Microwave (and gamm-ray!) constraints on dark matter annihilation

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Overview

WIMP annihilation to e^+e^- (directly or indirectly) could provide a synchrotron signal at radio / microwave frequencies. (Requires B-field model)

The same particles yield an inverse-Compton (IC) gamma-ray signal. (Requries ISRF model)

Both signals depend on WIMP density distribution (smooth? clumpy?) and propagation parameters (diffusion, energy loss, escape). Mass, annihilation channels also matter.

This is much harder than it looks.

There has been a lot of work the last few years:

Selected papers on radio/microwave constraints on WIMP annihilation in the inner Milky Way (apologies if I missed your favorite)

Hooper 2008	Constraining supersymmetric dark matter with synchrotron measurements
Caceres & Hooper 2008	Neutralino dark matter as the source of the WMAP haze
Borriello+ 2009	Radio constraints on dark matter annihilation in the galactic halo and its substructures
Ishiwata+ 2009	Synchrotron radiation from the Galactic center in the decaying dark matter scenario
Cholis+ 2009	High energy positrons and the WMAP haze from exciting dark matter
Barger+ 2009	Dark matter and pulsar signals for Fermi LAT, PAMELA, ATIC, HESS and WMAP data
Zhang+ 2009	Discriminating different scenarios to account for the cosmic e± excess by synchrotron and inverse Compton radiation
Regis & Ullio 2009	Testing the dark matter interpretation of the PAMELA excess through measurements of the galactic diffuse emission
Cuoco 2009	Dark Matter Multi-wavelength constraints from Synchrotron and Inverse Compton radiation
Bergstrom+ 2009	Gamma-ray and radio constraints of high positron rate dark matter models annihilating into new light particles
Cholis & Weiner 2009	MiXDM: Cosmic Ray Signals from Multiple States of Dark Matter
Kaplinghat+ 2009	Pulsars as a source of the WMAP haze
Cholis+ 2009	Case for a 700+GeV WIMP: Cosmic ray spectra from PAMELA, Fermi, and ATIC
Harding & Abazajian	Morphological tests of the pulsar and dark matter interpretations of the WMAP haze
LeZhang+ 2009	Galactic signatures of decaying dark matter
Lin+ 2010	The Electron Injection Spectrum Determined by Anomalous Cosmic Ray, Gamma Ray, and Microwave Signals
McQuinn+ 2010	Testing the Dark Matter Annihilation Model for the WMAP Haze
Pato+ 2010	Multi-messenger constraints on the annihilating dark matter interpretation of the positron excess
Borriello+ 2010	Radio Signal Constraints on Galactic Dark Matter Annihilation
Linden+ 2010	The Morphology of the Galactic Dark Matter Synchrotron Emission with Self-Consistent Cosmic Ray Diffusion Models
Crocker+ 2010	Radio and gamma-ray constraints on dark matter annihilation in the Galactic center

Additional papers focusing more on gamma-ray constraints

Hooper+ 2008	Prospects for detecting dark matter with GLAST in light of the WMAP haze
Mardon+ 2009	Dark matter signals from cascade annihilations
Borriello+ 2009	Secondary Radiation from the Pamela/ATIC Excess and Relevance for Fermi
Bringmann 2009	Antiproton and Radio Constraints on the Dark Matter Interpretation of the Fermi Gamma Ray Observations of the Galactic Center
Erkoca+ 2010	Muon fluxes and showers from dark matter annihilation in the Galactic center
Dobler+ 2010	The Fermi Haze: A Gamma-ray Counterpart to the Microwave Haze

And many others...

All Galactic center constraint papers assume a *steady state* solution.

Is this fair? Two views:

1. The Galaxy is in steady state unless proven otherwise.

2. Steady state assumption is never perfect -- how bad could it be?

We’ll see in a moment, but first...

Two targets for radio / microwave constraints:

1. The Galactic Center (inner few degrees)

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Two targets for radio / microwave constraints:

1. The Galactic Center (inner few degrees)

The New York Times

October 31, 2009

But Dr. Bloom said the authors were going too fast. "The galactic center is the Hells Kitchen of astrophysical forces," he said, borrowing a phrase from a recent talk by his French colleague Johann Coehn-Tanugi of Laboratoire de Physique Théorique et Astrophysique, and the University Montpellier 2.

We’ll see in a moment, but first...

Two targets for radio / microwave constraints:

1. The Galactic Center (inner few degrees)

2. The Inner Galaxy (inner tens of degrees): WMAP haze.

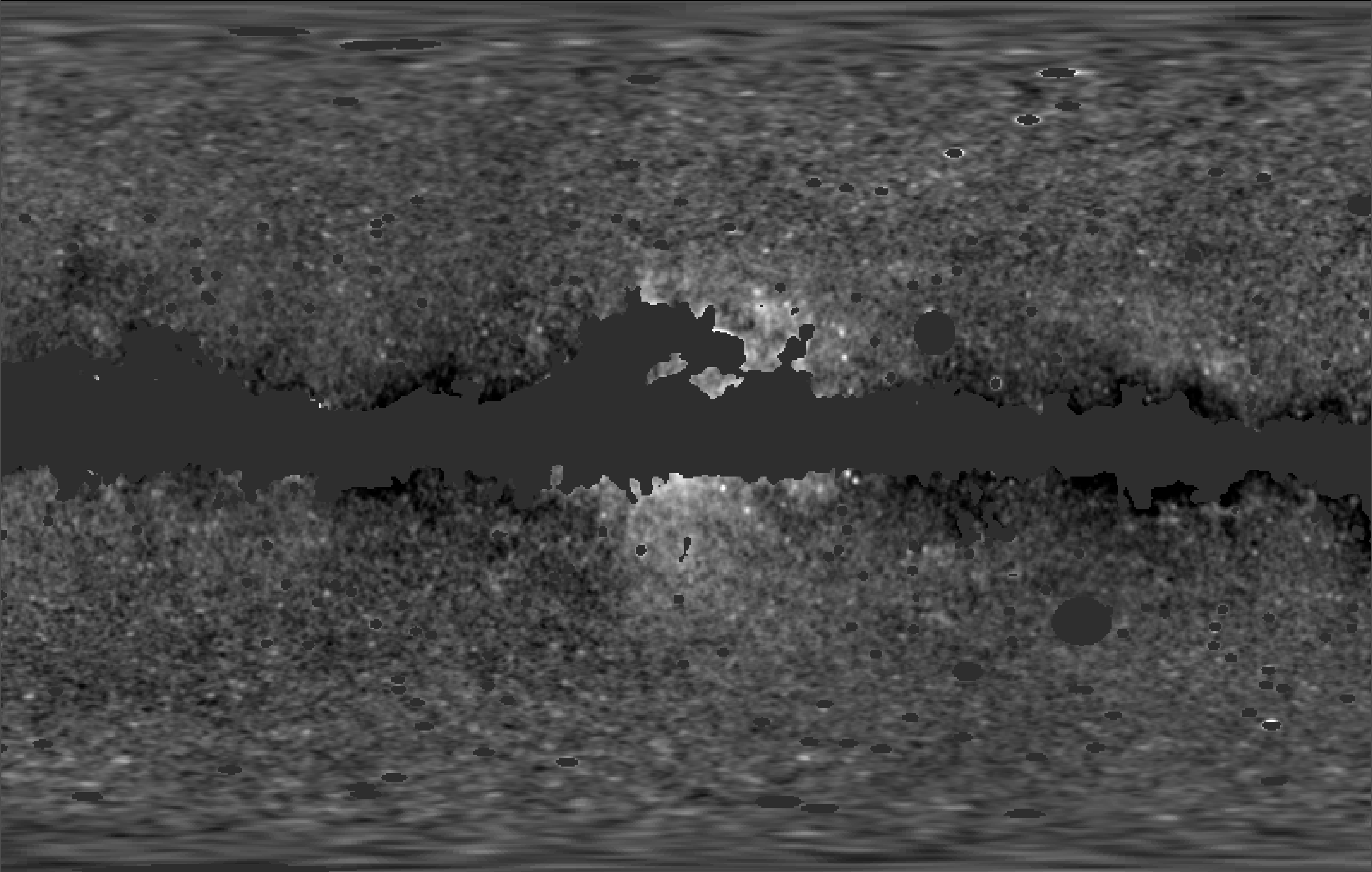
WMAP haze (Finkbeiner 2004)

Search for microwave emission from spinning dust in the WMAP data revealed an excess in the inner Galaxy.

Difficult to explain as free-free.

If synchrotron, must be unusually hard electron spectrum.

23 GHz residual: Spherical? Hourglass?



WMAP haze...

2004: excess microwave emission ("the haze")

3 views of the haze:
- Null 1: There is no excess synchrotron, merely free-free or spinning dust
- Null 2: The haze *is* synchrotron, but is normal spectral variation - nothing special.
- Haze hypothesis: Synchrotron from electrons produced by a distinct physical mechanism.

WMAP haze...

Actually - there is a fourth view:
Null 0: It is not even there -- it is all a template subtraction artifact.

Papers by Cumberbatch et al. (2009) and Mertsch et al. (2010)

These papers raise good points about the uncertainty near the Galactic plane (edge of the mask) but do not explain the emission far off the plane.

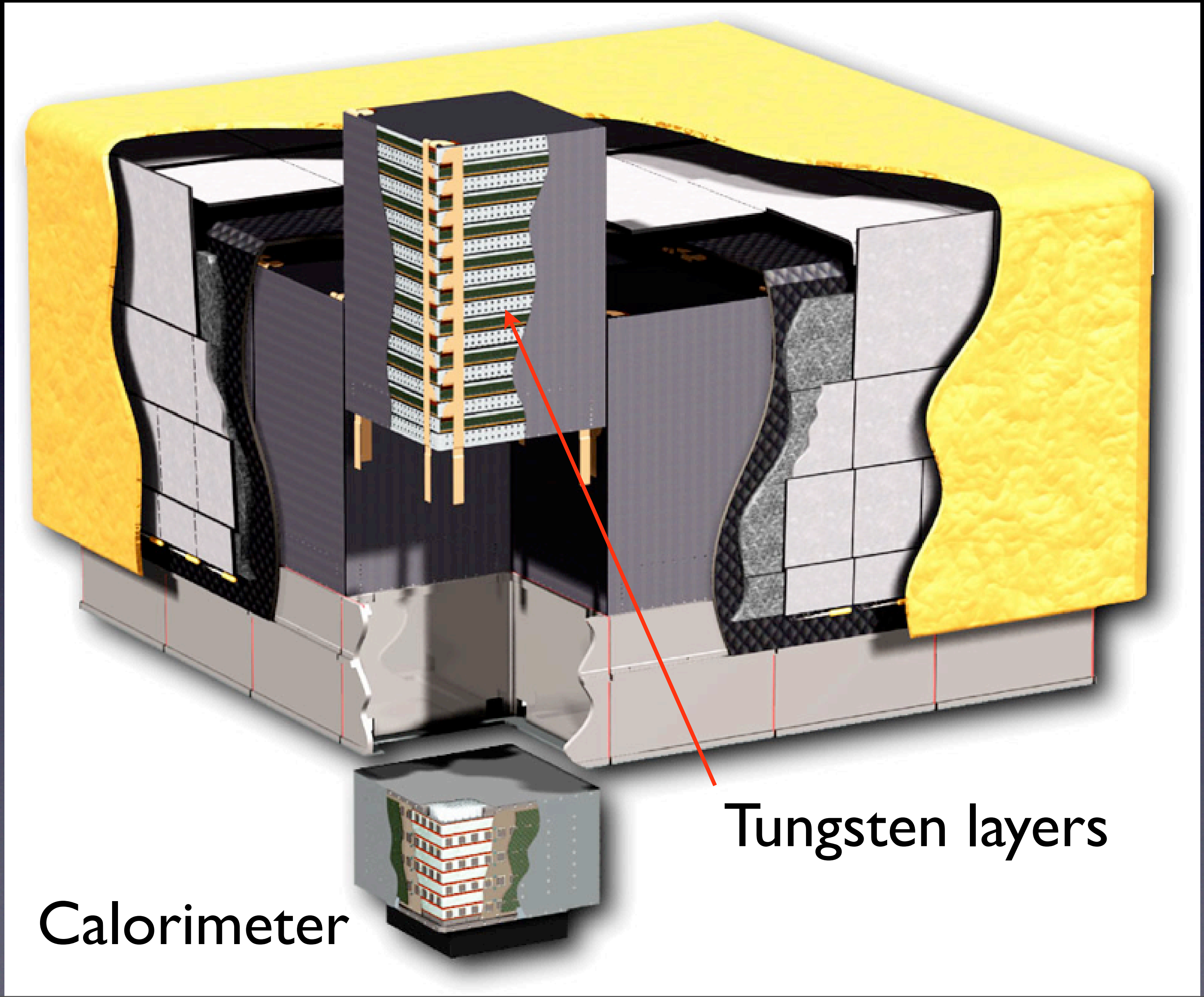
I.e., we trust some modes on the sky more than others.

How to test the WMAP haze idea?

