Detection of very-high-energy gamma-ray emission from Eta Carinae during its 2020 periastron passage

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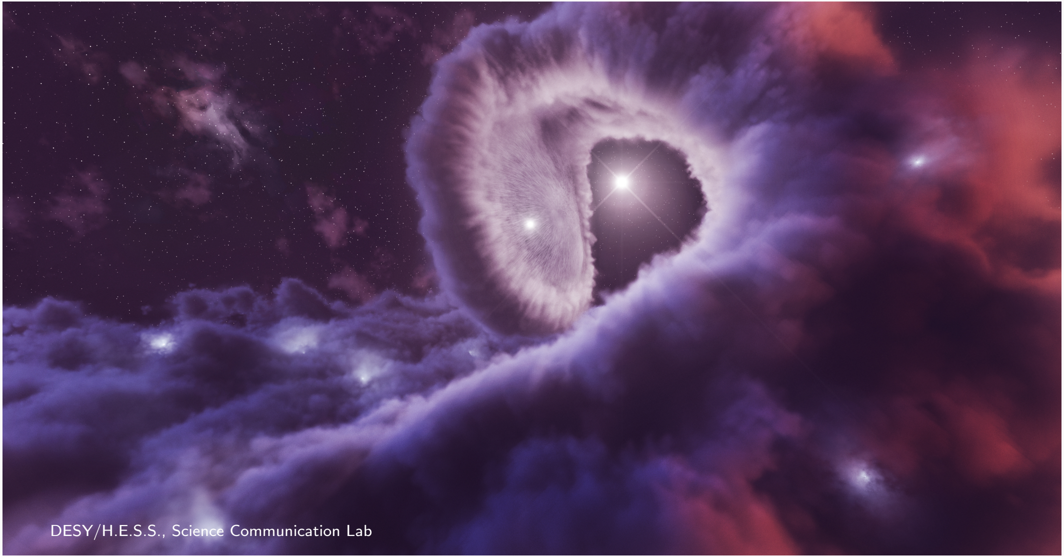
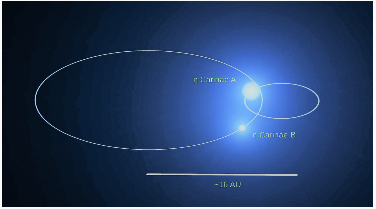
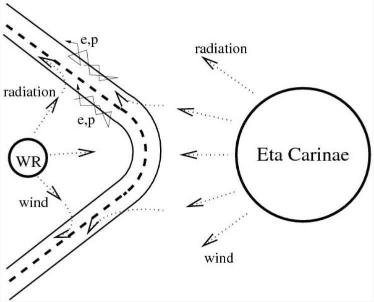
H.E.S.S.

Eta Carinae - A colliding wind binary



Eta Carinae - A unique system

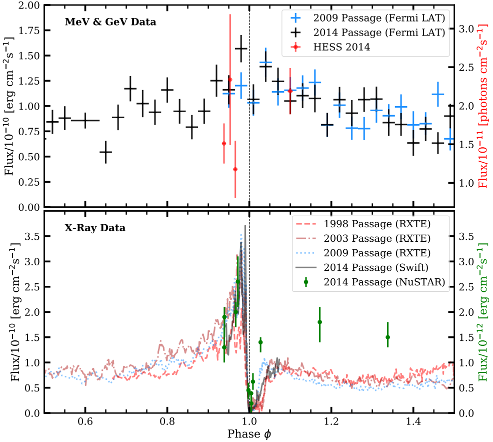




- Massive stellar binary system:
  - η Car A = Luminous Blue Variable, $\sim 100\ M_\odot$
  - η Car B = WR or O-type, $\sim 30\ M_\odot$
- Located in southern sky at 2.3 kpc
- Highly eccentric orbit ($\epsilon \sim 0.9$)
- Period P = 2022.7 days ($\sim$ 5.5 years) - latest periastron passage in Feb 2020
- Strong winds from both stars - colliding wind region
- Shocks on either side - laboratory for particle acceleration

