Gamma-ray emitting binaries

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Gamma 2022, Barcelona

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OUTLINE

- GREBs today
- recent highlights
- summary & perspectives

Gamma-ray *emitting* binaries (GREBs)

- **Gamma-ray binaries** (γBs) are binary systems whose spectral energy distribution peaks at energies $E \geq 1$ MeV.

- **Microquasars** (μQs) are binary systems powered by accretion onto a black hole or neutron star that display relativistic jets.

- **Colliding wind binaries** (CWBs) are binaries in which powerful stellar outflows develop strong shocks that can give rise to gamma-ray emission.

- **Novae** explosions are thermonuclear bursts in binary systems following strong accretion episodes onto the surface of a white dwarfs

Despite this heterogeneous sample, they all share a common property: their emission **physics can be constrained thanks to the periodic variation** of the physical conditions taking place within and around the binary system.

GREBs today

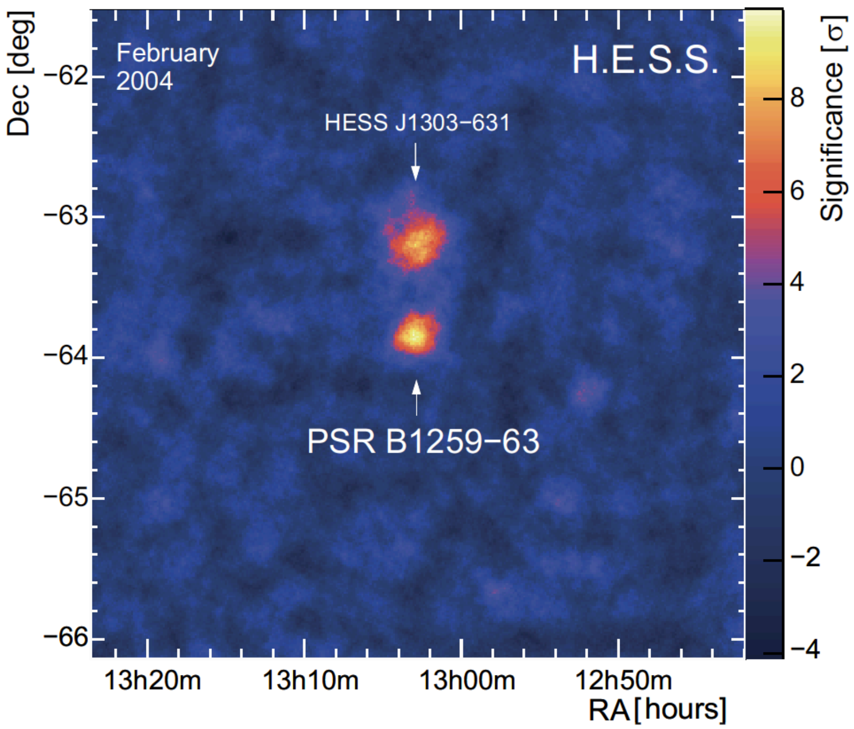
γBs	PSR B1259–63 [1], LS 5039 [2], LS I +61 303 [3], HESS J0632+057 [4], 1FGL J1018.6–5856 [5], LMC–P3 [6], PSR J2032+4127 [7], HESS J1832–093 [8] 4FGL J1405.1-6119 [9], HESS J1828-099* [10]
μQs	Cyg X-3 [11], Cyg X-1 [12], SS433 [13], V4641 Sgr [?] V404 Gyg* [14], AGL J2241+4454* [15]
CWBs	Eta Carinae [16], γ^2 Velorum [17], HD 93129A* [18]
Novae	V407 Cyg 2010 [19], V1324 Sco 2012 [20], V959 Mon 2012 [21], V339 Del 2013 [22], V1369 Cen 2013 [23], V5668 Sgr 2015 [24], V5855 Sgr [25], V5856 Sgr [26], V549 Vel [27], V357 Mus [28], V906 Car [29], V392 Per [30], V3890 Sgr [31], V1707 Sco [32], YZ Ret [33], V1674 Her [34], RS Oph [35]

updated from Paredes & Bordas (2019)

1. Aharonian et al. (2005), 2. Aharonian et al. (2005b), 3. Albert et al. (2006), 4. Aharonian et al. (2007), 5. Corbet et al. (2011), 6. Corbet et al. (2016), 7. Lyne et al. (2015), 8. HESS Collaboration (2015), 9. Corbet et al. (2019), 10. De Sarkar et al. (2022), 11. Tavani et al. (2009), 12. Albert et al. (2007), 13. Bordas et al. (2015), 14. Loh et al. (2016), 15. Lucarelli et al. (2010), 16. Tavani et al. (2009), 17. Mart-Devesa et al. (2020), 18. Chernyakova et al. (2019), 19. Abdo et al. (2010), 20. Cheung et al. (2012), 21. Cheung et al. (2012b), 22. Hays et al. (2013), 23. Cheung et al. (2013), 24. Cheung, et al. (2015), 25. Li, et al. (2016), 26. Li et al. (2016b), 27. Li et al. (2017), 28. Li et al. (2018), 29. Jean et al. (2018), 30. Li et al. (2018), 31. Buson et al. (2019), 32. Li et al. (2019), 33. Li et al. (2020), 34. Munari et al. (2021), 35. Cheung et al. (2021)

Gamma-ray binaries (γBs)

PSR B1259-63

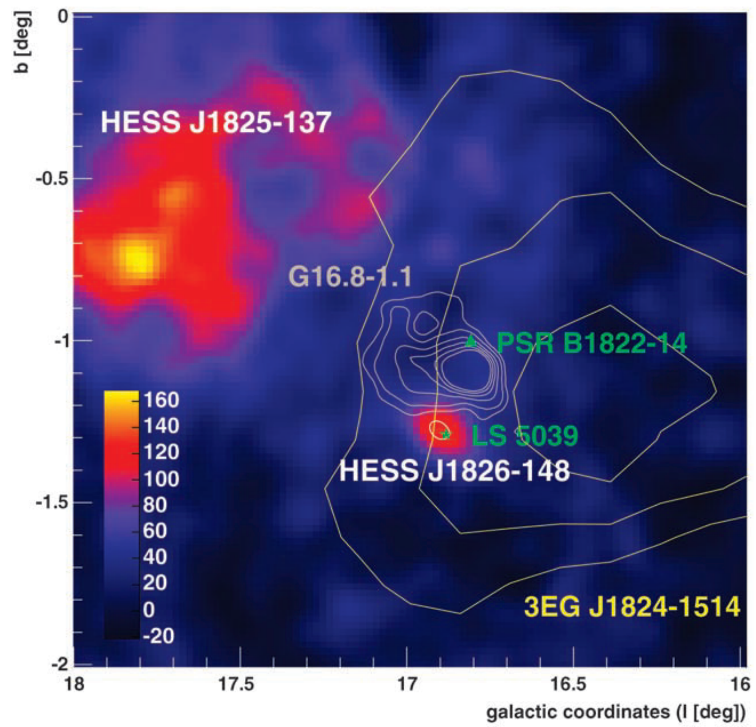


Aharonian et al. (2006a)

Johnston et al.(1992)

Tavani & Arons (1997)

LS 5039

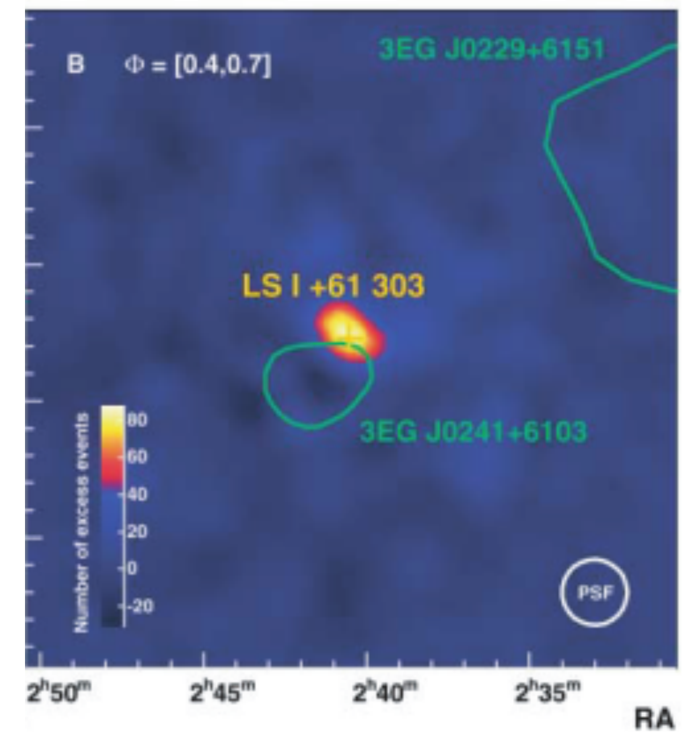


Aharonian et al. (2006b)

Motch et al. (1997)

Paredes et al. (2000)

LS I +61 303



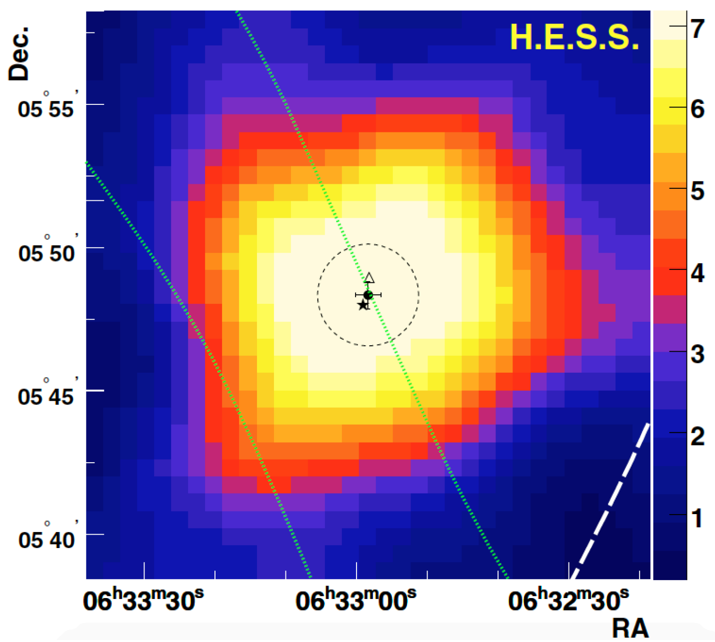
Albert et al. (2006)

Hermsen et al. (1977)

Gregory & Taylor (1978)

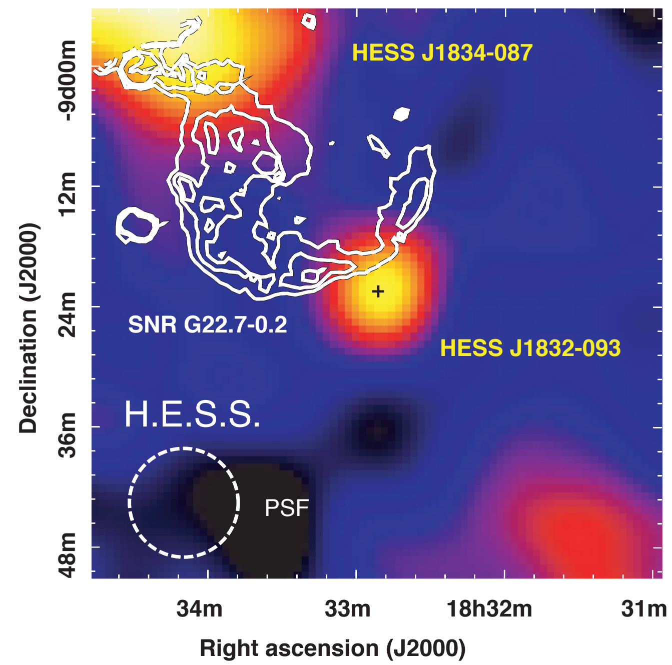
Gamma-ray binaries (γBs)

HESS J0632+057



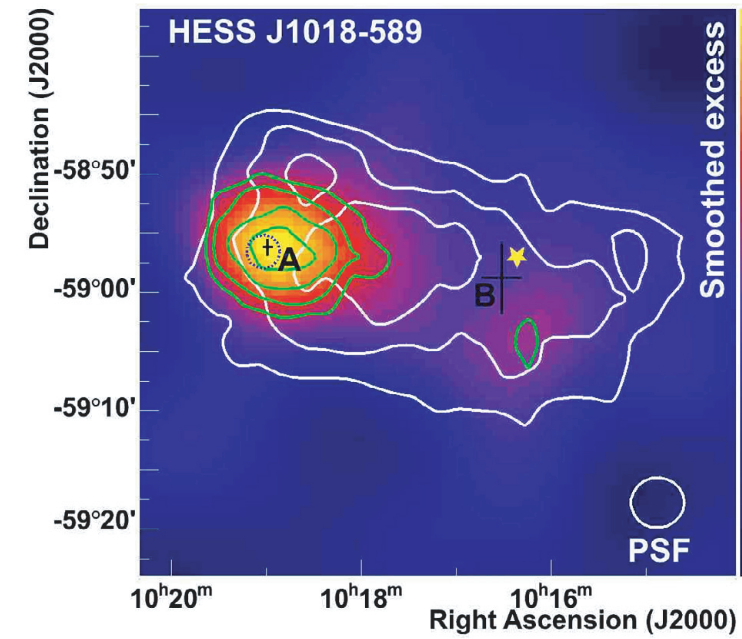
H.E.S.S. Col. (2007)

HESS J1832-093



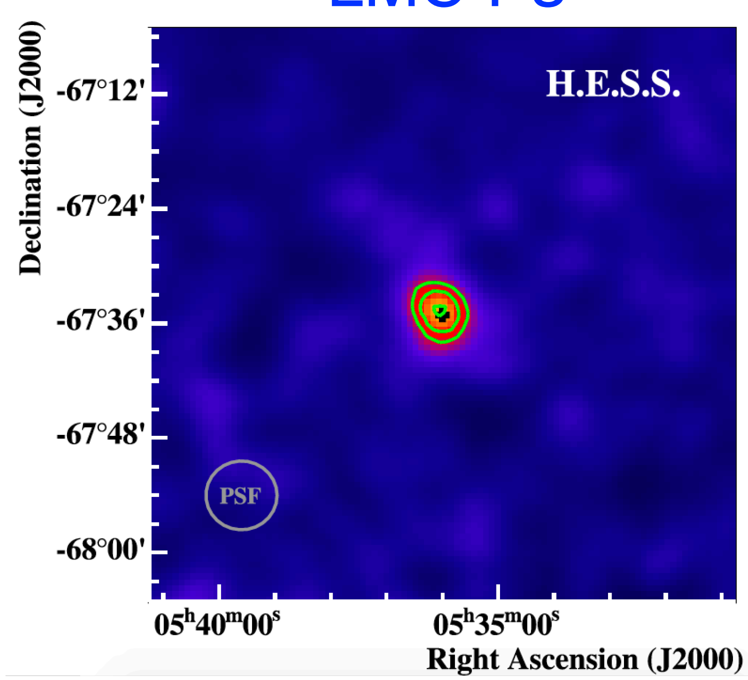
H.E.S.S. Col. (2014)

1FGL J1018.6–5856



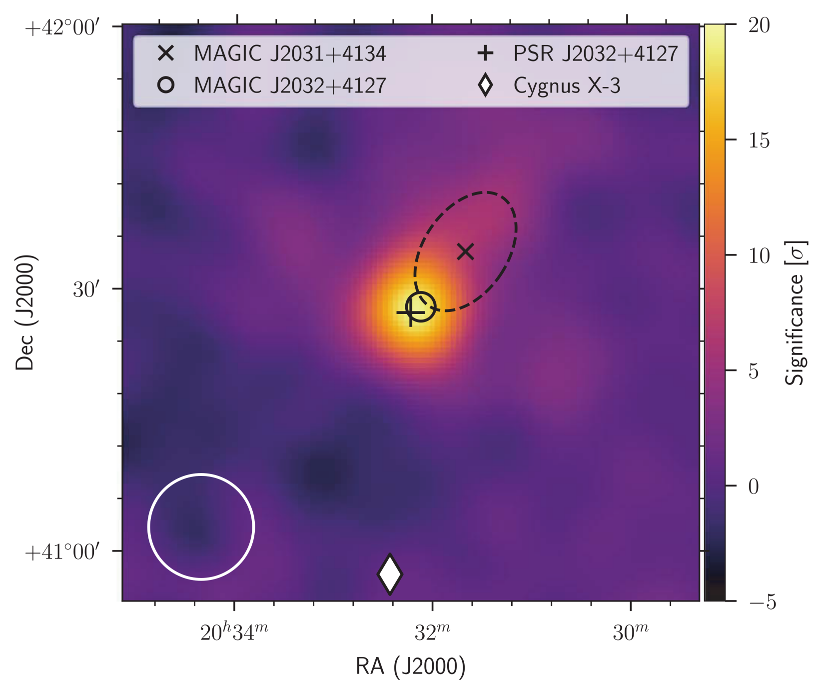
H.E.S.S. Col. (2012)

LMC P3



H.E.S.S. Col. (2018)

PSR J2032+4127



Abeysekara et al. (2018)

4FGL J1405.1-6119

Corbet et al. (2019)

