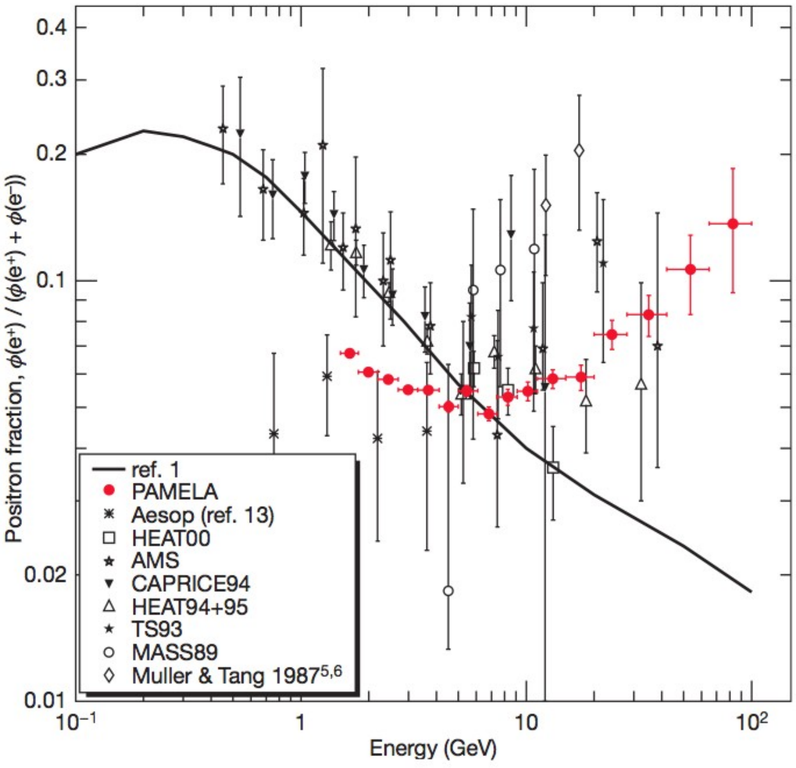
Indirect Detection of Dark Matter & Uncertainty in CR Propagation

P. Grajek

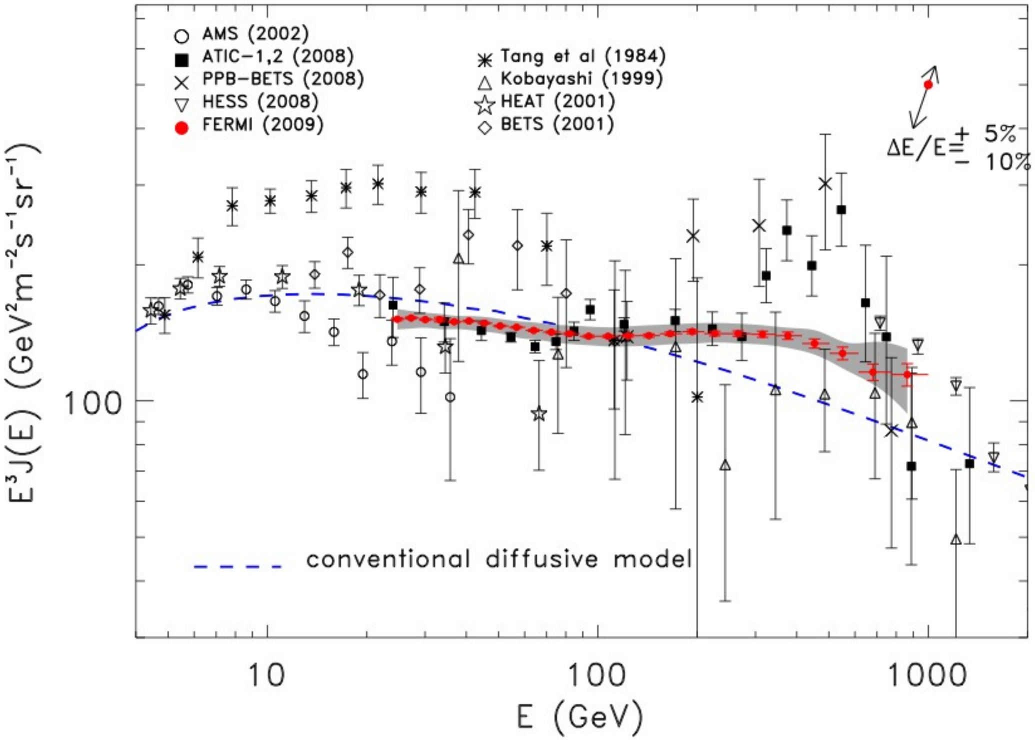
IIHE Seminar - 18 Feb 2010

Motivation

PAMELA Collab., Nature 458 (2009) 607-609



FERMI Collab., Phys.Rev.Lett.102:181101,2009



Several experiments report an anomalous signal.
(PAMELA, FERMI, ATIC, DAMA/LIBRA)

Explanations?

Motivation

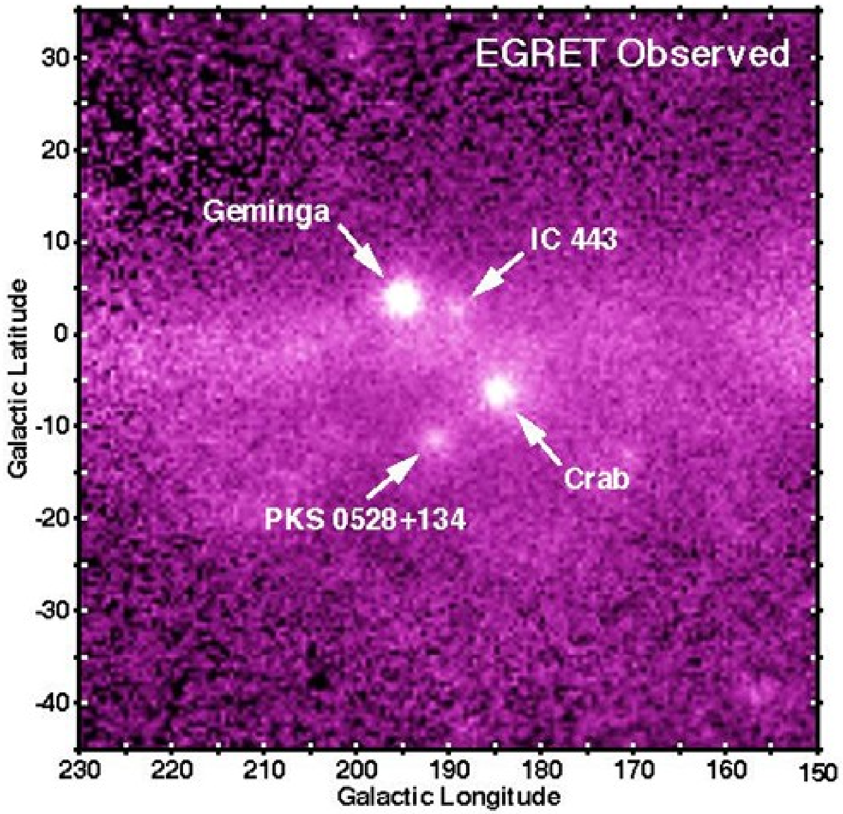
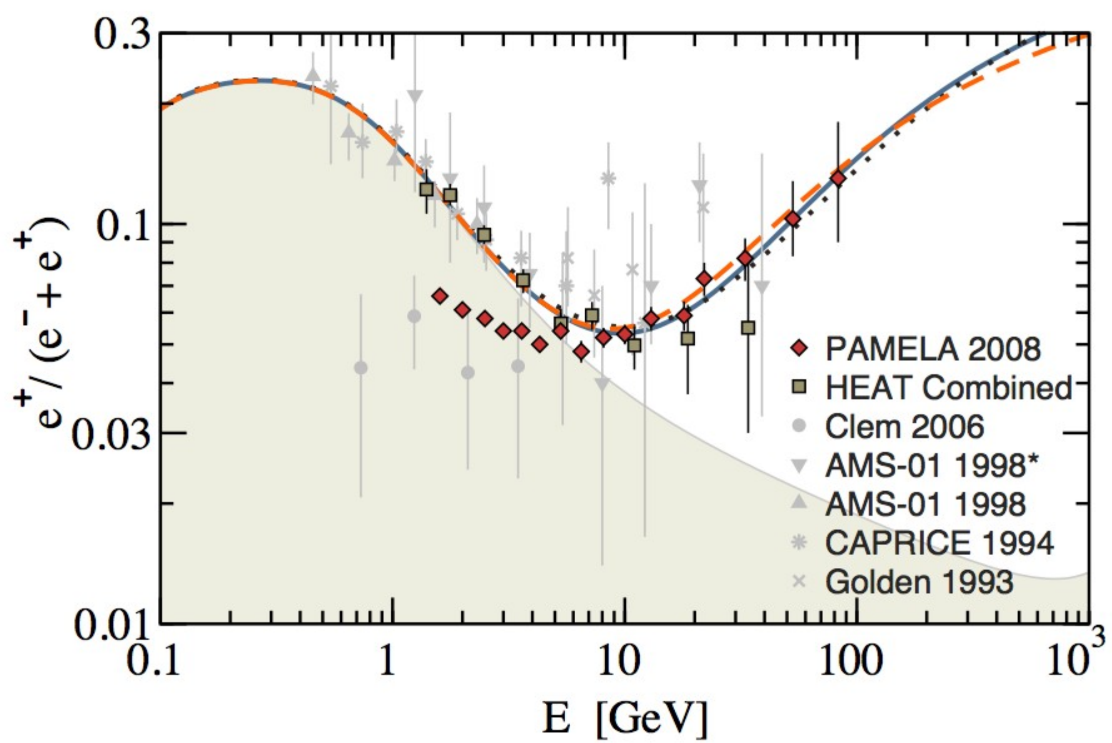


