Hazology 101: *WMAP* and *Fermi* haze

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KITP, 7 Dec, 2009

WMAP foreground templates

Full physical model:
pro: uses everything we know to fit data.
con: only uses what we put in the model.

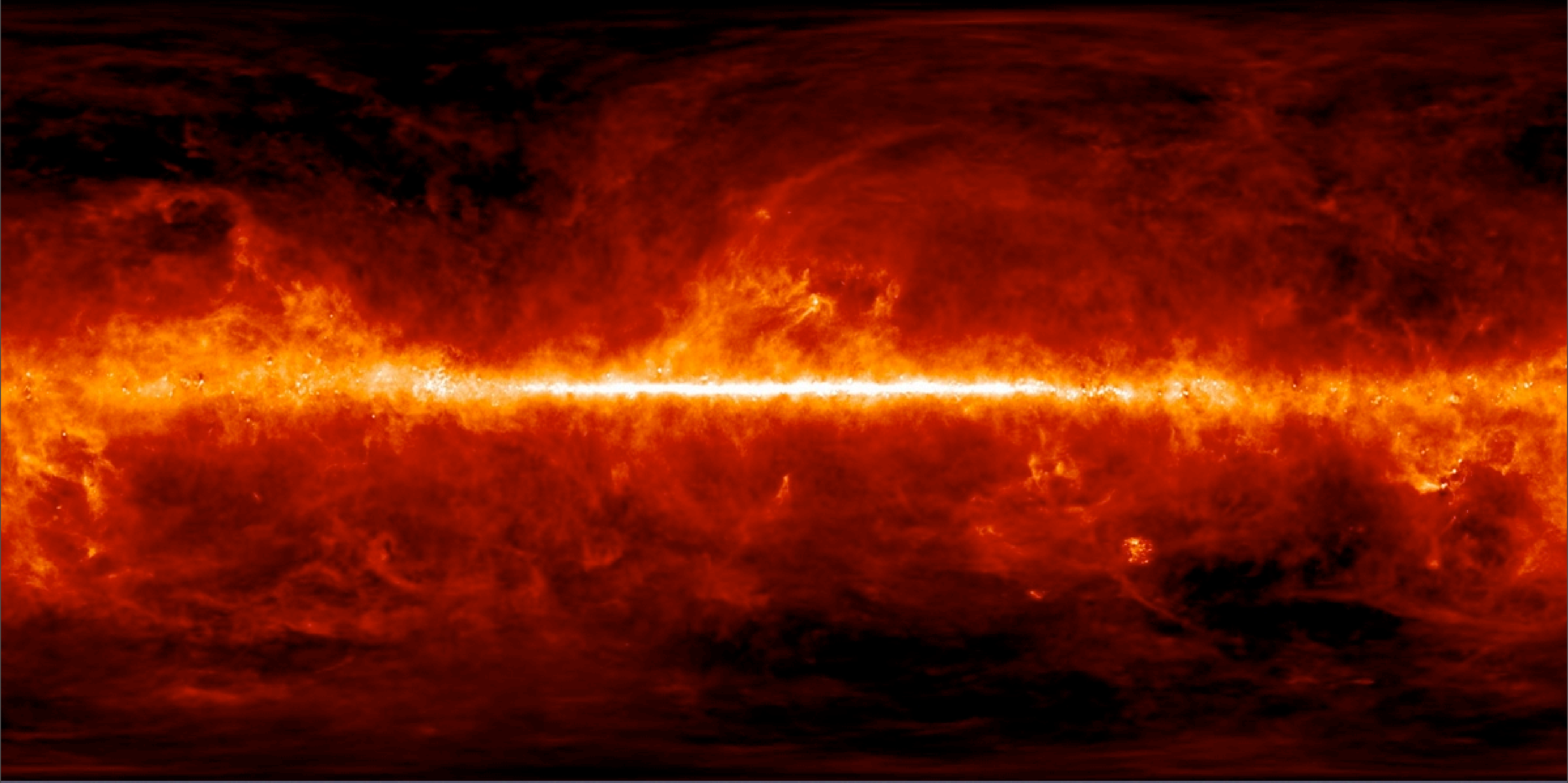
Template analysis:
pro: the templates work pretty well; may reveal new emission mechanisms. Simple.
con: must assess fit residuals carefully, because fit is never perfect.

WMAP foreground templates

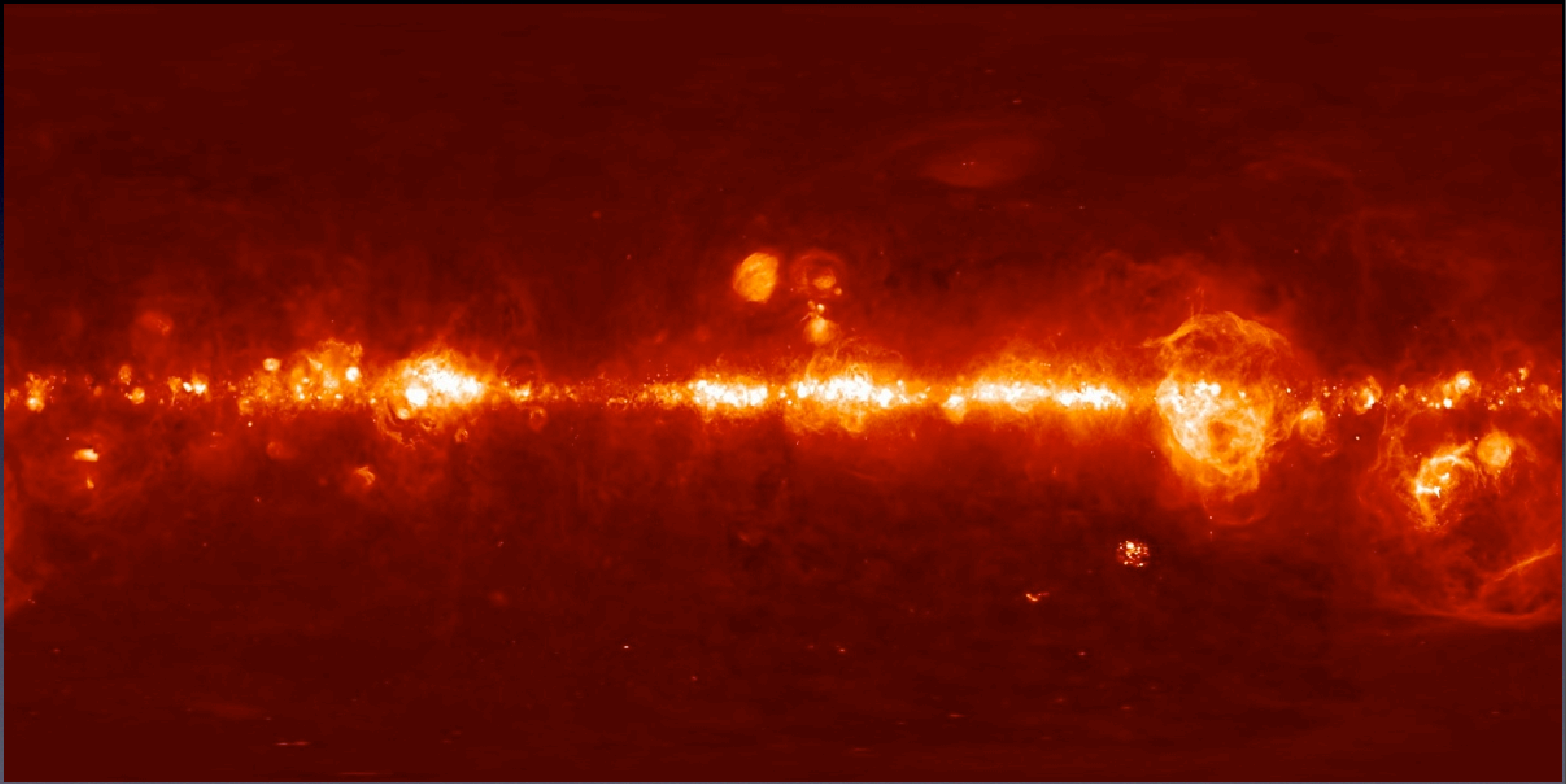
Available templates (as of 2003):

SFD dust - Far IR based dust map
Halpha - free-free template, must correct for extinction
Haslam - 408 MHz radio survey

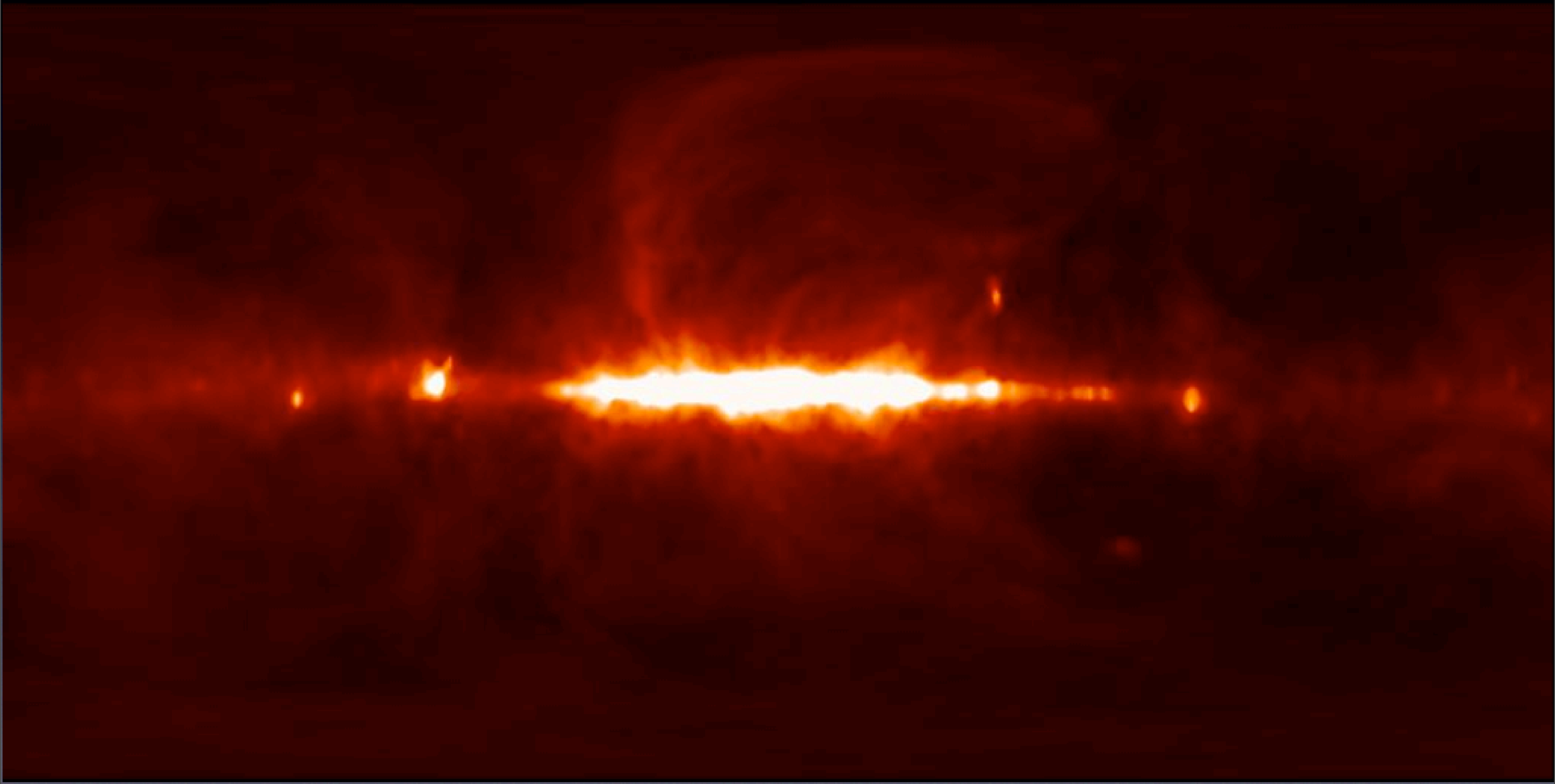
Interstellar Dust from IRAS, DIRBE (Finkbeiner et al. 1999) Map extrapolated from 3 THz (100 micron) with FIRAS.

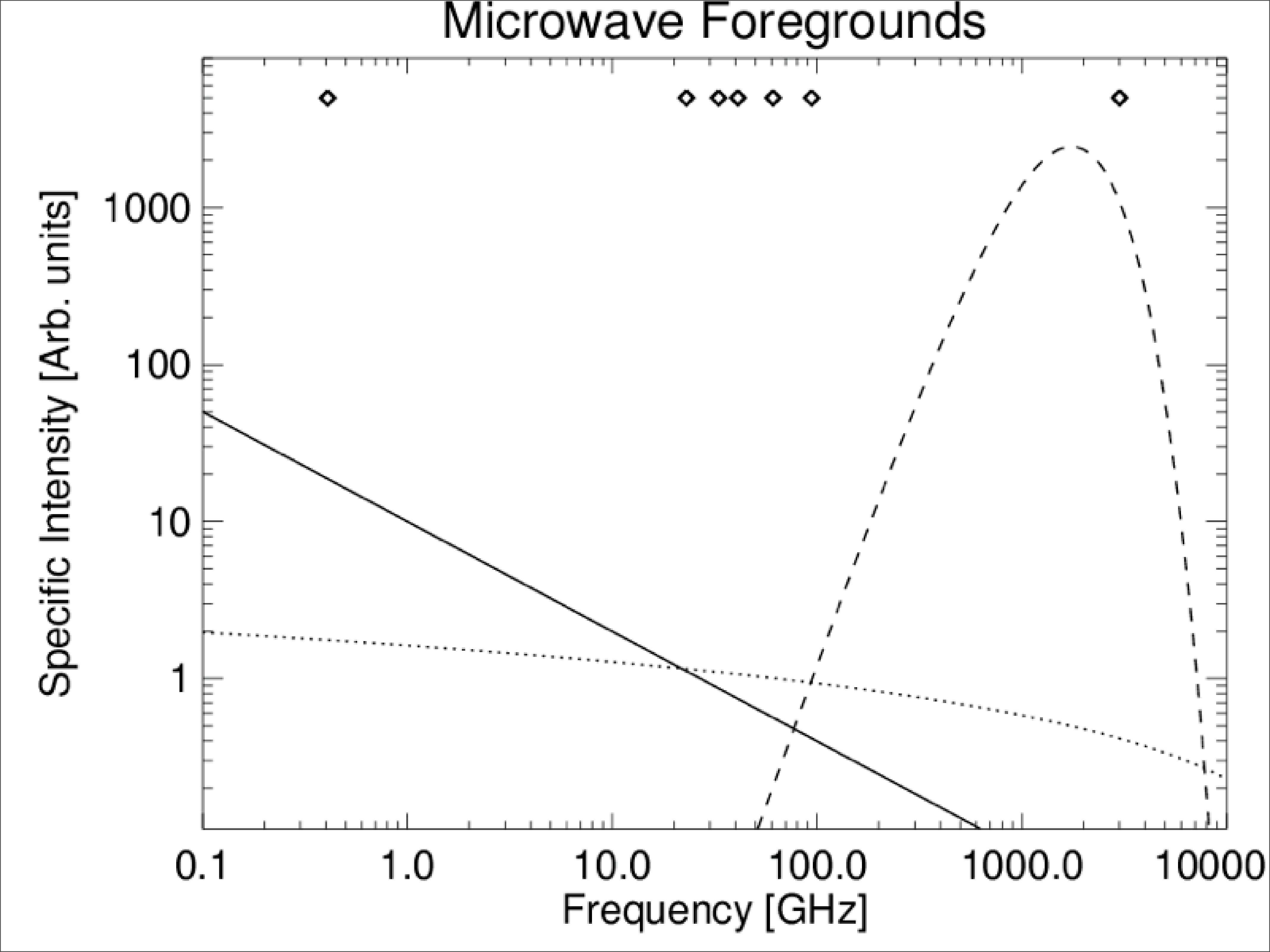


Ionized Gas from WHAM, SHASSA, VTSS (Finkbeiner 2003)
H-alpha emission measure goes as thermal bremsstrahlung.



Synchrotron at 408 MHz (Haslam et al. 1982)





Microwave Foregrounds
Specific Intensity [Arb. units]
1000
100
10
1
0.1
1.0
10.0
100.0
1000.0
10000
Frequency [GHz]

These spectra are representative, but can vary.

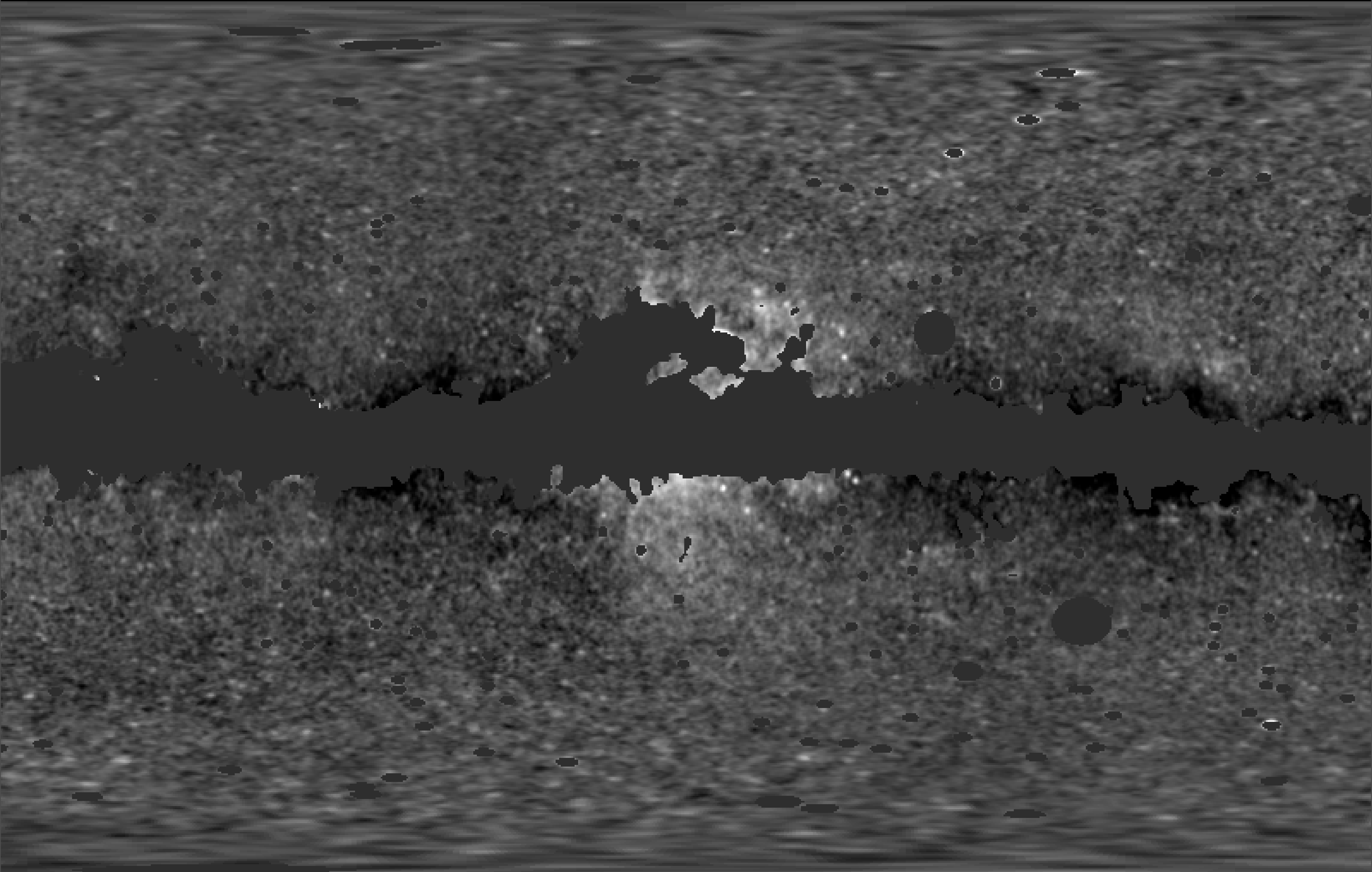
* Dust spectrum varies (see FDS 99)
Also, dust T correction, zody, etc...

