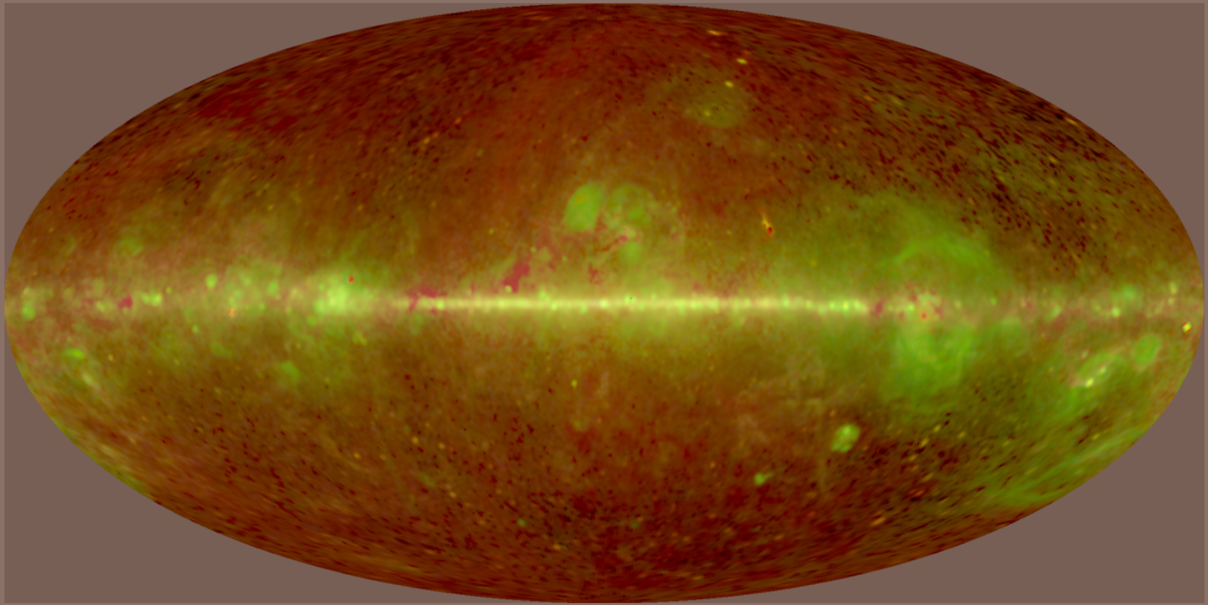
THE PROSPECTS FOR INDIRECT DETECTION OF DARK MATTER:
ANALYSIS OF THE WMAP HAZE

Tim Linden

with:

Stefano Profumo
Brandon Anderson

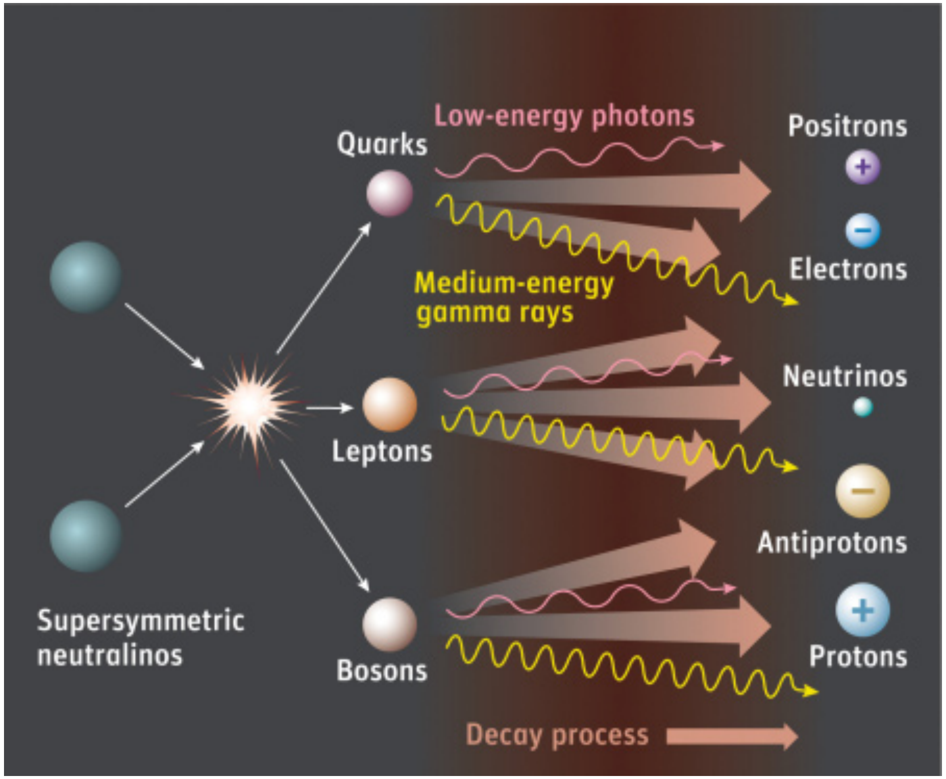


University of California – Santa Cruz

Overview of Talk

- 1.) Recent developments in the indirect detection of dark matter
- 2.) The dark matter interpretation of the WMAP Haze
- 3.) Astrophysical uncertainty in dark matter models

Dark Matter Annihilation



Thermal relic DM must annihilate, likely on a scale similar to the weak interaction

Typical Dark Matter masses exist on the weak energy scale (1 GeV – 1 TeV)

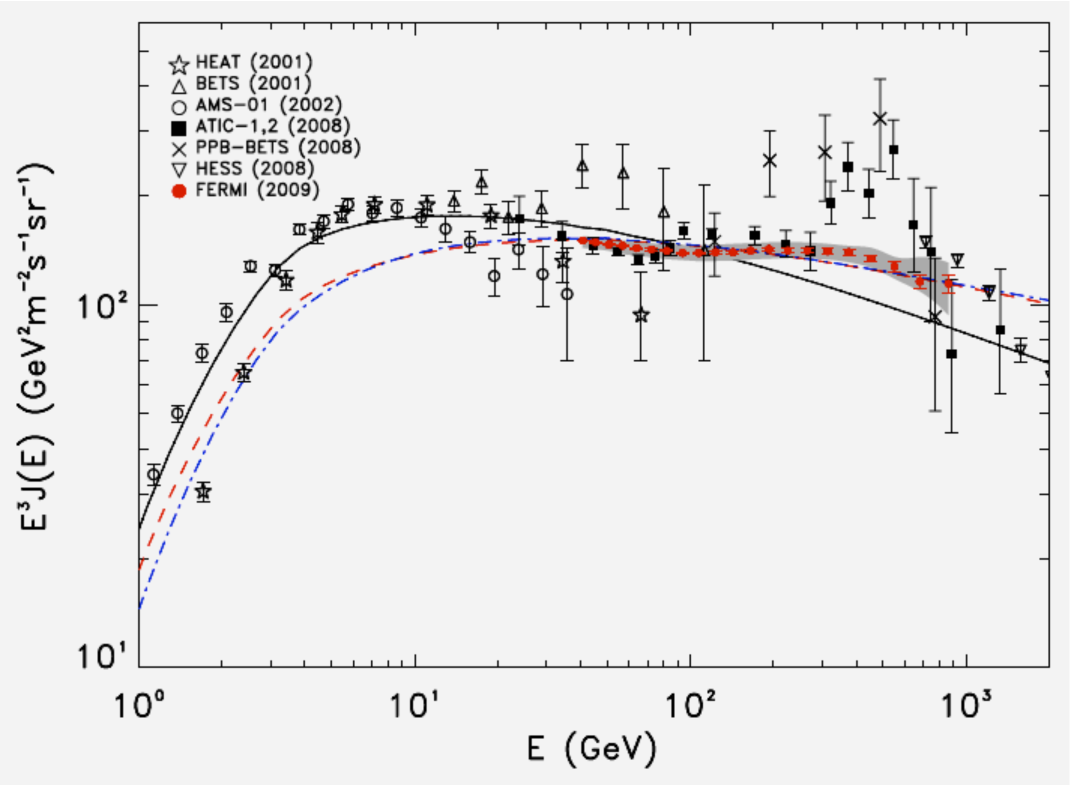
- Annihilation of two DM particles produces a cascade of both massive particles and photons

Image Courtesy of Fermilab Website

Dark Matter Indirect Detection

- Could directly observe stable end-states of DM annihilation
- However, cosmic rays are both local and isotropic (limits the obtainable information)
- Electron/Positron pairs in the interior of the galaxy will create both synchrotron and ICS radiation visible from Earth

Fermi Positron+Electron Spectrum



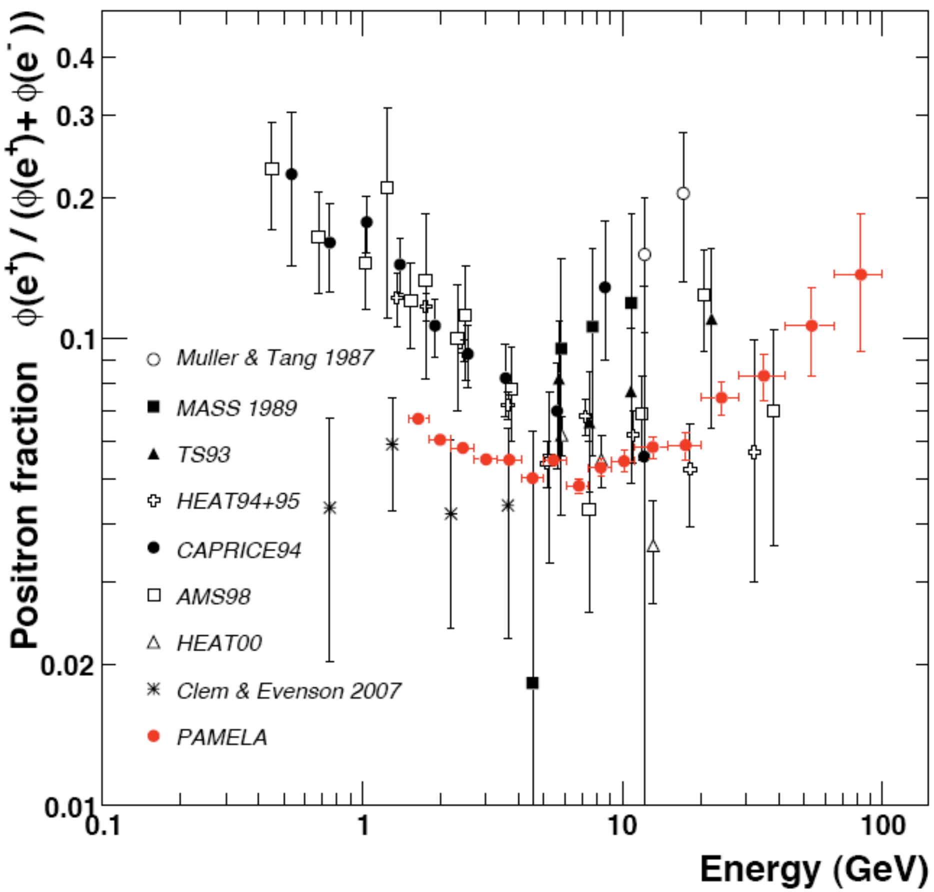
Electron+Positron spectrum can be accurately modeled with a power law γ = -2.42

(conventional model γ = -2.54)

- Fermi electron spectrum is harder than previous measurements

Pamela Positron Excess

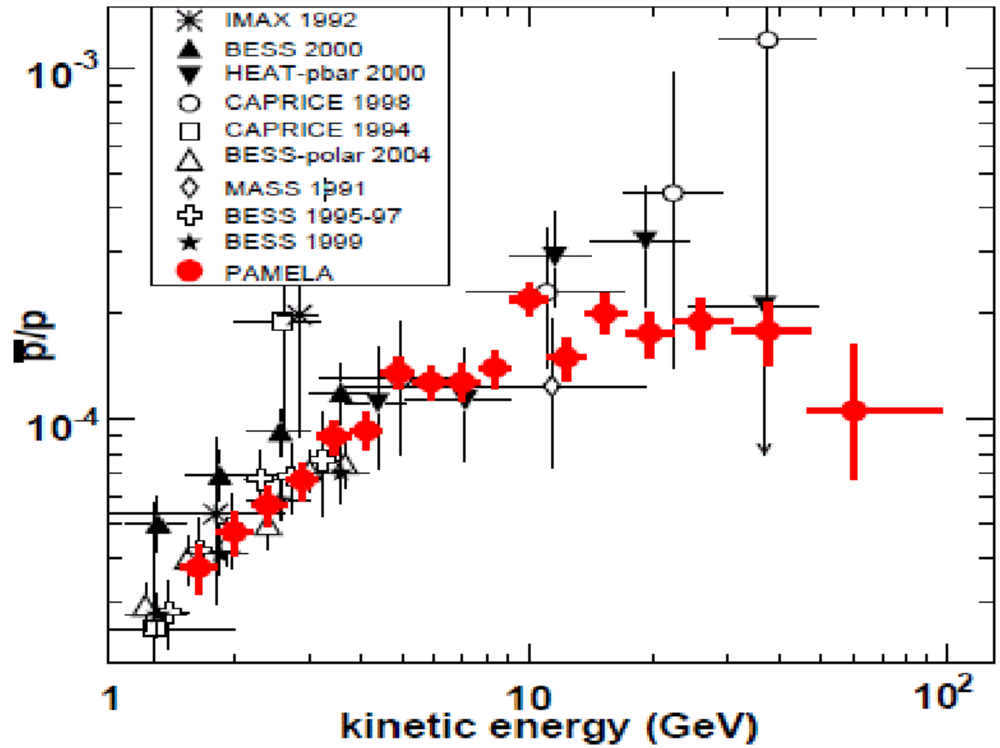
- Pamela data shows an unexpected upward trend in the positron fraction above 10 GeV



