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DM and the Galactic Center GeV excess

Frontier Objects in Astrophysics and Particle Physics

Instituto de Física Teórica UAM-CSIC

Vulcano Workshop

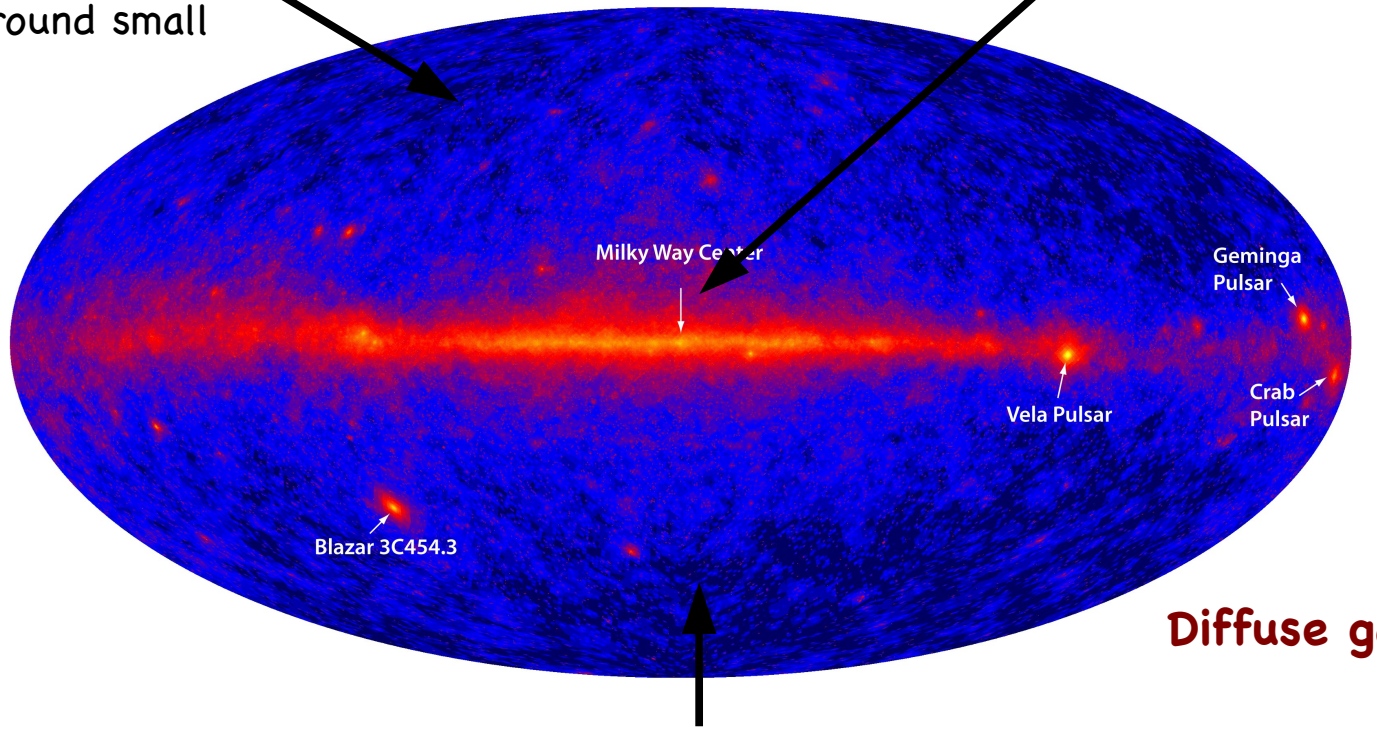
26-05- 2016

How and where to look for DM annihilations

$$\Phi \propto \int ds d\Omega \;\; \rho^2_{DM}(s,\Omega)$$

Dwarf galaxies
Large Mass/Luminosity ratio
Nearby
Astro background small

Galactic center
+ Large DM density
- lots of sources, large bkg



DM clumps

Diffuse galactic halo

Clusters of galaxies

Extragalactic diffuse emission

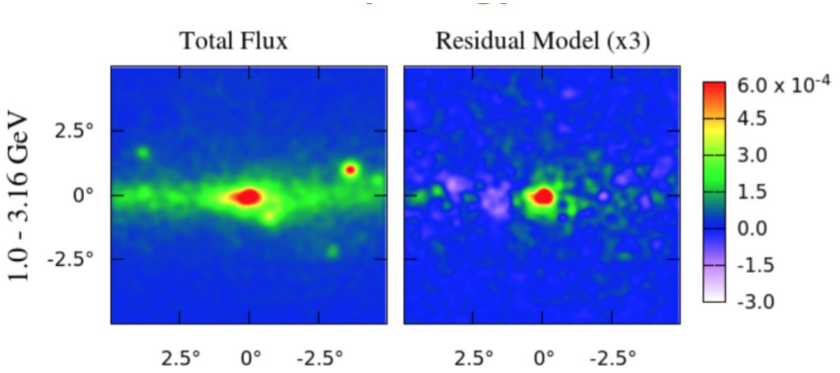
The Galactic Center GeV excess

- Circa 2010: is there an excess of photons from the GC ?

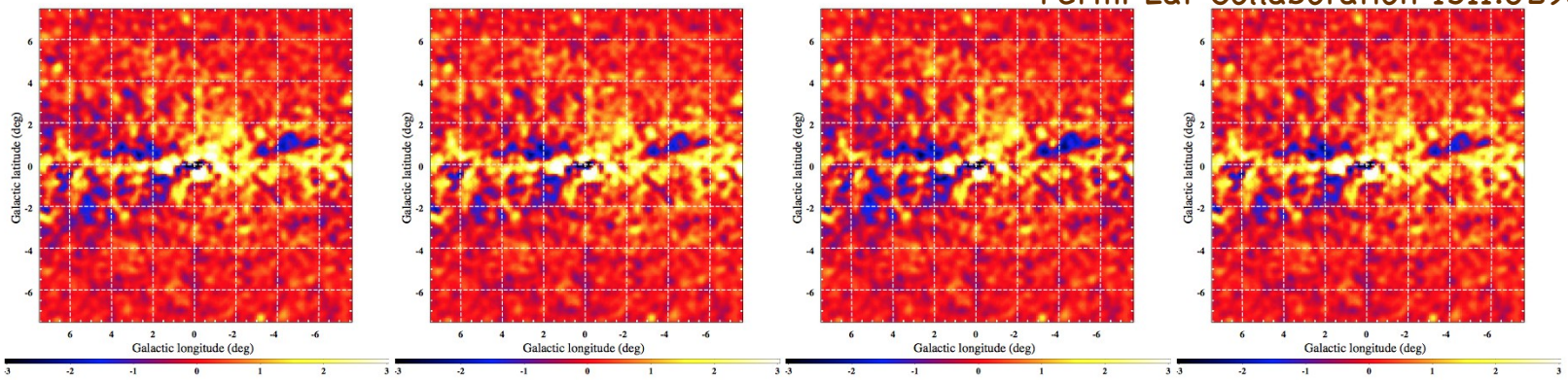
- Last few years: which are its properties?

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

Daylan et al. 1402.6703



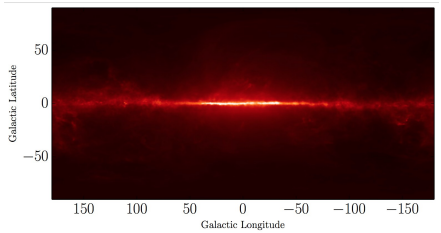
Fermi Lat Collaboration 1511.02938



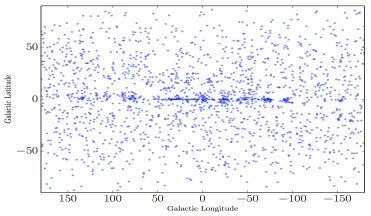
Vitale and Morsell 0912.3828, Godenough, Hooper 0910.29998; Hooper, Linden 110.0006; Abazajian Kaplinghat 1010.2752; Hooper, Slatyer 1302.6589; Gordon, Macias 1306.5725; Huang,Urbano,Xue 1307.6862; Abazajian,Canac,Horiuchi,Kaplinghat 1402.4090; Daylan,Finkbeiner,Hooper,Linden,Portillo,Rodd,Slatyer 142.4090;Calore et al. 1409.0042; Calore,Cholis,Weniger 1409.0042; Fermi Collaboration, + ...

Template fitting analysis

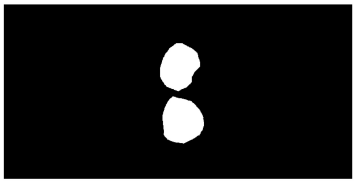
CR diffuse emission



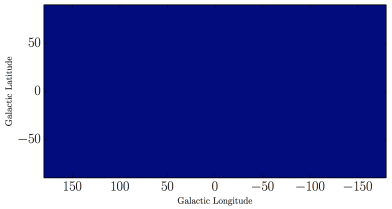
Point sources



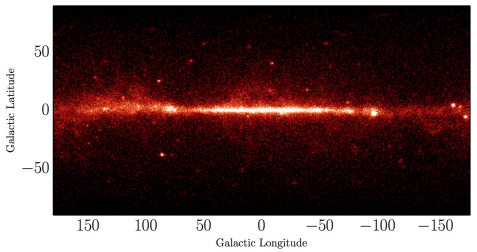
Bubbles



IGB



Fermi-LAT sky

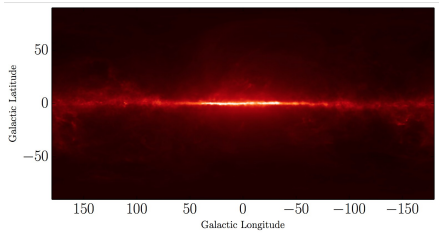


Describe the sky as a linear superposition of spatial templates. Determine coefficients from a Poisson Maximum Likelihood fit

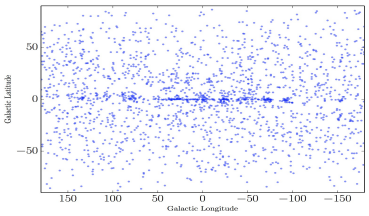
$$-2\ln(\mathcal{L}) = 2\sum_i (e_i - o_i \ \ln(e_i)) + 2\sum_i \ln(o_i!) + \chi^2_{\rm ext}$$

Template fitting analysis

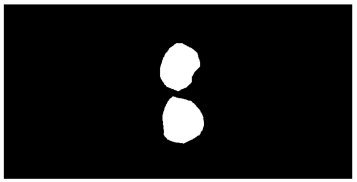
CR diffuse emission



Point sources



Bubbles



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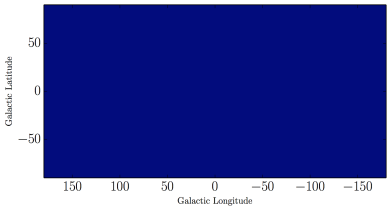
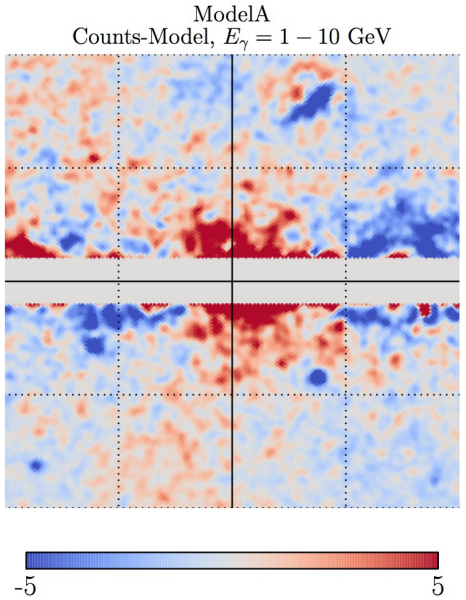


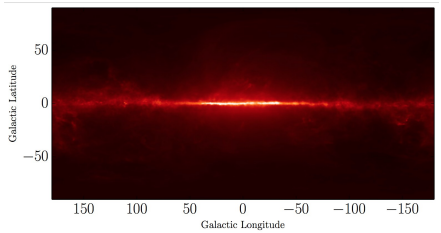
Data - Model =



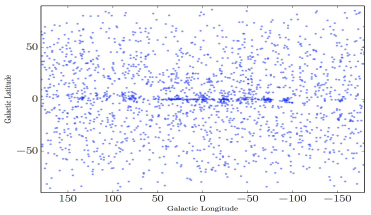
Something is missing!

