PAMELA without Dark Matter or Pulsars

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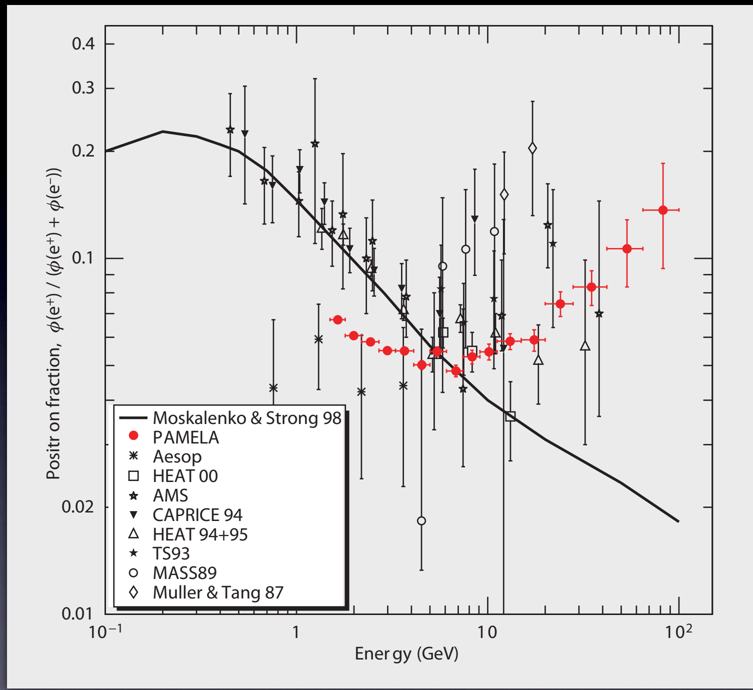
The Dark Matter Connection: Theory and Experiment; Florence 2010

Based on 1005.4668 [astro-ph]

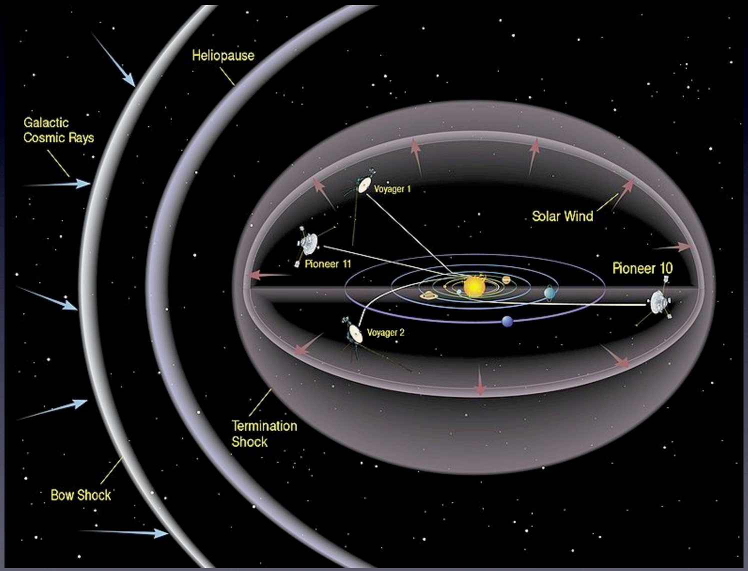


O. Adriani et. al, 2010

How do you solve a problem like PAMELA?

- Dark matter
- Pulsars

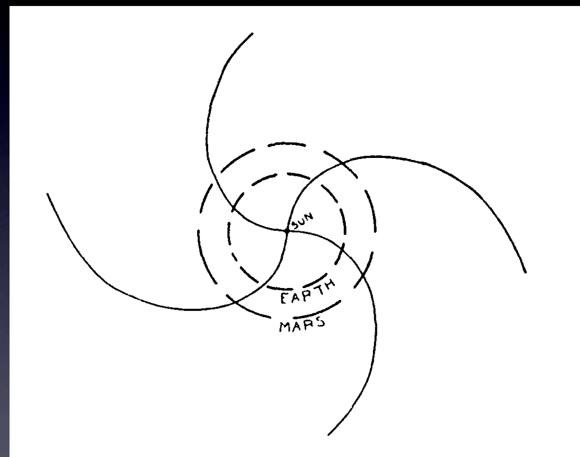
What else could it be?



