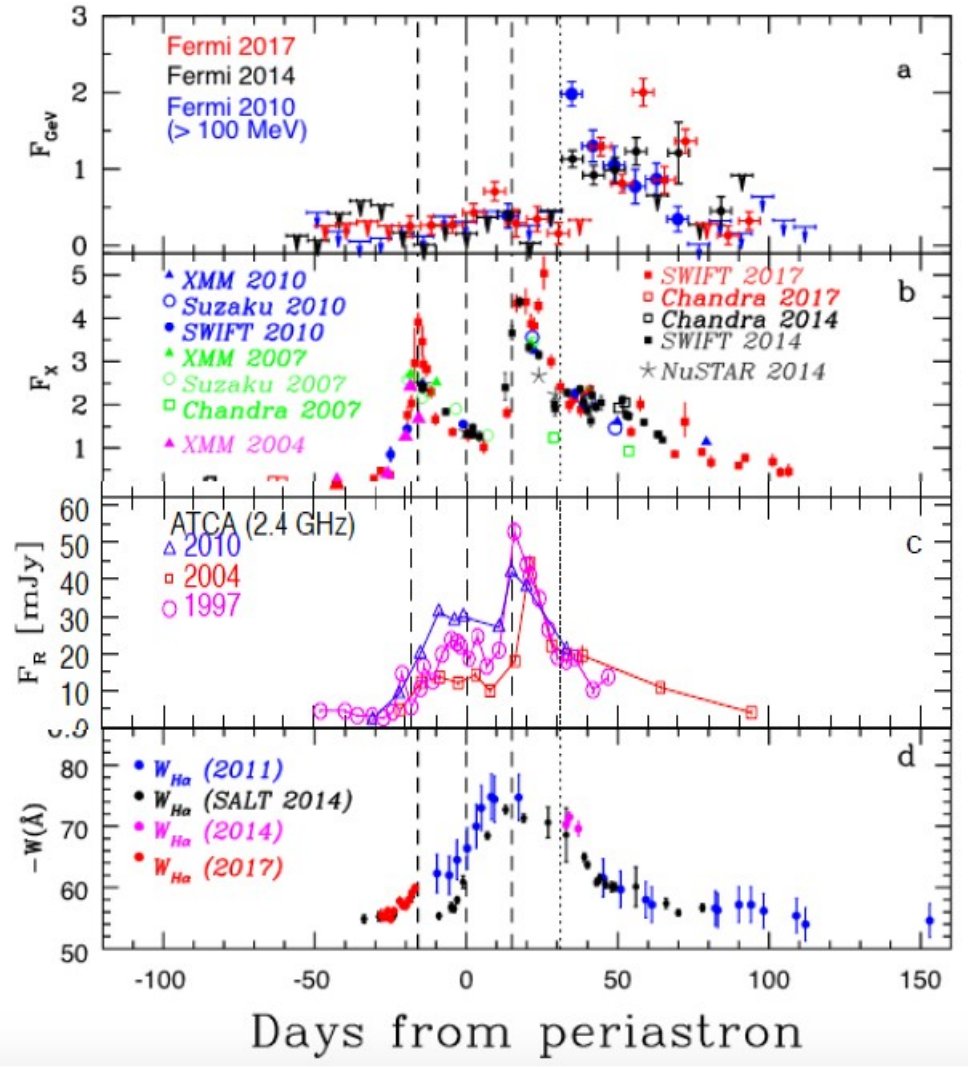
PSR B1259-63: highlights



"Usual" (pre 2021) behaviour:

- Two peaks in X-ray and radio
- Peaks ~15 days around the periastron.
- Correspond to the passage through the Be star disk.
- High level of GeV emission ~30+ day after the periastron.
- No obvious counterpart for GeV flare at other energies.

Chernyakova et al. 2020

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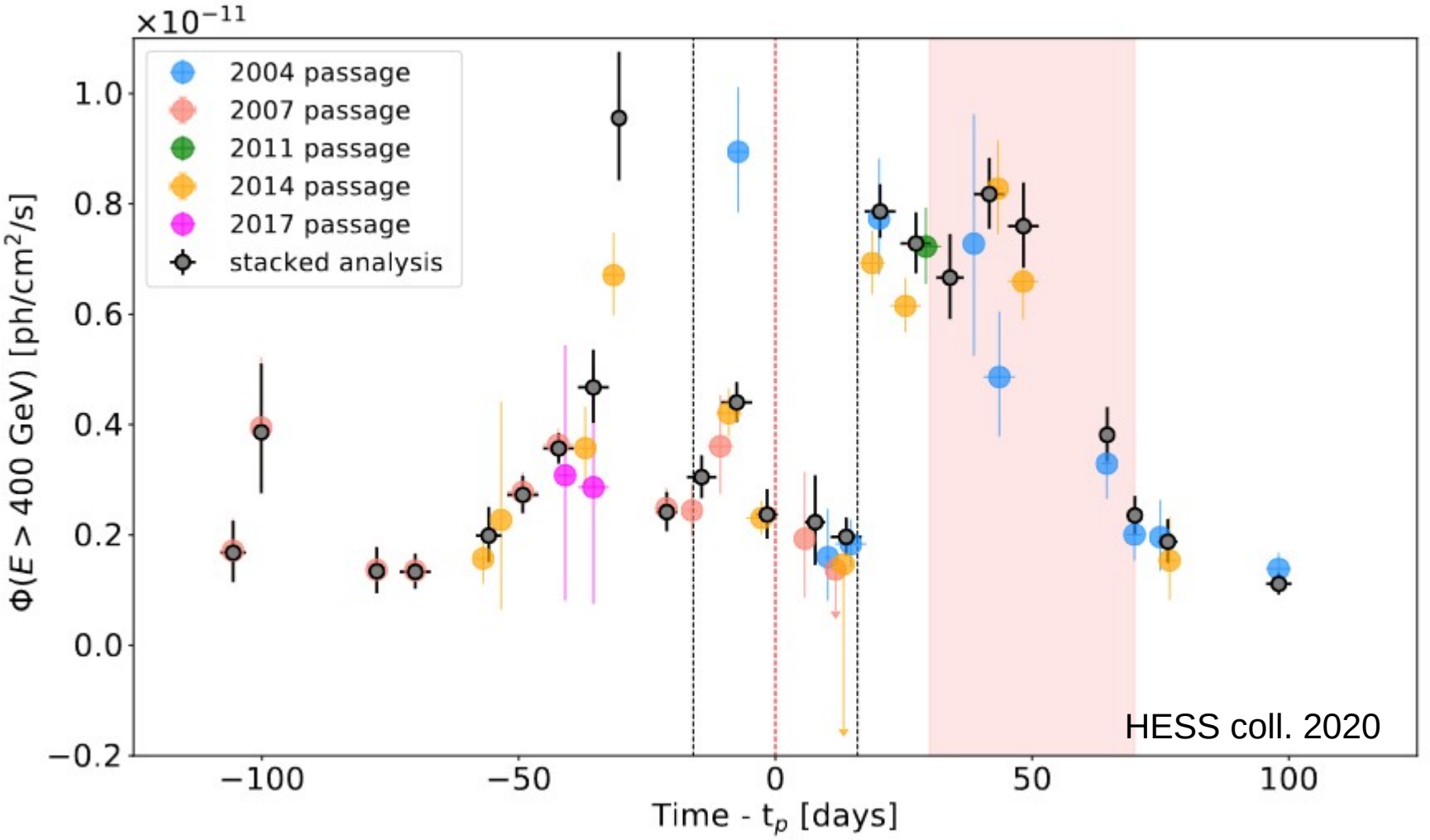
PSR B1259-63: highlights



