GeV Excess

and

Phenomenological Astrophysics Modeling

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The Niels Bohr
International Academy

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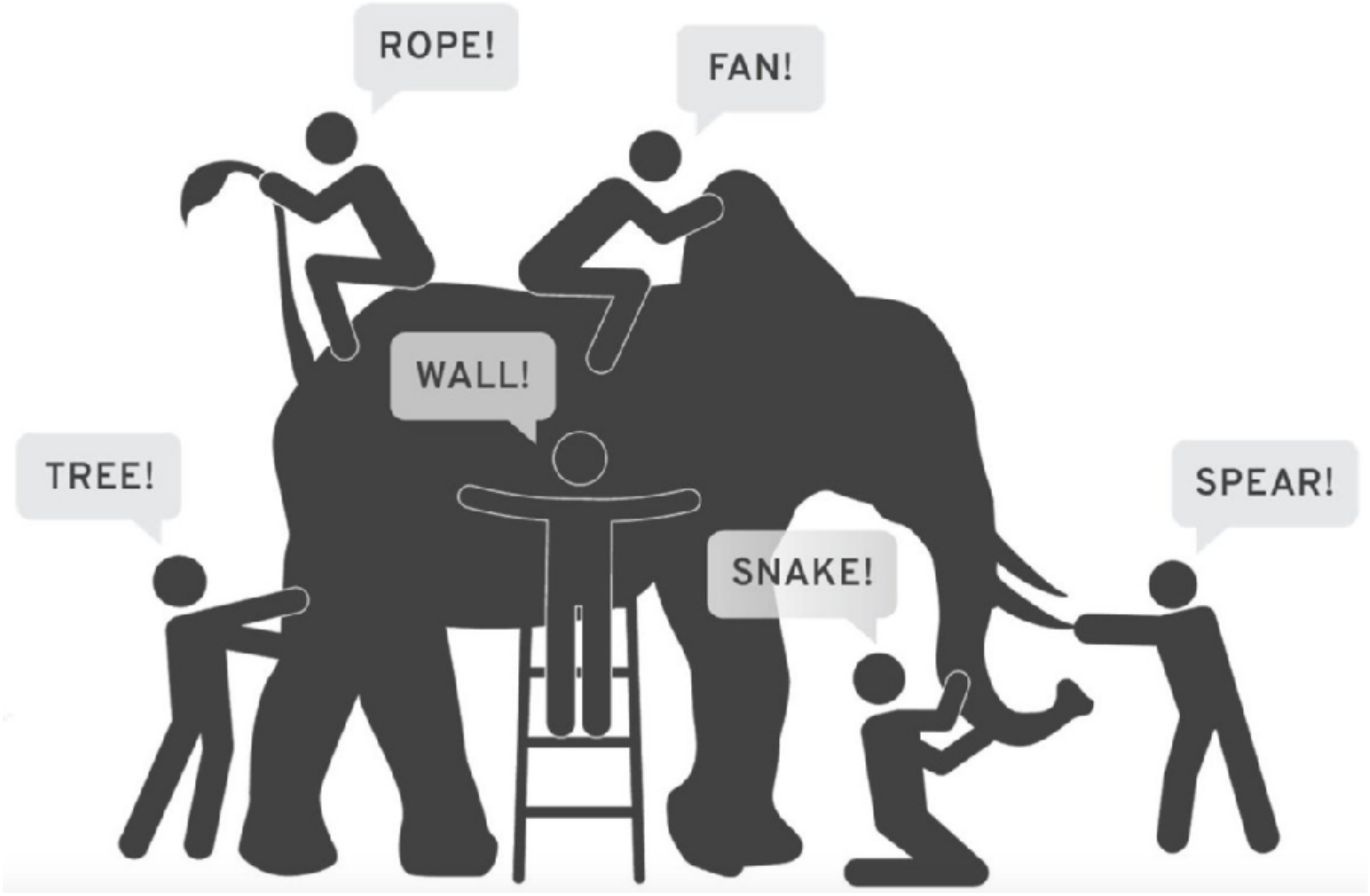
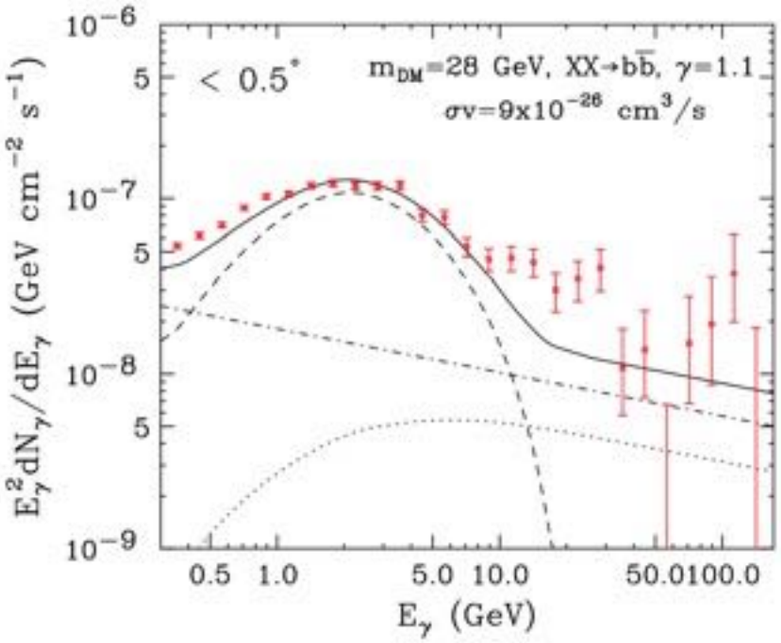
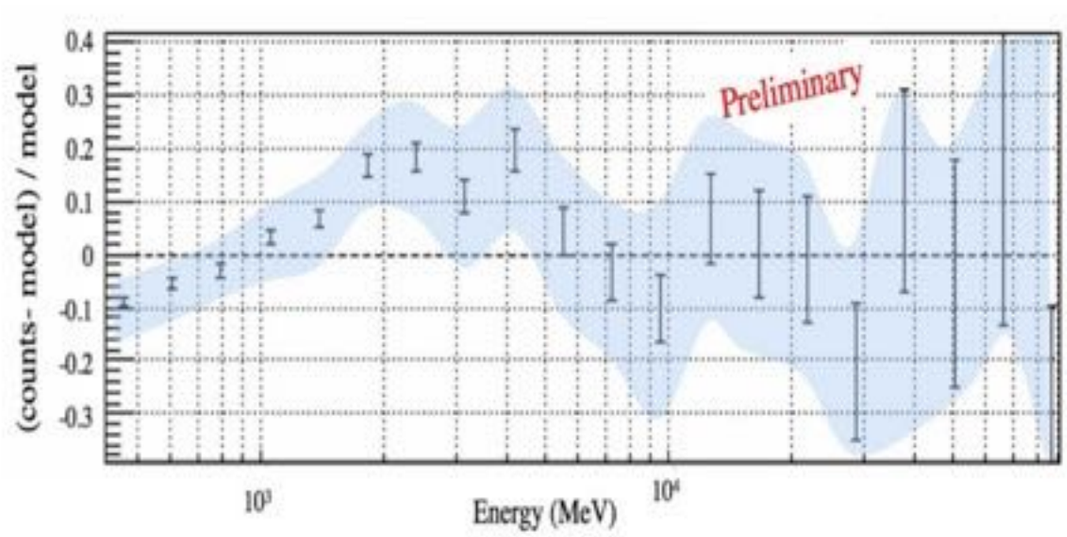
Blind Men and the Elephant



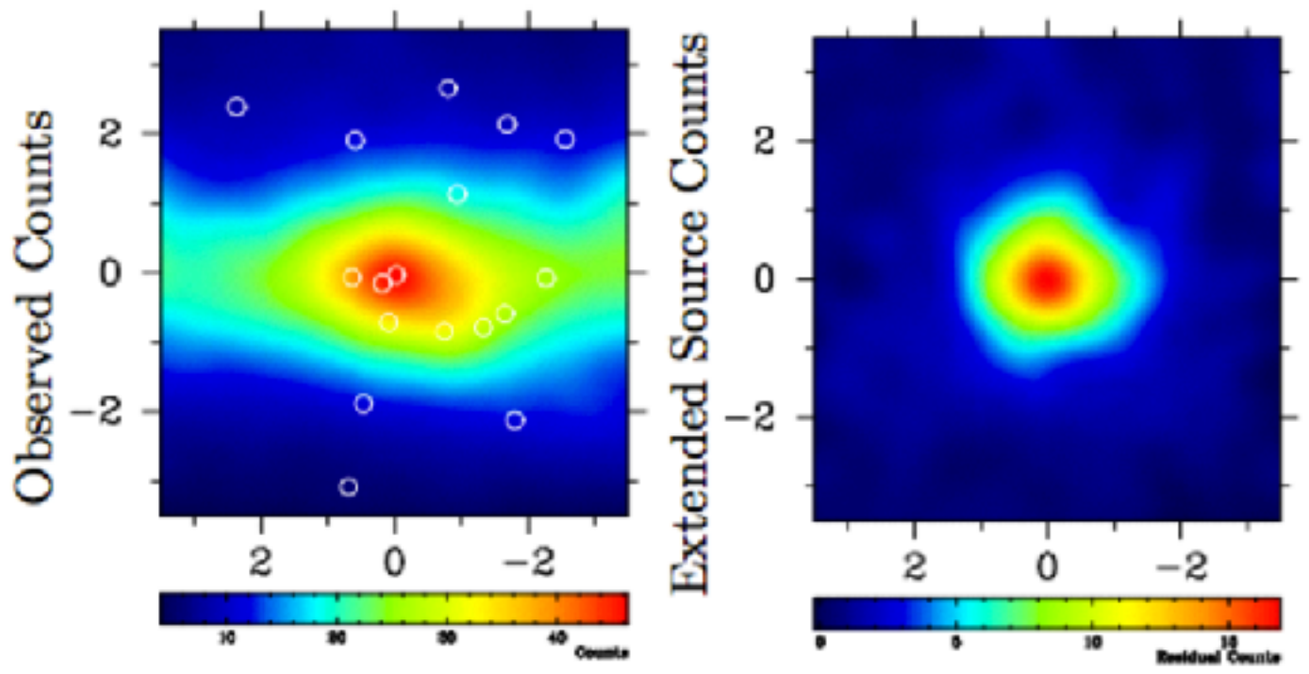
GeV Excess: a well known issue since 2009



Goodenough & Hooper 2009



Vitale & Morselli 2009



Abazajian & Kaplinghat 2012

Galactic Center

Boyarsky+ 2011

Gordon & Macias 2013

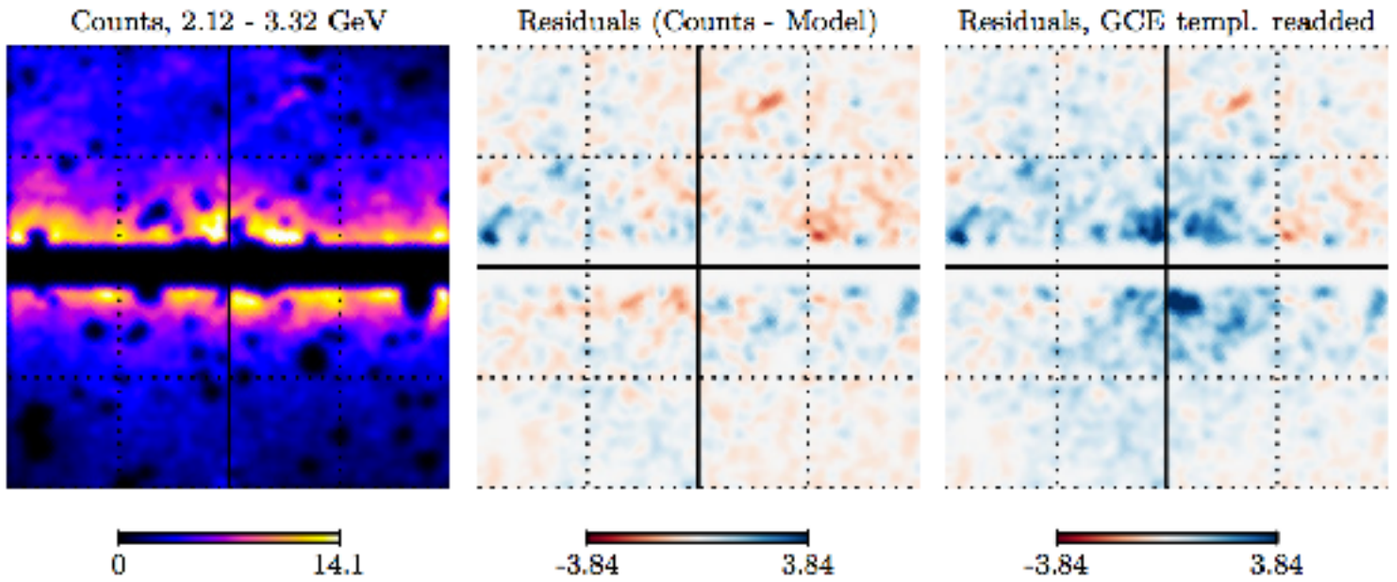
Macias & Gordon 2014

Carlson+ 2015

...

GeV Excess: a well known issue since 2009

Calore+ 2014



Inner Galaxy

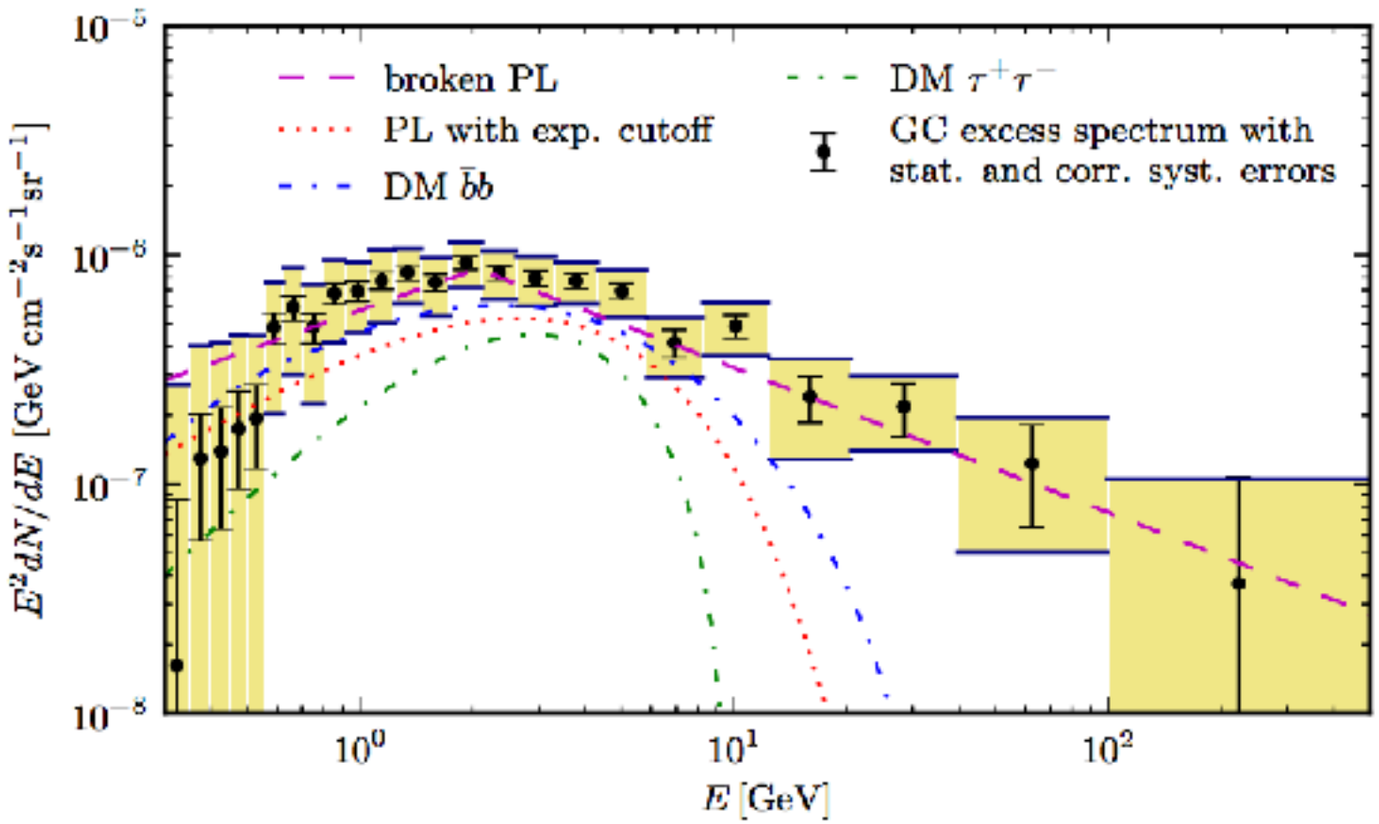
Hooper & Slatyer 2013

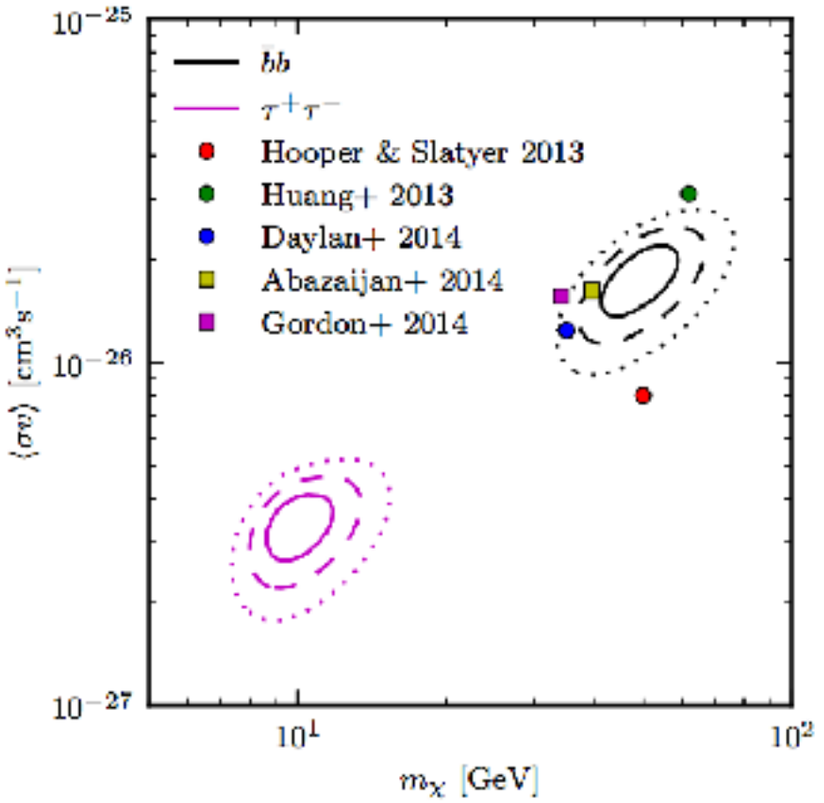
Huang+ 2013

Zhou+ 2014

Daylan+ 2014

...

