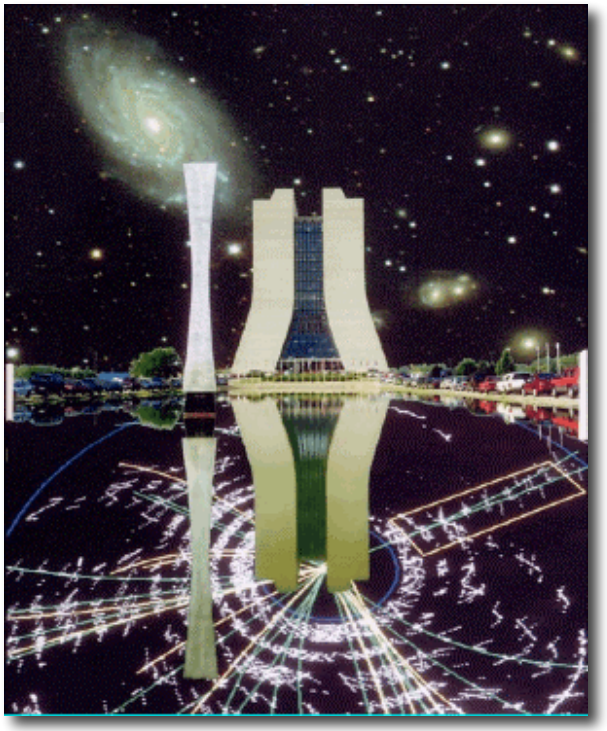
Dark Matter and Charged Cosmic Rays

Dan Hooper
Fermilab/University of Chicago

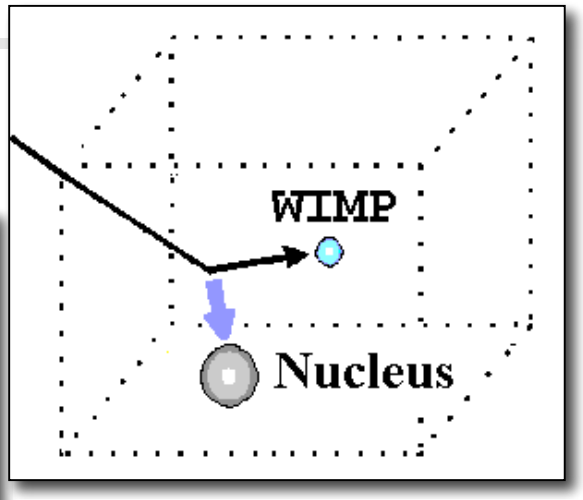
KICP Workshop on High Energy Astrophysics Experiments and Cosmological Physics

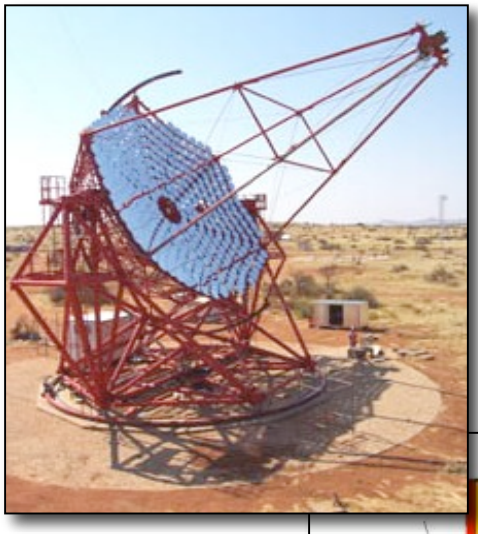
October 27, 2008

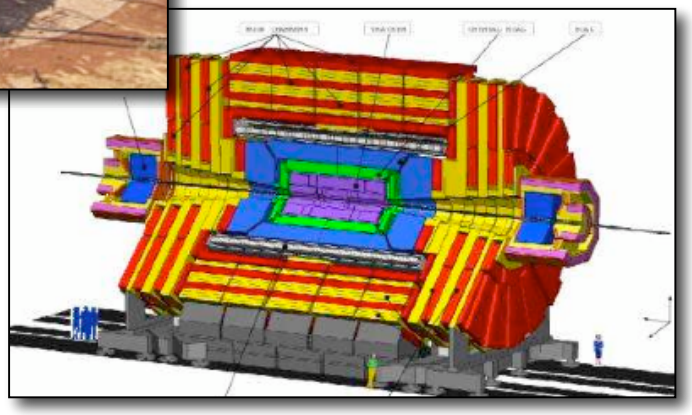


WIMP Hunting

- **Direct Detection**
- **Indirect Detection**
- **Collider Searches**

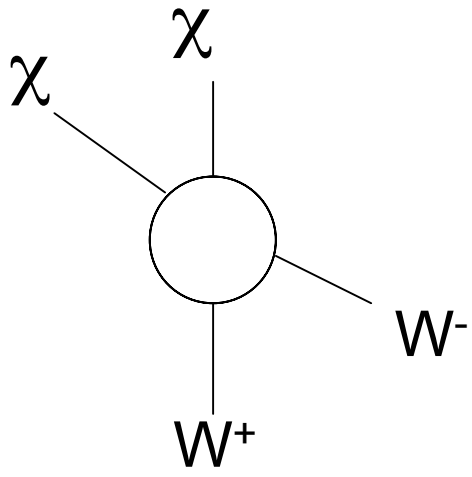






The Indirect Detection of Dark Matter

1. **WIMP Annihilation**
   Typical final states include heavy fermions, gauge or Higgs bosons



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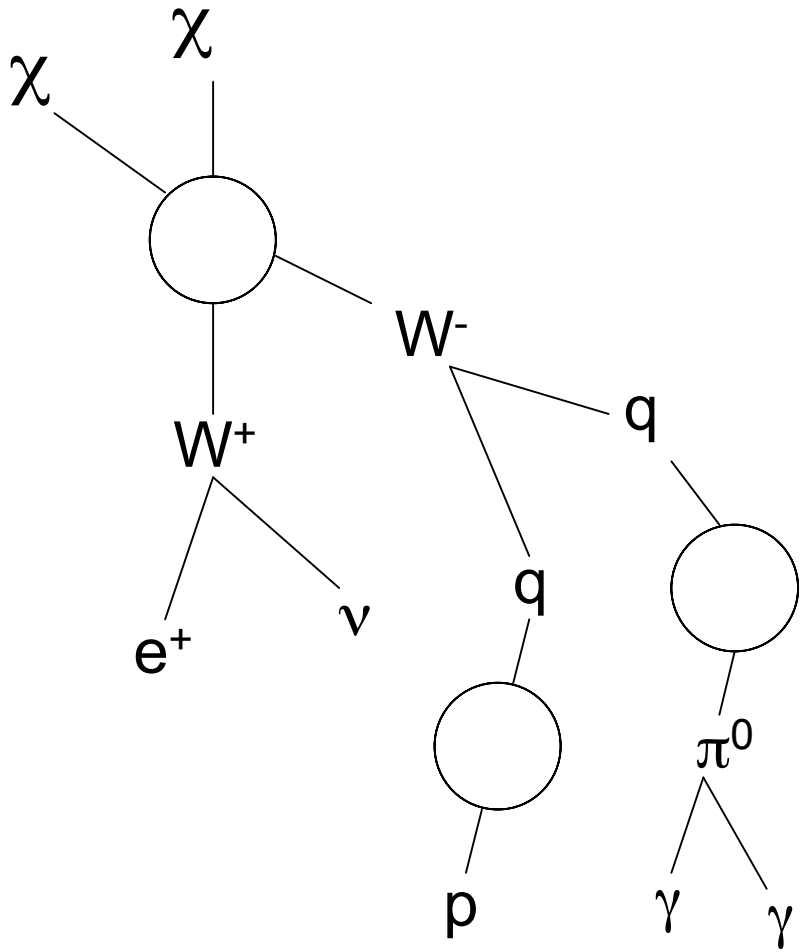
   Annihilation products decay and/or fragment into combinations of electrons, protons, deuterium, neutrinos and gamma-rays



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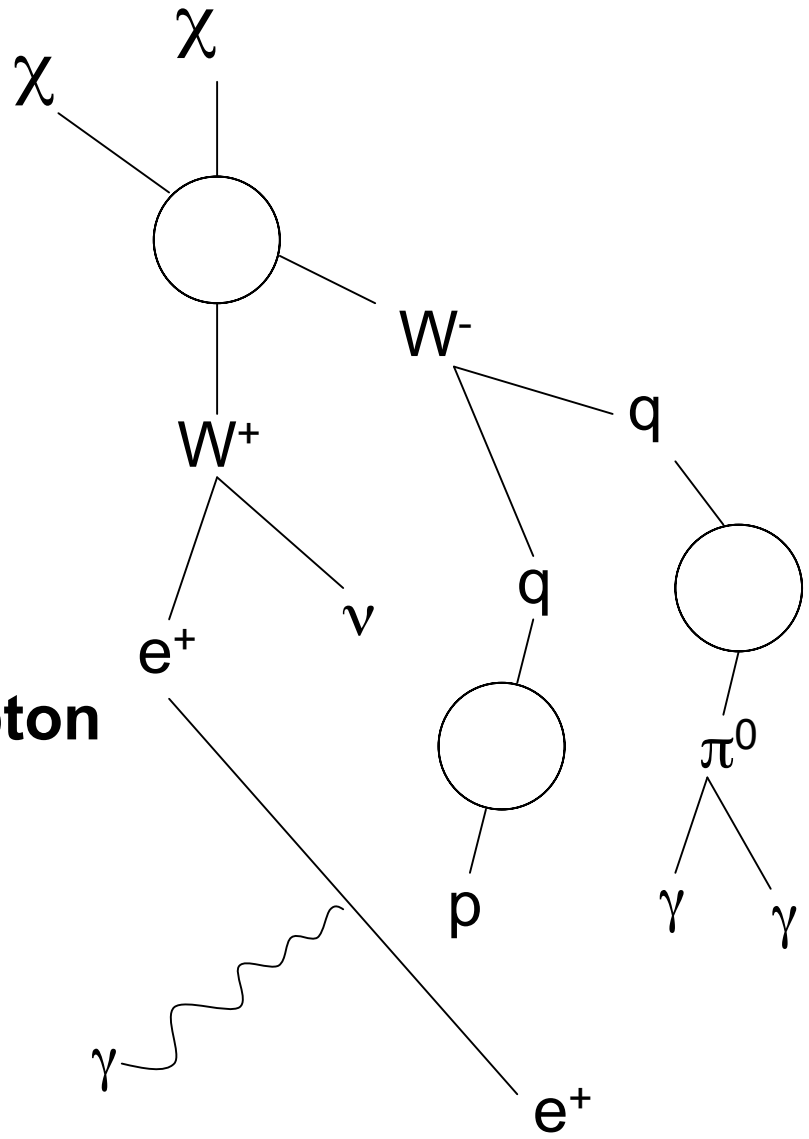
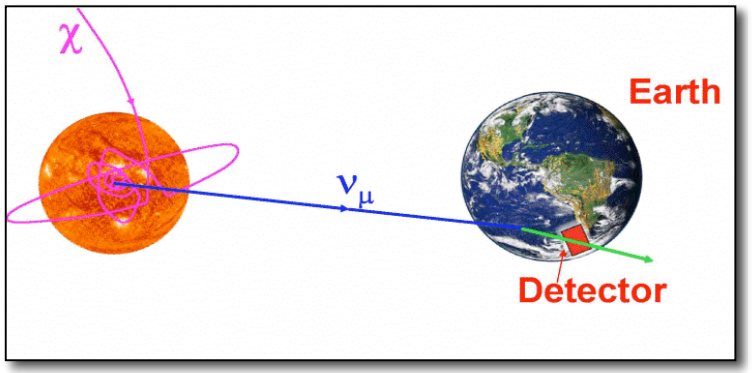
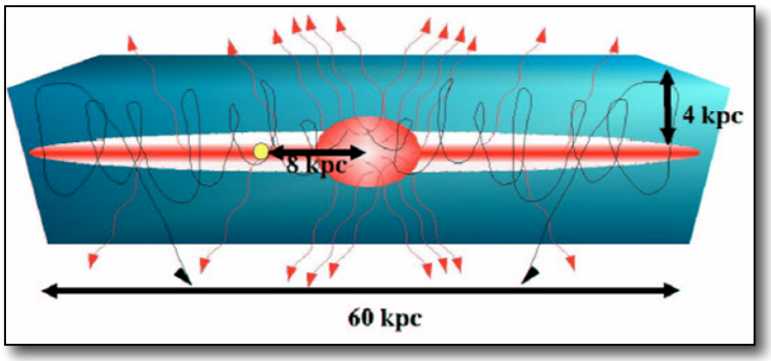
3. **Synchrotron and Inverse Compton**
   Relativistic electrons up-scatter starlight/CMB to MeV-GeV energies, and emit synchrotron photons via interactions with magnetic fields