- In TeV band system is detected at least from -100 to +100 days
- Totally different from GeV behavior in TeV band: 2-3(?) peaks LC

- No clear correlation to any other wavelength

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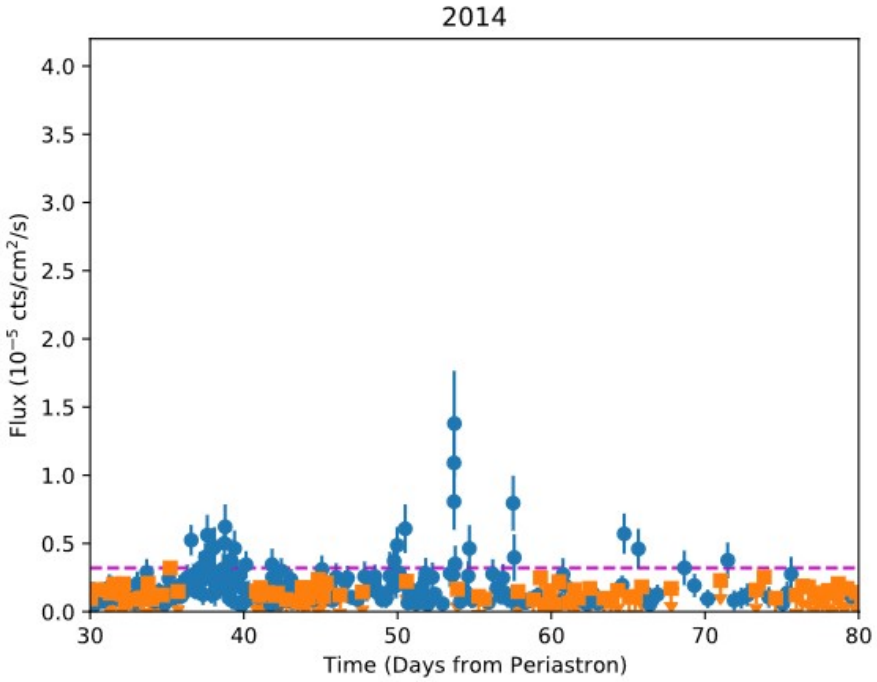
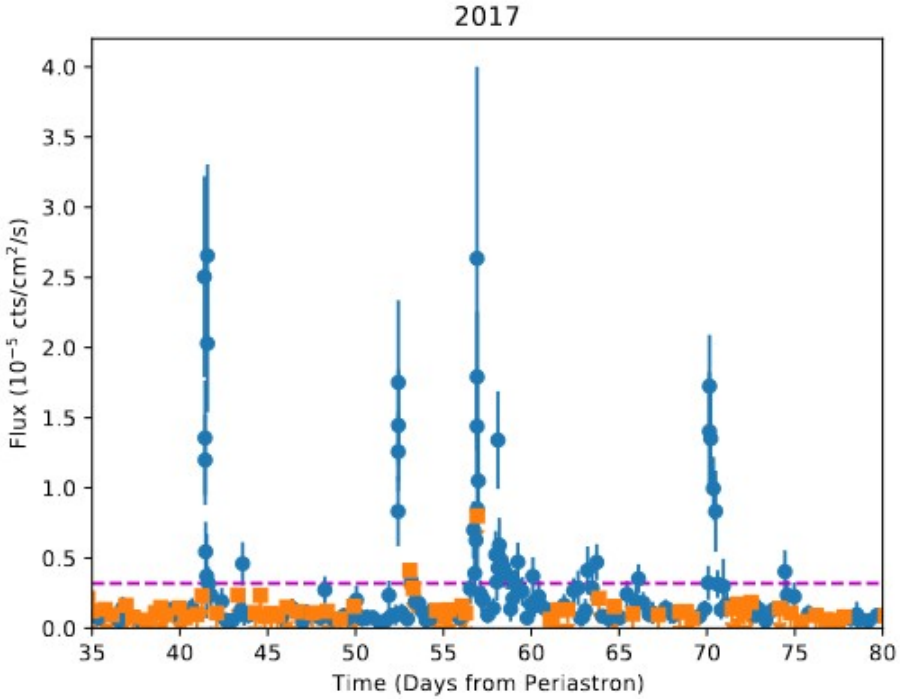
PSR B1259-63: key facts





- Very short and extremely strong GeV-subflares:
  – e.g. in 2017: 15 mins sub-flares with ~10s spin-down luminosity

- Various models to explain GeV, e.g. Tam et al. 2011, Kong et al. 2012,Khangulyan et al. 2012, Dubus & Cerutti 2013, Yi & Cheng 2017, but the source brings new and new suprises ...

