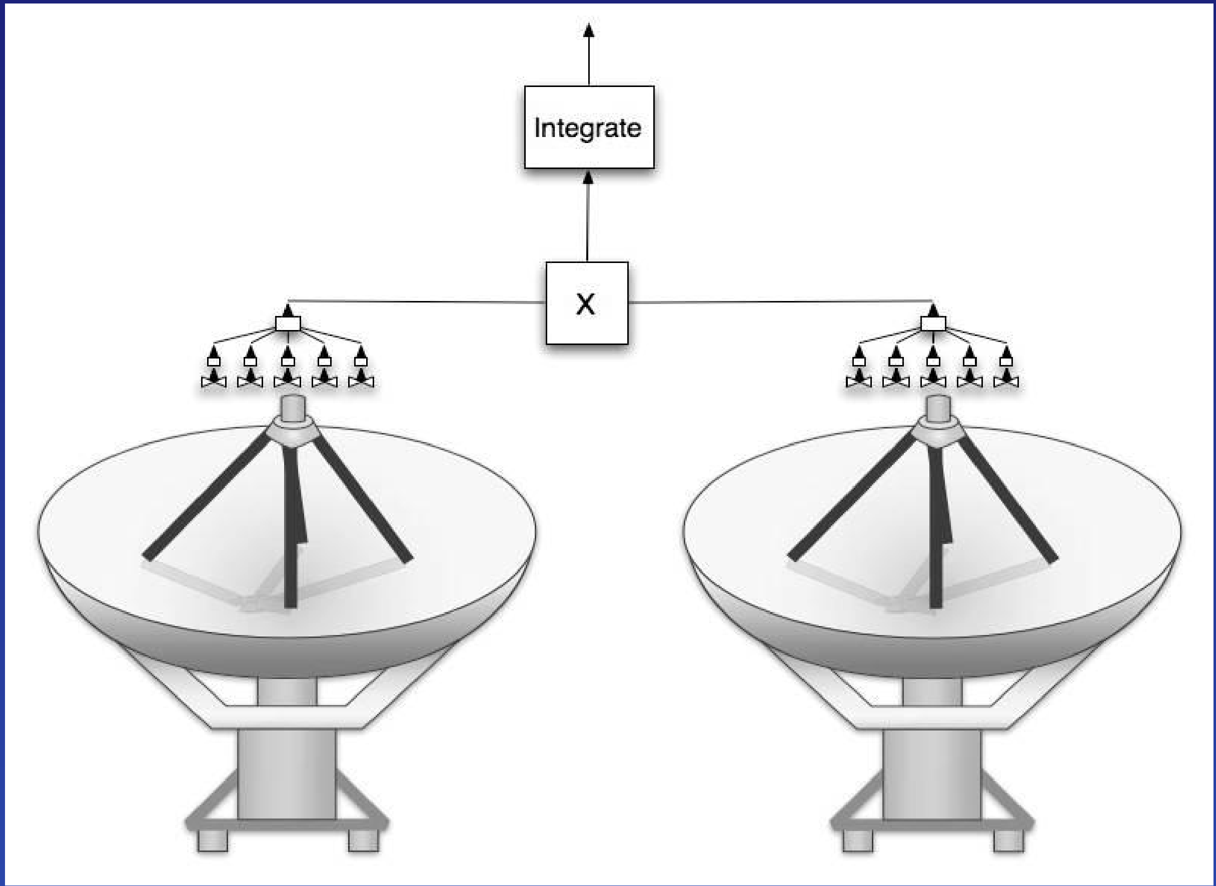
Calibration and simulation strategy for multi-feed interferometers