Image Credits: NASA; Bednarek & Pabich, 2011

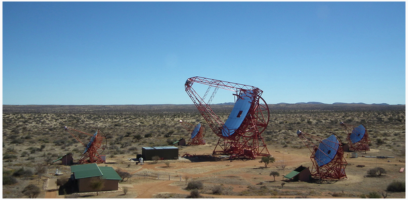
Eta Carinae - Non-thermal emission

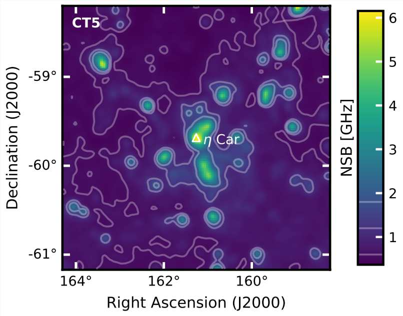


- Thermal and non-thermal X-ray light curve with large variability (e.g. Hamaguchi et al., 2018, Corcoran et al., 2017)
- Fermi-LAT light curve over several orbits (e.g. White et al., 2020; Marti-Devesa & Reimer, 2021)
- H.E.S.S. detection before (phase 0.96) and after (phase 1.09) 2014 periastron passage (H.E.S.S. Collaboration, 2020) $\longrightarrow$ Only colliding wind binary with detected VHE ($>$ 100 GeV) emission
- 2020 periastron passage visible for H.E.S.S.

Adapted from White et al., 2020

H.E.S.S. observation campaign

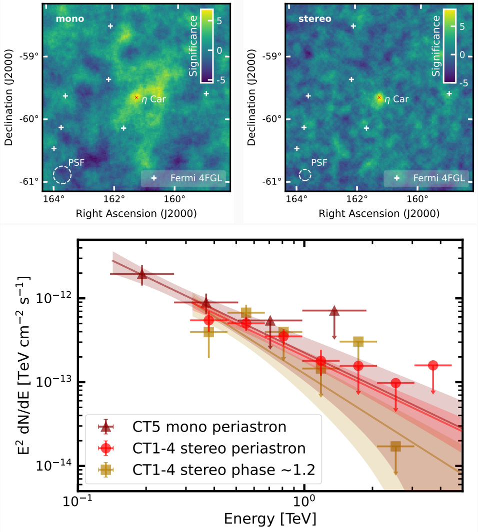




- Extensive observation campaign in 2020 ($\sim$ 100 h) - phase 0.97 - 1.05
- Usage of full 5-telescope array (stereo: 4 x 12 m + mono: 1 x 28 m)
- Additional campaigns in years prior + 2021
- Tricky field of view due to bright Carina Nebula - large night sky background (NSB)
- Customized observation settings
- Tailored analysis procedure (details in H.E.S.S. Collaboration, 2025)

H.E.S.S.; H.E.S.S. Collaboration, A&A, 2025

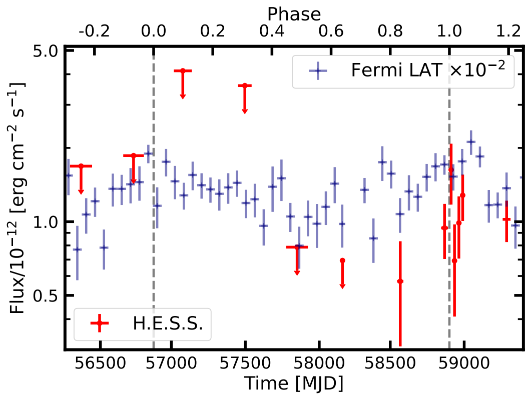
H.E.S.S. results - 2020 periastron passage



- Detected with 7.1 σ (mono)/ 8.5 σ (stereo)
- Energy threshold: 0.14 TeV / 0.31 TeV
- Modeled as power-law - soft spectrum with $\Gamma = 3.3 \pm 0.4$
- Mono and stereo results in good agreement
- Energy of last significant flux point $\sim$ 1 TeV
- Spectrum from 2021 campaign (phase $\sim$ 0.2) also consistent
- Flux level inconsistent with results from the 2014 periastron passage (presented in H.E.S.S., 2020)

