Advanced Beamforming on ASKAP

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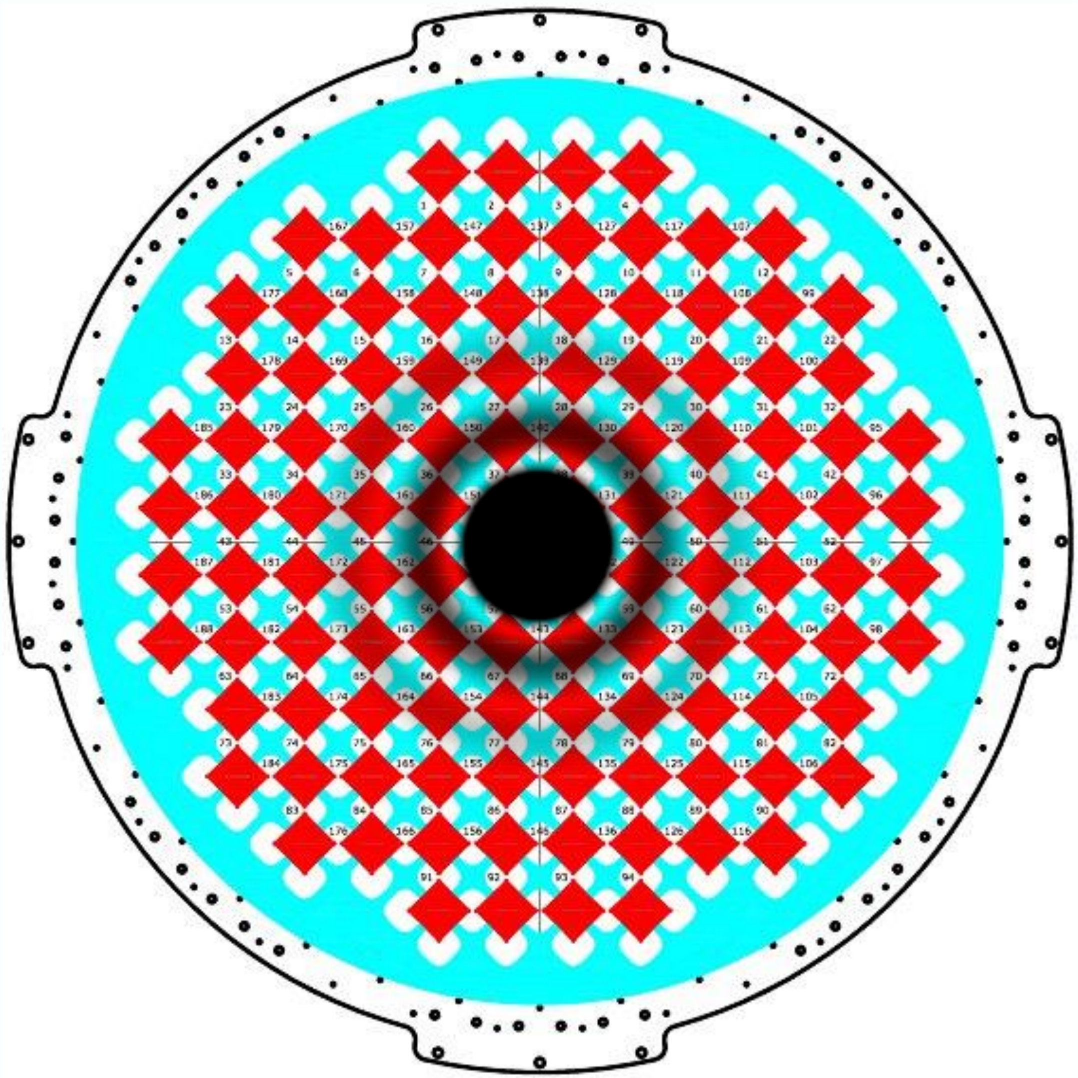
Beamforming from the PAF's perspective