* H-alpha/microwave f-f depends on T_gas

* Synchrotron spectrum depends on
electron CR spectrum.

WMAP haze

Subtracting all known Galactic foregrounds from the WMAP maps, we a residual in the inner ~ 25 deg of the Galaxy:



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.

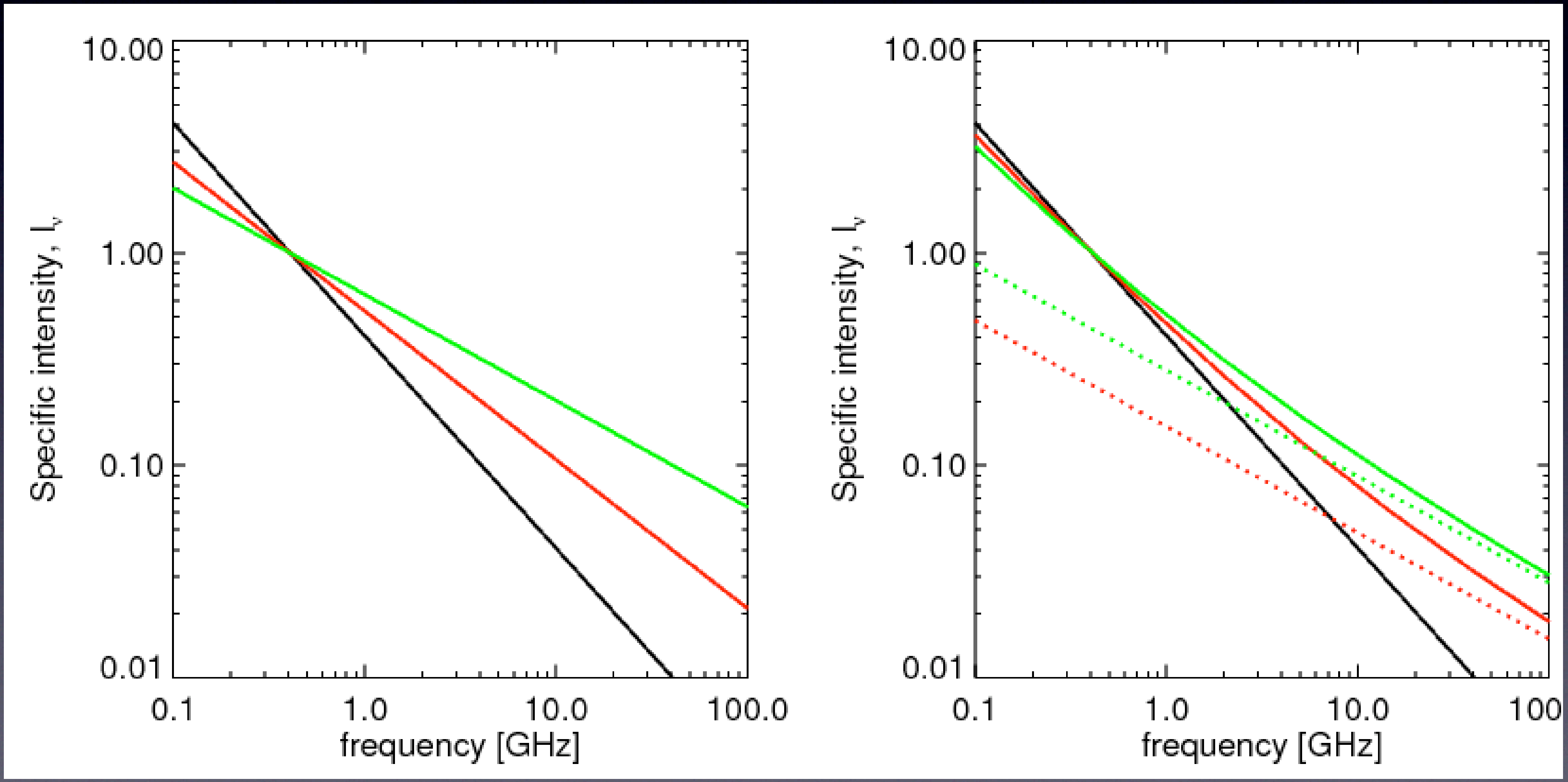
WMAP haze

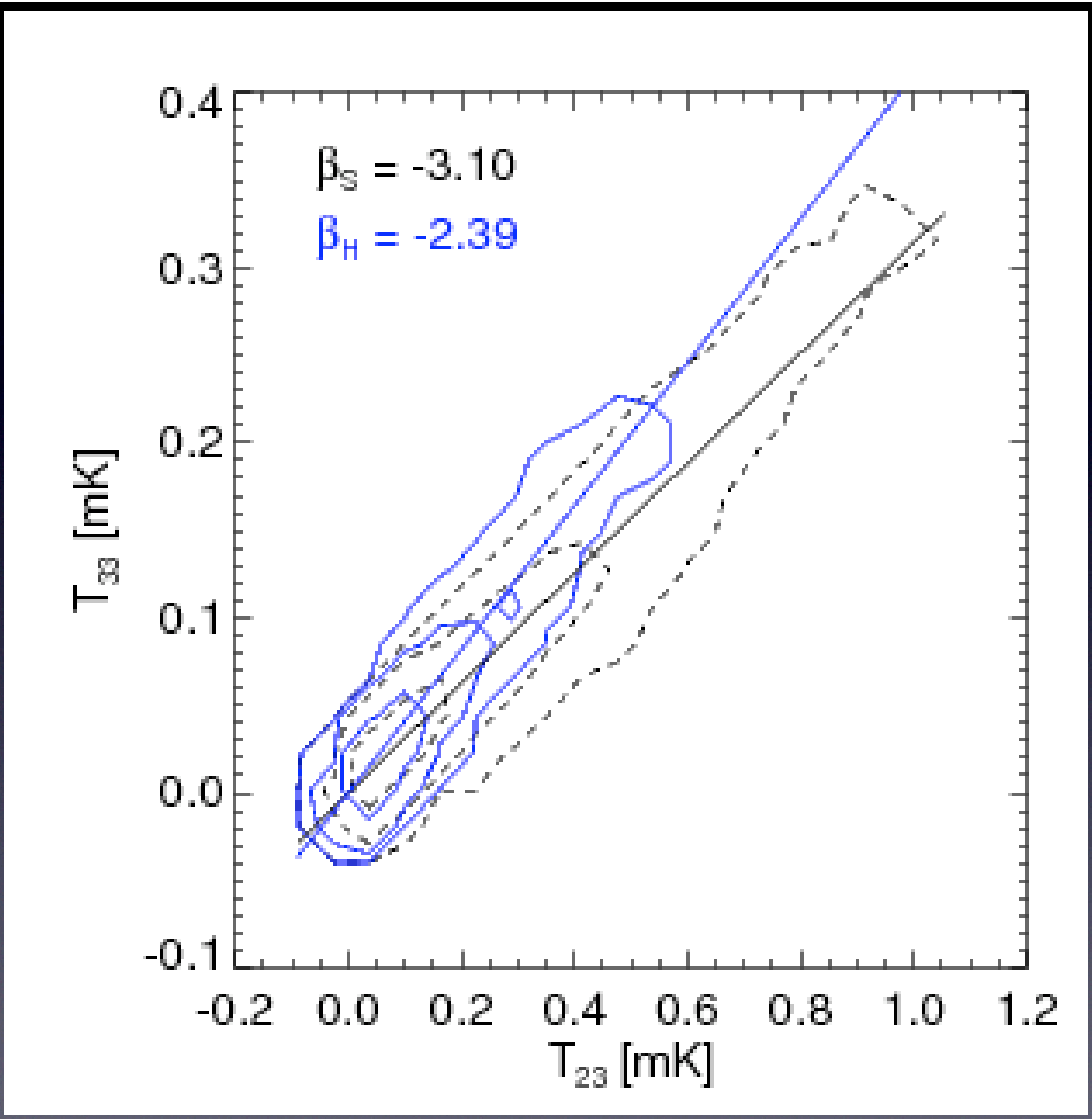
The Galaxy is complicated, but we understand it pretty well.

Free-free require too much 10^5 K gas.
Spinning dust is too well correlated with dust.

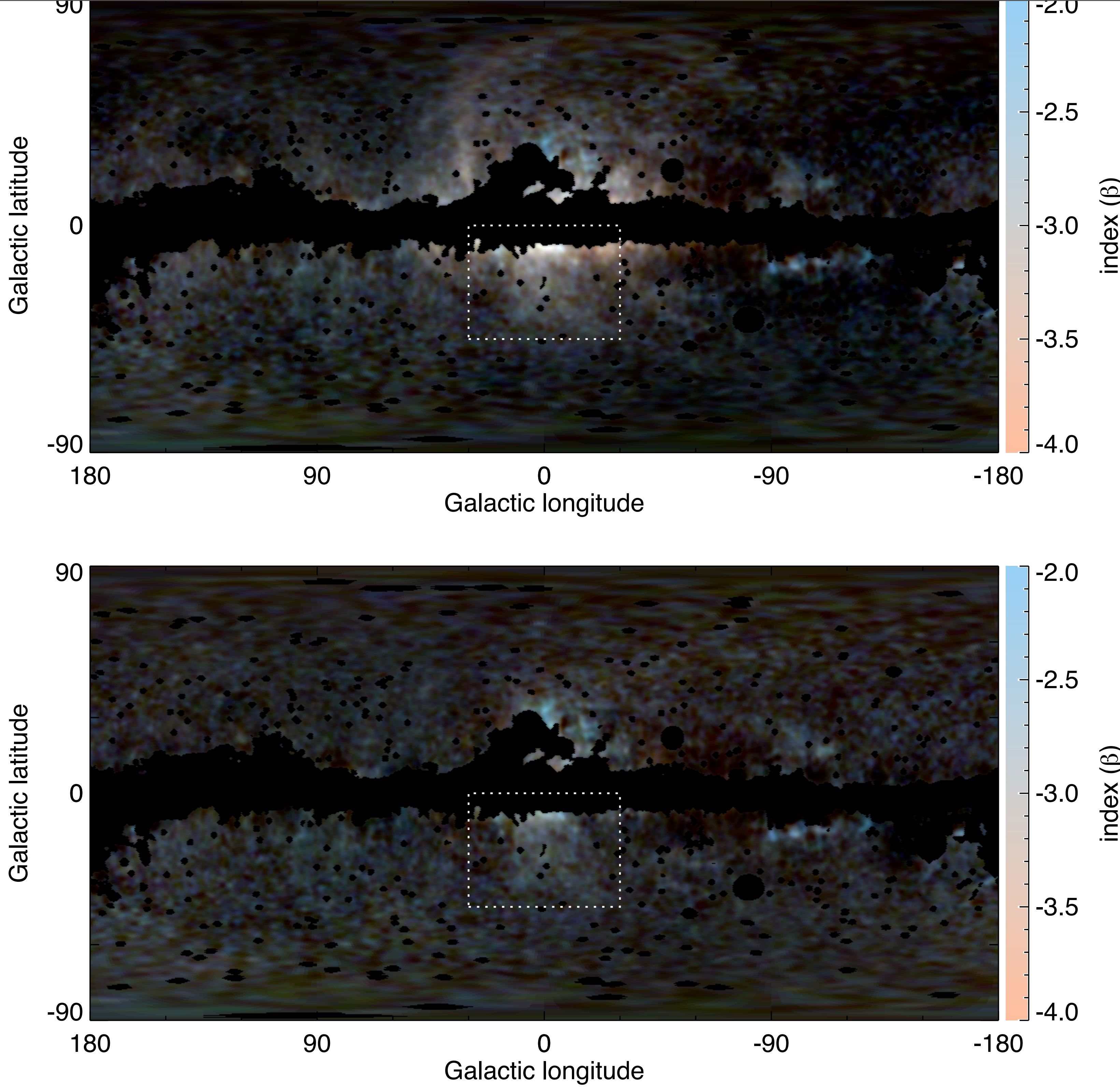
Could it be new physics? Or is it just extra supernovae? (i.e. one component or two?)

Spectral variation or new component?





β_S = -3.10
β_H = -2.39
0.4
0.3
0.2
0.1
0.0
-0.1
T_{33} [mK]
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
T_{23} [mK]


90
0
-90
Galactic latitude
180
90
0
-90
-180
Galactic longitude
-2.0
-2.5
-3.0
-3.5
-4.0
index (β)
90
0
-90
Galactic latitude
180
90
0
-90
-180
Galactic longitude
-2.0
-2.5
-3.0
-3.5
-4.0
index (β)

How to test the WMAP haze idea?

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

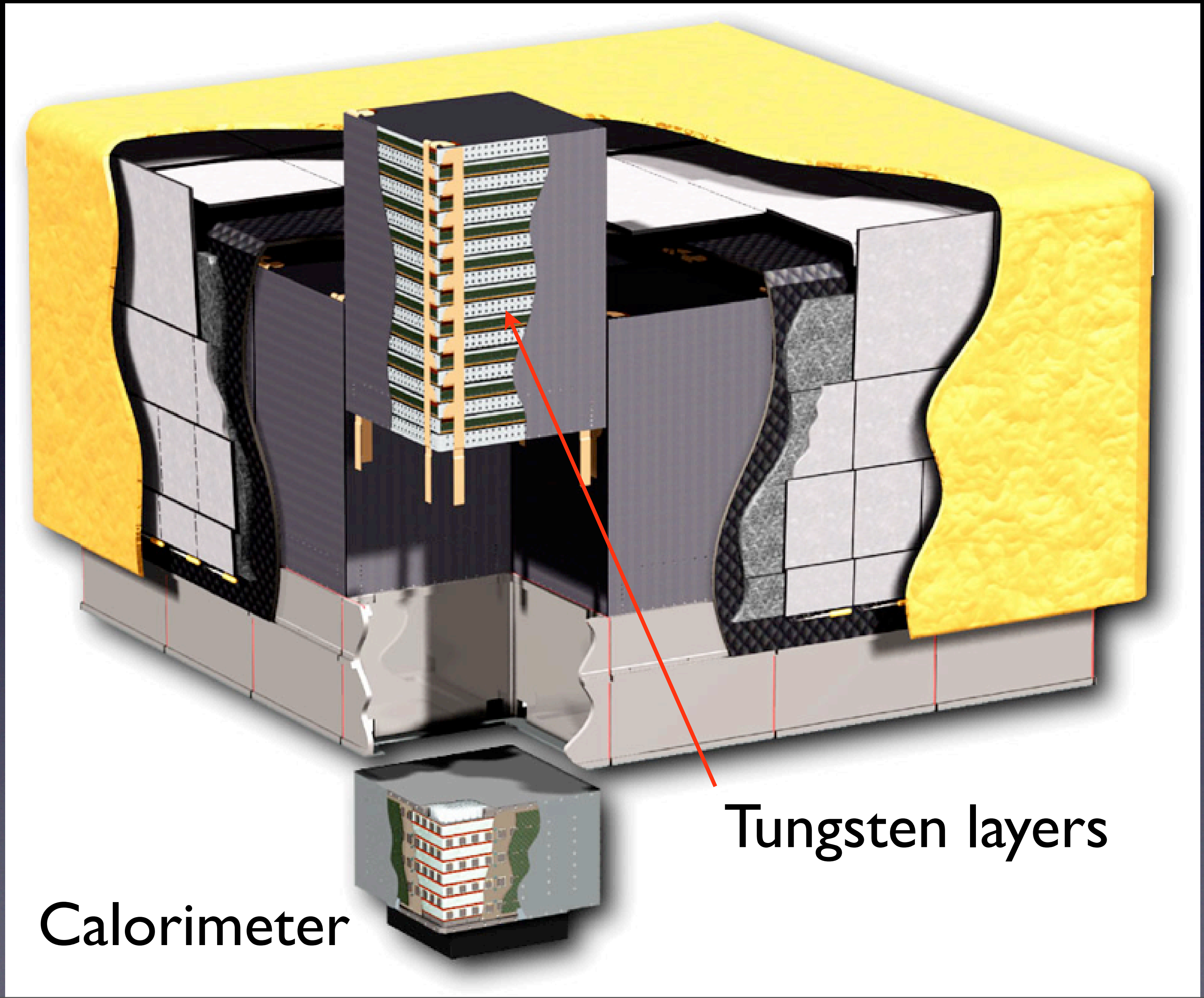
2) Do these electrons come from dark matter annihilation (or decay) ?