The Indirect Detection of Dark Matter

- **Neutrinos** from annihilations in the core of the Sun
- **Gamma Rays** from annihilations in the galactic halo, near the galactic center, in dwarf galaxies, etc.
- **Positrons/Antiprotons** from annihilations throughout the galactic halo
- **Synchrotron Radiation** from electron/positron interactions with the magnetic fields of the inner galaxy





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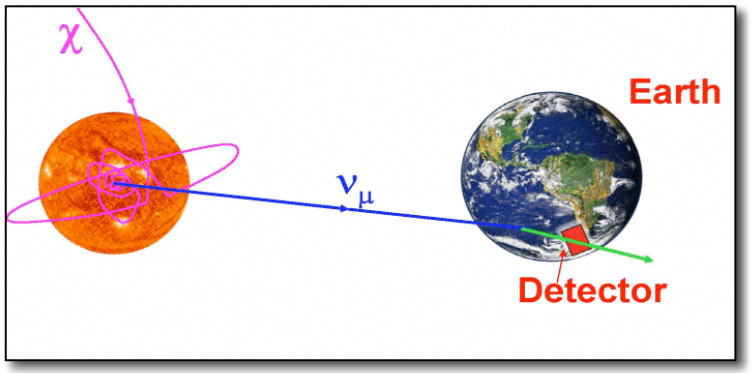
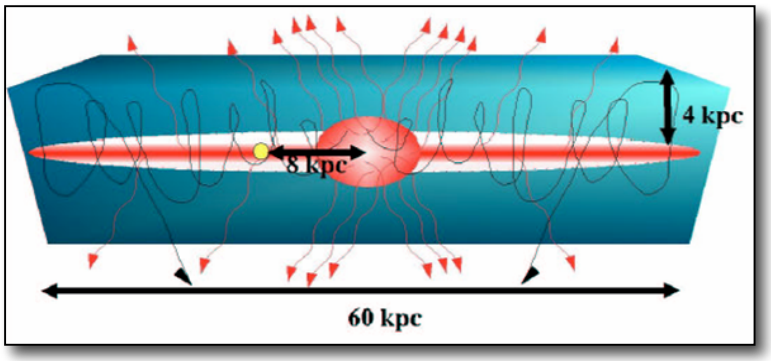
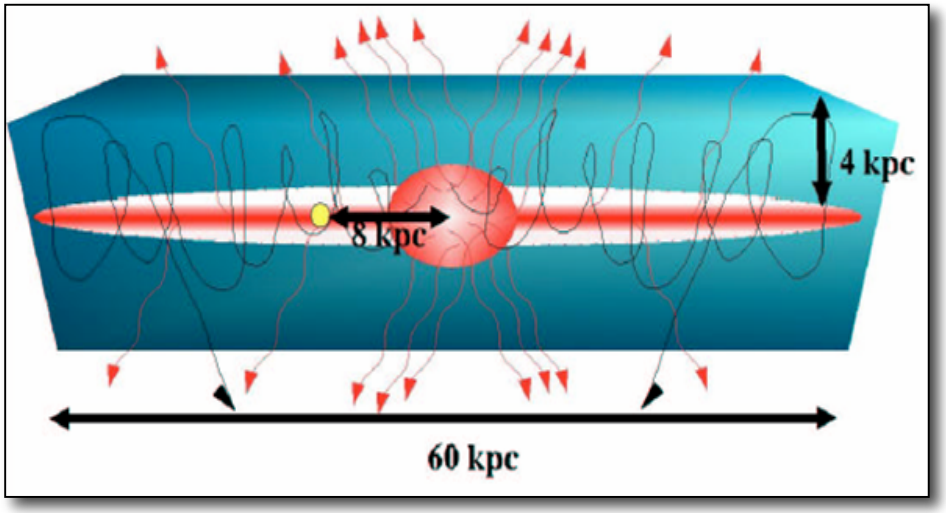




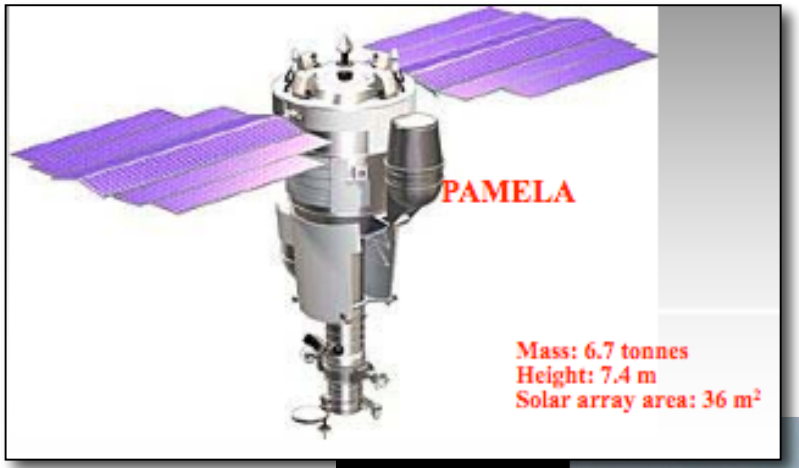
Dark Matter With Charged Cosmic Rays

- WIMP annihilation products fragment and decay, generating equal numbers of electrons and positrons, and of protons and antiprotons
- Charged particles move under the influence of the Galactic Magnetic Field; Electrons/positrons lose energy via synchrotron and inverse Compton scattering
- Astrophysical sources are generally expected to produce far more matter than antimatter - large positron/antiproton content in the cosmic ray spectrum could provide evidence for dark matter

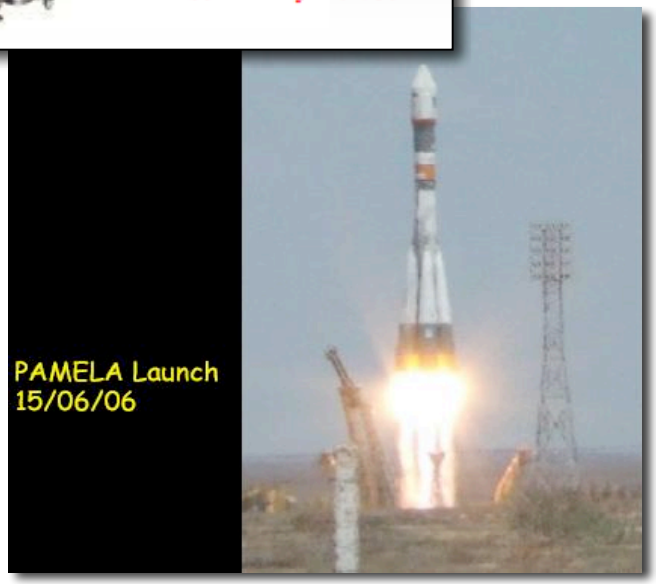


Charged Particle Astrophysics With Pamela

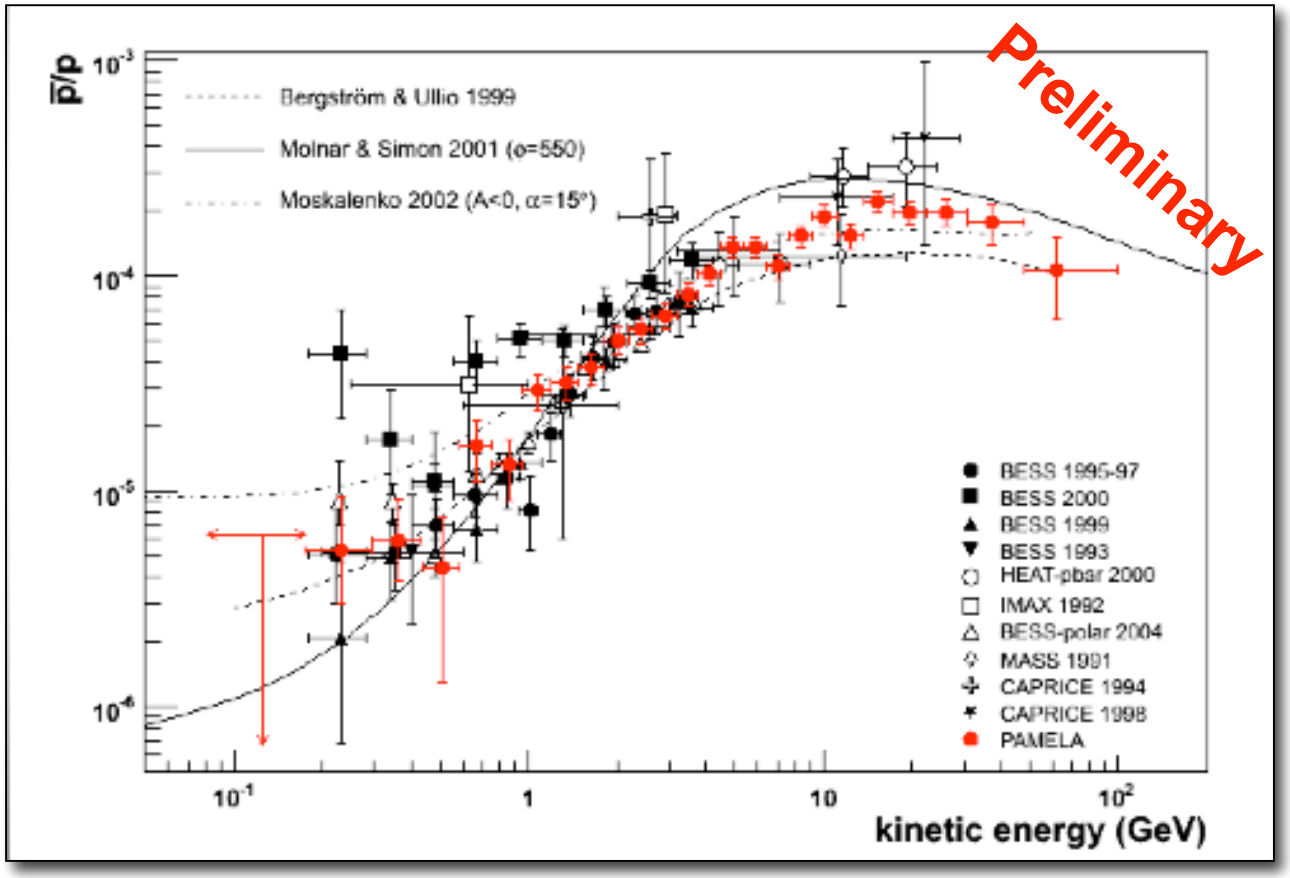
- Major step forward in sensitivity to GeV-TeV cosmic ray electrons, positrons, protons, antiprotons, and light nuclei



- Among other science goals, PAMELA hopes to identify or constrain dark matter annihilations in the Milky Way halo by measuring the cosmic positron and antiproton spectra

