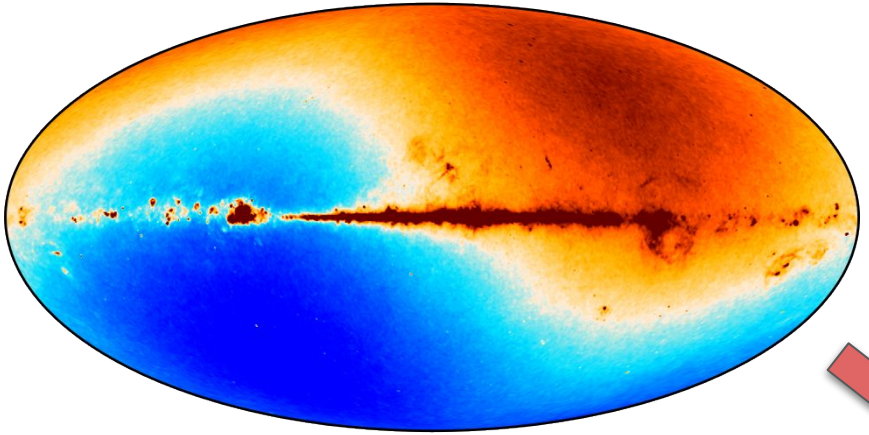
Stress Testing the Cosmological Principle with the SKA

Geraint F. Lewis

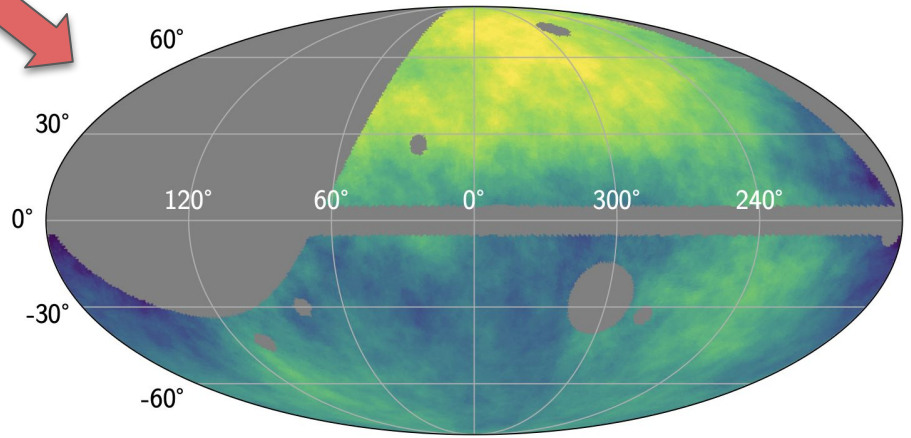
Sydney Institute for Astronomy

Testing the Cosmological Principle with Cosmic Dipole



CMB dipole interpreted as v~370 km/s relative to comoving frame.

Imprinted on galaxy/quasar surveys at <0.5% variation across the sky (E&B Test).



Tensions in the Cosmological Principle

Testing the Cosmological Principle with CatWISE Quasars: A Bayesian Analysis of the Number-Count Dipole

