What can Fermi teach us about Dark Matter?

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Concise answer...

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No.

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(but we will try anyway)

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We can look for anomalies in astronomy and physics that could be related to new physics, and ask “what would it take.”

Because signals (gamma rays, particles, and microwaves) have been found *above* the level expected for a weak-scale thermal relic WIMP, either

1. These signals *are* already from dark matter and we need to understand why they are so big, or

2. They are not, and we need to understand what they are, or we will simply never be able to detect particle annihilation/decay signals astrophysically.

WIMP detection, near and far:

Dark
Matter?

WIMP detection, near and far:

Local
(near Earth)

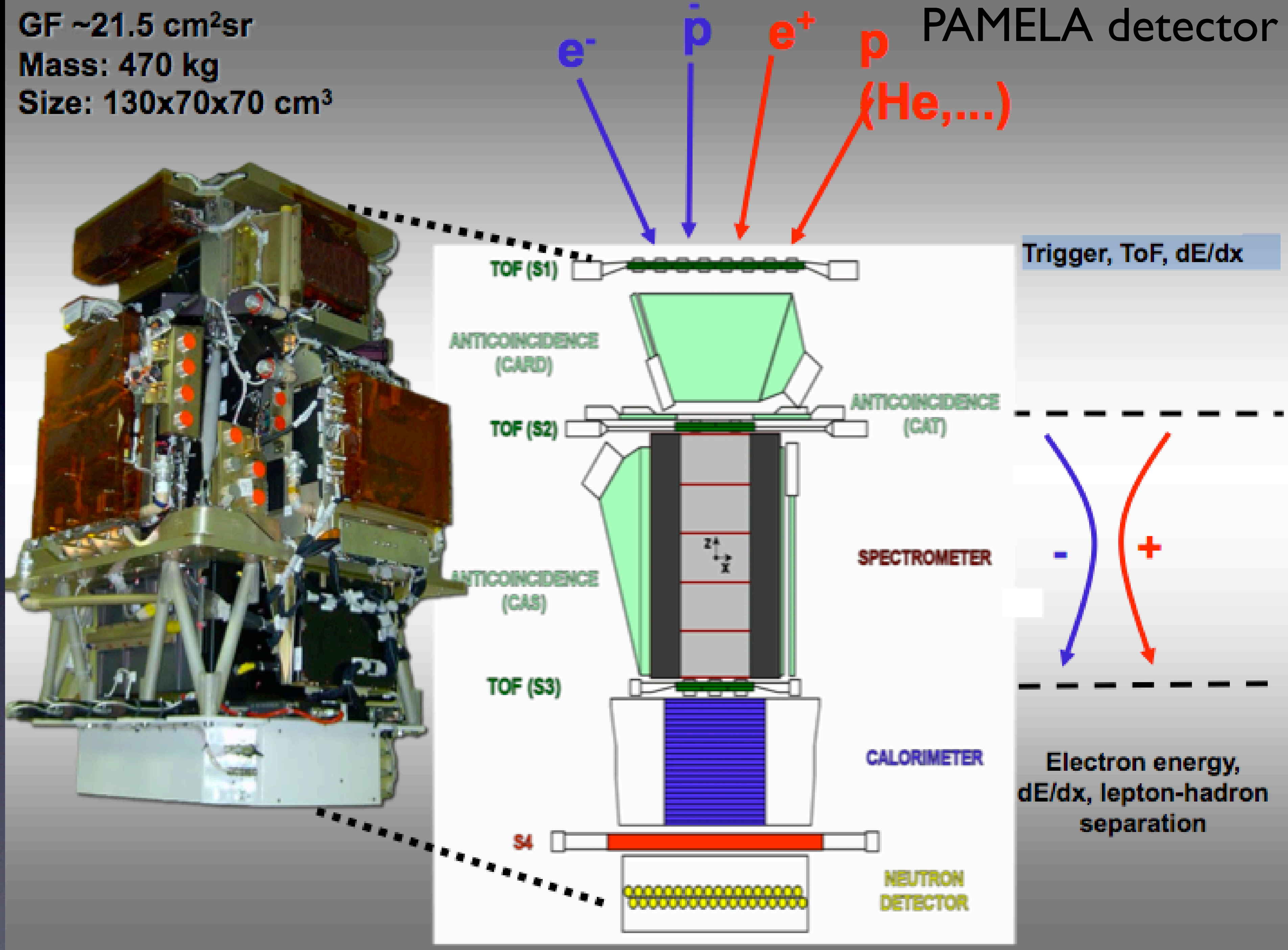
PAMELA
positrons

ATIC/
Fermi
e+ e-

Dark
Matter?

PAMELA detector

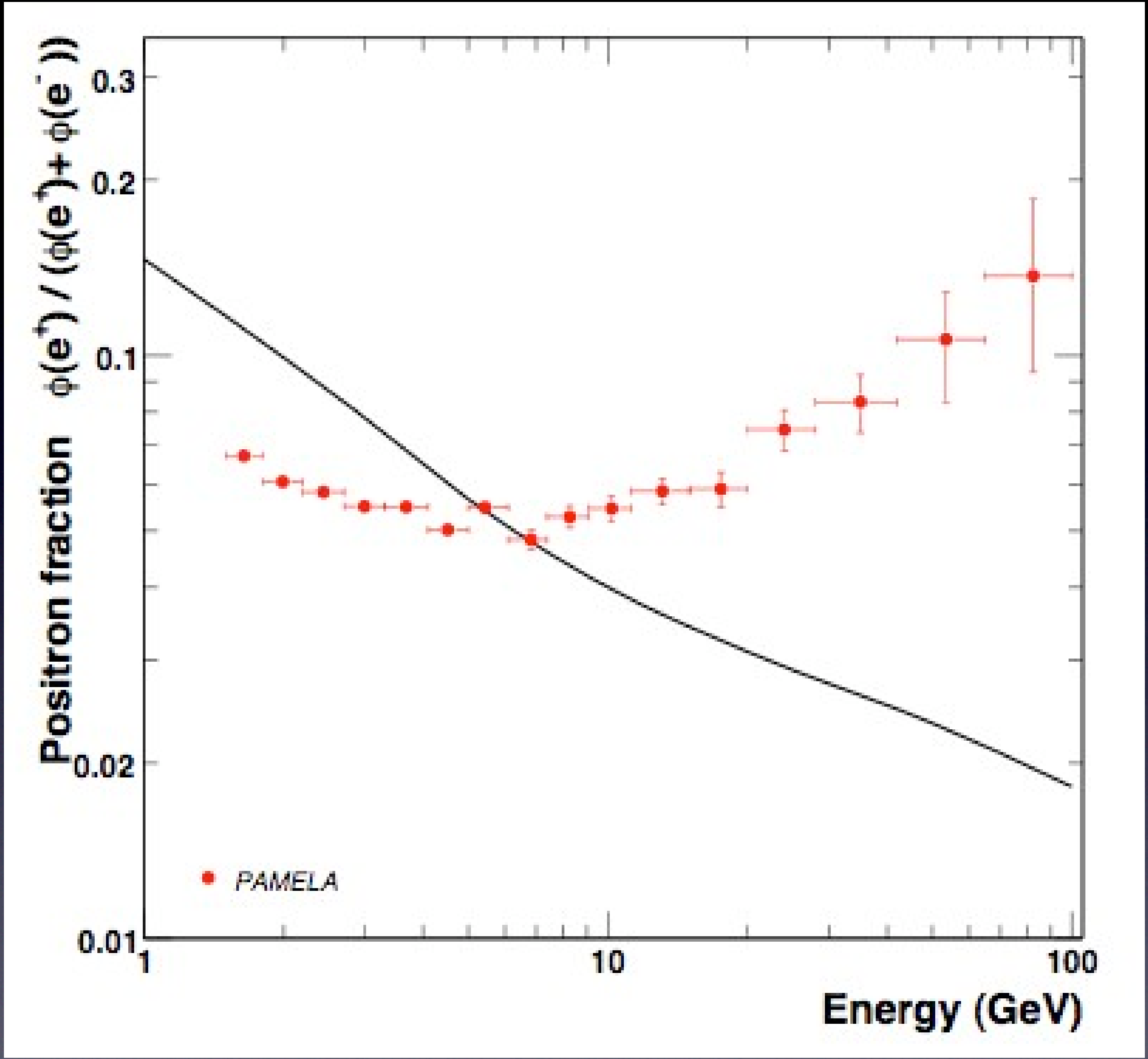
GF ~21.5 cm^{2}sr
Mass: 470 kg
Size: 130x70x70 cm^3



Trigger, ToF, dE/dx

Electron energy, dE/dx, lepton-hadron separation

courtesy Mirko Boezio



PAMELA positron fraction spectrum, Adriani et al. (2008)

ATIC and Fermi electrons

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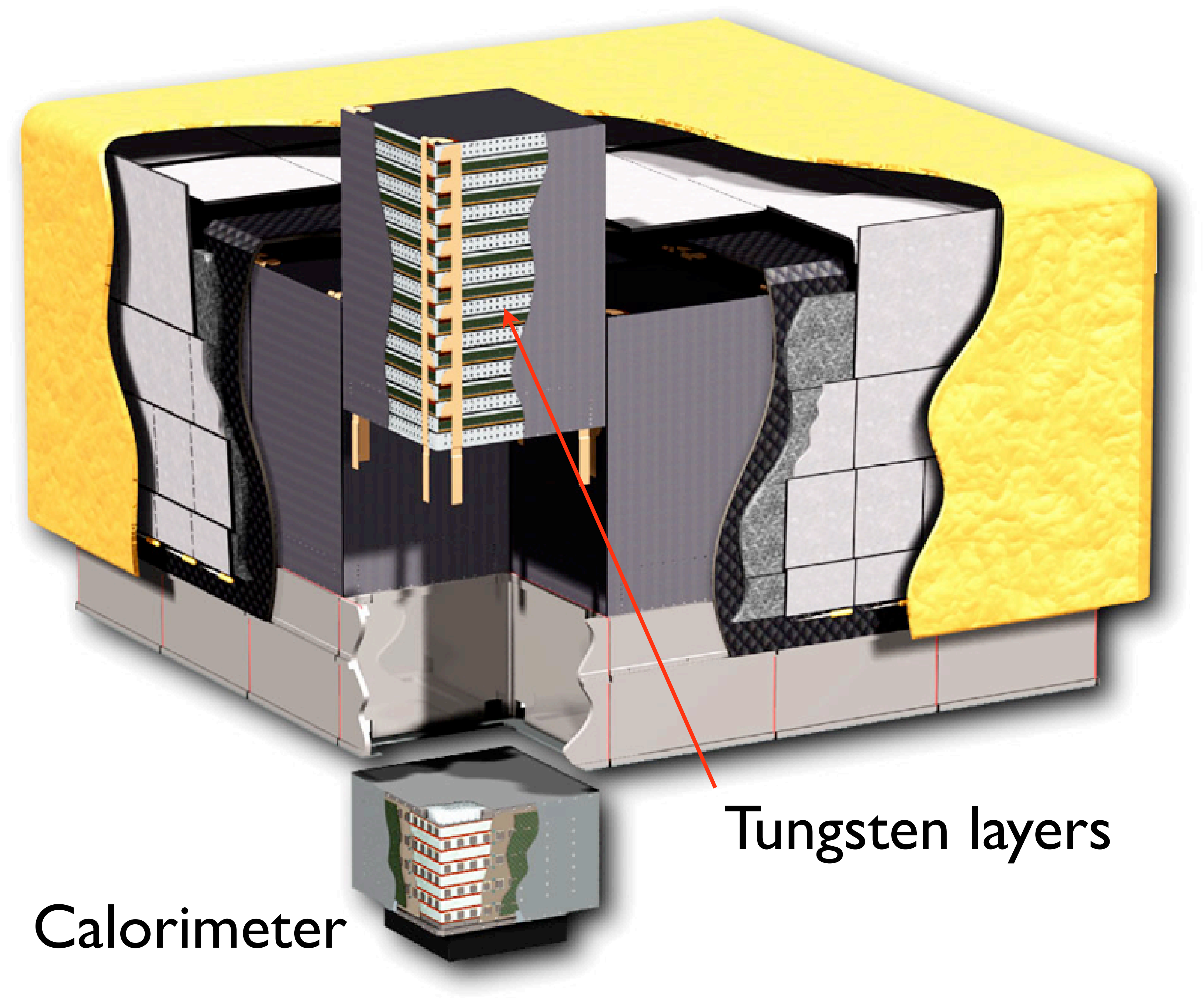
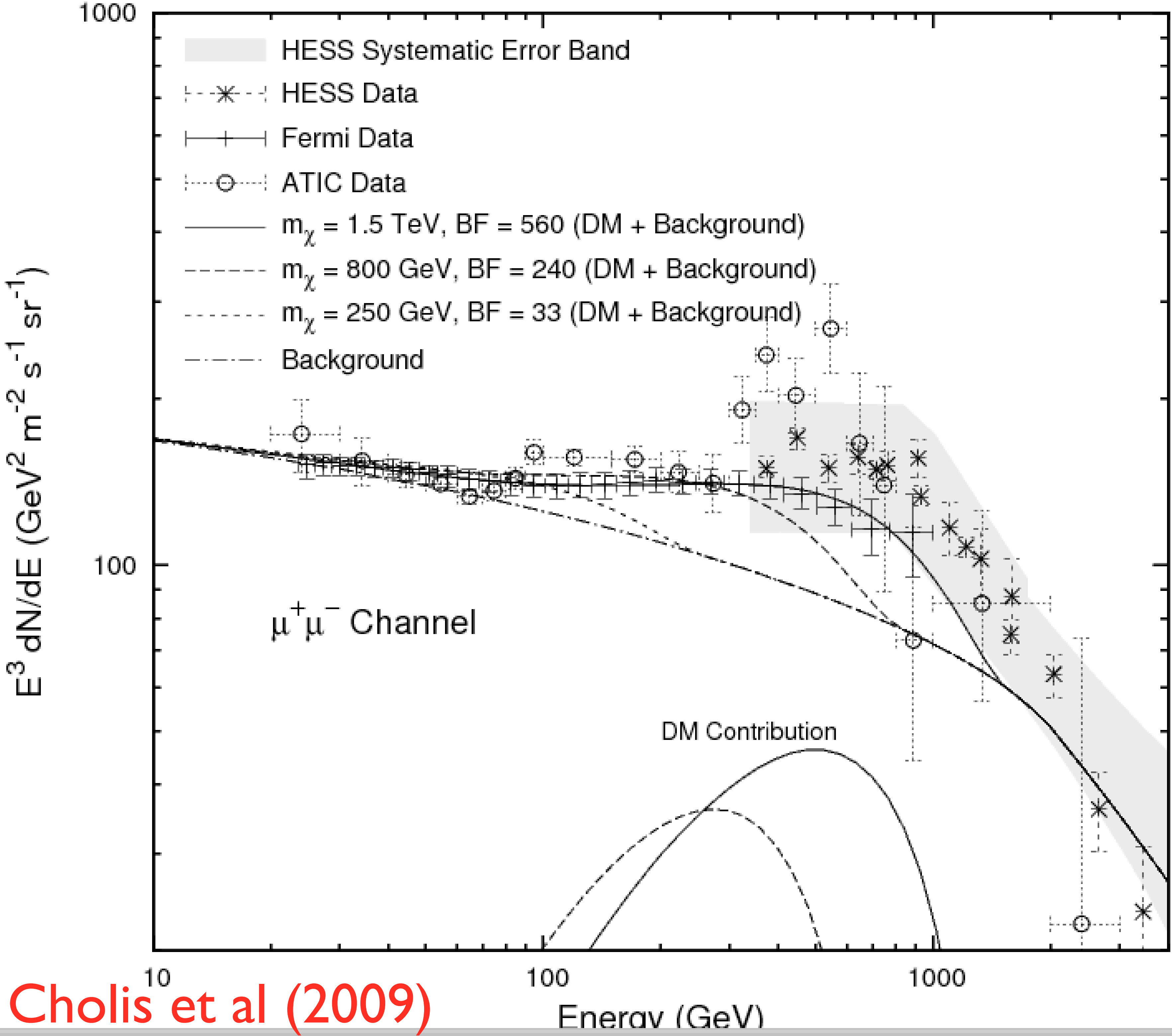
Fermi = Fermi Gamma-ray Space Telescope: pair conversion telescope, observes gammas up to 300 GeV and particles up to ~ 1 TeV.

Fermi LAT (large area telescope)





Cholis et al (2009)

Do the excess PAMELA positrons and the excess ATIC/Fermi e^+e^- have anything to do with each other?

What could make excess high energy electrons? (above and beyond SNe)

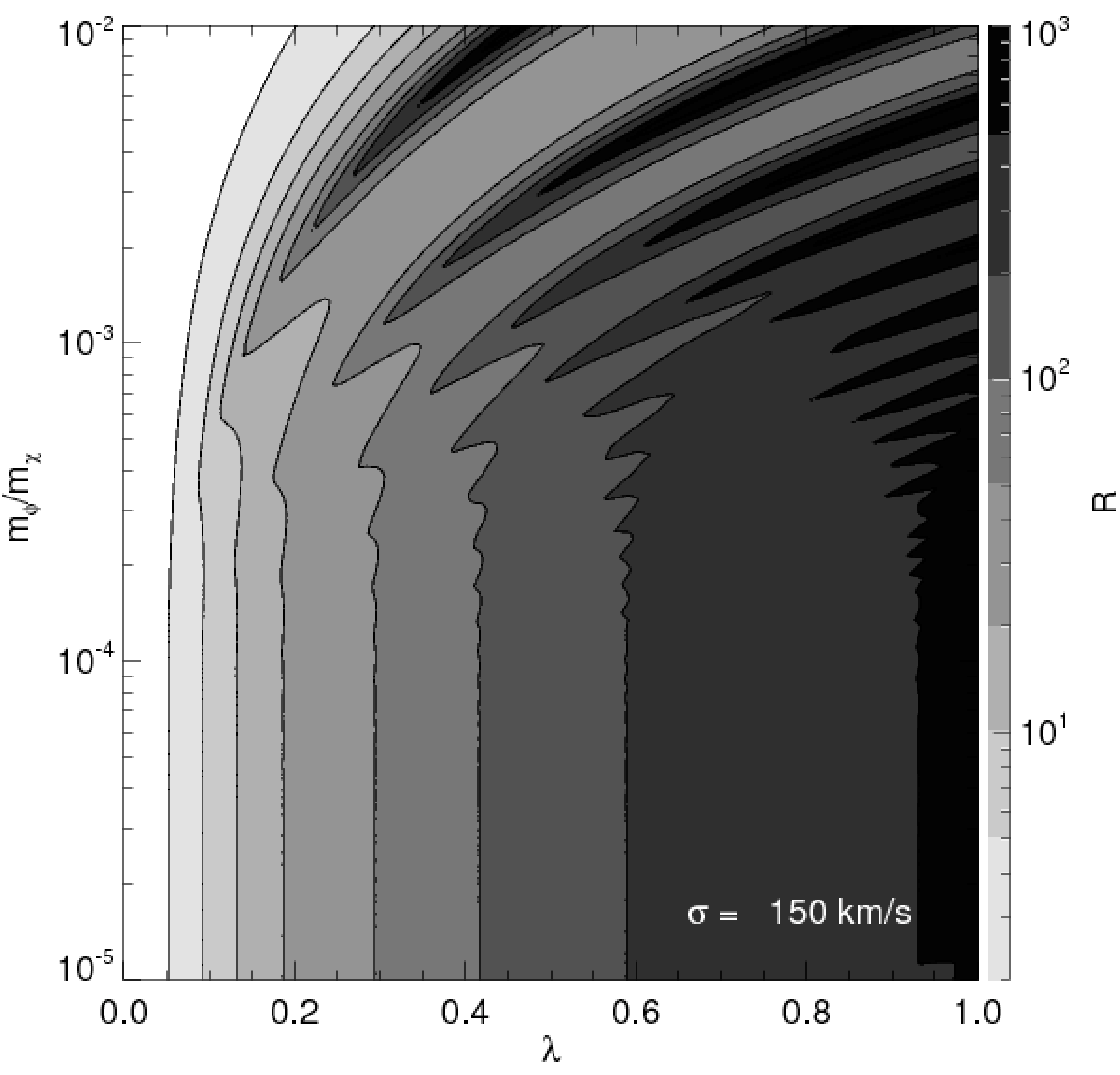
1. Pulsars (or other compact objects?)
2. Dark Matter (WIMP) annihilation?
3. Other new physics

But both ATIC & PAMELA require a large cross section.

Sommerfeld enhancement:

QM analog of gravitational focusing.

Depends on WIMP mass ratio, coupling to phi, and velocity



Arkani-Hamed et al. (2008) see also Nomura et al (2009)

So we need a large cross section
and
a high branching ratio to light leptons.

If we want the high cross section needed for PAMELA/ATIC, we have left MSSM-land.

i.e. there must be some new structure in the dark sector, beyond what you expect from minimal SUSY. This could be a new force, mirror dark matter, strongly-interacting DM (mesonic or baryonic) or "Axion Portal" DM, etc. But *something* is going on.

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Local
(near Earth)

PAMELA
positrons

Fermi
e+ e-

Dark
Matter?

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Local
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PAMELA
positrons

Fermi
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Dark
Matter?

INTEGRAL
511 keV

Fermi
gammas

WMAP haze
(microwaves)

Galactic Center

The WMAP haze

The Interstellar Medium:

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Gas and dust between the stars.

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What is the total column density of dust?

The Galaxy as a detector

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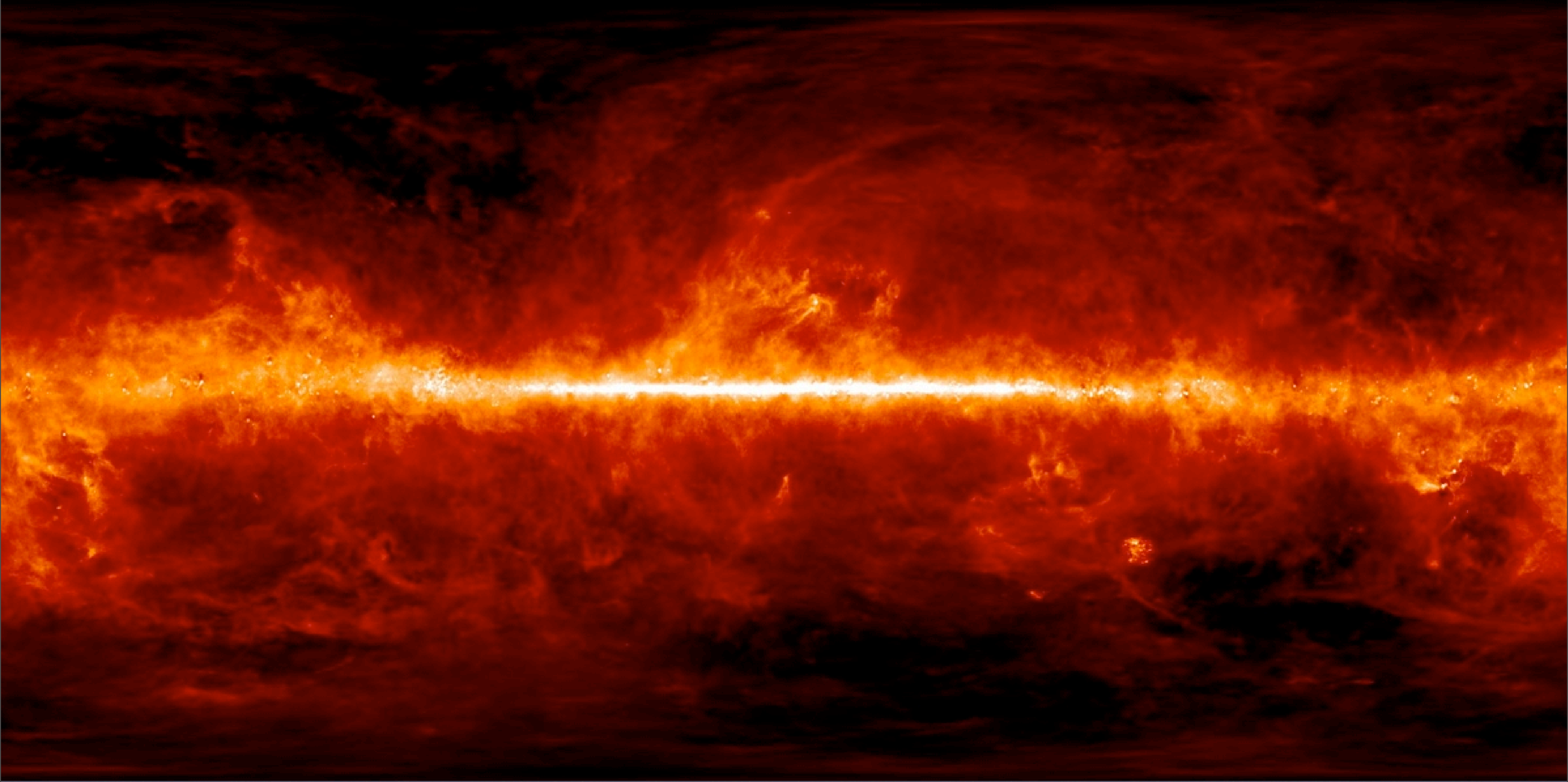
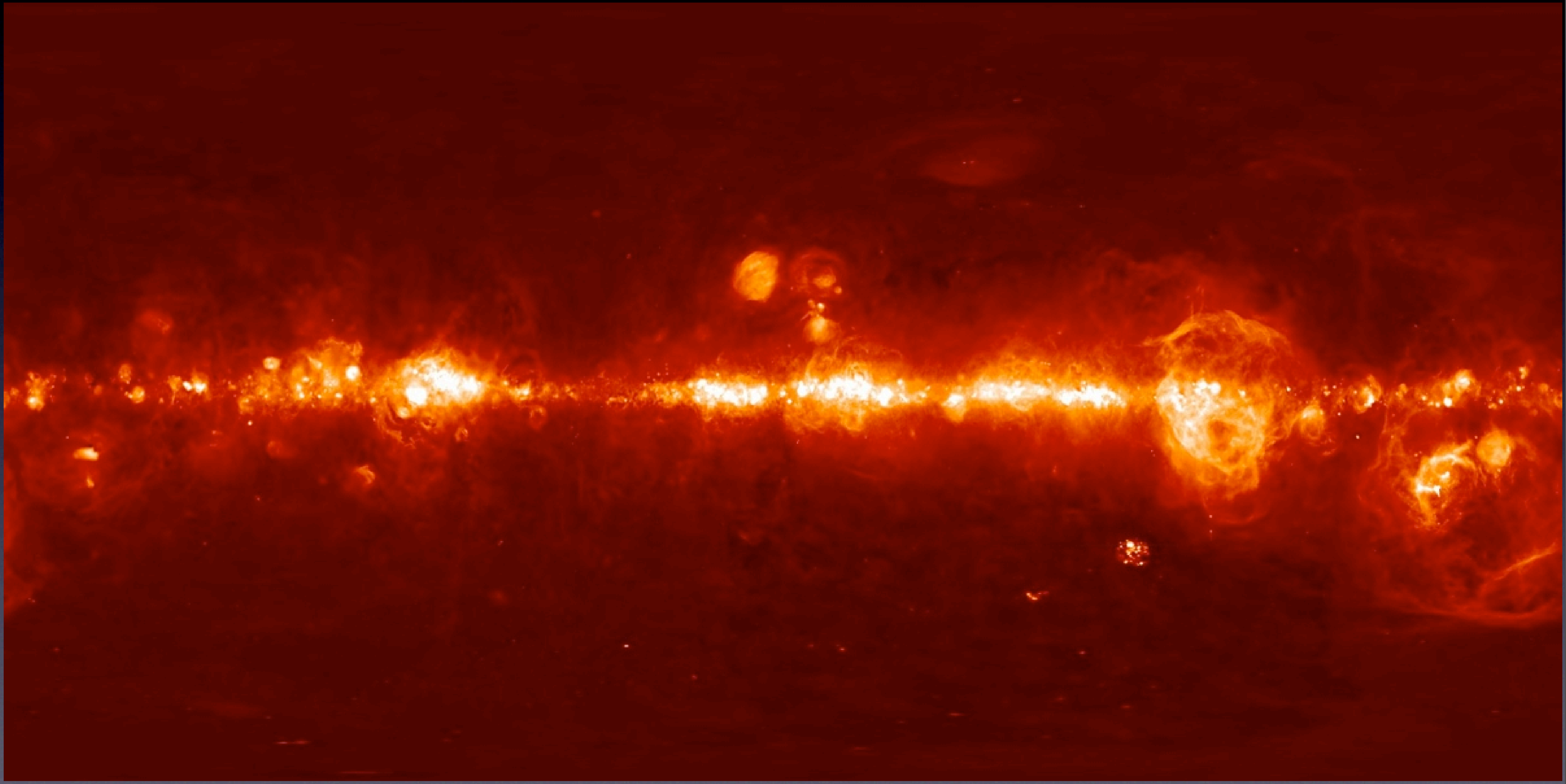
There is a lot going on just from "conventional" astrophysics - how do we model it?

