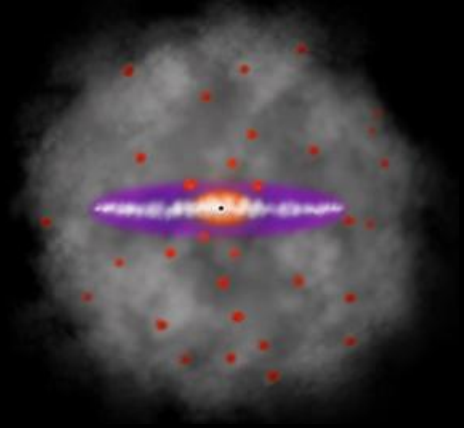
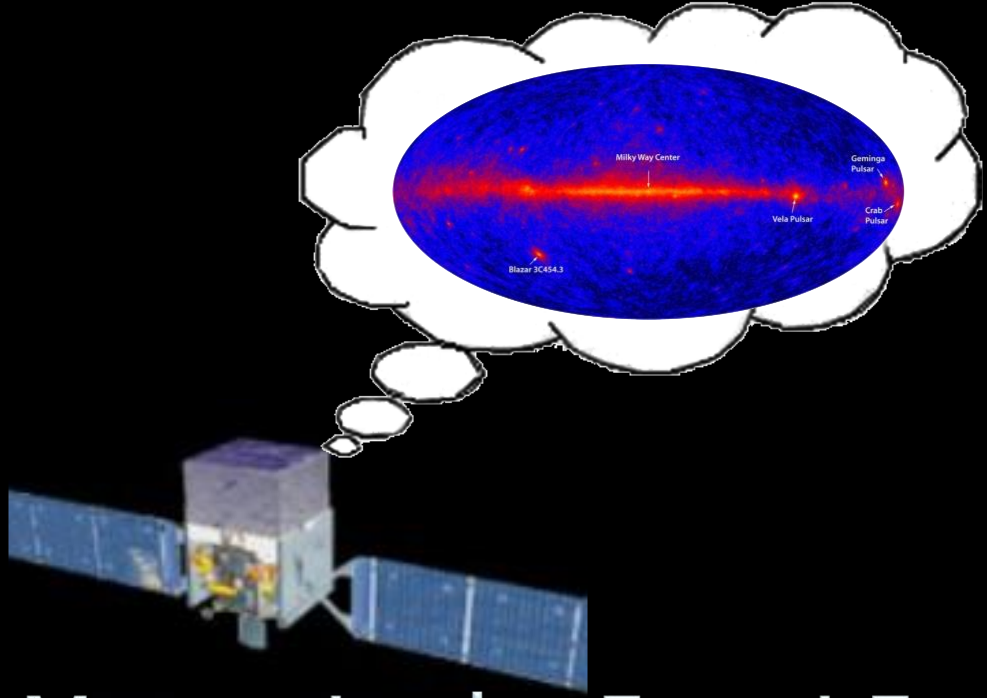




Searching for Dark Matter in the Fermi Era

Tim Linden

with Stefano Profumo

University of California – Santa Cruz

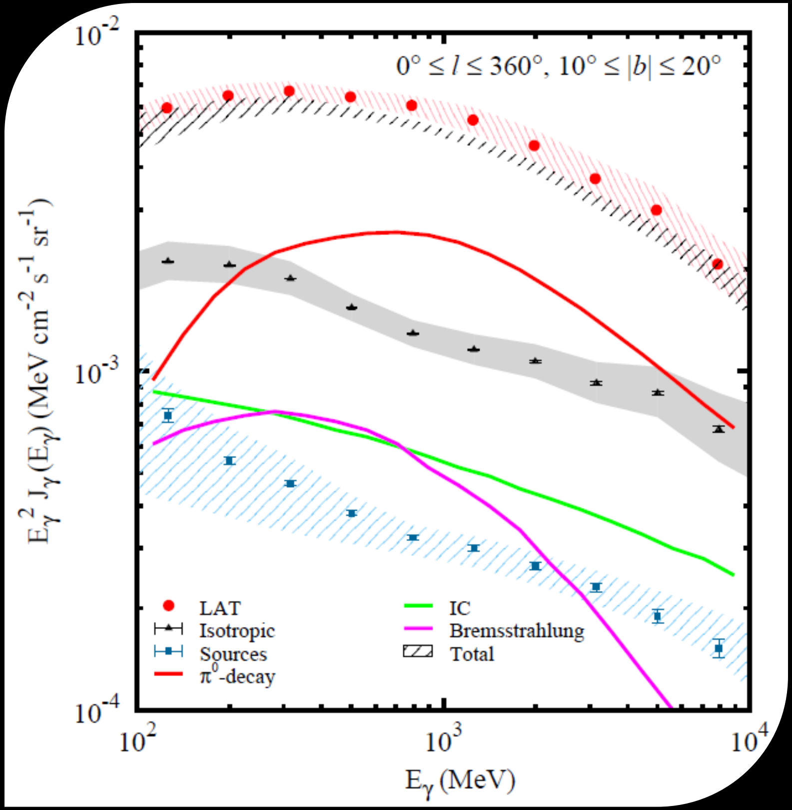
Caltech

April 13, 2010

Outline

- Are we already seeing dark matter?
- Difficulties in extracting a dark matter signal
- How could we determine whether an unknown signal is due to dark matter annihilation?

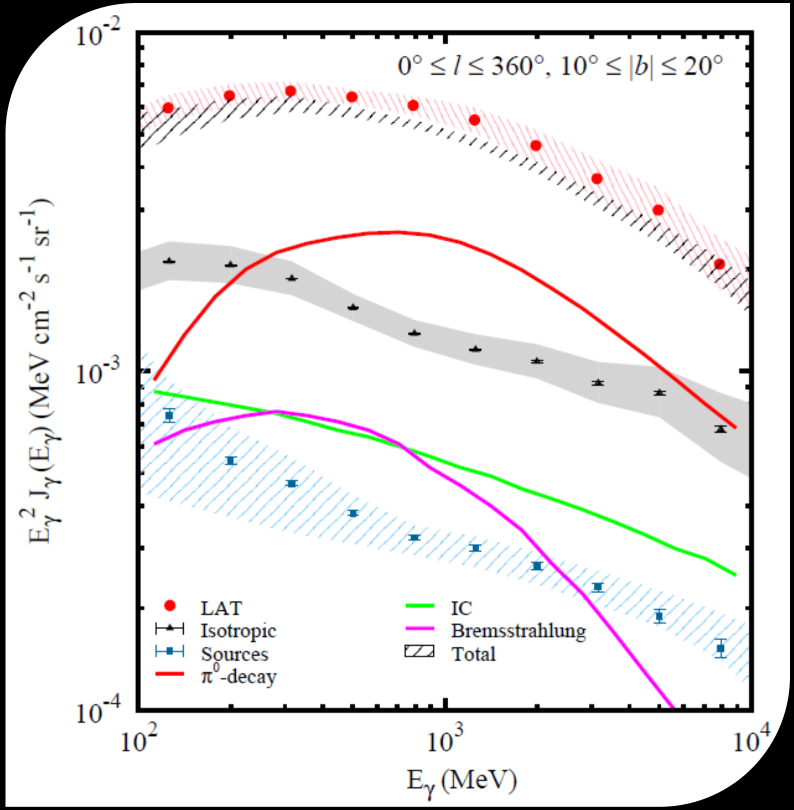
Observations of Diffuse Emission



T. Porter, 2009 (0907.0294)

- Many sources:
  - Extragalactic
  - π^0 decay
  - Inverse Compton Scattering
  - Bremsstrahlung Emission
  - Unresolved Point Sources

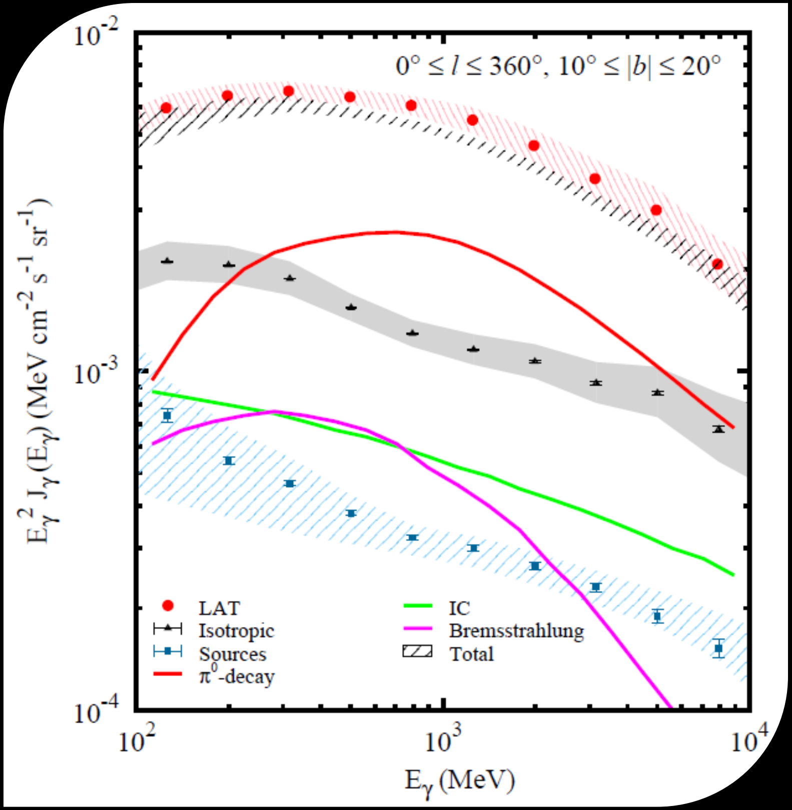
Observations of Diffuse Emission



T. Porter, 2009 (0907.0294)

- Many sources:
  - Extragalactic
    - Isotropic Source Classes
    - Sources include blazars, starburst galaxies
  - π^0 decay
  - Inverse Compton Scattering
  - Bremsstrahlung Emission
  - Unresolved Point Sources

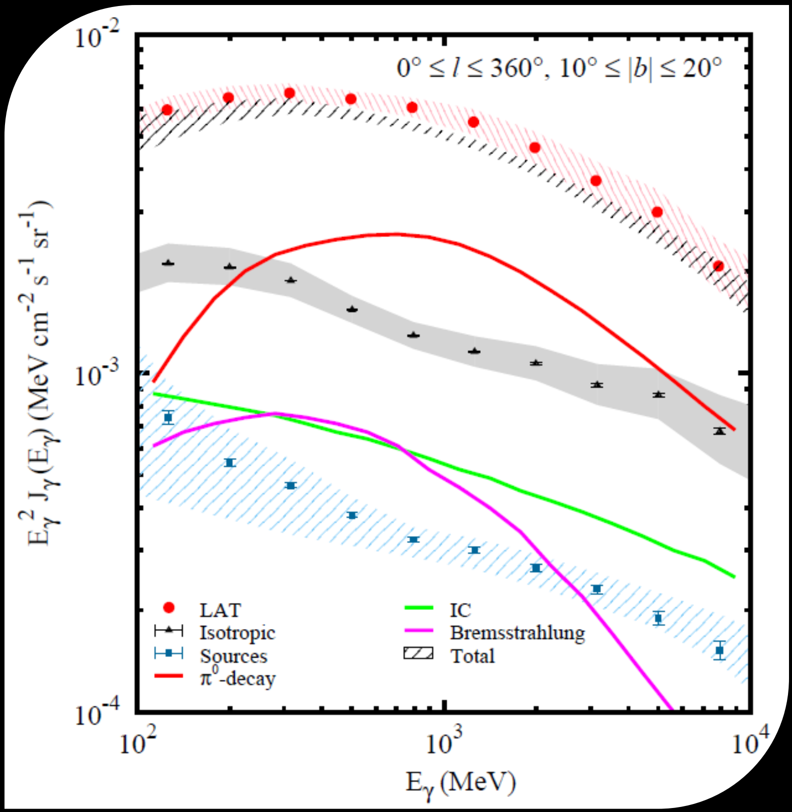
Observations of Diffuse Emission



T. Porter, 2009 (0907.0294)

- Many sources:
  - Extragalactic
  - π^0 decay
    - Proton collisions with galactic dust
    - Well defined emission spectra
  - Inverse Compton Scattering
  - Bremsstrahlung Emission
  - Unresolved Point Sources

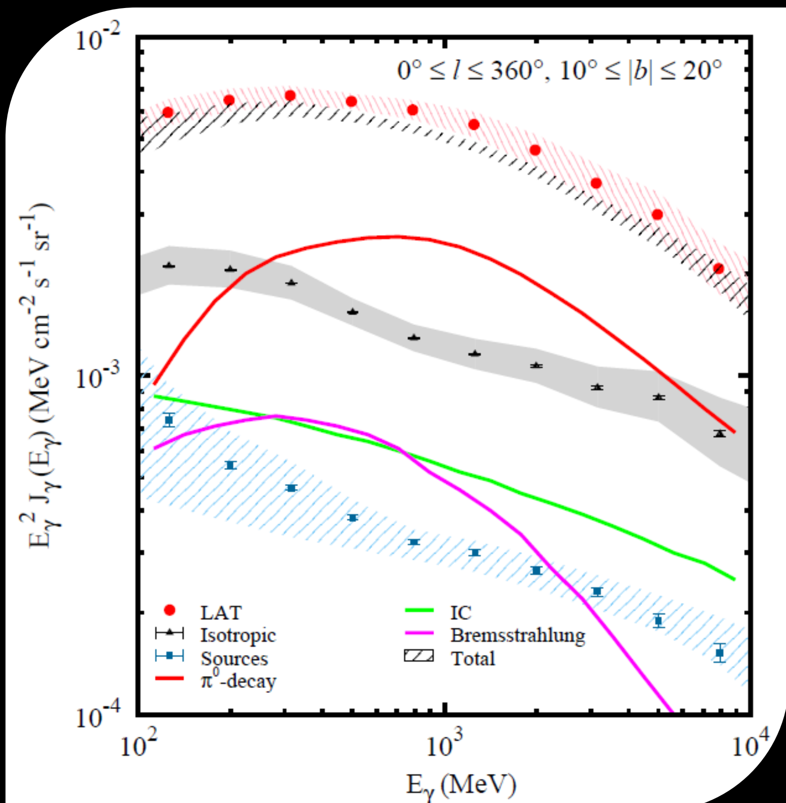
Observations of Diffuse Emission



T. Porter, 2009 (0907.0294)

- Many sources:
  - Extragalactic
  - π^0 decay
  - Inverse Compton Scattering
    - Interactions of charged leptons with Interstellar radiation field
  - Bremsstrahlung Emission
  - Unresolved Point Sources

