Galactic Science and CMB Foregrounds

Douglas Finkbeiner
(including work by Aaron Meisner, Gregory Green, Eddie Schlafly)

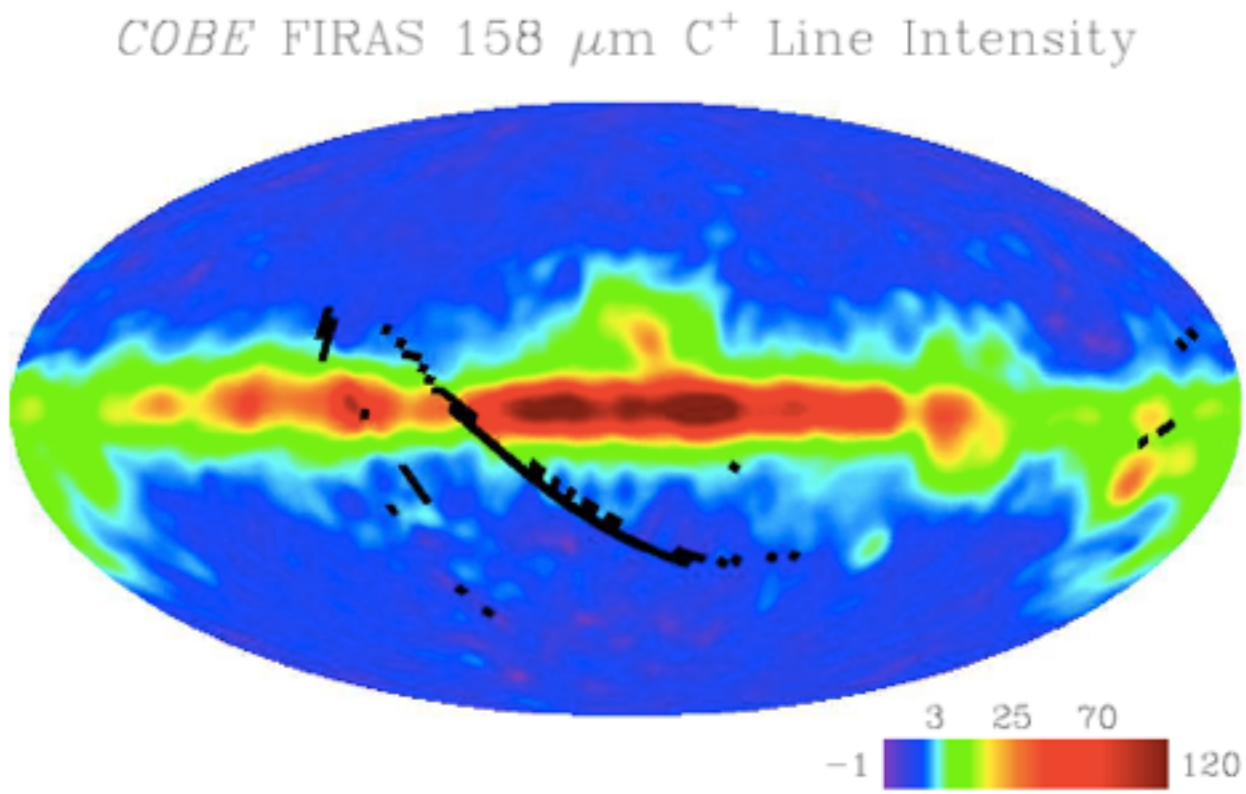
18 May, 2015
U. Chicago

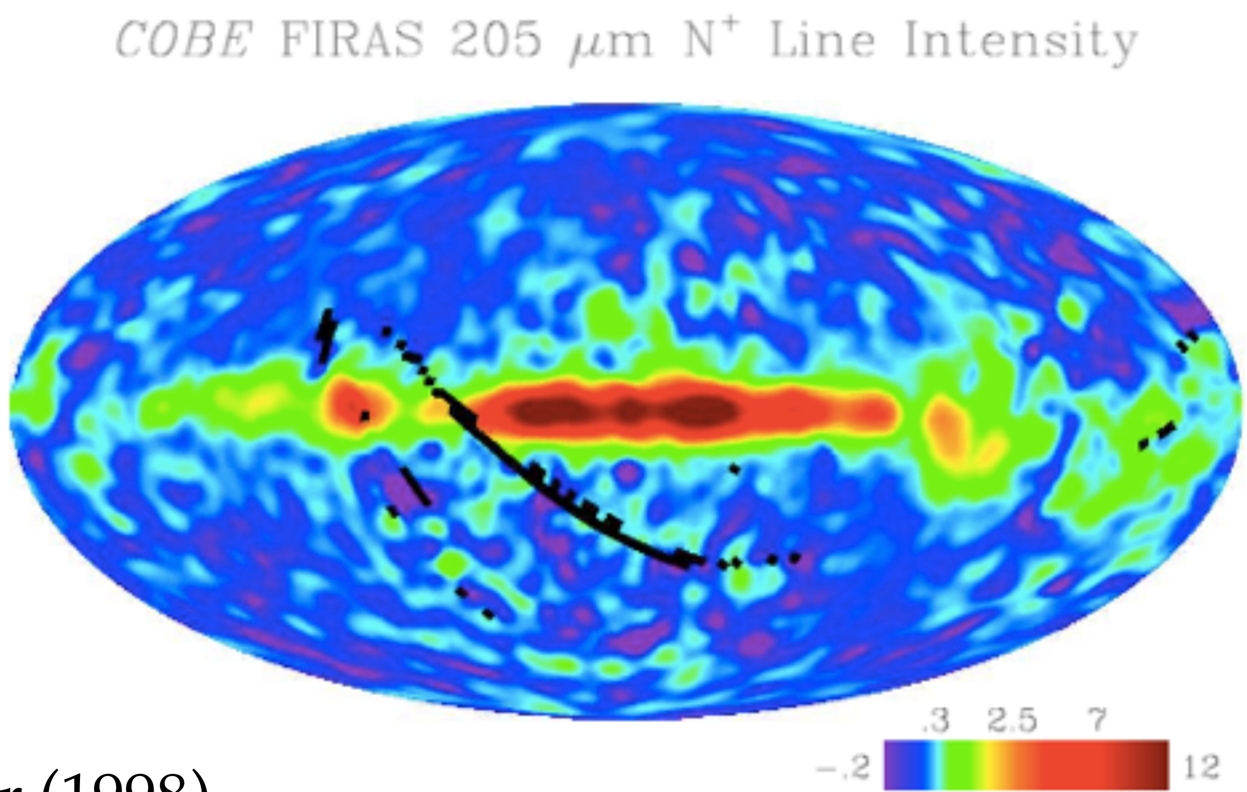
Ancillary science for CMB SD data:

- Milky Way ISM
  - dust spectrum (pretty well understood already)
  - ISM emission lines: [C II] 158 μm, [N II] 205 μm

Orders of magnitude better than FIR fine structure lines from COBE/FIRAS

FIR fine structure lines from COBE/FIRAS:





Fixsen, Bennett, Mather (1998)

What can we learn from these lines?

- [C II] ~ integrated pressure of ISM
- [N II] ~ radiation field from hot stars

Useful indicators of the physical state of the ISM, integrated along los.

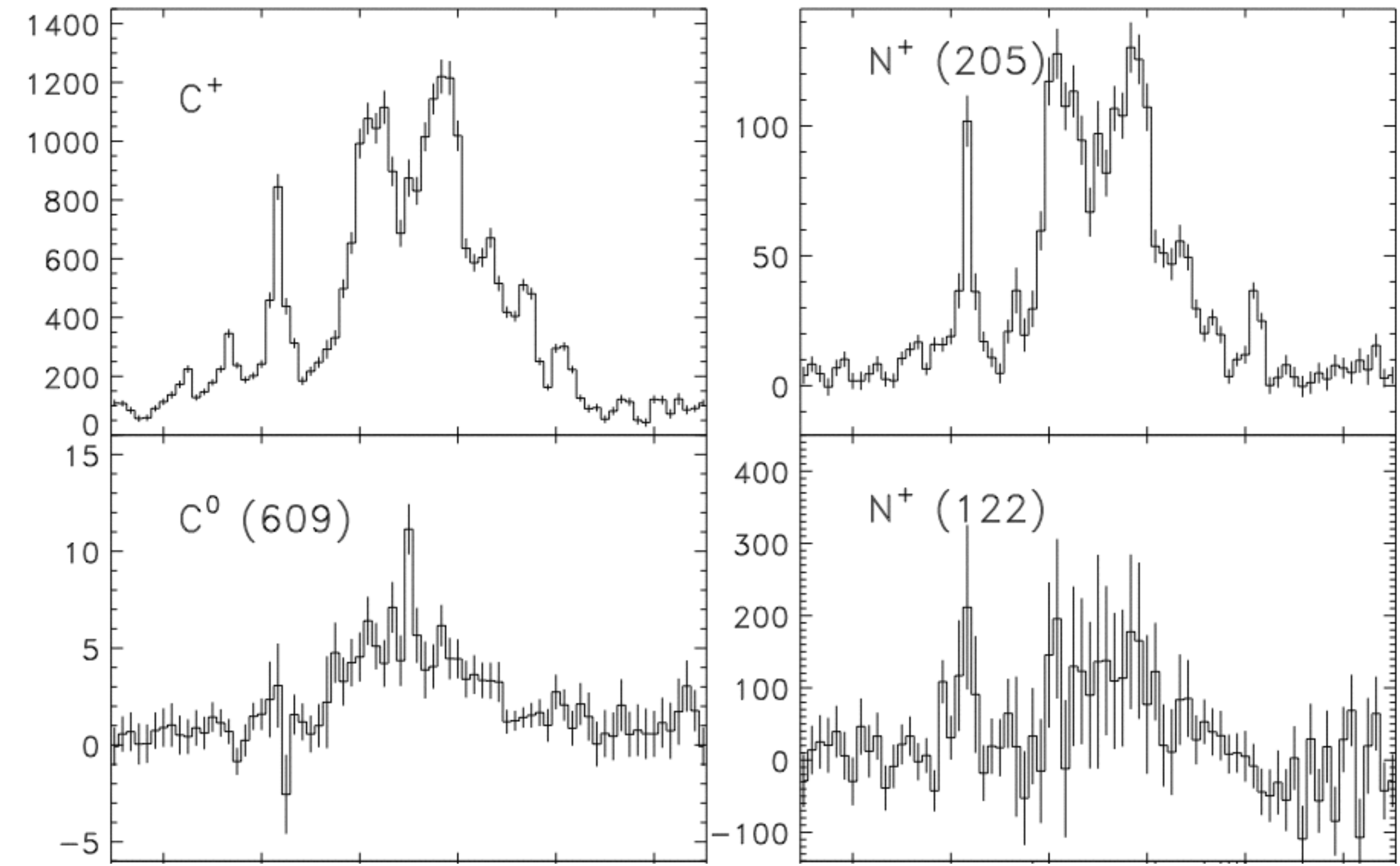
What can we learn from these lines?

- [C II] ~ integrated pressure of (neutral) ISM
- [N II] ~ radiation field from hot stars

Useful indicators of the physical state of the ISM, integrated along los.

Caveats:

- self-absorption
- no *detailed* velocity info unless $\Delta f / f \sim 10^{-4}$
- only integrated quantity available



Fixsen, Bennett, Mather (1998)

Why do we care?

Long-term project to map in 3D:

- dust density
- gas density (HI and CO)
- star density, dynamics (PMs from GAIA, etc.)
- radiation field (in 6D)

These have many applications.
Will tell you my favorite at the end.

Outline:

- Emission spectrum of dust: 2-comp vs. 1, (Beta,T), etc.
- 3-D dust and stars from PS1, 2MASS
- Applications

Planck-based two-component dust emission model

Aaron Meisner & Doug Finkbeiner


Aaron Meisner

FIR dust emission models

SFD98: single MBB, 1250-3000 GHz

emissivity power law index, constant

$$I_\nu = \tau_{\nu_0} (\nu/\nu_0)^2 B_\nu(T)$$

optical depth, 6.1' FWHM

dust temperature, ~1.3° FWHM

MAPS OF DUST INFRARED EMISSION FOR USE IN ESTIMATION OF REDDENING AND COSMIC MICROWAVE BACKGROUND RADIATION FOREGROUNDS

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Received 1997 October 17; accepted 1998 January 28

FIR dust emission models

Planck 2013: single MBB, 353-3000 GHz

0.5° FWHM

$$I_\nu = \tau_{\nu_0} (\nu/\nu_0)^\beta B_\nu(T)$$

optical depth, 5' FWHM

dust temperature, 5' FWHM

Planck* 2013 results. XXXI. All-sky model of thermal dust emission

Planck Collaboration: A. Abergel[61], P. A. R. Ade[88], N. Aghanim[61], D. Alina[9,96], M. I. R. Alves[61], C. Armitage-Caplan[93], M. Arnaud[74],
...

FIR dust emission models

But should you let beta vary continuously?

Or have two components and let the fraction vary?

Type I and Type II beach sand:

Santa Cruz Island, Galapagos

FIR dust emission models

FDS99: two MBBs, 100-3000 GHz

'cold' dust temp, 1.3° FWHM

'hot' dust temp, 1.3° FWHM

$$I_\nu \propto f_1 q_1 (\nu/\nu_0)^{\beta_1} B_\nu(T_1) + (1 - f_1) q_2 (\nu/\nu_0)^{\beta_2} B_\nu(T_2)$$

SED normalization has 6.1' FWHM

f_1	q_1/q_2	β_1	β_2
0.0363	13.0	1.67	2.70

EXTRAPOLATION OF GALACTIC DUST EMISSION AT 100 MICRONS TO COSMIC MICROWAVE BACKGROUND RADIATION FREQUENCIES USING FIRAS

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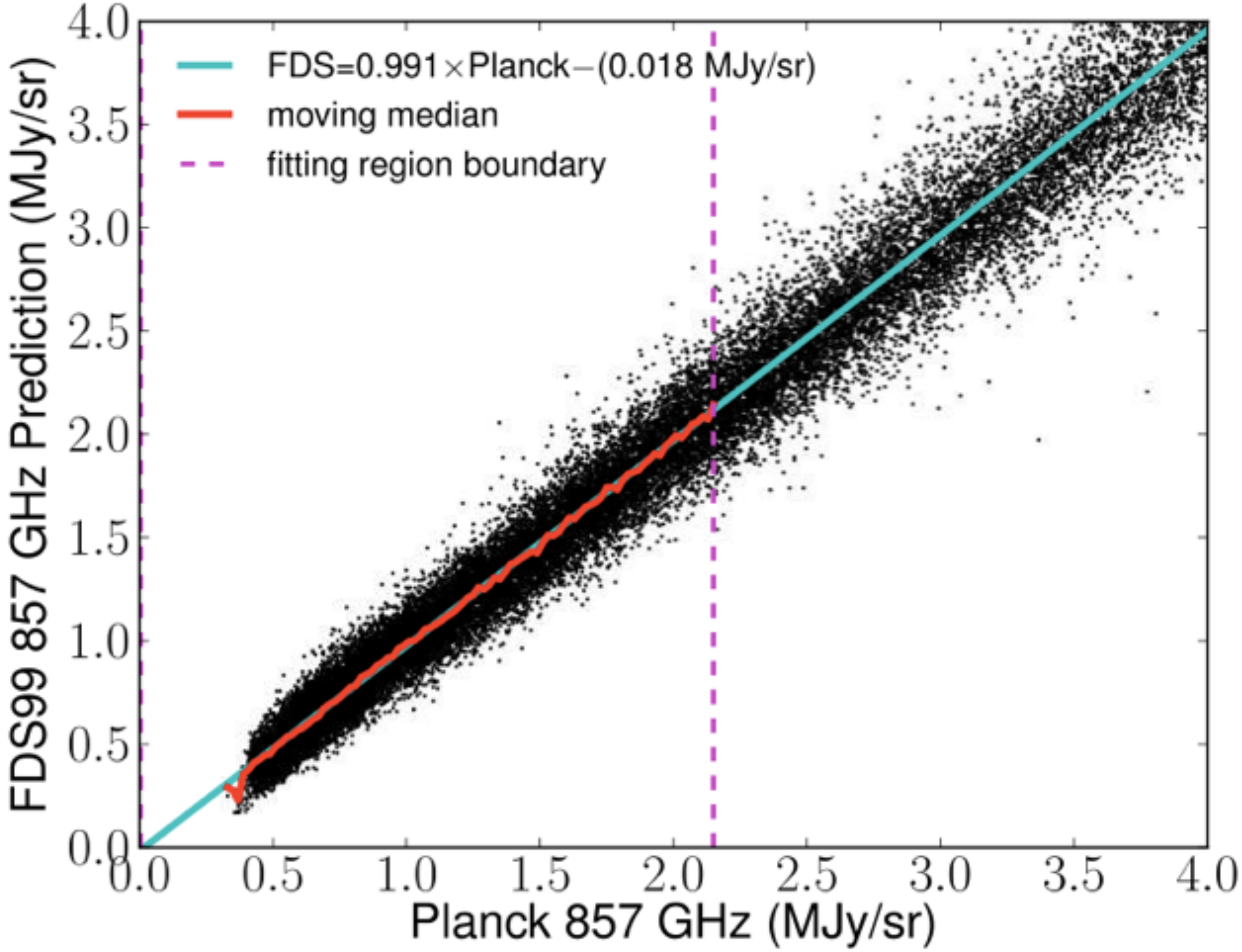
Received 1999 March 5; accepted 1999 June 8

Where is the zero point?

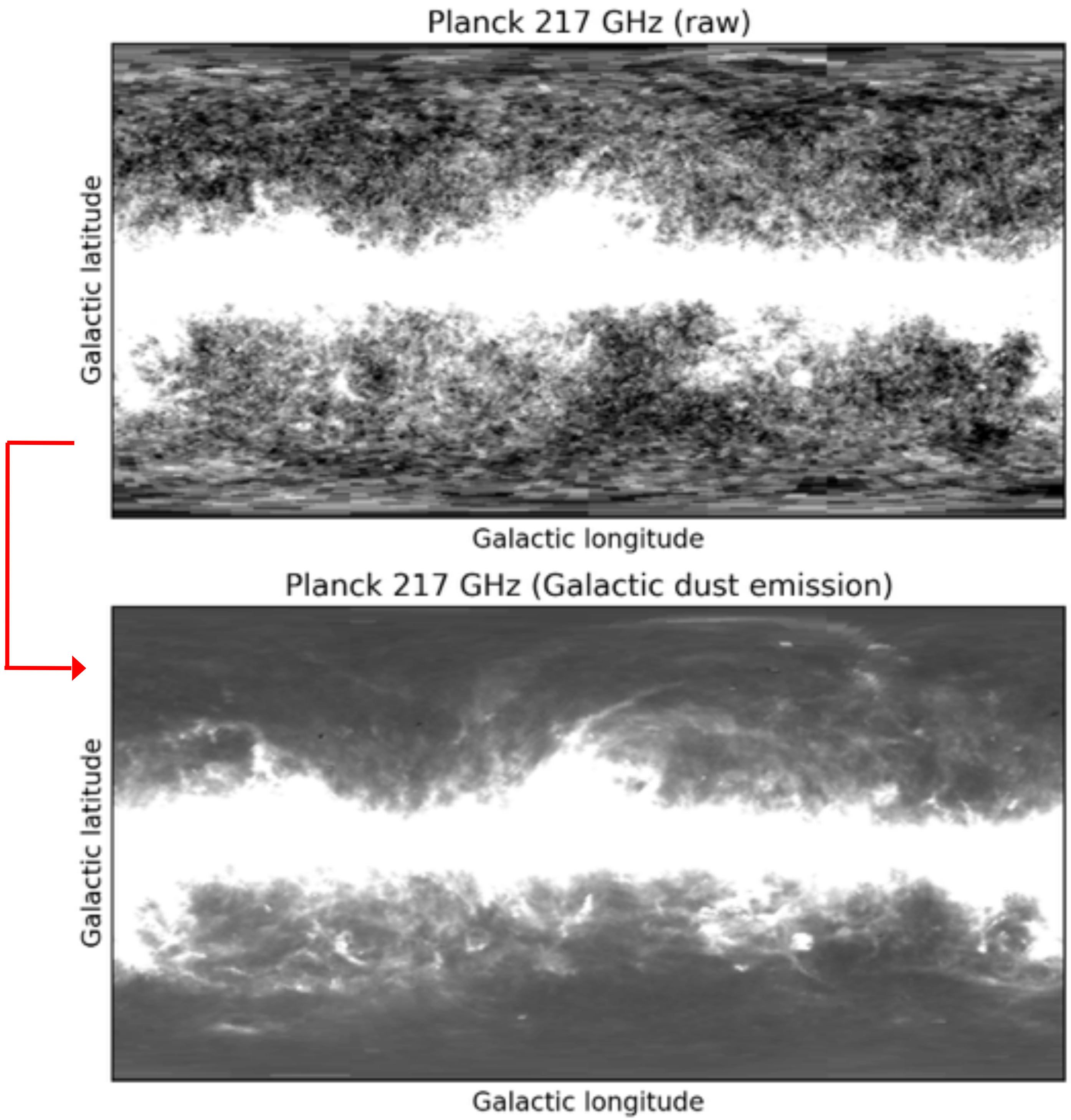
FDS99 prediction of 857 GHz is good, use this for zero point.

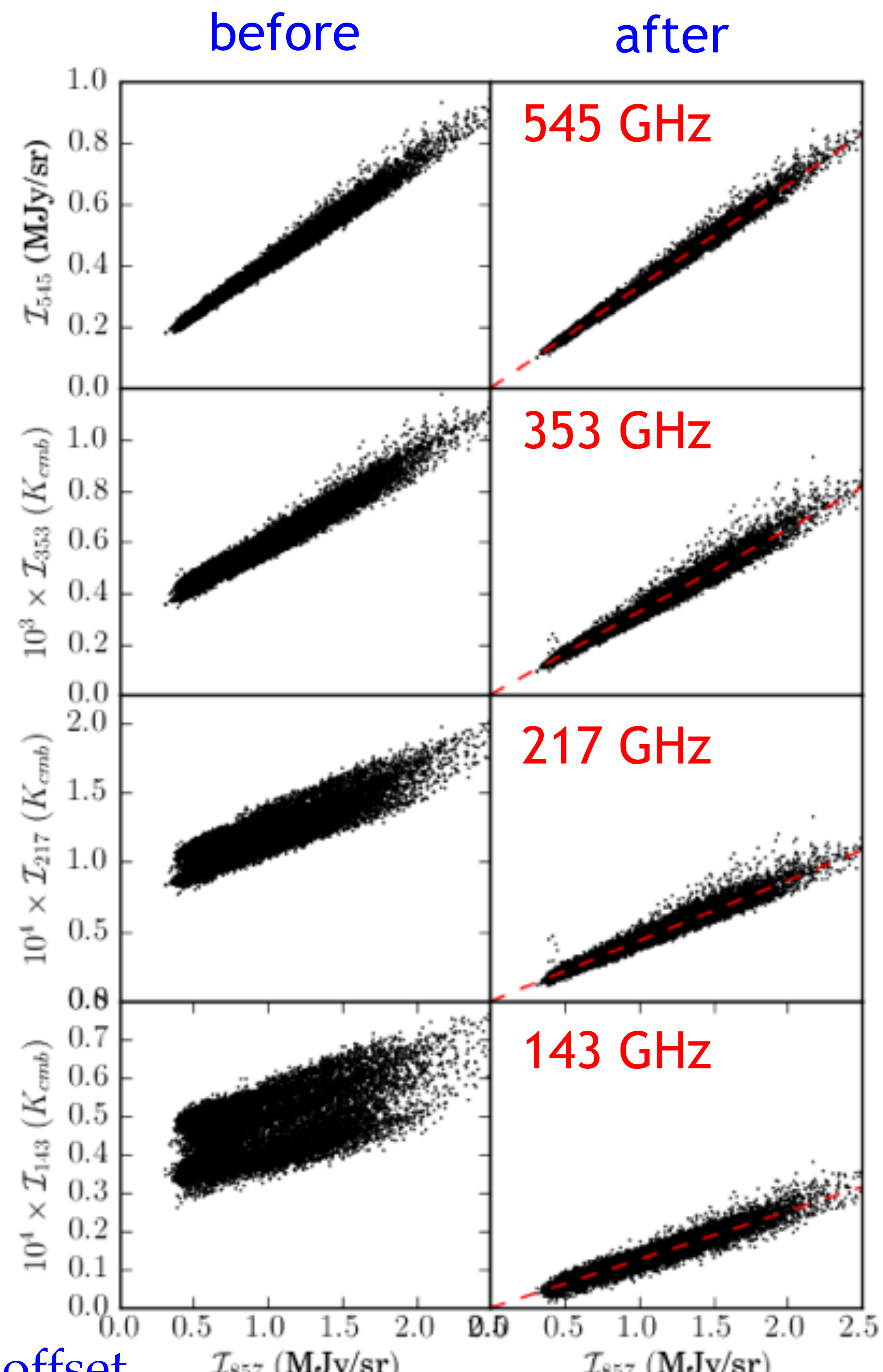
Planck bands -> Planck 857 -> FDS (via DIRBE,FIRAS) -> HI zero



Meisner & DF (2015)

Isolating Galactic thermal dust emission



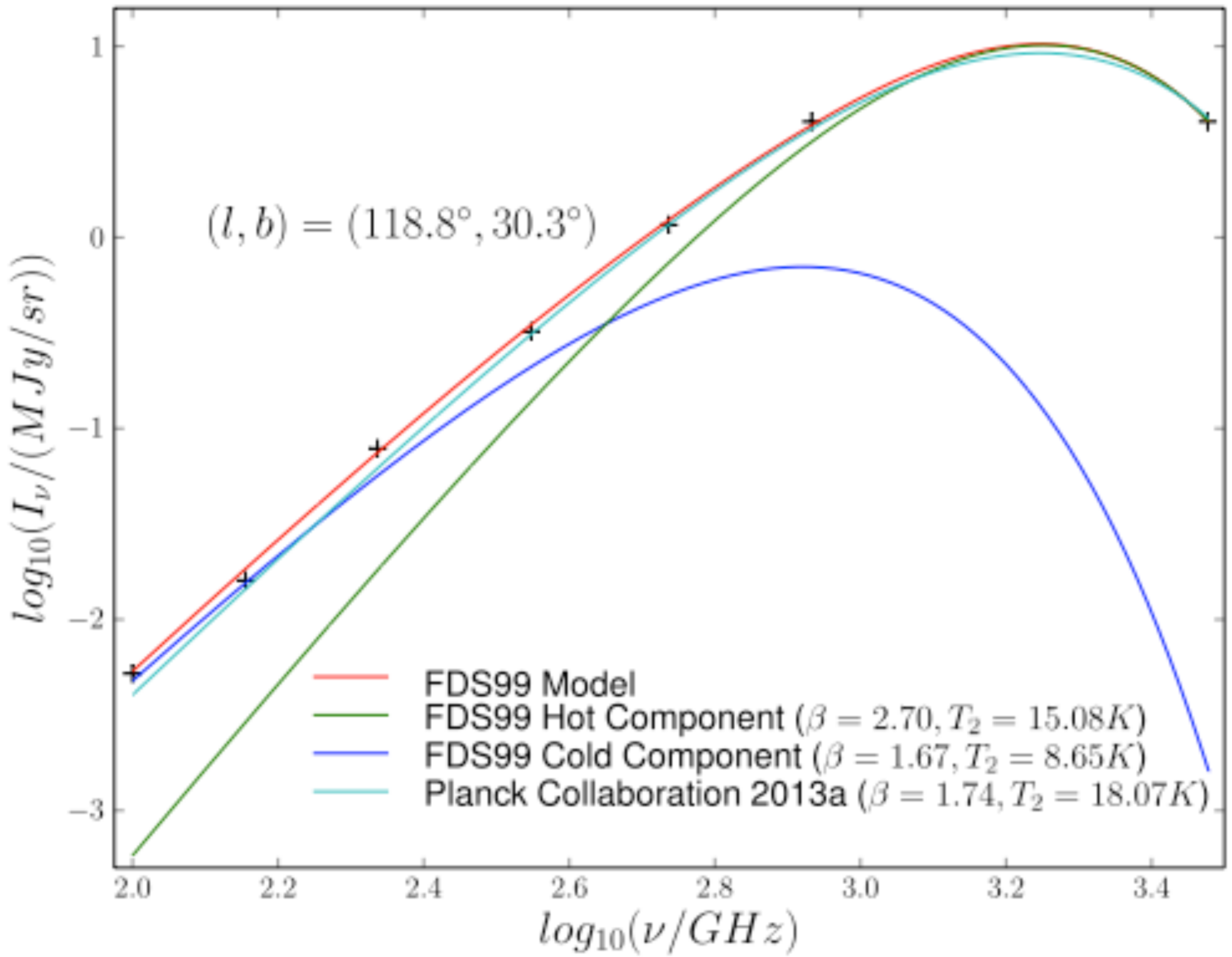


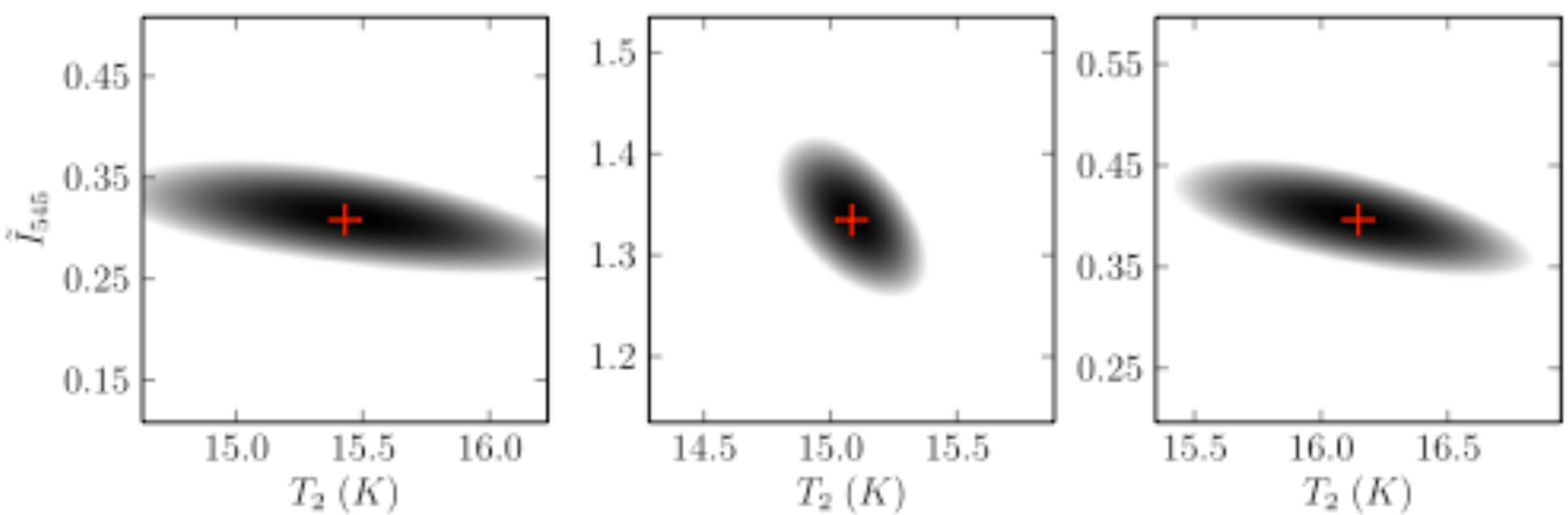
Remove CMB anisotropies, instrumental zero level offset, CIB monopole, residual Solar dipole, molecular emission, compact sources, …

