H.E.S.S.

Galactic Astrophysics with H.E.S.S.

Lars Mohrmann

DPG Spring Meeting ▪ Göttingen, April 4, 2025

Max-Planck-Institut für Kernphysik Heidelberg

Max Planck Gesellschaft

High Energy Stereoscopic System

- **Khomas Highland, Namibia**
- **4 telescopes with 12-m mirrors** (since 2004)
- **1 telescope with 28-m mirror** (since 2012)
- **Sensitive to γ-rays with energies 100 GeV – 100 TeV**
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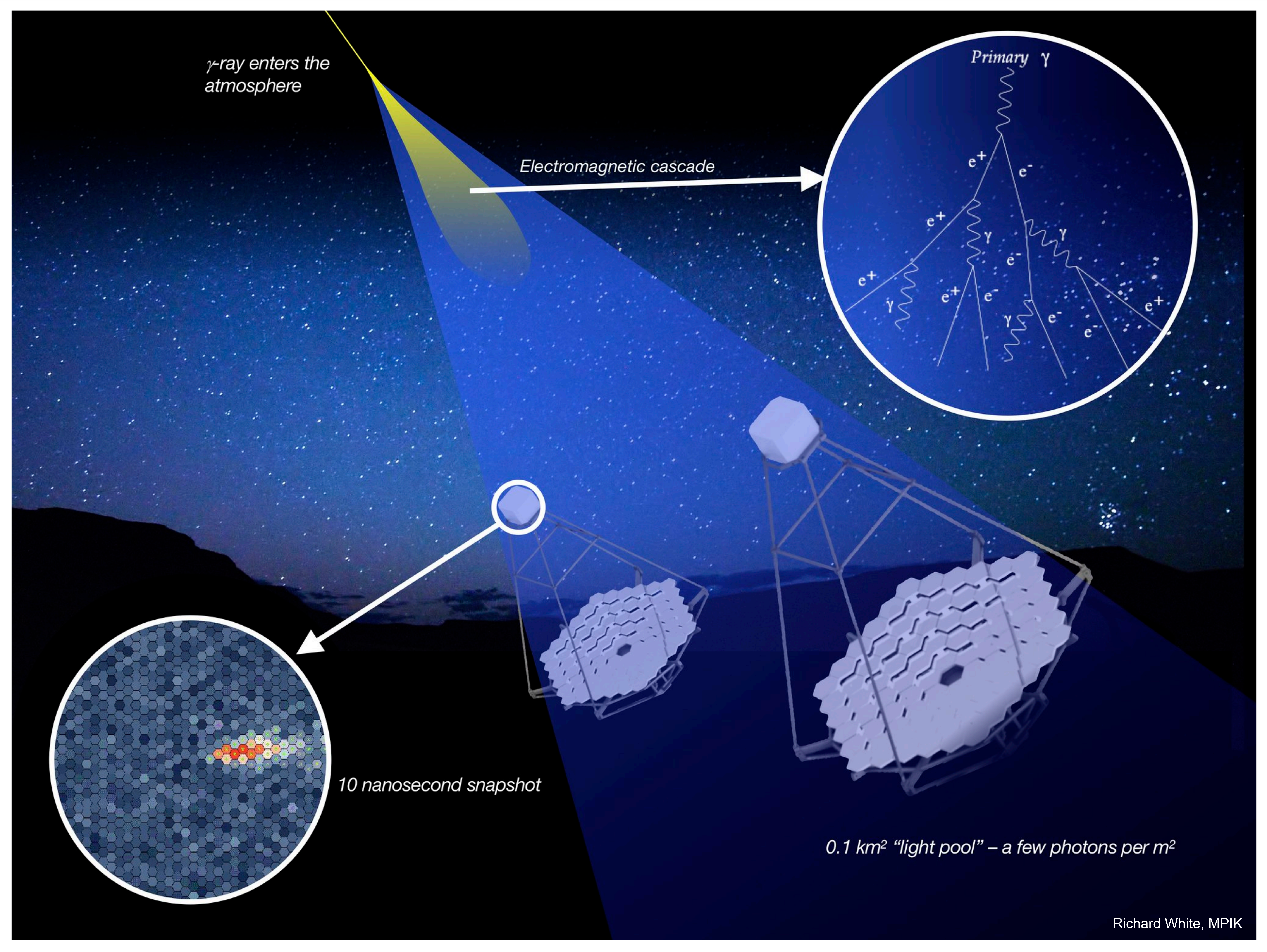
Imaging Atmospheric Cherenkov Telescopes



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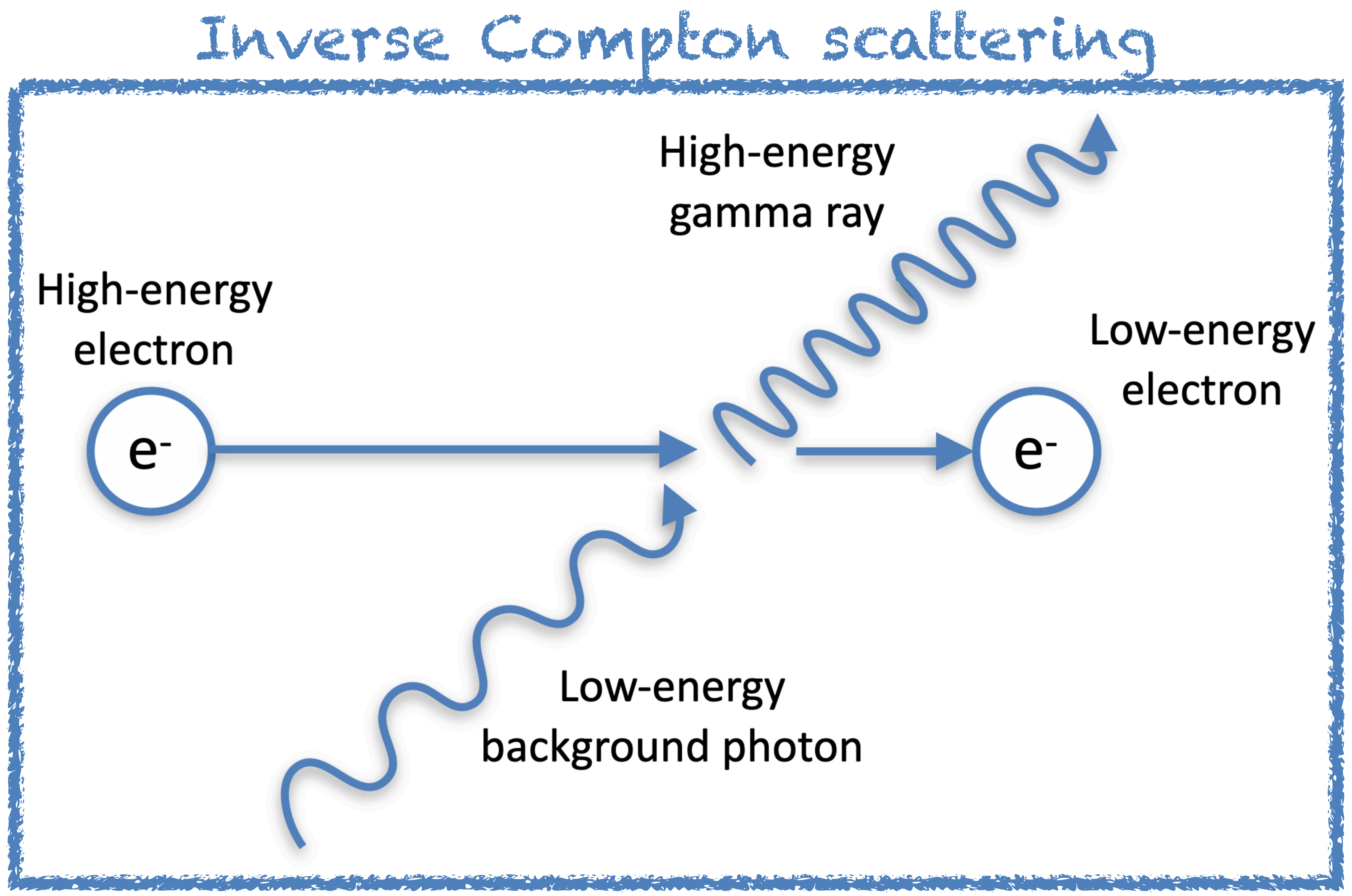

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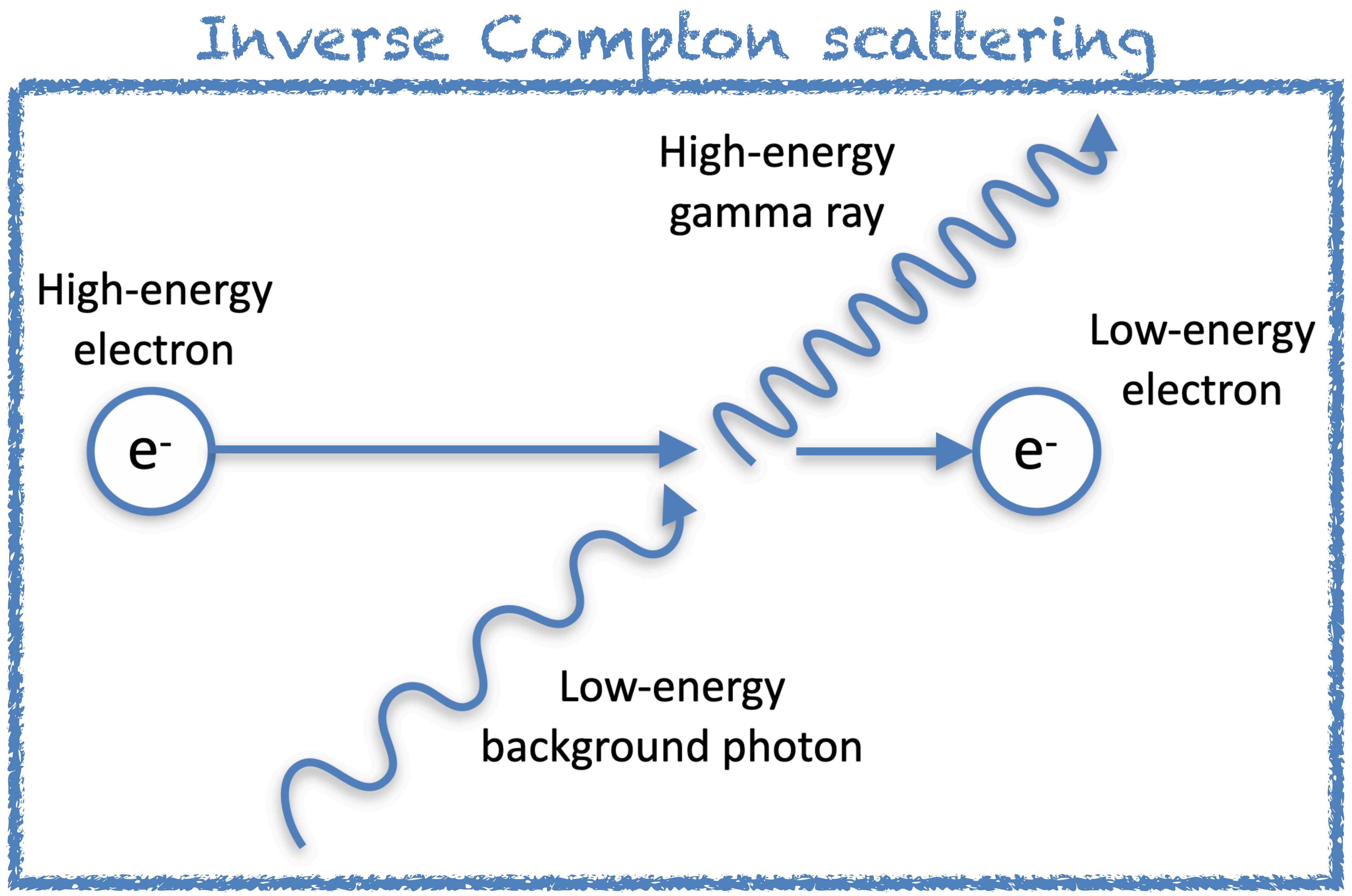

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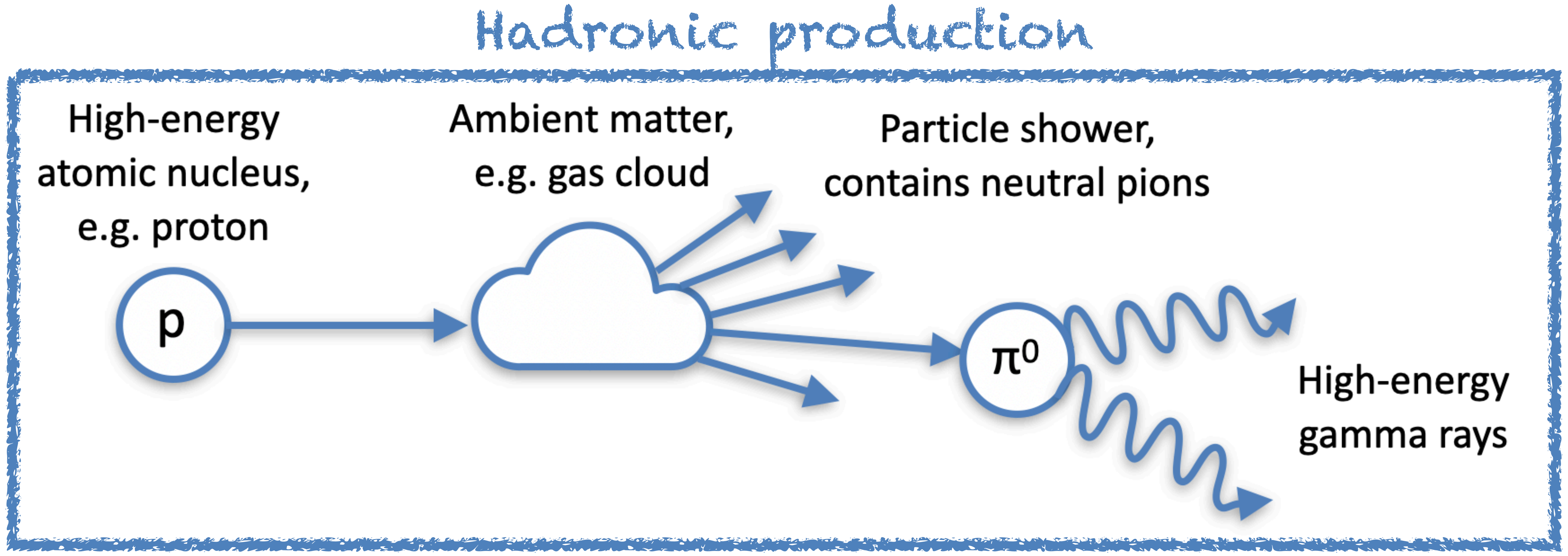

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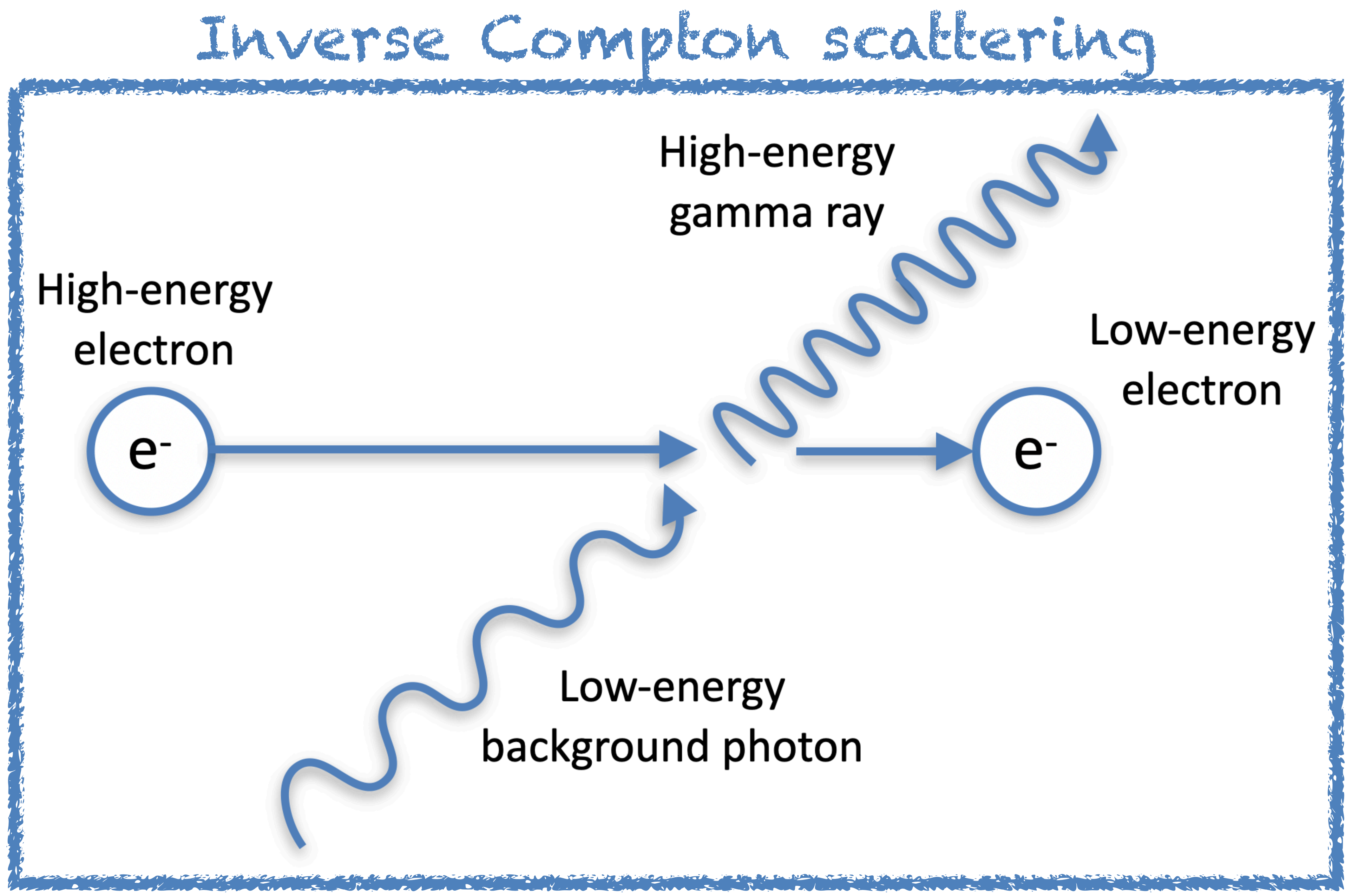
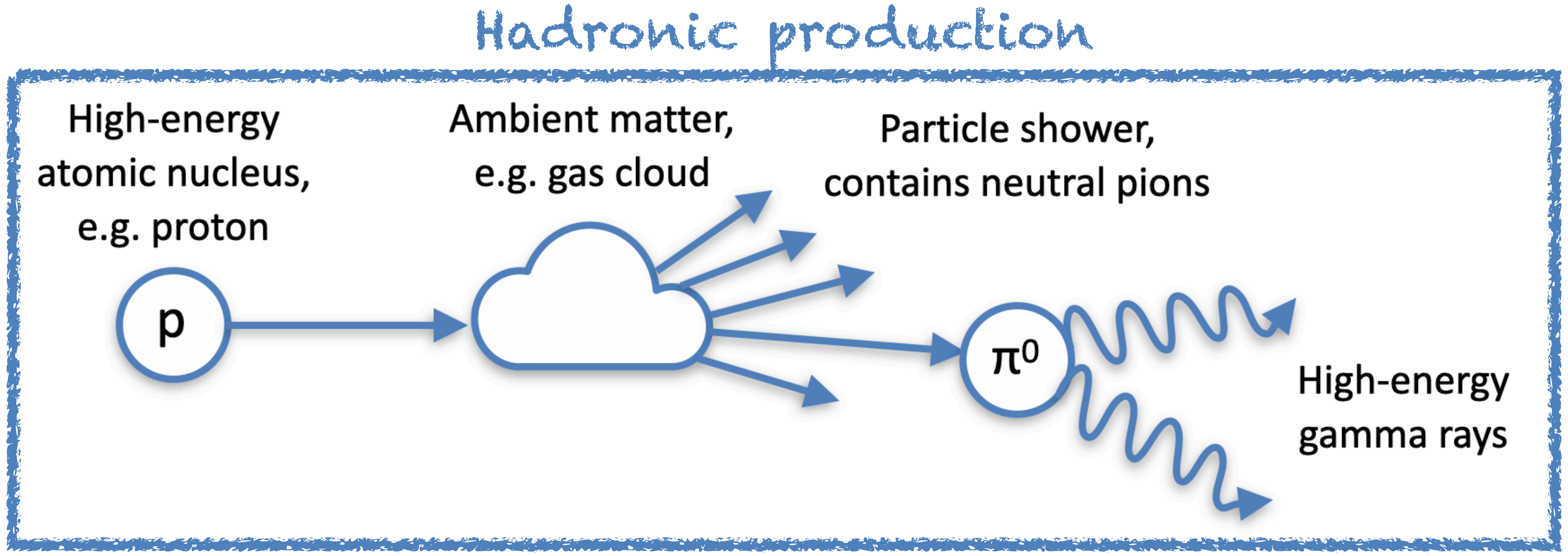
- ***Can use γ-rays to study acceleration of cosmic rays!***





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[A&A 2018]

- **Deep survey** along Galactic Plane (2004–2012)
- Much of the inner Galaxy is **only visible** from the **Southern Hemisphere**
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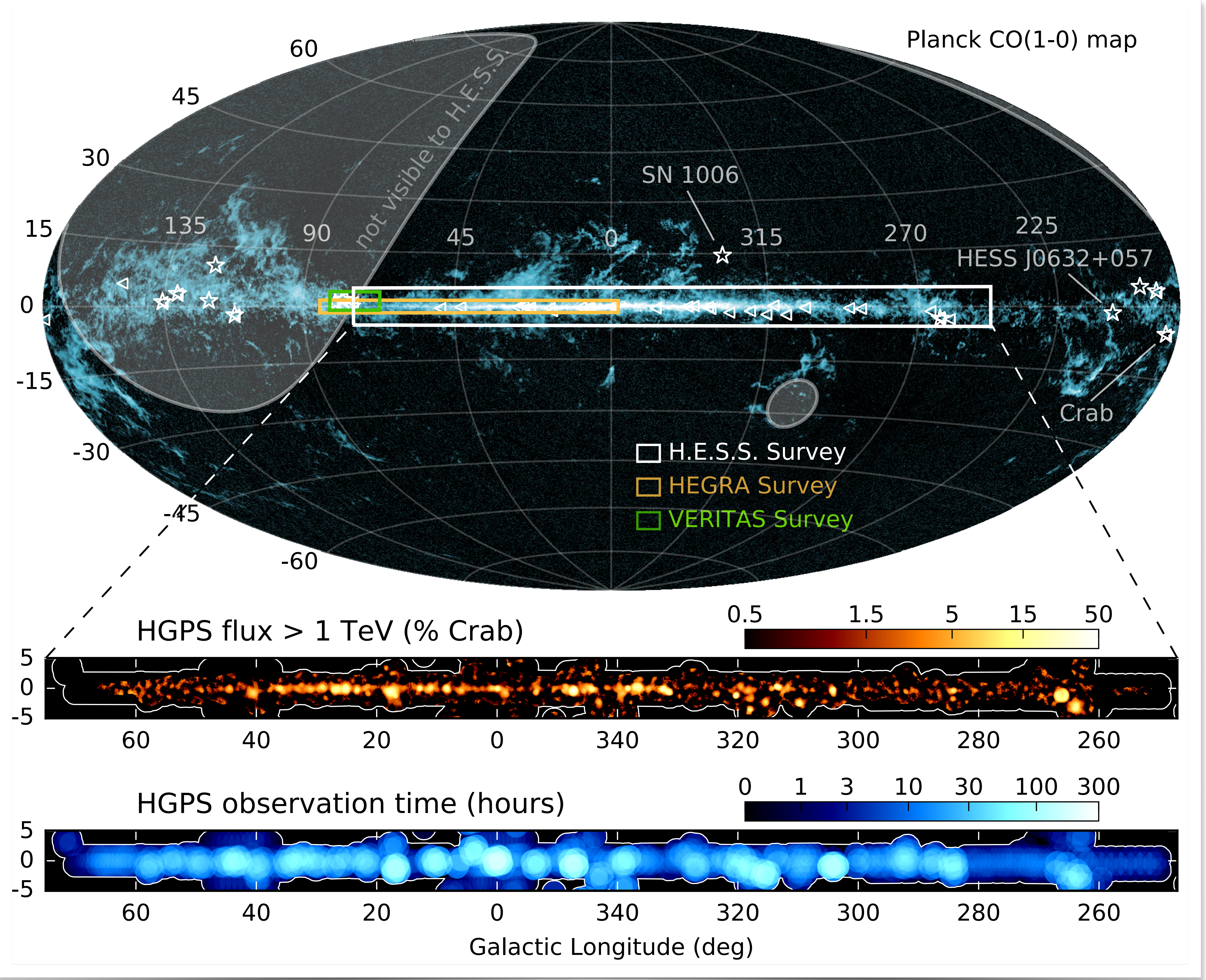