Maximum sensitivity beamforming

In general, the output of a beam-former can be expressed as:

$$y_k[i] = \mathbf{w}_k^T \mathbf{x}[i]$$

Beam k output at time i

Weight vector for beam k

PAF element outputs at time i

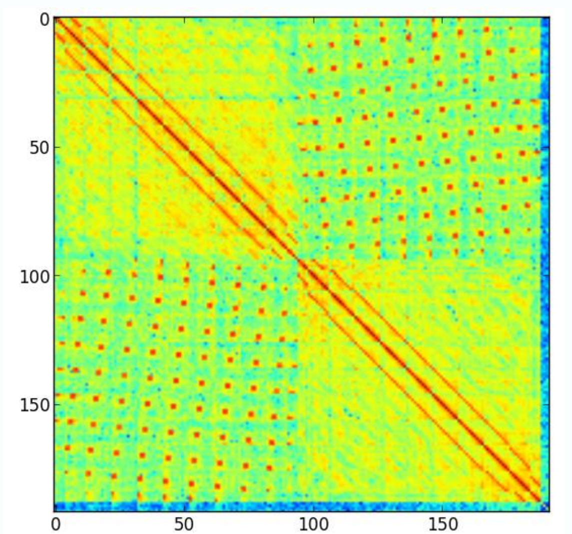
[Applebaum (1976)](#) derived a simple expression for the weights that define the maximum sensitivity beam:

$$\mathbf{w}_k = \hat{\mathbf{R}}_n^{-1} \hat{\mathbf{v}}_k$$

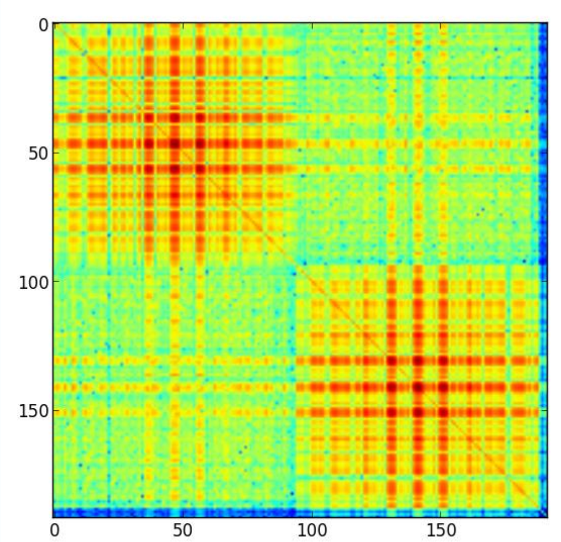
Noise covariance matrix
(ACM with no strong sources in the field)

Steering vector (response of PAF elements to a point source in the direction of interest for beam k)

