

Exploring the potential hadronic gamma-ray emission from a protostellar jet

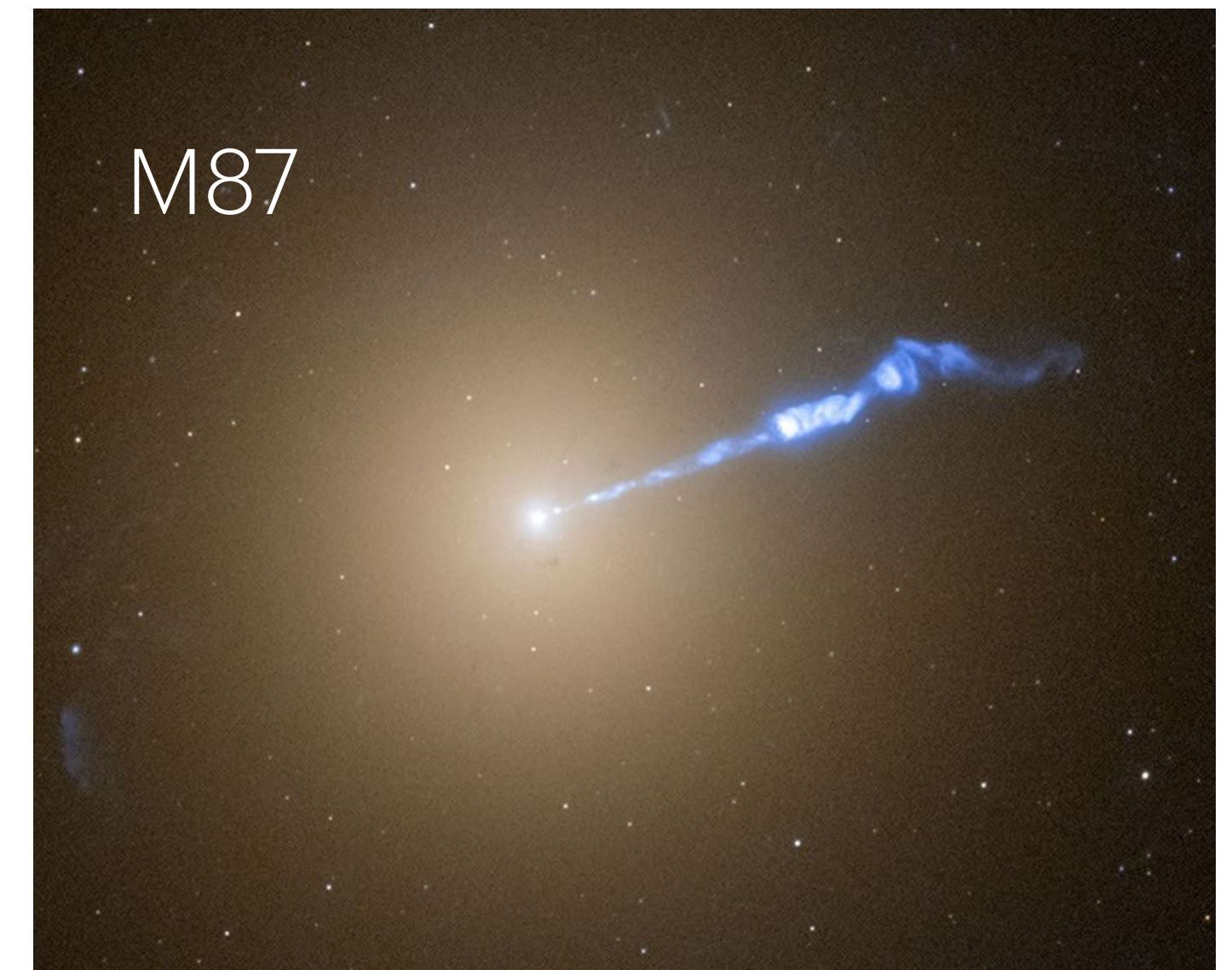
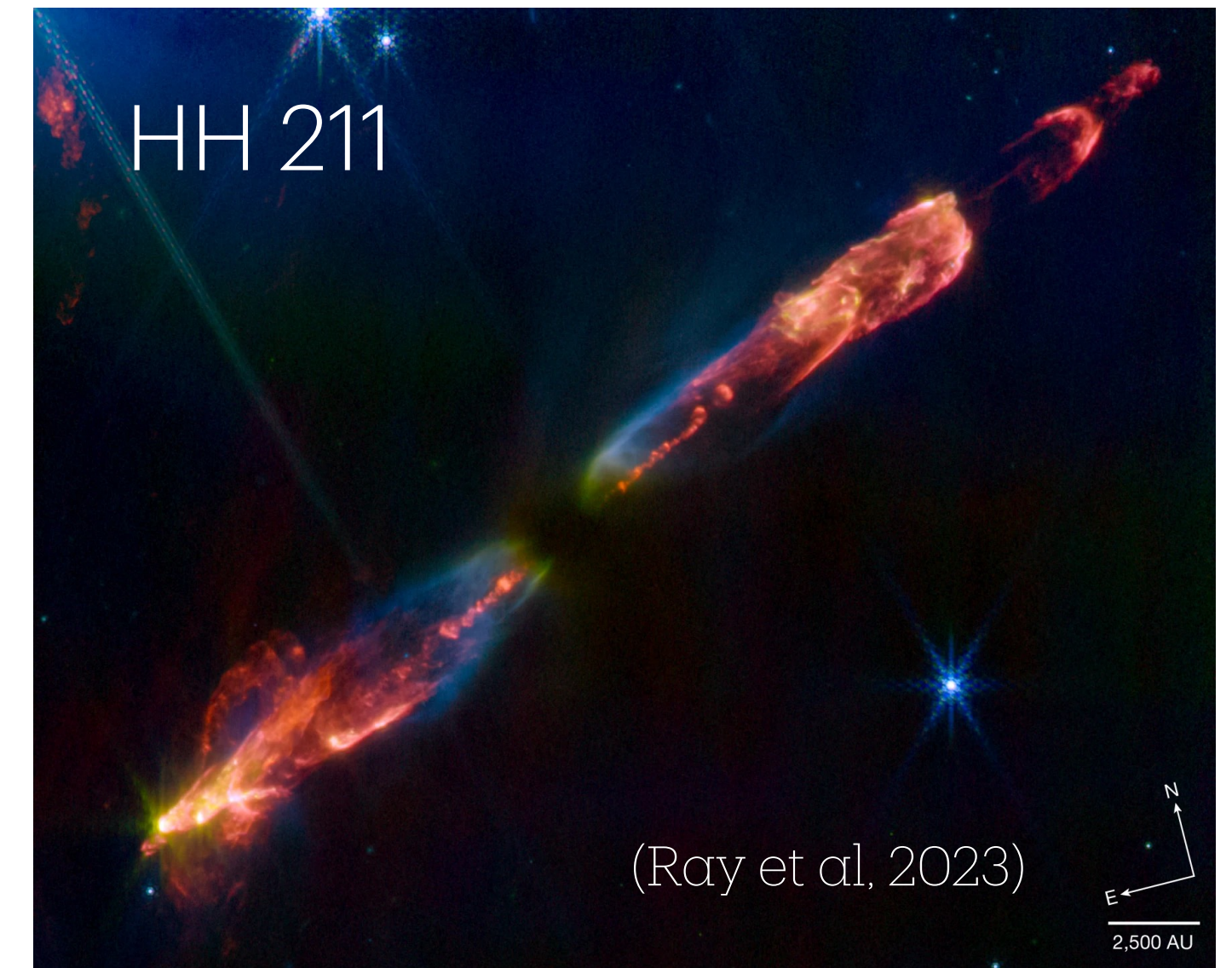


Méndez-Gallego, J et al. (2025) A&A, 695, A11

Méndez-Gallego, J.; López-Coto, R.; de Oña Wilhelmi, E.; Fedriani, R.; Otero-Santos, J.; and Cantürk, Y.

✦ Introduction

- Propulsion mechanism based in magneto-centrifugal forces (Blandford & Payne, 1982; Pudritz & Norman 1983).
- Non-relativistic jets ($\sim 100\text{-}1000\text{ km/s}$!!!).
- Dense environments ($\geq 100\text{ cm}^{-3}$).
- Bright at sub-mm and IR wavelengths.
- Thermal radiation is the dominant emission mechanism...

