Calibration of Phased Array Feeds

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(presented by John O'Sullivan)

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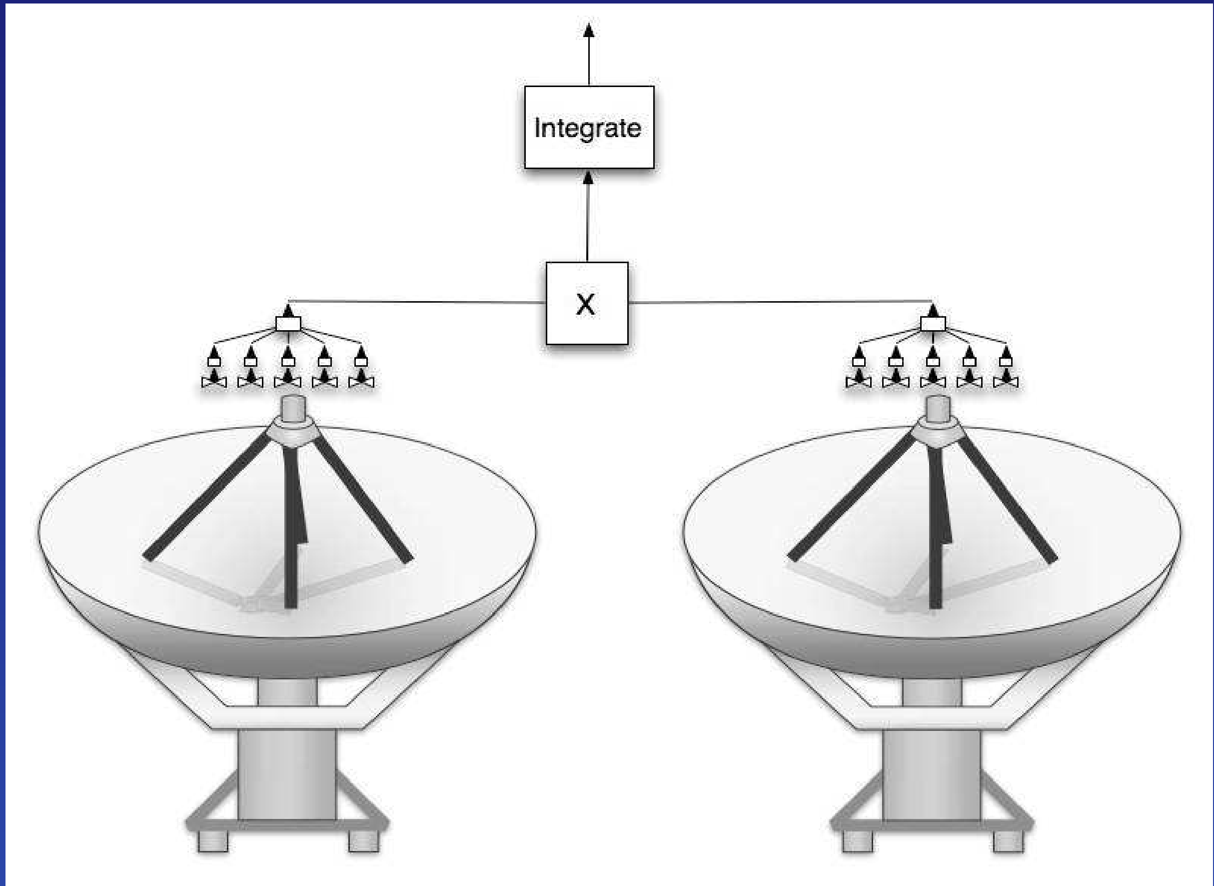
Multi-feed systems provide a way to achieve a large FOV



- ASKAP explores Phased Array Feed option:
  - Receiver outputs are not correlated directly
  - Linear combinations (beams) are formed first

Calibration issues

- Cross-talk between feeds
- Polarization leakages between feeds

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

Calibration issues

- 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 assumed to be stable (further study required for interferometers with PAF). Need stability on the time-scale of days.
    - Wide band $\Rightarrow$ need to know spectral indices

