3D dust, Pan-STARRS, and WISE

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11 February, 2015
WISE@5, Pasadena

Goal: provide estimates of dust reddening at high resolution in 2D, and also in 3D.

Emission maps provide high angular resolution (SFD 6′, Planck 5′, Akari 1-1.5′, WISE 6″)
WISE 12 micron resolution is amazing, but it is PAH emission, not the large dust grains that cause reddening. How to tie it to something to make it into a reddening estimate?

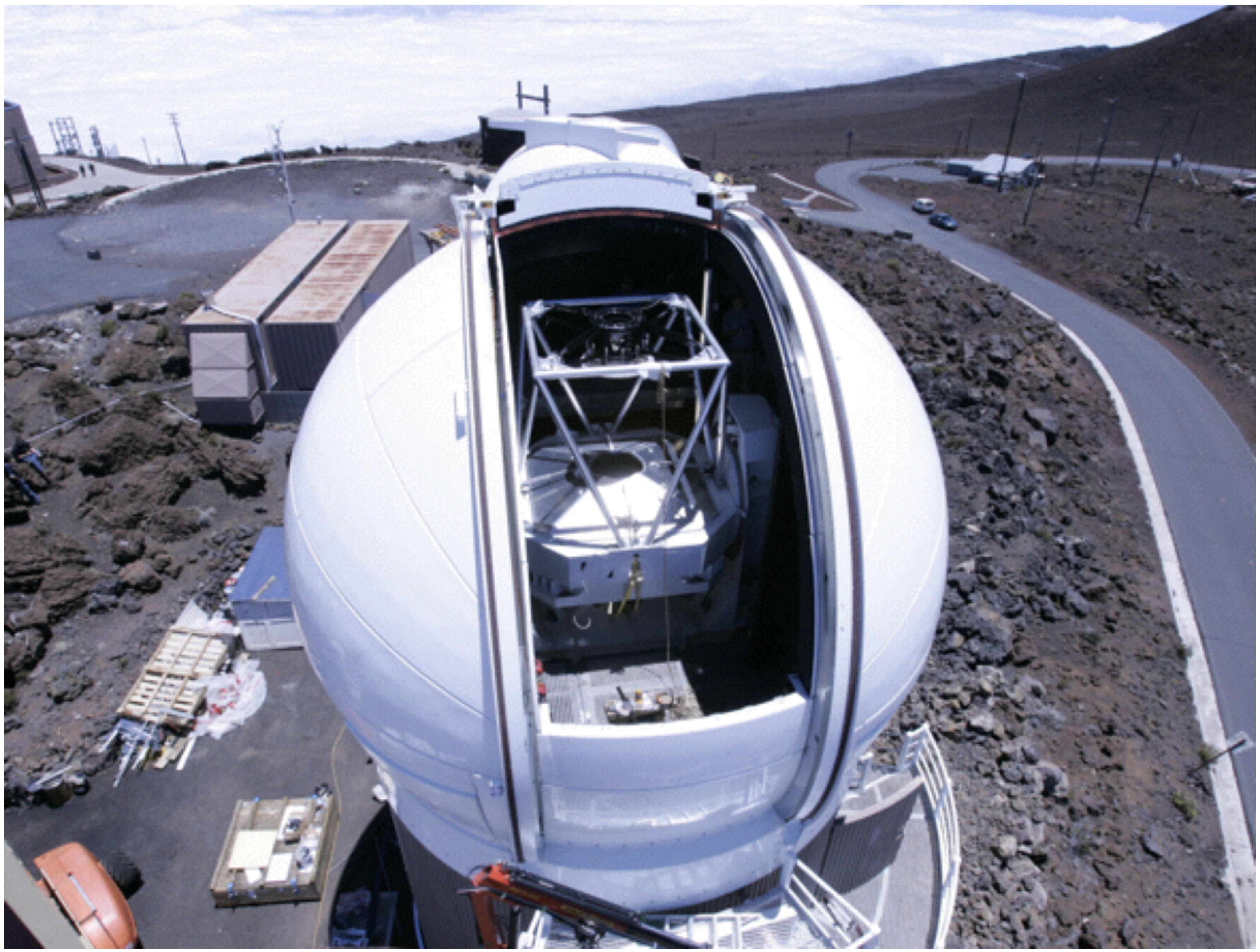
Tie to Planck
Tie to stellar photometry?

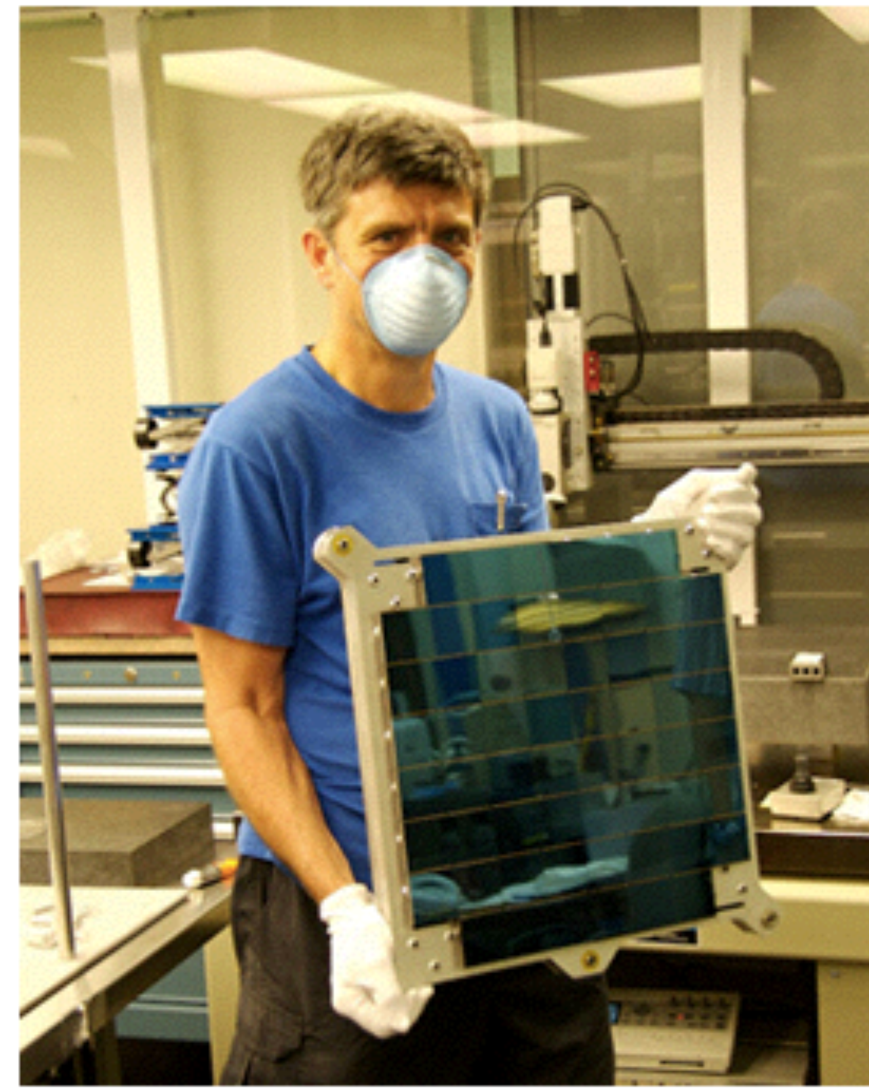
Pan-STARRS/2MASS 3D dust project

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

Pan-STARRS (Data release on April 1st! Or so…)

(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 500,000,000 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

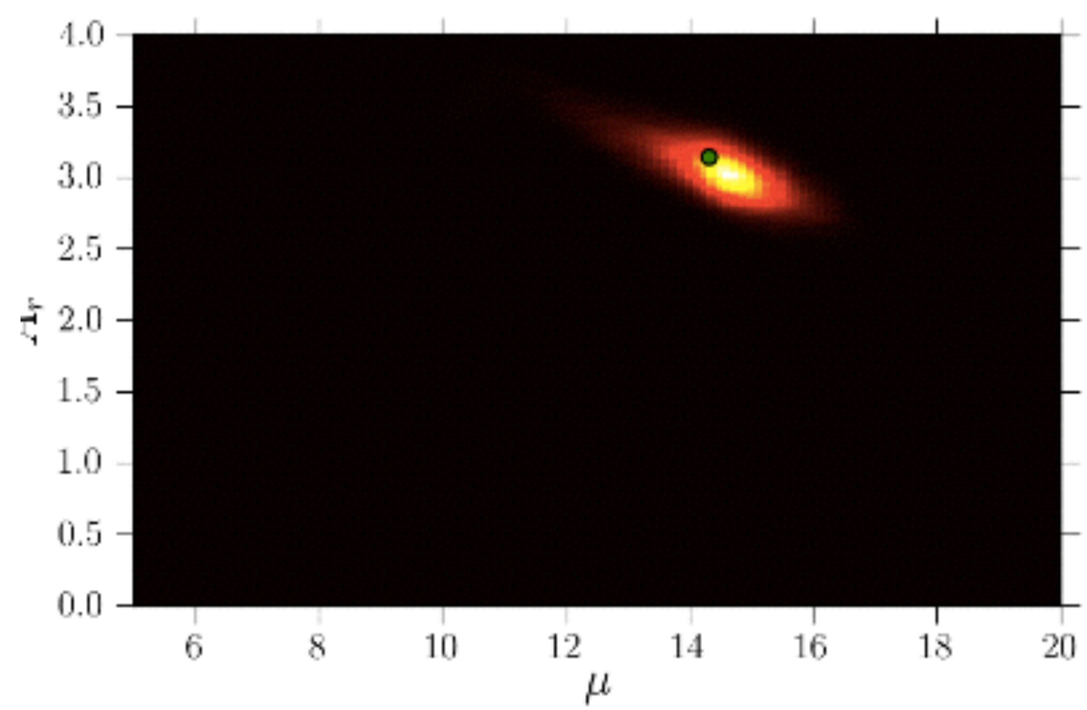
3-D dust with Pan-STARRS

- 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,

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



3-D dust with Pan-STARRS

Two intrinsic parameters used to describe star:

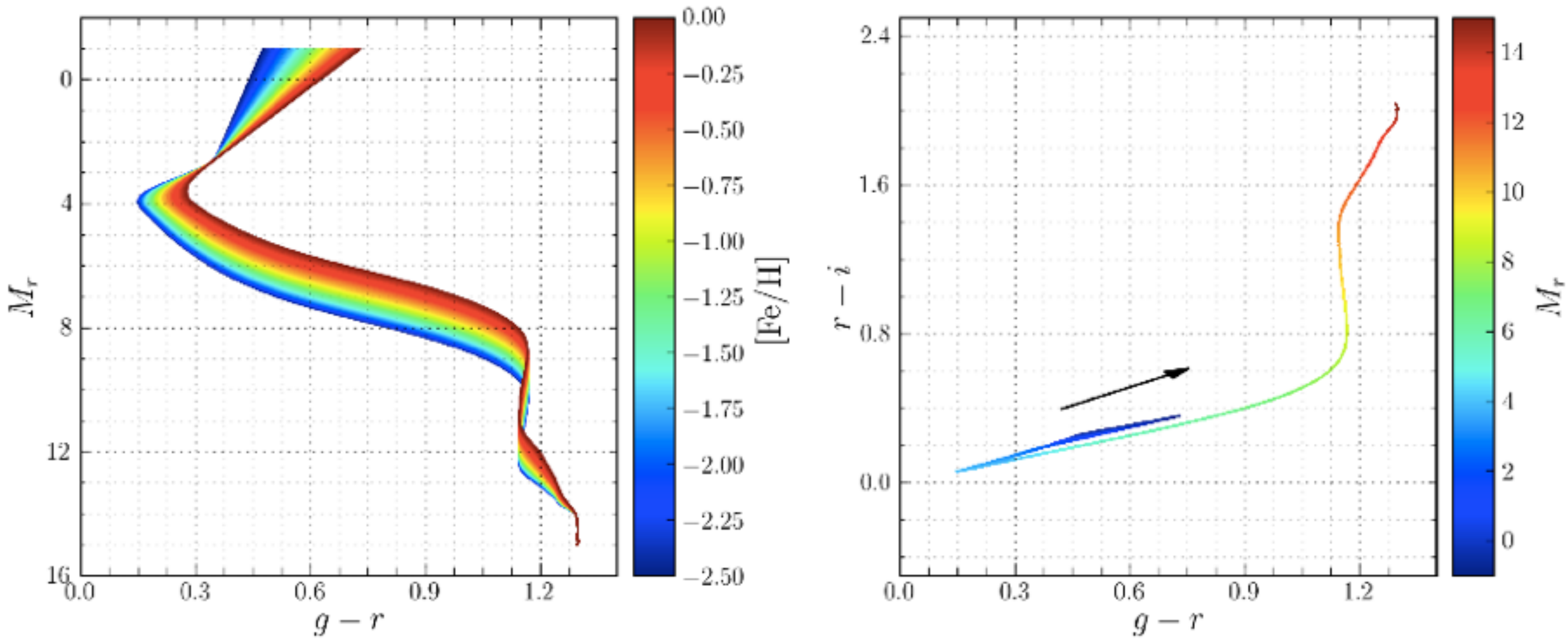
- M_r
- $\left[\frac{\mathrm{Fe}}{\mathrm{H}}\right]$

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

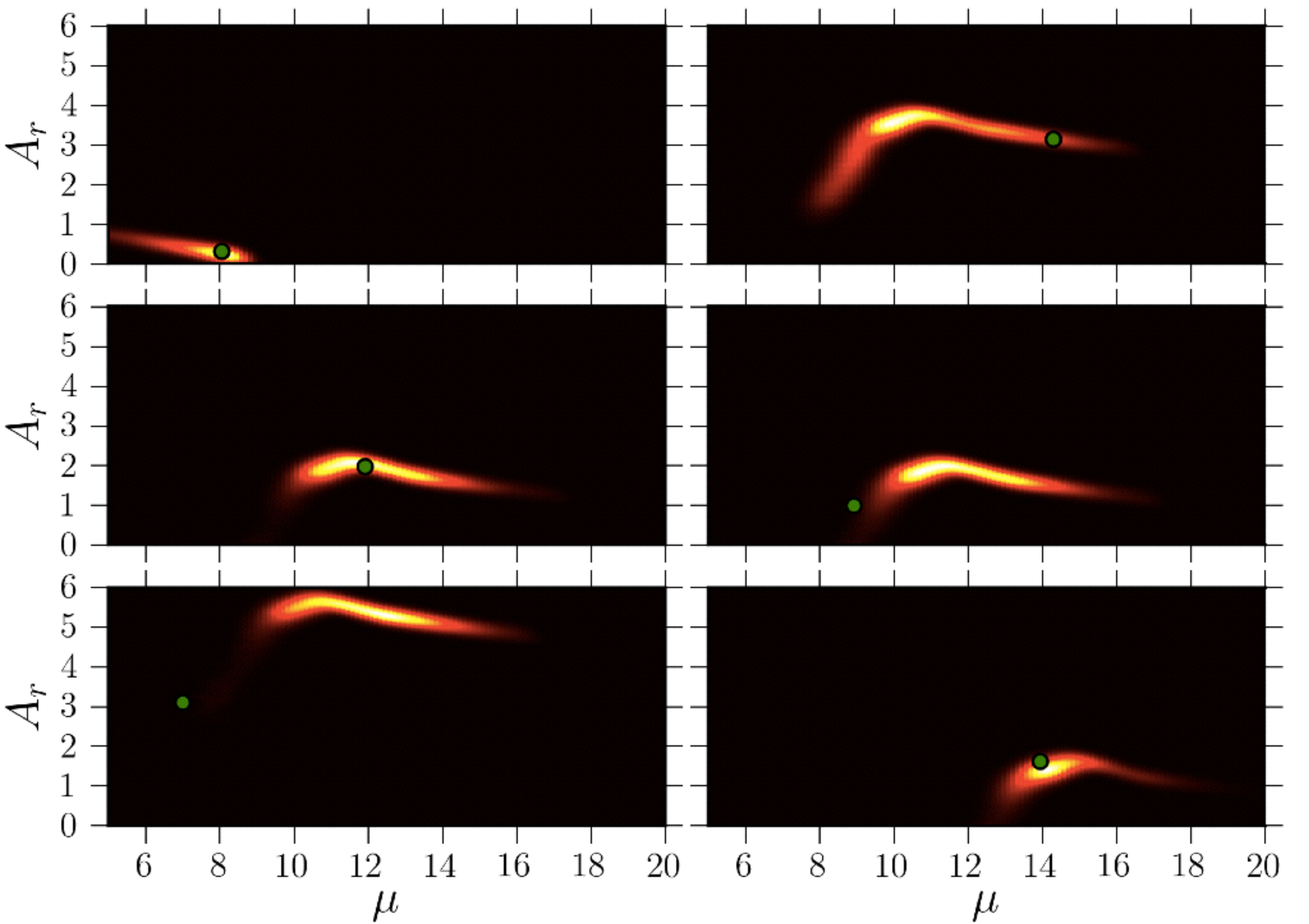
- Given M_r, $[{}^{Fe}/_{H}]$, μ and A_r, we generate apparent magnitudes:

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

- 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].