image: NASA (http://heasarc.nasa.gov/docs/cgro/cgro/egret_anti.html)

Yuksel, Kistler, Stanev, Phys.Rev.Lett. 103 (2009) 051101



Astrophysical?

Pulsars, GRB, SNr all possible

FERMI may shed light on this in a few years...

Motivation

Exotic (new) physics?

DM may exist as '**WIMPs**'

$$\chi + \chi \rightarrow q\,\bar{q}\,, W^{+}\,W^{-} \rightarrow e^{+}\,\bar{p}\,, \bar{D}\,, \gamma\,, \ldots$$

MSSM + R-Parity: *Neutralino LSP* the “classic” candidate

Thermal Relic: $\left(\Omega_{cdm} h^2 \approx 0.1109\right)$ $\langle \sigma^2_{\chi\chi} v \rangle \approx 3 \times 10^{-26}\, cm^3/s$

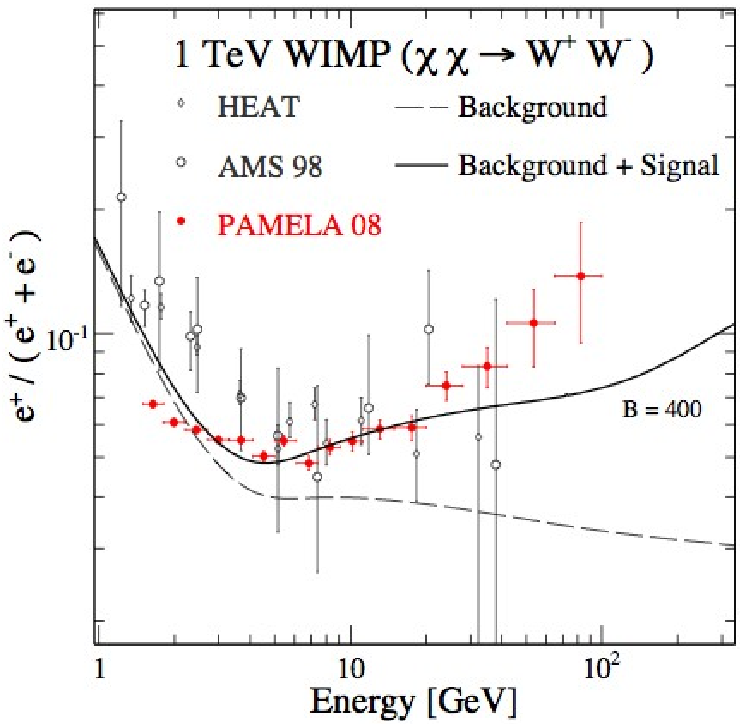
Required to reproduce excess: $\langle \sigma^2_{\chi\chi} v \rangle \approx O\left(10^{-24}\right) cm^3/s$

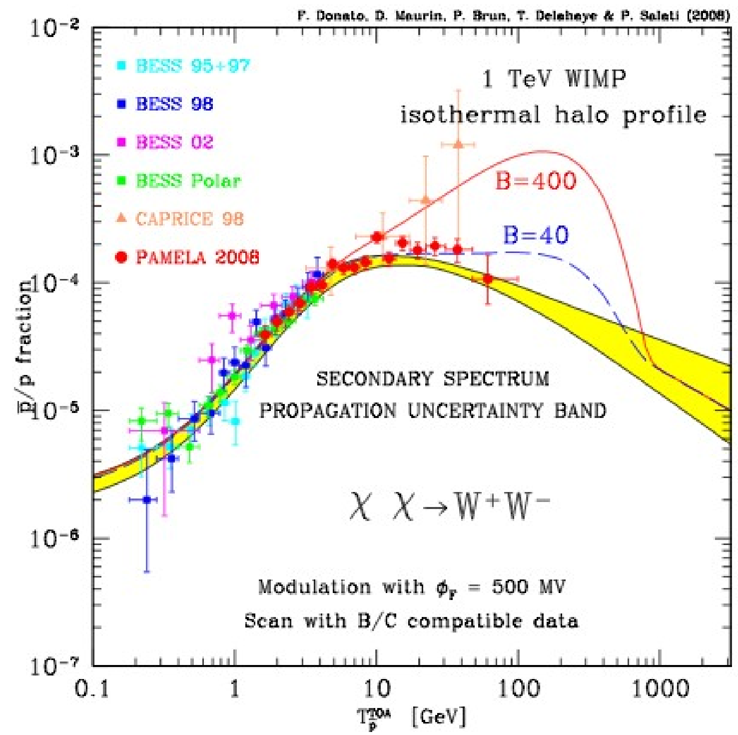
Need to **boost** the cross section somehow....

- Clumpy halo distribution,
- Sommerfeld Enhancement,
- Non-thermal production

Motivation

Problem: Anti-protons are enhanced as well...





[Donato, et. al., Phys.Rev.Lett. 102 (2009) 071301]

Alternative scenarios: Leptophilic DM, Axions, etc..

A Question: How well do we understand { ***backgrounds***? ***CR propagation***? }

Cosmic Rays

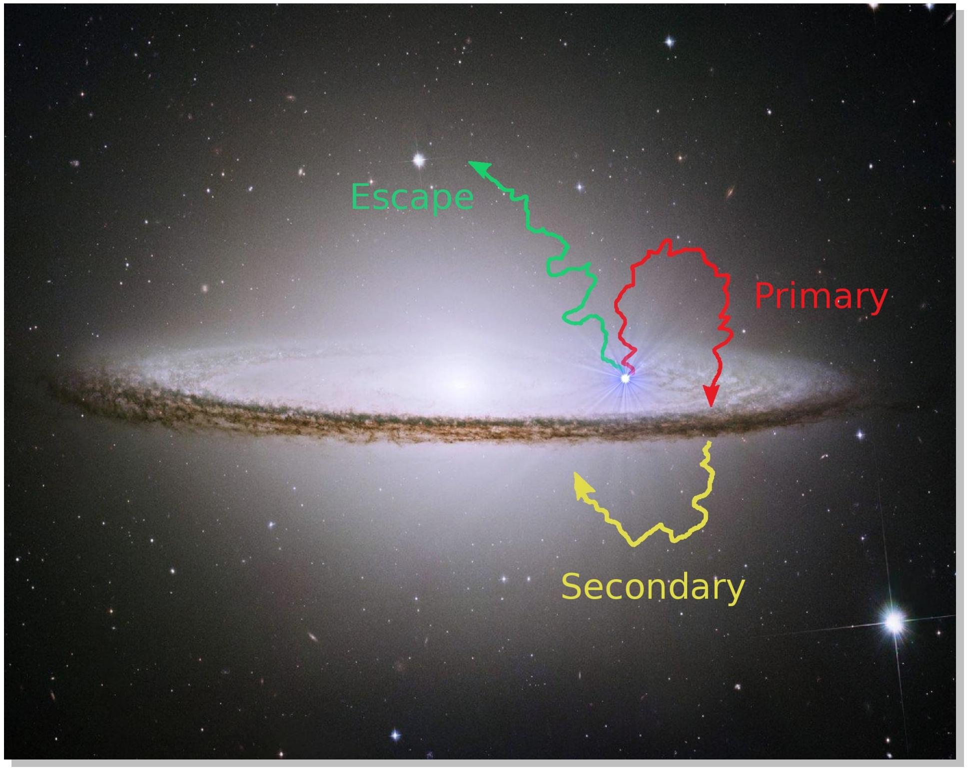
- Astophysical CR accelerated in shock front of SNe [DSA]

- Once launched, interact with complex magnetic fields

- CR scatter off of (*Alfven*) turbulences in B-field:

D i f f u s i o n

- Thermal/CR-driven galactic winds likely also play a role



- **Primaries** produce **secondaries** via interaction with matter/gas in disk. Many crossings in lifetime. Escape halo after 10^7 yr.