Calibration issues

- 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)
- This matrix has a maximum rank of 1 (composed from the same vector)
- Power beam is a quadratic form

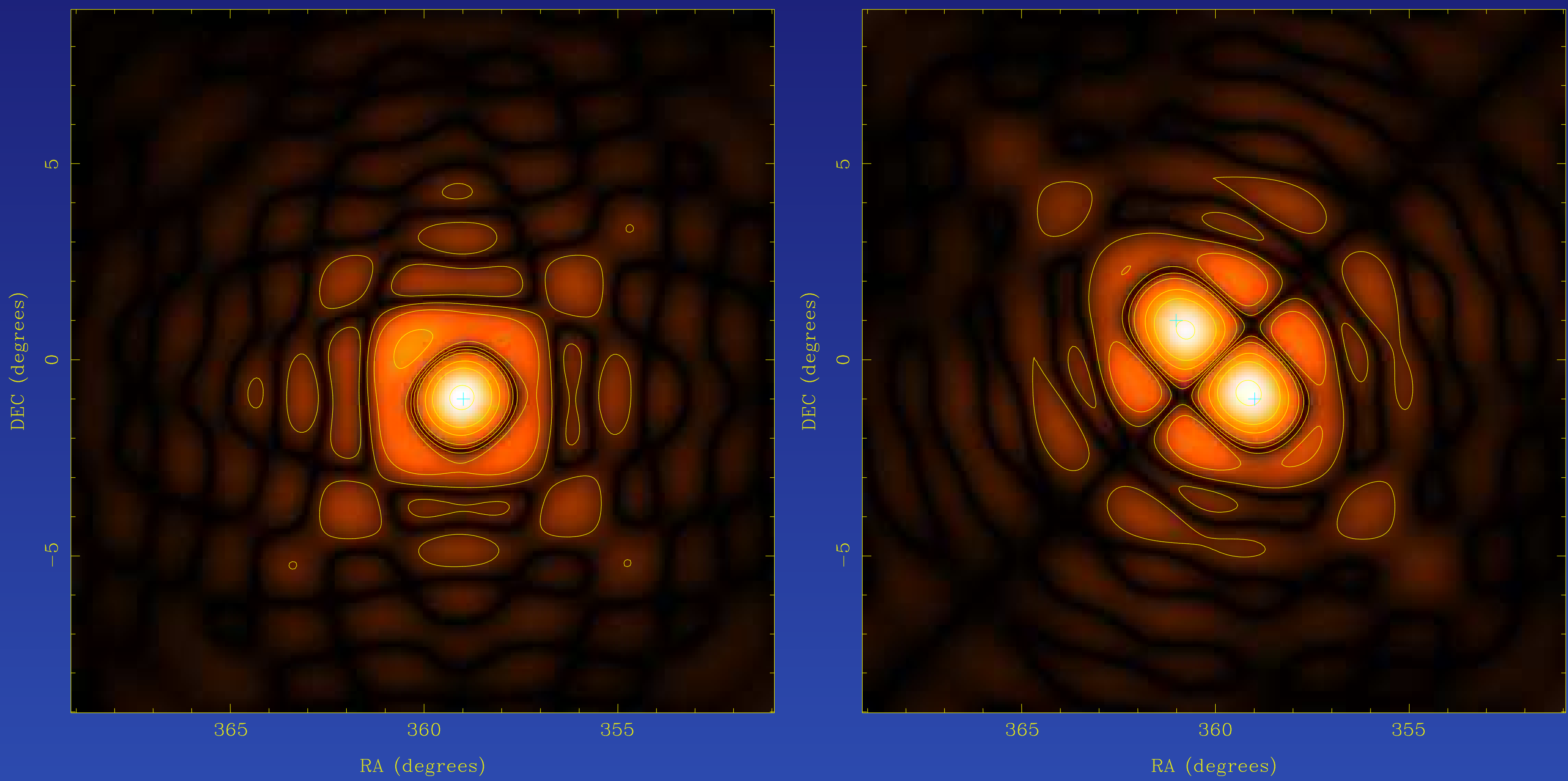
Flux maximization