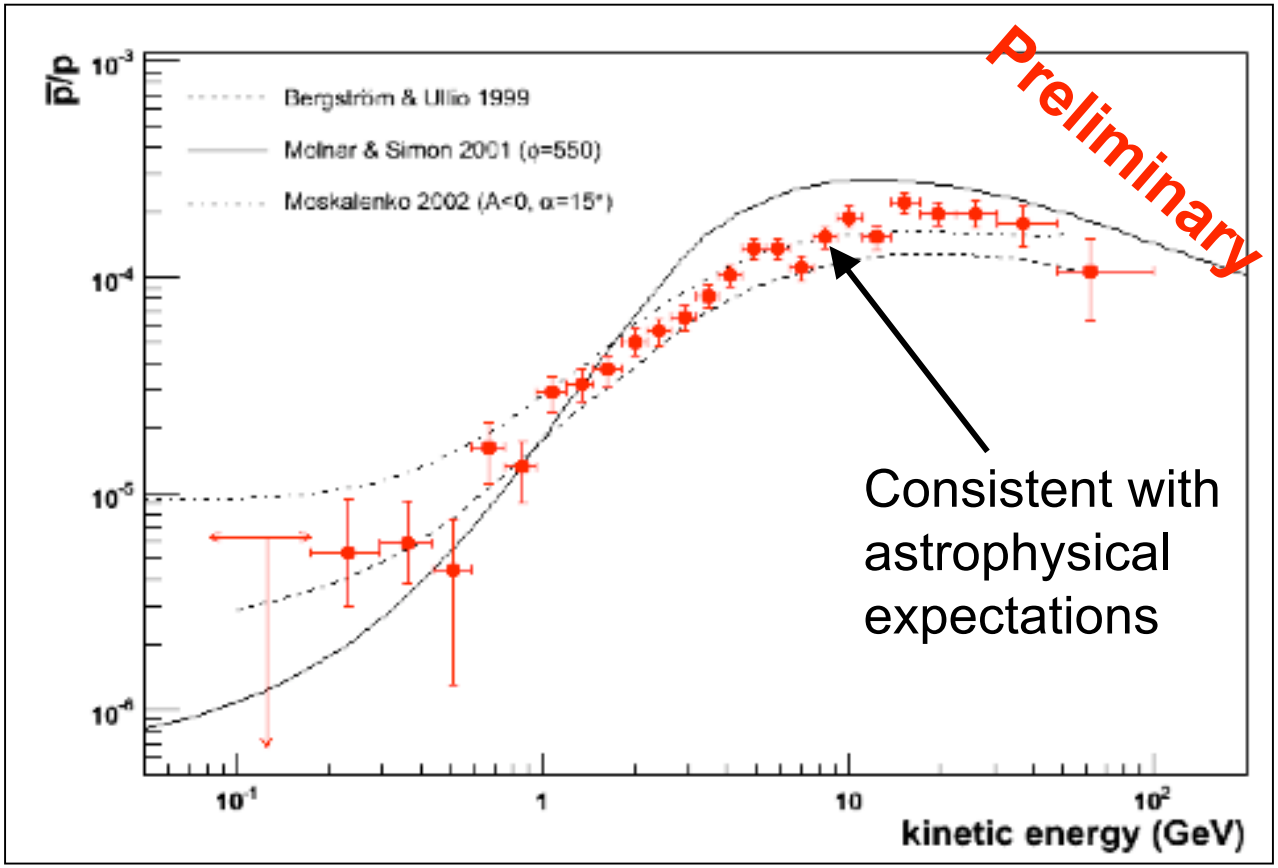


Pamela's New Antiproton Measurement



M. Boezio, ICHEP08

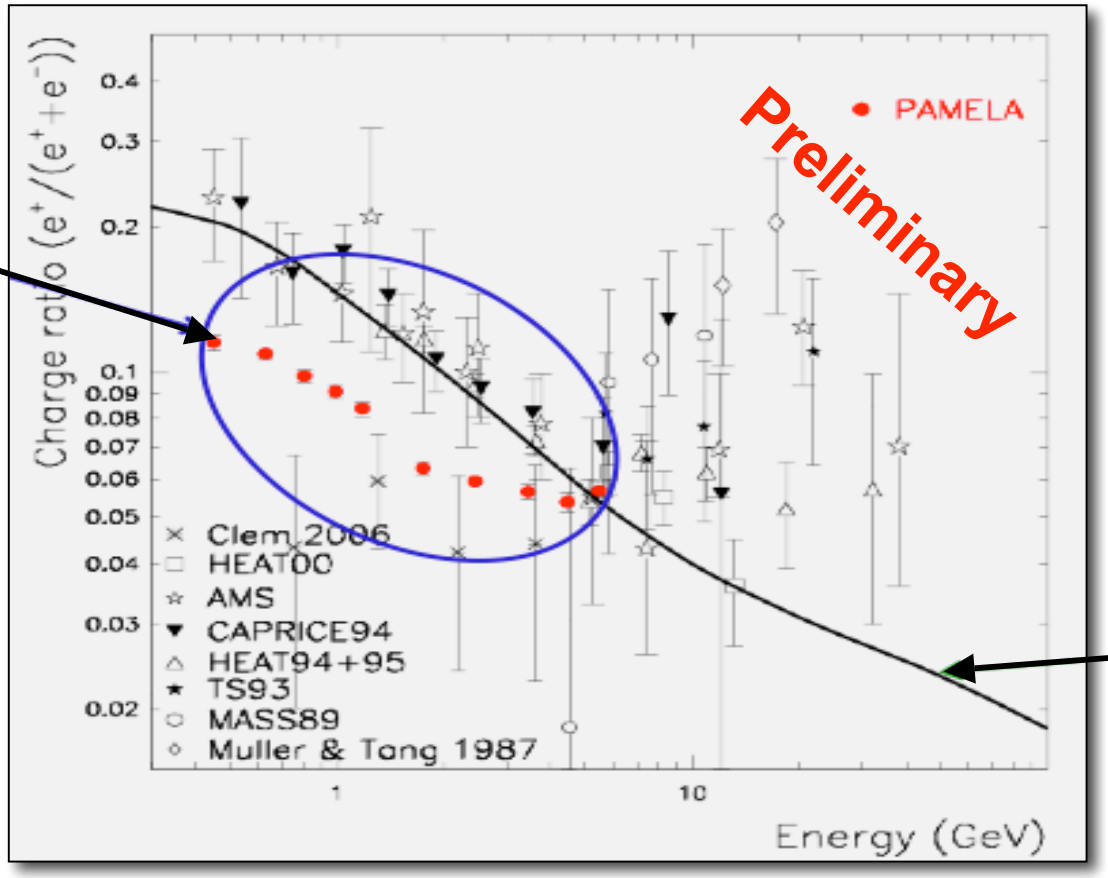
Pamela's New Antiproton Measurement



M. Boezio, ICHEP08

Pamela's New Positron Measurement

First glance:
- Is this all screwed up?
-Looks nothing like results from HEAT or other previous experiments



Astrophysical expectation (secondary production)

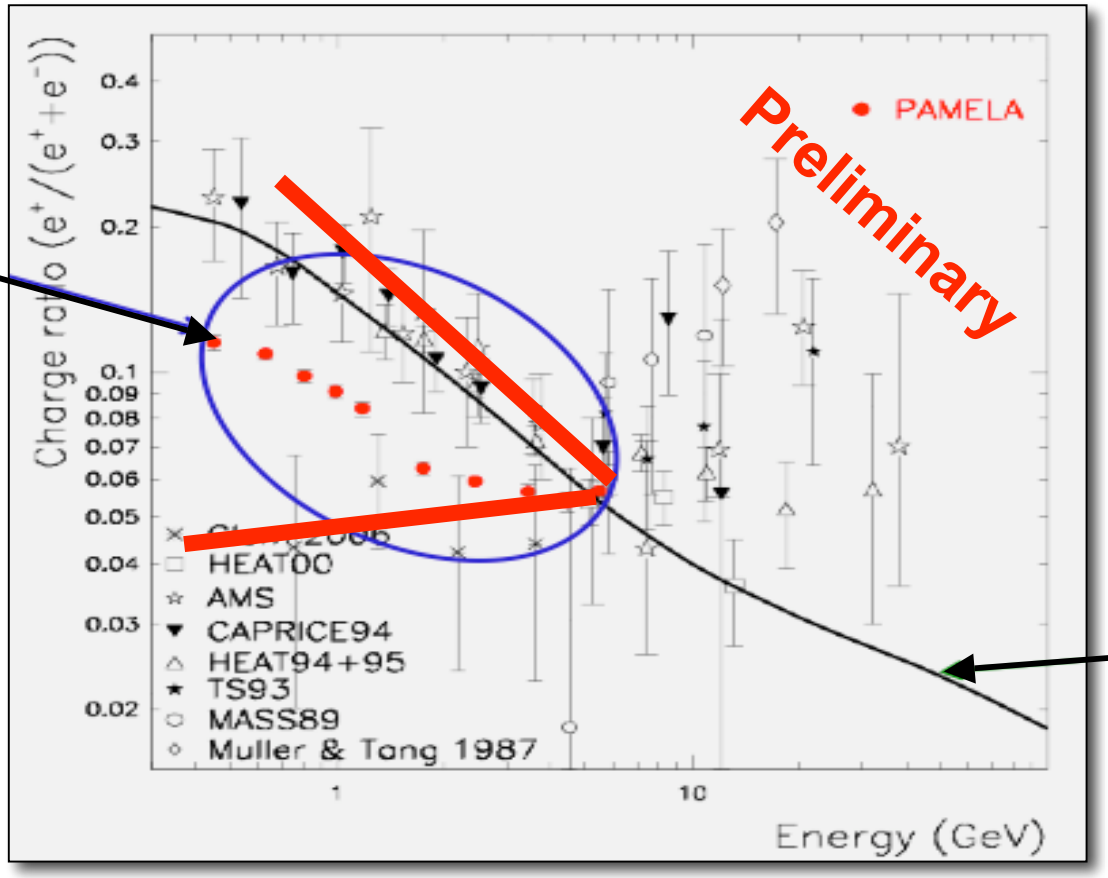
M. Boezio, ICHEP08

Pamela's New Positron Measurement

Charge-dependent solar modulation important below 5-10 GeV!

Varies in an understandable way with the solar cycle

(Pamela's sub-10 GeV positrons appear as they should!)

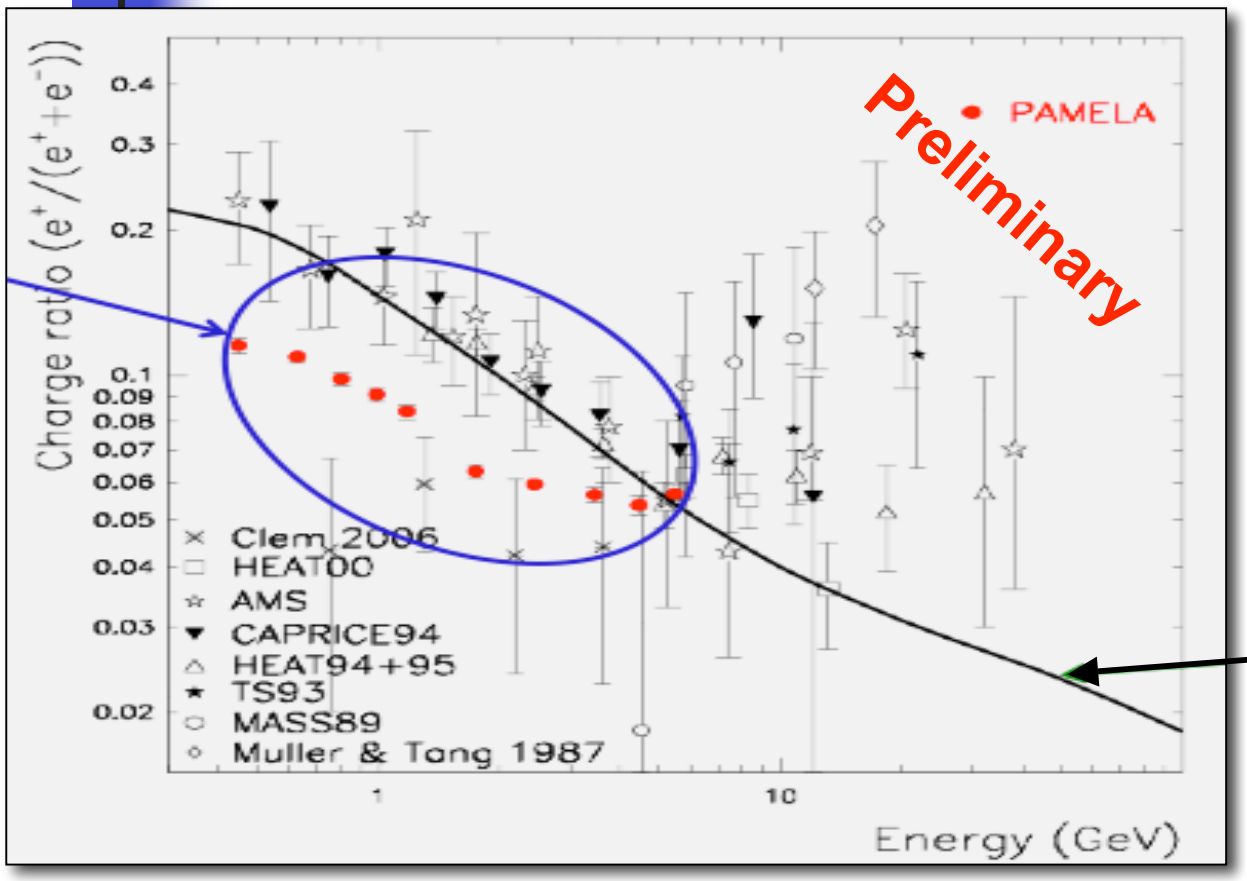


Astrophysical expectation (secondary production)

M. Boezio, ICHEP08

But that is not the interesting part…

Pamela's New Positron Measurement



- This ***is*** the plot you will on the ICHEP08 website, But it ***is not*** the plot they showed at ICHEP08… (or at IDM2008)

Astrophysical expectation (secondary production)

