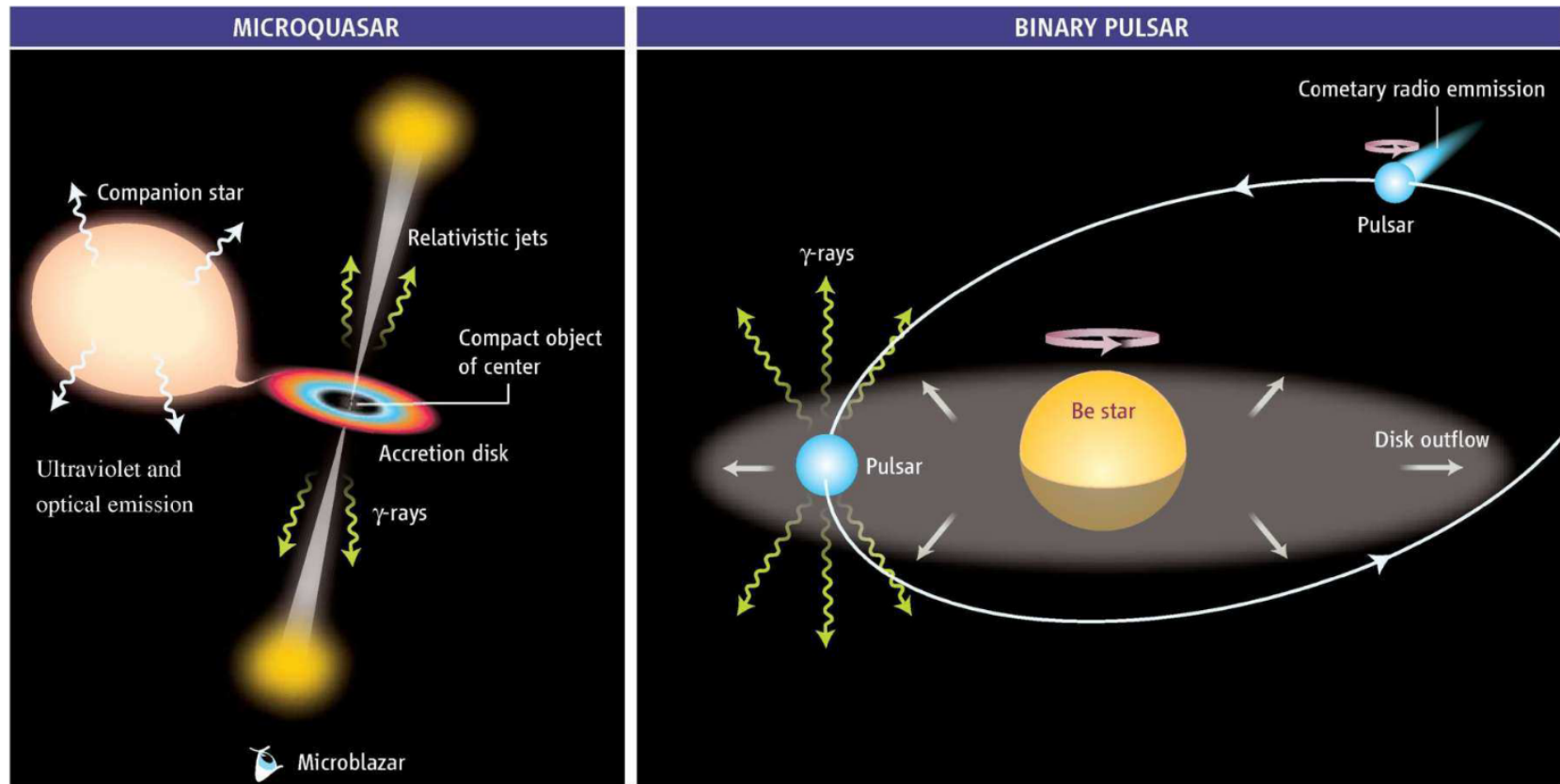


H.E.S.S. Observations of Binary Systems

L. Fisher on behalf of the H.E.S.S. Collaboration
University of the Free State
06. May 2025



Gamma-ray Emitting Binaries



Mirabel 2007

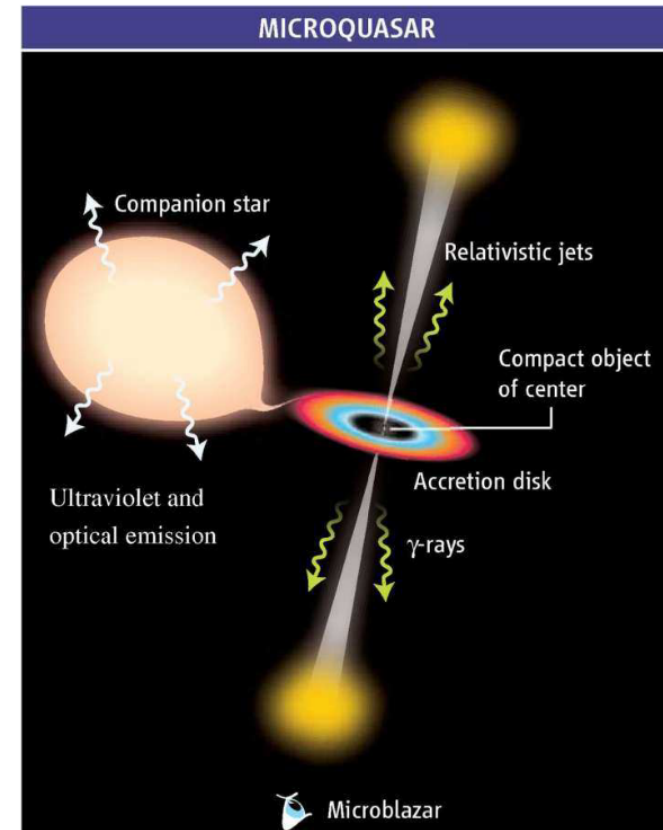
H.E.S.S.