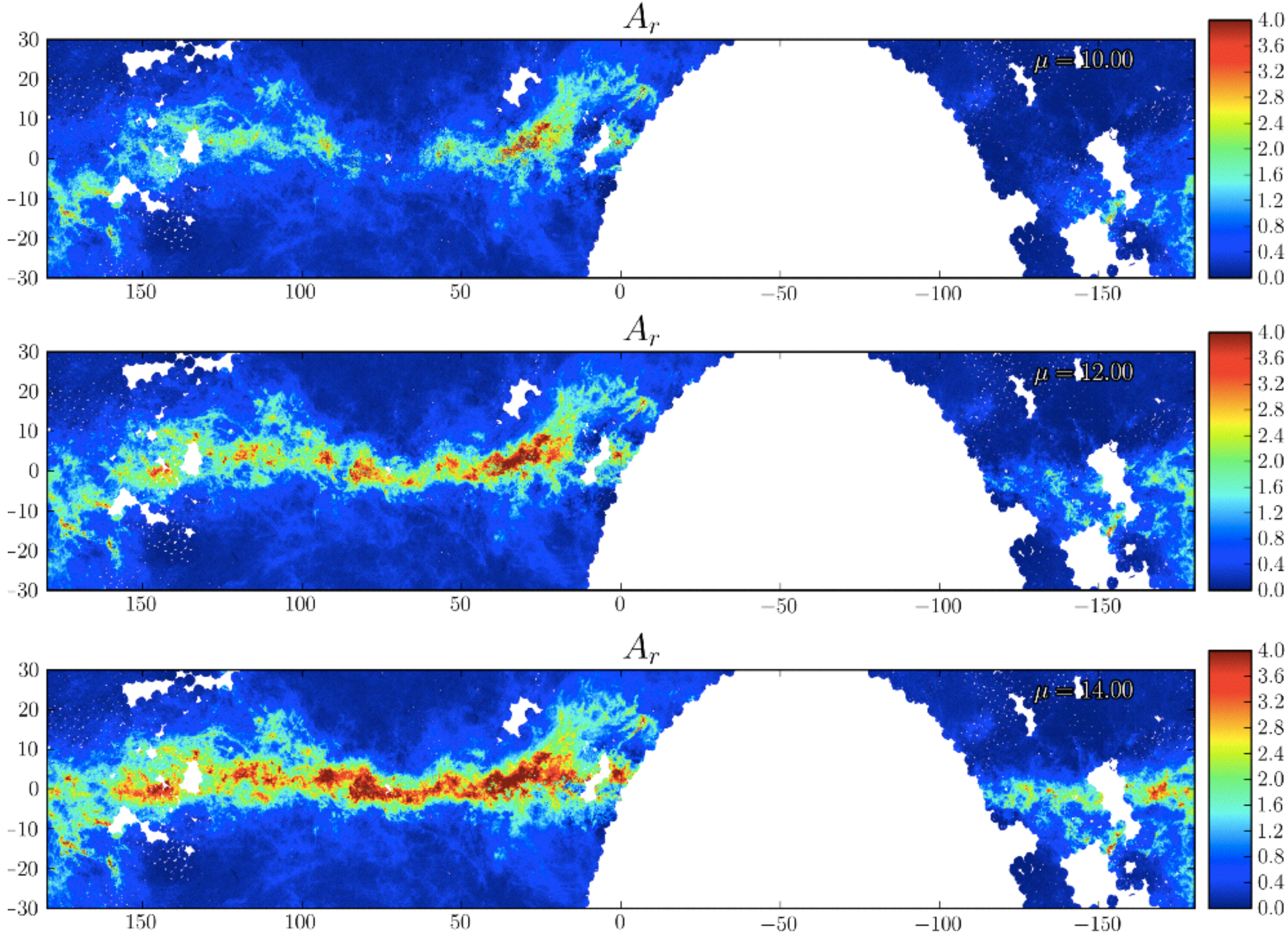


A_r
μ
0
1
2
3
4
5
6
8
10
12
14
16
18
20

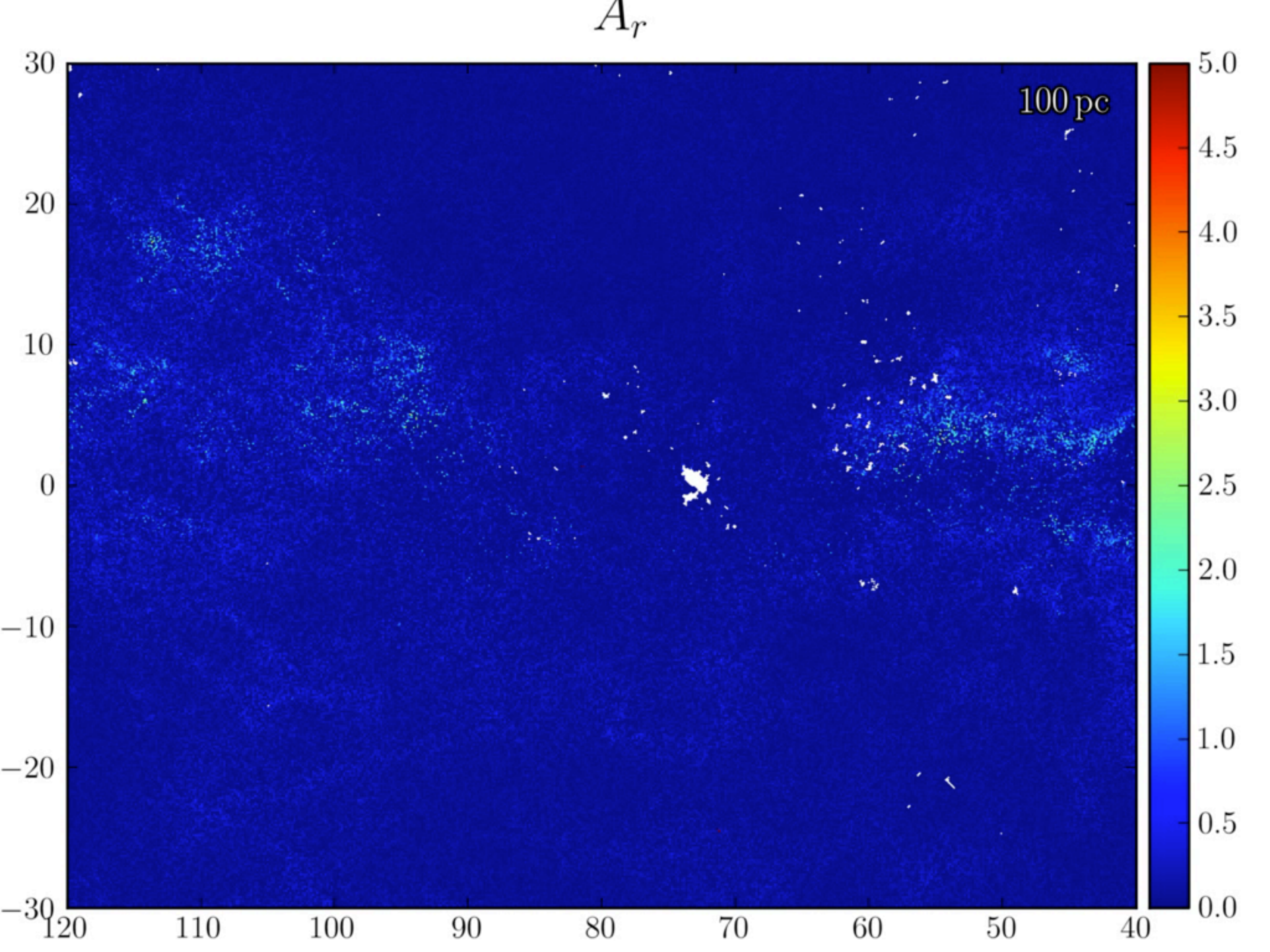
Do this for many stars.

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

Do this for millions of pixels.



A_r
$\mu = 10.00$
A_r
$\mu = 12.00$
A_r
$\mu = 14.00$
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

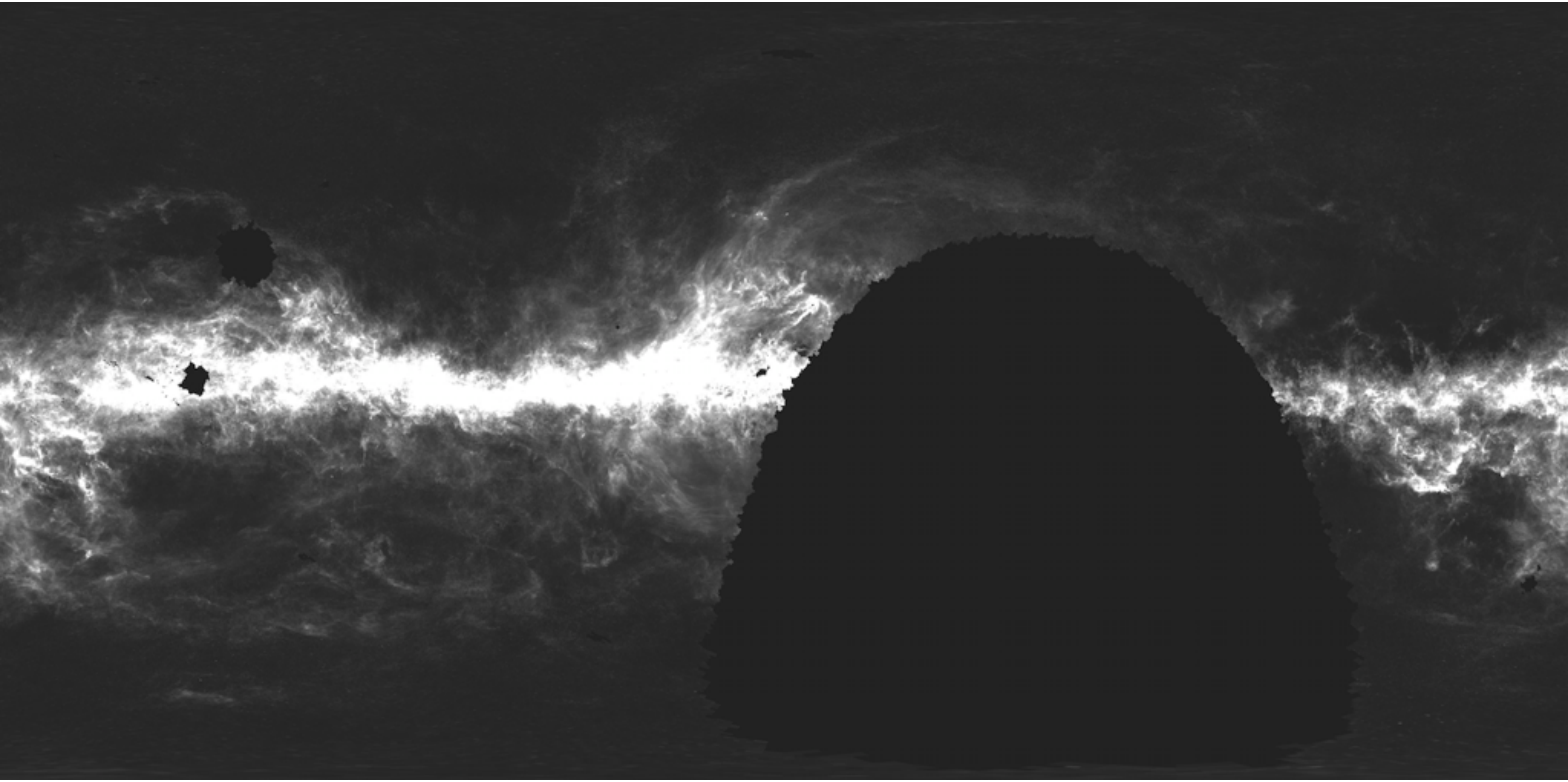
Gregory Maurice Green, Edward F. Schlafly, Douglas P. Finkbeiner, Mario Jurić, Hans Walter Rix, Will Burgett, Kenneth C. Chambers, Peter W. Draper, Heather Flewelling, Rolf Peter Kudritzki, Eugene Magnier, Nicolas Martin, Nigel Metcalfe, John Tonry, Richard Wainscoat, Christopher Waters

