Diffuse Galactic Gamma Rays at intermediate and high latitudes, Constraints on ISM properties and DM

Maryam Tavakoli(SISSA)
Carmelo Evoli (NAOC), Luca Maccione (DESY), Piero Ullio (SISSA)

arXiv:1105.5073
ApJ 717,825,(2010) (arXiv:0910.4583) (G. Dobler, D. Finkbeiner, I.C., T. Slatyer, N. Weiner), arXiv:1102.5095, (G. Dobler, I.C., N. Weiner)

Ilias Cholis (SISSA)

30/6/2011

CRISM 2011

Significance of diffuse gamma-rays

With gamma rays we can probe a large part of the Galaxy:

- large scale diffusion properties
- ISM gas(ses) distribution(s)
- large scale averaged known sources distribution
- new sources (Dark Matter)
- at high latitudes we can also check on the local assumptions for propagation
- combine with CR measurements
- new CR data and better gamma-ray statistics and systematics are under way

Methodology

Using DRAGON to solve:

$$\frac{\partial \psi(\vec{r},p,t)}{\partial t} = q(\vec{r},p,t) + \vec{\nabla}(D_{xx}\vec{\nabla}\psi) + \frac{\partial}{\partial p}\left[p^2 D_{pp}\frac{\partial}{\partial p}(\frac{\psi}{p^2})\right] - \frac{\partial}{\partial p}(\dot{p}\psi)$$
$$-\vec{\nabla}(\vec{V}\psi) + \frac{\partial}{\partial p}\left[\frac{p}{3}(\vec{\nabla}\vec{V})\psi\right] - \frac{\psi}{\tau_{frag}} - \frac{\psi}{\tau_{decay}}$$

Source term: $q_i(r,z,E) = f_s(r,z)q_{0,i}\left(\frac{R(E)}{R_0}\right)^{-\gamma^i}$

For protons : $\frac{dN_p}{dR} \propto \left(\frac{R}{R^p_{0,j}}\right)^{-\gamma^p_j}$ (based on *PAMELA* and CREAM data)

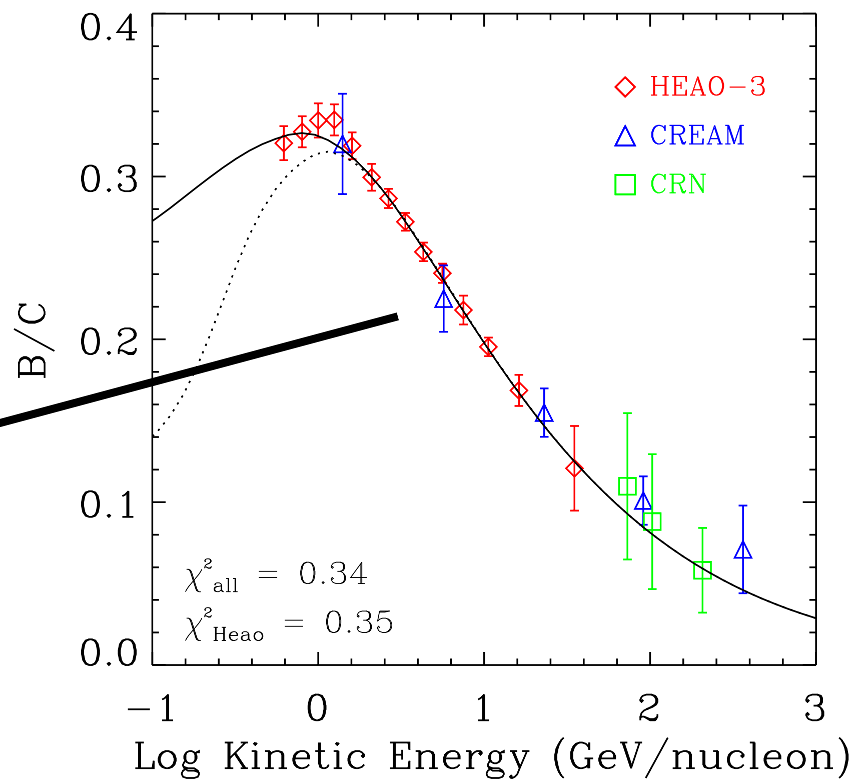
For diffusion in physical space:

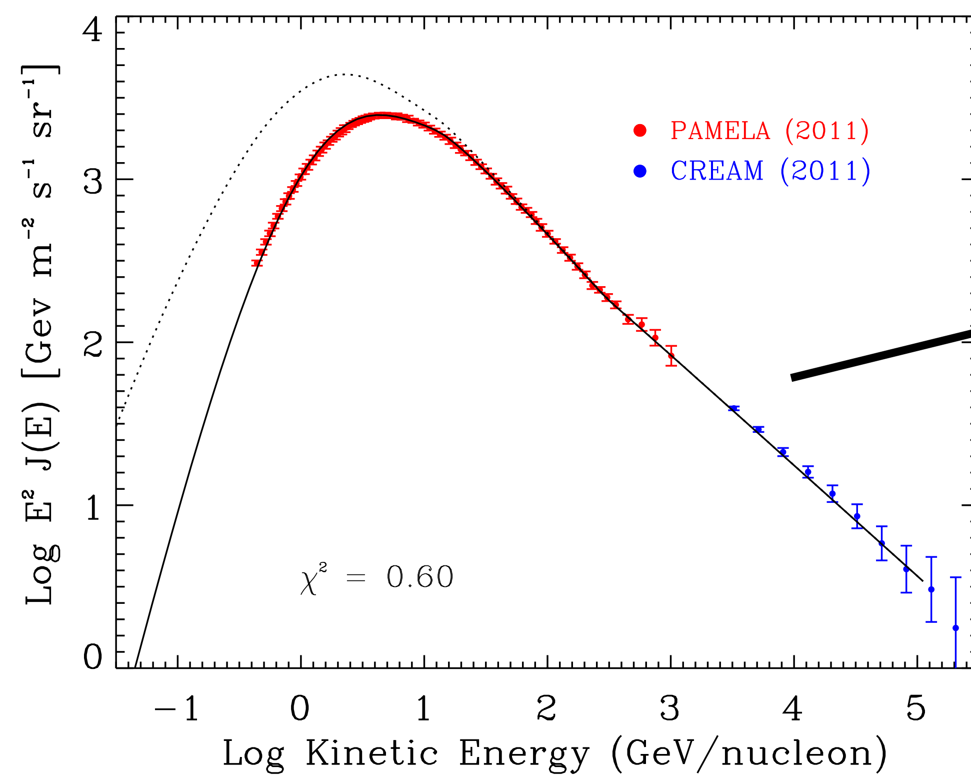
$$D(r,z,R) = D_0\beta^\eta(\frac{R}{R_0})^\delta \underbrace{\exp(\frac{r-r_\odot}{r_d})}_{\text{new part}} \exp(\frac{|z|}{z_d})$$

Fit to the CR data

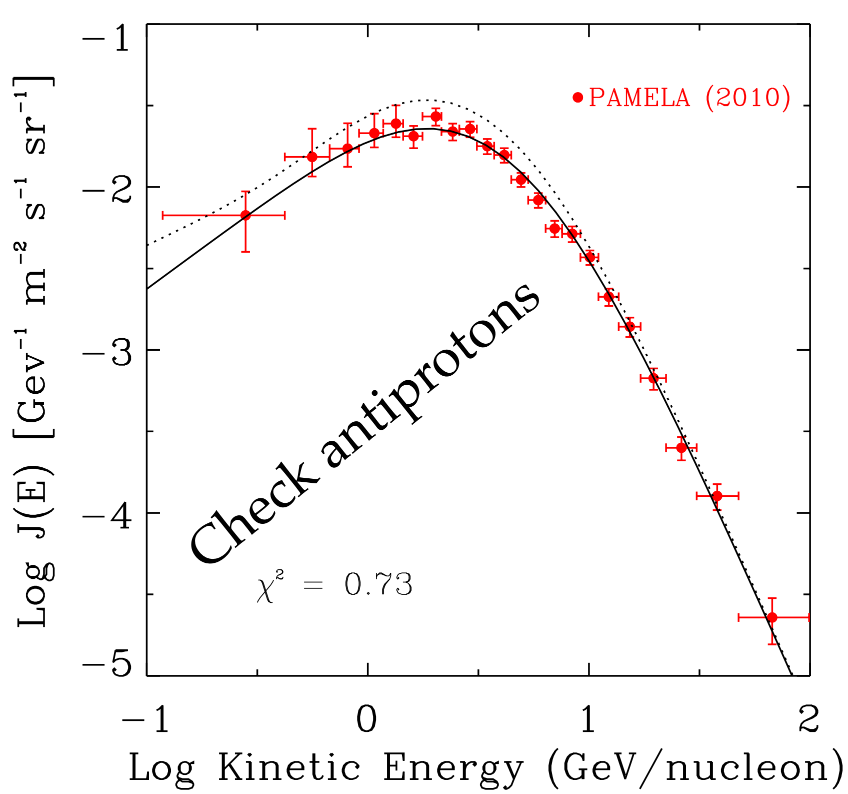
Choose: δ, r_d, z_d and convection (also assume ISM gas and source distribution)