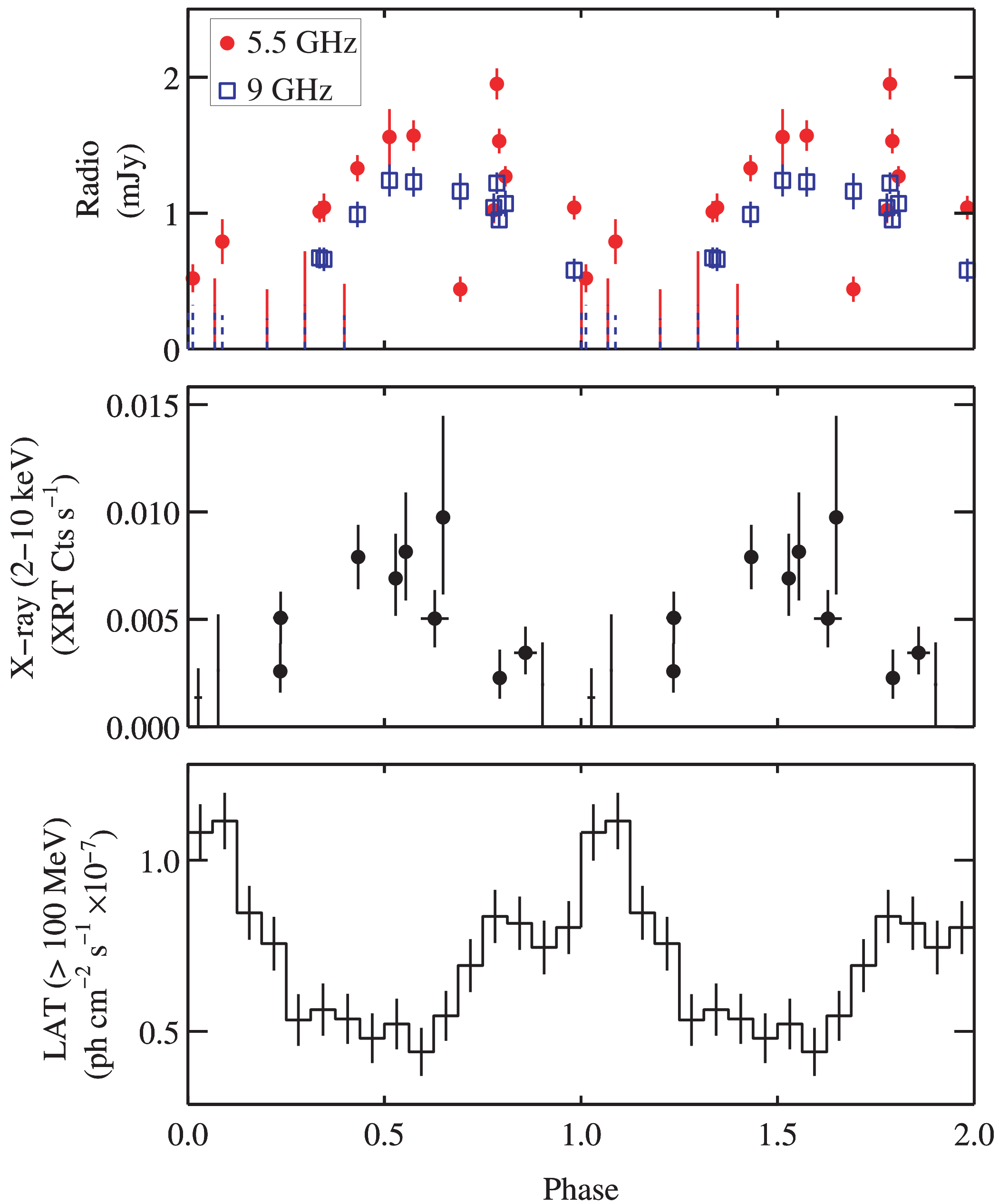
Gamma-ray binaries (γBs)

	HE	VHE	Class	Components	P_{orbit}
PSR B1259-63	yes	yes	PSR binary	Oe + NS	~3.4 yrs
LS I +61 303	yes	yes	**PSR binary**	B0 Ve + NS	26.5 d
HESS J0632+057	**yes**	yes	?	B0 pe + ?	**317.3 d**
PSR J2032+4127	**~yes**	**yes**	**PSR binary**	**B0 Ve + PSR**	**~50 yrs**
HESS J1832-093	**yes**	**yes**	**?**	**B8V - B1.5V + ?**	**86.3 d**
LS 5039	yes	yes	**PSR binary (?)**	ON6.5V + **PSR?**	3.9 d
1FGL J1018.6–5856	yes	yes	?	O6V + ?	16.5 d
LMC P3	yes	yes	?	O5III + ?	10.3 d
4FGL J1405.1-6119	**yes**	no	**?**	**O6.5 III + ?**	**13.7 d**

A luminous gamma-ray binary in the LMC

Corbet et al., ApJ, 829, 10 (2016)

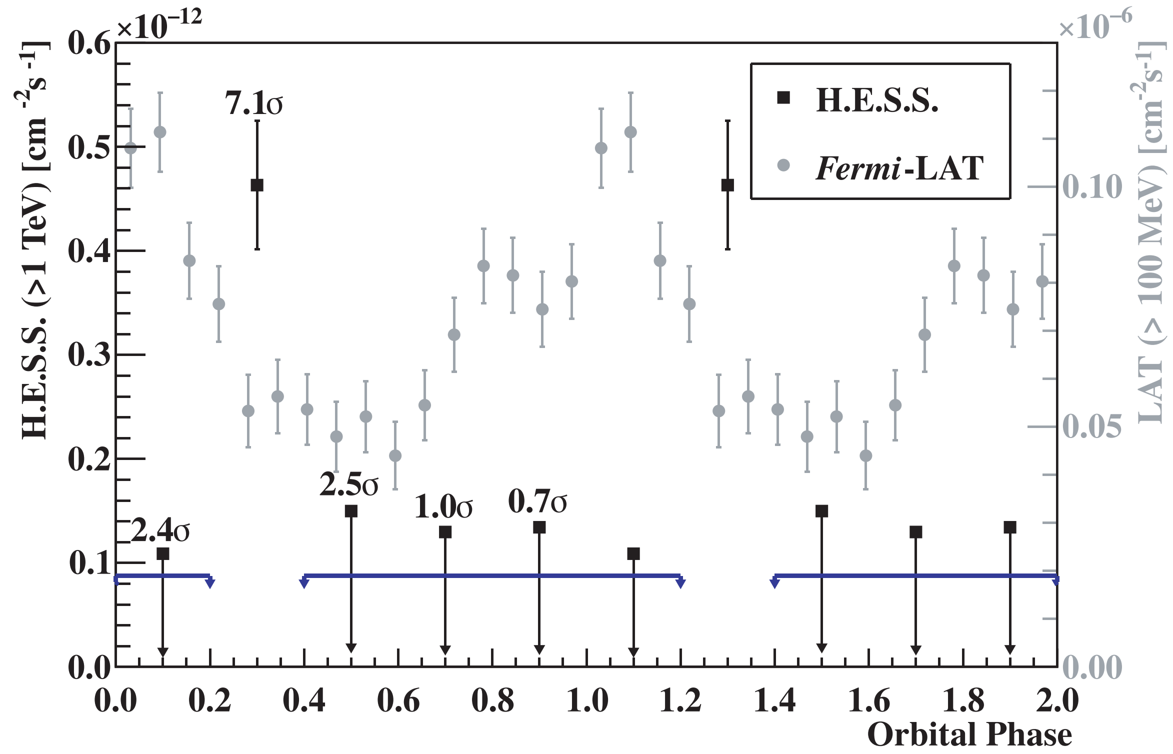
- Discovery following a **systematic blind-search** for periodic modulation - a method that turned to be rather successful: also 1FGL J1018 (LAT Col. 2012) and 4FGL J1405.1 (Corbet et al. 2022)
- **LMC P3**: **first γB outside the Milky Way**; association with a HMXB (Seward et al. 2012, Bamba et al. 2006) containing a massive O5III companion, **inside SNR** DEM L241
- Variable X-ray, radio and HE γ-ray emission, periodically modulated (**P_{orb} = 13.3** d); both radio and X-rays **anti-correlated with the HE emission.**
- **Strong similarities** to LS 5039, 1FGL J1018, but **significantly brighter**: (x4 at HE γ's, x 10 in radio and X-rays (but similar O-star luminosity and orbital separation). If a PSR, $\dot{E} = 4.5 \times 10^{36} \mathrm{erg\ s^{-1}}$



Detection of variable VHE γ-rays from the extragalactic γB LMC P3

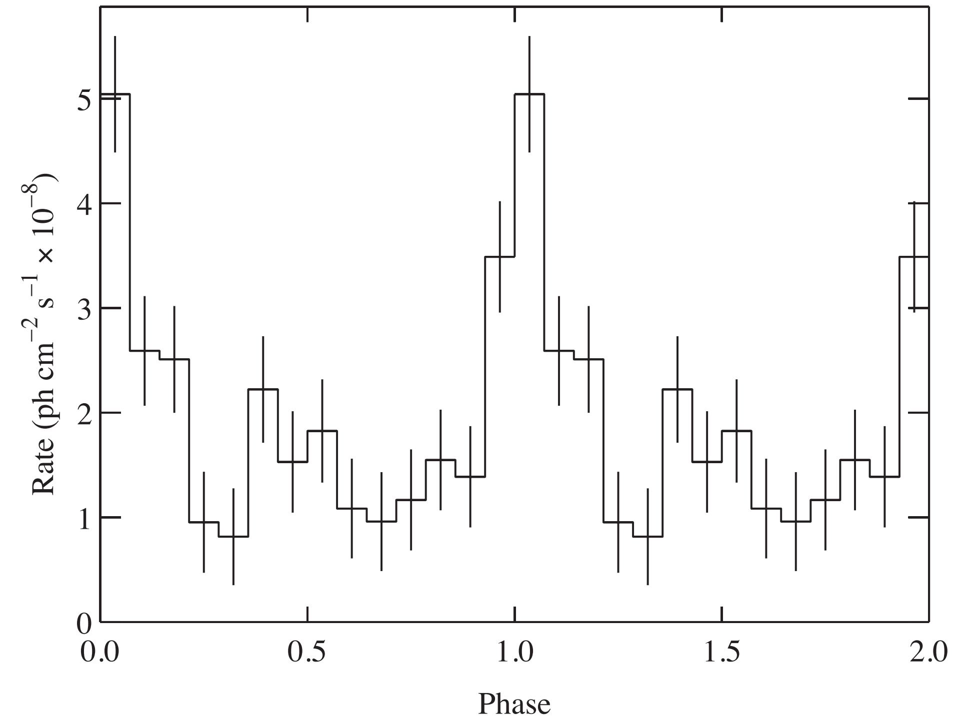
H.E.S.S. Col. A&A, 610, L17 (2018)

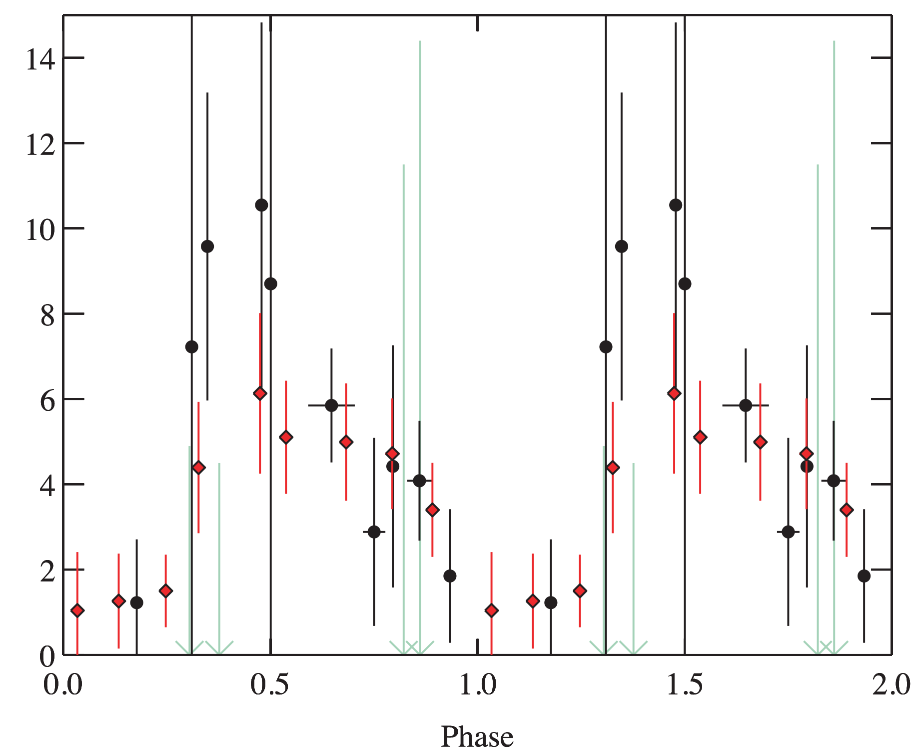
- Deep H.E.S.S. campaign on the LMC (>270h). For LMC P3 t_{obs} > 100h. z-angle conditions + offset => **E_{th} ~ 700 GeV**; ~**6.4σ** detection.
- **no periodicity based on H.E.S.S. data alone** (LS, Z-DCF tests), but **significant variability**. Phase-folded on P_{orb} = 13.3d, emission detected **only at phases [0.2 - 0.4]**
- Spectrum well-fit with PL, Γ = 2.0 ± 0.4, **L_{VHE} ~ 1.4e35 erg/s**, extending up to E > 10 TeV. Taking U_* at 0.32 AU, IC in KN requires **E_e ~1-50 TeV** and **W_e = 2.5e38 erg** injected with $Γ_e$ ~1.5. Cooling t_{ic} (KN) ~100 s. In a PSR scenario, a **spin-down power > 1e36 erg/s needed to sustain VHE emission alone.**
- VHE and HE are **anti-correlated** (= LS5039, but ≠ 1FGL J1018) => γγ absorption, and/or **different emitter locations** (e.g. Zabalza+ 2013)



Discovery of the galactic high-mass γB 4FGL J1405.1-6119
Corbet et al., AJ 884, 12 (2019)

- Similar detection procedure: **blind-search for modulation** in LAT catalogue + search for **counterparts in X-rays and radio**, try to confirm modulation at lower energies. For the companion star, optical => IR due to high obscuration -> **O6 III-type** companion star
- **Detection of periodic modulation of 4FGL1405 with P_{orb} = 13.7d** displaying a **main peak and a secondary peak only at ~soft energies** (> 200 MeV). X-ray and radio emission also modulated with P_{orb}, but with a single maximum, anti-correlated with the GeV "main" peak.
- 4FGL1405' L_γ = 5e33 erg/s at d ~7.7 kpc (≈ LS 5039's and ~1/2 of 1FGL J1018's). L_X = 6e33 erg/s also similar to LS 5039, (Bosch-Ramon et al. 2007, Rea et al. 2011).

