

Calibration

Introductory Radio Interferometry Course

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(RATT)

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Calibration

Calibration: Determining and correcting for **propagation effects** in order to compute the **brightness**.

i.e., solve for Jones matrices **J** to compute **B** :

Diagram illustrating the relationship between Visibility, Brightness, and Jones matrices:

$$\mathbf{V}_{pq} = \mathbf{J}_p \mathbf{B} \mathbf{J}_q^H$$

Labels: Visibility, Brightness, Jones matrices

$$\mathbf{B} = \mathbf{J}_p^{-1} \mathbf{V}_{pq} (\mathbf{J}_q^H)^{-1}$$

Direction-independent and direction-dependent effects

Propagation effects can be of two kinds:

- Direction-independent effects
- Direction-dependent effects

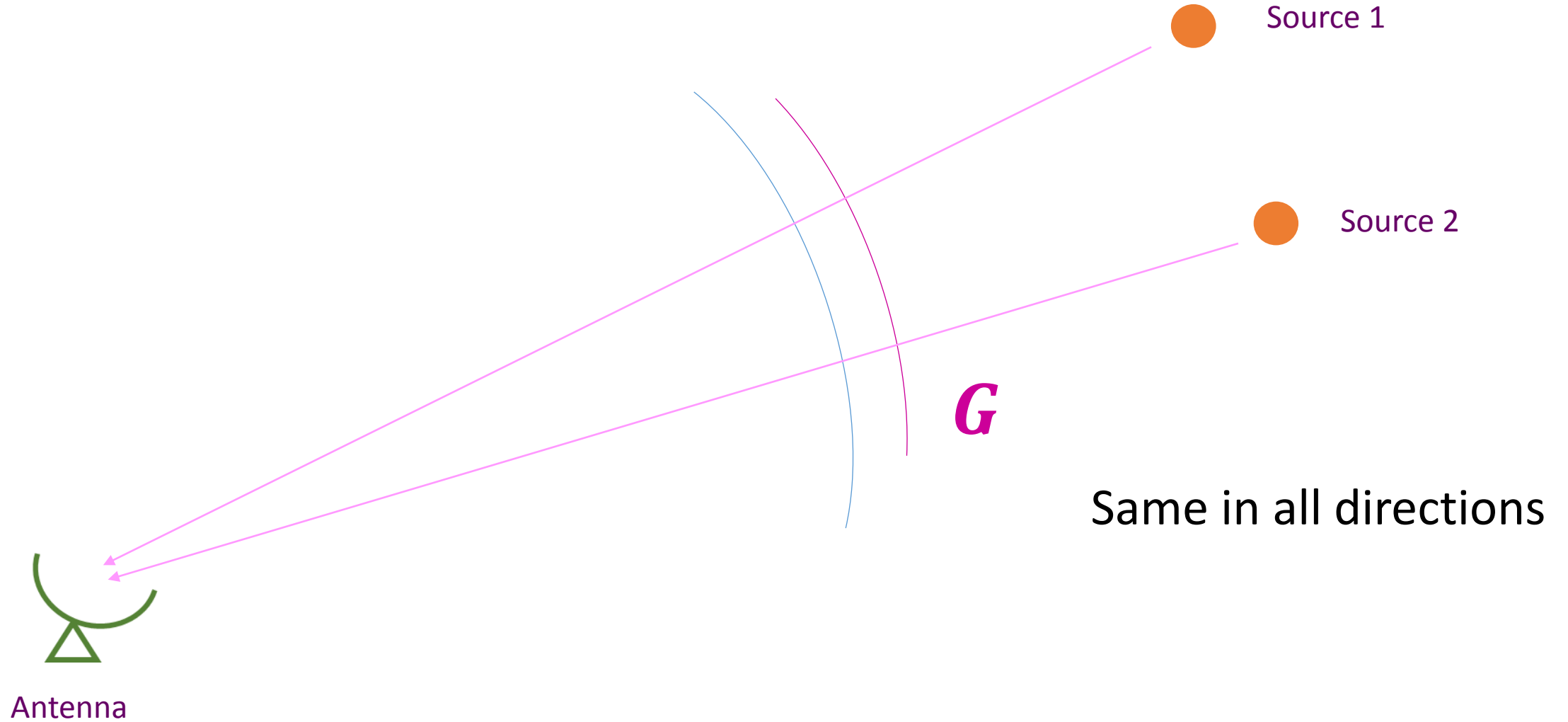
These effects can be represented by different Jones matrices:

The diagram illustrates the equation $J = G E$ where J is blue, G is magenta, and E is green. Three blue arrows point from labels below to the matrices: from 'Final Jones matrix' to J , from 'Direction-independent effects' to G , and from 'Direction-dependent effects' to E .

