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Beam Analysis: Impact on Mapmaking

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on behalf of the BINGO collaboration

IFUSP
Instituto de Física da USP

BINGO

Agenda

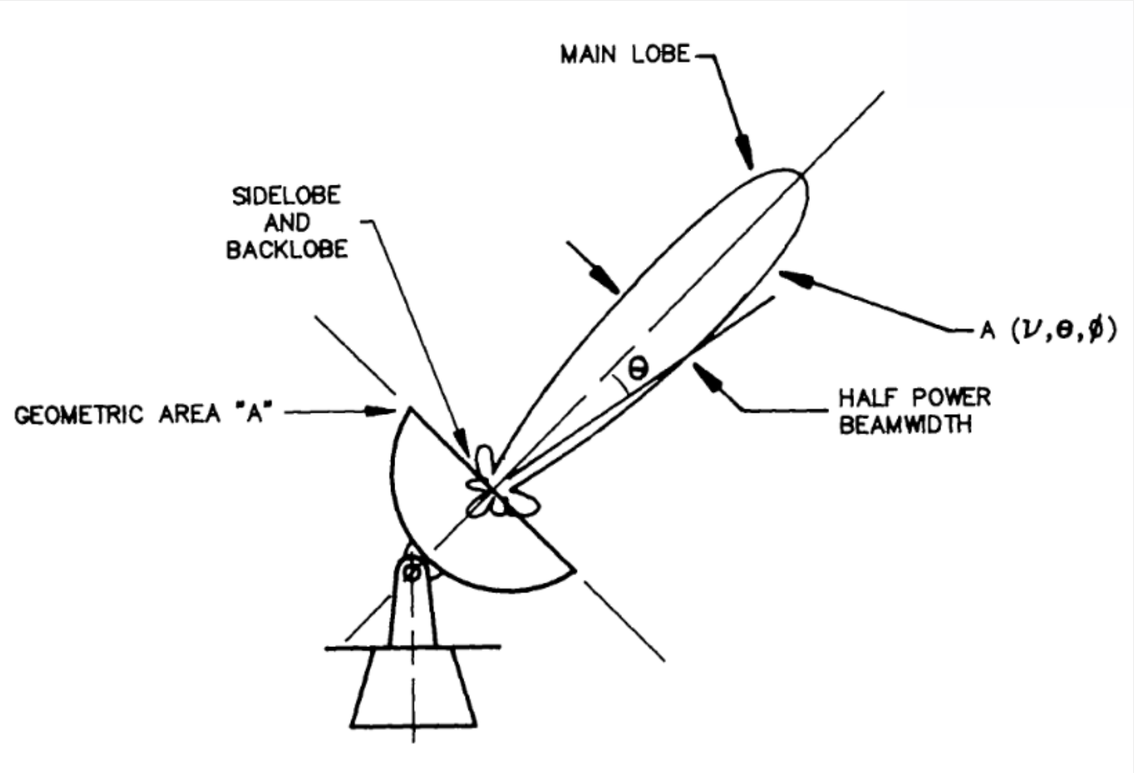
1) Beam Overview
    - Formation of Beams
    - The Beams of the BINGO Telescope
2) Beam Modelling
    - Gaussian Beams
    - Zernike Polynomials
3) Mapmaking
    - HIDE & SEEK
    - Impact on Maps

Beam Overview

A Brief Introduction

Power Pattern

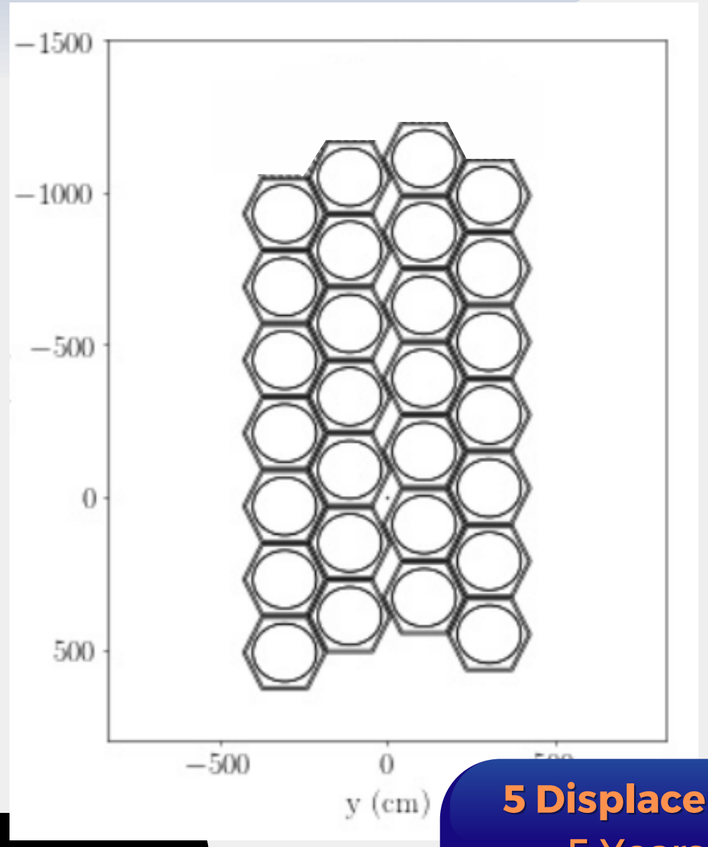
- Interference of the incoming reflected radiation generates a power pattern a.k.a. beam pattern.
- Diffraction pattern + asymmetries from reflector shape and positioning