arXiv: 0810.4995

Pamela Antiproton Results

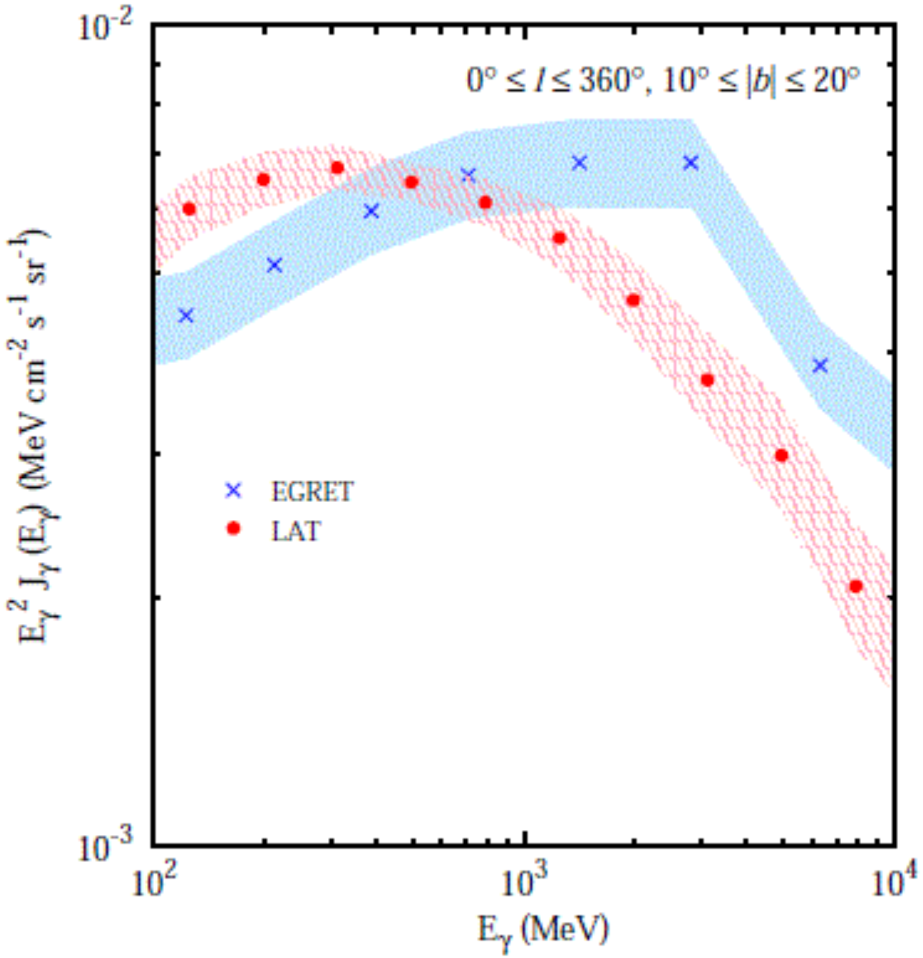
- However, Pamela observes no increase in antiproton fractions at similar energy scales
- Additional e^+/e^- flux must result from leptophilic source



arXiv: 0810.4994

Fermi Detection of photon signal

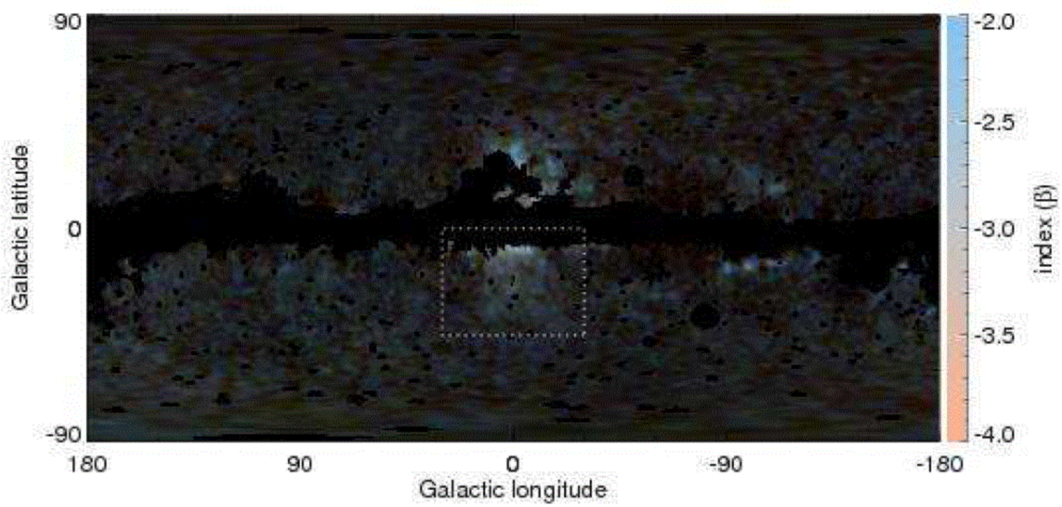
- Fermi does not observe the EGRET GeV excess
- Puts constraints on some (especially low mass) Dark Matter models

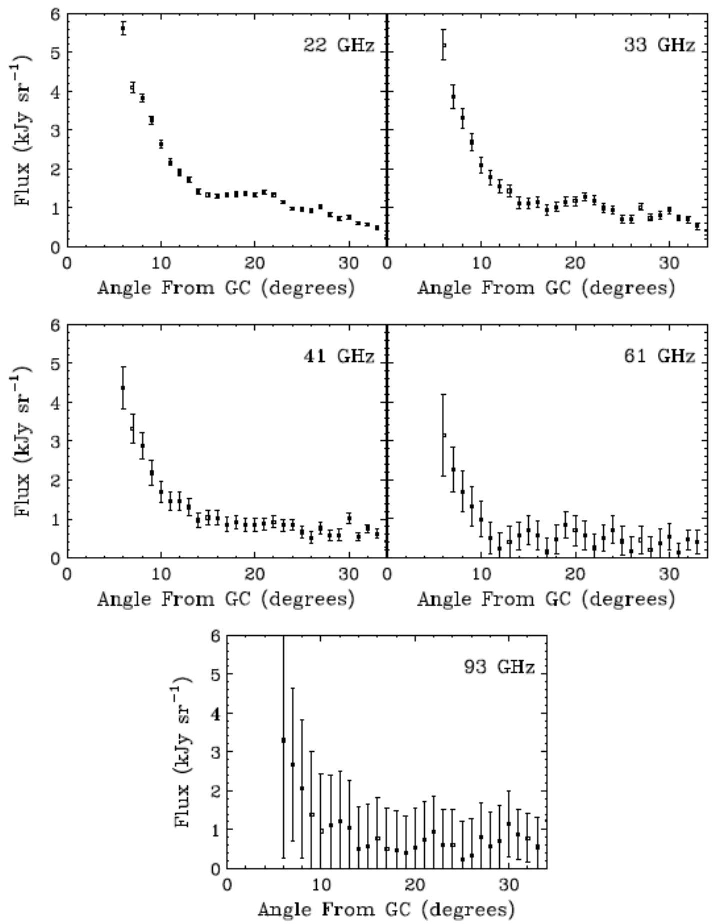


arXiv:0907.0294

WMAP Haze

- Finkbeiner (2004) found an excess residual in the WMAP Haze, not explained by background subtraction



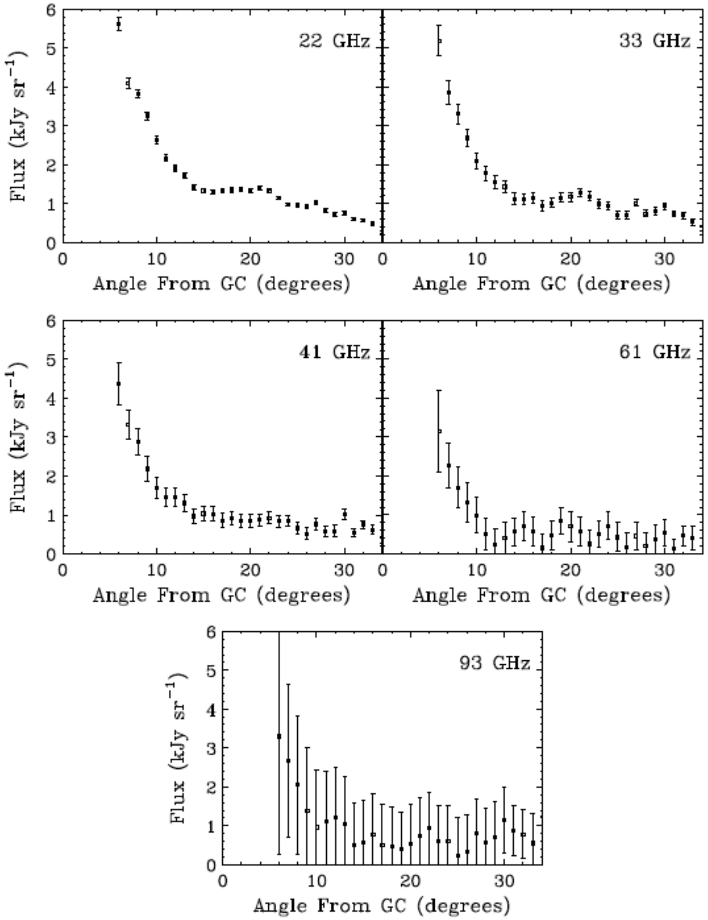


arXiv: 0712.1038

arXiv: 0705.3655

Spatial Dependence of WMAP Haze

- Haze is primary found at high galactic latitudes
- Clearest in southern hemisphere, due to dust contamination in north
- Stretches up to 30° (4.25 kpc) above galactic bulge

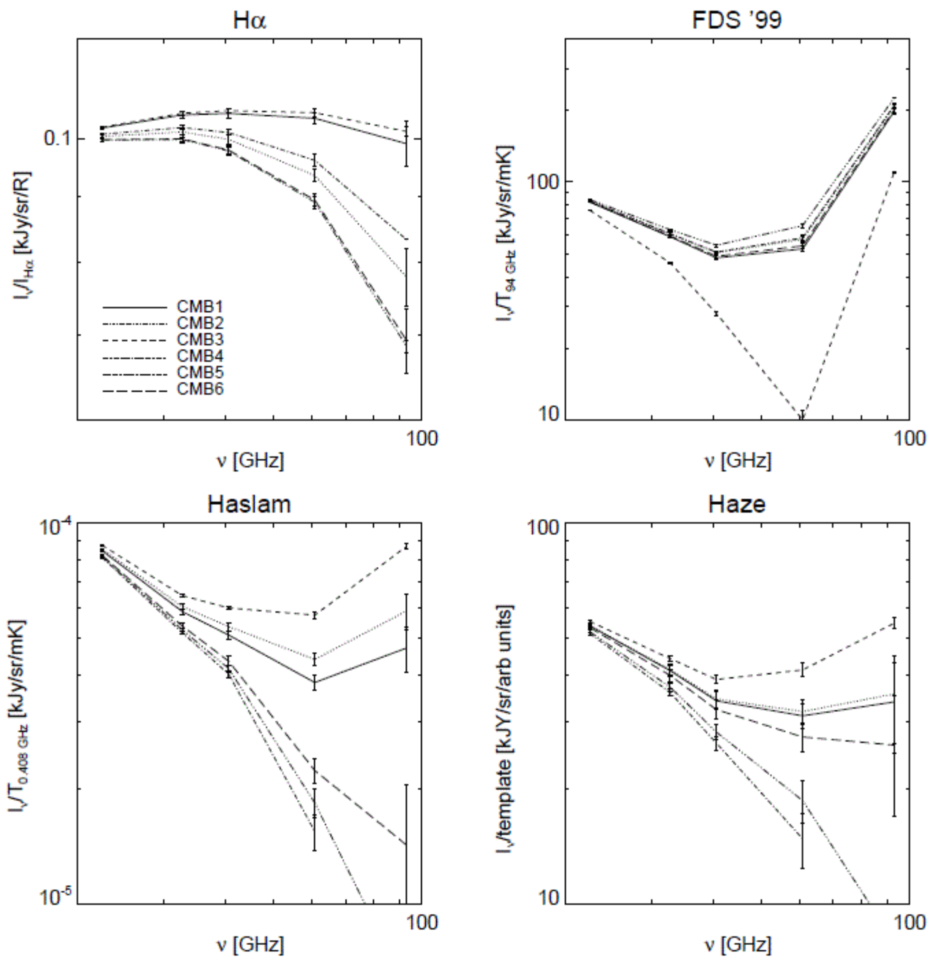


Energy Dependence of WMAP Haze

Haze spectrum is highly dominant to Hα emission, has a different energy dependence than thermal dust, and is dominant to soft synchrotron extrapolated from Haslam

Thus, Dobler and Finkbeiner (2007) conclude that the Haze results from a new primary source of energetic positron/electron pairs

But is it Dark Matter?



