Some Simulations of Future Radio Telescopes and other Things

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Stellingen

- Hen die het verleden niet kunnen herinneren worden veroordeeld om het te herhalen. - George Santayana
- Het is belangrijker om uit het windscherm dan in de achterspiegel te kijken. - Warren Buffet
- Vanaf het begin werd de serie ontworpen met volledige polarisatiemogelijkheden. Een van de redenen om de equatorially opgezette schotels te hebben moest polarisatieobservaties vergemakkelijken: de hemel zou niet met betrekking tot telescopes roteren. ... Dit was een belangrijke overweging gezien de beperkte snelheid en de mogelijkheden van elektronische computers. - Ernst Raimond
- Het is allemaal alleen informatie theorie - P.E. Dewdney

Some Topics ...

- Simulation of Focal Plane Arrays
- Pointing
- Short Spacings and the SKA

Focal Plane Arrays

- If they work well, they can make telescopes such as the WSRT and ASKAP enormously productive
- The engineering focus is on maximum sensitivity, which may lead to beams with asymmetric shapes.
- Are asymmetric beams a good thing?
  - Ask Gerry Harp

In the Year 2525 ...

- Firstly, all of Johan's concerns about polarimetry have been answered
- We have FPAs with elements that are perfectly stable for long period of time
- There is no electrical interaction between elements
- BUT we cannot avoid the laws of optics
- We can currently clone Dolly the sleep but in 2025 can we clone a million Olegs to make high dynamic range images from data collected with asymmetric beam shapes?
  - Probably not, but we can attempt to form well-shaped beams from focal plane array elements

Simulated FPA

- Here FPA is an acronym for Focal Plane Array of the Phased Array variety
- 90 dipole elements in each of X and Y directions
- Frequency = 1500 MHz; Spacing = lambda / 2
- Dish diameter = 10m; Focal length = 4.5m
- No coupling between elements; No feed struts in simulation
- Dipoles have linear polarization response
- Not meant as a ‘realistic’ final FPA design, but a good test bed for various aspects of software development and data processing
  - dipoles have high instrumental polarization
  - can we lower the instrumental polarization by using beamforming techniques?

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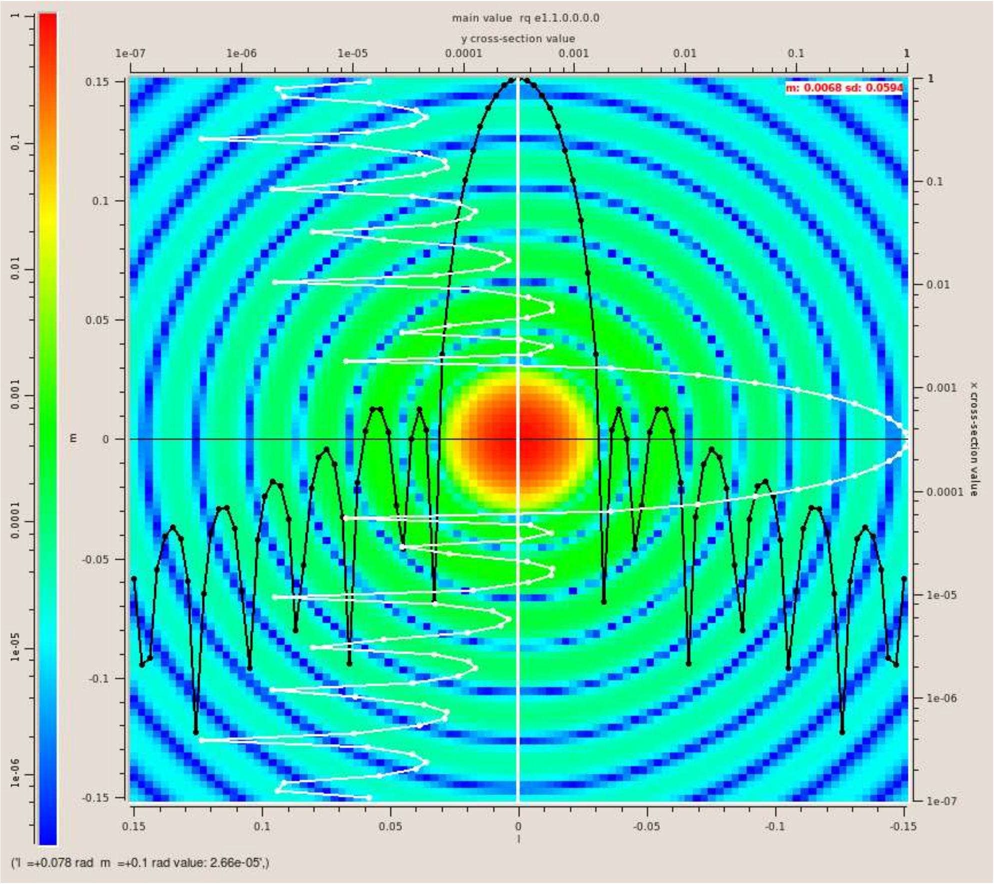
Beamformer Weighting

- Phase conjugate weighting
  - maximizes gain in observed direction, but does nothing particular for beam shape
  - can have high instrumental Q polarization
- Beamforming procedure
  - Obtain values for phase-conjugate weighting in a particular direction
  - Provide these values as initial guess for weights to MeqTrees solver
  - Solver adjusts for X and Y beam weights until phased beams have optimal shape
  - lowers instrumental polarization, especially Q term
- Here we attempt to fit phased up beam to 'ideal' central beam designed with GRASP

Theoretical Centred Beam

- FWHM = 79.1 arcmin
- Feed is centred at the focal point on bore-sight
- Feed illuminates the reflector with a linearly-polarized Gaussian radiation pattern
- At the dish edge the feed illumination has a taper of 12dB relative to that at the centre
- The dish has the same parameters as were used for the dipole FPA calculations