Maxim Voronkov, Tim Cornwell

Australia Telescope National Facility

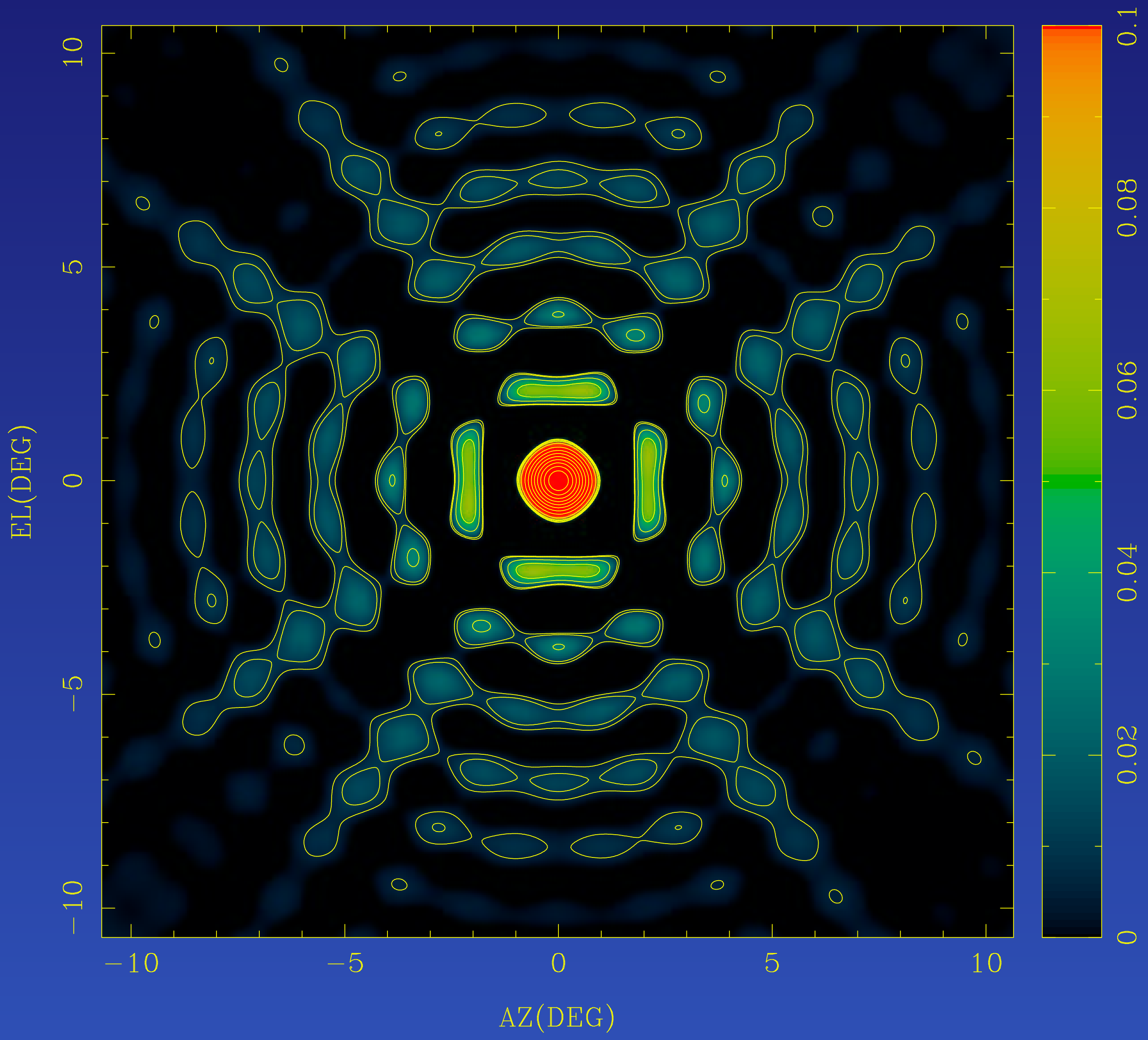
Cape Town, December 2006

Large FOV: multi-feed systems



- Wide FOV-specific effects
- Issues due to multi-feed design

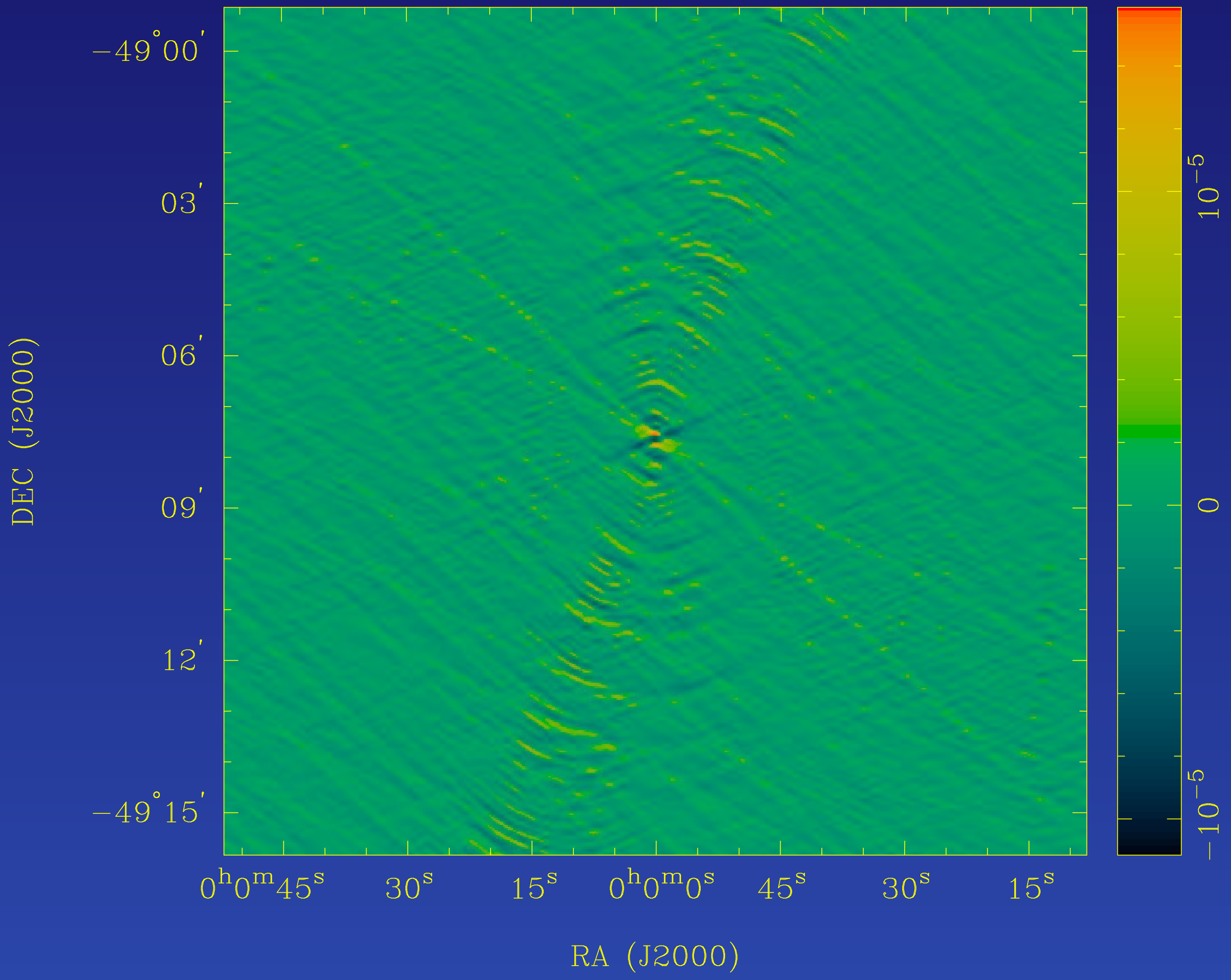
- Phased array feeds (xNTD)
- Feed clusters (KAT)



- Rotation of the primary beam causes artefacts

Possible solutions:

- Equatorial mount
- Field rotator
- Electronic rotation
- Correct in software
- Good uv-coverage can minimize the problem!



Pointing errors:

- Also cause amplitude variations
- Good uv-coverage can minimize the problem!
- ATCA simulations: the effect can be ignored unless we need a dynamic range higher than 5×10^4.

- Bhatnagar et al. (2004), EVLA Memo #84 $\Rightarrow$ solving for pointing errors and some simulations with idealized beams
- Multi-feed systems: solve on-line

Calibration issues due to multi-feed design

- Cross-talk between feeds
- Polarization leakages between feeds

- Gain calibration
  - Has to be done for each feed
  - Takes too much time if done by observing a calibrator separately for each feed
  - Full beam self calibration should help

Calibration issues due to multi-feed design

- Cross-talk between feeds
- Polarization leakages between feeds

- Gain calibration
- Bandpass calibration
  - Similar to gain calibration, but requires N_{ch} times longer integration or a $\sqrt{N_{ch}}$ stronger source
  - Bandpass shape is typically stable. It needs a further study for multi-feed interferometers. Need stability on the time-scale of days.
  - Fractional bandwidth $\Rightarrow$ need to know spectral indices

Calibration issues due to multi-feed design

- Cross-talk between feeds
- Polarization leakages between feeds

- Gain calibration
- Bandpass calibration
- Beamformer $\Rightarrow$ measure a number of linear combinations
  - Several sets of weights are required to get all gains
  - Frequency dependence?
  - Flexibility: many weighting schemes are possible
  - Full-beam self-calibration: one can think about maximization of the total flux in the field

Flux maximization

Voltage pattern of the k-th element

$$E(\theta, \varphi) = \sum_k w_k E_k(\theta, \varphi)$$

Synthetic voltage pattern; complex weights

Flux maximization

$$E(\theta,\varphi) = \sum_k w_k E_k(\theta,\varphi)$$

$$P(\theta,\varphi) = E(\theta,\varphi)E^*(\theta,\varphi) = \sum_{k,l} w_k^* E_k^* w_l E_l = \vec{w}^H \mathcal{E}(\theta,\varphi)\vec{w}$$

- $\mathcal{E}(\theta,\varphi) = \| E_k^*(\theta,\varphi) E_l(\theta,\varphi) \|_l^k$ for direction (θ,φ)
- Power beam is a quadratic form