Napier, P.J. , Synthesis Imaging in Radio Astronomy

BINGO Optical Design

28 horns on a **Double Rectangular** arrangement

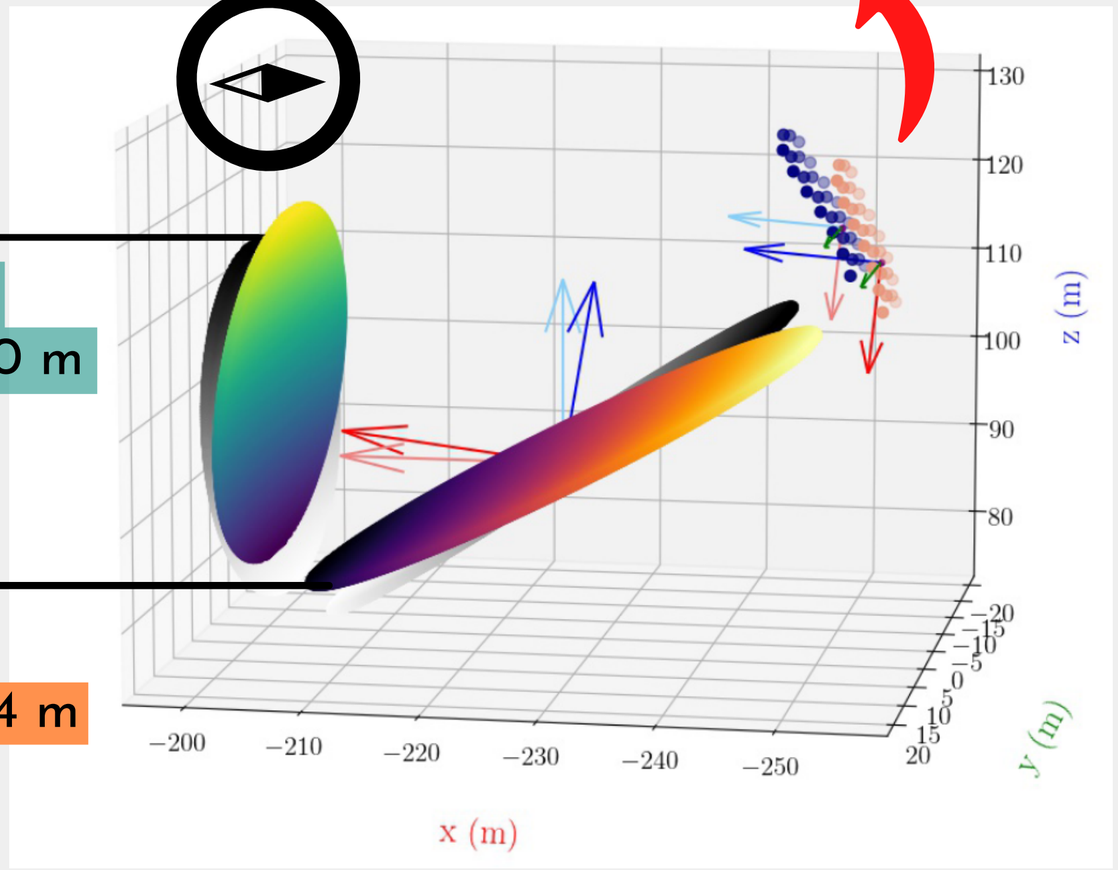


Hyperbolic Secondary

Diameter 40 m
Focal length 140 m

Parabolic Primary

Diameter 35 m
Focal length 124 m

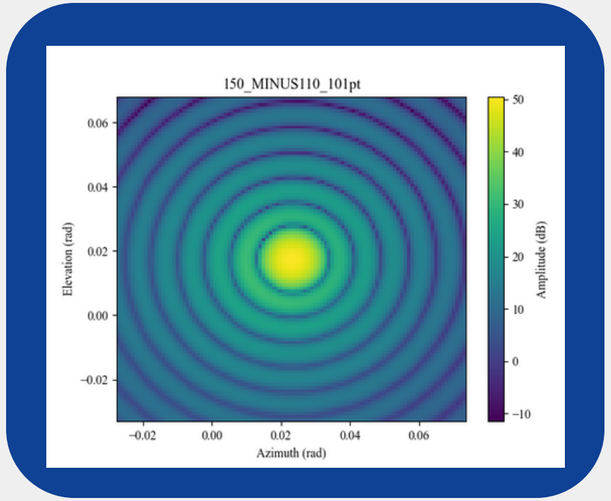


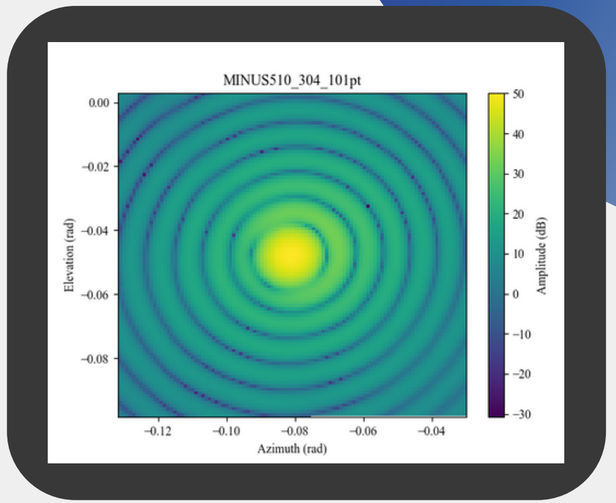
5 Displacements over 5 Years to get a better sky coverage

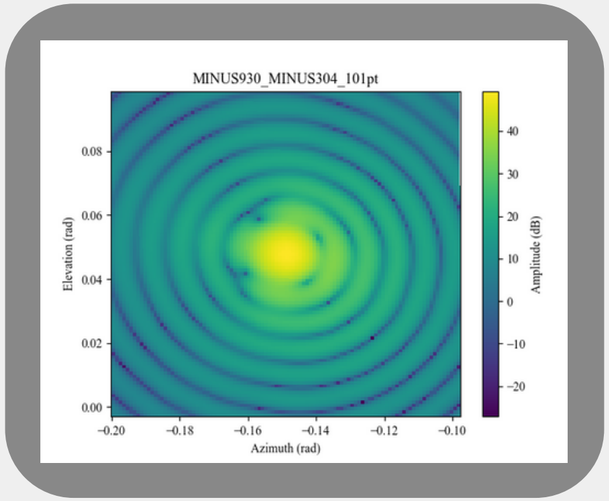
Abdalla, F. et al, BINGO Project **III**, 2021

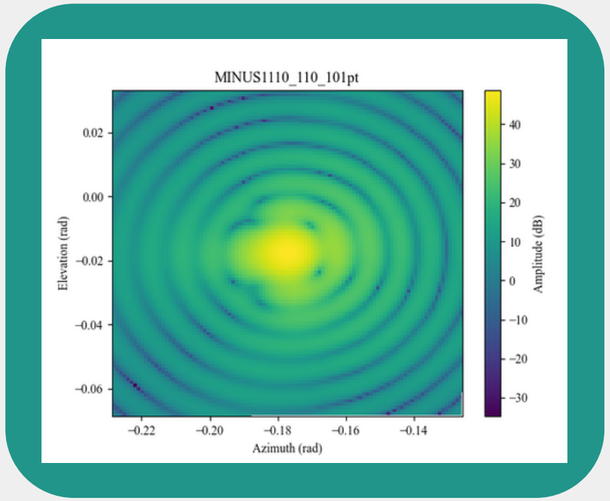
BINGO Beams

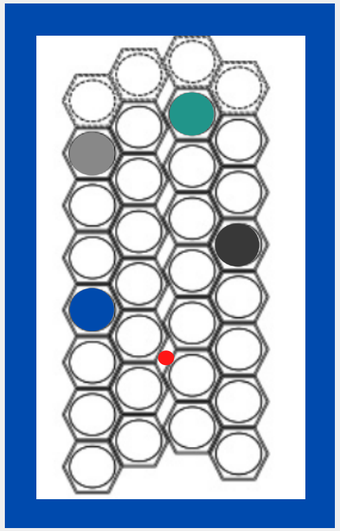
- Horns are displayed on the focal plane, generating different beam patterns for each horn.
- Beam data numerically simulated by the GRASP software.









