Fermi Bubbles, the Haze and Dark Matter

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with

Greg Dobler, Tracy Slatyer

Meng Su, Tongyan Lin

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- DM is a tempting possibility...

- AGN or starburst activity is more likely, though there are problems with both. (indeed, there are likely at least 2 things going on...)

Two *Fermi* papers

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- "Fermi haze" paper: There is a hard gamma-ray excess in the inner Galaxy. Could be DM, could be something else. (Dobler et al., arXiv:910:4583)

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- "Fermi bubbles" paper: better data / analysis reveals structures with sharp edges, appearing to rise up from the Galactic center. Much (not all!) of the "haze" emission is associated with these. (Su et al., arXiv:1005.5480)

Two motivations for looking at the Inner Galaxy with *Fermi*:

1. Indirect Detection of dark matter
2. Investigate the WMAP haze

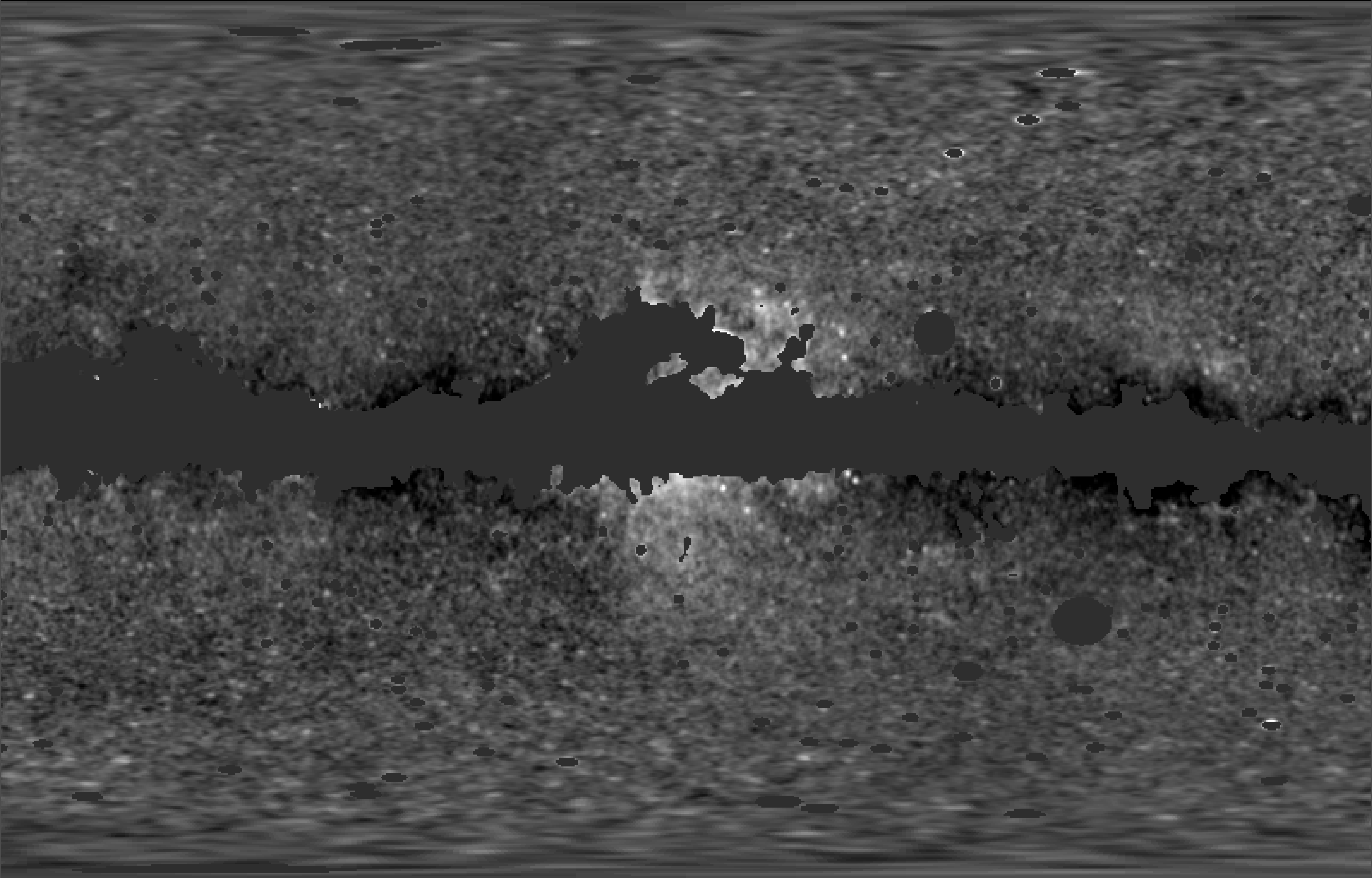
WMAP haze (Finkbeiner 2004)

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.

Key points

1) By construction, the WMAP haze does not look like the Haslam 408 MHz radio map; the haze has a harder spectrum.

2) It could be free-free from few x 10^5 K gas, but this would require a huge energy injection.

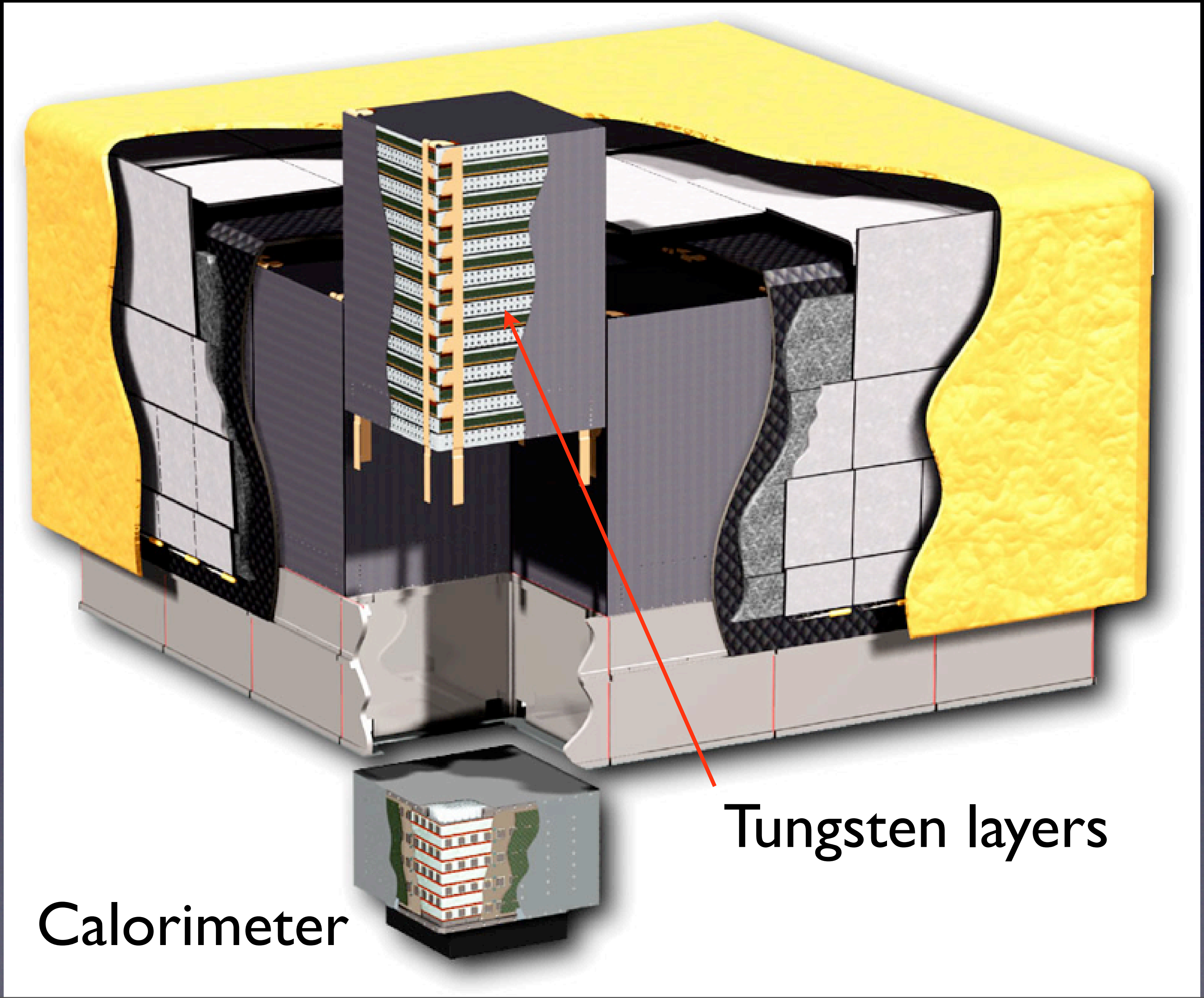
3) The WMAP polarization maps show no extra hard-spectrum signal in the haze region (Gold et al. 2010)

How to test the WMAP haze idea?

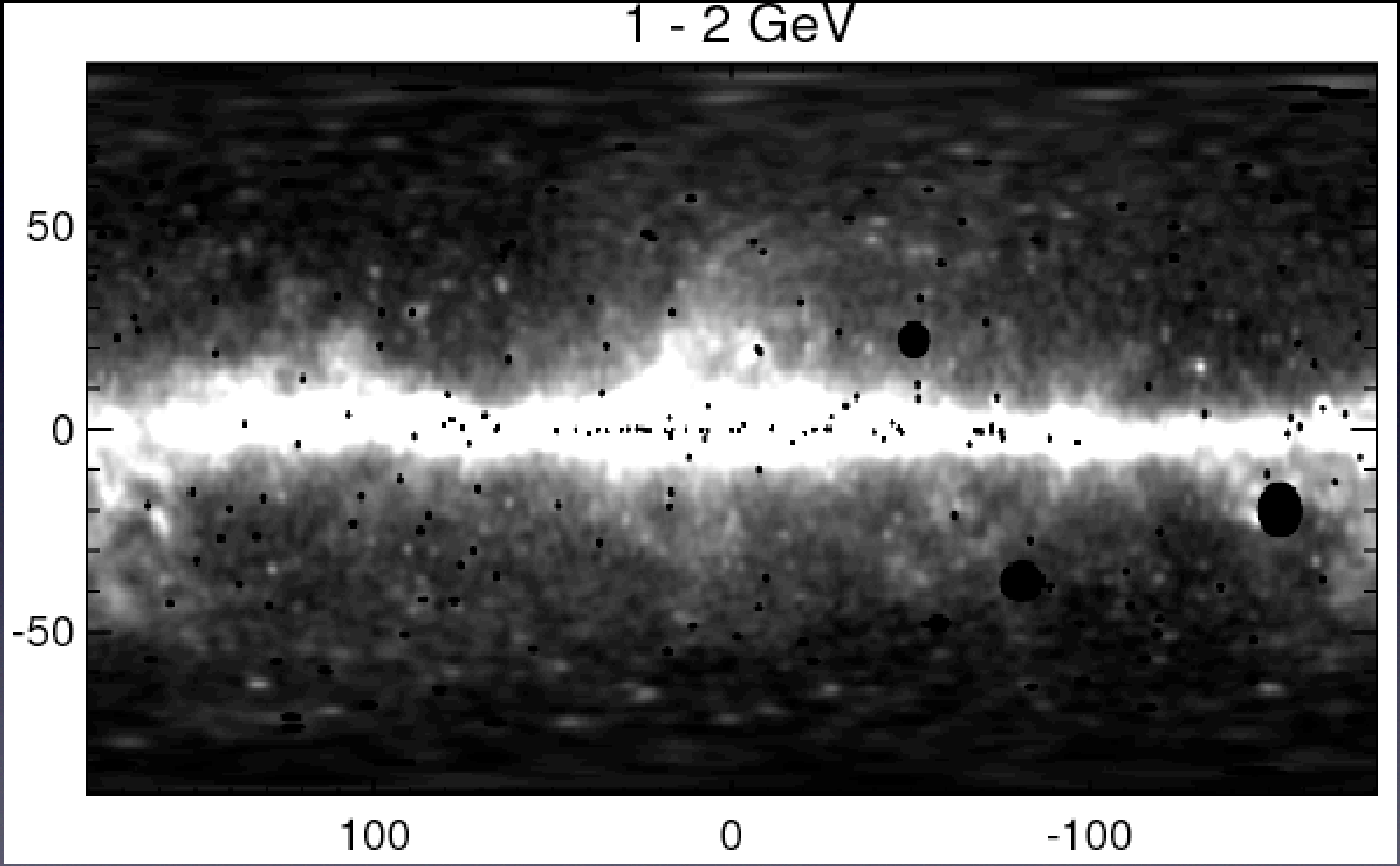
1) Can we see the IC gammas expected if the WMAP haze is synchrotron? (this would rule out null hypothesis 1)