Template fitting analysis

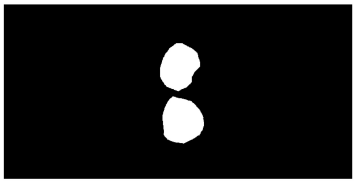
CR diffuse emission



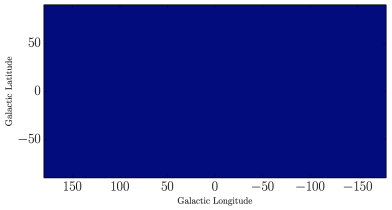
Point sources



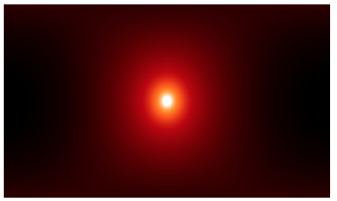
Bubbles



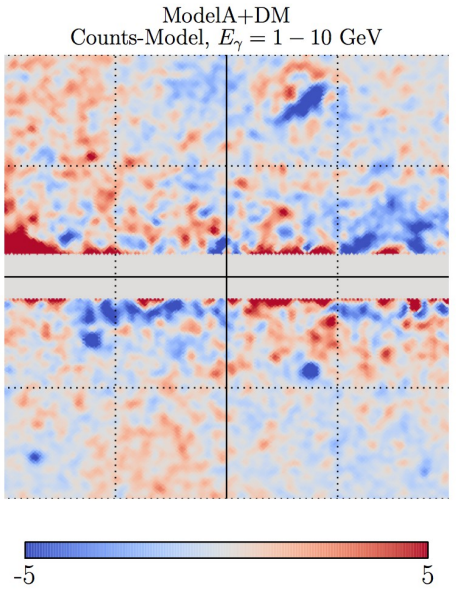
IGB

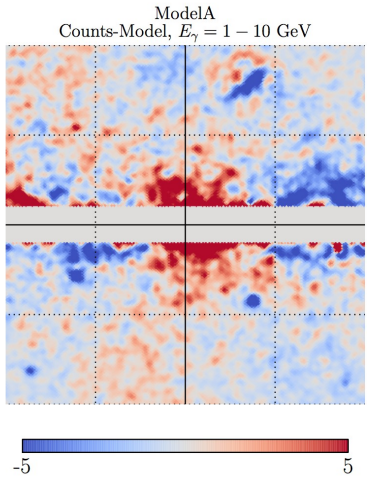


DM



Data − Model =

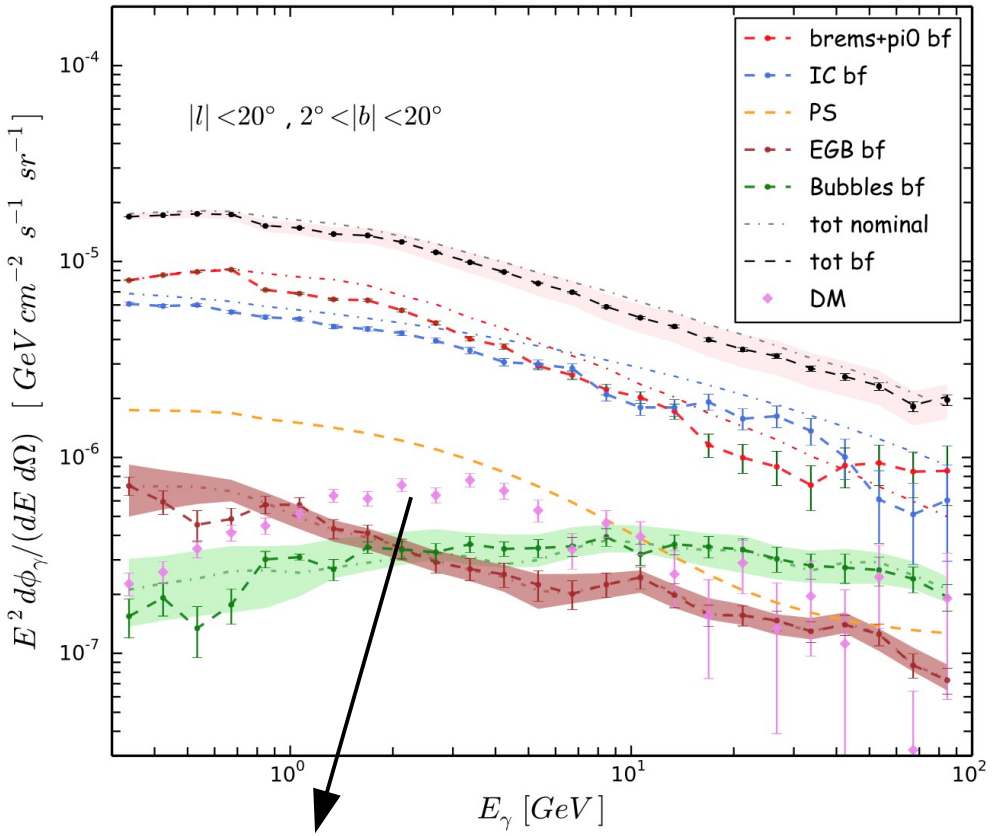




w/ DM

"Standard diffuse" + DM

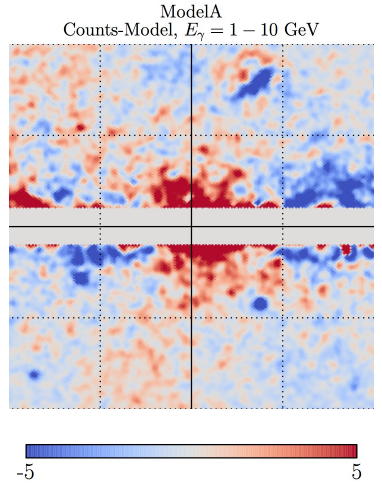
Adopting standard diffusion models, the presence of a DM template is favored by the fit by a large statistical significance.



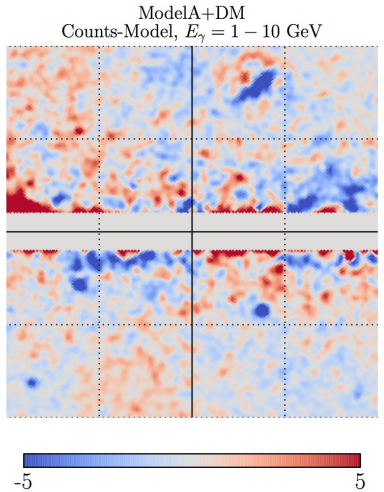
Bump-like DM energy spectrum

Data-Model

w/o DM

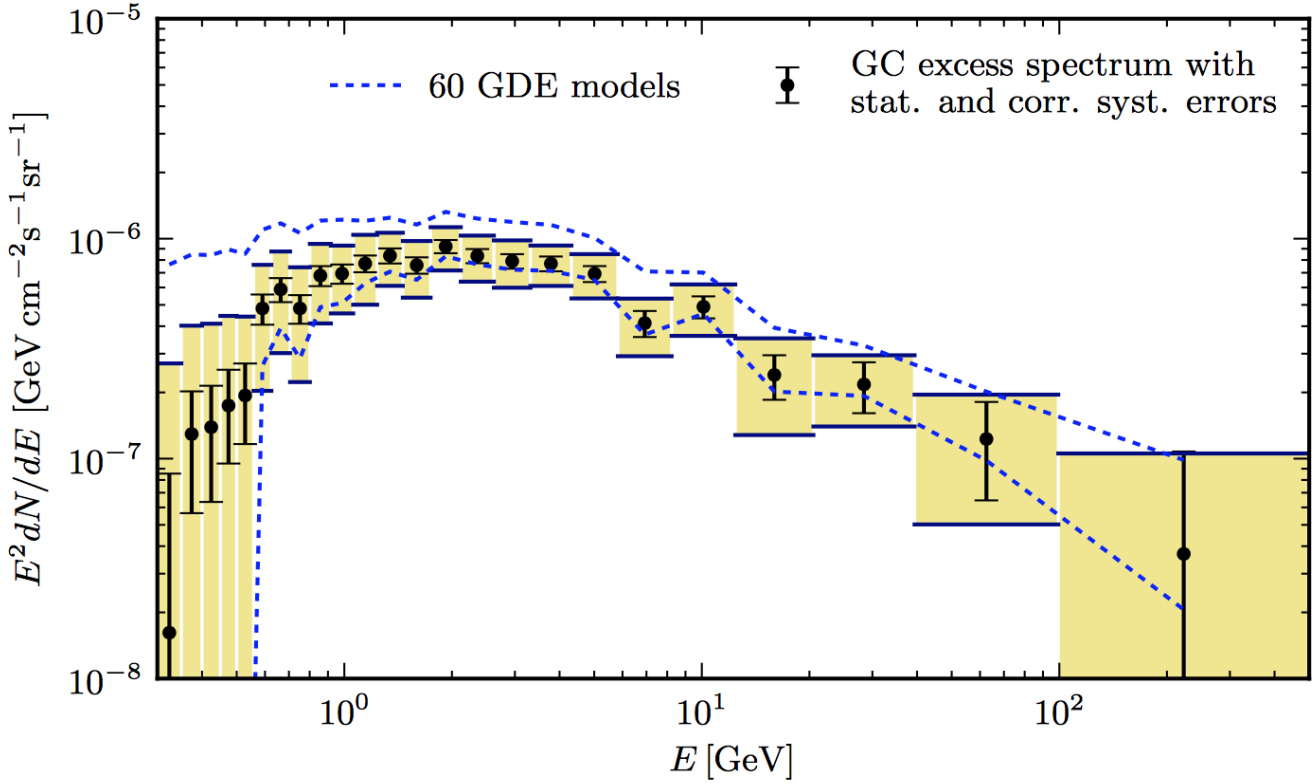


w/ DM



Some systematics on diffuse emission

Are we sure about our model of diffuse emission?
How the systematical uncertainties impact the properties of the excess that we infer?