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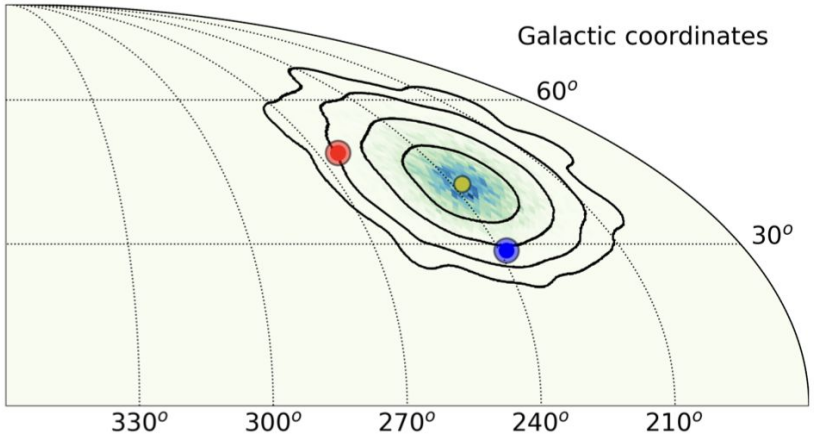
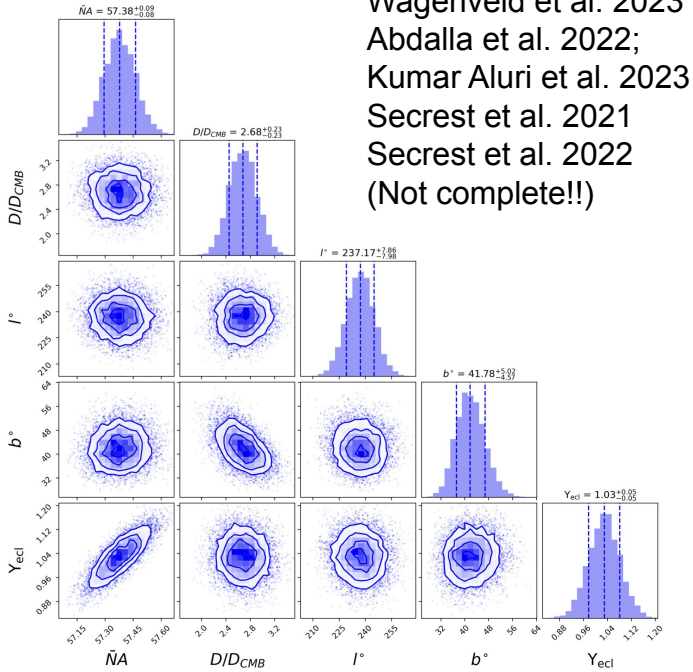
[3]*Department of Statistics, The University of Auckland, Private Bag 92019, Auckland 1142, New Zealand*





Some recent references:
Siewert et al. 2021
Singal 2023a, b;