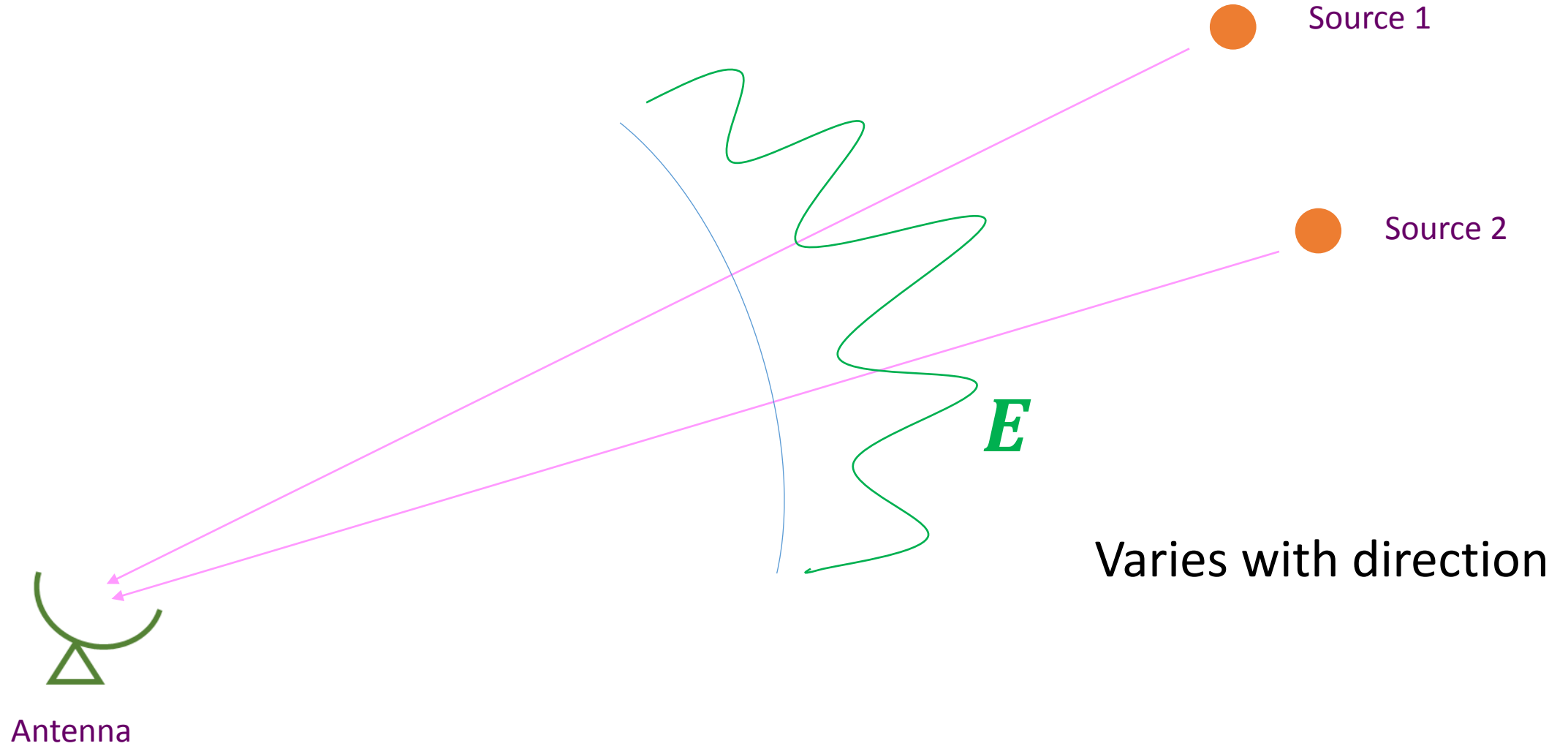
$$J = G E$$

Final Jones matrix Direction-independent effects Direction-dependent effects

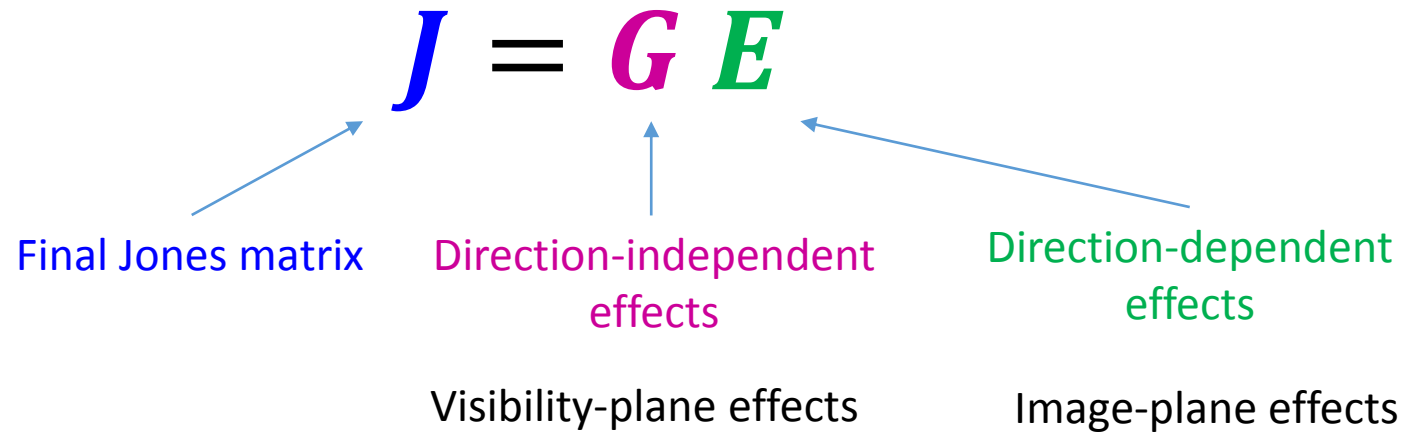
Direction-independent effects



Direction-dependent effects



Direction-independent and direction-dependent effects