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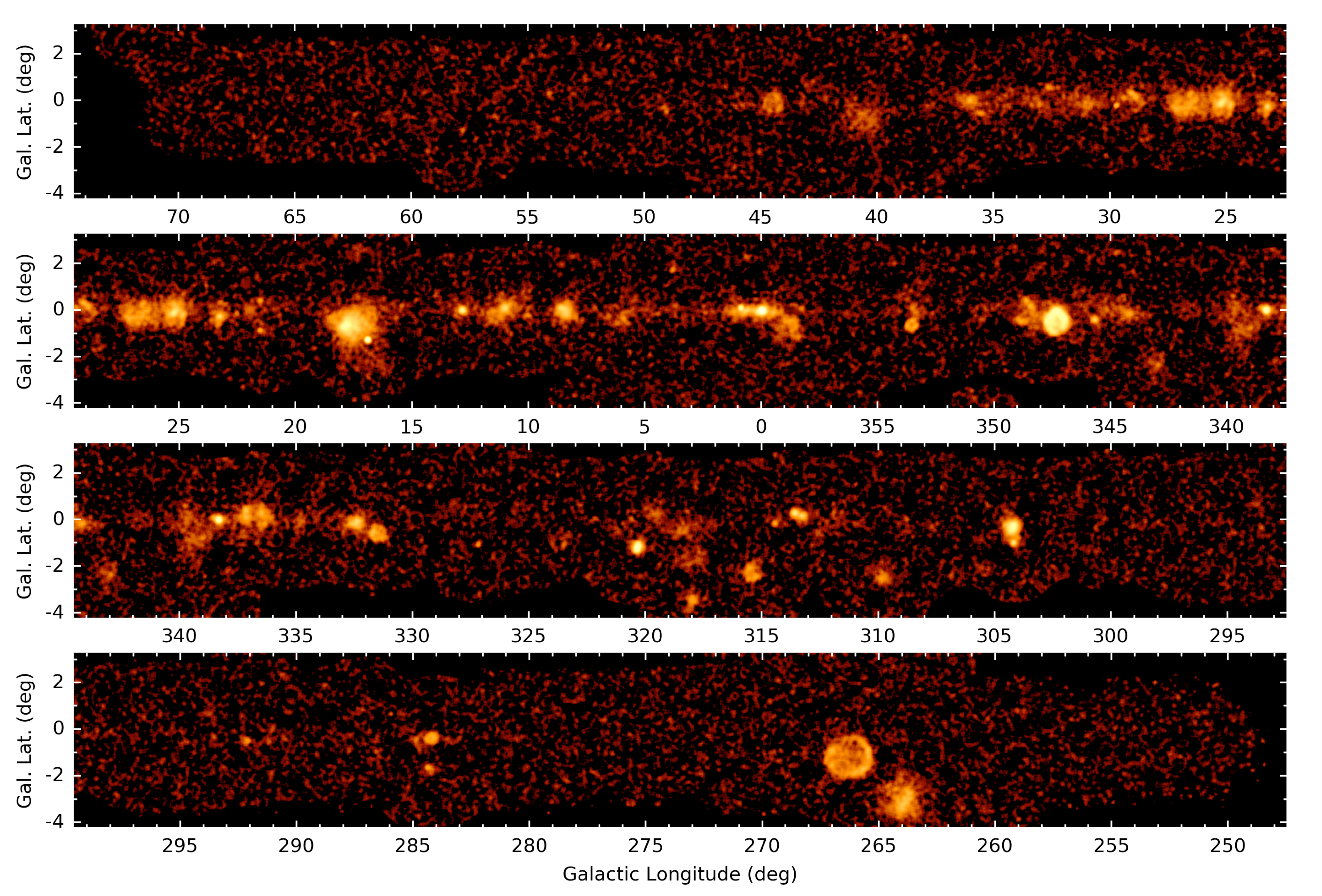

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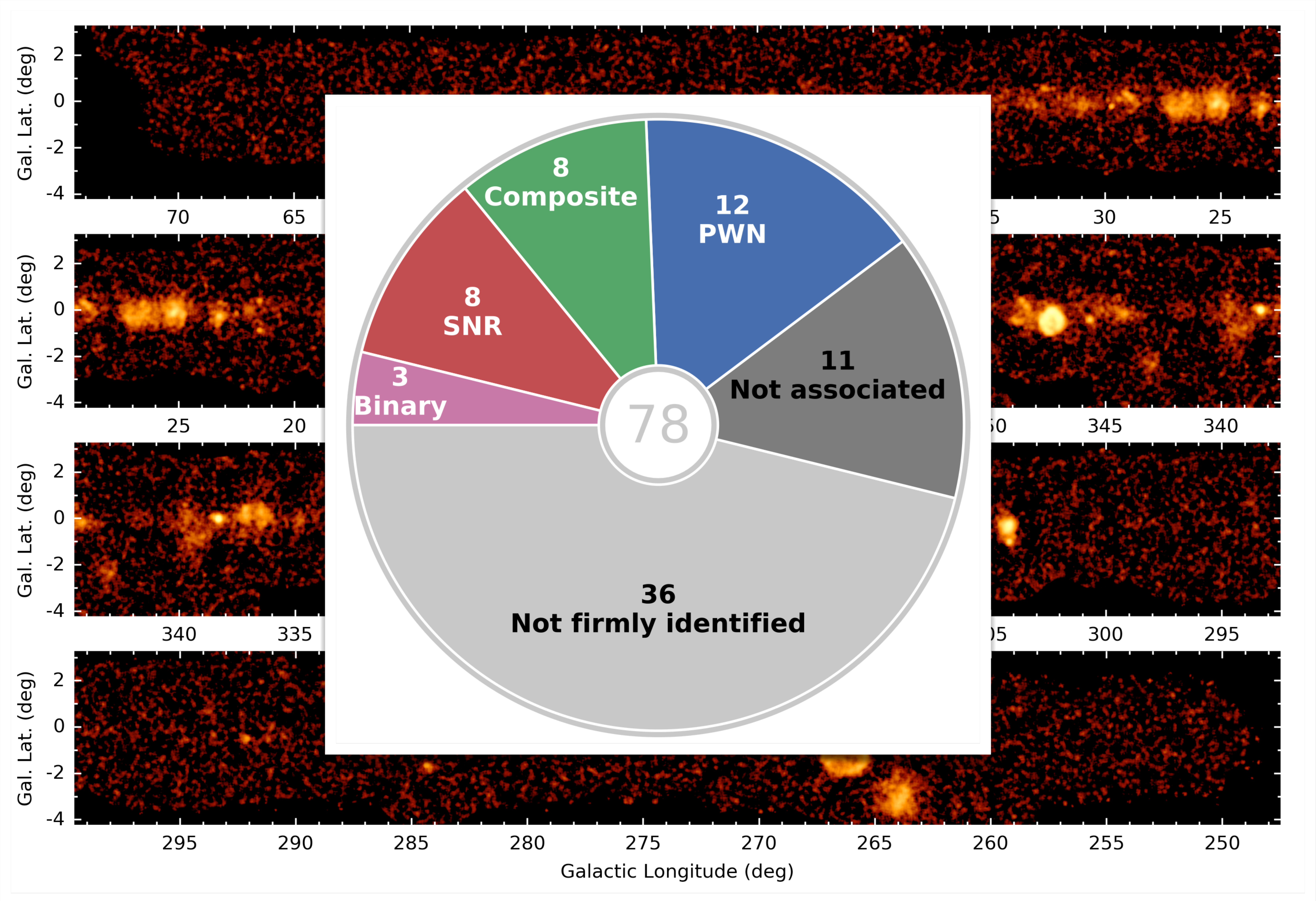

Recent Galactic science highlights from H.E.S.S.

(a personal selection)

The recurrent nova RS Ophiuchi [Science 2022]

- **RS Ophiuchi**
  - binary system: white dwarf + red giant
  - separation 1.48 AU → white dwarf accretes matter from red giant
  - every ~15 years: thermonuclear explosion → nova
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  - observations with H.E.S.S. starting August 9
  - first detection of a nova at ~TeV energies!
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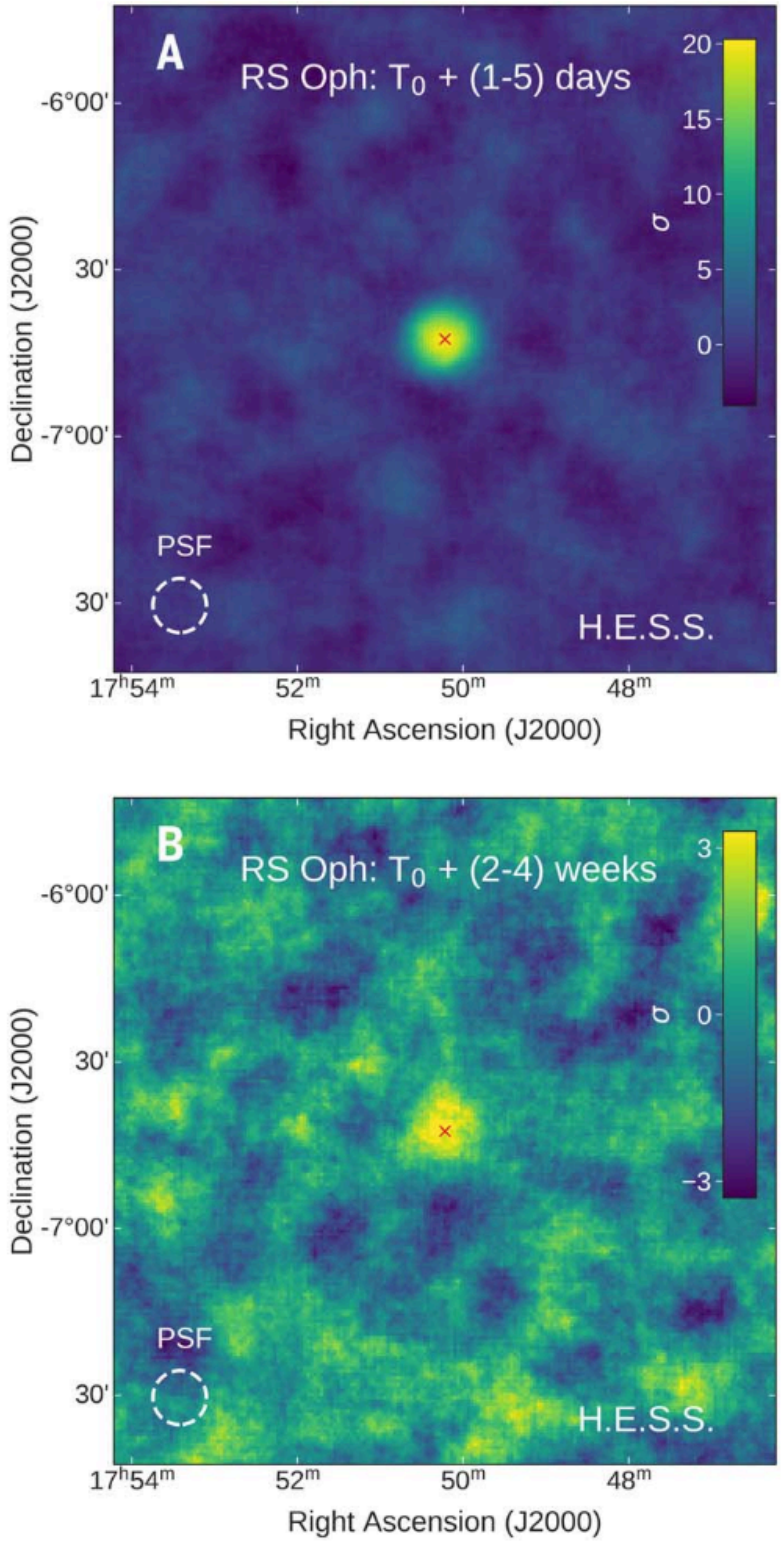

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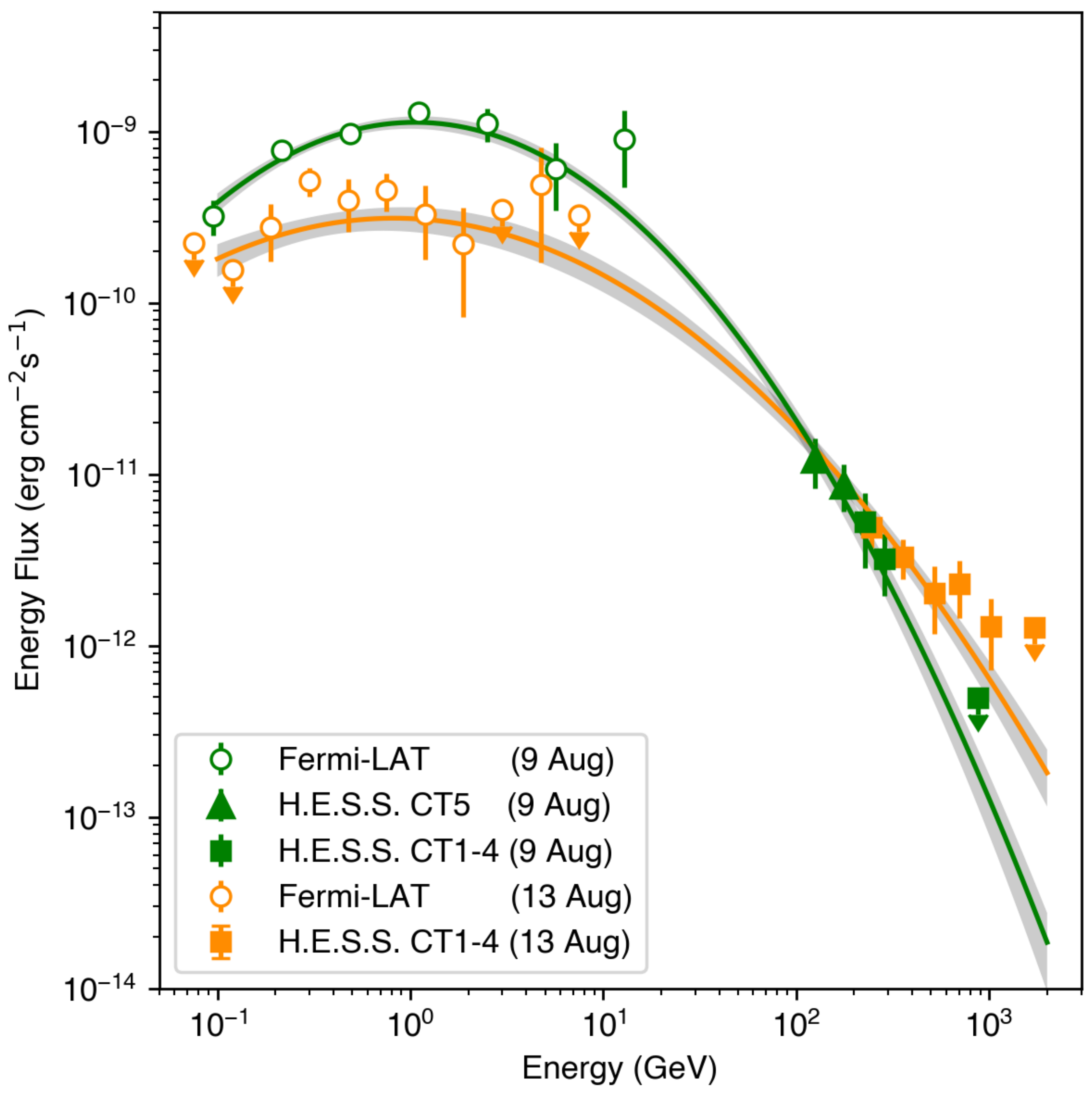
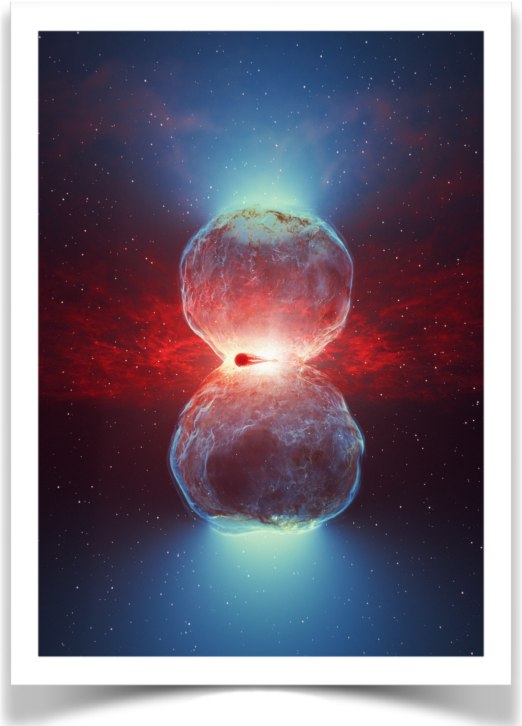
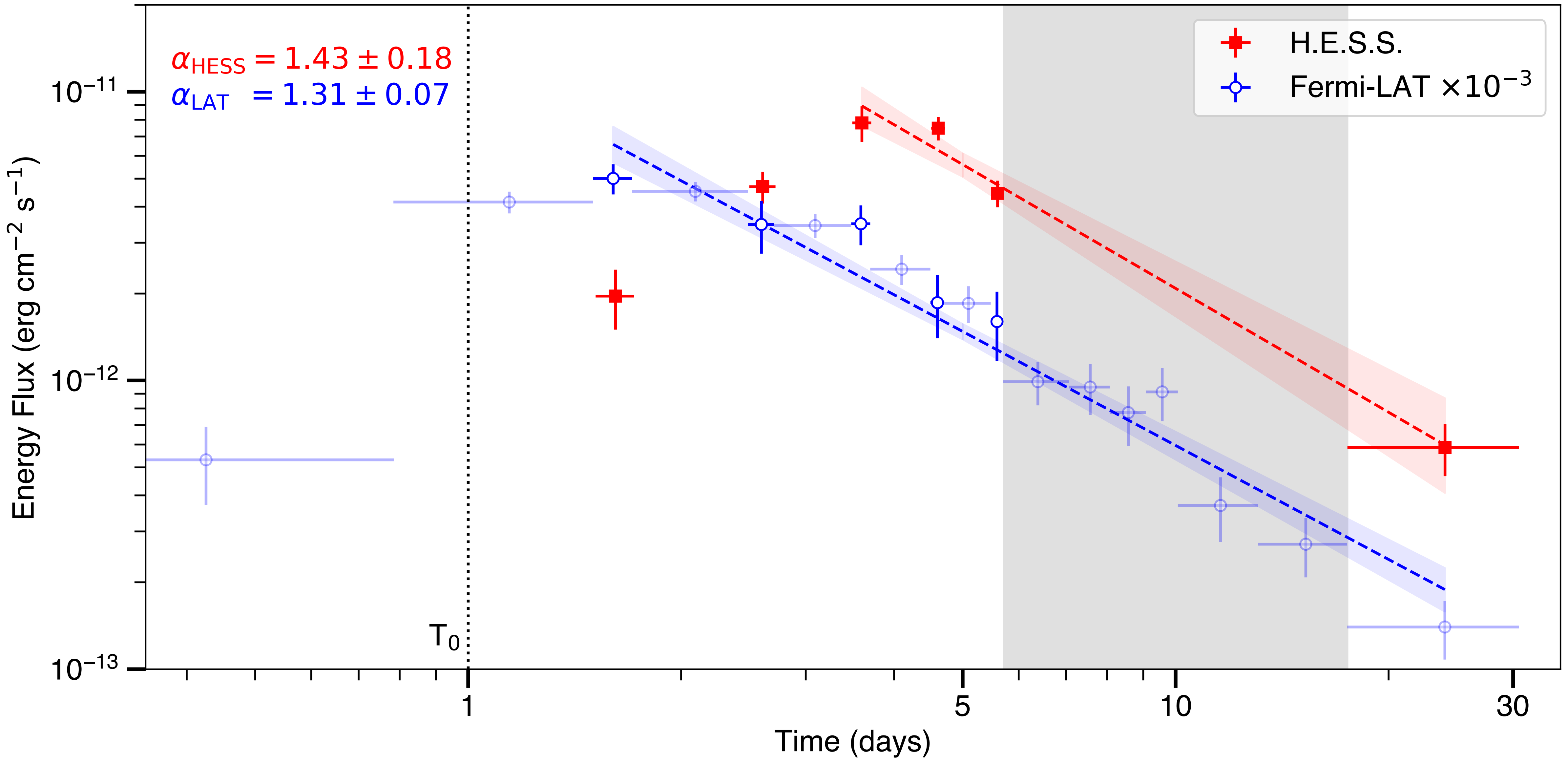
- **Combination of data with *Fermi*-LAT**
  - TeV light curve peaks ~2 days after GeV light curve
  - maximum photon energy observed with H.E.S.S. increases with time
  - "live view" of particle acceleration!
  - energy considerations → accelerated particles most likely protons

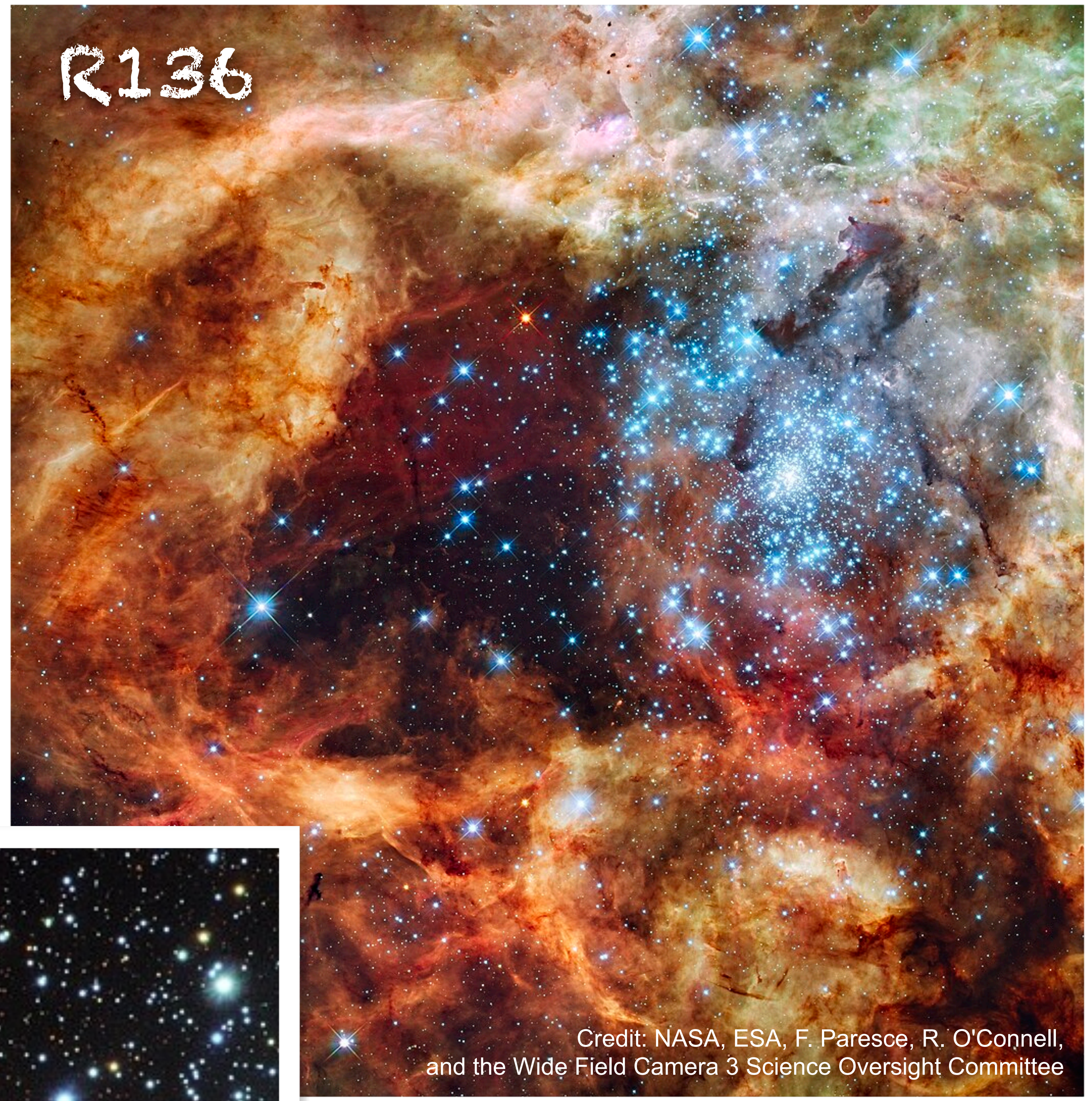






Young massive star clusters

- **What are they?**
  - dense clusters of massive stars (O/B stars, Wolf-Rayet stars)
  - total mass: $\gtrsim 10^4 M_\odot$
  - compact clusters: $r \lesssim \mathrm{few\,pc}$
  - superimposed stellar winds + supernovae
    $\rightarrow$ can blow “superbubble” into the interstellar medium



