Holographie d'antennes pour la calibration dépendante de la direction pour les interféromètres radio

K. Iheanetu, J. N. Girard, K. M. B. Asad, M. de Villiers, T. Ansah-Narh, S. Matshawule, O. Smirnov, and M. Santos

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Outline

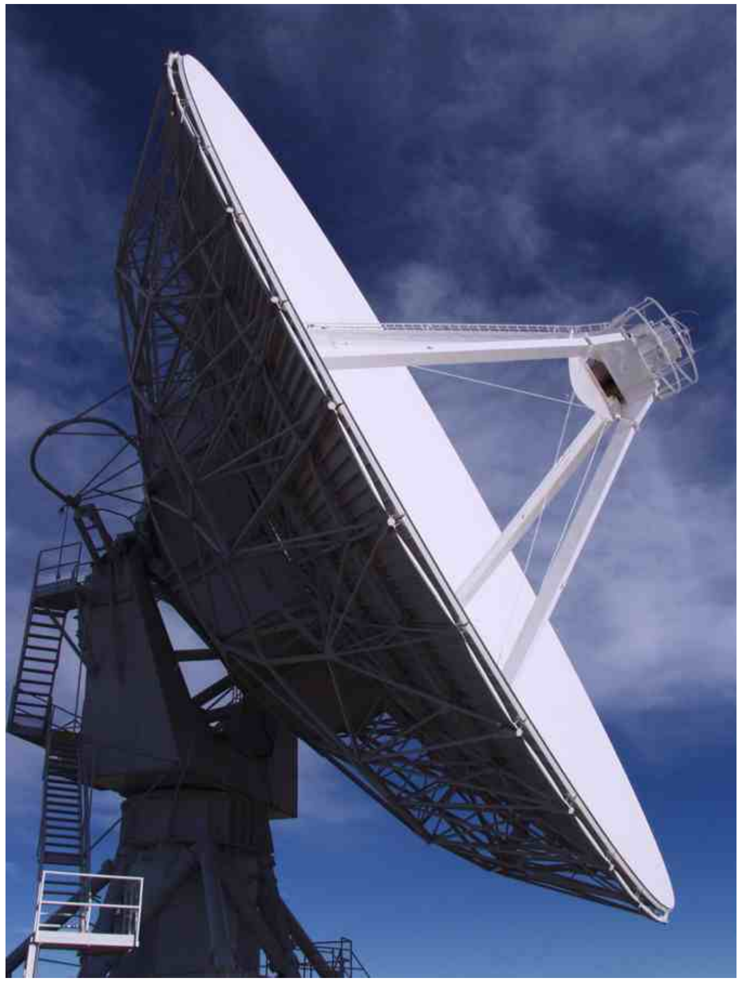
I. Why modelling beams is important ?

II. The JVLA antenna holography

III. Searching for sparse decompositions of the beam

Conclusion

Radio antennas



VLA

SKA/MeerKAT

Beams depends on

- time
- frequency
- direction
- mechanical/electronical constraints

Radio antennas

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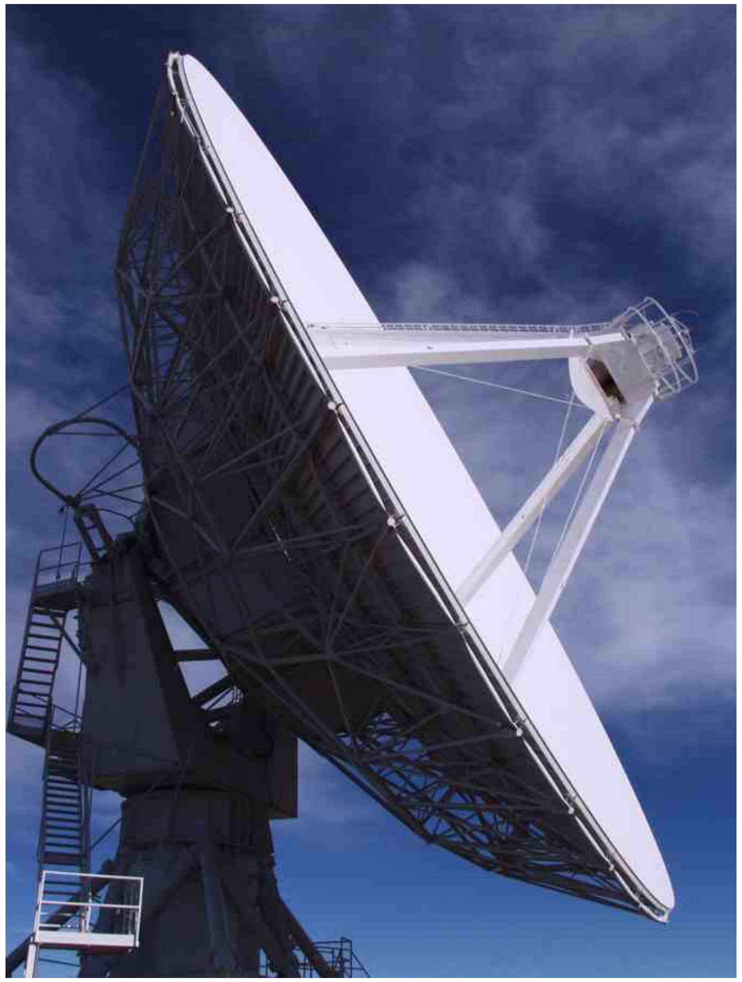

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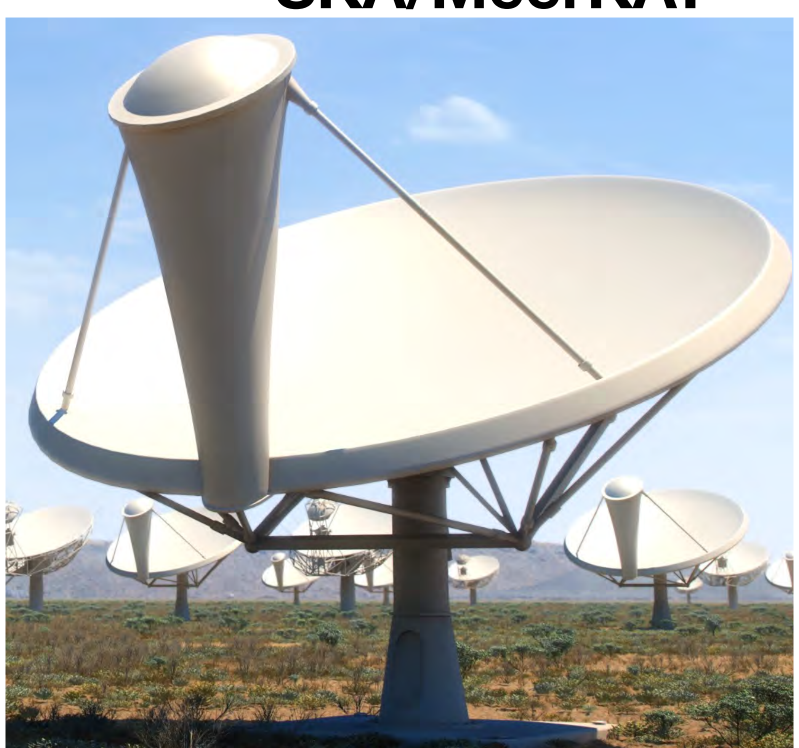
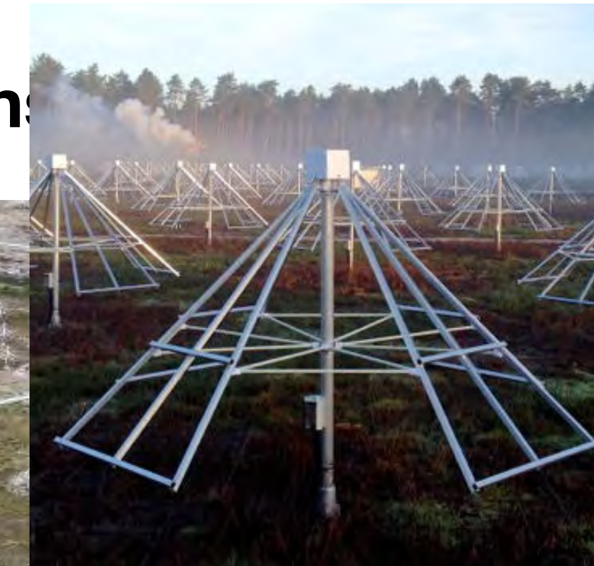
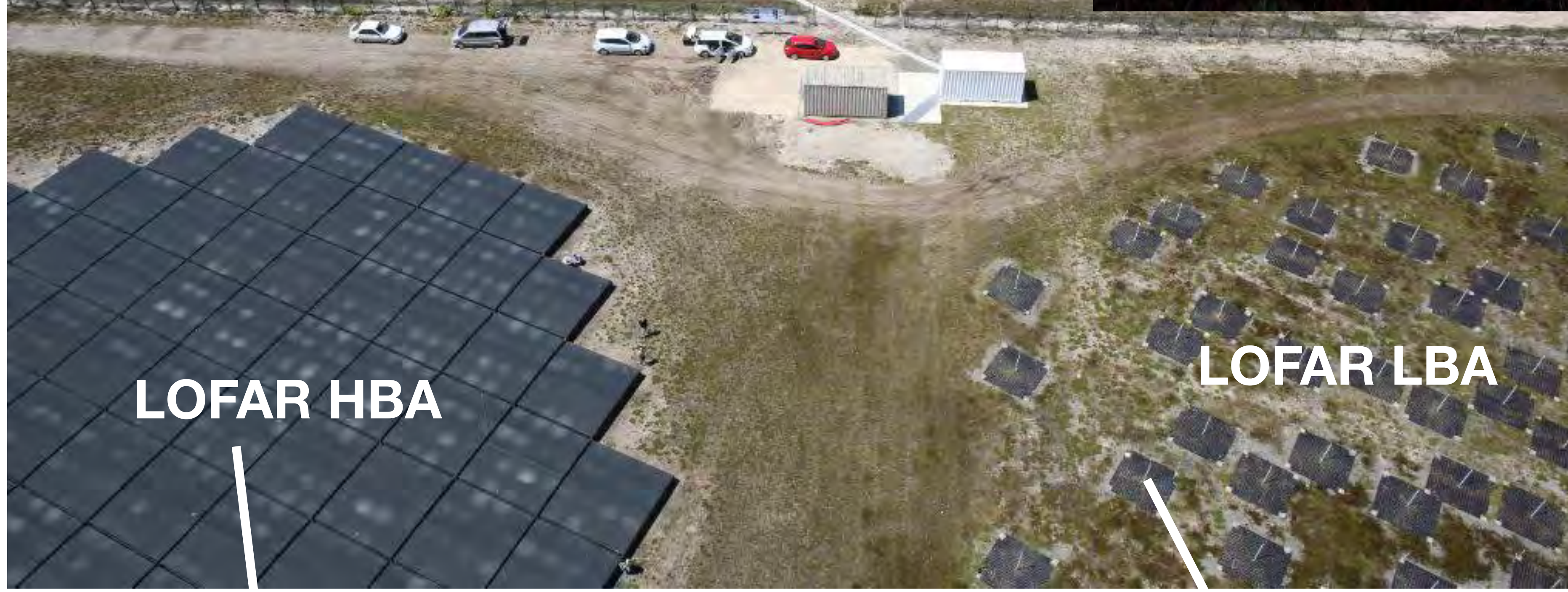