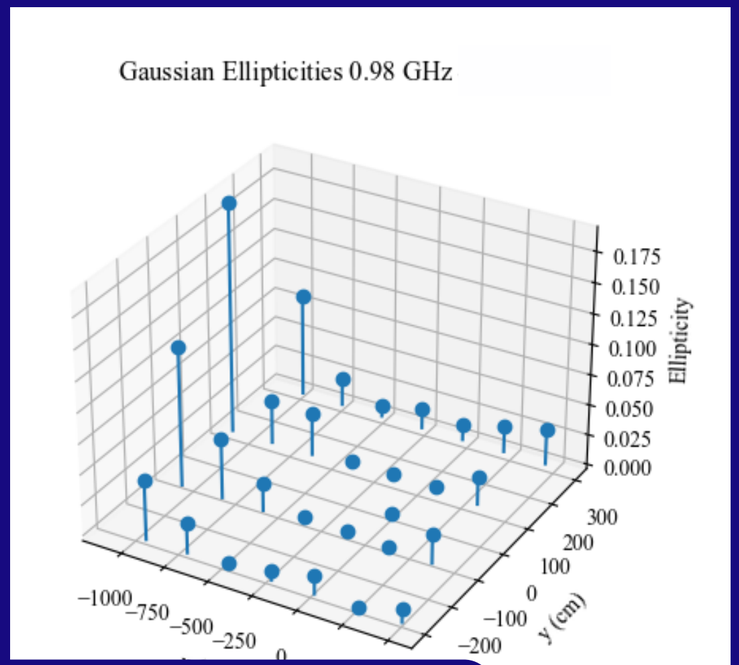


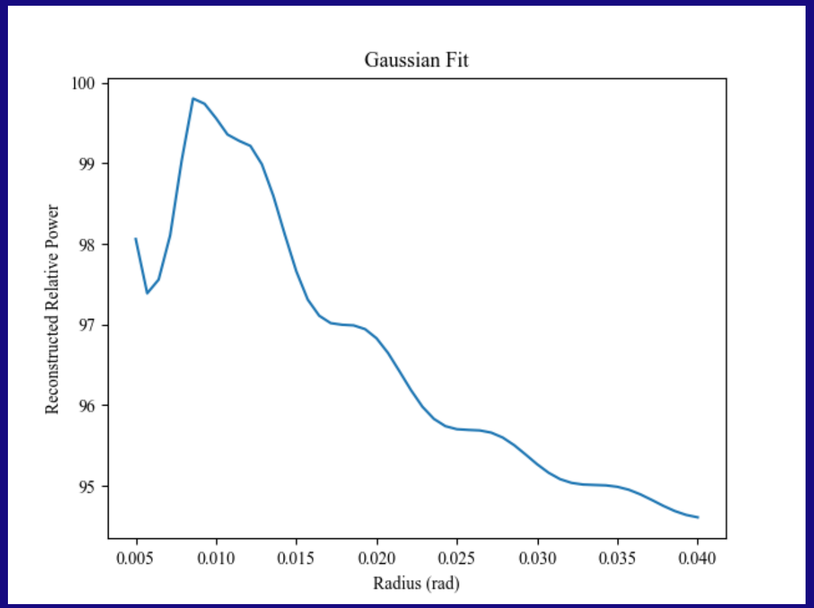
Beam Modelling

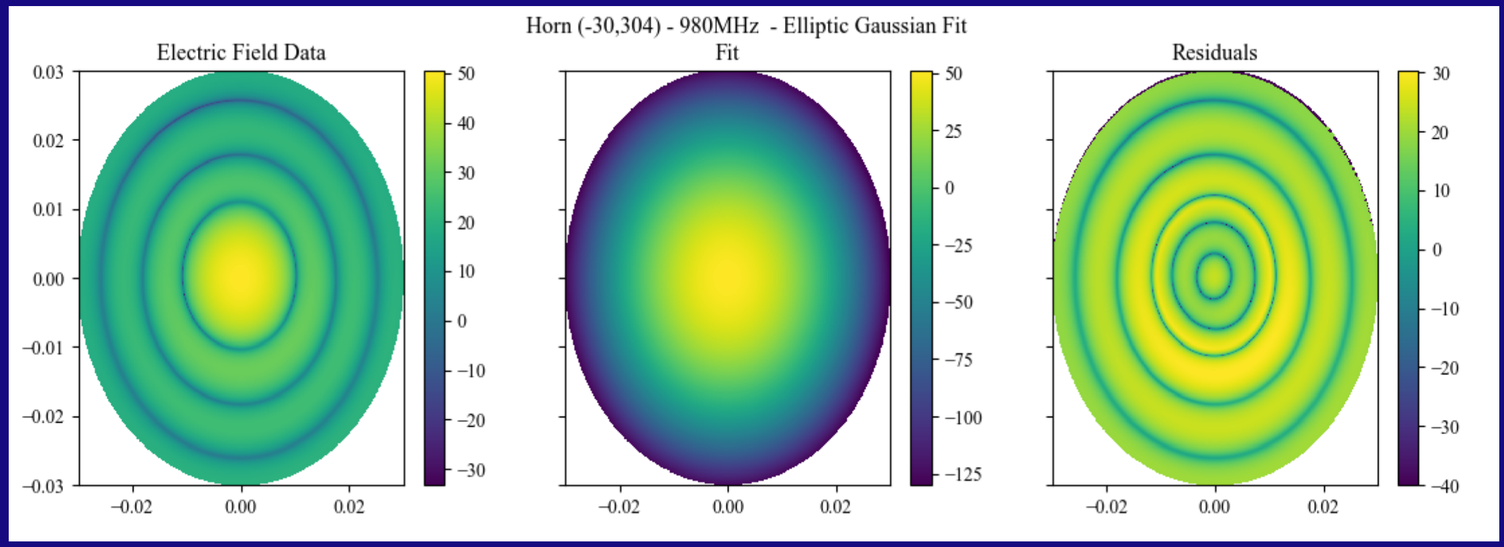
Gaussian Fits and Zernike Polynomials

Gaussian Beam

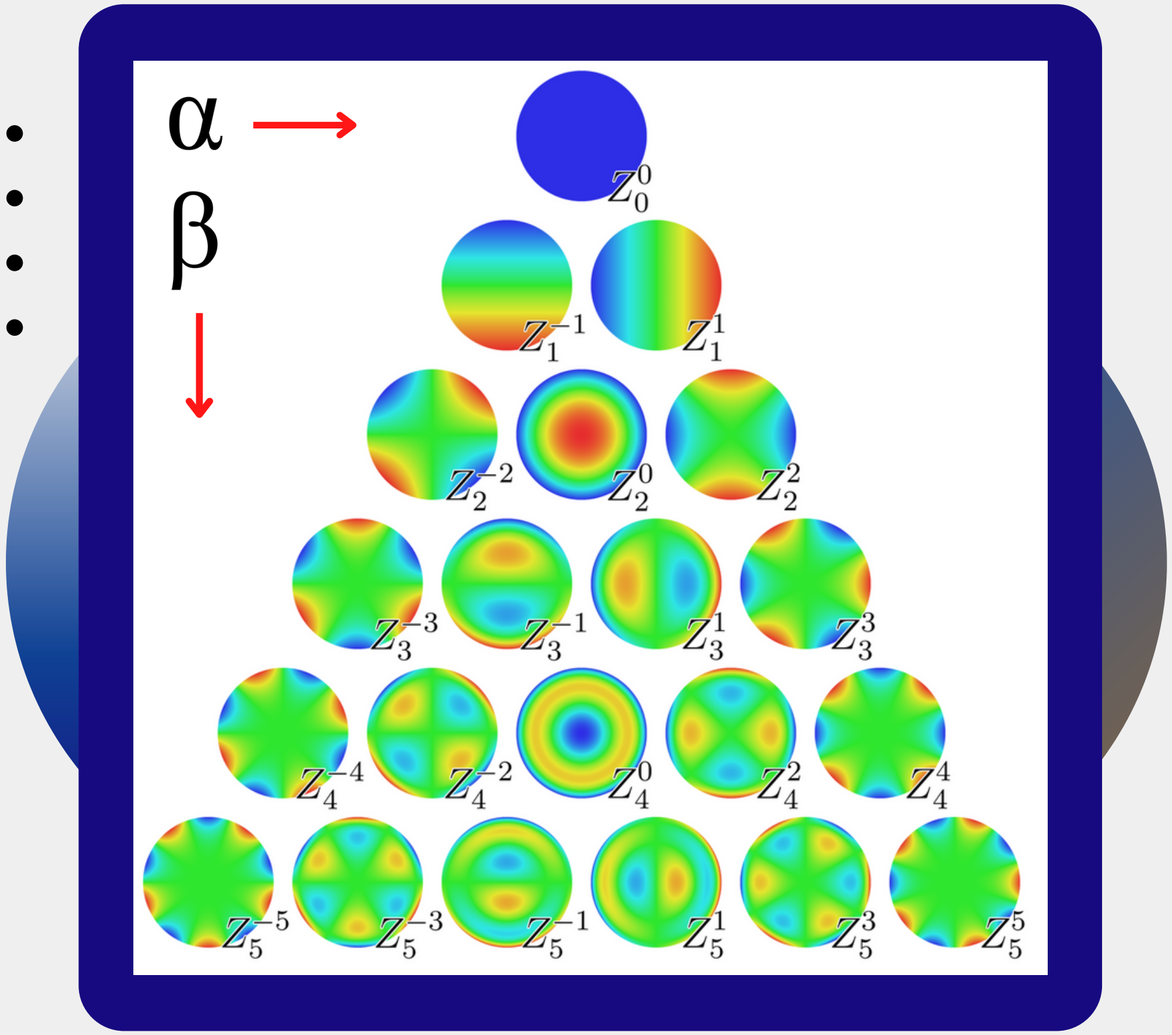
Main Lobe Fitting <---
Other spatial distribution features are left out







Zernike Polyn.