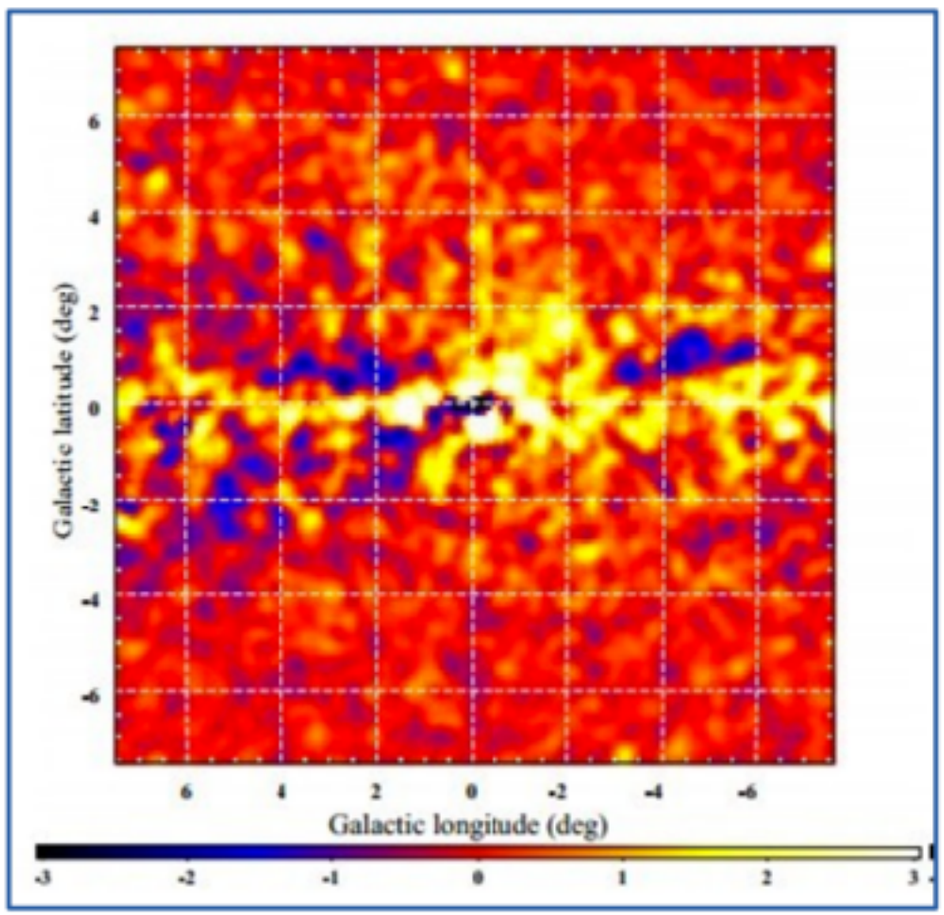


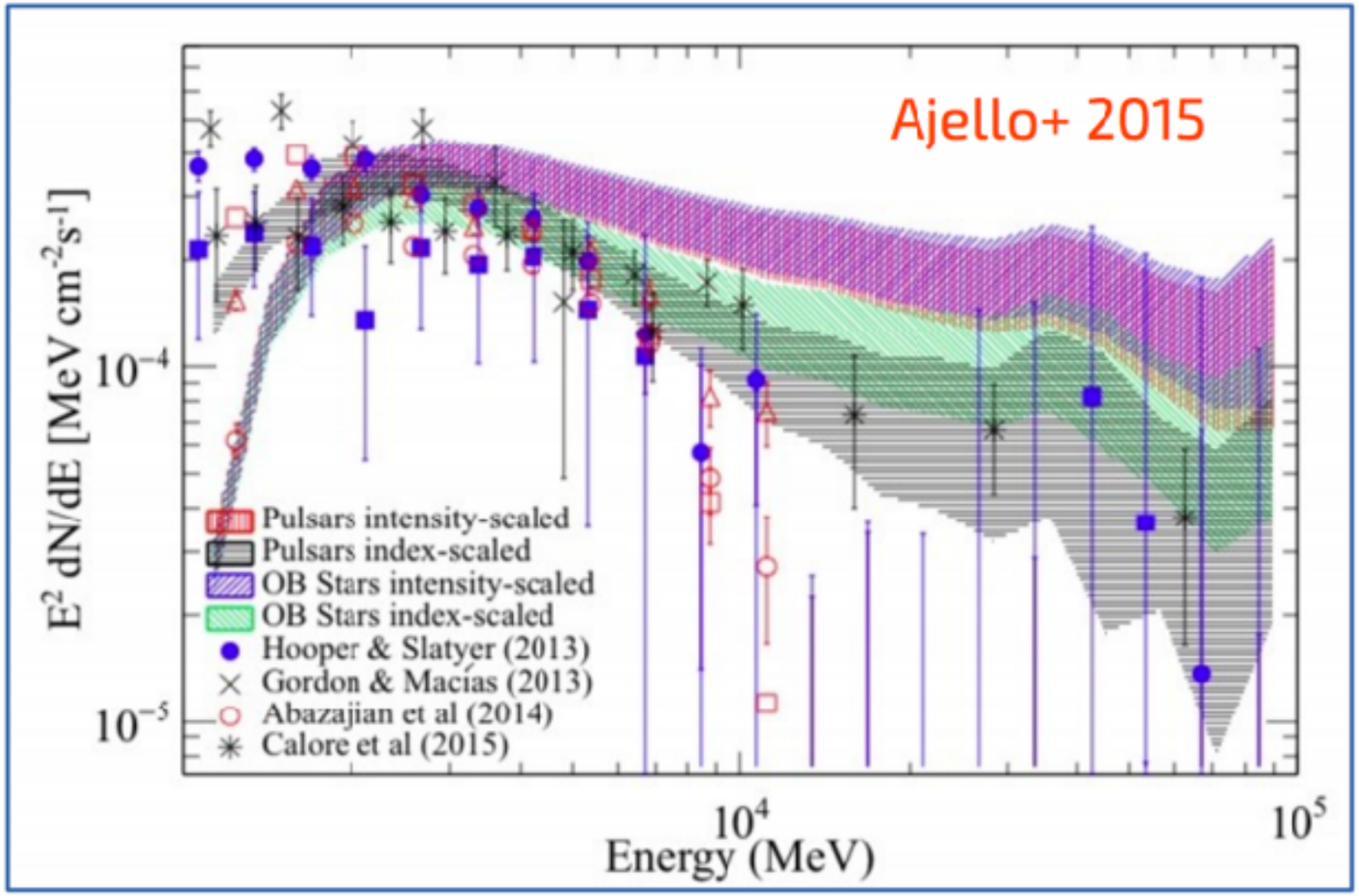


GeV Excess: confirmed by Fermi Collaboration

Fermi–LAT OBSERVATIONS OF HIGH-ENERGY γ-RAY EMISSION TOWARD THE GALACTIC CENTRE

of the interstellar emission and energy ranges used by the respective analyses. Three 1FIG sources are found to spatially overlap with supernova remnants (SNRs) listed in Green's SNR catalog; these SNRs have not previously been associated with high-energy γ-ray sources. Most 3FGL sources with known multi-wavelength counterparts are also found. However, the majority of 1FIG point sources are unassociated. After subtracting the interstellar emission and point-source contributions from the data a residual is found that is a sub-dominant fraction of the total flux. But, it is brighter than the γ-ray emission associated with interstellar gas in the inner $\sim$ 1 kpc derived for the IEMs used in this paper, and comparable to the integrated brightness of the point sources in the region for energies > 3 GeV. If spatial templates that peak toward the GC are used to model the

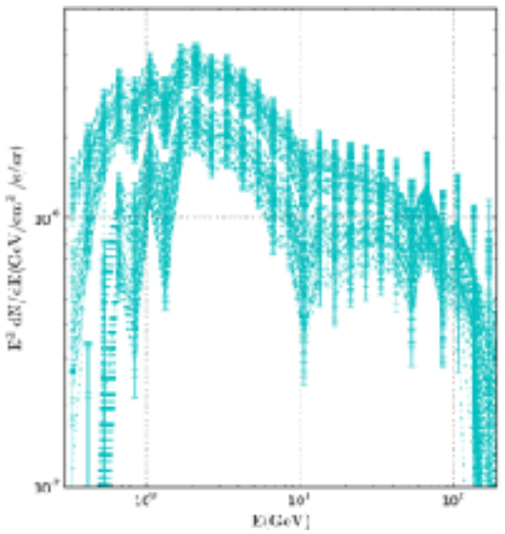


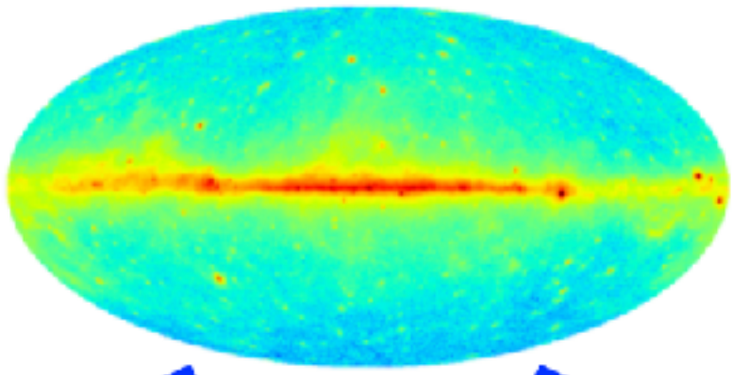


GeV Excess: depending on the astrophysical model

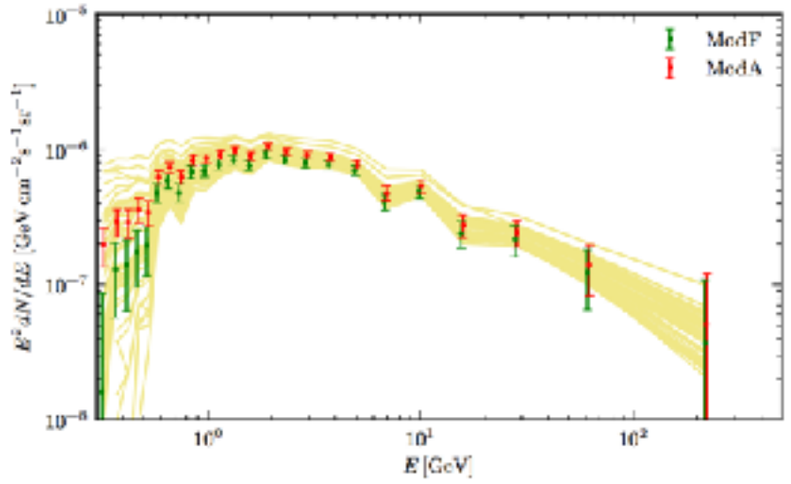
A: diffuse background

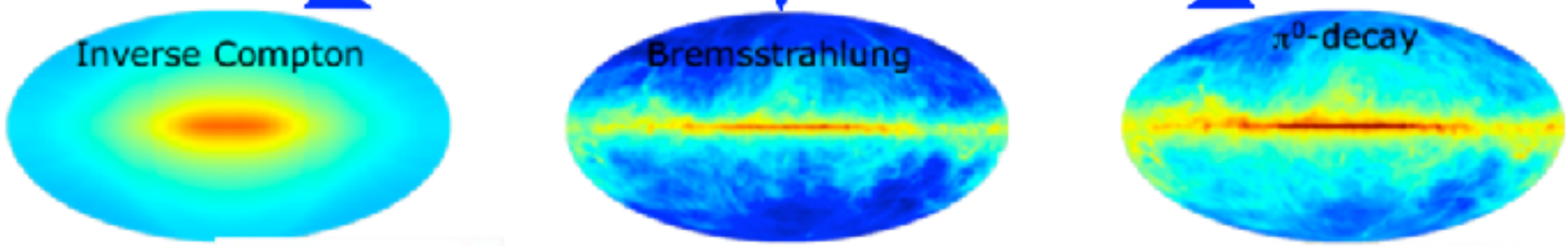
Zhou+ 2014

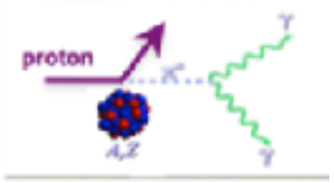


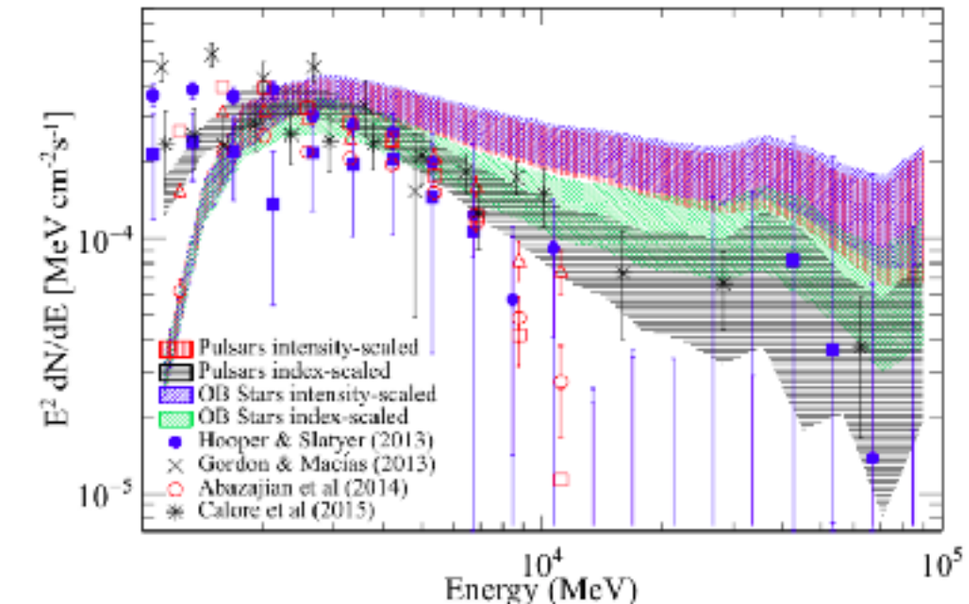


Calore+ 2014





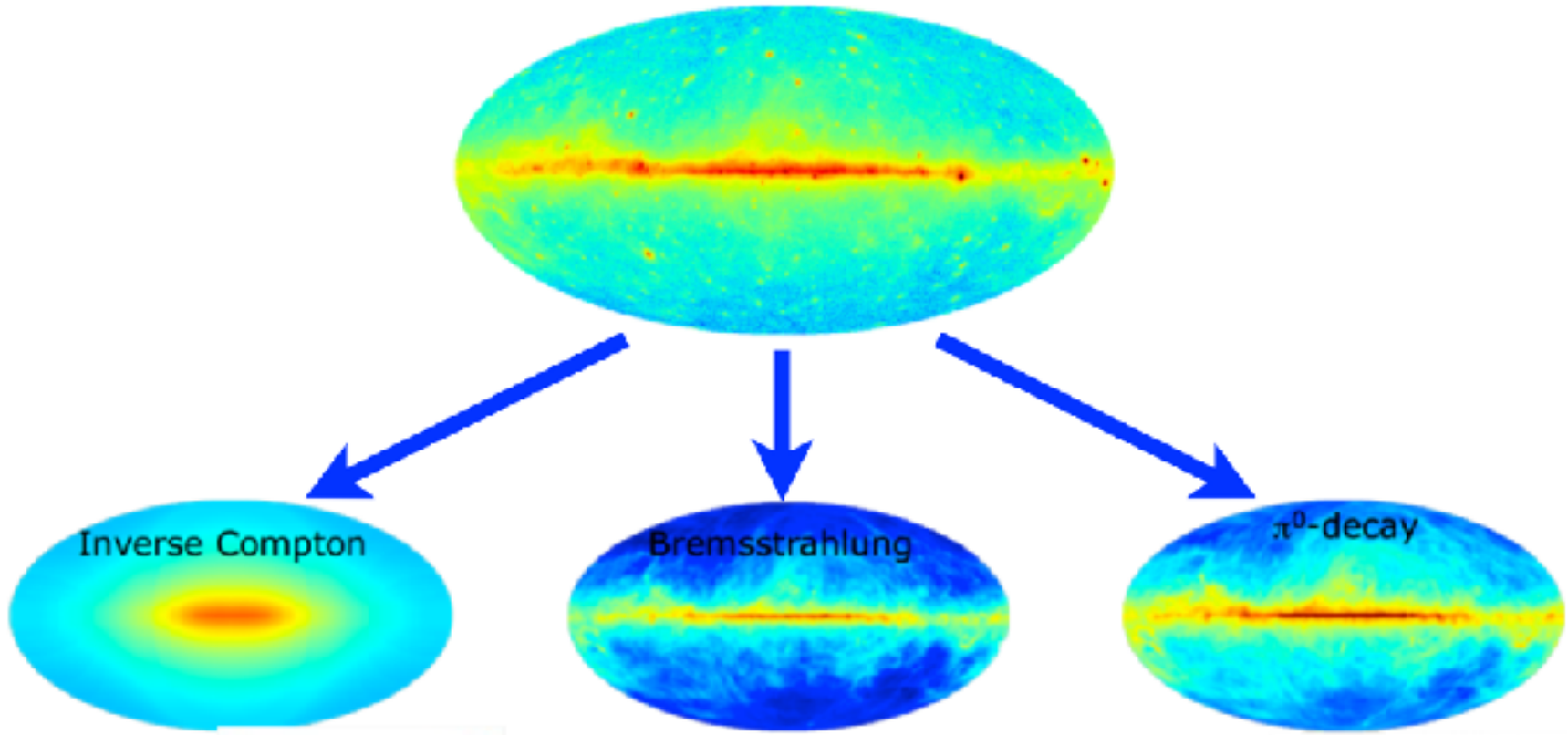




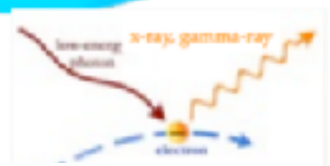
Ajello+ 2015

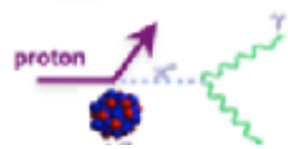
GeV Excess: depending on the astrophysical model