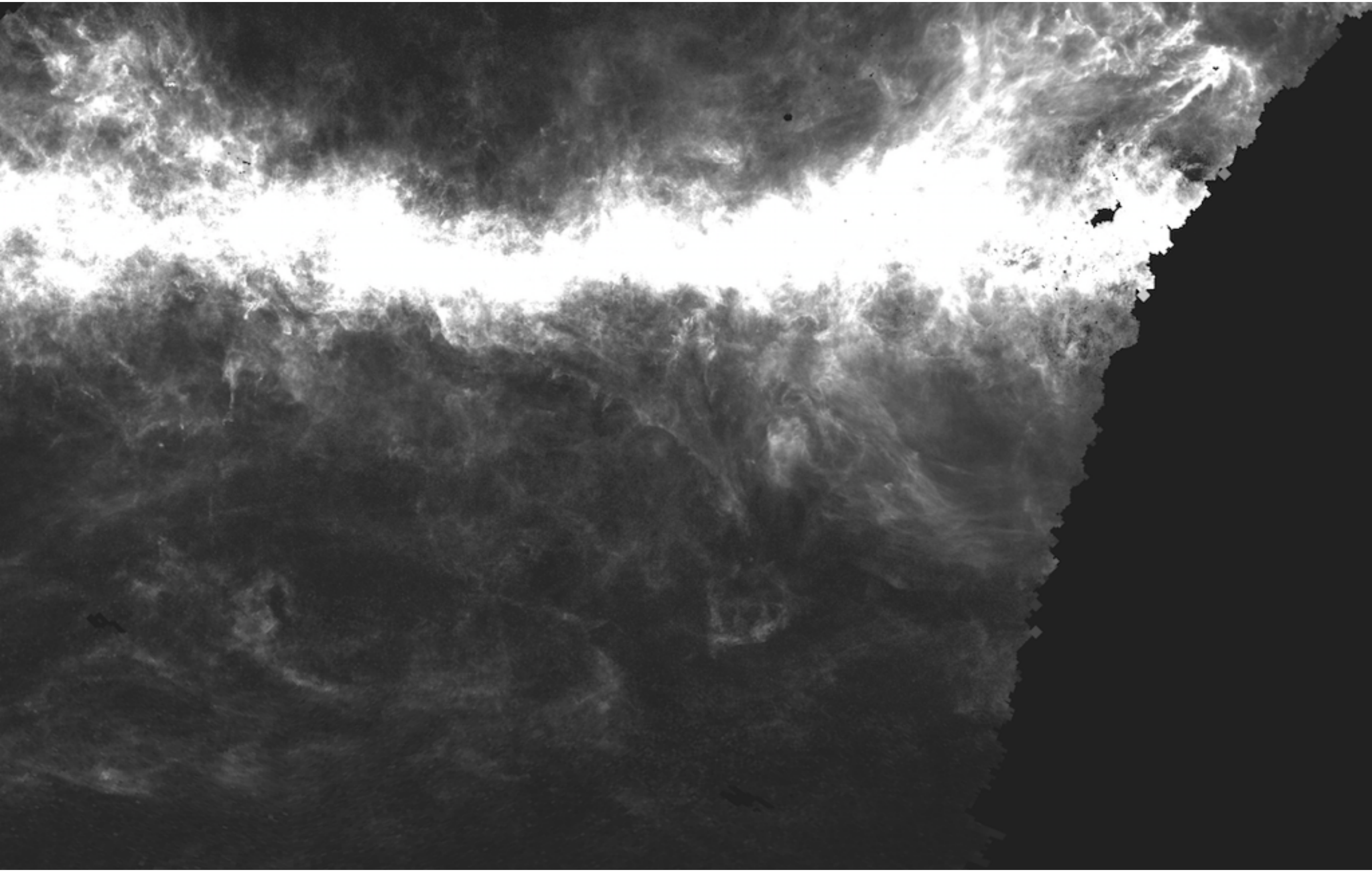
Comments: 18 pages, 12 figures

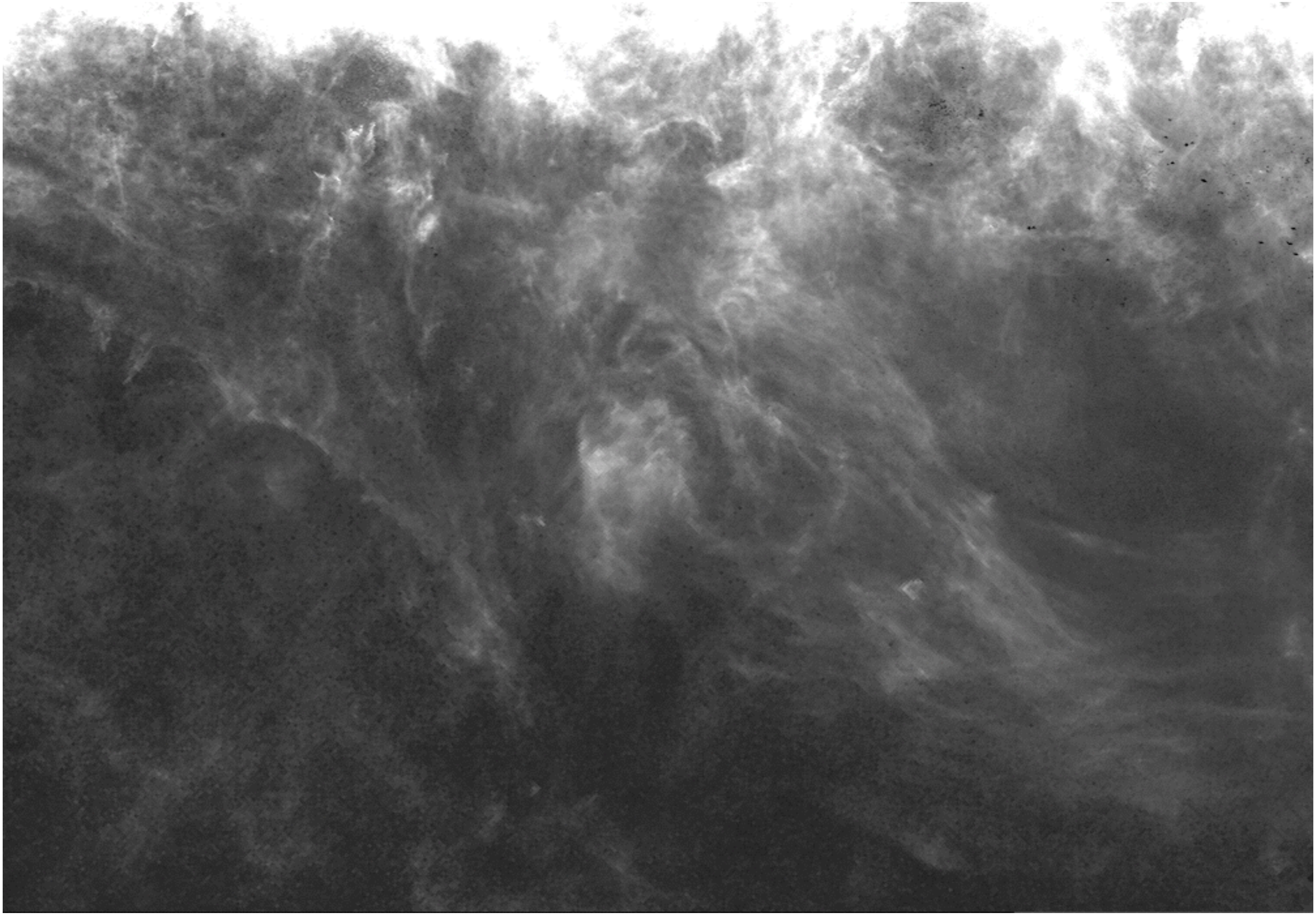
Subjects: **Astrophysics of Galaxies (astro-ph.GA)**

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.