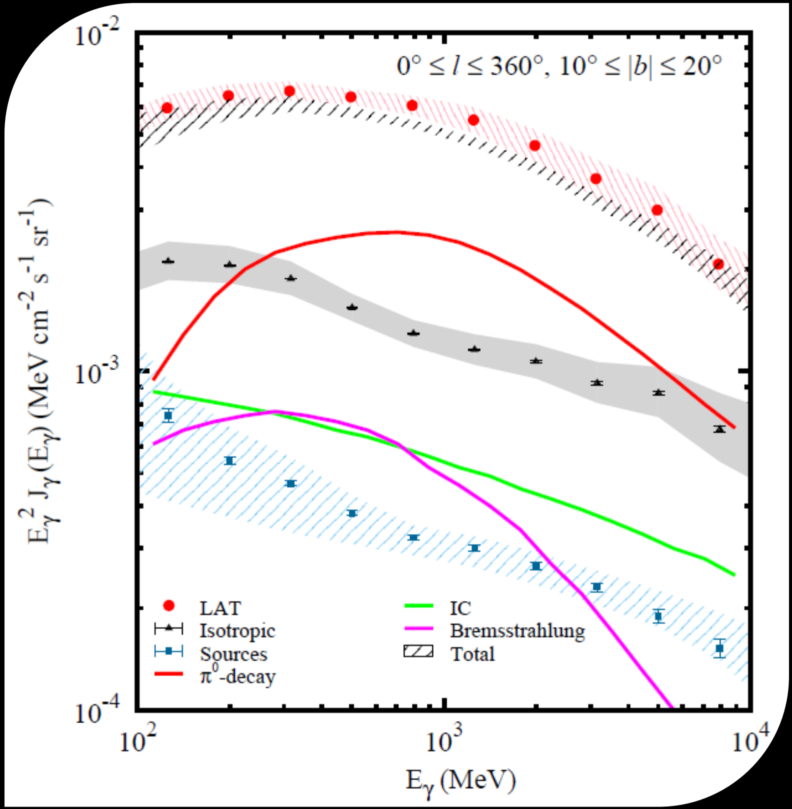
Observations of Diffuse Emission



T. Porter, 2009 (0907.0294)

- Many sources:
  - Extragalactic
  - π^0 decay
  - Inverse Compton Scattering
  - Bremsstrahlung Emission
    - Relatively weak sources at high energies and away from the galactic center
  - Unresolved Point Sources

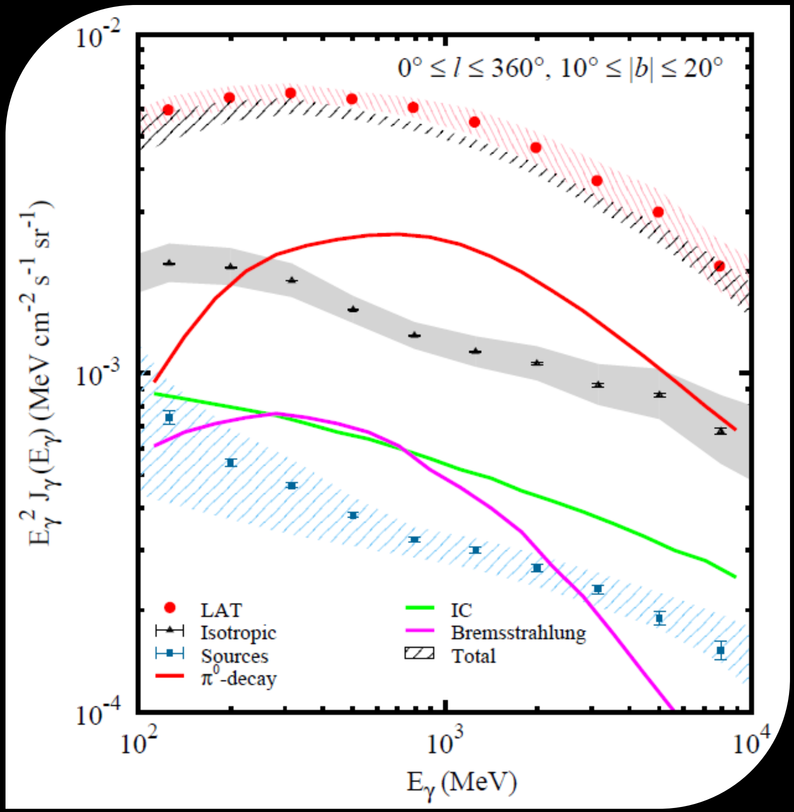
Observations of Diffuse Emission



T. Porter, 2009 (0907.0294)

- Many sources:
  - Extragalactic
  - π^0 decay
  - Inverse Compton Scattering
  - Bremsstrahlung Emission
  - Unresolved Point Sources
    - Systematic error – Intensity and spectra changes over time

Is There Any Room Left for DM?

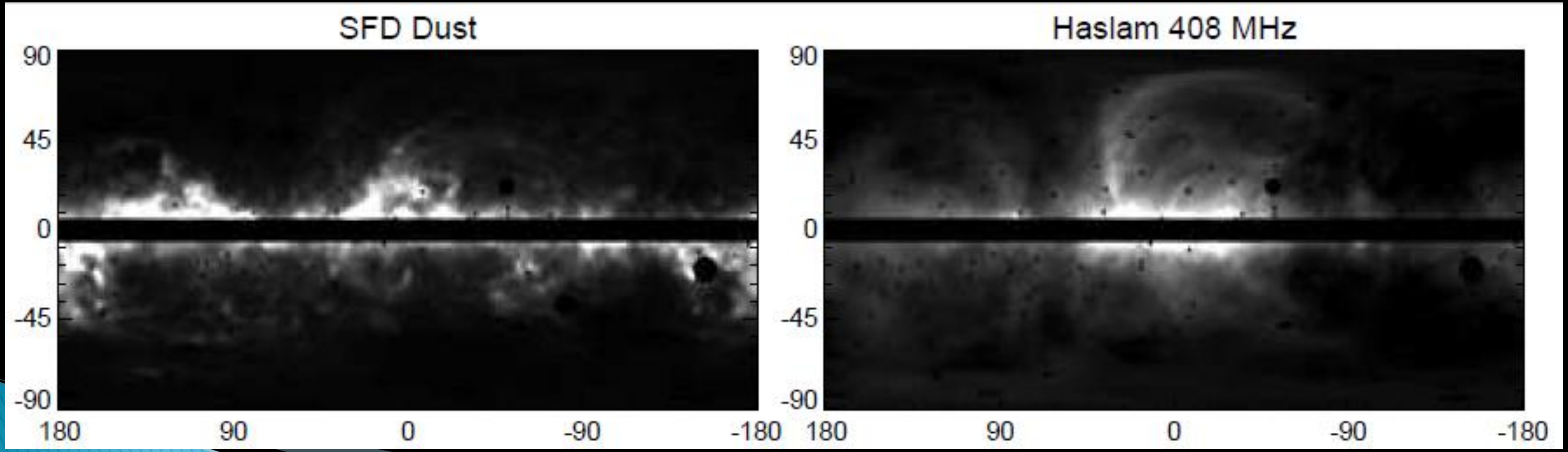


T. Porter, 2009 (0907.0294)

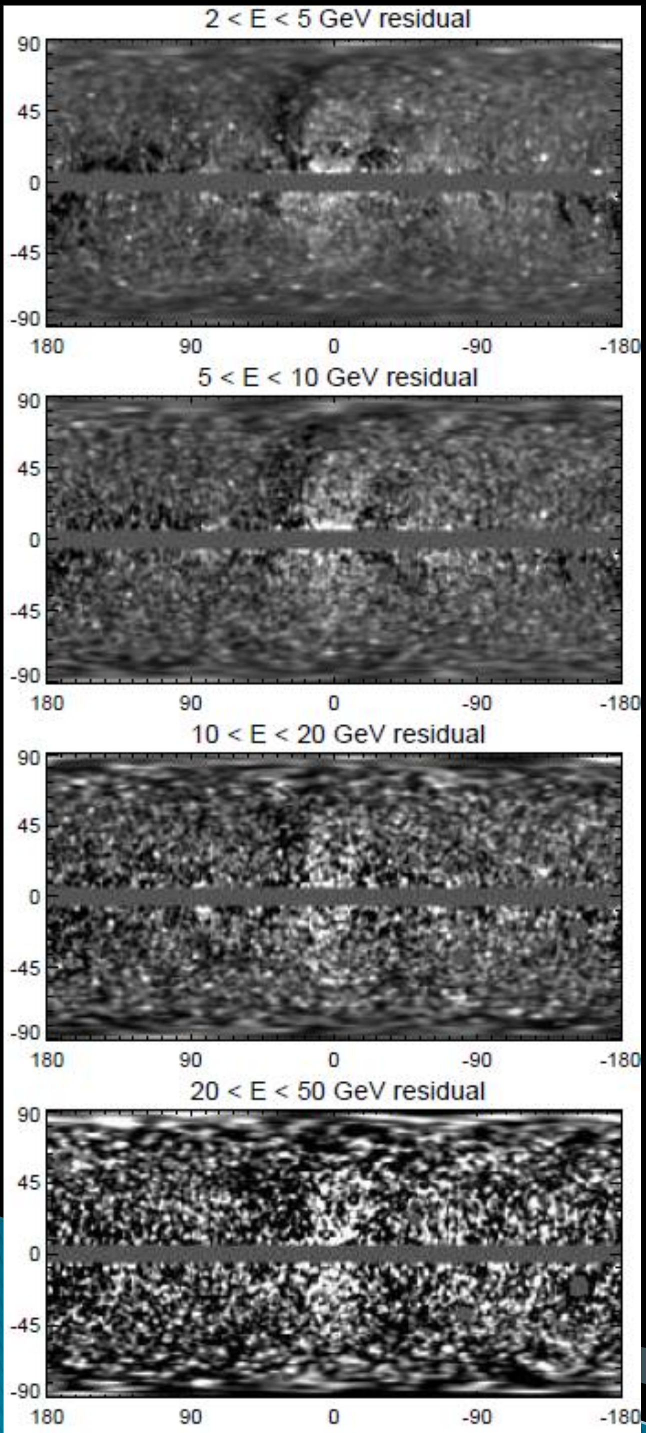
- How large are the astrophysical uncertainties in each of these background signals?
- Playing a very different game than direct dark matter detection (e.g. CDMS)
  - Should see millions of events
  - But no background rejection

Modeling Astrophysical Sources

- Dobler et al. (2009) created models for the morphology of these astrophysical components
  - SFD Dust Map for π^0 decay
  - Haslam 408 Mhz map for ICS
  - Point sources subtracted from 3-month Fermi catalog
  - Residual Map mean subtracted to eliminate isotropic



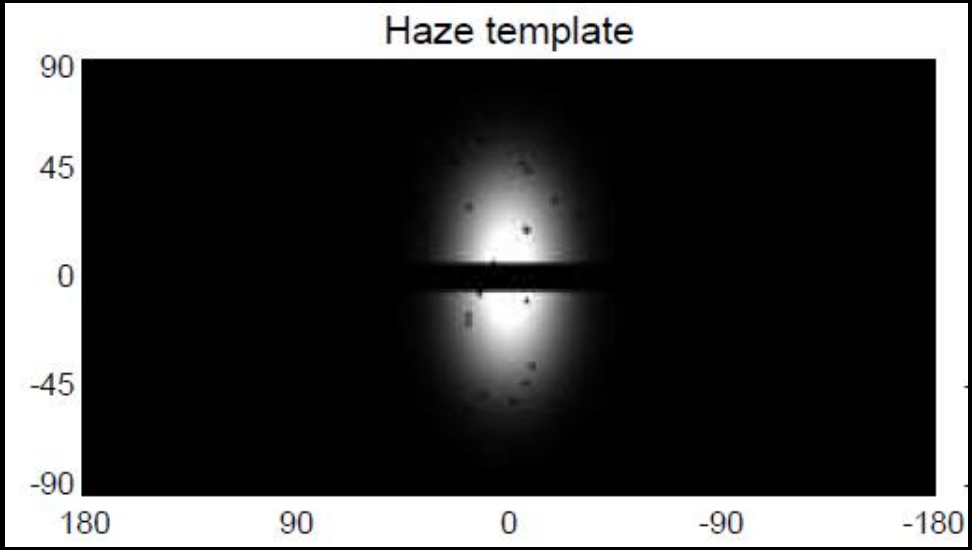
Dobler et al (2009) (0910.4583)



An Enticing Residual!