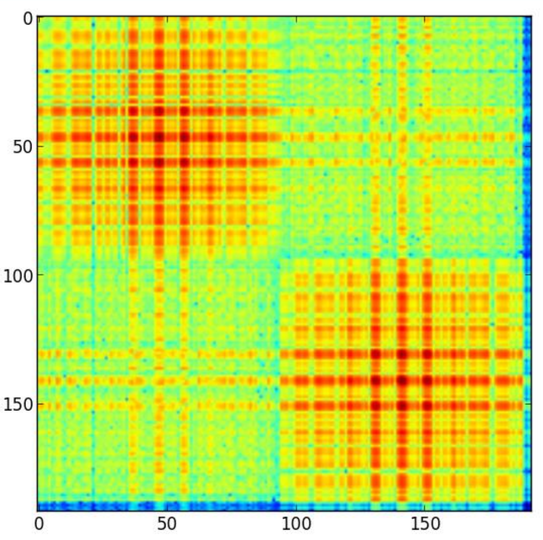
Beamforming on the Sun



$\widehat{\mathbf{R}}_n$



$\widehat{\mathbf{R}}_{s+n}$



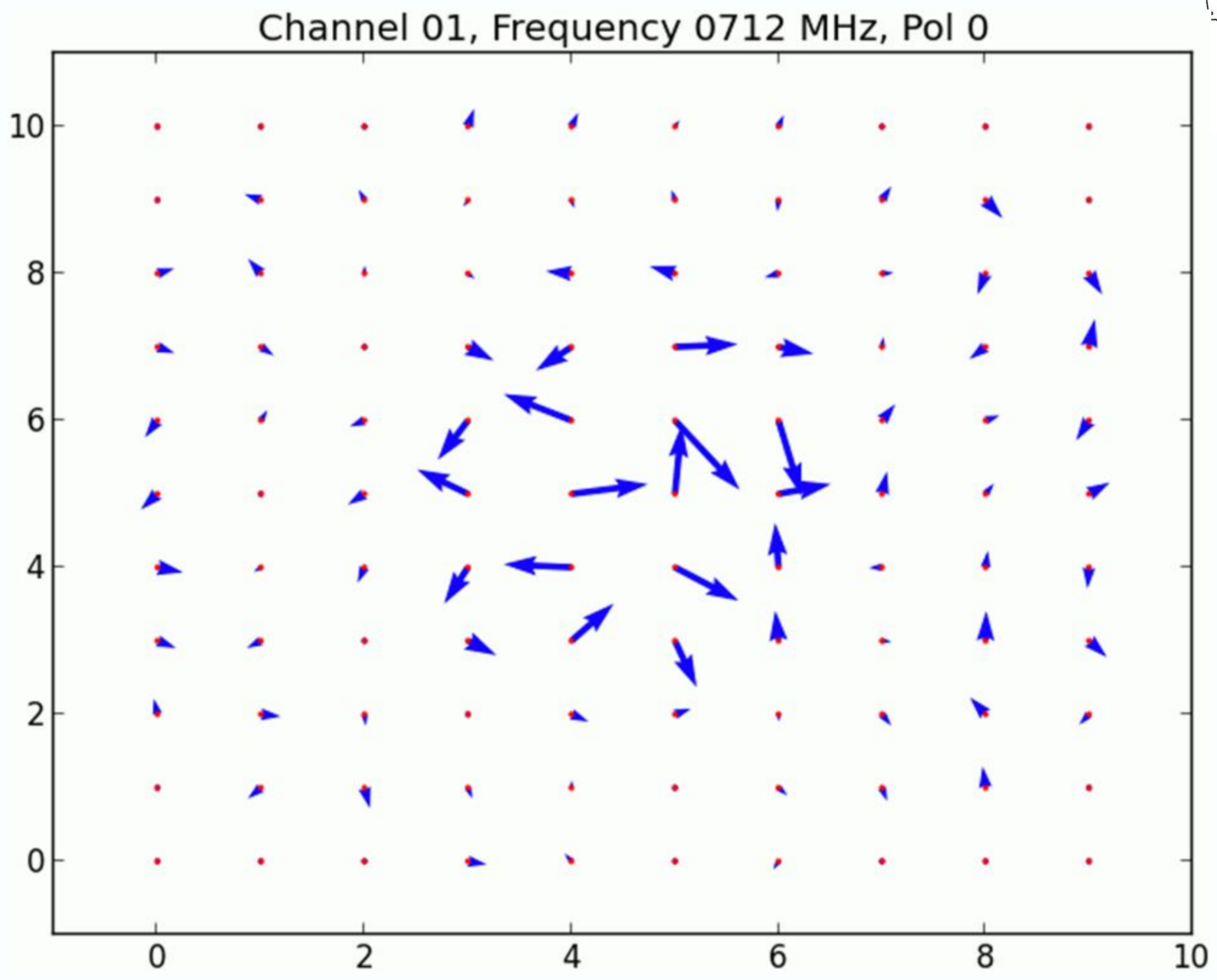
$\widehat{\mathbf{R}}_{s+n} - \widehat{\mathbf{R}}_n$

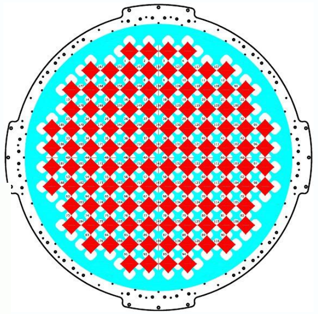
Our steering vector is the dominant Eigenvector of the difference above.

The Sun dominates the noise in this example. Weaker sources have proven less effective.

To make offset beams, point the antenna off-axis when measuring the steering vector. Need one observation for each beam.