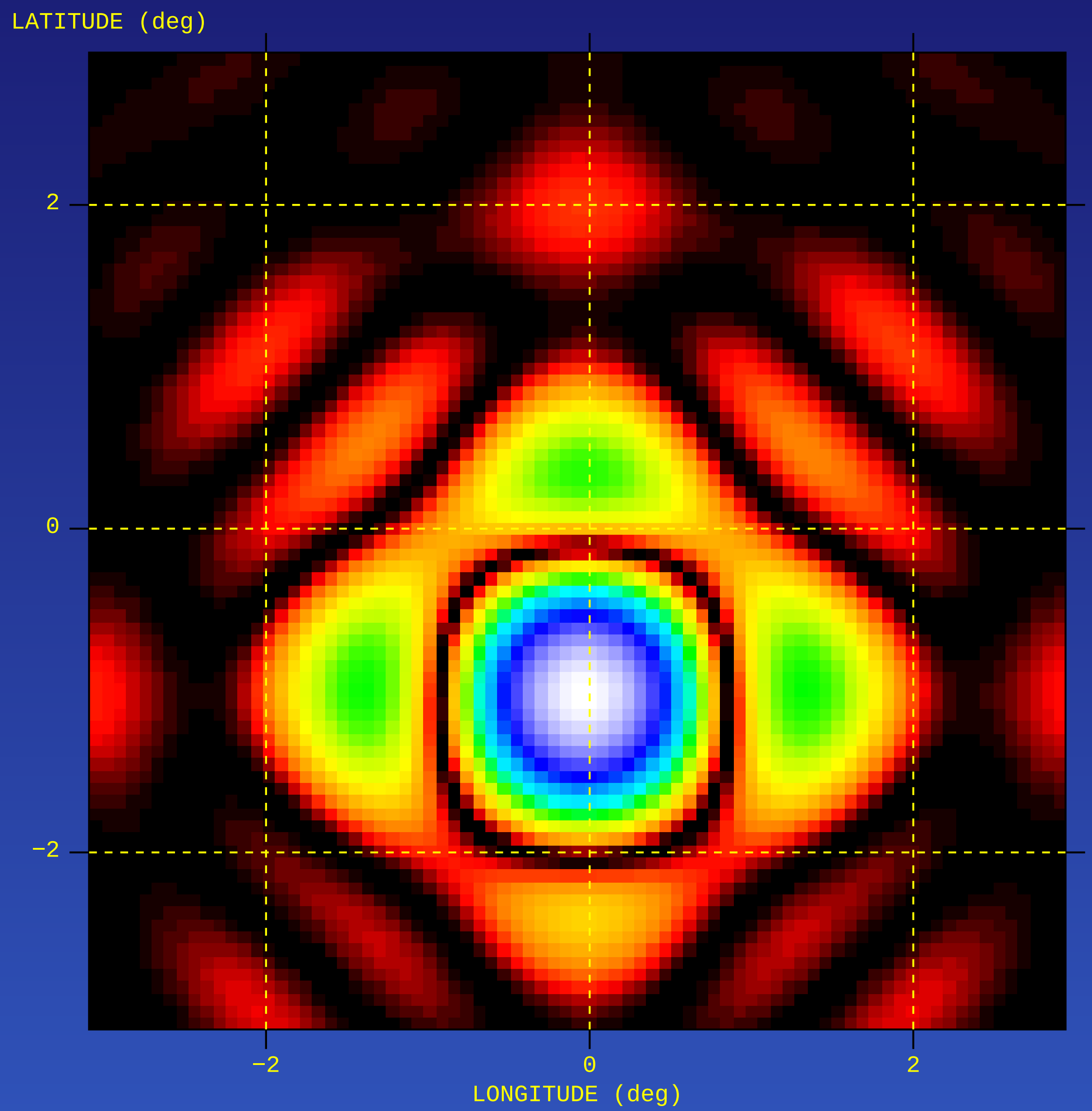
Flux maximization

$$E(\theta,\varphi) = \sum_k w_k E_k(\theta,\varphi)$$

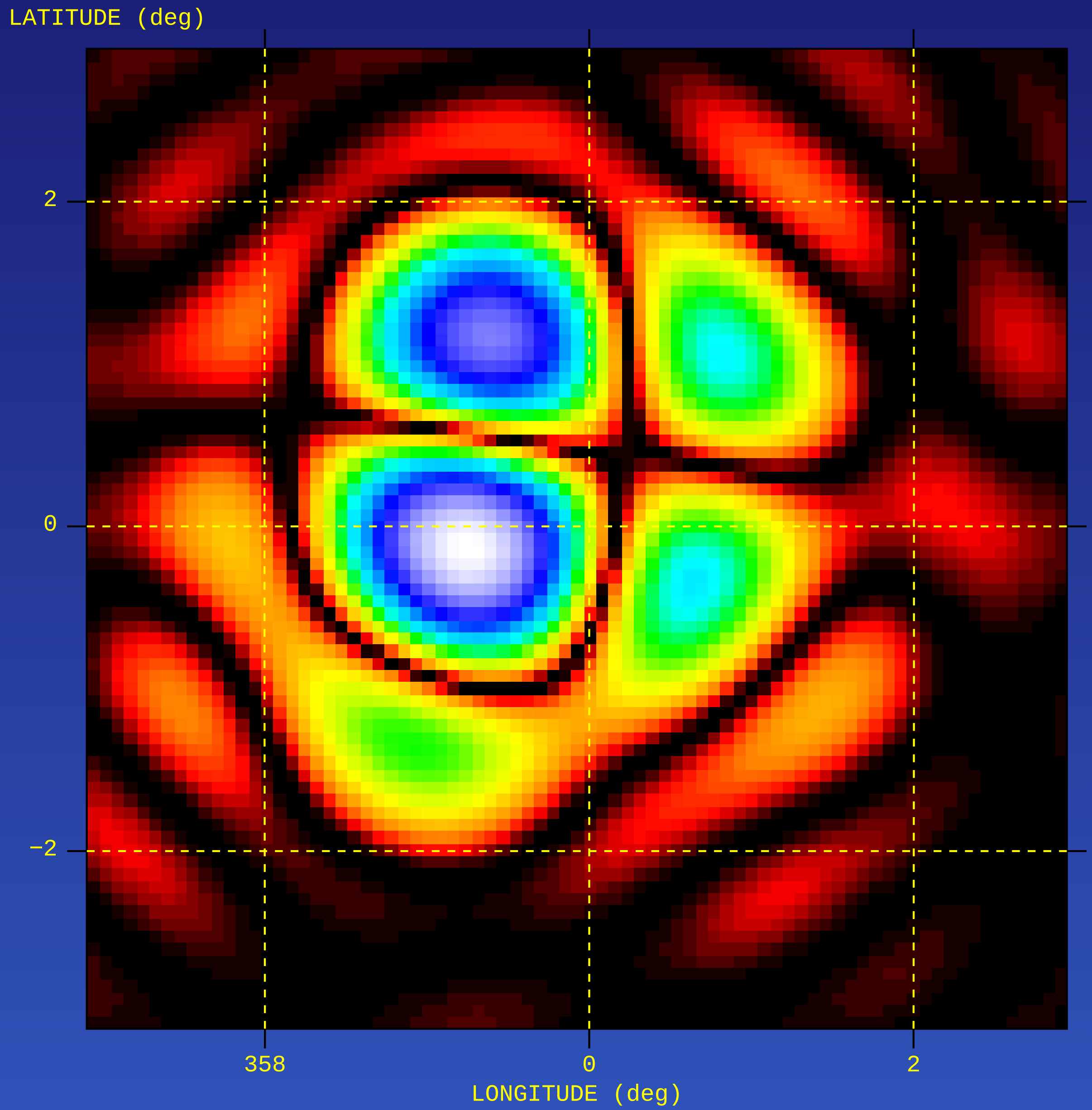
$$P(\theta,\varphi) = E(\theta,\varphi)E^*(\theta,\varphi) = \sum_{k,l} w_k^* E_k^* w_l E_l = \vec{w}^H \mathcal{E}(\theta,\varphi)\vec{w}$$

$$F = \int_\Omega P(\theta,\varphi) I(\theta,\varphi)\ d\Omega = \vec{w}^H \left(\sum_{i=1}^{N_{src}} F_i \mathcal{E}(\theta_i,\varphi_i) \right) \vec{w}$$

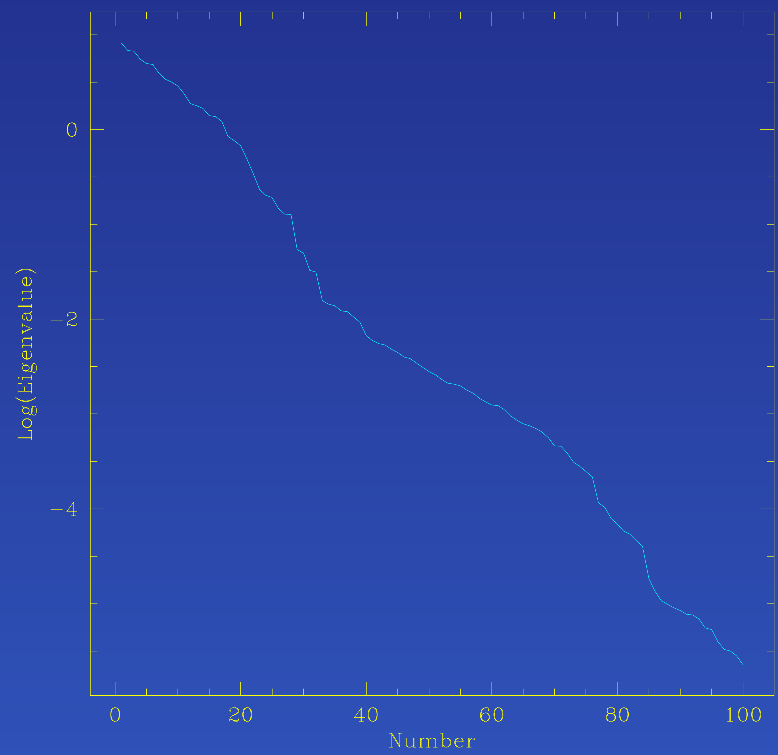
- Total flux in the field;
- sky model: point sources

