Wising up to CatWISE

Using simulation-based inference to measure the cosmic dipole

Oliver Oayda

PhD Candidate
Sydney Institute for Astronomy
The University of Sydney

Supervised by
Geraint Lewis
Tara Murphy

THE UNIVERSITY OF SYDNEY

HDR Student Symposium

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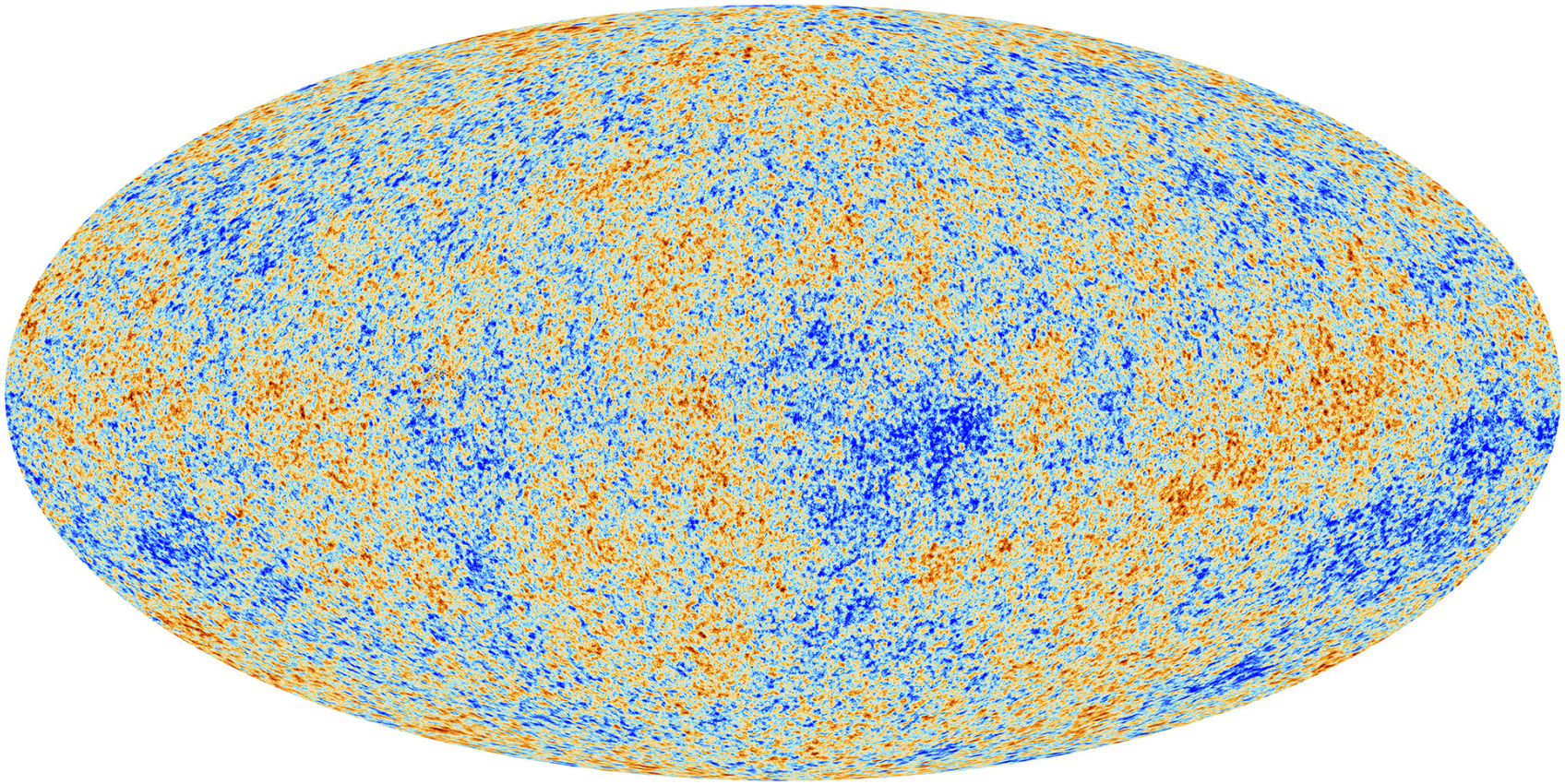
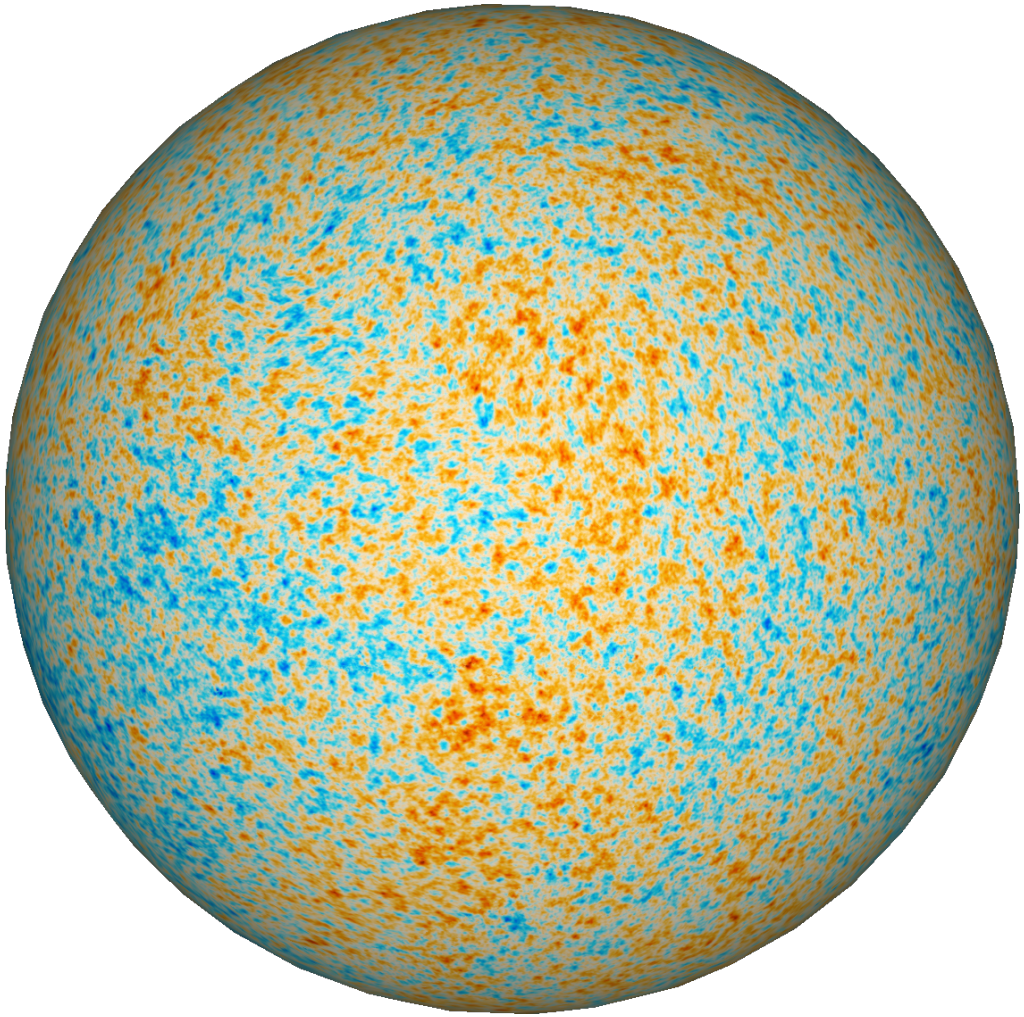
Simulation-based inference resolves systematics.

The Kinematic Dipole



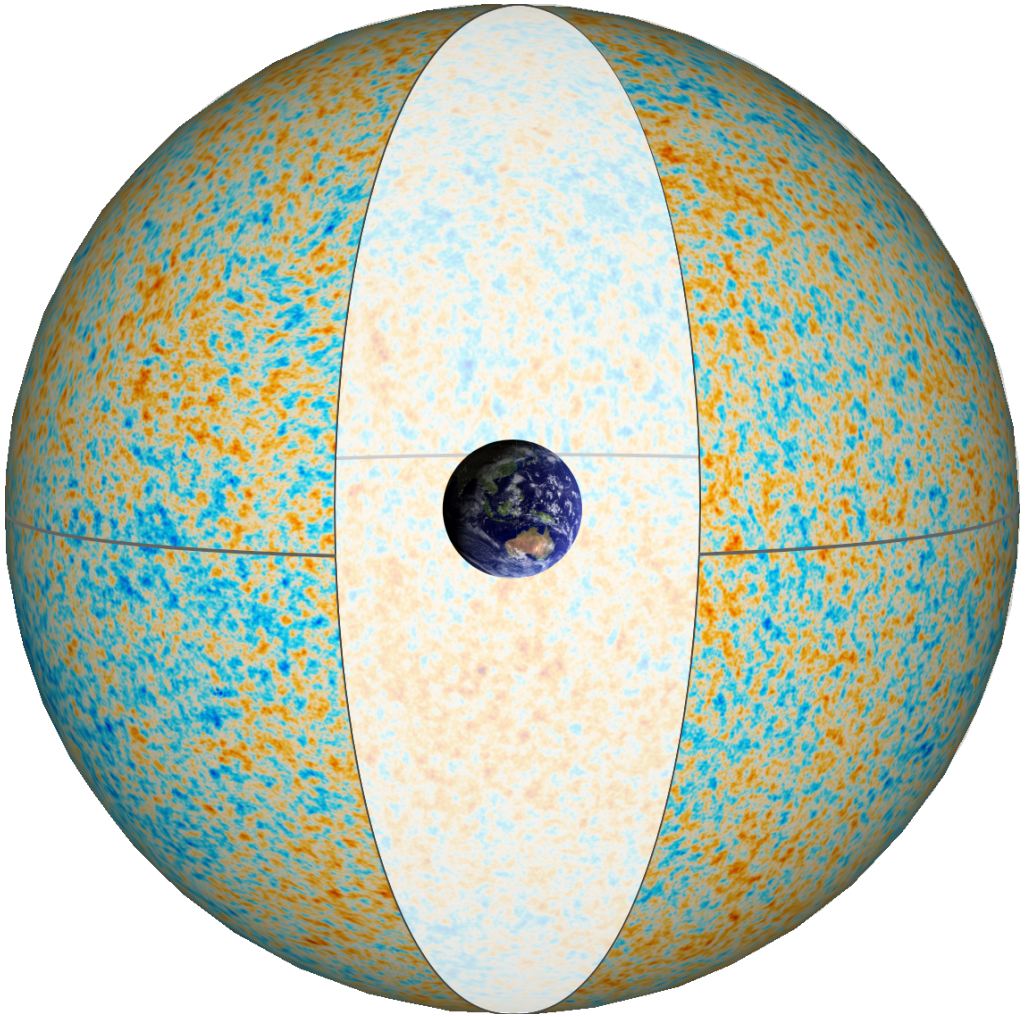
CMB temperature map (Planck satellite).

The Kinematic Dipole



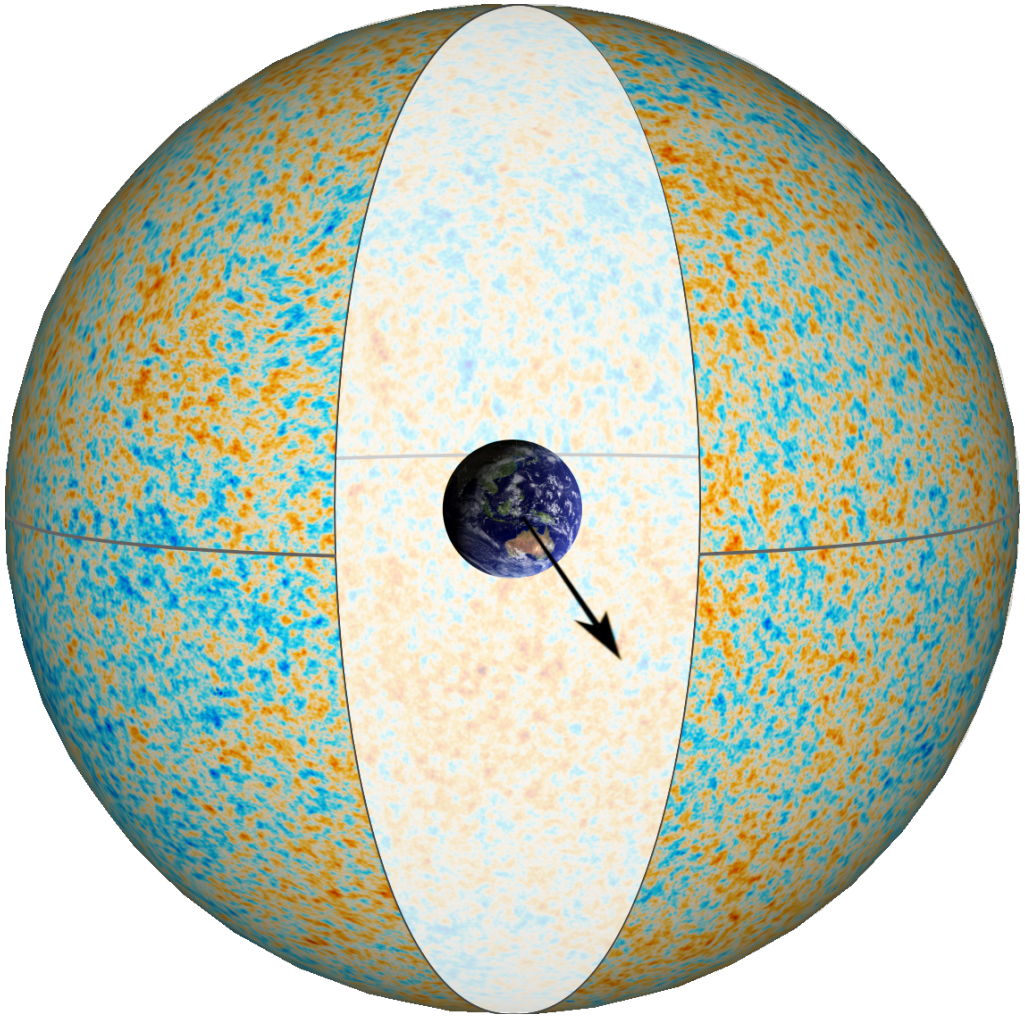
CMB as a sphere.