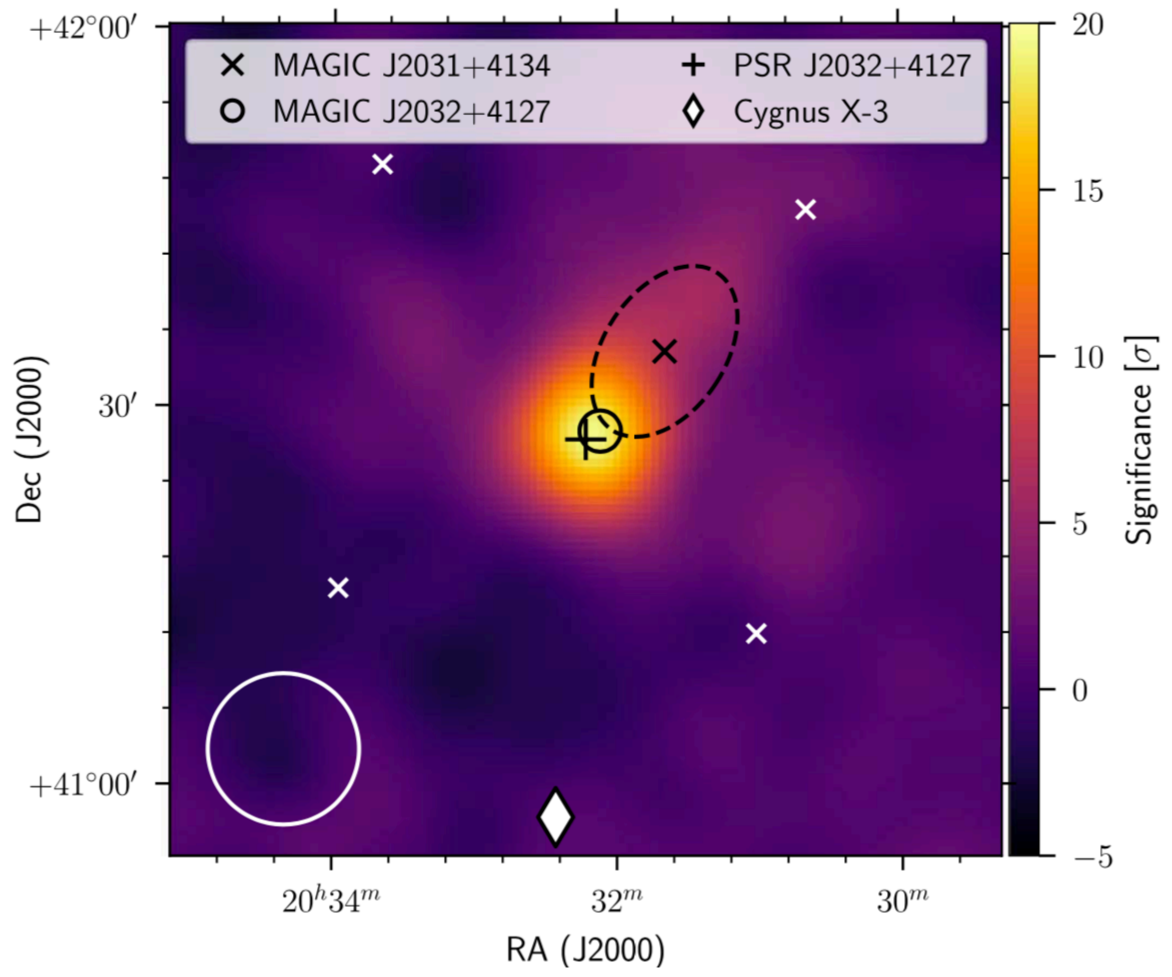




Highlights: detection of PSR J2032+4127

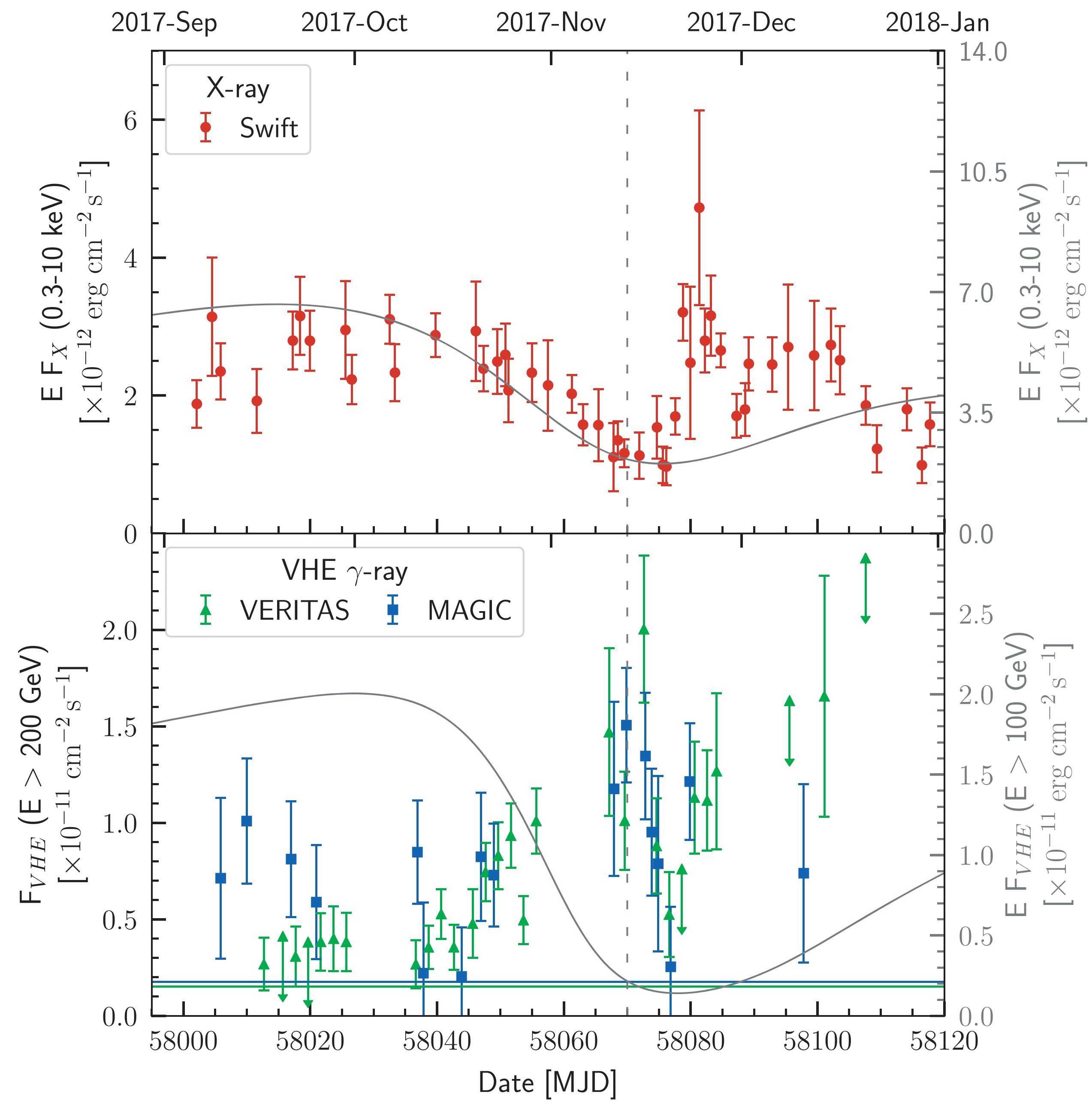
***Periastron observations of TeV γ-Ray emission from a binary system with a 50-year period* - MAGIC & VERITAS CoI, ApJ, 867, L19 (2018)**

- Pulsed emission from PSR J2032+4127 detected with *Fermi*-LAT and **association with a long-period binary system** (Lyne et al. 2015)
- Only gamma-ray binary apart from PSR B1259 with a **confirmed PSR as the powering engine** (see however LS I +61 303), in a system containing a **Be star with a circumstellar disk** displaying a varying size (by a factor ~2)
- **Deep MAGIC and VERITAS observation campaign** (combined t_{obs} ~180h) around periastron (P_{orb} ~50 yrs).
- Clear detection (**~20 σ**) of a **point-like VHE source coincident with PSR J2032+4127** on top of the **steady extended emission** from the HEGRA source **TeV J2032.**



Periastron observations of TeV γ-Ray emission from a binary system with a 50-year period - MAGIC & VERITAS Col, ApJ, 867, L19 (2018)

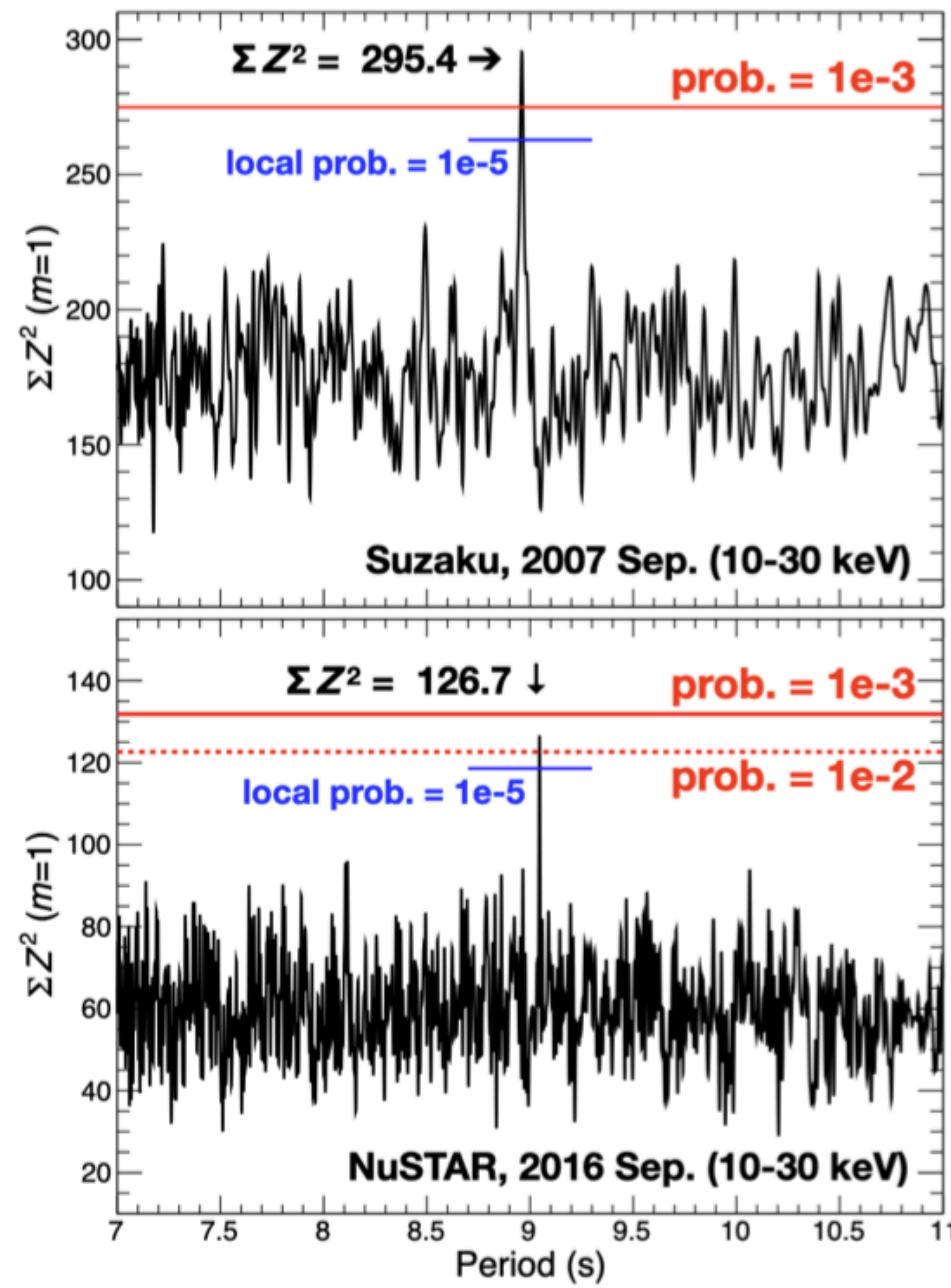
- **Significant variability in VHEs.** Increasing flux up to peak at t_{per} (x10 that of TeV J2032) + sudden drop + recovery to t_{per} values (**similar to PSR B1259** but no GeV variability nor flares).
- VHE spectrum best fit: baseline emission from TeV J2032 (PL) + binary (**PL+ expCut, with E_c ~0.5 TeV**). When dividing the data set ("low" and "" state), data around t_{per} **do not require the cutoff.**
- X-rays: variability at ~weeks time-scales on top of long-term increase towards t_{per} (Li et al. 2018, Petropoulou et al. 2018). **No GeV variability** (masked by magnetospheric PSR emission? Li et al. 2018).
- Predictions of both X-ray (Li et al. 2018) and TeV (Takata et al. 2018) emission at t~ t_{per}, **inconsistent with observations. No apparent X-ray/TeV correlation.**



Sign of Hard-X-Ray Pulsation from the γ-Ray Binary System LS 5039

Yoneda et al. Phys. Rev. Lett. 125, 111103 (2020)

- Search for pulsations in LS 5039 in hard X-rays using *Suzaku* (181 ks) and *NuSTAR* (191 ks) archival data.
- To avoid Doppler modulation effects, requires >10 ph per chunk of data analysed, which imposes a **limit for the putative pulsation period: P_{NS} > 1 s**.
- Fourier analysis of Suzaku data: P_{NS} = 8.96 s with chance probability **P_{ch} = 0.0011**. A Z^2 test (de Jager et al. 1989) provides also P_{NS} = 8.96 s, with **P_{ch} = 0.0015.**
- The same Fourier analysis on **NuSTAR data did not provide any clear signal**. A Z^2 test provides P_{NS} = 9.05s, with **P_{ch} = 0.031**.
- X-check: look for the **orbital period in each data-set using the same Z^2 test ->** P_{orb} = 3.90 ± 0.05 d (*Suzaku*) and P_{orb} = 3.90 ± 0.05 d (*NuSTAR*).
- These results favor the dissipation of the NS **magnetic energy as the powering source**, implying a magnetic field value > 3e10 T, and therefore **a magnetar nature of LS 5039**.

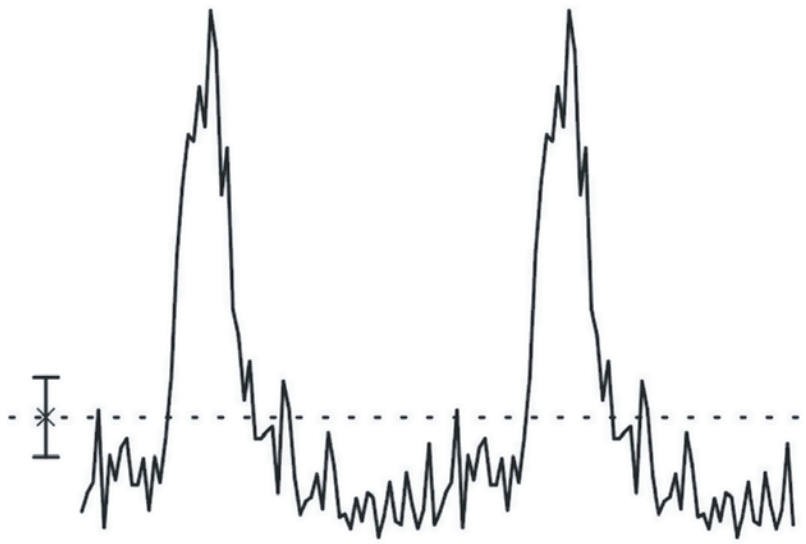


Yoneda et al. (2020)

Highlights: detection of pulsations in LS I +61° 303

Radio pulsations from a neutron star within the γB LS I +61° 303
Weng et al., Nat. Ast. 6, 698 (2022)

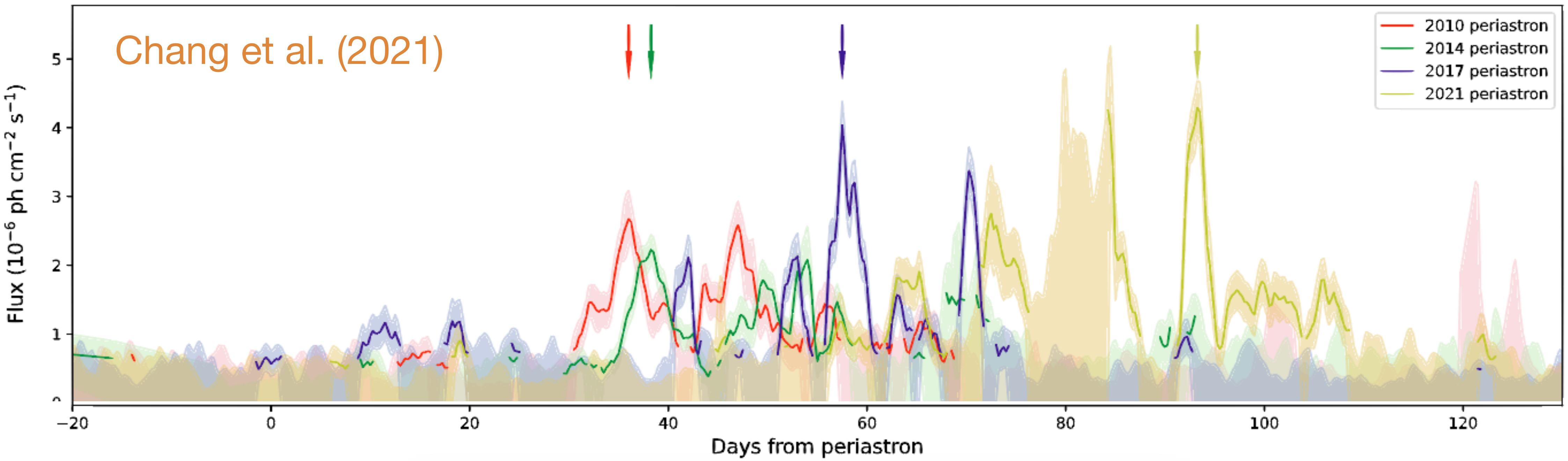
- **LS I 61303 is powered by a pulsar**, with a **rotation period of 0.27s** as clearly detected (**>20σ**) with the FAST radio telescope in 2020.
- Pulsations **seem to disappear** for a significant lapse of time, with **non-detection at similar orbital phases** (ϕ = 0.6, minimum free-free absorption) for observations taken a few months apart.
- Switching on/off mechanism still unknown (most likely **changes in environment**, see e.g. rapid radio flux variations and orbit-to-orbit changes in pulsation disappearing times in PSR B1259).
- Claims of **magnetar-like flares** from LS I 61303 are reinforced with the identification of a PSR powering the system. If confirmed, this would be the first confirmed magnetar in a binary system, (probably a low B-field magnetar)



Weng et al. (2022)

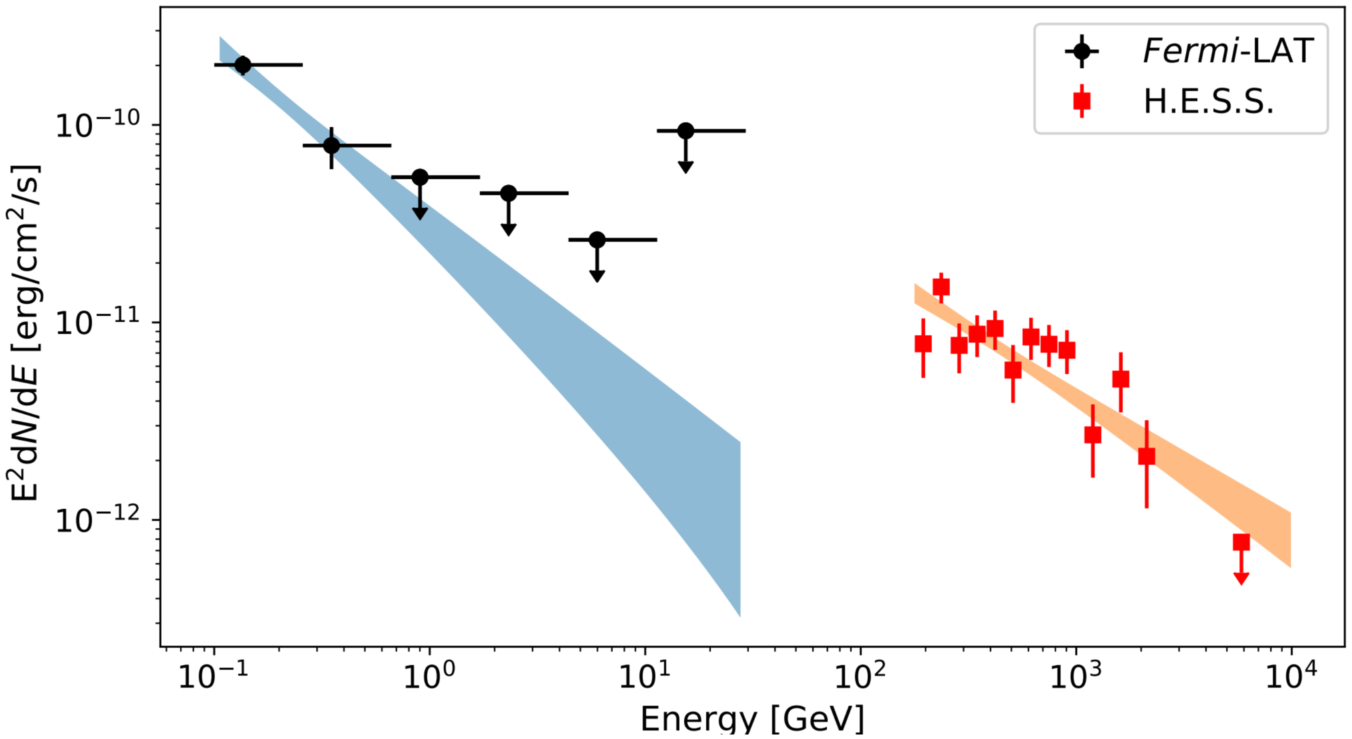
Detailed report in D. Torres talk (ID-278) this afternoon