H.E.S.S. Collaboration, A&A, 2025

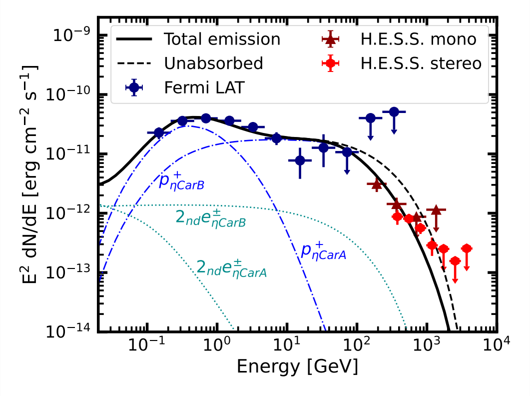
H.E.S.S. + Fermi LC results



H.E.S.S. Collaboration, A&A, 2025

- Using data from 2012 - 2021 campaigns
- H.E.S.S. stereo analysis only, energy flux > 0.31 TeV
- Fermi LAT energy flux > 100 MeV
- Hint at qualitatively similar long term behavior H.E.S.S. - Fermi-LAT
- No significant variability during 2020 periastron passage (phase 0.97 - 1.05) considering flux uncertainties

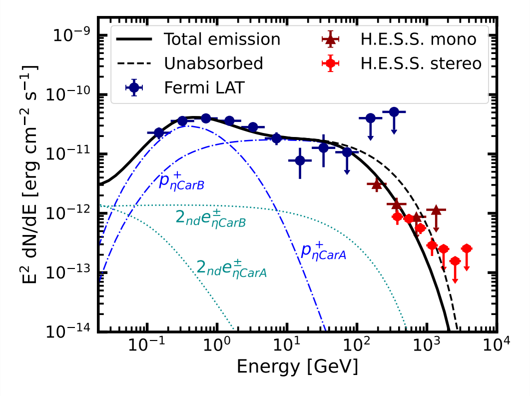
H.E.S.S. + Fermi spectral results - 2020 periastron passage



H.E.S.S. Collaboration, A&A, 2025

- Analysis of contemporaneous data from Fermi-LAT ($>$ 100 MeV)
- Overall Fermi-LAT spectral result similar to previous periastron passages
- Fermi-LAT spectrum described with two components (e.g. Balbo & Walter, 2017; Marti-Devesa & Reimer, 2021)
- H.E.S.S. result continuation of high energy ($>$ 10 GeV) Fermi-LAT component

Eta Carinae - a powerful proton accelerator



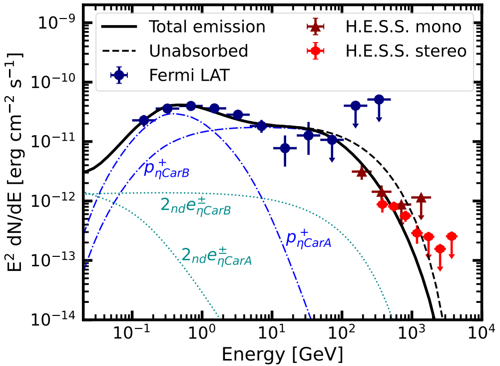
H.E.S.S. Collaboration, A&A, 2025

- Colliding wind shock-acceleration model from White et al., 2020 → predicted gamma-ray spectra before absorption for periastron phase

Parameter	η Car-A	η Car-B	References
$R_\star$ [$R_\odot$]	100 / 843	20	1,2
$T_\star$ [10^4 K]	2.58 / 0.94	3.0	3,2
$L_\star$ [10^6 $L_\odot$]	4 / 5	0.3	3,2
$\dot{M}$ [$M_\odot$ yr^{-1}]	4.8×10^{-4}	1.4×10^{-5}	4
v_∞ [km s^{-1}]	5×10^2	3×10^3	4
$B_\star$ [G]	100	100	
v_{rot} [v_∞]	0.15	0.15	
η_{acc}	15	5	
P_p [P_{wind}]	10 %	9 %	
P_e/P_p	3 %	3 %	

(1) Corcoran & Hamaguchi, 2007; (2) Groh et al. 2012; (3) Davidson & Humphries, 1997; (4) Parkin et al., 2009