- Dobler et al. finds a significant residual when these maps are applied
- Residual has a pronounced morphology above and below the galactic center

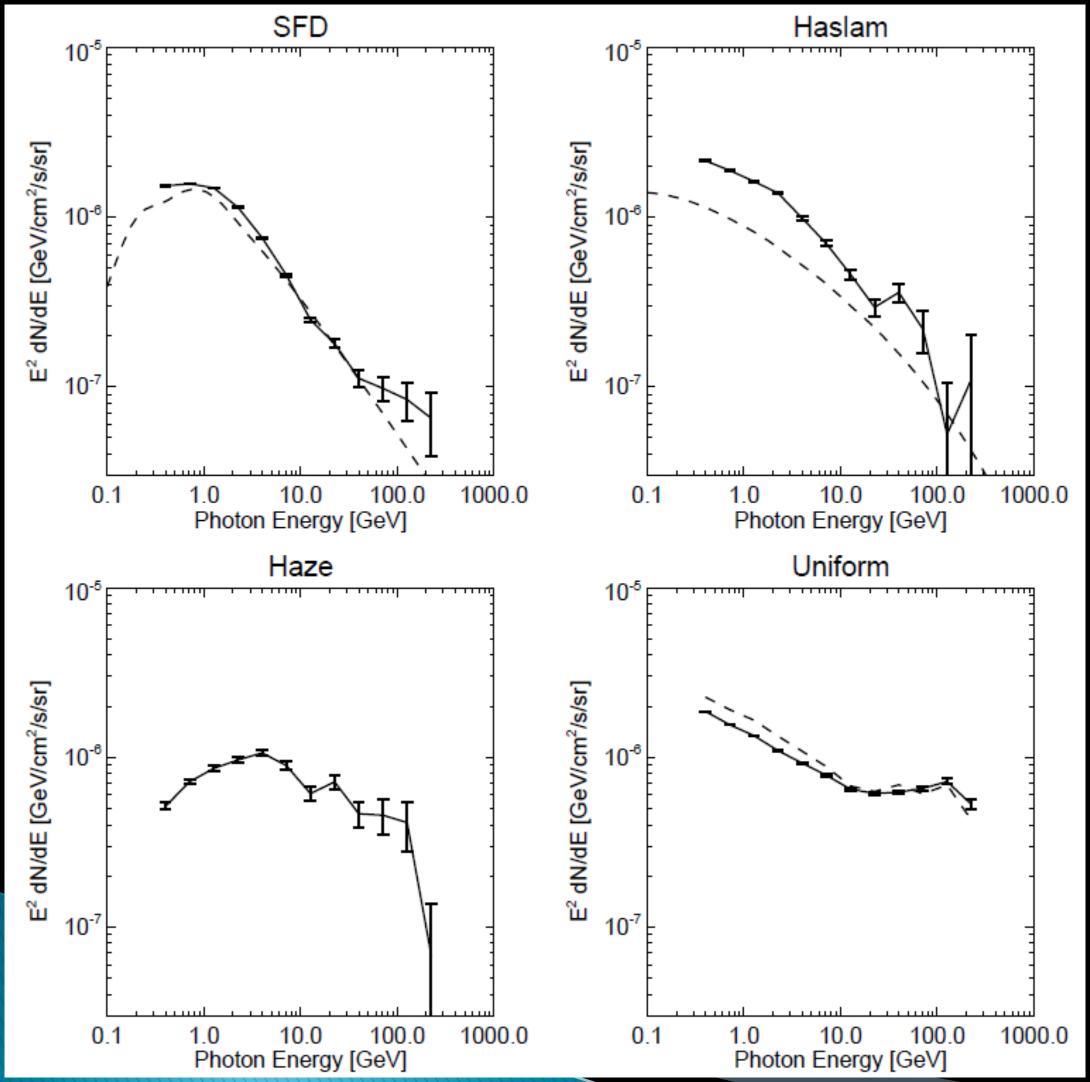
Modeling this residual



- To map this residual, Dobler et al add an ad hoc template

This template is a bivariate gaussian with latitudinal scale height $\sigma_b = 25^o$, and a longitudinal scale height of $\sigma_l = 15^o$

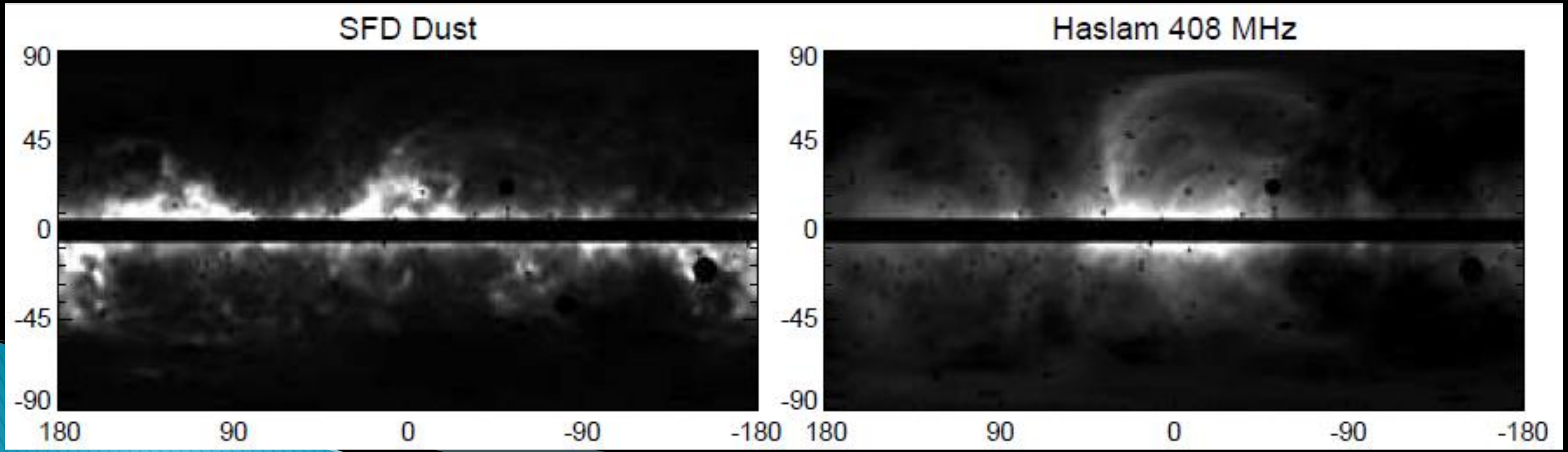
These residuals are large!



- The haze template is co-dominant with the isotropic background above 10 GeV
- Other templates have reasonable spectra

But do we trust these templates?

- SFD Dust Map for π^0 decay
  - Dust is a reasonable tracer for galactic gas
  - Gas acts as the target of energetic protons



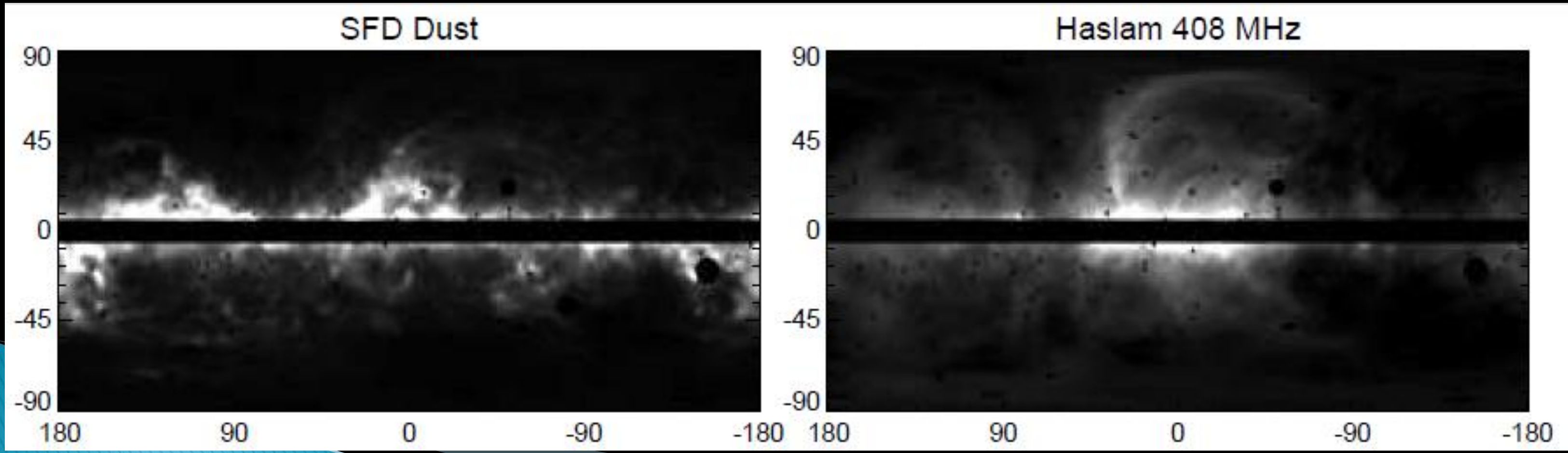
But do we trust these templates?

- SFD Dust Map for π^0 decay
  - But the cosmic ray distribution is not isotropic!

$$\Phi_{\pi 0} = \text{BEAM x TARGET}$$

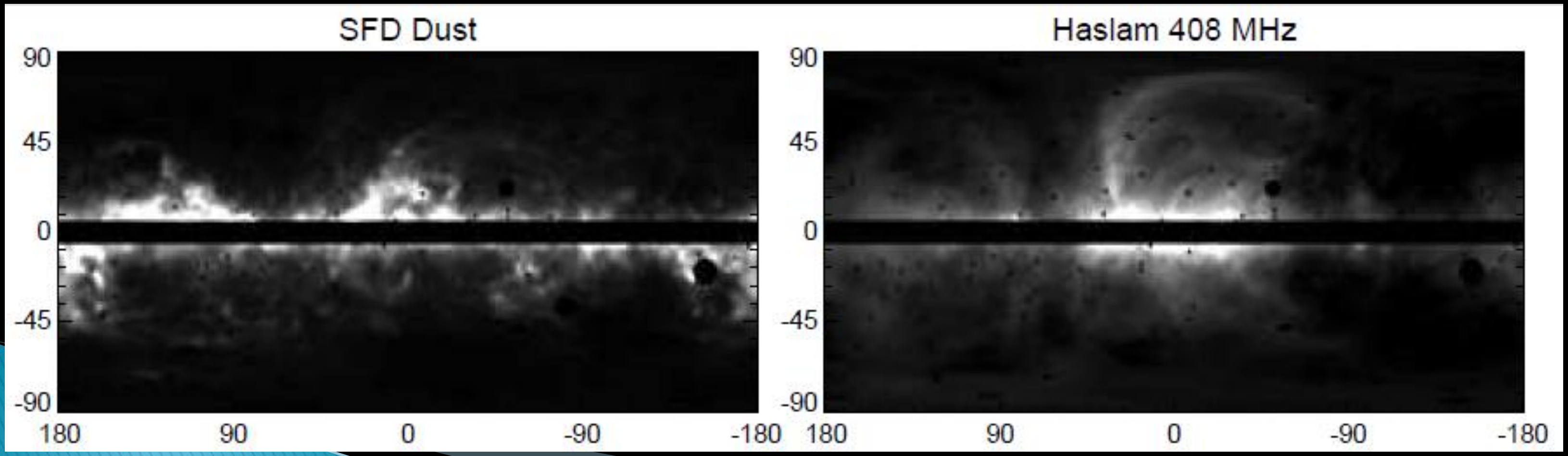
Cosmic rays

Galactic Gas



But do we trust these models?

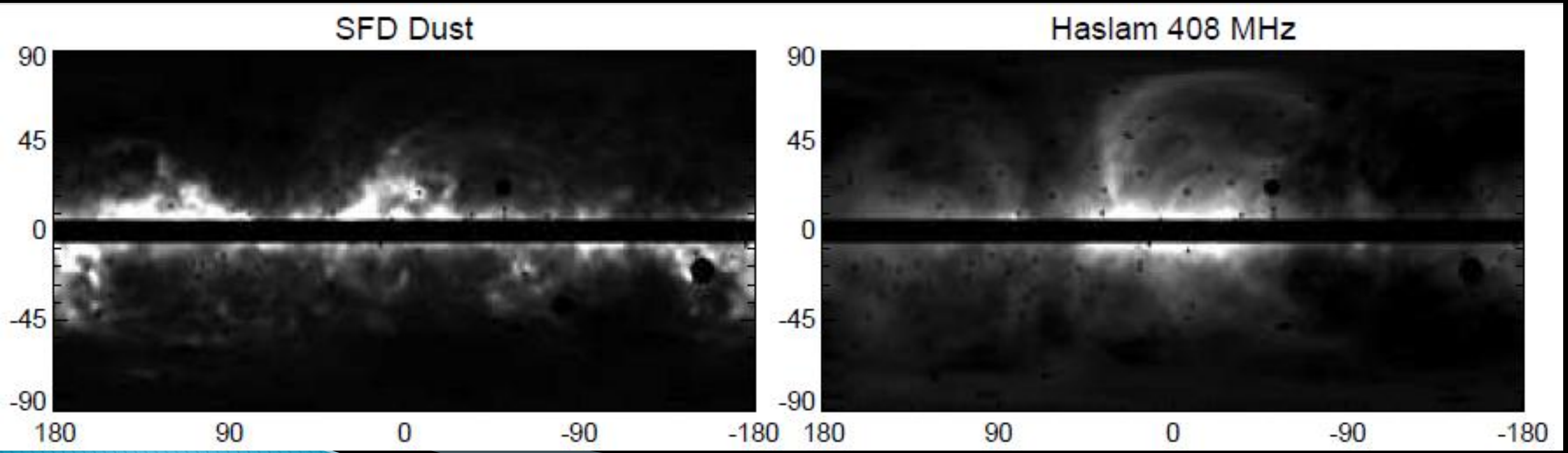
- Haslam 408 Mhz skymap for inverse Compton scattering
  - At 408 Mhz, the radio sky should be dominated by synchrotron of energetic leptons.
  - These same leptons should create γ-ray emission due to ICS of the interstellar radiation field.