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

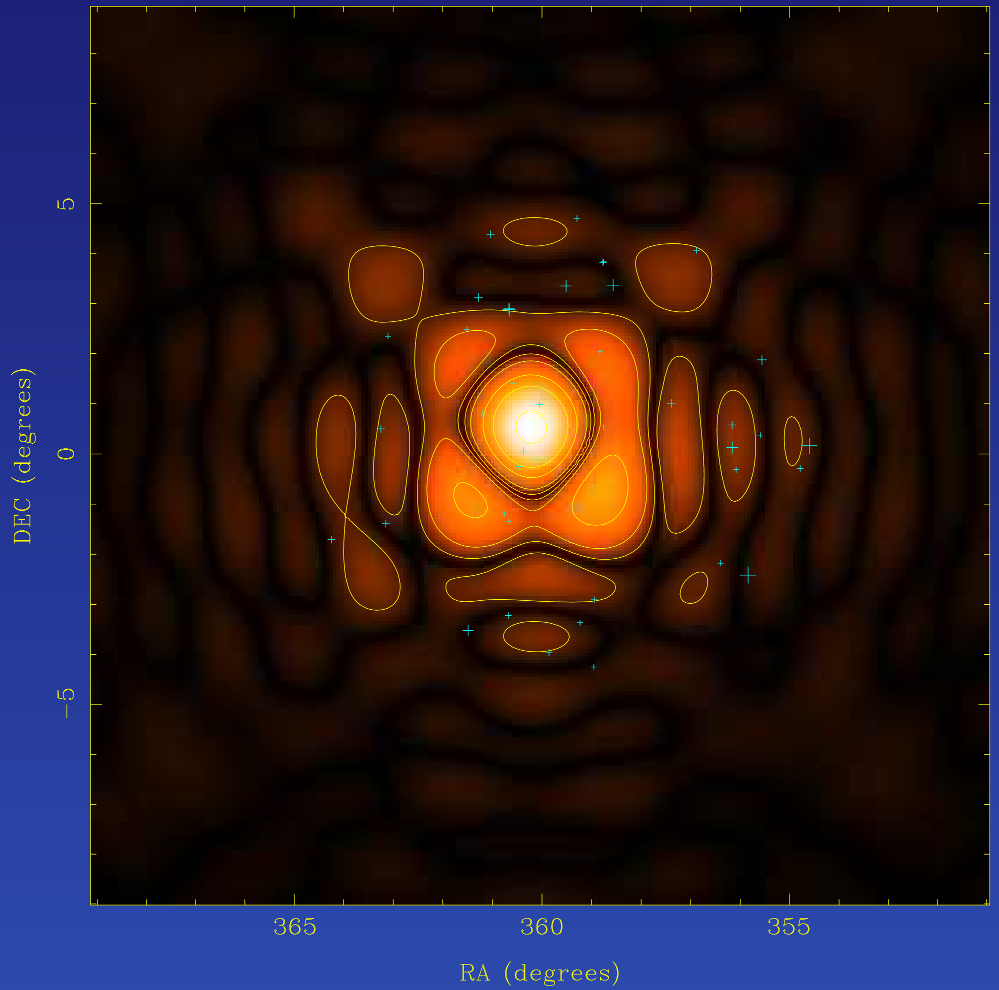
$$P(\theta,\varphi) = E(\theta,\varphi)E^*(\theta,\varphi) = \sum_{k,l} w_k^* E_k^* w_l E_l = \vec{w}^H \mathcal{E}(\theta,\varphi)\vec{w}$$