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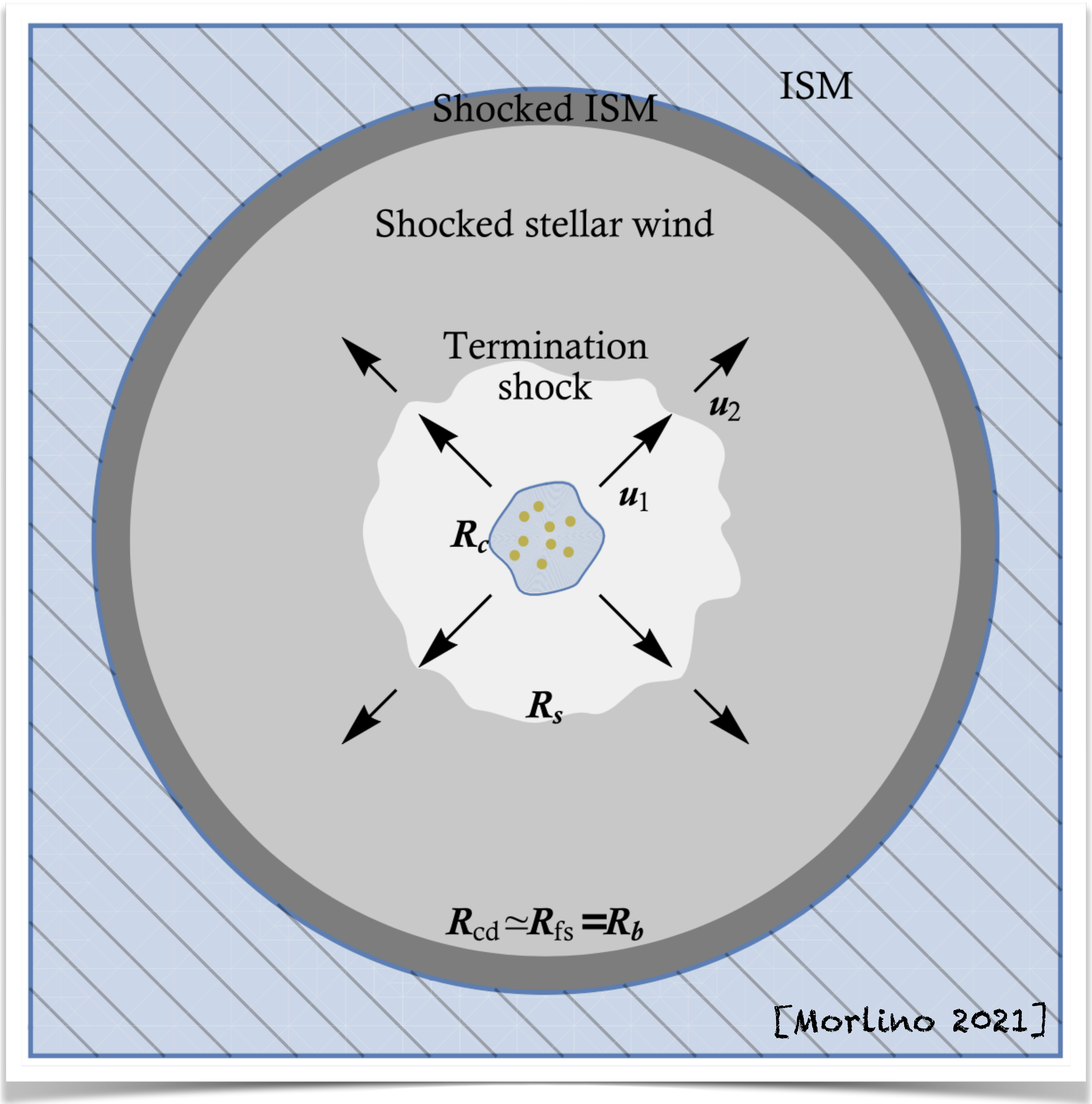
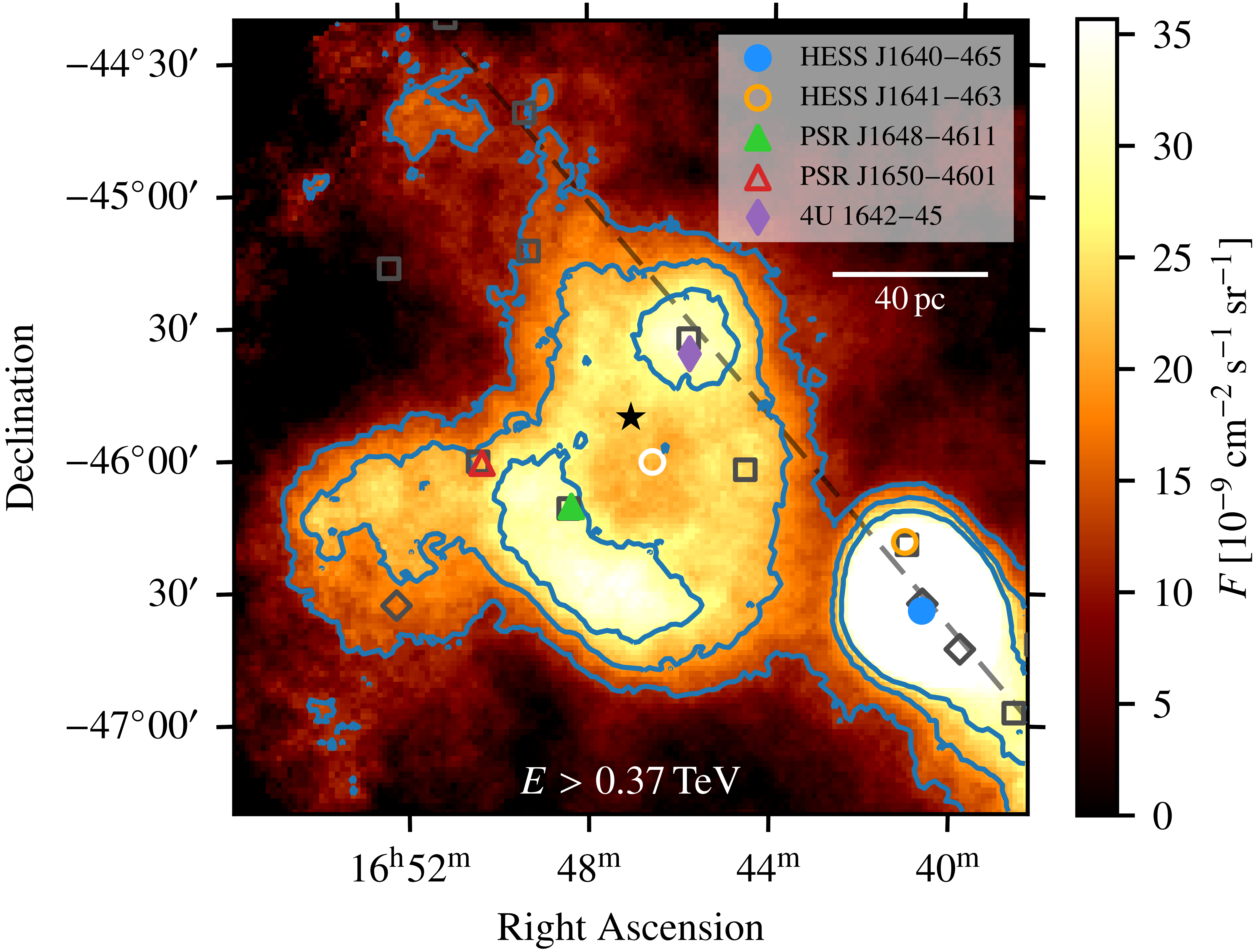
- **Why are they interesting for us?**
  → superbubble environments potentially are great for cosmic-ray acceleration
  - wind/wind interactions inside cluster
  - turbulence in shocked medium
  - collective wind termination shock



Young massive star clusters: Westerlund 1 [A&A 2022]



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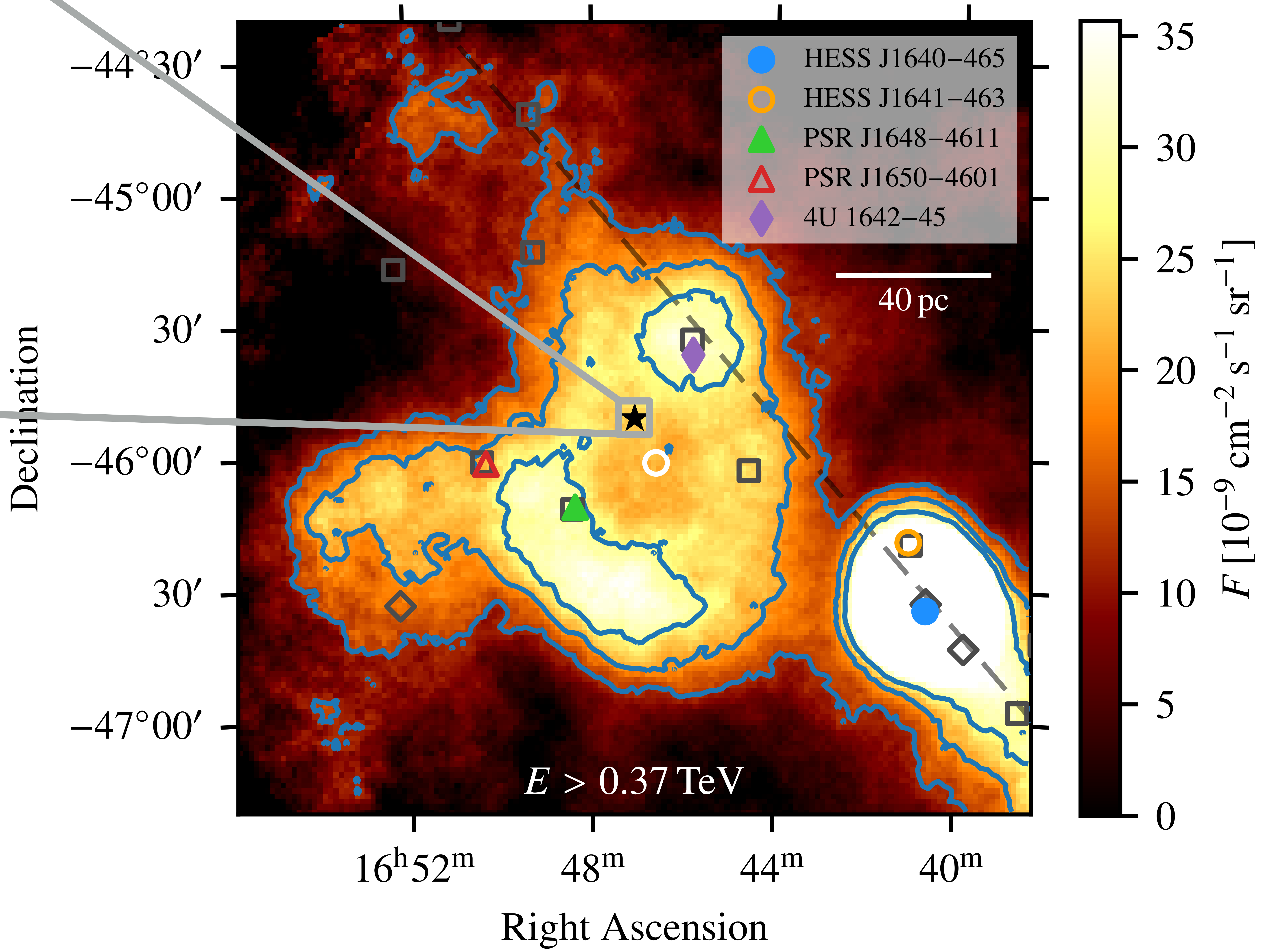

- **Westerlund 1**
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  - $M \sim 10^5\,M_\odot$
  - half-mass radius ~ 1 pc
  - age $\sim 3-5$ Myr
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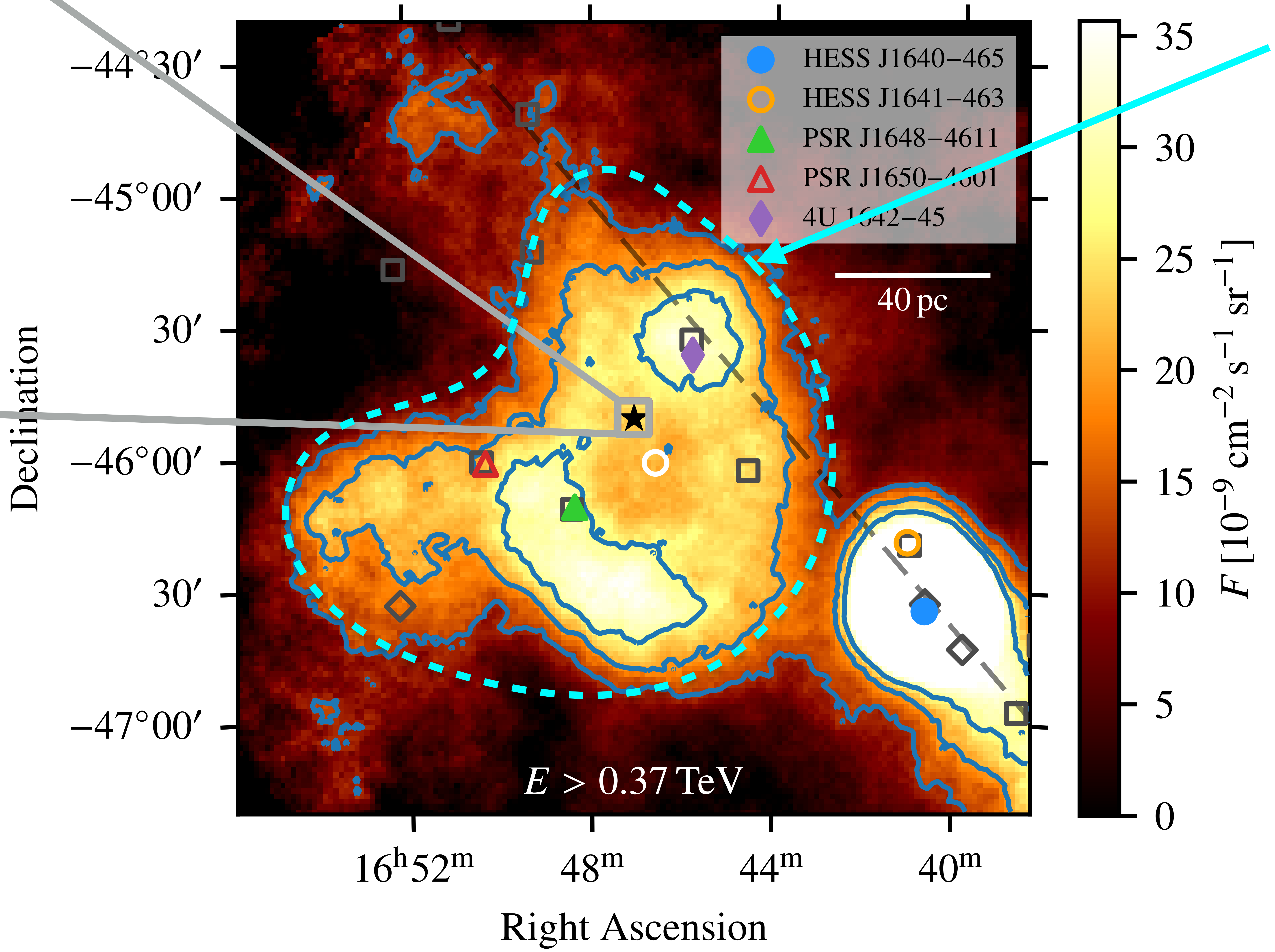
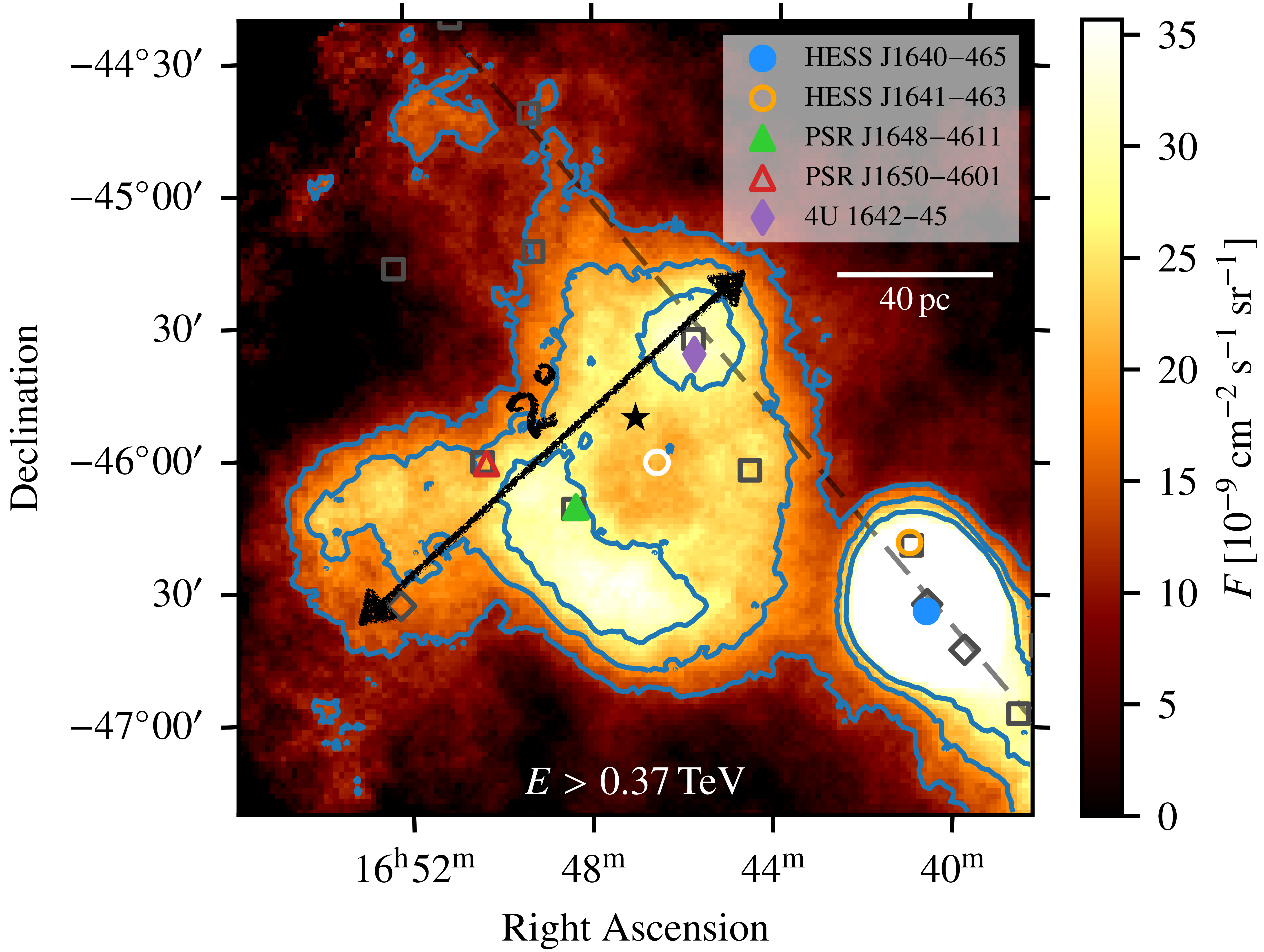


- **HESS J1646–458**
  - largely extended γ-ray source
  - very likely associated with Westerlund 1

Young massive star clusters: Westerlund 1 [A&A 2022]

- **Source extent**
  - diameter ~ 2° (140 pc)
  - 100 × larger than cluster itself!