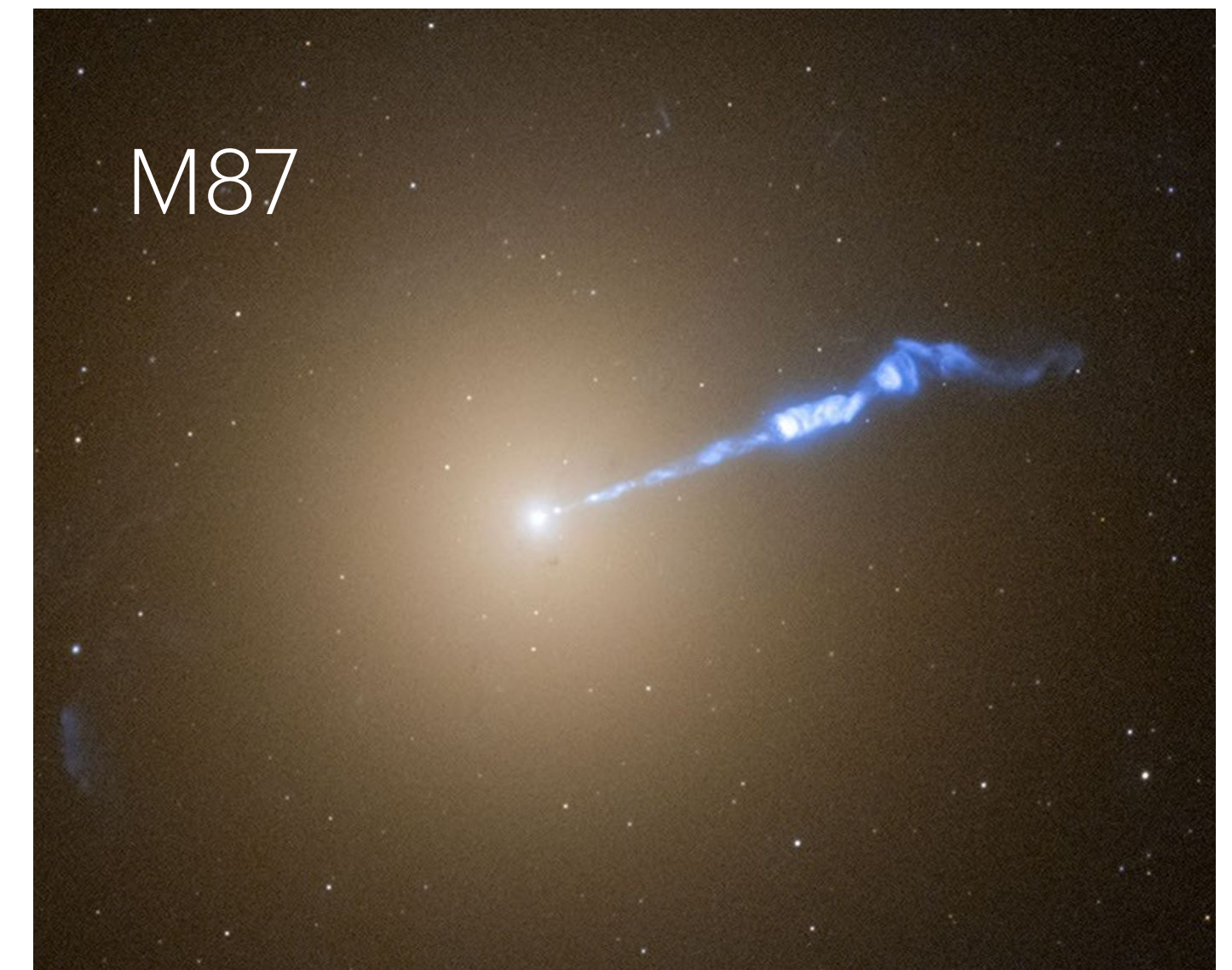
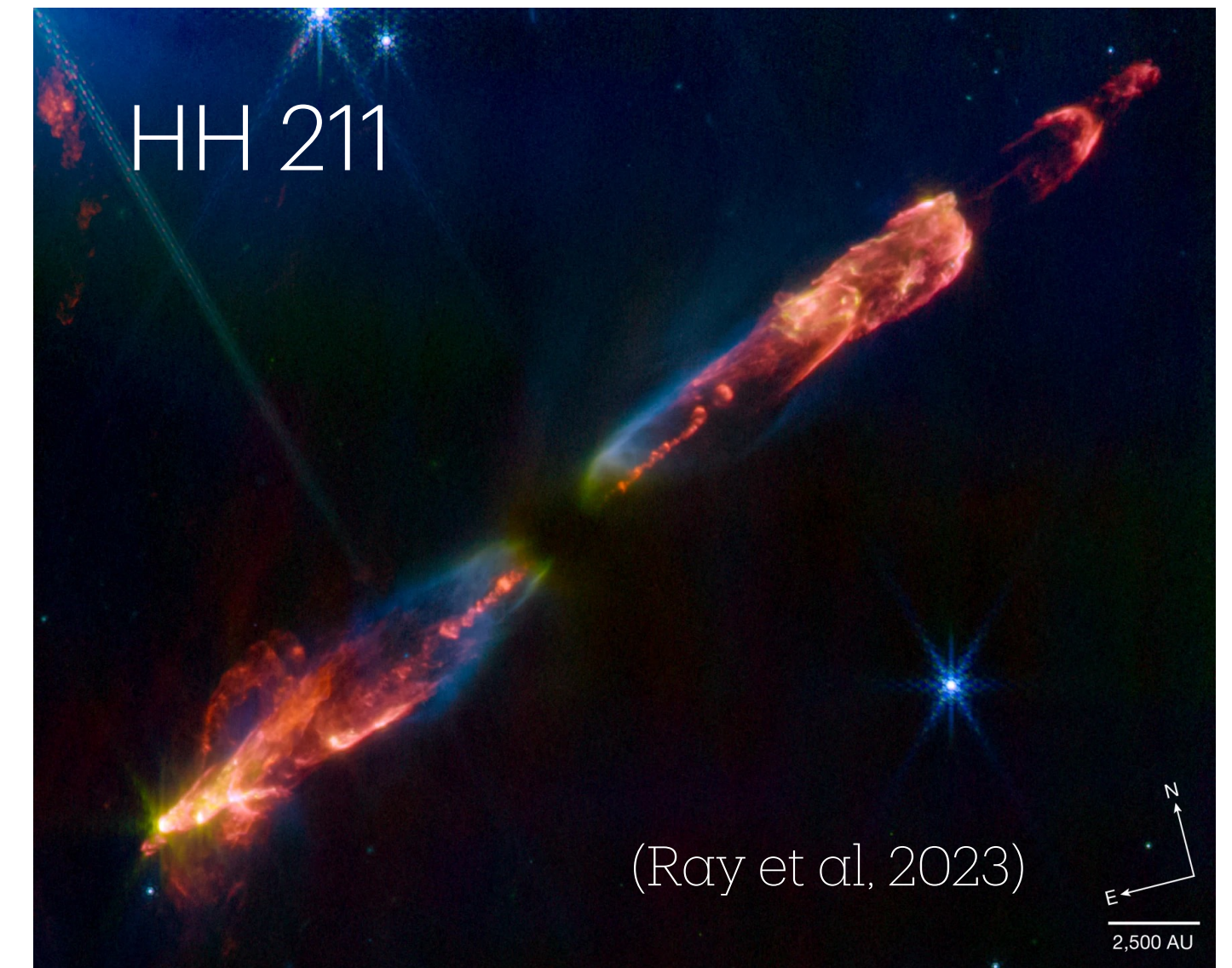


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- Dense environments ($\geq 100\text{ cm}^{-2}$).
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- Thermal radiation is the dominant emission mechanism...

...but 50% of radio jets show partial signatures of non-thermal emission!!!

(e.g., blind observations carried out by Obonyo et al., 2024)



Introduction

- Negative radio spectral index compatible with synchrotron emission. (e.g., Obonyo et al., 2019)
- Electrons detected reach at least GeV energies.
- **Gamma rays can observe protons/electrons even at higher energies.**

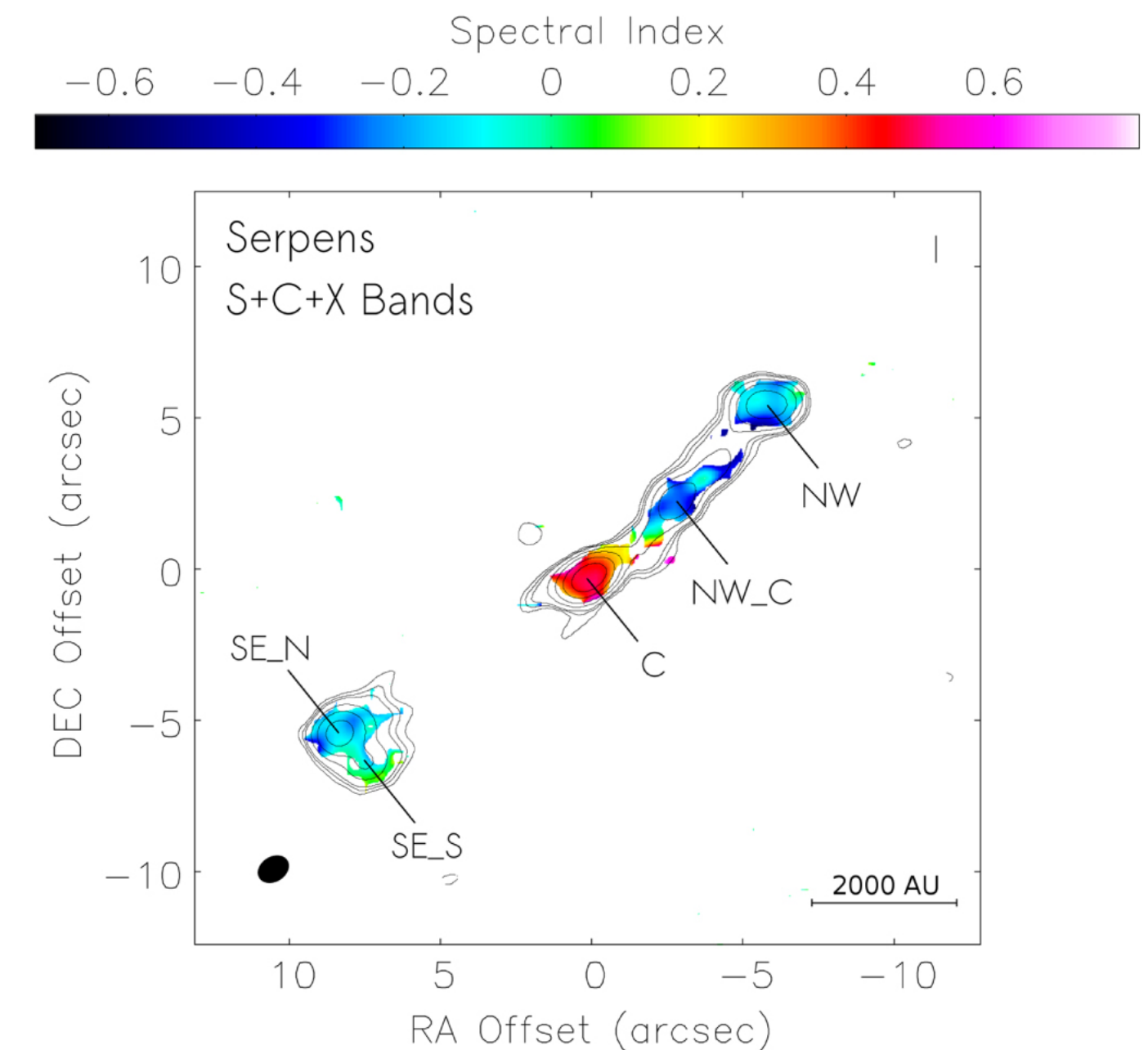
2022MNRAS.510.2277A 2022/02 cited: 3
Probing the origin of 4FGL J0822.8-4207: cosmic ray illumination from the SNR Puppis A and the Herbig-Haro object HH219
 Araya, M.; Gutiérrez, L.; Kerby, S.