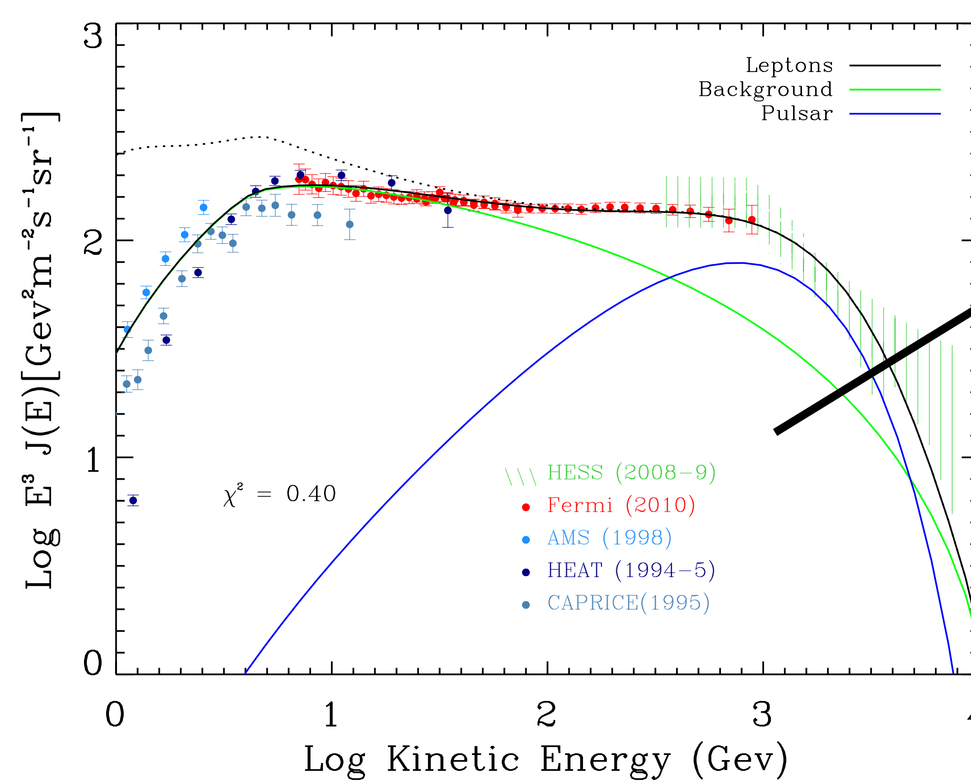
Fit D_0, η, v_A





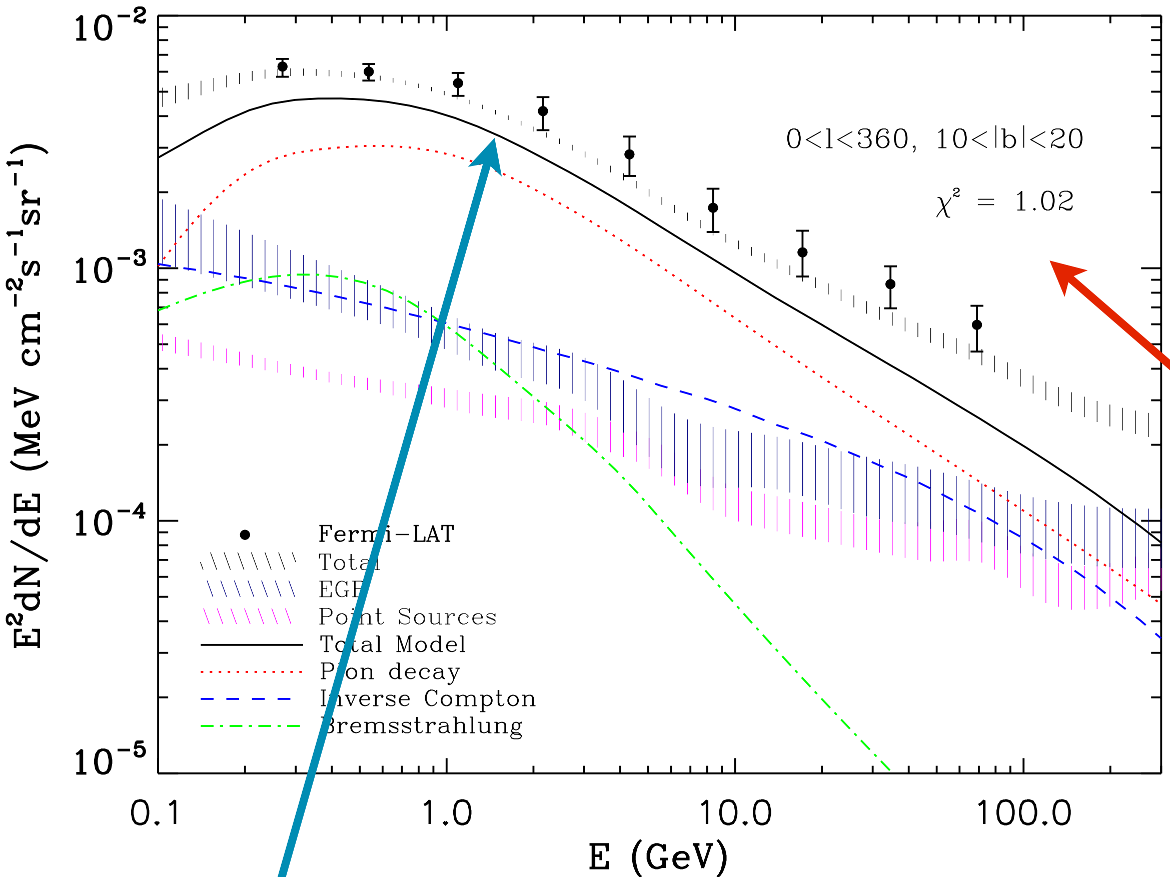
Get $\gamma_j^p, R_{0,j}^p$

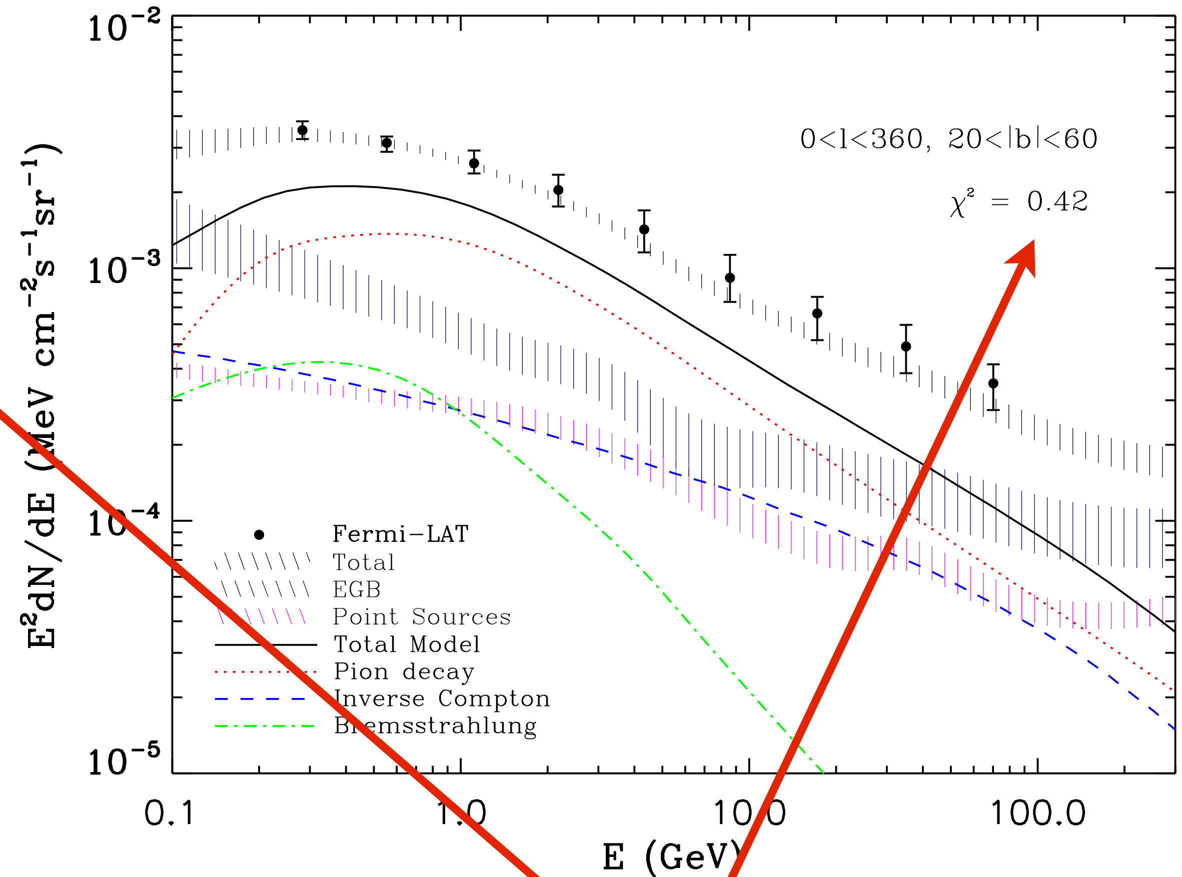




Assume middle aged pulsars and fit their *averaged* properties

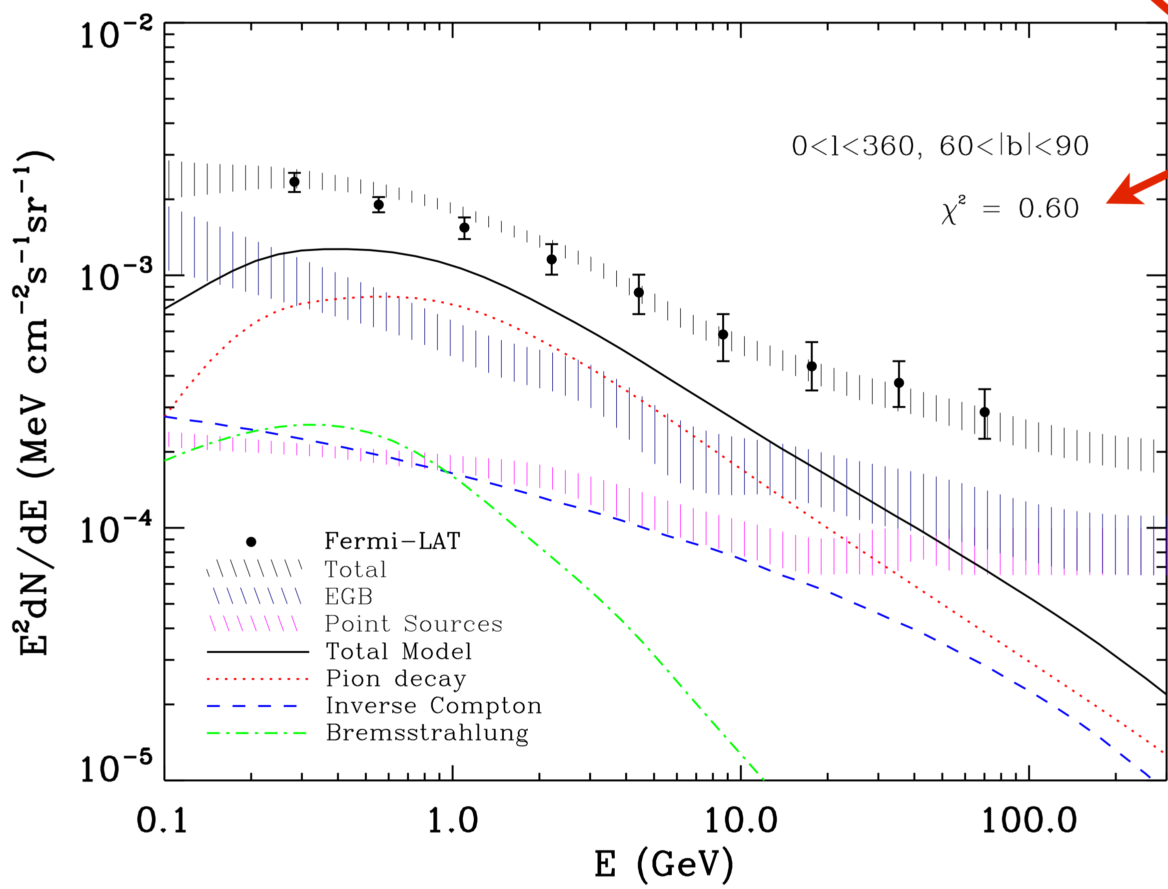
Gamma Ray data





Need ~ 10^4

MSPs



Good fit to the data

$$r_d = 20 \text{ kpc}$$

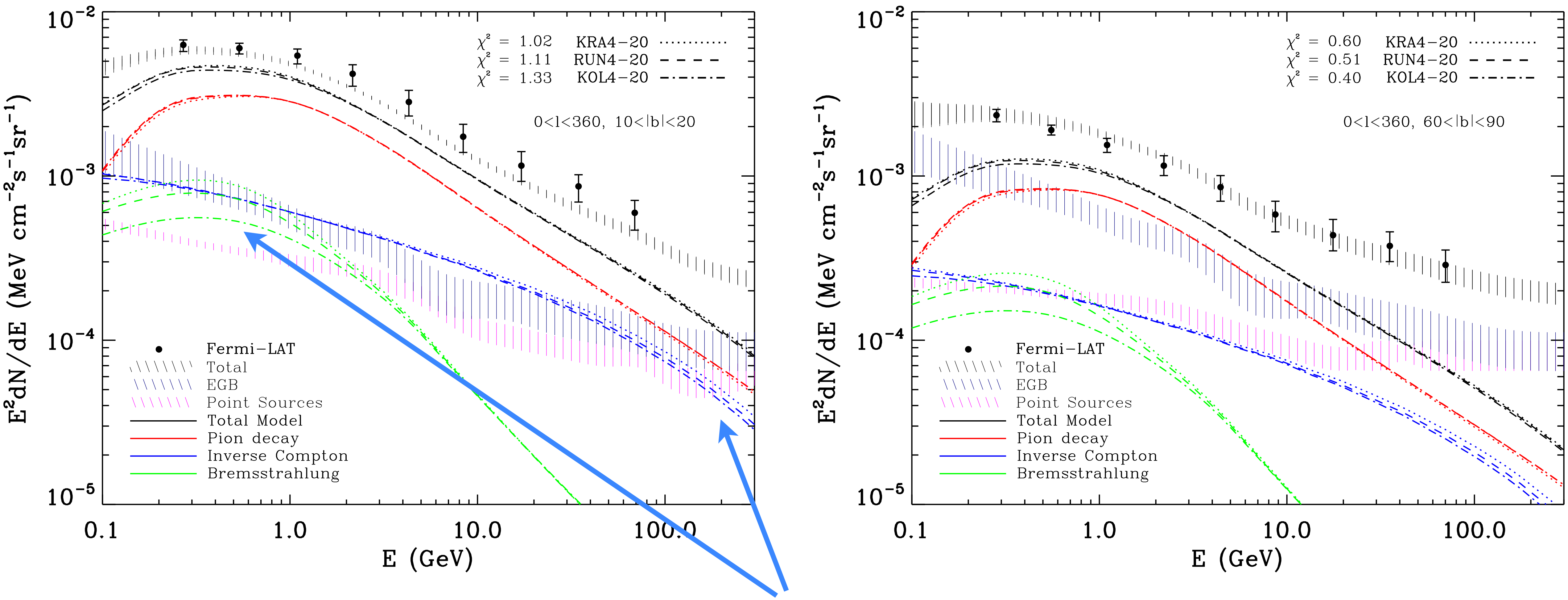
$$z_d = 4 \text{ kpc}$$

$$\text{and } \delta = 0.5$$

Constraining the Diffusion Properties

Varying delta:

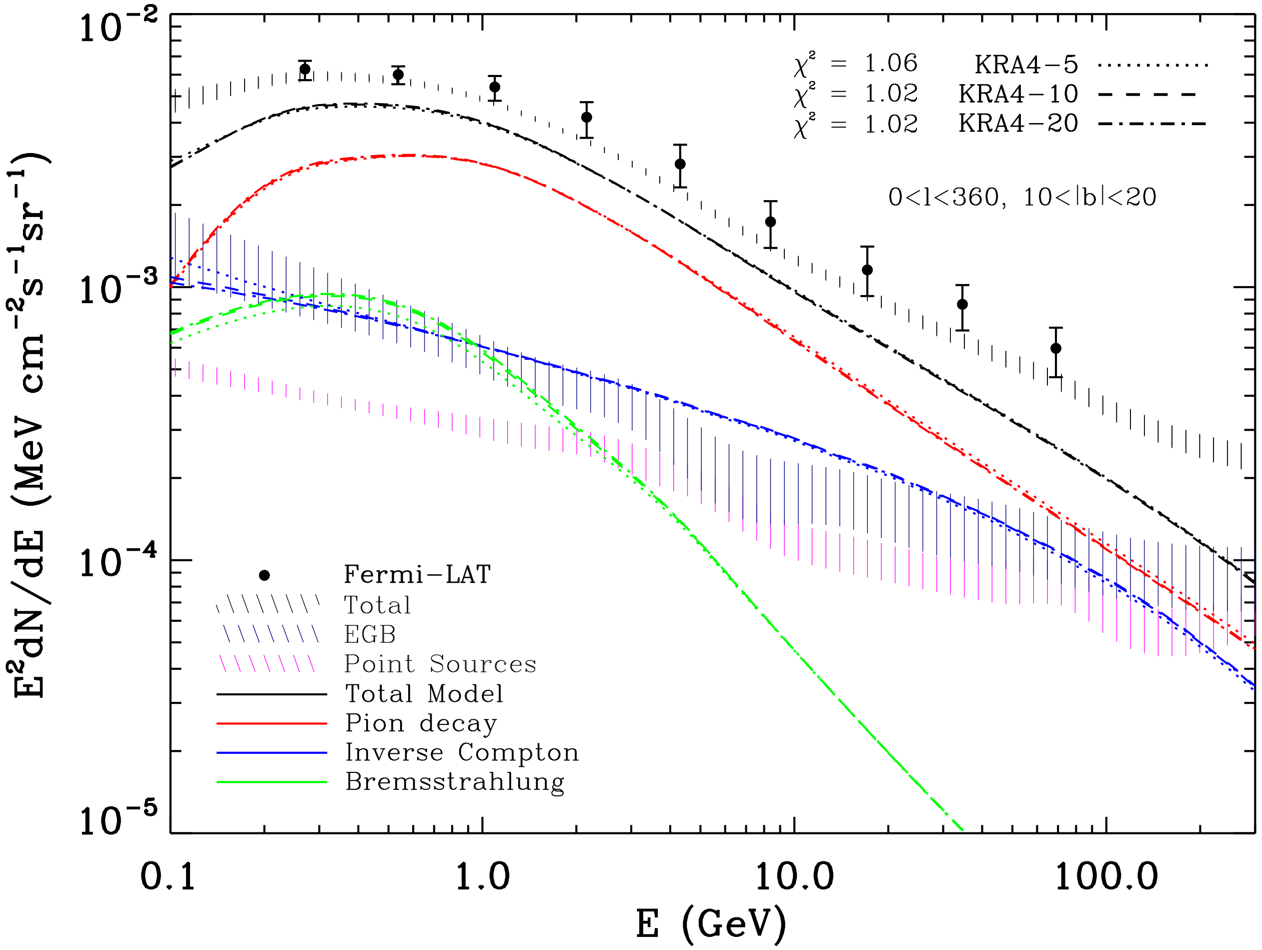
For every case we refit the Diffusion, re-acceleration and injection properties



Differences appear mainly in the electron's signal

Including antiprotons data Kraichnan model is slightly preferred to a Kolmogorov

Ilias Cholis 30/6 CRISM 2011

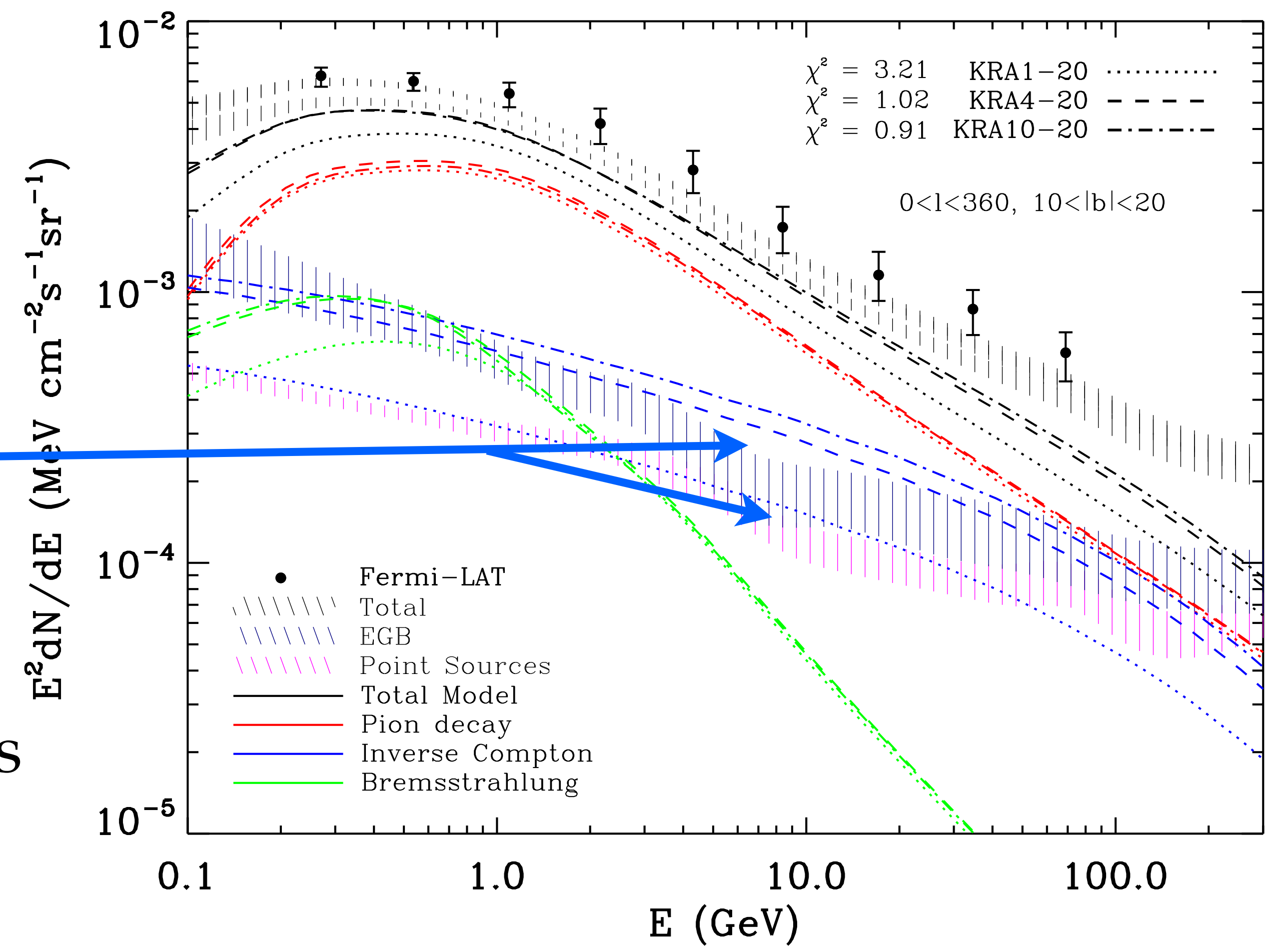


: varying the radial profile of diffusion

differences are too small

Varying the z profile of the diffusion (diffusion zone hight):