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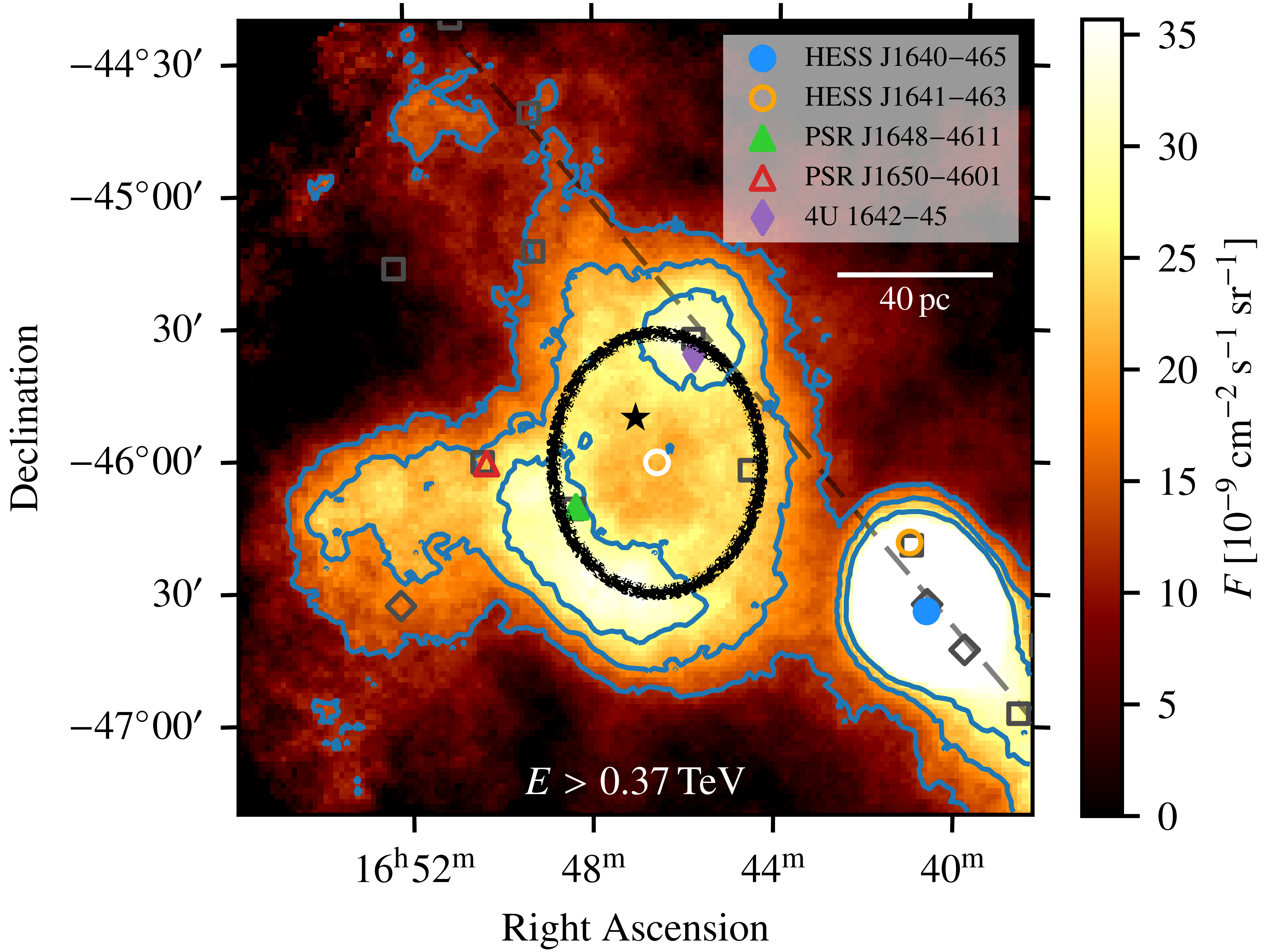

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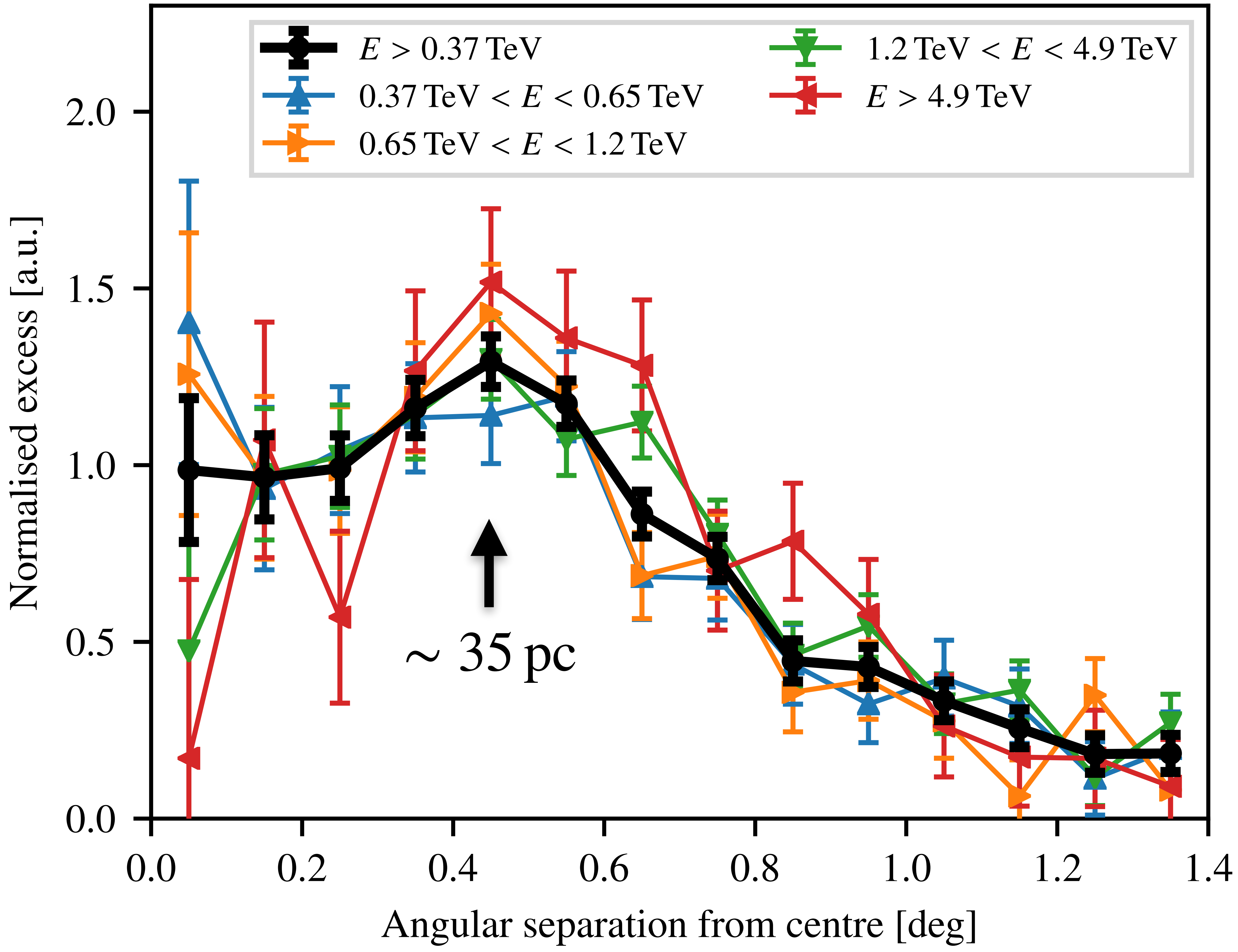

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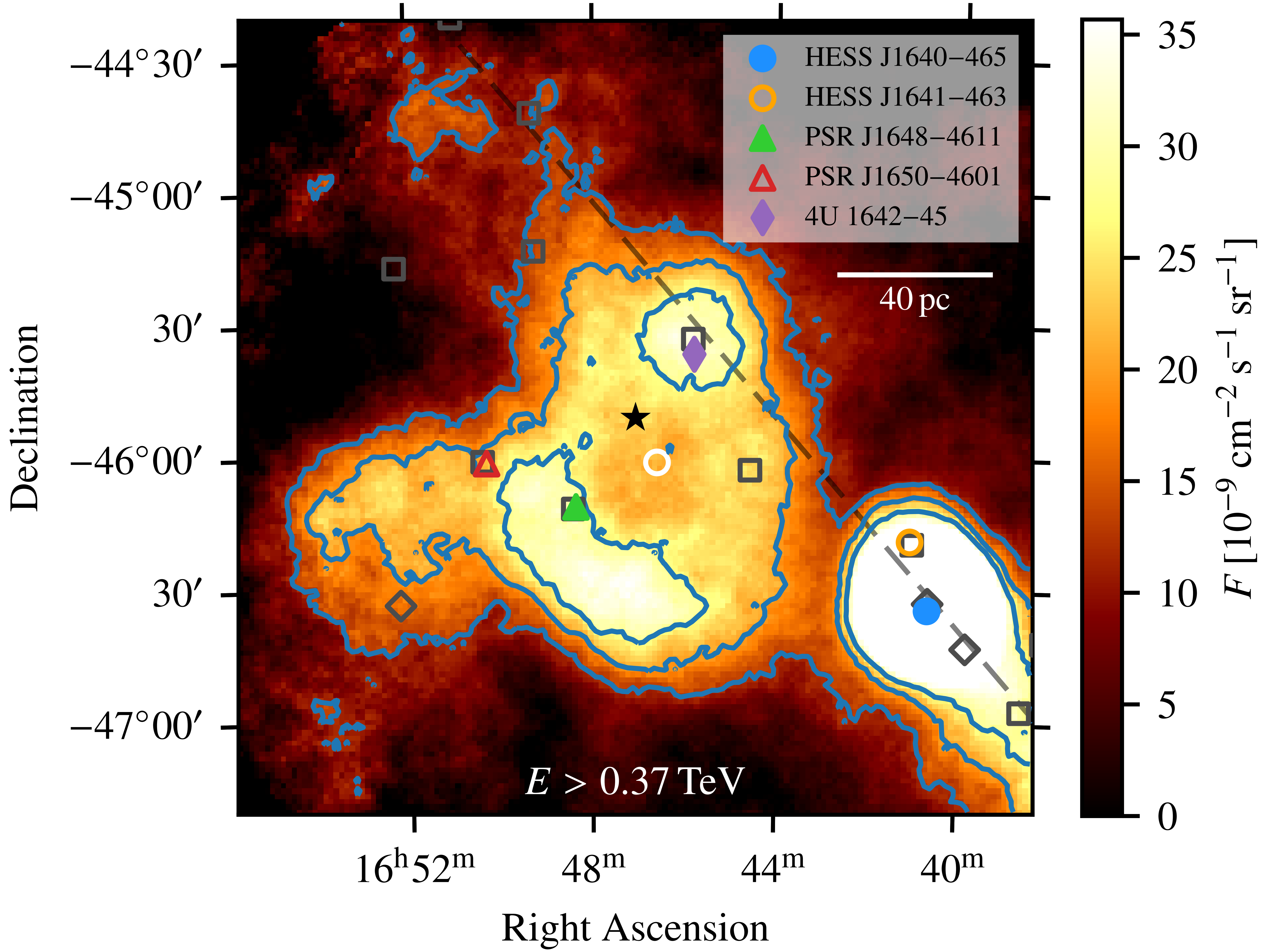
- **Conclusions**
  - Westerlund 1 is a very powerful cosmic-ray accelerator
  - ring-like structure is evidence for acceleration beyond bounds of cluster itself – possibly at termination shock of collective cluster wind



Young massive star clusters: R136 [ApJL 2024]

- **The Tarantula Nebula in the Large Magellanic Cloud**
  - most active starburst region in Local Group
  - one of the largest known H II regions
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Credit: ESO

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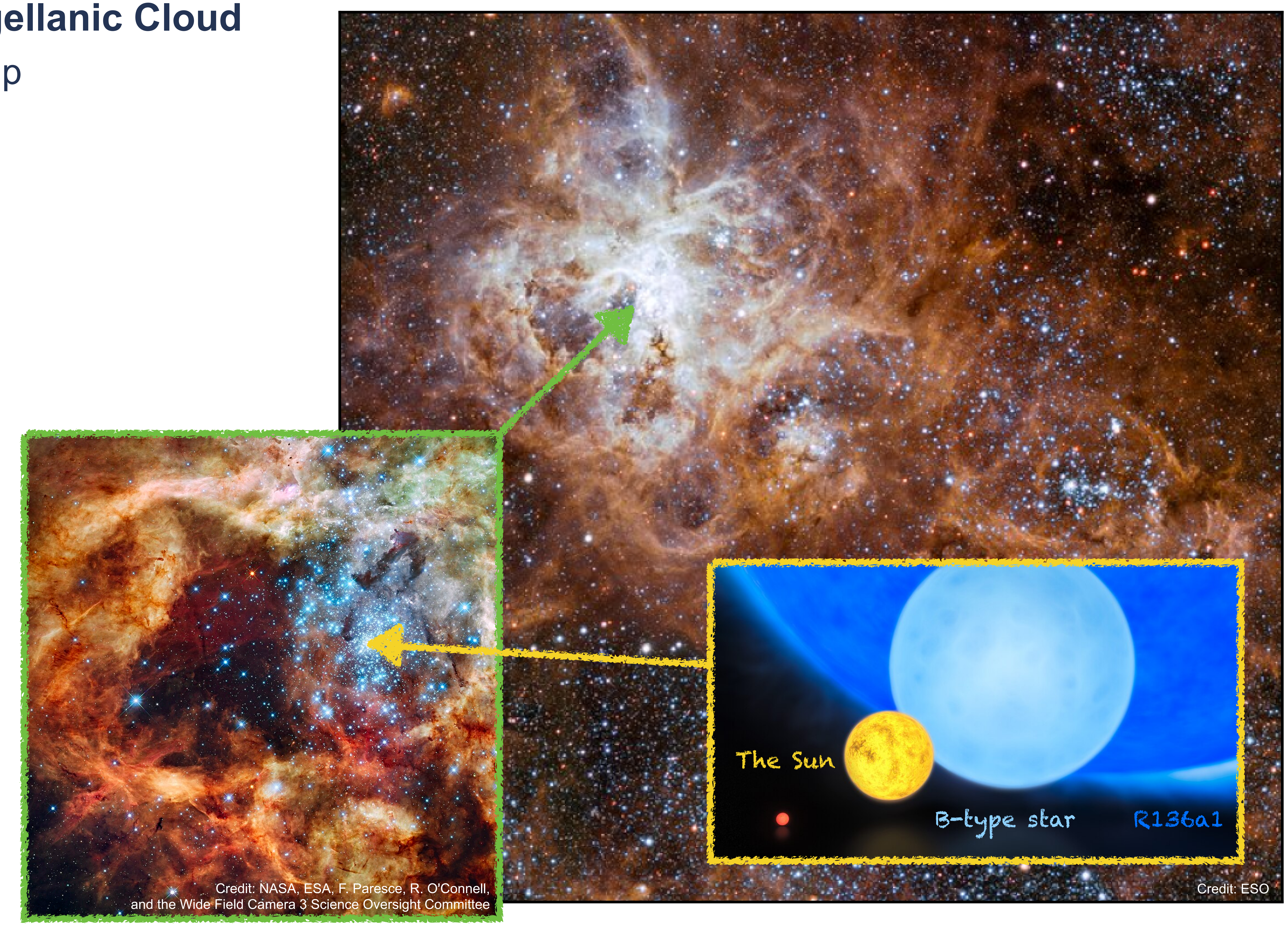
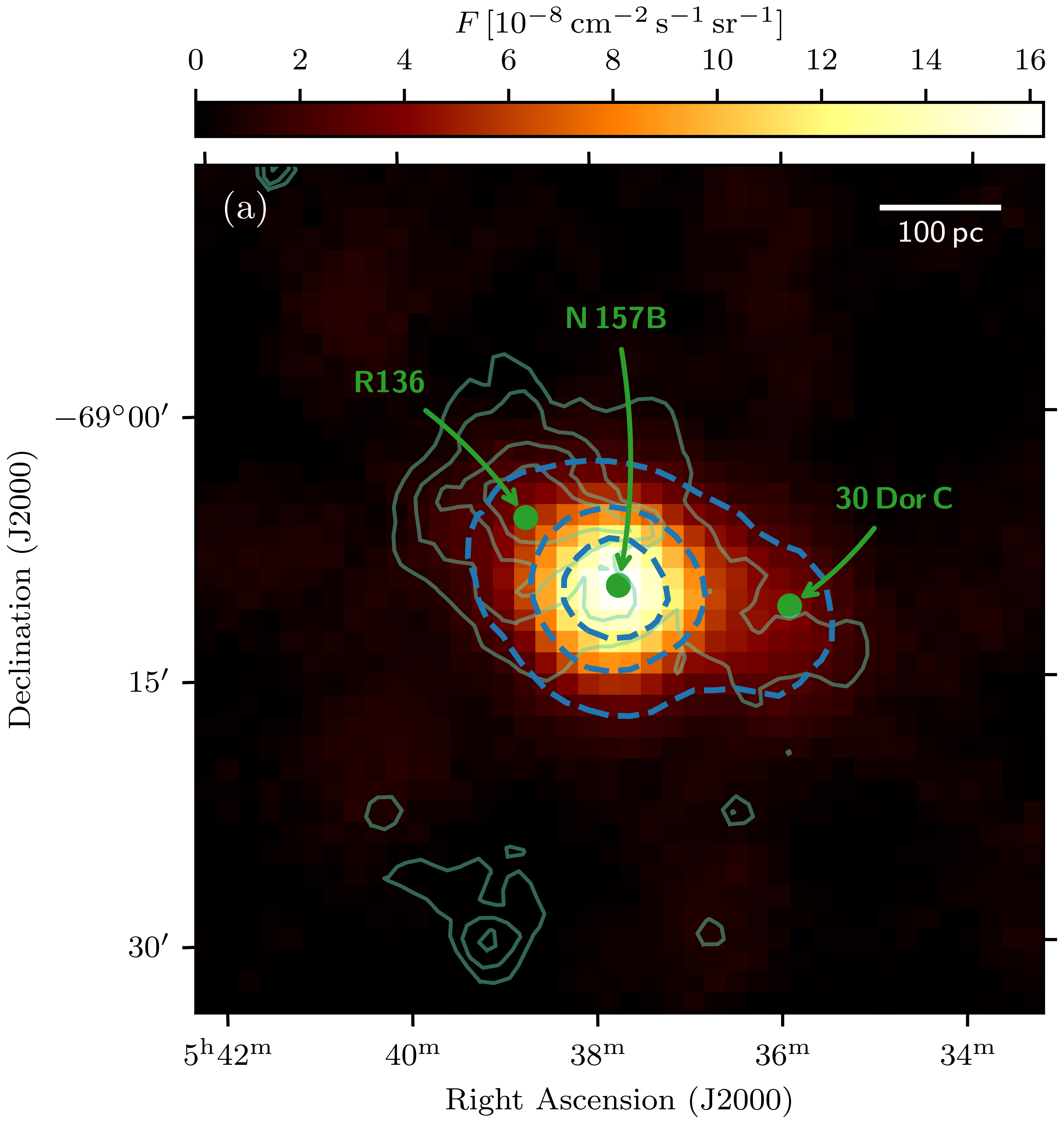
    with $M > 100\,M_\odot$
  - most massive star known: R136a1
    - initial mass: $251^{+48}_{-35}\,M_\odot$
    - luminosity: $4.7 \times 10^6\,L_\odot$



Young massive star clusters: R136

[ApJL 2024]

- **H.E.S.S. flux map of Tarantula Nebula**
  - nearby pulsar wind nebula N 157B outshines entire Tarantula Nebula
  - impossible to claim a signal from R136 based on this map



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[ApJL 2024]

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  - three-dimensional likelihood fit (2 spatial + 1 energy)
  - 2D Gaussians as spatial models
  - power law / log-parabola as spectral models
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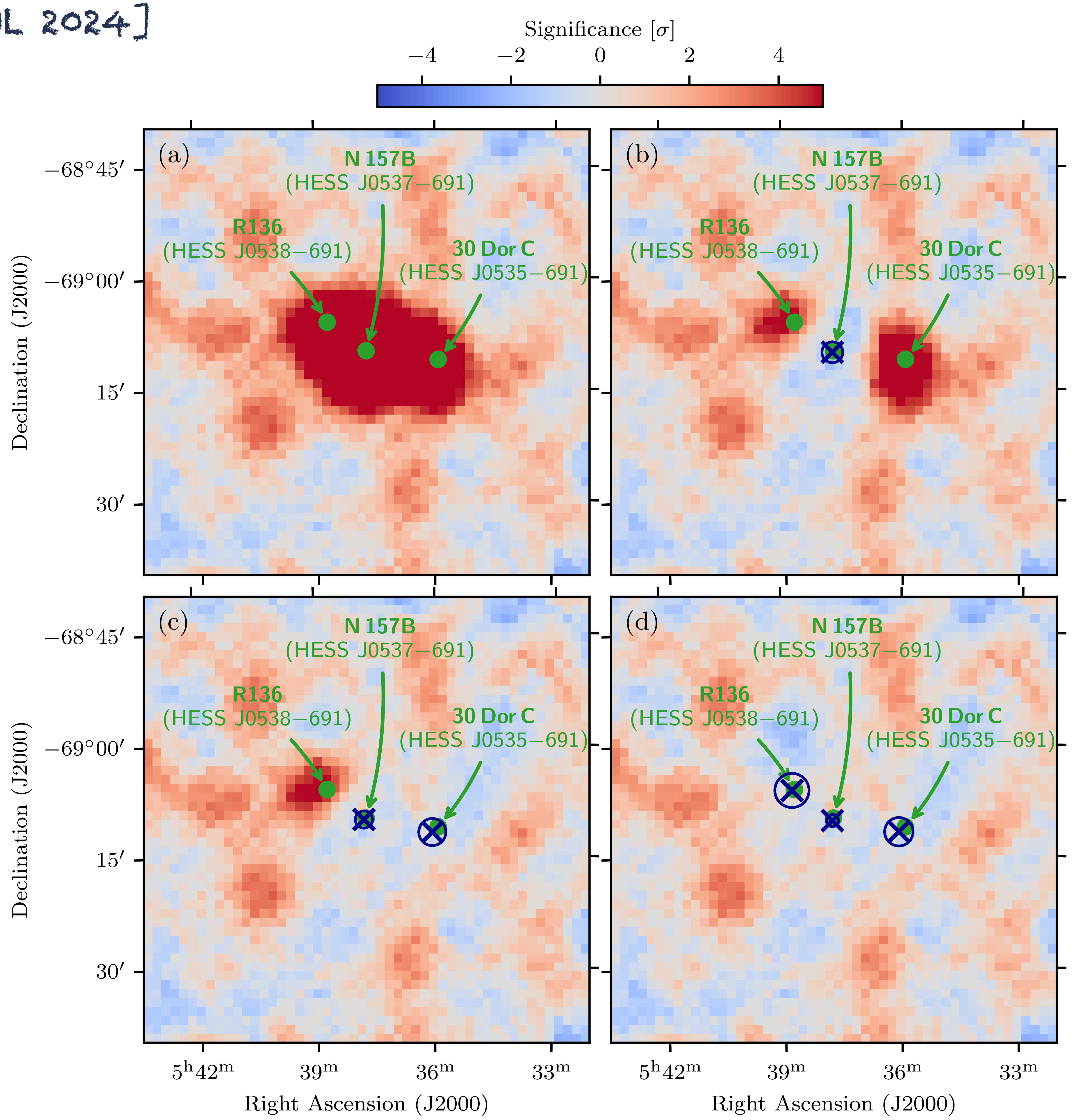

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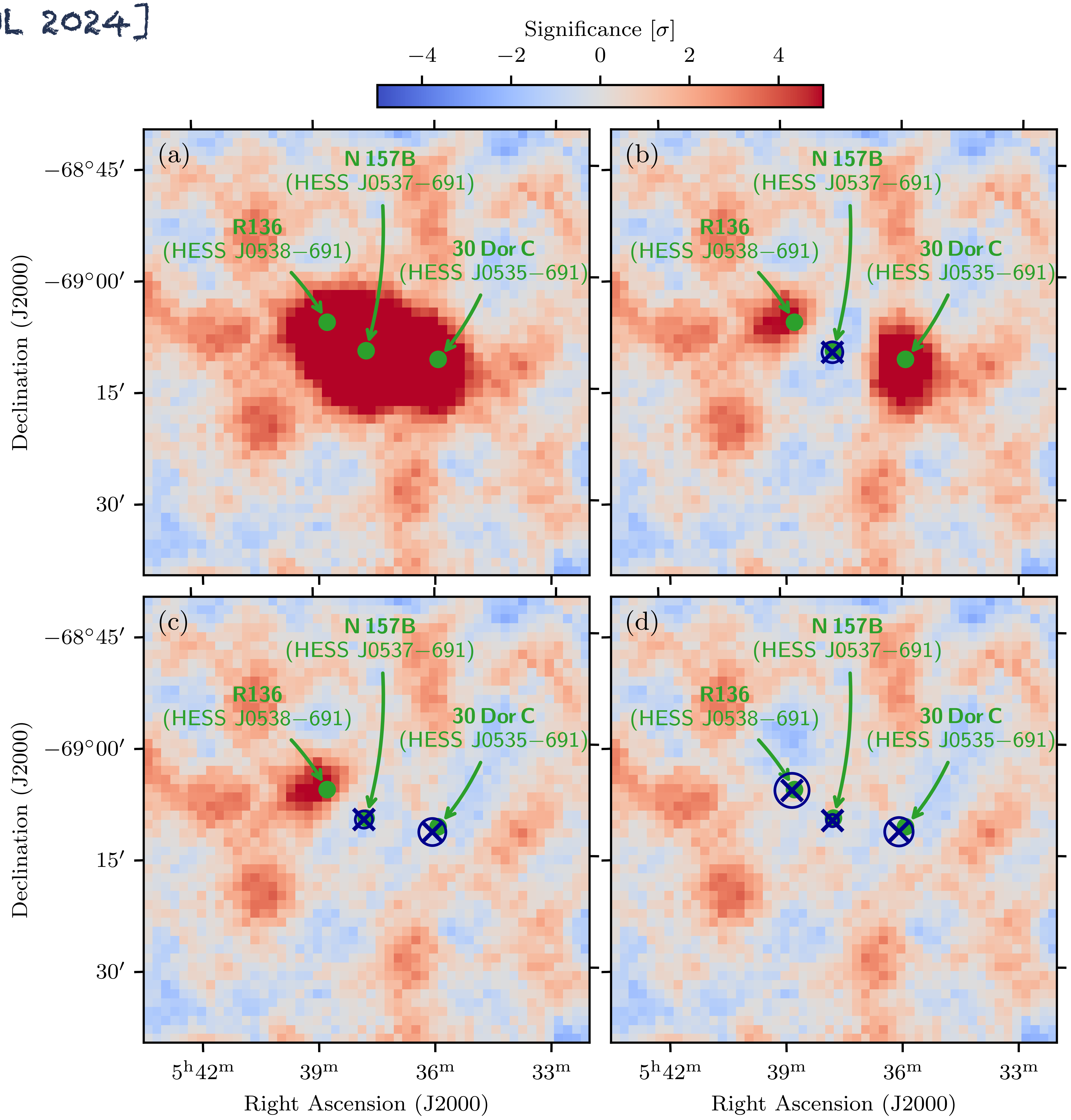
- **Results**
  - N 157B ($> 50\sigma$)
  - 30 Dor C (11σ) ← also a star cluster / superbubble!
  - R136 (6.3σ) ← significant detection!



