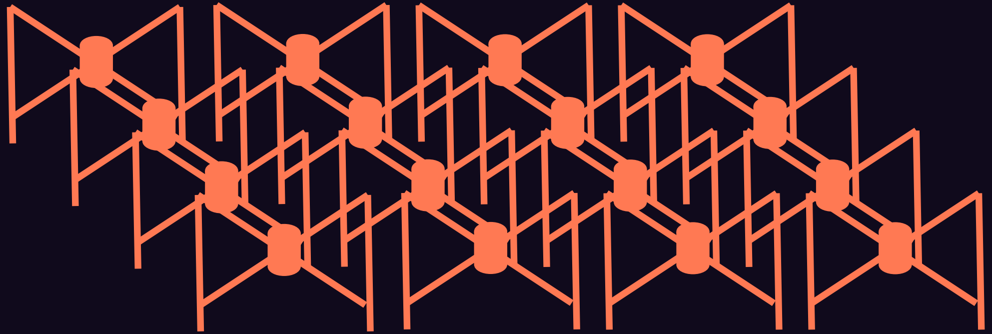
Lessons from the MWA: the Good, the Bad, and the Ugly

21 cm Cosmology Workshop 2024

Dr. Nichole Barry



UNSW SYDNEY

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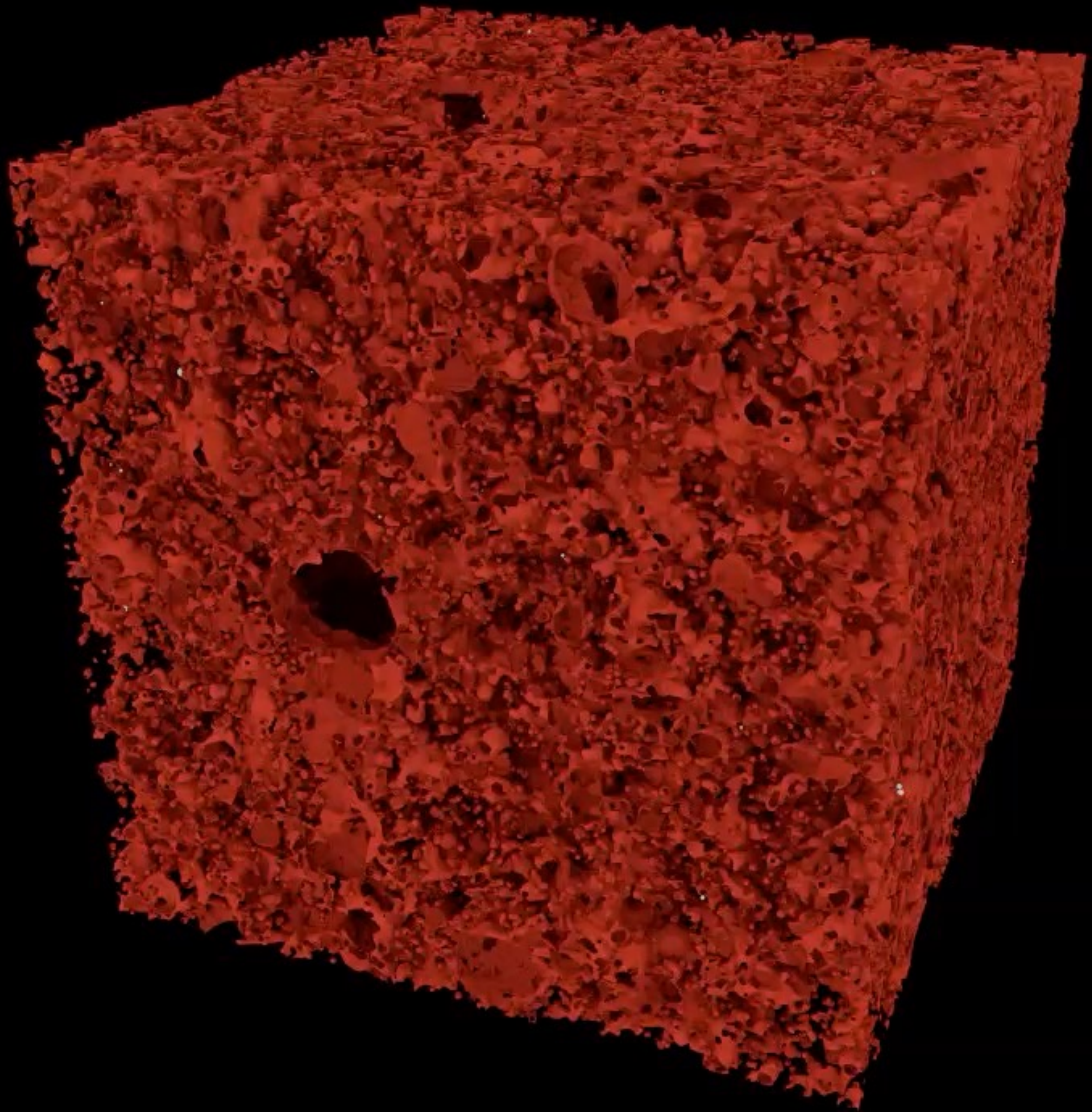
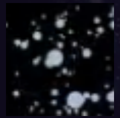
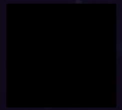


Neutral hydrogen



Ionising sources



Ionised hydrogen

Credit: DRAGONS,
Paul Geil,
& Simon Mutch

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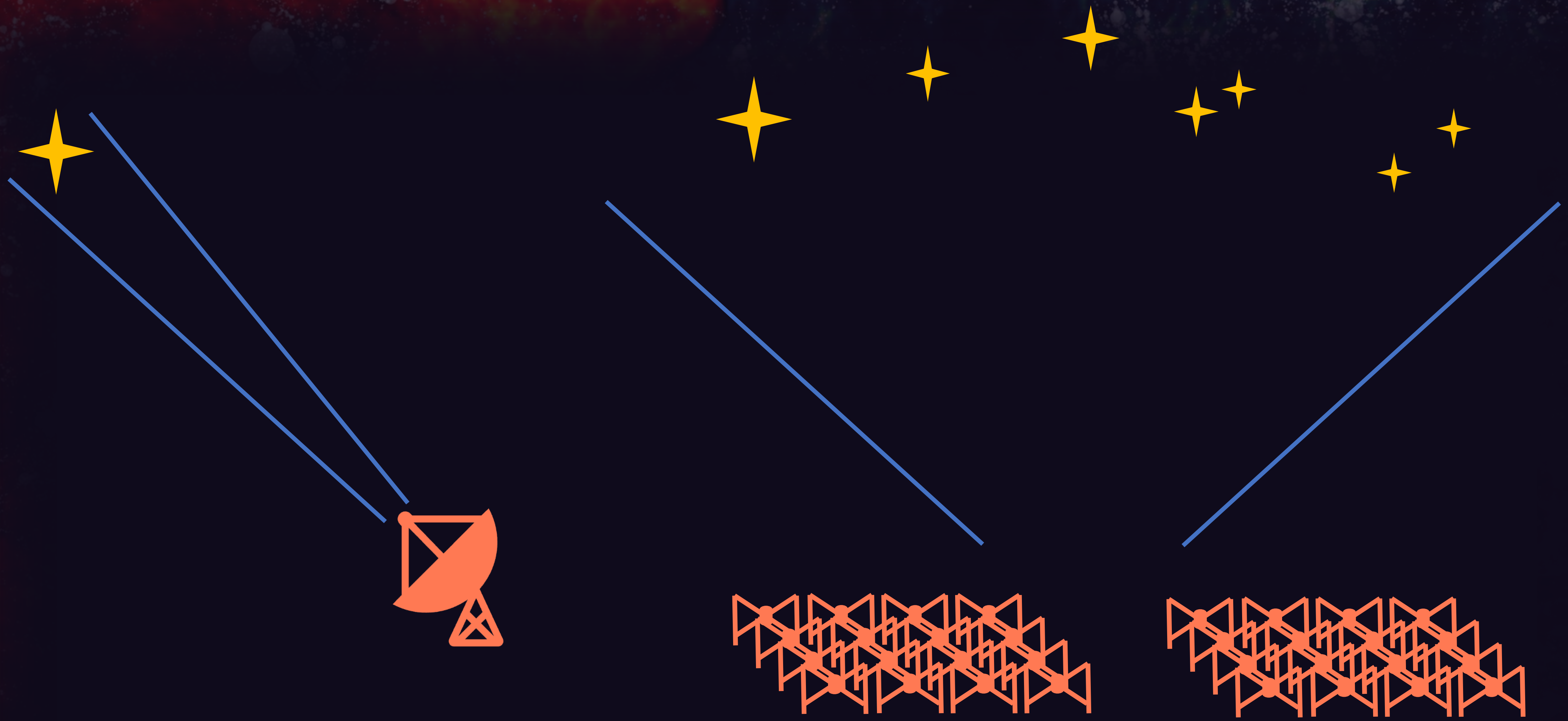

An example of MWA thinking

Remove the contribution of the instrument: calibration

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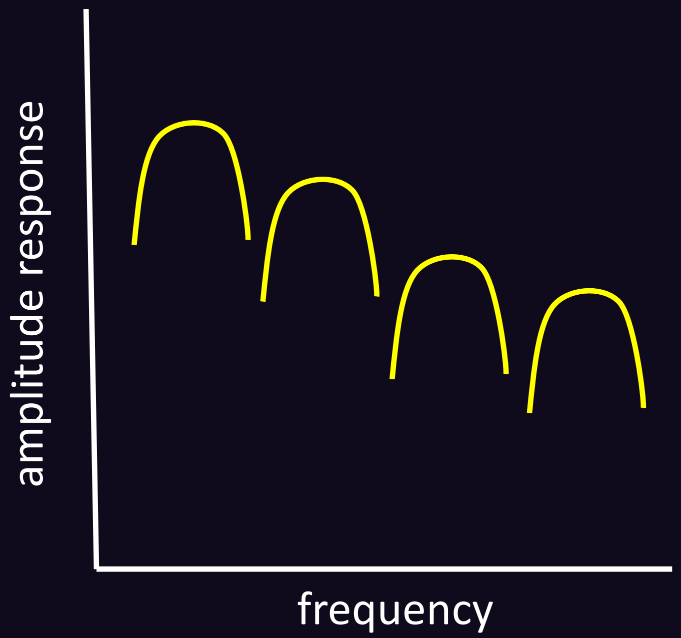
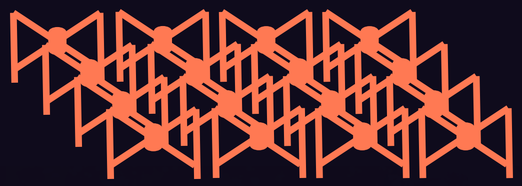
Instrument adds spectral structure