Fitting FDS99 model to *Planck* maps

Details

- Each spatial pixel has 5-7 SED measurements, one intensity per *Planck*/IRAS band
- Fit two parameters per pixel: SED normalization, hot dust temperature
- Run independent Markov chain for each pixel
- Temperature prior 16.2 +/- 1.4 K to constrain low S/N pixel fits

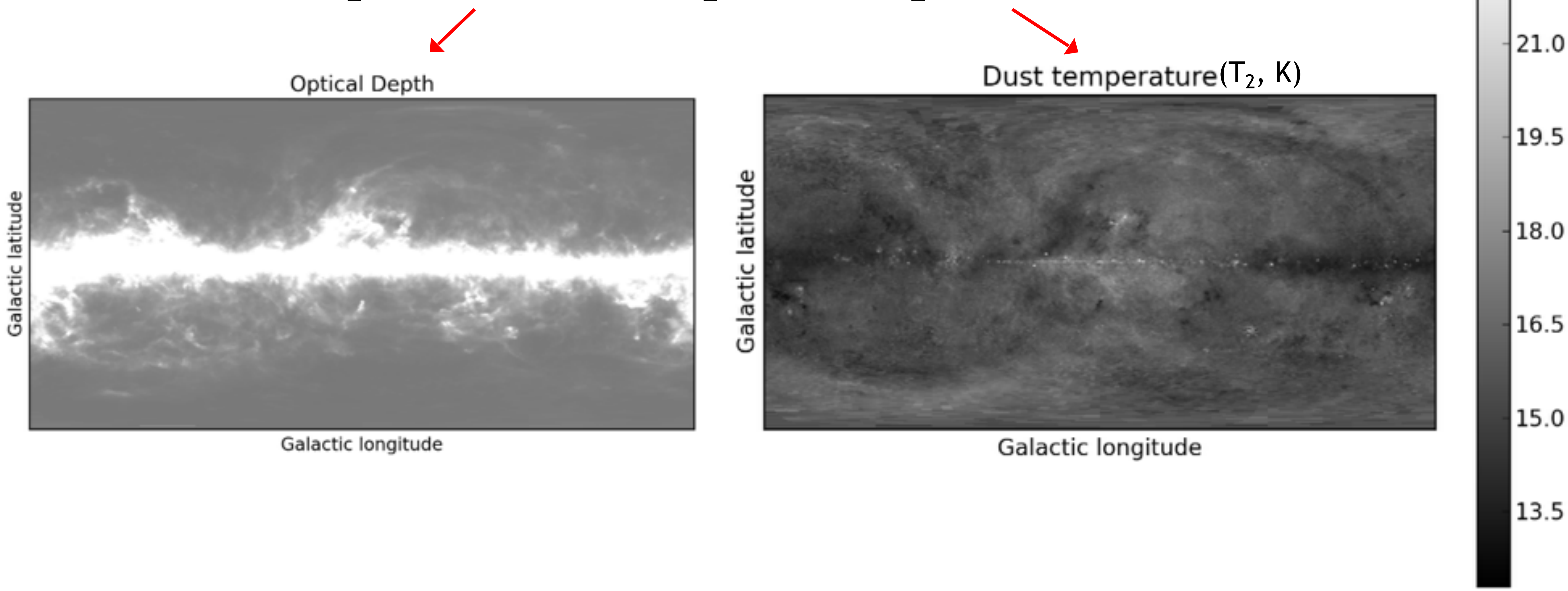




posteriors

Results: Full-sky

both temperature and optical depth have 6.1′ FWHM



Meisner & DF (2015)

So far, the fraction of each component is fixed.
Could also vary f1

$$M_\nu \propto f_1 q_1 (\frac{\nu}{\nu_0})^{\beta_1} B_\nu(T_1) + (1 - f_1) q_2 (\frac{\nu}{\nu_0})^{\beta_2} B_\nu(T_2)$$

f1 (cold comp fraction)

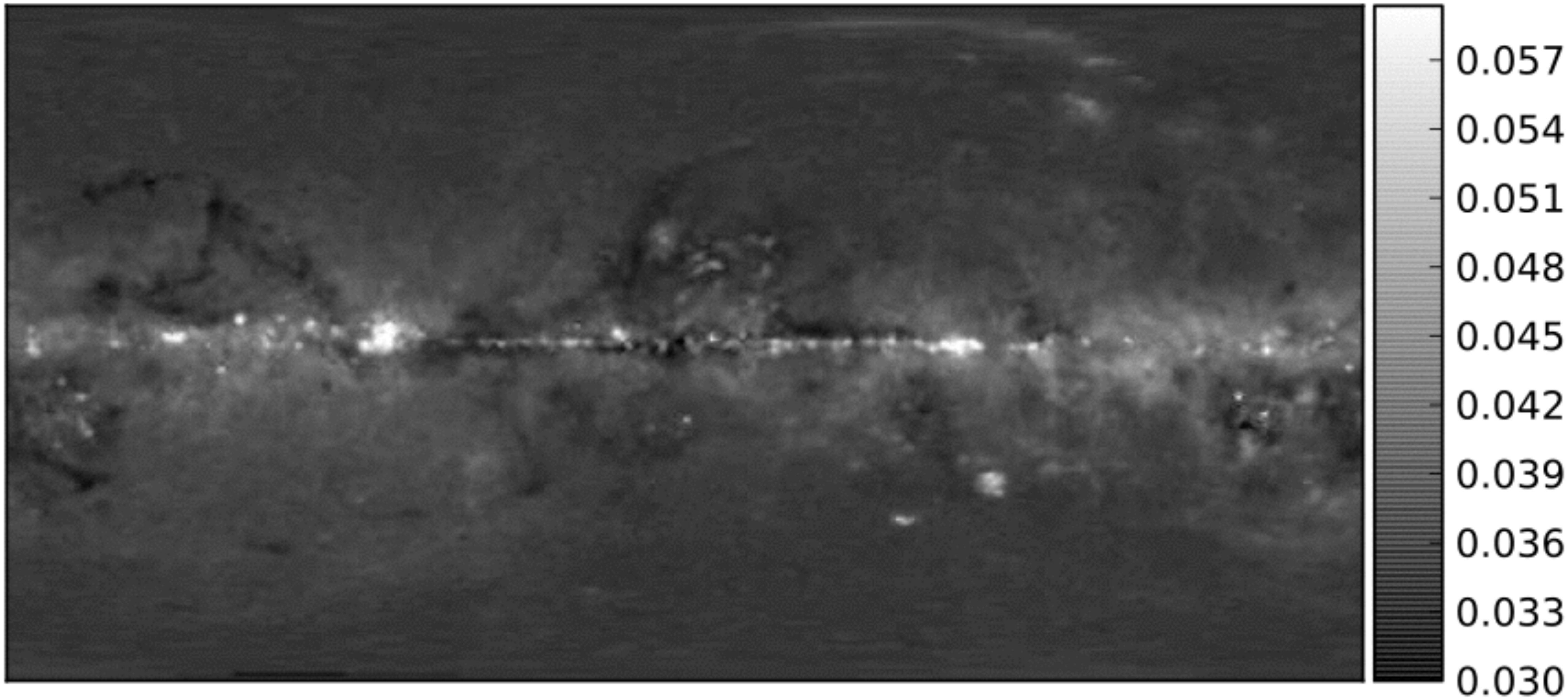


FIG. 7.— The results of our low-resolution fit with f_1 allowed to vary.

Meisner & DF (2015)

f1 (cold comp fraction)
correlates somewhat with T
How to disentangle ISRF variation on composition variation?

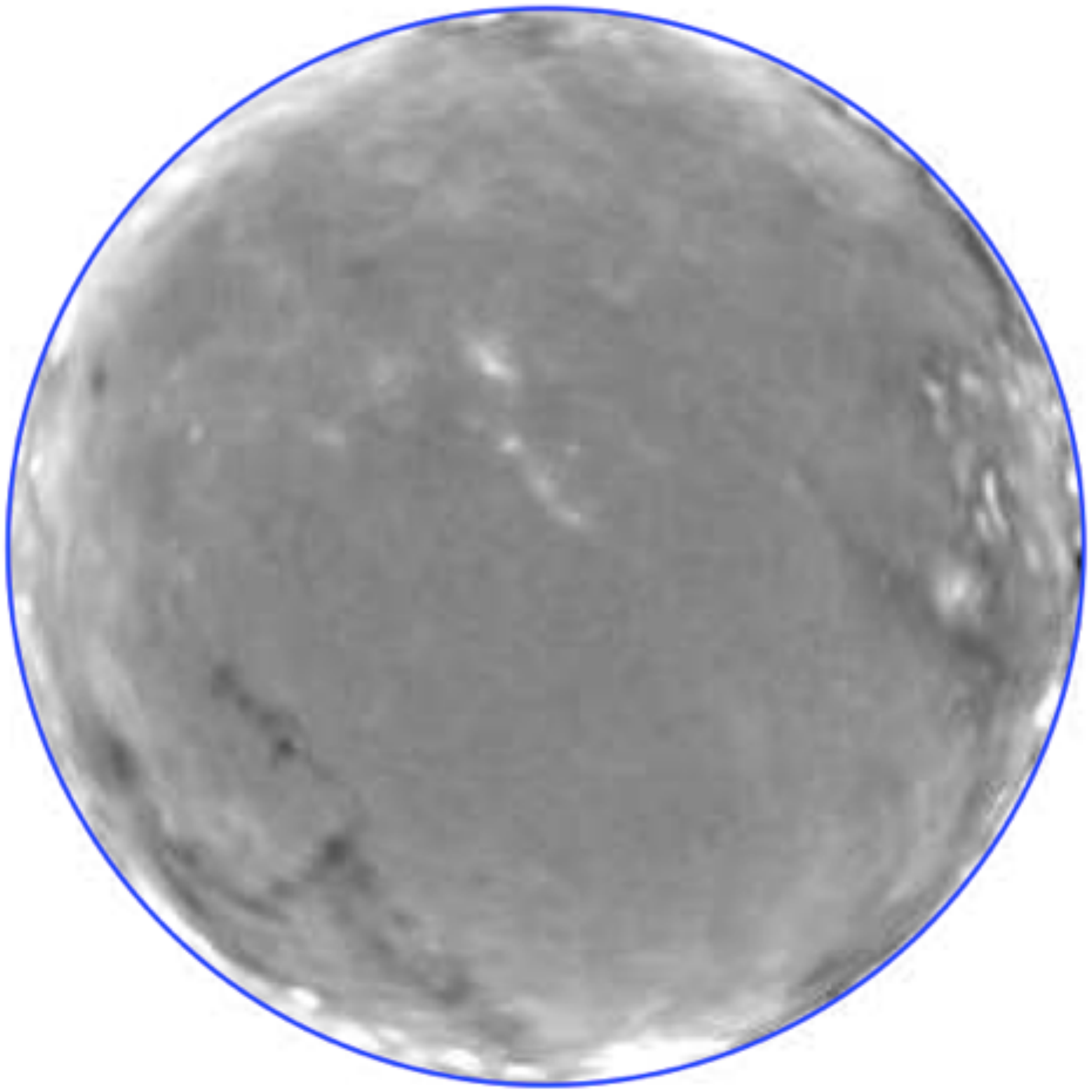
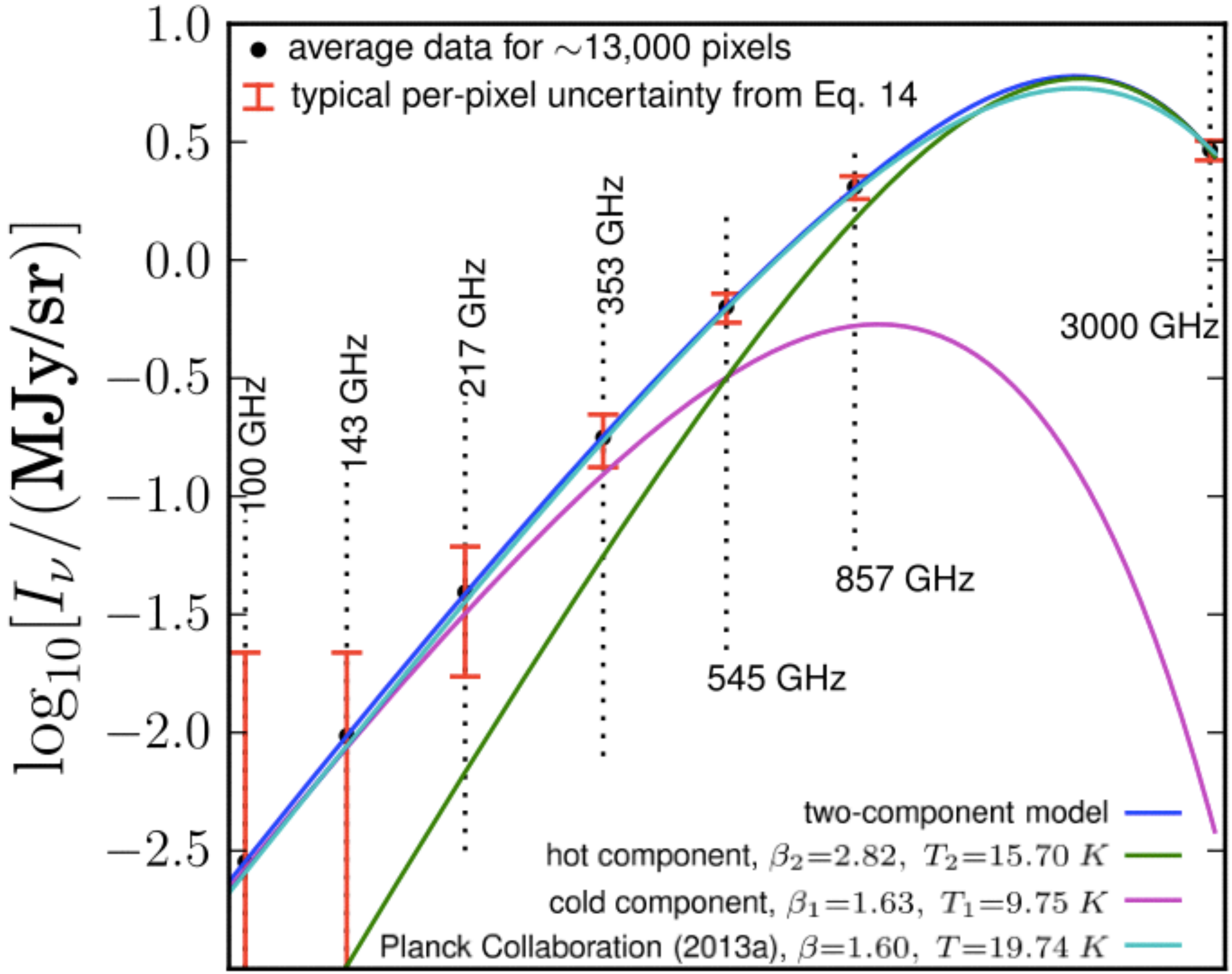


FIG. 8.— The results of our low-resolution fit with f_1 allowed to vary, shown in Lambert projection to highlight the salient features near the north Galactic pole.

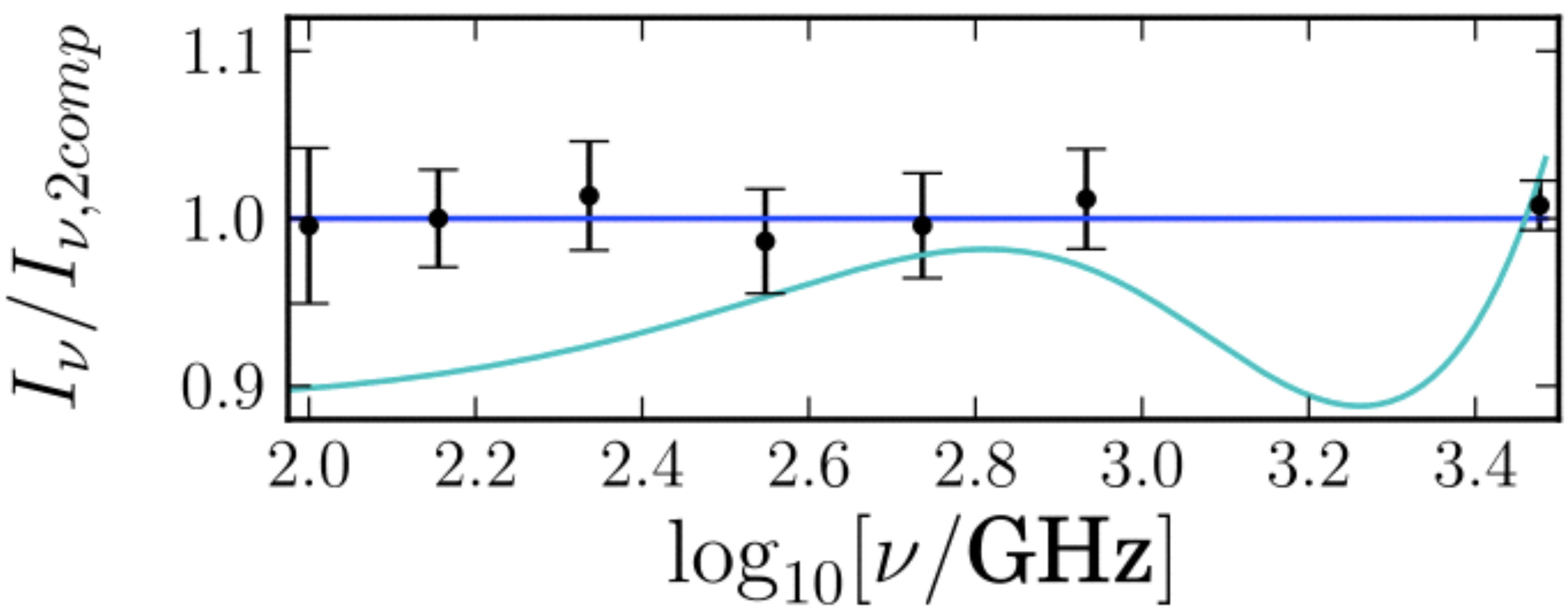
Meisner & DF (2015)



average data for ∼13,000 pixels
typical per-pixel uncertainty from Eq. 14
$\log_{10}[I_\nu/(\mathbf{MJy/sr})]$
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
100 GHz
143 GHz
217 GHz
353 GHz
545 GHz
857 GHz
3000 GHz
two-component model
hot component, β_2=2.82, T_2=15.70 K
cold component, β_1=1.63, T_1=9.75 K
Planck Collaboration (2013a), β=1.60, T=19.74 K

Agreement between MBB (cyan) and 2-comp (blue) is good, especially at the frequencies where they are fit!

At the peak and low frequencies, ~ 10% differences.



Conclusions from FIRAS-DIRBE-Planck:

- The emission is roughly a modified BB.
- It is not exactly, though.
- With PIXIE precision, it *really* isn't. (esp. near peak)
- "Spatially varying beta" vs. "2-component model" have very different interpretation.
- Better data will help
    - lower noise
    - better spectral resolution (line rejection)
    - polarization?

The importance of 3D:

The maps we make are (usually) integrated along the los over space or velocity (for HI, CO, etc.).

The physics in the ISM happens in 3D, not 2D!

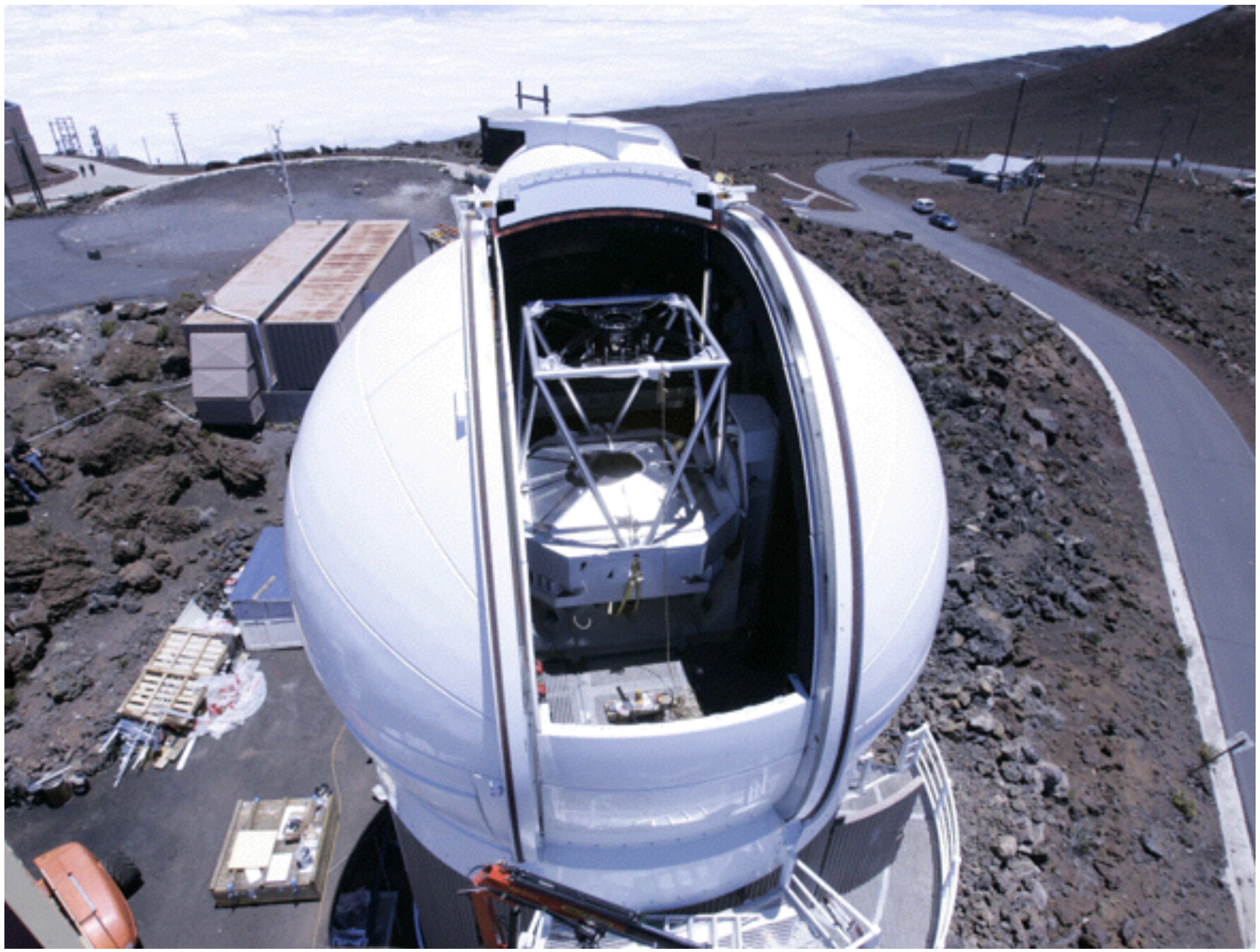
How can we generate a 3D template of ISM density, and use it to disentangle other data sets?

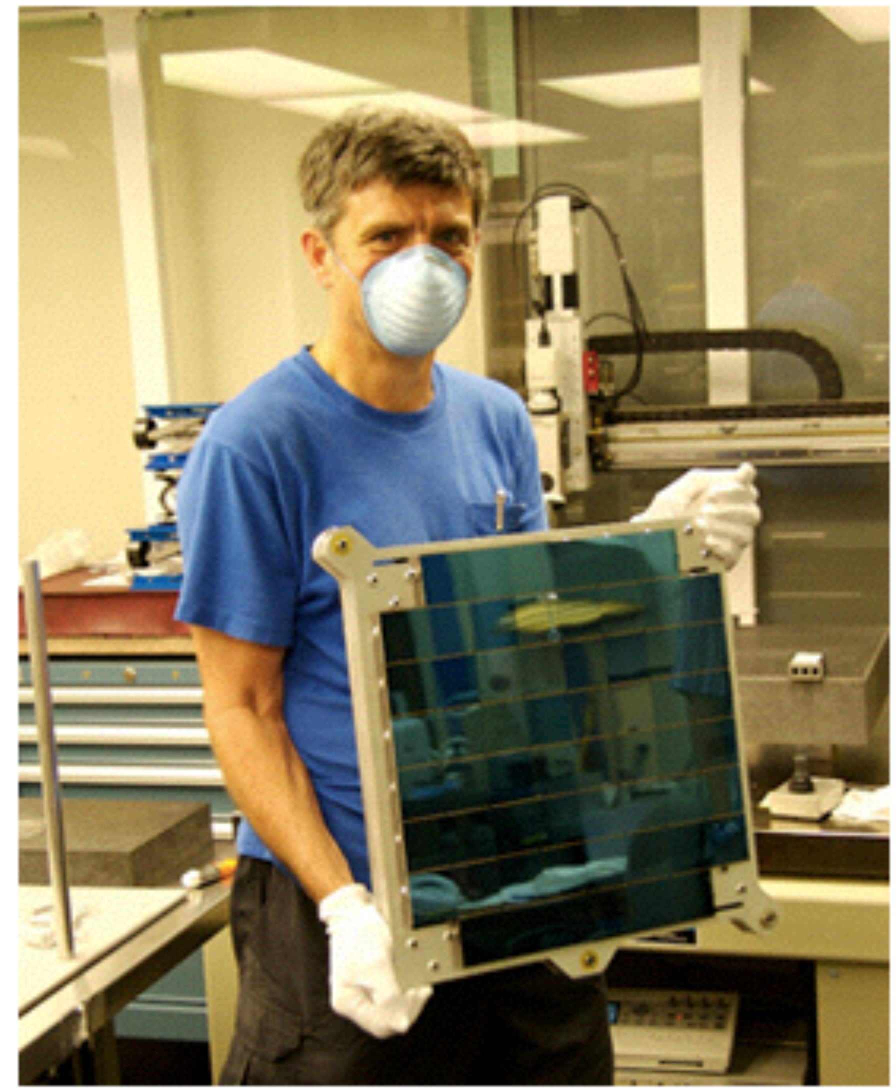
Pan-STARRS / 2MASS 3D dust project

Estimate reddening to 30 distance bins in 2.4 million pixels using only stellar photometry!

Pan-STARRS (Data release late July)

(The Panoramic Survey Telescope and Rapid Response System)





John Tonry of the Institute for Astronomy holds an entire array of 60 chips; an array of 60 OTAs will be installed in the focal plane of each of the four telescopes in the Pan-STARRS facility.

1.4 billion pixel camera

1.8m telescope on Haleakala

3π sr coverage in 5 bands (g,r,i,z,y)

Eugine Magnier (UH IfA), Peter Draper & Nigel Metcalfe (Durham University), ©PS1 Consortium

3-D dust with Pan-STARRS

What can we learn about dust using g,r,i,z,y photometry of 800,000,000 stars?

