WMAP Excess Interpreted as WIMP Annihilation

FNAL
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Conclusions

- There is strong evidence for a smooth, ~ spherical component of microwave emission (the “haze”) in the Galactic center. The power and morphology are about right for this to be WIMP annihilation, and the spectrum of the required electrons is hard.
- At the very least, this is a robust upper limit on the power in WIMP annihilation products going to e^+e^- at 10s of GeV and above.

Outline

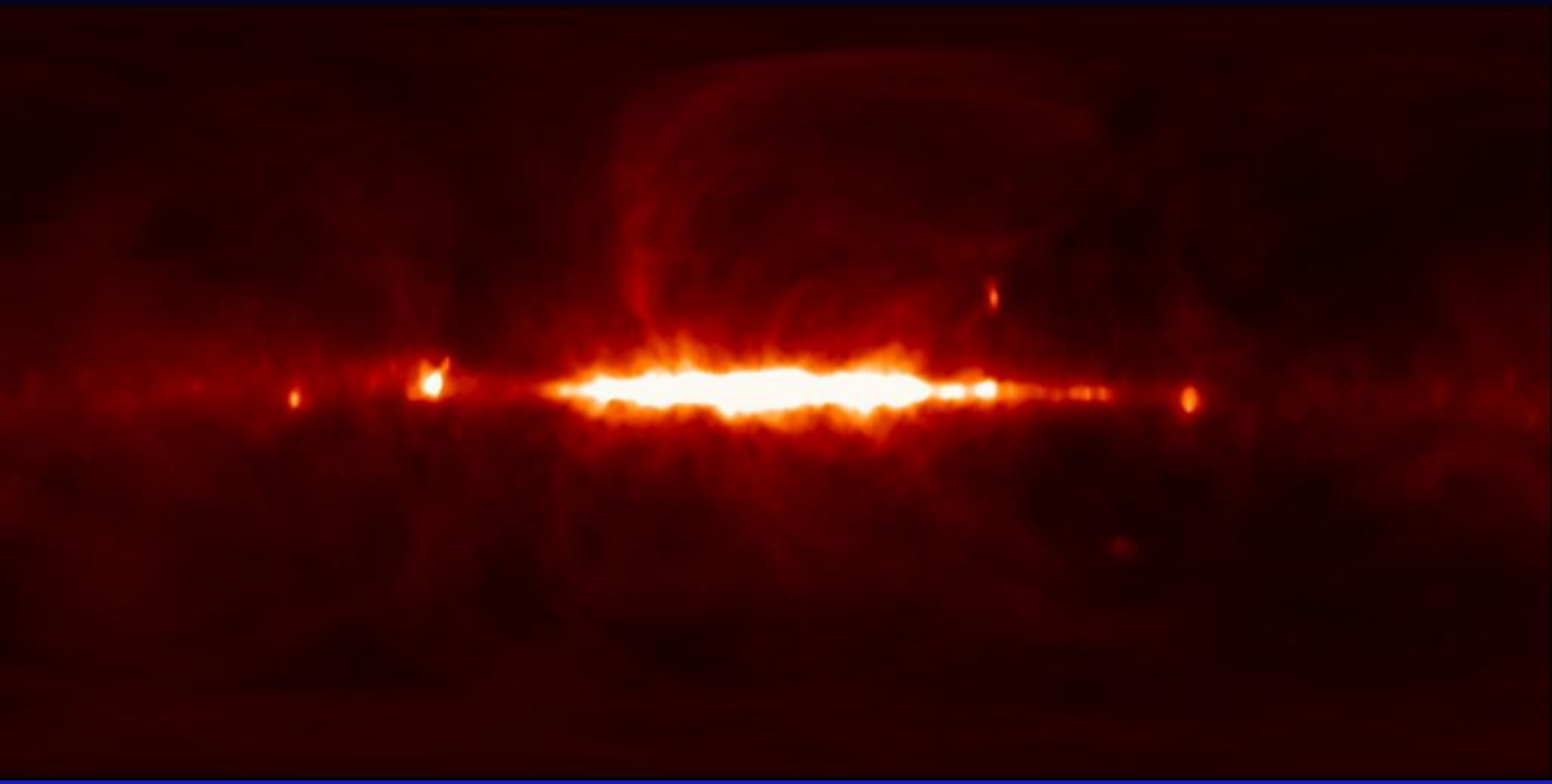
- WMAP ISM emission (expected)
- The Galactic synchrotron “Haze” (unexpected)
- WIMP annihilation (speculative)

"Standard Model" of Microwave Continuum Emission in the ISM

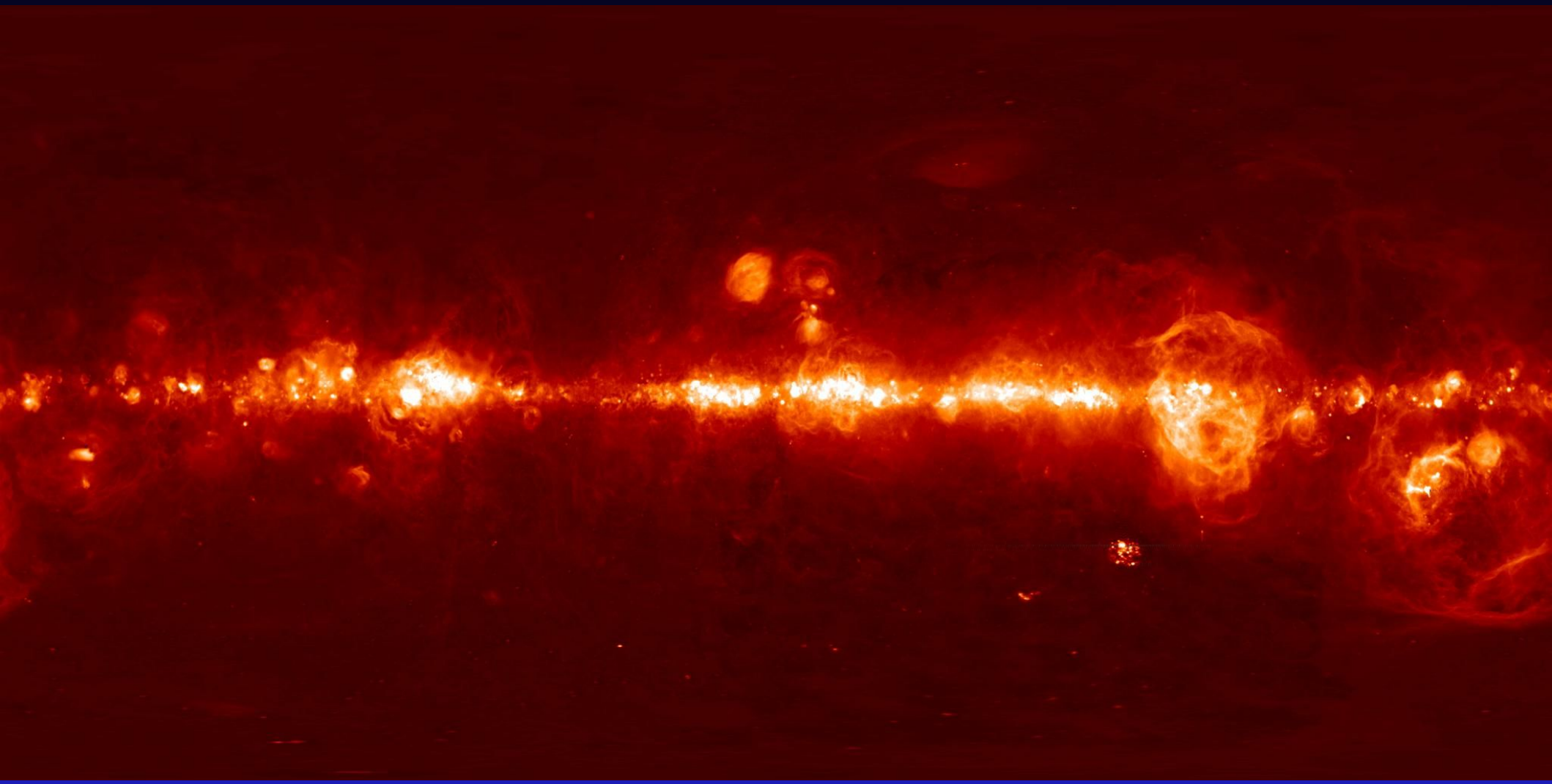
Synchrotron (relativistic electrons)	$T \sim \nu^{-2.7}$ (-2.5? -3.0?)
Free -free (ionized H)	$T \sim \nu^{-2.1}$
"Thermal" dust (vibrational)	$T \sim \nu^{+2}$ (1.6? 2.2?) (optically thin limit)

These are all well established.
(convention: $I \sim \nu^{\alpha}$, $T \sim \nu^{\beta}$)

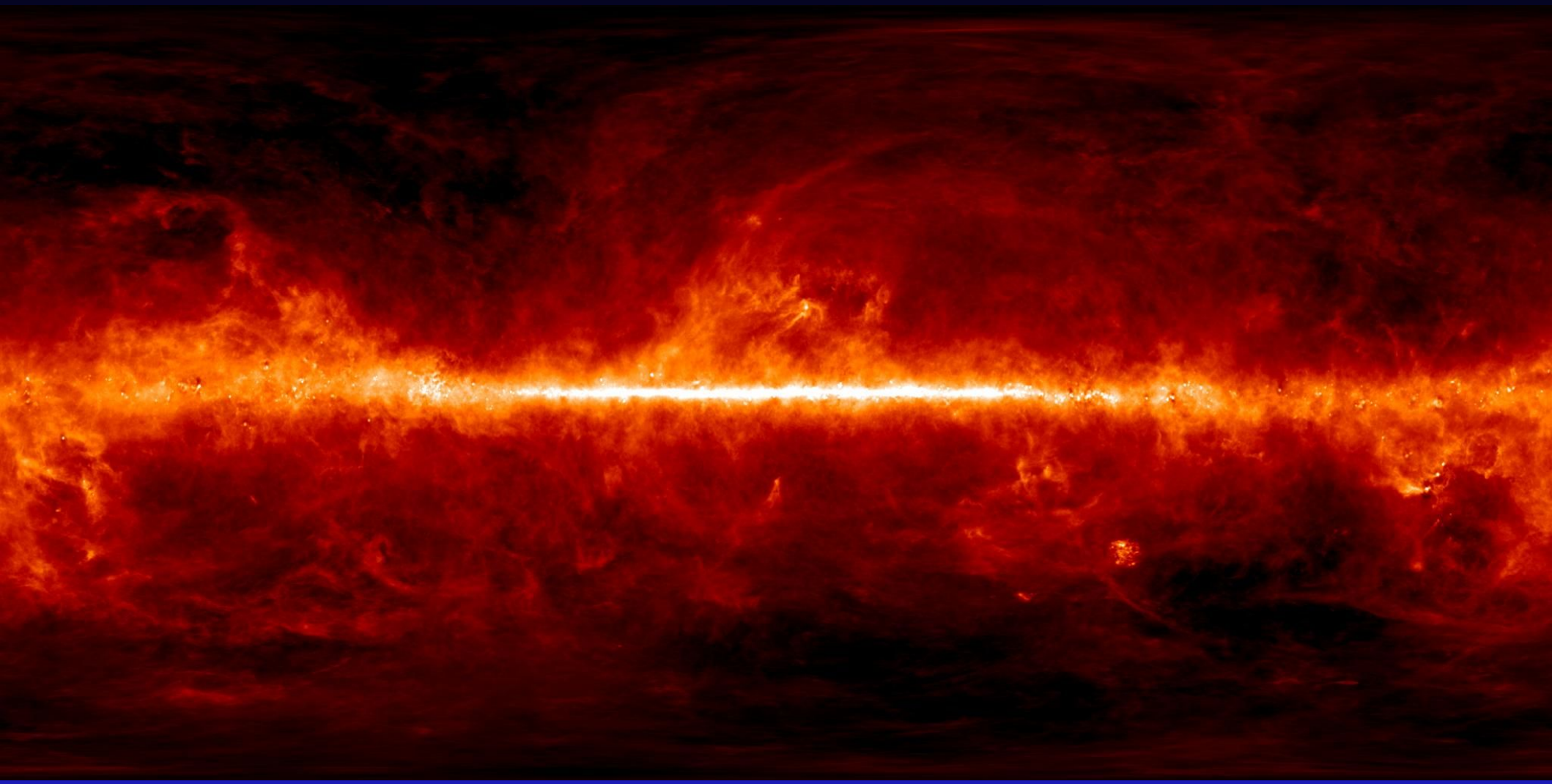
Synchrotron emission (Haslam 1982)



H emission (Finkbeiner 2003)



Dust emission (Schlegel et al. 1998)



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These are all well established.