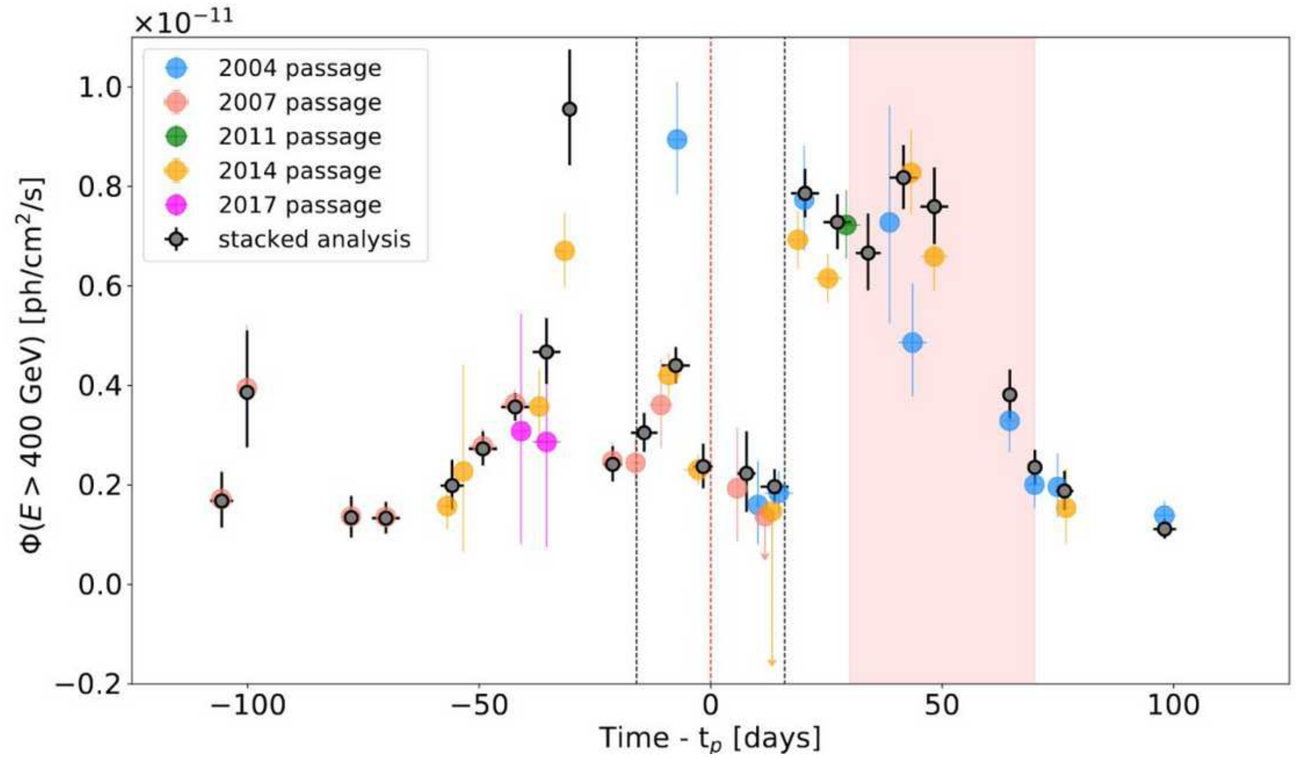
Highlights: PSR B1259 periastron passage(s)



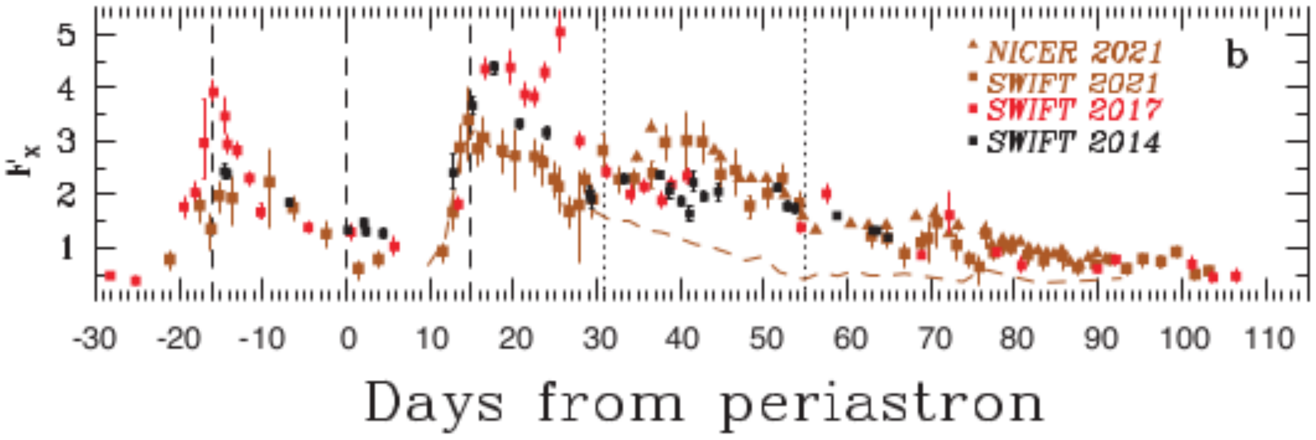
- L_γ > pulsar spin-down power (if isotropic) => **Doppler-boosting**, e.g. Kong et al. 2012, may not be however efficient enough (see Khangulyan et al. 2014); see also numerical MHD simulations in Bogovalov et al. 2012, 2019 in which **both for low and high magnetisation winds** collimation seems rather difficult to attain.
- Other models do not rely on Doppler boosting, e.g. **Comptonization of a cold pulsar wind** (Khangulyan et al. 2012), **GeV-emitting pairs with a Maxwellian distribution** injected in shock at high pulsar latitudes (Dubus & Cerutti 2013), **IC of soft photons from an accretion disk** formed around the PSR (Yi & Cheng 2017), or a combination of **bremsstrahlung +IC emission** from unshocked and weakly-shocked electrons of the pulsar wind (Chernyakova et al. 2020)

Highlights: PSR B1259 periastron passage(s)





H.E.S.S. Col. (2020)

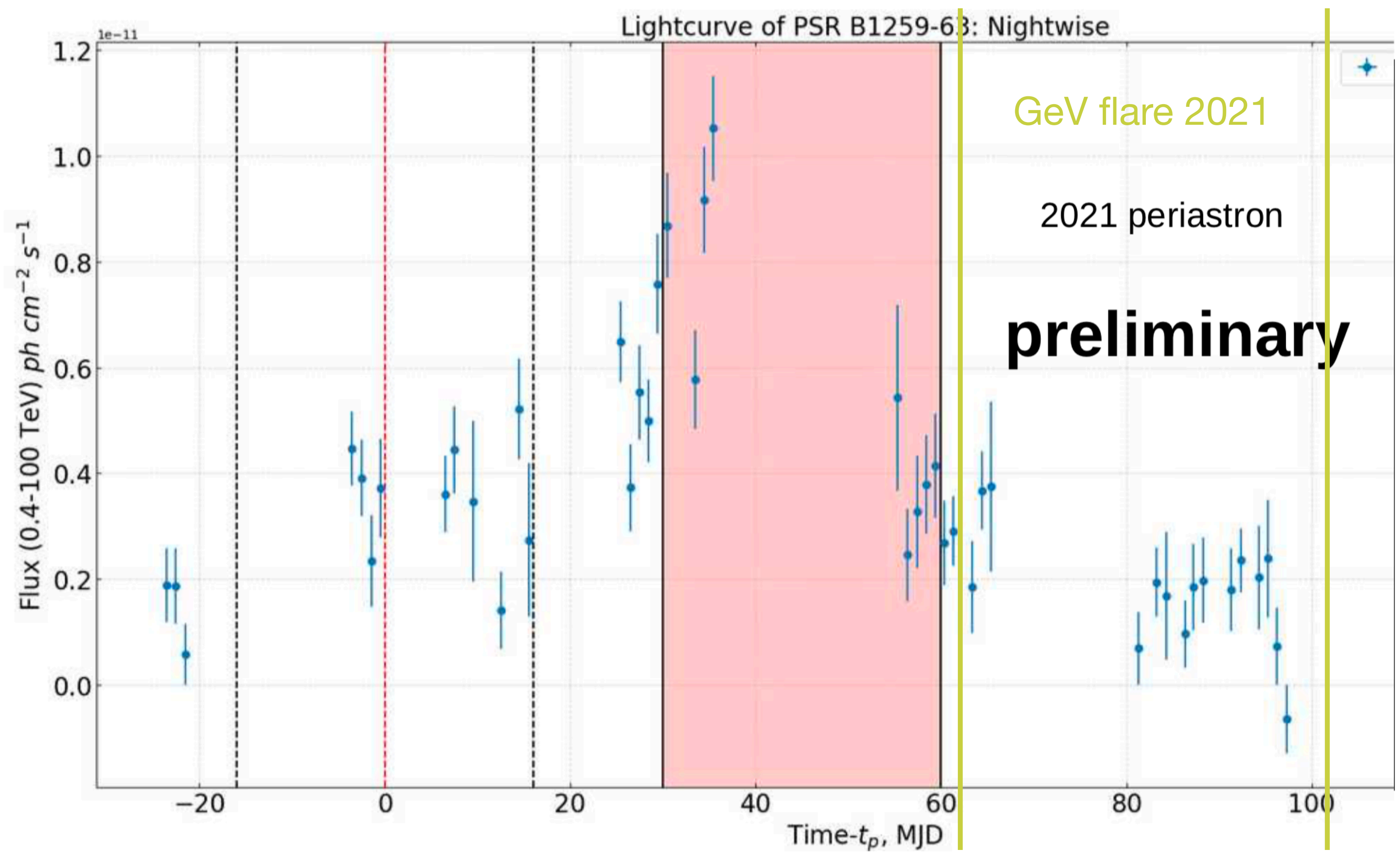


Chernyakova et al. (2021)

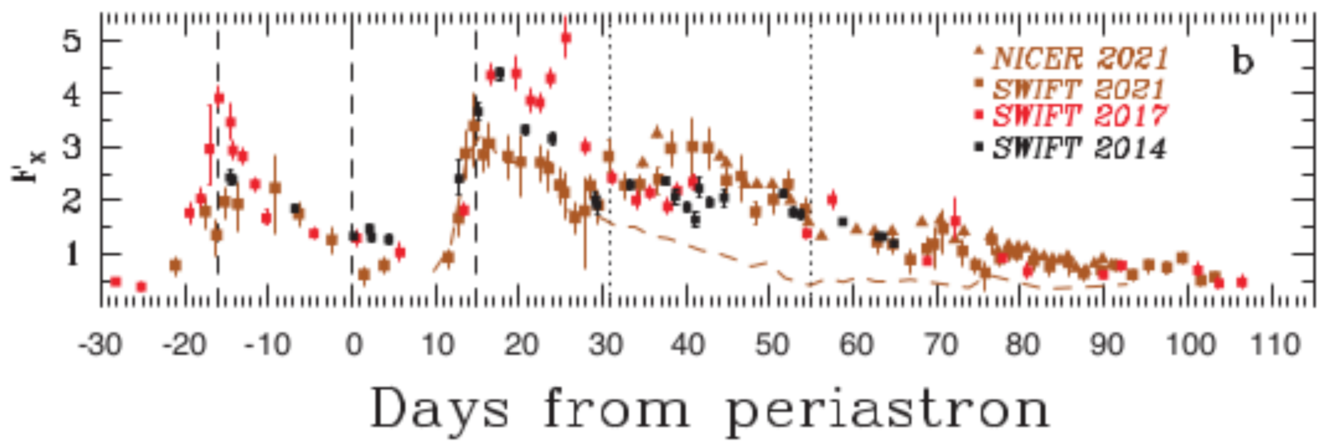
C. Thorpe-Morgan talk (ID-413)

M. Chernyakova talk (ID-413)

Highlights: PSR B1259 periastron passage(s)



from S. Wagner's H.E.S.S. highlights talk on Monday (ID328



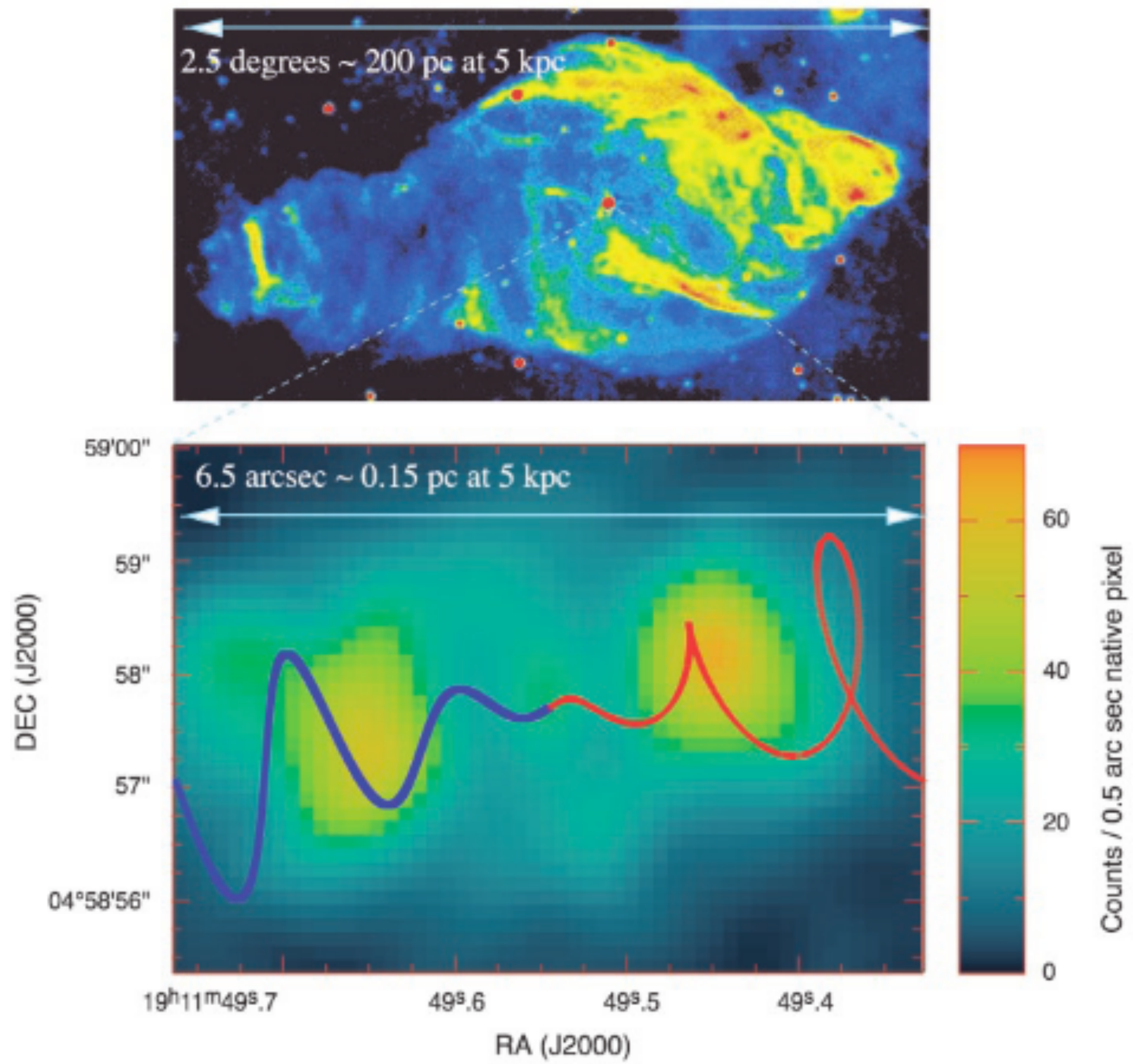
Chernyakova et al. (2021)

C. Thorpe-Morgan talk (ID-413)

M. Chernyakova talk (ID-413)

Highlights: detection of SS433 at γ-rays

- **Binary system**
  - d ~ 5.5 kpc, τ_{SS433} ~ 3 × 10^4 yrs
  - likely BH (M~10-20 $M_\odot$) + A-supergiant (Fabrika 2004)
  - supper-critical accretion rate, dM/dt ~ 10^{-4} $M_\odot$/yr
  - 13d (162d) orbital (precession) period (Gies+ 2002)
- **jets**
  - mildly relativistic vjets= 0.26 c, *i* = 78°, θ_{prec} = 21°
  - extremely powerful, $L_{jet} \gtrsim 10^{39}$ erg/s
  - evidence of baryons (Marshall+ 2002, Migliari+ 2002)
  - detected in radio, IR, optical, X-rays



(Dubner et al 1998, Migliari et al. 2002)

