Diffuse emission

an experimental overview from GeV to PeV energies

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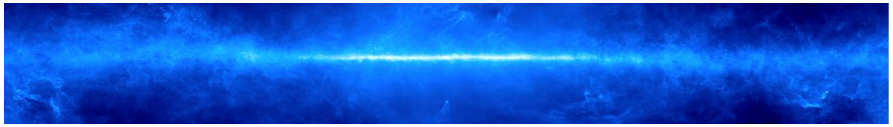
Diffuse emission = *everything that is not a resolved/discrete source*

Important **background** contribution

Truly-diffuse emission
The collective contribution of the bulk of cosmic rays contributed by galactic accelerators



[Fermi-LAT standard Galactic diffuse background @ 1 GeV]

Unresolved sources
Sources that individually don't overcome the detection threshold

[Unresolved source contribution calculated from Vecchiotti+2022]

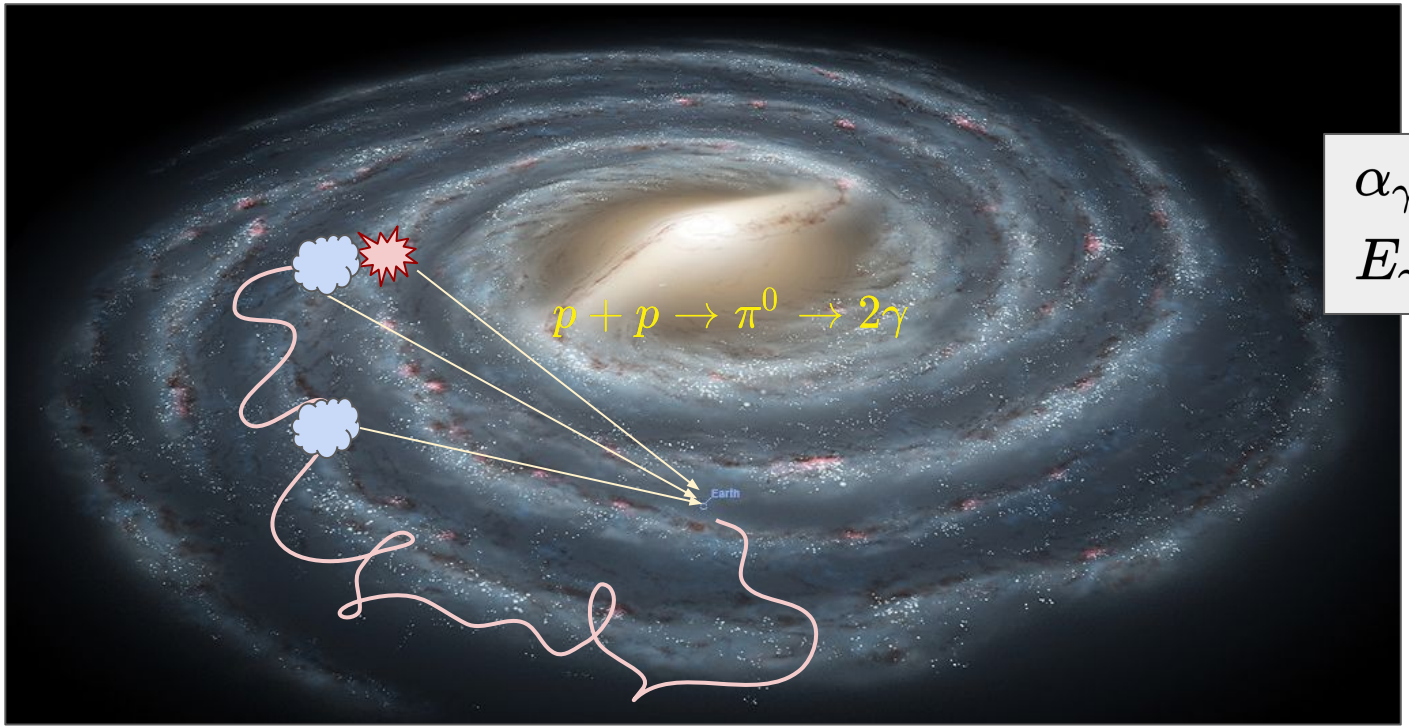
Can be used as **a source to probe CR** far from sources

Diffuse emission

Target column density

$$F_\gamma^{pp} = \xi_N \int n_H d\Omega \int dE_p \frac{d\sigma}{dE_\gamma} J(E_p)$$

Galactic CR spectrum



$$\alpha_\gamma \sim \alpha_p + 0.1$$
$$E_\gamma \sim 0.1 E_p$$

Diffuse emission

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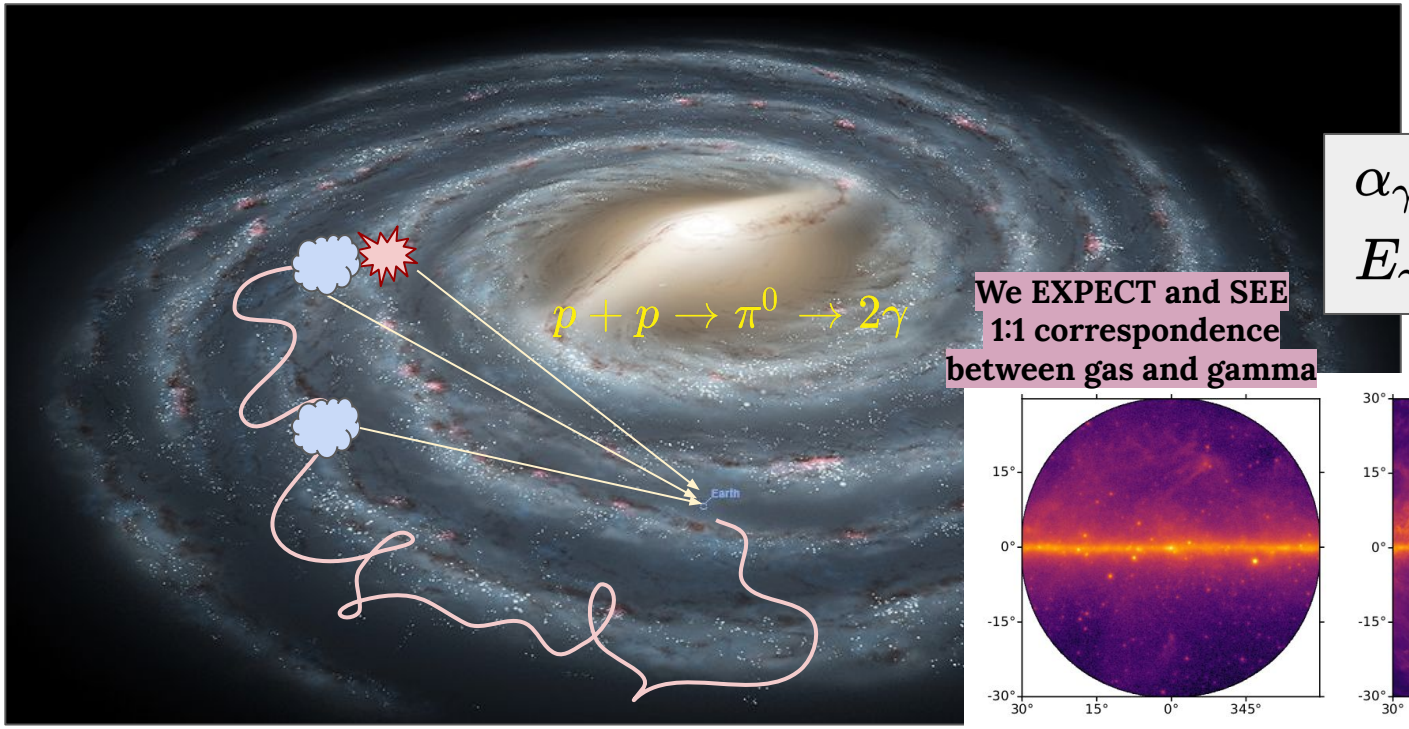
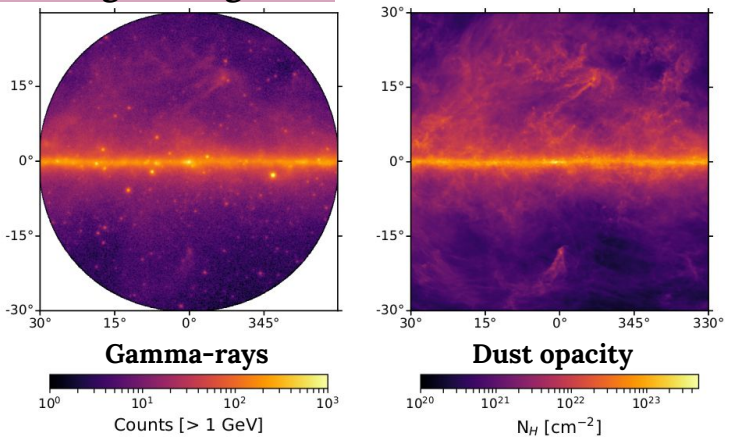
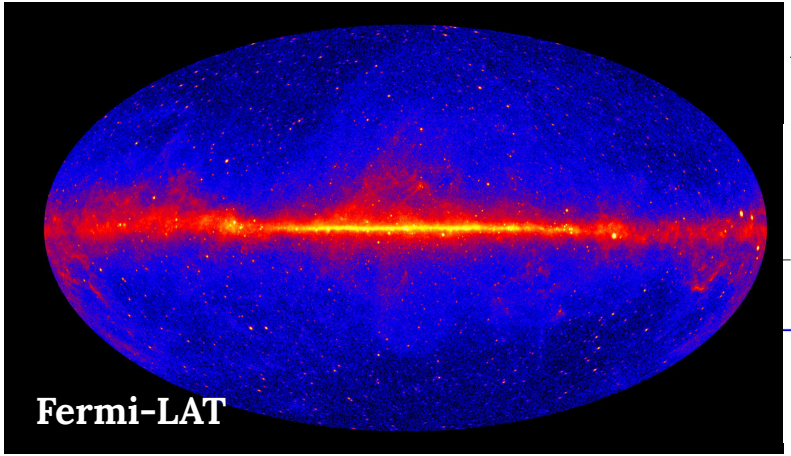


