On the Positron Fraction in Cosmic Rays and Models of Cosmic-Ray Propagation

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Abstract

- The positron fraction should reach 0.6 at approximately $E \geq 5$ TeV
- Data on cosmic-ray anisotropies support models of propagation that include significant spallation at approximately $E \lesssim 20$ GeV/nucleon in cocoons surrounding cosmic-ray sources
- Observed B/C ratio may be interpreted in the NLB Model as being comprised of two components: 1) an energy-dependent fraction generated in a cocoon surrounding the source and 2) a nearly energy-independent component generated in the general interstellar medium
- The positron fraction calculated using such a model fits the observed positron fraction well
- The cosmic-ray anisotropies calculated with such a model are consistent with observations
- Dark matter annihilation/decay does not dominate the positron fluxes

Positron Fraction Asymptotically Approaches ~0.6 for E ≥ 5 TeV

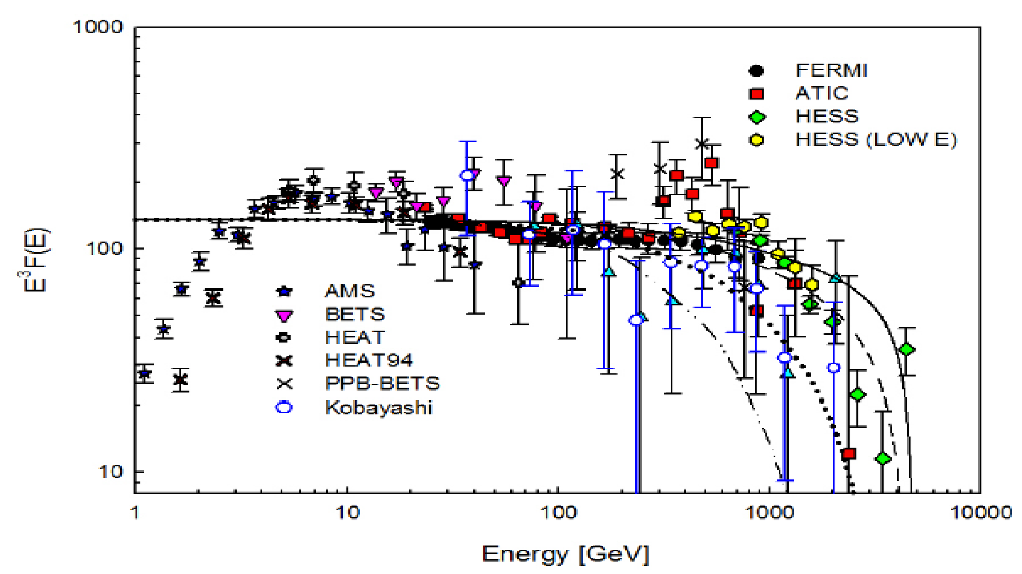

Figure 1: The primary electron spectra due to a single source at various distances from the source, with a cutoff energy $E_x = 5$ TeV, compared to the primary electron spectrum. [$r_1 = 0.1$ kpc (solid line), $r_1 = 0.2$ kpc (dashed line), $r_1 = 0.5$ kpc (dotted line), $r_1 = 1.0$ kpc (dot-dashed line)].

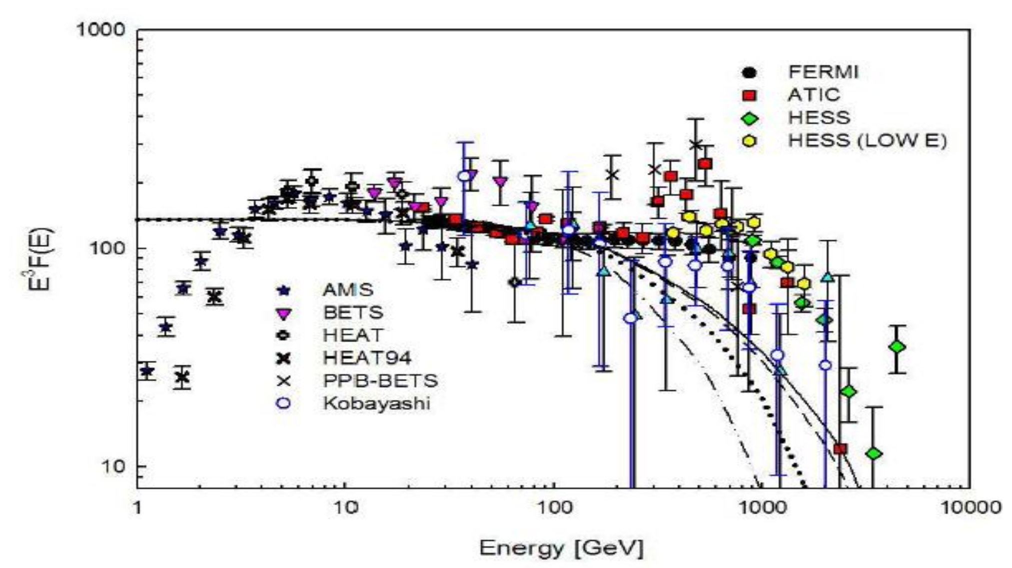

Figure 2: The theoretical primary electron spectra resulting from an ensemble of cosmic ray sources for various values of the mean spacing and a cutoff energy $E_x = 5$ TeV is compared with the primary electron spectrum $F_{e-}(E)$. The mean spacing between the sources is taken to be < r >= 0.1 kpc (solid line), < r >= 0.2 kpc (dashed line), < r >= 0.5 kpc (dotted line), and < r >= 1.0 kpc (dot-dashed line).

