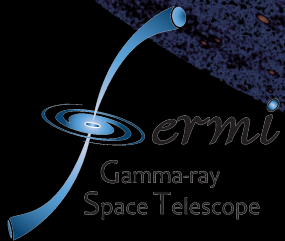


Hadronic or leptonic astrophysical particle accelerators? Breaking model degeneracy with gamma-ray variability

G. Martí-Devesa, O. Reimer, and C.C. Cheung

on behalf of the Fermi-LAT Collaboration

TAUP 2023, Vienna – 31.08.2023



①

Which populations of particle accelerators do we know?

①

Which populations of particle accelerators do we know?

②

How reliably can we relate them to Galactic neutrinos
and PeV cosmic rays?

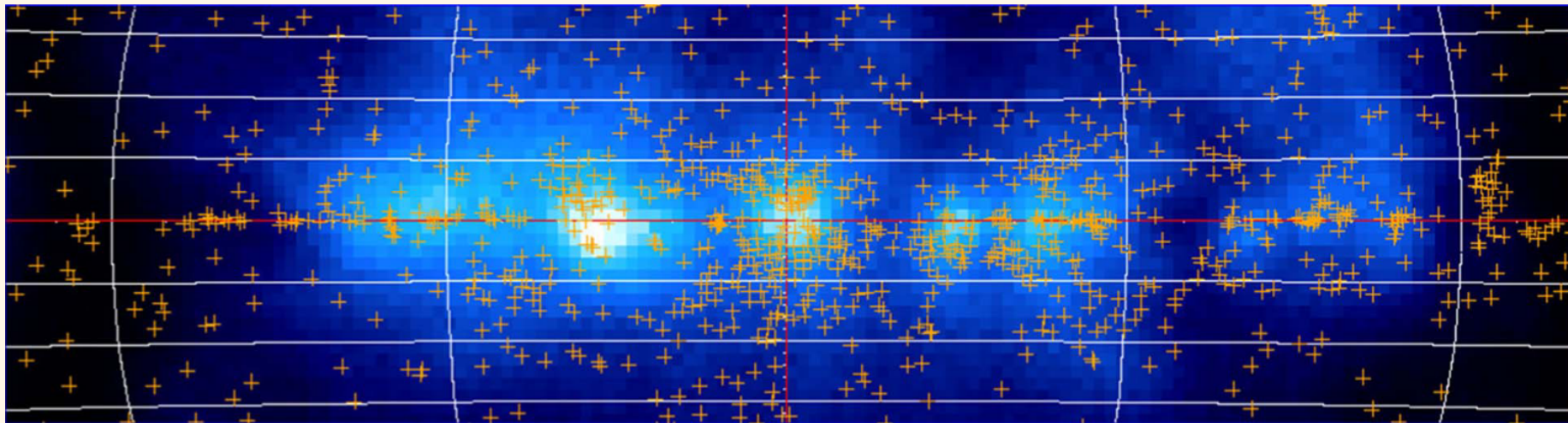
(1) 15 years of *Fermi*-LAT

New catalog released! **4FGL-DR4**
with 7194 sources (14-yr; AGN, SNR, PWN, ...)

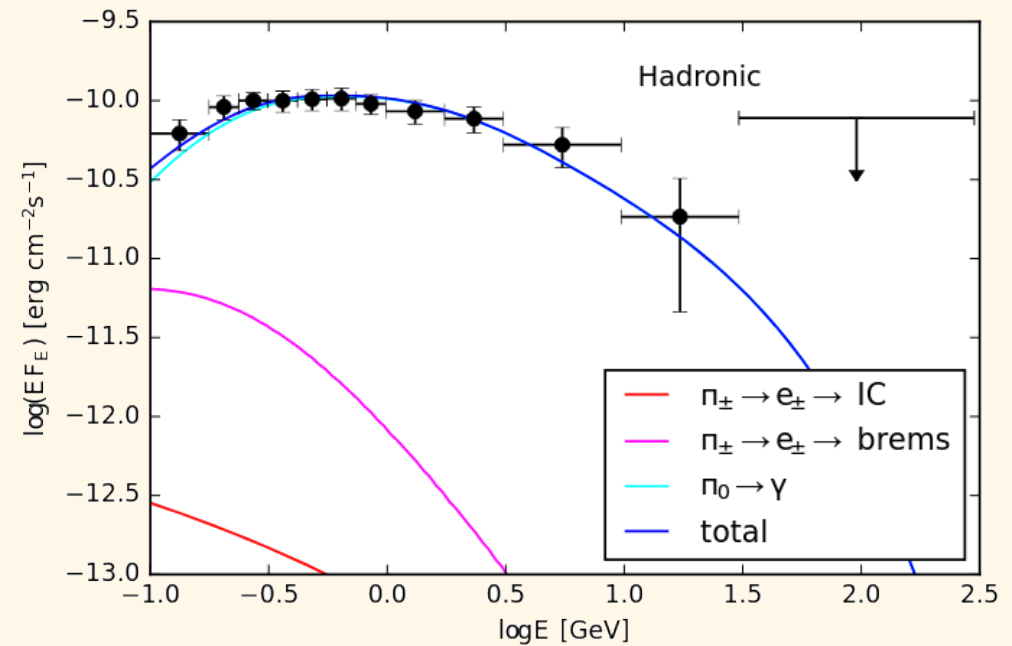
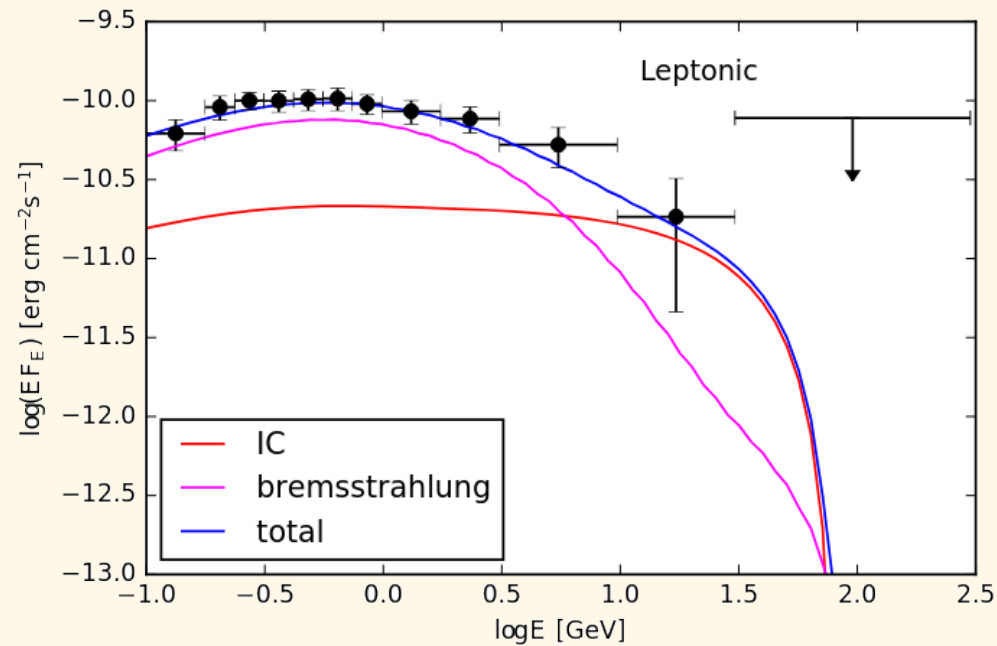
Substantial amount of **unassociated** sources
~ 40%



GC region, $|b| < 15^\circ$, $|l| < 70^\circ$, patch background color-scale. Credit: Abdollahi et al. 2022, ApJS

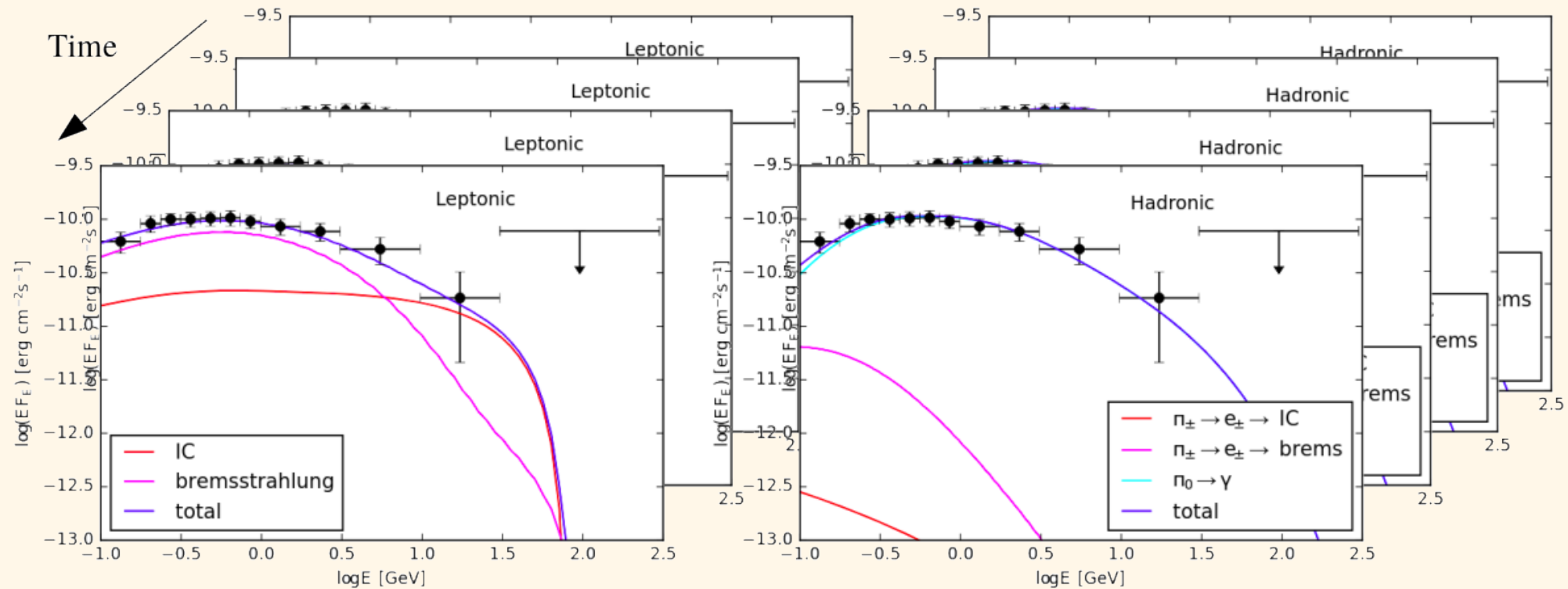


(2) A multi-messenger doubt: leptons or hadrons?