The Heliospheric Magnetic Field - a Brief Summary

- The sun is a spinning dipole
- It rotates fully once every 27 days and 6 hours
- Its polarity flips every 11 years (or so).
- Around the time it flips the magnetic field is turbulent (Solar Maximum)
- Between Solar Maxima the magnetic field is stable over large distances

The Parker Spiral



The magnetic field is carried by the supersonic solar wind

The rotational retardation pulls the field into a spiral

E. N. Parker, 1958

Parker Magnetic Field Equations

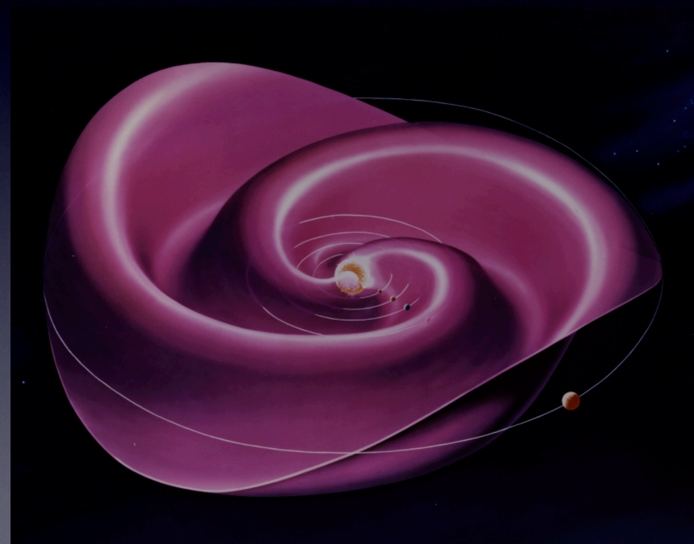
$$\mathbf{B} = B_0 \frac{r_0^2}{r^2} \left[\hat{\mathbf{e}}_r - \frac{\Omega_\odot (r-b)\sin\theta}{V} \hat{\mathbf{e}}_\phi \right]$$

$\Omega_\odot$ is the rotation speed of the sun
V is the solar wind speed (about 400km/s)
b is the radius at which the field is purely radial
B_0 is the field strength at r_0

