Fermilab

WIMP ante portas? The Fermi galactic center excess

Discuss the excess:

(Convince you the excess is REAL and relatively well understood)

Hooper & Goodenough: (1010.2752), Linden & Hooper (1110.0006), Abazajian & Kaplinghat (1207.6047), Hooper & Slatyer (1302.6589) Huang, Urbano & Xue (1307.6862),Daylan, Finkbeiner, Hooper, Linden, Portilo, Rodd, Slatyer, 1402.6703, Calore, Cholis, Weniger JCAP 2015 (1409.0042).

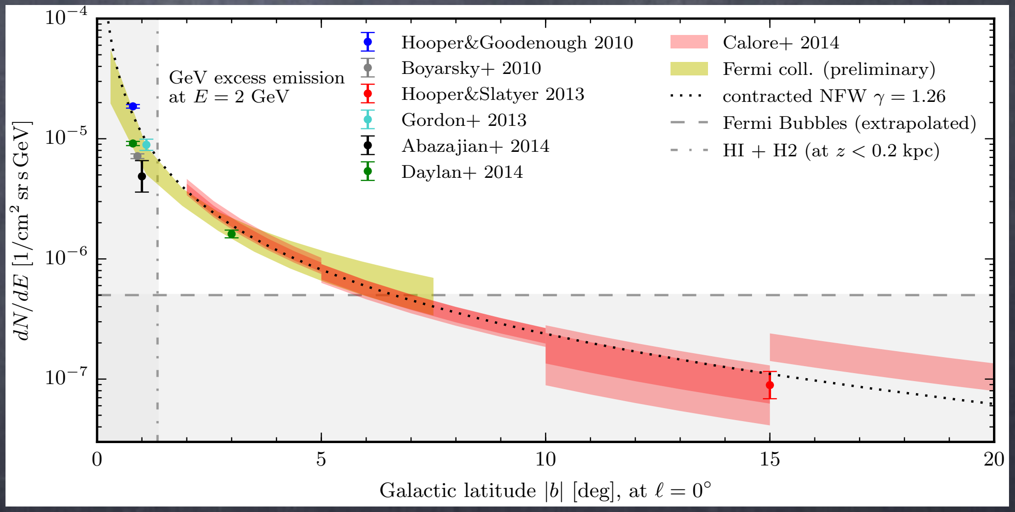
Discuss the interpretations:

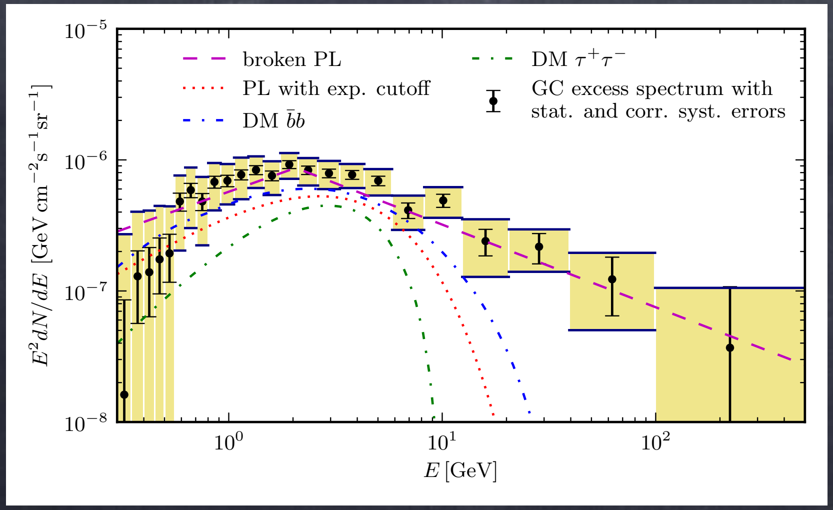
(DM vs Millisecond Pulsars vs Bursts of CRs)

Hooper, Cholis, Linden, Siegal-Gaskins & Slatyer (1305.0830), Gordon & Macians (1306.5725)

Cholis, Hooper, Linden (1407.5625), Calore, Cholis, McCabe, Weniger JCAP 2015 (1411.4647),

Cholis, Calore, Evoli, Hooper, Linden, Weniger (in prep.)

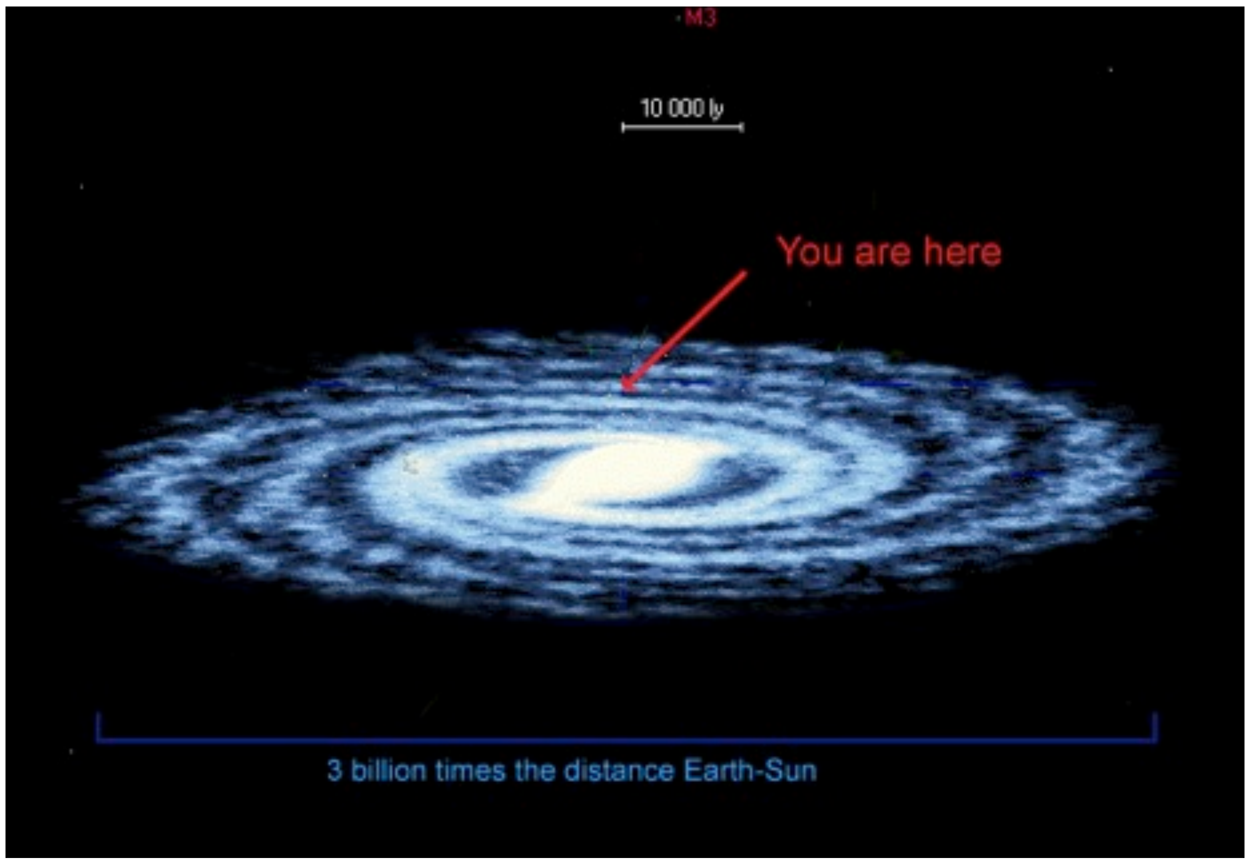


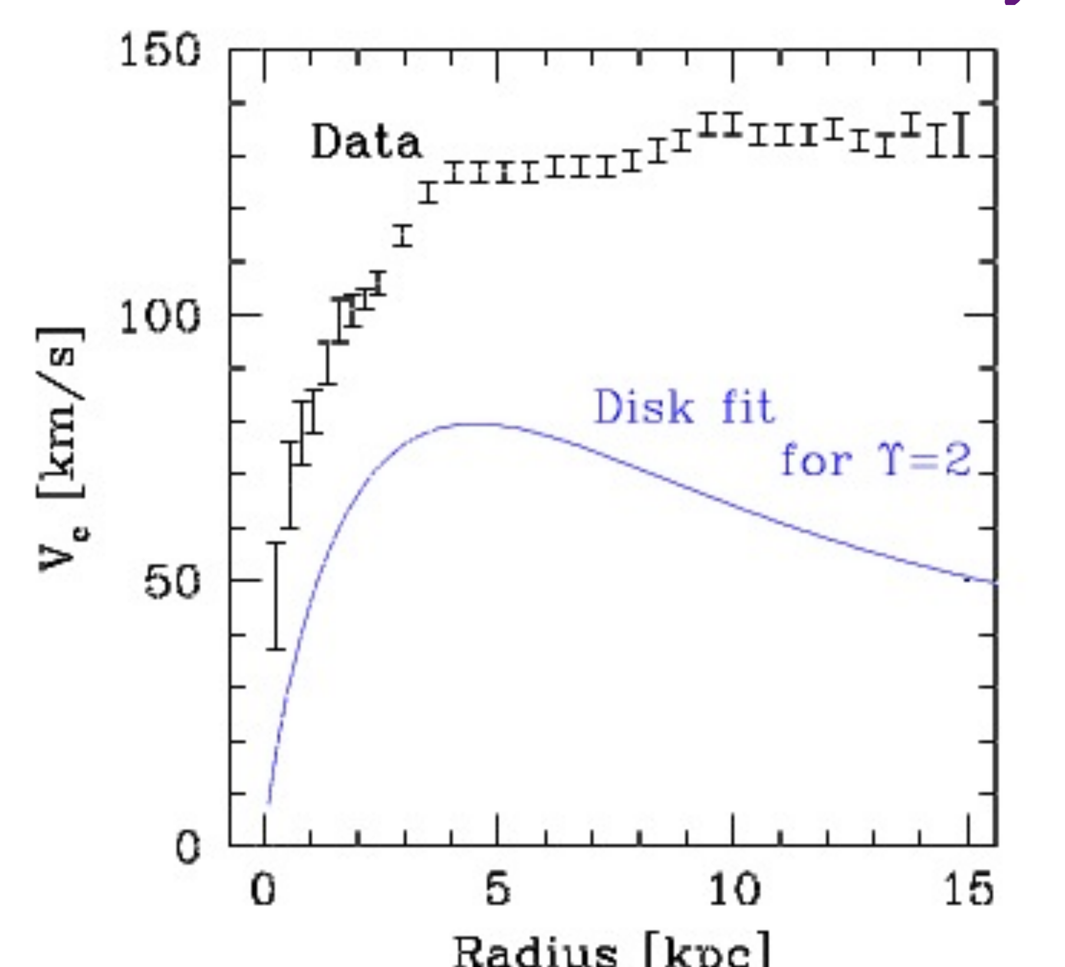


Ilias Cholis, Particle Physics Seminar, 4/10/2015

evidence for CDM (Cold Dark Matter)

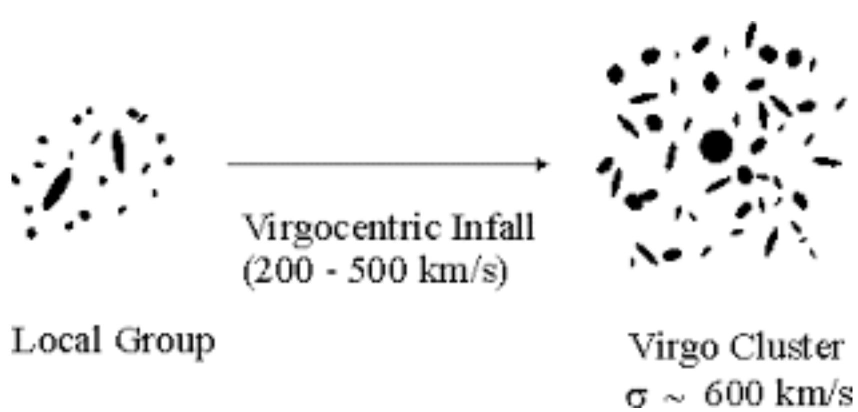
- galactic rotation curves

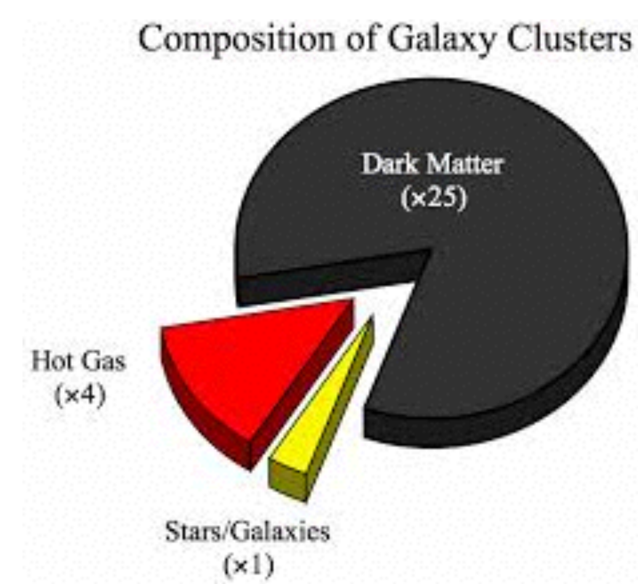




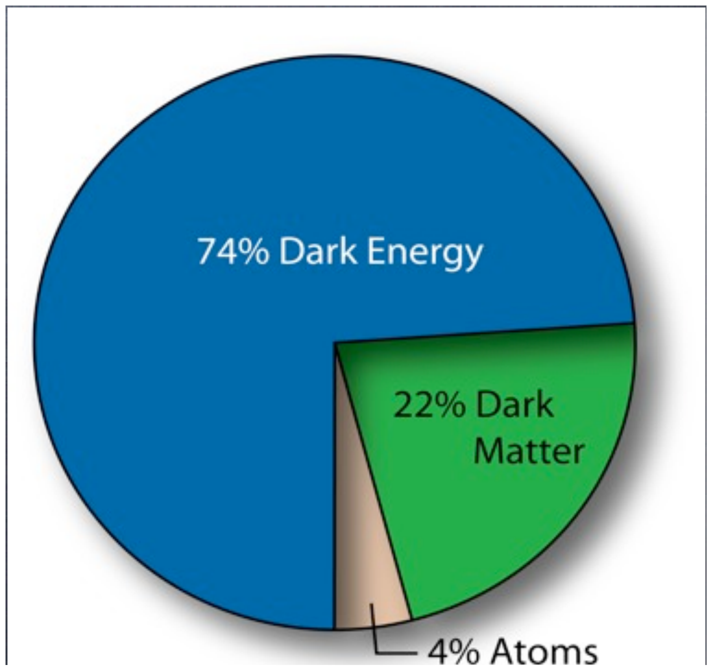
NGC 2403 rotation curve and model

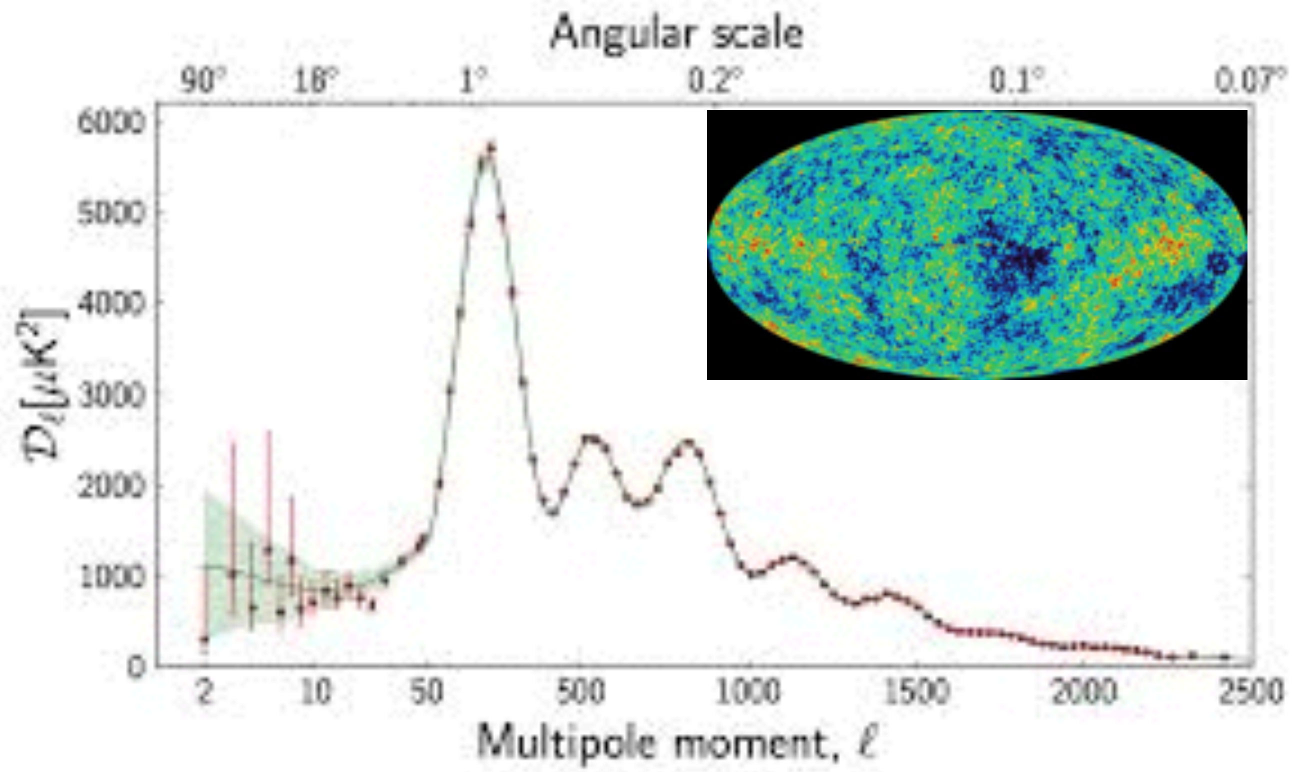
- velocity dispersion of galaxies in clusters



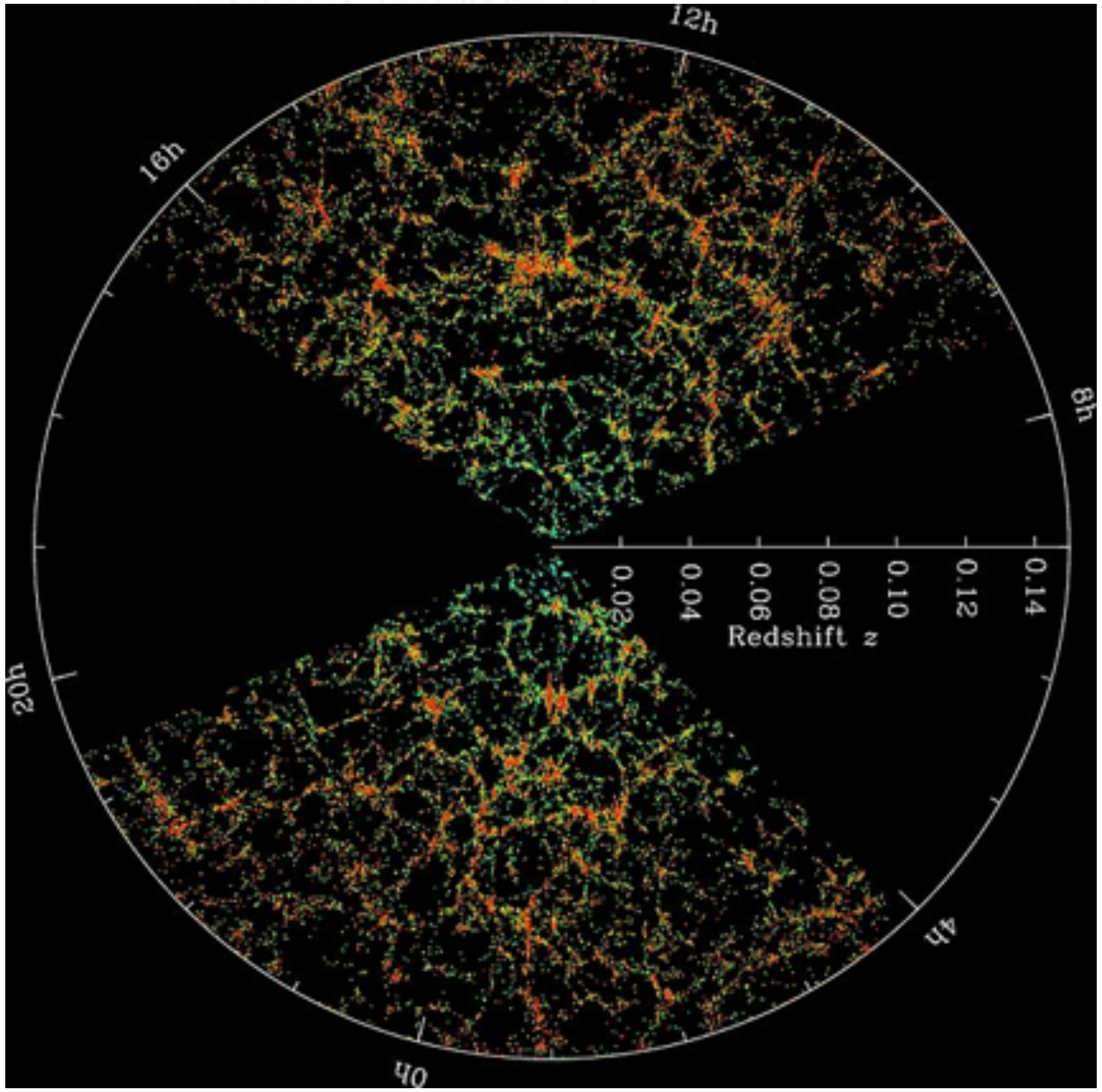


- CMB data and SN Ia data

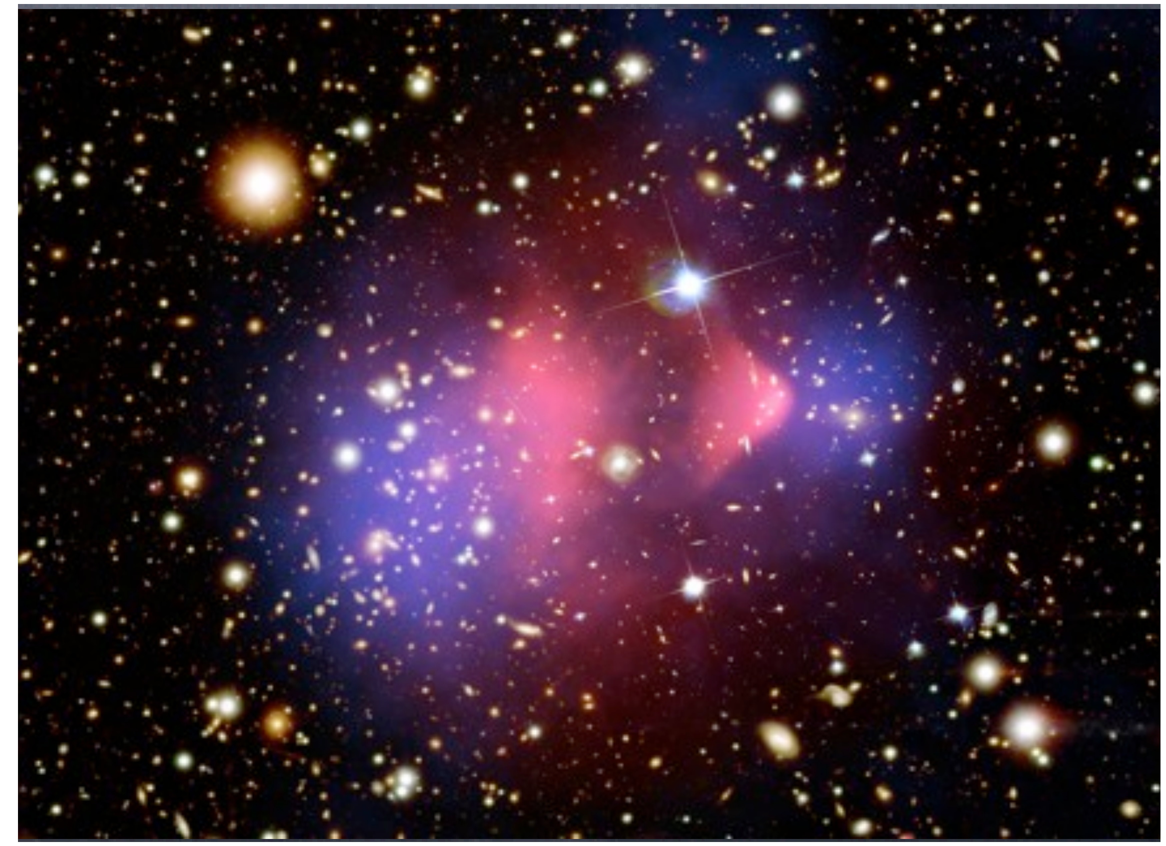


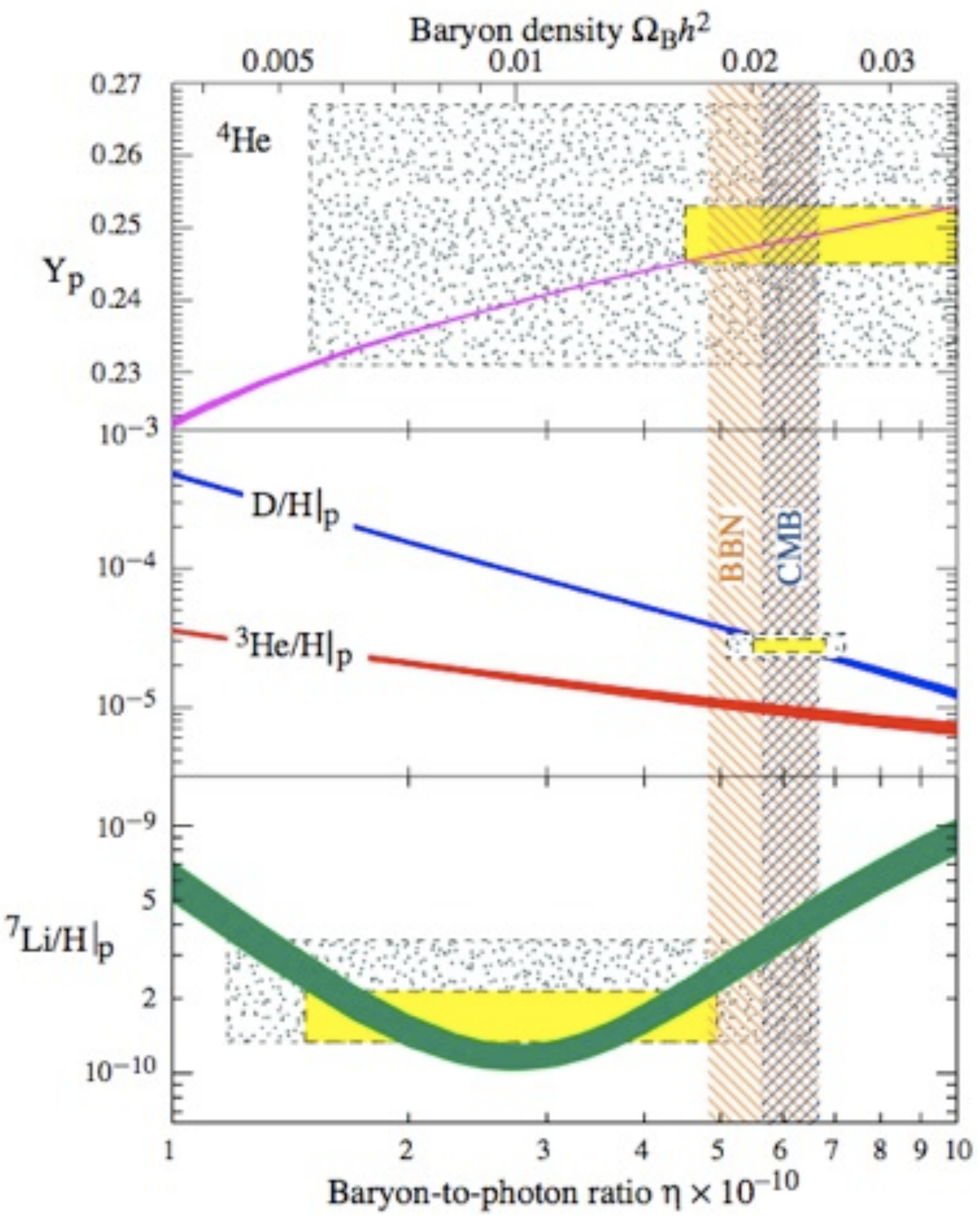


- Observed distribution of galaxies:
- strong lensing measurements of background objects (usually galaxies)

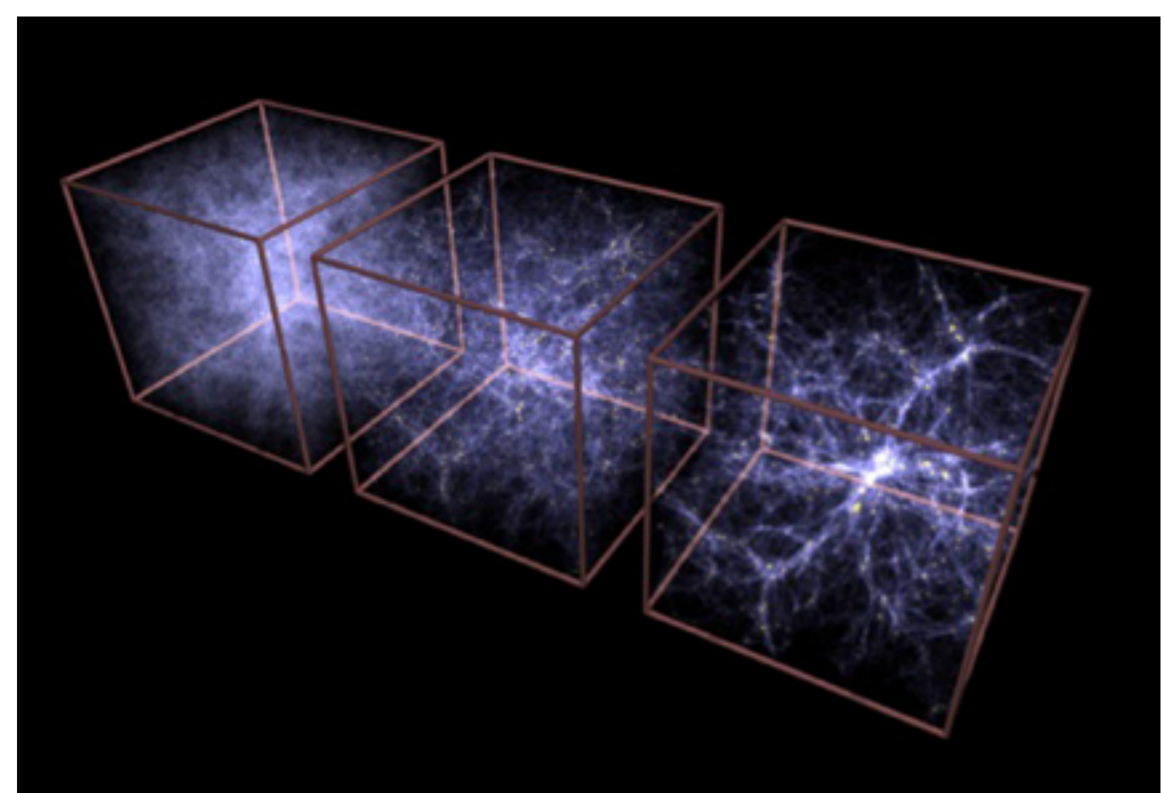


- collisions of galaxy clusters (e.g. bullet cluster)



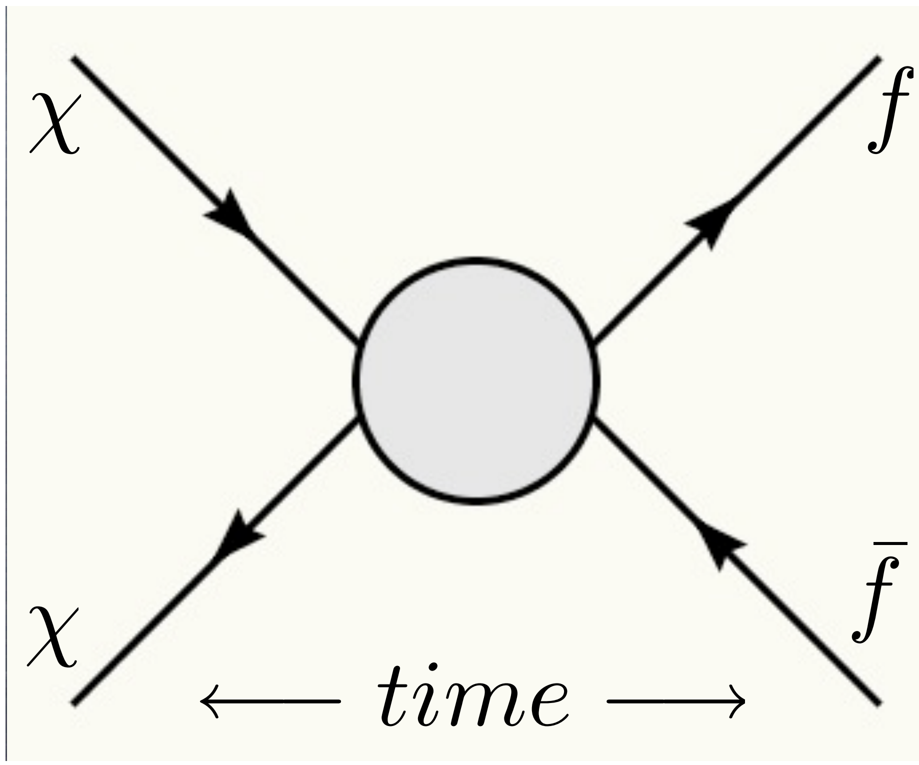


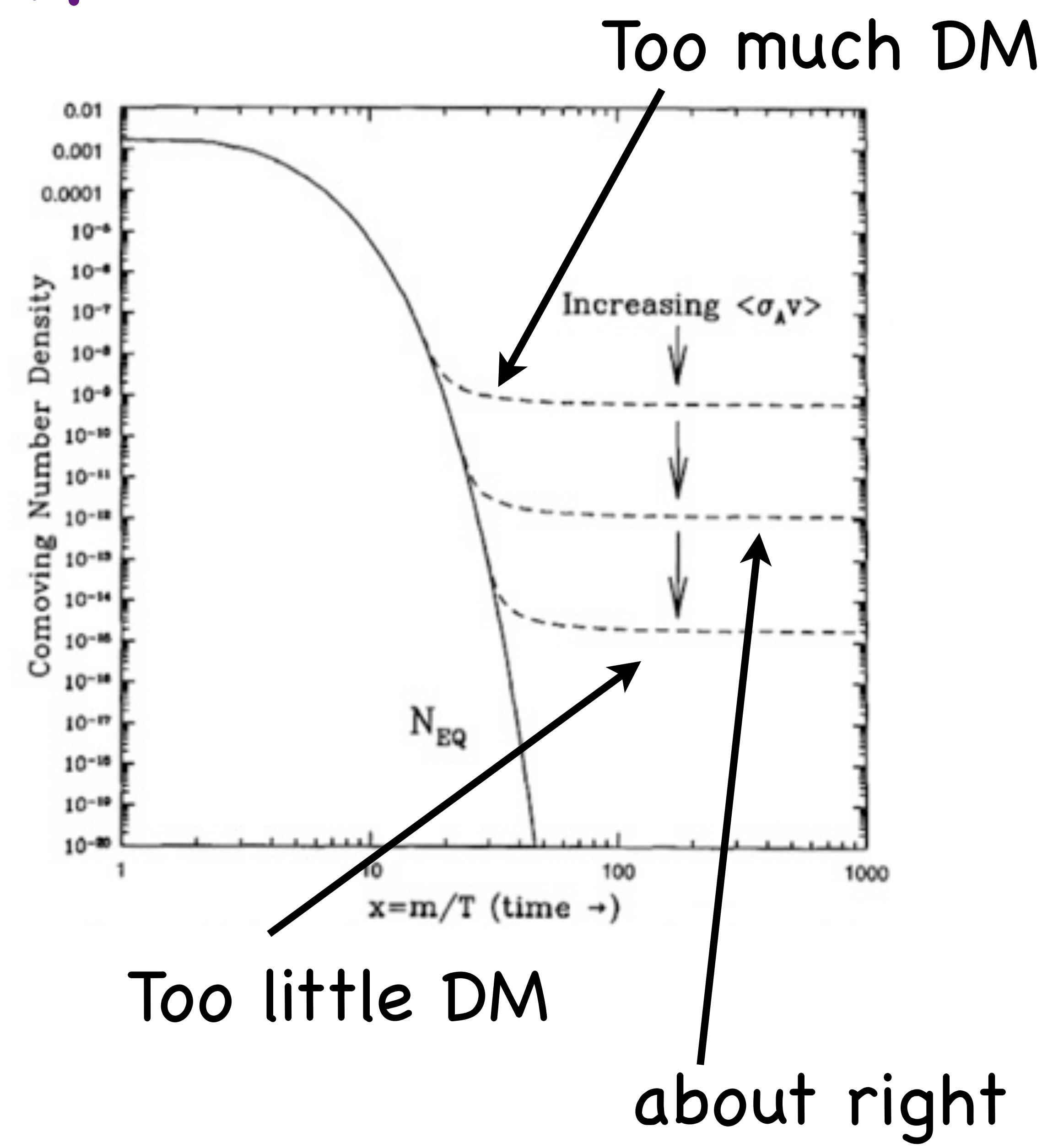
- success of BBN (DM is non-baryonic)
- growth of structure (cold DM)



WIMP DM

Assuming thermal equilibrium:



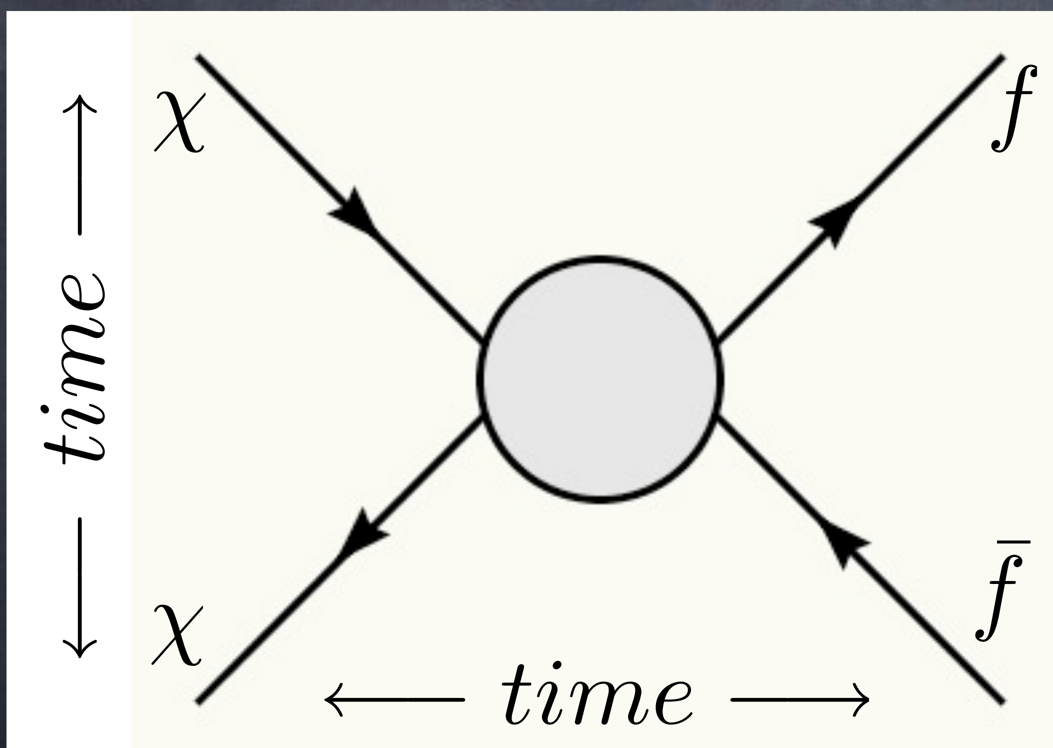


For: $T \ll M_\chi$ $\quad\quad N_{eq} \propto e^{-M_\chi/T}$

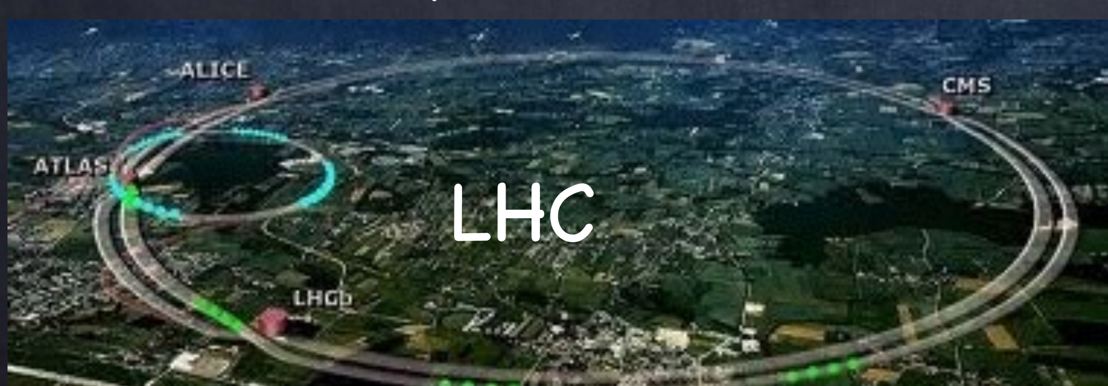
$$\Omega h^2 \approx 0.1 \times \frac{3 \times 10^{-26} cm^3 s^{-1}}{\langle \sigma v \rangle} \quad \approx 0.1 \times \frac{\alpha^2/(100GeV)^2}{\langle \sigma v \rangle}$$

Thermal DM signals

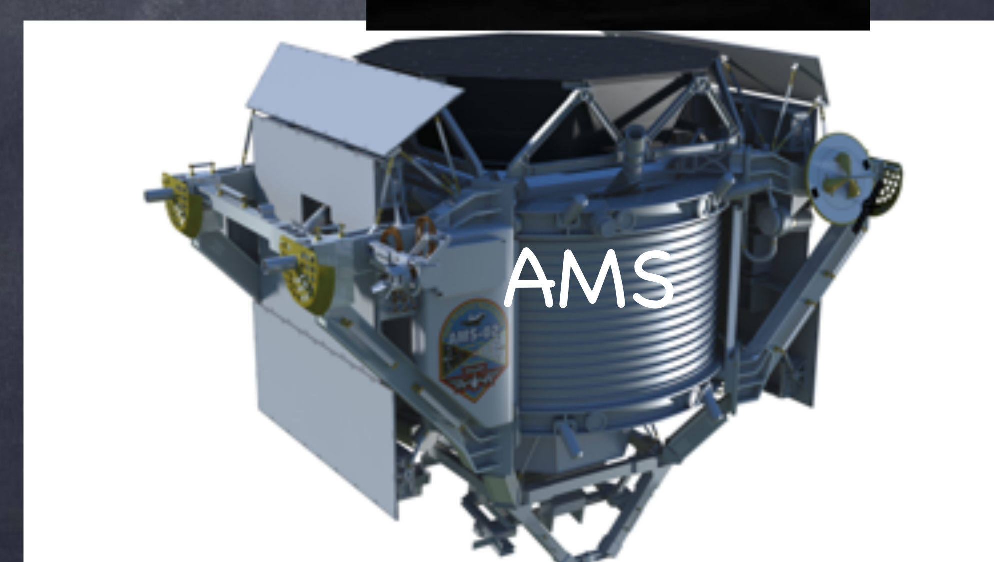
Direct Detection scattering off normal matter, Xe, Ar, Ge, Si:



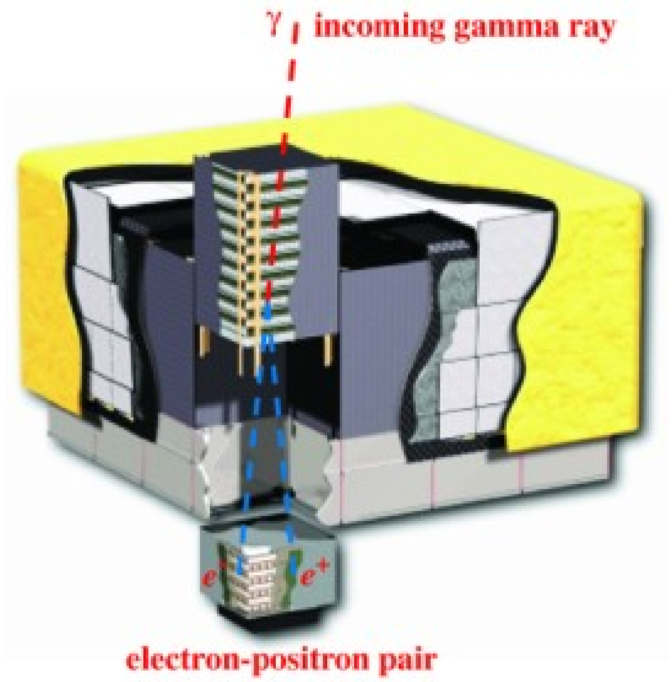
Dark matter production at colliders



Indirect detection: Dark matter annihilation into gamma-rays, cosmic rays, neutrinos

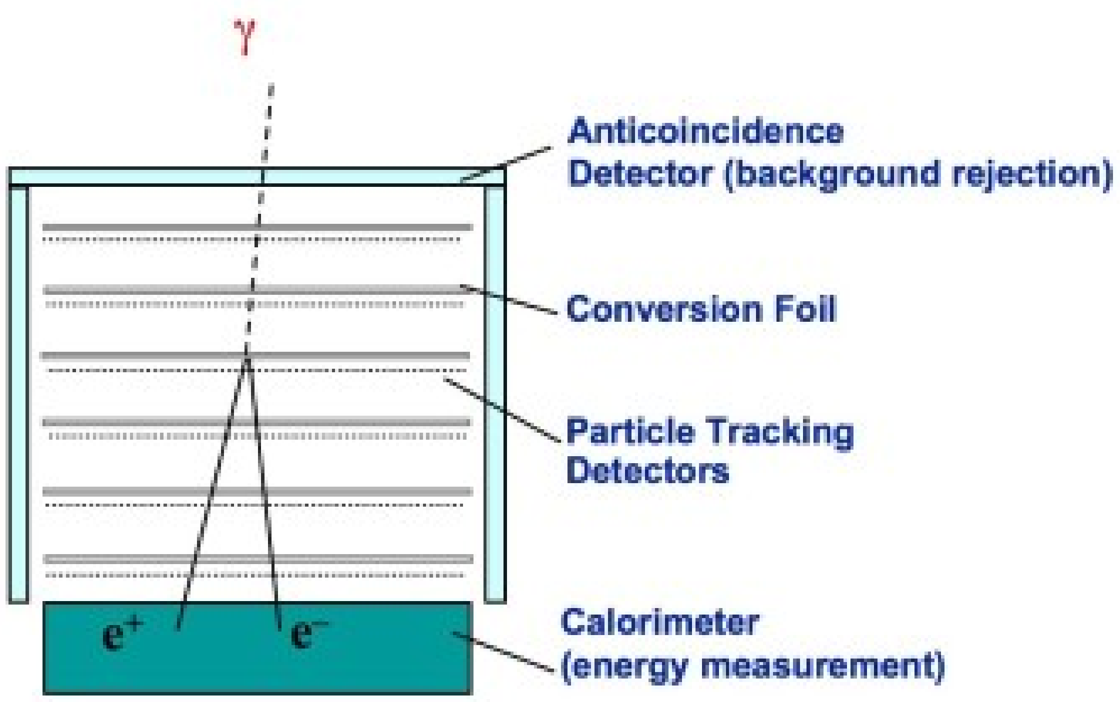


Fermi Large Area Telescope



The Fermi LAT is a <u>pair conversion detector</u> on board the Fermi Gamma-Ray Space Telescope.

Characteristics:
- Energy range: 20 MeV to above 300 GeV
- Field of view (FOV): 2.4 sr
- Energy resolution: <10% (above 10 GeV)
- Angular resolution: < 0.15º (above 10 GeV)
- Launched: 2008



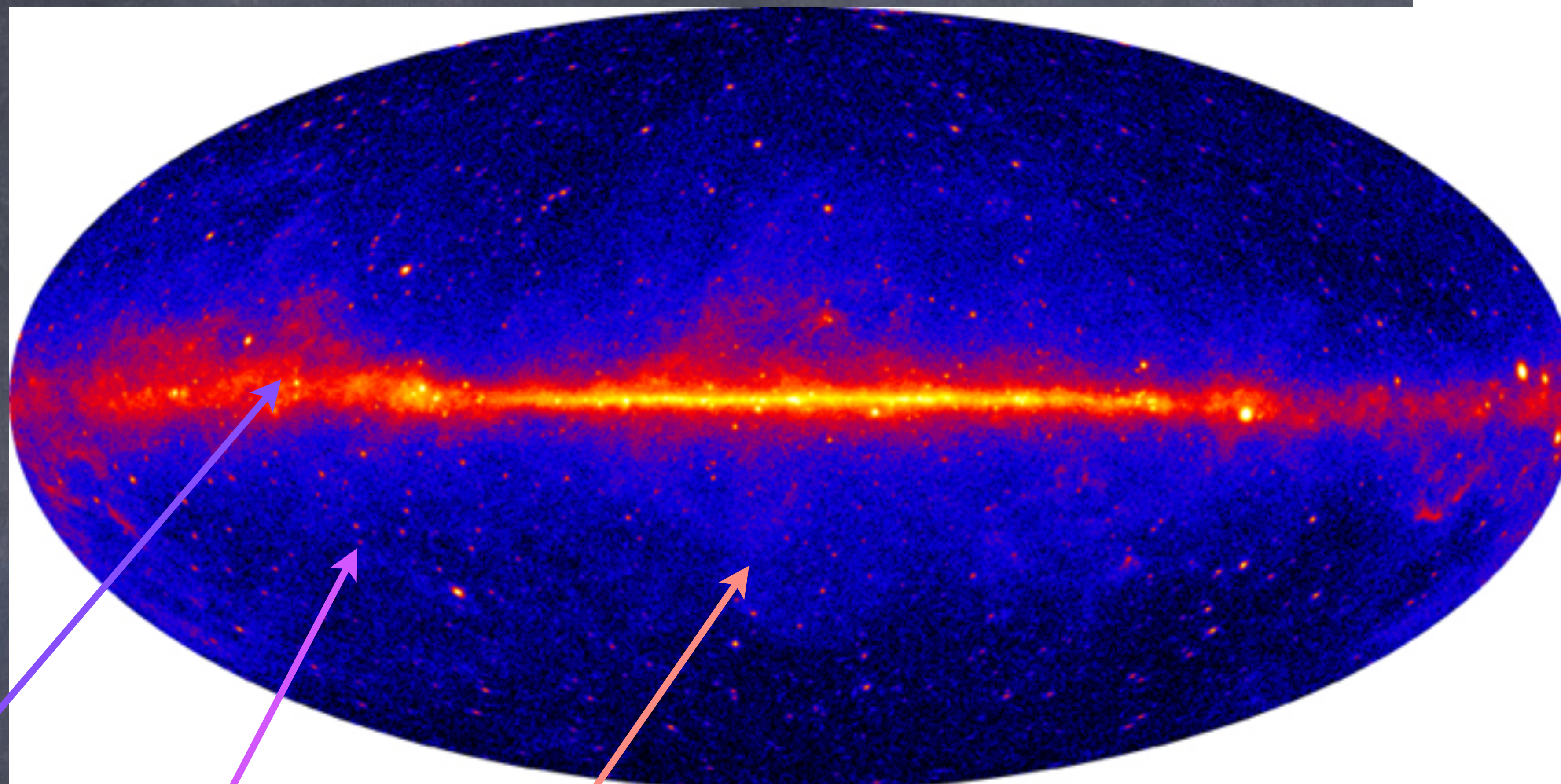
<u>Main components:</u>

Anti-coincidence shield (plastic scintillator) with photomultiplier tubes

Tracker (silicon strip detectors) with conversion foils (tungsten)

Electromagnetic Calorimeter (CsI)

The Fermi-LAT Gamma-ray SKY



Known sources for the observed gamma-rays are:

i)Galactic Diffuse: decay of pi0s (and other mesons) from pp (NN) collisions (CR nuclei inelastic collisions with ISM gas), bremsstrahlung radiation off CR e, Inverse Compton scattering (ICS): up-scattering of CMB and IR, optical photons from CR e

ii)from point sources (galactic or extra galactic) (3033 detected in the first 4 years)

iii)Extragalactic Isotropic

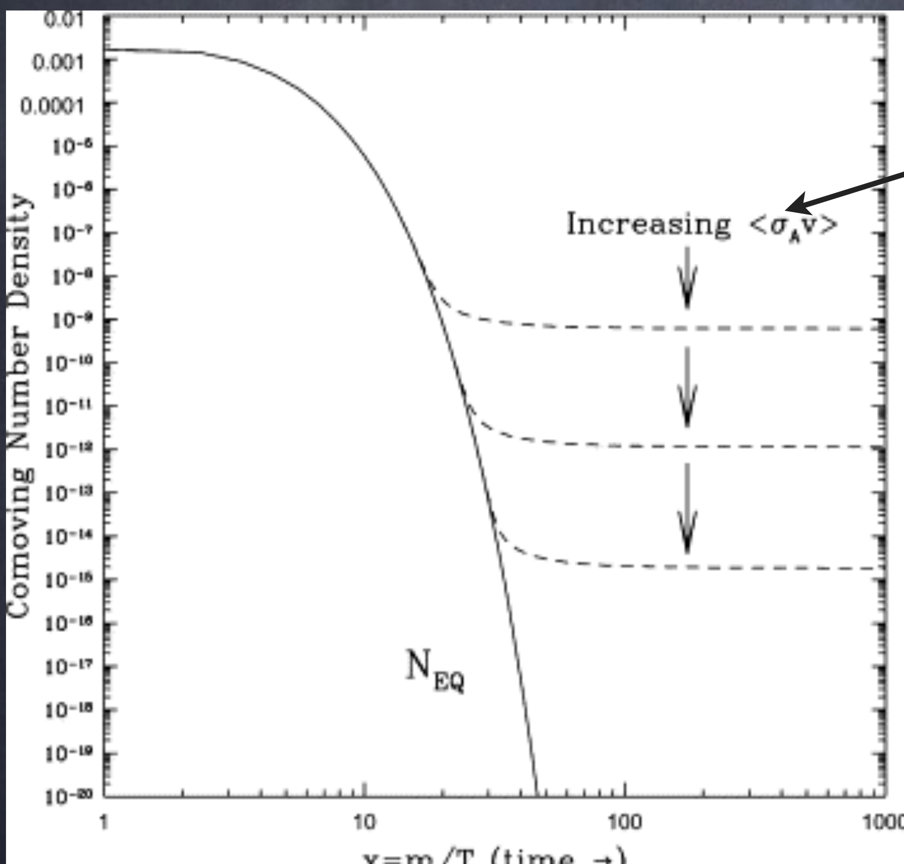
iv)"extended sources"(Fermi Bubbles, Geminga, Vela ...)

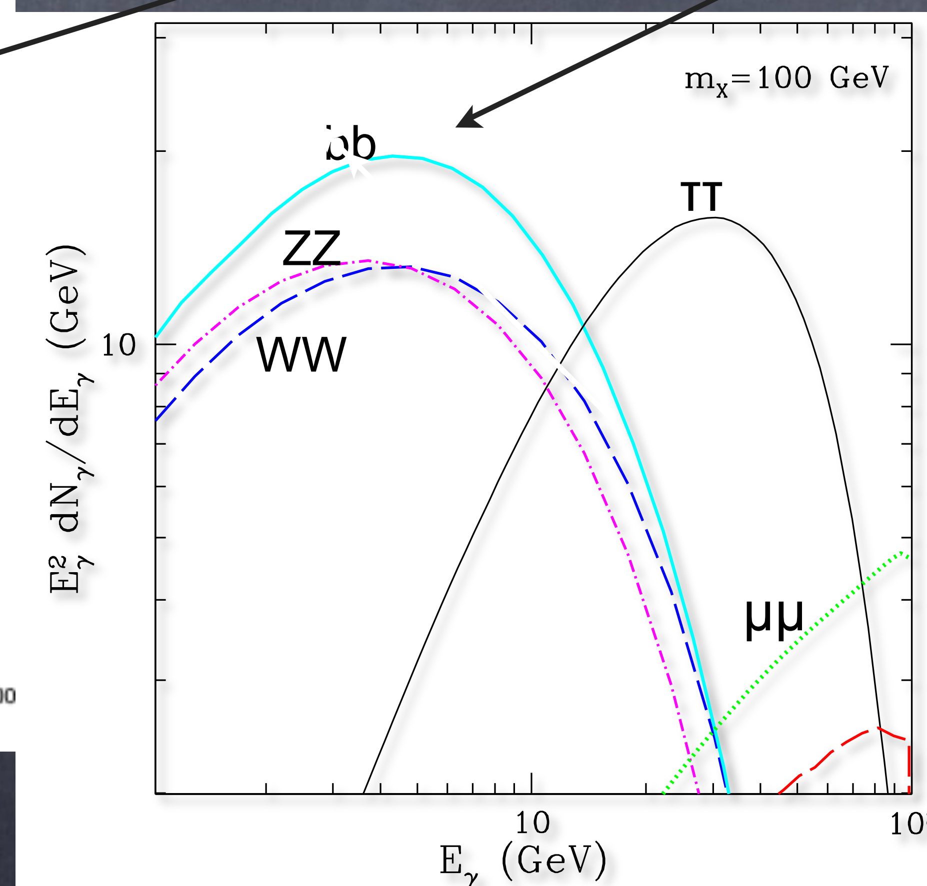
iv)misidentified CRs (isotropic due to diffusion of CRs in the Galaxy)

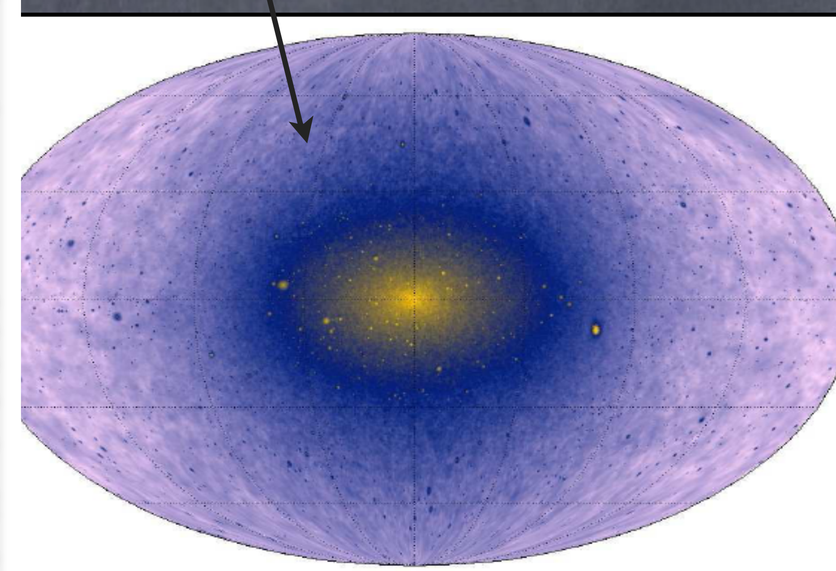
BUT ALSO the UNKOWN, e.g. Looking for DM annihilation signals

For a DM annihilation signal

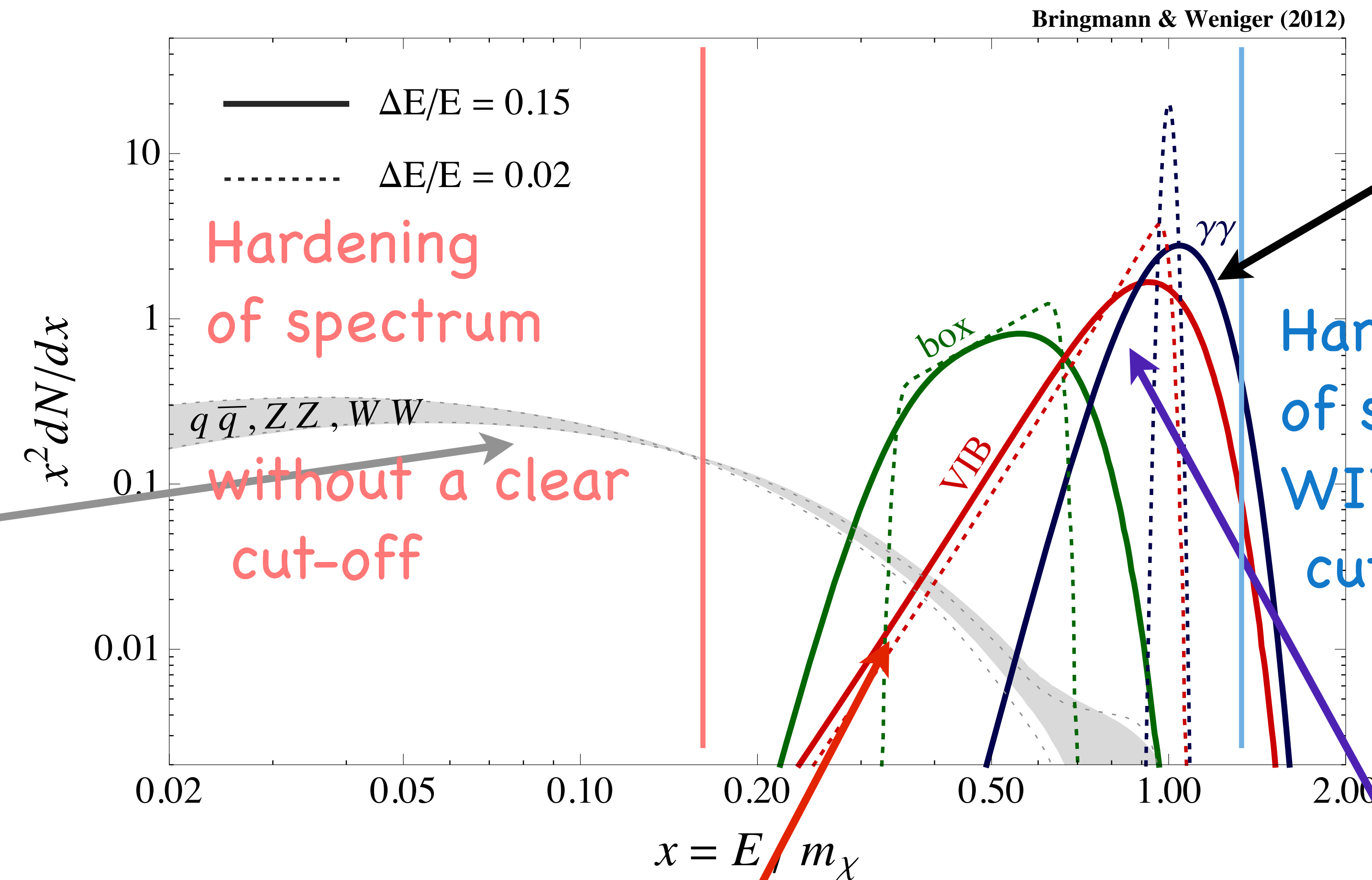
We want to observe: $$\frac{d\Phi_\gamma}{dE} = \int\int \frac{\langle \sigma v \rangle}{4\pi} \frac{dN_\gamma}{dE}_{DM} \frac{\rho^2_{DM}(l,\Omega)}{2\,m_\chi^2} dl d\Omega$$







DM annihilation spectra



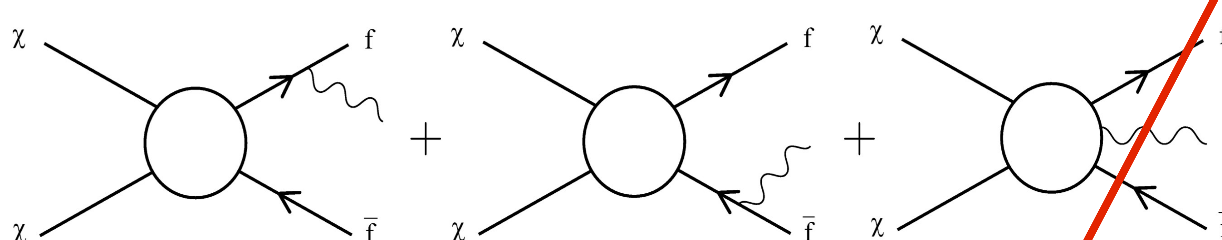
Continuum emission, tree level, relatively hard spectrum, but featureless

Hardening of spectrum without a clear cut-off

Hardening of spectrum WITH a cut-off

LINE(S)

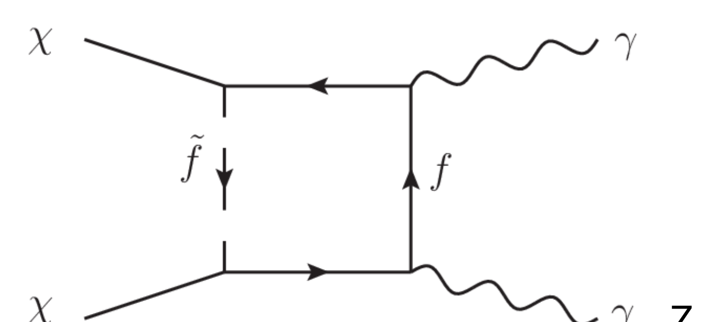
Two body annihilation to photons. Almost monochromatic Line, but suppressed at O(a^2).



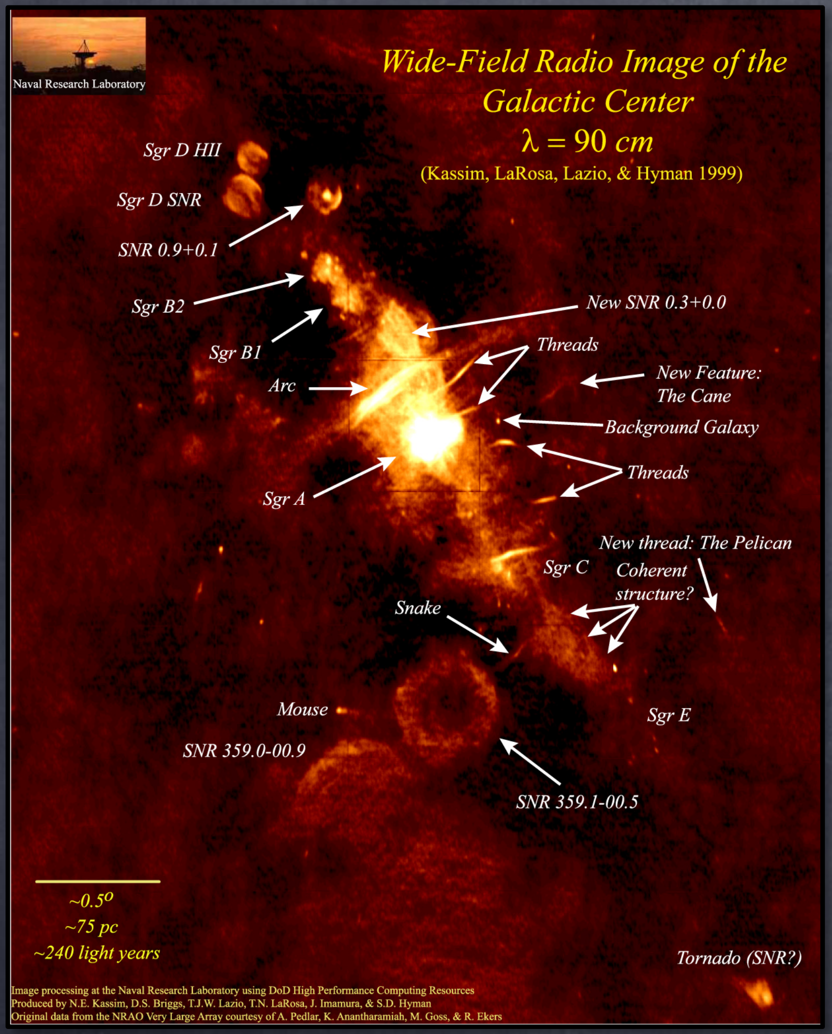
Final state radiation

Virtual Internal Bremss.

Comes from radiative corrections to processes with charged particles. Suppressed by O(a), but with a much harder spectrum; FSR has an additional suppression factor of (mf/Mchi)^2

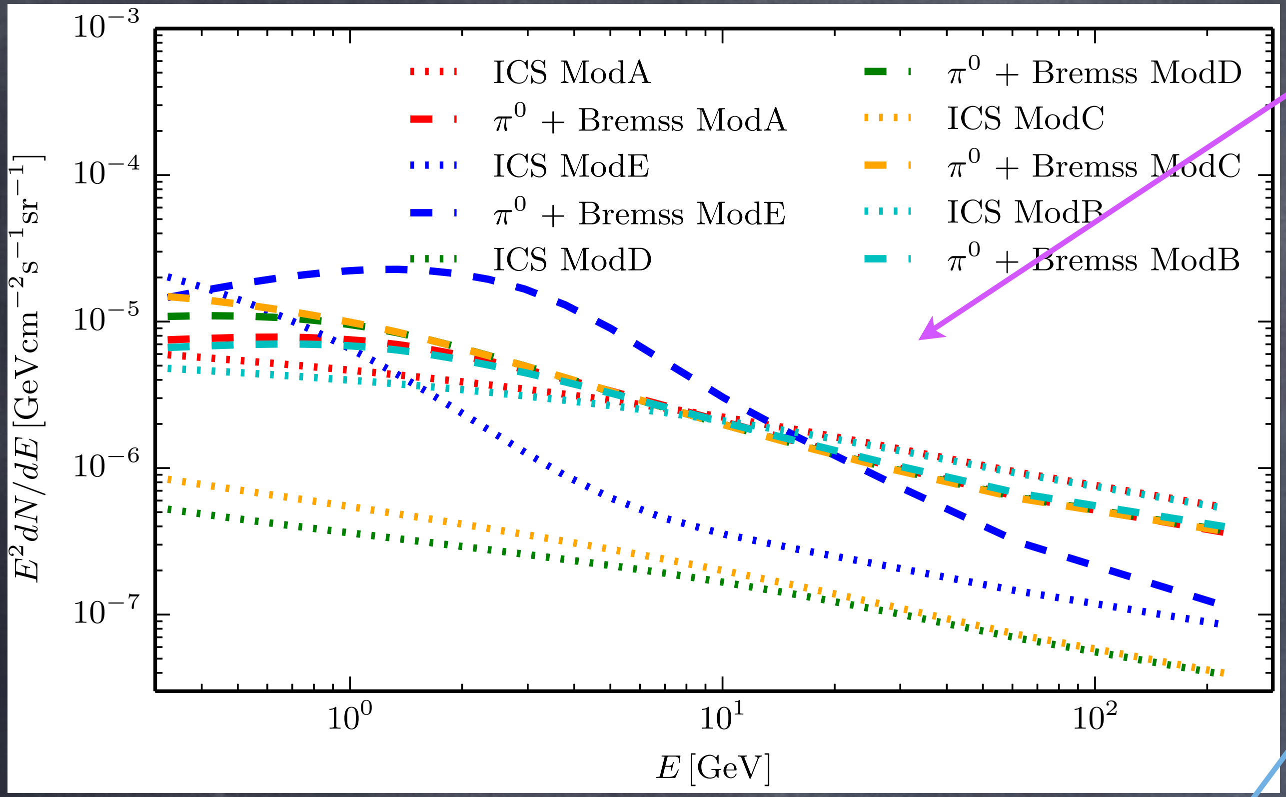


One of the most likely targets is the GC (though backgrounds also peak), others are the known substructure (dSphs) or Galaxy clusters



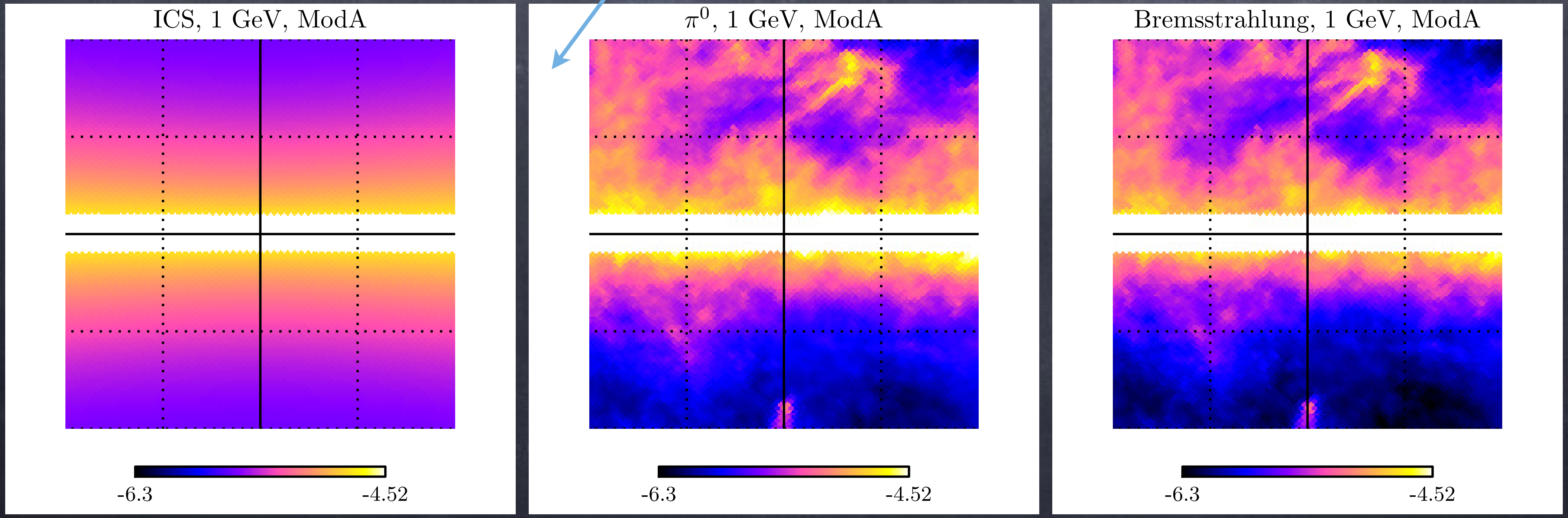
- The region of the galactic center is complex with uncertainties in the gas and the CR distribution
- A DM annihilation signal also peaks with significant uncertainties though on the DM distribution
- Take advantage of multi-wavelength searches, different gamma-ray spectra and distinctively different morphologies between the backgrounds and a DM signal

On the gamma-ray backgrounds ALONG THE LINE OF SIGHT towards the inner galaxy



Calore, Cholis, Weniger, 2014

- Spectrally the galactic diffuse gamma-ray components can be modeled (WITH significant variations though). In addition we can model their morphology on the galactic sky, WHICH varies with energy AND depends the physical assumptions (fast/slow diffusion, strong convection, energy losses)
- Extended sources can also be modeled (morphologically and spectrally)and subtracted (yet with some uncertainties related to the mechanism producing their signal)

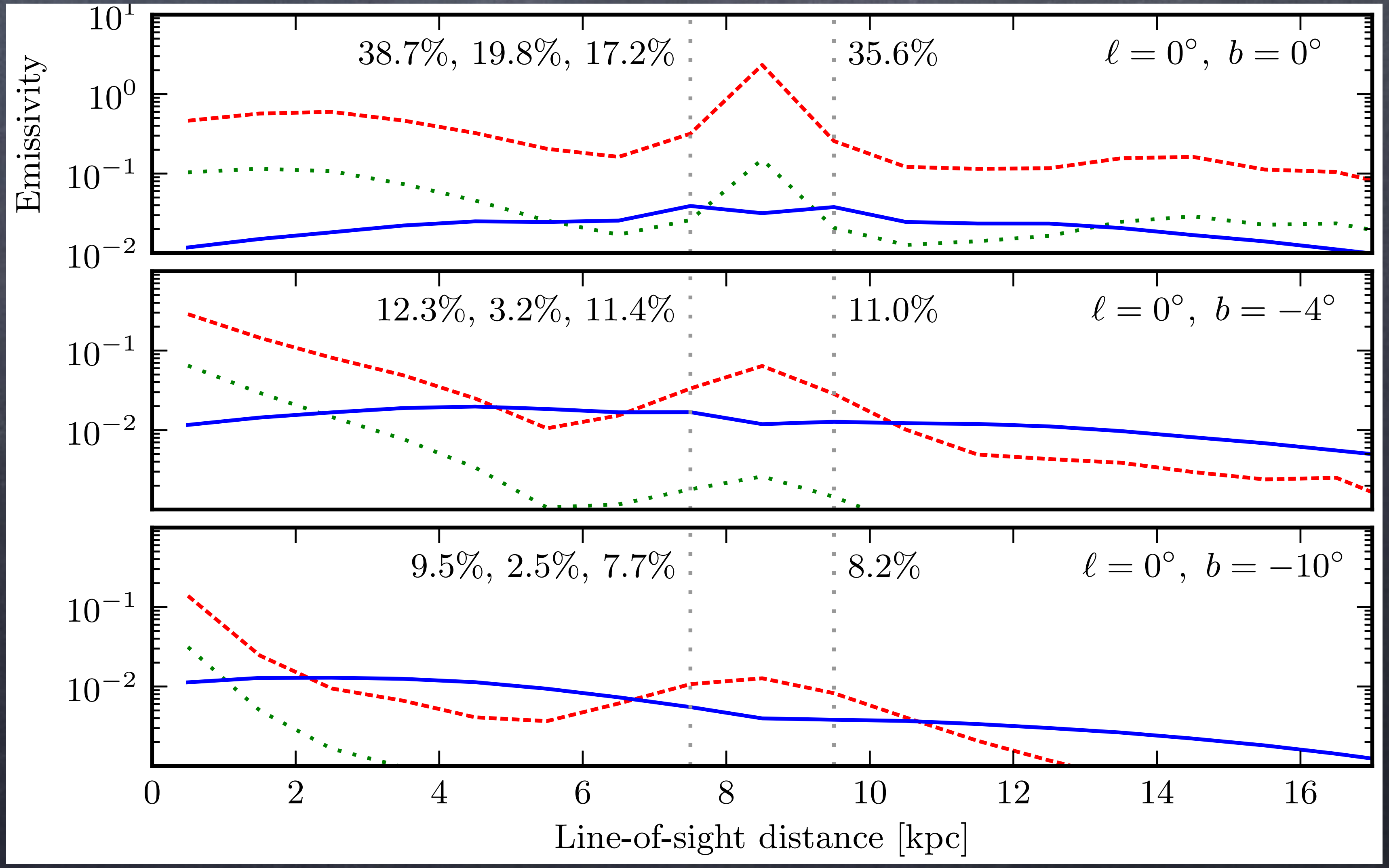


- Extragalactic point sources can either be resolved or unresolved extragalactic sources (AGNs, Star forming or starburst galaxies etc). But are isotropic and thus can not contribute significantly to an excess in the inner galaxy. Misidentified GeV scale CRs are also isotropic due to diffusion.
- Galactic point sources that can give strong gamma-ray signals in the GeV range include SNRs in the inner part of the Galaxy and pulsars (see later slides).