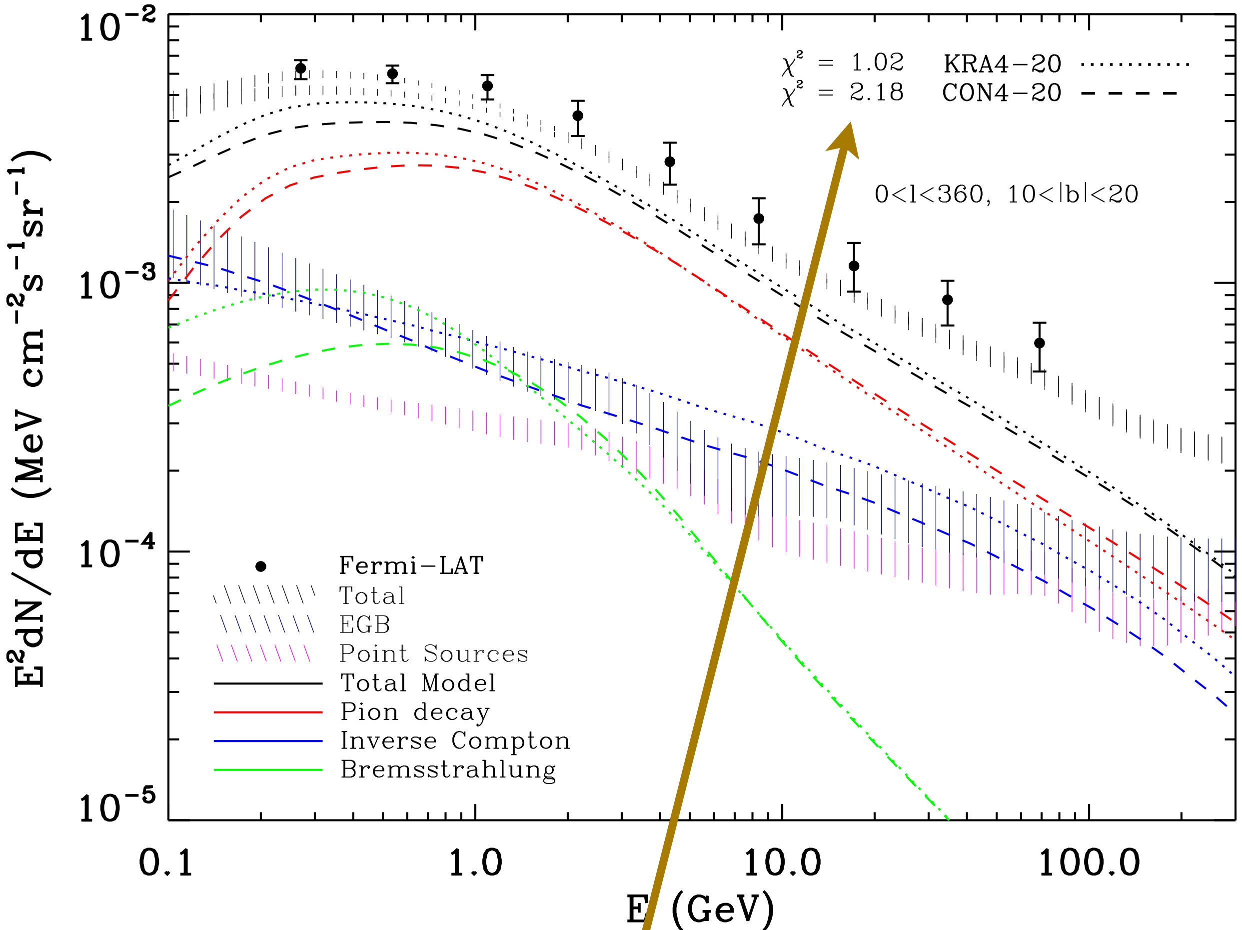
Line of sight effects for ICS

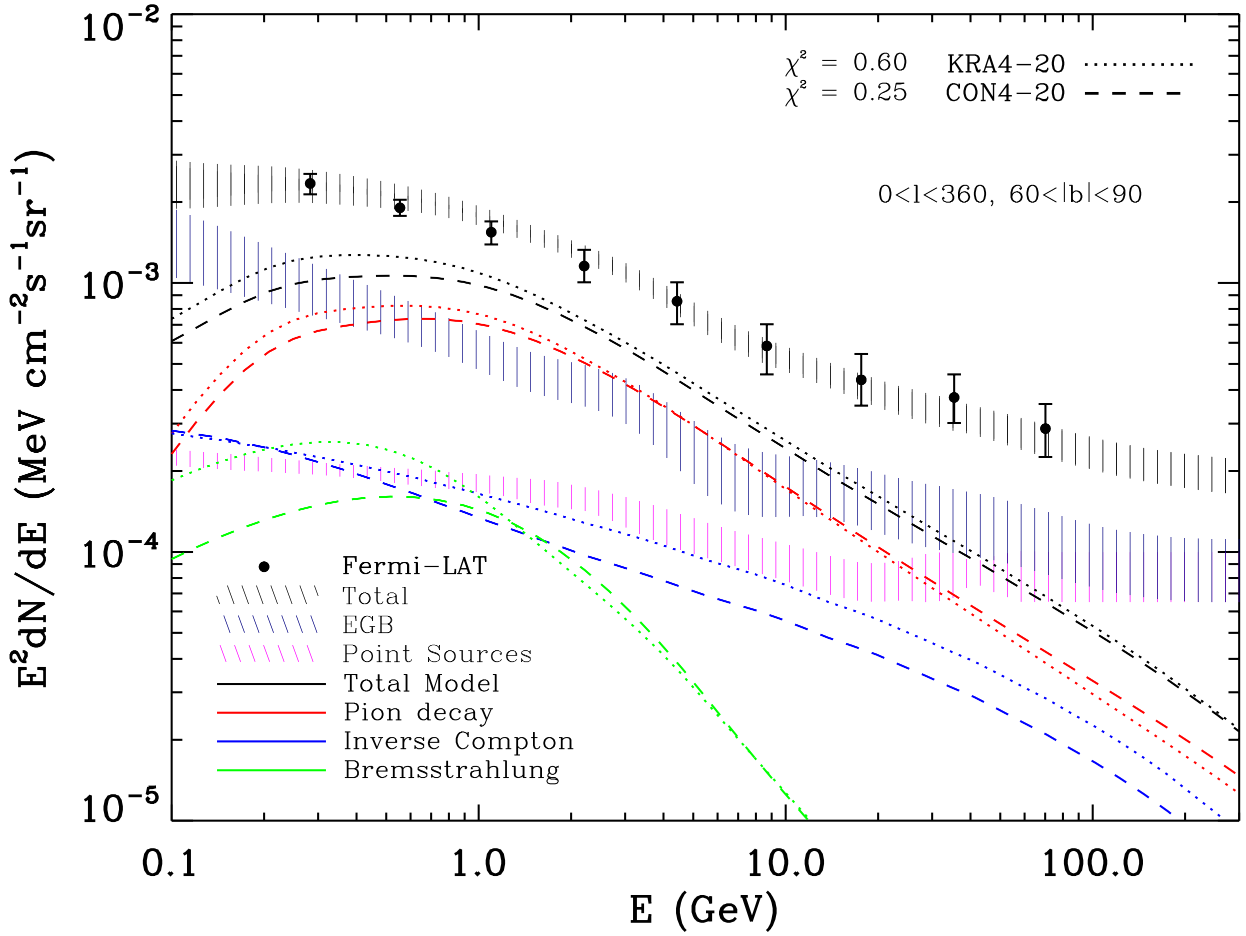


Thinner diffusion zones are less preferable (implications for DM models (e.g. Hooper and Zurek 2009))

The case of convection

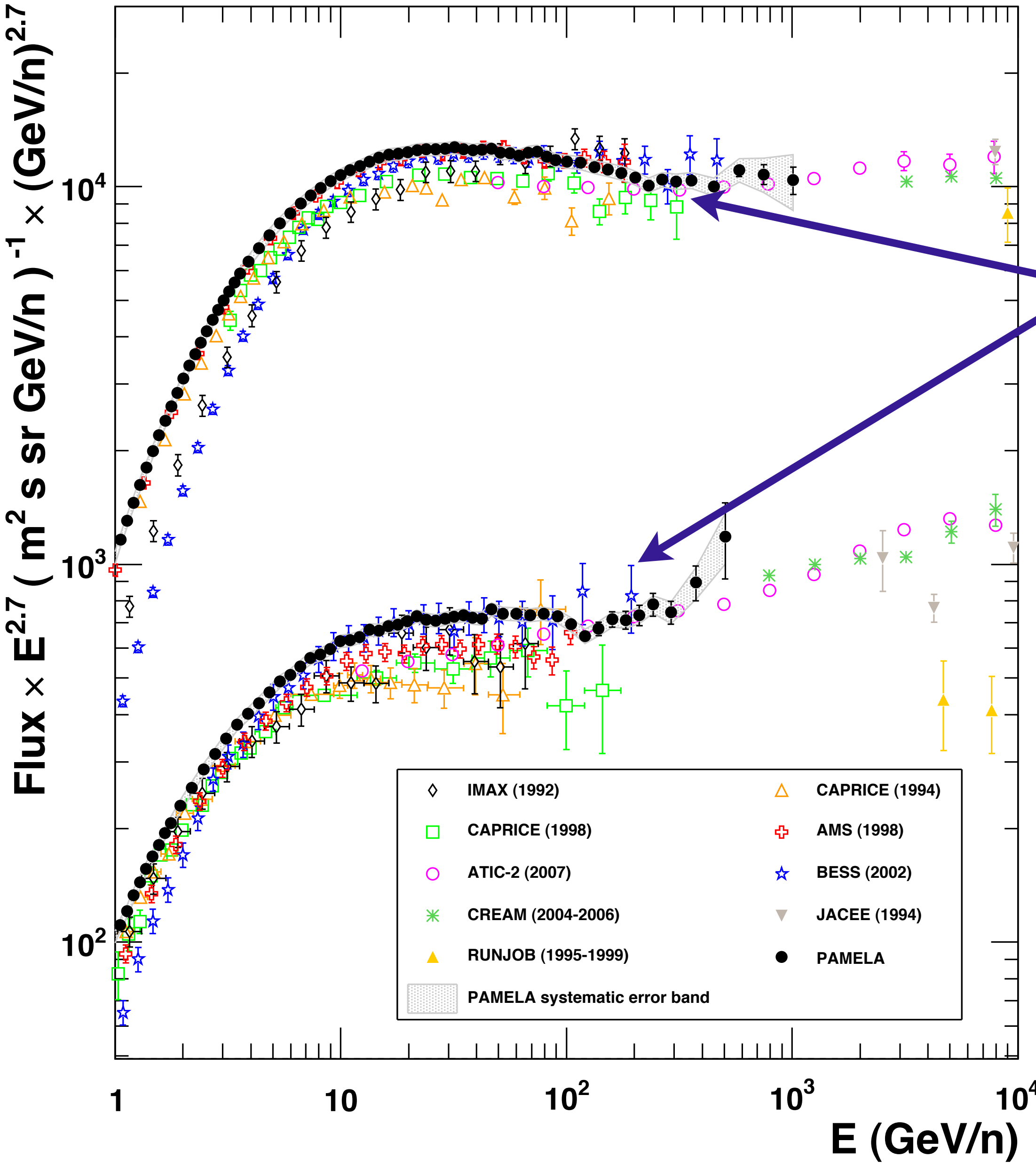
Adding a "strong" convection wind: $dv_C/dz = 50\ \mathrm{km/s/kpc}$





Strong convection in the entire galactic disk is disfavored from the lower latitudes (and to a smaller extend from antiprotons)

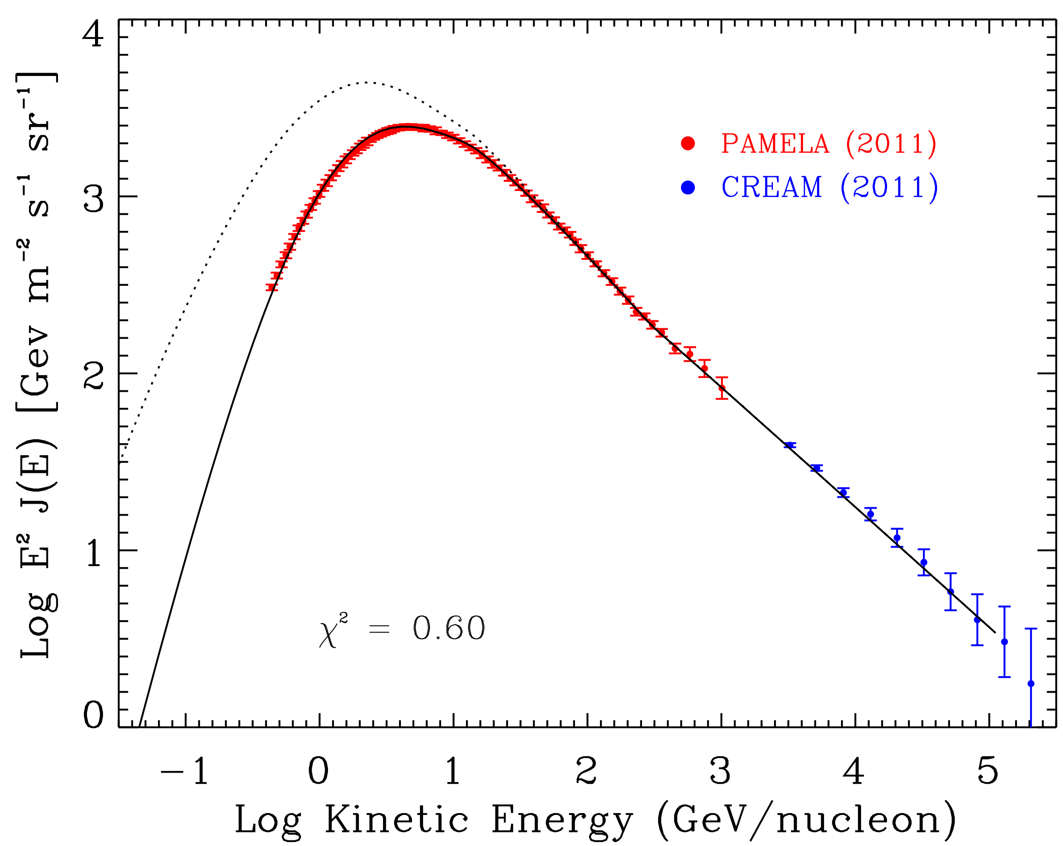
The CR proton and He rigidity break. Break at the injection or the diffusion?



Science.1199172 (arXiv:1103.4055)

What could be the origin of the rigidity break?

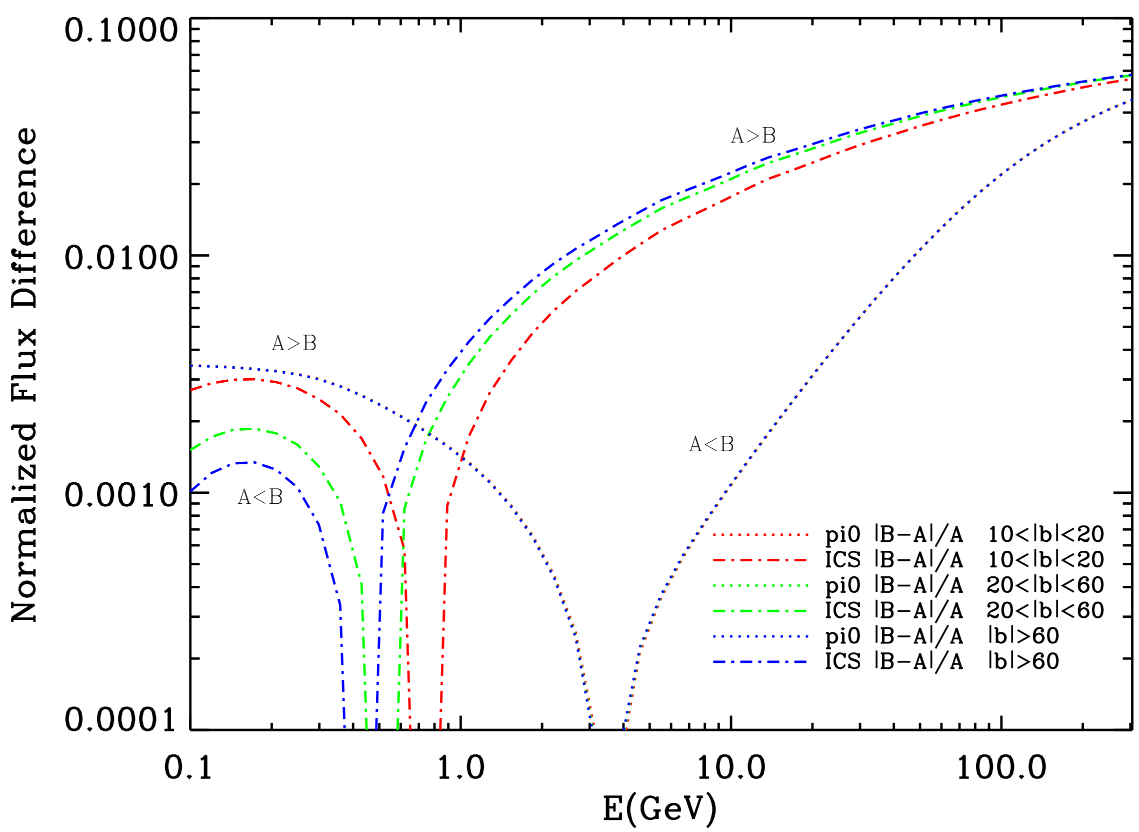
DRAGON is good for the steady state approximation (not for some local recent events)