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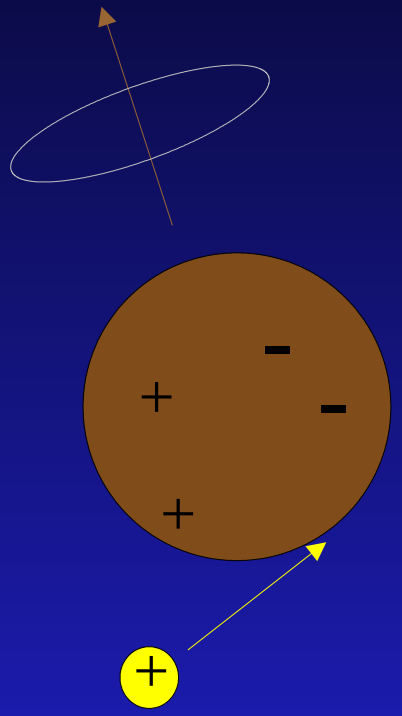
--> But cannot explain all observed ISM emission!

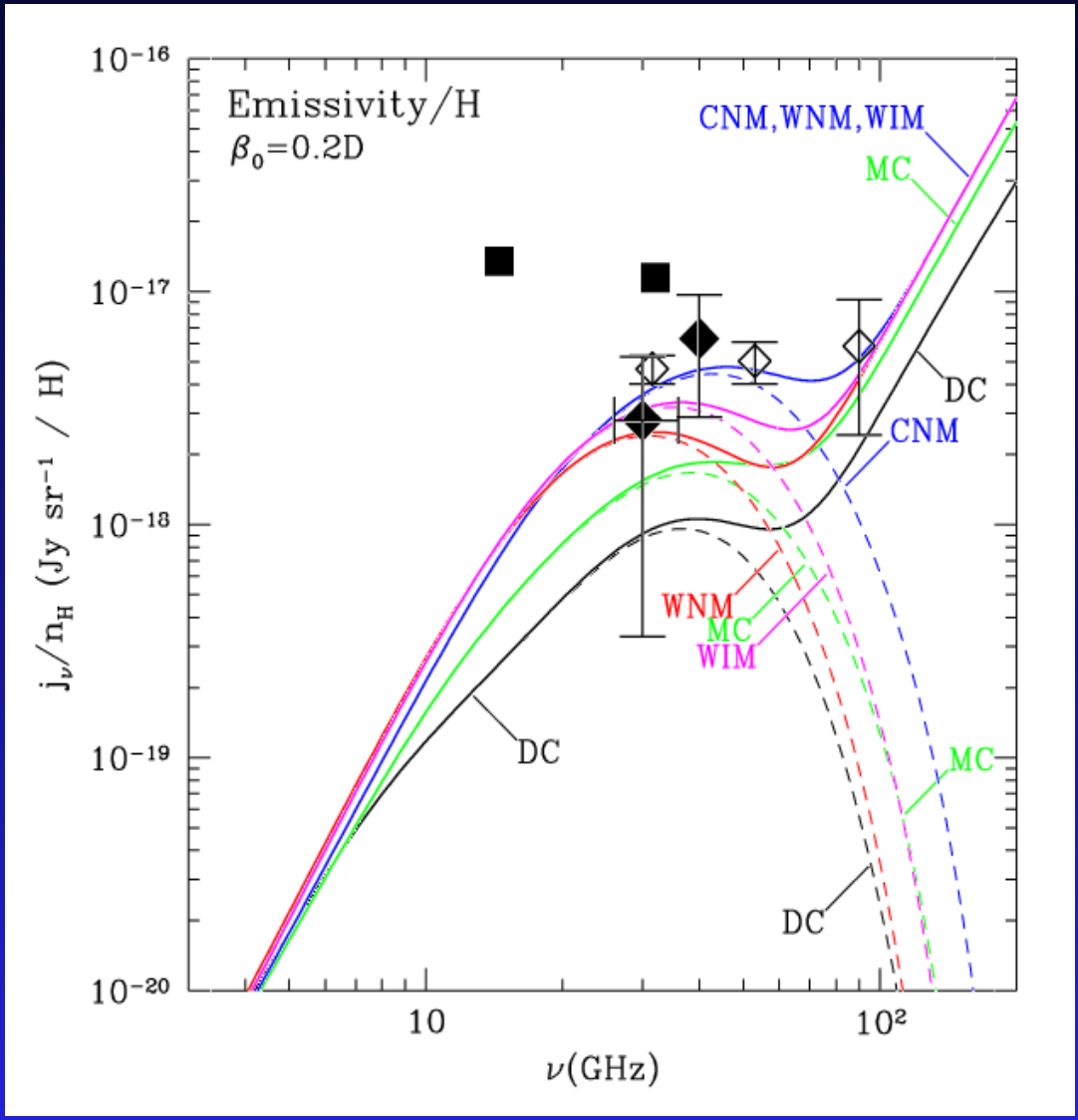
Spinning Dust Emission

Draine & Lazarian (1998)

- Small dust grains (1 nm, ~500 atoms)
- Not in T equillibrium with ISRF
- Have non -zero electric dipole
  (like most hydrocarbons)
- Fast ions spin them up to 10 -30 GHz
- Spin down by electric dipole emission



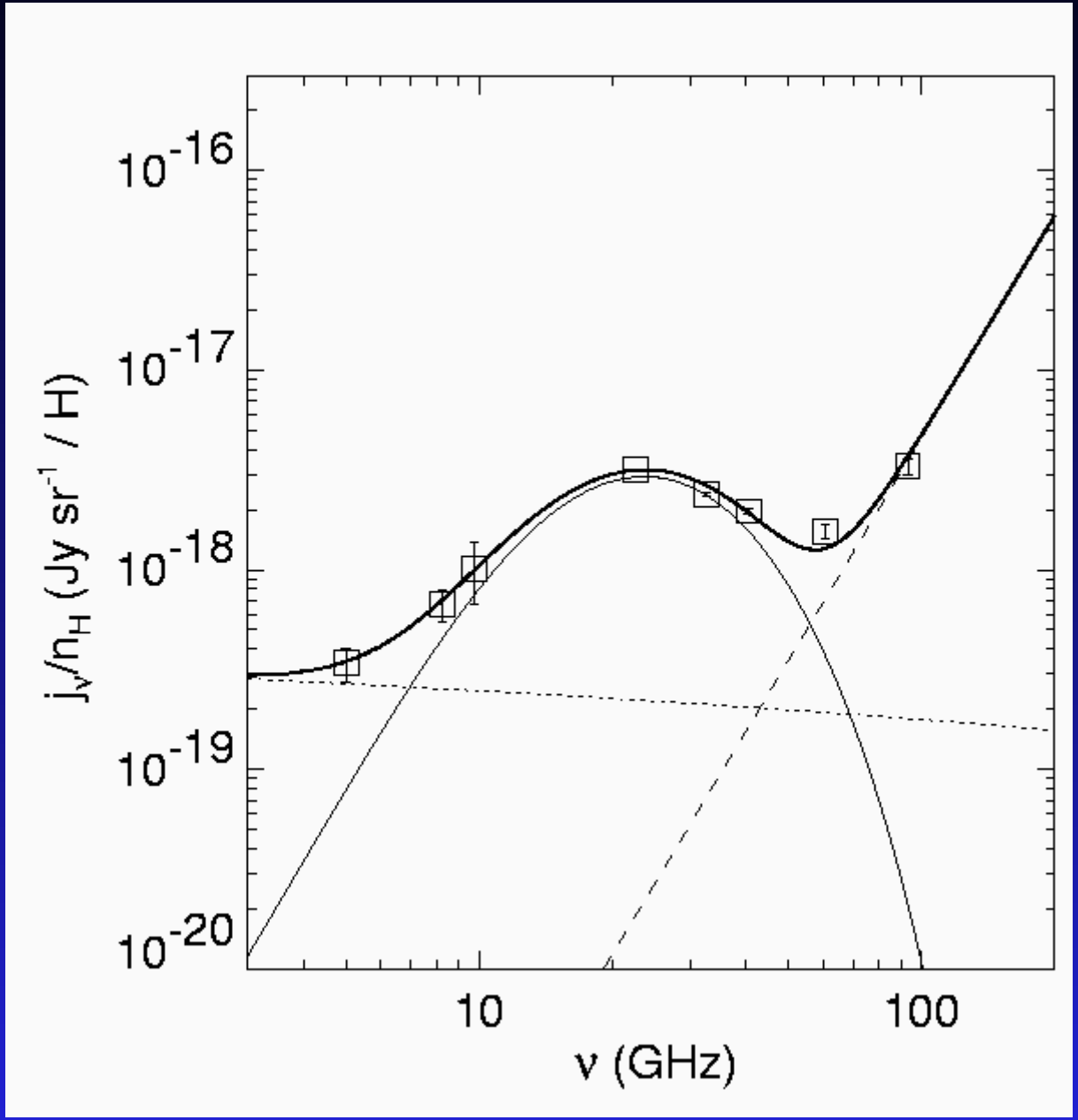
Microwave Emission per H atom



Draine & Lazarian 1998
with 5 dust models
and data from
- COBE
- Saskatoon
- OVRO

Note: OVRO too high

Lynds 1622 - Green Bank & WMAP



What about the diffuse ISM?

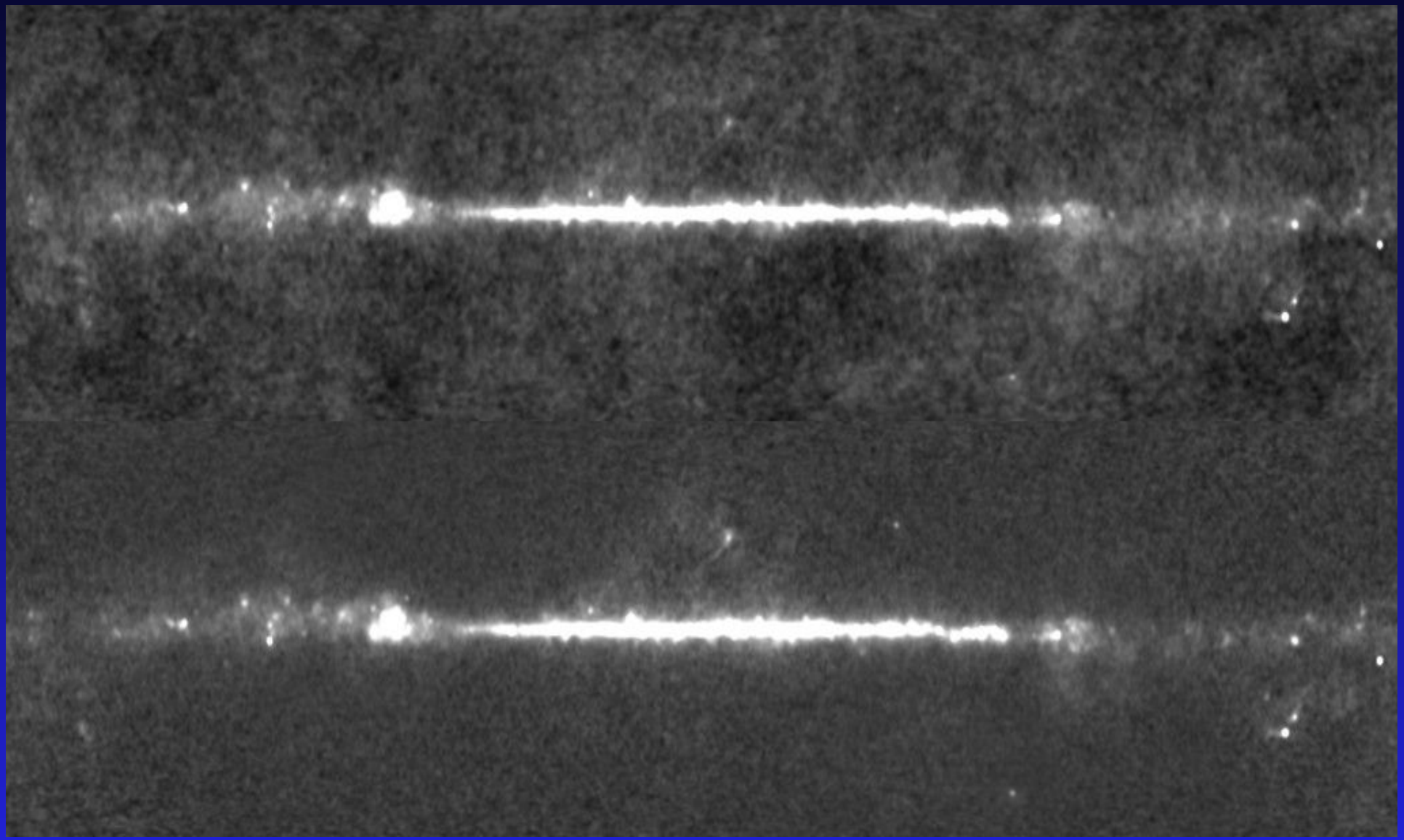
In order to measure this signal in the diffuse ISM, a high sensitivity, large scale survey is needed...