Nova V5856 Sgr. Credit: Li et al. 2017, Nature Astronomy

Let's look for time evolution

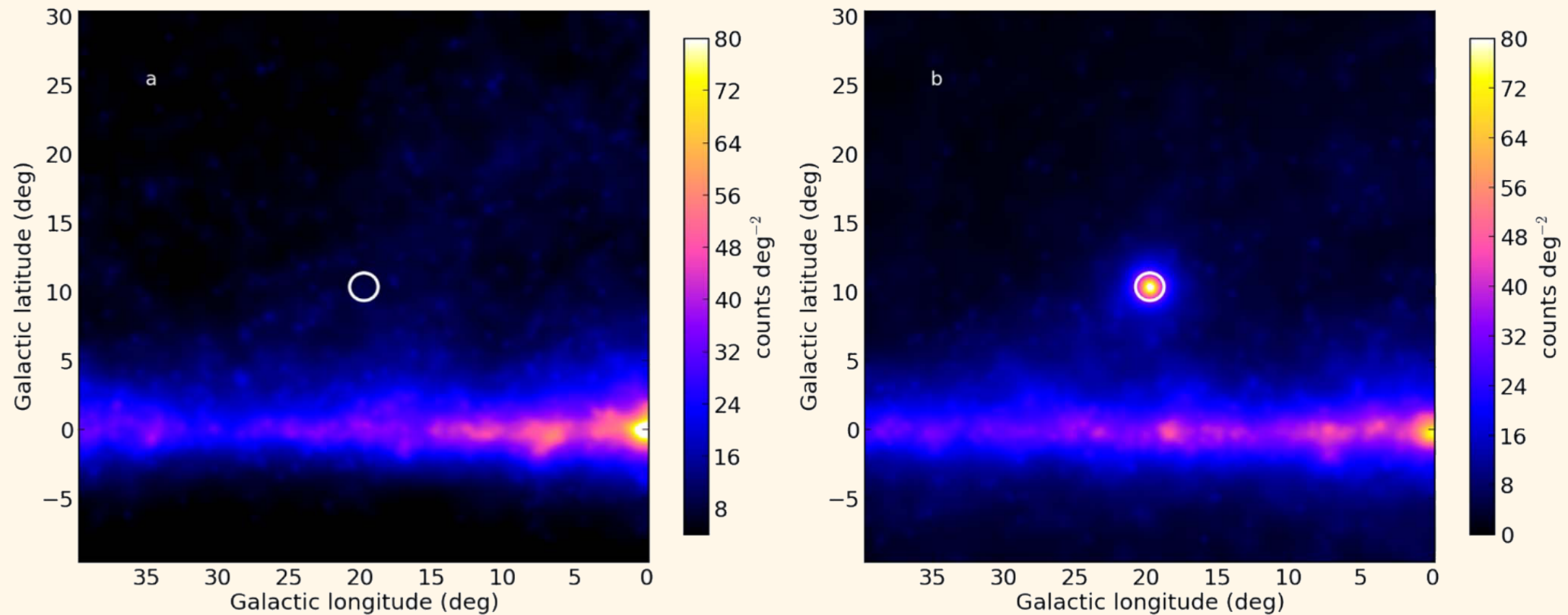


Nova V5856 Sgr. Credit: Li et al. 2017, Nature Astronomy



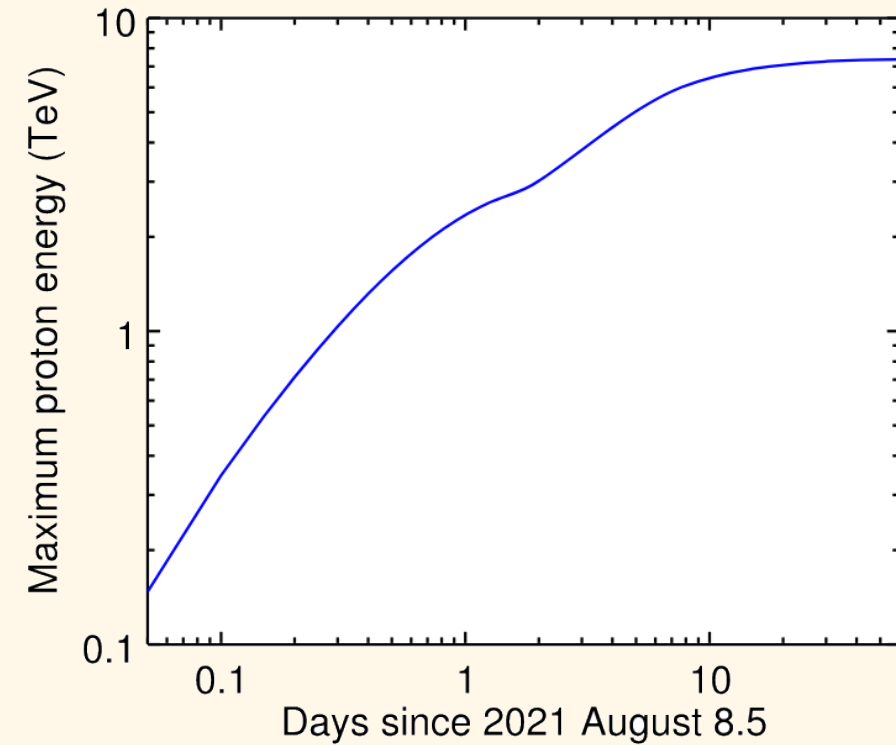
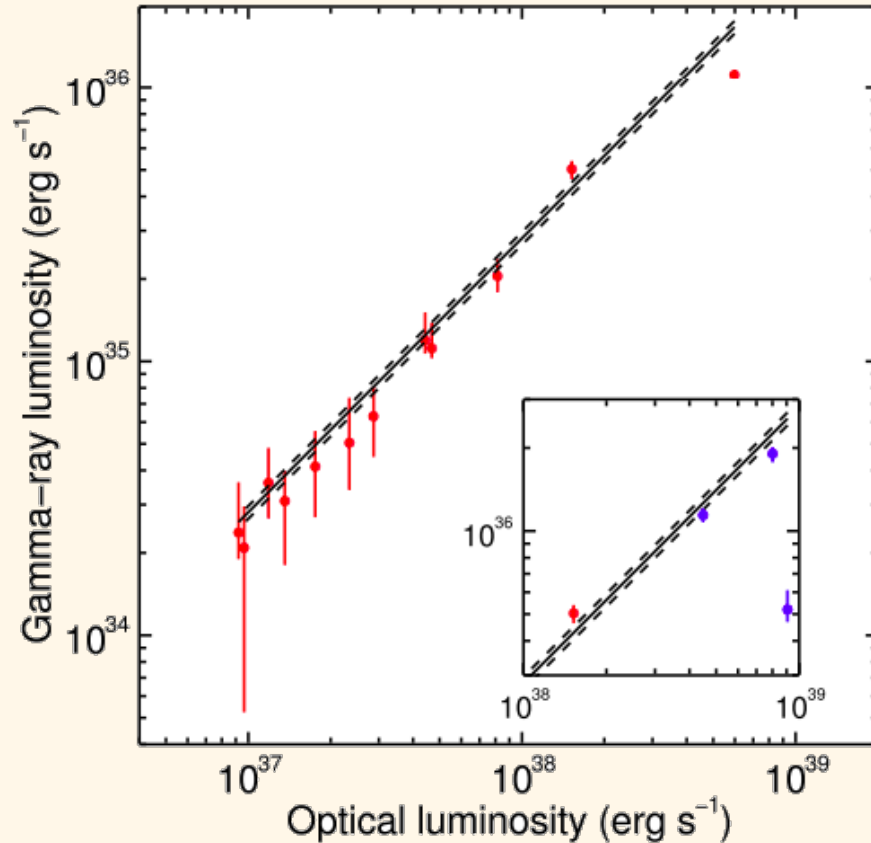
Example: RS Oph