Wagenveld et al. 2023
Abdalla et al. 2022;
Kumar Aluri et al. 2023
Secrest et al. 2021
Secrest et al. 2022
(Not complete!!)

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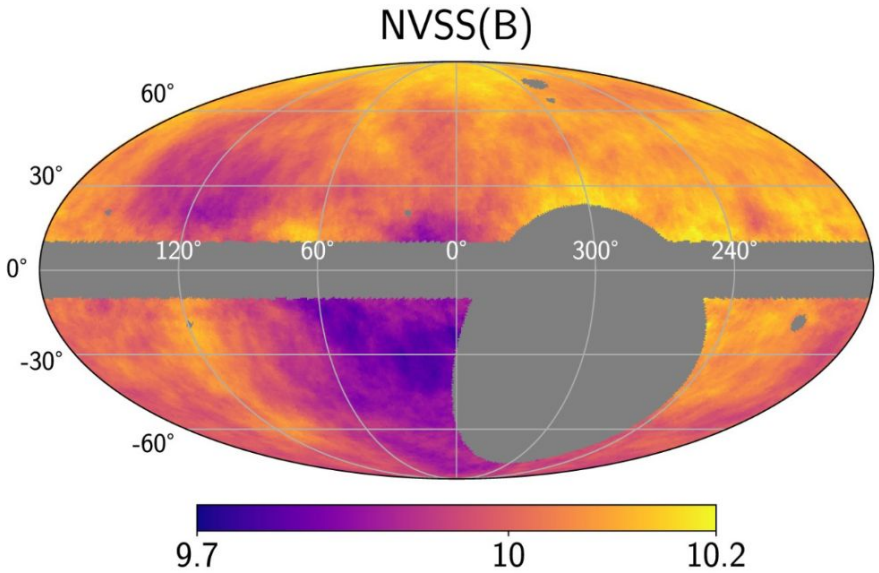
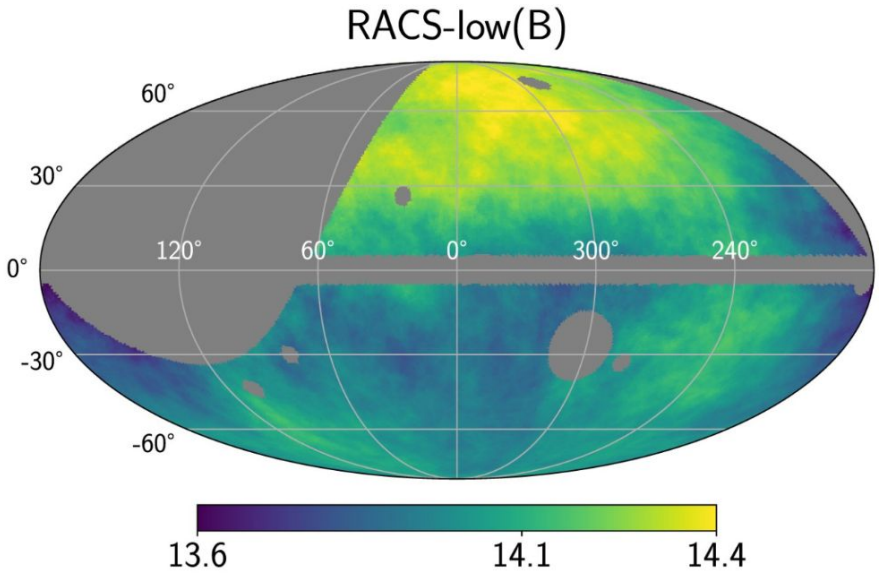
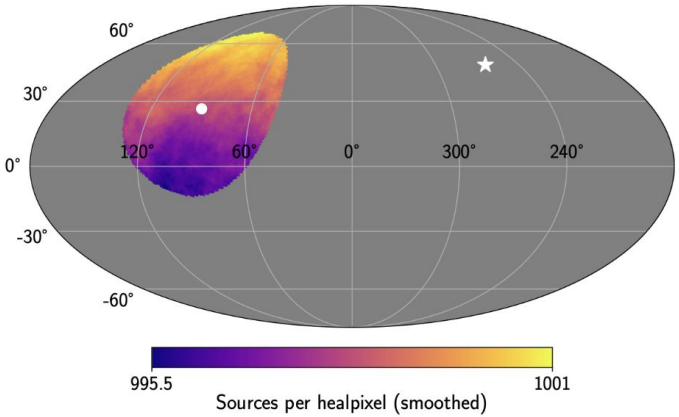
Sky Coverage