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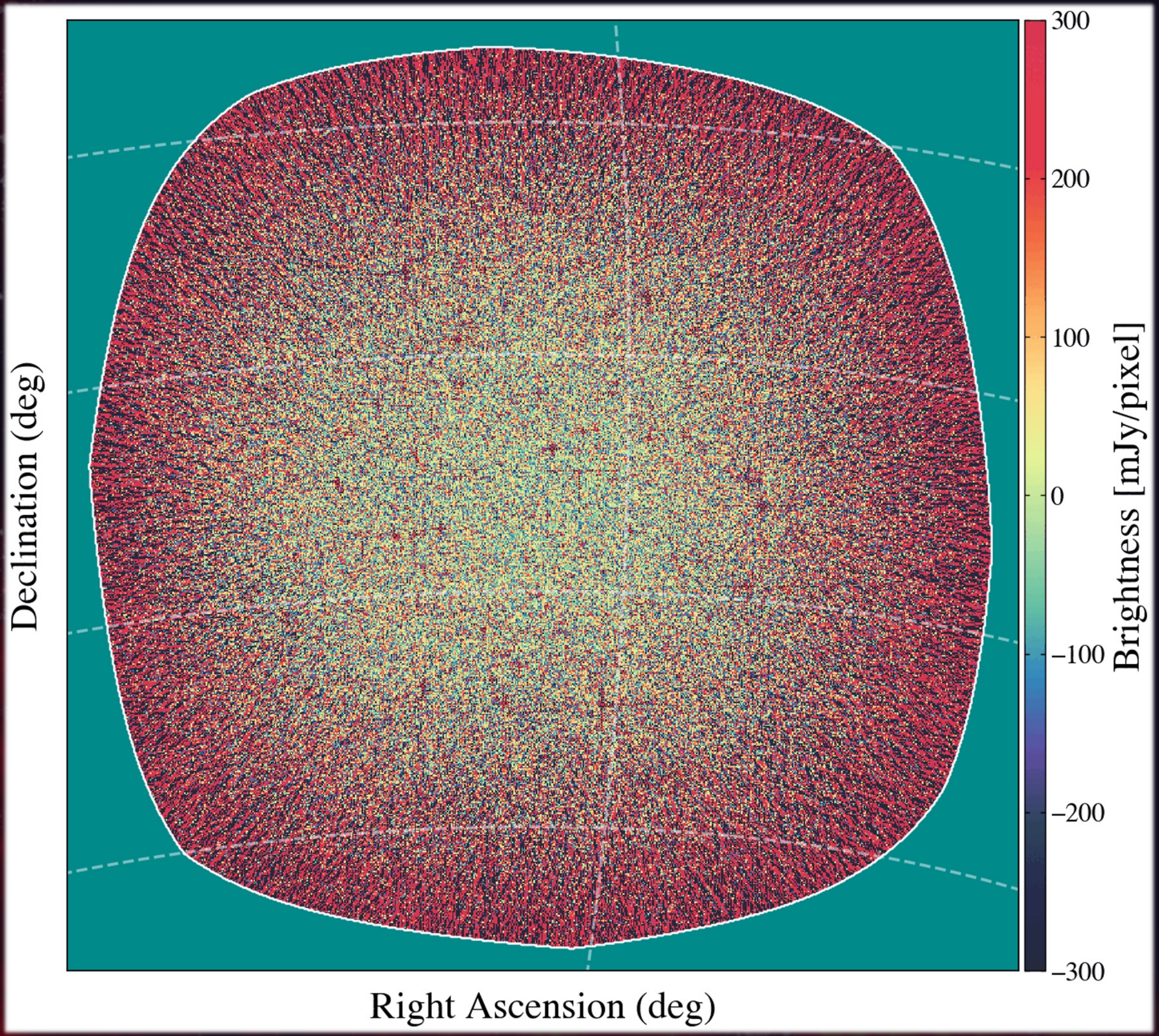
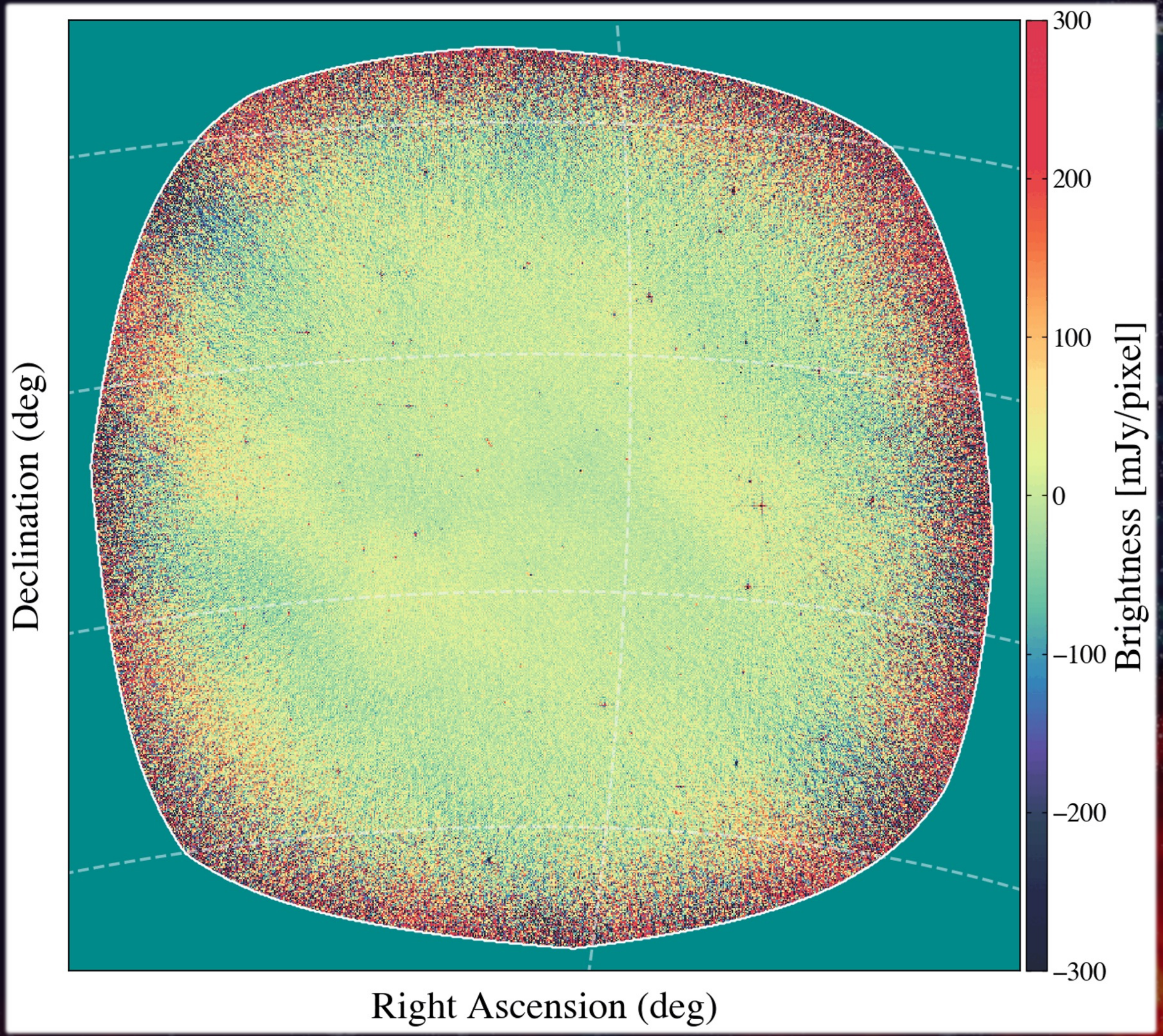
Data



Residual / Model



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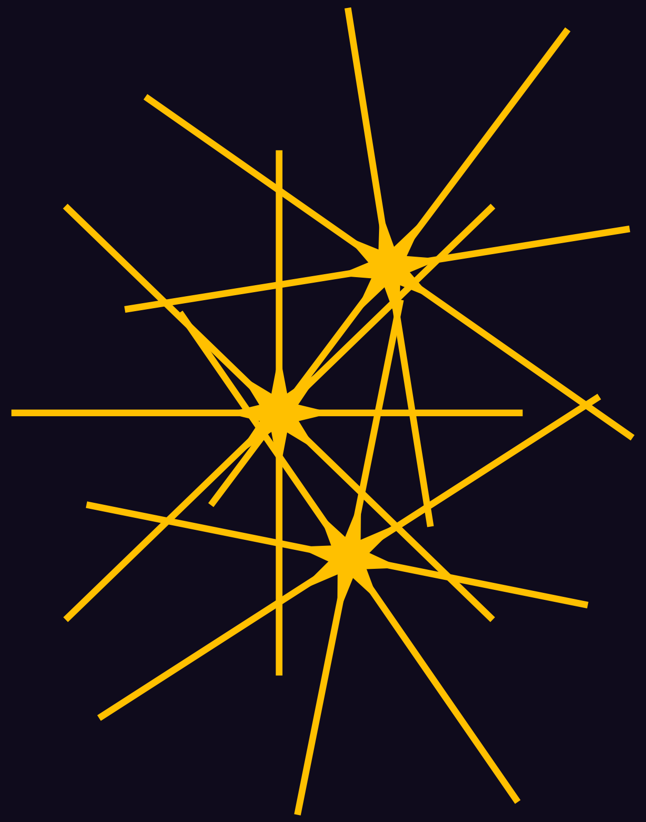
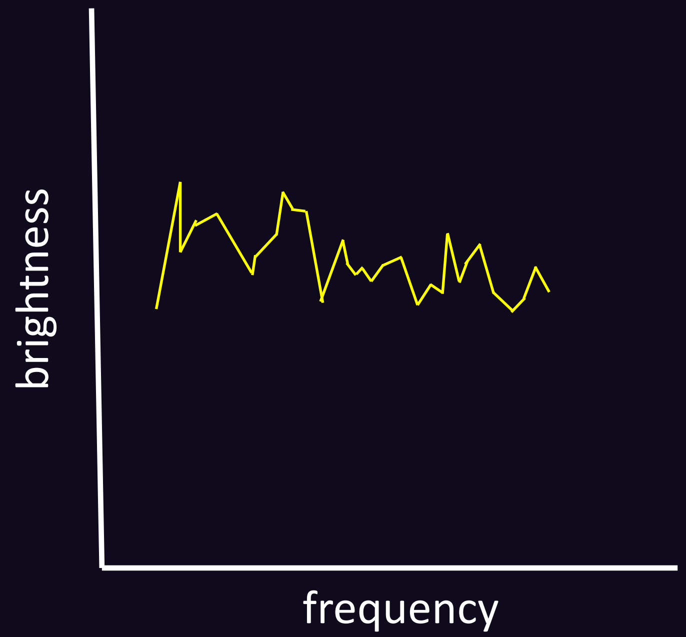
Looks great, right? Well...