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

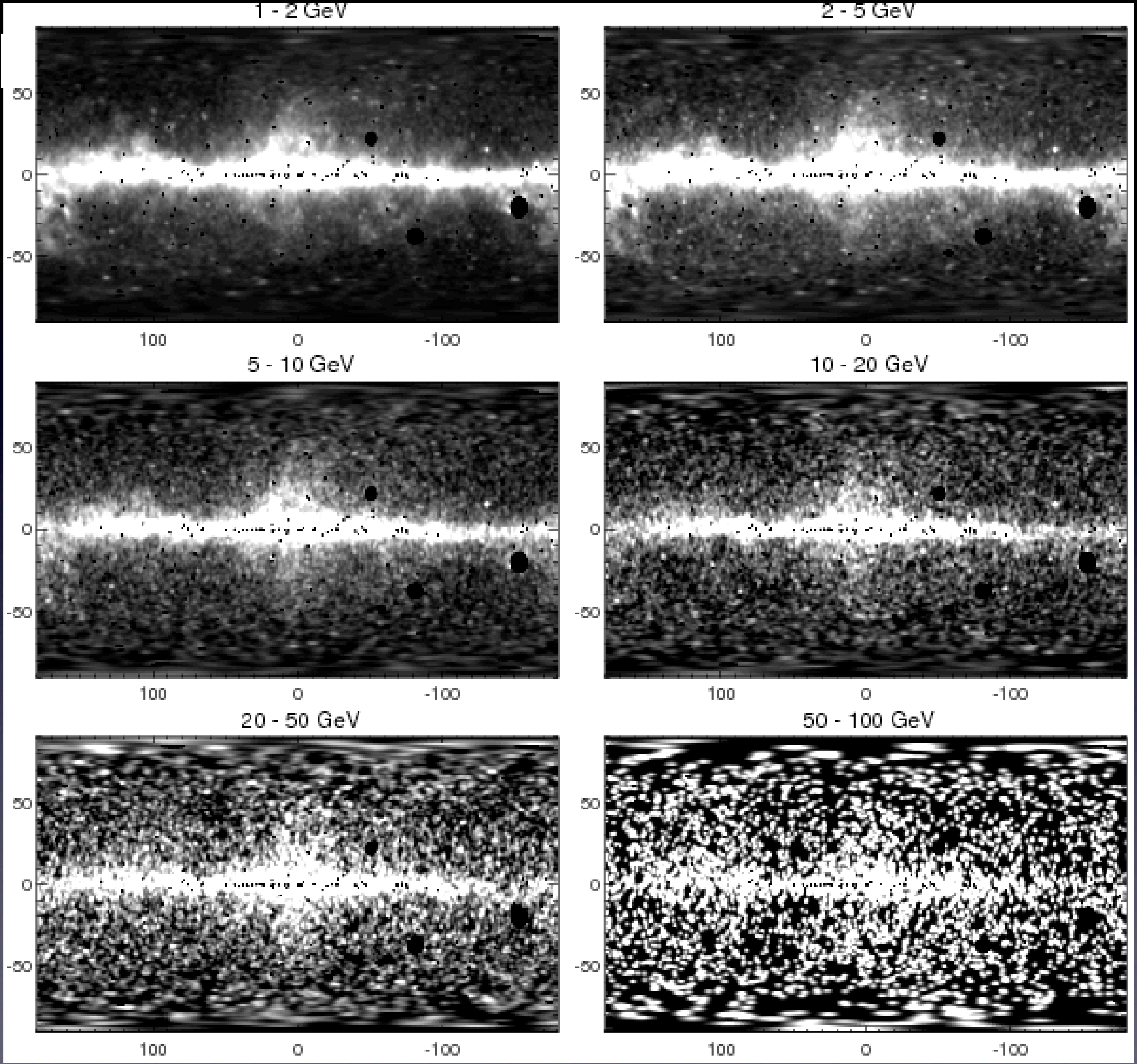
Fermi LAT (large area telescope)



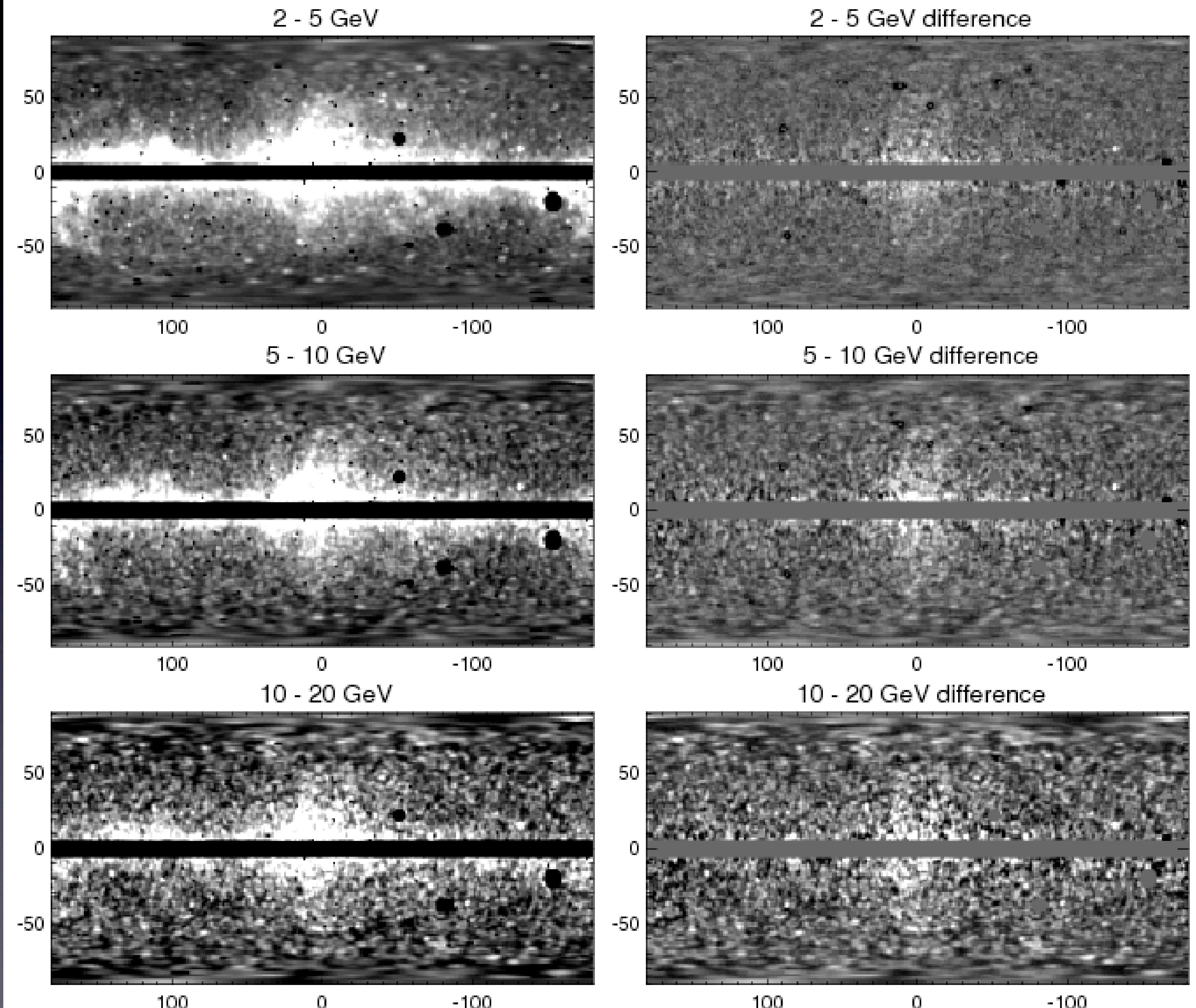
Paper I: *Fermi* first year sky map
(3 month point source cat. subtracted):



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

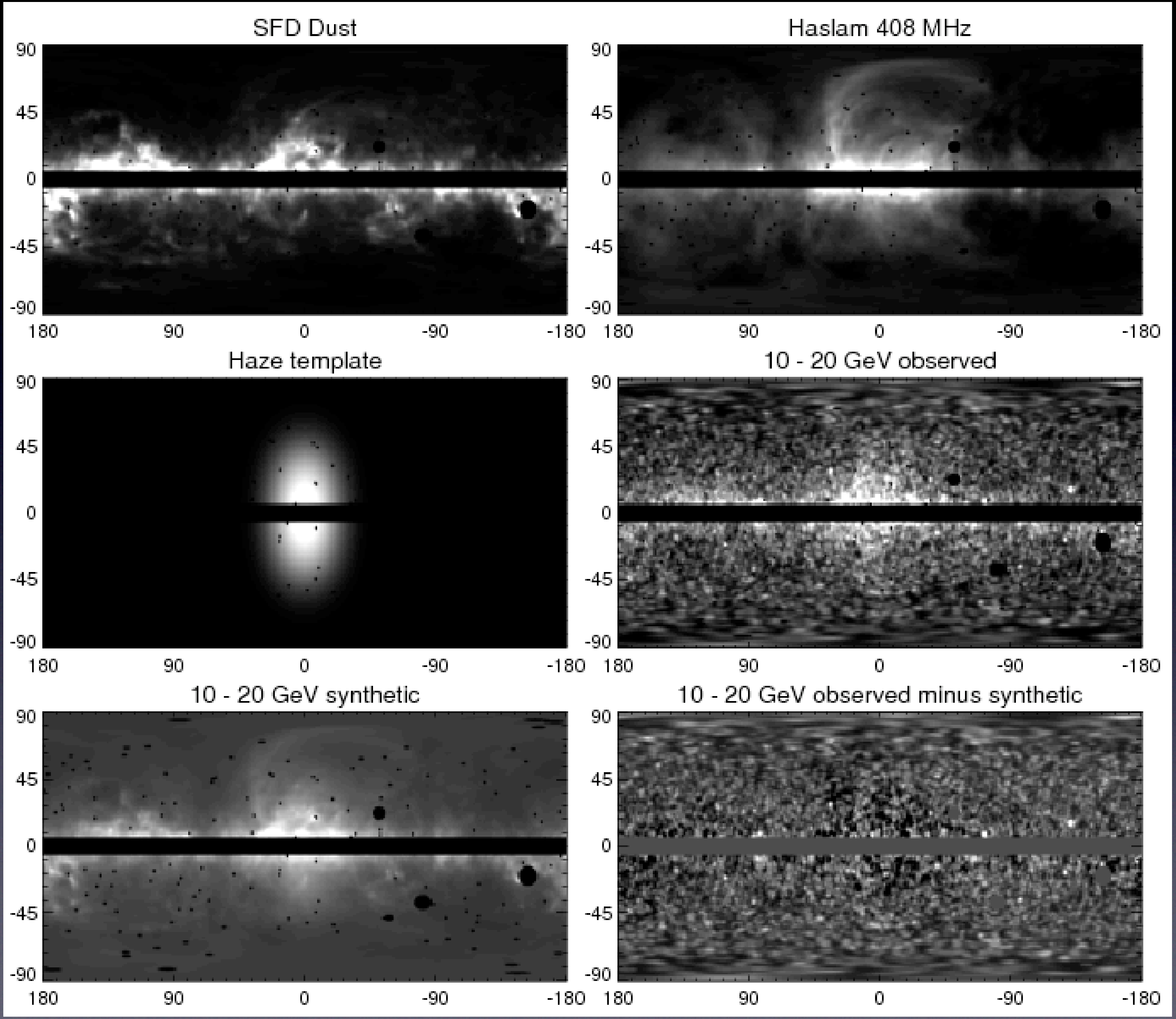


Dobler et al.
(0910.4583)



Dobler et al. (0910.4583)