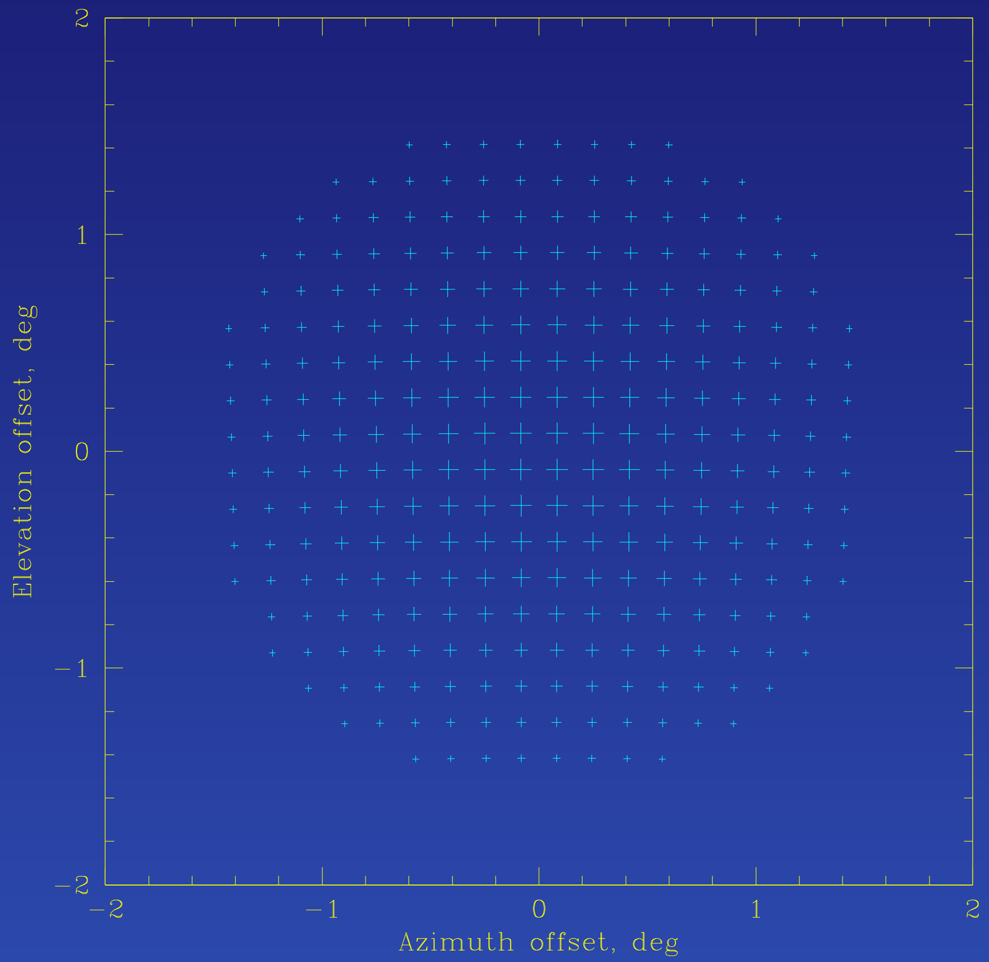


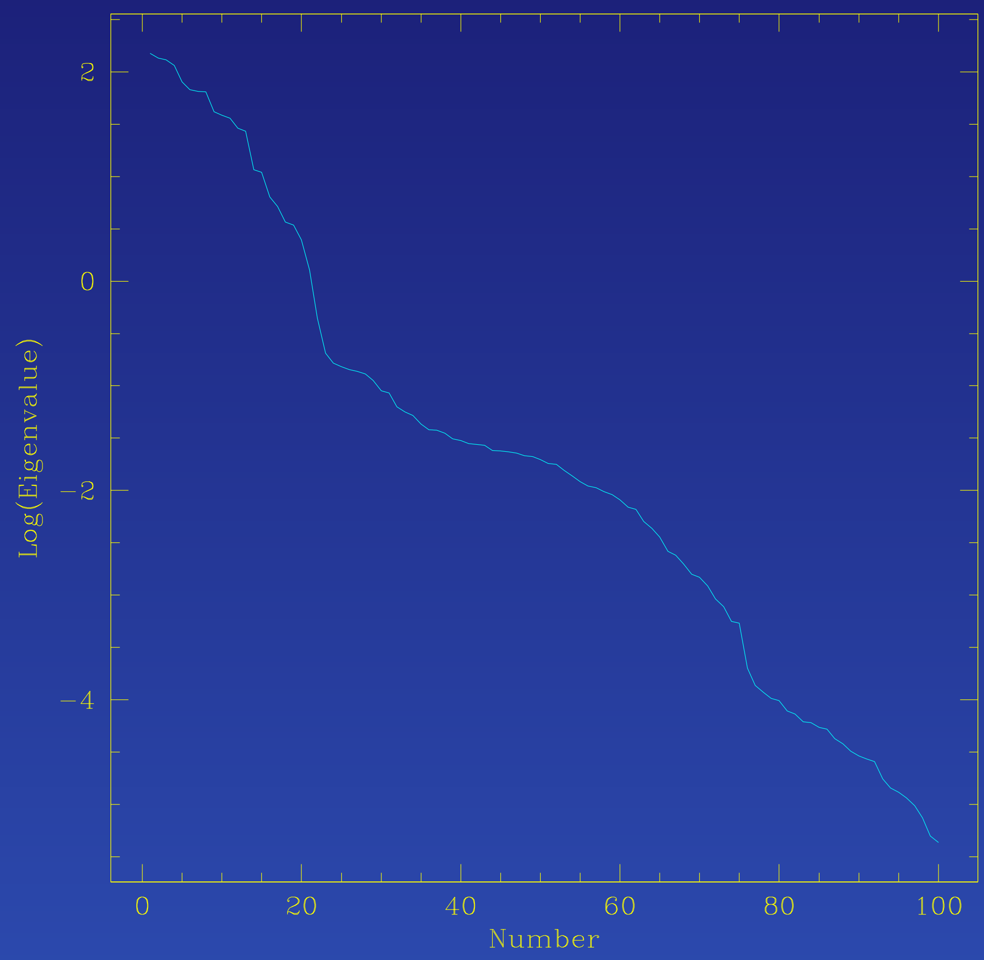
- 10×10 phased array feed, 20’ separation
- Single point source offset 1^o to the south from the dish pointing centre



- 10×10 phased array feed, 20’ separation
- NVSS field (reflected w.r.t. the $\delta = 0^o$ plane)