- **High Energy Stereoscopic System**
 - named after Viktor Hess, discoverer of the Cosmic Rays
 - location: Namibia
- 4 small telescopes (\varnothing 12m), since 2004
 - square array, side length 100m
 - camera upgrade 2017
- 1 big telescope (\varnothing 28m), since 2013
 - centre of array
 - camera upgrade 2019
- energy range: 50 GeV ... tens of TeV
- angular resolution 0.07°
- operated by international collaboration
 - Europe: Germany, France, Poland, Austria, Netherlands, Denmark, UK, Ireland
 - Australia, Japan
 - Africa: Namibia, South Africa



Microquasars

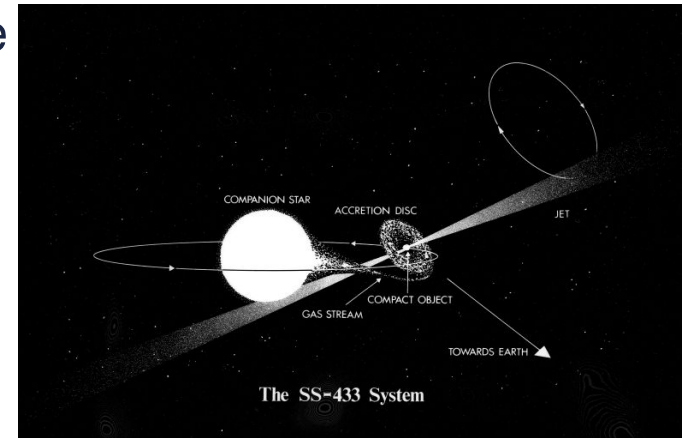
- galactic analogues to AGN
- matter accreted onto CO (likely stellar mass black hole)
- CO launches jets that drive particle acceleration
- → relativistic outflows of matter
- sites of particle acceleration
- how do they accelerate particles?
- where does the acceleration occur?
- is the emission dominated by leptonic or hadronic processes?
- what can we learn about them from H.E.S.S.?



Mirabel 2007

SS 433/V1343 Aql

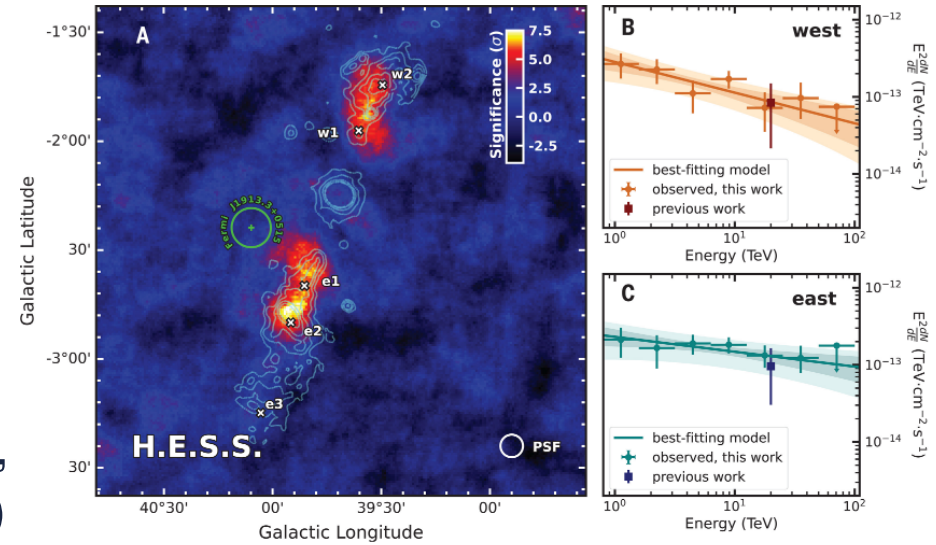
- Type-A supergiant, and likely a black hole
- jets launch at ~ 0.26 speed of light
- jets almost perpendicular to LOS
- jets precess with a half-opening angle of 20° , $P = 162$ d
- inner jets: extend to $\sim 10^{-3}$ pc in optical and ~ 0.1 pc in radio
- outer jets: terminate ~ 100 pc from the blackhole and start ~ 25 pc from the BH



Credit: ESO

SS 433 jets in TeV!

- First TeV microquasar (first HAWC, then H.E.S.S.)
- resolved
- TeV emission traces large-scale (10s of pc) jets
- east jet 7.8σ , west jet 6.8σ
- both follow a power-law spectrum, with no significant evidence ($>3\sigma$) of curvature or cut-off



