Antiproton Flux in Cosmic Ray Propagation Models with Anisotropic Diffusion

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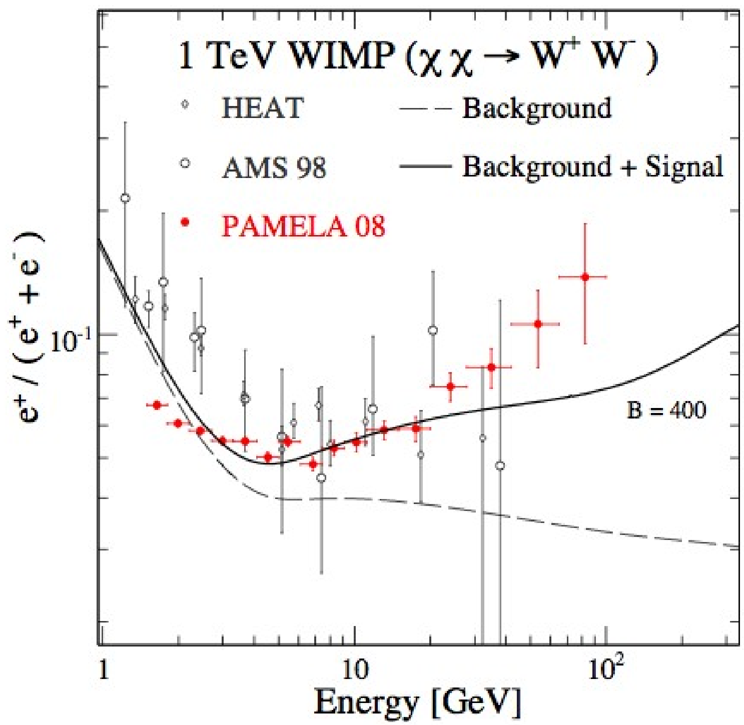
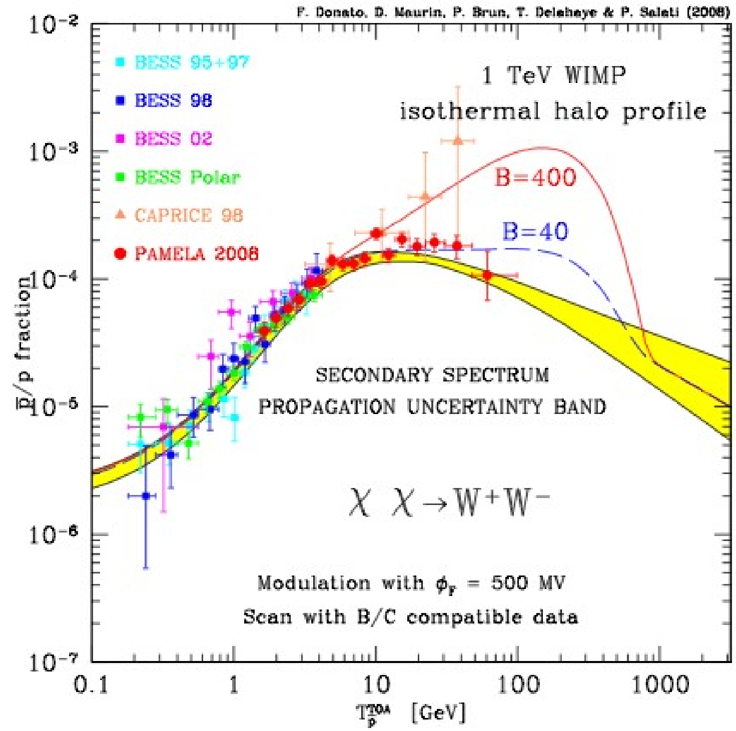
arXiv:1012.0587 [astro-ph.HE]

Pheno 2011

Motivation

- Antimatter excess observed above background (PAMELA, FERMI, ...)