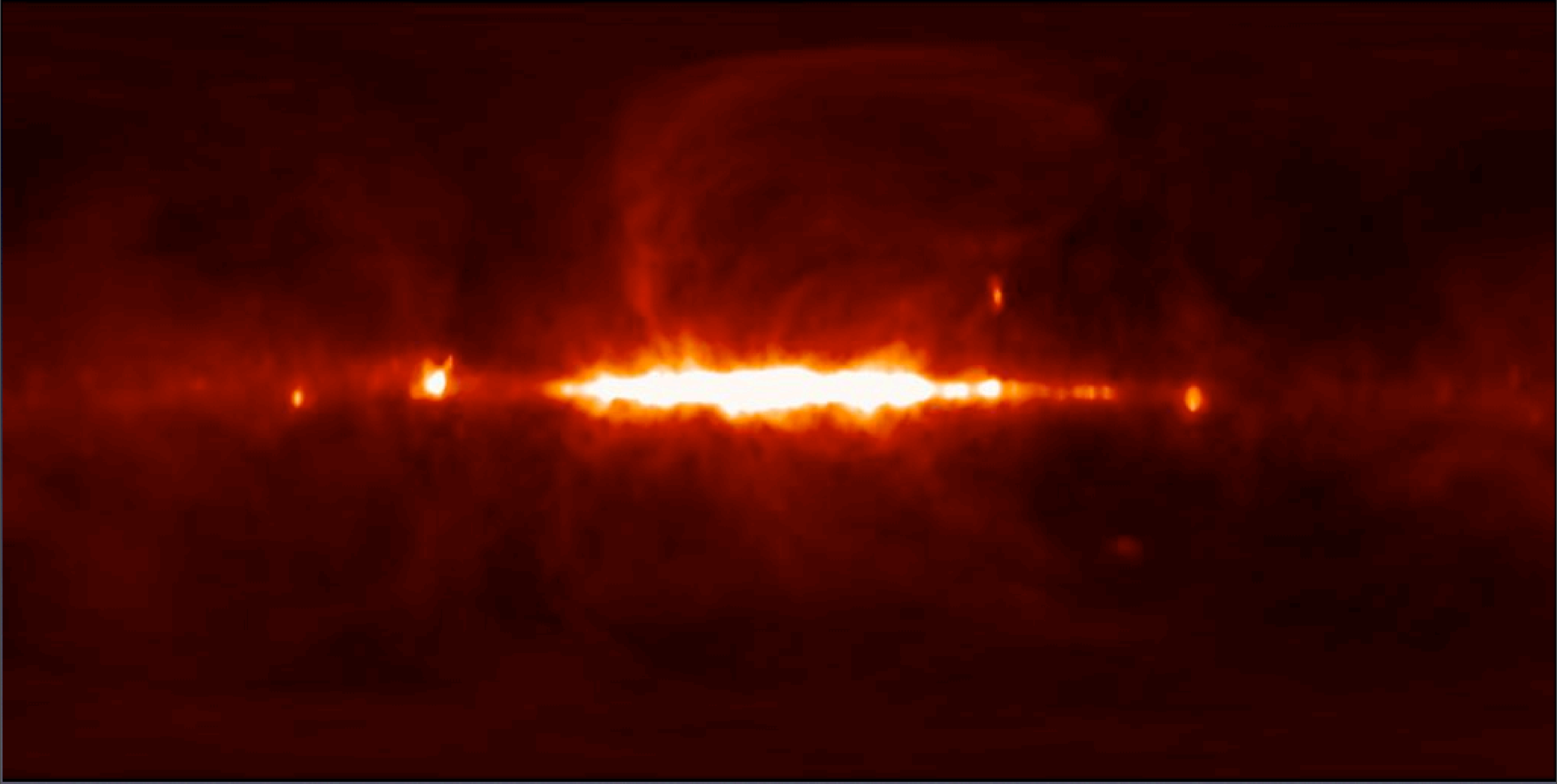
Interstellar Dust from IRAS, DIRBE (Finkbeiner et al. 1999) Map extrapolated from 3 THz (100 micron) with FIRAS.

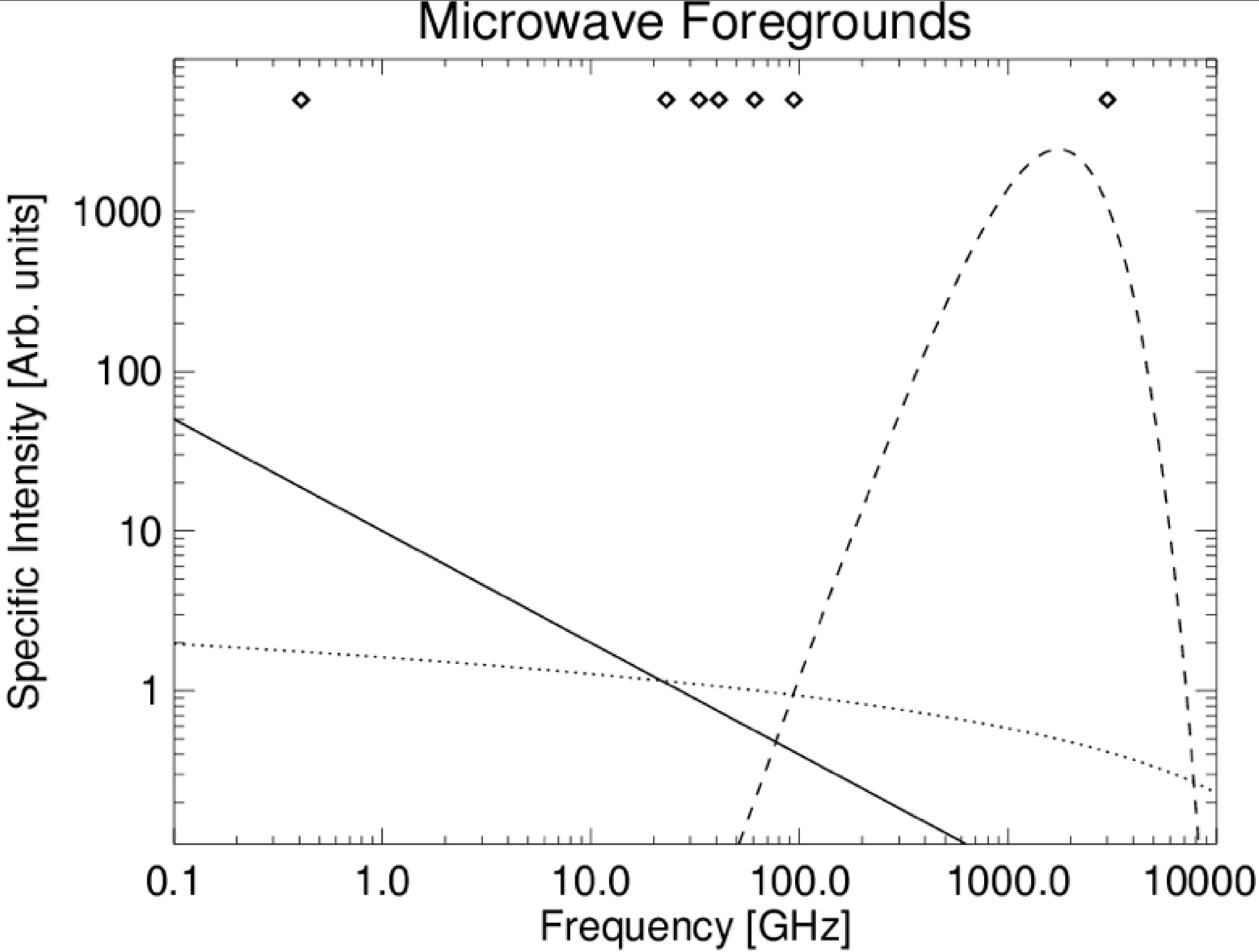


Ionized Gas from WHAM, SHASSA, VTSS (Finkbeiner 2003) H-alpha emission measure goes as thermal bremsstrahlung.



Synchrotron at 408 MHz (Haslam et al. 1982)





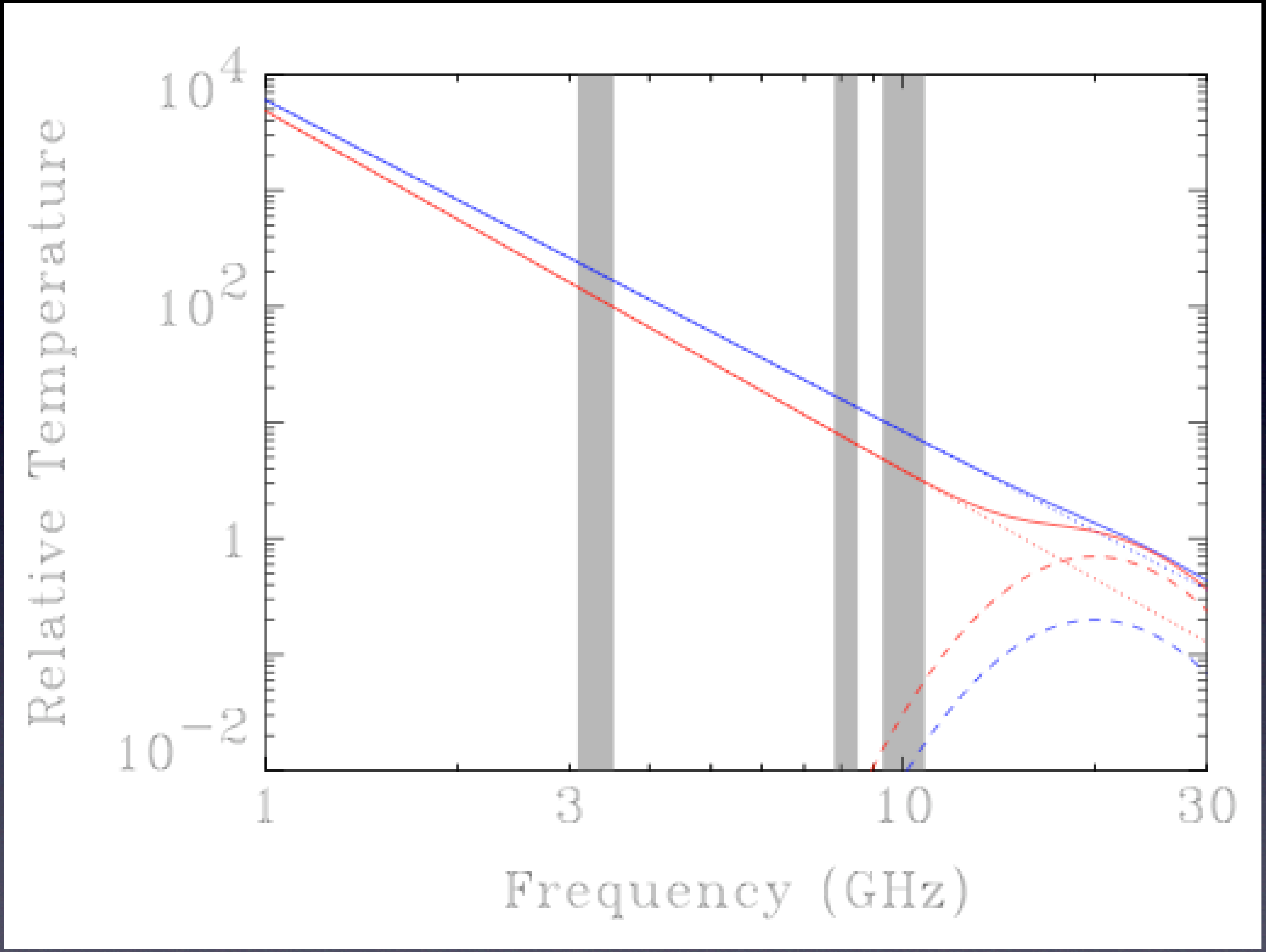
Microwave Foregrounds
Specific Intensity [Arb. units]
1000
100
10
1
0.1
1.0
10.0
100.0
1000.0
10000
Frequency [GHz]

There is also “spinning dust” emission,
i.e. electric dipole emission from rapidly
rotating small dust grains.

This emission is spatially similar to the thermal
dust, but spectrally different.

(Kogut et al 1996; Draine & Lazarian 1998;
de Oliveira-Costa et al., 1998,1999,2000,2002,2004;
Finkbeiner et al. 2002, 2004, etc...)

Digression - latest evidence for spinning dust from ARCADE:



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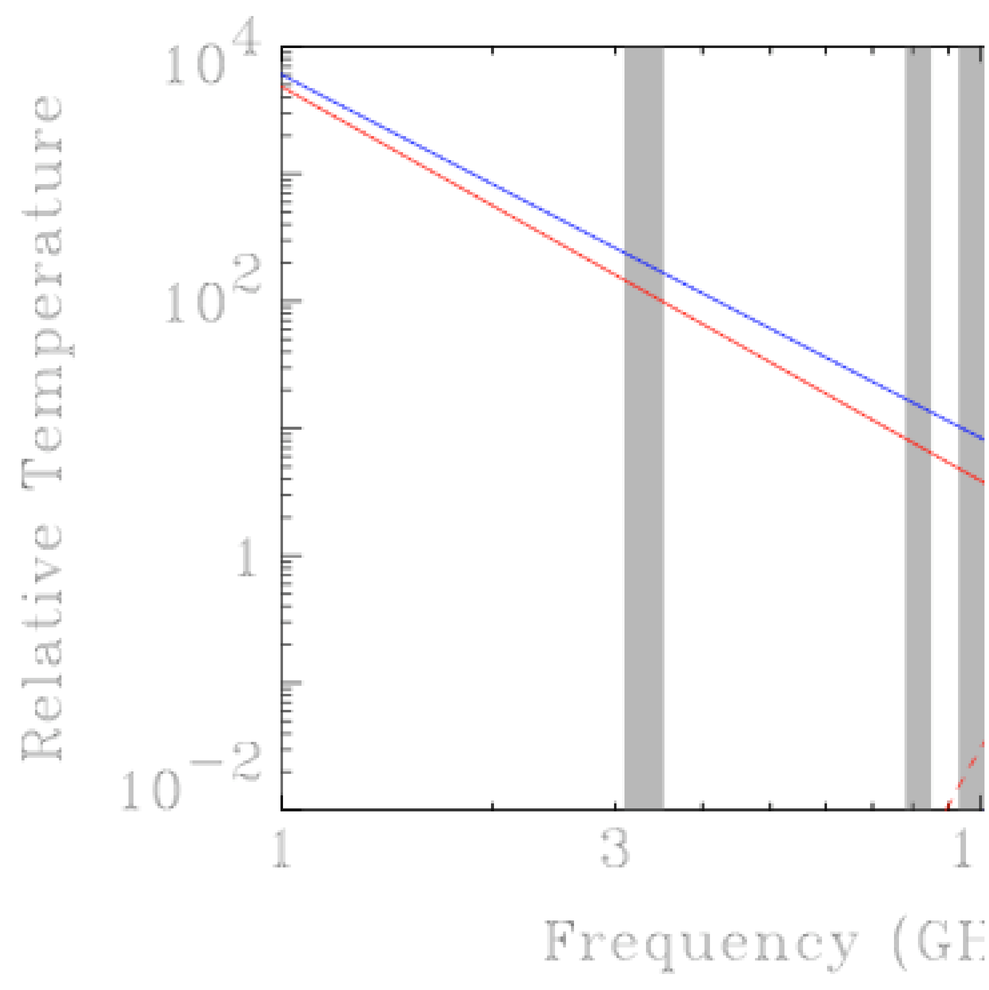

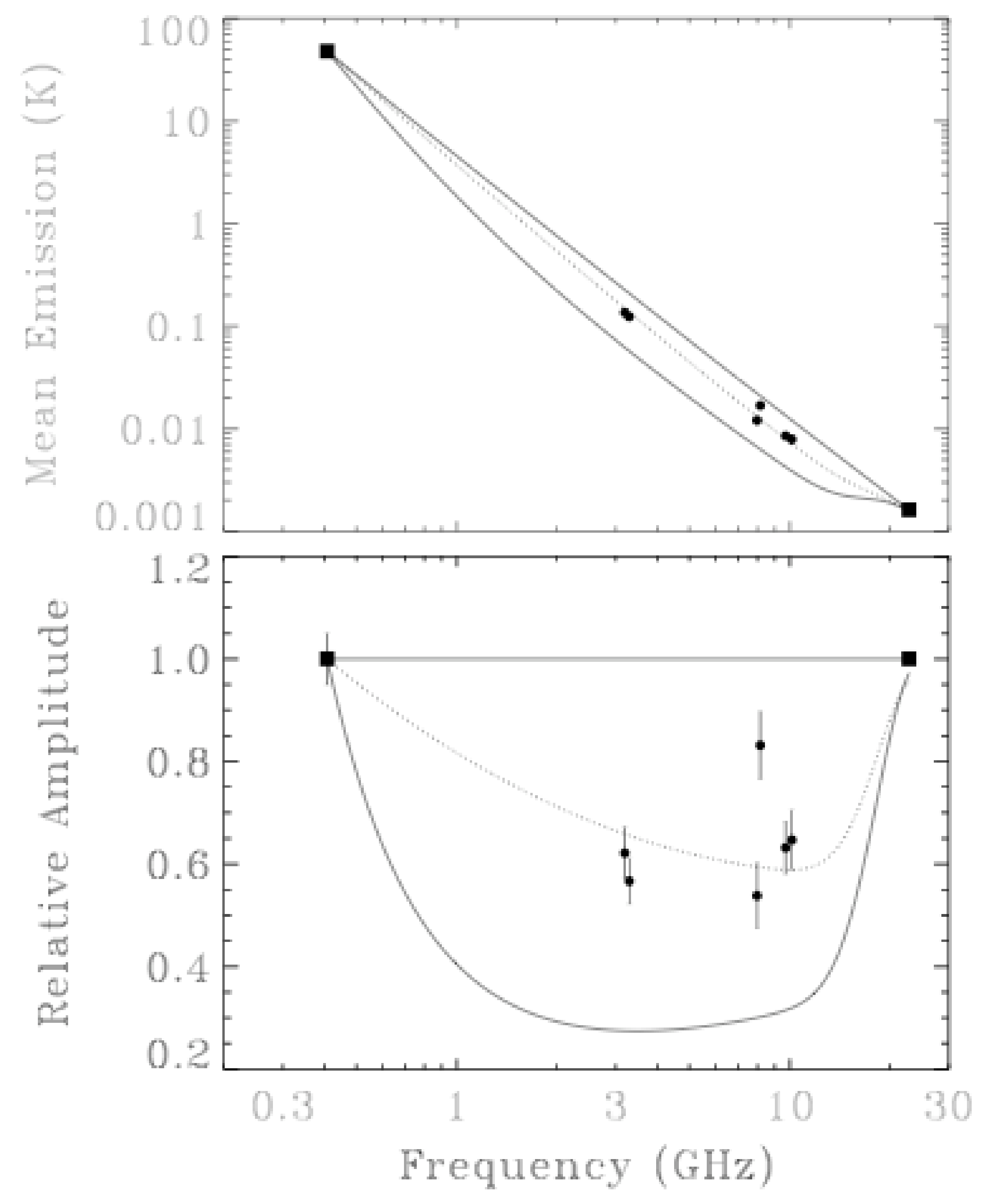

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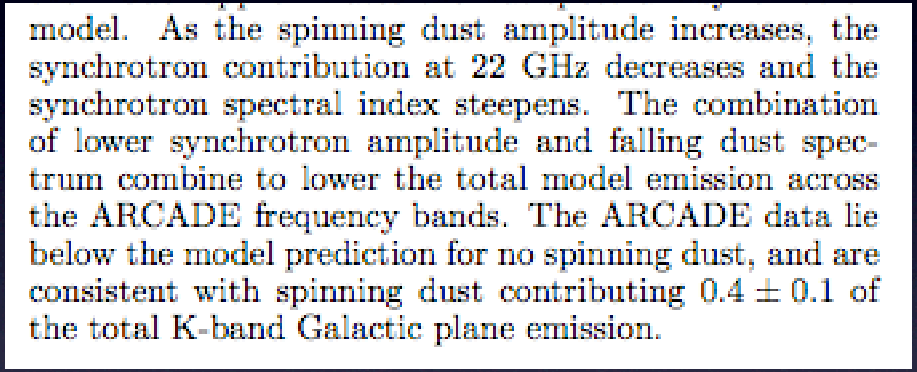

model. As the spinning dust amplitude increases, the synchrotron contribution at 22 GHz decreases and the synchrotron spectral index steepens. The combination of lower synchrotron amplitude and falling dust spectrum combine to lower the total model emission across the ARCADE frequency bands. The ARCADE data lie below the model prediction for no spinning dust, and are consistent with spinning dust contributing 0.4 ± 0.1 of the total K-band Galactic plane emission.

