CR PROPAGATION IN THE GALAXY: INSIGHTS FROM TeV HALOS AND THE DIFFUSE γ-RAY BACKGROUND

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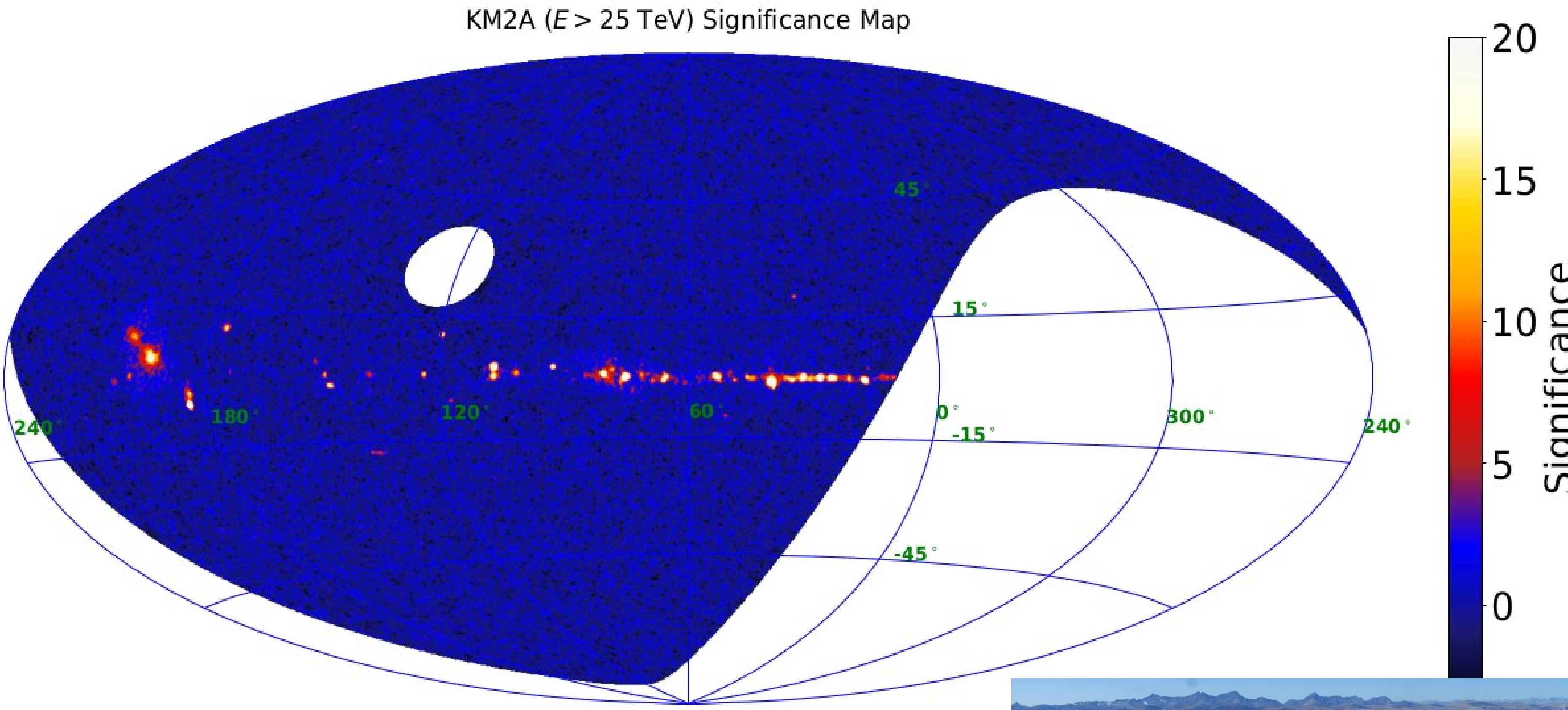
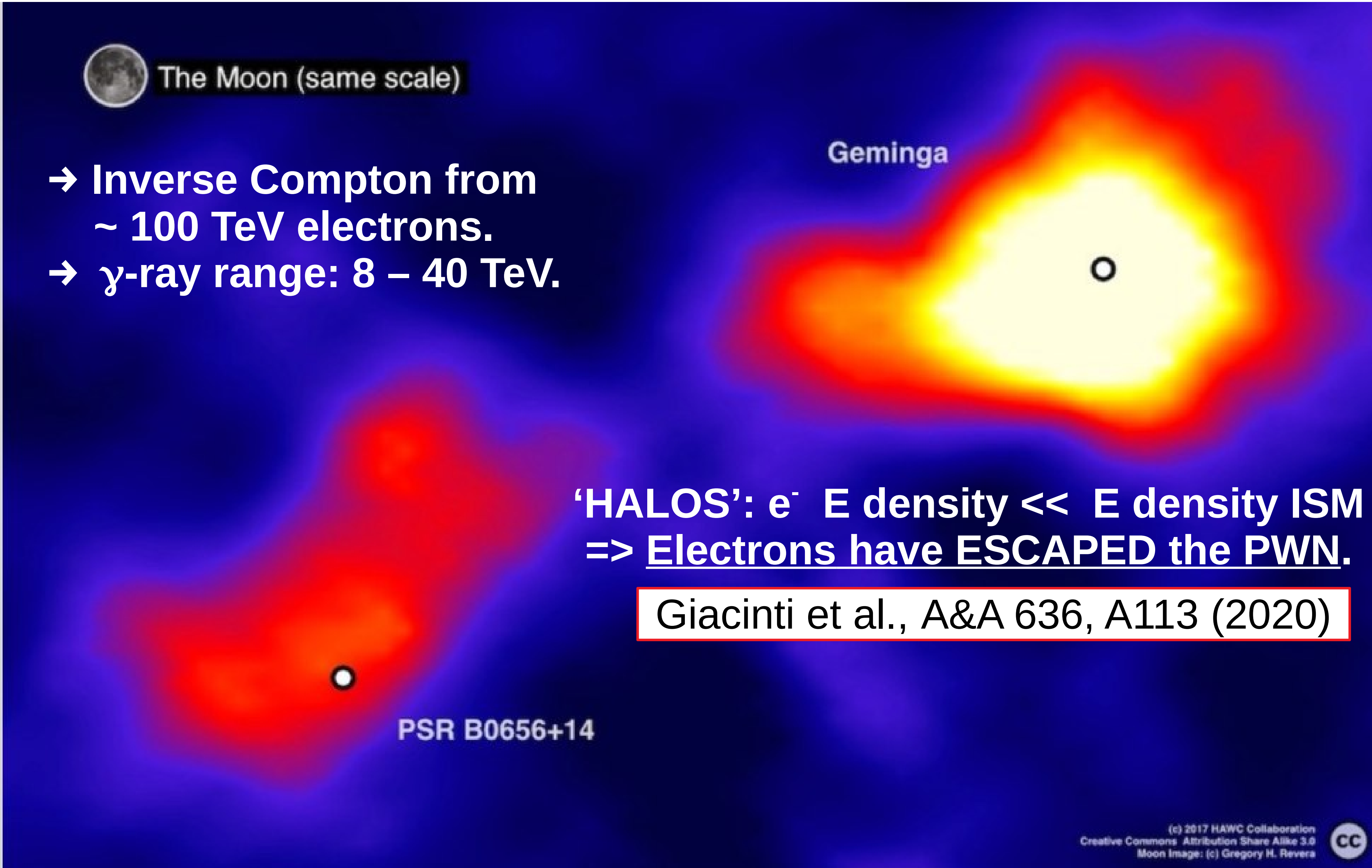
Sky at 25 TeV – 1 PeV with LHAASO