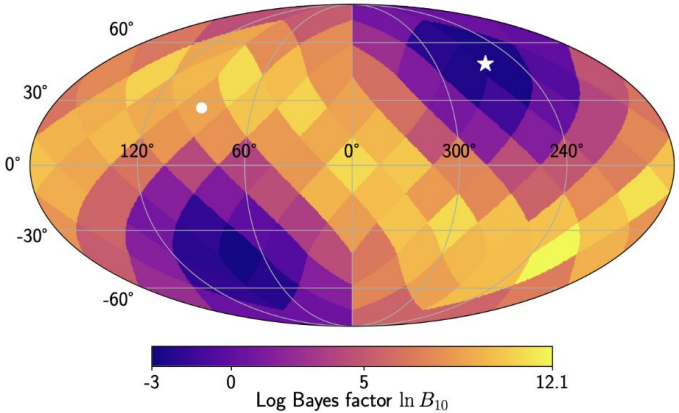




As “all-sky” as possible? Catalogue match Northern and Southern surveys and cross-calibrate to construct a single catalogue.

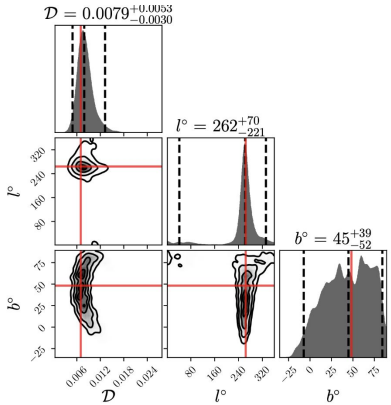
Sky Coverage

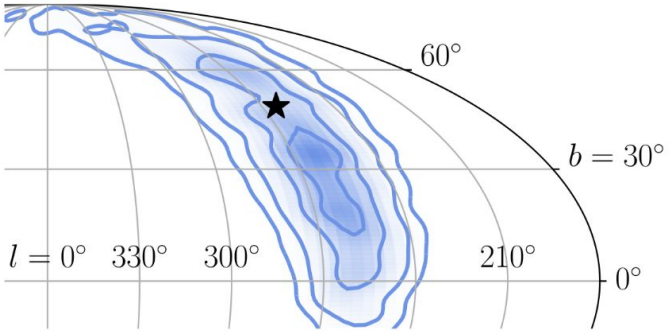




We've been exploring the sensitivity of Bayesian-based modeling to limited sky-coverage, finding that this is sensitive to the properties of the sky patch, including area and direction. Building a framework to calibrate information gained.