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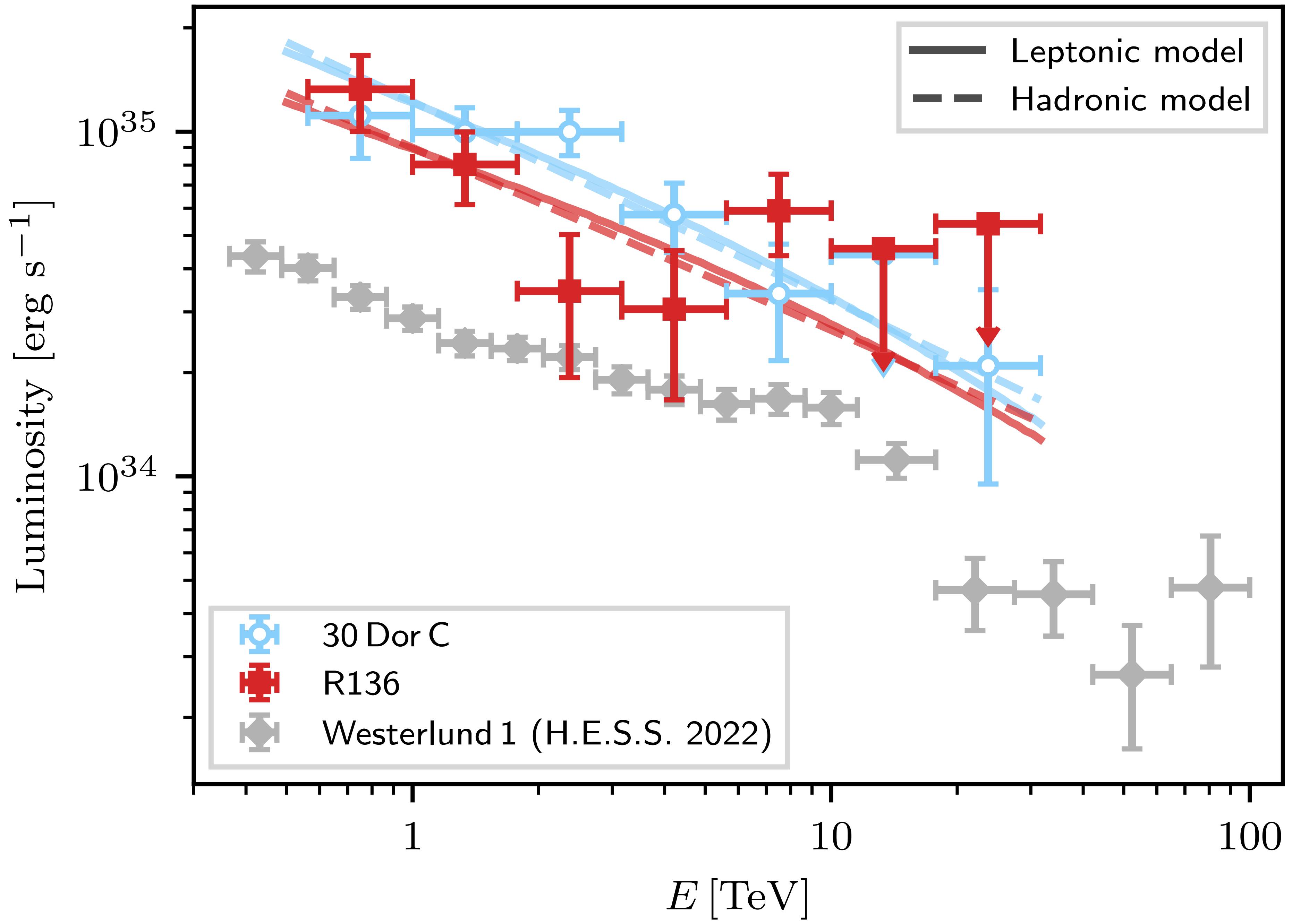

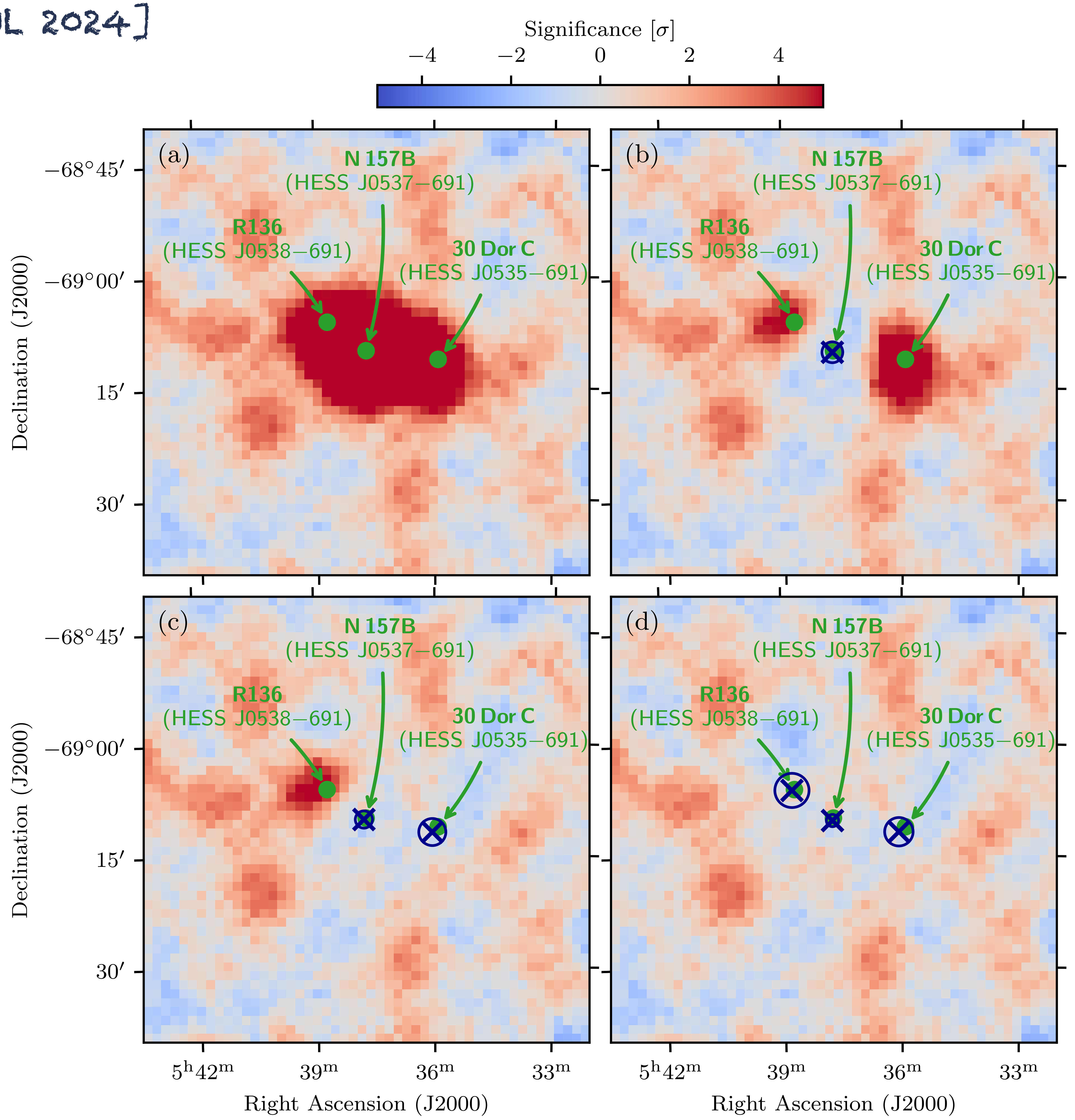

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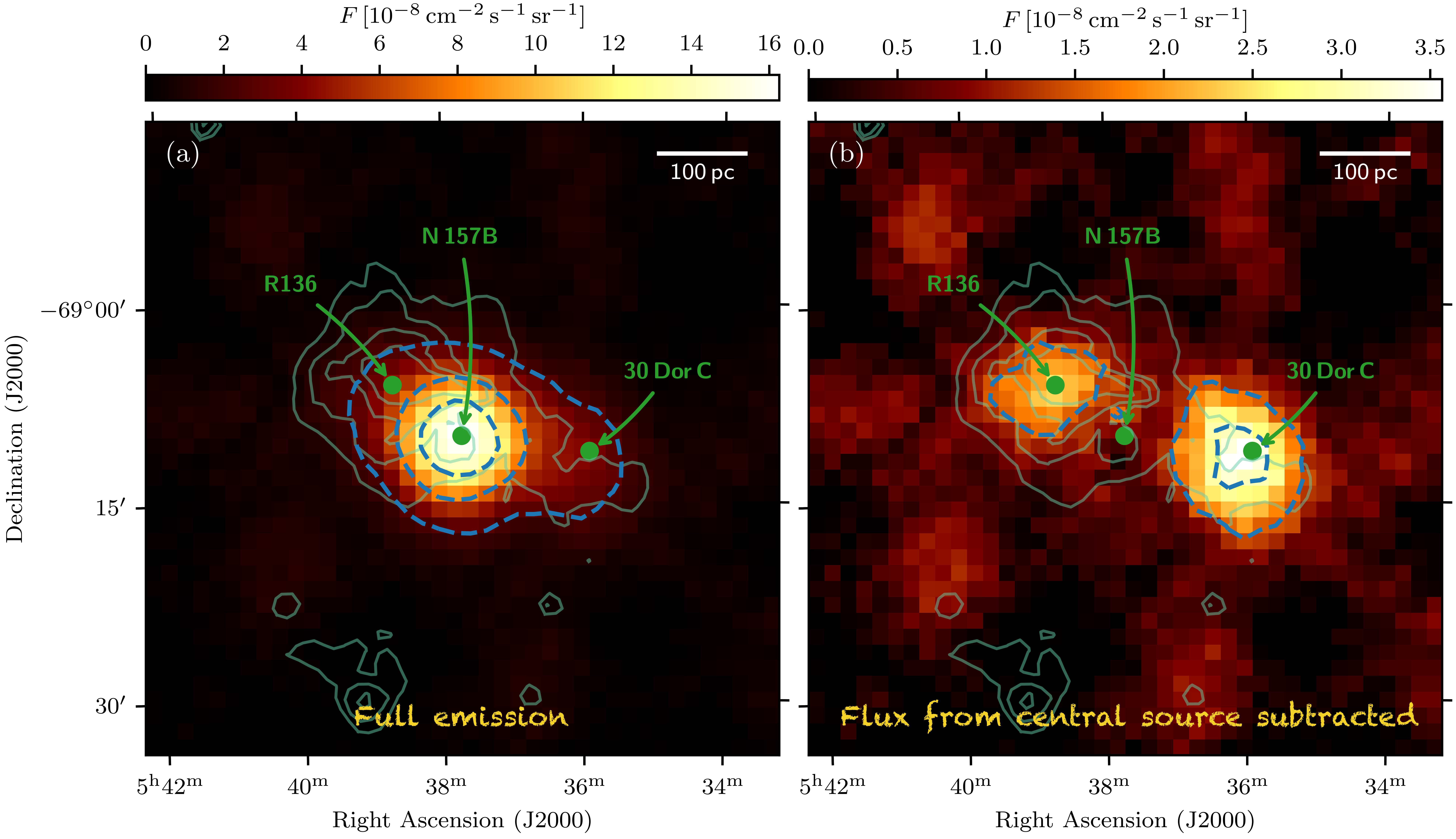

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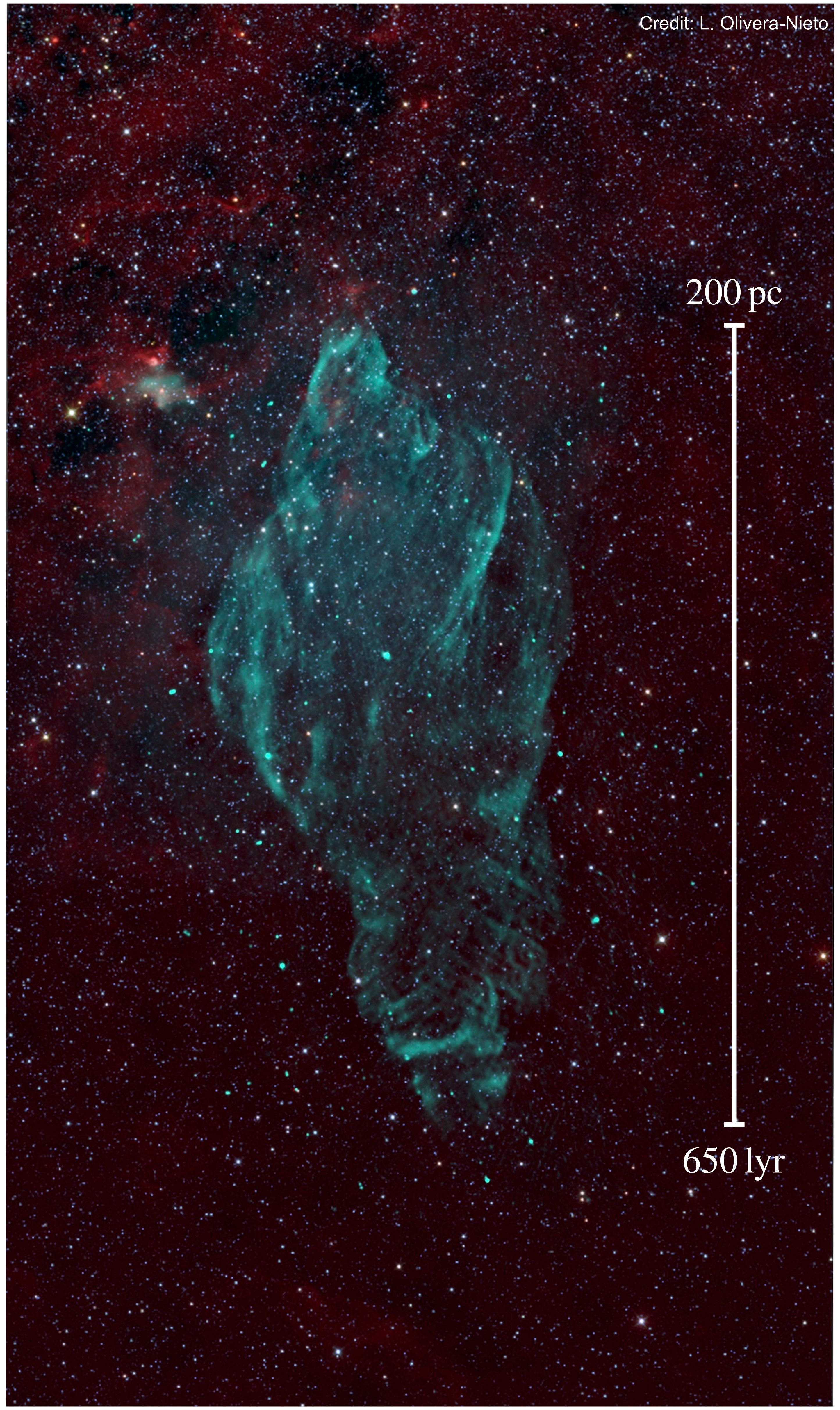

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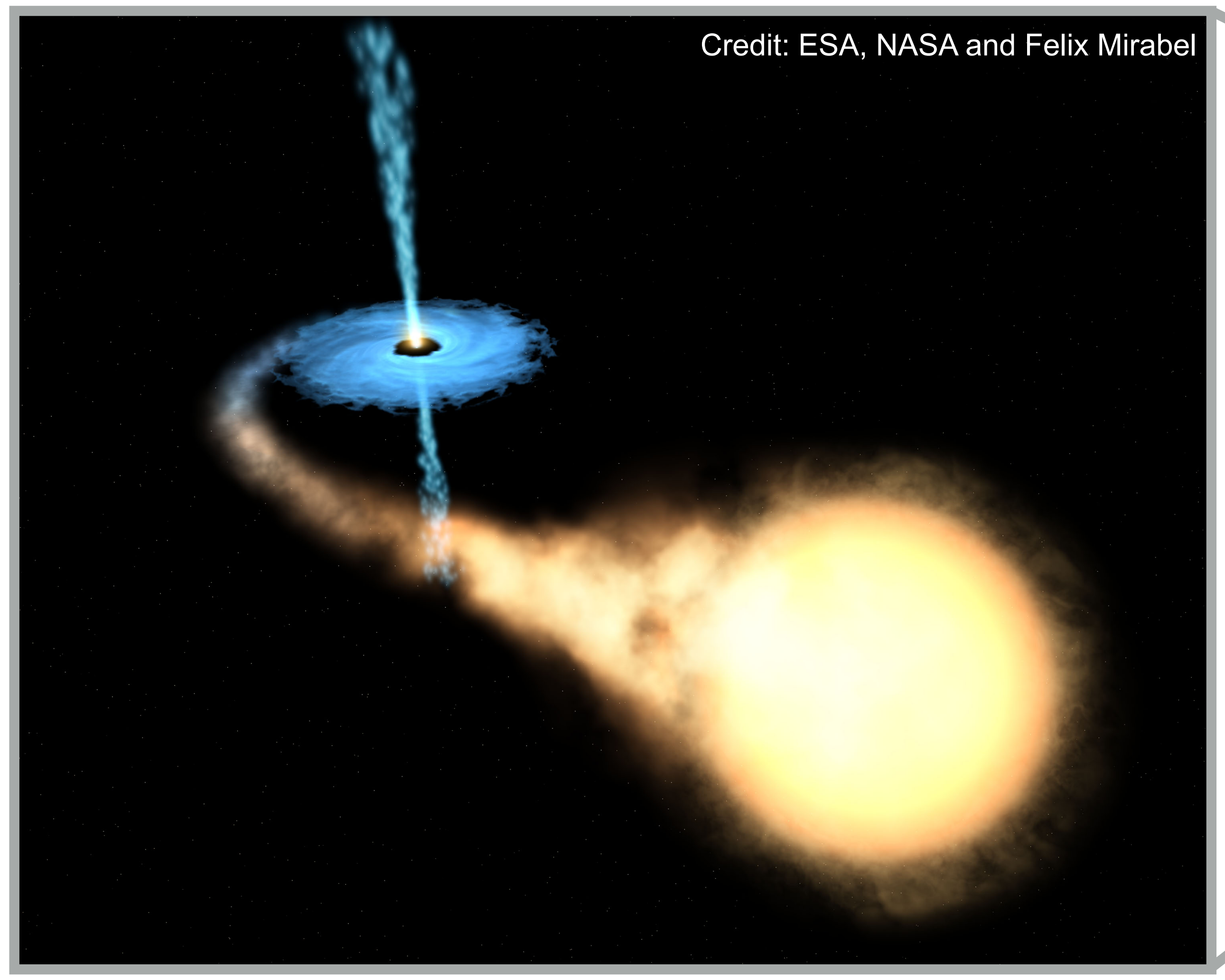

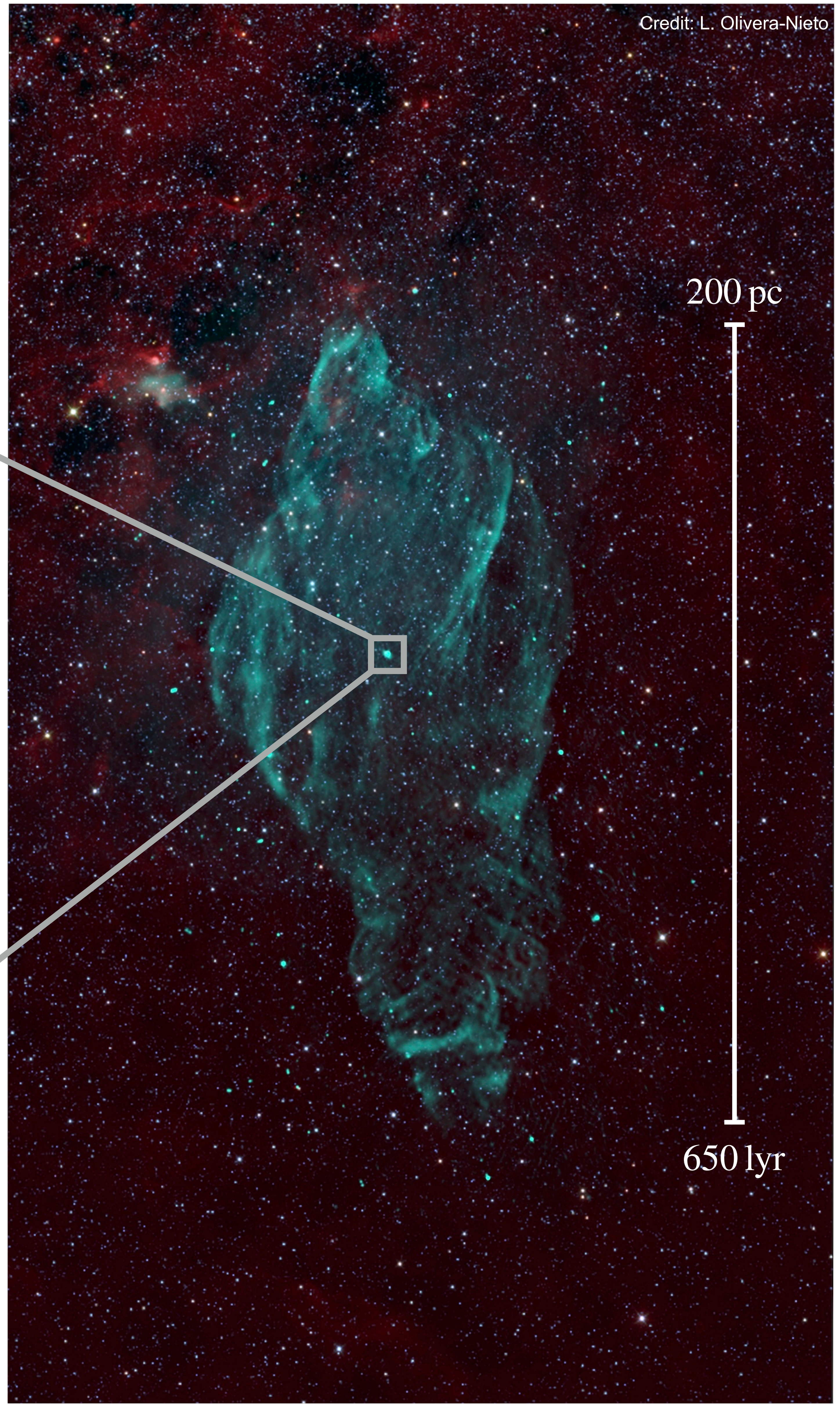

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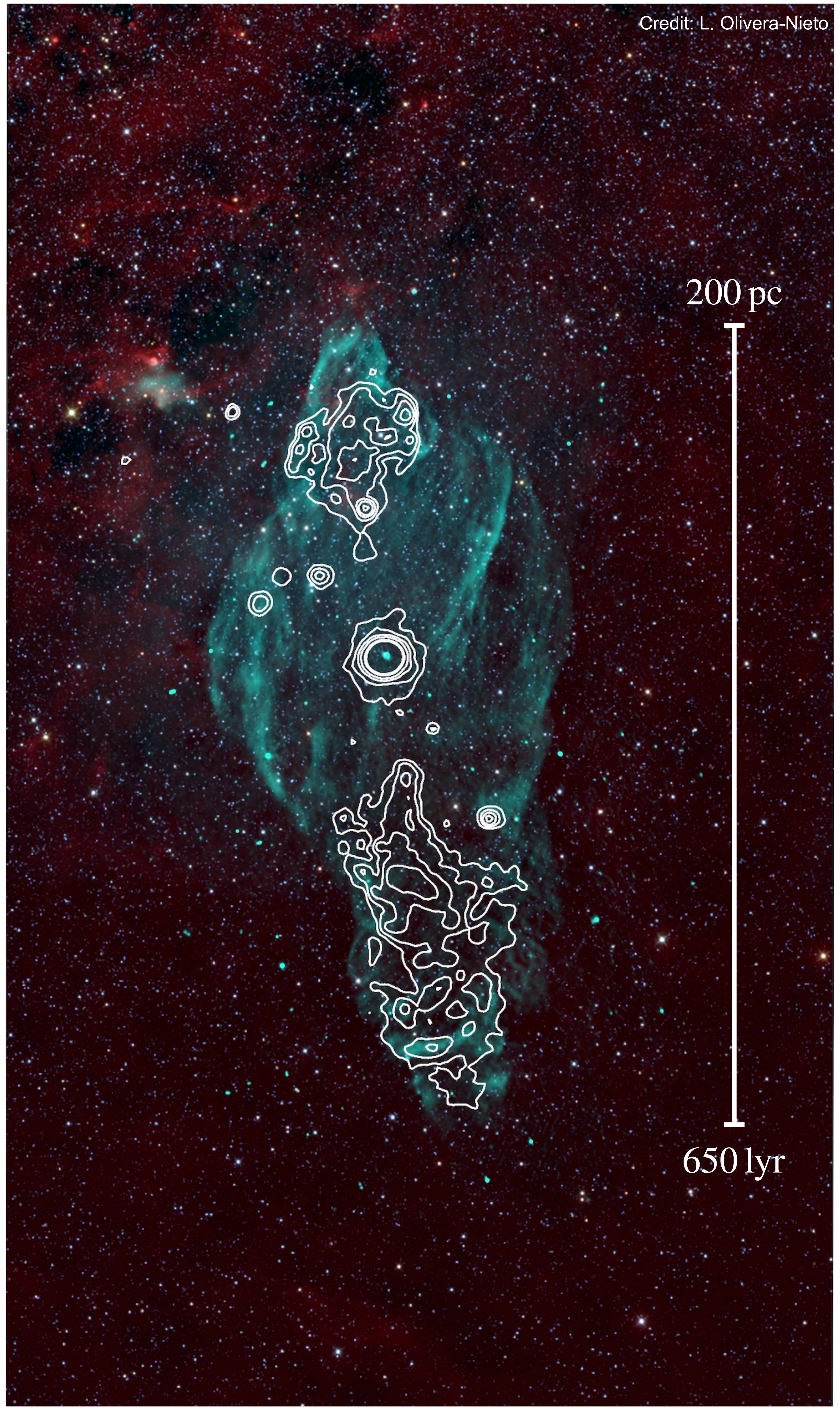