Nova RS Oph: a transient gamma-ray source



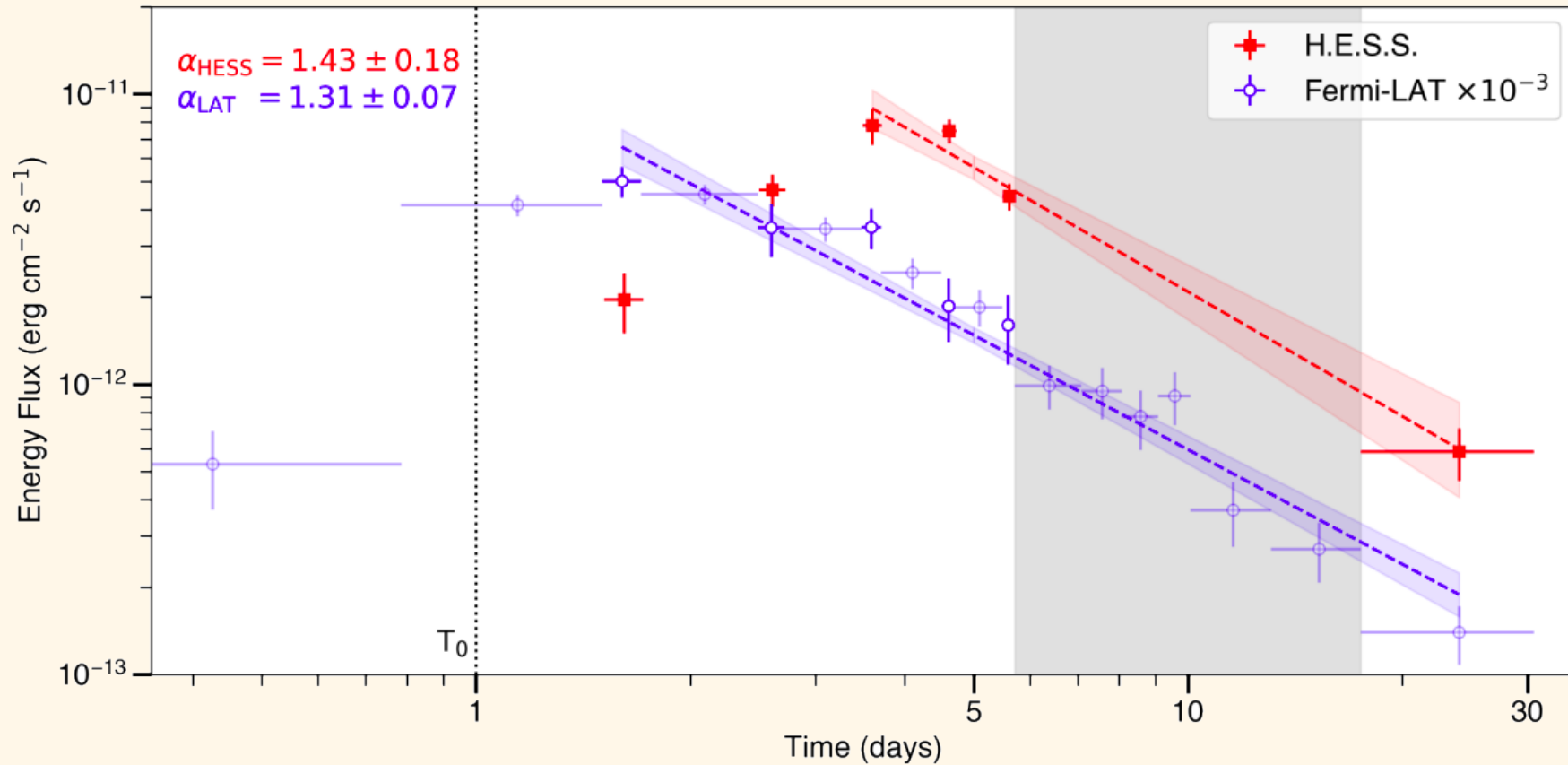
Credit: Cheung et al. 2022, ApJ

Proton evolution



Model by Tatischeff and Hernanz (check [arXiv:2302.01276](https://arxiv.org/abs/2302.01276)!). Credit: Cheung et al. 2022, ApJ

H.E.S.S. and MAGIC detection at VHE



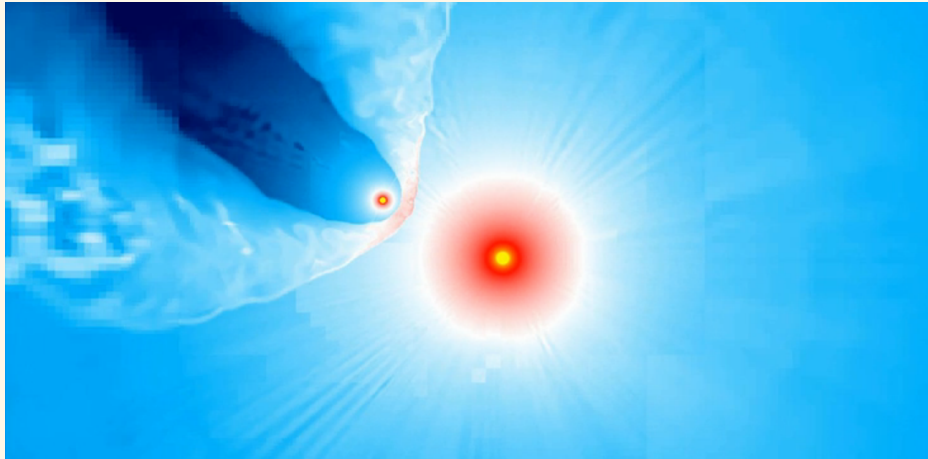
Check out also MAGIC Collaboration et al. 2022, Nature Astronomy! Image credit: H.E.S.S. Collaboration 2022, Science



Orbitally modulated shocks

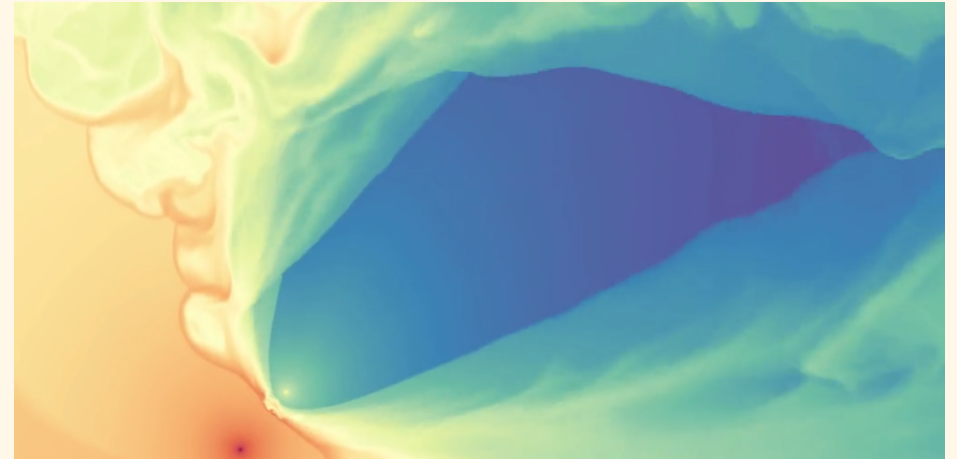
Binaries with modulated shocks

Binaries with massive stars can display shocks with varying conditions along the orbit



Credit: E. R. Parkin and E. Gosset

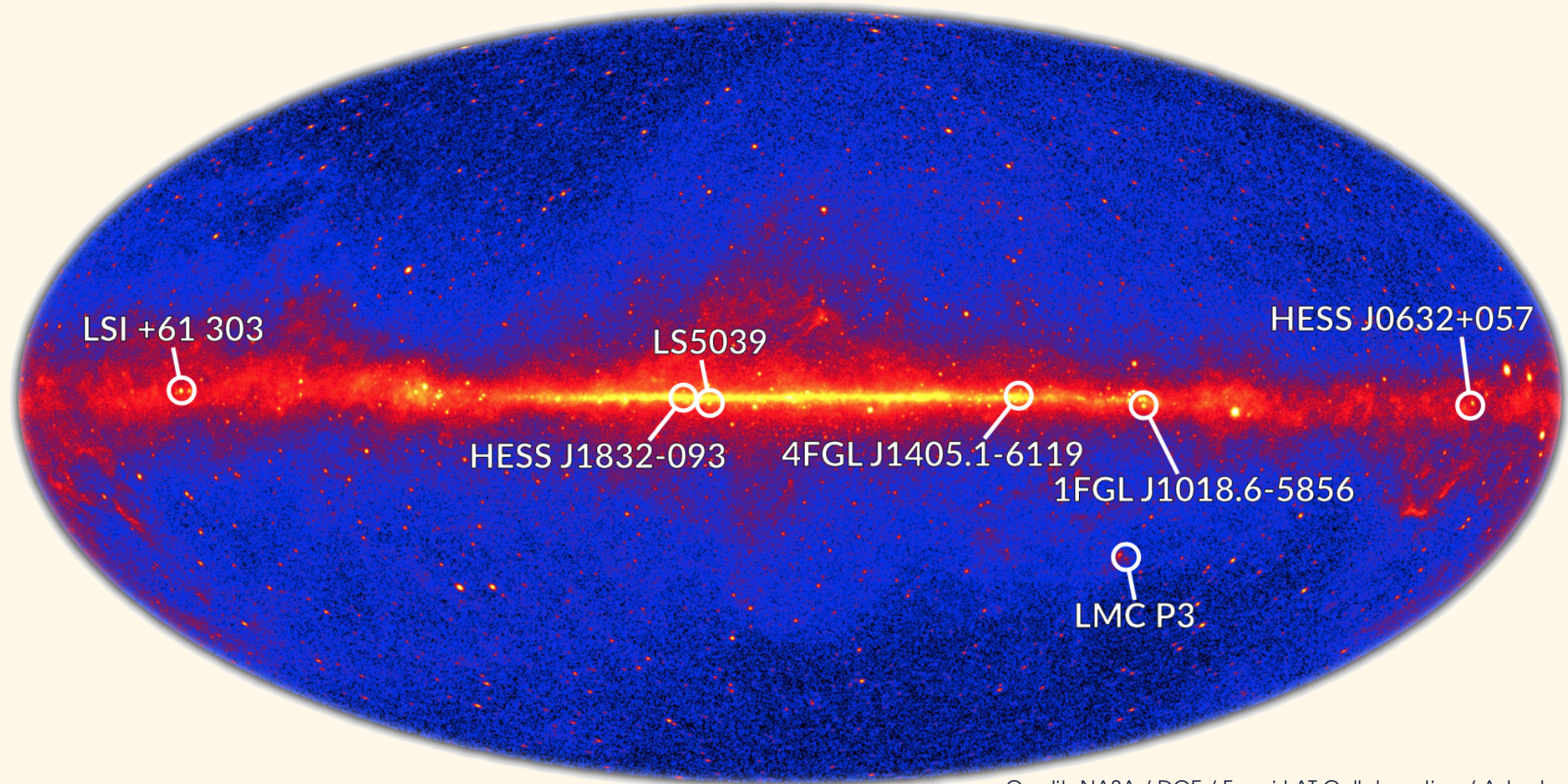
Colliding-wind binaries
(★ + ★)