- Distance to specific dust clouds
- Combine with HI, CO maps to identify distances to velocity components
- 3-D stellar map
- “Virgo overdensity,” tidal streams, dwarf galaxies...
- Prelude to GAIA

3-D dust with Pan-STARRS

Greg Green

Bayesian pundit,
MCMC connoisseur

Eddie Schlafly

Calibrator in chief

Mario Jurić

Database guru

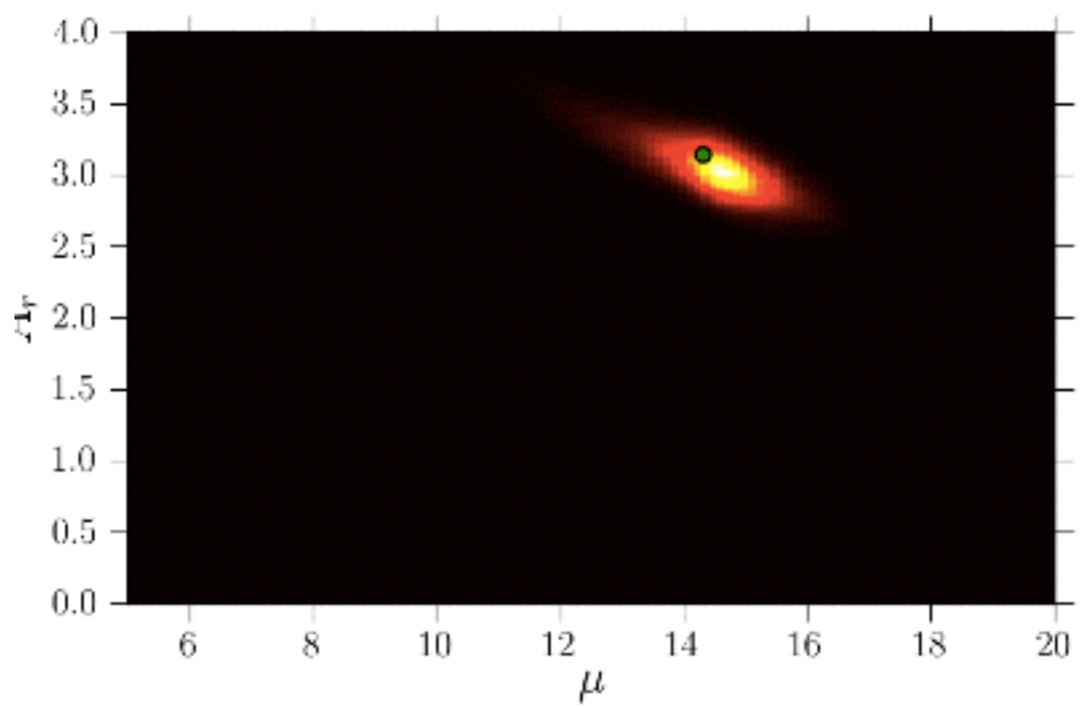
3-D dust with Pan-STARRS

- Pan-STARRS has collected photometry on $\sim 5 \times 10^8$ stars.
- Group stars into sufficiently small pixels.
- Calculate photometric parallax and reddening for each star.
- Find reddening profile as a function of distance which is consistent with all stars in pixel.

3-D dust with Pan-STARRS

For each star our goal is to compare a stellar template library with observed apparent stellar magnitudes in order to determine the joint posterior $p(\mu, A_r \,|\, \vec{m}_{\rm obs})$. Here,

$$\mu = \text{Distance Modulus}\,,$$
$$A_r = \text{Extinction in } r \text{ band}\,,$$
$$\vec{m}_{\rm obs} = \text{Observed } grizy \text{ apparent magnitudes}\,.$$



3-D dust with Pan-STARRS

Two intrinsic parameters used to describe star:

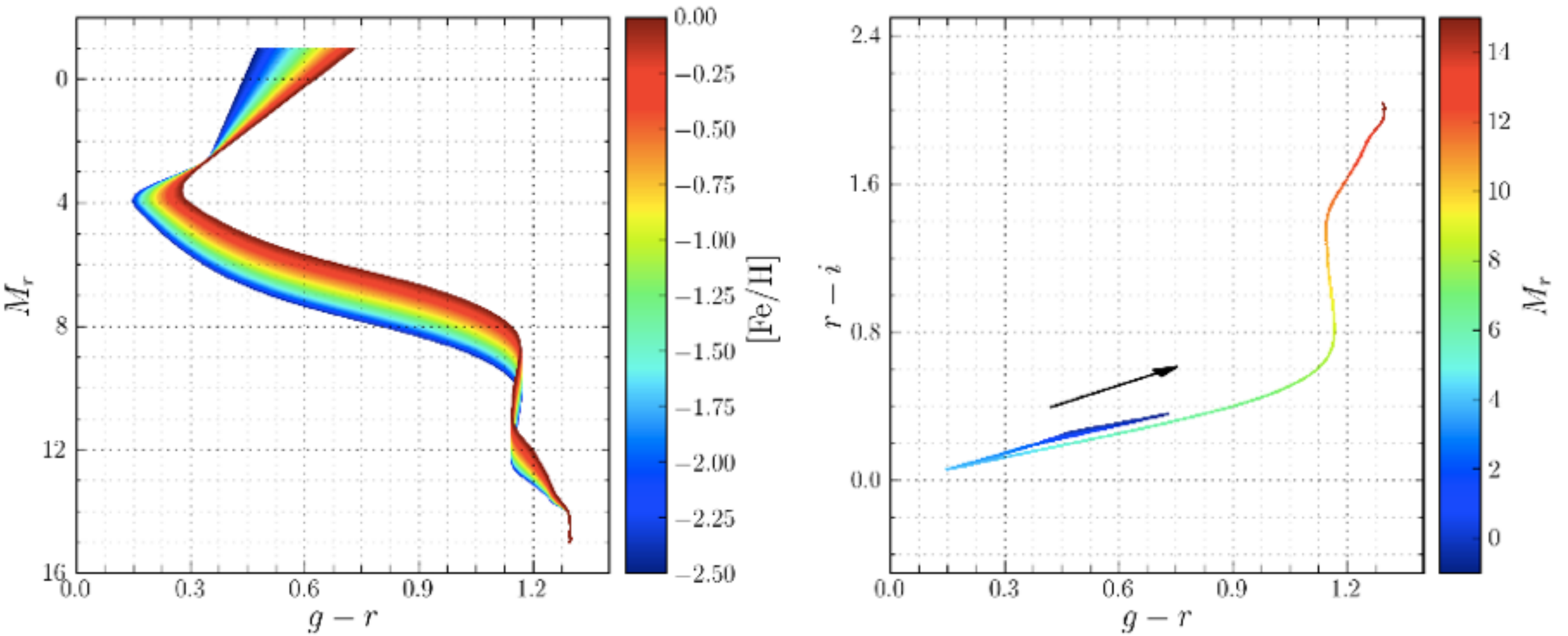
- M_r
- $\left[\frac{\mathrm{Fe}}{\mathrm{H}}\right]$

Two extrinsic parameters per star:

- μ = distance modulus
- A_r = extinction in r-band

3-D dust with Pan-STARRS

- Colors are queried in a stellar template library indexed by M_r and $[{}^{Fe}/_{H}]$.
- $R_V = 3.1$ is assumed, fixing reddening vector.



3-D dust with Pan-STARRS

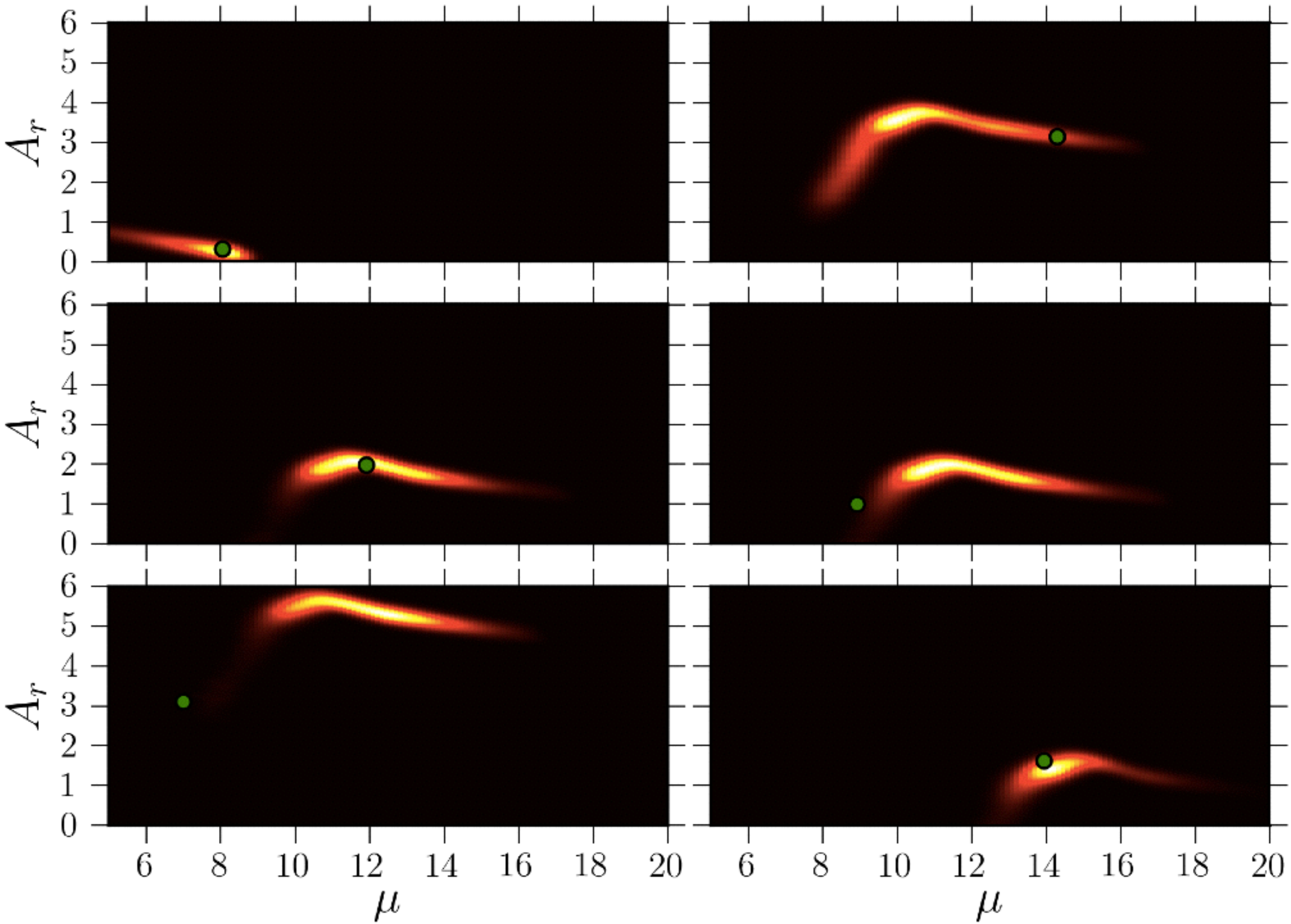
- Given M_r, $[^{Fe}/_{H}]$, μ and A_r, we generate apparent magnitudes:

$$\vec{m} = \vec{M}(M_r, [^{\mathrm{Fe}}/_{\mathrm{H}}]) + \vec{A}(A_r) + \mu \, .$$

- We can calculate the likelihood of the observed magnitudes, given a set of model parameters:

$$p\left(\vec{m}_{\mathrm{obs}} \,|\, \mu, \, A_r, \, M_r, \, [^{Fe}/_{H}]\right) = \mathcal{N}\left(\vec{m}_{\mathrm{obs}} - \vec{m}, \, \vec{\sigma}\right) \; .$$

- Use Markov-Chain Monte Carlo technique to sample from posterior.
  - Multimodality of posterior.
  - Population-based MCMC – “affine sampler” [Goodman & Weare, 2010].

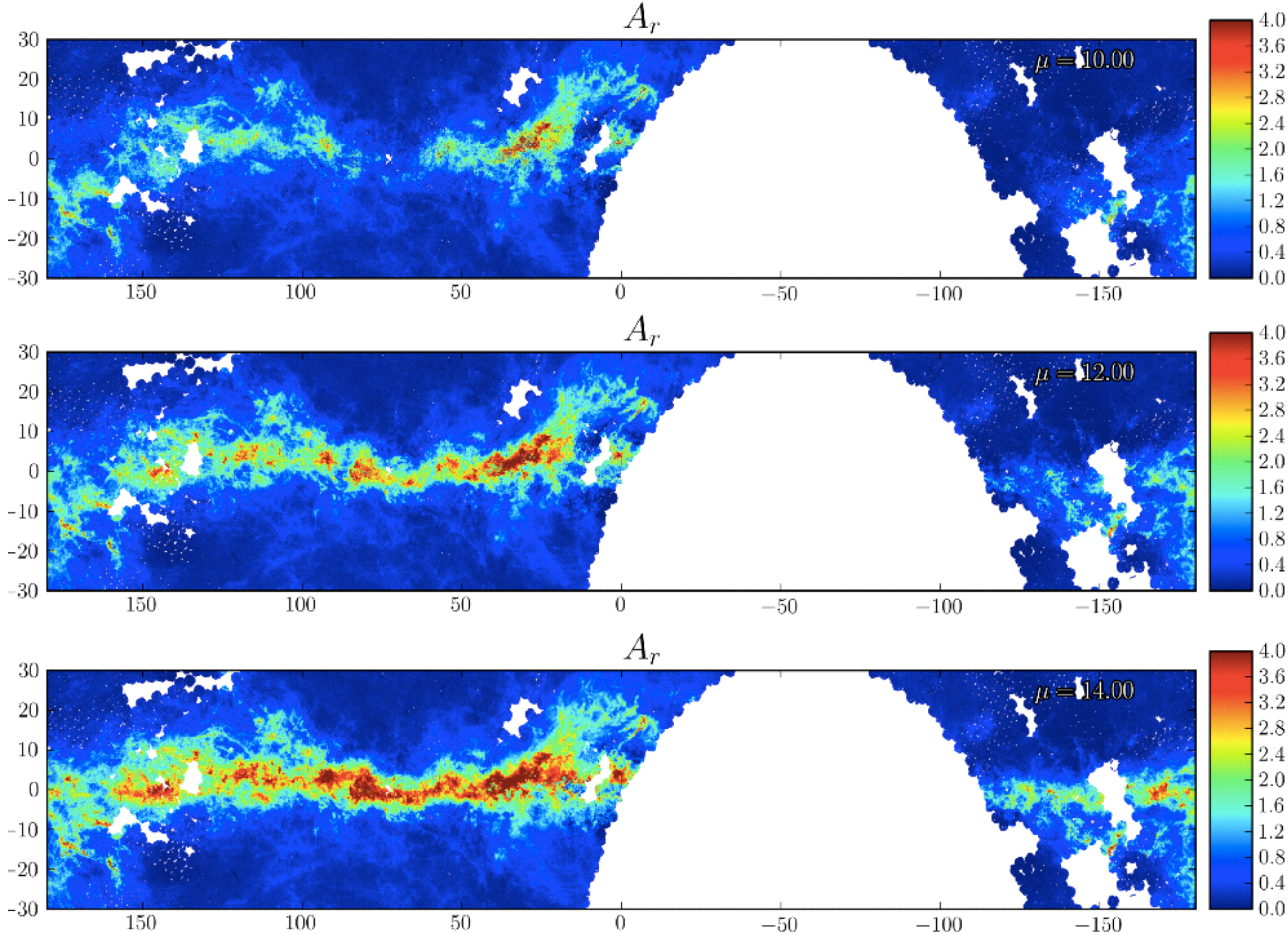


A_r
μ
0
1
2
3
4
5
6
8
10
12
14
16
18
20

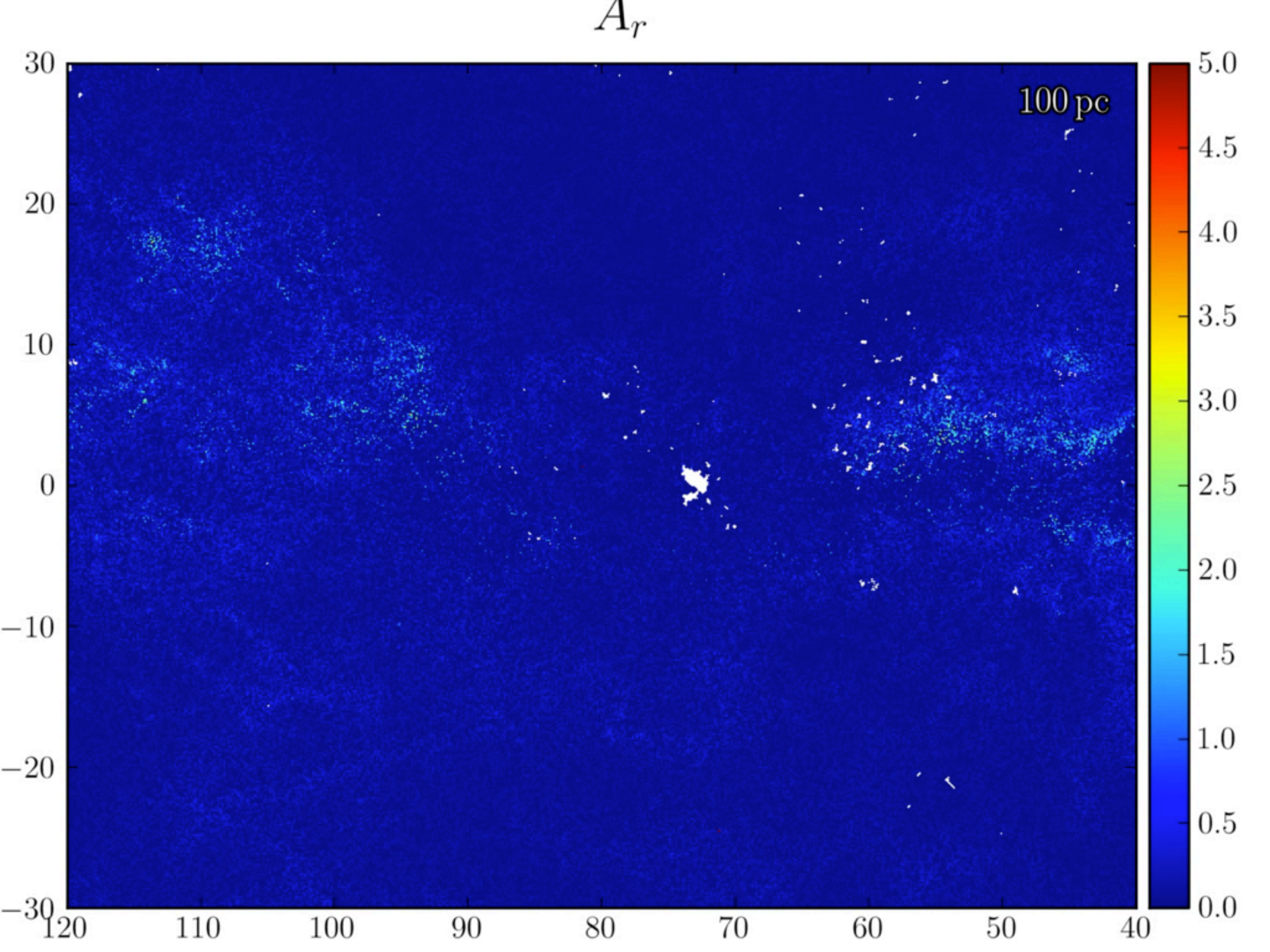
Do this for many stars.

Combine 100-1000 stars per pixel to obtain estimate of dust along each line of sight.

Do this for millions of pixels.



A_r
$\mu = 10.00$
$\mu = 12.00$
$\mu = 14.00$
30
20
10
0
−10
−20
−30
150
100
50
0
−50
−100
−150
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0



A_r
100 pc
30
20
10
0
−10
−20
−30
120
110
100
90
80
70
60
50
40
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0

1. arXiv:1405.2922 [pdf, ps, other]

A Map of Dust Reddening to 4.5 kpc from Pan-STARRS1

E. F. Schlafly, G. Green, D. P. Finkbeiner, M. Juric, H.-W. Rix, N. F. Martin, W. S. Burgett, K. C. Chambers, P. W. Draper, K. W. Hodapp, N. Kaiser, R.-P. Kudritzki, E. A. Magnier, N. Metcalfe, J. S. Morgan, P. A. Price, C. W. Stubbs, J. L. Tonry, R. J. Wainscoat, C. Waters

Comments: 10 pages, 7 figures, accepted for publication in ApJ

Subjects: **Astrophysics of Galaxies (astro-ph.GA)**

2. arXiv:1403.3393 [pdf, ps, other]

A Large Catalog of Accurate Distances to Molecular Clouds from PS1 Photometry

E. F. Schlafly, G. Green, D. P. Finkbeiner, H.-W. Rix, E. F. Bell, W. S. Burgett, K. C. Chambers, P. W. Draper, K. W. Hodapp, N. Kaiser, E. A. Magnier, N. F. Martin, N. Metcalfe, P. A. Price, J. L. Tonry

Comments: 16 pages, 4 figures

Subjects: **Astrophysics of Galaxies (astro-ph.GA)**

3. arXiv:1401.1508 [pdf, ps, other]

Measuring Distances and Reddenings for a Billion Stars: Towards A 3D Dust Map from Pan-STARRS 1

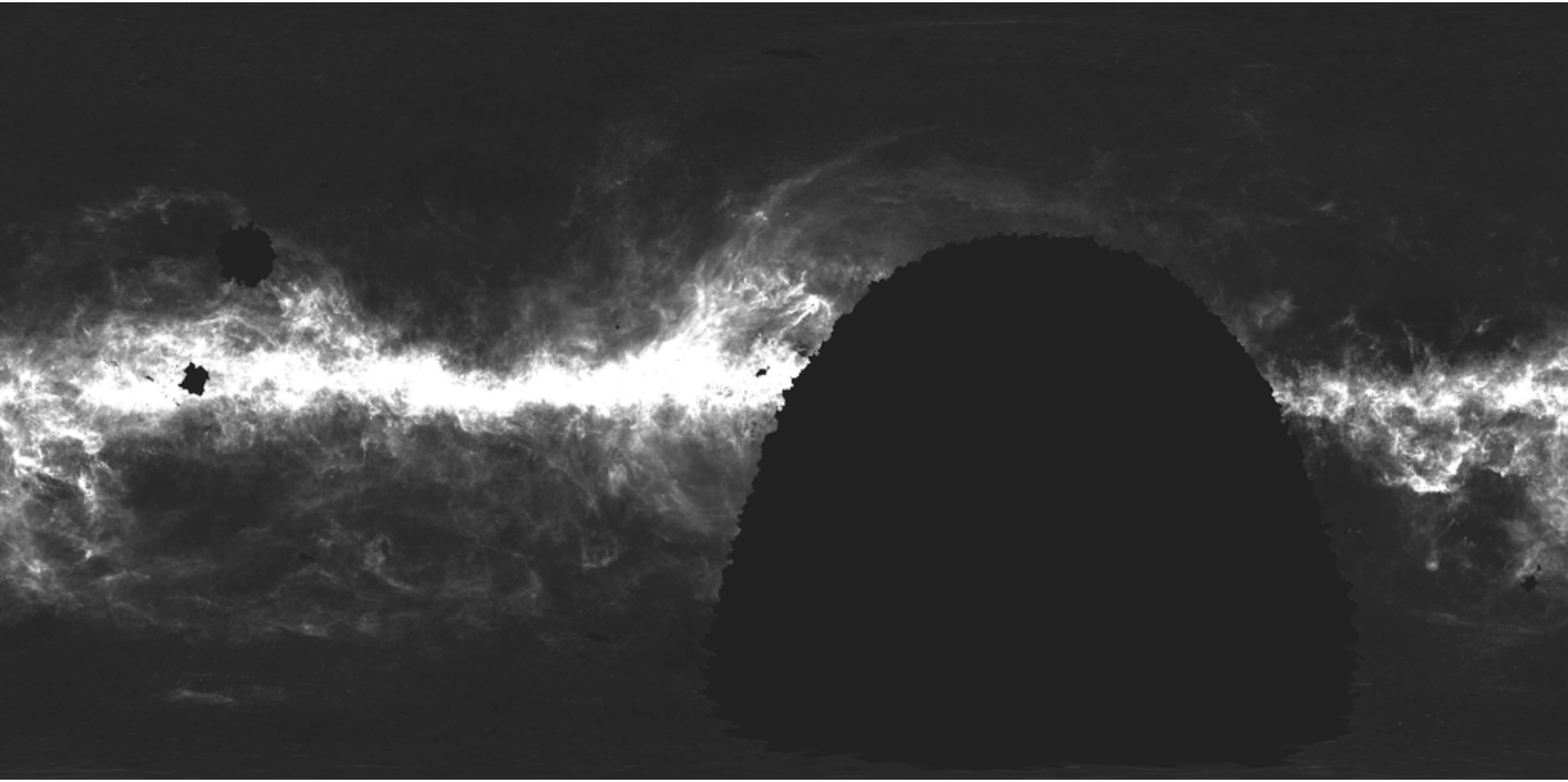
Gregory Maurice Green, Edward F. Schlafly, Douglas P. Finkbeiner, Mario Jurić, Hans Walter Rix, Will Burgett, Kenneth C. Chambers, Peter W. Draper, Heather Flewelling, Rolf Peter Kudritzki, Eugene Magnier, Nicolas Martin, Nigel Metcalfe, John Tonry, Richard Wainscoat, Christopher Waters

Comments: 18 pages, 12 figures

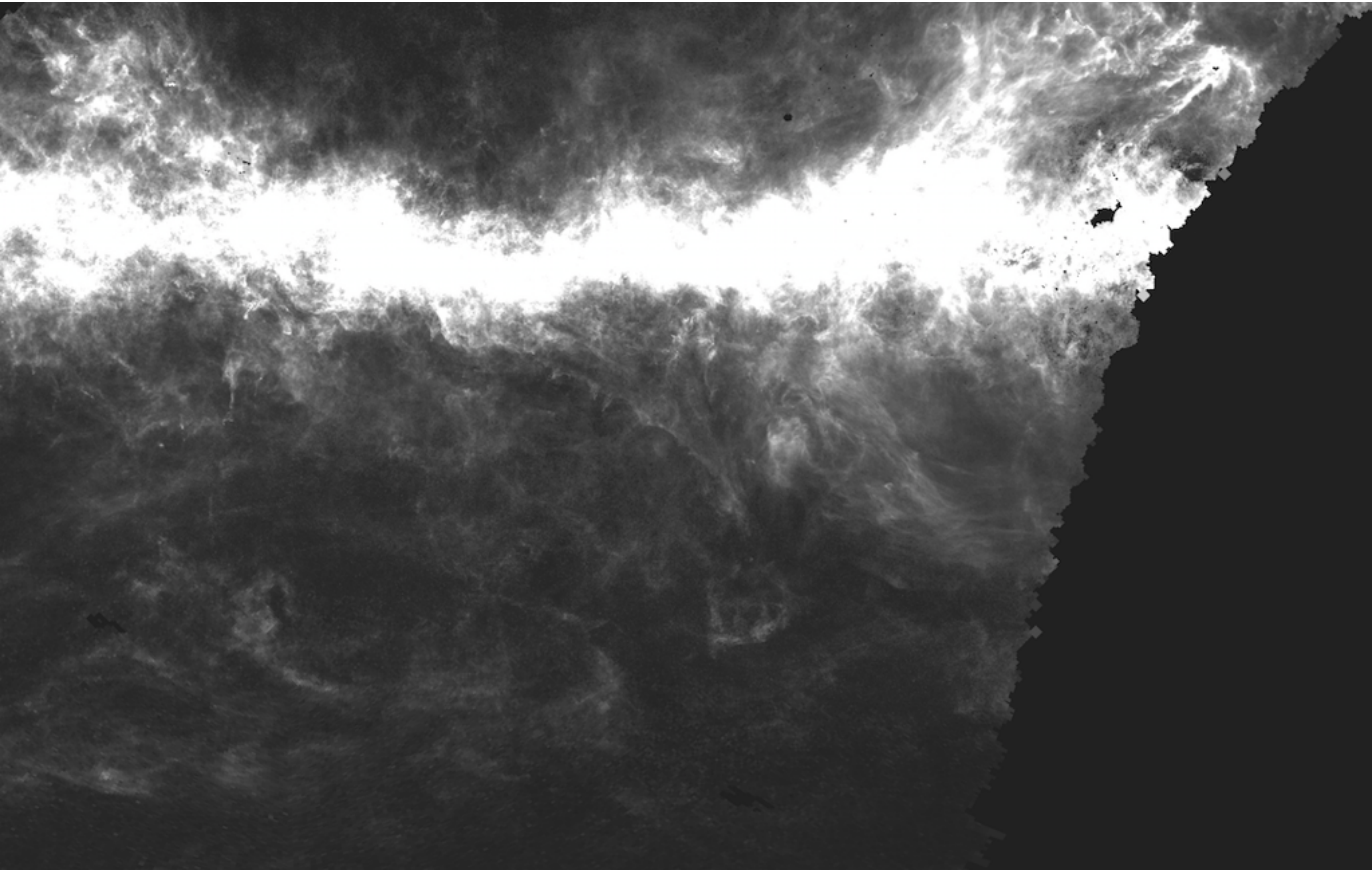
Subjects: **Astrophysics of Galaxies (astro-ph.GA)**

We have PS1/2MASS-based maps over 3/4 of the sky. DECam will fill in the rest (eventually).