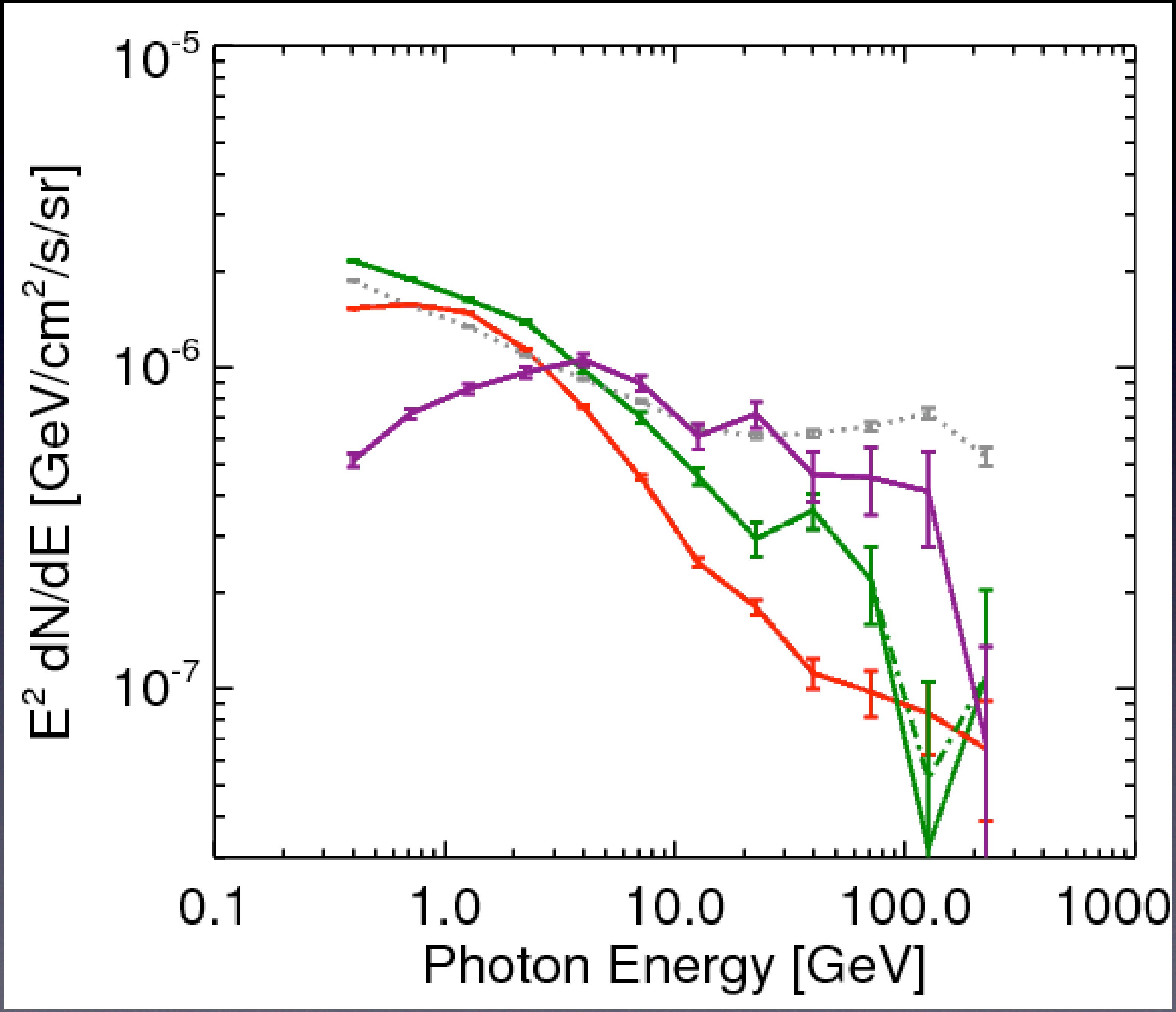
1 GeV Template



Dobler et al. (0910.4583)

Templates

Fermi spectrum in the “haze” region



Dobler et al.
(0910.4583)

Paper I 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 numerous 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.

(Both Sommerfeld and unusual DM distribution)

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

Recent work by Su, Slatyer, and Finkbeiner

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!

arXiv.org > astro-ph > arXiv:1005.5480

Sear

Astrophysics > High Energy Astrophysical Phenomena

Giant Gamma-ray Bubbles from Fermi-LAT: AGN Activity or Bipolar Galactic Wind?

Meng Su, Tracy R. Slatyer, Douglas P. Finkbeiner

(Submitted on 29 May 2010)

Data from the Fermi-LAT reveal two large gamma-ray bubbles, extending 50 degrees above and below the Galactic center, with a width of about 40 degrees in longitude. The gamma-ray emission associated with these bubbles has a significantly harder spectrum (dN/dE ~ E^-2) than the IC emission from electrons in the Galactic disk, or the gamma-rays produced by decay of pions from proton-ISM collisions. There is no significant spatial variation in the spectrum or gamma-ray intensity within the bubbles, or between the north and south bubbles. The bubbles are spatially correlated with the hard-spectrum microwave excess known as the WMAP haze; the edges of the bubbles also line up with features in the ROSAT X-ray maps at 1.5-2 keV. We argue that these Galactic gamma-ray bubbles were most likely created by some large episode of energy injection in the Galactic center, such as past accretion events onto the central massive black hole, or a nuclear starburst in the last ~10 Myr. Dark matter annihilation/decay seems unlikely to generate all the features of the bubbles and the associated signals in WMAP and ROSAT; the bubbles must be understood in order to use measurements of the diffuse gamma-ray emission in the inner Galaxy as a probe of dark matter physics. Study of the origin and evolution of the bubbles also has the potential to improve our understanding of recent energetic events in the inner Galaxy and the high-latitude cosmic ray population.

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 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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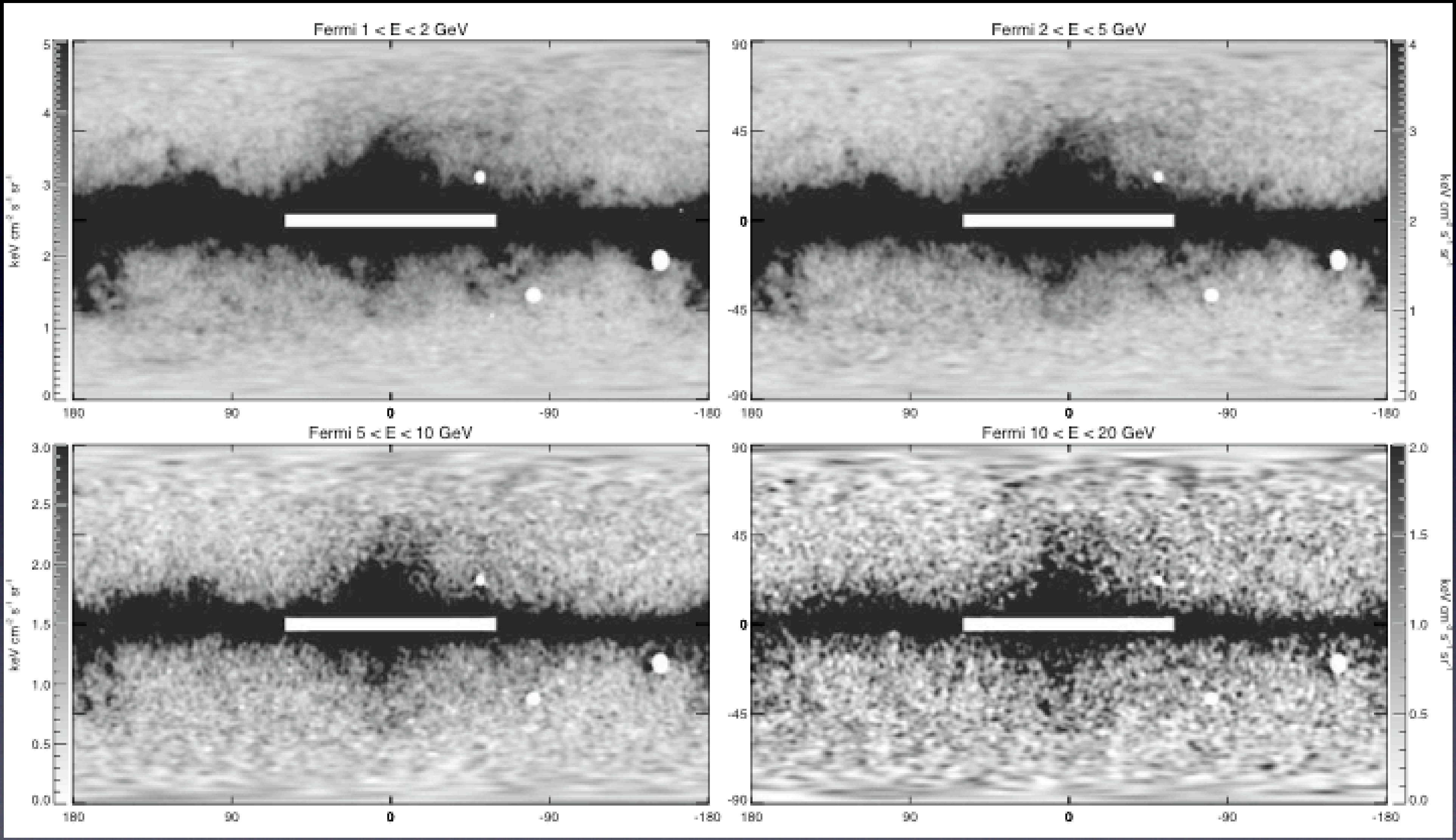
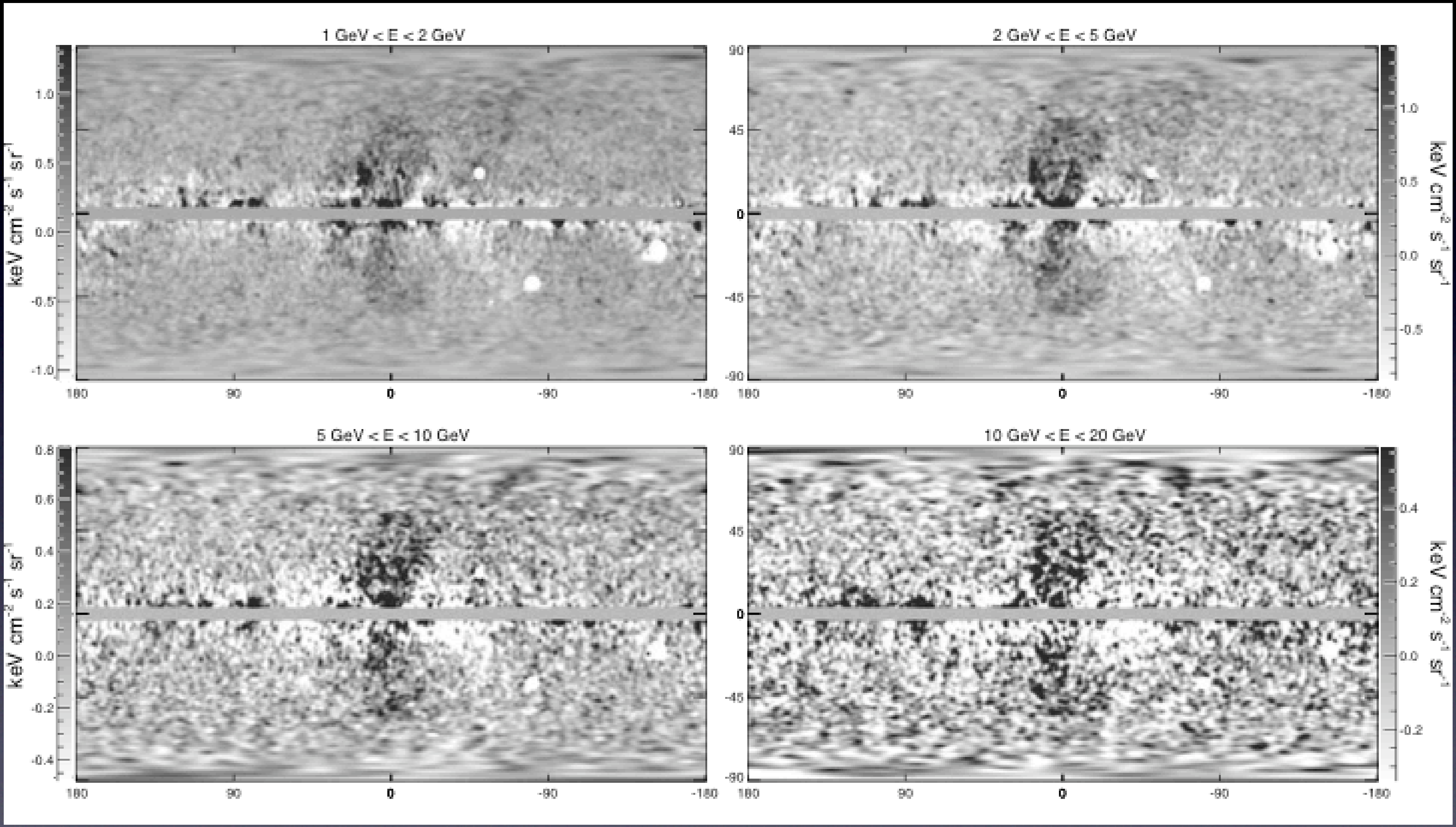
DM agnostic:
Astrophysics is complicated. How long until dinner?