The Kinematic Dipole



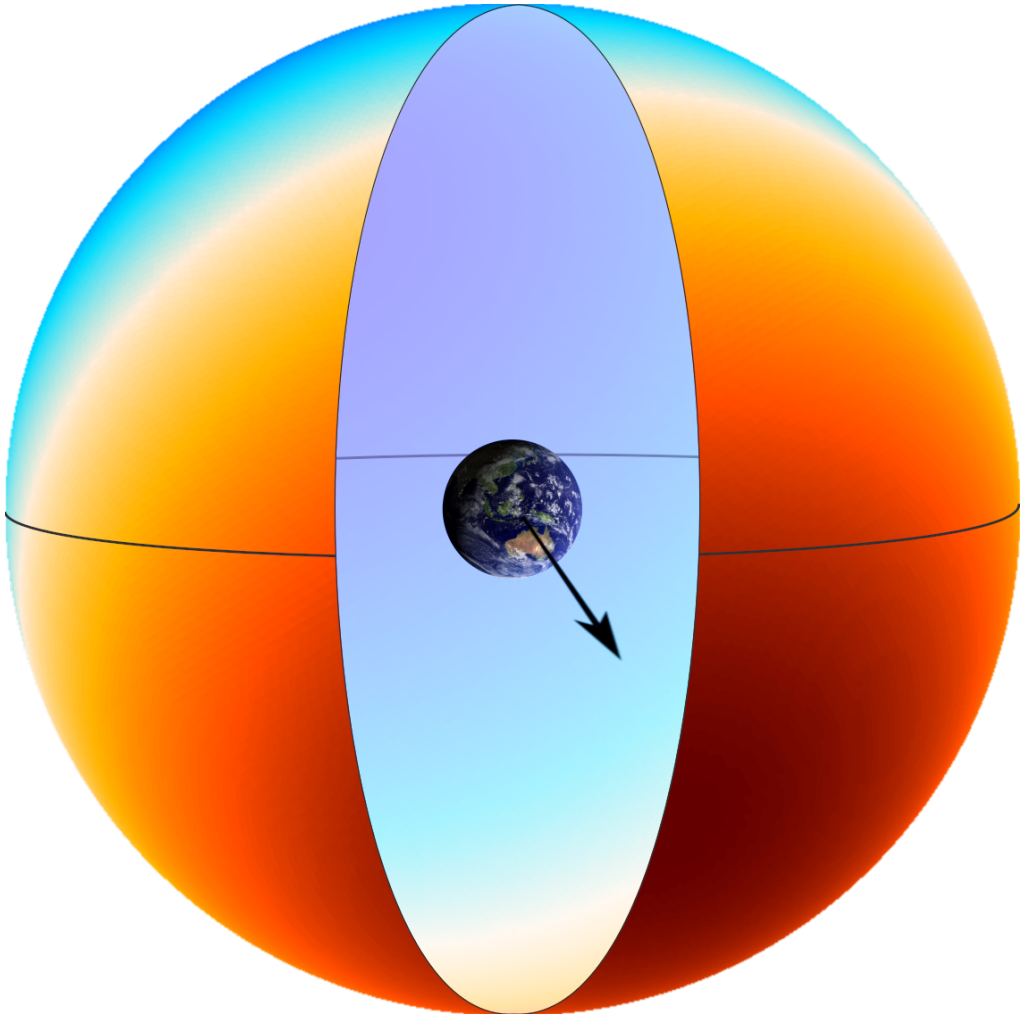
CMB as a sphere (Earth inside).

The Kinematic Dipole



We're moving through the Universe!

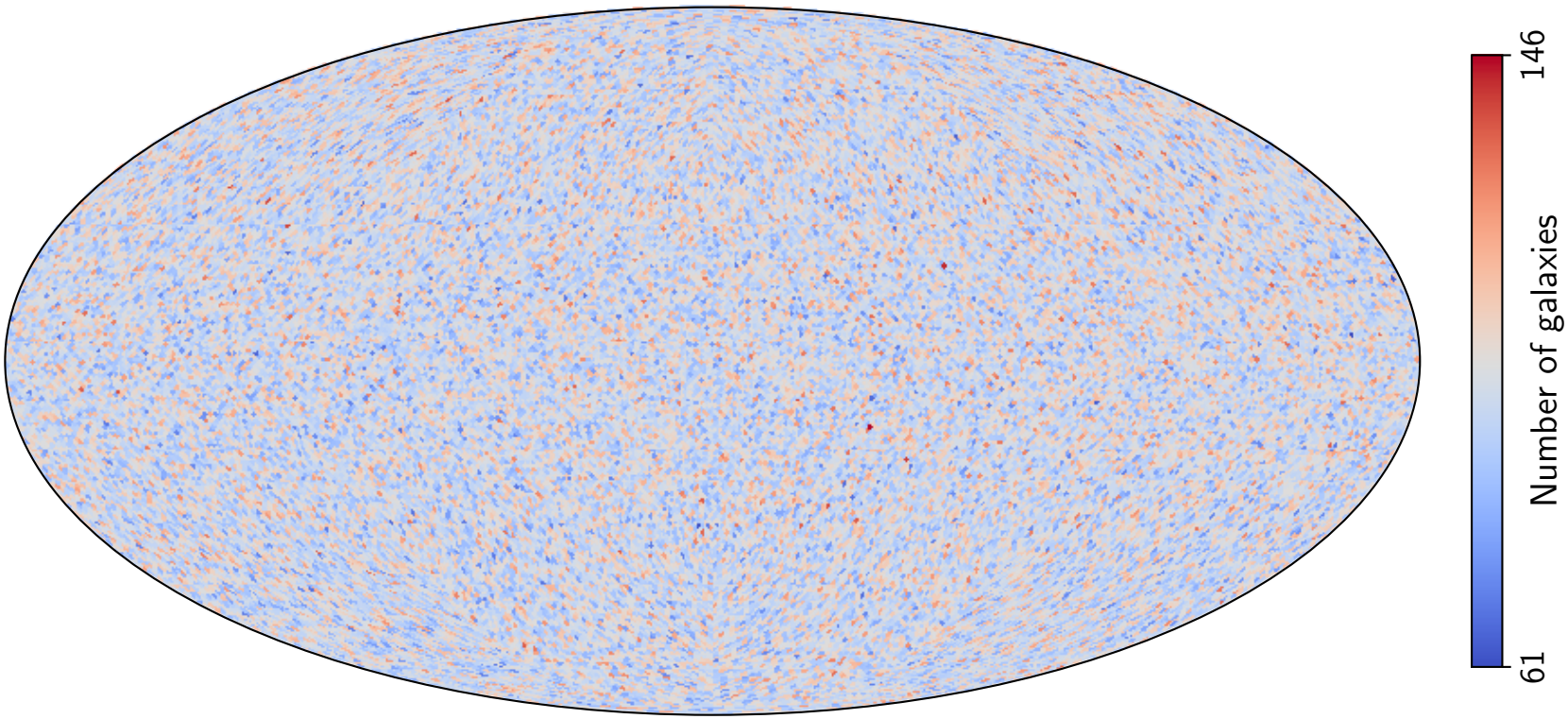
The Kinematic Dipole



CMB dipole as sphere (Earth inside).

Counting Galaxies

$$N_i = \overline{N}(1 + \mathcal{D}\cos\theta_i)$$



Simulated isotropic galaxy map (+ dipole).

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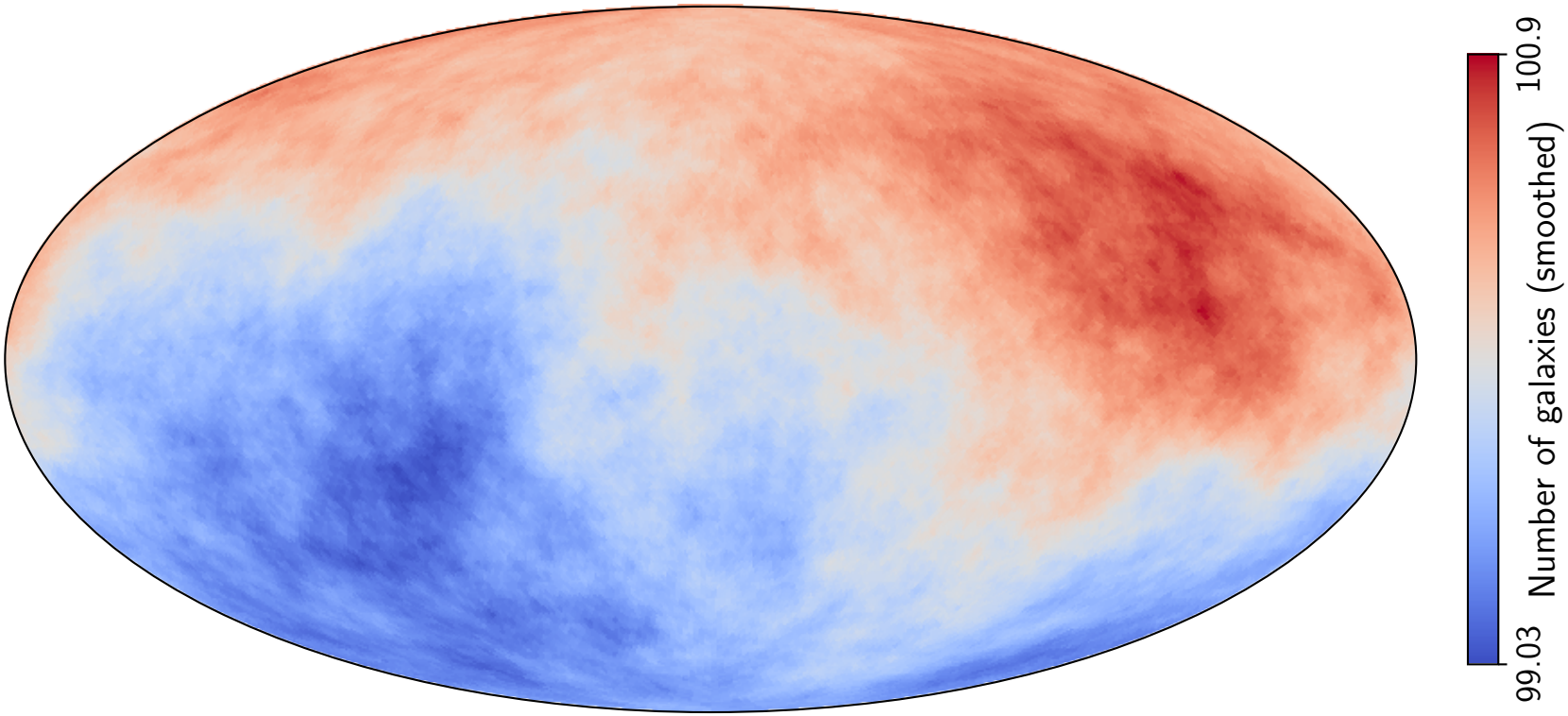

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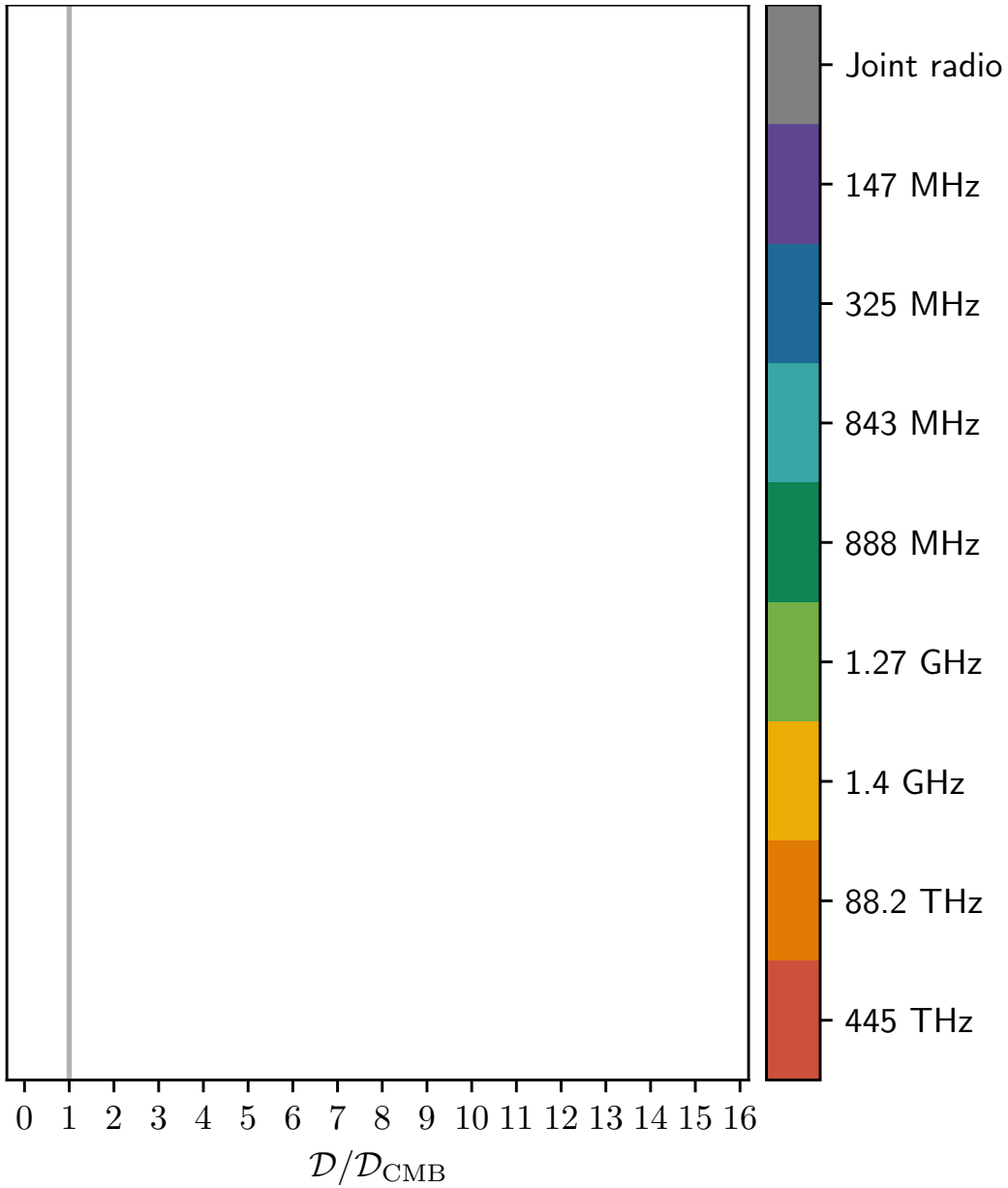
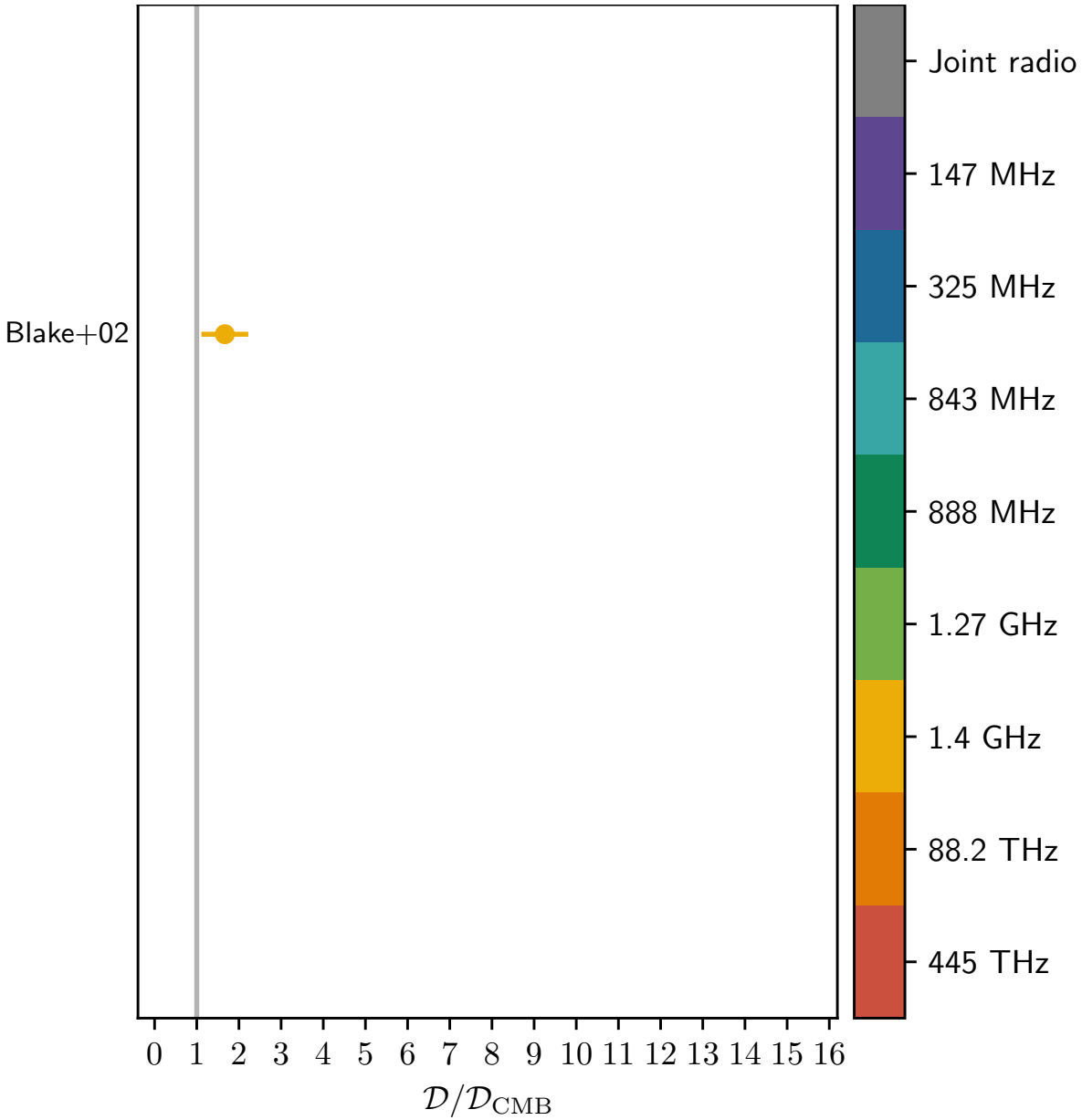
The Amplitude Excess