A: diffuse background

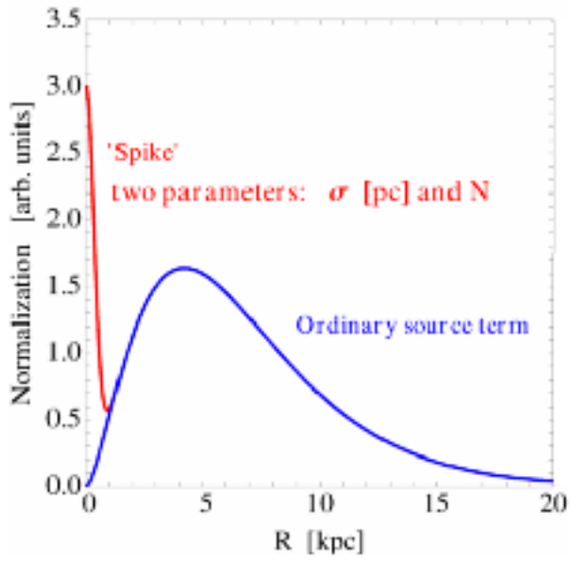


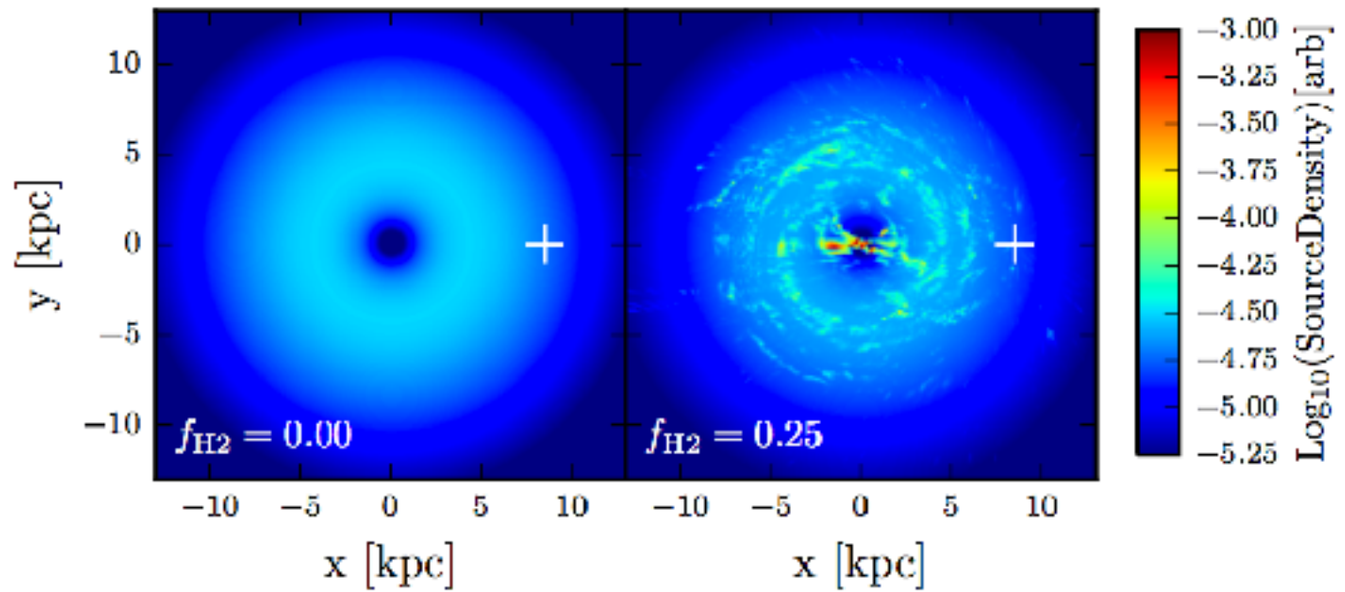
Gaggero+ 2015





Carlson+ 2015

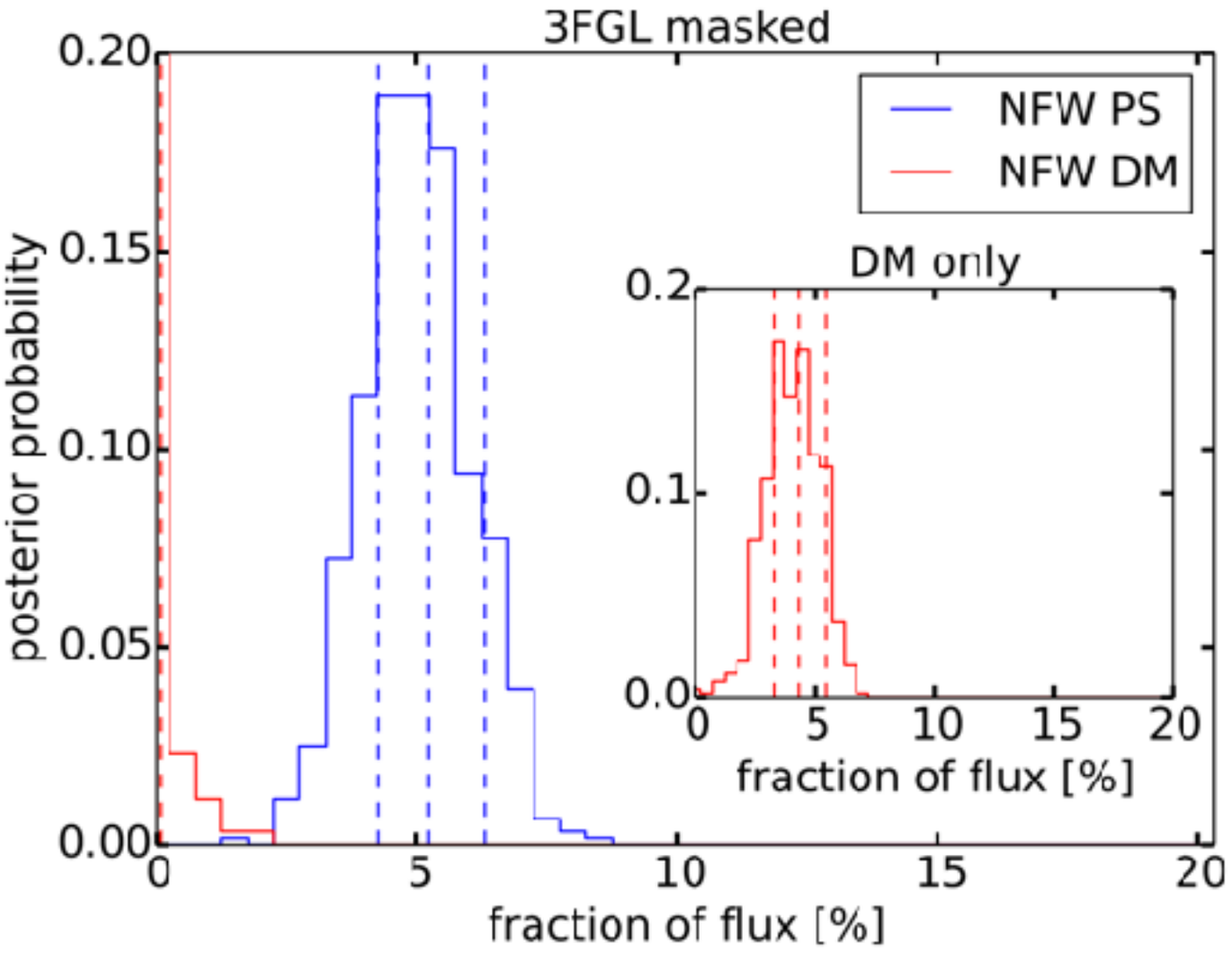




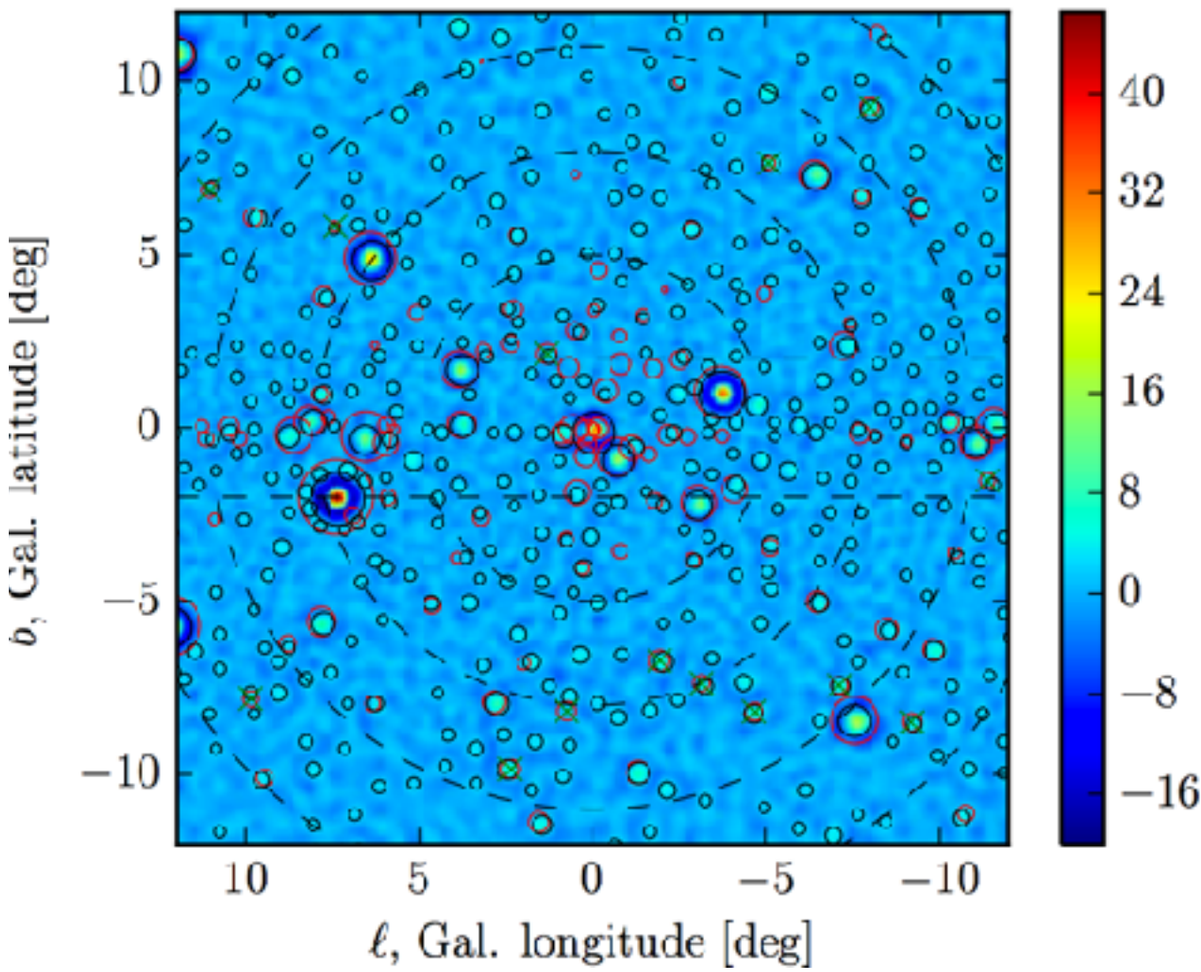
GeV Excess: depending on the astrophysical model

