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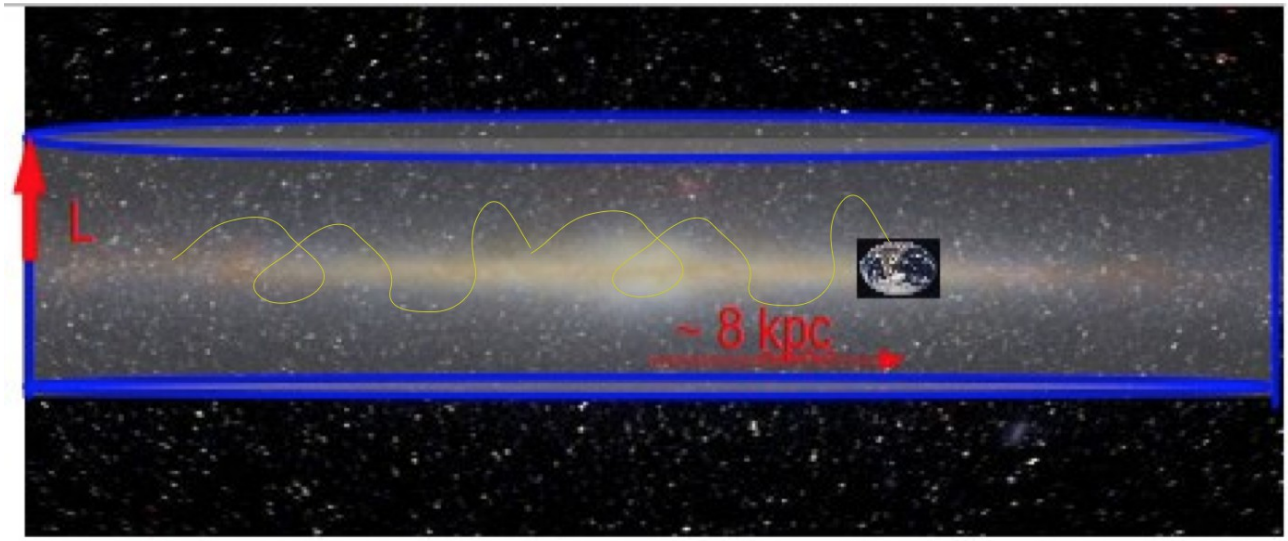
Confronting cosmic-rays models with gamma-rays observations

MultiDark Consolider Workshop
Instituto de Física Teorica
26/05/2017

Instituto de Física Teórica UAM-CSIC

MultiDark
Multimessenger Approach for Dark Matter Detection

Cosmic rays transport



Spatial diffusion

Energy losses

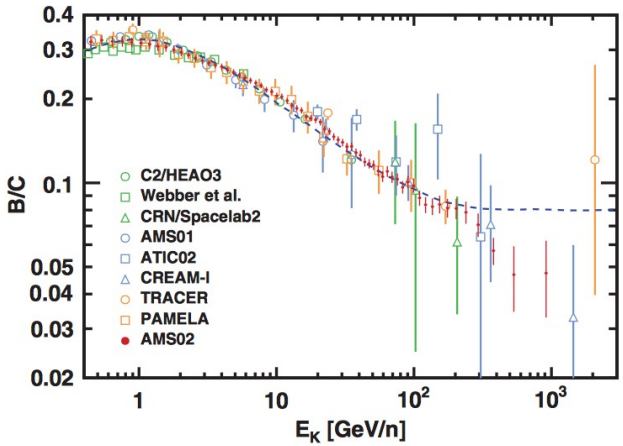
$$\nabla \cdot (\vec{J}_i - \vec{v}_w N_i) + \frac{\partial}{\partial p}\left[p^2 D_{pp} \frac{\partial}{\partial p}\left(\frac{N_i}{p^2}\right)\right] - \frac{\partial}{\partial p}\left[\dot{p} N_i - \frac{p}{3}\left(\vec{\nabla} \cdot \vec{v}_w\right) N_i\right] =$$

$$Q + \sum_{i<j}\left(c\beta n_{\rm gas}\,\sigma_{j\to i} + \frac{1}{\gamma \tau_{j\to i}}\right) N_j - \left(c\beta n_{\rm gas}\,\sigma_i + \frac{1}{\gamma \tau_i}\right) N_i$$

