Alternative Propagation Models for Cosmic Positrons

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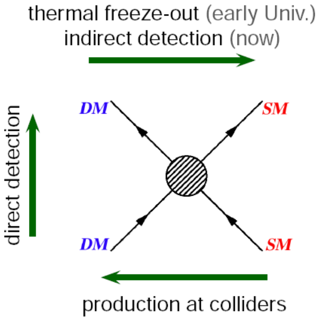
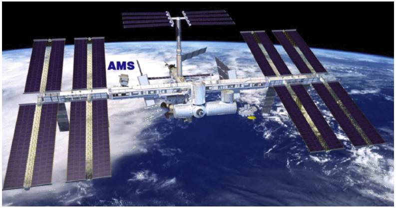
Motivation

indirect dark matter detection: search for hints of DM annihilation or decay into standard model particles

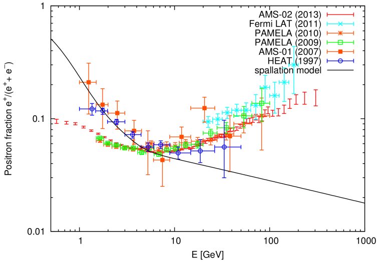




compare cosmic rays to astrophysical background
$\rightarrow$ better understood for antiparticles

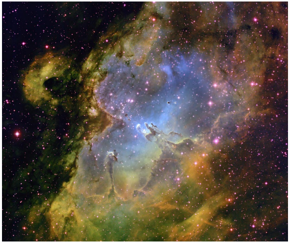
The Positron Excess

- the positron fraction $\frac{e^+}{e^+ + e^-}$ rises above 10 GeV
- different explanations possible:
  $\rightarrow$ further primary sources: e.g. pulsars, dark matter
  $\rightarrow$ alternative propagation models [Blum, Katz]
- low energy regime is split due to solar modulation



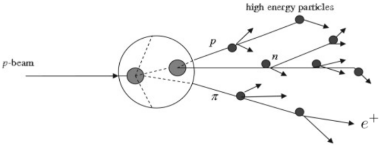
[Ibarra et al.,1307.6434]

The Origin of Cosmic Rays



- primary sources: stars, supernovae, pulsars, etc.
- secondary production: spallation of cosmic rays → derived from interstellar fluxes and differential cross sections

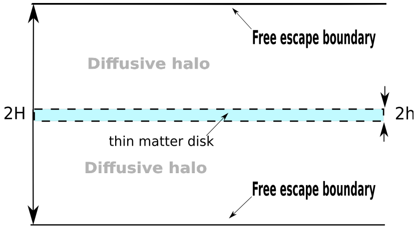
$$Q(E_e) = 4\pi n_0 \int \Phi_0 \frac{d\sigma}{dE_e} dE_0$$



- particles propagate in the interstellar medium

Cosmic Ray Transport

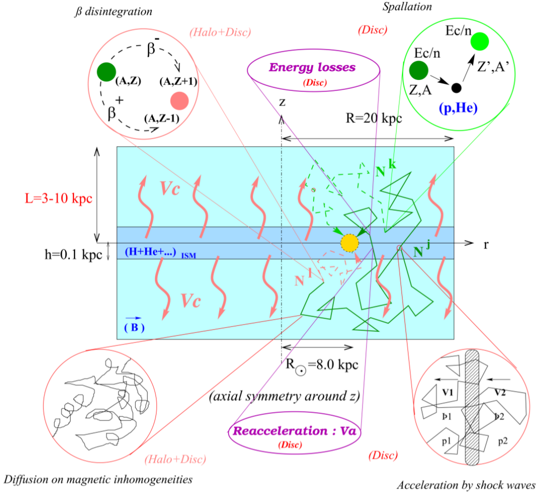
most commonly used: the <u>two-zone diffusion model</u>



[Genolini et al., 1504.03134]

cosmic rays are produced in a thin disk $h \approx 0.1\,\mathrm{kpc}$
scatter on magnetic field in galactic halo $H \approx 4\,\mathrm{kpc}$
random walk macroscopically described by diffusion equation

