An Alternative Propagation Model for Cosmic Positrons

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joint work with Rolf Kappl
to appear

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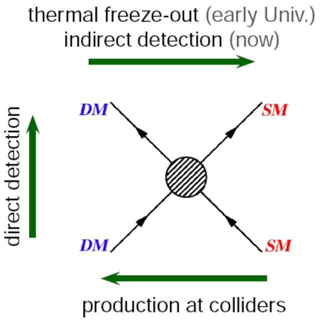
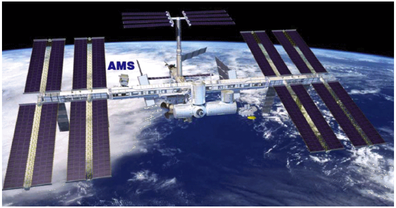
Motivation

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 (e^+, $\bar{p}$)

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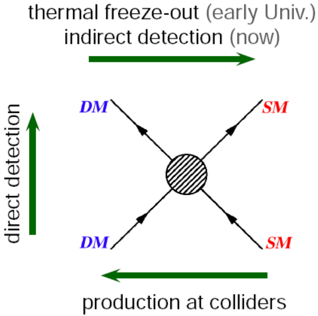

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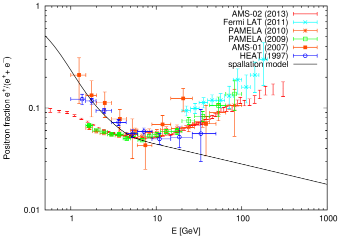
The Positron Excess

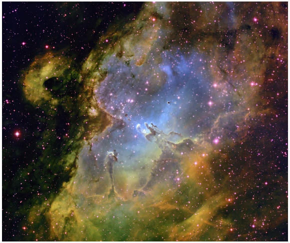
- the positron fraction $\frac{e^+}{e^+ + e^-}$ rises above $10\,\mathrm{GeV}$
- different explanations possible:
  → further primary sources: e.g. pulsars, dark matter
  → alternative propagation models [Blum, Katz]
- low energy regime is split due to solar modulation

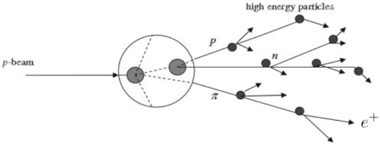


[Ibarra et al.]

The Origin of Cosmic Rays

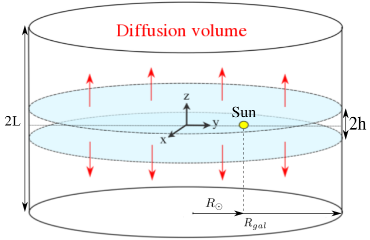
- primary sources: stars, supernovae, pulsars, DM, ...
- secondary production: collisions of cosmic rays with the interstellar medium $\rightarrow$ derived from interstellar fluxes and differential cross sections
- particles propagate in the interstellar medium





Cosmic Ray Transport

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



[Genolini et al.]

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

The Diffusion Equation

The particle flux $\phi(E,\vec{x}) = \frac{\beta}{4\pi}\mathcal{N}(E,\vec{x})$ is connected to the density $\mathcal{N}$ which is determined by the stationary diffusion equation:

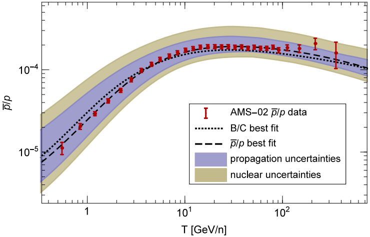
$$\underbrace{-\nabla(K(E,\vec{x})\nabla\mathcal{N})}_{\text{diffusion}} + \underbrace{\nabla V_c(z)\mathcal{N}}_{\text{convection}} + \underbrace{\frac{\partial}{\partial E}\left(b(E)\mathcal{N} - K_{EE}(E,z)\frac{\partial\mathcal{N}}{\partial E}\right)}_{\text{energy losses and reacceleration}} = \underbrace{Q(E,\vec{x})}_{\text{sourceterm}}$$

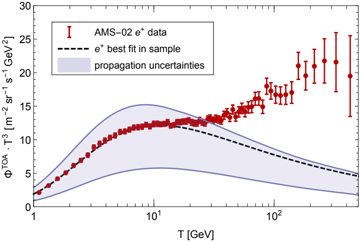
$K(E,\vec{x}) = K_0 E^{\delta} f(\vec{x})$ diffusion coefficient
$\vec{V}_c(z)$ galactic wind
$b(E) = -b_0 E^2$ energy losses (Compton scattering, synchrotron radiation)
$K_{EE}(E)$ diffusion in momentum space

with $\vec{x} = (x,y,z)^T$

Secondary Spectra in the Two-Zone Diffusion Model

isotropic diffusion: $K = K_0 E^{\delta}$





The antiproton fraction can accurately be described within this model.[Kappl, AR, Winkler '15]

The positron spectrum is not entirely reproduced.