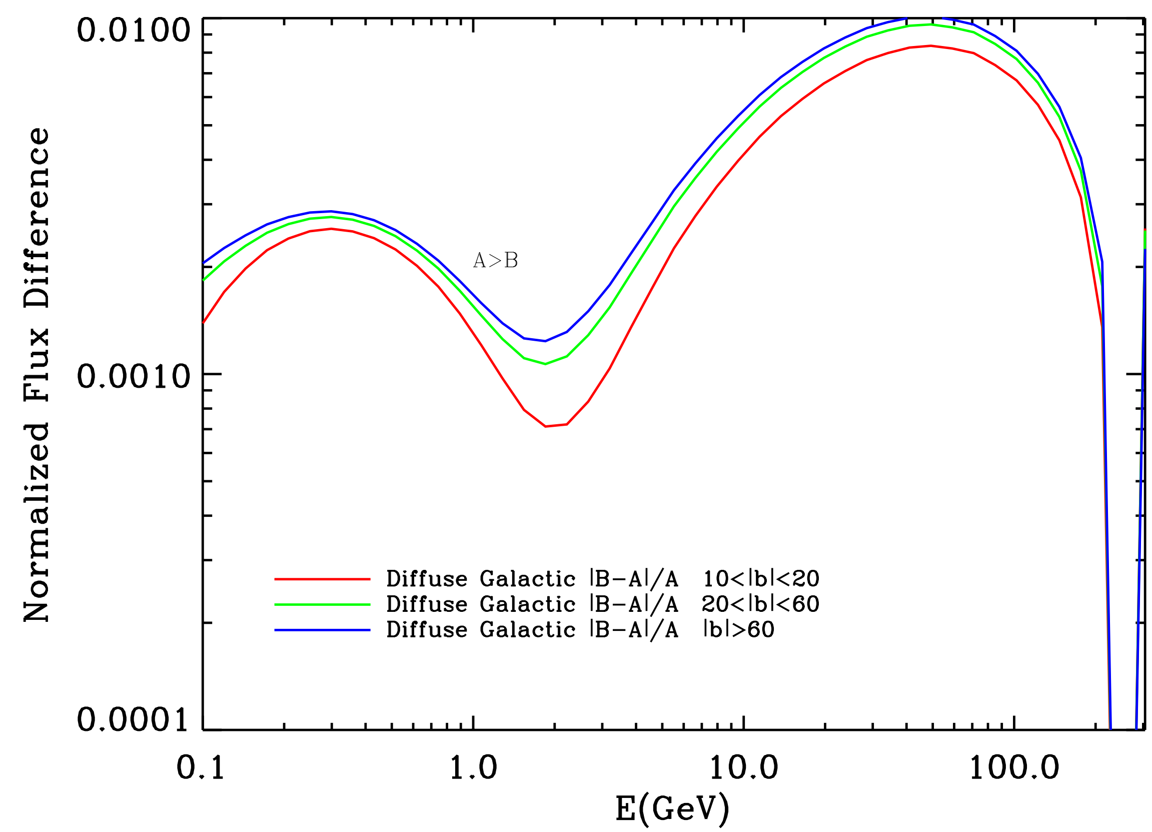


Break in the injection: suggested by studies of SNRs gamma-ray (Picozza 07) and from semi-analytical work (presence of a precursor) (work by: Caprioli, Amato, Blasi, Volk, Malkov).
Also we could simply be observing the emergence of a second population of sources with slightly harder inj. spectrum. (case A)

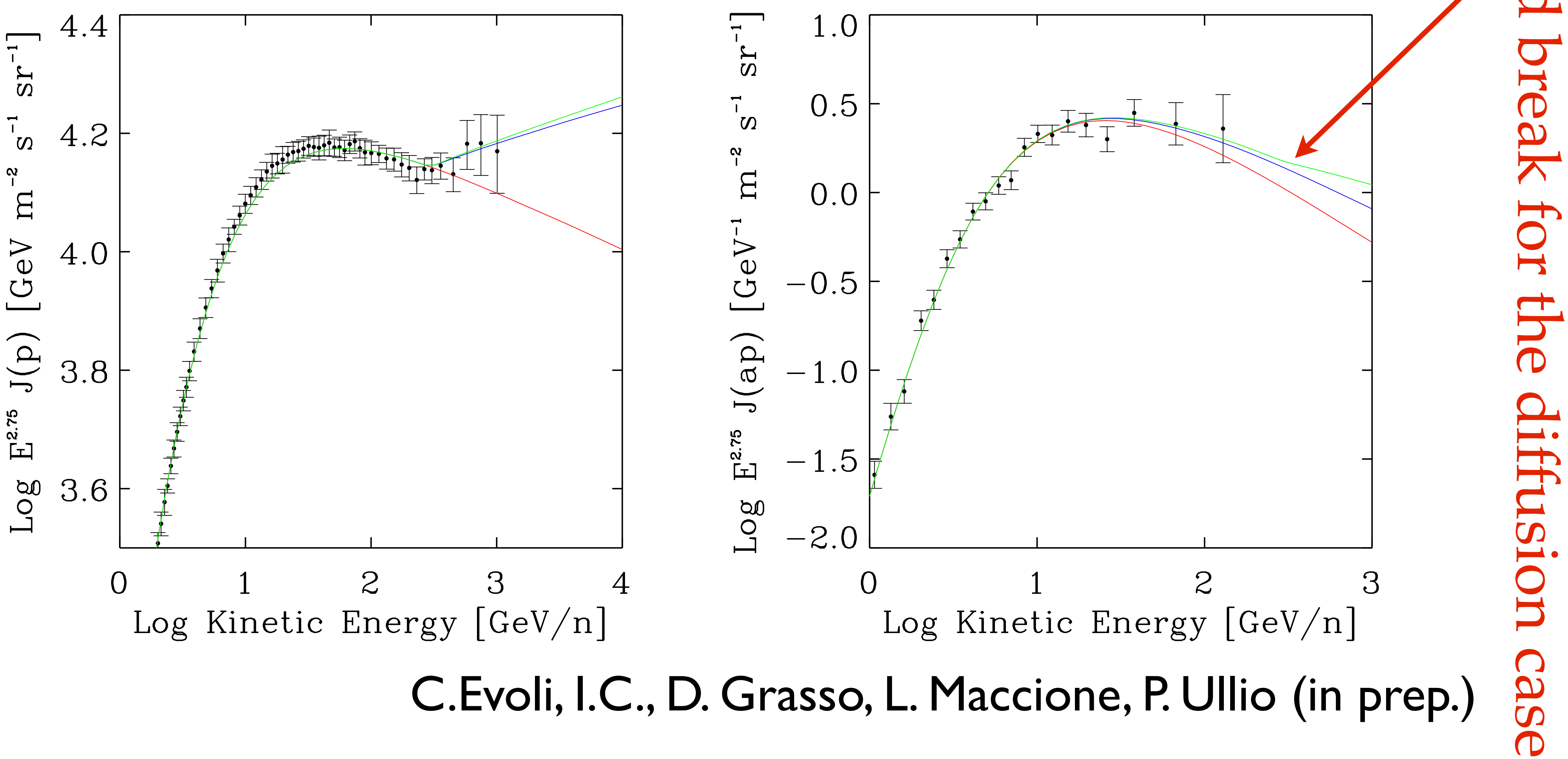
Break in the diffusion (a smooth hardening has already been suggested by Donato and Serpico 2010).
For a break we could be observing a transition from Kraichnan to Kolmogorov. (case B)

The difference is too small in gamma-rays





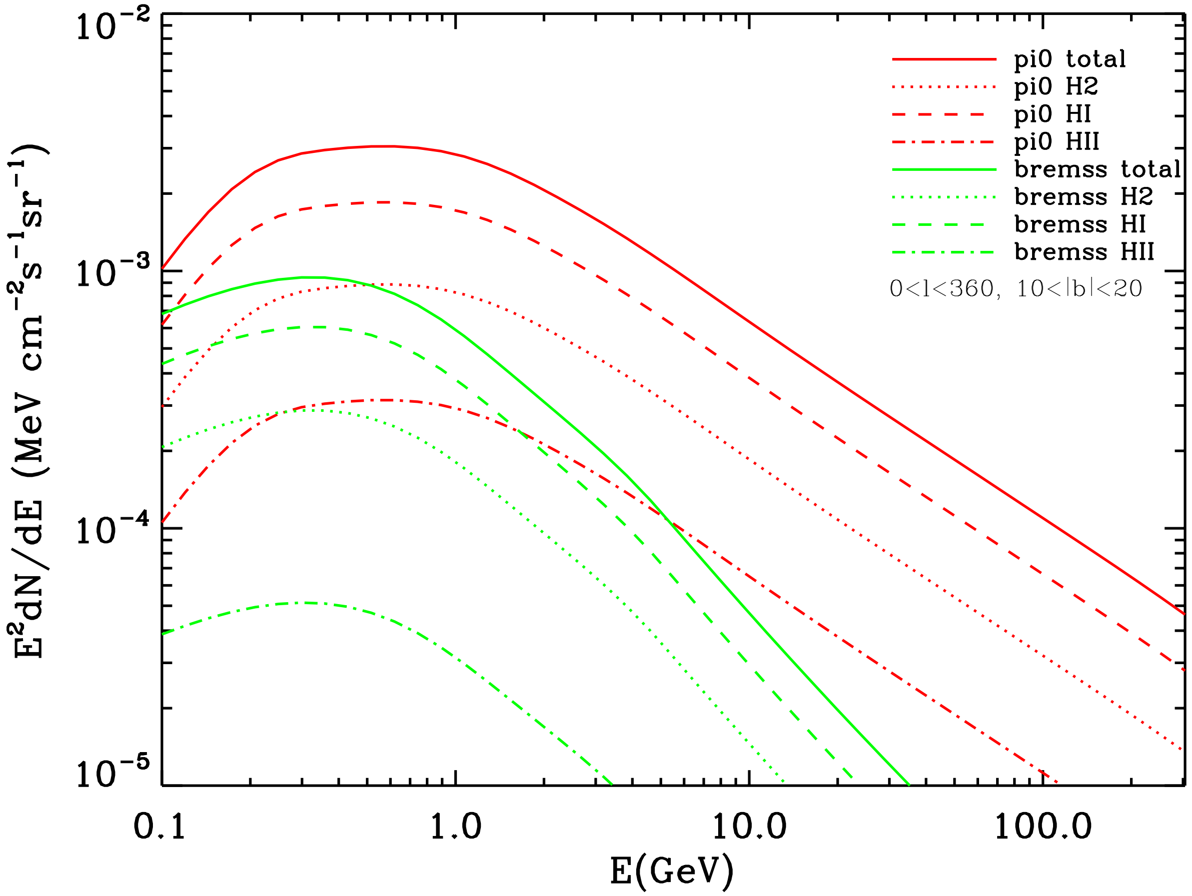
CR antiprotons:

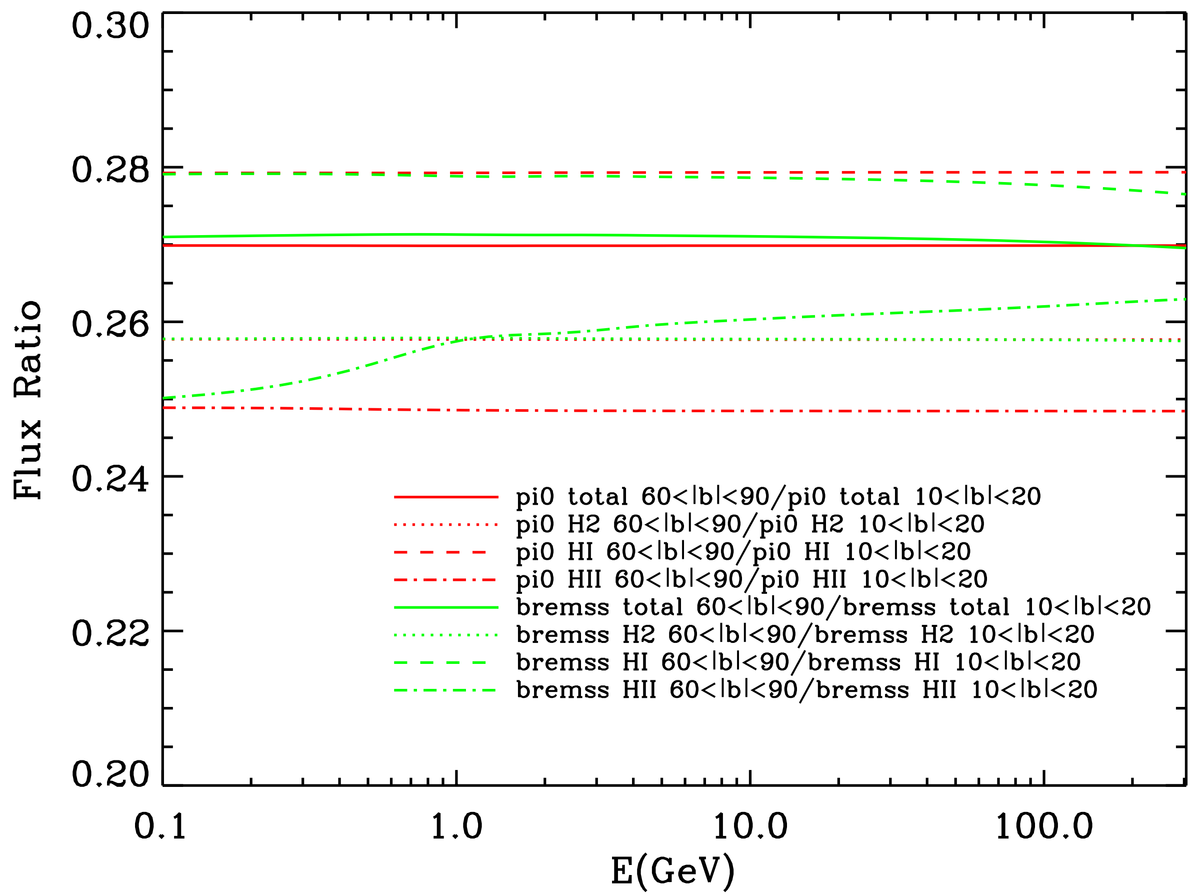


C.Evoli, I.C., D. Grasso, L. Maccione, P. Ullio (in prep.)

AMS 02 could possibly indicate a second rigidity break at ~230 GV?