2022RAA....22b5016Y 2022/02 cited: 7
Detection of Gamma-Rays from the Protostellar Jet in the HH 80-81 System
 Yan, Da-Hai; Zhou, Jia-Neng; Zhang, Peng-Fei

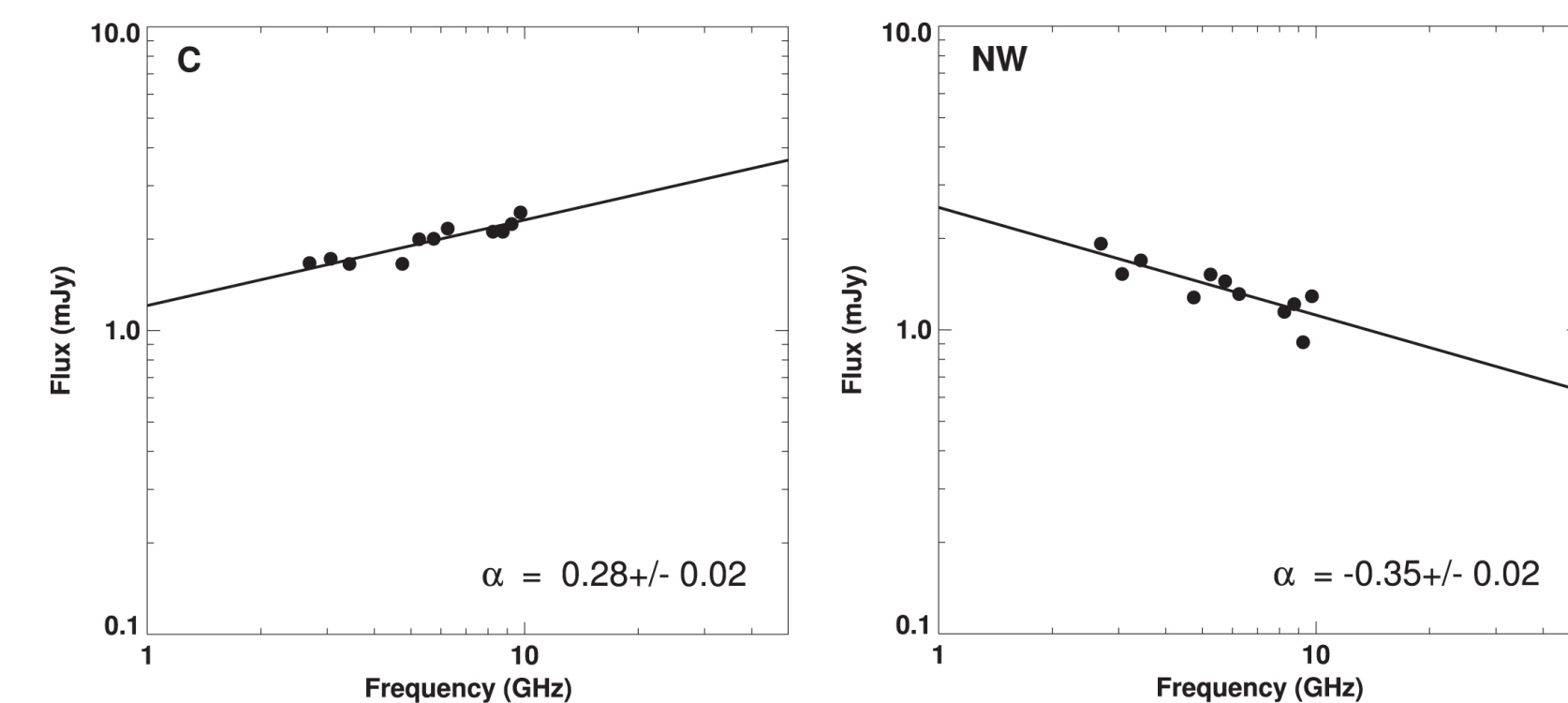
2023MNRAS.523..105D 2023/07 cited: 5
High-energy gamma-ray emission powered by a young protostar: the case of S255 NIRS 3
 de Oña Wilhelmi, Emma; López-Coto, Rubén; Su, Yang

2024MNRAS.532.4446O 2024/08 cited: 4
A comprehensive analysis towards the Fermi-LAT source 4FGL J1846.9-0227: jets of a protoplanetary nebula producing γ -rays?
 Ortega, M. E.; Petriella, A.; Paron, S.

Serpens tripe radio continuum source



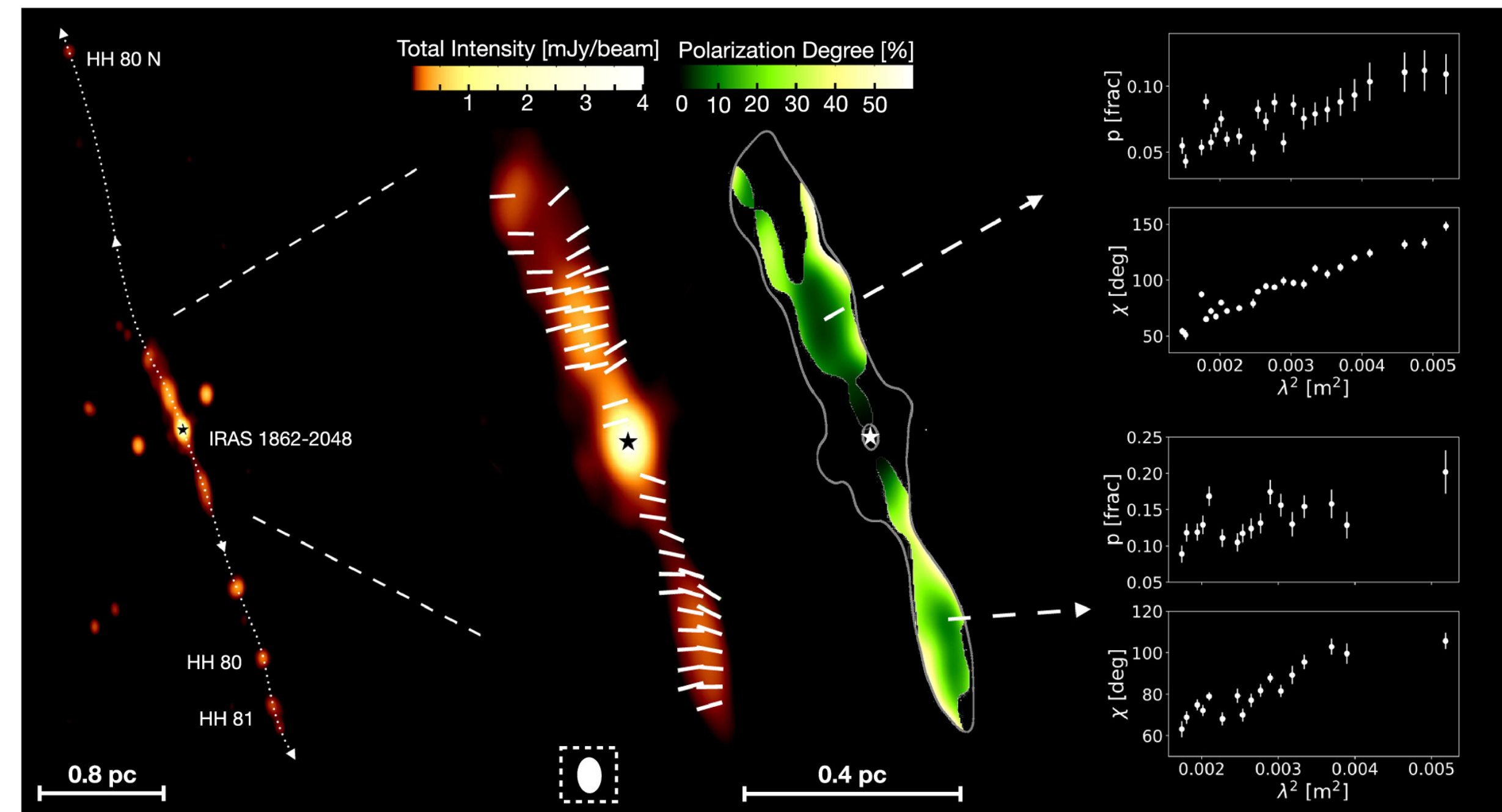
(Rodríguez-Kamenetzky et al, 2016)



✦ The case of HH 80-81

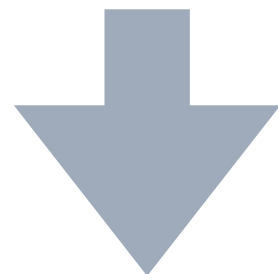
- Driven by IRAS 18162-2048 ($\sim 20 M_{\odot}$).
- One of the largest (~ 5 pc) and most collimated jets known so far.
- High speed knots (>1000 km/s) with 10^{37} erg/s of jet mechanical power.
- Polarized non-thermal synchrotron emission in radio wavelengths.
(Carrasco-González et al., 2010)
- Non-thermal emission from the main knots in hard X-rays.
- Gamma-ray detection by Yan et al. (2022).