The cosmic dipole should be consistent with CMB dipole.

The Amplitude Excess



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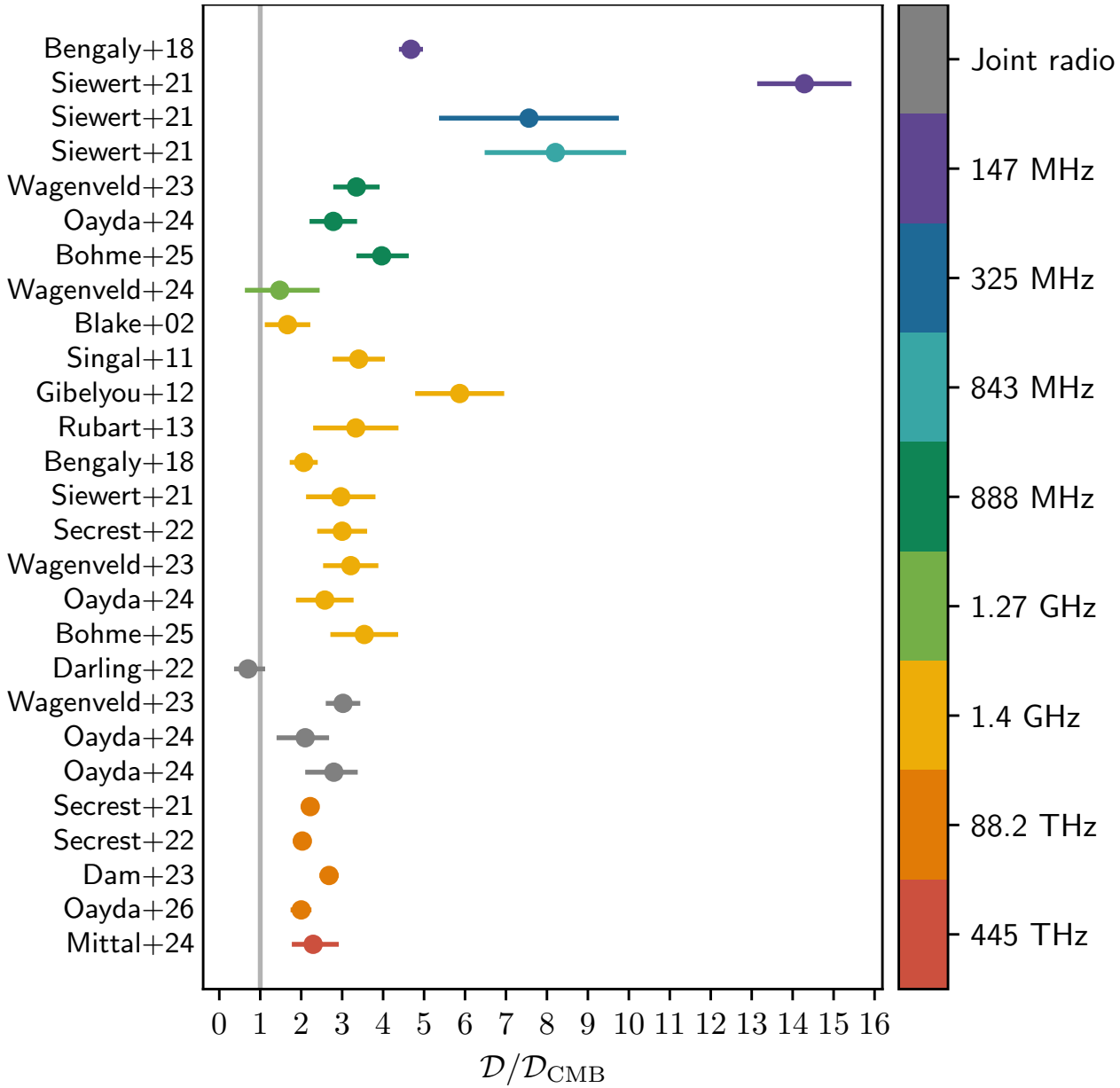
All is well!

The Amplitude Excess



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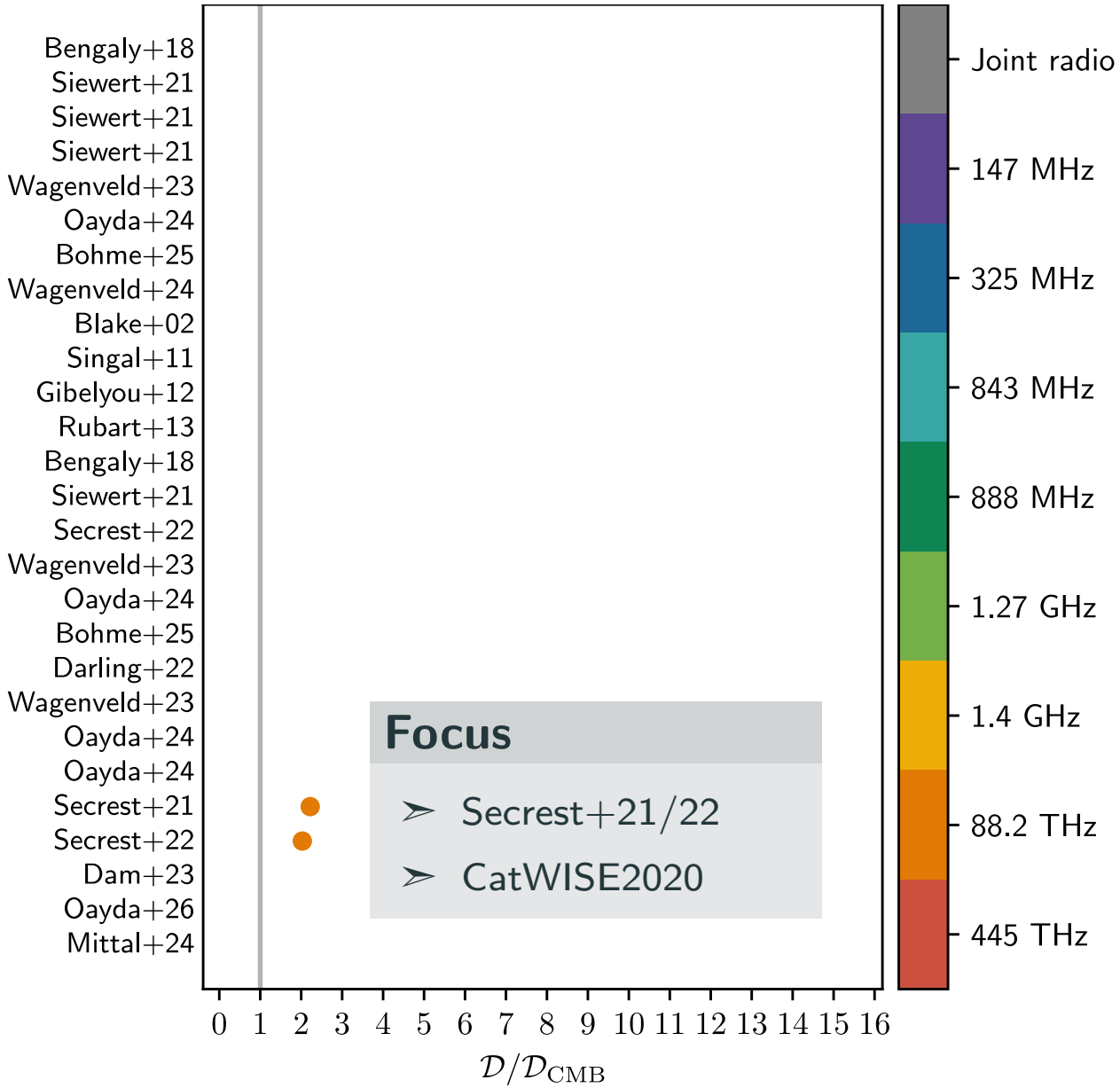

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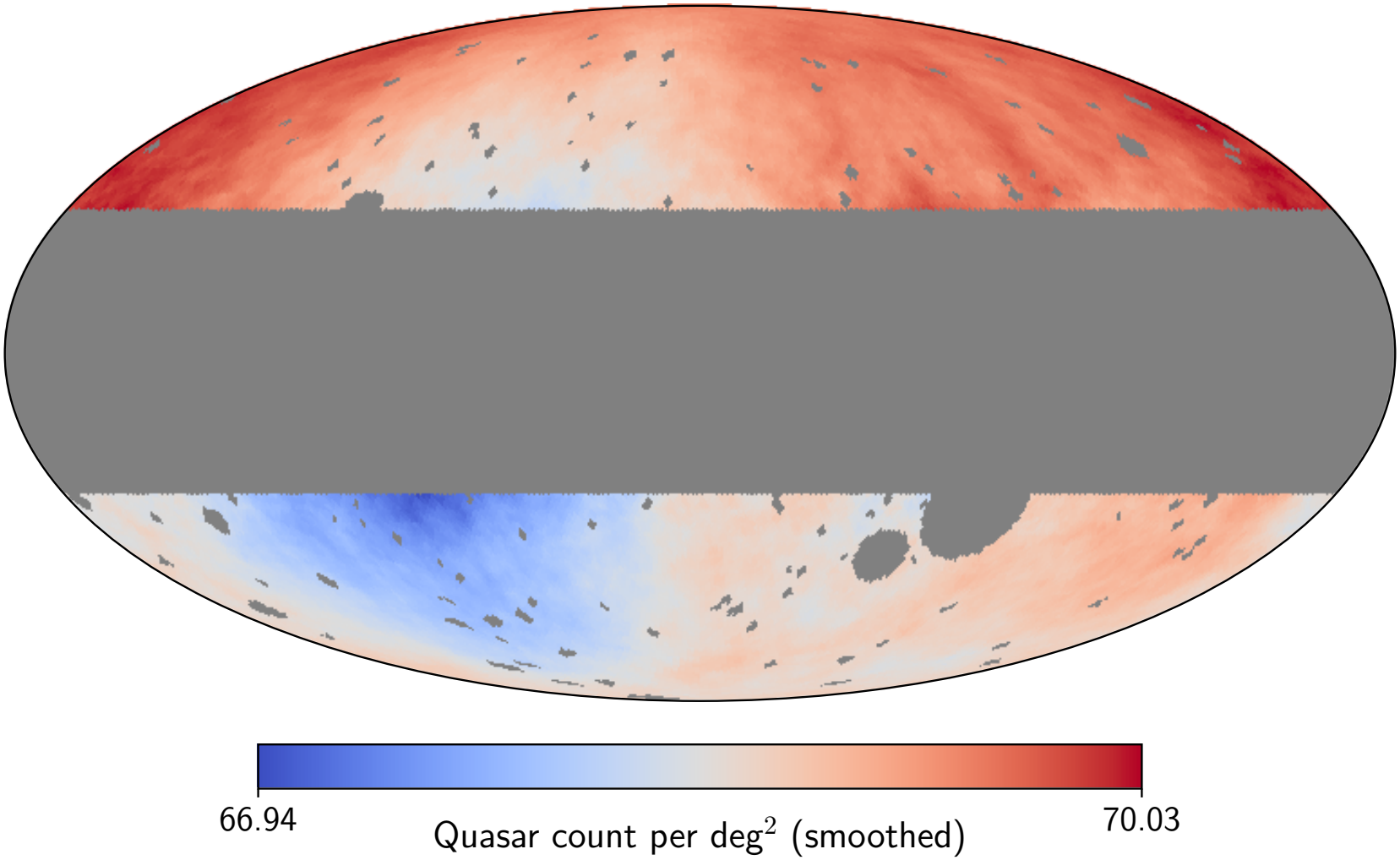
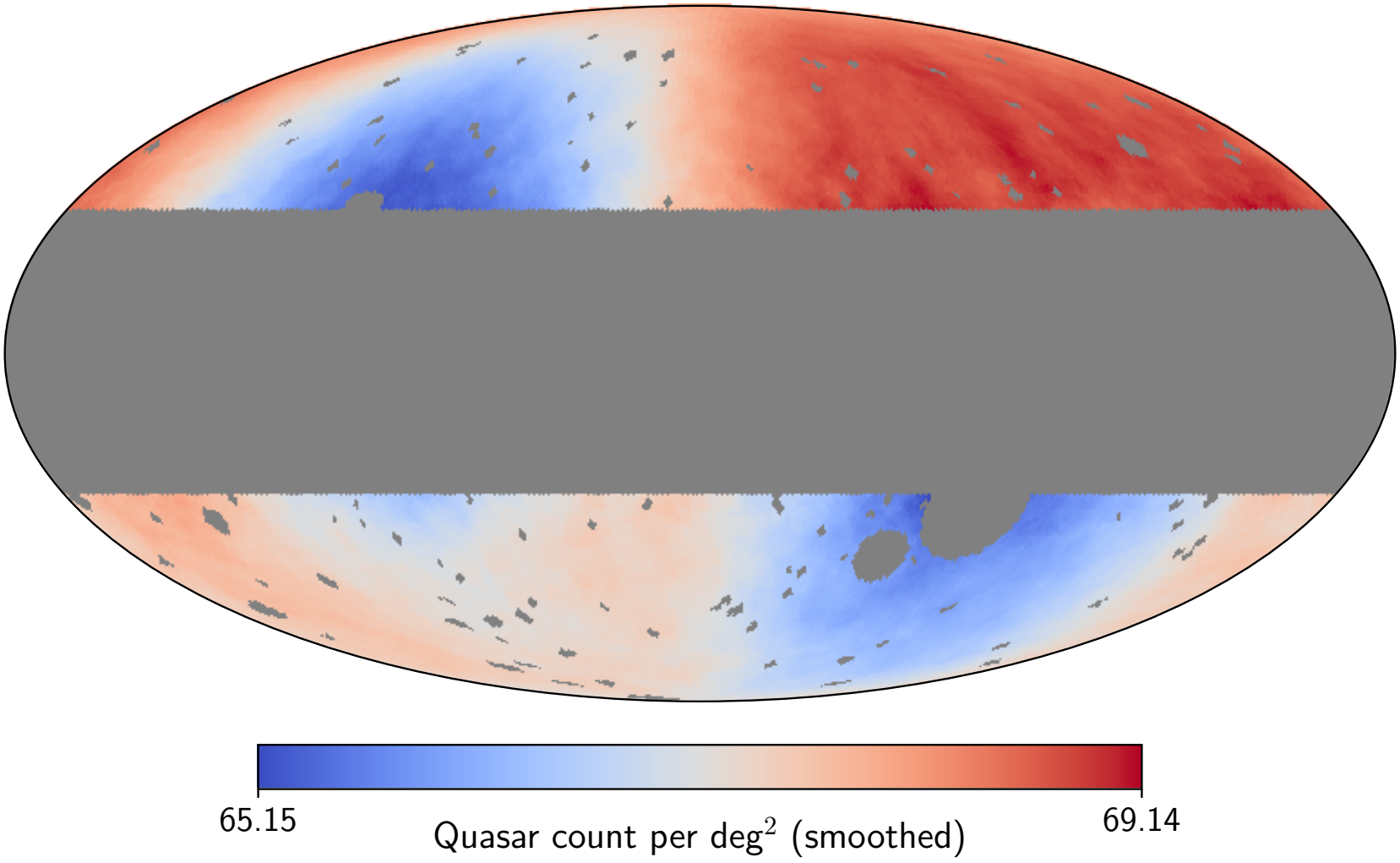
The CatWISE Sample