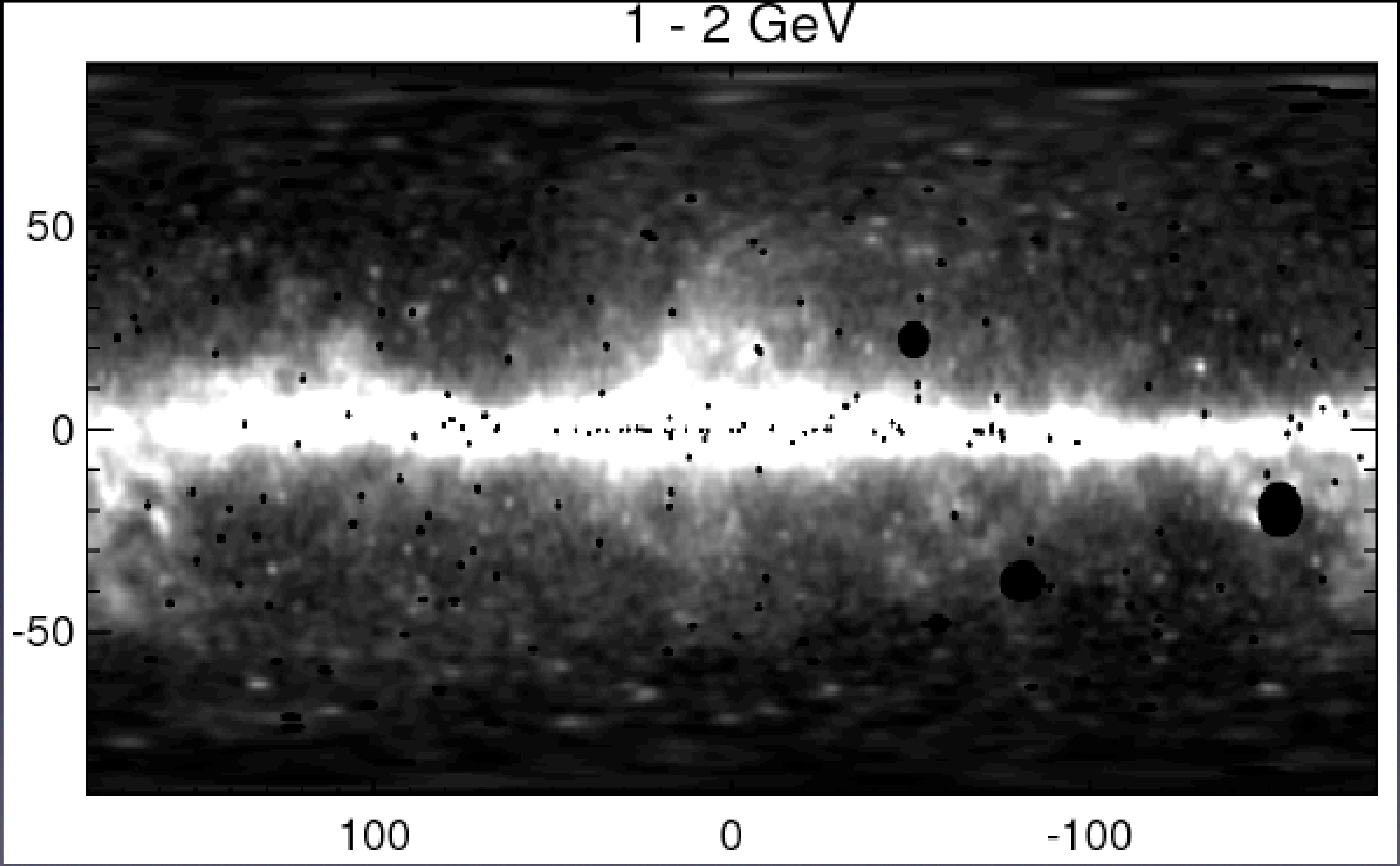
1) Can we see the IC gammas expected if the WMAP haze is synchrotron? (this would rule out null hypothesis 1)

2) Does the structure look like a transient, or steady state?

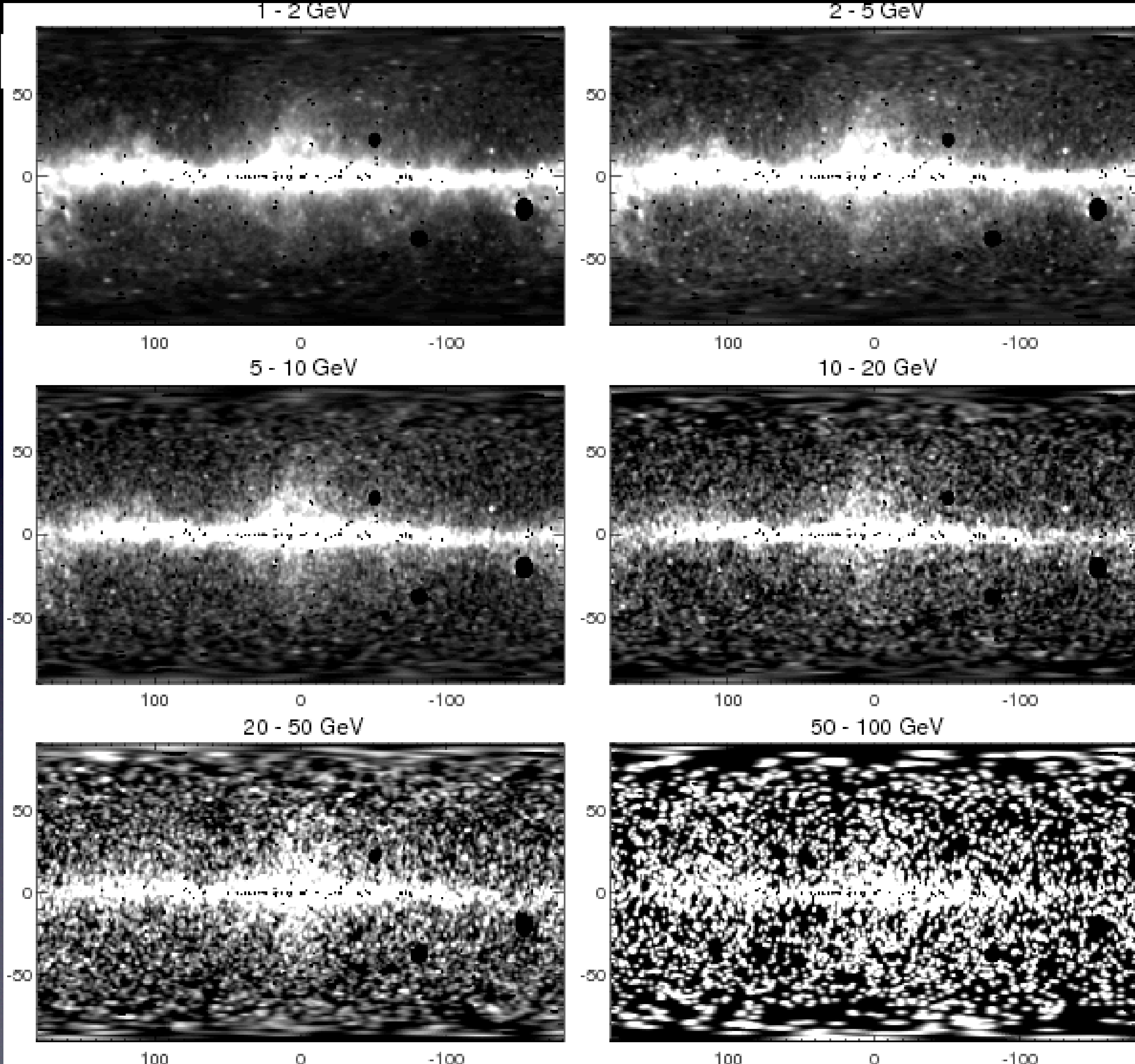
Fermi LAT (large area telescope)



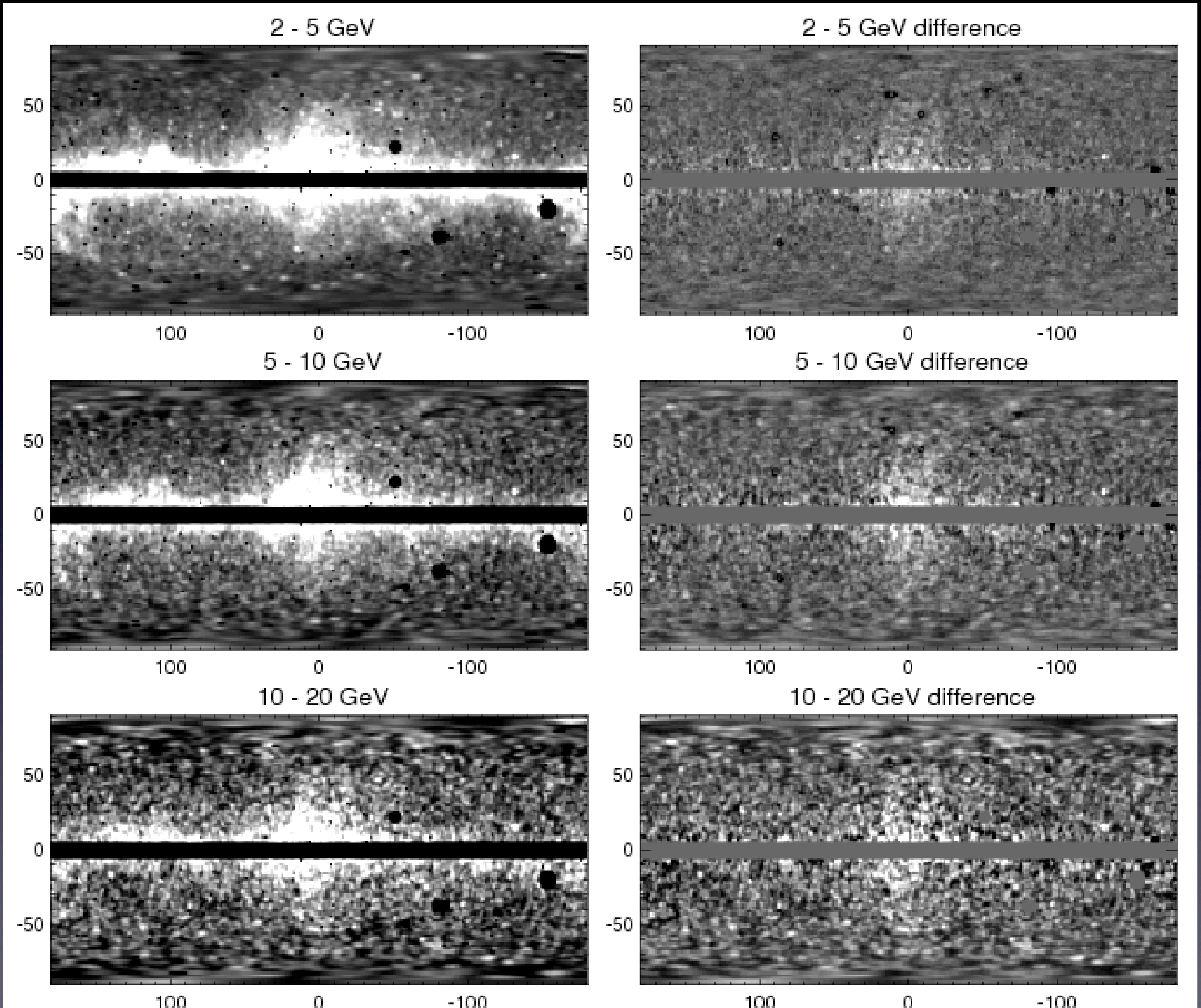
Paper I: *Fermi* first year sky map
(3 month point source cat. subtracted):



From Dobler et al. ApJ in press, and arXiv/0910.4583

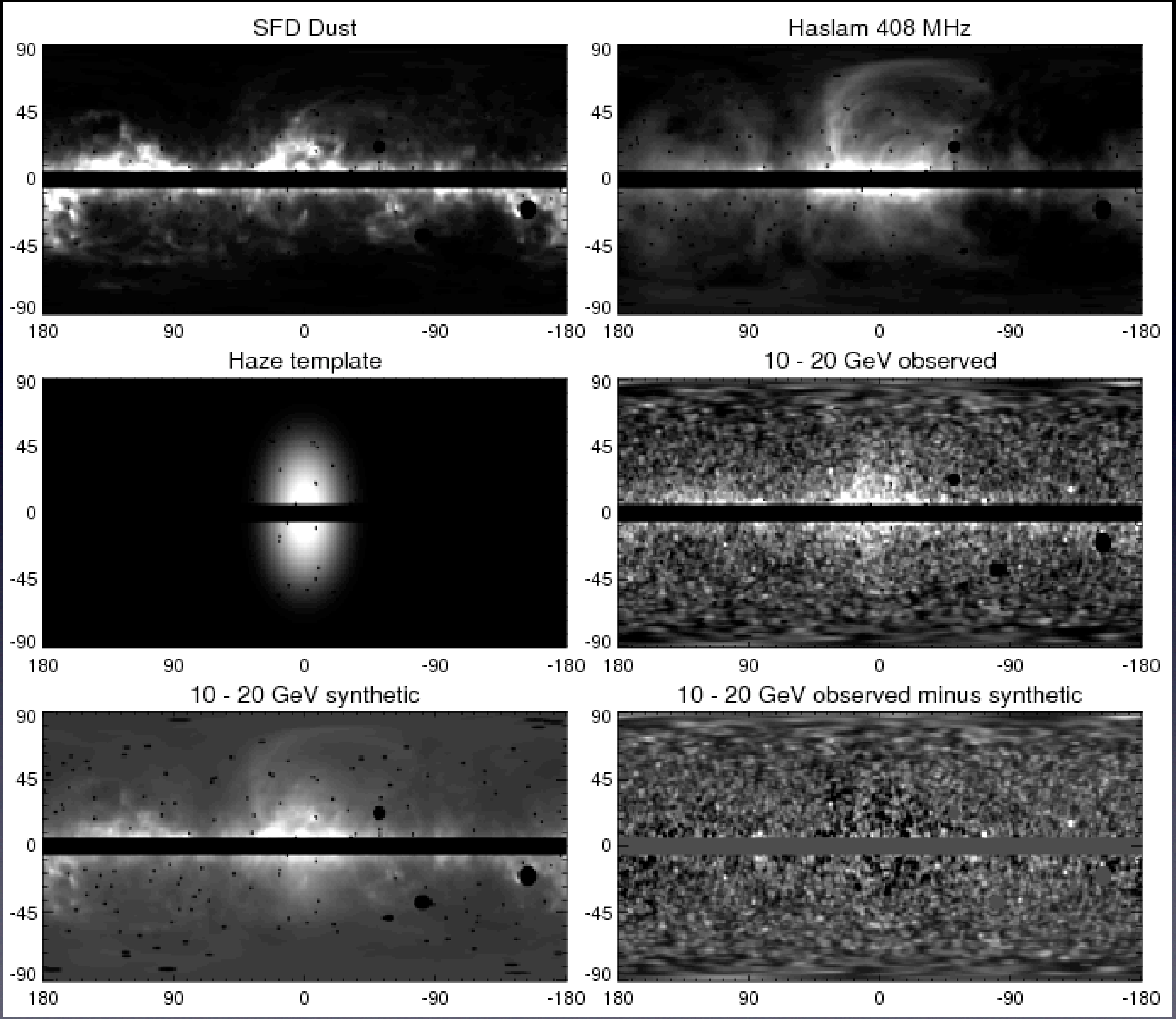


Dobler et al.
(0910.4583)