Fermi 1.6 yr maps, point sources removed.



Data minus *Fermi* diffuse emission model:

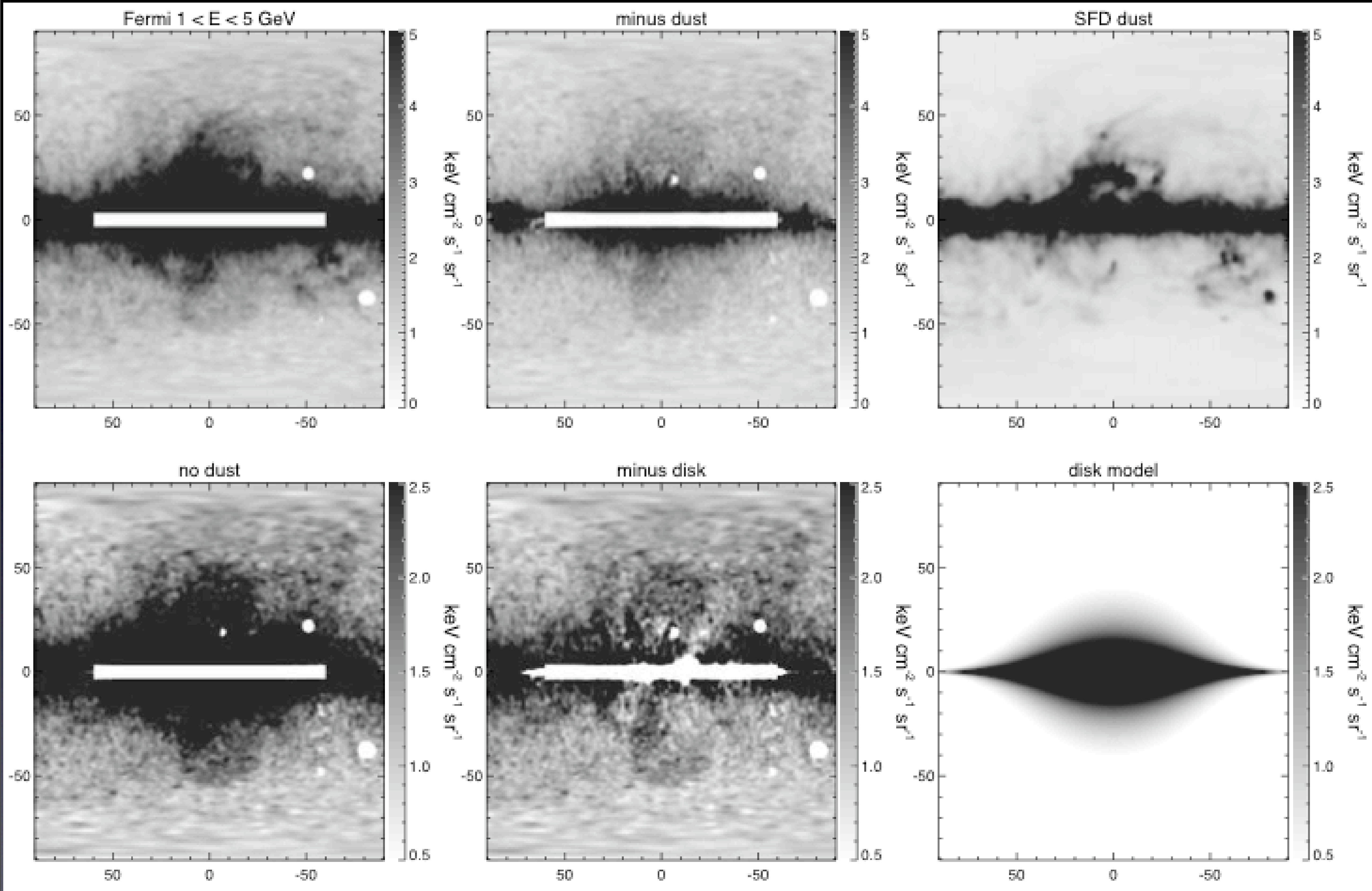


Subtracting the *Fermi* diffuse emission model reveals a faint bilobular structure in the inner Galaxy.

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.



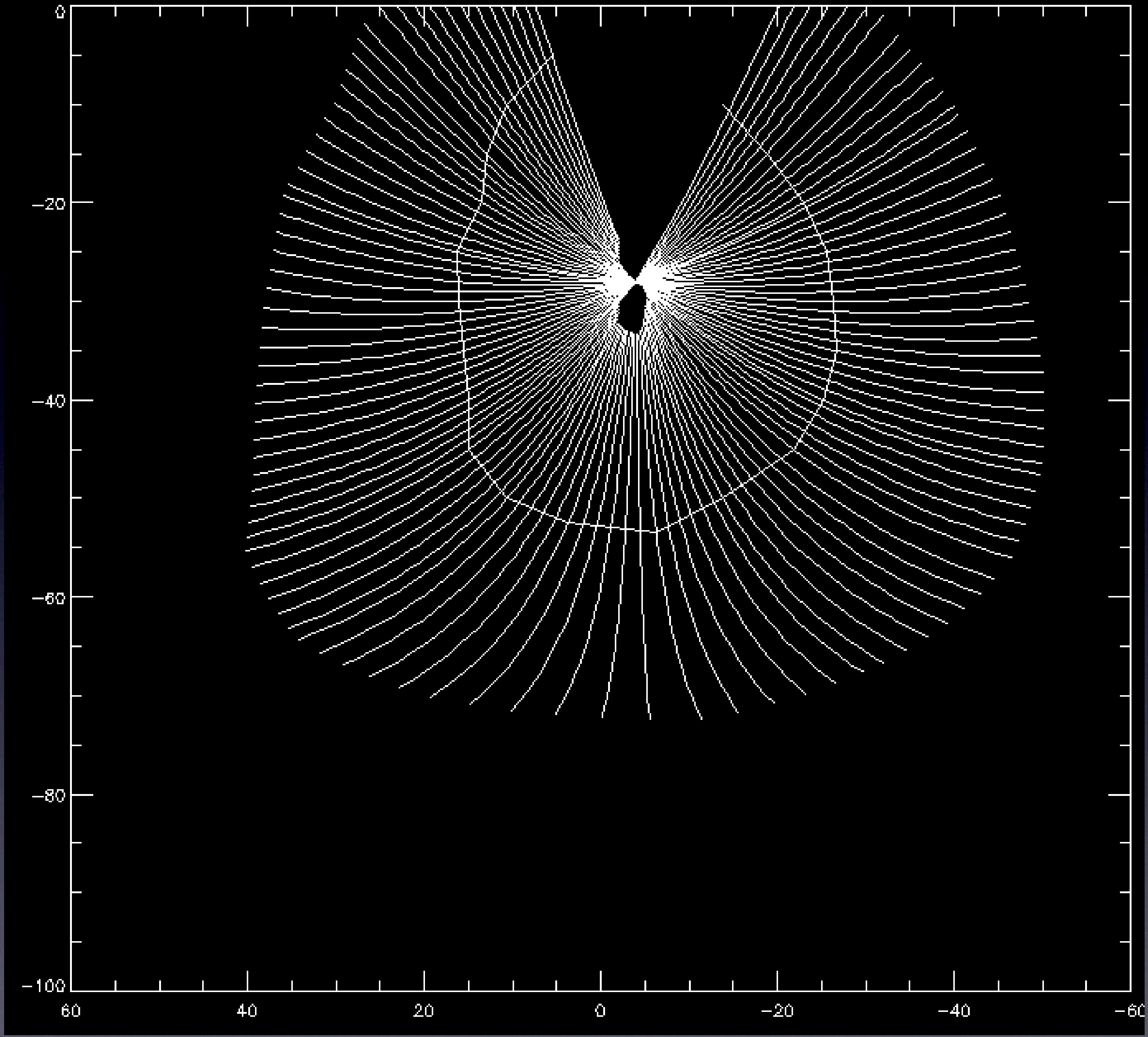
Fermi 1 < E < 5 GeV
minus dust
SFD dust
no dust
minus disk
disk model
keV cm^{-2} s^{-1} sr^{-1}

Su et al. (2010)

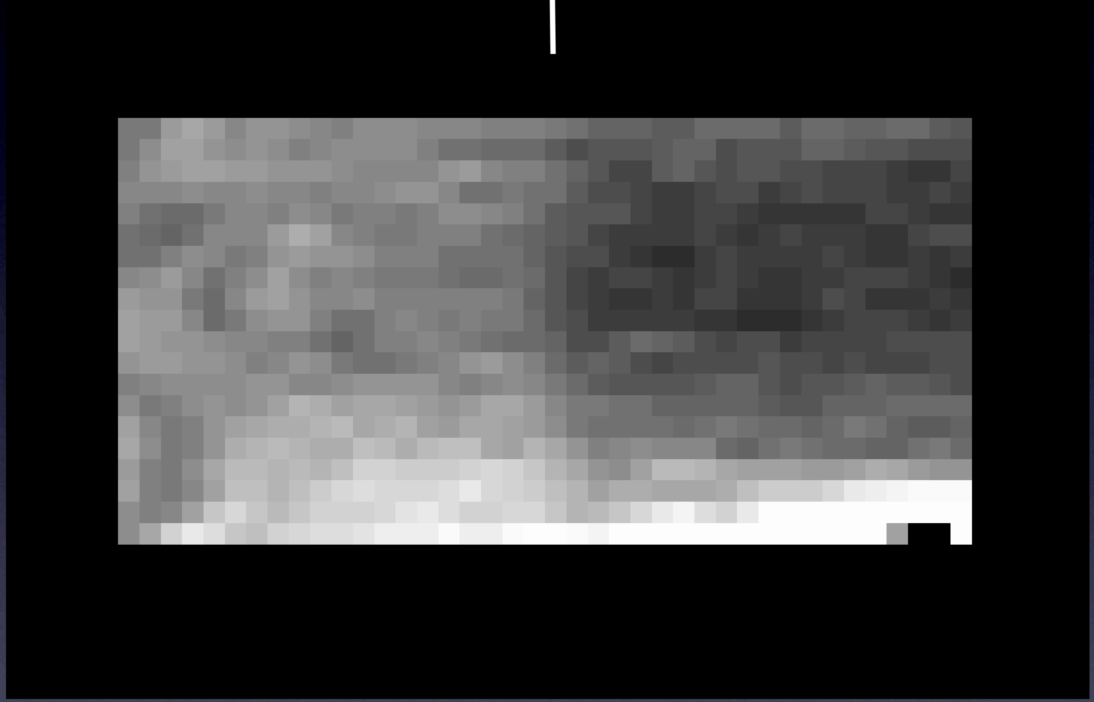
Even subtracting only two templates (dust and a “simple disk” model) we see the structure.

Therefore, the sharp edges are real.

How sharp are the edges?