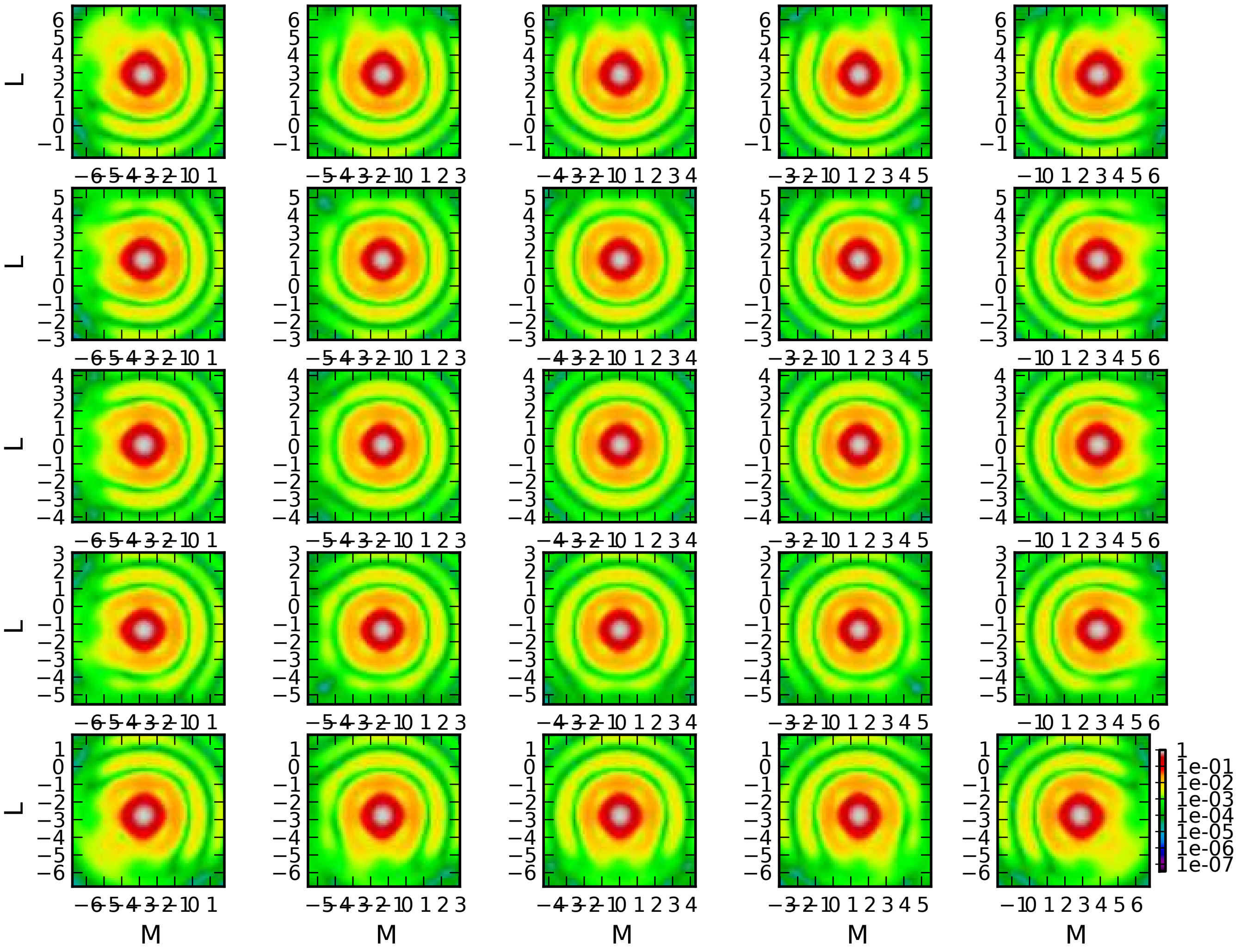


Phased-up Beams

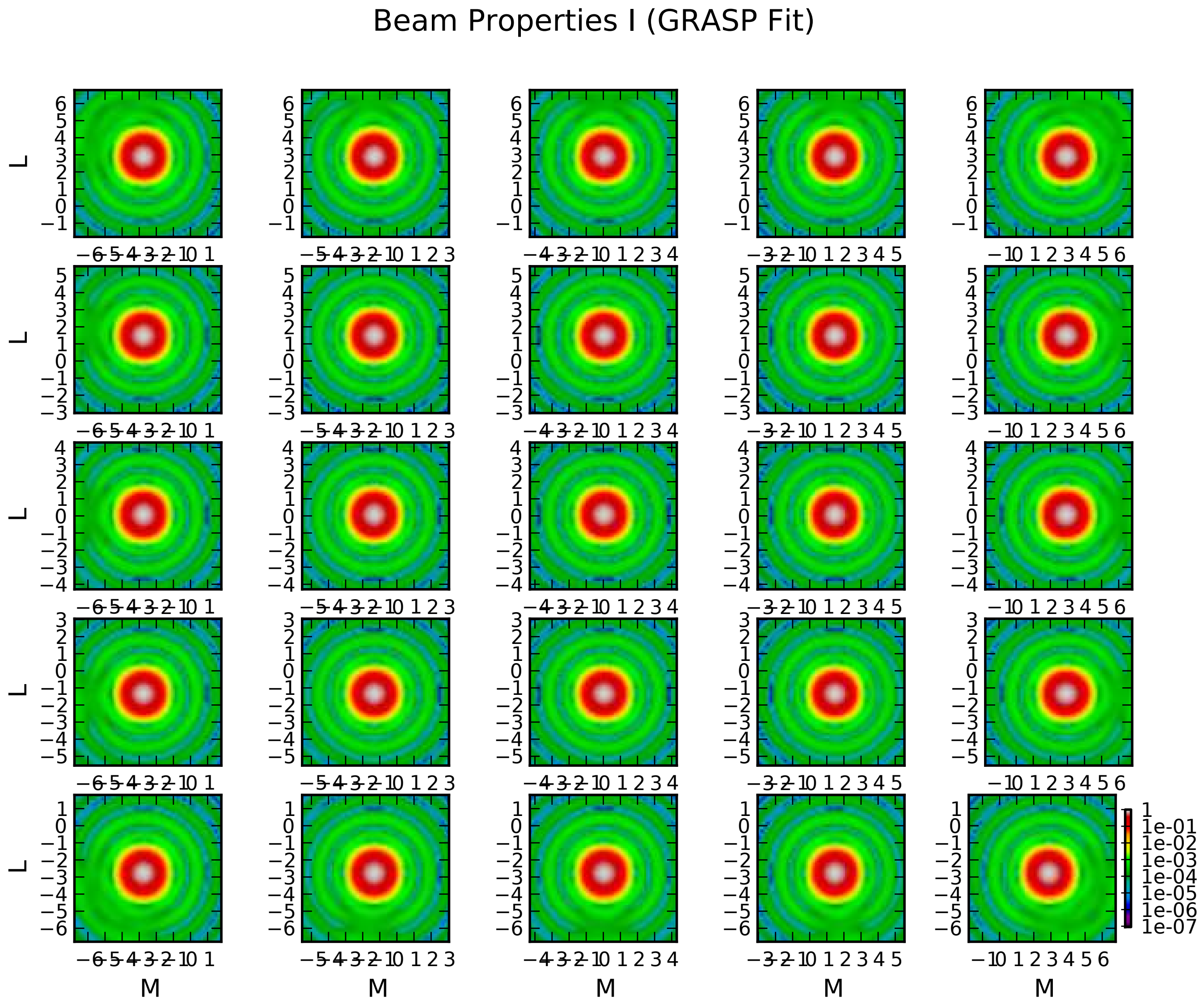
- Next four slides show phased-up I and Q beams
- Beams are shown in increments of 1 x FWHM out to 2 x FWHM in L and M
- Coordinates in images give offset from boresight in degrees
- Each beam is centred in its frame but note coordinate offsets