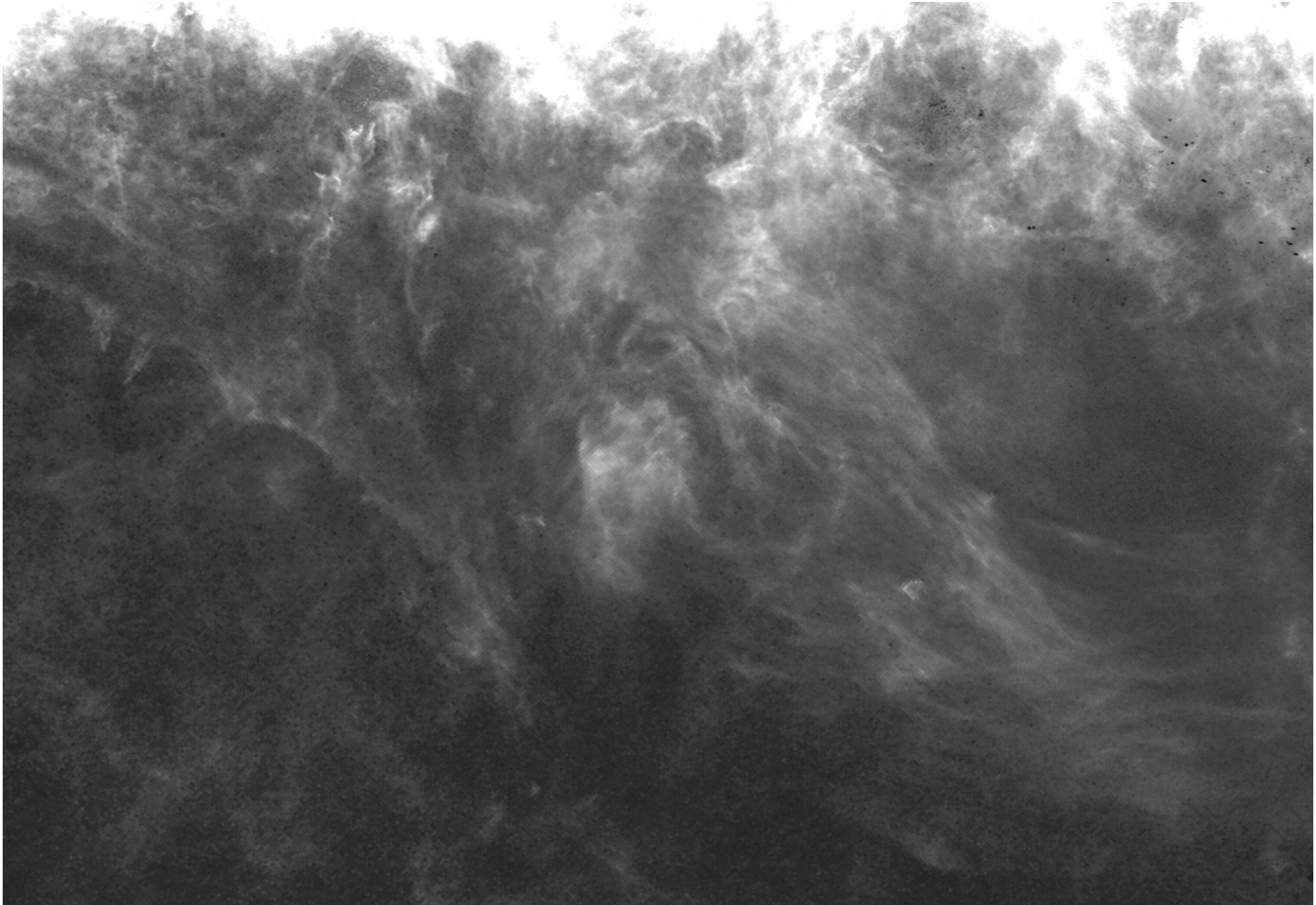
GAIA and LSST will be a big help.



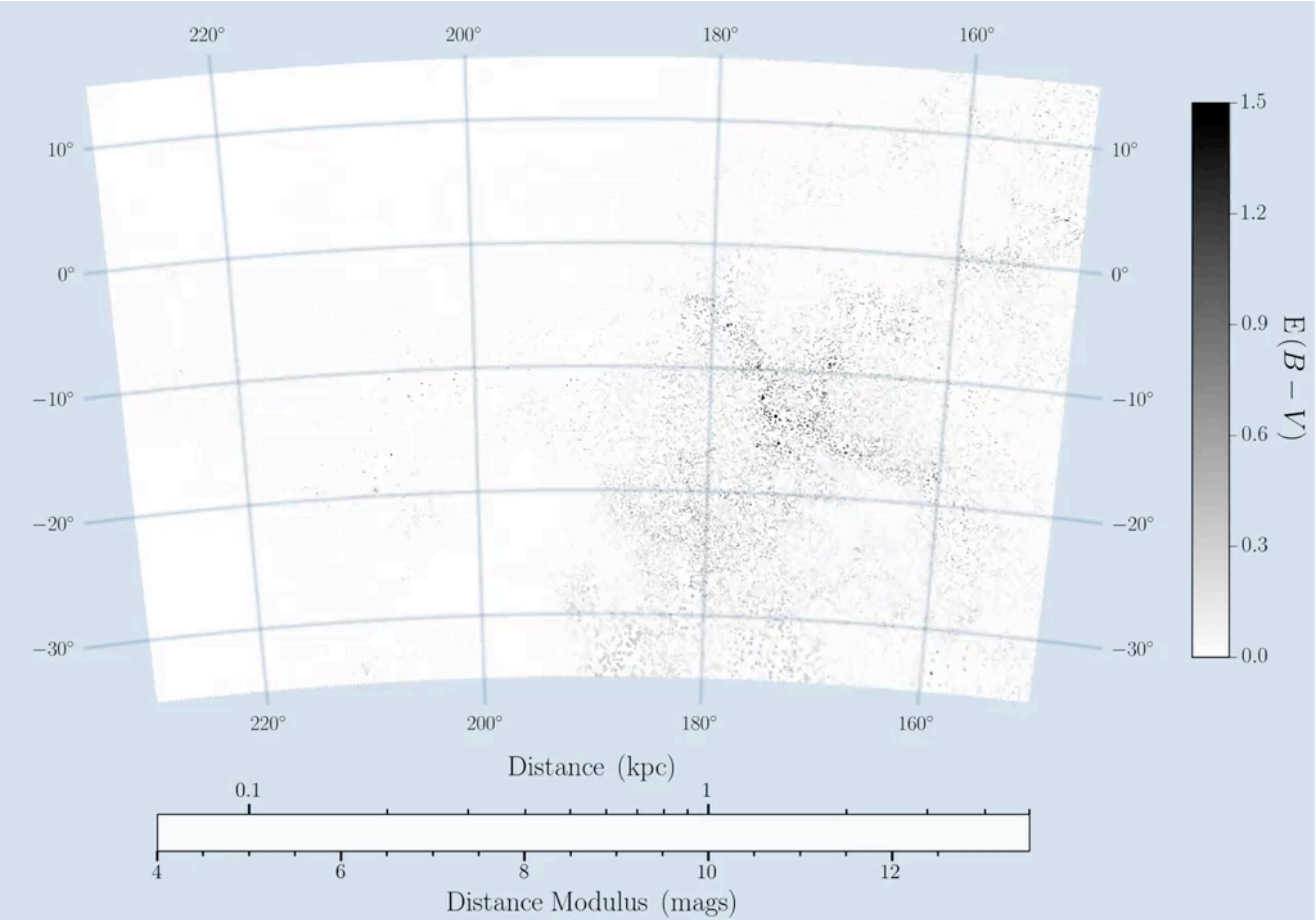
Green+ (2014), Schlafly+ (2014)

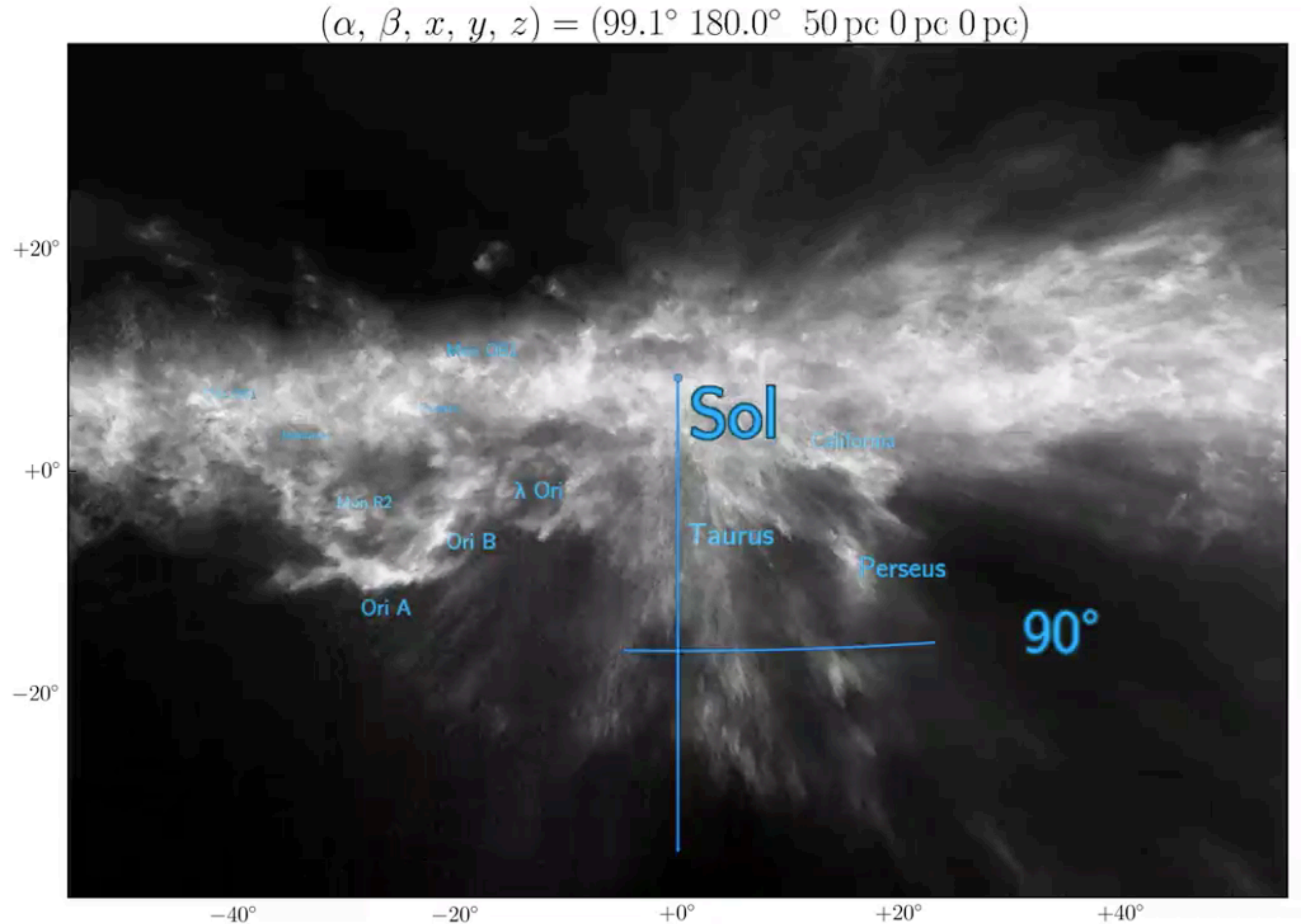


Green+ (2014), Schlafly+ (2014)

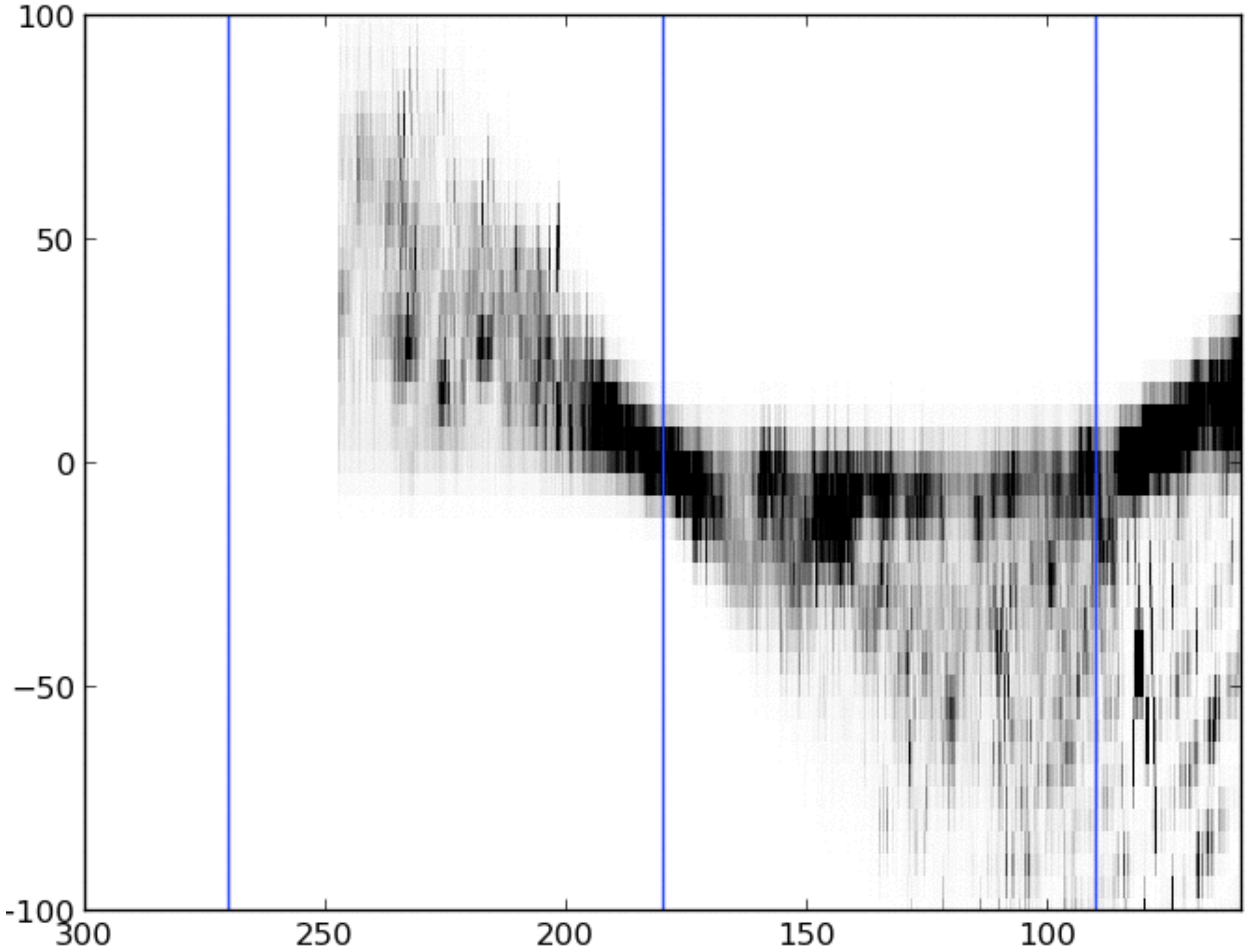


Green+ (2014), Schlafly+ (2014)


220°
200°
180°
160°
10°
0°
−10°
−20°
−30°
1.5
1.2
0.9
0.6
0.3
0.0
E(B − V)
Distance (kpc)
0.1
1
4
6
8
10
12
Distance Modulus (mags)


$(\alpha, \beta, x, y, z) = (99.1° \; 180.0° \;\; 50\,\mathrm{pc} \; 0\,\mathrm{pc} \; 0\,\mathrm{pc})$
Sol
California
λ Ori
Mon R2
Ori B
Taurus
Perseus
Ori A
90°
+20°
+0°
−20°
−40°
−20°
+0°
+20°
+40°

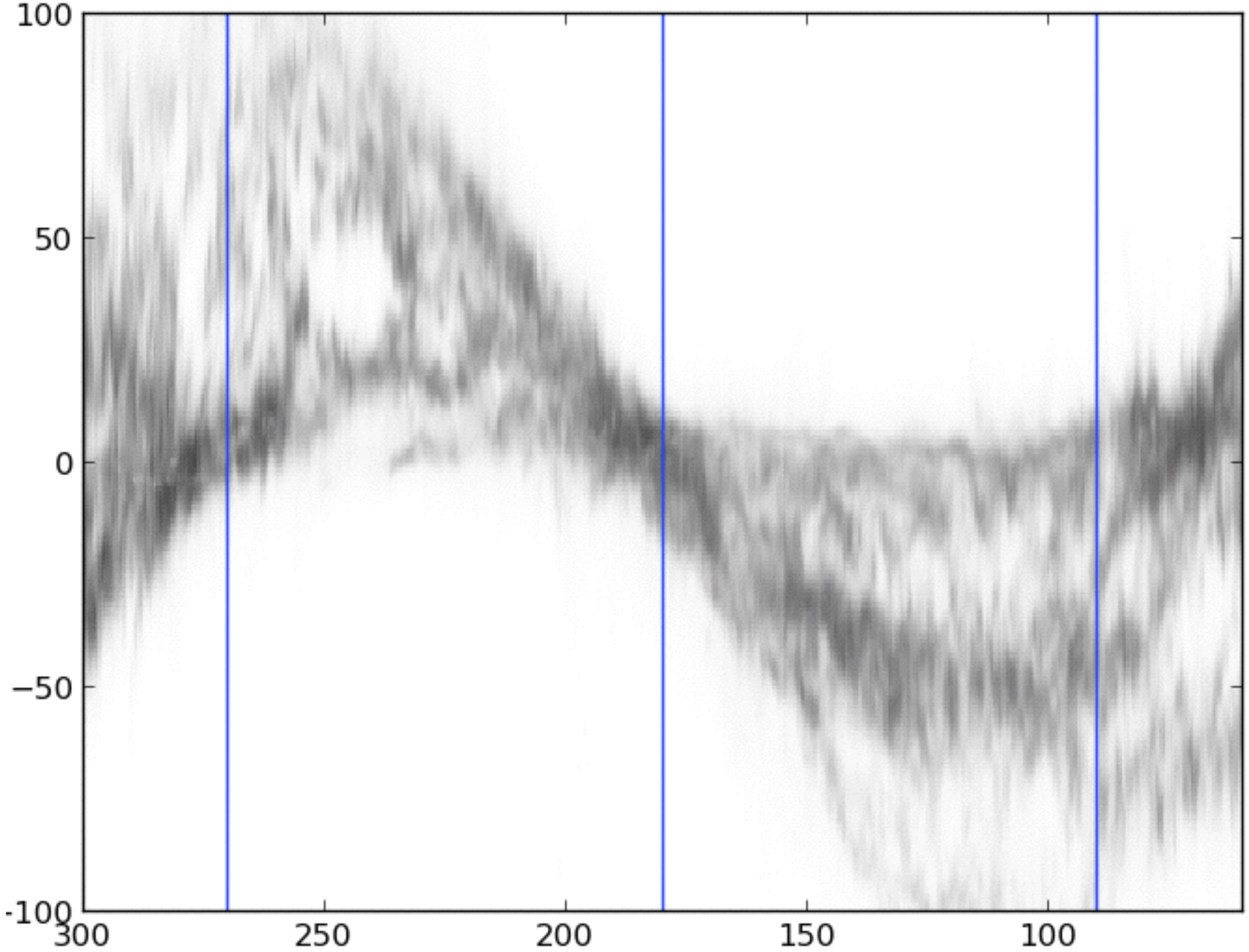
Given rotation curve, map distance to v:



Preliminary!

From E. Schlafly

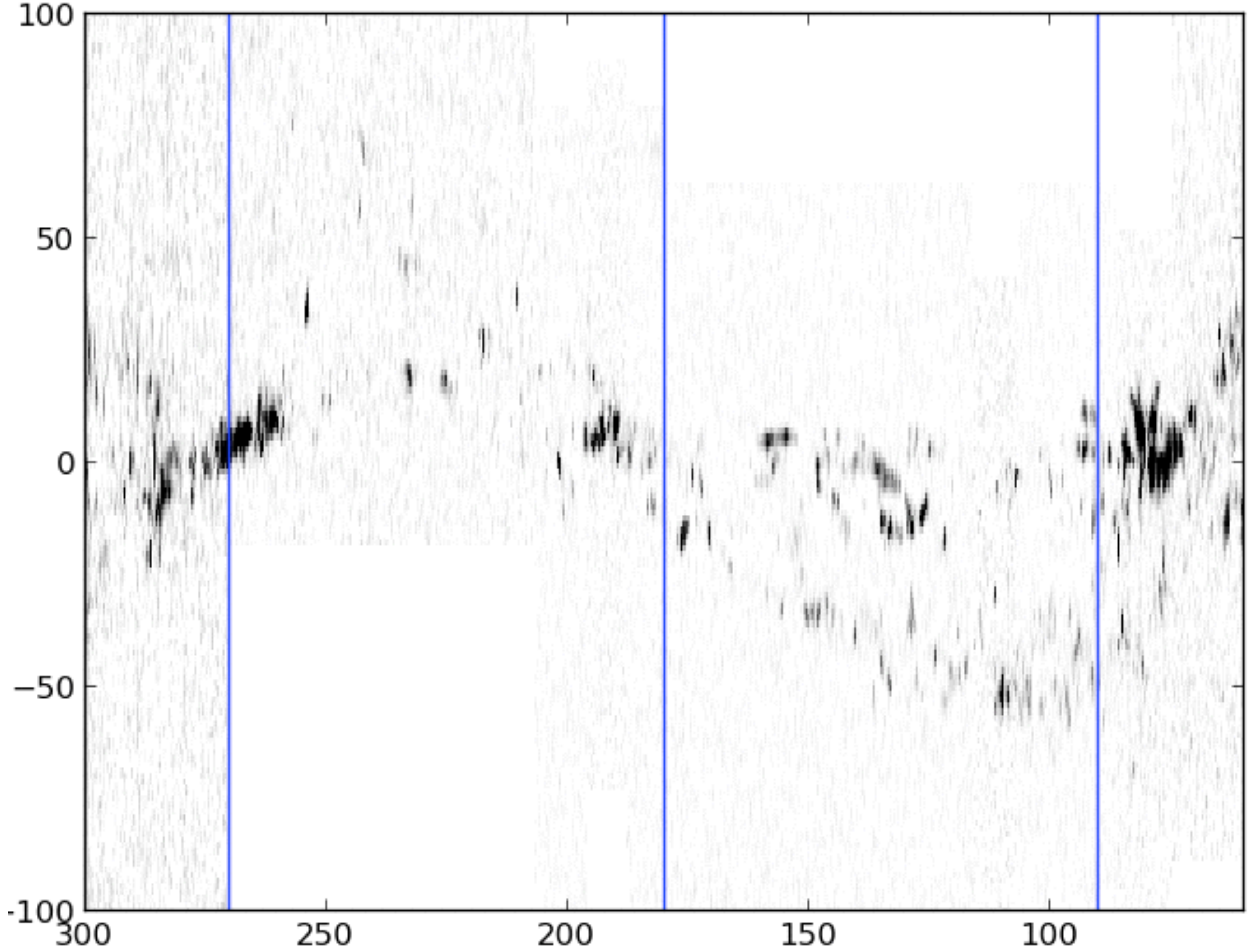
HI



Preliminary!

From E. Schlafly

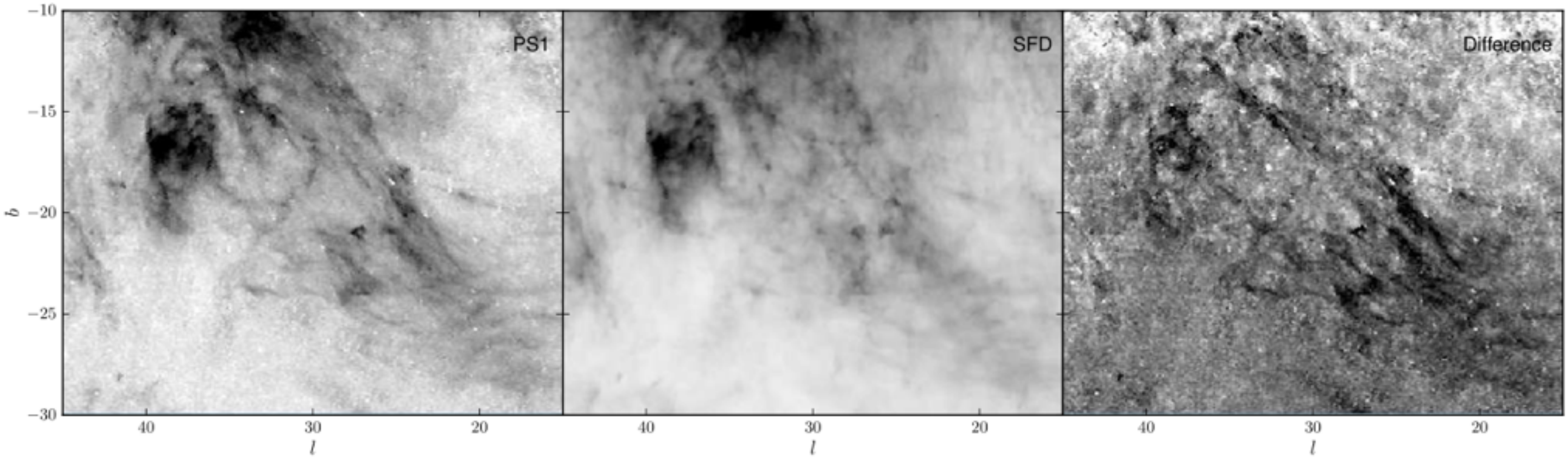
CO



Preliminary!

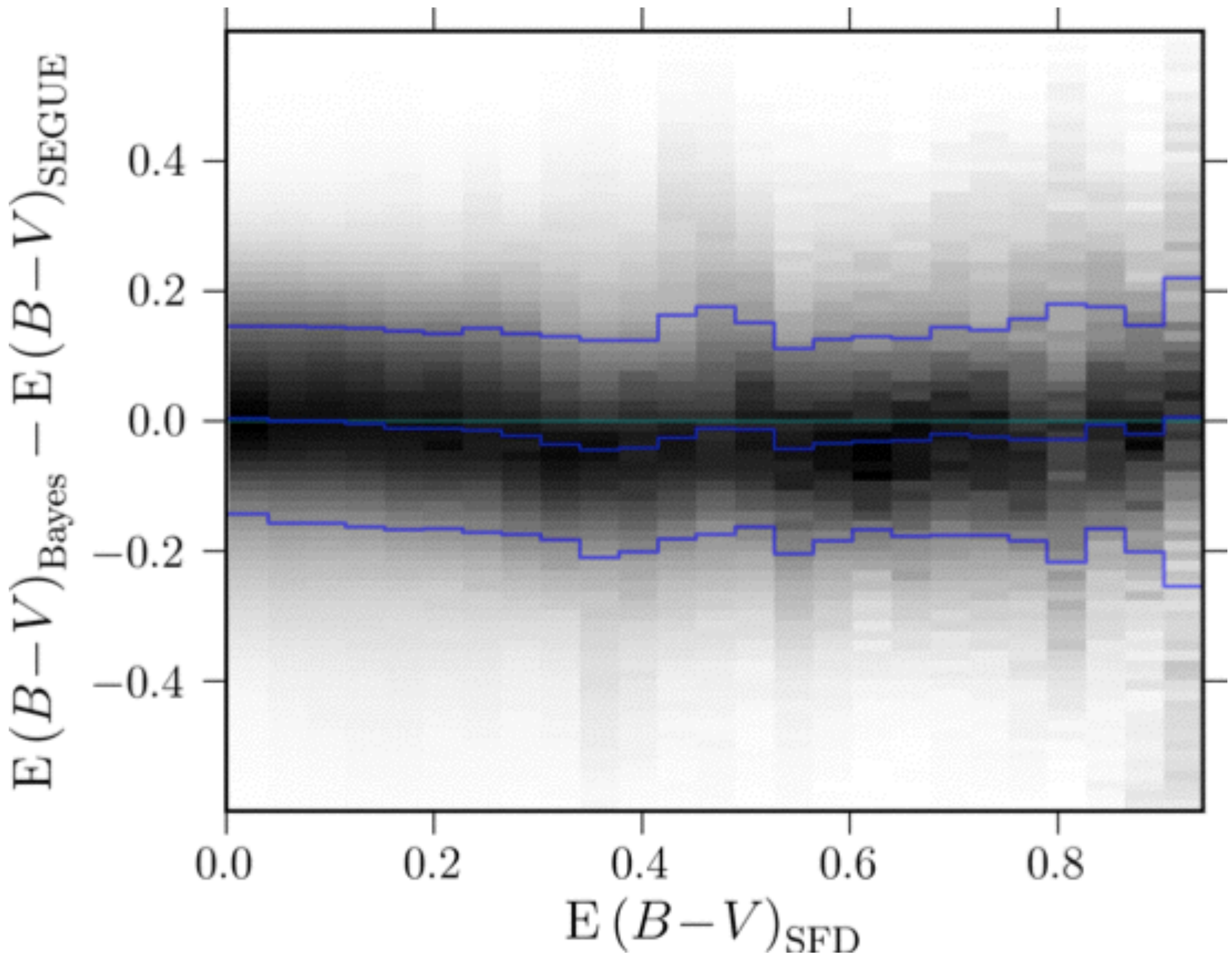
From E. Schlafly

Comparison to SFD



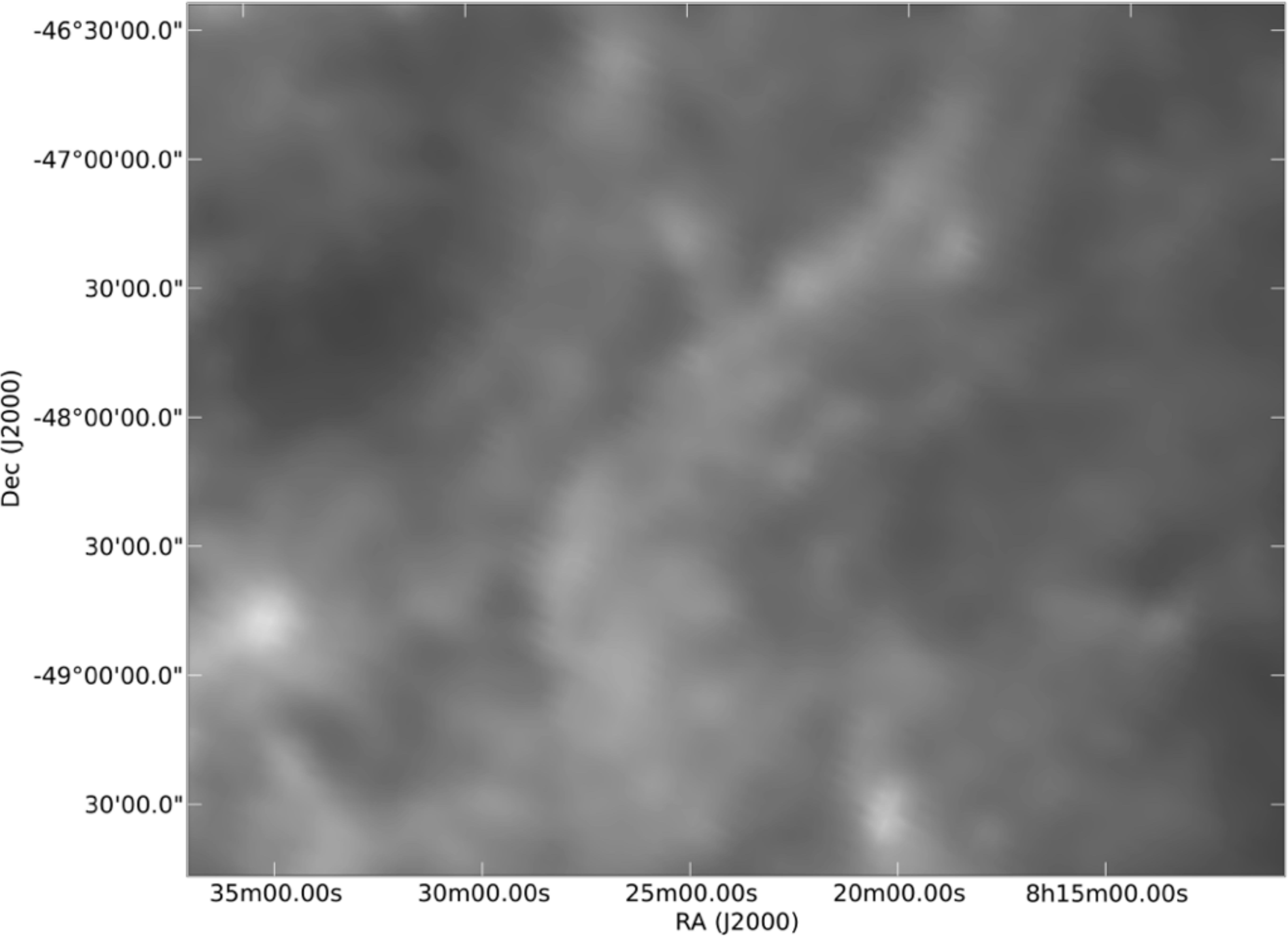
Green+ (2014), Schlafly+ (2014)