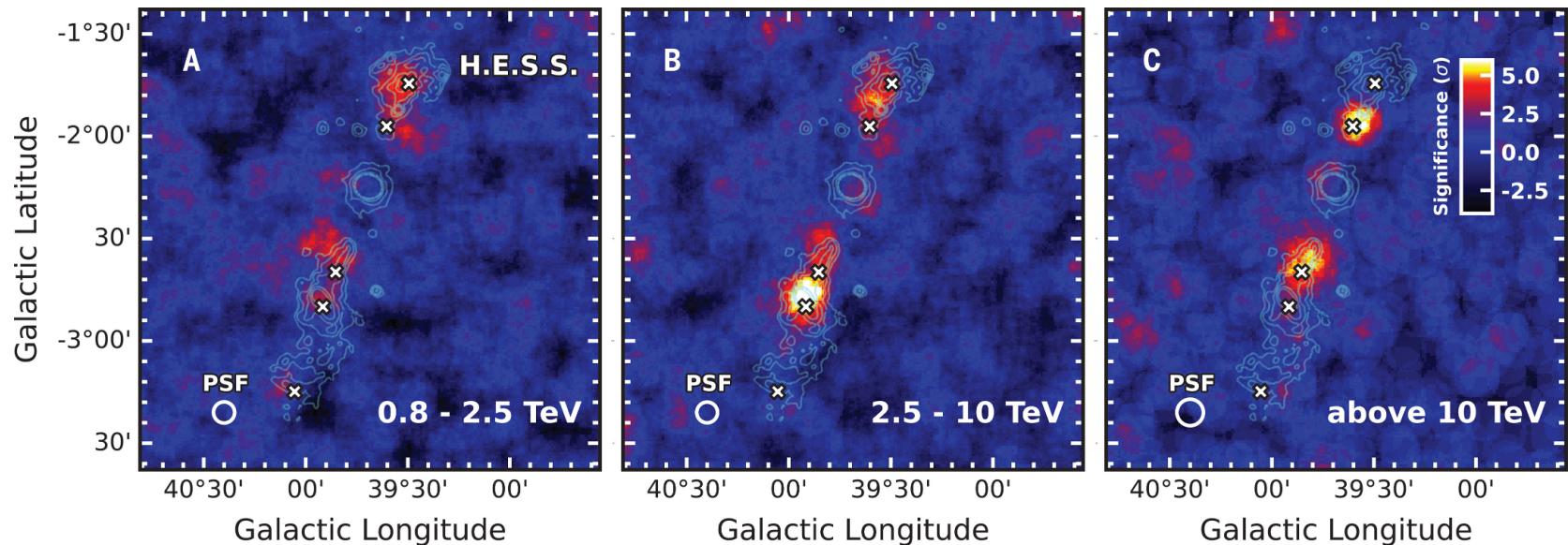
H.E.S.S. *Science* 2024

	ϕ_0 ($10^{-13} \text{ TeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$)	E_0 (TeV)	Γ
east	$2.30 \pm 0.58_{\text{stat.}} \pm 0.32_{\text{syst.}}$	1	$2.19 \pm 0.12_{\text{stat.}} \pm 0.12_{\text{syst.}}$
west	$2.83 \pm 0.70_{\text{stat.}} \pm 0.39_{\text{syst.}}$	1	$2.40 \pm 0.15_{\text{stat.}} \pm 0.13_{\text{syst.}}$

H.E.S.S. detection of energy-dependent morphology

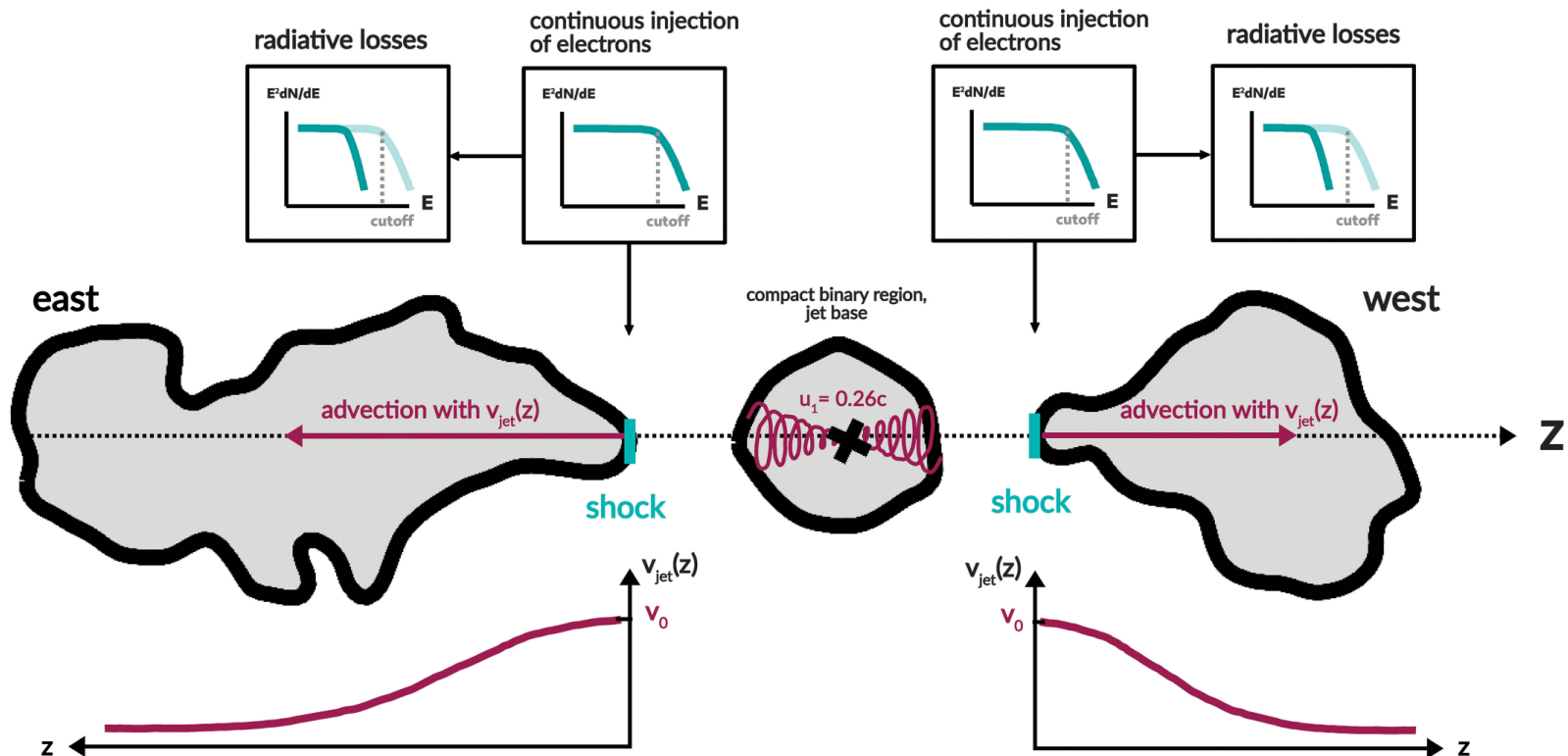
jet	0.8-2.5 TeV	2.5-10 TeV	>10 TeV
east	4.4σ	7.6σ	5.9σ
west	4.7σ	5.6σ	6.6σ