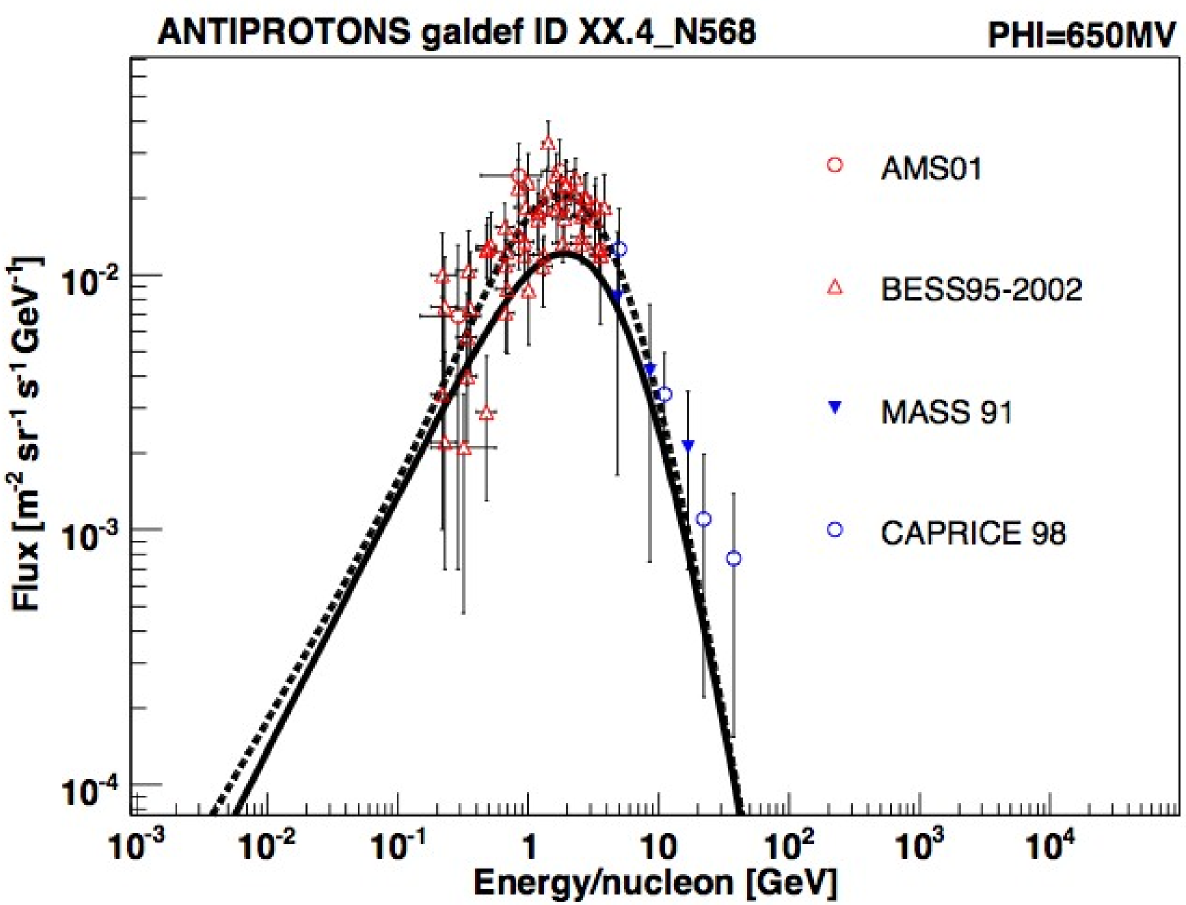
[Donato, et. al., Phys.Rev.Lett. 102 (2009) 071301]

- Several potential explanations: Pulsars, Leptophilic DM, etc..

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

Motivation

Improved modelling can change backgrounds (and our interpretation):



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

Cosmic Rays

- CR accelerated in shock front of SNe

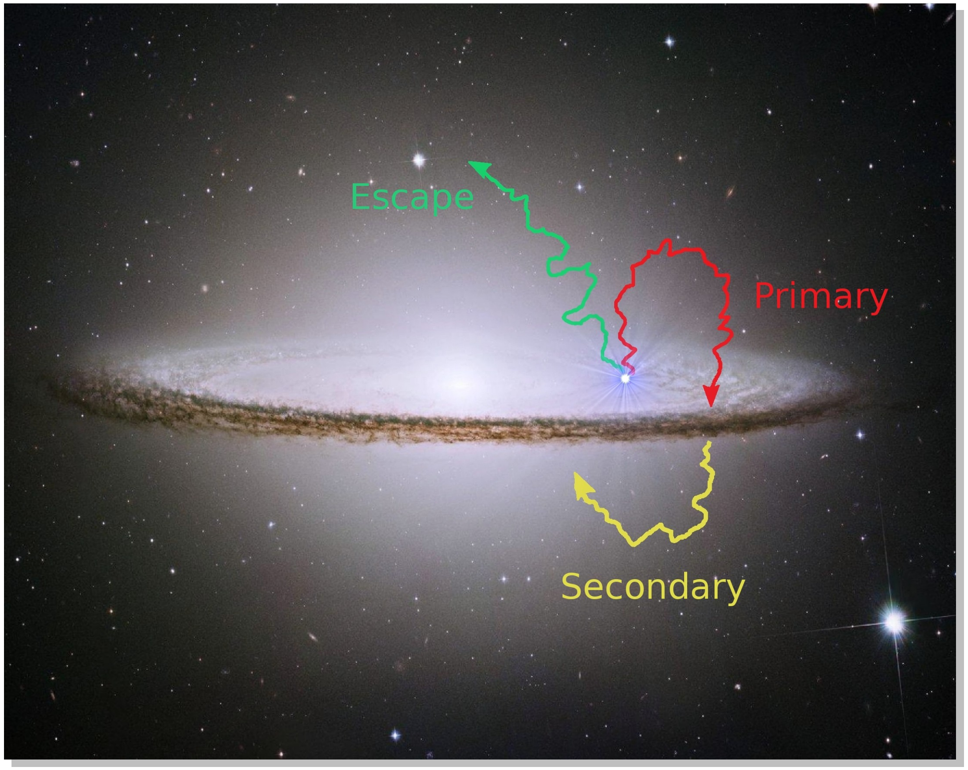
- Once launched, interact with complex magnetic fields