LHAASO Collaboration

1 – TeV halos as a probe of CR propagation in the ISM

HAWC observ. of Geminga & Monogem



- ➜ **Inverse Compton from ~ 100 TeV electrons.**
- ➜ **γ-ray range: 8 – 40 TeV.**

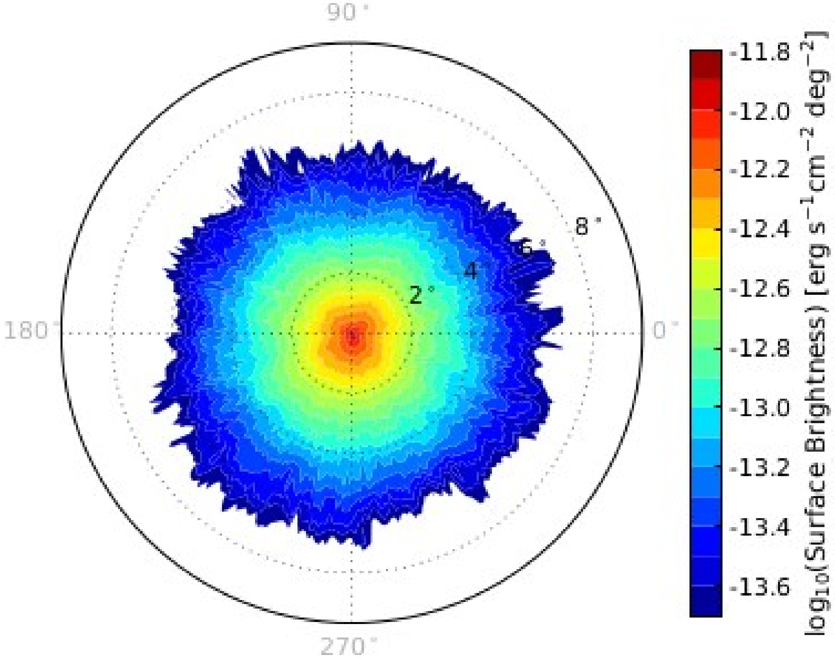
'HALOS': e^- E density << E density ISM
=> <u>Electrons have ESCAPED the PWN</u>.

Giacinti et al., A&A 636, A113 (2020)