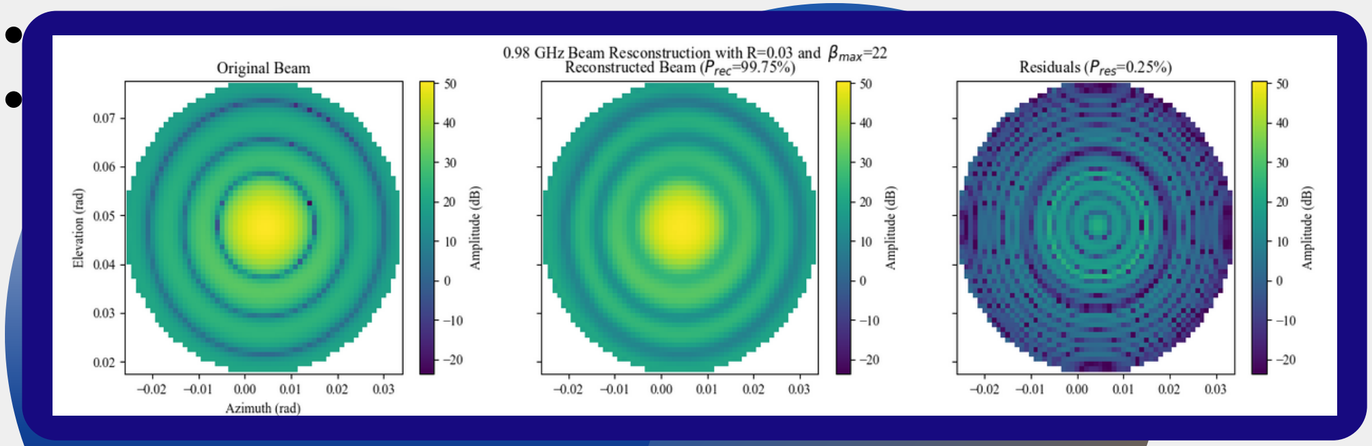
Wikipedia

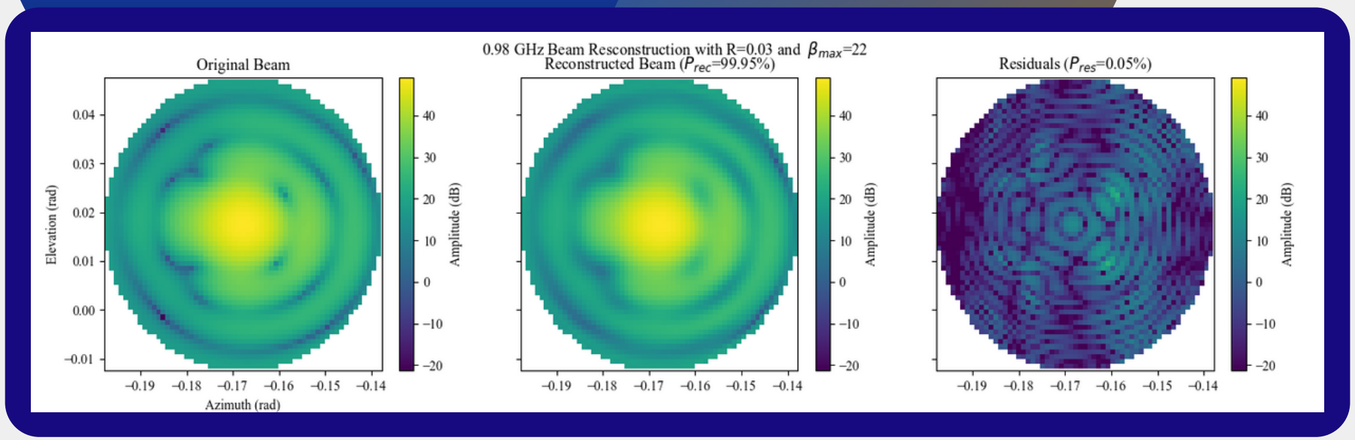
Widely used in optics <---
Due to orthogonality, any function on the plane may be represented using a Zernike Polyn. series.

$$\Phi(\rho,\theta) = \sum_{\beta,\alpha}^{M} C_\beta^\alpha Z_\beta^\alpha(\rho,\theta)$$

$$-\beta \leq \alpha \leq \beta$$

Beam Modelling



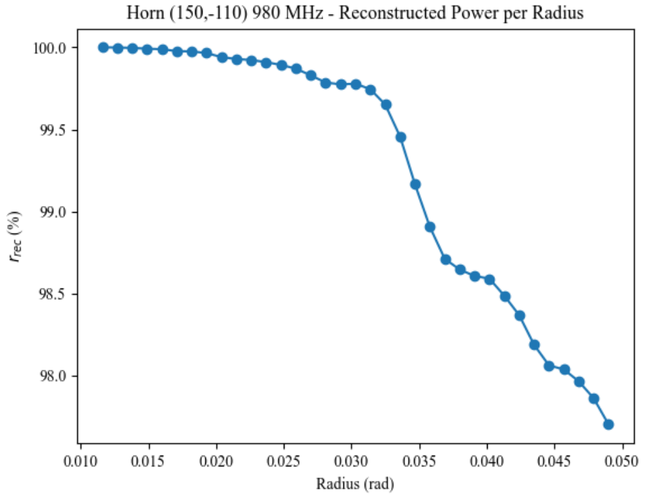


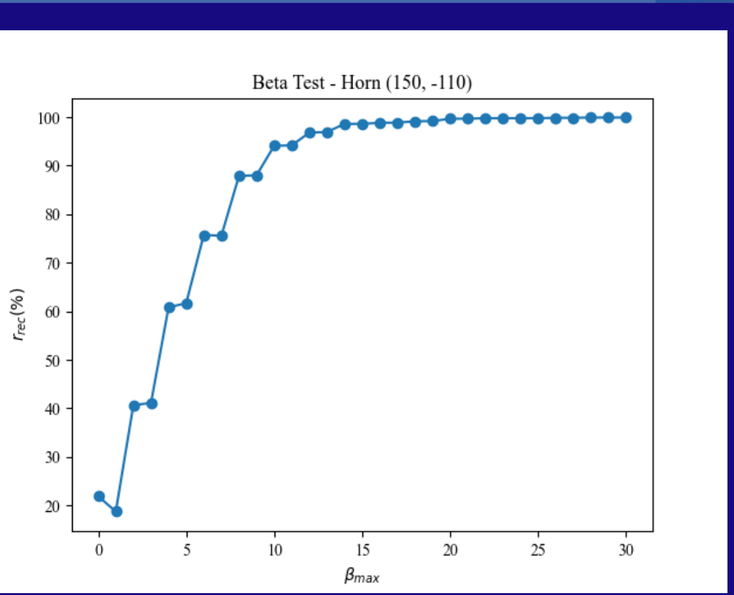
Adequately model beam patterns with few coefficients, leading to an efficient reconstruction of the beam, with low power loss.

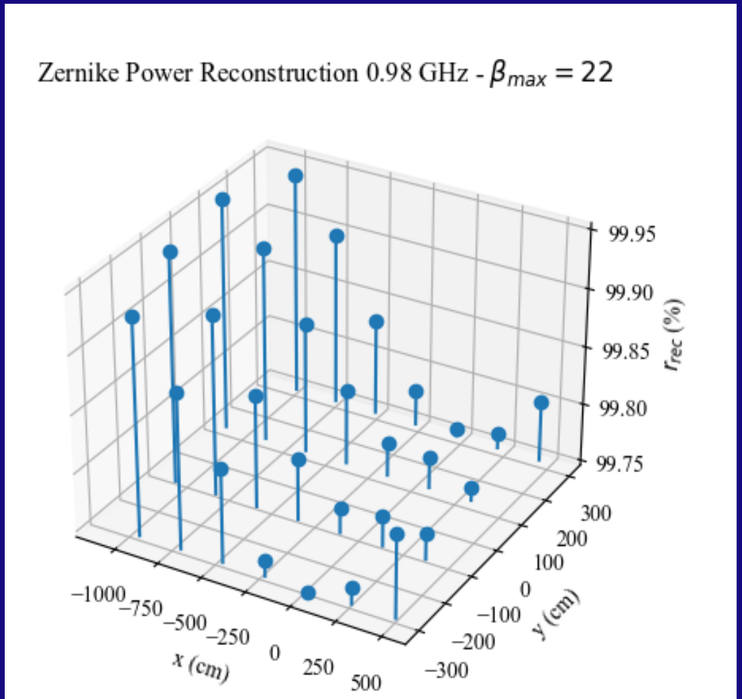
$$r_{res} = \frac{P_Z - P_{data}}{P_{data}}$$

$$r_{rec} = 1 - r_{res}$$

Fitting Performance







Fitting parameters such as beta and angular radius have a major influence on the reconstructed power fraction.

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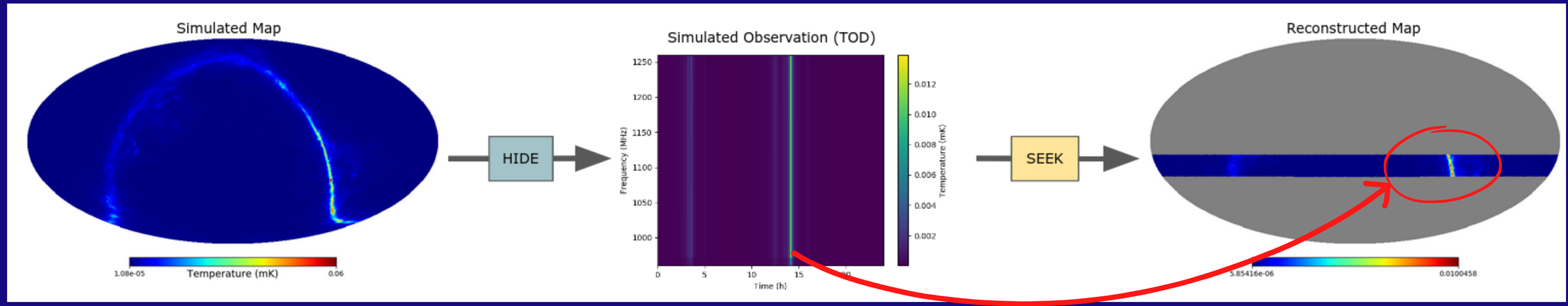
Map Making

HIDE & SEEK and beam impact

HIDE & SEEK

HIDE: HI Data Emulator
SEEK: Signal Extraction and Emission Kartographer



HIDE

Emulates a sky observation from a given map.
Considers noise (WN+1/f), gain, **beam convolution**, RFI.