What does WISE have to do with this?

- We would like to use redder bands in the plane. WISE forced photometry at locations of known sources may help.
- WISE 12 micron map provides a “subpixel spatial prior.”

Tracing dust with WISE band 3

Challenges:

- 12 μm emission is PAH, not large grains
- Correlates well with large grains, except for dense cores
- Zodiacal light is much worse at 12 μm than 100 μm
- Bright star artifacts (ghosts, latents)
- Scattered light from Moon

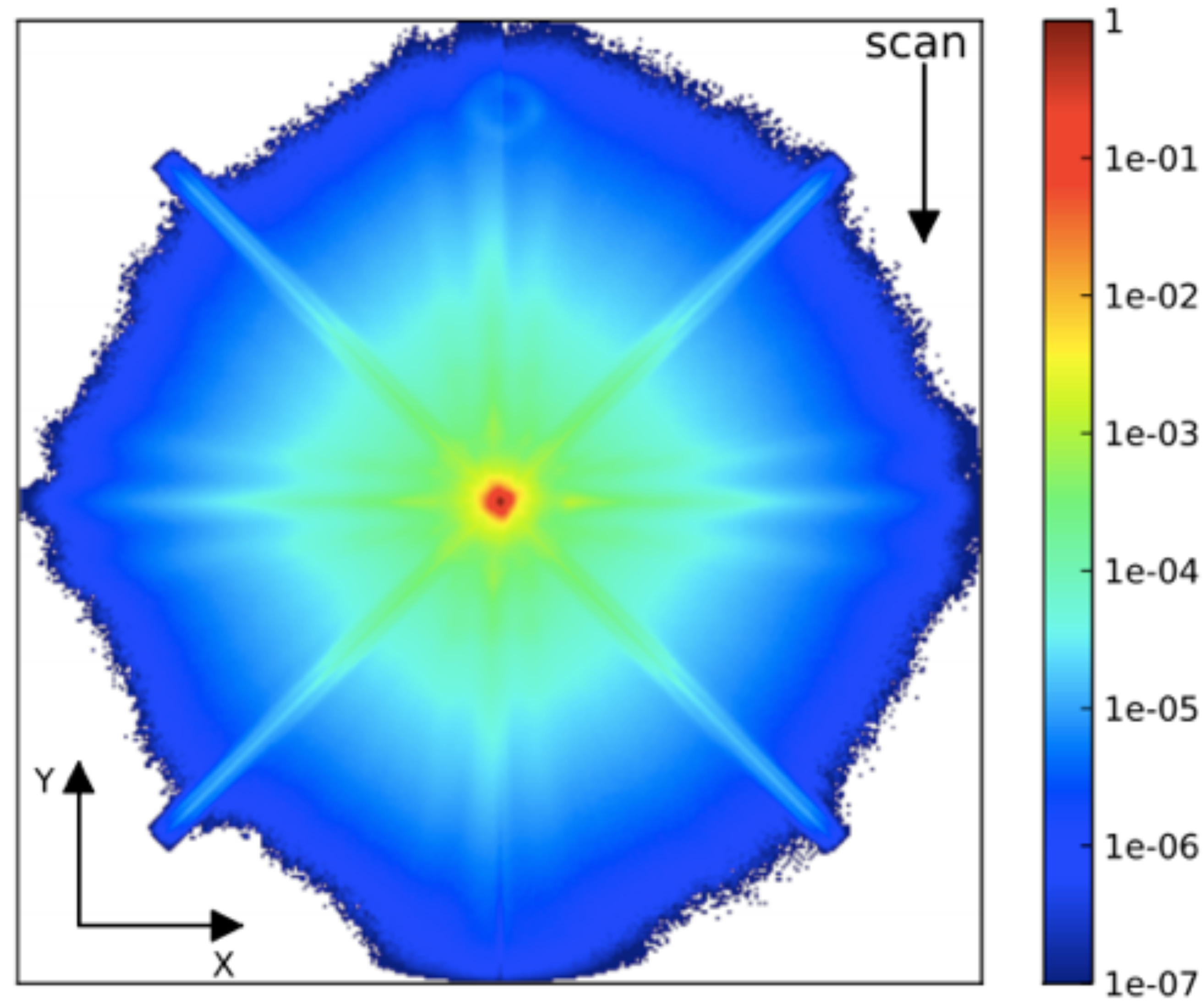
Aaron Meisner

But, this is tractable because:

PSF is very stable

Repeat measurements help eliminate artifacts

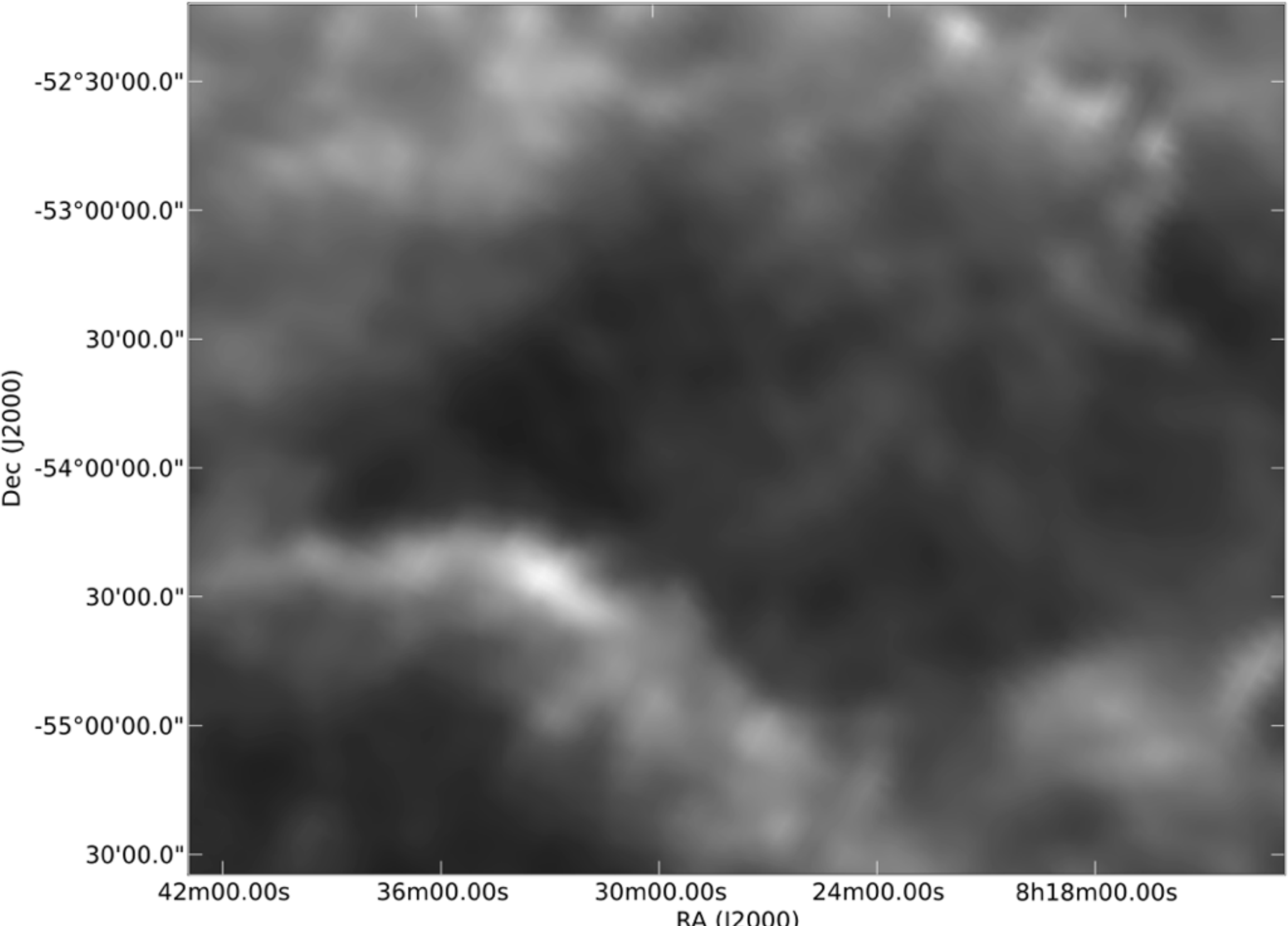
Tie to Planck on ~ 2 deg scales to suppress zodiacal light



The Wide-field Infrared Survey Explorer (WISE)

Aaron has cleaned up the 1.5 million WISE exposures over the full sky and built 430 12x12^{o} mosaics.

see Meisner & Finkbeiner, ApJ 781, 5 (2014)