- Twenty-five independent beams on the sky
- Simulated array has boresight symmetry but MeqTrees software makes no assumptions about symmetry so can be easily adapted to real-world measurements

Conjugate Weight I Beams

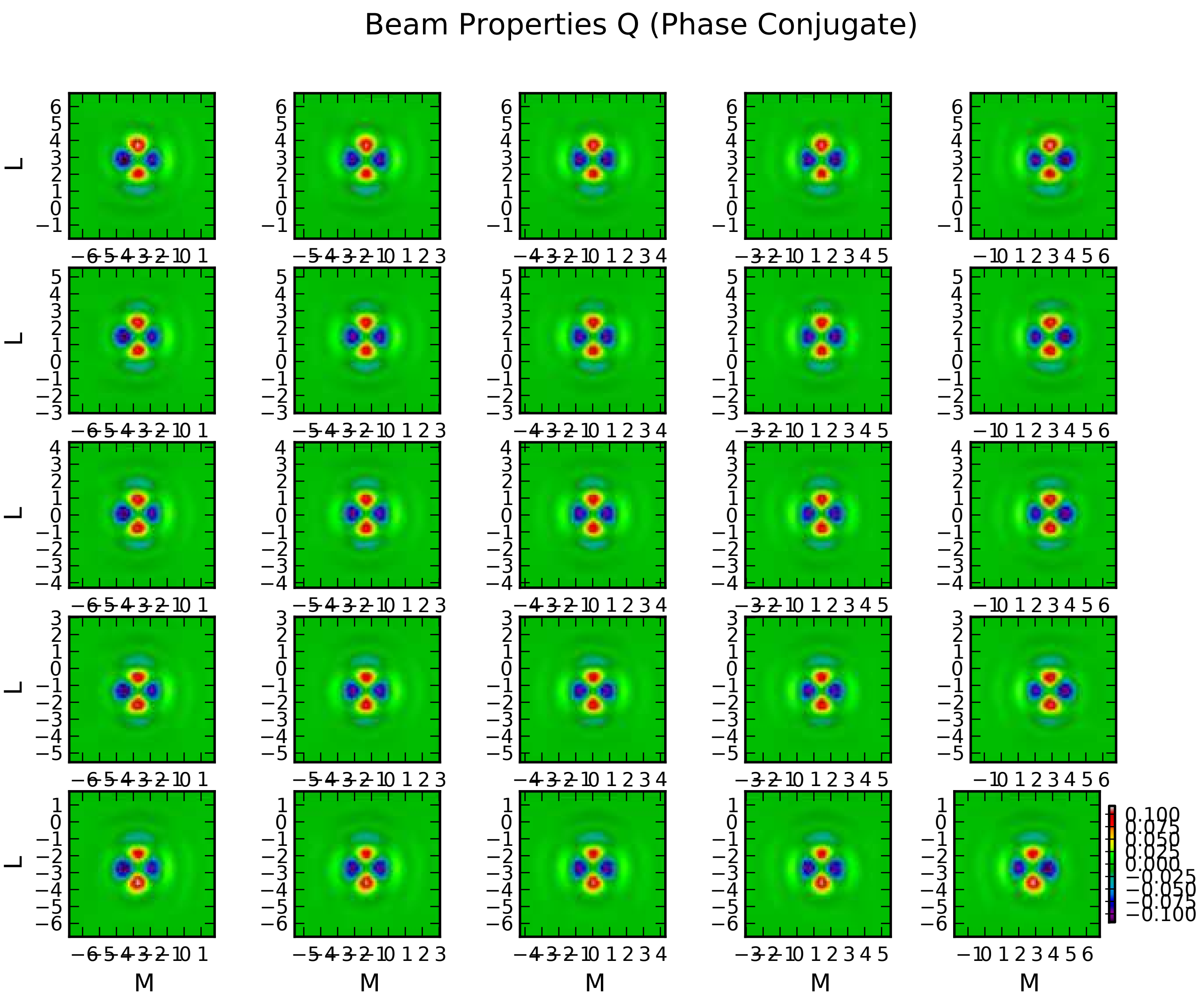
Beam Properties I (Phase Conjugate)