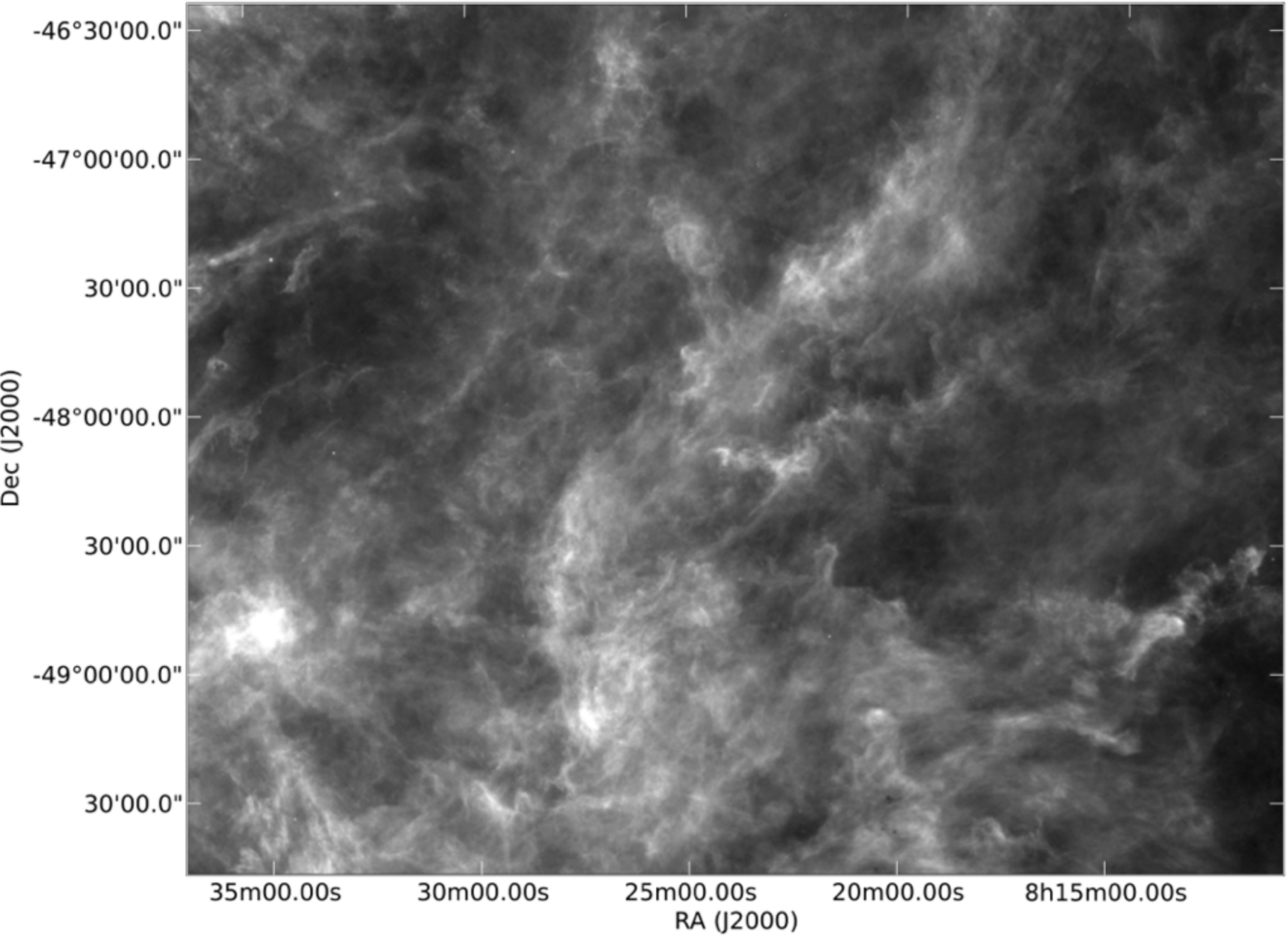
Comparison to SEGUE standards



Green+ (2014), Schlafly+ (2014)

Subpixel priors?


-46°30'00.0"
-47°00'00.0"
30'00.0"
-48°00'00.0"
30'00.0"
-49°00'00.0"
30'00.0"
Dec (J2000)
35m00.00s
30m00.00s
25m00.00s
20m00.00s
8h15m00.00s
RA (J2000)


-46°30'00.0"
-47°00'00.0"
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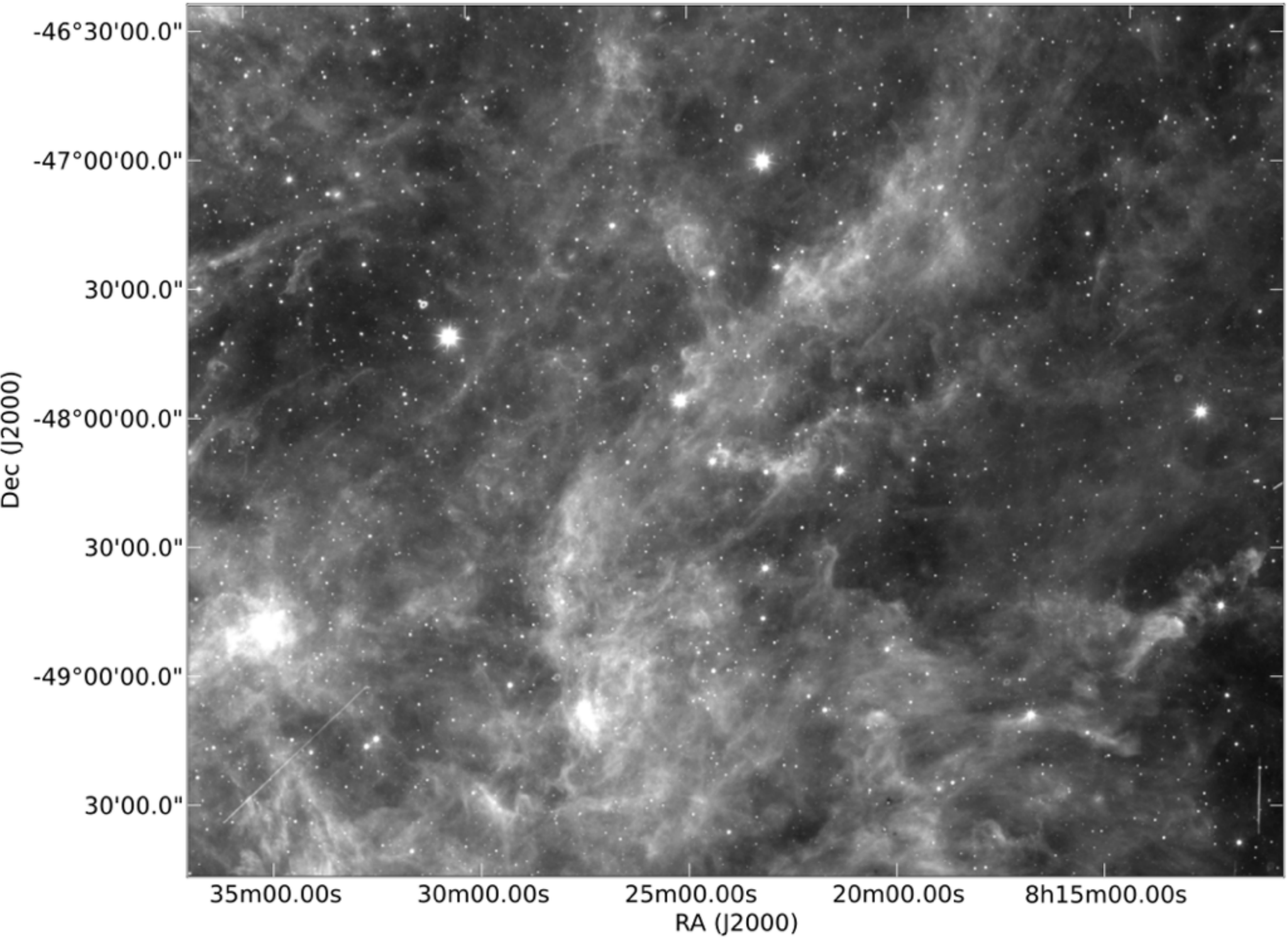
25m00.00s
20m00.00s
8h15m00.00s
RA (J2000)

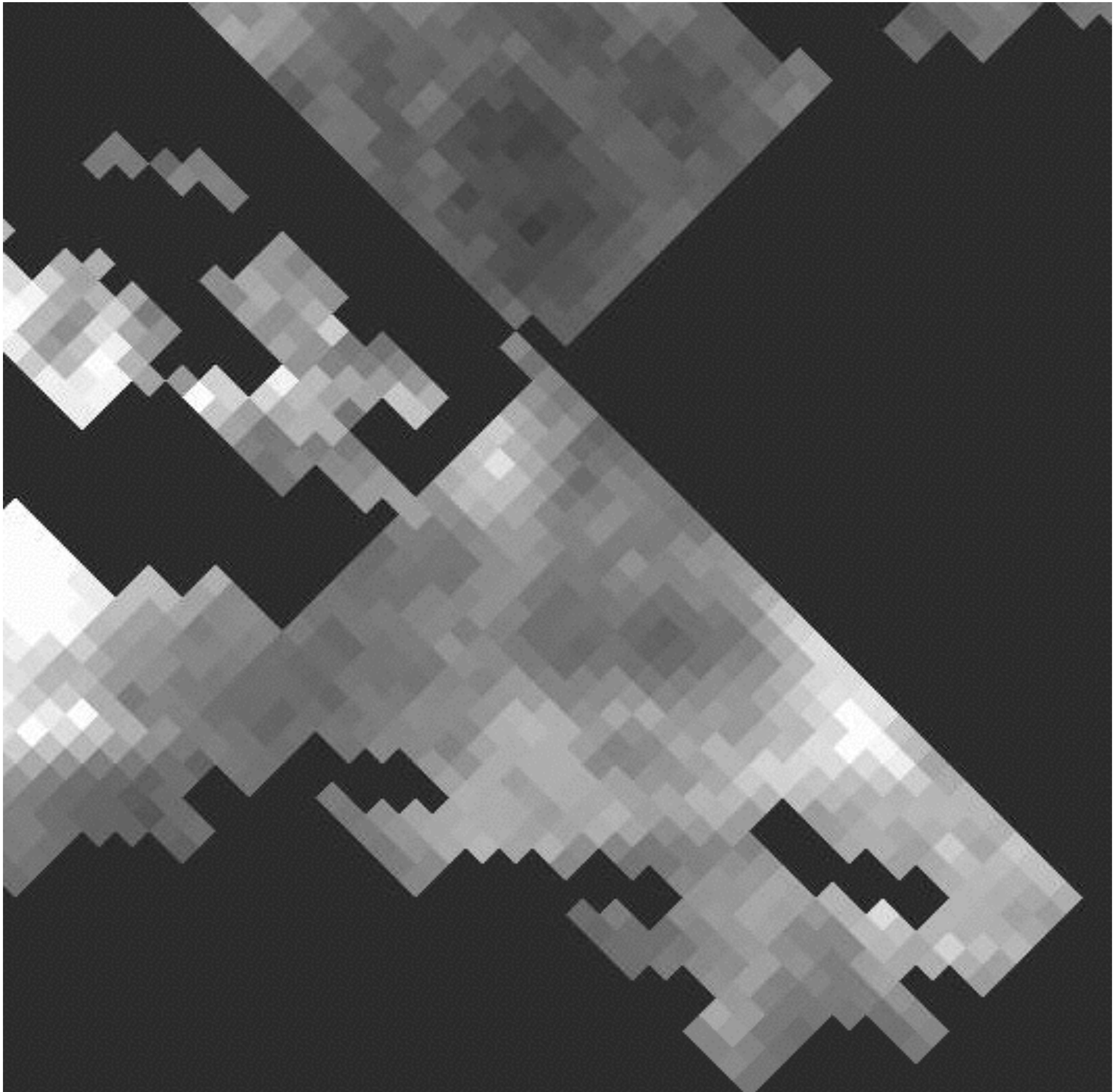


-46°30'00.0"
-47°00'00.0"
30'00.0"
-48°00'00.0"
30'00.0"
-49°00'00.0"
30'00.0"
Dec (J2000)
35m00.00s
30m00.00s
25m00.00s
20m00.00s
8h15m00.00s
RA (J2000)

With such high angular resolution, can we use WISE 12 micron as a "subpixel spatial prior" for the 3D dust fit?

Then instead of fitting reddening as a function of distance in each Nside ~ 512 pixel (~ 7′) we fit the coefficient of Wise 12 micron as a function of distance.

]



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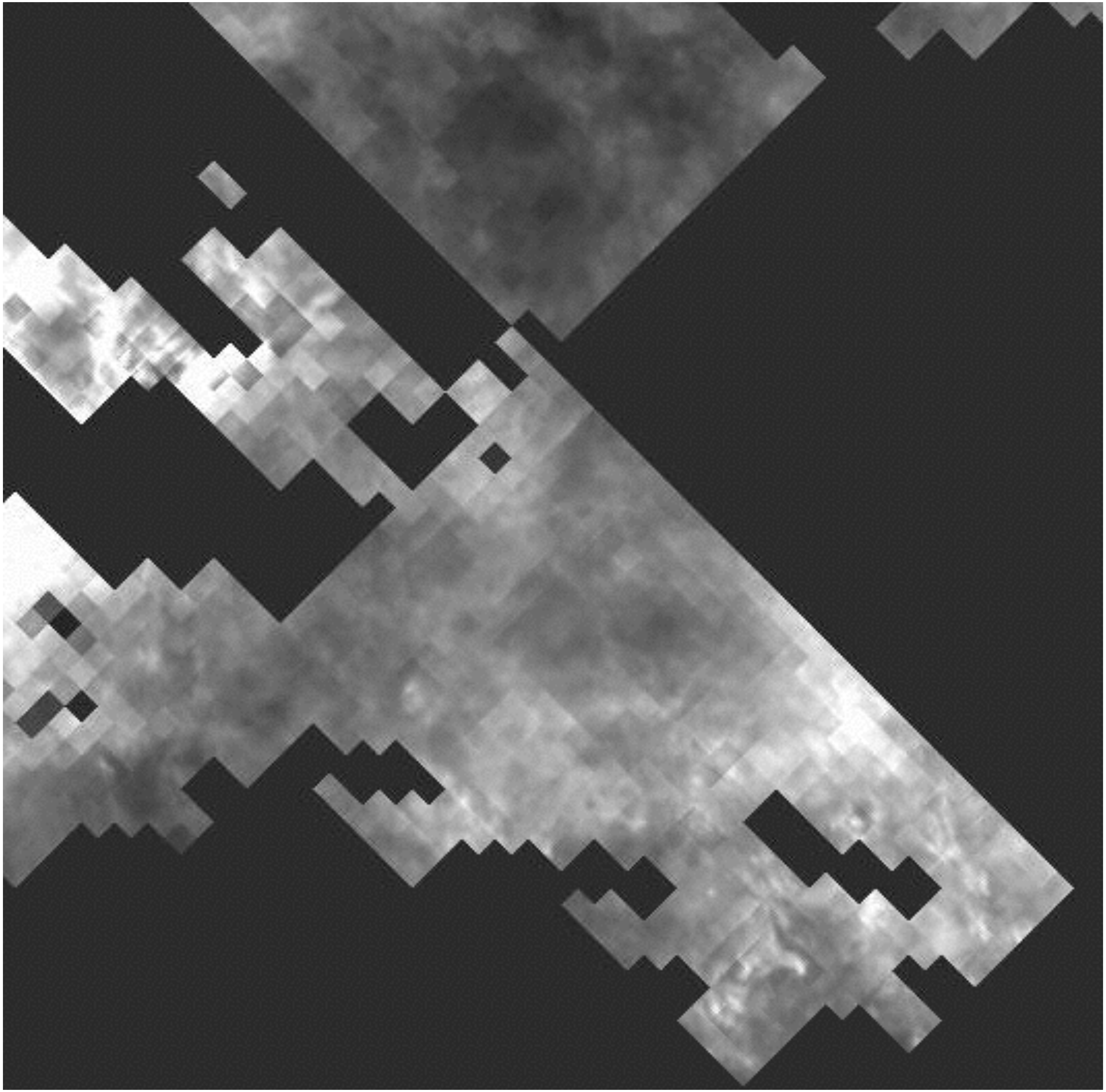


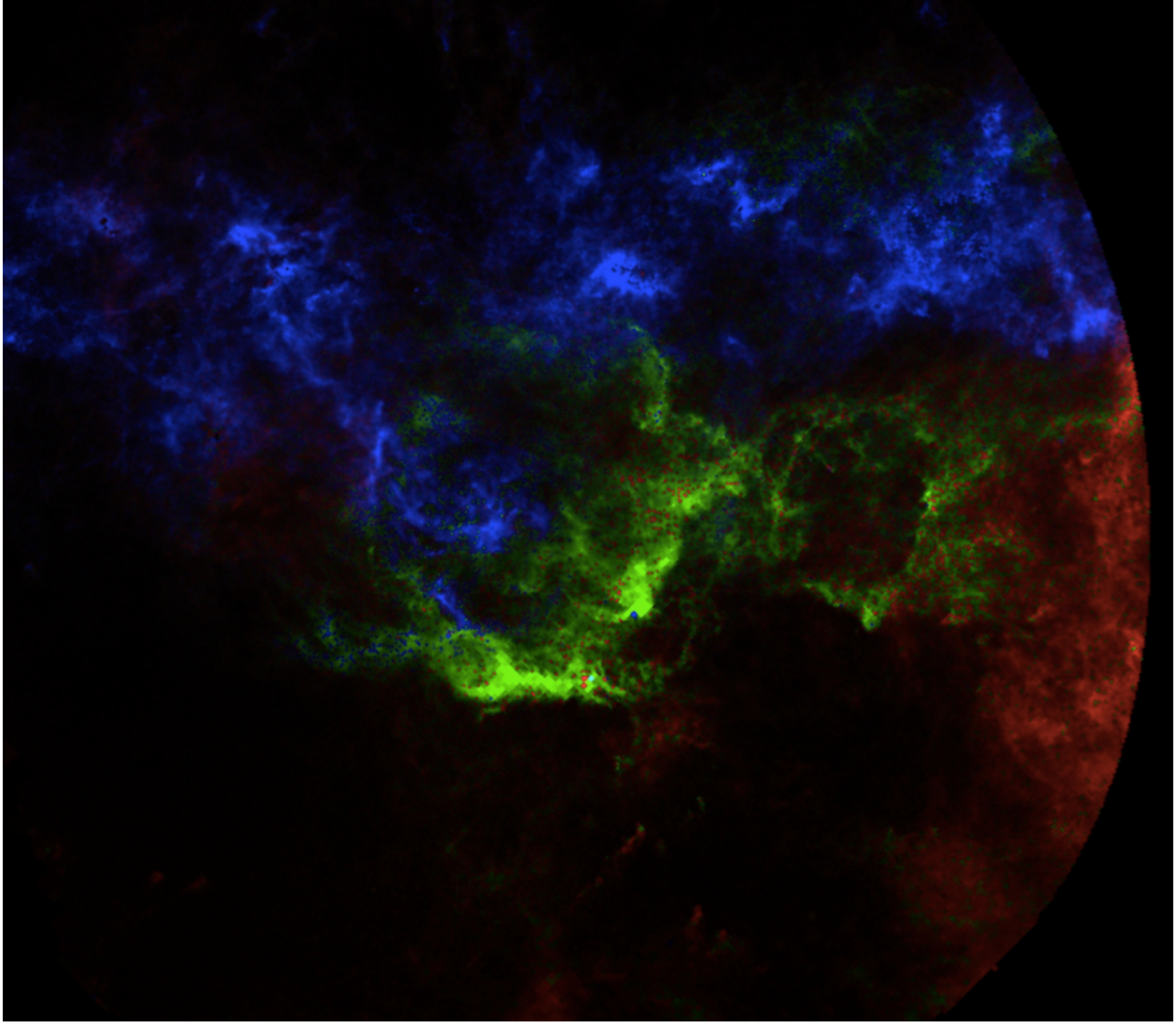
]

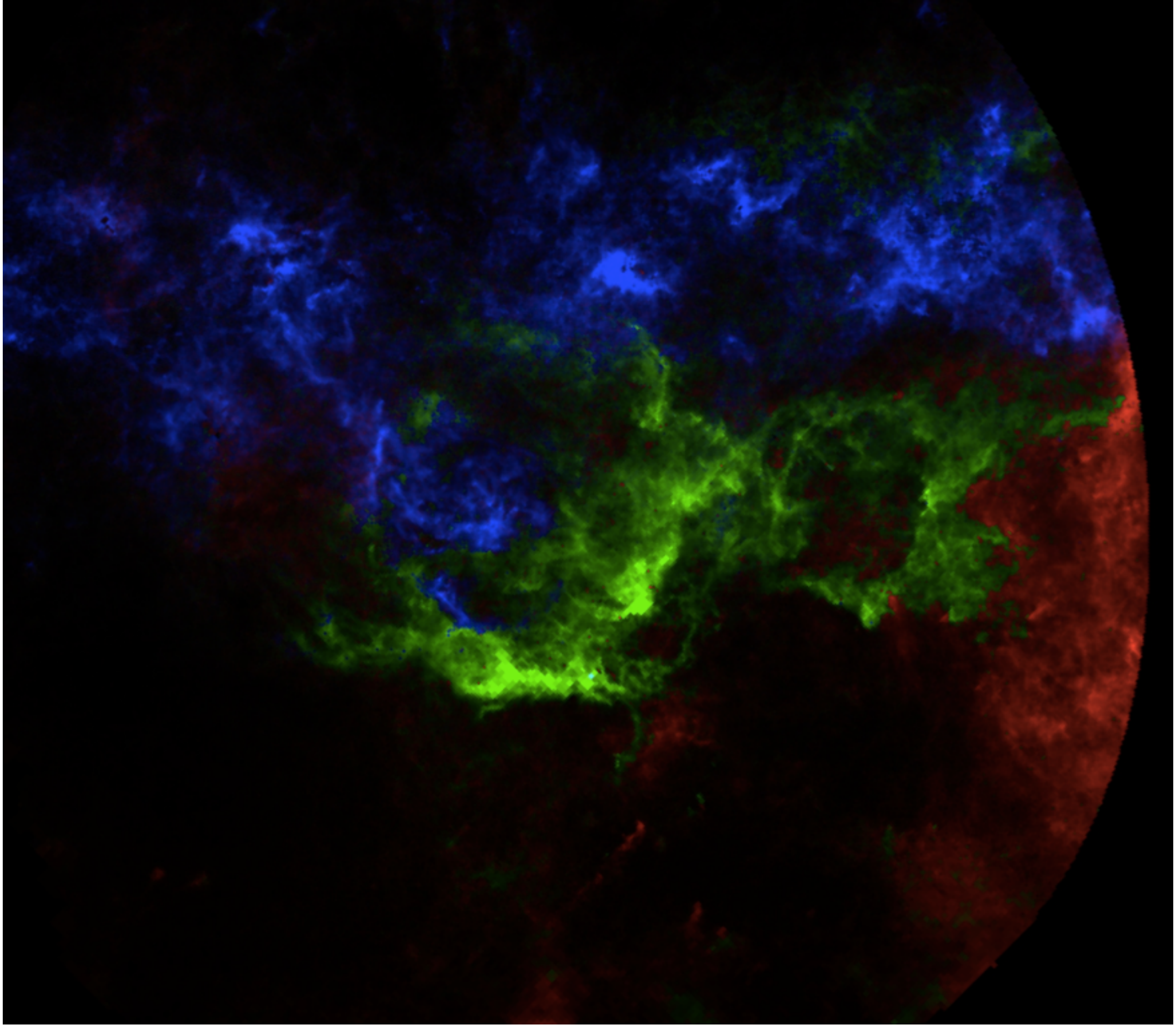
Regularization

Dust structures are coherent across pixels, so each pixel should know something about the neighbors.

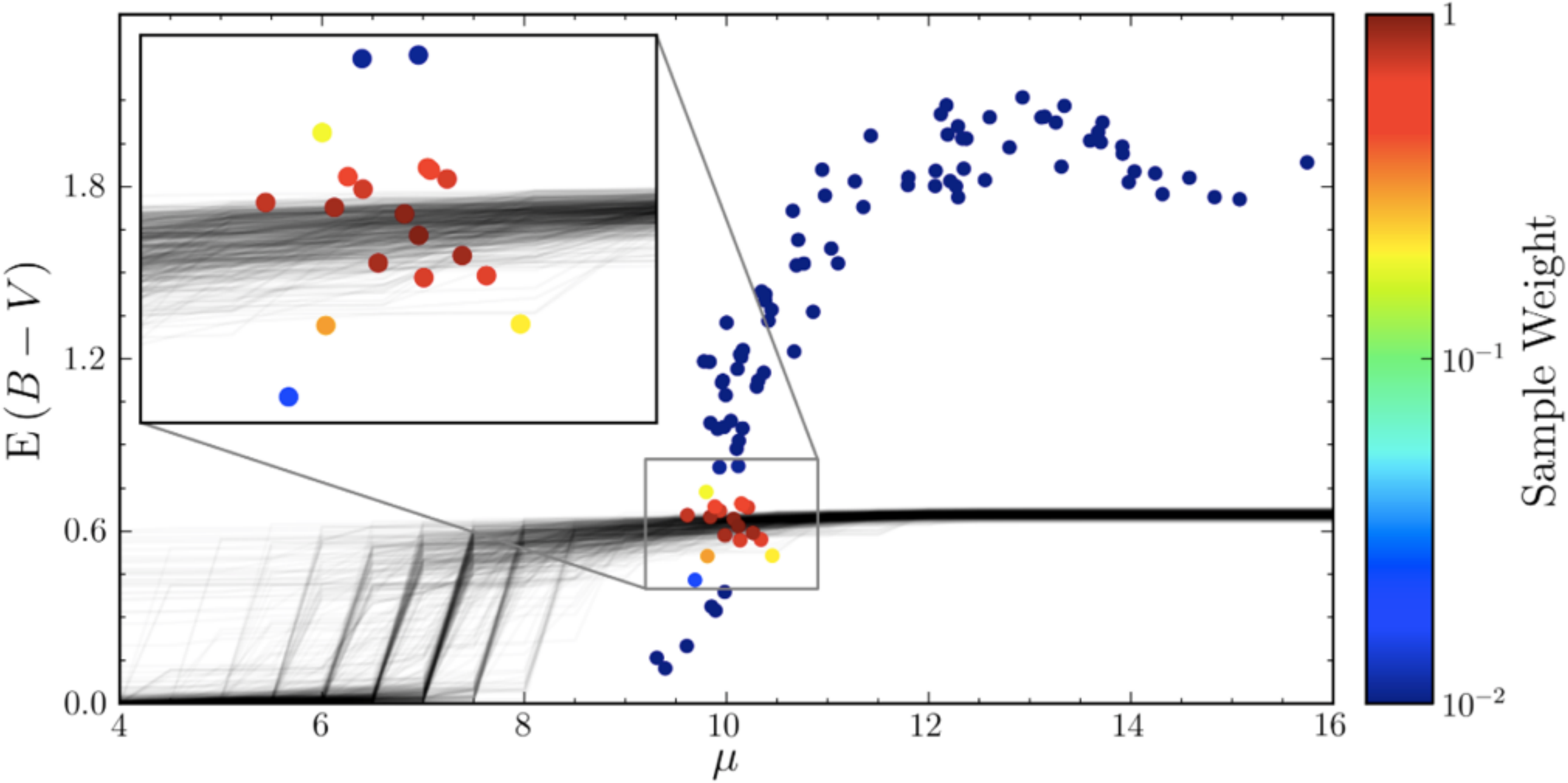
Simplest thing is to take dot product of each current pixel dust vector with 500 samples each of 8 nearest neighbors, add that term to likelihood, and resample. Do this for all pixels. Iterate.

2.4M x 500 x 8 x 10,000 = 10^{14} dot products. So, nothing.