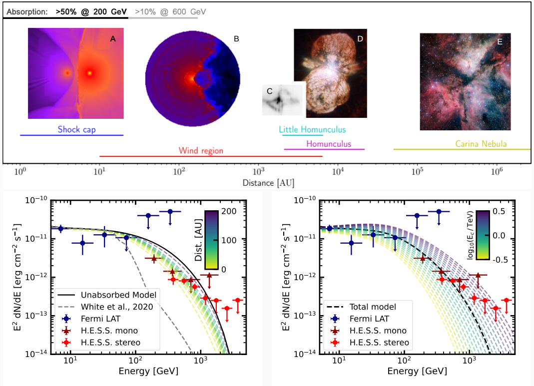
Eta Carinae - a powerful proton accelerator



H.E.S.S. Collaboration, A&A, 2025

- High energy component: hadronic emission
  - Protons accelerated at the termination shock of the companion's wind
  - acc. protons mix with the shocked material of the denser primary's wind
  - $\rightarrow$ γ-ray emission produced in the ballistic region right outside the shock cap
  - Need to take into account γ-γ absorption
  - H.E.S.S. spectrum constrains γ-γ absorption and proton cutoff energy
- What about electrons? $\rightarrow$ experience strong in-situ cooling

Eta Carinae - a powerful proton accelerator

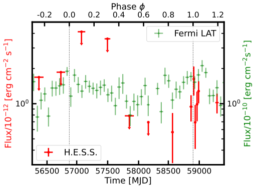


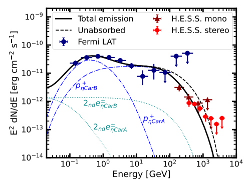
Steinmassl et al., A&A, 2023; H.E.S.S. Collaboration, A&A, 2025

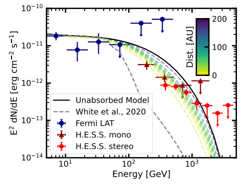
- Absorption curves for several distances from the centre of mass of the binary system calculated
- $\rightarrow$ γ-ray emission at a distance of 10 au to 20 au from the binary preferred
- $\rightarrow$ longer mixing length
- Can also explain lack of flux reduction during periastron
- Cut-off energy of $\sim$ 1.5 TeV describes the shape of the H.E.S.S. SED well

Summary

- η Carinae detected at energies > 0.14 TeV during 2020 periastron passage
- Soft spectrum in continuation of high energy Fermi-LAT component
- First long term light curve covering full orbit
- Eta Carinae as powerful hadronic accelerator
- Restricting emission region (10-20 au) and proton cutoff energy (~ 1.5 TeV)







H.E.S.S. Collaboration, A&A, 2025

Thanks for listening!

Any Questions?