$$\alpha_\gamma \sim \alpha_p + 0.1$$
$$E_\gamma \sim 0.1 E_p$$

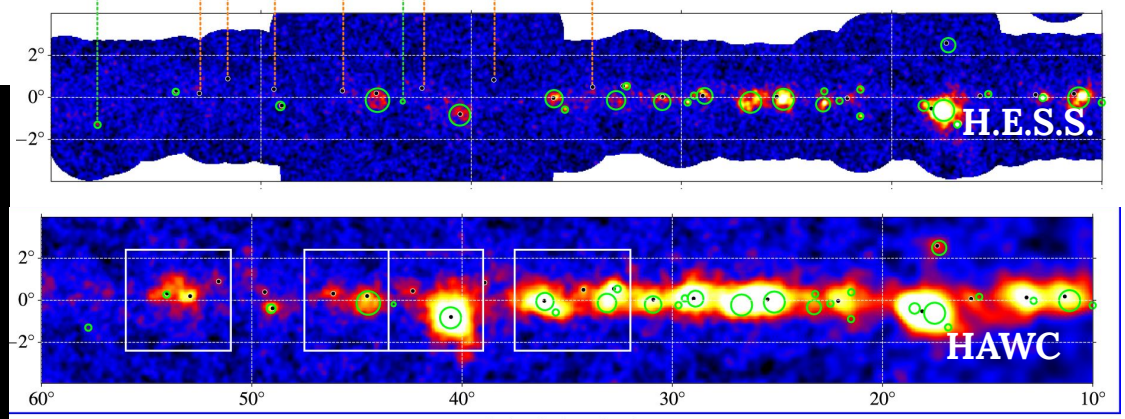
We EXPECT and SEE 1:1 correspondence between gas and gamma



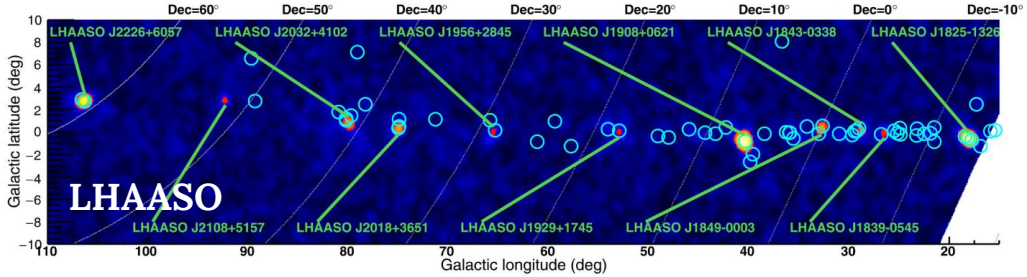
Gamma-ray sky: GeV vs. TeV and PeV



Abdalla+2021



Cao+2021



Physical: steep emission, peaks at GeV
Technical: small FoV (IACTs), background rejection

Analysis technique: GeV vs. TeV

@ GeV energies

TEMPLATE FITTING

Galactic diffuse emission:

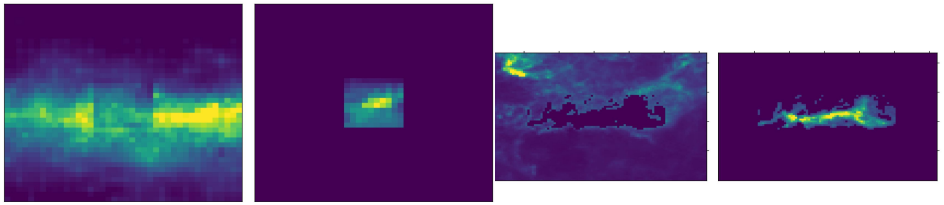
- Pion decay
- Inverse Compton
- Bremsstrahlung

Extragalactic isotropic emission

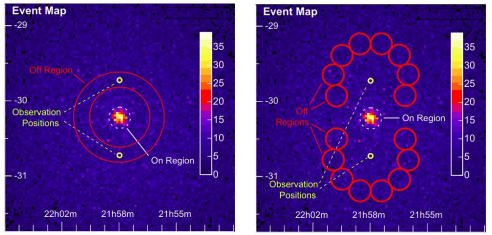
- Contributed by extragalactic sources;

Discrete sources

- e.g. 4FGL catalog;



@ TeV energies



ON-OFF ANALYSIS

Background is evaluated in a region around the source
Less sensitive to low surface brightness sources

TEMPLATE FITTING

Now used also at VHE (e.g. gammapy)
More sensitive to low surface brightness sources

Mohrmann+2019

$$F_\gamma^{pp} = \xi_N \int n_H \, d\Omega \int dE_p \frac{d\sigma}{dE_\gamma} J(E_p)$$