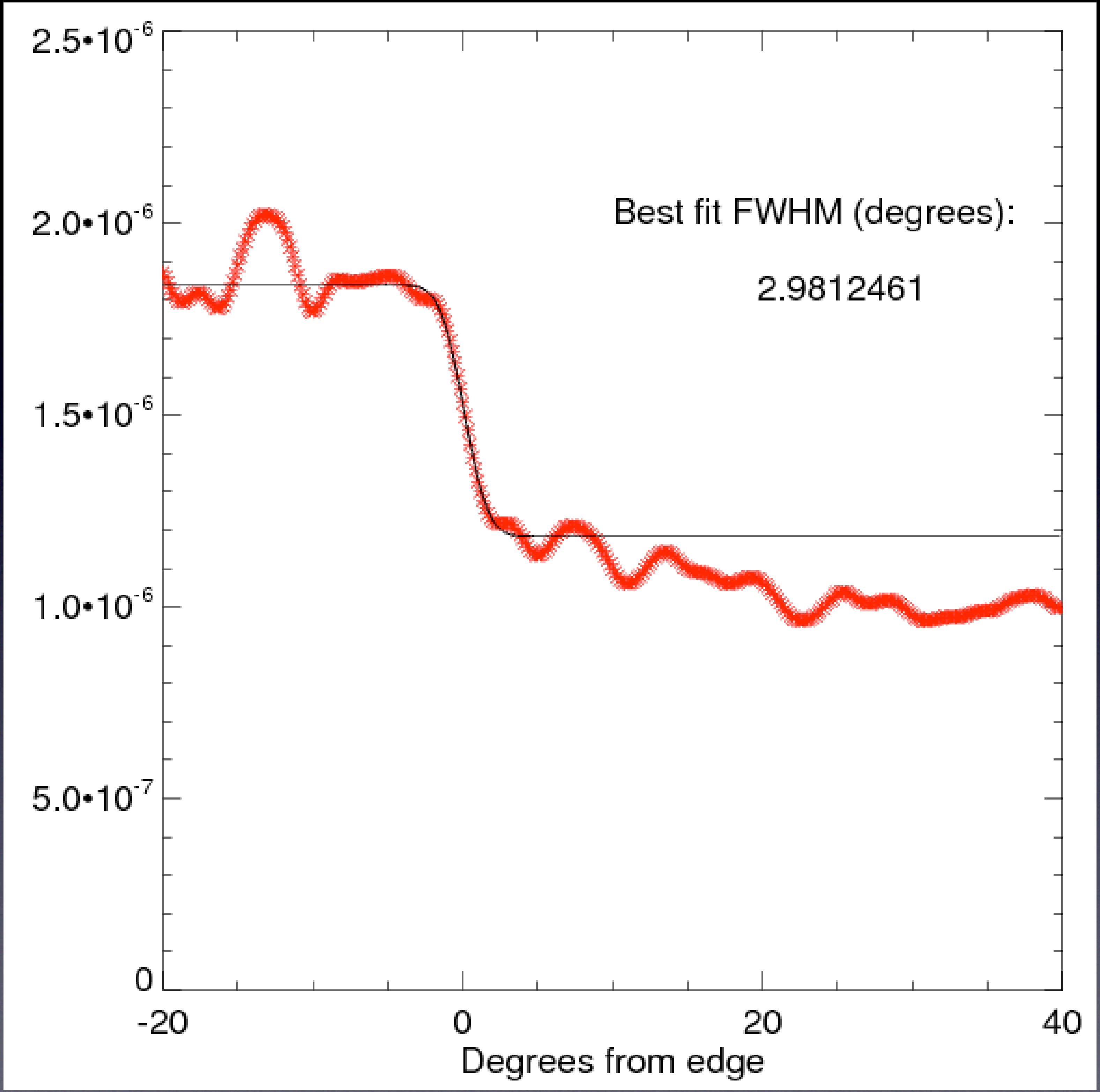
Sample map along great circles starting at bubble center



Grayscale image of intensity along several rays

2-5 GeV

|b|>30



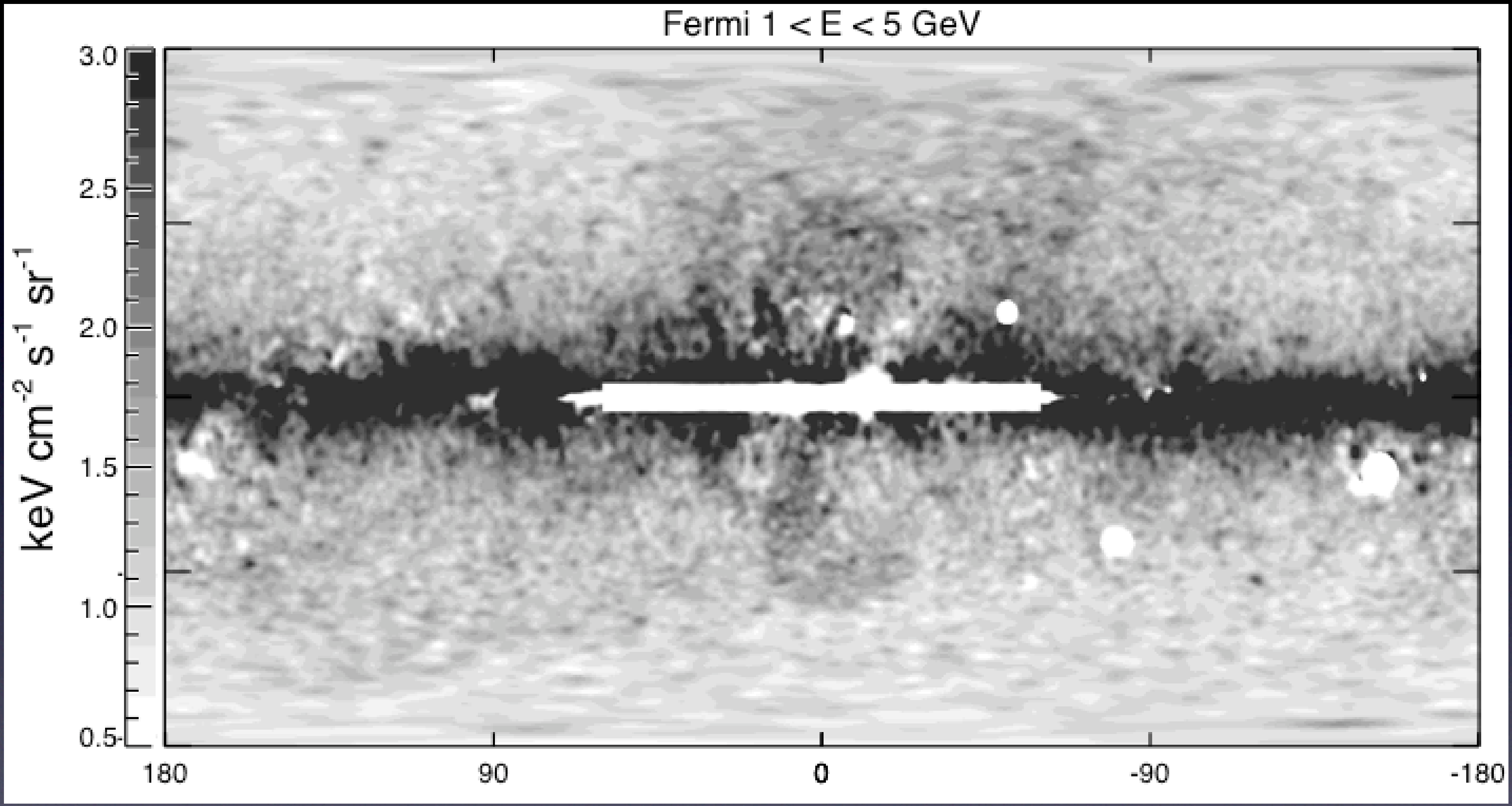
2.5•10^-6
2.0•10^-6
1.5•10^-6
1.0•10^-6
5.0•10^-7
0
-20
0
20
40
Degrees from edge
Best fit FWHM (degrees):
2.9812461

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

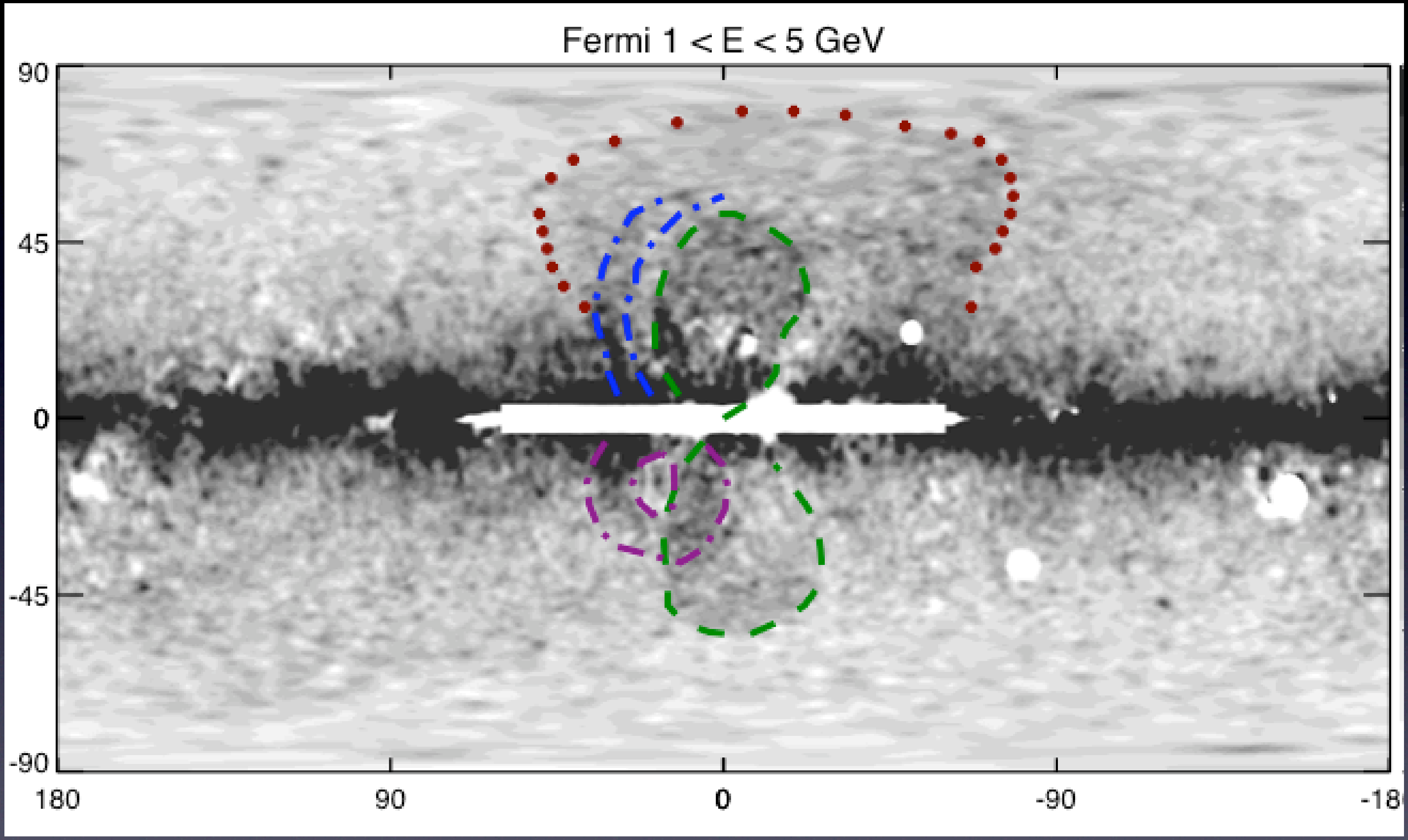
Therefore, the sharp edges are real.

The detailed intensity profile is still in question.

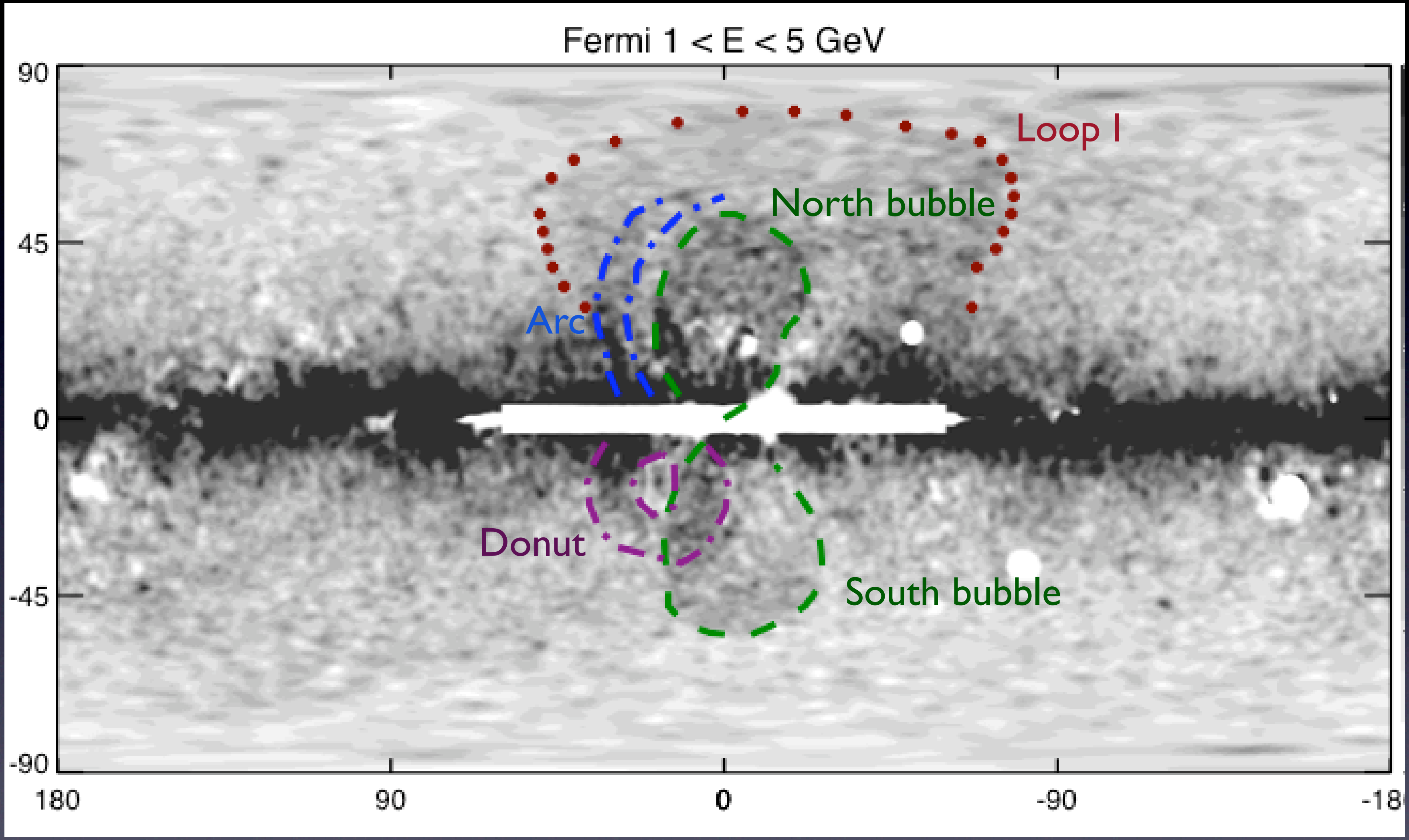
Let’s identify some features so we can study them further...