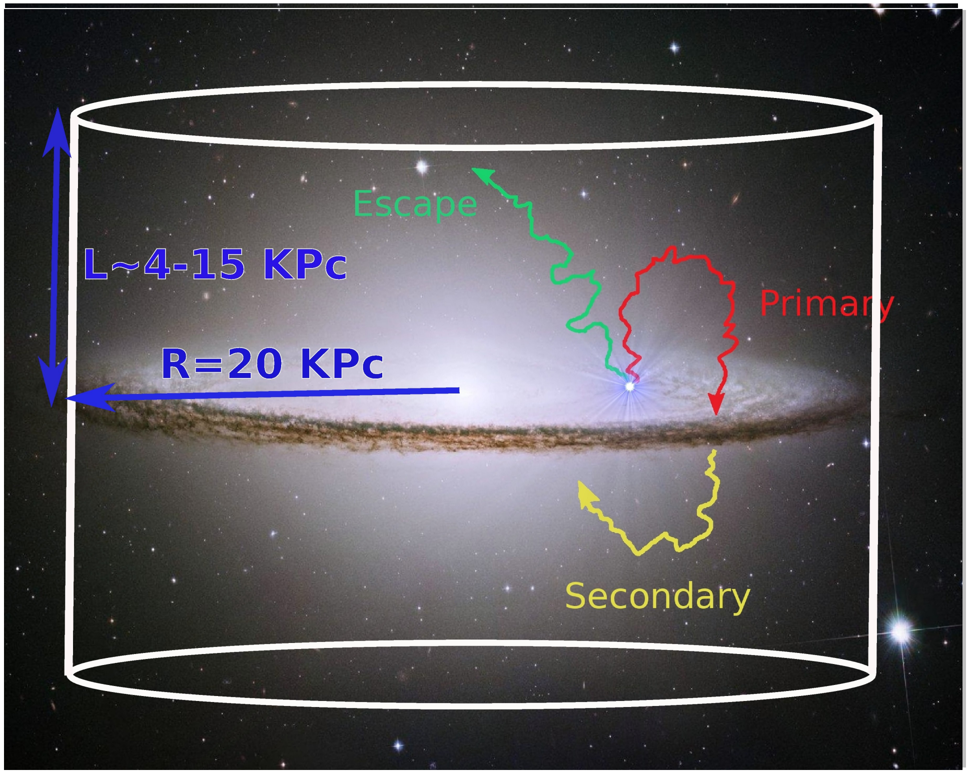
Cosmic Rays

How is this modelled?

- Assume cylindrical symmetry

- Max radial distance ~20 KPc

- Max height z_{max} not well constrained



- Free escape boundary conditions at edge

Abrupt transition to free space [no diffusive scattering]

Transport Equation

$$\frac{\partial \Psi}{\partial t} = q(\boldsymbol{r}, t) + \nabla \cdot D_{xx} \nabla \Psi - \nabla \cdot (\boldsymbol{V} \Psi) + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \Psi$$

$$- \frac{\partial}{\partial p} \left(\dot{p} \Psi \right) + \frac{\partial}{\partial p} \left[\frac{p}{3} (\nabla \cdot \boldsymbol{V}) \Psi \right] - \frac{1}{\tau_f} \Psi - \frac{1}{\tau_r} \Psi$$

Transport Equation

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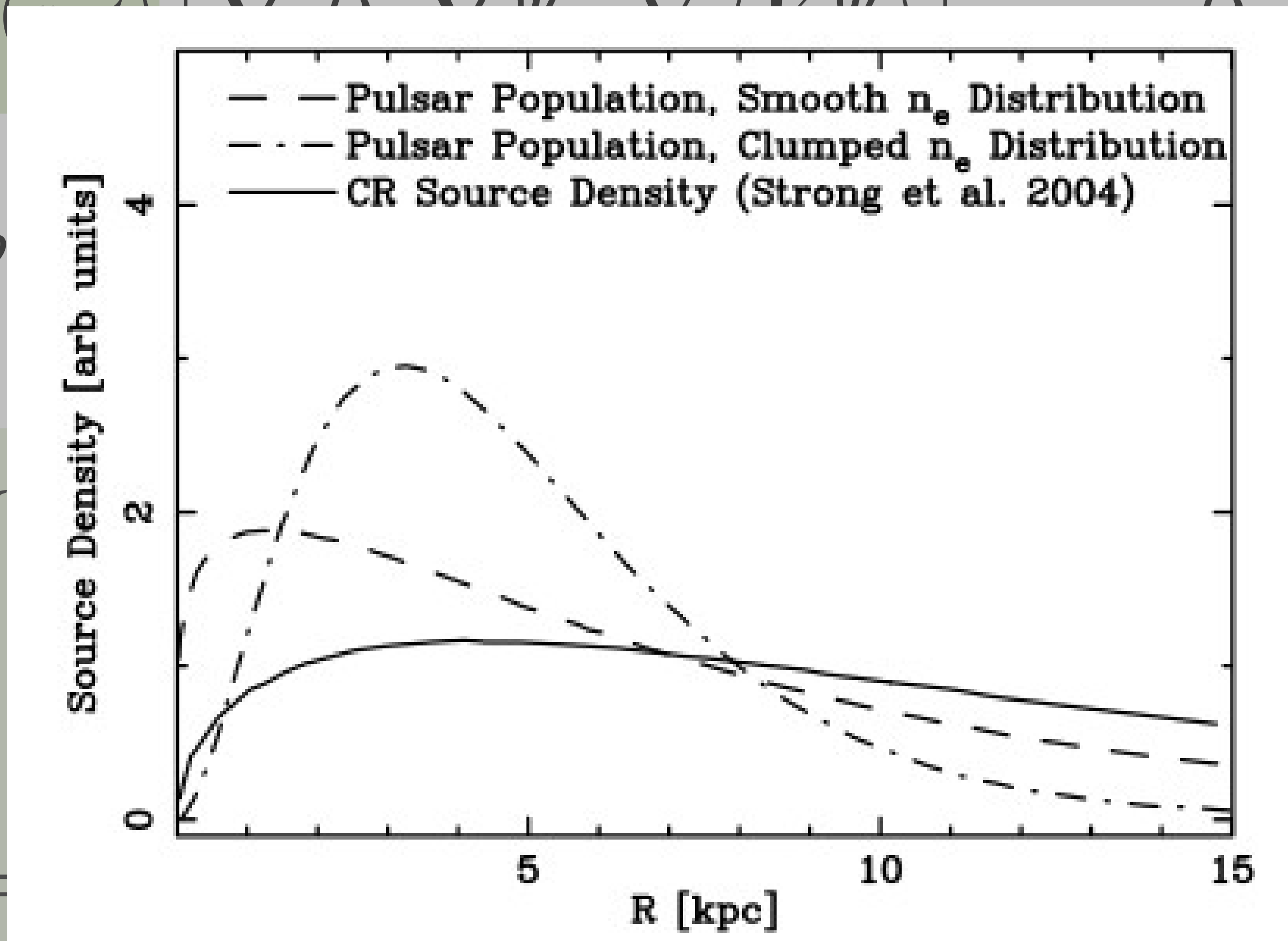
$\Psi \rightarrow \Psi(\vec{r}, p, t)$ CR density per unit particle momentum

$q(\vec{r}, t)$ Source term: Inc. primary + secondary contributions

Transport Equation

$$\frac{\partial \Psi}{\partial t} = q(\ldots \quad \ldots \frac{\partial}{\partial p}\frac{1}{p^2}\Psi$$

$$-\frac{\partial}{\partial p}(\dot{p} \ldots$$



$\Psi \rightarrow \Psi$ … omentum

… econdary

$q(r, z) =$ … $= 3.33$

… $= 0.2\,kpc$

Transport Equation

$$\frac{\partial \Psi}{\partial t} = q(\boldsymbol{r}, t) + \boldsymbol{\nabla} \cdot D_{xx} \boldsymbol{\nabla} \Psi - \nabla \cdot (\boldsymbol{V} \Psi) + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \Psi$$