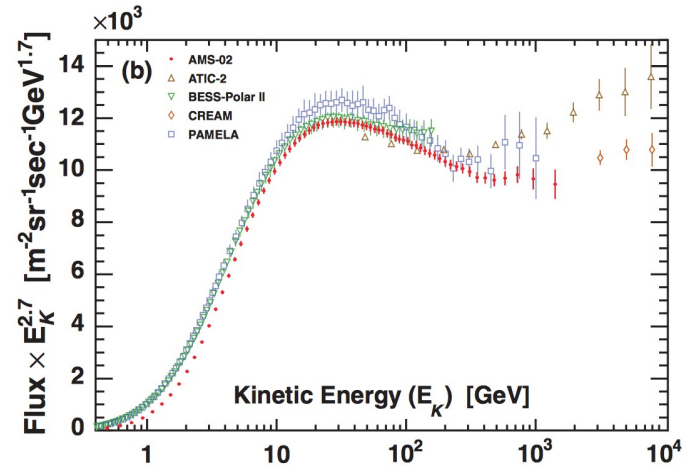
Source term

Spallation

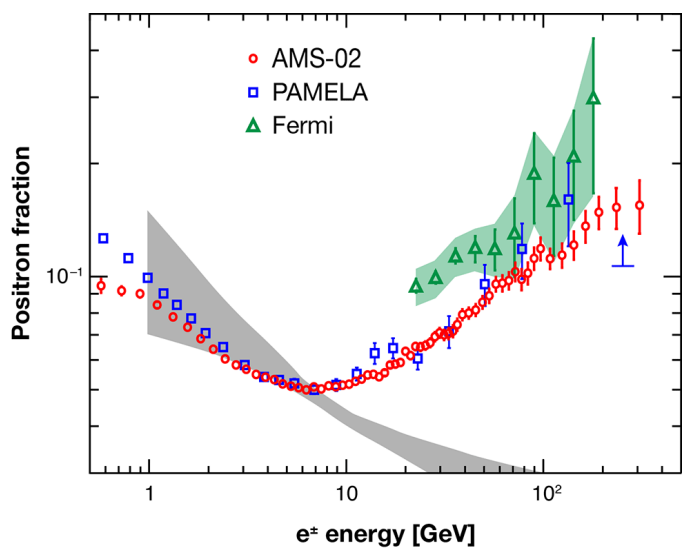
Observations and anomalies



B/C: tool to constrain diffusion coefficient

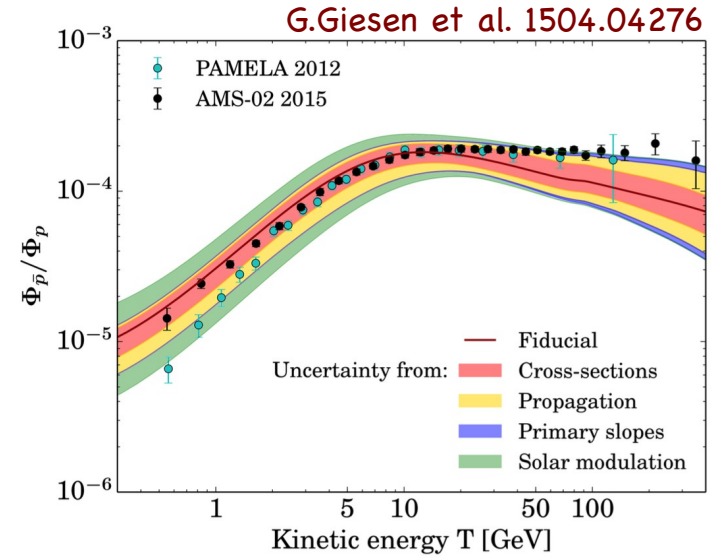


Break in p and He spectrum. Compatible with CREAM at larger energies. Why?



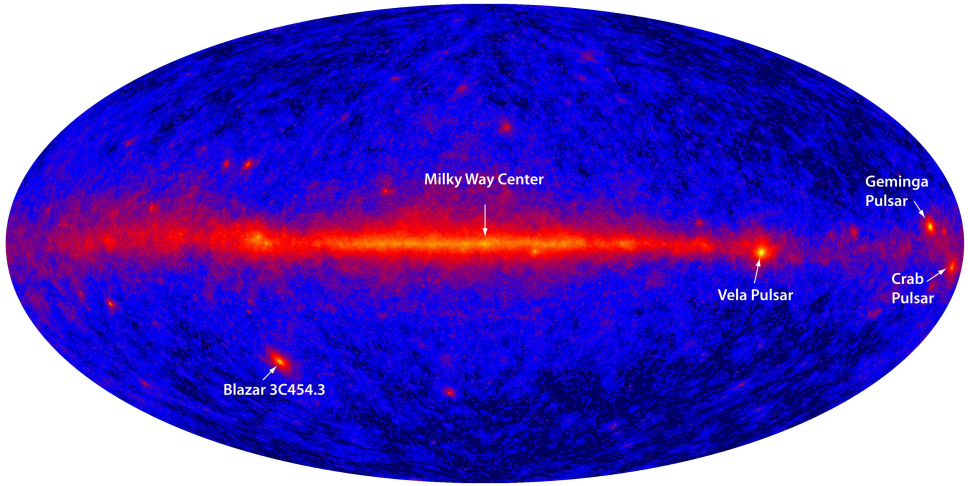
Long standing anomaly: pulsar hypothesis most likely explanation

G.Giesen et al. 1504.04276



Small (2-sigma) excess at high energies.

Gamma-rays - CR connection



Fermi-LAT observations: 300MeV-500 GeV

Gamma-rays produced as pion decays (CR nuclei interactions with the gas), bremsstrahlung and Inverse Compton (CR electrons interactions respectively with gas and Interstellar Radiation Field).

Large fraction of detected emission is from these processes!

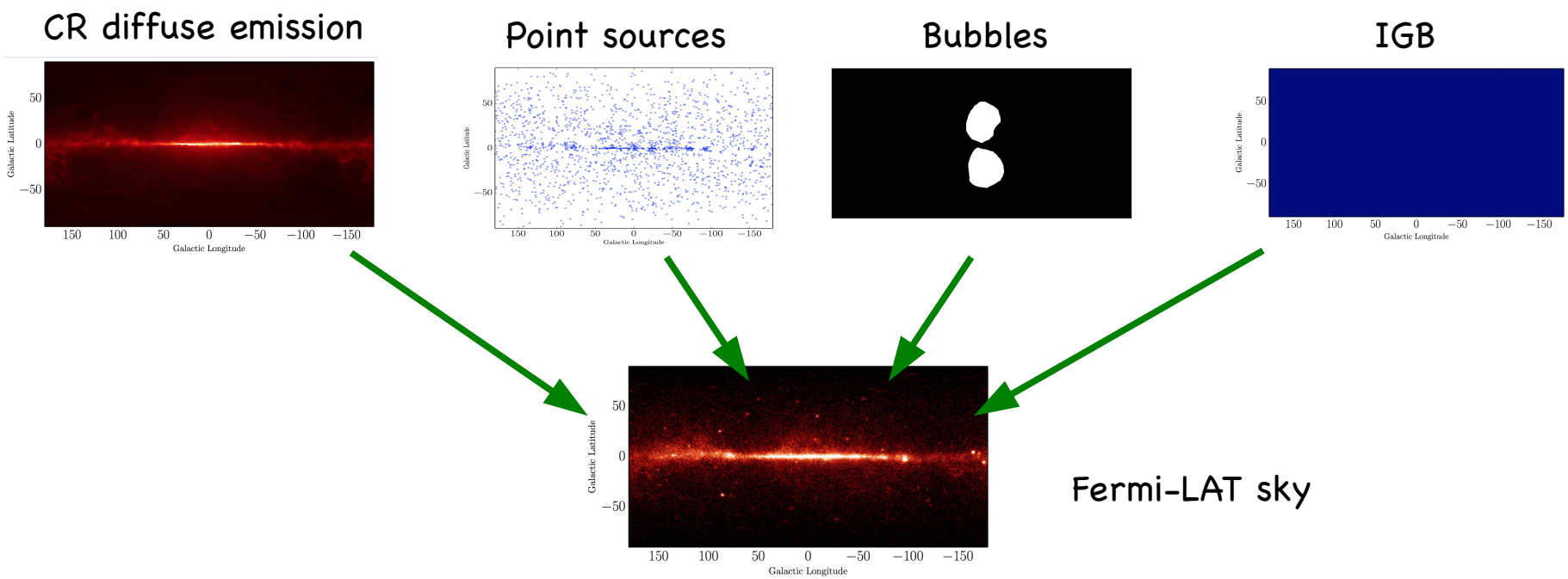
Gamma-rays are a precious tool to indirectly study the CR distribution in different regions of the galaxy.