Fermi results (very recent):

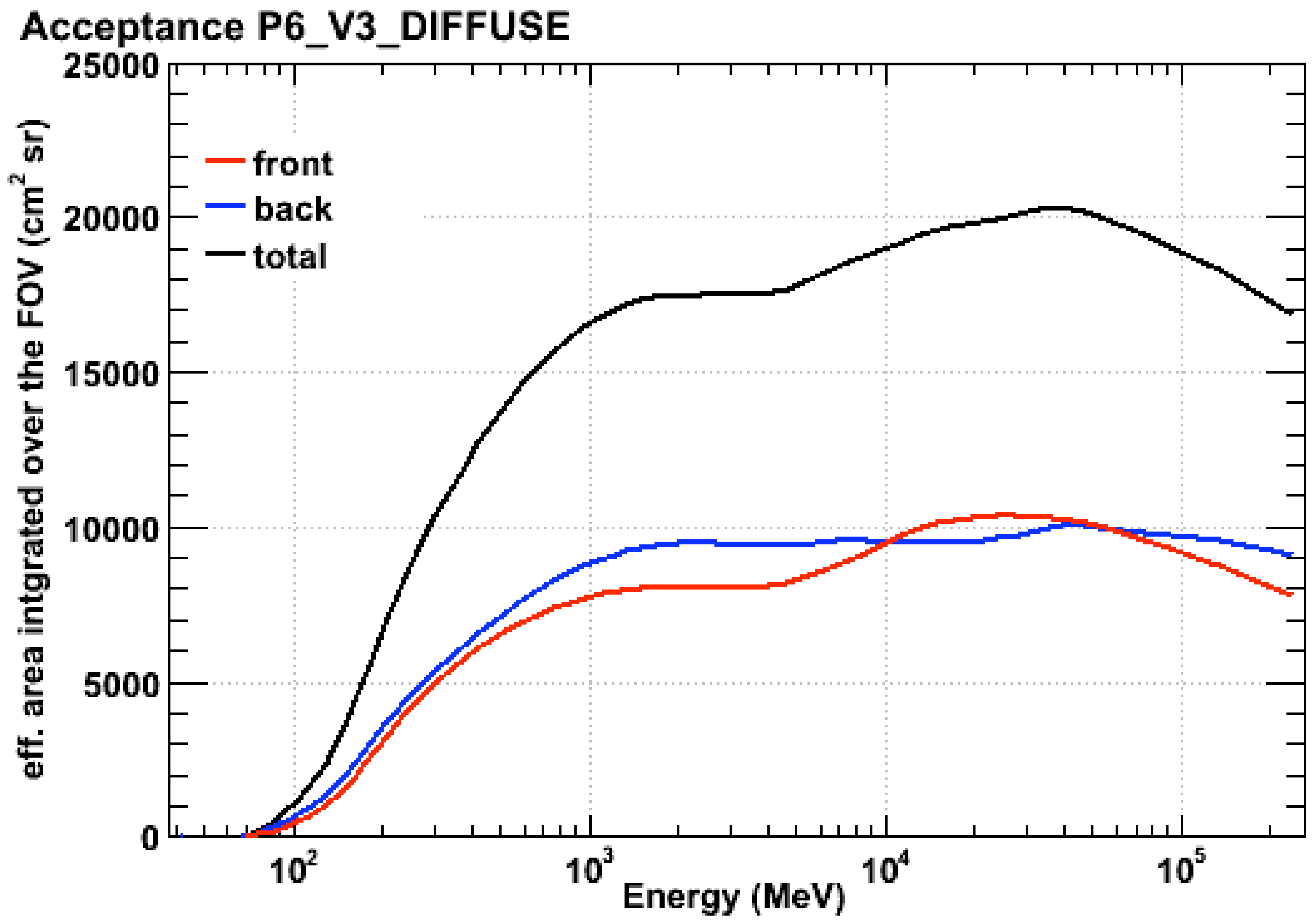
Fermi has released 15,878,650 "class 3" events useful for mapping diffuse emission. Available for download from the Fermi Science Support Center.

Fermi performance has been great!

Fermi LAT (large area telescope)

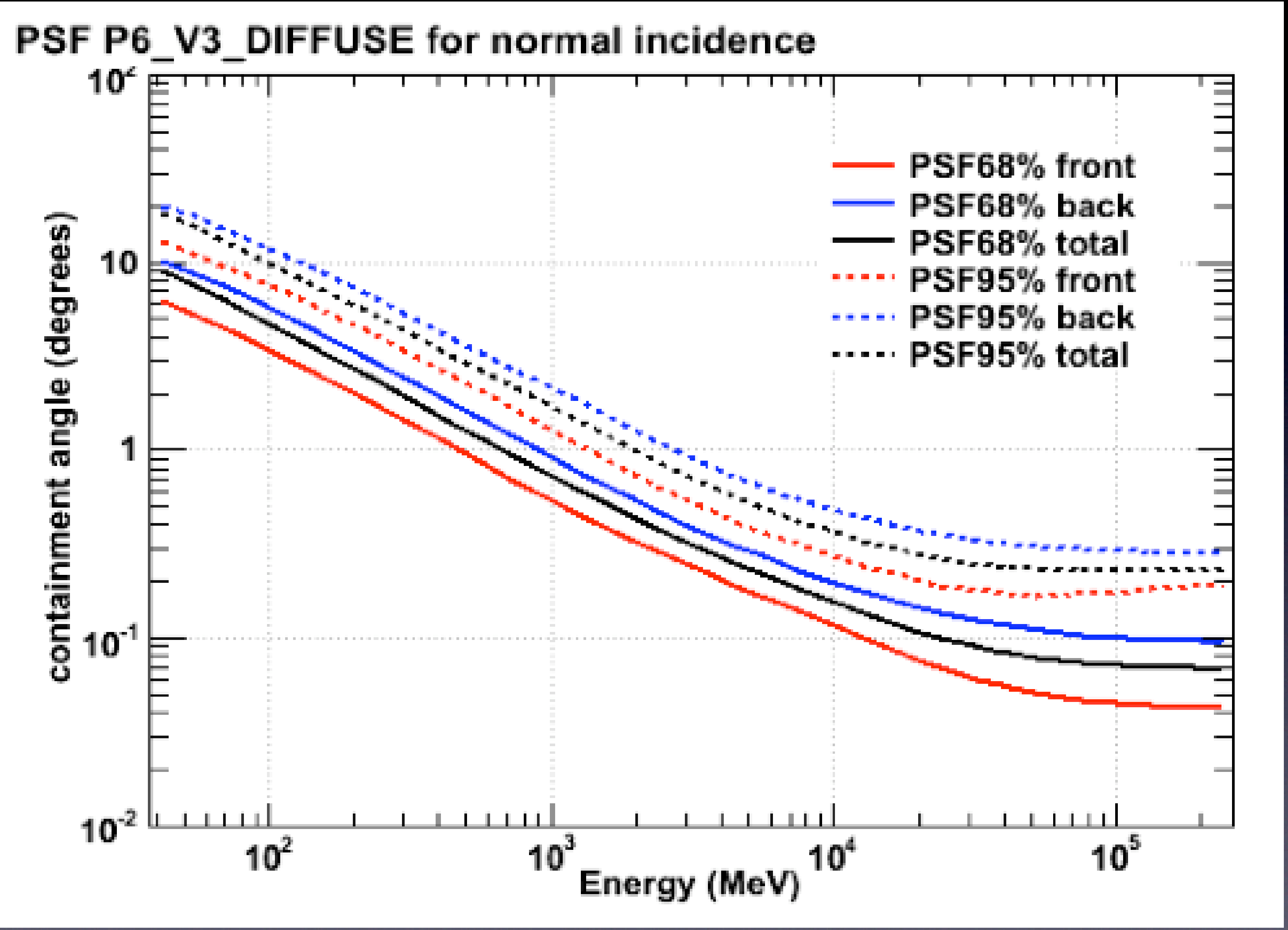


Fermi performance:



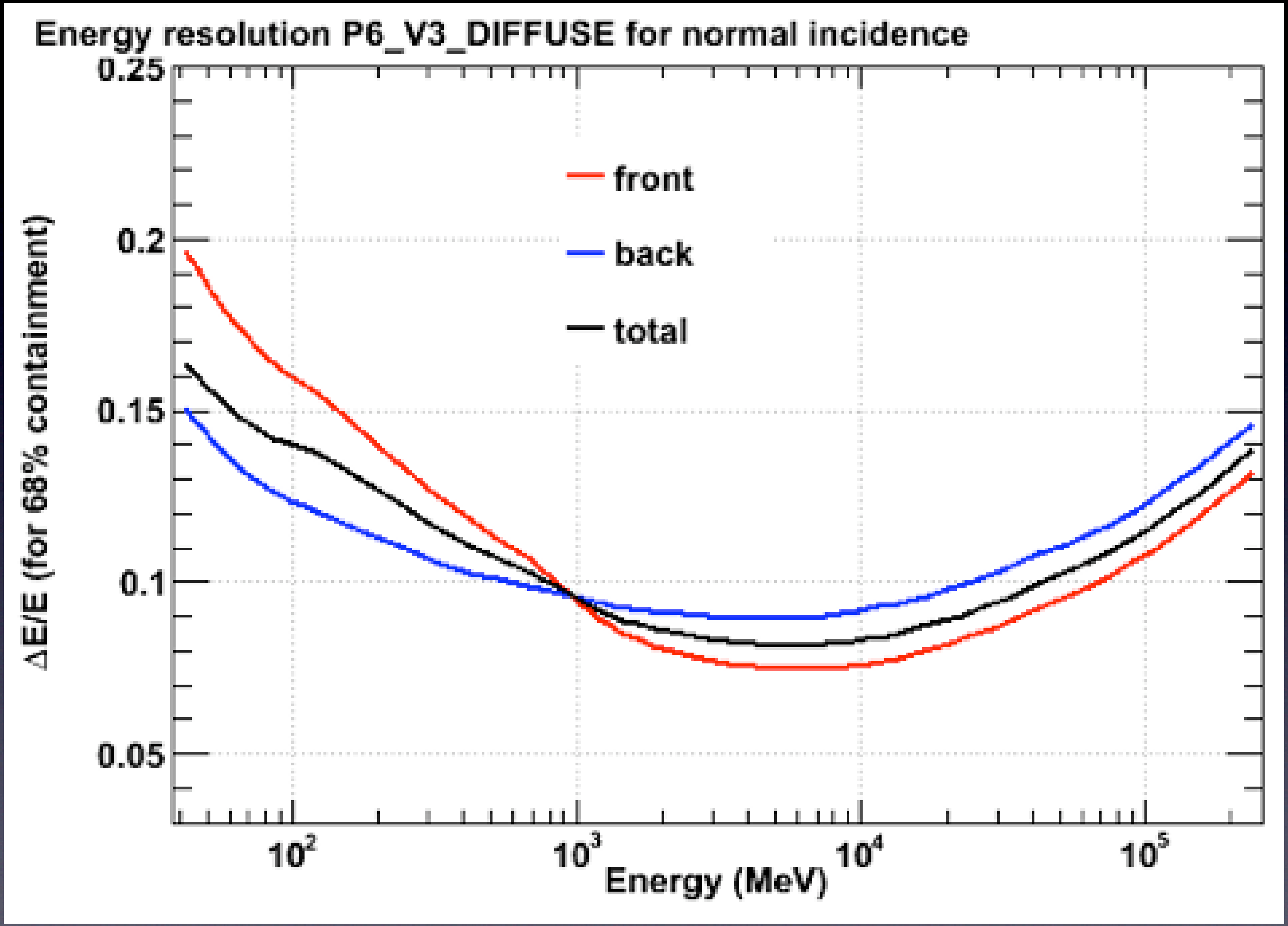
http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm

Fermi performance:



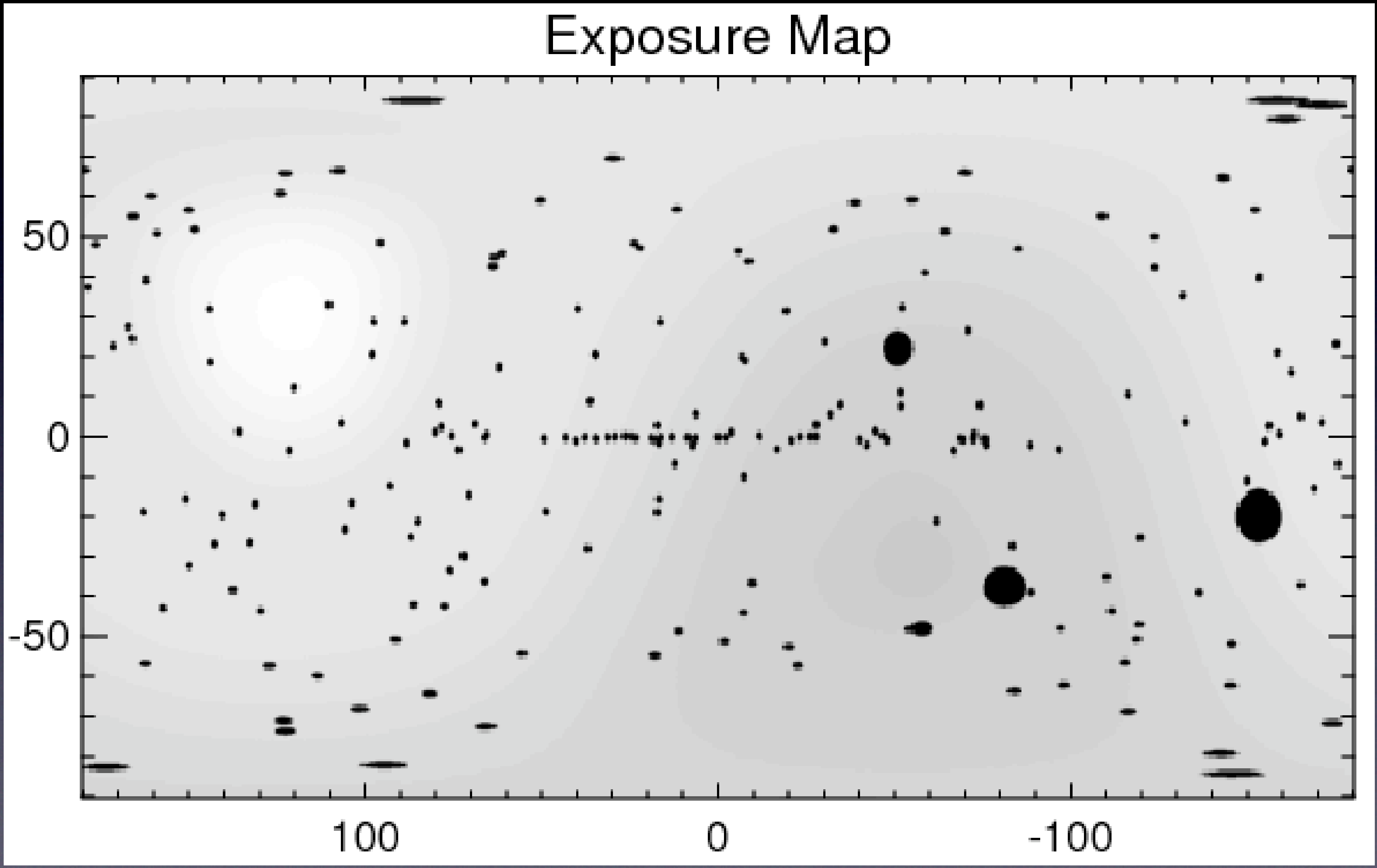
http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm

Fermi performance:

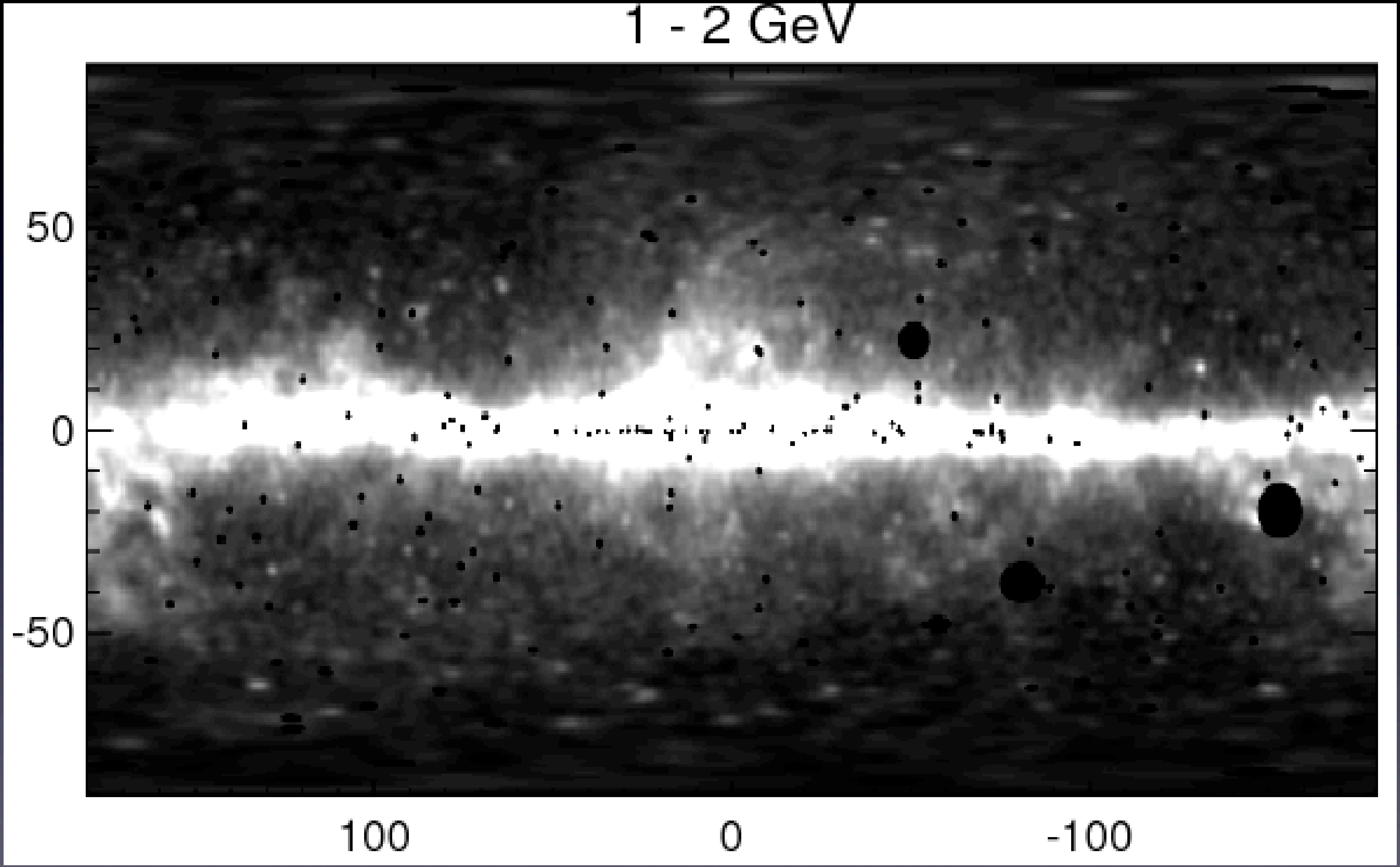


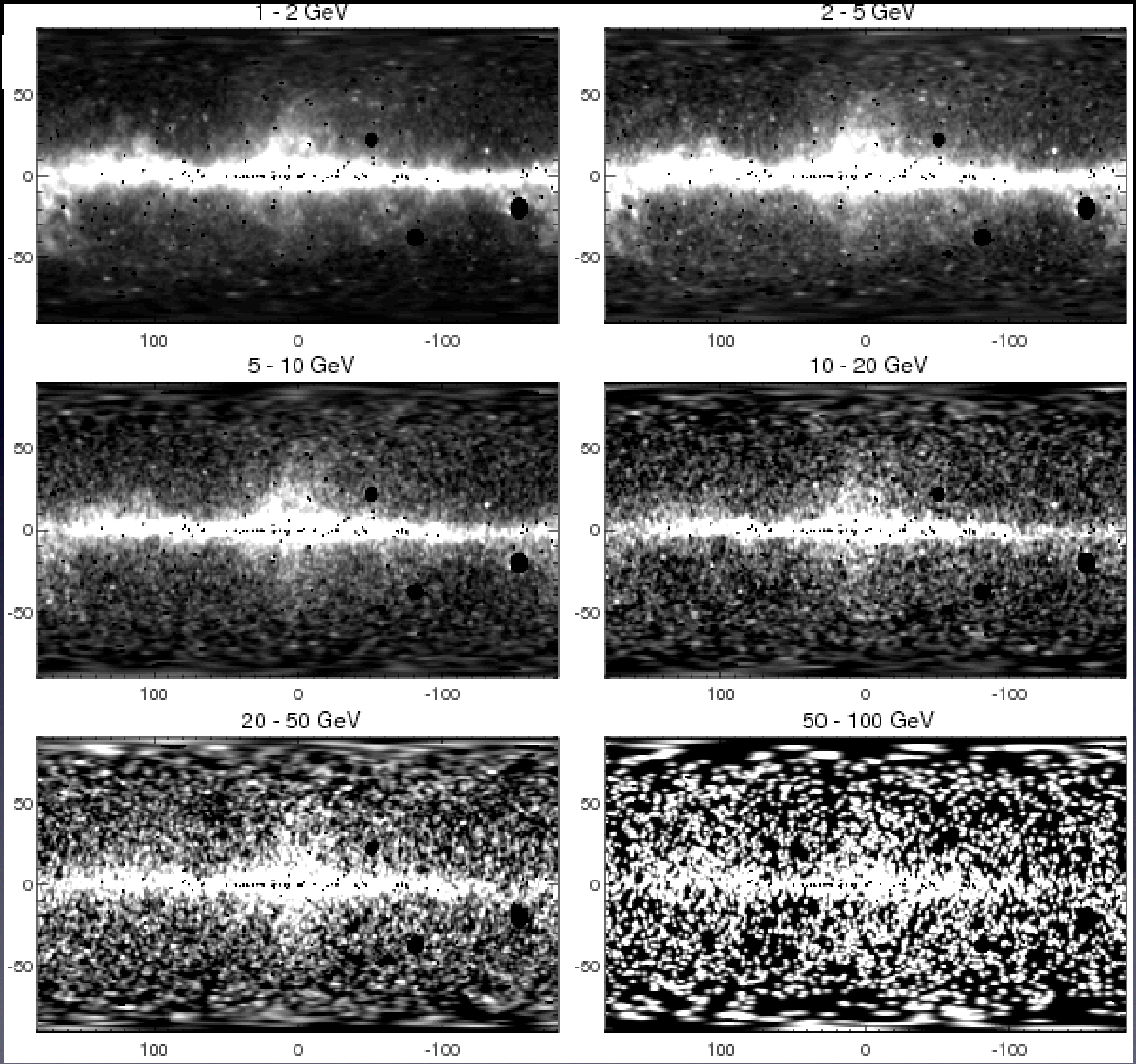
http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm

Fermi performance:



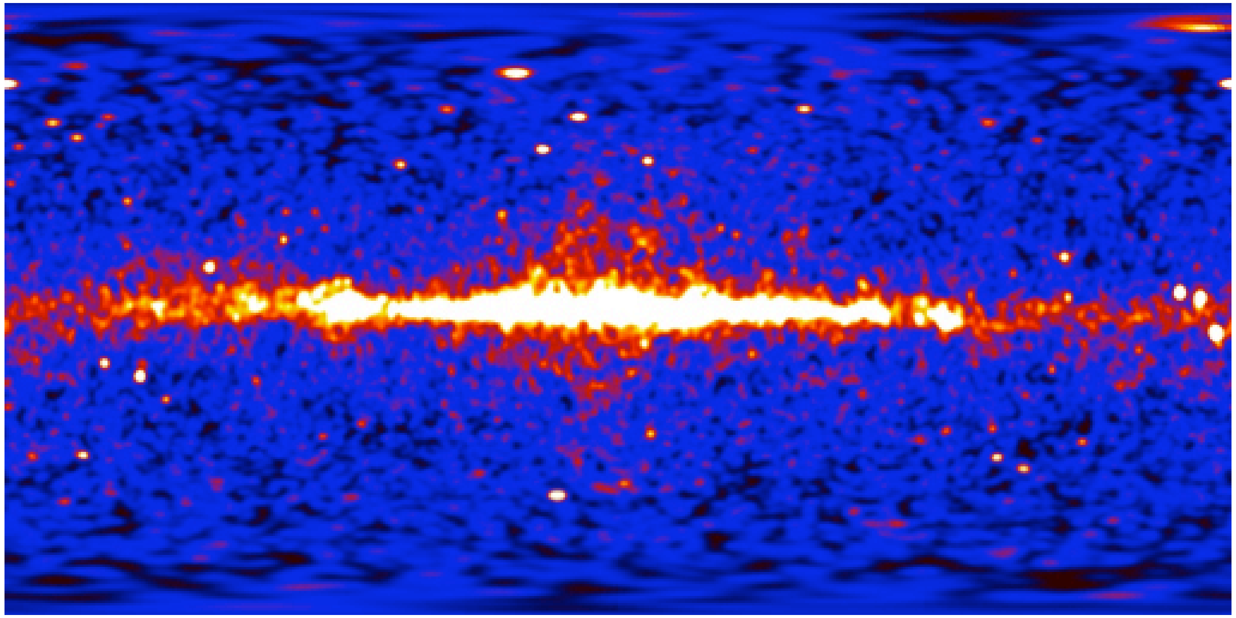
Fermi sky map (point source subtracted):




1 - 2 GeV
2 - 5 GeV
5 - 10 GeV
10 - 20 GeV
20 - 50 GeV
50 - 100 GeV
50
0
-50
100
0
-100

You can get these maps as HEALPix FITS files at
http://fermi.skymaps.info

Fermi LAT maps



This web page provides access to the Fermi LAT maps used in

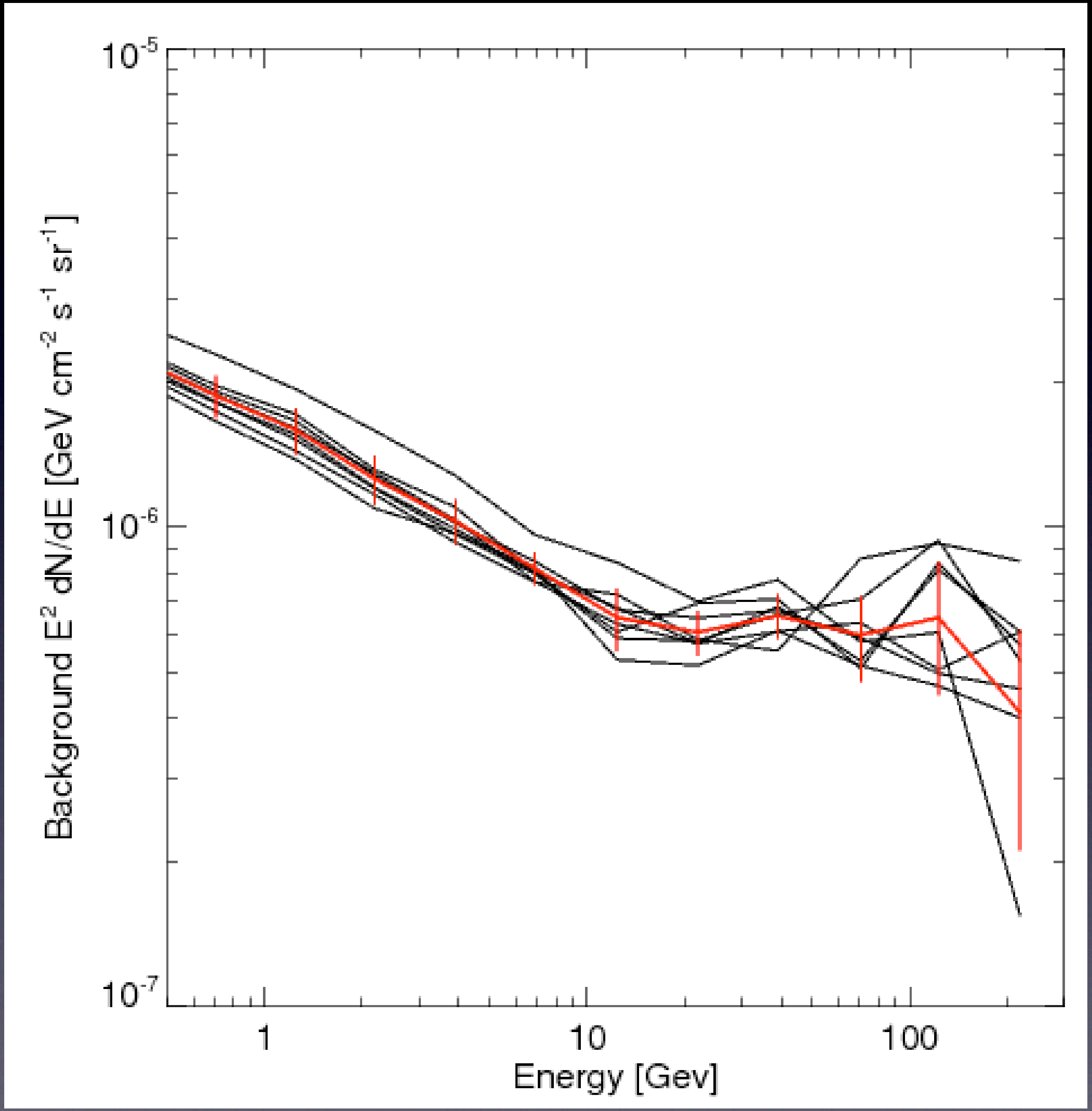
"The *Fermi* Haze: A Gamma-Ray counterpart to the Microwave Haze,"
G. Dobler, et al. 2009, arXiv:0910.4583

The maps were made by Douglas Finkbeiner and Gregory Dobler, and are *not an official data release of the Fermi collaboration*.

Official Fermi home page

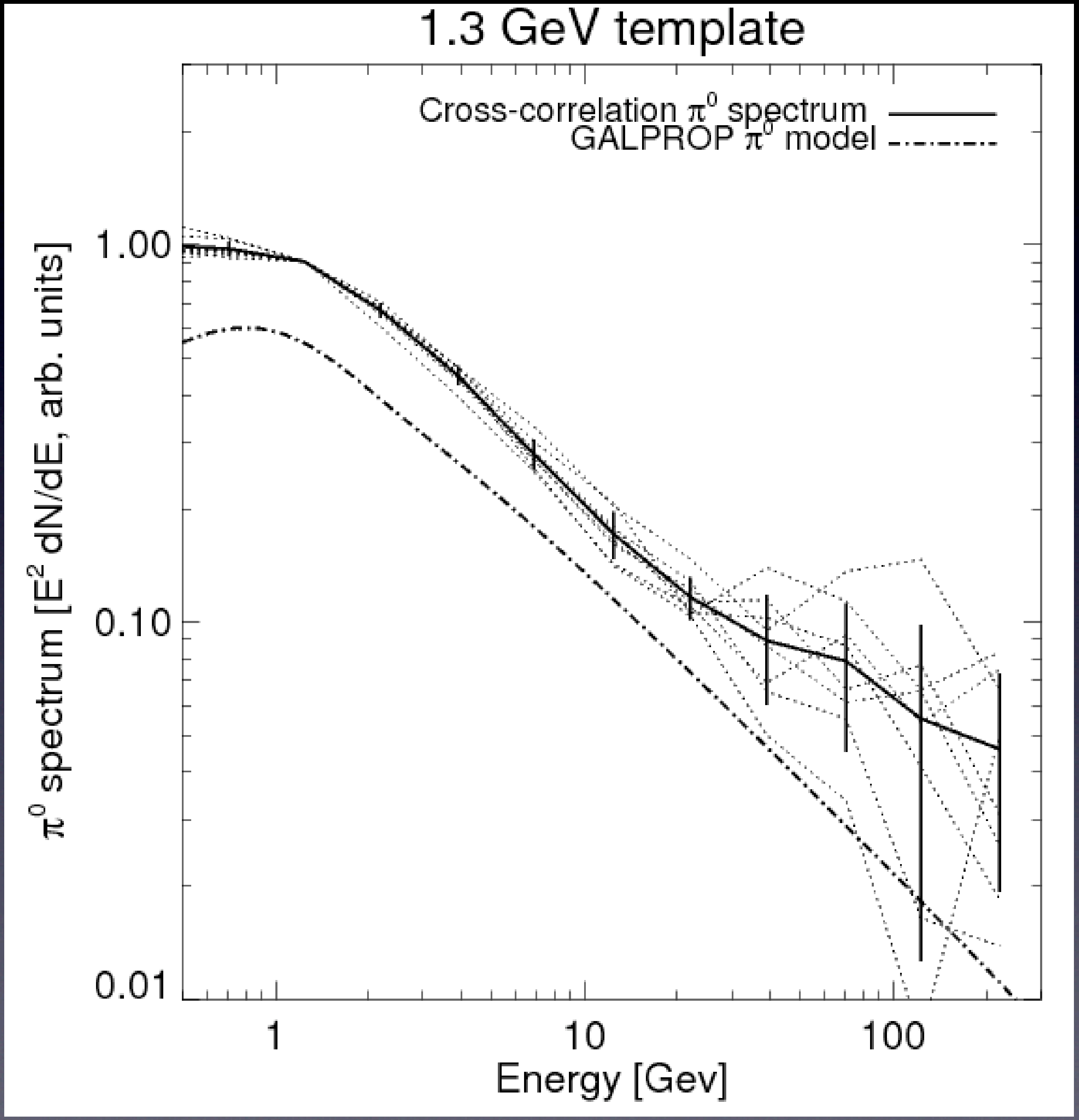
data v1_0

Fermi spectra - background:

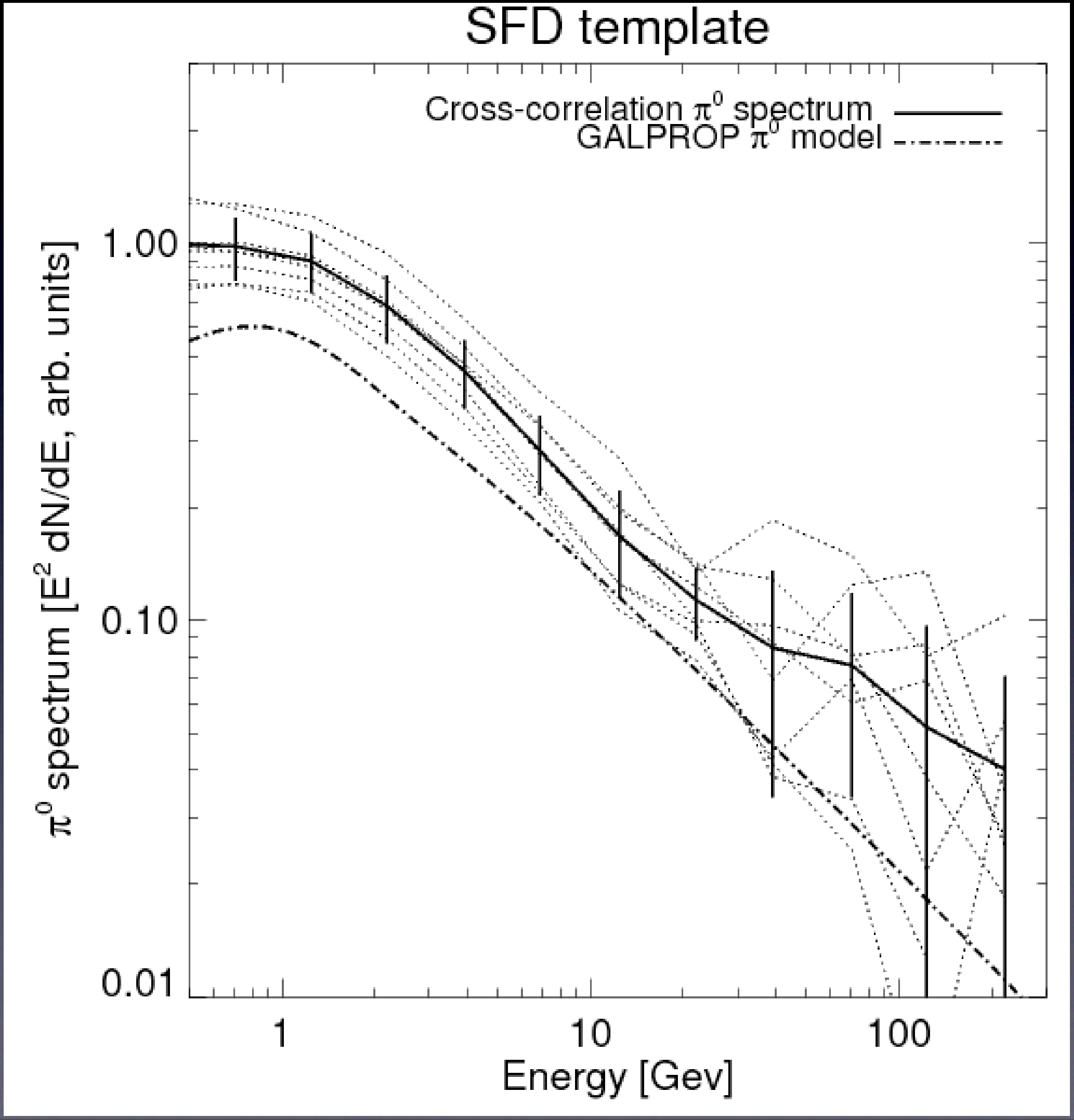


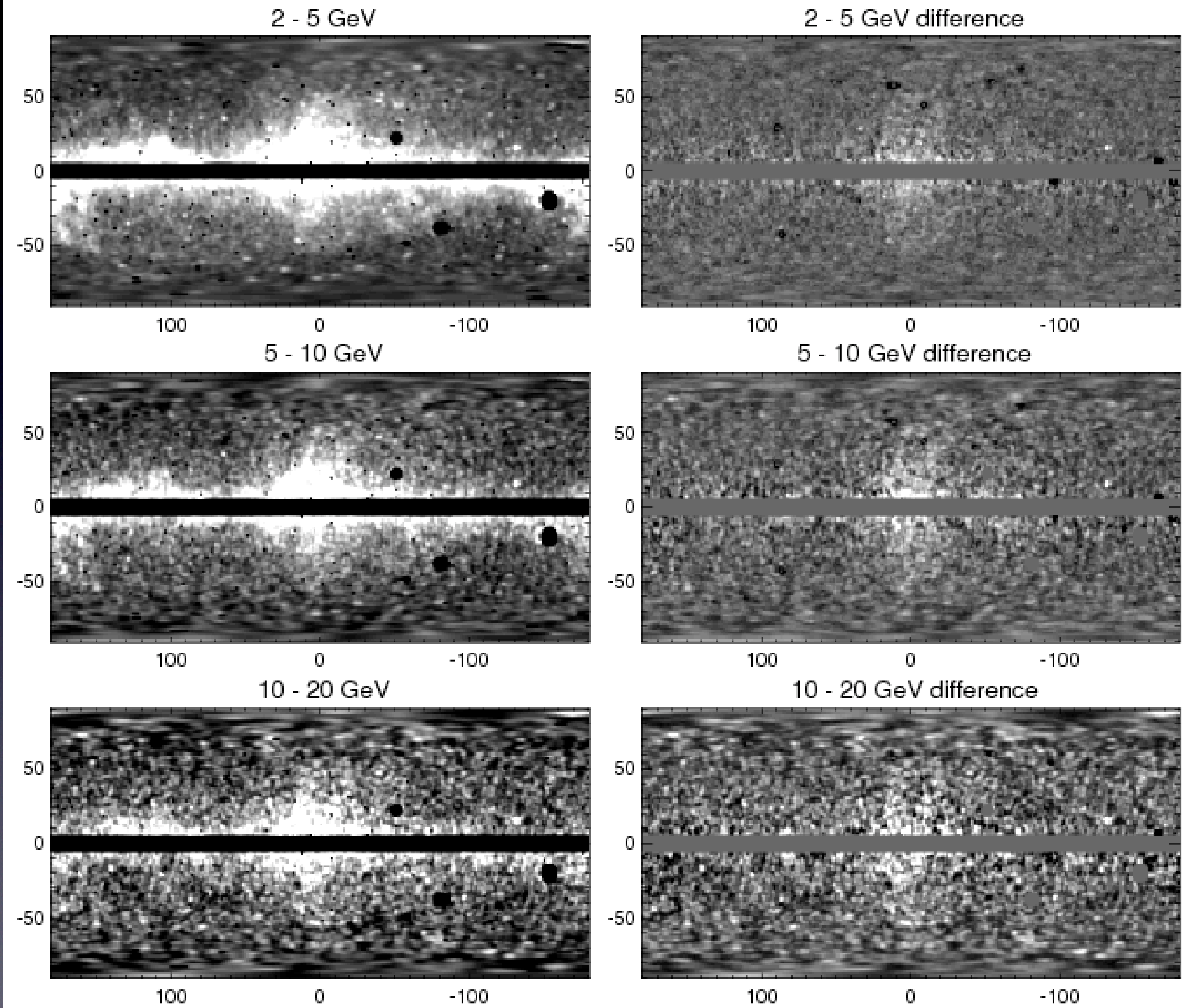
Dobler et al. (0910.4583)

Fermi spectra - pi 0 gammas?