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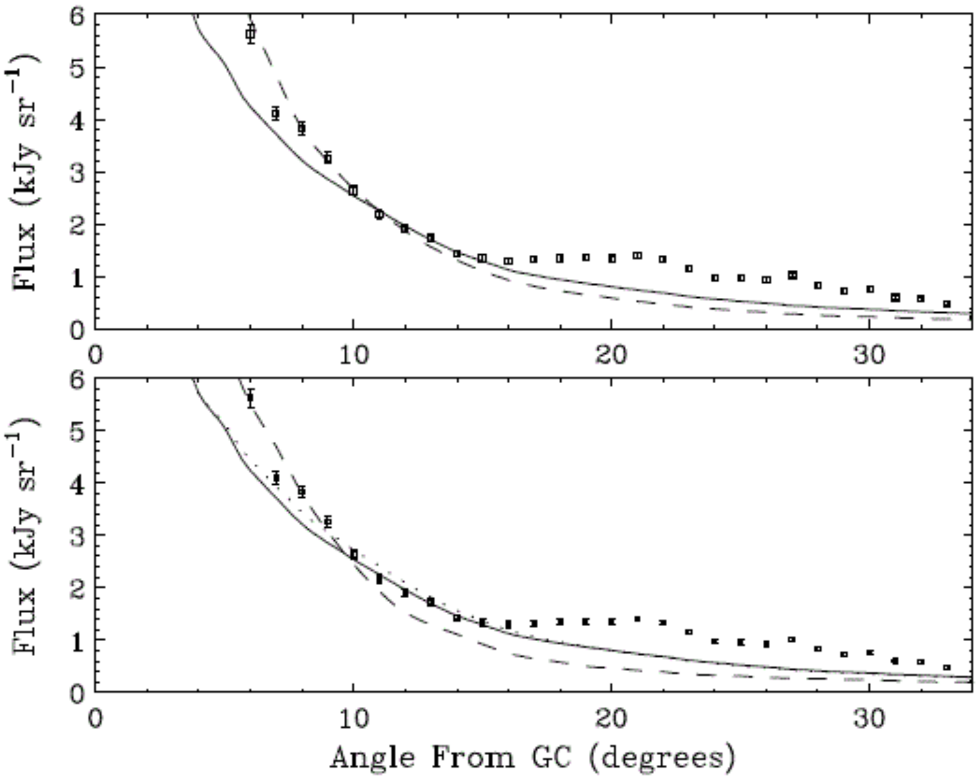
Dark Matter Modeling of WMAP



arXiv: 0705.3655

Hooper et al. (2007) used Galprop models to simulate the WMAP Haze

M_X = 100 GeV

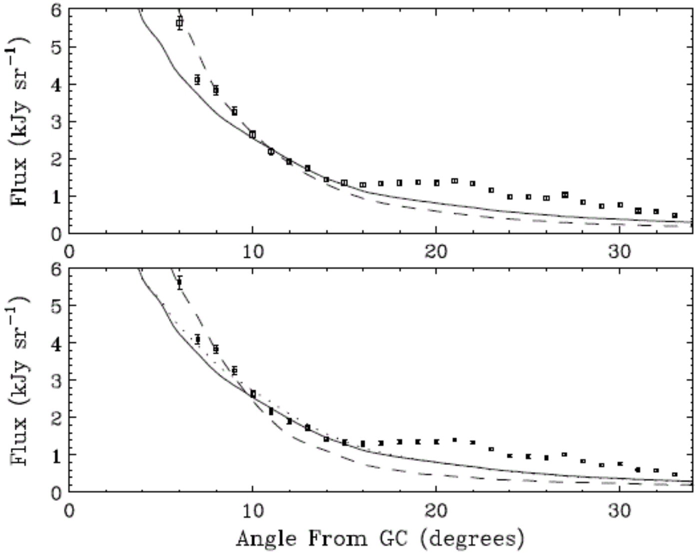
B = 10 μG

XX → e^+e^-

NFW Profile

$D_0 = 1 \times 10^{28}$ cm^2s^{-1} (at 1 GeV)

Dark Matter Modeling of WMAP



Hooper et al. (2007) used Galprop models to simulate the WMAP Haze

M_X = 100 GeV

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XX → e^+e^-

NFW Profile

$D_0 = 1 \times 10^{28}\ cm^2 s^{-1}$ (at 1 GeV)

Not Consistent with current best fit cosmic ray propagation models

arXiv: 0705.3655

Research Goals

- Evaluate a select range of well motivated annihilating WIMP theories

- Test the DM interpretation of the WMAP haze using cosmic ray propagation models that are consistent with all current observations and data

Simulation Models

- 1.) Use DarkSUSY to calculate the primary e^+e^- spectrum for a range of well motivated DM models
- 2.) Use Galprop to determine the synchrotron emission and nuclear abundances in each propagation model
- 3.) Isolate the simulated DM haze by subtracting the synchrotron component from the corresponding simulation with DM disabled.

Dark Matter Models

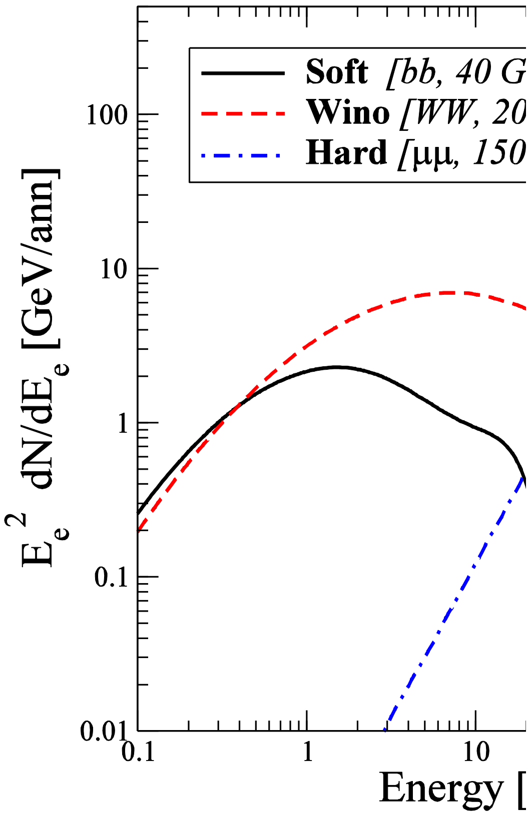
- We test three DM annihilation channels which span a range of motivated WIMP decay models

Soft (40 GeV XX → b b-bar)

Wino (200 GeV XX → W^+W^-)

Hard (1500 GeV XX → $\mu^+\mu^-$)

- Employ NFW profile with R_C = 22 kpc



Galprop Models

- We use Galprop (v. 53[1]) and take standard values for several important propagation parameters
  - $D_0 = 5.8 \times 10^{28}\ cm^2 s^{-1}$
  - Simulation Height = 4 kpc
  - $V_{alfven} = 30\ km\ s^{-1}$
  - Convection = Disabled
- We multiply the simulated haze by a universal constant to match the observed WMAP haze at 10 degrees latitude and 23 Ghz.

[1] Galdef file 02X_varh7S

Boost Factors

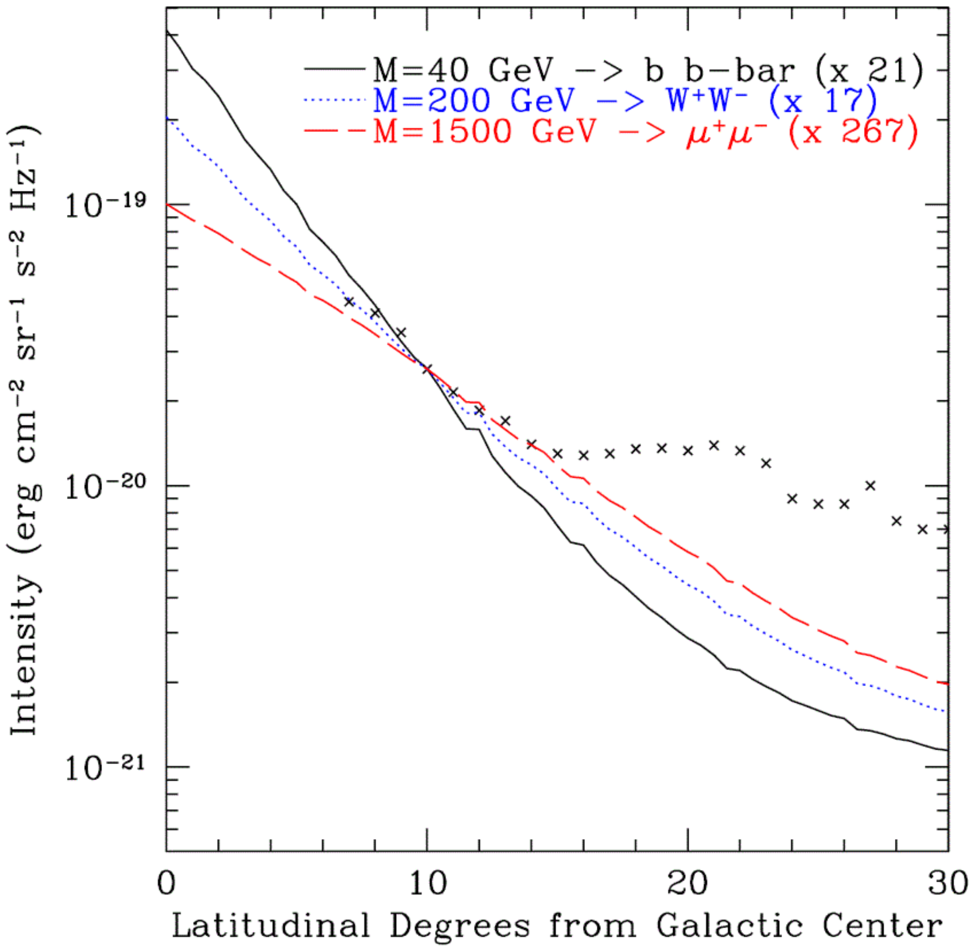
- Boost factors describe deviations of the DM annihilation rate from that given by the DM density and annihilation cross-section

$$\Phi = \rho^2(x)/M_{DM}^2 \ \langle\sigma v\rangle \qquad \langle\sigma v\rangle \sim 3 \times 10^{-26}\ cm^2 s^{-1}$$

- 1.) Changes in $\langle\sigma v\rangle$
- 2.) Density fluctuations in DM substructure
- 3.) Sommerfield enhancements

Default Model Predictions

- Our default parameters predict a steeper decline in the DM haze as a function of galactic latitude than observed in the WMAP haze



Parameter Space

- We test variations in three regimes of parameter space, checking our results against the best constraint on each model
  - Cosmic Ray diffusion parameters
    - Affect primary to secondary nuclei ratios
  - Galactic magnetic fields
    - Affect synchrotron emission from all galactic sources
  - DM density profiles
    - Affect both direct and indirect DM detection, as well as galactic rotation curves

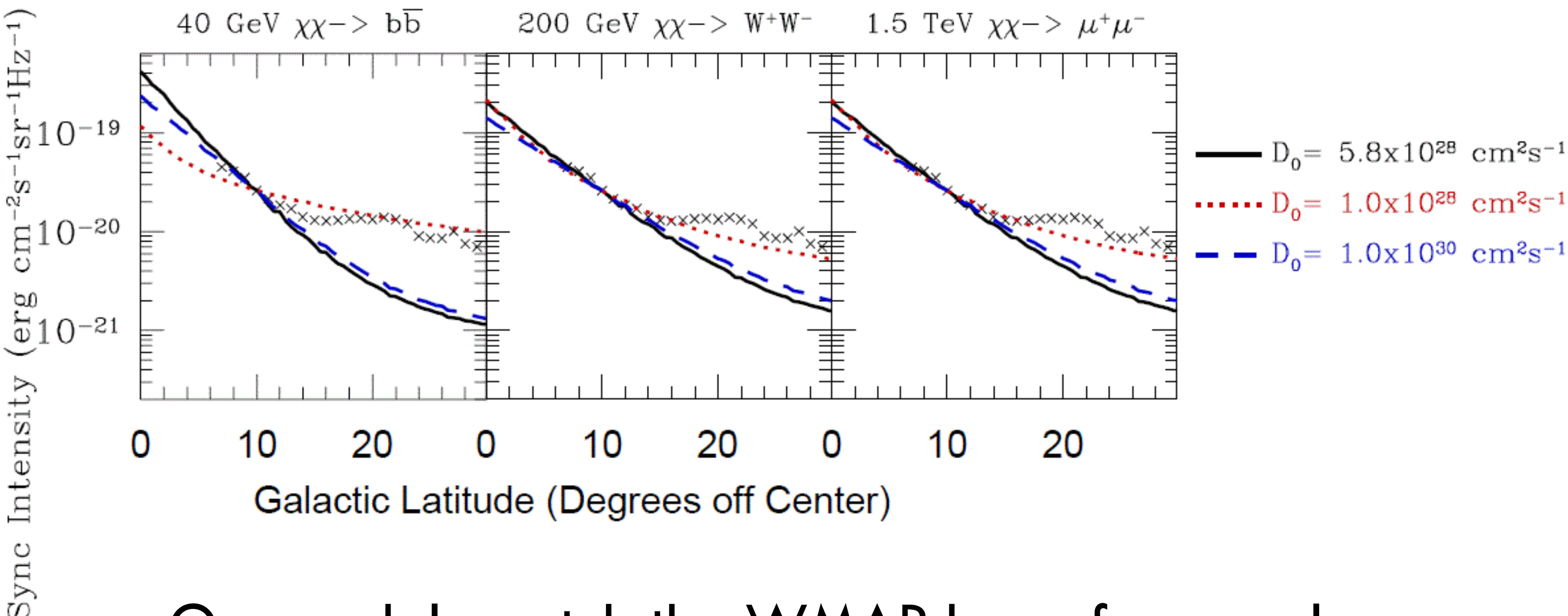
Diffusion Parameters

- We test four important diffusion parameters
  - 1.) Diffusion constant (5.8×10^{28} $cm^2 s^{-1}$)
  - 2.) Simulation height (4 kpc)
  - 3.) Alfven velocity (30 km s^{-1})
  - 4.) Convection velocity (disabled)