But do we trust these models?

- Haslam 408 Mhz skymap for inverse Compton scattering
  - The morphology of the interstellar radiation field is <u>not</u> the same as the morphology of the galactic magnetic fields.

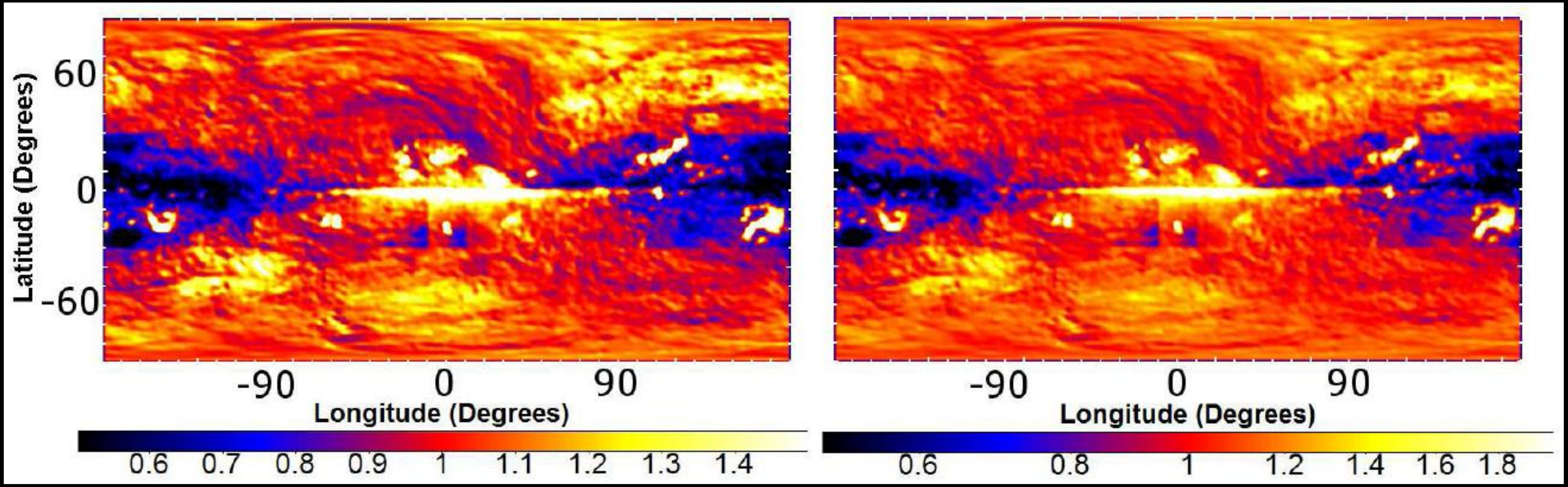
$$\frac{\text{ISRF}}{B^2} \neq 1$$



Our Setup

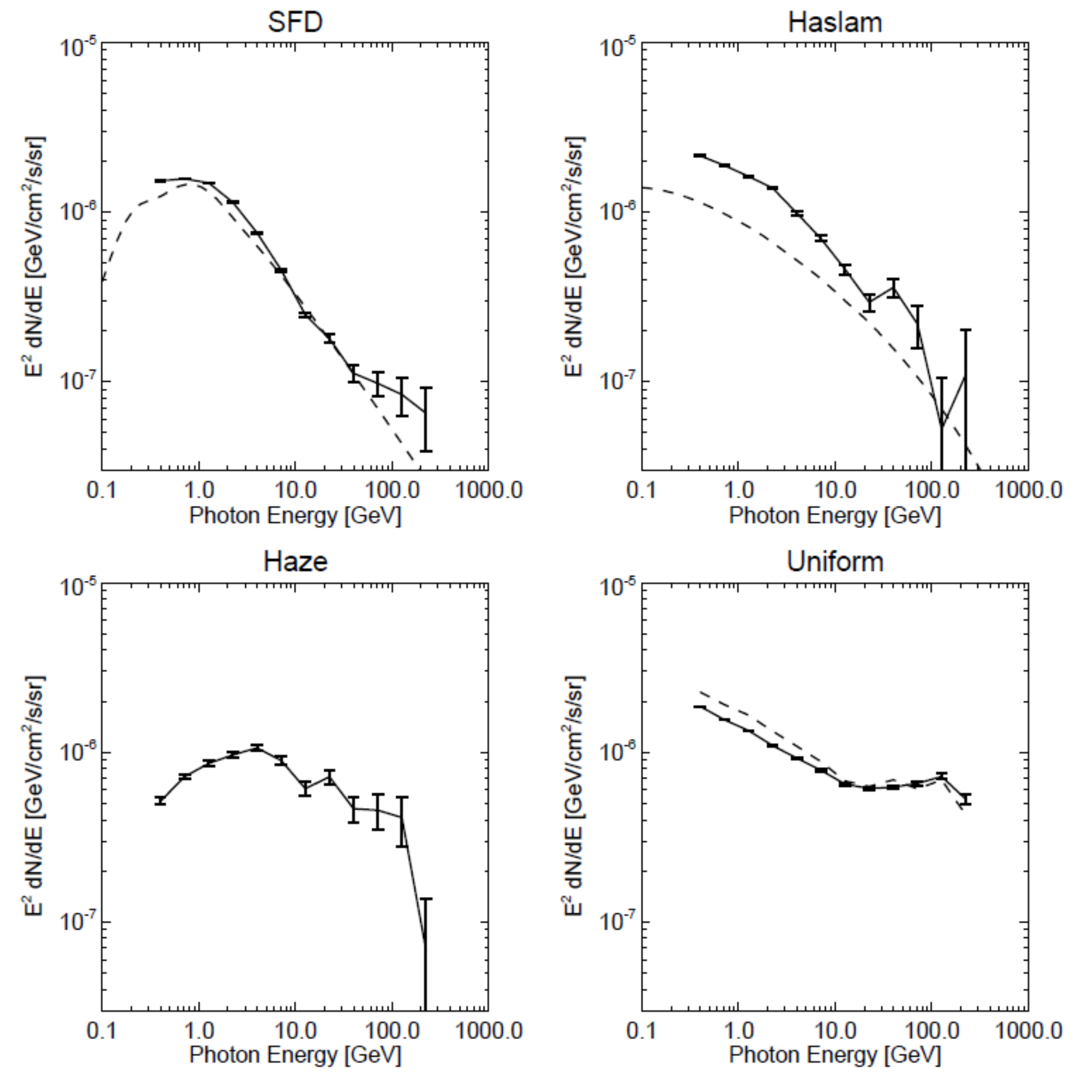
- We use GALPROP models to test the morphological consistency of:
  - 1.) The π^0 decay morphology and the input gas map
  - 2.) The ICS decay morphology and the 408 Mhz synchrotron morphology

π^0 Decay divided by Gas Map



- The resulting skymap has a haze-like morphology that can be fit with a Gaussian 17% as strong as the estimated π^0 skymap

Important at low energies



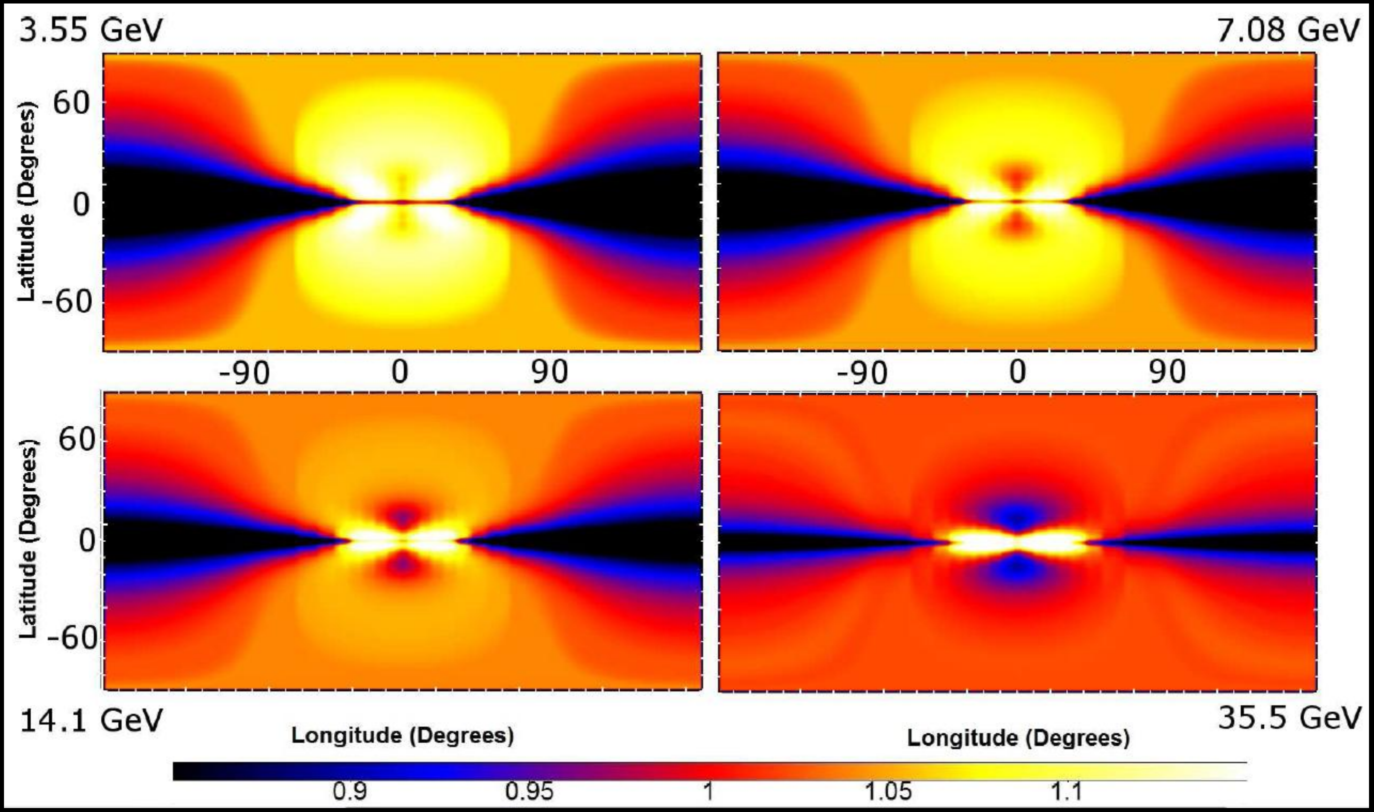
- The π^0 decay morphology is dominant up to several GeV
- A 17% Gaussian residual can explain the majority of the haze around 1 GeV

ICS divided by Synchrotron

- The ratio of the ICS map to the synchrotron map also show a haze morphology

Highly energy dependent

Low intensity 16% to -4%



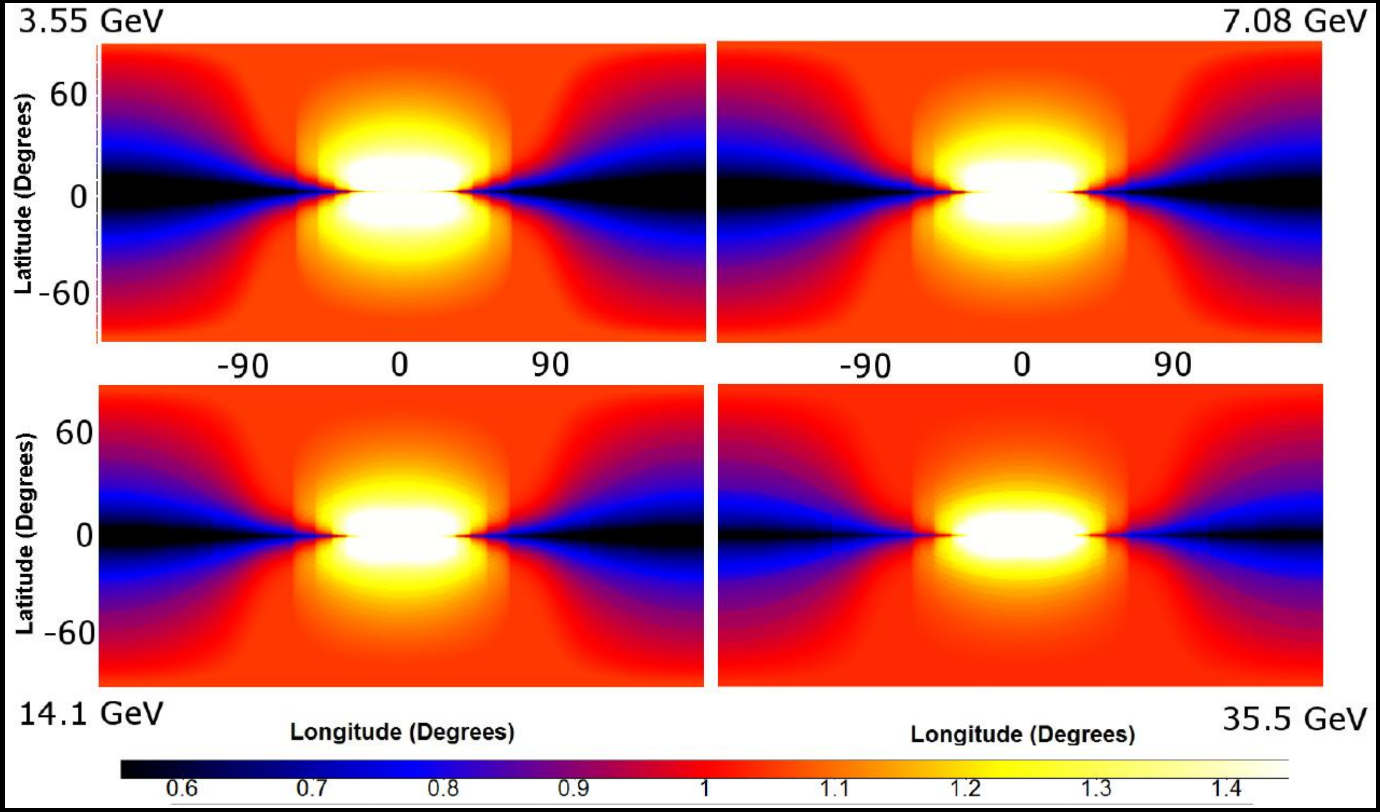
$B = 11.6\ \mu G\ e^{-r/10\ kpc\ -z/2kpc}$