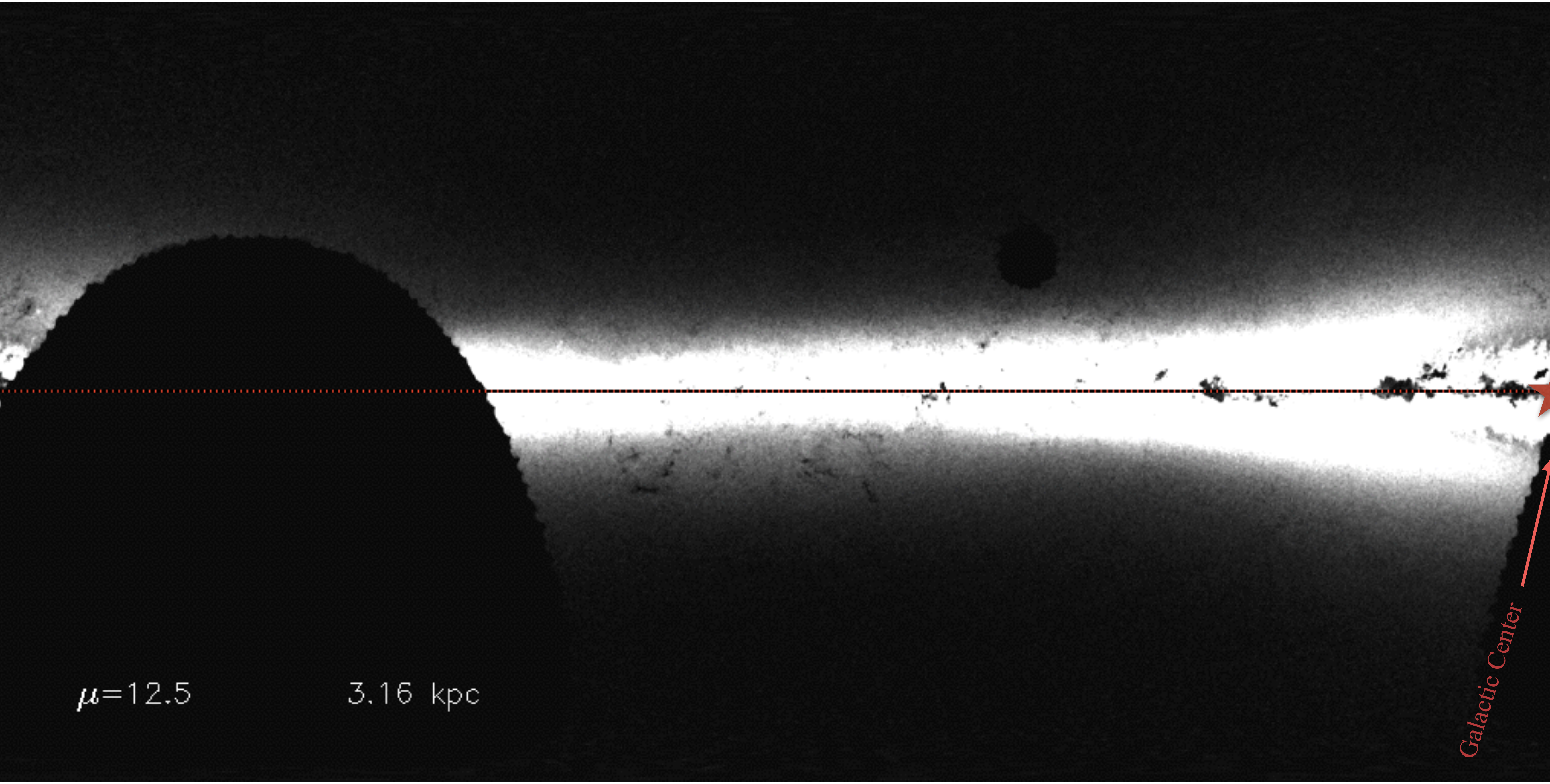


F-star distances



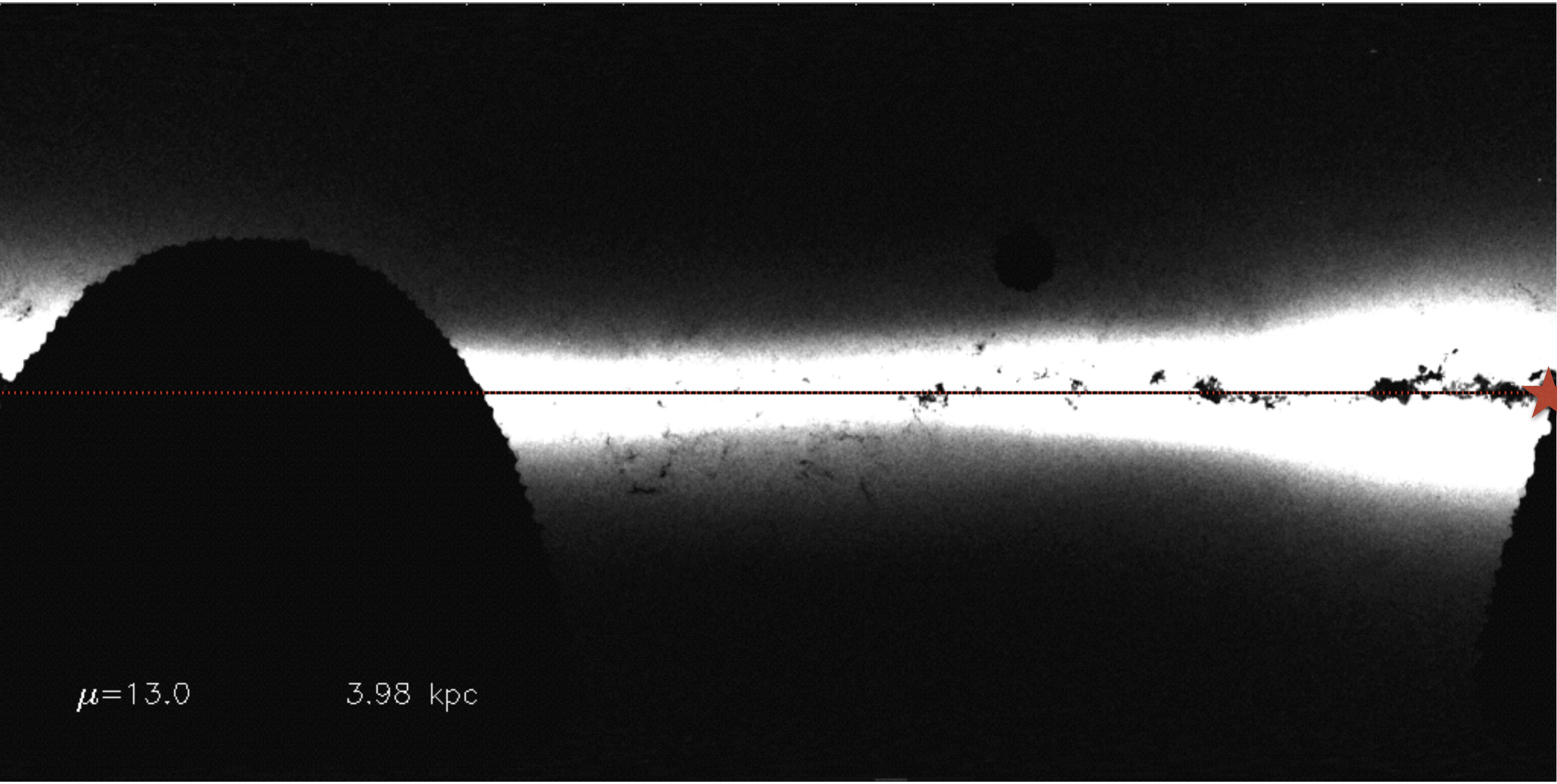
E(B − V)
1.8
1.2
0.6
0.0
4
6
8
10
12
14
16
μ
1
10^−1
10^−2
Sample Weight

]



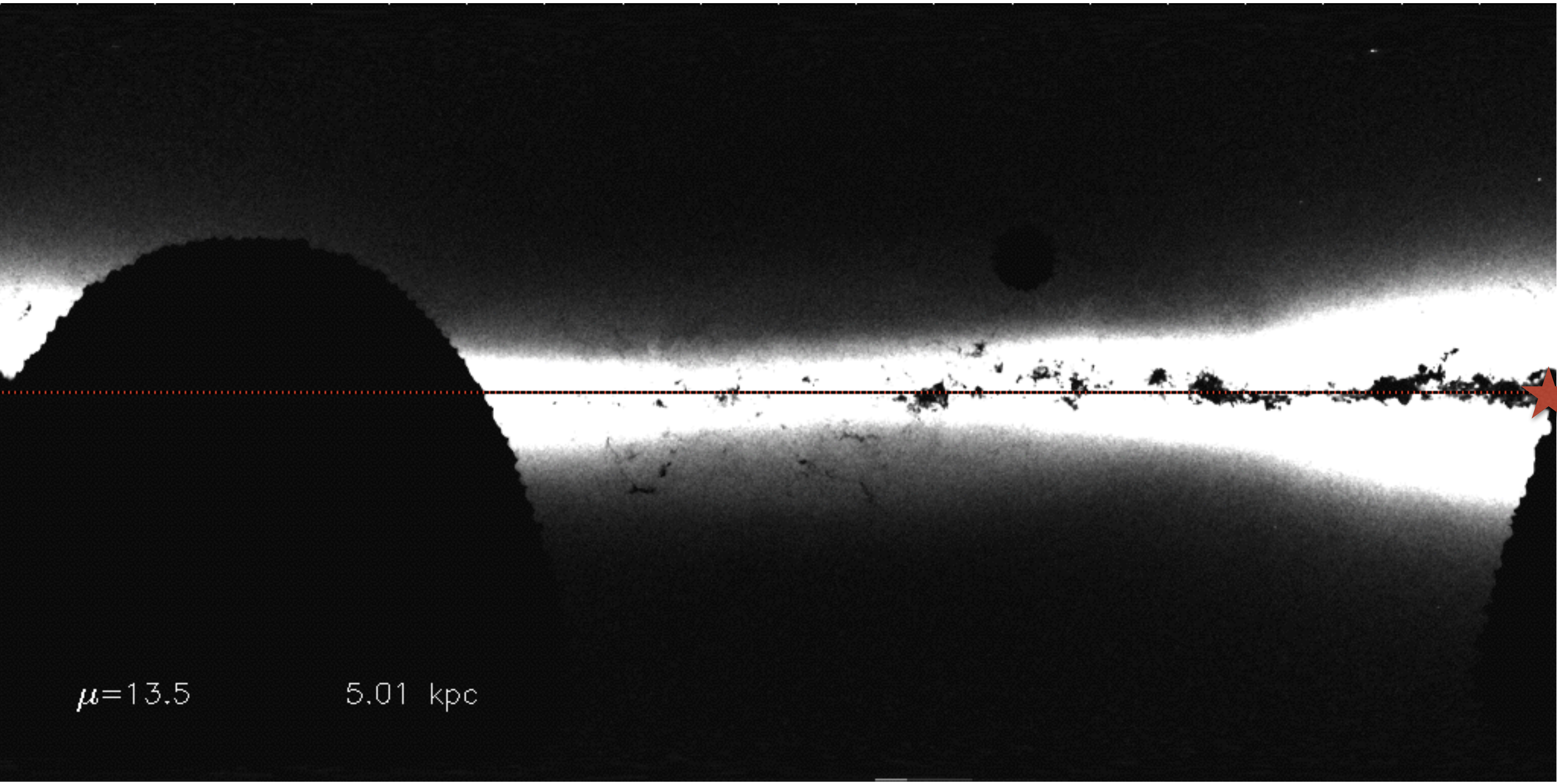
μ=12.5
3.16 kpc
Galactic Center

]

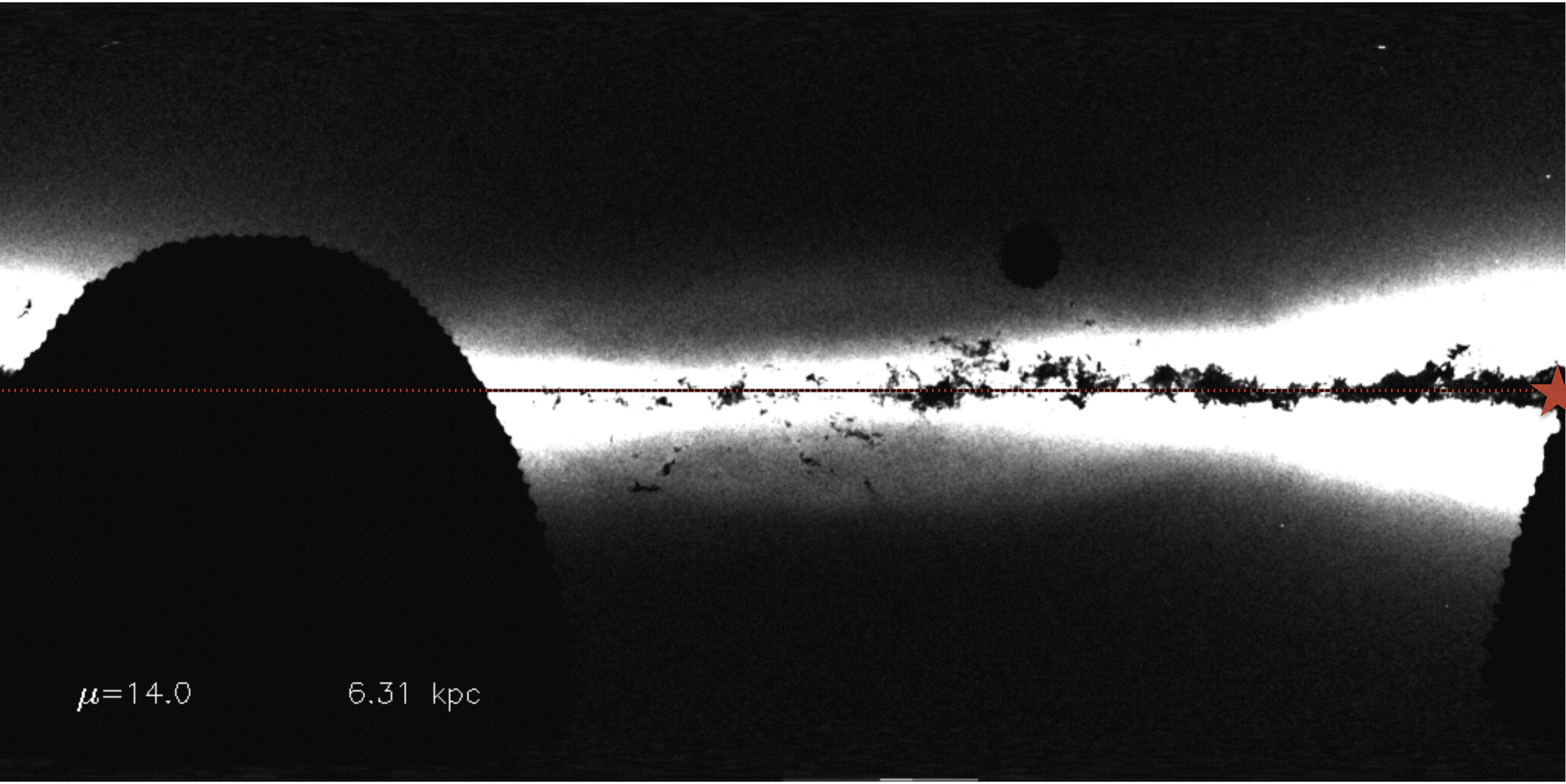


μ=13.0
3.98 kpc

]

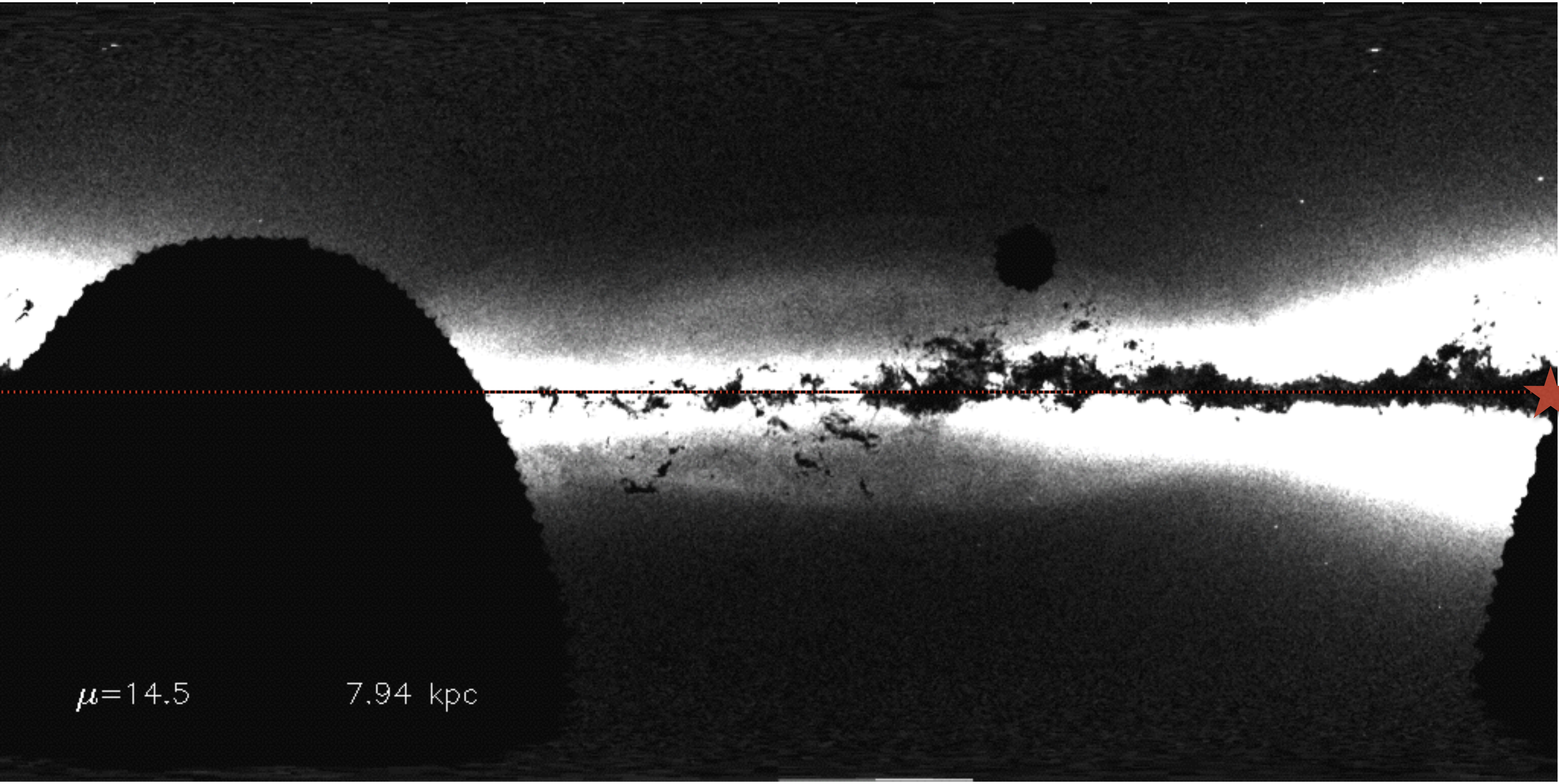

μ=13.5
5.01 kpc

]



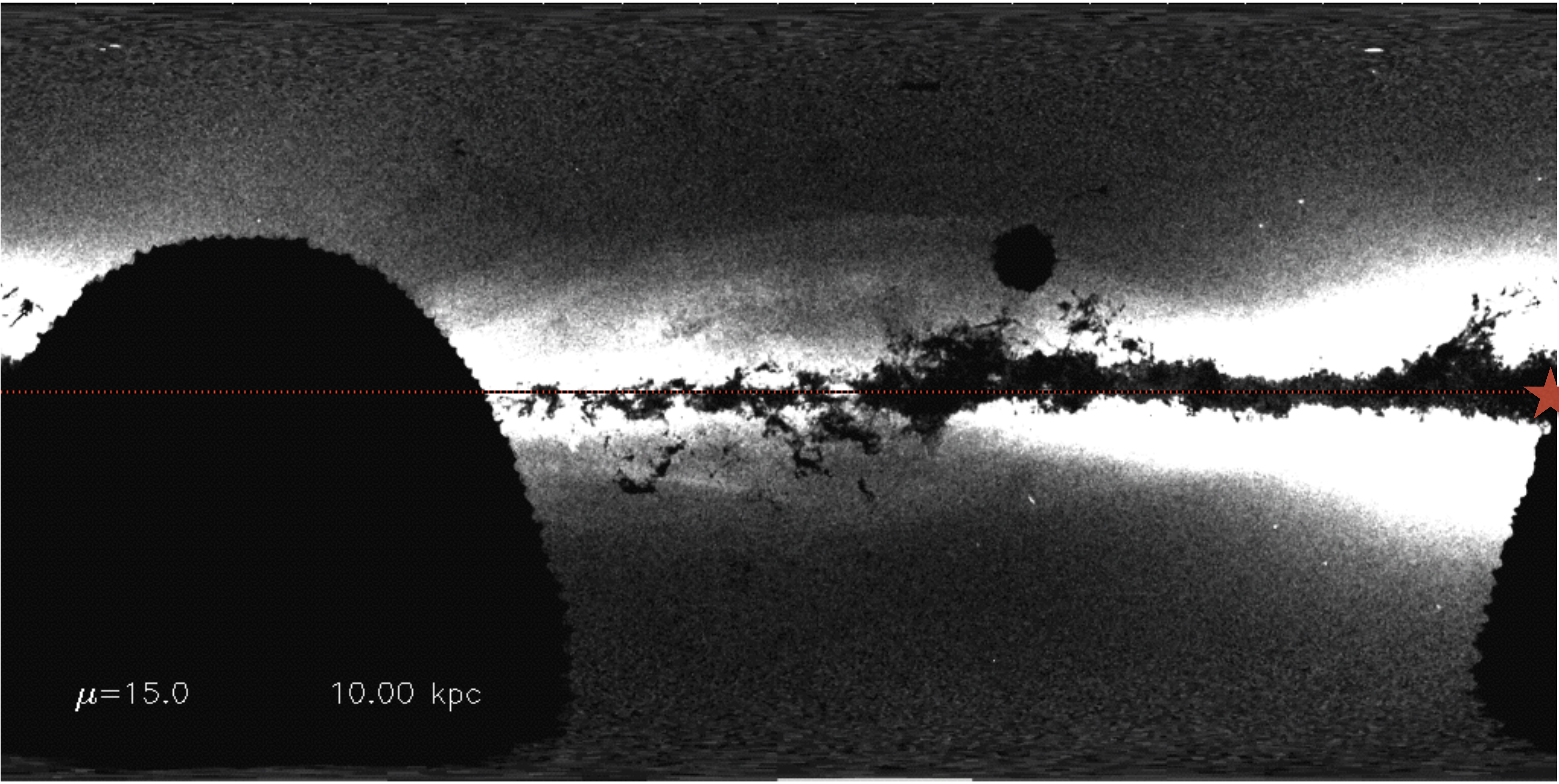
μ=14.0
6.31 kpc

]

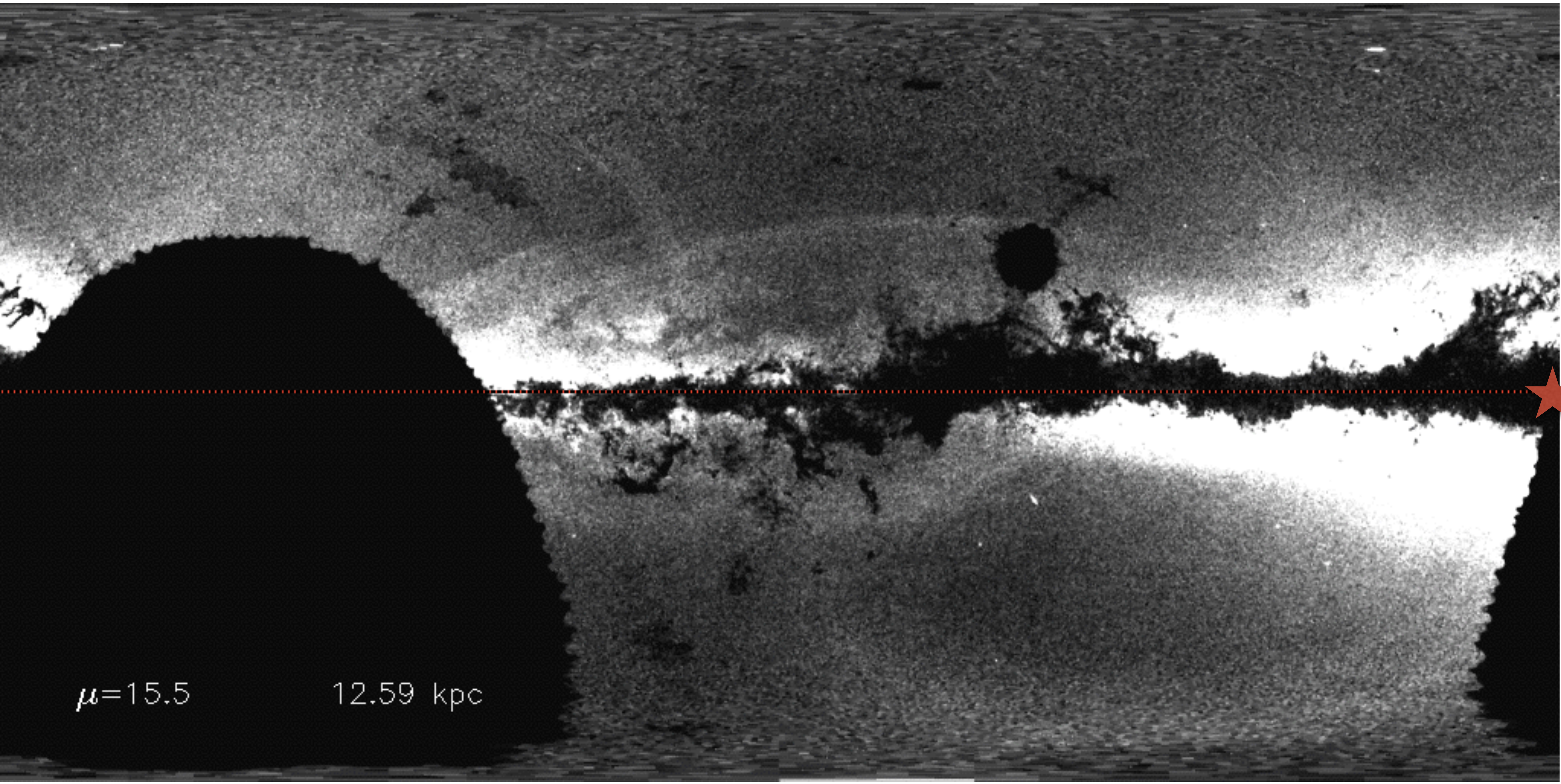


μ=14.5
7.94 kpc

]


μ=15.0
10.00 kpc

]



μ=15.5
12.59 kpc

]

Lessons:

- PS1 photometry of a billion stars -> wonderful playground for inference methods.

- Can separate big problem into millions of small problems

- Save your samples! (Allows post facto regularization)

- Reweighting can be fun.

]

We will know a lot more before PIXIE launches:

This is only the beginning. Some future
PS1 - DECam - GAIA - LSST - WISE - Planck map
will do all this better!

Some links:
Meisner & Finkbeiner WISE Sky Survey Atlas (WSSA)
http://faun.rc.fas.harvard.edu/ameisner/wssa/

3D dust map stuff
http://argonaut.rc.fas.harvard.edu

MW dust video on YouTube:
https://www.youtube.com/watch?v=cJedzj0eREY

]

If we knew ISM density and radiation field in 3D (6D), along with B field and CR density, what could we do?

- ISM + CR -> π-0 gammas
- ISM + e- CR -> brem gammas
- ISRF + e- CR -> inverse-Compton gammas
- B-field + e- CR -> synchrotron microwaves

These gamma-ray foregrounds are important for dark matter searches.