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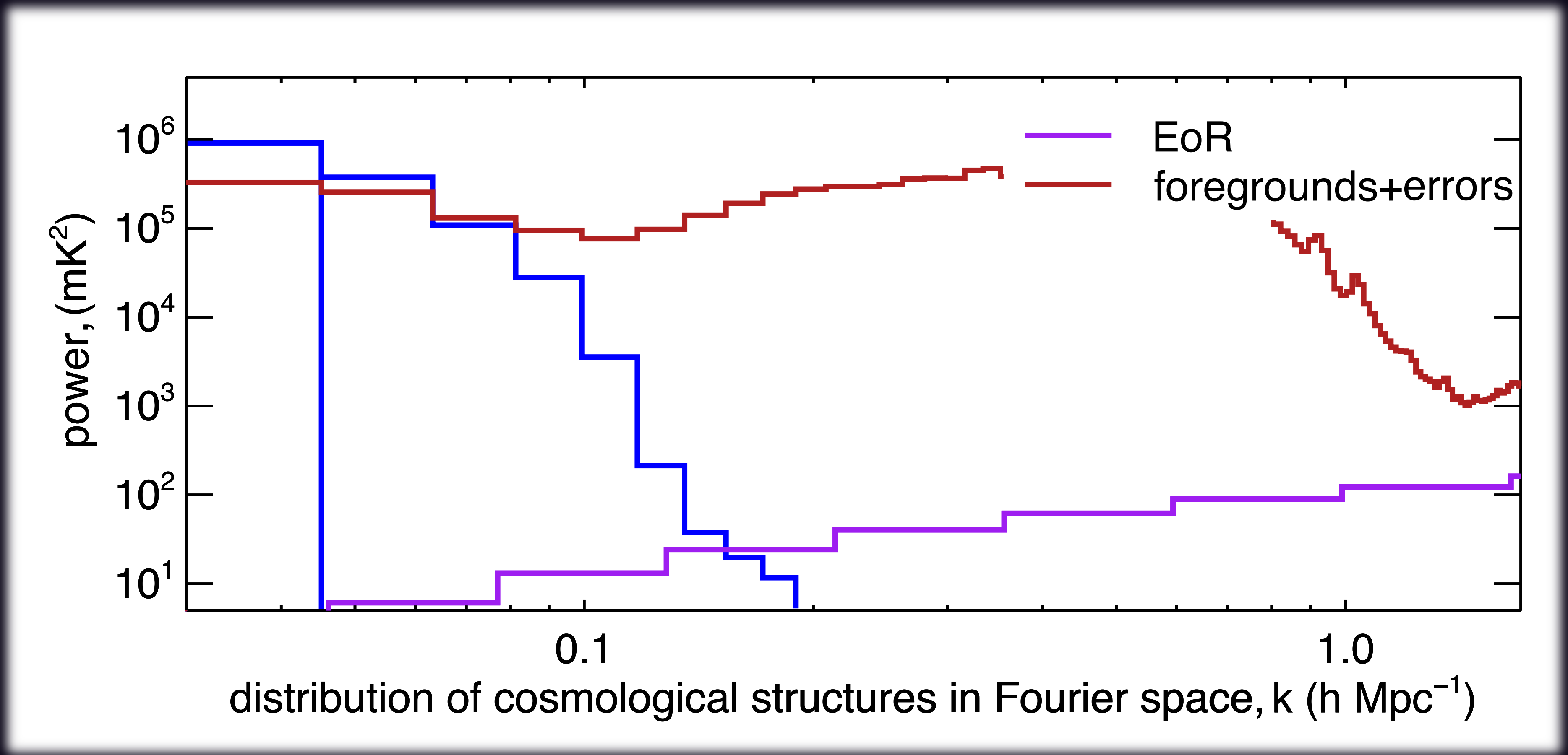
Spectral accuracy requirement: 0.001%



Barry et al 2016

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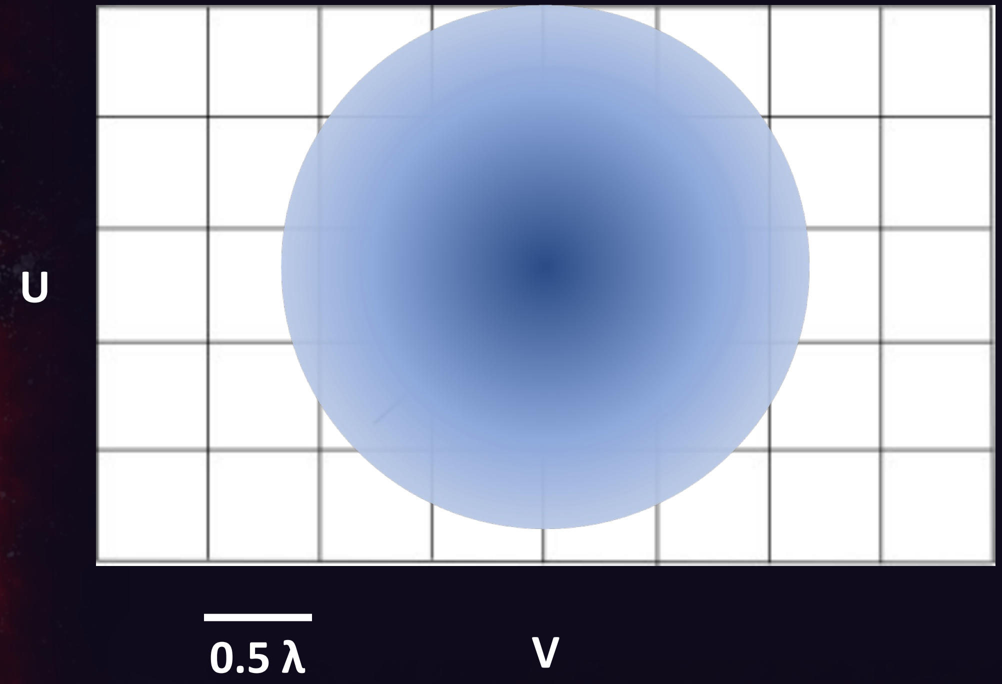
Another example of MWA thinking

2D histogram of many observations

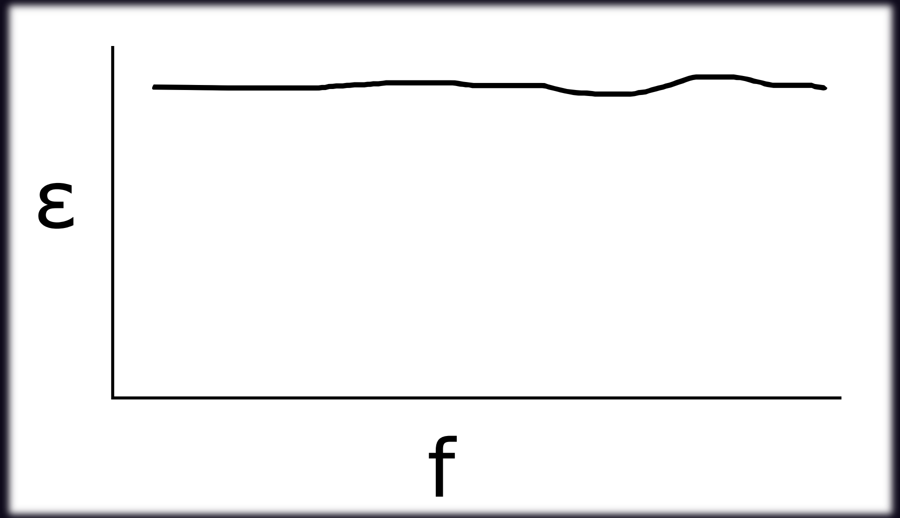
Smooth, inaccurate beam kernel

Very accurate beam kernel



Less discrete sum errors *spectrally*

Discrete sum errors



Choudhuri et al. 2016, Barry et al. 2019b

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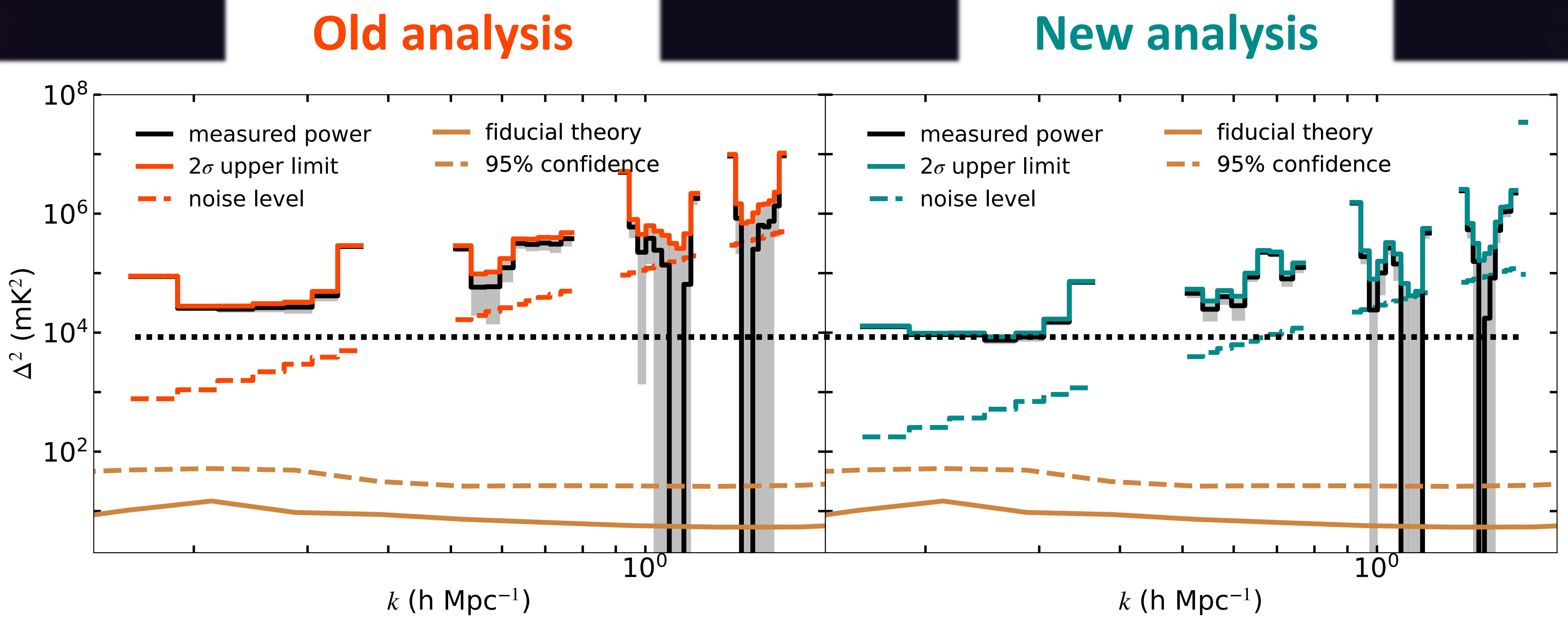