Calore,Cholis,Weniger 1409.0042

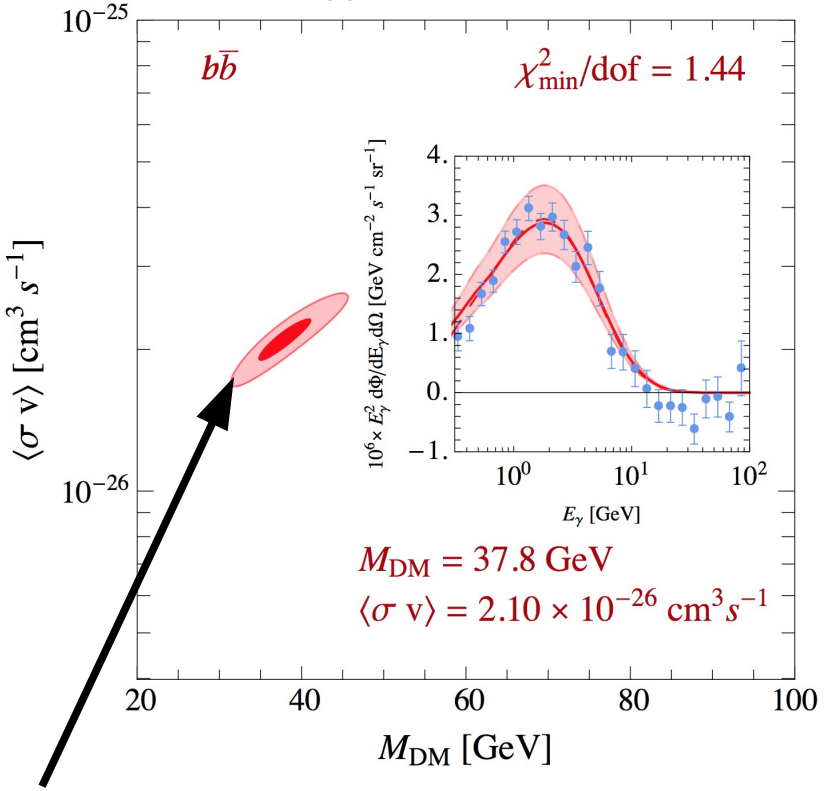
See also Zhou, Liang, Huang, Li, Fan, Feng, Chang, 1406.6948

Dark Matter Interpretation

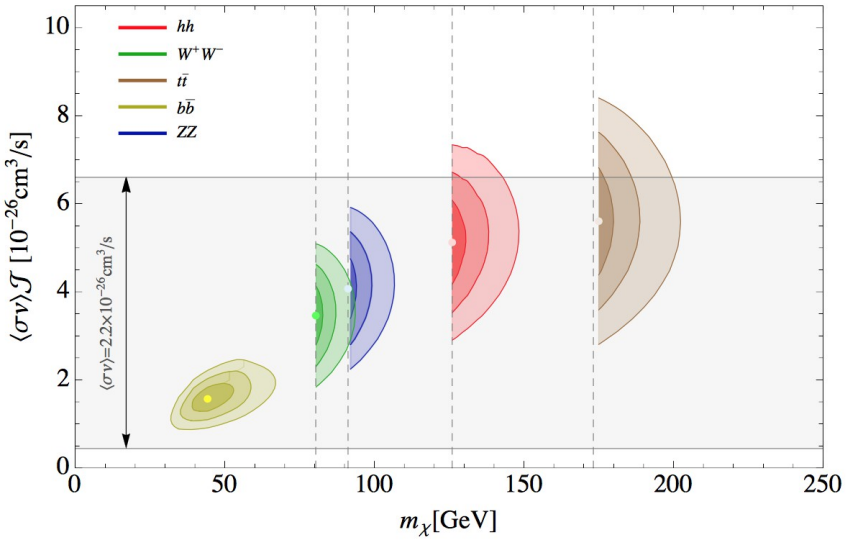
Dark Matter annihilations

- ✓ Requires NFW-like density profiles, or slightly steeper.
- ✓ Spectra from standard DM annihilation channels work.
- ✓ Cross-sections & masses are ok for thermal WIMPS.

Cirelli,Gaggero,Giesen,MT,Urbano 2014



Agrawal et al/ 1411.2592
See also Calore et al. 1411.4672



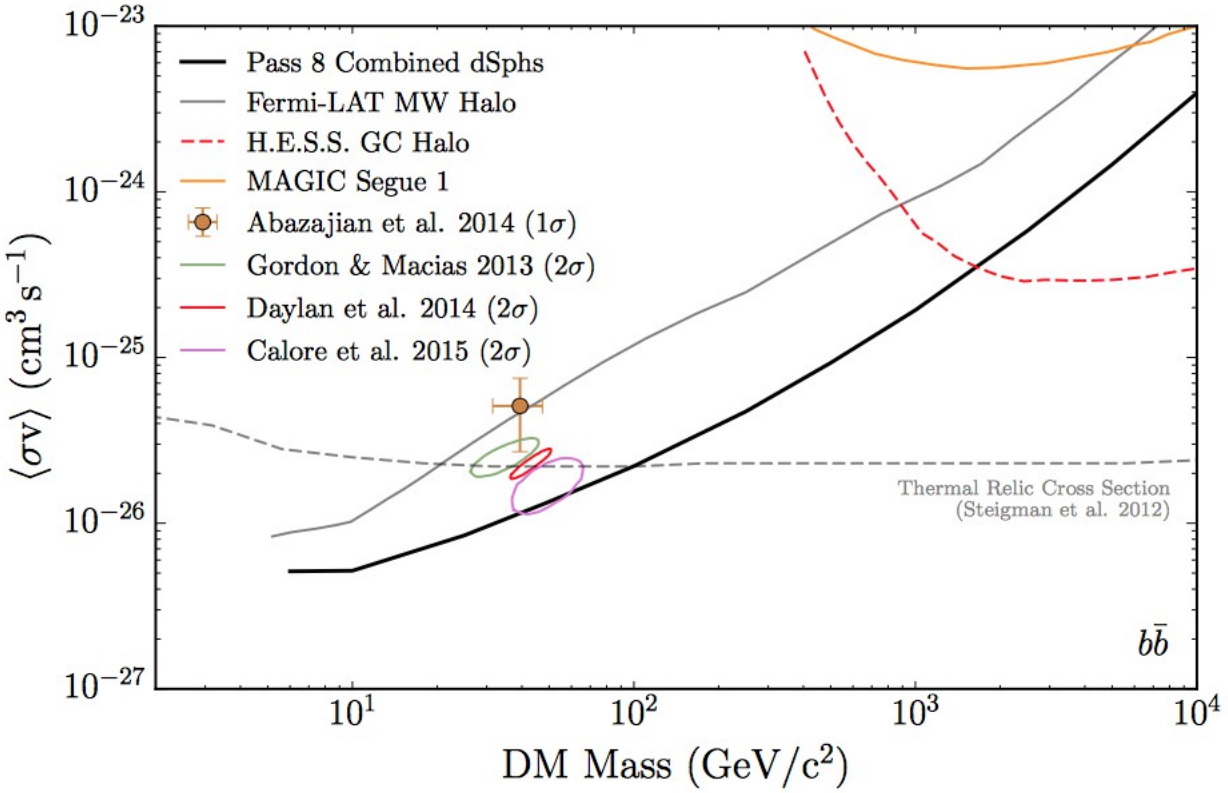
Cross-section close to thermal value!

Constraints

Bounds from Fermi observations of Dwarf Galaxies cut the GC excess region
Beware of uncertainties on J-factors! **See P.Ullio talk**

New dwarfs discovered in recent years (DES, LSST).
Promising avenue for DM.

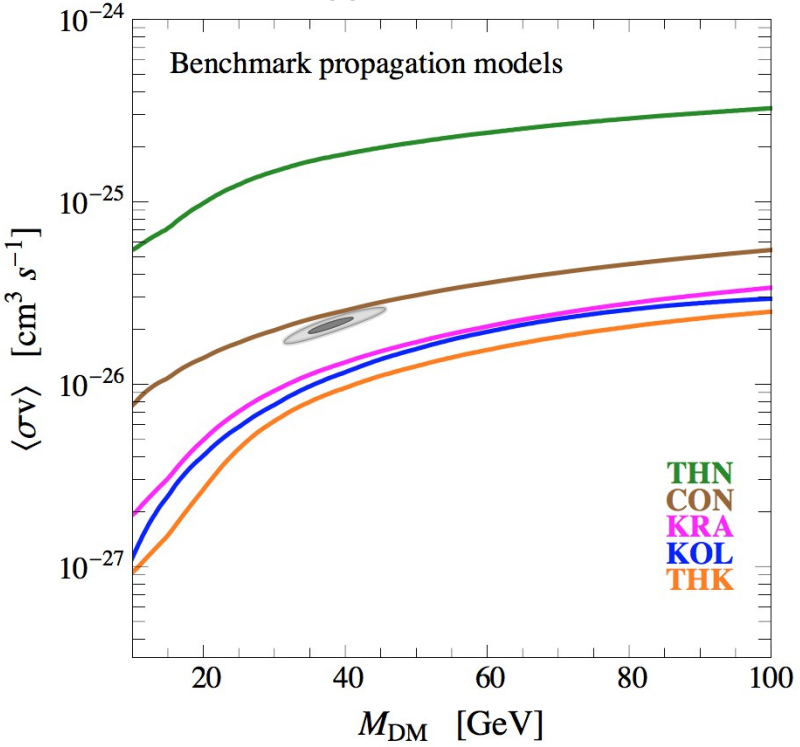
Fermi Collaboration 1503.02641



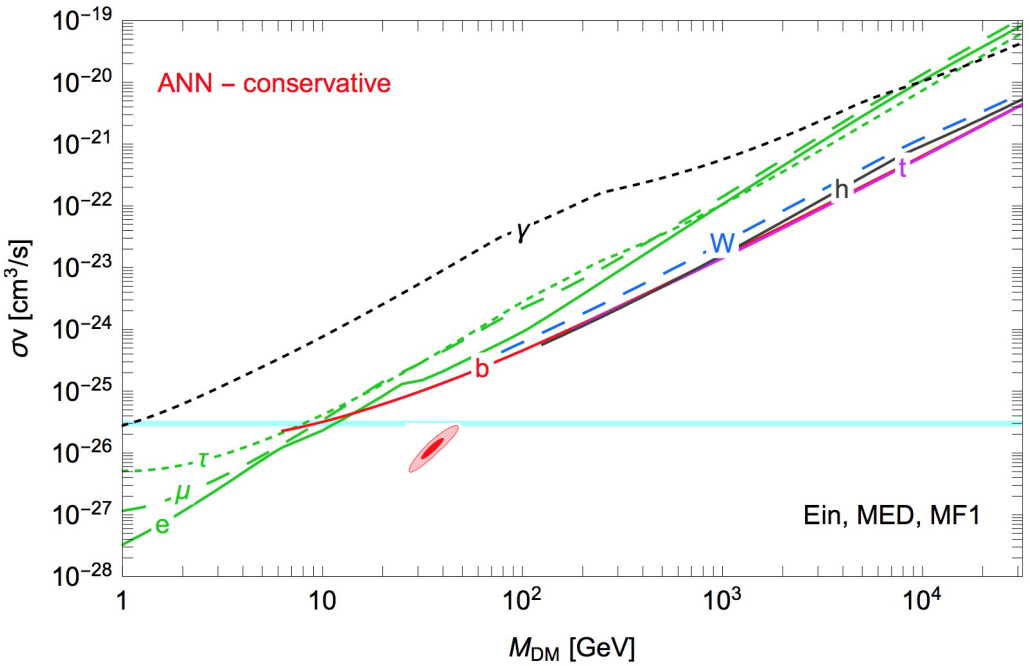
Constraints II

DM annihilations produce also antimatter and secondary photon emissions, e.g. synchrotron fluxes at radio-microwave frequencies.