NenuFAR

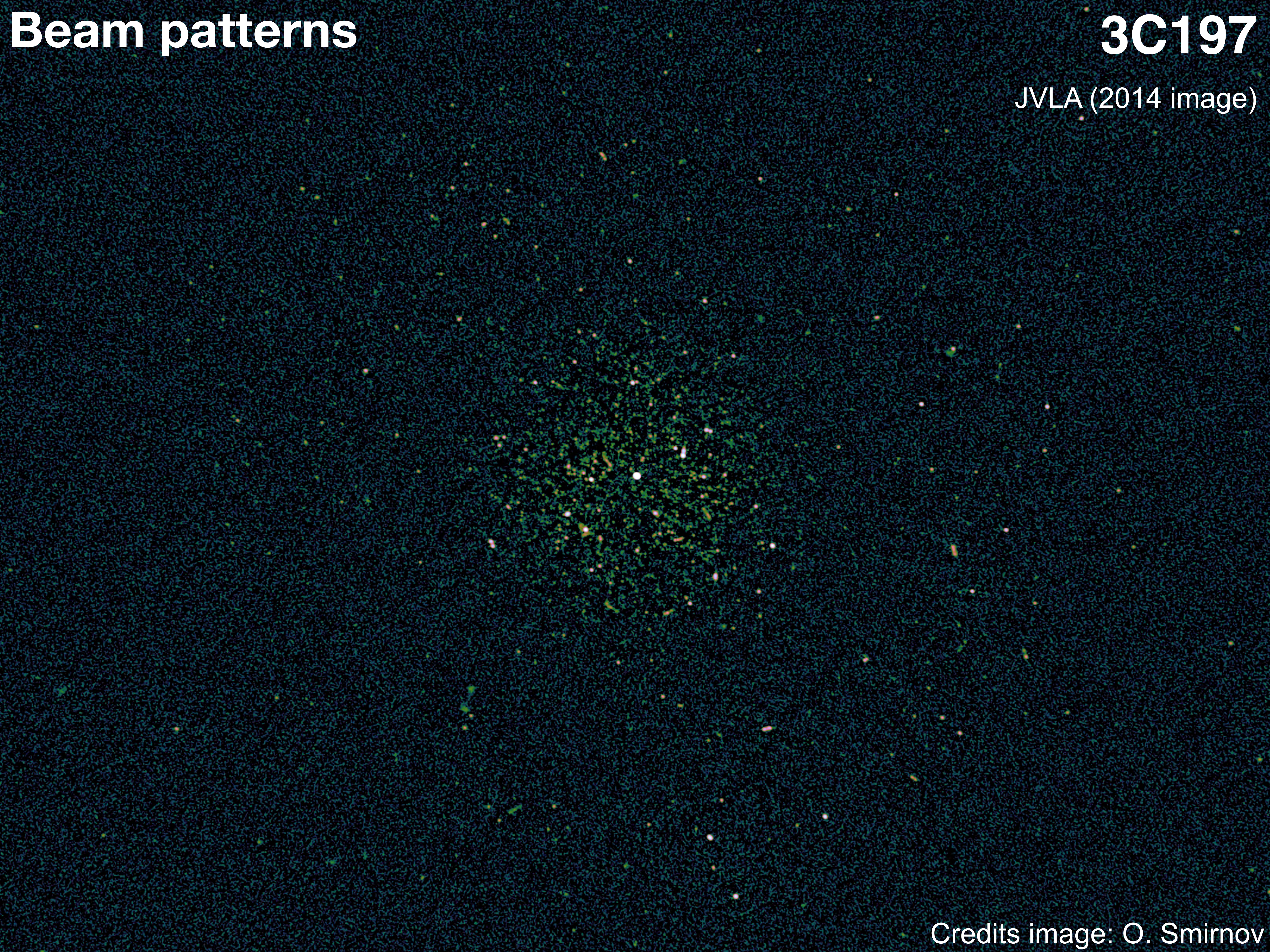




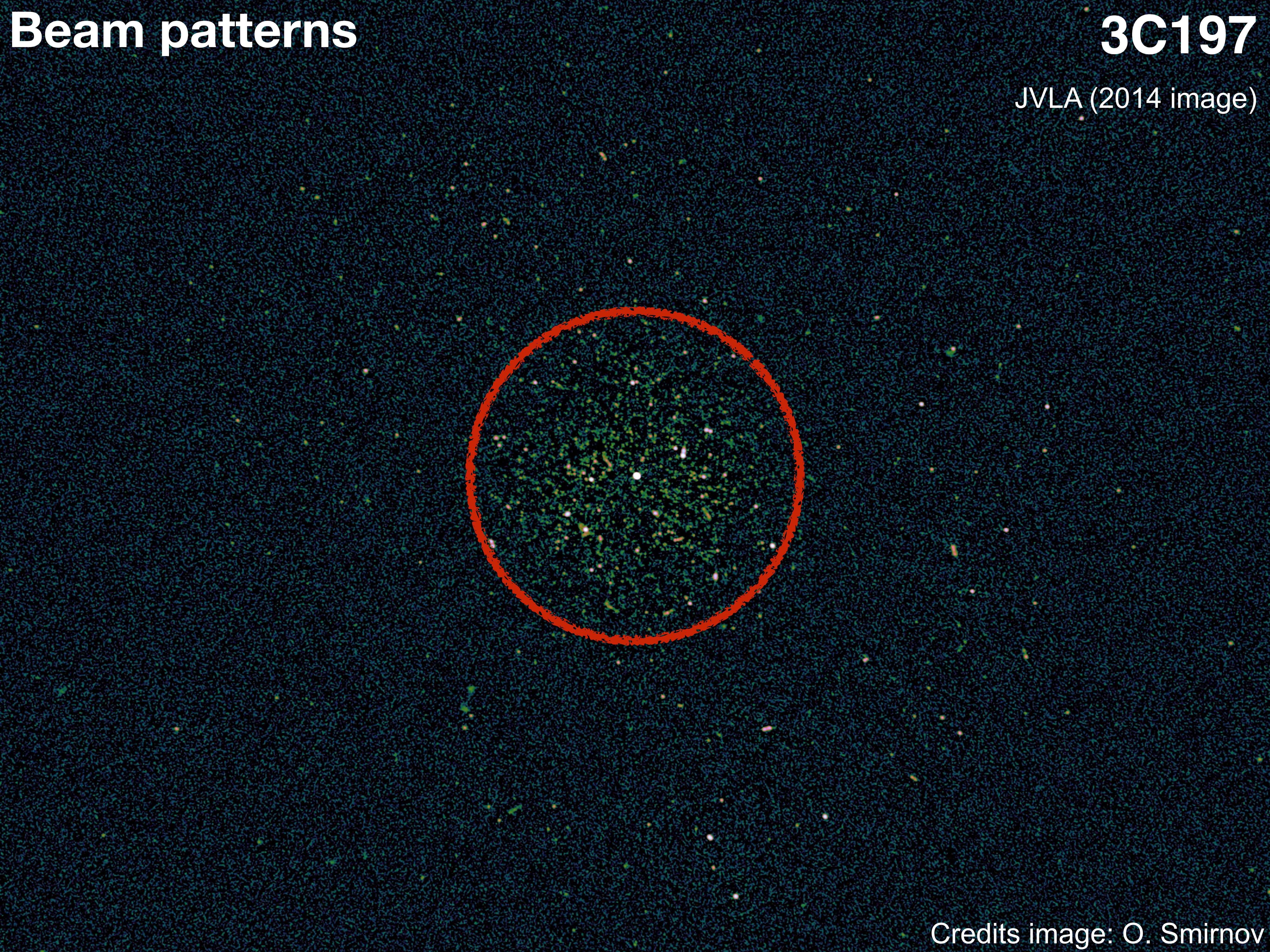
LOFAR HBA

LOFAR LBA

Beam patterns



Credits image: O. Smirnov


Beam patterns
3C197
JVLA (2014 image)
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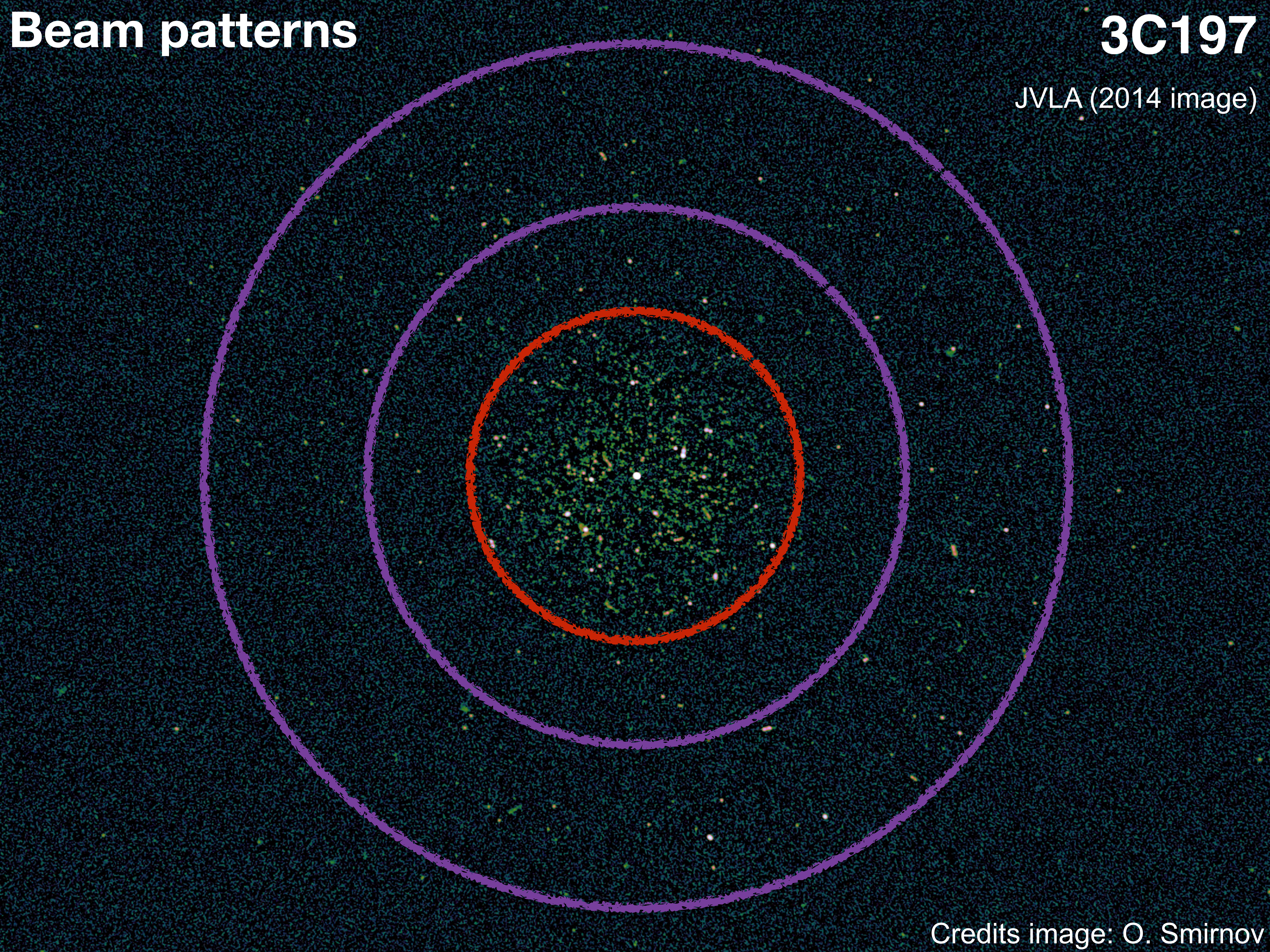
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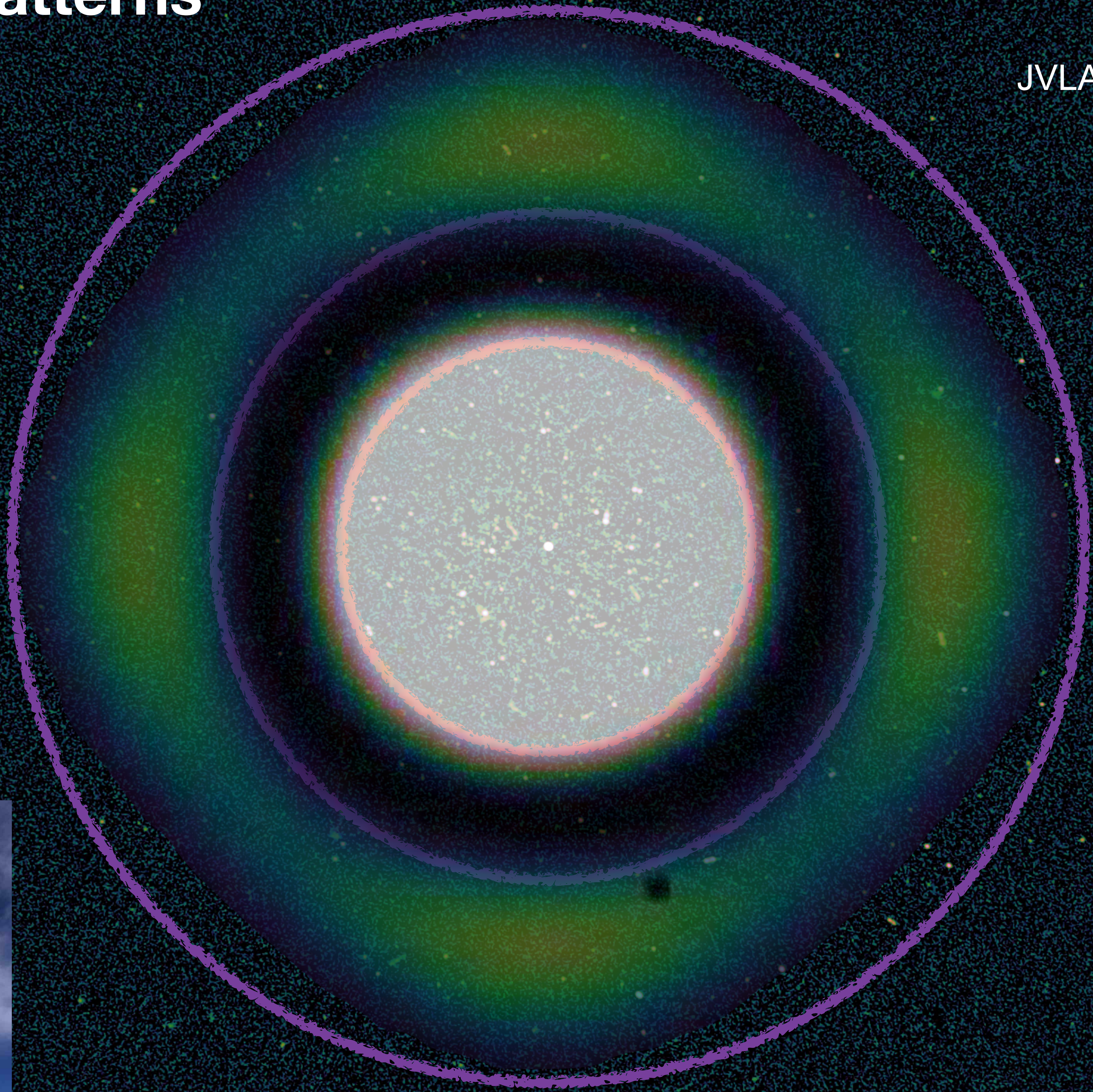

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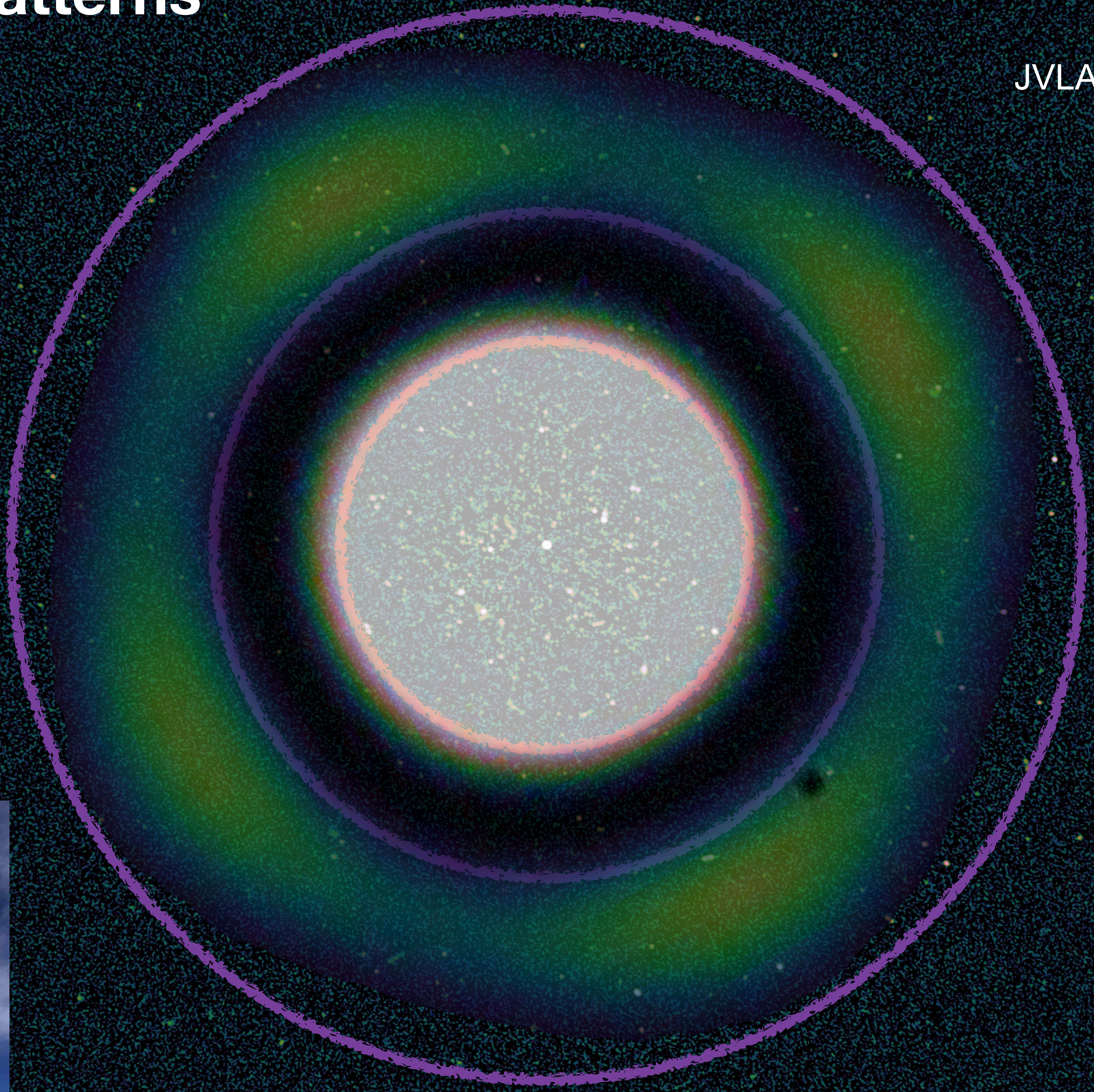

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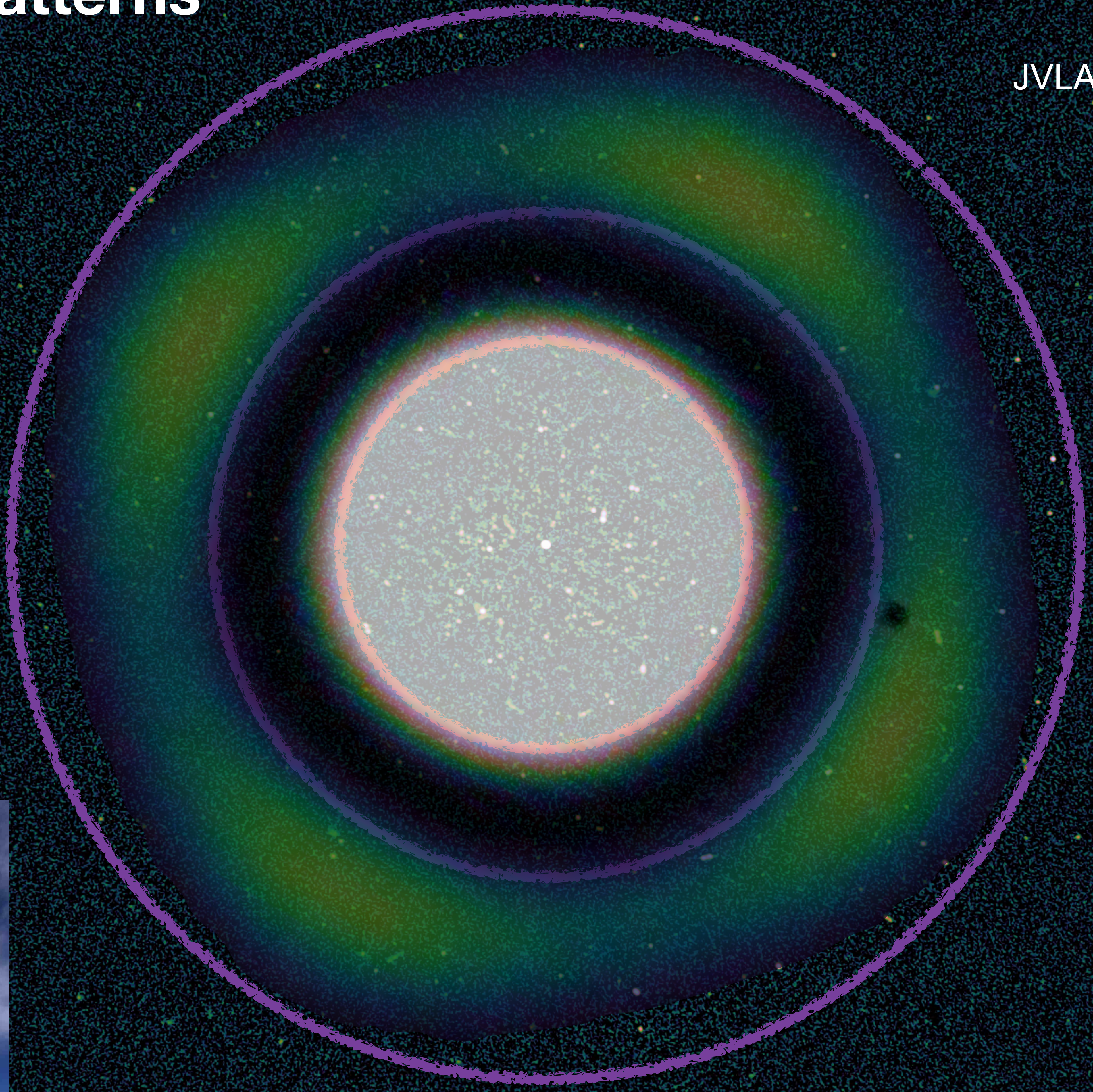