Maps -> TOD

SEEK

Performs map reconstruction from Time Ordered Data (**map making**)
Plugins: RFI cleaning, object masks

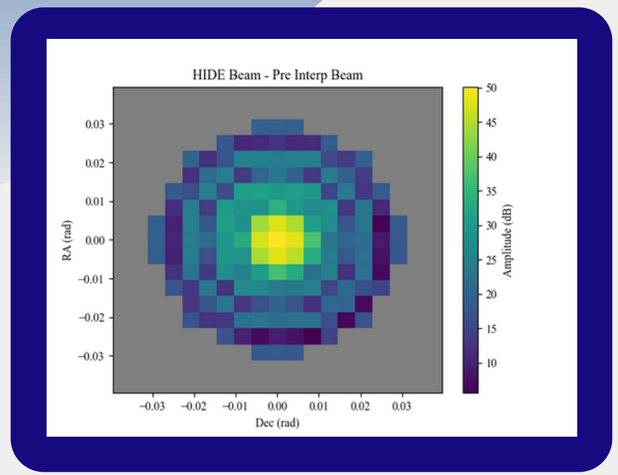
TOD -> Maps

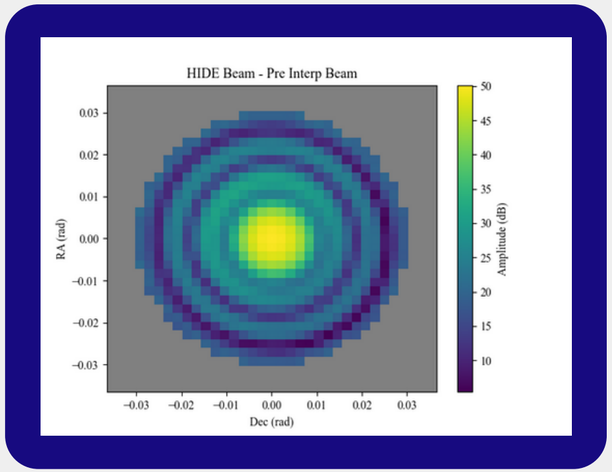
Interpolation

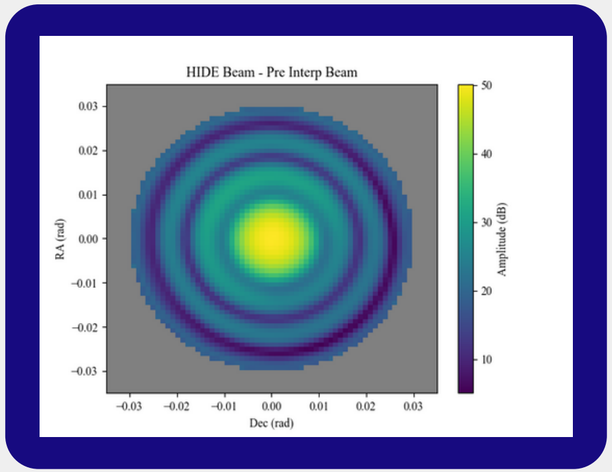
RA-Dec Grid

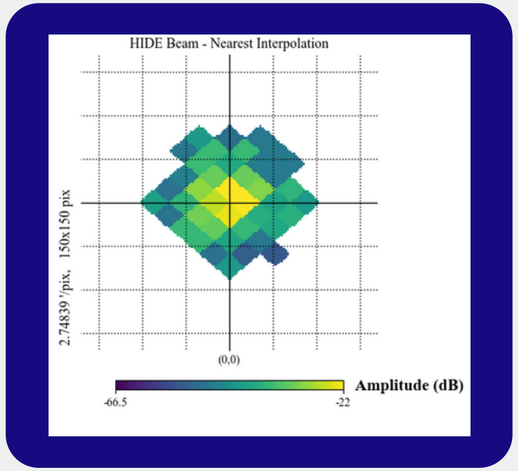
Nearest Neighbor Interpolation

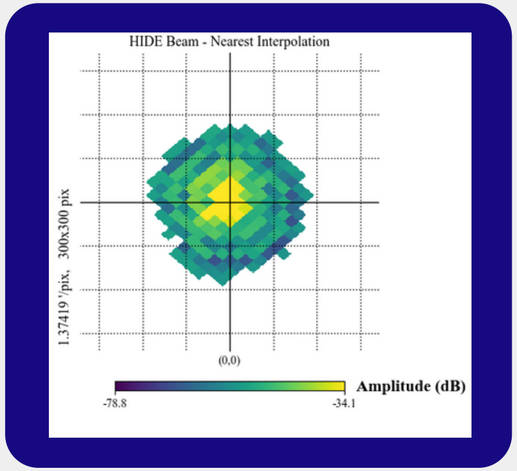
HEALPix maps

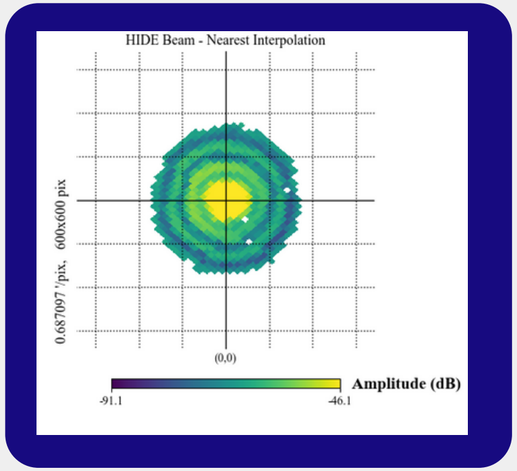












Nside

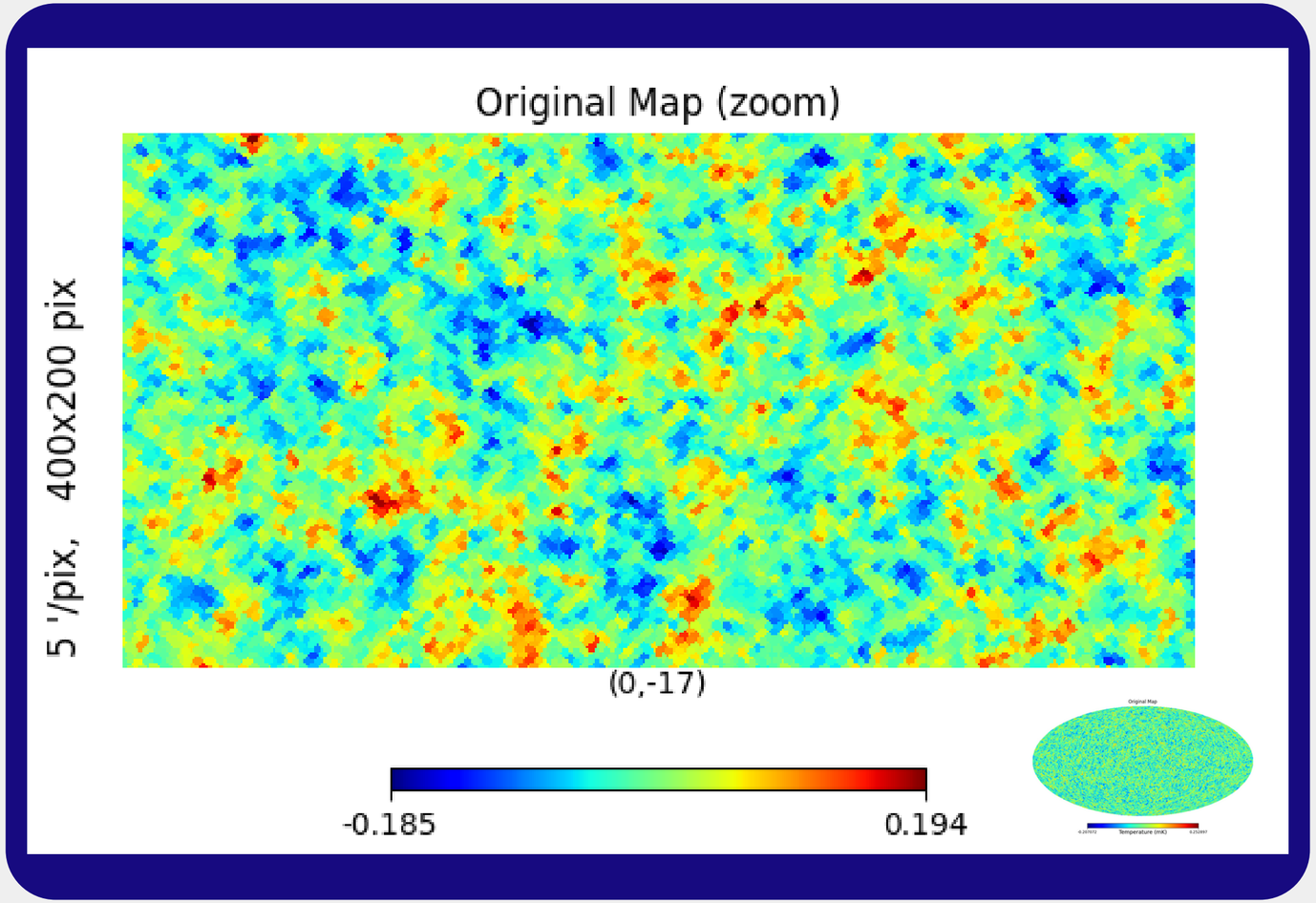
128

256

512

Map Reconstruction

Maps Reconstructed using Naive Map Making.