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$\nabla \cdot (D_{xx} \nabla \Psi)$ Spatial diffusion term

$D_{xx} = \beta D_0 \left(\frac{\rho}{\rho_0} \right)^{\delta}$ Diffusion coefficient - usually assumed **independent of position / isotropic**

Index associated with power spectrum of turbulence

$\delta = 1/3$ Kolmogorov $\quad$ $\delta = 1/2$ Kraichnan

Transport Equation

$$\frac{\partial \Psi}{\partial t} = q(\boldsymbol{r}, t) + \nabla \cdot D_{xx} \nabla \Psi - \nabla \cdot (\boldsymbol{V} \Psi) + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \Psi$$

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$\nabla \cdot (\boldsymbol{V} \Psi)$ Convective transport via galactic wind

$\boldsymbol{V} = \hat{\boldsymbol{z}} \left(V_0 + \frac{dV}{dz} \cdot z \right)$ Wind velocity perpendicular to galactic plane

$\frac{\partial}{\partial p} \frac{p}{3} (\nabla \cdot \boldsymbol{V}) \Psi$ Wind gradient gives rise to adiabatic energy loss

Transport Equation

$$\frac{\partial \Psi}{\partial t} = q(\boldsymbol{r}, t) + \boldsymbol{\nabla} \cdot D_{xx} \boldsymbol{\nabla} \Psi - \nabla \cdot (\boldsymbol{V} \Psi) + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \Psi$$

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Moving Alfven waves give rise to momentum diffusion

$$\frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \Psi$$

Reacceleration Term
(stochastic acceleration)

$$D_{pp} D_{xx} \propto p^2 v_a^2$$

Transport Equation

$$\frac{\partial \Psi}{\partial t} = q(\boldsymbol{r}, t) + \nabla \cdot D_{xx} \nabla \Psi - \nabla \cdot (\boldsymbol{V} \Psi) + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \Psi$$

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$$\frac{-\partial}{\partial p}(\dot{p} \Psi)$$

Momentum loss due to ionization,
brems., inverse Compton

$$-\frac{1}{\tau_f} \Psi - \frac{1}{\tau_r} \Psi$$

Loss due to particle fragmentation
+ radioactive decay

Transport Equation

$$\frac{\partial \Psi}{\partial t} = q(\boldsymbol{r}, t) + \nabla \cdot D_{xx} \nabla \Psi - \nabla \cdot (\boldsymbol{V} \Psi) + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \Psi$$

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Analytic solution only with significant assumptions

via Green's function if no convection and no re-acceleration.

Fully Numerical: **GALPROP**

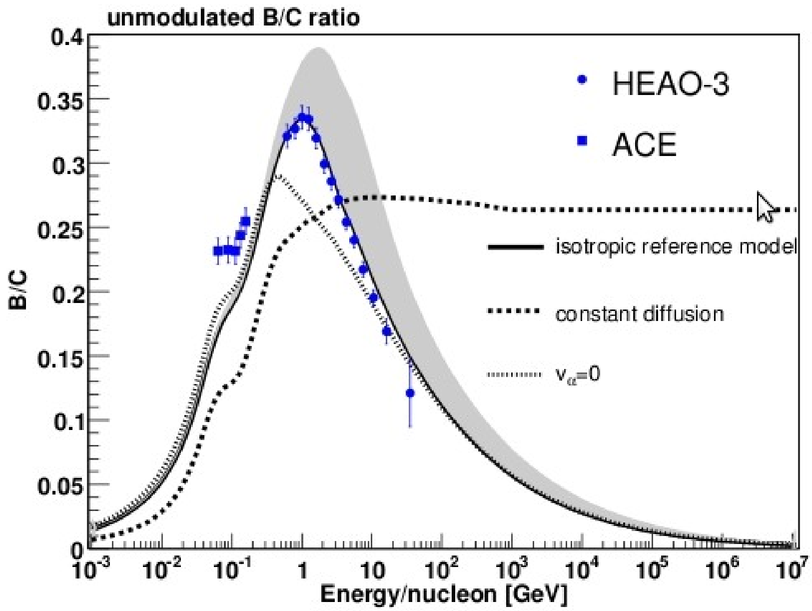
[Moskalenko, Strong, Astrophys. J. 493 (1998) 694–707]

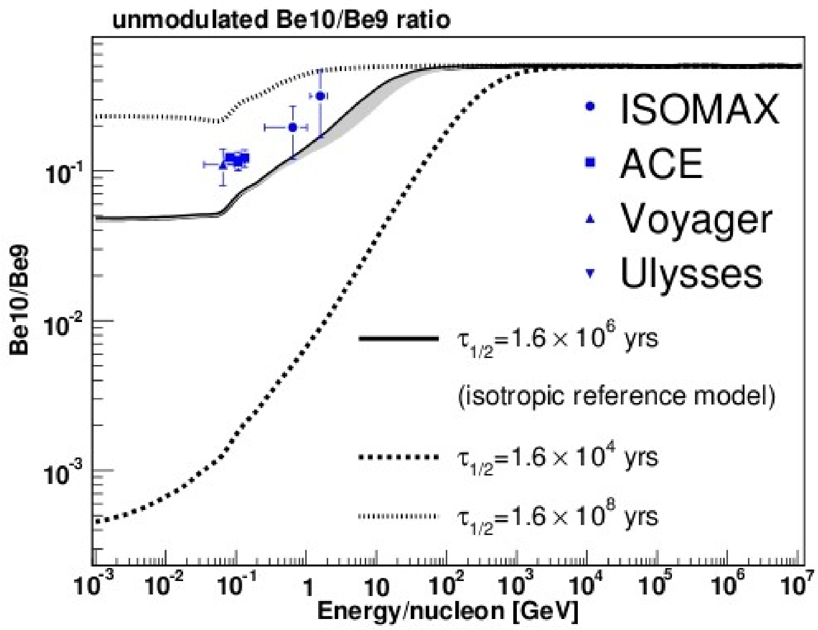
Accurate ISRF / B-Fields, gas-maps, spallation cross-sections.

Alternative (?) **DRAGON** [Evoli, Gaggero, Grasso, Maccione., JCAP 0810 (2008) 018]

Setting Parameters

Parameters are fixed using data: $\{D_0, \delta, v_A, V_{0,} dV/dz, L\}$





[Gebauer, de Boer, arXiv:0910.2027 [astro-ph.GA]]

$$D \sim 4\times10^{28} - 6\times10^{28}\, cm^2/s \qquad v_A \sim 30 - 40\, km/s$$

$$\delta \sim 0.33 - 0.6 \qquad L \sim 4 - 15\, kpc$$

$$dV/dz \sim 10\, km/s/kpc \qquad V_0 \leq 20\, km/s$$

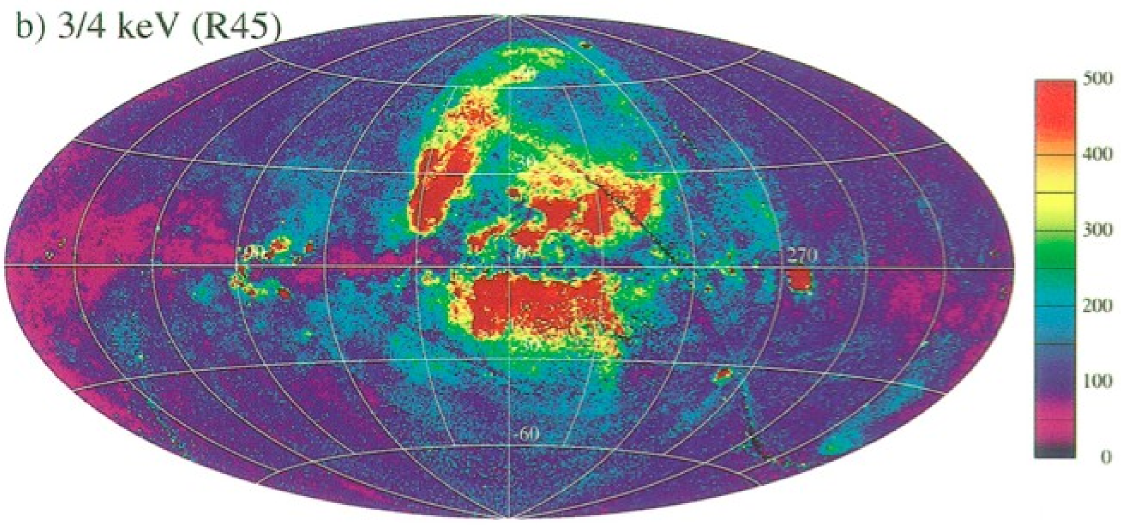
Some Problems

This "standard model" works well...agreement with many measurements

However, galactic wind velocities cannot be **too large**

For a long time this was considered okay:
no evidence that Milky Way exhibited a galactic wind

However: ROSAT experiment measured an enhanced X-ray emission toward galactic center.