Dobler et al. (0910.4583)

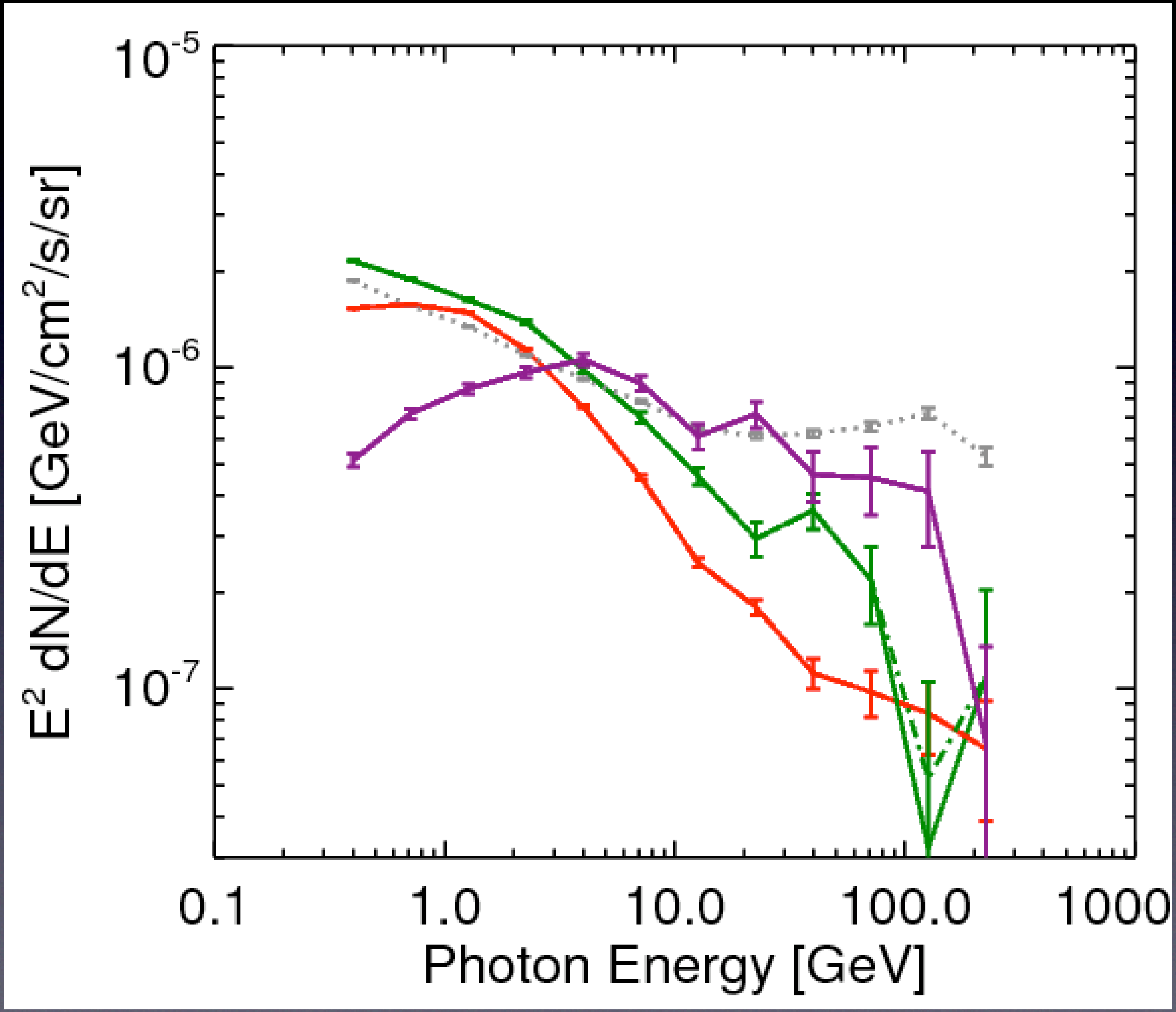
1 GeV Template



Dobler et al. (0910.4583)

Templates

Fermi spectrum in the “haze” region



Dobler et al. (0910.4583)

Paper I (Dobler et al.) conclusions:

- There is a signal in the "haze" region in excess of that expected. (we noticed some sharp edges, but did not think them significant)

- The spectrum is harder than the π^0 spectrum.

- It is difficult to explain both the morphology and spectrum unless the signal is IC from the same electrons that produce the WMAP haze.

Paper I conclusions:

So, this at least a robust upper bound on DM annihilation. However, electrons seem to be at 200-1000 GeV to make this ICS signal. They are 4-8 kpc off the plane. How?

Either (GALPROP-style diffusive) propagation is very wrong, or they are created *in situ*.

OR, there is a new source population much larger than the bulge. Either way, it is a good mystery.

There have been many recent papers on pulsars vs. DM to explain the haze.

Sommerfeld-enhanced dark matter appears to be able to explain the “hazes” ... but ...

Dark matter still doesn’t fit THAT well, and requires a rather far-fetched explanation.

(Sorry Neal!)

When presented with 2 options, choose the third...

Recent work by Su, Slatyer, and Finkbeiner
(arXiv:1005:5480)

Extend Dobler et al. analysis with
- 1.66 years of data
- better point source subtraction / masking
- better choices of energy bins
- more careful template construction

Fermi bubbles!

Disclaimer:

The purpose of the Su et al. paper is to study these sharp-edged "bubble" objects. This is not to say that these objects contain all of the "haze" emission; indeed there are interesting residuals in the data after subtracting a very simple model of the bubbles.

We should separate the question of whether there is any DM signal from the question of whether the gamma-ray bubbles are real.

DM pessimist:

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The existence of these structures, and the large episode of energy injection they imply, will make it nearly impossible to derive anything about dark matter in the inner Galaxy.

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DM agnostic:

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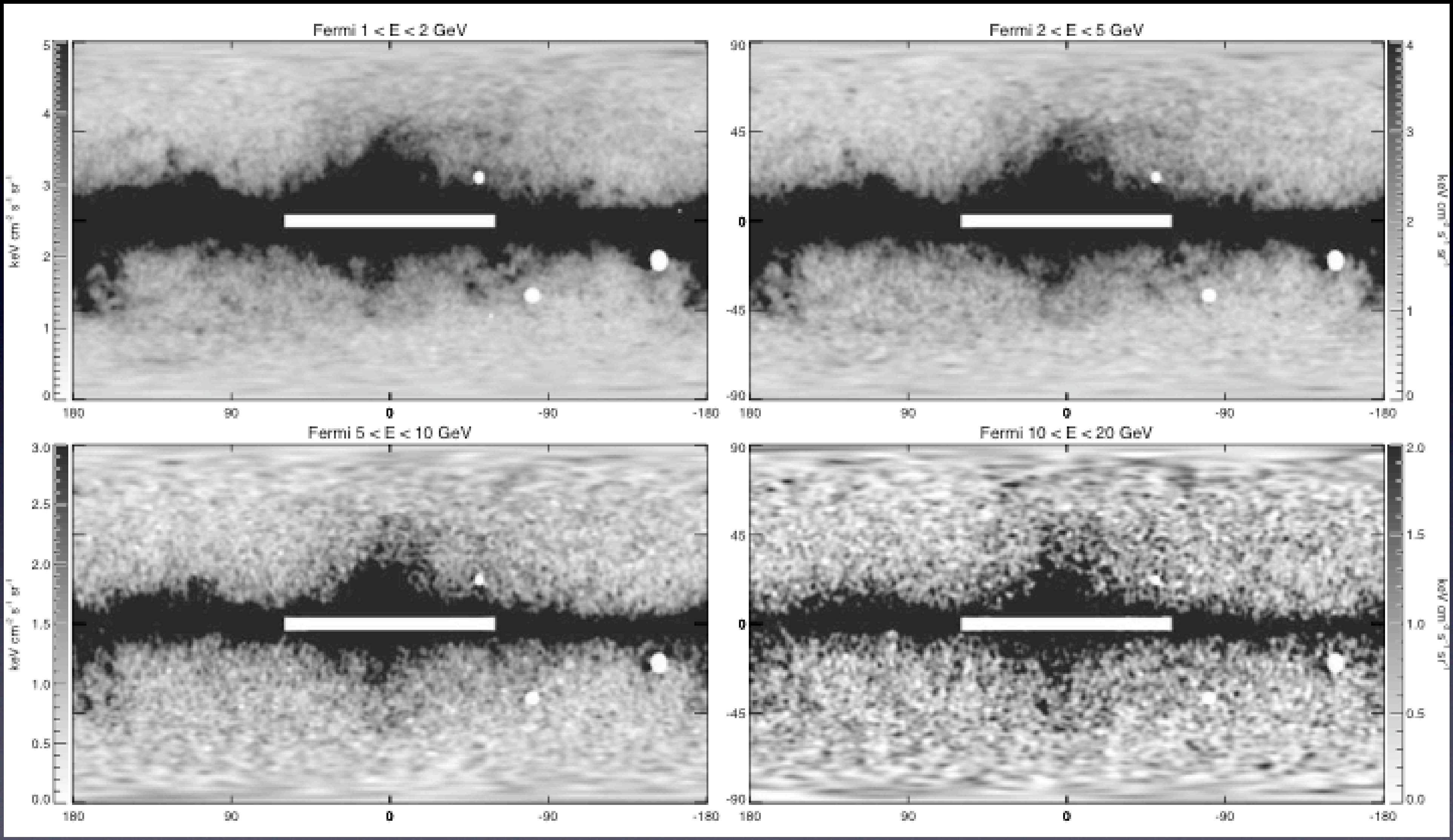
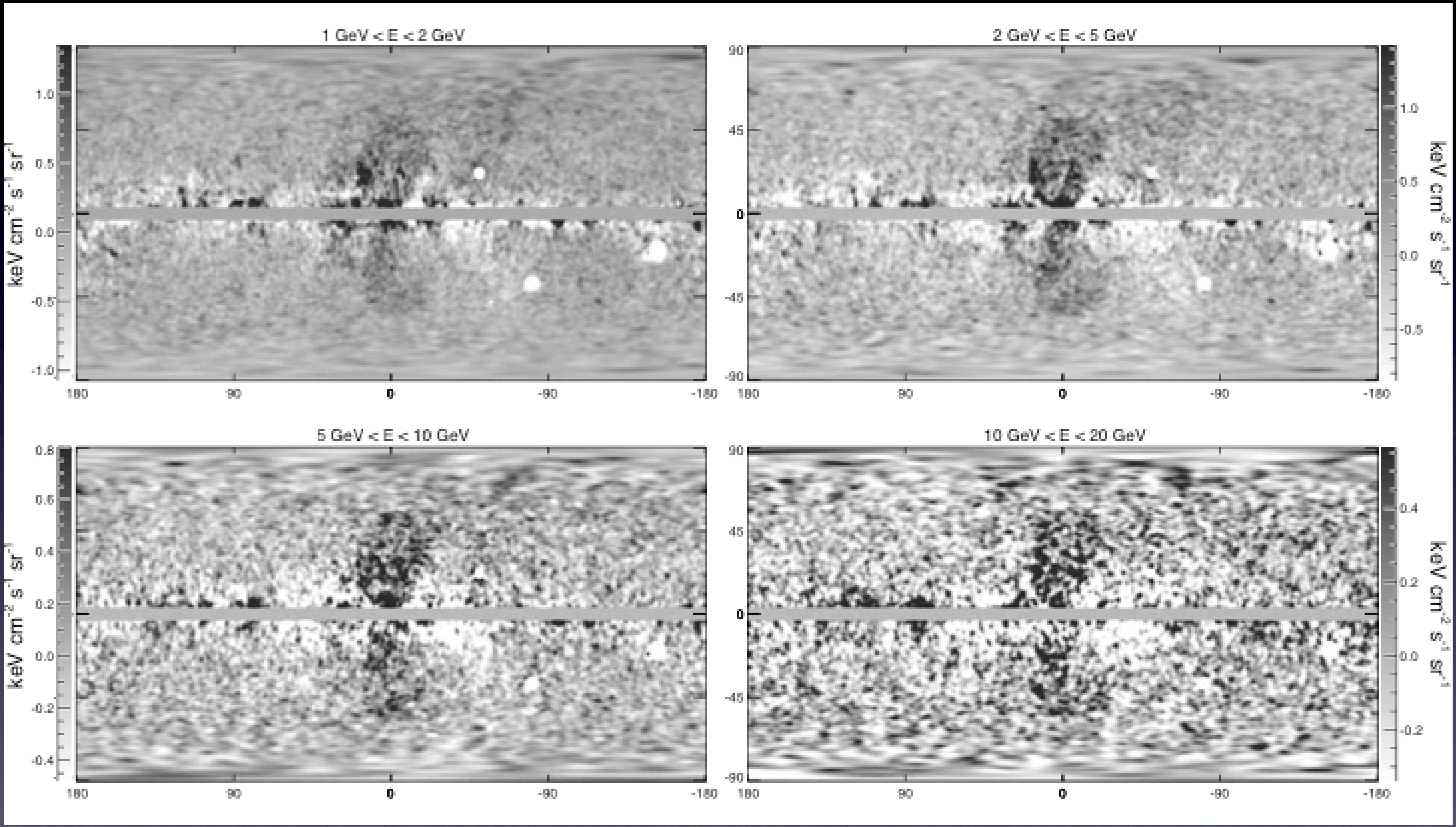
DM optimist:
There are some structures there we didn't expect, but we can model them and dig deeper to find the DM annihilation signal. No worries!