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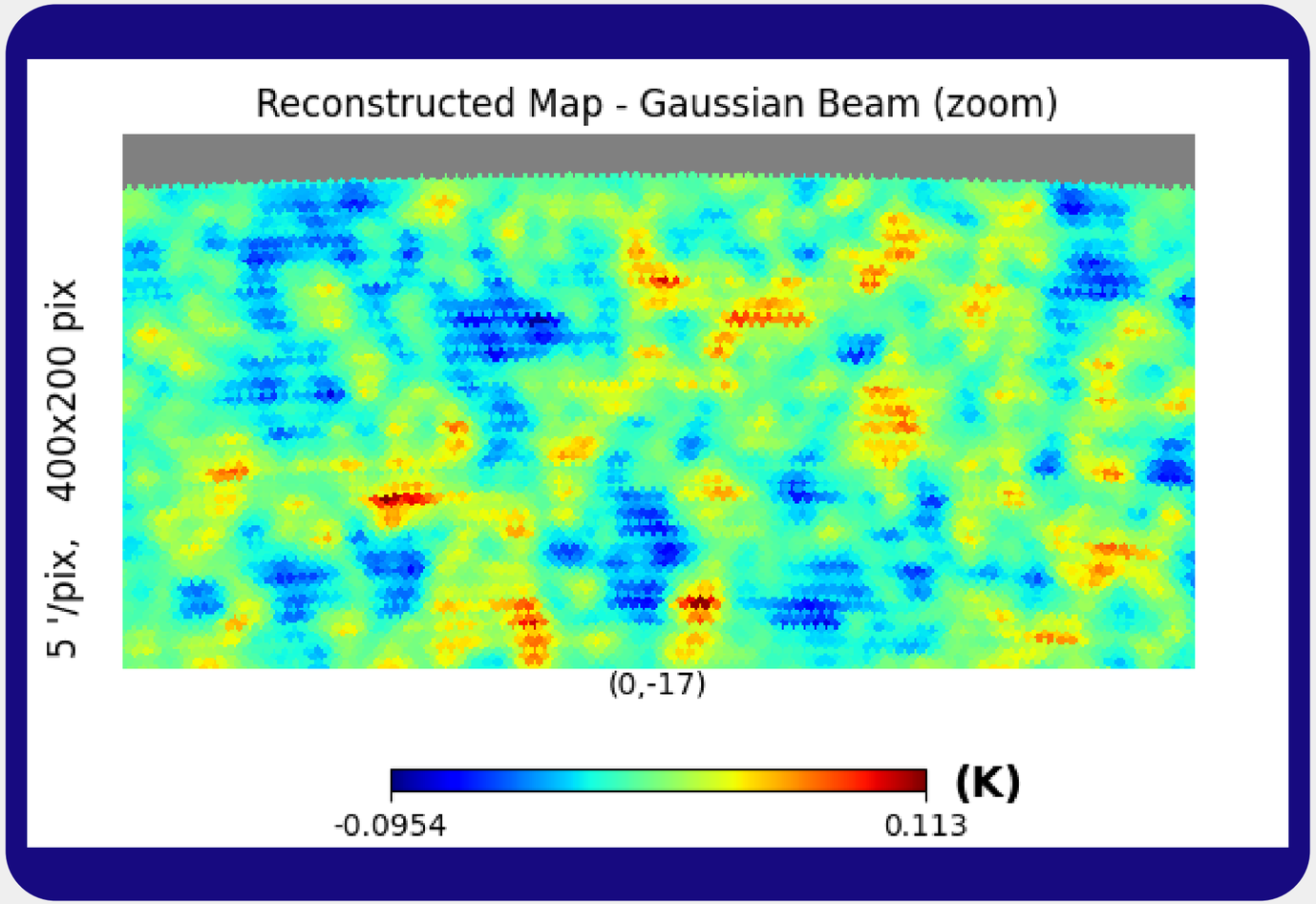

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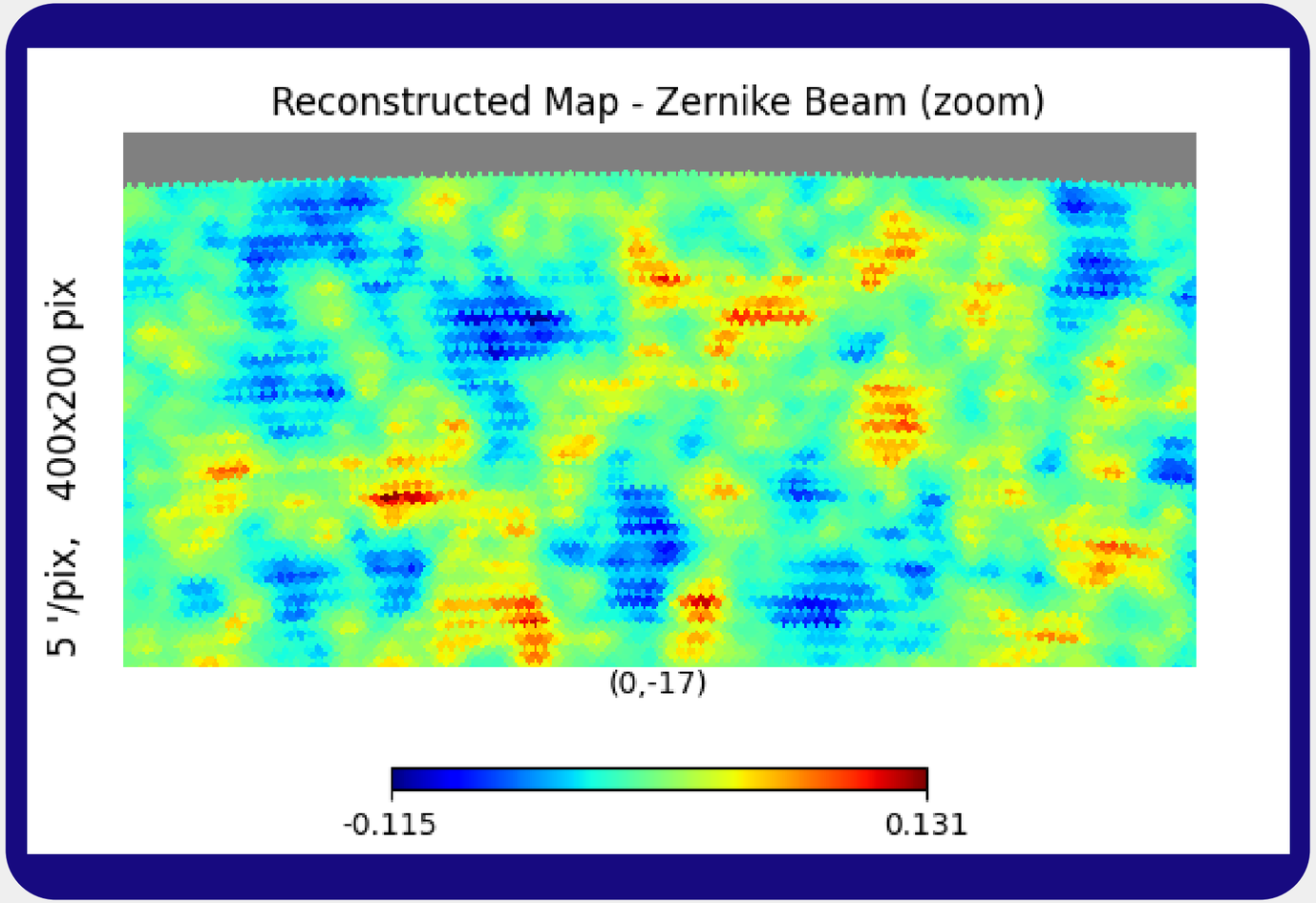