[Snowden, et. al., Astro.Phys.J 1997, 485, 125]

This emission is best modeled with a thermal + CR-driven **galactic wind** with moderate velocity

[Everett, et. al., Astro.Phys.J 2008, 674, 258]

$$173 \leq |V_{conv}| \leq 760\, km/s$$

Some Problems

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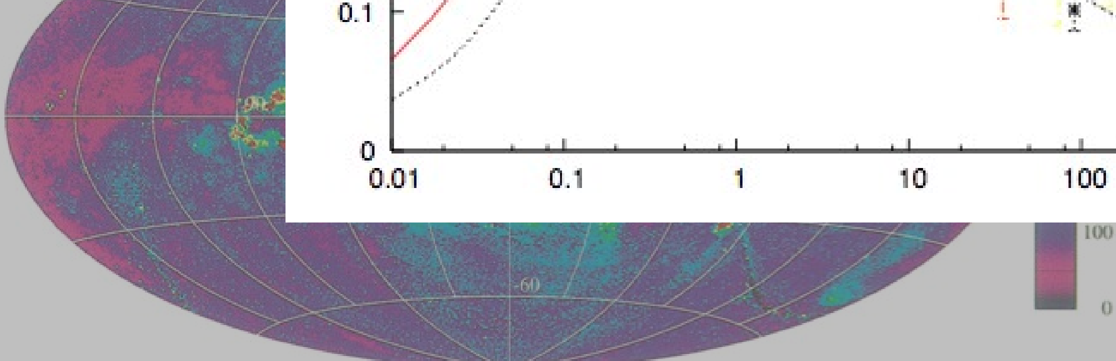

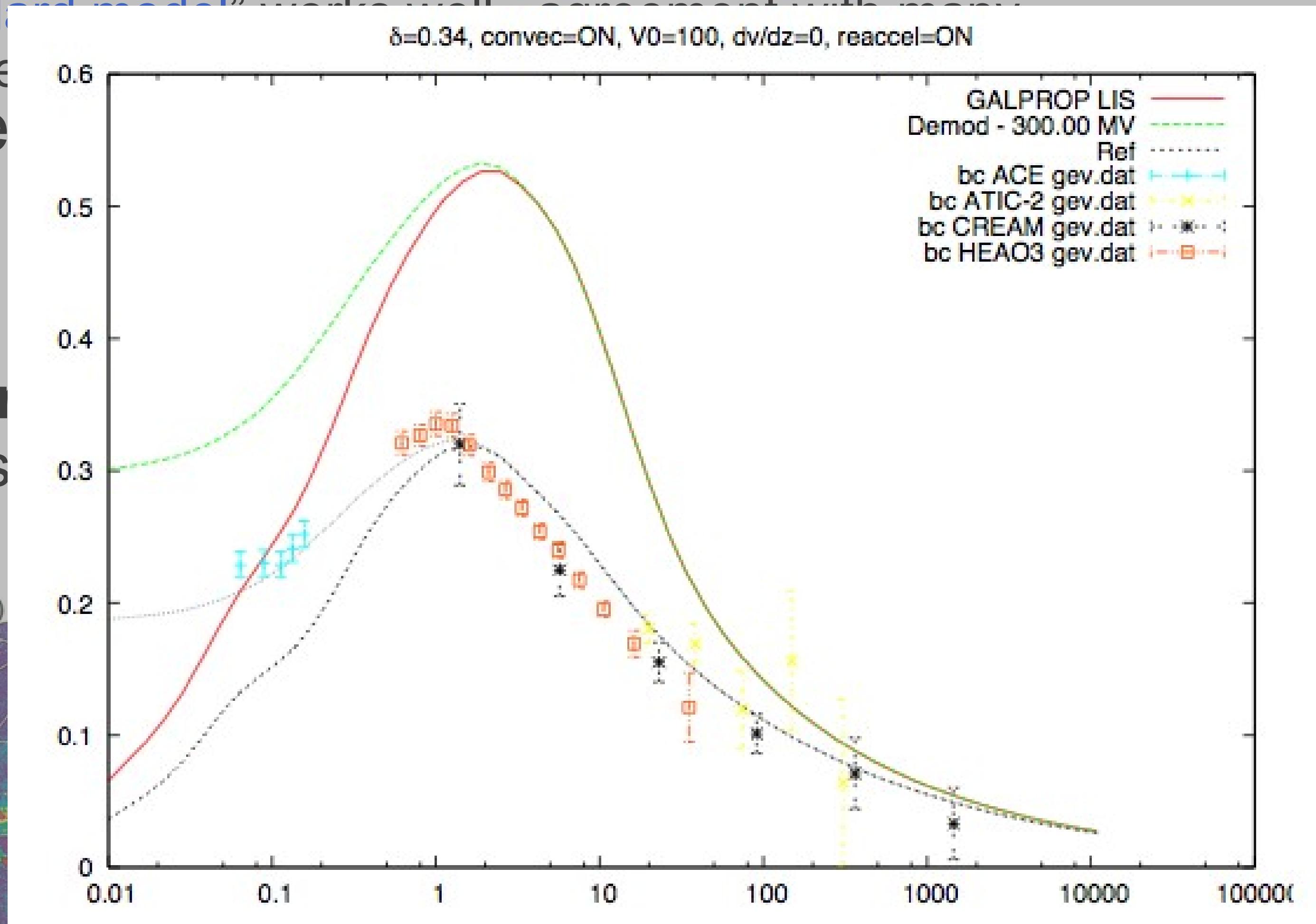

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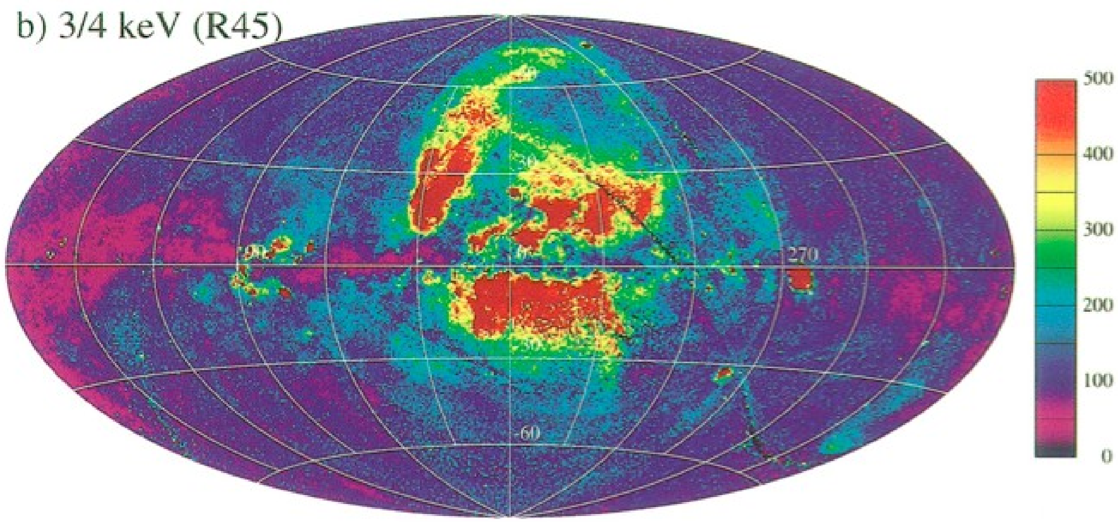

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The SOFT γ-RAY GRADIENT

SNR (pulsar) source distribution peaks **towards galactic center**

>50 MeV Photon emission dominated by CR interactions with ISM

Naively: Photon emission intensity **should follow SNR distribution**

IT DOESN'T: EGRET, COS-B observed soft gradient

Can be explained by strong "mixing" due to convective winds.