Maximum sensitivity beam weights

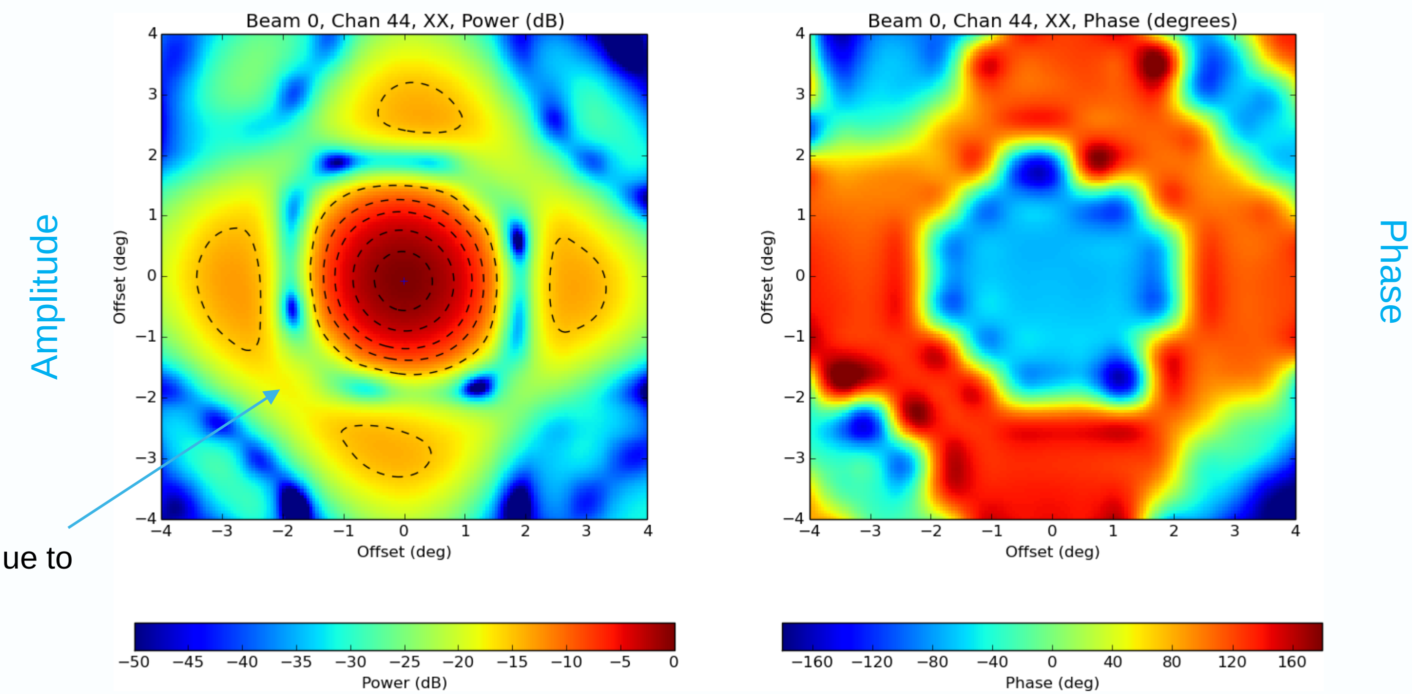




Shape of maximum sensitivity beams

Maximum sensitivity beam-forming does not constrain the shape of the beam, its symmetry, side-lobe levels, etc.

- Good for detecting point sources, but may not be optimal for mosaicking.
- Holography measurements can be used to study the beam shape.



Asymmetry due to feed support structure

Considerations

- Each beam requires an independent observational constraint.
  - Beams are not formed "in advance" from stored data.
  - Beams currently have a "life span" measured in sampler stability units.
- ASKAP's antennas are small, so a very strong source is needed.
- ACMs are captured in frequency multiplexed mode, increasing the observing time by a factor of 8.

- Long-term, we will employ different methods to the baseline approach described above. Planning to investigate:
  - Using the interferometer to define the steering vector.
  - Adding additional observational constraints.