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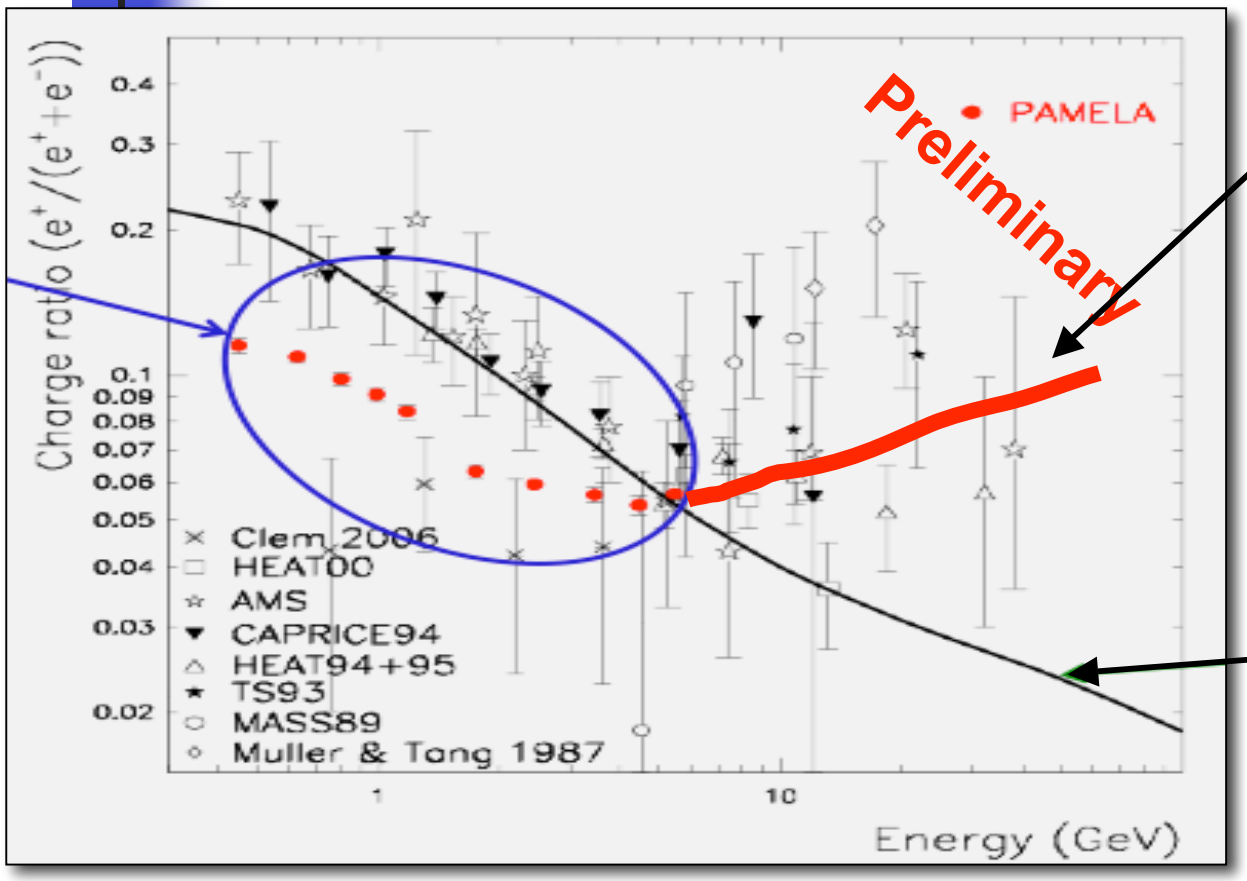
Pamela's New Positron Measurement



- The positron content of the comic ray spectrum begins to rise at 8-10 GeV, and climbs to ~10% at 60 GeV

Astrophysical expectation (secondary production)

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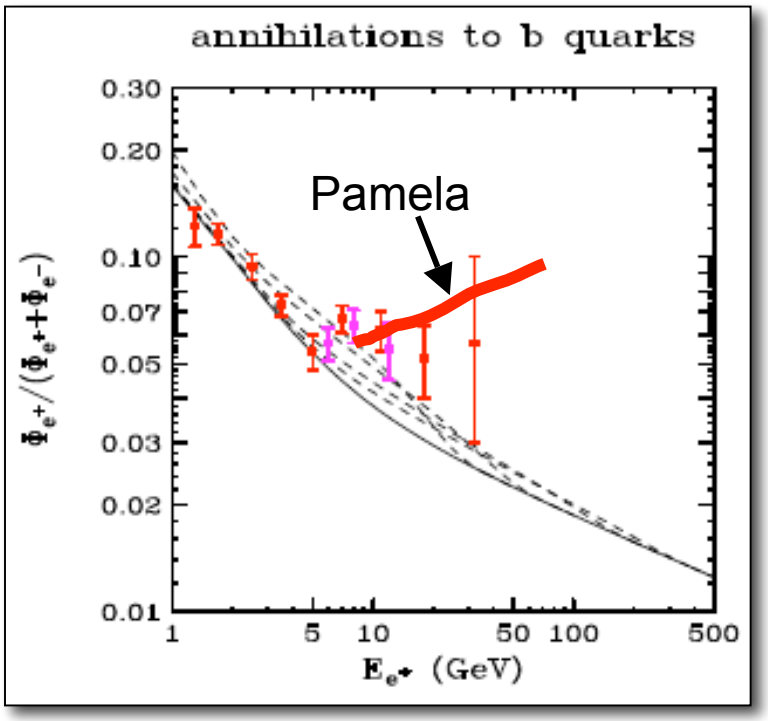
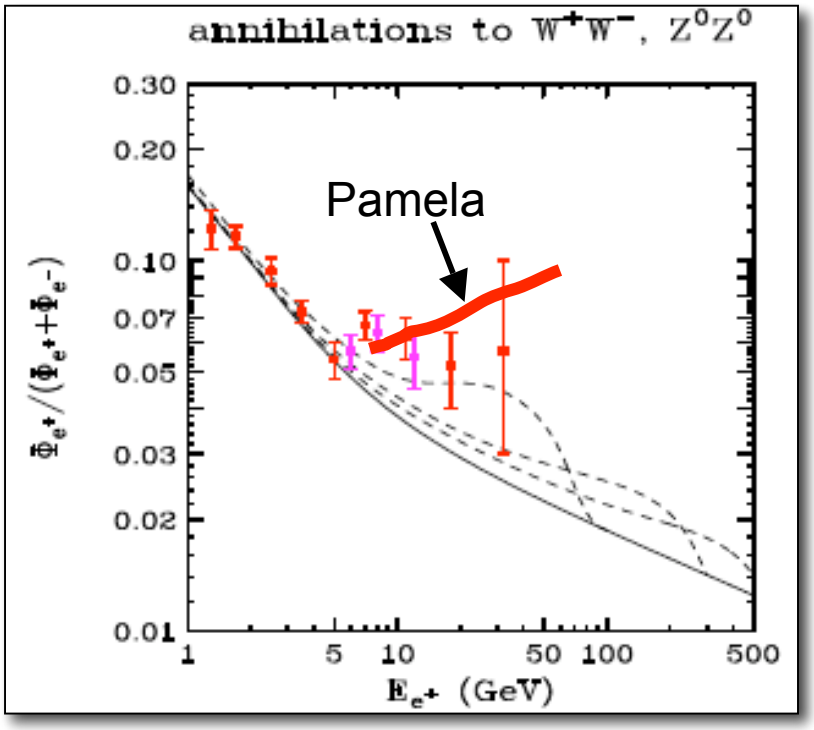
A Dark Matter Interpretation of Pamela's Positrons

Somewhat difficult to get so many high energy positrons





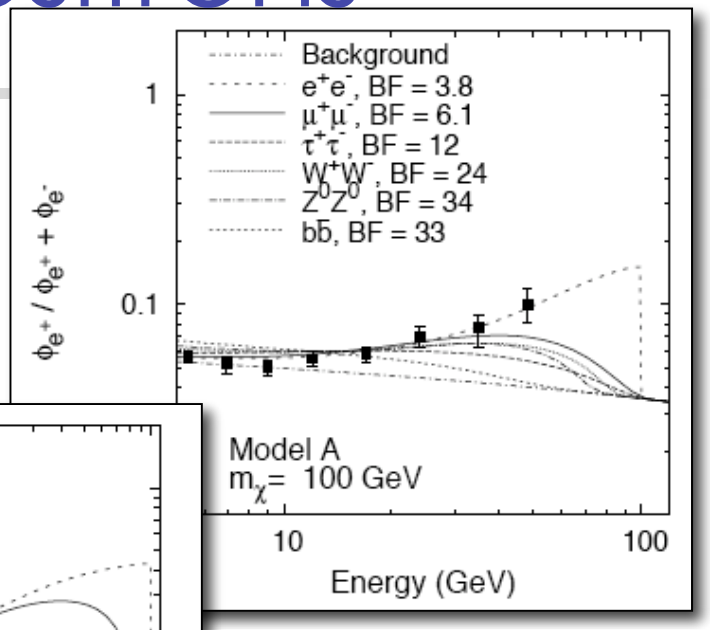
Dan Hooper - *Dark Matter And Charged Cosmic Rays*

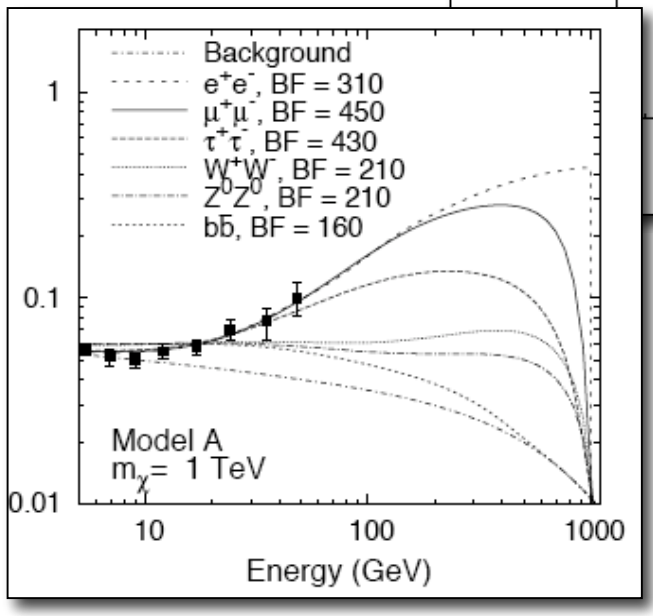
D. Hooper and J. Silk, PRD, hep-ph/04091040

A Dark Matter Interpretation of Pamela's Positrons

Could be accomodated by:

1) Very hard injection spectrum (a large fraction of annihilations to e^+e^-, $\mu^+\mu^-$ or $\tau^+\tau^-$)





Dan Hooper - *Dark Matter And Charged Cosmic Rays*

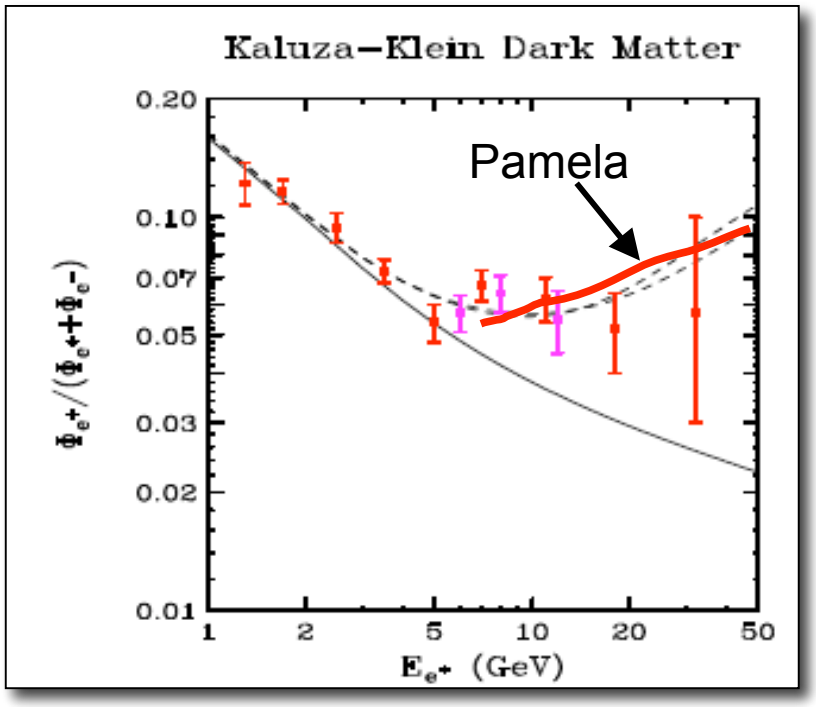
Cholis, Goodenough, Hooper, Simet and Weiner
arXiv:0809.1683

A Dark Matter Interpretation of Pamela's Positrons

Could be accomodated by:

1) Very hard injection spectrum (a large fraction of annihilations to e^+e^-, $\mu^+\mu^-$ or $\tau^+\tau^-$)

- For example, the lightest Kaluza-Klein state in a model with a universal extra dimenison (UED) fits remarkably well (or a KK-ν or other particle which annihilates to light fermions through a Z)