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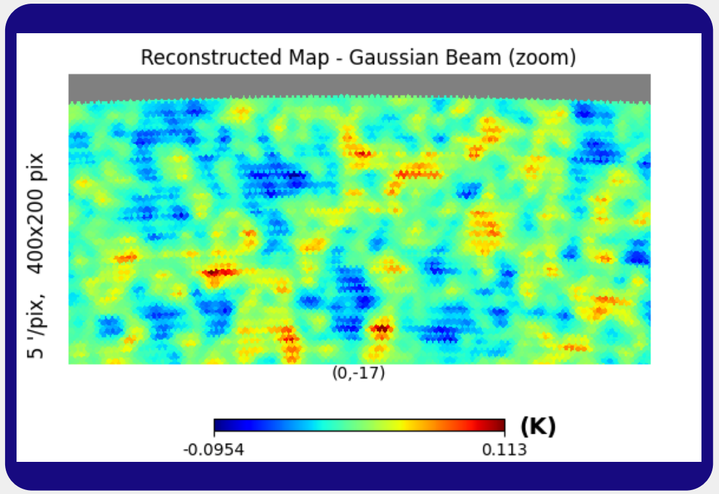
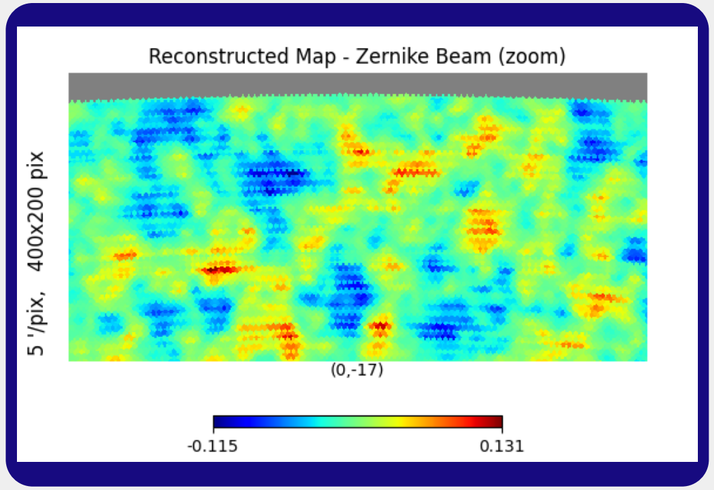
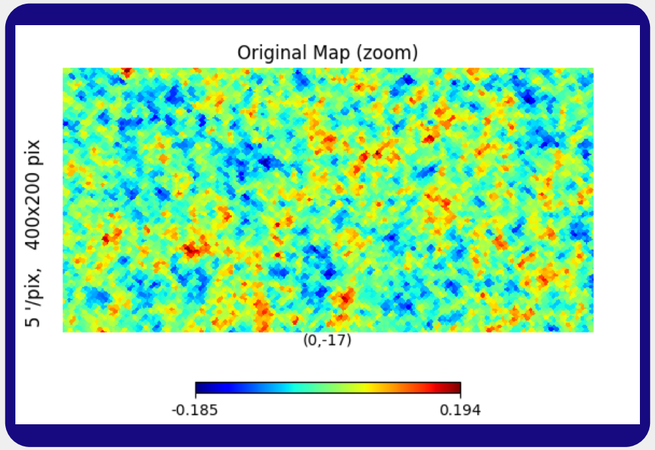
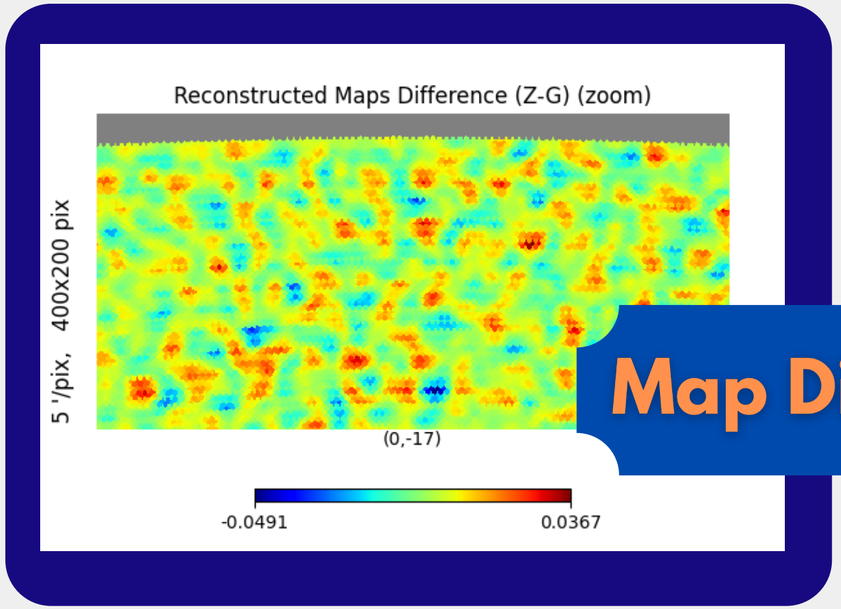