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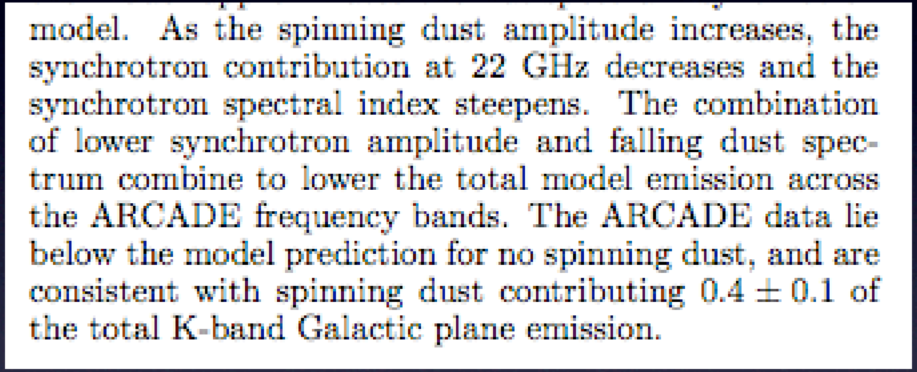
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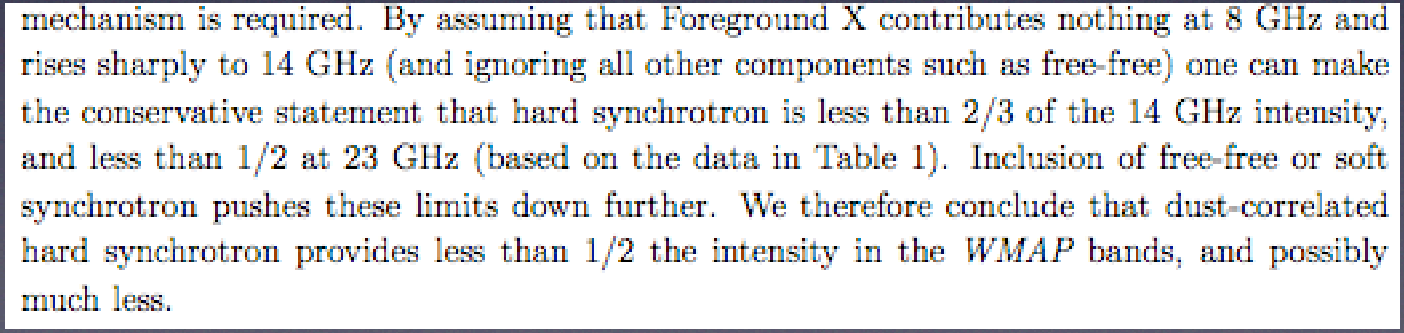
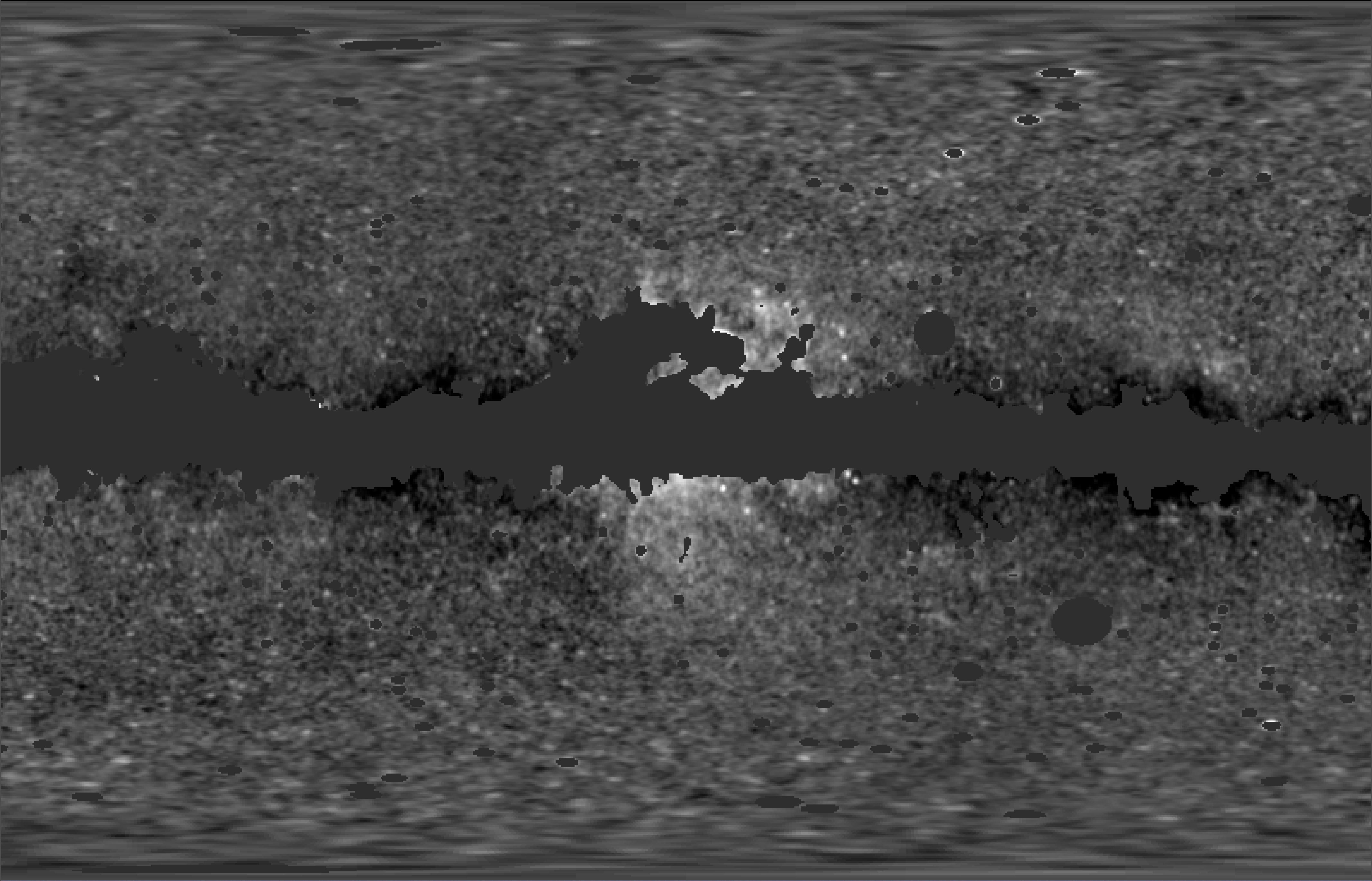
Compare to Finkbeiner et. al. (2004)


mechanism is required. By assuming that Foreground X contributes nothing at 8 GHz and rises sharply to 14 GHz (and ignoring all other components such as free-free) one can make the conservative statement that hard synchrotron is less than 2/3 of the 14 GHz intensity, and less than 1/2 at 23 GHz (based on the data in Table 1). Inclusion of free-free or soft synchrotron pushes these limits down further. We therefore conclude that dust-correlated hard synchrotron provides less than 1/2 the intensity in the *WMAP* bands, and possibly much less.

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



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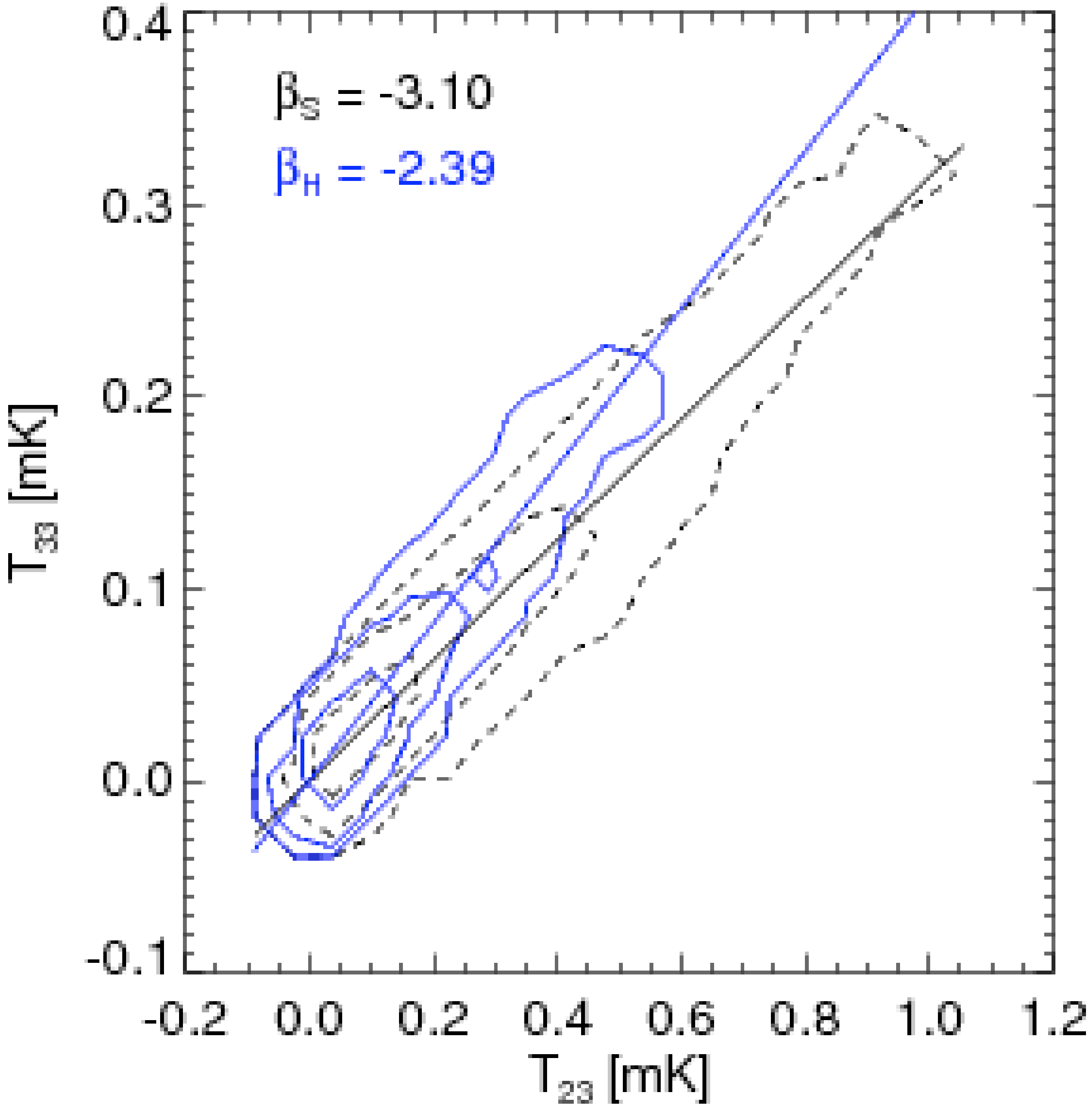
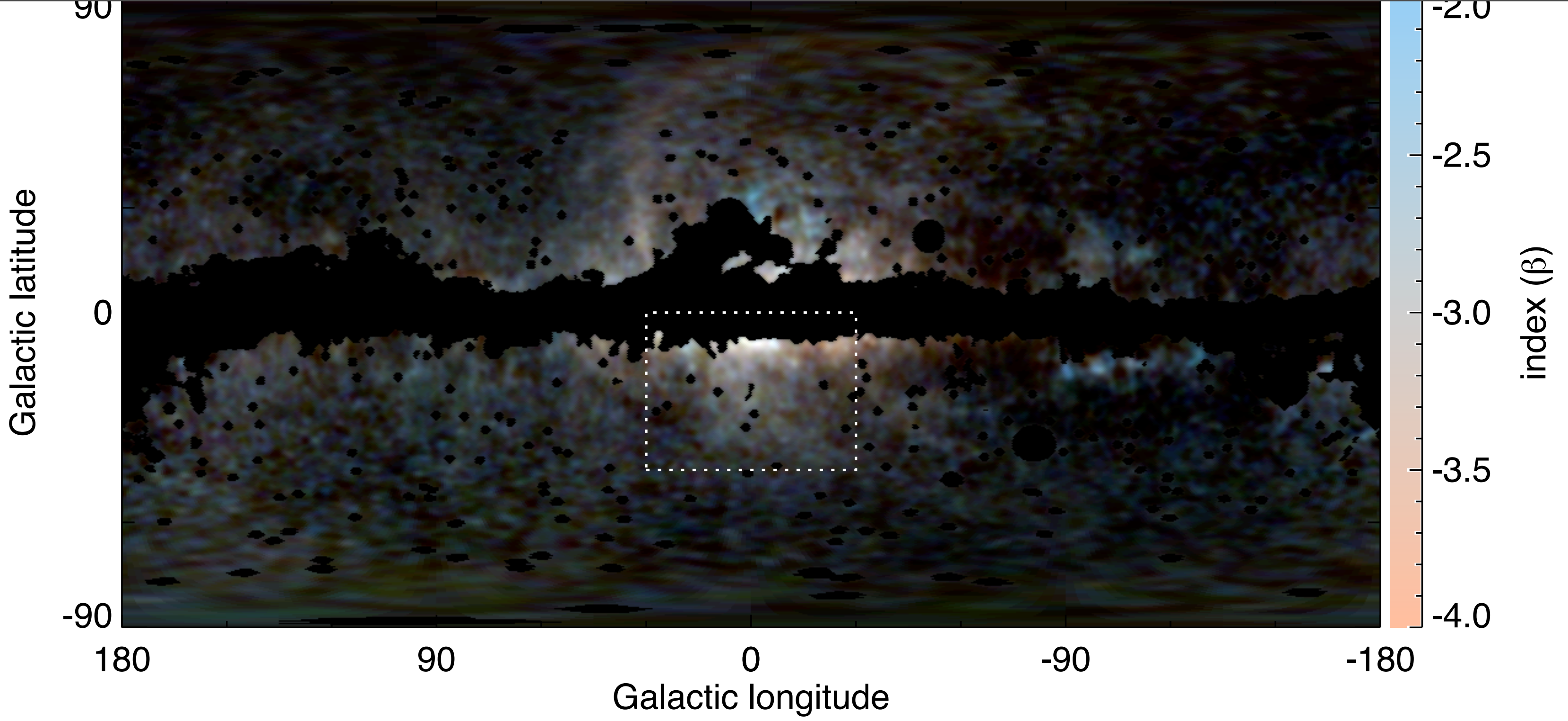
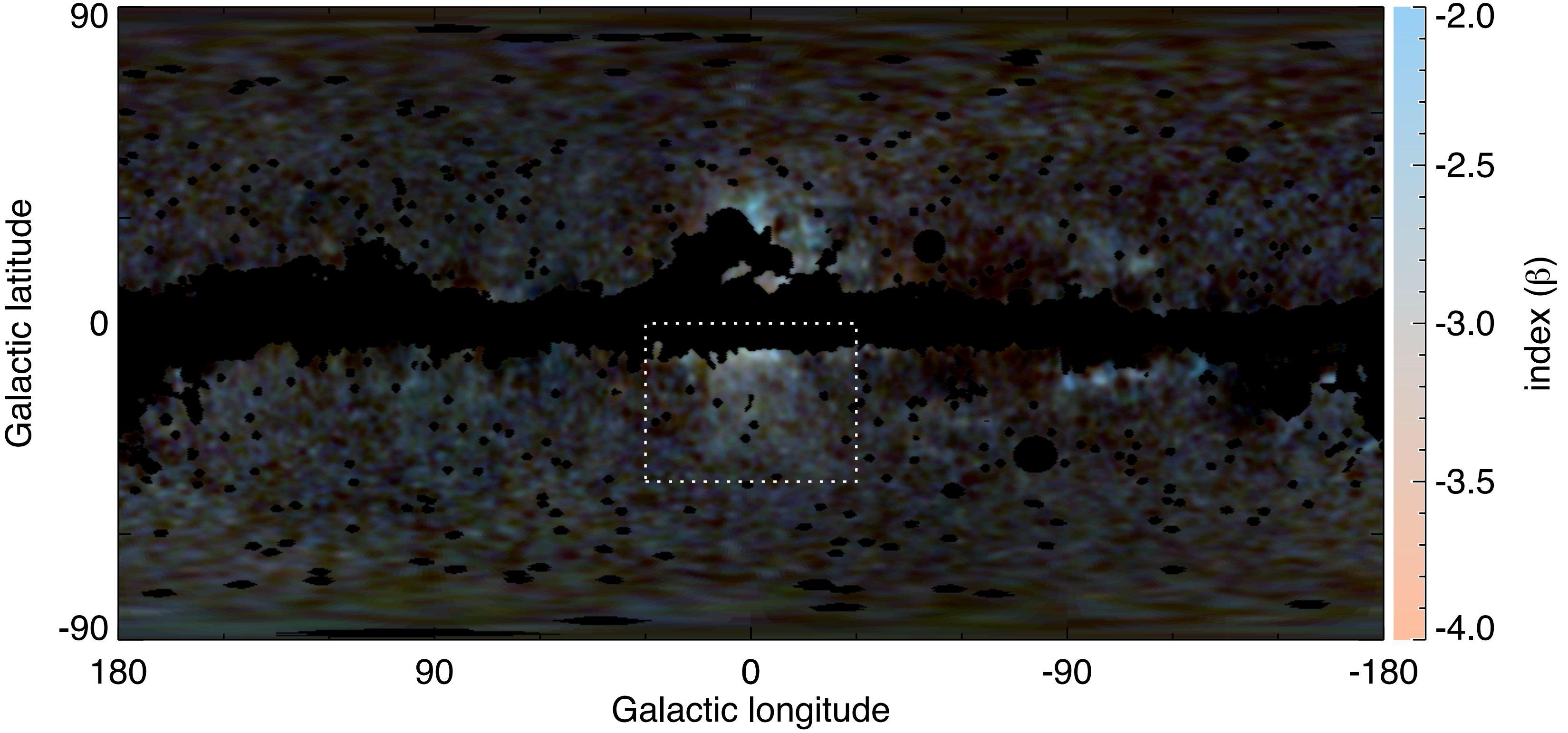
Could it be new physics? Or is it just extra supernovae?


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


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)

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1) Can we see the ICS gammas expected if the WMAP haze is synchrotron?

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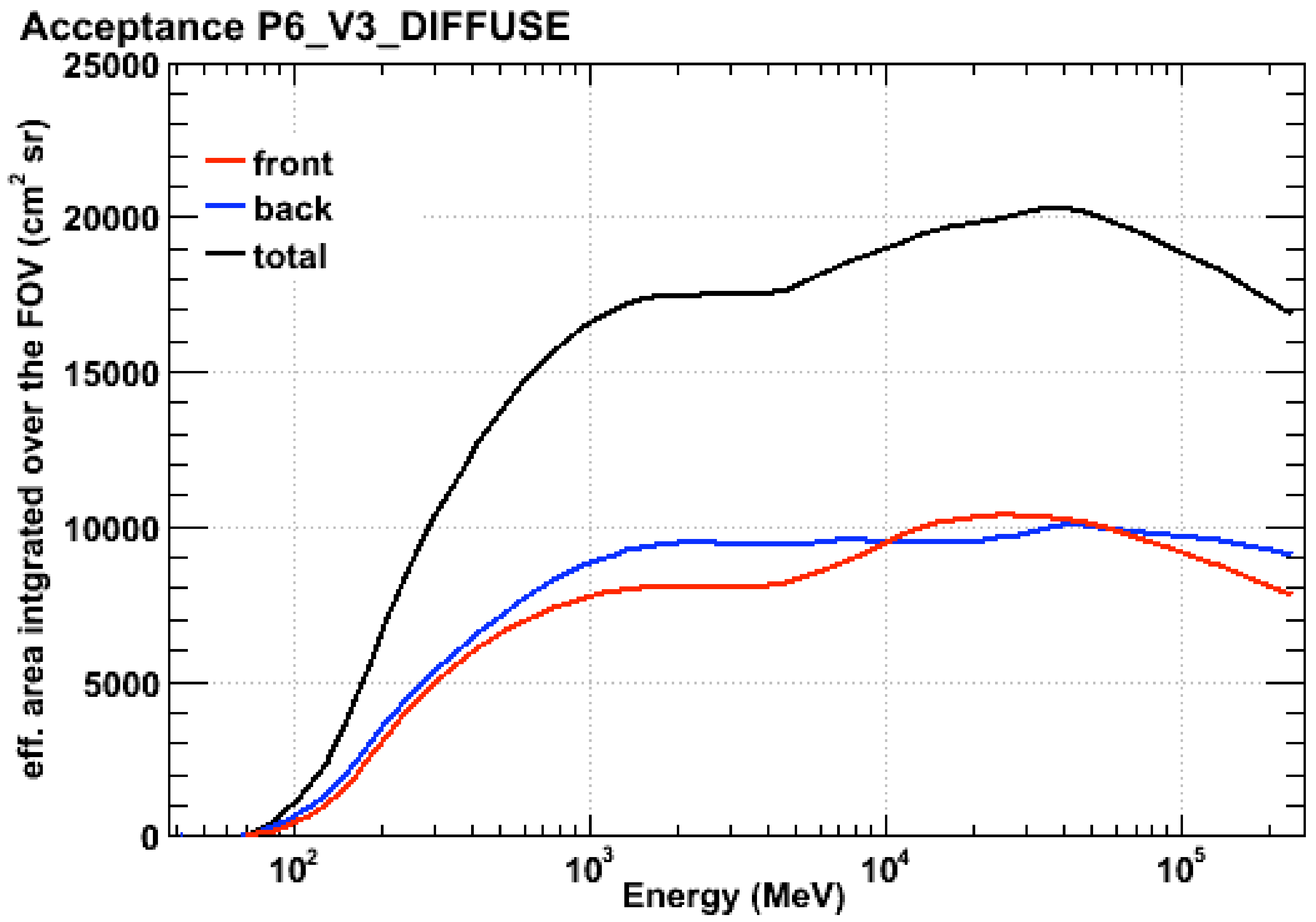
2) Do these electrons come from dark matter annihilation (or decay) ?

Fermi results (brand new):

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

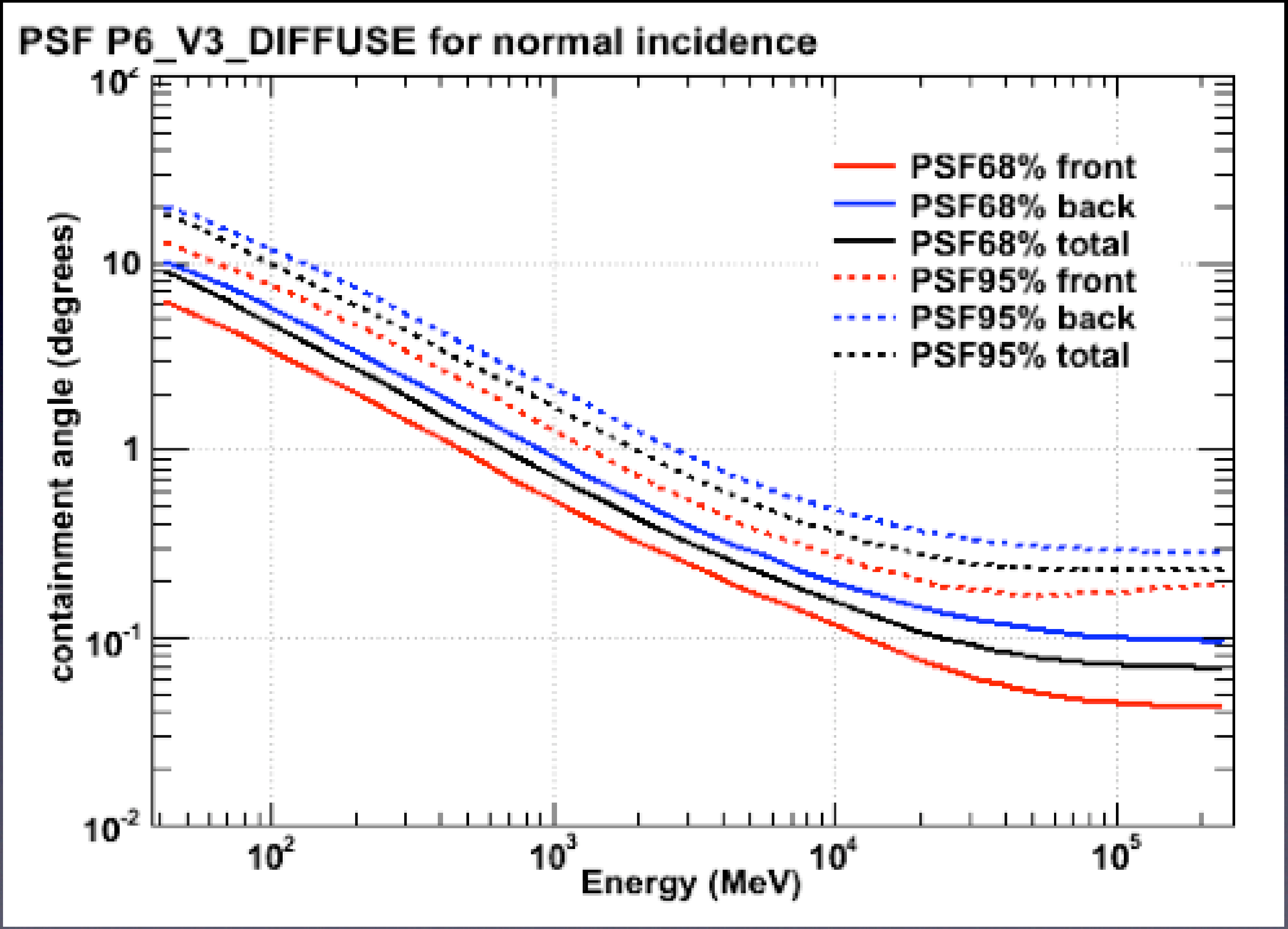
Fermi performance has been good:

Fermi performance:



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

Fermi performance:



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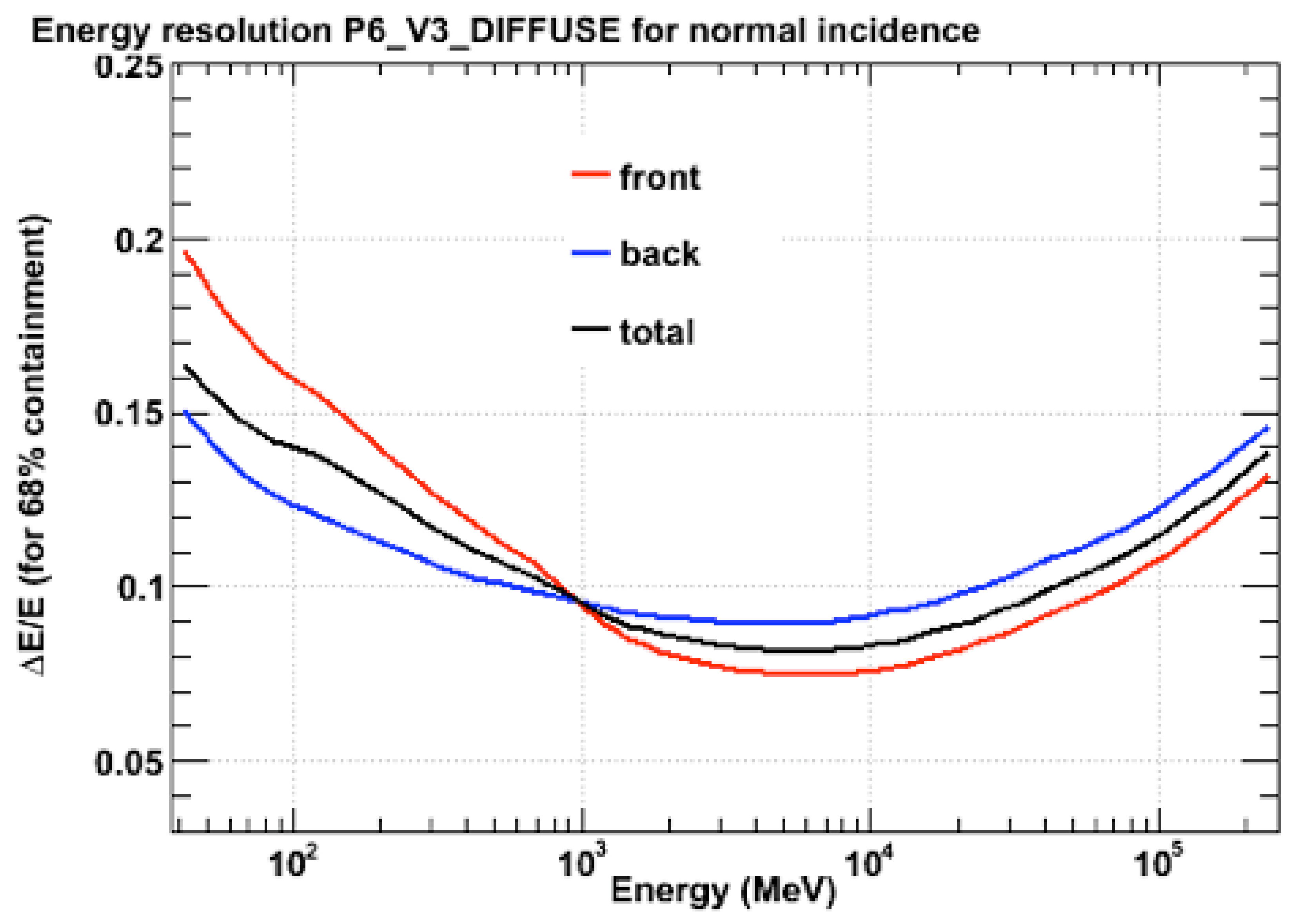