Shape constrained beamforming

- Shape constrained beams – obtaining beam-former weights by fitting the summation of single port patterns to a template.
- Proof of concept completed about a year ago, recently tested in prototype mode on the BETA array.
  - Measure 18 single port patterns via holography (BETA limitation)
  - Create an amplitude template matching the desired astronomy beam
  - Fit for weights by optimising the match of the weighted sum of all single port patterns with the template beam
- This approach is entirely based on observational constraints.
  - Assumes good knowledge of the single-element embedded patterns

ADE single port holography (input)

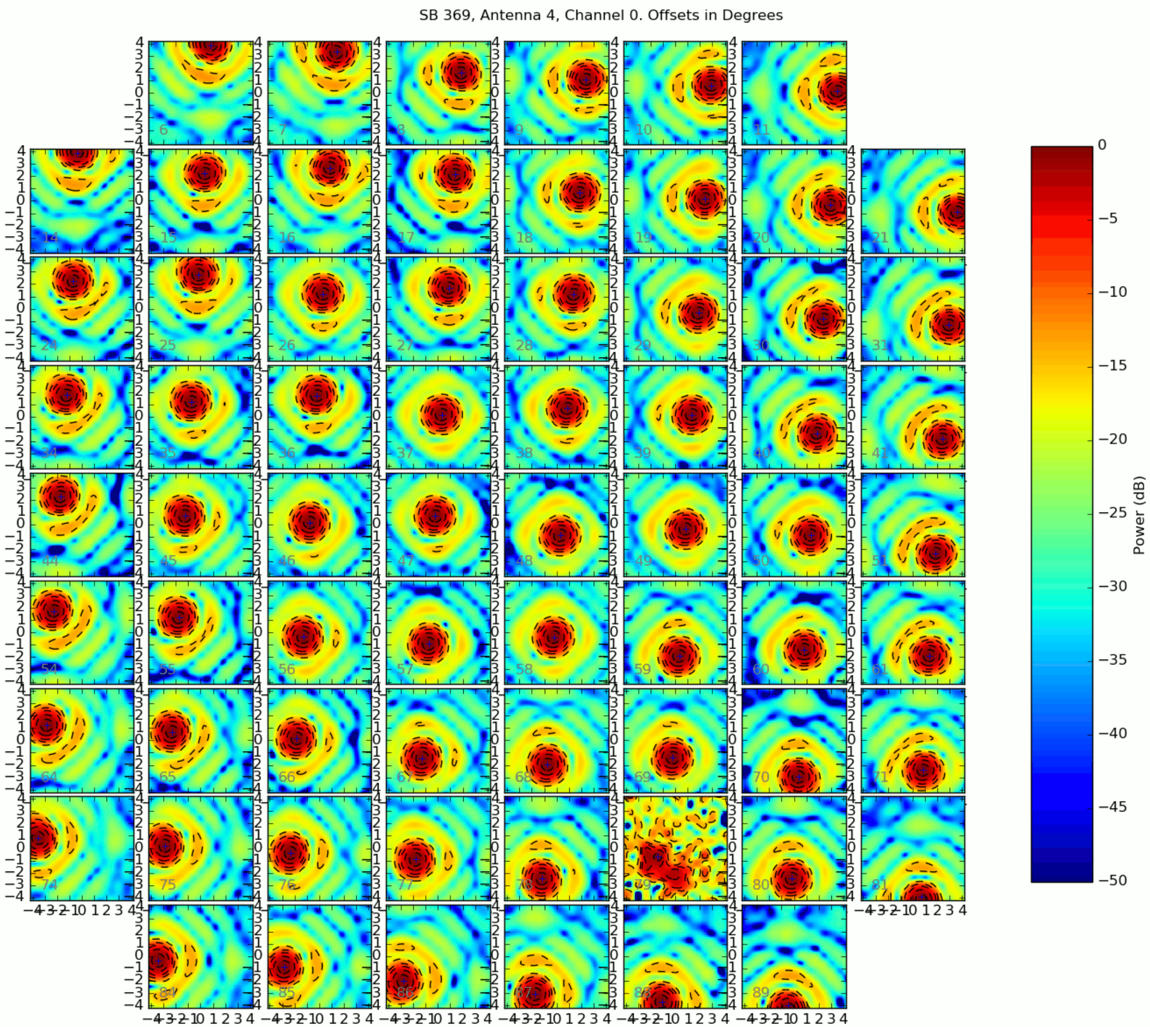
SB 369

68 single ports

Virgo raster

8x8 deg field

Might need to scan a larger area for the edge ports!