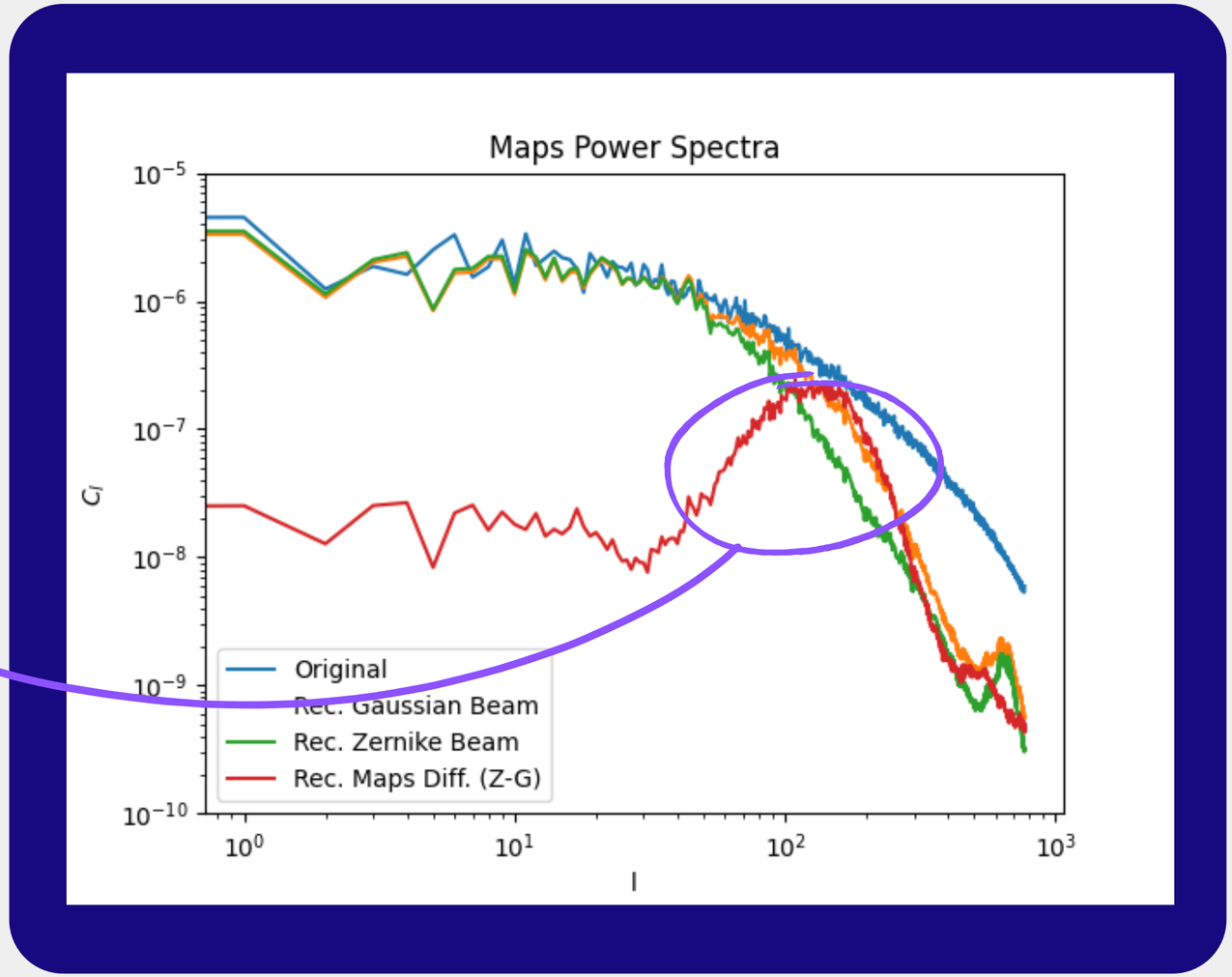




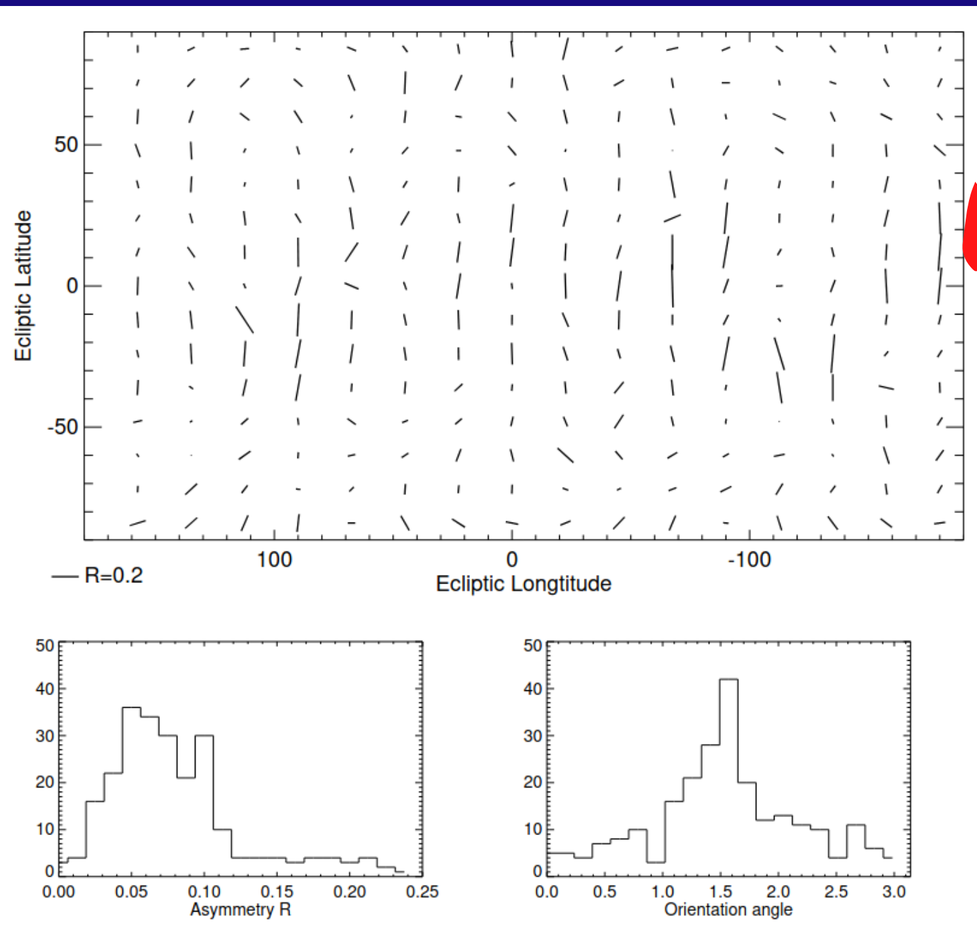
Map Difference

Power Spectrum

--> Large scale structure is preserved (as expected);
--> Small scale structure is greatly affected by the difference between the beams;
--> This could be affecting how we extract information from modes as high as $l \gtrsim 70$!

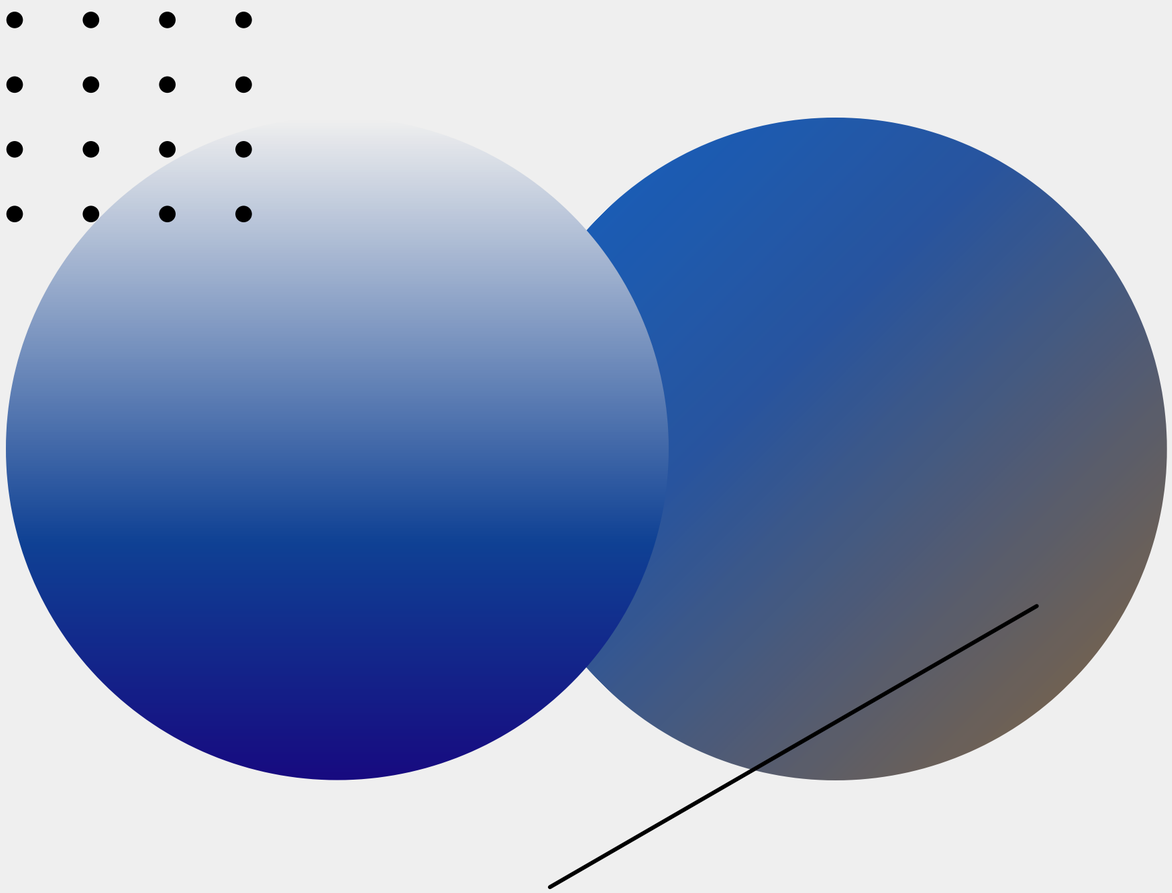


More on Beam Effects



"ASYMMETRY AND NON-RANDOM ORIENTATION OF THE INFLIGHT FFECTIVE BEAM PATTERN IN THE WMAP DATA"
CHIANG, L.Y., 2013.

"SIMULATIONS OF PRIMARY BEAM EFFECTS ON THE COSMIC BISPECTRUM PHASE OBSERVED WITH THE HYDROGEN EPOCH OF REIONIZATION ARRAY"
CHARLES, N., 2021.



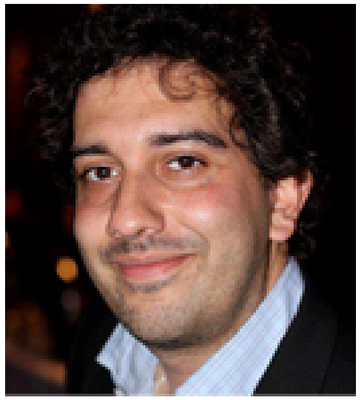
Next Steps

1. Check how much impact is left even on better map making algorithms;
2. Investigate aliasing effects (striping and nside influence);
3. Consider more realistic beams with more complex structures.

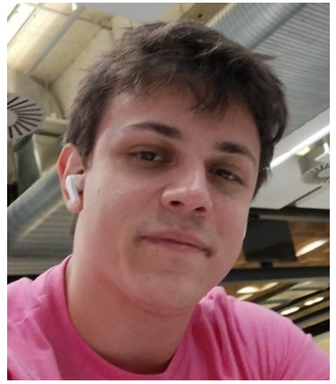
HIDE & SEEK + Beam Team

João Alberto
(me)
PhD, team

Elcio Abdalla
Staff, Core (P.I.)



Filipe Abdalla
Staff, Core



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Alessandro
Marins
PhD, team

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CAPES

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Thank you

Do you have any questions?

More results on upcoming paper (Barretos, 2023).

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