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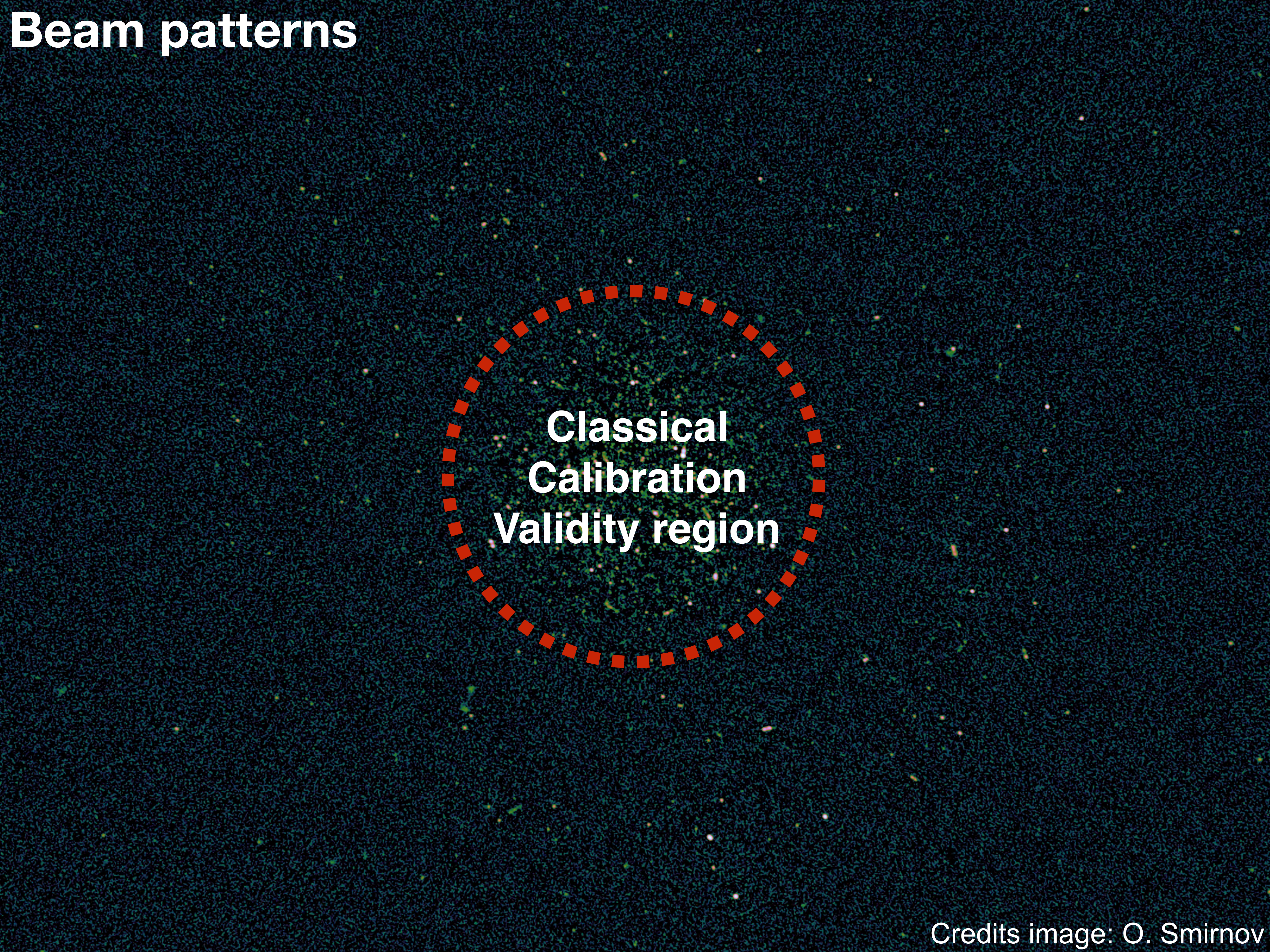

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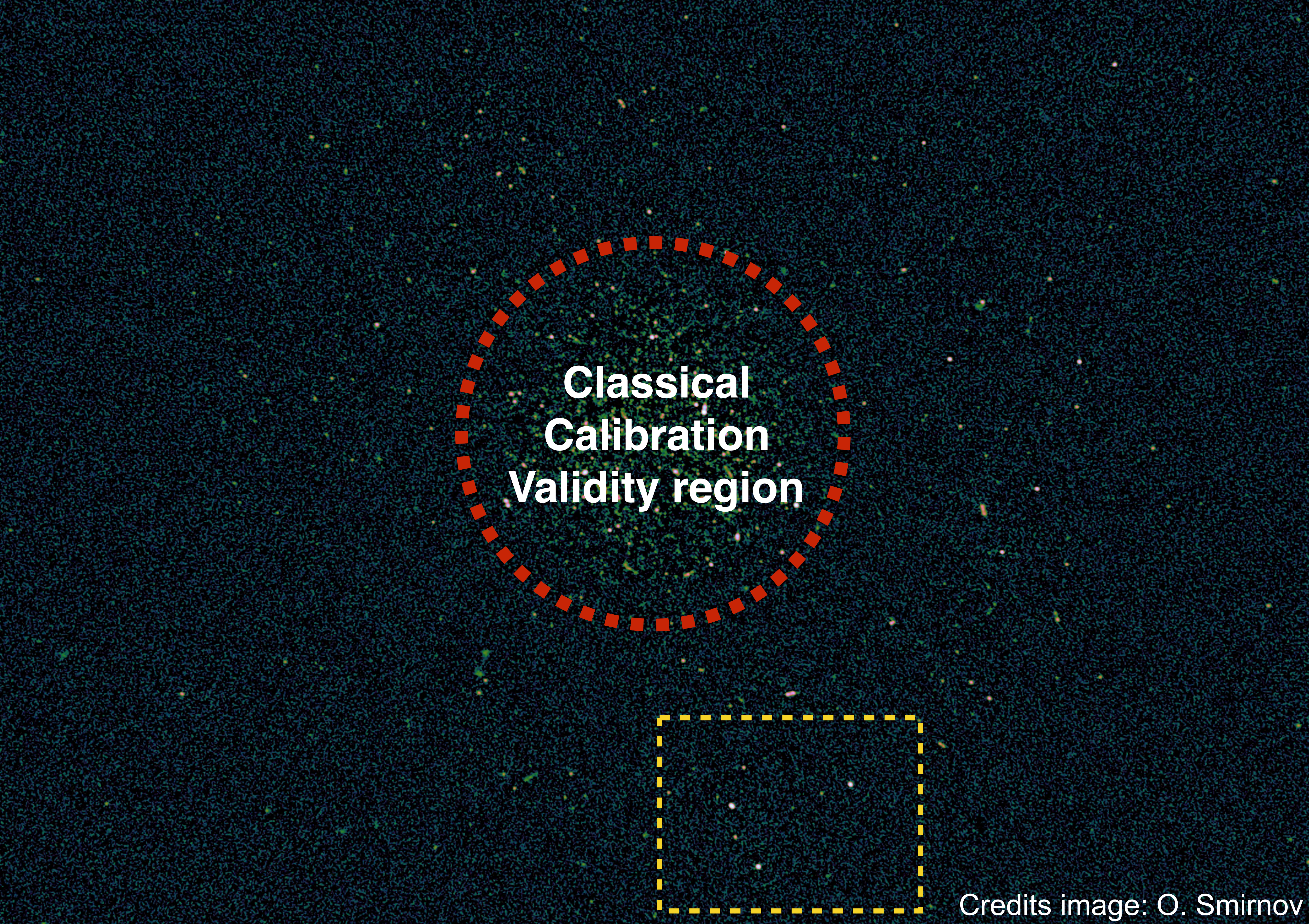

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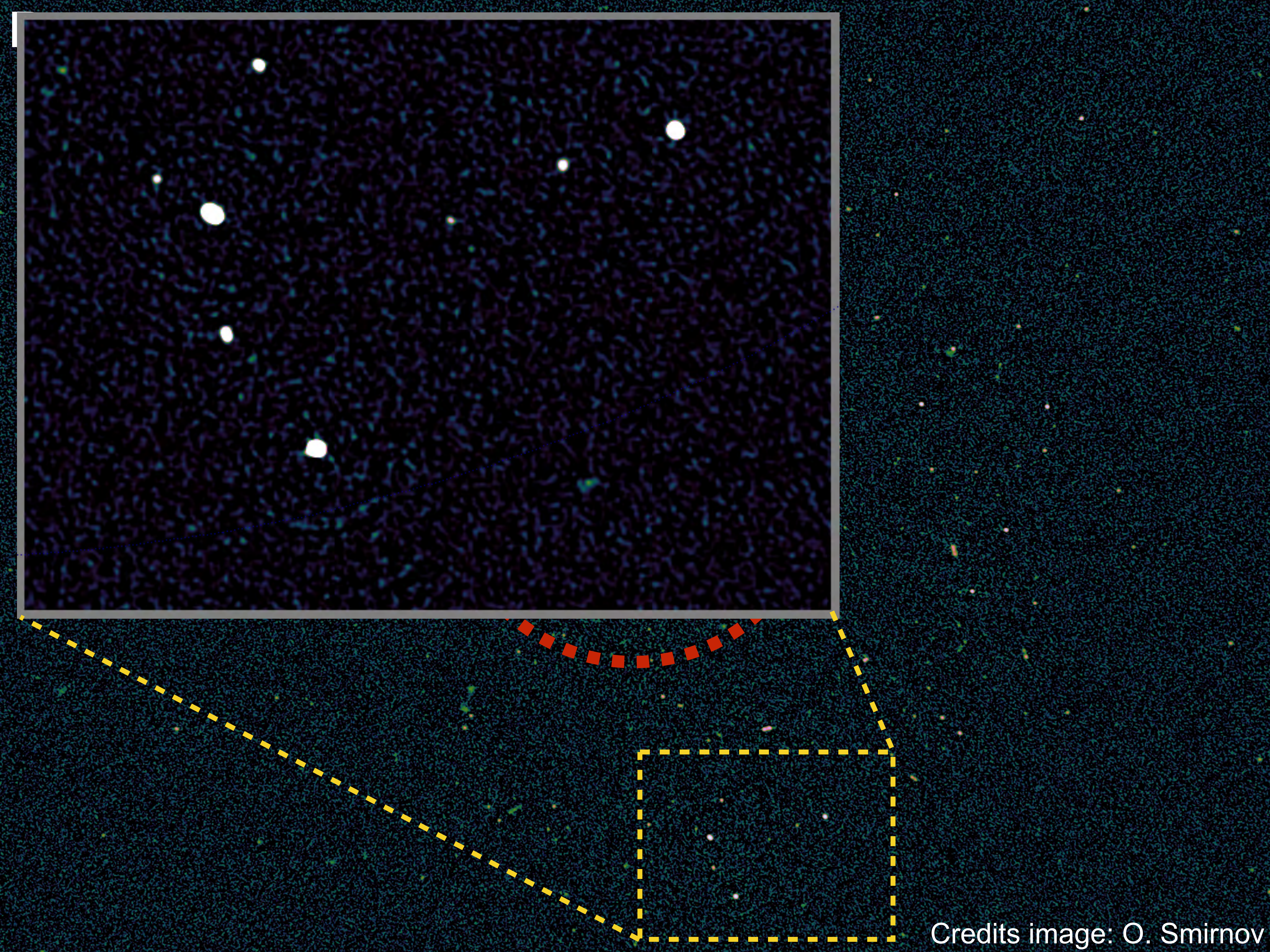
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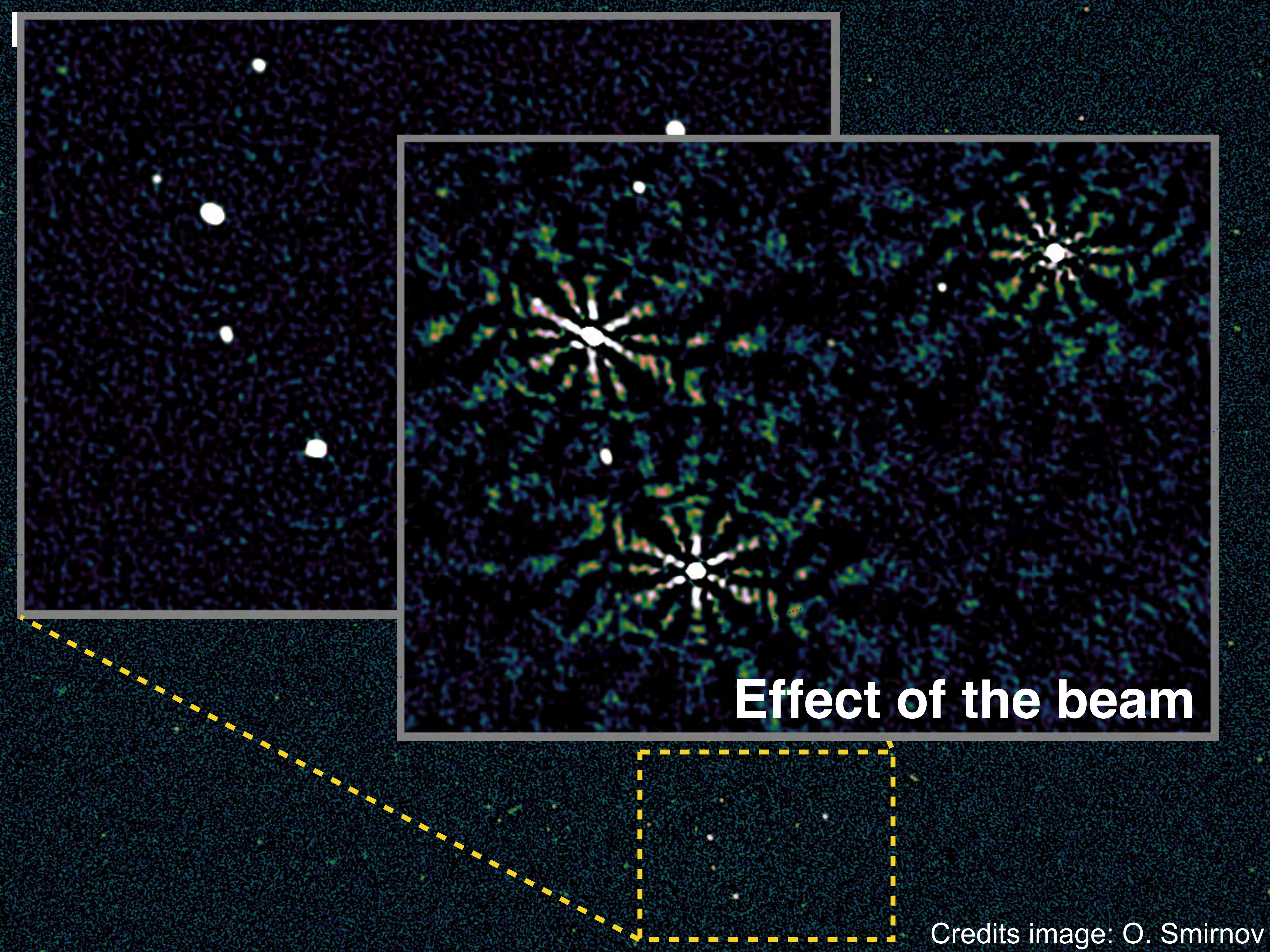
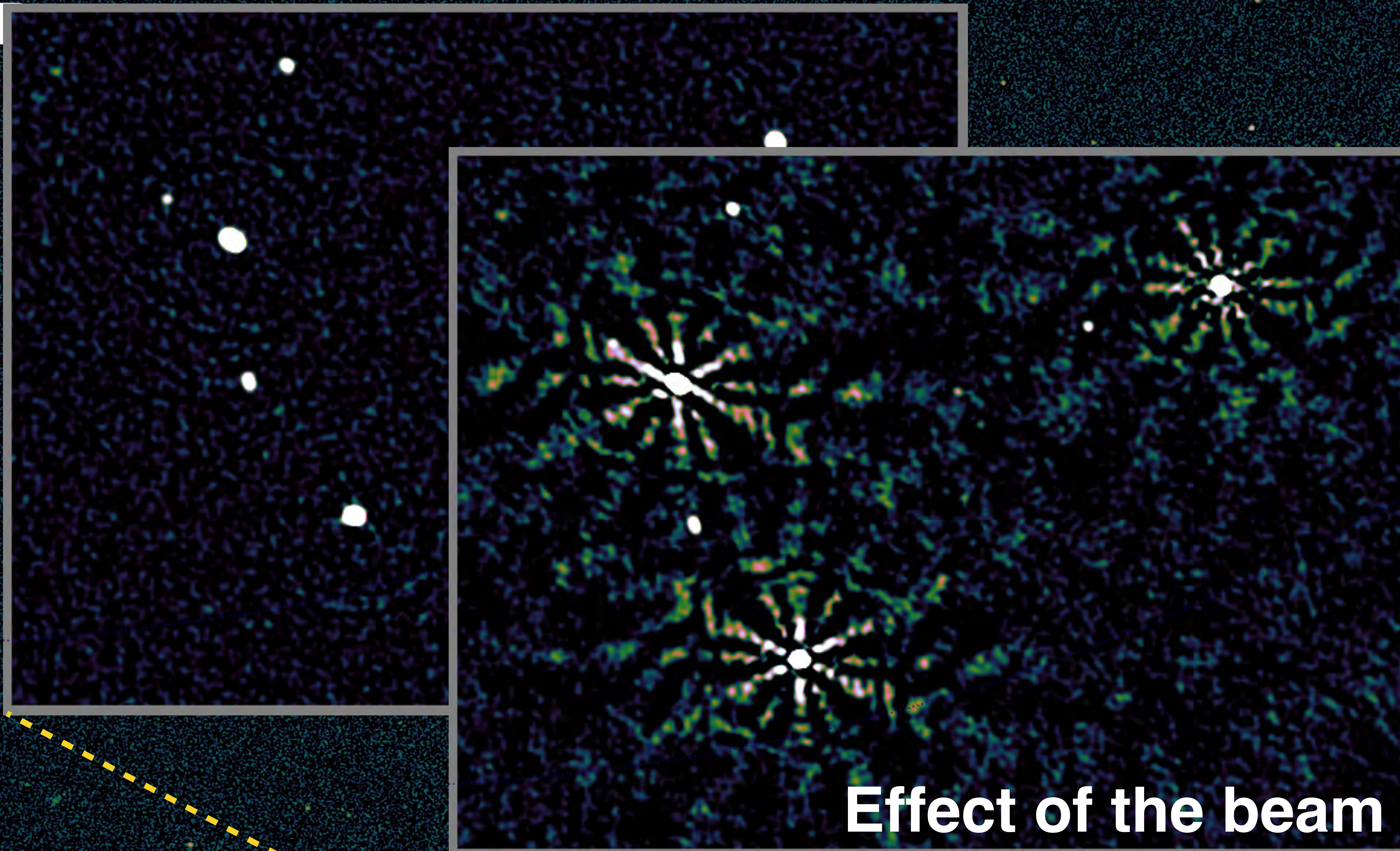