WMAP!

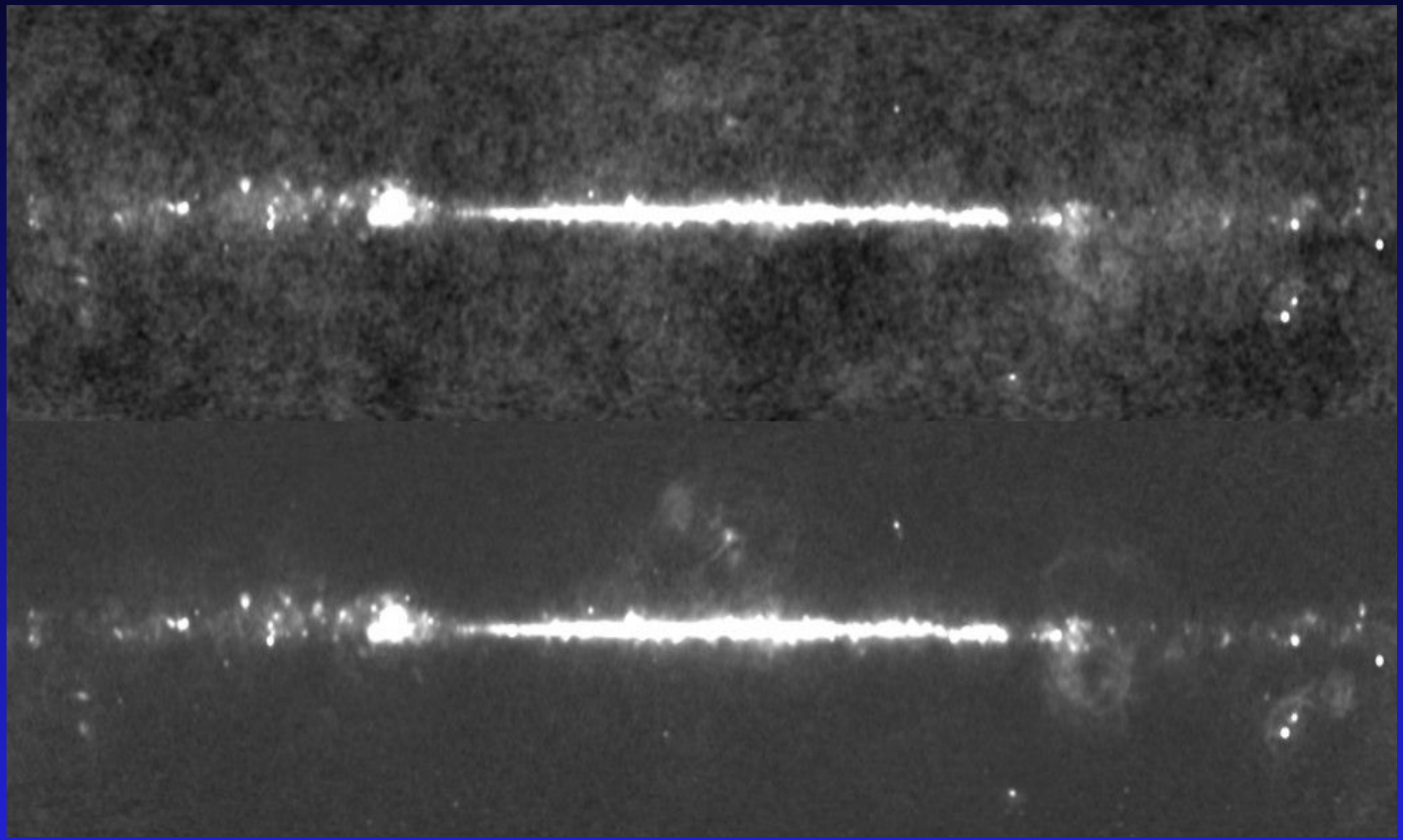
Wilkinson Microwave Anisotropy Probe

Full -sky data
~ 0.2 mK in first year data
(23, 33, 41, 61, 94) GHz
13' FWHM at 94 GHz
Data public as of Feb, 2003

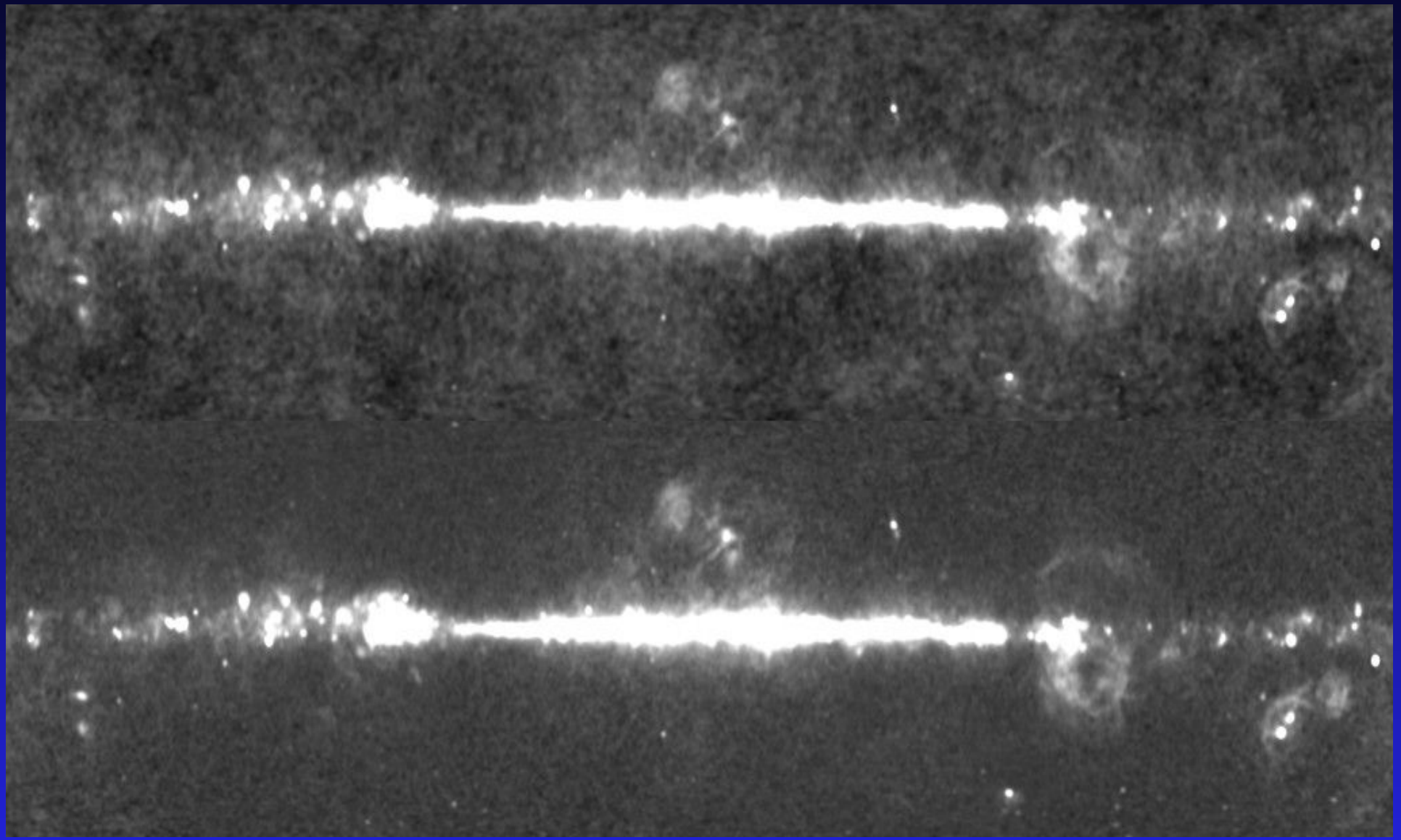
WMAP W-band (94 GHz)



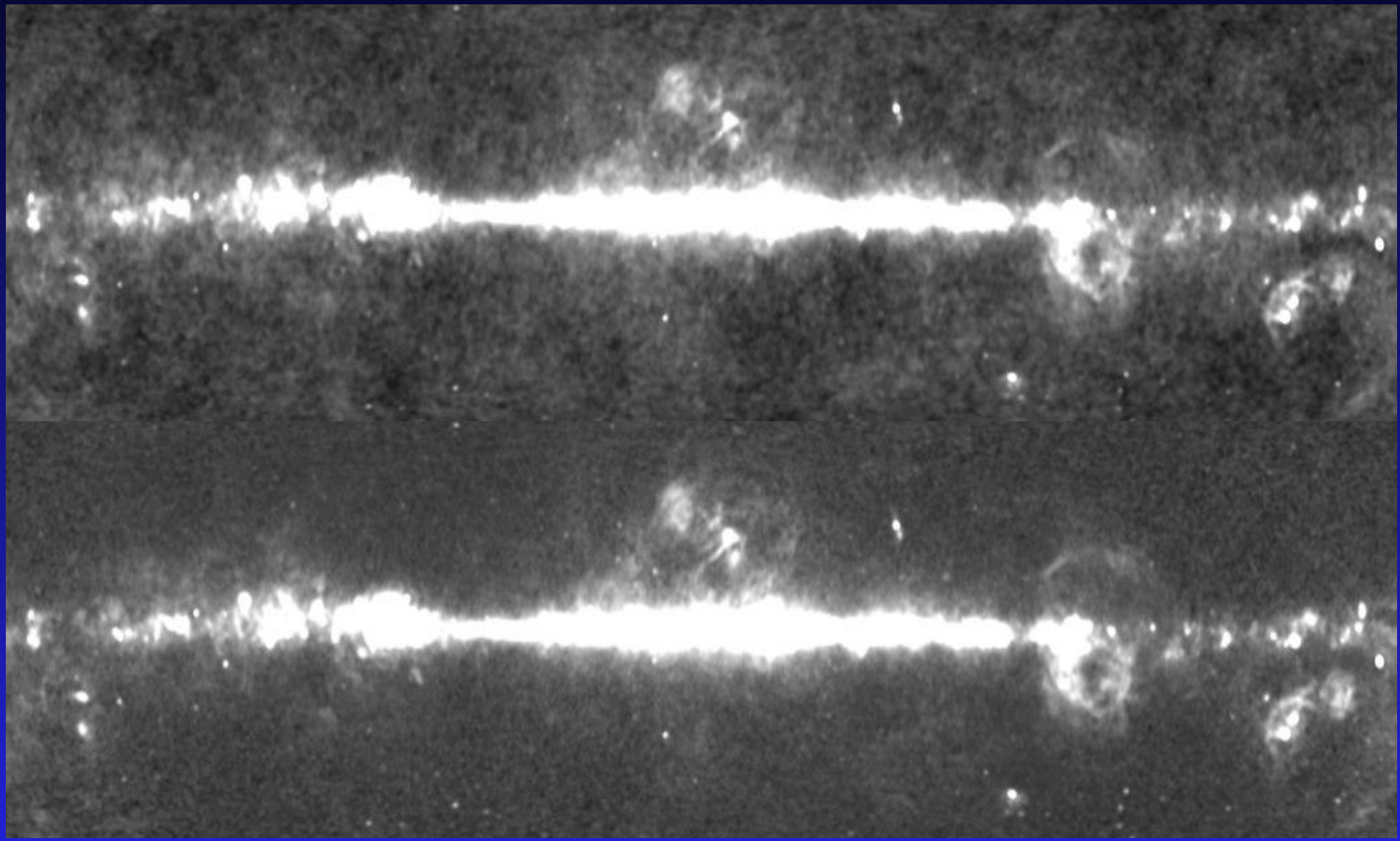
WMAP V-band (61 GHz)