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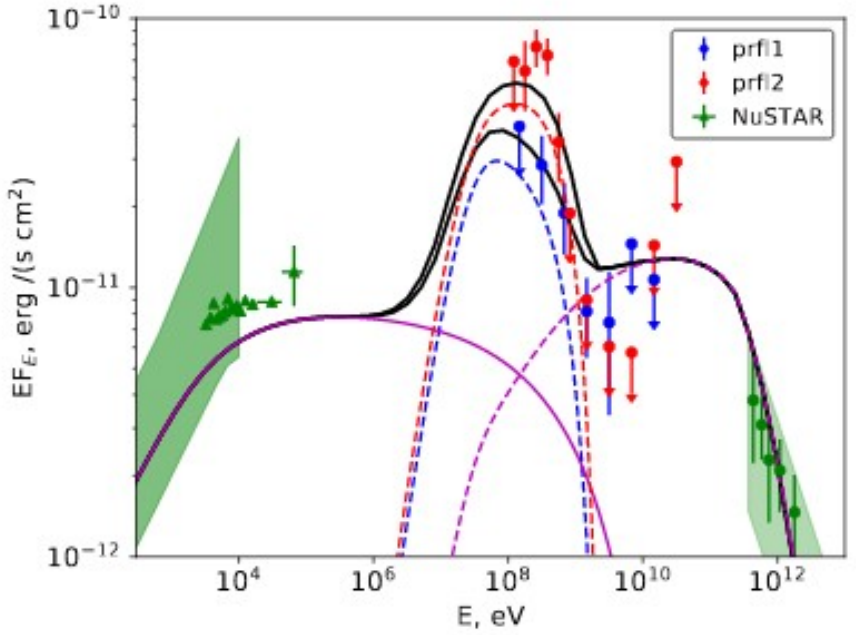
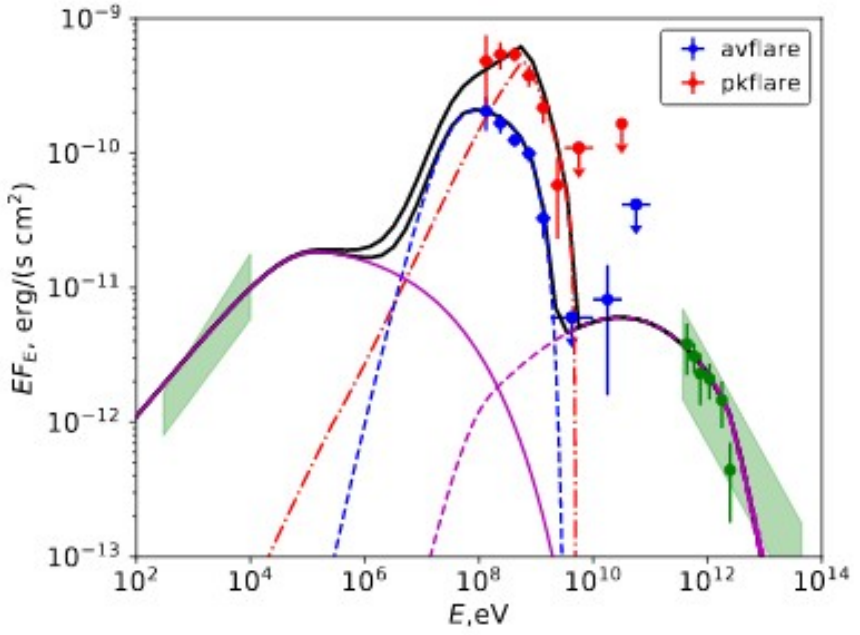
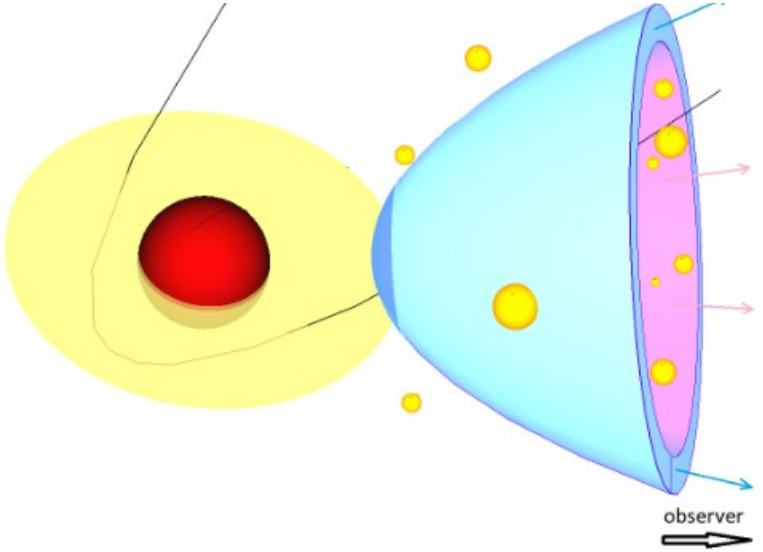
PSR B1259-63: models







- Simple models (radio-X-rays – synchrotron; GeV-TeV – IC) do not work!
- Indications for a cone-like geometry of the PSR wind in the system?

Chernyakova et al. 2020

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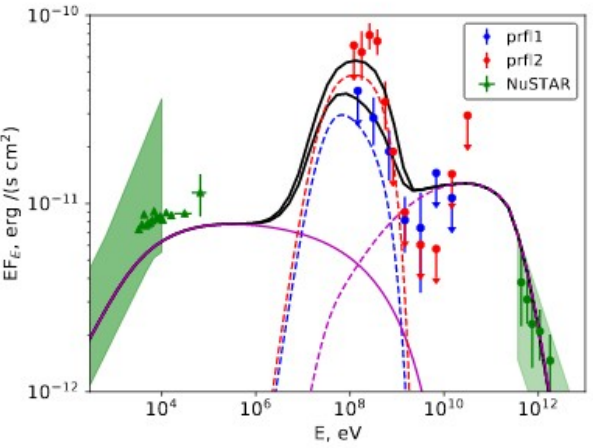
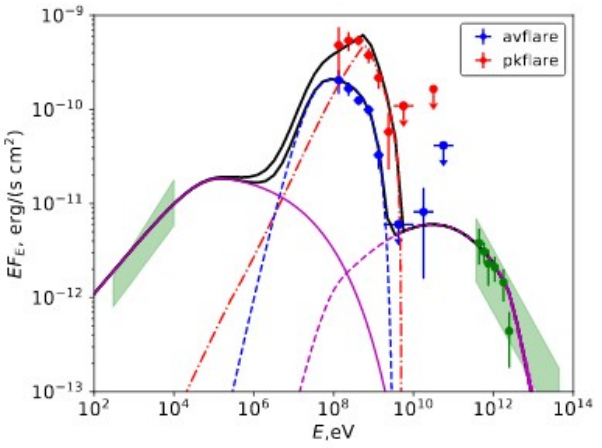
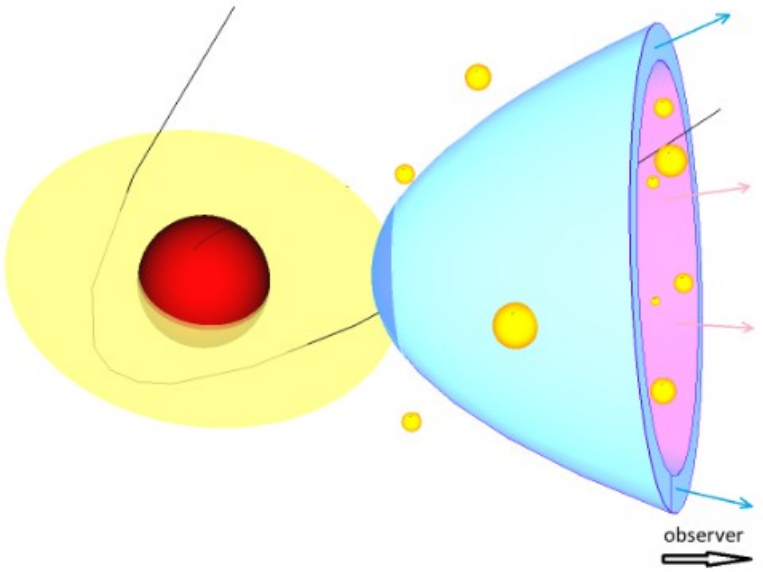
PSR B1259-63: models