IMPORTANT CAVEAT!!! Calore, Cholis, Weniger, 2014

We live inside the Milky Way;
thus we see A LOT of emission
from distances closer to us than the GC:

THUS WE NEED TO ACCOUNT FOR THESE UNCERTAINTIES.



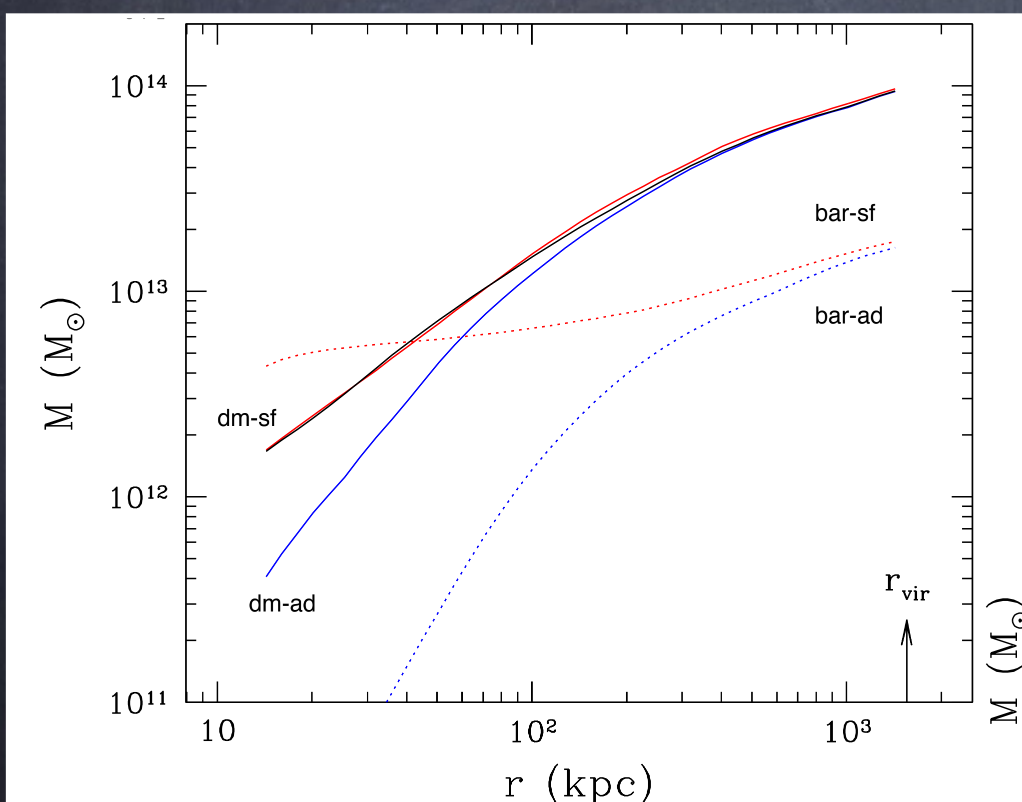
On the DM distribution in the inner galaxy

From hydrodynamical simulations there are suggestions from different groups in favor of contraction in the Milky-Way like halos with an inner slope gamma from 1.0 up to 1.5.

Yet there still are groups suggesting flattening of the halo profile if baryonic feedback processes are efficient.

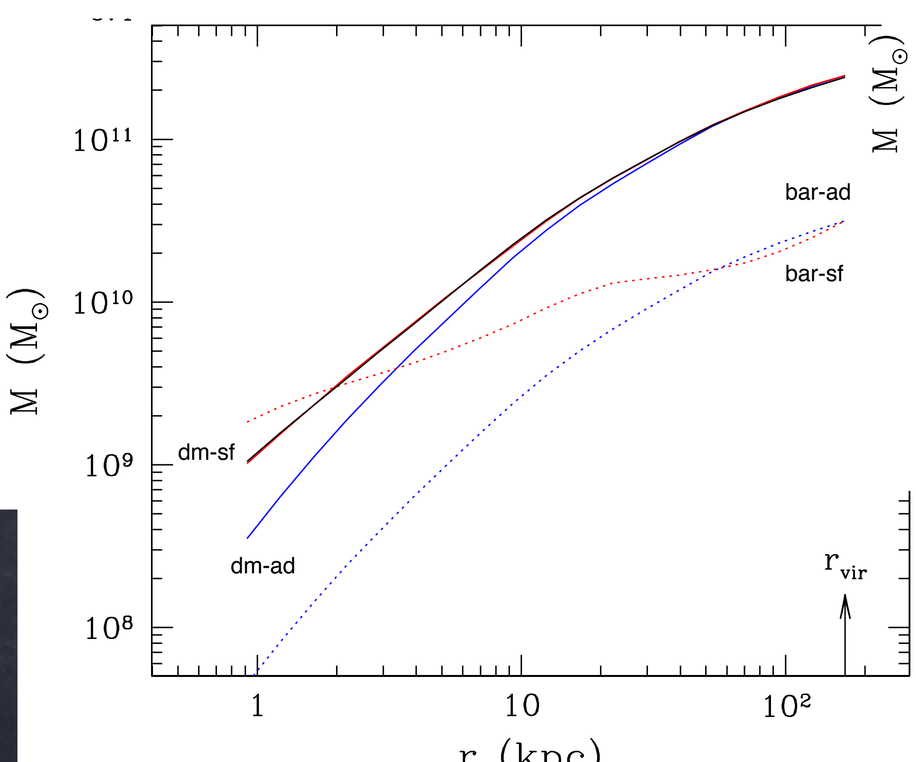
Assuming NFW-like profile with some uncertainty in the inner slope is the way to treat any search for a signal of DM from the inner galaxy.

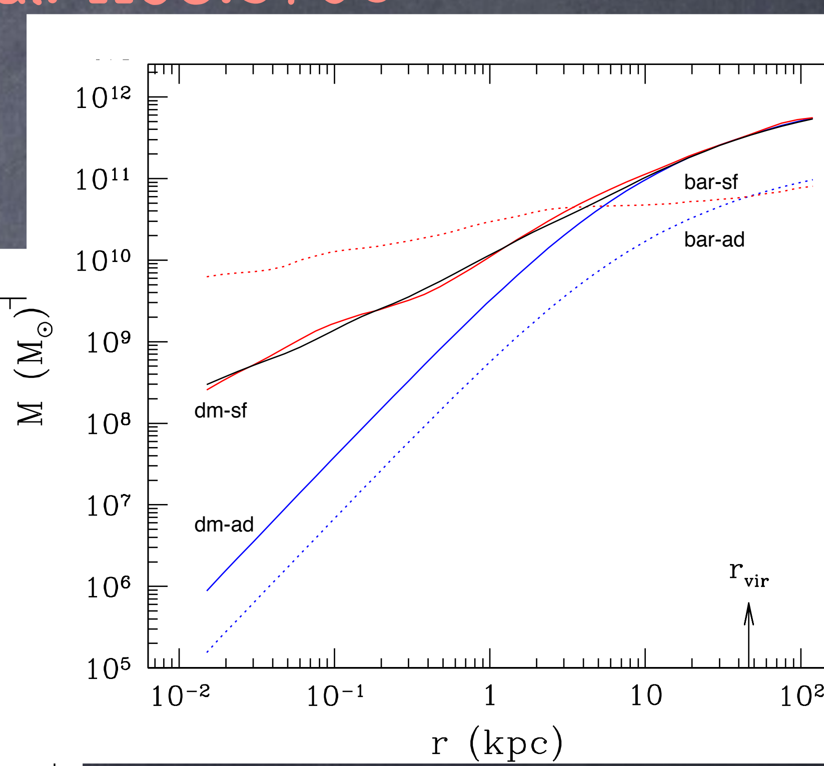
Gnedin et al. 1108.5736



Nagai 2006 ApJ 650, 538

Gottglober et al. 1005.2687



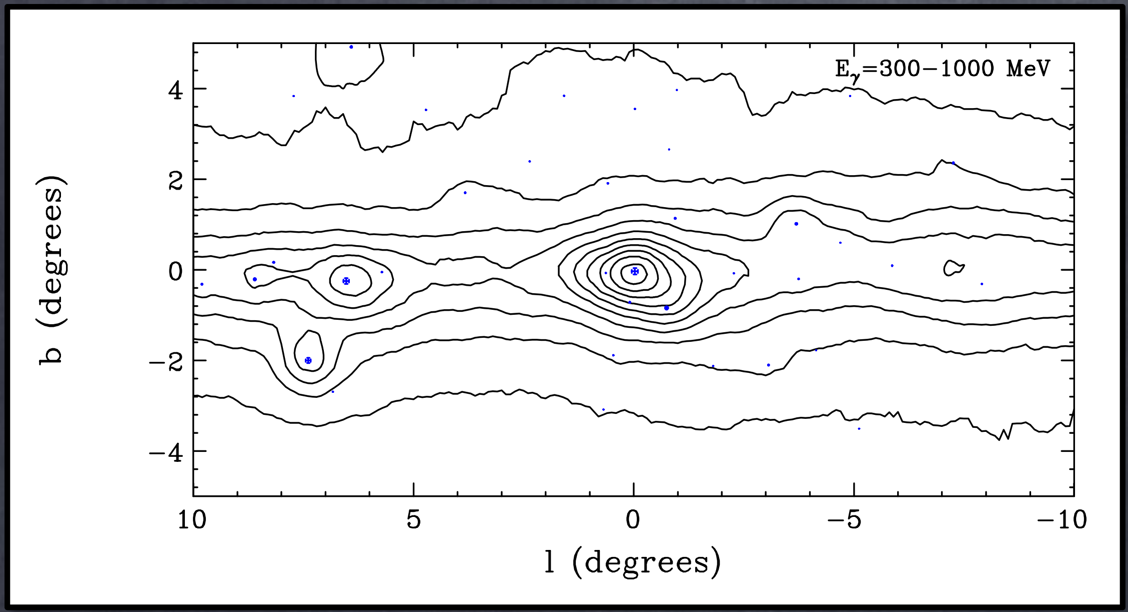


Levine at al. 2008 ApJ 678, 154

Looking for excesses in the inner galaxy

Smoothed Raw gamma-ray map

Hooper&Linden 1110.0006



− POINT SOURCES (2yr catalogue)

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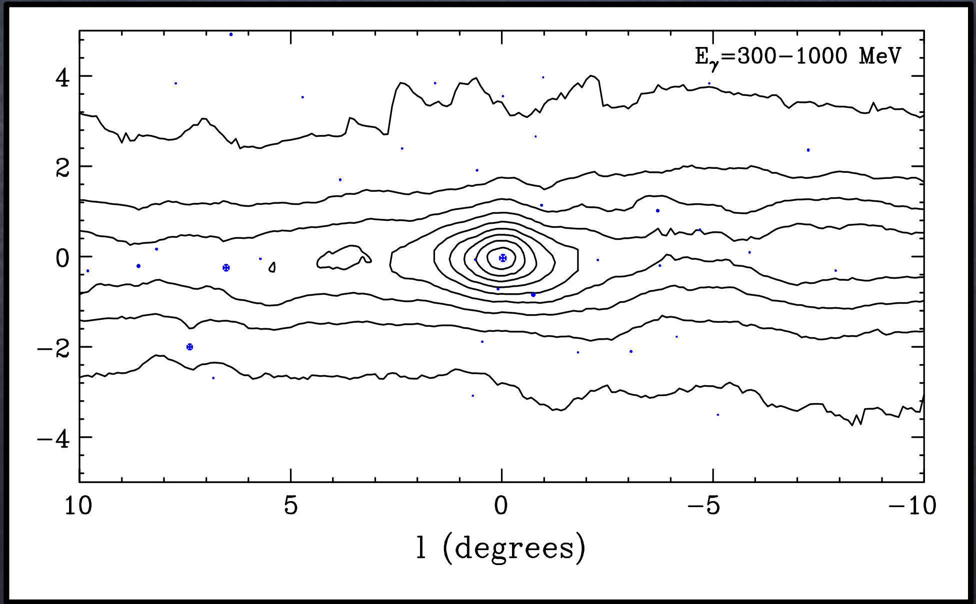

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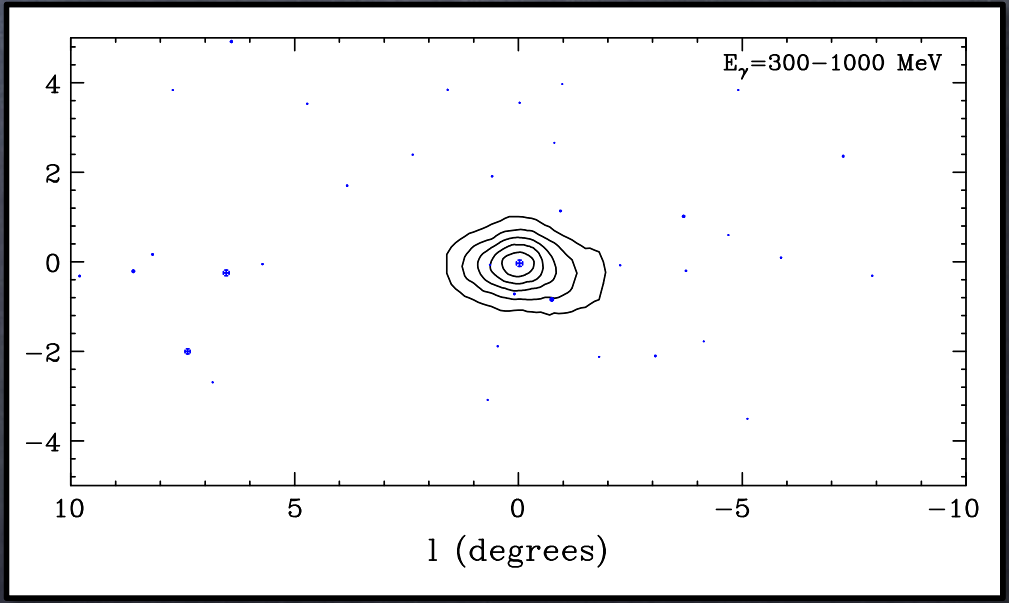
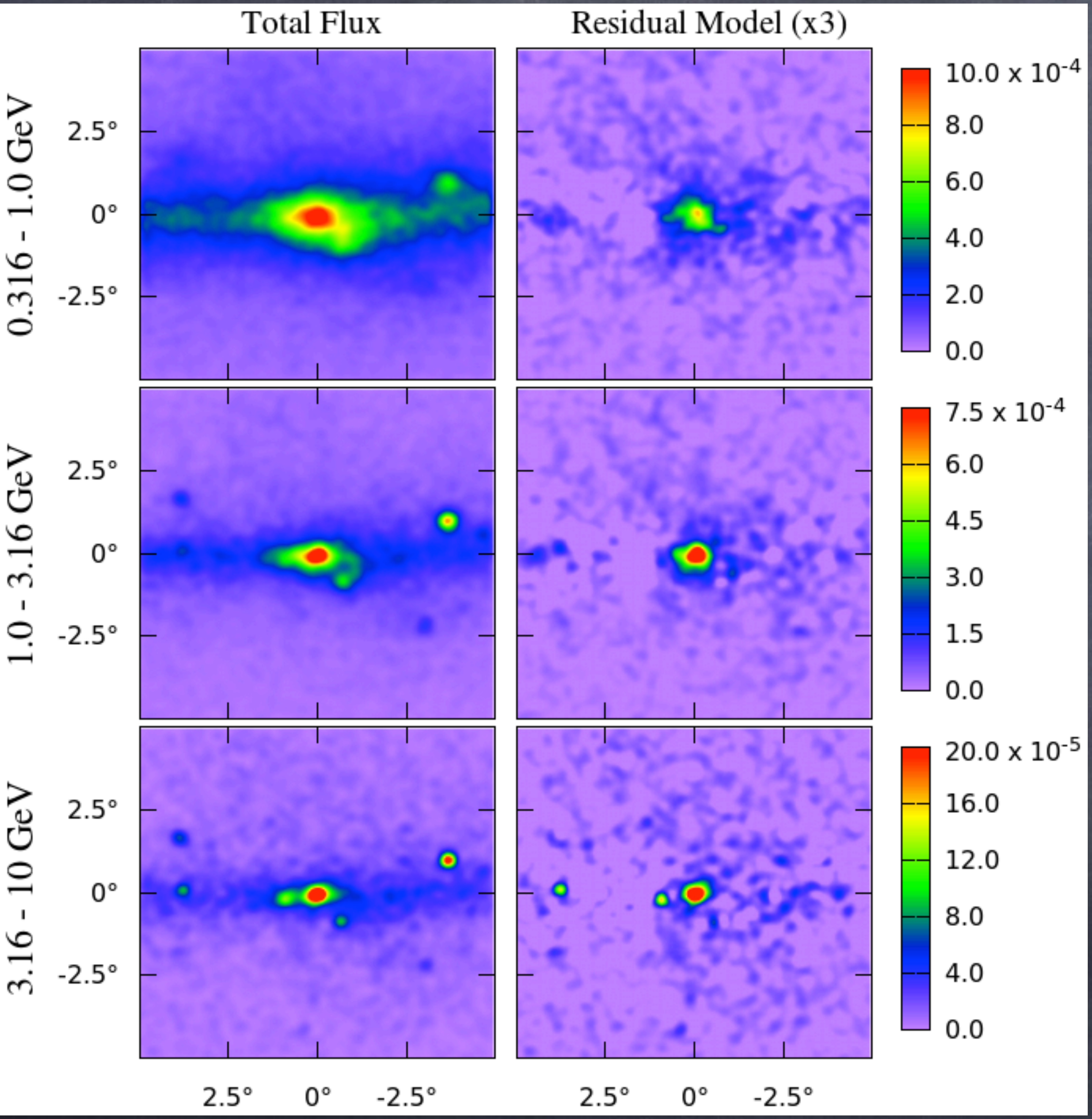


Model for Galactic Diffuse Emission

Excess Diffuse Emission

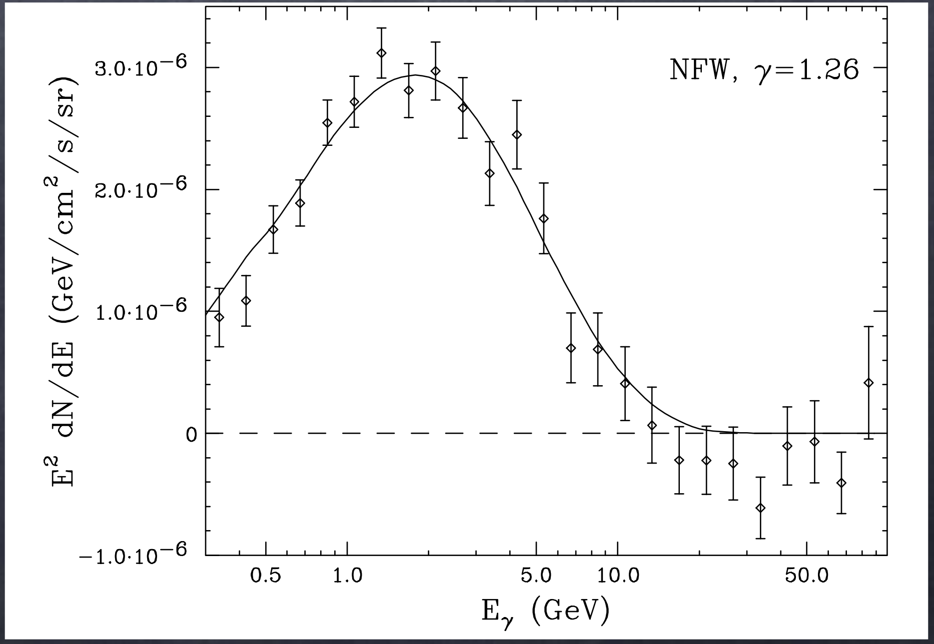
Similar results to earlier Hooper & Goodenough papers in 0910.2998 and 1010.2752 and later from: Abazajian & Kaplinghat (1207.6047), Gordon & Macias (1306.5725)

Repeating the exercise in different energies (updated analysis, using a new class of photon cuts allowing for better angular resolution)



Daylan, Finkbeiner, Hooper, Linden, Portilo, Rodd, Slatyer, 1402.6703

- A clear excess emission in the galactic center emerges
- 90% of the total emission in the inner few degrees is removed
- Residuals not related to the galactic center (GC) are up to ~5% as bright as the GC residual
- Excess emission cuts-off at ~10 GeV (is in some dis-agreement with later findings)



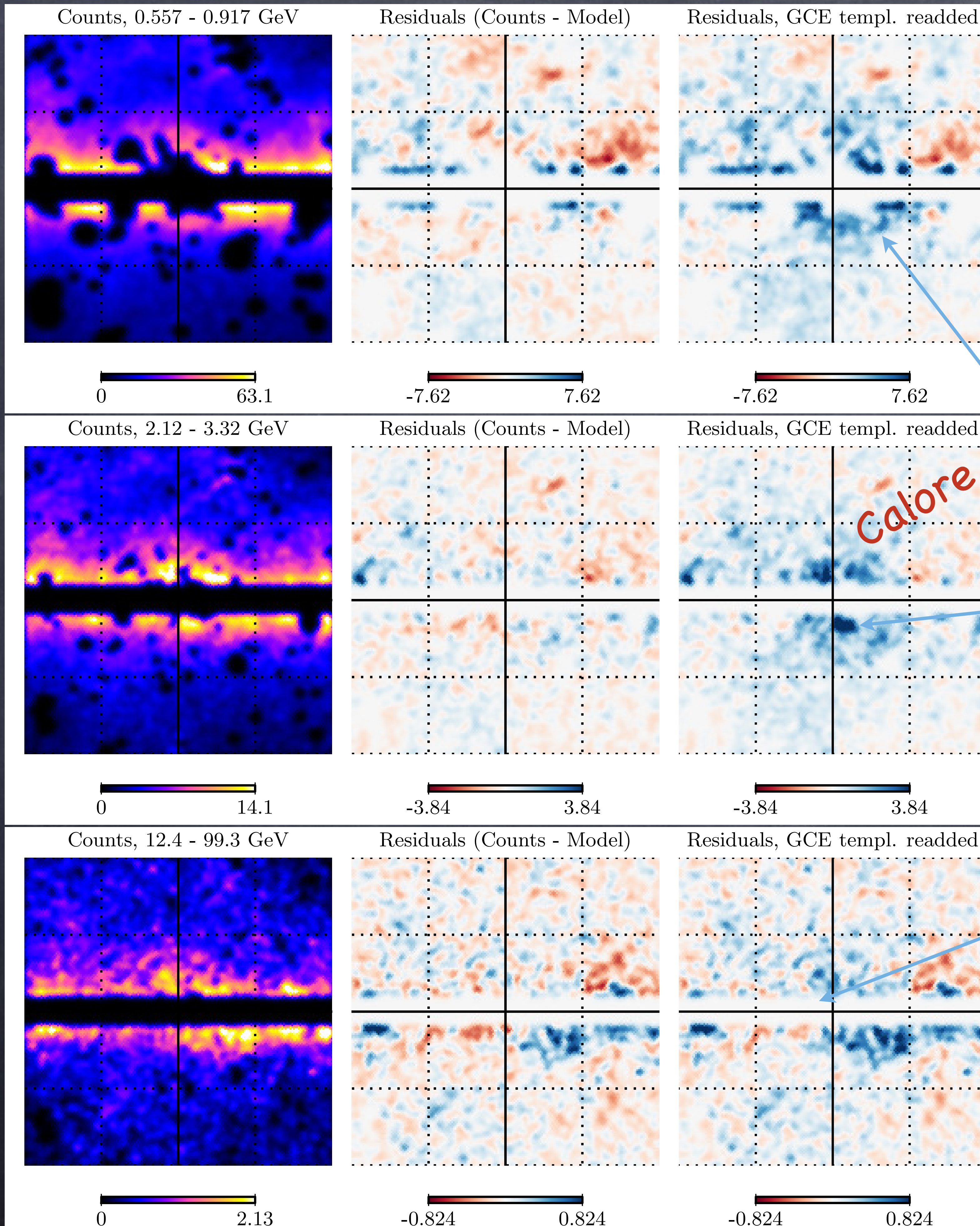
Going to High Latitudes

For a DM signal you want to look outside the galactic disk but still just above the galactic center (also dSph galaxies can be an alternative target)

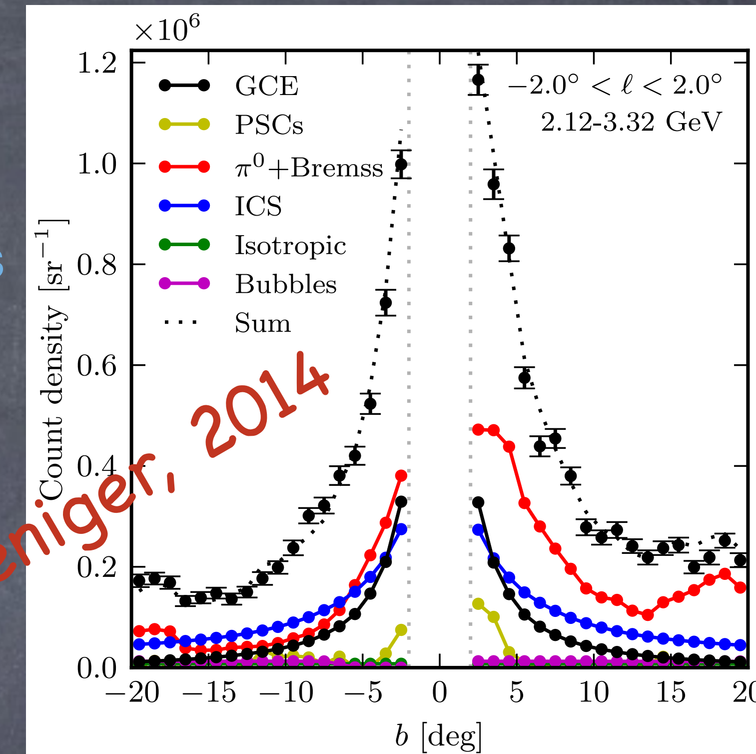
Advantages of going outside the inner few degrees:

i) if a DM signal: you have a prediction on how the spectrum should look (same shape) and how its normalization should be (contracted NFW)

ii) Different region on the galactic sky suffer from different uncertainties in the background models: In the inner part of the Galaxy point source subtraction is a very important uncertainty, the gas density is also an important uncertainty and also the radiation field is an other. At higher latitudes : Fermi Bubbles, possibly unknown gas (unaccounted for in spectral line observations). Also propagation assumptions on the CRs may differ significantly between different regions of the Galaxy (due to strong wind outflows or magnetic fields causing anisotropic and preferential diffusion).



40 degrees in latitude



Calore, Cholis, Weniger, 2014

Excess emission towards the GC that extends up to possibly ~100 GeV and certainly above 10 GeV

It extends with a lower limit of 10 degrees away from the Galactic Center at 95% CL.

See also Slatyer&Hooper2013, Huang, Urbano & Xue 2013

Important Questions regarding the Robustness of the DM-like signal

- How well have we probed the relevant uncertainties? Are the different methods used to probe the excess signal in the inner few degrees and at higher latitudes DIFFERENT/ORTHOGONAL ENOUGH?

- How well do we understand the diffusion/propagation of CRs in the inner part?

- Can we build up a new distribution of sources in the inner 1-2 kpc that have the right properties but are not close by to us? How would we see them?

- How about dSphs? (I will come back to this in a bit)

- How about galaxy clusters? (not optimistic yet due to large contamination from both background and foreground emission)

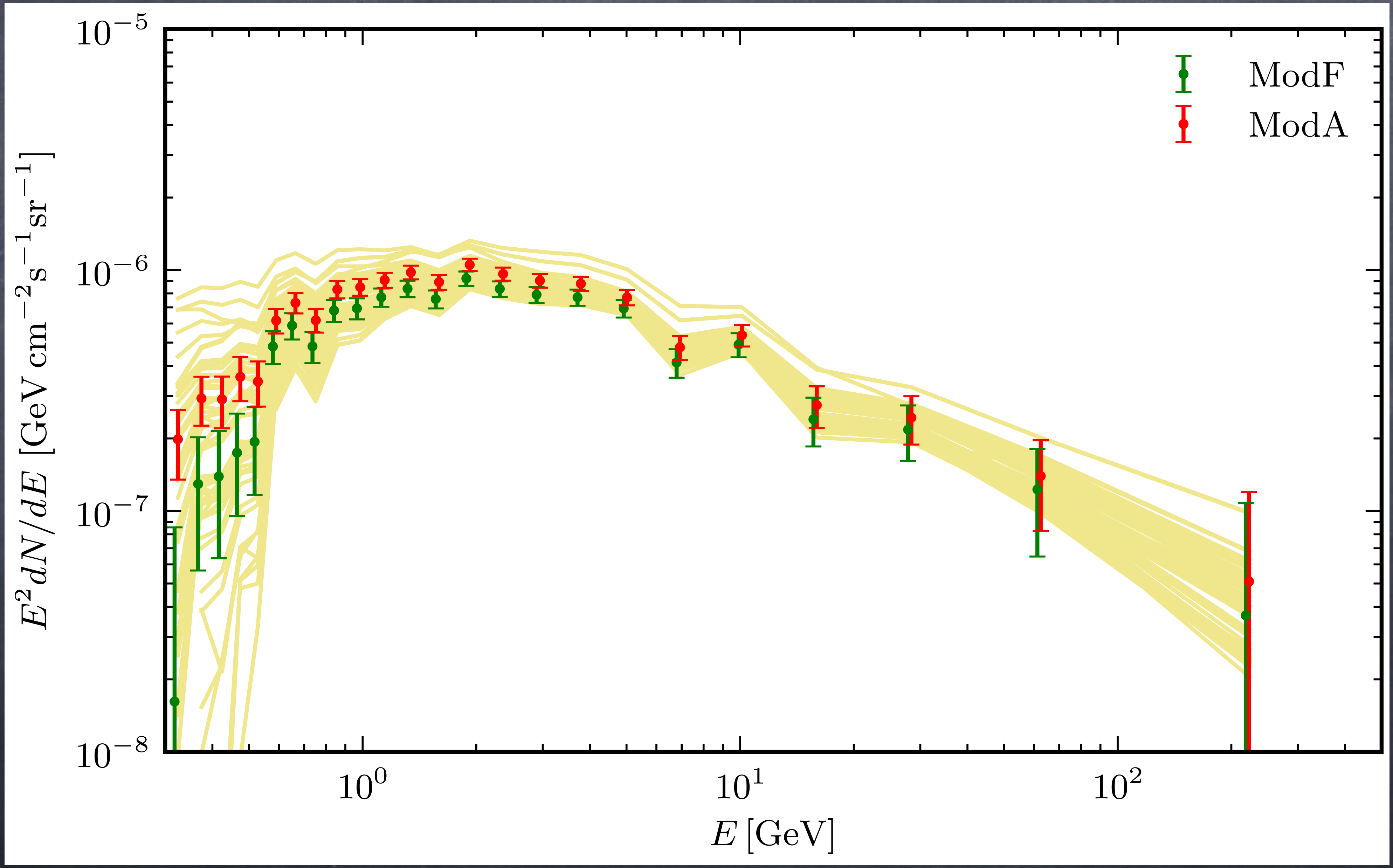
- How about the extragalactic diffuse emission and cross-correlating with other wavelengths (a new era for gamma-ray astronomy).

Accounting for the galactic diffuse emission uncertainties

- Properties of the diffusion zone within which cosmic rays (CR) diffuse before escaping to the intergalactic medium
- How fast do CRs diffuse? are there convective winds and how strong?
- How important are the effects of CR diffusive re-acceleration (diffusion in momentum space)
- Distribution of cosmic rays sources (does it follow SNRs?, pulsars? OB stars?)
- Spectral properties of CRs. Are they the same everywhere?
- How well do we understand the gas distribution along the line of sight and towards the inner Galaxy?
- How well do we understand the galactic magnetic field that affects the energy losses of CR electrons
- How well do we understand the interstellar radiation field properties? (these are the target photons that get up-scattered into gamma-rays from CR electrons).

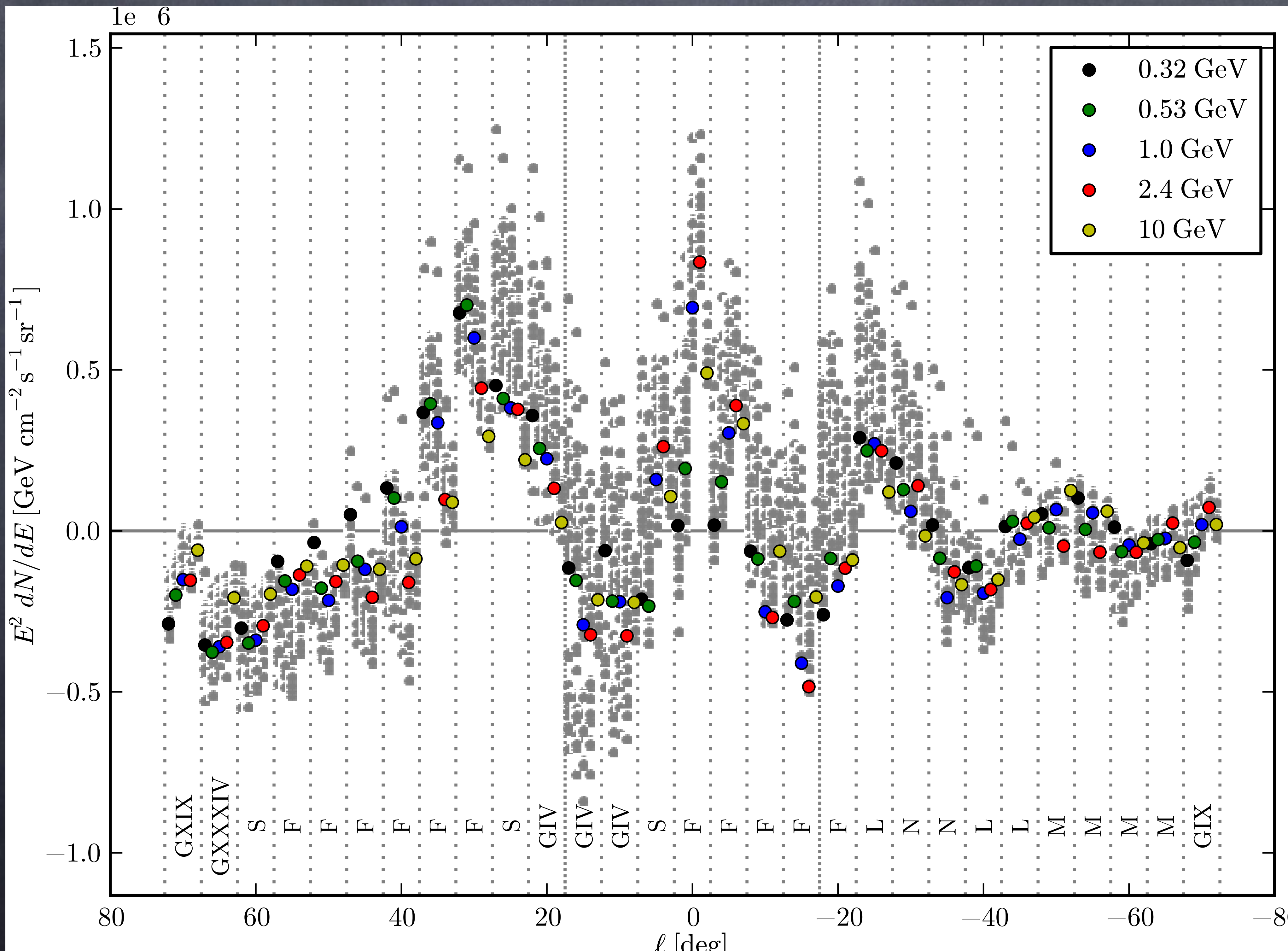
We used models from the existing literature and created our own (60 models shown in our paper).