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

Diffusion

- Thermal/CR-driven galactic winds

Convection



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

Transport Equation

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

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

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- CR density per unit particle momentum
- Cosmic Ray Sources
- Spatial Diffusion
- Convection (“Galactic Wind”)
- “Re-acceleration” (momentum diffusion)
- Losses (spallations, decay)

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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$$D_{xx} = \beta D_0 \left(\frac{\rho}{\rho_0} \right)^{\delta}$$

Diffusion coefficient
independent of position / isotropic

Index associated with power spectrum of turbulence

$\delta = 1/3$ Kolmogorov $\delta = 1/2$ 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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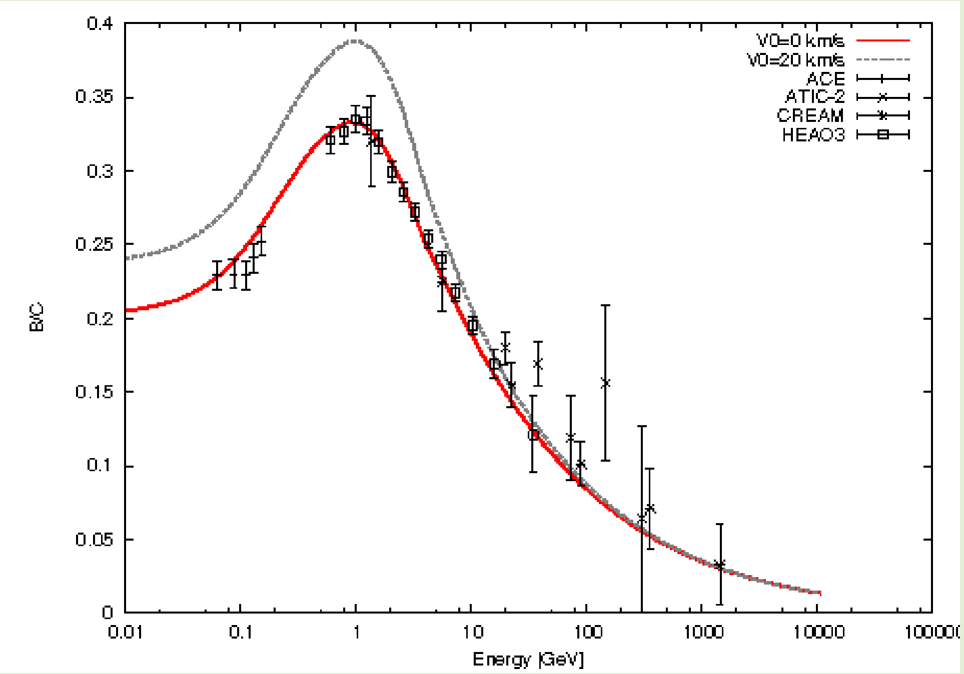
Good agreement with measurements:

$$B/C \qquad {}^{10}Be/{}^{9}Be$$

However, convection velocity must be low:

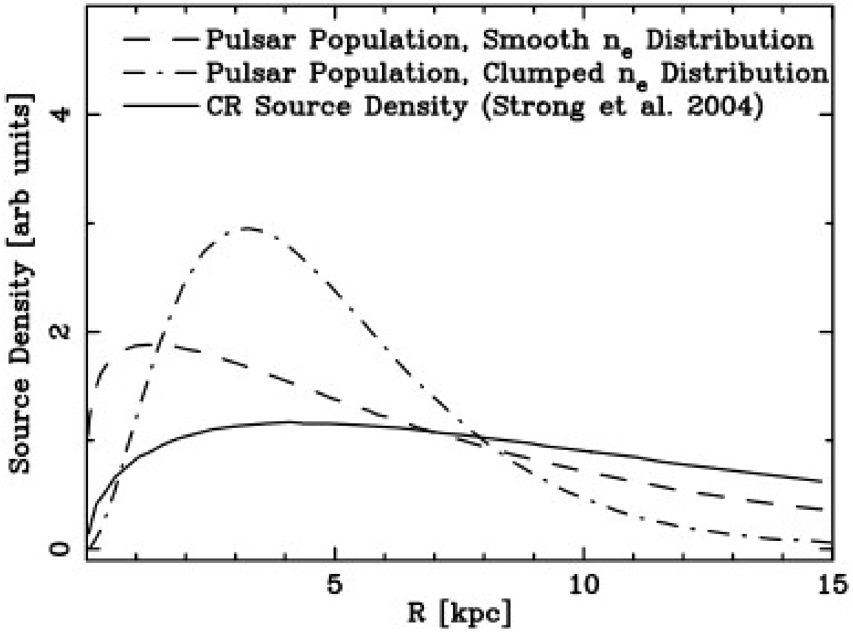
$$|V_{conv}| \leq 10-15\, km/s$$



A Problem...

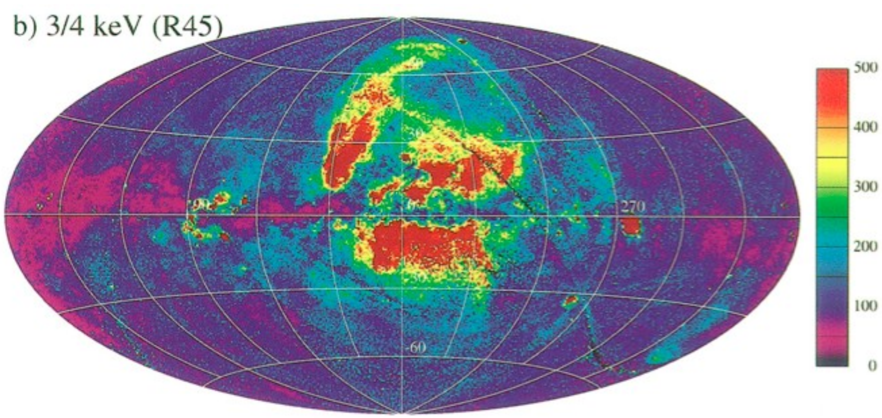
•SOFT γ-RAY GRADIENT:
>50 MeV photon distribution does not follow SNe distribution. Can be explained by **presence of convective wind**

[Everett, et. al., Astro.Phys.J 2008, 674, 258]
[Breitschwerdt, Dogiel, Volk, A&A 2002, 385, 216]



•ROSAT X-ray emission:
modeled best assuming thermal + CR-driven **galactic wind**

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



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

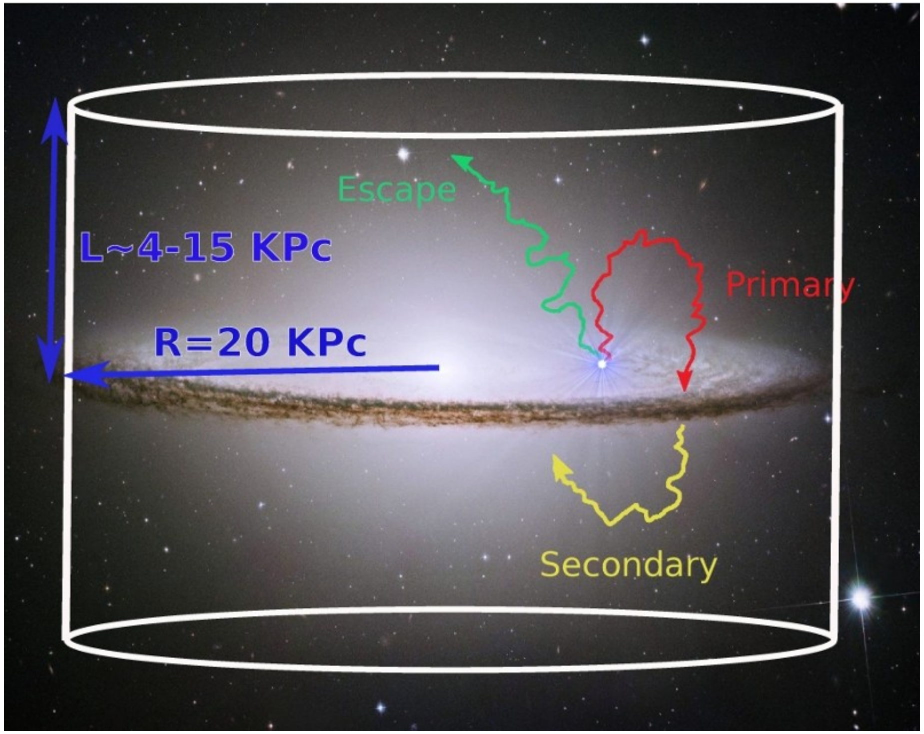
Anisotropic Diffusion

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

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

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

- Density of scattering centers decreases with distance from the galactic disk
- Smooth transition to free space
- Allows advected CR to escape halo
- B/C and Be10/Be9 ratios reproduced with O(100 km/s) ROSAT-compatible convection