ICS / Sync is very uncertain

- By slightly altering the magnetic field morphology, we can create larger deviations

Same energy dependence as before

Large Gaussian errors (54% to 40%)



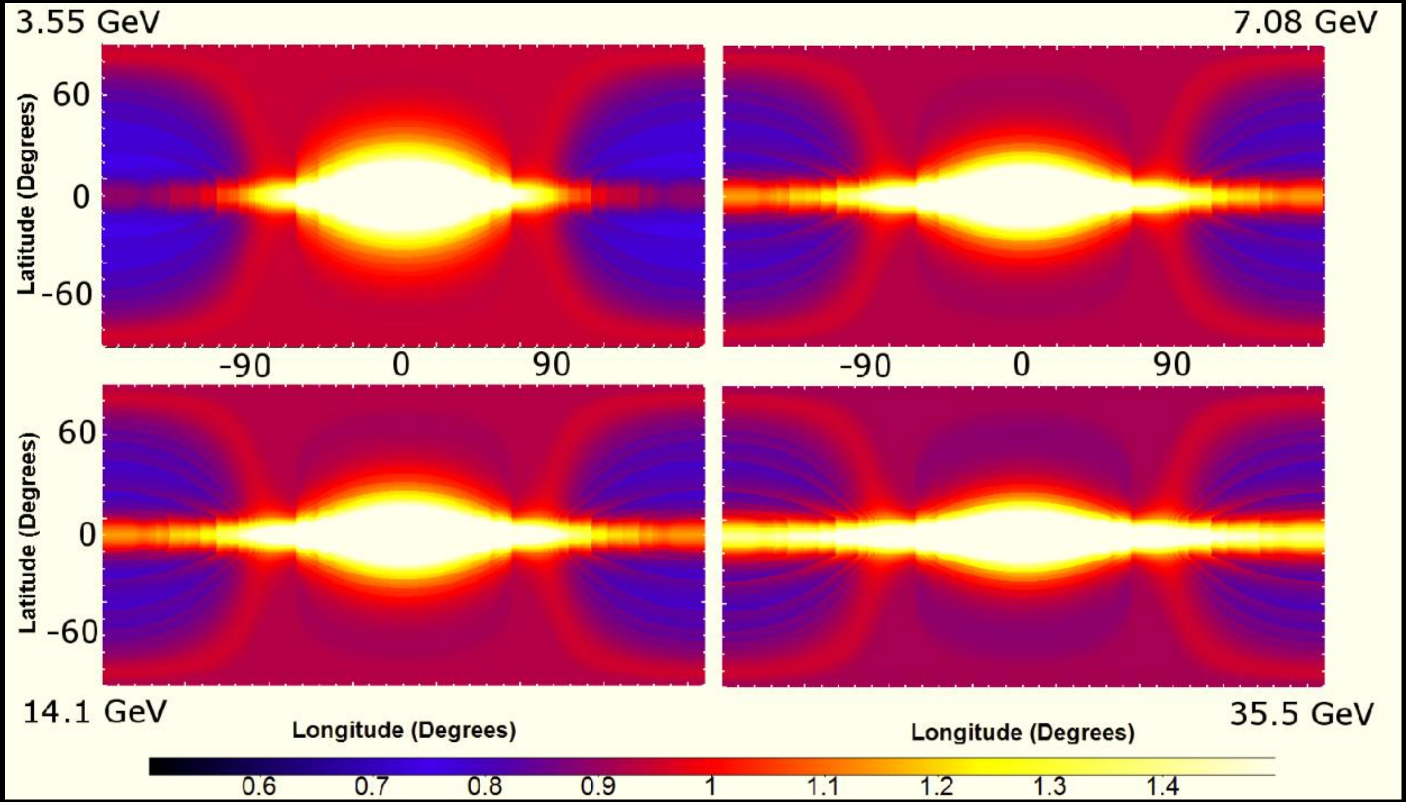
$$B = 11.6\ \mu G\ e^{-r/20\ kpc\ -z/2kpc}$$

ICS / Sync is very uncertain

- By slightly altering the magnetic field morphology, we can create larger deviations

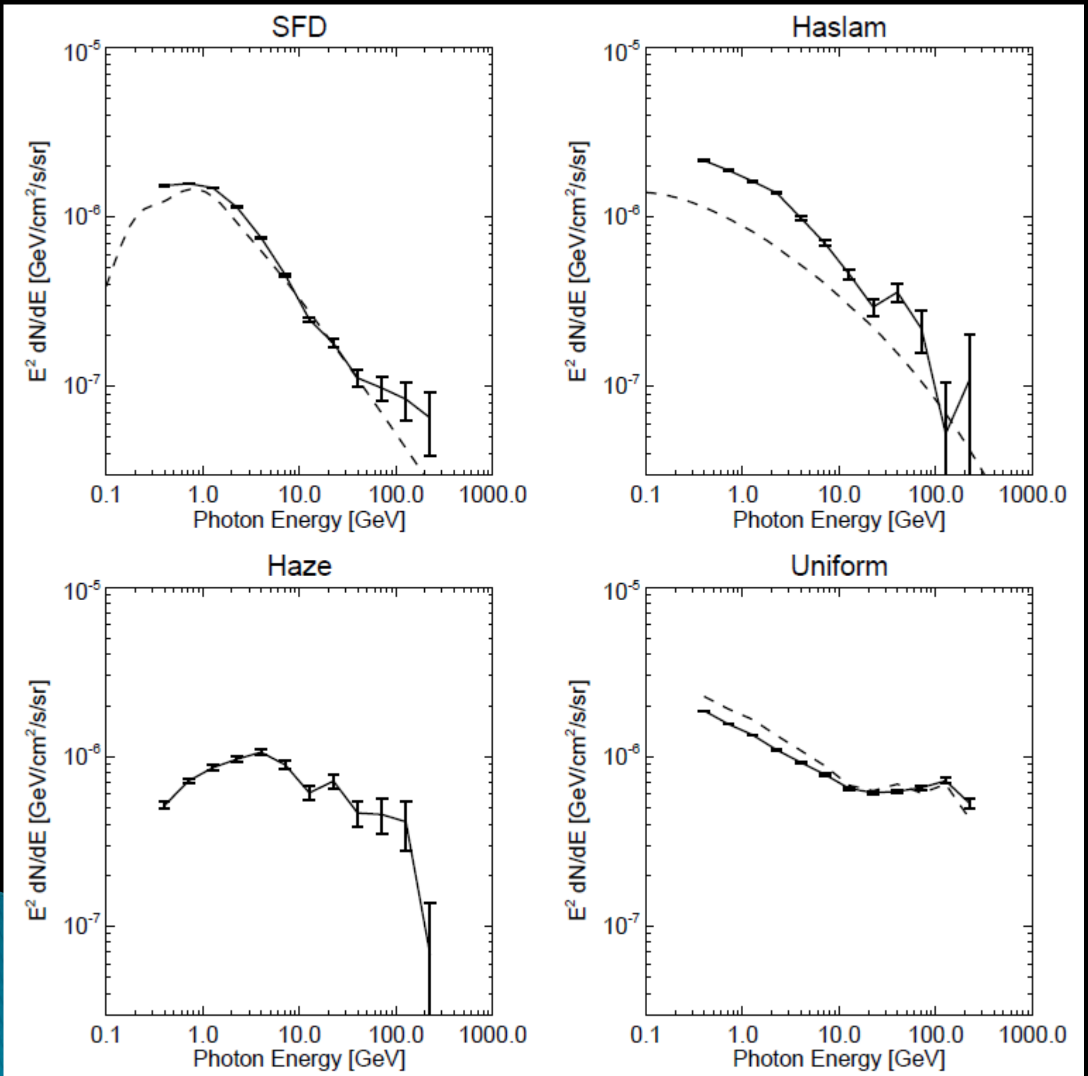
Flat magnetic field model

This model was used to generate the WMAP haze morphology



$$B = 10.0\ \mu G\ e^{-r/99.9\ kpc\ -z/99.9kpc}$$

Also Important at low energies



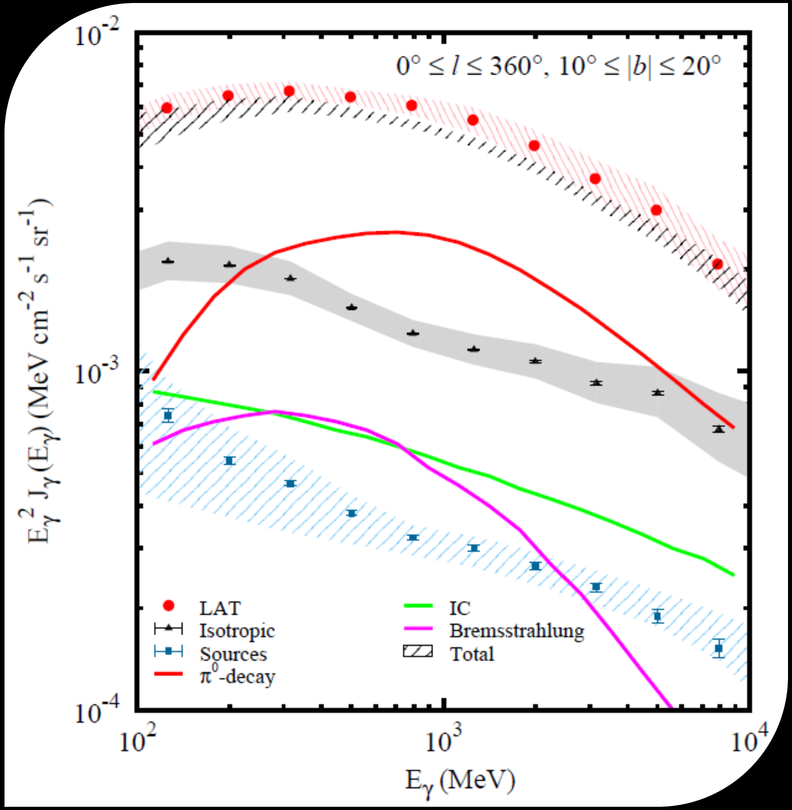
- Expected ICS signal is a significant fraction of the haze residual below 10 GeV
- This appears to leave a discrepancy at high energies, but eliminates it below ~10 GeV

First Conclusions

- The current analysis of the Fermi-Haze is insufficient to determine either the intensity or the spectrum of any Fermi residual

- Early measurements suggest that the Fermi haze at low energies (<10 GeV) could be entirely explained with theoretically correct templates for pi0 and astrophysical ICS emission.