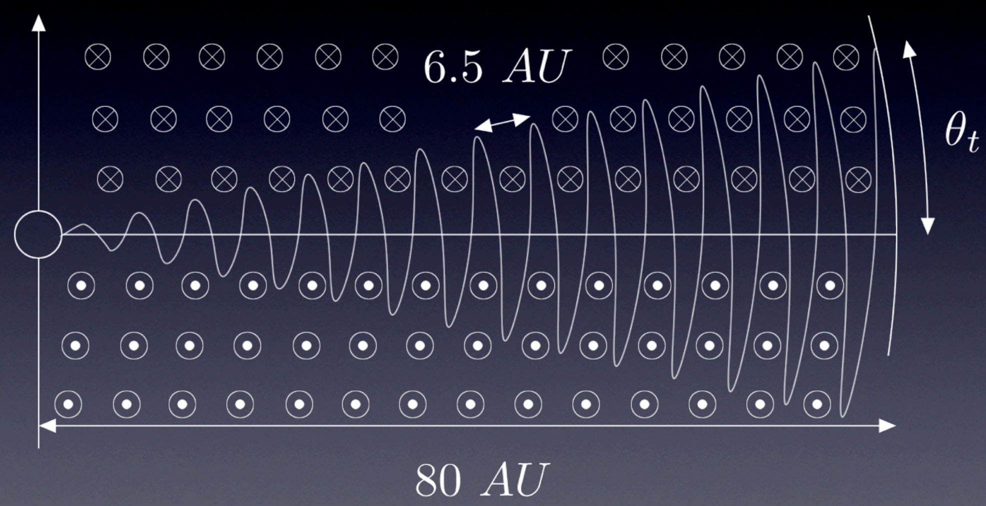
Important features

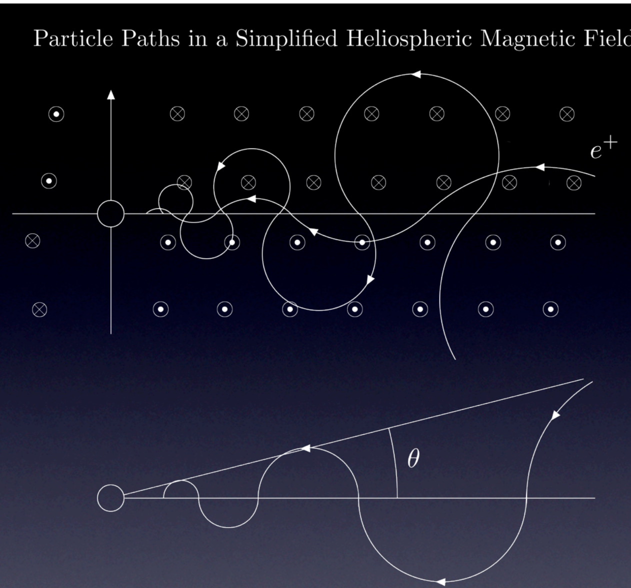
- The azimuthal component falls off as 1/r
- After a short distance the field is almost purely azimuthal (after a few AU)
- The lines are oppositely directed above and below the current sheet
- The magnetic field at earth is around 3.3nT

It’s never quite so simple...



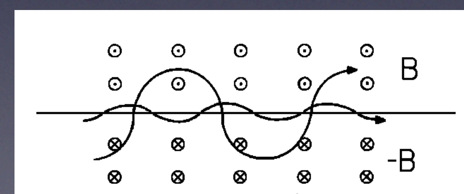
The Magnetic Field in the Heliosphere





JPR: 1005.4668 [astro-ph]

... or E H Levy, 1976



So now that we have a lense - what can we do with it?

- Cosmic rays can't get directly to us at low energies

$$r_g(AU) = \frac{2.2 \times 10^{-2} p_\perp (GeV/c)}{|q| B(nT)}$$

- They need to be around a few TeV to make it directly through the magnetic field
- At lower energies they take the long way round.

The Transport Equation

Convection

Drifts

$$\frac{\partial U}{\partial t} = -\nabla\cdot(C\mathbf{V}U) - \nabla\cdot(\langle\mathbf{v}_d\rangle U) + \nabla\cdot(\kappa^{(S)}\cdot\nabla U) - \frac{1}{3}\frac{\partial}{\partial p}(p\mathbf{V}\cdot\nabla U)$$

Diffusion

Adiabatic Energy Loss

Cosmic Ray Transport

- Parallel diffusion is much more efficient than perpendicular diffusion
  - Particles mostly follow the field lines
- Convection pushes particles out
  - Creates a radial gradient in density
- Drifts allow for more efficient motion perpendicular to magnetic field lines

But between a few GeV and a few TeV particles go from following field lines to travelling across them.

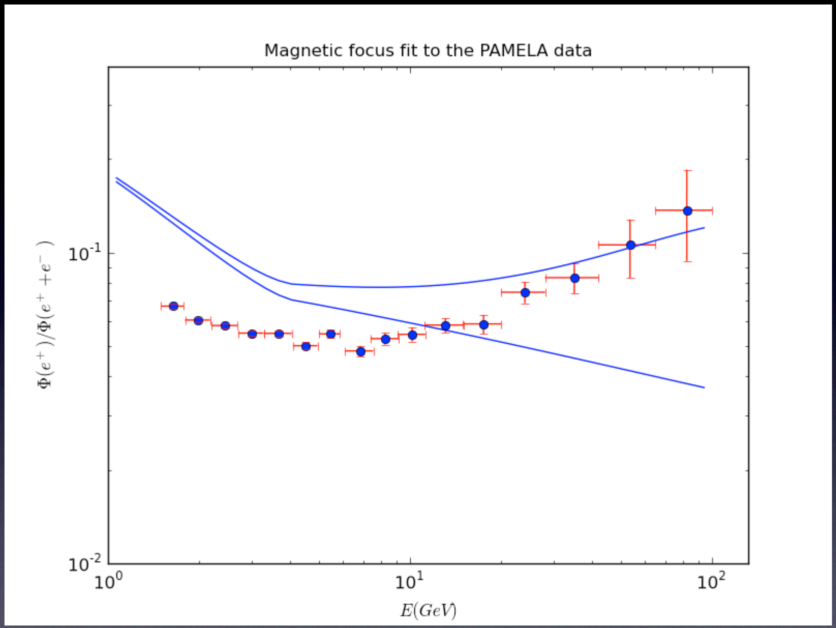
What now?