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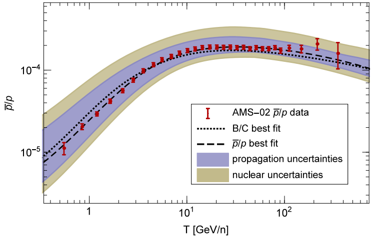

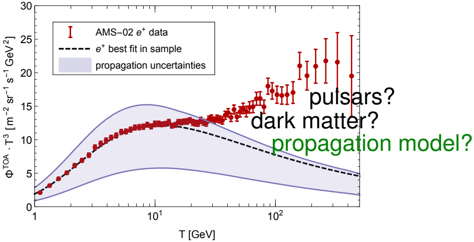

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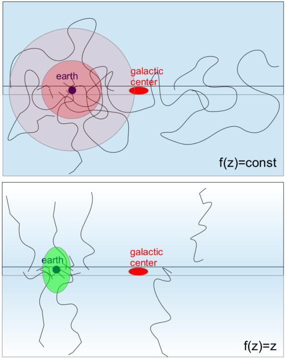
A Space Dependent Diffusion Coefficient

anisotropic diffusion: $K = K_0 E^{\delta} f(z)$

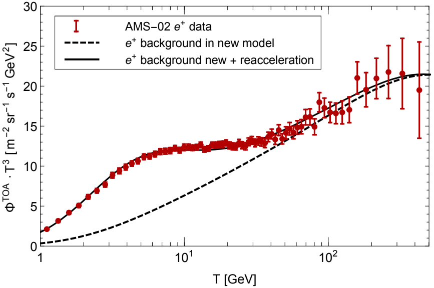
[Evoli, Gebauer, Tomassetti]

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



Positron Spectrum in the Anisotropic Diffusion Model

- for $K = K_0 E^{\delta}(|z| + z_h)^{\mu}$ we solve the diffusion equation analytically
- including reacceleration semi-analytically allows to reproduce the entire positron spectrum



- in exploration: consistency with other particle species, like B/C

Conclusion

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

★

An anisotropic diffusion-reacceleration model allows to reproduce the positron spectrum.

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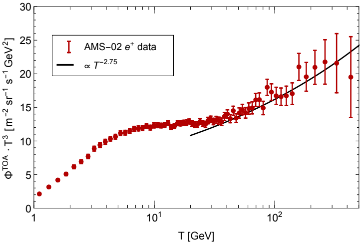
The better the astrophysical backgrounds are understood the more severe constraints on dark matter can be made.

The Spectral Slope in Different Diffusion Models

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



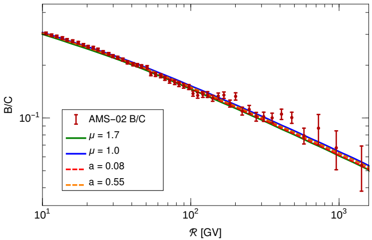
spectral index γ:

- $\gamma_0 \approx 2.7$
- $\gamma^{\text{exp}} \approx 2.75$
- $\gamma^{\text{two-zone}} = \gamma_0 + 0.5 + \frac{\delta}{2}$

- anisotropic model:

$$\gamma^{\text{theo}} \approx \begin{cases} \gamma_0 + \delta & E \text{ "small"} \\ \gamma_0 + 1 & E \text{ "large"} \end{cases}$$

Reproducing the B/C spectrum



- the hadronic spectrum is not much affected by the anisotropy
- different propagation parameters are required

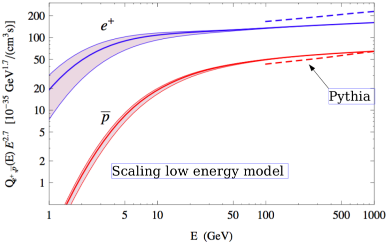
[Cowsik '14, Blasi '09, Katz '10]

- different propagation parameters for hadrons and leptons?
- coupling to magnetic field depends on $\frac{q}{m}$ $\rightarrow$ affects K_0
- different production features for light and heavy elements $\rightarrow \delta$

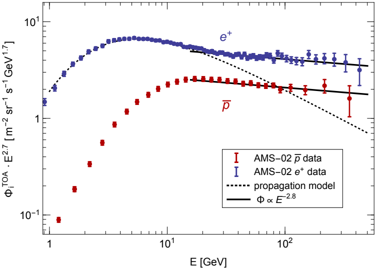
Motivation II

secondary positrons e^+ and antiprotons $\bar{p}$ originate from collisions of CR with the ISM

$\Rightarrow$ *source term* has a similar energy dependence:



[Lipari]



the spectral similarity is also manifest in the *measured flux*

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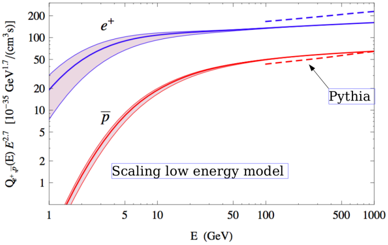

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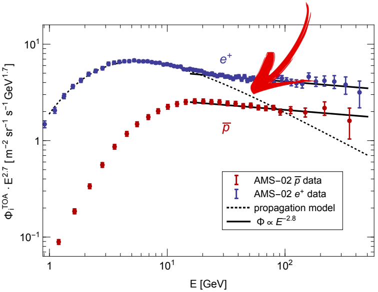
energy losses



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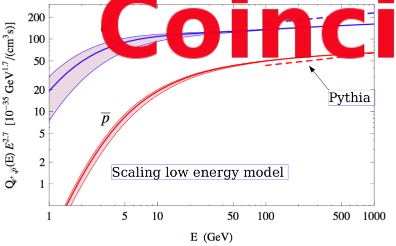
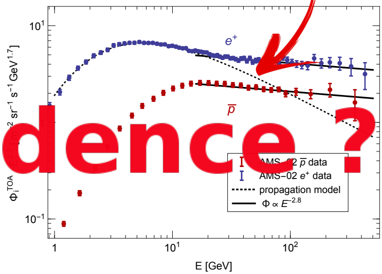
Coincidence ?





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