Reduction of 3 in power

Barry et al. 2019b

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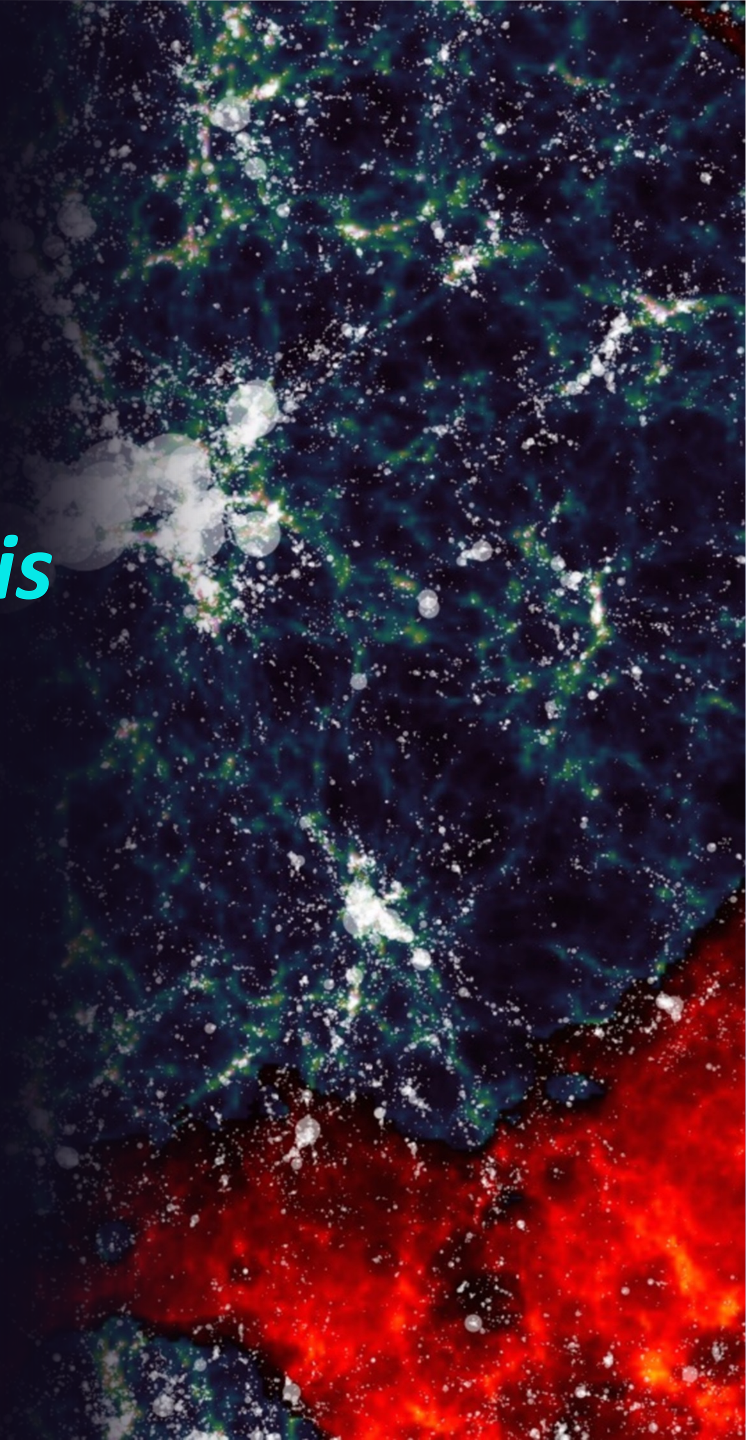
Recent improvements on MWA EoR analysis

- *Beam measurements*
- *Digital non-linearity corrections*
- *Ultra-faint RFI*
- *GPU simulations*
- *Galactic plane models*



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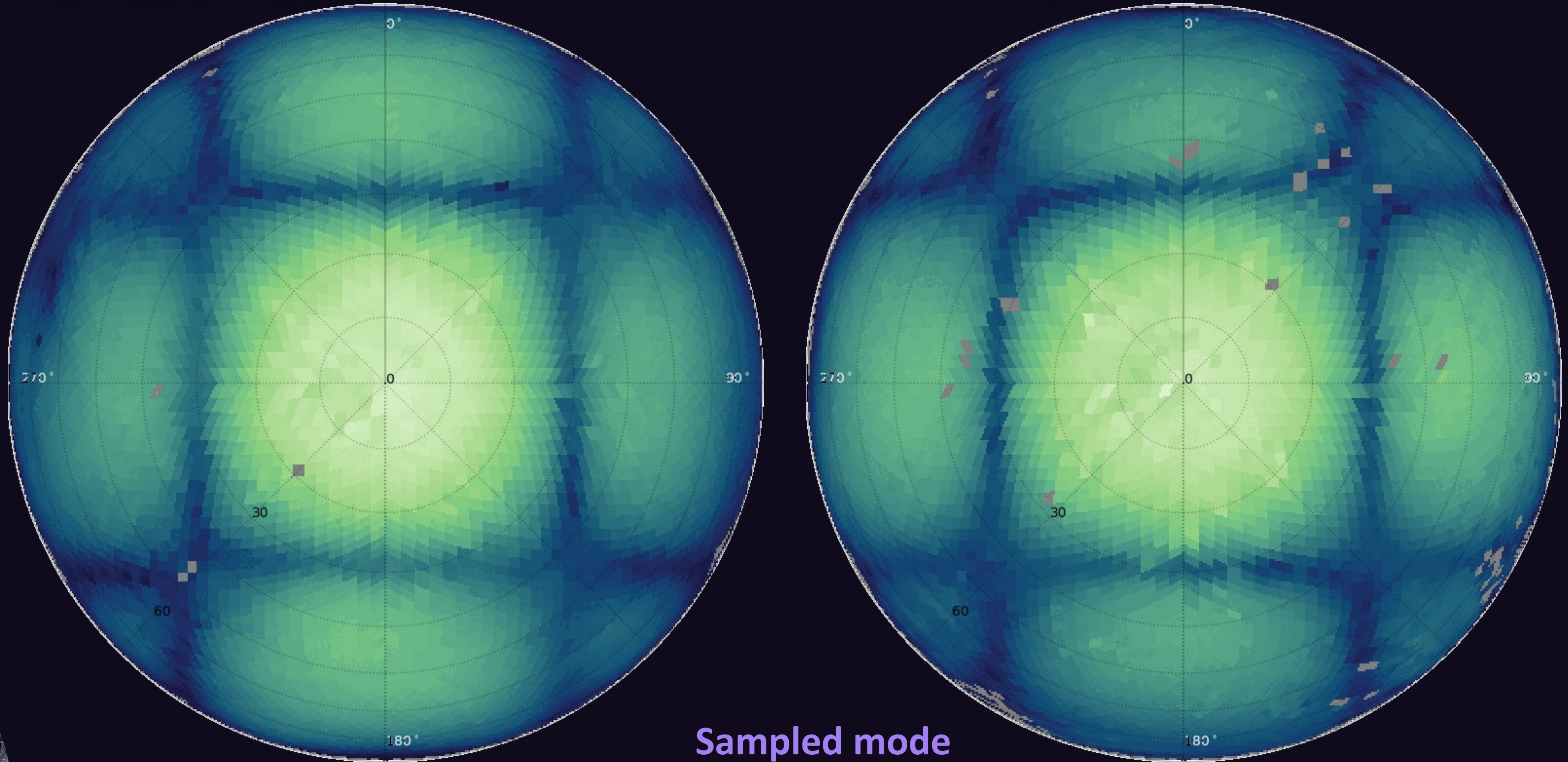
Communication satellite measurements of beam sensitivity



$$V = \iint A(\hat{s})\, I(\hat{s})\, e^{-2\pi i \vec{b}\cdot\hat{s}/\lambda}\, d\Omega$$

Sampled mode

Beam response

Sky intensity

Chokshi et al. 2020, 2021

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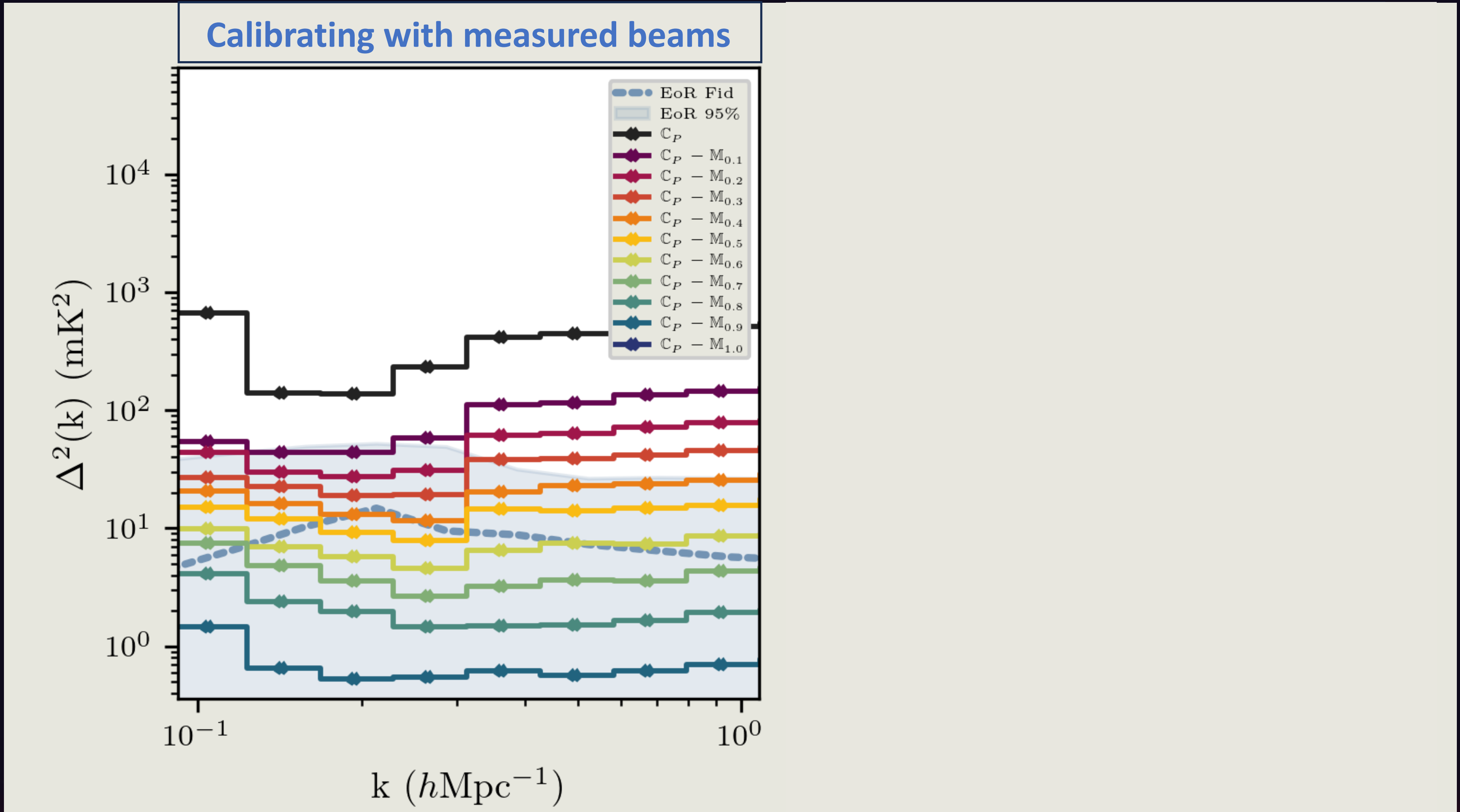
Variations in instrument encode spectral structure