CatWISE quasar map from Secrest+21.

The CatWISE Sample



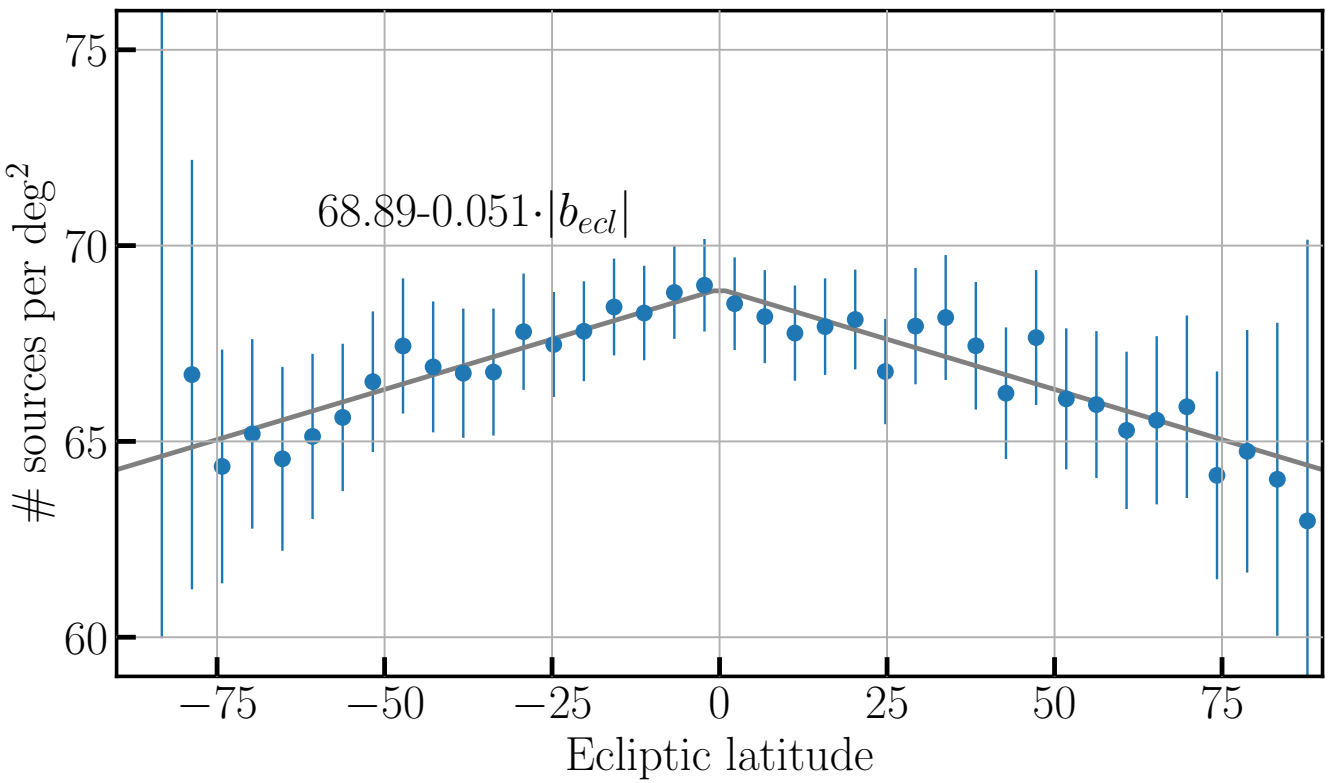
CatWISE quasar map, no linear weighting.

The CatWISE Sample

The Astrophysical Journal Letters, 908:L51 (6pp), 2021 February 20 https://doi.org/10.3847/2041-8213/abdd40

A Test of the Cosmological Principle with Quasars

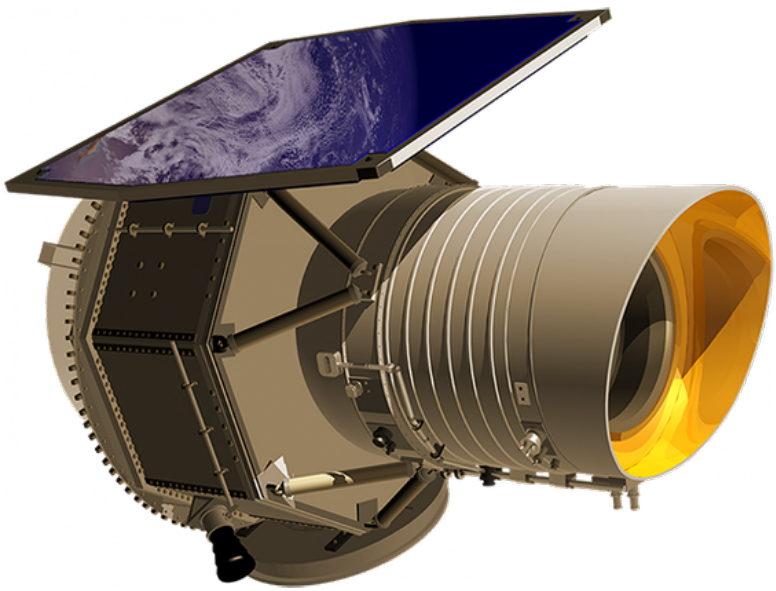
Nathan J. Secrest[1], Sebastian von Hausegger[2,3,4], Mohamed Rameez[5], Roya Mohayaee[3], Subir Sarkar[4], and Jacques Colin[3]



Linear fit to density vs. declination (Secrest+21).

Is it good enough to make an ad hoc correction after the fact?

WISE's Scanning Law



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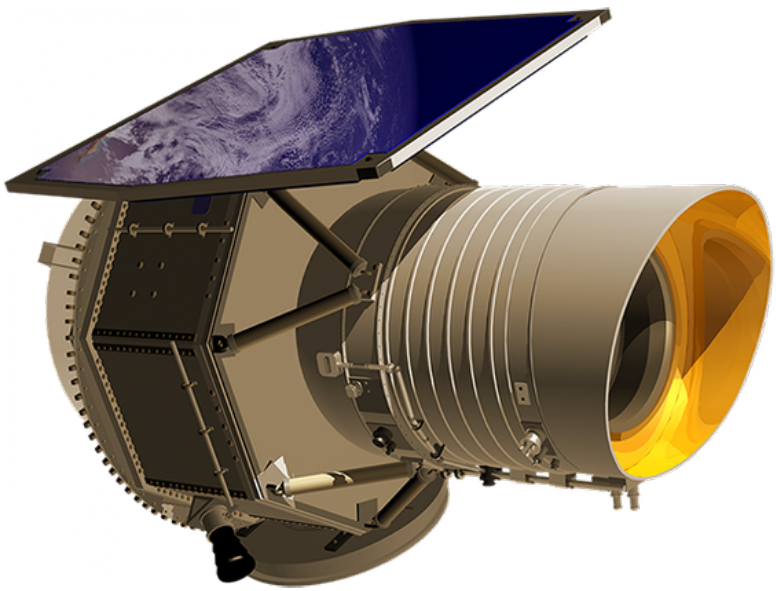
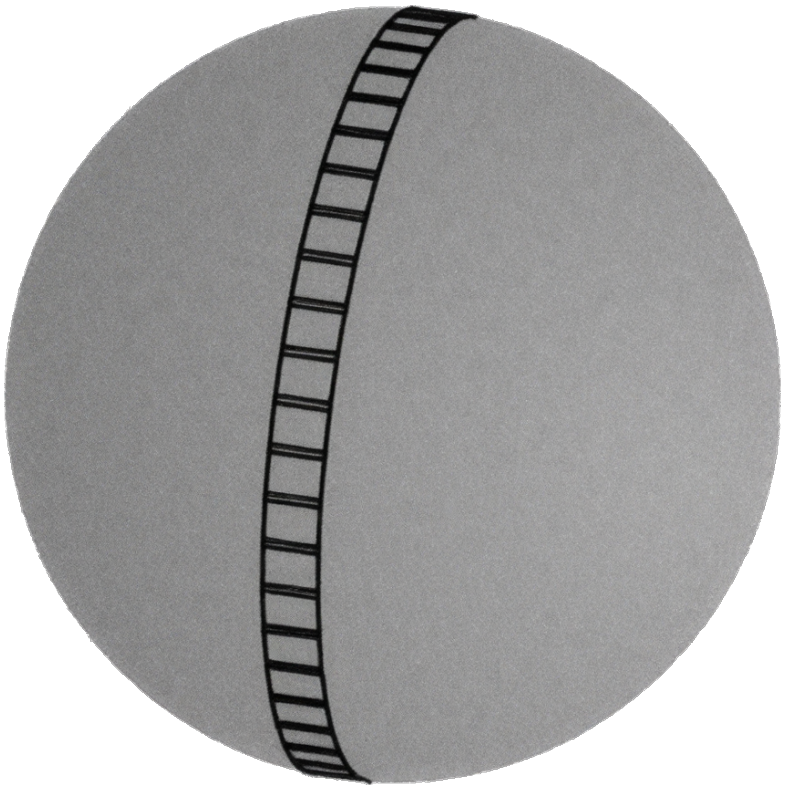
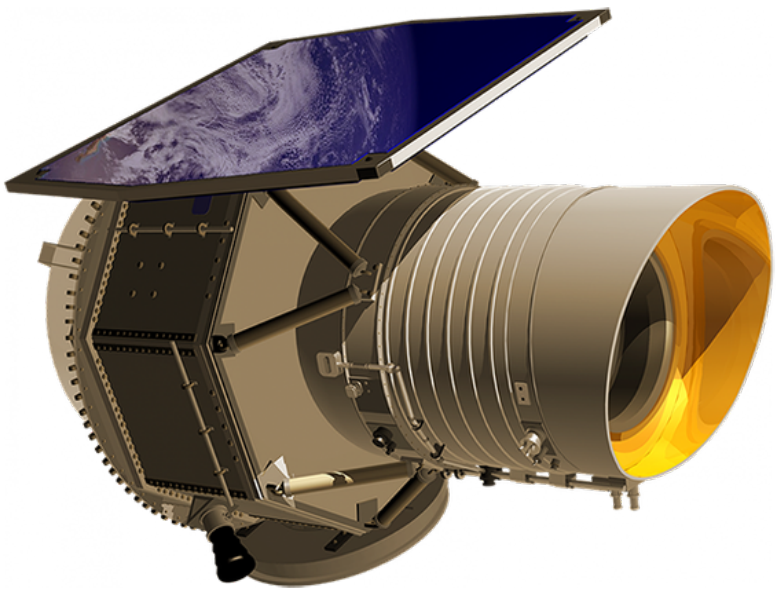
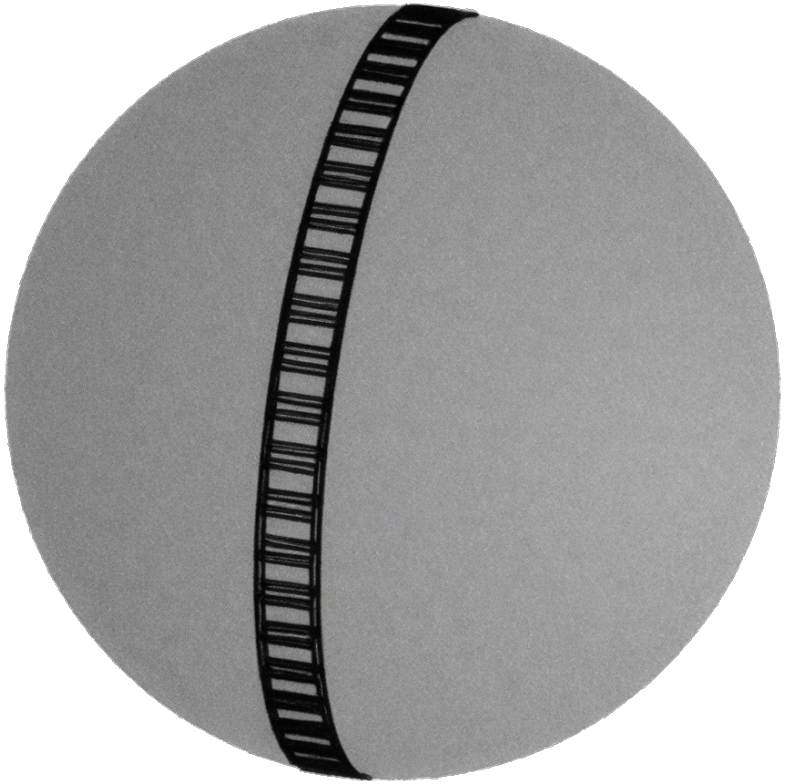




Frames over 1 orbit.