A More Direct Analysis

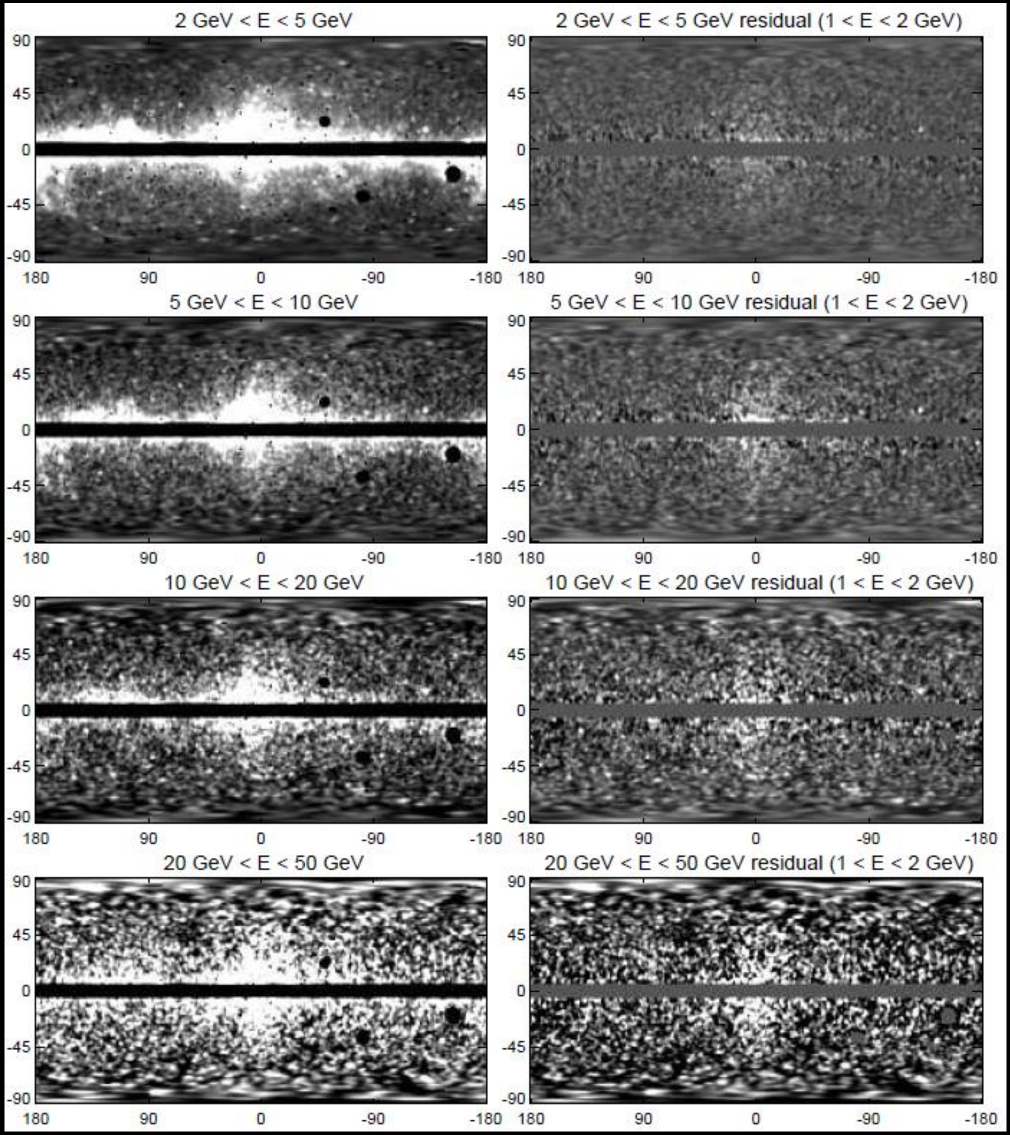


T. Porter, 2009 (0907.0294)

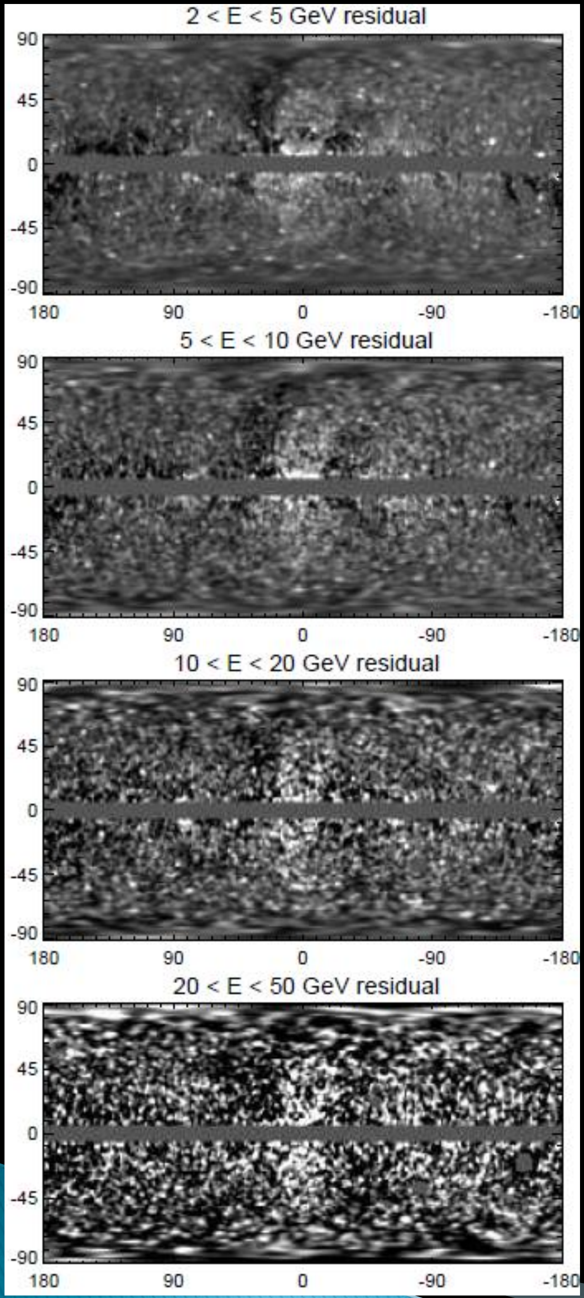
- At 1-2 GeV, emission from π^0 decay should be highly dominant
- Note that the π^0 decay morphology should be constant as a function of energy

Residuals!

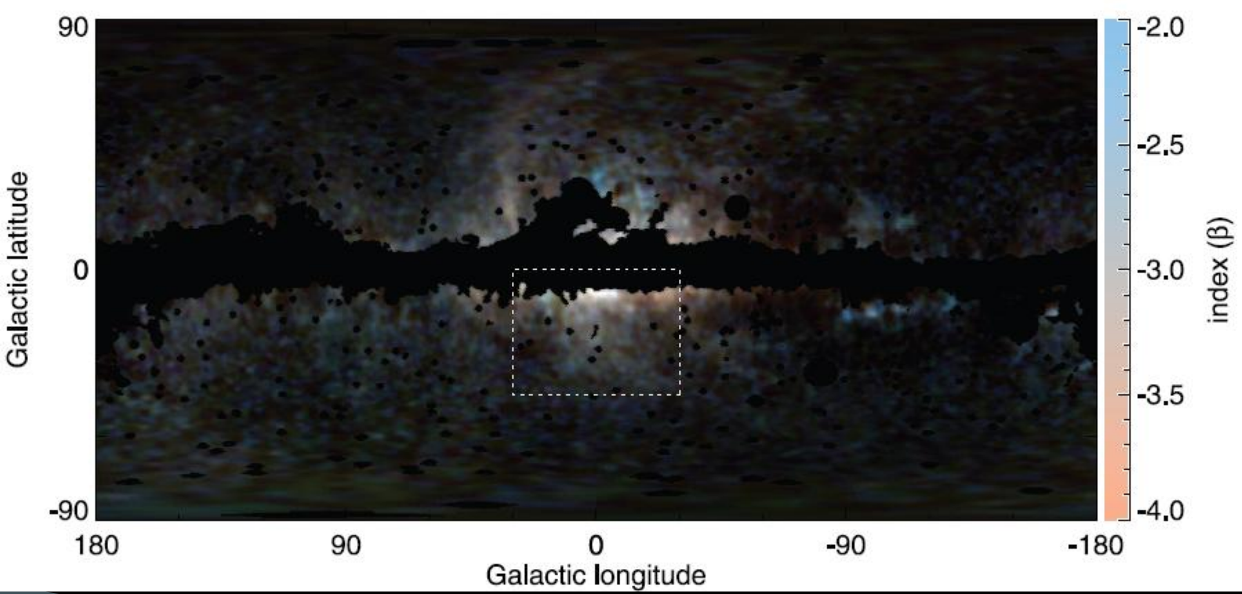
- Process:
  - 1.) Subtract out the morphology of the 1-2 GeV map
  - 2.) Find the morphology of the residual
- Dobler et al. find there is still a visible haze
- Some/Most of this haze is likely astrophysical ICS
- Can't determine an intensity/spectrum



Understanding Residuals

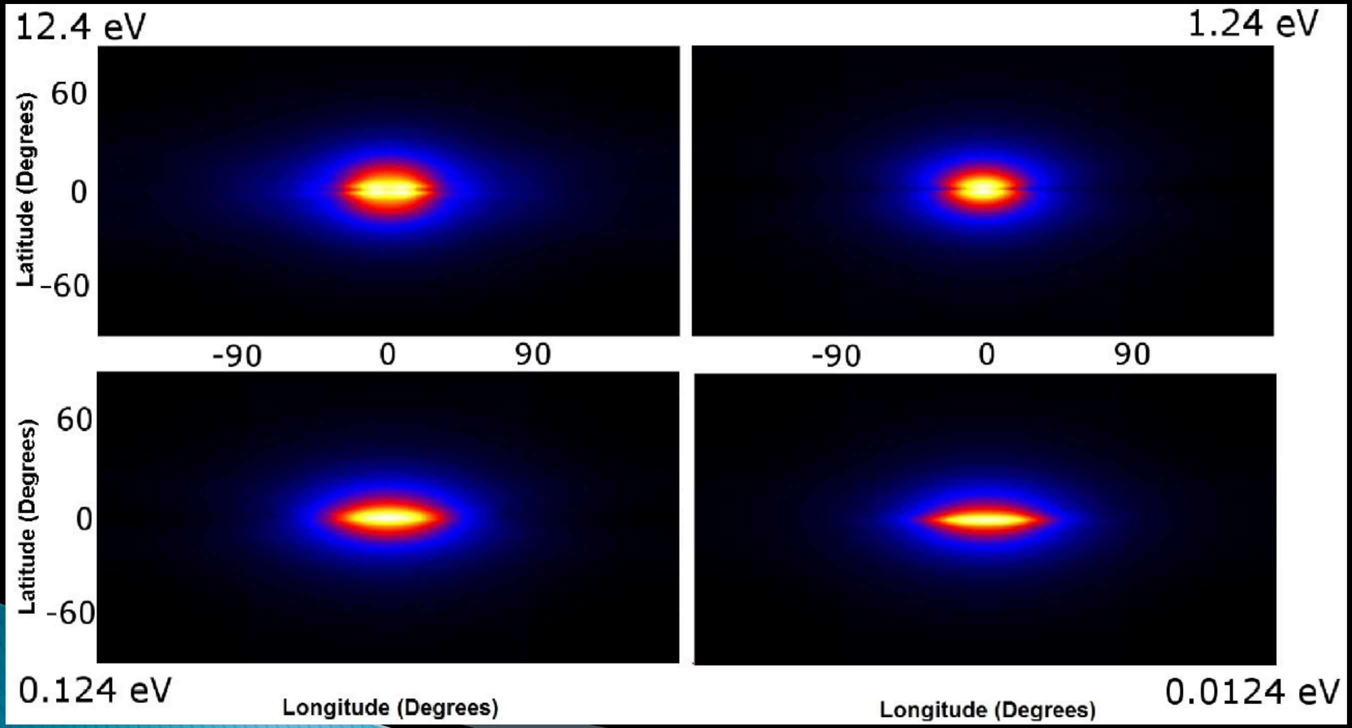


- Dobler et al note a correlation between the Fermi haze and the WMAP haze
- Find that this suggests a new primary electron source near the galactic center



Understanding Residuals

But it is difficult to model the Fermi haze with only a new lepton input class, as the interstellar radiation function falls off too quickly.

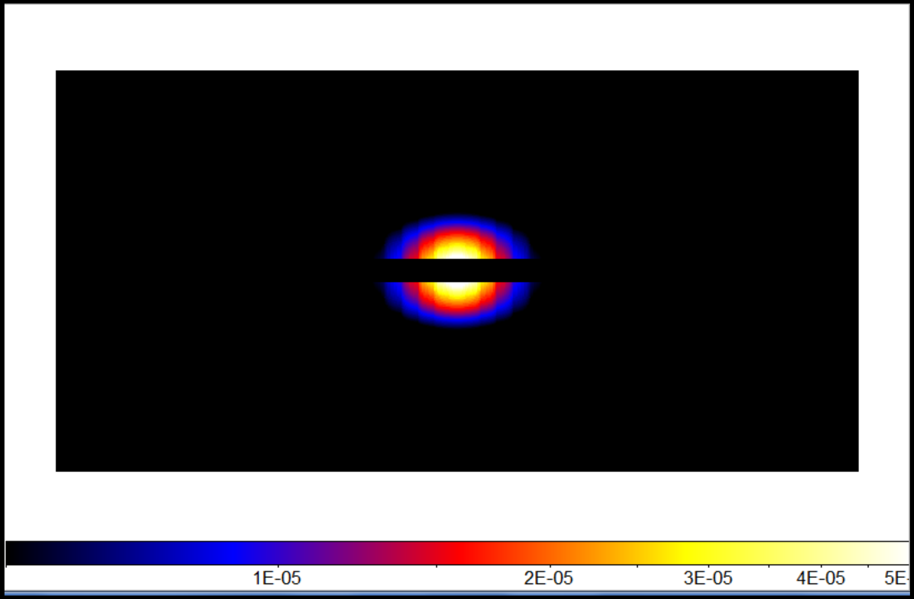


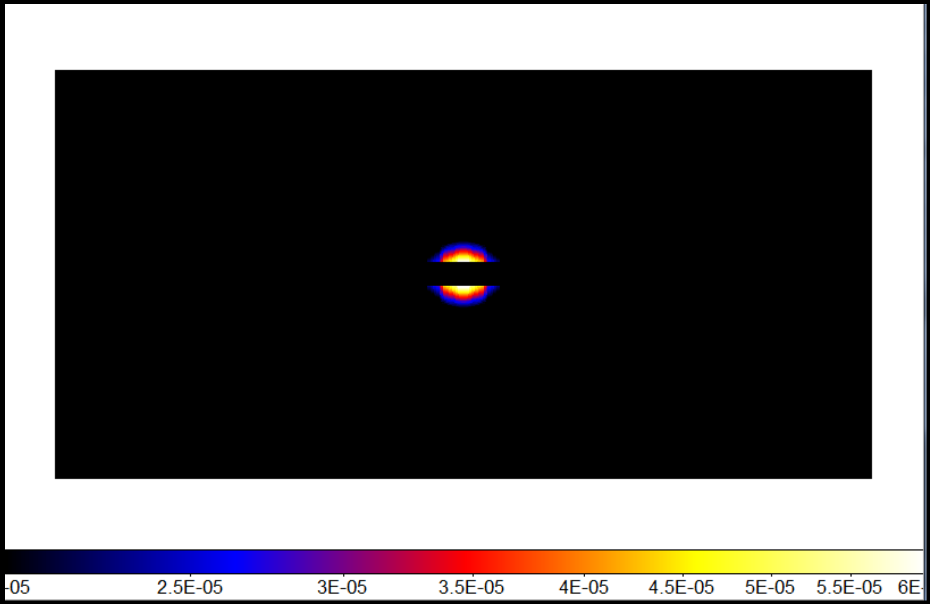
Between 10º to 30º latitude, the ISRF dims by between 63–72%

The longitudinal to latitudinal extent moves from 5–4 to 9–1 at low energies

DM Interpretation?