GRASP Fitted I Beams



Conjugate Weight Q Beams



GRASP Fitted Q Beams

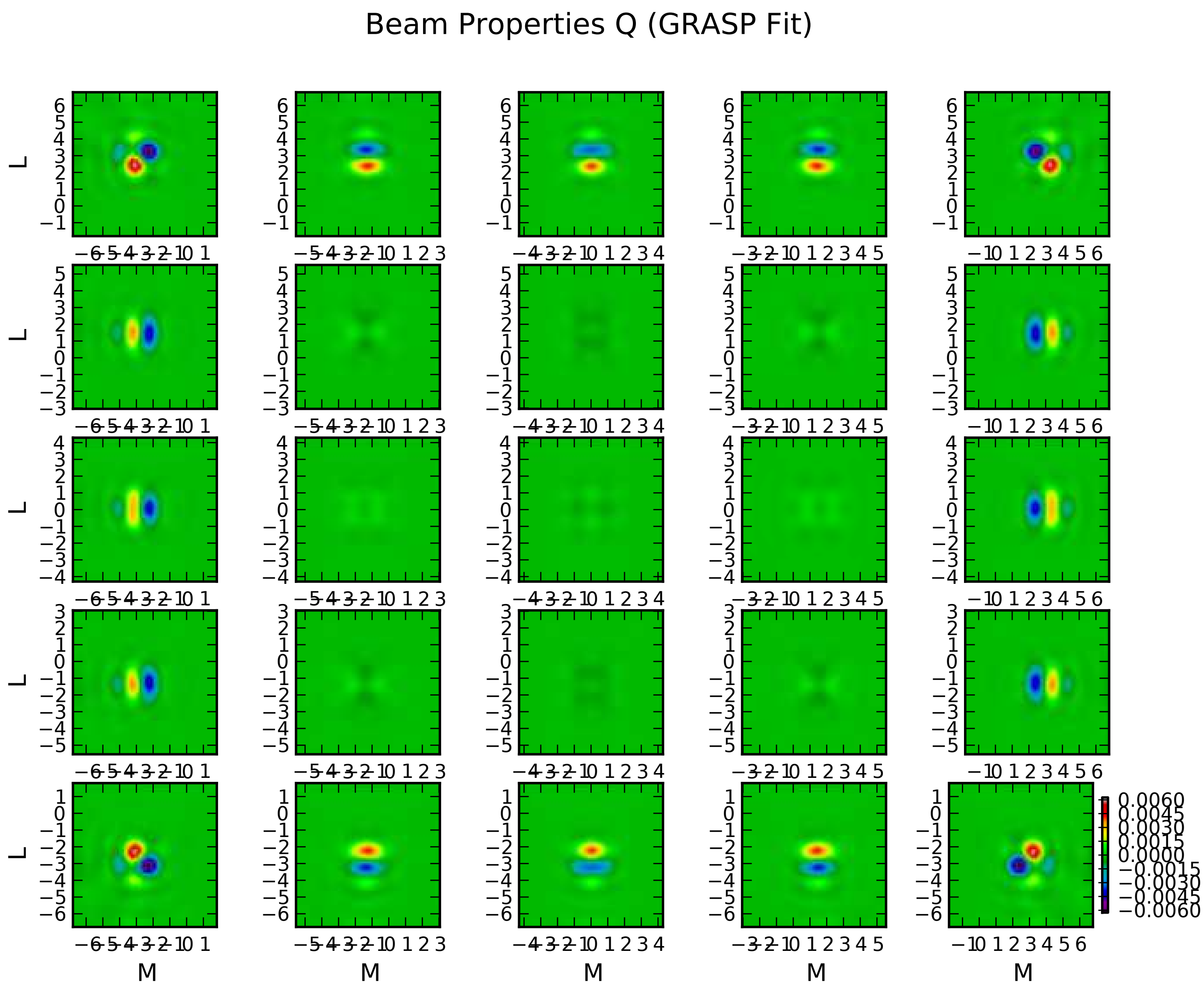
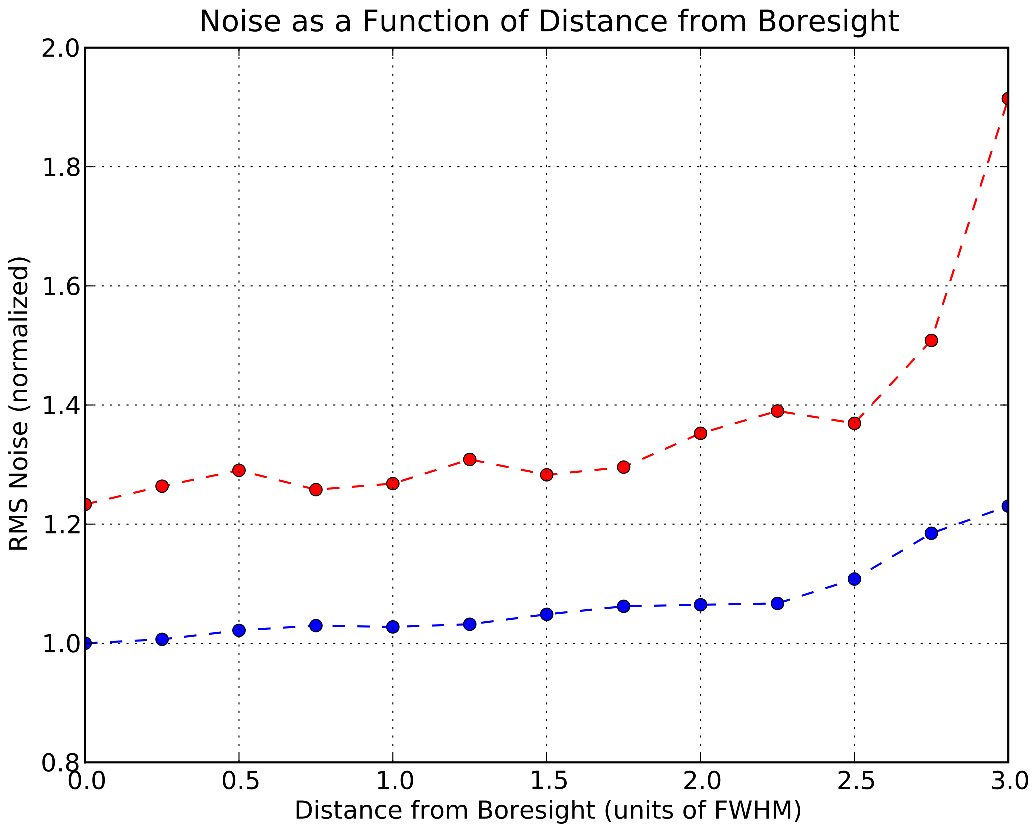