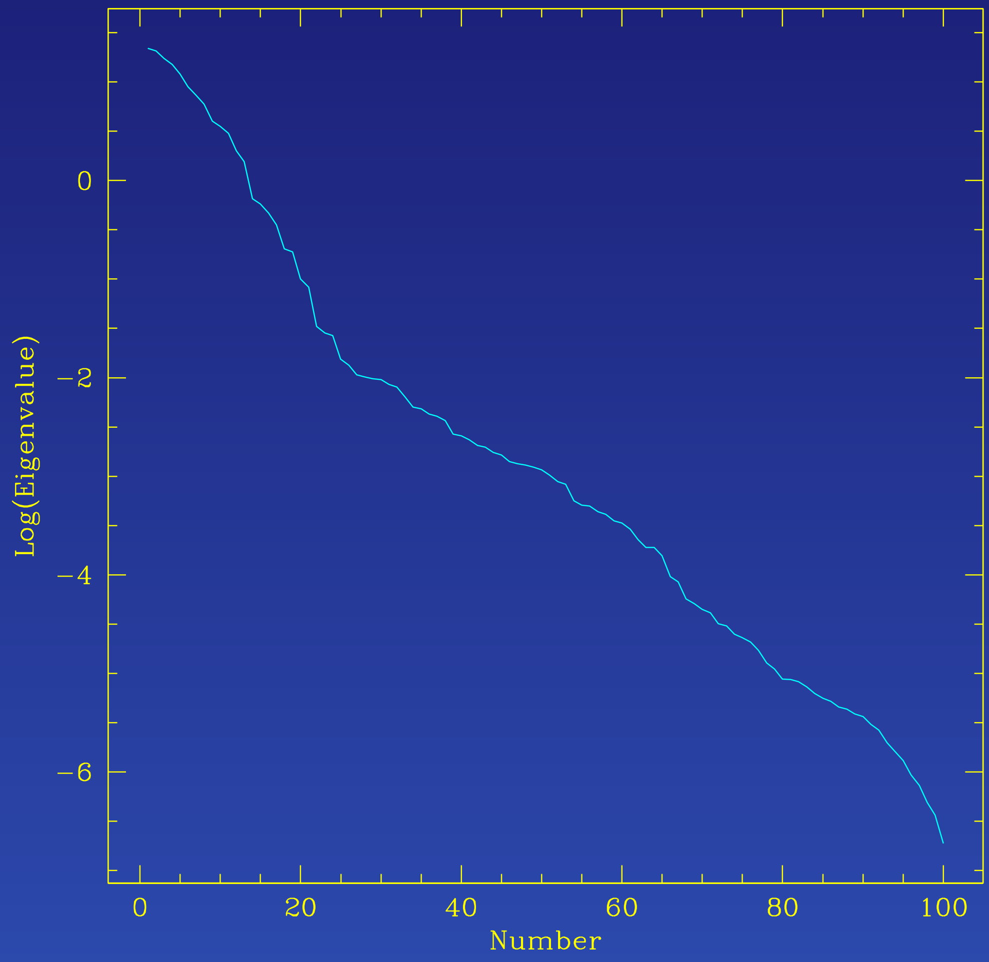
$$F = \int_\Omega P(\theta,\varphi) I(\theta,\varphi)\, d\Omega = \vec{w}^H \left(\sum_{i=1}^{N_{src}} F_i \mathcal{E}(\theta_i,\varphi_i) \right) \vec{w}$$

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



- 10×10 phased array feed, 20’ separation
- Single offset point source (left) and double source (right)





