Testing Cosmic-Ray Propagation Scenarios with AMS-02 and Voyager Data

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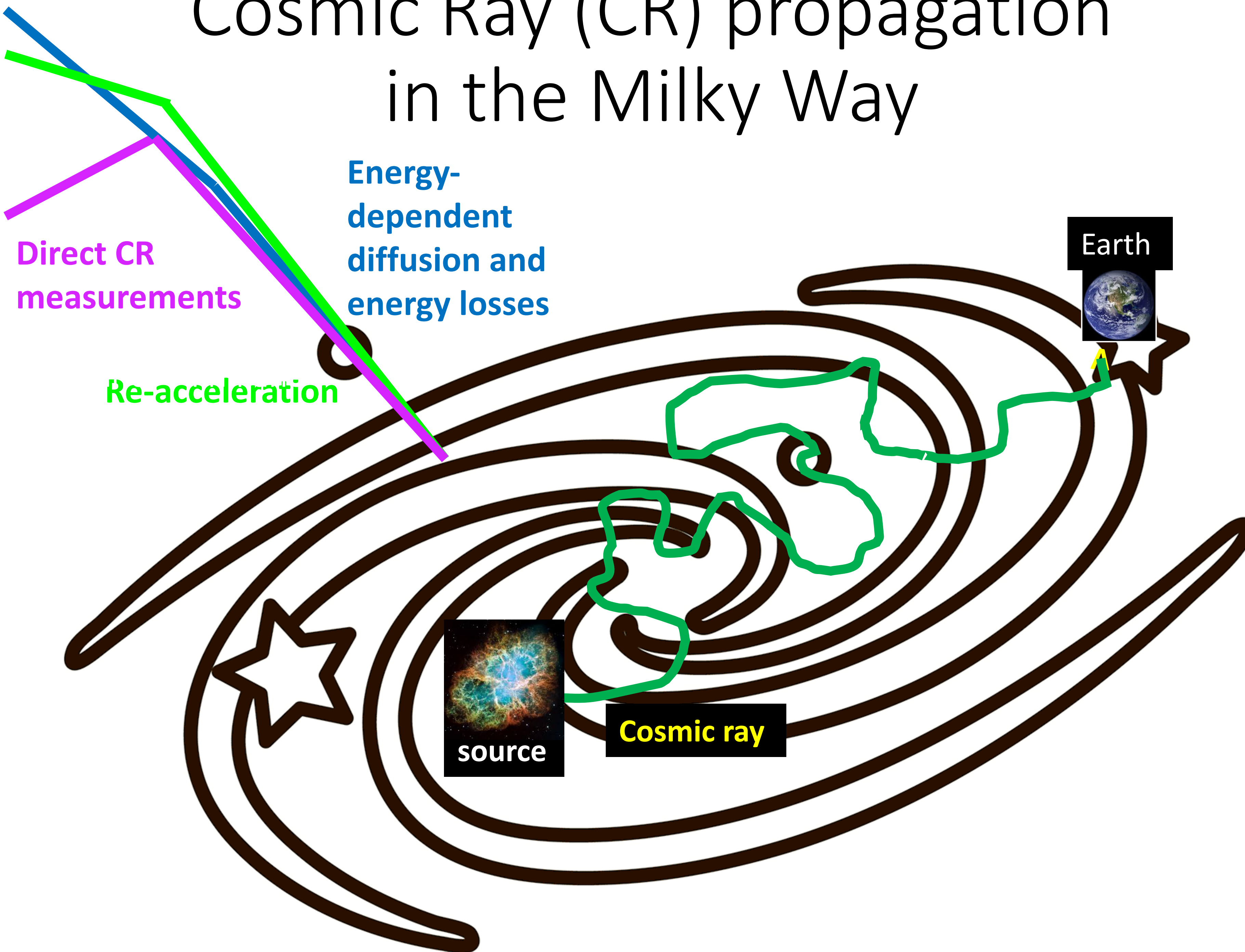
Cosmic Ray (CR) propagation in the Milky Way



CR Transport Equation

$$\frac{\partial \psi(\vec{r}, p, t)}{\partial t} = \overbrace{q(\vec{r}, p, t)}^{\text{Sources}} + \vec{\nabla} \cdot (\overbrace{D_{xx} \vec{\nabla} \psi}^{\text{Diffusion}} \overbrace{- \vec{V} \psi}^{\text{Convection}})$$

$$+ \underbrace{\frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \psi}_{\text{Re-acceleration}} \underbrace{- \frac{\partial}{\partial p} \left[\dot{p} \psi - \frac{p}{3} (\vec{\nabla} \cdot \vec{V}) \psi \right]}_{\text{Energy losses}} \overbrace{- \frac{1}{\tau_f} \psi}^{\text{Spallation/ Fragmentation}} \underbrace{- \frac{1}{\tau_r} \psi}_{\text{Decay}}$$

CR Propagation Scenarios Tested

PD (pure diffusion)
DR (diffusion and reaccelera)
DC (diffusion and convection)
DRC (diffusion, convection, and reacceleration)

- **DRC1**: One break in spectral indices
- **DRC2**: Two breaks in spectral indices
- **DRC_conv**: Two breaks in spectral indices, stronger convection

Fitting Details

- Same propagation parameters for all species
- Isotropic diffusion
- Data: mainly Voyager (in interstellar space) & AMS02
- Force-field approximation for modulation
- High-energy break in propagation @ few hundread GV

Fitting Results (depending on the scenario):