Image Noise as a Function of FPA Phase-up Position

- Conjugate weighting - blue
- Gaussian fitting - red
- Gaussian fitting - emphasis on fewer elements - see previous slides - so noise is higher



Observing with FPAs - Experimental Setup

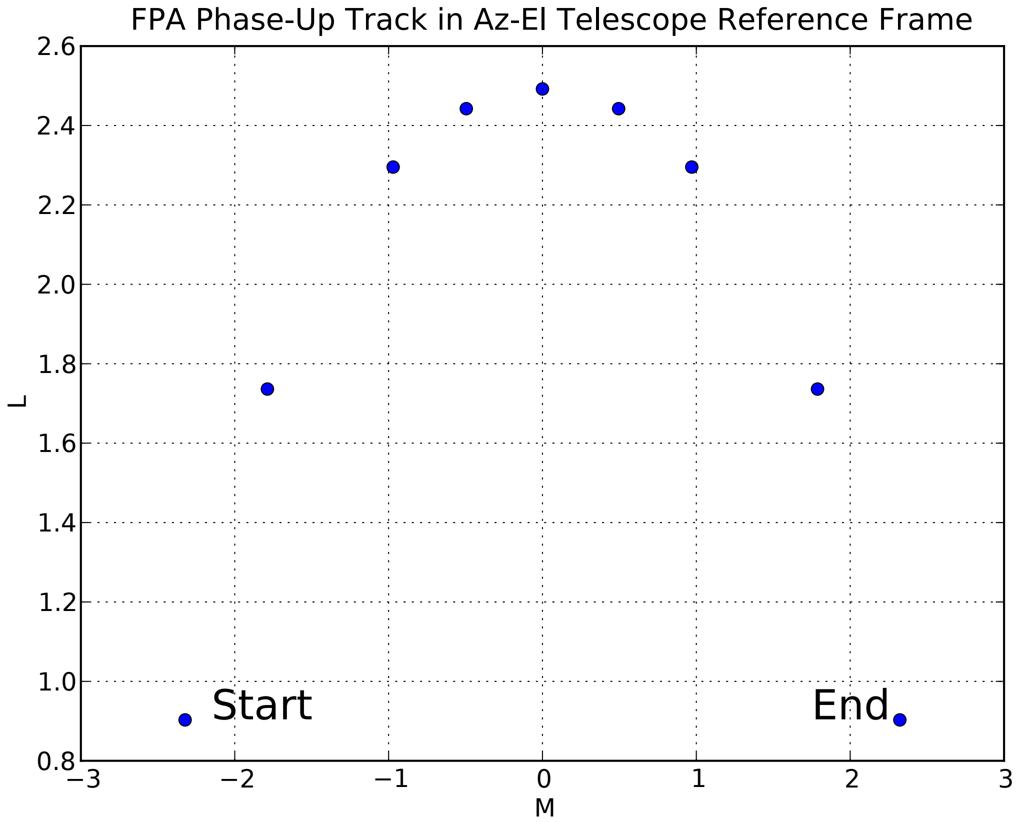
- Use antenna positions of 36 element ASKAP array
  - But divide by 4 so maximum baseline is about 1.5 km
  - Allows us to use an integration time of 60s
- Place array at VLA site (easier for northern hemisphere people to understand results!)
- Observation frequency is 1400 MHz with a single channel of 5MHz Bandwidth
- Antennas are assumed to have simple Az El mounts with fixed focal plane array systems
- Can observe all sorts of simulated skies - grids, point sources, SKADS sky simulations etc
- Observations shown here were done at Declination 28 degrees. The latter declination is within about 5 degrees of the VLA zenith.

Tracking Offset Field with an FPA

- Continuously adjust phased array weights to track a field offset by 2 x FWHM in L at transit over this time period
- Dipoles are linearly polarized so P Jones matrix is a rotation matrix that is a function of parallactic angle
- In following slides, all polarizations have been rotated back into sky reference frame
- How accurately can we maintain beams shapes as we use the phased array to track the field?
- NOTE!! Actual SKA pathfinders/precursors that plan to use FPAs (ASKAP and WSRT APERTIF) avoid this problem by using either equatorial mounts (WSRT) or a third-axis sky rotator (ASKAP). These devices can be considered a type of analog, rather than digital, computer.