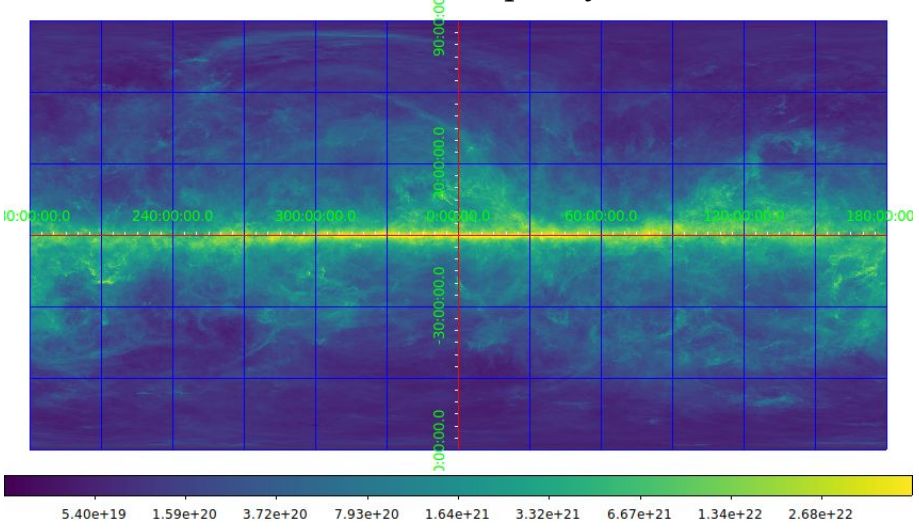
Targets for gamma-ray production

Diffuse gas

$n_H \sim 1$ cm^{-3}
R > kpc

Traced by

- molecular and atomic lines (e.g. CO and HI)
- dust opacity



Molecular Clouds

$n_H \sim 1000$ cm^{-3}
R ~ 10-100 pc

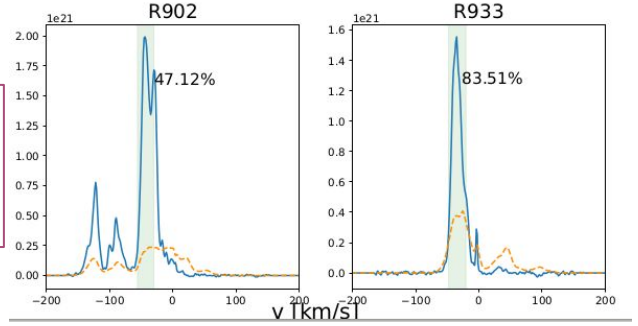
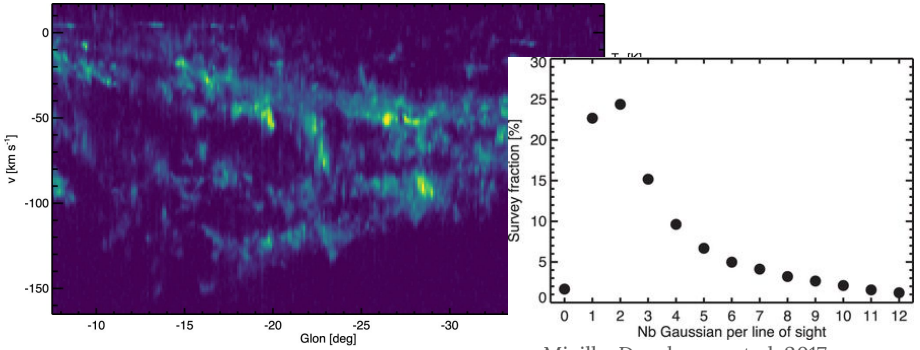


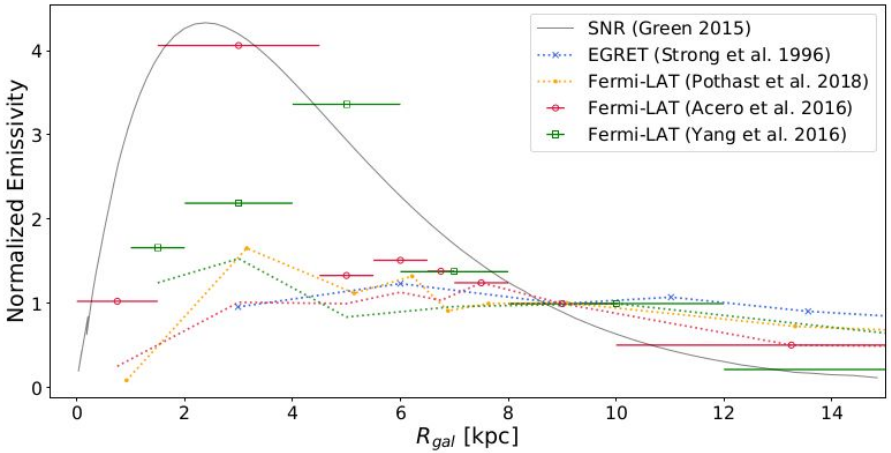
Fig. adapted from Peron 2020 [PhD thesis]

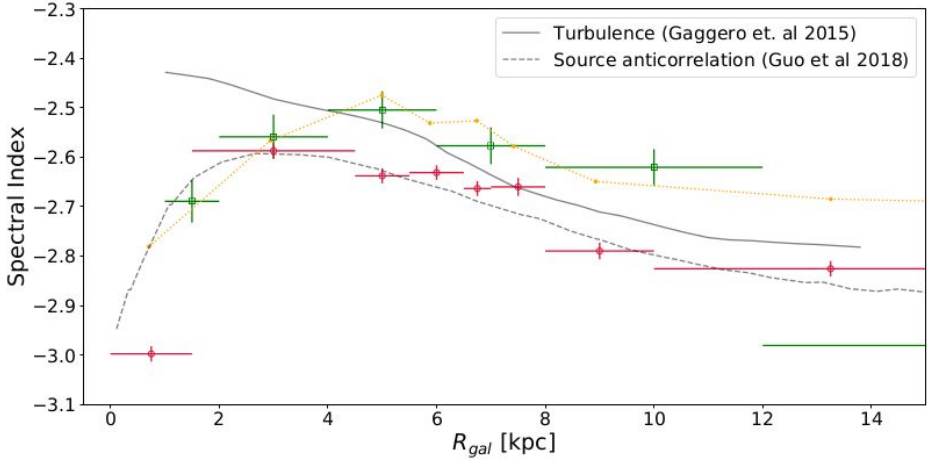


Map derived from Dame et al. 2000

Miville-Deschenes et al. 2017

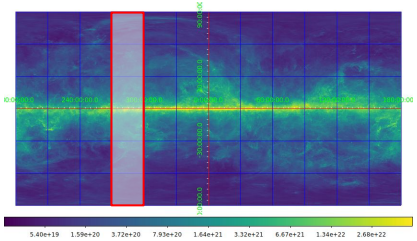
Gamma-rays from diffuse gas @ GeV energies





Enhancement and hardening towards the GC

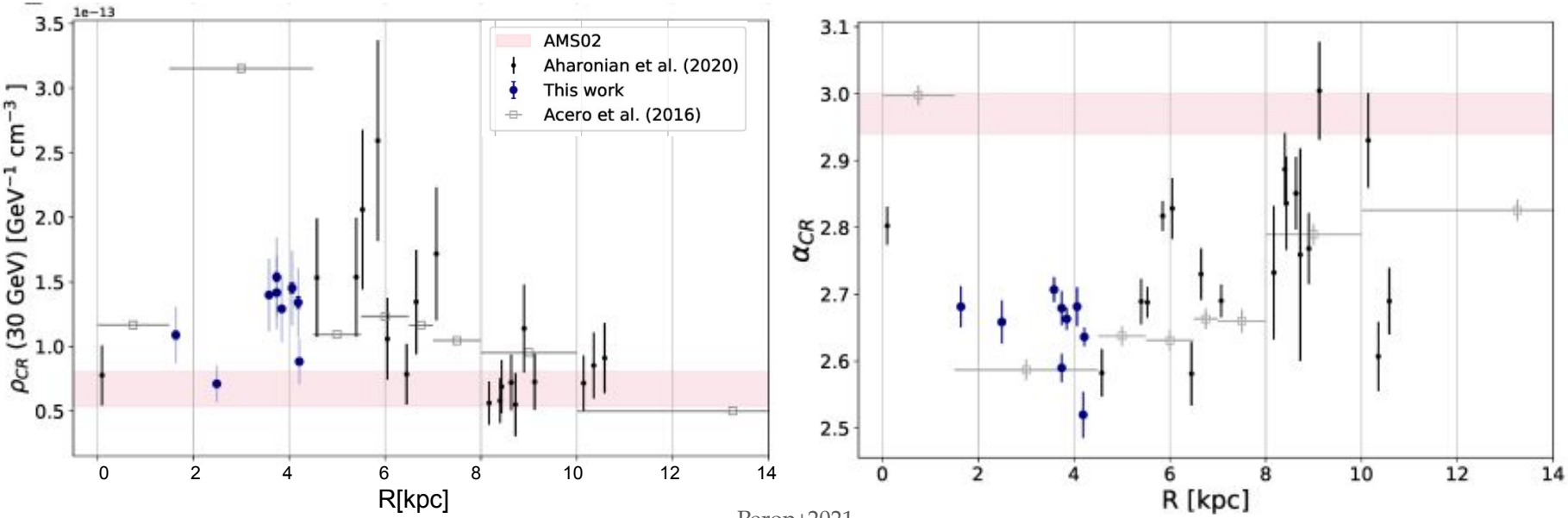
- is this a global effect? (e.g. due to propagation)
- is this a local effect? (e.g. due to sources)
- is the contamination of unresolved sources?