It turns out that it actually does not affect dramatically the excess spectrum:



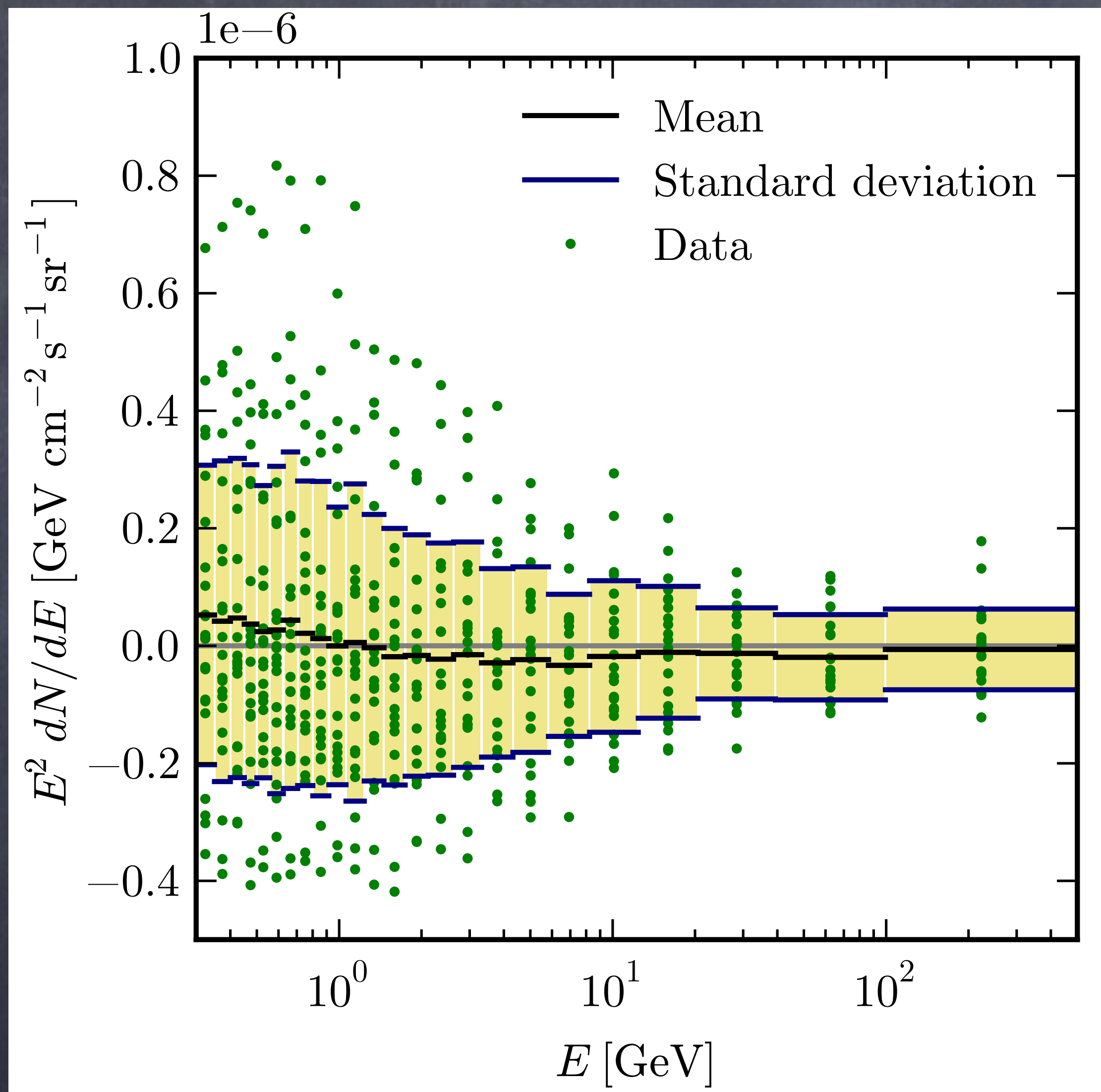
Calore, Cholis, Weniger, 2014

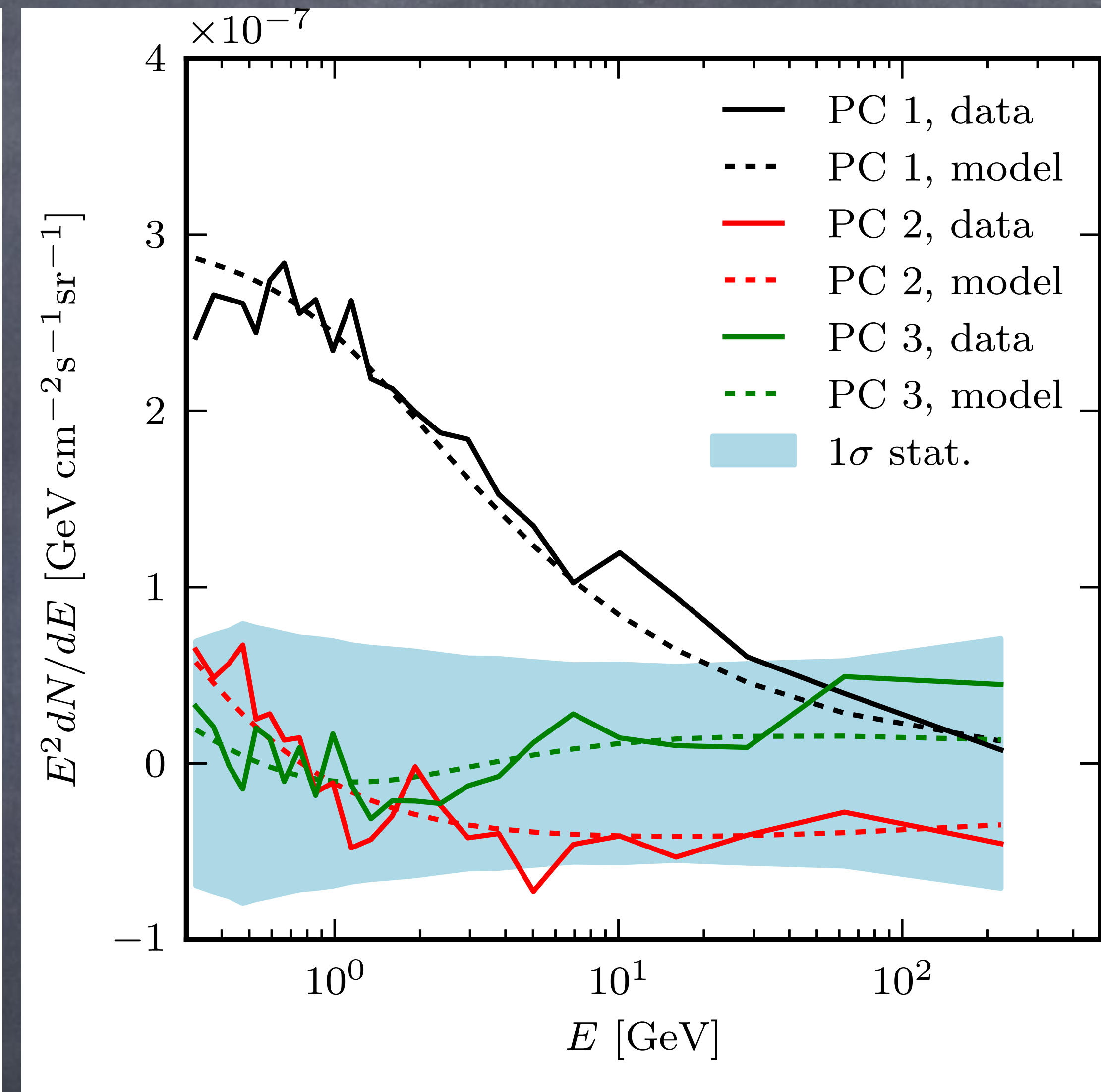
An alternative way, look along the galactic disk:
We basically repeat the same procedure but now change the window that we fit by moving it along the galactic disk; cross-checking every time with our 60 diffuse emission models



Calore, Cholis, Weniger, 2014

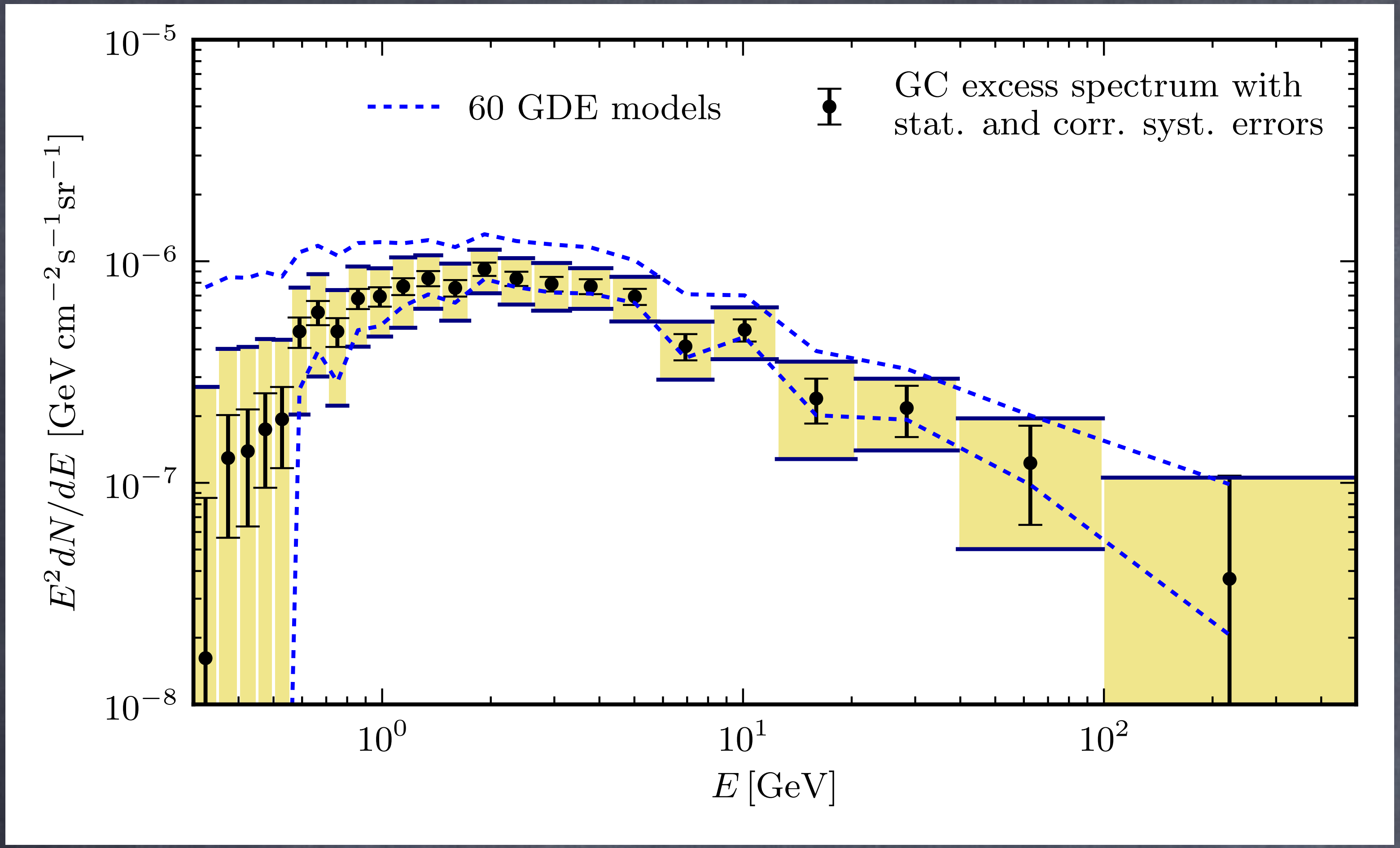
One can then calculate a covariance matrix which allows to properly quantify the correlated systematic errors (associated to the lack of better understanding of the galactic diffuse emission) which uncertainties are bigger than the statistical one (associated to number of gamma-ray events):



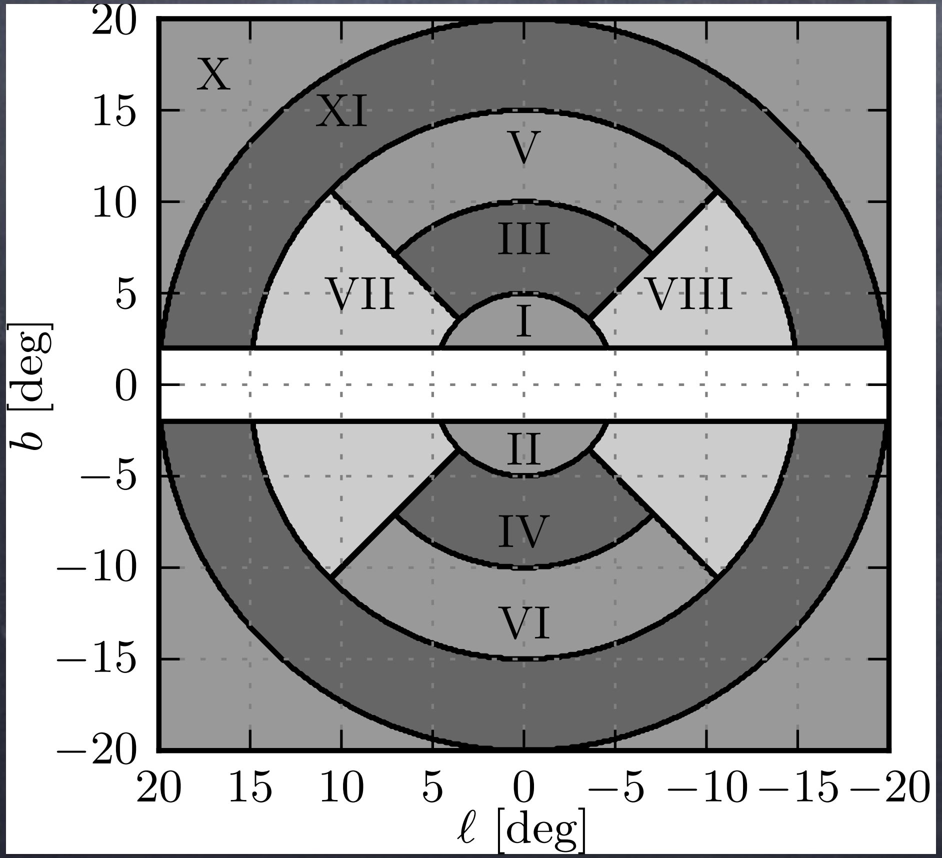


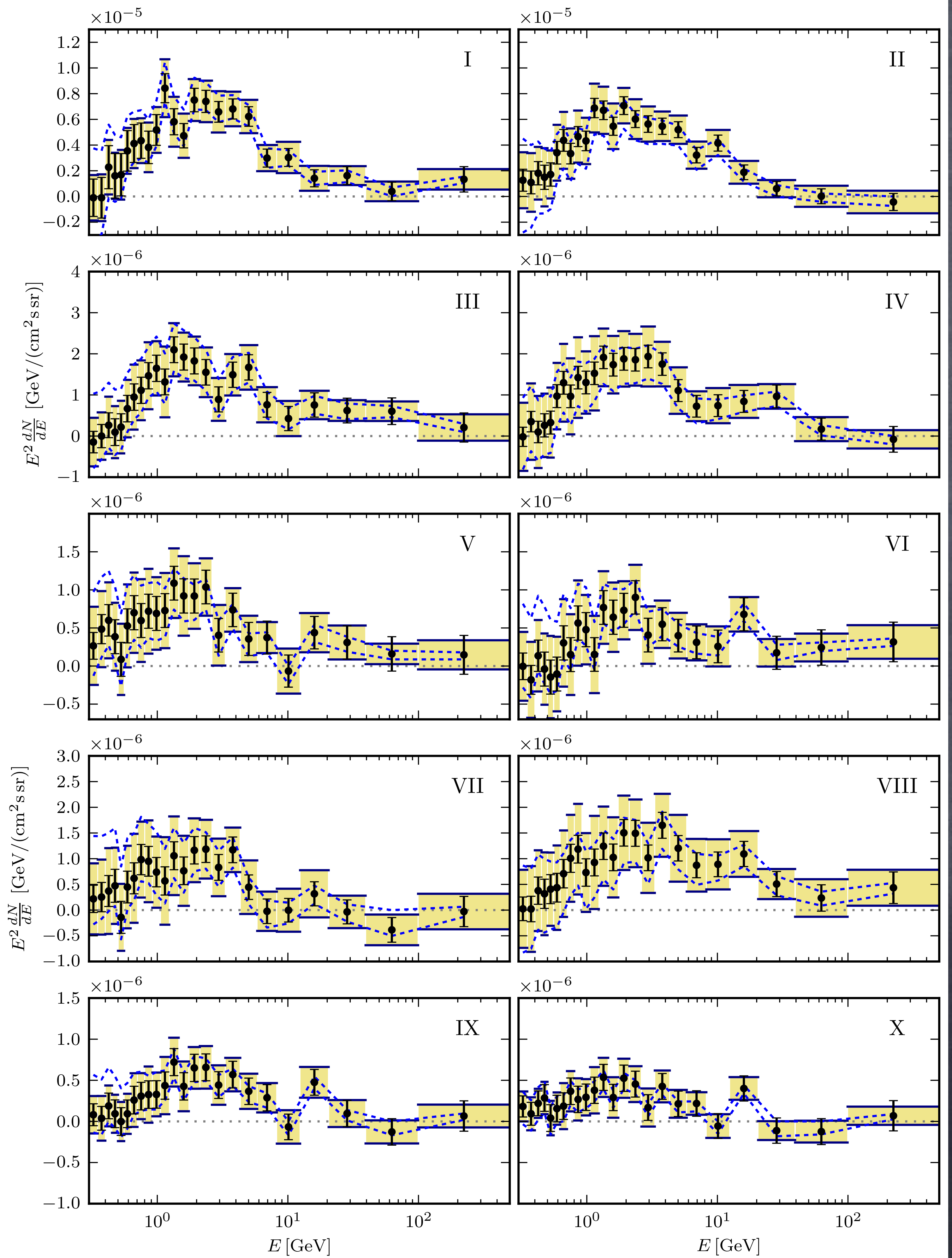
Residuals of the transported GCE template. No evident bias is seen. Green points show all 22 regions tested.

Decomposition of the covariance matrix in terms of principal comp. Only the first 3 are important. Only the 1st is above the statistical errors. The observed variations can be traced back to uncertainties in the pi0 and ICS slopes and amplitudes.



One can repeat the same exercise to smaller regions:

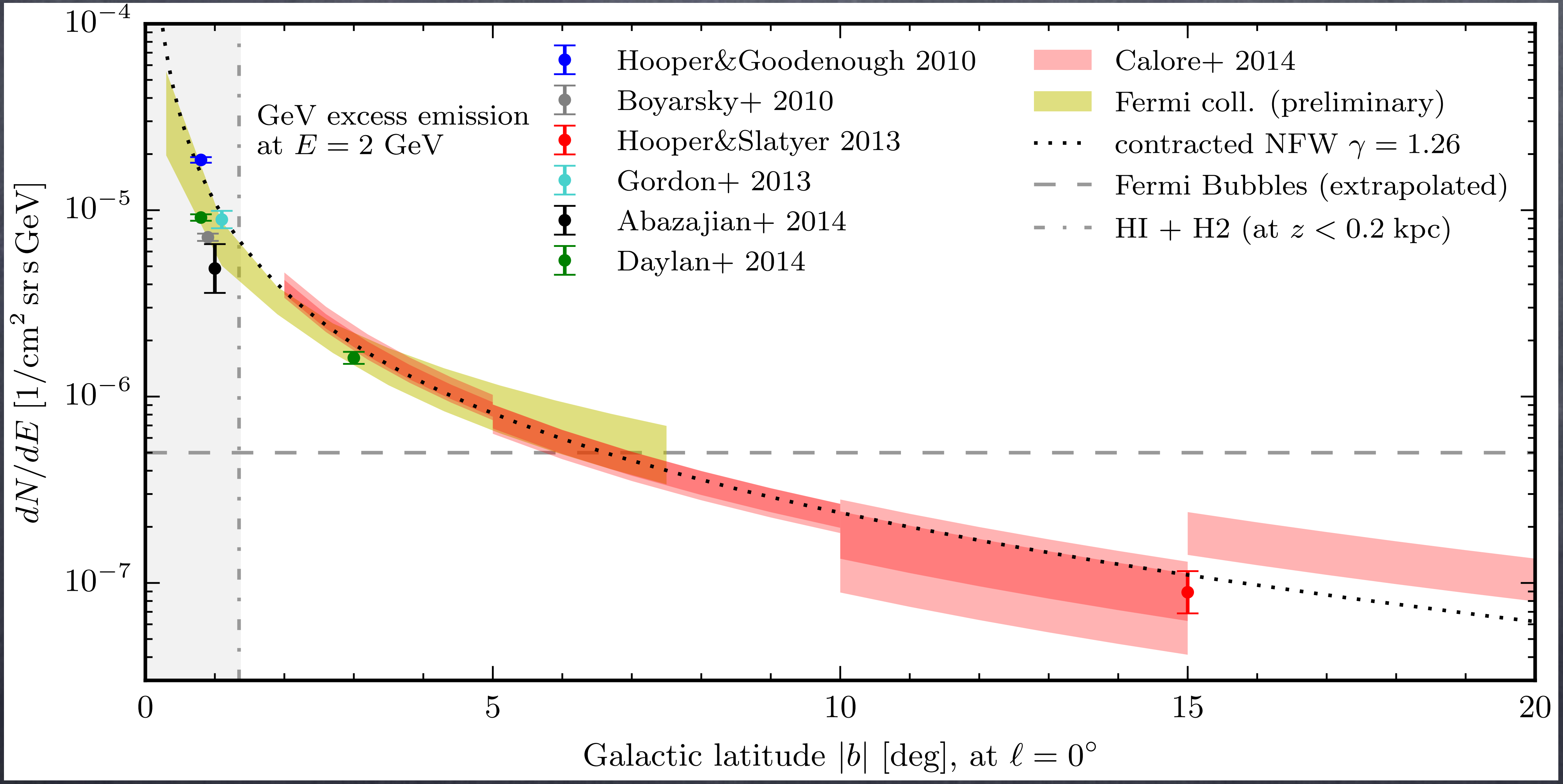




I
II
III
IV
V
VI
VII
VIII
IX
X
$\times 10^{-5}$
$\times 10^{-6}$
$E^2 \frac{dN}{dE}$ [GeV/(cm^2 s sr)]
E [GeV]

A different way of seeing the level of agreement between individual results

The flux associated to the excess emission at 2 GeV vs galactic latitude: Calore, Cholis, McCabe, Weniger, 2014



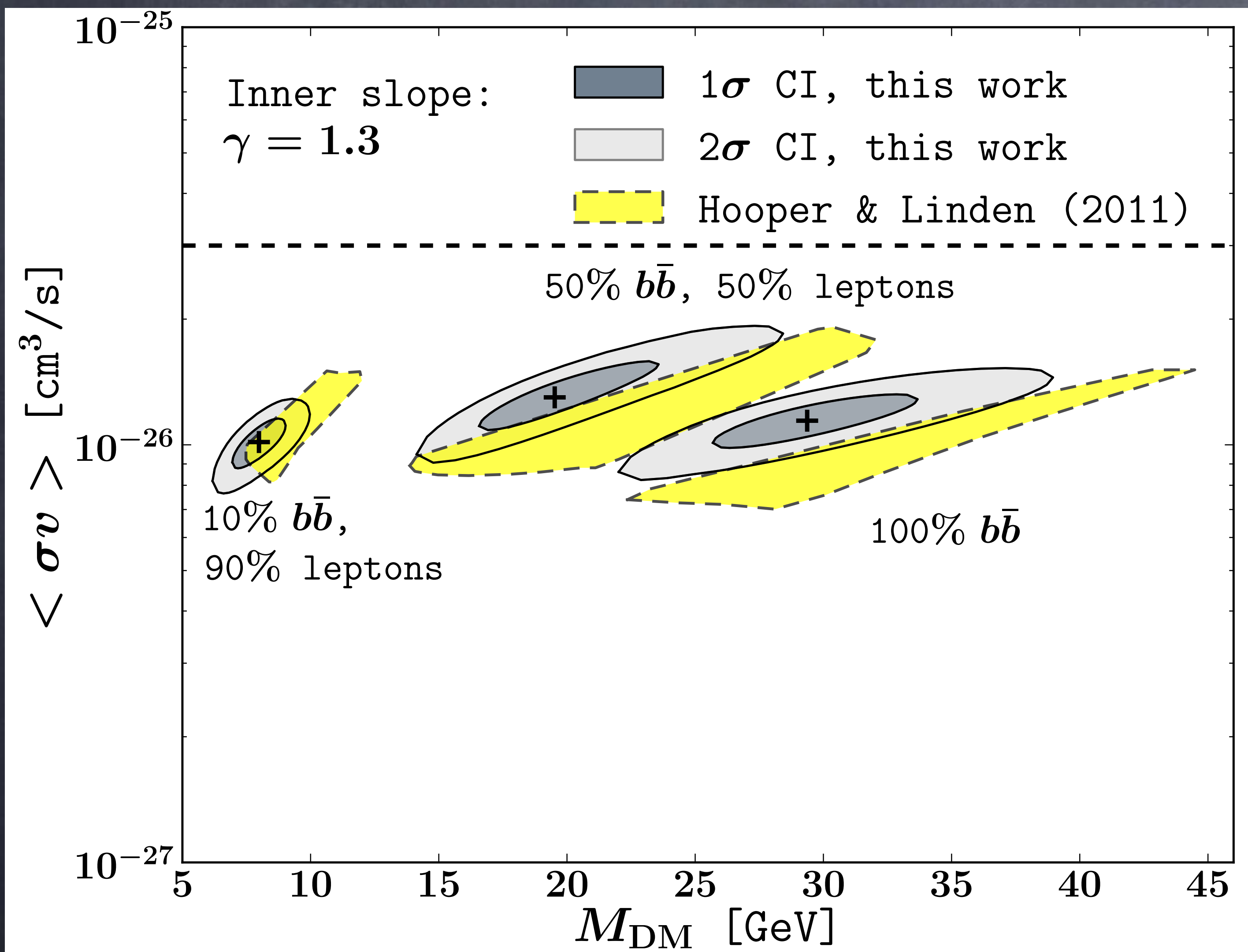
The excess signals from different analyses, agree within a factor of less than 2 in terms of total emission (that is wether it is DM or MSPs or CR outbursts).

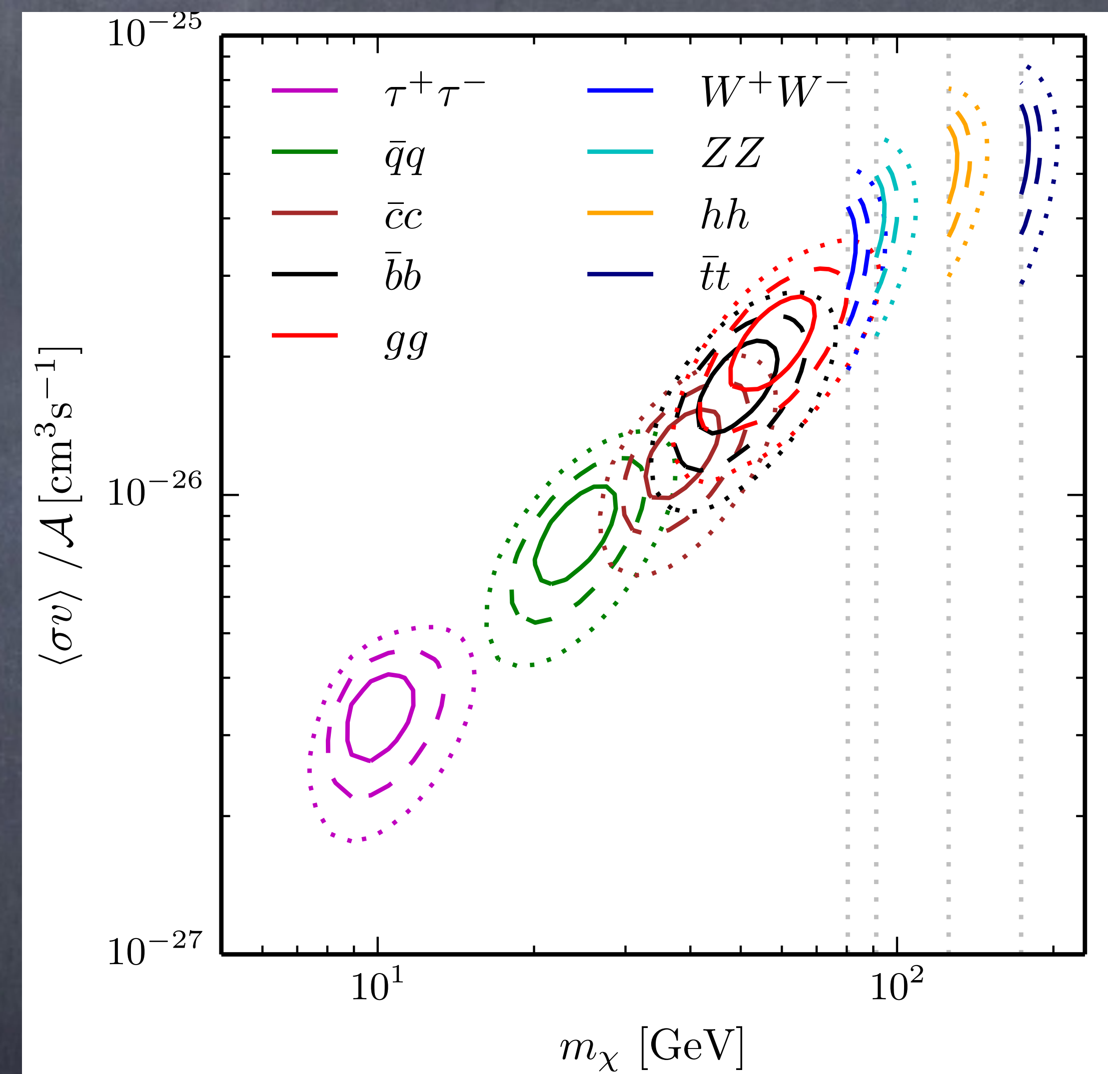
If this is a DM annihilation signal:

The range of possibilities (phenomenologically) becomes much larger. Because of the correlated errors.

BEFORE:

AFTER:



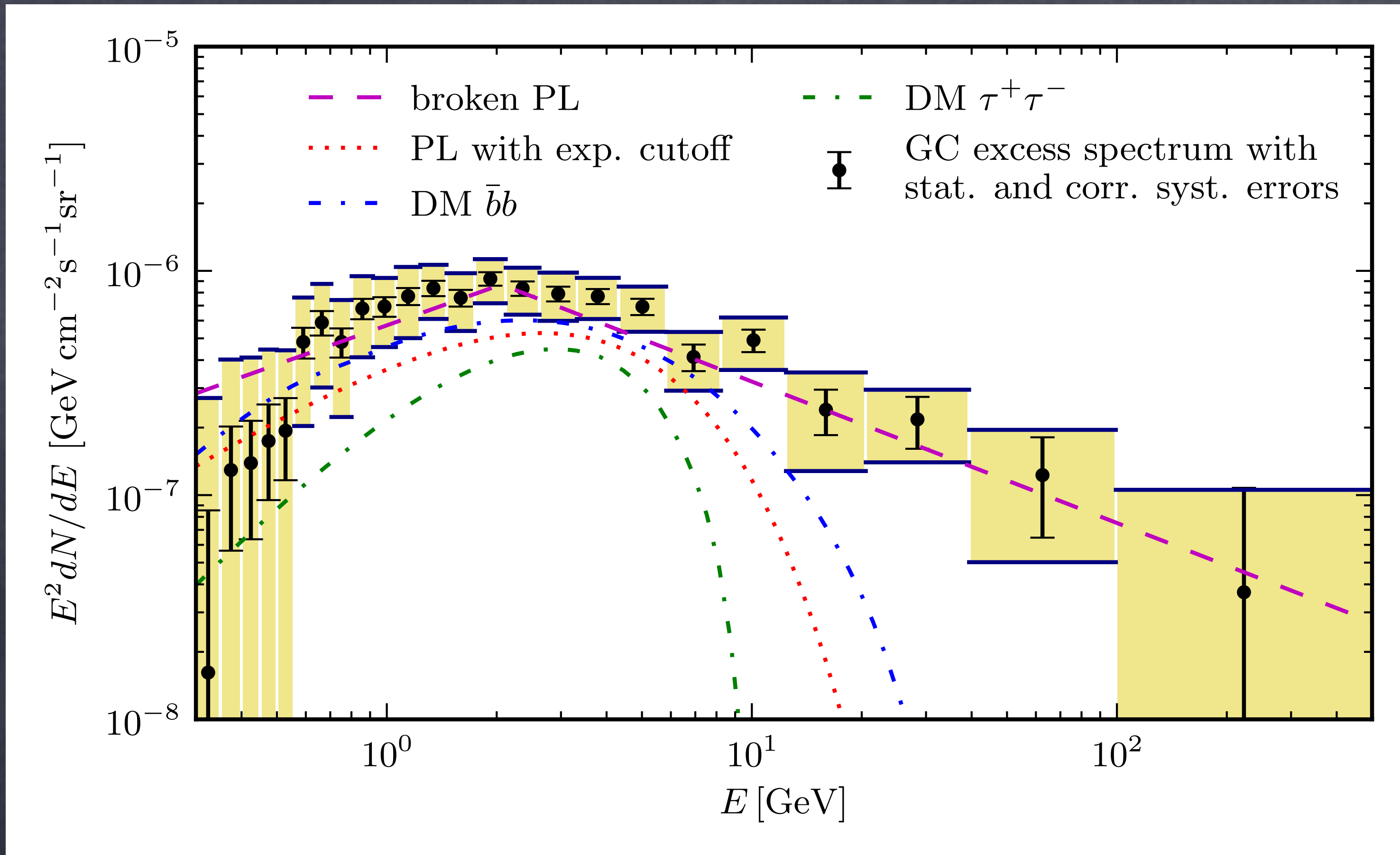


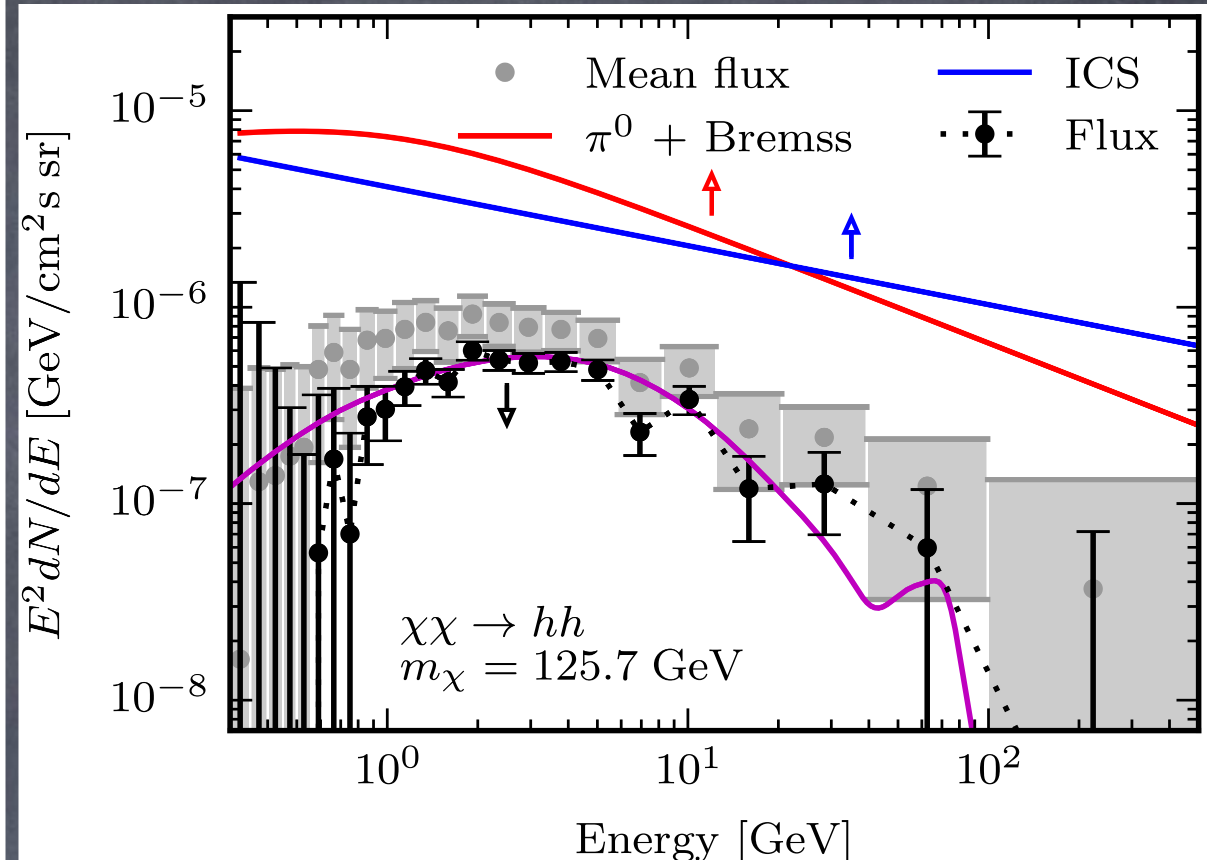
Gordon & Macias (1306.5725)

Calore, Cholis, McCabe, Weniger, 2014

The mass range preferred is actually higher. Even though still light DM models can work.