- Fraction of volume in which perpendicular travel can occur is given by:

$$f = \sin\theta = \frac{2.2 \times 10^{-2} p_{\perp}(GeV/c)}{|q| B_E(nT)}$$

- Parameterise the effect using a boost on this portion of the volume:

$$F_l(e^+) = F(e^+)(1 - f + f B_l)$$

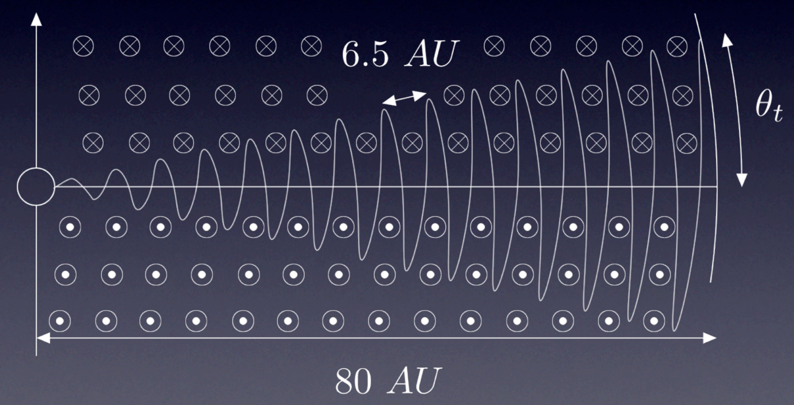


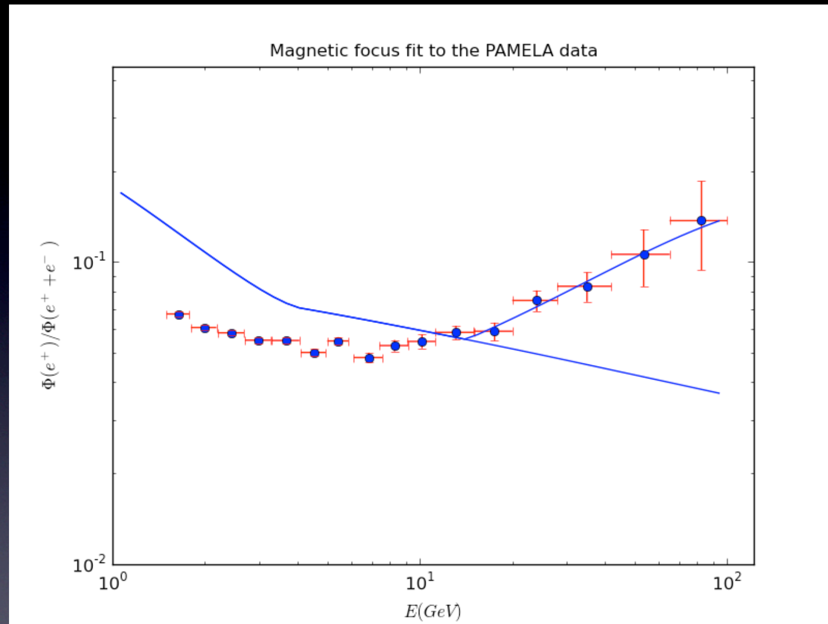
Magnetic focus fit to the PAMELA data
$\Phi(e^+)/\Phi(e^+ + e^-)$
10^{-1}
10^{-2}
10^0
10^1
10^2
$E(GeV)$

$$B_l = 5$$

But it's not flat...

The Magnetic Field in the Heliosphere





$$B_l = 7.5,\ \alpha = 6^o$$

Conclusions

- It's not true that heliospheric effects only matter below a few GeV
- Between a few GeV and a few TeV the manner in which cosmic rays traverse the solar system changes.
- This is not charge symmetric.
- If it's a heliospheric effect the PAMELA result will go away in a couple of years.
- The signal should vary with the tilt of the current sheet.