DM agnostic:
Astrophysics is complicated. *yawn*

Fermi 1.6 yr maps, point sources removed.



Data minus *Fermi* diffuse emission model:



Subtracting the *Fermi* diffuse emission model reveals a faint bilobular structure in the inner Galaxy.

This is a complicated model - could the residual structure be an artifact?

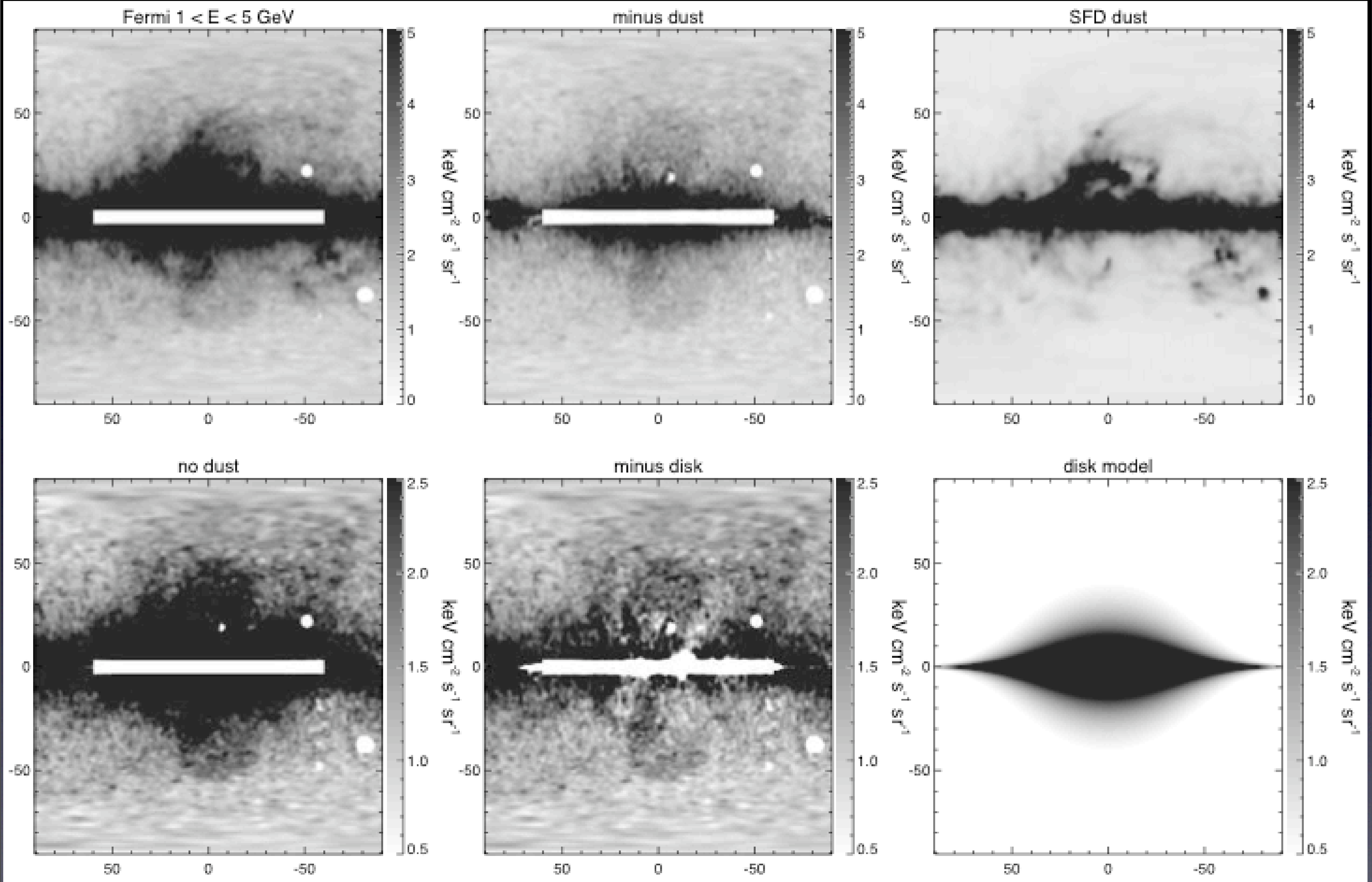
Model contains π^0 and bremsstrahlung from gas maps; IC from GALPROP; North Polar Spur feature from Haslam.

Let's try something *very* simple and see how robust this is.

Aside:

When you want to make plausible the existence of a new signal, a simple analysis is more persuasive.

A quantitative physical interpretation requires a sophisticated physical model.

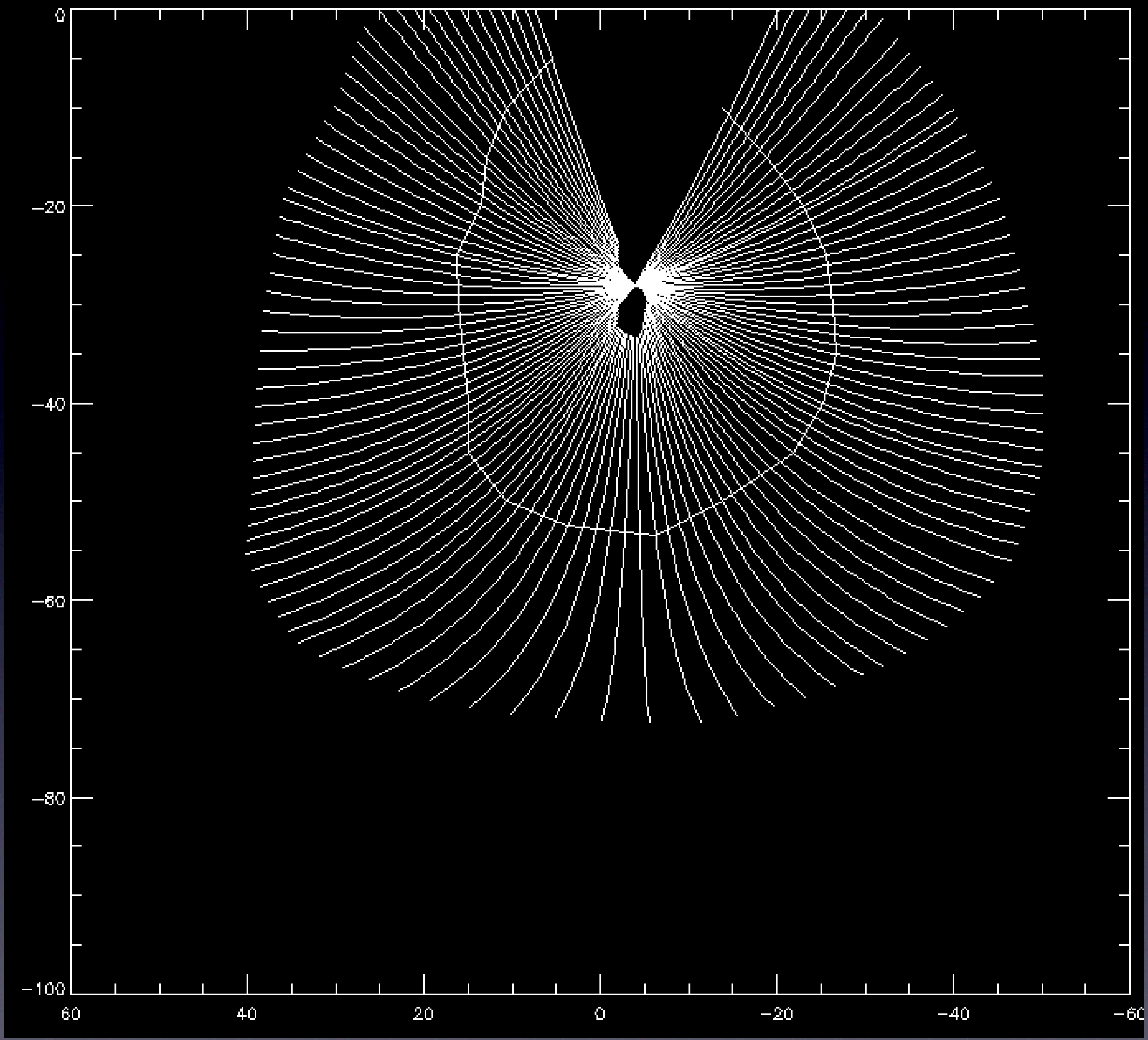

Fermi 1 < E < 5 GeV
minus dust
SFD dust
no dust
minus disk
disk model
keV cm^{-2} s^{-1} sr^{-1}

Su et al.
(2010)

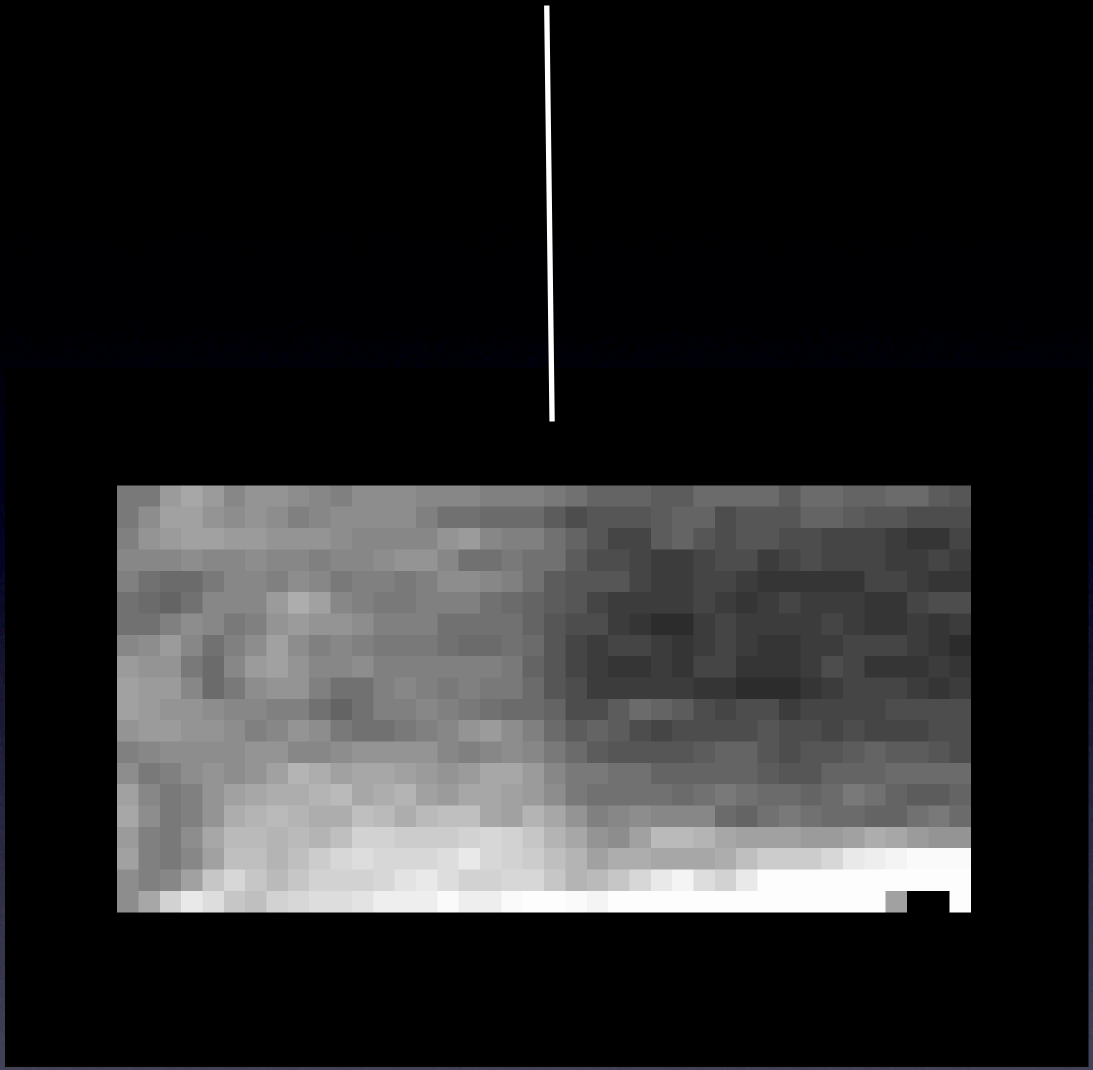
Even subtracting only two templates (dust and a “simple disk” model) we see the structure.

>> The edges did not arise from artifacts in the Fermi diffuse model, but are actually in the data.

How sharp are the edges?