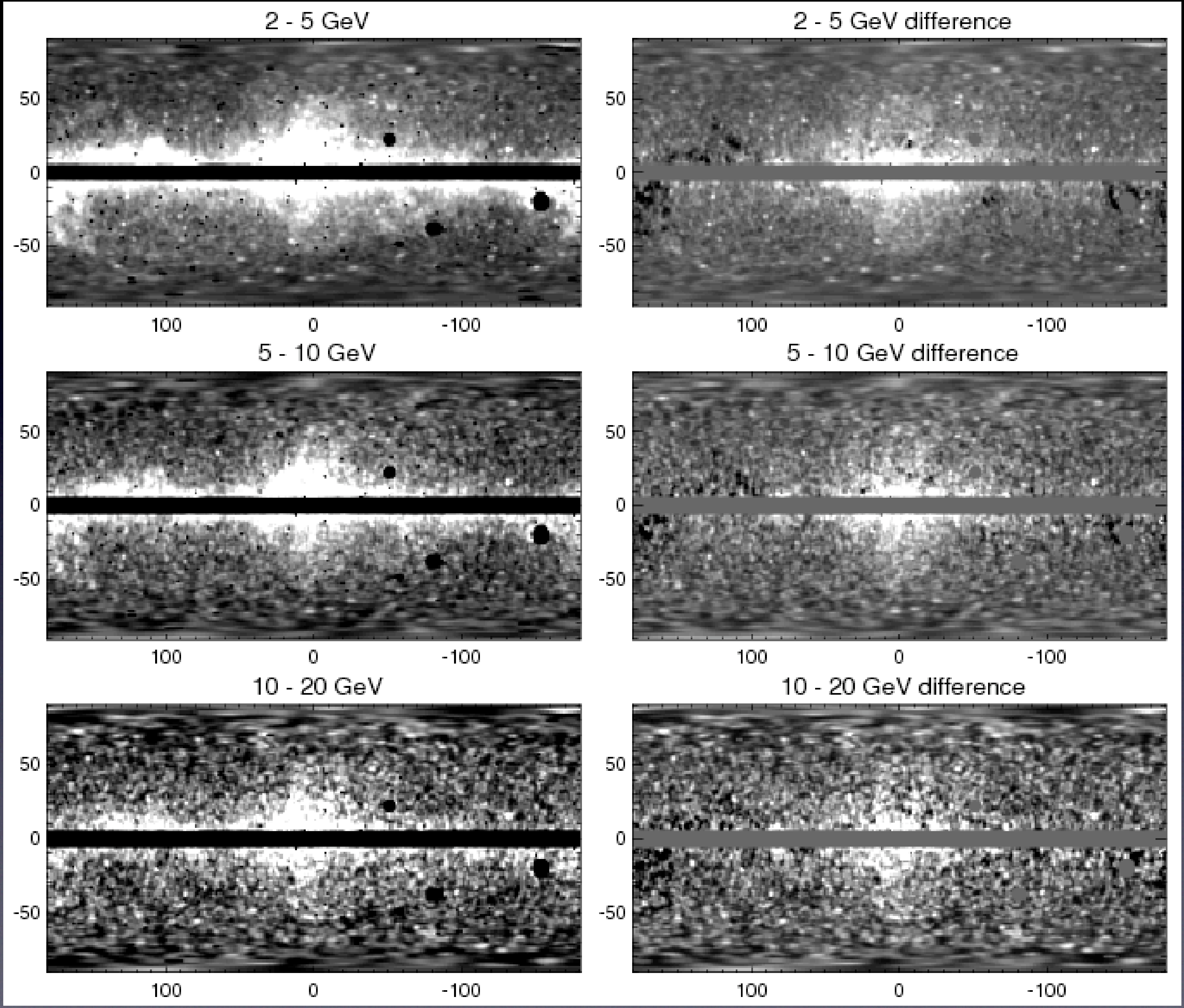
Regress against dust instead...





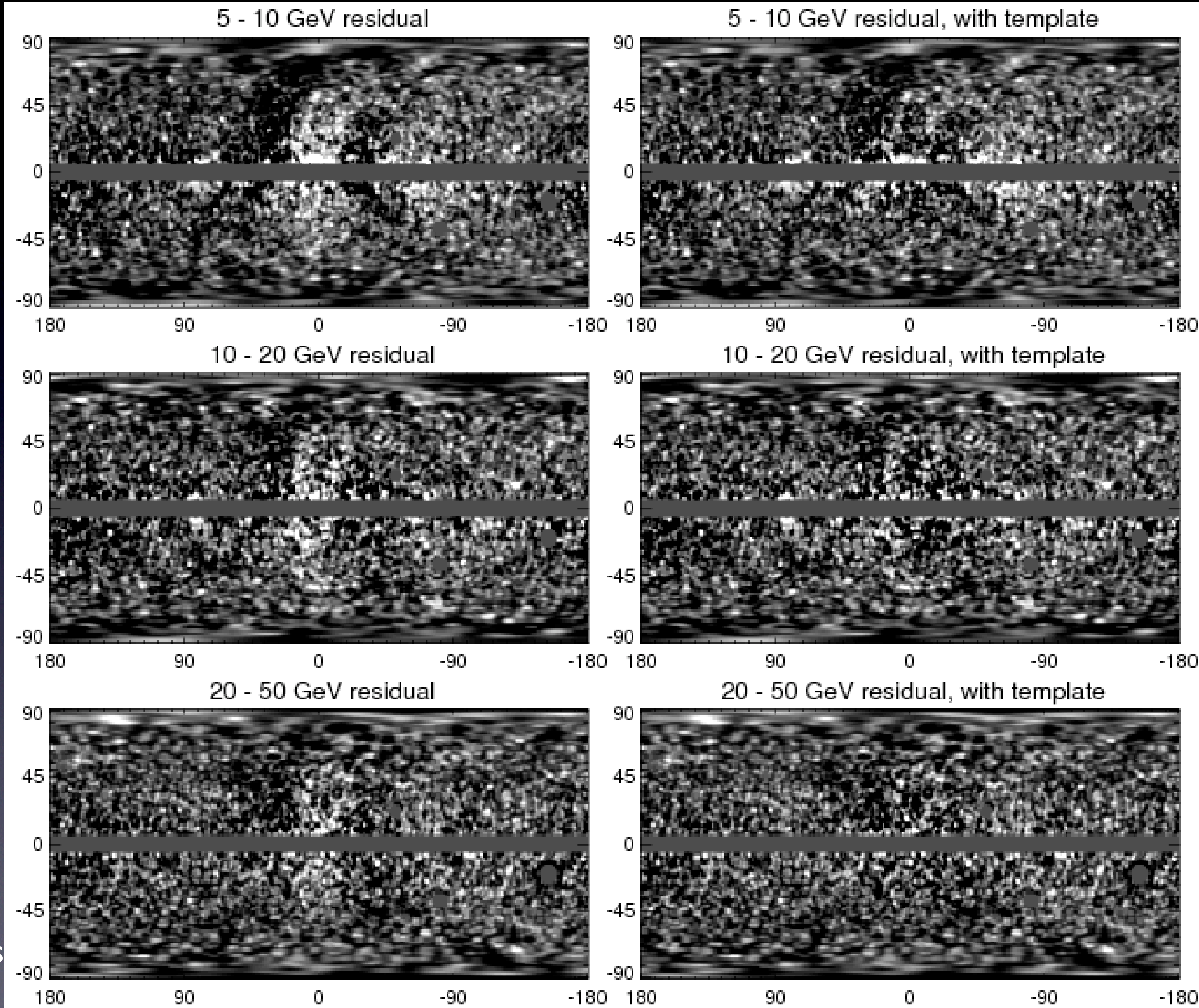
Dobler et al. (0910.4583)

1 GeV Template



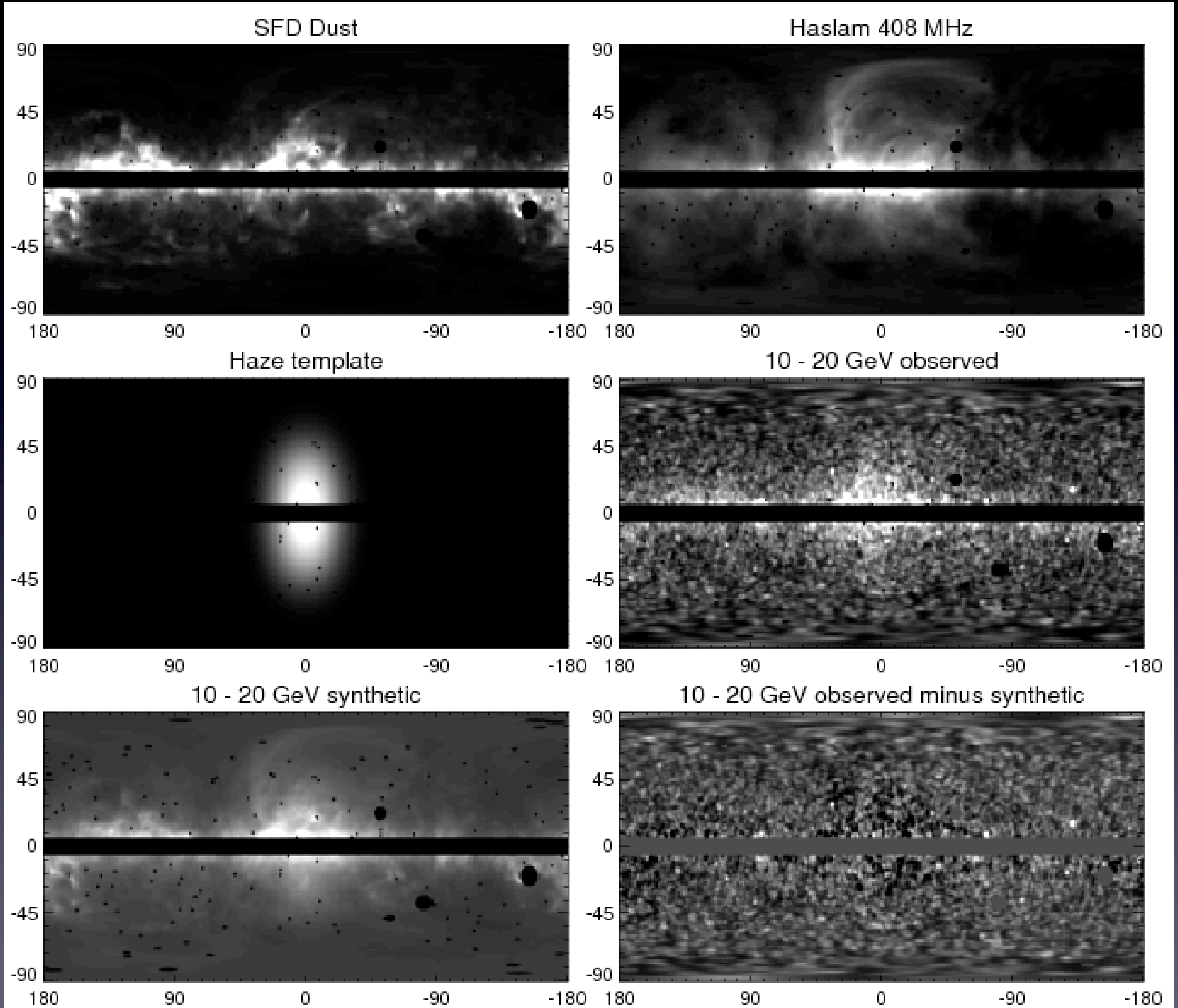
Dobler et al. (0910.4583)

Dust



Dobler et al. (0910.4583)

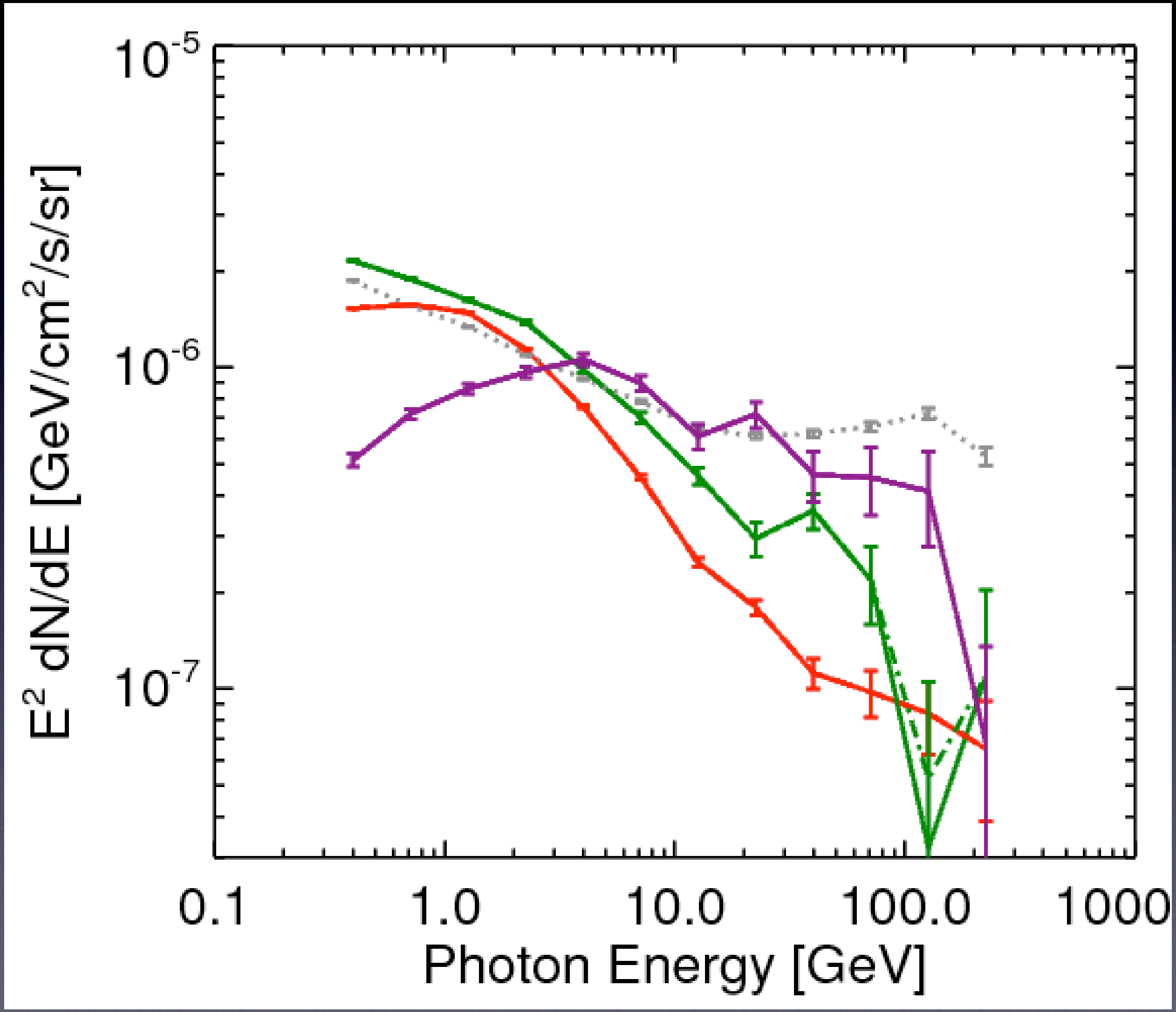
Fit residuals



Dobler et al. (0910.4583)

Templates

Fermi spectrum in the "haze" region



Dobler et al. (0910.4583)

Fermi (very preliminary) conclusions:

- There is a signal in the "haze" region in excess of that expected.

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

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

Fermi (very preliminary) conclusions:

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

Either 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.