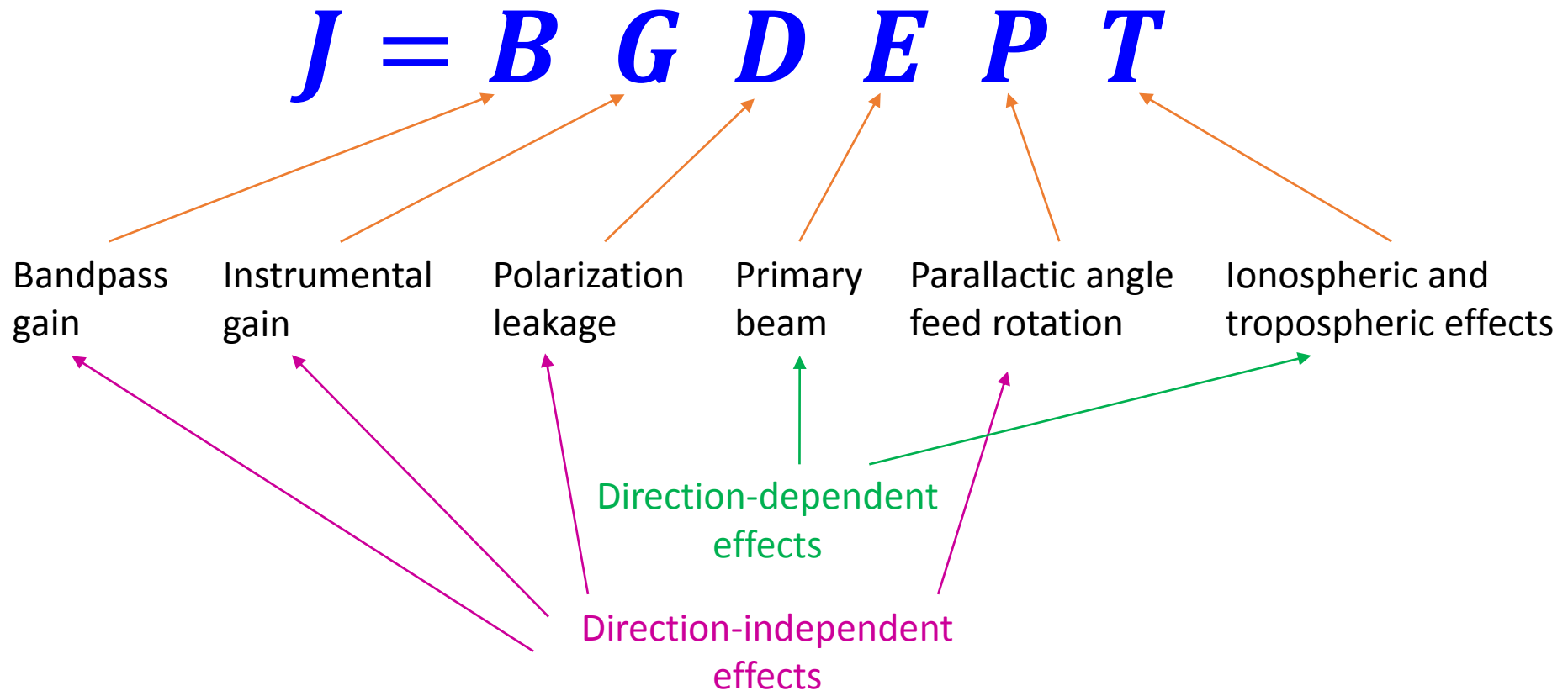


$$\mathbf{V}_{pq} = J_p \mathbf{B} J_q^H$$

$$\mathbf{V}_{pq} = G_p (E_p \mathbf{B} E_q^H) G_q^H$$

Direction-independent and direction-dependent effects

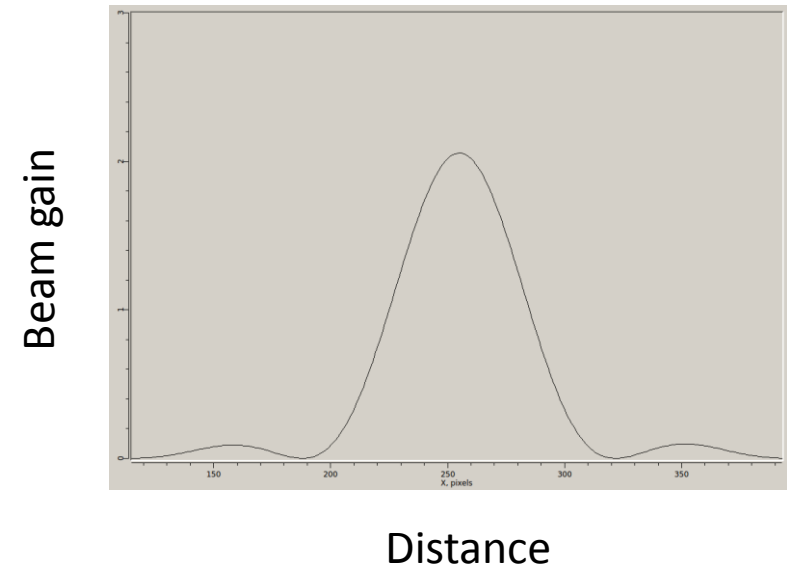
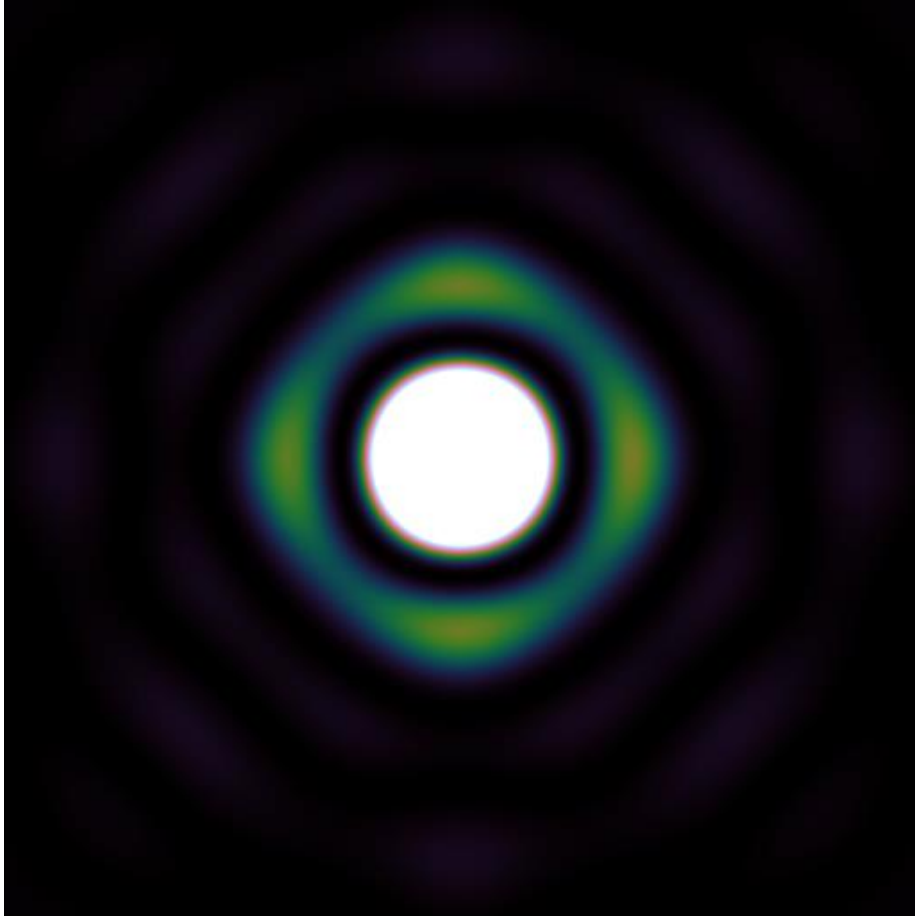
Example:



Direction dependent effects: Primary beam

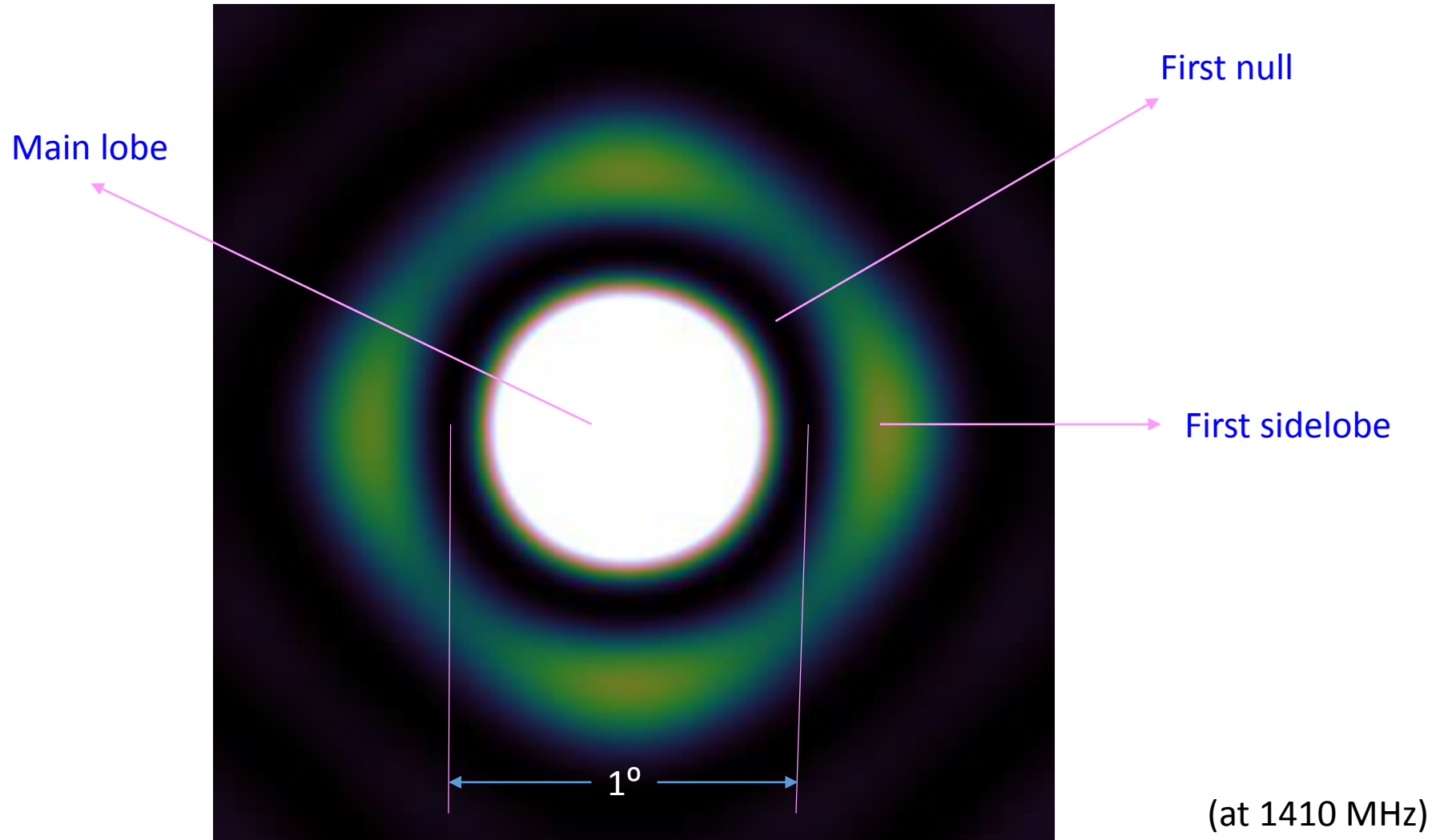
- The primary beam of the antenna is the most important direction-dependent effect.
- Becomes important in wide-field, wide-band observations.
- The primary beam pattern has a multiplicative effect in the image plane, convolutional effect in the visibility plane.
- We will consider the example of a JVLA (Jansky Very Large Array) antenna here.