Su et al.
(2010)

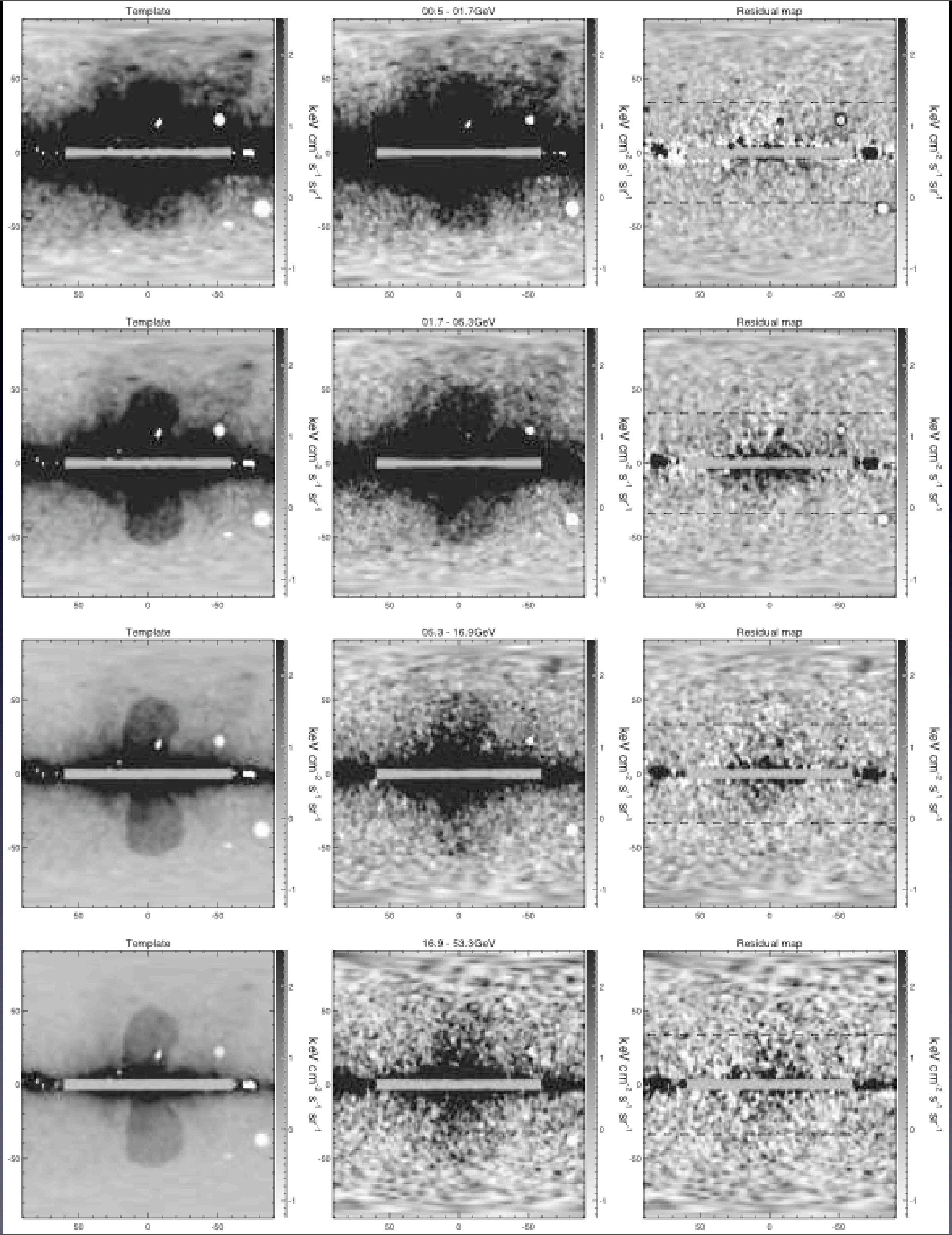


Su et al. (2010)


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

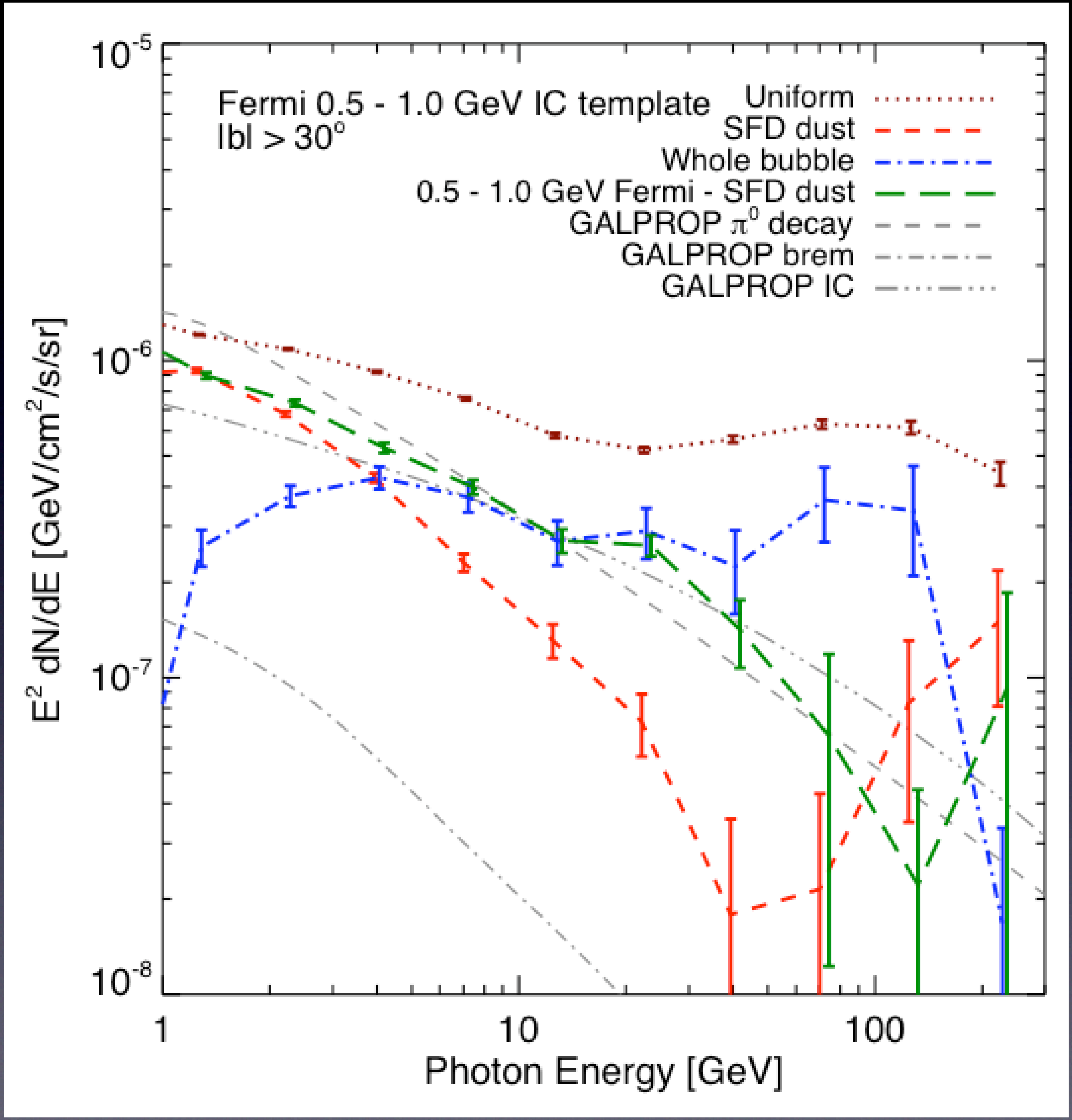
Su et al.
(2010)

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



Template
00.5 - 01.7GeV
Residual map
Template
01.7 - 05.3GeV
Residual map
Template
05.3 - 16.9GeV
Residual map
Template
16.9 - 53.3GeV
Residual map
keV cm^{-2} s^{-1} sr^{-1}

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
10^{-5}
10^{-6}
10^{-7}
10^{-8}
E^2 dN/dE [GeV/cm^2/s/sr]
1
10
100
Photon Energy [GeV]

Su et al. (2010)

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

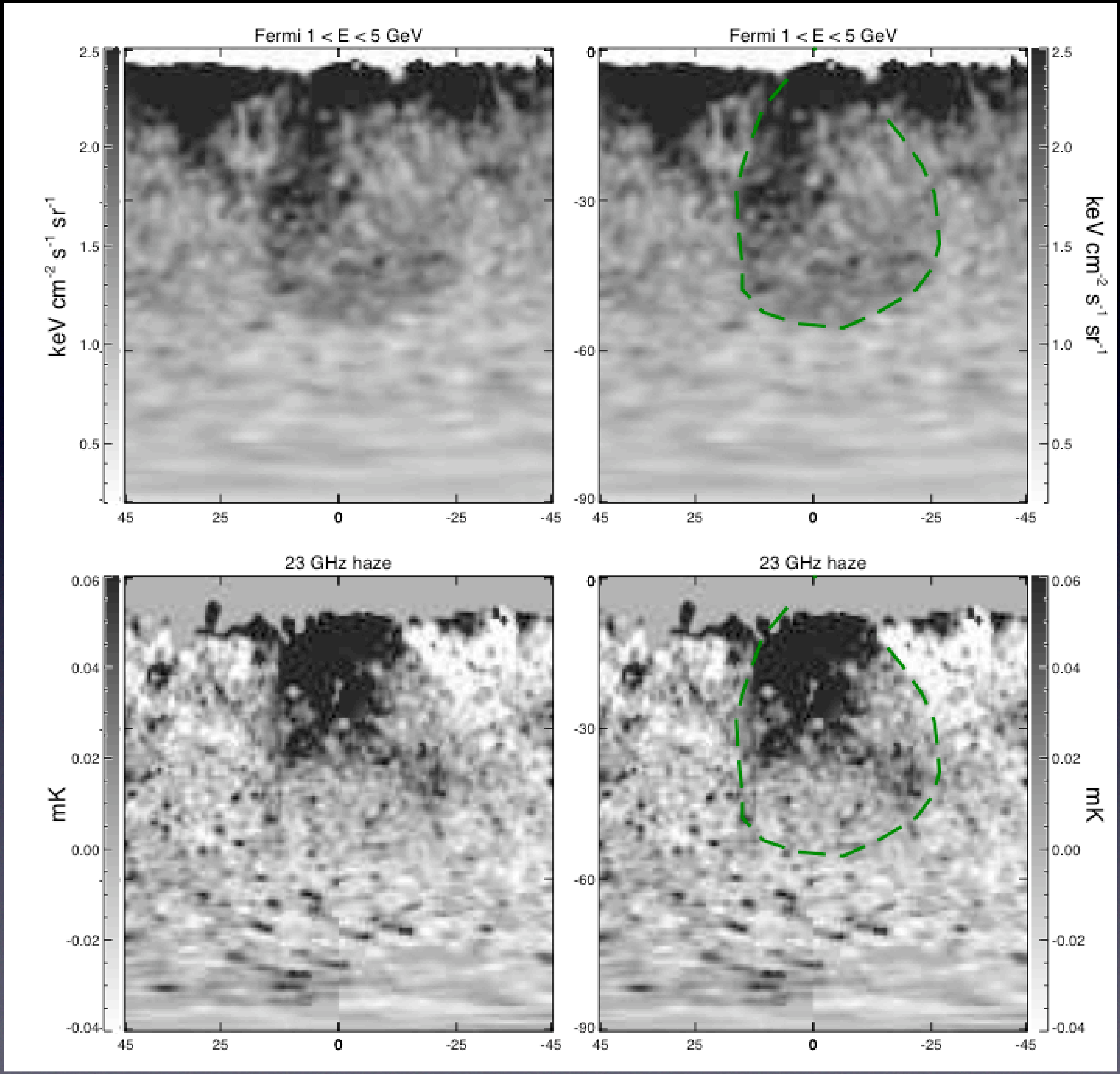
Is the north harder than the south?   NO.