Simulated Dark matter models produce a haze that decays much too quickly at high latitudes to match the observed haze.





1500 GeV -> $\mu^+\mu^-$
Snapshot at 8 GeV

Possible Sources

- There are quite a few possible sources for this residual:
  - Nearby sources
  - Jets from galactic center
  - Magnetic anomalies (e.g. Loop 1 – Casandjian et al. 2009, 0912.3478)
  - Changes in the Interstellar radiation field
  - Energy dependence changes in diffusion parameters
- But it is very difficult to match emission using purely diffuse sources or spherical distributions, as they will always have more longitudinal extent.

How do we distinguish?

- New methods are necessary for distinguishing between various emission mechanisms
  - Multi-wavelength studies
  - Anisotropic studies

Multi-wavelength Studies

- Several Important cross-checks:
  - WMAP – Energetic leptons should also produce microwave radiation through synchrotron in the galactic B-field
  - ROSAT – SNR and galactic anomalies may produce X-ray signatures
  - PAMELA – New primary sources may match the observed positron/electron spectrum
  - HESS – Very high energy γ-ray's should match these observations

Multi-wavelength Studies

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  - ROSAT – SNR and galactic anomalies ma
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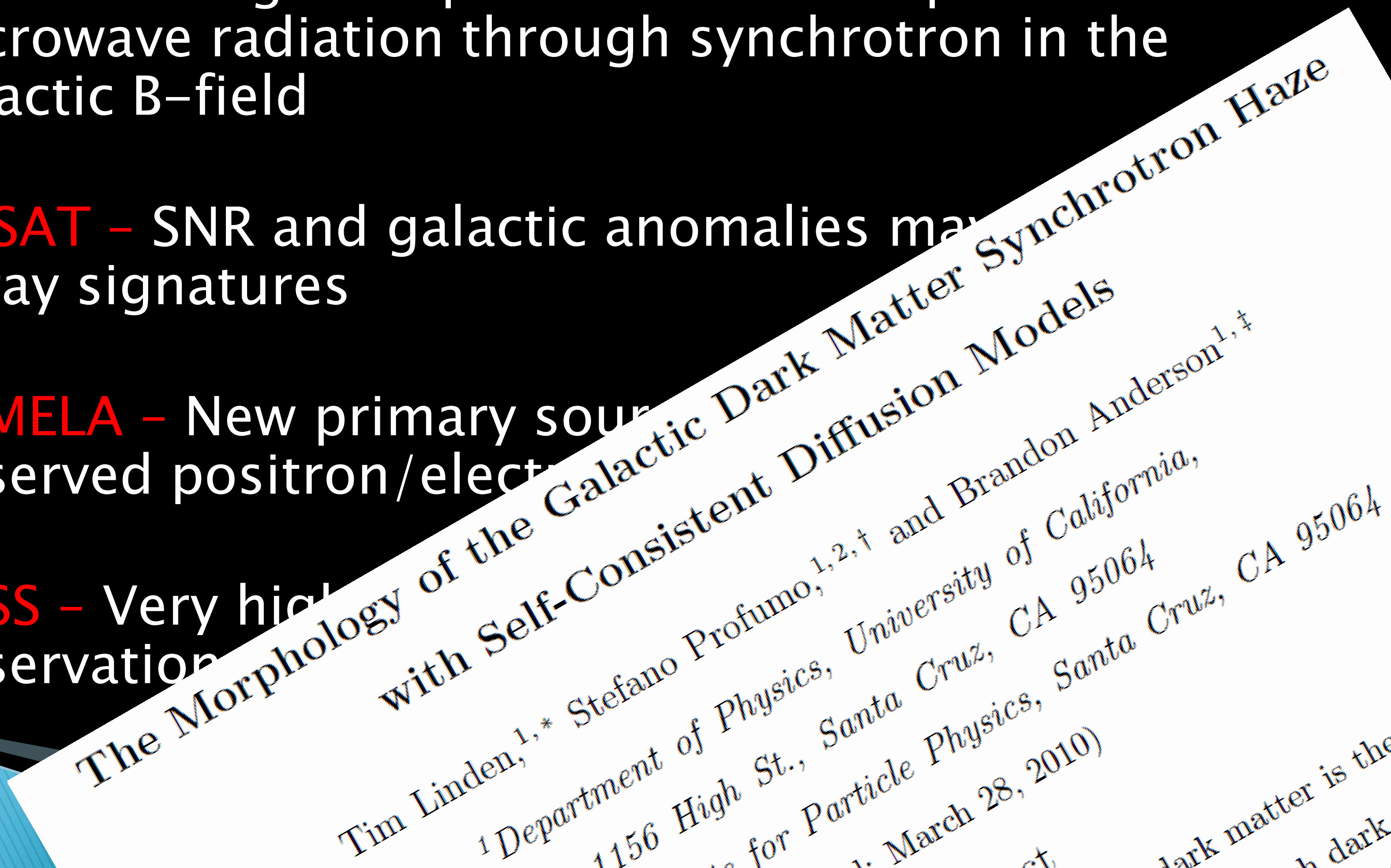
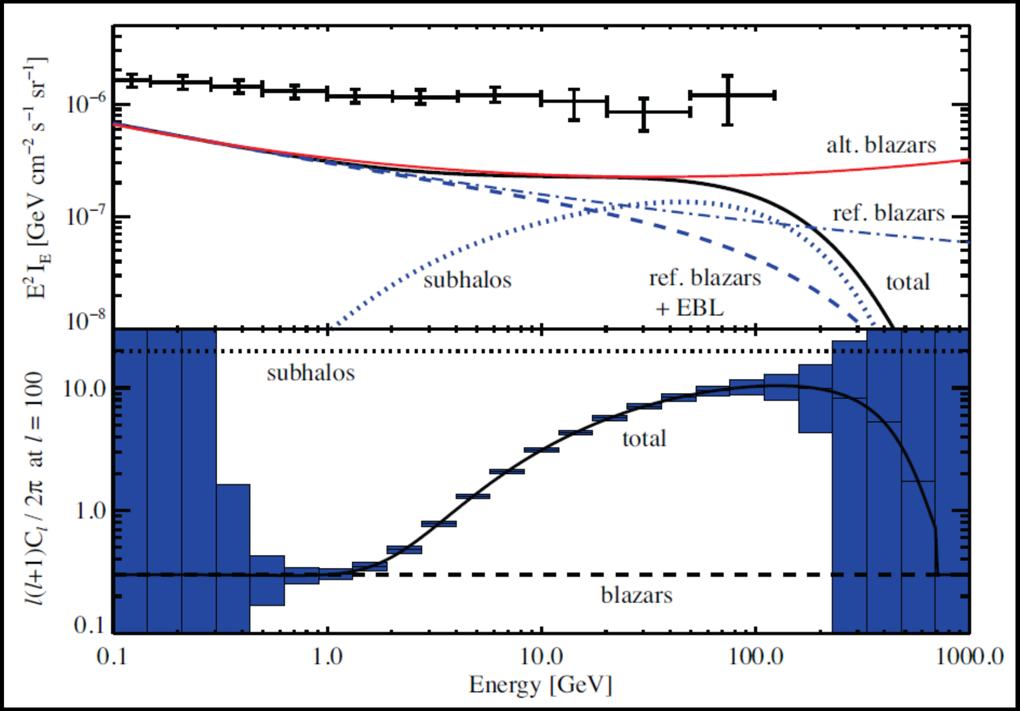

The Morphology of the Galactic Dark Matter Synchrotron Haze
with Self-Consistent Diffusion Models

Tim Linden,[1,*] Stefano Profumo,[1,2,†] and Brandon Anderson[1,‡]

[1] *Department of Physics, University of California,*
1156 High St., Santa Cruz, CA 95064
for Particle Physics, Santa Cruz, CA 95064
March 28, 2010)

Anisotropy Studies



Siegal-Gaskins and Pavlidou (2009)

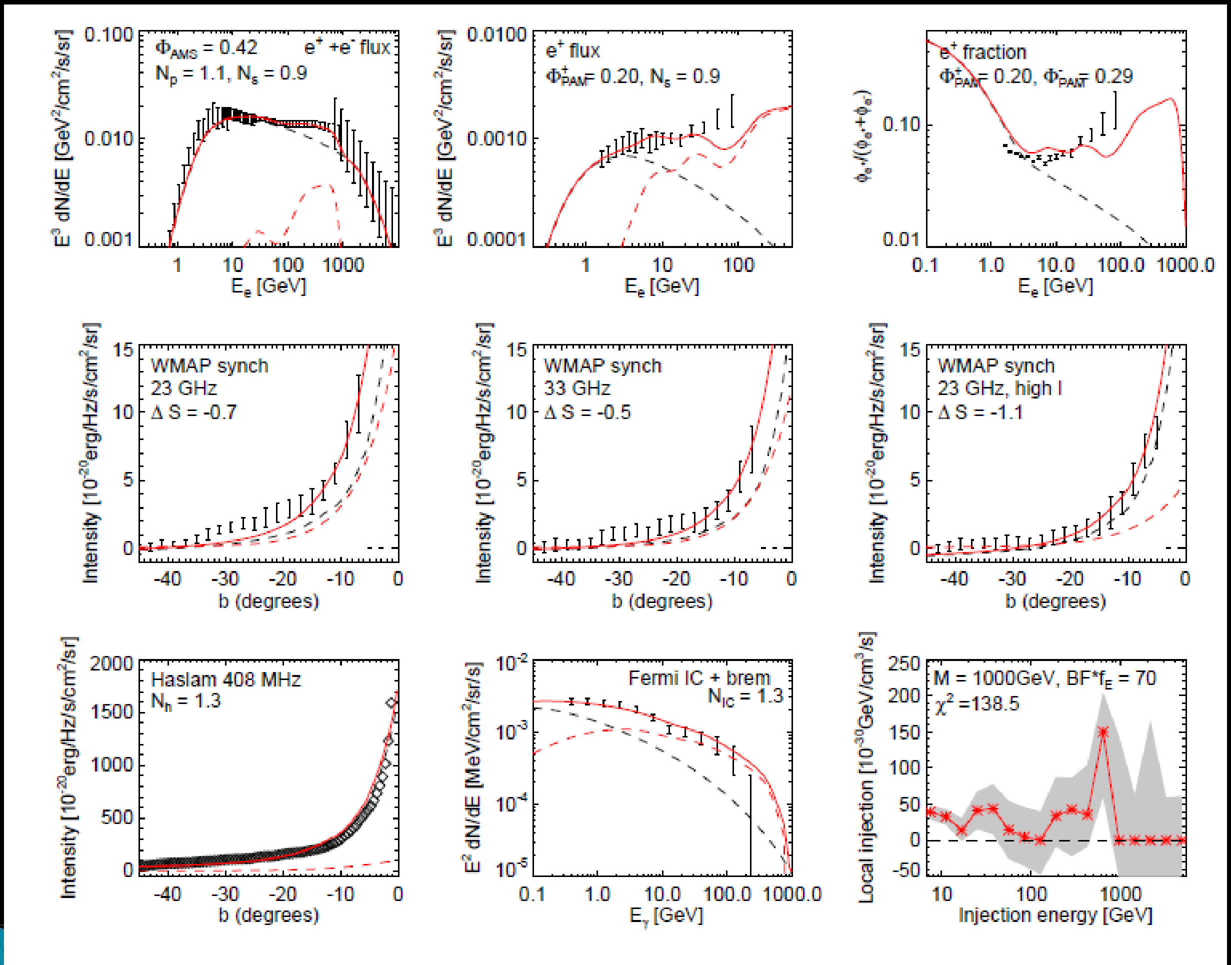
- Measurements of the anisotropy as a function of energy allow us to differentiate between different source classes

Conclusions

- 1.) There does appear to be a significant high energy emission in the Fermi sky which is not explained by current theoretical models
- 2.) However, this emission is not easily matched by models which only add a new source class
- 3.) More research is needed into the theoretical understanding of diffuse emission before we can untangle the principle cause of the Fermi haze