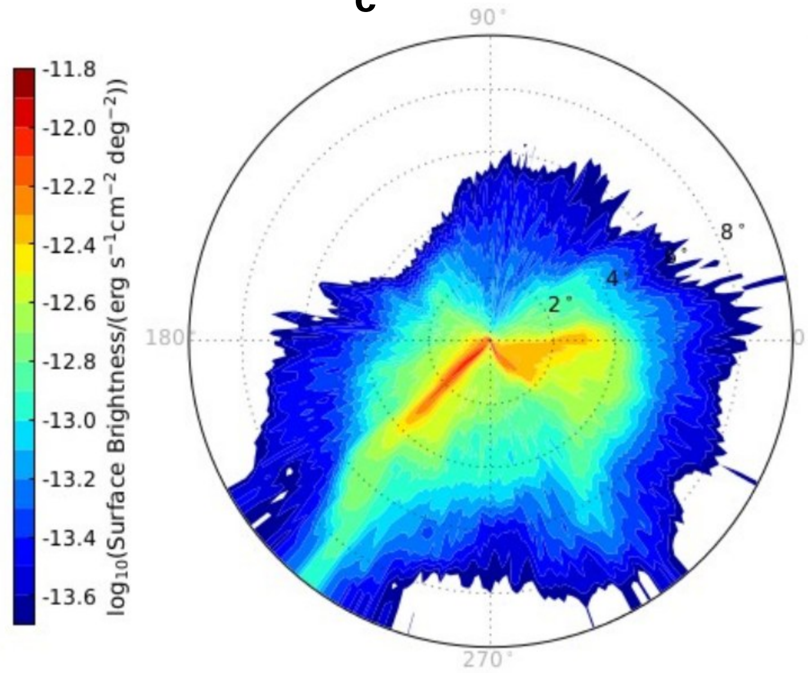
Predicted γ-ray surface brightness

Kolmogorov, B_{rms}=3 μG

L_c = 1 pc (best fit)



L_c = 40 pc

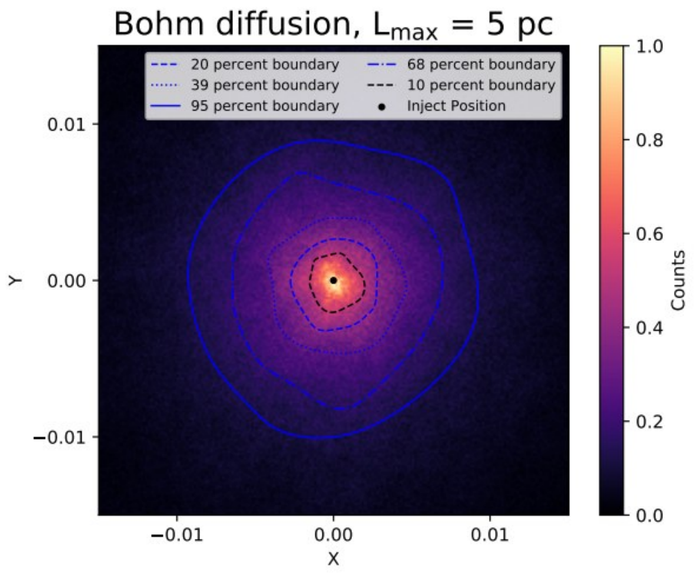


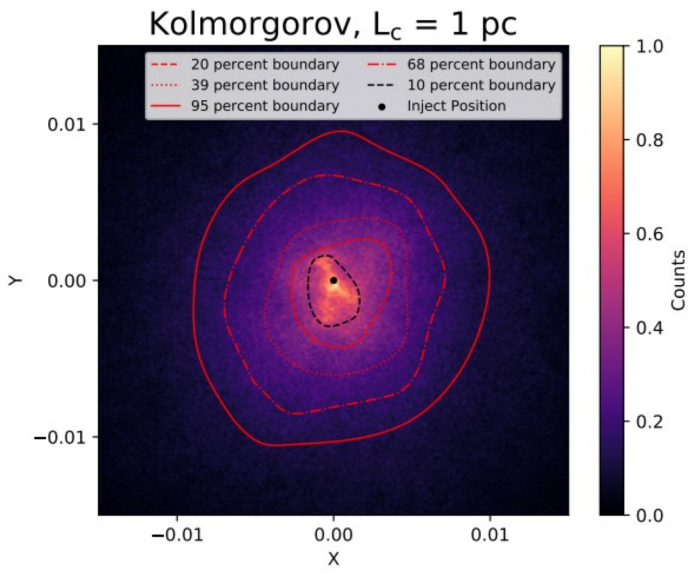
Large coherence lengths (> 10 pc) ruled out (Too asymmetric)

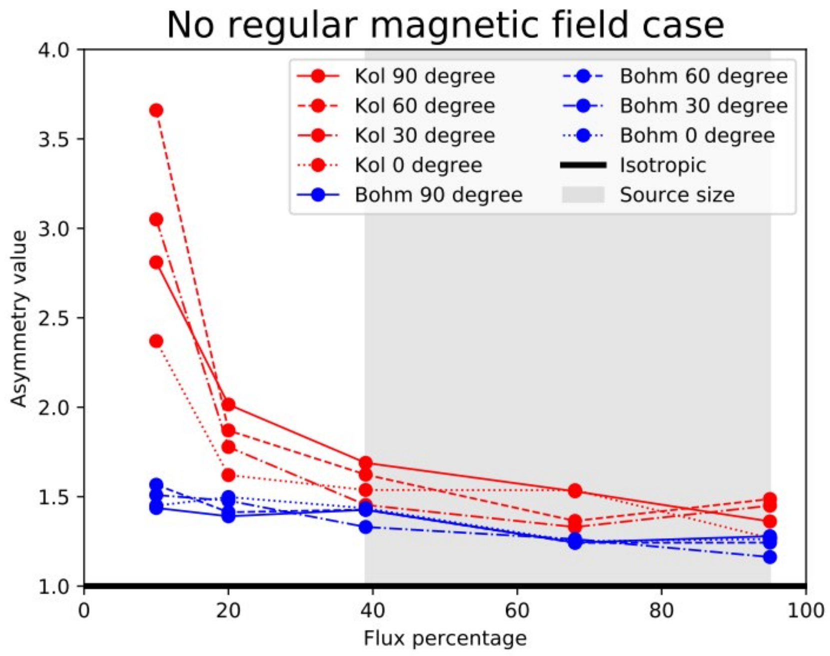
Lopez-Coto & Giacinti, MNRAS 479, 4526 (2018) [arXiv:1712.04373]