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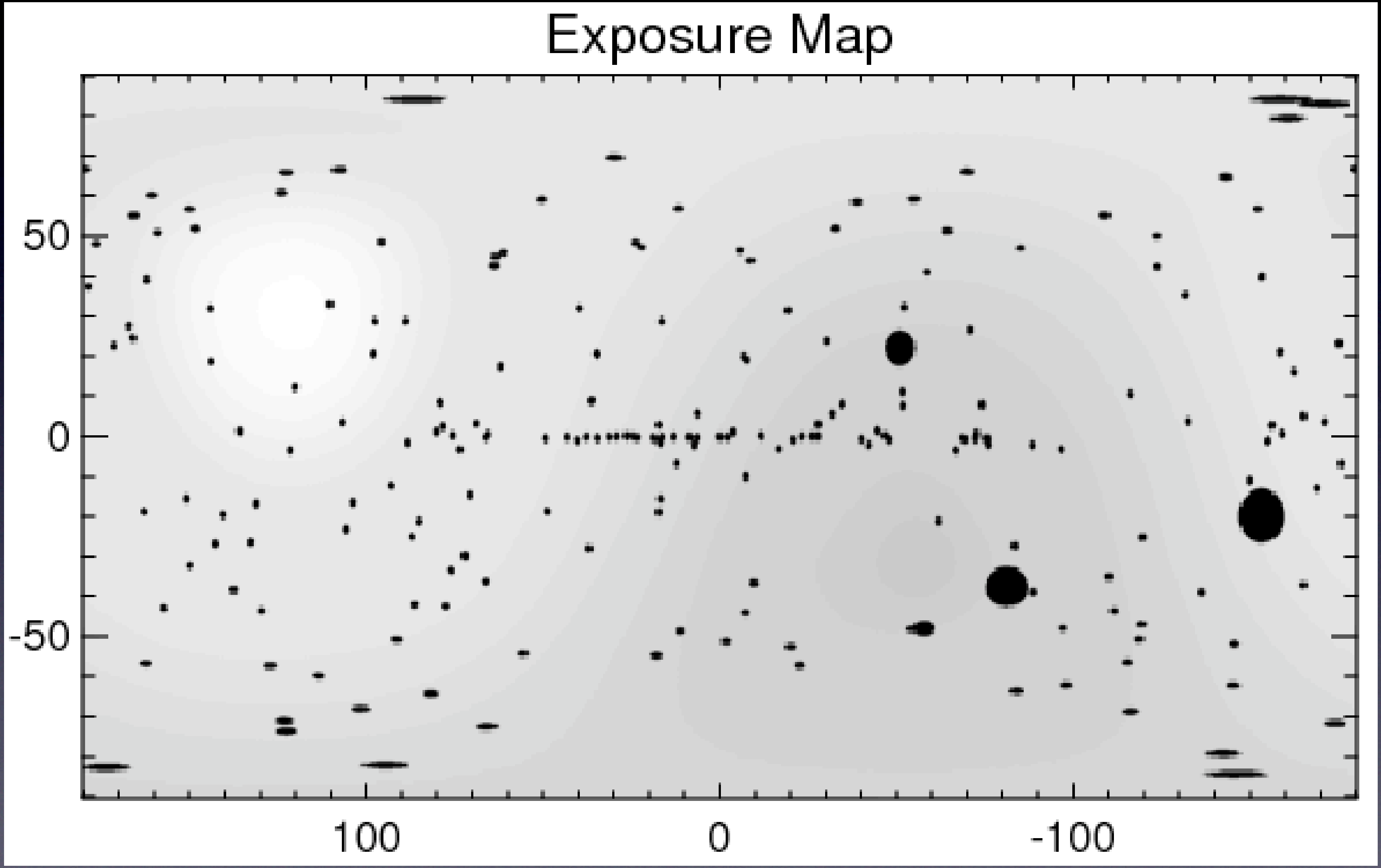
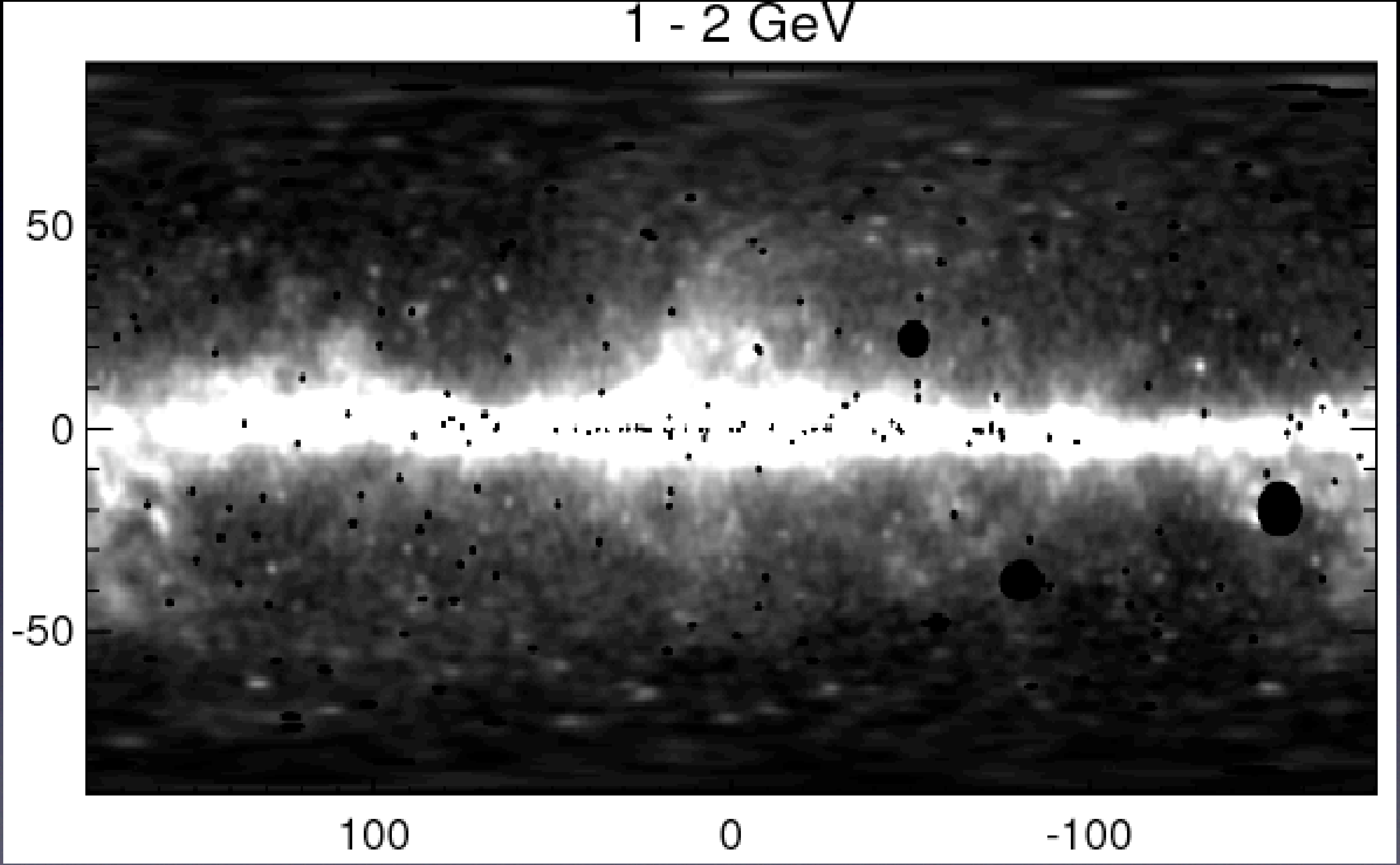
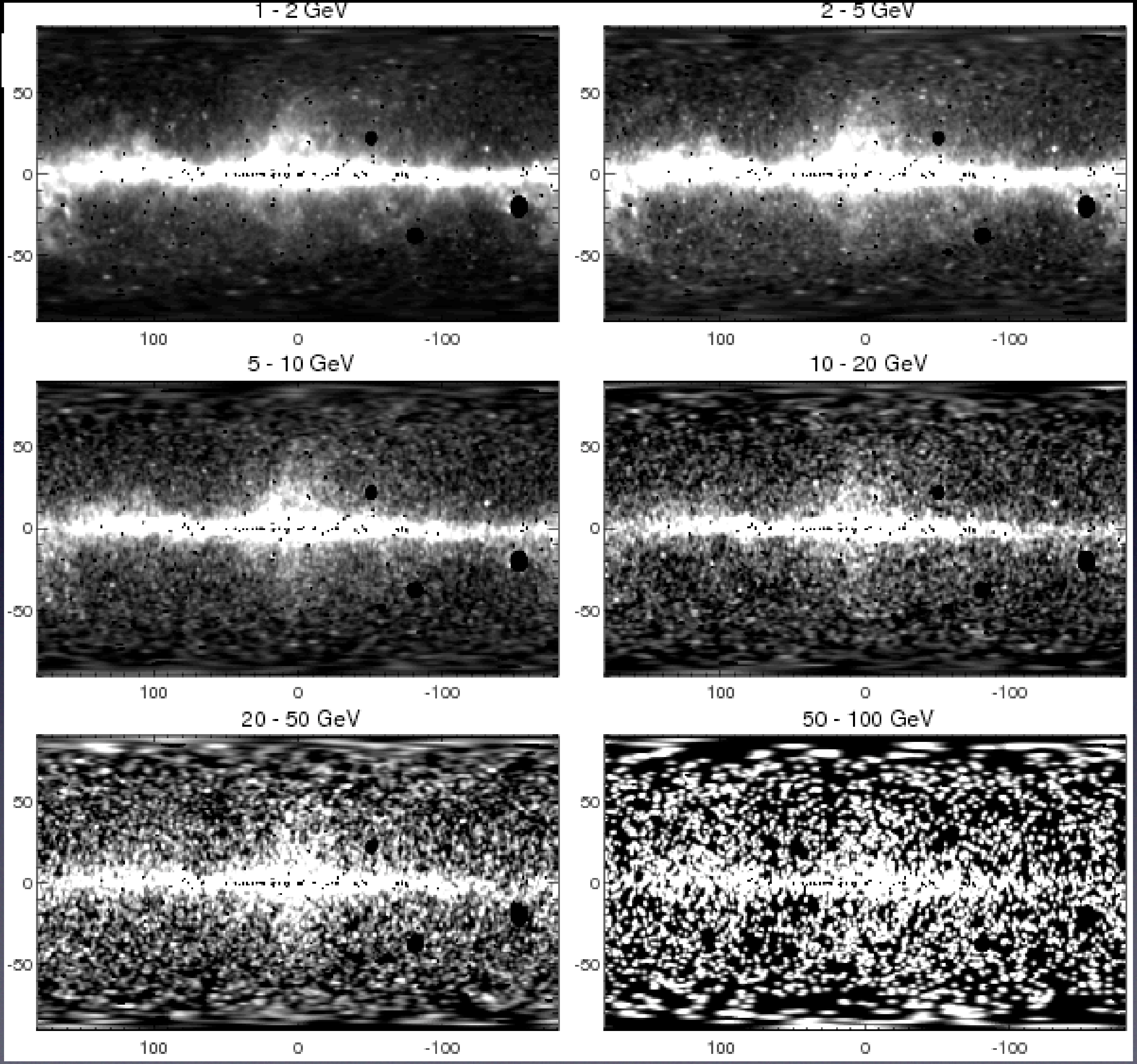
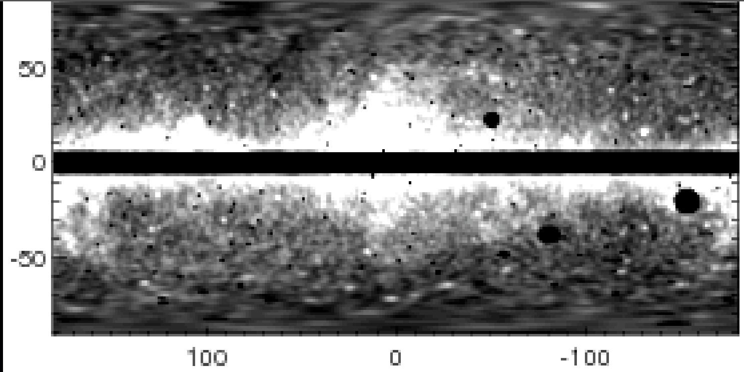
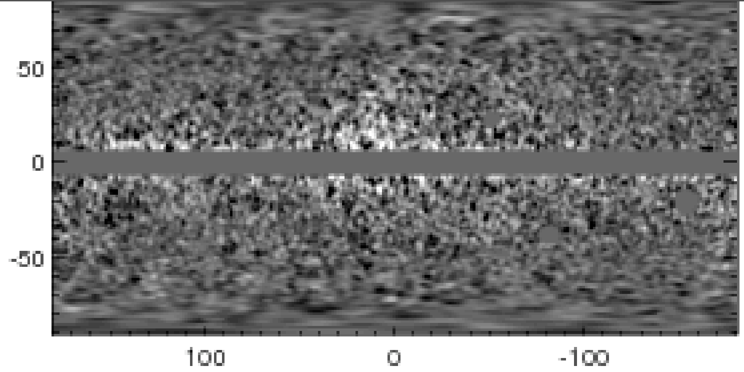


Fermi sky map (point source subtracted):

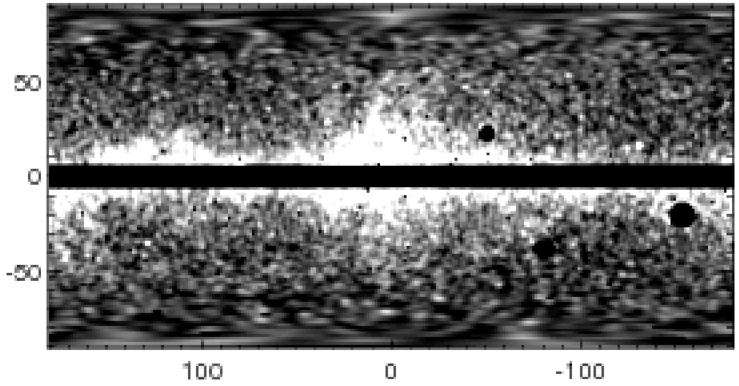



1 - 2 GeV
2 - 5 GeV
5 - 10 GeV
10 - 20 GeV
20 - 50 GeV
50 - 100 GeV
50
0
-50
100
0
-100

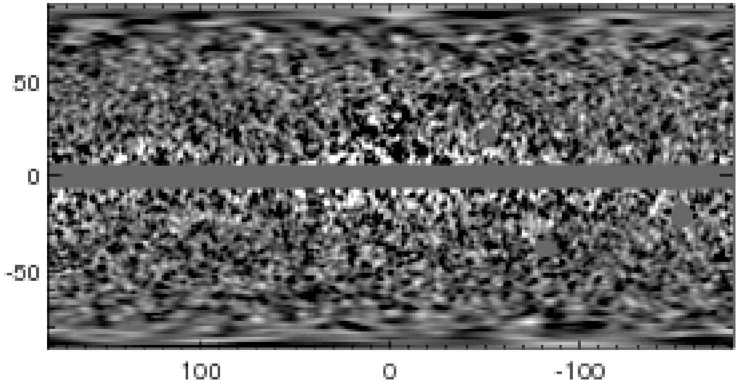




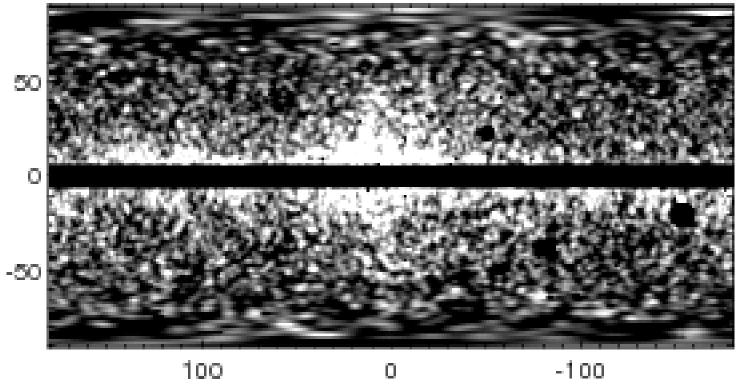
5 - 10 GeV



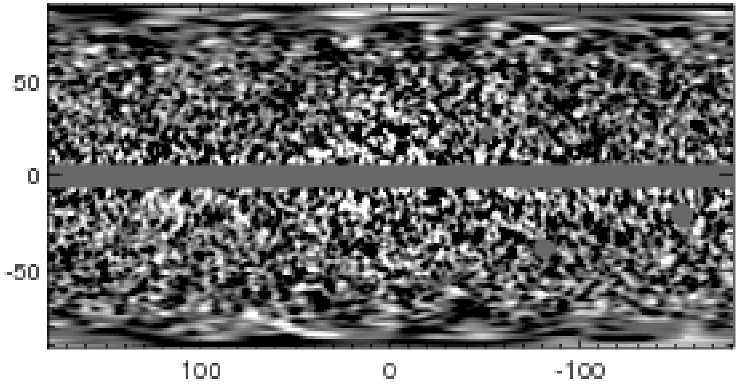
5 - 10 GeV front minus back difference



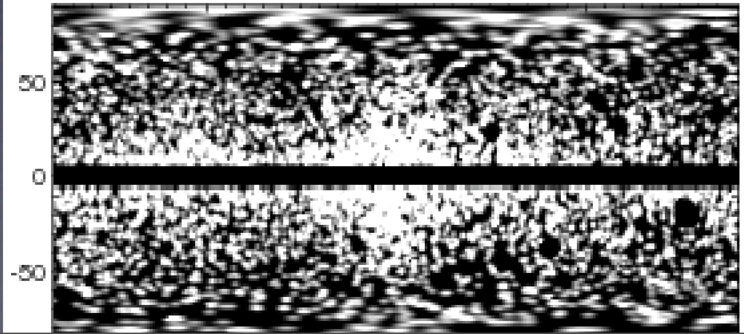
10 - 20 GeV



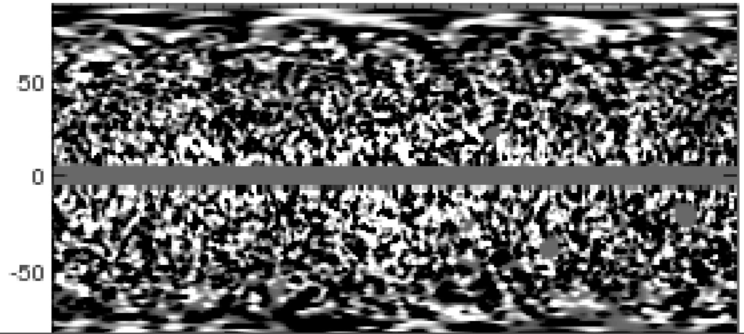
10 - 20 GeV front minus back difference



20 - 50 GeV

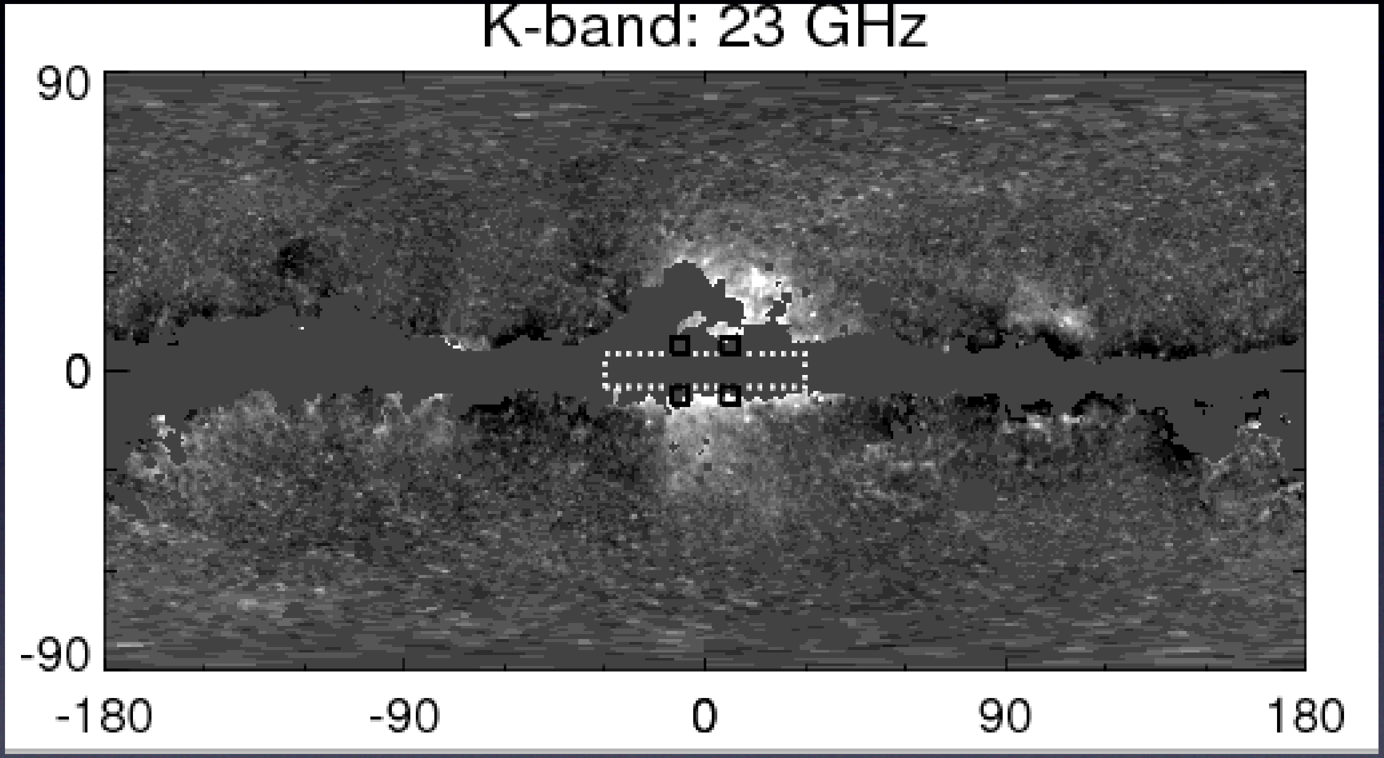


20 - 50 GeV front minus back difference

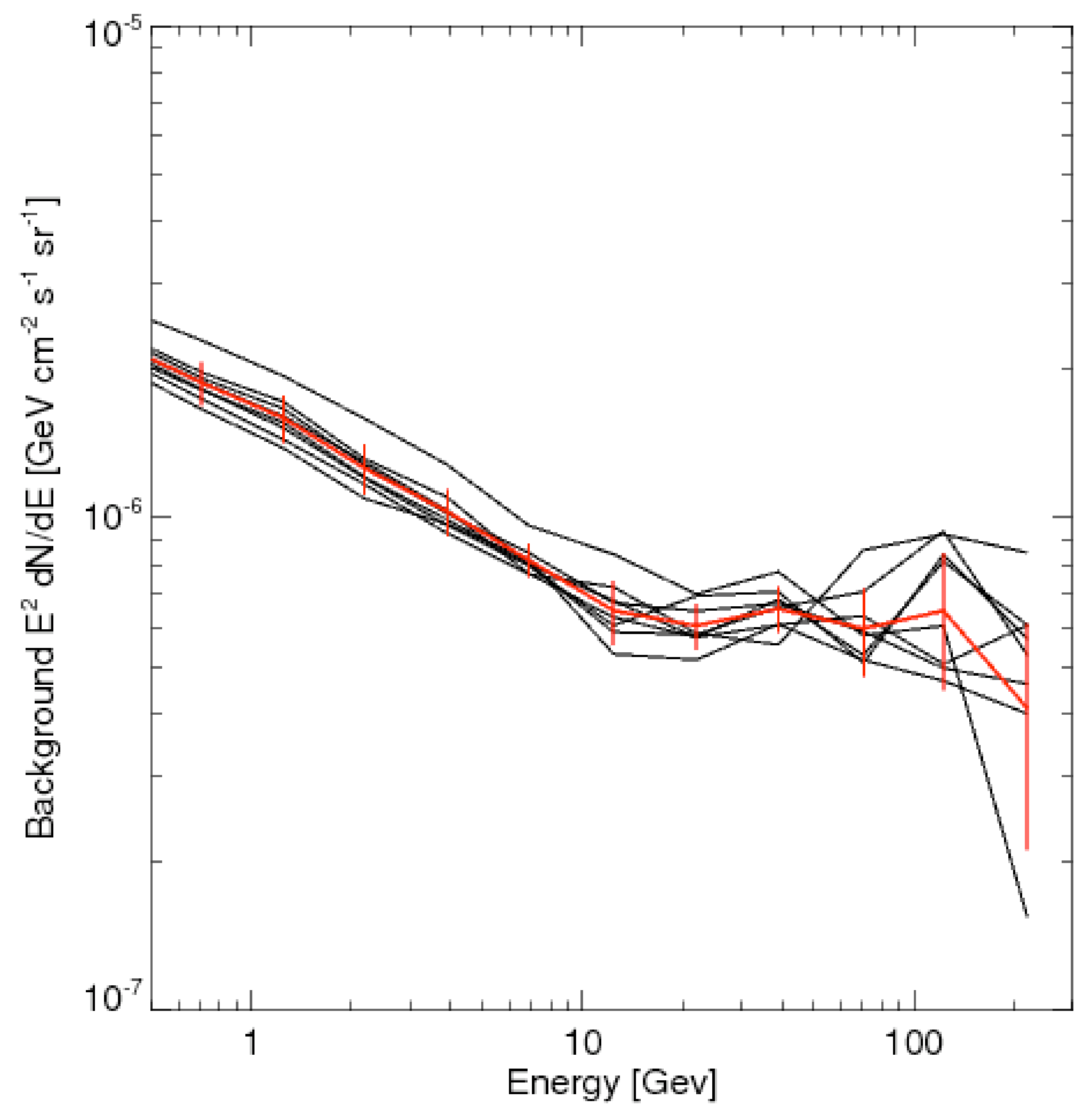


F-B

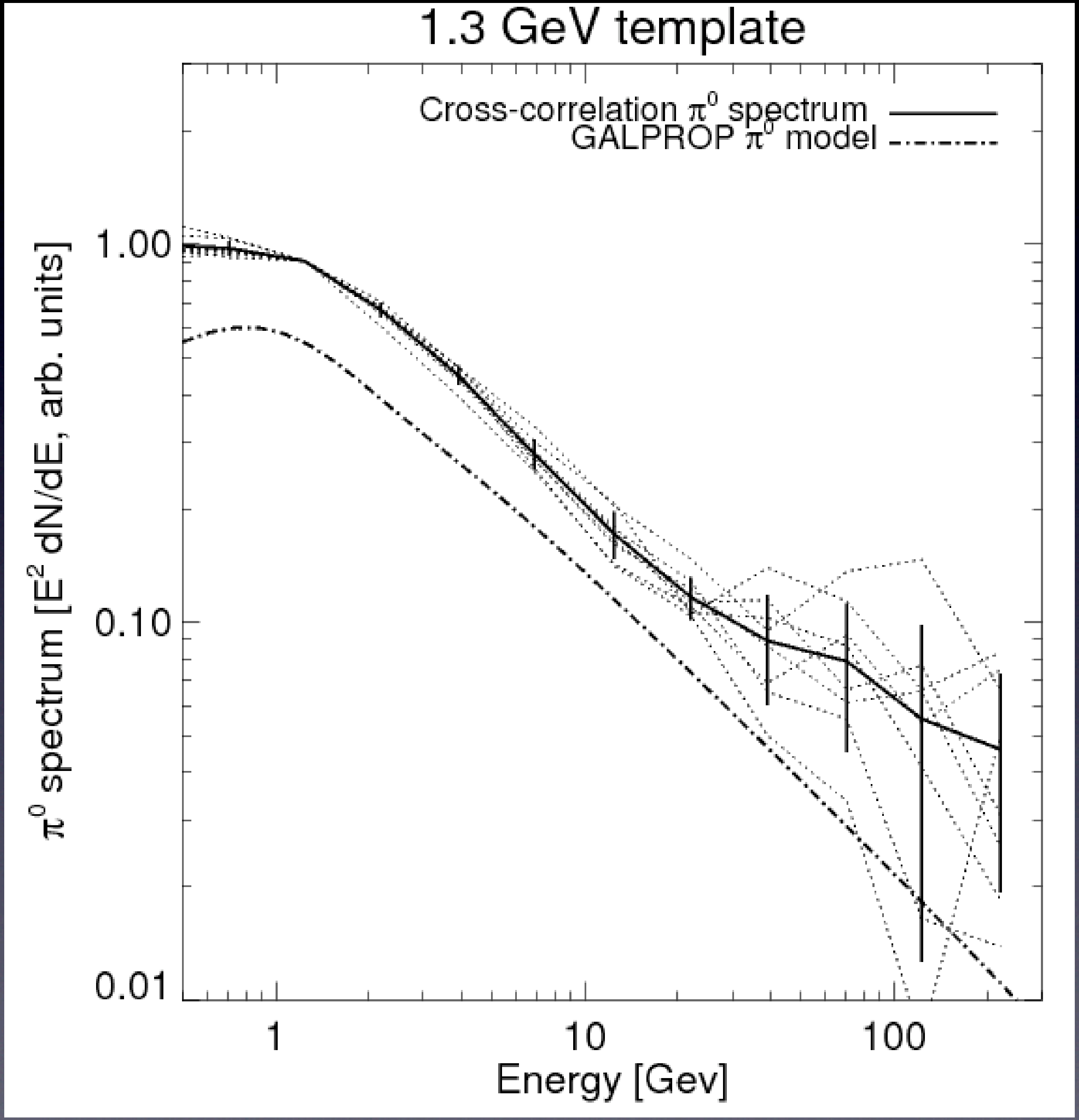
WMAP haze (for comparison)