Cirelli, Gaggero, Giesen, MT, Urbano 1407.2173



Cirelli, MT, Urbano 1604.06267



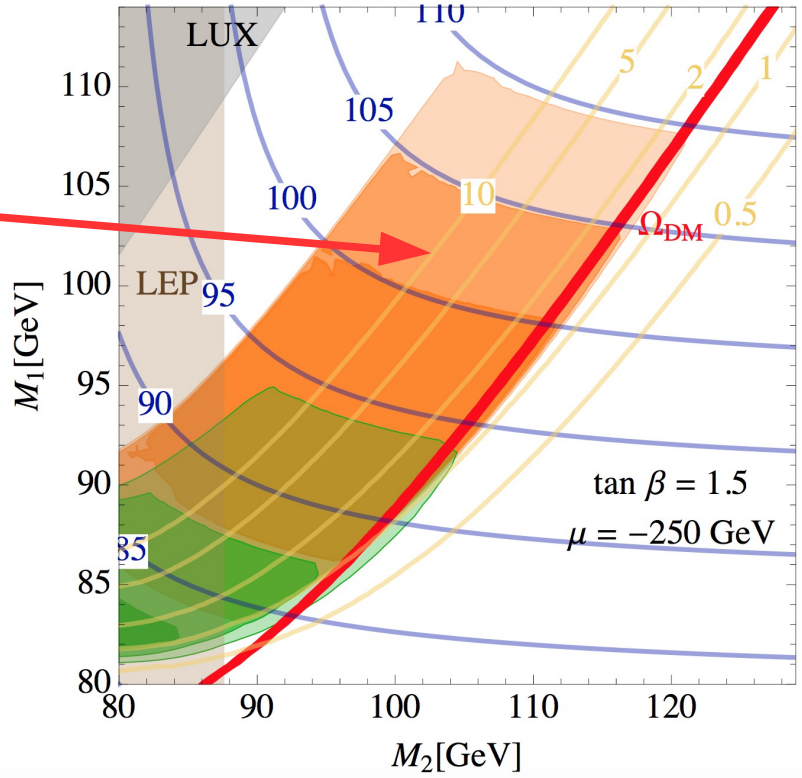
See also Bringmann et al. PRD 14, Hooper et al JCAP 2015, Cholis et al. PRD15, Evoli et al. 2015, ...

DM again

Possible to identify scenario consistent with direct detection (avoid unsuppressed scalar and vector couplings with nuclei) and collider searches.

This is an example in MSSM with a Bino-Wino mixture

GC region



Agrawal et al. 1411.2592

One could even speculate that the X(750) resonance mediates DM interactions and explain both the GC excess and the 750 di-photon excess.

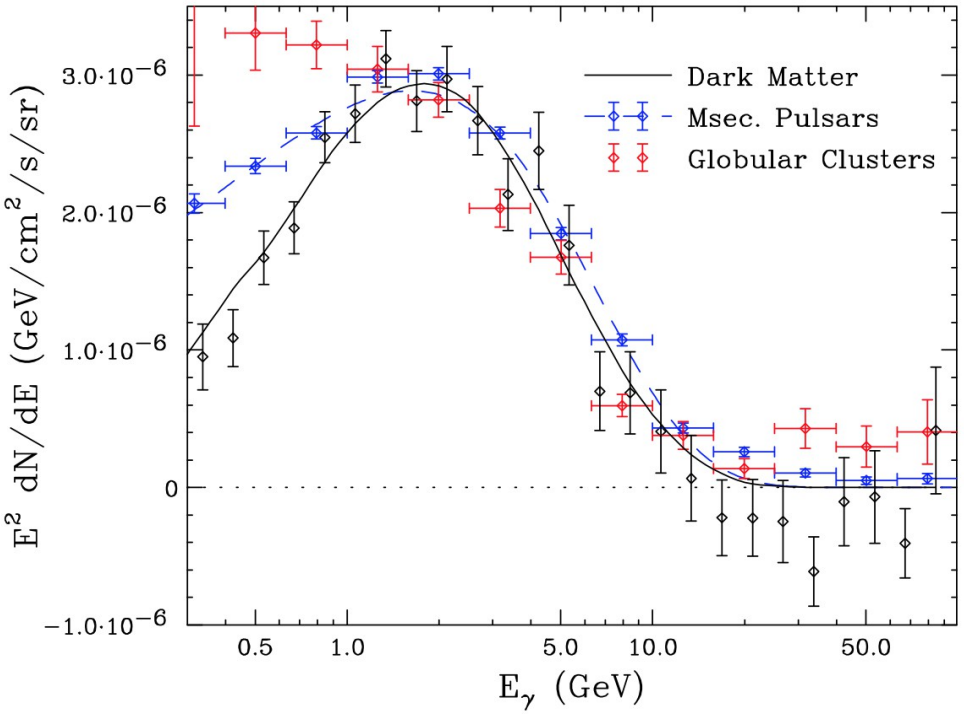
e.g. Huang et al. 151208992,. Hektor et al. 1602.00004, Krauss et al. 1605.05327

DM impostor

Population of unresolved point-sources at the GC?

Milli-second pulsars in the bulge are plausible candidates.
MSP detected by FERMI in globular clusters and in a region of few kpc from us.
Spectrum similar to those of the excess.

Petrovic et al. 1411.2980, Cholis et al. 1407.5625 Yuang et al. 1404.2318, Hooper 1305.0830, O'Leary et al. 1504.02477, ...

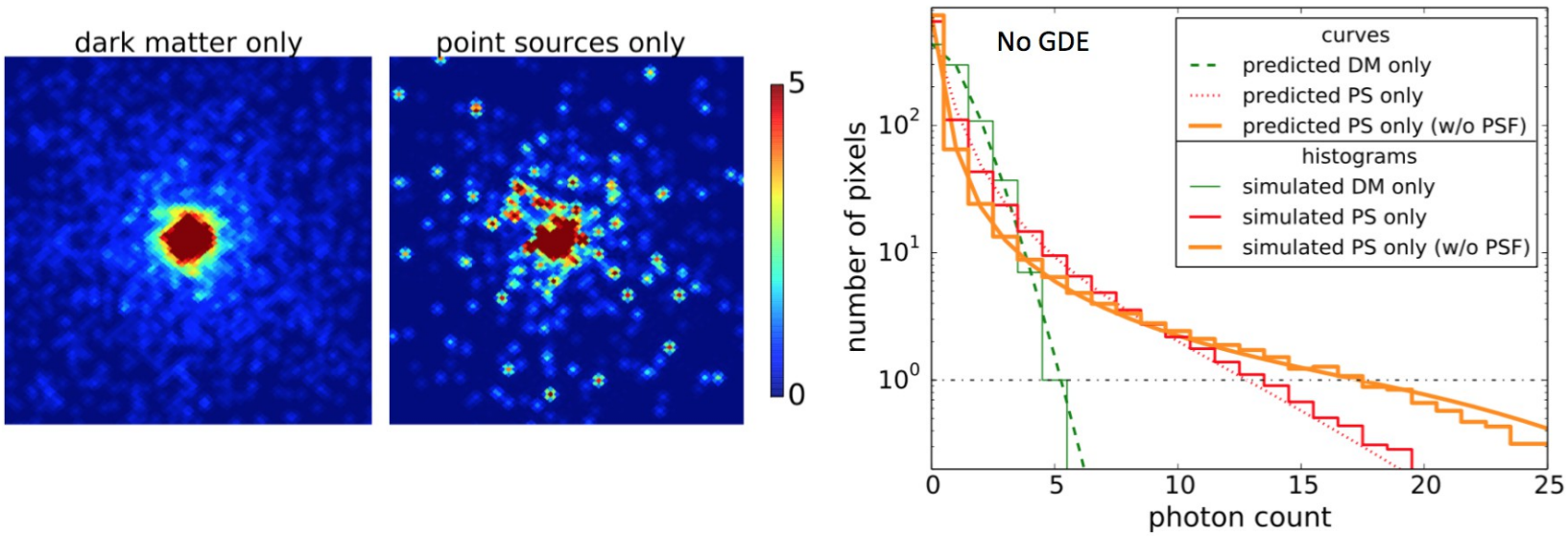


Cholis et al. 1407.5625

Evidence for unresolved point sources?

Statistics of photon counts might help to discriminate 1) point sources from 2) more diffuse emission.
Recent analysis show preference for 1) Lee et al. 1506.05124, Bartels et al. 1506.05104

Lee et al. 1506.05124



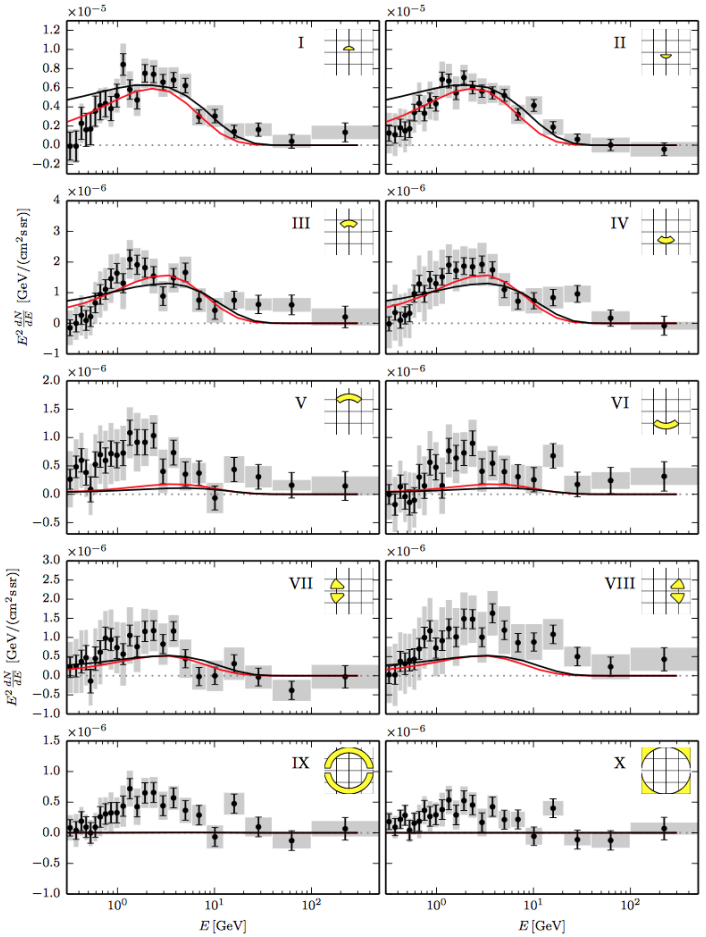
Dozens or hundreds of sources at the reach of radio surveys?

Calore et al. 1512.06825

Time dependent source

CR electrons injection burst from GC region

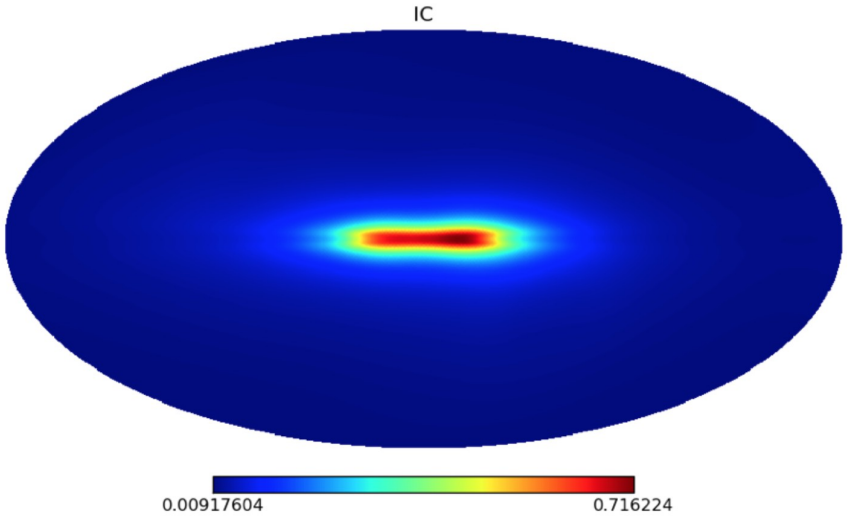
Works with tuning of the parameters: more than one events, hard injection index,..