Possible Objections:

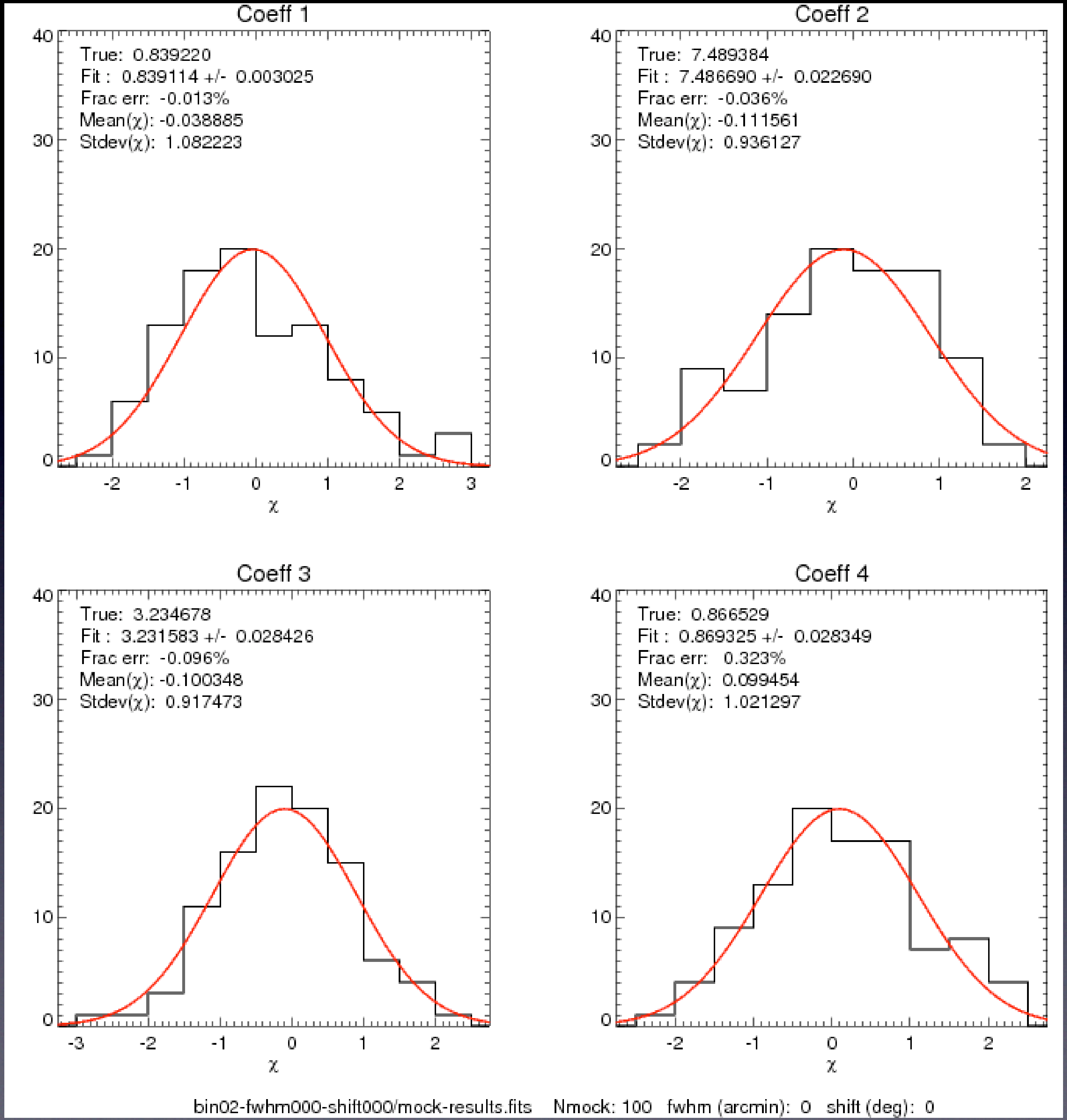
1. You don’t know how to do statistics.
2. The haze is merely particle contamination.
3. “It’s all Loop I”
4. It’s all point sources.
5. But GALPROP predicts this already...
6. What is the double-lobed structure?

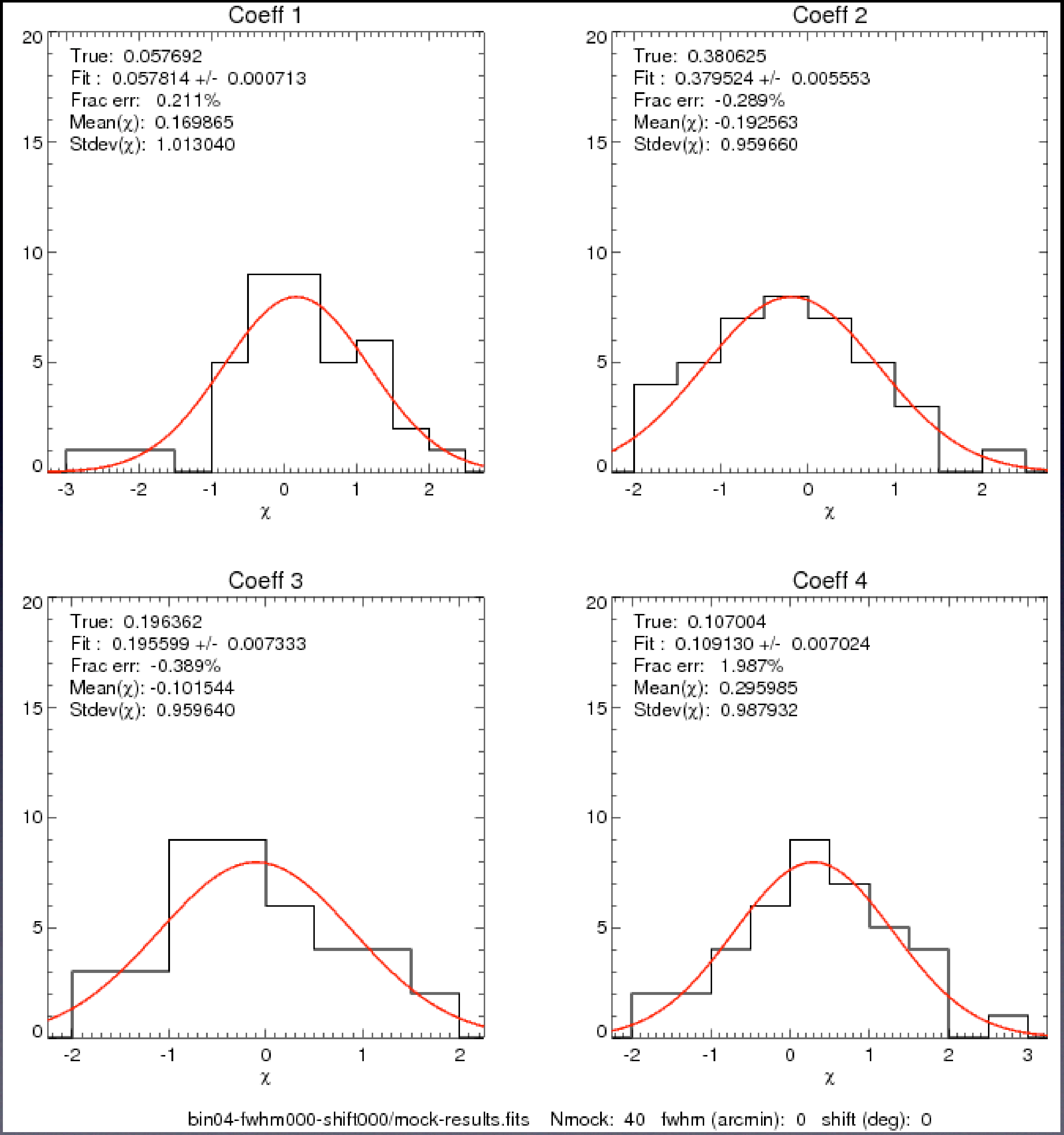
1. You don't know how to do statistics.

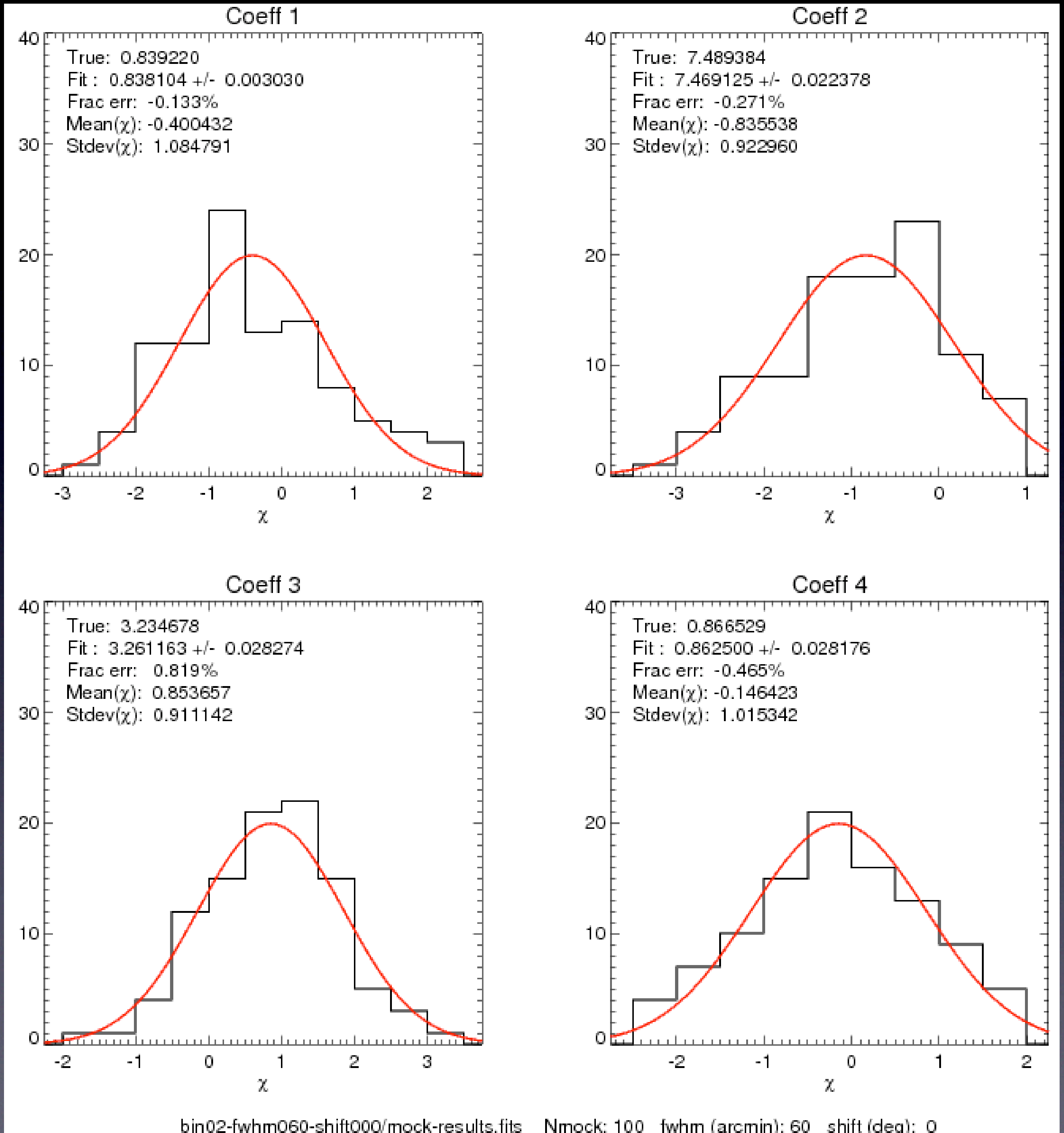
For each set of model parameters, we evaluate the Poisson likelihood of the Fermi exposure yielding the observed counts (outside of point source regions) after PSF matching templates and data.

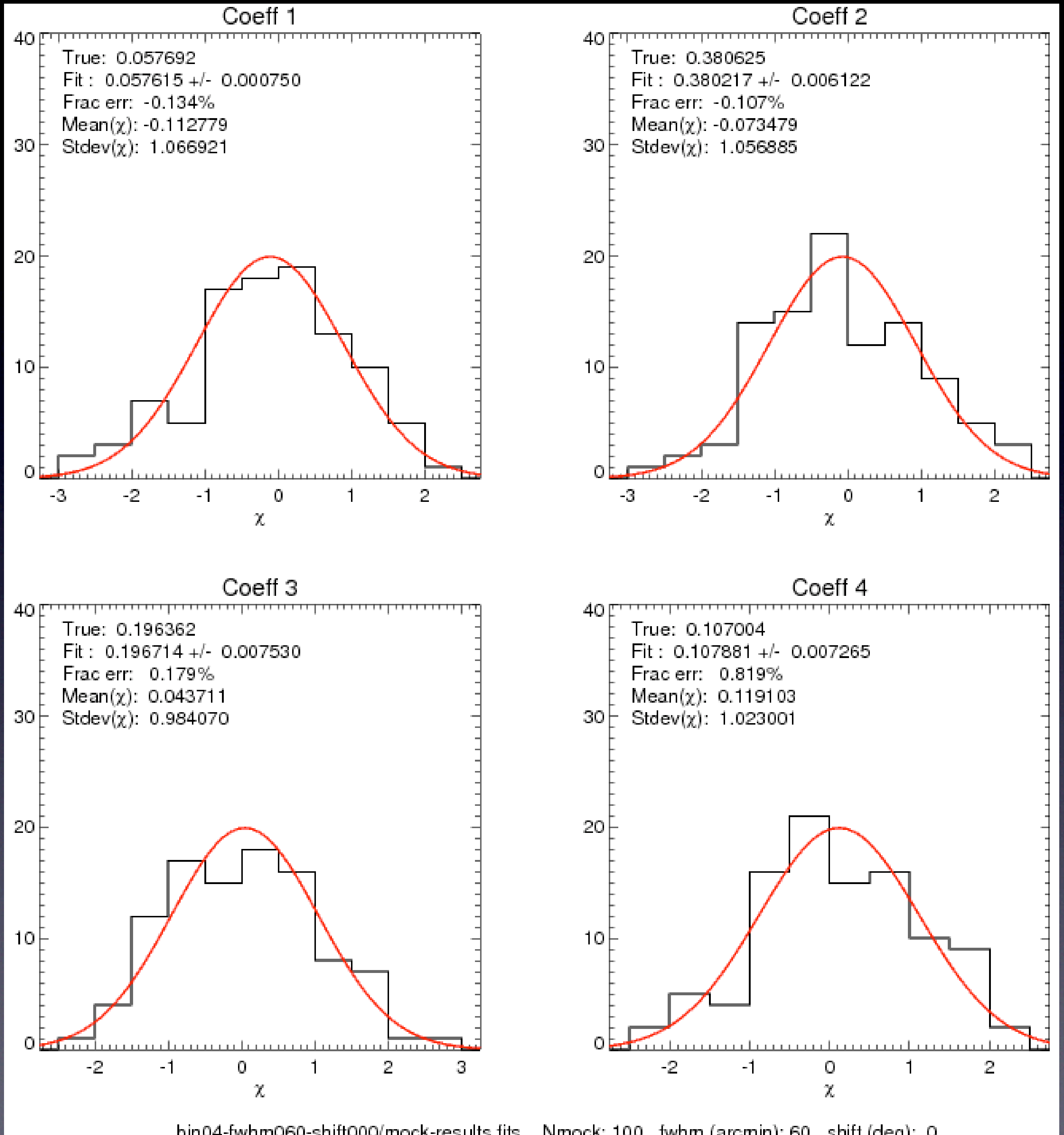
We generate mock maps (given parameters and the exposure map) and run them through the analysis to verify that the estimated parameters and uncertainties are correct.

$$\log \mathcal{L} = \sum_i k_i \log \mu_i - \mu_i - \log(k_i!)$$


Coeff 1
True: 0.839220
Fit : 0.839114 +/- 0.003025
Frac err: -0.013%
Mean(χ): -0.038885
Stdev(χ): 1.082223
χ
Coeff 2
True: 7.489384
Fit : 7.486690 +/- 0.022690
Frac err: -0.036%
Mean(χ): -0.111561
Stdev(χ): 0.936127
χ
Coeff 3
True: 3.234678
Fit : 3.231583 +/- 0.028426
Frac err: -0.096%
Mean(χ): -0.100348
Stdev(χ): 0.917473
χ
Coeff 4
True: 0.866529
Fit : 0.869325 +/- 0.028349
Frac err: 0.323%
Mean(χ): 0.099454
Stdev(χ): 1.021297
χ
bin02-fwhm000-shift000/mock-results.fits Nmock: 100 fwhm (arcmin): 0 shift (deg): 0


Coeff 1
True: 0.057692
Fit : 0.057814 +/- 0.000713
Frac err: 0.211%
Mean(χ): 0.169865
Stdev(χ): 1.013040
Coeff 2
True: 0.380625
Fit : 0.379524 +/- 0.005553
Frac err: -0.289%
Mean(χ): -0.192563
Stdev(χ): 0.959660
Coeff 3
True: 0.196362
Fit : 0.195599 +/- 0.007333
Frac err: -0.389%
Mean(χ): -0.101544
Stdev(χ): 0.959640
Coeff 4
True: 0.107004
Fit : 0.109130 +/- 0.007024
Frac err: 1.987%
Mean(χ): 0.295985
Stdev(χ): 0.987932
χ
bin04-fwhm000-shift000/mock-results.fits Nmock: 40 fwhm (arcmin): 0 shift (deg): 0


Coeff 1
True: 0.839220
Fit : 0.838104 +/- 0.003030
Frac err: -0.133%
Mean(χ): -0.400432
Stdev(χ): 1.084791
Coeff 2
True: 7.489384
Fit : 7.469125 +/- 0.022378
Frac err: -0.271%
Mean(χ): -0.835538
Stdev(χ): 0.922960
Coeff 3
True: 3.234678
Fit : 3.261163 +/- 0.028274
Frac err: 0.819%
Mean(χ): 0.853657
Stdev(χ): 0.911142
Coeff 4
True: 0.866529
Fit : 0.862500 +/- 0.028176
Frac err: -0.465%
Mean(χ): -0.146423
Stdev(χ): 1.015342
χ
bin02-fwhm060-shift000/mock-results.fits Nmock: 100 fwhm (arcmin): 60 shift (deg): 0


Coeff 1
True: 0.057692
Fit : 0.057615 +/- 0.000750
Frac err: -0.134%
Mean(χ): -0.112779
Stdev(χ): 1.066921
Coeff 2
True: 0.380625
Fit : 0.380217 +/- 0.006122
Frac err: -0.107%
Mean(χ): -0.073479
Stdev(χ): 1.056885
Coeff 3
True: 0.196362
Fit : 0.196714 +/- 0.007530
Frac err: 0.179%
Mean(χ): 0.043711
Stdev(χ): 0.984070
Coeff 4
True: 0.107004
Fit : 0.107881 +/- 0.007265
Frac err: 0.819%
Mean(χ): 0.119103
Stdev(χ): 1.023001
χ
bin04-fwhm060-shift000/mock-results.fits Nmock: 100 fwhm (arcmin): 60 shift (deg): 0

1. You don’t know how to do statistics.

The parameters are unbiased (at the 1/10th sigma level) and the uncertainties are correct (at the 10% level) as expected for 100 mock trials.