Oayda, Mittal & Lewis (2024; *Submitted*)

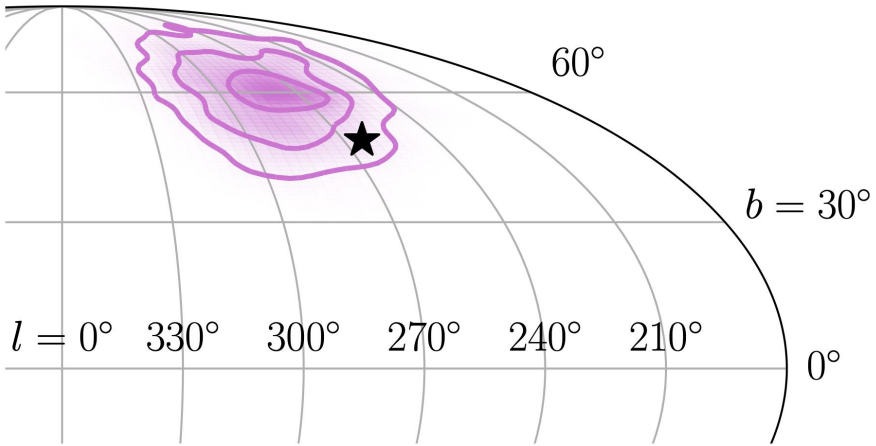


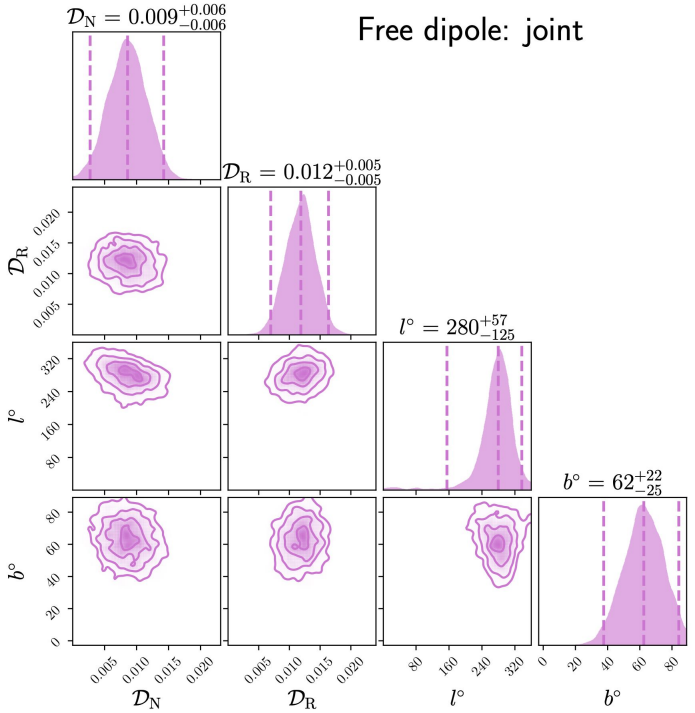


Sky Coverage: Combining Surveys

A Bayesian approach to the cosmic dipole in radio galaxy surveys: Joint analysis of NVSS & RACS

Oliver T. Oayda,[1]★ Vasudev Mittal[1,2], Geraint F. Lewis[1], and Tara Murphy[1]
[1]*Sydney Institute for Astronomy, School of Physics A28, The University of Sydney, NSW 2006, Australia*
[2]*Department of Physical Sciences, IISER Mohali, Knowledge City, Sector 81, SAS Nagar, Manauli PO 140306, Punjab, India*





Free dipole: joint

$$\ln \mathcal{L} = \ln \mathcal{L}_{\mathrm{NVSS}} + \ln \mathcal{L}_{\mathrm{RACS}}$$