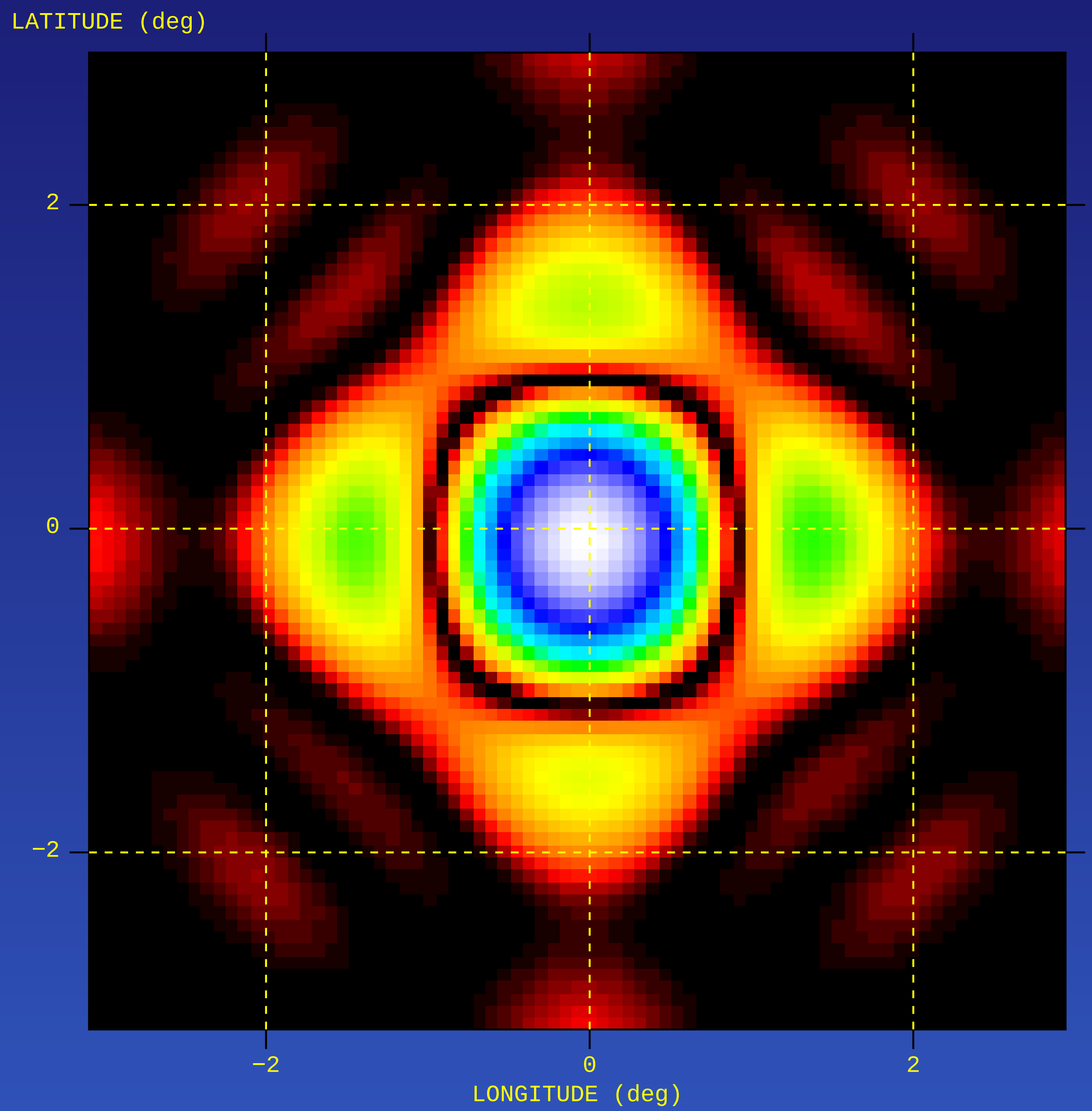




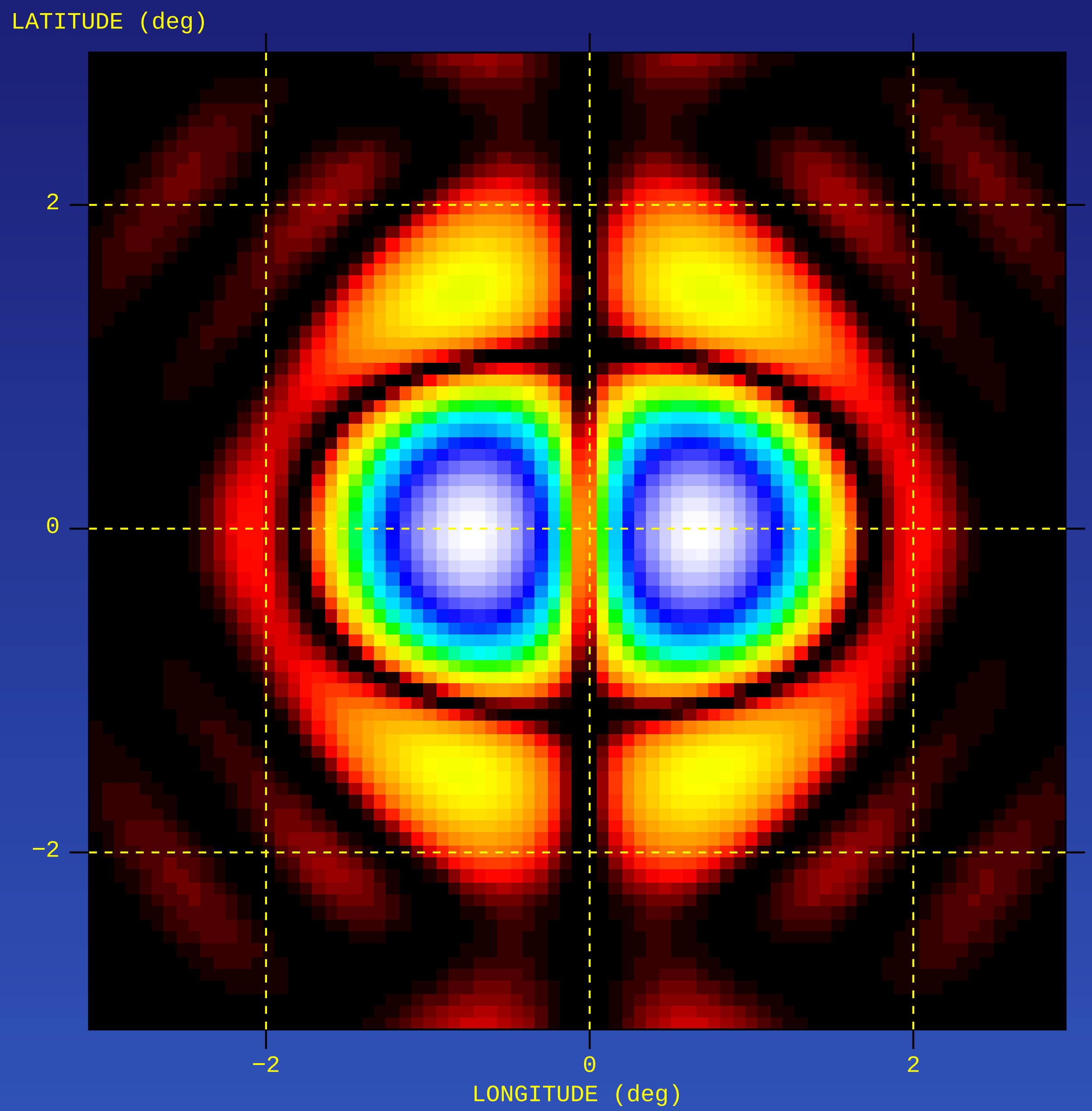


- Fake sky: grid of sources with tapered flux
- Maximize the integral flux

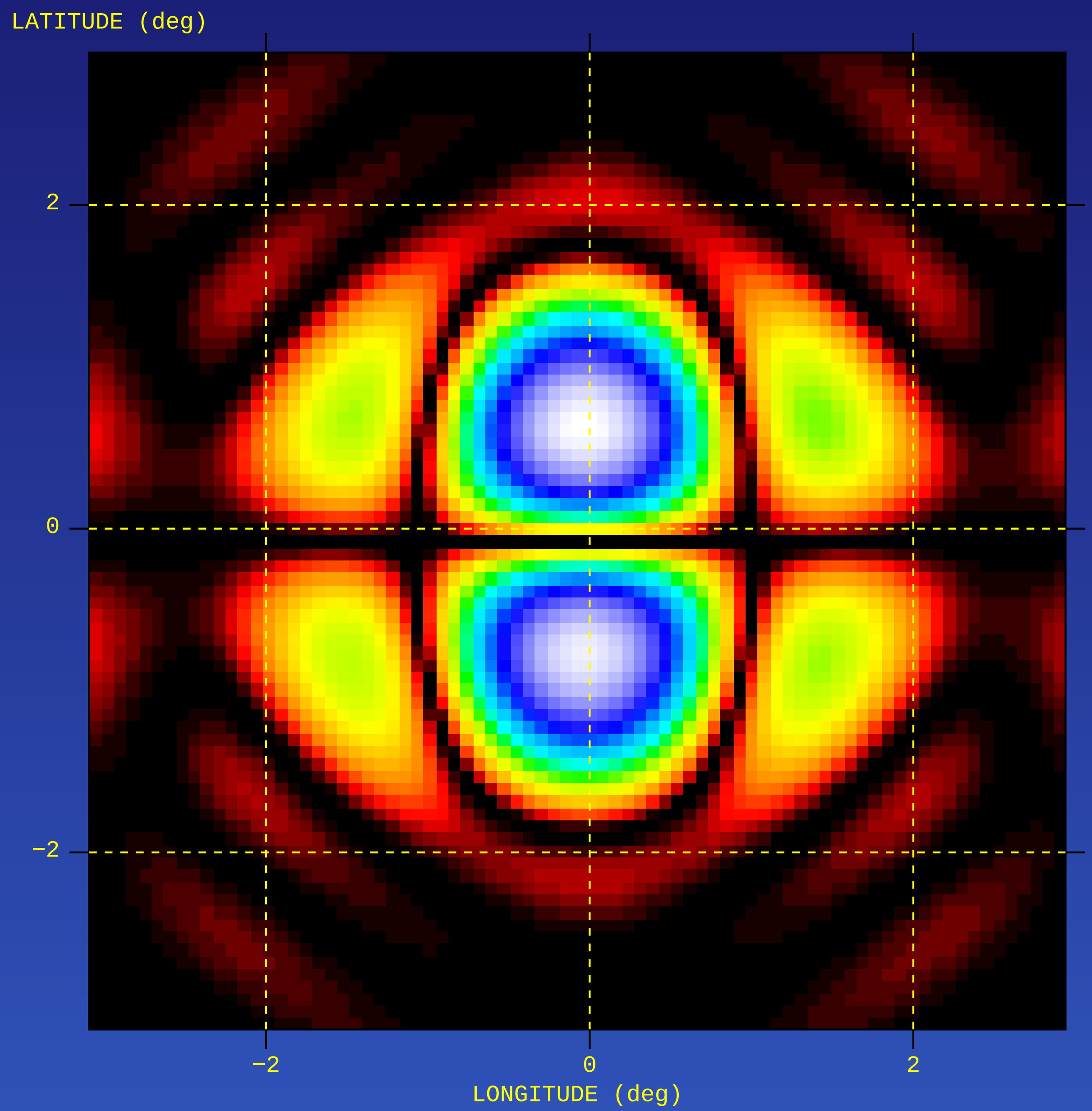
- Eigenspectrum: 20 eigen-beams should still be enough