Offset Field in Telescope Reference Frame

- The plot shows the positions of the field we are tracking in the antenna reference frame at parallactic angles of
  - -1.2, -0.8, -0.4, -0.2, 0, 0.2, 0.4, 0.8, 1.2 radians
- Coordinates are degrees



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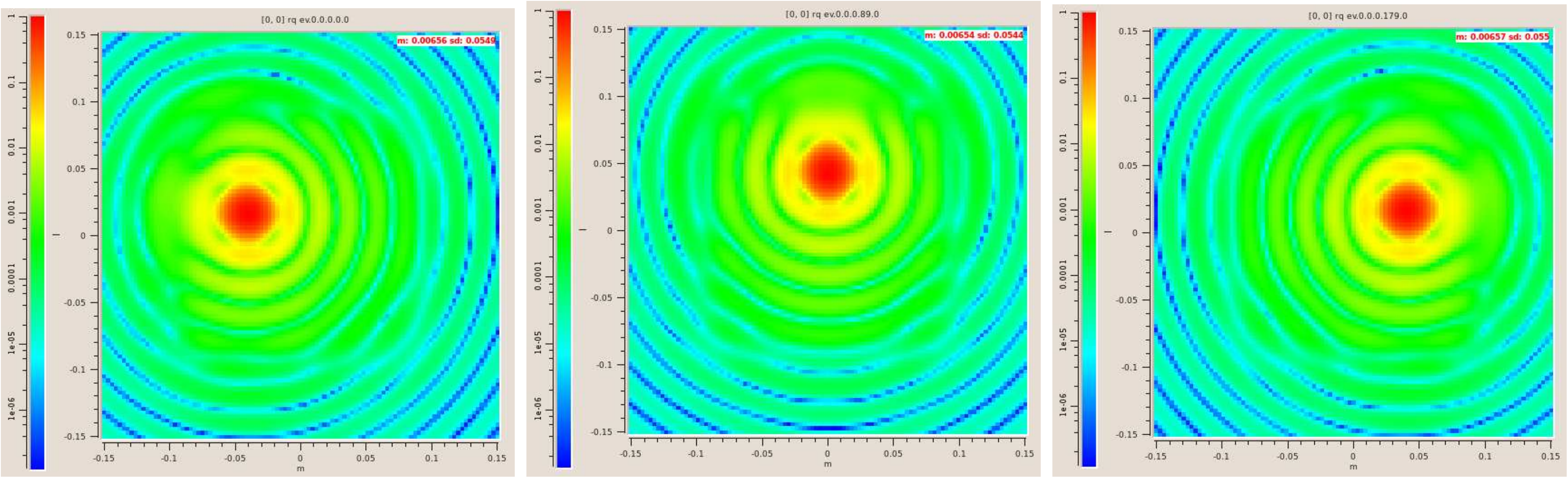
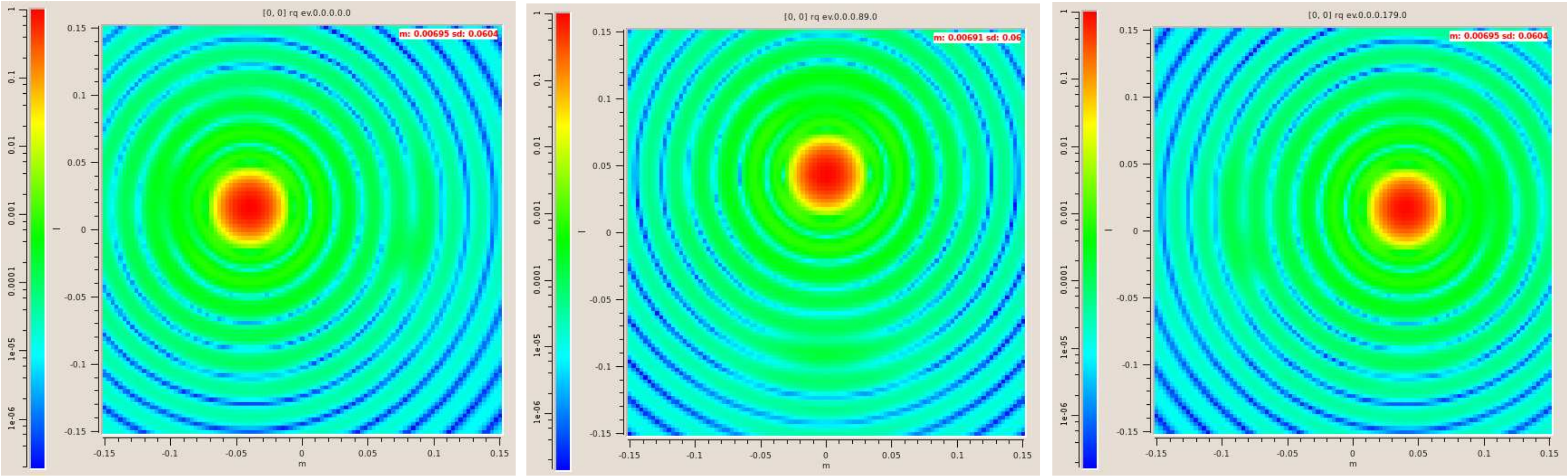
Phase Conjugate Weighted Beam

- Phase conjugate weighting maximizes gain in observed direction, but does nothing particular for beam shape
- demo shows I beams phased for L =2 , M = 0 at transit for conj array