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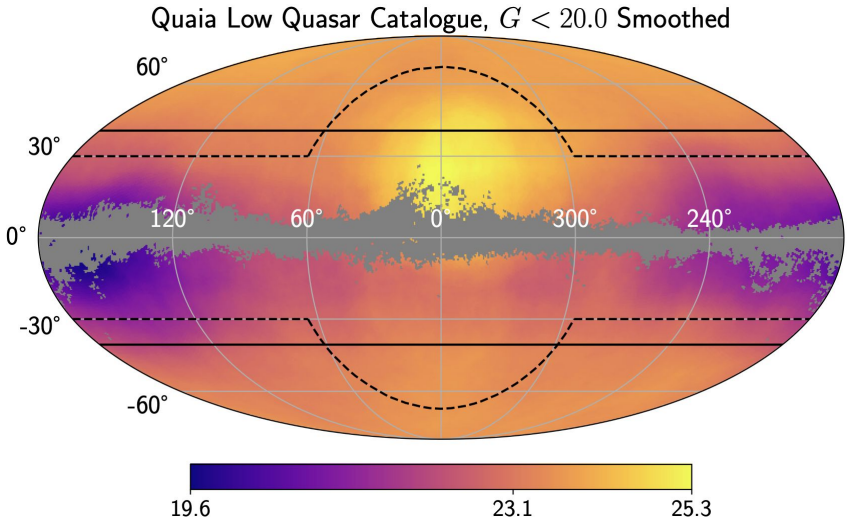
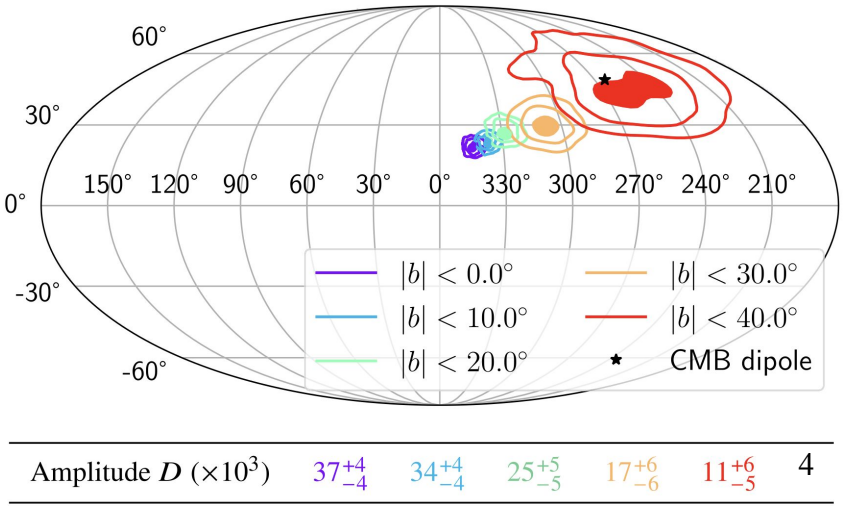
Selection Functions & Contamination

The Cosmic Dipole in the Quaia Sample of Quasars: A Bayesian Analysis

Vasudev Mittal,[1,2*★] Oliver T. Oayda,[2*†] and Geraint F. Lewis[2]
[*] *Joint first author*
[1] *Department of Physical Sciences, IISER Mohali, Knowledge City, Sector 81, SAS Nagar, Manauli PO 140306, Punjab, India*
[2] *Sydney Institute for Astronomy, School of Physics A28, The University of Sydney, NSW 2006, Australia*





Amplitude D ($\times 10^3$)	37^{+4}_{-4}	34^{+4}_{-4}	25^{+5}_{-5}	17^{+6}_{-6}	11^{+6}_{-5}

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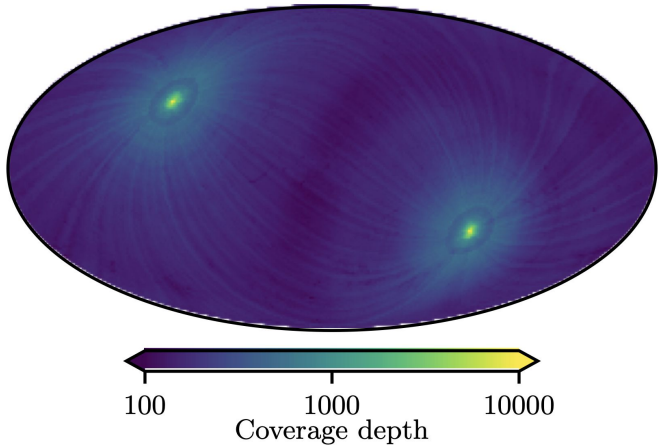
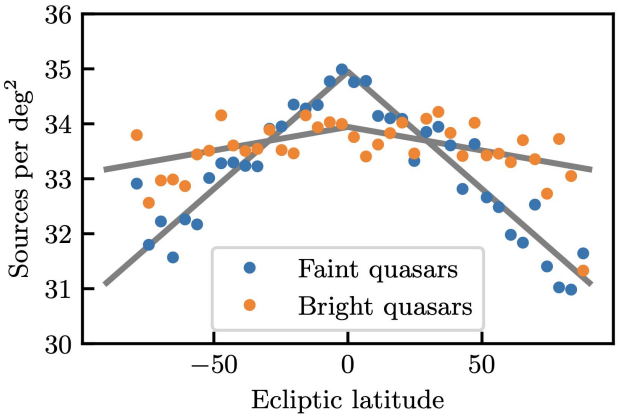
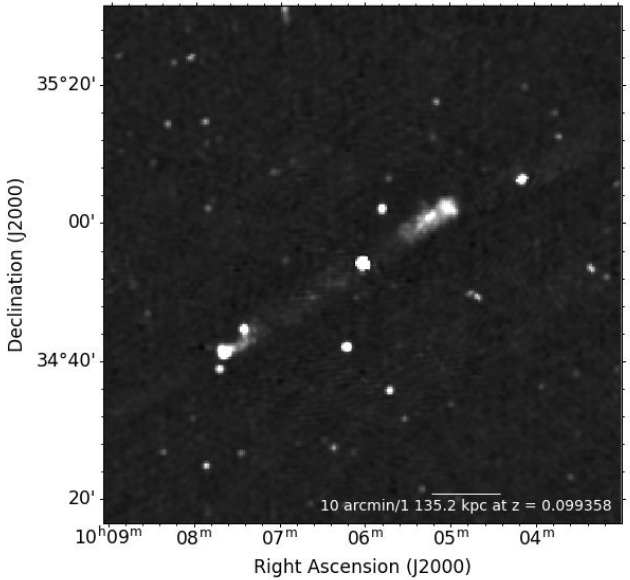
Selection Functions, Classification & Contamination