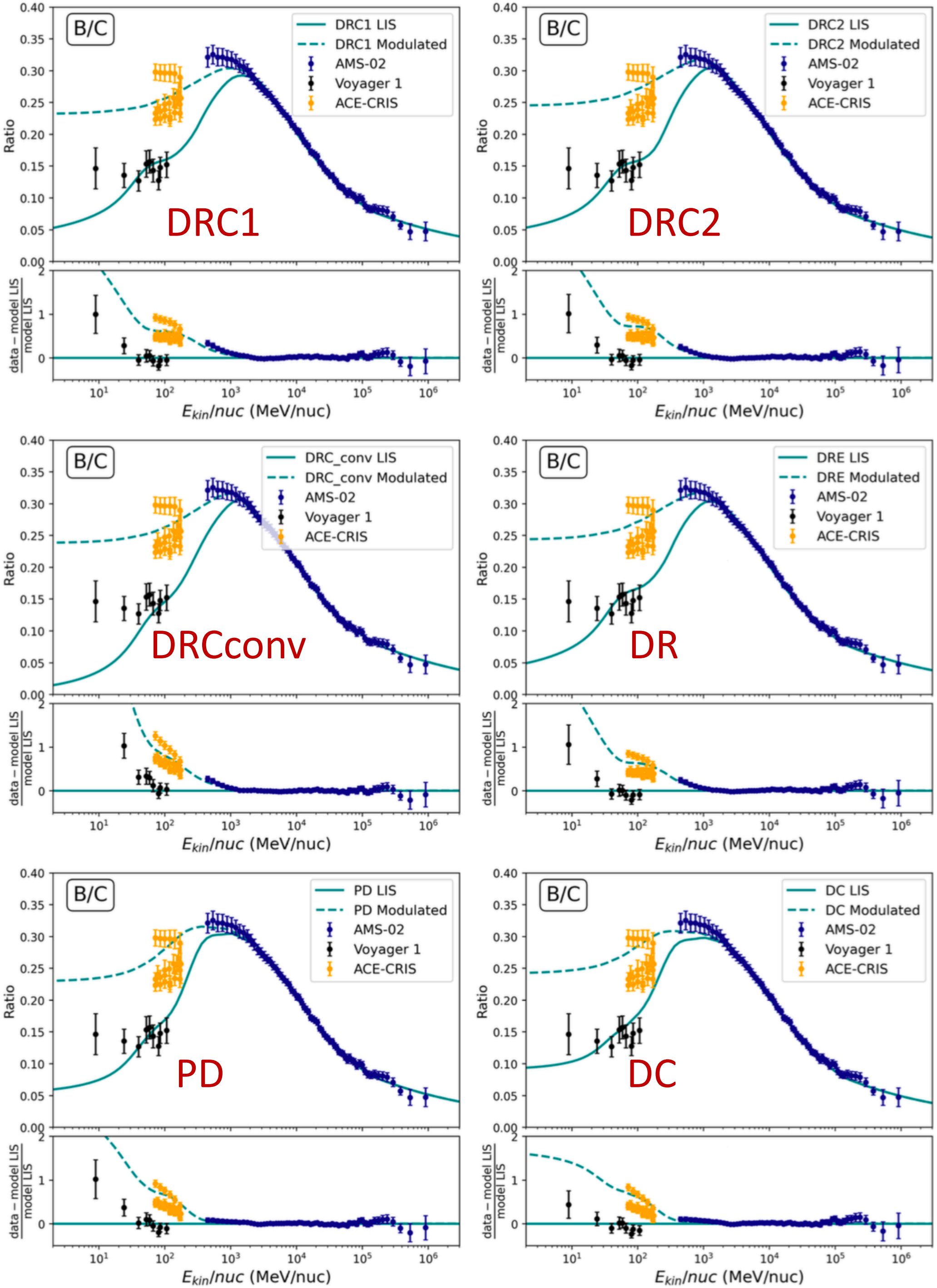
δ_1: ~ 0.4; δ_2: 0.2

D_0: ~$4.5 \times 10^{28} cm^2 s^{-1}$ at 4 GV

0 km s^{-1}< V_A < 50 km s^{-1}

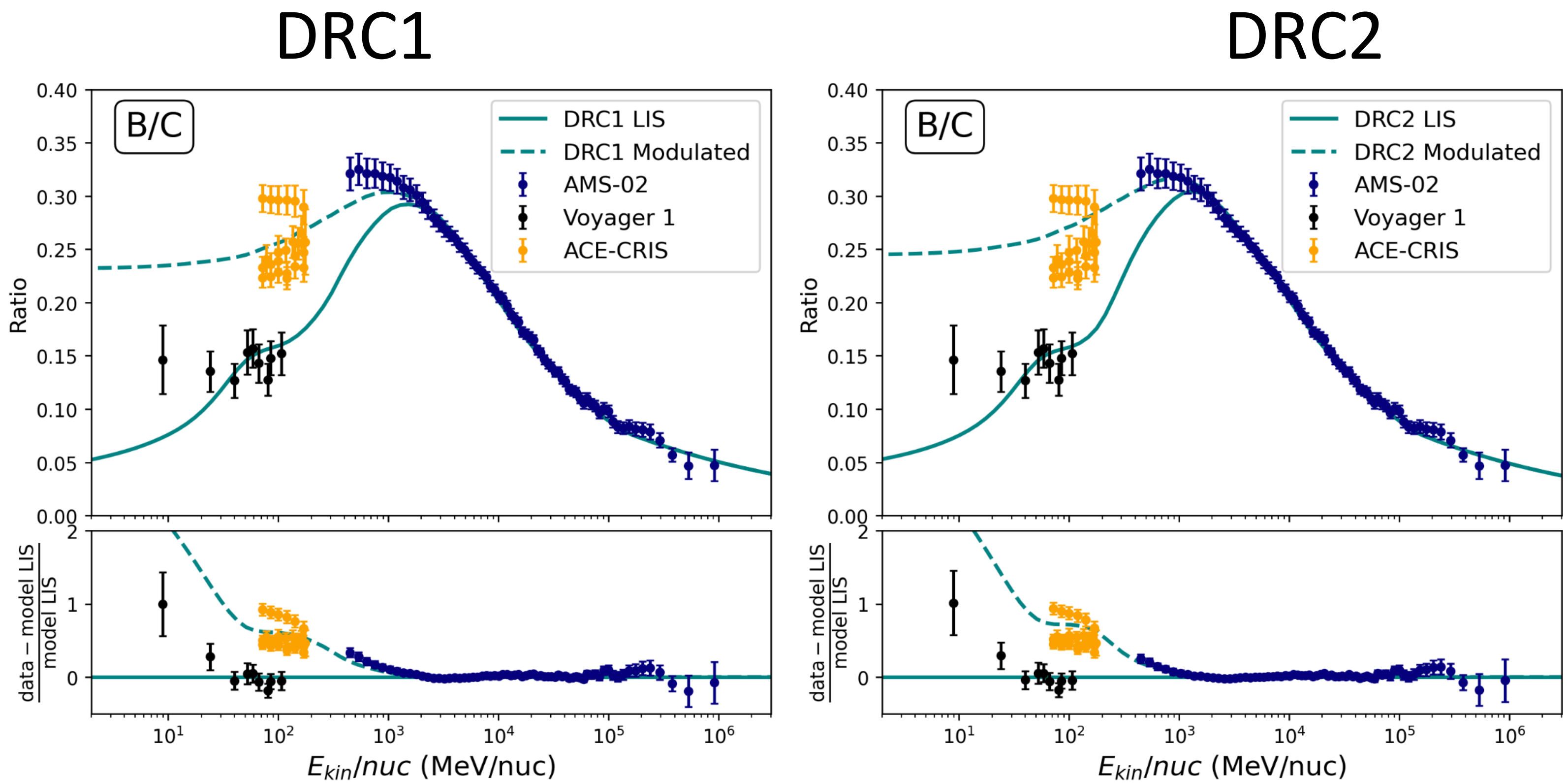
0 km s^{-1} kpc^{-1} <dV/dz < 55 km s^{-1} kpc^{-1}

B/C



All scenarios are able to reproduce the main species (H, He, B, C, B/C, O, Ne, Mg, Si) Voyager and AMS-02 data.