Diffusion Coefficient

- Changes in the diffusion coefficient can affect the angular dependence of the DM haze in two ways
  - 1.) Changing the number of e^+e^- pairs which travel out of the top of the simulation region
  - 2.) Changing the number of e^+e^- pairs which travel out of the galactic center into the low latitude regions of the simulation region

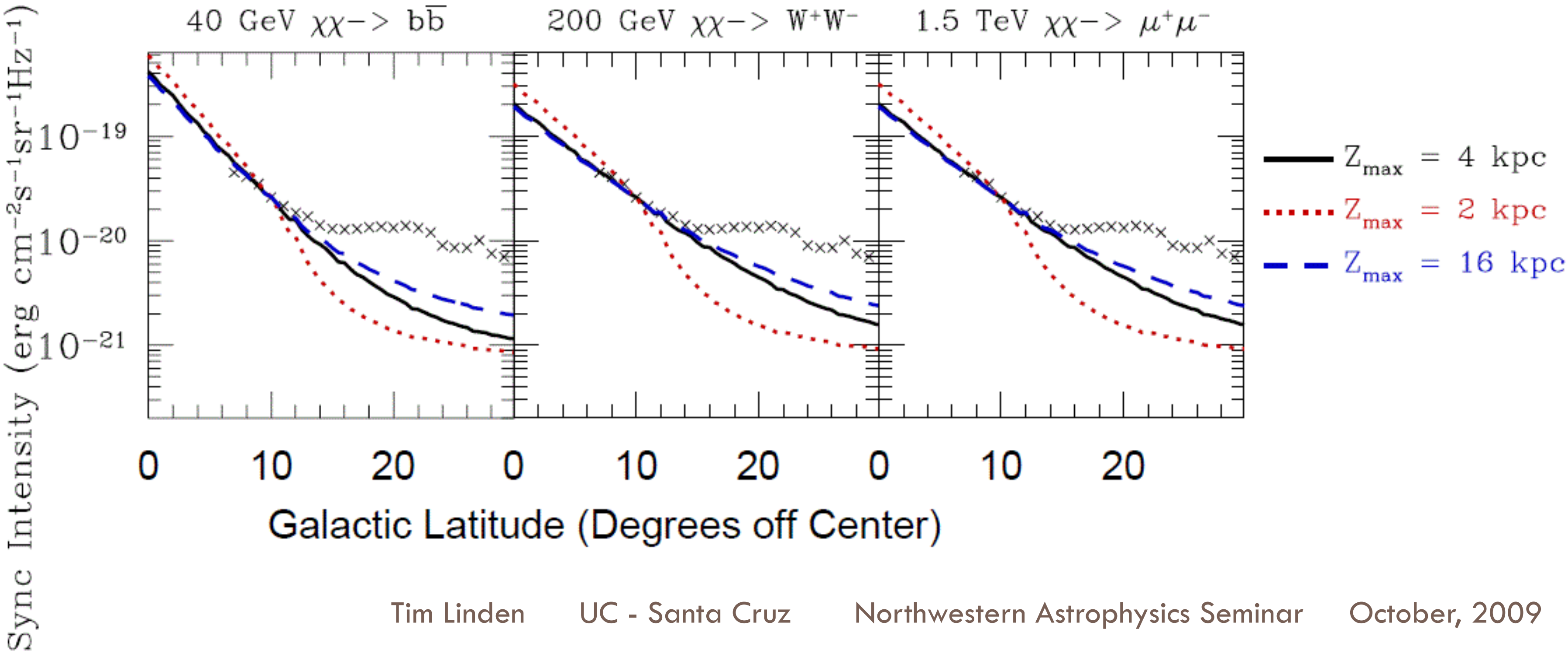
Match to WMAP Haze



- Our models match the WMAP haze for very low diffusion coefficients such as $D_0 = 1.0 \times 10^{28}\ cm^2s^{-1}$

Changes in Simulation Height

- We are restricted by the angular range of the haze observations (8.5 kpc * sin(30) = 4.25 kpc)
- Signal is not affected by including higher latitudes

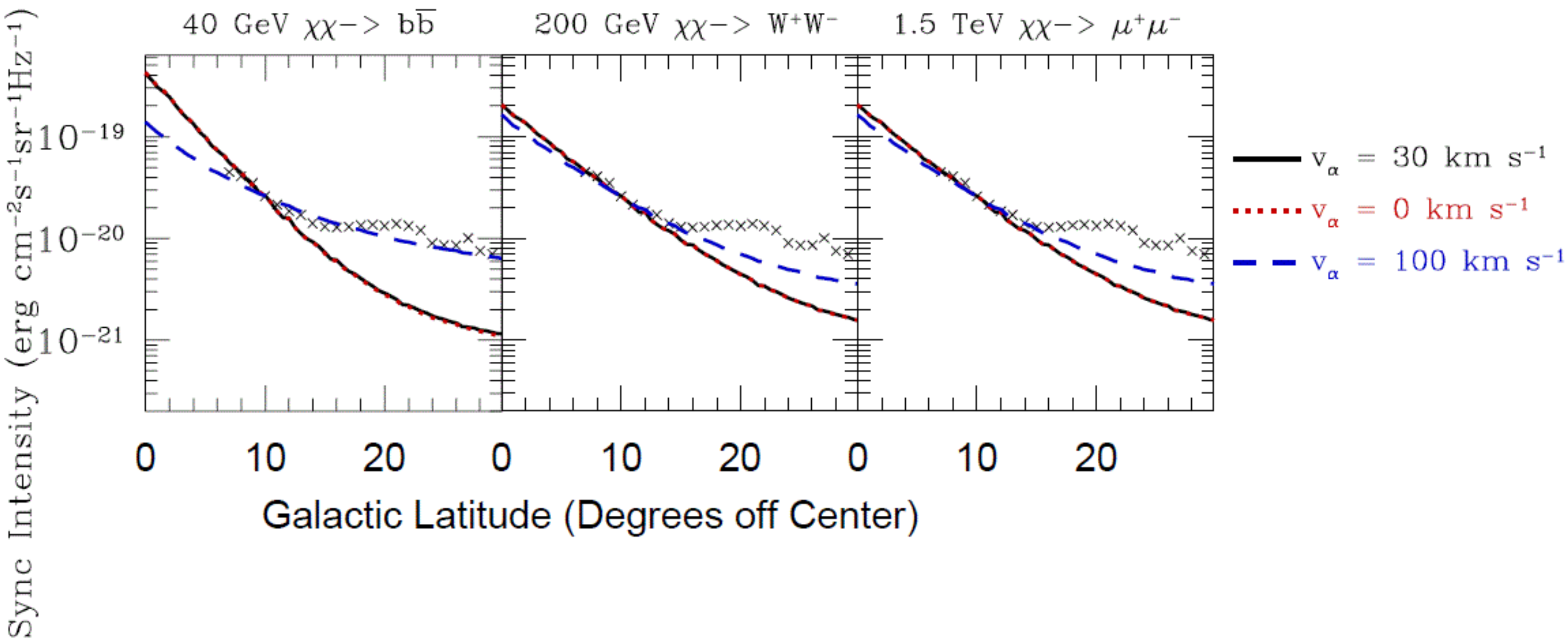


Alfven Velocity

- Alfven velocity helps control the reacceleration of particles throughout the ISM
- Can become the dominant source of particle motion for high values of the v_{α}
- Will also have the effect of transporting nuclei out of the galactic plane

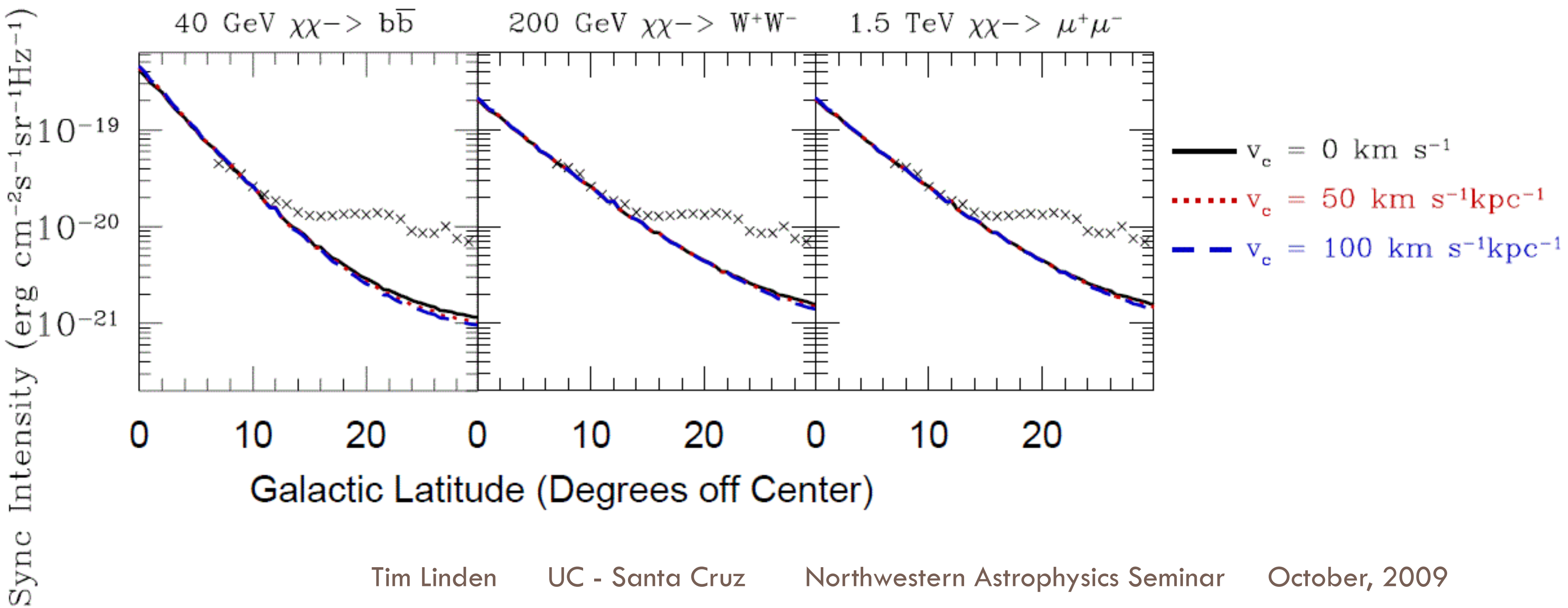
Match to WMAP Haze

- Our models match the WMAP Haze for very high Alfven velocities (near 100 km s^{-1})



Convection Velocity

- Convection velocity only serves to move material out of the top of our simulation. Our original choice to disable convection velocity is optimal