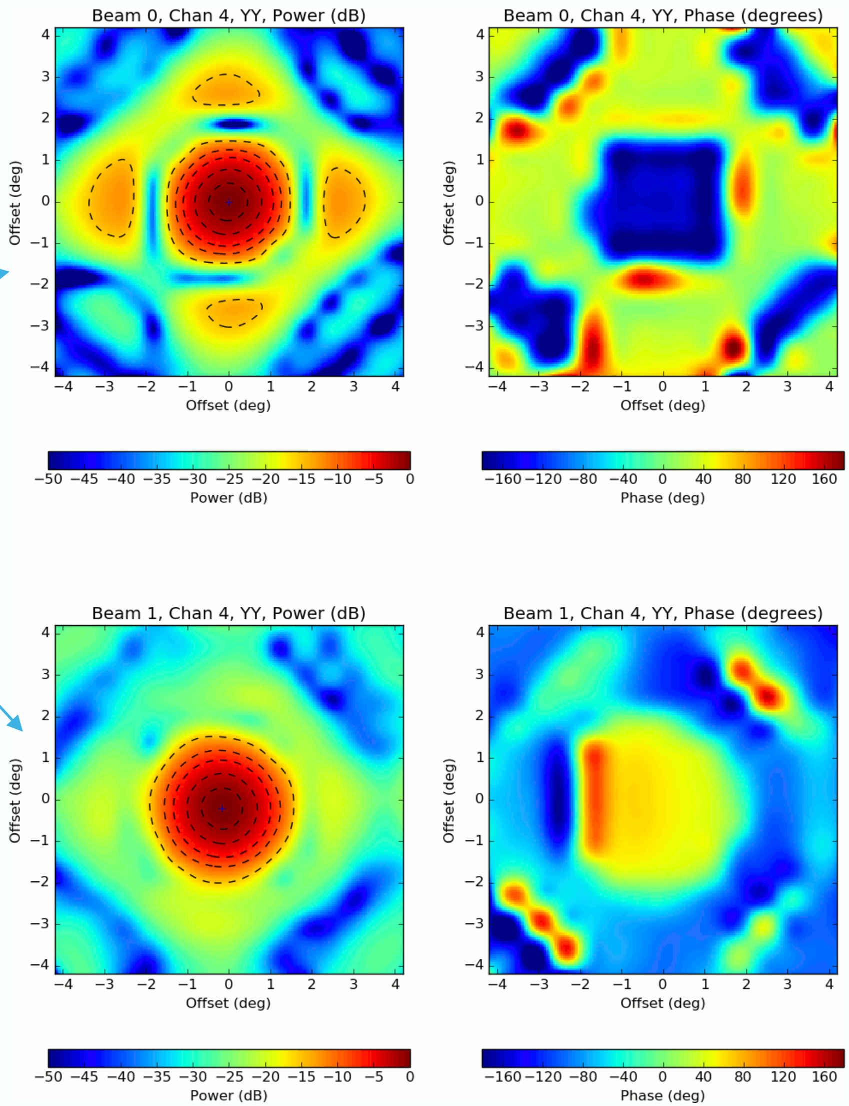


Shape constrained beam pattern (output)