- 10×10 phased array feed, 20’ separation
- Representative NVSS field

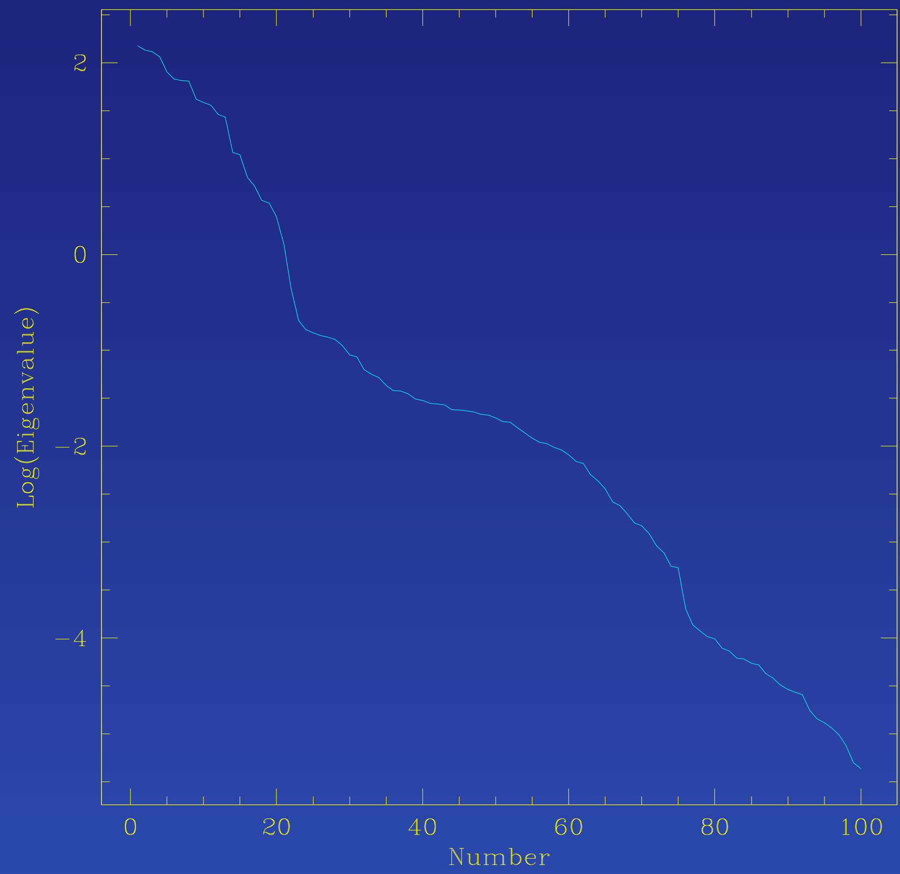
Imaging with eigenbeams?

- Linear mosaicing

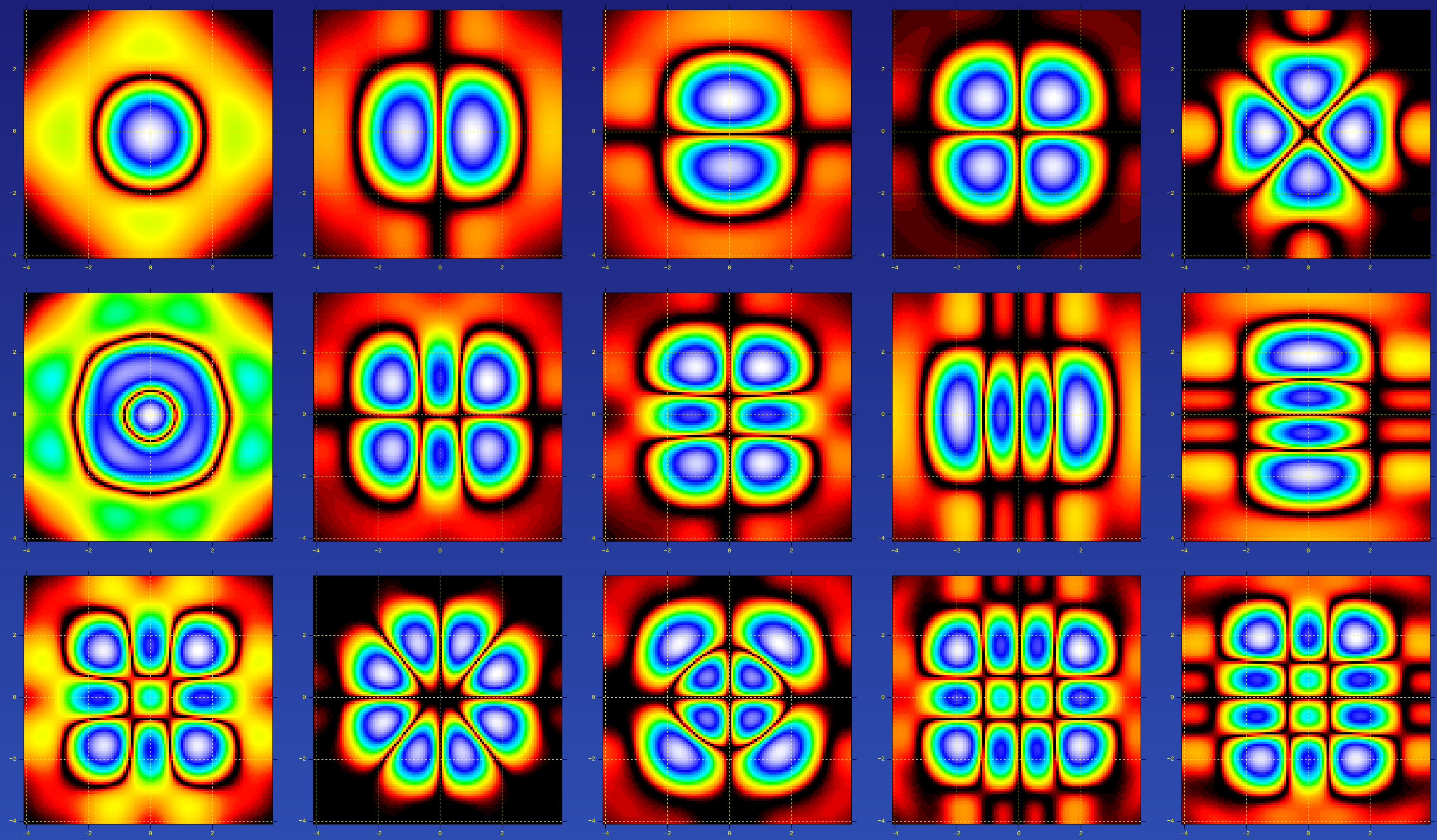
$$\begin{cases} \tilde{I}_1(\vec{s}) & = & I(\vec{s})A_1(\vec{s}) \\ & \dots & \\ \tilde{I}_N(\vec{s}) & = & I(\vec{s})A_N(\vec{s}) \end{cases}$$