B: point sources

Lee+ 2015



Bartels+ 2015

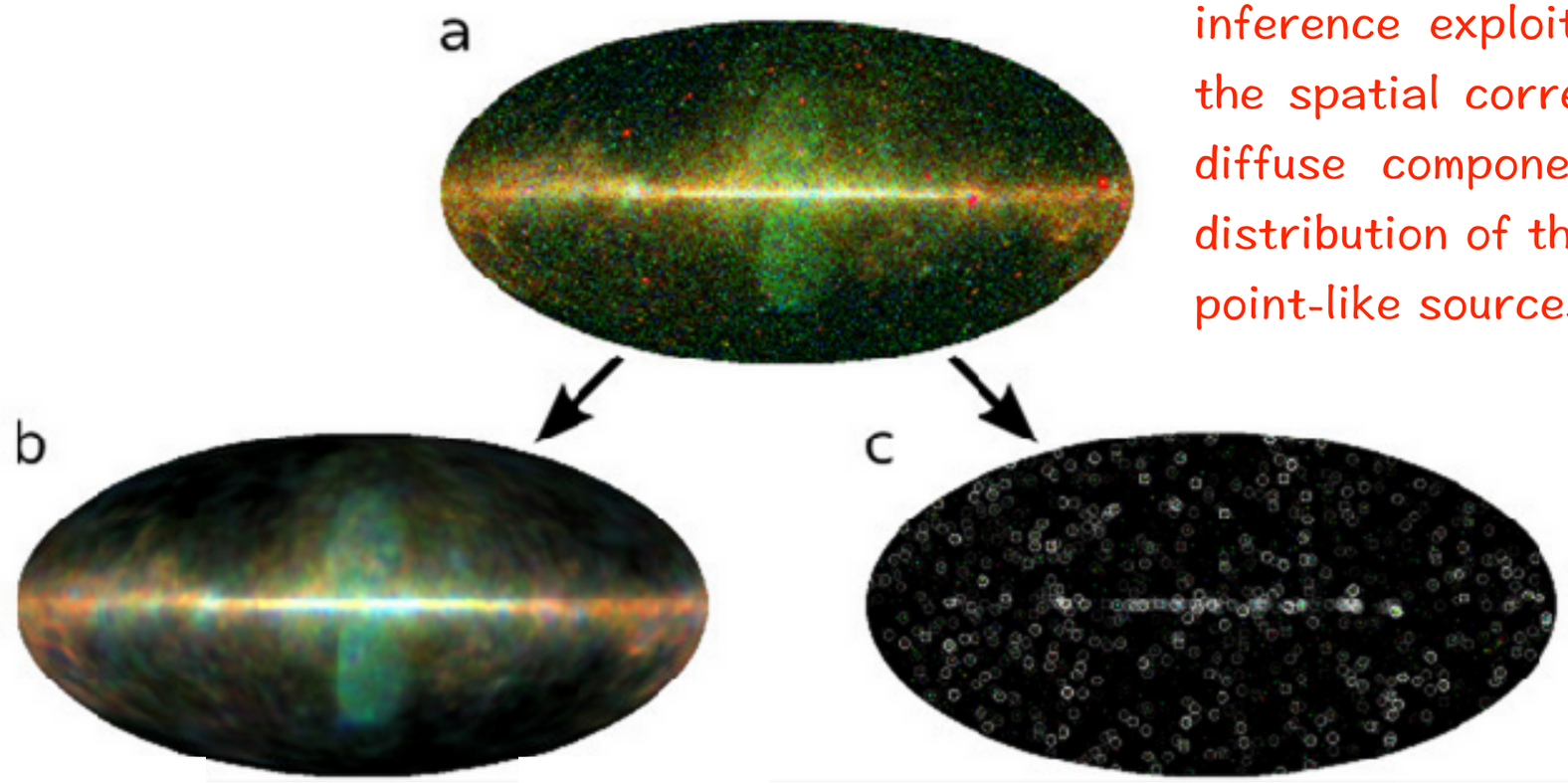


Unresolved MSPs could be the source of this excess

Abazajian & Kaplinghat 2012

D3PO and Gamma-ray Sky

Selig+ 2014



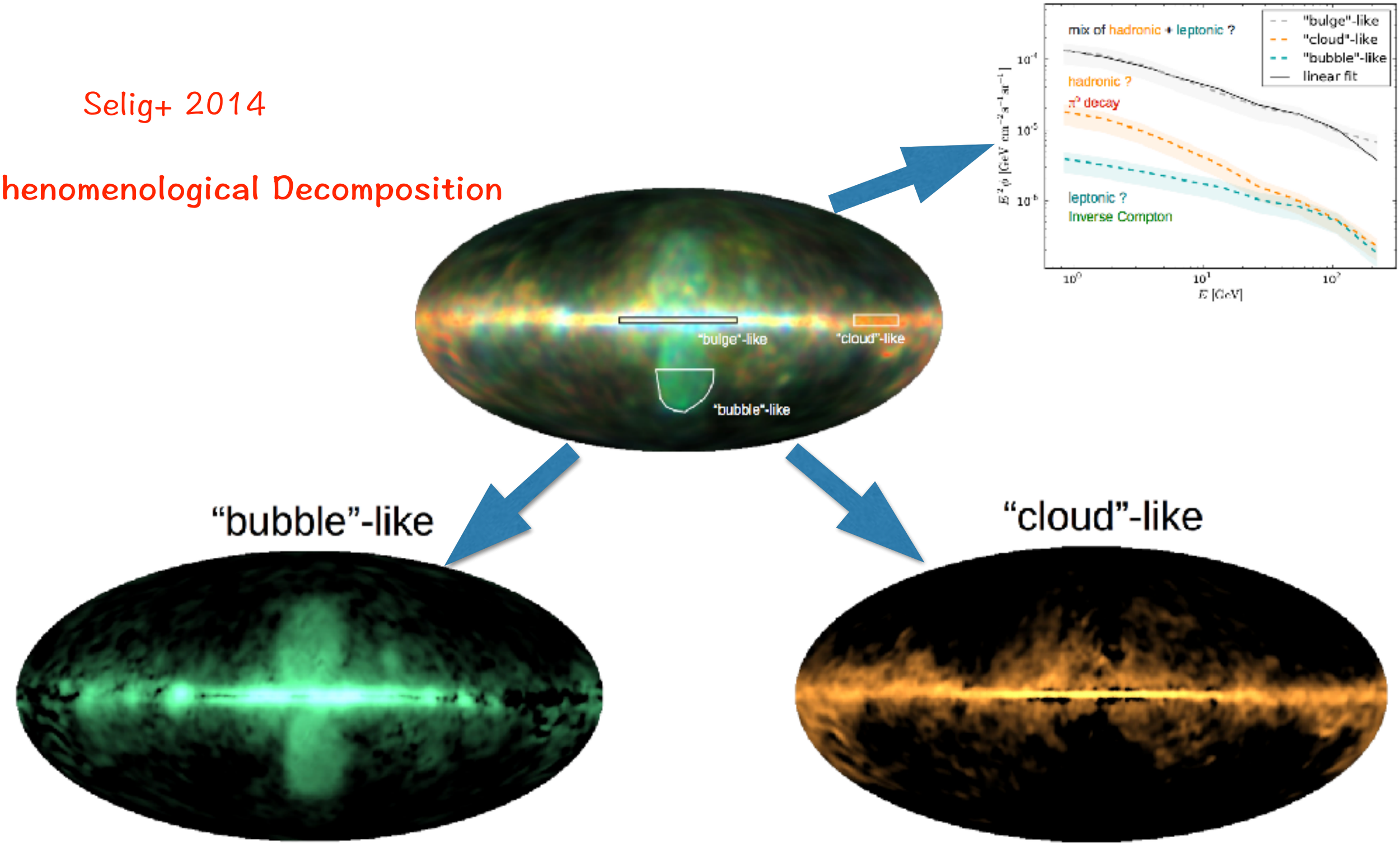
D3PO package: Based on a hierarchical Bayesian parameter model, the signal inference exploits prior information on the spatial correlation structure of the diffuse component and the brightness distribution of the spatially uncorrelated point-like sources.