Credit: D. Huber

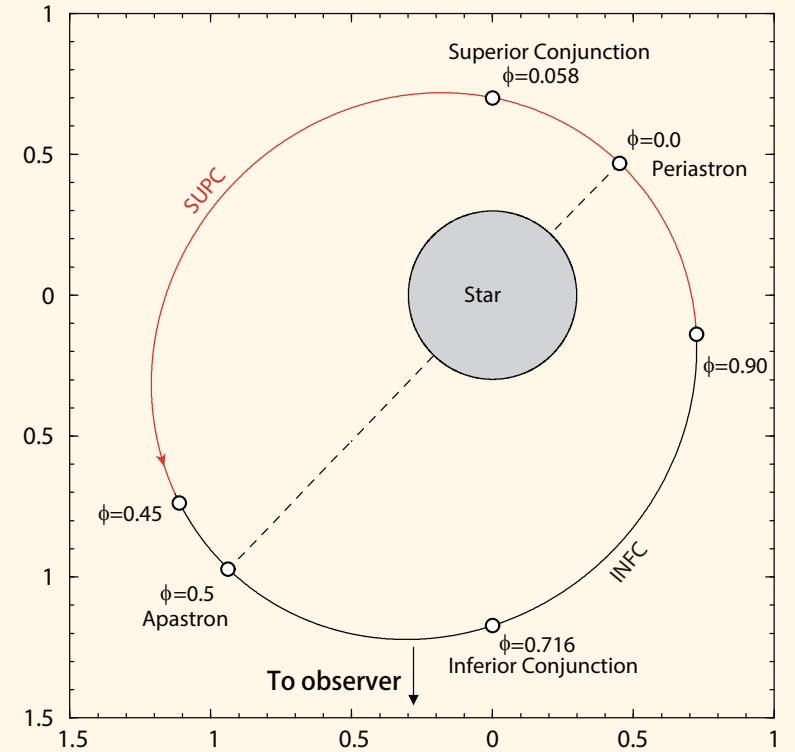
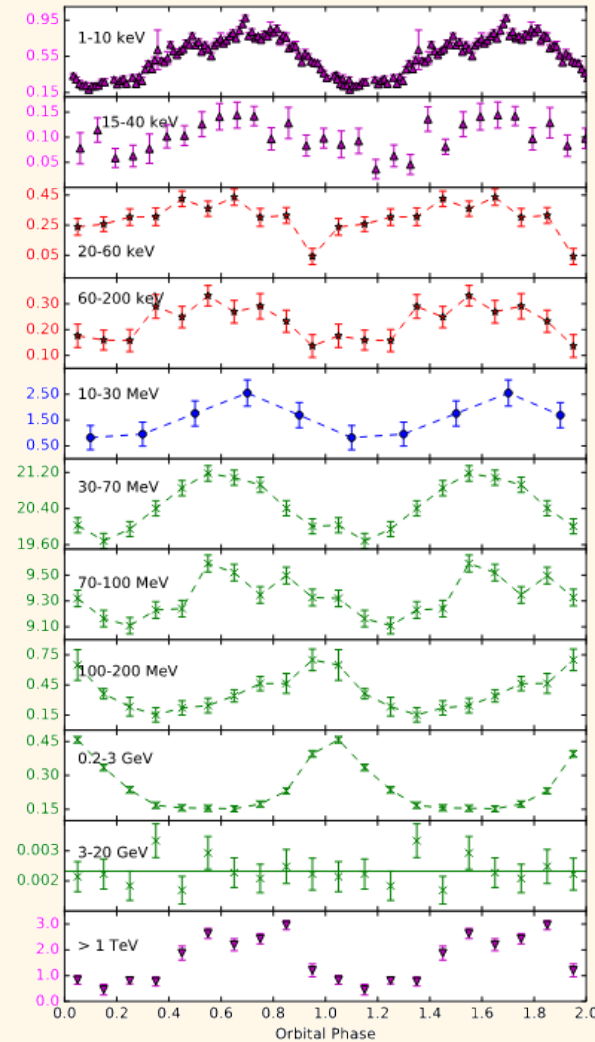
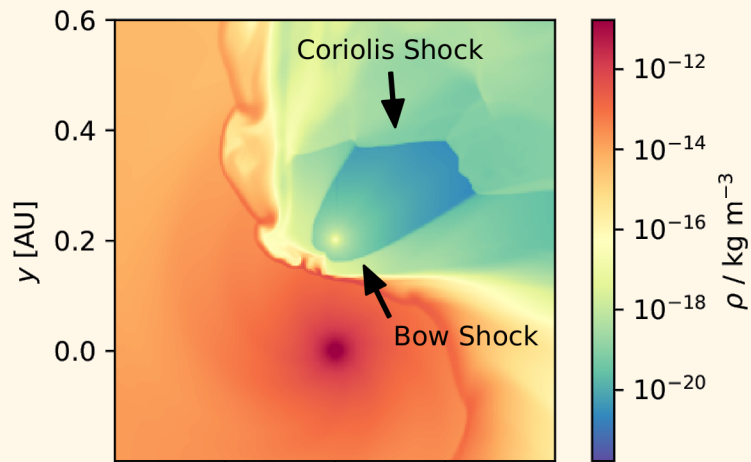
High-mass γ -ray binaries
(★ + ☉)

High-mass γ -ray binaries



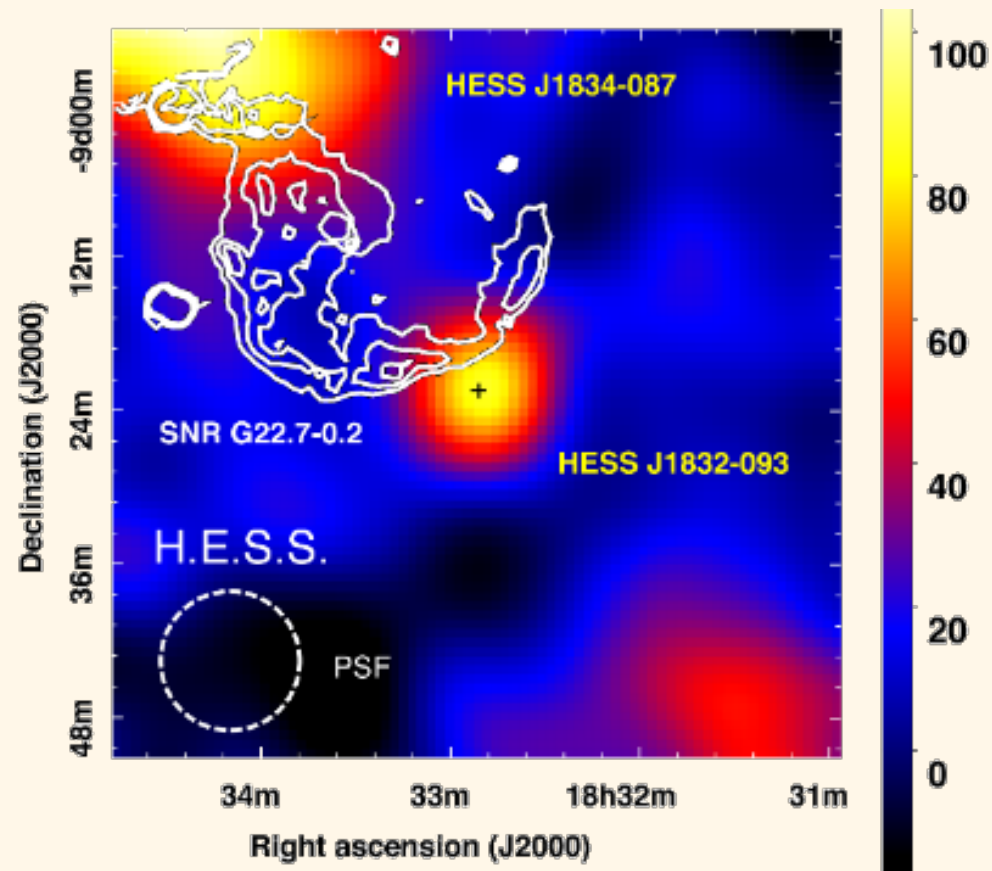
Credit: NASA / DOE / Fermi-LAT Collaboration / Adapted by D. Huber