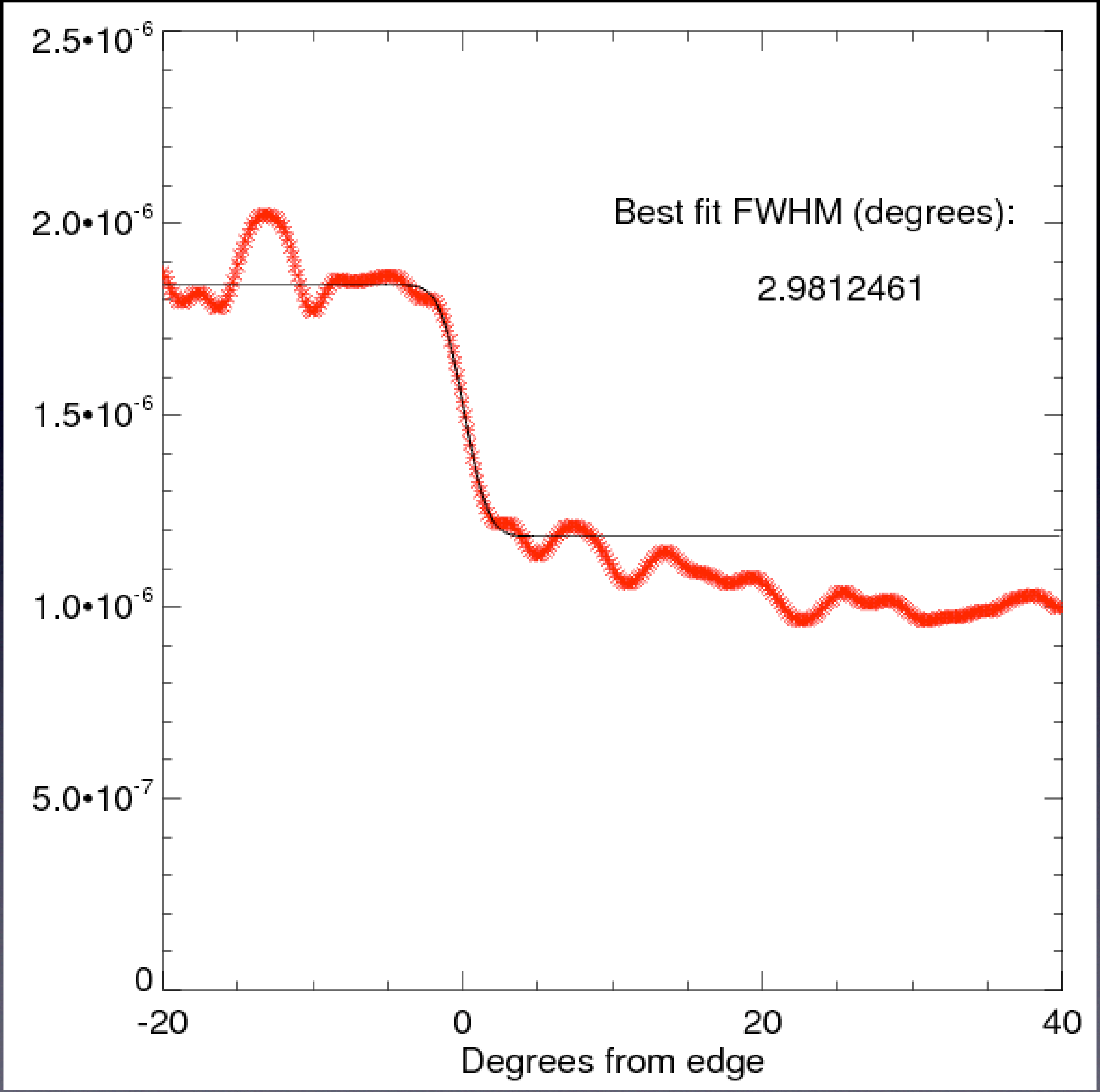
Sample map along great circles starting at bubble center



Grayscale image of intensity along several rays

2-5 GeV

|b|>30



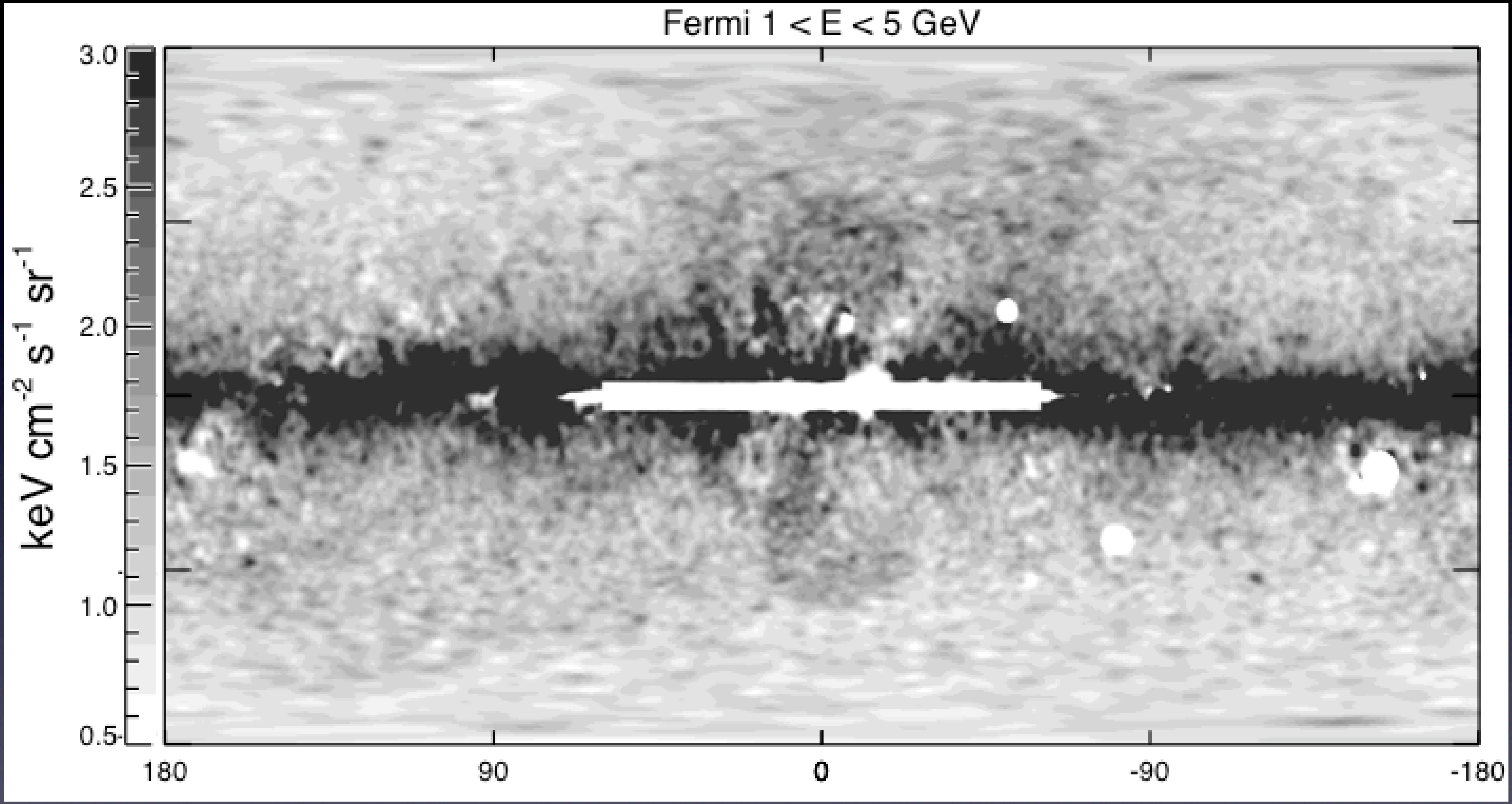
2.5•10^-6
2.0•10^-6
1.5•10^-6
1.0•10^-6
5.0•10^-7
0
-20
0
20
40
Degrees from edge
Best fit FWHM (degrees):
2.9812461

Even subtracting only two templates (dust and a “simple disk” model) we see the structure.

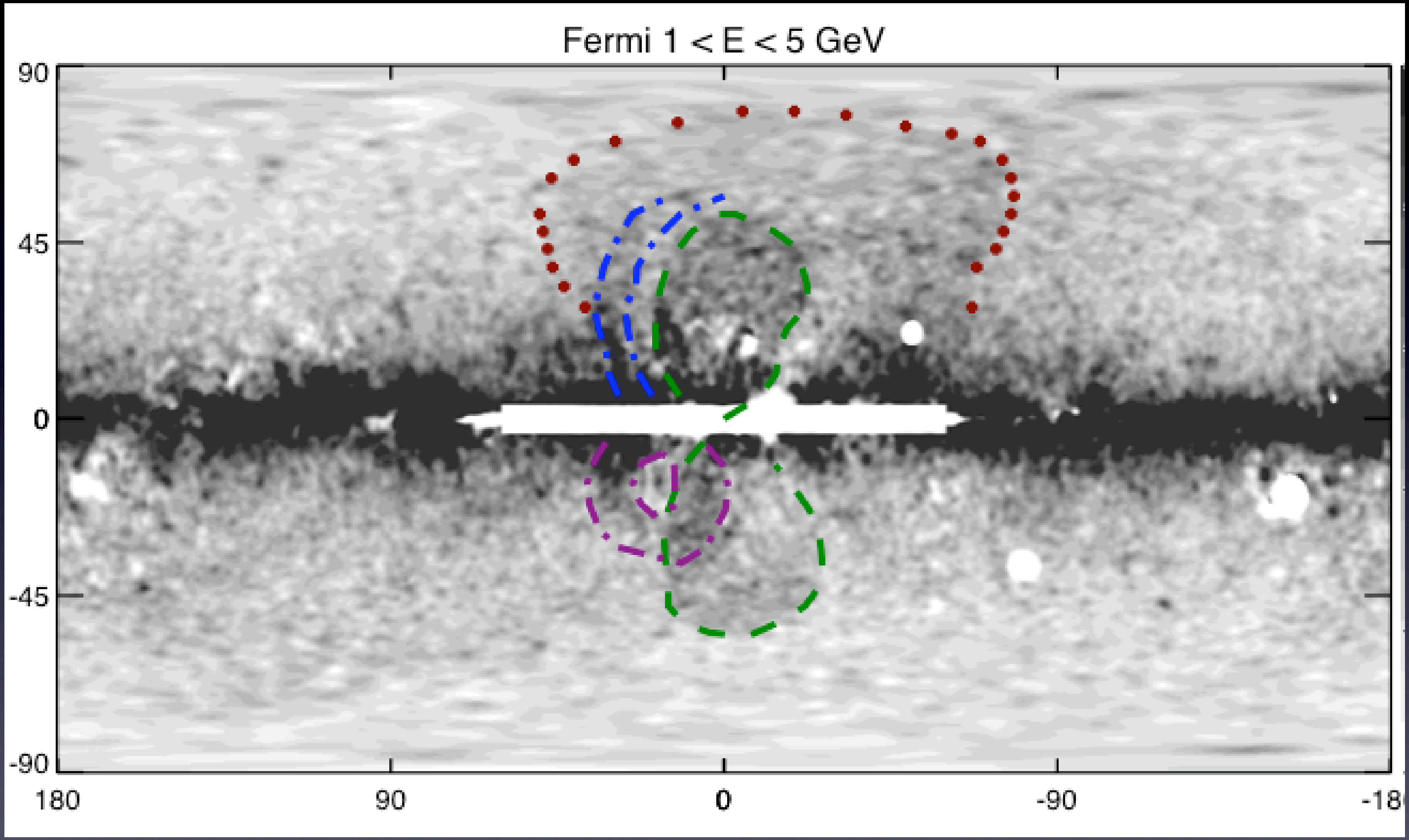
Therefore, the sharp edges are real.

The detailed intensity profile is still in question.

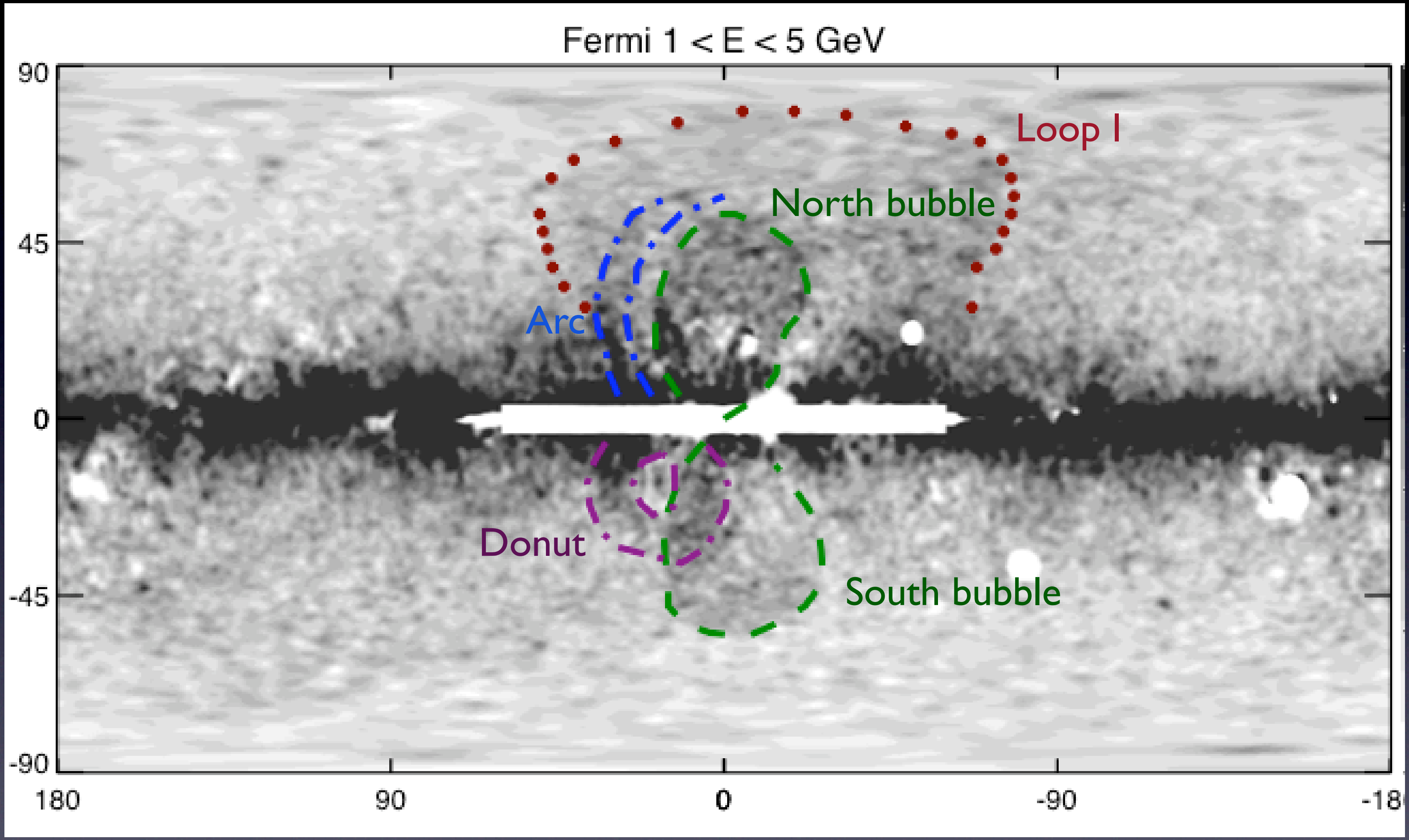
Let’s identify some features so we can study them further...