$$I(\vec{s}) = \frac{\sum_{k=1}^{N} \tilde{I}_k(\vec{s})A_k(\vec{s})}{\sum_{k=1}^{N} A_k(\vec{s})^2}$$

- Eigenproblem ensures $\sum_{k=1}^{N} A_k(\vec{s})^2$ is non-zero
- Fake uniform sky model
- Linear mosaicing can be used with any shape of the primary beam



- Eigenspectrum: 20 eigenbeams are enough for imaging



Example of the first 15 eigenbeams

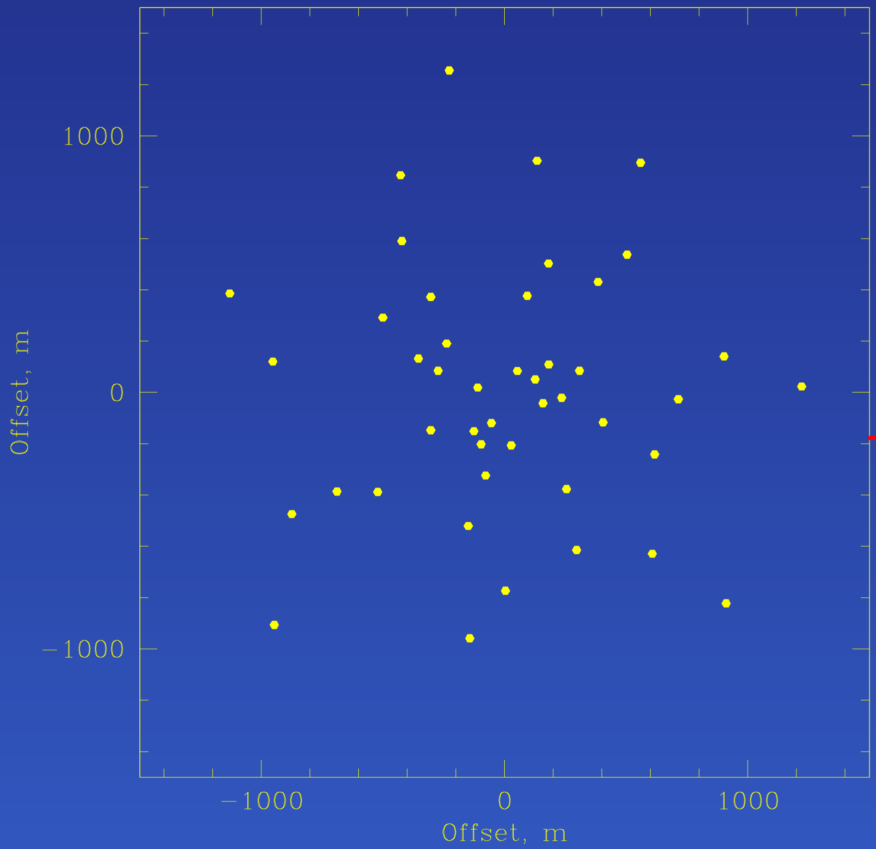
Gain calibration simulations - Description