- The electron component accelerated in discrete sources is sharply cut off at energies that depend on the distance to the nearby source

$$F_e(E, r_n) \sim exp\left(-\frac{br_n^2 E E_x}{4\kappa(E_x - E)}\right)$$

- The interstellar production, $\sim E^{-\beta}$, where $\beta \approx 2.67$, is given by a spatial continuum of sources. At high energies, there is a steady state spectrum given by $E^{-(\beta+1)} \sim E^{-3.67}$. These spectra are model independent.
- The contribution from the interstellar medium will dominate over the contribution of discrete sources at high energies.
- The p/n ratio is greater than unity in cosmic rays so the positron fraction, R, at large energies is

$$R\left(\frac{e^+}{e^+ + e^-}\right) \approx R\left(\frac{\mu^+}{\mu^+ + \mu^-}\right)_{secondary} \approx 0.6$$

The Positron Fraction at Moderate Energies

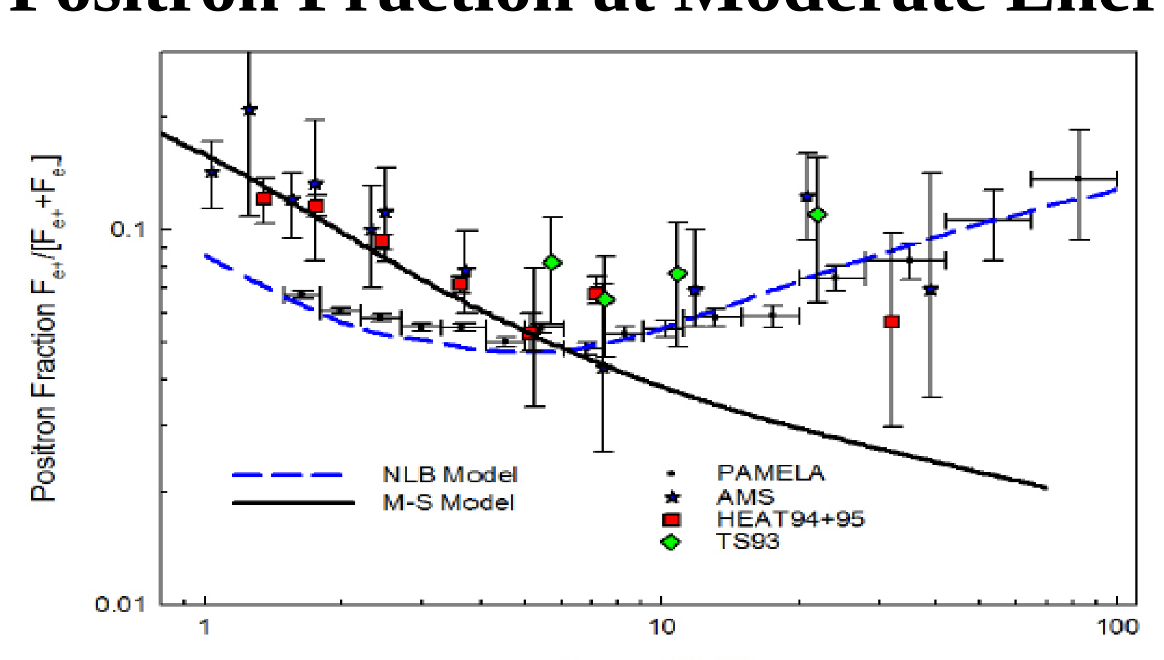

Figure 3: The positron fraction measured by PAMELA along with the earlier measurements are shown. The effects of gradient drifts in solar modulation may account for some of the difference in the data sets at E < 10 GeV. The energy dependence of the positron fraction expected in the M-S model (Strong, Moskalenko & Ptuskin 2007) is shown as a solid line and in the nested leaky-box model as a dashed line.

- The solid line corresponds to the Moskalenko-Strong (M-S) model, using the same parameters as the solid line in the anisotropy fig. 5.
- In the nested leaky-box (NLB) model and the M-S model, the source spectrum of e^+ is the same, $s(E) \sim E^{-2.67}$, being proportional to the observed flux of the nuclear component of cosmic-rays and the matter density in the interstellar medium.
- In the NLB model, the leakage of cosmic rays from the Galaxy is not energy-dependent so the residence time $\tau_G \approx$ constant.
- The positron flux in the NLB model is given by $F_+(E) \sim \tau_G\, s(E) \sim$ const. x $E^{-2.67}$.
- In fig. 3, $F_+(E)/F_e$ (from fig. 1 or fig. 2) is shown as a dashed line.
- The NLB model (fig. 4, dashed line) fits the positron fraction well.