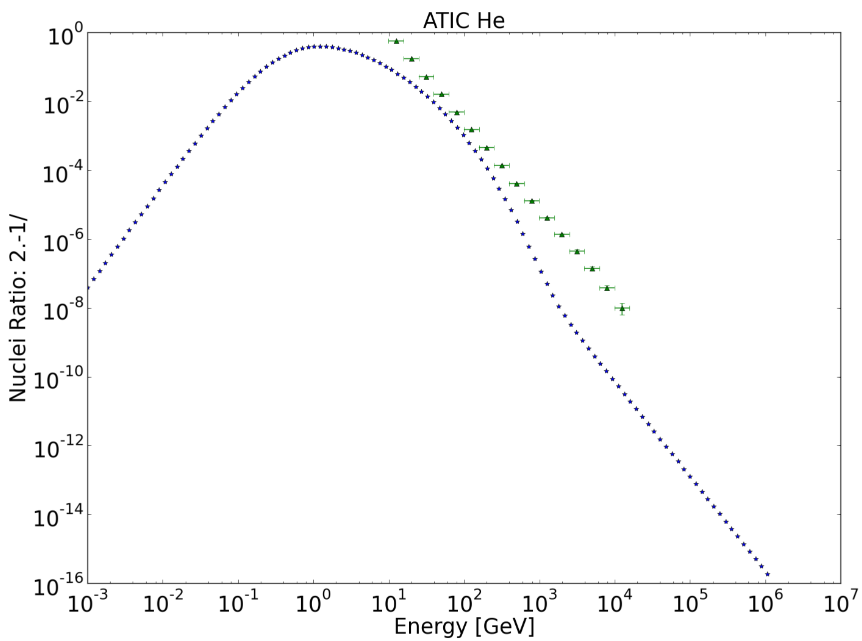


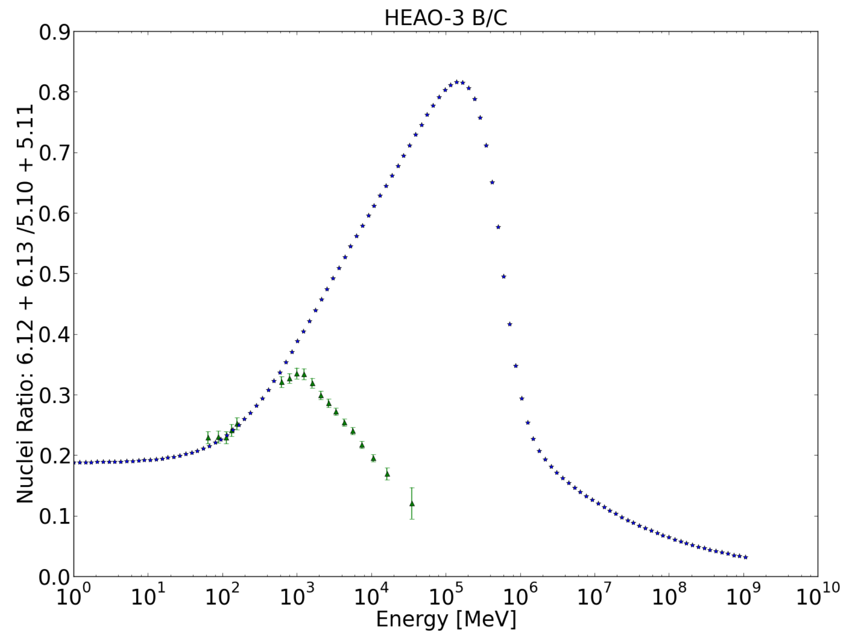
Primary/Secondary Ratios

- We test our matching choices of diffusion constant and Alfven velocity against the observed primary/secondary ratios

- We take nuclei observations from a wide variety of sources including:
  - ATIC
  - HEAO-3

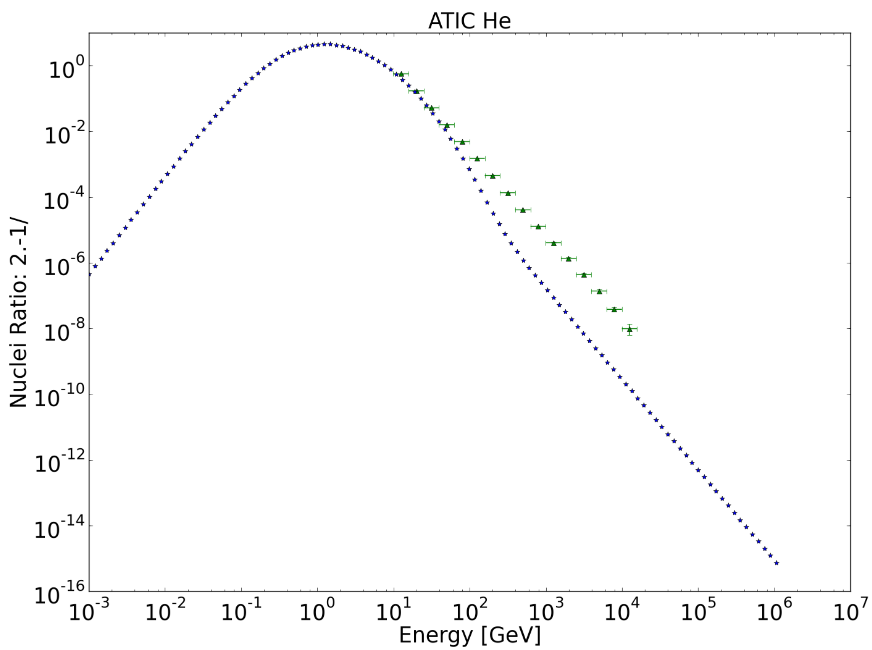
Diffusion Constant Nuclei Ratios

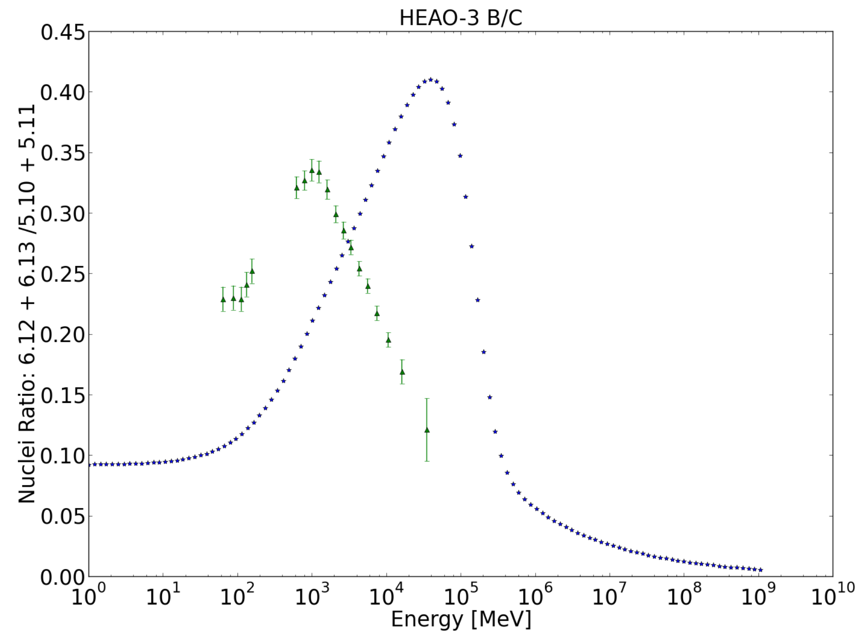




- Large changes in the diffusion constant create nuclei primary/secondary ratios which are <u>not</u> consistent with observation

Alfven velocity nuclei ratios





- Similarly, large changes in the Alfven velocity creates nuclei ratios which are not compatible with observation

Propagation Parameters - Conclusion

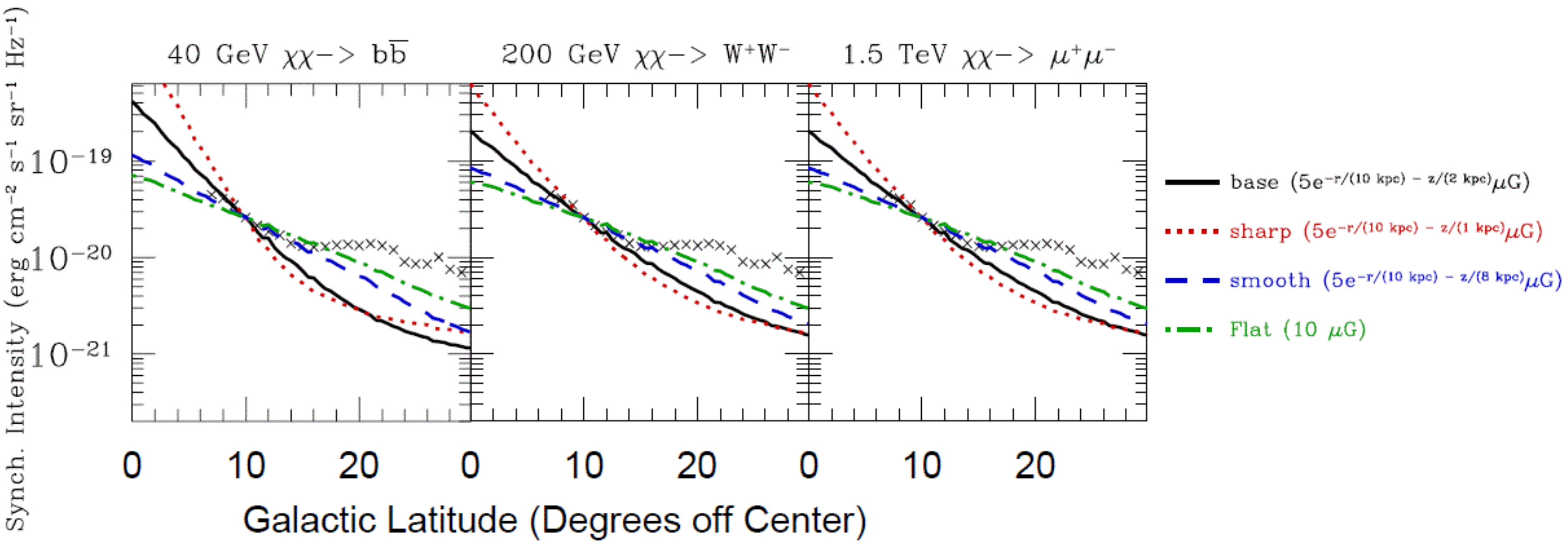
- Changes in the parameters for cosmic ray propagation cannot reproduce the WMAP haze while remaining consistent with nuclei observational constraints

Magnetic Fields

- Changing the angular dependence of magnetic fields will greatly change the angular dependence of synchrotron radiation in the galaxy

- We test 4 models of the form $B = B_0 e^{-(r/r0) - (z/z0)}$
  - $B_0 = 5\mu G$ $r_0 = 10$ kpc $z_0 = 2$ kpc (default)
  - $B_0 = 5\mu G$ $r_0 = 10$ kpc $z_0 = 1$ kpc (smooth)
  - $B_0 = 5\mu G$ $r_0 = 10$ kpc $z_0 = 8$ kpc (sharp)
  - $B_0 = 10\mu G$ $r_0 = 99.9$ kpc $z_0 = 99.9$ kpc (flat)

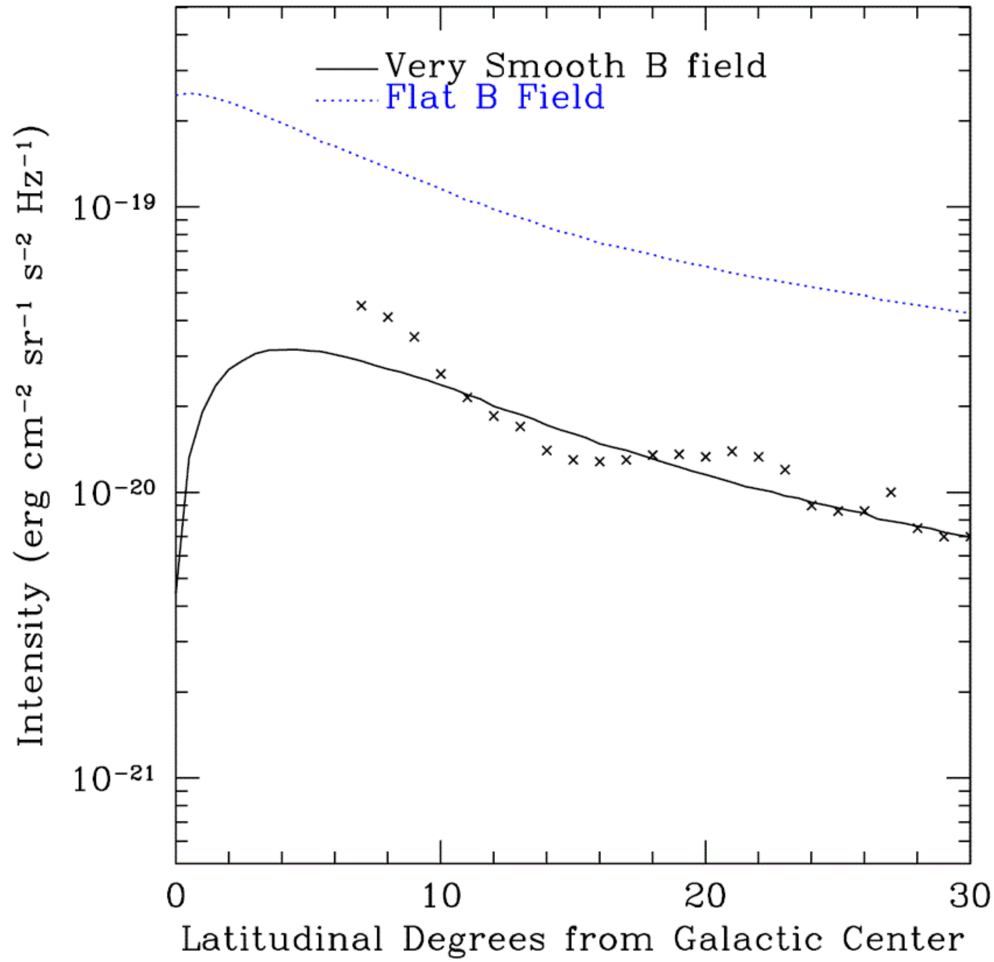
Match to WMAP Haze



We note that changing magnetic fields can greatly change the angular dependence of the DM haze. However, even for the most optimistic (flat) profile, we are unable to generate a great match to the WMAP Haze. This scenario requires more thorough investigation