Effect of the beam
Credits image: O. Smirnov



How can we know the shape of the beam ?

Credits image: O. Smirnov

Beam patterns

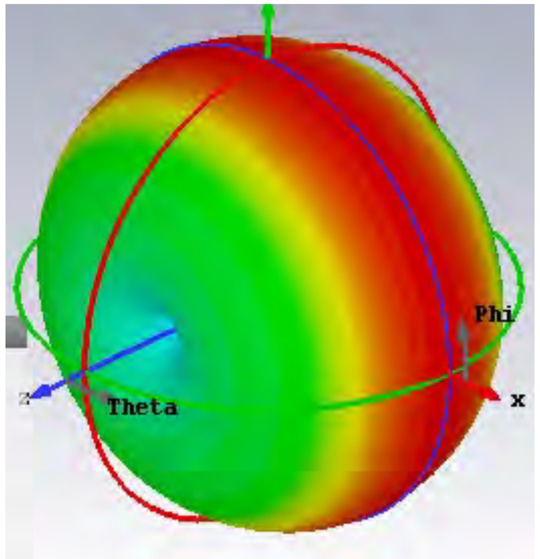
A) Numerical E.M. simulations

Analytical (LOFAR LBA) *(Yatawatta, 2009)*

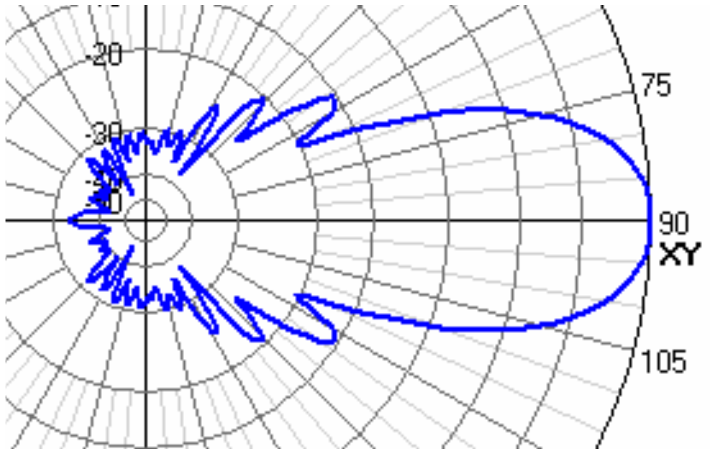
Ray tracing (VLA) *(Brisken, 2003)*

Solving Maxwell equations

NEC, CST, HFSS, etc.



CST



NEC

Beam patterns

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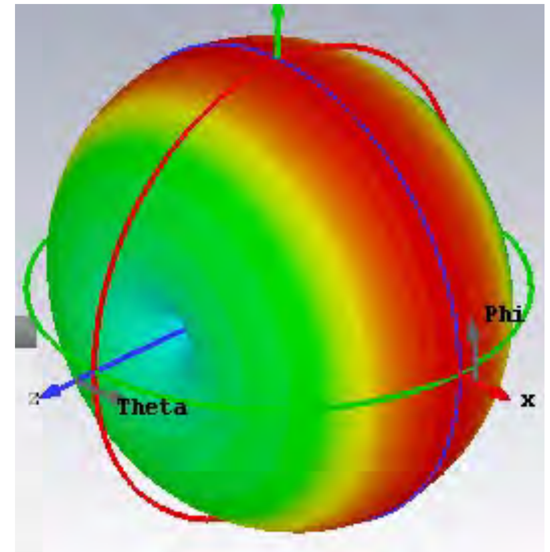

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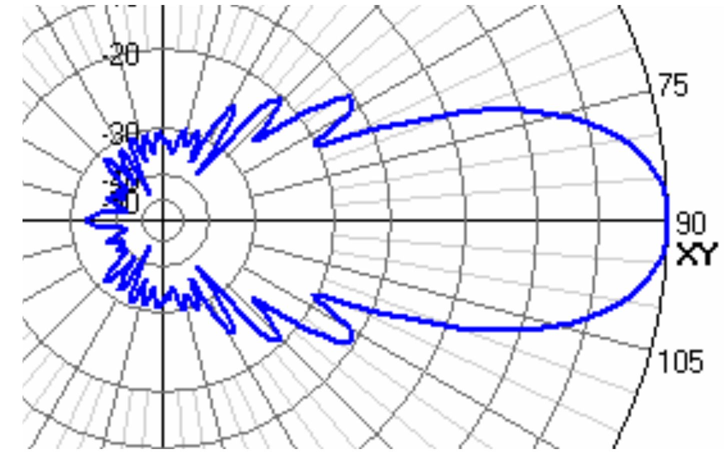

NEC

B) Measurements

Anechoic chamber

Beam patterns

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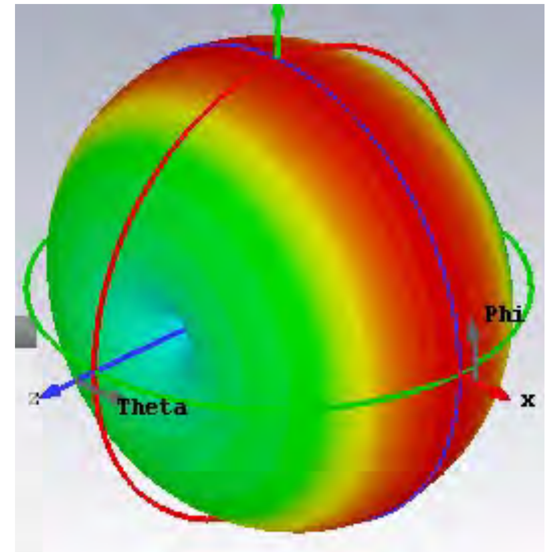

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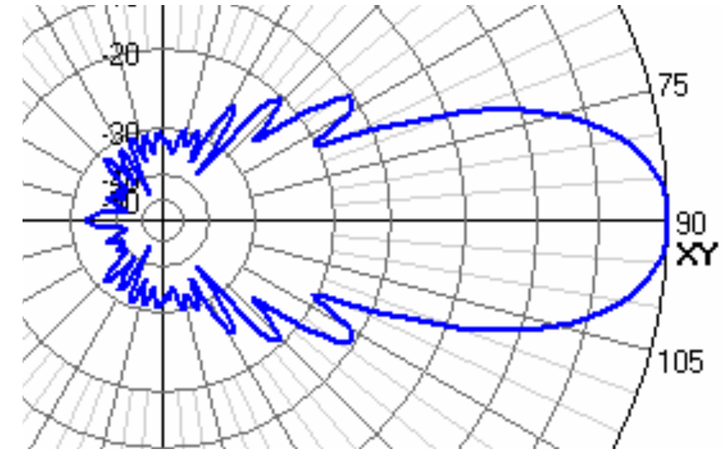

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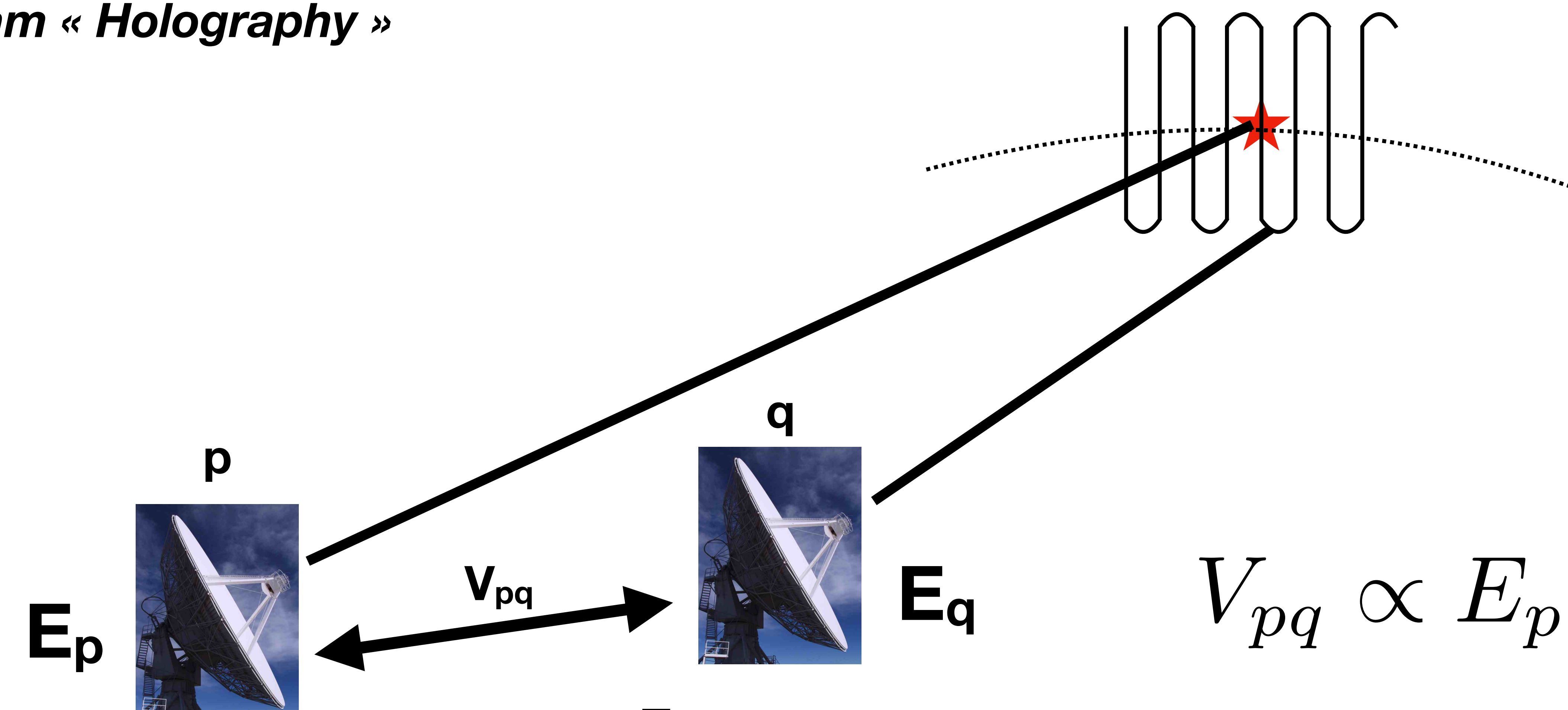
Beam « Holography »