(Rodríguez-Kamenetzky et al. 2025)



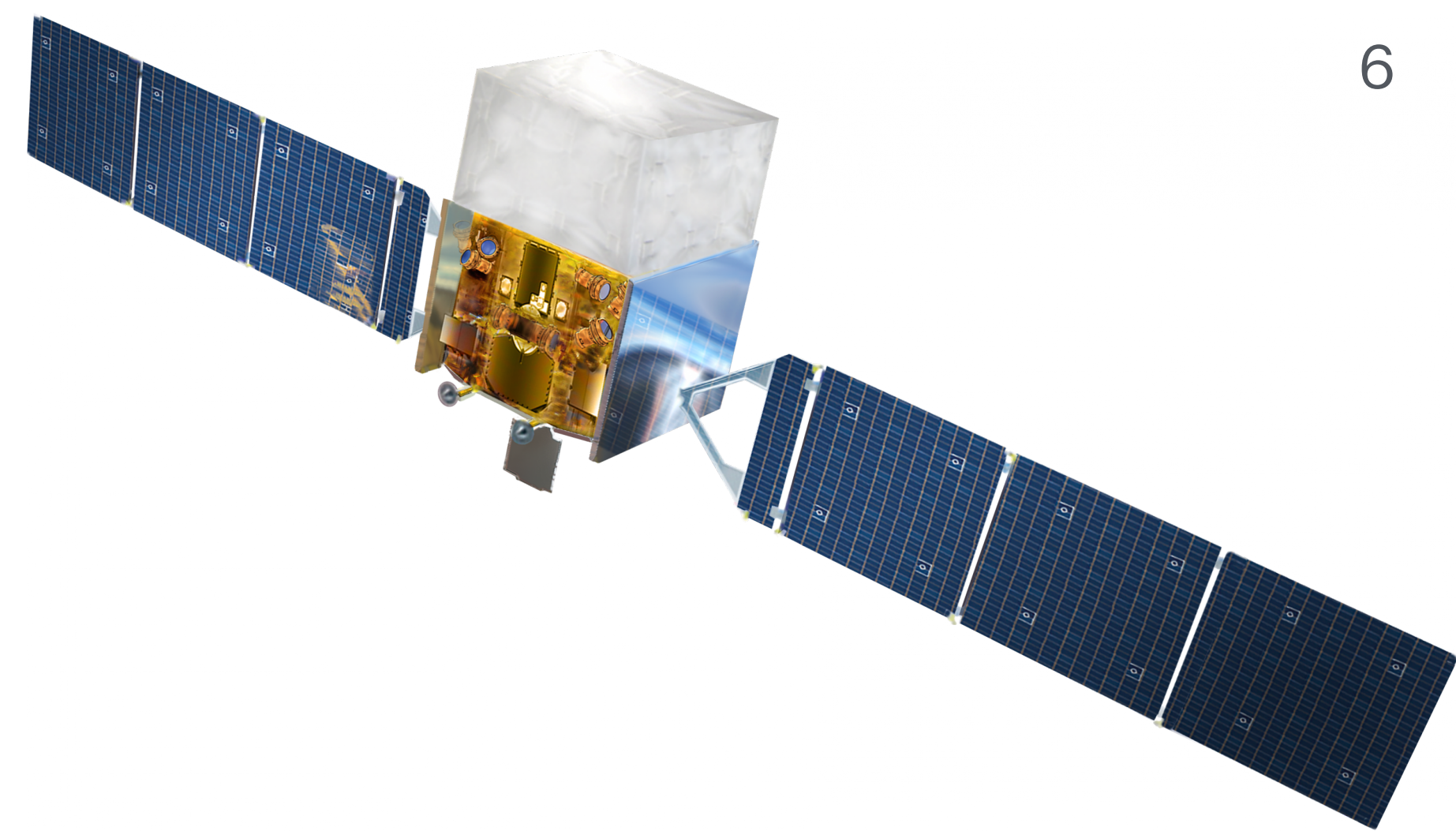
✦ Fermi-LAT

- Gamma-ray spacecraft telescope: from 30 MeV to 300 GeV.
- Launched in 2008 (we used 15 yr of exposure time).
- Limited angular resolution (68% containment angle of $\sim 4^\circ$ at 100 MeV).
- High contamination from the Galactic diffuse emission.