Chokshi in prep

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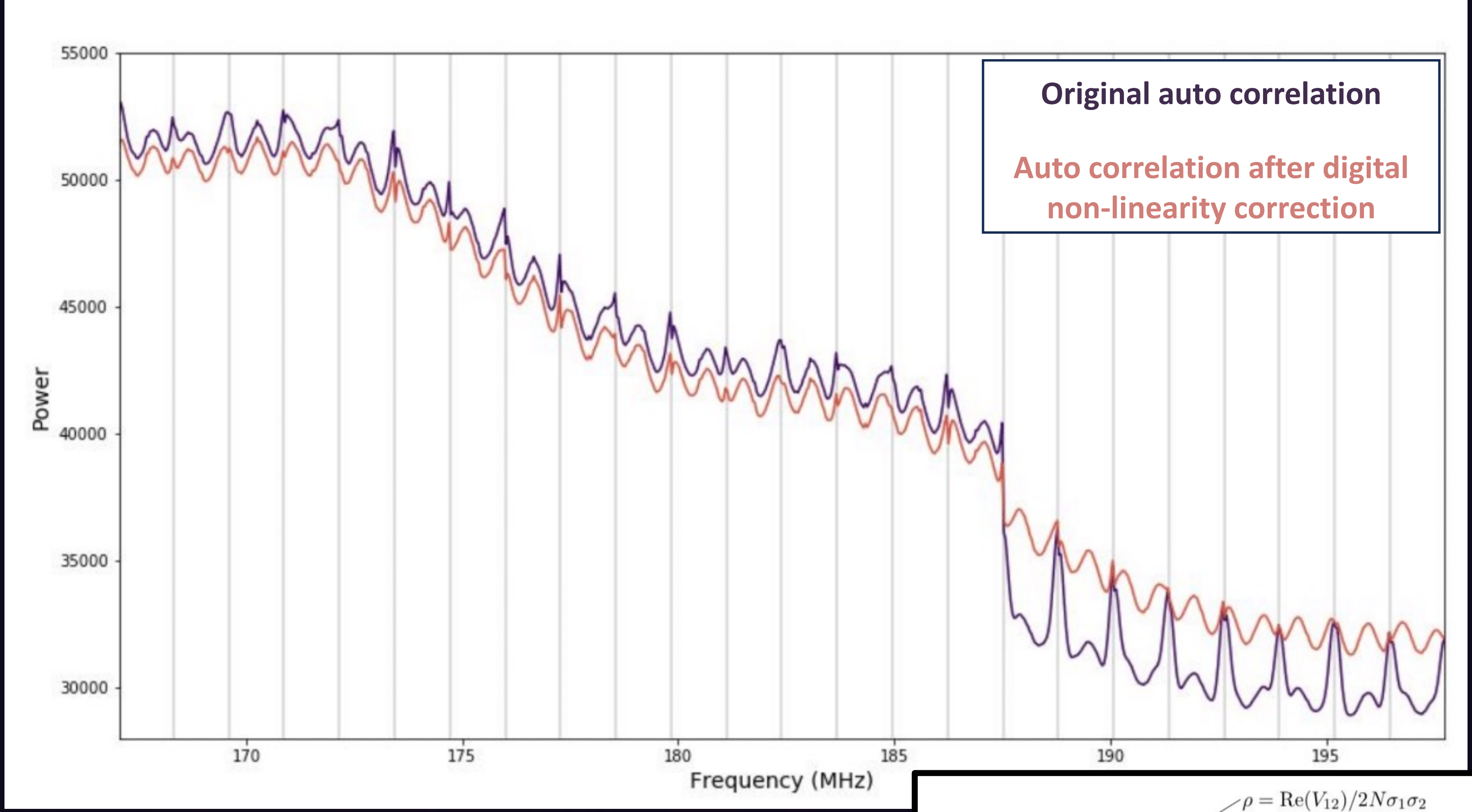
van Vleck corrections to account for quantization errors



$$E[\hat{X}_1\hat{X}_2] = \sum_{i=-7}^{6}\sum_{j=-7}^{6}\int_0^{\rho} d\rho' \frac{1}{2\pi\sqrt{1-\rho'^2}} \exp\Big[-\frac{1}{2(1-\rho'^2)}\Big(\frac{(i+0.5)^2}{\sigma_{x_1}^2} + \frac{(j+0.5)^2}{\sigma_{x_2}^2} - \frac{2\rho'(i+0.5)(j+0.5)}{\sigma_{x_1}\sigma_{x_2}}\Big)\Big]$$

$\rho = \mathrm{Re}(V_{12})/2N\sigma_1\sigma_2$

$E[\hat{X}_1\hat{X}_2] = \mathrm{Re}(\hat{V}_{12})/2N$

Star, 2024

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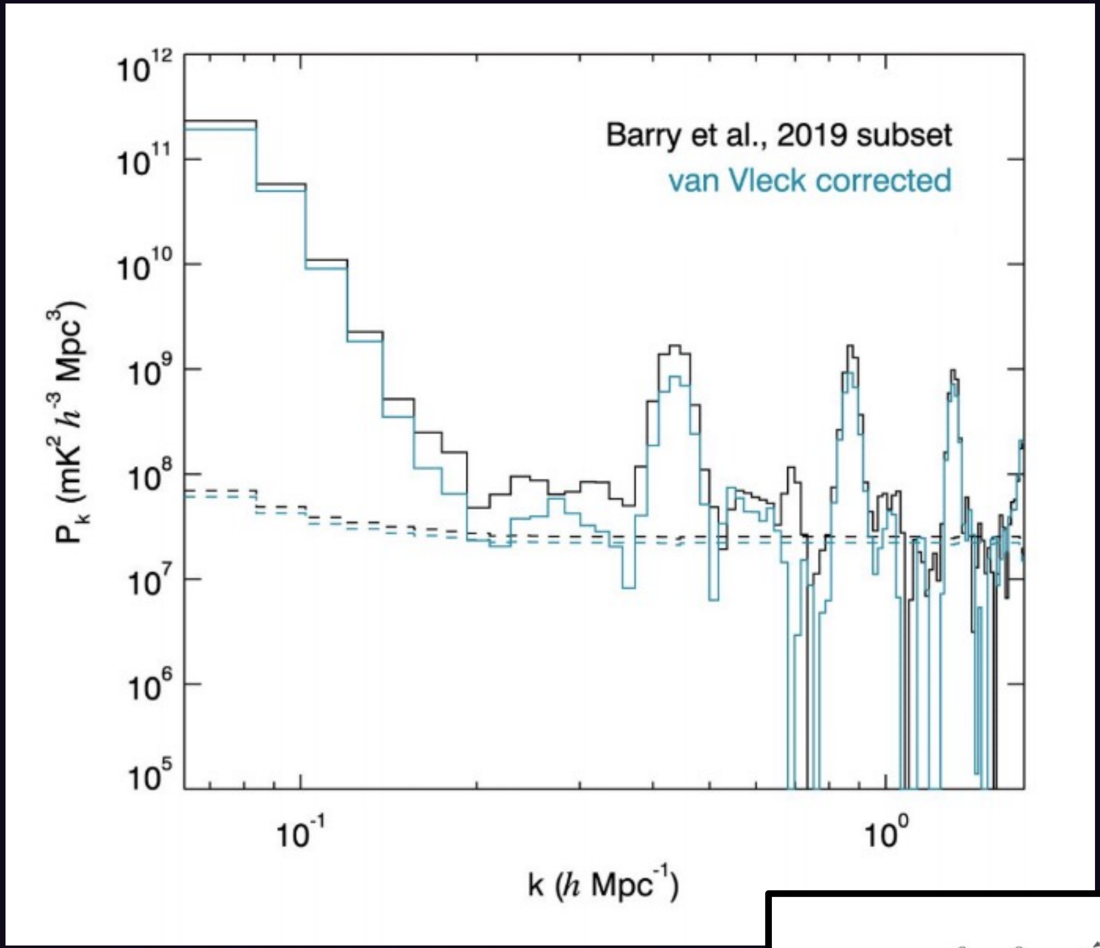
van Vleck corrections to account for quantization errors



$\rho = \mathrm{Re}(V_{12})/2N\sigma_1\sigma_2$

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$E[\hat{X}_1\hat{X}_2] = \mathrm{Re}(\hat{V}_{12})/2N$