Su et al.
(2010)



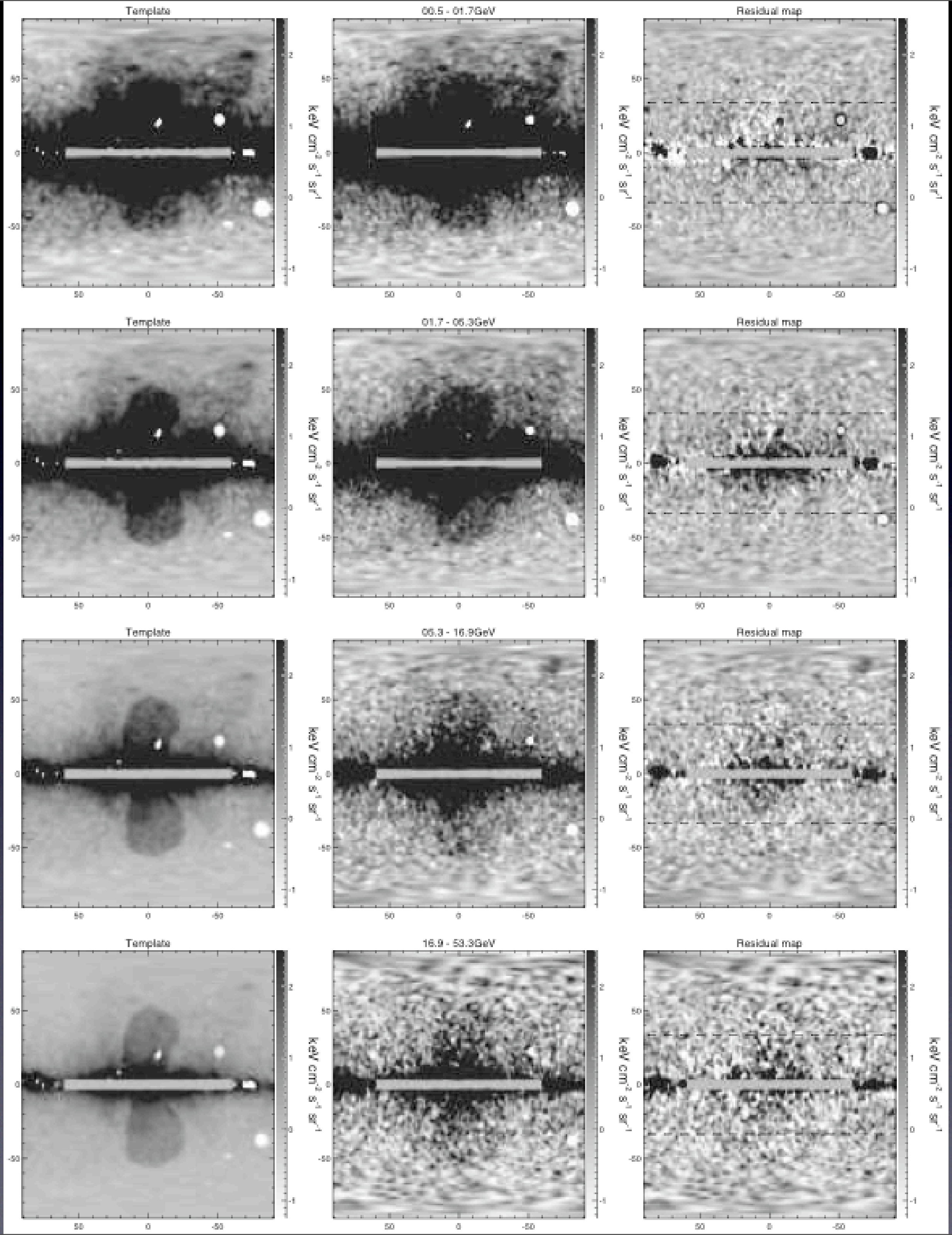
Su et al. (2010)


Fermi 1 < E < 5 GeV
90
45
0
-45
-90
180
90
0
-90
-18
Loop I
North bubble
Arc
Donut
South bubble

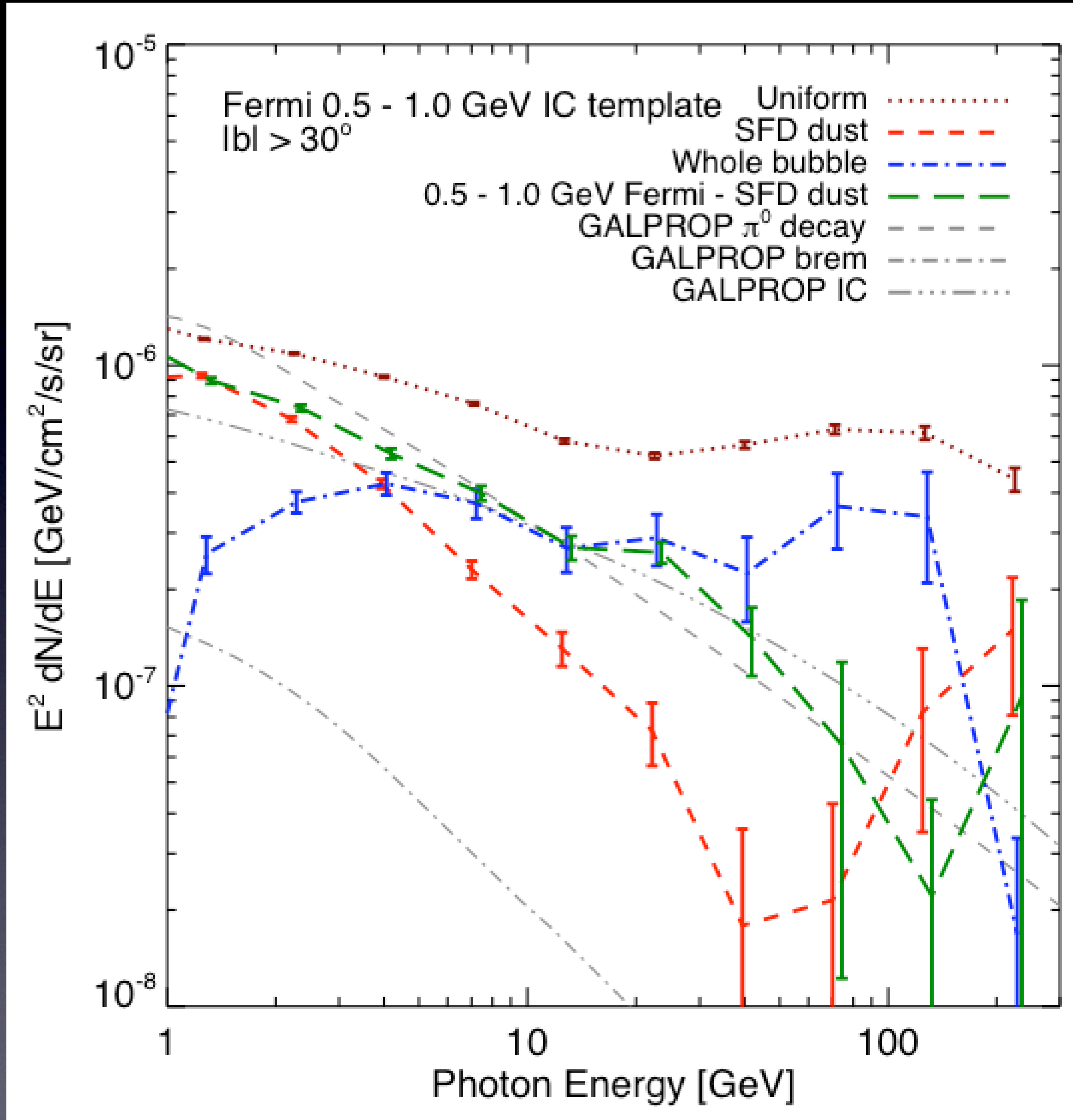
Su et al.
(2010)

We can use a low E gamma-ray template (dust-subtracted) as the IC component.

Fit done at
|b| > 30°



Su et al.
(2010)



Fermi 0.5 - 1.0 GeV IC template
|b| > 30°
Uniform
SFD dust
Whole bubble
0.5 - 1.0 GeV Fermi - SFD dust
GALPROP π^0 decay
GALPROP brem
GALPROP IC
E^2 dN/dE [GeV/cm^2/s/sr]
10^{-5}
10^{-6}
10^{-7}
10^{-8}
1
10
100
Photon Energy [GeV]

Su et al. (2010)

Does the edge have a harder spectrum than the interior?   NO.

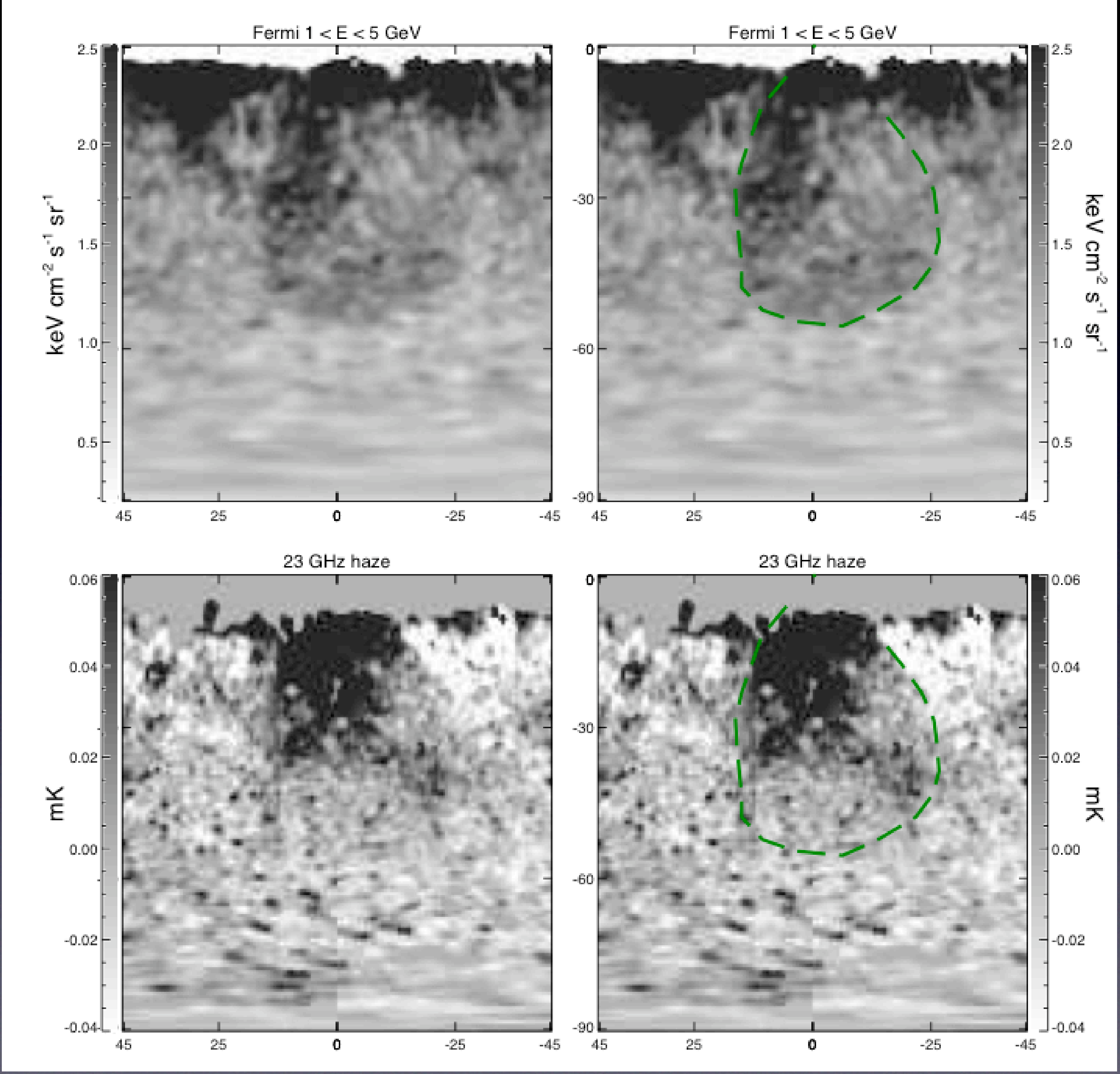
Is the north harder than the south?   NO.