catalog with 3106 candidates,
1897 of them known in 3FGL

D3PO and Gamma-ray Sky

Selig+ 2014

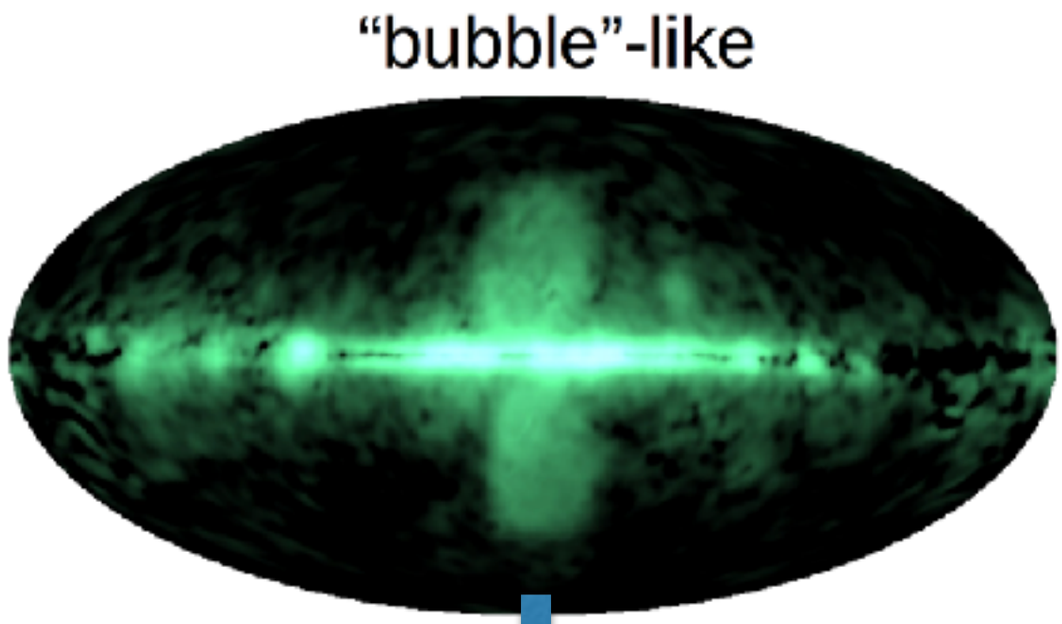
Phenomenological Decomposition

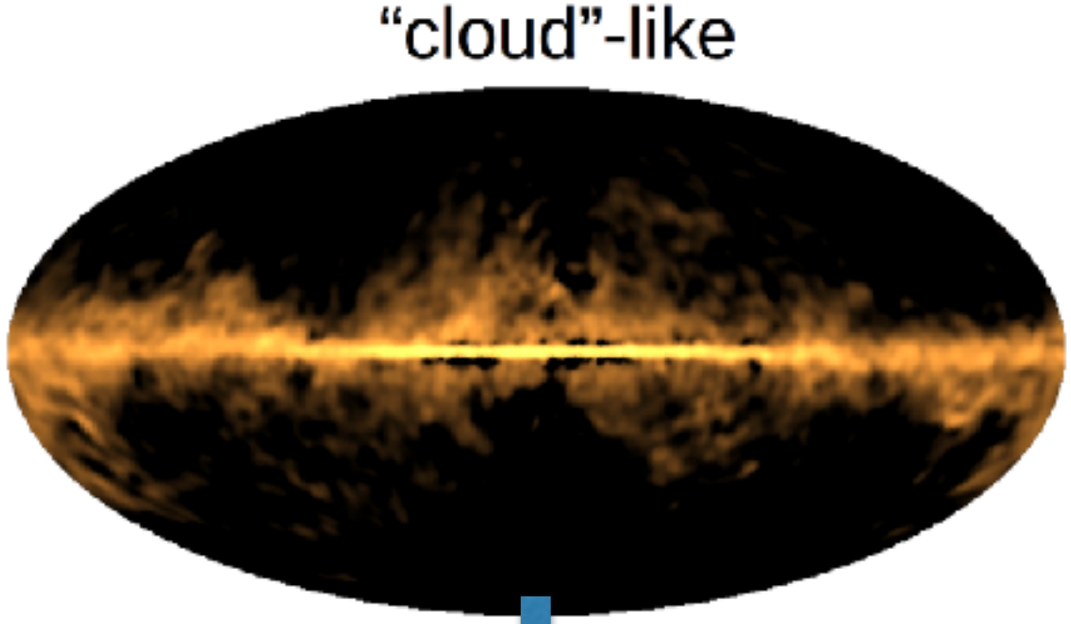


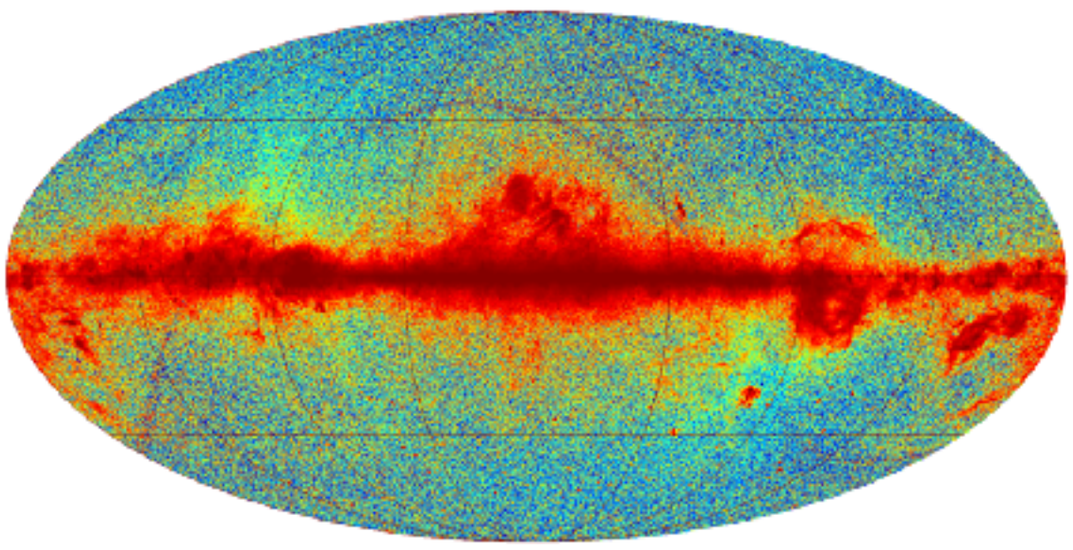
D3PO and Gamma-ray Sky

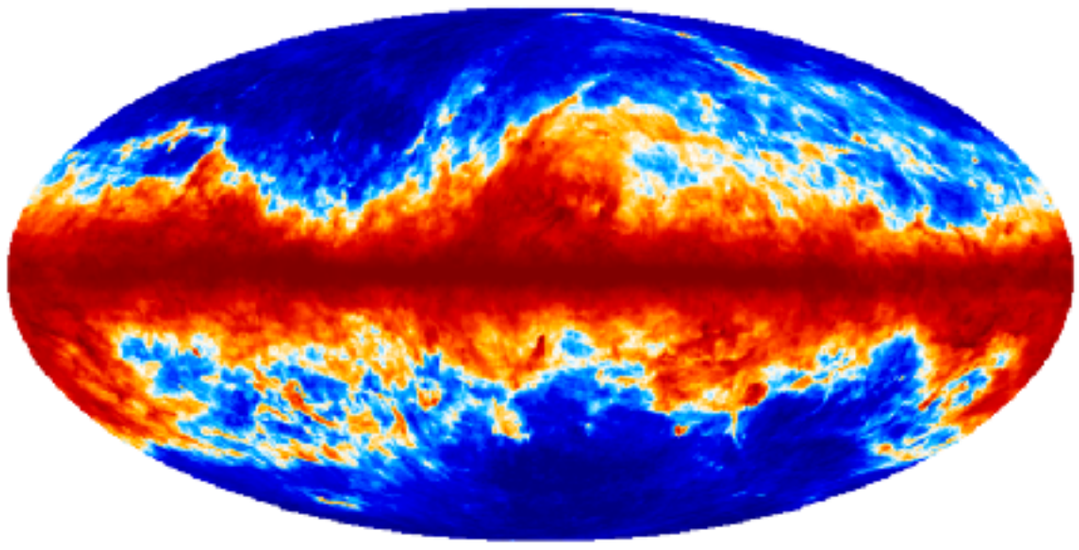
Selig+ 2014

Phenomenological Decomposition





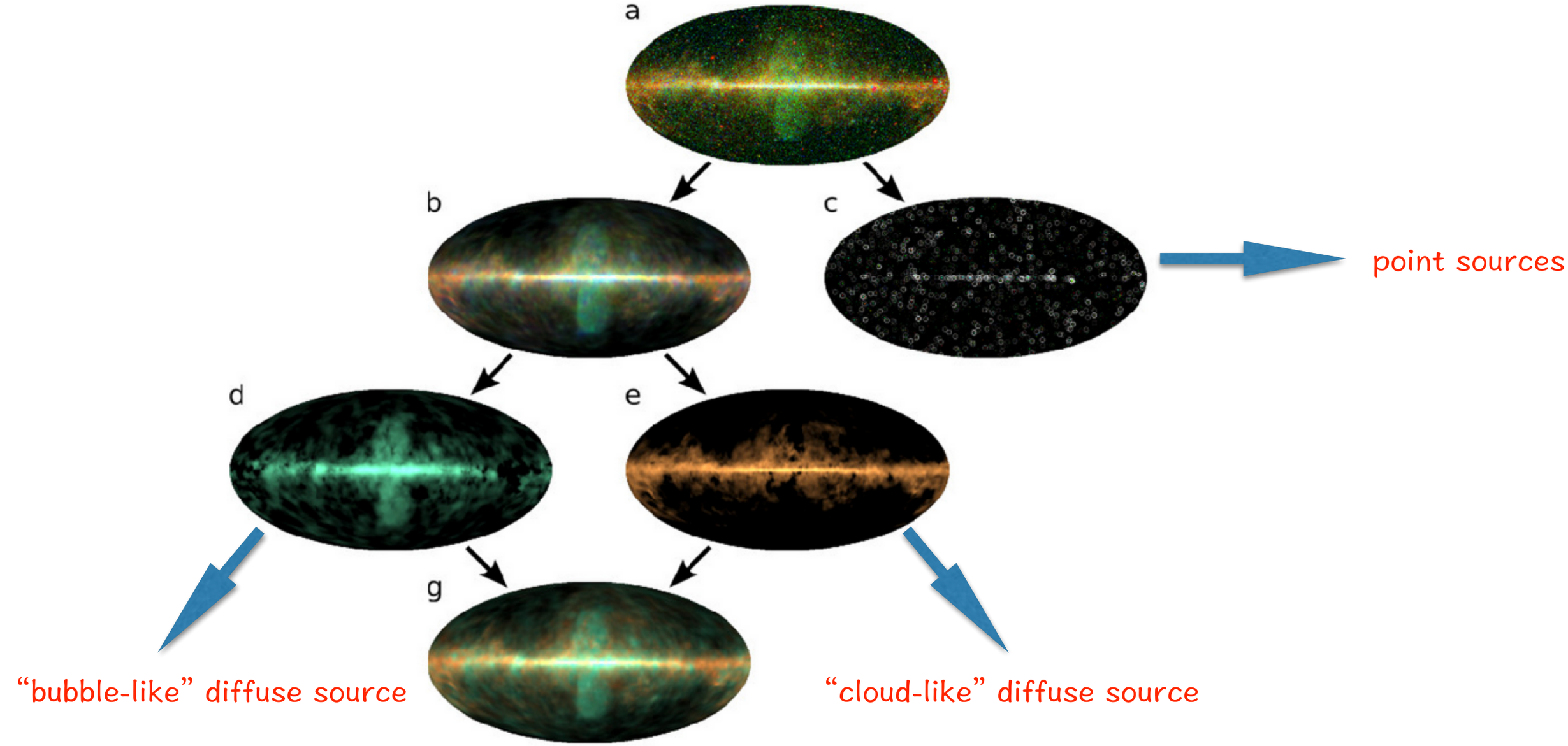




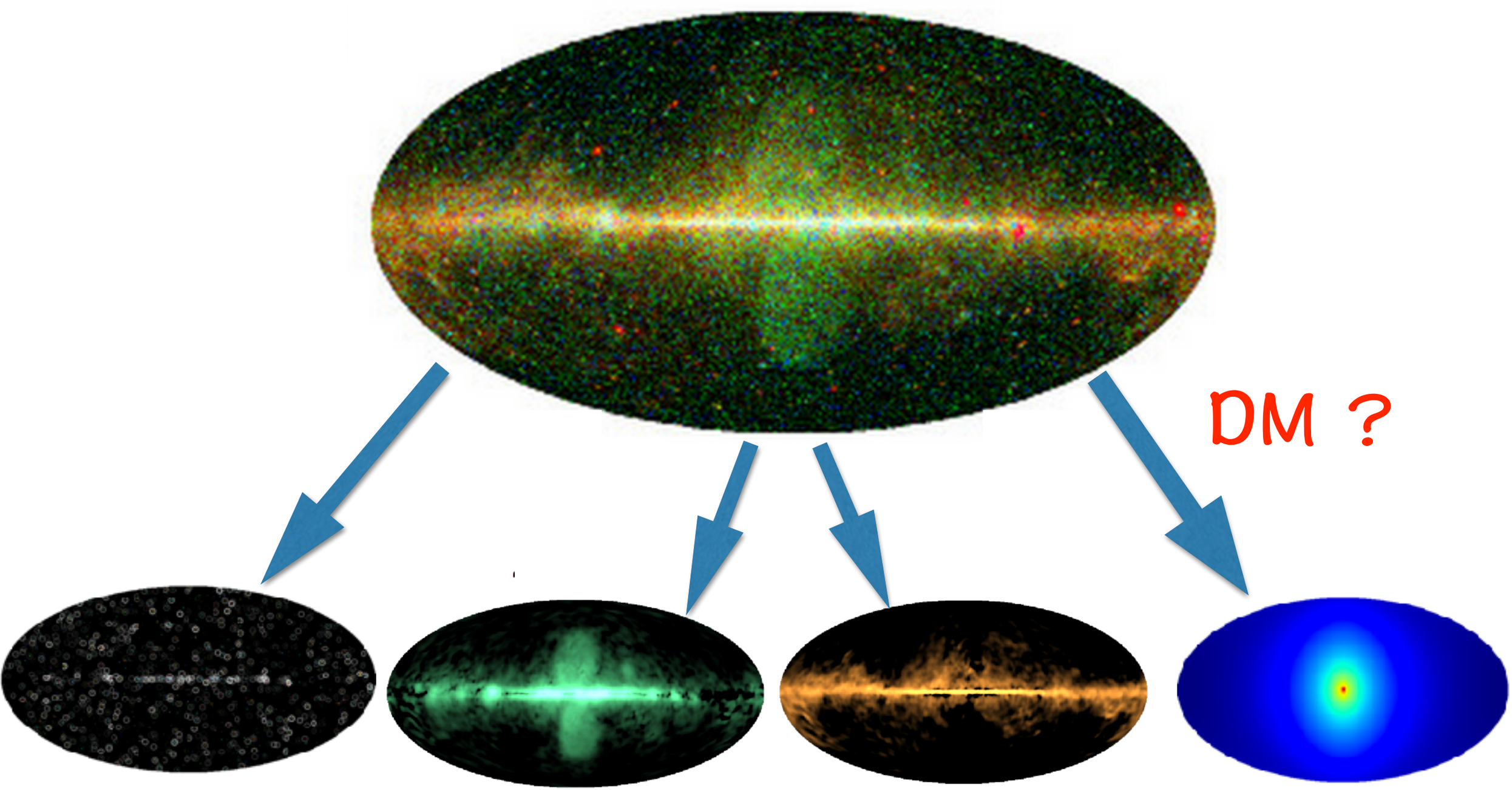
D3PO and Gamma-ray Sky

Selig+ 2014

Phenomenological Decomposition



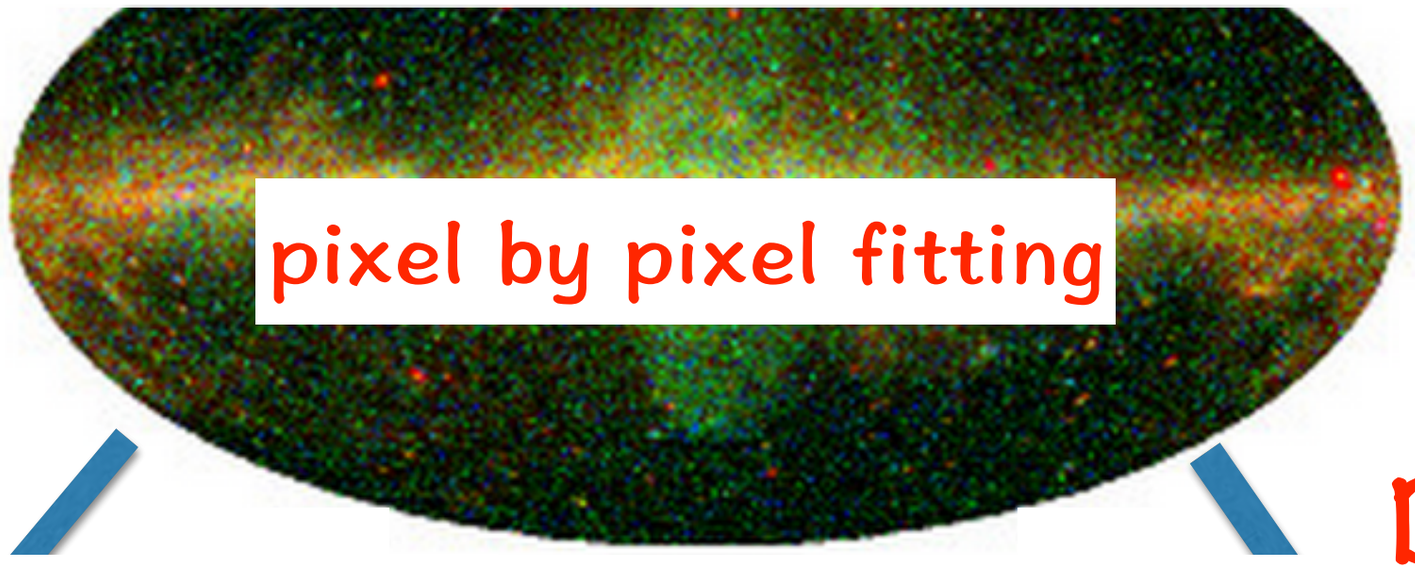
D3PO and Dark Matter



D3PO and Dark Matter

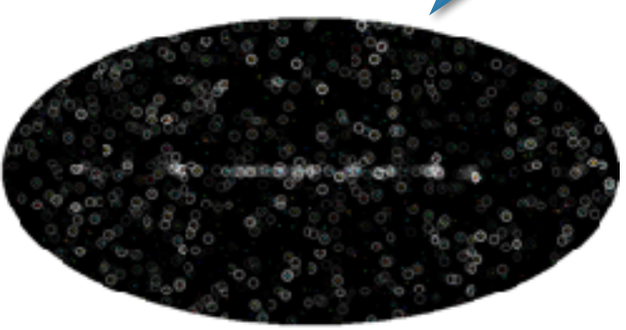
$$\chi^2_{\mathrm{ROI}}(p) = \sum_{i \in \mathrm{ROI}} \chi^2_i(p)$$

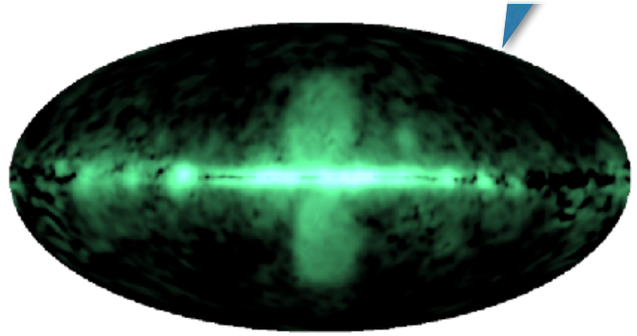
$$\chi^2_i(p) = -2 \sum_{jk} \left[n^{ijk}_{\mathrm{obs}} \ln \lambda^{ijk} - \lambda^{ijk} - \ln \left(n^{ijk}_{\mathrm{obs}}! \right) \right]$$

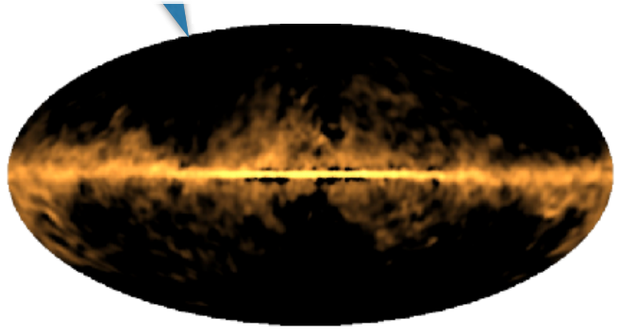


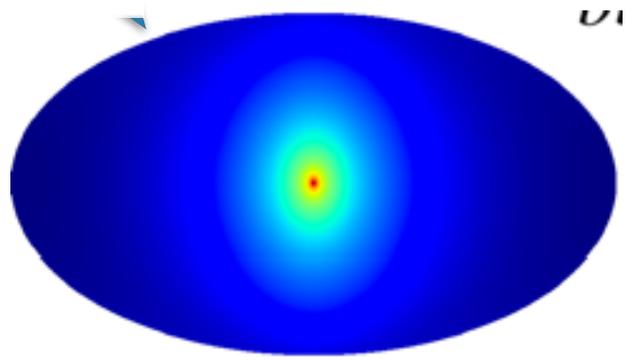
DM ?

$$\lambda^{ijk} = n^{ijk}_{dm} + \alpha_i n^{ijk}_{c} + \beta_i n^{ijk}_{b} + n^{ijk}_{point}$$



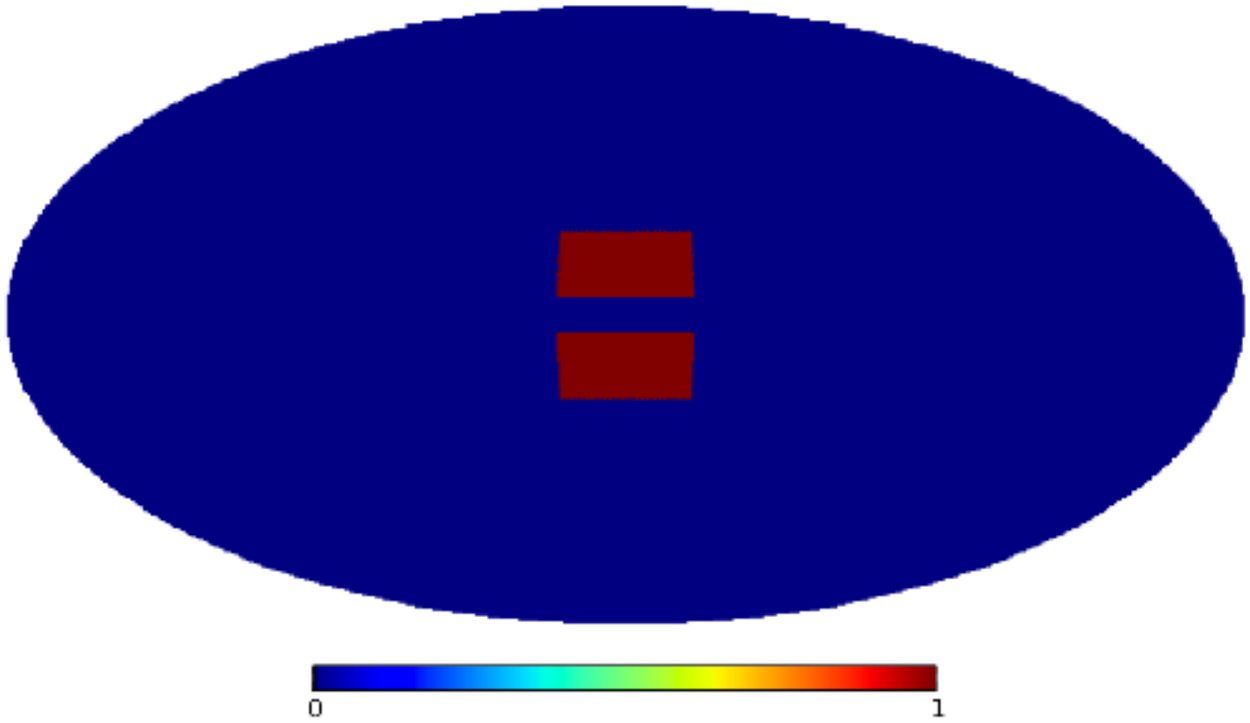




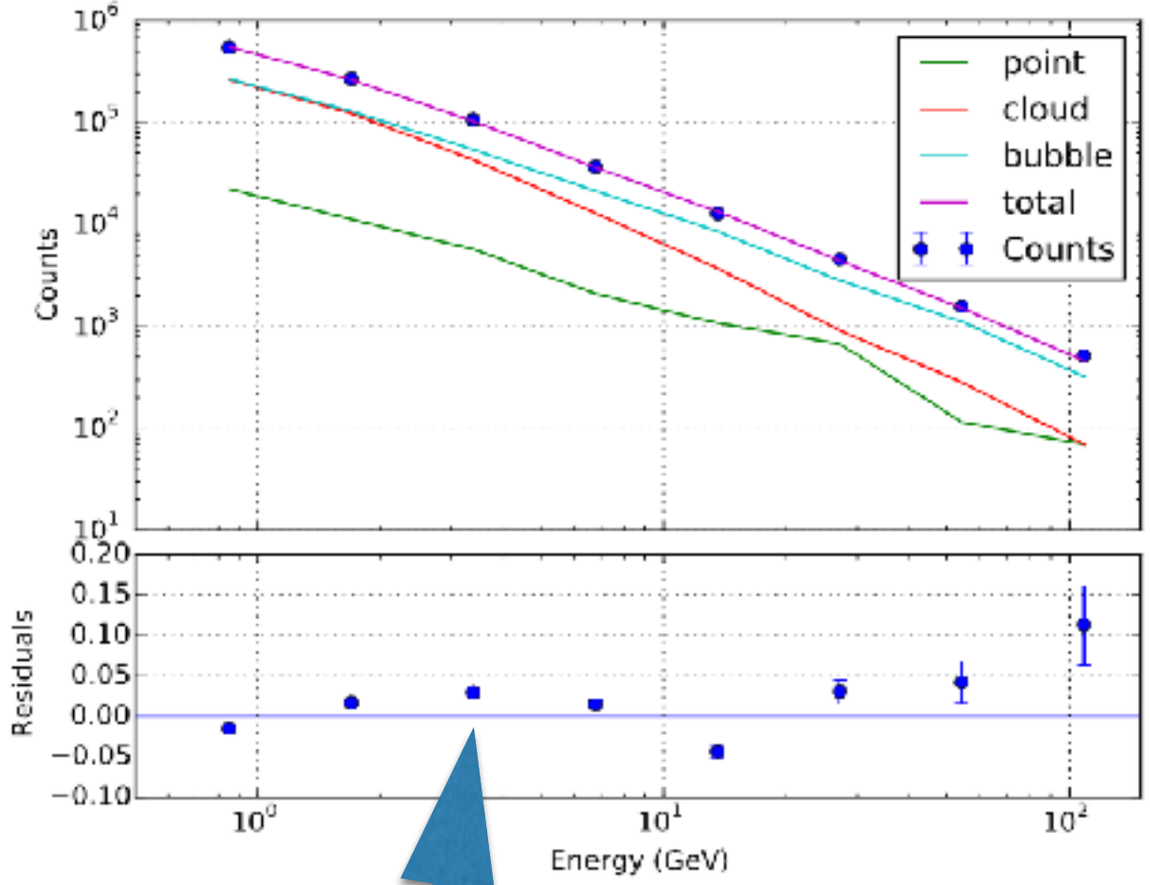


GeV excess ?

Inner Galaxy



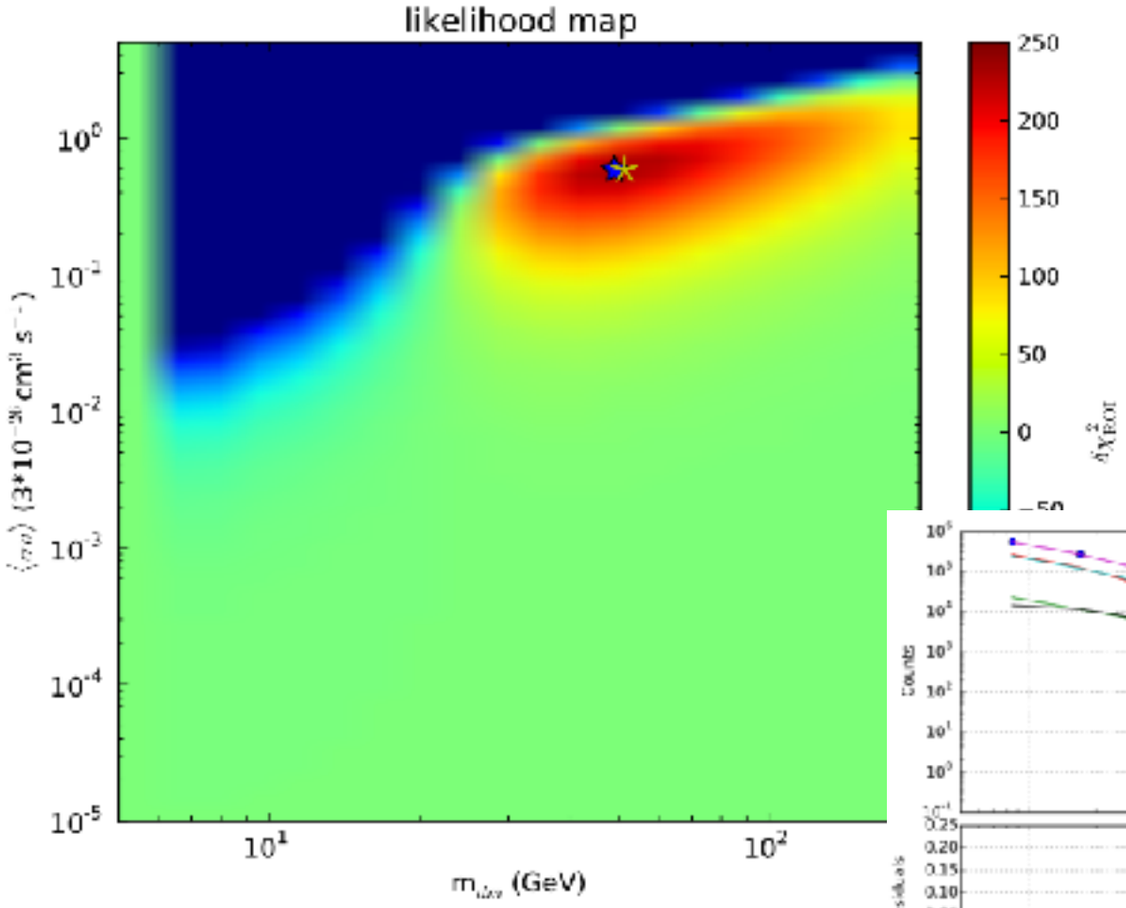
Fitted with astrophysical model

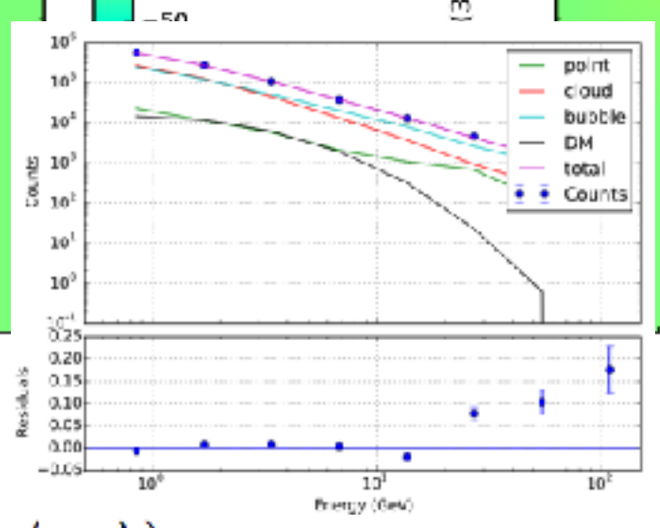


Reported GeV excess?