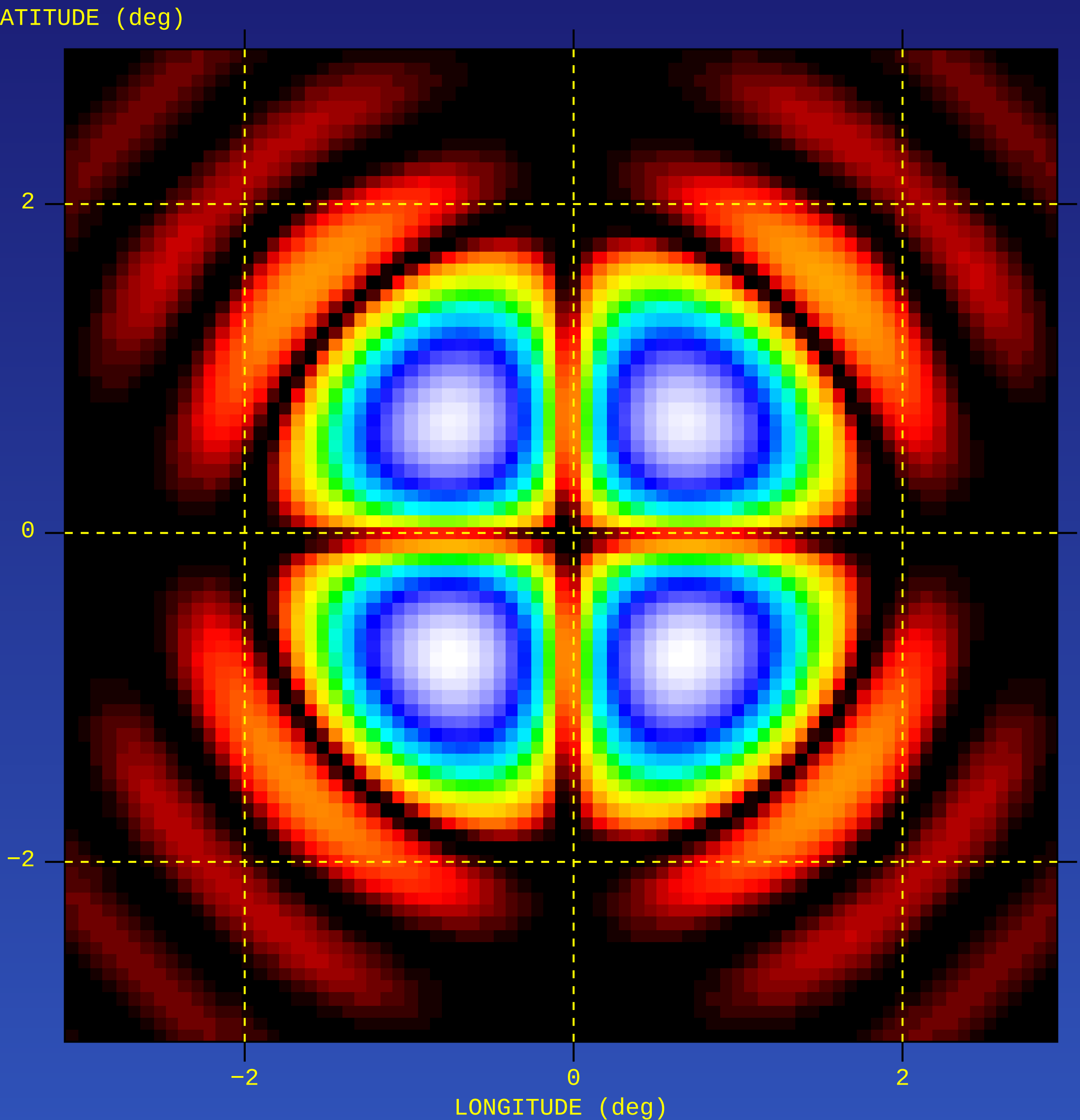
- 1st eigenbeam
- 10×10 phased array feed, 20’ separation
- A number of sources arranged in a regular 20x20 grid with 10’ separation
- Source fluxes are tapered with a 60’ Gaussian.