Understanding the gamma-ray sky

In the recent years dramatic improvement in quality of gamma-ray data due to Fermi and ACTs.
Comparison with data:
Simulate galactic diffuse emission from cosmic-rays (CR) interactions with medium.
Sum extra templates (isotropic, sources...)
Let the data choose the best model, eventually allowing a rescaling of the templates and a tuning on the CR sources (template fitting method).

This is lead a satisfactory description of data in large part of the sky (residual around/below 10%).

Caveat: simplified description of CR transport? Need to rethink this ingredient?

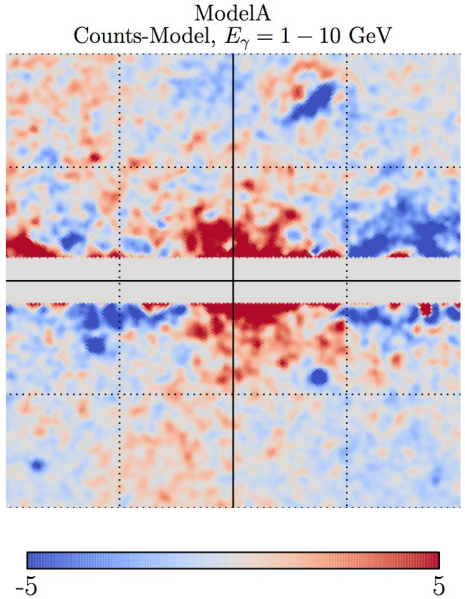


The Galactic Center GeV excess

Excess of photons from the central region of the Galaxy

- Roughly spherically symmetric
- Extended at least up to 10 degrees.
- Spectrum peaks in the GeV range.

Data - Model =

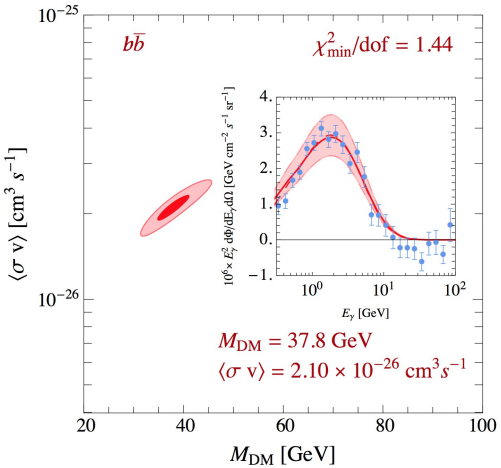


Compatible with DM annihilations

Unresolved populations of sources?

Mis-modeling of the background?

Simplified description of CR transport?
Central region of galaxy present large reservoir of CR sources which is not captured in models tailored to describe large-scale "local" observations

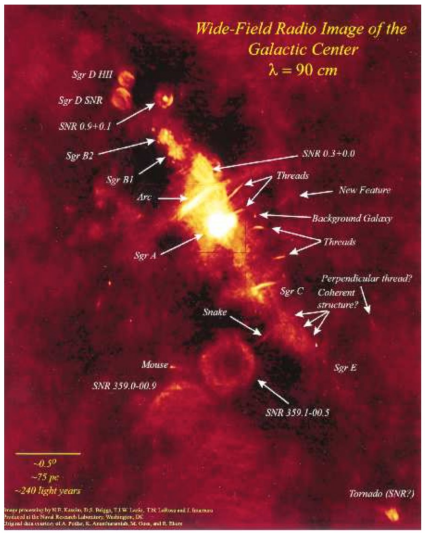


Do we understand the diffuse emission from cosmic-rays at the GC?

GC region very peculiar: large reservoir of gas in the 200-300 pc inner region, **large Star Formation Rate**, factor few hundreds larger than average galaxy rate (roughly few % of total SFR of the galaxy).

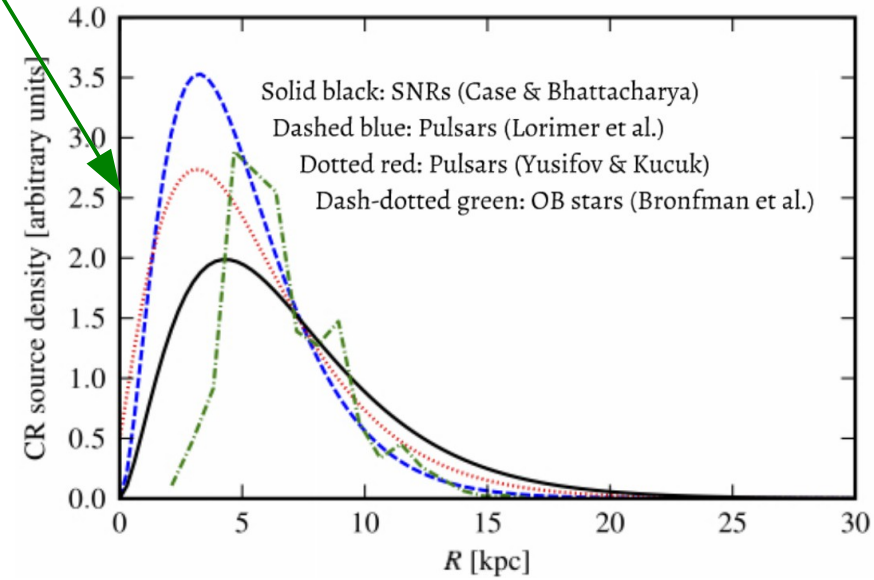
Ferriere et al. astro-ph/0702532, Figer et al. astro-ph/0208145, Longmore et al. 1208.4256, Yusef-Zadeh et al. AJ 2009, Immer et al. 2009

Central Molecular Zone



Something is missing here!