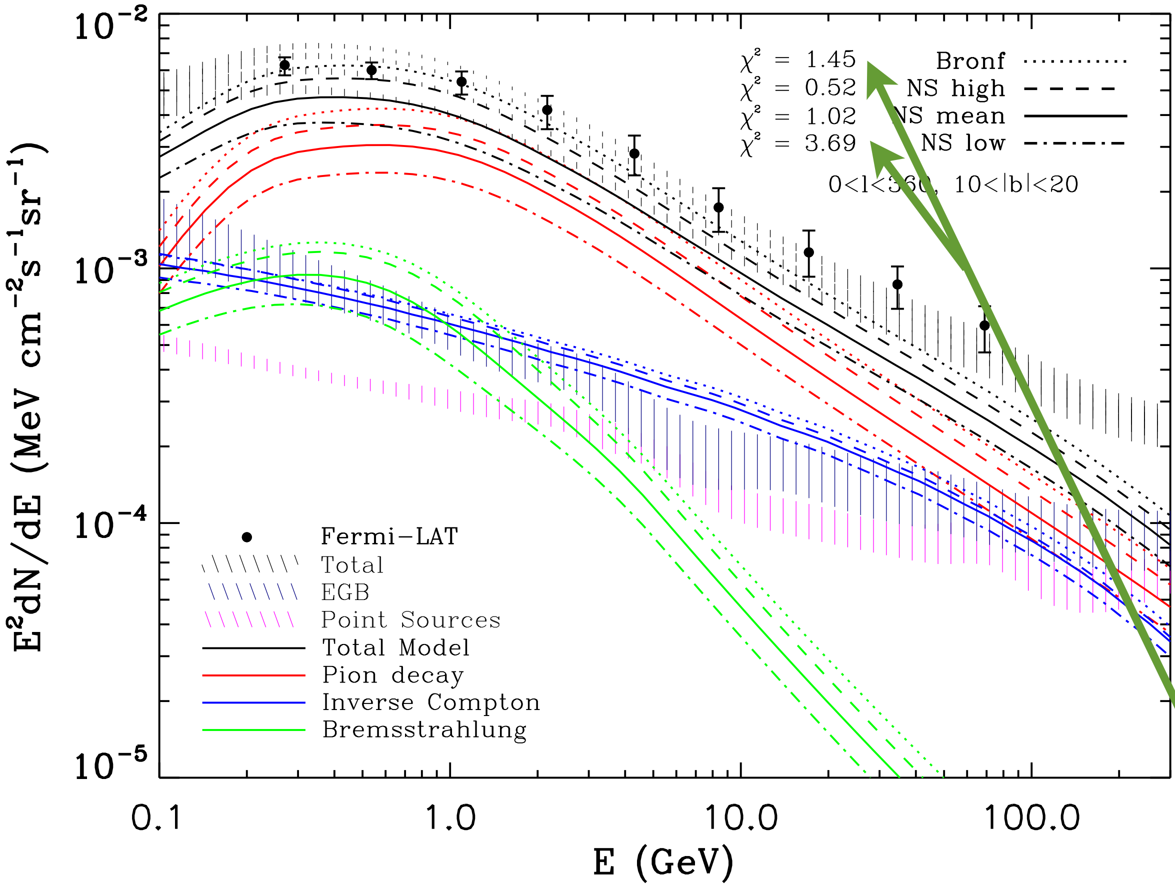
Varying the ISM Gas

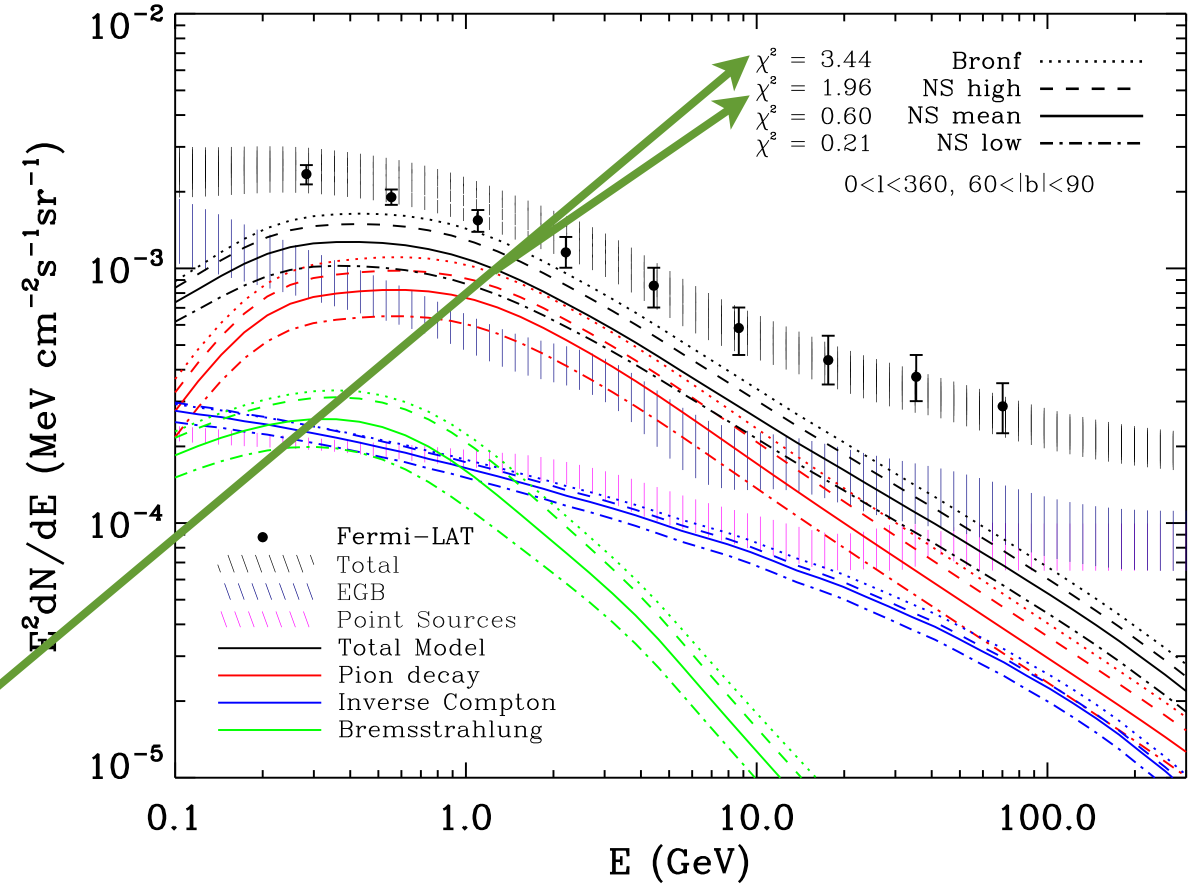


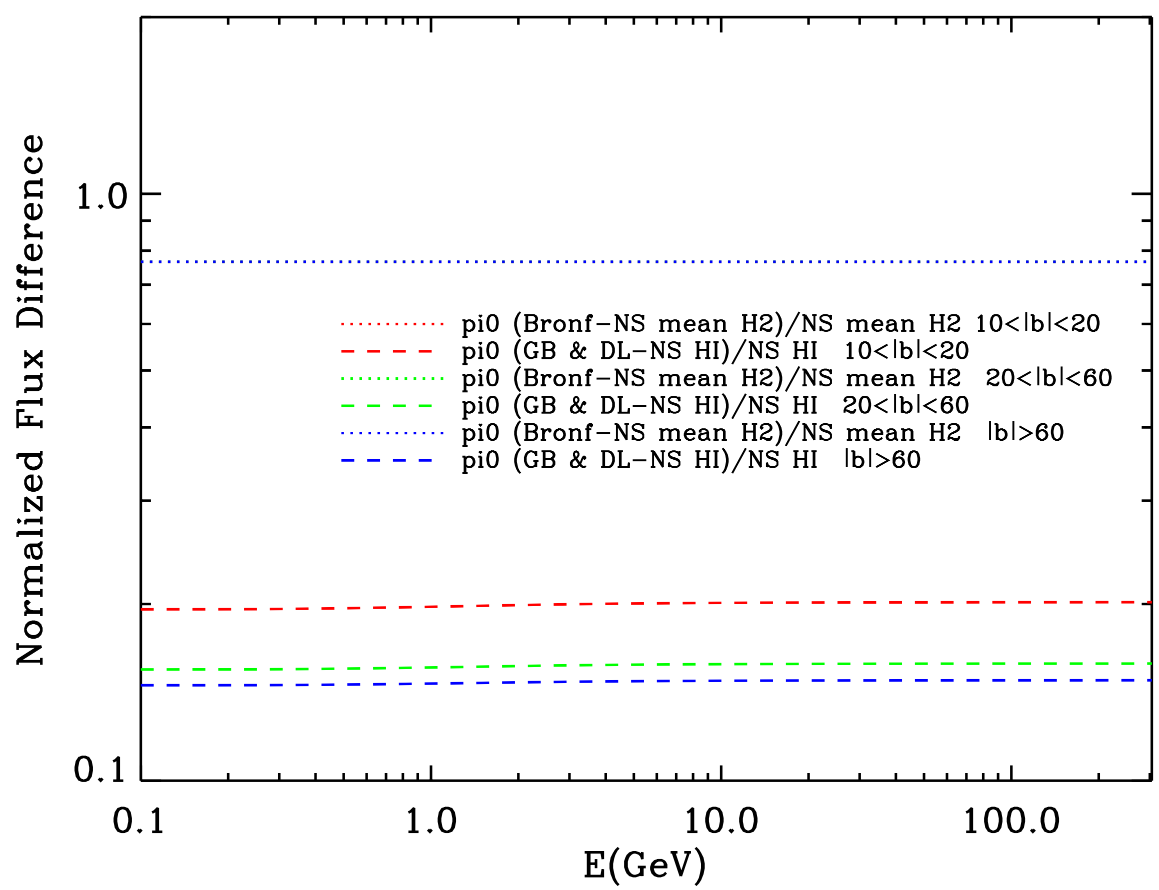


Uncertainties in H2 and HI large scale distribution are important,
(HII contributes to O(0.1) to the total "pi0")

See also the complementary work from T.Delahaye, A. Fiasson, M. Pohl & P. Salati (1102.0744) on the uncertainties on the hadronic part of gammas.

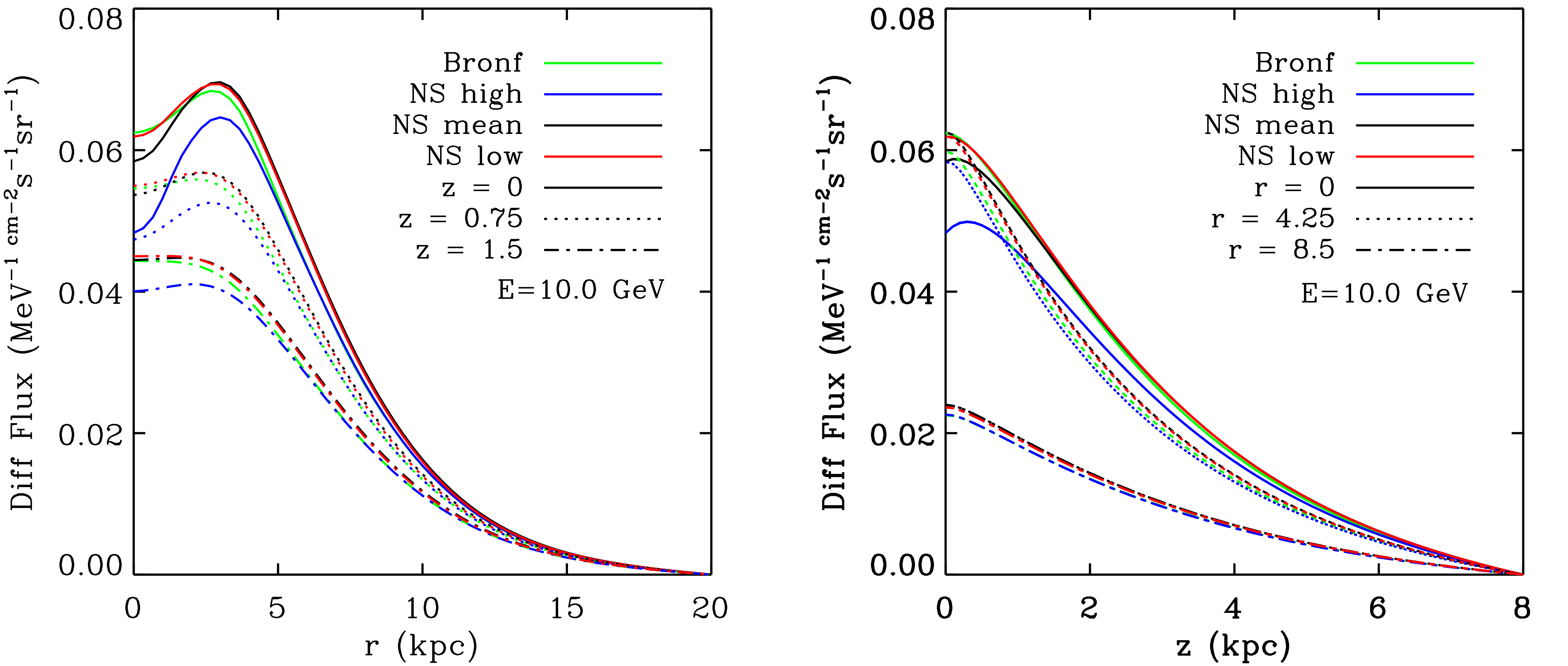






Specific assumptions in the literature such as Bronfmann & Cohen are in tension with the data

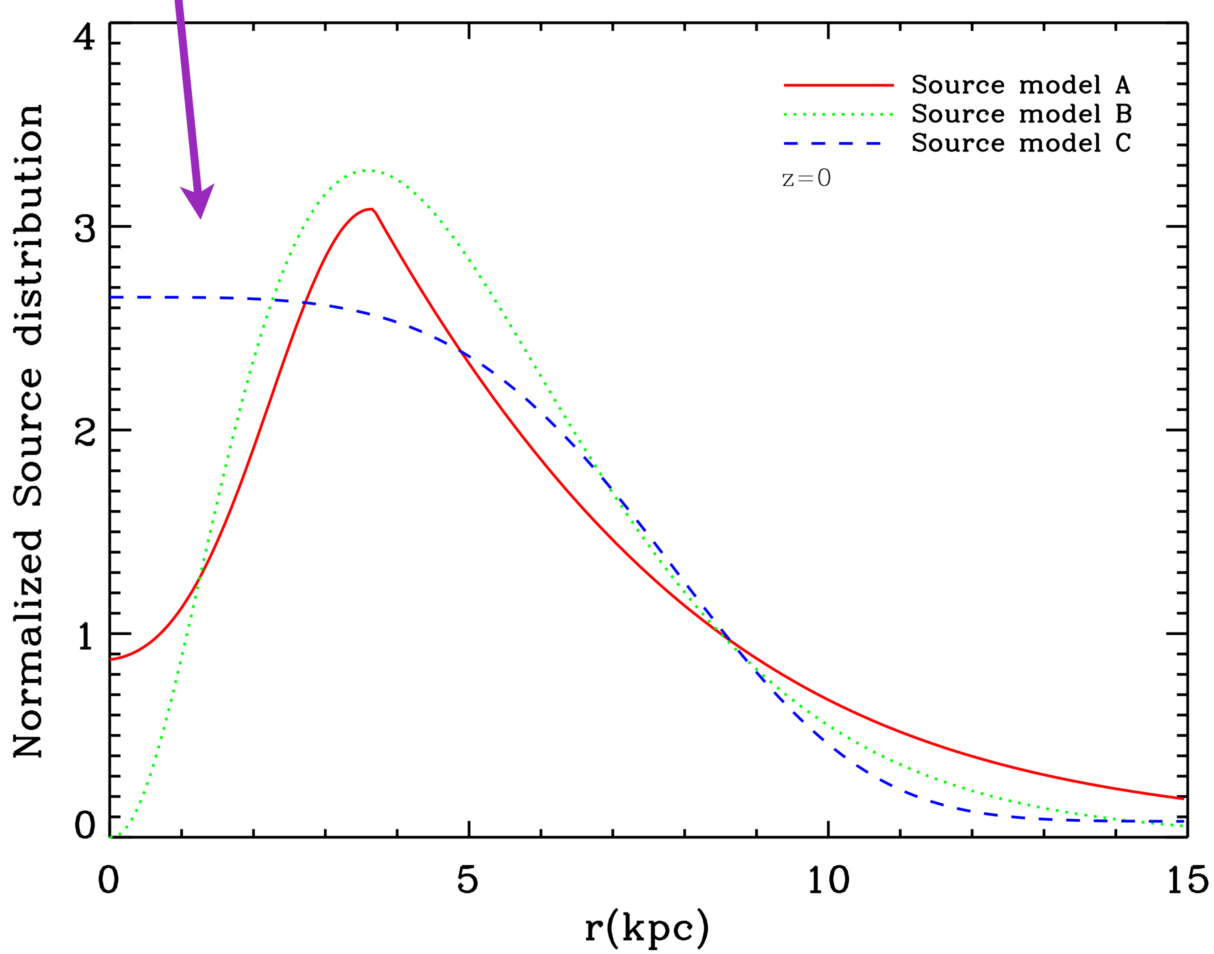
We can pin down preferred models for the gas. Uncertainties to H2 are the most affected (since they are the largest).

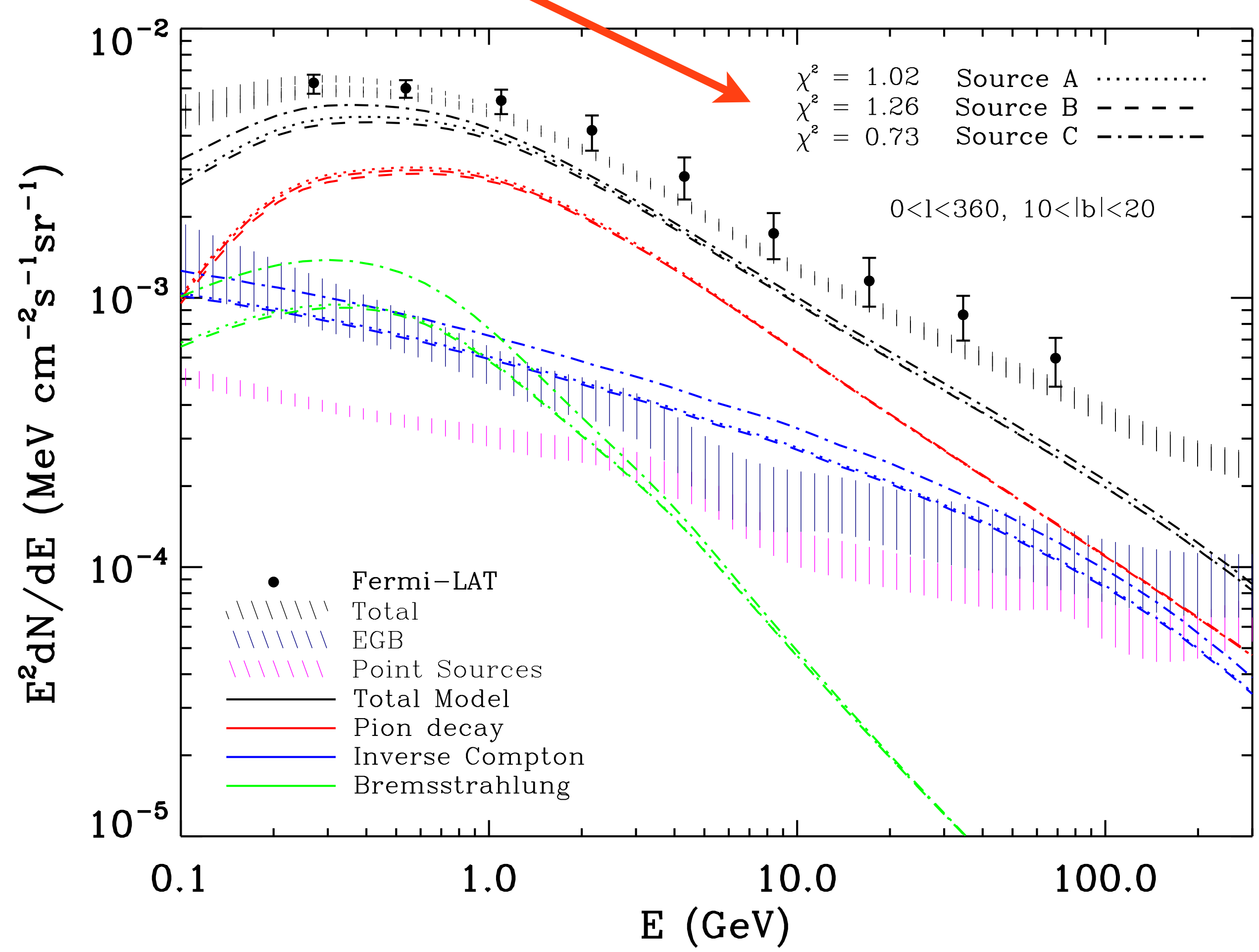


Protons (unlike electrons) can be predicted from their local CR spectrum, and after refitting the diffusion properties for certain gas and source distribution assumptions, their profiles are practically the same, thus with gamma-rays (after fitting the CRs) we probe the targets (gas).