- 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

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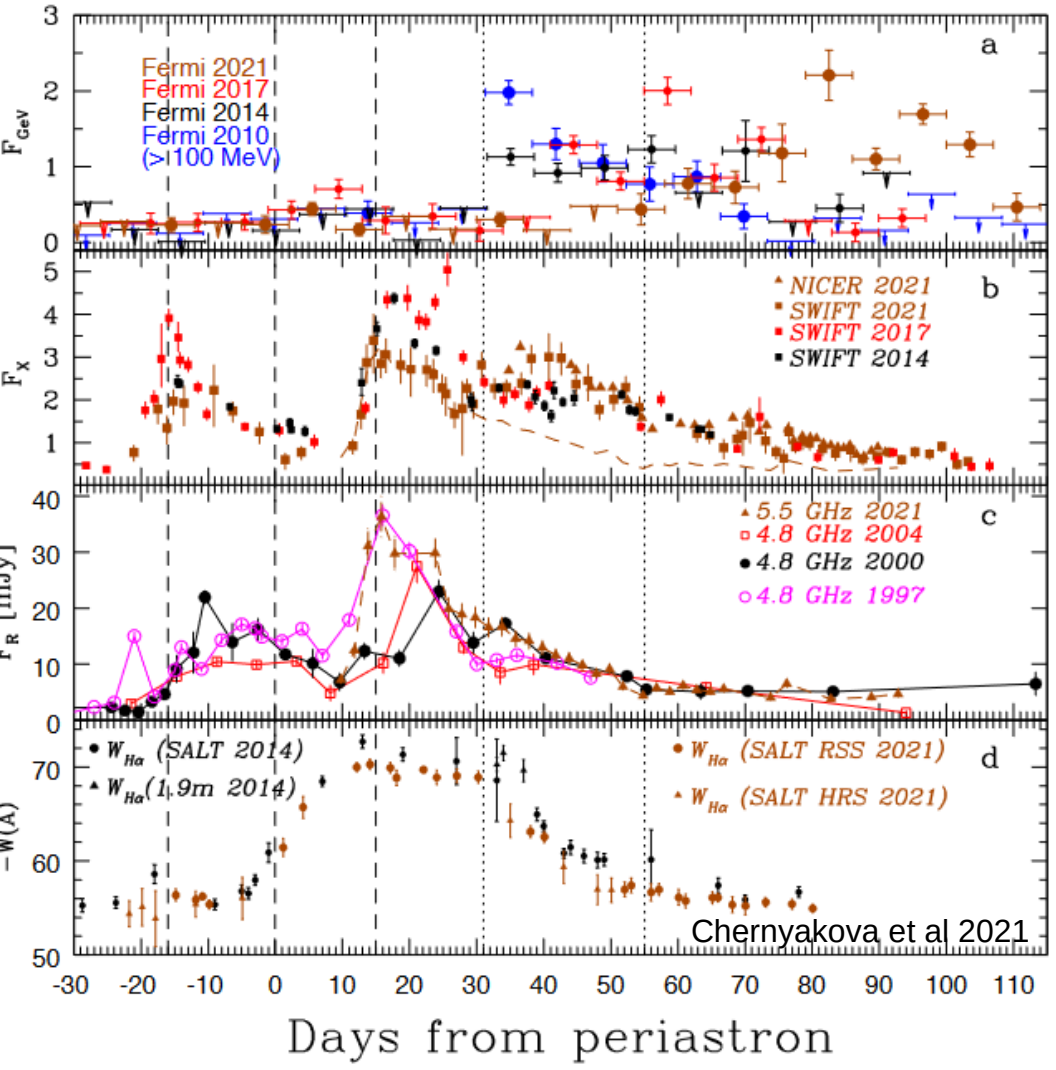
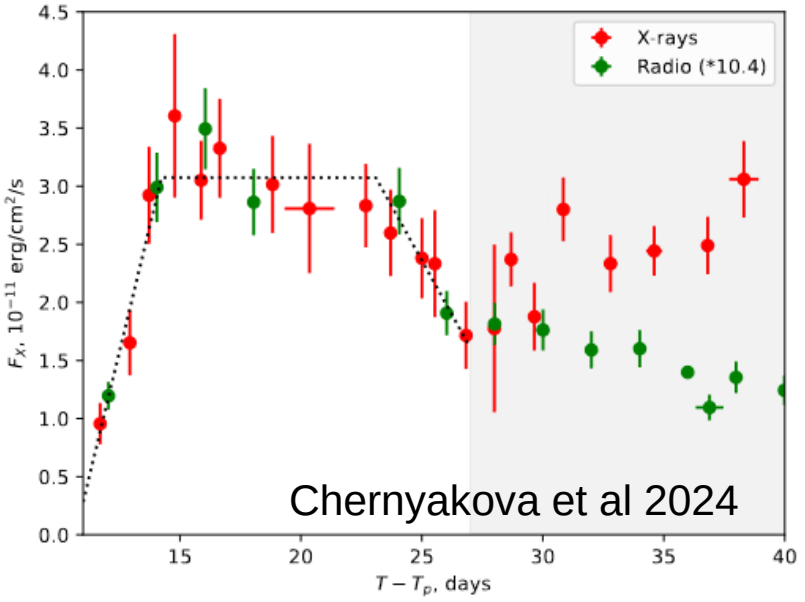
PSR B1259-63: 2021 periastron



- Somewhat delayed Fermi flare
- New LC feature: 3rd X-ray peak
- Radio – X-ray correlation broke down during 3rd X-ray peak