EXTRA SLIDES

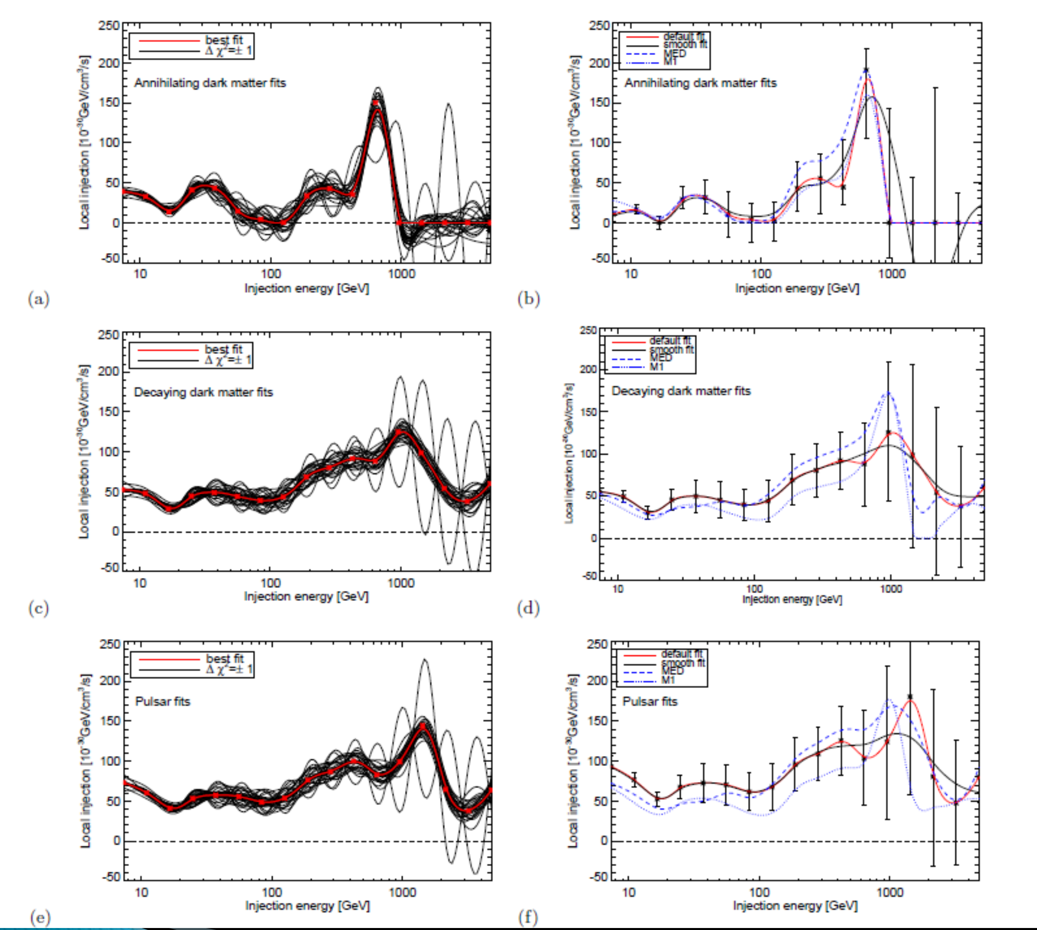
Matching the Fermi Haze



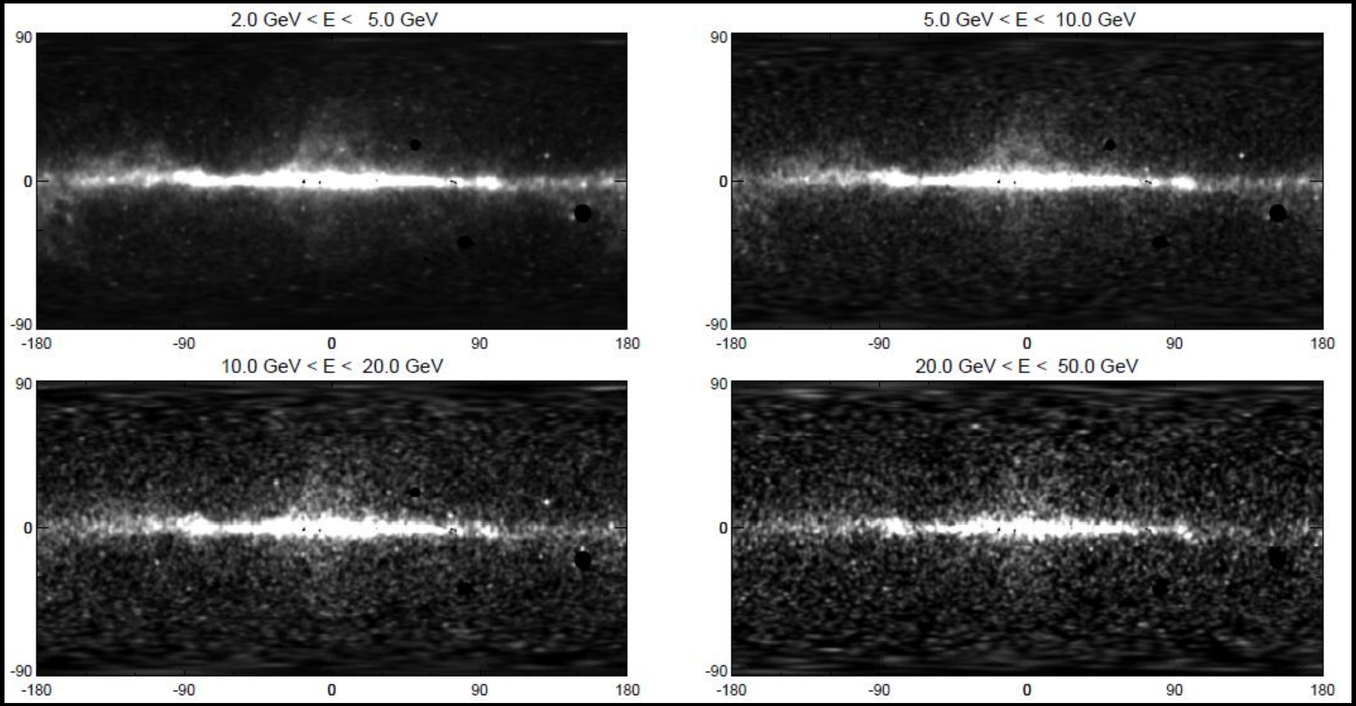
Liu et al. (2010)

Matching the Fermi Haze

Liu et al. (2010)



The Fermi Sky

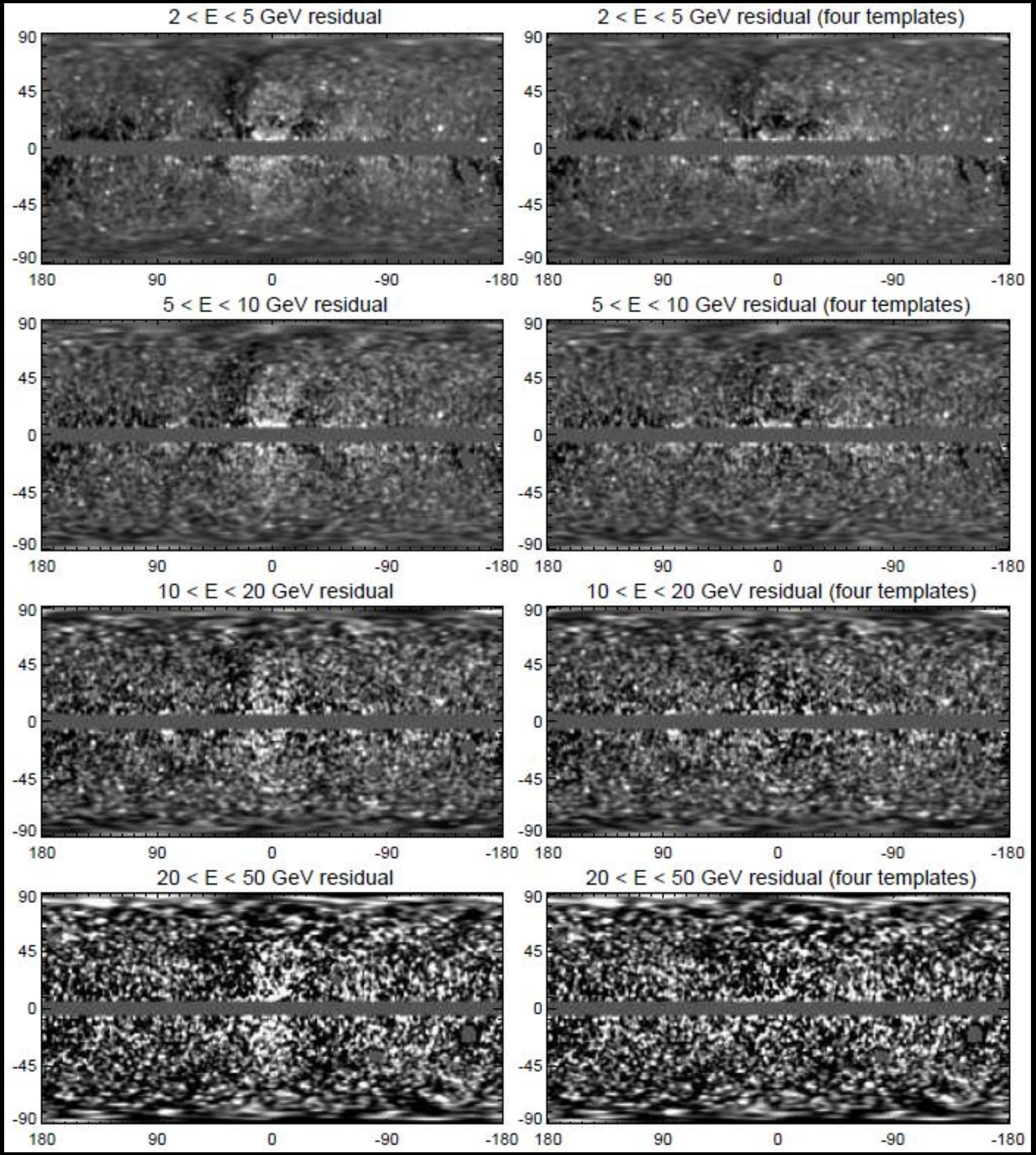


Dobler et al (2009) produced skymaps of the Fermi diffuse emission

- This skymaps come from many classes –

Results

- Haze template effectively eliminates the morphology of the residual
- Residual now appears to be random noise



WMAP Haze

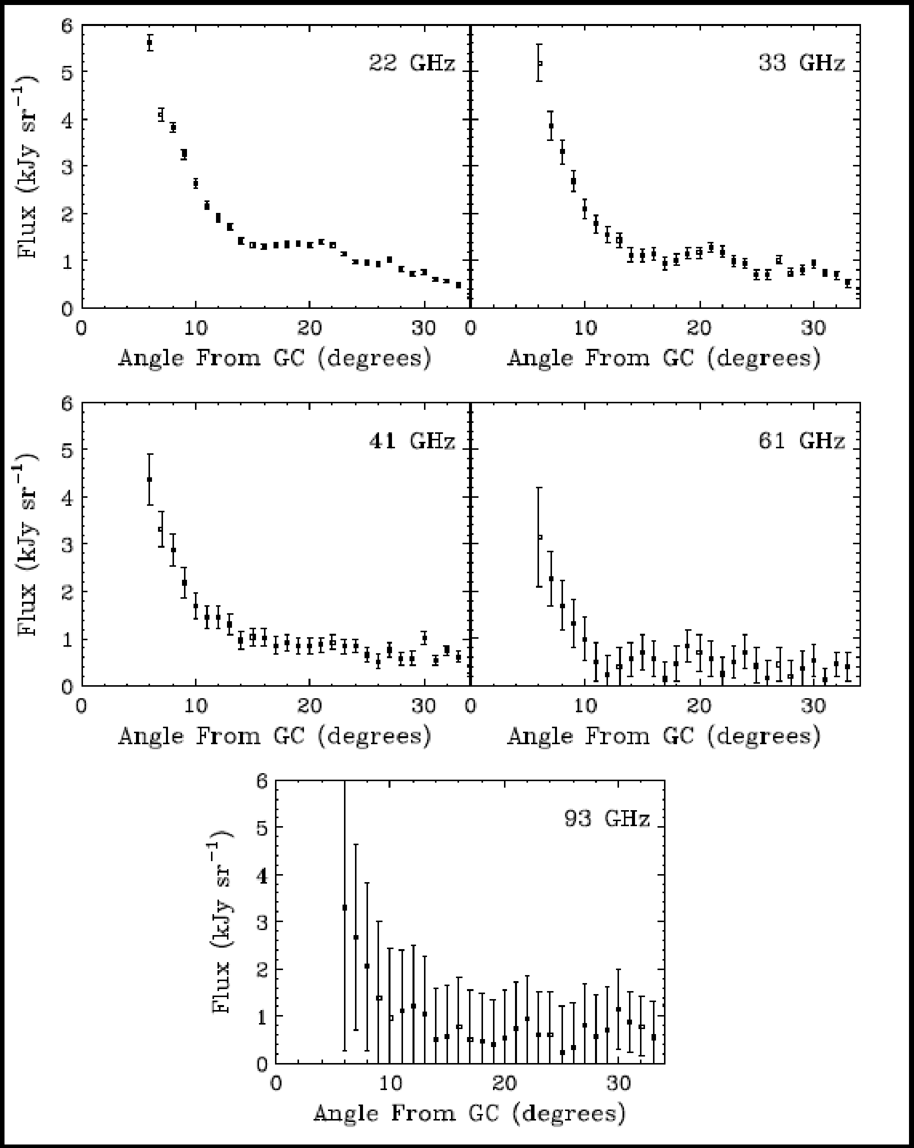
- Excess microwave found in the WMAP dataset by Finkbeiner (2004)
- Postulated as a signal of Dark Matter annihilation (Hooper et al. 2007, and many others), or pulsars (Kaplinghat et al. 2009)
- Also may not exist (Gold et al. 2010)

WMAP Haze

- We also find

The WMAP Haze

- Finkbeiner (2004) pointed out an unexplained residual in the WMAP dataset
- The existence of this residual is controversial, and is not detected by the WMAP team



Matching this spectrum

- Nevertheless, it is worth testing whether we can match this spectrum with new electron inputs (specifically dark matter)
- We employ Galprop models including a dark matter contribution, and determine the morphology of the output WMAP spectrum

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