Reference antenna

« Target » antenna

$$V_{pq} \propto E_p E_q^*$$

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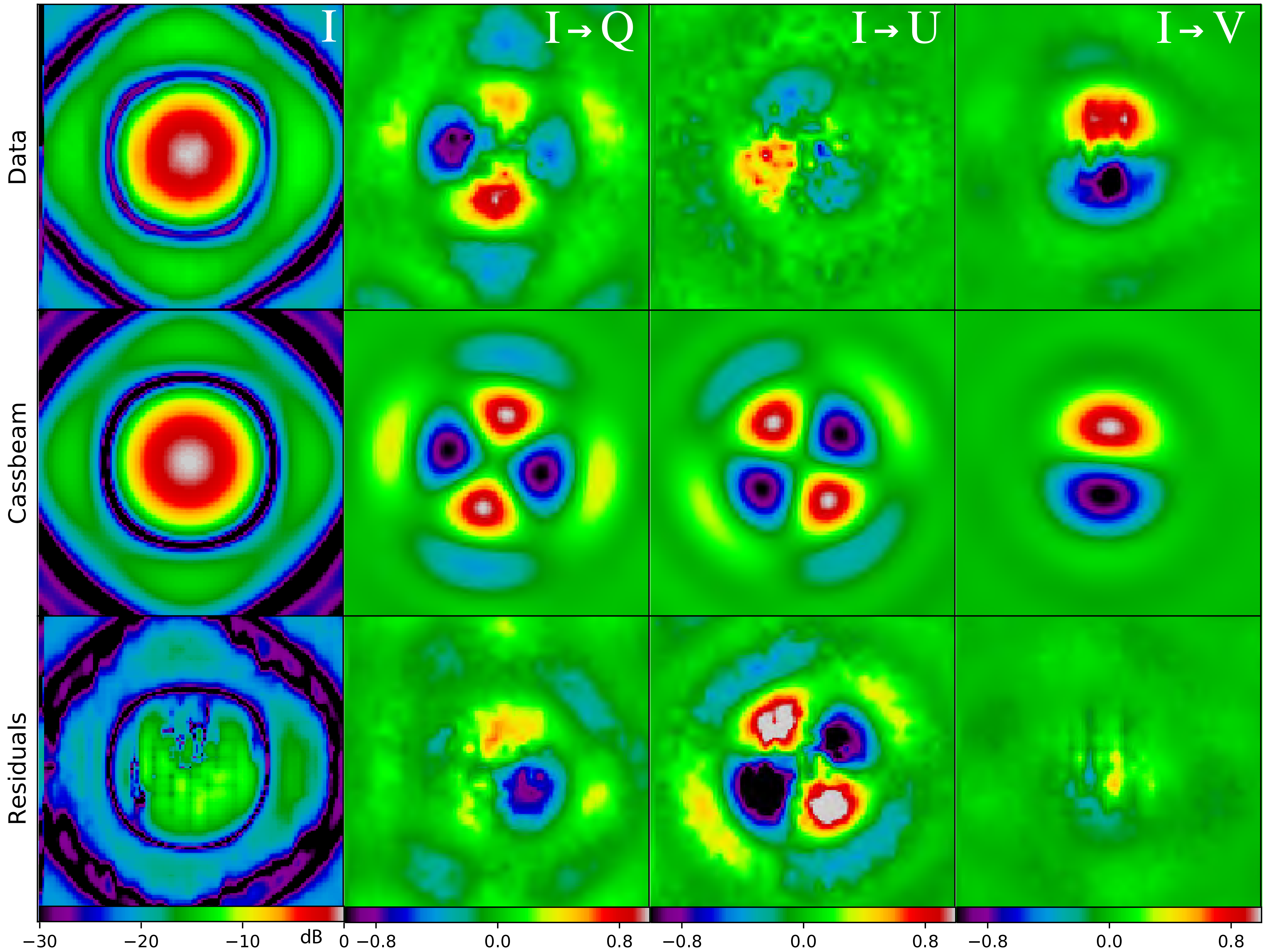
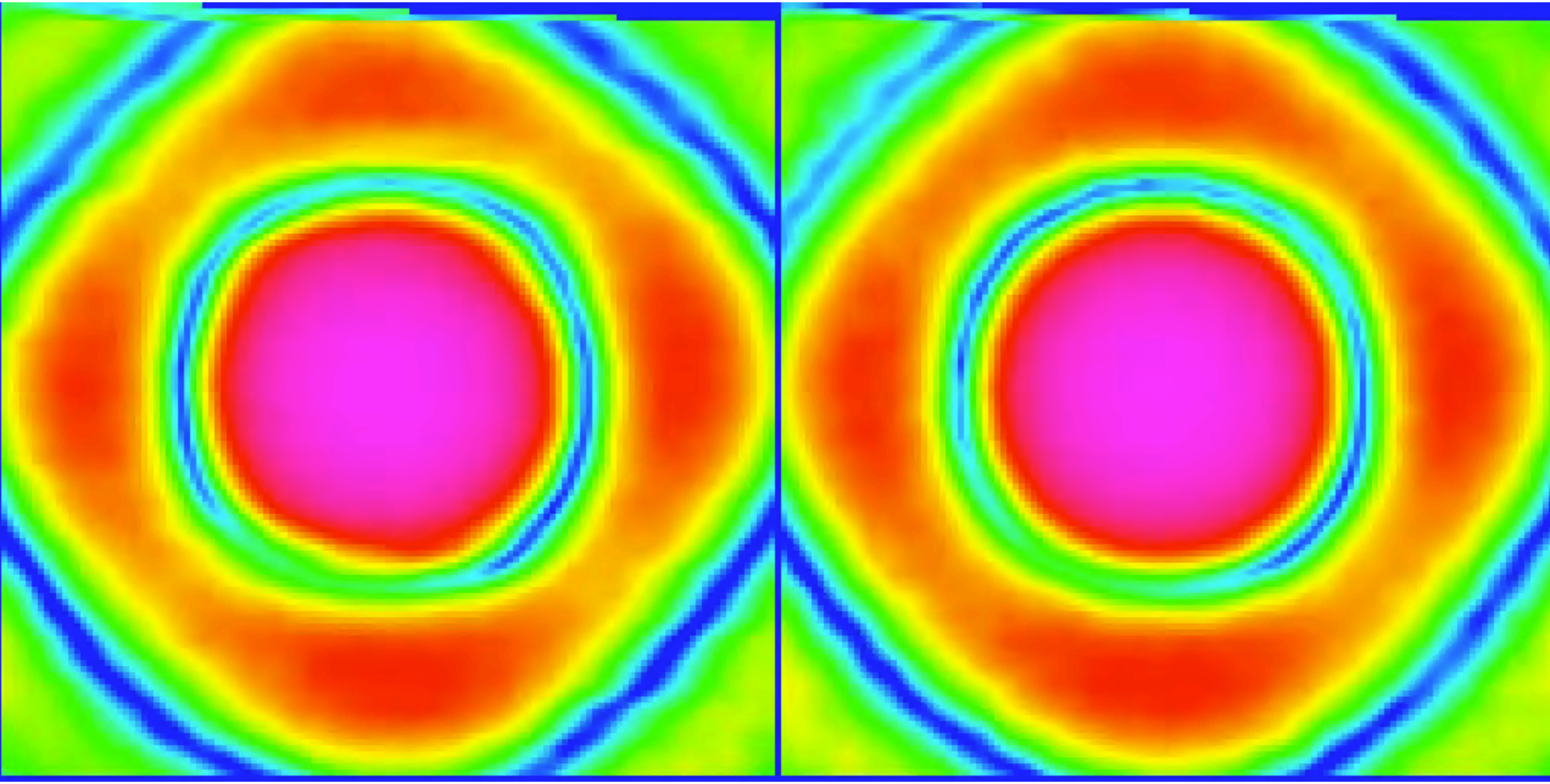
Beam shape: Holography vs. Cassbeam model (Brisken, 2003)



VLA beam holography

ant 5 LL ant 28



Animation in frequency

1008 —> 2032 MHz

Data: R. Perley
Anim: O. Smirnov

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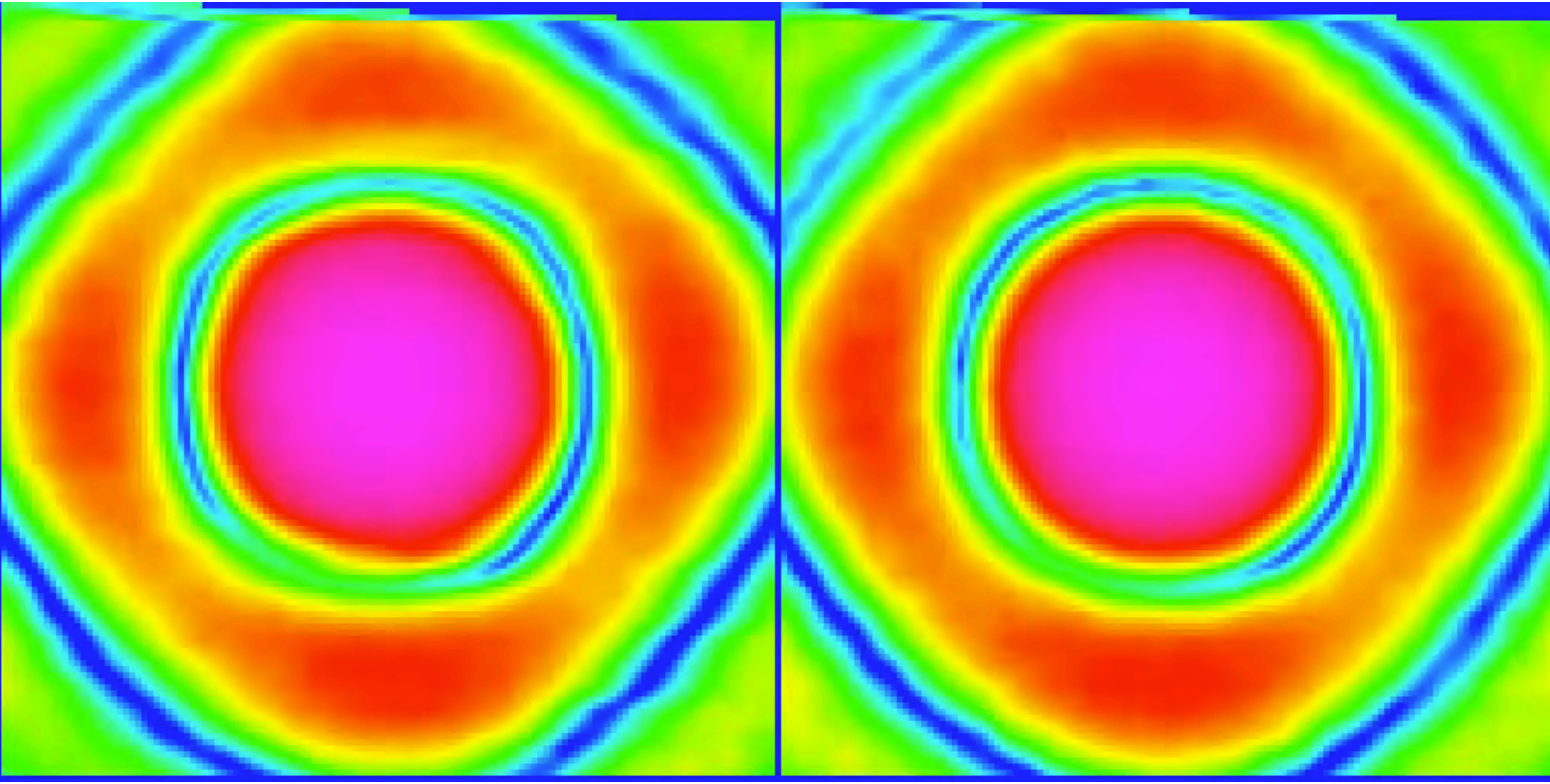
ant 5 LL ant 28



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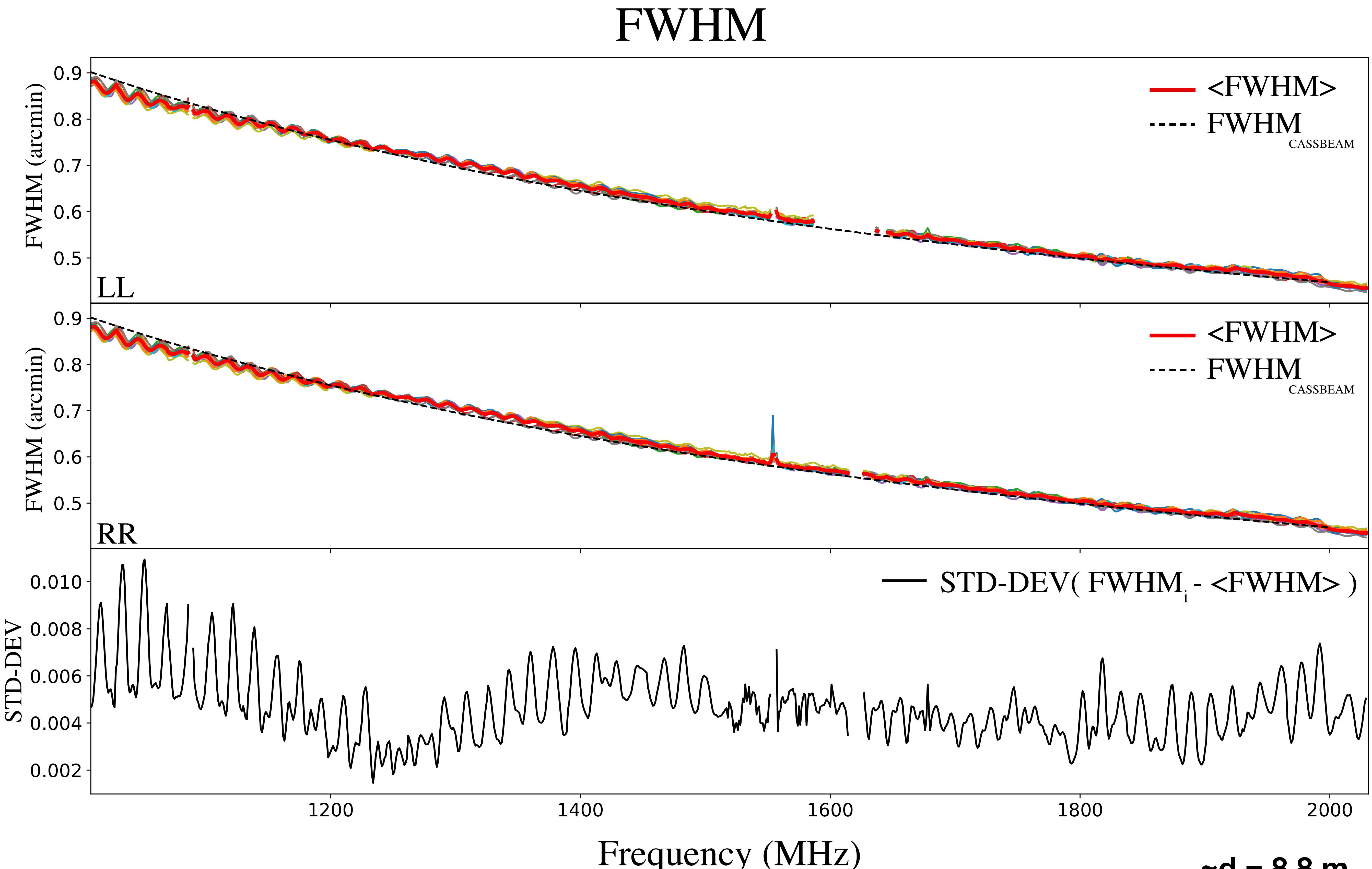
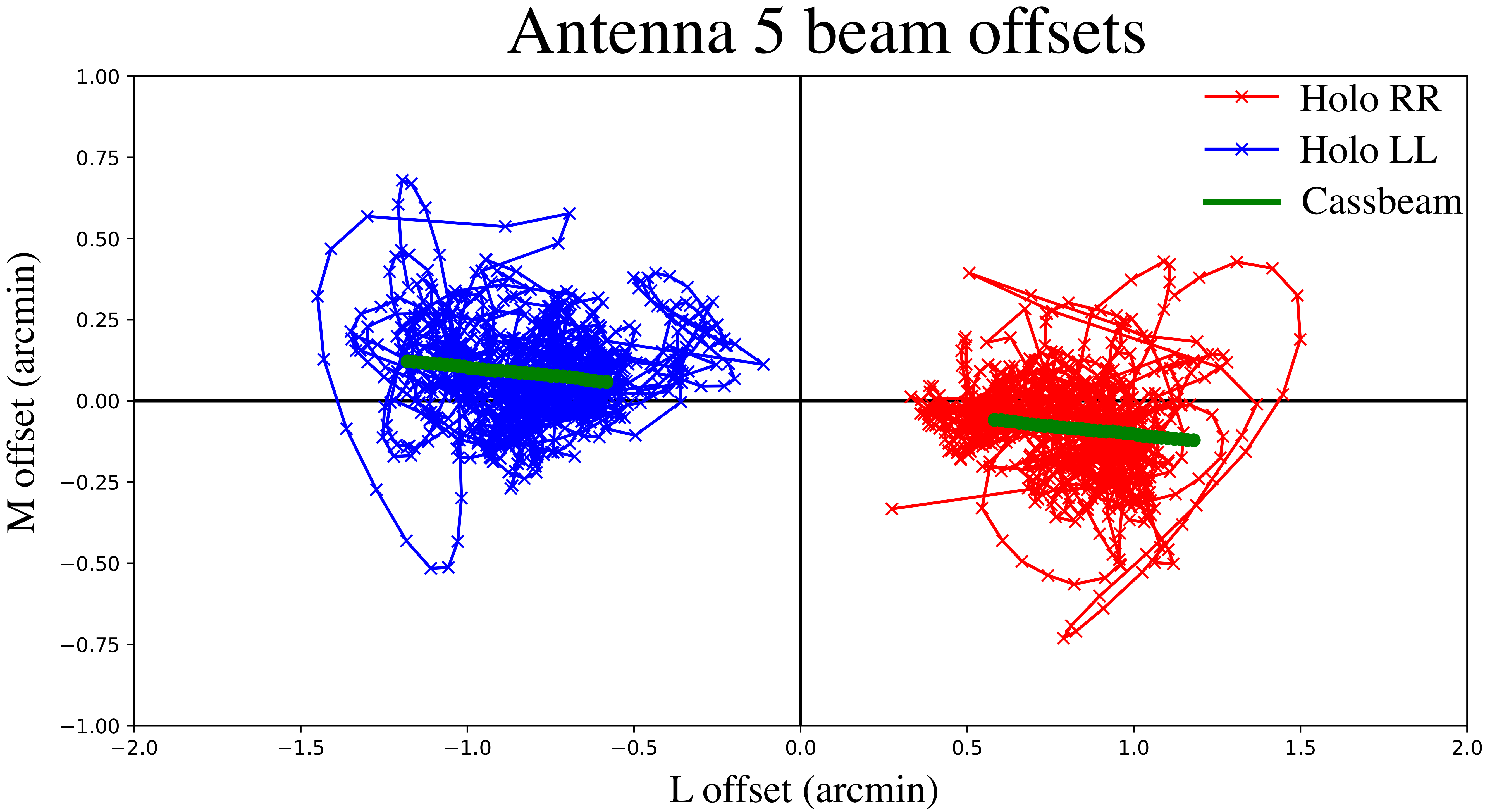
FWHM: Holography vs. Cassbeam model (Brisken, 2003)