Bottom line: No matter how we do the fit, the bubbles have a harder spectrum (index ~ -2) than the other IC emission (~ -2.5).

The gamma-ray spectrum extends up to ~ 50 GeV or more, implying >~ 100 GeV electrons.

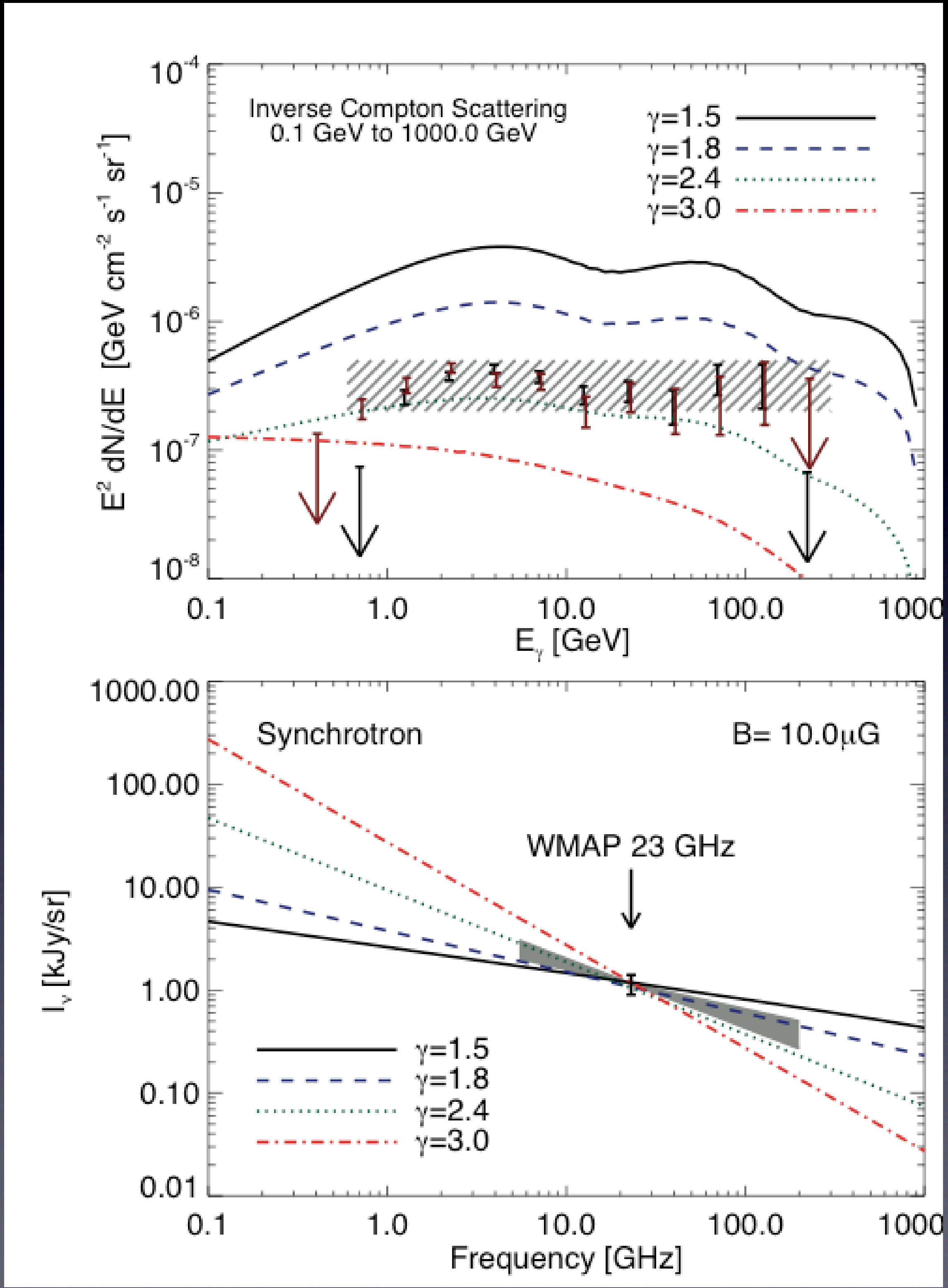
If it is CMB scattering, we have ~ 1 TeV electrons!

Are there any associated structures in Microwaves or X-rays?



Fermi 1 < E < 5 GeV
Fermi 1 < E < 5 GeV
23 GHz haze
23 GHz haze
keV cm^{-2} s^{-1} sr^{-1}
mK
2.5
2.0
1.5
1.0
0.5
0.06
0.04
0.02
0.00
-0.02
-0.04
0
-30
-60
-90
45
25
0
-25
-45

Su et al. (2010)



Su et al. (2010)

The Fermi bubbles are clearly associated with the WMAP haze.

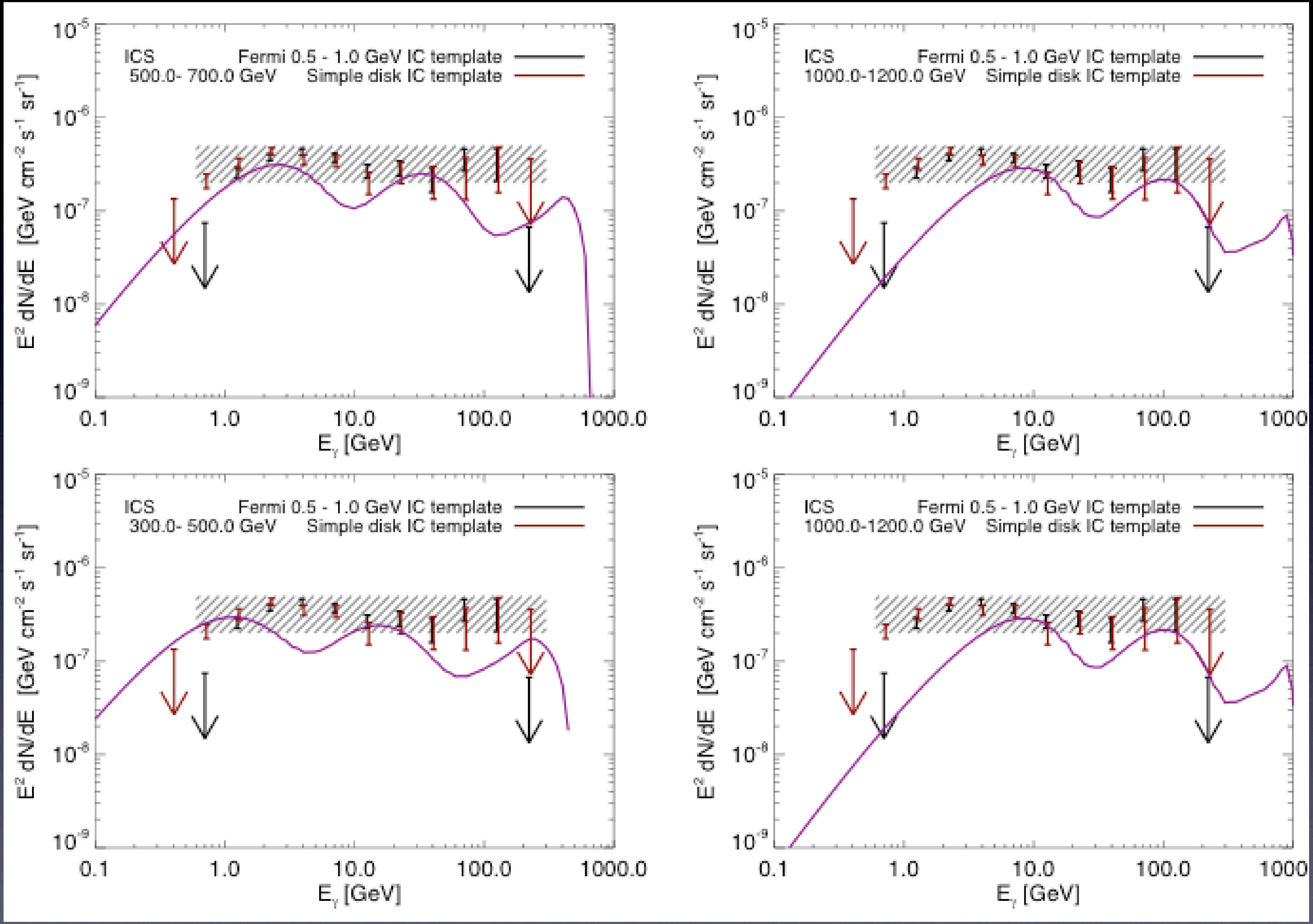
The same electron spectrum can easily make both.

2 arguments for CMB scattering:

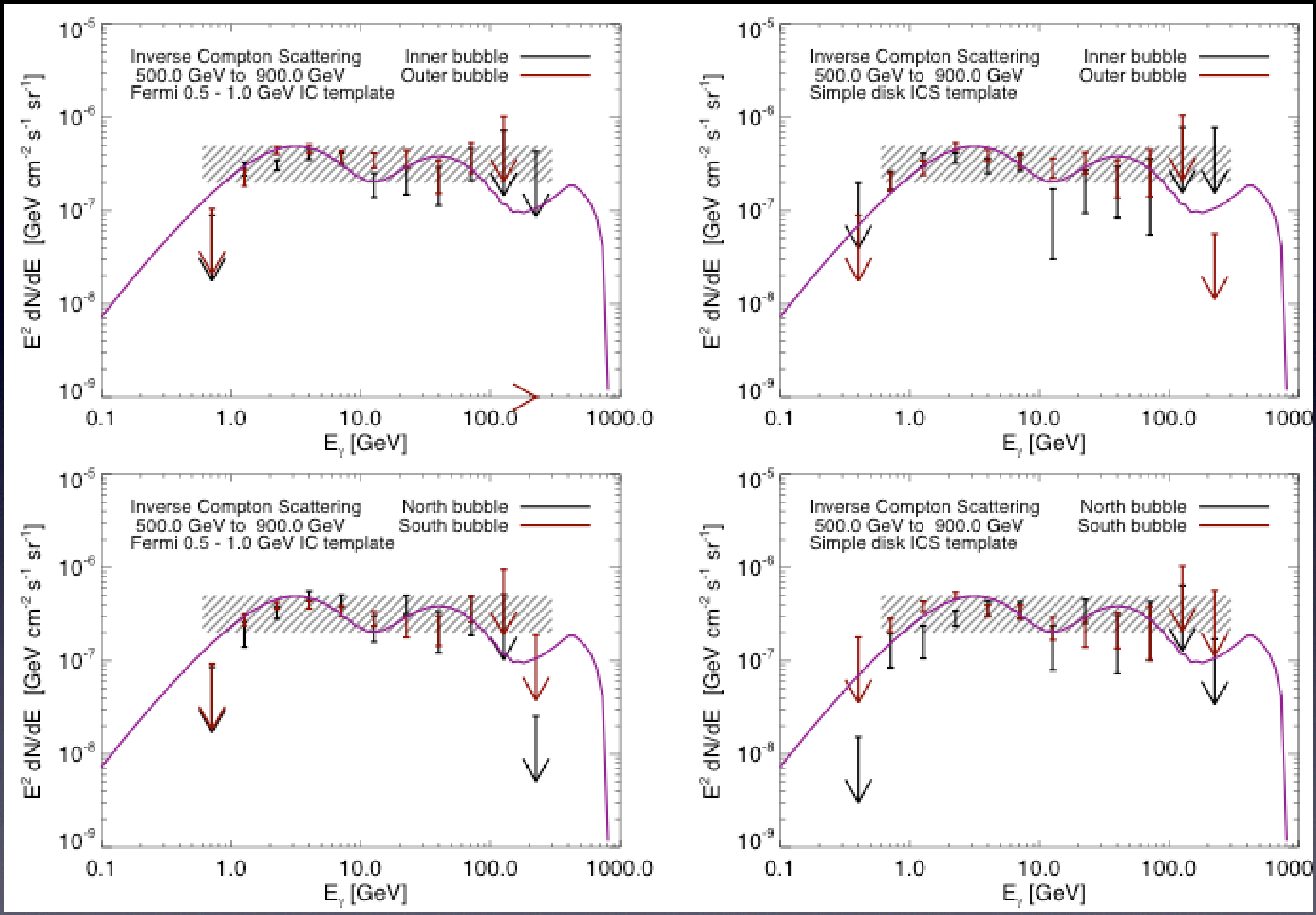
1. The bubble intensity is ~flat with latitude, while starlight density is falling.

2. The shape of the IC spectrum.

It is easy to get bumps and wiggles in the wrong places...