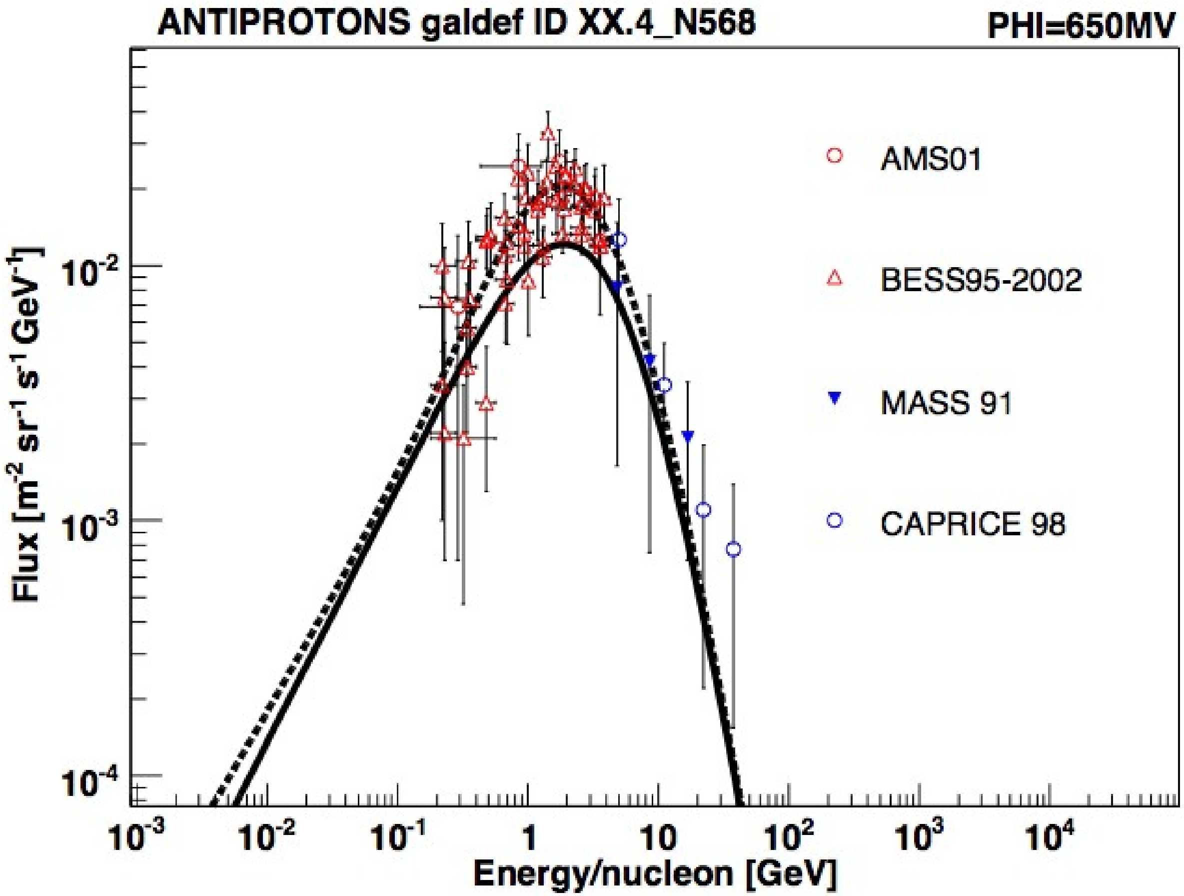


[M. Perelstein, B. Shakya, arXiv:1012.3772v2 [astro-ph.HE]]

[C. Evoli, D. Gaggero, D. Grasso and L. Maccione, JCAP 0810, 018 (2008) [arXiv:0807.4730 [astro-ph]]]

Anisotropic Diffusion

An interesting feature is a reduction in anti-proton flux background:



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

Implementation

GALPROP: Numerical solution to transport equation.
Accurate ISRF / B-Fields, gas-maps, spallation cross-sections.
[Moskalenko, Strong, Astrophys. J. 493 (1998) 694–707]

Convective Wind:

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

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

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

} Model by Everett, et.al.