- > 10 TeV γ -rays only at the base of the outer jets ≈ 25 pc
- lower-energies further out*



What does this tell us?

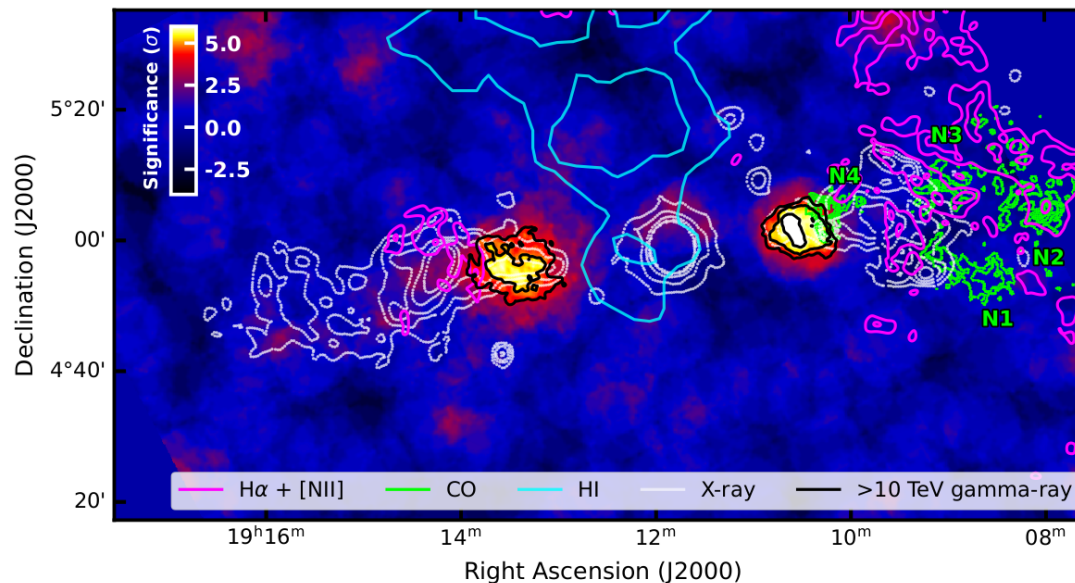
- Observations trace the energetic population **emission is likely leptonic, acceleration mechanism likely shock**
- offsets in the energy \rightarrow transport of particles dominated by bulk jet flow
- dominant E-loss likely synchrotron cooling



What does this tell us?

- leptonic emission \neq only leptons accelerated !!
- In theory capable of PeV acceleration: but from data we could only say >200 TeV
- LHAASO has the last word :-)

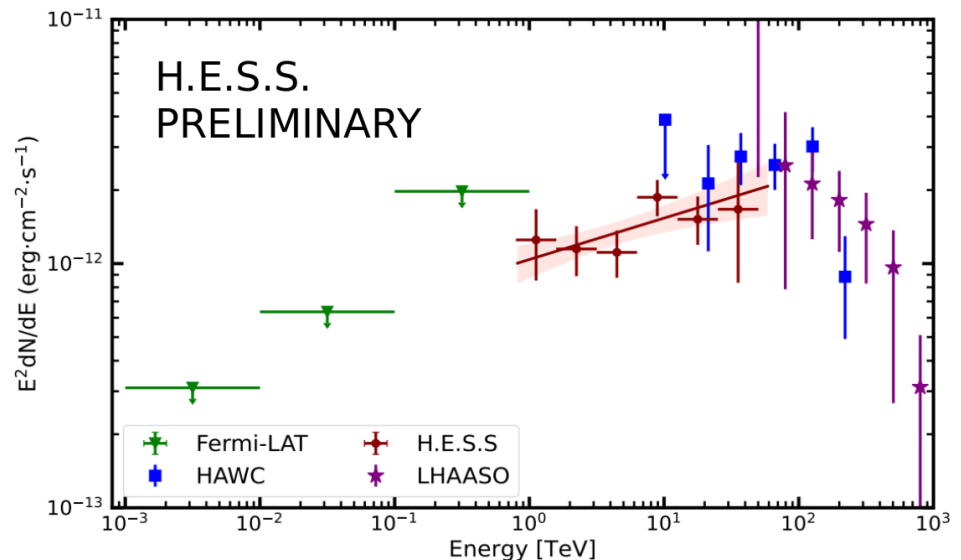
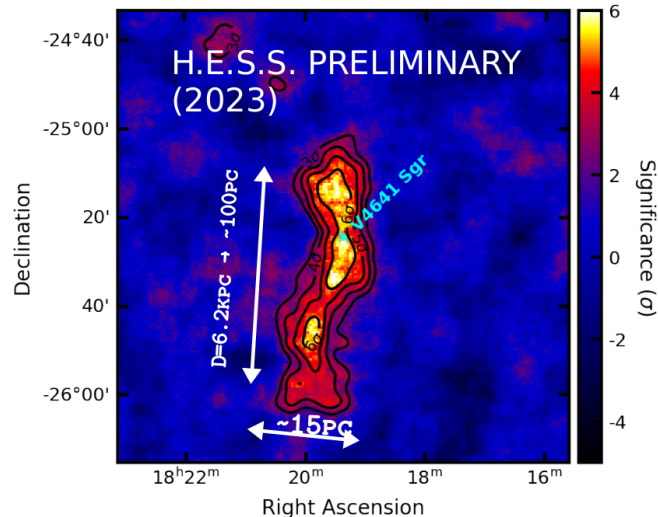
$$E_{Hillas} \approx 10Z \left(\frac{B}{20\mu\text{G}} \right) \left(\frac{u_i}{0.26c} \right) \left(\frac{R}{1.6\text{pc}} \right) \text{PeV}$$