Conclusion: we know how to do statistics.

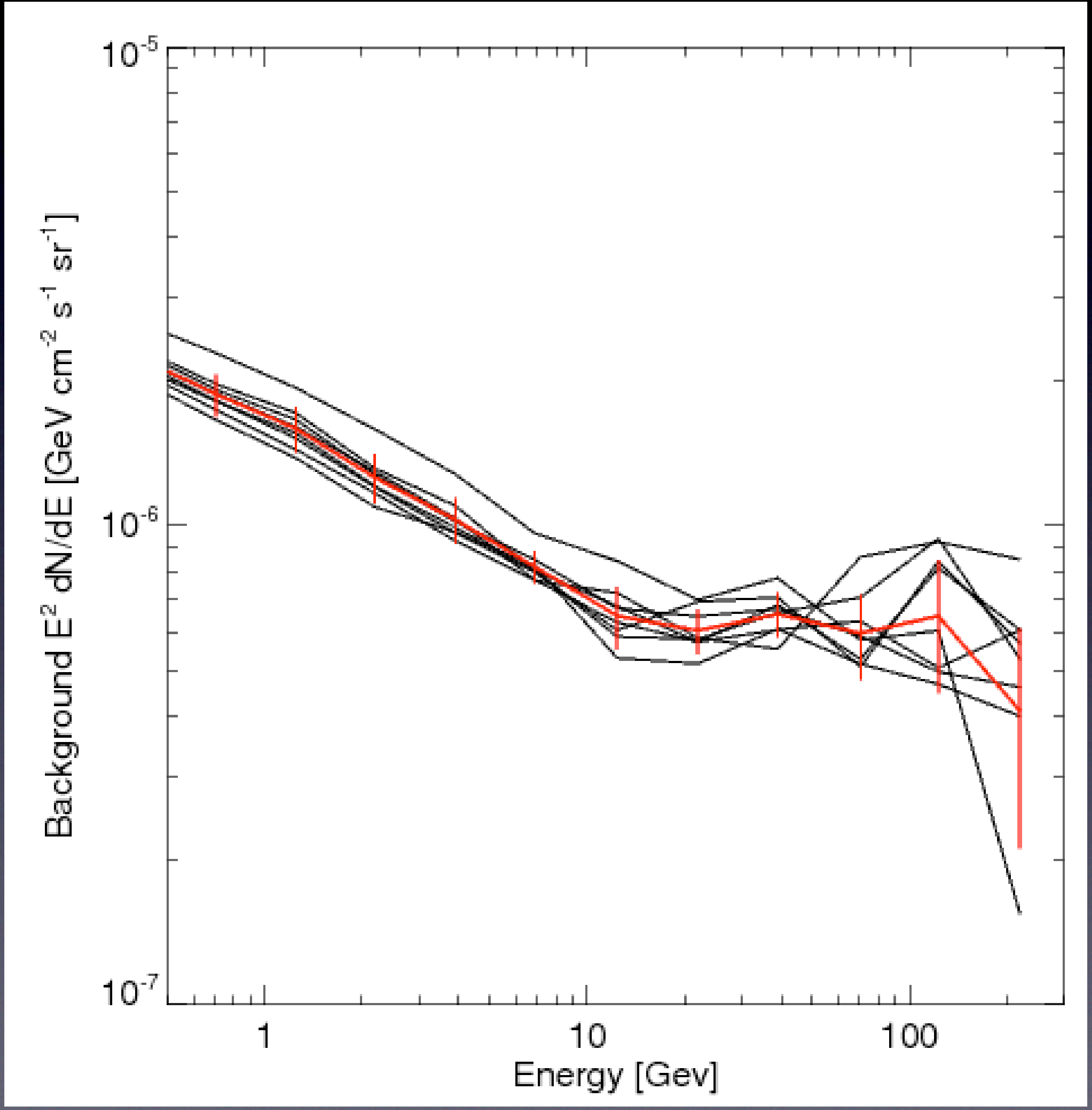
2. The haze is merely particle contamination.

Even in the “class 3” events, there are particle events mimicking gamma-rays, especially at high energy.

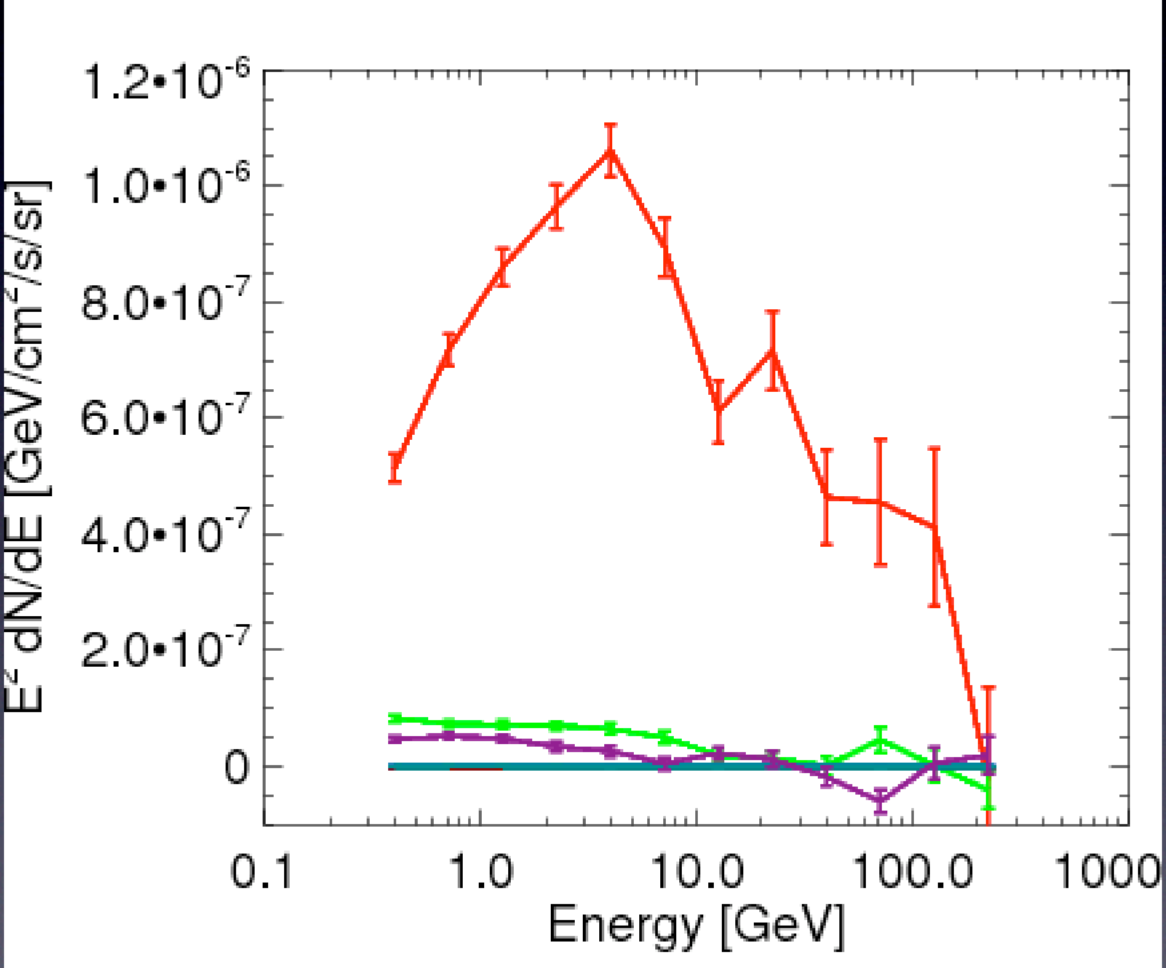
These particles have a small gyroradius, so they forget where they originated. However they are *not* isotropic because of the Earth’s magnetic field.

How do we know that the haze is not particle contamination on part of the sky?

We look at the spectrum of 8 high-latitude (|b| > 60) patches of sky; the variation in these 8 regions is much smaller than the haze signal:



As another test (suggested by E. Bloom) we shift the "egg" around the sky in longitude, and repeat the fit. At 12 30 degree intervals, we find that the egg only has a significant coefficient at l=0.



One of these lines is not like the others...

2. The haze is merely particle contamination.

The Galactic Center is unrelated to the celestial pole, ecliptic pole, magnetic pole, Fermi scan strategy, or anything else we can think of. So many events from the inner Galaxy, with a spectrum very different from background, would be quite a coincidence.

Conclusion: For it to be particle contamination would require a conspiracy. However, we look forward to the next release of Fermi data with improved cuts.

3. “It’s all Loop I”

Loop I is a “supershell” produced (presumably) by one or more SNe in the last few million years.

The 4 classical radio loops were defined by Elly Berkhuisen based on 820 MHz data from her thesis.

A Survey of the Continuum Radiation at 820 MHz between Declinations −7° and +85°

II. A Study of the Galactic Radiation and the Degree of Polarization with Special Reference to the Loops and Spurs

ELLY M. BERKHUIJSEN
Max-Planck-Institut für Radioastronomie, Bonn, Germany

Received April 26, 1971

Table 1. *Geometrical characteristics of the loops*

Object	Circle centre l	Circle centre b	Diameter
Loop I	329° ± 1°.5	+17.5° ± 3°	116° ± 4°
Loop II	100 ± 2	−32.5 ± 3	91 ± 4
Loop III	124 ± 2	+15.5 ± 3	65 ± 3
Loop IV	315 ± 3	+48.5 ± 1	39.5 ± 2

(Loop I is thought to be within ~ 200 pc)

3. "It's all Loop I"

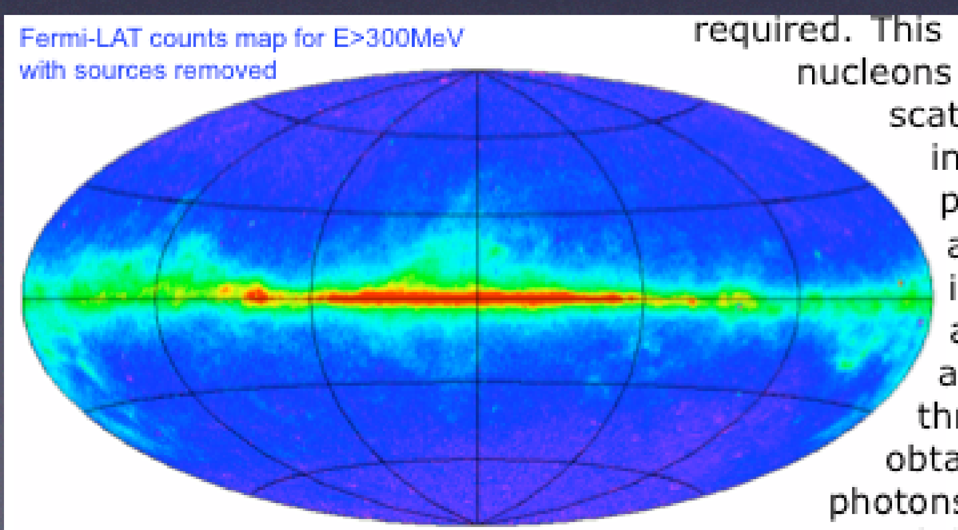
From poster at the *Fermi Symposium*:

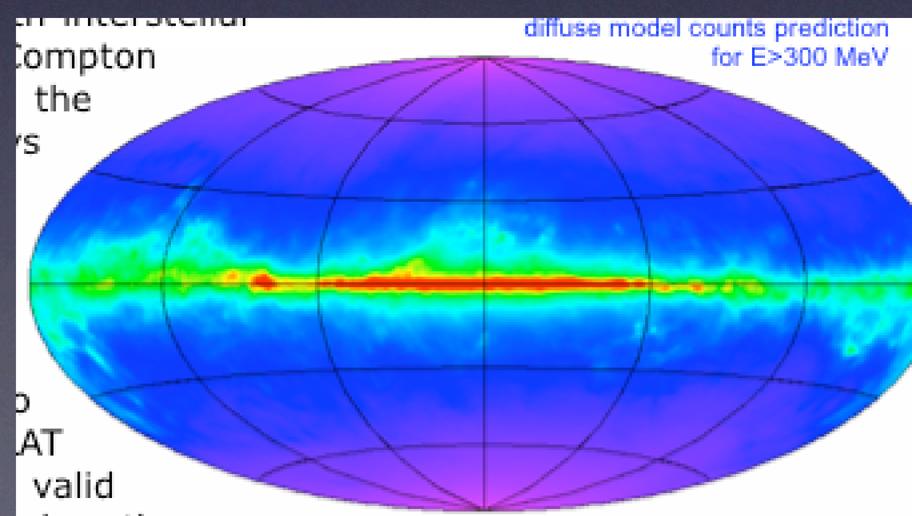
High Energy γ-Ray Emission from the Loop I region

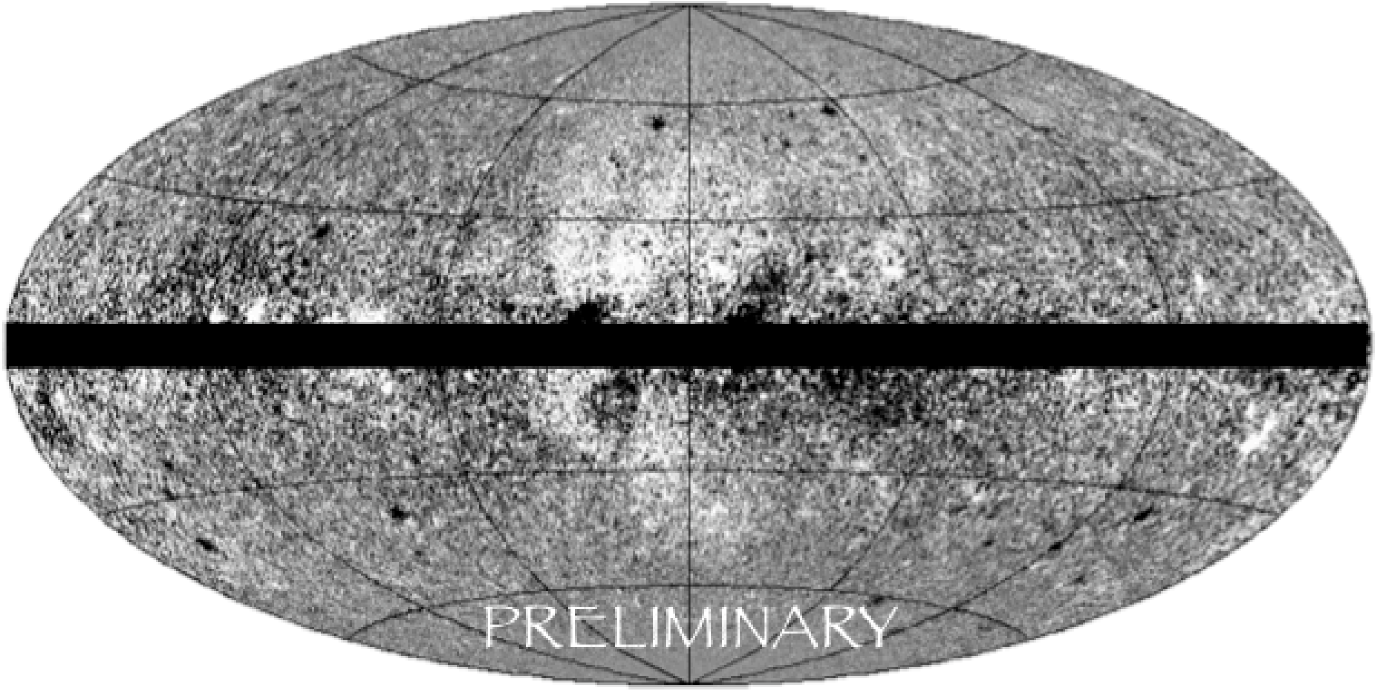
Jean-Marc Casandjian[1], Isabelle Grenier[1]

on behalf of the Fermi Large Area Telescope Collaboration

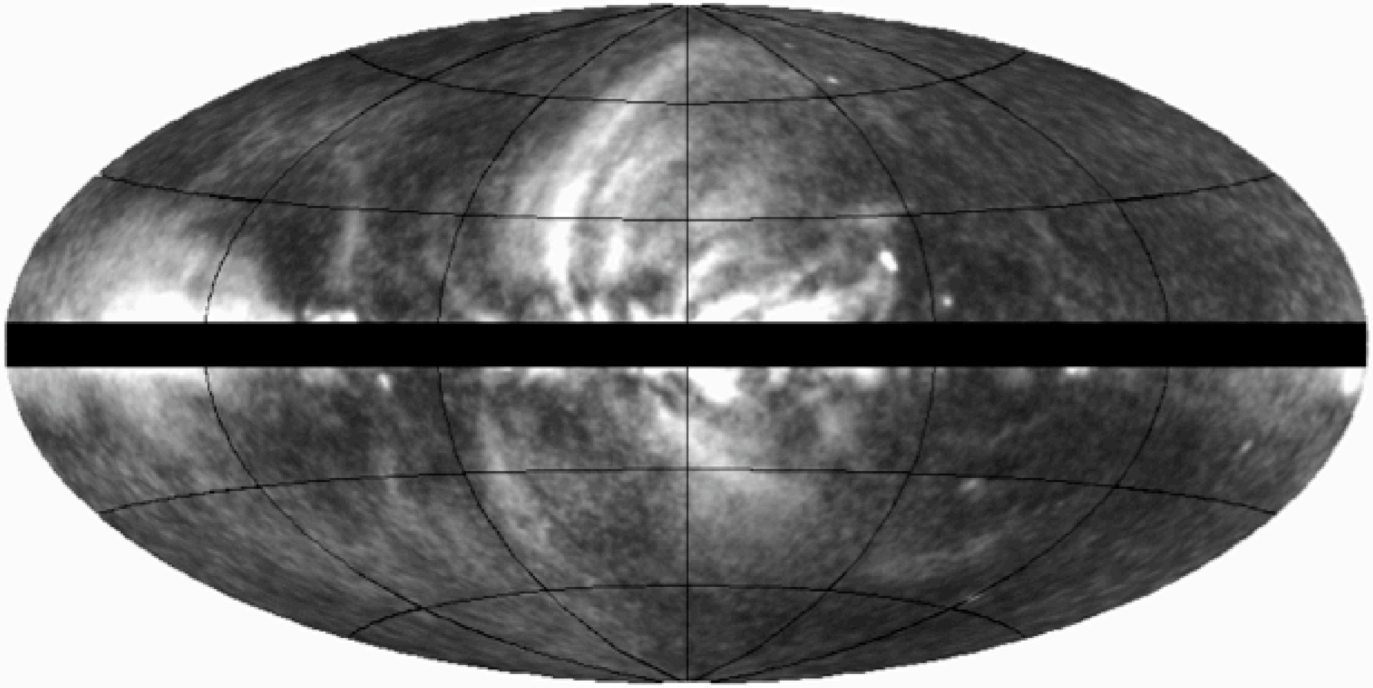
[1]Laboratoire AIM, CEA-IRFU/CNRS/Université Paris Diderot, Service d'Astrophysique, CEA Saclay, 91191 Gif sur Yvette, France







Residual map (data-model) for photons with E>300 MeV



WMAP 23GHz polarized intensity convolved with Fermi-LAT PSF for E>300 MeV

3. "It's all Loop I"

Polarized synchrotron emission associated with Loop I at 23 GHz resembles the fit residual at low energies (~ 300 MeV). Nobody doubts this.