Asymmetry results ($B_{regular} = 0$):

Li, Giacinti & Lopez-Coto, To be submitted (2026)



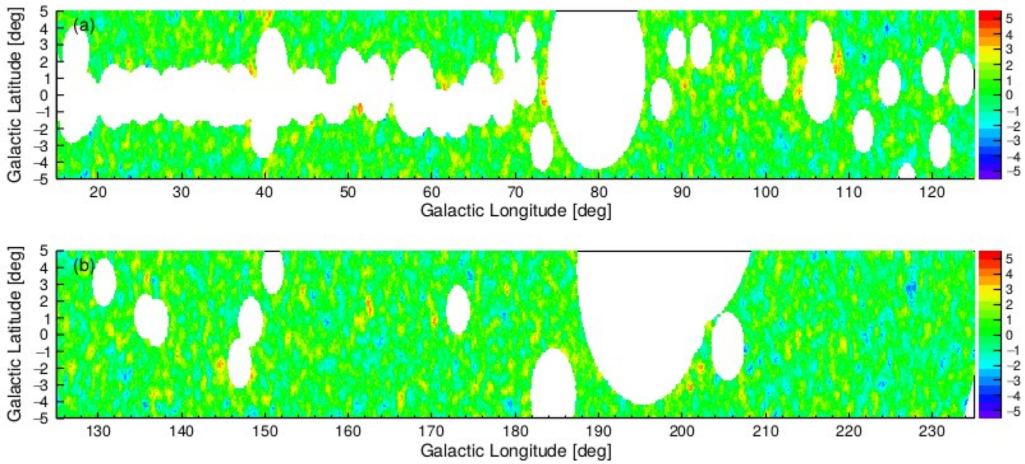


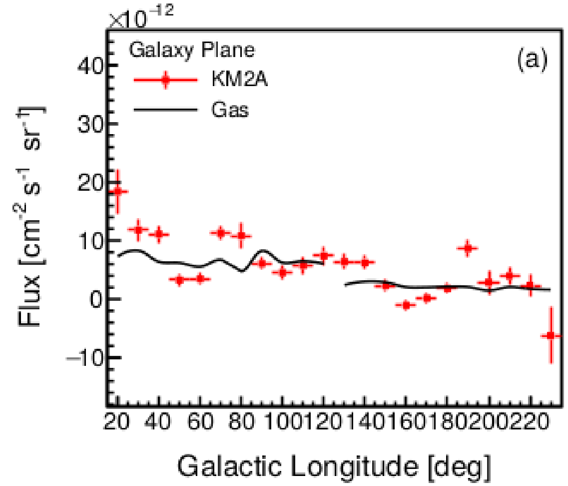


2 – Diffuse VHE γ-ray emission:

The sky at ~ 10 TeV – 1 PeV: Diffuse emission from LHAASO

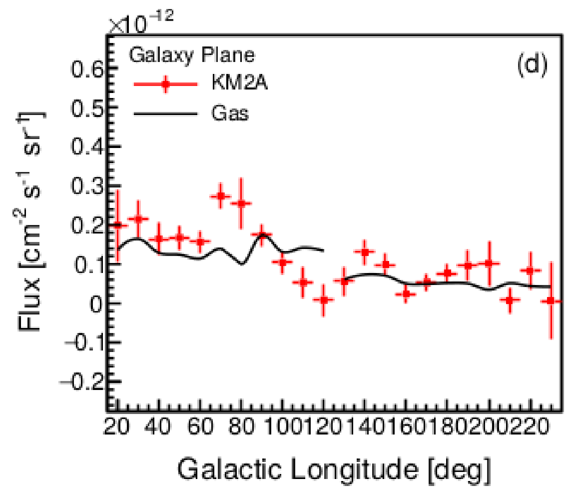
LHAASO Collaboration, Phys. Rev. Lett. 131, 151001 (2023)