How do we identify HMGBs



Credit to D. Huber and Z. Chang

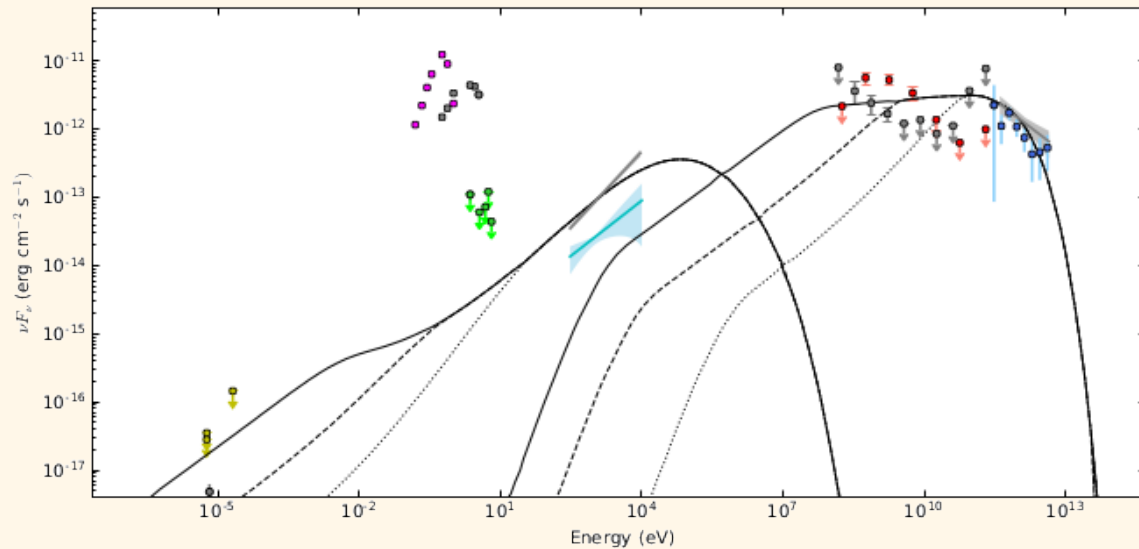
The latest addition, HESS J1832-093



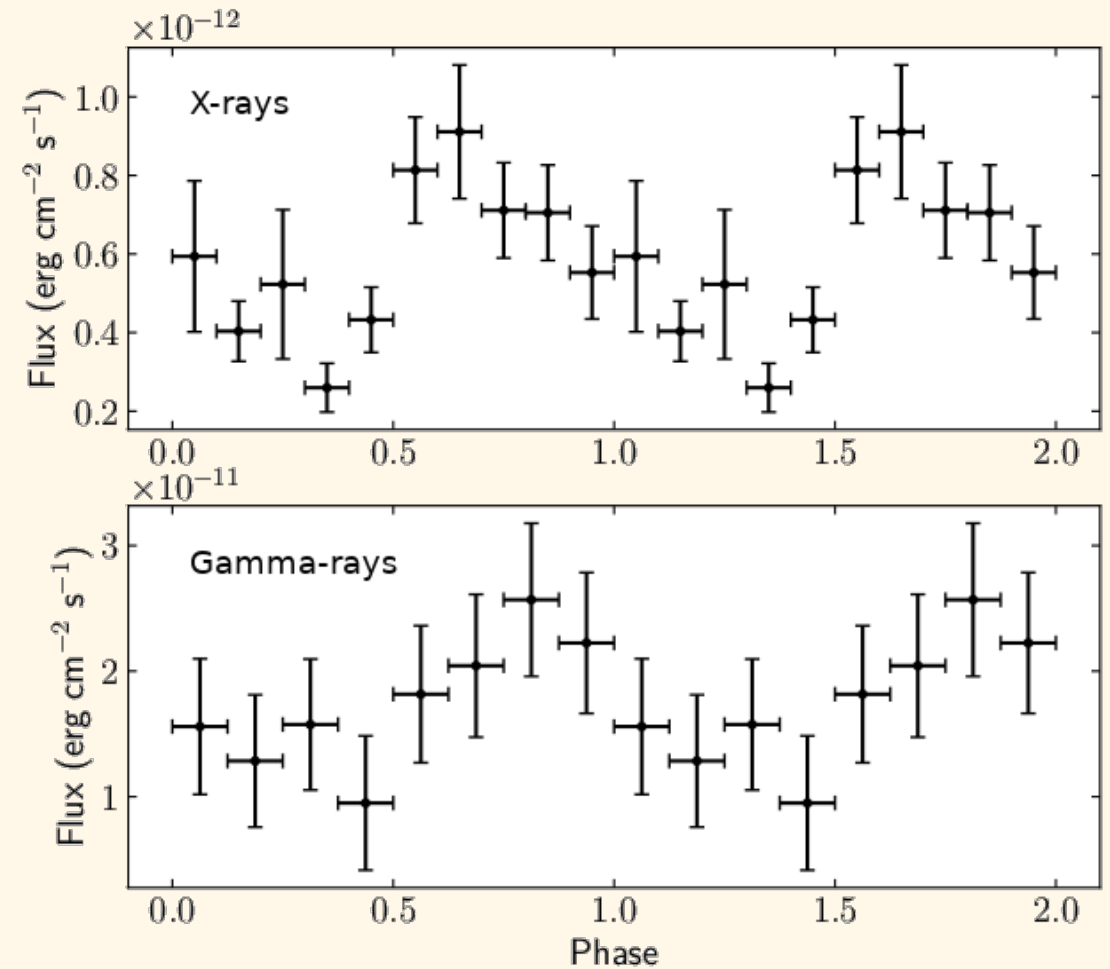
H.E.S.S. Collaboration 2015, MNRAS

The latest addition, HESS J1832-093

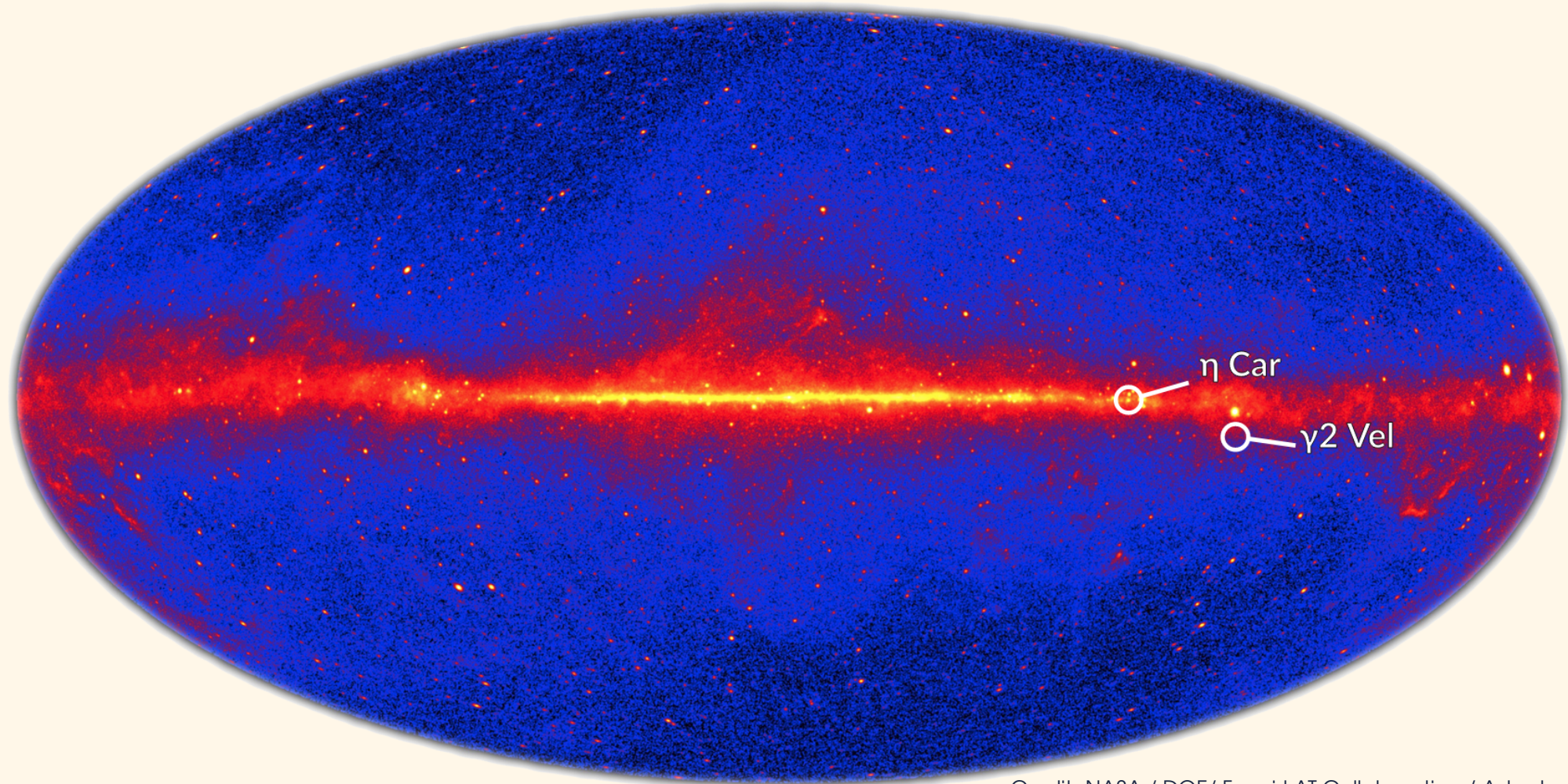
Considerably **fainter** in the GeV window, as HESS J0632+057 (in grey).