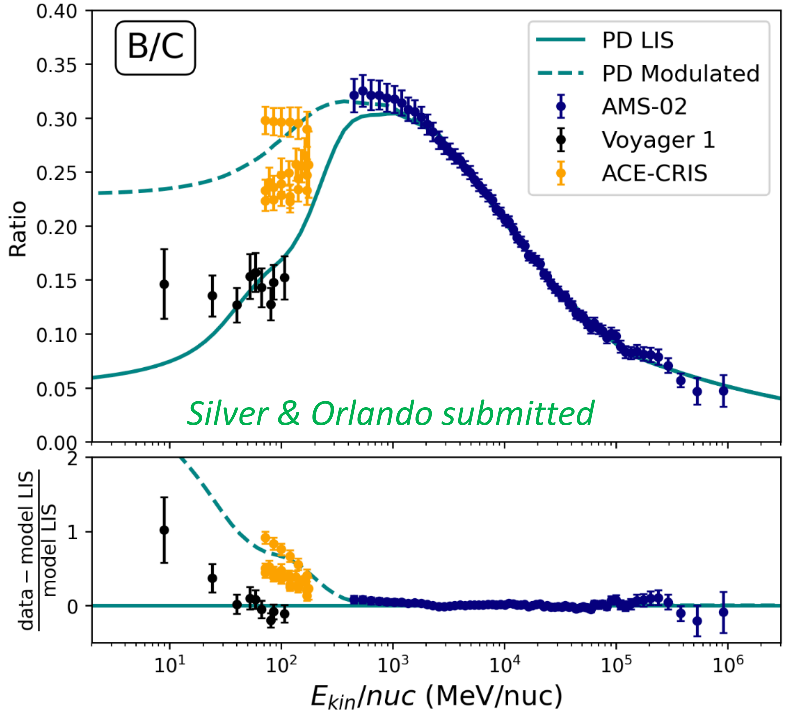
B/C



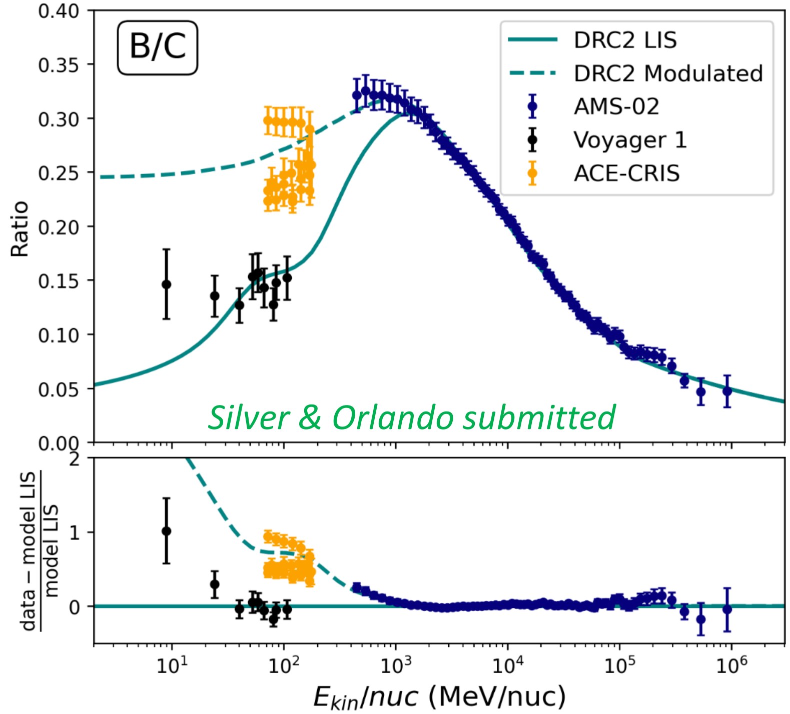
In general the highest the number of parameters, the better the chi-square (except for PD)

B/C

PD

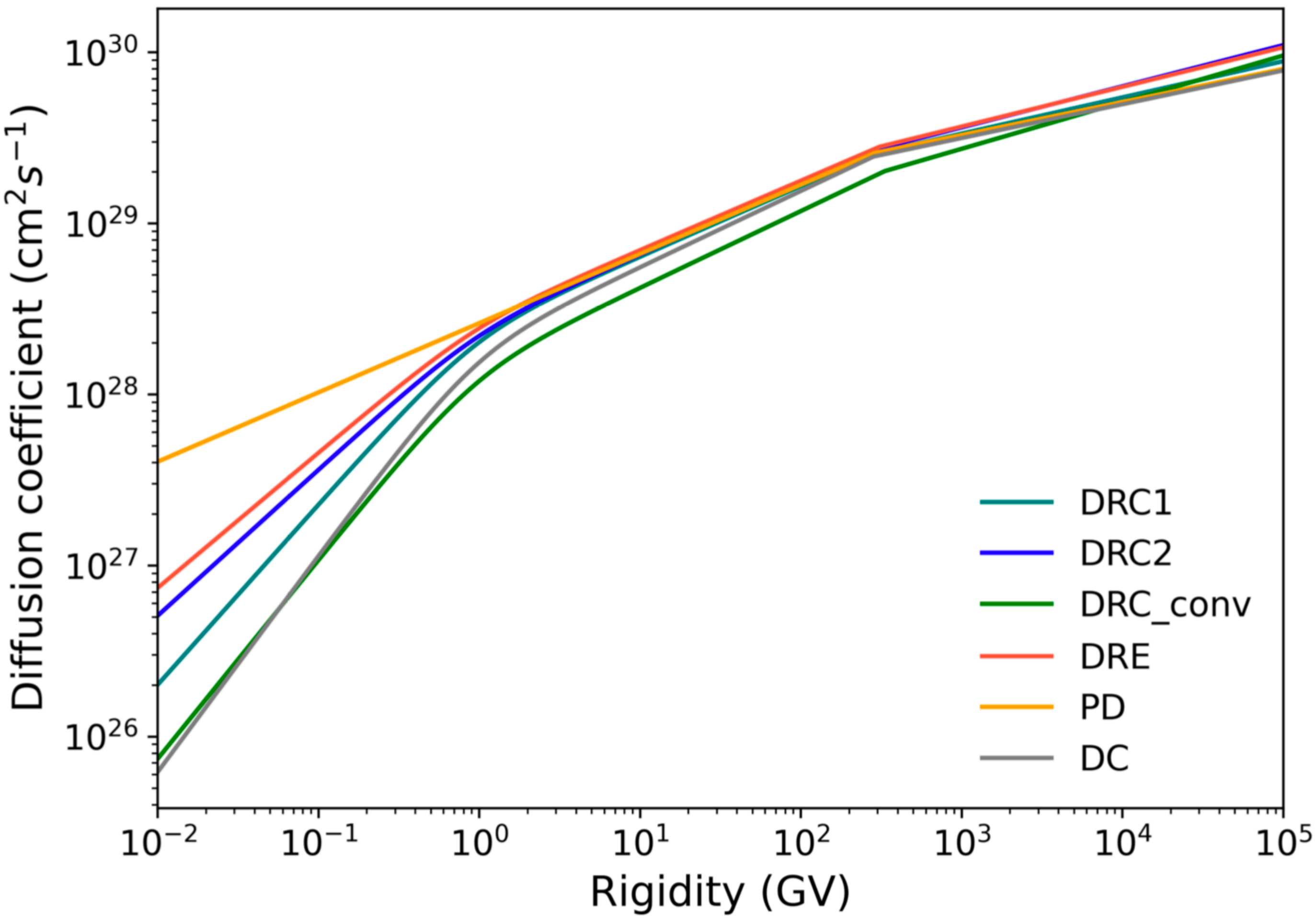


DRC2



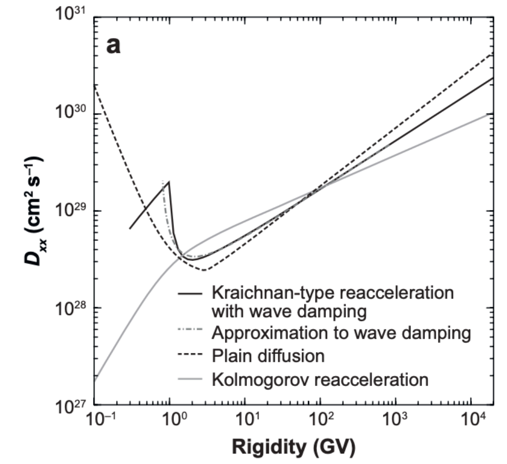
contrary to what has been usually assumed, pure diffusion models do not need a break in the diffusion coefficient at low energy to fit B/C, while they need the same number of low-energy breaks in the injection spectrum as diffusive-reacceleration models