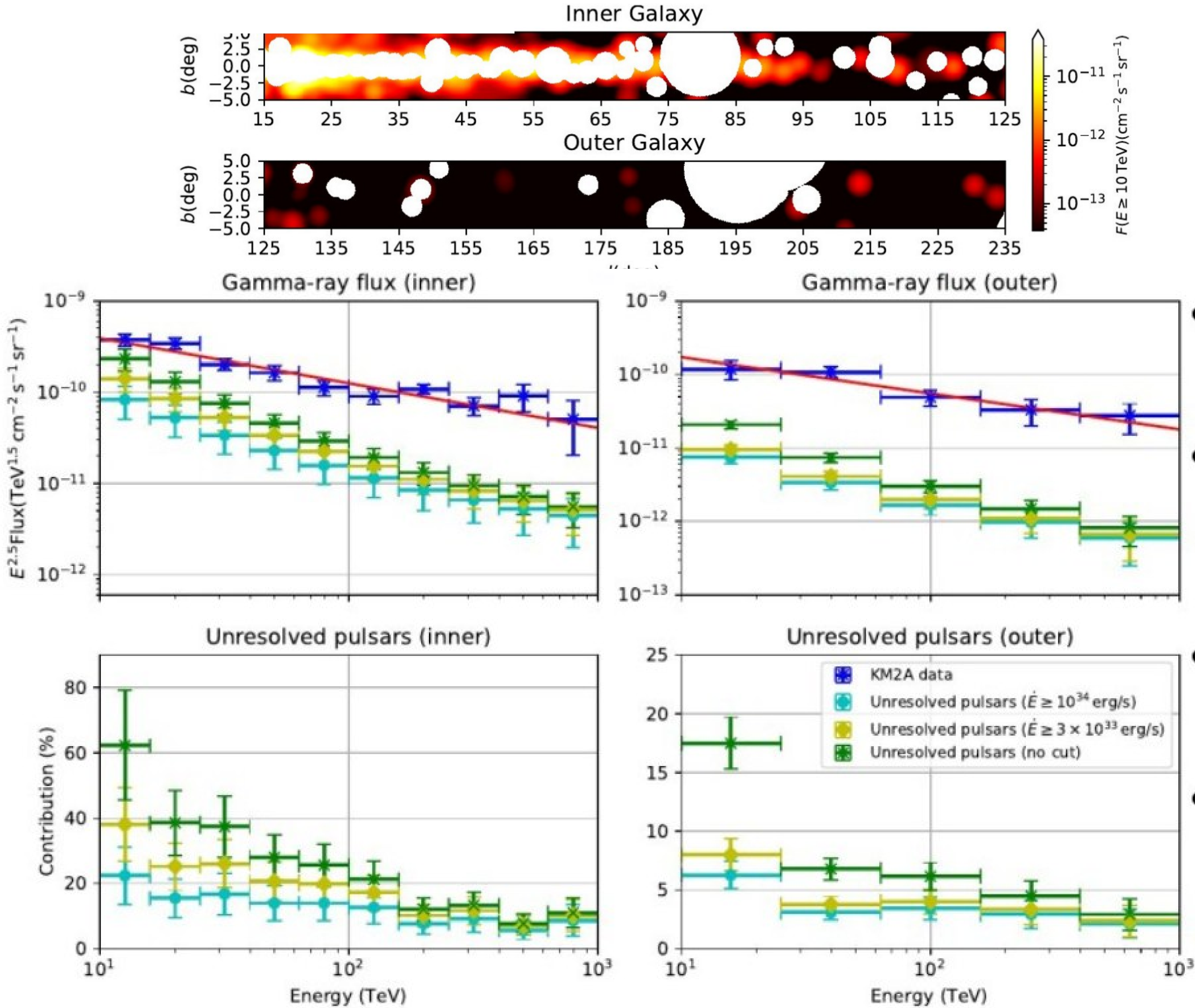
Emission in Galactic longitude does not follow target gas…

→ **Leptonic origin?**
→ **Stochasticity of CR injection?**



Upper Limits unresolved PWNe/halos

Kaci, Giacinti, Semikoz, ApJ Lett. 975, L6 (2024)



Diffuse VHE γ-ray emission from discrete sources

SIMULATION:

Kaci & Giacinti, JCAP 01, 049 (2025)

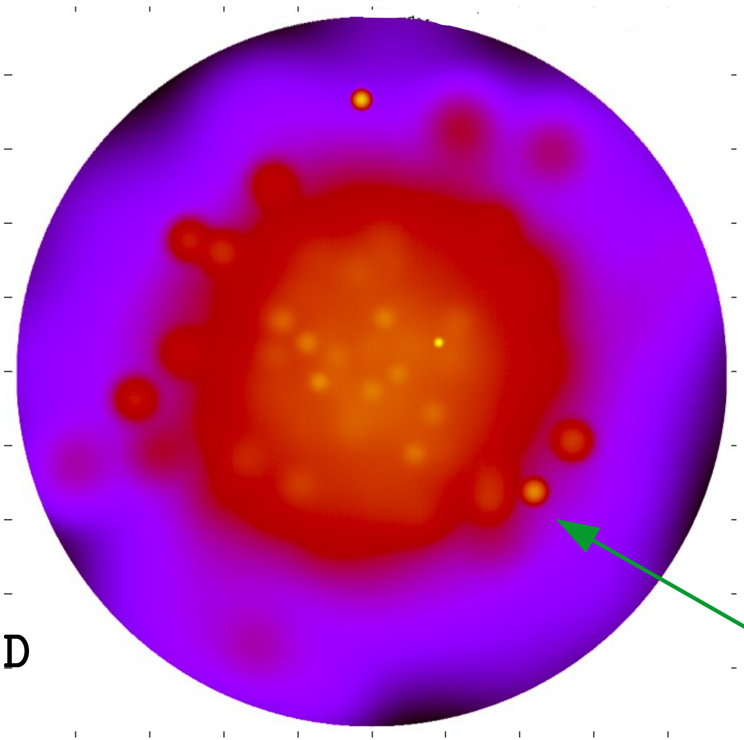
Isotropic and homogeneous diffusion

1) GALPROP-like (d=1/3) :