Martí-Devesa & Reimer 2020

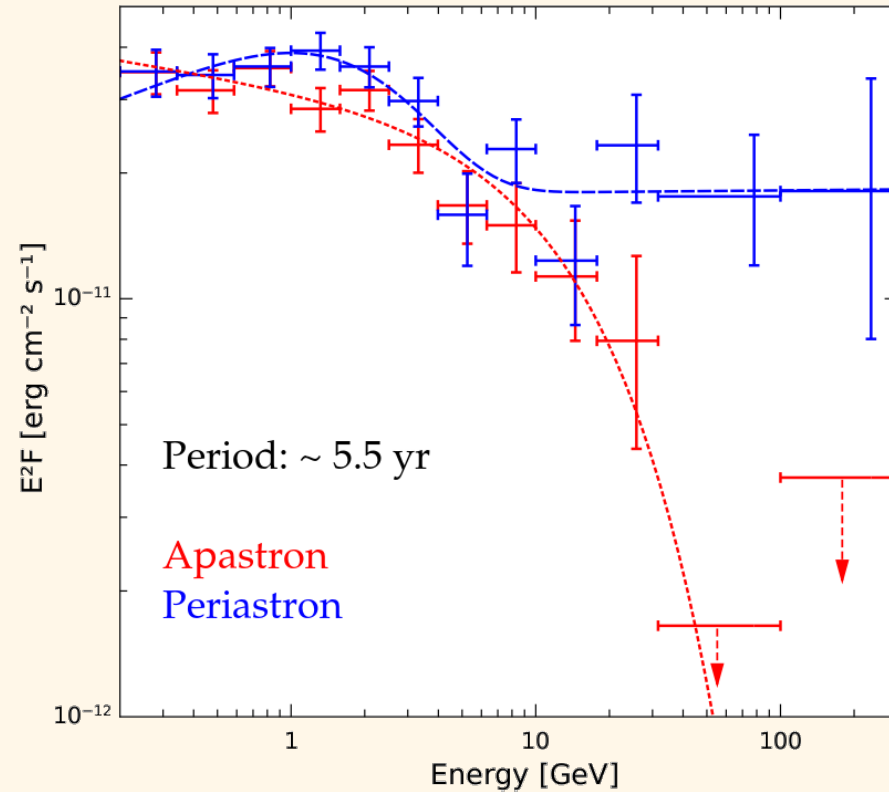


Colliding-wind binaries (CWBs) at high energies

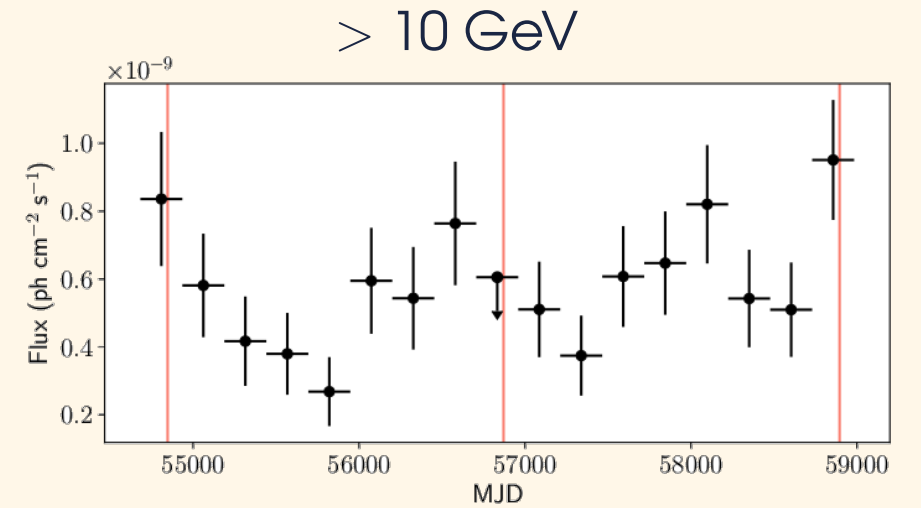
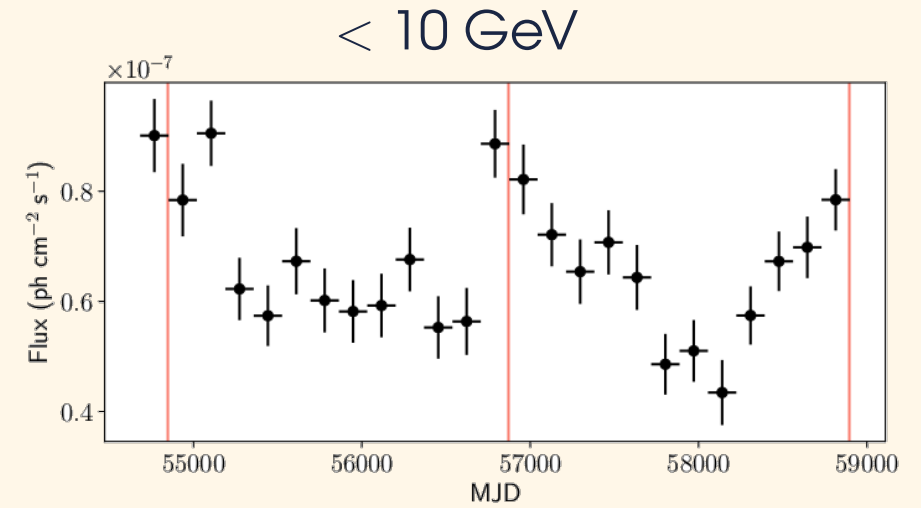


Credit: NASA / DOE/ Fermi-LAT Collaboration / Adapted by D. Huber

η Carinae at high energies

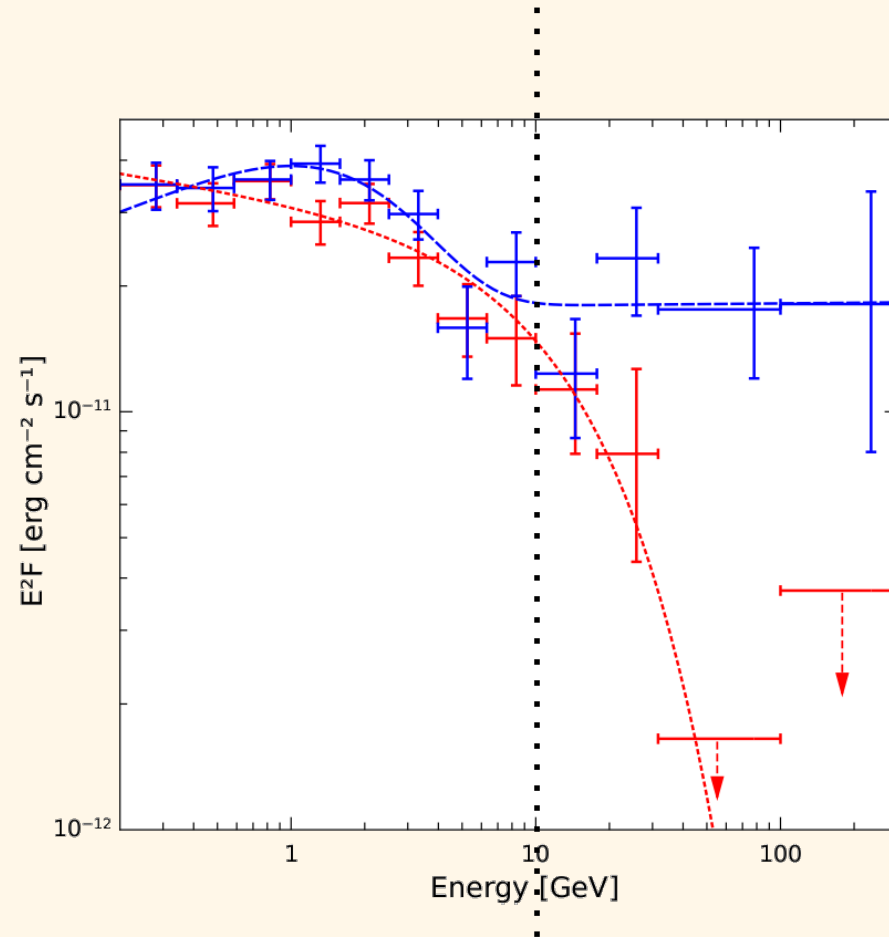


Reitberger et al. 2015, A&A

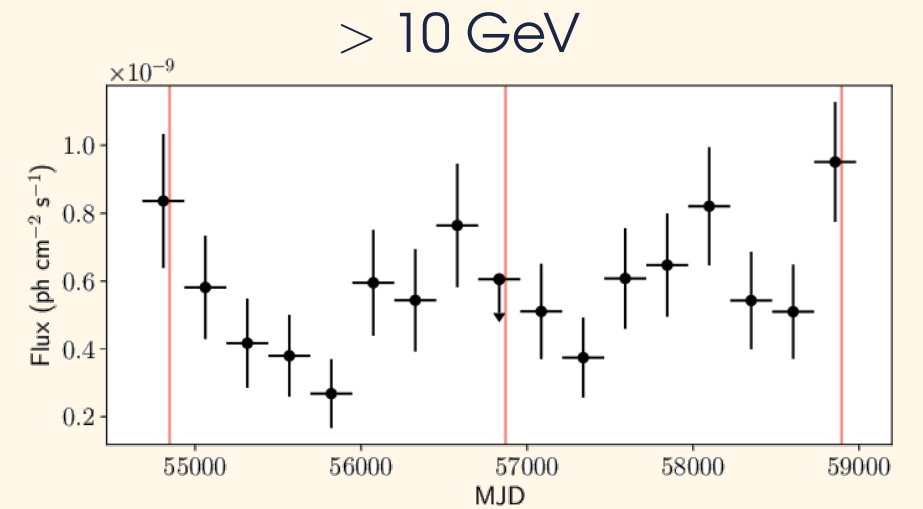
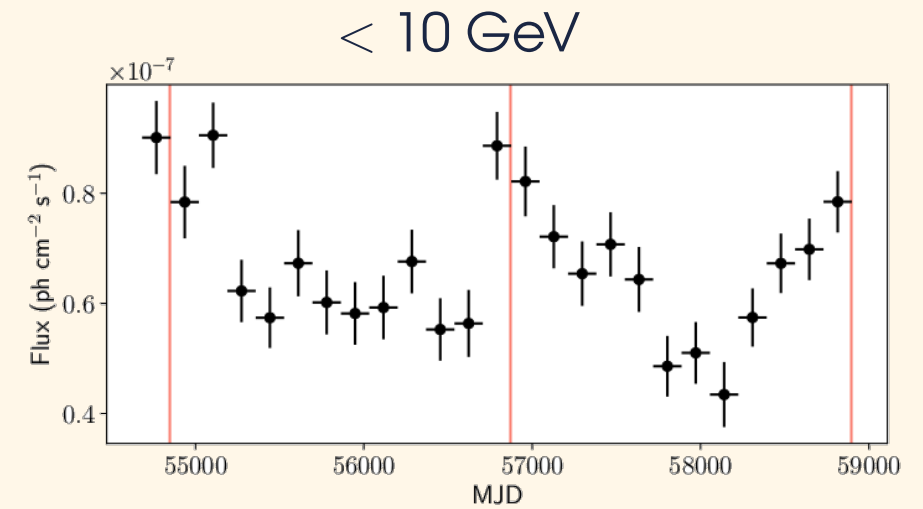