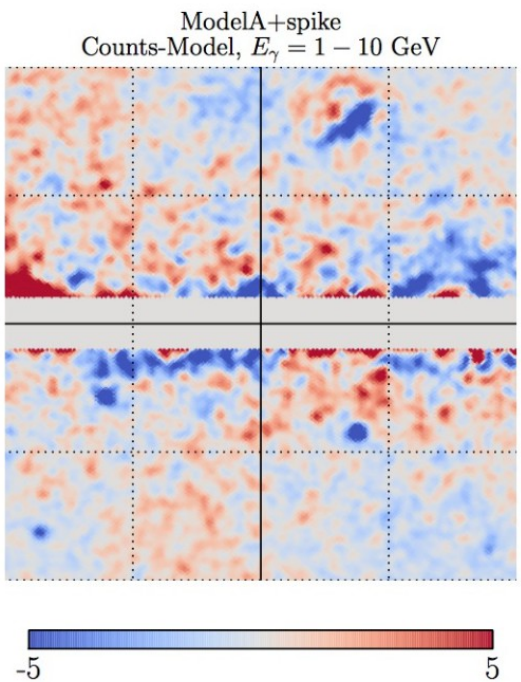
"Standard "CR sources distribution

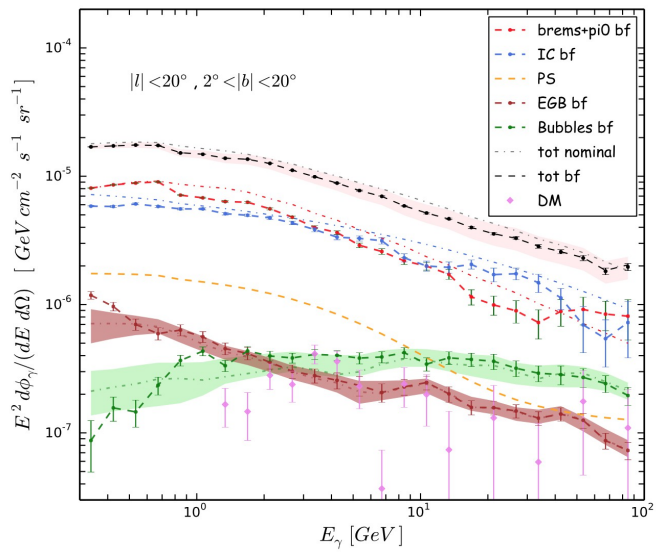


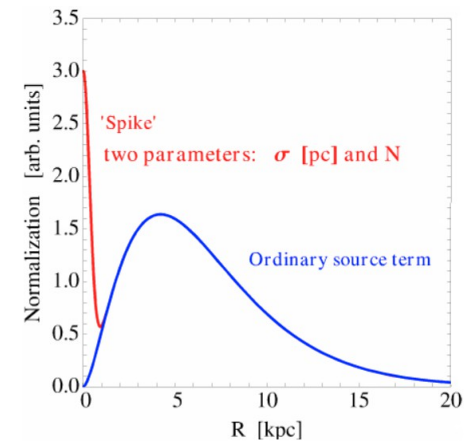
New CR source term in the inner galaxy

Add to the standard CR source distribution an extra source term with a spatial extent and normalization compatible with obs.
Excess (partially) reabsorbed

D.Gaggero, M.T., P.Ullio, A.Urbano, M.Valli 1507.06129







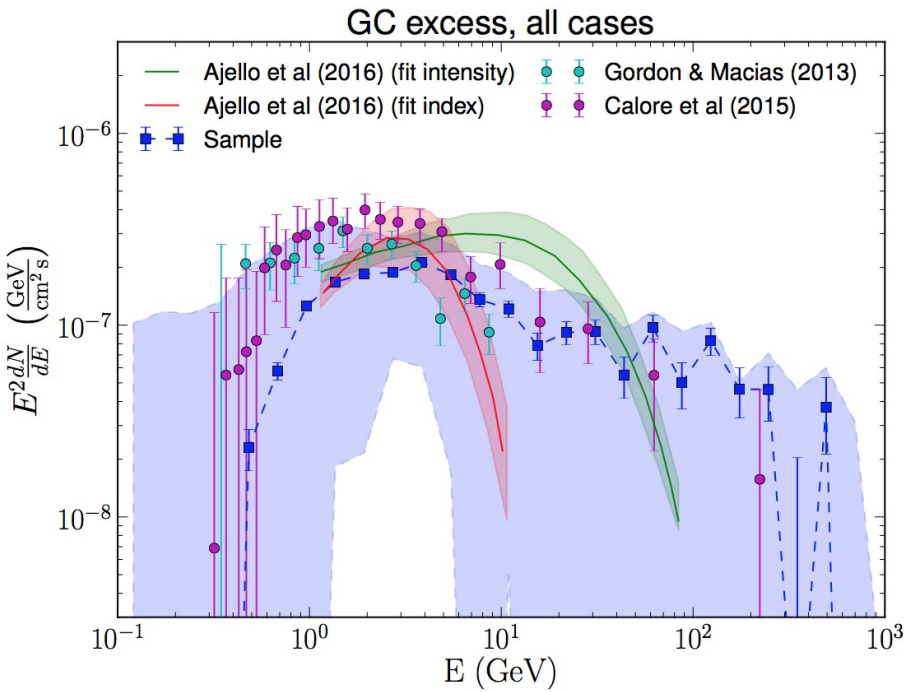
Recent analysis: Carlson,Profumo, Linden 1510.0469, 1603.06584 and Fermi-LAT Coll 1704.03910

The Galactic Center GeV excess

Sources in CMZ region and low-latitude emission of Fermi Bubbles matter!

Still an excess at few-GeVs

Fermi-LAT Coll 1704.03910



Fermi-LAT Coll 1705.00009

Recent Fermi-LAT analysis supports the evidence for a population of gamma-ray pulsars in the galactic bulge. Spatial profile and energy spectrum compatible with the GC GeV excess.
Results consistent with previous analysis Lee et al. 1506.05124, Bartels et al. 1506.05104

Need experiment with superior performances at GeV energy to finally confirm this interpretation and/or radio-observations (Dozens or hundreds of sources at the reach of radio surveys?).

Proton hardening in the inner galaxy

Conventional diffuse models based on homogenous diffusion in the galaxy under-predict gamma-ray fluxes at high energies towards the center of the galaxy.