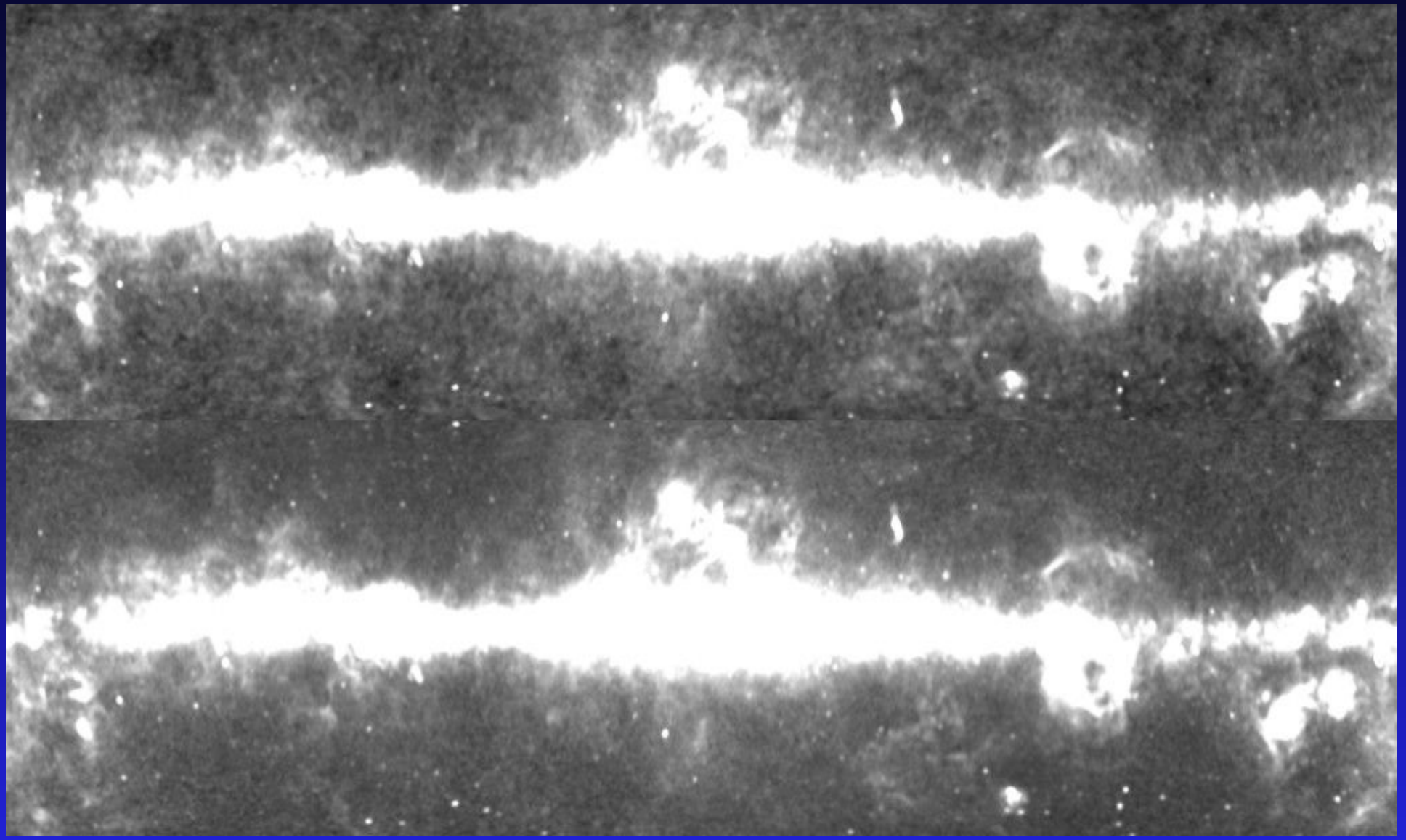
WMAP Q-band (41 GHz)



WMAP Ka-band (33 GHz)

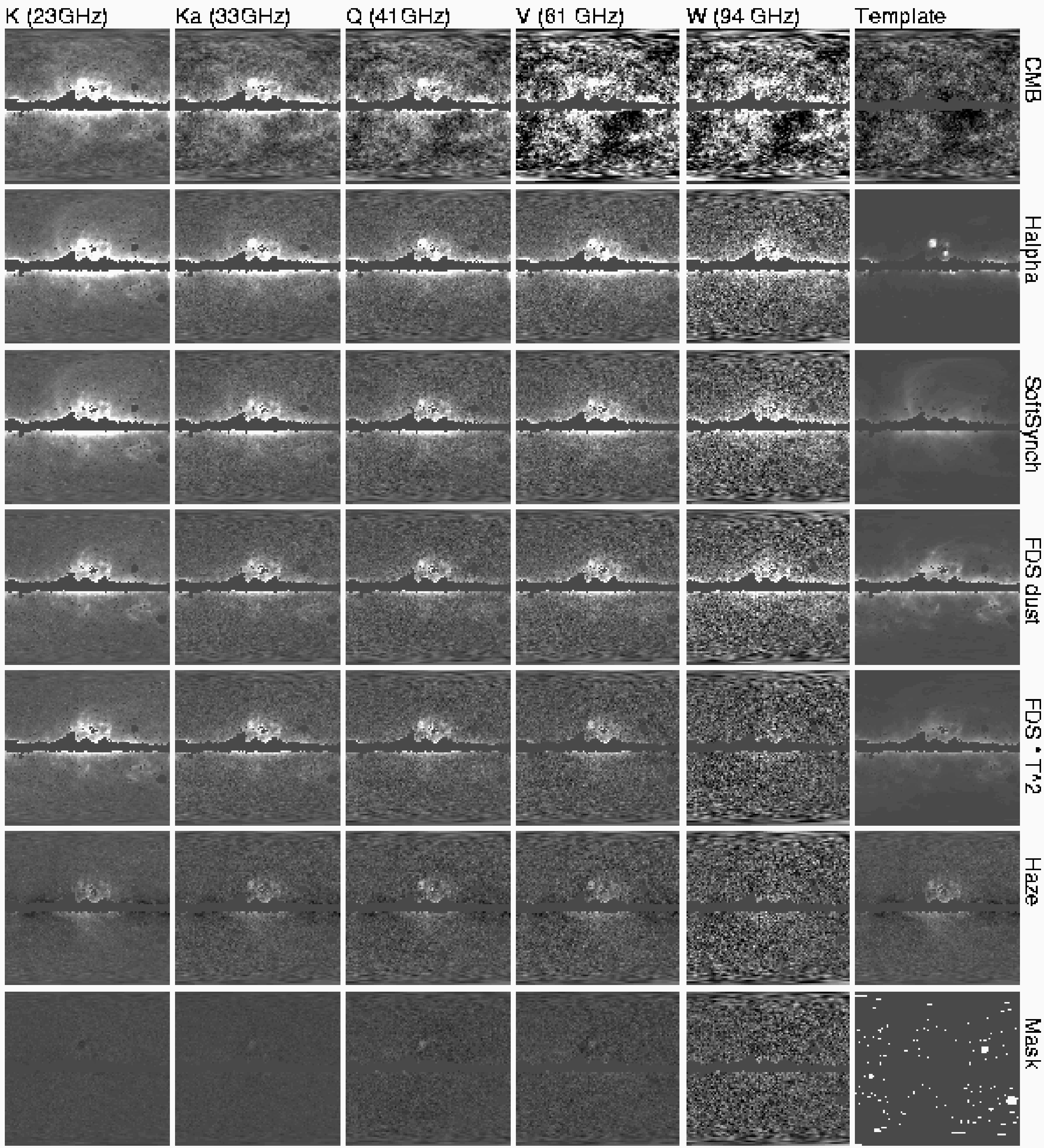


WMAP K-band (23 GHz)

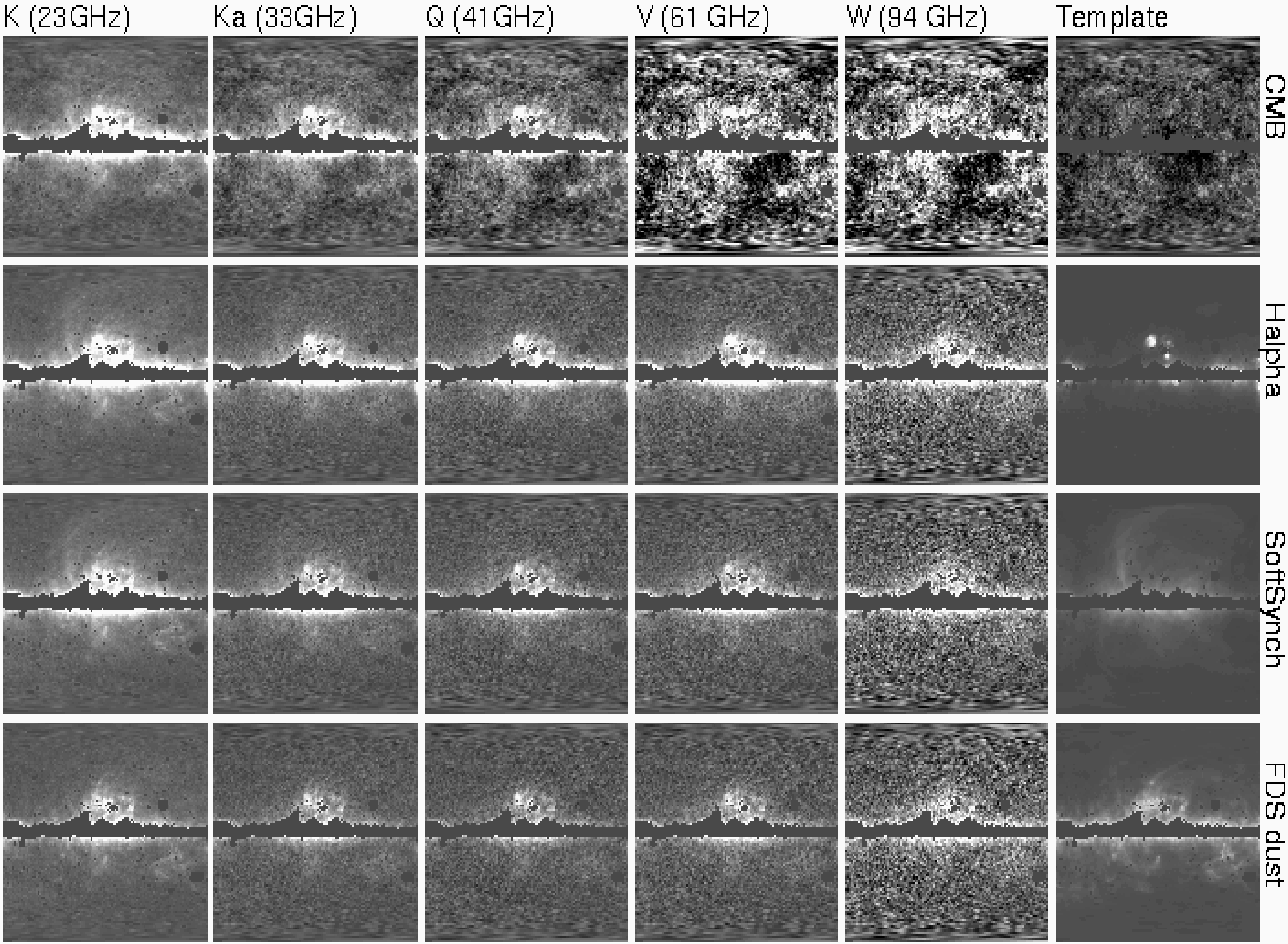


ISM Templates:

- Thermal dust - Finkbeiner et al. (1999)
- "Soft" synchrotron - Haslam 408 MHz
- Free -free - Finkbeiner (2003)
- Spinning dust - Finkbeiner (2004)



K (23GHz)
Ka (33GHz)
Q (41GHz)
V (61 GHz)
W (94 GHz)
Template
CMB
Halpha
SoftSynch
FDS dust
FDS * T^2
Haze
Mask


K (23GHz)
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Template
CMB
Halpha
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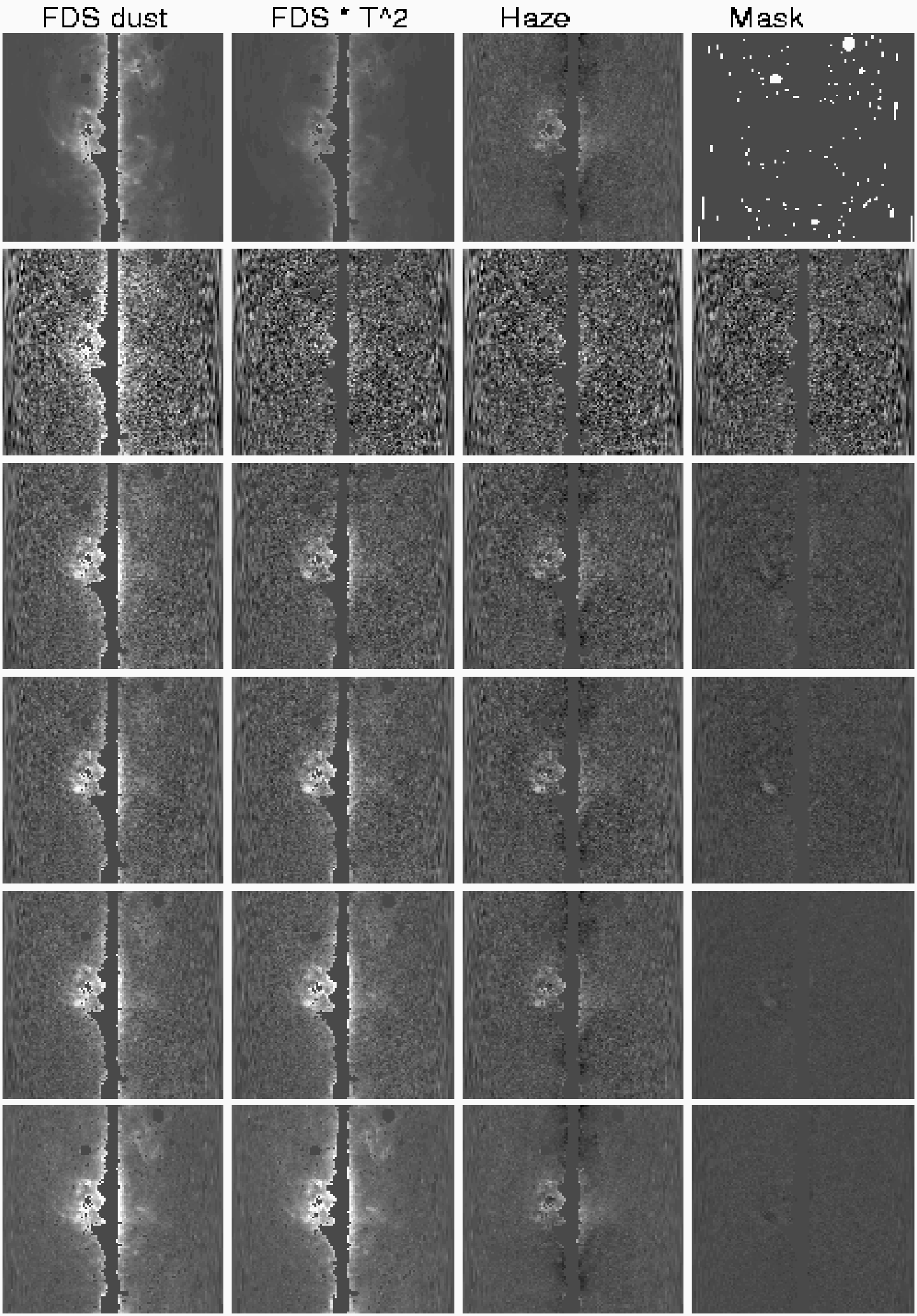
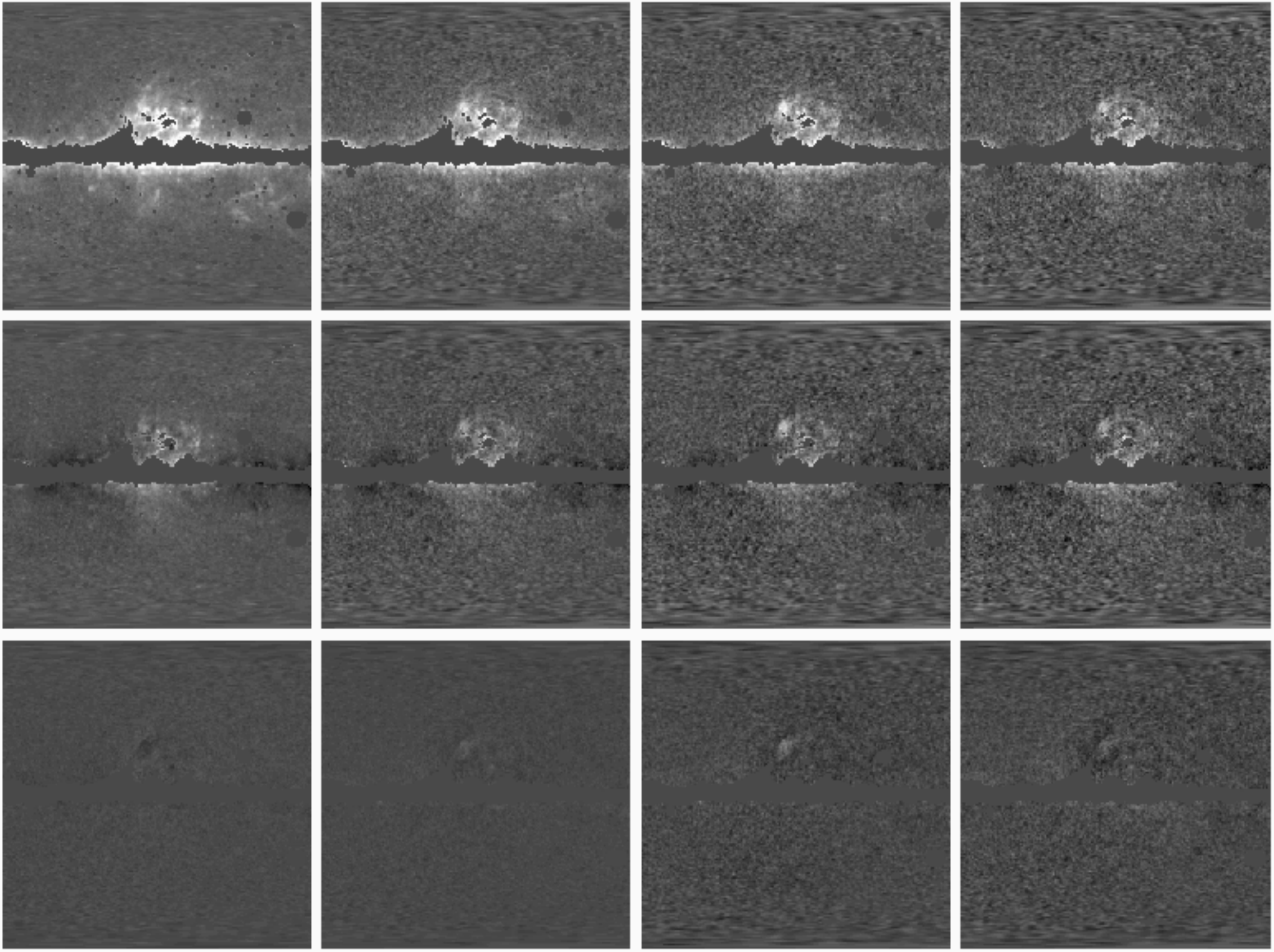
FDS dust


FDS dust
FDS * T^2
Haze
Mask



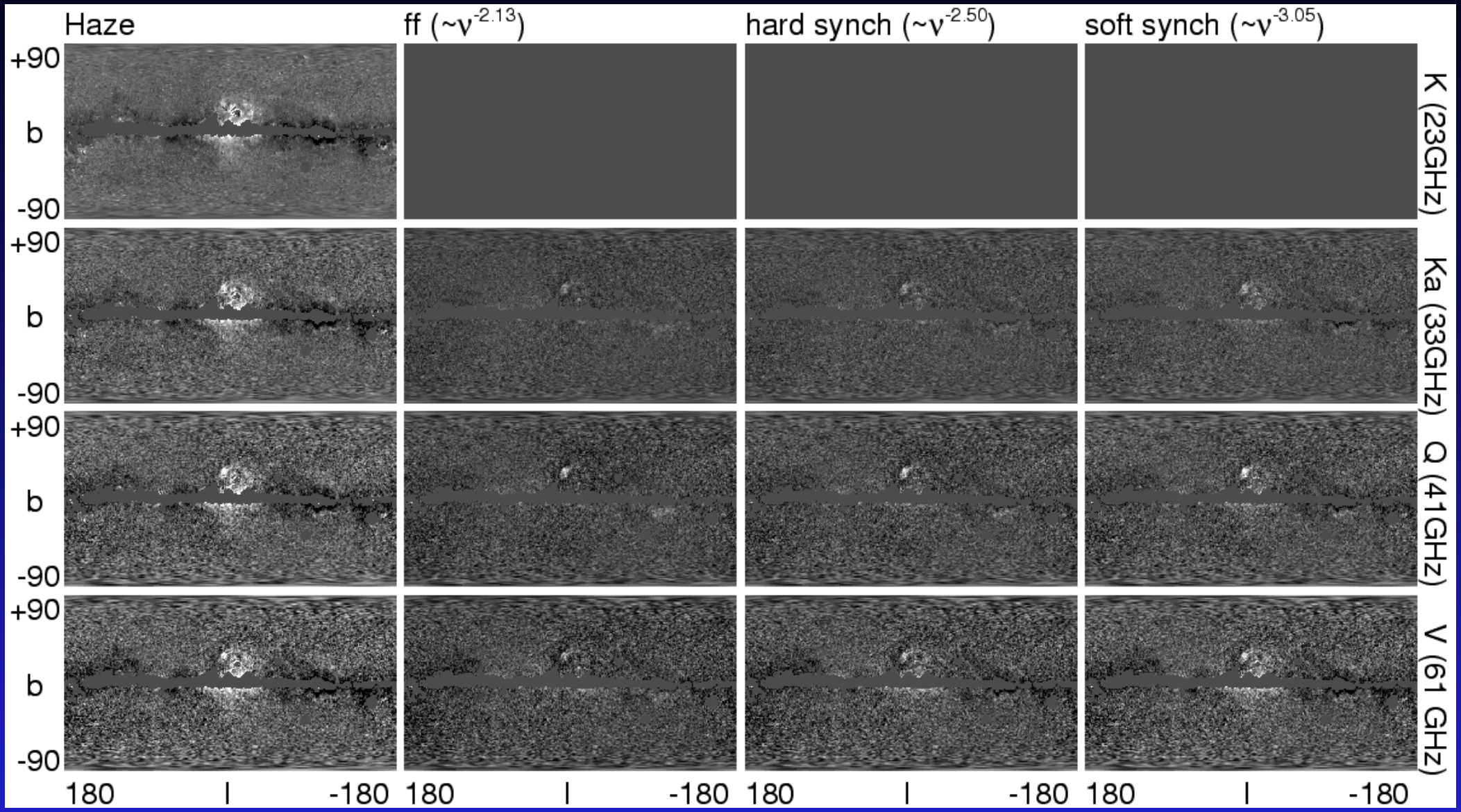
The Haze

Appears south of Galactic center (within 20-30 deg)
Not much emission in other templates
Has a free -free spectrum

IF it is free-free, the Gas must be hot (~ 100,000 K)
Chi^2 near unity for most bands

Other than haze, this four component template fit, including "spinning dust," fits well.