Any WIMP annihilation signal from the inner MW will have these all as backgrounds — *we must understand them!*

]

arXiv:1010.2752

Dark Matter Annihilation in The Galactic Center As Seen by the Fermi Gamma Ray Space Telescope
Dan Hooper, Lisa Goodenough

arXiv:1110.0006

On The Origin Of The Gamma Rays From The Galactic Center
Dan Hooper, Tim Linden

arXiv:1402.6703

The Characterization of the Gamma-Ray Signal from the Central Milky Way: A Compelling Case for Annihilating Dark Matter
Tansu Daylan, Douglas P. Finkbeiner, Dan Hooper, Tim Linden, Stephen K. N. Portillo, Nicholas L. Rodd, Tracy R. Slatyer

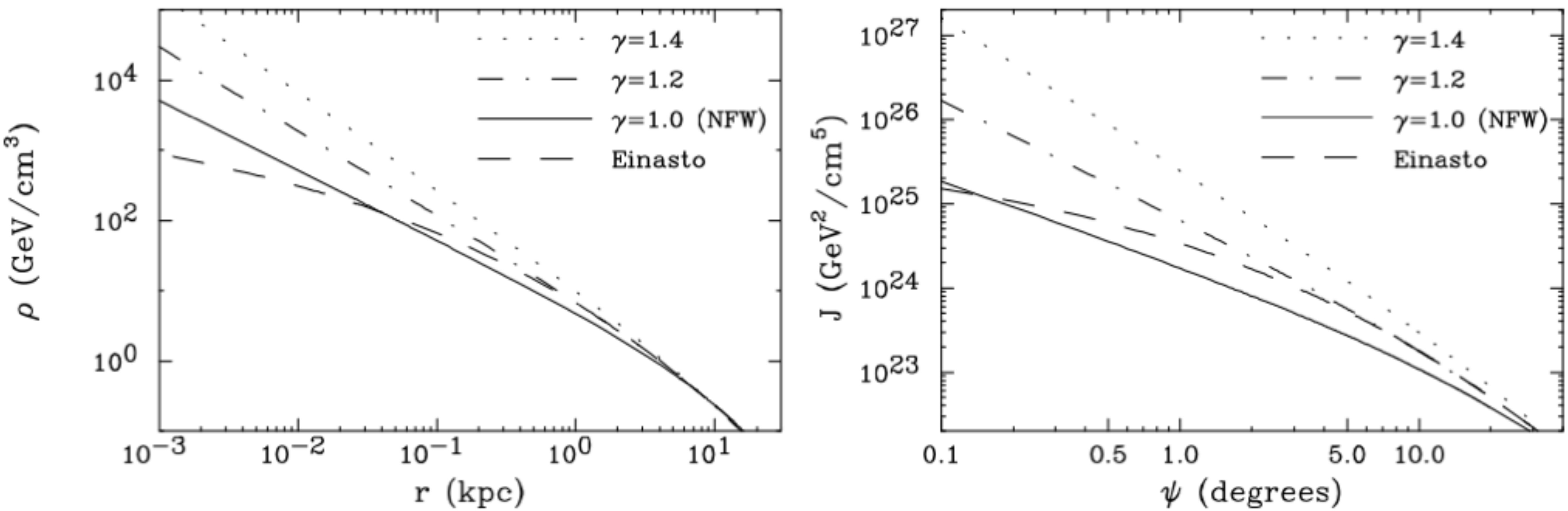
arXiv:1404.0022

Simplified Dark Matter Models for the Galactic Center Gamma-Ray Excess
Asher Berlin, Dan Hooper, Samuel D. McDermott

arXiv:1404.1373

Flavored Dark Matter and the Galactic Center Gamma-Ray Excess
Prateek Agrawal, Brian Batell, Dan Hooper, Tongyan Lin

Dark matter profiles



$$\Phi(E_\gamma, \psi) = \frac{\sigma v}{8\pi m_X^2} \frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma} \int_{\mathrm{los}} \rho^2(r)\, \mathrm{d}l,$$

Daylan+ 2014

Assume the observed gamma-ray map at each energy is a linear combination of template maps:

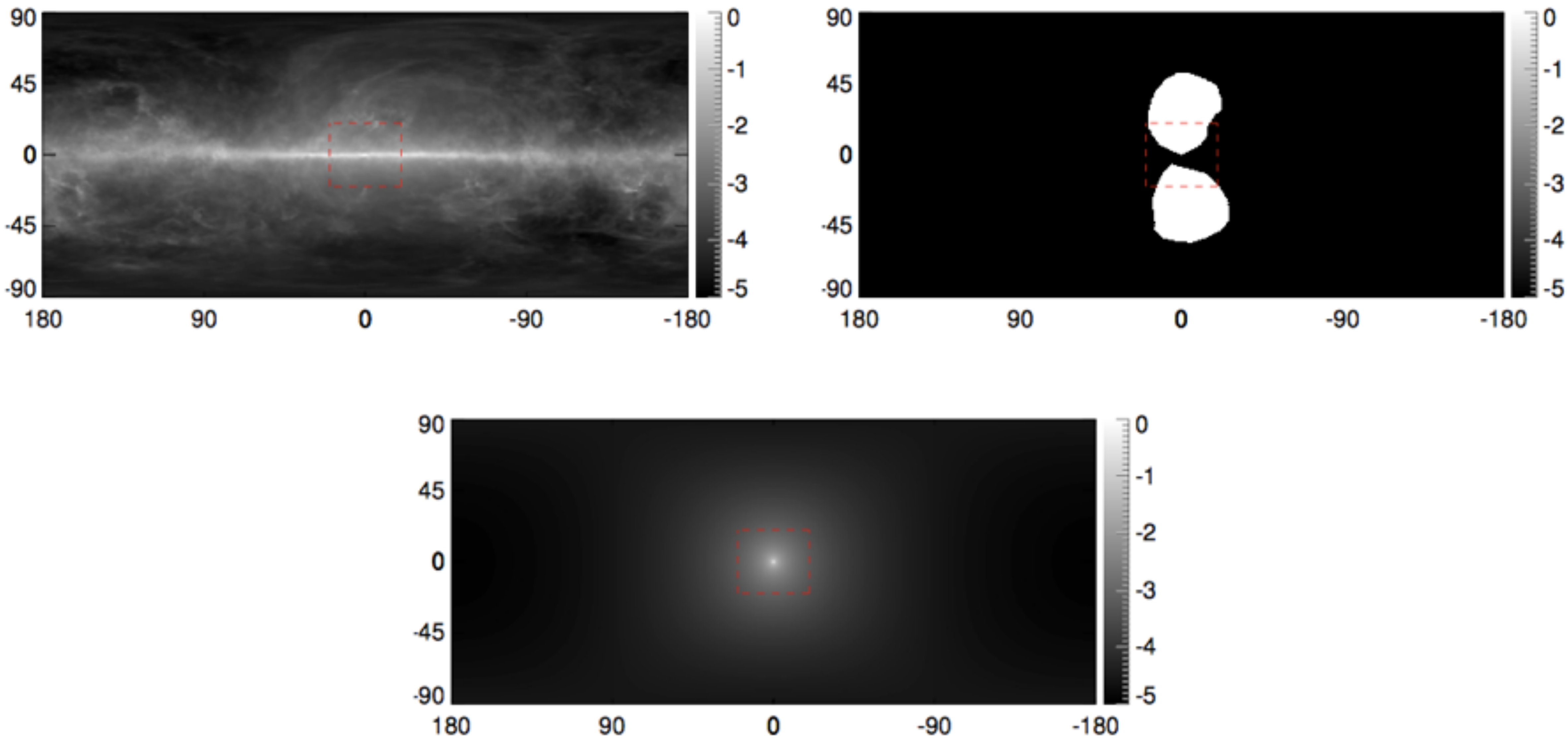
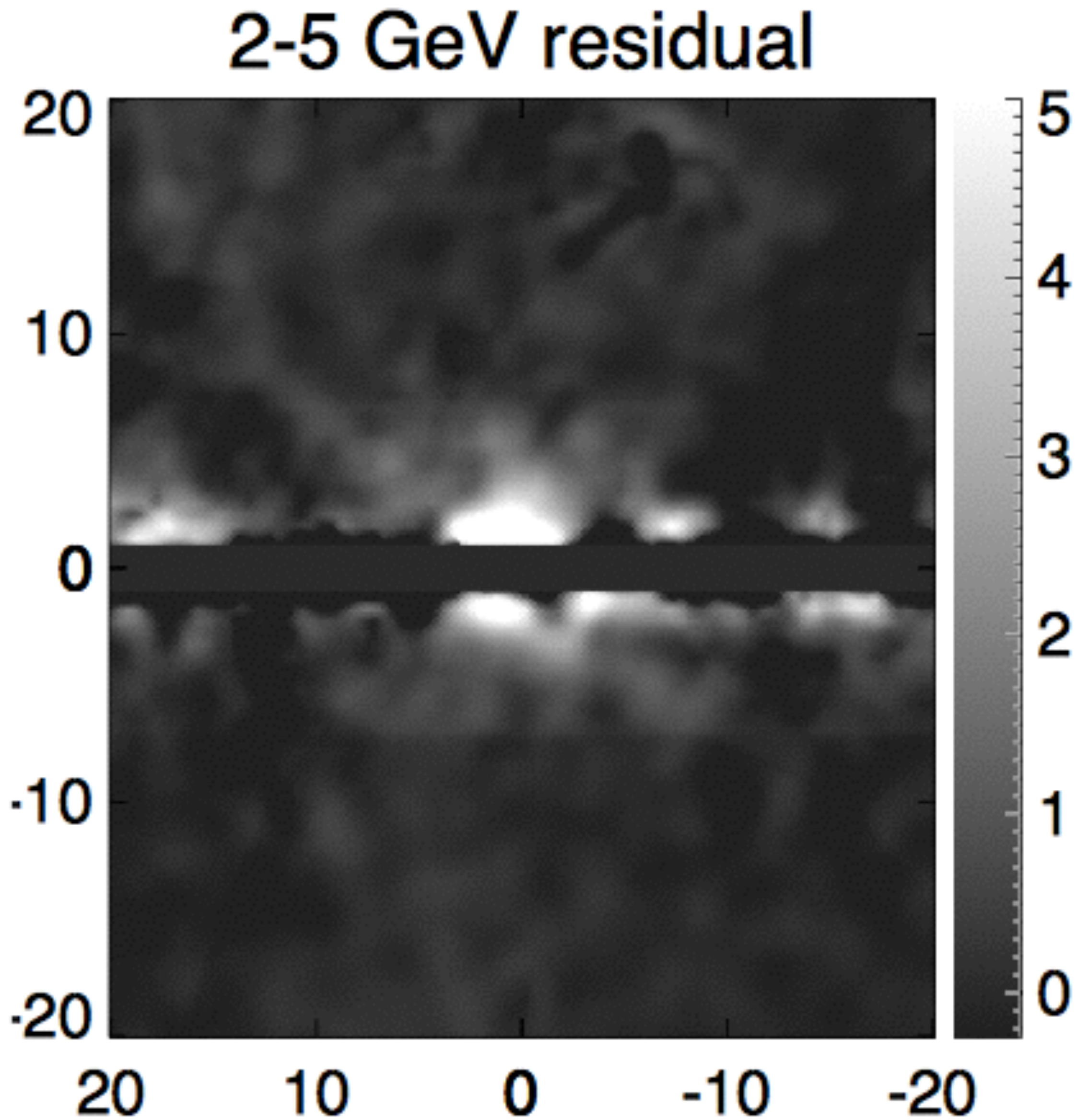


FIG. 4: The spatial templates (in galactic coordinates) for the Galactic diffuse model (upper left), the *Fermi* bubbles (upper right), and dark matter annihilation products (lower), as used in our Inner Galaxy analysis. The scale is logarithmic (base 10), normalized to the brightest point in each map. The diffuse model template is shown as evaluated at 1 GeV, and the dark matter template corresponds to a generalized NFW profile with an inner slope of $\gamma = 1.18$. Red dashed lines indicate the boundaries of our standard Region of Interest (we also mask bright point sources and the region of the Galactic plane with $|b| < 1^\circ$).

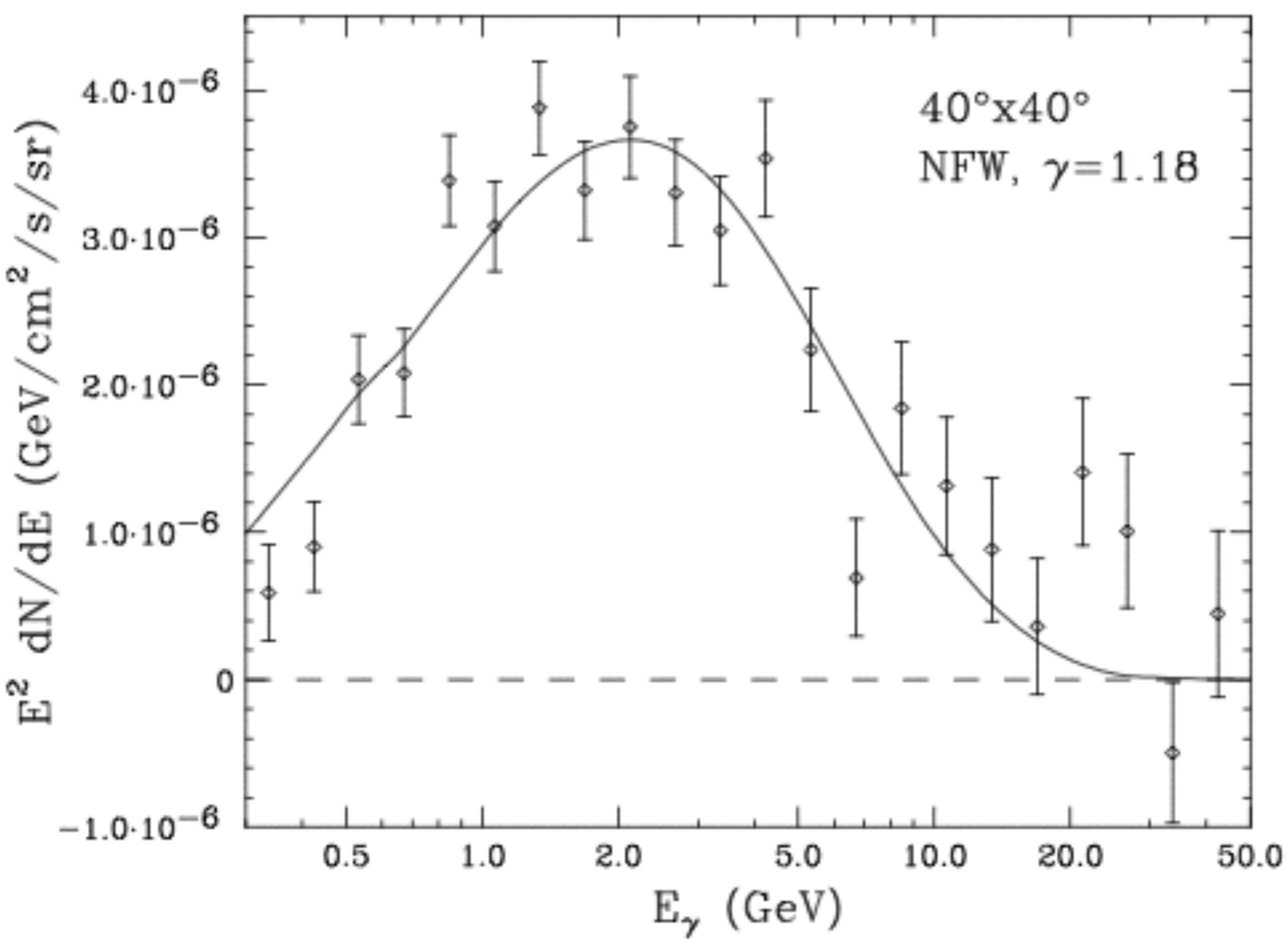
Daylan+ 2014

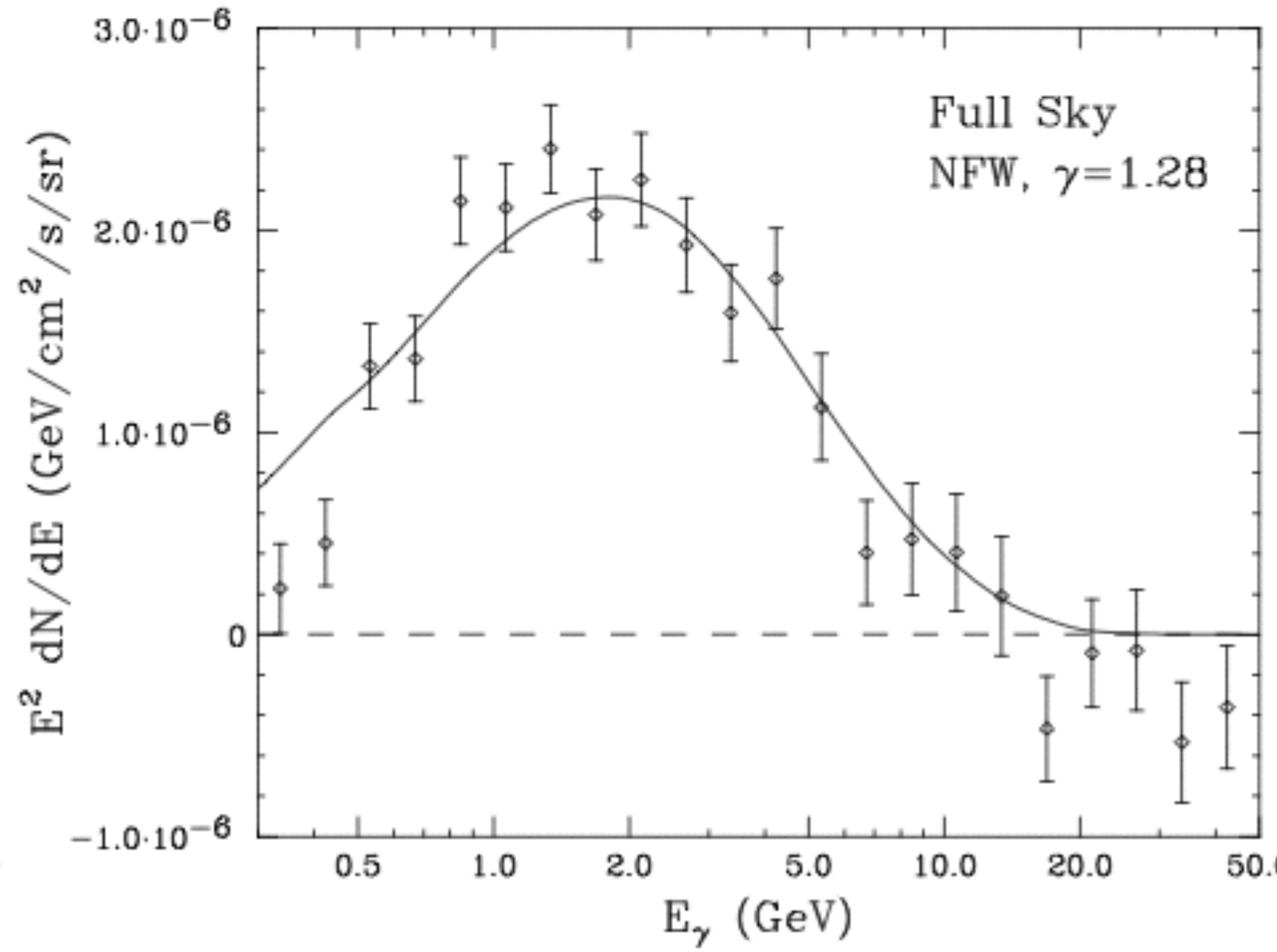
The residual if we do not include the "NFW" template looks like this:



Daylan+ 2014

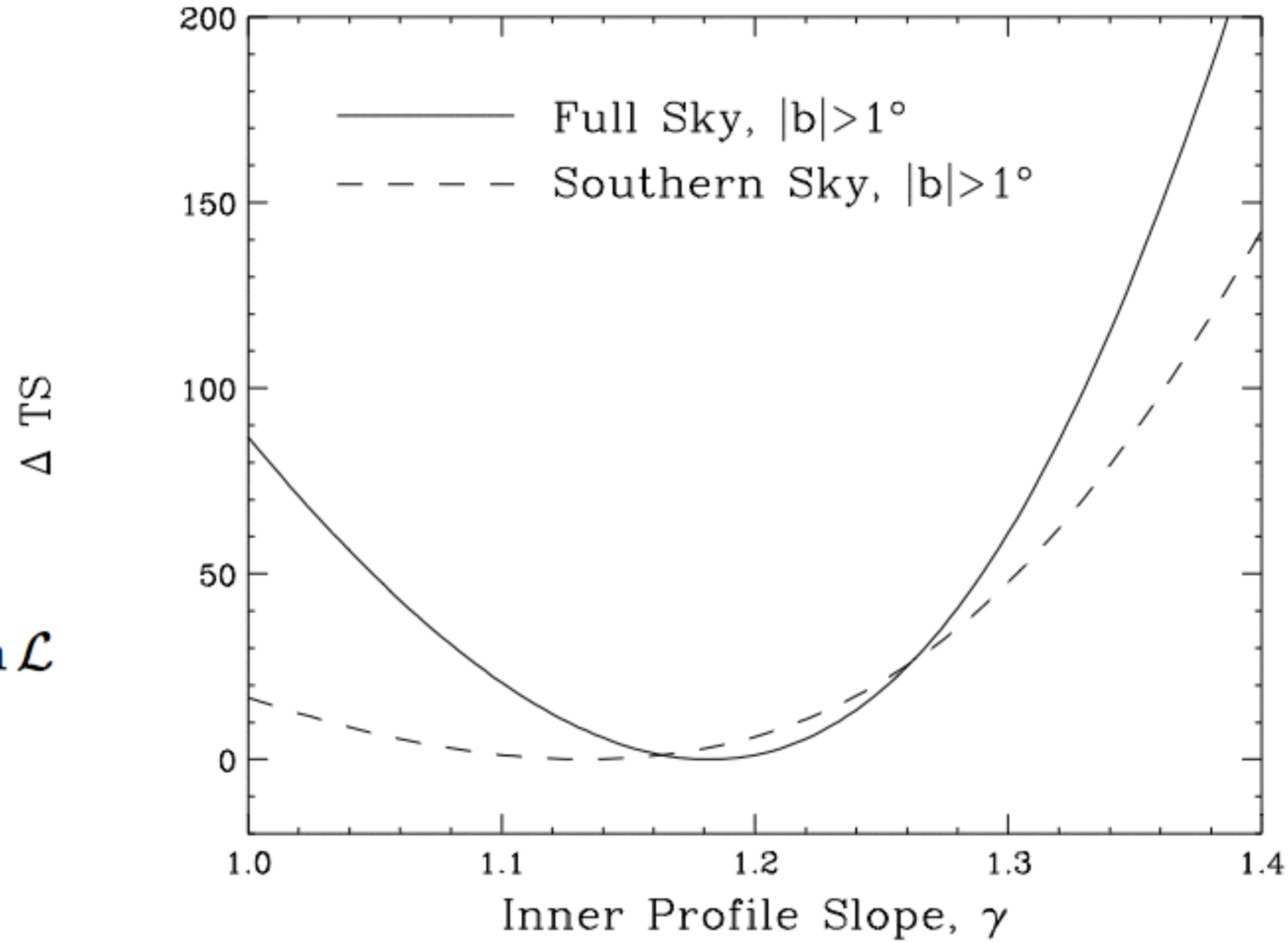
If we do include it, the spectrum is:





Daylan+ 2014

We can even constrain the slope of the profile



$-2\Delta \ln \mathcal{L}$

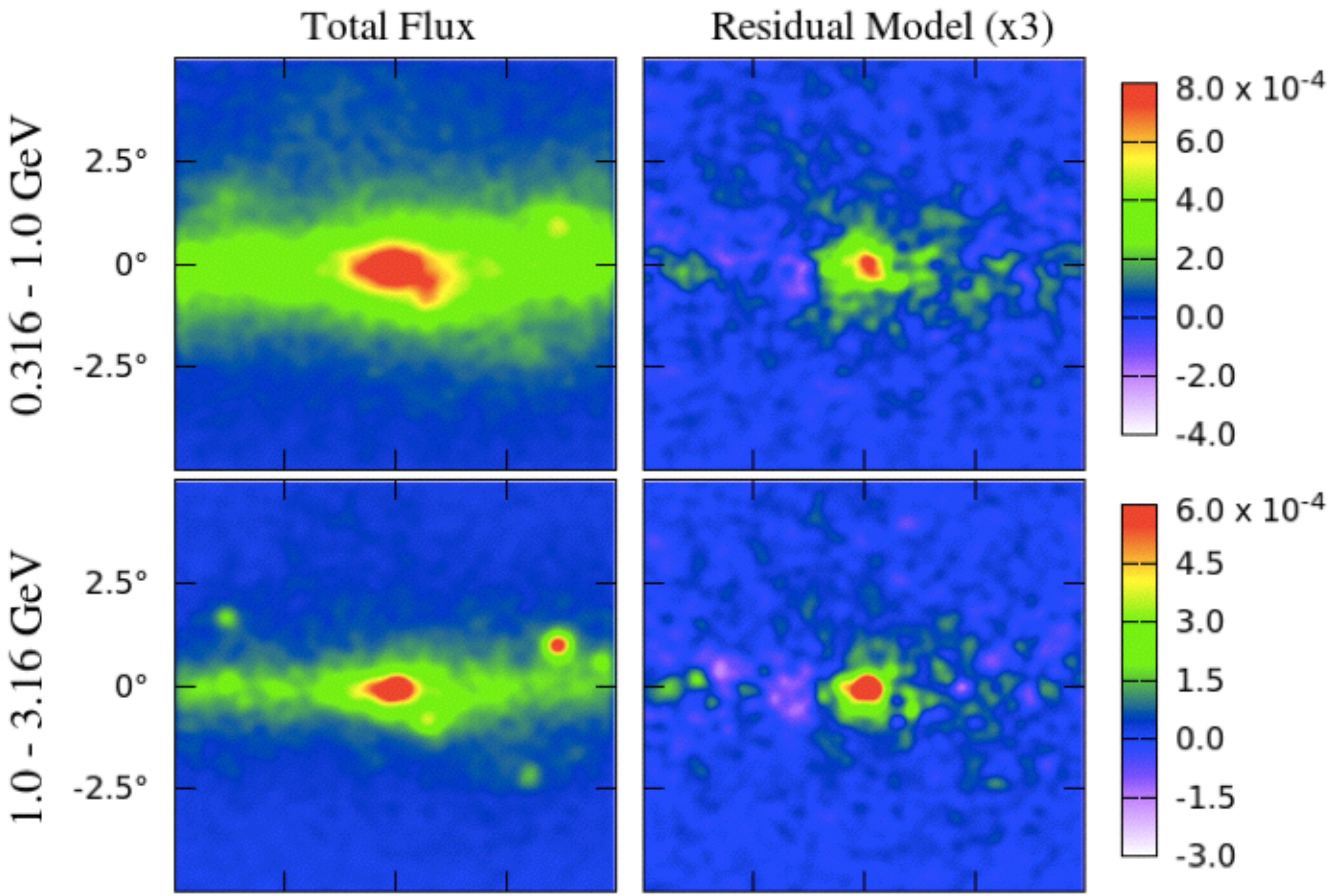
Daylan+ 2014

Now, the Galactic center ($|b| < 1$ degree)

model point sources explicitly, including GC source, look for excess

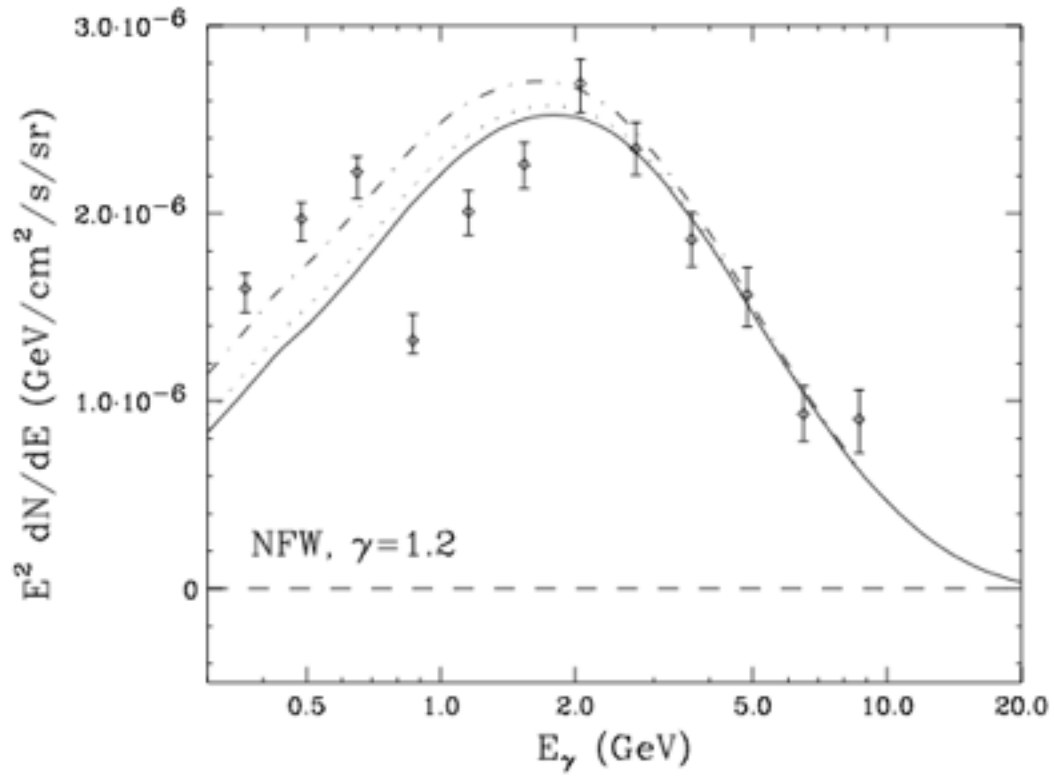
Daylan+ 2014

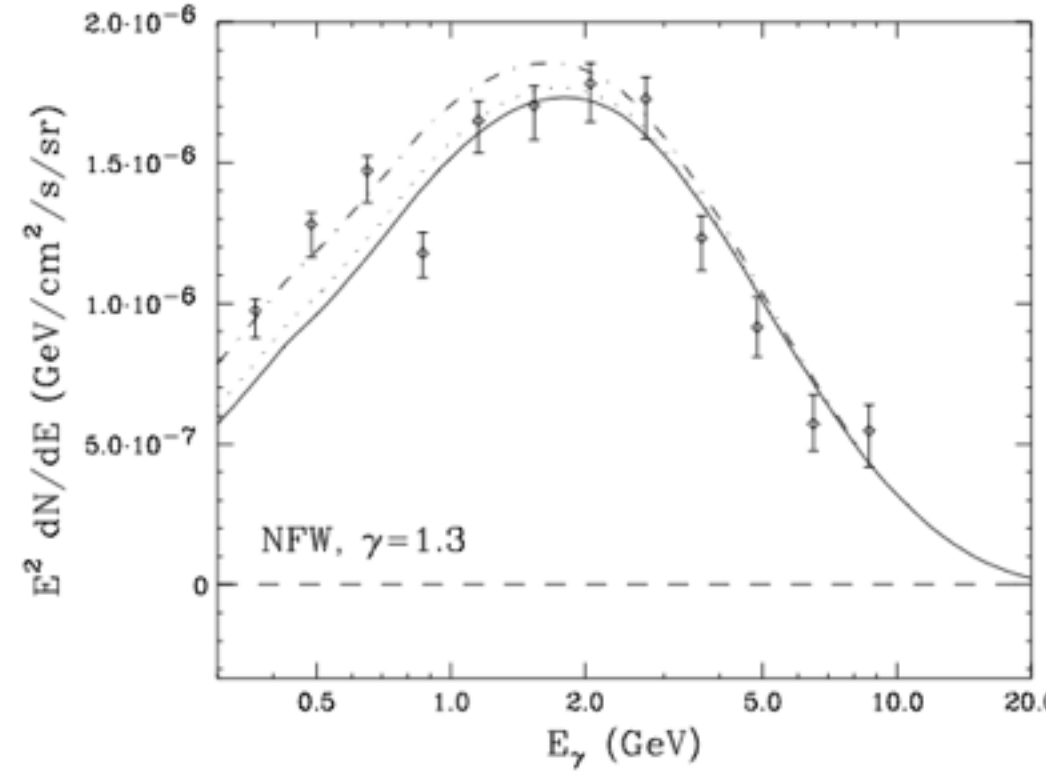
Now, the Galactic center (|b| < 1 degree)