Star, 2024

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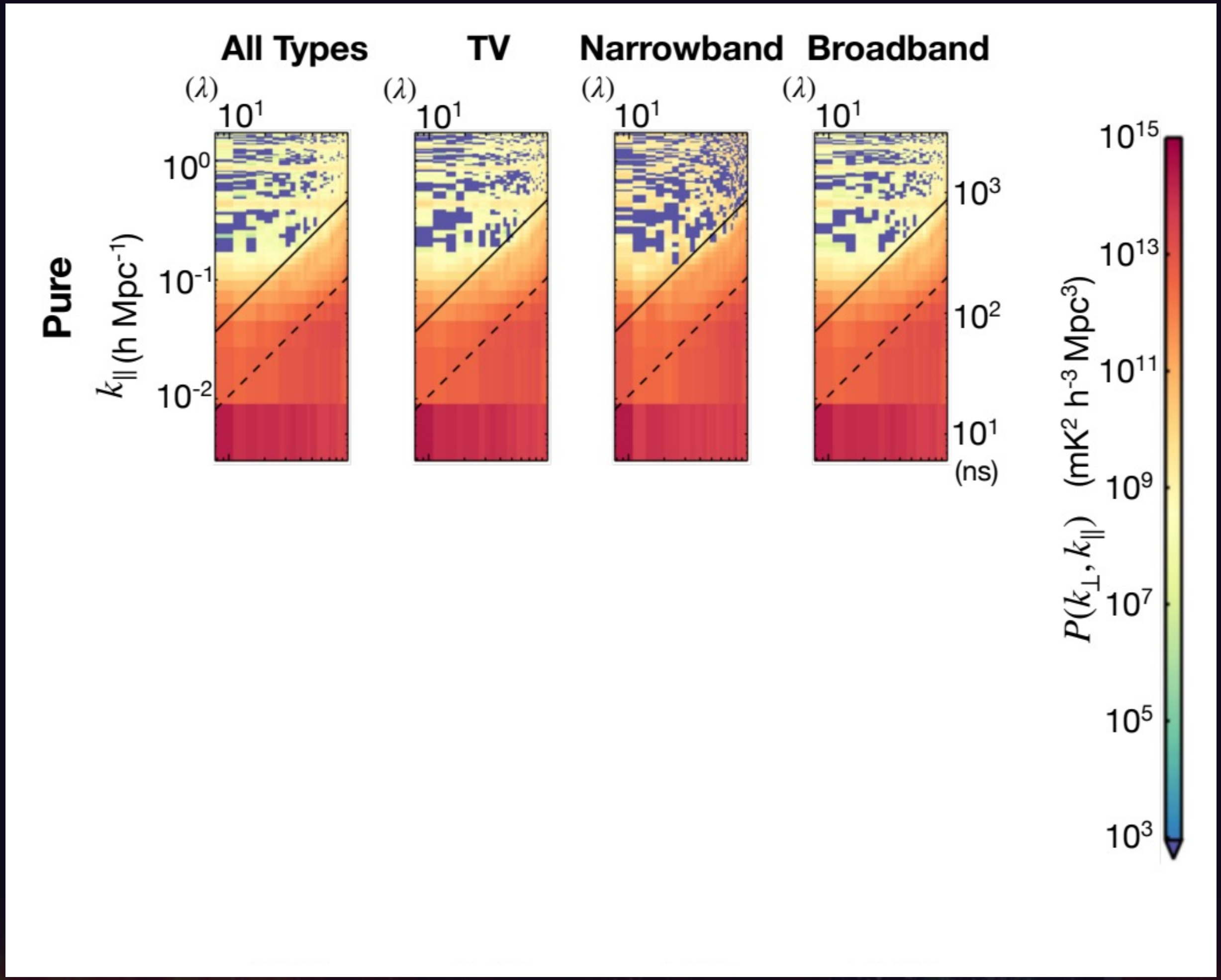
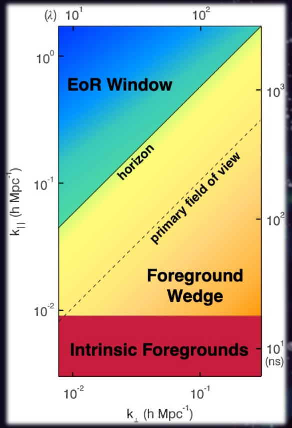
Faint Radio Frequency Interference

RFI signature type

Observations with no RFI signature

Observations with RFI signatures *that have been flagged*





Wilensky et al. 2023

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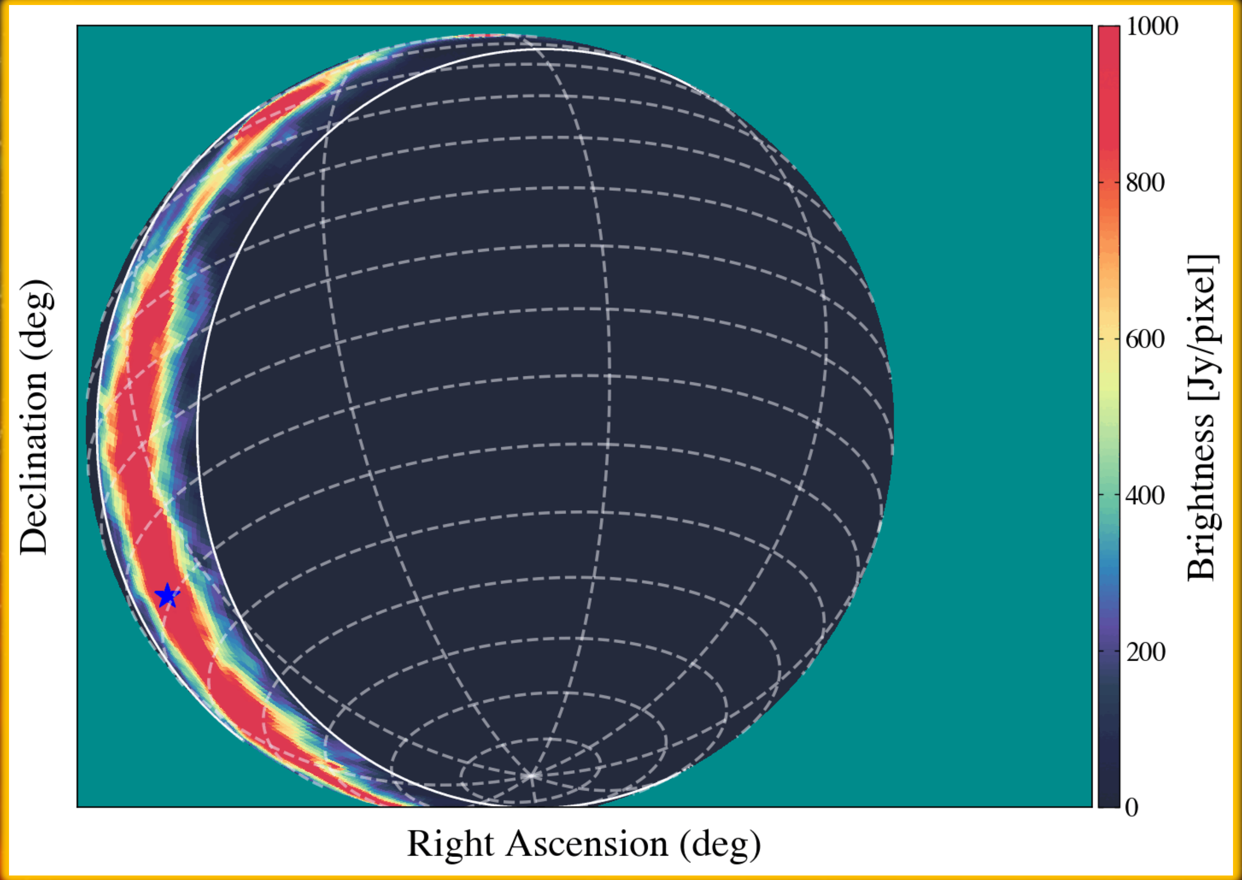

Model of the Galactic Plane from the Engineering Development Array 2 (EDA2)

Kriele et al. 2022

The galactic plane sets over the course of a night of MWA observation

Requires a point source model due to beam gradient, and thus a powerful GPU simulator

Woden -- Line 2022

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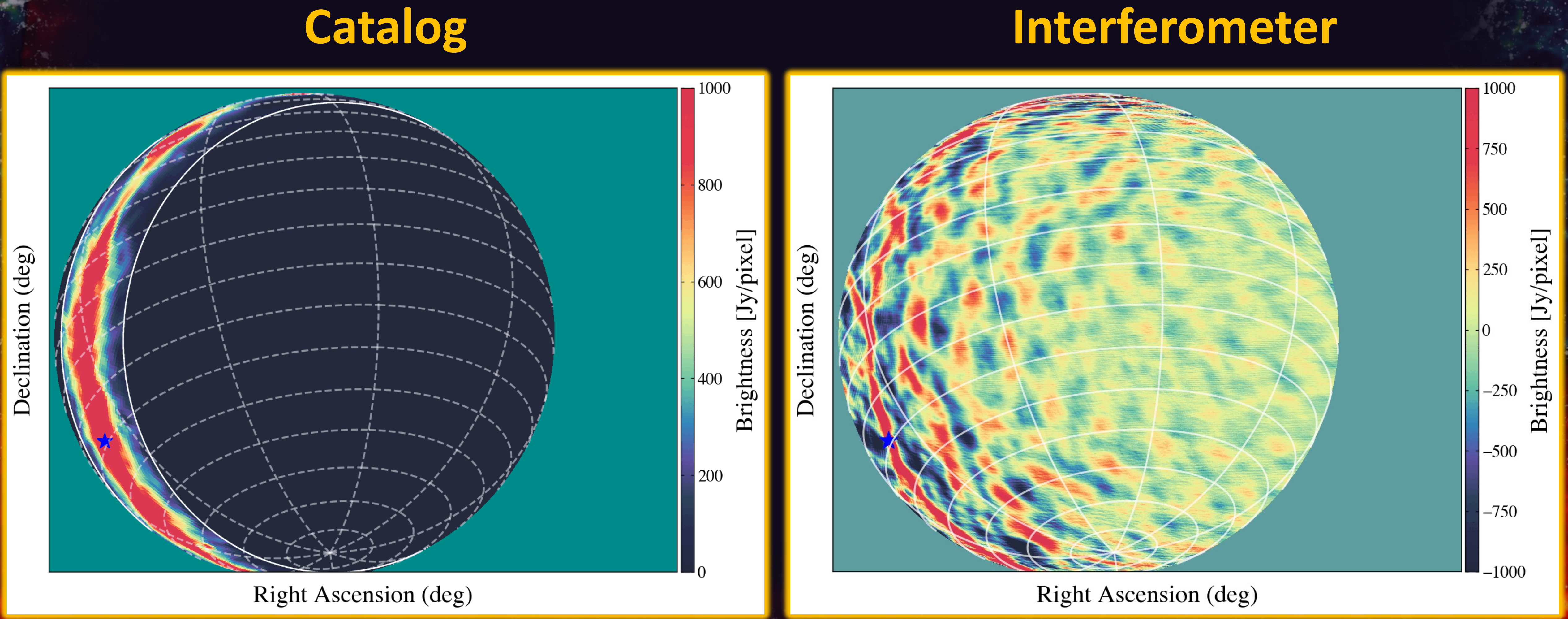