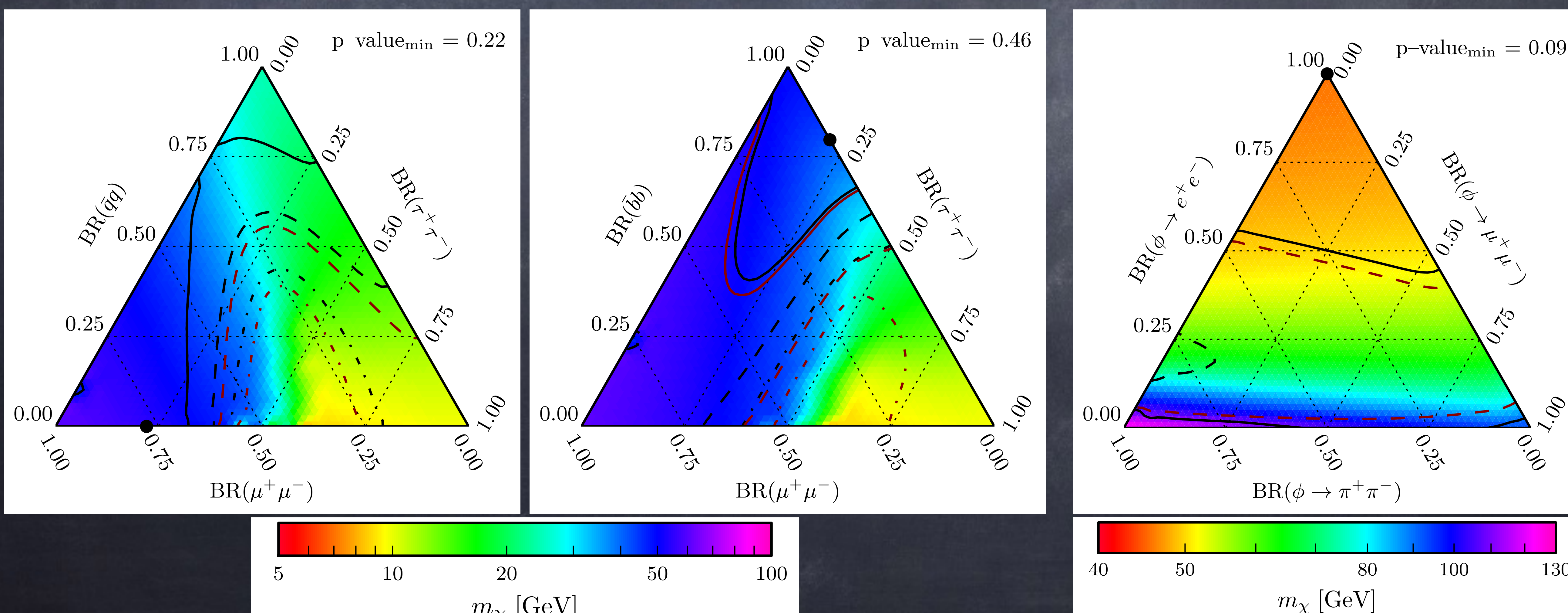
(see also P. Agrawal, B. Battel, P. Fox, R. Harnik, 1411.2592)





Calore, Cholis, Weniger, 2014

Calore, Cholis, McCabe, Weniger, 2014



A specific example on MSSM

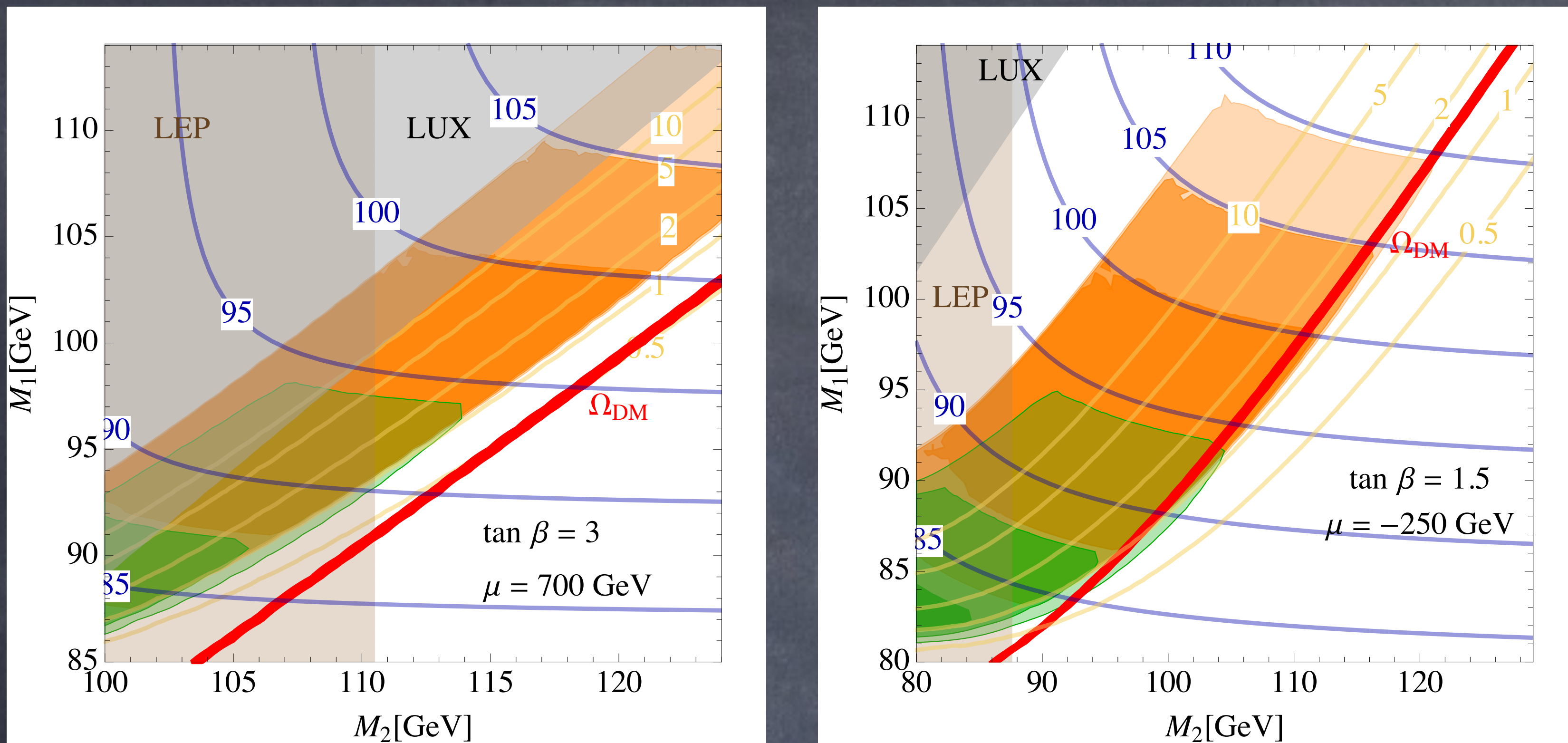
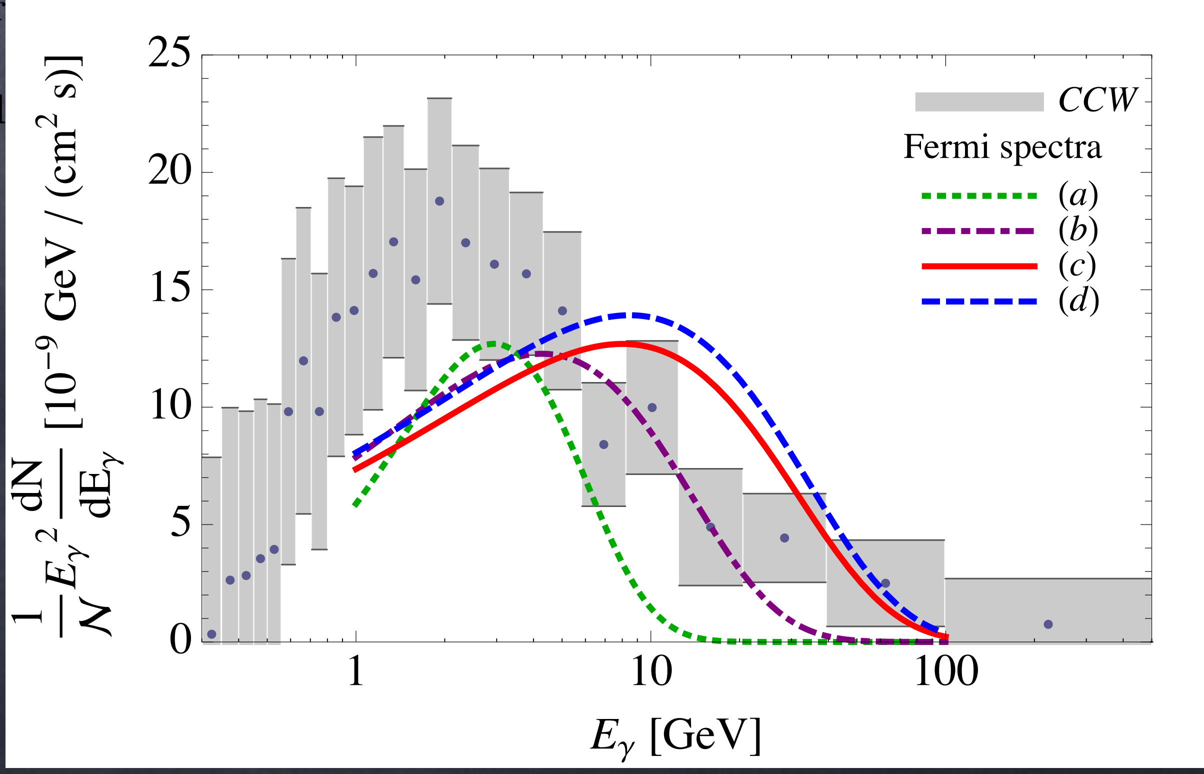


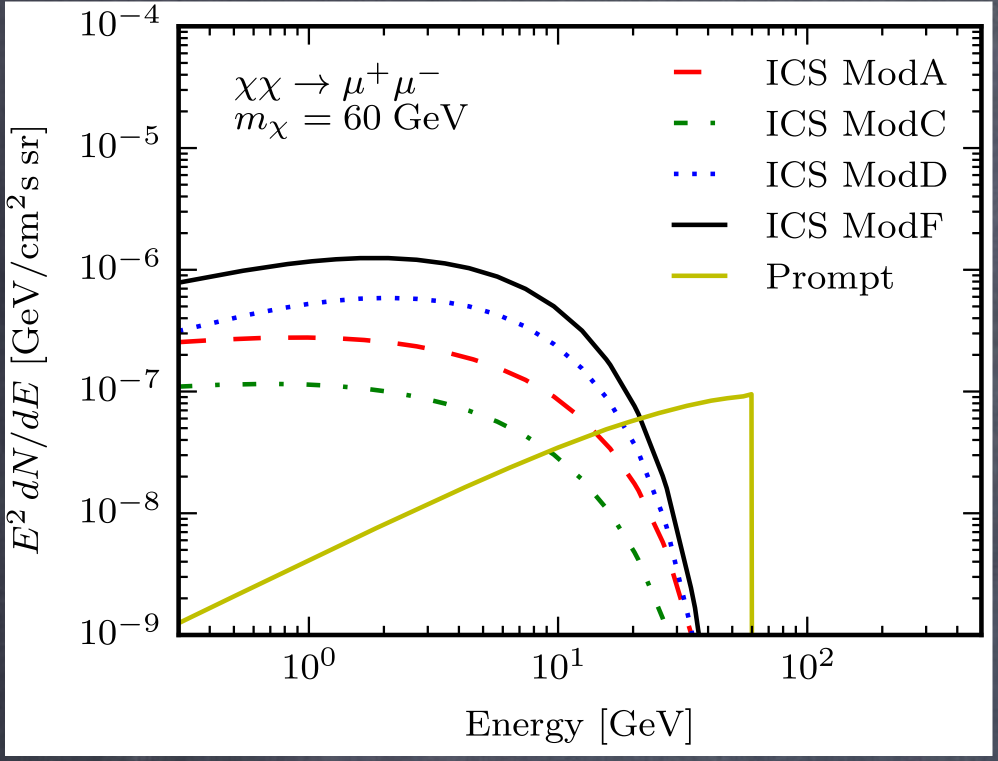
Figure 6: *Mixed MSSM neutralino.* We display the 1,2,3σ best-fit GCE regions for the WW final state in the $M_2 - M_1$ plane for CCW (green) and Fermi spectrum (b) (orange). We also overlay constraints from LEP chargino searches (brown) and LUX (gray). In the (red) region denoted $\Omega_{\rm DM}$ the thermal relic abundance for the DM is within 3σ of the observed value. For convenience, we also show the mass of the DM and the annihilation cr[...] to WW as blue and yellow contours in units of GeV and 10^{-26} cm$^2/s$ respectively. [...] plot we have fixed μ = 700 GeV, tan β = 3, while in the right plot we have fixed [...] GeV, tan β = 1.5.

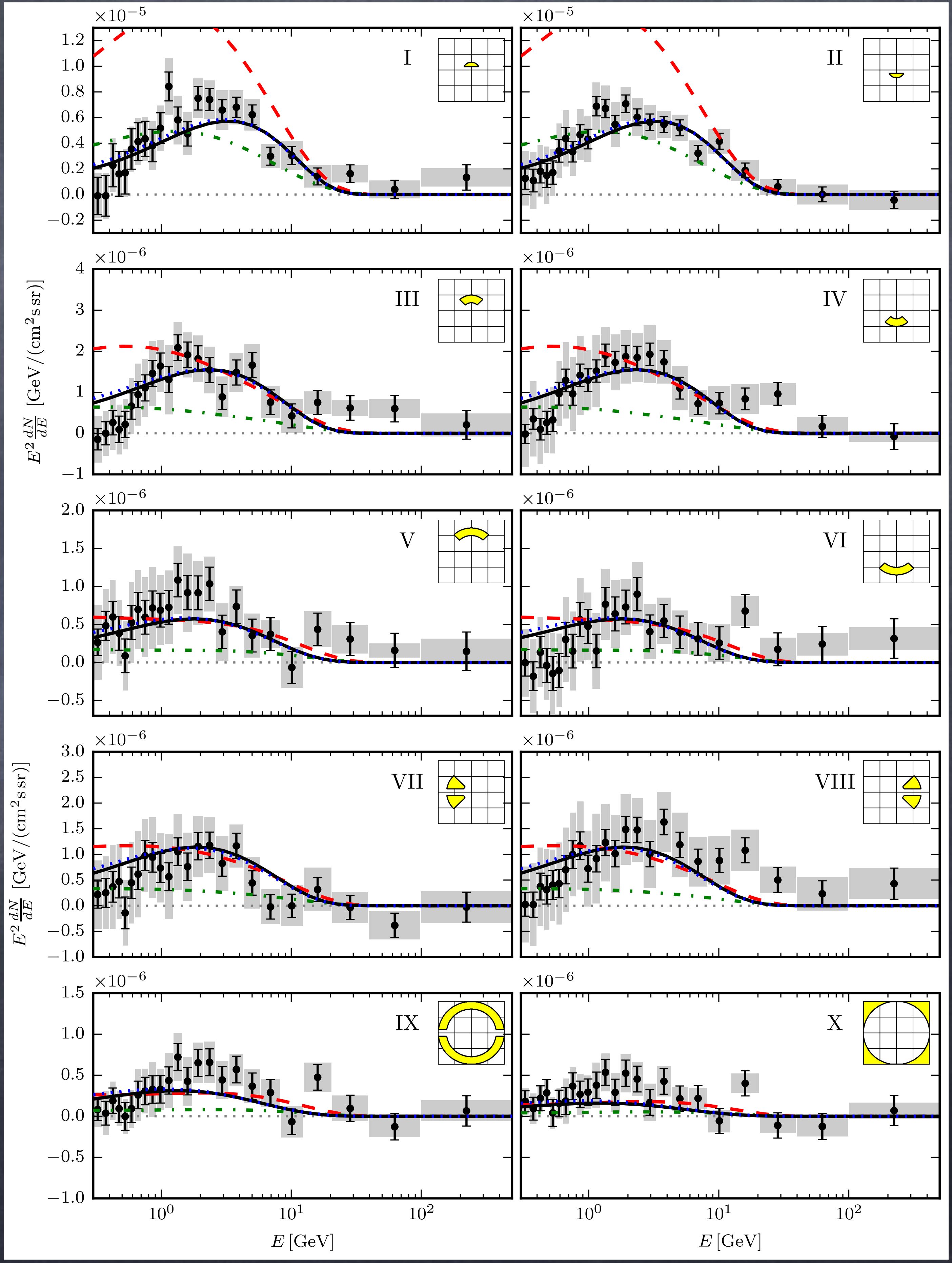


P. Agrawal, B. Battel, P. Fox, R. Harnik

1411.2592

One can also study the ICS signal from DM annihilations (including astrophysical uncertainties):

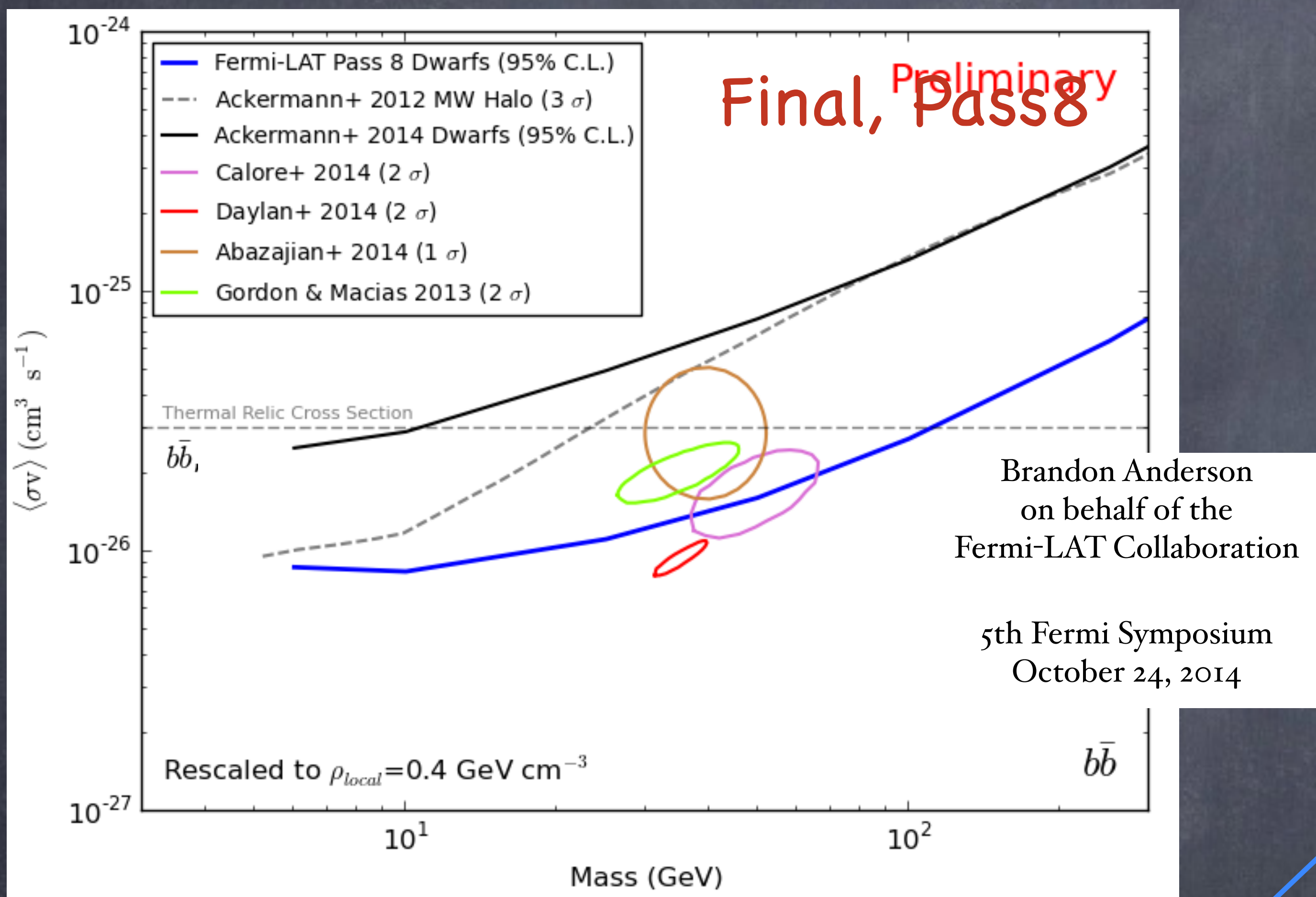


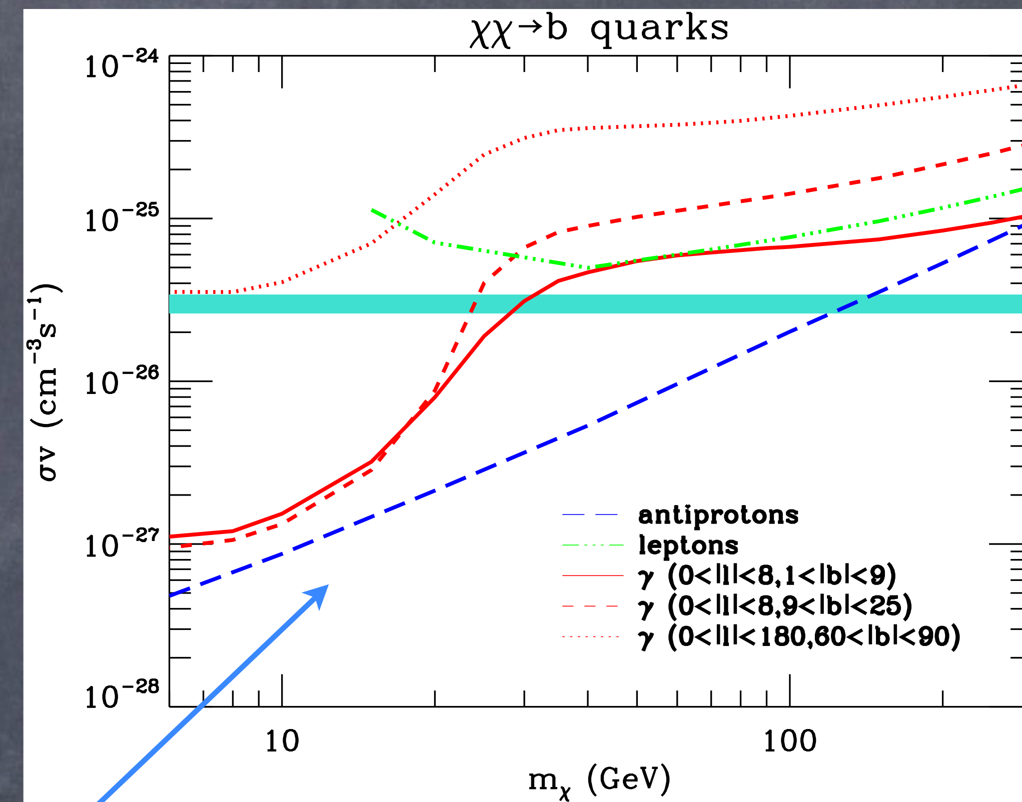


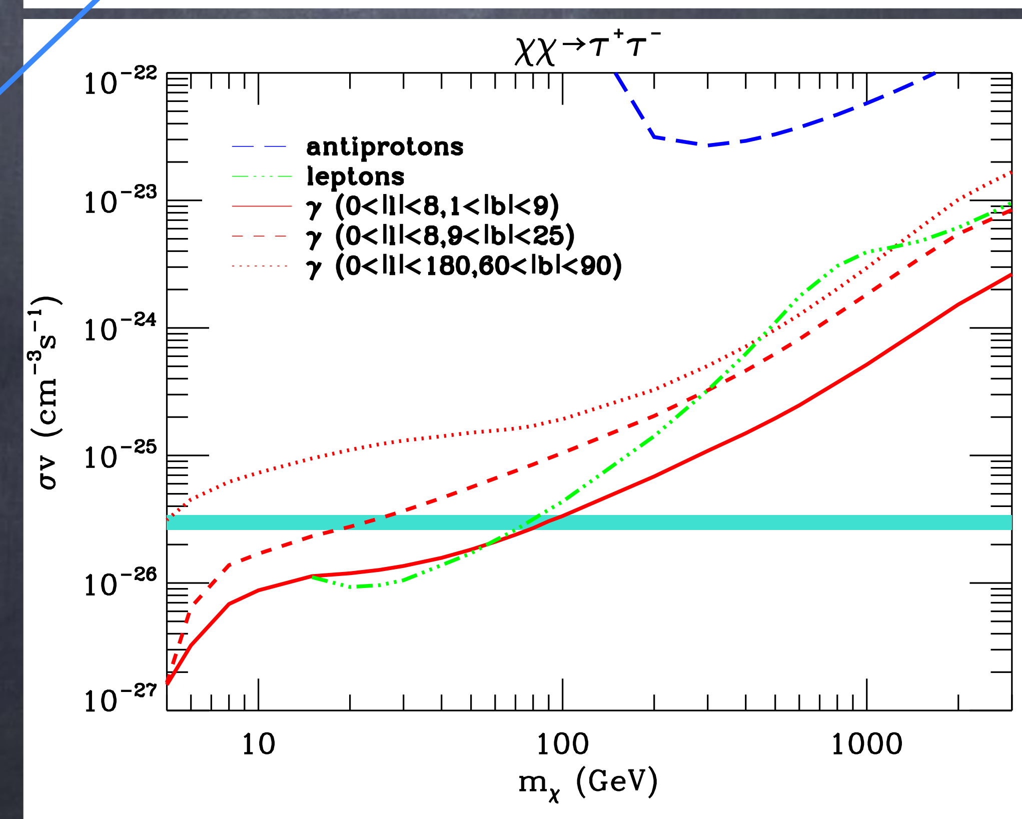
Understanding the morphology of the signal in various windows can be crucial; FOR ANY model that wants to explain the GC excess via CR electrons(positrons) whether of DM origin or Not.

One last thing; If this is a DM annihilation signal:

The amplitude of the signal is in general agreement with constraints from other indirect probes: Dwarf spheroidal galaxies, other DM galactic substructures antiprotons, gamma-rays from other regions of the galactic sky







Tavakoli, Cholis, Evoli, Ullio (1308.4135)

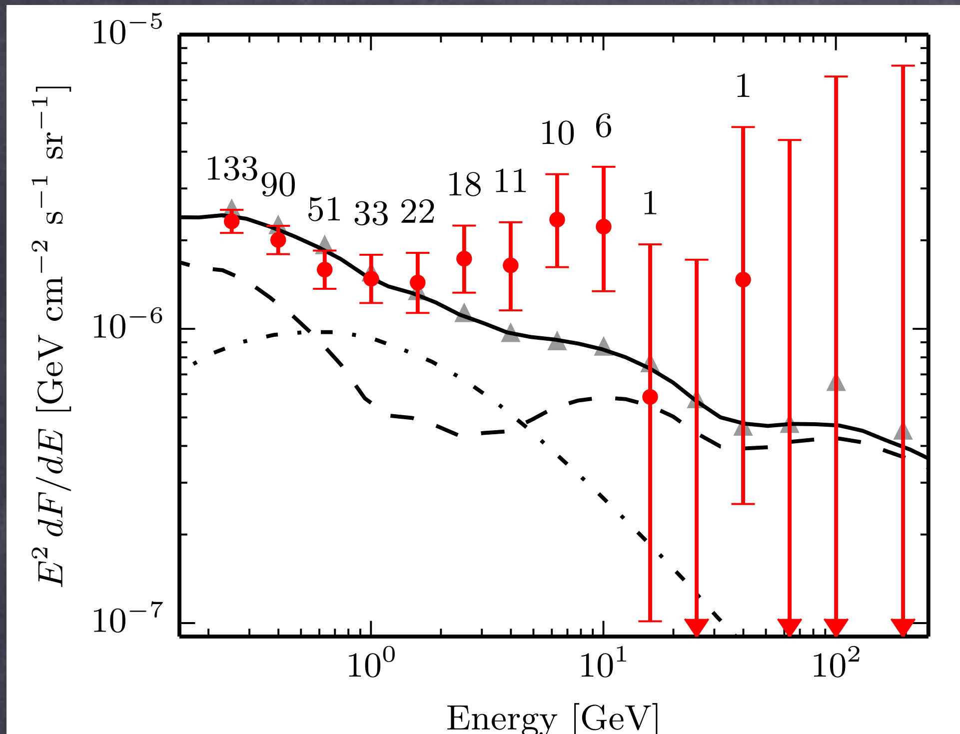
strong limits from dwarf spheroidal galaxies (see results at 1503.02641)

Antiprotons can still give stronger limits for b-quarks by a factor of ~2.

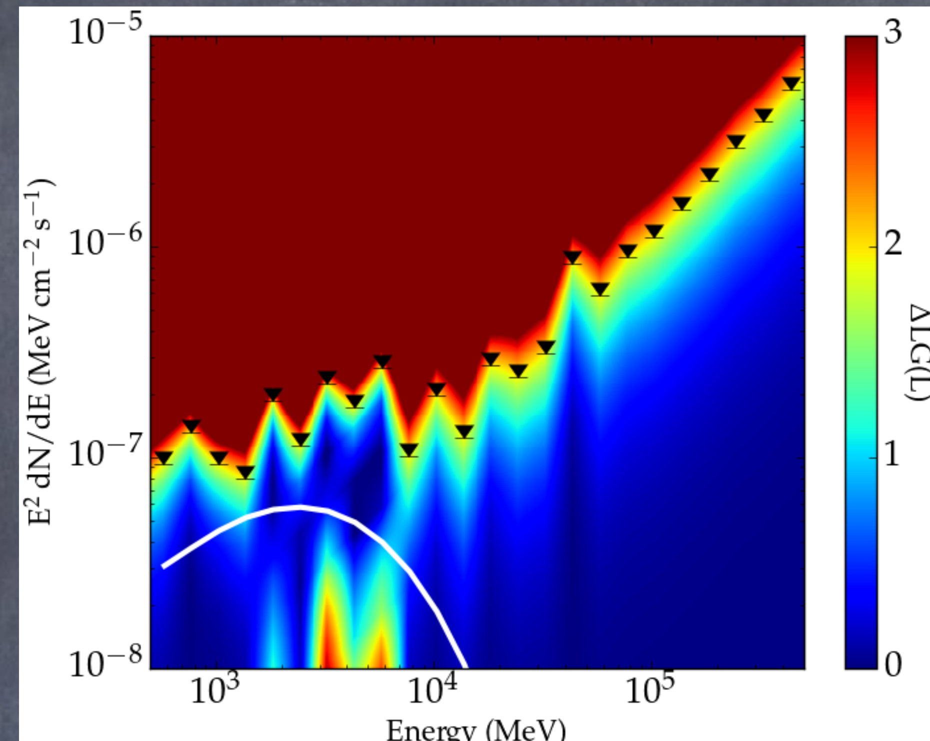
For DM models with high BRs to leptons the AMS-02 data actually provide the best limits instead.

Some excitement the last few weeks...days

From Reticulum II (DES J 0355.6-5403) a new *likely* dwarf spheroidal



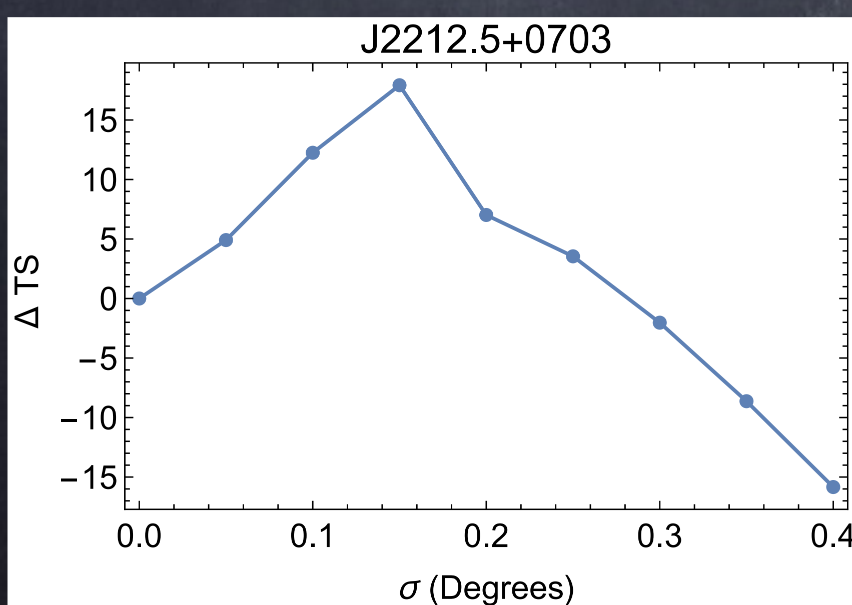
A. Geringer-Sameth et al.
arXiv:1503.02320



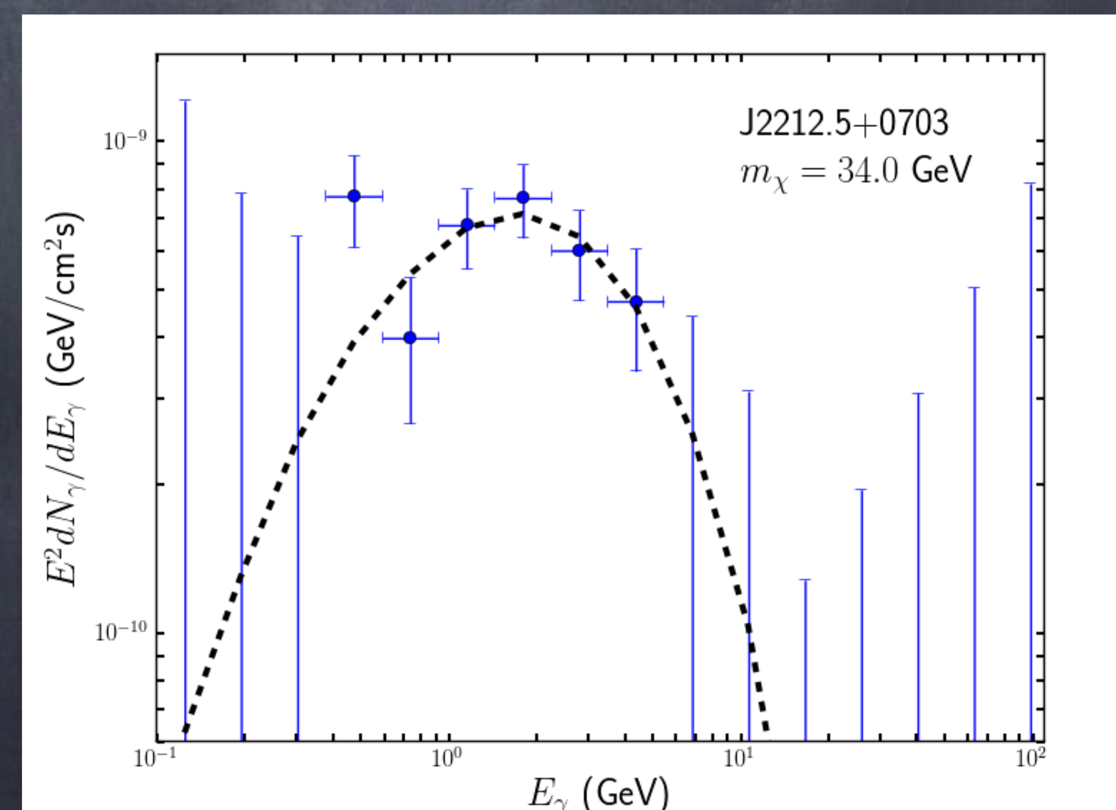
D. Hooper & T. Linden
arXiv:1503.06209

The Ret. II excess is still ~20 photons

From un-associated gamma-ray sources



B. Bertoni,
D. Hooper,
T. Linden
arXiv:1504.02087



A non-DM interpretation: Millisecond Pulsars (MSPs)?

How about a collection of Unresolved MSPs ?

Consider a large population of unresolved points sources distributed throughout the inner 100 parsecs of the Galaxy could produce the observed signal, Most likely scenario ~10^3 millisecond pulsars.

Why MSPs? : The observed spectra of Fermi's observed MSPs are qualitatively similar to that from the extended emission from the Galactic Center.

Still the Galactic Center emission appears to have a significantly harder spectral index below ~1-2 GeV and a high energy tail.

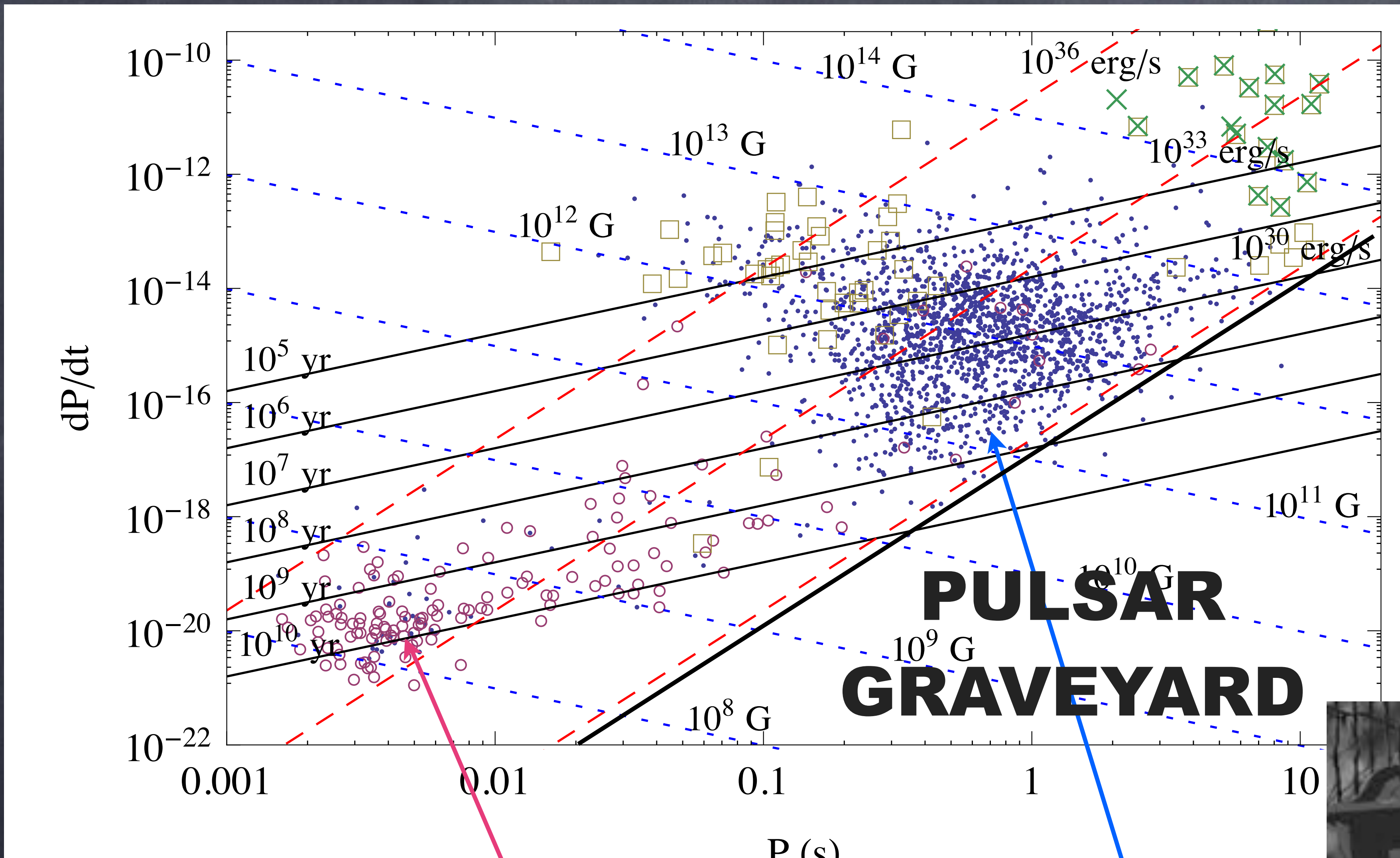
Also the suggested morphology in the inner few degrees of the observed flux implies a very concentrated distribution of sources ($F \propto r^{-2.6}$), while the observed stellar distribution is much more shallow ($n_{star} \propto r^{-1.25}$)
Yet, MSPs are born as a result of star-star interactions, so in that environment they may have been formed over the last many Gyrs at a preferable rate (and distribution).