Phase: uniform from 0 to 2π

Amplitude: uniform from 0.7 to 1.3

Gaussian noise with zero mean

Sky model generated from NVSS



Random gains

Simulate MS with noise

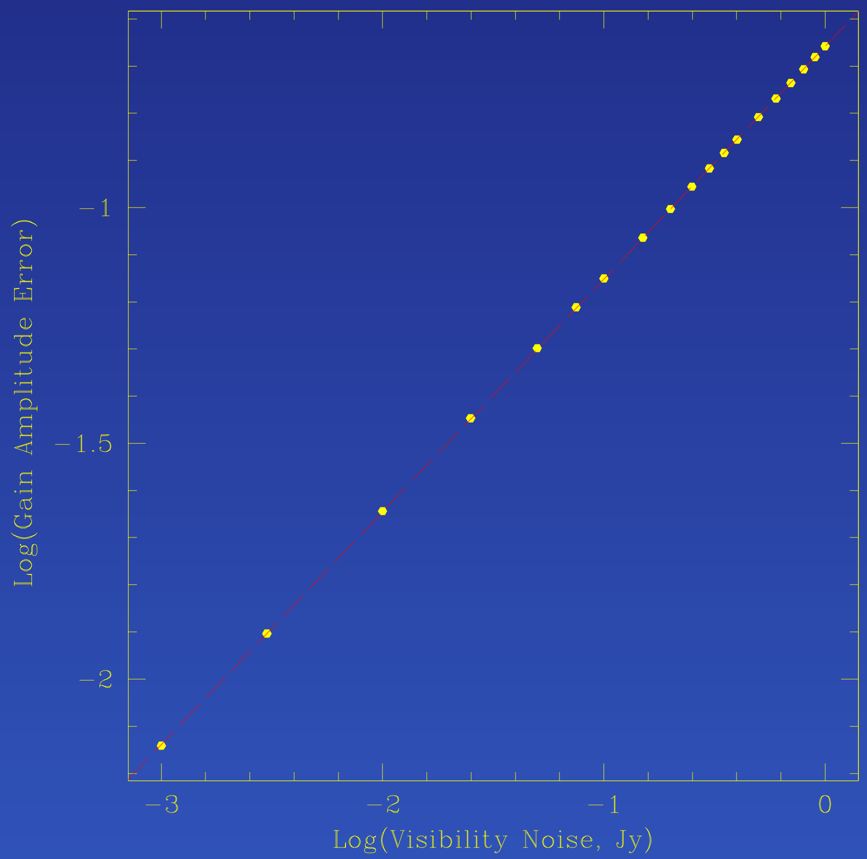
Solve for gains

Assess the difference

Gain calibration simulations - Results

Gain amplitude uncertainty $\approx 20\% \sqrt{\text{Visibility noise, Jy}}$

This noise is for one polarisation, full bandwidth, 10 second sample. Same noise is assumed for both real and imaginary part,



12m dishes with 0.7 efficiency, T_{sys}=30 K, 256 MHz bandwidth

↓

Visibility noise $\approx$ 20mJy

↓

Gain amplitude uncertainty after 5 min of observations $\approx$ 3%

Summary

- Eigenbeams can be used for calibration as well as for imaging
- 20 eigenbeams represent the beam up to 0.1% accuracy
- Self-calibration can determine only a small number of gains using just astronomical sources
- Need a way to track relative gains for every element.
- Assuming 12m dish, efficiency of 0.7, system temperature of 30 K and 256 MHz bandwidth, 5 minutes of integration on a random field constrains gain amplitudes to within 3%.

More info in ATNF SKA Memo 12
http://www.atnf.csiro.au/projects/askap/Memoseries.html