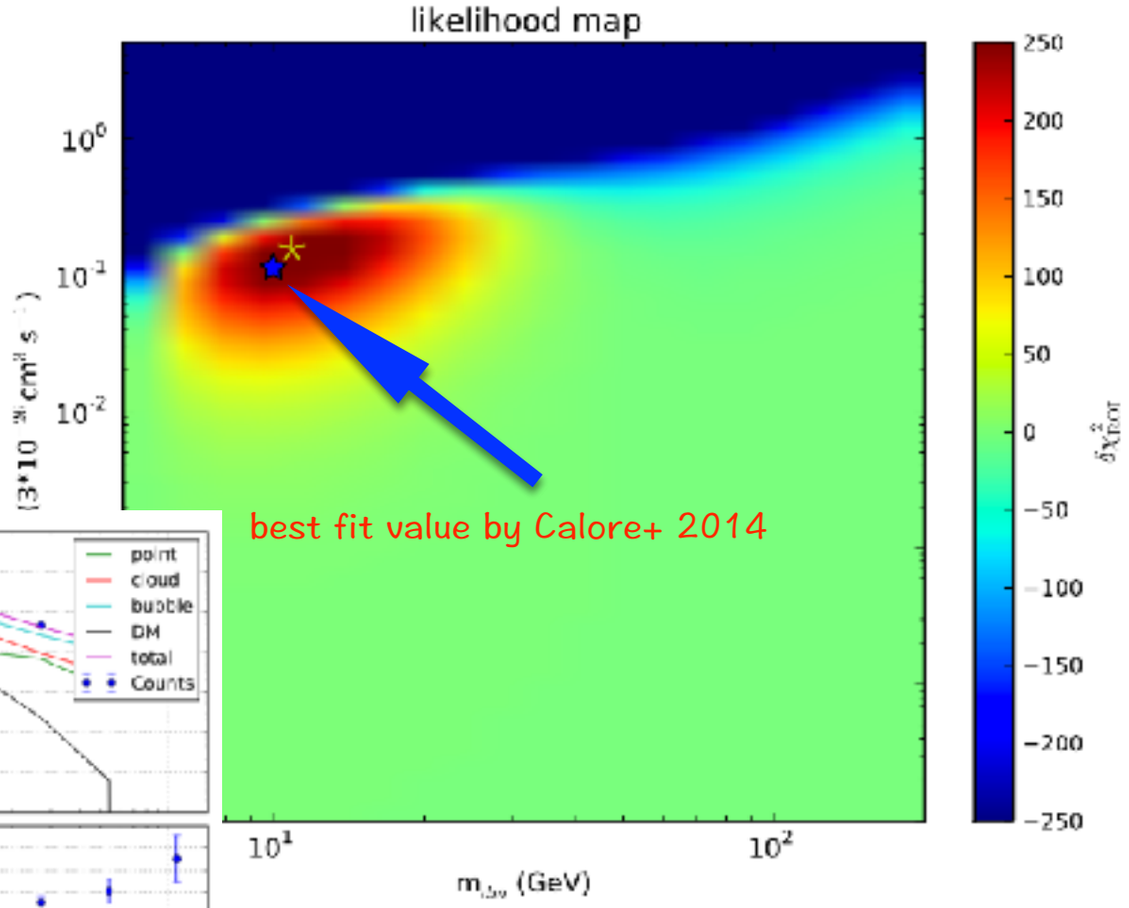
GeV excess and Dark Matter

$b\bar{b}$





$\tau^-\tau^+$

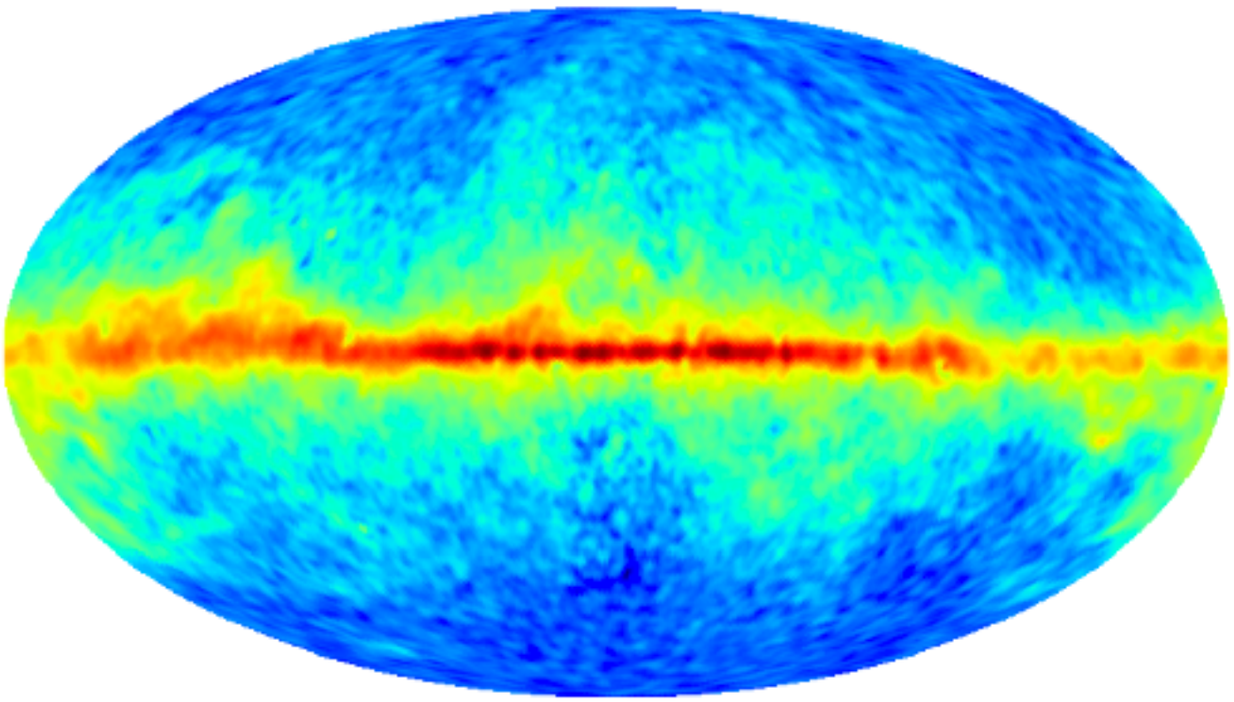


$$\delta\chi^2_{\mathrm{ROI}}(m_{\mathrm{dm}}, \langle\sigma v\rangle) =$$
$$\min_{\alpha,\beta}\chi^2_{\mathrm{ROI}}(0, 0, \alpha, \beta) - \min_{\alpha,\beta}\chi^2_{\mathrm{ROI}}(m_{\mathrm{dm}}, \langle\sigma v\rangle, \alpha, \beta).$$

GeV excess and Dark Matter

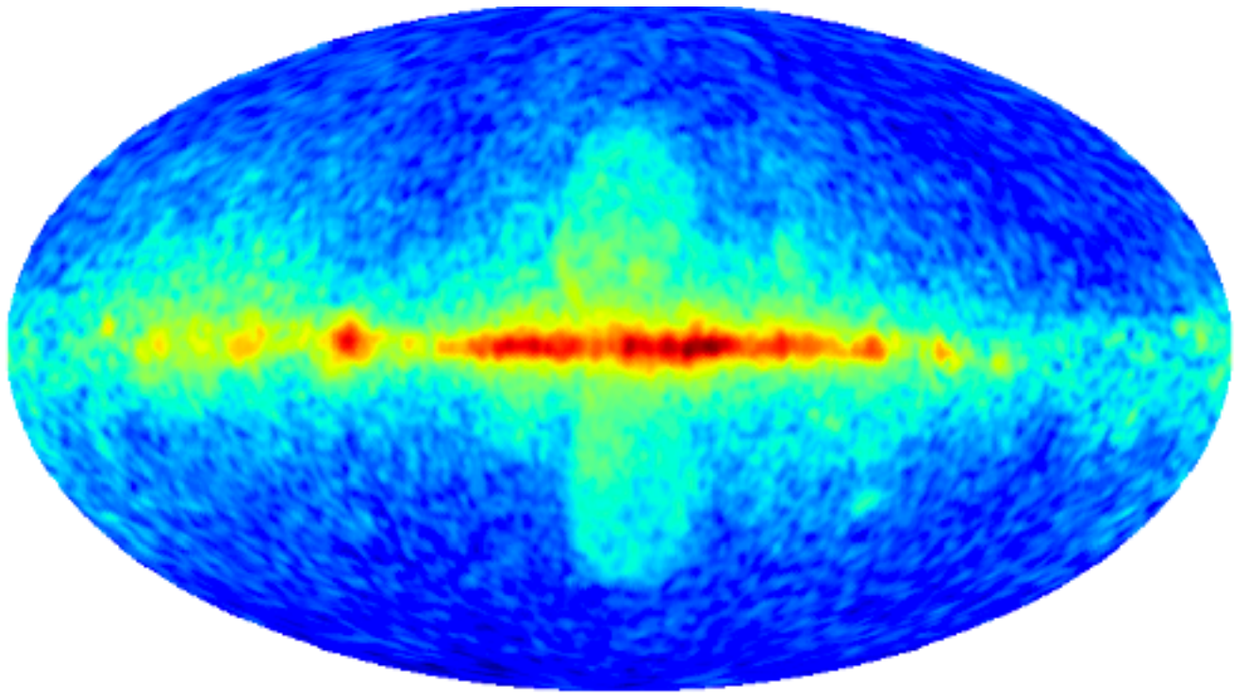
Including DM in the fitting will not obviously disturb "cloud"-like and "bubble"-like components

$\alpha_i n_c^{i30}$



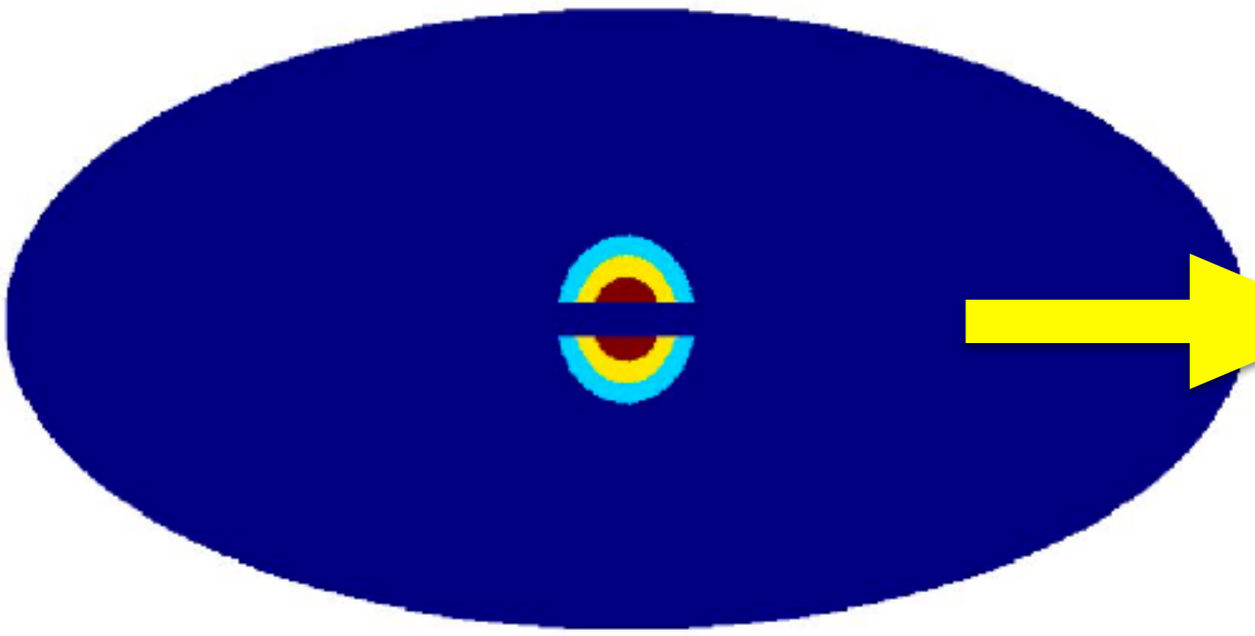
"Cloud"-like (cold ISM)

$\beta_i n_b^{i30}$

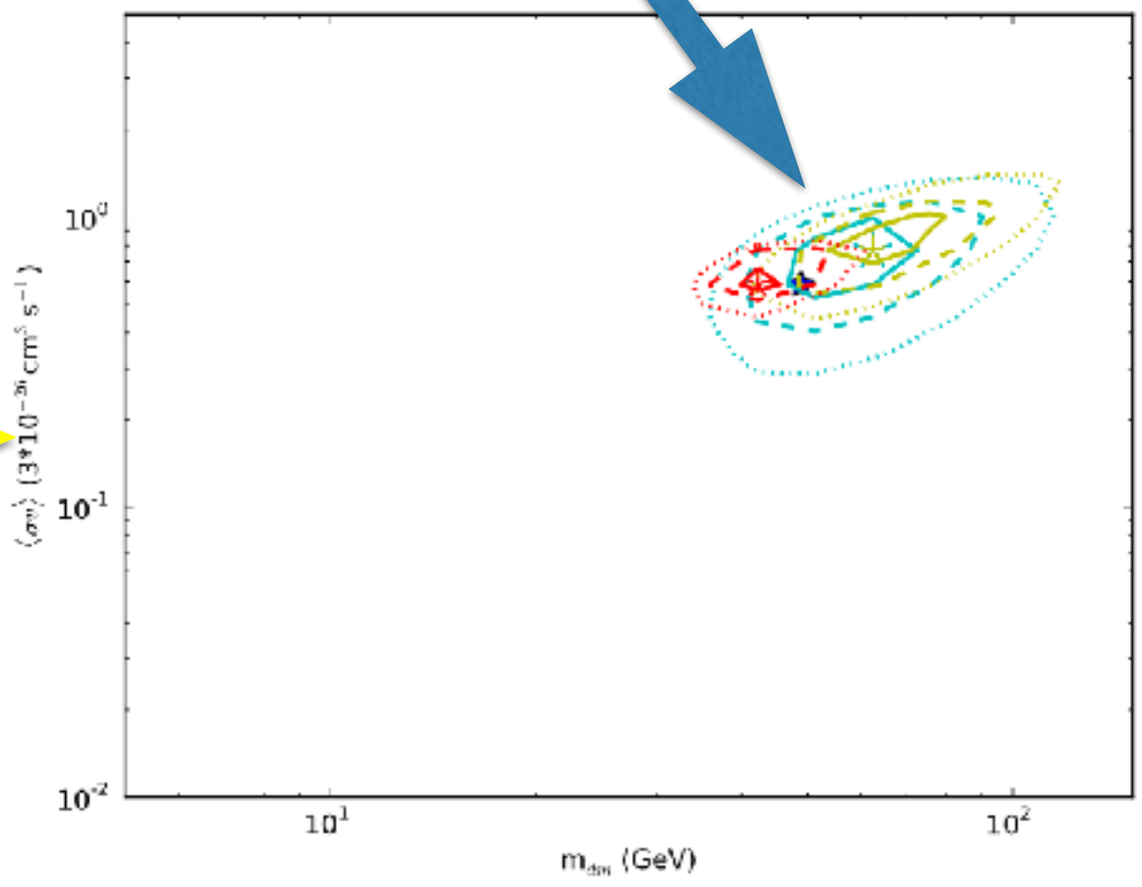


"Bubble"-like (hot ISM)