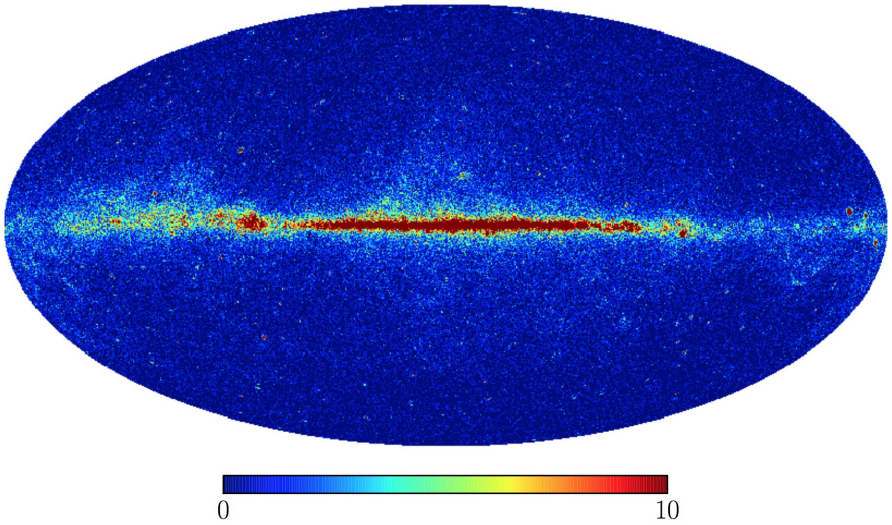


Cholis et al. 1506.05119

Cholis et al. 1506.05119
Carlson et al. 1405.7685
Petrovic et al. 1405.7928

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





Model

Data

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

Inverse Compton emission depends on 1) CR electrons distribution and 2) Interstellar Radiation Field

1) CR electrons distribution obtained solving transport equation

$$\frac{\partial N^i(r,z,p)}{\partial t} = \frac{\partial}{\partial x_i} D_{ij} \frac{\partial N^i}{\partial x_j} + \boldsymbol{v}_c \cdot \boldsymbol{\nabla} N^i - \frac{\partial}{\partial p}\left(\dot{p} - \frac{p}{3}\boldsymbol{\nabla}\cdot\boldsymbol{v}_c\right) N^i + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p}\frac{N^i}{p^2} + Q(r,z,p)$$

See C.Evoli's talk

GC environment can be more complex than what is assumed in "standard" diffuse emission models, e.g.

- anisotropic diffusion along coherent X-shaped magnetic field Jansson, Farrar 2012
- large convective winds in the GC region

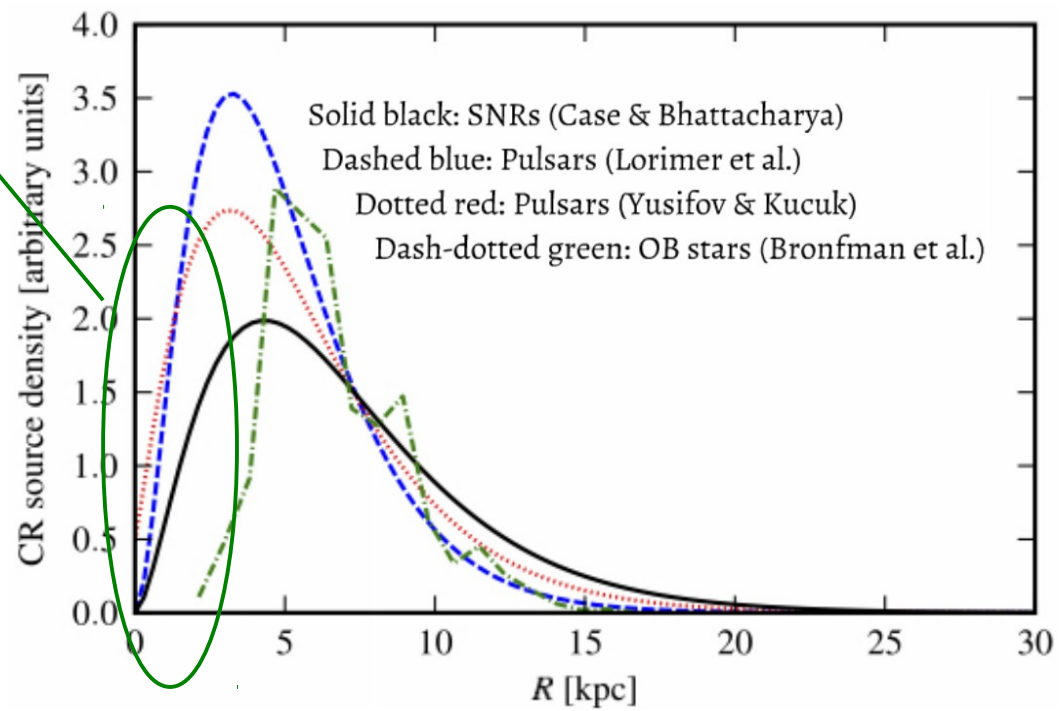
Do we understand diffuse emission from cosmic-rays at the GC?

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

Something is missing here!

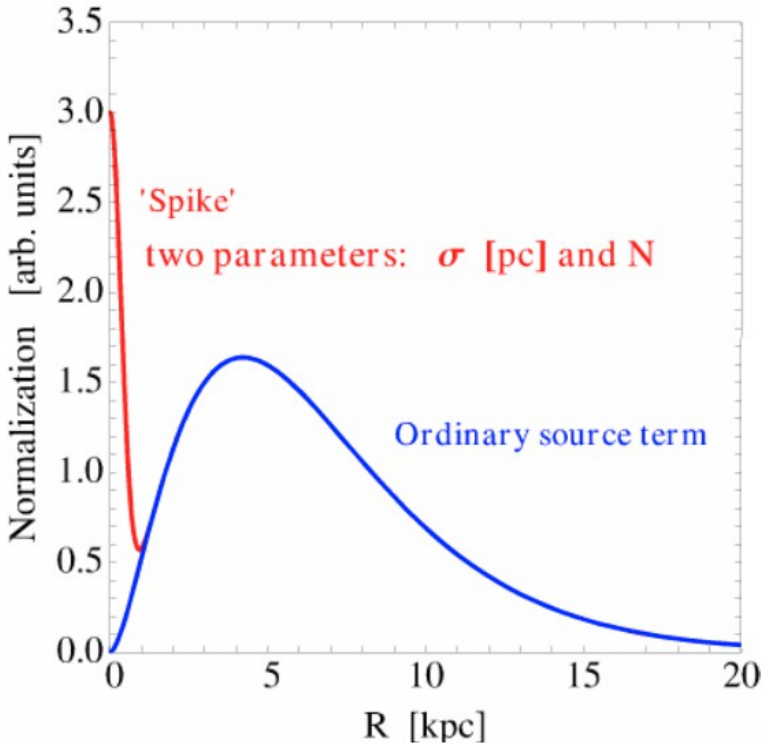
"Standard "CR sources distribution

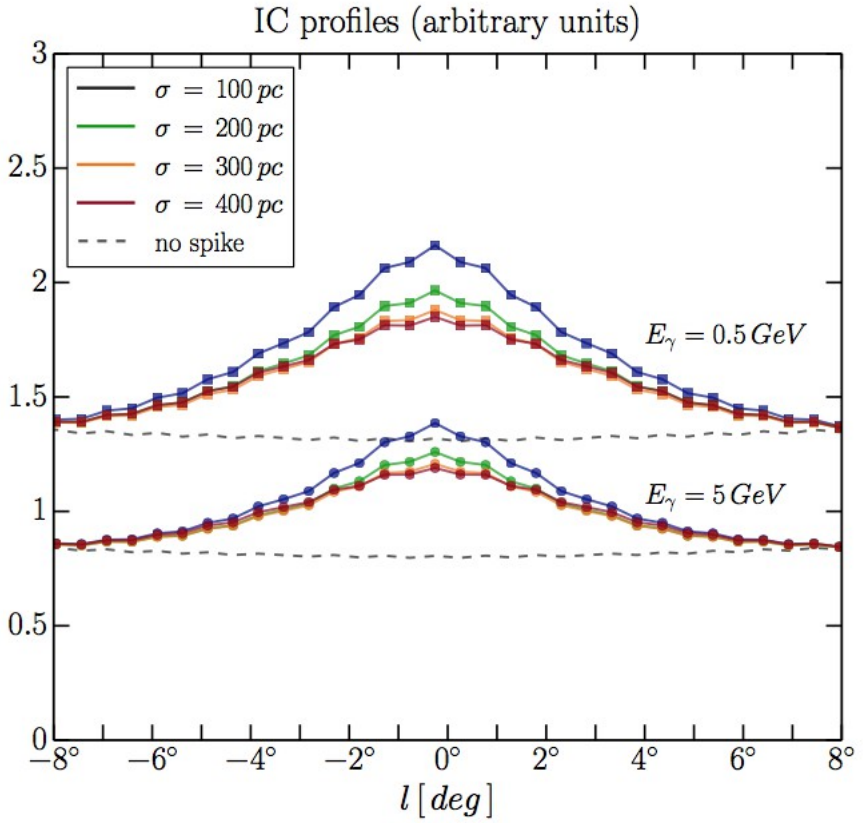


Increased CR source at the GC center

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

We add to the standard CR source distribution an extra term, modeled as a gaussian with a spatial extent around 100-400 pc.
Normalization should be compatible with estimate of SFR @ GC