[Breitschwerdt, Dogiel, Volk, A&A 2002, 385, 216]

Some Problems

INTEGRAL Bulge/Disk Ratio

Type-1a SN can produce copious positrons via β-decay of ^{56}Co

Annihilation with electrons observed through 511 keV line emission

SN1a concentration higher in disk than galactic bulge

&

Low energy positrons don't diffuse significantly:
$$D_{xx} = \beta D_0 (\rho / \rho_0)^\delta$$

SO, expect annihilation close to sources

Computed annihilation rate in bulge/disk ~ 0.1
INTEGRAL observed B/D ~ 5

Radially-dependent galactic wind transports positrons from disk to bulge.
[N. Prantzos, A&A, 449, 869 (2006)]

Anisotropic Diffusion

Ultimately need to **include higher velocity galactic winds**.

>>>> **Spatially dependent**, ***ANISOTROPIC*** diffusion.

[Gebauer, de Boer, arXiv:0910.2027 [astro-ph.GA]]

$$D_{xx} = \beta D_0 (\rho / \rho_0)^{\delta} \quad \rightarrow \quad D_{xx} = \beta D_0 (\rho / \rho_0)^{\delta} |z|$$

Here the **density** of scattering centers **DECREASES** with distance away from the galactic disk

Assuming $V = \hat{z}(V_0 + \frac{dV}{dz} \cdot z)$ transport in z-direction: $\frac{\partial \Psi}{\partial t} = q(\boldsymbol{r}, t) + \nabla \cdot D_{xx} \nabla \Psi - \nabla \cdot (V \Psi)$

$$\left[\frac{\partial D_{xx}}{\partial z} - V_0 - \frac{dV}{dz} \cdot z \right] \frac{\partial \Psi}{\partial z} + D_{xx} \frac{\partial^2 \Psi}{\partial z^2} - \frac{dV}{dz} \Psi = \frac{d \Psi}{dt}$$

Anisotropic Diffusion

- This approach is **VERY NATURAL**

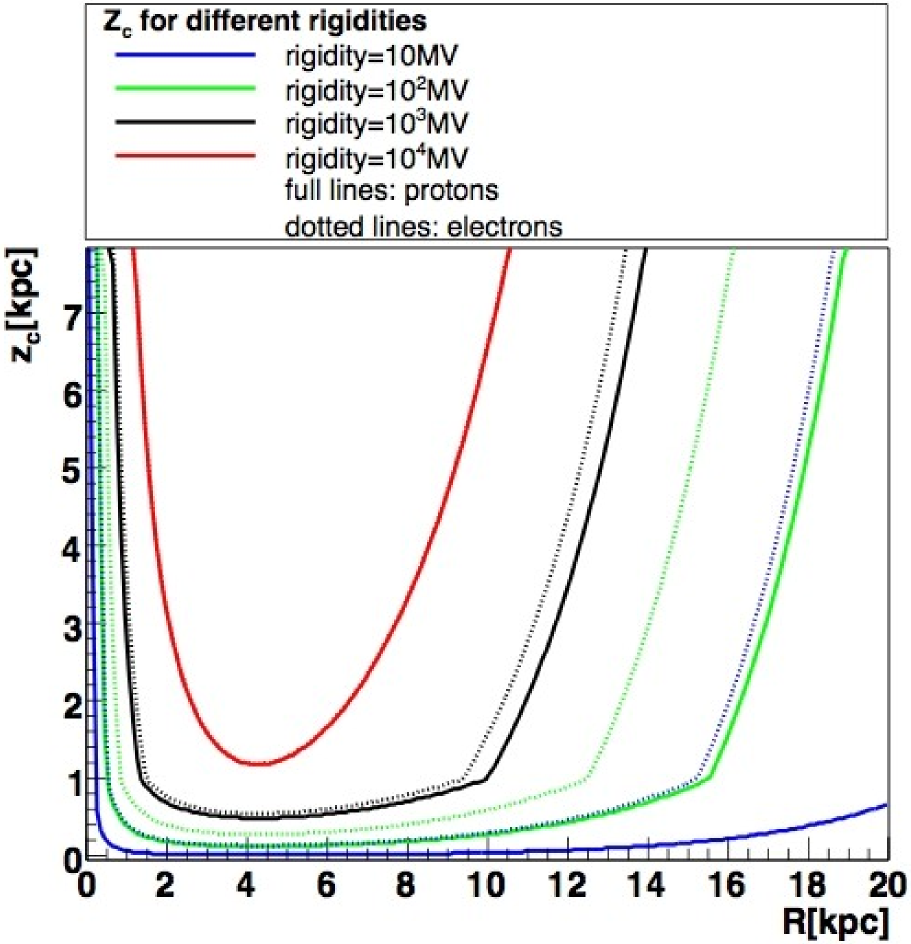
Diffusion intensity transitions **SMOOTHLY** to free space

- No longer sensitive to cylinder height

Instead:

DIFFUSION/CONVECTION BOUNDARY

$$Z \sim D_{xx} / V_c$$

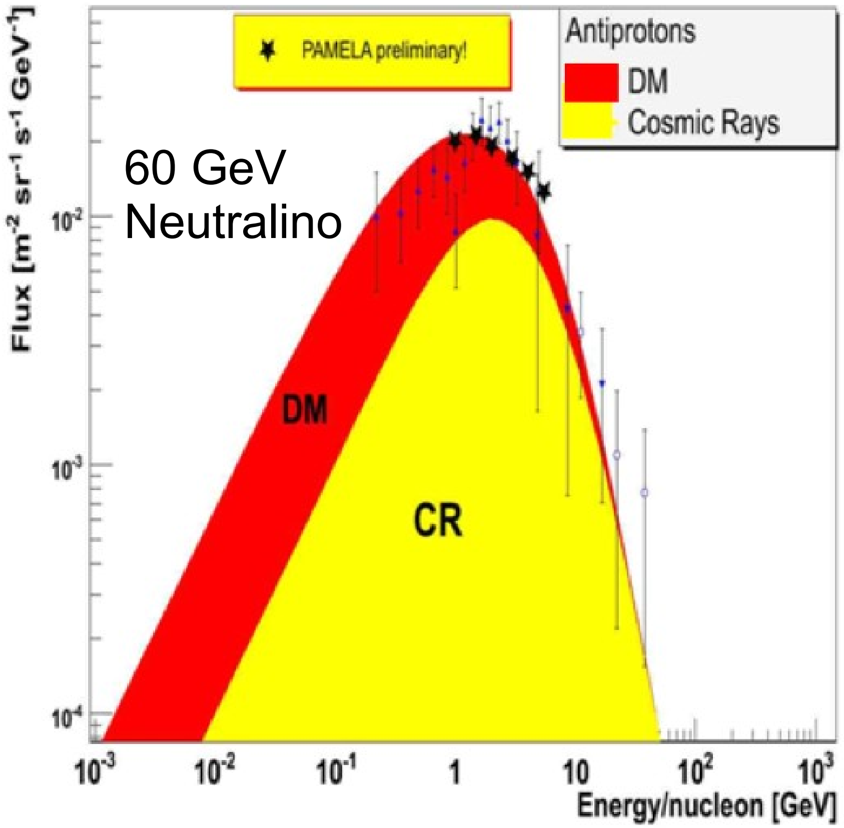


[Gebauer, de Boer, arXiv:0910.2027 [astro-ph.GA]]

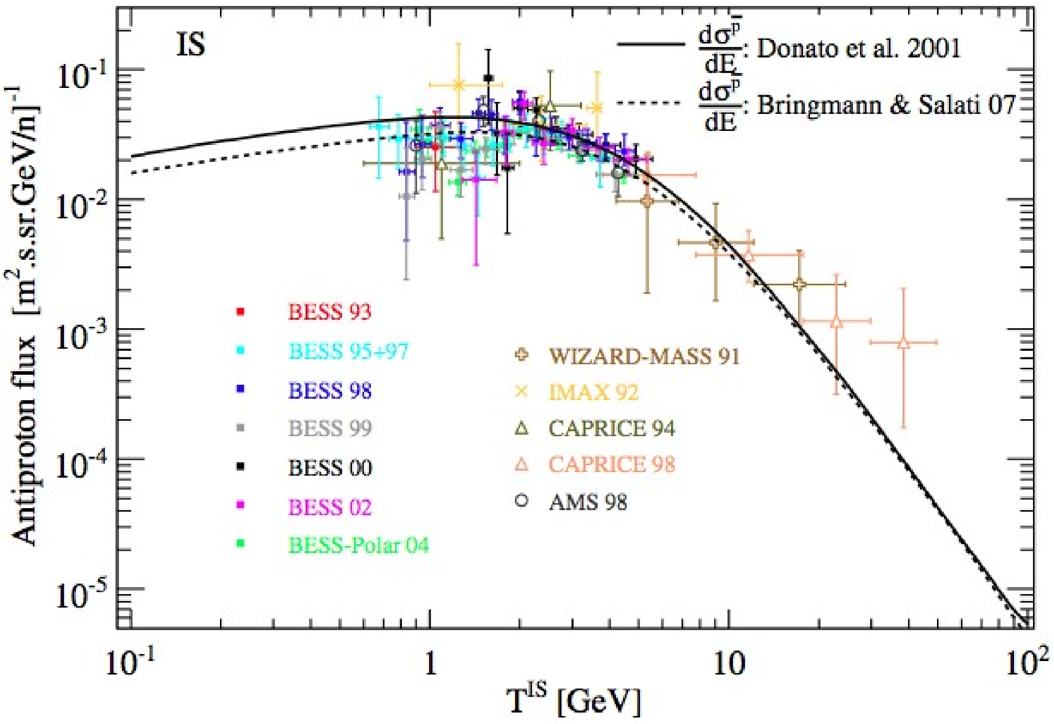
Anisotropic Diffusion

An interesting outcome:

REDUCTION in Anti-Proton Background



[de Boer, arXiv:0910.2601 [astro-ph.CO]]



[Donato, et. al., Phys.Rev.Lett. 102 (2009) 071301]

Fits to Data

Modifications to GALPROP v50.1

Convective Wind:

$$V(r,z) = Q(r)\left(V_0 + \frac{dV}{dz}\cdot z\right)$$

$$V_0 = 100\, km/s$$

$$\frac{dV}{dz} = 35\, km/s/kpc$$

} Compatible with ROSAT

$$Q(r,z) = \left(\frac{r}{r_0}\right)^{\alpha} e^{-\beta(r-r_0)/r_0} e^{-|z|/z_s}$$

(Case & Bhattacharya)

$\alpha = 1.69$ $\beta = 3.33$

$r_0 = 8.5\, kpc$ $z_s = 0.2\, kpc$

Diffusion Coefficient:

$$D_{xx} = \beta D_0 (\rho/\rho_0)^{\delta} \qquad |z| < 1\, kpc$$

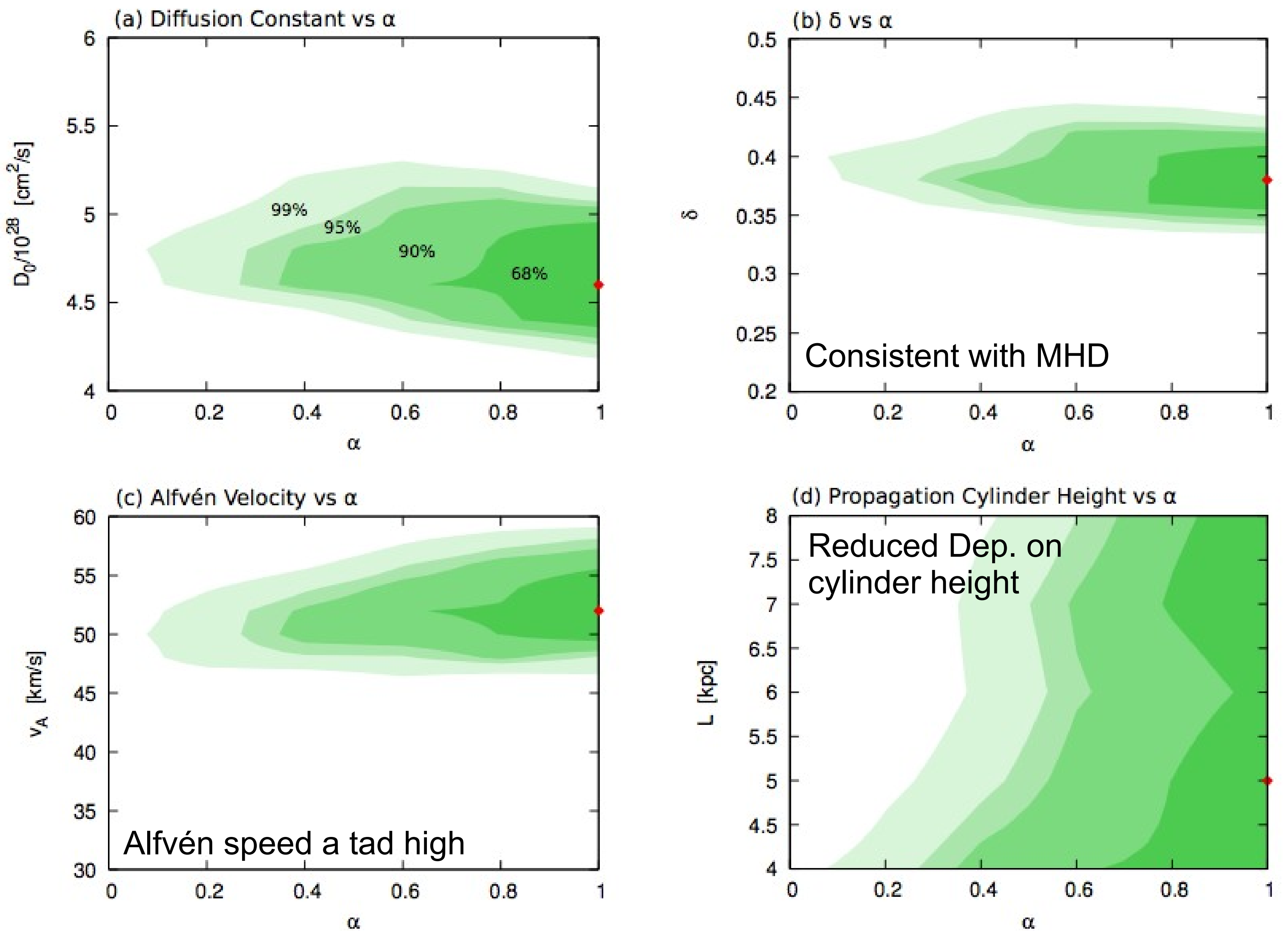
$$D_{xx} = \beta D_0 (\rho/\rho_0)^{\delta} |z|^{\alpha} \qquad |z| \geq 1\, kpc$$

Fits to Data

Combined Fit	Parameter	Best Fit Value	3σ Range
B/C, $^{10}Be/^{9}Be$ $\chi^2_{min}/n_{dof} = 38.3/31$	α	1.0	> 0.27
	D_0	4.6×10^{28} cm^2/s	4.3 - 5.1 $\times 10^{28}$ cm^2/s
	v_A	52 km/s	47 - 58 km/s
	δ	0.38	0.35 - 0.43
B/C, $^{10}Be/^{9}Be$, $\bar{p}/p$ $\chi^2_{min}/n_{dof} = 73.7/54$	α	1.0	> 0.51
	D_0	4.4×10^{28} cm^2/s	4.1 - 4.8 $\times 10^{28}$ cm^2/s
	v_A	46 km/s	43 - 49 km/s
	δ	0.36	0.33 - 0.38

With strong convection: Best fits occur with anisotropic diffusion coefficient.