~d = 8.8 m

—> Oscillations in frequency (~17 MHz period) —> Standing wave between Iary & IIary

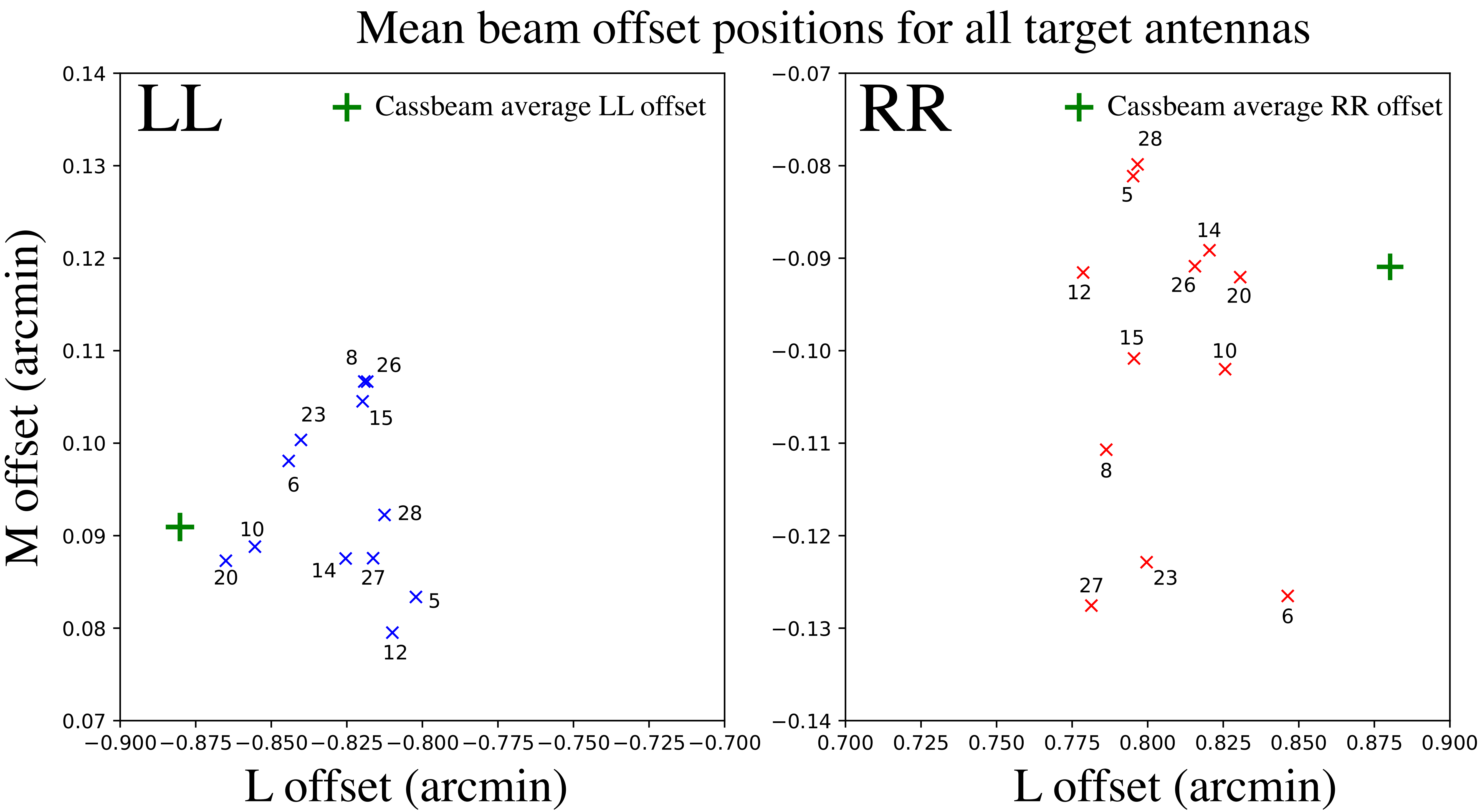
Pointing offset: Holography vs. Cassbeam



—> Known beam squint at the VLA (± 0.5 - 1 arcmin)

—> More complex frequency excursion (red & blue) compared to simulation (green)

Pointing offset: Holography vs. Cassbeam



—> Dispersion of the mean offset position from antenna to antenna

—> Unexplained overall shift, not explained by the EM model

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Previous work on modelling JVLA/MeerKAT Antennas

2003 **Brisken, 2003** EVLA Memo 58

Modeling VLA antenna with optical Ray Tracing (GRASP8)

« Cassbeam » model

...

2013 **Young, Maaskant, Ivashina et al. 2013**

2016 **Mutonkole et al., 2016**

CBFP « Characteristics Basis Function Patterns »

$$F_r(\Omega, s) = \sum_{n=1}^{N} \alpha_n f_n(\Omega, s),$$

Using CBFP to interpolate and predict the effect of gravity and mechanical constraint (e.g. support arm deformation) on the beam

2018 **Jagannathan et al., 2018 (and references therein)**

Improved « Cassbeam » model accounting for frequency variations

Iheanetu, Girard et al., sub. modelling from JVLA L-band beam from holography

Asad, Girard et al., in prep modelling from MeerKAT L-band beam from holography

Modelling

Iheanetu, Girard et al. sub

Holography data are 3D (2 for space, 1 for frequency)

How to find the relevant space to have sparse representations ?

We need to compress the information while insuring fidelity

	Spatial behavior	**Frequency behavior**
Data		

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Iheanetu, Girard et al. sub

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Spatial behavior

Frequency behavior

Data

« Data-driven » representation

PCA/SVD

Orthonormal basis representation

Zernike

(Spherical Harm)

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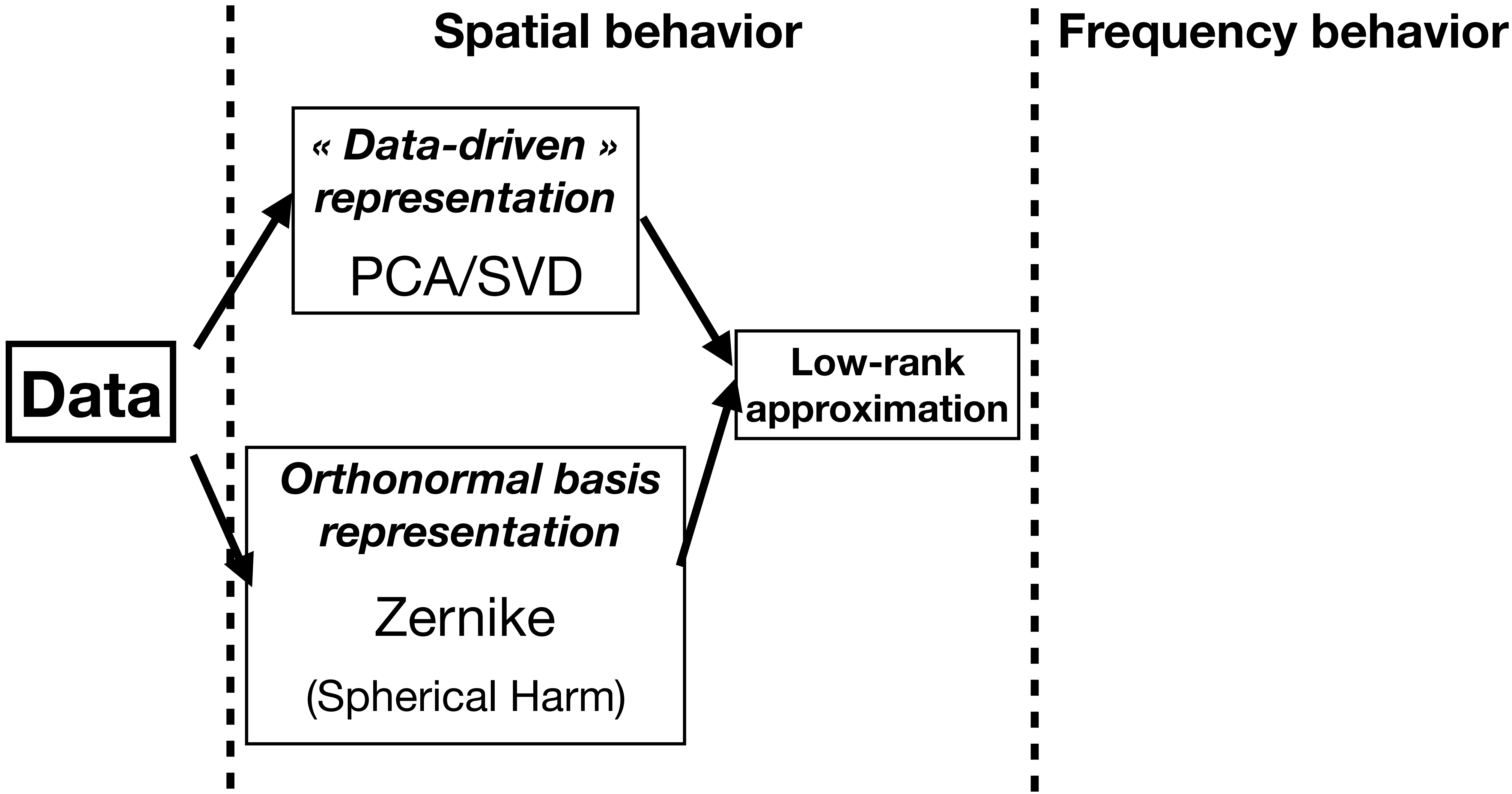

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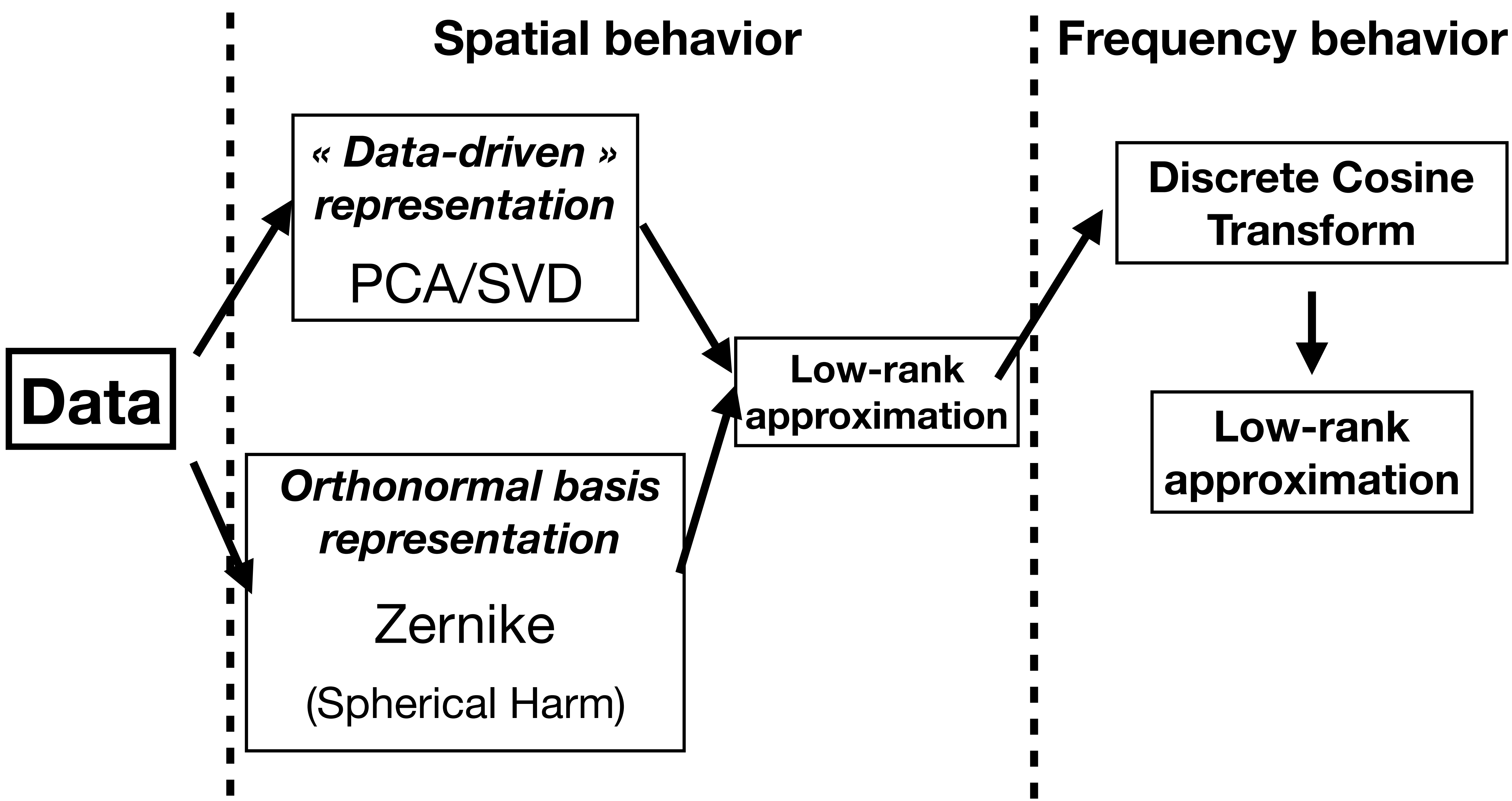

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Data

Spatial behavior

« Data-driven » representation

PCA/SVD

Orthonormal basis representation

Zernike

(Spherical Harm)

Low-rank approximation

Frequency behavior

Discrete Cosine Transform

Low-rank approximation

Modelling

Iheanetu, Girard et al. sub

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Spatial behavior | **Frequency behavior**

Data

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PCA/SVD

Orthonormal basis representation

Zernike

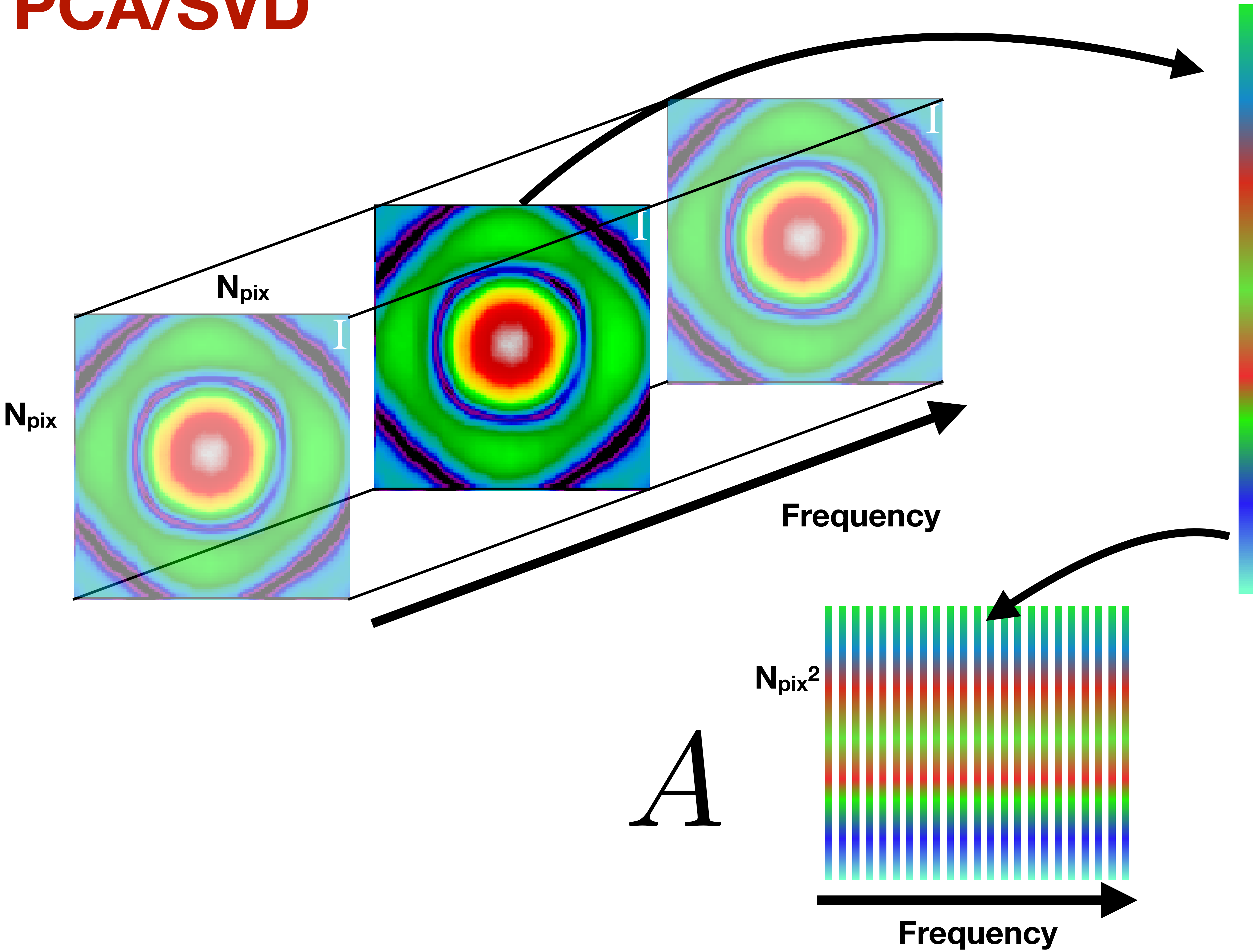
(Spherical Harm)