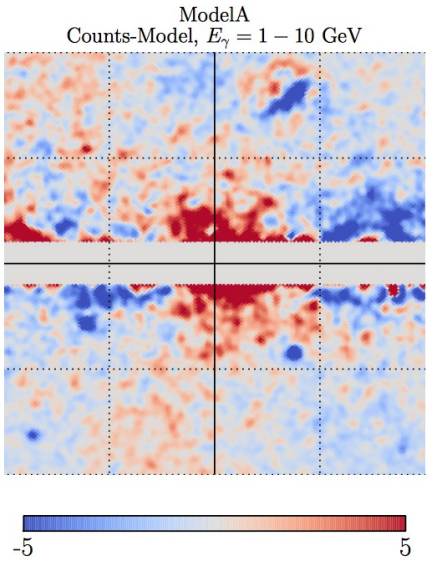




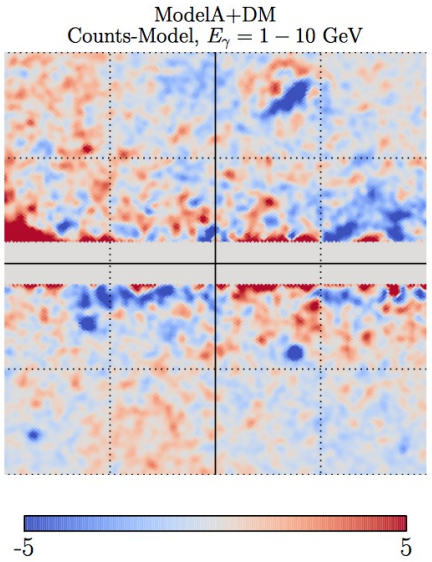
Residual counts

Most of the excess absorbed by the modified IC templates

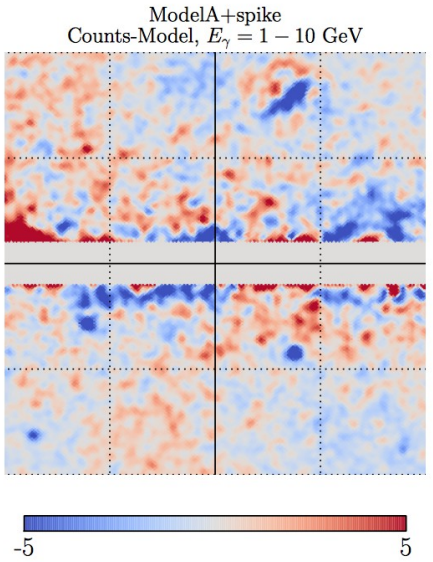
Reference diffuse



Reference diffuse+DM

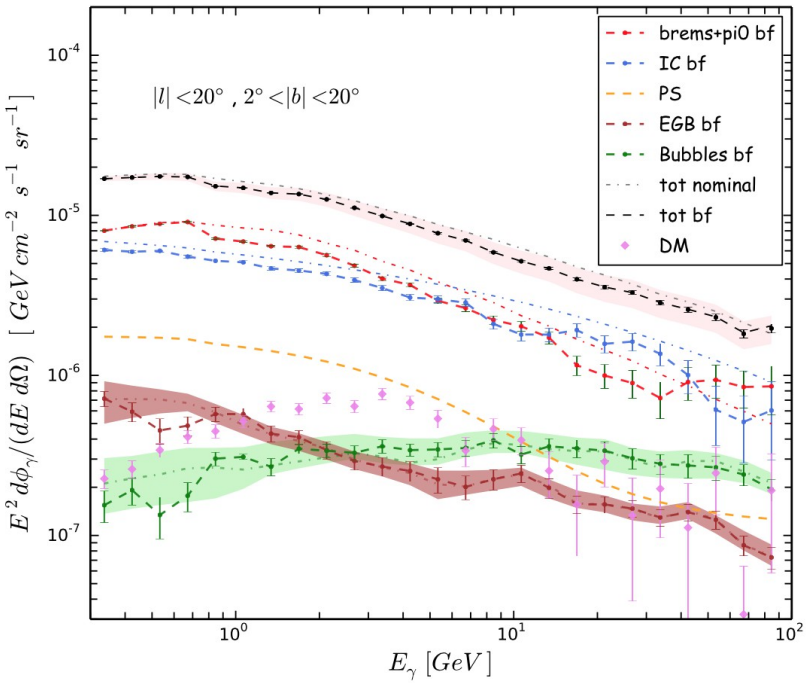


Model with modified source term

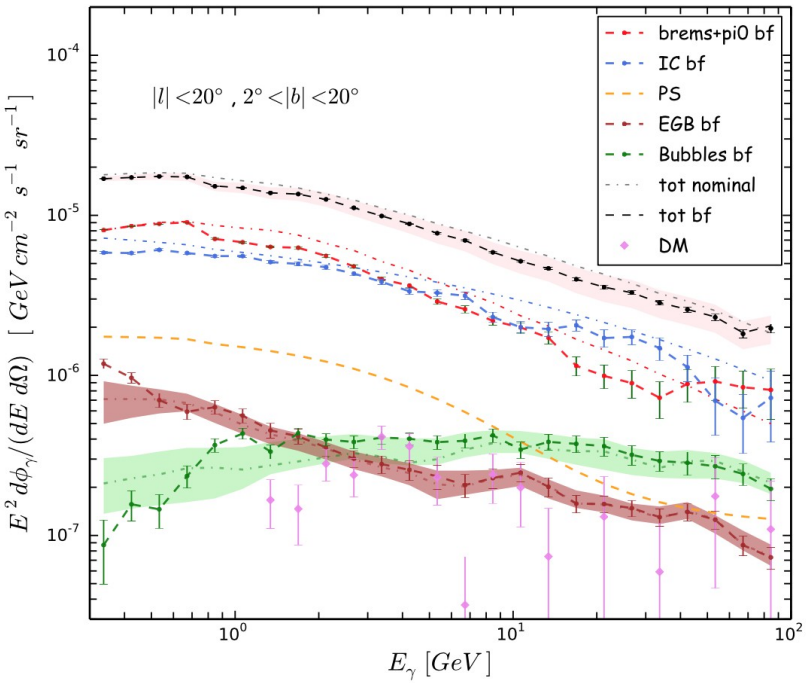


Spectrum of the excess

Without CR spike



With CR spike

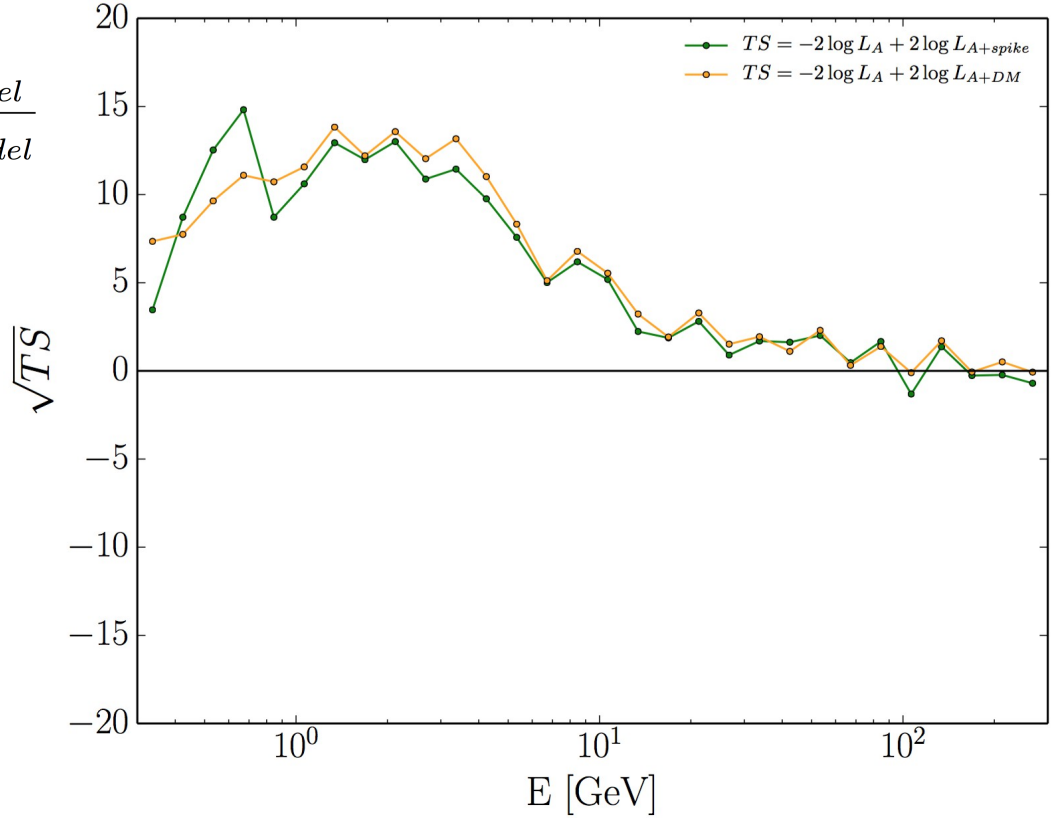


The GC excess template is degenerate with the IC emission from the spike!

Improvement of the fit

$$TS = -2 \log \frac{\mathcal{L}_{reference\ model}}{\mathcal{L}_{alternative\ model}}$$

σ = 300 pc, N = 2.2%

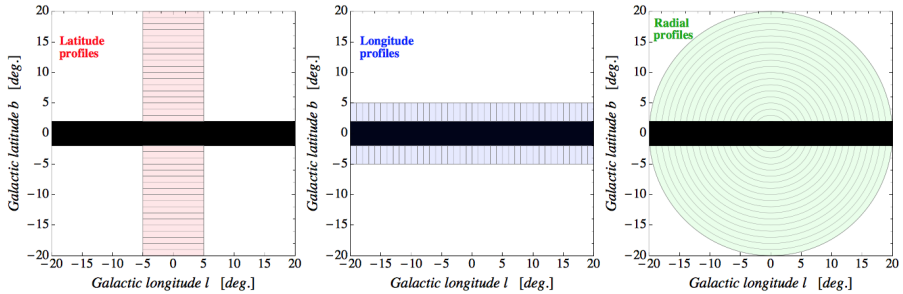


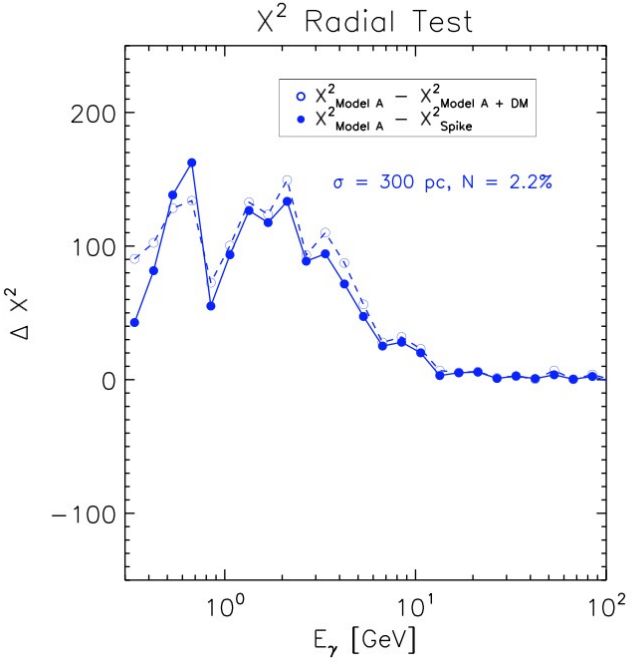
DM template and the new CR model gives similar improvement of the likelihood.

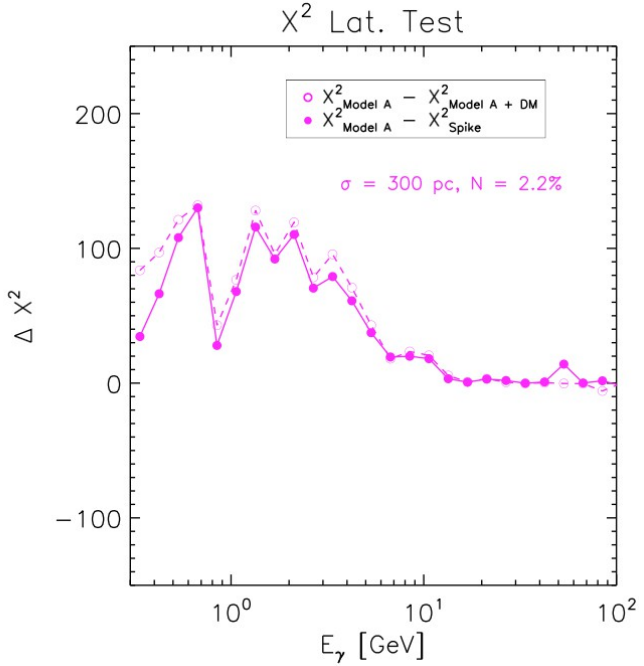
Need source term at the center giving around 2% of the total CR injection in the galaxy: reasonable value according to current literature.