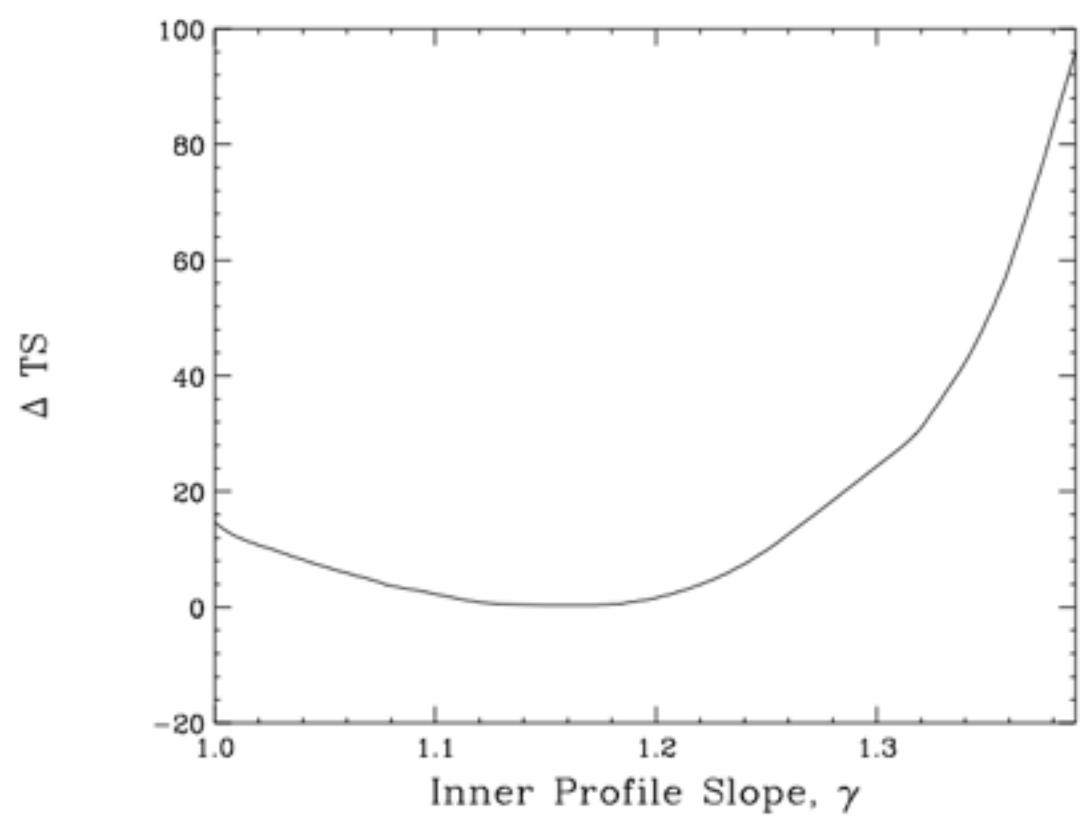


Daylan+ 2014

The spectrum is similar, and so is the implied DM profile







Daylan+ 2014

There is a blob there… and it is round (azimuthally symmetric)

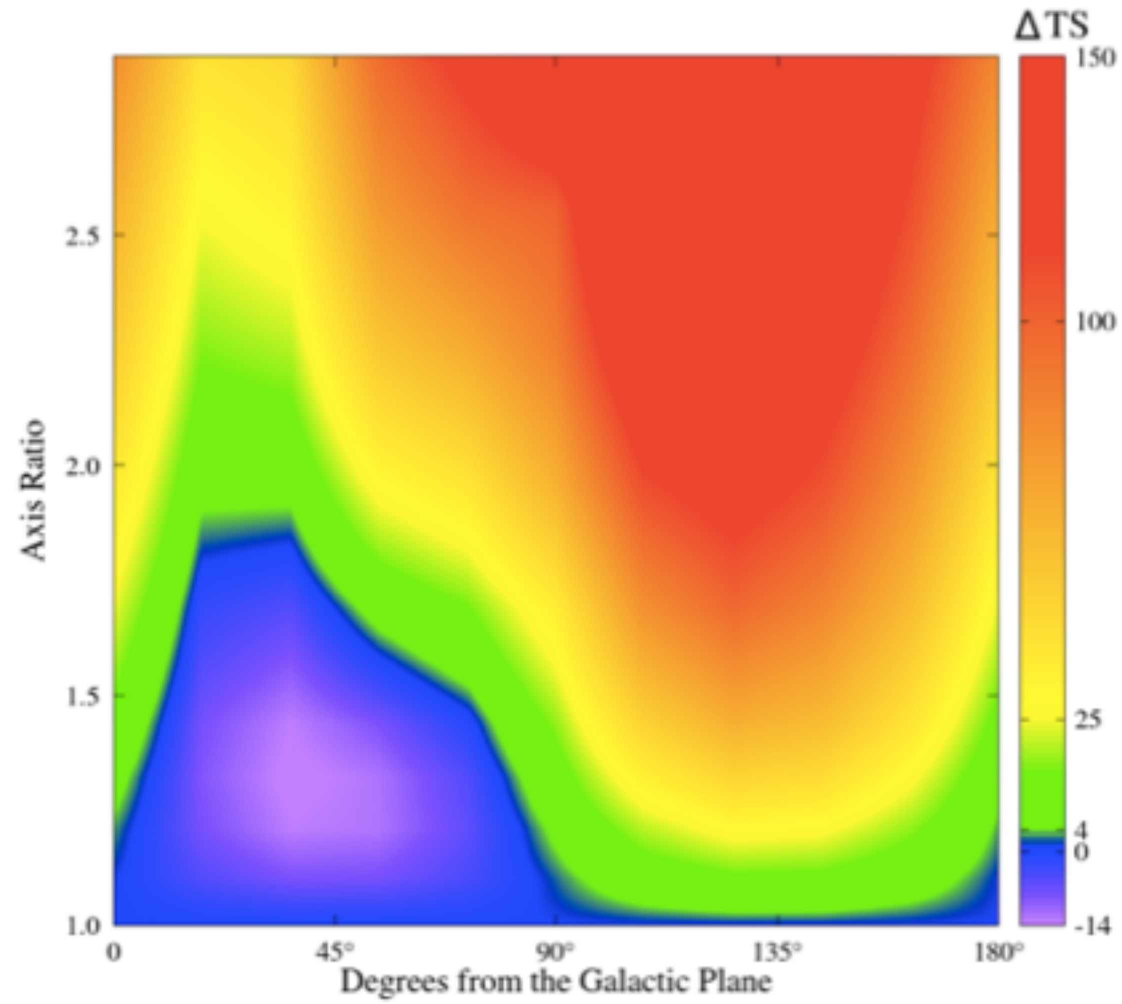


FIG. 12: The change in the quality of the fit in our Galactic Center analysis, for a dark matter template that is elongated along an arbitrary orientation (x-axis) and with an arbitrary axis ratio (y-axis). As shown in Fig. 11, the fit worsens if the this template is significantly stretched either along or perpendicular to the direction of the Galactic Plane (corresponding to 0° or 90° on the x-axis, respectively). A mild statistical preference, however, is found for a morphology with an axis ratio of ∼1.3-1.4 elongated along an axis rotated ∼35° clockwise from the Galactic Plane.

Daylan+ 2014

But we have *forced* it to have an NFW-like shape.
Now let's fix the energy spectrum and let the radial profile float:

Daylan+ 2014

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Now let's fix the energy spectrum and let the radial profile float:

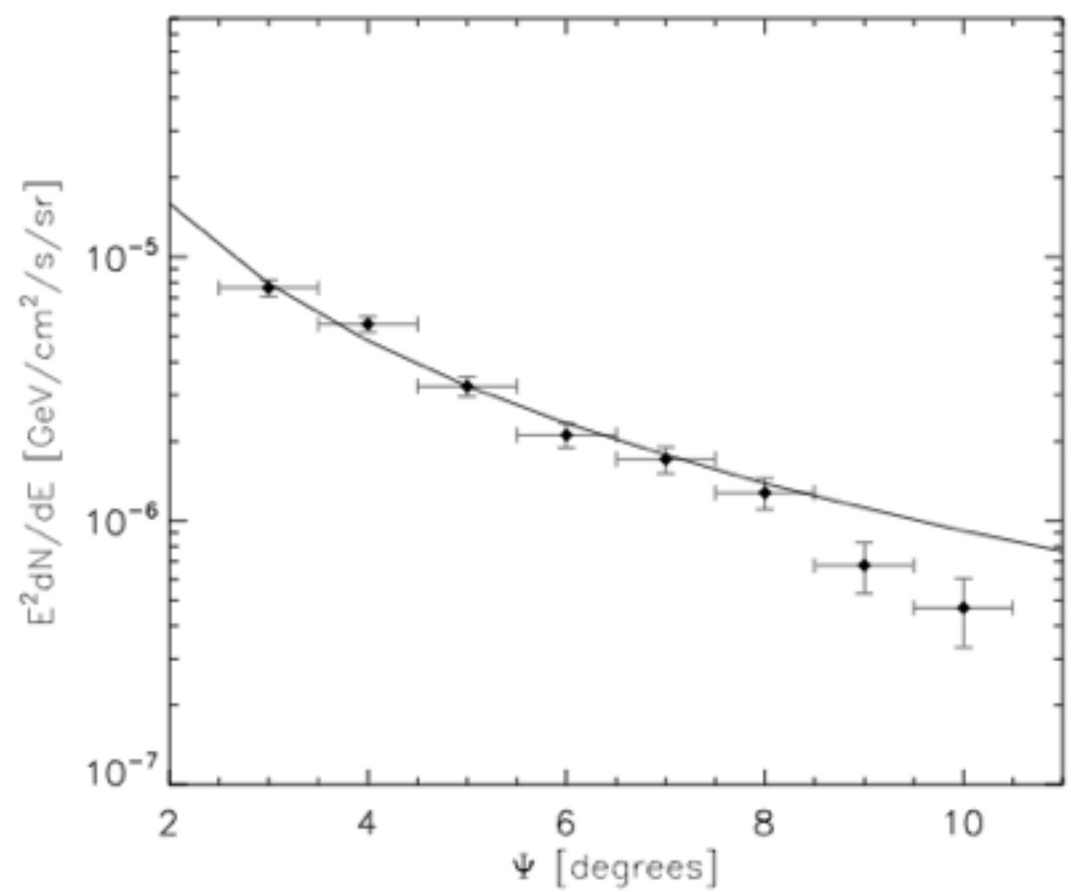


FIG. 14: To constrain the degree to which the gamma-ray excess is spatially extended, we have repeated our Inner Galaxy analysis, replacing the dark matter template with a series of concentric ring templates centered around the Galactic Center. The dark-matter-like emission is clearly and consistently present in each ring template out to ∼10°, beyond which systematic and statistical limitations make such determinations difficult. For comparison, we also show the predictions for a generalized NFW profile with $\gamma = 1.3$. The spectrum of the rings is held fixed at that of Fig. 6, and the fluxes displayed in the plot correspond to an energy of 2.67 GeV.

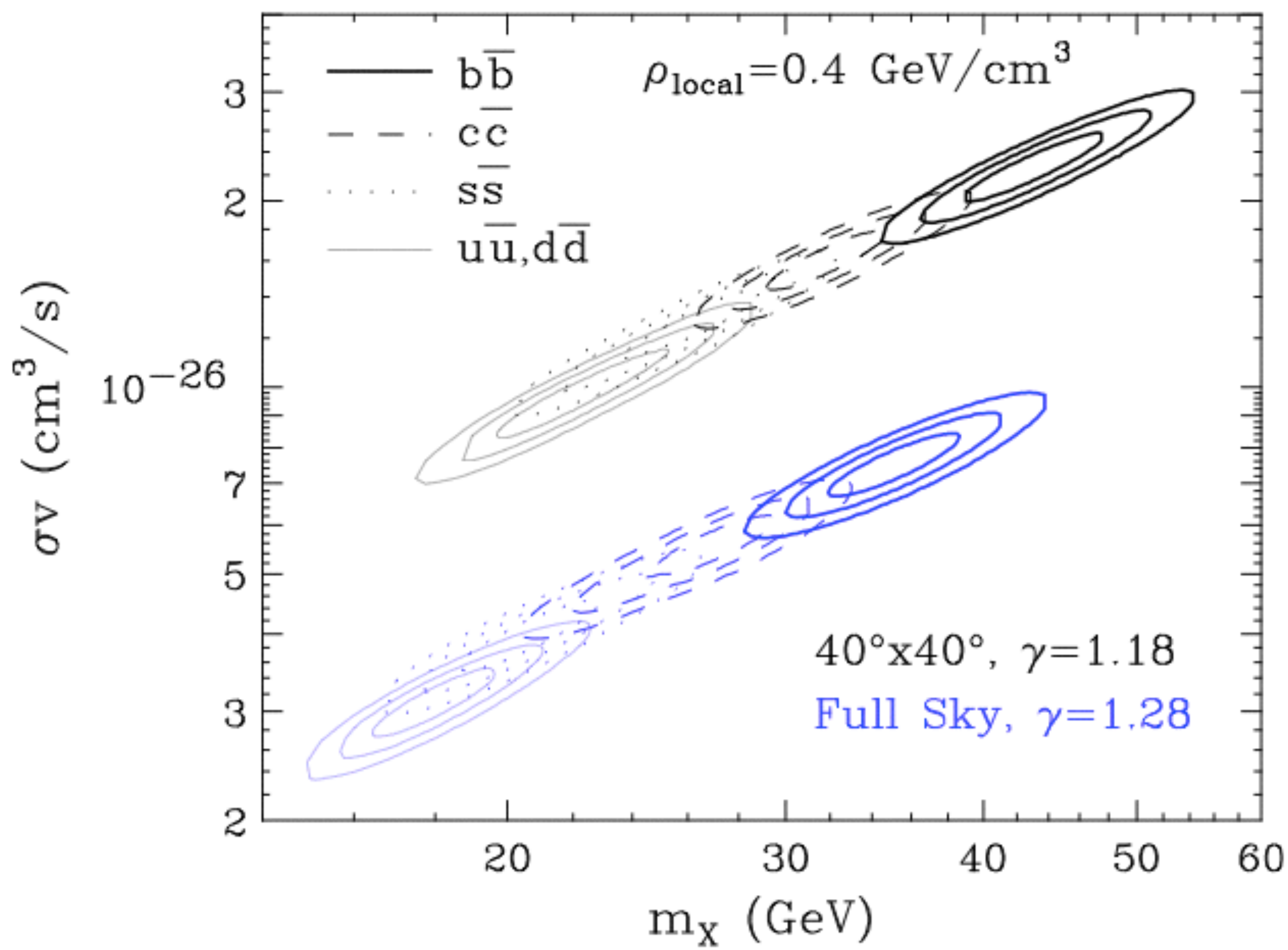
Daylan+ 2014

OK, so there is some signal there that is not in the Fermi diffuse model.
What if it is DM?

Daylan+ 2014

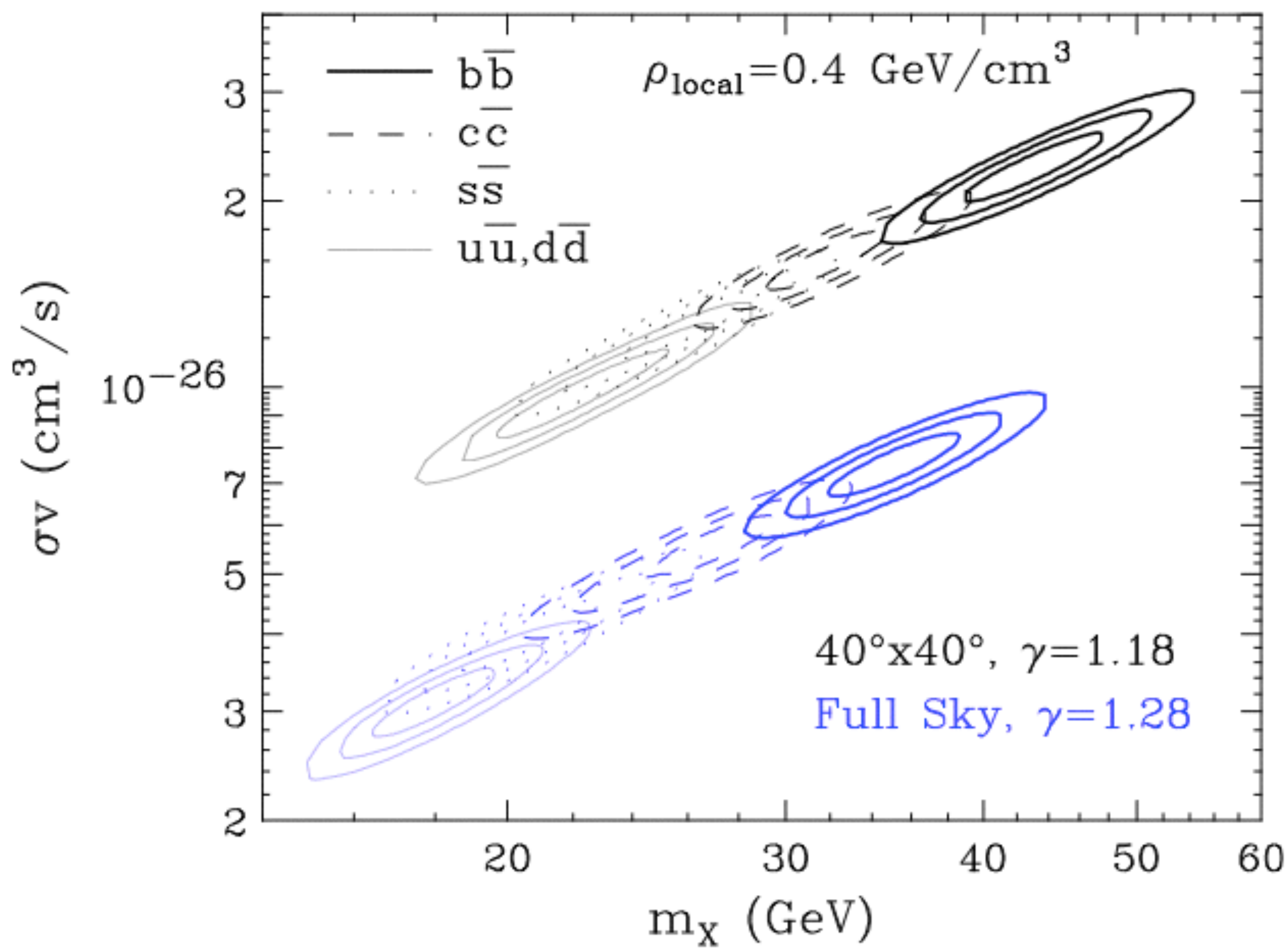
OK, so there is some signal there that is not in the Fermi diffuse model.
What if it is DM?

The implied mass is 20-40 GeV and cross section is just below thermal relic(!)



Daylan+ 2014

So maybe DM is something simple after all. A WIMP with $M=M_z/3$, thermal relic cross section, and boring annihilation channels. (so natural… yawn)



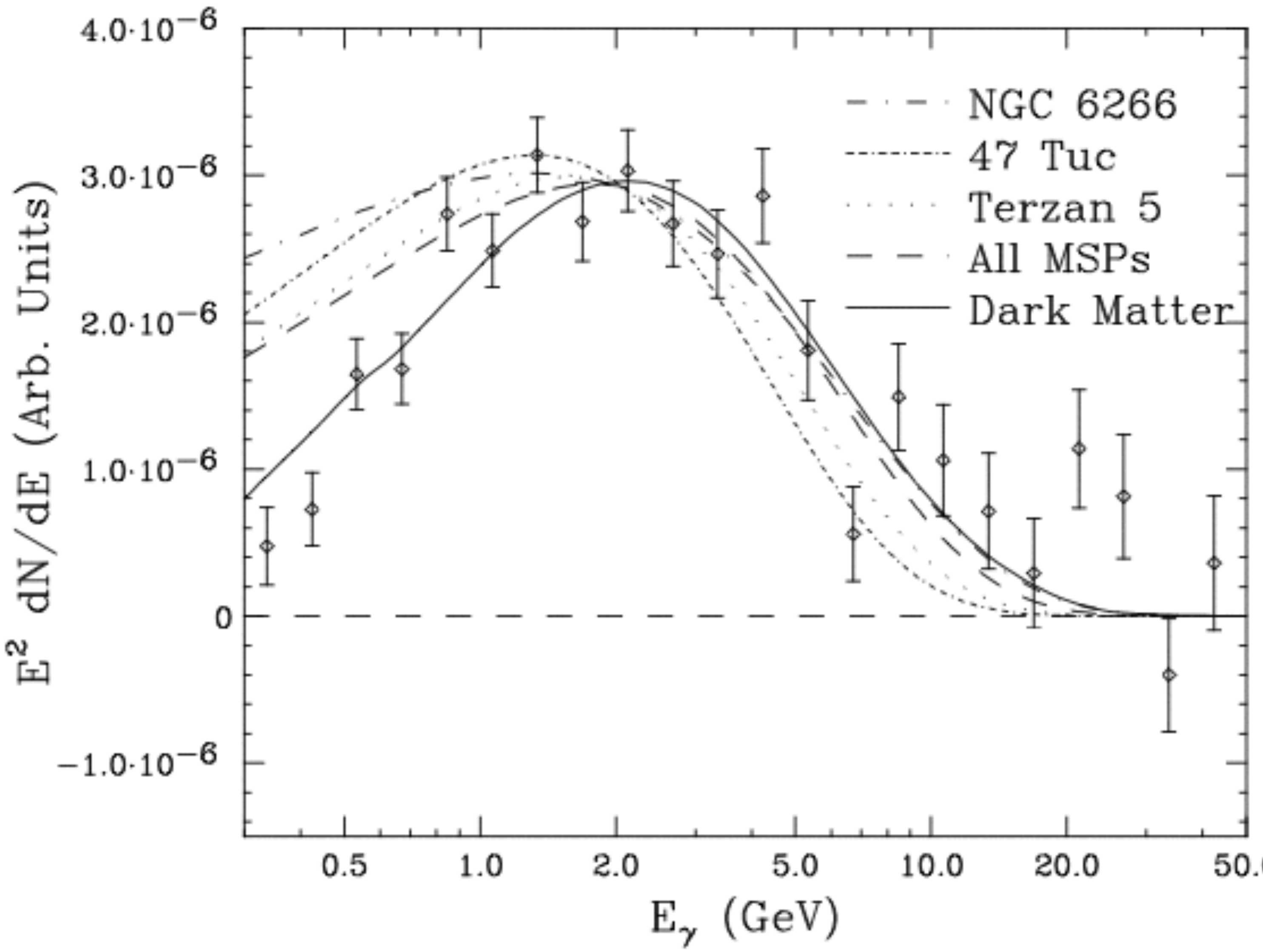
Daylan+ 2014

But why can't it be pulsars?

Especially millisecond pulsars (MSPs). They shine in gamma rays, and have a similar spectrum.

Daylan+ 2014

The low energy rolloff is a distinguishing feature.



Daylan+ 2014

The low energy rolloff is a distinguishing feature.
Also, the spatial distribution ($\sim r^{-2.5}$)
And the luminosity function

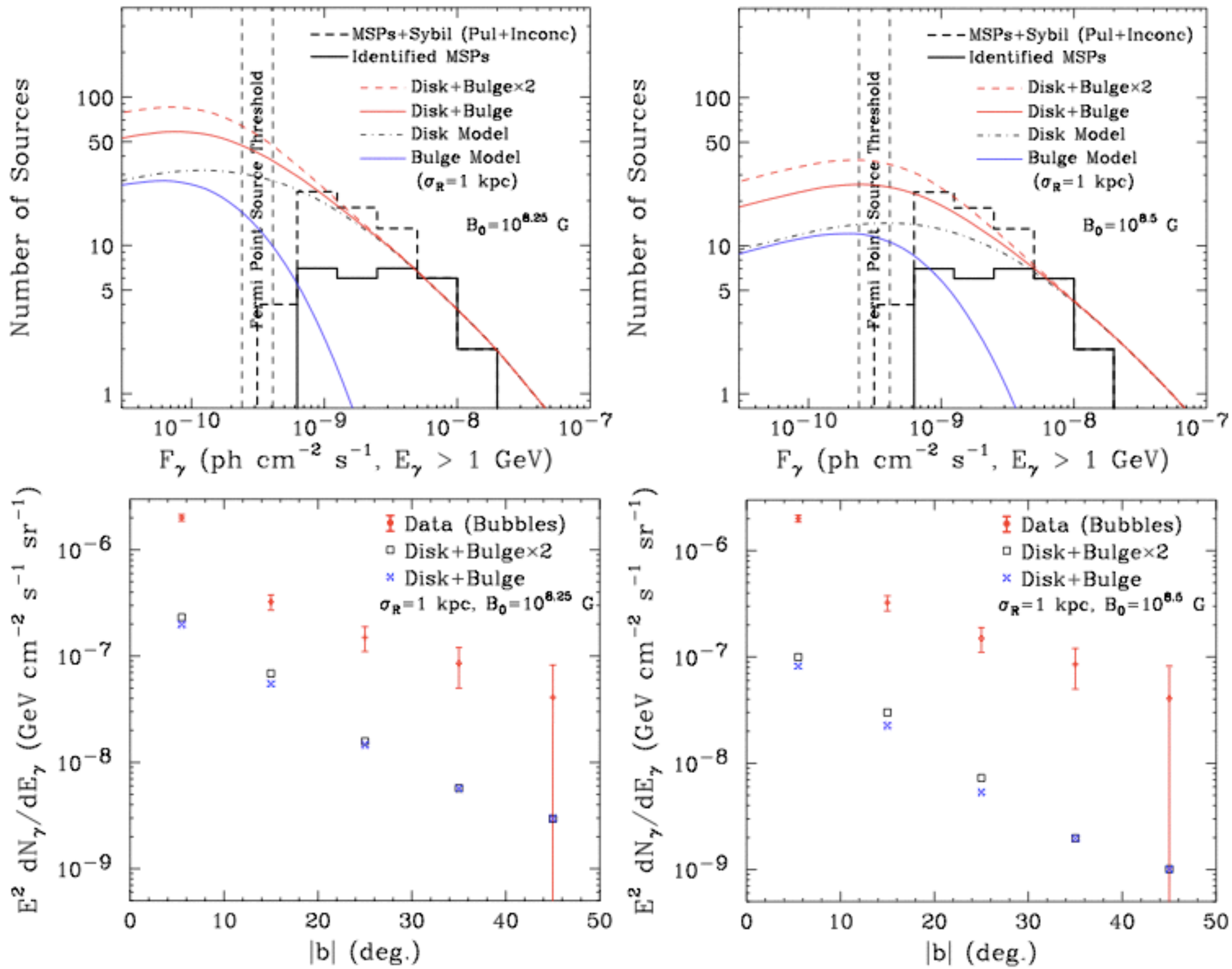


FIG. 11: Top: As in Fig. 10, but now also showing the bulge, disk, and bulge+disk contributions from millisecond pulsars. Here, we have adopted σ_R =1 kpc and $\langle |z| \rangle = 0.5$ kpc. We have normalized the bulge contribution such that the number of millisecond pulsars per stellar mass is the same in the bulge as in disk (solid blue and solid red) and by a factor that is 2 times larger (dashed red). Bottom: As in the lower frames of Fig. 9, but for the sum of disk and bulge contributions. The total diffuse emission from millisecond pulsars is in each case found to be much less than that needed to account for the observed GeV excess.

Hooper+ 2013

So, it could be pulsars if pulsars in the bulge have

- a different energy spectrum, *(but not hugely)*
- different spatial distribution, *(round vs. flattened)*
- different luminosity function *(8x more per stellar mass!)*

than we think.

But at this point we are just inventing a new class of objects. You can always explain the signal with a new class of objects. In the limit where the objects are small and annihilate, we recover the DM scenario.

Summary:

Reasons to believe:

- Signal found 4 years ago, keeps getting stronger.
- Improved analysis (e.g. the CTBCORE cut) makes the result look better.
- DM model is very simple.
- Relic cross section is fine, no need for Sommerfeld enhancement, etc.

Reasons to doubt:

- The inner Galaxy is a confusing place. Lots of other emission mechanisms.
- We really don't know that much about MSPs.
- We are leaning on the Fermi diffuse model, *which was not made for this*.

Wrap-up

- We can *model* FIR/sub-mm emission from dust. (We don't understand it)
- Correlation with RV.
- 1-comp, 2-comp degeneracy
- know ~ where dust is in 3D, will get much better
- stars in 3D also
- want 6D radiation field
- C II, N II can be really useful as tests of MW model

This is all helpful for DM annihilation searches in the MW.

Therefore, it is cosmology, and *NASA should fund it!*