Diffusion Coefficient



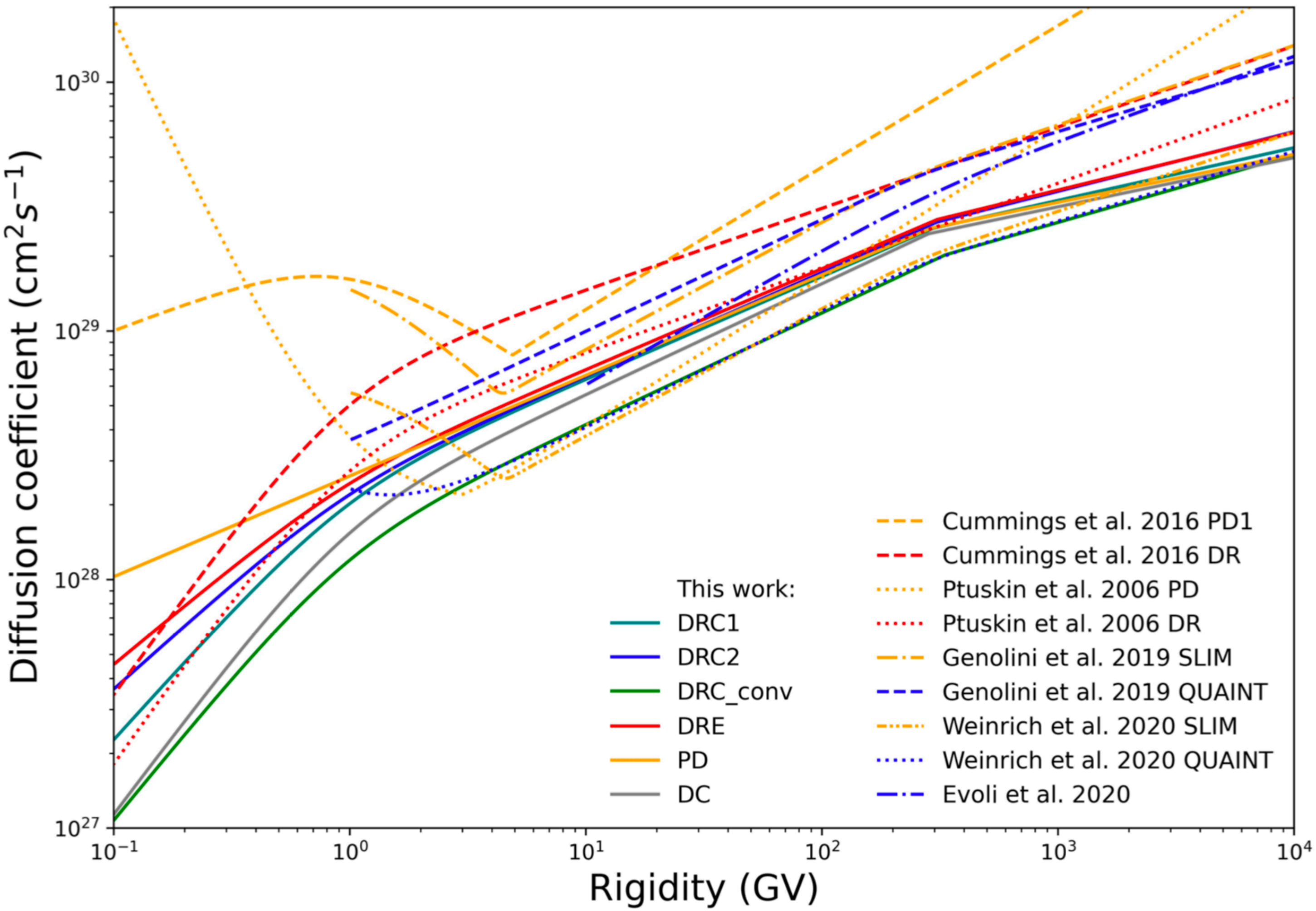
Pure diffusion does not need an upturn in the diffusion coefficient, as previously required to fit B/C

Typical models (*Strong et al. 2007*)