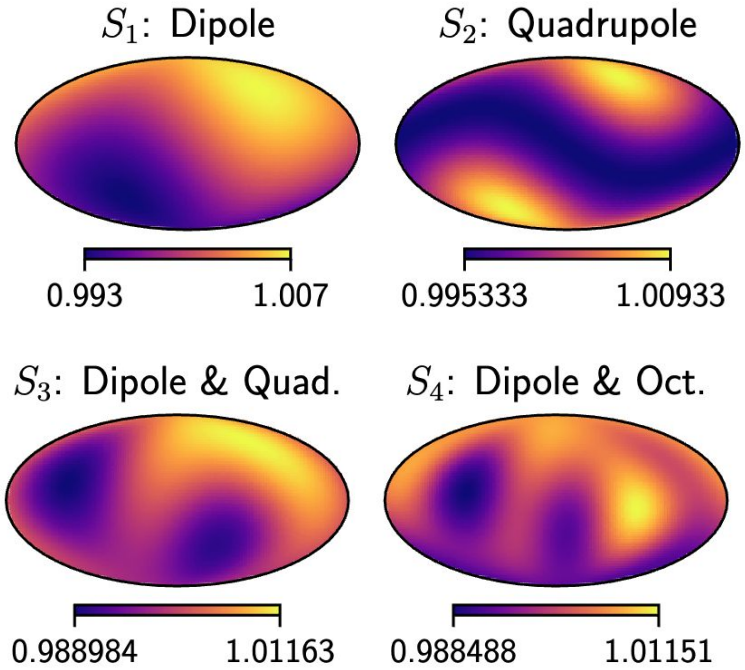


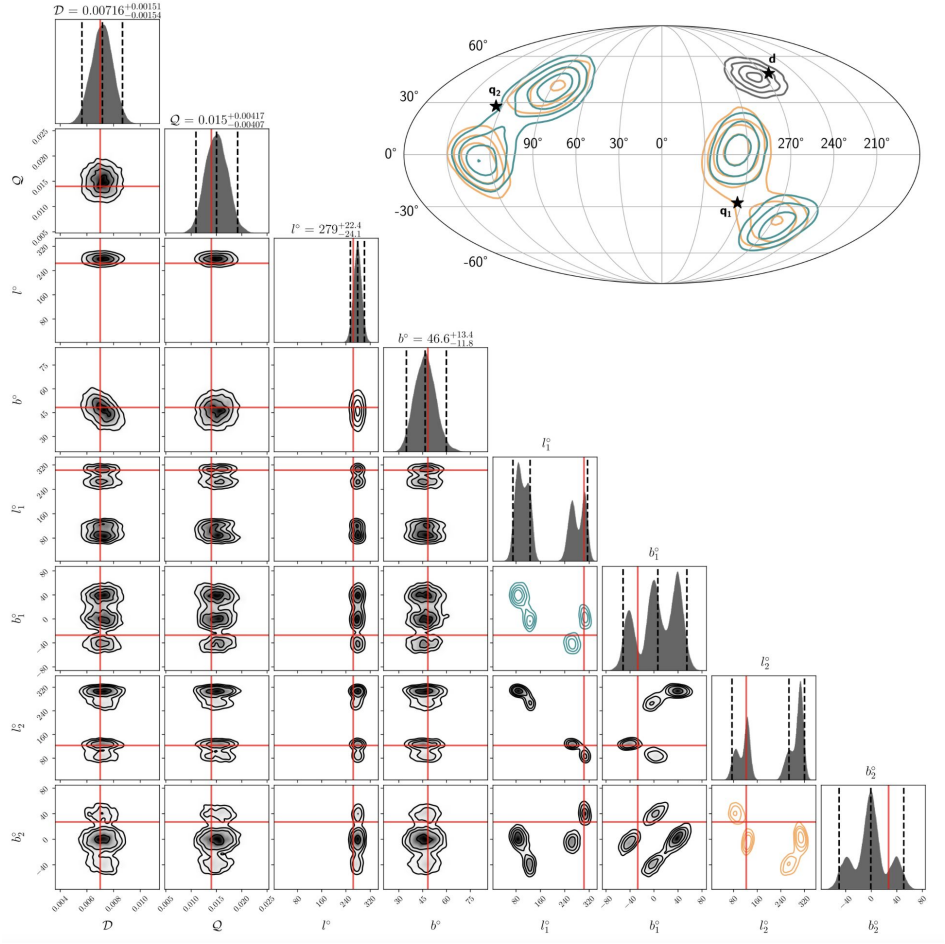
Abghari et al (arXiv:2405.09762)



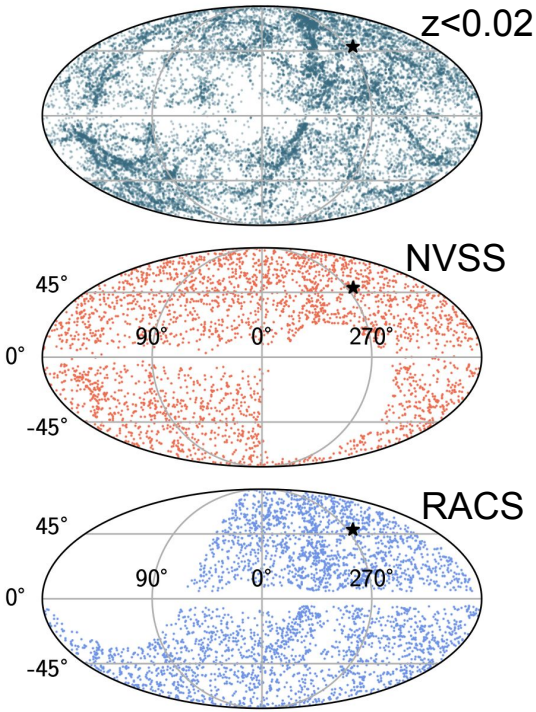
One source, or many?

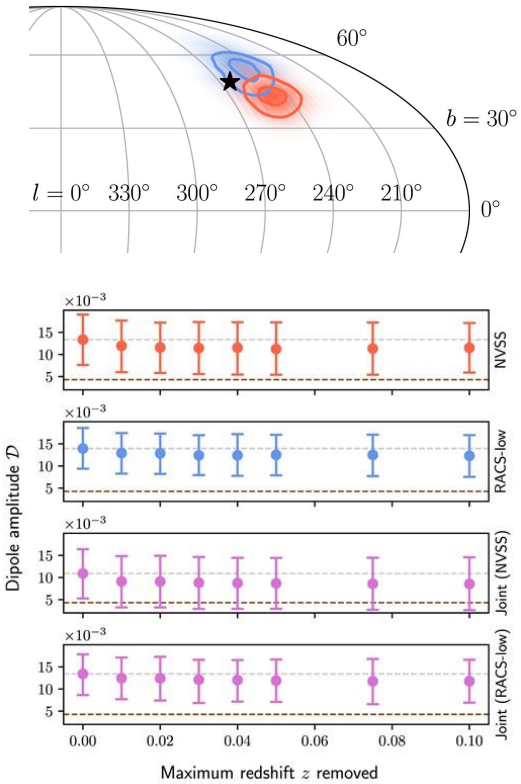
Higher-Order Multipoles





Local Structure





It will be crucial to understand the impact of local structure.

~1% of sources in NVSS and RACS can be cross-matched with z=0.02 sources.