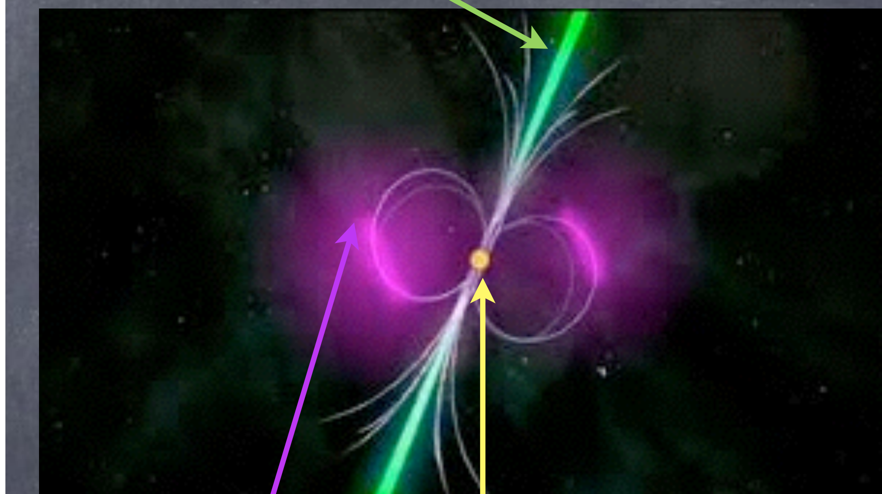
Within the inner 2 degrees BOTH DM annihilation and MSPs ARE VIABLE

A bit about Pulsars in General

Basic model assumed Magnetic dipole radiation (n=3)

$$\tau = \frac{P}{(n-1)\dot{P}}\left[1-\left(\frac{P_0}{P}\right)^{n-1}\right]$$





synchrotron pulse

Neutron Star

Gamma-Rays

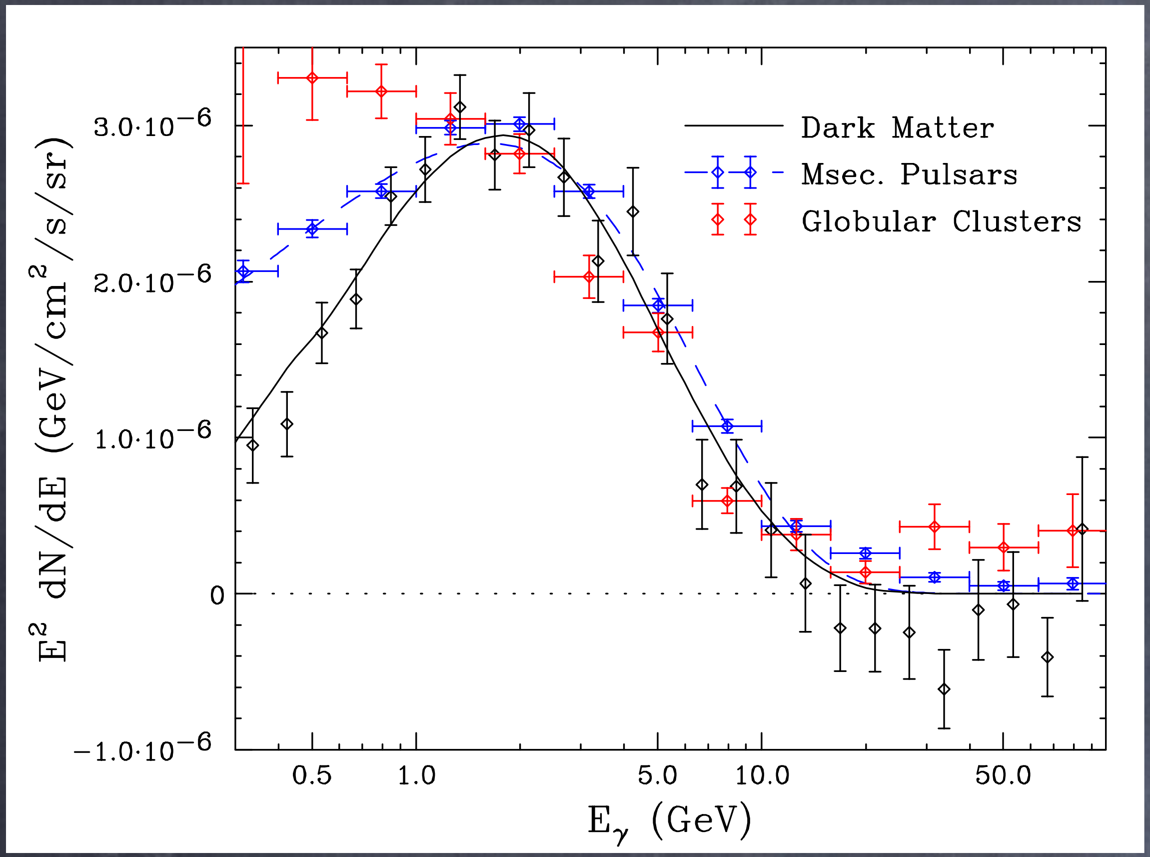
Spinning Up of a normal pulsar (with a period of seconds) to a milli-second ("zombie") pulsar: NEED A COMPANION

$$\dot{E} = -\frac{B_s^2 R_s^6 \Omega^4}{6c^3} \approx 10^{31} B_{12}^2 R_{10}^6 P^{-4}\ \mathrm{erg\ s^{-1}}$$

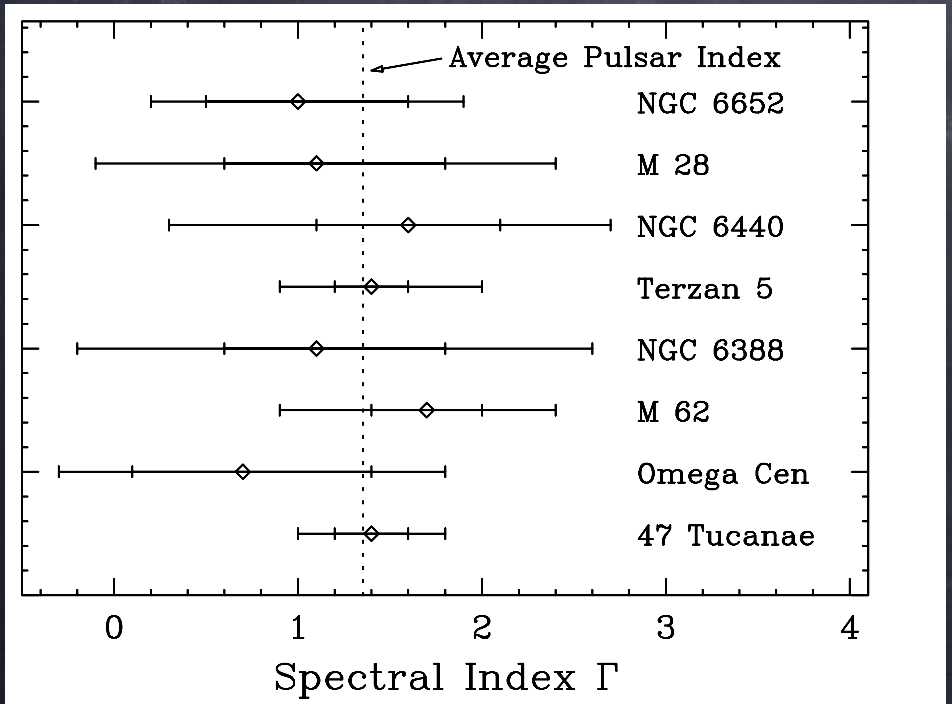
$$\dot{P} = 3.3 \times 10^{-15}\,(B/10^{12}\,\mathrm{G})^2\,(P/0.3\,\mathrm{s})^{-1}$$

Spectral Arguments

Known MSPs (61 individual MSPs from Fermi & 36 Globular Cluster spectra)



Cholis, Hooper, Linden (1407.5625)



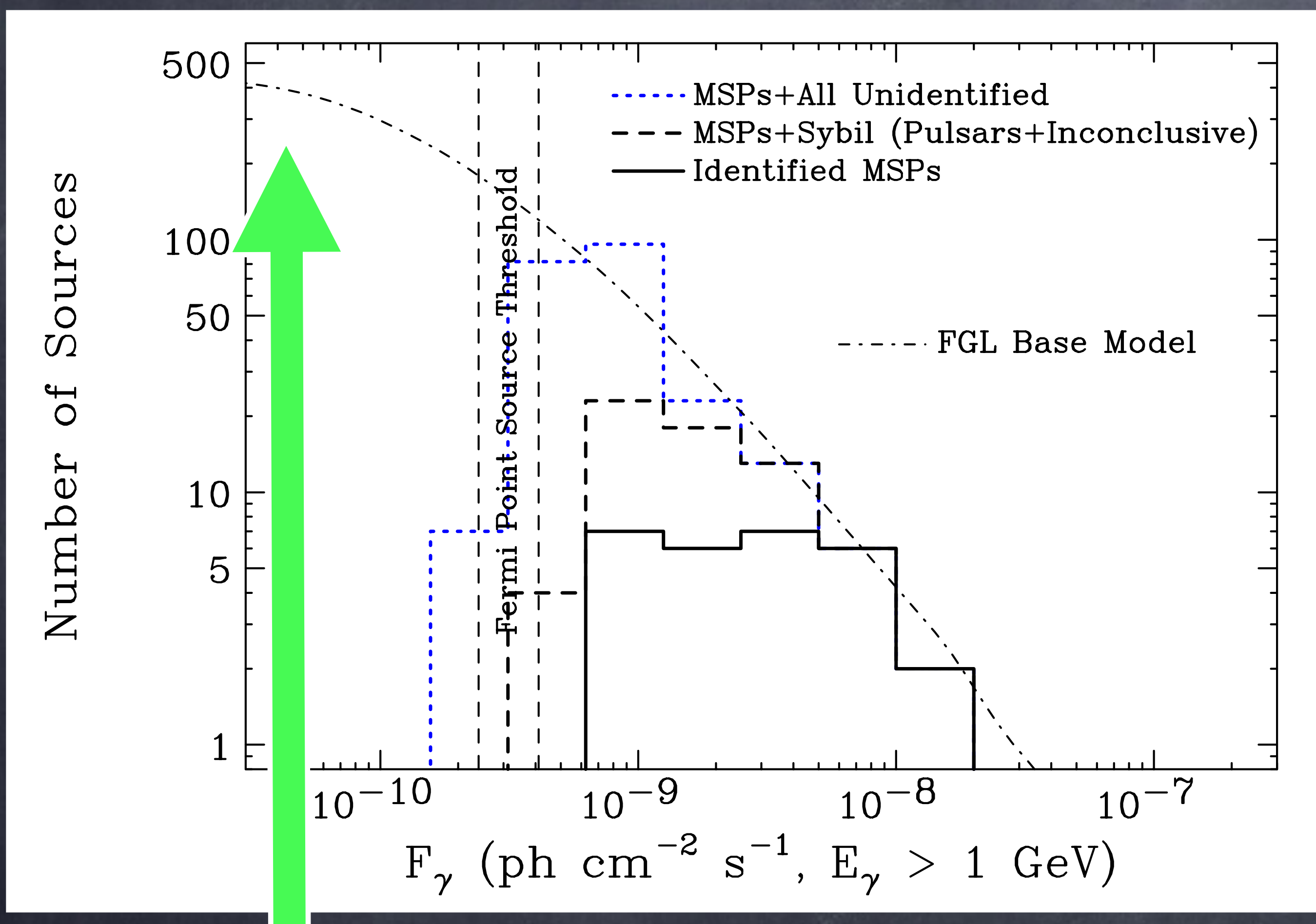
If we change the power-law to E^-1 (Ecut=2.75 GeV), E-^0.5 (Ecut=2.0 GeV)we can get a better fit to the excess.

BUT excluded from the data on the left at a high significant level.

Hooper, Cholis, Linden, Siegal-Gaskins, Slatyer (1305.0830)

"We should have seen them elsewhere" arguments

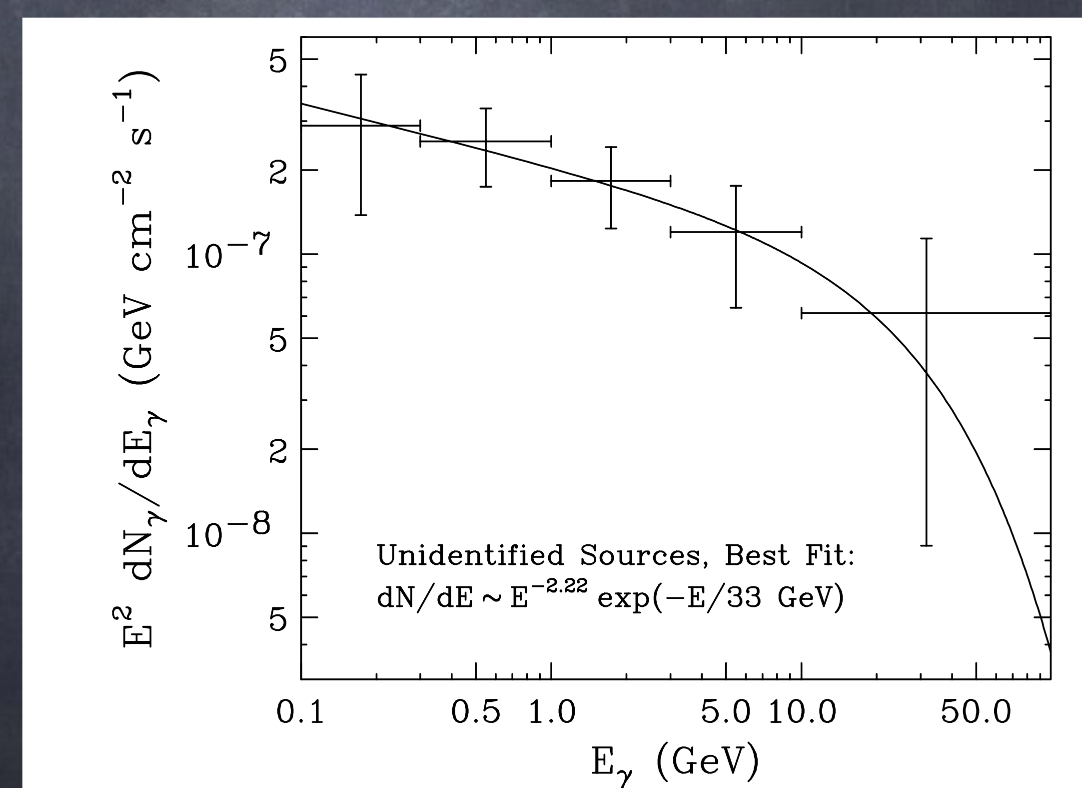
$n(r,z) \propto \exp(-r^2/2\sigma_r^2)\,\exp(-|z|/\langle|z|\rangle)$: spatial distribution in the Galaxy



:Based on some reference assumptions on the MSP spatial and B-field distribution, that still over-predict the number of dimmer but observable sources

As reference we need 1-3x10^3 MSPs in the inner 2 kpc bellow threshold

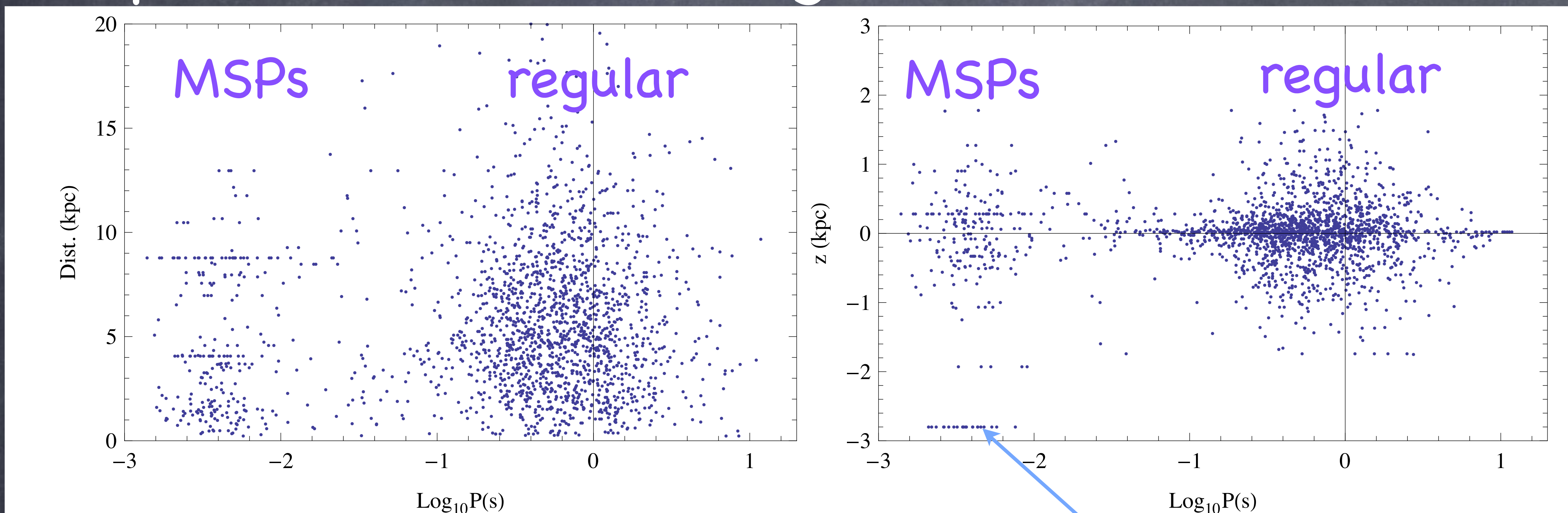
Fermi unresolved p.s. above |b|>10:
Disagrees with the excess spectrum.
They are dominated by the AGN sample



What is the information on their location

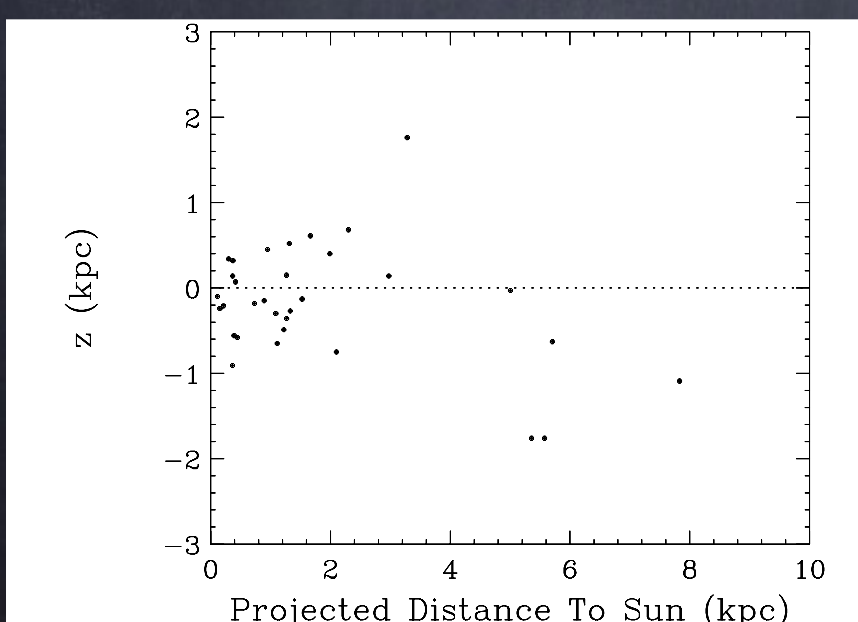
MSPs have a characteristic time of Gyrs and kick velocities ~10 km/s Will travel ~1 kpc inside the Galaxy. Thus a non Glob Clust. population can not be very concentrated.

ALL pulsars (ATNF catalogue)

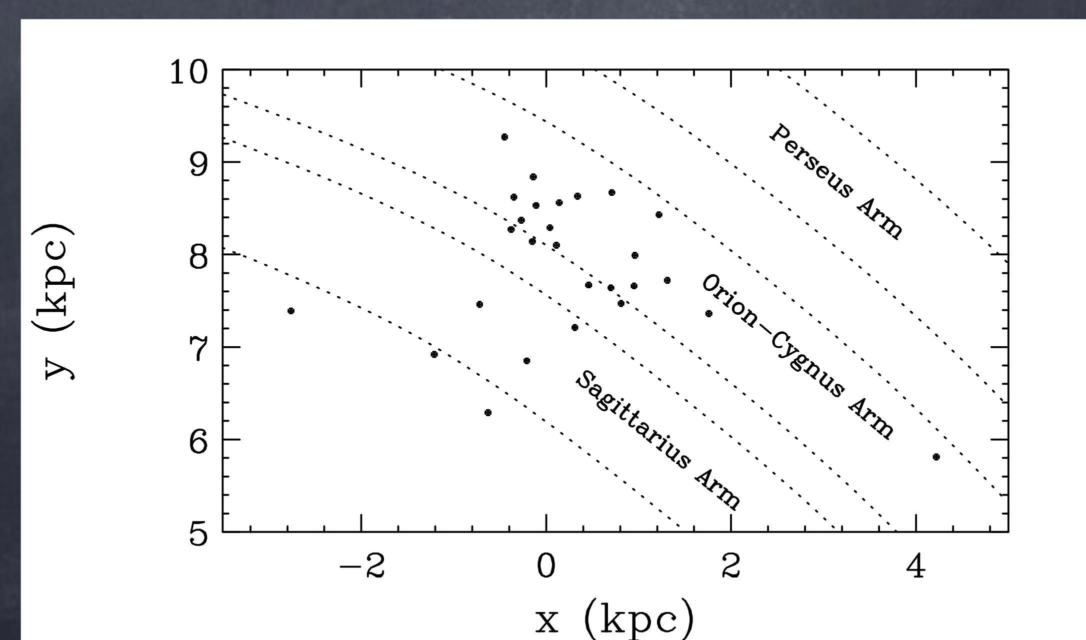


Globular cluster MSPs

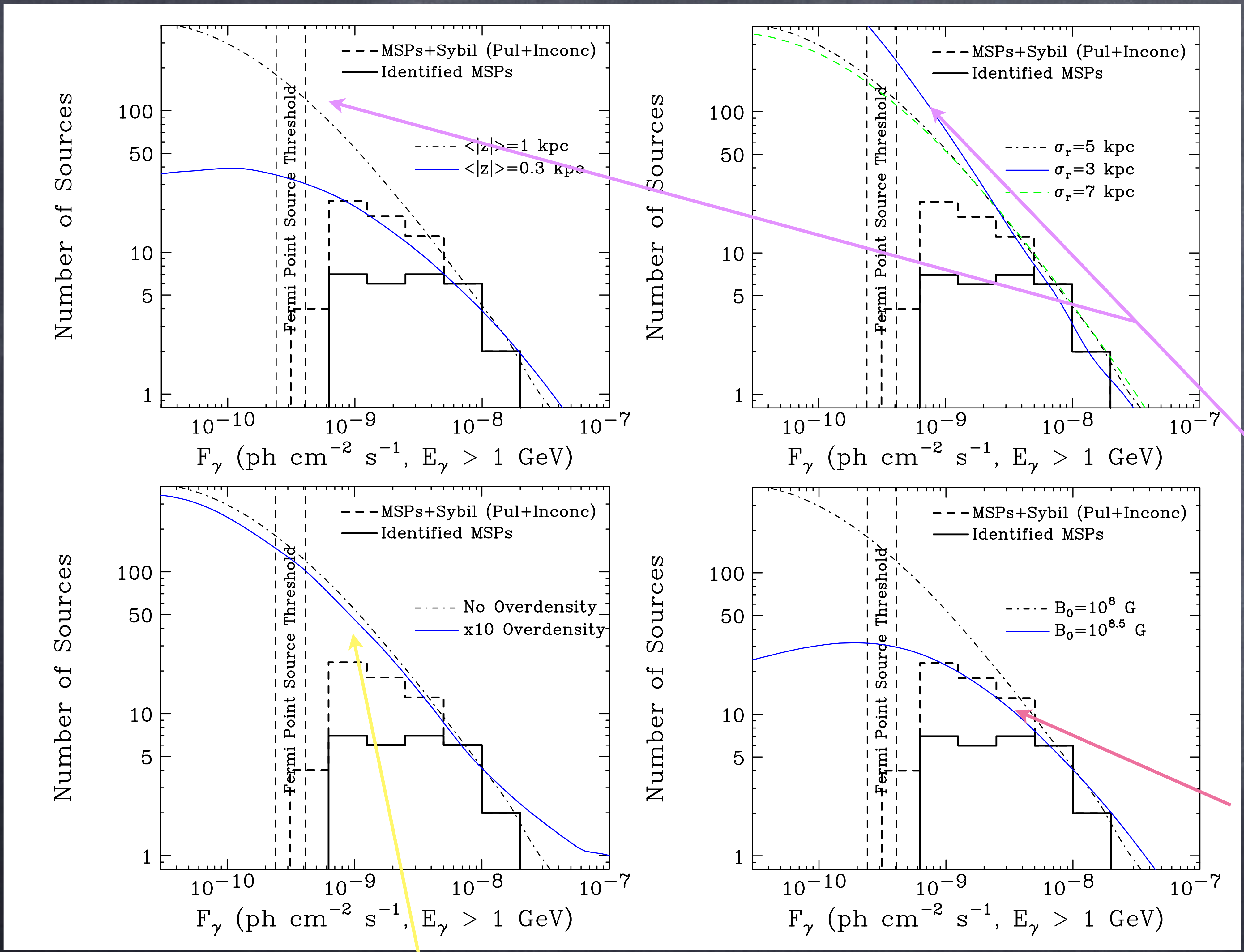
Fermi MS Pulsars (37<) in 2013



In gamma -rays they are close by.



Varying the distribution assumptions



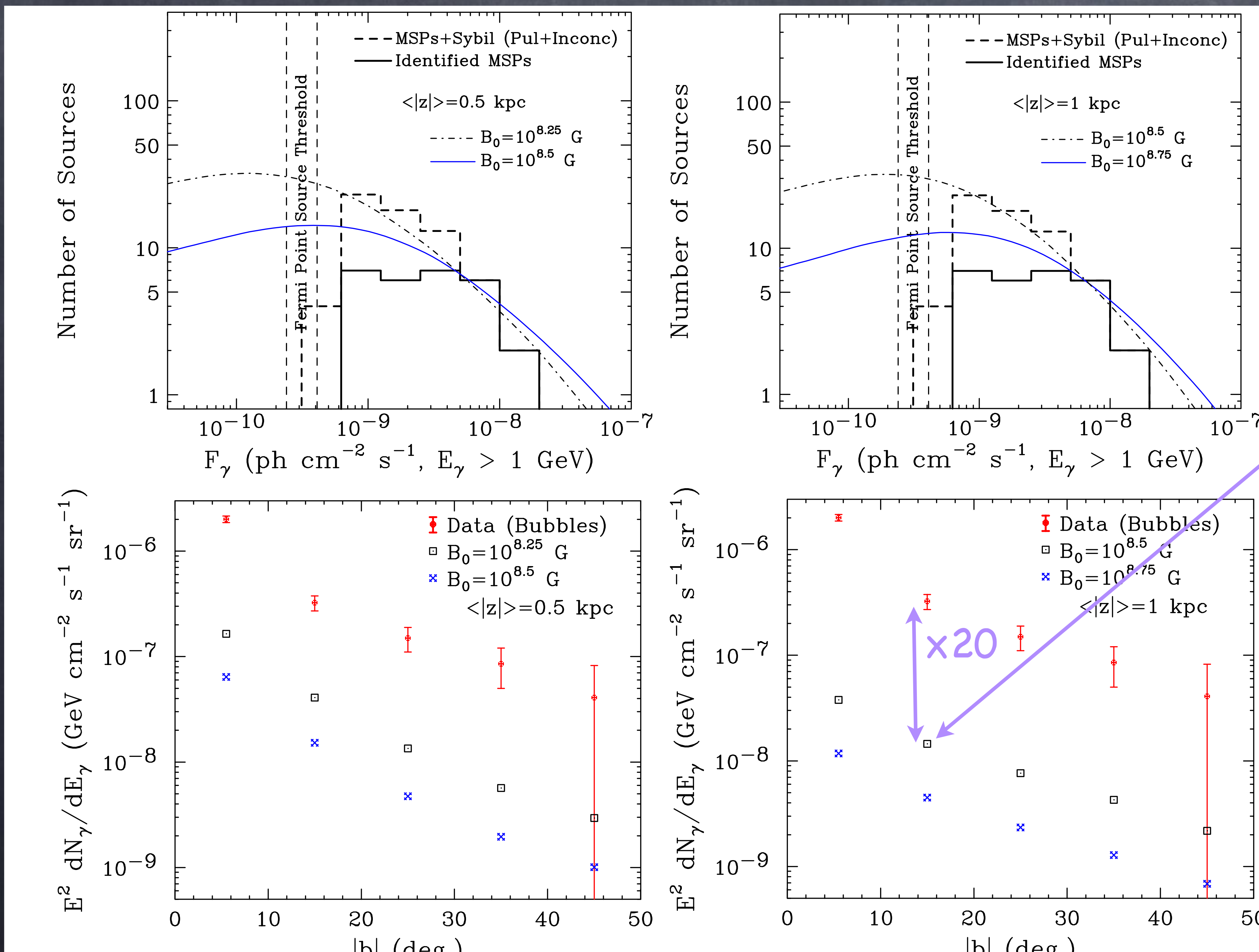
Models that would give enough MSPs in the inner 2 kpc over-predict the number of MSPs that should have already been observed by LAT at locations closer to the Earth

Preferred B-field assumptions do not give a dim MSP population

Hooper, Cholis, Linden, Siegal-Gaskins, Slatyer (1305.0830)

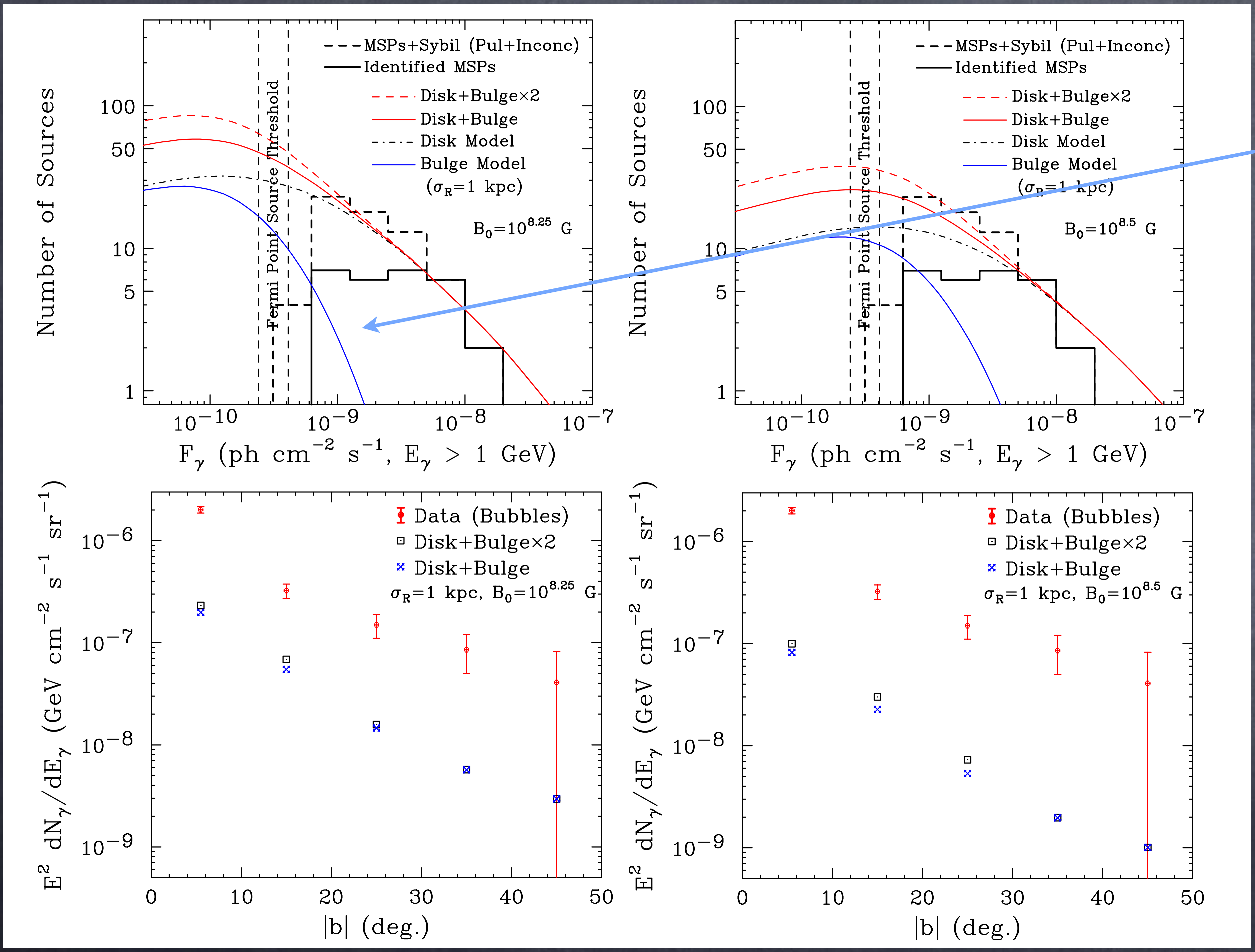
Being in at a local overdensity/underdensity can not affect much the results

Assumptions that agree with everything



MSP models that are consistent with the observed (suggested) population can give only 5-10% of the observed diffuse emission in the inner 2kpc of the Galaxy.

Adding a bulge (but staying in agreement with observations)



Having a bulge can result in adding dim MSPs (since there are no local MSPs from the bulge).

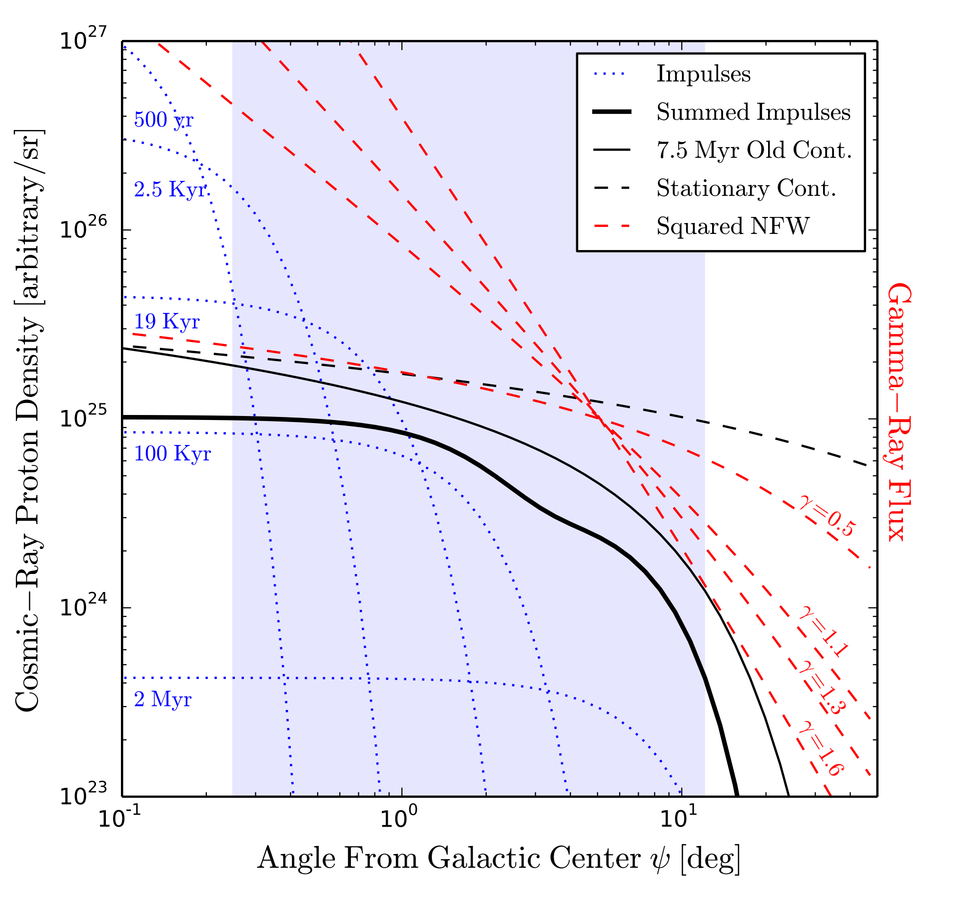
Yet that does not help much, especially above |b|>5 where the bulge population can not contribute.

Rough approx. for Bulge MSP distr. :

$$n(R) \propto \exp(-R^2/\sigma_R^2)$$

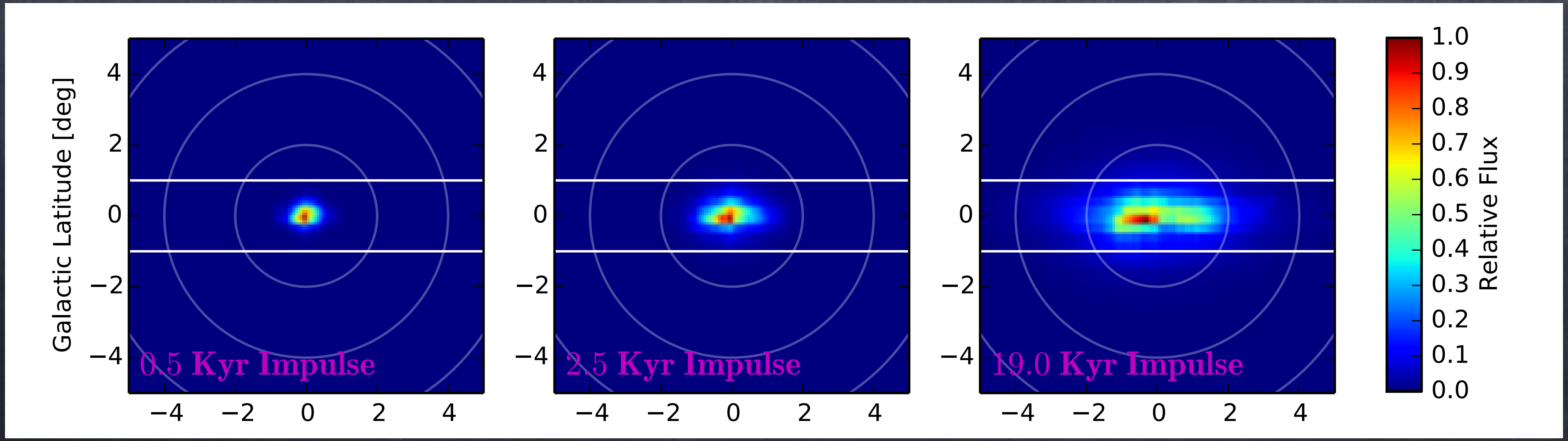
Also from connection to LMXBs (progenitors or MSPs) we have arguments that MSPS can not explain more than ~0.1 of the amplitude of the GeV excess in the inner 5 degrees (Cholis, Hooper, Linden 1407.5625)

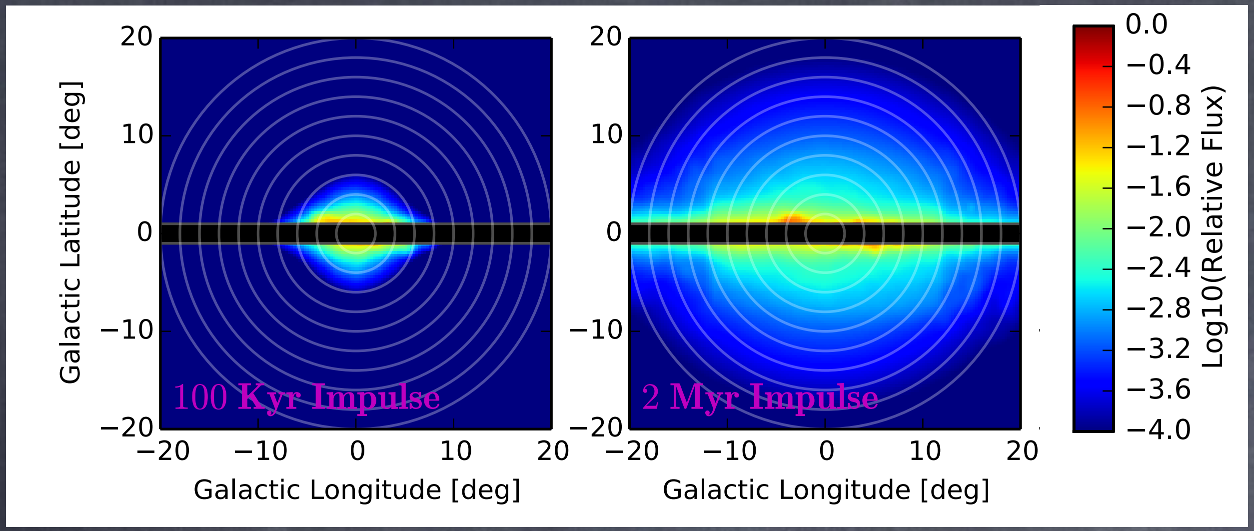
Outbursts of Cosmic Rays from the Galctic Center



While CR protons can explain the, averaged spectrum, and the averaged angular dependence of the excess, they fail to explain the robustly observed sphericity of the excess, as has been confirmed by Daylan et al. at low latitudes and Calore et al. at higher latitudes.