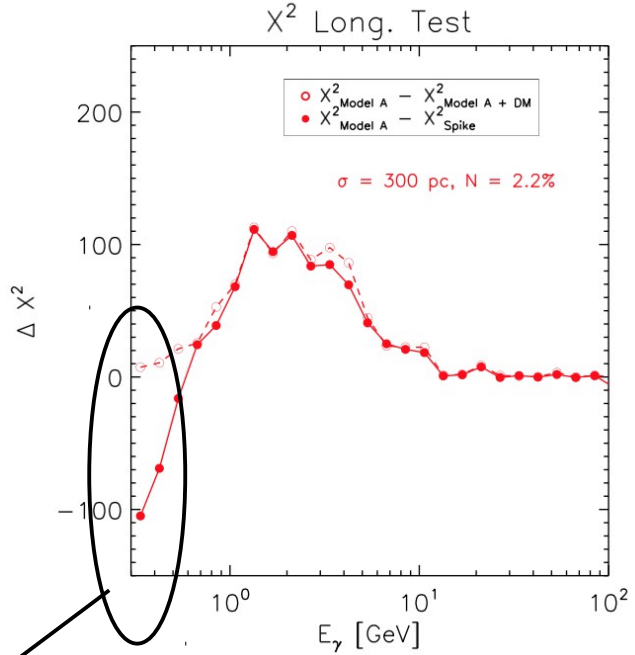
Analysis of gamma-ray profiles

Inside the ROI compute the counts profiles in radial-longitudinal-latitude directions and compare with the outcome of the fit performed in the entire ROI.







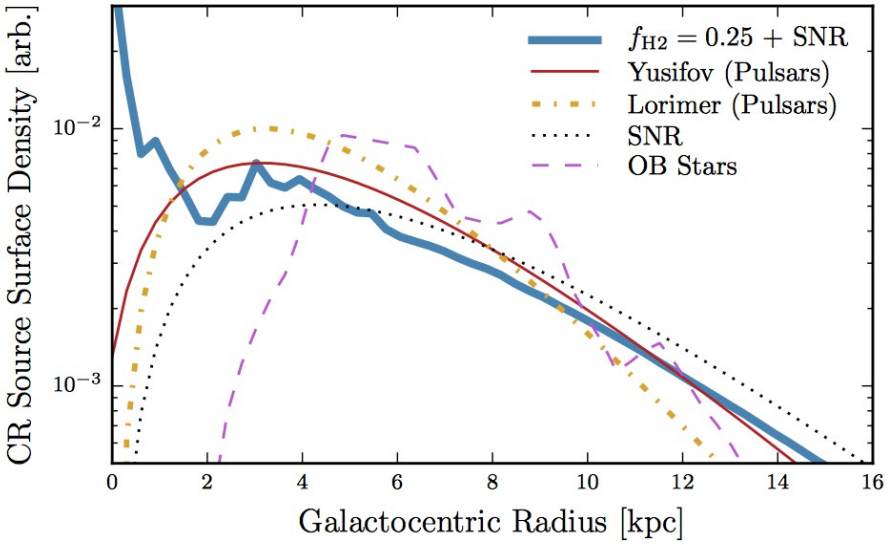


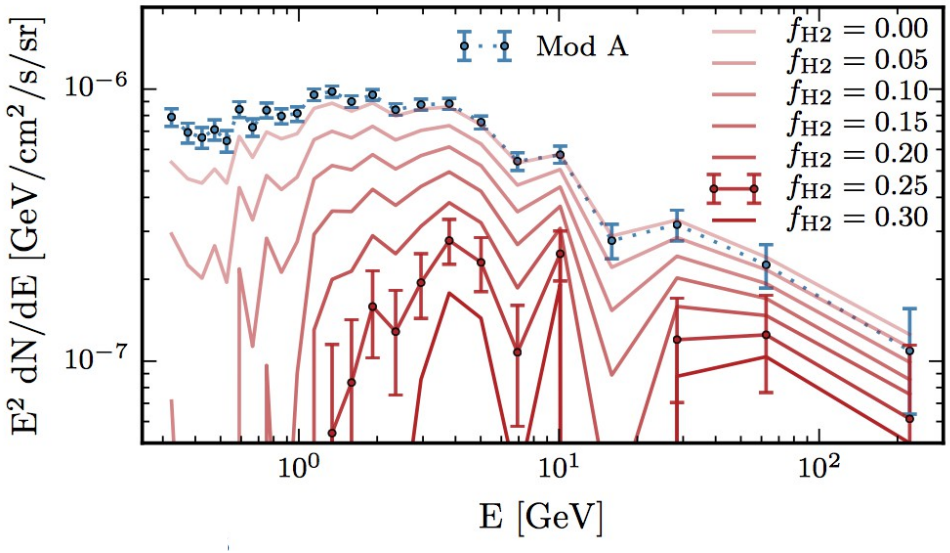
Slight overshoot at low energies.
Too simple descriptions? For these low energy electrons, what about the role of anisotropic diffusion, winds,... ?

Recent developments

Recently, similar results found with a extra CR injection component tracing the H_2 map.

The GC excess can be significantly altered, both the spectrum and the morphology (less peaked and spherically symmetric).





Carlson,Profumo, Linden 1510.0469, 1603.06584

See also preliminary analysis of Fermi-Lat Collaboration

Conclusions

- GC GeV excess interesting for astrophysics and dark matter

- Several ways to test different hypothesis: dwarf galaxies, search of point sources...

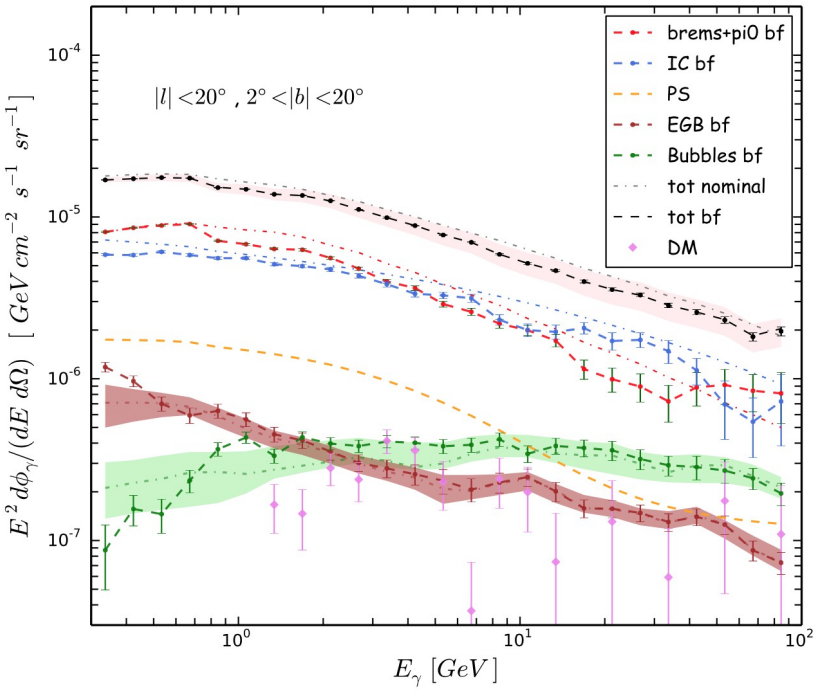
- Emission from the inner galaxy is far to be well understood and it can affect at a large extent the analysis of the diffuse emission, thus the searches for DM signals

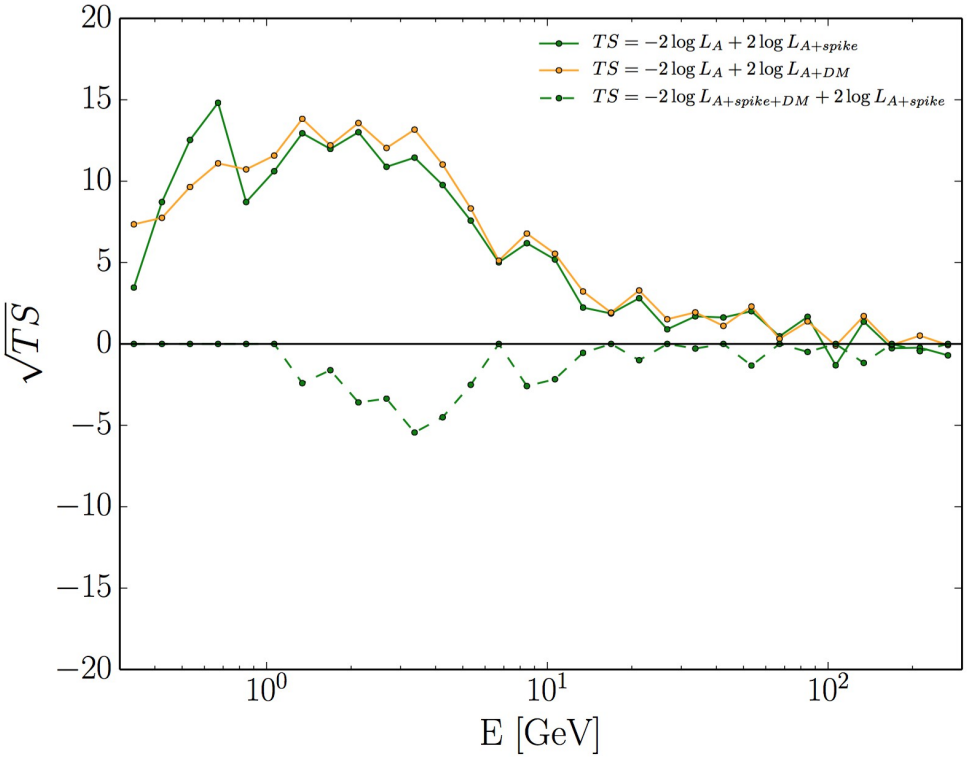
THANKS

THANKS

Add also DM template

Adding the DM template to the new diffuse emission model gives a moderate improvement of the fit in few energy bins.

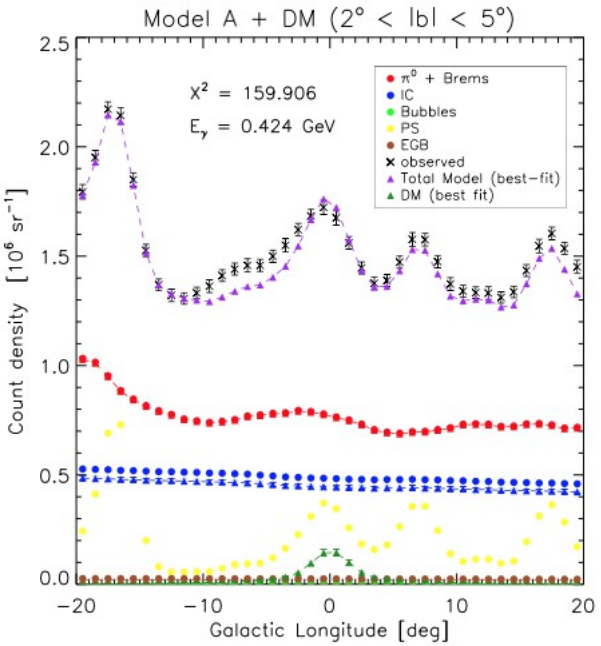




Analysis of gamma-ray profiles

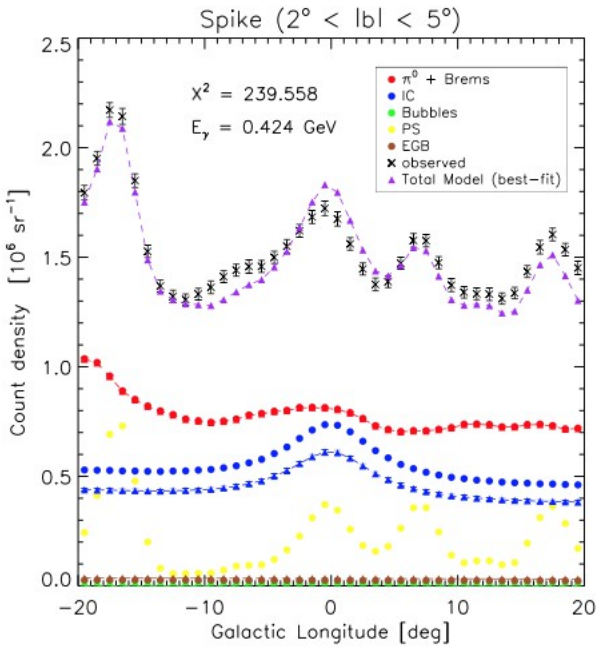
In the first energy bins the model with the extra source slightly overshoots the data at low latitudes.