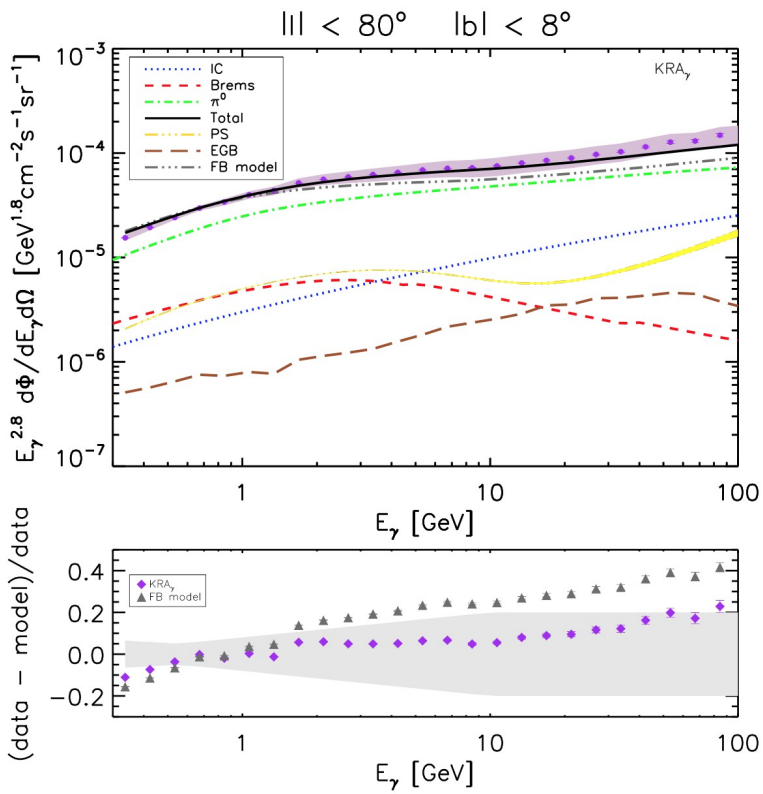
What about environmental dependence of CR transport?

Gaggero, Urbano, Valli, Ullio 1411.7623

Model based on spatial dependence of diffusion index

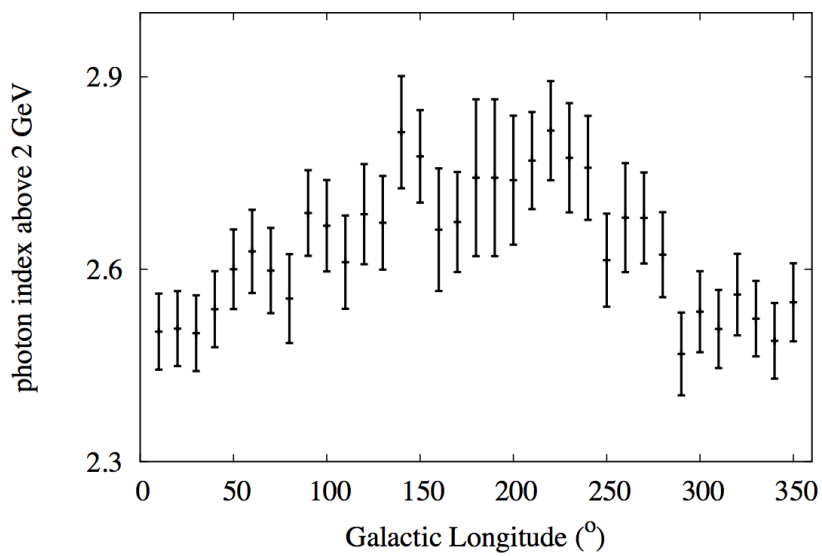
$$D(\rho) = D_0 \beta^\eta \left(\frac{\rho}{\rho_0}\right)^{\delta(r)}$$

$$\delta(r) = ar + b$$

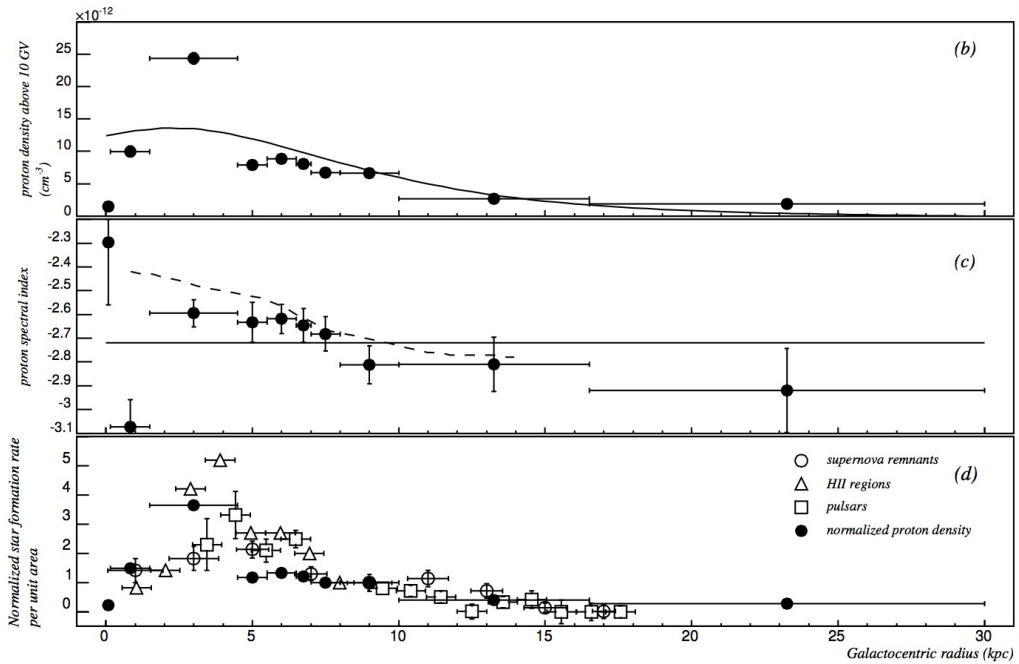


Other analysis on the proton hardening

Evidence of hardening of proton spectrum from gamma-ray maps.