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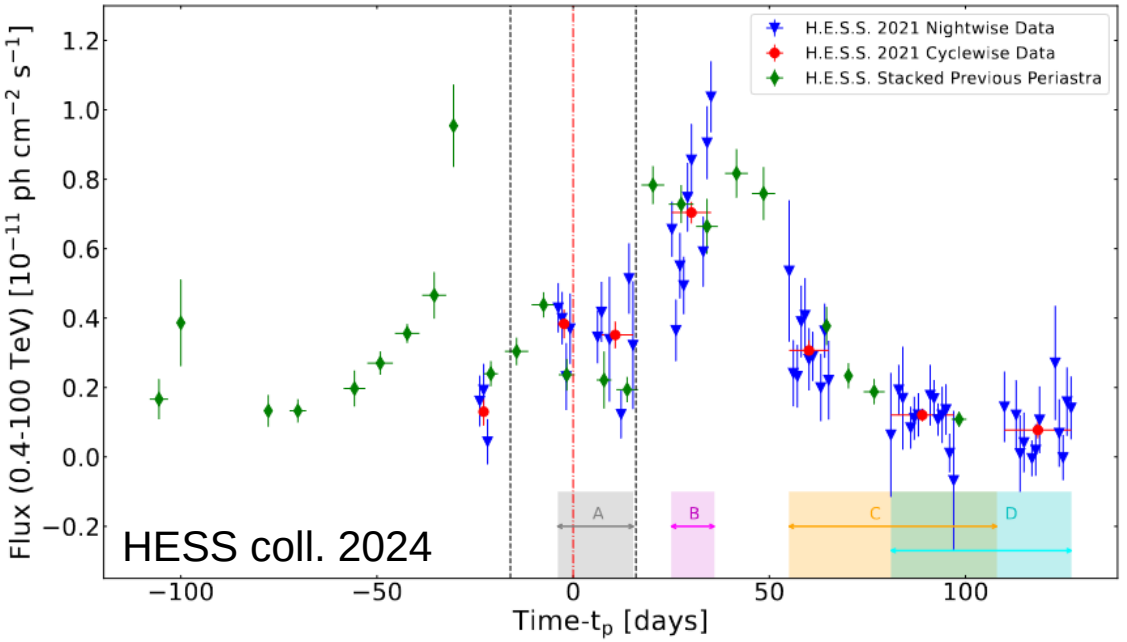
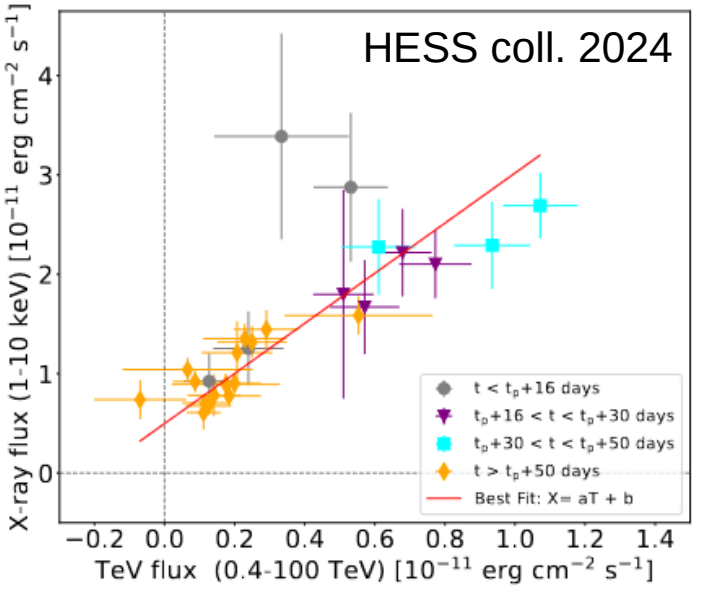
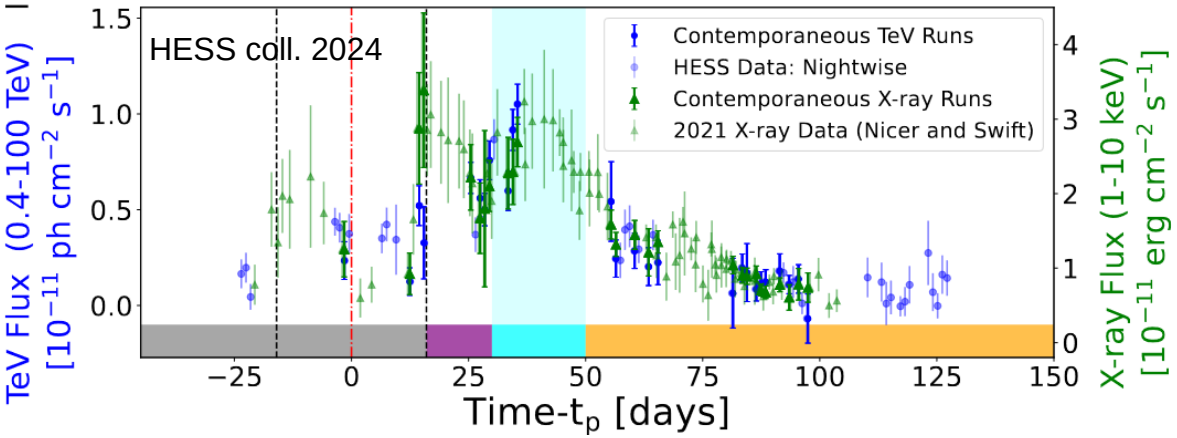
PSR B1259-63: 2021 periastron







- For the 1st time reported X-ray/TeV correlation during 2nd and 3rd X-ray peaks
- Same population of electrons?
- Or similarly-changing conditions in X-ray/TeV emitting regions?

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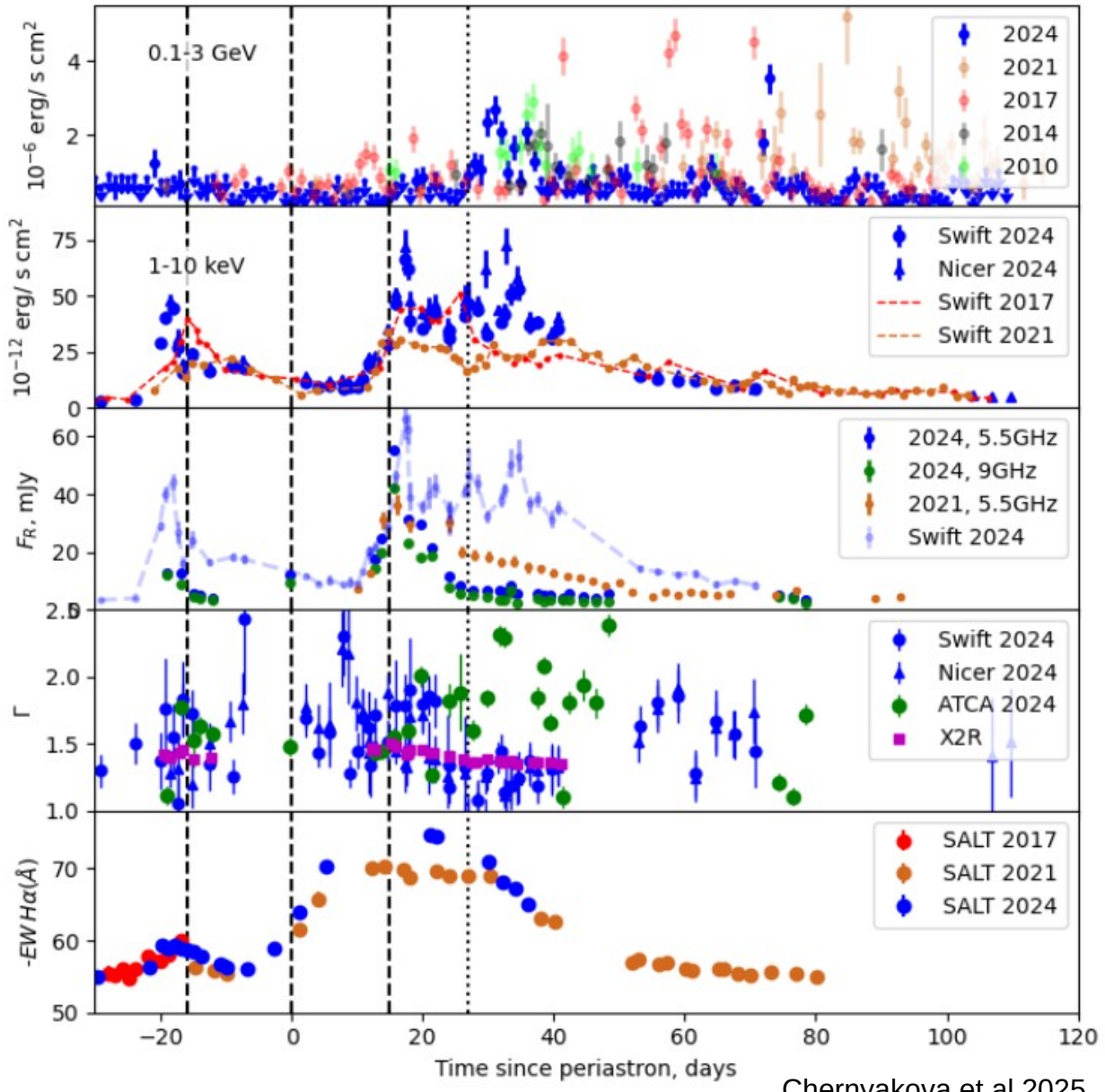
PSR B1259-63: 2024 periastron