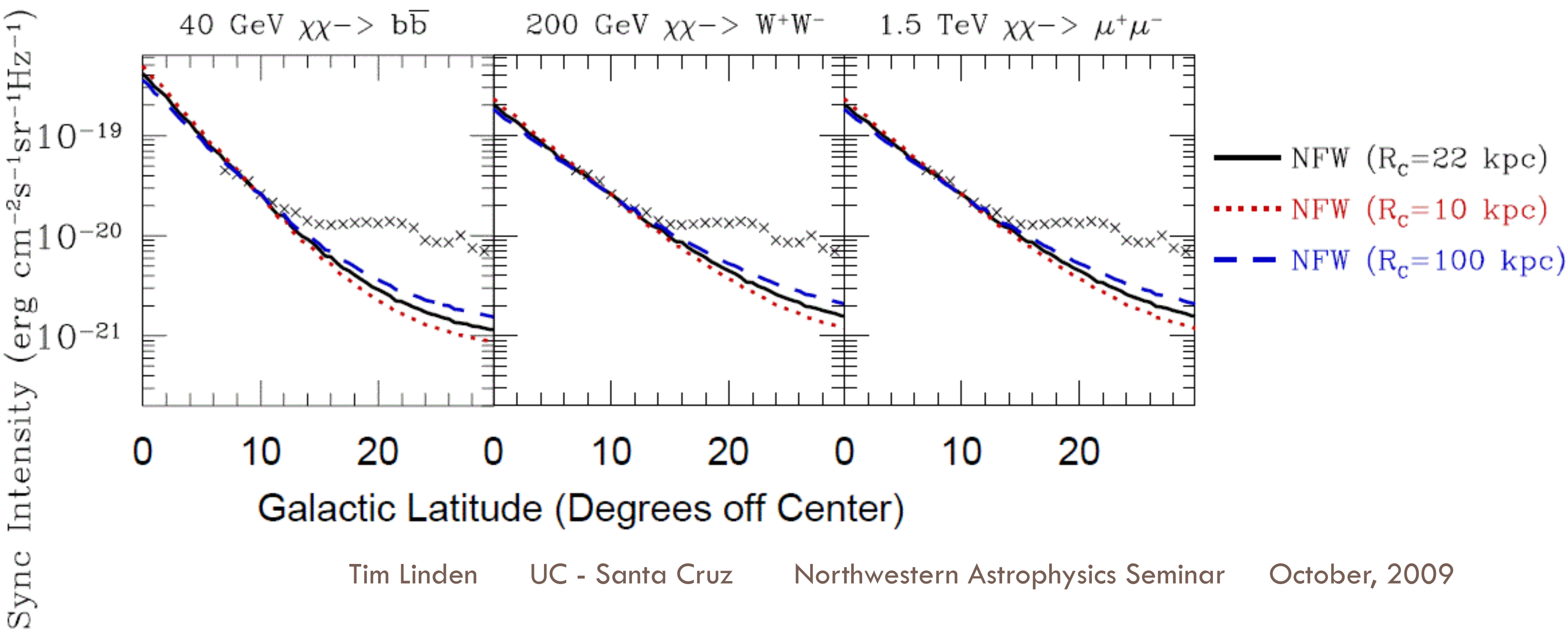
Magnetic field subtraction

Changing magnetic fields can greatly change the synchrotron intensity of non-DM electrons, changing which residual we would call the WMAP haze



NFW Profile

- We test several different NFW profile scale radii
- Even extreme choices for R_C do not show agreement with the WMAP Haze



DM Density Profiles

- We test four models supported by N-body simulations and theoretical arguments

1.) NFW Profile (R_C = 22 kpc)

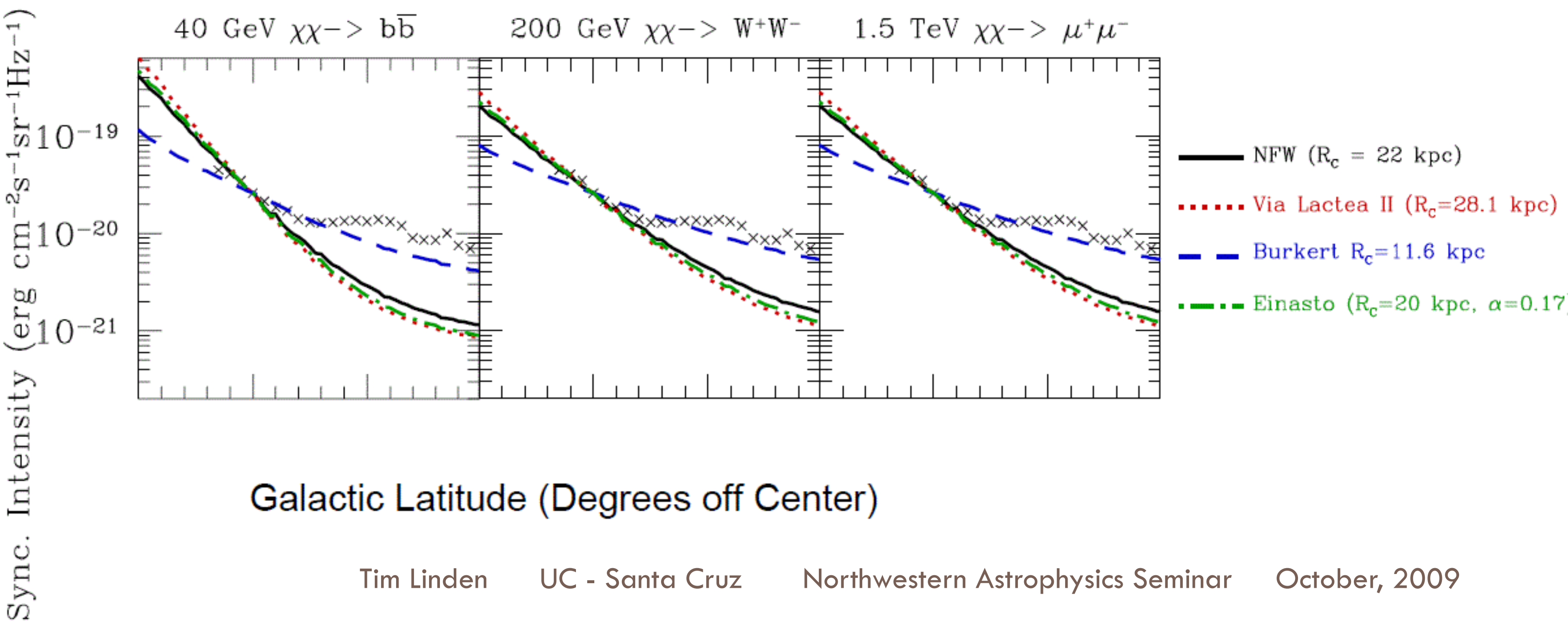
2.) Via Lactea II Simulation (R_C = 28.1 kpc)

3.) Einasto Profile (Aquarius Simulation) (R_C = 11.6 kpc α=0.17)

4.) Burkert Profile (R_C = 11.6 kpc)

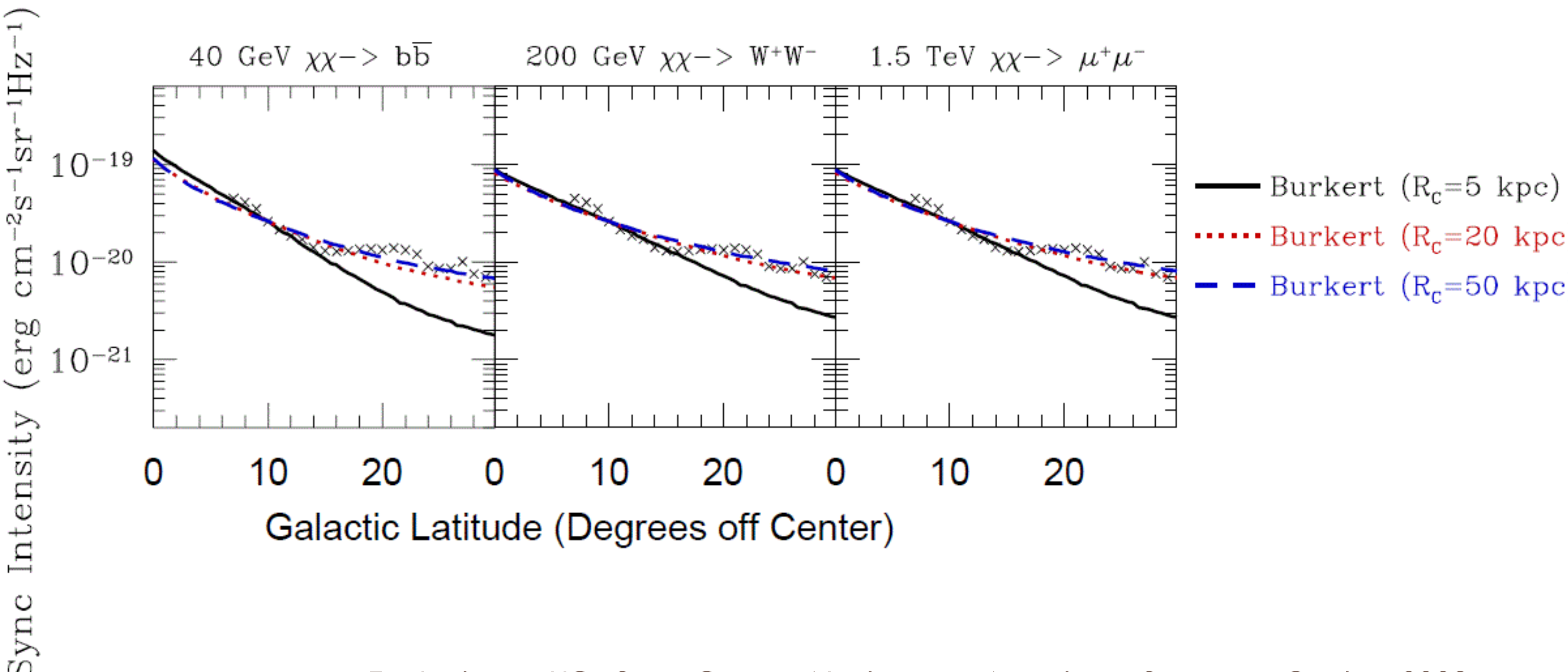
Effect on DM Haze

- All cored profiles show a striking (and consistent) disagreement with the WMAP haze. However non-cored profiles are in agreement with observation



Burkert Profile

- Slightly larger scale radii in the Burkert profile may provide a match for the WMAP Haze

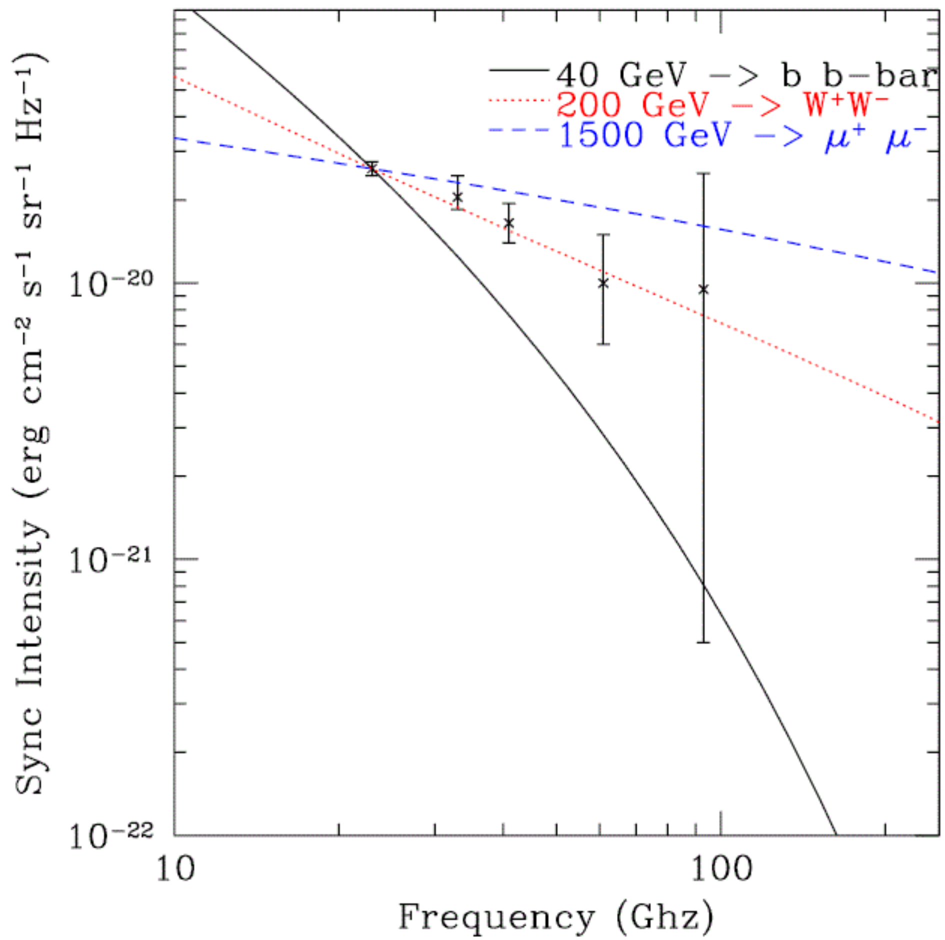


Modeling of WMAP Haze

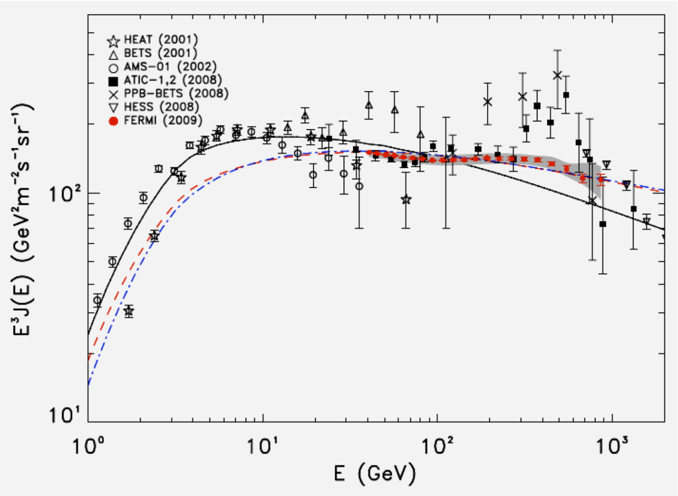
- Large astrophysical uncertainties make it difficult to claim any firm conclusion from a DM match to the WMAP haze
- But can we extract any more information from the WMAP survey?