Sources large scale *averaged* distribution

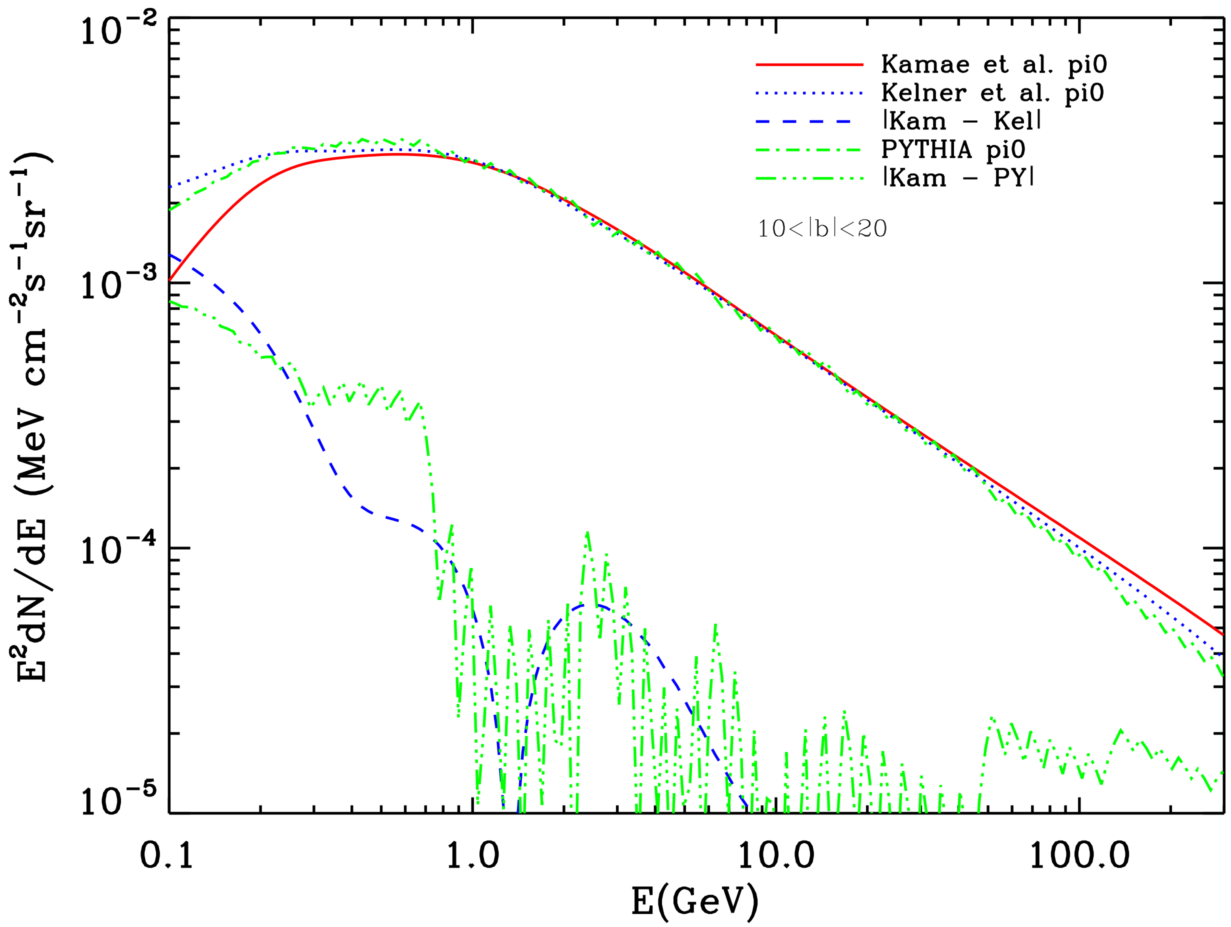
Sources distribution are sensitive to selection effects in the inner part of the Galaxy. This can effect the gamma-rays prediction.





We need lower latitudes studies which probe more directly the sources.

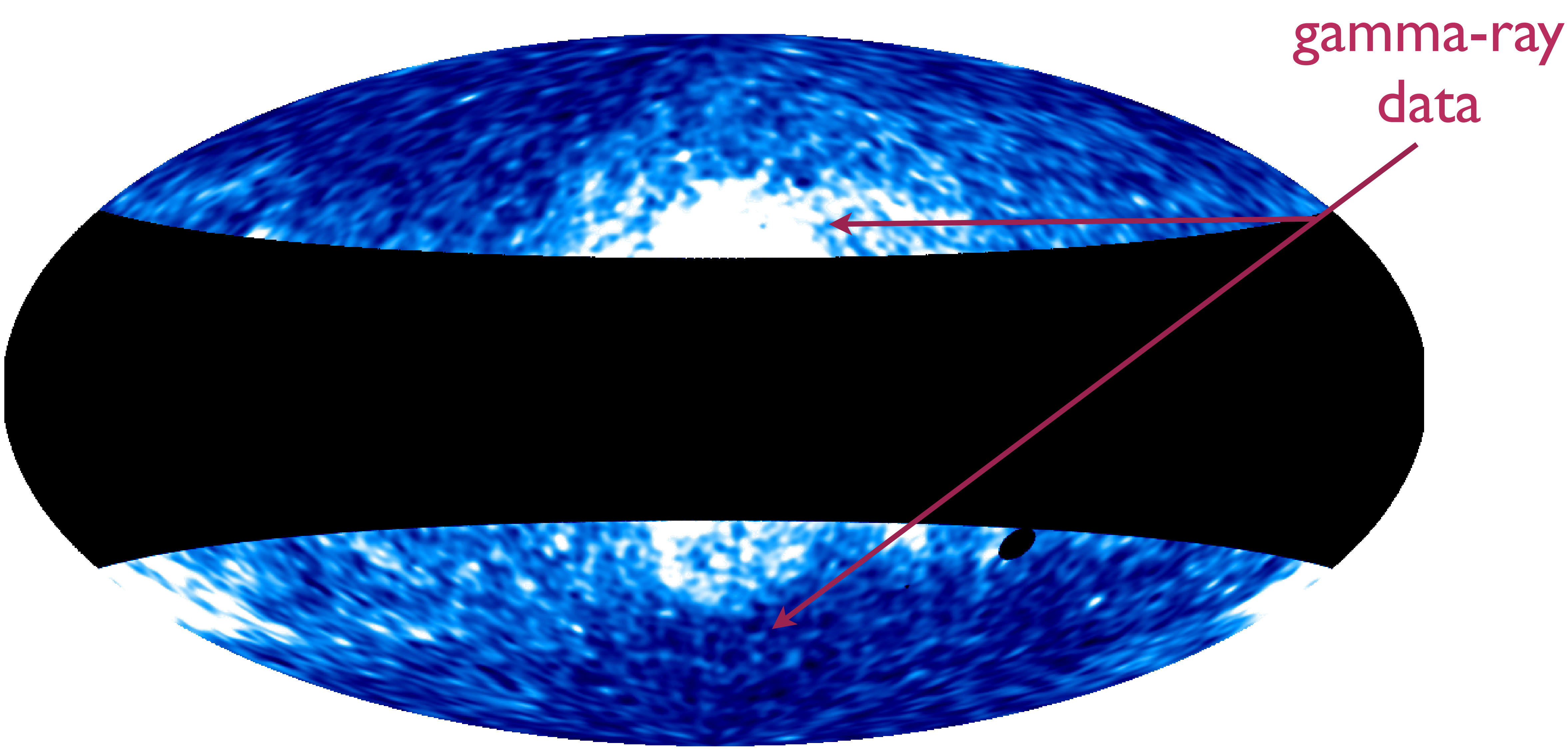
pp-collision:



Our analysis is robust with respect to gamma-ray production spectrum parametrization from pp-collisions.

All these information can be used as a basis for searches on DM at gamma-rays.

The Fermi haze/bubbles are seen even from the gamma-ray data

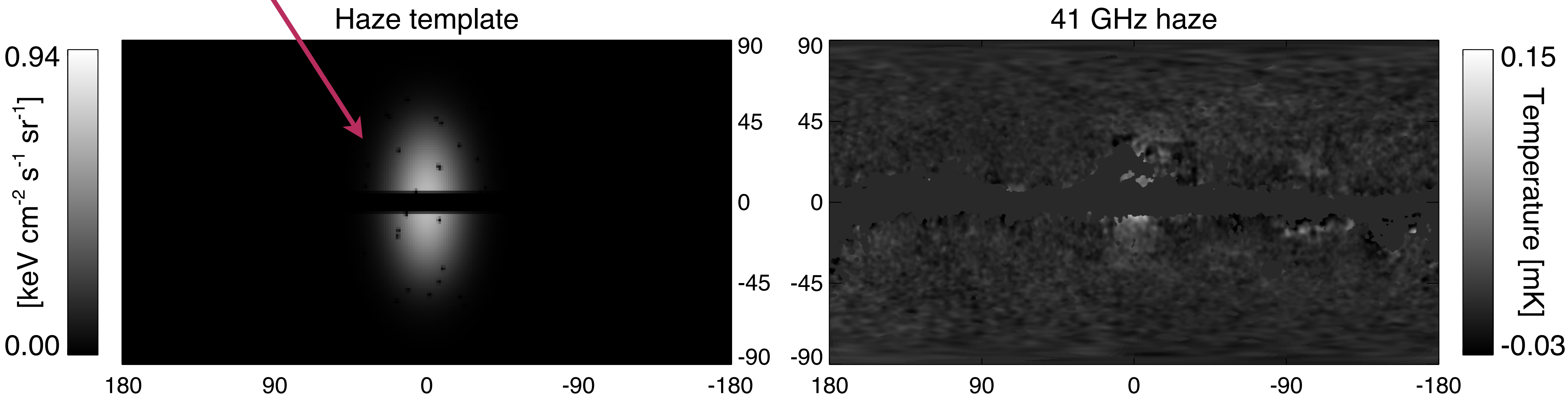


G.Dobler

Ilias Cholis 30/6 CRISM 2011

First template

The two haze signals



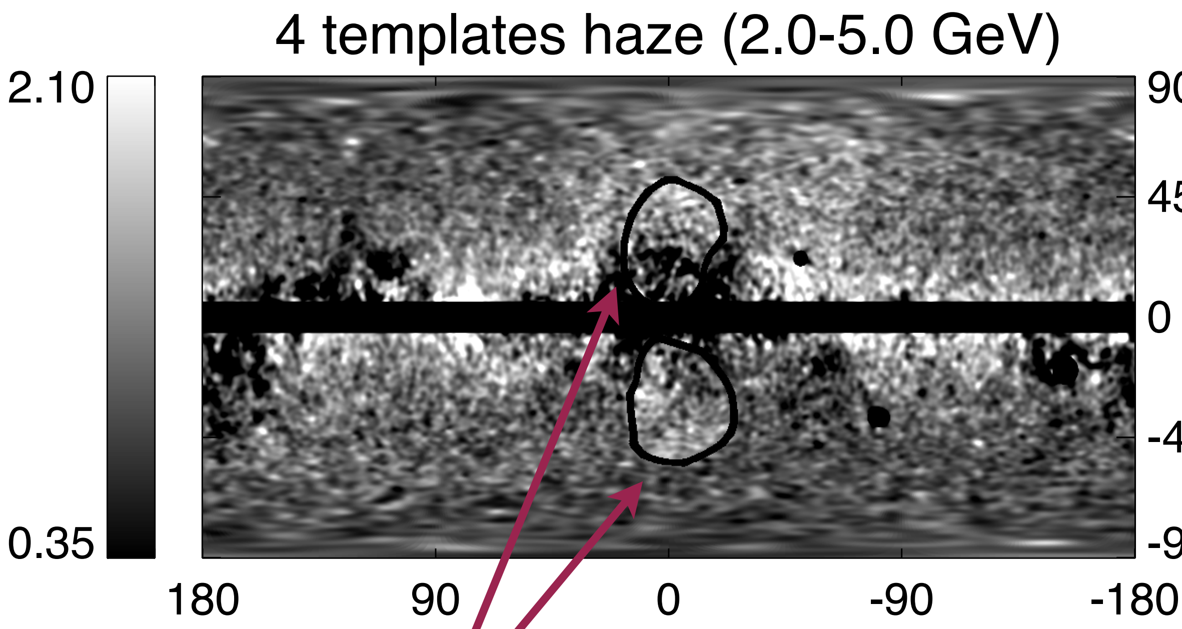
Probe a distribution of hard-spectrum electrons, (steady state diff. spectrum of $\frac{dN_e}{dE} \sim E^{-2}$)

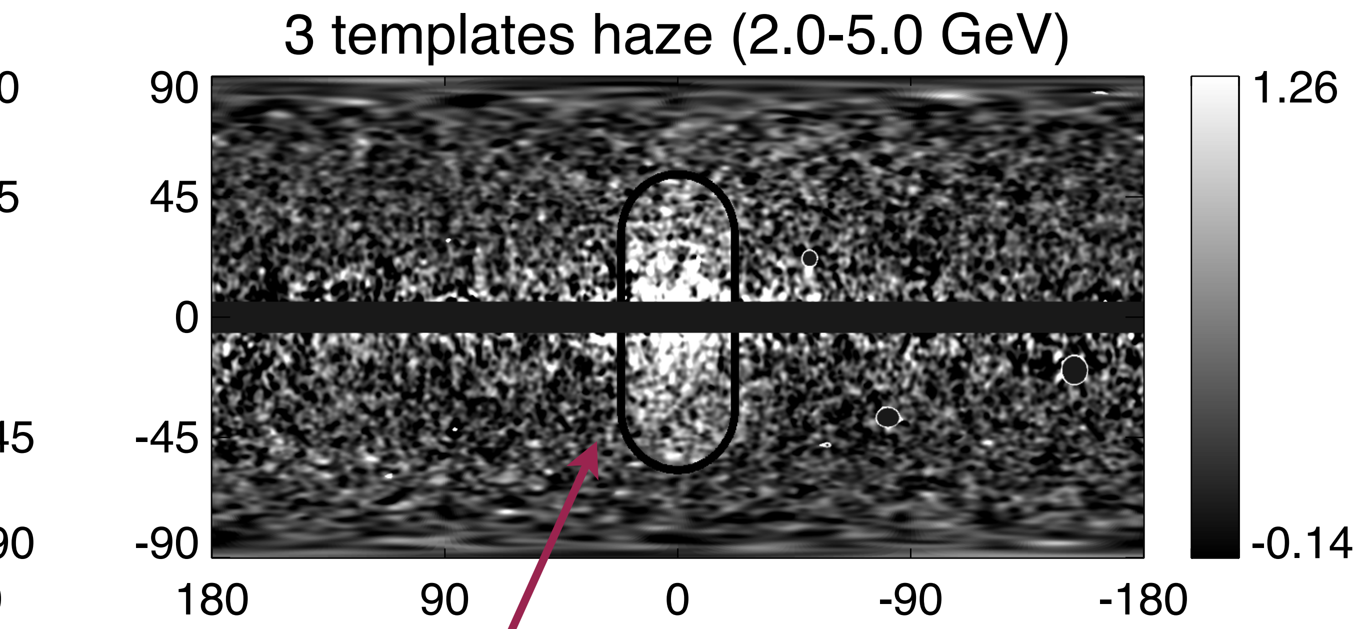
Fermi haze: inverse Compton scattering

WMAP haze: synchrotron radiation

Non-trivial morphology of the Fermi haze (template:bivariate Gaussian)

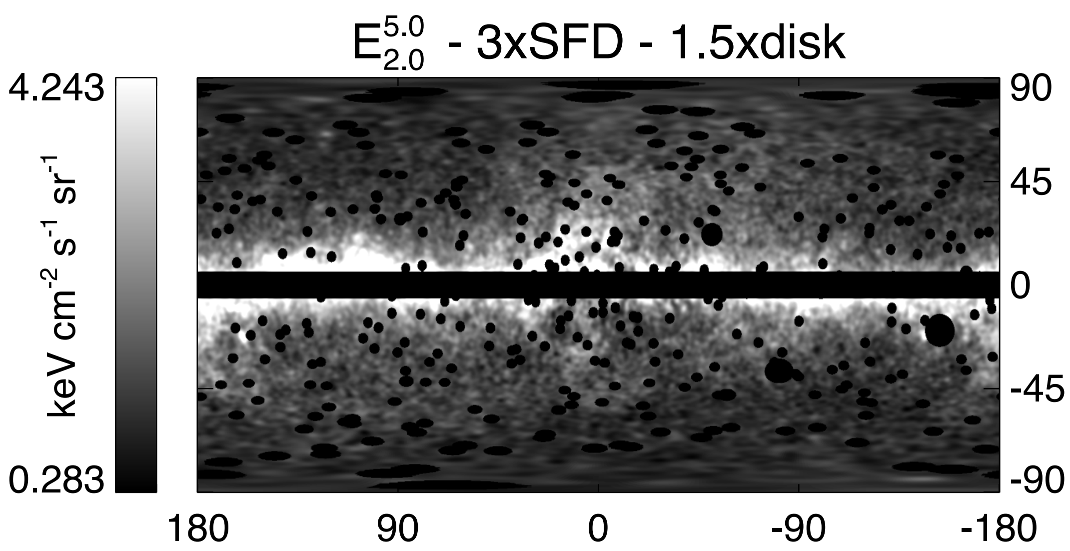
The source(s) responsible for the signal must explain both spectra AND the non-disk-like morphology