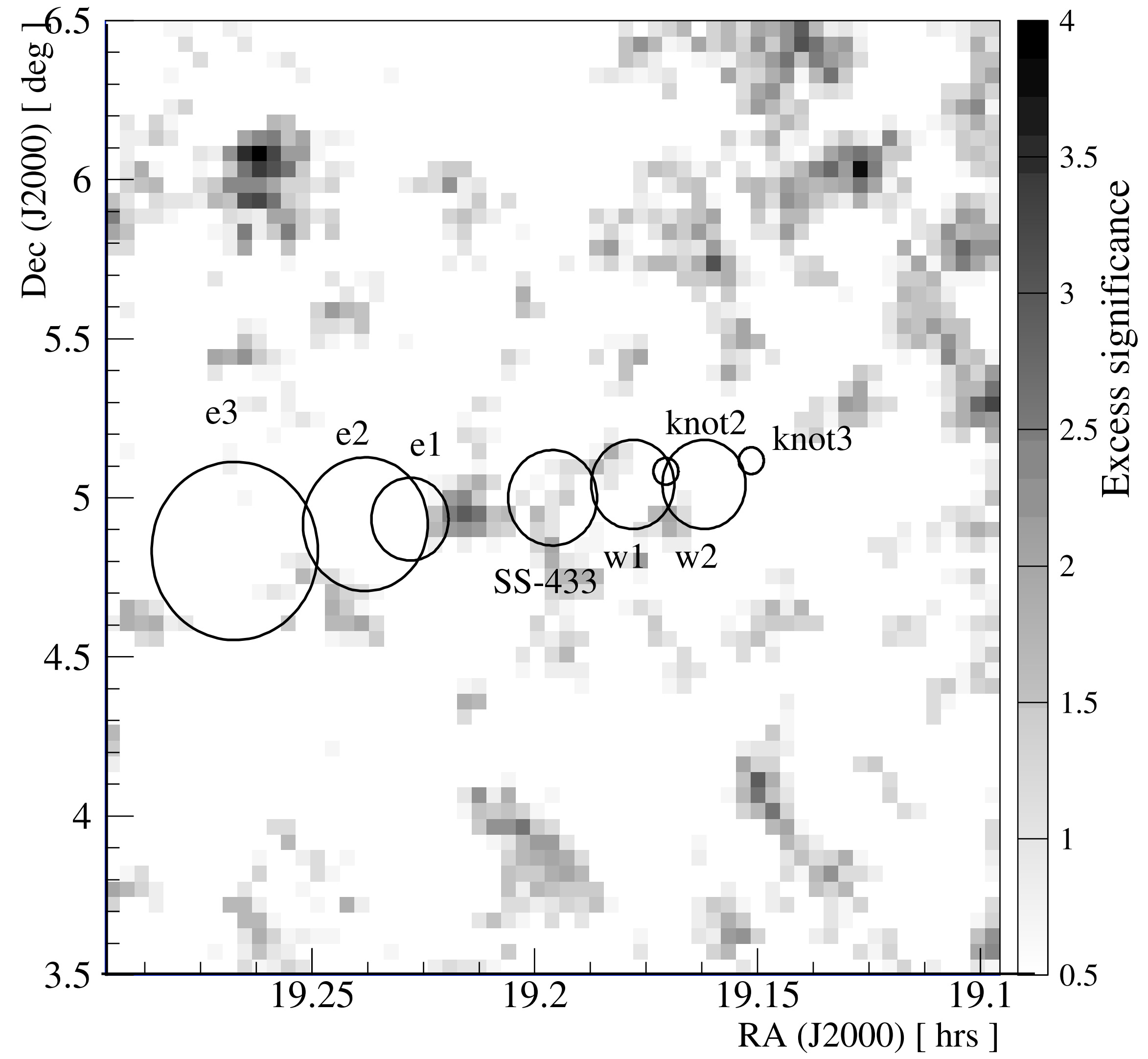
Talk by L. Olivera (ID-382) on Monday

Talk by S. Safi-Harb (ID-371) on Monday

Talk by J. Goodman (ID-497) on Tuesday

Aharonian et al. (HEGRA Collaboration)
(2005, A&A, vol. 439, p. 635–643)

- ~100h HEGRA data, uull (E > 800 GeV): ~30 mCrab



Aharonian et al. (2005)

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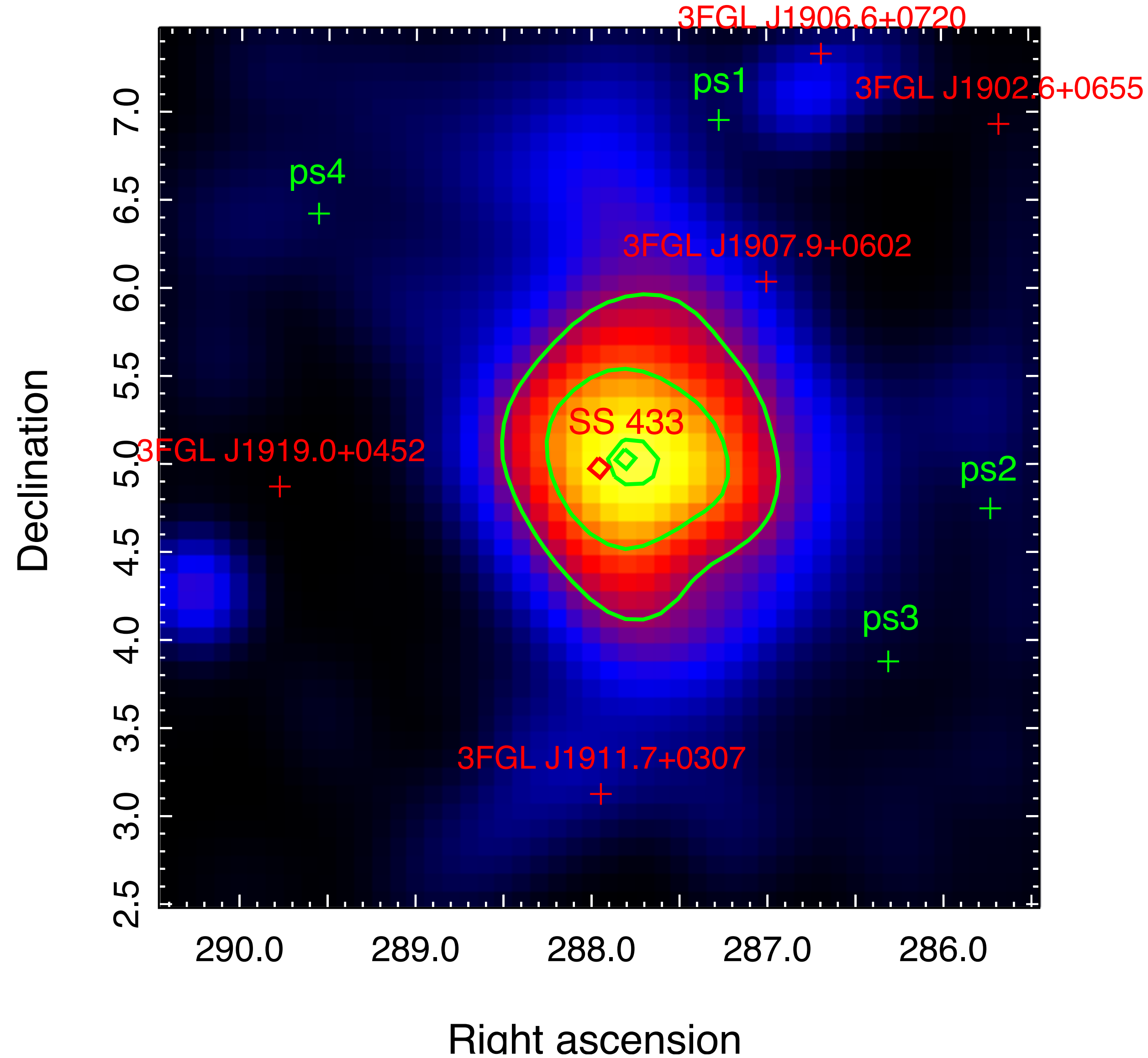
Bordas, Sun, Yang, Kafexhiu & Aharonian
(γ-2016, AIP, vol. 1792, p 20B)

- ~7 years LATdata, TS = 62.41 (~ 7.9 σ)



Bordas et al. (2015)

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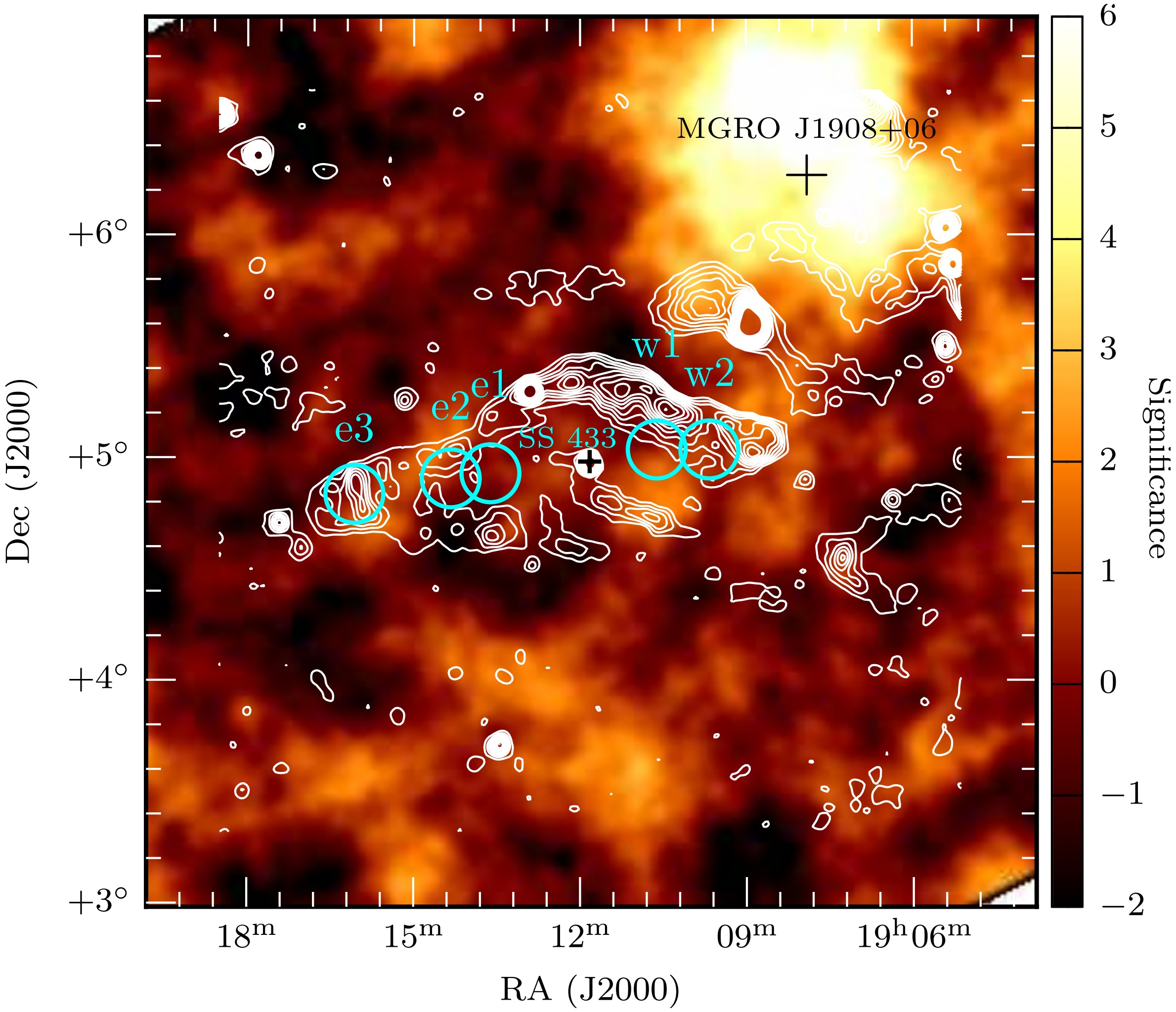
MAGIC & H.E.S.S. Collaborations
(2018, A&A, vol. 612A, p. 14M)

- ~10h on SS433, 20-60h for int. regions
  uull (E > 250 and 800 GeV): ~10 mCrab



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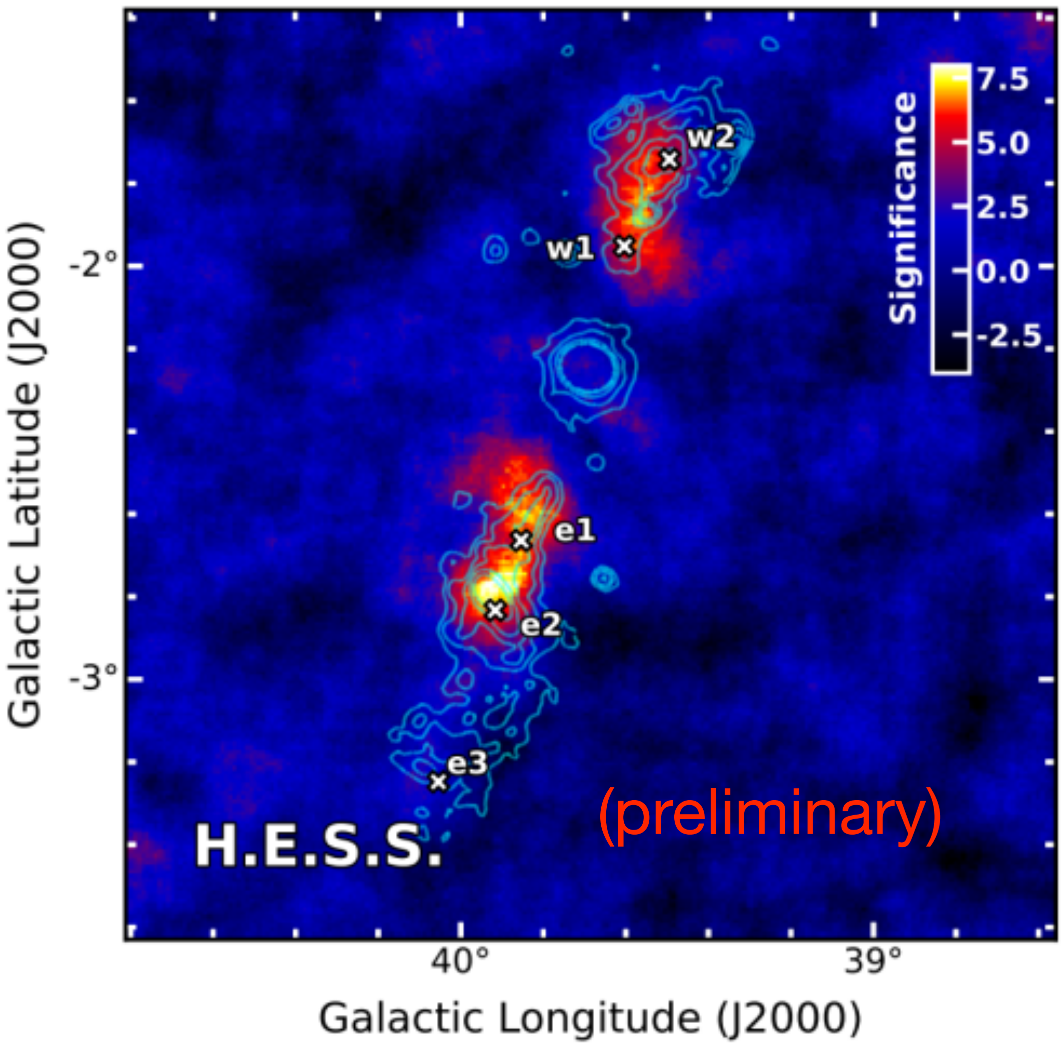
H.E.S.S. Collaboration (in prep.)

- H.E.S.S. data set of **~300h on SS433**
- **Improved analysis**: *super hard* config optimized for faint, hard sources + use of CT5 for bkg rejection + Gammapy
- Western/eastern lobes **detected at a 6.8σ** and **7.8σ** respectively



Report by L. Olivera (ID-382) on Monday

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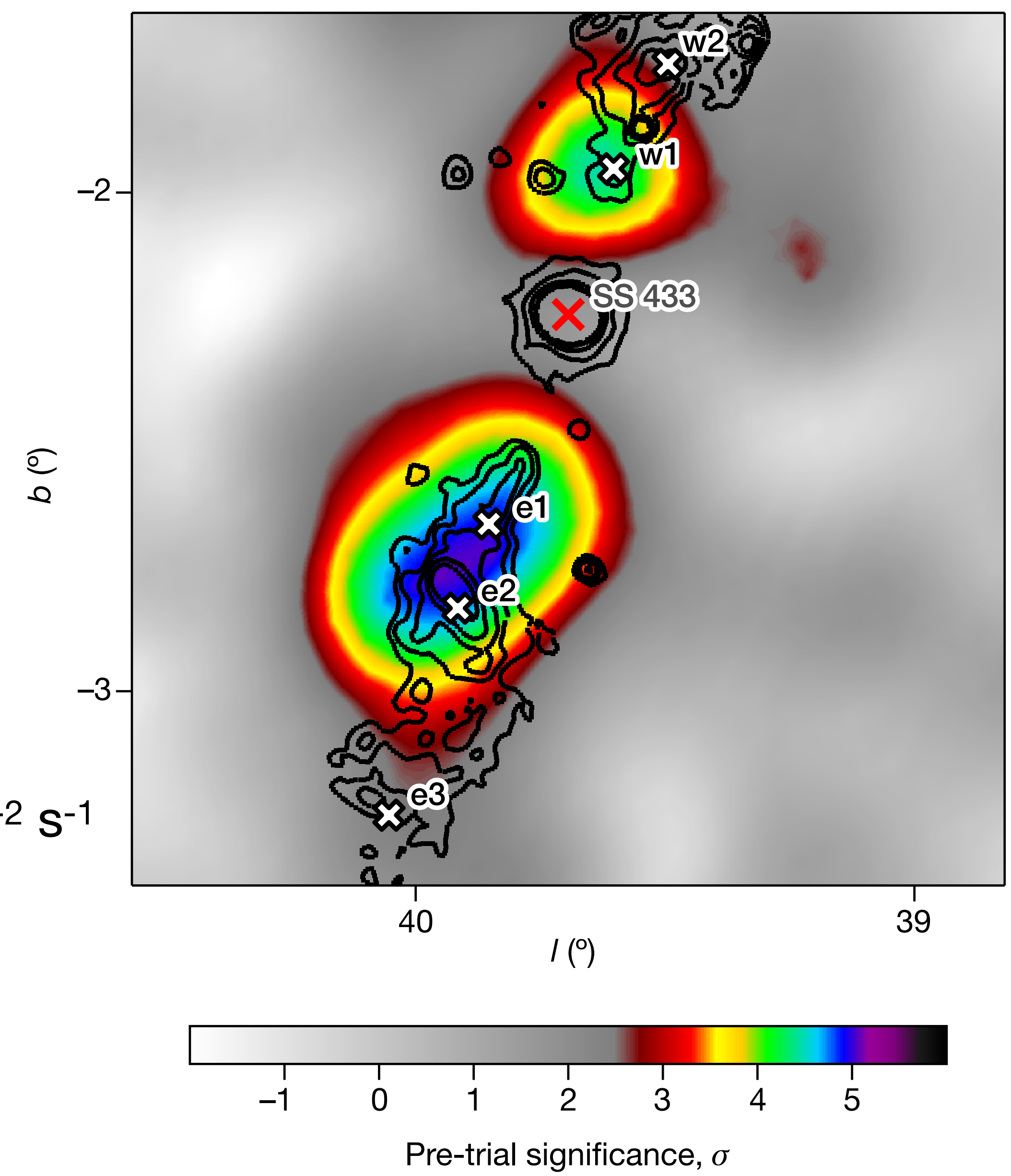
**Abeysekara et al. (HAWC Collaboration)
(2018, Nature, vol. 562. p. 82A)**