V4641 Sgr

Laura Olivera Nieto+, Gamma 24

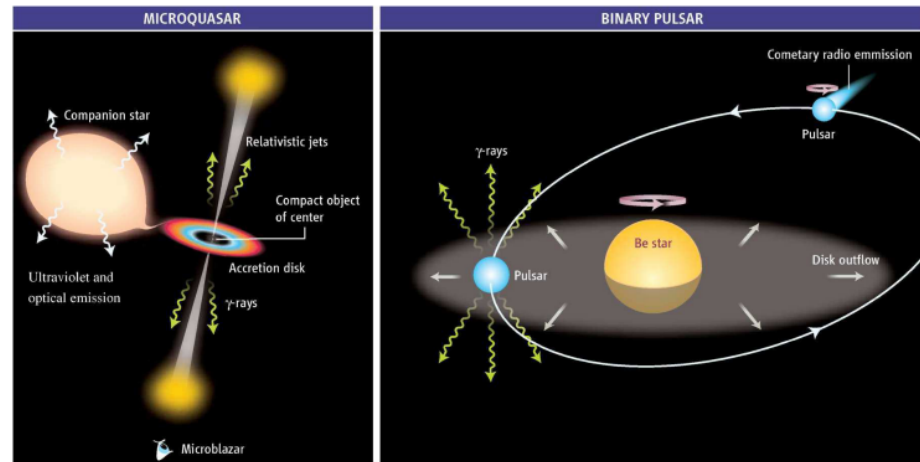
- Fairly unassuming x-ray binary: one big outburst in 1999, never as bright since.
- Jets are supposed to be pointed at us
- detected by HAWC and LHAASO, highly extended, **peaks at 100 TeV**
- paper in progress using new 2024 data (about to enter internal review)



H.E.S.S. PRELIMINARY

Gamma-ray Loud Binaries

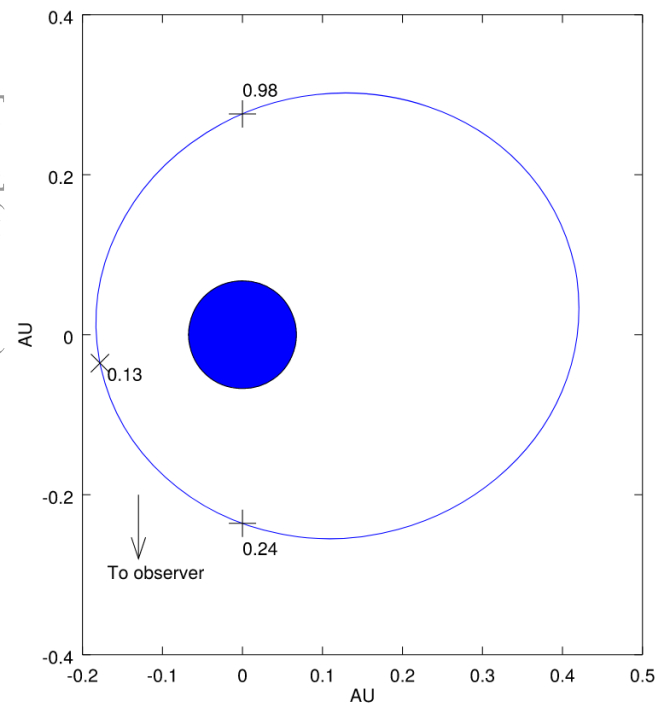
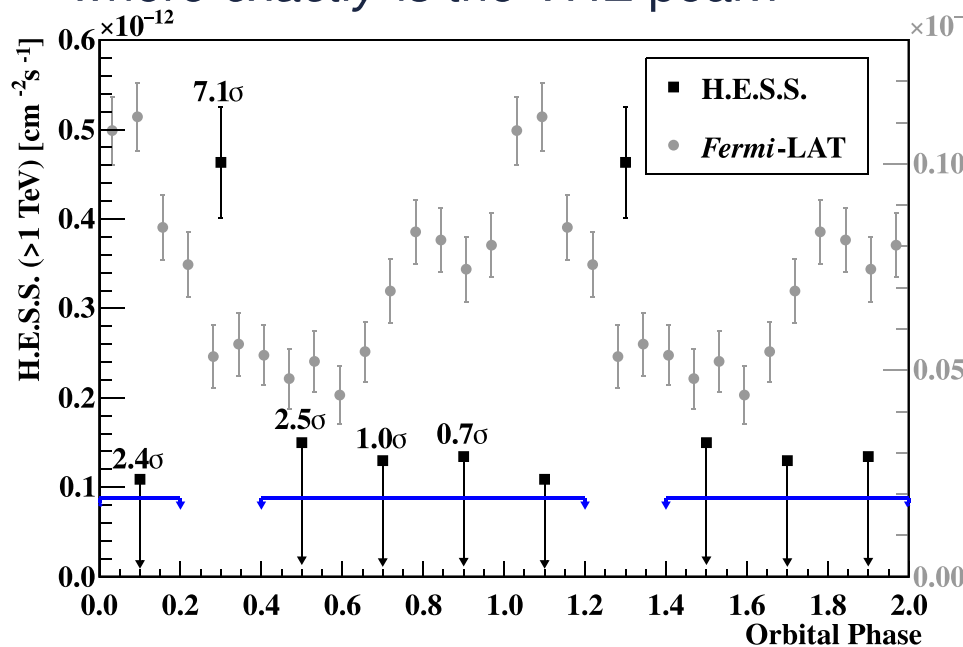
- gamma-ray binary: peak SED > 1 MeV
- orbital variability (emission)
- compact obj. + O- or Be-star
- nature of HE/VHE emission debated:
 - microquasar: accretion driven (BH or NS)
 - pulsar wind interacts with stellar wind
- orbital modulation seen in all systems across EM spectrum