Chernyakova et al 2025

- 2024: Early 1st X-ray peak
- Fermi flare started early (~2010) with a similar to 2010 intensity.
- Re-brightening at ~70 days after the periastron
- No X-ray/radio correlation during 1st X-ray peak
- Marginal X-ray/radio correlation during 2nd X-ray peak
- 3rd X-ray peak again?

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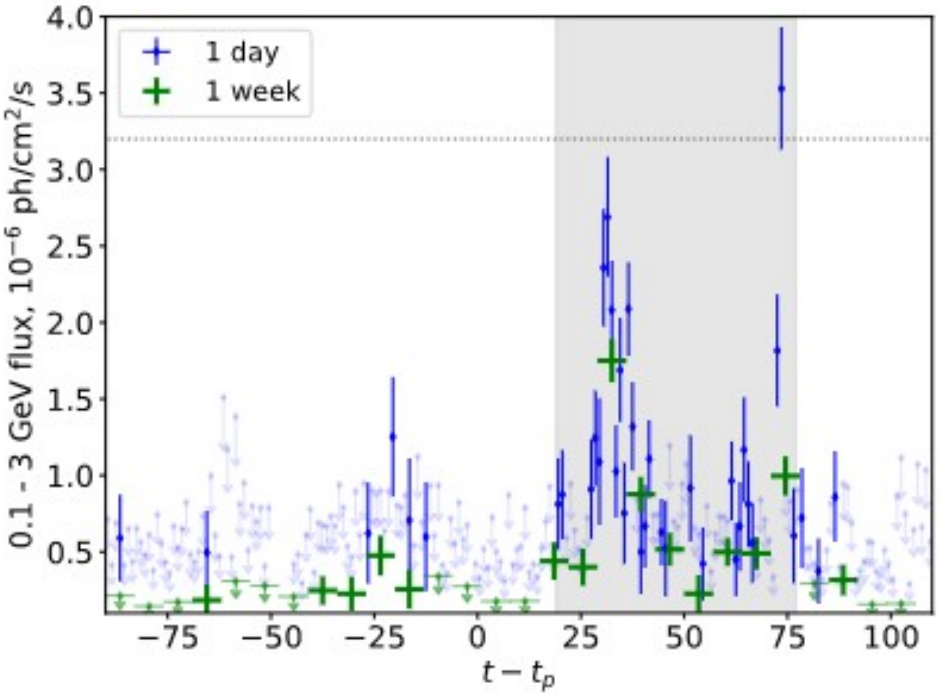
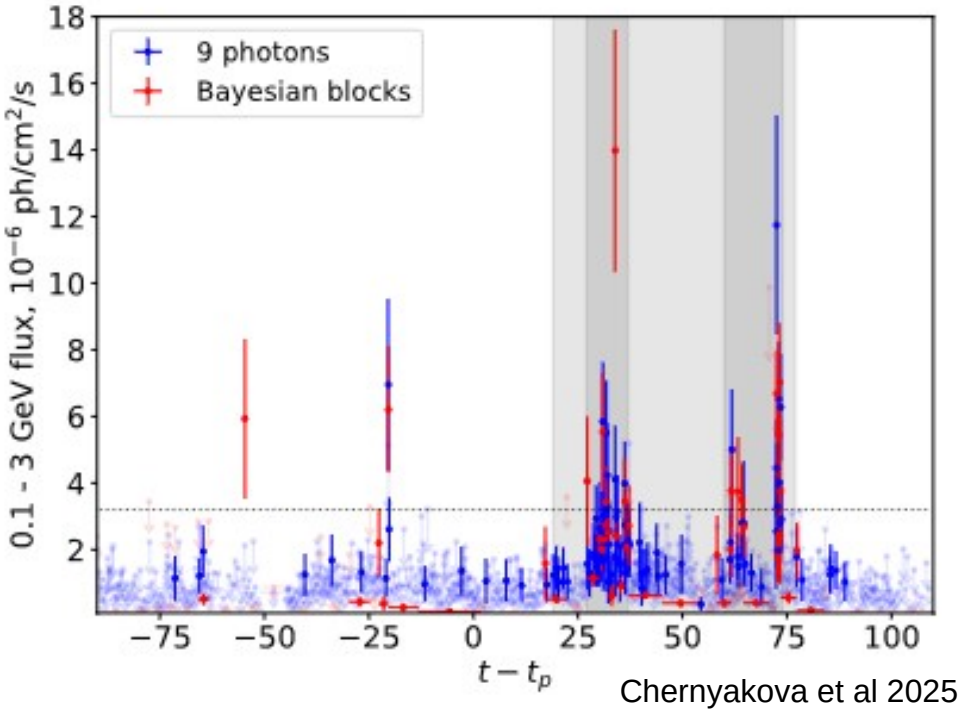
PSR B1259-63: 2024 periastron





Chernyakova et al 2025

- Relatively low number of short flares up to ~5*spin-down luminosity
- Some hints of *pre-periastron* flares? *Low statistical significance!*