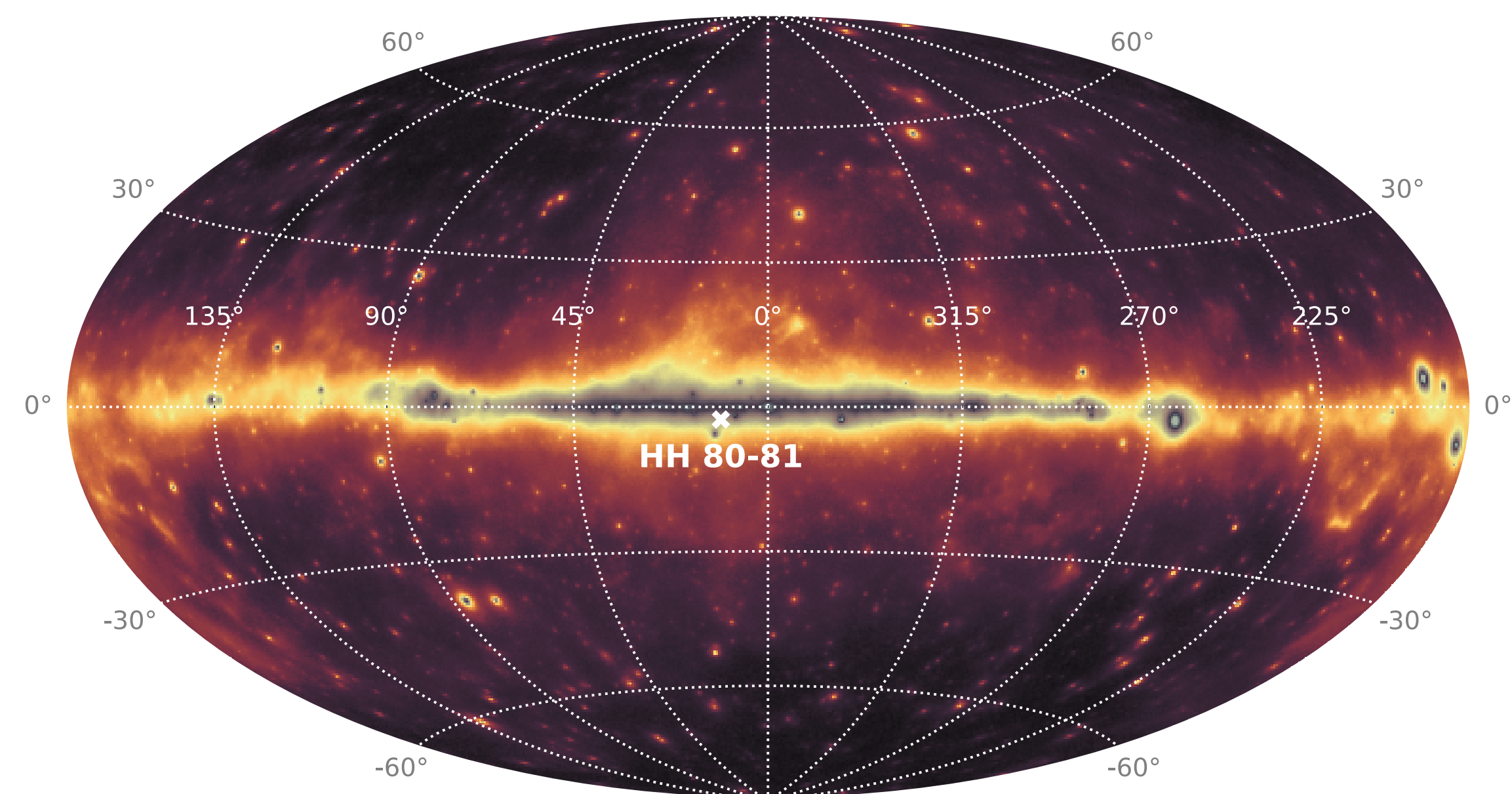


300 MeV of lower limit.

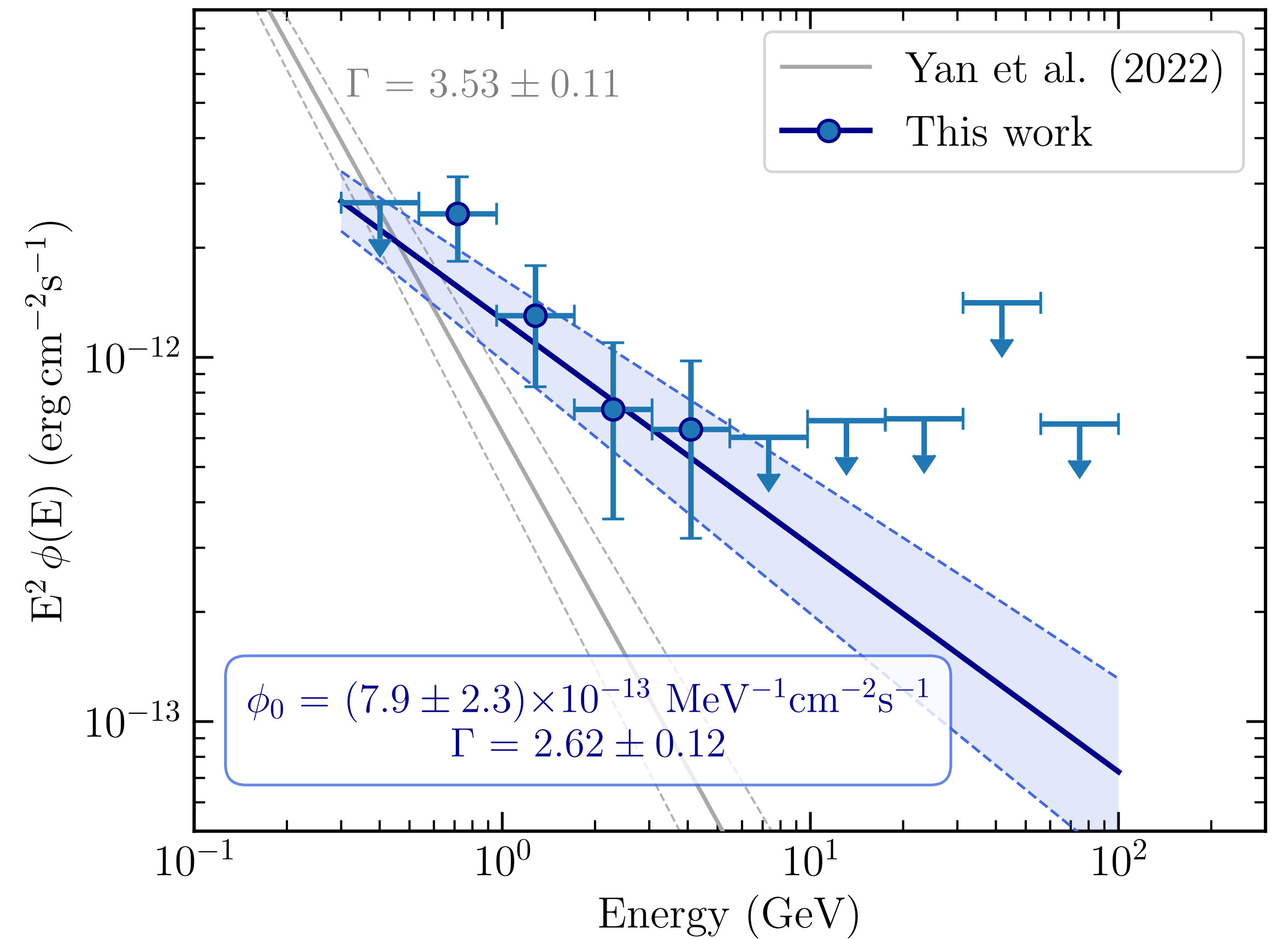
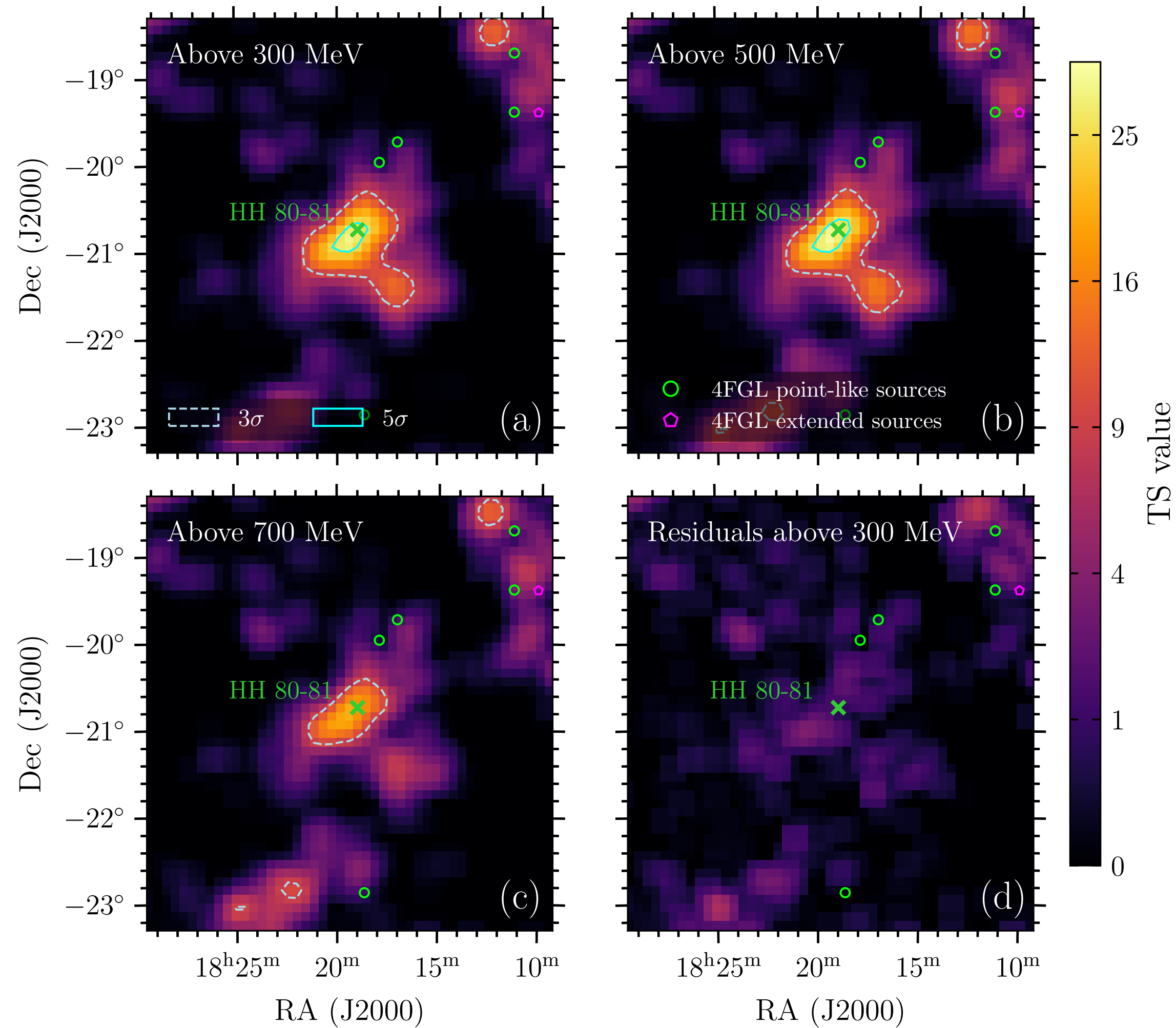
Detection of 5.4σ !!



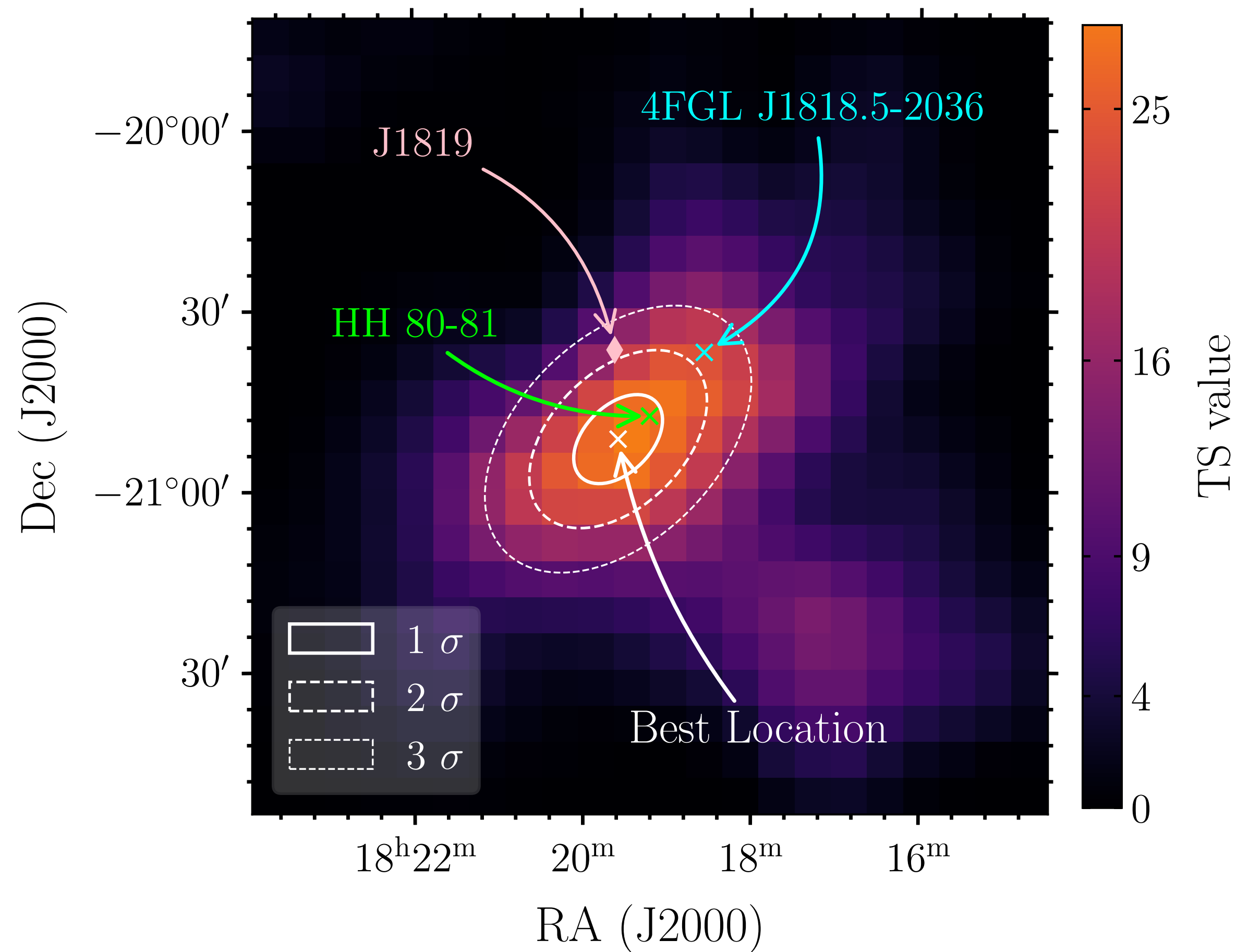
4FGL DR4 Catalog



Gamma-ray source characterization



Gamma-ray source identification

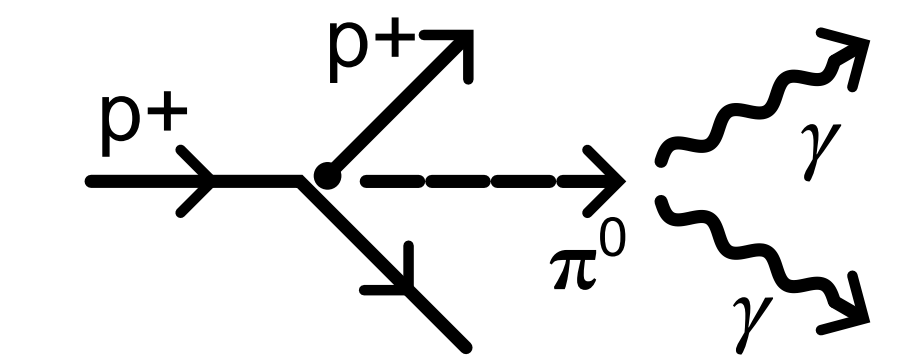


Two candidates inside the 99% confidence area:

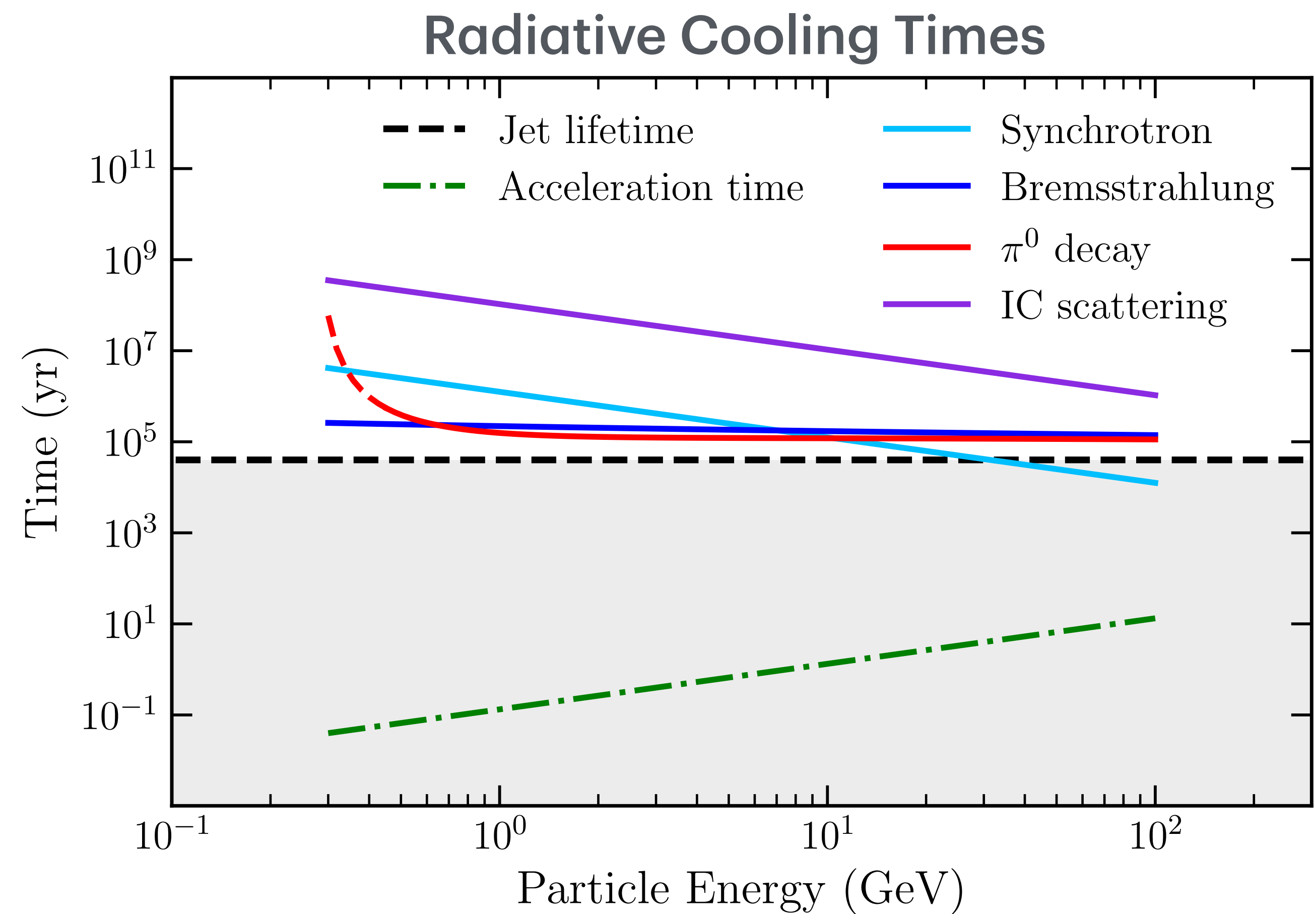
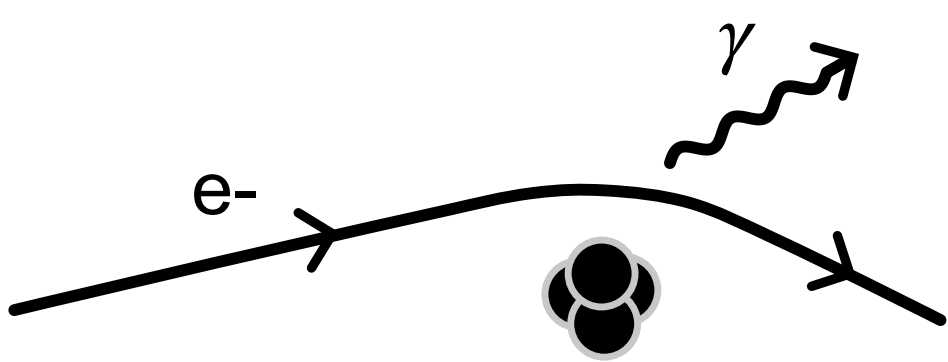
- J1819: Extragalactic compact source.
 - Non detected in X-rays and VHE.
- HH 80-81: Identified as the most probable gamma-ray emitter.

Gamma-ray production

- **Protons:** Pion decay.



- **Electrons:** Bremsstrahlung emission.



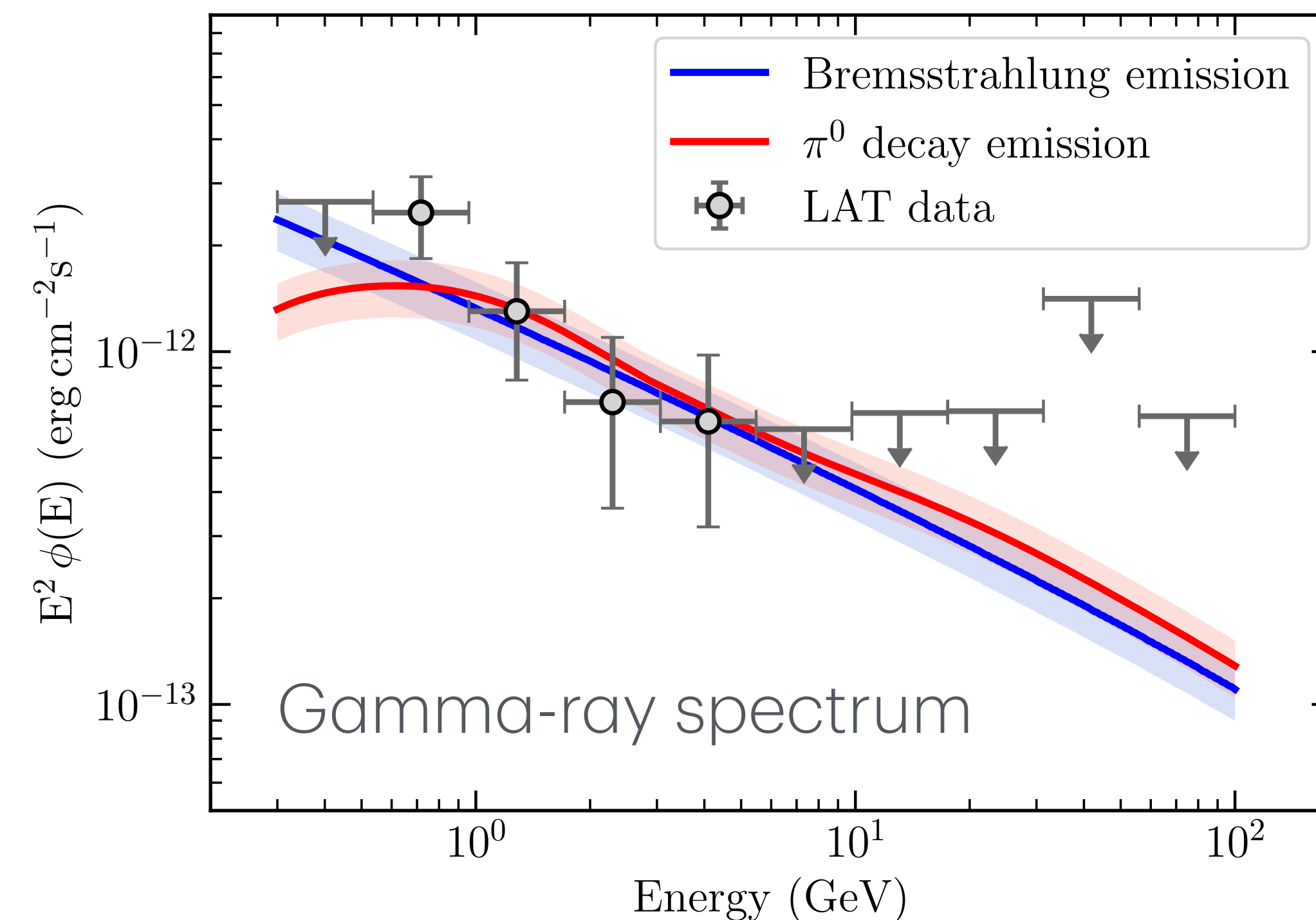
✦ Gamma-ray production

- From photo-spectrum to particle spectrum. (NAIMA)

Particle distribution:

$$\phi(E) = \phi_0 \left(\frac{E}{1 \text{ GeV}} \right)^{-\Gamma} \exp \left(-\frac{E}{E_{\text{cutoff}}} \right)$$

**We obtain the total amount
of energy in Cosmic Rays**



✦ Gamma-ray production

- From photo-spectrum to particle spectrum. (NAIMA)