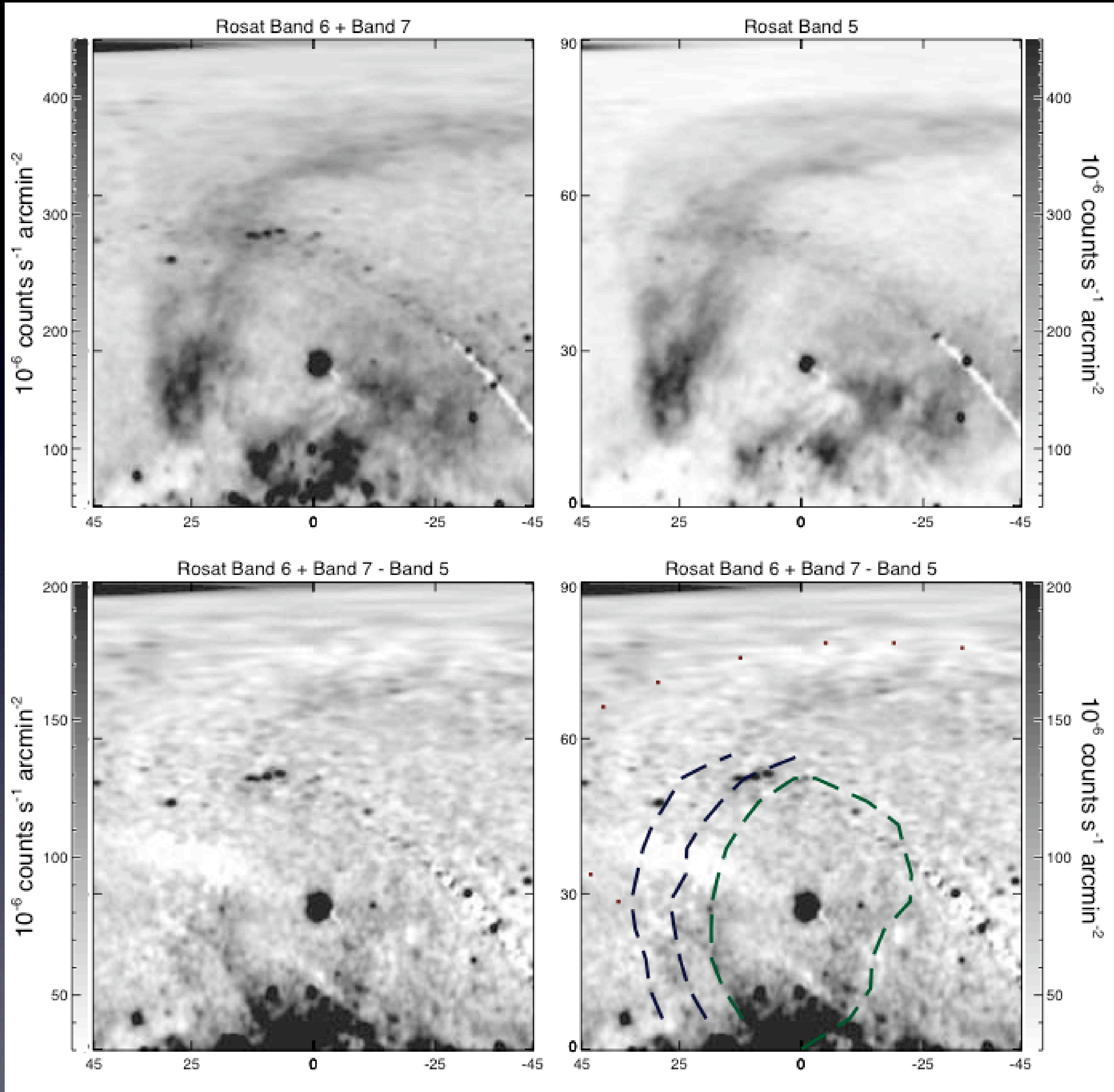
500-900 GeV electrons scattering CMB roll off at the right (low) energy.



Together these imply that the Fermi bubbles are mainly ~ TeV electrons scattering the CMB.

(Note that the WMAP haze is produced by ~ 10 GeV electrons.)

Now, how about X-rays?


Rosat Band 6 + Band 7
Rosat Band 5
Rosat Band 6 + Band 7 - Band 5
Rosat Band 6 + Band 7 - Band 5
10^{-6} counts s^{-1} $arcmin^{-2}$
10^{-6} counts s^{-1} $arcmin^{-2}$
10^{-6} counts s^{-1} $arcmin^{-2}$
10^{-6} counts s^{-1} $arcmin^{-2}$
400
300
200
100
90
60
30
0
45
25
0
-25
-45
200
150
100
50

Su et al. (2010)

So far: there appear to be a pair of giant (50° high) gamma-ray bubbles at 1-5 GeV, and probably up to at least 50 GeV.

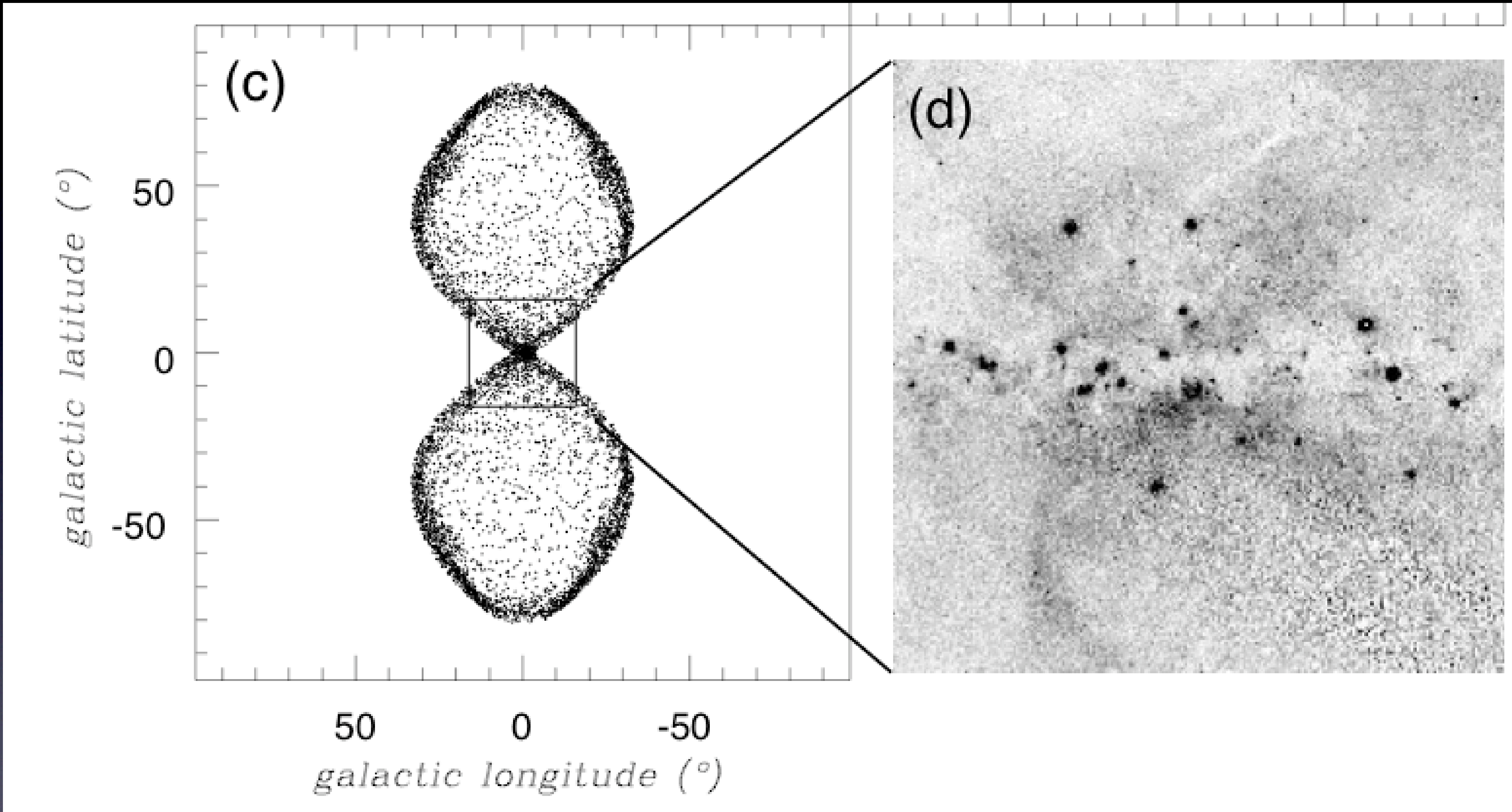
What are they?

Black hole "burp"

Superwind bubble?

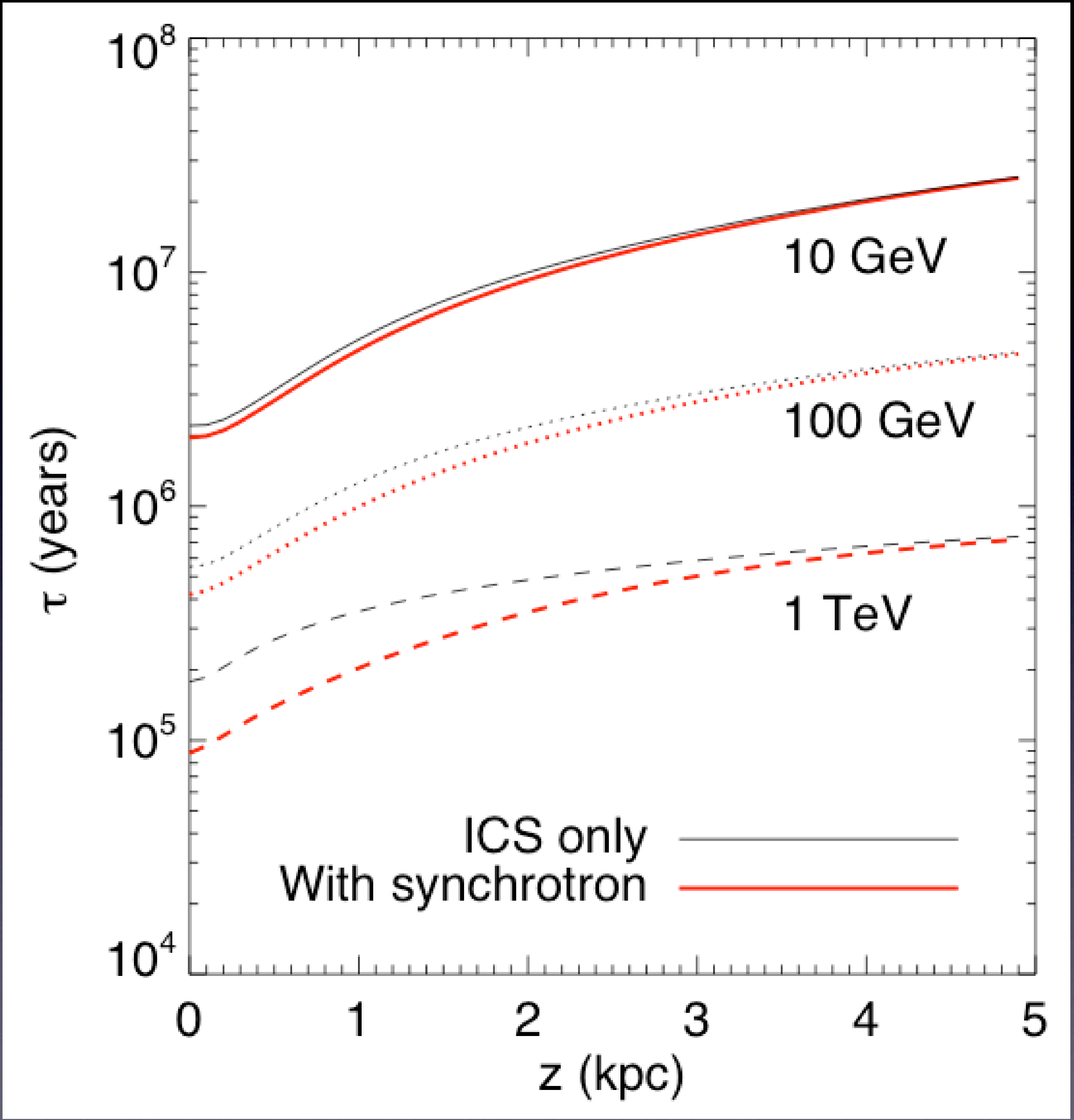
Based only on ROSAT X-ray data and some FIR data (MSX) near the plane, previous authors suggested the presence of large starburst-produced bubbles containing ~ 10^{55} erg of thermal energy.

Fermi bubbles



e.g. Bland-Hawthorn & Cohen (2003)

However, this explanation has a severe cooling time problem. The bubbles should be ~ 10 Myr old, but cooling time for TeV (or even 100 GeV) electrons is much shorter.



10^8
10^7
10^6
10^5
10^4
τ (years)
10 GeV
100 GeV
1 TeV
ICS only
With synchrotron
0
1
2
3
4
5
z (kpc)

Mystery: How do we get TeV electrons 10 kpc off the disk in the last < Myr?

Must be *in situ* acceleration.

Shocks? Reconnection?

If they are formed quickly by AGN activity, then KE >> 10^{55} erg.
Could do, but this would be an impressive event for our humble little BH.

Caveats:

The sharp edge at high latitude is robust, but there are other ways to look at the data at low latitude.

Because of this uncertainty, and because the sharp edges are a problem for both astrophysical and DM explanations, it is good to consider all options.

My best guess is that the bubble structures have nothing to do with DM, but that does not mean there is no DM signal there.

Caveats:

In any case, they imply steady state assumption is bad, that there is rapid transport of plasma & CRs out of the "Hell's Kitchen" and the transport time might be 10 - 100x shorter than cooling time at ~ 10 GeV.

This raises grave concerns about using the GC for radio / microwave / IC gamma constraints, and could weaken such constraints *by 1-2 orders of magnitude!*

(Of course, this does not apply to direct / FSR photons from annihilations)

Conclusions

There are two large gamma-ray "bubbles" in the *Fermi* data (in addition to several other interesting structures, including emission associated with Loop I).

These are associated with the WMAP haze, and ROSAT x-rays

They require a hard electron CR spectrum.

Cooling time << formation time, so more than one mechanism at work.

The implied rapid transport of the plasma & CRs out of the inner galaxy greatly weakens GC constraints on dark matter.