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.

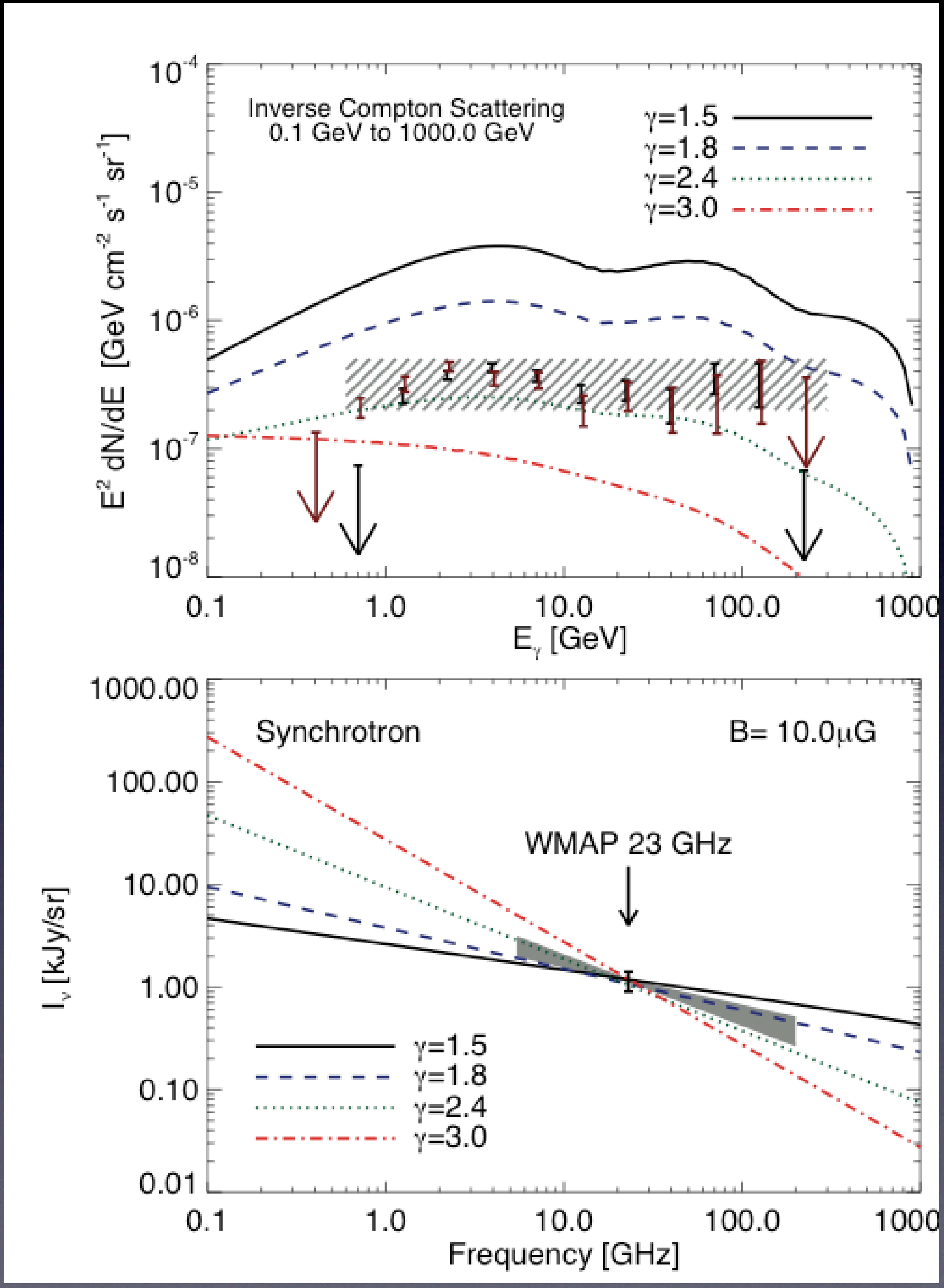
If it is CMB scattering, we have ~ 1 TeV electrons!

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



Fermi 1 < E < 5 GeV
Fermi 1 < E < 5 GeV
keV cm^-2 s^-1 sr^-1
keV cm^-2 s^-1 sr^-1
23 GHz haze
23 GHz haze
mK
mK

Su et al.
(2010)



The Fermi bubbles are clearly associated with the WMAP haze.

The same electron spectrum can easily make both.

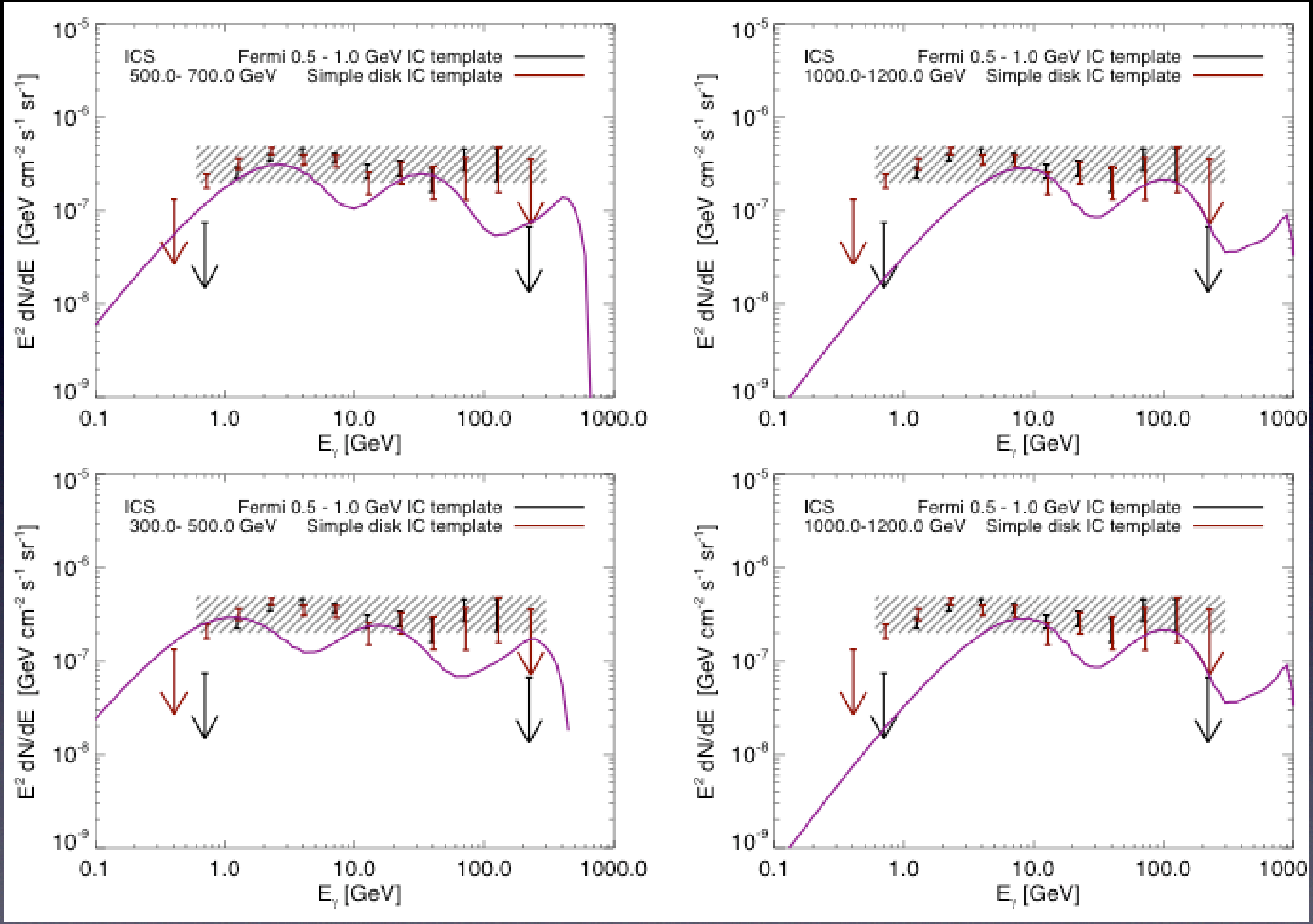
Su et al. (2010)

2 arguments for CMB scattering:

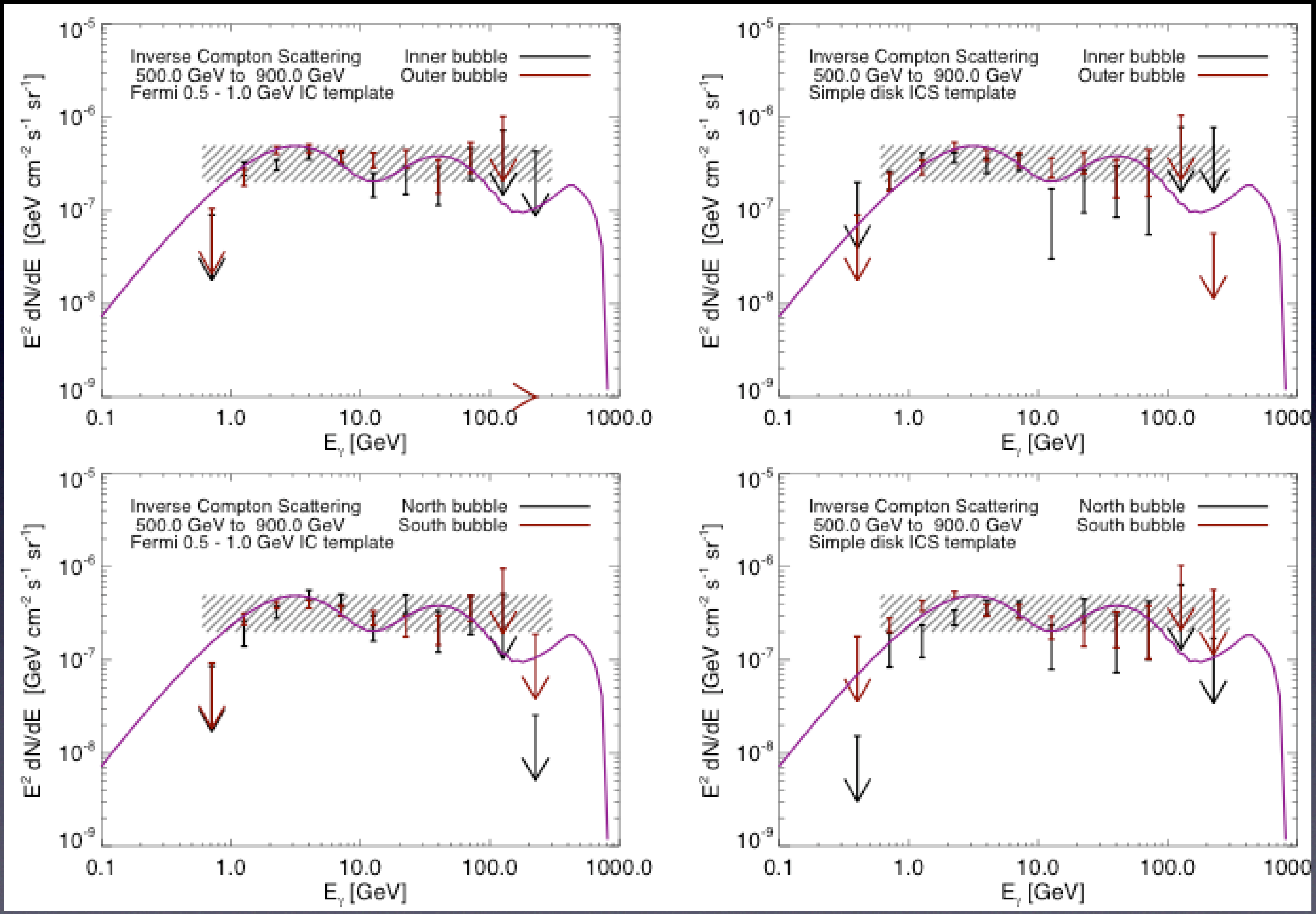
1. The bubble intensity is ~flat with latitude, while starlight density is falling.