- ~3 years of HAWC data: e1 + w1: ~ 5.4σ
- E> 20 TeV, SS433: $\Phi < 5.3 \times 10^{-17}$ TeV^{-1} cm^{-2} s^{-1}

Abeysekara et al. (2018)



Aharonian et al. (HEGRA Collaboration)
(2005, A&A, vol. 439, p. 635–643)

- ~100h HEGRA data, uull (E > 800 GeV): ~30 mCrab

Bordas, Sun, Yang, Kafexhiu & Aharonian
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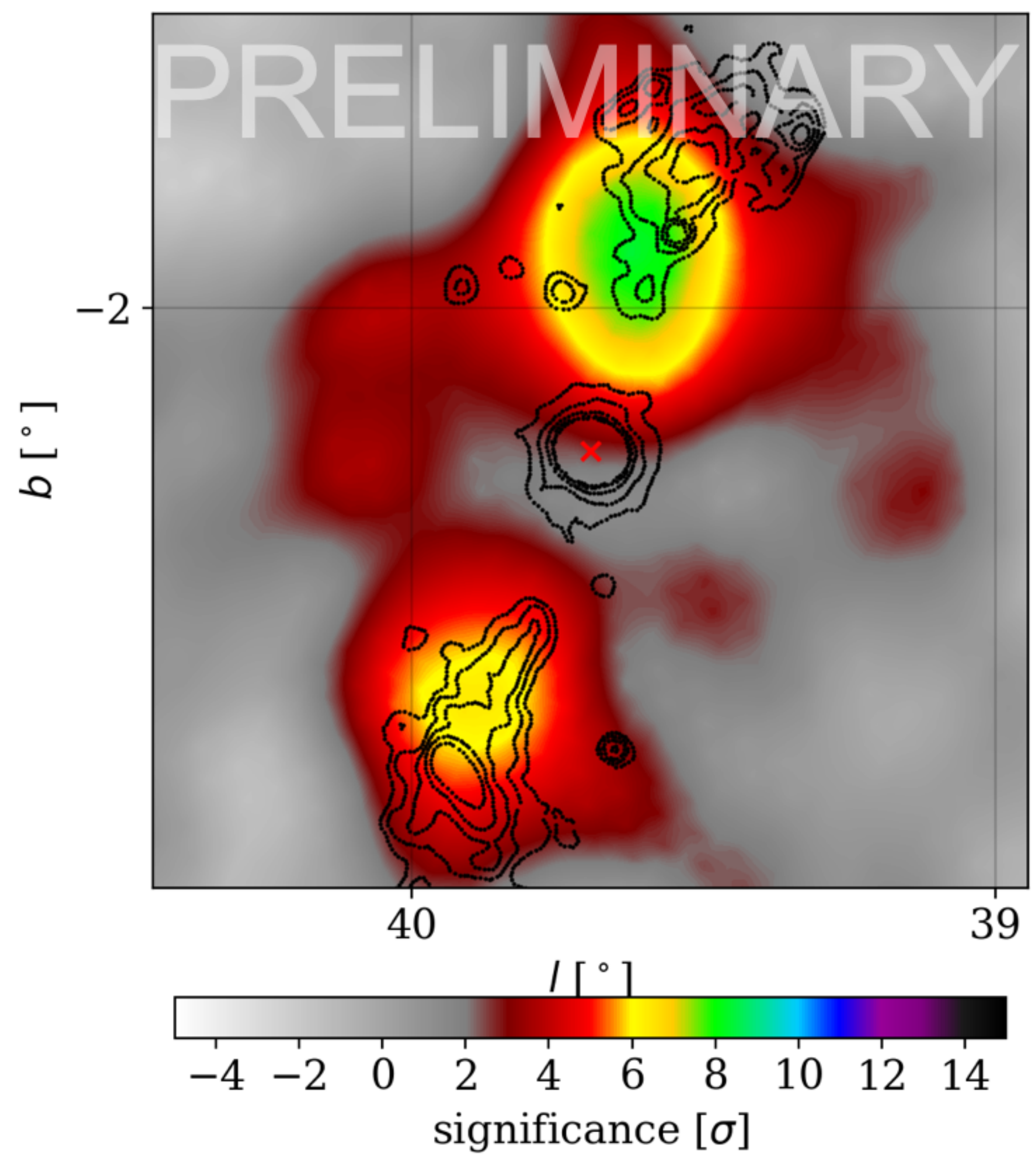
- ~7 years LATdata, TS = 62.41 (~ 7.9 σ)

MAGIC & HESS Collaborations
(2018, A&A, vol. 612A, p. 14M)

- ~10h on SS433, 20-60h for int. regions
  uull (E > 250 and 800 GeV): ~10 mCrab

HAWC Collaboration (in prep.)

- ~7 years of HAWC data:
- **e1 detected at ~7.6σ**, **w1 at ~9.2σ**
- **spectral analysis available**:
  $\Gamma_{e1} = 2.47 \pm 0.2$, $\Gamma_{e1} = 2.41 \pm 0.09$



Talk by J. Goodman (ID-497) on Tuesday

Highlights: detection of SS433 at γ-rays

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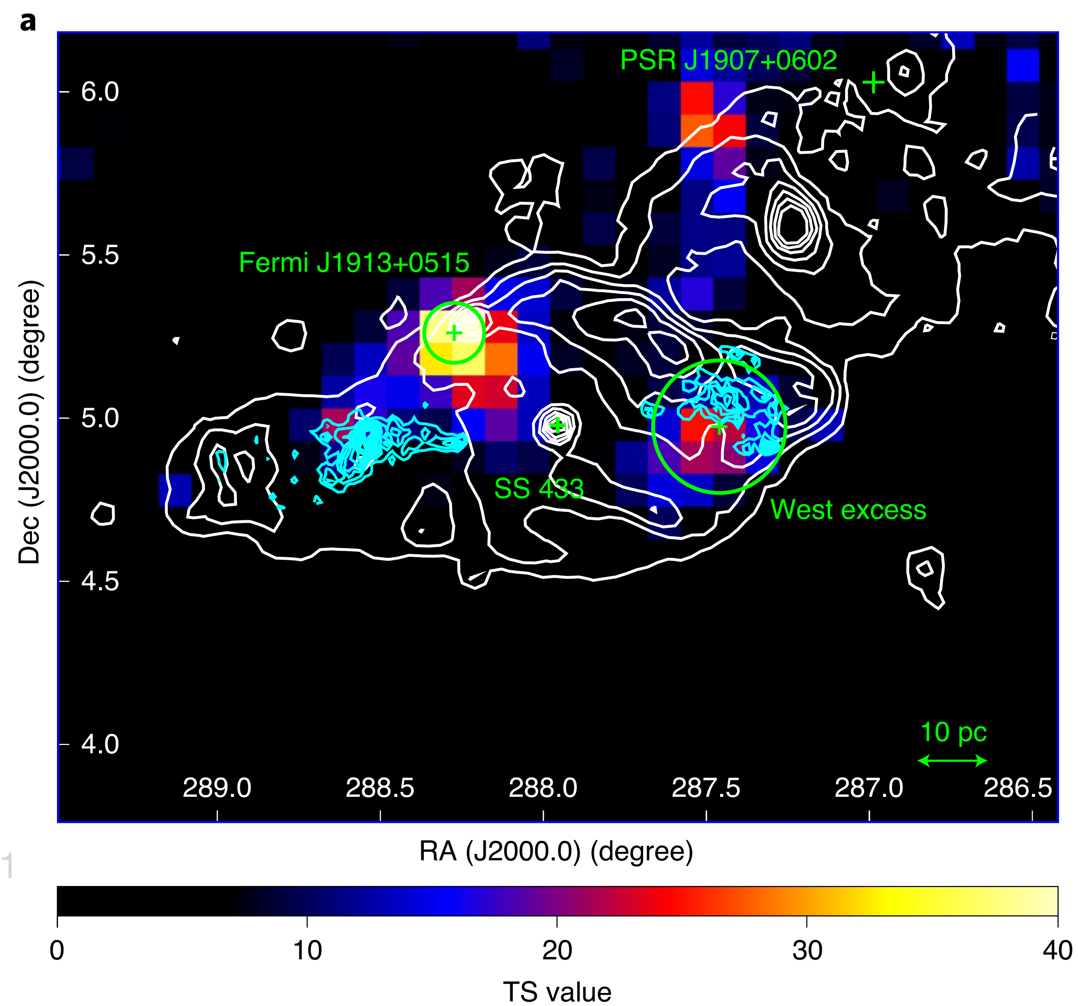
Abeysekara et al. (HAWC Collaboration)
(2018, Nature, vol. 562. p. 82A)

- ~3 years of HAWC data: e1 + w1: ~ 5.4σ
- E> 20 TeV, SS433: $\Phi < 5.3 \times 10^{-17}$ TeV^{-1} cm^{-2} s^{-1}



Li et al. (2020)

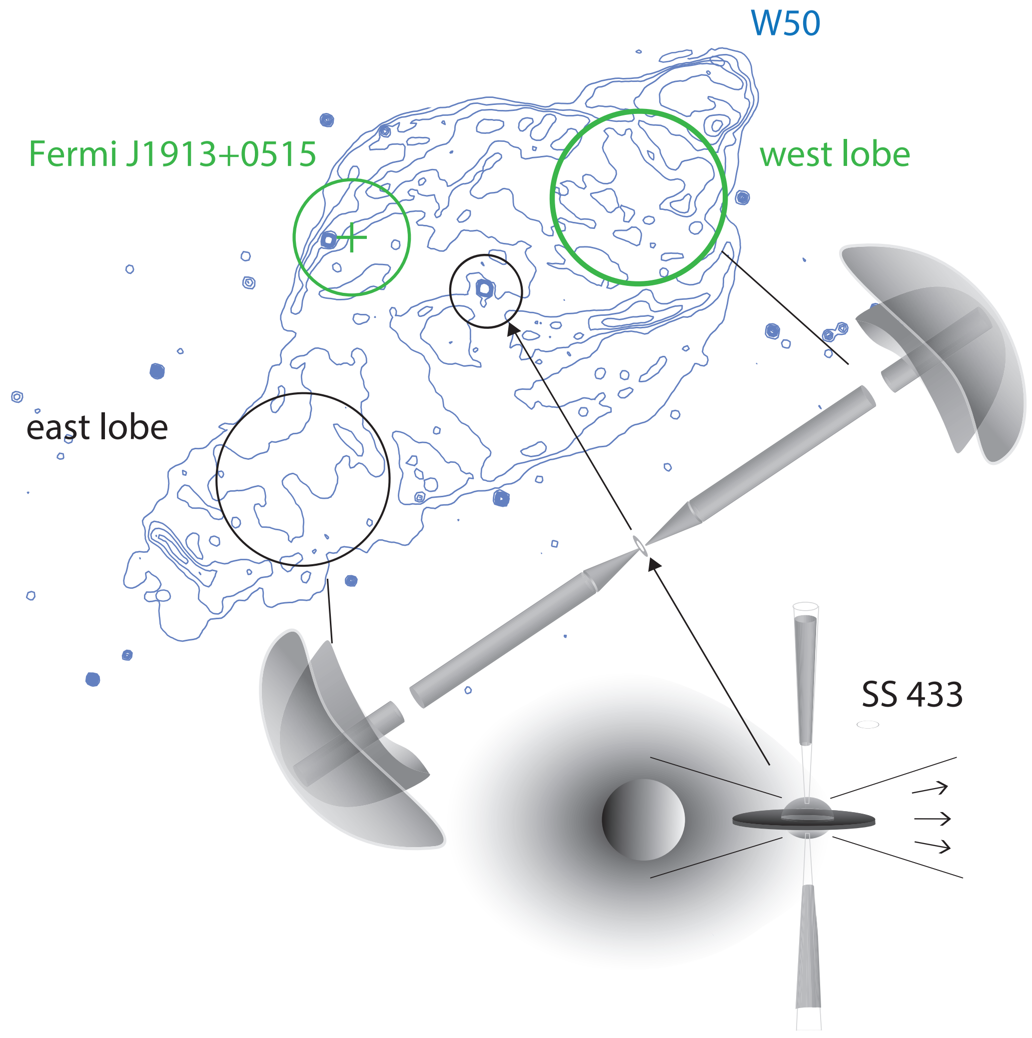
Li, Torres, Liu, Kerr, de Oña Wilhelmi & Su
(2020, Nature Astronomy, 162L)

- ~ 10.5 years of LAT data
- **Fermi J1913+0515**: TS = 39 (6.5σ)
- west int. region: TS = 15 (3.5σ)

Highlights: detection of SS433 at γ-rays

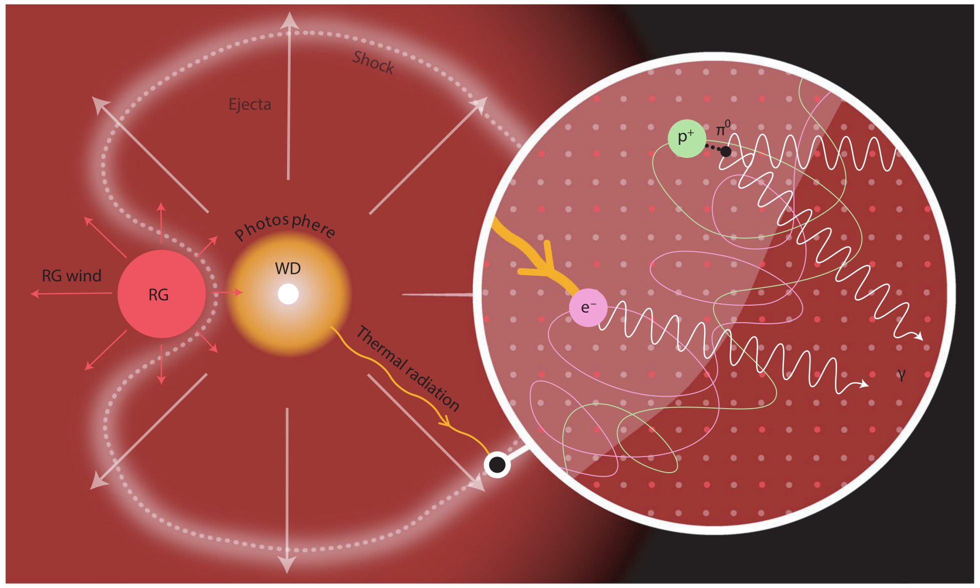
- Origin of the GeV periodic emission ?
  - location **~35 pc away** => modulation by absorption not feasible (Reynoso et al. 2008)
  - **not in the jet "precession cone"** => illumination by east jet not feasible
  - hadronic origin?
    - proton injection by **equatorial outflow**
    - $W_p \approx 2.5 \times 10^{48} (L_\gamma/10^{34})(n/20)^{-1}$
      => accumulate 100 yr of injection power
      so **periodicity completely smeared out**
  - alternative: **20% of jet/outflow kinetic power in rel. protons** + assume a **very dense** (10^4 cm^{-3}) density “cusp" at the cloud as target material (allowing gamma-rays to be produced within
    timescales t < half-period)
  - channel the whole of these accelerated protons towards the gas enhancement/cusp: this requires a **highly-anisotropic diffusion mechanism** at play: “**magnetic tubes**”?

SS433/W50



Bordas 2020

Highlights: detection of Novae at VHEs



from Acciari et al. (2022)

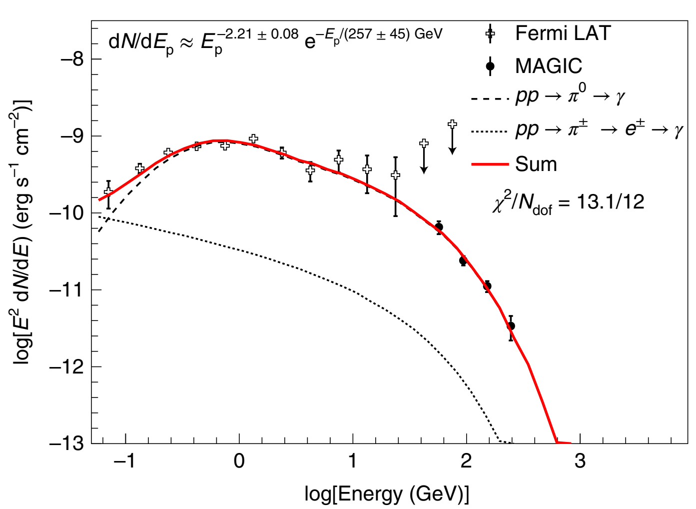
- Novae are produced by the **thermonuclear fusion** of hydrogen on the surface layers of a WD when accreting the mass from its companion star in a binary system.
- In classical nova the companion star is a MS star, and the WD is “smoothly" fed by the wind from the companion through Roche-lobe overflow.
- Symbiotic recurrent novae are instead composed of a ~massive WD (> 1.1 M_{sun}) and a red giant companion, and the WD accretes from the massive star wind.