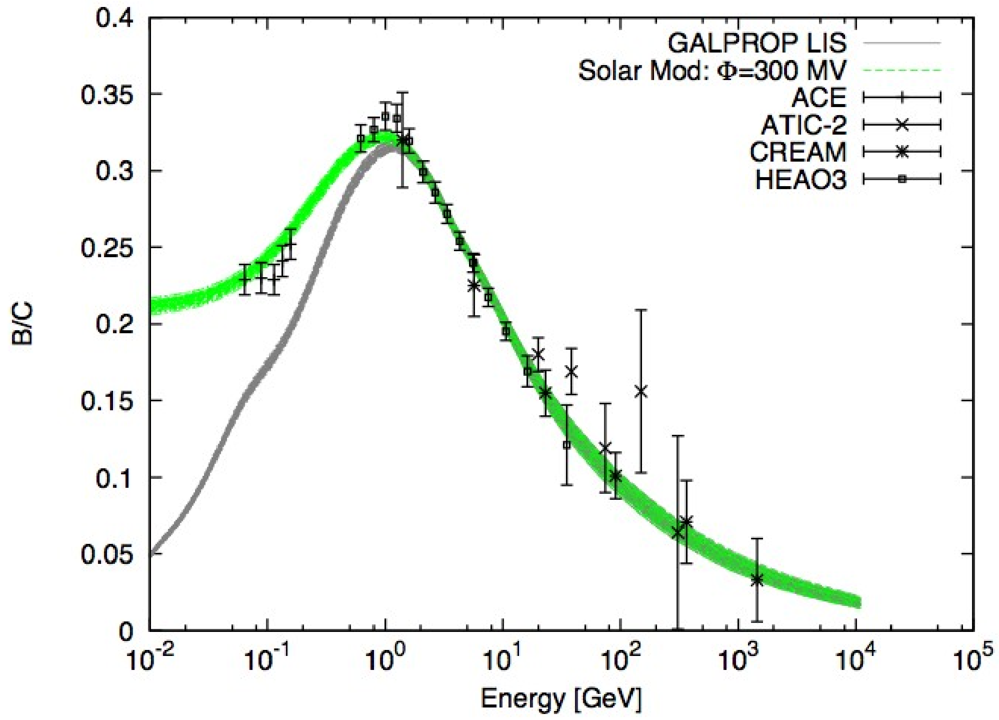
Fits to Data

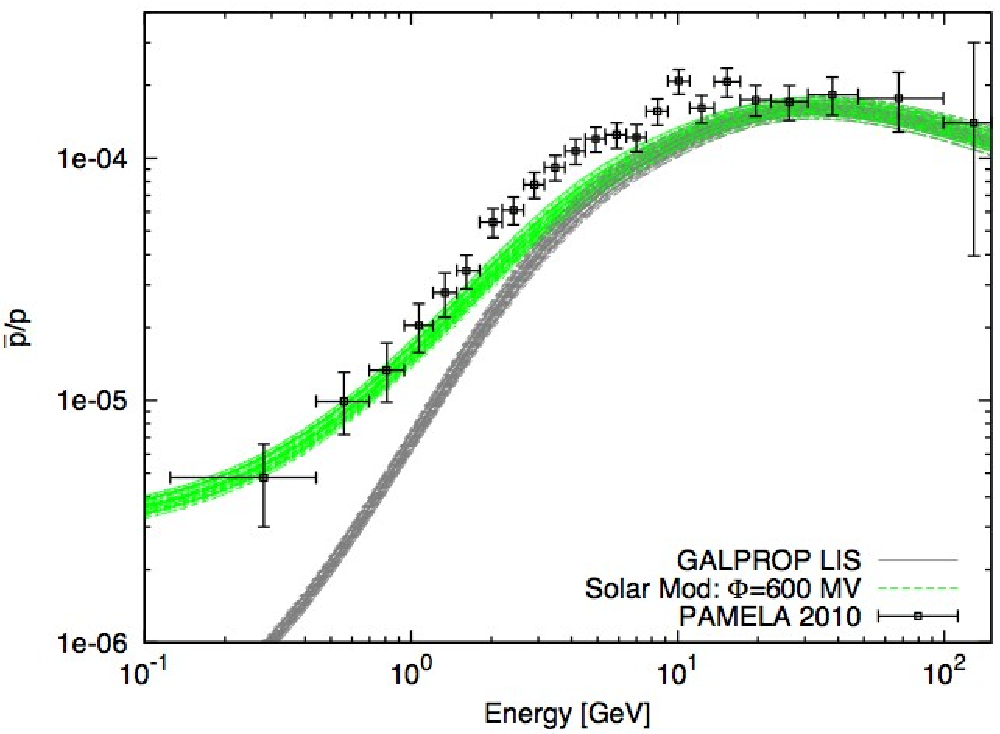


[PG, K. Hagiwara, arXiv 1012.0587 [astro-ph.HE]]

Fits to Data

Fit to B/C and Be^{10}/Be^{9}



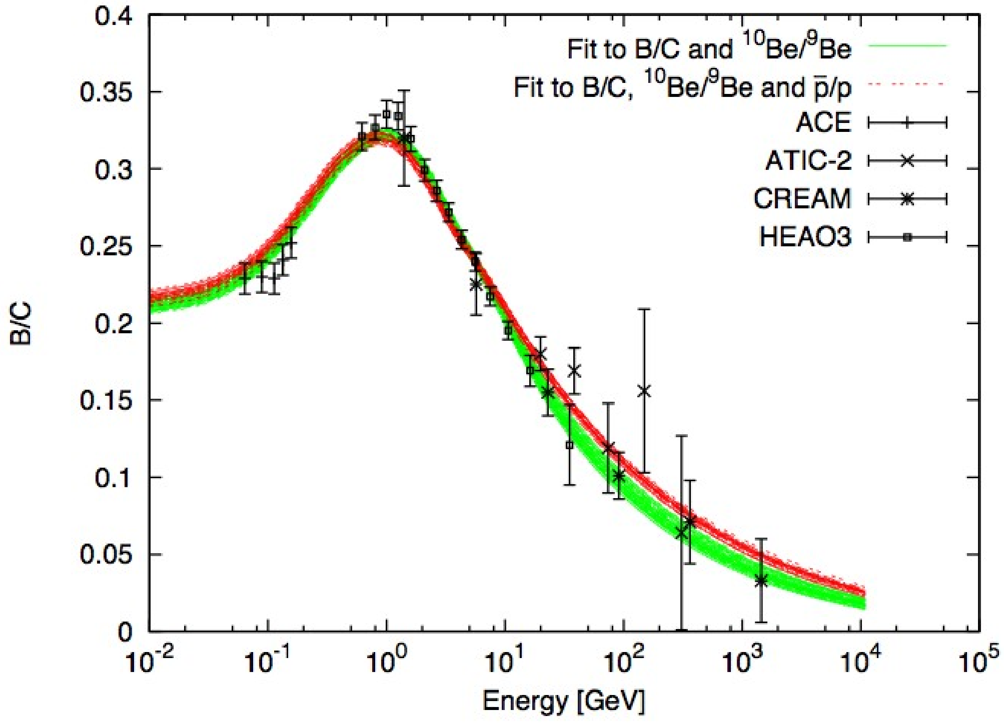


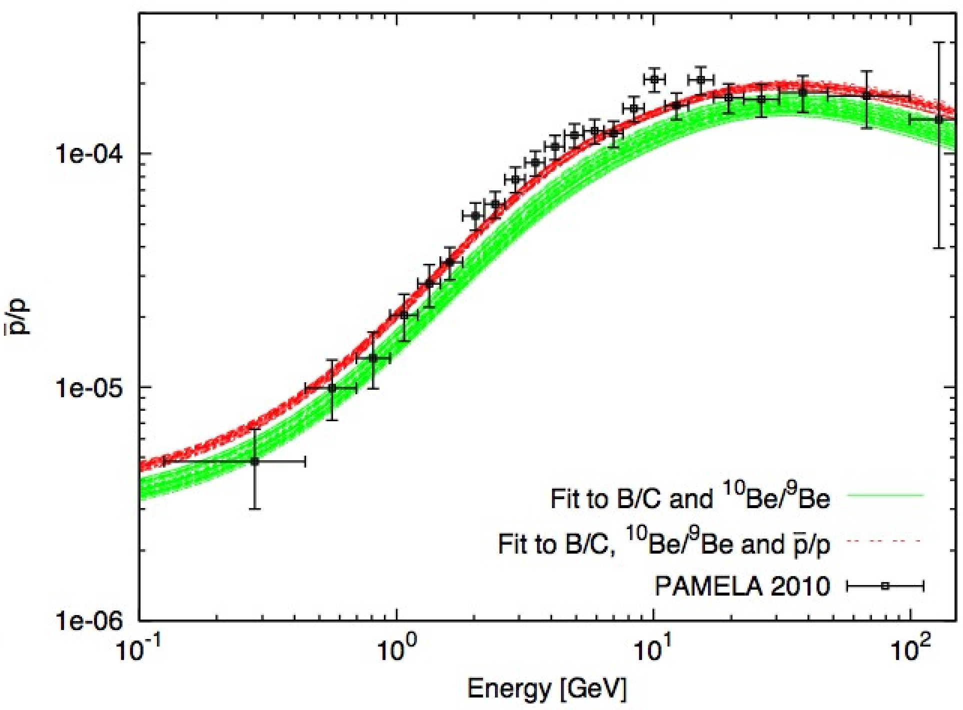
Decent fit to B/C

Excess in $\bar{p}/p$ flux

Fits to Data

Fit to PAMELA, B/C, Be^{10}/Be^{9}





Degraded fit to B/C

Marginal fit

Conclusions

- Hints that Milky Way drives a strong galactic wind - existing CR models cannot support this.

- Viable model with adoption of anisotropic diffusion

- Resulting reduced anti-protons means that a light neutralino is not ruled out?

- CR propagation (backgrounds) extremely important (overlooked by many?).