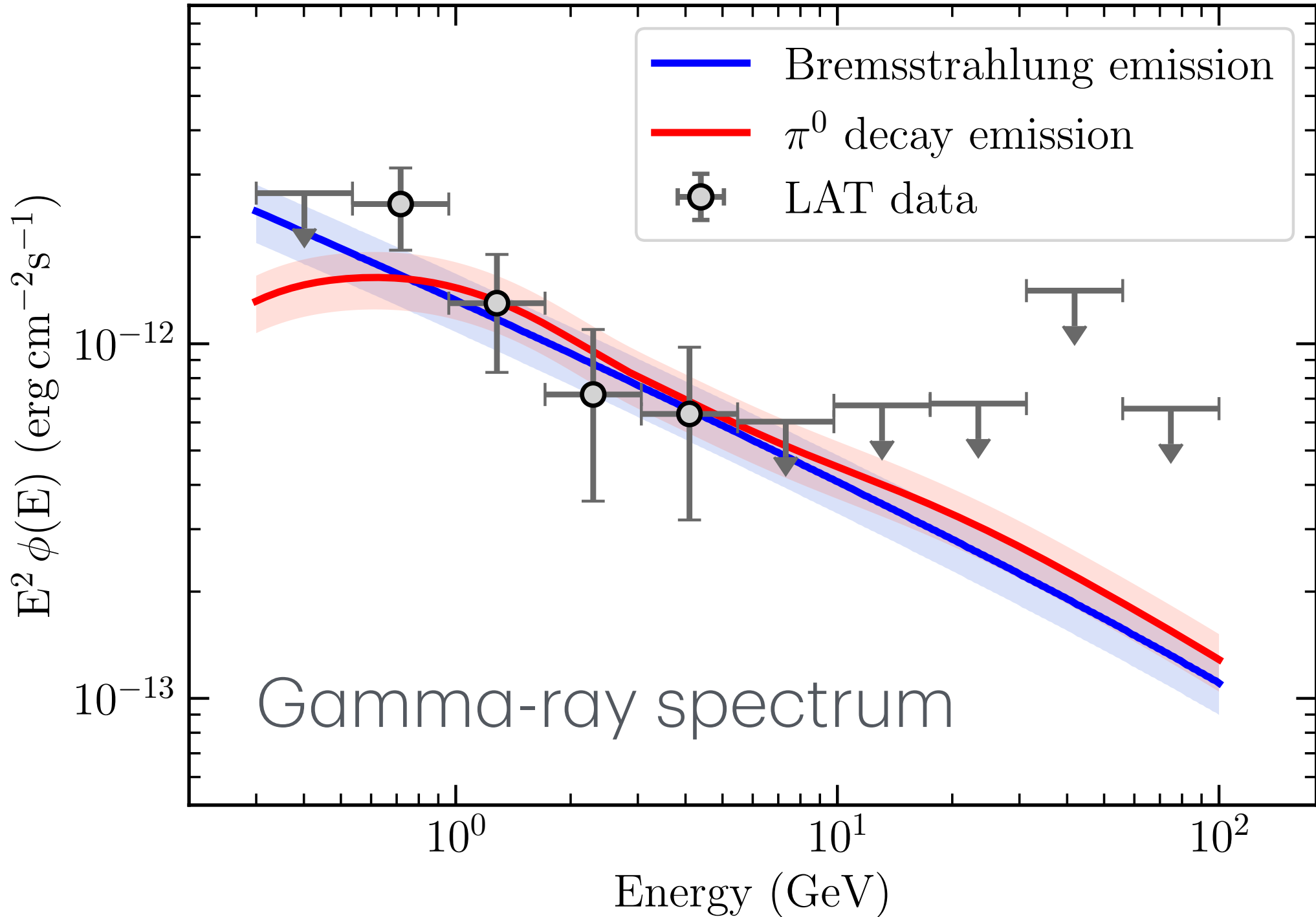
Particle distribution:

$$\phi(E) = \phi_0 \left(\frac{E}{1 \text{ GeV}} \right)^{-\Gamma} \exp \left(-\frac{E}{E_{cutoff}} \right)$$

←

$$t_{\text{injection}} = \frac{E_{\text{particles}}}{0.05 \times L_{\text{jet}}} \quad (\text{efficiency } \sim 5\%)$$

Model	Energy (erg) $\left(\times \frac{n}{100 \text{ cm}^{-3}}\right)^{-1}$	Injection time (yr)
Bremsstrahlung	$(1.4 \pm 0.3) \times 10^{46}$	$(8.9 \pm 1.7) \times 10^2$
Pion decay	$(2.9 \pm 0.5) \times 10^{47}$	$(1.9 \pm 0.4) \times 10^4$



$$\tau_{\text{jet}} \simeq 4 \times 10^4 \text{ yr}$$

(Masqué et al. 2012; Qiu et al., 2019)

Final remarks

- We performed a detailed source identification concluding that the HH 80-81 protostellar system is the most probable candidate for producing the detected gamma rays. **Protostars driving jets can produce detectable gamma rays.**
- The conditions present on a protostellar jet indicate that the only possible mechanism for producing gamma rays from a leptonic population is **relativistic Bremsstrahlung**. Meanwhile, **gamma rays present a unique window for studying the presence of accelerated protons in this objects.**
- The kinetic energy contained in the particle distribution leaves the door open to a **potential proton acceleration**, while the definite nature of the accelerated particles remains unclear.

Stay tune for future papers!

Thanks for your attention!

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Exploring the capability of the HH 80-81 protostellar jet to accelerate relativistic particles

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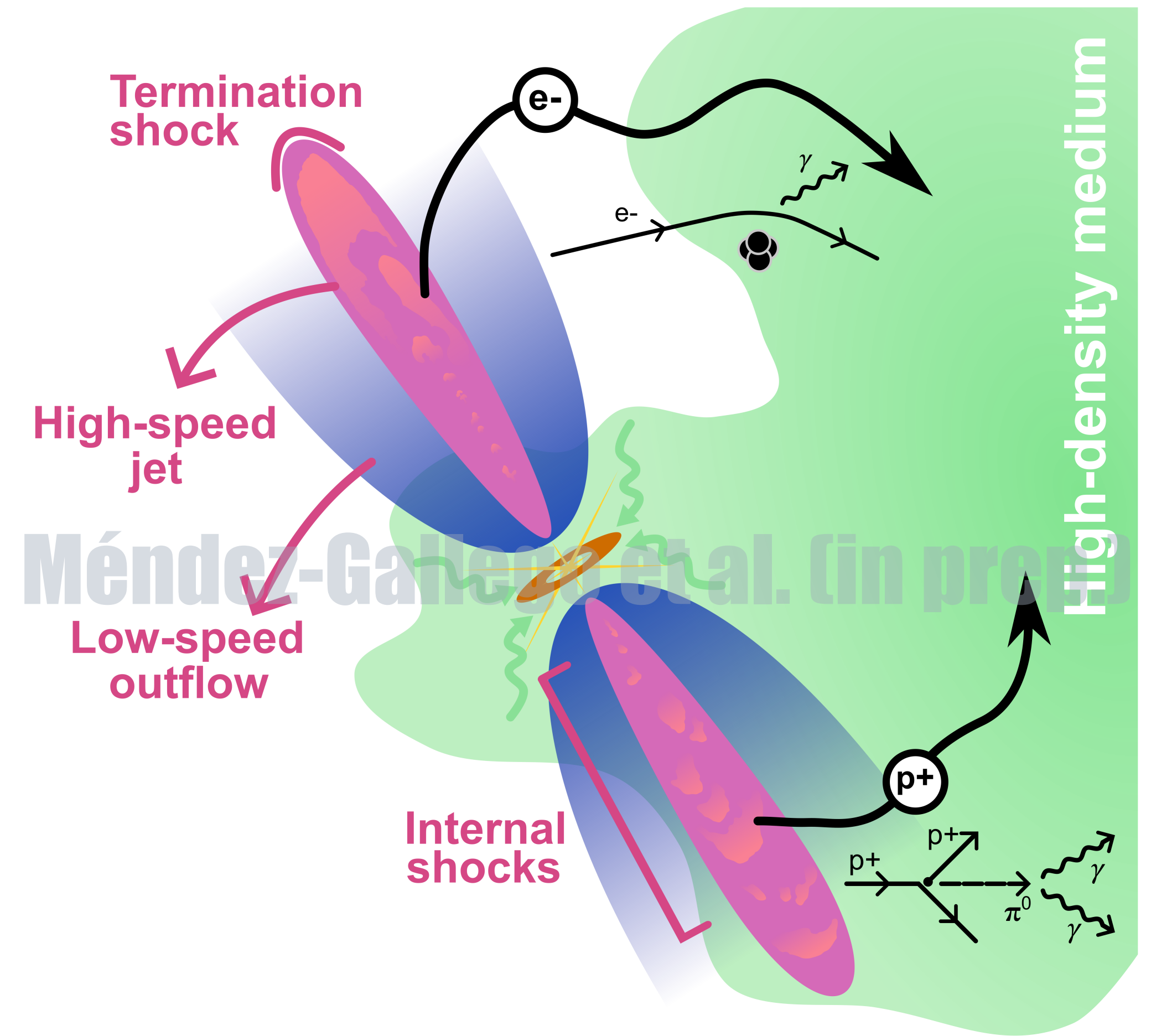
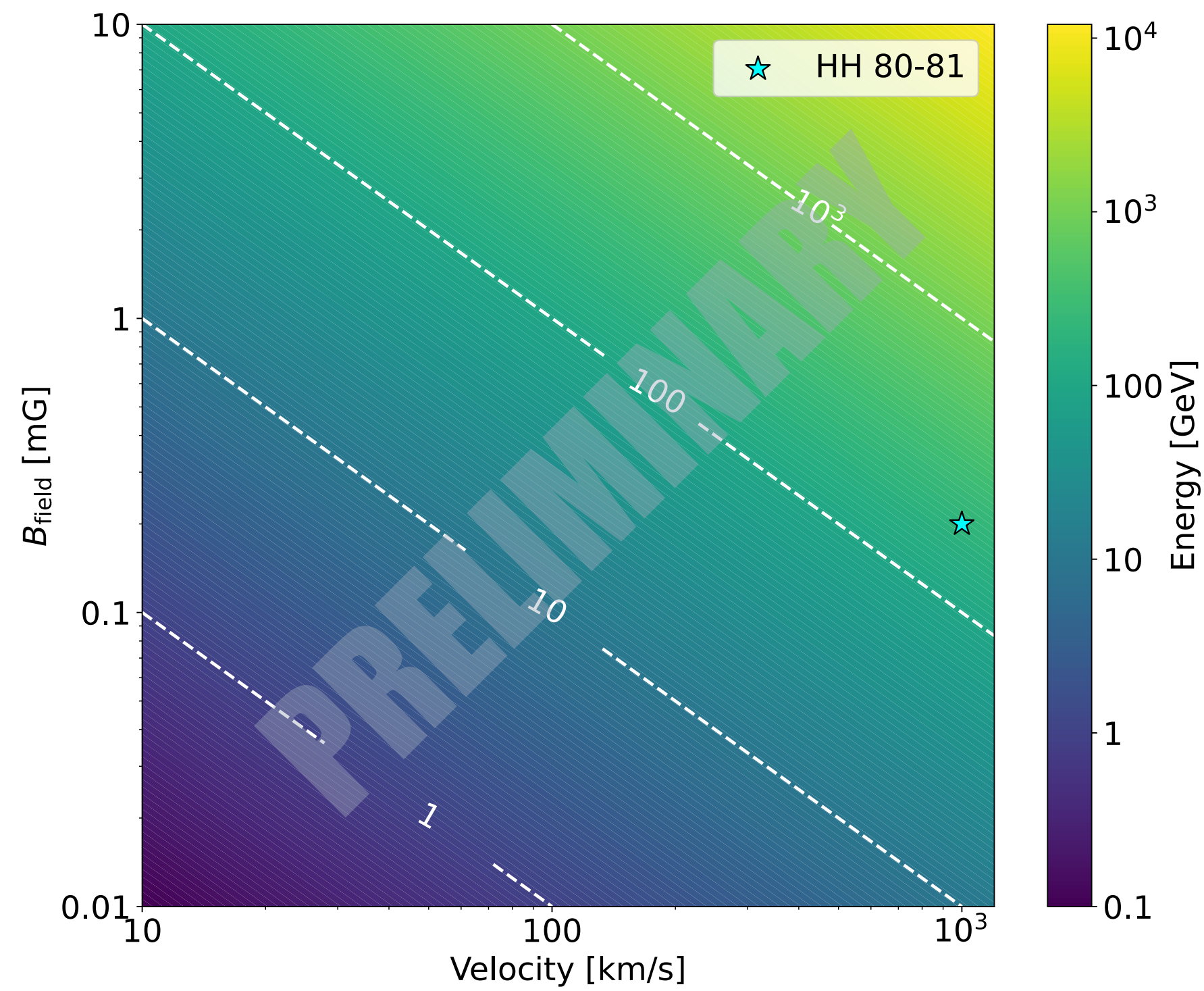
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Abstract