Mirabel 2007

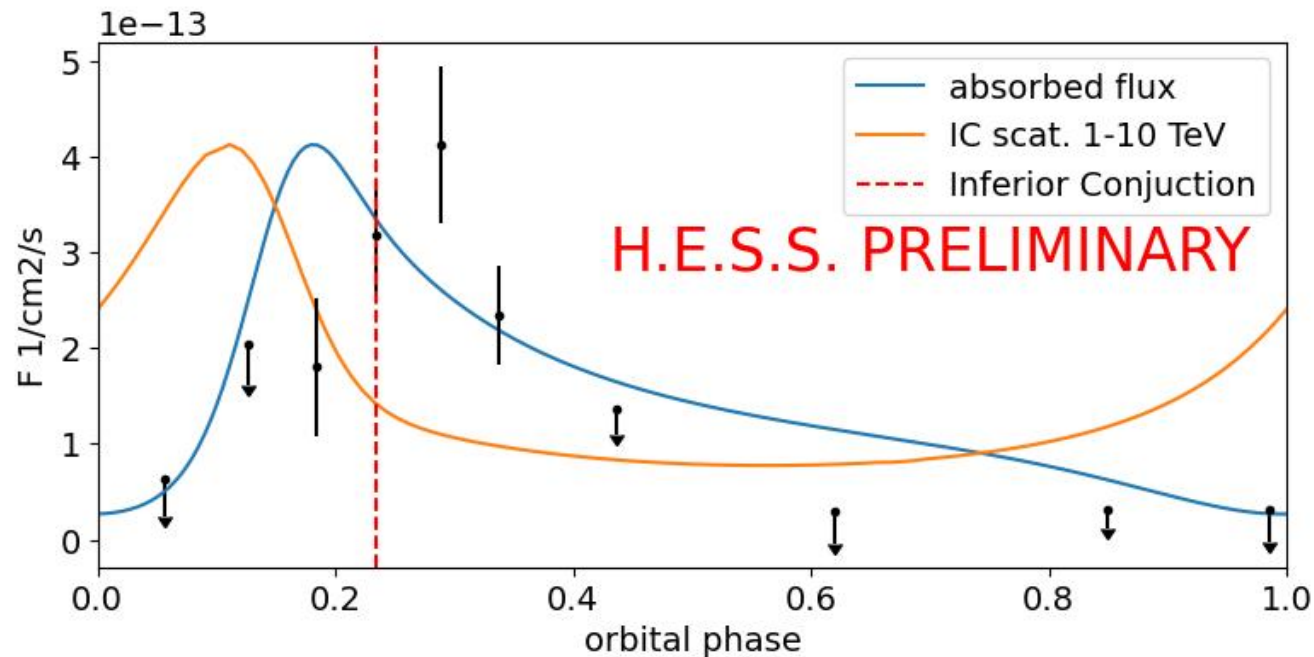
Overview LMC P3

- discovered as GRLB [Fermi 2016, ApJ]
- $P = 10.301$ days, O5 III-star, unknown CO, $d = 50$ kpc
- VHE detection and variability [HESS 2018, A&A]
- (peak) emission only in 0.2-0.4 phase bin
- orbital solution [van Soelen+2019] \rightarrow INFC at phase 0.24
- where *exactly* is the VHE peak?