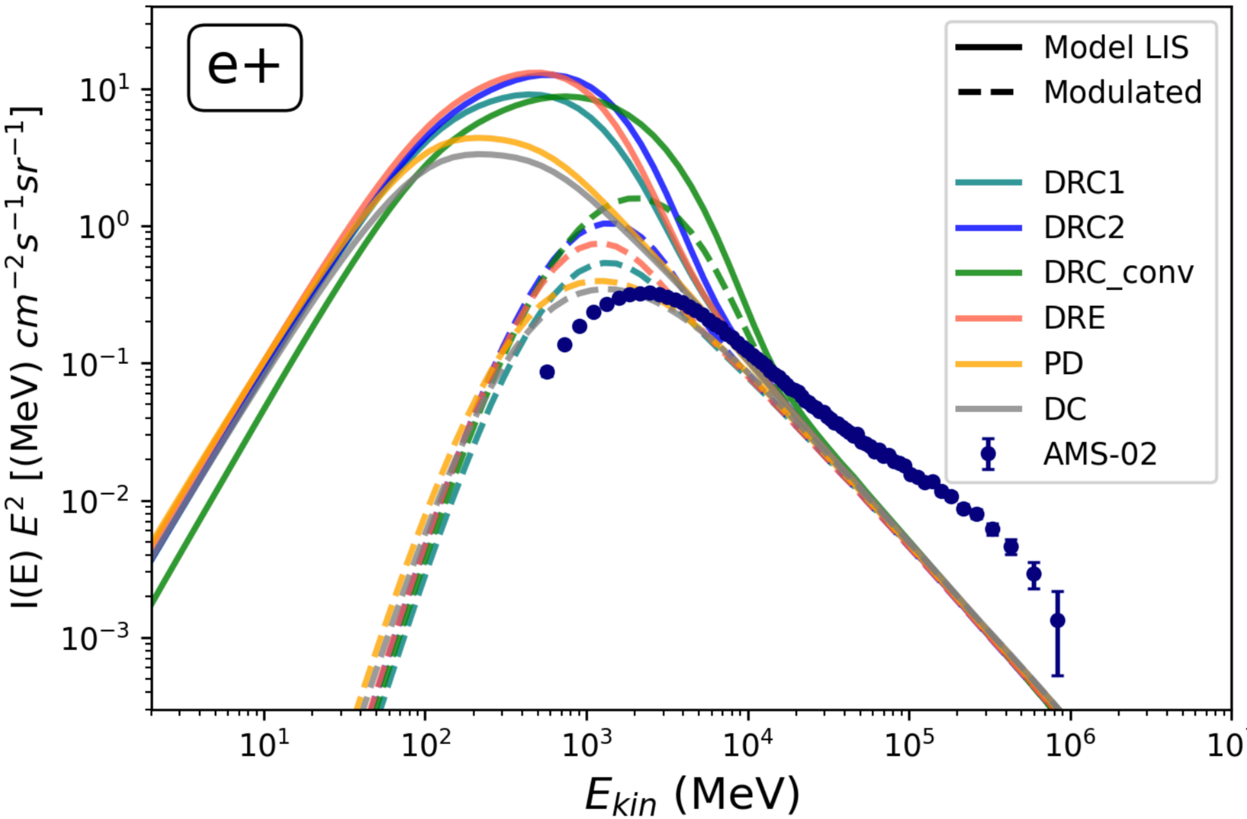


Diffusion Coefficient

comparison with other works

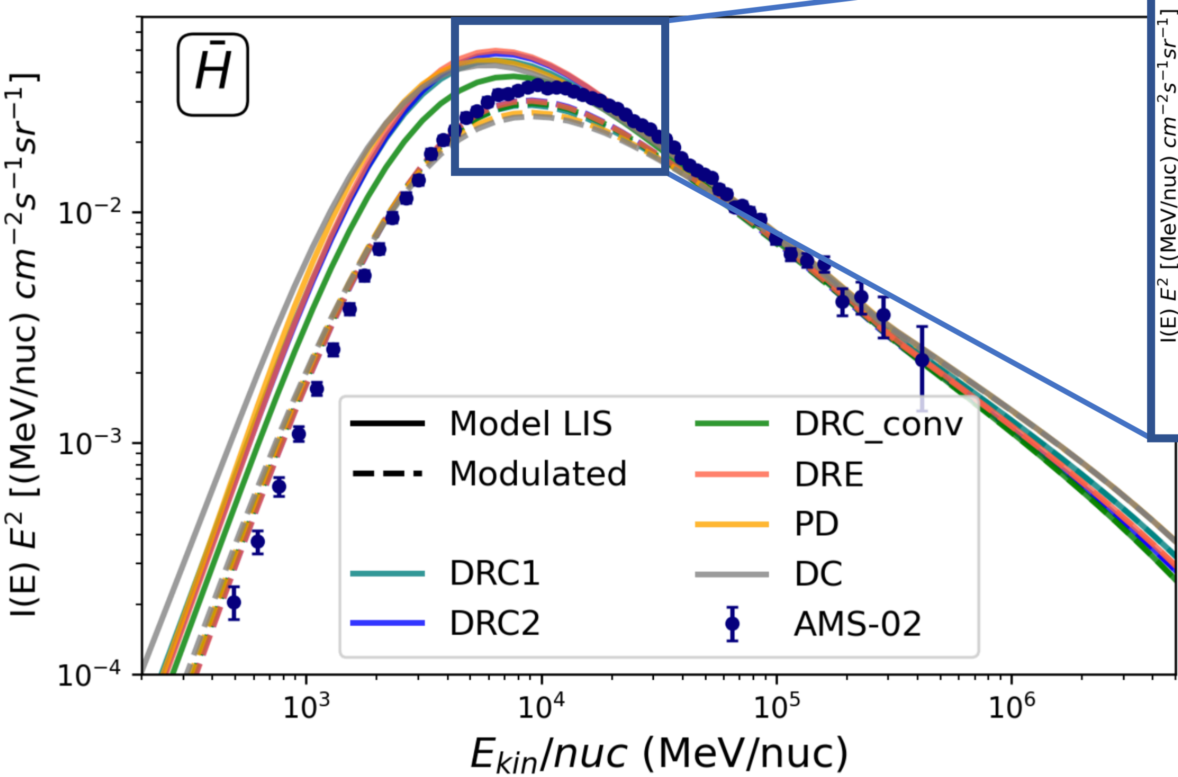


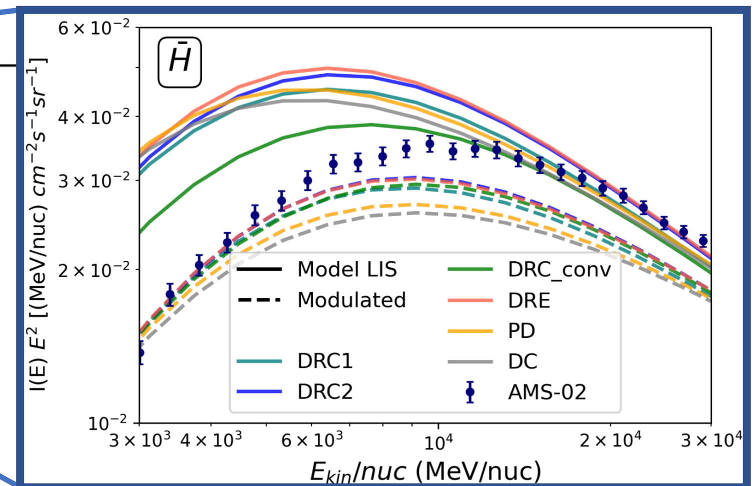
Positrons



Different scenarios produce positrons that differ for one order of magnitude at ~GeV.
Positrons need to be modulated more than nuclei.
None of the scenarios can explain the poositron excess.