The Boron/Carbon Ratio and Cosmic-ray Anisotropies

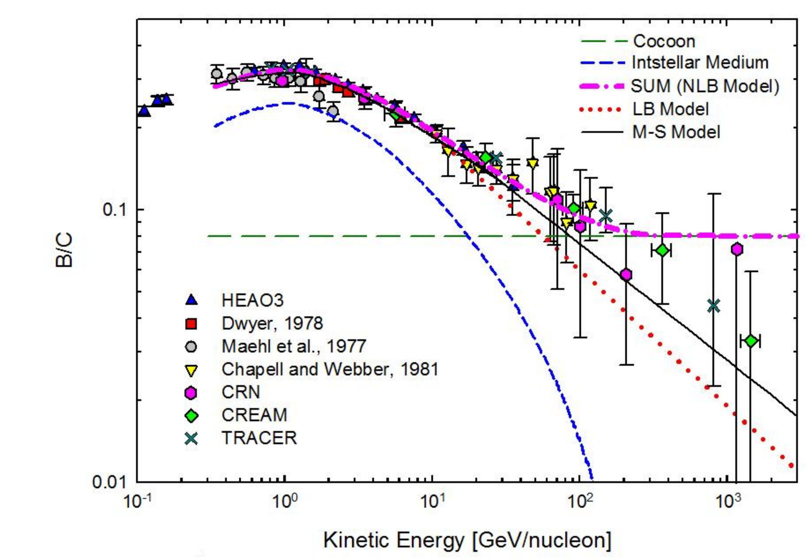

Figure 4: The observed *B/C* ratio is plotted along with the spectra expected from the M-S model and nested leaky-box model.

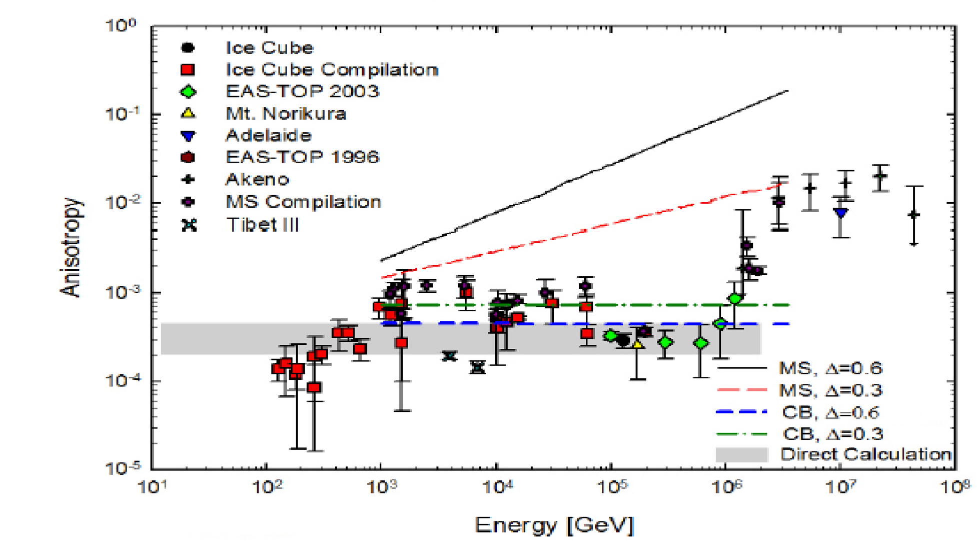

Figure 5: Measurements of the cosmic-ray anisotropy from various compilations. Also plotted are the predictions from the models in Moskalenko and Strong (MS) and the predictions from the nested leaky-box model (CB). The shaded region shows an estimate from a direct calculation of the anisotropy.

- Fitting the B/C ratio with an energy-dependent leakage from the Galaxy (eg. M-S model), shown as a solid line in fig. 4, predicts an anisotropy much higher than observations, shown as the red and black lines in fig. 5.
- The two-component NLB model, with energy-dependent residence time in the cocoon (fig. 4, dashed green line) and constant residence time in the interstellar medium (fig. 4, dashed blue line) adding up to the pink chain-dotted line in fig. 4, predicts anisotropies shown as the blue and green lines in fig. 5 by scaling down the M-S calculations according to eq. 1 or as a grey stripe estimated independently by eq. 2.

$$\delta_{NLB}(E) = \frac{\tau_{LB}(E)}{\tau_G}\delta_{M-S}(E) \approx \left(\frac{100\ GeV}{E}\right)^{\Delta}\delta_{M-S}(\Delta, E) \qquad (1)$$

$$\delta_{NLB} = \frac{3\kappa\nabla\rho}{c\rho} \approx \frac{3\kappa}{h_0 c} \approx 3\times10^{-4} \qquad (2)$$

The NLB fits the B/C observations and the anisotropy limits well.

Conclusions

- The NLB model fits the B/C ratio, anisotropy bounds, and the positron fraction well.
- Dark matter decay/annihilation is not a significant part of the positron fraction in cosmic rays.

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