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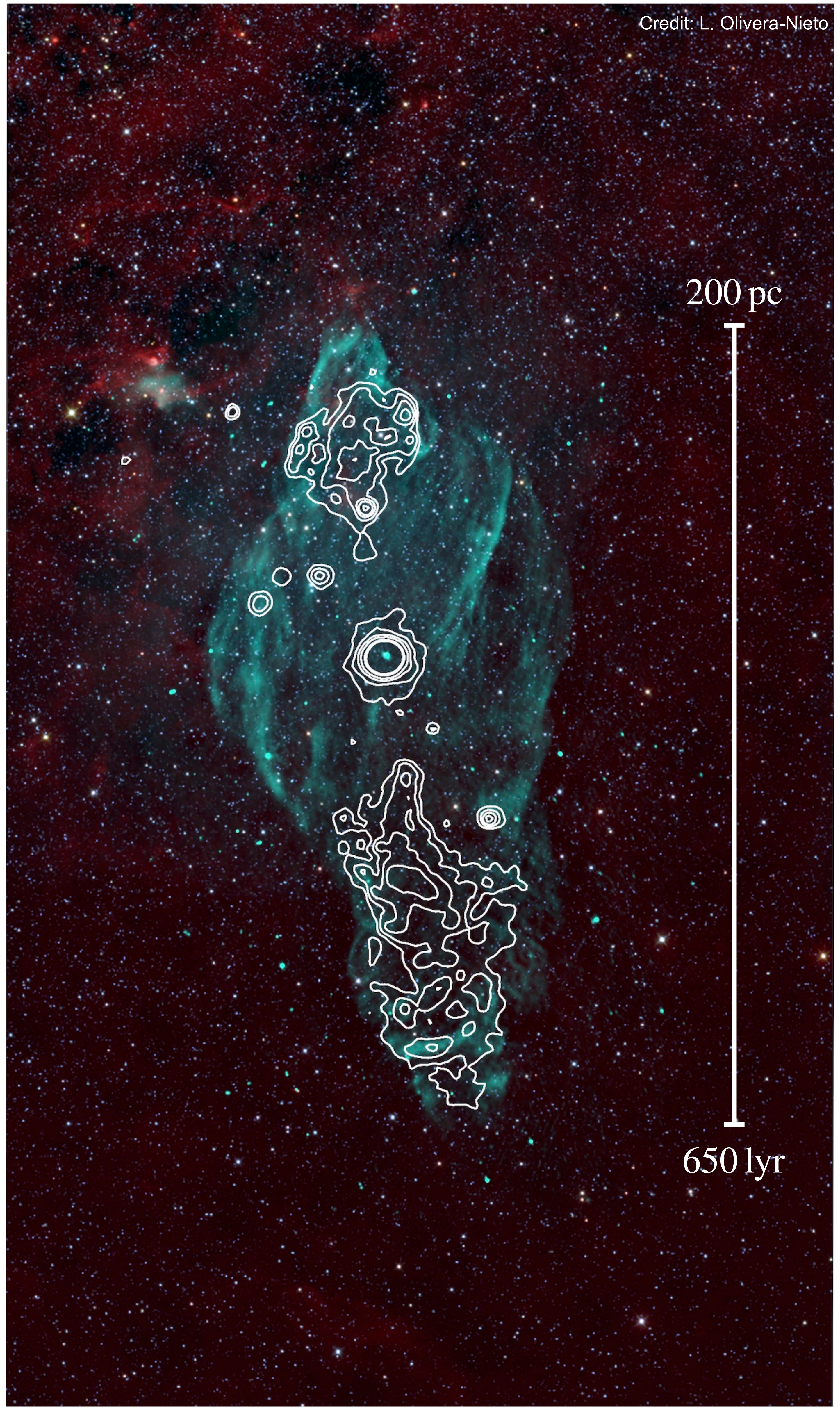
- **But we don't know:**
  - where are those electrons accelerated?
  - why do the jets "re-appear" at ~25 pc from the centre?



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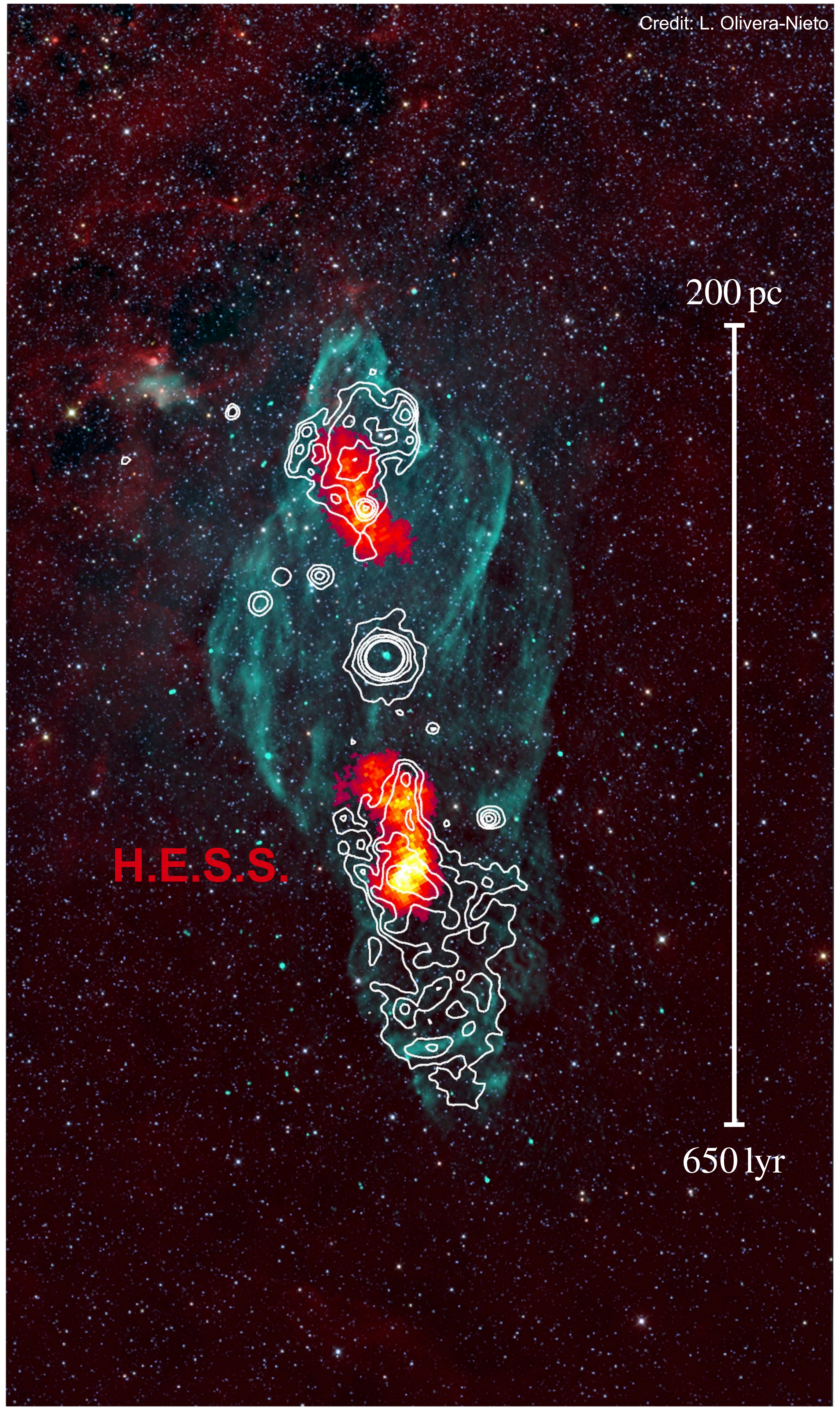
- **H.E.S.S. measurement**
  - TeV gamma-ray emission from jets



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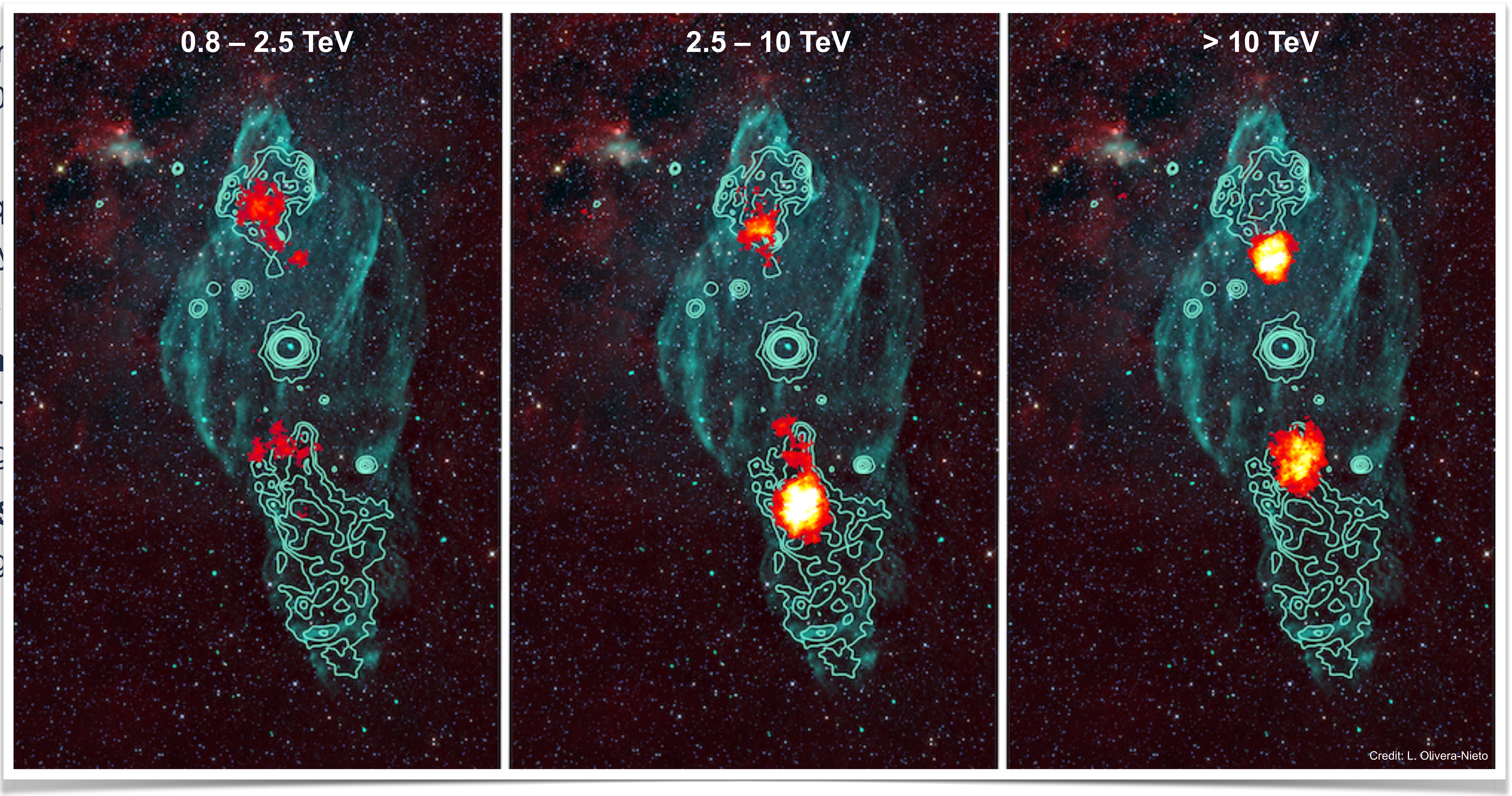

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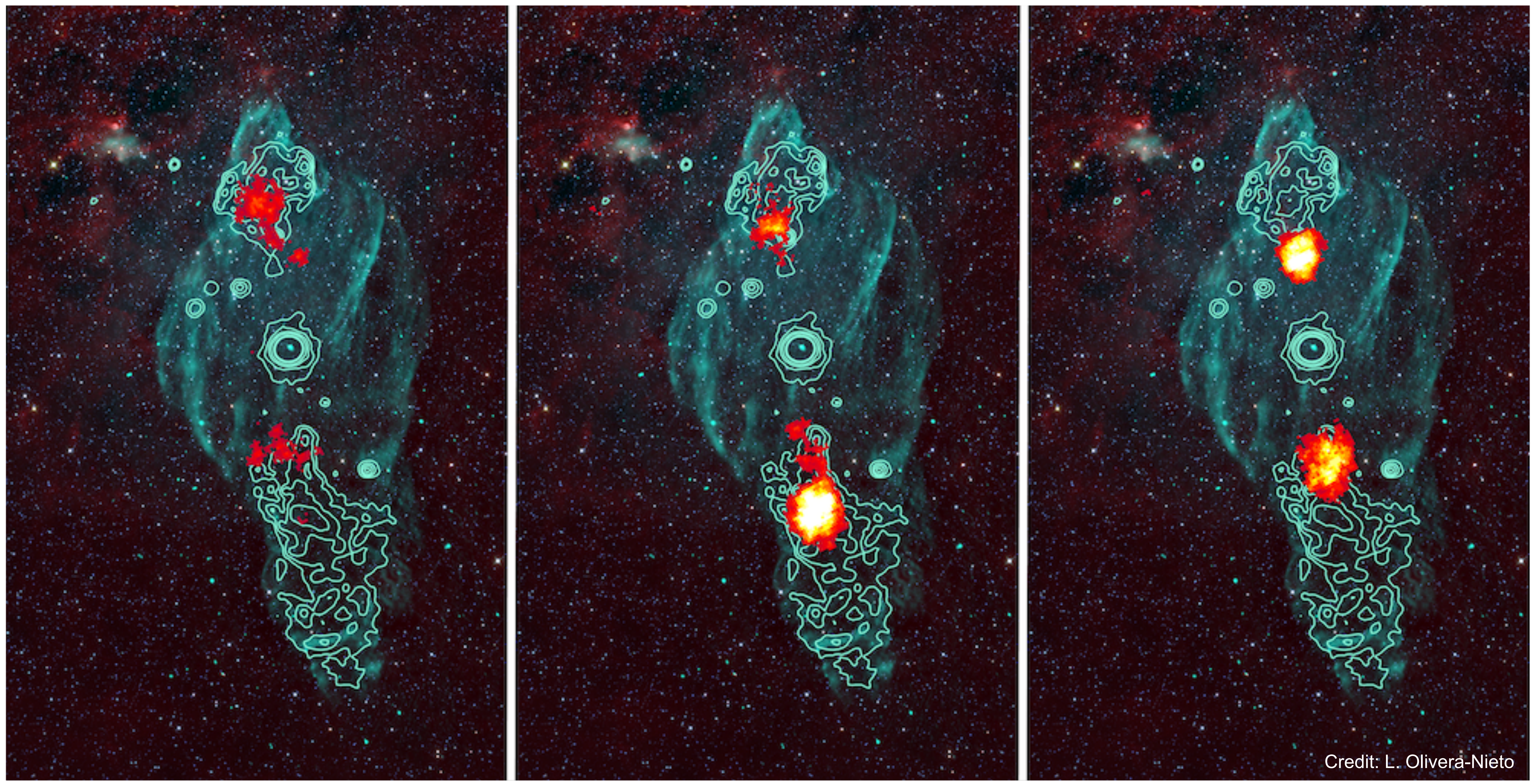
- **H.E.S.S. measurement**
  - TeV gamma-ray emission from jets
  - energy-dependent morphology!

    → inverse-Compton emission from electrons

    → acceleration at base of jets

    → advection along the jet flow



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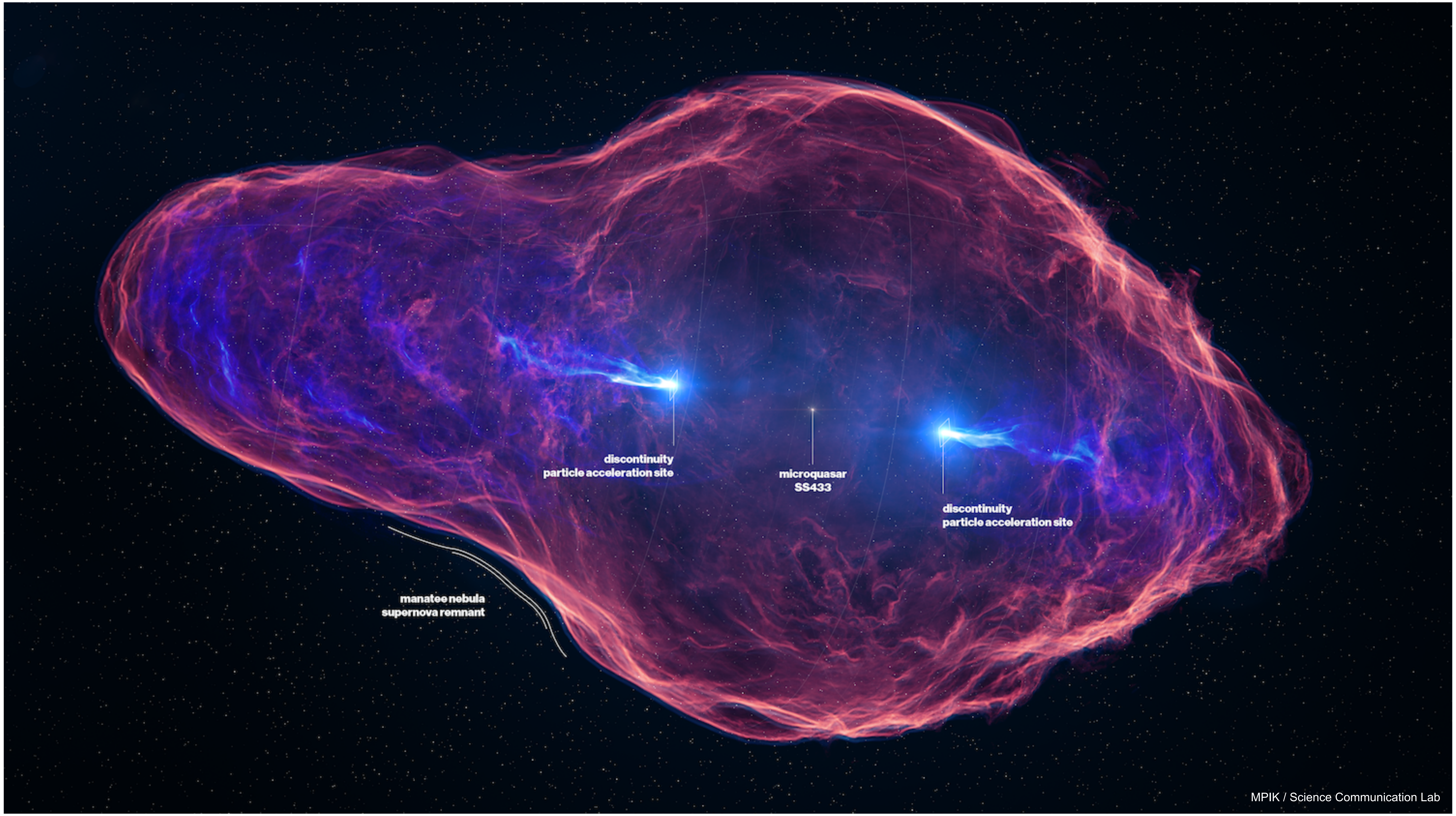
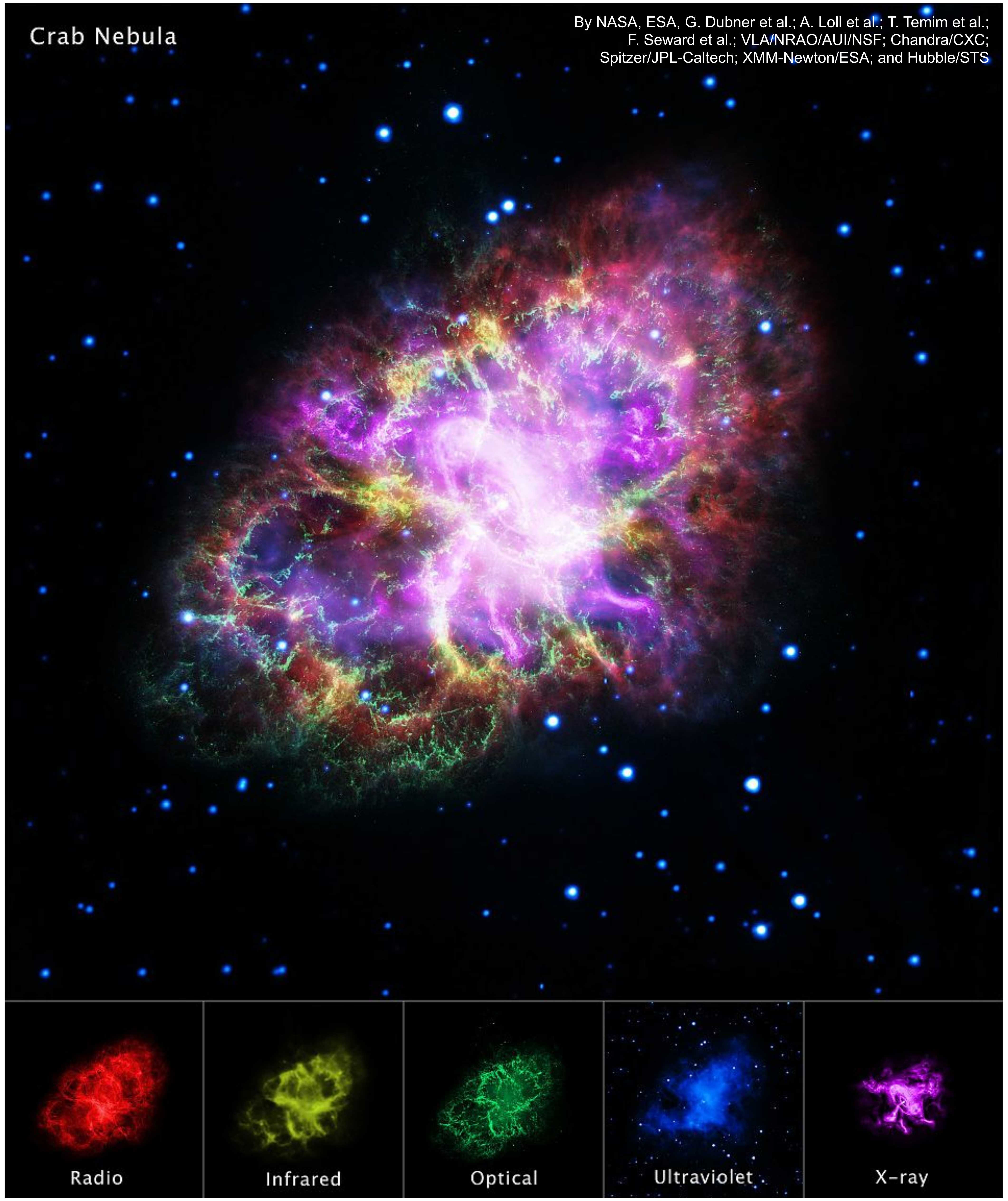