Yang, Aharonian, Evoli 1602.04710



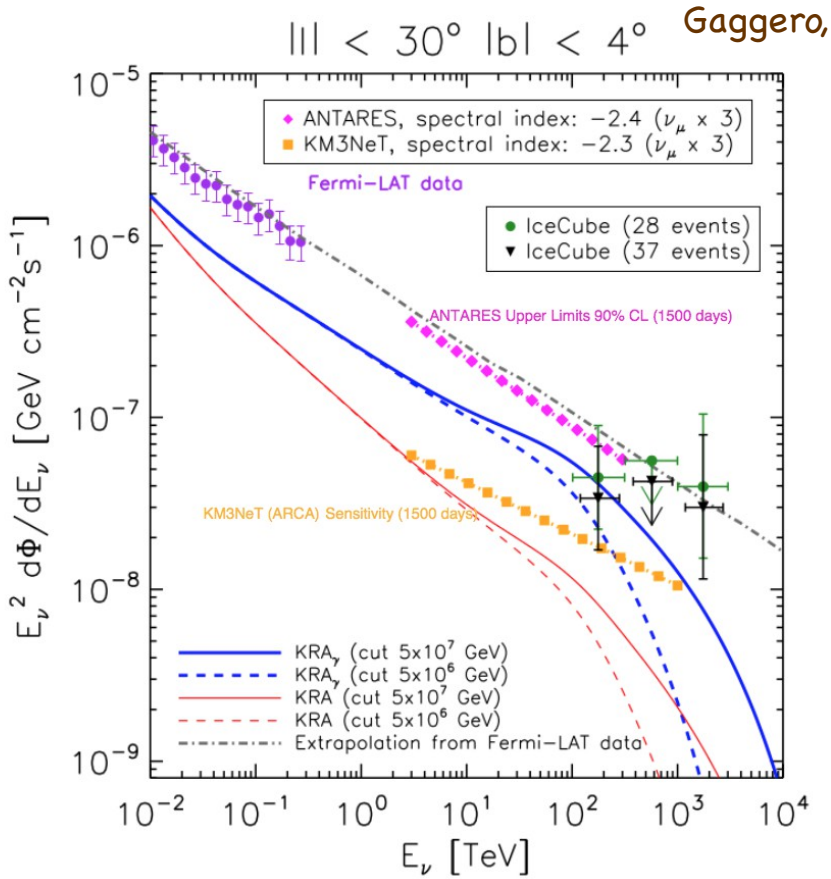
Fermi-LAT Coll. 2016, 1602.07246

Implications for neutrinos

The model predicts an harder neutrino spectrum and may account for a significant fraction of the full-sky astrophysical flux measured by IceCube

Interesting predictions for IceCube, ANTATES, KM3NET

Gaggero, Grasso, Marinelli, Urbano, Valli 1411.7623



Expectations for diffuse HE neutrinos from CRs

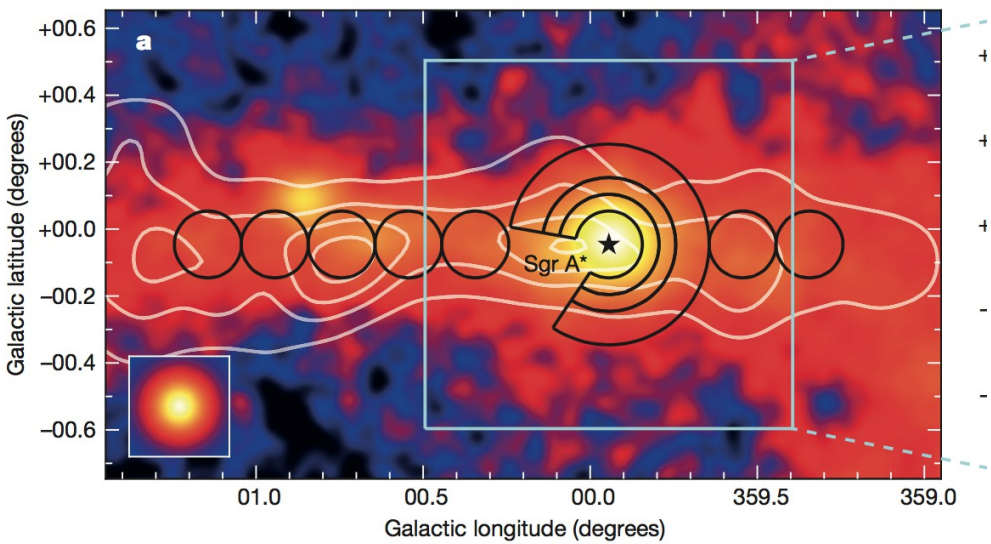
Pagliaroli et al. 1606.04489, Vissani et al. 1604.08791

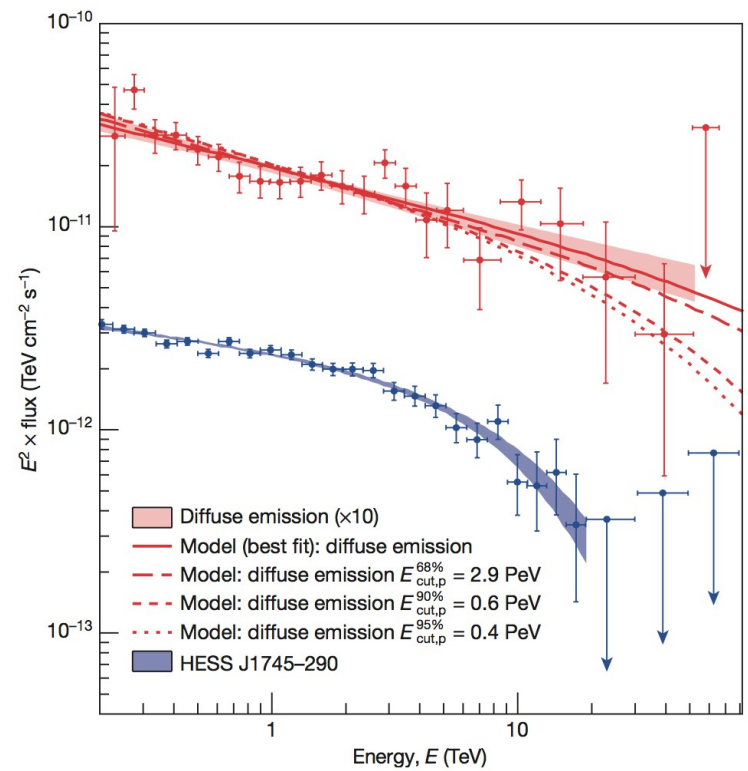
High energy gamma-rays

High-energy emission observed by HESS in the Galactic Ridge.