Standard diffuse +DM



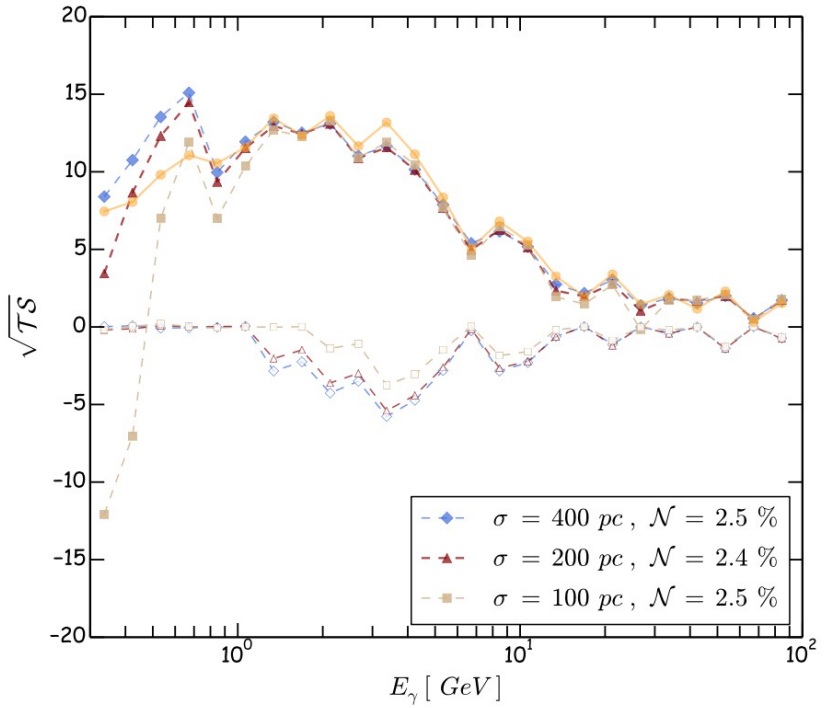
0.4 GeV

Modified diffuse model



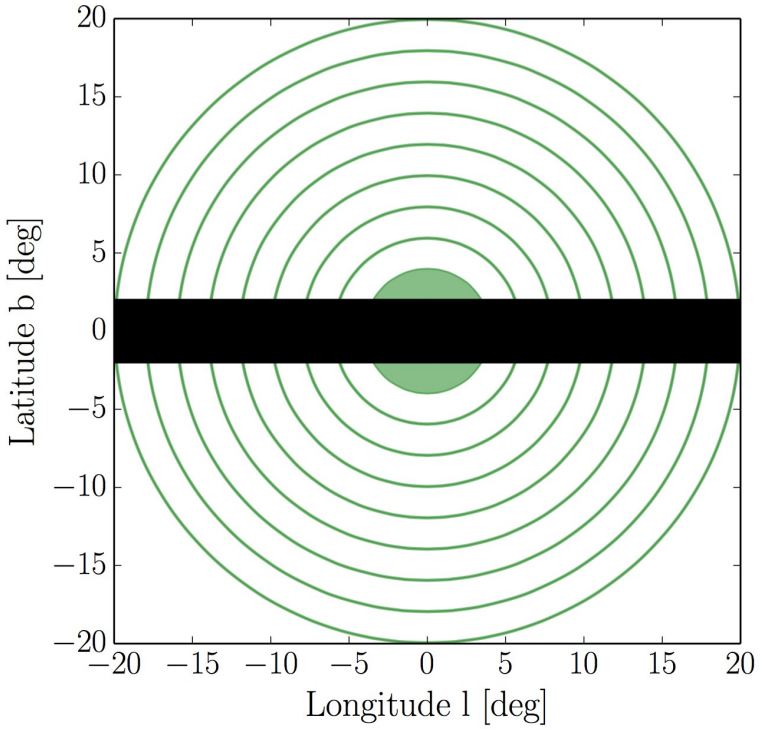
Spatial extension of CR source at the center

We test different sizes of the source term at the center of the galaxy.
Results: for enhancements inside 200-400 pc and with a CR injection around 2% of the total, we obtain similar results than before.
The new ingredient produces a large improvement of the fit and reabsorbs (at least partially) the GC excess.
For smaller spatial extents the IC template is too narrow.

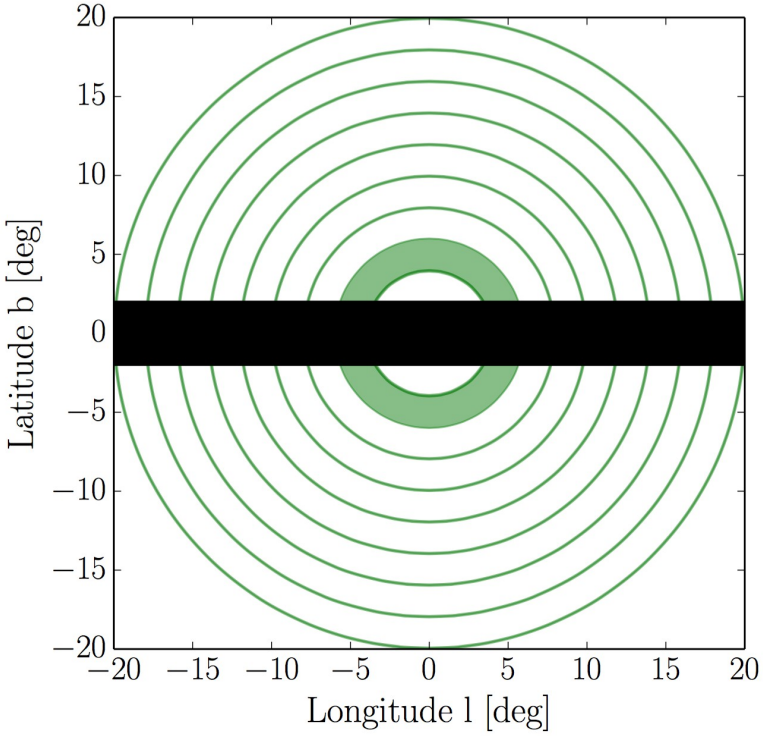


Subregions

2-4 deg

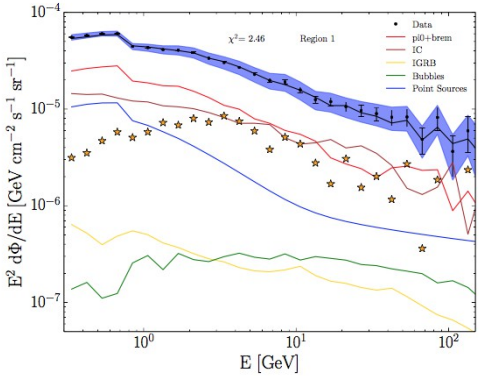


4-6 deg

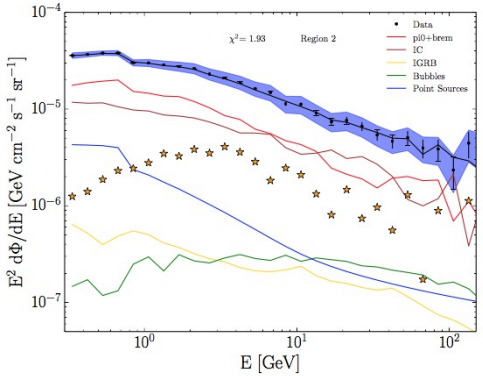


Subregions

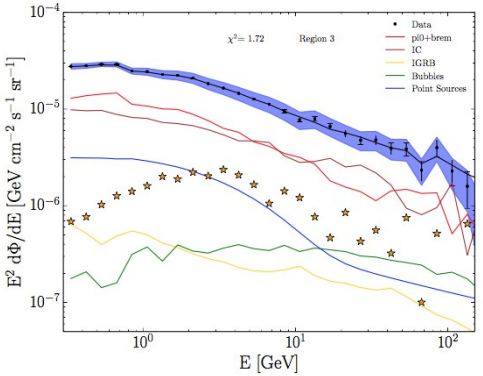
2-4 deg



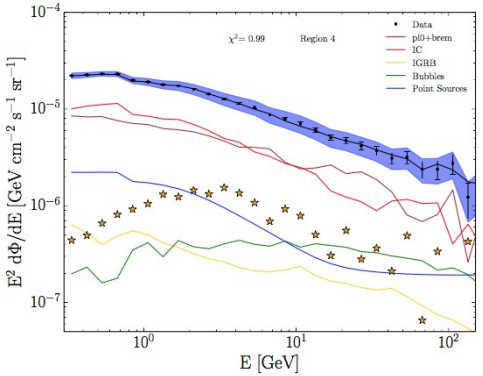
4-6 deg

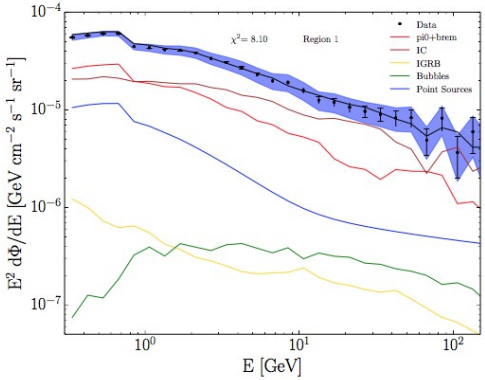


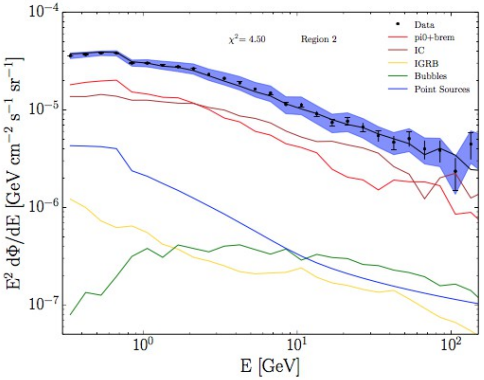
6-8 deg

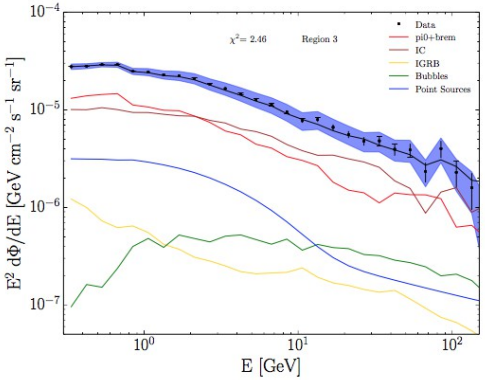


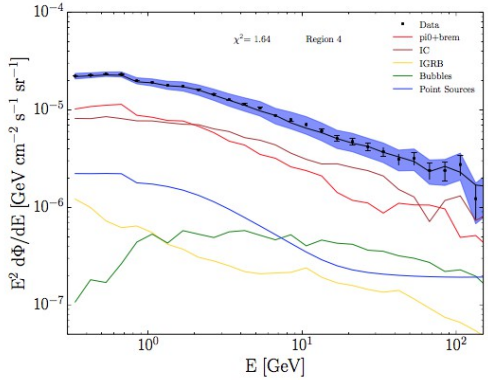
8-10 deg











First row: "Standard" diffuse + DM

Second row: diffuse with modified CR term