The Crab Nebula

[A&A 2024]

- **Pulsar wind nebula**
  - remnant of a supernova in 1054 C.E.
  - powered by Crab pulsar ($P = 33\,\mathrm{ms}$, $\dot{E} = 4.6 \times 10^{38}\,\mathrm{erg\,s^{-1}}$)

- One of the **best-studied objects** across the electromagnetic spectrum
  - emission from radio to X-ray wavelengths is (largely) synchrotron radiation from relativistic electrons

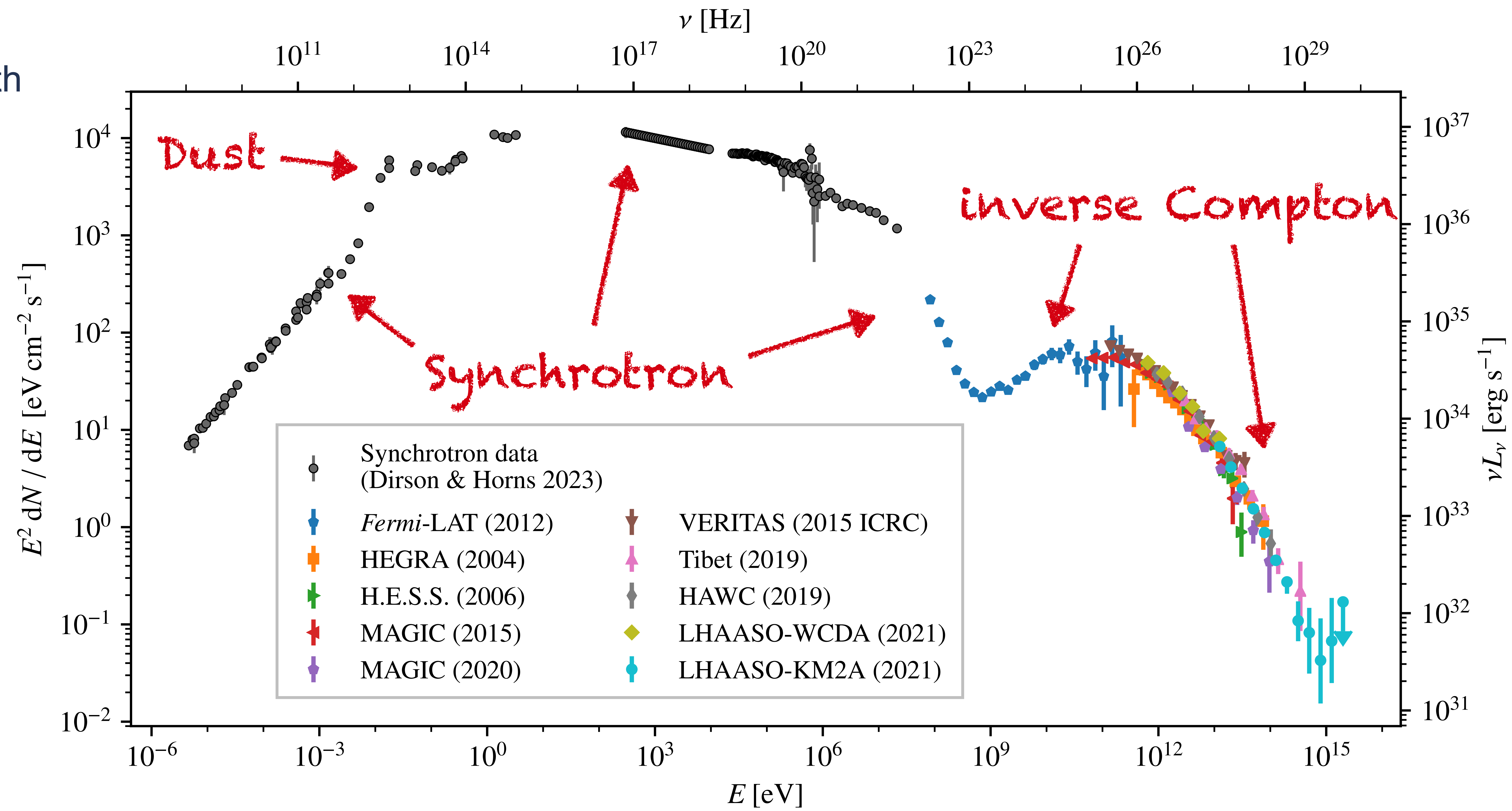


The Crab Nebula

[A&A 2024]

Spectral energy distribution:

- **Synchrotron emission**
  - depends on magnetic field strength (not very well constrained)
  - difficult to infer distribution of electrons
- **Inverse Compton emission**
  - independent of magnetic field
  - more direct tracer of electron distribution



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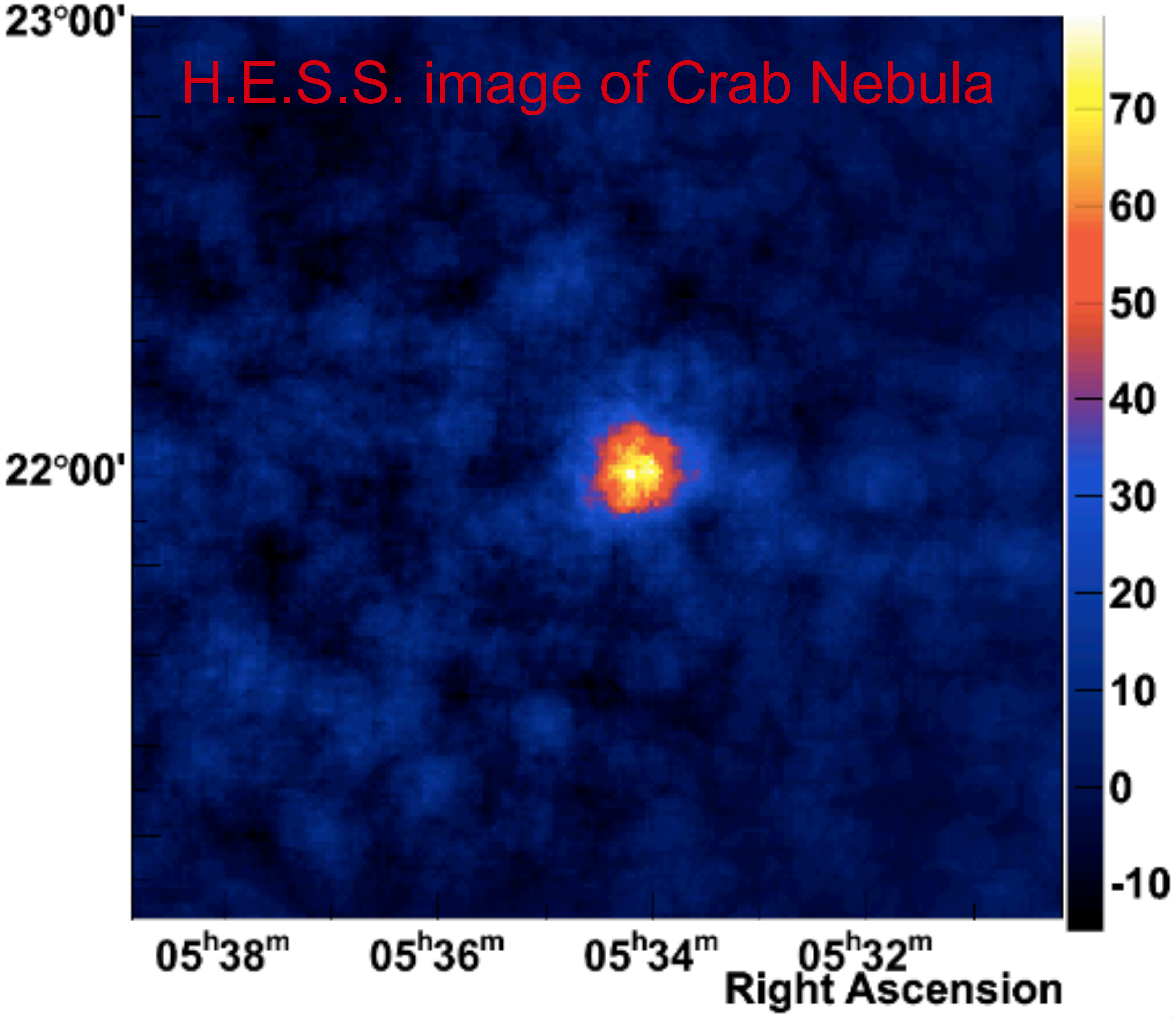
  - our image of the Crab Nebula does not look as nice



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  - Gaussian width of $52''$
  - in between UV and X-ray extension
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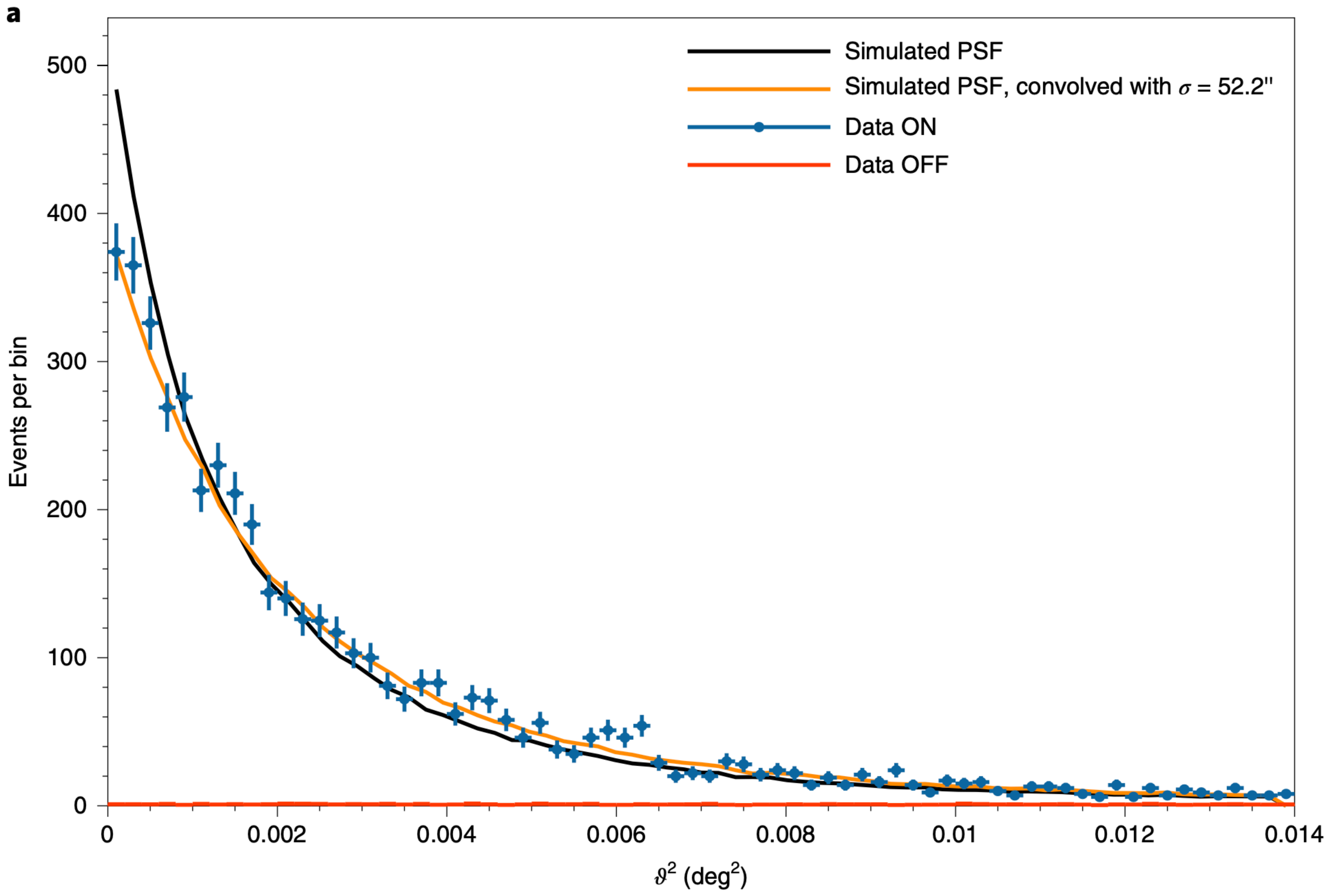

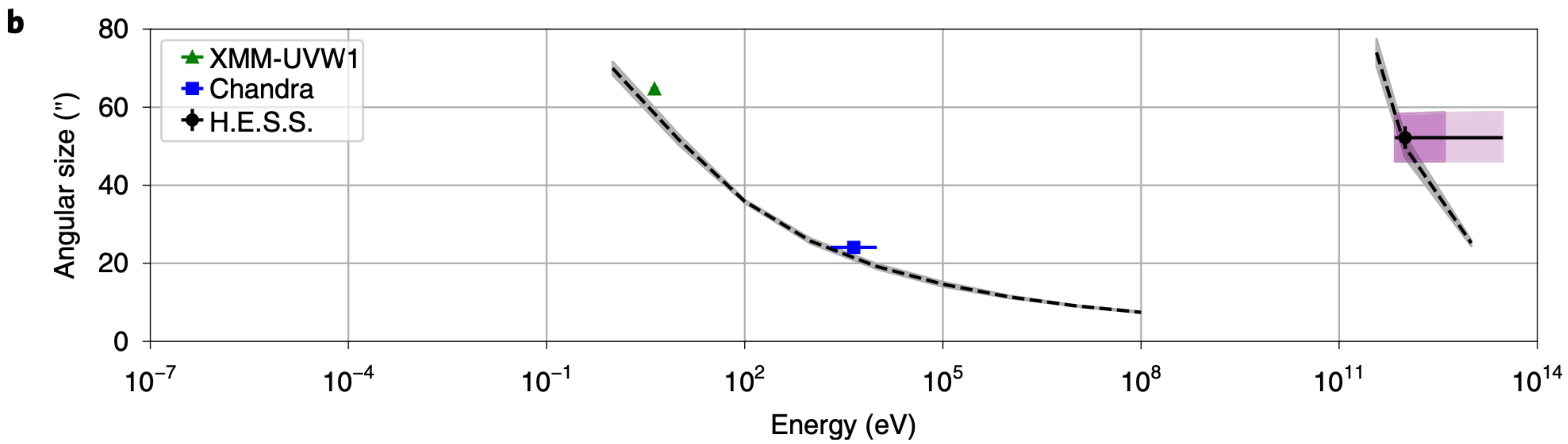

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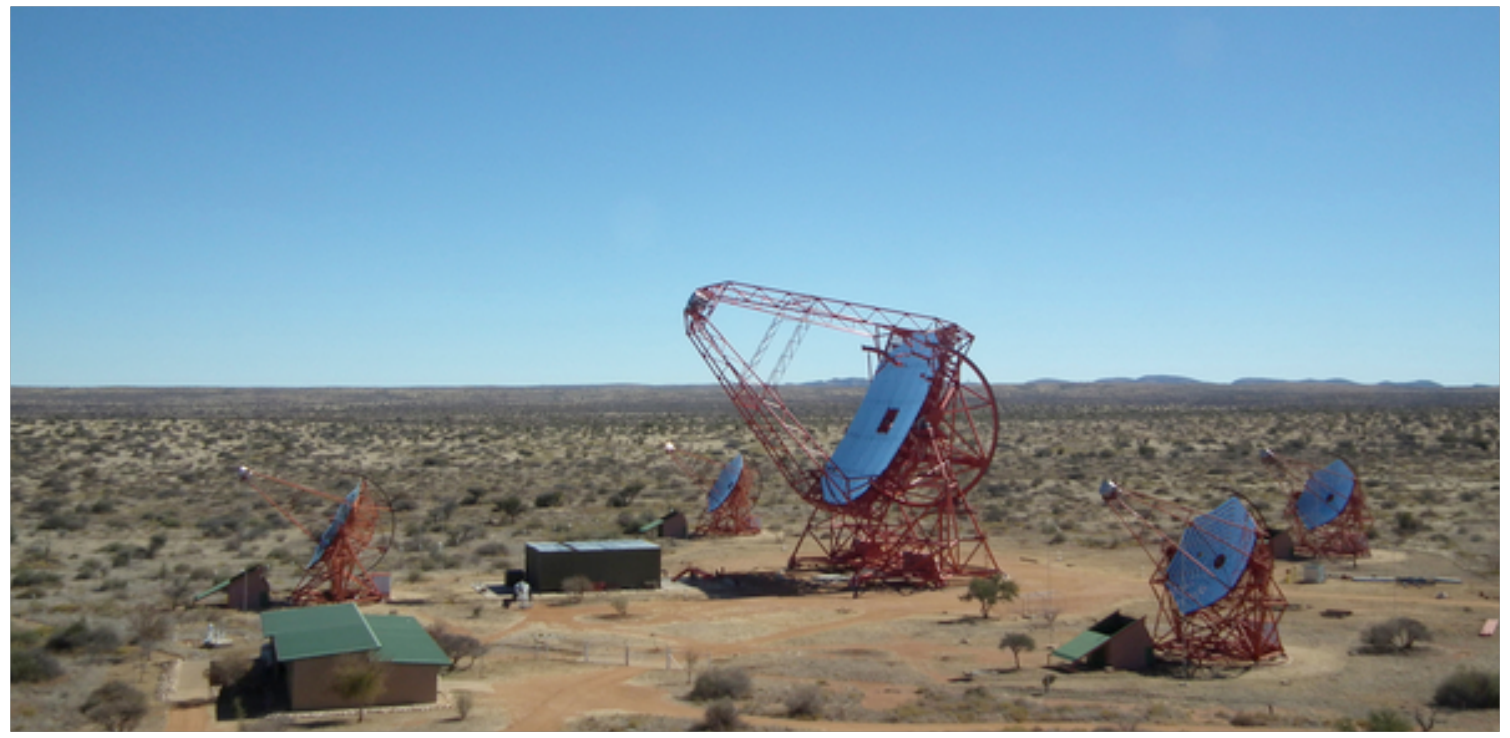

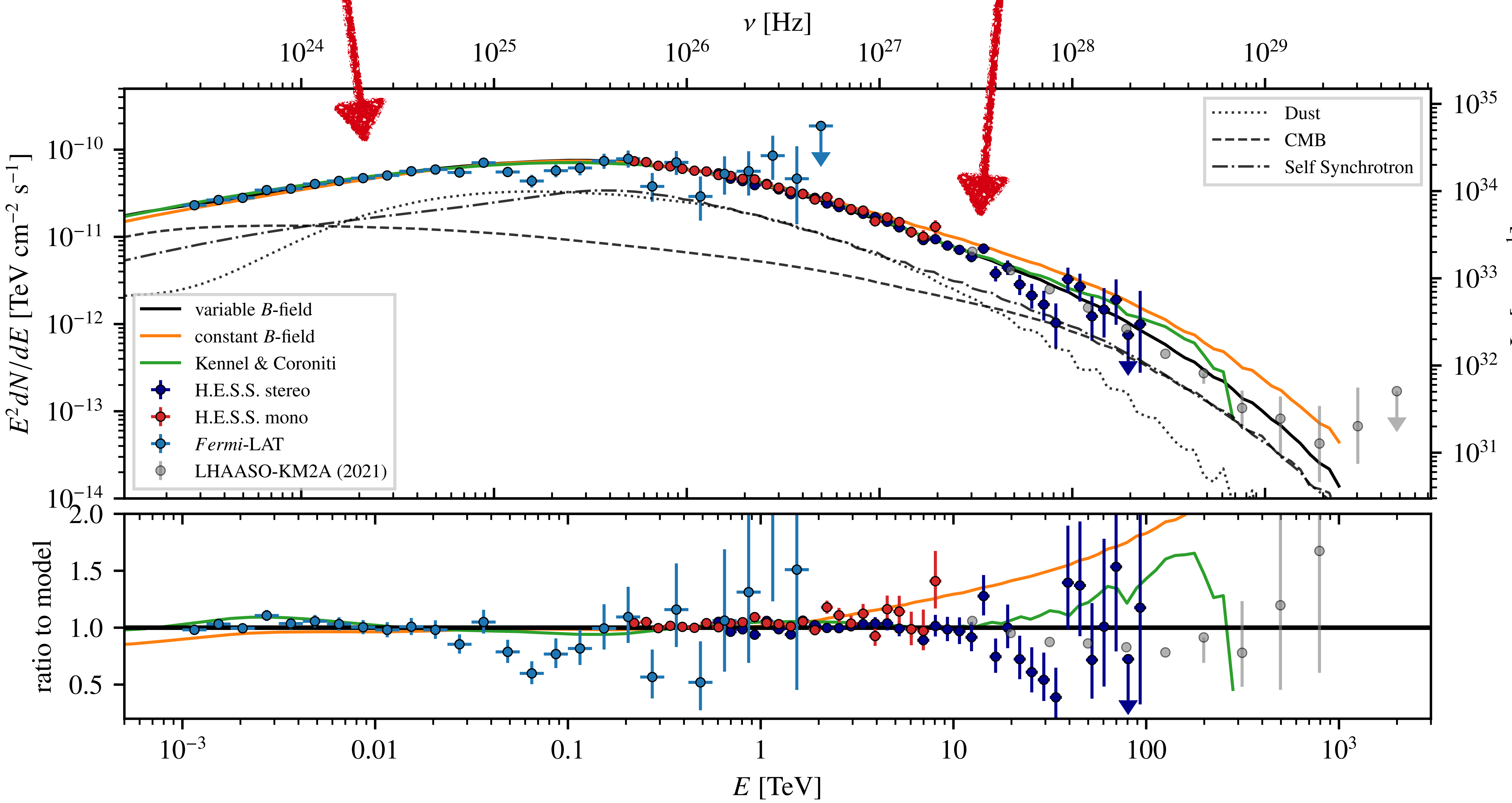

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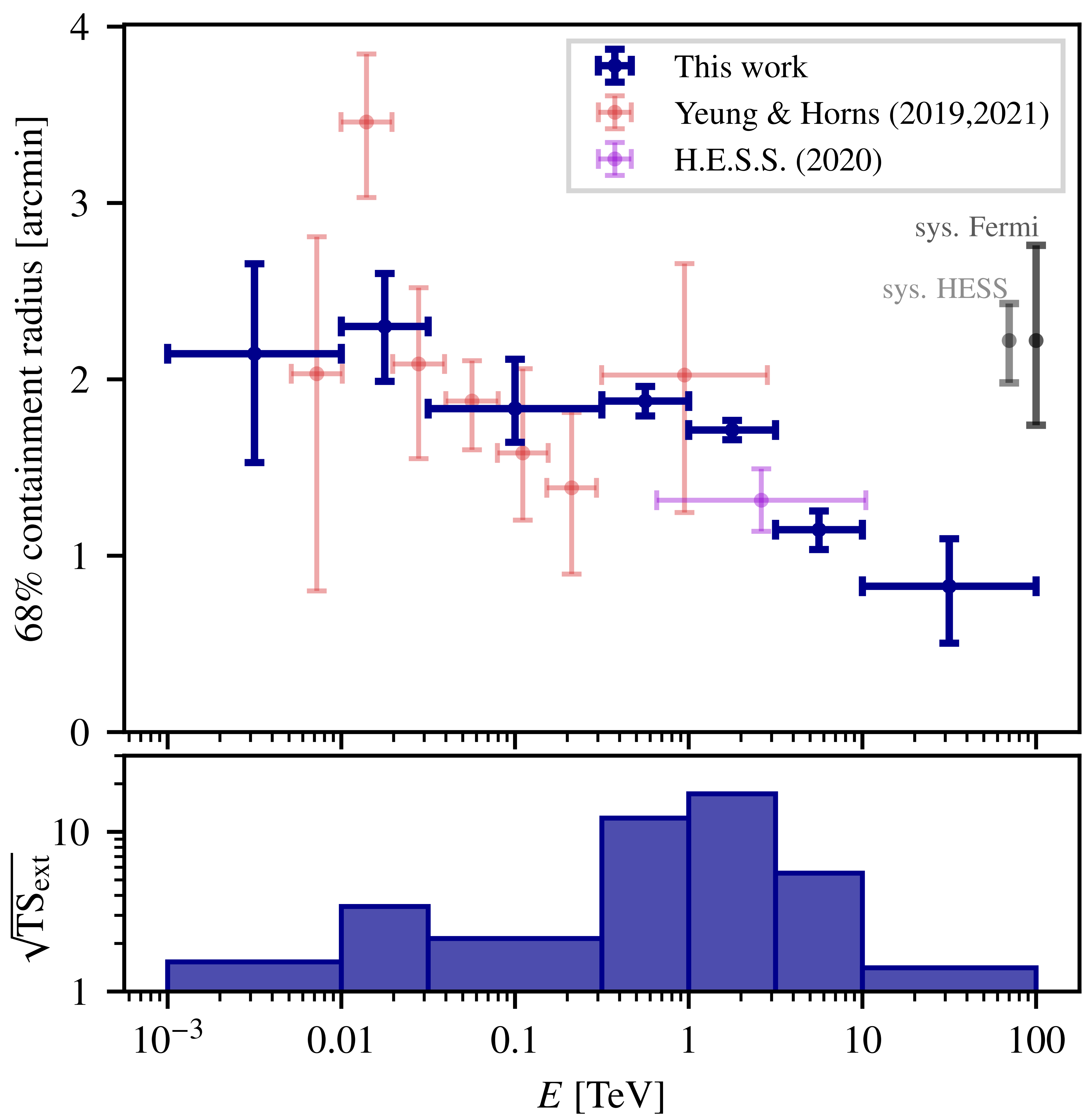