-Emission extracted in galactocentric rings of gas

- Template based on HI and CO lines emission

Gamma-rays from molecular clouds @ GeV energies

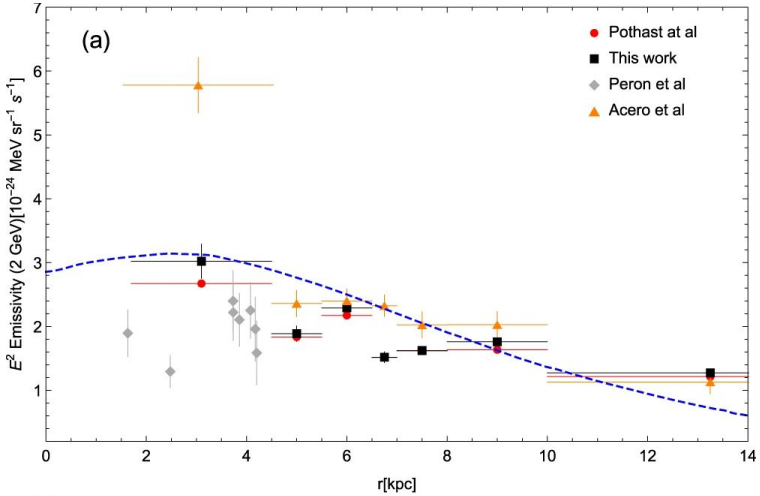


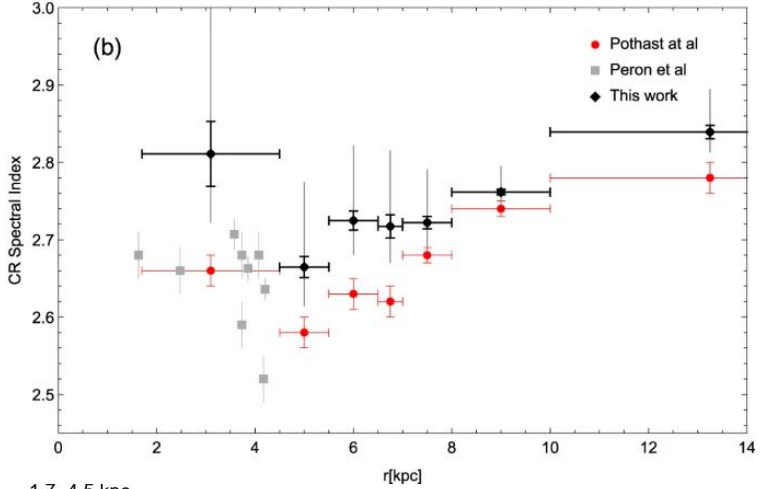
Peron+2021

Several locations share the same value as the local emission

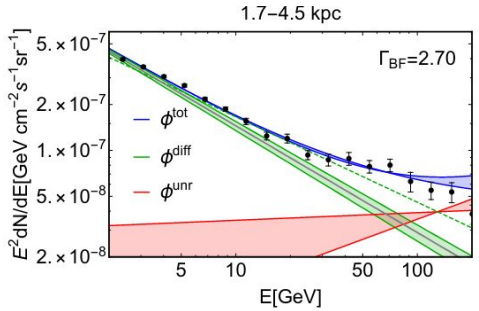
The contribution of unresolved sources

Vecchiotti+2022





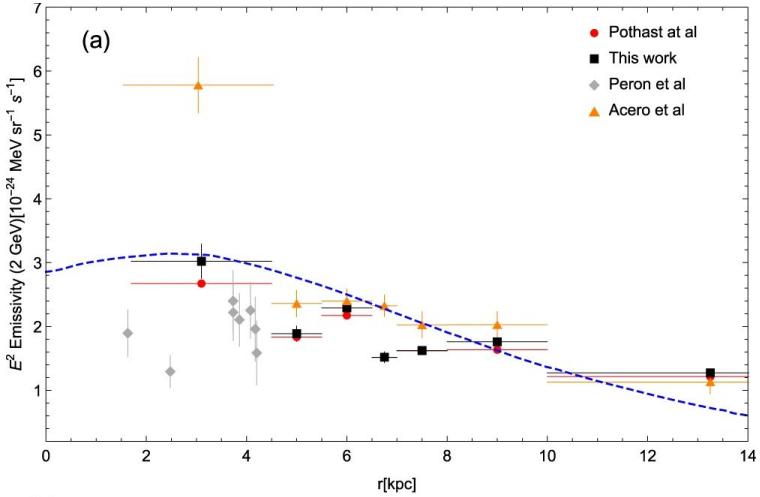
The enhancement is reabsorbed by a population of unresolved sources

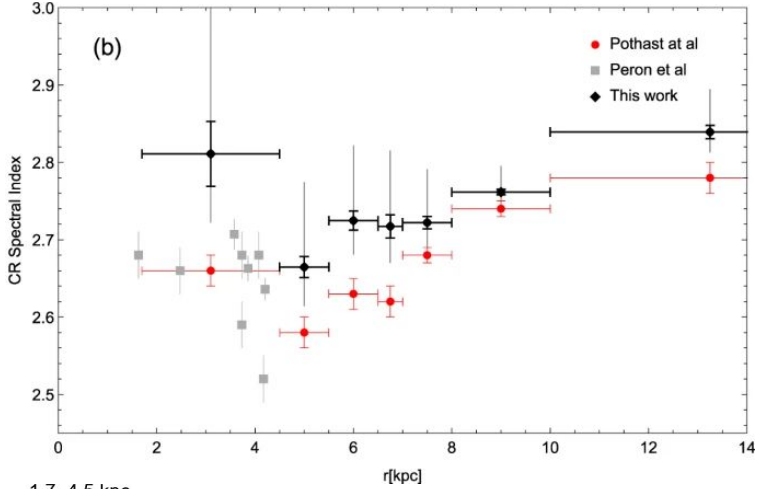


The net CR spectrum is quite flat

The contribution of unresolved sources

Vecchiotti+2022





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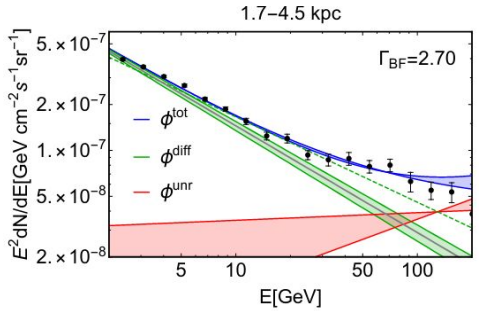


The net CR spectrum is quite flat

Raising contribution with energy

Diffuse emission at > TeV energies

As a source

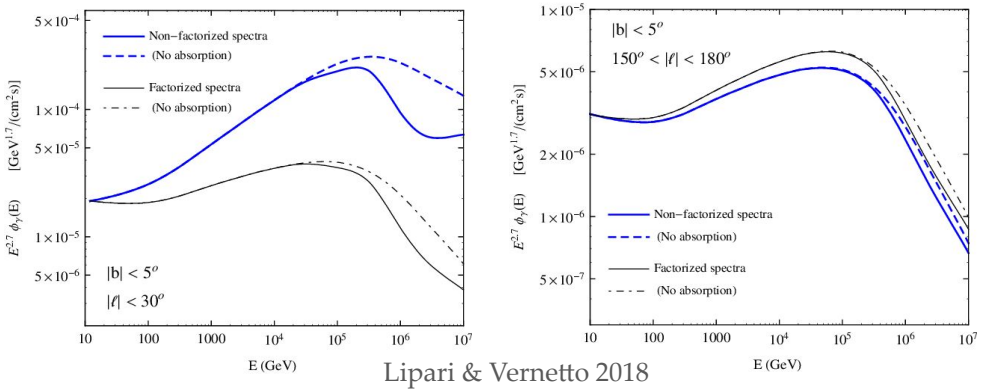
Clarify the nature of the enhancement seen at GeV

Probe the CR far from Earth up to the knee region

As a background

Cannot be avoided for large FoV and sensitive instruments:

LHAASO, CTA, SWGO…

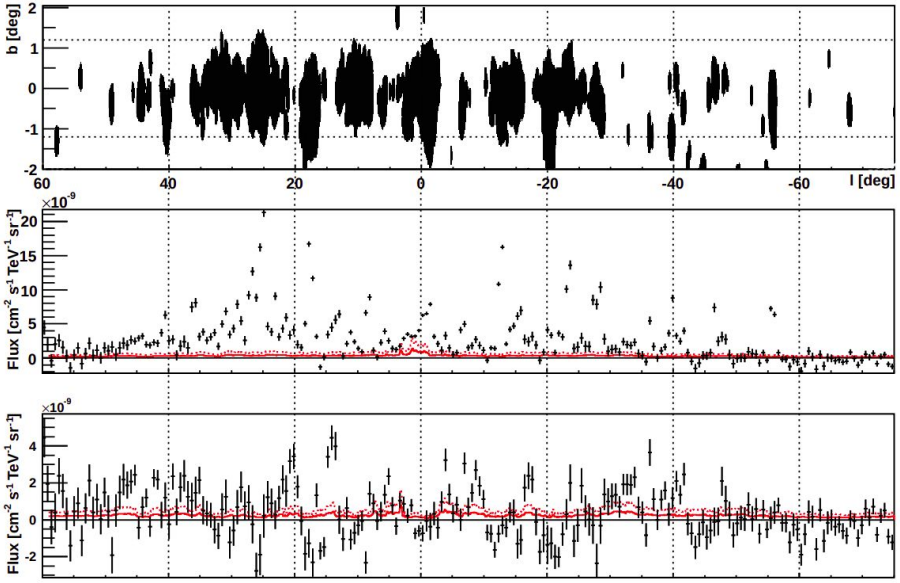


Lipari & Vernetto 2018

TeV Gamma rays from diffuse: observations

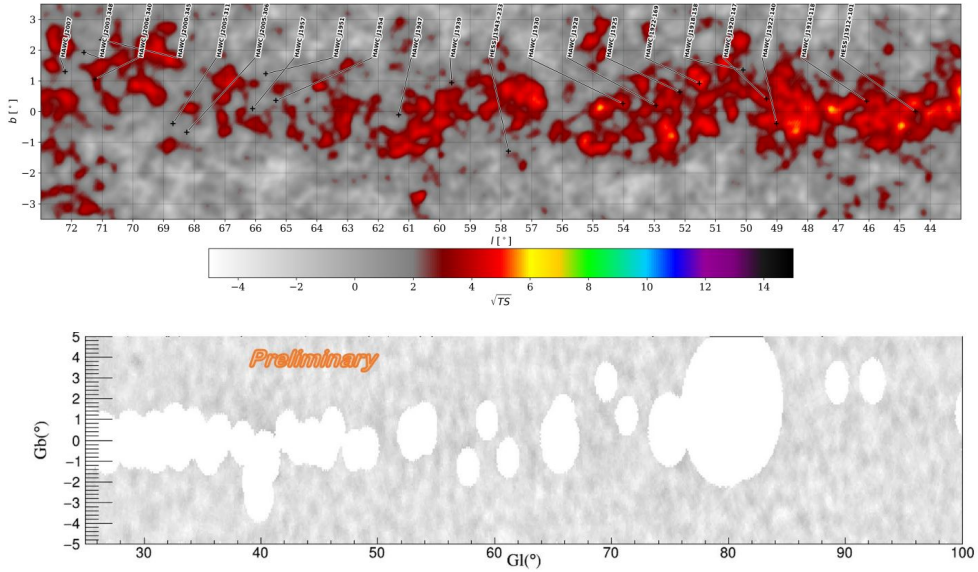
@ TeV energies

Flux is extracted from source-free regions



H.E.S.S. Collaboration 2014

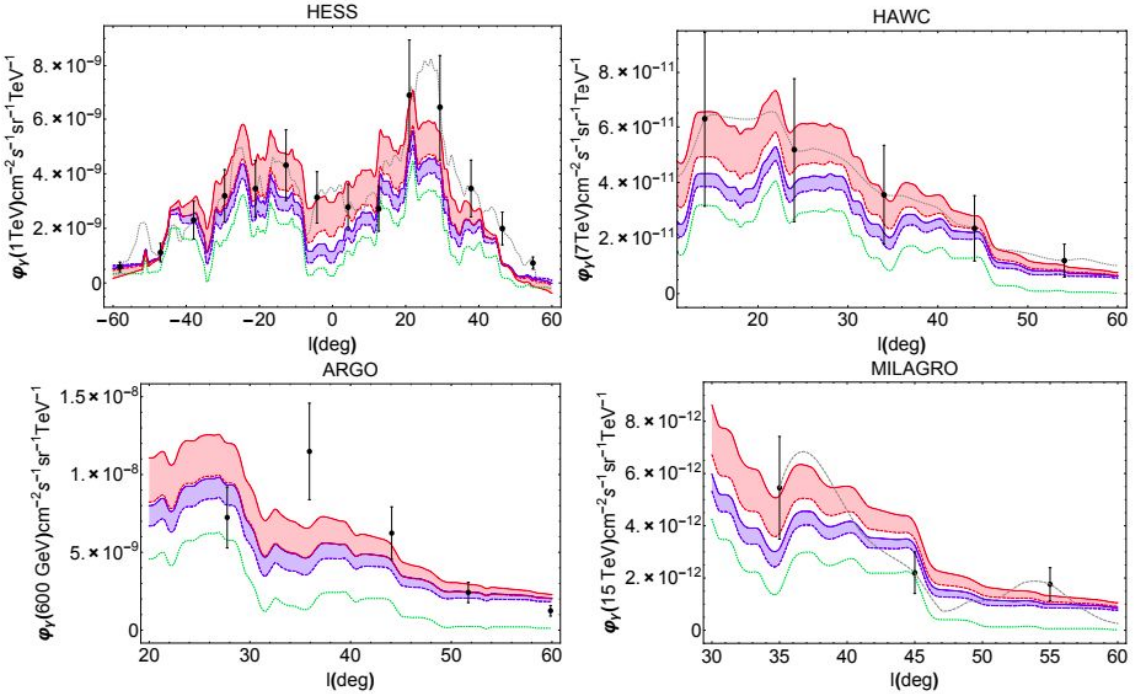
Nayerhoda+2021 for the HAWC Collaboration



LHAASO Collaboration @ICRC2021

Gamma rays from diffuse

@ TeV energies

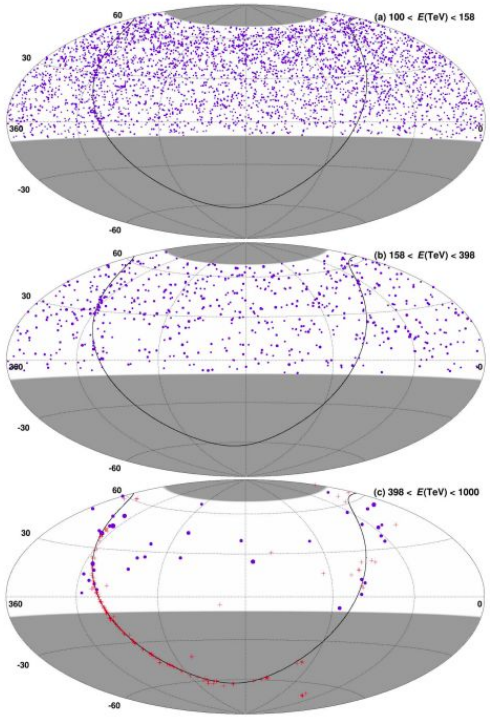


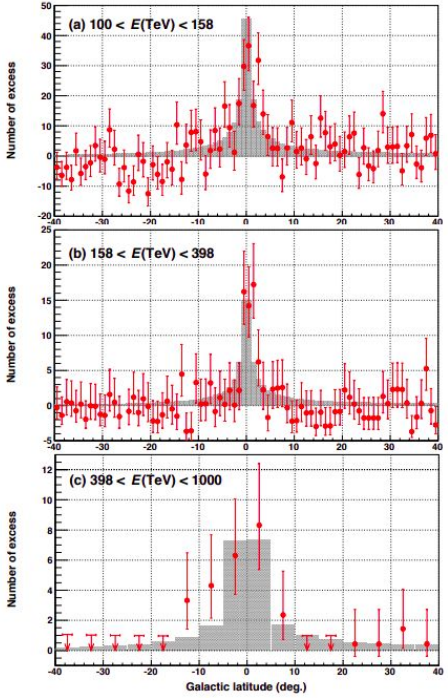
Spatial dependent diffusion leads to saturation of the data without unresolved sources which are expected to contribute ~60%