GeV excess and Dark Matter



agree well with each other



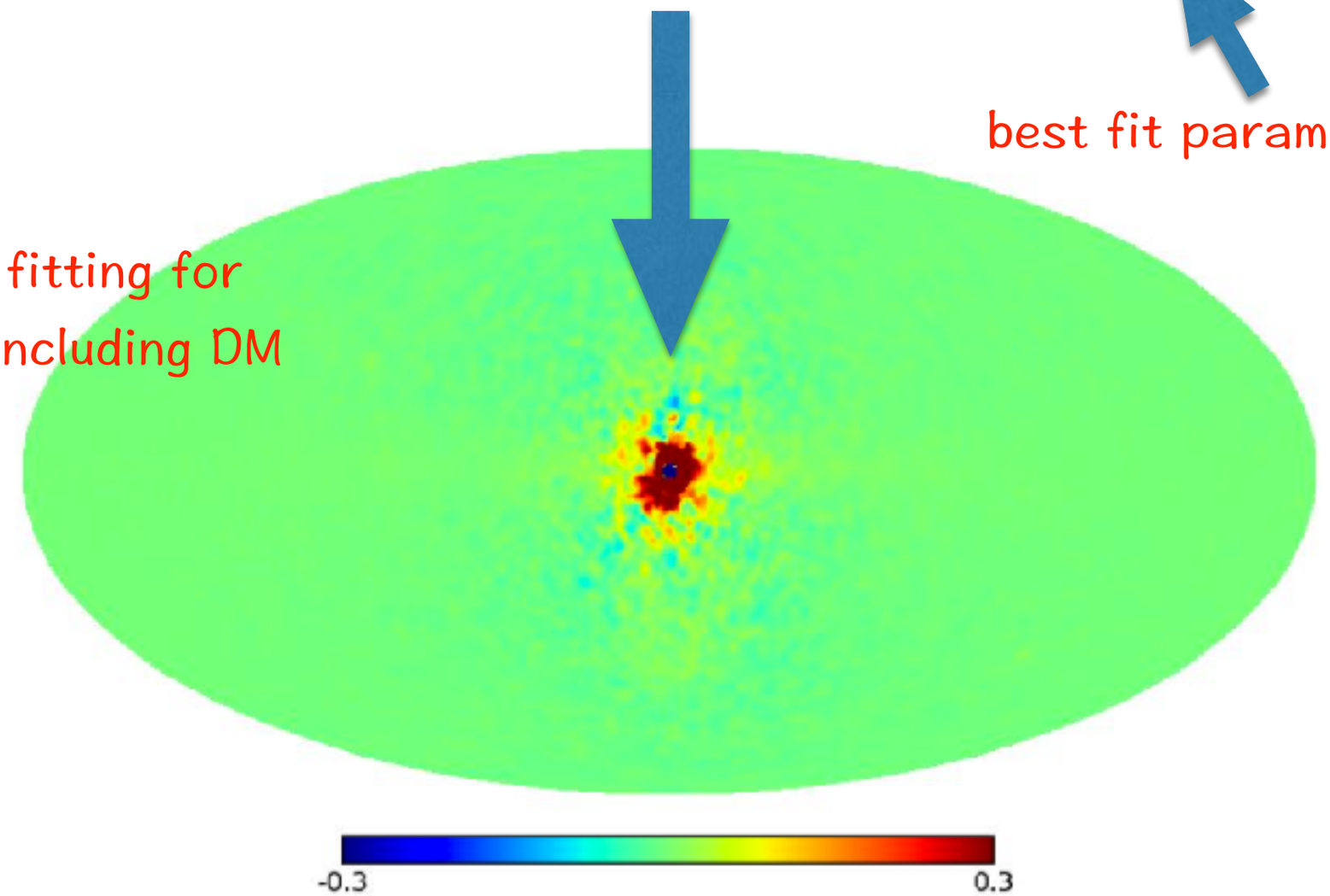
Different regions to check the consistency of dark matter interpretation

GeV excess and Dark Matter

$$\delta\chi^2_{\star i} = \min_{\alpha_i,\beta_i}\chi^2_i(0,0,\alpha_i,\beta_i) - \min_{\alpha_i,\beta_i}\chi^2_i(m_{\rm dm\star},\langle\sigma v\rangle_\star,\alpha_i,\beta_i)$$

best fit parameters

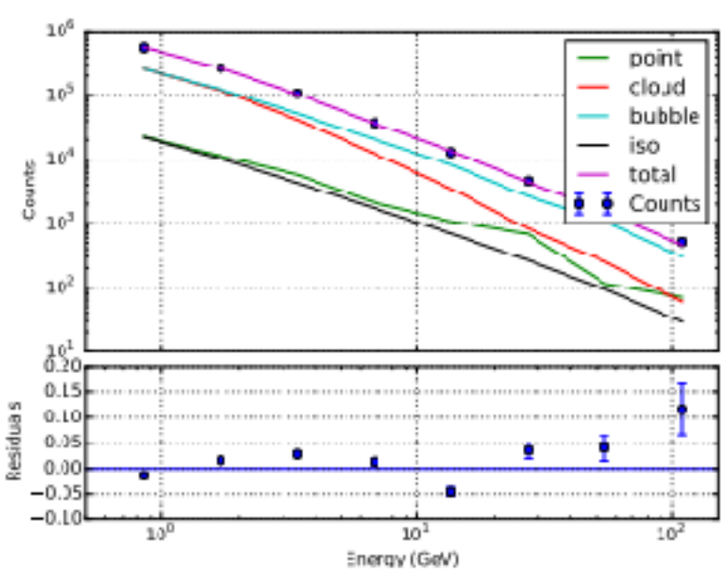
Improvement of fitting for each pixel after including DM

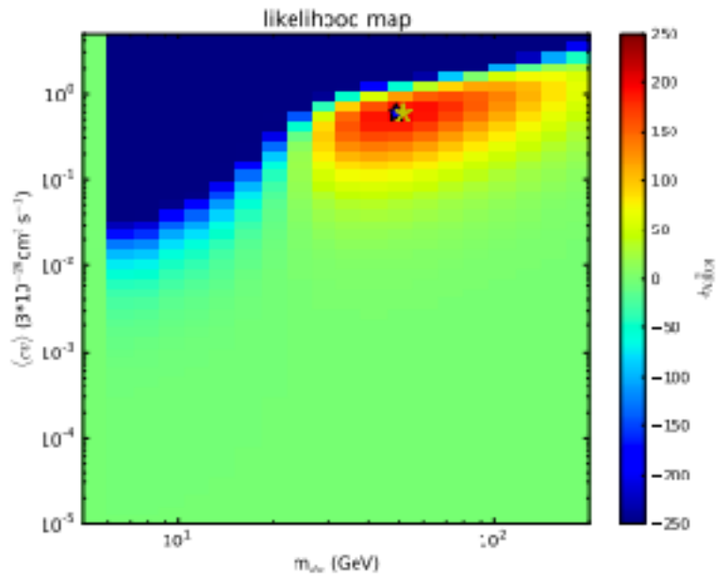


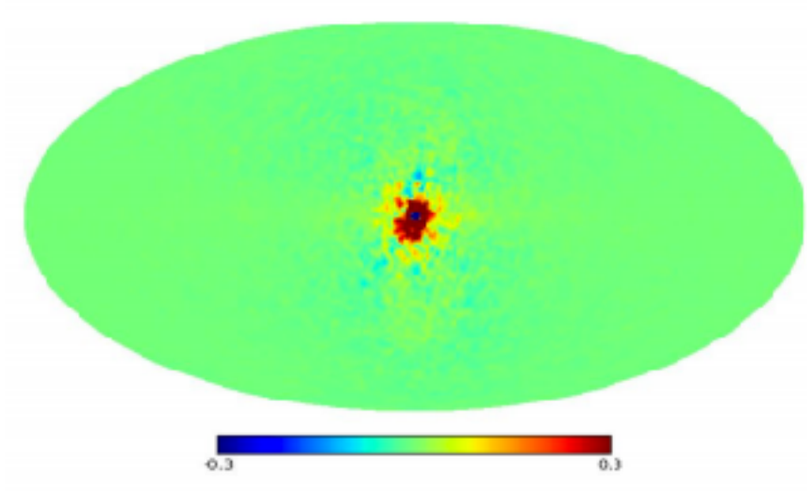
Improvement due to the inclusion of DM annihilation contribution is almost spherically distributed around the GC. This is consistent with the anticipation that this signal has a DM annihilation origin.

GeV excess and Dark Matter

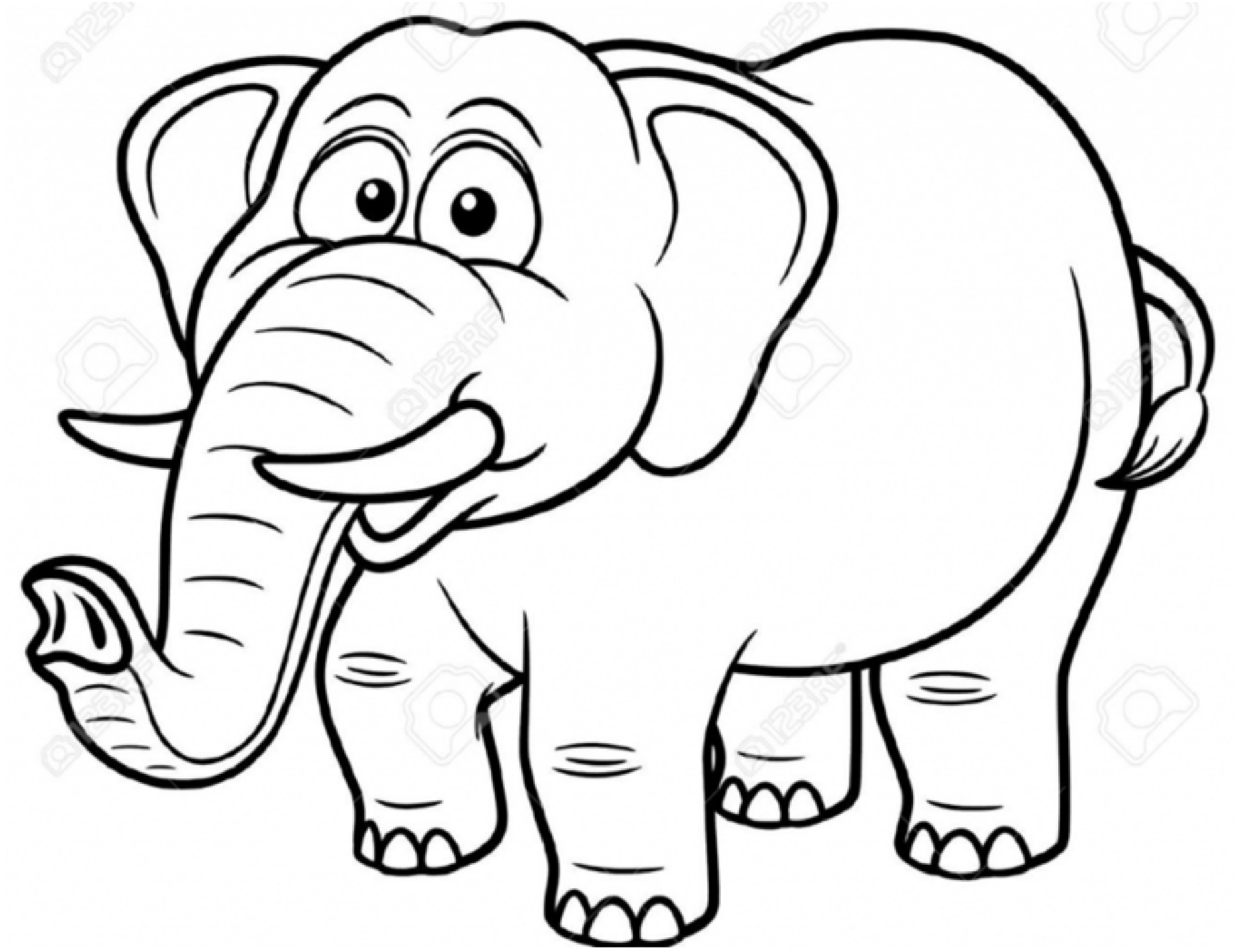
What's the effect of another astrophysical component?







GeV excess is still there!

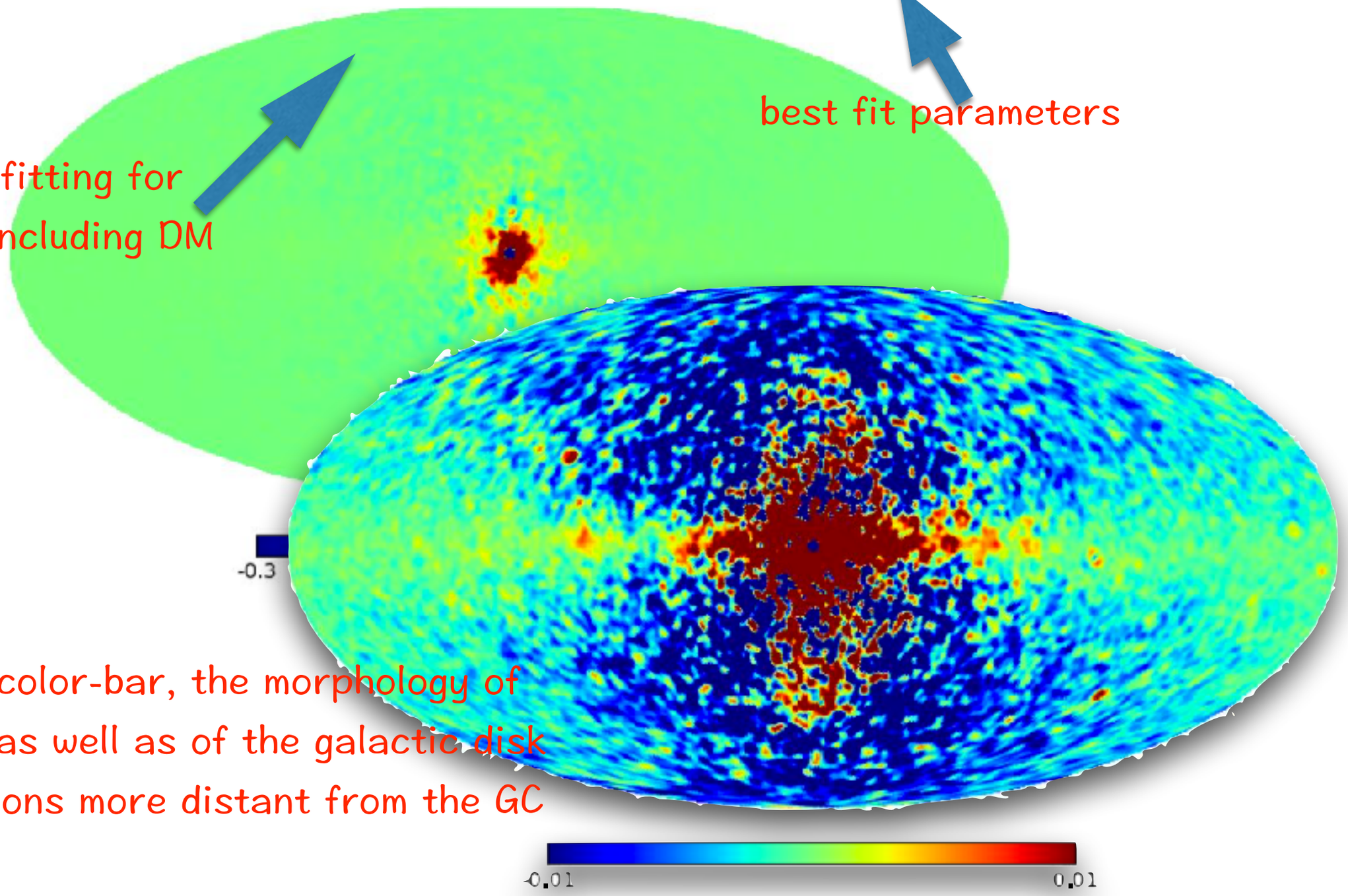


Astrophysical structures?