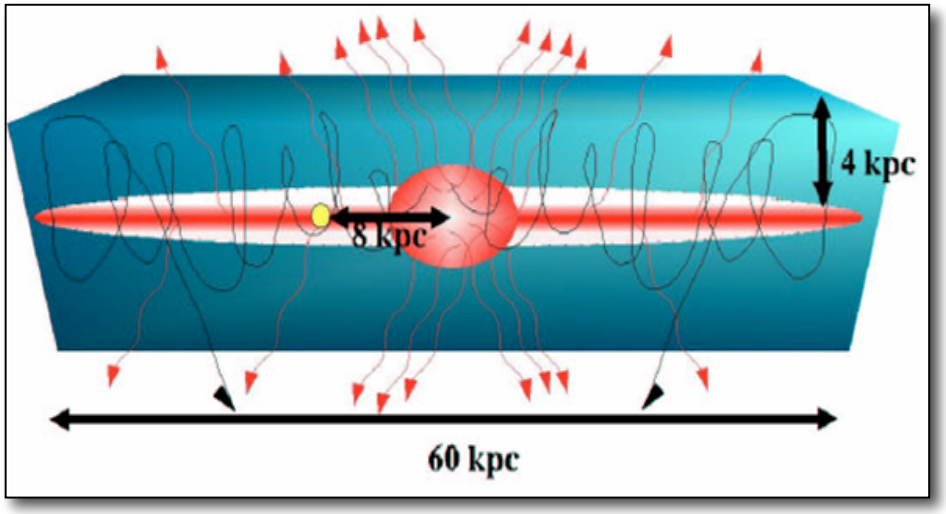


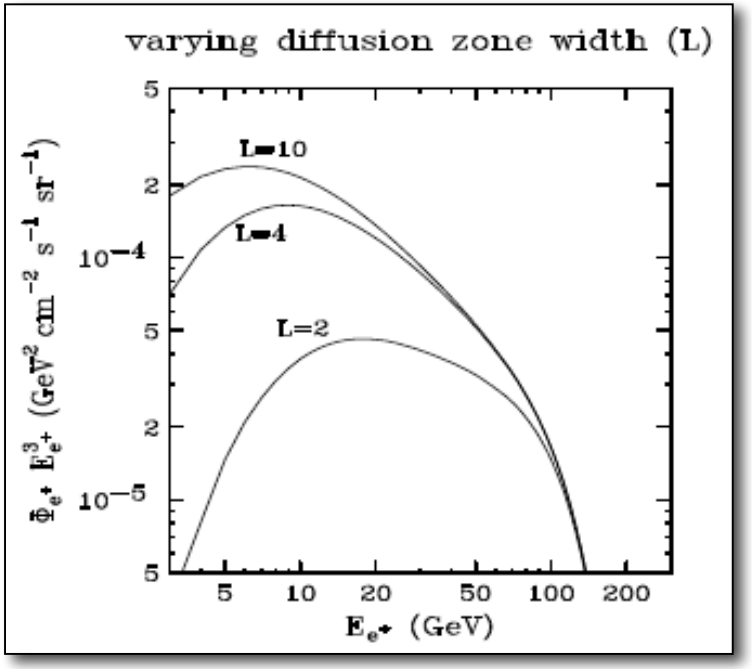
H. Cheng, J. Feng, K. Matchev, PRL, hep-ph/0207125;
D. Hooper, G. Kribs, PRD, hep-ph/0406026;
D. Hooper and J. Silk, PRD, hep-ph/04091040

A Dark Matter Interpretation of Pamela's Positrons

Could be accomodated by:

1) Very hard injection spectrum (annihilation modes)
2) A narrow diffusion region or large diffusion coefficient





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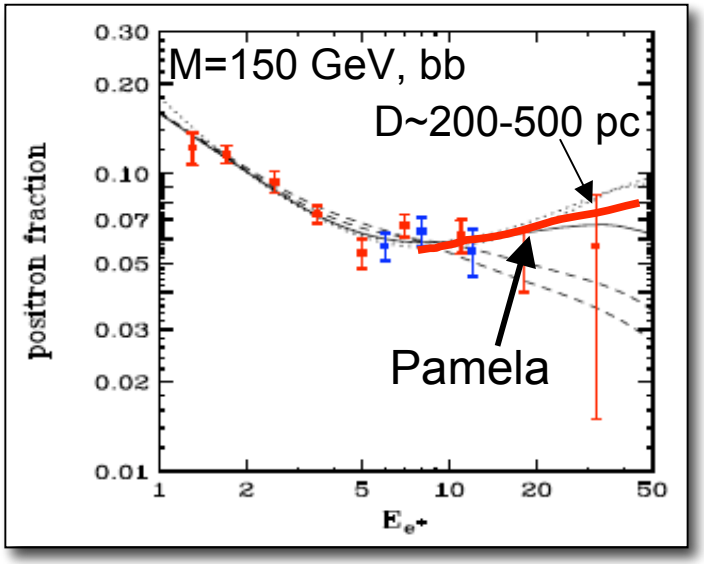
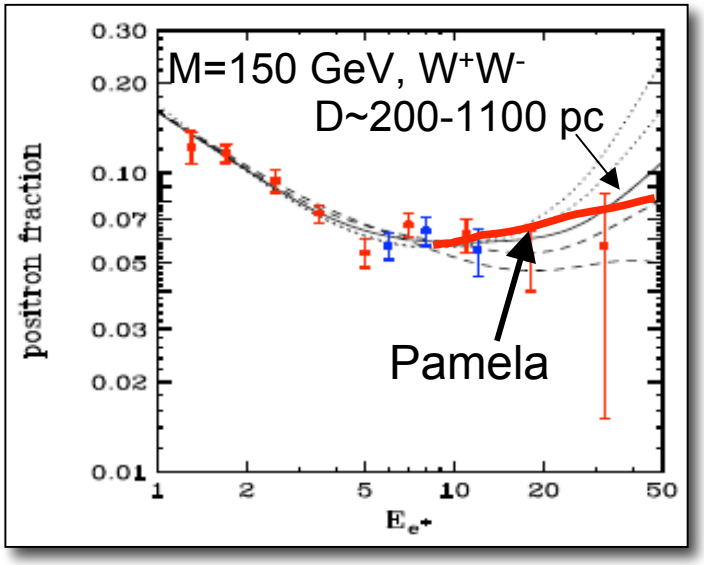
D. Hooper and J. Silk, PRD, hep-ph/04091040

A Dark Matter Interpretation of Pamela's Positrons

Could be accomodated by:

1) Very hard injection spectrum (annihilation modes)
2) A narrow diffusion region or large diffusion coefficient
3) A nearby source/clump of annihilating dark matter

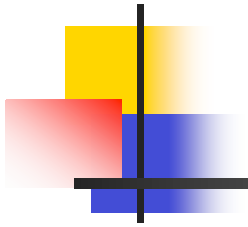




Dan Hooper - *Dark Matter And Charged Cosmic Rays*

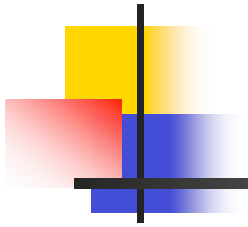
D. Hooper J. Taylor and J. Silk, PRD, hep-ph/0312076

A Dark Matter Interpretation of Pamela's Positrons?



Some Words of Caution

A Dark Matter Interpretation of Pamela's Positrons?



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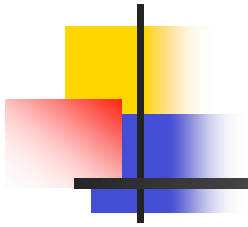

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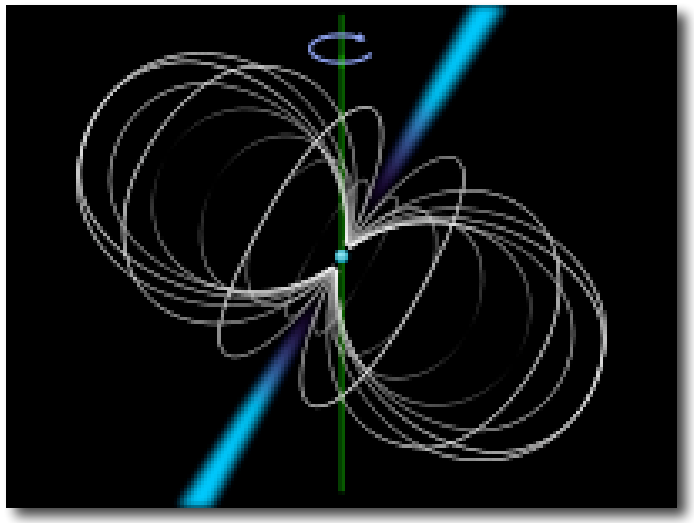
- An astrophysical source of the positrons is unexpected, but might be possible (a nearby and luminous young pulsar perhaps?)

See Hooper, Blasi and Serpico, arXiv:0810.1527; Yuksel, Kistler and Stanev, arXiv:0810.2784

High-Energy Positrons From Nearby Pulsars

- Rapidly spinning (~msec period) neutron stars, accelerate electrons to very high energies (power from slowing rotation - spindown)



High-Energy Positrons From Nearby Pulsars

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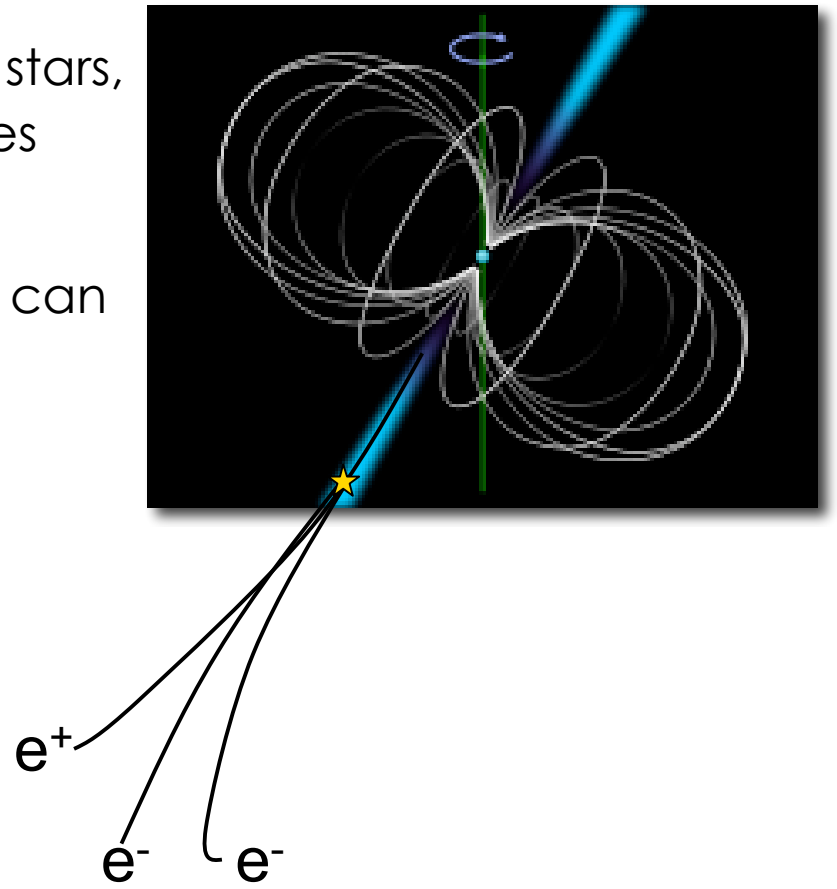

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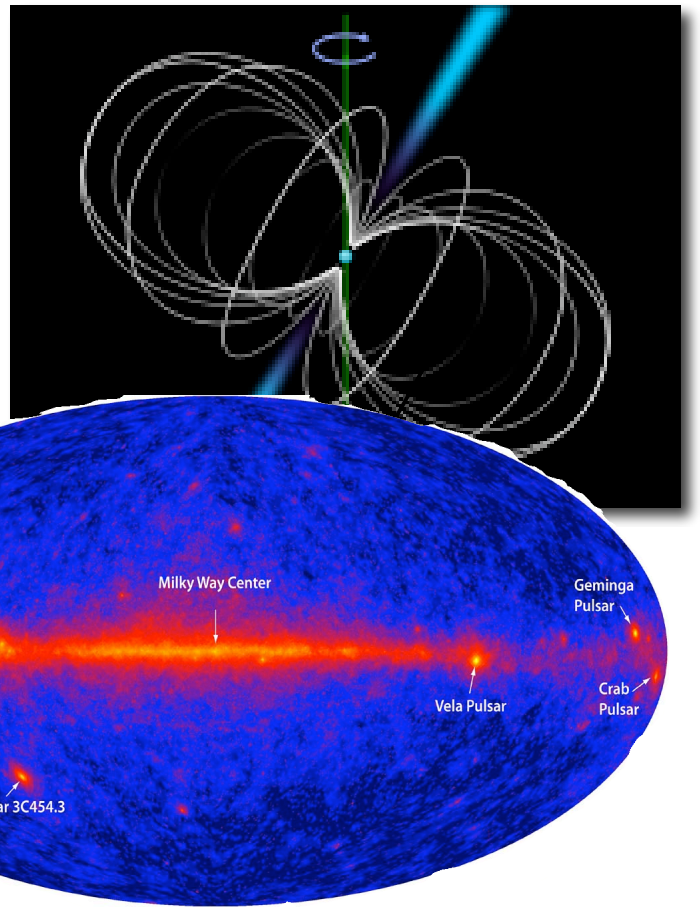