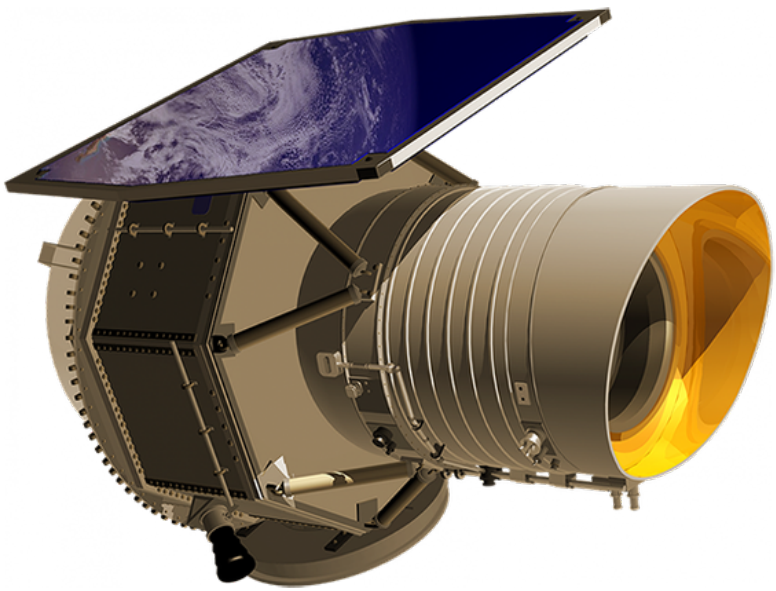
WISE's Scanning Law

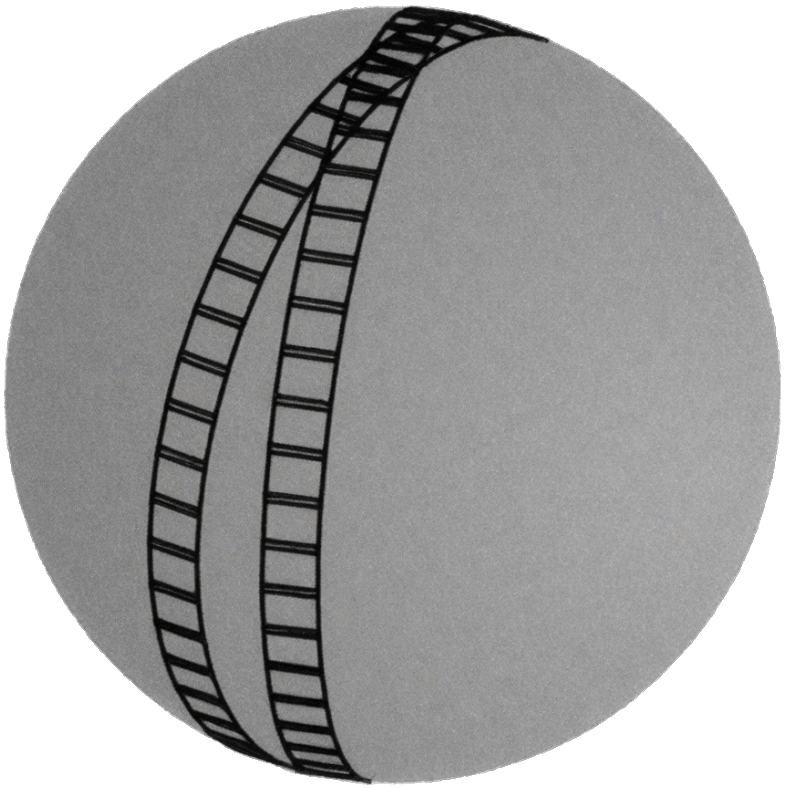




Frames over 2 orbits.

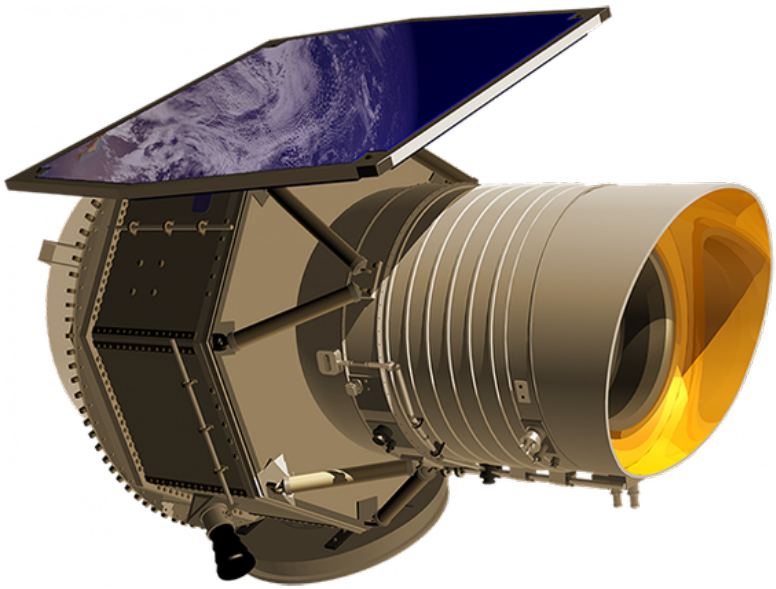
WISE's Scanning Law

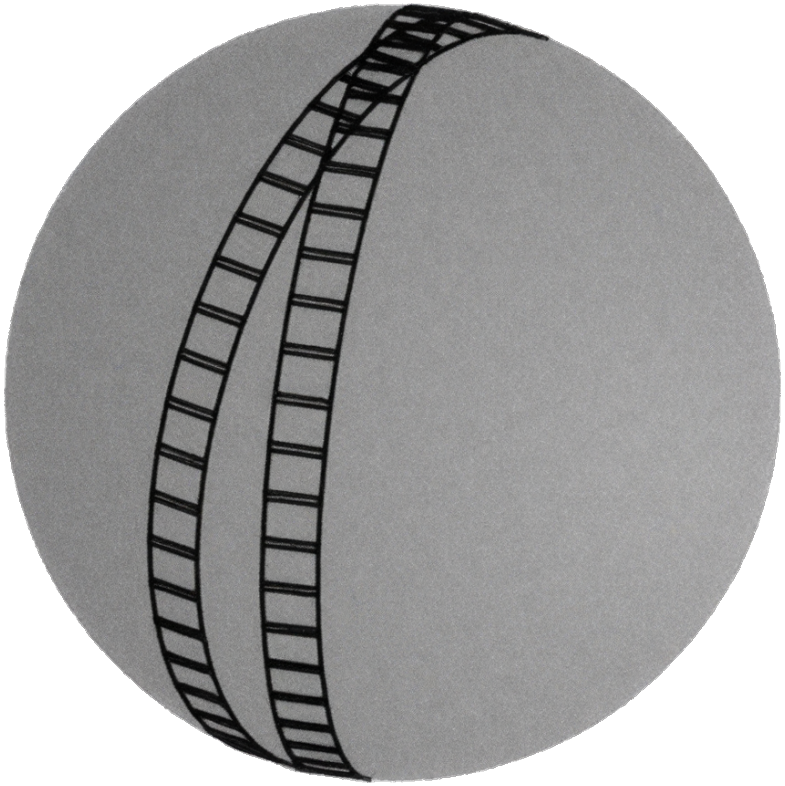




Frames over 2 orbits 20 days apart.

WISE's Scanning Law

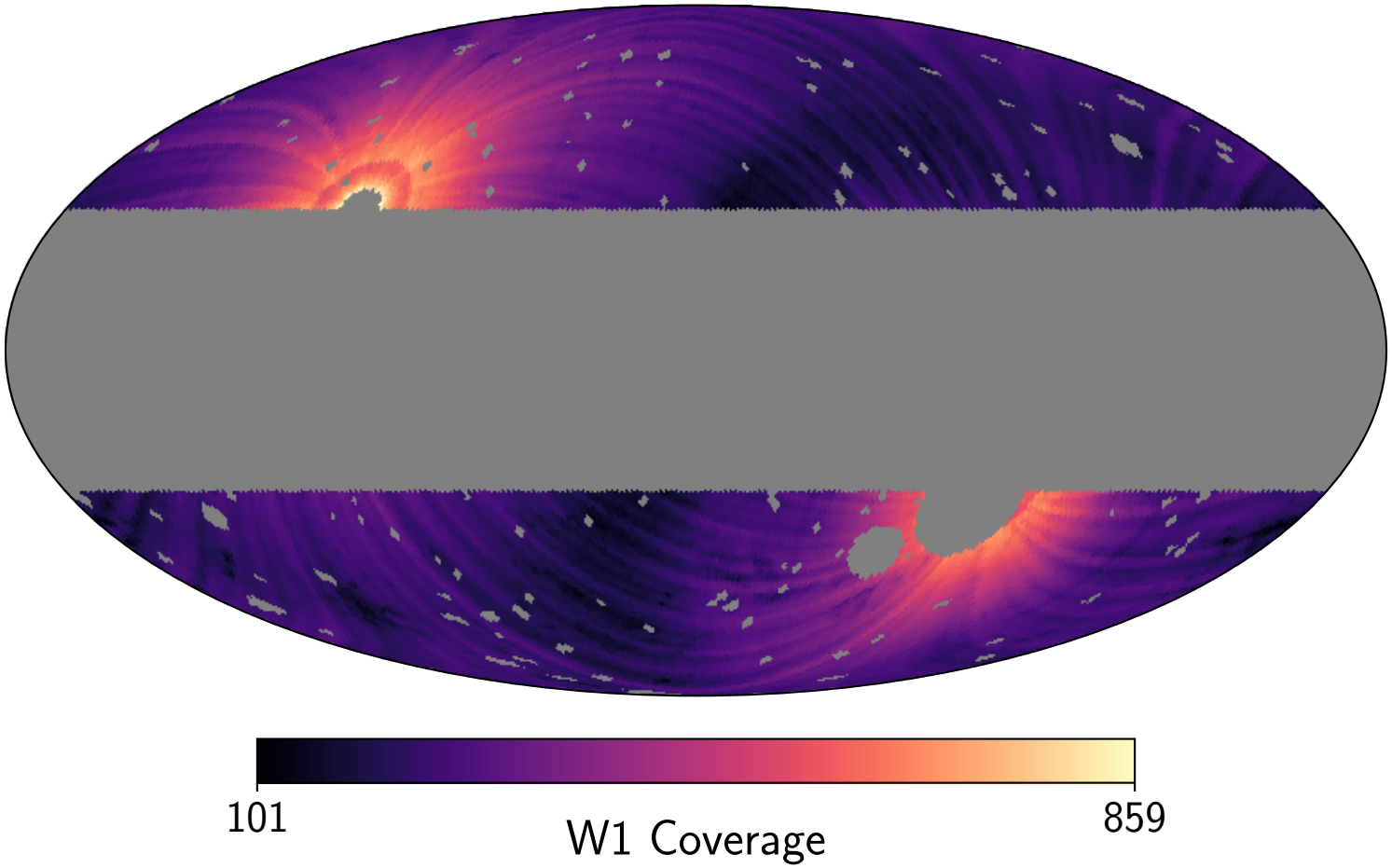




Frames over 2 orbits 20 days apart.

Obeys a scanning law over the survey's lifetime.

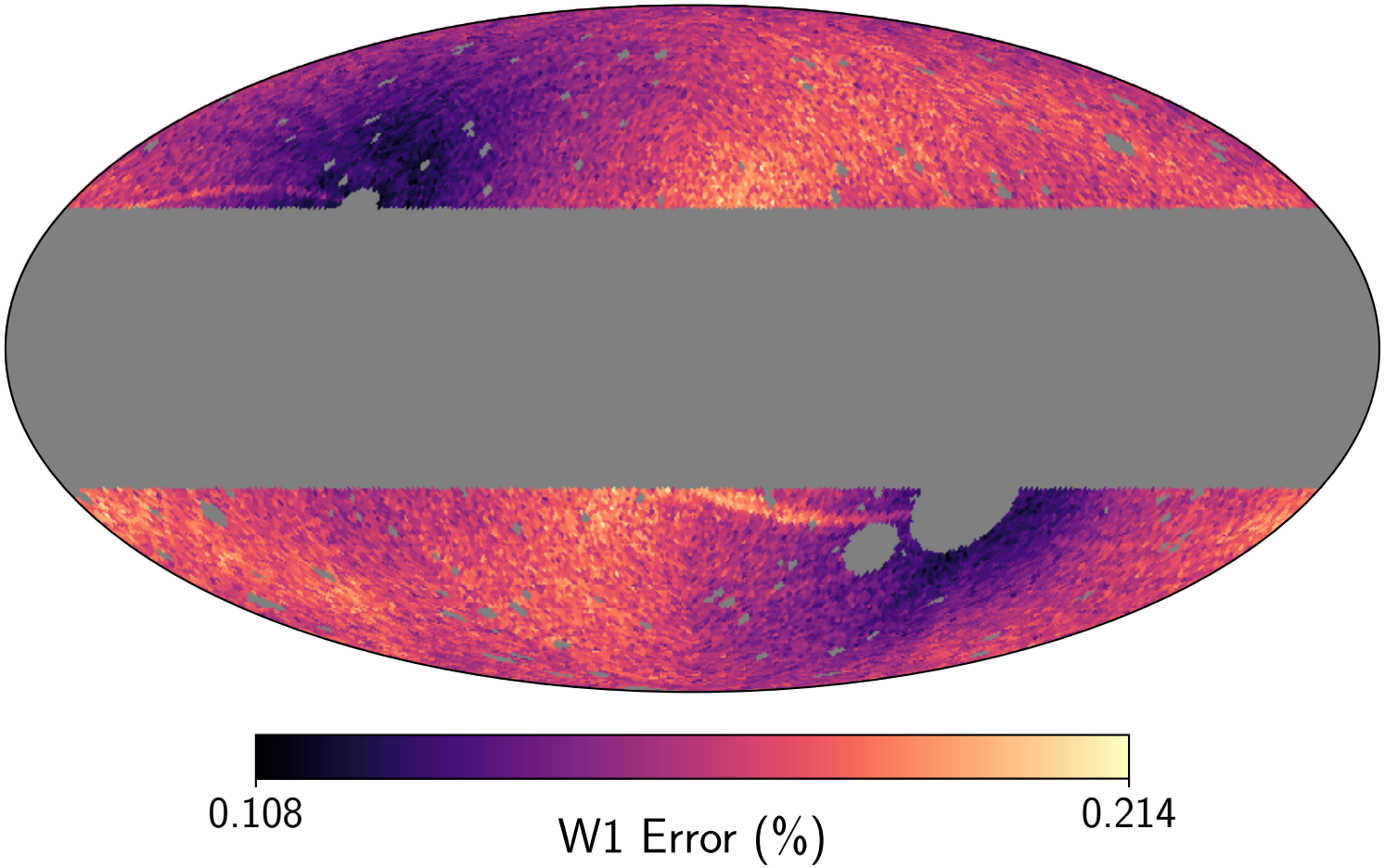
Photometric Errors



WISE coverage in W1 band for the Secrest+21 sample.