Martí-Devesa & Reimer 2021, A&A

η Carinae at high energies

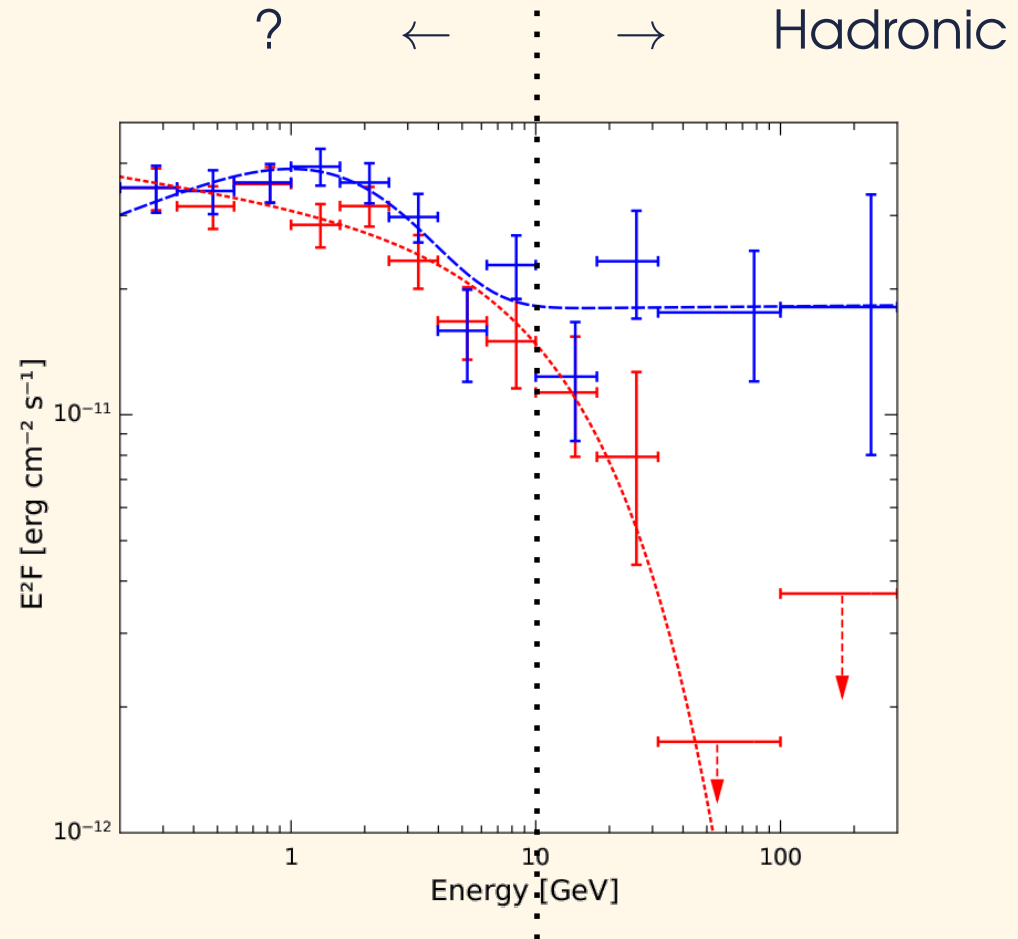


Reitberger et al. 2015, A&A

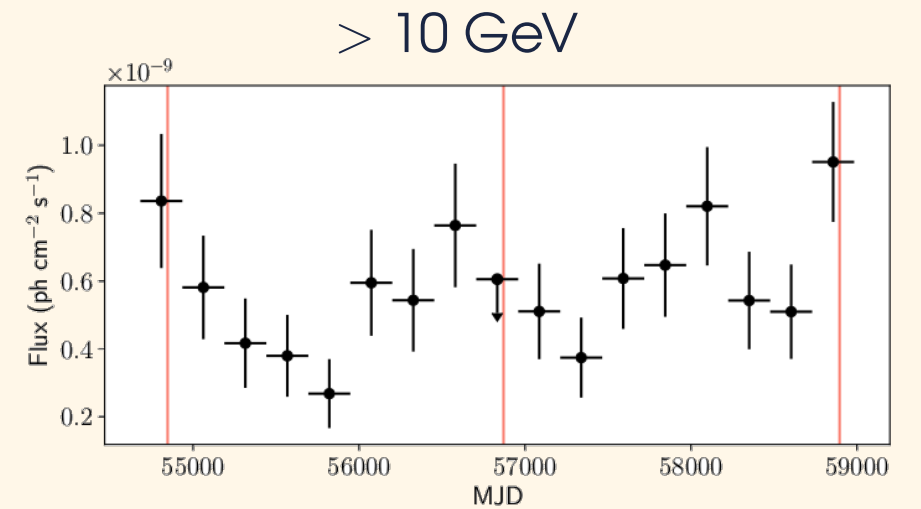
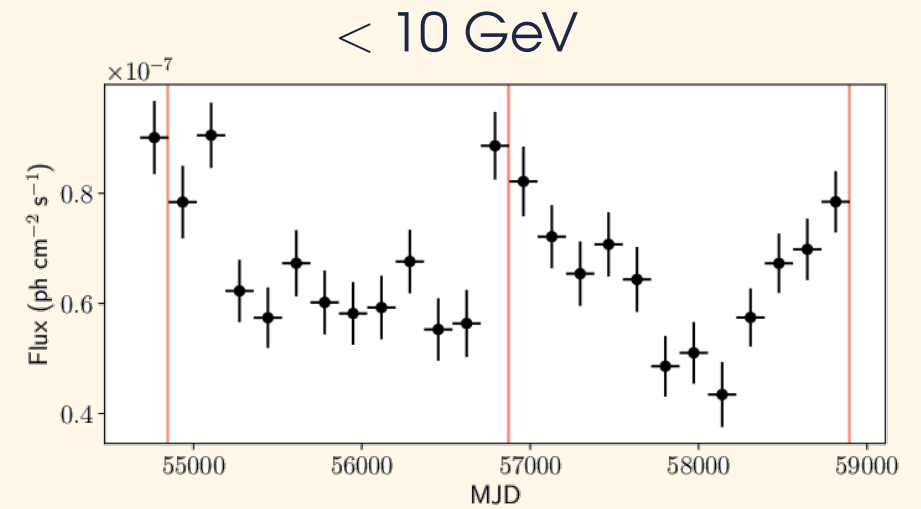


Martí-Devesa & Reimer 2021, A&A

η Carinae at high energies



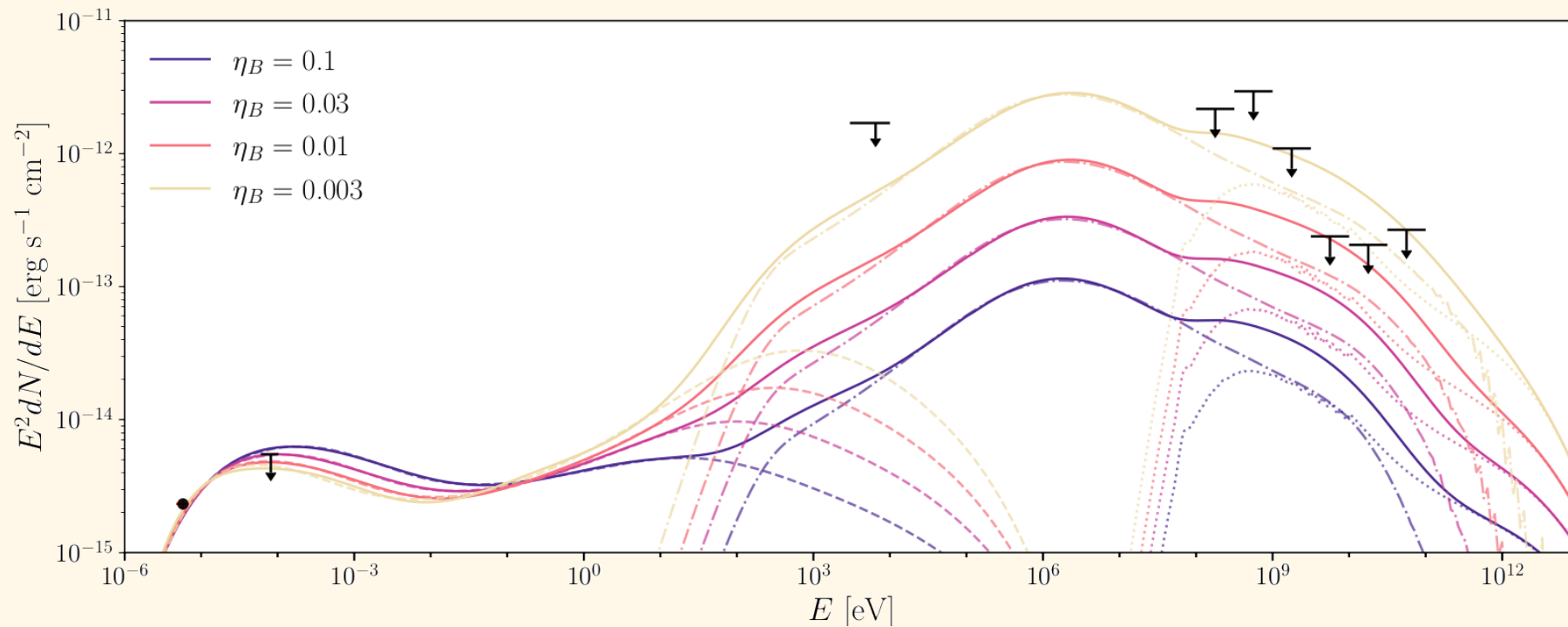
Reitberger et al. 2015, A&A



Martí-Devesa & Reimer 2021, A&A

Towards testing protons beyond standard DSA?