Antenna 8 SB 3581

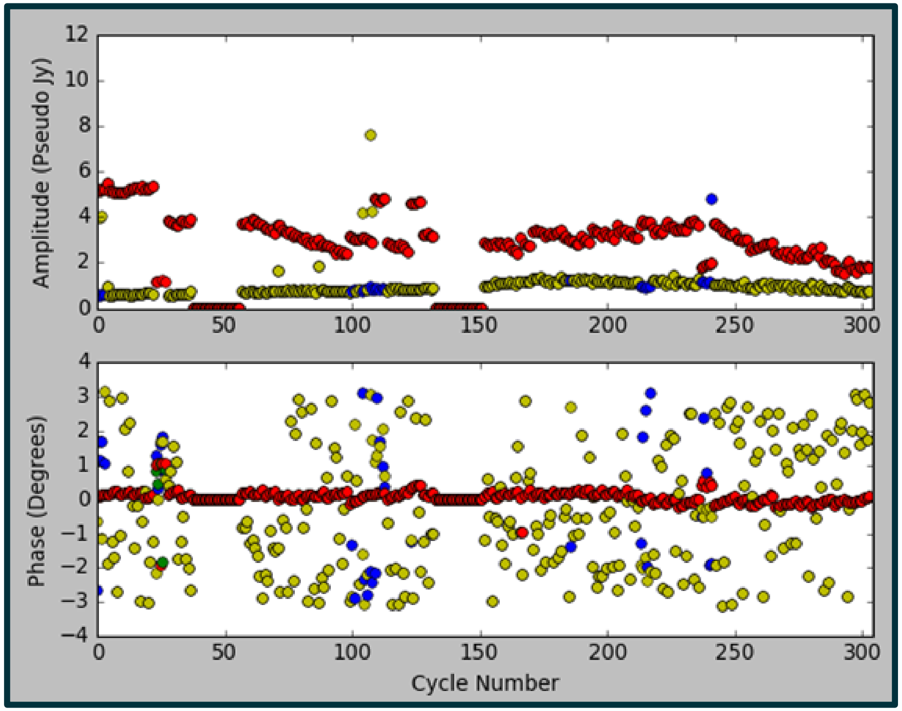
Max S/N

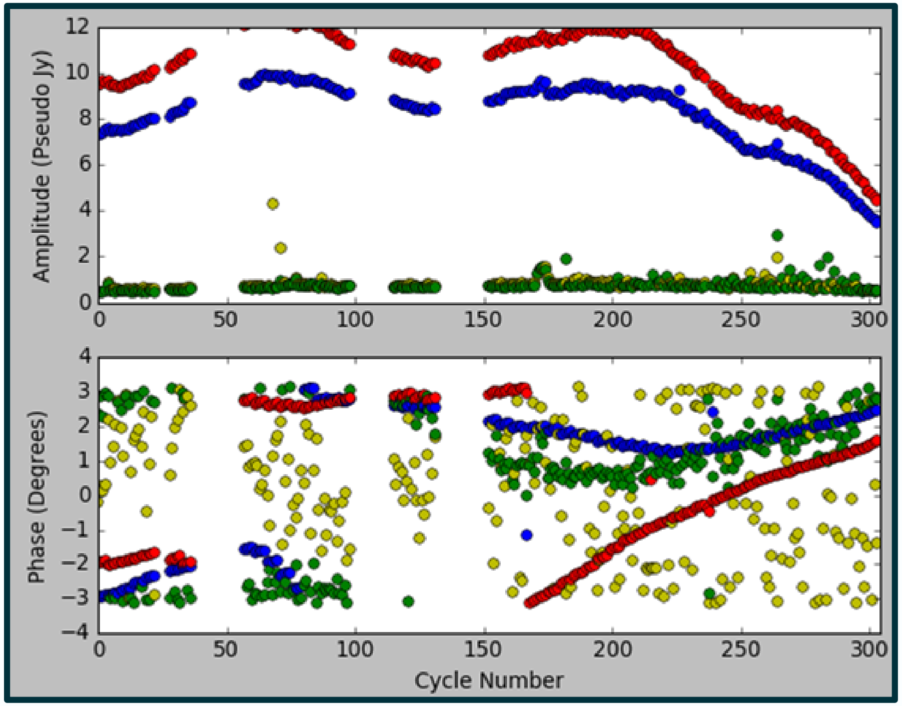
Shape constrained



Shape constrained beam SEFD

Antenna 8 SB 3585





Shape Constrained

Max S/N

Conclusions

- We are actively exploring a range of different beamforming methods for use on ASKAP during early science and beyond
- The “baseline” method provides good sensitivity, but at the expense of some asymmetry and strong side-lobes
- We have demonstrated that it is possible to constrain the shape of a beam on the sky, but this comes with a sensitivity penalty
  - More work to be done quantifying the trade-off on ADE