$$D(E) = 10^{28} D_{28} \left(\frac{R}{3GV}\right)^{\delta} cm^2/s$$

$$D_{28} = 1.33 \times \frac{H}{kpc}$$

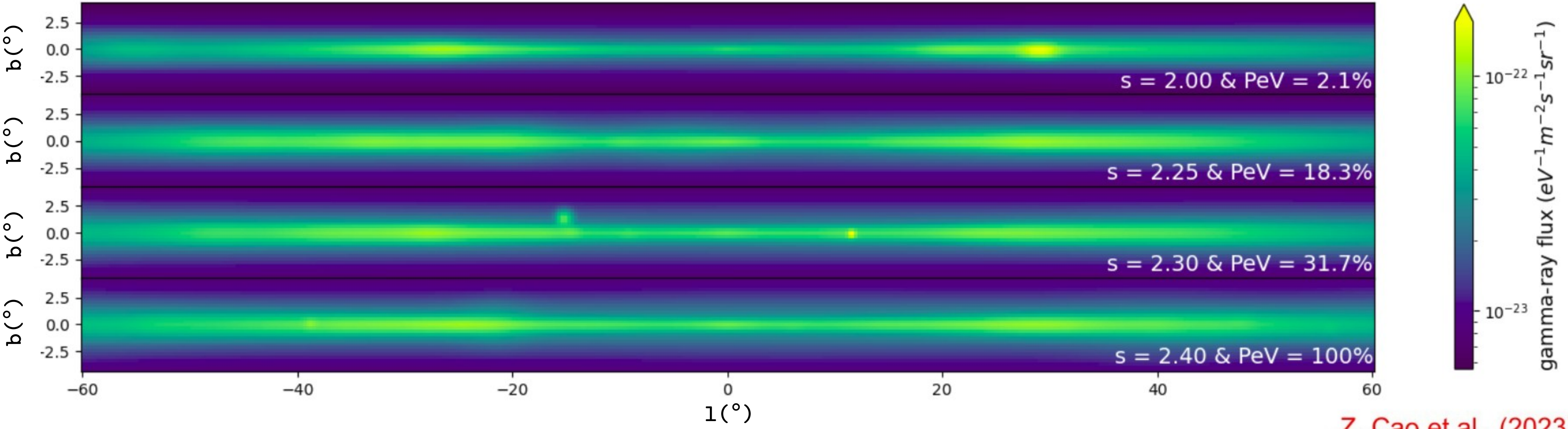
2) Time-dependent (mimics self-confinement): 1/100 x D around sources for 10 kyr.



Discrete injection of cosmic rays

Sky Maps and sources (case 1)

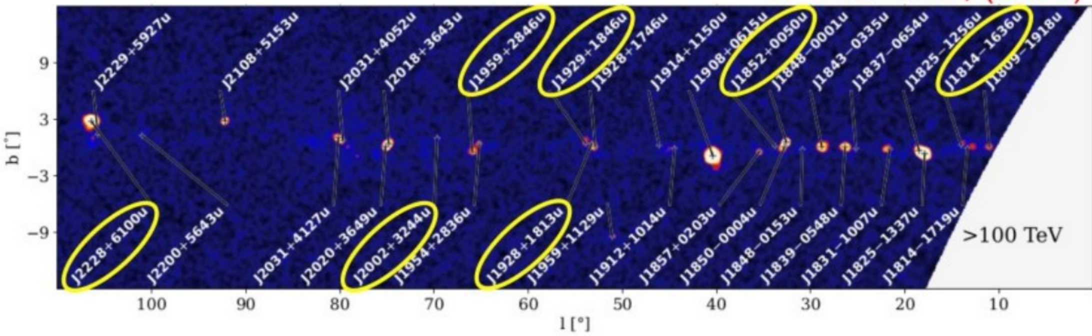
Kaci & Giacinti, JCAP 01, 049 (2025)



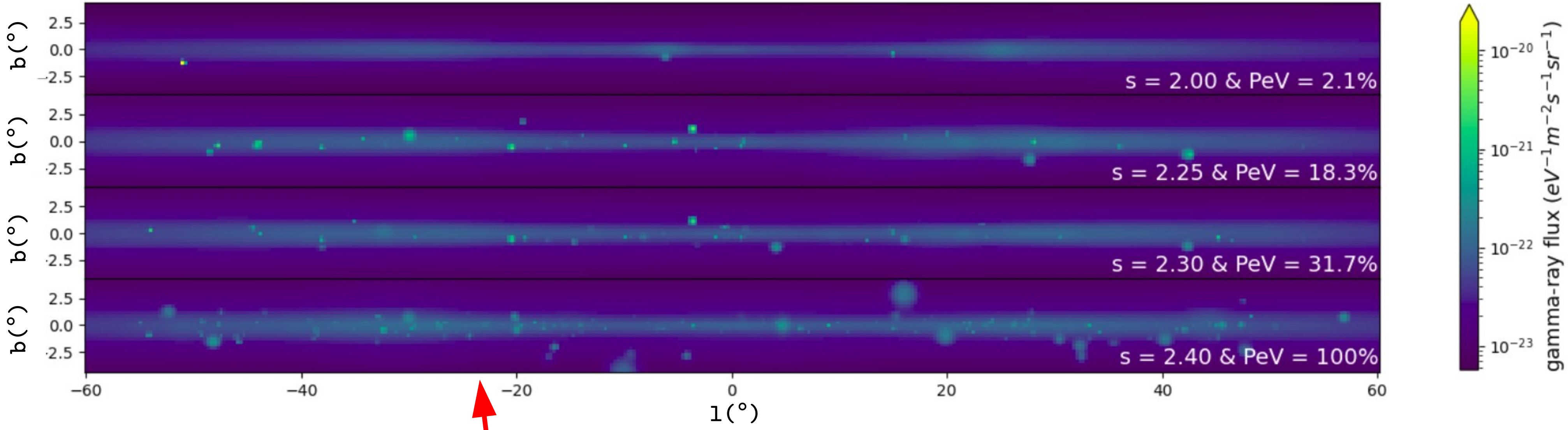
Very few visible sources for case 1

For standard isotropic diffusion, few PeVatrons are detectable

Z. Cao et al., (2023)



Sky Maps and sources (case 2)