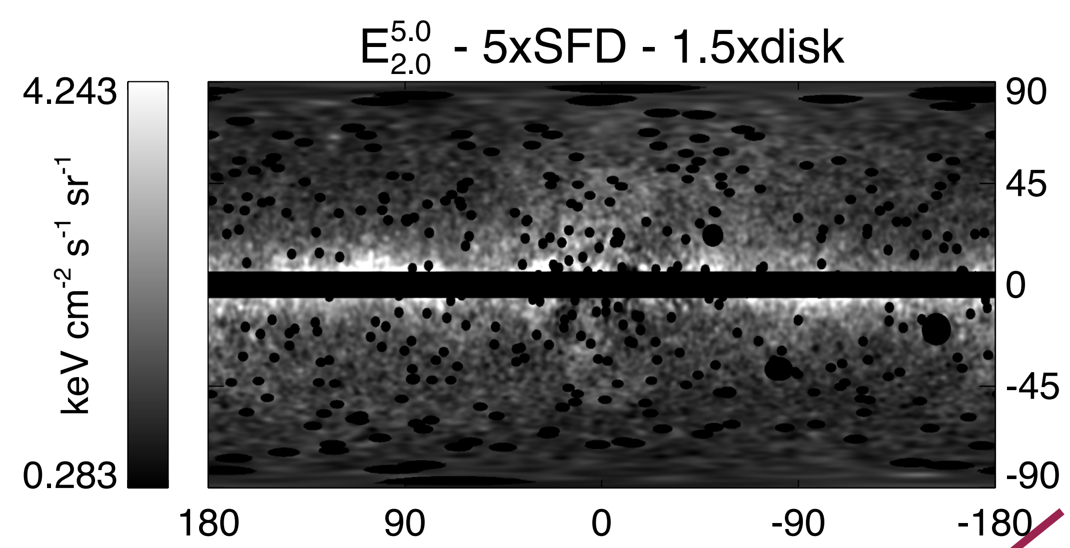


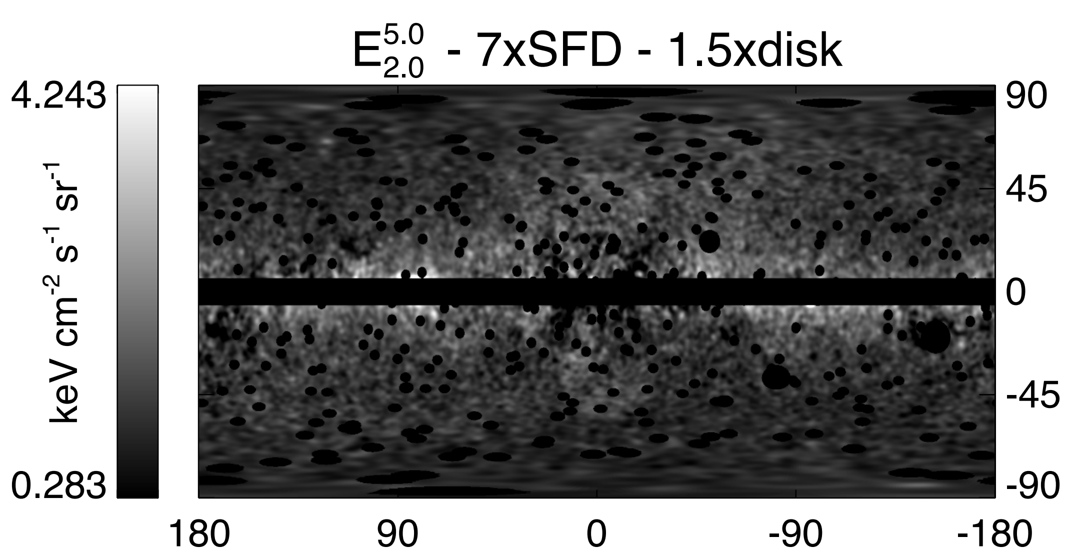


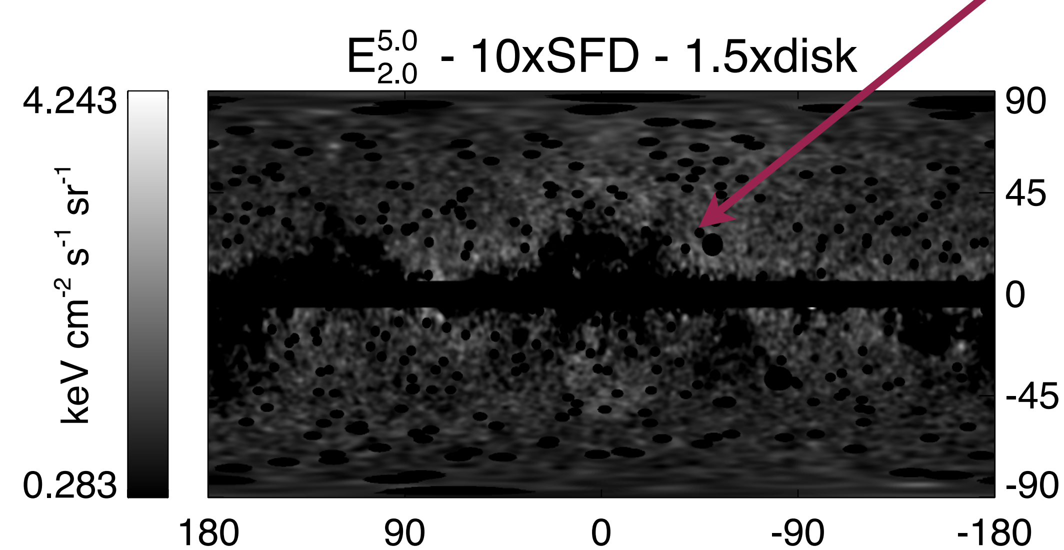
Fermi Bubbles (Su, Slatyer,Finkbeiner)

(Updated) Fermi haze (G. Dobler, I.C., N.Weiner)









Dust (emission) to gas (density) may vary with position

Thank you.

Additional slides

Fermi (gamma-ray) haze

Since 2004 Finkbeiner has proposed the WMAP (microwave) haze, which suggests the existence of a population of electrons with a spectrum harder than the SNe accelerated electrons, of roughly spherical shape and extending out to at lest 2kpc (~10 kpc considering Fermi data).

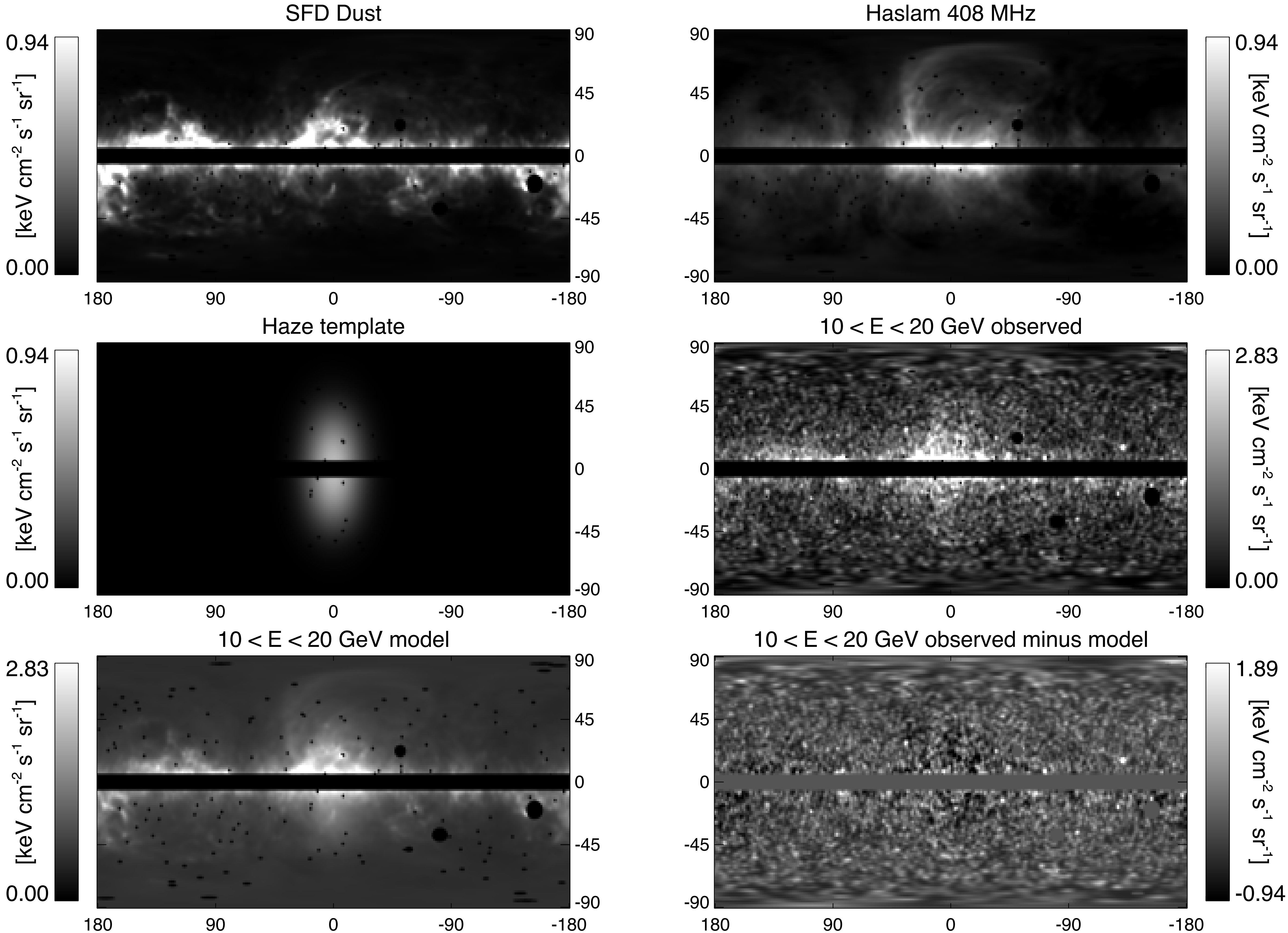
Such a population of hard electrons should also give an ICS signal as well. The Fermi haze is the gamma-ray counterpart of the microwave haze.

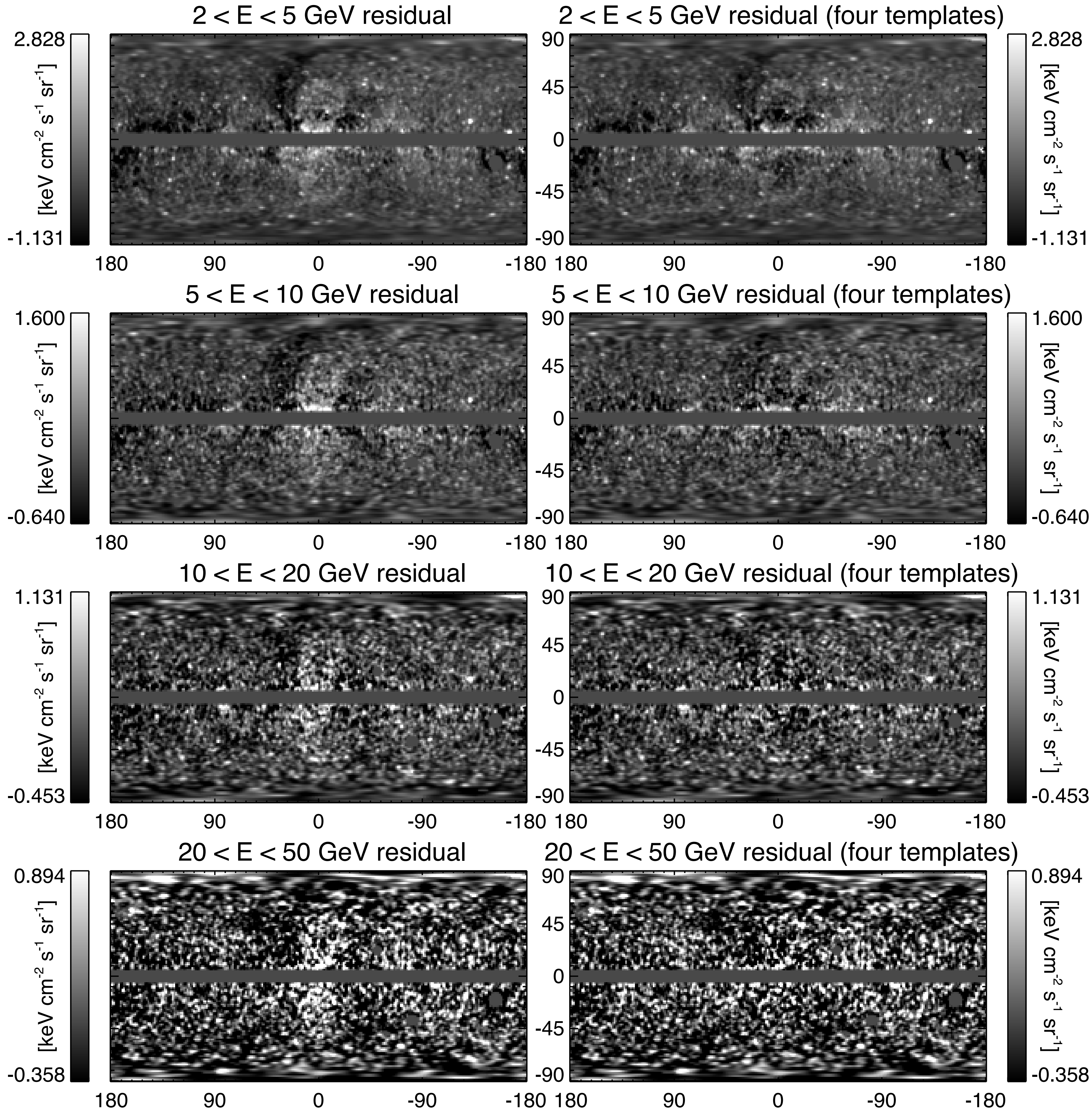
As in the case of the WMAP haze, all-sky templates were used to model the back-ground components.

Background γ s: decaying π^0s produced at inelastic pp collisions, ICS and bremsstrahlung from the softer (SNe) electrons, point sources, isotropic γs.

3 different template sets were used, that all resulted in the need for an extra γ-ray template (the haze template) in order to fit well the entire γ-ray sky. The haze template was in all cases non-disky and suggested a hard population of electrons, similarly to the microwave haze.

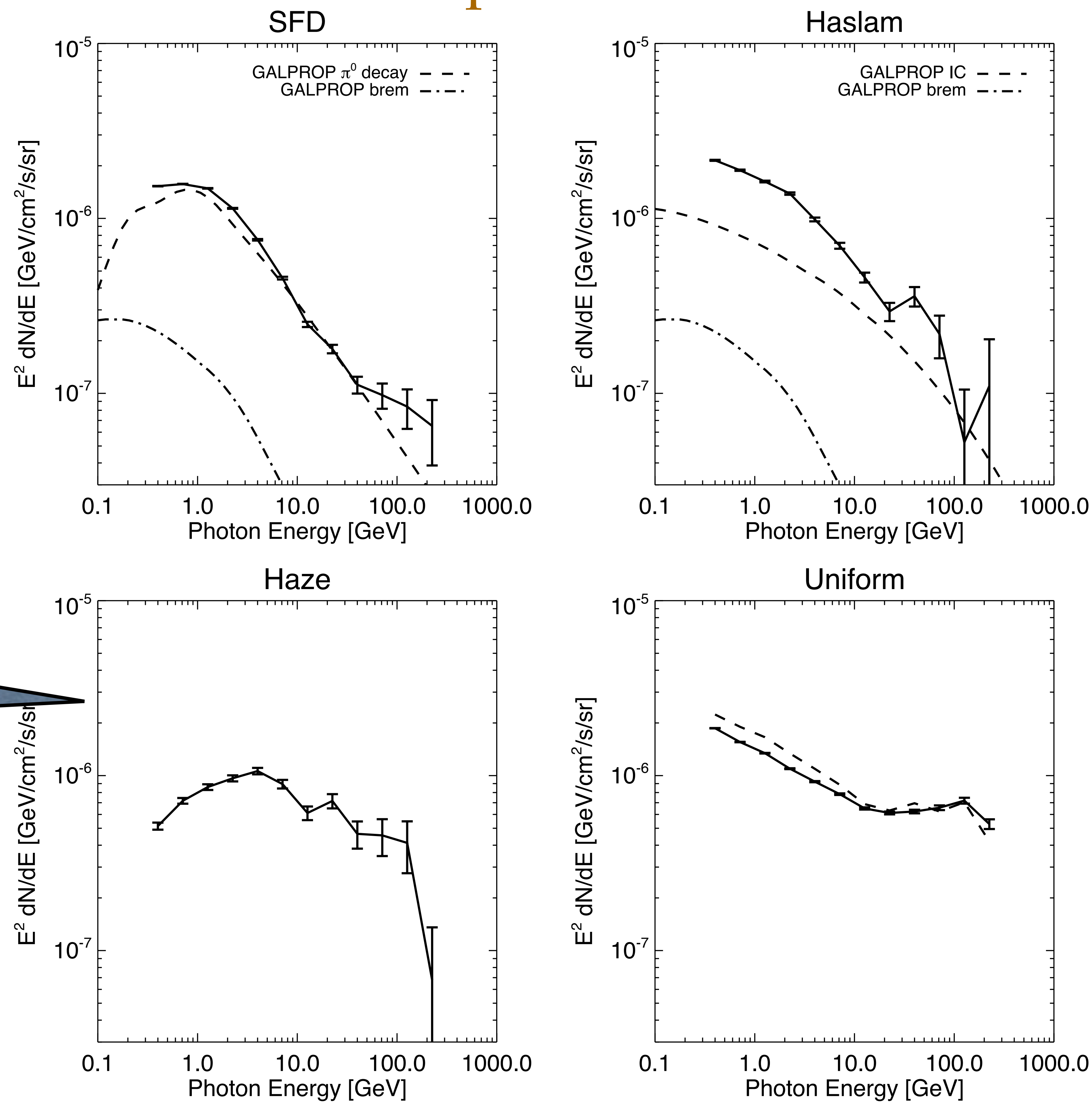
The Fermi haze template





2 < E < 5 GeV residual
2 < E < 5 GeV residual (four templates)
5 < E < 10 GeV residual
5 < E < 10 GeV residual (four templates)
10 < E < 20 GeV residual
10 < E < 20 GeV residual (four templates)
20 < E < 50 GeV residual
20 < E < 50 GeV residual (four templates)
[keV cm^-2 s^-1 sr^-1]
2.828
-1.131
1.600
-0.640
1.131
-0.453
0.894
-0.358
90
45
0
-45
-90
180
90
0
-90
-180