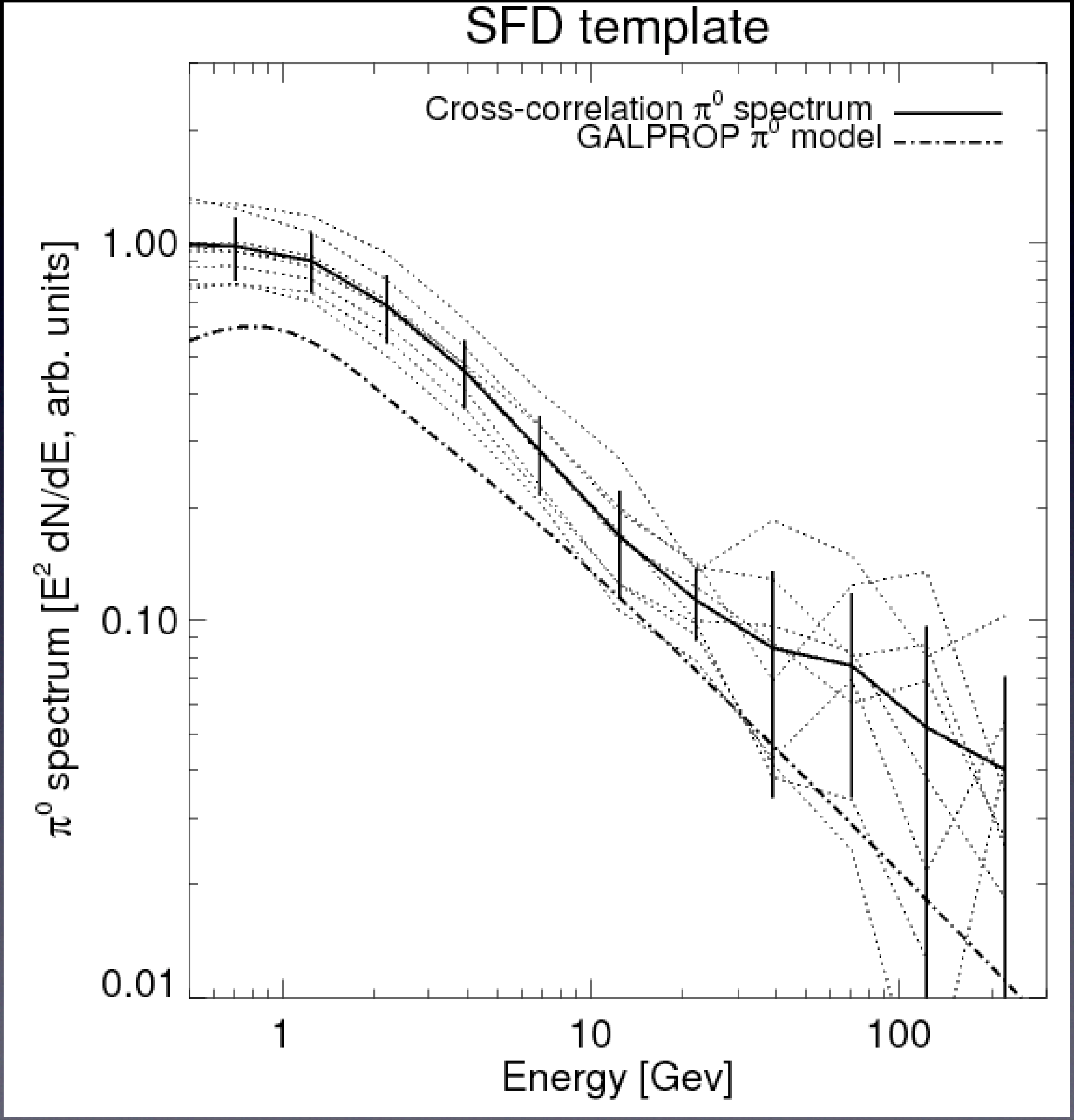
Fermi spectra - background:

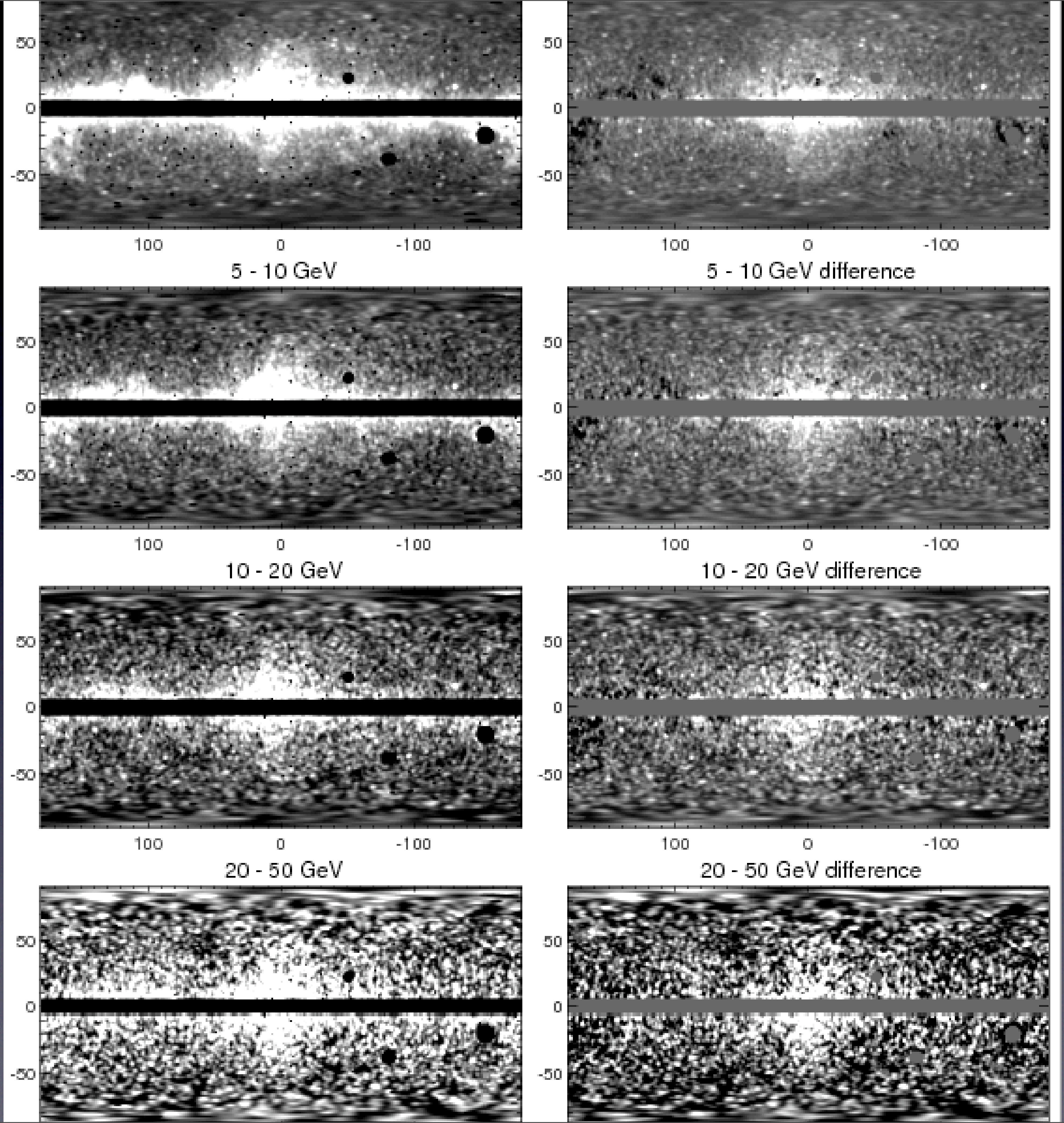


Fermi spectra - pi 0 gammas?

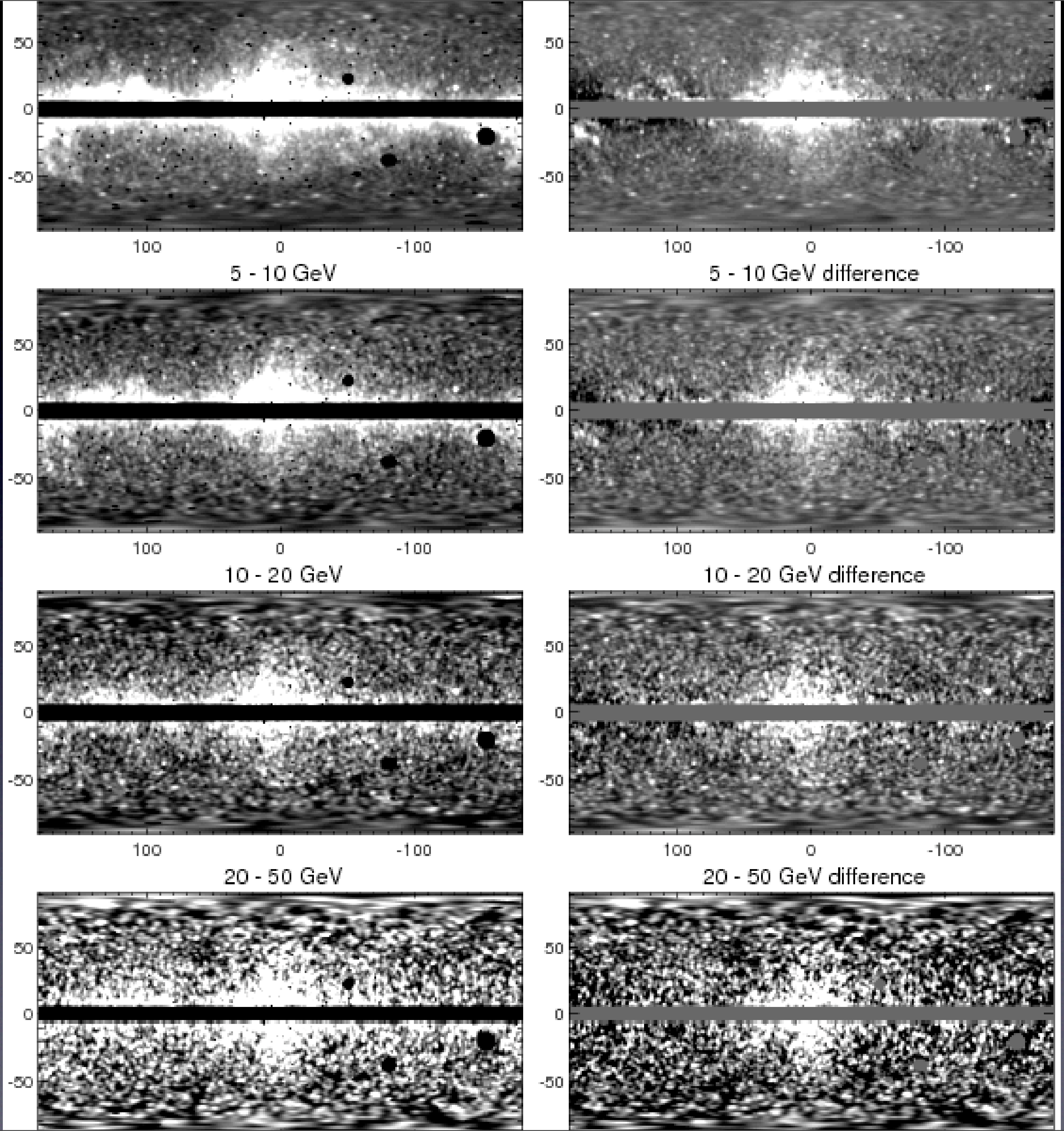


Regress against dust instead...




50
0
-50
100
0
-100
5 - 10 GeV
5 - 10 GeV difference
10 - 20 GeV
10 - 20 GeV difference
20 - 50 GeV
20 - 50 GeV difference