Sky map very sensitive to CR propagation assumptions

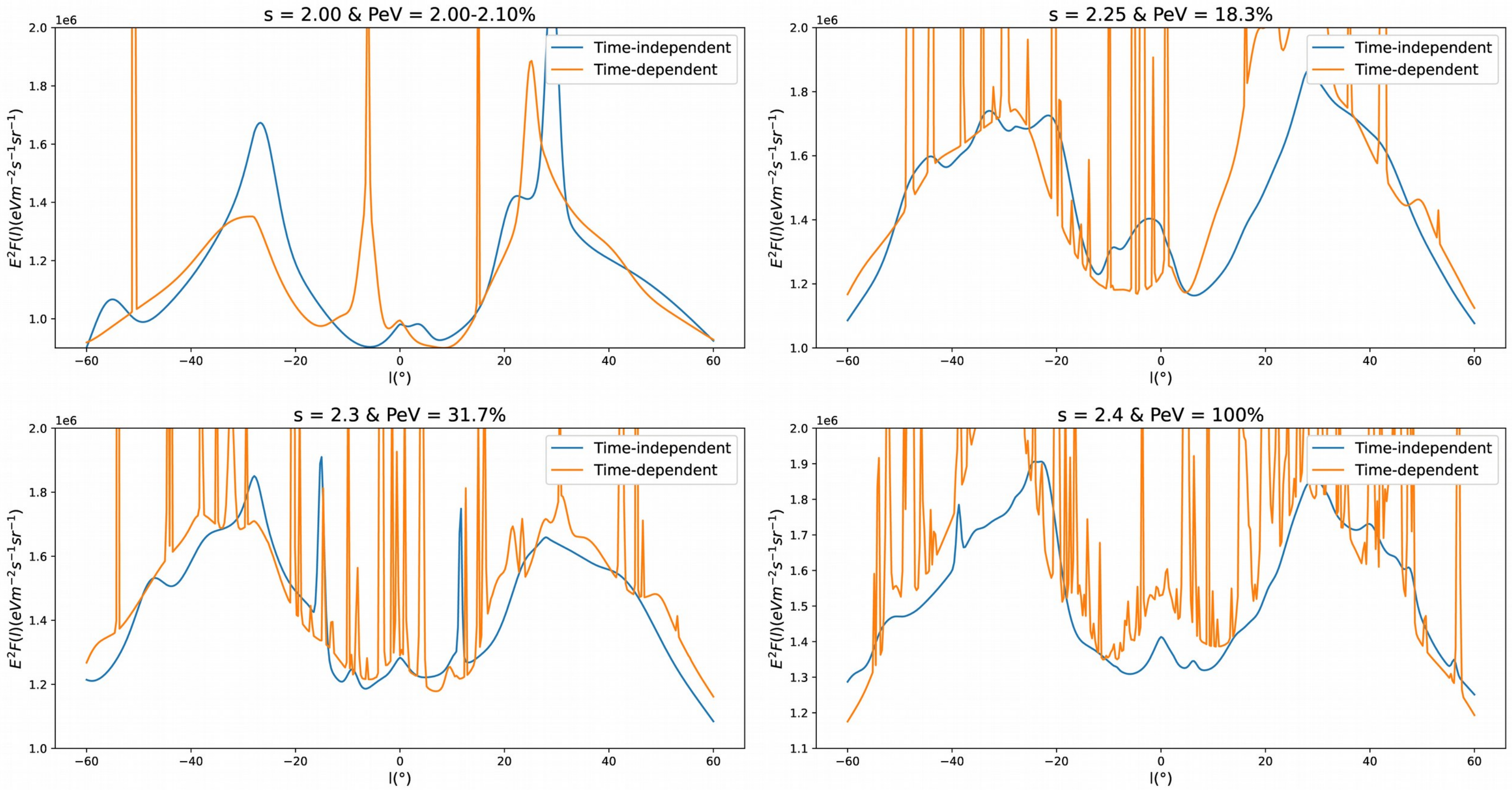
Many more visible sources

Implies a PeVatron SNR rate < 3.6/kyr

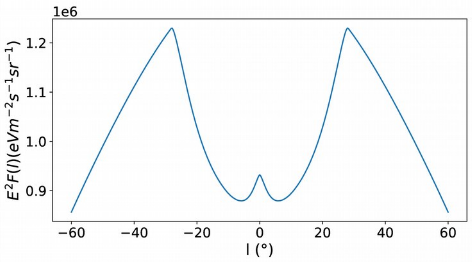
Kaci & Giacinti, JCAP 01, 049 (2025)

Clumps in the gamma-ray flux

Kaci & Giacinti, JCAP 01, 049 (2025)