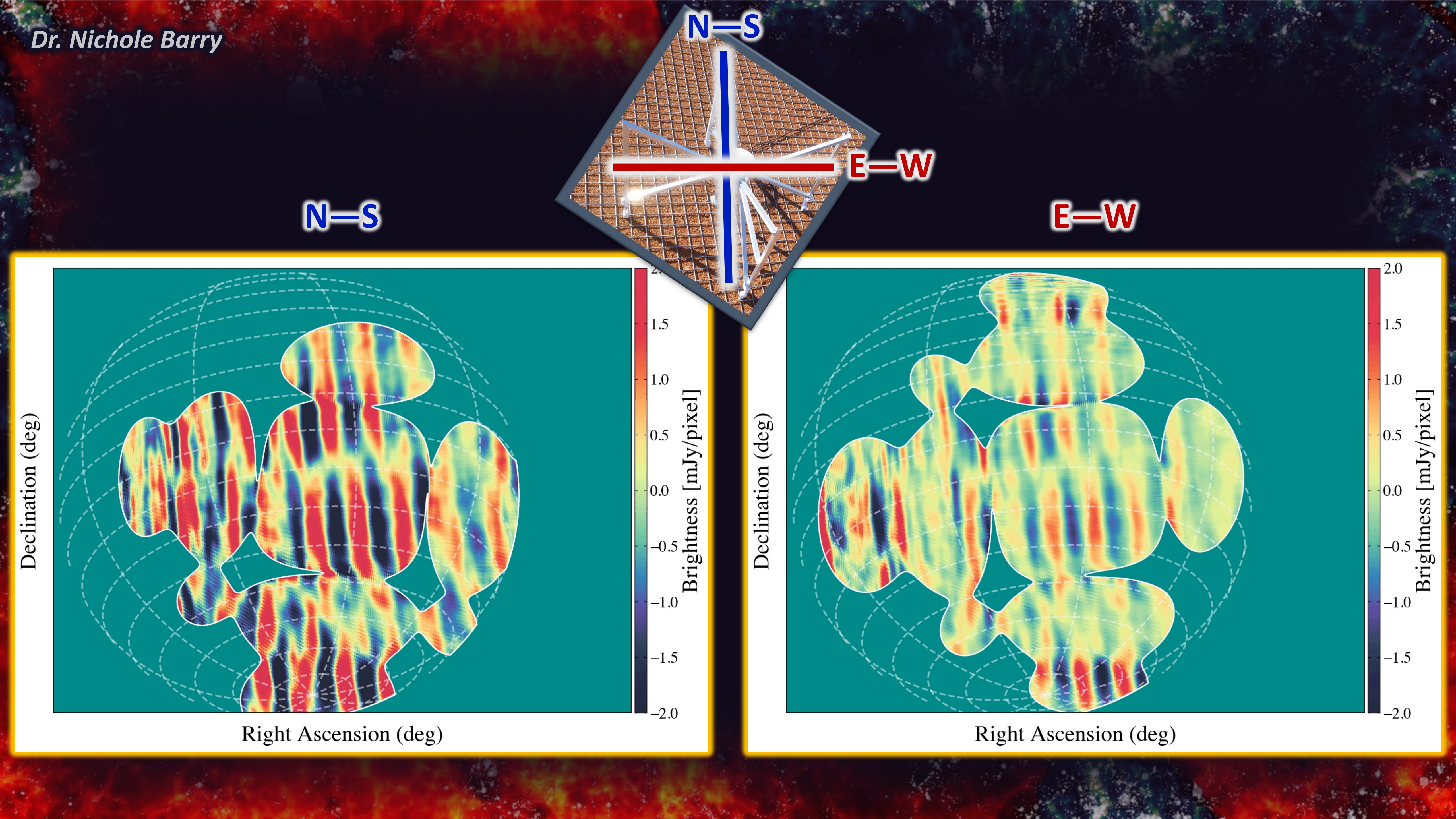
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N—S
E—W
N—S
E—W
Declination (deg)
Right Ascension (deg)
Brightness [mJy/pixel]
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
Declination (deg)
Right Ascension (deg)
Brightness [mJy/pixel]
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0

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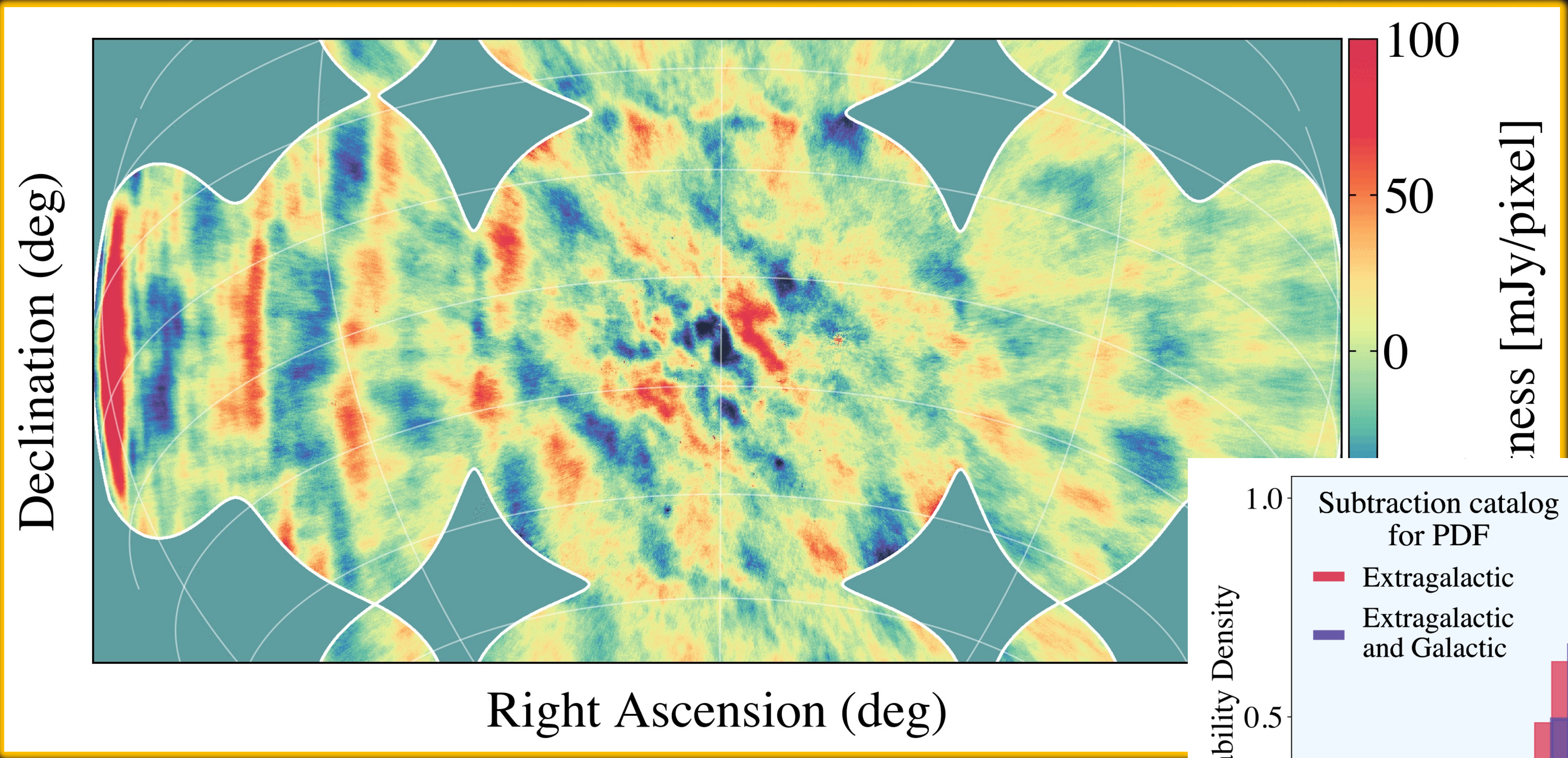