Dust



5 - 10 GeV

5 - 10 GeV difference

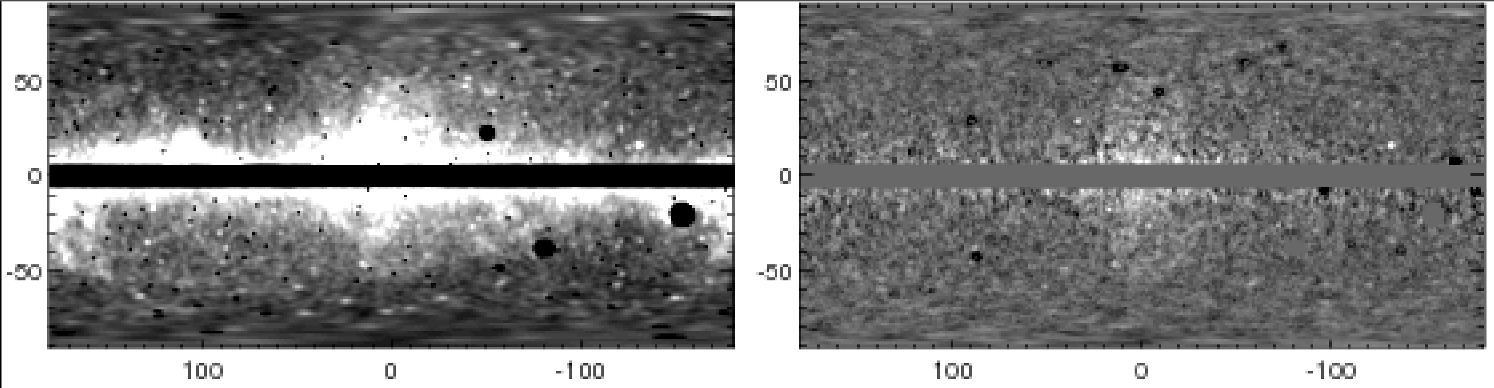
10 - 20 GeV

10 - 20 GeV difference

20 - 50 GeV

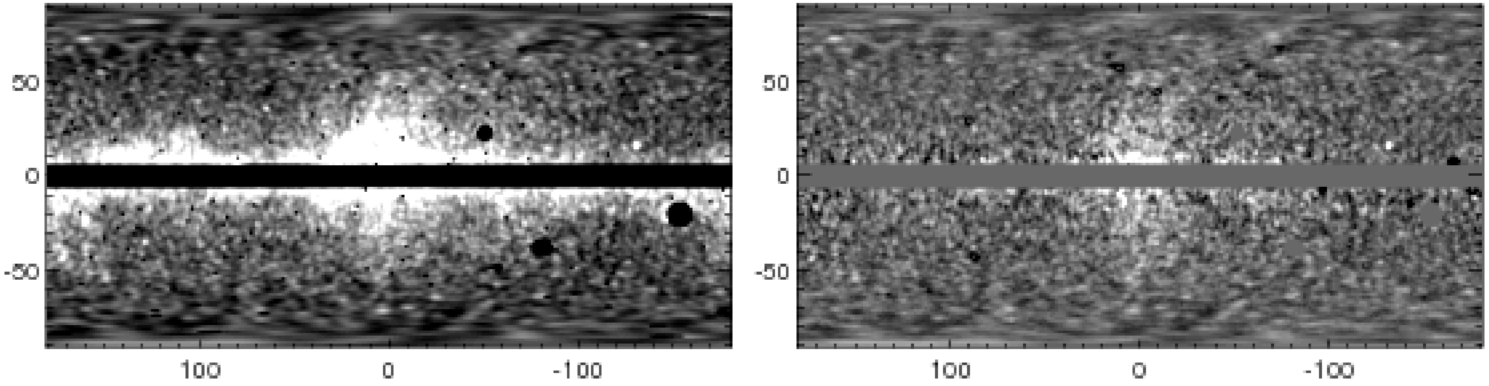
20 - 50 GeV difference

H



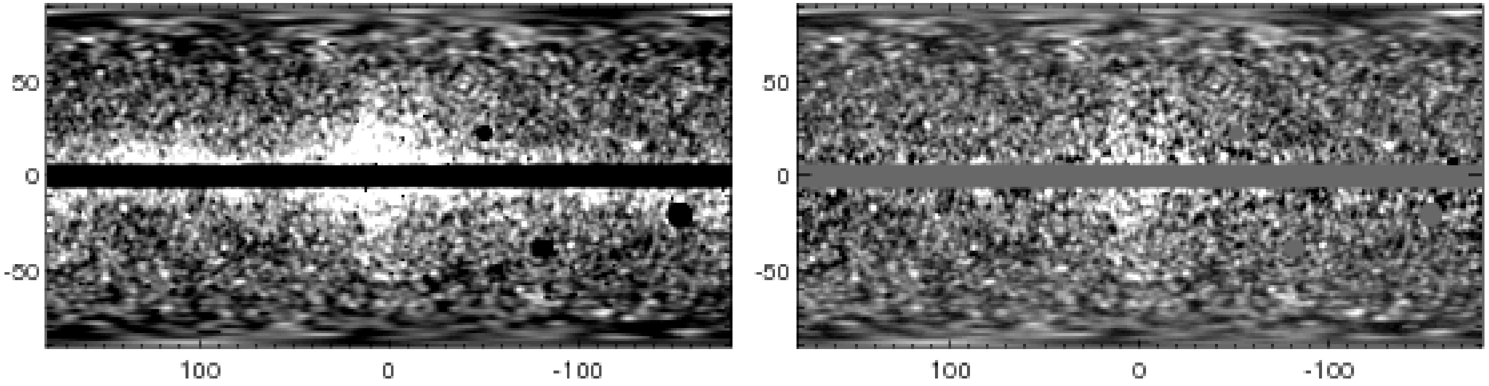
5 - 10 GeV

5 - 10 GeV difference



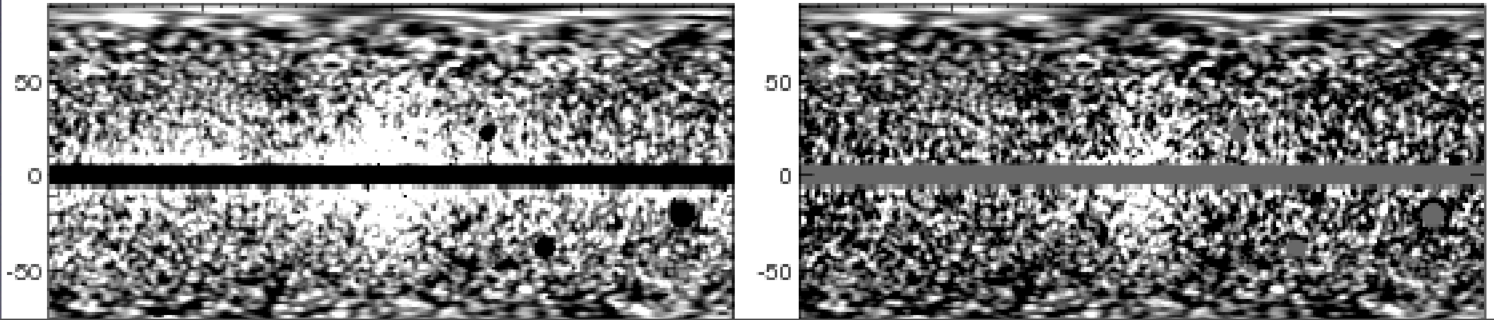
10 - 20 GeV

10 - 20 GeV difference

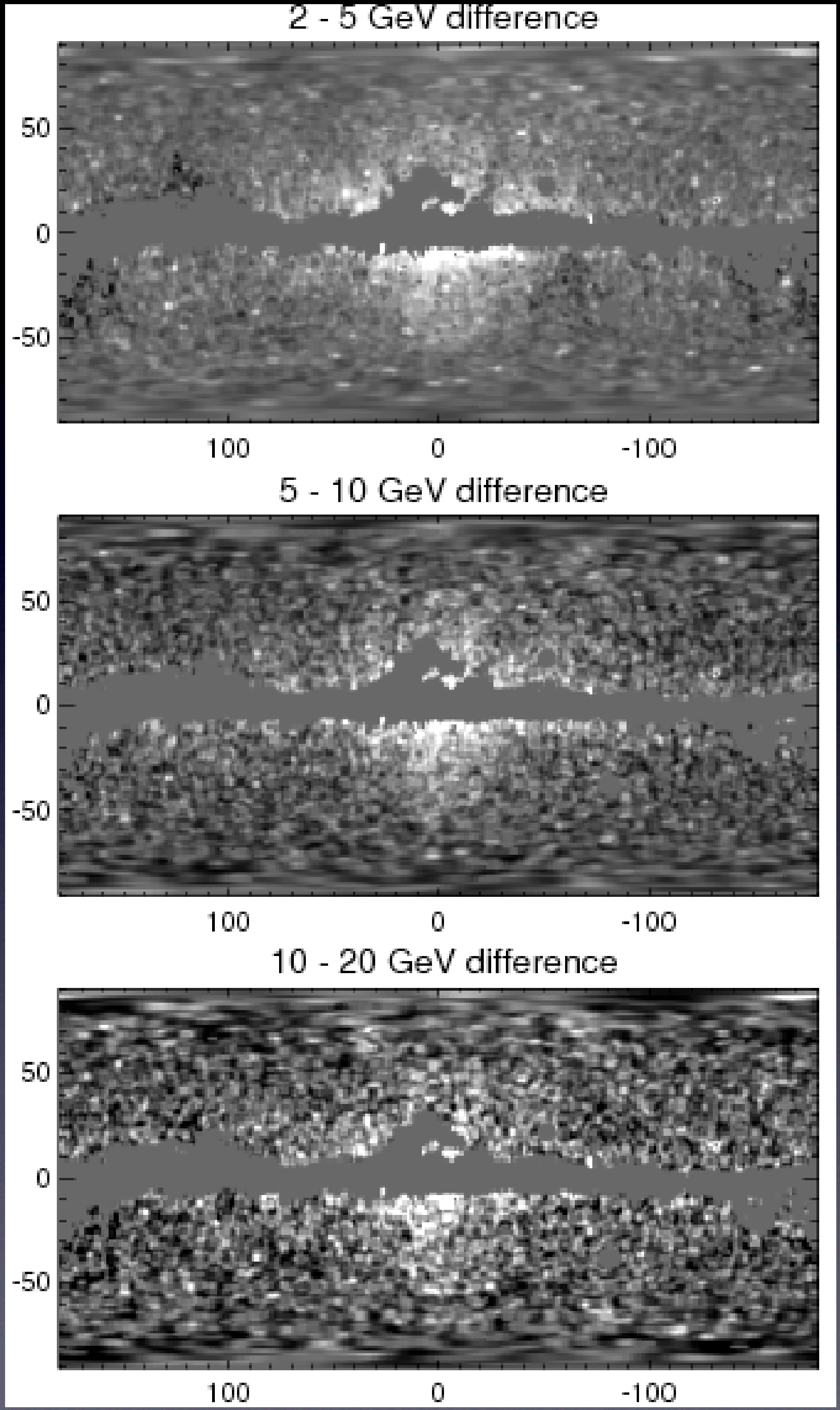


20 - 50 GeV

20 - 50 GeV difference

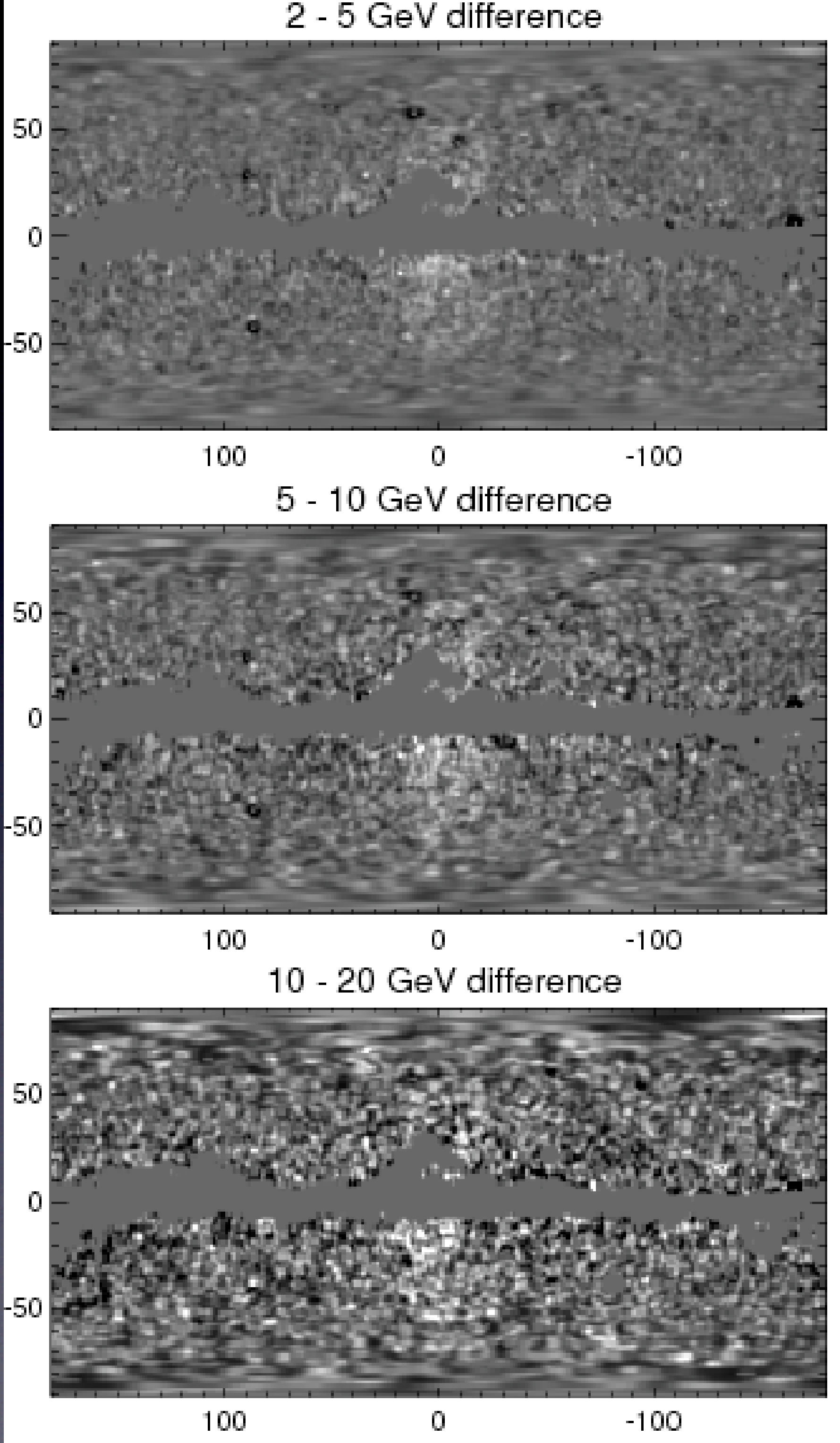


1 GeV


2 - 5 GeV difference

5 - 10 GeV difference

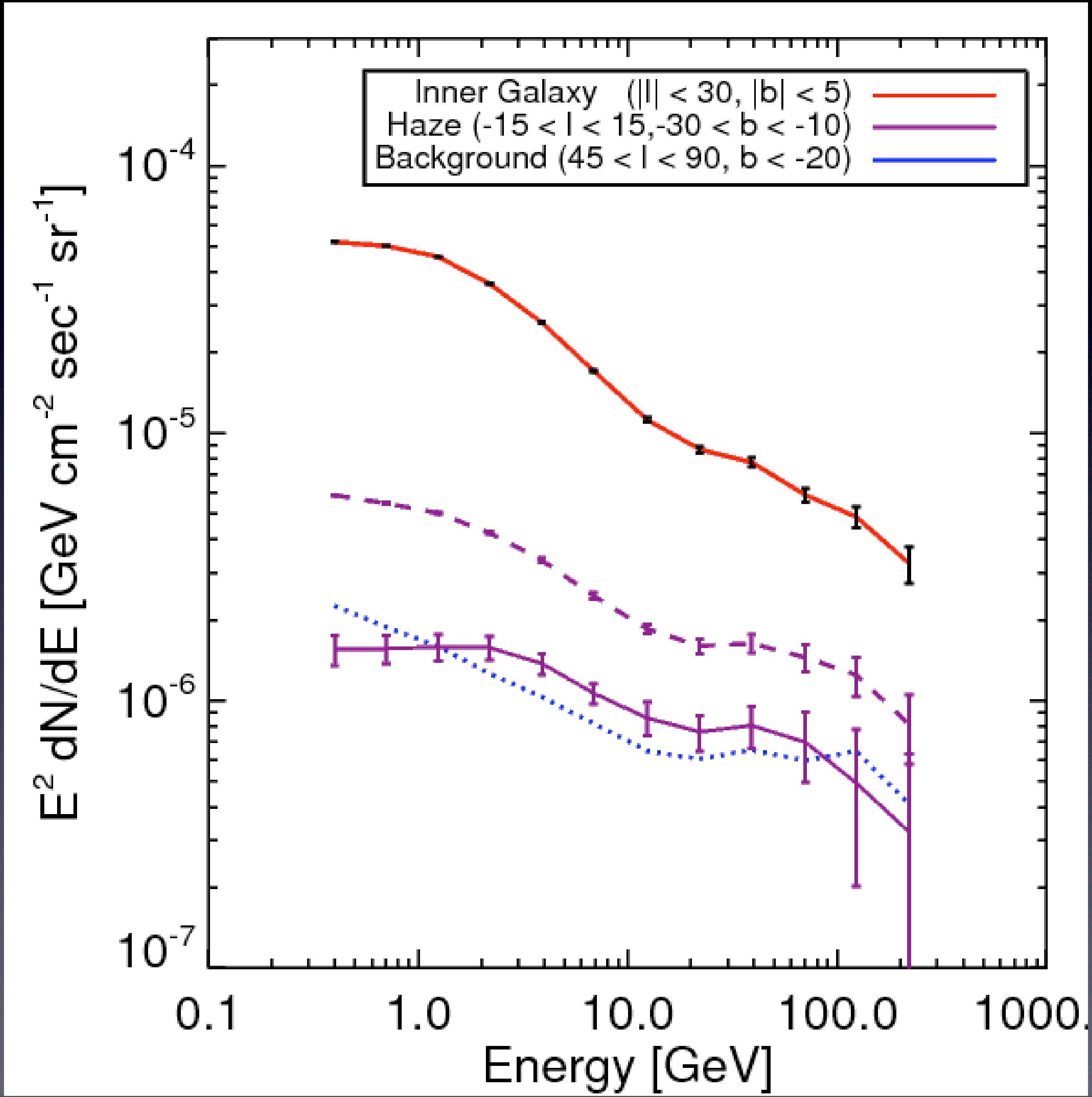
10 - 20 GeV difference


2 - 5 GeV difference

5 - 10 GeV difference

10 - 20 GeV difference

Fermi spectrum in the "haze" region



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.

Other signals: INTEGRAL

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Too many 511 keV photons from center of Galaxy.

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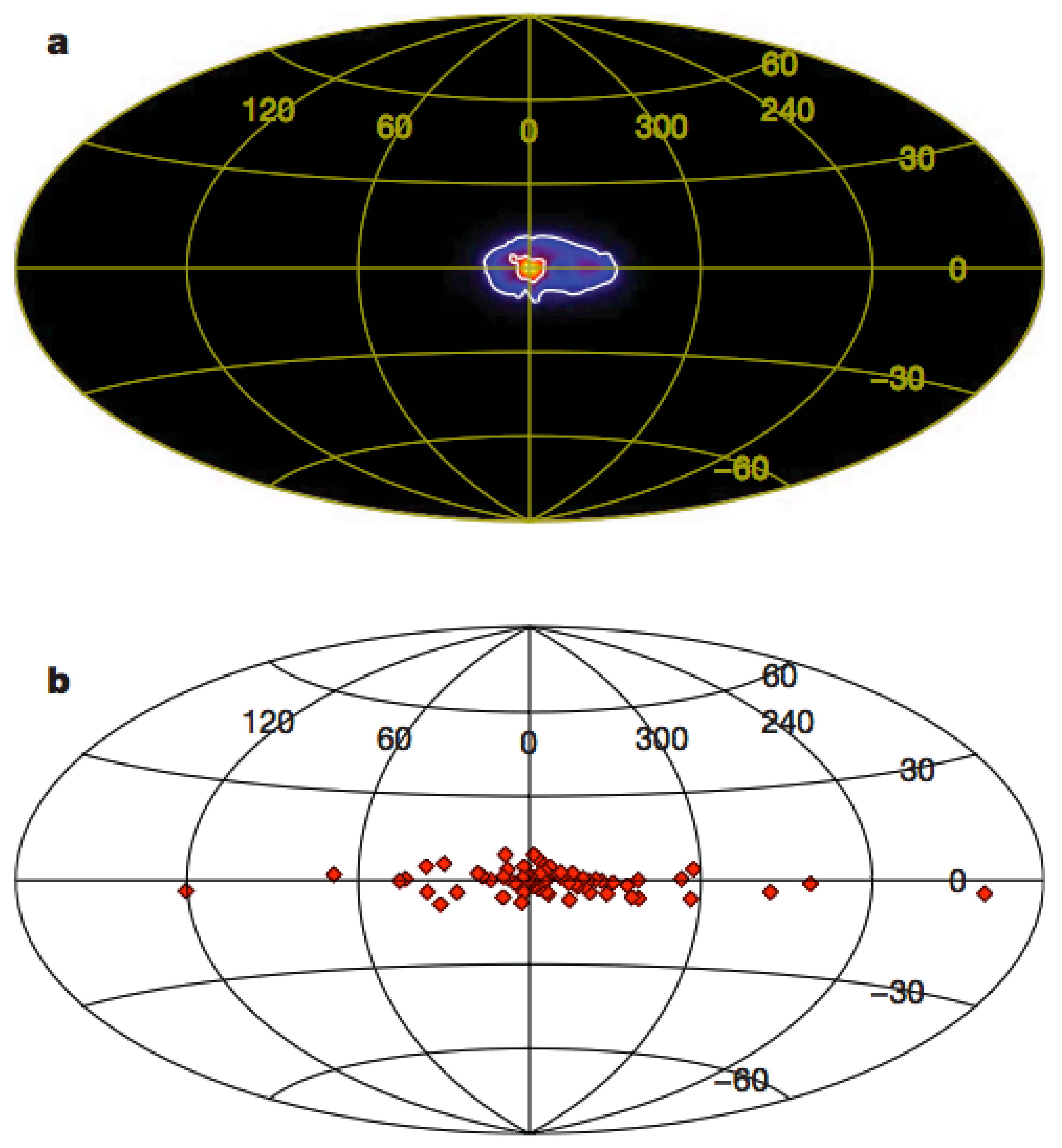
Too many 511 keV photons from center of Galaxy.

37 year old result, still not understood.



Weidenspointner et al. (2008)   Integral signal (top) and LMXBs (bottom)

Weidenspointner (2006)

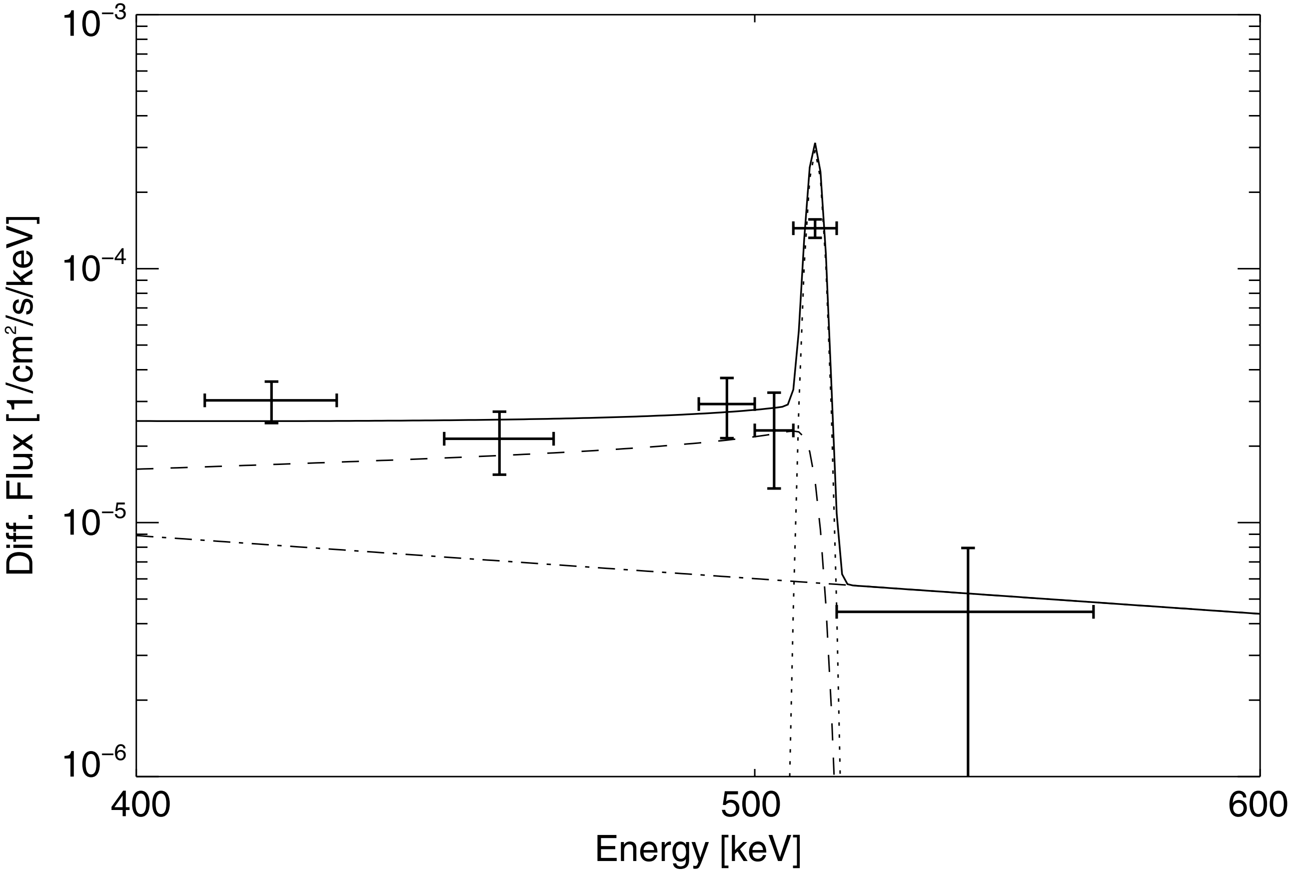


Fig. 2. A fit of the SPI result for the diffuse emission from the GC region ($|l|, |b| \leq 16°$) obtained with a spatial model consisting of an 8° *FWHM* Gaussian bulge and a CO disk. In the fit a diagonal response was assumed. The spectral components are: 511 keV line (dotted), Ps continuum (dashes), and power-law continuum (dash-dots). The summed models are indicated by the solid line. Details of the fitting procedure are given in the text.

WIMP detection, near and far:

Local
(near Earth)

PAMELA
positrons

DAMA
annual mod.

Na I scintillation;
exposure:
200,000 kg day.

Fermi
e+ e-

Dark
Matter?

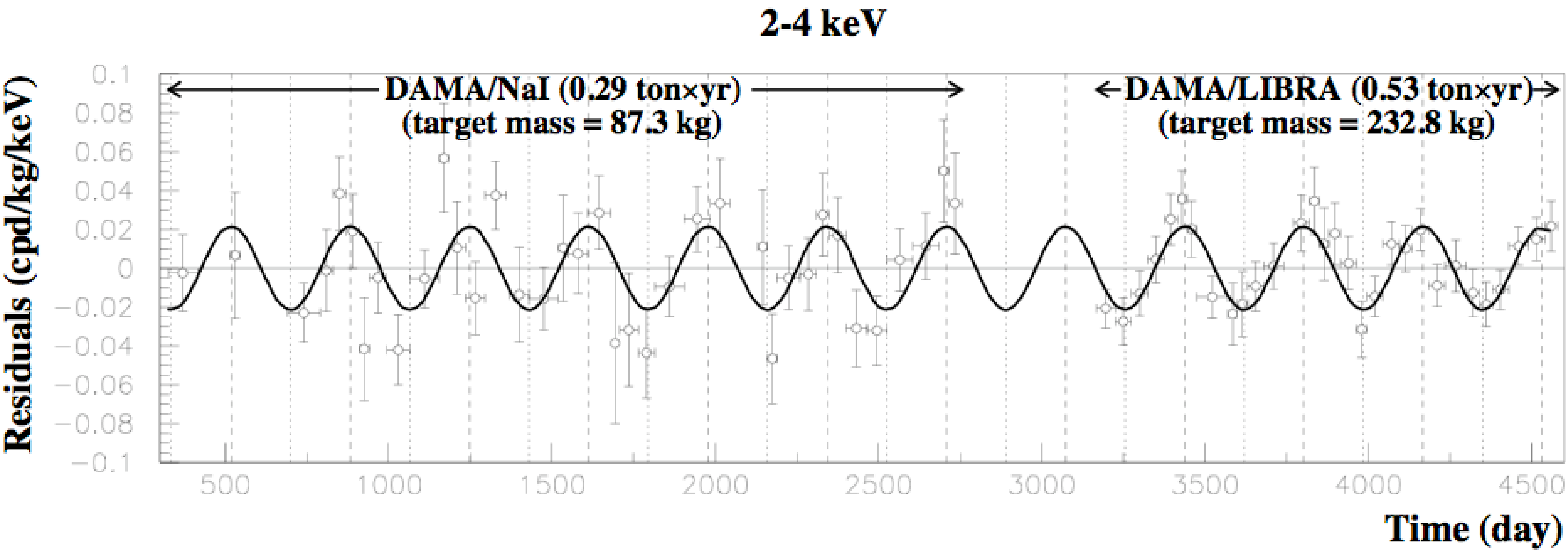
INTEGRAL
511 keV

EGRET
gammas

WMAP haze
(microwaves)

Galactic Center

Bernabei et al. (DAMA/LIBRA, 2008)



DAMA sees a convincing signal (8.2 sigma) but other experiments rule out *elastic nuclear scattering* at this level (by large factors).

Conclusion: DAMA is *not* seeing elastic nuclear scattering.

Claims that DAMA is “wrong” are dependent on a narrow theoretical bias that the scattering must be elastic.

Idea: DAMA is seeing *inelastic* nuclear scattering of ~ 200 GeV WIMPs with 100 keV mass splitting.

Why does inelastic scattering help?

1. On tail of velocity distribution: annual modulation signal can be much larger than expected (30%)

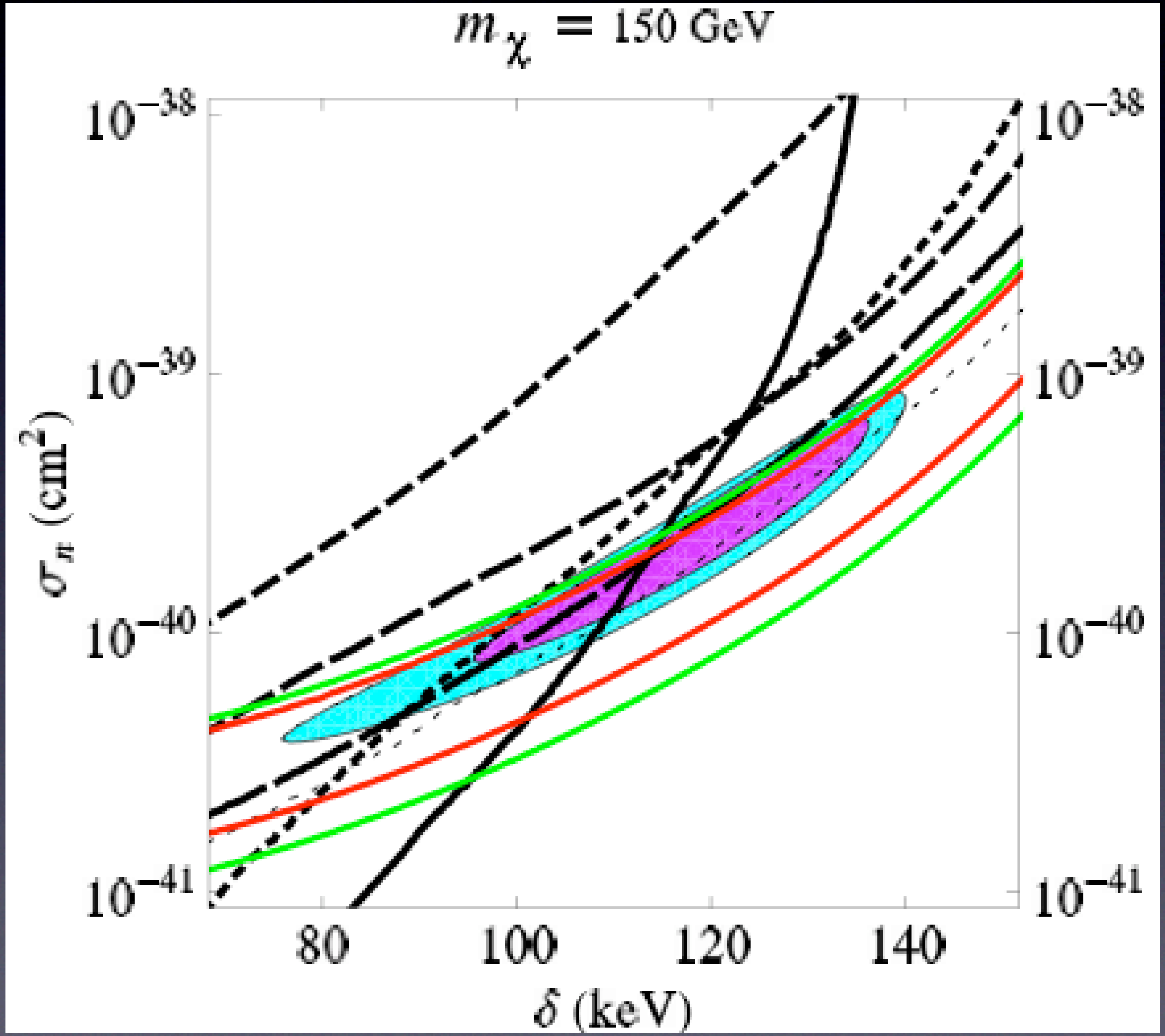
2. Bigger nuclei better (I better than Ge, worse than W)

3. Higher energies are better (because of built-in enegy scale) DAMA has huge exposure time but little sensitivity to low energy events.

Smith & Weiner (2001), Chang et al. (2008)

Channeling is also possible, but forces us to a mass of < 5 GeV. Energy dependence of events looks wrong.

So, DAMA (most likely) implies inelastic scattering.