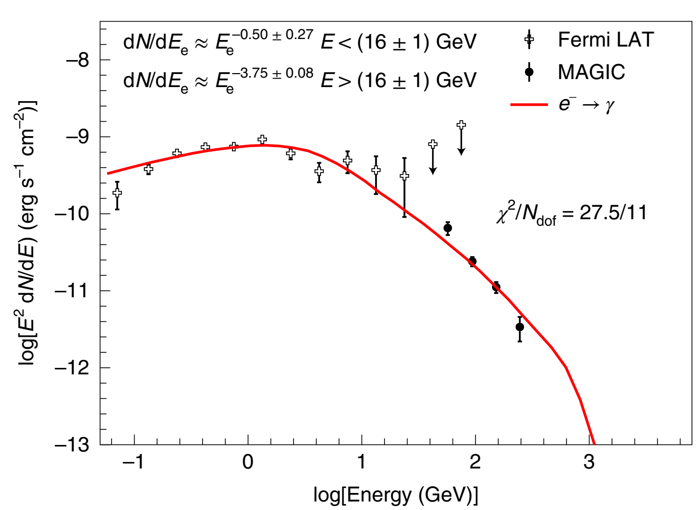
Dedicated talk by M. Hernanz (ID-494) right after this talk

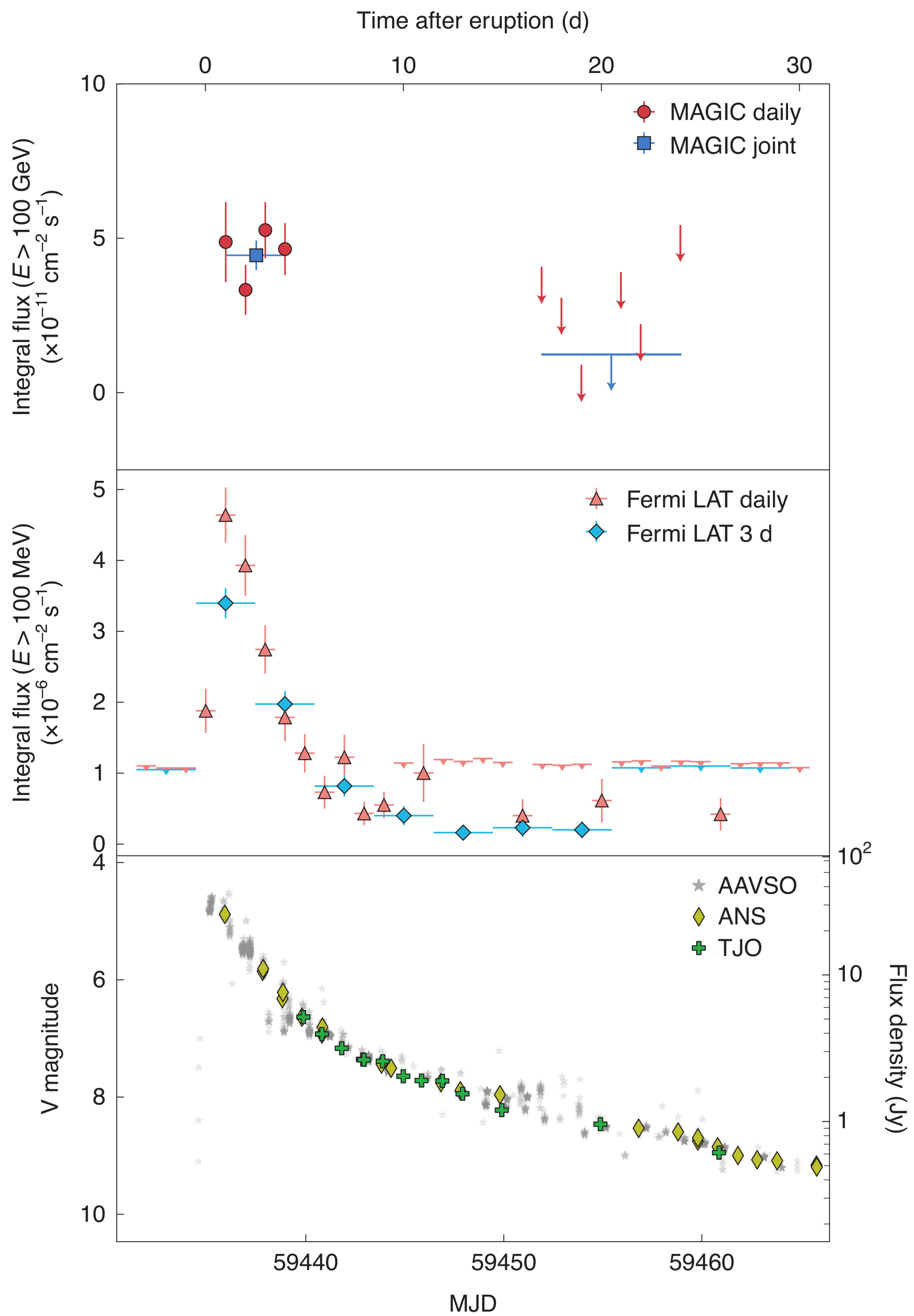
Proton acceleration in thermonuclear nova explosions revealed by γ-rays

Acciari et al. Nat. Astron, 6, 689 (2022)

- **Detection (13.2σ) of the recurrent nova RS Ophiuchi** with MAGIC at energies 60-250 GeV.
- MAGIC flux ~cte in the first 4 days, while LAT flux decreases => **migration of the γ-ray emission towards higher E <=>** increase of particle's E_{max}
- The *Fermi*-LAT and MAGIC measurement **can be well described** with a proton-only model**, with a PL + expCut with Γ ≈ 2, with E_{cutoff} increasing with t**
- Un-cooled accelerated protons will eventually escape, and contribute (dominate) to the galactic CR see in the immediate surroundings (~0.5 pc)



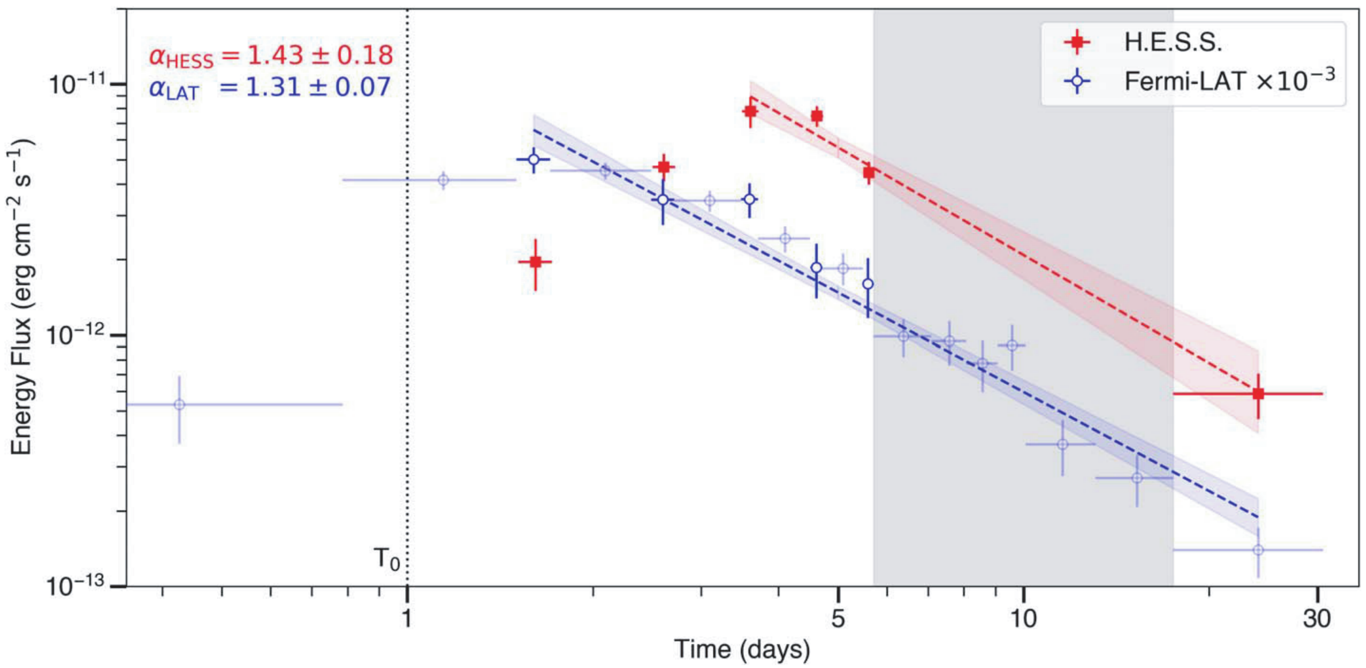


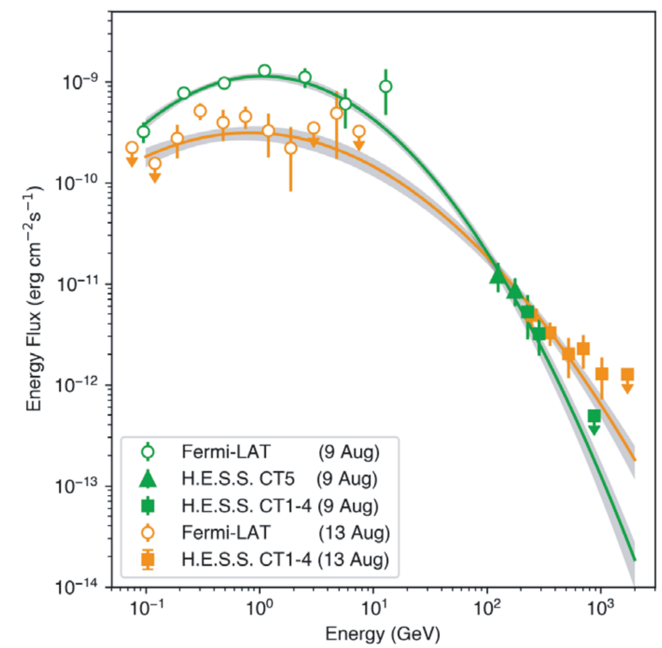


Acciari et al. (2022)

Highlights: detection of Novae at VHEs

Time-resolved hadronic particle acceleration in the recurrent nova RS Ophiuchi
Acciari et al. Nat. Astron, 6, 689 (2022)





H.E.S.S. Col (2022)

- H.E.S.S. detected RS Oph **up to ~1 month after the 2021 outburst** with a **daily significances ~6σ** for the first 5 nights. **The VHE flux profile closely follows that at HEs** with a shift/delay of ~2 days.
- RS Oph spectrum **consistent with a log-parabola model, with N_0 decreasing and the parabola widening over time,** also similar to the LAT spectrum.
- An hadronic scenario is favoured over a leptonic model, with proton **E_{max} increasing with time** up to ~10 TeV, and a **conversion efficiency > 10%**.
- The **contribution to the local CR density** can be significant within ~1pc^3 volume. If a similar accel. efficiency operates in SNe, **these could sustain the galactic CR flux at PeV energies**.

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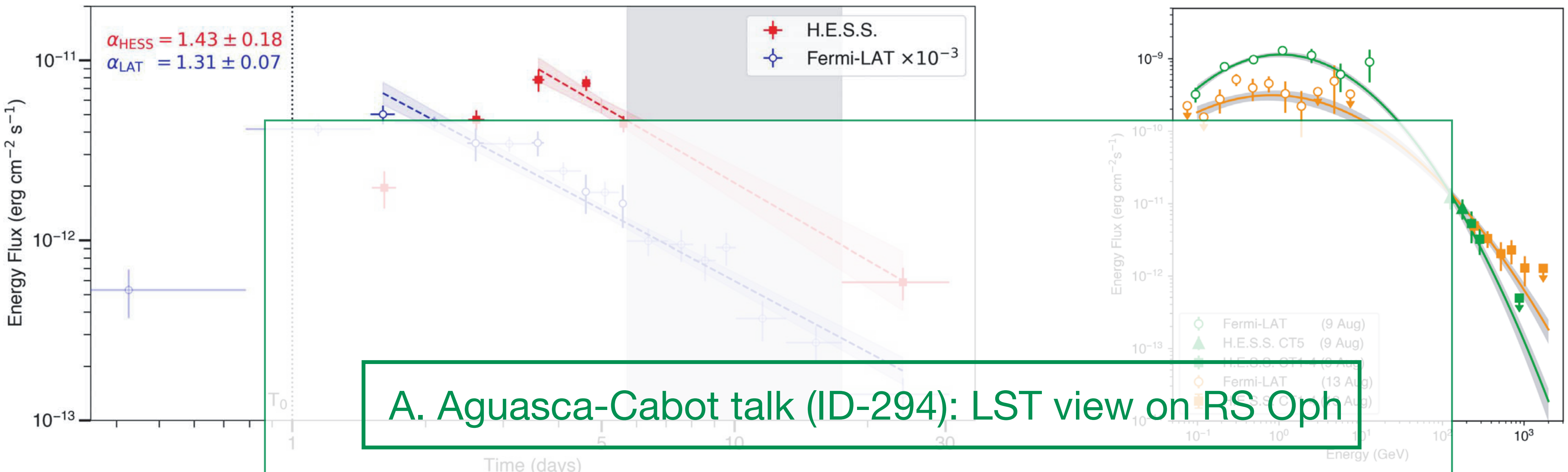

H.E.S.S. Col (2022)

A. Aguasca-Cabot talk (ID-294): LST view on RS Oph

A. López-Oramas talk (ID-222): MAGIC results

S. Steinmassl talk (ID-222): H.E.S.S. results

- H.E.S.S. detected RS Oph **up to ~1 month after the 2021 outburst** with a **daily significances** ~6σ for the first 3 nights. **The VHE flux profile closely follows that at HEs** with a shift/delay of ~2 days.
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Summary (1/2)

- The variety of GREBS has increased in the last years, and today include now γBs, μQs, CWBs and Novae. These are now accessible at different γ-ray regimes: **MeV**, **GeV**, **TeV**, and **multi-TeV**. Some of them emit in the whole γ-ray domain (c.f. γBs, SS433)
- In all cases **γ-rays are produced in strong shocks developing at the** interaction of powerful outflows (jets, winds) with nearby material: the winds and/or the circumstellar disk from the companion star (γBs, CWBs, Novae, μQs ?) or the surrounding ISM (e.g. SS433).
- Emission mechanisms can vary across GREB types: **leptonic (IC)** and **hadronic (π^0-decay)** channels invoked separately (γBs, Novae) or conjointly (μQs, CWBs). In all cases, exceptional acceleration efficiencies seem to be at play.

Summary (2/2)

- **New** γBs **keep being discovered.** after the detection of LMC P3 it was suggested that almost "*all the observable population of γ-ray binaries in our Galaxy had been already discovered*". However, systems like HESS J0632 or HESS J1832, and the recent discovery of 4FGL J1405.1–6119, doesn't seem to support these estimations => CTA, LST, HAWC, LHAASO… **may provide a number of new γBs.**

- For known γBs**, every single system** seems to be "the exception to the rule", making life much more interesting. Lots of observation and modelling efforts ongoing… and the number of **open questions seems to grow accordingly.** Some of them are **almost disturbing** (e.g. PSR' flares…)

- μQs back in the game, with SS433 in the forefront (**with results that truly defer a deep rethinking**, e.g. Fermi J1913) but also unexpected surprises: V4641 Sgr **detected by HAWC**!

- Novae were a kind of "surprise" at the start of *Fermi*-LAT era. With the detection of RS Oph by MAGIC, H.E.S.S. and LST, a bright future seems to be ahead in the next years

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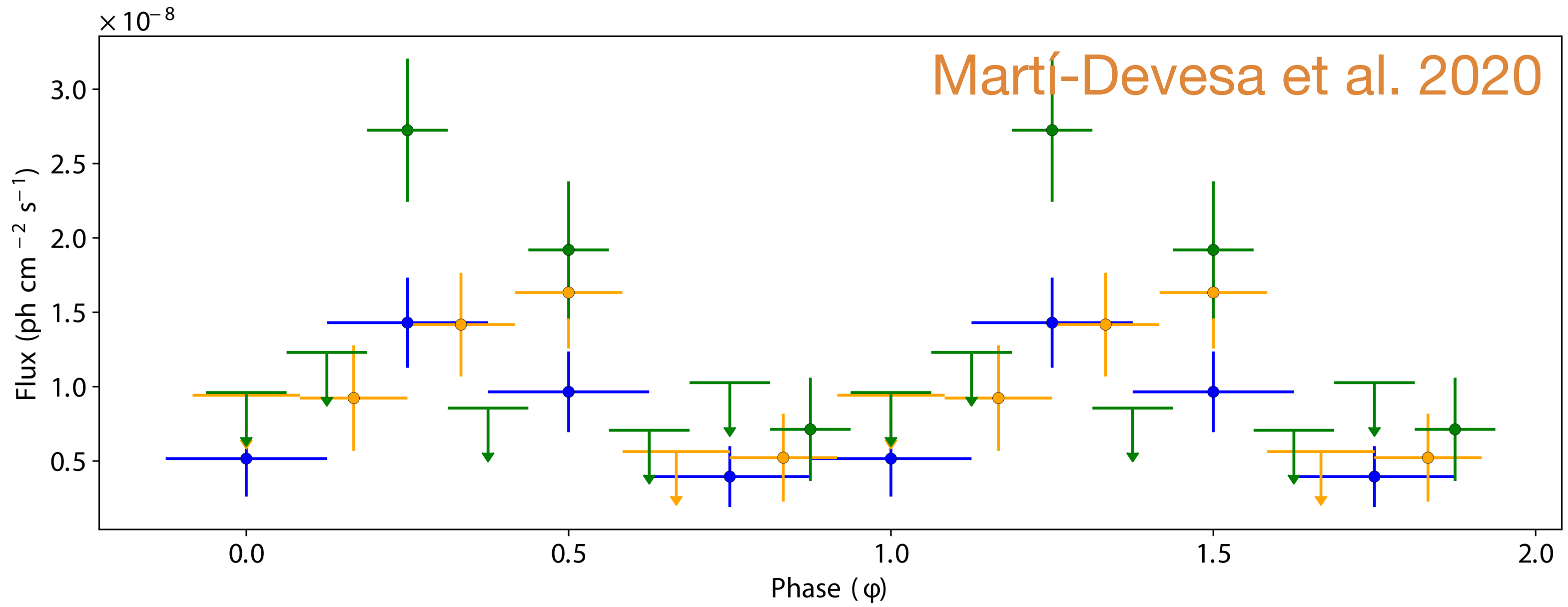
Thanks for your attention!