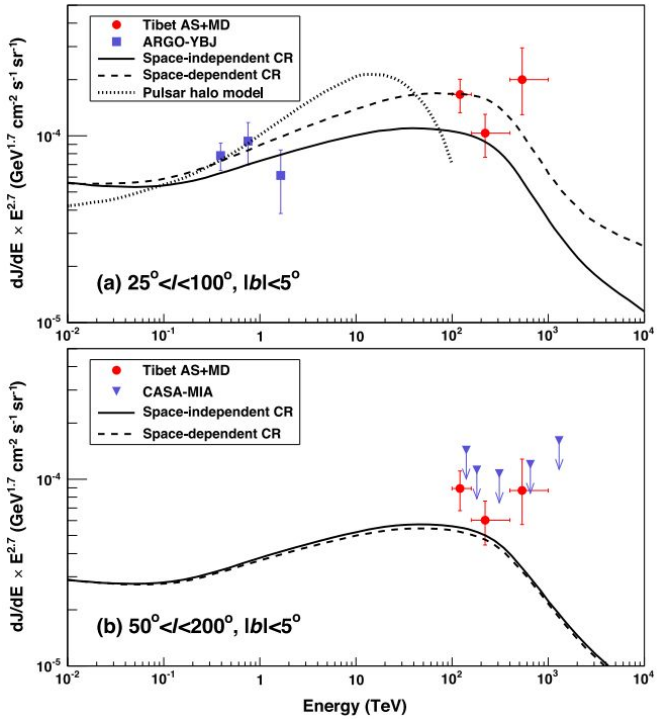
Cataldo+2019 and 2020

Gamma rays from diffuse

@ sub-PeV energies



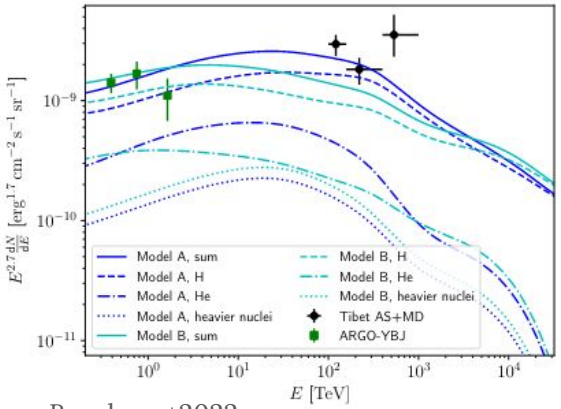




Amenomori et al. 2021 for the TIBET collaboration

Gamma rays from diffuse: different interpretations

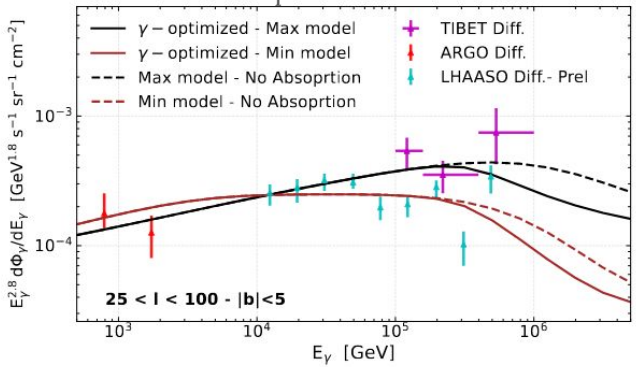
Change in composition



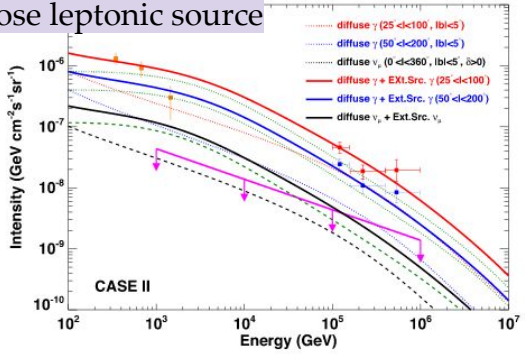
Breuhaus+2022

Spatial dependent diffusion

De La Torre Luque+2022

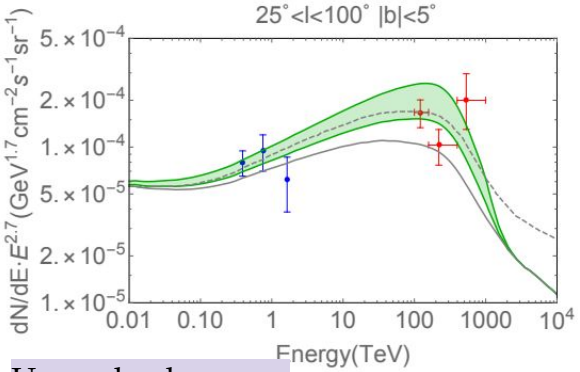


A close leptonic source

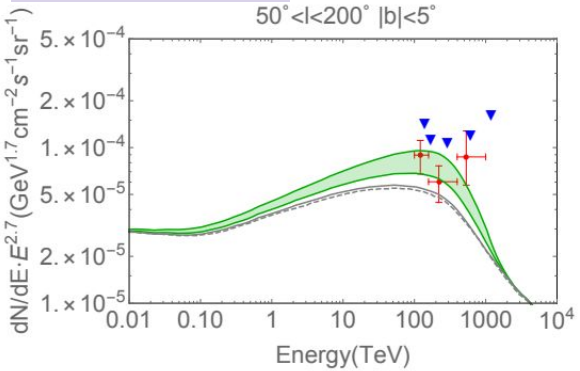


Liu&Wang+2021

+Fang&Murase 2021



Unresolved sources



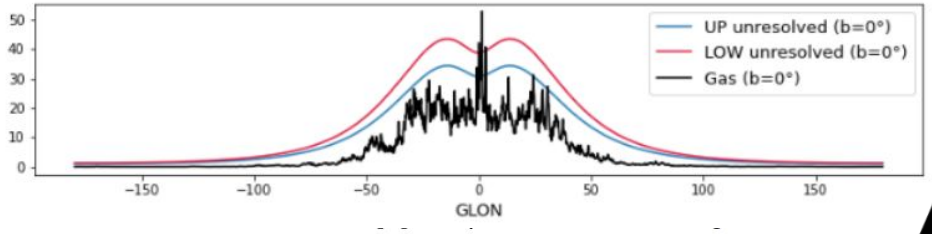
Vecchiotti+2021

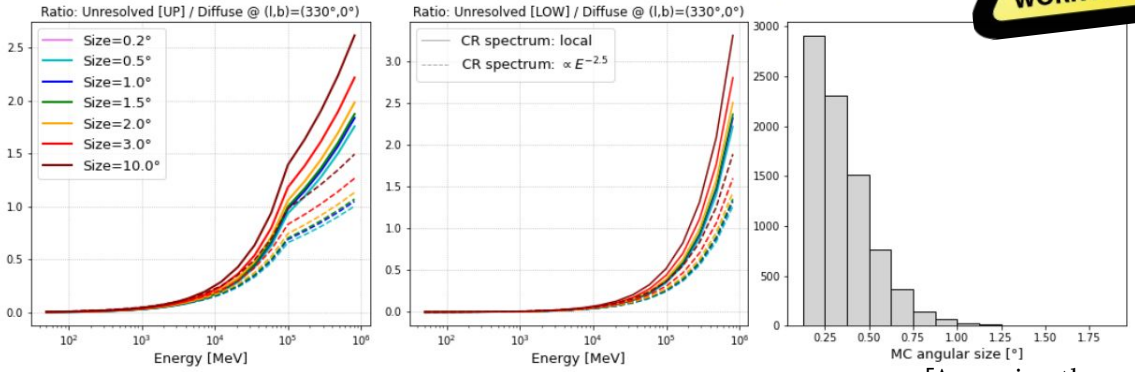
Gamma rays from GMCs

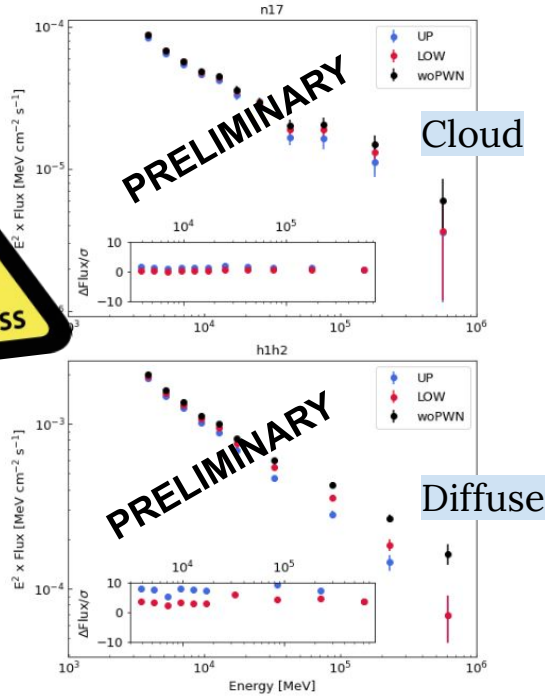
(l,b) = (333.4,-0.43)°
Size = 0.85°
R_{gal} = 5.5 kpc
M_5/d^2_{kpc} = 1.3

Are clouds affected by unresolved sources?