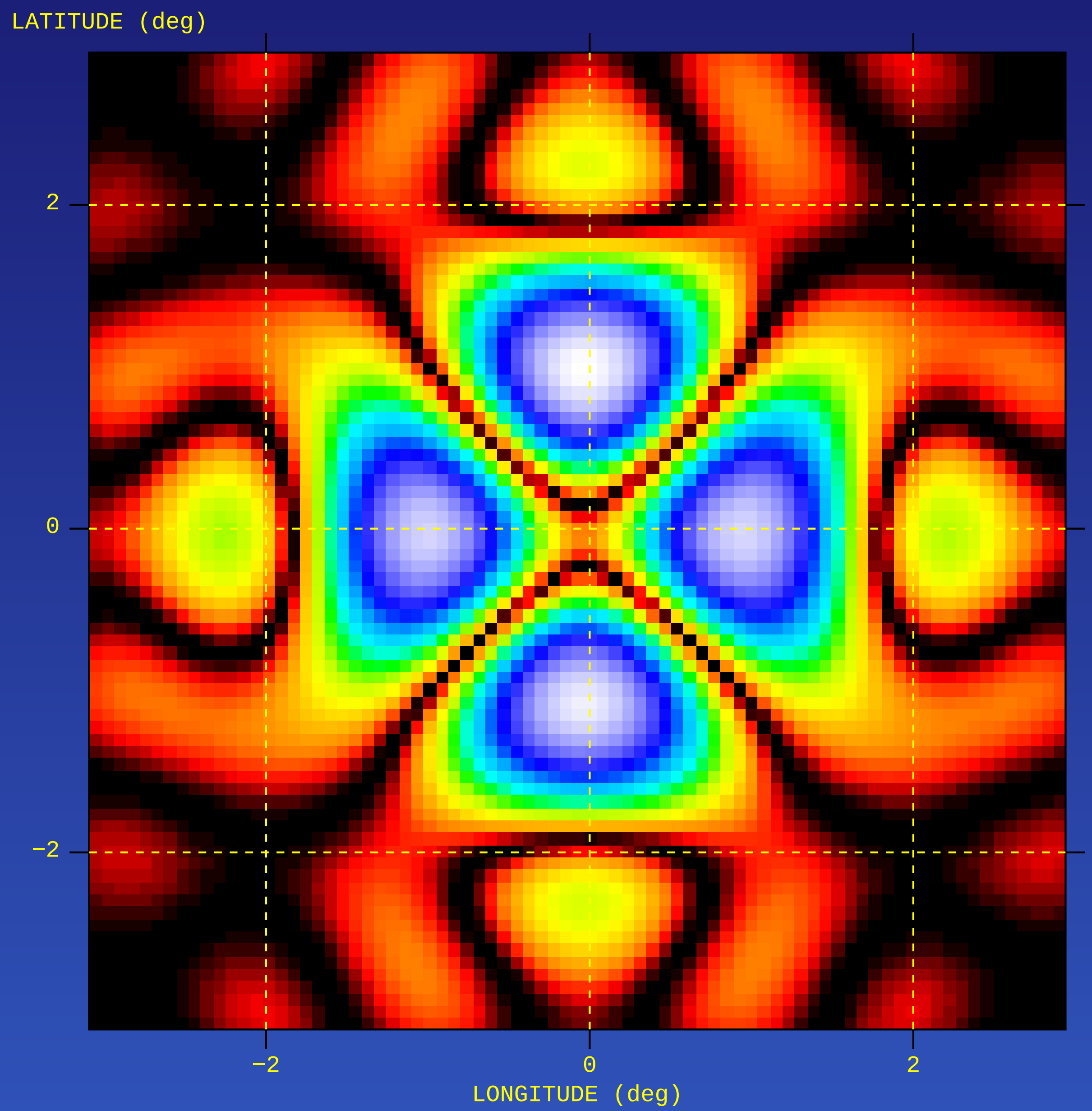
- 2nd eigenbeam
- 10×10 phased array feed, 20’ separation
- A number of sources arranged in a regular 20x20 grid with 10’ separation
- Source fluxes are tapered with a 60’ Gaussian.



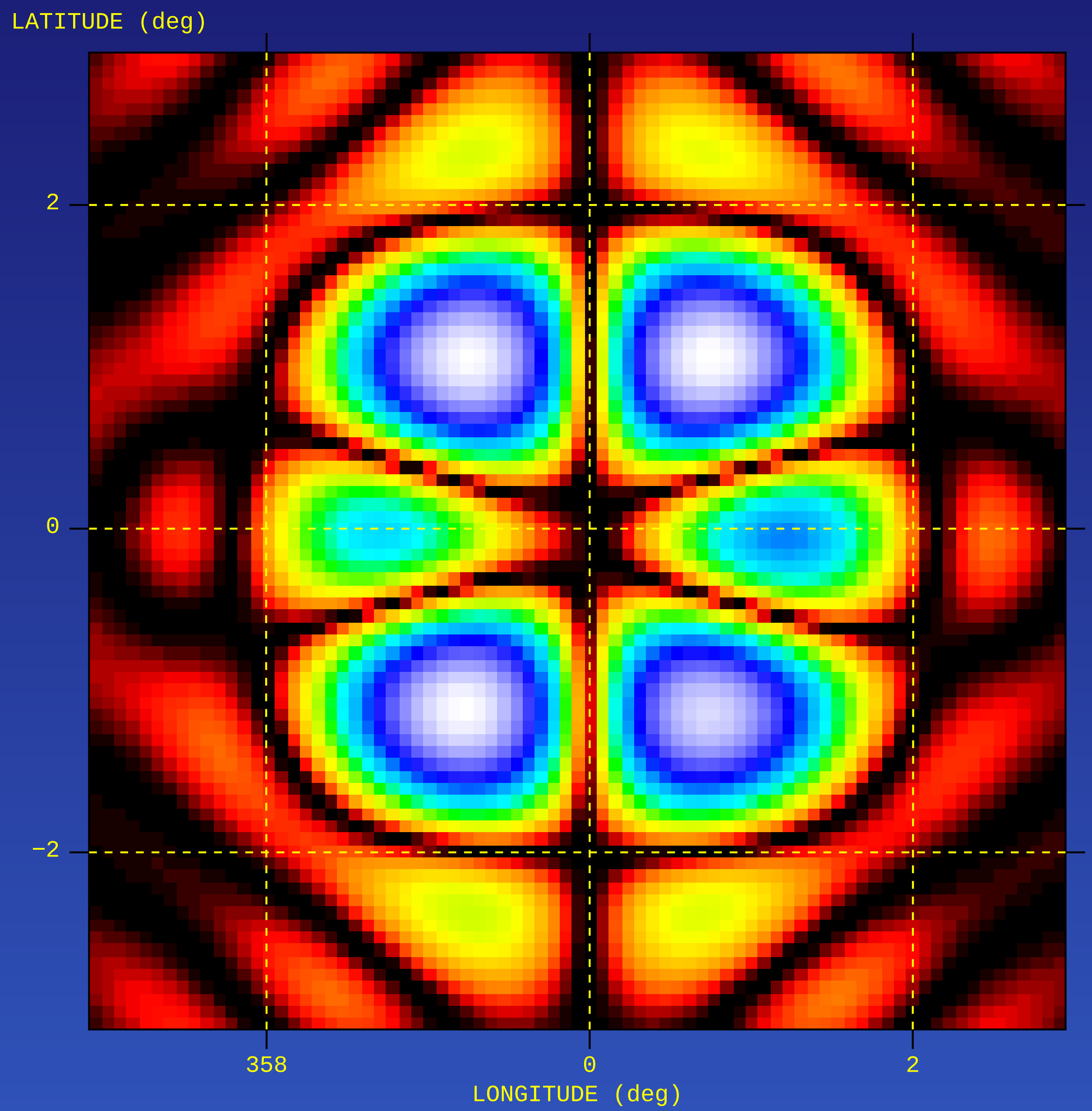
- 3rd eigenbeam
- 10×10 phased array feed, 20’ separation
- A number of sources arranged in a regular 20x20 grid with 10’ separation
- Source fluxes are tapered with a 60’ Gaussian.