Frequency Dependence

- Spectrum of e+/e- injection controls the frequency dependence of WMAP Haze
- Show the necessity of a hard primary spectrum in model

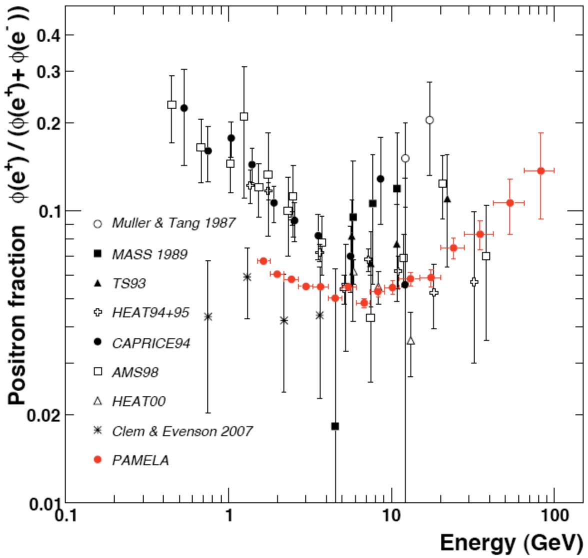


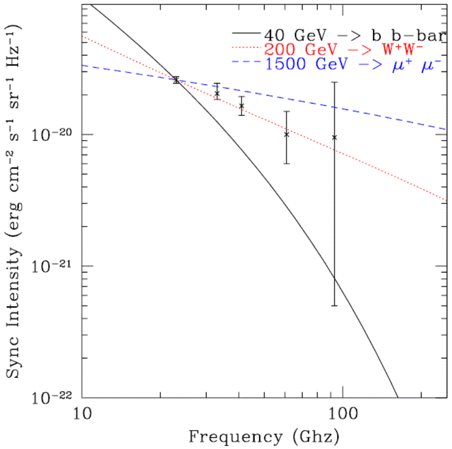
Comparison to Fermi/Pamela



Fermi e+/ e- flux

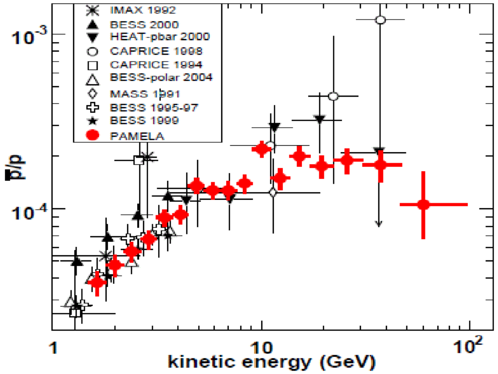
Pamela positron ratio





WMAP Haze Energy Dependence

Pamela antiproton ratio



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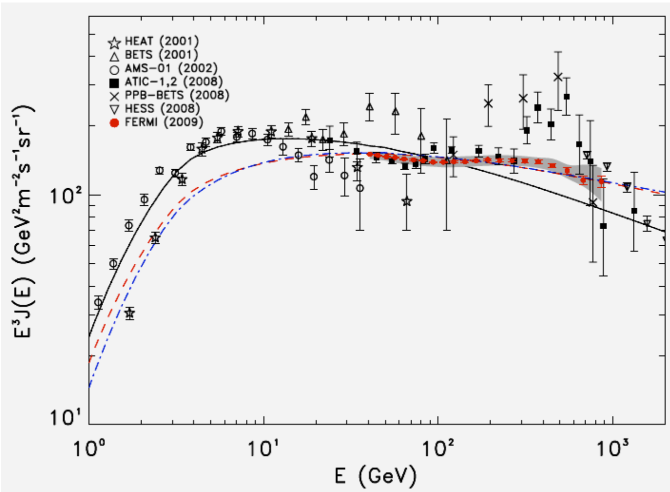
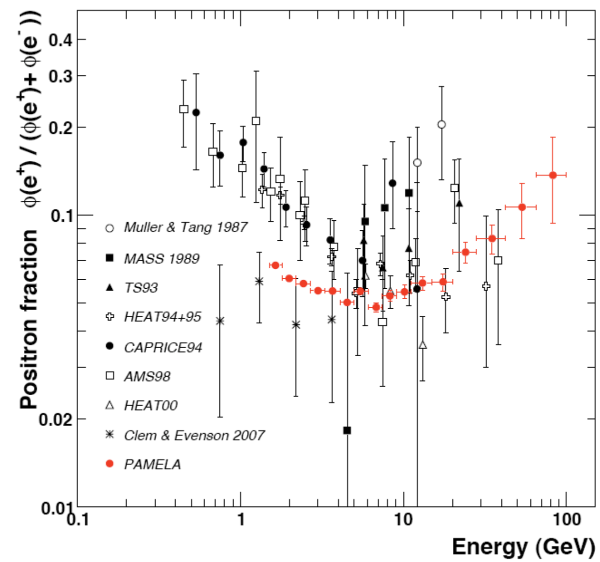
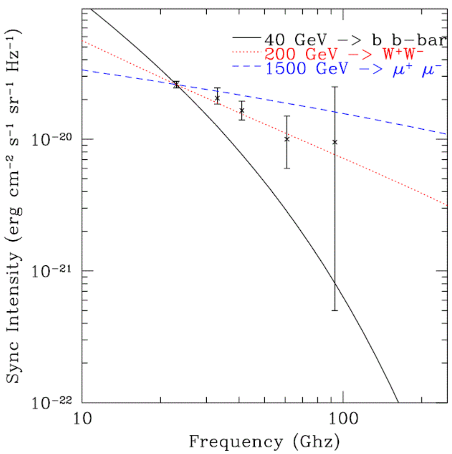
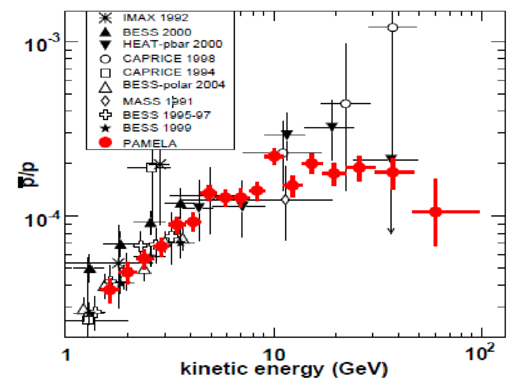


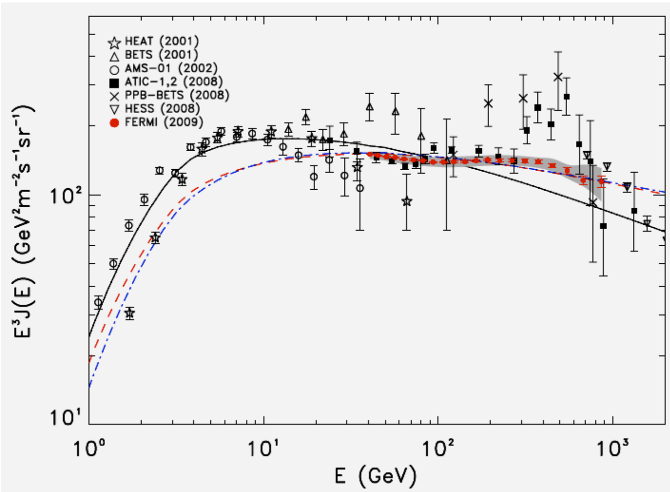


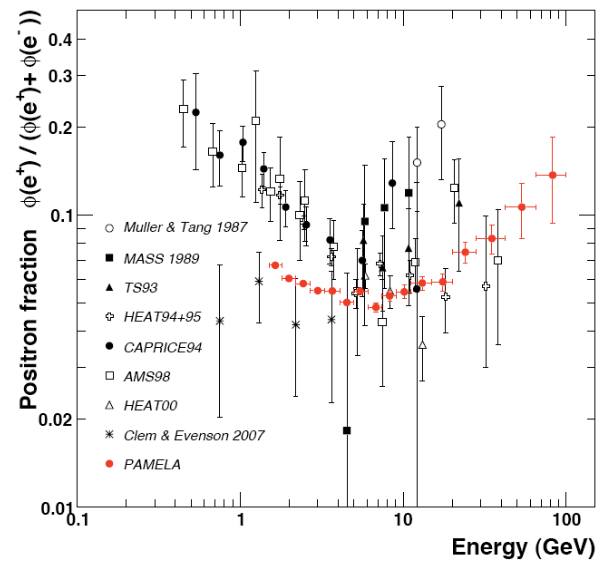


Require Additional High Energy Positron/ Electron Flux

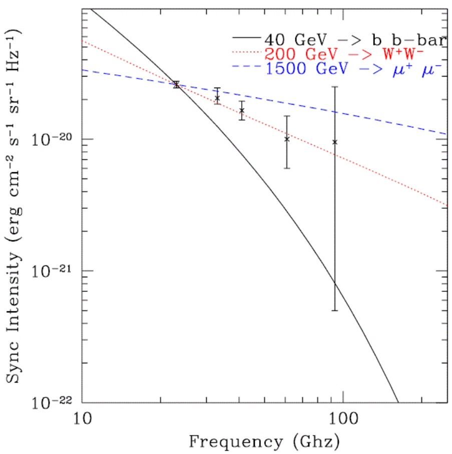


Comparison to Fermi/Pamela

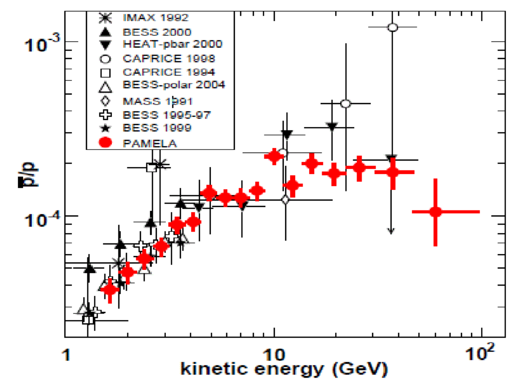




Local Measurements



Measurement of Galactic center



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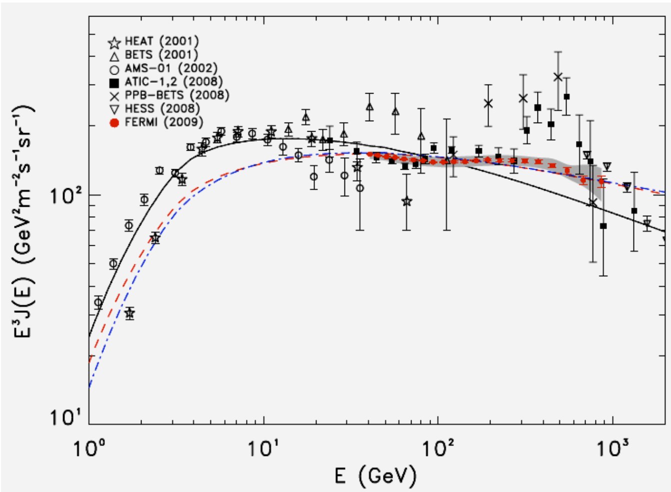
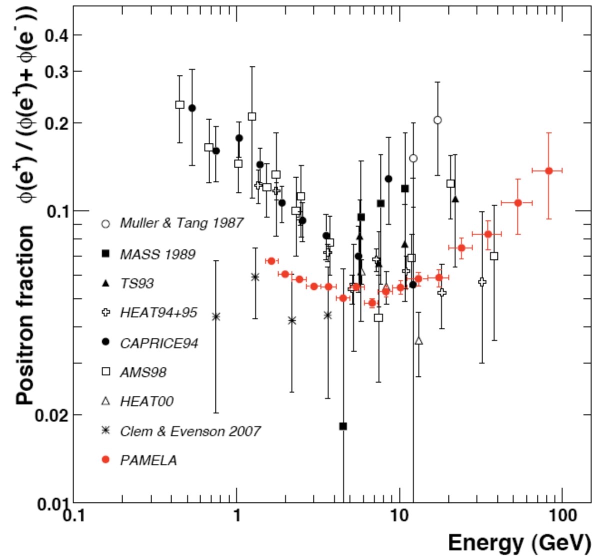
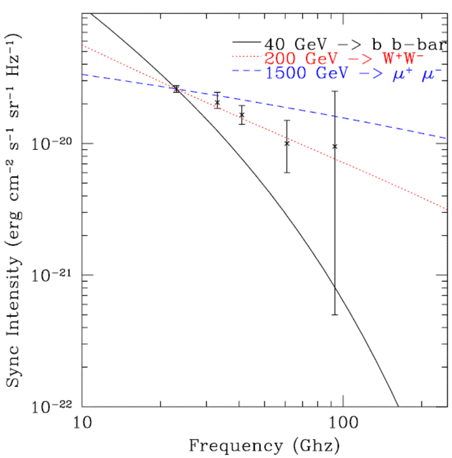
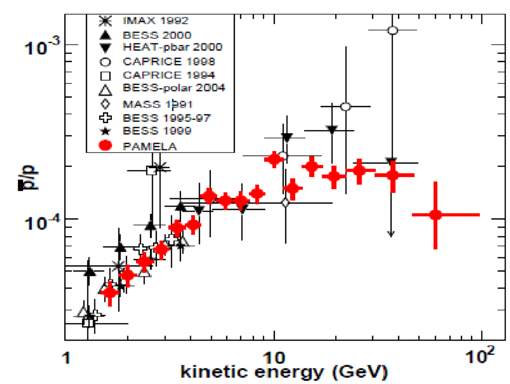