Low-rank approximation

Discrete Cosine Transform

Low-rank approximation

PCA/SVD

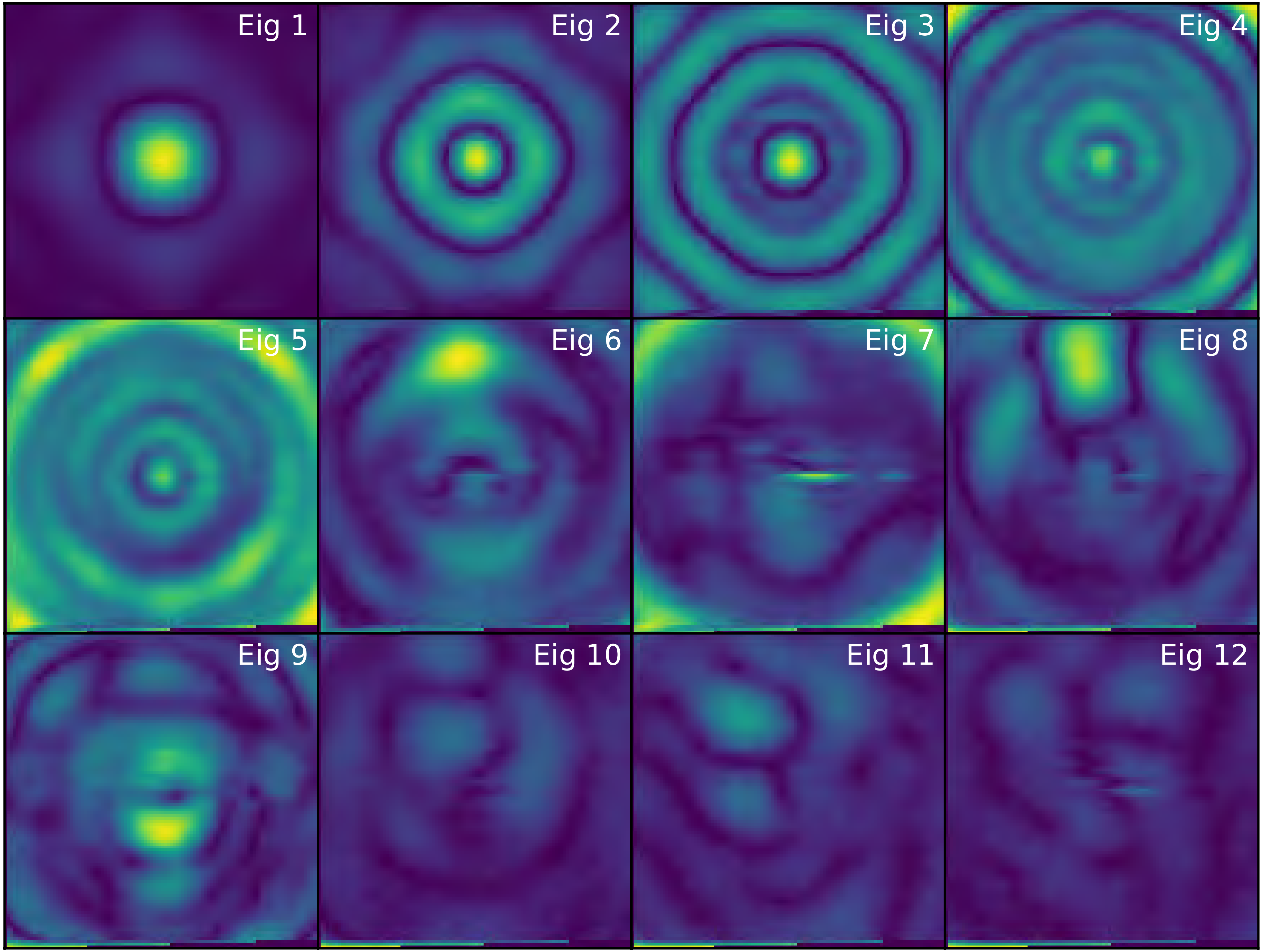


PCA/SVD

PCA through Singular Value Decomposition

$$A = U\Sigma V^T$$

« Eigenbeams » **+ weights**



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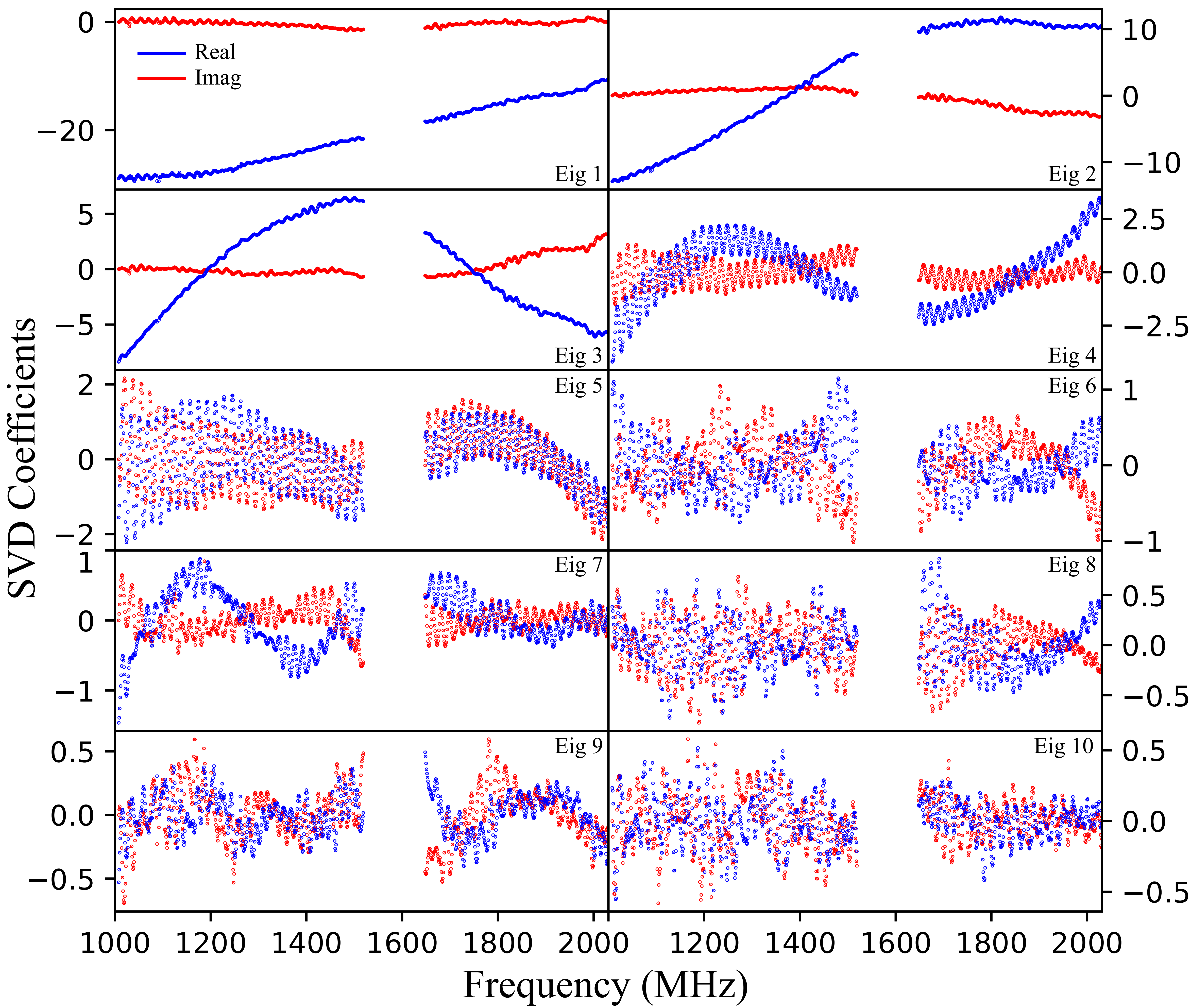
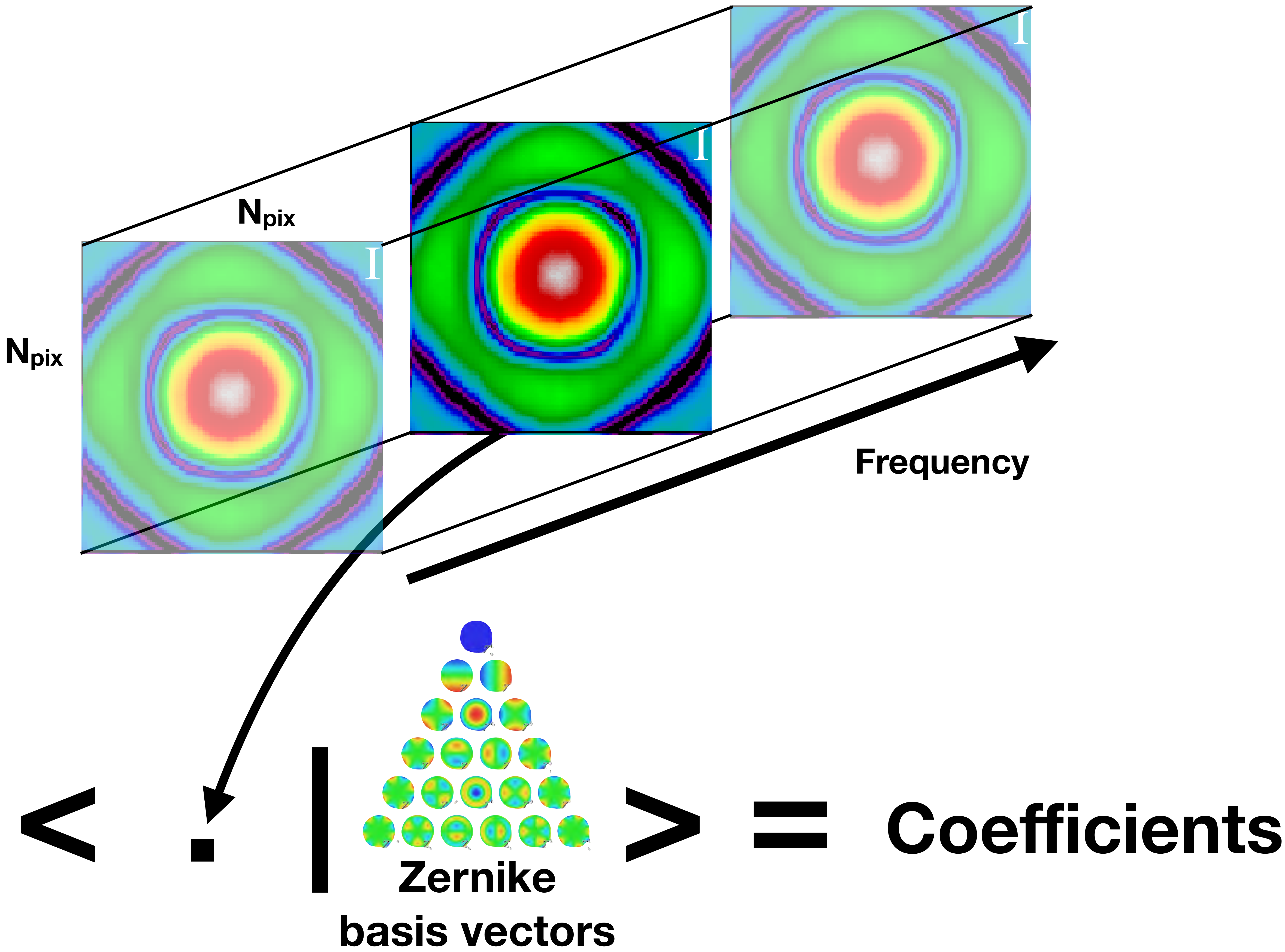
PCA
SVD

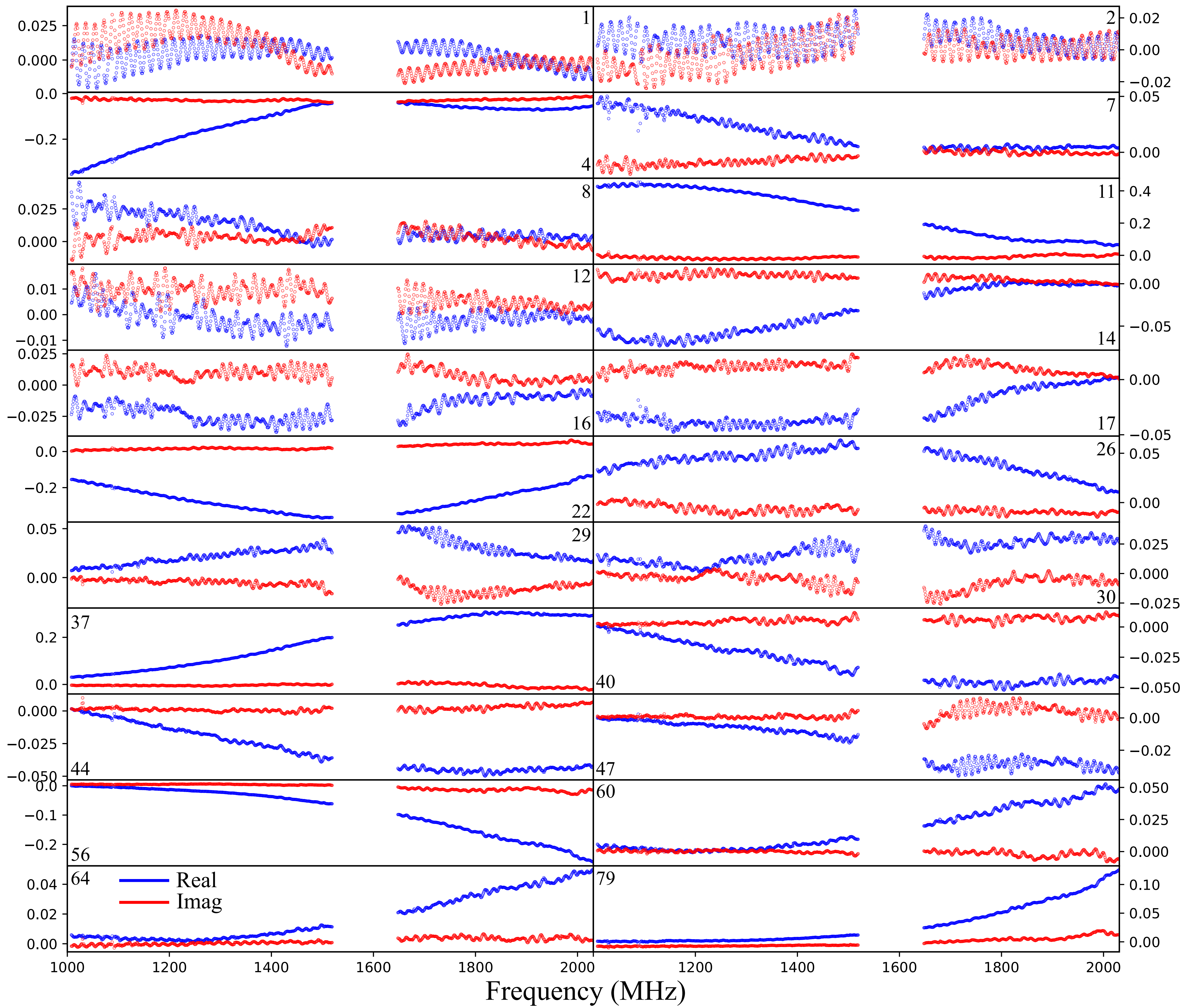


Real
Imag
Eig 1
Eig 2
Eig 3
Eig 4
Eig 5
Eig 6
Eig 7
Eig 8
Eig 9
Eig 10
SVD Coefficients
Frequency (MHz)