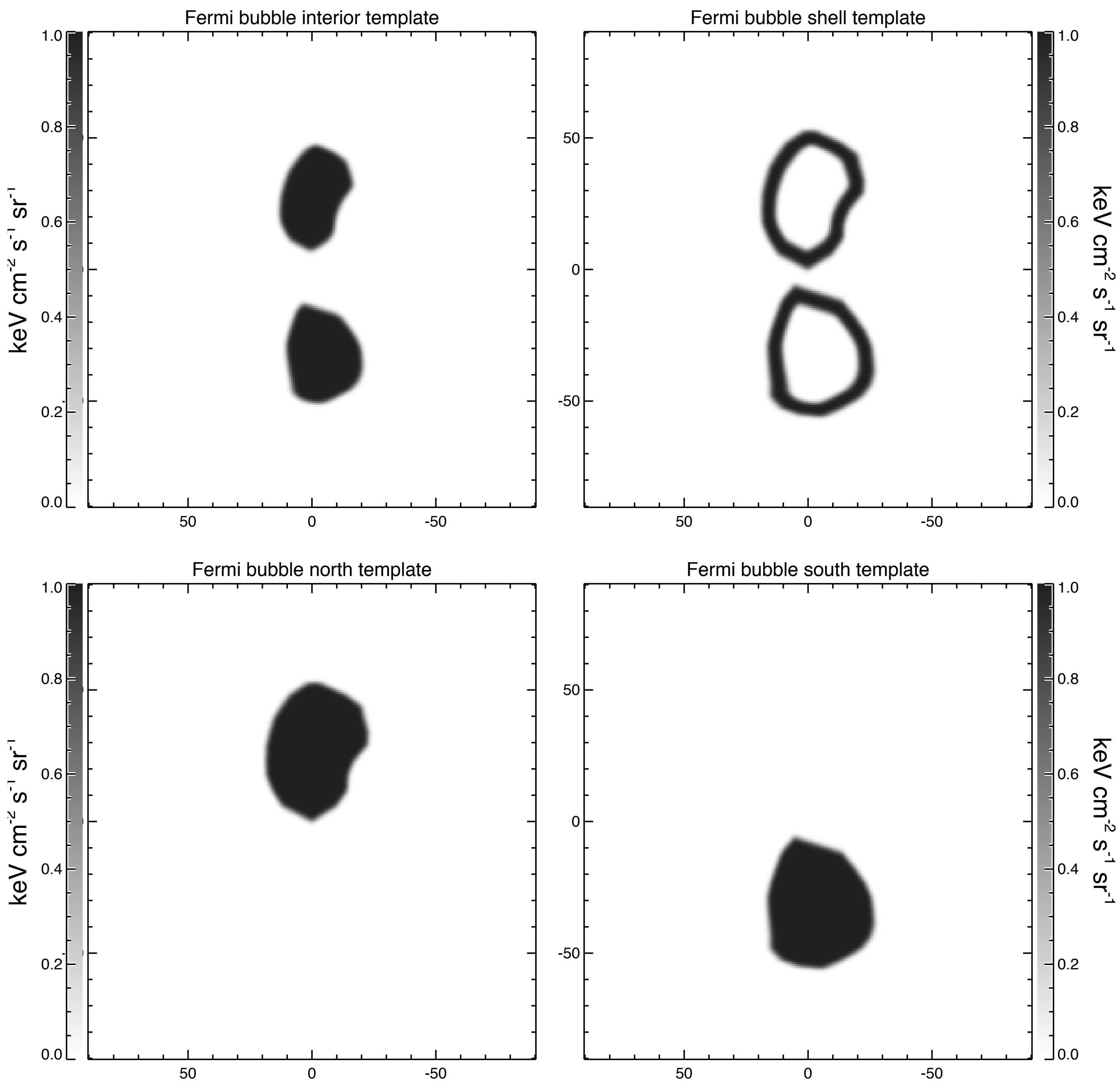
Spectra



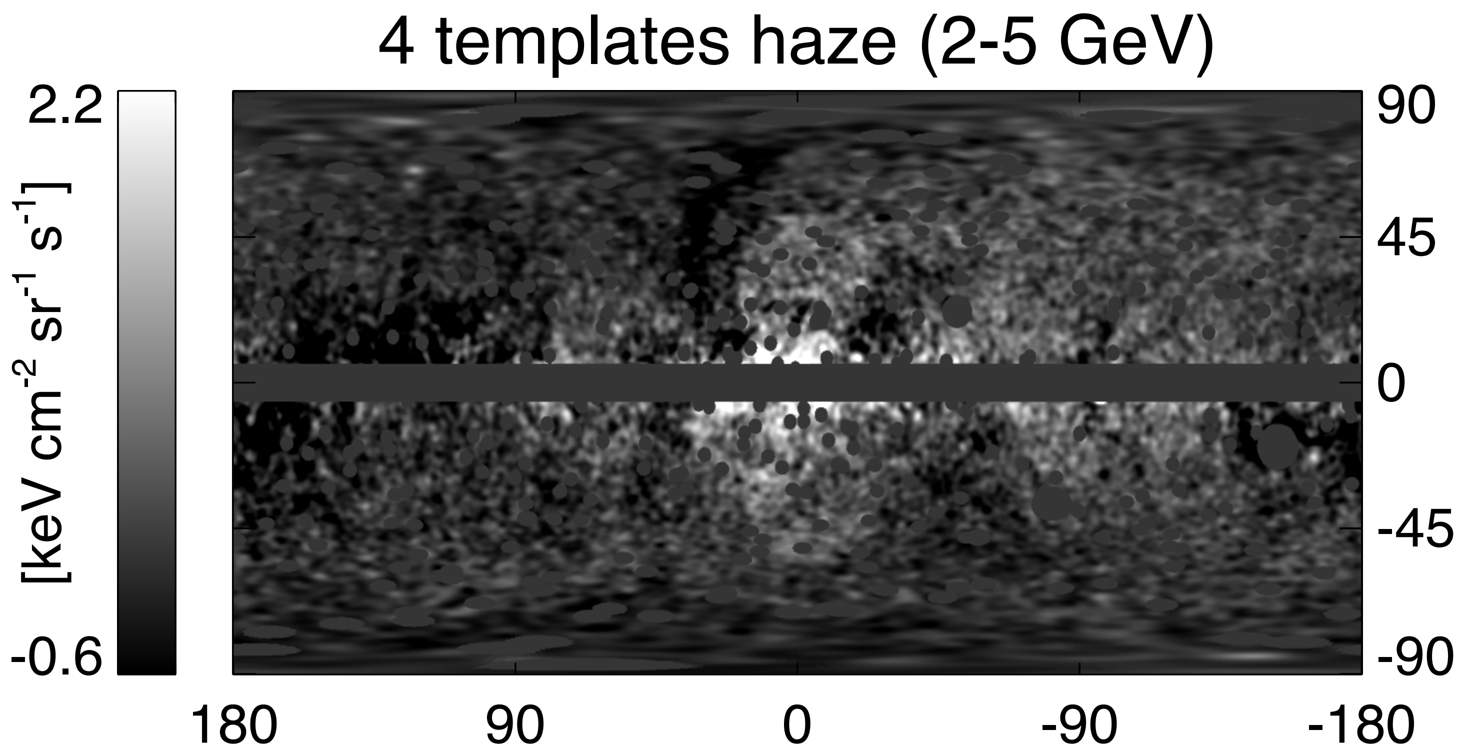
Harder than typical galactic

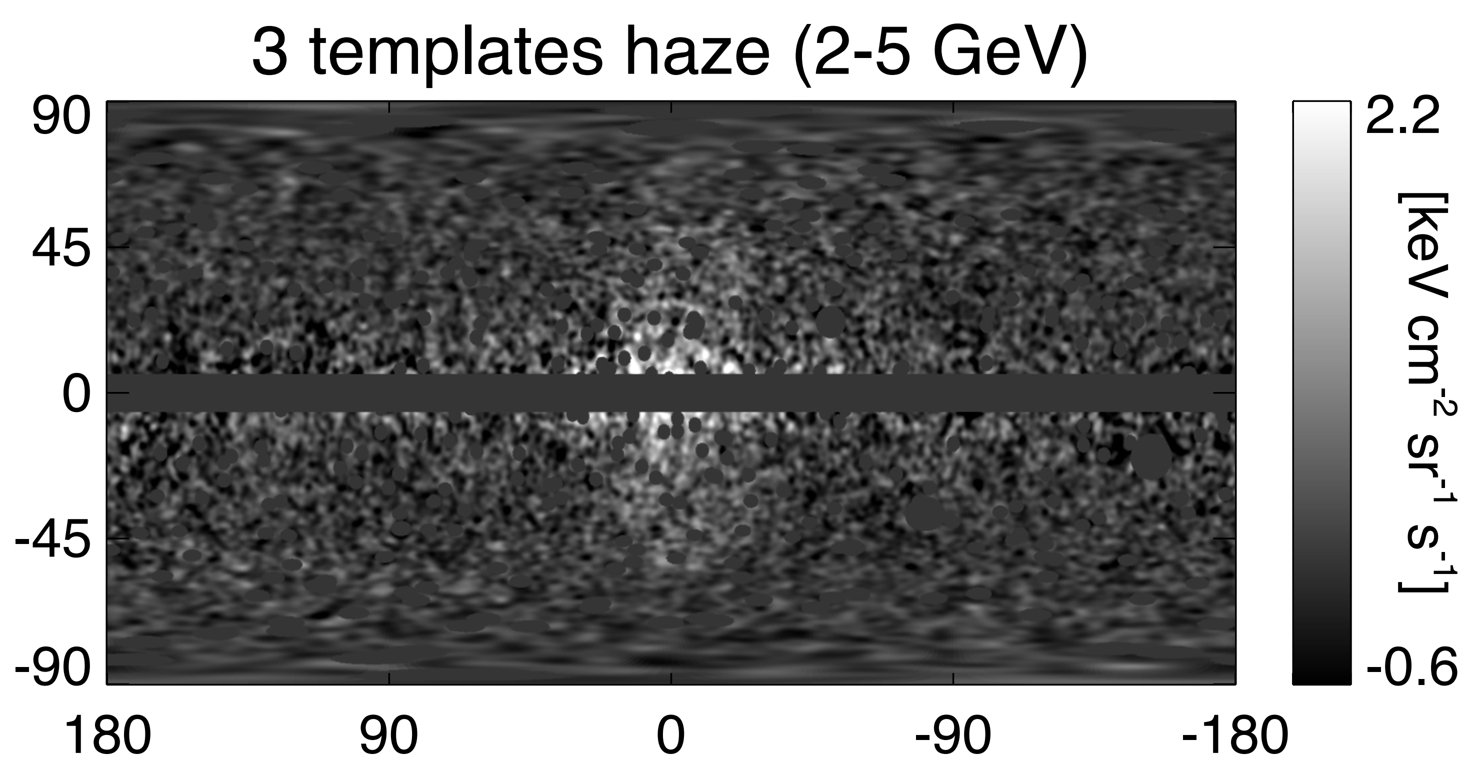
Su, Slatyer and Finkbeiner work

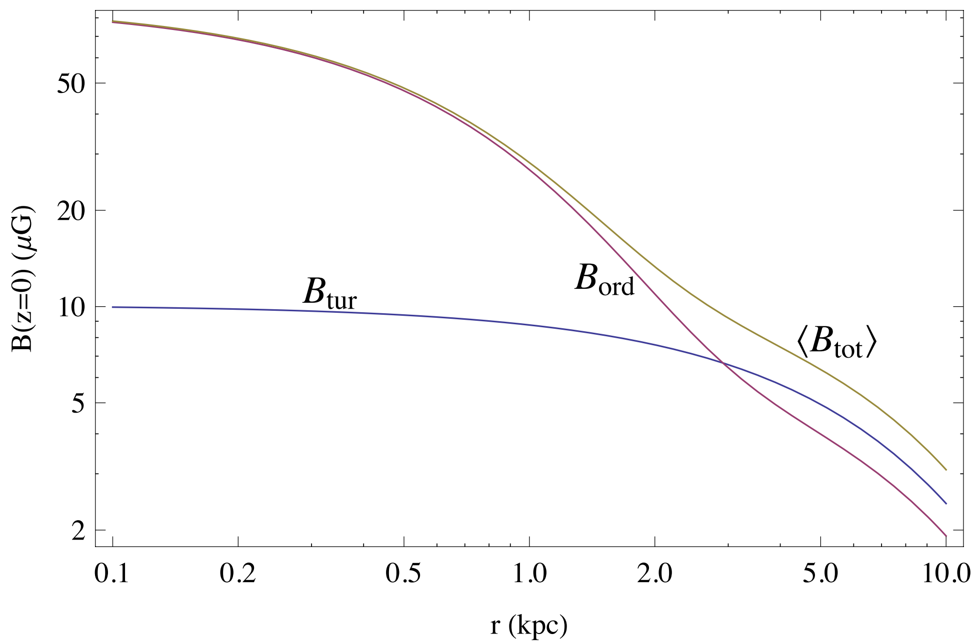
ApJ 724, 1044 (2010) (arXiv:1005.5480)

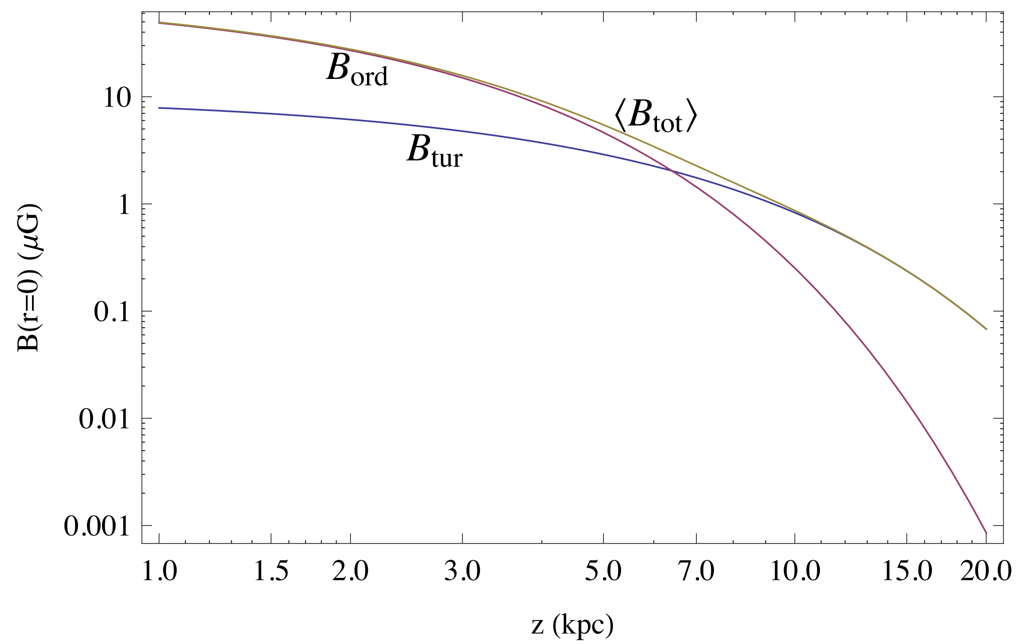


One needs to be very careful for small (but significant in the interpretation) caveats with using templates.









Yusef-Zadeh & Morris (1987), Morris & Yusef-Zadeh (1989), Morris (2007), have suggested mag. fields up to few mG in large non-thermal radio filaments (with widths of pc and lengths ~ 50pc). Beck (2008) suggested 0.5 mG. Those non-thermal filaments seen by VLA are directed perpendicular to the disk plane, and are probes of the general B-field properties, suggesting a predominantly bipolar field extending ~200pc in r (Nord et. al. (2004)).

Also arguments of CR cooling by synchrotron radiation in the inner 500pc have been used to avoid over-production of gamma-rays by ICS.