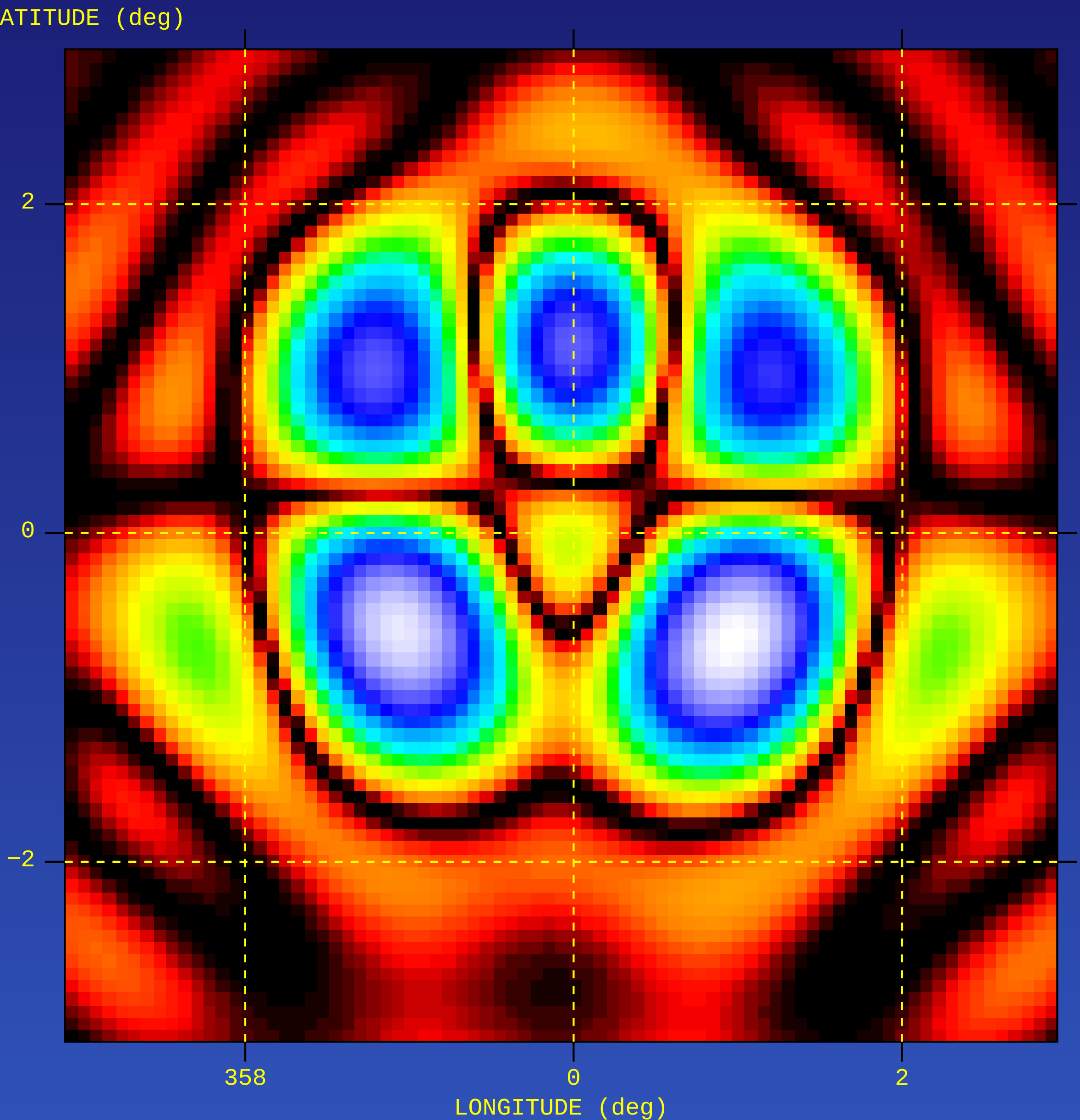
- 4th eigenbeam
- 10×10 phased array feed, 20’ separation
- A number of sources arranged in a regular 20x20 grid with 10’ separation
- Source fluxes are tapered with a 60’ Gaussian.



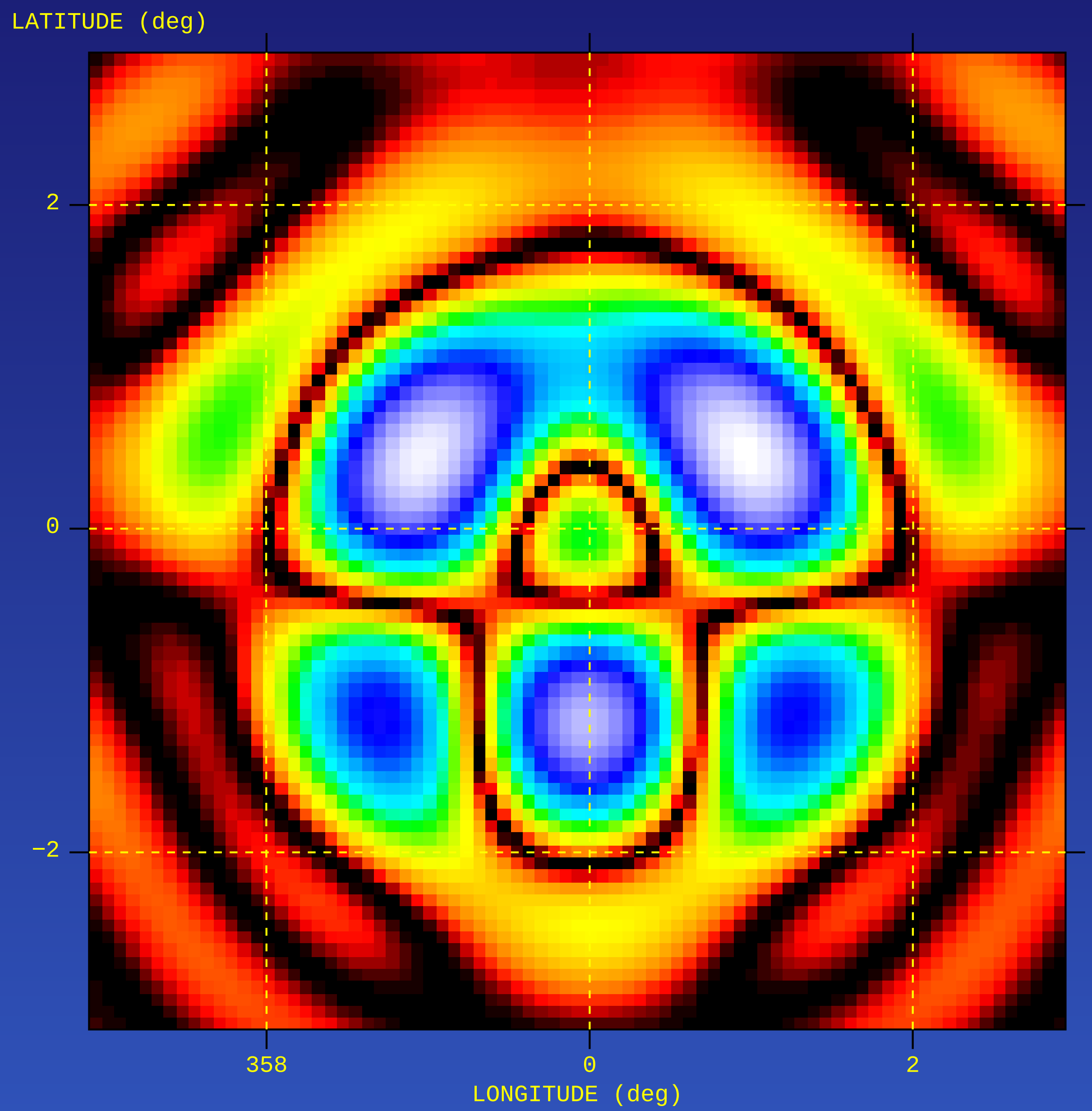
- 5th eigenbeam
- 10×10 phased array feed, 20’ separation
- A number of sources arranged in a regular 20x20 grid with 10’ separation
- Source fluxes are tapered with a 60’ Gaussian.



- 6th eigenbeam
- 10×10 phased array feed, 20’ separation
- A number of sources arranged in a regular 20x20 grid with 10’ separation
- Source fluxes are tapered with a 60’ Gaussian.



- 7th eigenbeam
- 10×10 phased array feed, 20’ separation
- A number of sources arranged in a regular 20x20 grid with 10’ separation
- Source fluxes are tapered with a 60’ Gaussian.



- 8th eigenbeam
- 10×10 phased array feed, 20’ separation
- A number of sources arranged in a regular 20x20 grid with 10’ separation
- Source fluxes are tapered with a 60’ Gaussian.

Summary

- 20 eigenbeams represent the beam up to 0.1% accuracy
- around 6 eigenbeams fill the aperture without holes
- Mosaicing code has to support inhomogeneous beams
- Self-calibration can determine a small number of gains only

What can be simulated?

- Given a uv-coverage and the dynamic range requirements, the simulations can give an upper limit for the pointing errors
- Simulations can be used to compare the imaging performance in the following cases: the equatorial mount, the azimuthal mount with the field rotator, and without it.
- Feasibility of the full-beam self-calibration of the feed-dependent gains and bandpasses. Implications of the large fractional bandwidth.