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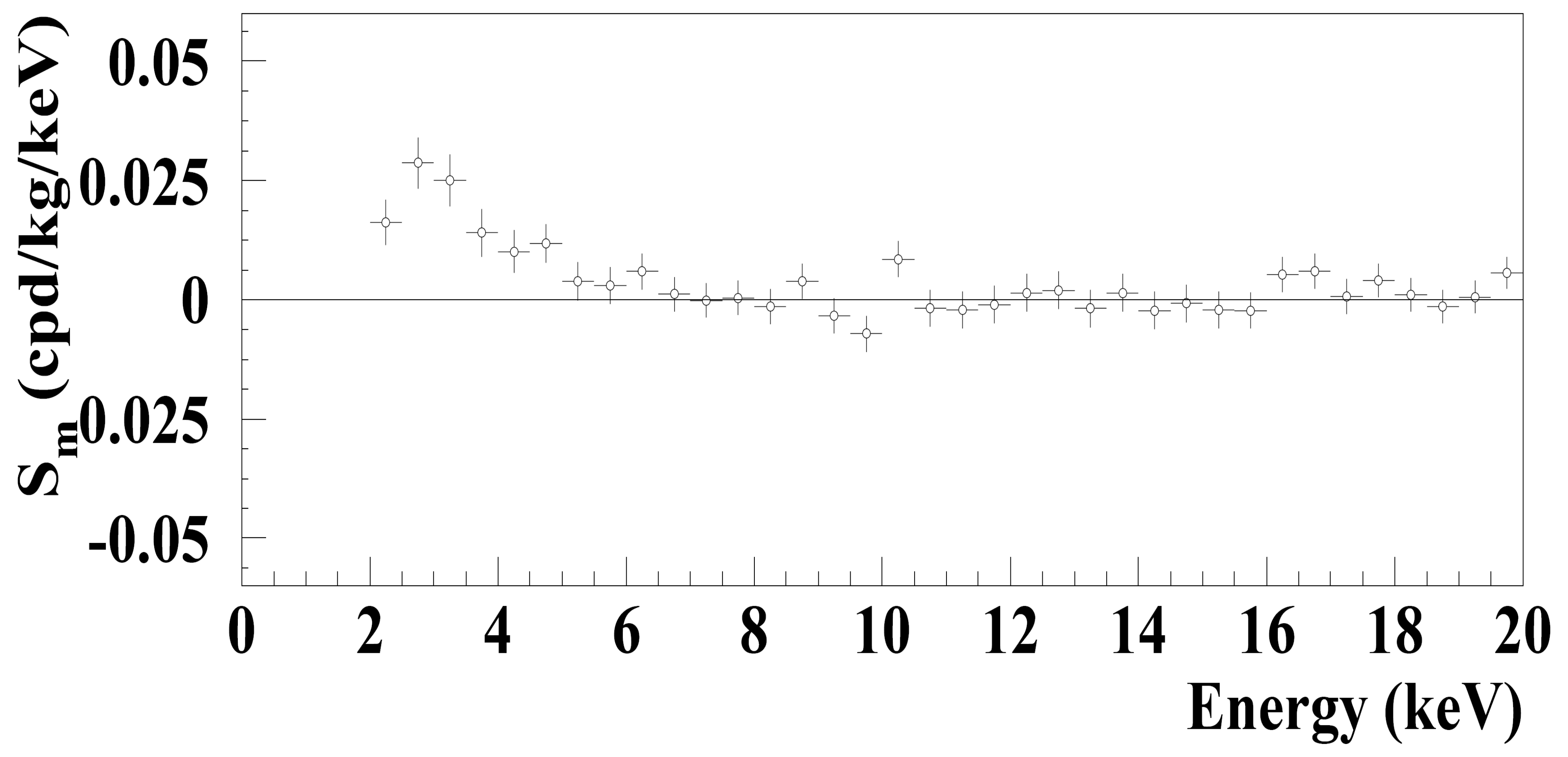
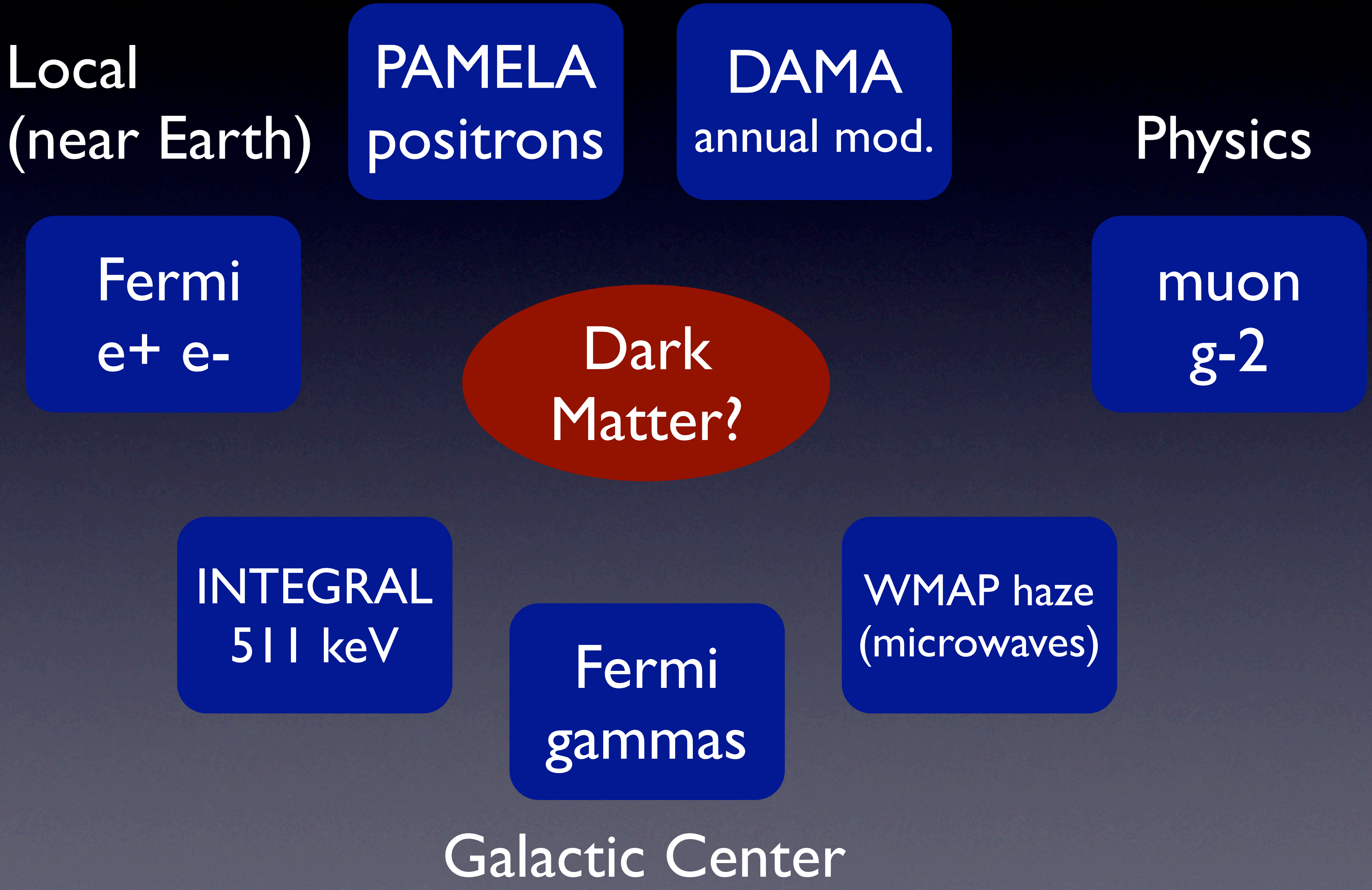


Bernabei et al. (2008)

XENON100, LUX will provide much better results in the next few years.

XENON100 is already running
LUX begins in February, 2010.

WIMP detection, near and far:



Local
(near Earth)

PAMELA
positrons

DAMA
annual mod.

Physics

Fermi
e+ e-

Dark
Matter?

muon
g-2

INTEGRAL
511 keV

WMAP haze
(microwaves)

Fermi
gammas

Galactic Center

Strategy:

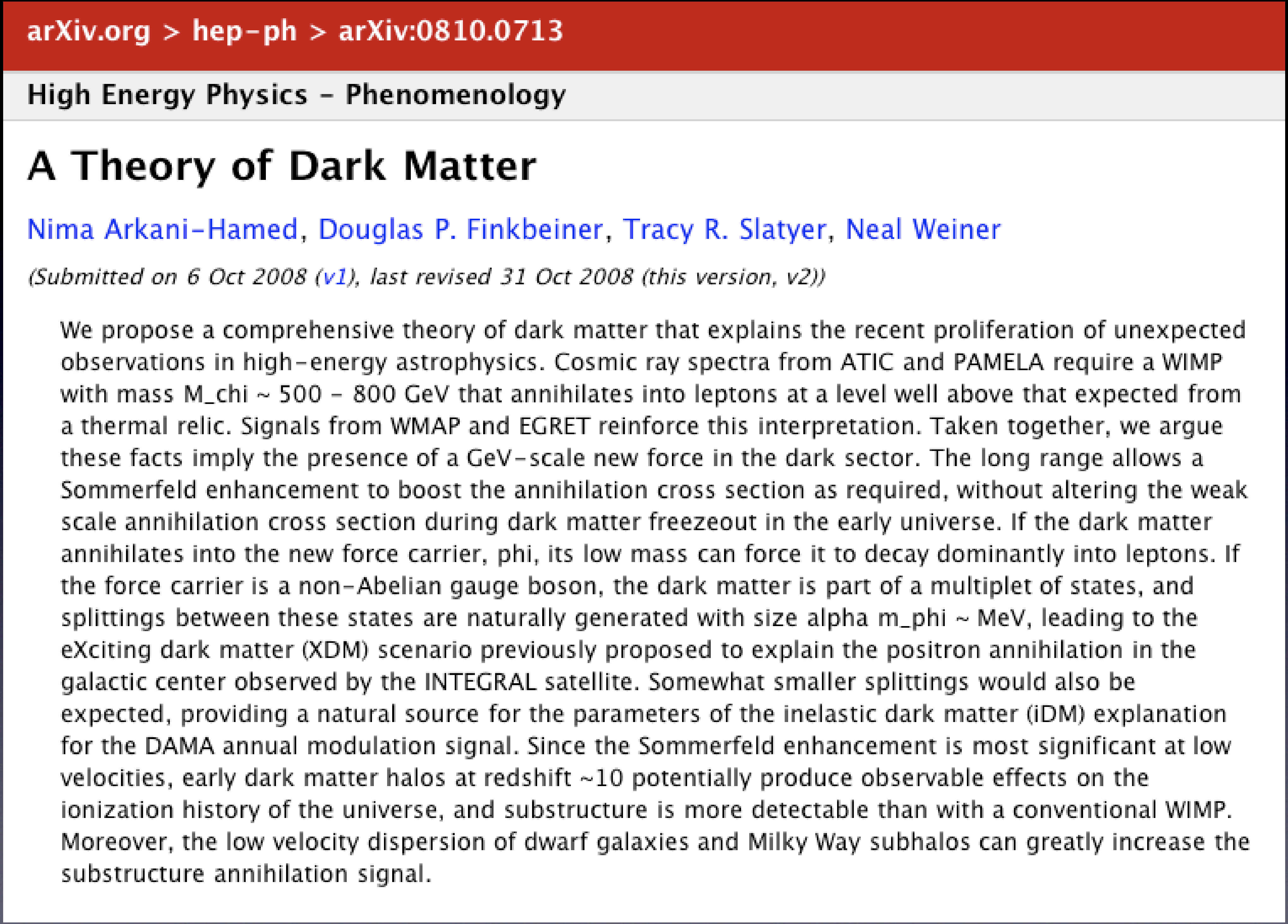
Strategy:

Lots of signals; some may be wrong; some may have nothing to do with dark matter.

Strategy:

Lots of signals; some may be wrong; some may have nothing to do with dark matter.

Let's take claimed signals seriously, and build models to explain them, searching for conclusions that are robust to the exact subset of results that are "right."



arXiv.org > hep-ph > arXiv:0810.0713

High Energy Physics – Phenomenology

A Theory of Dark Matter

Nima Arkani-Hamed, Douglas P. Finkbeiner, Tracy R. Slatyer, Neal Weiner

(Submitted on 6 Oct 2008 (v1), last revised 31 Oct 2008 (this version, v2))

We propose a comprehensive theory of dark matter that explains the recent proliferation of unexpected observations in high-energy astrophysics. Cosmic ray spectra from ATIC and PAMELA require a WIMP with mass M_chi ~ 500 – 800 GeV that annihilates into leptons at a level well above that expected from a thermal relic. Signals from WMAP and EGRET reinforce this interpretation. Taken together, we argue these facts imply the presence of a GeV-scale new force in the dark sector. The long range allows a Sommerfeld enhancement to boost the annihilation cross section as required, without altering the weak scale annihilation cross section during dark matter freezeout in the early universe. If the dark matter annihilates into the new force carrier, phi, its low mass can force it to decay dominantly into leptons. If the force carrier is a non-Abelian gauge boson, the dark matter is part of a multiplet of states, and splittings between these states are naturally generated with size alpha m_phi ~ MeV, leading to the eXciting dark matter (XDM) scenario previously proposed to explain the positron annihilation in the galactic center observed by the INTEGRAL satellite. Somewhat smaller splittings would also be expected, providing a natural source for the parameters of the inelastic dark matter (iDM) explanation for the DAMA annual modulation signal. Since the Sommerfeld enhancement is most significant at low velocities, early dark matter halos at redshift ~10 potentially produce observable effects on the ionization history of the universe, and substructure is more detectable than with a conventional WIMP. Moreover, the low velocity dispersion of dwarf galaxies and Milky Way subhalos can greatly increase the substructure annihilation signal.

Summary of "Theory of DM" paper:

A new force in the dark sector, mediated by a new gauge boson, ϕ, has these appealing features:

- It can mediate scatterings.
- The ϕ vev can generate mass splittings,
- ... so the scatterings can be inelastic.
- The WIMP annihilates through the ϕ so if the mass is O(1 GeV) can annihilate to leptons.
- Attractive force mediated by ϕ gives rise to Sommerfeld enhancement to annihilation Xsec.

- This is a framework - there are specific realizations... (Arkani-Hamed & Weiner 2008)

Why is the claim of a new light gauge boson robust?

* If you only had PAMELA
  => high cross section => Sommerfeld
  => goes to leptons => annihilate through light state

* If you believe DAMA
  => inelastic scattering => mass splittings generated
    by phi vev

* If you have WMAP haze and/or Fermi ICS gammas
  => hard spectrum => decay through phi

Inelastic dark matter:
Many possible mechanisms, including

- composite WIMPs (analog: nuclei - messy)
- new force in the dark sector (simple, clean, big leap)

How big is the leap?
1/6 of the matter in the Universe interacts via a very complicated SU(3) x SU(2) x U(1) force. One minimal extension is to posit an additional U(1) gauge force that (almost) only interacts with DM: a new "dark force."

What is the simplest WIMP you can have?

- Majorana fermion or a real scalar.
- Particle is its own anti-particle.
- No conserved quantum numbers.

Suppose the new force is a U(1) gauge force, mediated by a vector boson. (analogy: electromagnetism)

- New boson couples to the “dark charge” but in the Majorana basis they have no charge.
- Any Majorana fermion can be written as a linear combination of 2 Dirac fermions which *do* have the charge.
- These do not have to be mass eigenstates.

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- These do not have to be mass eigenstates.

Said another way, the WIMP is part of a doublet under the dark U(1) symmetry.
(A spin-1 boson cannot have a coupling to a single neutral state.)
If the symmetry is perfect, the two members of the doublet are degenerate.
Broken symmetry leads to a mass difference.

The important point is, the *mass eigenstate* is not the eigenstate the force couples to. That is, the coupling is *off-diagonal.*

Example from Electromagnetism:

An electron is a doublet (right-handed and left-handed) The force is mediated by a spin-1 boson (photon) which couples off-diagonally, so the vertex joins a RH electron, LH electron, and photon. The RH and LH electron have the same mass, so we "sweep this under the rug."

E/M is a good symmetry, but in general our new symmetry is weakly broken by some amount, leading to a mass splitting, δ, between the two mass eigenstates.

We can think of these as "ground state" and "excited."

See Arkani-Hamed et al. (2009; 0810.0713) for details

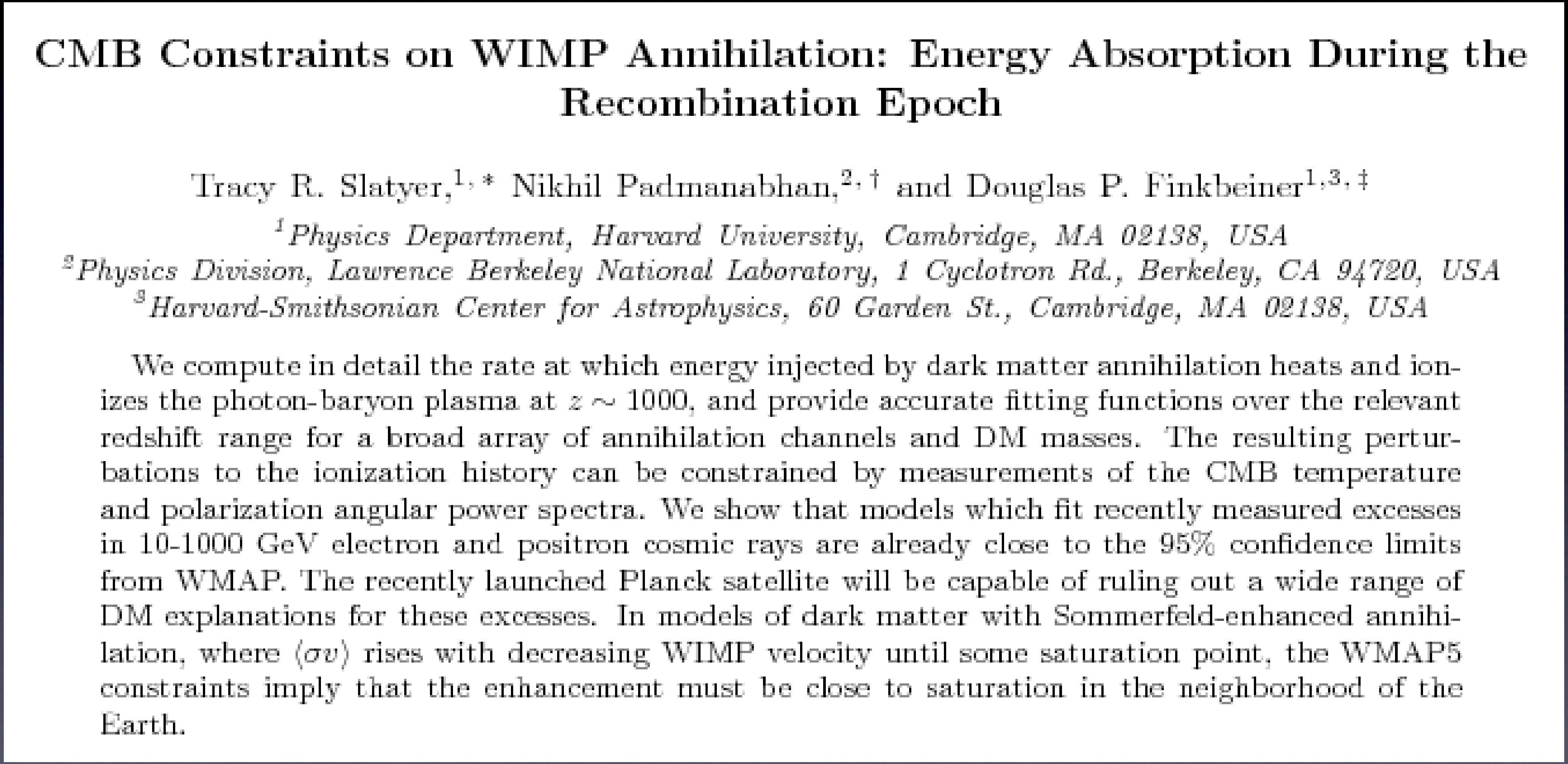
Summary: if we assume

- new force in the dark sector (simplest gauge force),
- simple WIMP (no conserved quantum numbers), and
- imperfect symmetry for new force (generic),

we arrive at the startling conclusion that inelastic scattering between the two mass eigenstates is the generic behavior, and elastic scattering is the special case.

This motivates a broad consideration of the effects of inelastic WIMP scattering in both astronomy and physics.

CMB digression

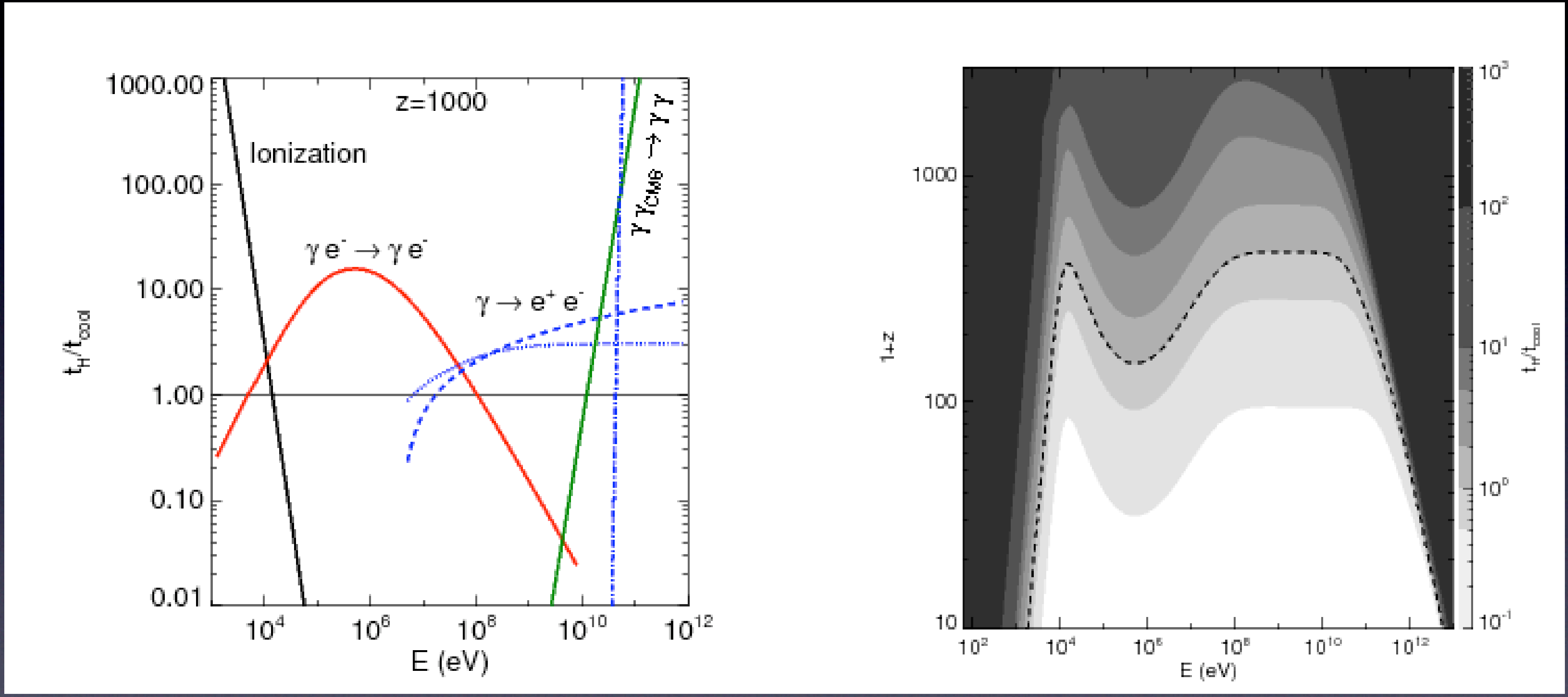


CMB Constraints on WIMP Annihilation: Energy Absorption During the Recombination Epoch

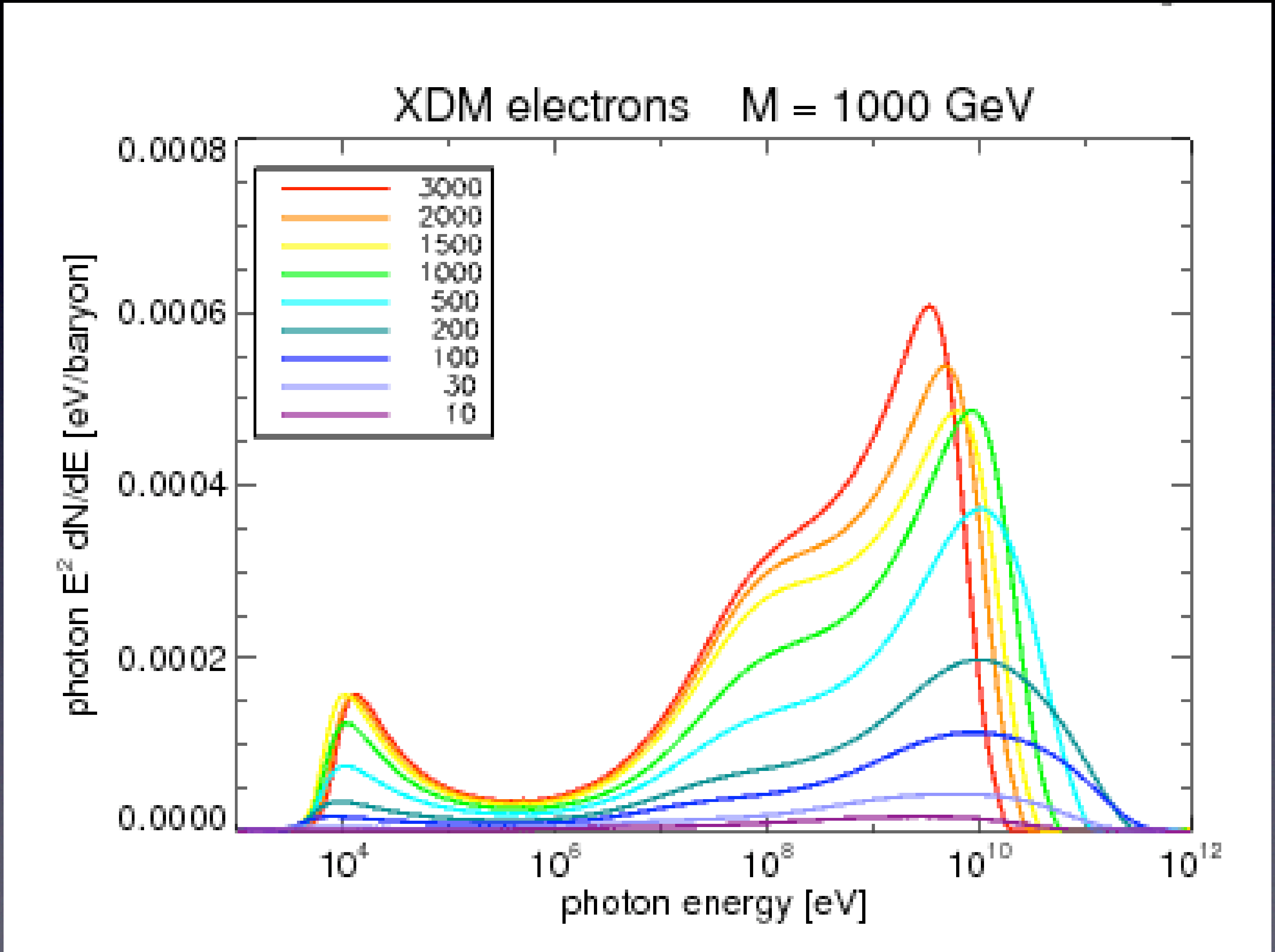
Tracy R. Slatyer,[1,*] Nikhil Padmanabhan,[2,†] and Douglas P. Finkbeiner[1,3,‡]
[1] *Physics Department, Harvard University, Cambridge, MA 02138, USA*
[2] *Physics Division, Lawrence Berkeley National Laboratory, 1 Cyclotron Rd., Berkeley, CA 94720, USA*
[3] *Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, USA*

We compute in detail the rate at which energy injected by dark matter annihilation heats and ionizes the photon-baryon plasma at $z \sim 1000$, and provide accurate fitting functions over the relevant redshift range for a broad array of annihilation channels and DM masses. The resulting perturbations to the ionization history can be constrained by measurements of the CMB temperature and polarization angular power spectra. We show that models which fit recently measured excesses in 10-1000 GeV electron and positron cosmic rays are already close to the 95% confidence limits from WMAP. The recently launched Planck satellite will be capable of ruling out a wide range of DM explanations for these excesses. In models of dark matter with Sommerfeld-enhanced annihilation, where $\langle \sigma v \rangle$ rises with decreasing WIMP velocity until some saturation point, the WMAP5 constraints imply that the enhancement must be close to saturation in the neighborhood of the Earth.