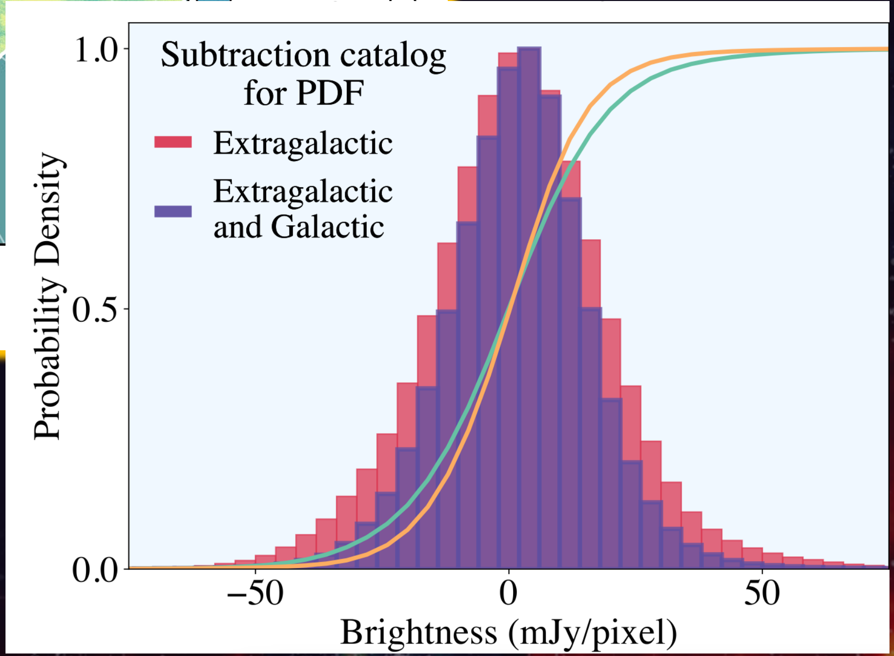

Galacticset affects all precision science with the MWA

Barry et al. 2024

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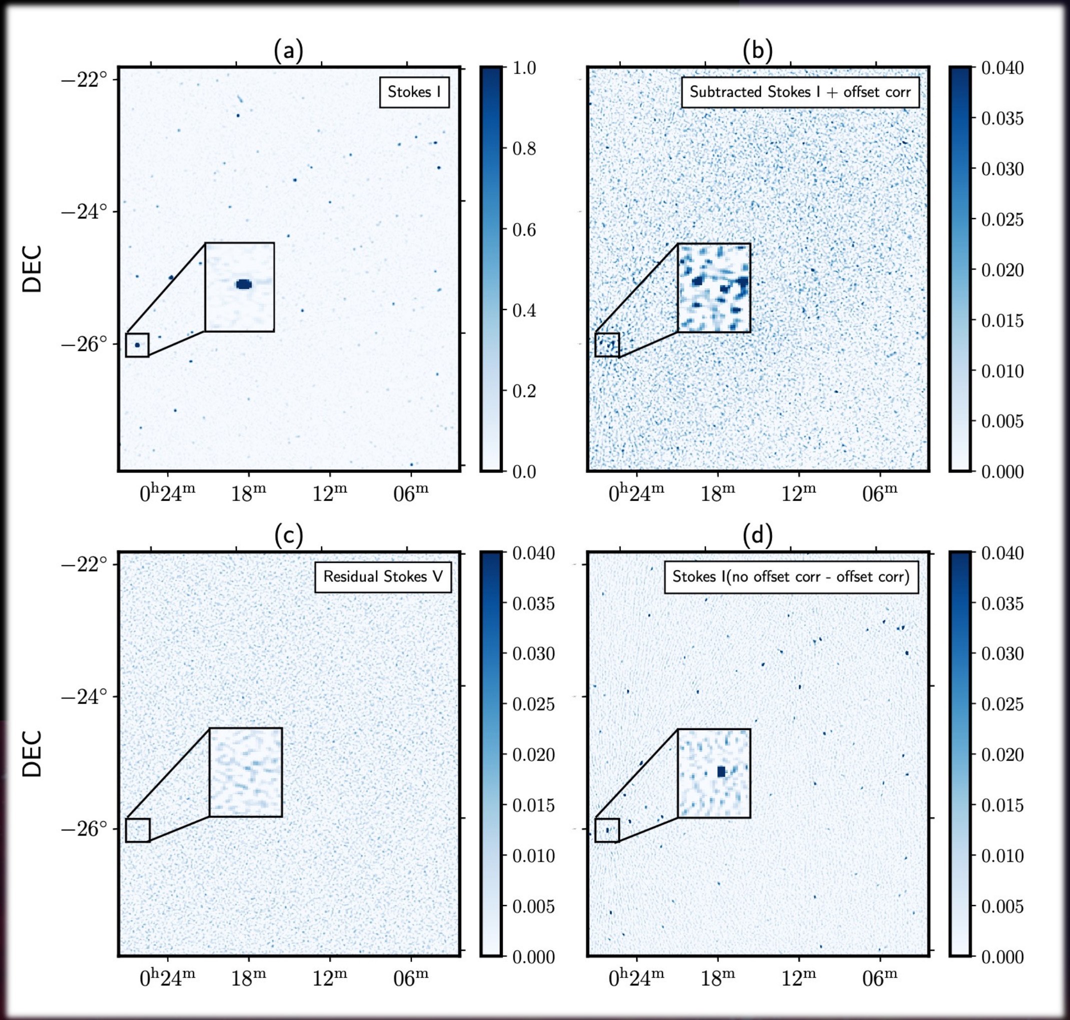
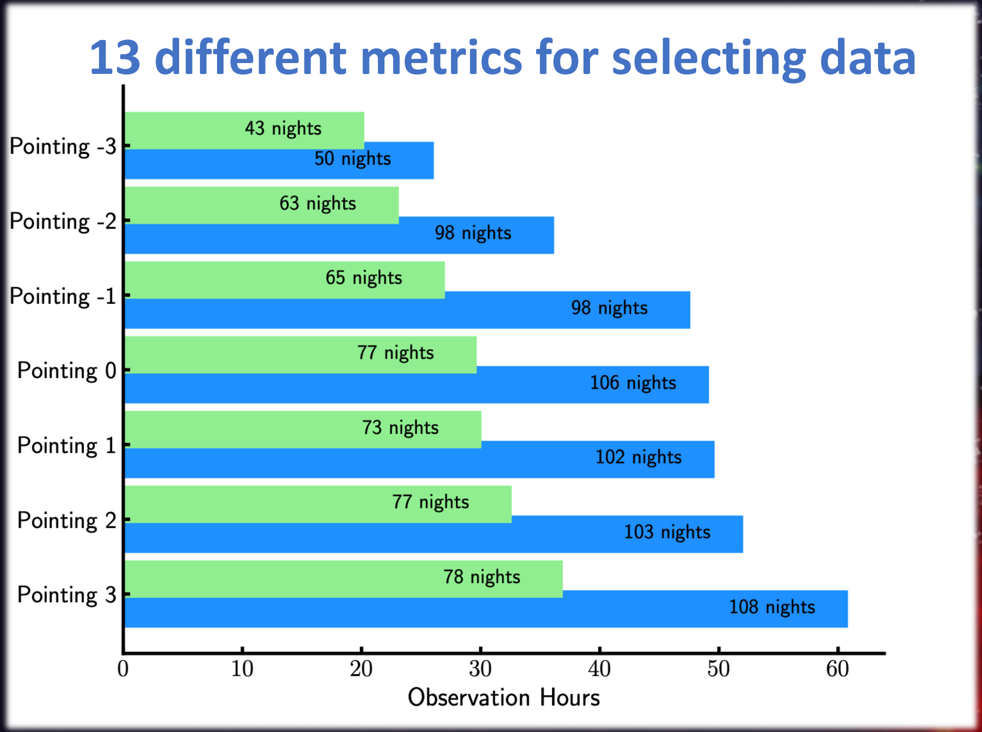
Ionospheric offset corrections



Nunhokee et al. in review

Many metrics required to select the best quality MWA data; almost half of data is cut.



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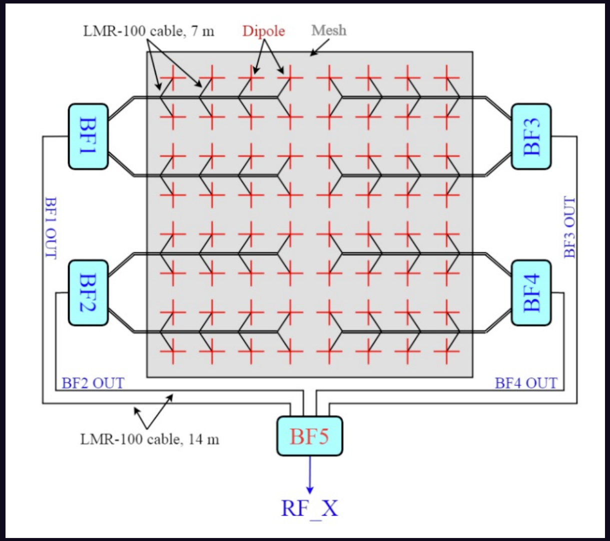
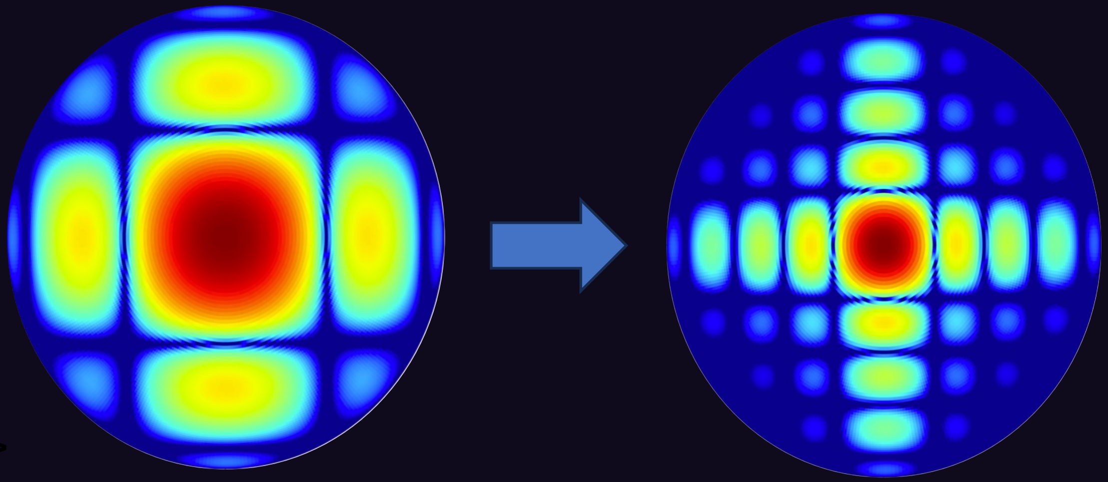
Central Redundant Array Mega-tile (CRAM)





See Ash's talk at 5:15pm

Foregrounds can be reduced by over two orders of magnitude by clever mix-and-matching of instruments.

Selvaraj et al. 2024, Selvaraj et al. in review

10.1017/pasa.2024.33, and in review

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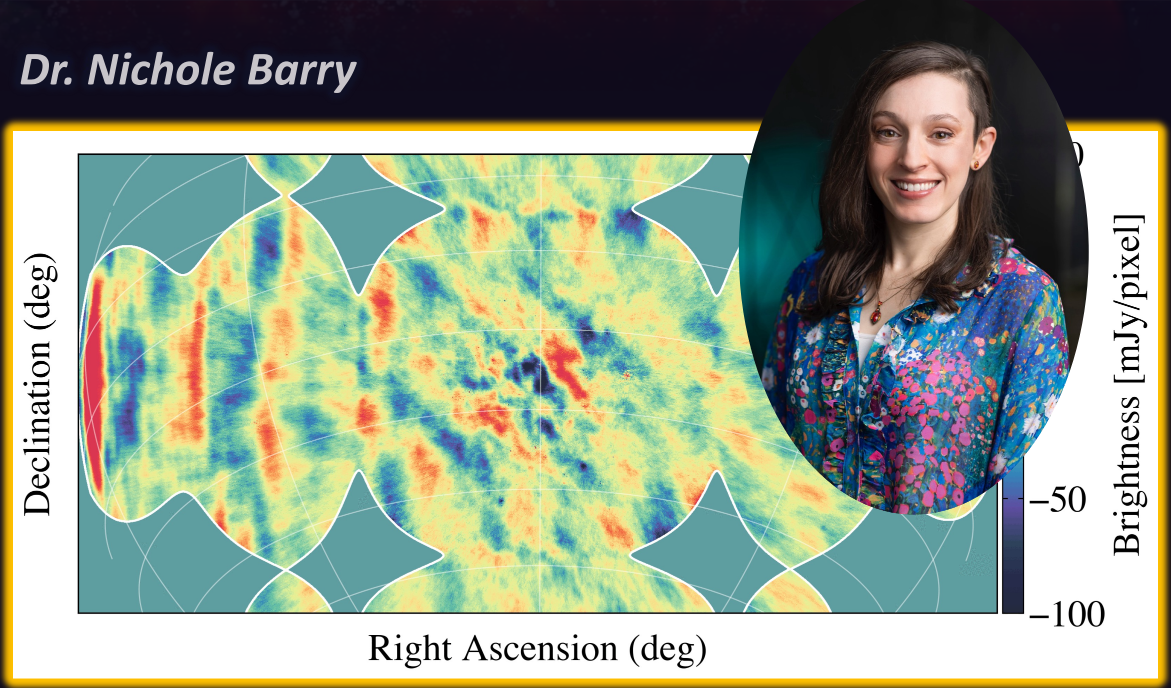

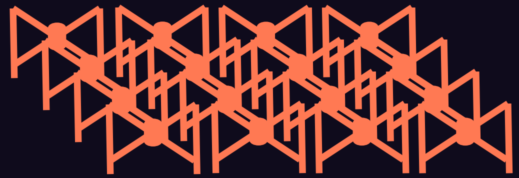

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The Murchison Widefield Array is driven by the research of Early Career Researchers (ECRs)

Advancements in RFI detection, van Vleck corrections, GPU simulations, beam measurements, Galactic plane models, and much more.

New limit later this year / early next year.