Fermi/Glast Sky Map

High-Energy Positrons From Nearby Pulsars

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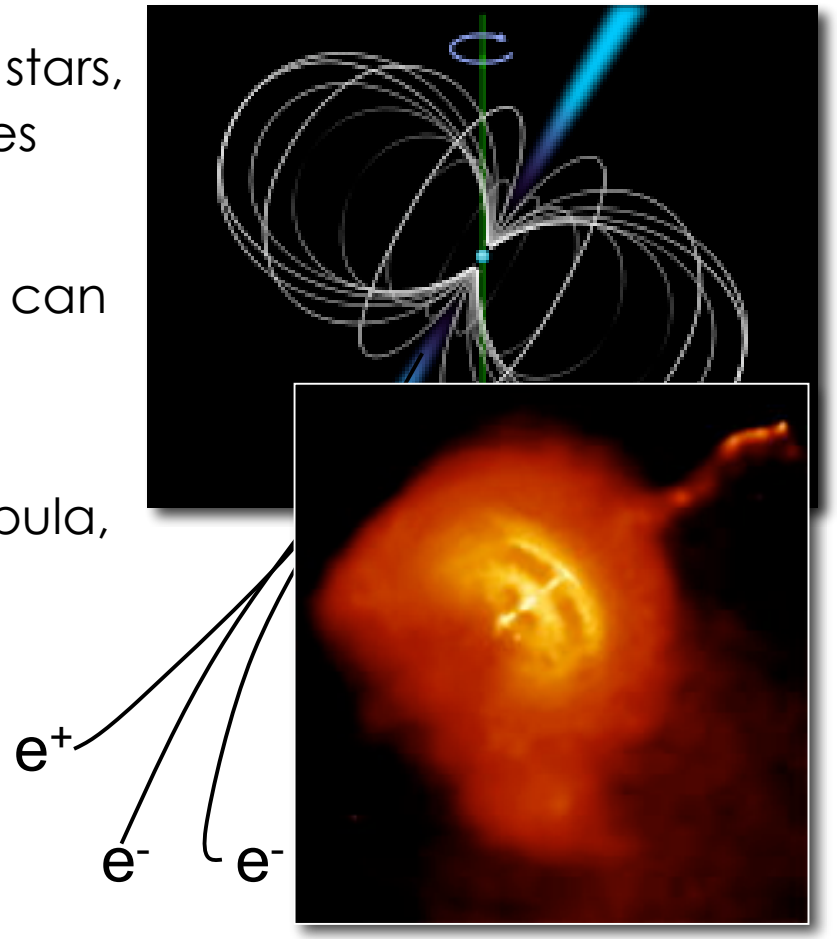

Vela Pulsar (12,000 years old)

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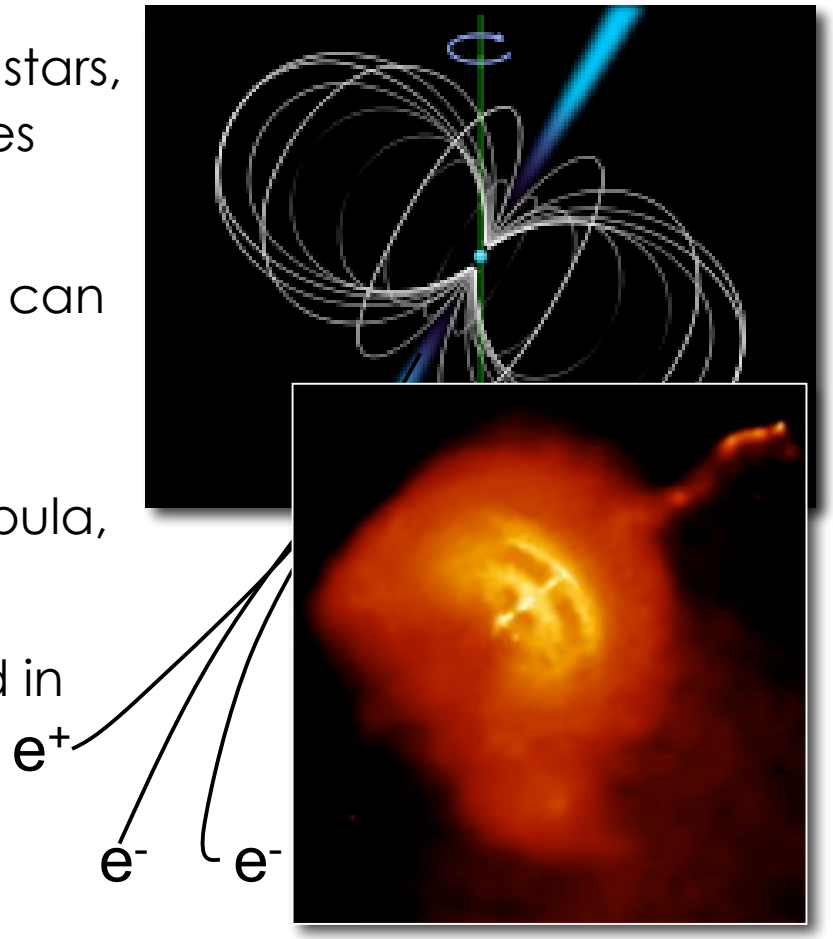
- Most of the spindown power is expended in first ~10^5 years

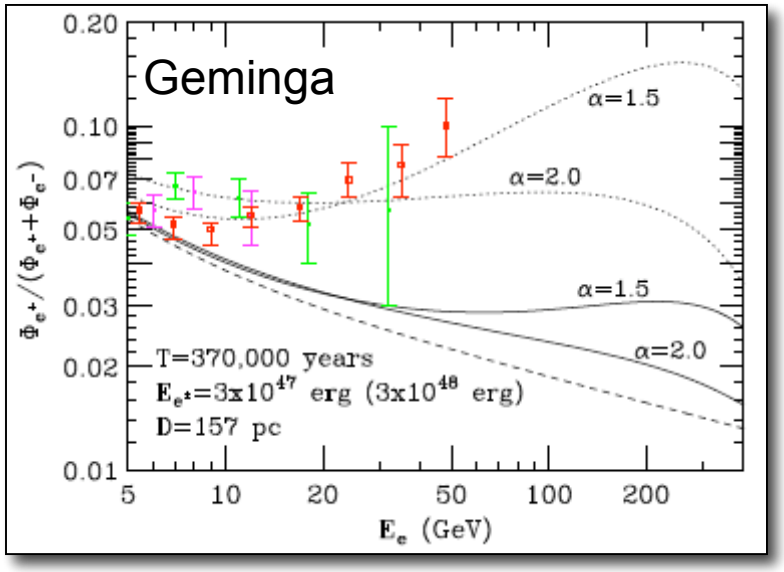


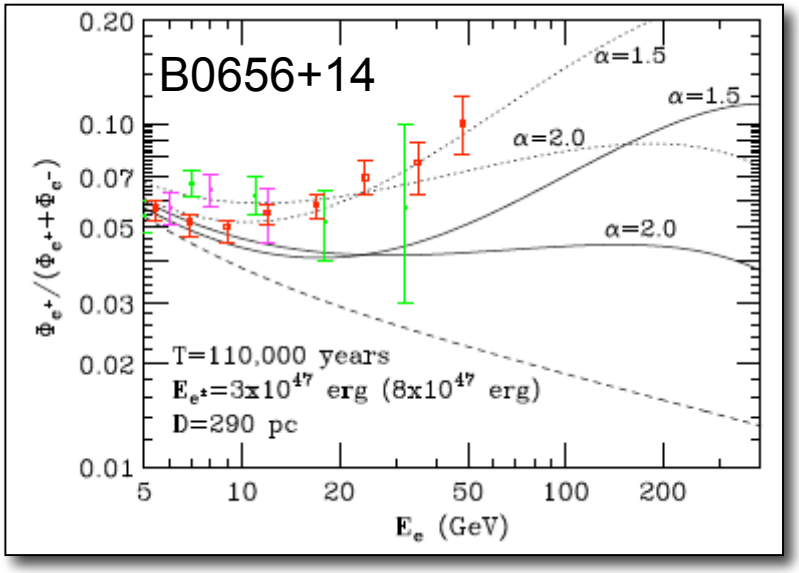
Vela Pulsar (12,000 years old)

High-Energy Positrons From Nearby Pulsars

Two promising candidates:

- Geminga (157 pc away, 370,000 years old)
- B0656+14 (290 pc, 110,000 years)





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Hooper, P. Blasi, P. Serpico, arXiv:0810.1527

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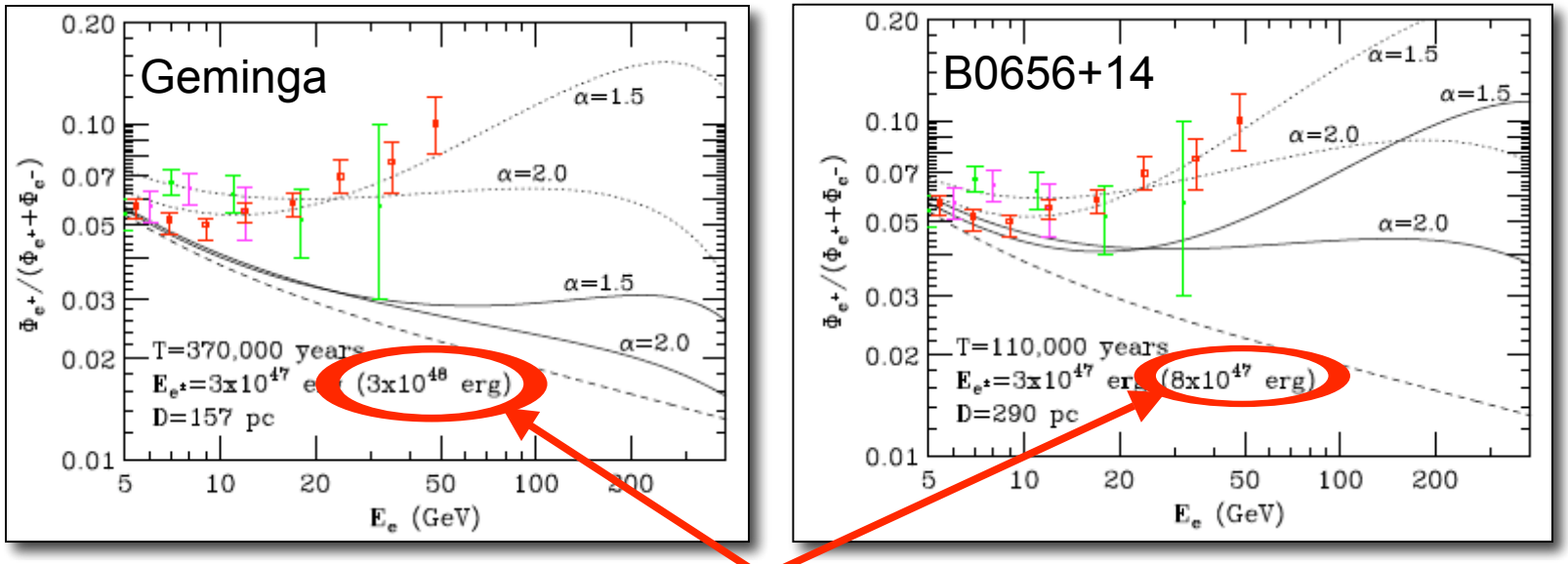

A few percent of the total spindown energy is needed in high energy e^+e^- pairs

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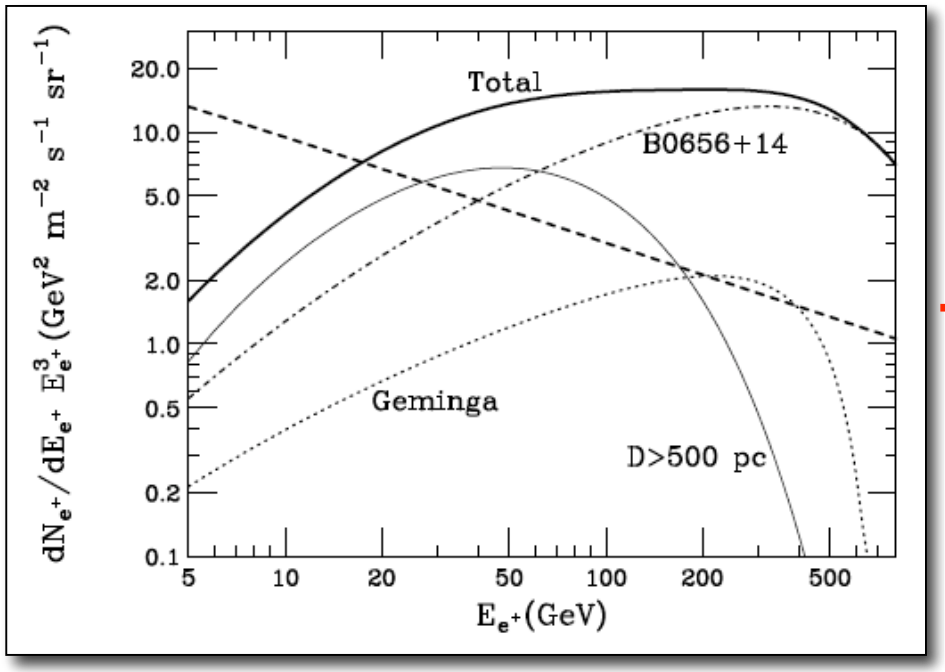
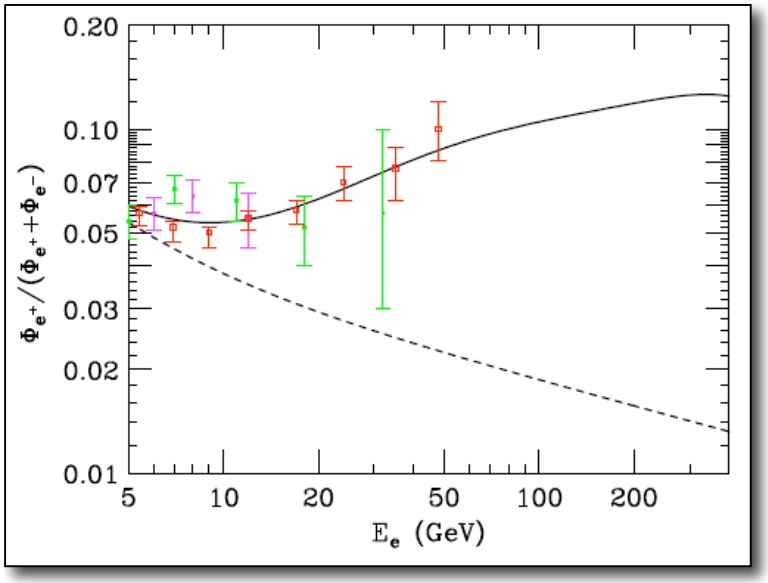
Hooper, P. Blasi, P. Serpico, arXiv:0810.1527