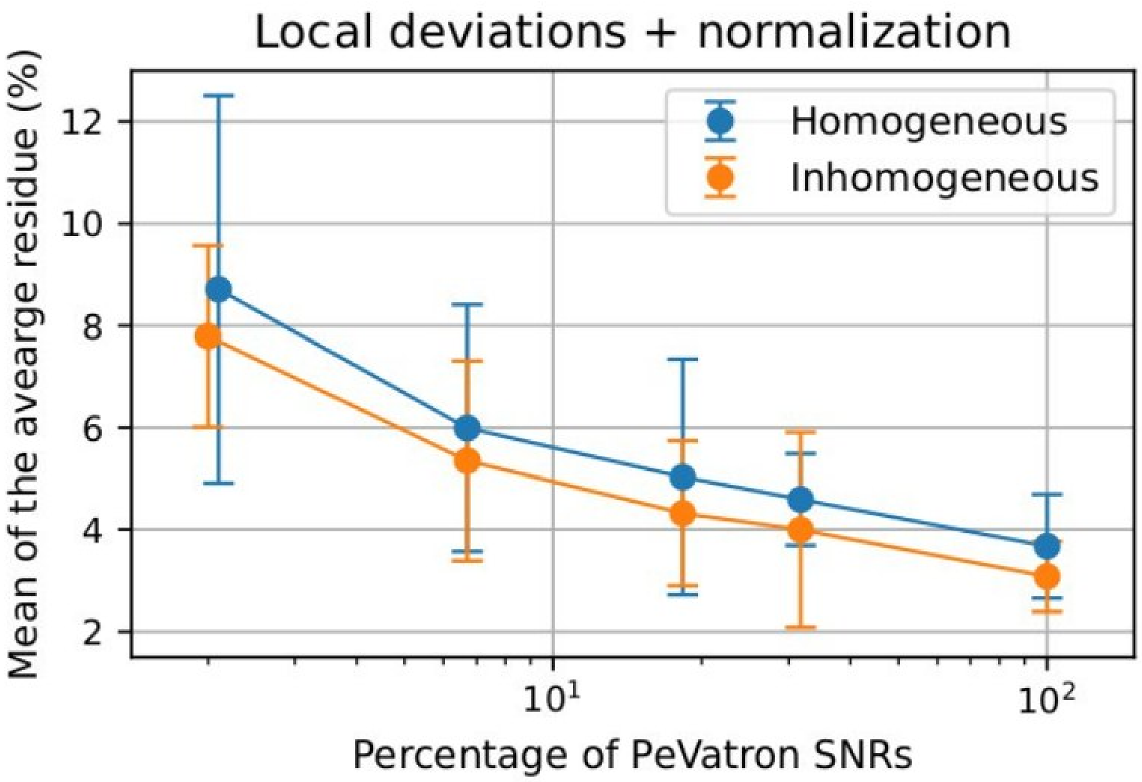


vs shape from Lipari & Vernetto(2018):



Morphology of the diffuse background

Kaci & Giacinti, JCAP 01, 049 (2025)



- The diffusion mechanism does not really impact the diffuse background.
- Variations are more important for small numbers of SNRs.

Microquasars as Galactic super-PeVatrons

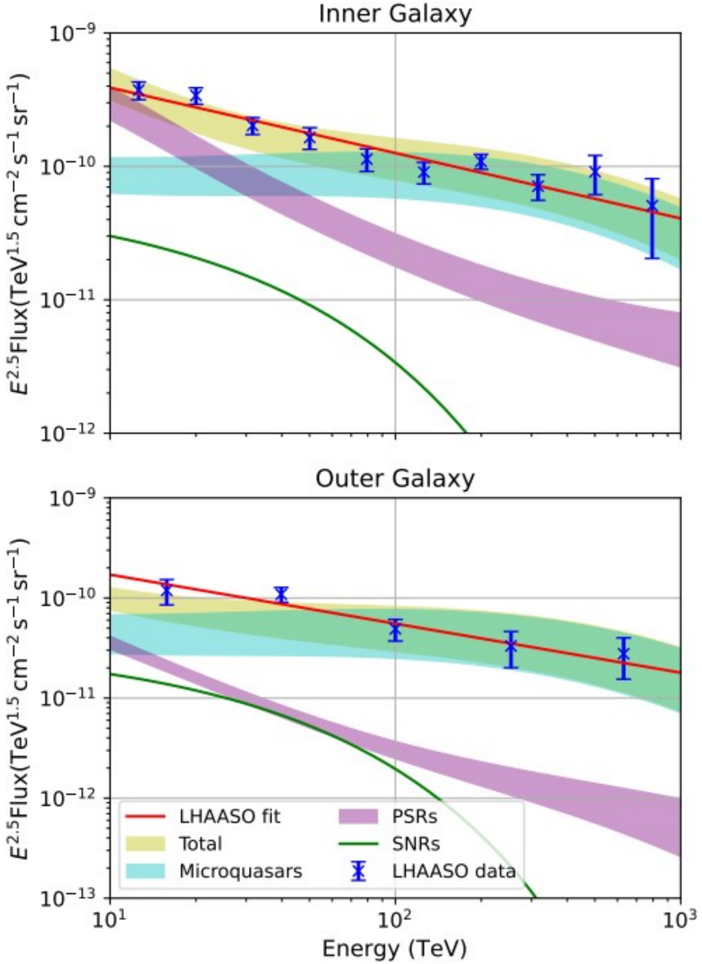
Kaci, Giacinti, Aharonian & Wang, Submitted to PRL

LHAASO detection of microquasars (LHAASO Coll., National Science Review 2025)

Microquasars: inj. -2 spectrum, cutoff at 10 PeV, 100 kyr lifetime, 0.1/kyr rate, power $10^{39\text{-}40}$ erg/s.

(Standard/SNR sources: -2.7 Power-law & exponential cutoff at ~ 150 TeV.)

Contribution to the diffuse emission:



Conclusions & Perspectives

→ **TeV halos** constrain CR propagation in the ISM,

→ **Clumpy diffuse γ-ray background** at VHE,

→ **Few SNR visible** even if 100% of them are PeVatrons,

→ **Reduced CR diffusion** around SNRs would imply a **PeVatron SNR rate < 3.6 / kyr,**

→ **Level of clumpiness** of the diffuse background **constrains the CR source rate.**