Depends on angular size, position, spectrum and energy





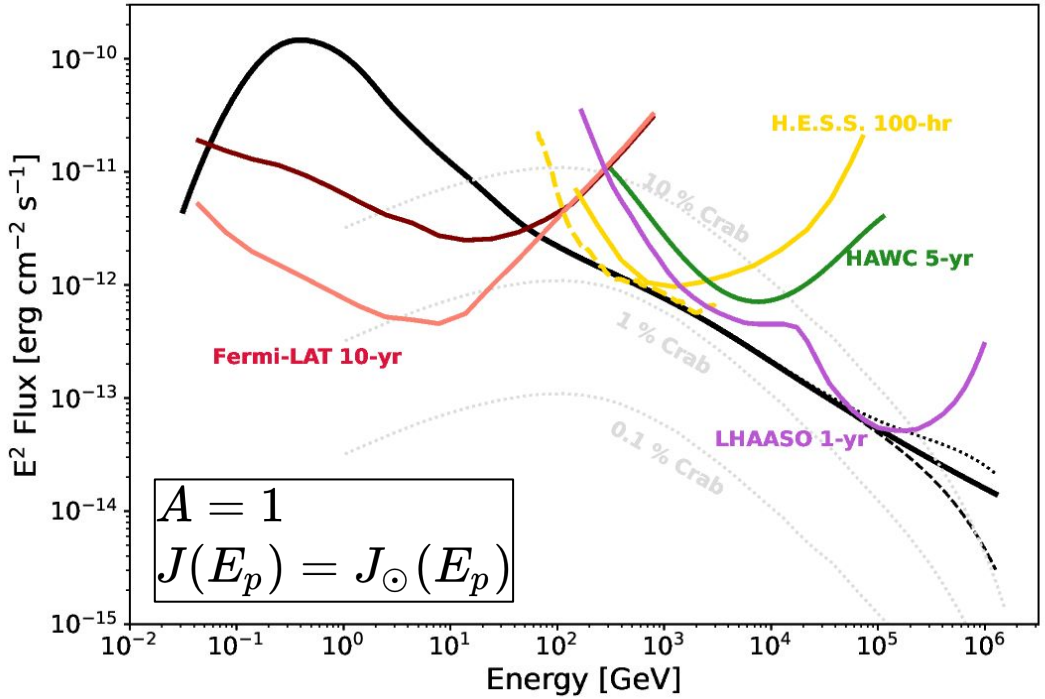


[Assuming the model for unres sources at GeVs from Vecchiotti et al. 2022]

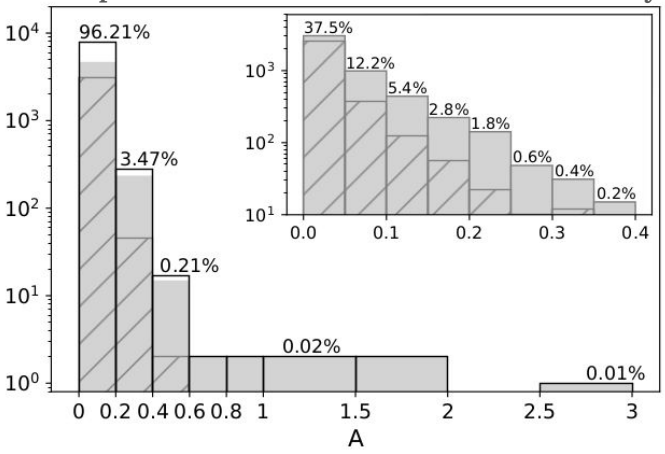
Gamma rays from GMCs

$$F_\gamma^{pp} = \xi_N \int n_H d\Omega \int dE_p \frac{d\sigma}{dE_\gamma} J(E_p)$$

$$A \equiv \frac{M_5}{d_{kpc}^2} = 8 \times 10^{-20} \int n_H d\Omega$$



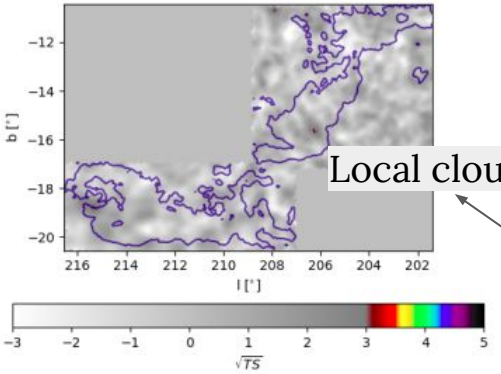
A parameter for MCs in the Galaxy



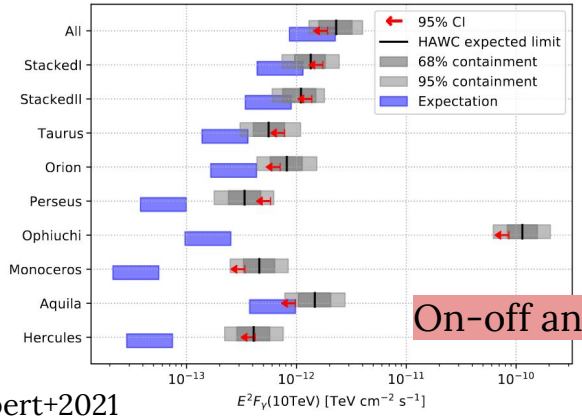
Peron & Aharonian 2022

Gamma rays from GMCs

@ TeV energies



HAWC

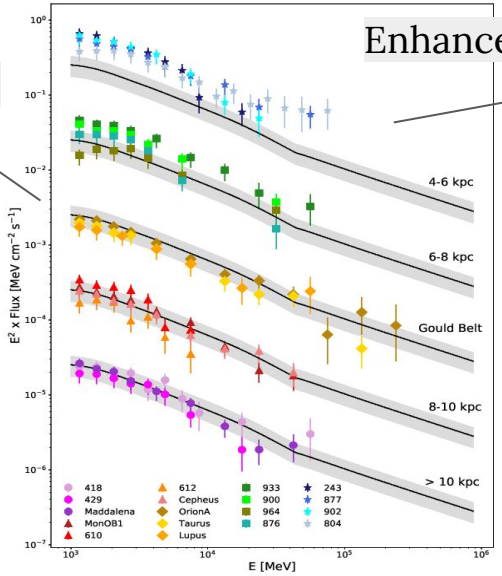


Albert+2021

Local clouds

On-off analysis

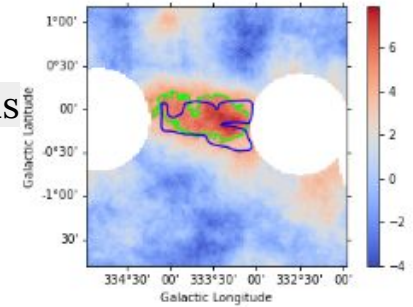
Fermi-LAT

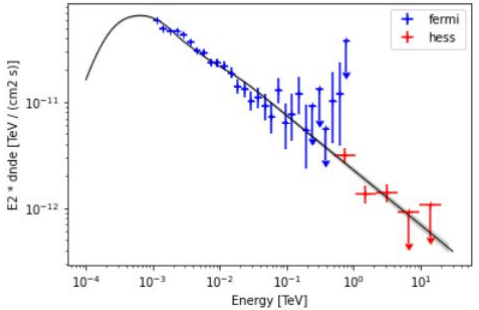


Aharonian,Peron+2020

Enhanced clouds

H.E.S.S.