2. The shape of the IC spectrum.

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



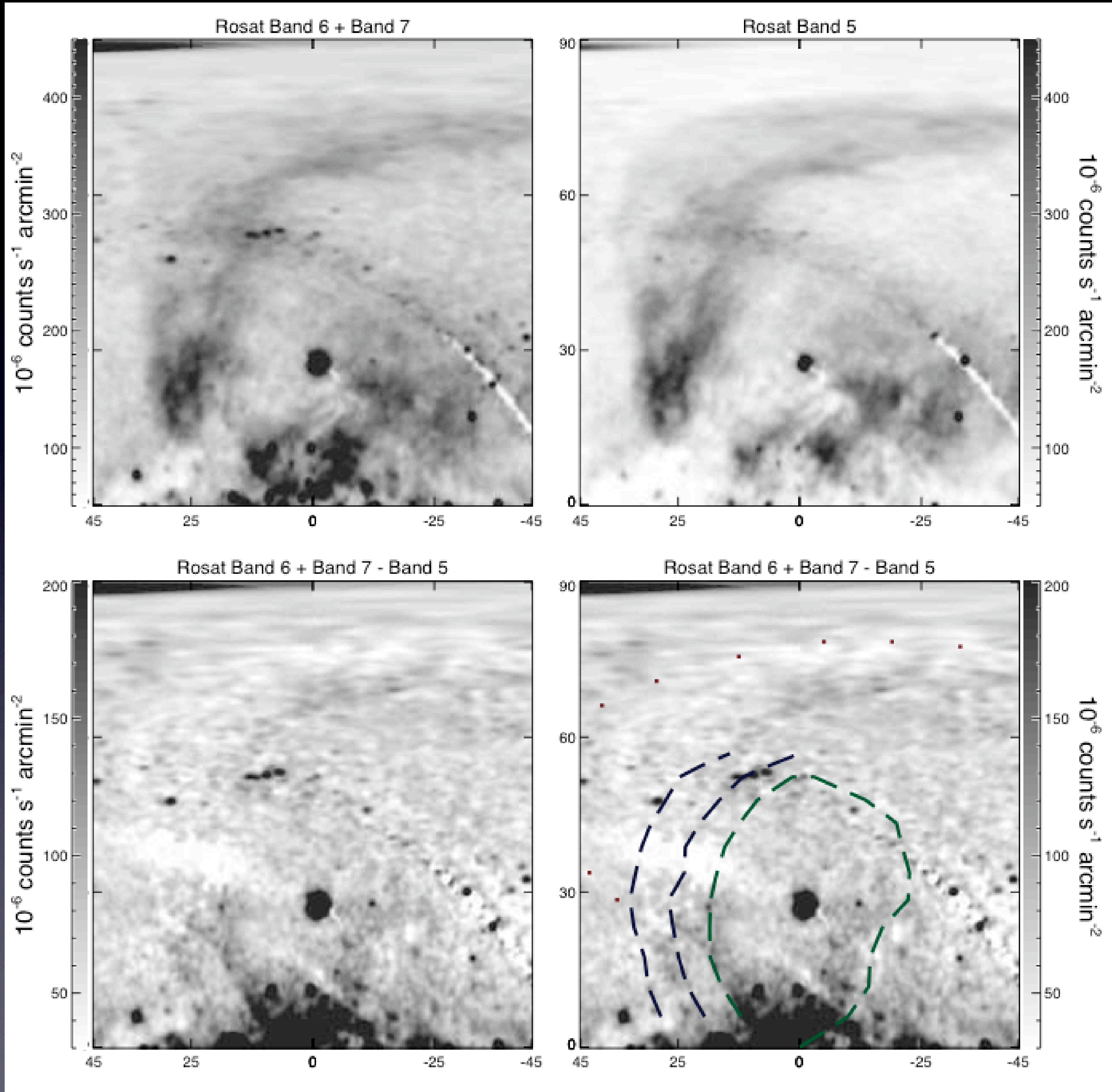
500-900 GeV electrons scattering CMB roll off at the right (low) energy.



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

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.

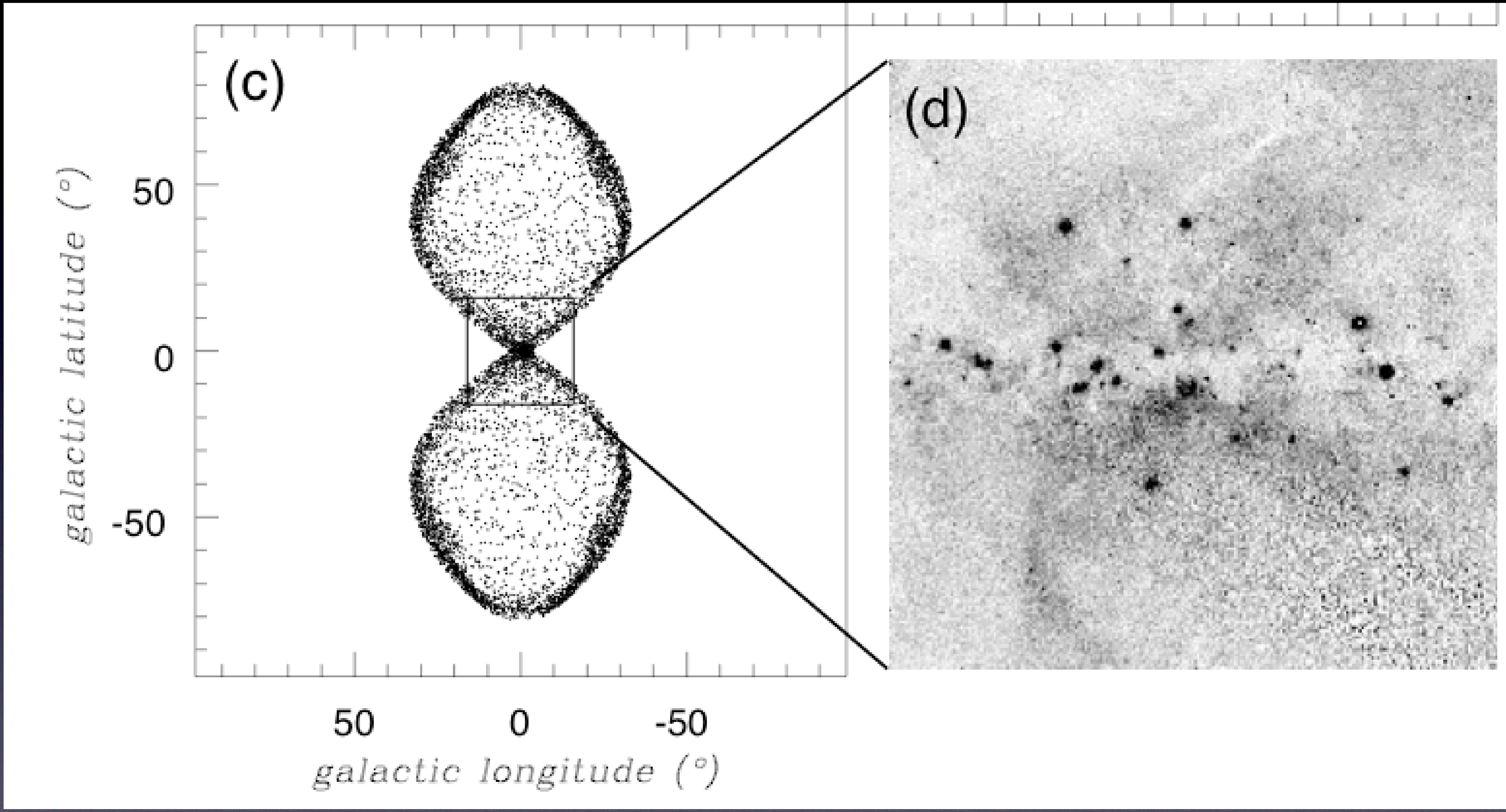
What are they?

Black hole “burp”

Superwind bubble?

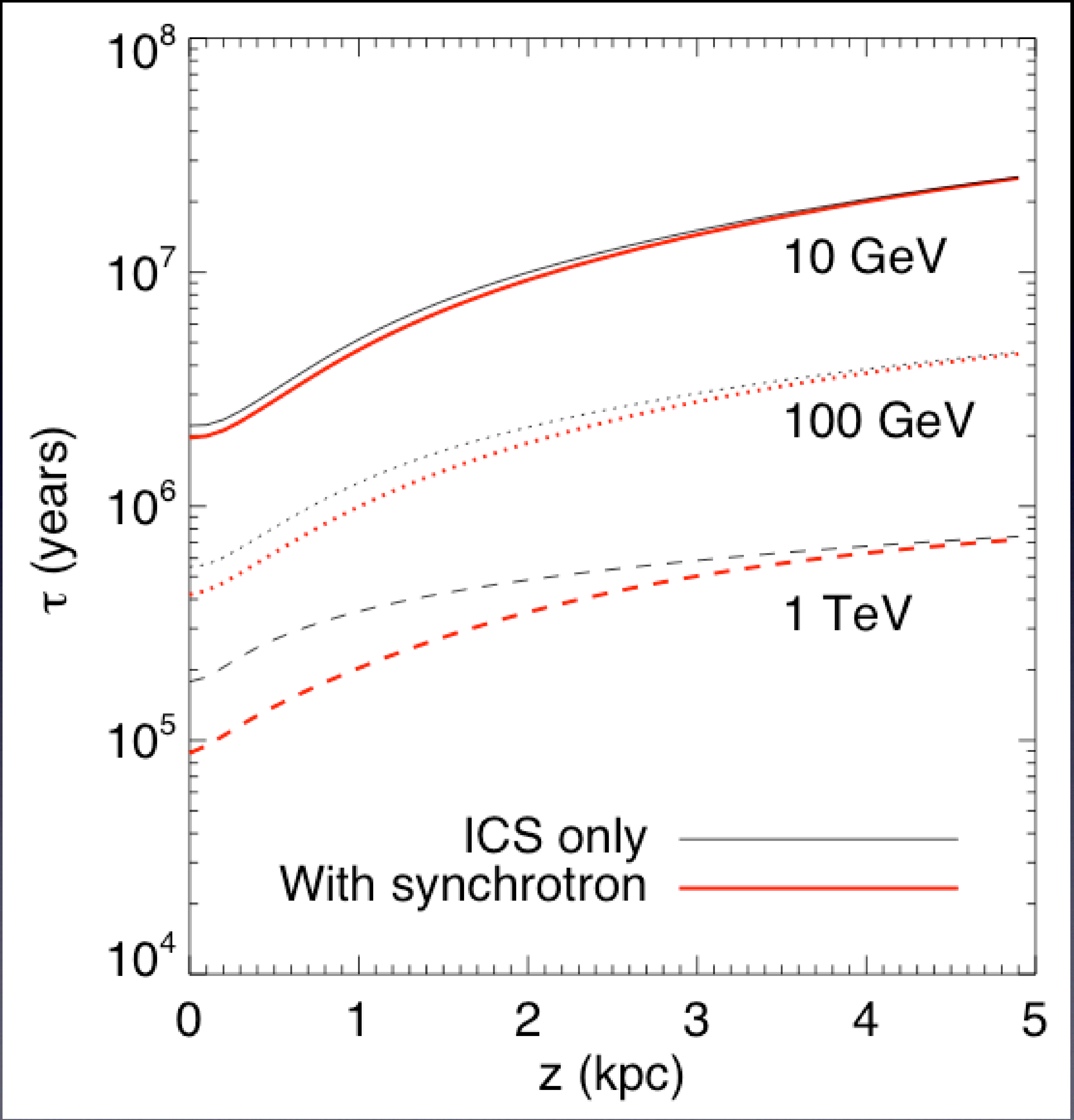
Based only on ROSAT X-ray data and some FIR data (MSX) near the plane, previous authors suggested the presence of large starburst-produced bubbles containing ~ 10^{55} erg of thermal energy.

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

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.

Other interpretations

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. (see next talk).

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.

"Many failures are people who did not know how close they were to success when they gave up"

- Thomas Edison (Age 30, *before* light bulb success)

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.