Carlson & Profumo (1405.7685)

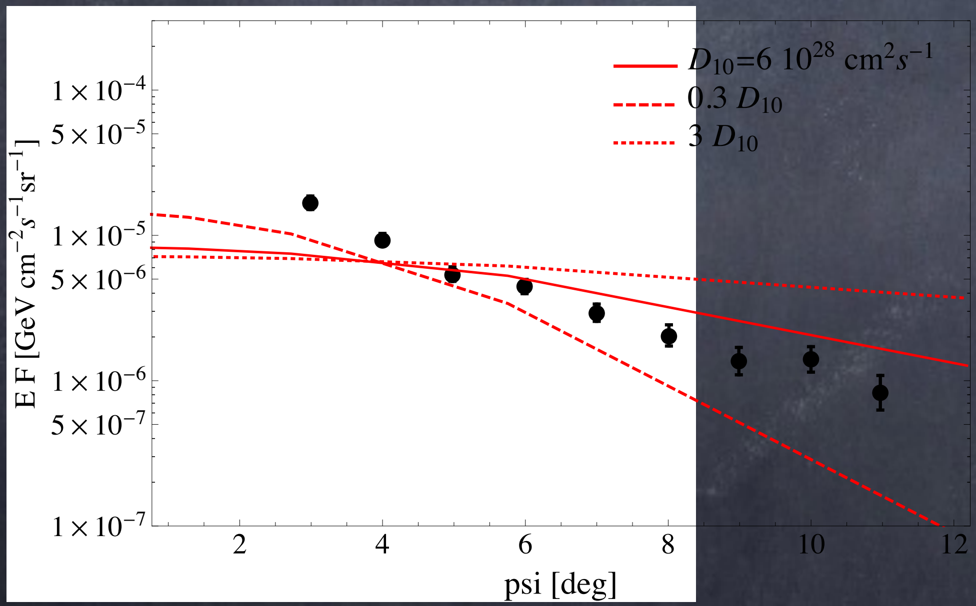


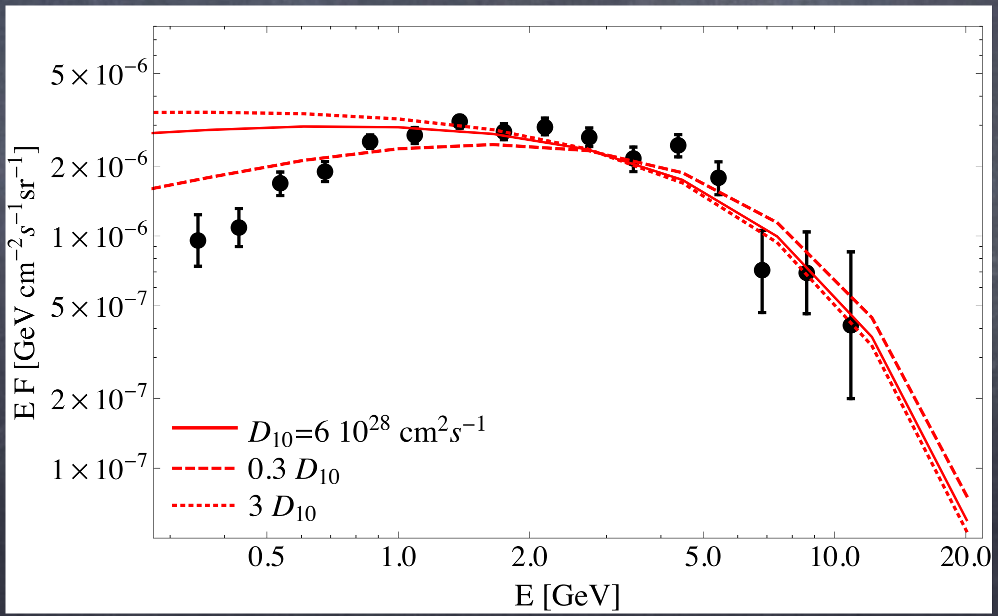


The main reason is simply that CR protons scatter off the interstellar gas, thus producing a disky / filamentary gamma-ray structure.

Carlson & Profumo (1405.7685)

CR electrons can potentially avoid the morphological issues that protons encounter (that is if ICS dominated over bremsstrahlung emission)

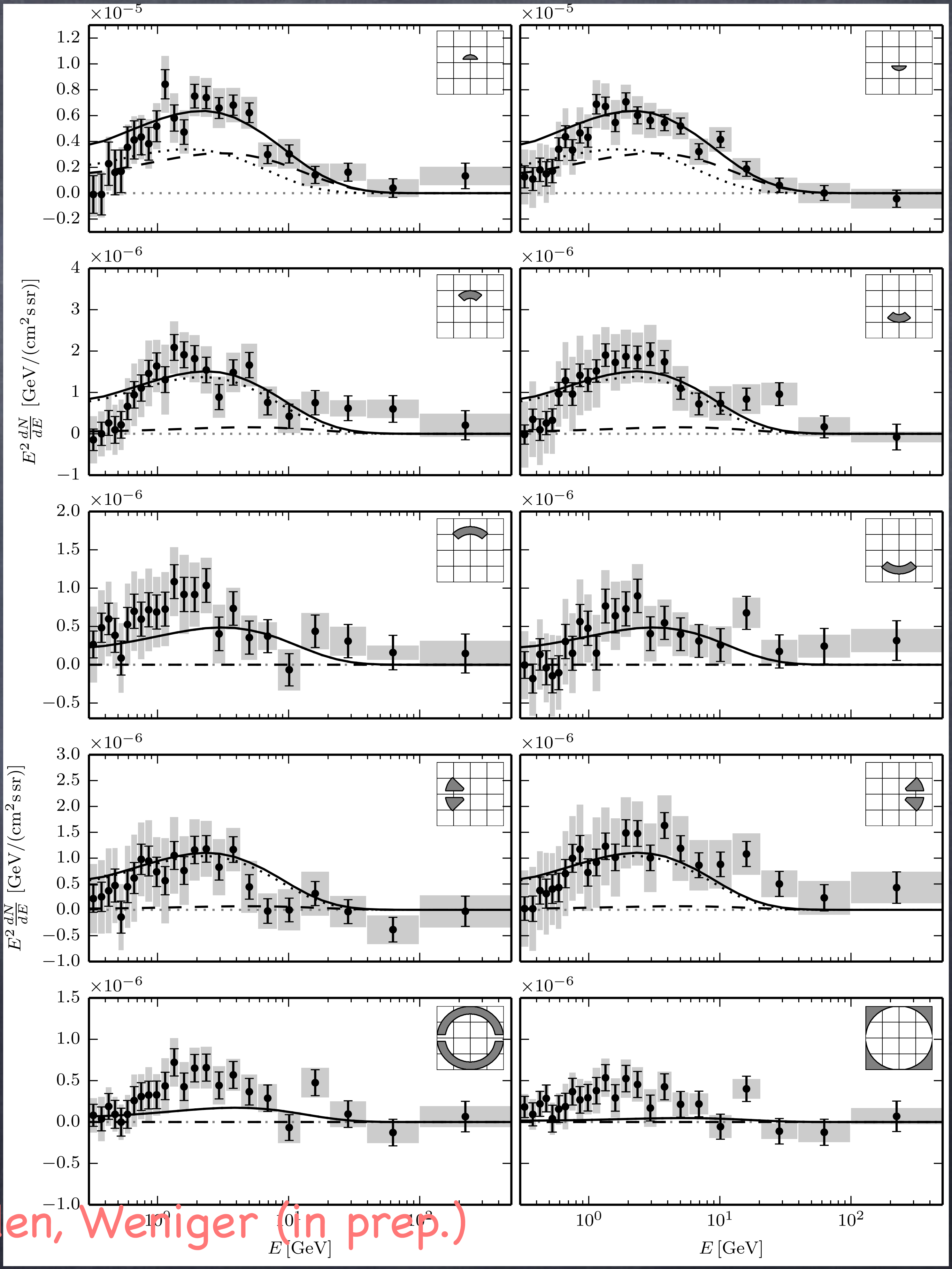




Petrovic, Serpico & Zaharijas (1405.7928)

Testing the morphology and the physical assumptions (both on the GC conditions and on the outbursts)

A example of a combination of CR electrons injected at 0.1 and 1 Myrs ago with an injection index of 1.2 (exceptionally hard compared to Fermi 1st order acceleration BUT could be motivated by strong diffusive re-acceleration in the inner O(10) pc of the Galaxy) and cut-offs at 20 and 40 GeV respectively. Typical energy outputs of 10^51 ergs can naturally occur.



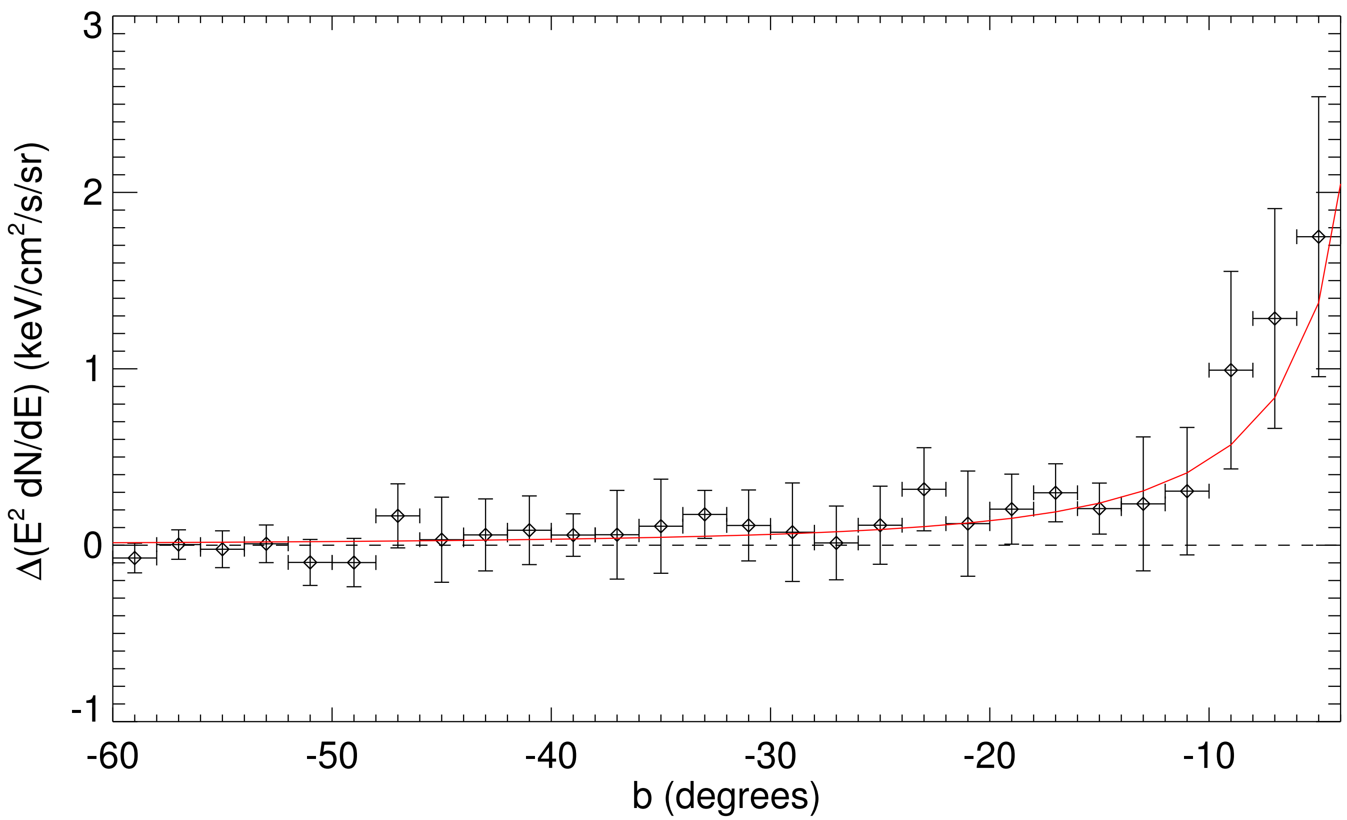
Cholis, Calore, Evoli, Hooper, Linden, Weniger (in prep.)

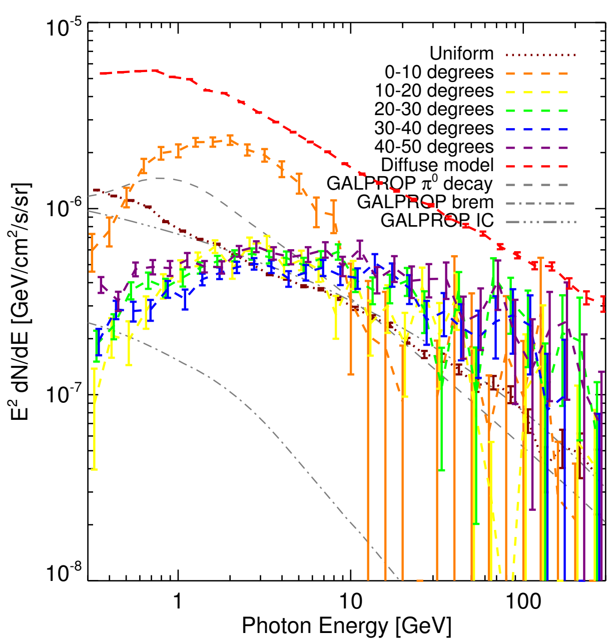
Conclusions…and further thinking

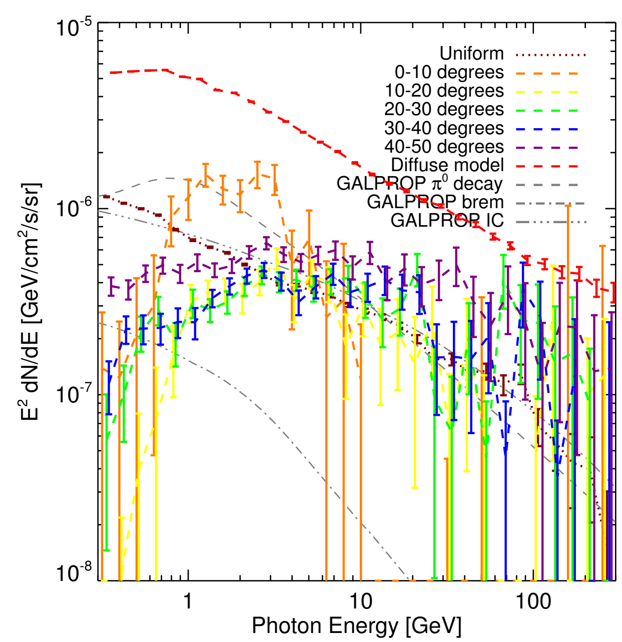
- The excess is robust to background model systematics, very well correlated to the galactic center.
- The emission is observed both at the inner degrees and at higher-latitudes.
- The DM case has been explored and seems compelling.
- For the DM case we need to start looking in other indirect detection probes: CRs other gamma-ray targets.
- Dwarf spheroidals is the next one. Further advances in extragalactic gamma-ray astronomy but also at other wavelengths will strengthen the indirect DM searches in the future as well. Also some direct detection signal?
- The MSPs explanation has problems in terms of both the spectrum and the normalization of the needed "signal".
- Outburst of CRs… Especially CR electrons can produce an ICS signal that could possibly be spherical in nature
- We need to further understand emissions as those giving the Fermi Bubbles (what is it that creates them) … and also move beyond the standard leaky box approximation for the study of CRs.

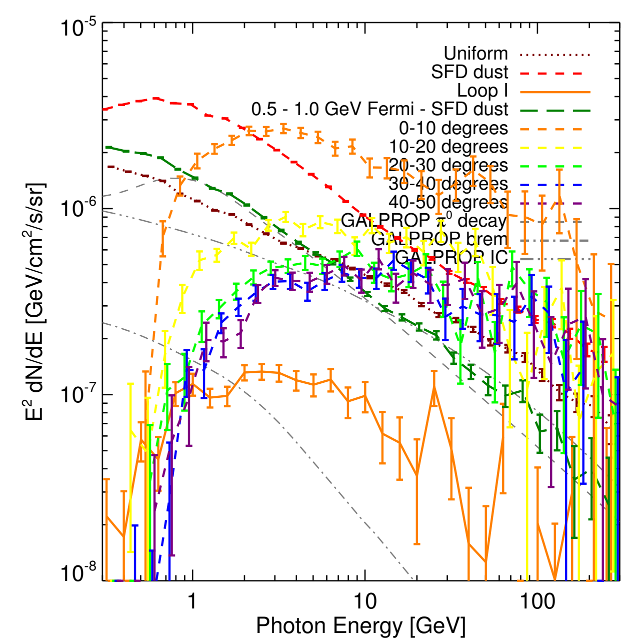
Thank you!

Additional Slides

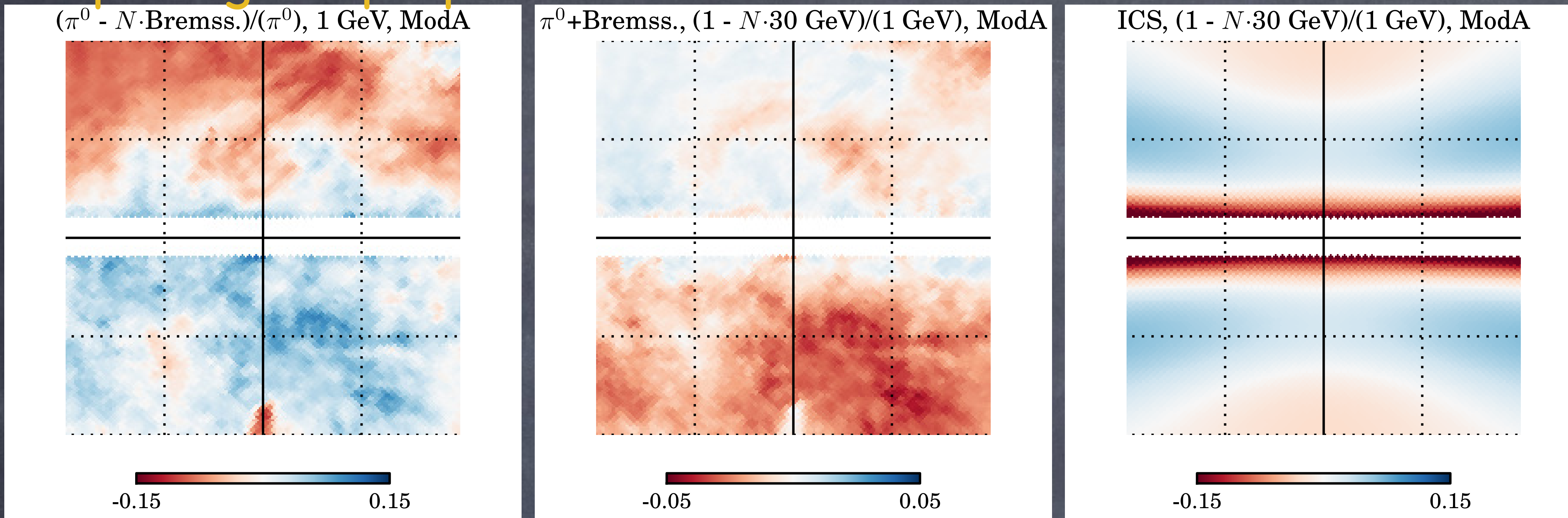






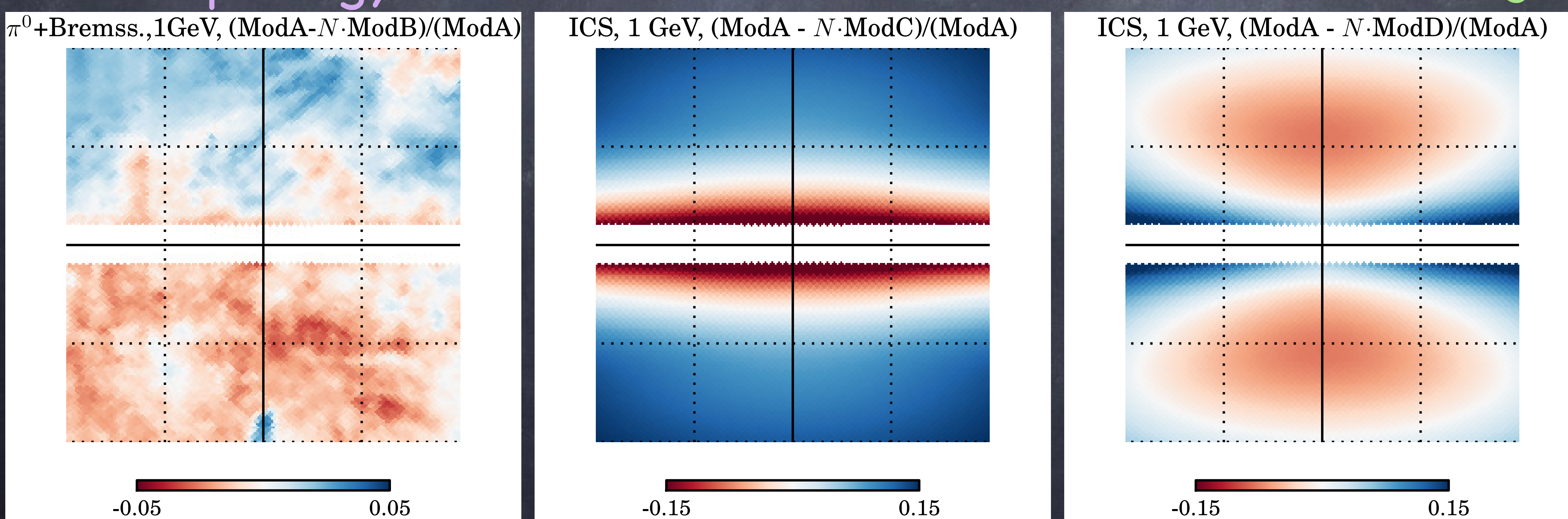


We need to account for the energy dependence of the morphological properties of the emission:



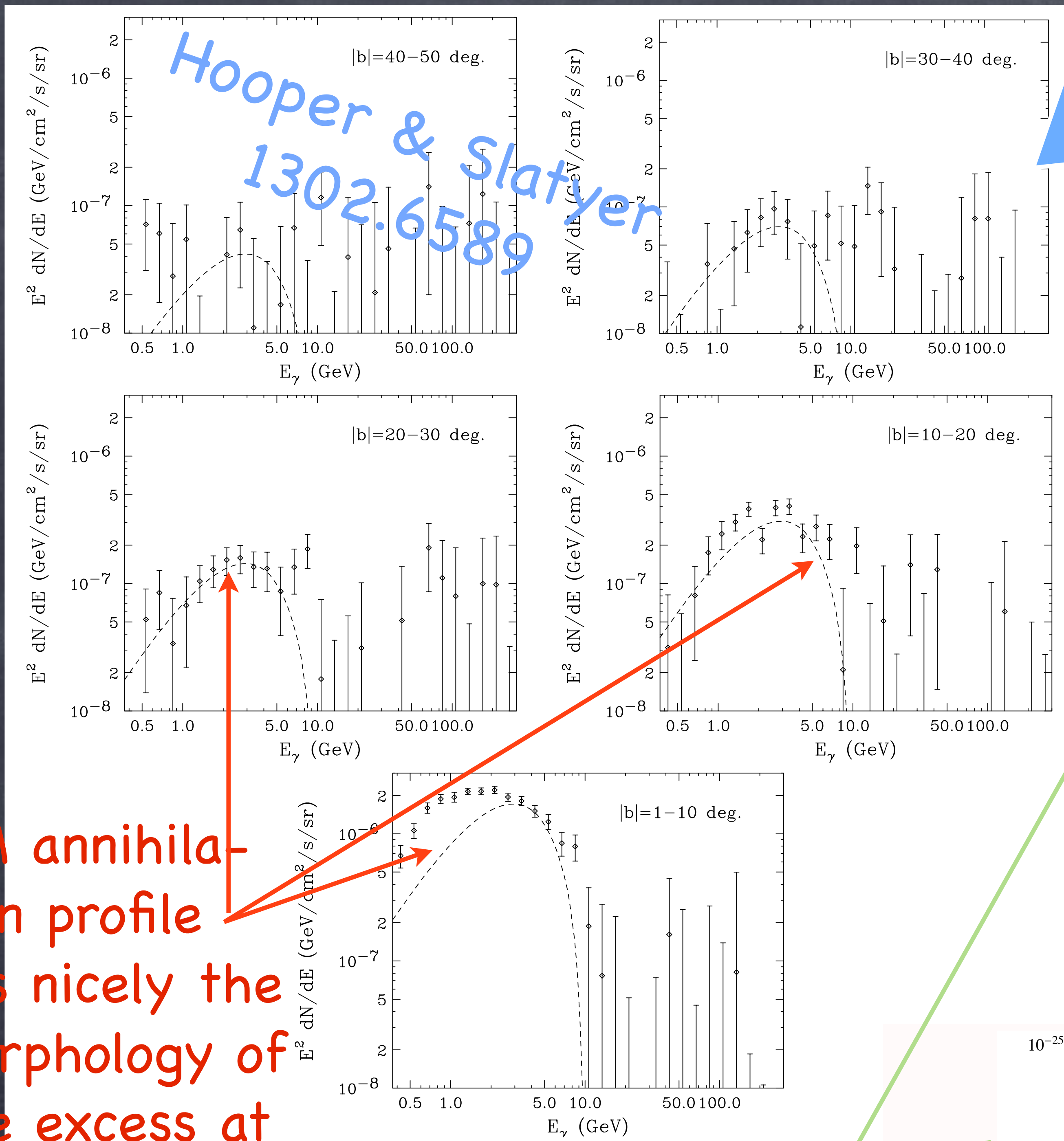
And even more importantly on the model dependence of the morphology of the emission:

Calore, Cholis, Weniger, 2014



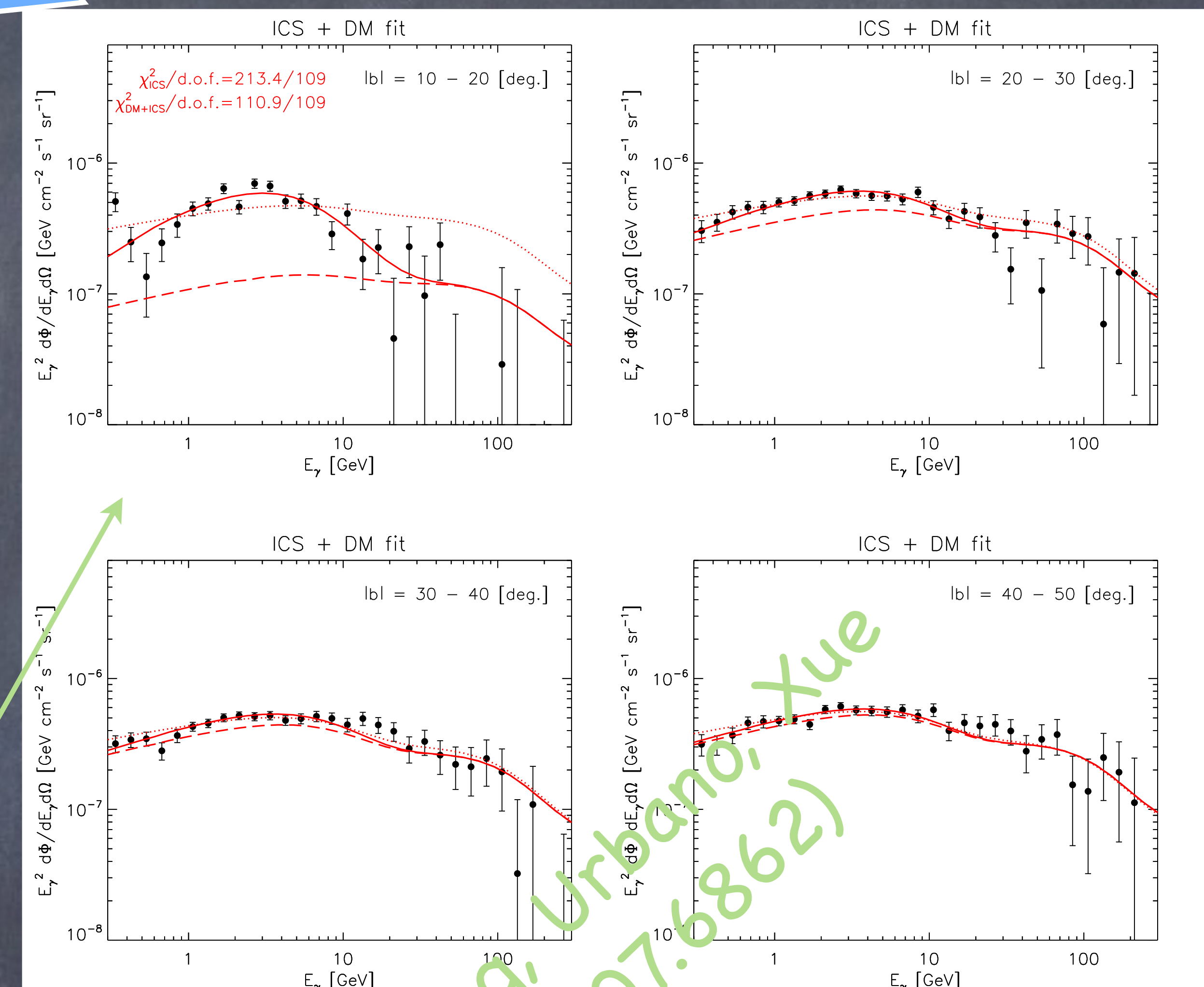
Residuals in different parts of the galactic sky

Hooper & Slatyer 1302.6589



DM annihilation profile fits nicely the morphology of the excess at high latitudes

Huang, Urbano, Xue (1307.6862)



Similar results at high latitudes from independent group

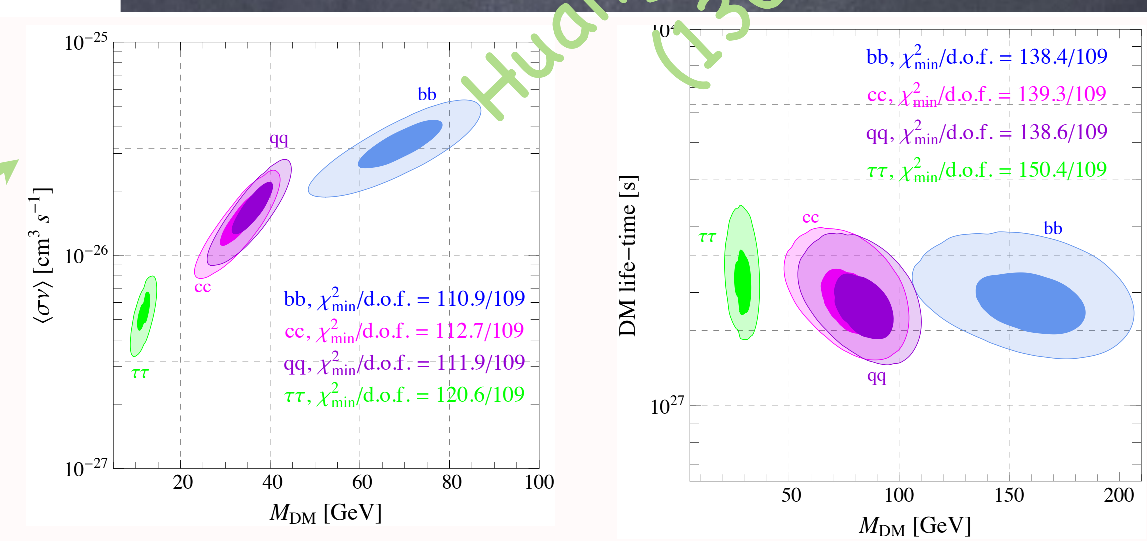
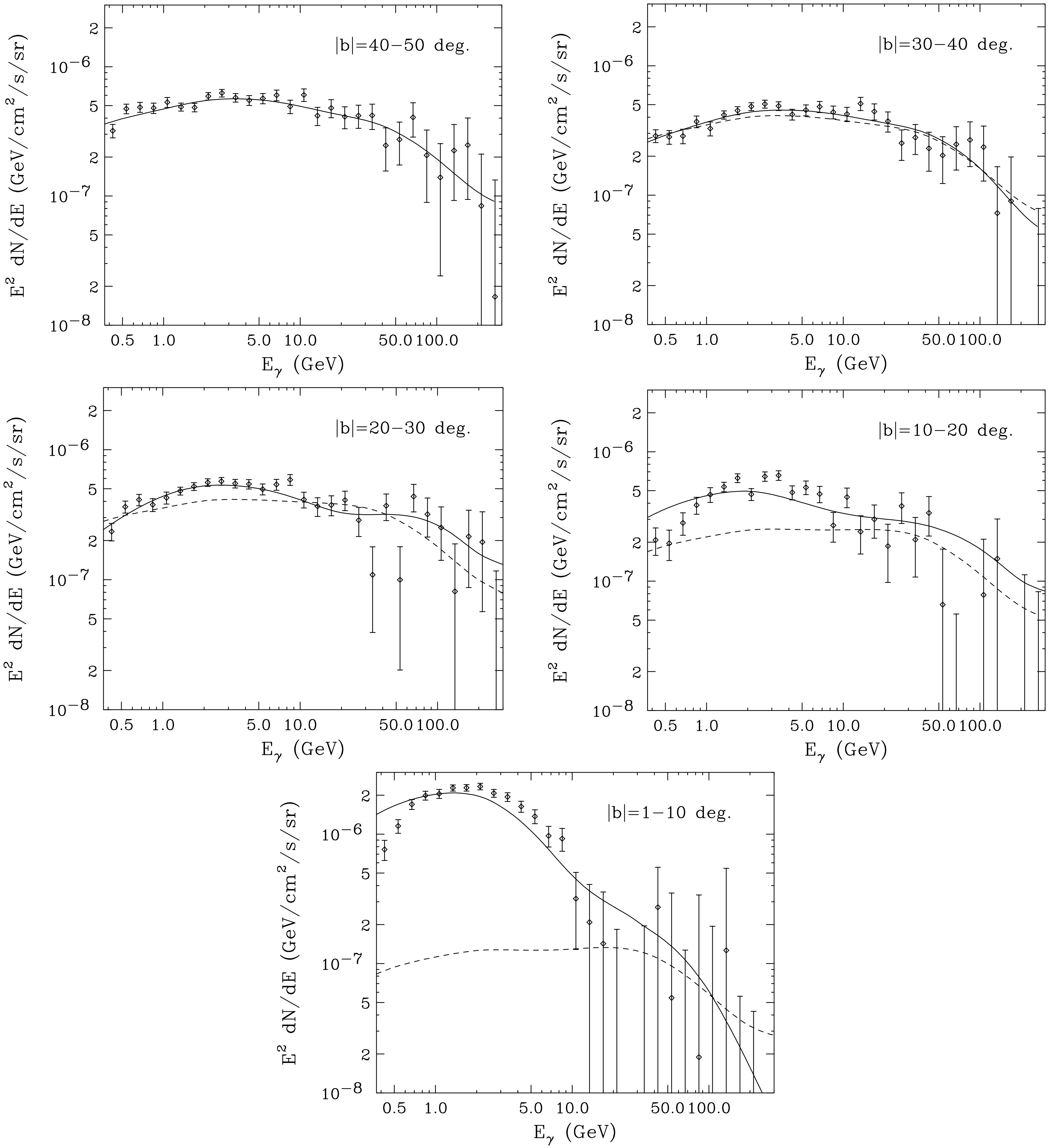
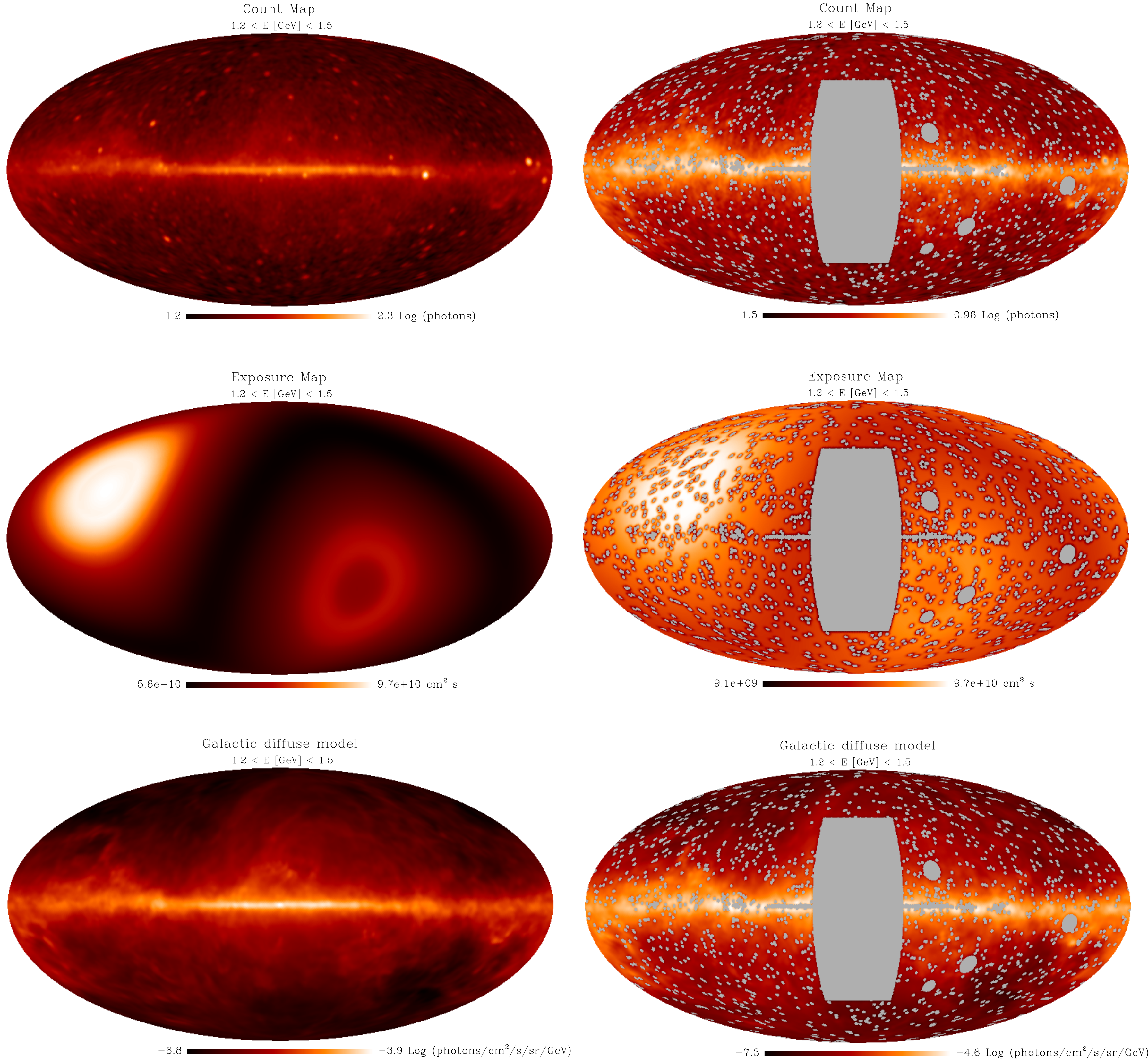