Zernike decomposition

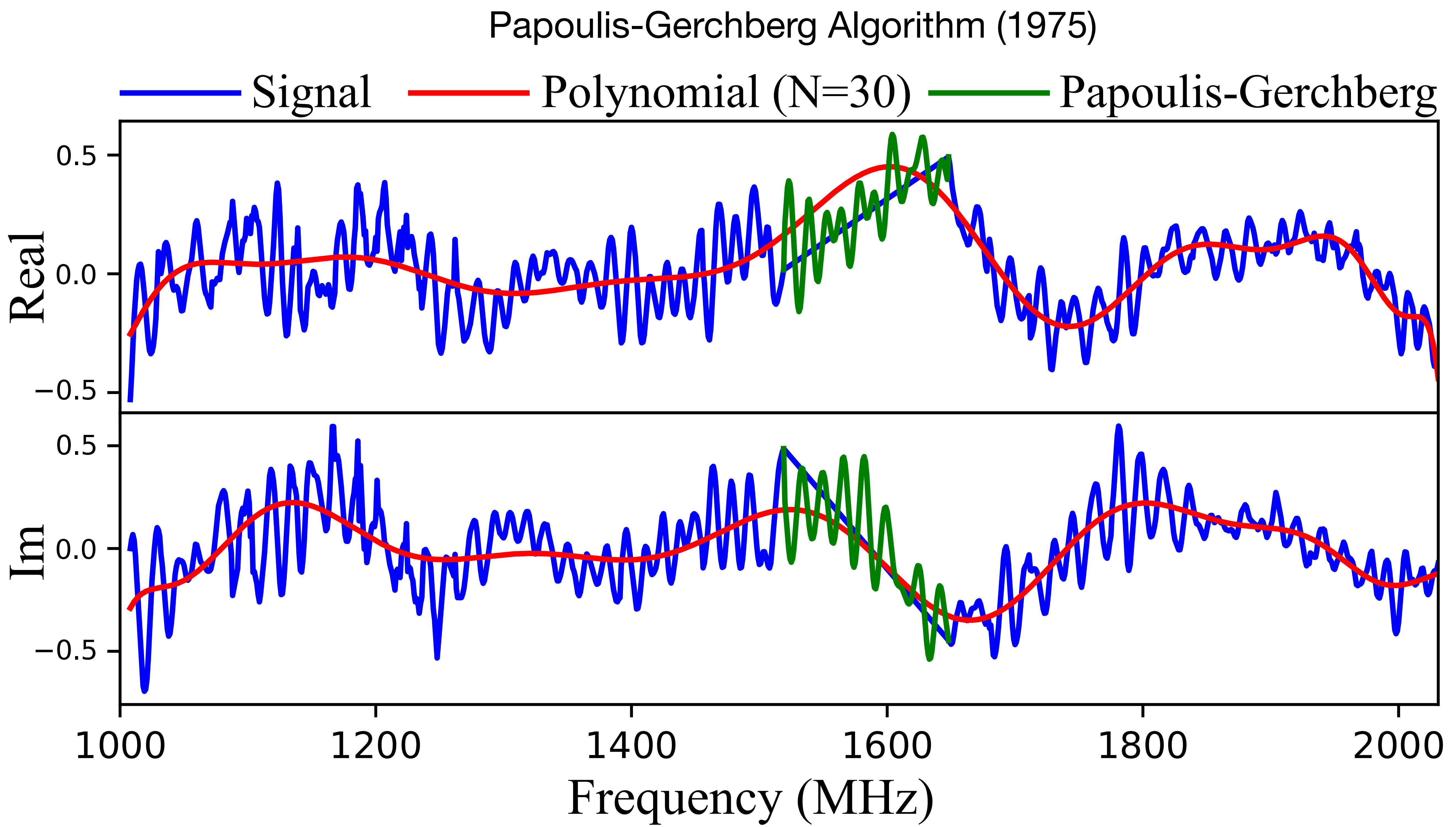


Zernike decomposition

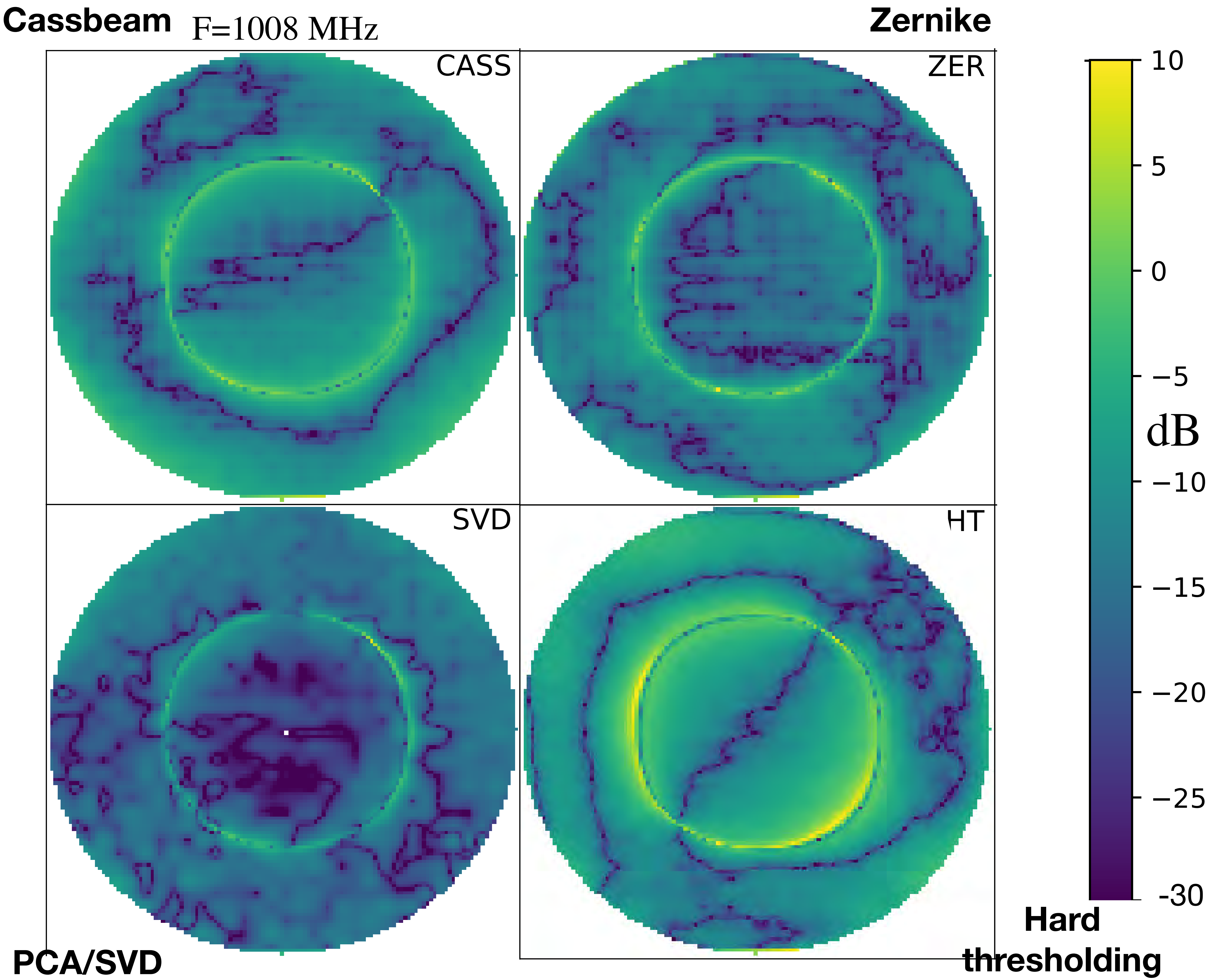


Reconstructing missing information

~ Sparse reconstruction in the DCT space



Reconstruction residuals



Compressibility

SVD

$$N_{\mathrm{SVD}} = 2 \times \underbrace{k_{lm} \times k_{\nu}}_{\text{coeffs}} + \underbrace{k_{lm} \times N_{\mathrm{pix}} \times N_{\mathrm{pix}}}_{\text{eigenbasis } v^T_{k_{lm}}}$$

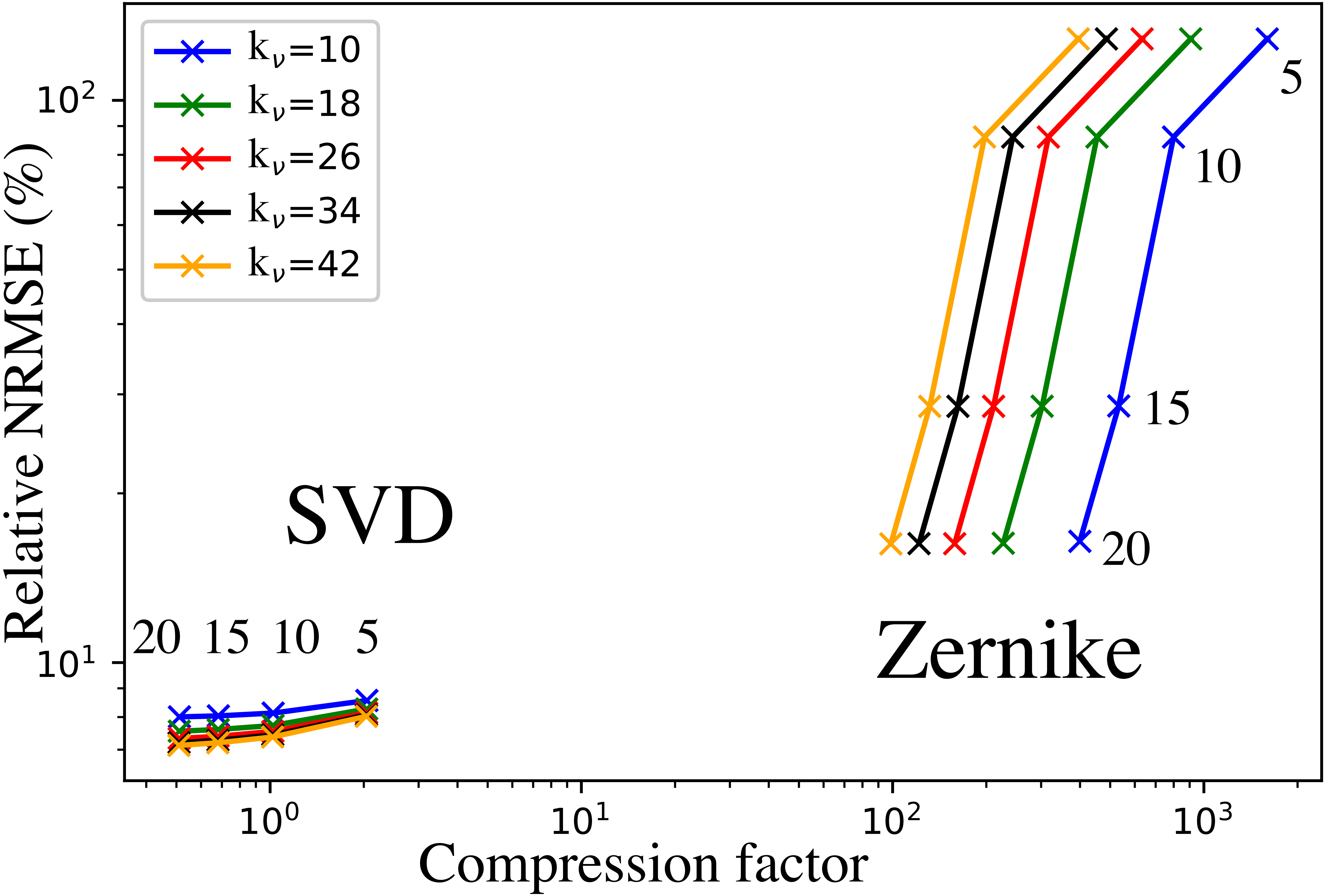
Zernike

$$N_{\mathrm{Zernike}} = 2 \times \underbrace{k_{lm} \times k_{\nu}}_{\text{coeffs}} + \underbrace{k_{lm}}_{\text{list of Noll indices}}$$

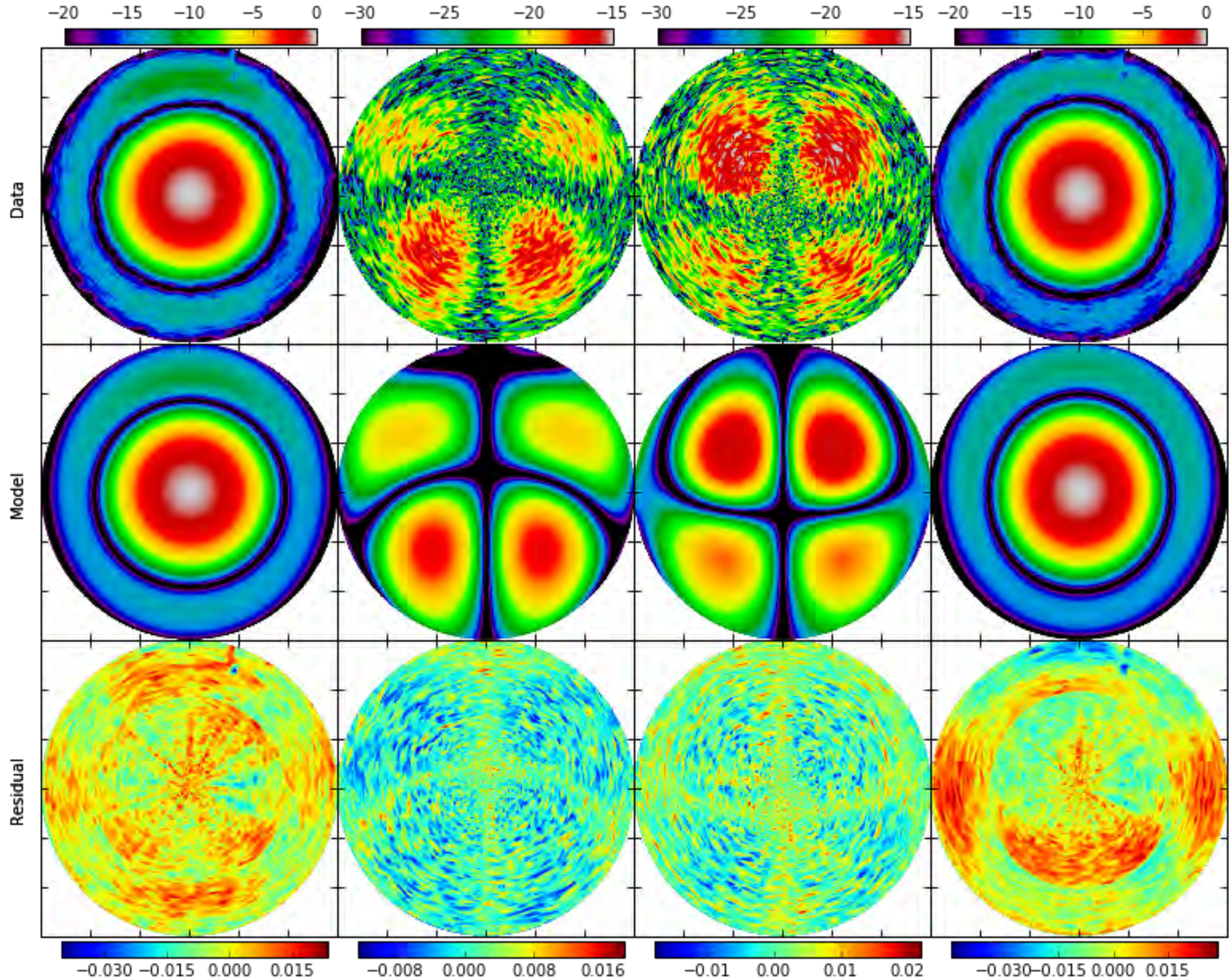
Cassbeam

$$N_{\mathrm{Cassbeam}} = \underbrace{7 \times k_{\nu}}_{\textbf{Jagannathan et al., 2018}} + \underbrace{N_{CB}}_{\text{other fixed model params}}$$

Compressibility vs. fidelity



Khan Asad current work on MeerKAT beams



Asad, Girard et al. in prep

Conclusion

—> Knowledge of the beam is fundamental for « modern » calibration

—> Holography measurements rather than direct EM modelling

—> Data-driven vs orthonormal basis

—> Compression vs. fidelity

—> Compression for fidelity

Next steps

—> Model Full-Pol beams and other bands

—> Going from modelling to « solving » for parameters

The less degree of freedom, the less parameters to solve for

—> Apply this to the calibration of LOFAR/NenuFAR-Class instruments