LMC P3

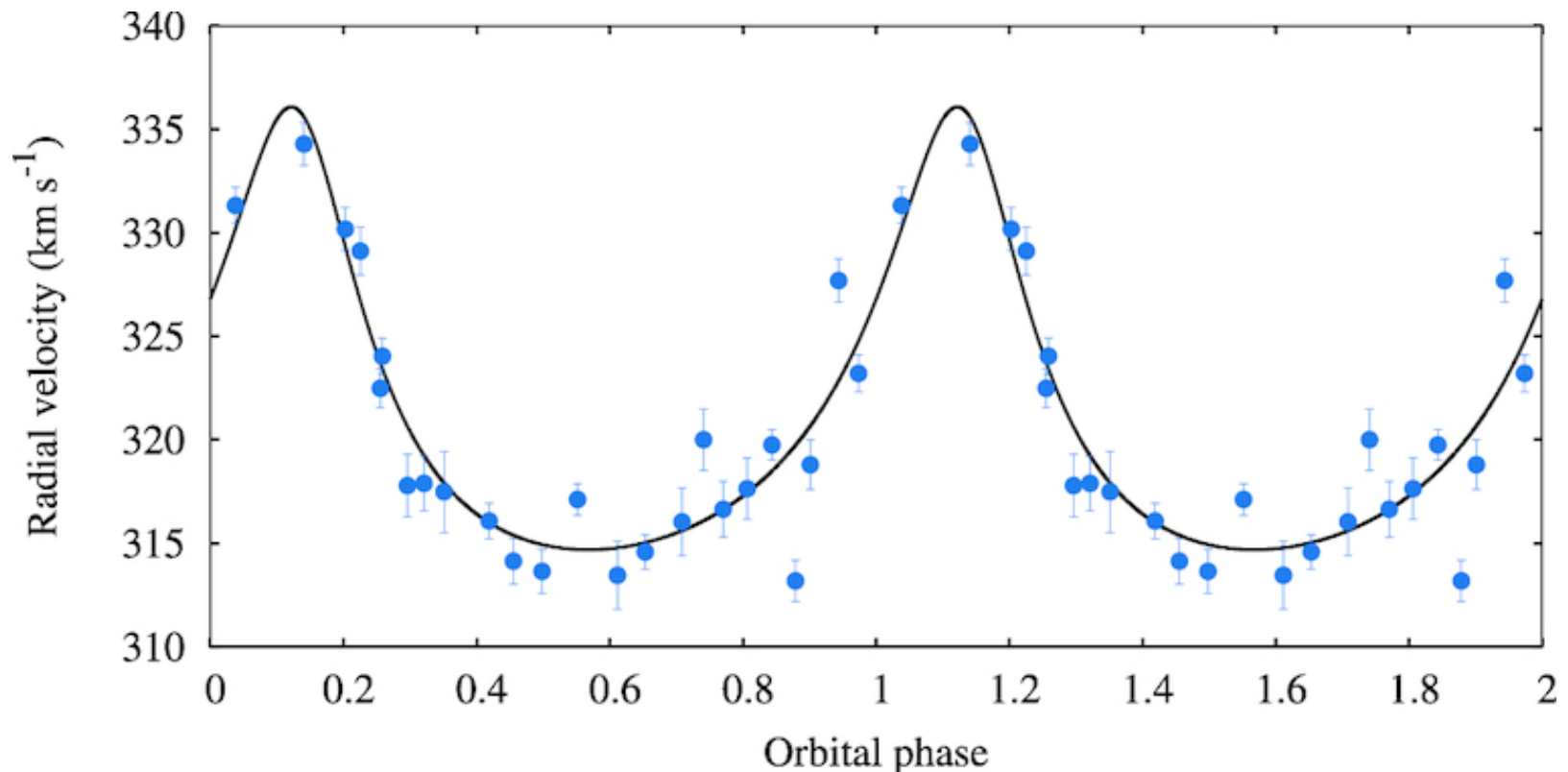
- resolved peak
- new result (paper in prep) resolved 0.2-0.4 peak
- with orbit sol. \rightarrow peak after INF
- IC scattering + $\gamma\gamma$ absorption, orbit test



H.E.S.S. PRELIMINARY

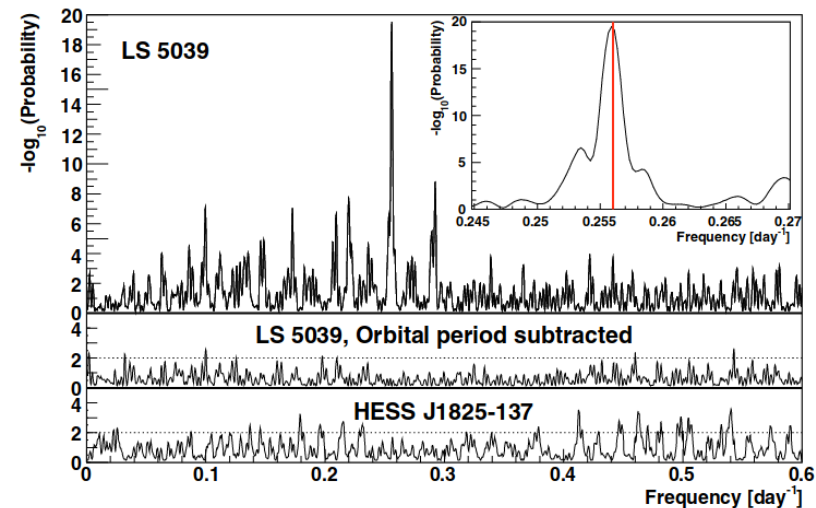
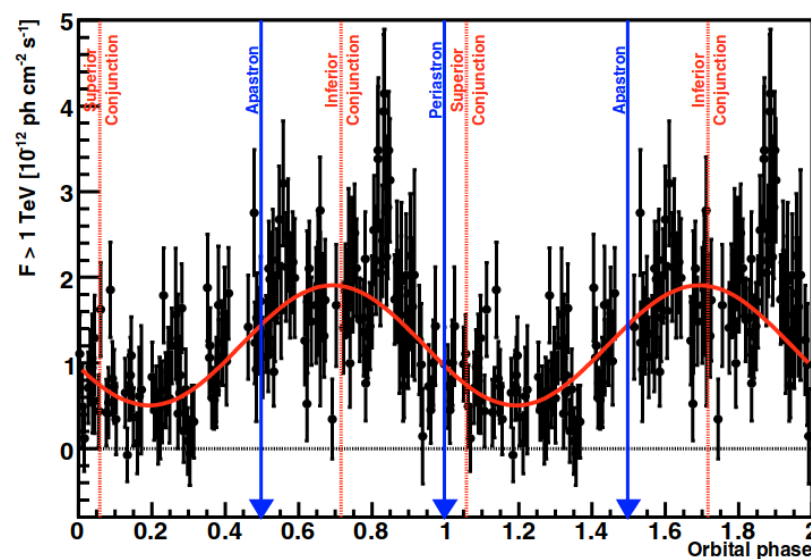
Orbit test