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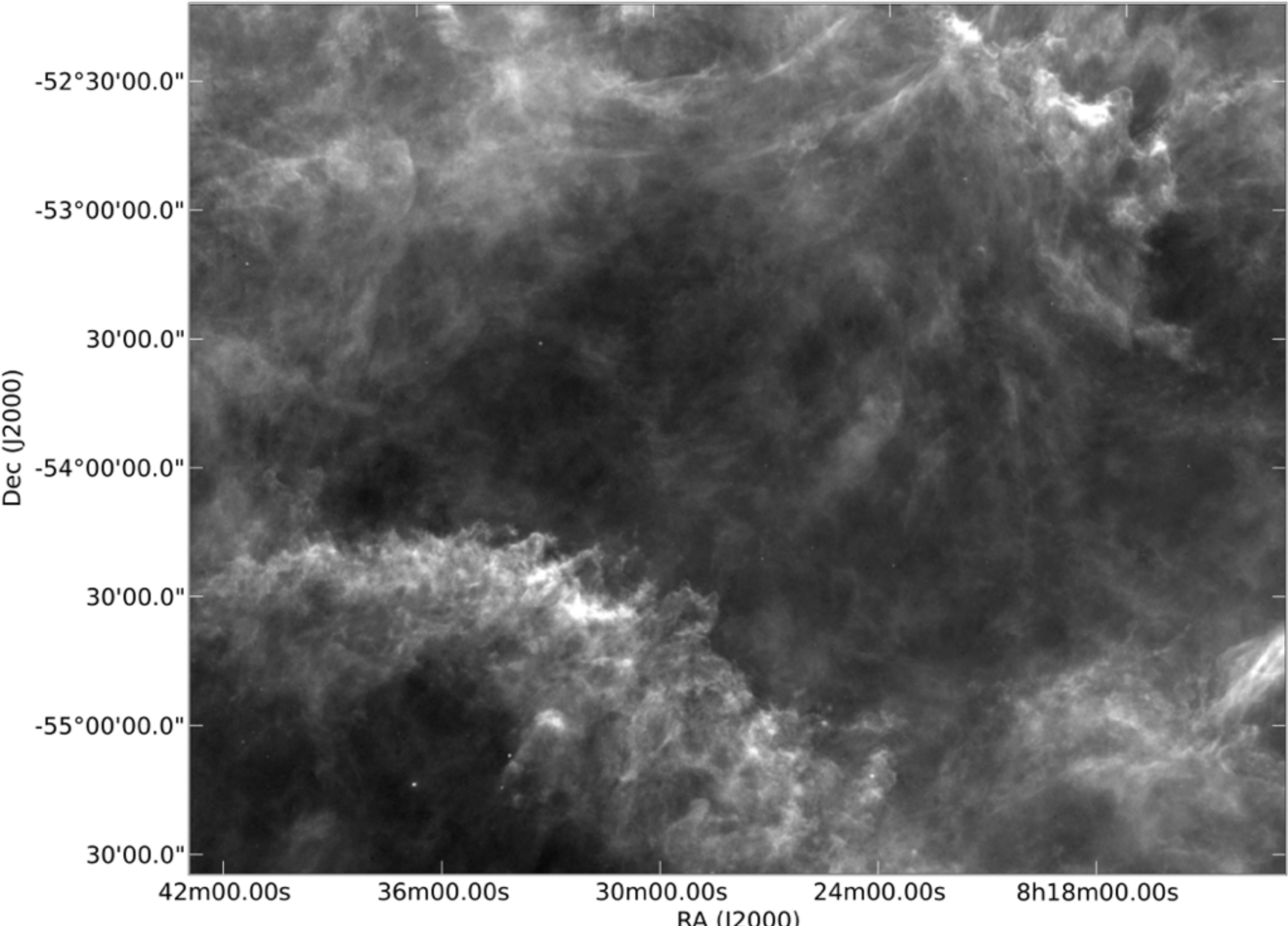
8h18m00.00s
RA (J2000)