The Haze



Is it free -free or synchrotron?

What is the “haze”

Problems with free-free interpretation:

gas must be an awkward temperature
no hotter gas seen
EM -> DM of several thousand unless very clumpy
Need much of SN power of Galaxy to support

What is the "haze"

Best current guess:
synchrotron emission from a "hard" cosmic ray electron spectrum (harder than $dN/dE \sim E^{-2}$)

Tests:
*cosmic ray ICS scattering observed by EGRET
*microwave polarization (coming soon!)

What is the "haze"

What is the source of the electrons?

The "standard" WIMP with electroweak-scale mass
self-annihilates;
produces high energy (10s – 100s) GeV particles.

We know the cross section and approximate mass.
We know the MW dark matter halo (roughly!)
-> Can model electron creation, propagation, and
energy loss, and predict synchrotron...

Assumptions:

$< v> = 2\ 10^{-26}$ cm^3/s
mass = 100 GeV
spherical symmetry (only care about center)
diffusion is isotropic
$K(E) \sim (3 + (E/1\text{GeV})) 3\ 10^{27}$ cm^2/s; =0.6
(Webber et al.)
injection spectrum is hard
starlight from Strong, Moskalenko & Reimer (2000)
B-field from Han (2004)

all reasonable assumptions; all could be better...

Annihilation power

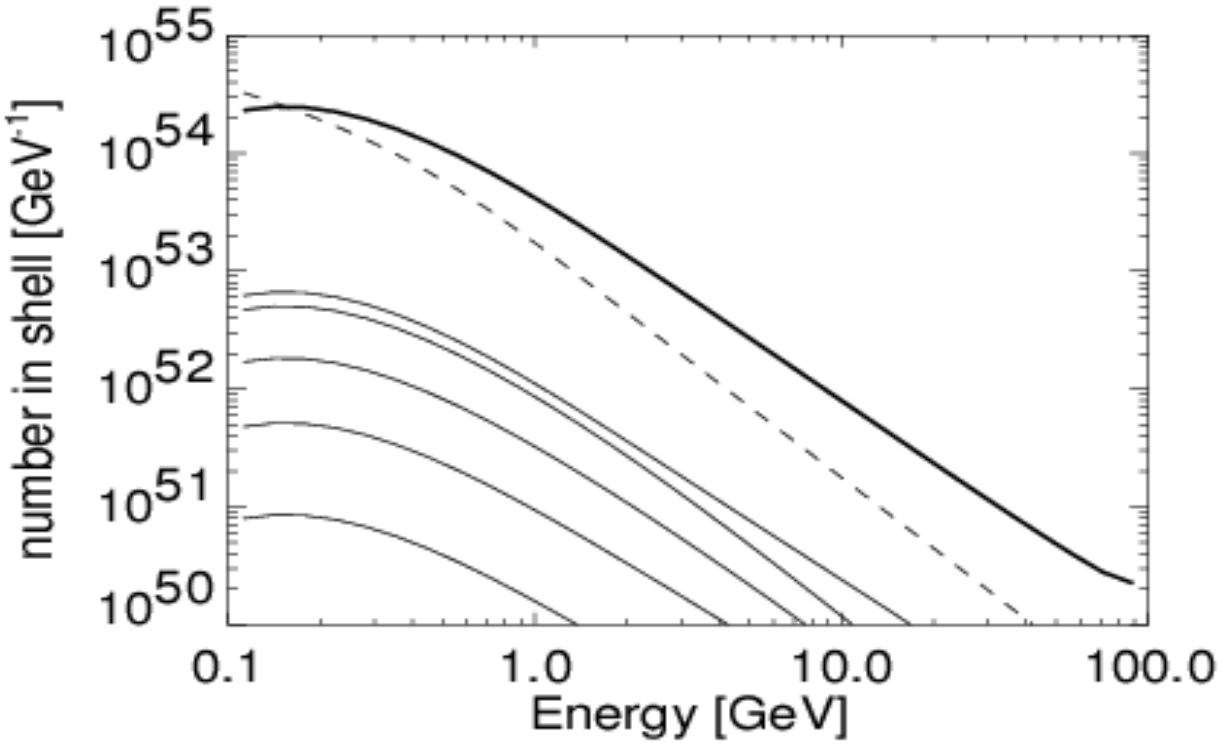
Just by assuming
*mass lower limit from accelerators
*$< v> = 2\ 10^{-26}$ cm^3/s, i.e. thermal relic
*WMAP parameters
*NFW profile for MW dark matter

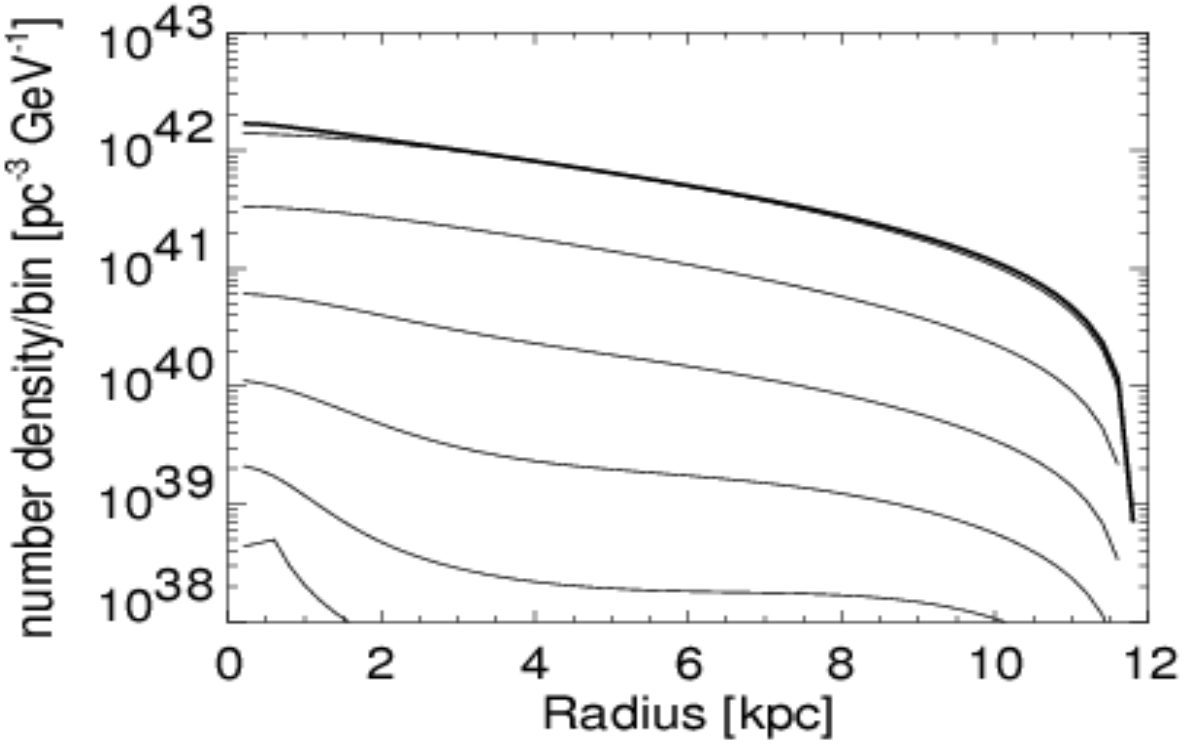
=> upper limit on power of ~ $2x10^{38}$ erg/s

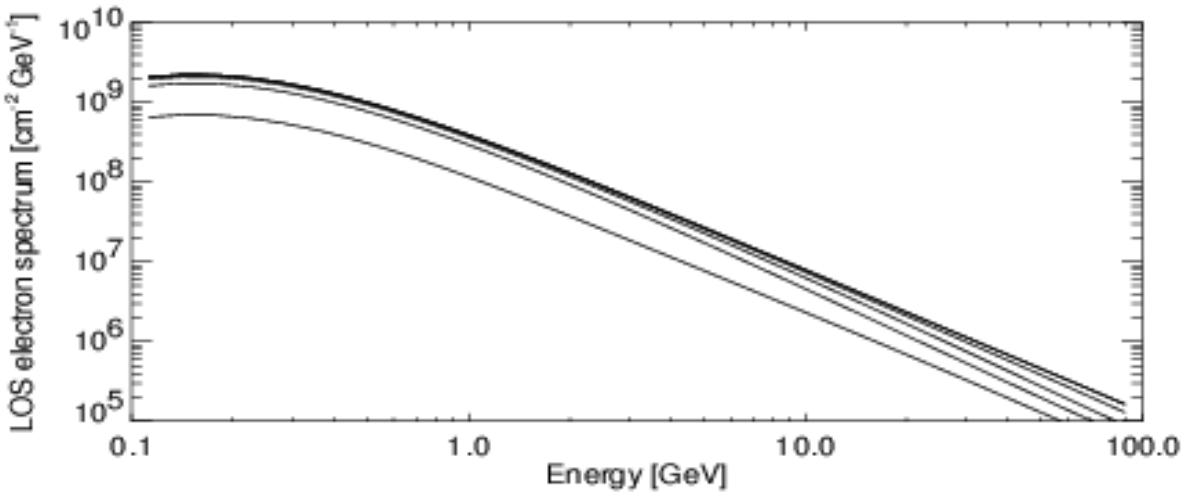
We can now detect this with WMAP.

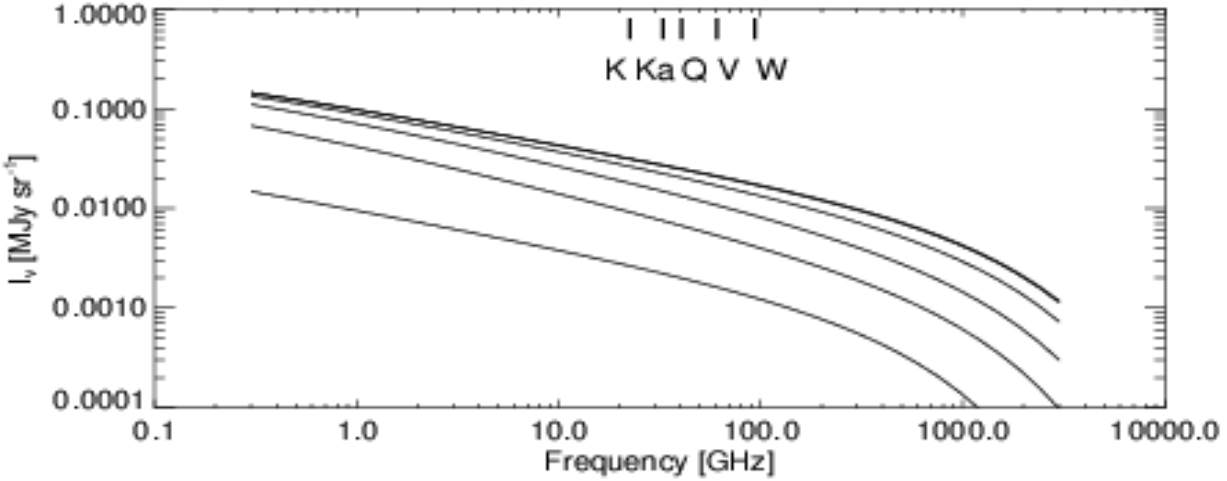
$$\frac{d}{dt}n(E,\mathbf{x}) = \nabla \cdot (K(E,\mathbf{x})\nabla n) + \frac{\partial}{\partial E}\left[b(E,\mathbf{x})n\right] + Q(E,\mathbf{x})$$