$$\delta\chi^2_{\star i} = \min_{\alpha_i,\beta_i}\chi^2_i(0,0,\alpha_i,\beta_i) - \min_{\alpha_i,\beta_i}\chi^2_i(m_{\mathrm{dm}\star},\langle\sigma v\rangle_\star,\alpha_i,\beta_i)$$

best fit parameters

Improvement of fitting for each pixel after including DM

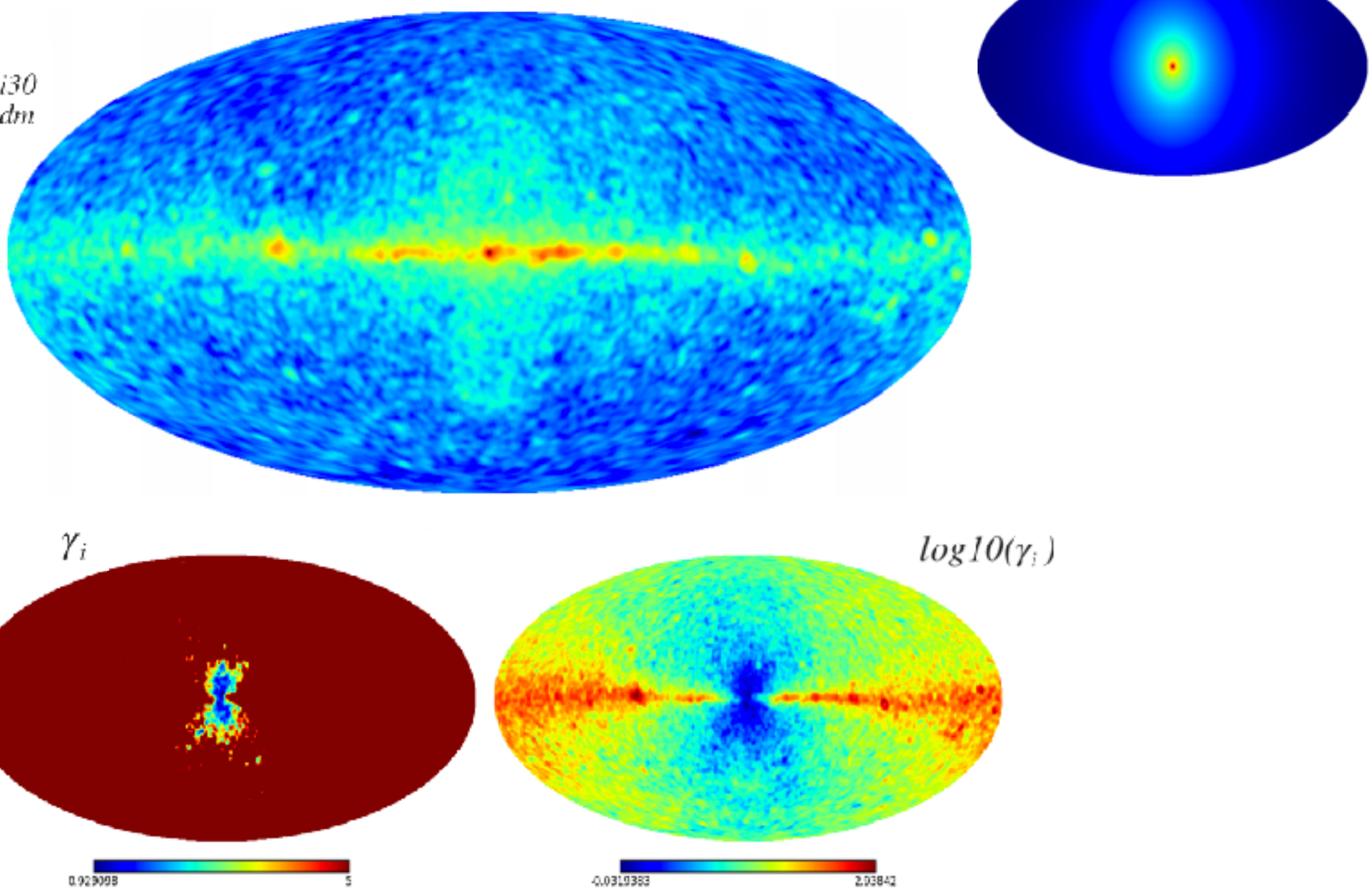


After tuning the color-bar, the morphology of the Fermi bubbles as well as of the galactic disk is shown at locations more distant from the GC

"DM"-Like Component

$$\lambda^{ijk} = \gamma_i n_{dm}^{ijk} + \alpha_i n_c^{ijk} + \beta_i n_b^{ijk} + n_{point}^{ijk}$$

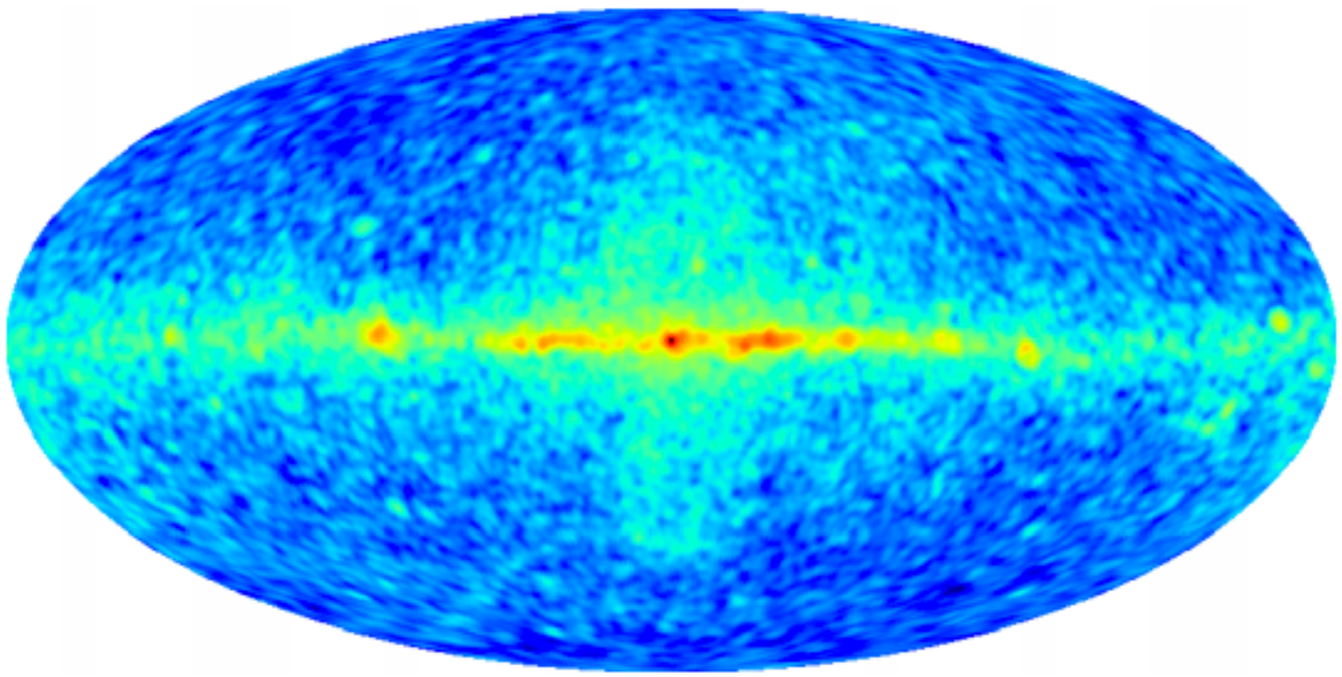
gnfw



"DM"-Like Component Vs. "Bubble"-like Component

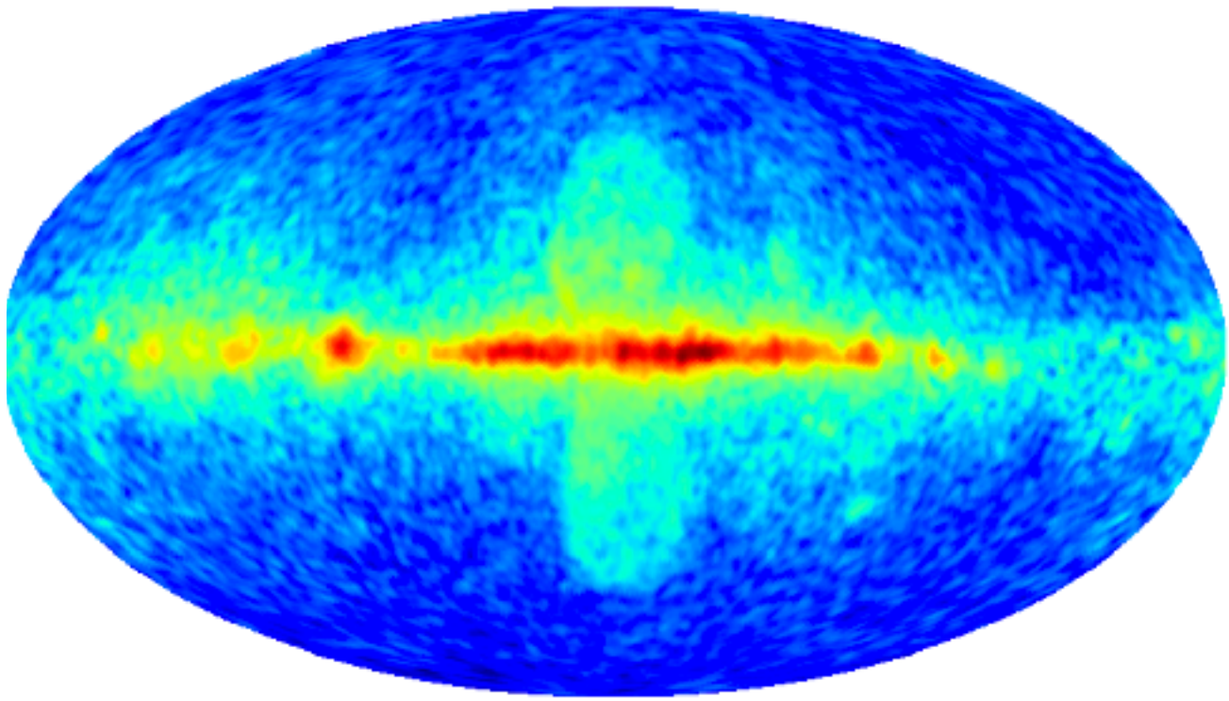
After freeing the normalization of
DM component in each pixel, the morphology
of the Fermi bubbles as well as of the galactic
disk is shown at locations more distant from the GC

$\gamma_i n_{dm}^{i30}$



"DM"-like (?)

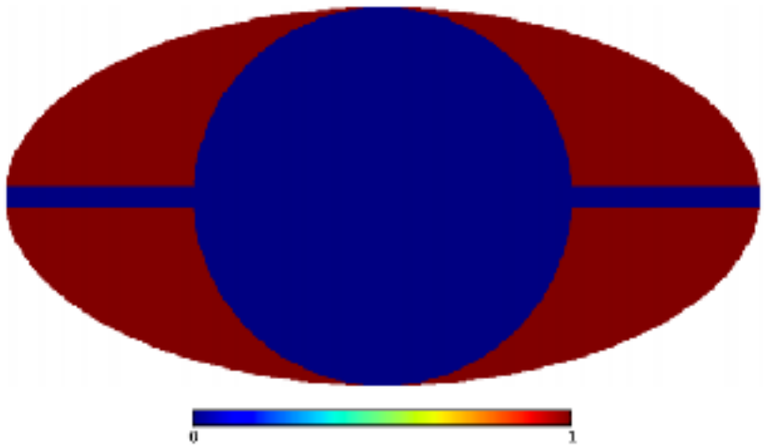
$\beta_i n_b^{i30}$

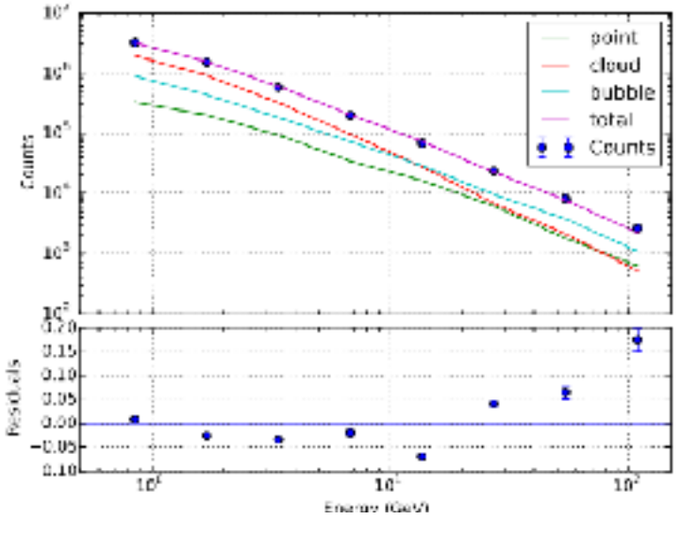


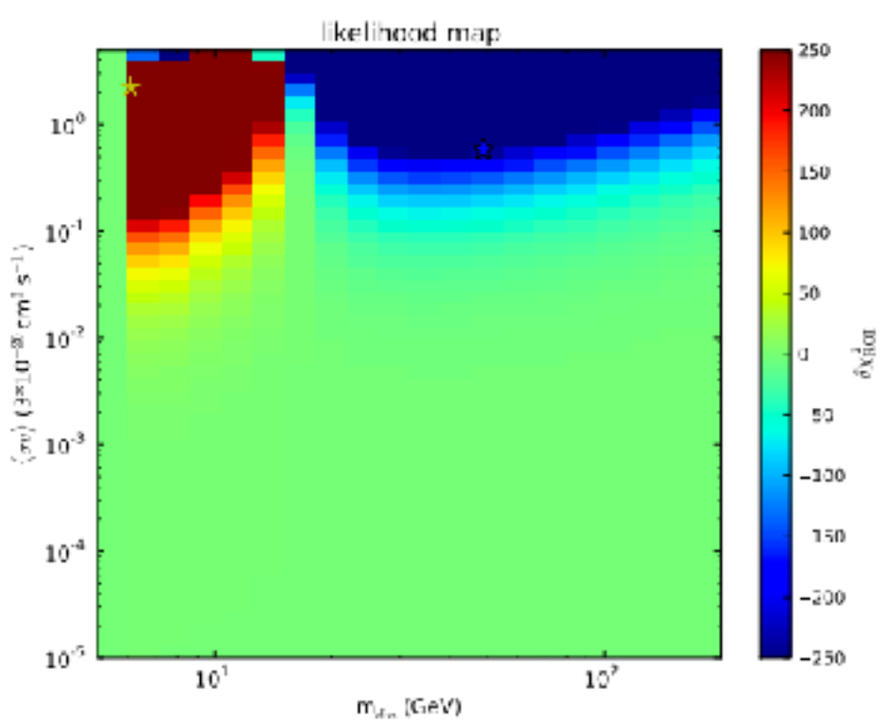
"Bubble"-like (hot ISM)

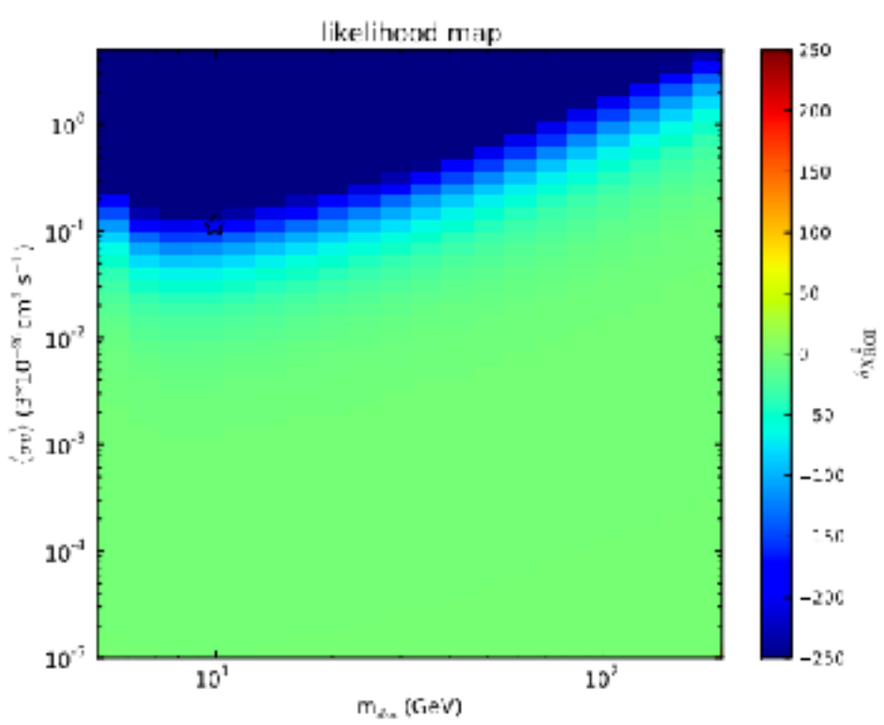
Do similar structures indicate "similar" origin?

Constraints from Anti-Galactic Center Region









Tension with dark matter interpretation?

AFRICAN ELEPHANT

ASIAN ELEPHANT

What are the differences?

EARS: Large, “Africa-shaped” ear
TRUNK TIP: Two “fingers” for grasping
HEAD: Single dome
HEIGHT *(tallest at shoulder)*: 9 – 13'
WEIGHT: 8,800 – 15,400 lbs.

EARS: Small, rounded ear
TRUNK TIP: One “finger” for grasping
HEAD: Twin dome
HEIGHT *(tallest at back)*: 6.5 – 9'
WEIGHT: 6,600 – 13,200 lbs.

THOMSON SAFARIS

Conclusions

With our phenomenological astrophysics modeling

(1) We find a excess in our ROI, and it is coincident with the GeV excess reported in the literature

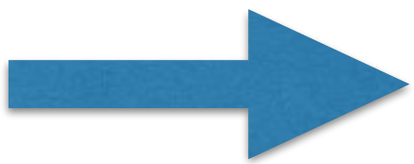
(2) Fitting this excess with DM annihilation signal, we get consistent parameters with those in the literature

(3) Data favor a spherical component centered at GC, which is consistent with a DM annihilation signal

However..

(1) Find also preference of data for such DM-like component in astrophysical emission regions

(2) Very strong constraints from anti-Galactic center region



(a) Additional astrophysical components may mimic DM annihilation signal

(b) More accurate astrophysical gamma-ray emission model is needed!

THANK YOU!