Diffusion Coefficient:

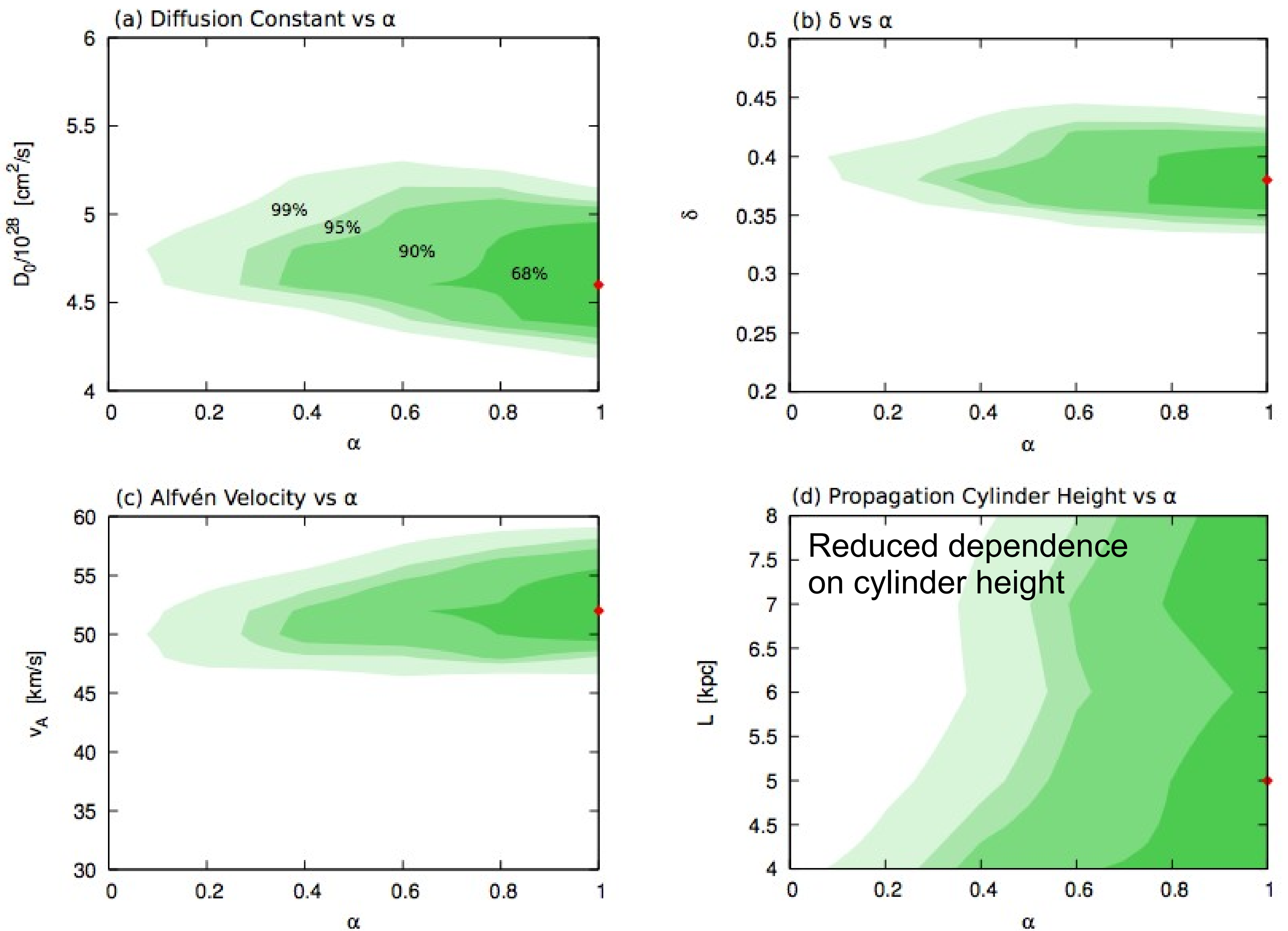
$$D_{xx}=\beta D_0(\rho/\rho_0)^\delta \qquad |z|<1\,kpc$$

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

Parameter Scan and χ^2 Analysis:

$$\{D_0,\delta,v_A,L,\alpha\}$$

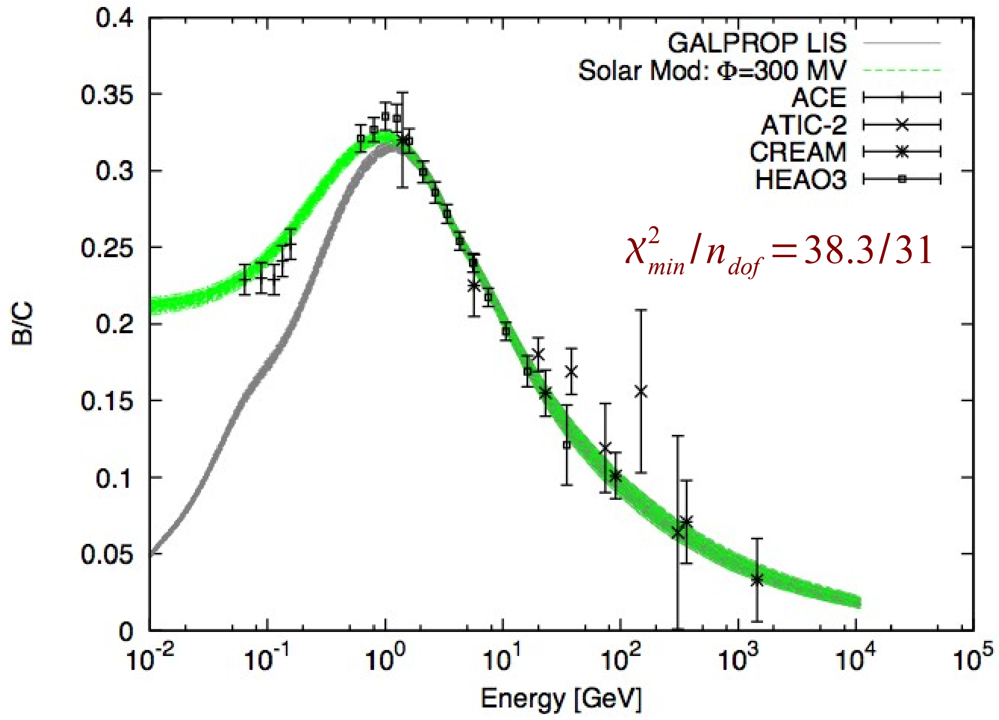
χ^2 Analysis

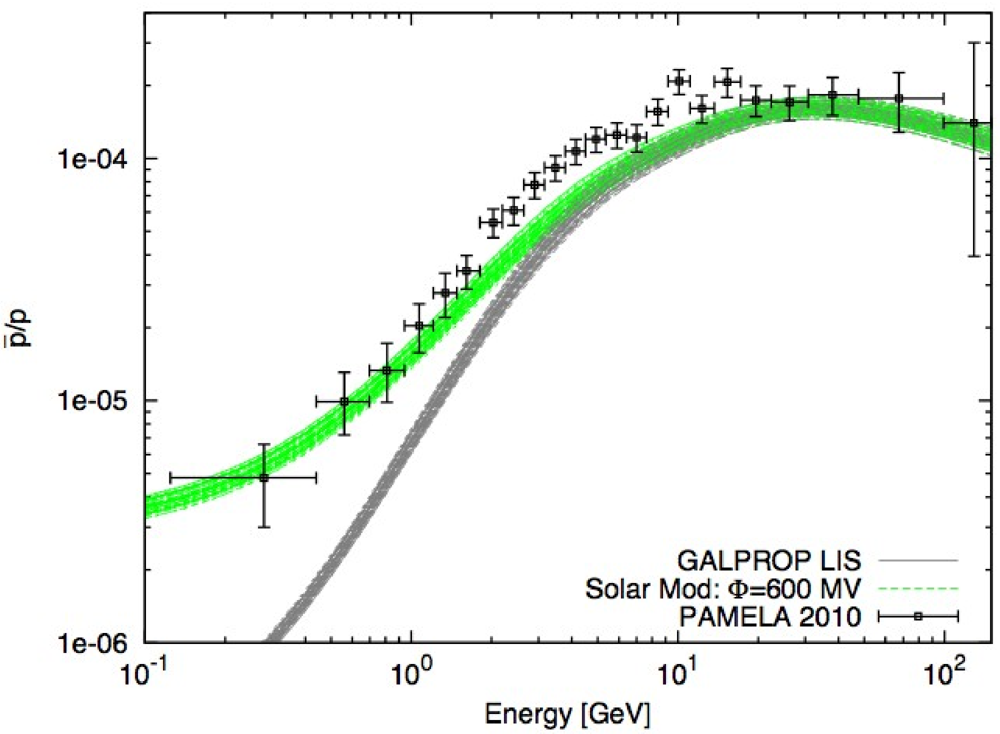


[PG, K. Hagiwara, arXiv 1012.0587 [astro-ph.HE]]