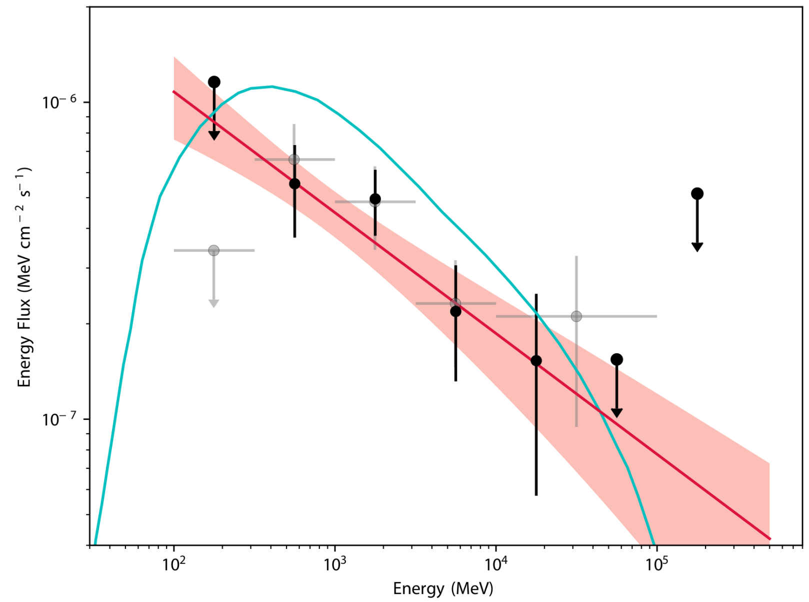
backup

CWBs: massive stellar systems with powerful stellar winds



- CWBs: powerful winds from non-deg., extremelly powerful stars interact, forming a bow-shocked wind collision with two separated shock fronts surrounding the star with a weaker wind (Eichler & Usov 1993). DSA can occur under these circumstances, accelerating particles up to high energies and leading to the emission of non-thermal radiation (Benaglia & Romero 2003; Reimer et al. 2006; De Becker 2007; Reitberger et al. 2014; Grimaldo et al. 2019; Pittard et al. 2020).
- **Eta Car** spectrum above 100 MeV displays two distinct components: above (High Energy; HE) and below (Low Energy; LE) 10 GeV. Despite the consensus that the HE component has a hadronic origin, at LE the situation is unclear: both leptonic (Farnier et al. 2011; Gupta & Razzaque 2017) and hadronic (Ohm et al. 2015; White et al. 2020) scenarios are still plausible.
- Another CWB has been detected in γ-rays: **γ2 Velorum** (Pshirkov 2016; Martí-Devesa et al. 2020). **This source showed HE emission during apastron**, with no detection of radio synchrotron (Benaglia et al. 2019; Martí-Devesa et al. 2020).

CWBs: massive stellar systems with powerful stellar winds



Martí-Devesa et al. 2020

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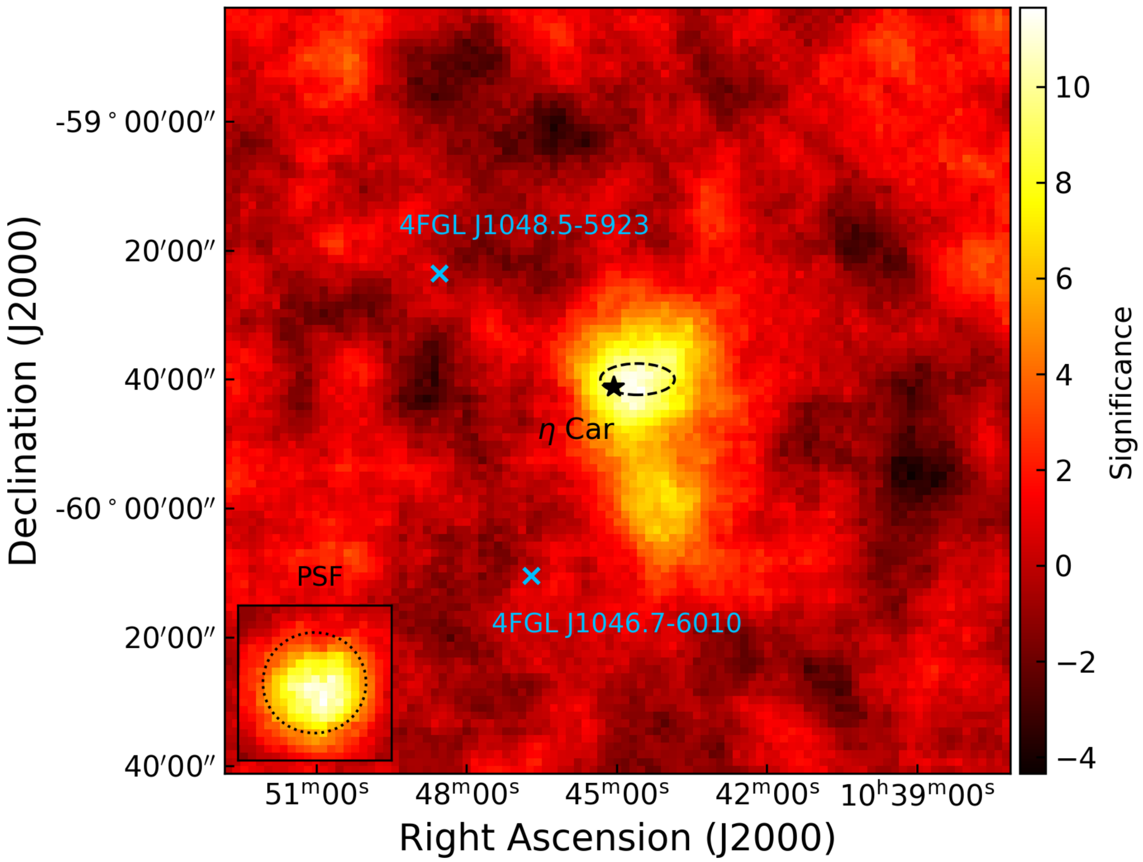
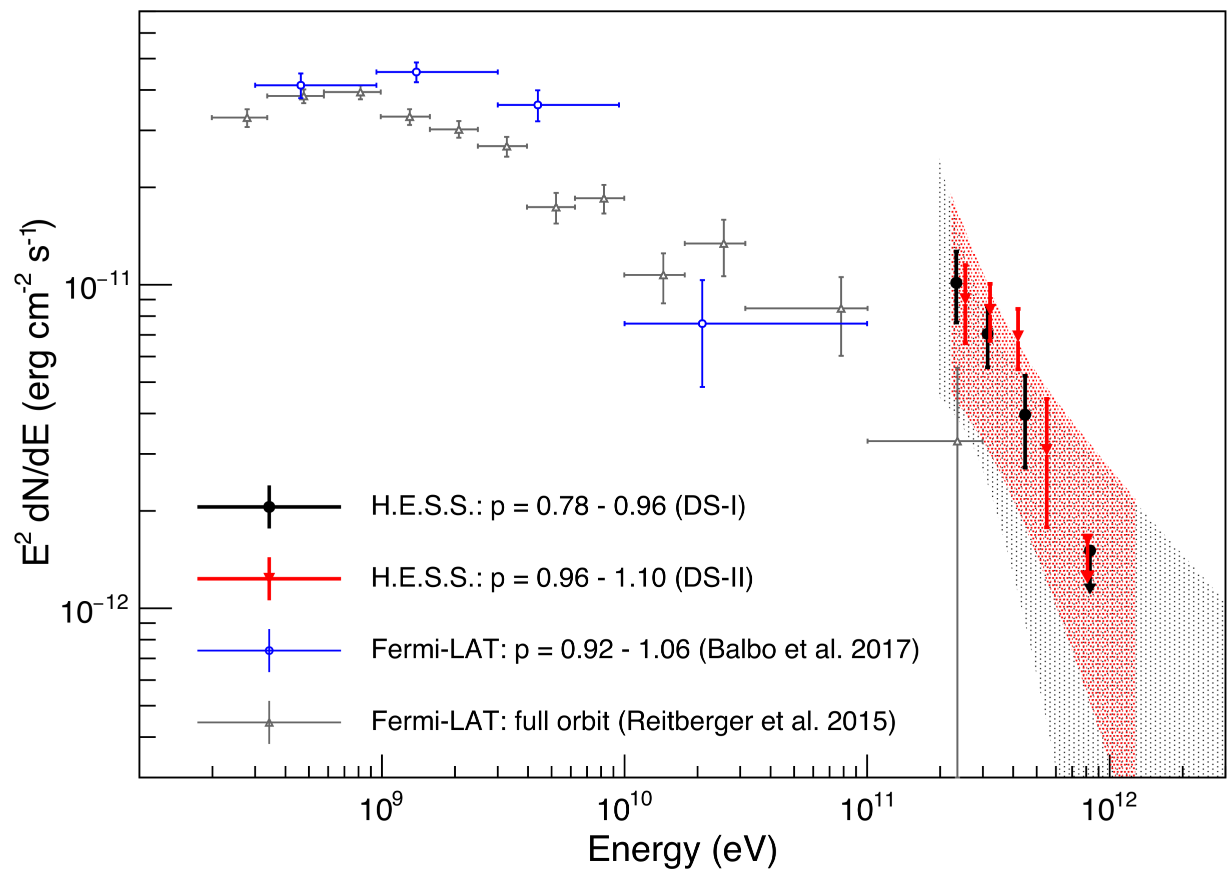
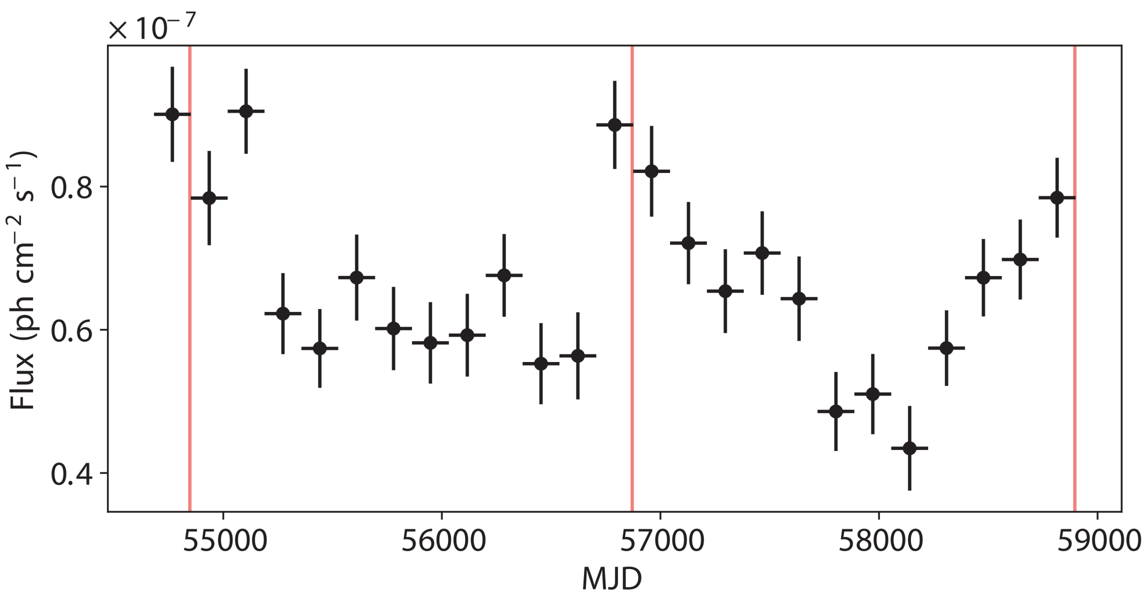
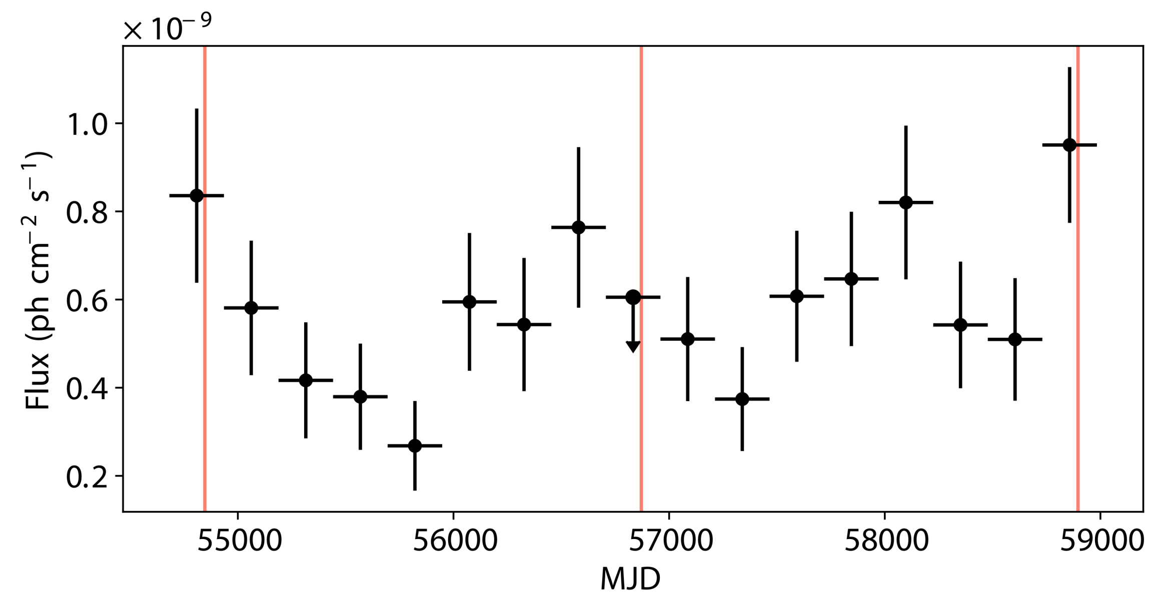
Colliding wind binaries





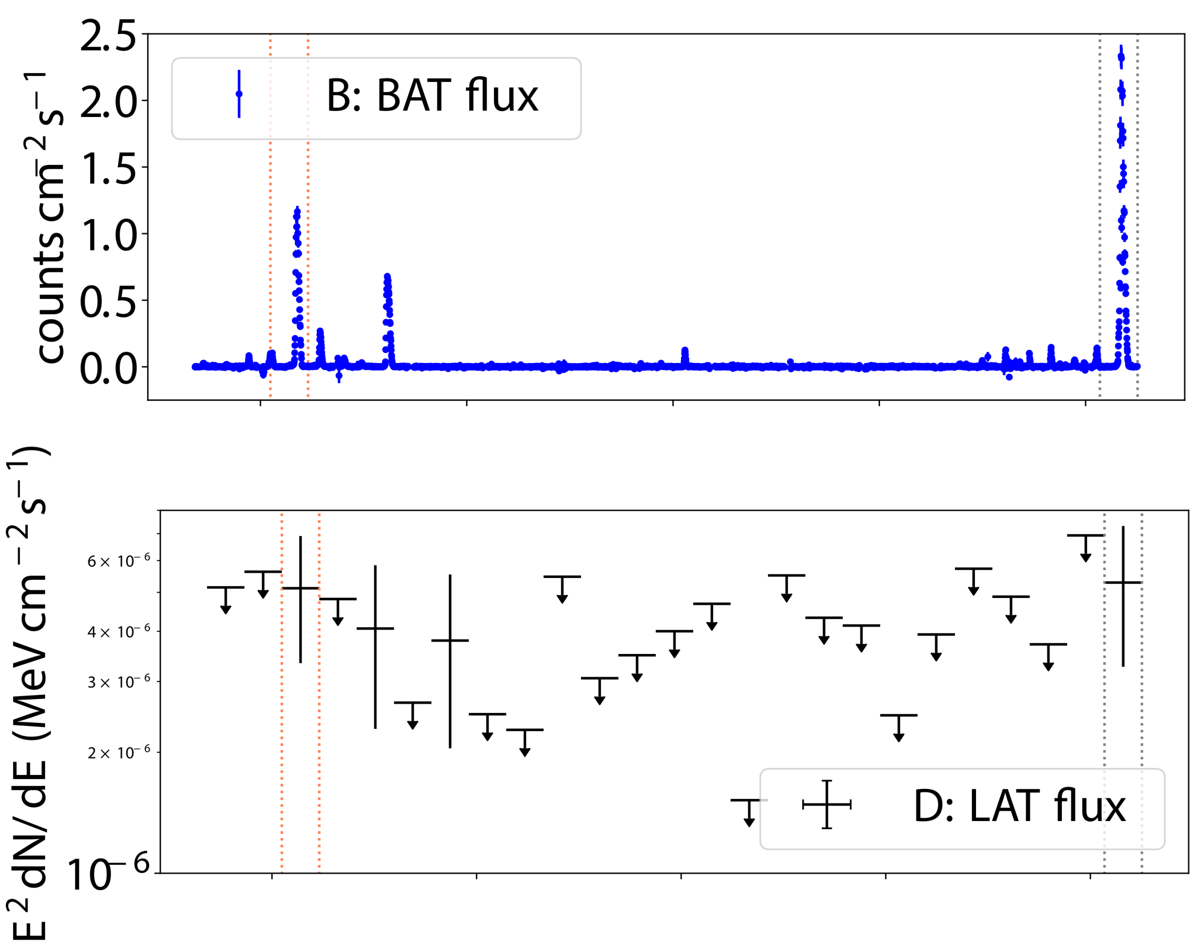
(H.E.S.S. Coll. 2020)





(Martí-Devesa et al. 2021)

- 1A 0535+262 is a well-studied pulsar-Be star binary system with an orbital period of 110.3 days (Finger et al. 1996). 1A 0535+262 has been the target of previous searches for γ-ray emission (Acciari et al. 2011 & Lundy et al. 2021) and is well known for its giant X-ray outbursts, the most recent of which was in November 2020



(Harvey et al. 2021)