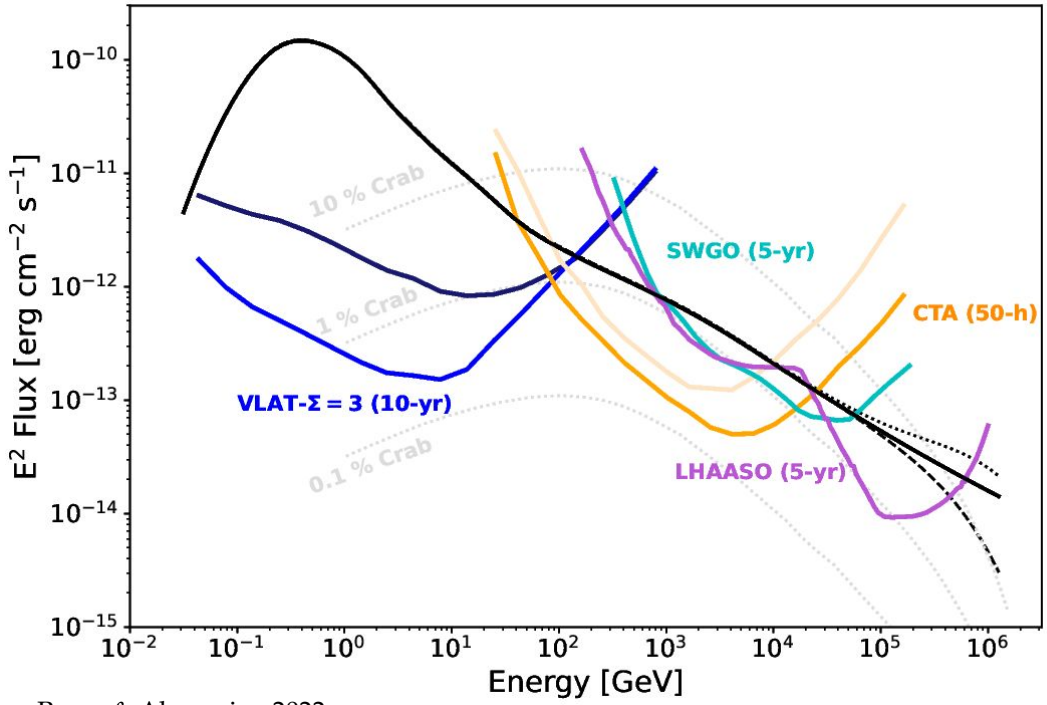
Template fitting

Sinha, Baghmanyan, GP+2021 [@ICRC2021]

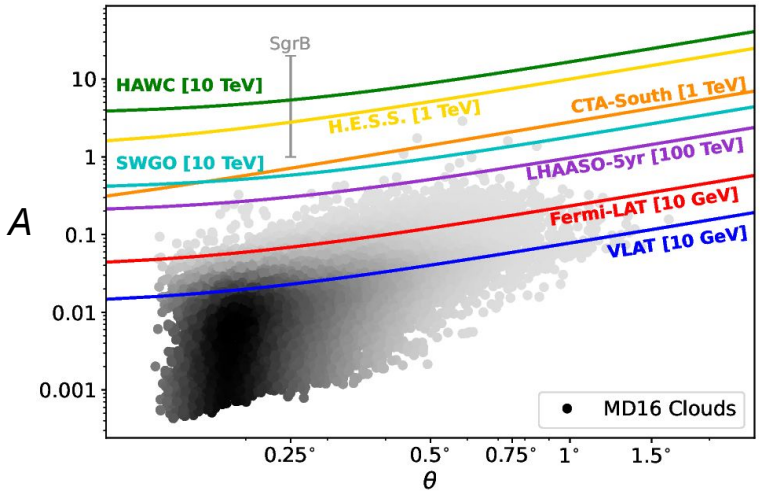
The prospects for the future

$$\omega \propto \frac{\sqrt{\sigma_{PSF}^2+\theta^2}}{\sigma_{PSF}}$$

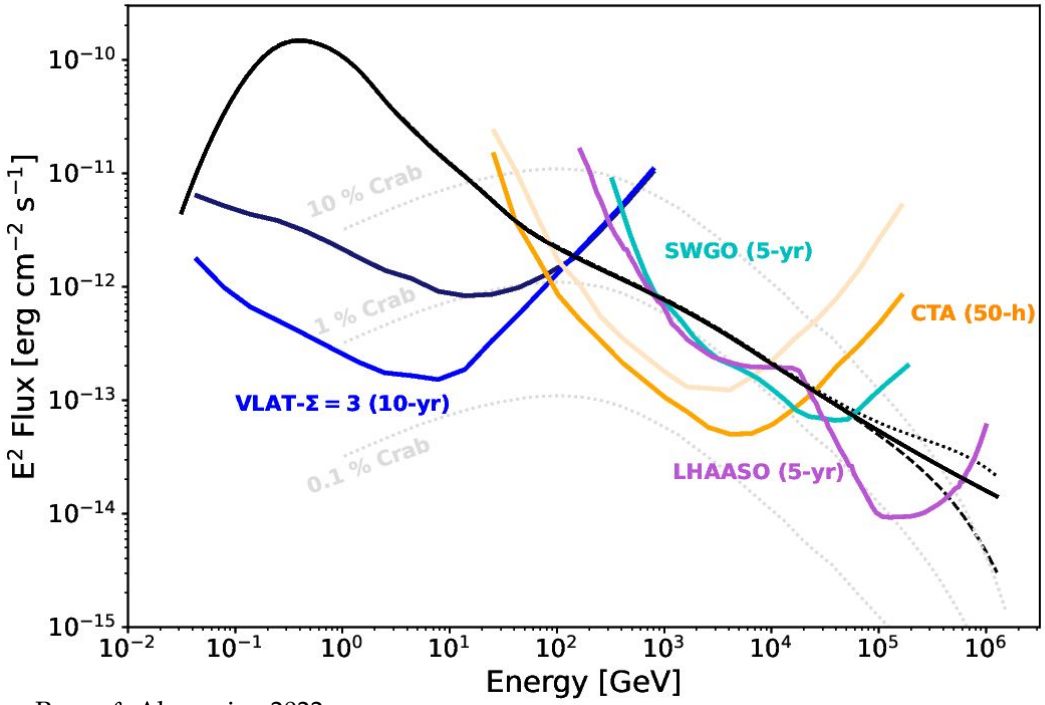
approximate worsening in the sensitivity



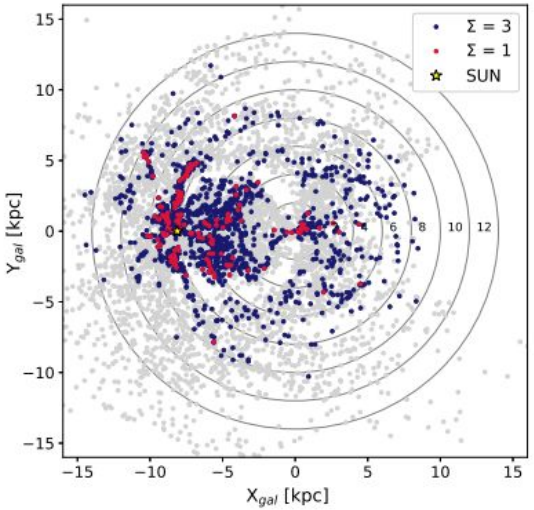
Peron & Aharonian 2022

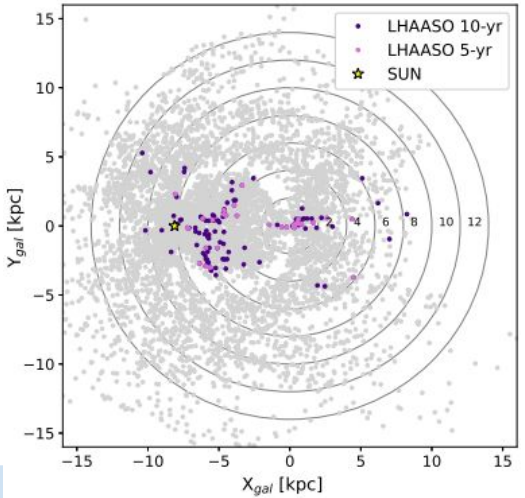


The prospects for the future



Peron & Aharonian 2022





Summary

- Diffuse emission is an important component that can be used as a **source** to probe CRs in the Galaxy and must be used as a **background** for the detection of discrete sources;
- The contribution of **unresolved sources** cannot be ignored and it increases with energy;
- **Molecules clouds** are localized enhancement of gas density that can serve as targets to constrain the CR density point by point;
- LHAASO, CTA and SWGO have large chances for detection of diffuse emission and molecular clouds at very high energies;
- **Template fitting** analysis is more sensitive to low brightness sources and is now possible also at VHE energy.

THANK YOU!