χ^2 Analysis

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





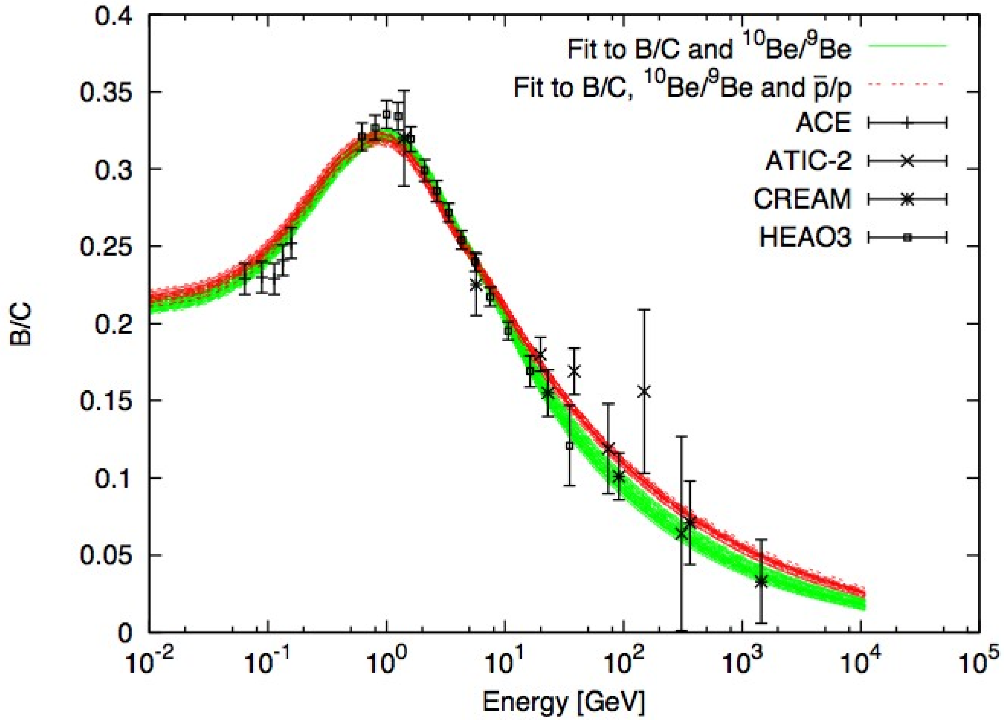
Good fit to B/C

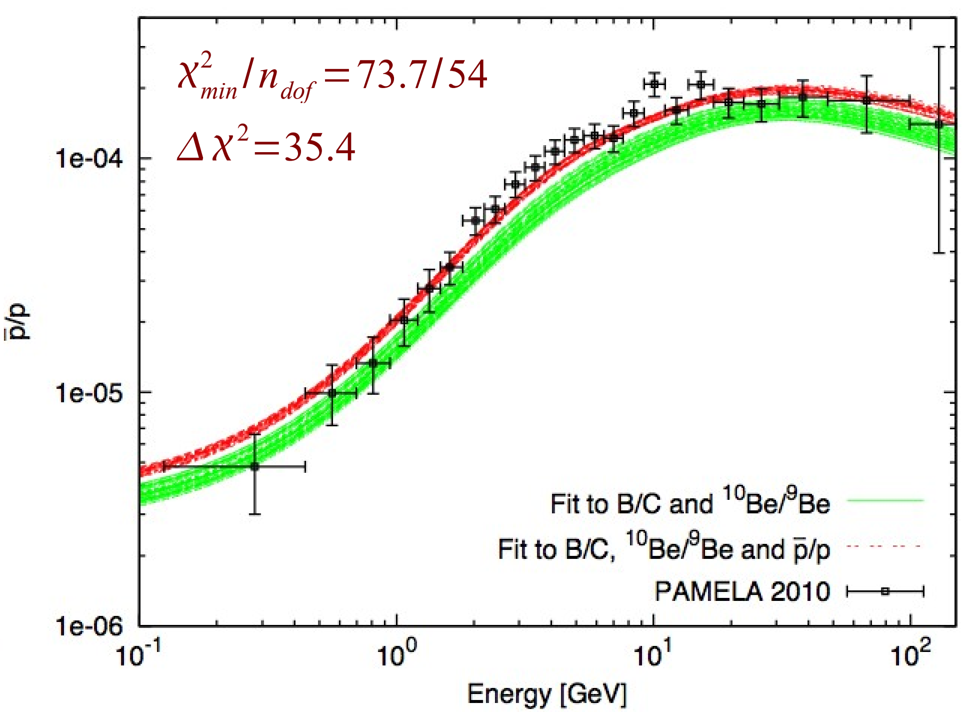
Excess in $\bar{p}/p$ flux

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

χ^2 Analysis

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





Degraded fit to B/C

Marginal fit

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

Conclusions:

- Improved understanding of galactic environment suggests conventional CR propagation model should be updated: high velocity convection.

- Spatially-dependent/anisotropic diffusion may provide a solution. Implies a lower anti-proton flux background.

- Updated scenario does not provide a good fit to the PAMELA measurement - may be seeing an excess - but no strong indication.

- This was a first-step. Many other aspects of model open for exploration - more computation time required.