Backup slides

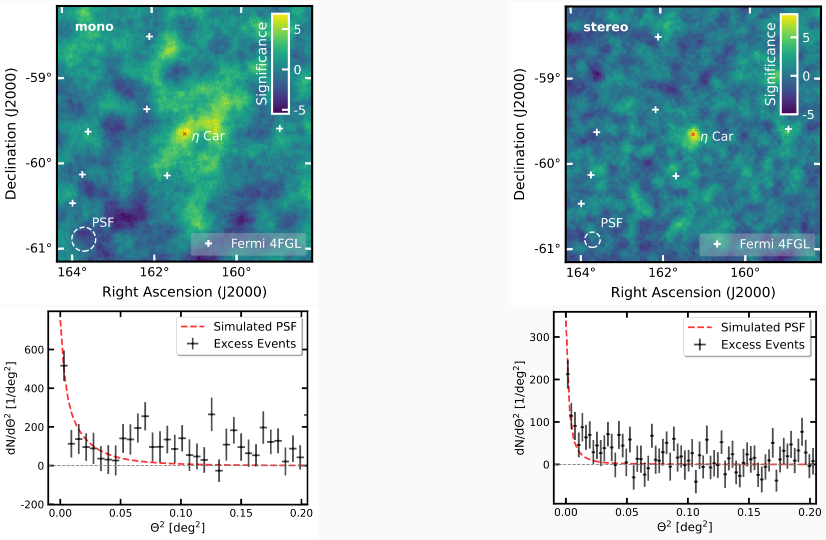
Backup - H.E.S.S. data set

Table 1. Basic properties of η Car datasets

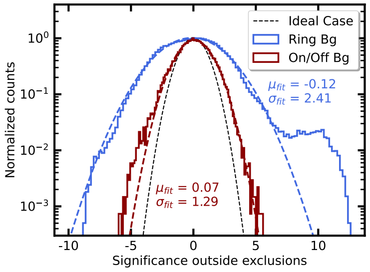
Dataset	Start Date	End Date	Phase Range	Live Time [h]	Mean zenith [$^\circ$]	Telescopes considered
DS-A	Jan 13, 2013	May 30, 2016	−0.28-0.29	20.6	39.2	CT1-4[a]
DS-B	Jan 29, 2017	Apr 7, 2019	0.45-0.84	63.3	39.2	CT1-4[b]
DS-C	Dec 23, 2019	May 24, 2020	0.97-1.05	97.8	39.9	CT1-5[c]
DS-D	Feb 15, 2021	Apr 10, 2021	1.18-1.21	31.5	37.2	CT1-4[b]

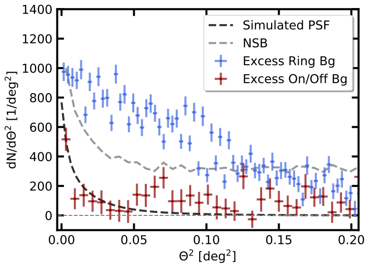
Notes. The phase is given with respect to the 2014 periastron passage (phase = 0) following the ephemeris from Teodoro et al. (2016). The live time is given for the stereo observation time and is corrected for dead time. [(a)] CT1-4 with the original cameras. [(b)] CT1-4 with upgraded cameras (H.E.S.S.1U, Giavitto et al. 2018). [(c)] H.E.S.S.1U and CT5 with FlashCam (Bi et al. 2022).

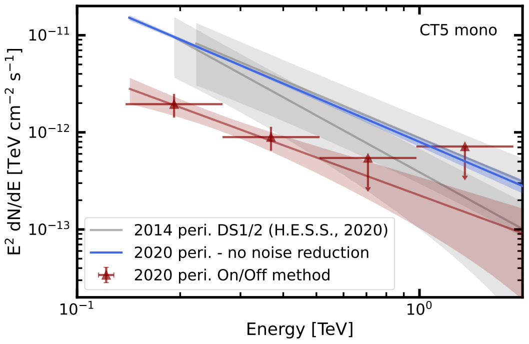
Backup - Periastron data set - detection details



Backup - Comparison to H.E.S.S. Collaboration, 2020







Backup - Model details

Table D.1. Assumed orbital parameters

Parameter	Value	Reference
Eccentricity ϵ	0.9	1
Semi-major axis a [au]	16.64	2
Inclination [°]	135	3
Position angle [°]	10	3

References. (1) Damineli et al. (2008); (2) Hillier et al. (2001); (3) Madura et al. (2012).

Table D.2. Stellar and model parameters

Parameter	η Car-A	η Car-B	References
$R_\star$ [$R_\odot$]	100 / 843	20	1,2
$T_\star$ [10^4 K]	2.58 / 0.94	3.0	3,2
$L_\star$ [10^6 $L_\odot$]	4 / 5	0.3	3,2
$\dot{M}$ [$M_\odot$ yr^{-1}]	4.8×10^{-4}	1.4×10^{-5}	4
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$v_{\rm rot}$ [v_∞]	0.15	0.15	
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$P_{\rm p}$ [$P_{\rm wind}$]	10 %	9 %	
$P_{\rm e}/P_{\rm p}$	3 %	3 %	

Notes. Adapted from Table 1 in White et al. (2020). $R_\star$ denotes the stellar radius, $T_\star$ the surface temperature, $L_\star$ the luminosity, $\dot{M}$ the mass loss rate and v_∞ the thermal velocity. The surface magnetic fields $B_\star$, the rotation velocities $v_{\rm rot}$, the acceleration efficiency parameters $\eta_{\rm acc}$, the wind power going into the acceleration of protons $P_{\rm p}$ and the ratio $P_{\rm e}/P_{\rm p}$ of the power going into the acceleration of electrons above 1 MeV and protons above 1 GeV were chosen in their model. For the photon field of η Car-A two different scenarios were assumed.

References. (1) Corcoran & Hamaguchi (2007); (2) Groh et al. (2012); (3) Davidson & Humphreys (1997); (4) Parkin et al. (2009).