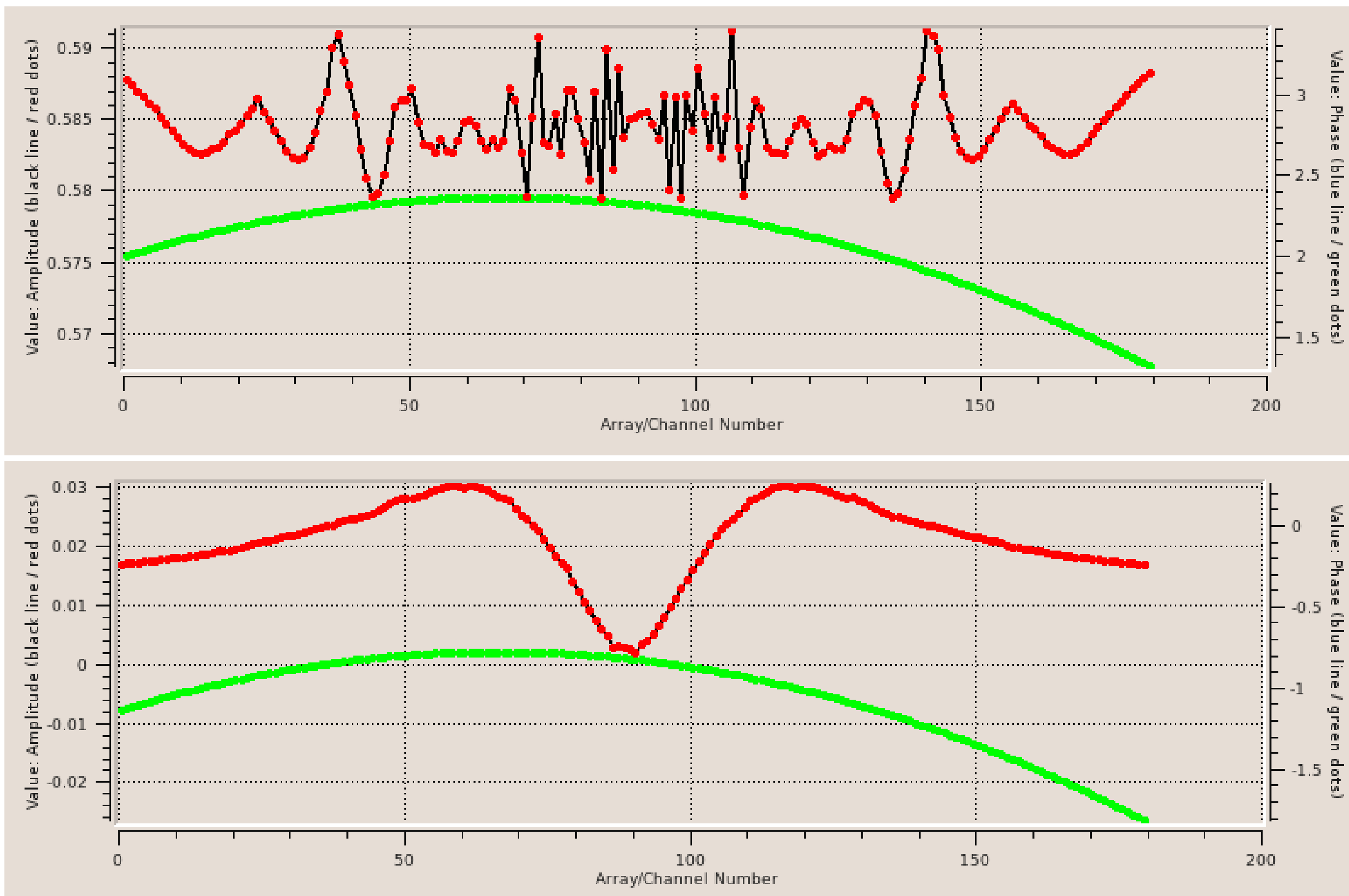
Central Fitted Beam

- Phase conjugate weighting maximizes gain in observed direction, but does nothing particular for beam shape
- demo shows I beams phased for L =2 , M = 0 at transit for fitted beam array



Fitted Weighted Beam

- 3 hour track of source near half-power point centred on transit
- upper plot gives I, bottom gives corresponding Q