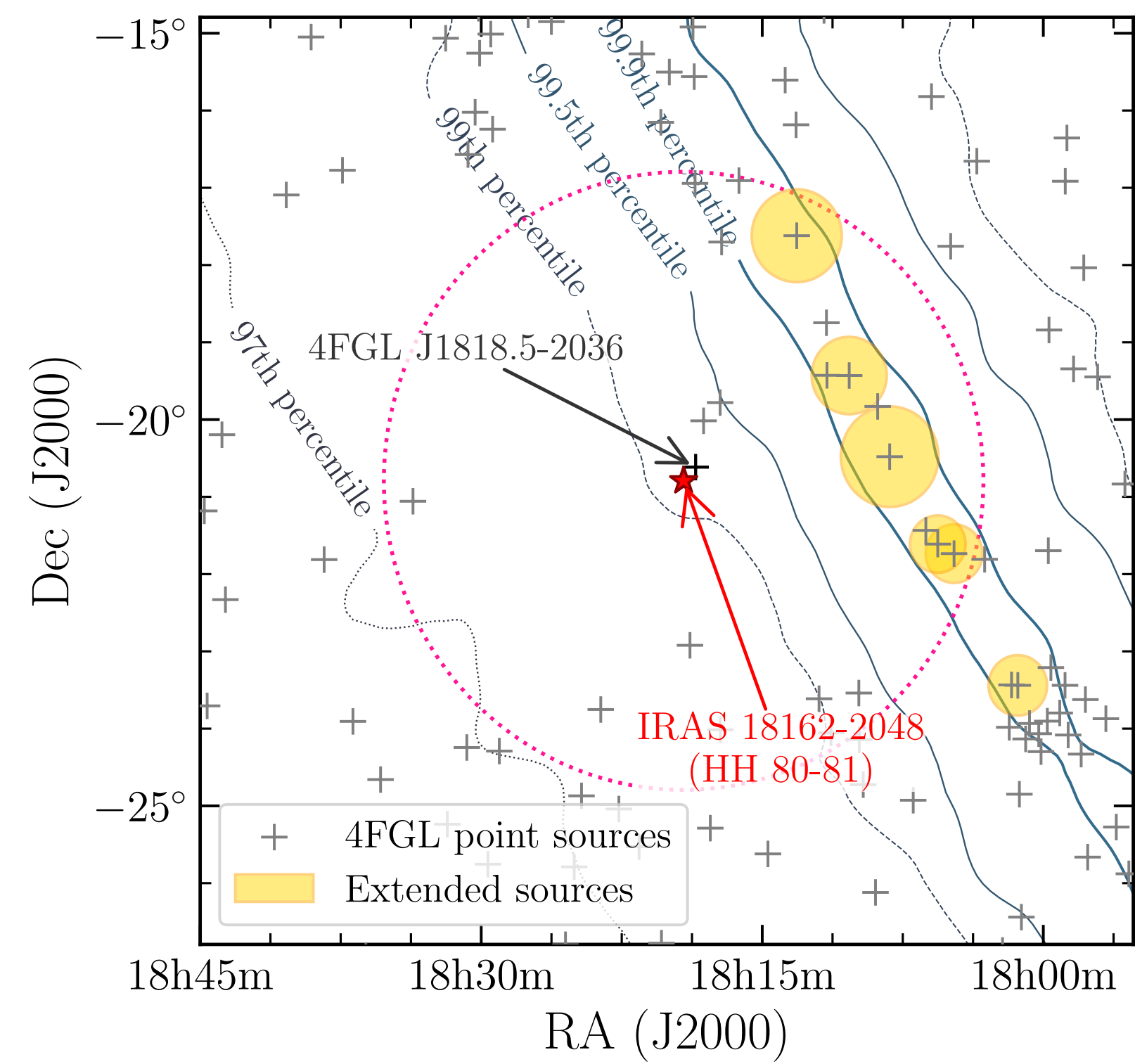
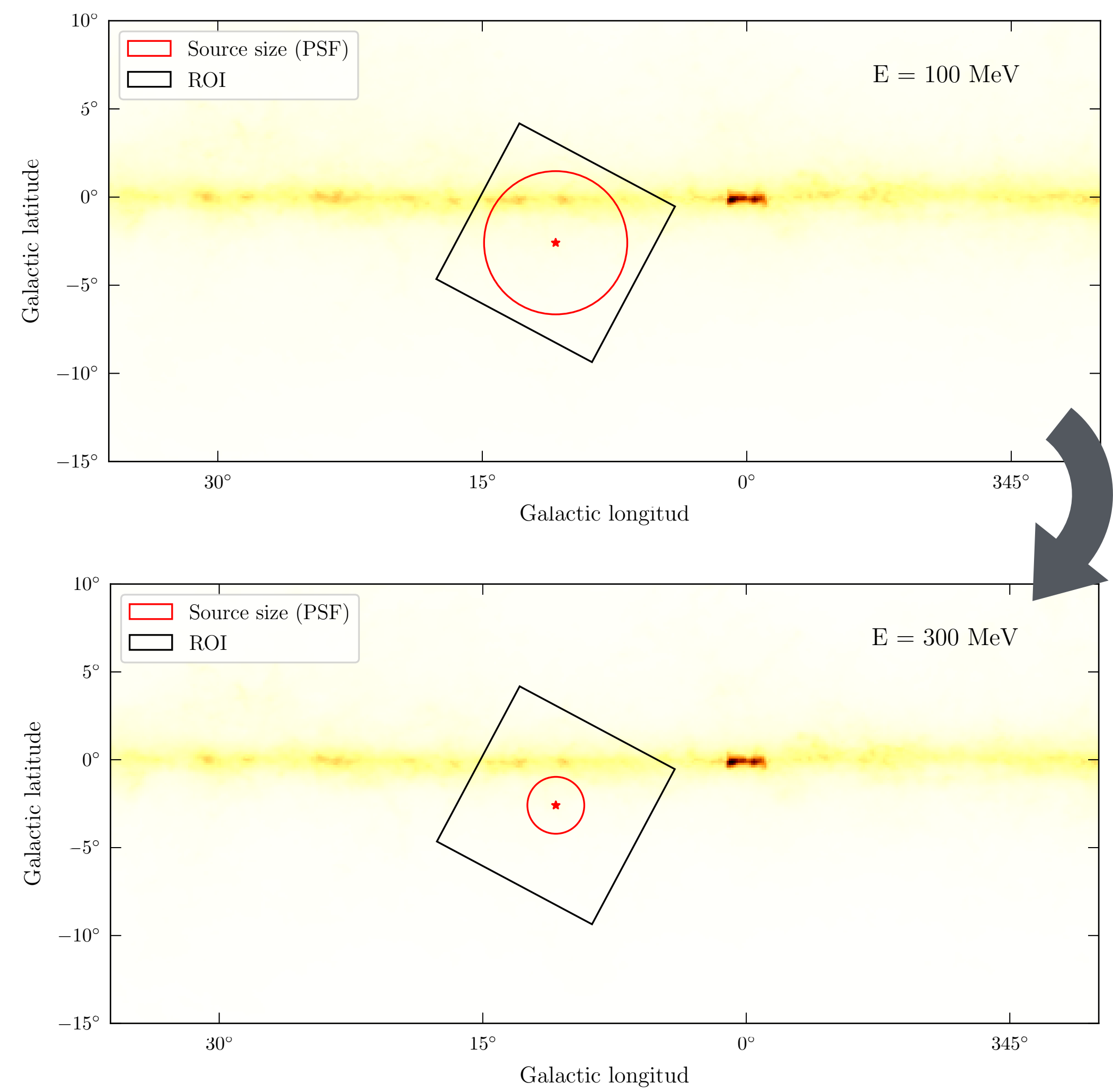
Context. Protostellar jets driven by massive protostars are collimated outflows producing high-speed shocks through dense interstellar medium. Fast shocks can accelerate particles up to relativistic energies via diffusive shock acceleration, producing non-thermal emission that can generate γ -ray photons. HH 80-81 is one of the most powerful collimated protostellar jets in our Galaxy, with non-thermal emission detected in radio, X-ray, and γ -ray bands. Characterizing the γ -ray emission that originates in the accelerated particles of the region is crucial for

Maximum energy constrained by:

- Escape of particles (Hillas).
- Age of the system.
- Radiative losses.



Galactic contamination



Gamma-ray source variability