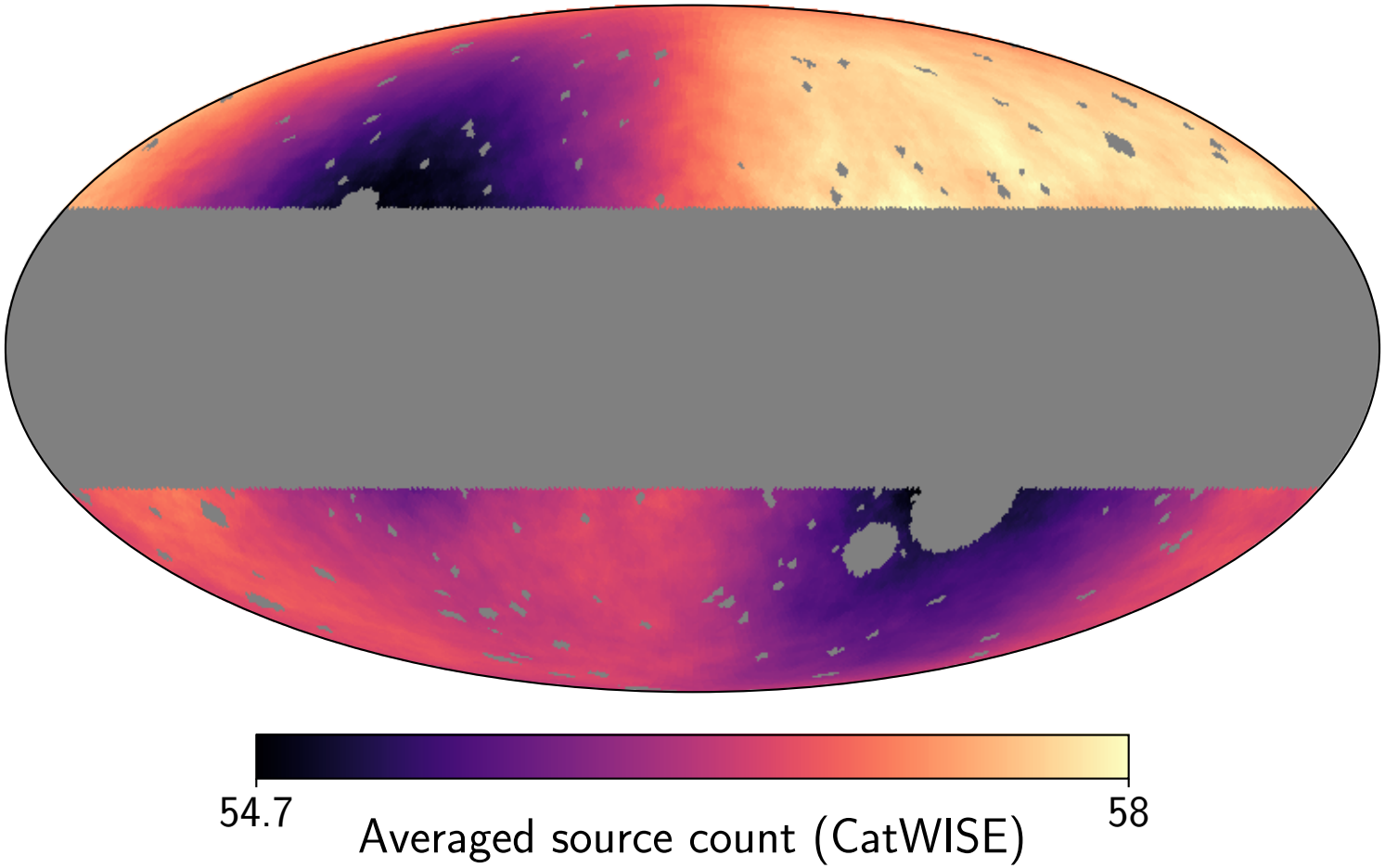
Oayda & Lewis (2026) MNRAS 546(4)

Photometric Errors



Source photometric error (%) in W1 band for the Secrest+21 sample.

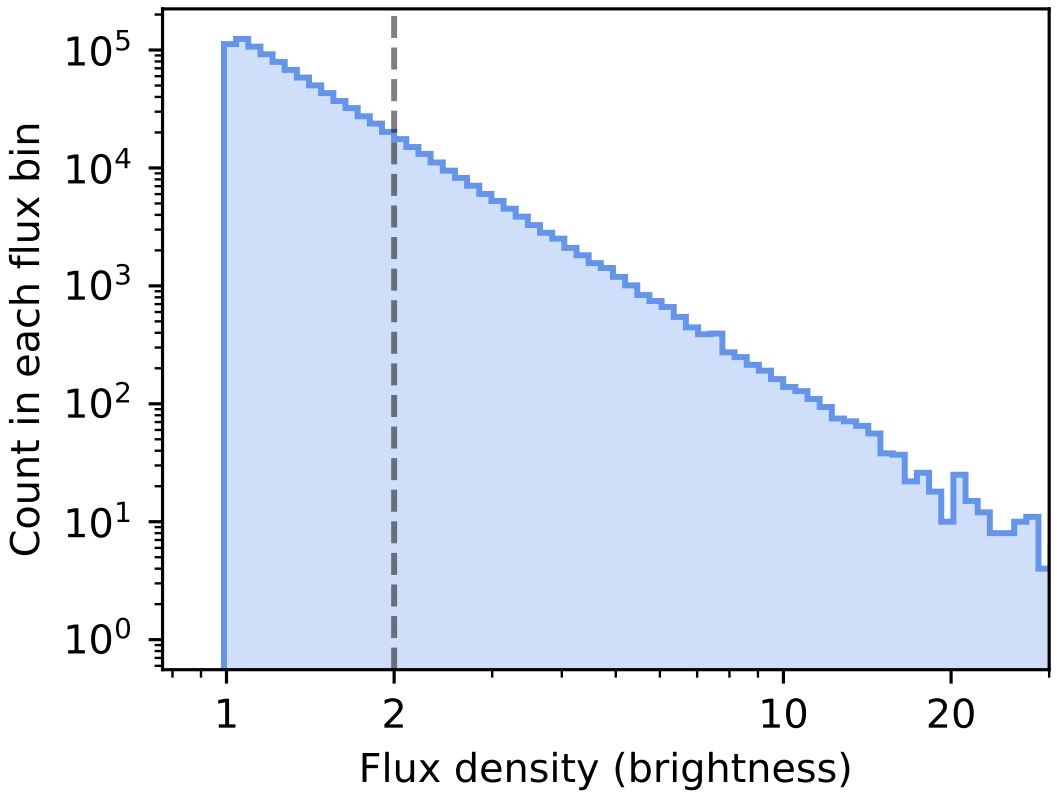
Photometric Errors



CatWISE quasar map, no linear weighting.

Eddington Bias

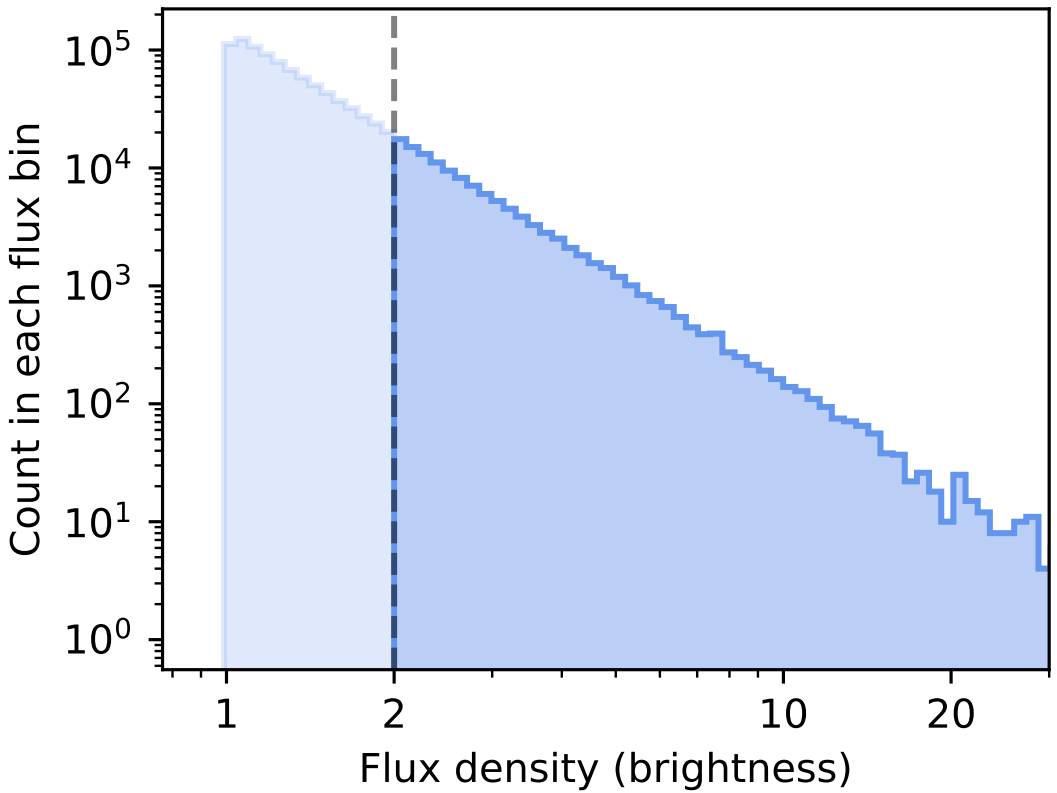
Sampled flux = True flux



True distribution of flux densities.

Eddington Bias

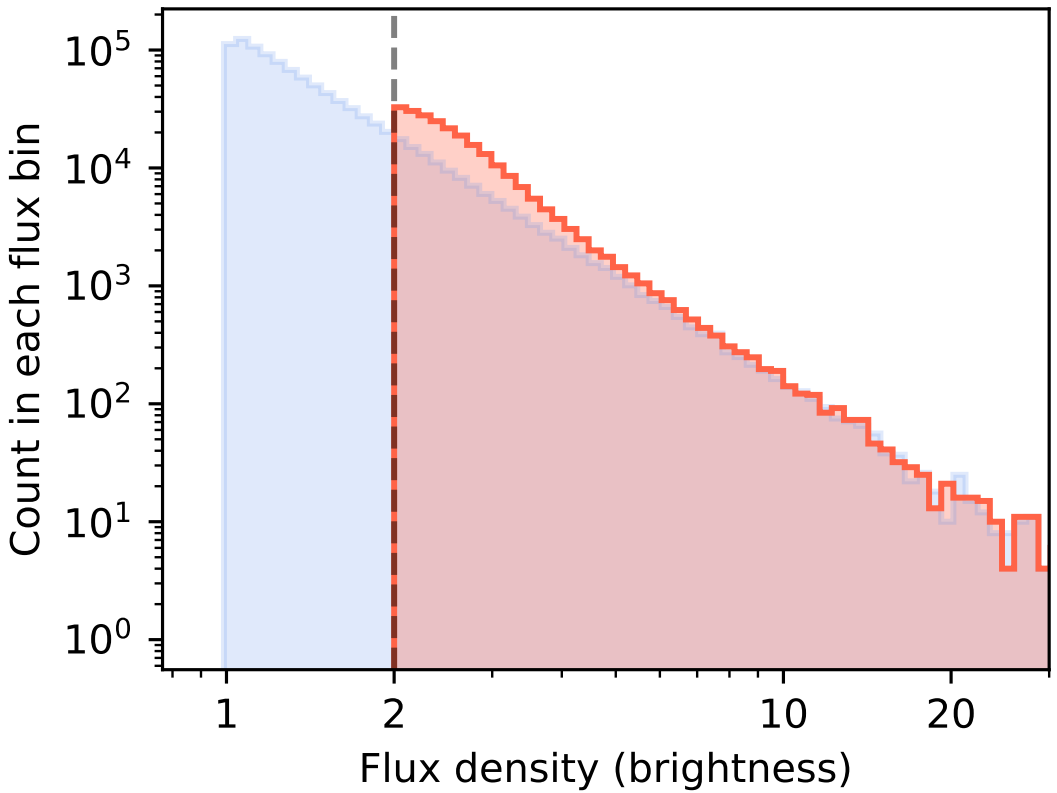
Sampled flux (> 2) = True flux (> 2)



True distribution of flux densities with **flux cut**.

Eddington Bias

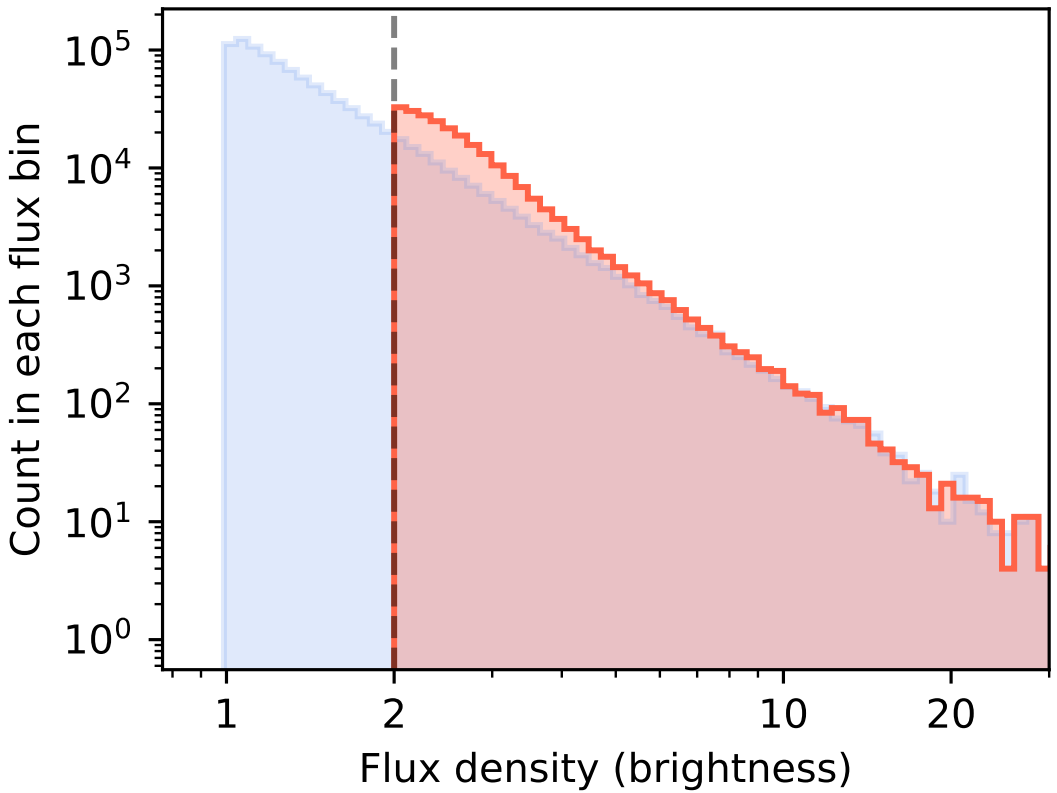
$$\text{Sampled flux } (> 2) = \text{True flux } (> 2) + \text{Noise}$$



Noisy distribution of flux densities with **flux cut**.

Eddington Bias

Sampled flux (> 2) = True flux (> 2) + Noise



Noisy distribution of flux densities with **flux cut**.

What if the noise varies over the sky? 🤔

This is just something we can simulate!

What Now...?