High-Energy Positrons From Nearby Pulsars





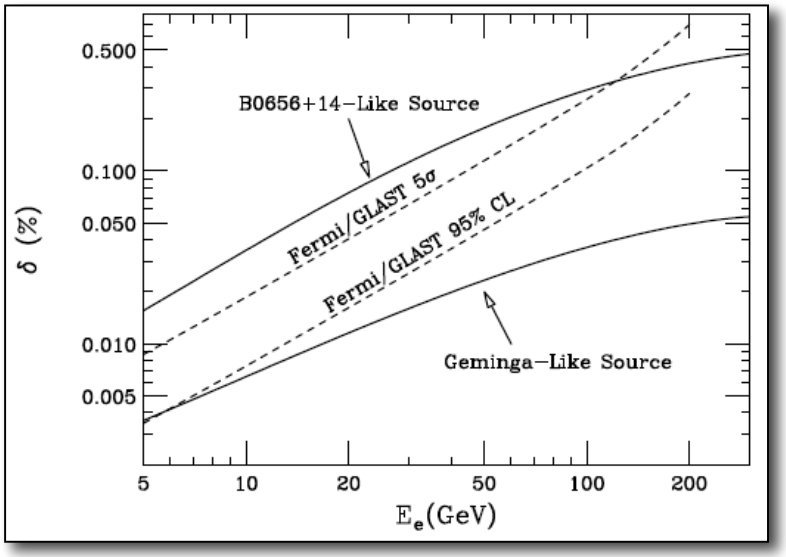
Pamela may be seeing a mixture of positrons from nearby and more distant pulsars

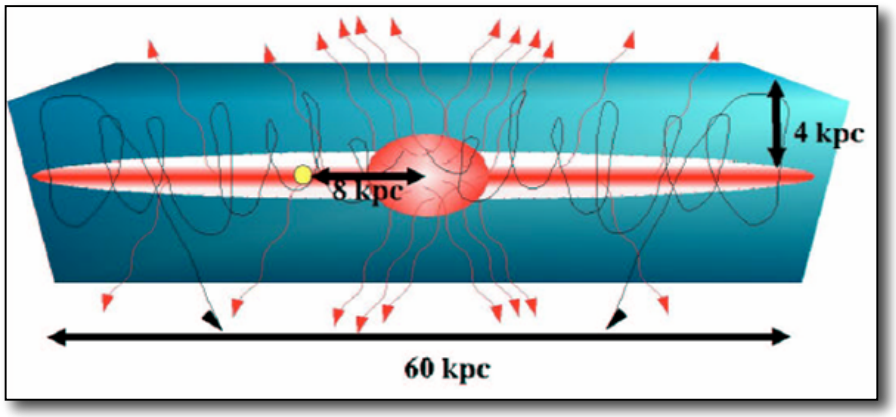
Dan Hooper - *Dark Matter And Charged Cosmic Rays*

Hooper, P. Blasi, P. Serpico, arXiv:0810.1527

An Electron/Positron Dipole Anisotropy?

- Diffusion of electrons/positrons remove almost all directional information - *but a 0.1% dipole anisotropy can remain*
- *Too small to be seen by Pamela, but may be within the reach of Fermi/Glast*





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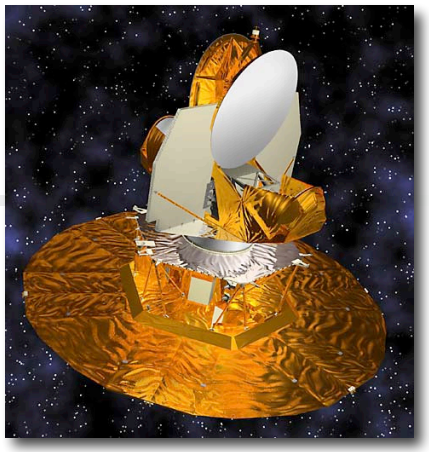
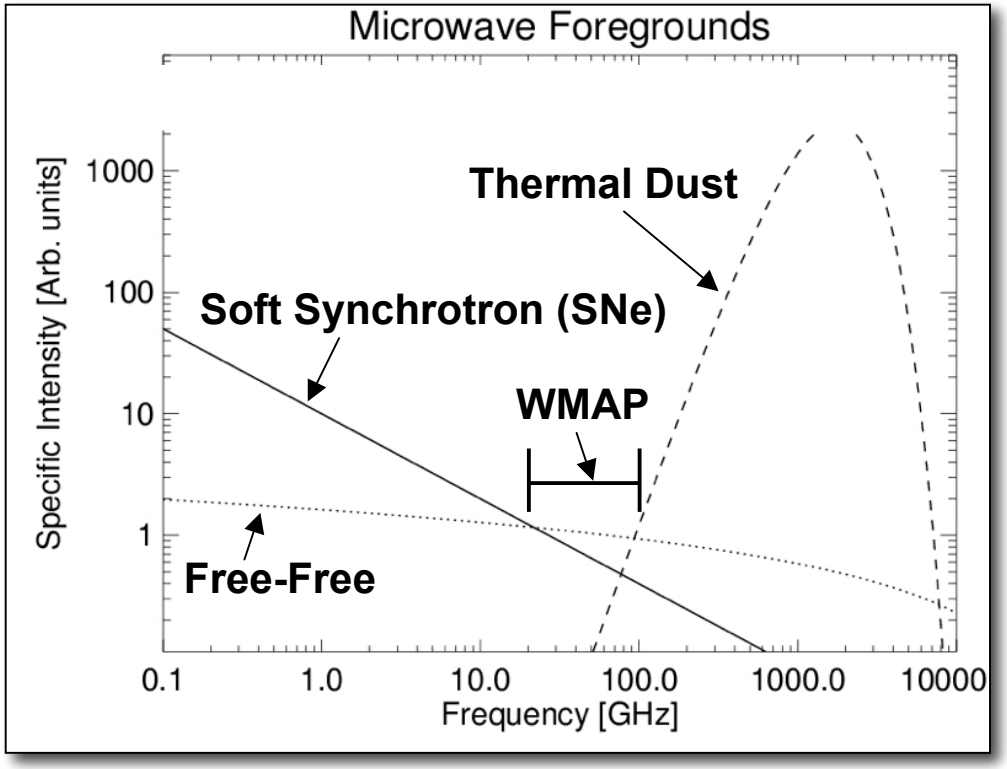
WMAP As A Dark Matter Telescope



- WMAP does not only detect CMB photons, but also a number of galactic foregrounds

- Dark matter annihilations produce electrons/positrons which can emit hard synchrotron in the frequency range of WMAP



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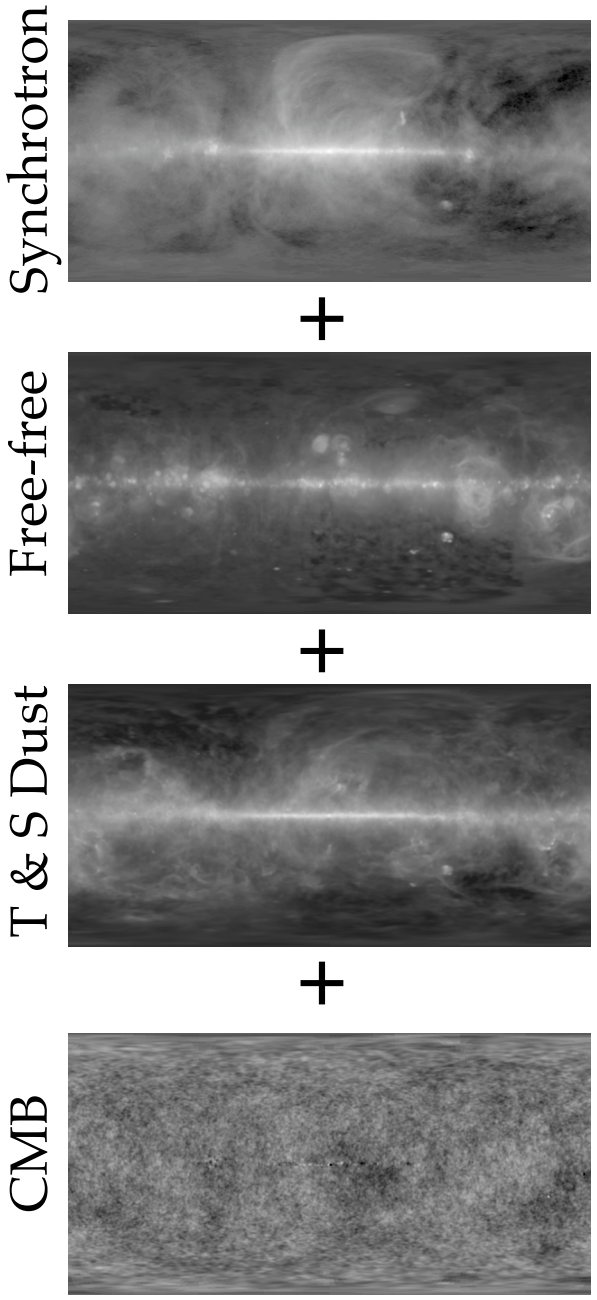

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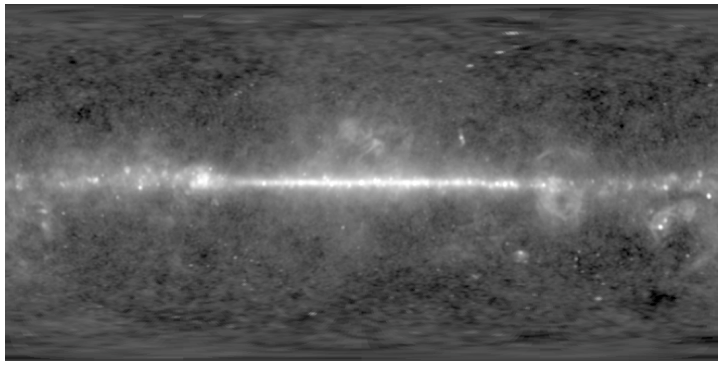