Primary beam amplitude variation with distance from center

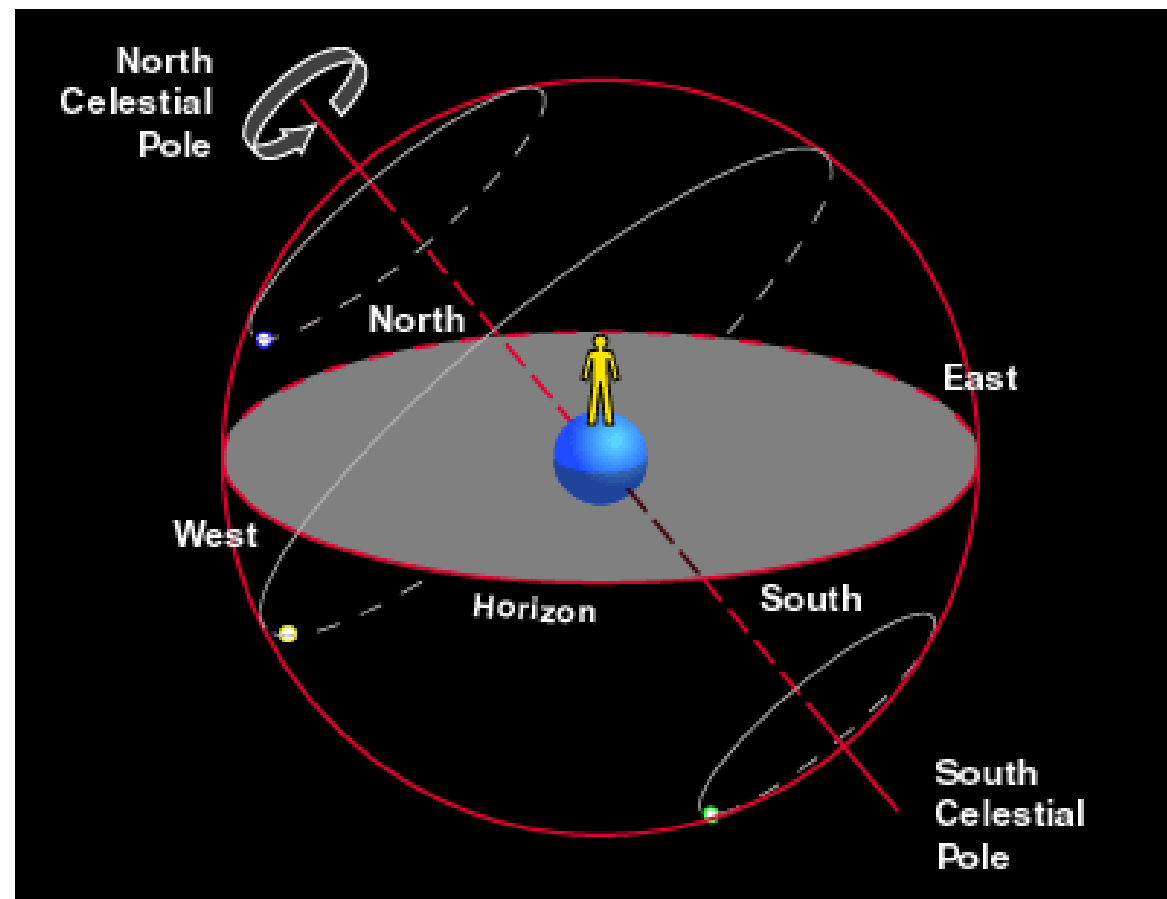


Horizontal cross-section of the beam
through the center

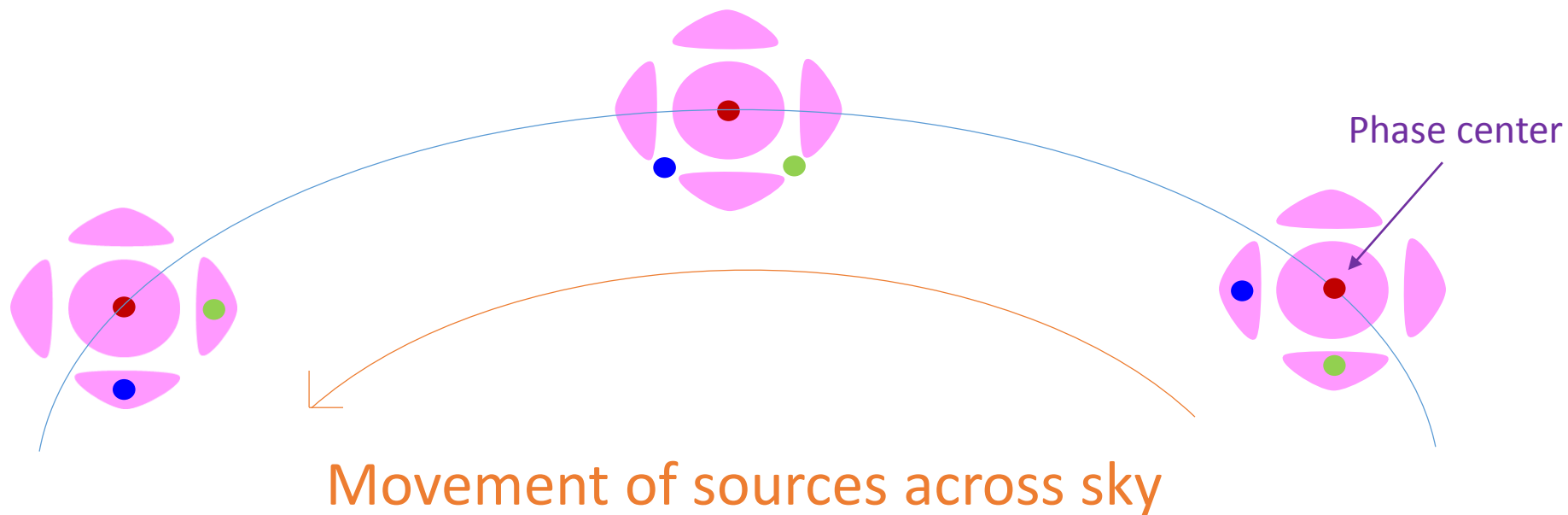
JVLA primary beam



Movement of sources in sky

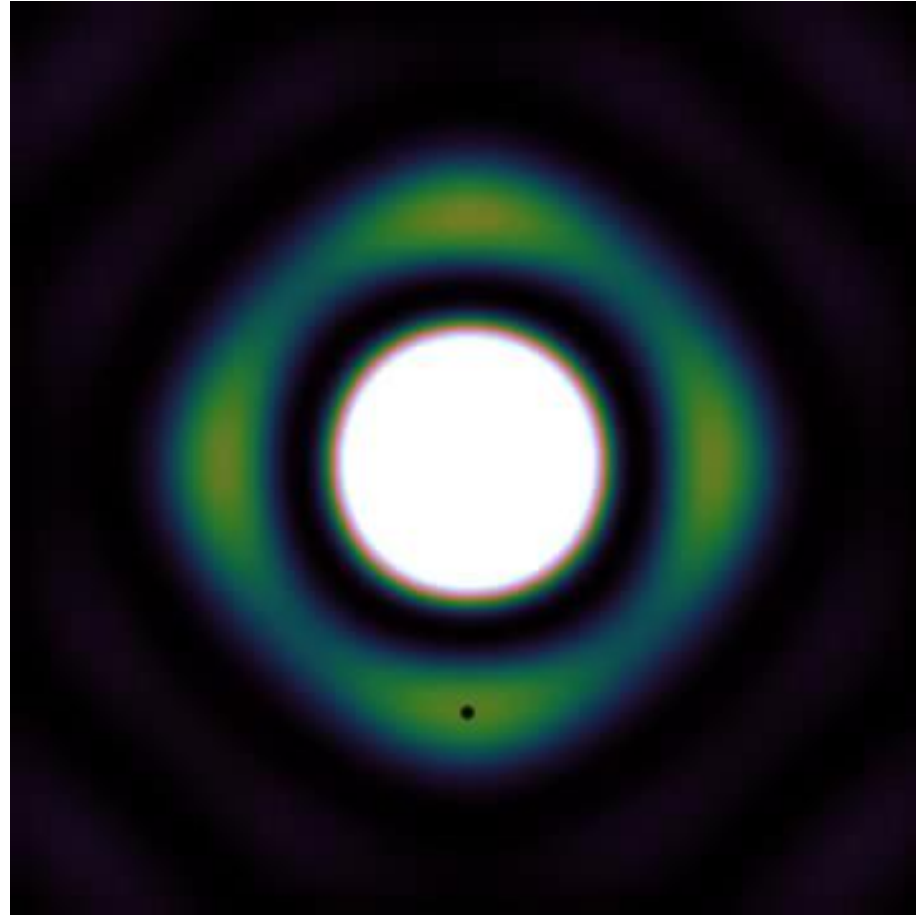


Relative rotation of alt-az beam wrt sky

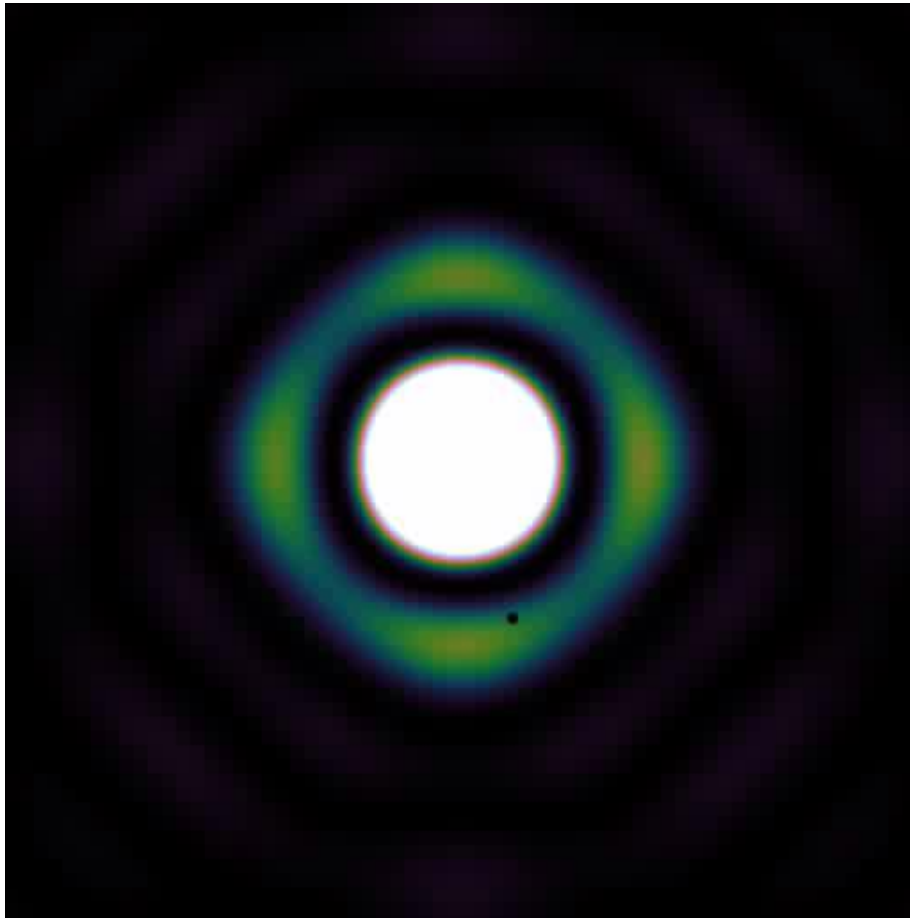


Primary beam rotation