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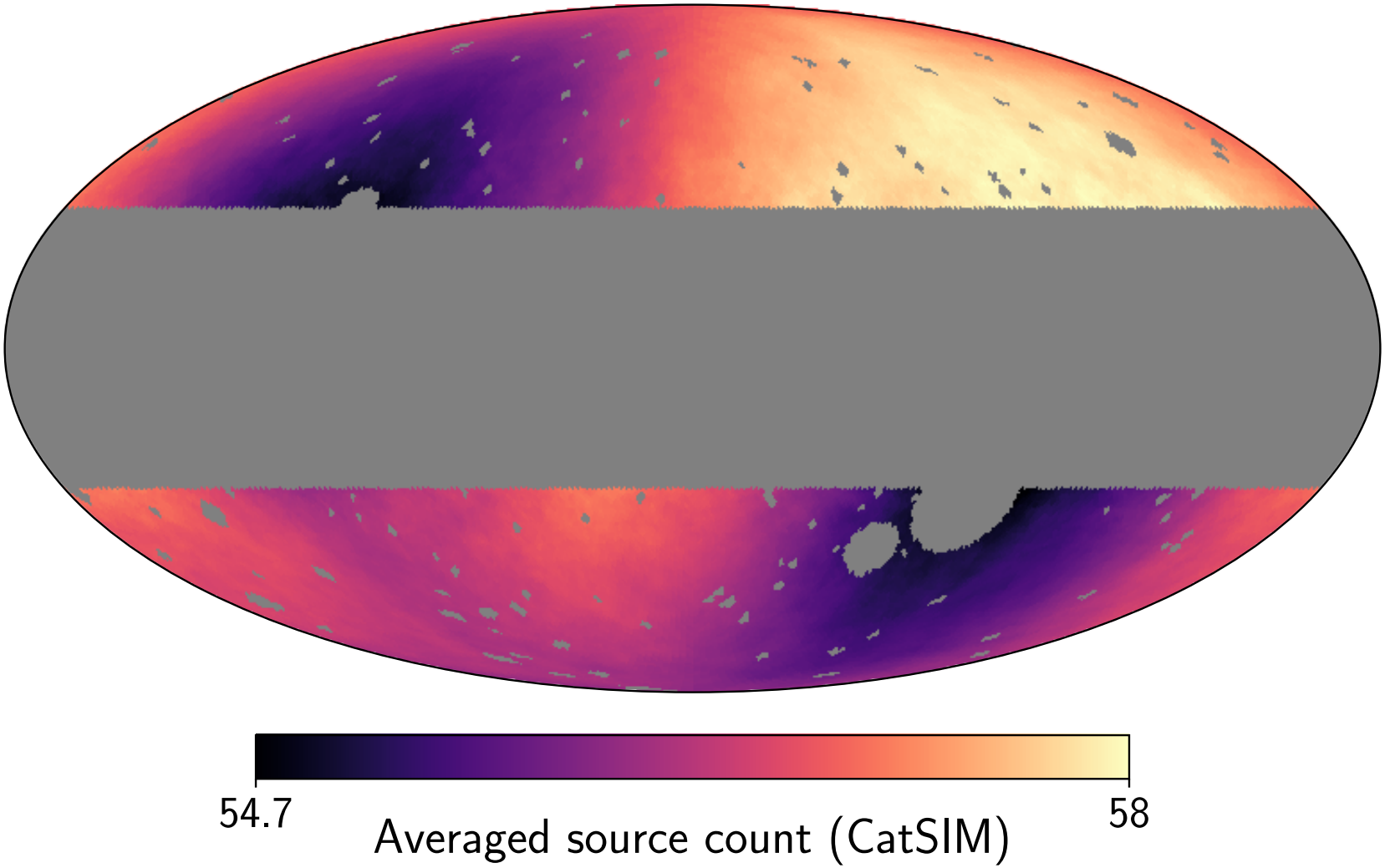
- This is **S**imulation-**B**ased **I**nference.

Posterior Predictive



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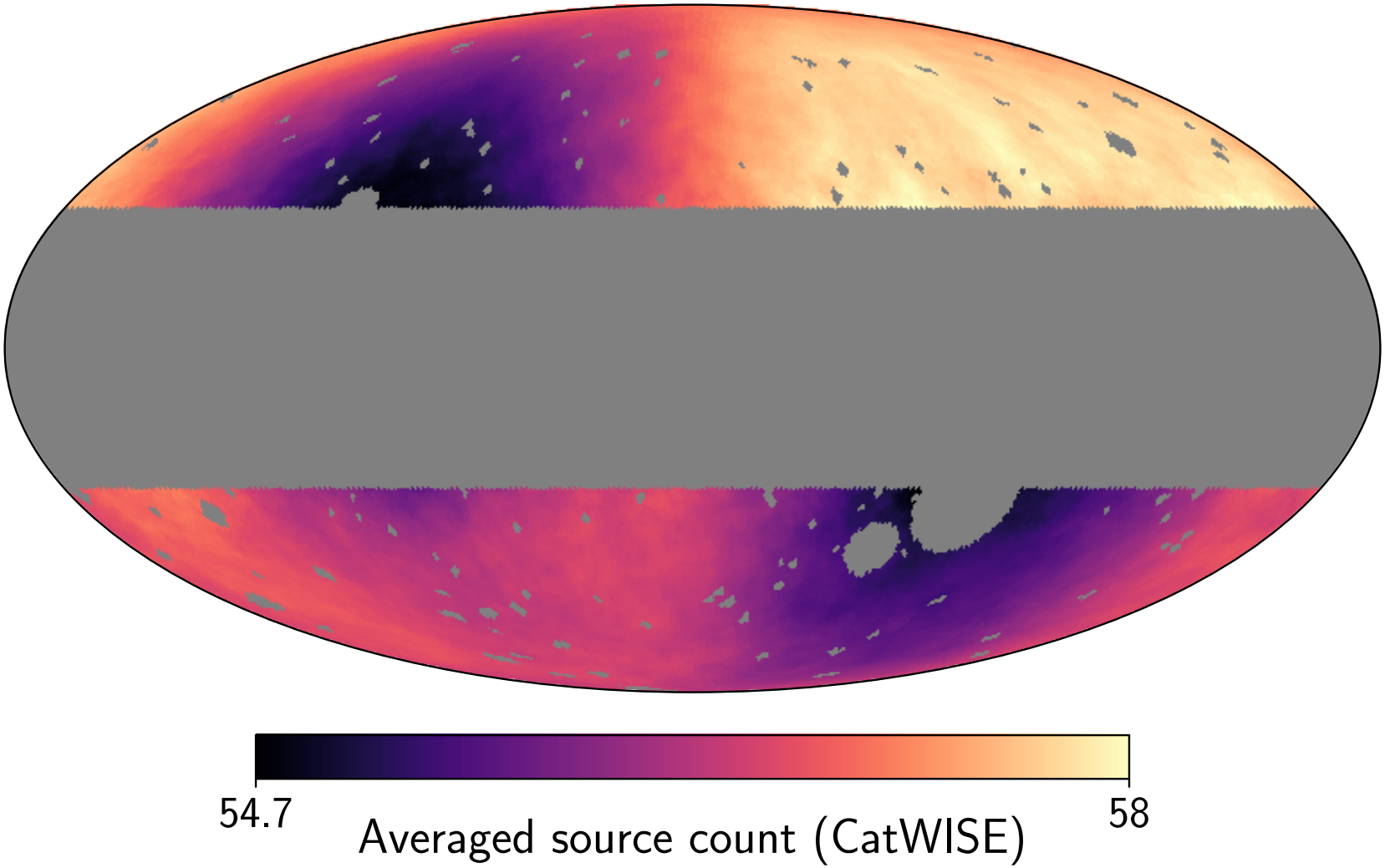
Posterior Predictive



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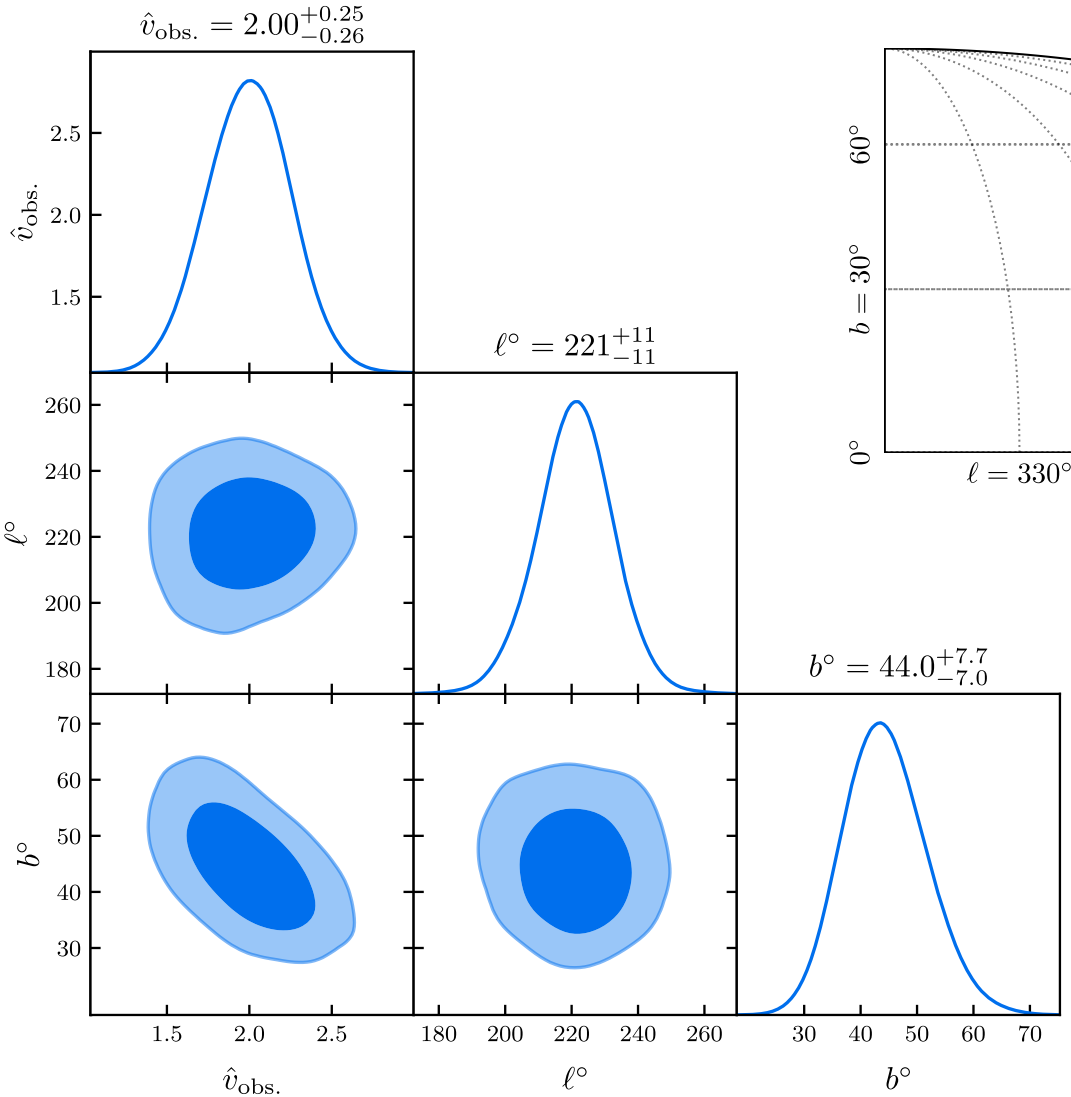
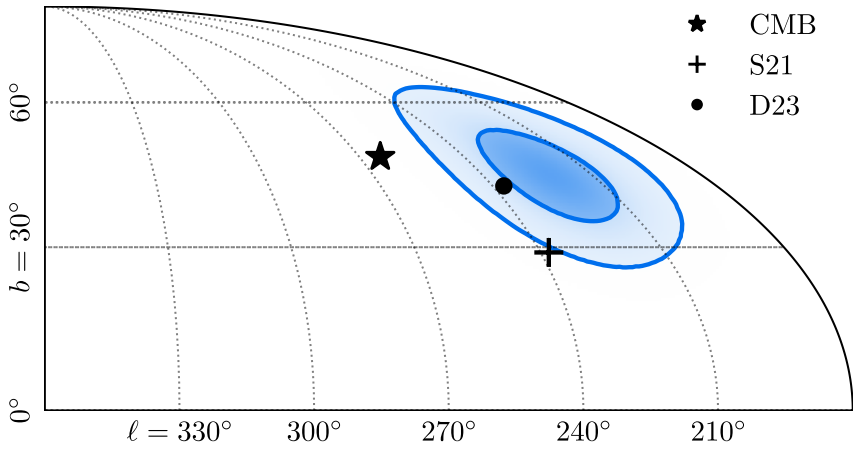
CatSIM Results





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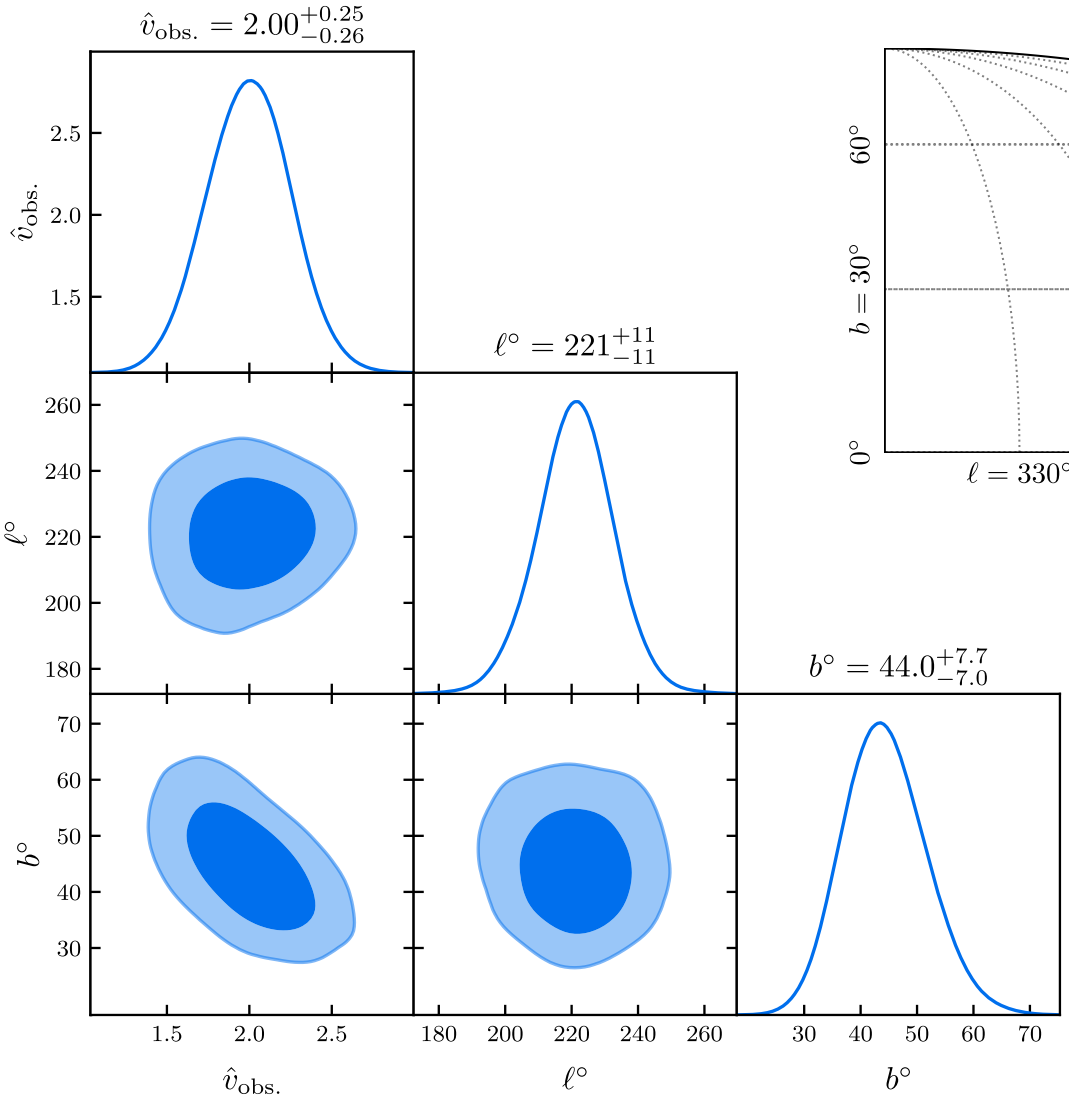

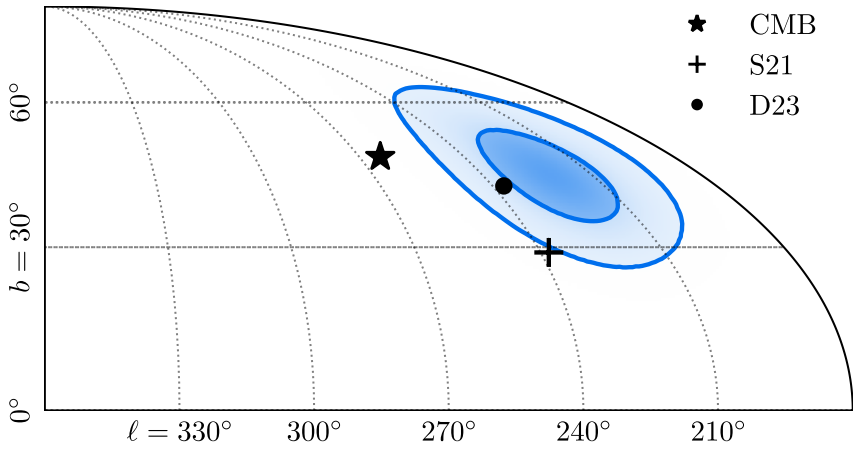

Conclusion

Confirms cosmic dipole tension.