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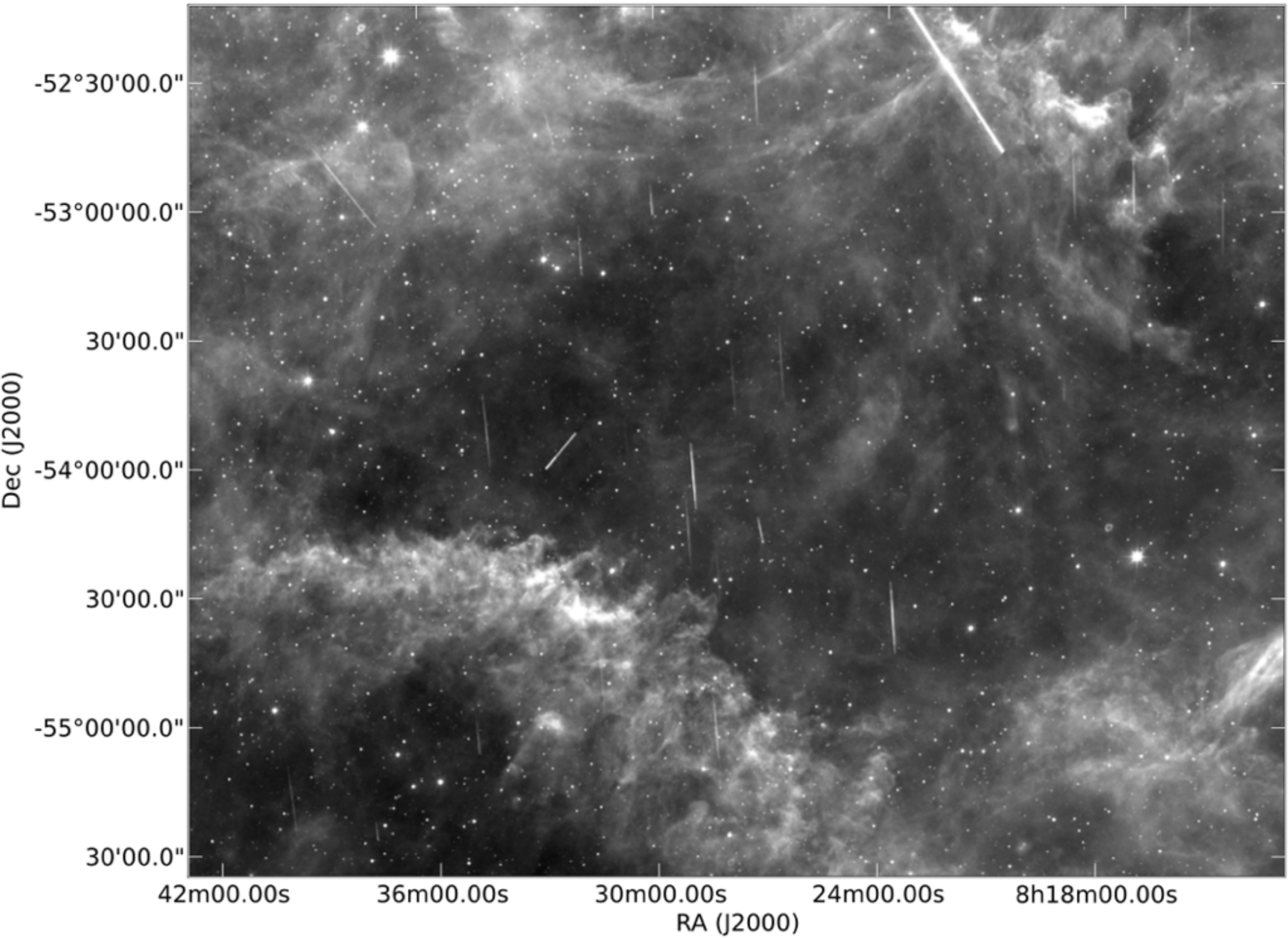
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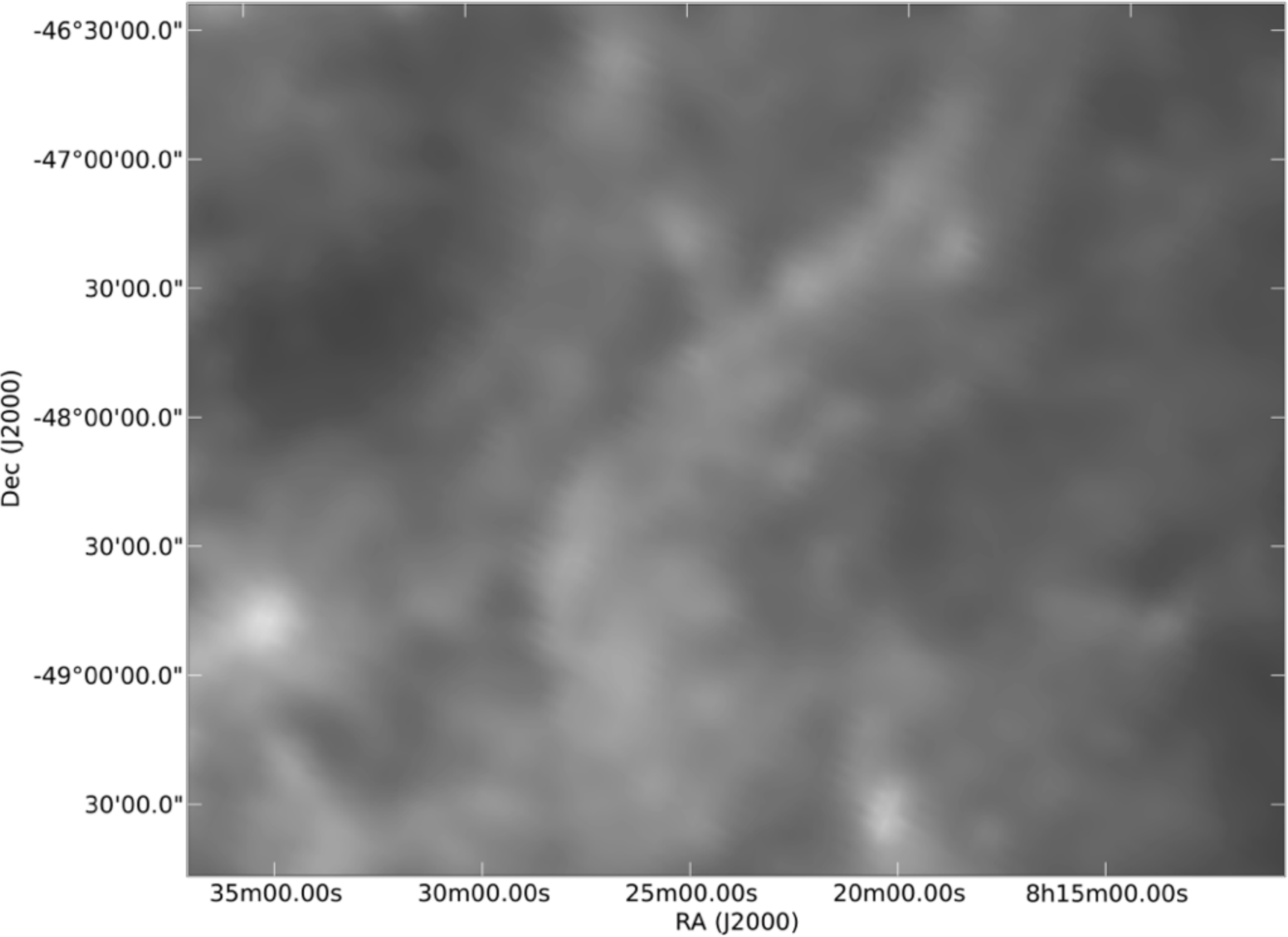
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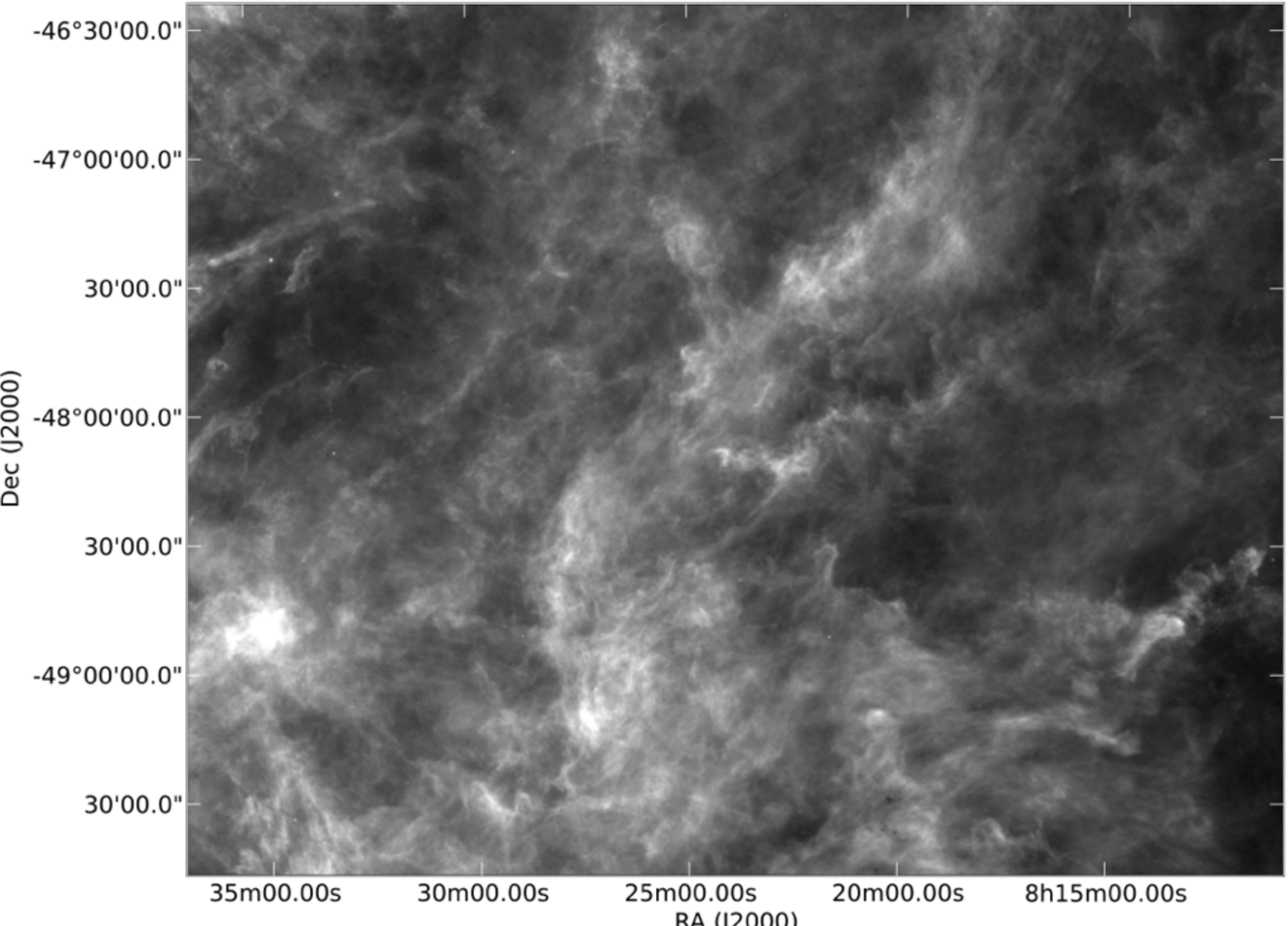

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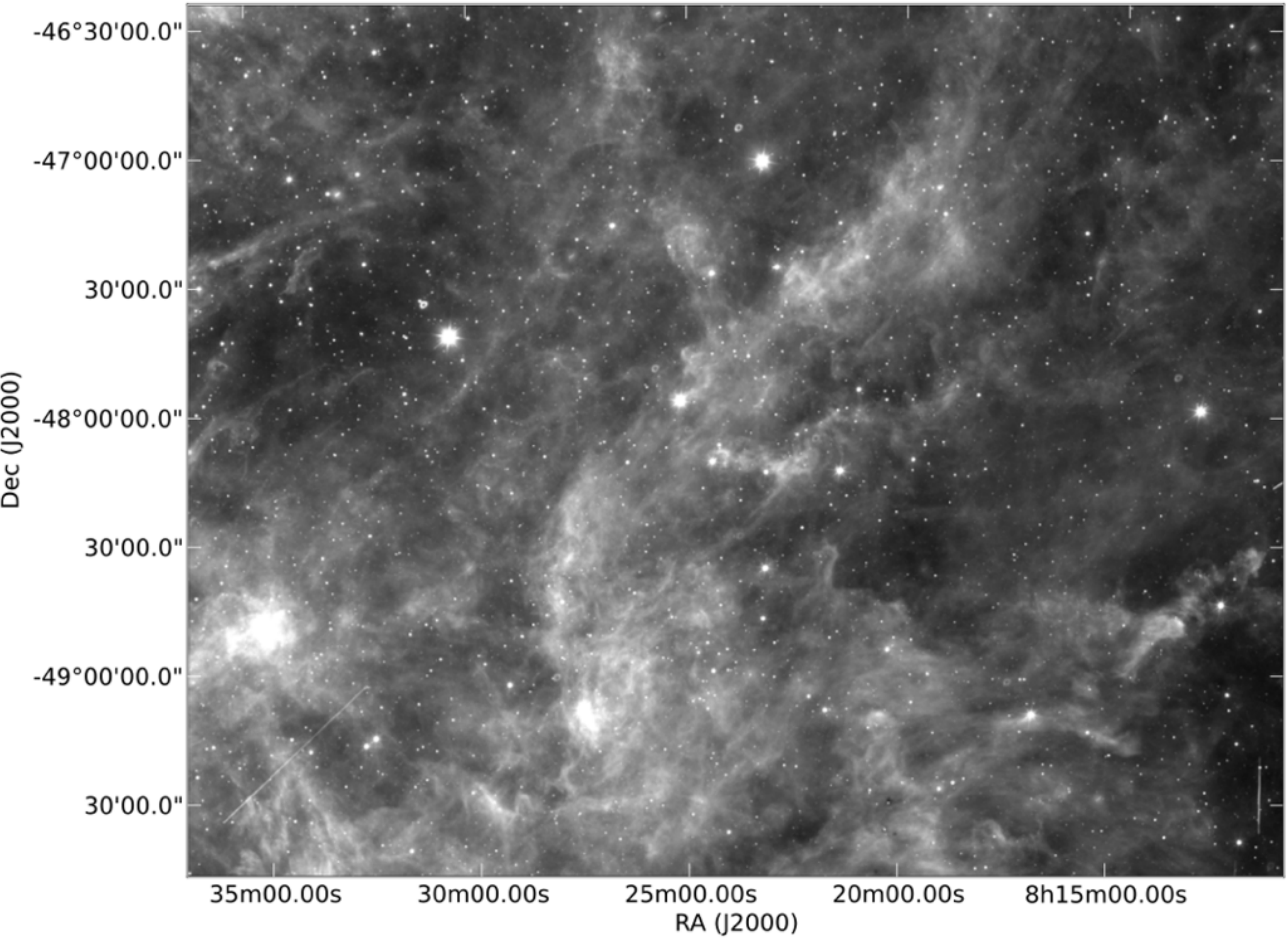
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8h15m00.00s
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With such high angular resolution, can we use WISE 12 micron as a "subpixel spatial prior" for the 3D dust fit?