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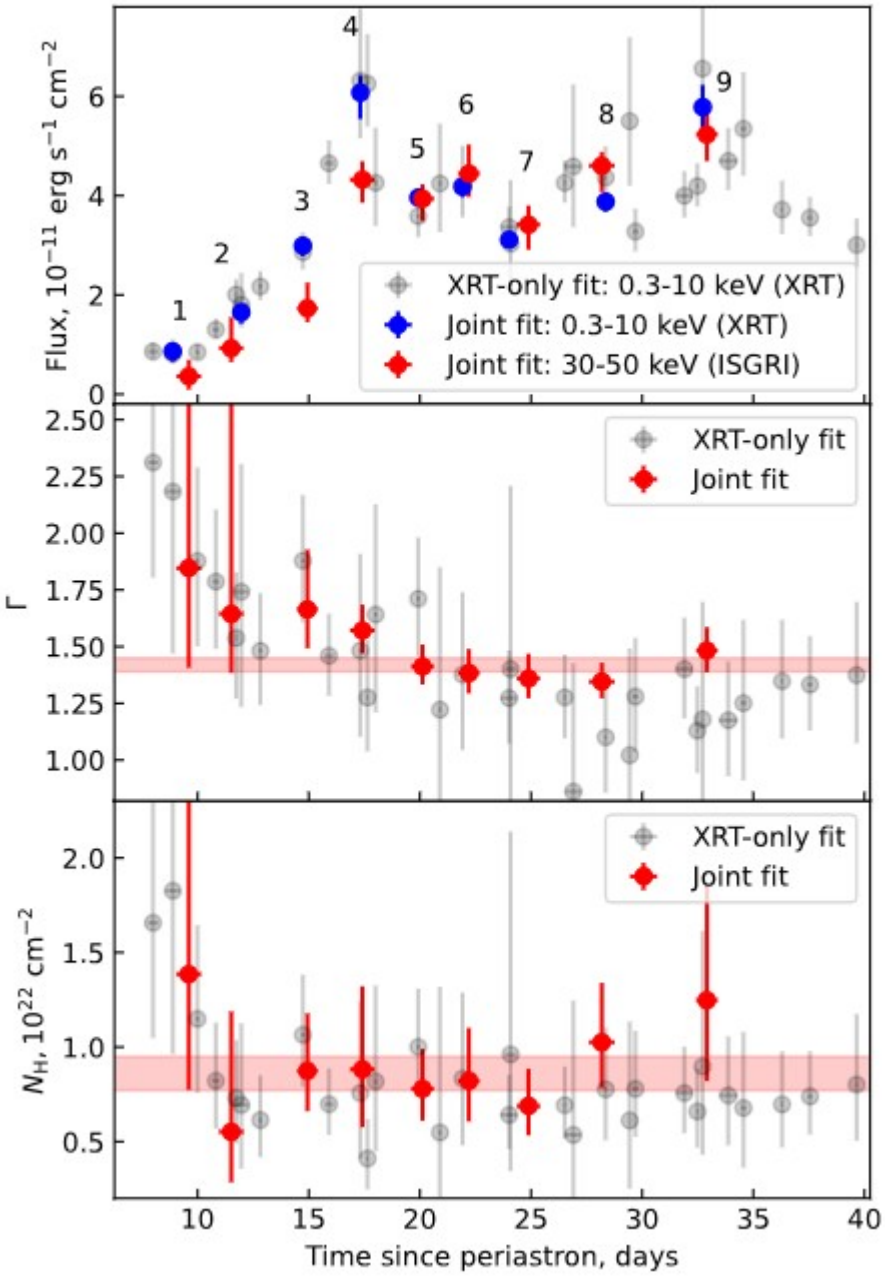
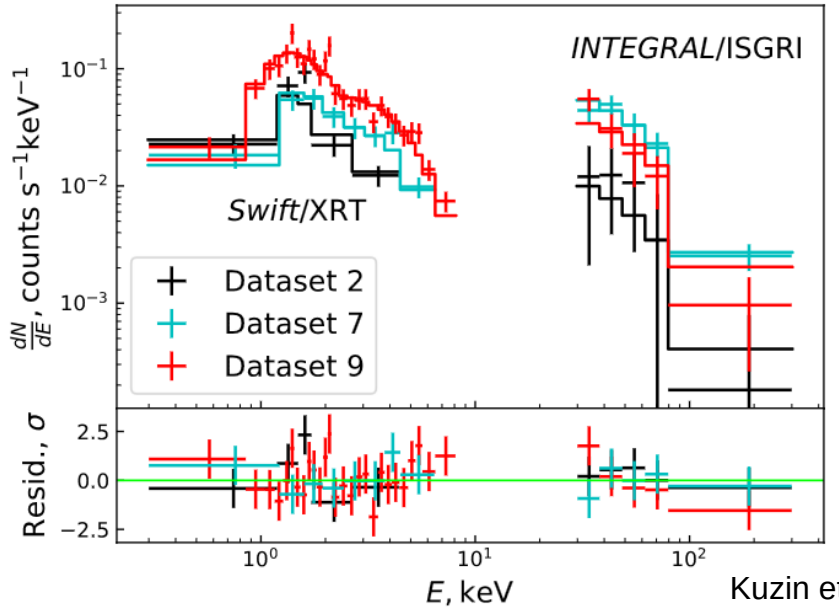
PSR B1259-63: 2024 periastron





Kuzin et al 2025

- Intensive monitoring in hard X-rays with INTEGRAL/ISGRI. Detection up to 200 keV.
- Lightcurve consistent with Swift/XRT (0.3-10 keV). Indications of post-periastron hardening of the spectrum.