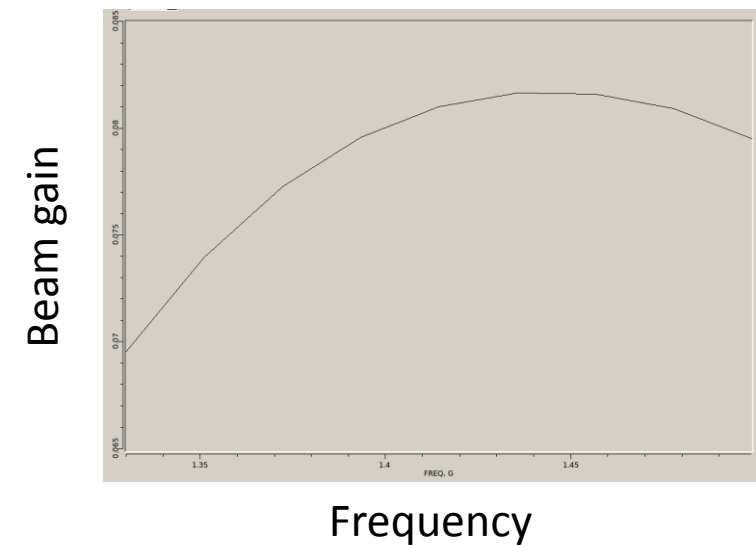
A JVLA antenna has an alt-azimuth mount;
the primary beam rotates during the course of an observation



Variation of primary beam with frequency



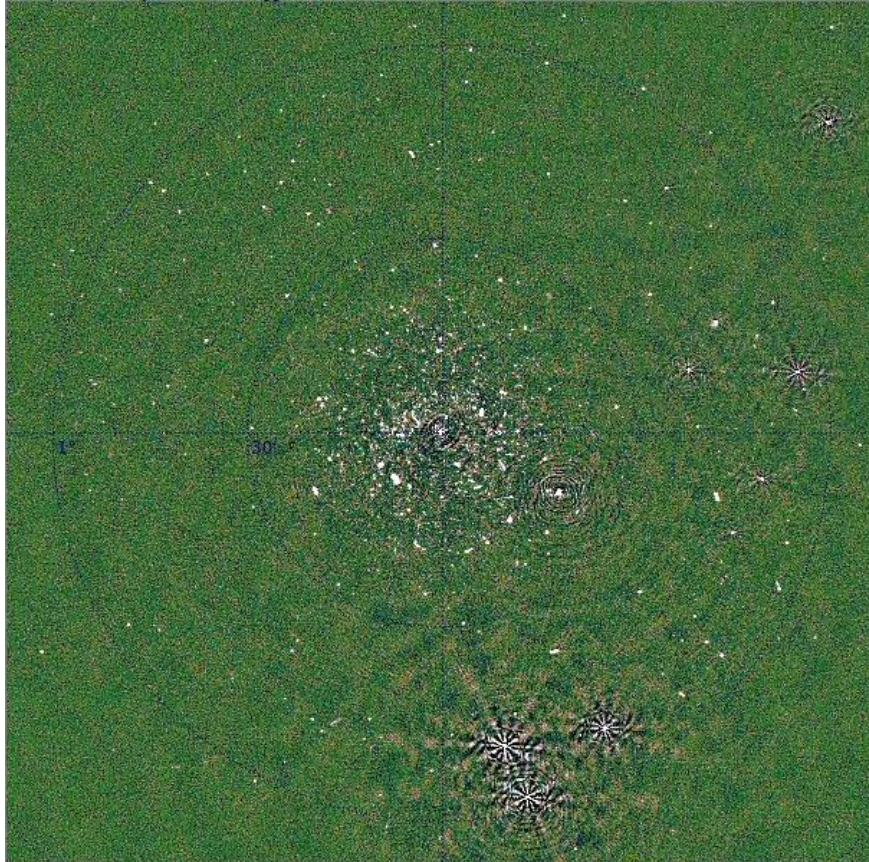
The beam pattern becomes more compact with increasing frequency



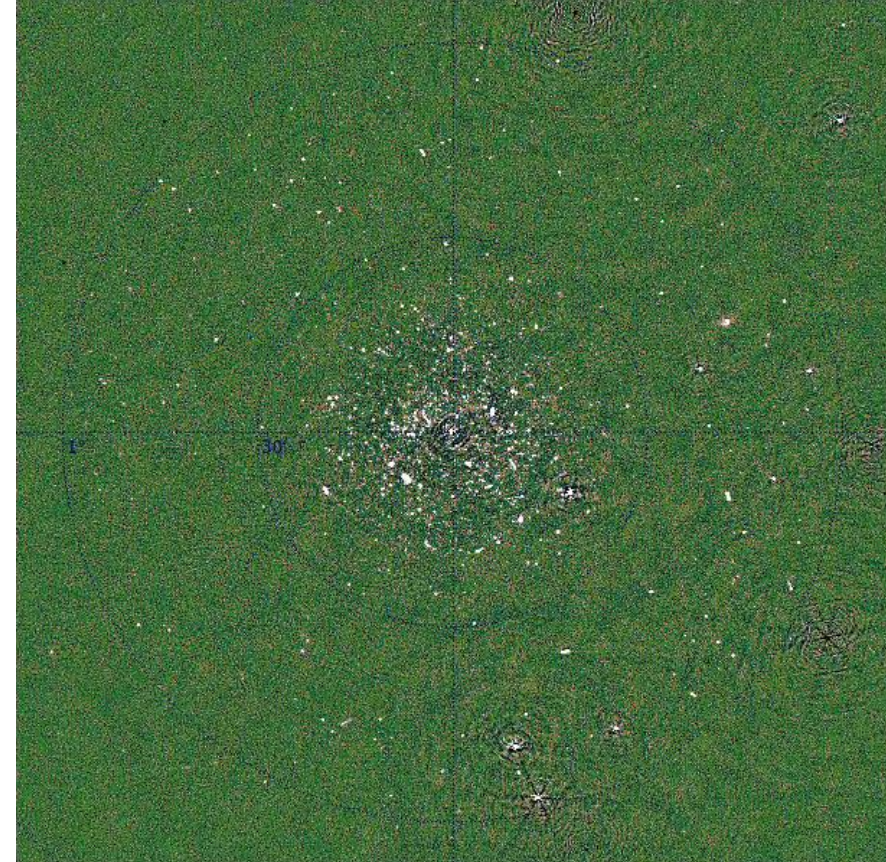
Beam-induced spectral variation
for the source represented by a dot