Antiprotons

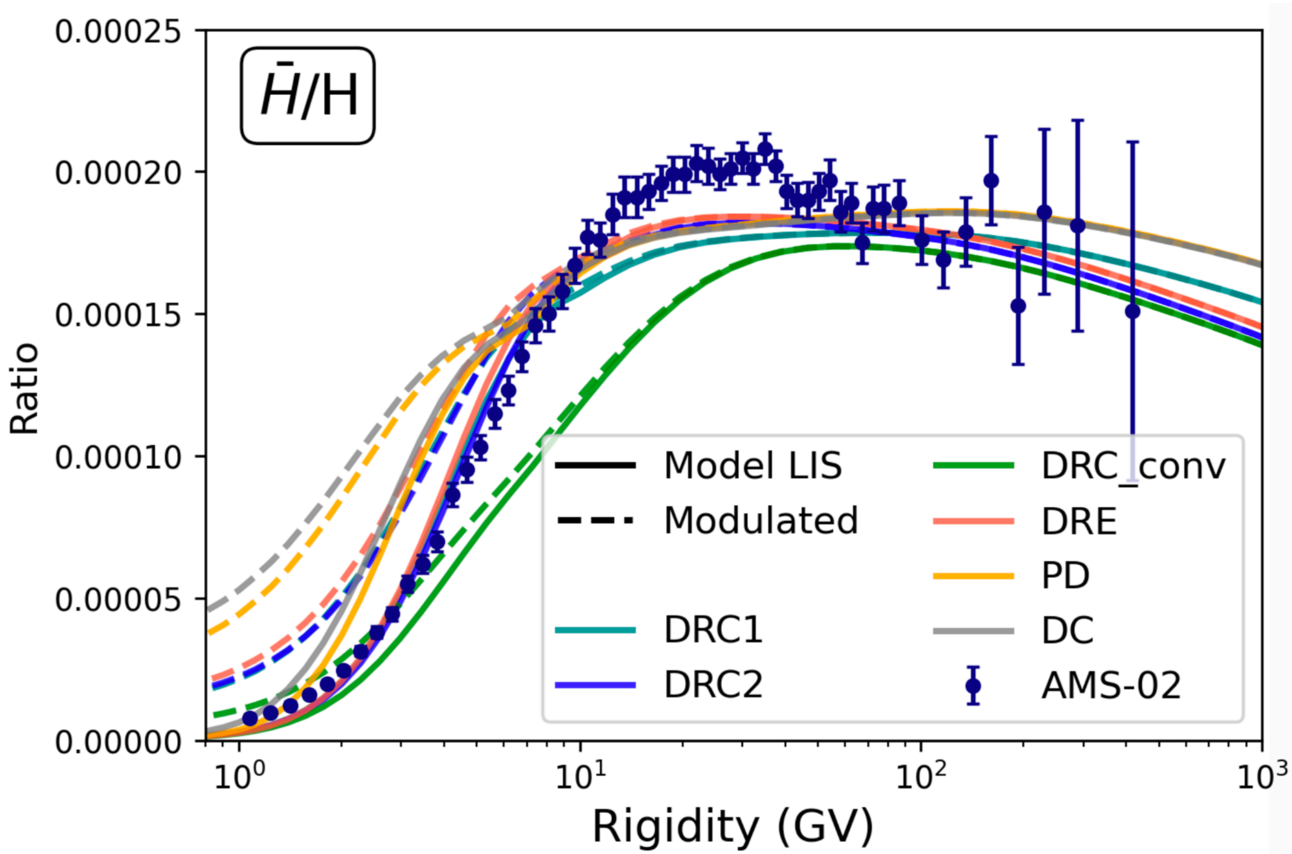




~10 GeV excess for all scenarios

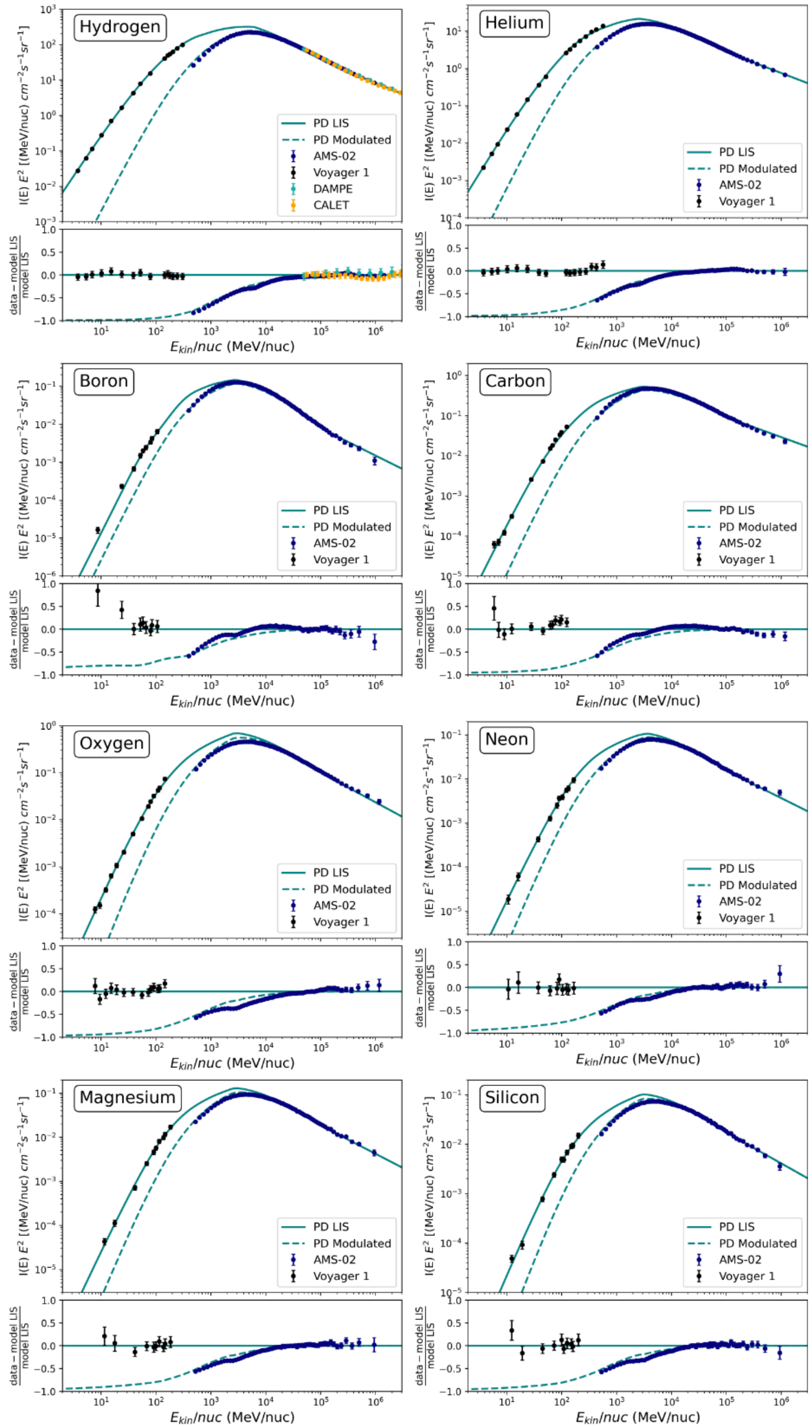
Different scenarios produce antiprotons that differ for a factor of 2 ~10 GeV/nucl

Antiprotons/Protons



Above 40 GV no need of a new high-energy source, espe- cially for the PD scenario, which does not show a clear rigidity dependence in this range.

PD scenario


Hydrogen
PD LIS
PD Modulated
AMS-02
Voyager 1
DAMPE
CALET
Helium
Boron
Carbon
Oxygen
Neon
Magnesium
Silicon
I(E) E^2 [(MeV/nuc) cm^-2 s^-1 sr^-1]
data − model LIS / model LIS
E_kin/nuc (MeV/nuc)

Results

- All scenarios are able to reproduce Voyager and AMS-02 data (the highest the number of free parameters, the better the chi-square)
- Pure diffusion scenario does not need a break in the diffusion coefficient at low energy to fit B/C, while it needs the same number of low-energy breaks in the injection spectrum as diffusive-reacceleration scenarios
- Pure diffusion does not need an upturn in the diffusion coefficient, as previously required to fit B/C
- Different scenarios produce positrons that differ for one order of magnitude
- Different scenarios produce antiprotons that differ for a factor of 2
- We confirm the $\sim$10 GeV excess in the antiproton spectra for all scenarios
- The force-field approximation for modulation describes data well the species analyzed.
- injection spectrum of He harder than that of H
- He and C: same injection spectral index above several GV as in AMS02 data
- for all propagation scenarios, the resulting modulation should be stronger for positrons than for nuclei, with reacceleration models requiring a much larger modulation
- O: softer injection spectral index than He and C above several GV (contrary to AMS02 data) possibly due to the contribution of secondaries: O has less secondaries)

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