Recently HESS reported the evidence of a diffuse emission associated to PeV protons possibly associated to the central source

The spectrum is much harder than those obtain from CR with a local spectrum





HESS Coll. 2016, 1603.07730

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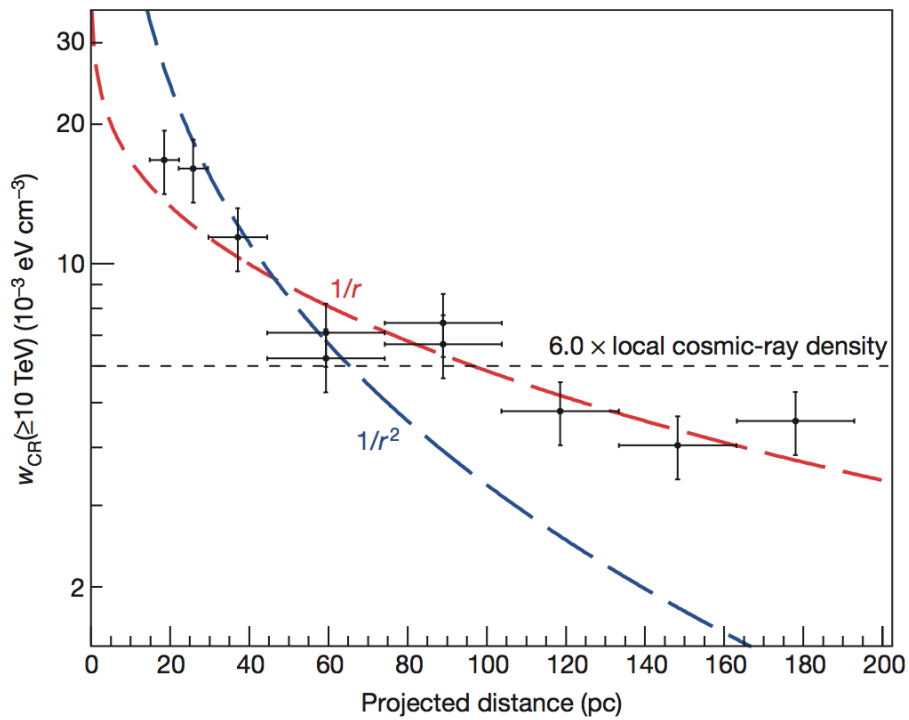
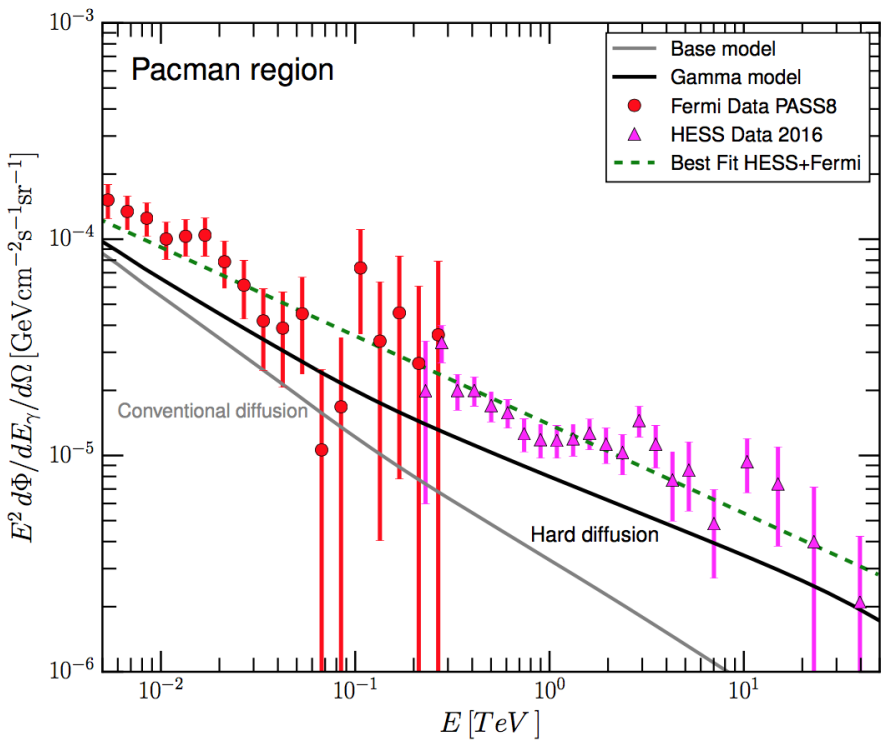
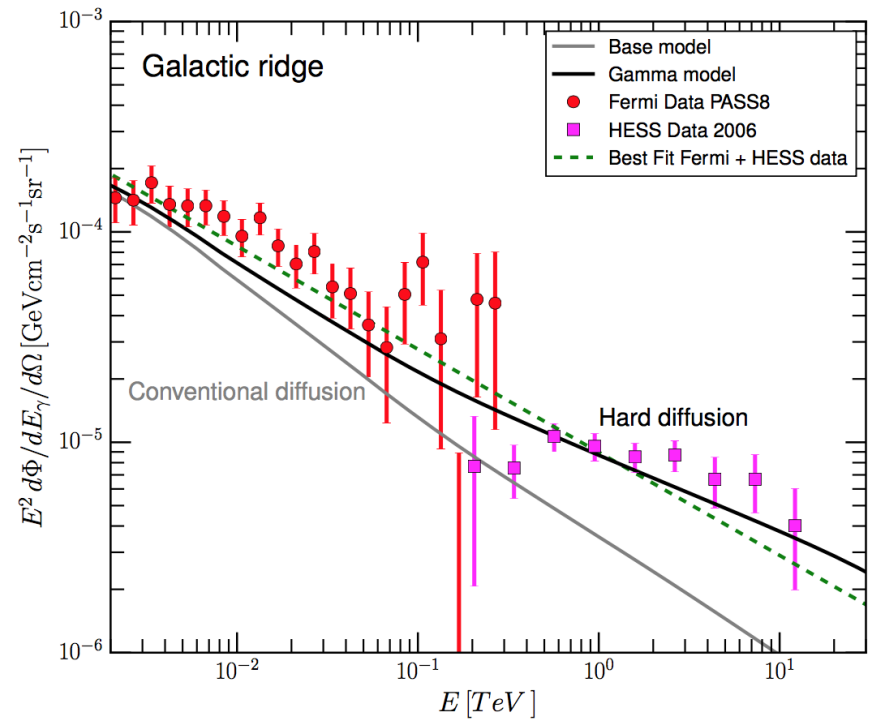


HESS Coll. 2016, 1603.07730

Interpretation of HESS measurements

This model predicts an hard photon spectrum in the Galactic Ridge and it might explain most of the emission! Good target for CTA!