Incorporating primary beam in calibration

EVLA image of the field around the radio source 3C147



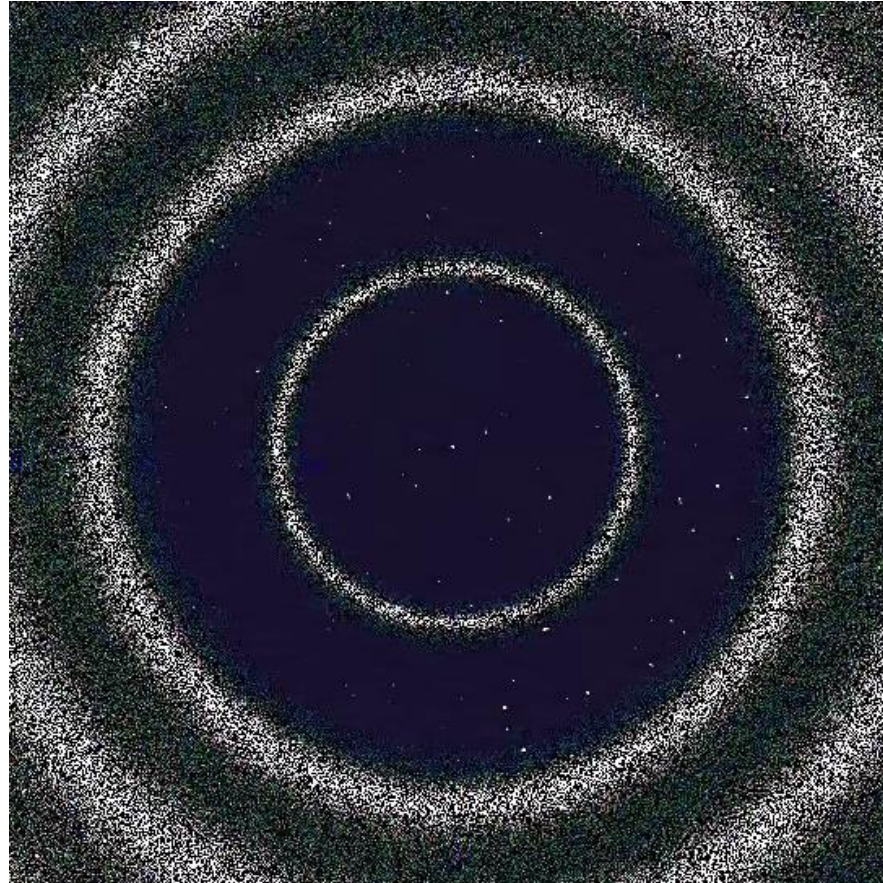
Calibration **without primary beam** included



Calibration **with primary beam** included

Multiplying the noise by the primary beam illustrates the variation in SNR across the field of view

EVLA image of the field around the radio source 3C147



Calibration procedure

1. Start with visibility data, \mathbf{V}_{pq} , and initial brightness model, \mathbf{B} .
2. Solve $\min_J |\mathbf{V}_{pq} - J_p \mathbf{B} J_q^H|$ for J s.
3. Calculate residual visibility data $\mathbf{V}_{pq}^{\text{residual}} = \mathbf{V}_{pq} - J_p \mathbf{B} J_q^H$.
4. Image $\mathbf{V}_{pq}^{\text{residual}}$ to create a residual image, I .
5. Perform a source-finding procedure to find sources in the residual image, and add these to the initial model \mathbf{B} to form a new, updated model \mathbf{B}^{new} .
6. Set $\mathbf{B} = \mathbf{B}^{\text{new}}$, and repeat steps 2-5 until the residual image I is noise-like.

Differential gains

- Differential gain solutions encompass the unknown and unmodeled direction-dependent effects in the signal path.
- The Jones matrix in the direction of source s is then given by:

$$J^{(s)} = G E \Delta E^{(s)}$$

Final Jones matrix in the direction of source s

Direction-independent effects

Known and modeled direction-dependent effects

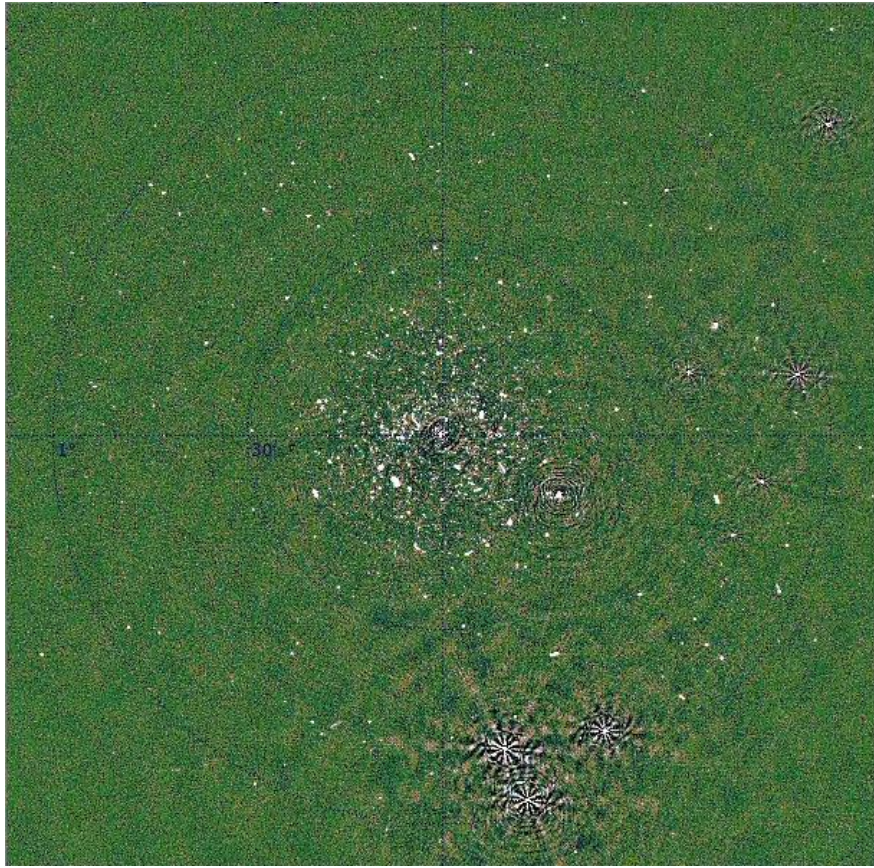
Differential gain: Unknown/unmodeled direction-dependent effects in the direction of source s