- current thinking is that the orbit is slightly different
- took six new observations with SALT
- in the meantime, test IC with absorption to see how much the orbit would need to shift



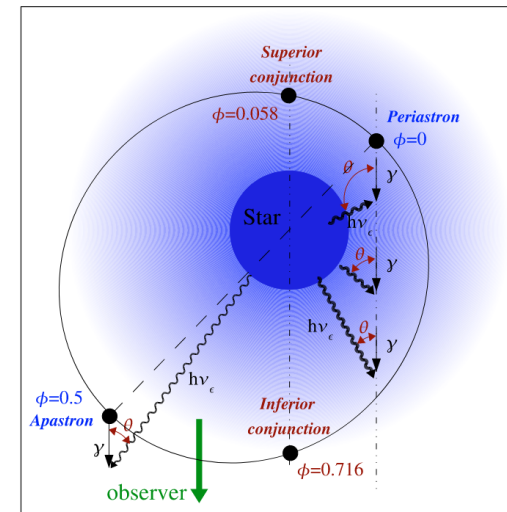
LS 5039

- $P = 3.9$ days, O6.5V-star, unknown CO
- initial paper [HESS 2005, Science] detection of VHE emission
- in [HESS 2006, A&A] first time orbital modulation obs and periodicity established in VHE astronomy
- modulated by absorption
- absorption via pair production sig. modulates emission



Update on LS 5039?

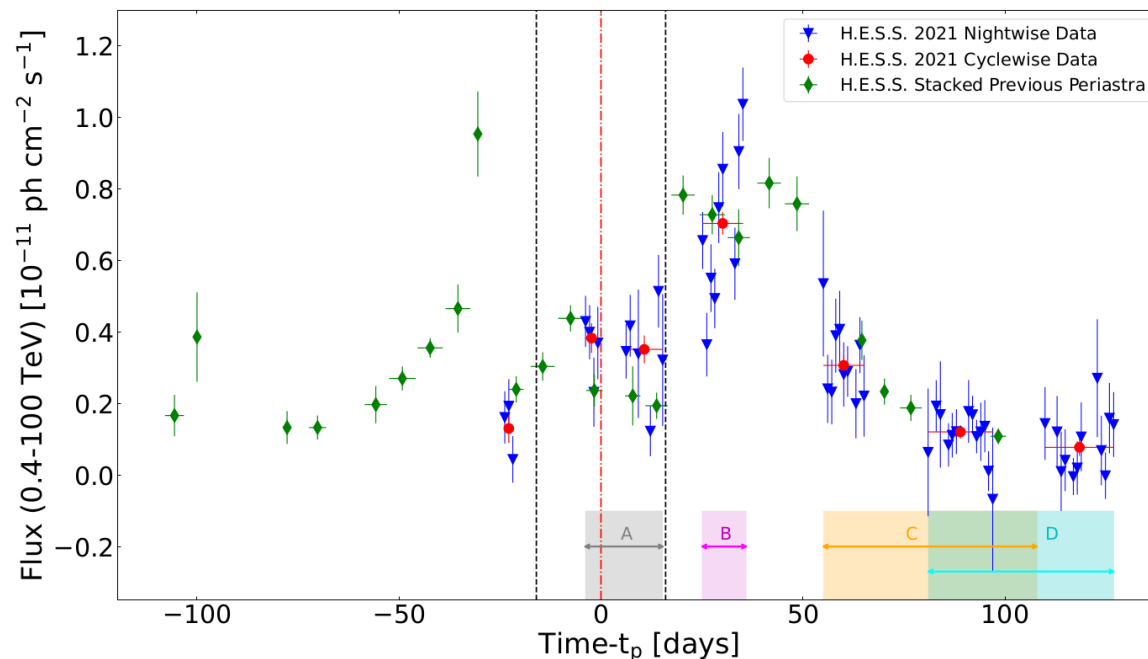
- 69.2 hours published, now 257 live hours
- **update soon!**
- **"Deep observation of the gamma-ray binary LS 5039 with H.E.S.S."** -Mathieu de Naurois+, ICRC 2025 (15–24 July)



Casares 2005

PSR B1259–63/LS 2883

- $P = 3.4$ years, O9.5Ve-star, pulsar
- emission clearly associated with disk-crossings near periastron
- H.E.S.S. obs. 8 periastra (2004-2021) & **2024! :)**
- **see " Multi-wavelength properties of binary pulsar system PSR B1259-63/LS2883 " Denys Malyshev, 07/05 @ 10:30**



Summary

- **SS 433**: TeV traces ~ 10 s of pc jets, likely leptonic emission
- How much do microquasars contribute to galactic cosmic rays?
 - wait for more observations (SS 433 w/ LHAASO)
 - study more sources (**V4641 Sgr, paper incoming!**)
- **LMC P3**: resolved peak with perplexing result
 - orbit constrained?
- **LS 5039**: new result at ICRC 2025
- **PSR B1259–63/LS 2883**: see talk by Denys Malyshev tomorrow!

**Thank you for
your attention!**