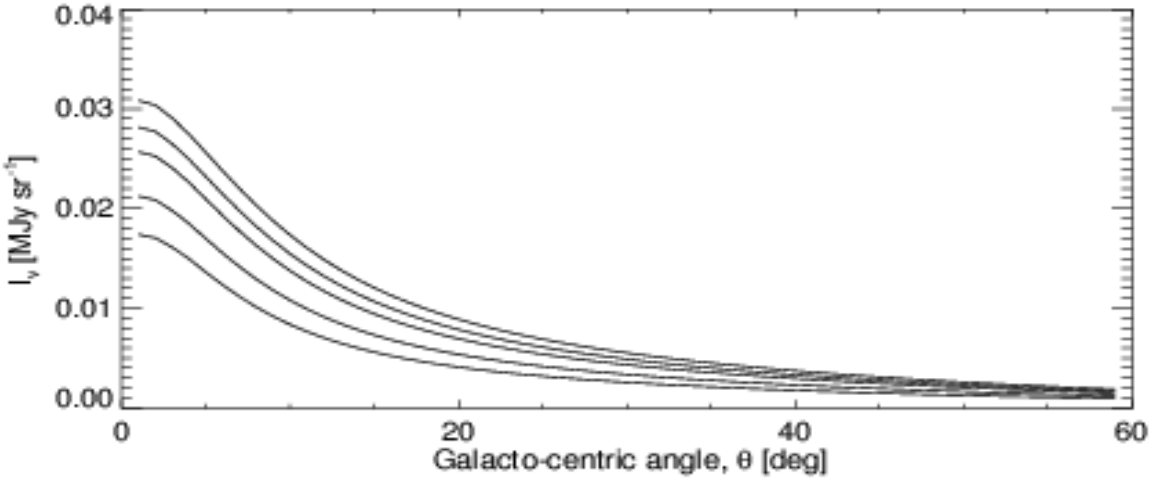
Finkbeiner (2004) astro-ph/0409027

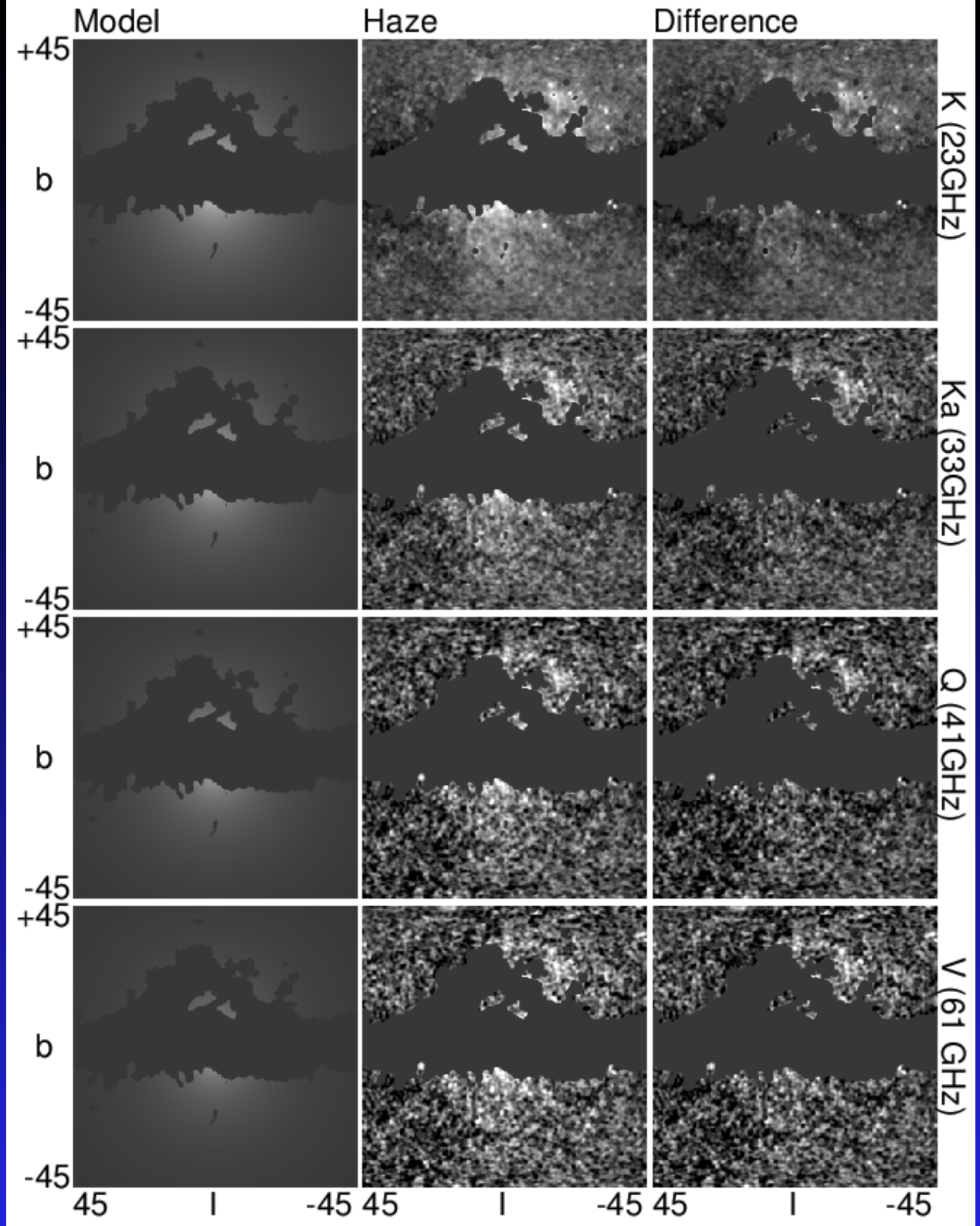

number in shell [GeV^{-1}]
10^{55}
10^{54}
10^{53}
10^{52}
10^{51}
10^{50}
0.1
1.0
10.0
100.0
Energy [GeV]


number density/bin [pc^{-3} GeV^{-1}]
10^{43}
10^{42}
10^{41}
10^{40}
10^{39}
10^{38}
0
2
4
6
8
10
12
Radius [kpc]


LOS electron spectrum [cm^{-2} GeV^{-1}]
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
0.1
1.0
10.0
100.0
Energy [GeV]


K Ka Q V W
1.0000
0.1000
0.0100
0.0010
0.0001
I_ν [MJy sr^{-1}]
0.1
1.0
10.0
100.0
1000.0
10000.0
Frequency [GHz]


0.04
0.03
0.02
0.01
0.00
I_ν [MJy sr^{-1}]
0
20
40
60
Galacto-centric angle, θ [deg]


Model
Haze
Difference
+45
b
-45
K (23GHz)
Ka (33GHz)
Q (41GHz)
V (61 GHz)
45
l
-45

Summary of “simple model”

*The cross section and density are fixed
(in the simplest case).
*mass is free parameter, but constrained.

*A dark matter model using very simple assumptions and one free parameter fits the data.

*This could have been off by many orders of magnitude, and wasn't.

Other options: Kaluza-Klein

The lightest stable Kaluza-Klein particle is also a dark matter candidate. In simple cases, annihilation cross sections can be computed and e^+e^- energy spectra estimated.

For the NFW dark matter density profile ($\rho \sim 1/r$ in the inner Galaxy) there is not enough to explain the observed power.

Moore profile is better. (or need substructure)

Kaluza-Klein

Pro:
* energy spectrum right
* get electrons without pions (gamma-ray limits)
* KK may be some limit of the correct theory

Con:
* power too low by factor of at least 10 for
  the simplest models.

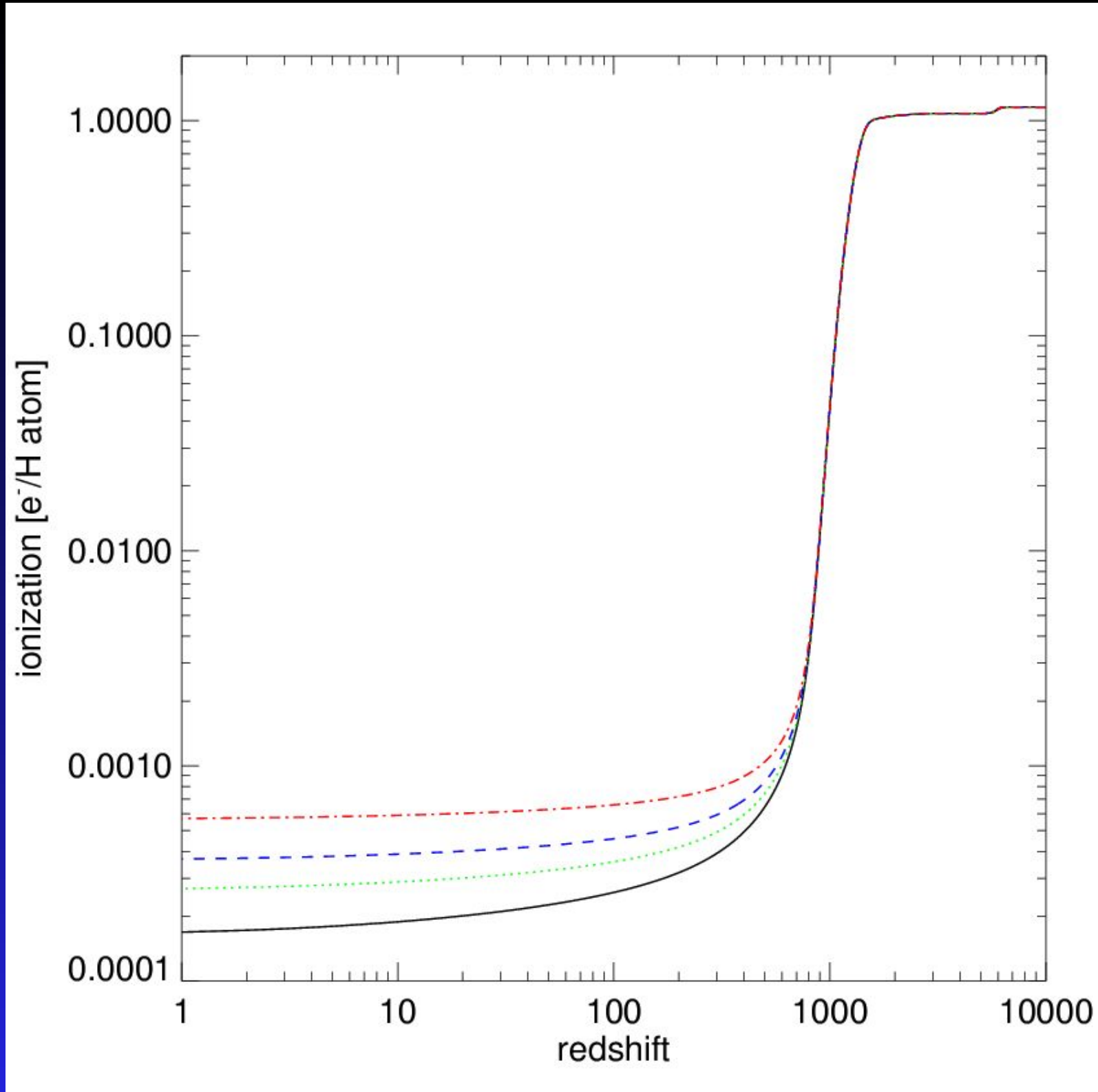
Testing the Idea:

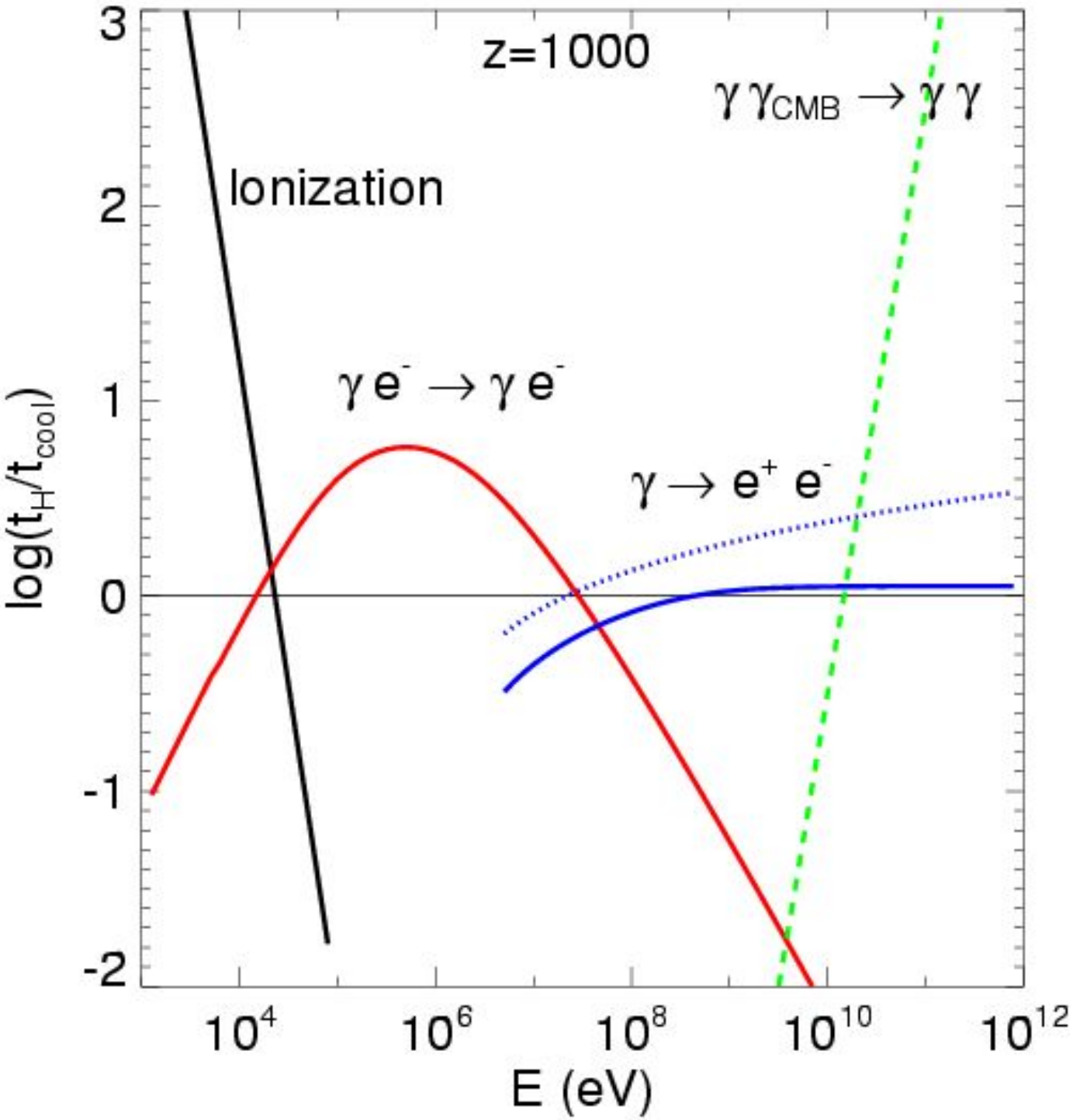
- WMAP 2nd yr data: polarization of the haze.
- Search for haze in other galaxies
- Effects on BBN, e.g. D abundance
- Gamma ray constraints
- Excess positrons from HEAT, etc.

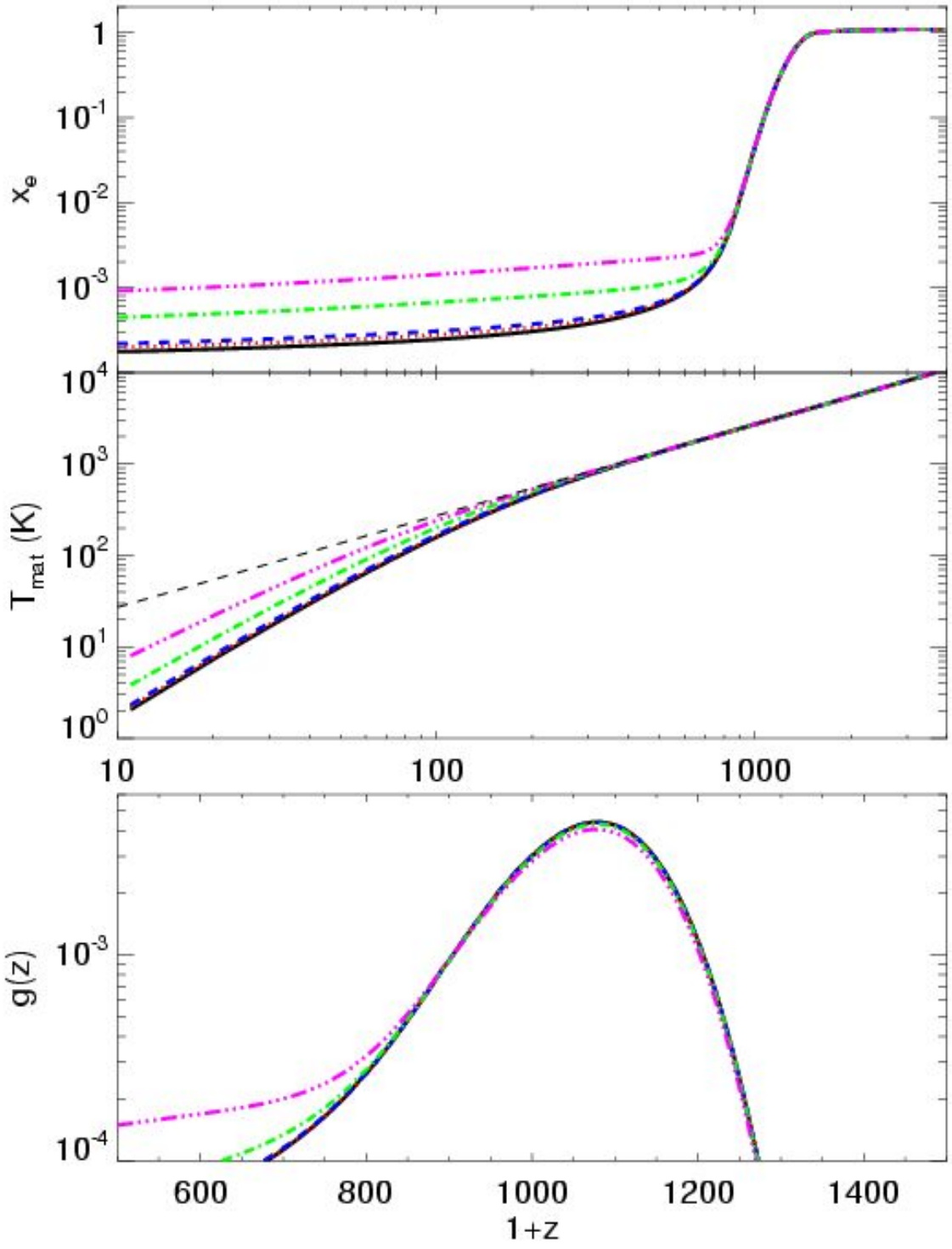
Ionization History (z<~1000)

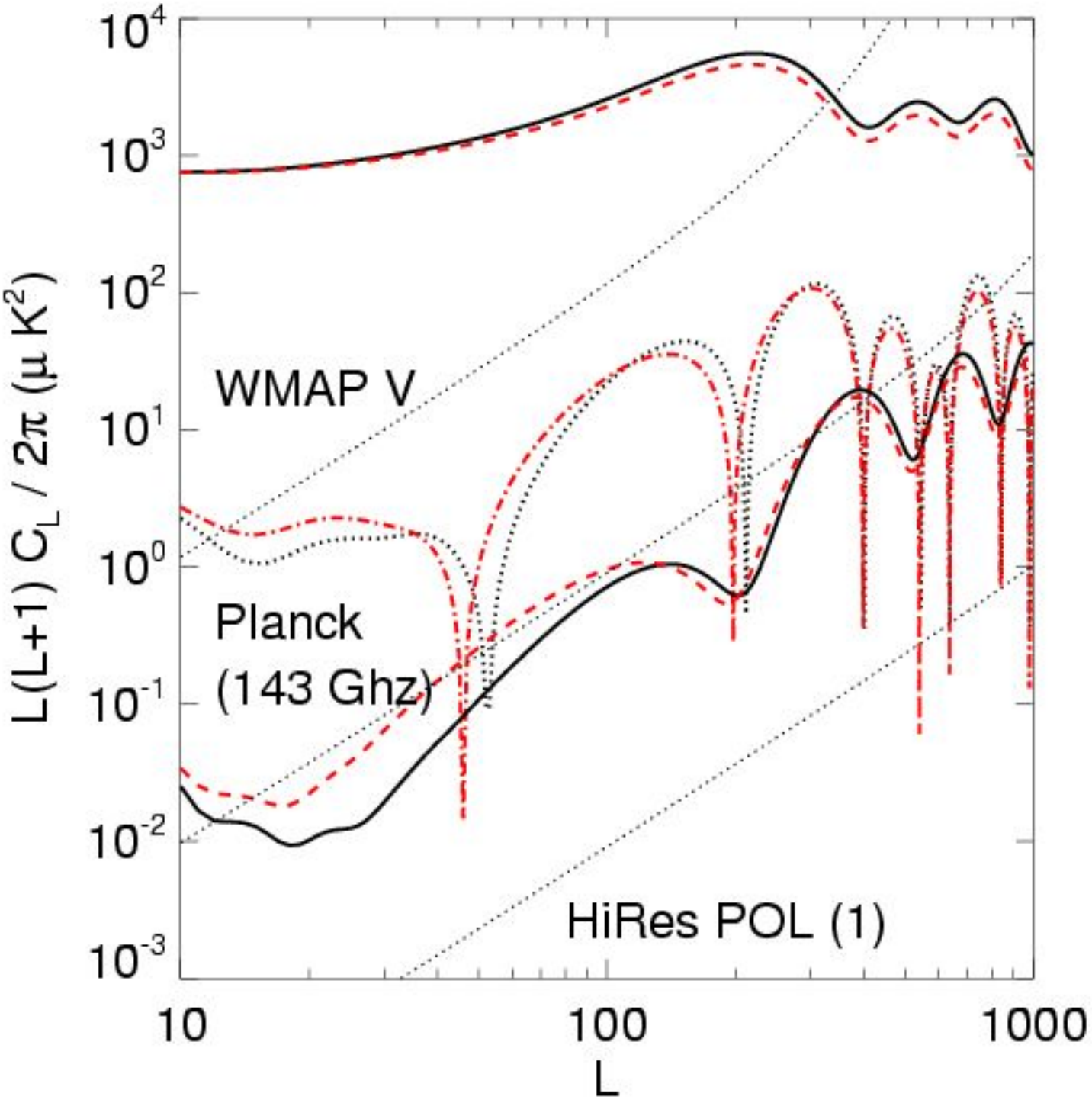
If dark matter annihilates, the annihilation products can partially ionize H, He at z=1000 (the time of "re-combination") and cause a higher residual ionization than otherwise expected.

We must verify that the proposed scenario does not ionize so much that it conflicts with CMB data.
N. Padmanabhan & DF astro-ph/0503486


1.0000
0.1000
0.0100
0.0010
0.0001
ionization [e⁻/H atom]
1
10
100
1000
10000
redshift


z=1000
γ γCMB → γ γ
Ionization
γ e- → γ e-
γ → e+ e-
log(tH/tcool)
3
2
1
0
-1
-2
10^4
10^6
10^8
10^10
10^12
E (eV)


1
10^{-1}
10^{-2}
10^{-3}
x_e
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
T_{mat} (K)
10
100
1000
10^{-3}
10^{-4}
g(z)
600
800
1000
1200
1400
1+z


10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
$L(L+1)\,C_L / 2\pi\ (\mu\,K^2)$
WMAP V
Planck
(143 Ghz)
HiRes POL (1)
10
100
1000
L

More optimistically

With GLAST and LHC
coming on line in the next two years,
we will get some guidance on what is possible.

If a particle is discovered in the lab, we can make specific predictions for the astrophysical consequences.

Future work

Model propagation/diffusion better
- more realistic boundary conditions
- better magnetic field estimate

Model expected ICS better
- photon field, with directional information

Obtain better gamma-ray measurements
(GLAST, VERITAS, INTEGRAL, etc.)

Improve WMAP foreground analysis
-> determine required injection spectrum
--> constrain models!

Future work

Look at other galaxies, e.g. edge on spirals like NGC 4565 or radio-quiet ellipticals with no dust. Signal should be there, too!

Expected antenna temperatures of ~hundreds of micro K (SZA!)

Planck maps of Milky Way -> detailed information about the "haze."

Conclusions

- There is strong evidence for a smooth, ~ spherical component of microwave emission (the “haze”) in the Galactic center. The power and morphology are about right for this to be WIMP annihilation, and the spectrum of the required electrons is hard.
- At the very least, this is a robust upper limit on the power in WIMP annihilation products going to e^+e^- at 10s of GeV and above.