Differential gains

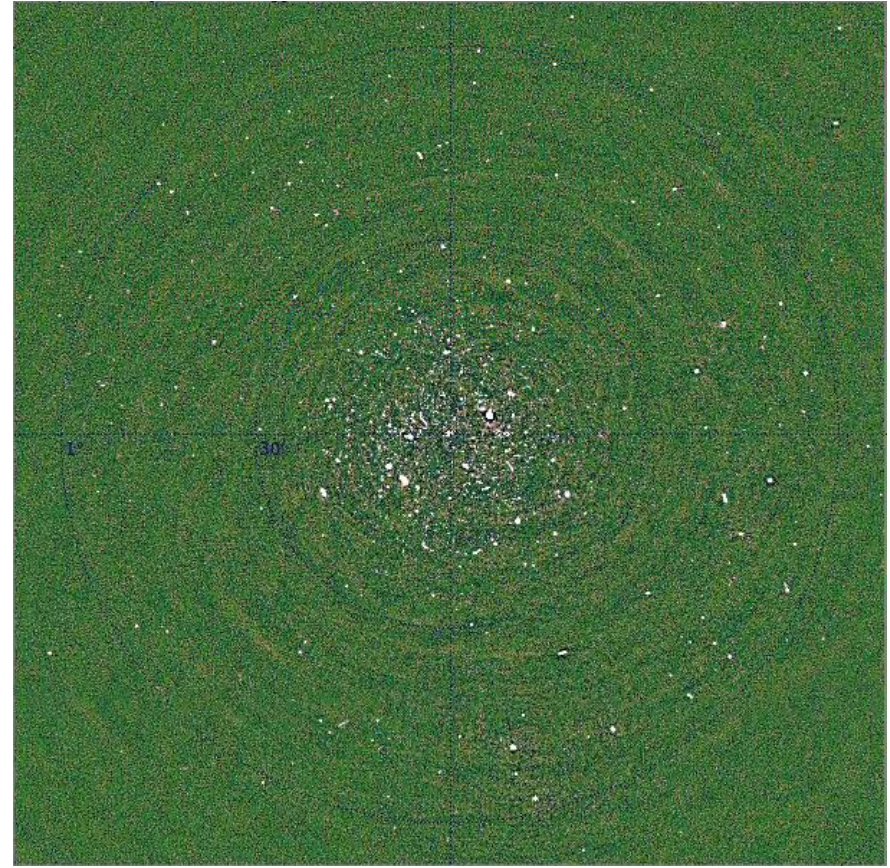
- Differential gain solutions are computed (in the direction of a few bright sources) and applied after regular calibration in order to correct for leftover, uncalibrated effects.

Incorporating differential gains in calibration

(Without primary beam incorporated in calibration)



Without differential gain solutions



With differential gain solutions applied

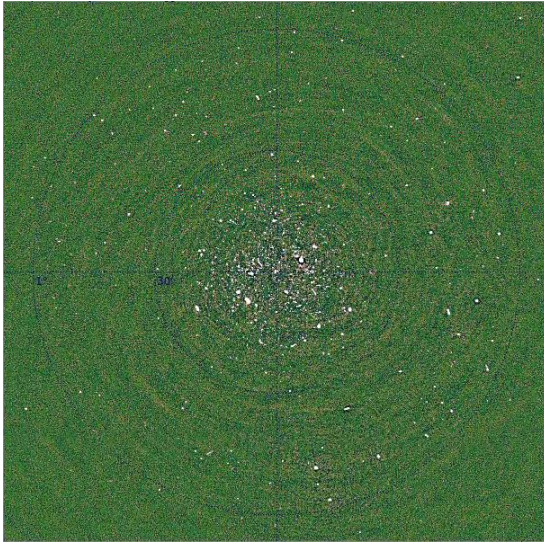
Differential gains

- As more corrupting effects are modeled and accounted for, the calibration becomes more comprehensive, and differential gain solutions approach unity.

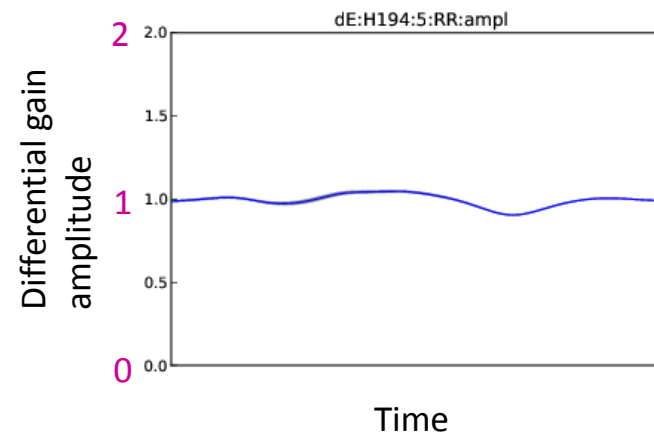
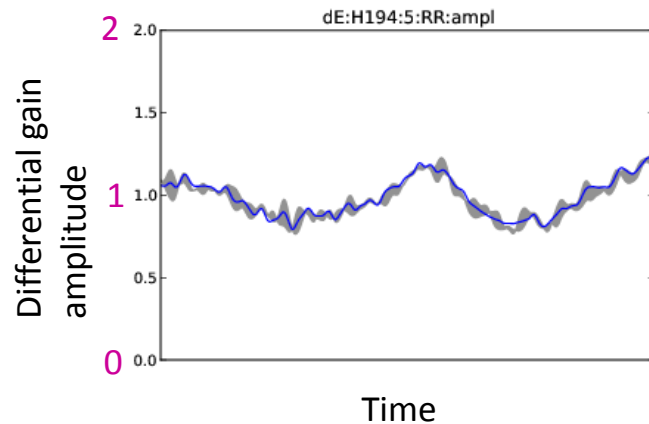
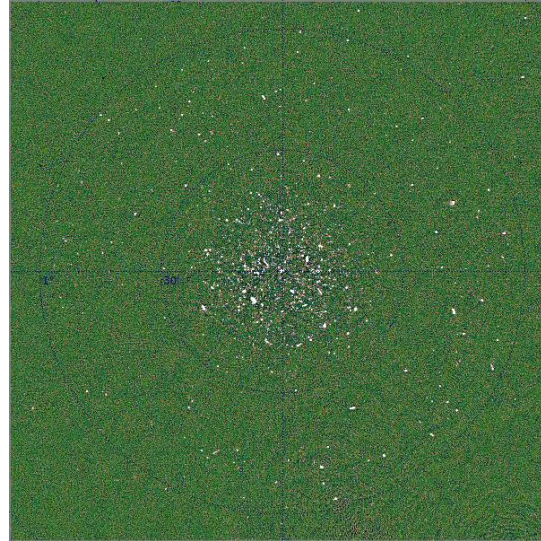
Incorporating primary beam in calibration

Differential gain plots

Without primary beam



With primary beam



- Flattened differential gain curves, ~ 1 over the whole range
- Residual variation due to remaining uncorrected direction-dependent effects (like antenna pointing errors)

References

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