Require leptophilic primary sources



Compatible with leptophilic primary sources



Pulsar Modeling of WMAP

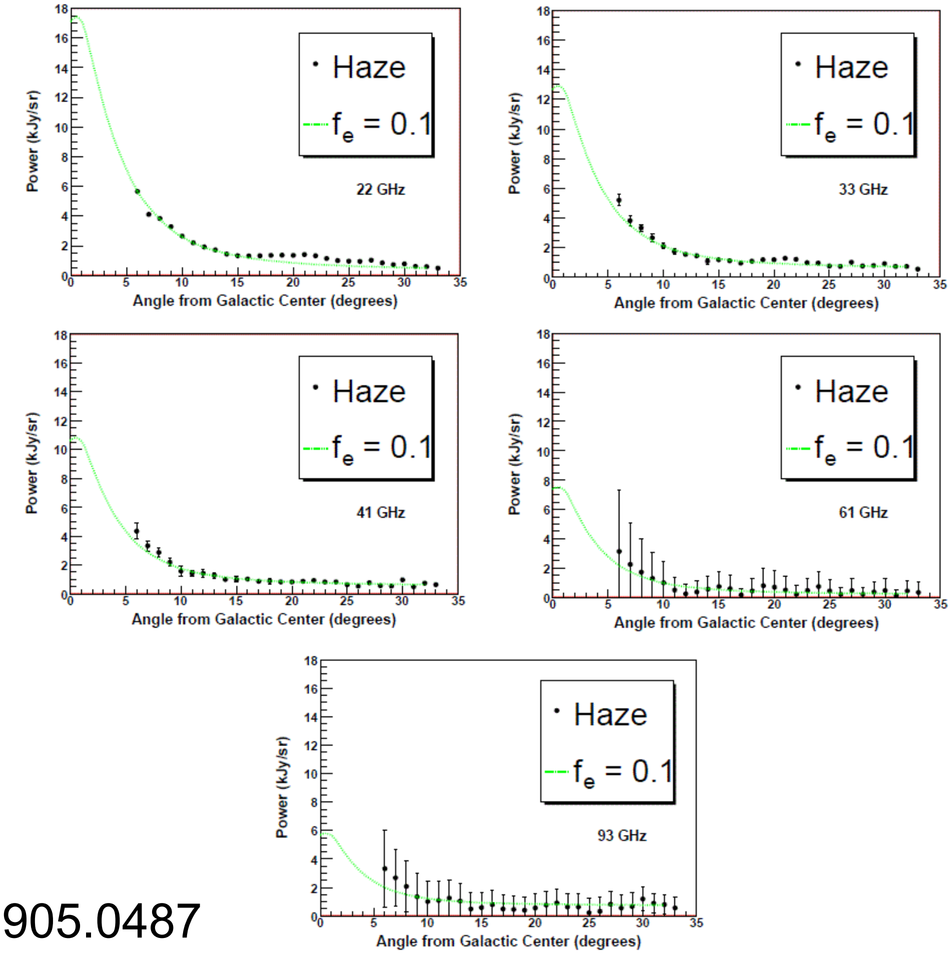
- Kaplinghat modeled the WMAP Haze with an additional pulsar distribution

$$\rho(x) = N^{-1} e^{-r/r0 - |z|/z0}$$

$$Q(E) \sim (E)^{-1.6} e^{-E/Ecut}$$

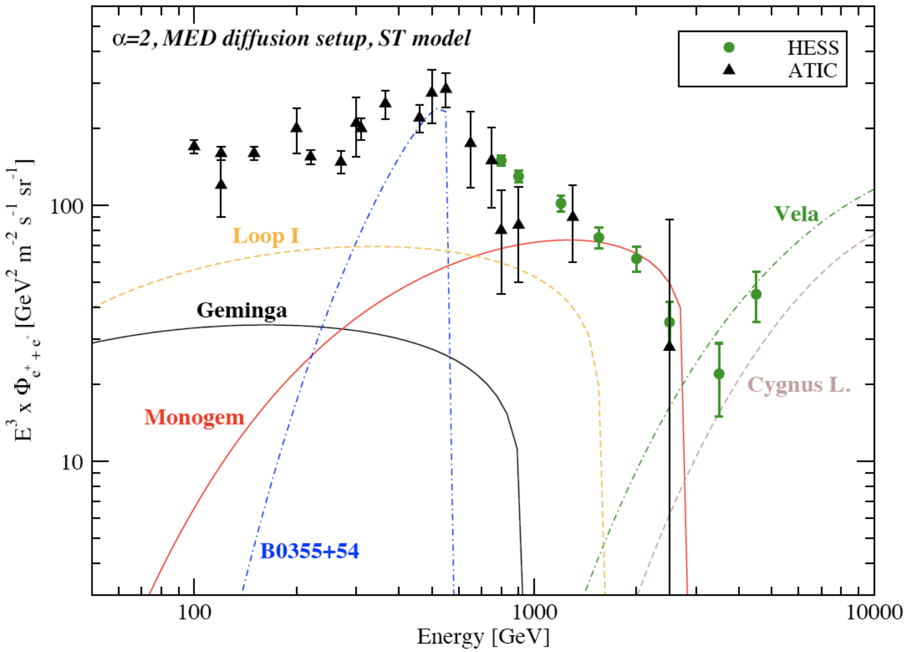
10% efficiency to e^+e^-

$$E_{cut} = 100 GeV$$

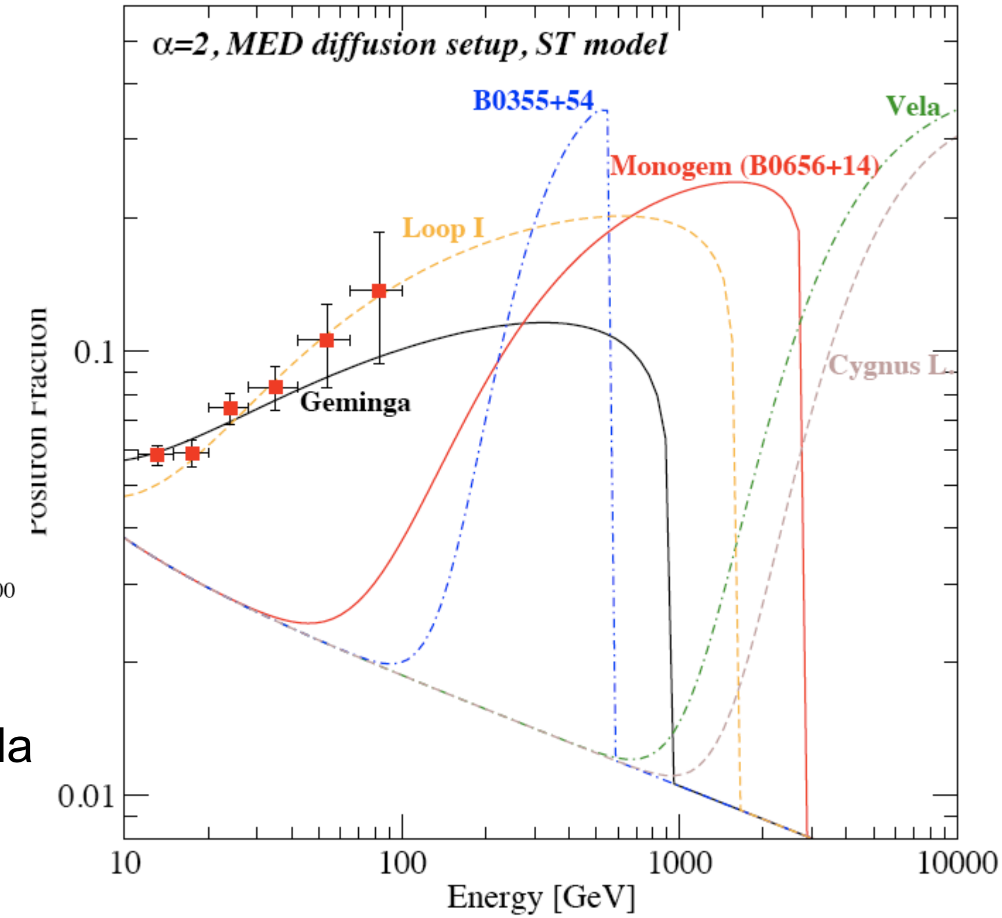


arXiv: 0905.0487

Pulsar Modeling of Pamela/Fermi



Fermi



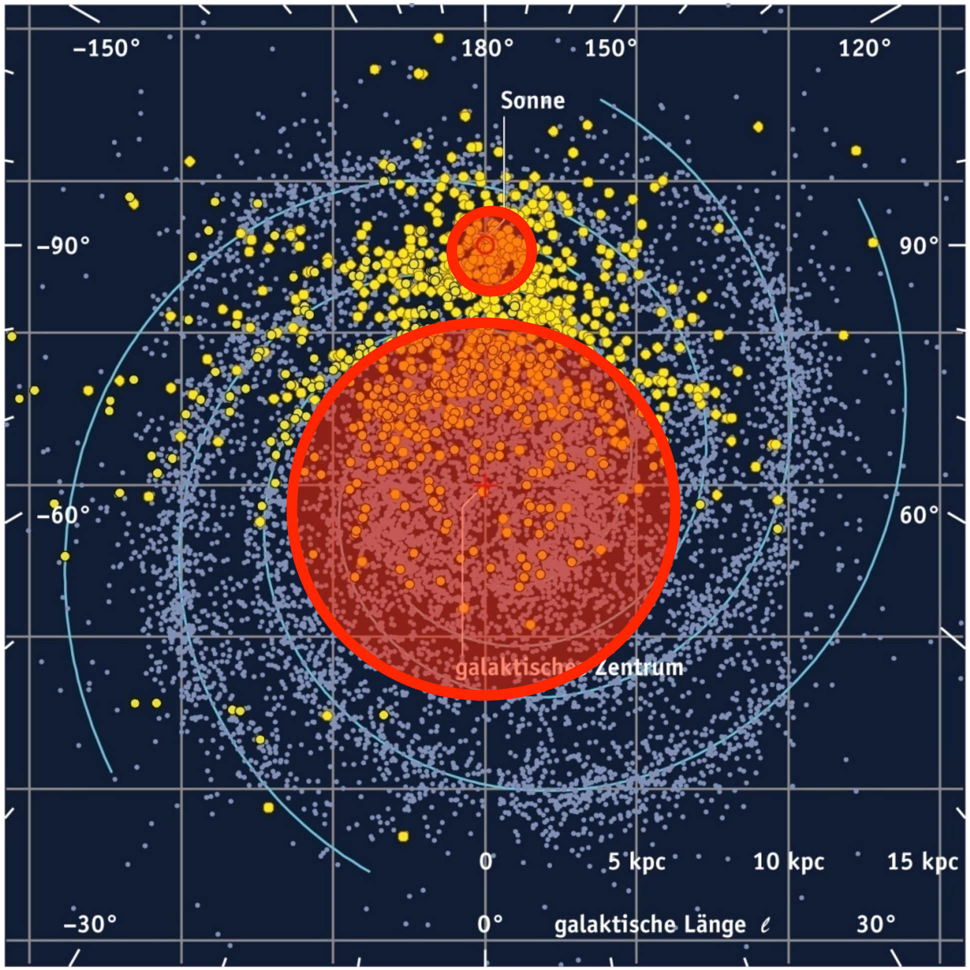
Pamela

Known pulsars may naturally explain local positron/electron signals

Profumo, 0812.4457

Pulsars – Massive Particles vs. Photons

- Pulsars needed to create e^+/e^- spectrum observed by Fermi/Pamela must be different pulsars than those needed to produce ICS/Synchrotron signals



Conclusions

- 1.) Evidence from multiple sources suggests an additional energetic primary electron spectrum
- 2.) DM and Pulsars are two primary candidates
- 3.) Further astrophysical inspection will be necessary to determine the nature of the additional primary source

Future Prospects

- Several possibilities for separating pulsars from DM
  - 1.) AMS-02 may detect spike in e+/e- ratio
    - No reasonable astrophysical source for such a signature
  - 2.) e+/e- ratio may continue to higher energies
    - May be difficult to posit an astrophysical source

Conversely:

  - 3.) LHC may provide DM mass not compatible with high energy leptophilic decay models