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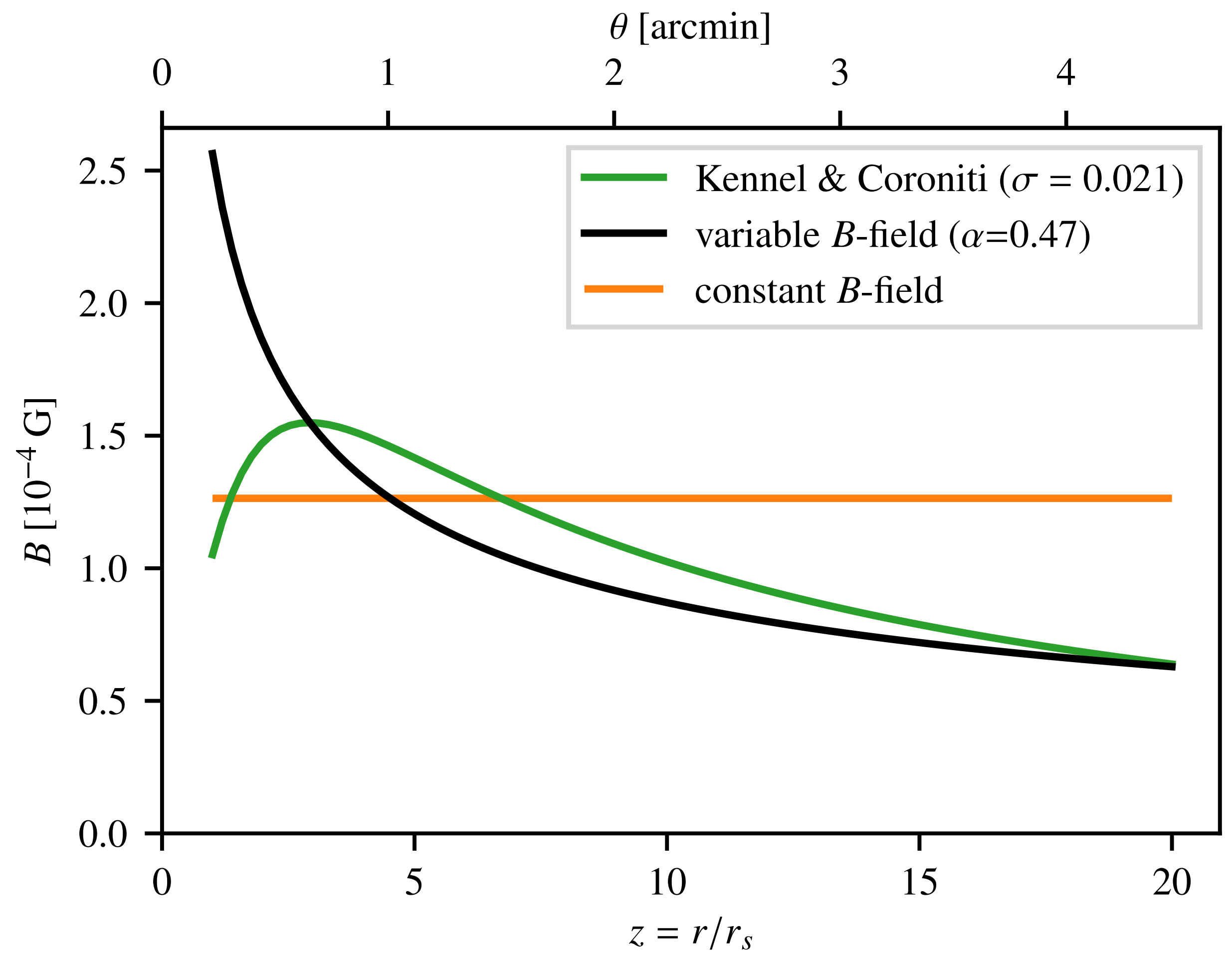

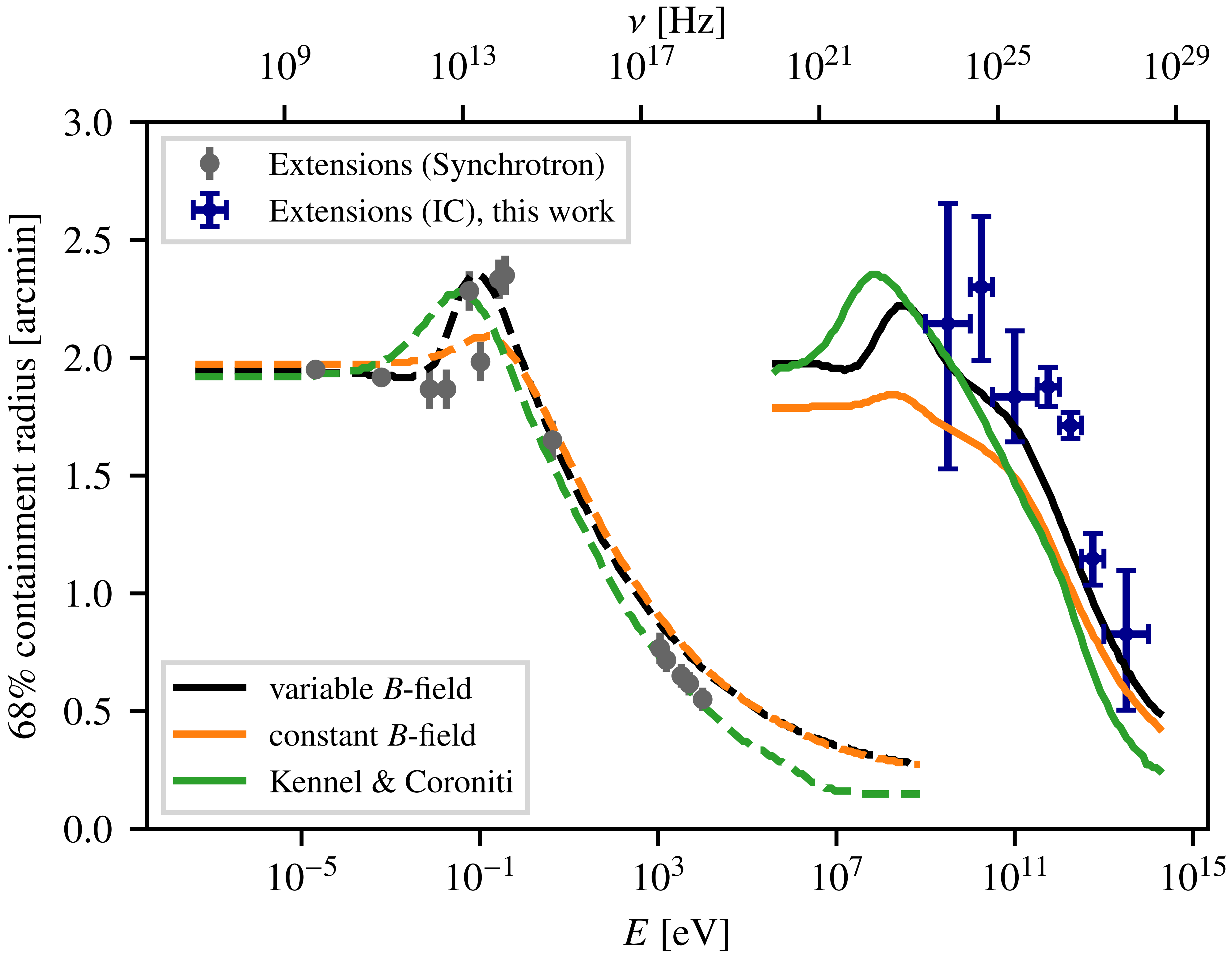

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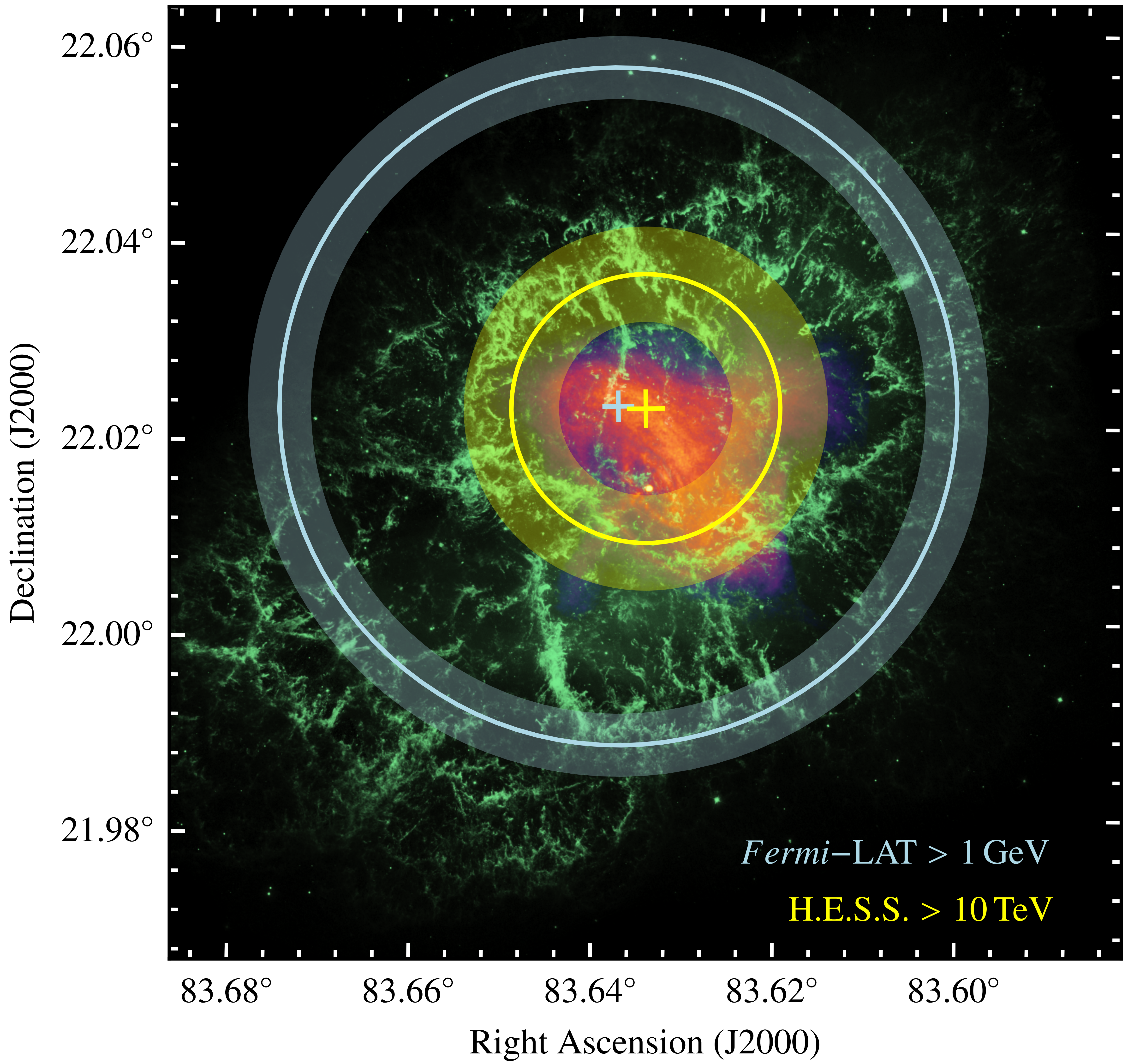

Summary

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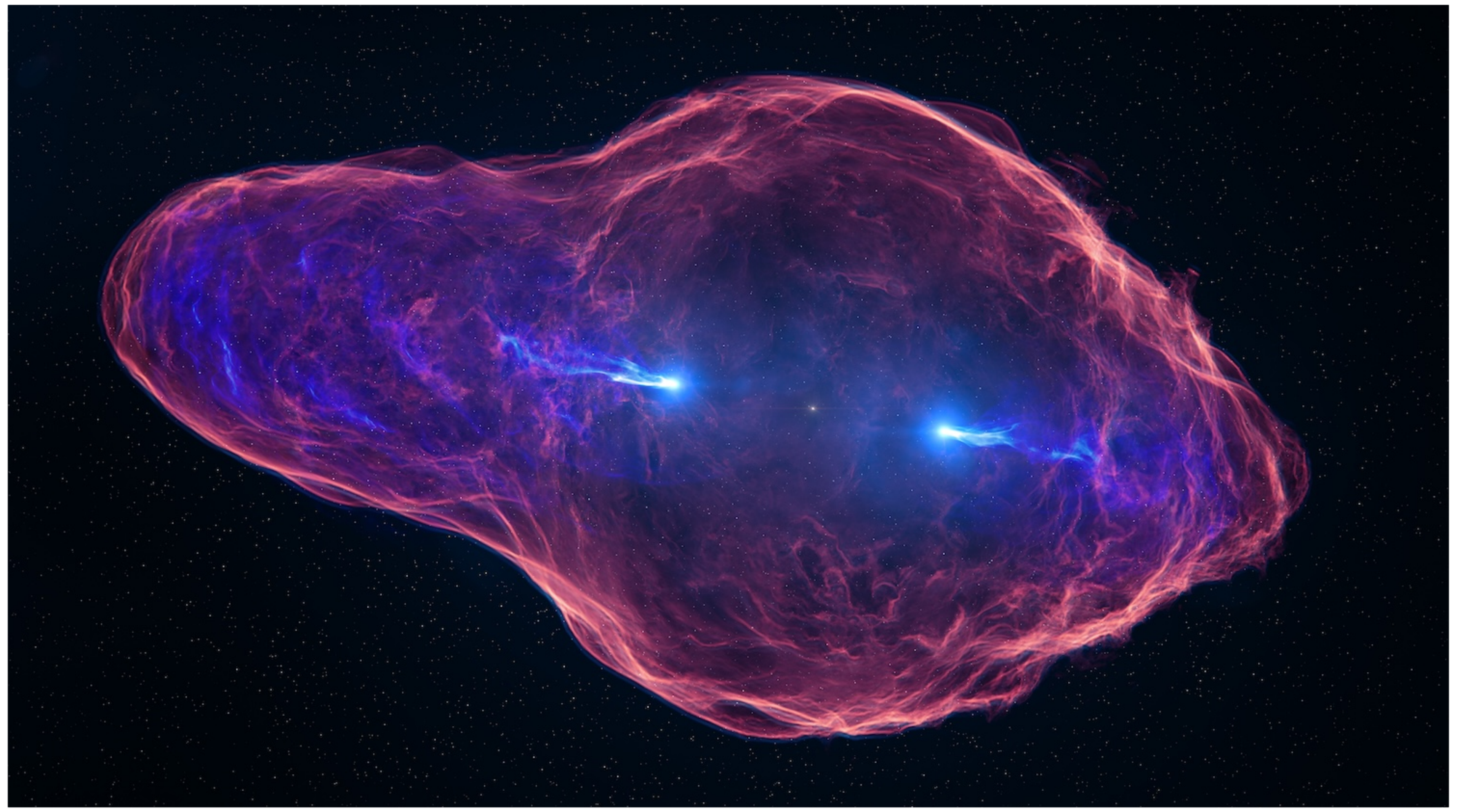

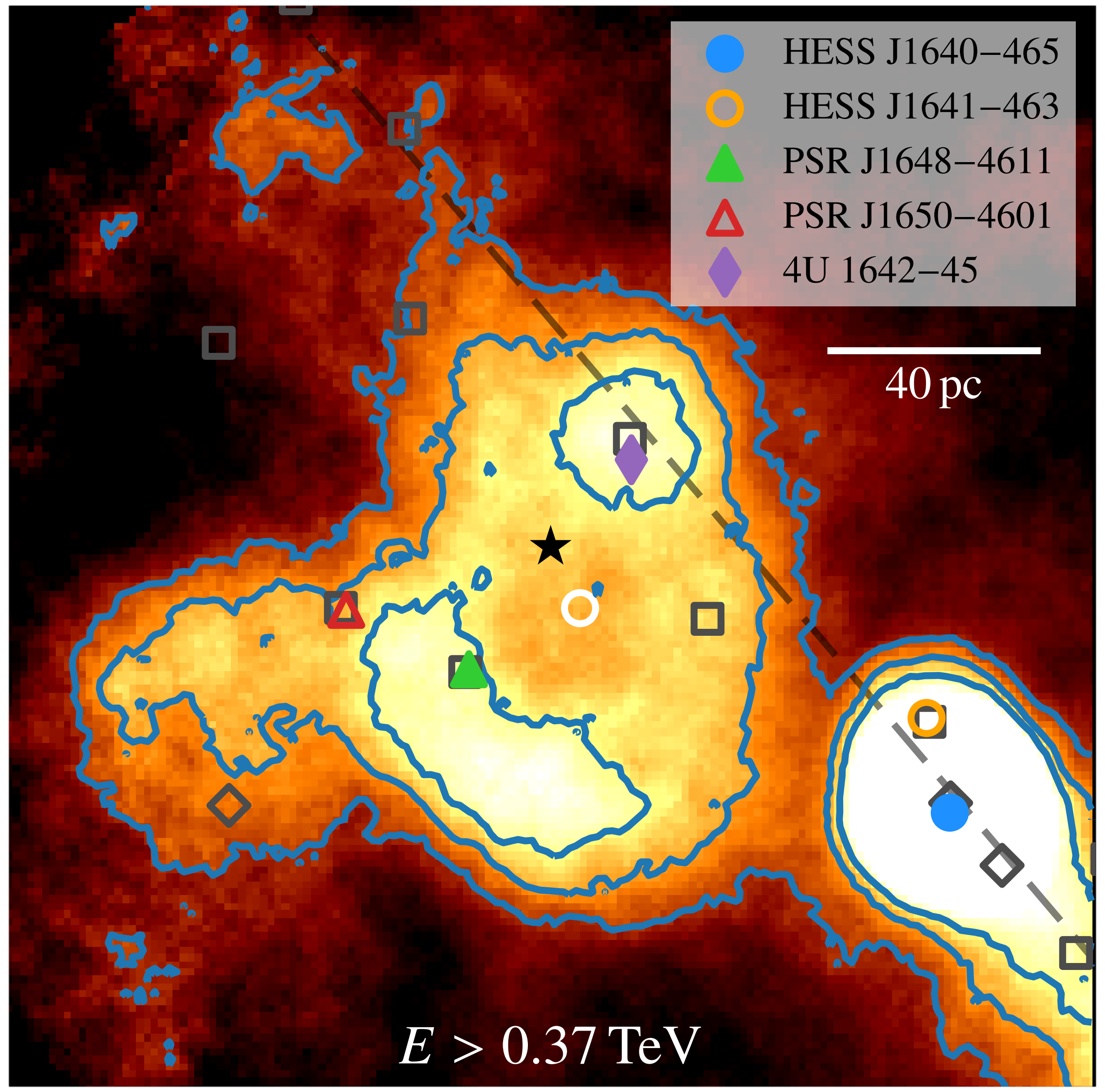

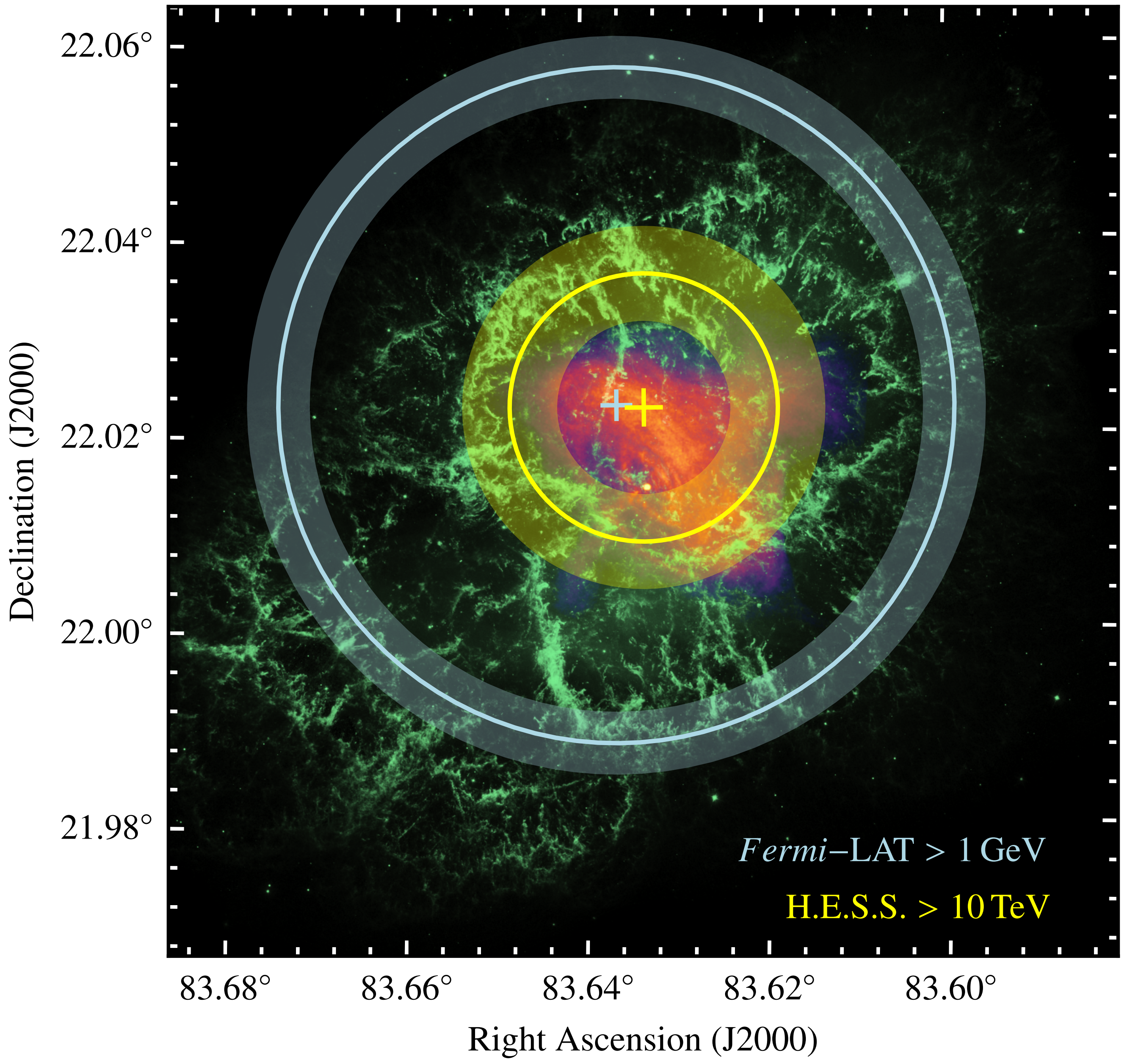

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