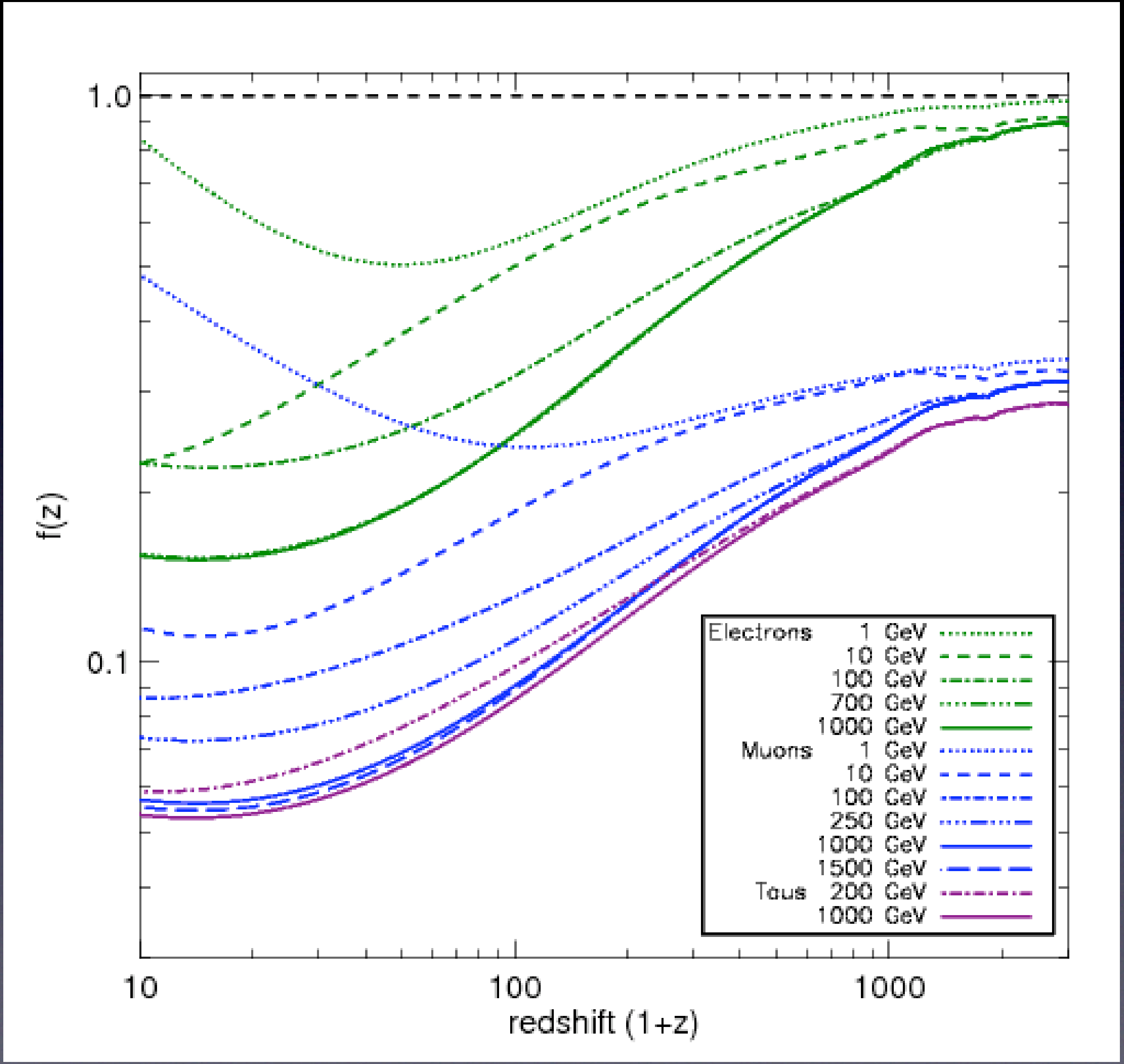
CMB digression



CMB digression



The Slatyer-Padmanabhan-Finkbeiner (SPF) factor.



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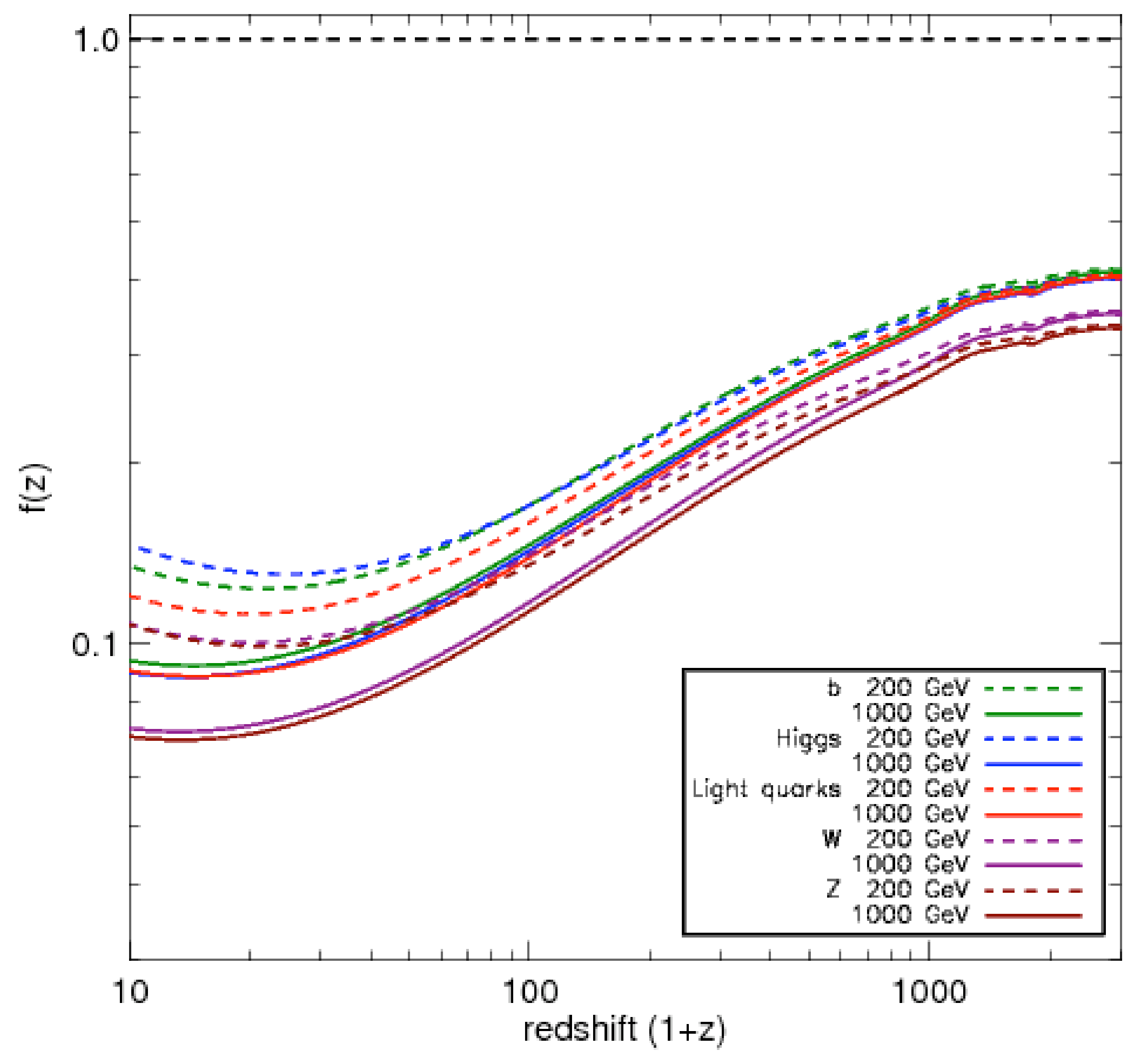

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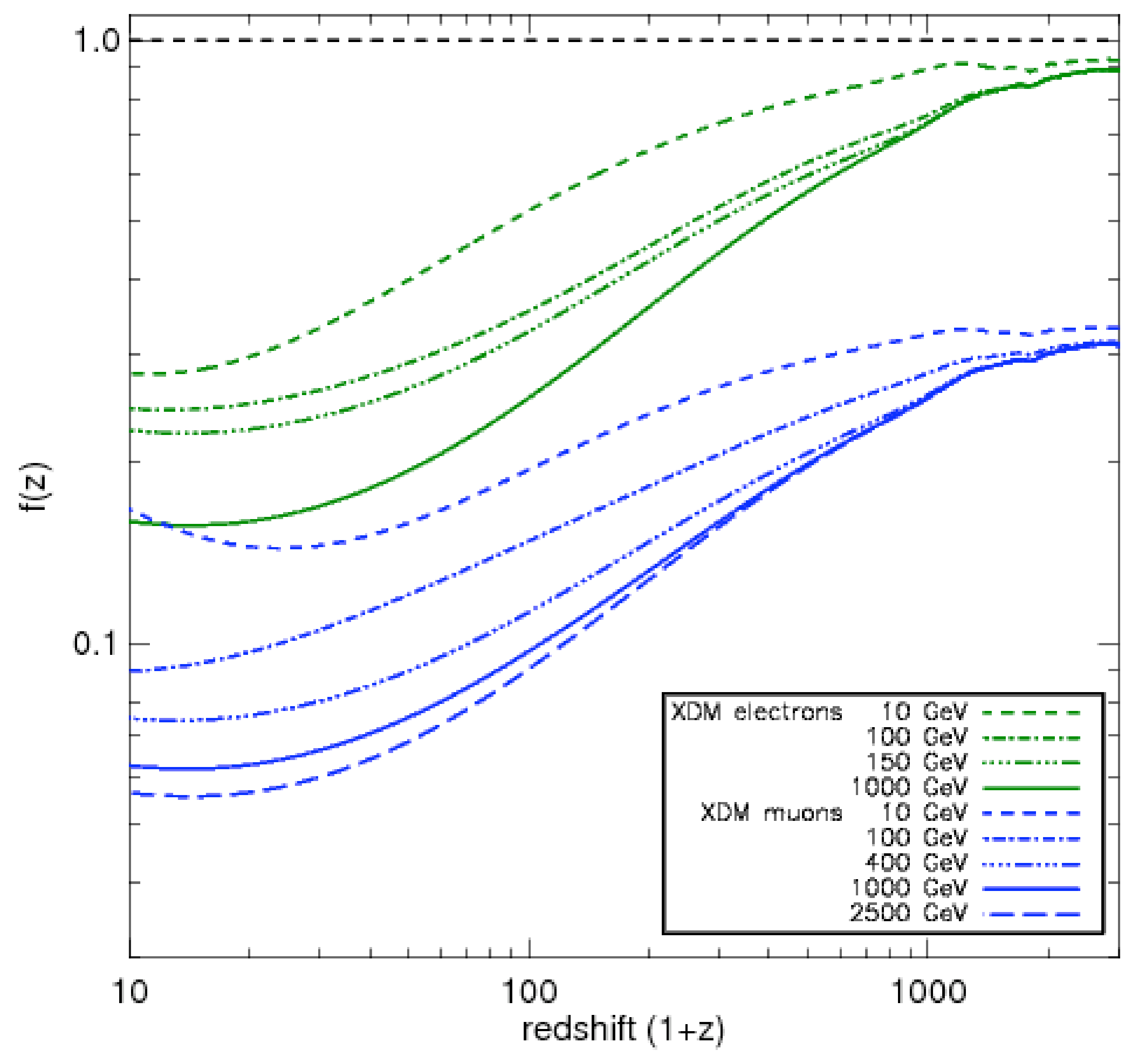
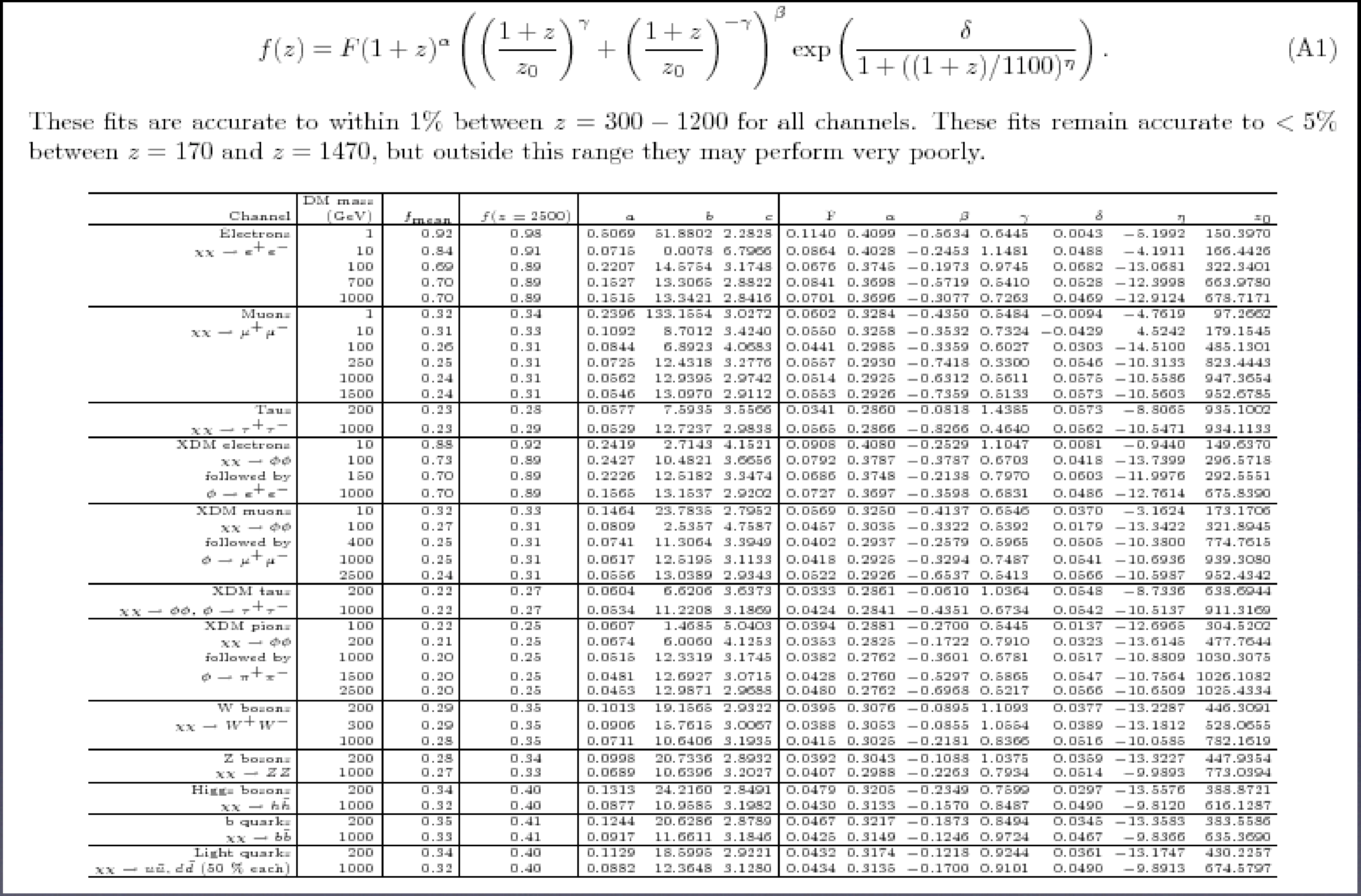


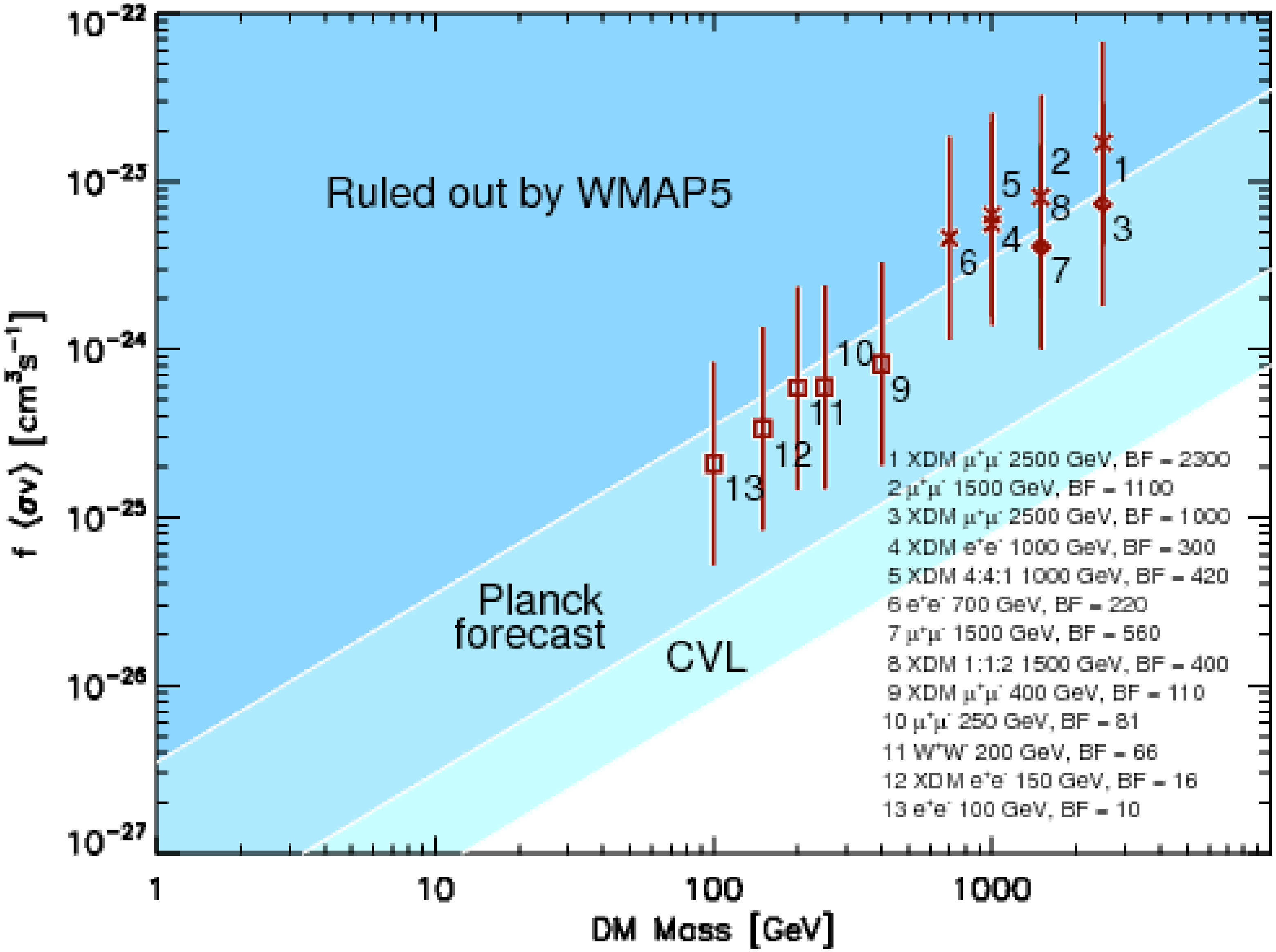


$$f(z) = F(1+z)^{\alpha}\left(\left(\frac{1+z}{z_0}\right)^{\gamma} + \left(\frac{1+z}{z_0}\right)^{-\gamma}\right)^{\beta} \exp\left(\frac{\delta}{1+((1+z)/1100)^{\eta}}\right). \tag{A1}$$

These fits are accurate to within 1% between $z = 300 - 1200$ for all channels. These fits remain accurate to $< 5\%$ between $z = 170$ and $z = 1470$, but outside this range they may perform very poorly.

Channel	DM mass (GeV)	f_{mean}	$f(z = 2500)$	a	b	c	F	α	β	γ	δ	η	z_0
Electrons	1	0.92	0.98	0.5069	51.8802	2.2828	0.1140	0.4099	−0.5634	0.6445	0.0043	−5.1992	150.3970
$\chi\chi \to e^+e^-$	10	0.84	0.91	0.0715	0.0078	6.7966	0.0864	0.4028	−0.2453	1.1481	0.0488	−4.1911	166.4426
	100	0.69	0.89	0.2207	14.5754	3.1748	0.0676	0.3745	−0.1973	0.9745	0.0682	−13.0681	322.3401
	700	0.70	0.89	0.1527	13.3066	2.8822	0.0841	0.3698	−0.5719	0.5410	0.0528	−12.3998	663.9780
	1000	0.70	0.89	0.1516	13.3421	2.8416	0.0701	0.3696	−0.3077	0.7263	0.0469	−12.9124	678.7171
Muons	1	0.32	0.34	0.2396	133.1554	3.0272	0.0602	0.3284	−0.4350	0.5484	−0.0094	−4.7619	97.2662
$\chi\chi \to \mu^+\mu^-$	10	0.31	0.33	0.1092	8.7012	3.4240	0.0550	0.3258	−0.3532	0.7324	−0.0429	4.5242	179.1545
	100	0.26	0.31	0.0844	6.8923	4.0683	0.0441	0.2986	−0.3359	0.6027	0.0303	−14.5100	485.1301
	250	0.25	0.31	0.0726	12.4318	3.2776	0.0567	0.2930	−0.7418	0.3300	0.0546	−10.3133	823.4443
	1000	0.24	0.31	0.0562	12.9396	2.9742	0.0514	0.2926	−0.6312	0.5611	0.0576	−10.5586	947.3654
	1500	0.24	0.31	0.0546	13.0970	2.9112	0.0553	0.2926	−0.7359	0.5133	0.0573	−10.5603	952.6785
Taus	200	0.23	0.28	0.0577	7.5935	3.5566	0.0341	0.2860	−0.0818	1.4385	0.0573	−8.8065	935.1002
$\chi\chi \to \tau^+\tau^-$	1000	0.23	0.29	0.0529	12.7237	2.9838	0.0565	0.2866	−0.8266	0.4640	0.0562	−10.5471	934.1133
XDM electrons	10	0.88	0.92	0.2419	2.7143	4.1521	0.0908	0.4080	−0.2529	1.1047	0.0081	−0.9440	149.6370
$\chi\chi \to \phi\phi$	100	0.73	0.89	0.2427	10.4821	3.6656	0.0792	0.3787	−0.3787	0.6703	0.0418	−13.7399	296.5718
followed by	150	0.70	0.89	0.2226	12.5182	3.3474	0.0686	0.3748	−0.2138	0.7970	0.0603	−11.9976	292.5551
$\phi \to e^+e^-$	1000	0.70	0.89	0.1566	13.1537	2.9202	0.0727	0.3697	−0.3598	0.6831	0.0486	−12.7614	675.8390
XDM muons	10	0.32	0.33	0.1464	23.7836	2.7952	0.0569	0.3250	−0.4137	0.6546	0.0370	−3.1624	173.1706
$\chi\chi \to \phi\phi$	100	0.27	0.31	0.0809	2.5357	4.7587	0.0457	0.3036	−0.3322	0.5392	0.0179	−13.3422	321.8945
followed by	400	0.25	0.31	0.0741	11.3064	3.3949	0.0402	0.2937	−0.2579	0.5965	0.0506	−10.3800	774.7615
$\phi \to \mu^+\mu^-$	1000	0.25	0.31	0.0617	12.5196	3.1133	0.0418	0.2926	−0.3294	0.7487	0.0541	−10.6936	939.3080
	2500	0.24	0.31	0.0556	13.0389	2.9343	0.0522	0.2926	−0.6537	0.5413	0.0566	−10.5987	952.4342
XDM taus	200	0.22	0.27	0.0604	6.6206	3.6373	0.0333	0.2861	−0.0610	1.0364	0.0548	−8.7336	638.6944
$\chi\chi \to \phi\phi,\ \phi \to \tau^+\tau^-$	1000	0.22	0.27	0.0534	11.2208	3.1869	0.0424	0.2841	−0.4351	0.6734	0.0542	−10.5137	911.3169
XDM pions	100	0.22	0.25	0.0607	1.4685	5.0403	0.0394	0.2881	−0.2700	0.5445	0.0137	−12.6965	304.5202
$\chi\chi \to \phi\phi$	200	0.21	0.25	0.0674	6.0060	4.1253	0.0353	0.2826	−0.1722	0.7910	0.0323	−13.6146	477.7644
followed by	1000	0.20	0.25	0.0516	12.3319	3.1745	0.0382	0.2762	−0.3601	0.6781	0.0517	−10.8809	1030.3075
$\phi \to \pi^+\pi^-$	1500	0.20	0.25	0.0481	12.6927	3.0715	0.0428	0.2760	−0.5297	0.5865	0.0547	−10.7564	1026.1082
	2500	0.20	0.25	0.0453	12.9871	2.9688	0.0480	0.2762	−0.6968	0.5217	0.0566	−10.6509	1025.4334
W bosons	200	0.29	0.35	0.1013	19.1565	2.9322	0.0396	0.3076	−0.0895	1.1093	0.0377	−13.2287	446.3091
$\chi\chi \to W^+W^-$	300	0.29	0.35	0.0906	15.7615	3.0067	0.0388	0.3053	−0.0855	1.0554	0.0389	−13.1812	528.0555
	1000	0.28	0.35	0.0711	10.6406	3.1935	0.0415	0.3026	−0.2181	0.8366	0.0516	−10.0586	782.1619
Z bosons	200	0.28	0.34	0.0998	20.7336	2.8932	0.0392	0.3043	−0.1088	1.0375	0.0369	−13.3227	447.9354
$\chi\chi \to ZZ$	1000	0.27	0.33	0.0689	10.6396	3.2027	0.0407	0.2988	−0.2263	0.7934	0.0514	−9.9893	773.0394
Higgs bosons	200	0.34	0.40	0.1313	24.2160	2.8491	0.0479	0.3205	−0.2349	0.7599	0.0297	−13.5576	388.8721
$\chi\chi \to h\bar{h}$	1000	0.32	0.40	0.0877	10.9585	3.1982	0.0430	0.3133	−0.1570	0.8487	0.0490	−9.8120	616.1287
b quarks	200	0.35	0.41	0.1244	20.6286	2.8789	0.0467	0.3217	−0.1873	0.8494	0.0345	−13.3583	383.5586
$\chi\chi \to b\bar{b}$	1000	0.33	0.41	0.0917	11.6611	3.1846	0.0425	0.3149	−0.1246	0.9724	0.0467	−9.8366	635.3690
Light quarks	200	0.34	0.40	0.1129	18.5995	2.9221	0.0432	0.3174	−0.1218	0.9244	0.0361	−13.1747	430.2257
$\chi\chi \to u\bar{u}, d\bar{d}$ (50 % each)	1000	0.32	0.40	0.0882	12.3648	3.1280	0.0434	0.3136	−0.1700	0.9101	0.0490	−9.8913	674.5797

CMB digression



From SPF, modeled on Galli et al.

CMB Conclusions:

- For models that can explain PAMELA, the Sommerfeld enhancement must be (nearly) saturated in the Milky Way today.

Overall Conclusions:

Fermi sees the WMAP haze electrons!

A new force in the dark sector, mediated by a new gauge boson, ϕ, has these appealing features:

- It can mediate scatterings.
- The ϕ vev can generate mass splittings,
- ... so the scatterings can be inelastic.
- The WIMP annihilates through the ϕ so if the mass is O(1 GeV) can annihilate to leptons.
- Attractive force mediated by ϕ gives rise to Sommerfeld enhancement to annihilation Xsec, producing the WMAP haze and Fermi ICS haze.

The Future: Origin of the WMAP / Fermi haze

* Model compact sources better (e.g. pulsar spectrum from first principles?)
  - Tie these models to radio/Xray observations

* Model propagation better
  - Global topology of the B field
  - New, improved GALPROP
    B-field direction effects on diffusion & synchrotron

* Consider new options for doing this with new physics. Avoid false dichotomy (DM vs. pulsars)