Well, actually… No

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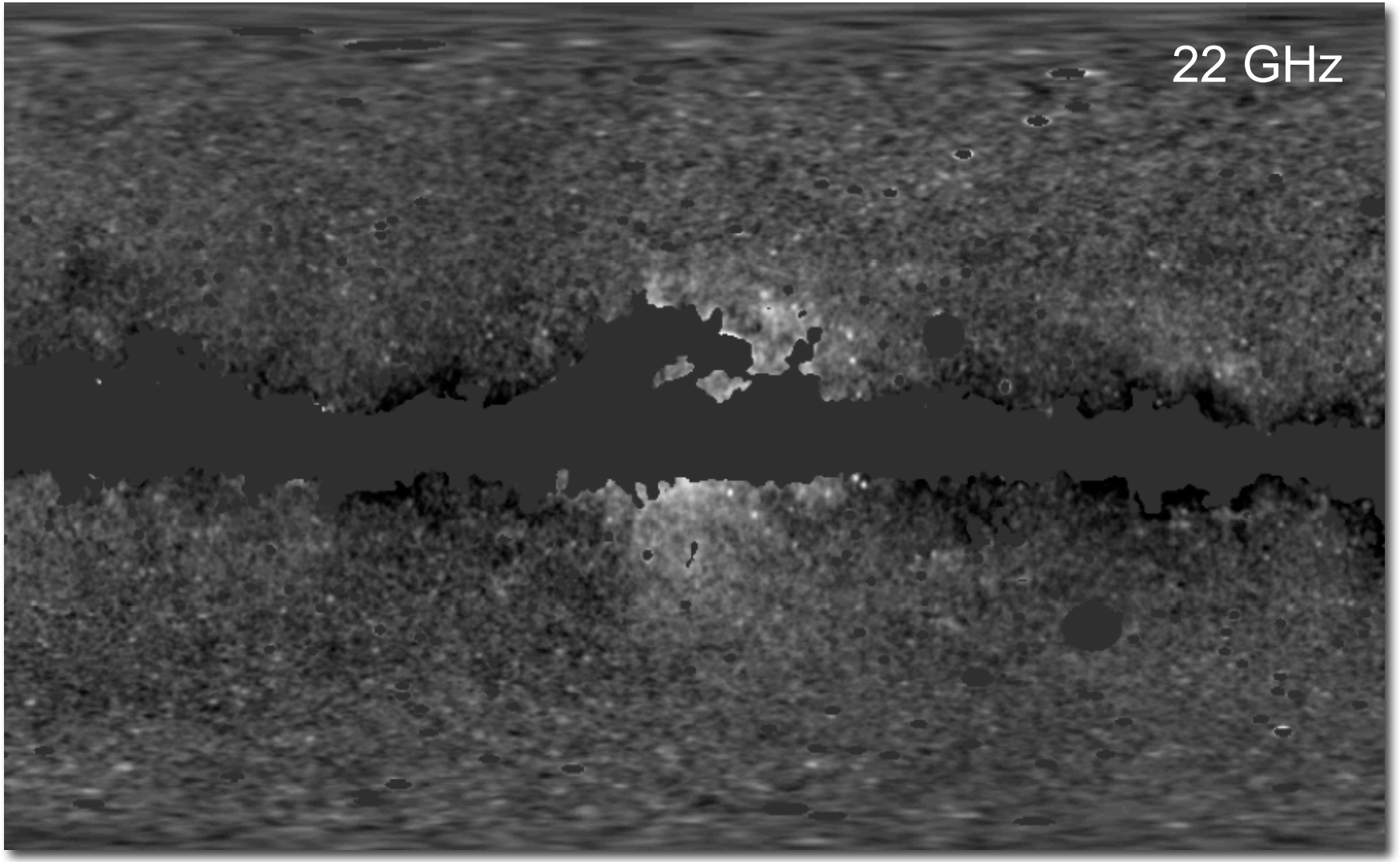
"The WMAP Haze"



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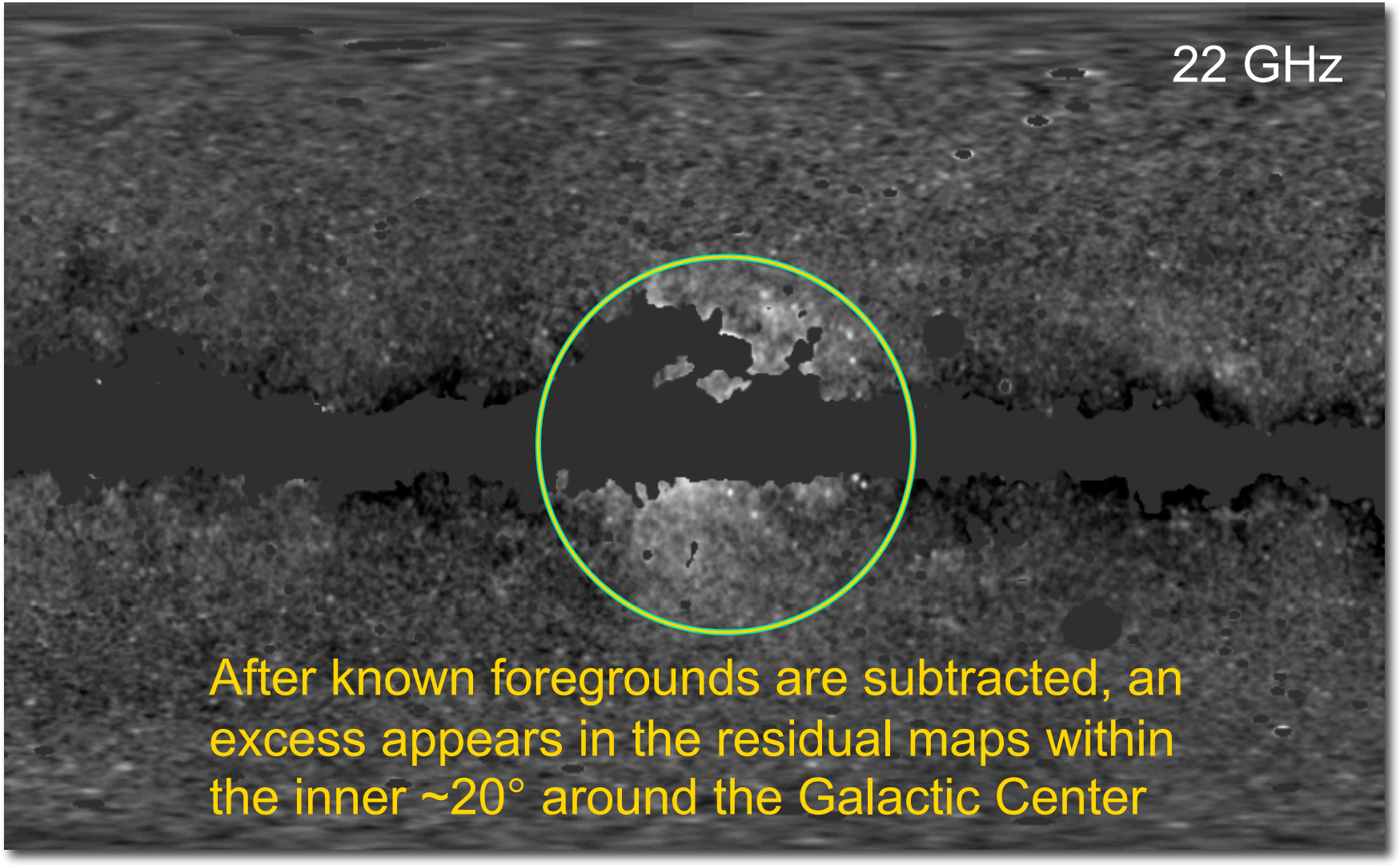

Dan Hooper - *Dark Matter And Charged Cosmic Rays*

The remarkable match of the WMAP Haze to the signal expected from Dark Matter

The Haze is consistent with dark matter annihilations with the following characteristics:

1. Dark matter distributed with $\rho \alpha R^{-1.2}$ in the inner kiloparsecs of our galaxy
2. A dark matter particle with a ~100-800 GeV mass, and that annihilates to typical channels (heavy fermions, gauge bosons, etc.)
3. An annihilation cross section near the value required of a thermal relic (~3×10^{-26} cm^3/s)

A completely vanilla dark matter scenario!

Hooper, G. Dobler and D. Finkbeiner, PRD, arXiv:0705.3655

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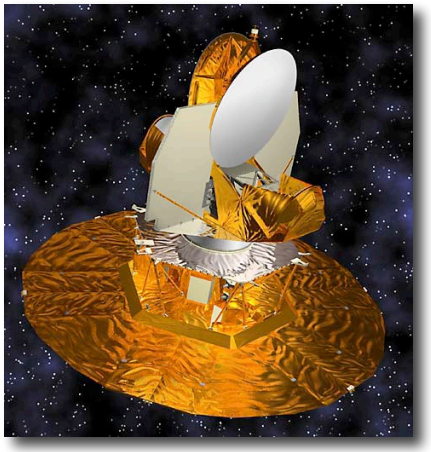
A completely vanilla dark matter scenario!

Added Bonus: *Will be tested definatively with* ***Fermi/Glast*** *and* ***Planck*** *- this is a verifiable/falsifiable hypothesis!*

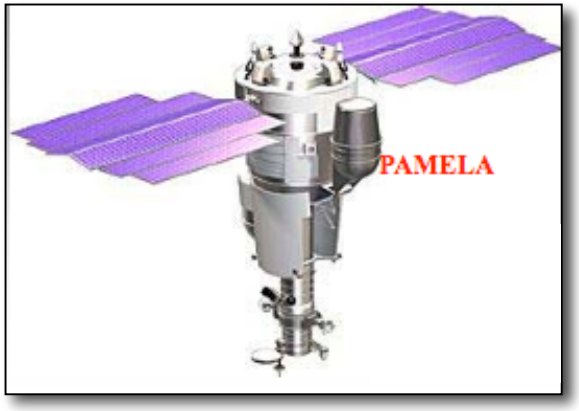
Hooper, G. Dobler and D. Finkbeiner, PRD, arXiv:0705.3655

The WMAP Haze and Pamela's Positrons

- We now have two independent measurements indicating the presence of a large population of high-energy (10-100 GeV) electrons/positrons in the Milky Way (in addition to other indications from HEAT, AMS-01, ATIC and PPB-BETS)



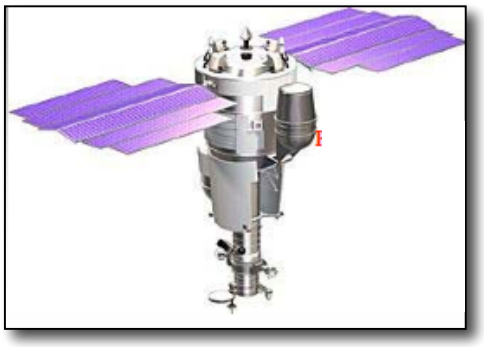
- While direct comparisons are somewhat difficult (different diffusion parameters and dark matter distribution in the Galactic Center and local halo) these two measurements are consistent with being of the same dark matter origin

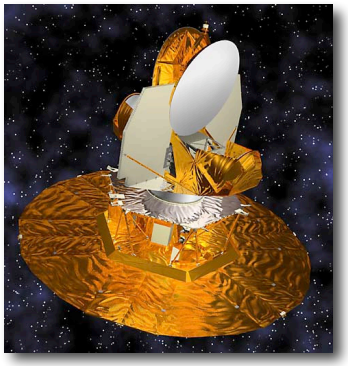


Summary

- Observations from Pamela, WMAP (as well as HEAT, AMS-01, ATIC, PPB-BETS) each indicate that the the Milky Way's ISM is full of high energy electrons/positrons - a very surprising result!

- Although the origin of these particles is not known, the signal appears consistent with being the product of either dark matter annihilations or pulsars

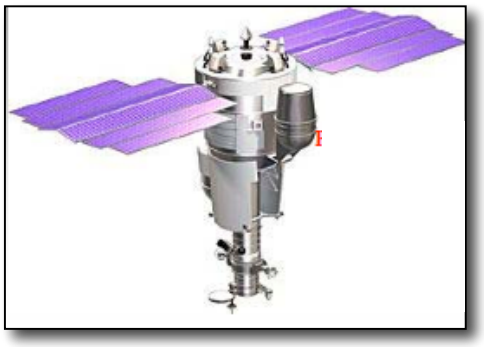


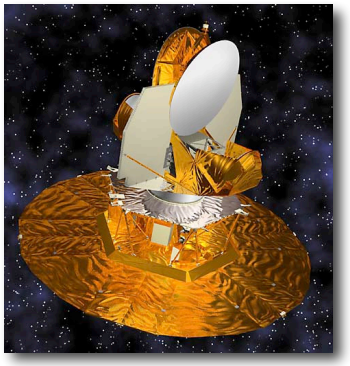


Summary

One Year From Now

- Pamela positron spectrum up to 100-270 GeV?
- First full year of Fermi/Glast data
  - -Dark matter searches
  - -New pulsars; Detailed pulsar spectra
  - -Electron dipole anisotropy?
- Launch of Planck
- Further input from ground based gamma-ray telescopes, and observations at other wavelengths





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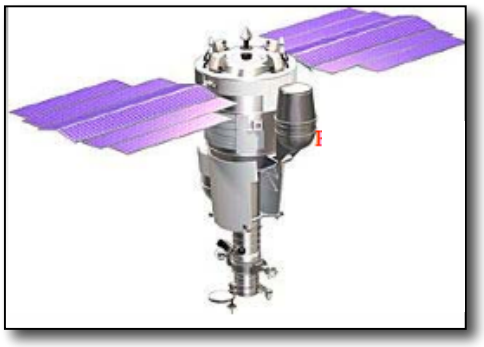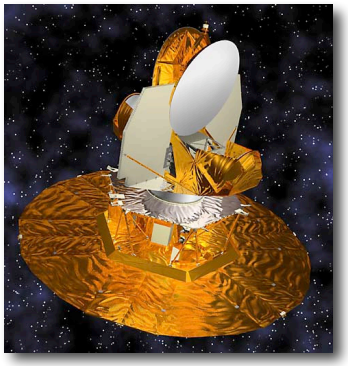
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- Further input from ground based gamma-ray telescopes, and observations at other wavelengths
- Currently, we are facing a puzzling, ambiguous and incomplete picture
- With the wide range of observational tools available, we may be able to move from puzzle to discovery