Apep, the first Galactic **WR-WR binary**. Brightest CWB in radio, **not detected at HE** → magnetic field larger than expected, **inefficient proton accelerator**



Model from del Palacio et al. 2022, PASA. Image credit: Martí-Devesa et al. 2023, A&A



Summary

Summary

- The periodical conditions of orbitally modulated shocks allow you **not only to identify the particle accelerator**, but to constrain the origin of the parent **particle population: leptonic or hadronic**
- Nonetheless, the large **phenomenological variety** among γ -ray emitting binaries makes their modelling highly non-trivial
- After **15 years**, *Fermi*-LAT is still a key instrument for the study of HE astrophysical sources



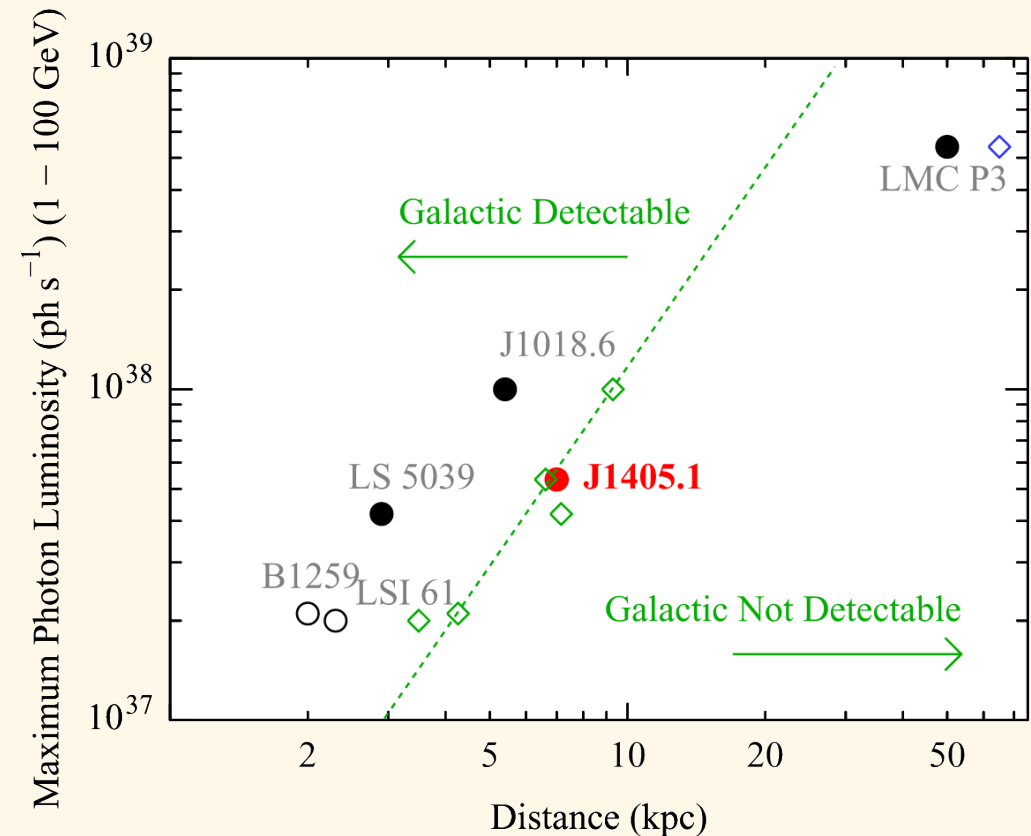
Backup slides

How large is the population?

After the discovery of LMC P3, Corbet et al. 2016 suggested we got already all binaries

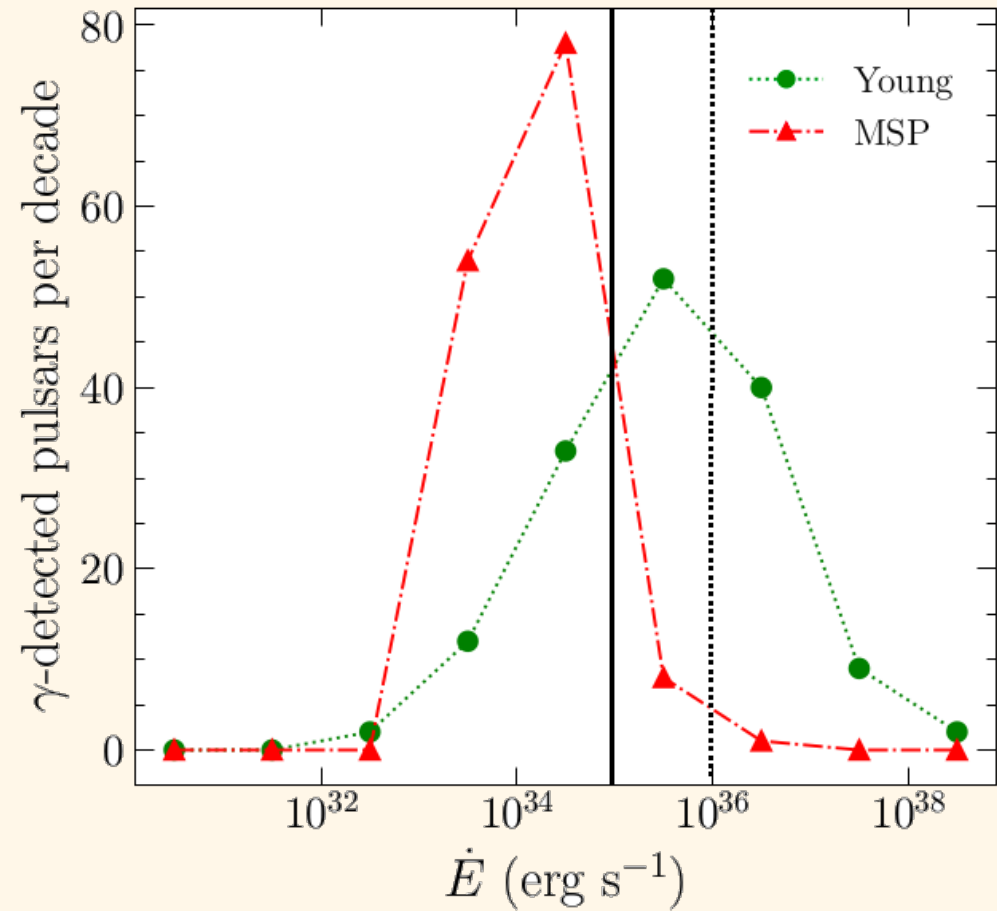
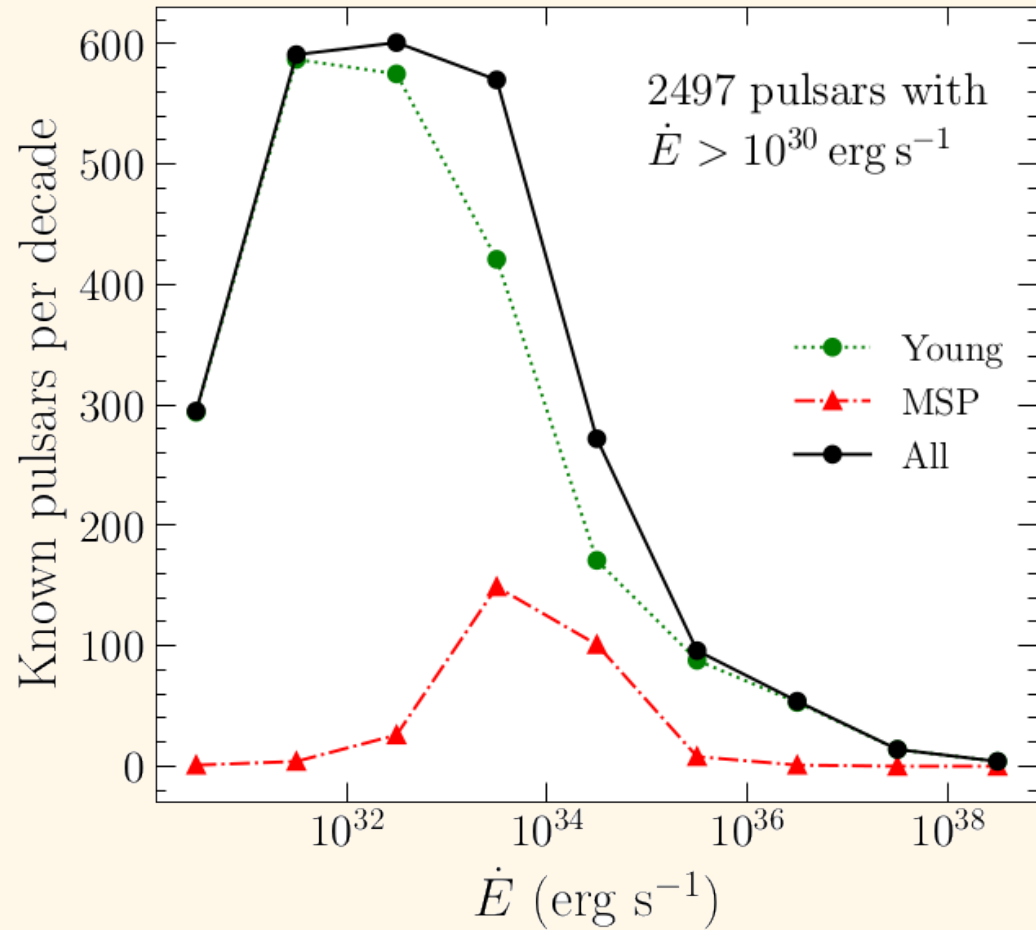
But they later detected 4FGL J1405.1-6110 (Corbet et al. 2019)

Alternative methods? Or how do we push down this limit? Do we expect more?



Corbet et al. 2019

On the parent young pulsar population



Adapted from Smith et al. 2023, submitted (3PC)