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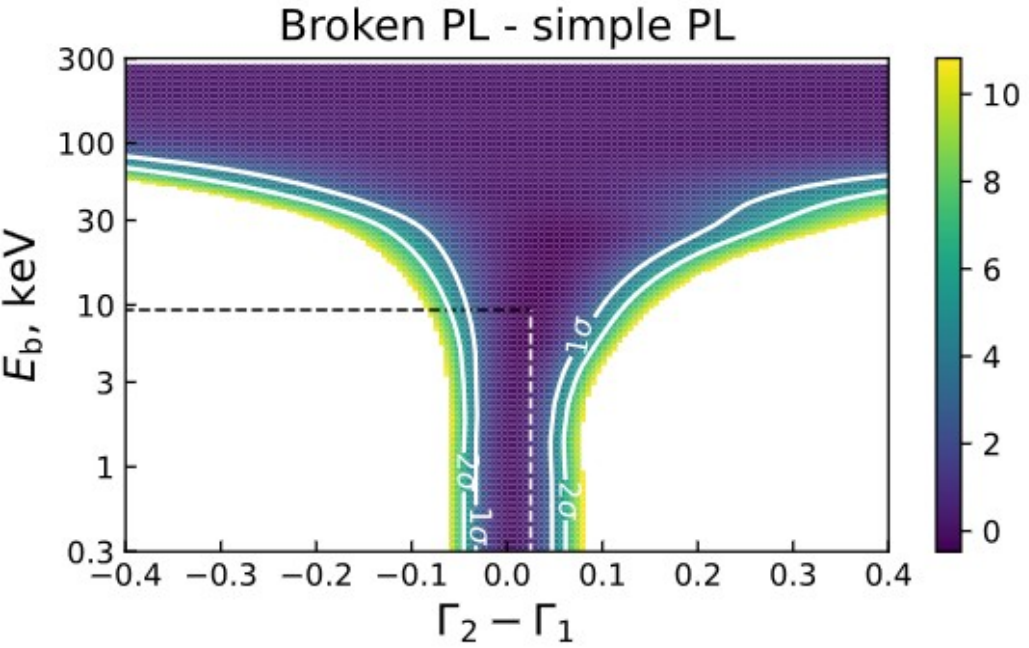
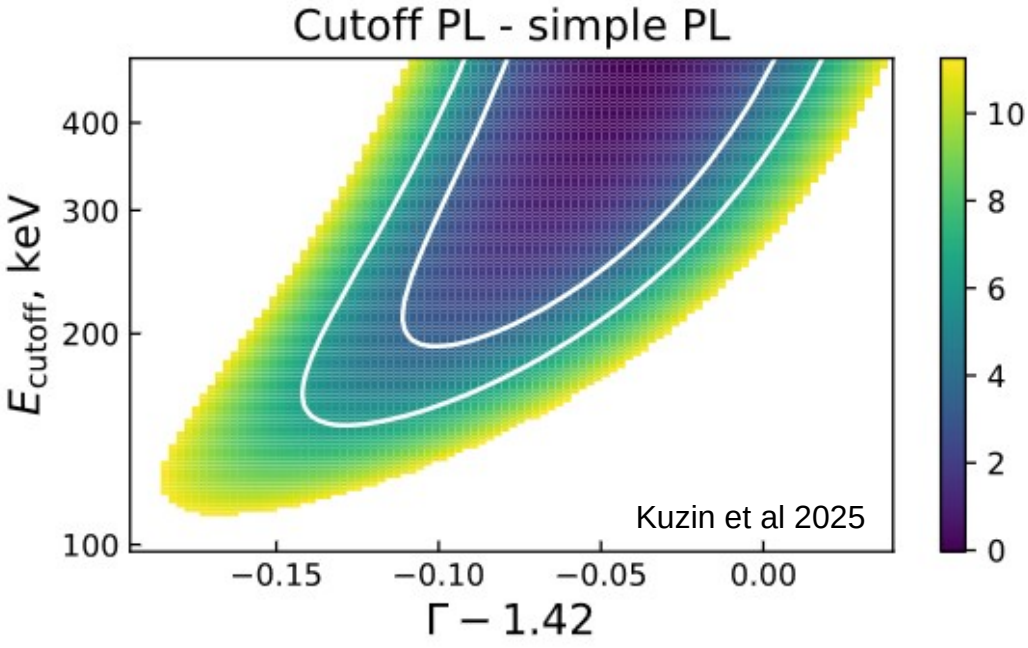
PSR B1259-63: 2024 periastron





- No indication of a break up to 10 keV and cutoff up to 150 keV
- For the characteristic magnetic field of 1 G corresponding electrons' energies are ~0.4 TeV (break) and ~2 TeV (cutoff)
- Consistent with HESS results for 2021 periastron passage (E_c>27 TeV)

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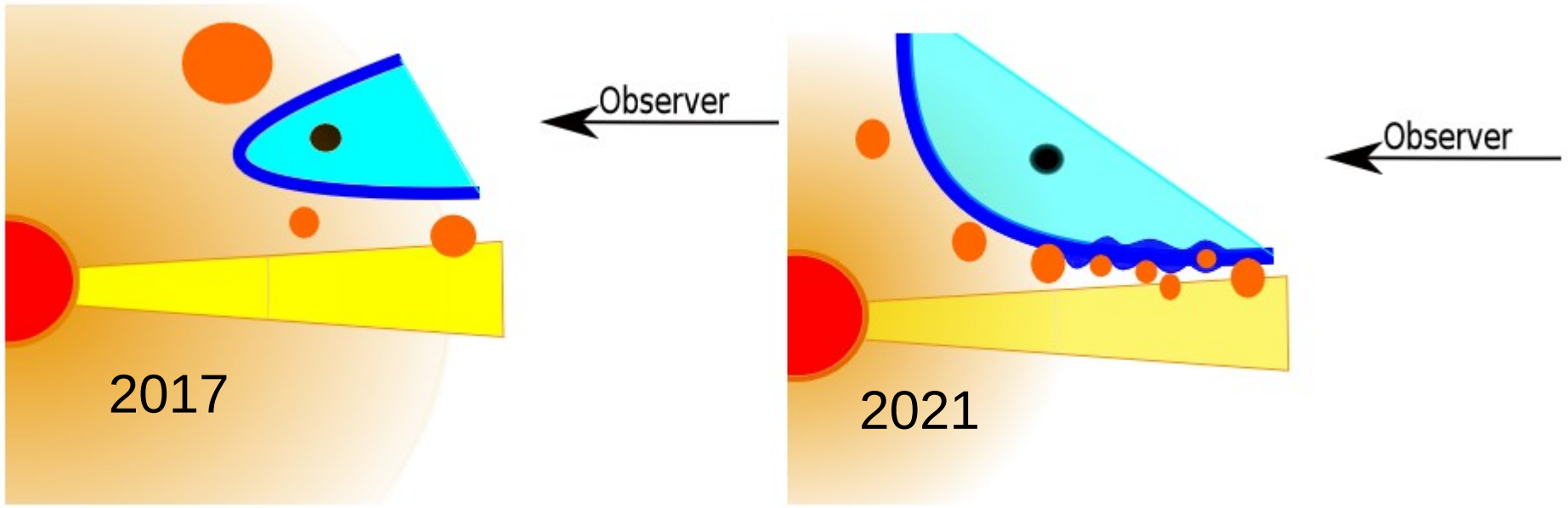
PSR B1259-63: 2024 periastron



- Dense, large decretion disk of Be star? Supported by optical Halpha observations
- Small opening angle of the cone – earlier and brighter Fermi flare?
- Low number of clumps – low number of short flares?

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Conclusions

- Very high energy emission from gamma-ray binaries is a result of interaction of relativistic wind from the compact star with the non-relativistic wind of the massive optical companion (O- or Be-type star).
- PSR B1259-63 is a classical pulsar-hosting gamma-ray binary detected close to periastron from radio to TeVs
- Rapid short-timescale variability in the GeV band corresponds to luminocities exceeding spin-down by up to a factor of 10. Such luminosity can be explained in “cone-geometry” model
- 2021 periastron brought a number of surprises: 3rd X-ray peak, X-ray/TeV correlation during 2nd-3rd X-ray peak; disappearence of radio-X-ray correlation in 2021
- Intense observational campaigns in 2024: no (marginal?) X-ray-radio correlation; early GeV flare with re-brightening. Hints of pre-periastron short flares.
- Detailed modeling still ongoing, stay tuned!

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¡Muchas gracias!