However, at higher energies, this emission is relatively less important, and the morphology of the haze "egg" dominates the map.

There are (at least) 2 things going on here. While local emission from Loop I is important at low energy, the spatial morphology at high energy looks much more symmetrical and haze-like.

Conclusion: It's not all just Loop I.

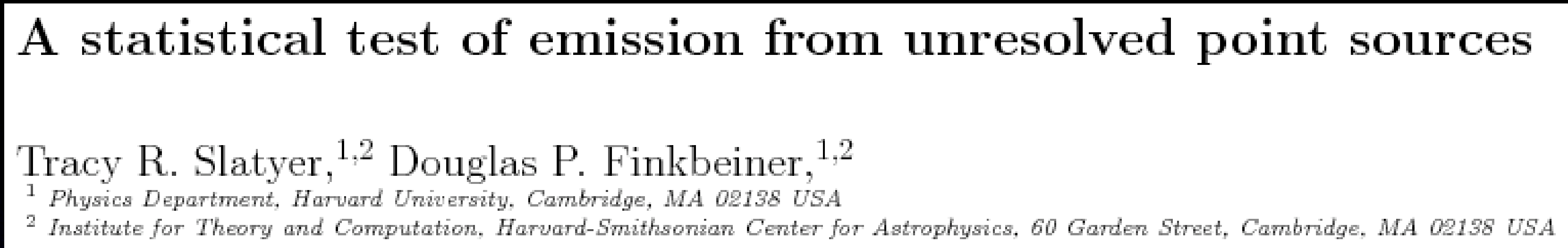
4. It’s all point sources.

There are no point sources from the 3-month 10-sigma Fermi point-source list in the “haze” region.

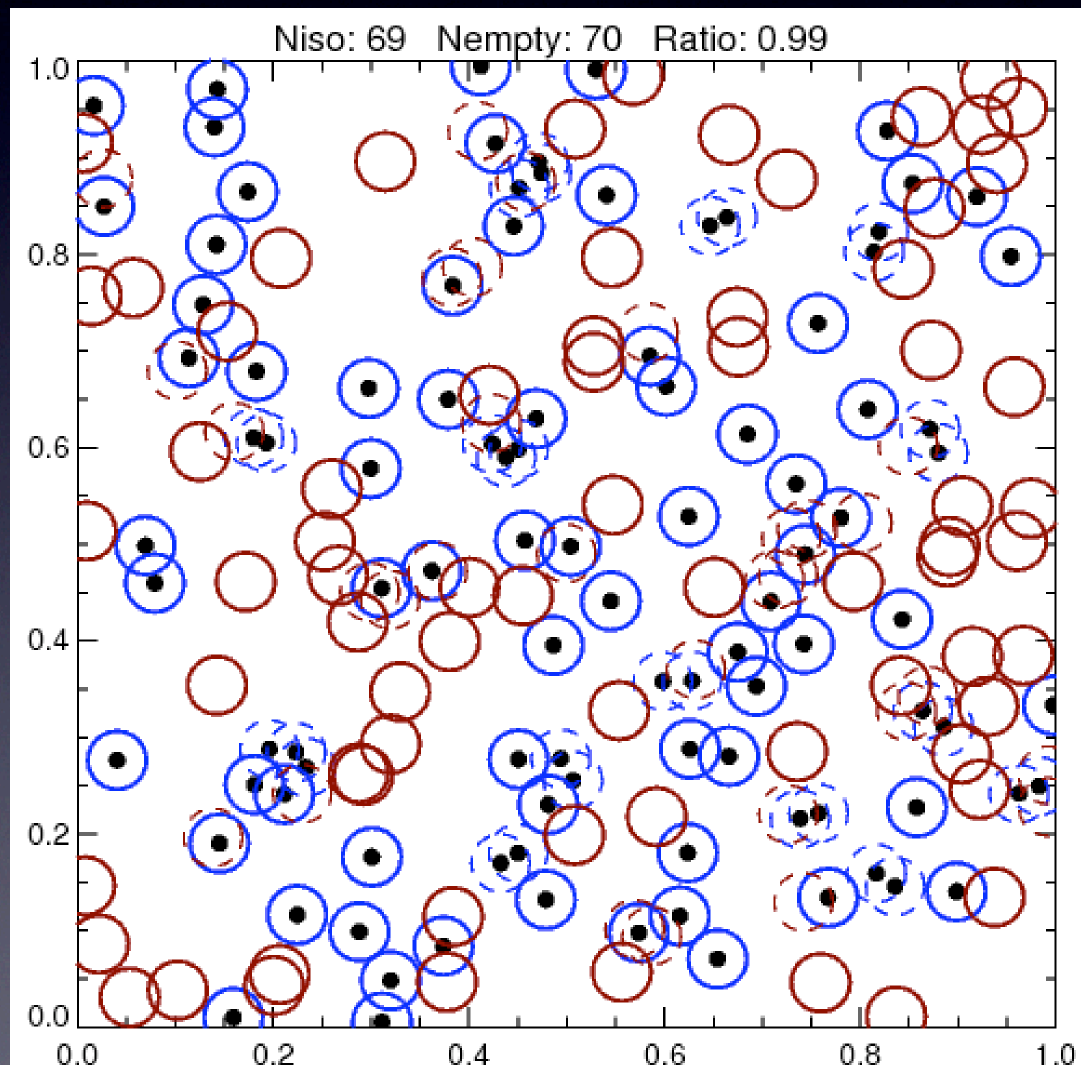
But what about faint, unresolved sources?

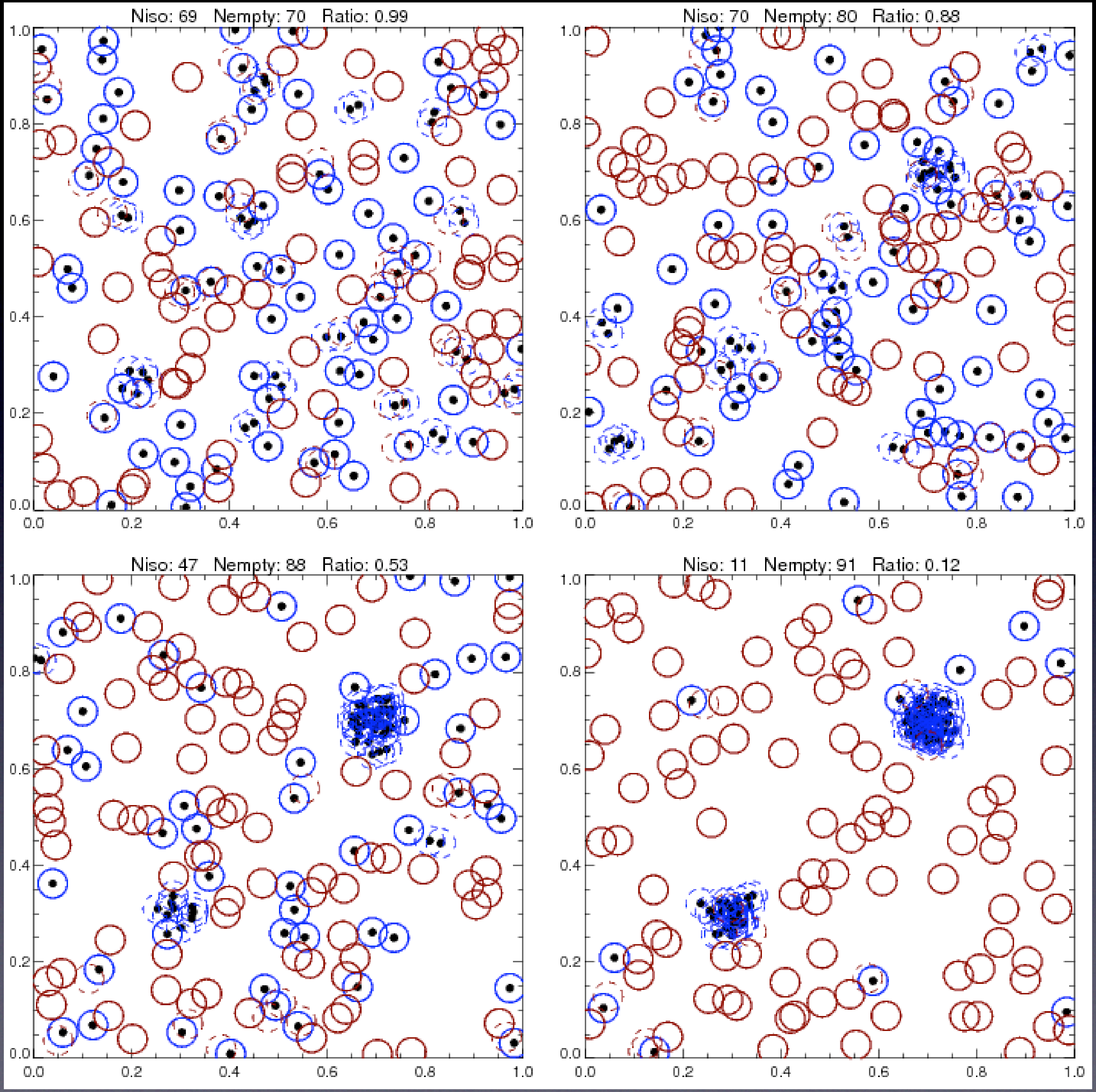
We invented a statistic for just such an application.

4. It's all point sources.


A statistical test of emission from unresolved point sources

Tracy R. Slatyer,[1,2] Douglas P. Finkbeiner,[1,2]
[1] Physics Department, Harvard University, Cambridge, MA 02138 USA
[2] Institute for Theory and Computation, Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138 USA




Niso: 69 Nempty: 70 Ratio: 0.99
Niso: 70 Nempty: 80 Ratio: 0.88
Niso: 47 Nempty: 88 Ratio: 0.53
Niso: 11 Nempty: 91 Ratio: 0.12
0.0
0.2
0.4
0.6
0.8
1.0

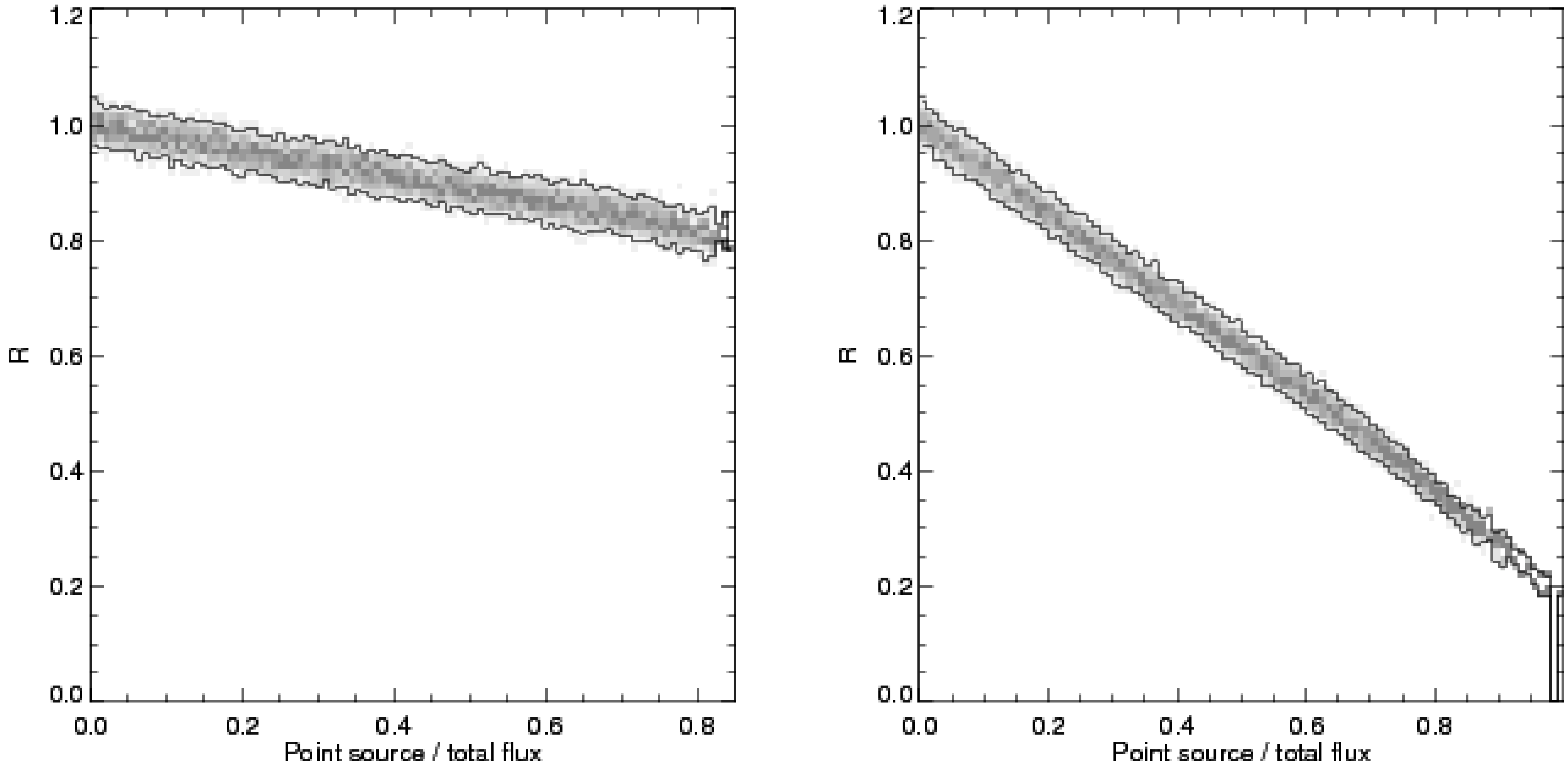
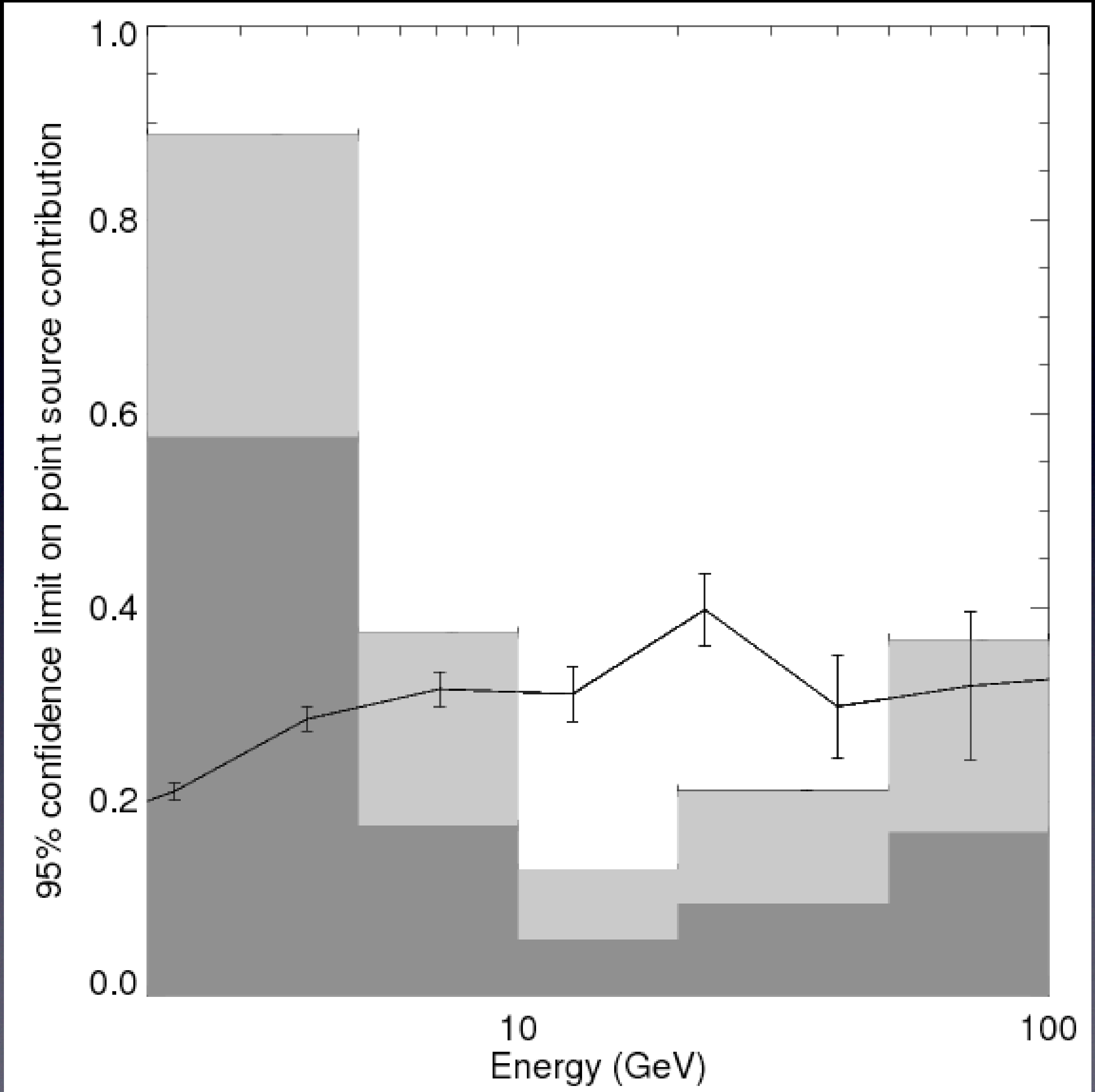


Figure 2. The isotropy ratio R, in Monte Carlo simulated data, in (*left*) benchmark model 1 and (*right*) benchmark model 2. See Table 1 for definitions of the benchmarks. Lines are 5% and 95% confidence bounds.

The isotropy ratio, R, is indistinguishable from 1 for the *Fermi* data above 10 GeV. I.e. there is no evidence that point sources produce the *Fermi* haze.



1.0
0.8
0.6
0.4
0.2
0.0
95% confidence limit on point source contribution
10
100
Energy (GeV)

4. It's all point sources.

We find that point sources become relatively less important at higher energies. Even for a rather pessimistic -2.2 power law for dN/dS, and 0.1 counts per year for Smin, we find little evidence for point sources at high energy. Vast numbers of very faint point sources (Nsource >> Nphoton) cannot be ruled out, of course.

Conclusion: Unlikely to be all from point sources.