These sources possess a strong dipole signature (D~0.25) and bias the cosmic dipole measurement.

A Bayesian approach to the cosmic dipole in radio galaxy surveys: Joint analysis of NVSS & RACS

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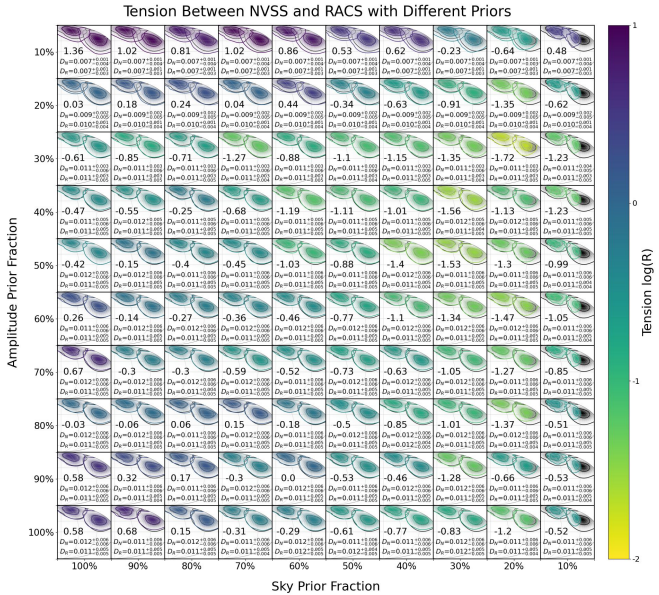
Combining Surveys: Suspicion & Consistency

Tension quantification

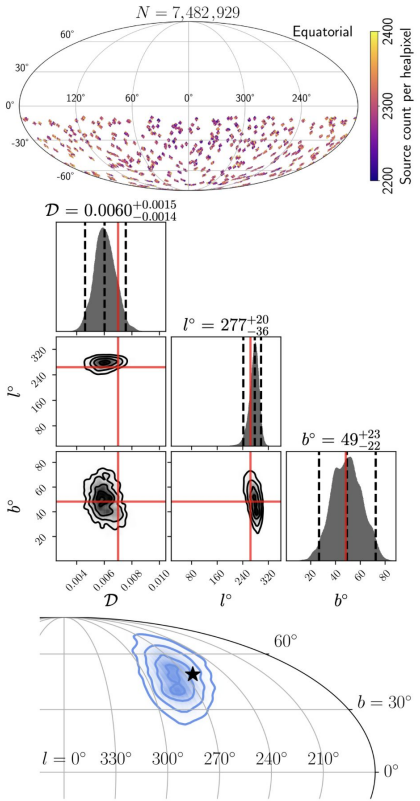
Do different datasets make consistent predictions from the same model? *e.g. CMB vs Type IA supernovae data*

$$\mathcal{R} = \frac{\mathcal{Z}_{AB}}{\mathcal{Z}_A \mathcal{Z}_B}$$



How much information does each dataset bring? Are results consistent, or are they suspicious? Need to go beyond standard approaches. (Land-Strykowski et al. in prep)

Prospects for Future Surveys



EMU (ASKAP's Evolutionary Map of the Universe)

- ~70 million galaxies for declinations less than 30 degrees.
- EMU pilot survey covered 220,000 sources in a keyhole 270 degrees squared area.
- The pilot survey has an insufficient count, but the full will allow robust detection of the cosmic dipole.

EWS (Euclid Wide Survey)

- 14,500 degrees squared, identifying ~ 40 million AGN in at least one photometric band.
- Selection of pure AGN catalog ~5 million AGN
- Sufficient source count for a dipole measure.

LSST

- ~ 10 million quasars will be surveyed over the southern sky by the Legacy Survey of Space and Time.
- This is will be more than sufficient for detection of the cosmic dipole.

SKA

- Phase 1 will cover 5000 square degrees, with ~ 5 million galaxies up to z ~ 0.5.
- Phase 2 will contain 900 million galaxies over 30,000 square degrees.
- While Phase 1 will be insufficient, Phase 2 will be more than sufficient.

Conclusions

- The Cosmic Dipole Tension appears to be a real tension
- As a small signal, it’s a numbers game
- Future surveys will deliver these numbers but:
  - Accurate selection functions are essential
  - Surveys of varying depth can be combined
  - Need to understand the impact of local structure
  - Tension analysis needed to ensure a consistent picture is emerging
- Need anisotropic cosmological simulations as a benchmark