Include Further Effects



[Maurin et al., 0212111]

Diffusion Equation for Positrons

The positron density $\mathcal{N}(E,\vec{x})$ is described by the stationary diffusion equation:

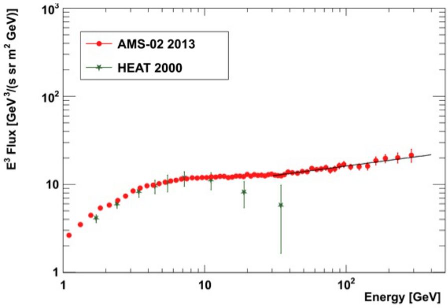
$$\underbrace{-\nabla(K(E,\vec{x})\nabla\mathcal{N})}_{\text{diffusion}}+\underbrace{\nabla V_c(z)\mathcal{N}}_{\text{convection}}+\underbrace{2h\delta(z)\frac{\partial}{\partial E}\left(b(E)\mathcal{N}-K_{EE}(E)\frac{\partial\mathcal{N}}{\partial E}\right)}_{\text{energy losses and reacceleration}}=\underbrace{Q(E,\vec{x})}_{\text{sourceterm}}$$

$K(E,\vec{x}) = K_0 E^{\mu} f(\vec{x})$ diffusion coefficient
$\vec{V}_c(z)$ galactic wind
$b(E) = -b_0 E^2$ energy losses (Compton scattering, synchrotron radiation)
$K_{EE}(E)$ diffusion in momentum space

The Positron Spectrum after Propagation

$$\Phi(E,\vec{x}) = \frac{\beta}{4\pi}\mathcal{N}(E,\vec{x})$$

$$\text{source term } Q \propto E^{-\gamma_0} \xrightarrow{\text{propagation}} \text{flux } \Phi \propto E^{-\gamma}$$



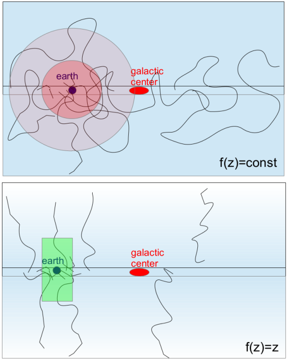
[AMS-02]

spectral index γ:

- $\gamma_0 \approx 2.7$
- $\gamma^{\text{theo}} = \gamma_0 + \frac{1}{2}(\mu + 1)$
- $\gamma^{\text{exp}} \approx 2.7$

$$K = K_0 E^{\mu} f(z)$$

- galactic magnetic field is expected to decrease (exponentially) with galactic height
  $\rightarrow$ increasing diffusion coefficient
- non-isotropic diffusion
  $\rightarrow$ particles having left the disk come back less likely
- energy losses less relevant



The Positron Spectrum in Different Diffusion Models

The spectral shape of the positron flux $\Phi(E,z=0)$ in the galactic disc arising from a sourceterm $Q \propto E^{-\gamma_0}$ is affected according to the spatial behavior of the diffusion coefficient:

$$K = K_0 E^{\mu} : \qquad \Phi \propto E^{-(\gamma_0 + \frac{1}{2}(1+\mu))}$$

$$K = K_0 E^{\mu} e^{\alpha z} : \qquad \Phi \propto E^{-(\gamma_0 + \mu)}$$

$$K = K_0 E^{\mu} z^{\delta} : \qquad \Phi \propto E^{-(\gamma_0 + \mu)} \quad \text{for} \quad \delta \geq 1$$

$\mu = 0 – 0.7$ for consistency with other particle species
new data from AMS-02 seem to favor small μ

Conclusion & Outlook

Cosmic ray transport in the diffusion model affects the spectral shape of the positron flux.

⋆

A diffusion coefficient which increases with galactic height, accounting for the changes of the magnetic field, yields a flatter positron spectrum.

⋆

The better the cosmic ray backgrounds are understood the more severe constraints on dark matter can be made.

Thank You!