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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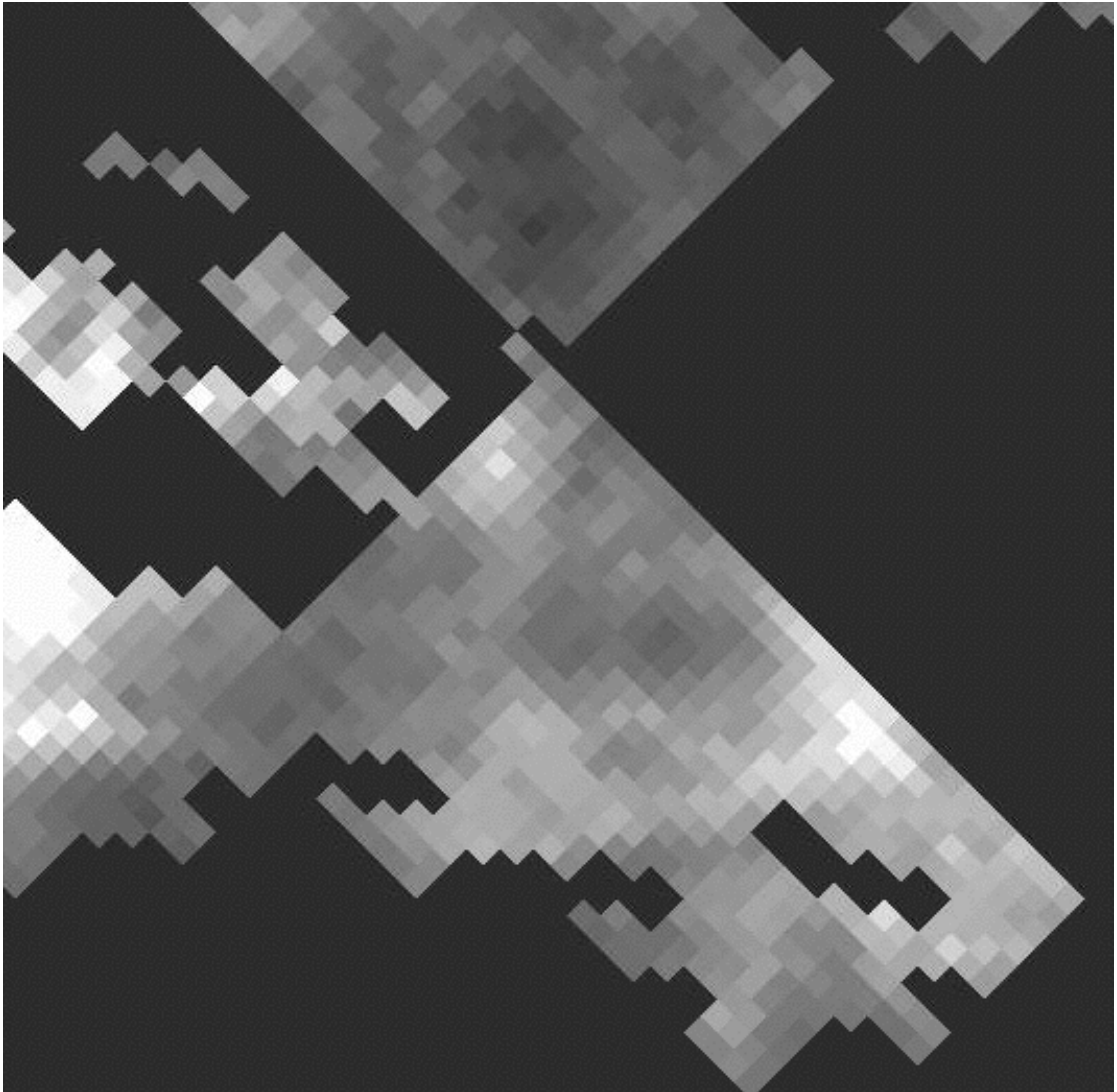

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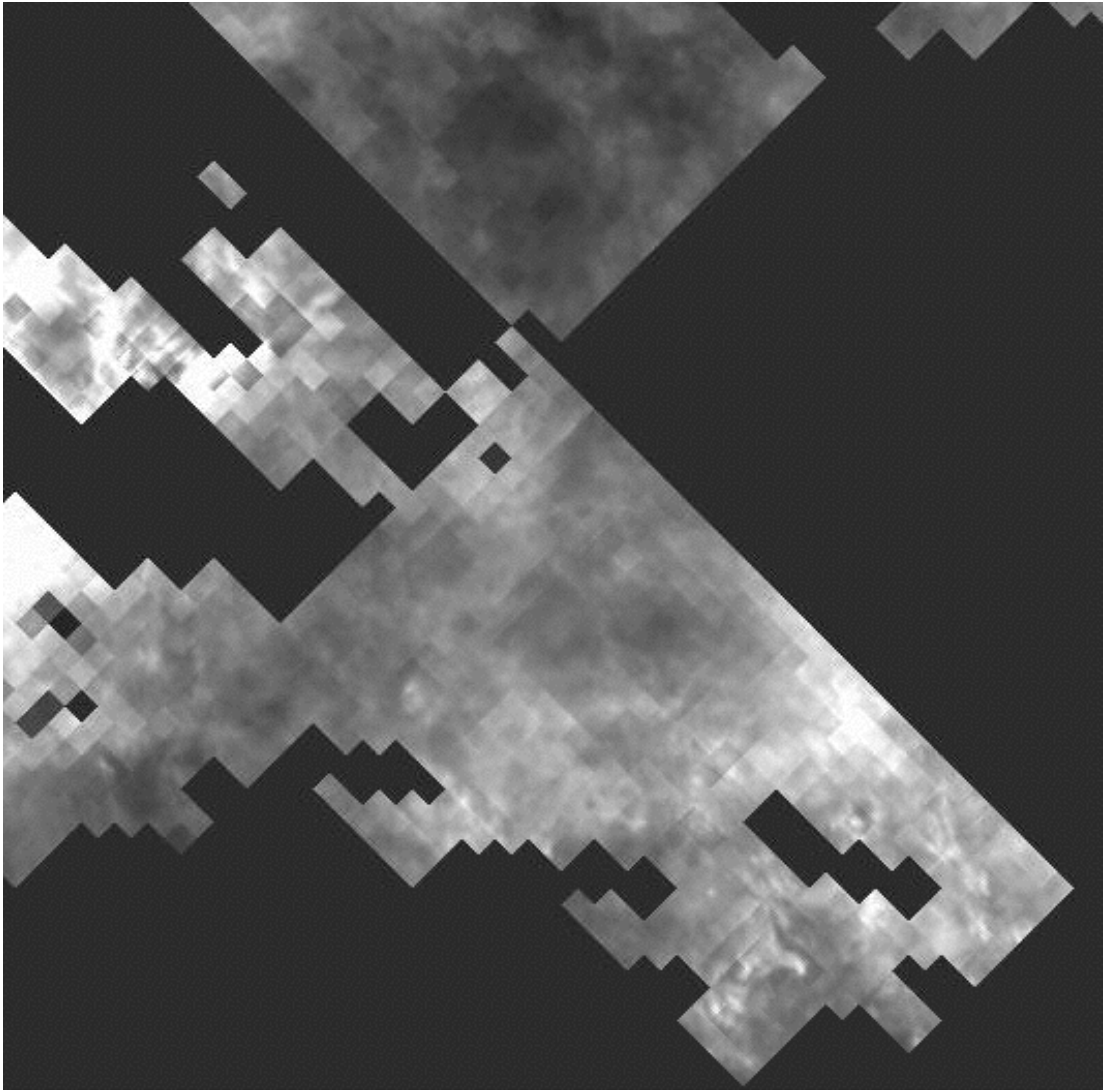

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Conclusion:

PAH emission observed by WISE at 12 micron is stunning beautiful, and an important contribution to understanding the ISM.

Reddening estimates: not directly related to E(B-V) — need to tie it to something. Most direct choice is to tie to a billion stars.

WISE gives us an 8x8 (or 16x16) “image” inside of each of our PS1/2MASS pixels. This stabilizes the fit and provides the correct calibration of WISE on 7’ scales when WISE correlates with dust.

If uncorrelated, result is probably not worse than doing nothing!

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Conclusion:

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

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