Gaggero, Grasso, Marinelli, Taoso, Urbano 1702.01124

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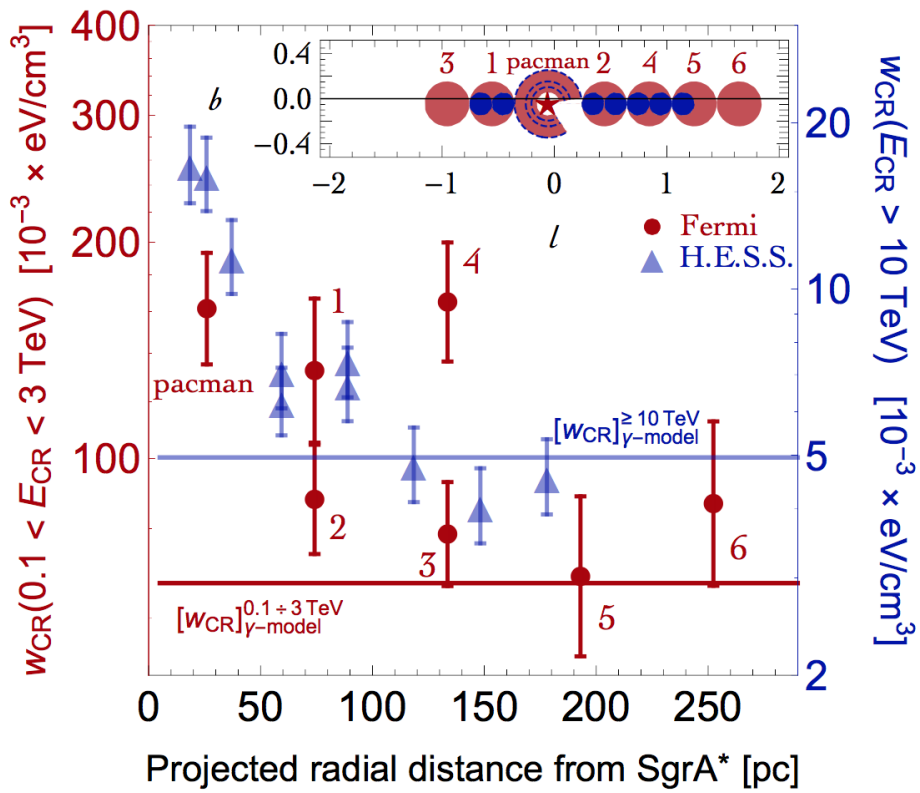


Gaggero, Grasso, Marinelli, Taoso, Urbano 1702.01124

Outlook

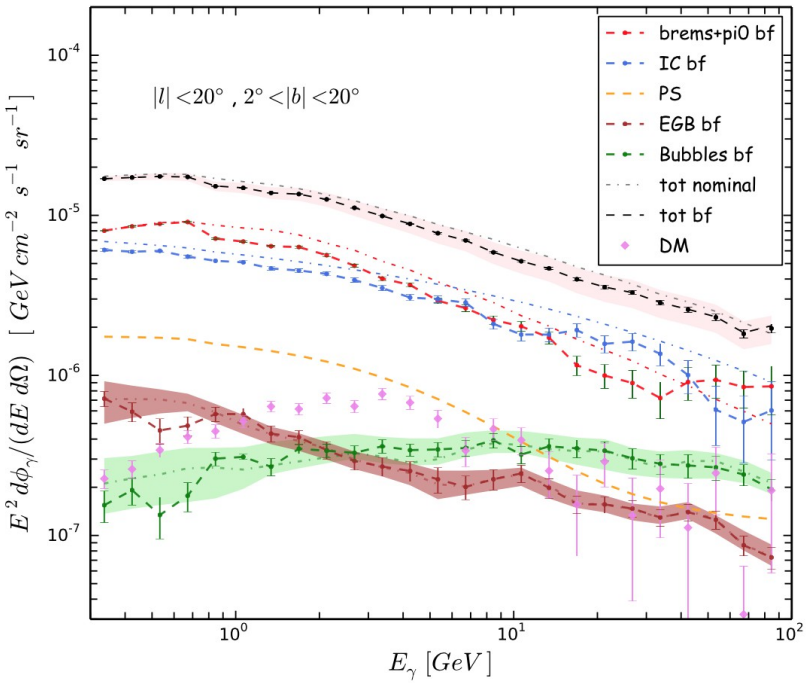
Gamma-rays observations (and maybe neutrinos) are an opportunity to improve our knowledge of the cosmic-rays transport and complement the information from local cosmic-rays measurements.

Observations are pushing us towards more sophisticated and realist models.

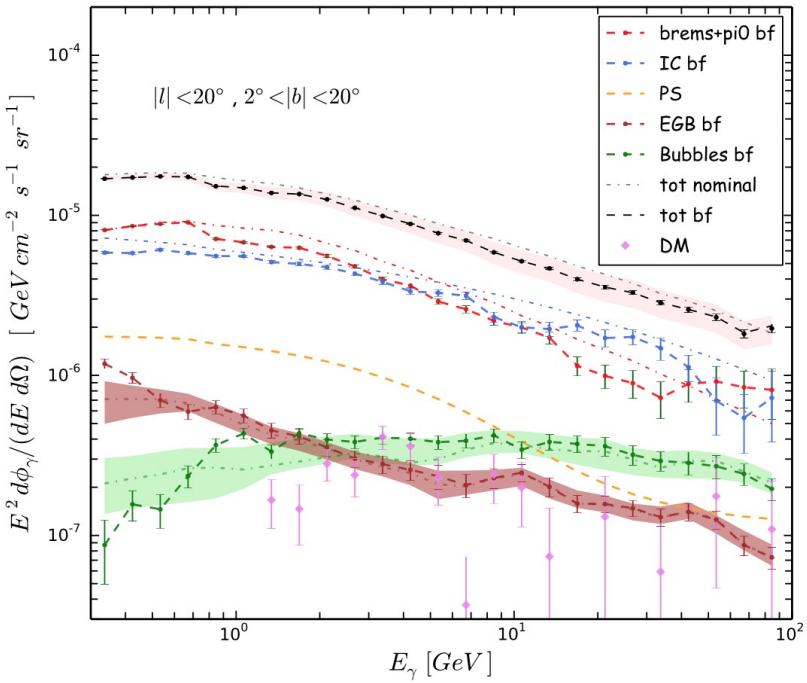
THANKS

Spectrum of the excess

Without CR spike



With CR spike



The GC excess template is degenerate with the IC emission from the spike!