Figure 9: *Confidence regions (99% C.L. and 68% C.L.) for the annihilating (left panel) and decaying (right panel) DM component in the analysis of the Fermi bubbles spectrum (see text for details).*


|b|=40−50 deg.
|b|=30−40 deg.
|b|=20−30 deg.
|b|=10−20 deg.
|b|=1−10 deg.
E^2 dN/dE (GeV/cm^2/s/sr)
E_γ (GeV)


Count Map
1.2 < E [GeV] < 1.5
−1.2
2.3 Log (photons)
Count Map
1.2 < E [GeV] < 1.5
−1.5
0.96 Log (photons)
Exposure Map
1.2 < E [GeV] < 1.5
5.6e+10
9.7e+10 cm² s
Exposure Map
1.2 < E [GeV] < 1.5
9.1e+09
9.7e+10 cm² s
Galactic diffuse model
1.2 < E [GeV] < 1.5
−6.8
−3.9 Log (photons/cm²/s/sr/GeV)
Galactic diffuse model
1.2 < E [GeV] < 1.5
−7.3
−4.6 Log (photons/cm²/s/sr/GeV)

DM annihilation	$M_{\rm DM}$ $[GeV]$	$\langle\sigma v\rangle$ $[cm^3 s^{-1}]$	$\chi^2_{\rm min}$/d.o.f.
$b\bar{b}$	$61.8^{+6.9}_{-4.9}$	$3.30^{+0.69}_{-0.49} \times 10^{-26}$	$110.9/109$
$c\bar{c}$	$29.3^{+2.4}_{-3.4}$	$1.54^{+0.26}_{-0.30} \times 10^{-26}$	$112.7/109$
$q\bar{q}$	$32.0^{+2.6}_{-3.8}$	$1.73^{+0.30}_{-0.30} \times 10^{-26}$	$111.9/109$
$\tau^+\tau^-$	$10.6^{+0.5}_{-0.6}$	$5.63^{+0.58}_{-0.64} \times 10^{-27}$	$120.6/109$

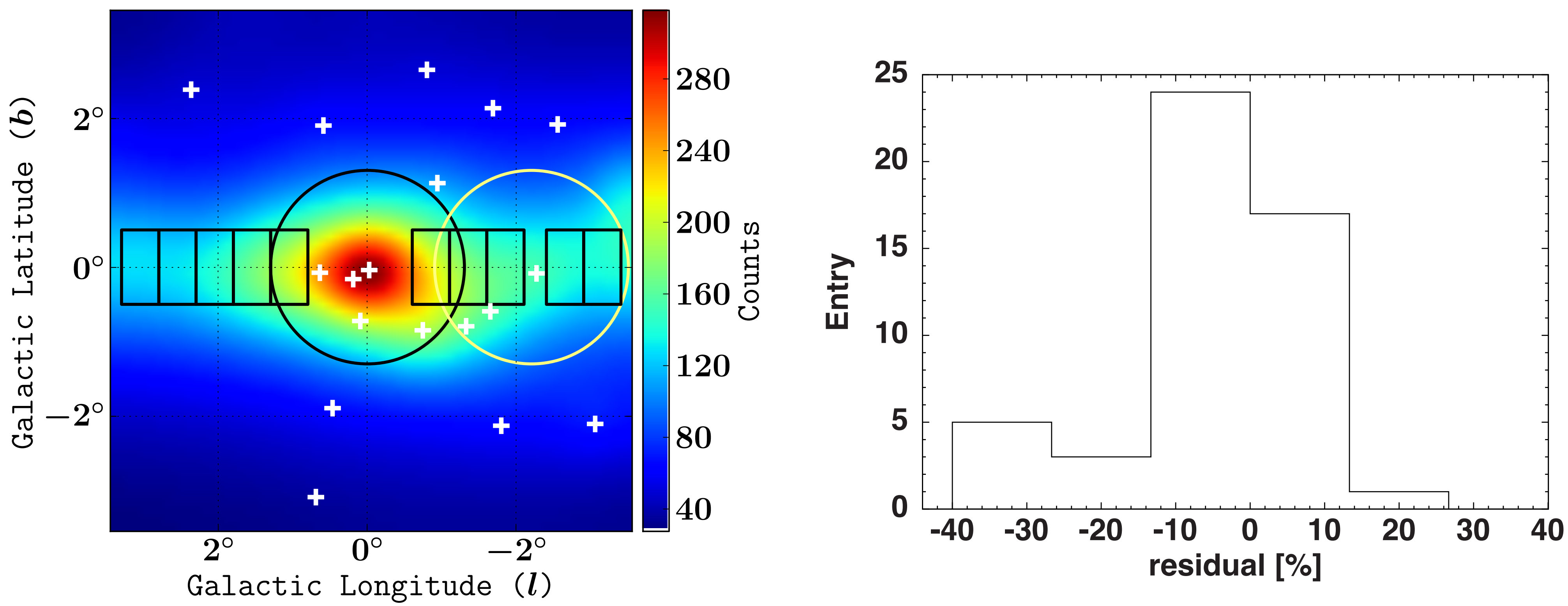
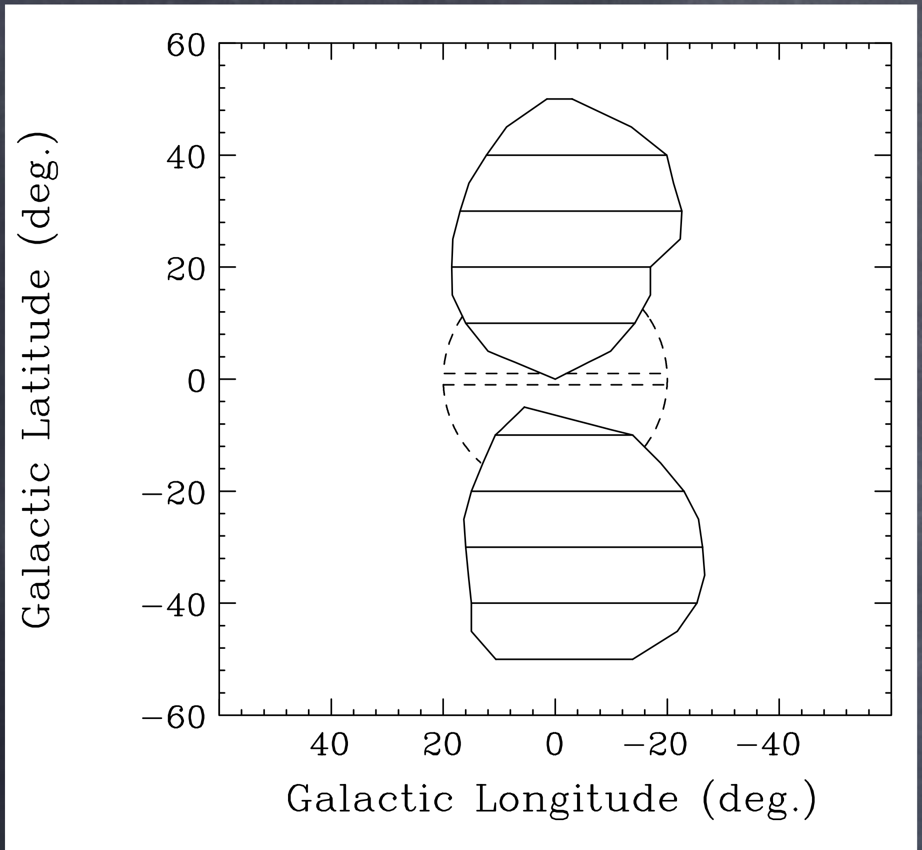
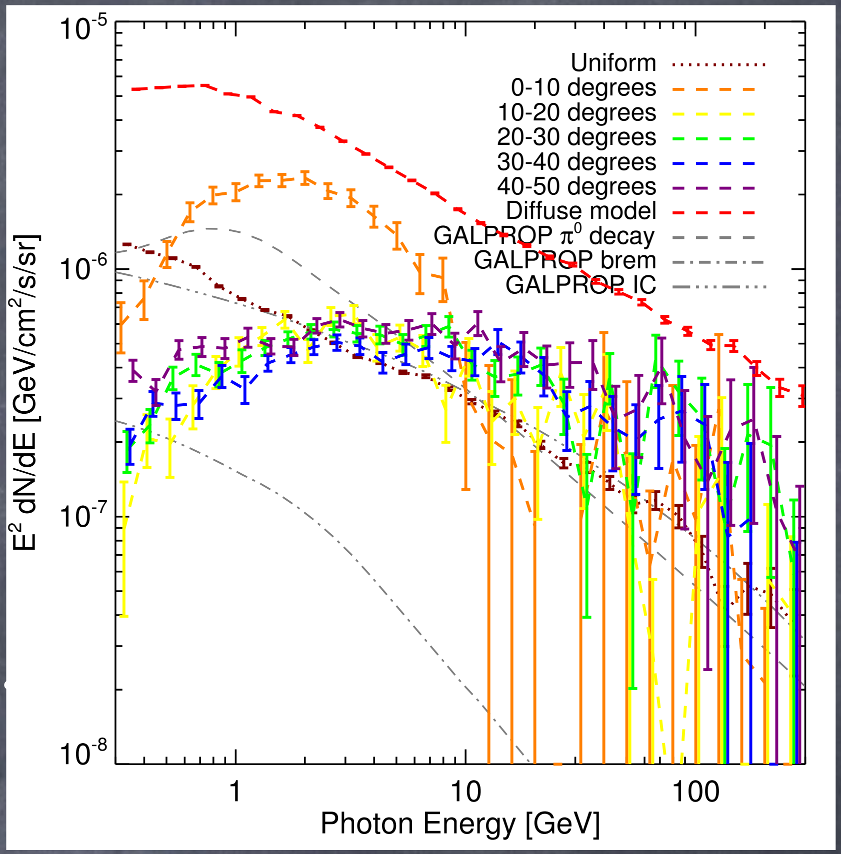


FIG. 6. (a) Counts map in the 0.3−100 GeV energy band smoothed with a Gaussian filter of radius $\sigma = 0.3°$. The black rectangles ($1.0° \times 0.5°$) highlight the regions selected for the examination of the spatial uncertainties in the Galactic diffuse background. The black and yellow circles show the regions where the flux of the file `gal_2yearp7v6_v0.fits` was varied to evaluate the effects of the spatial dispersion of the model. (b) Histogram of the fractional residuals for ten rectangular regions in five energy bands: 0.30−0.50 GeV, 0.50−0.80 GeV, 0.80−1.30 GeV, 1.3−10 GeV and 10−100 GeV. The residuals were calculated as (observed-model)/model, where we also subtracted the best fit fluxes of all the sources (except for the Galactic diffuse background source) from the observed counts map.

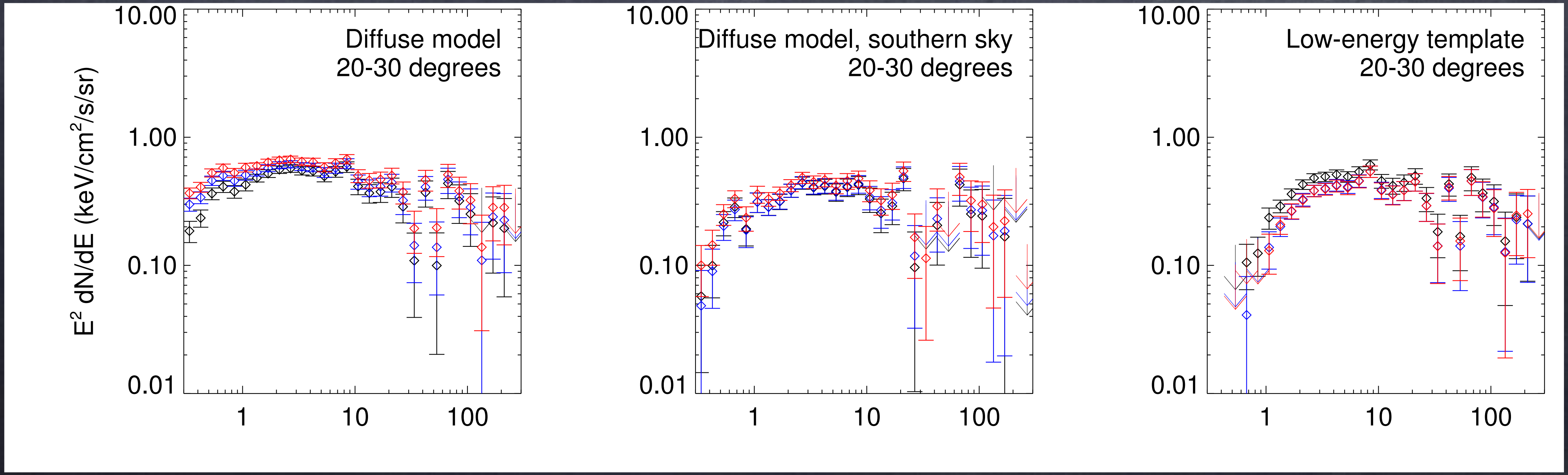
Hooper & Slatyer
1302.6589



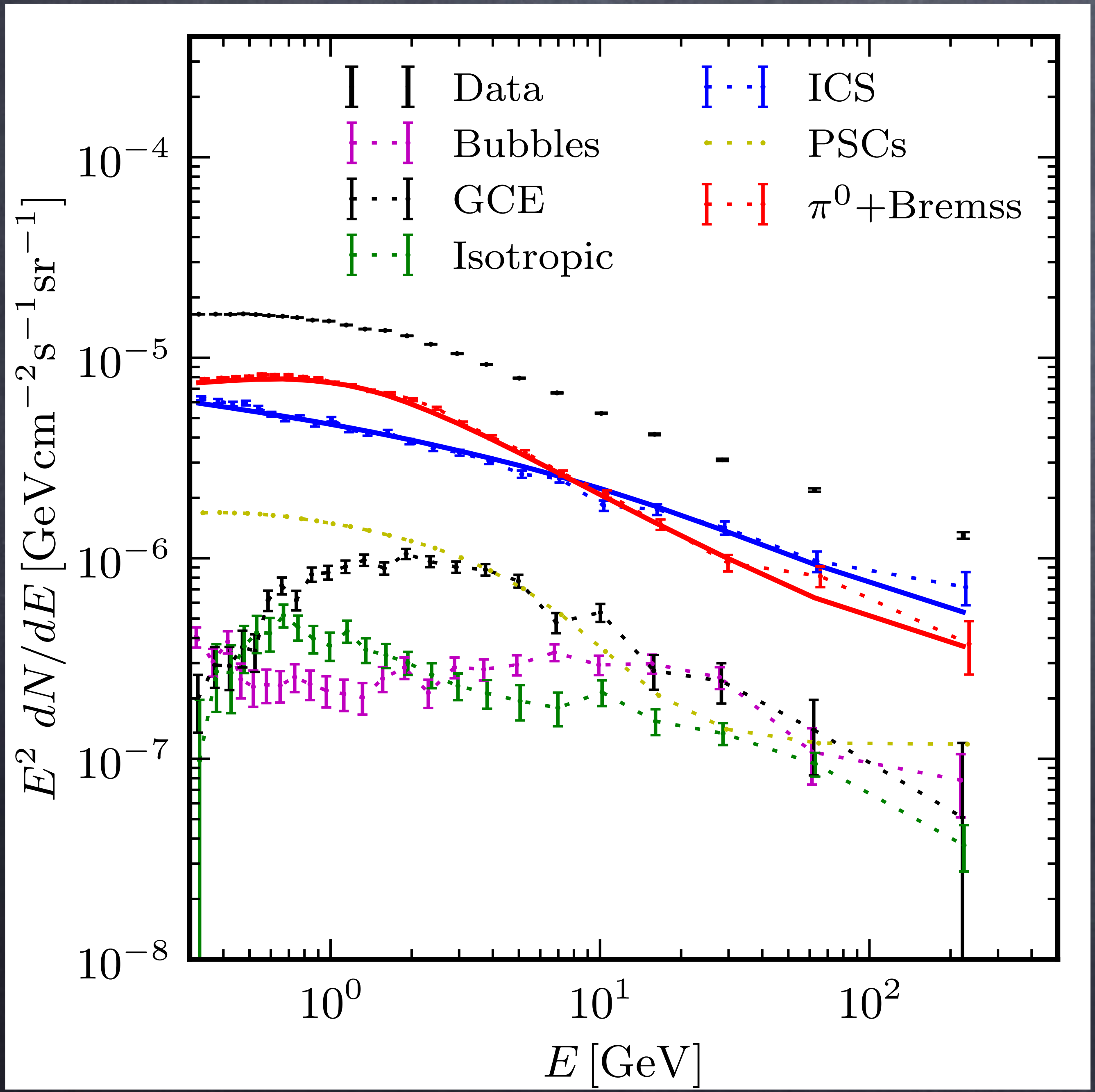
Search for residuals at higher latitudes account-ing for the Fermi bubbles. Account for diffuse gam-ma rays (isotropic and galactic). Account for p.s. Residuals can be retrieved.



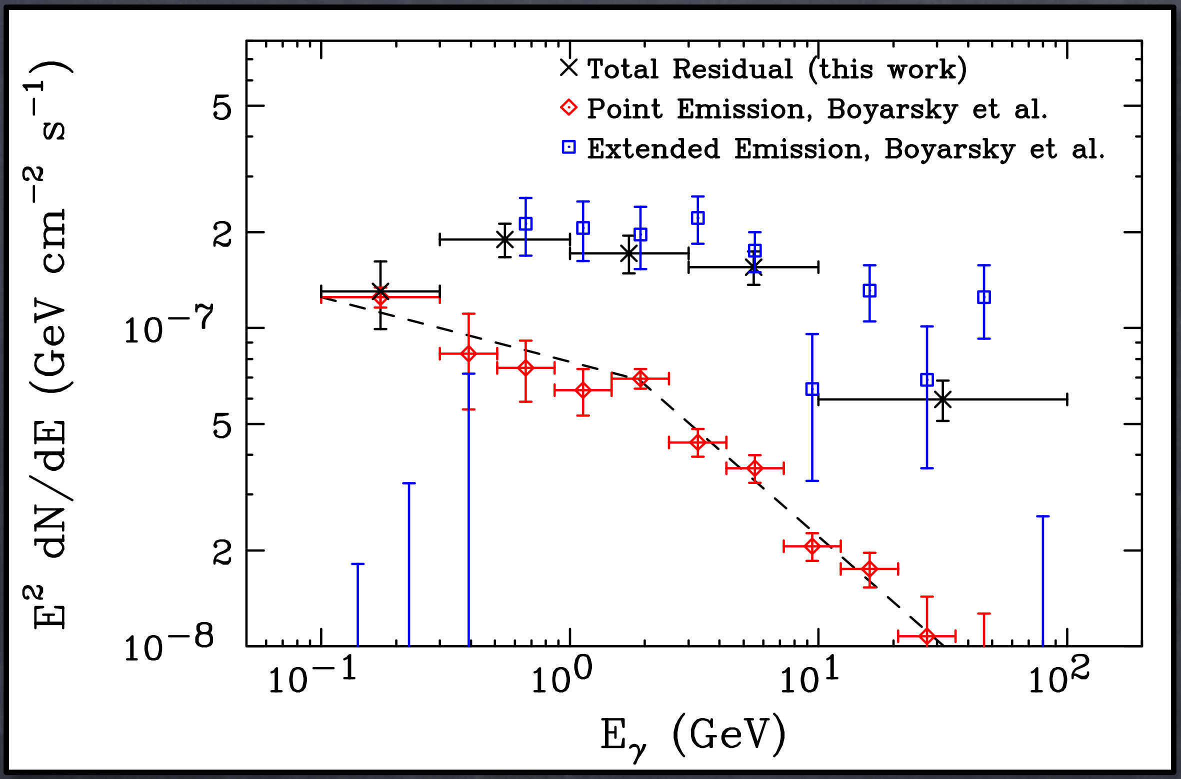
Most important uncertainties remain to be the ones associated to the diffuse model assumptions: AN EXAMPLE:



Finally it is important (a mistake that sometimes is done in template regression analyses) that the starting assumptions for the templates are the same or close to those suggested by the fit.

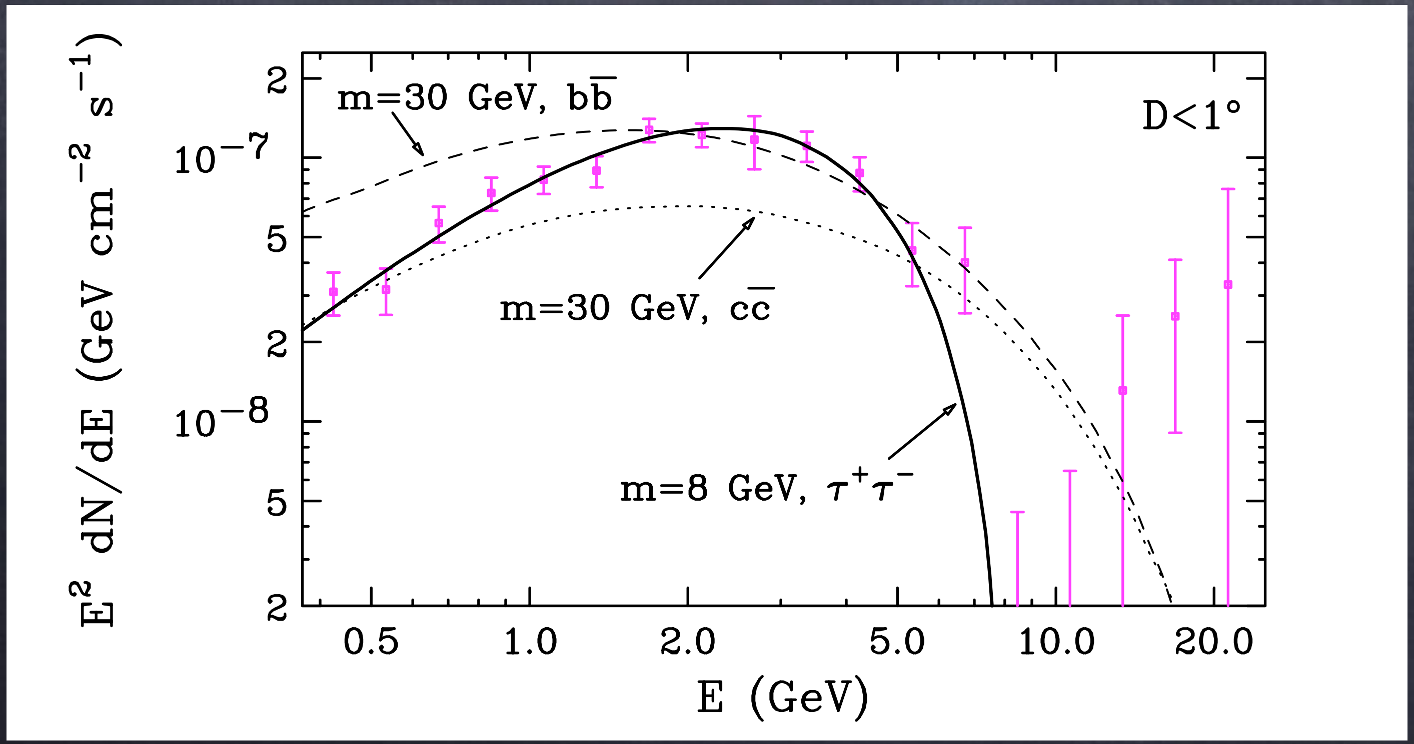


Calore, IC, Weniger, 2014



Only a small fraction of the emission can be associated to the TeV point source emission in the GC

Similar results with earlier study: Hooper & Goodenough: (arXiv:1010.2752)



Non-Dan Hooper related groups on the inner 1-2 degrees

Abazajian & Kaplinghat (1207.6047)

- Different method: isotropic and galactic diffuse gamma-ray components are modeled using the Fermi tools. So are the point sources
- The excess is found at a significance level of Delta(ln(L))=400 in log likelihood difference
- The morphology of the excess is confirmed, the spectrum is similar
- Suggestive of the fact that the excess is not just the result of mis-subtraction of somewhat well understood backgrounds

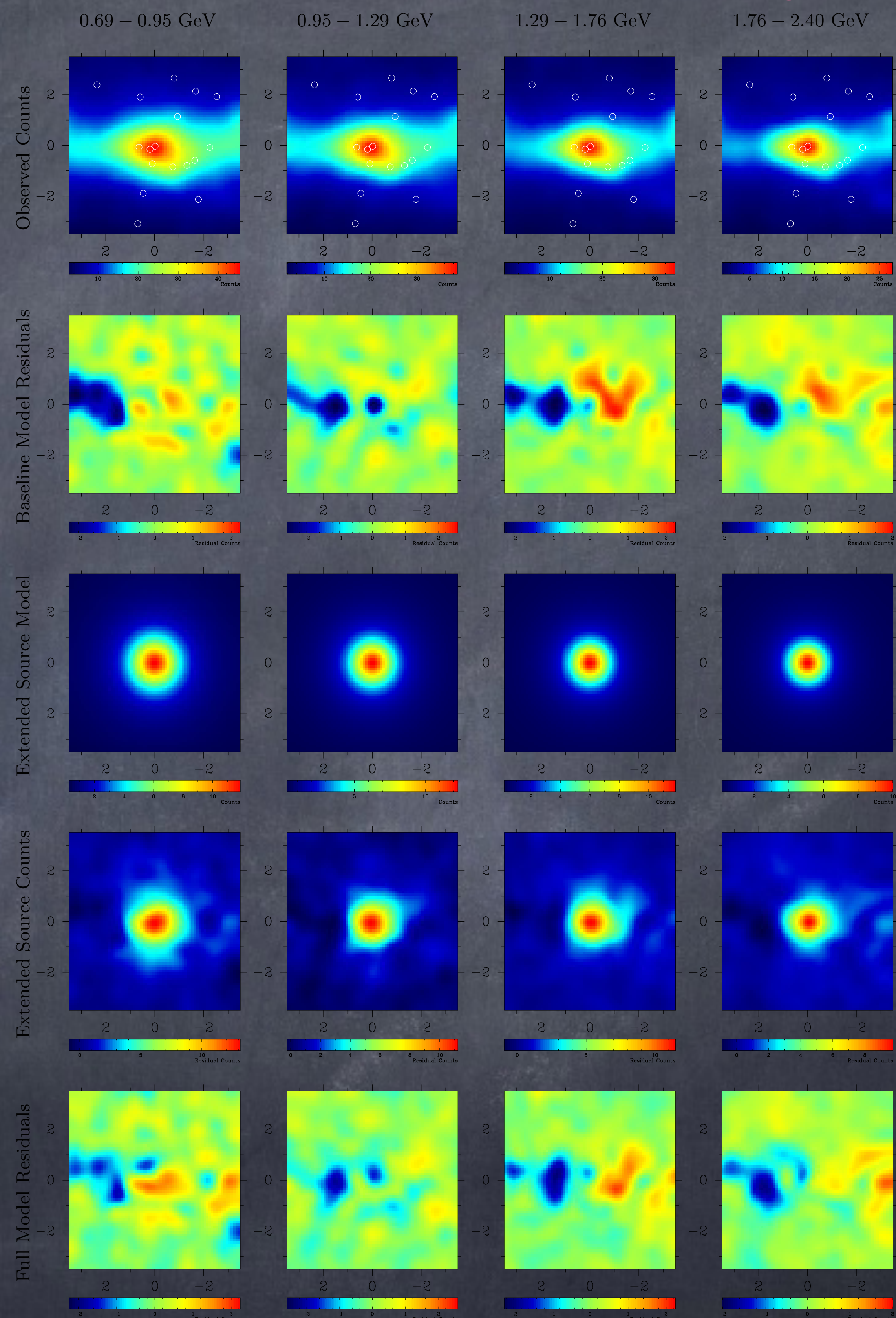
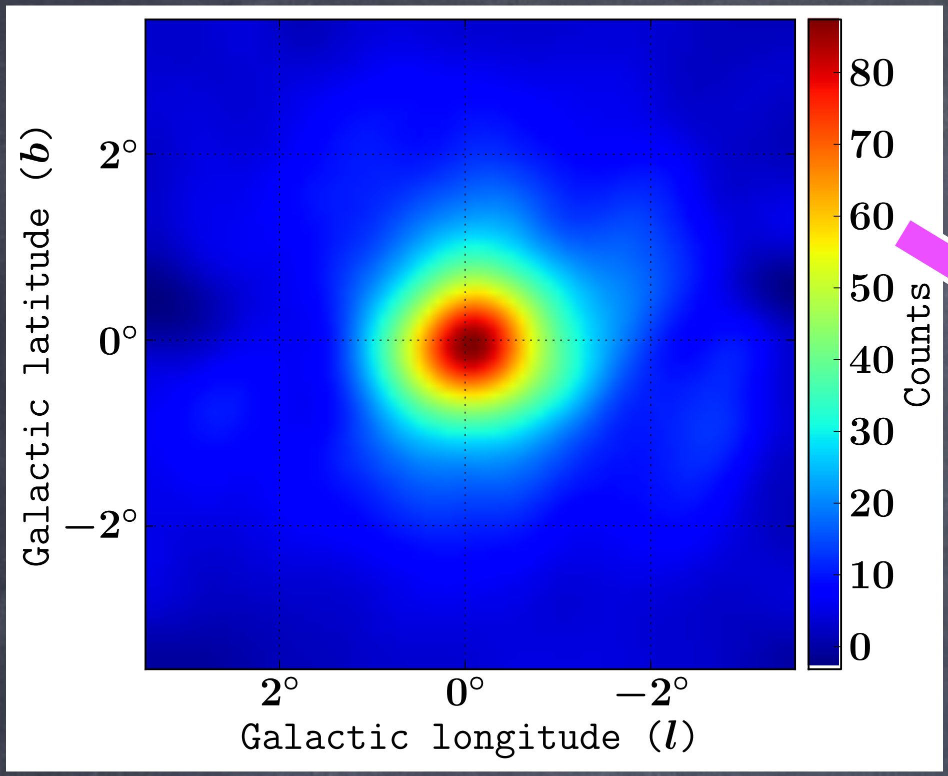
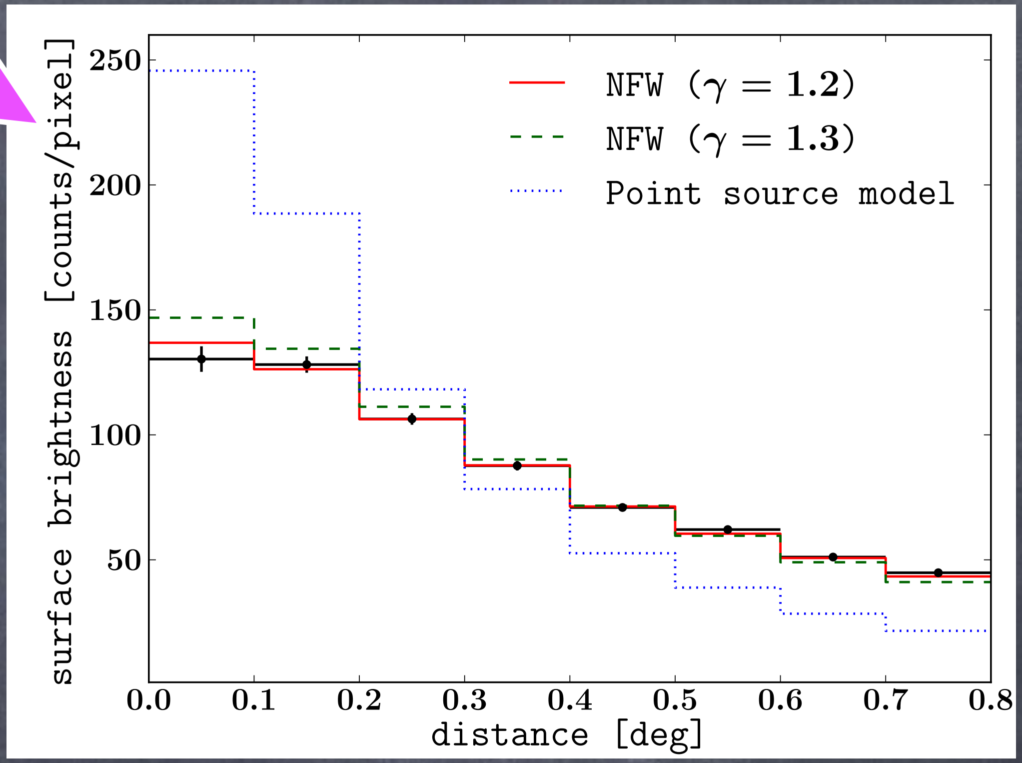


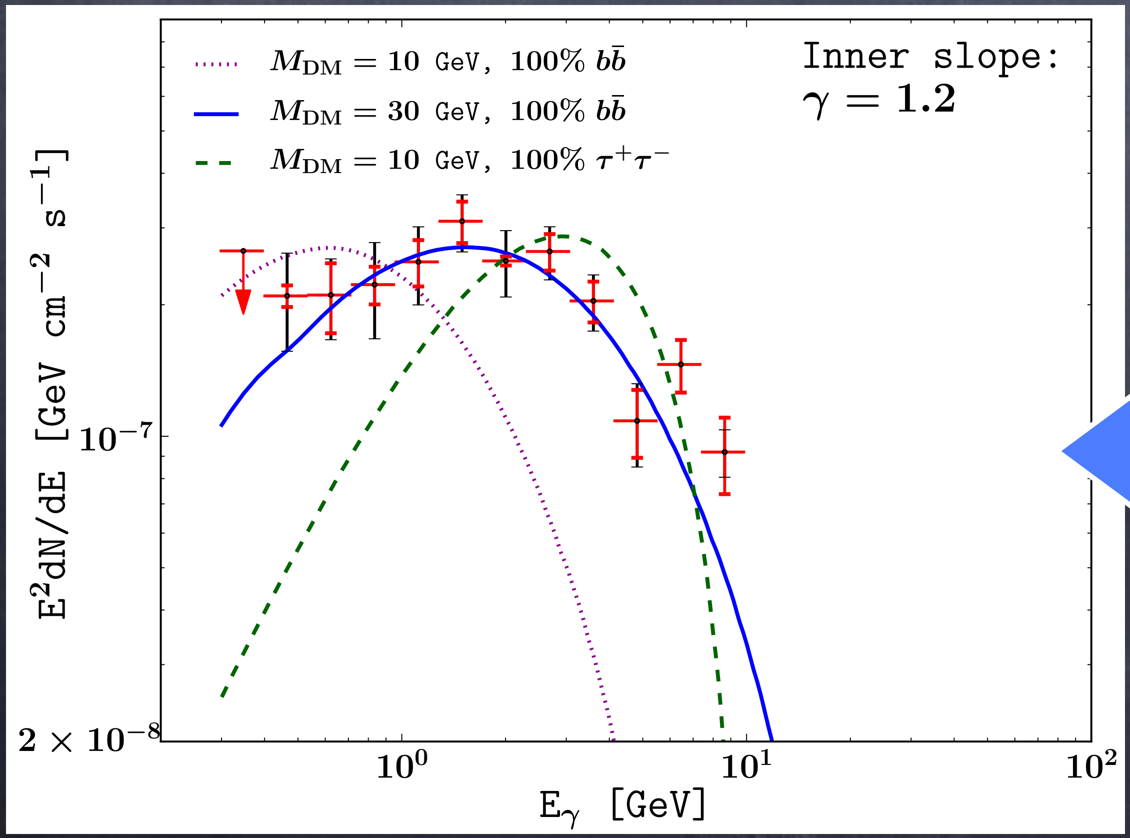
FIG. 1. Shown in the top row are photon counts in four energy bins that have significant evidence for an extended source with a spectrum, morphology, and rate consistent with a 30 GeV mass WIMP annihilating to $b\bar{b}$-quarks in the $7^\circ \times 7^\circ$ region about the GC. This row shows the 17 2FGL point sources in the ROI as circles. The second row shows the residuals for the fit to the region varying all the sources in the 2FGL catalog as well as the amplitudes of Galactic diffuse and isotropic diffuse models. The presence of an extended source and oversubraction of the central point sources are visible here. The third row shows the best fit model counts for 30 GeV WIMP annihilating to $b\bar{b}$-quarks. The fourth row is the residual emission for this model without subtracting the extended component. The fifth row contains the residuals when the extended component is also subtracted. The maps have been filtered with a Gaussian of width $\sigma = 0.3^\circ$.

Gordon & Macias (1306.5725)



Morphology is cuspy





Spectrum has a sharp cut-off