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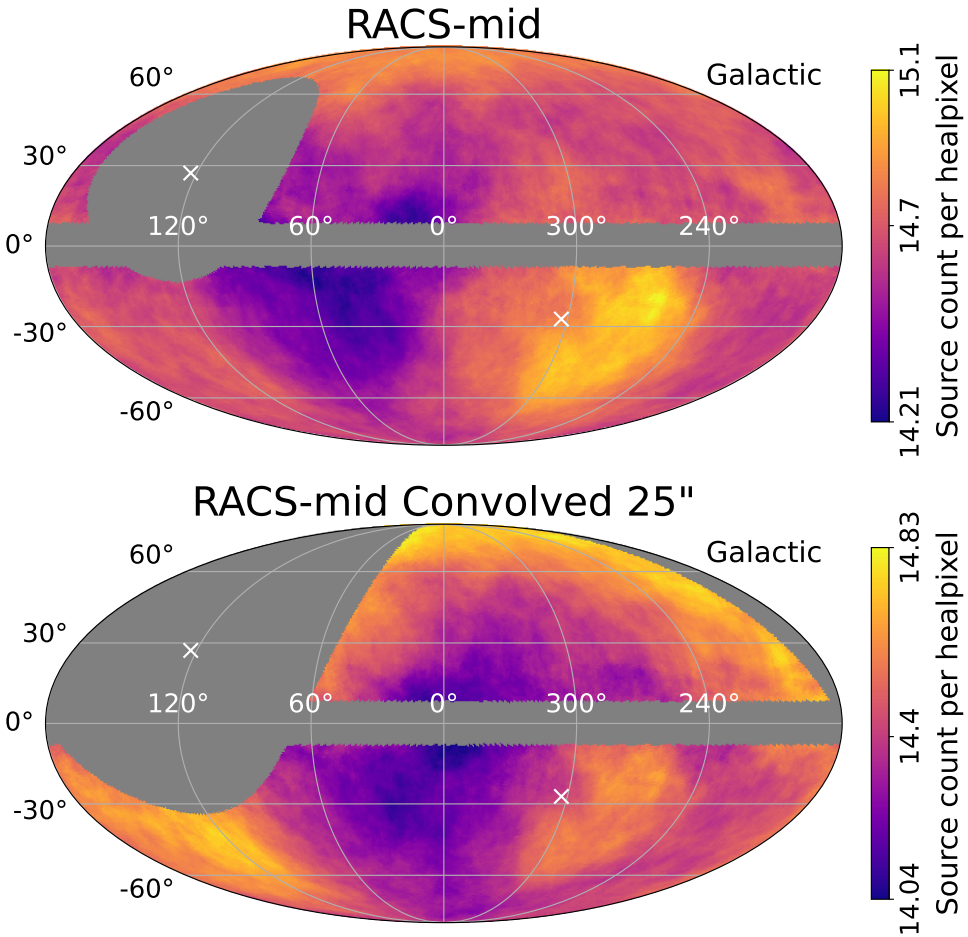
Where To Next?



RACS & beyond

- Can we extend to other surveys? E.g. RACS.

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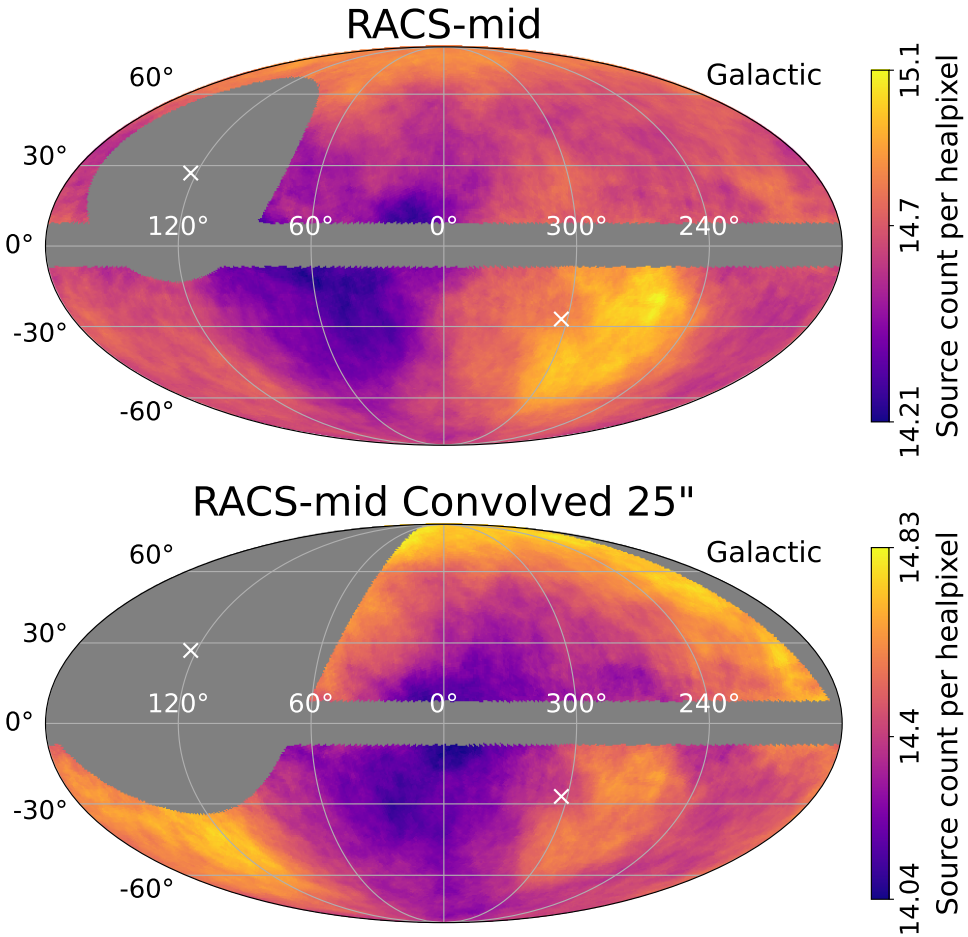

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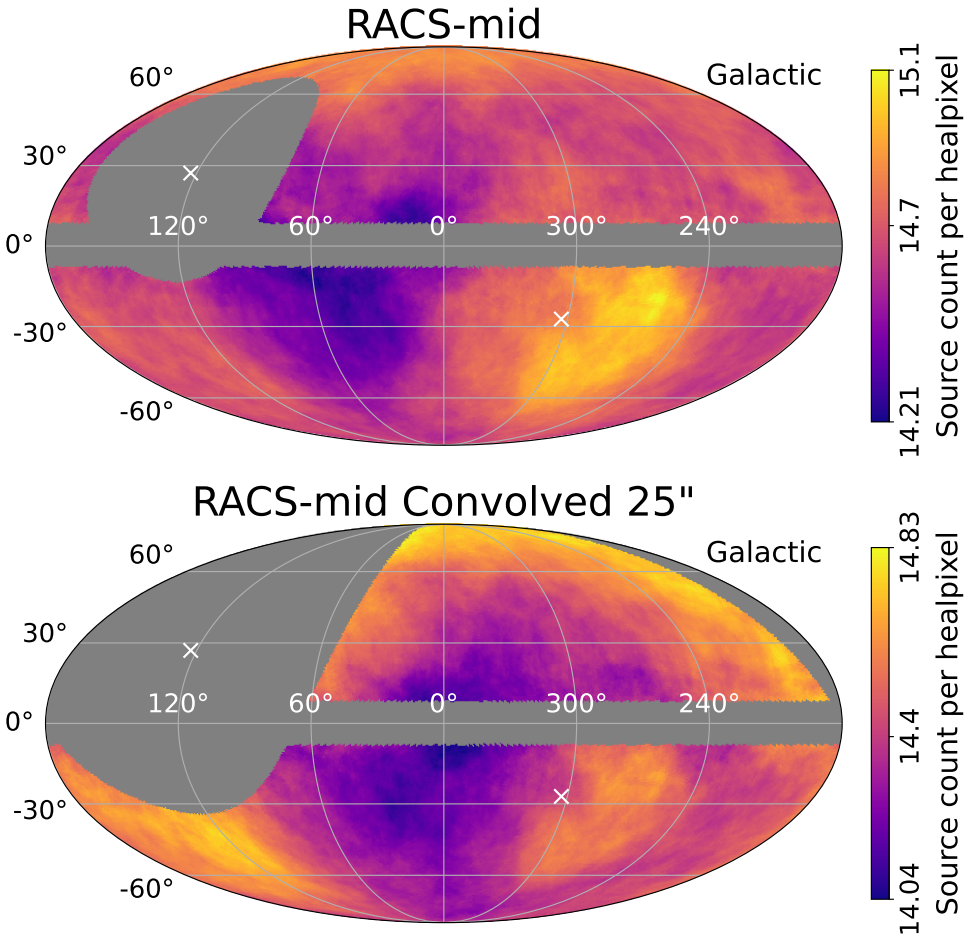

RACS & beyond

- Can we extend to other surveys? E.g. RACS.
- Let's forward model! Account for resolution, flux calibration, etc.
- Infer cosmology and systematics together.

- **Describe and account for ecliptic bias** ✓

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- **Measure cosmic dipole** ✓

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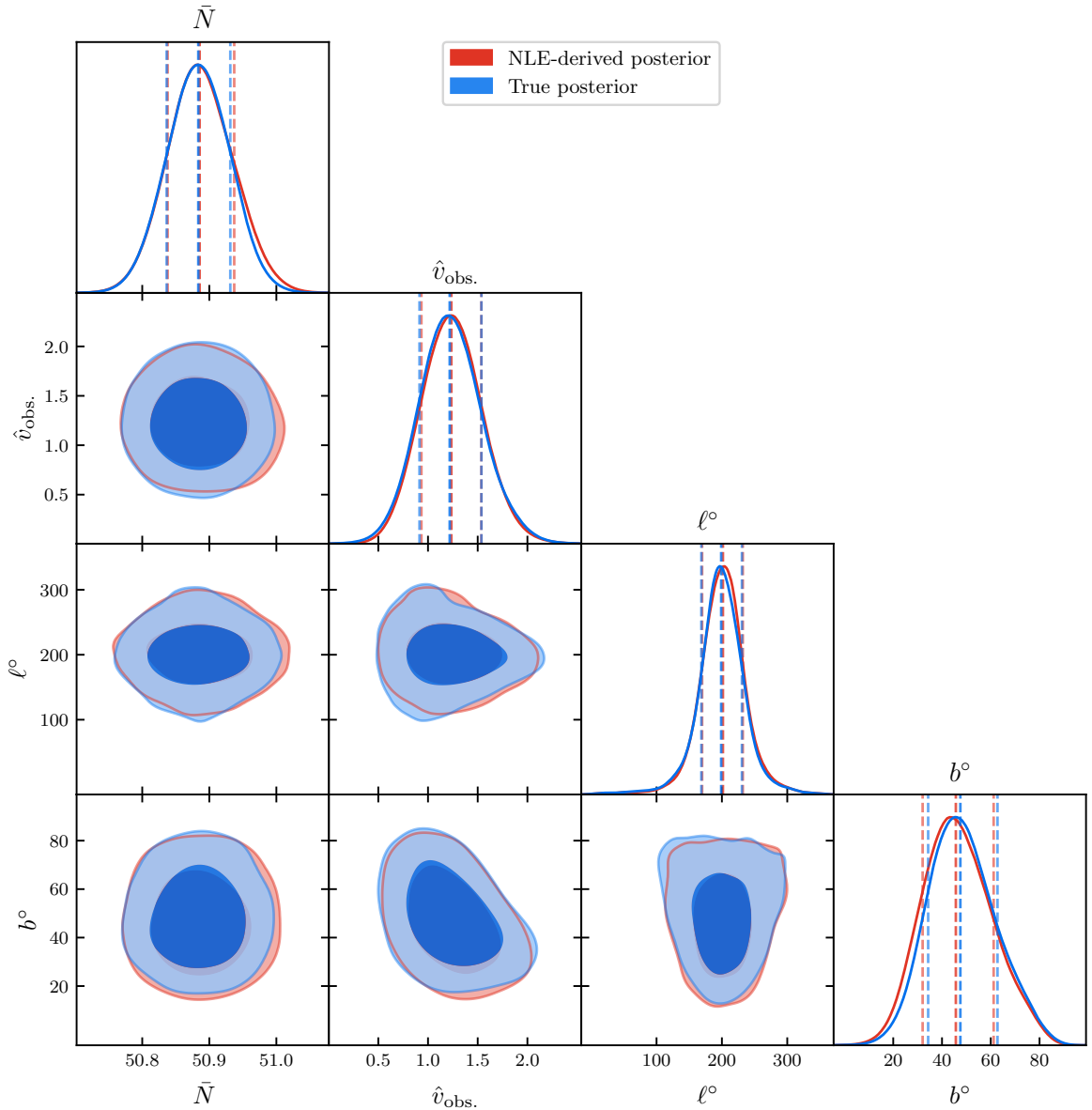
- **Measure cosmic dipole** ✓
- **Leverage power of simulations and SBI** ✓

Appendix

Consistency Check — Posteriors

SBI-derived posterior versus ground truth.



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