Phase Conjugate Weighted Beam

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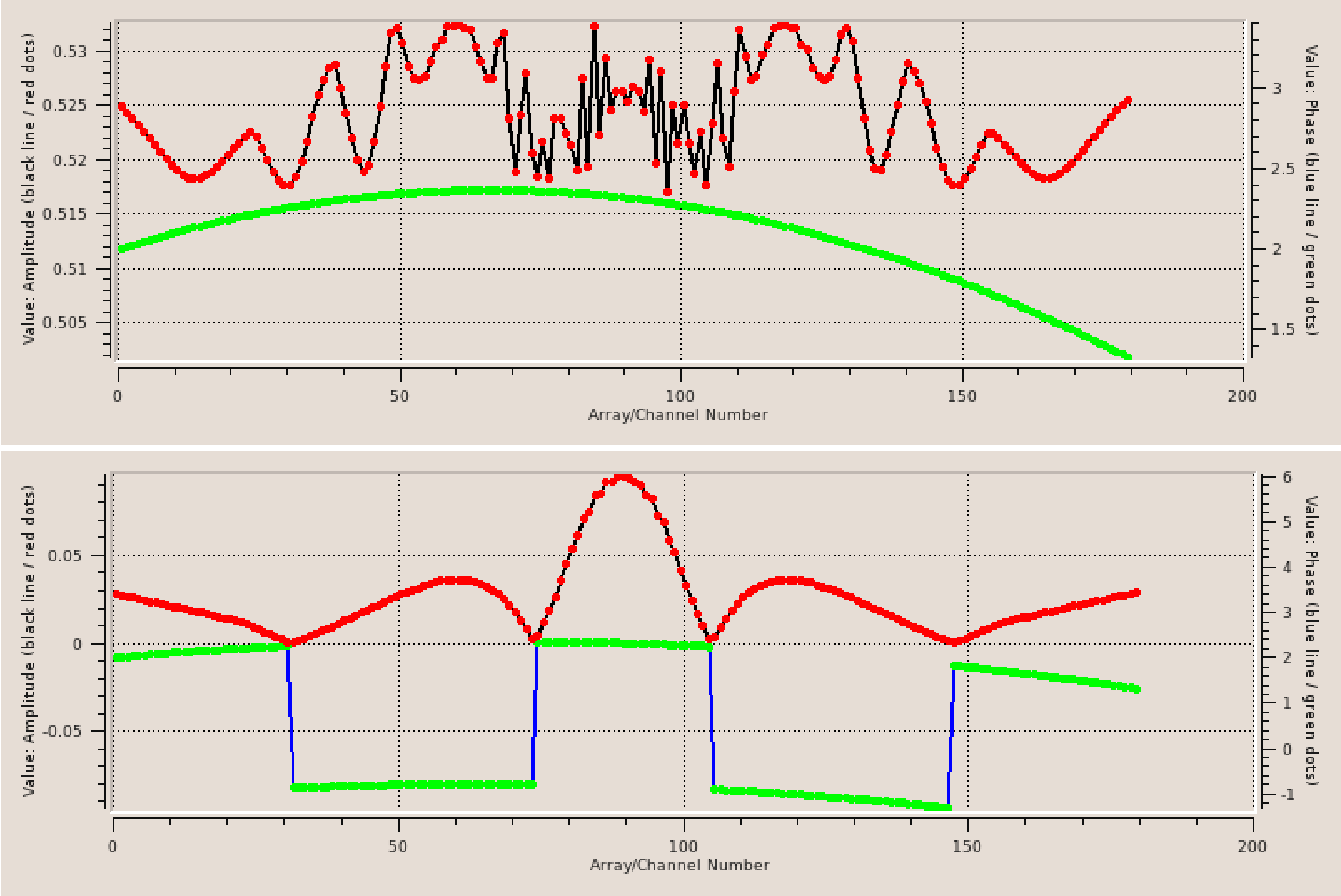
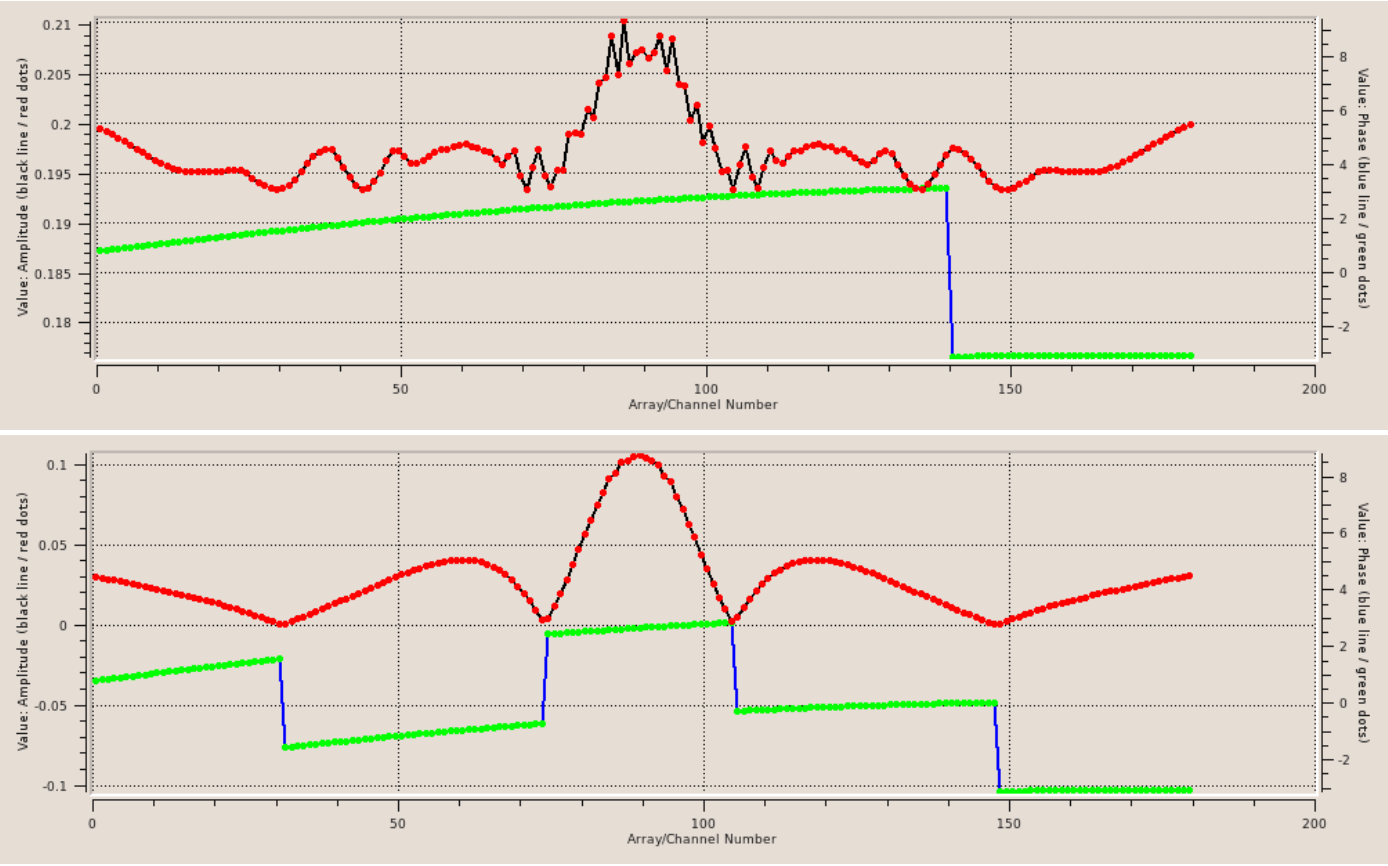


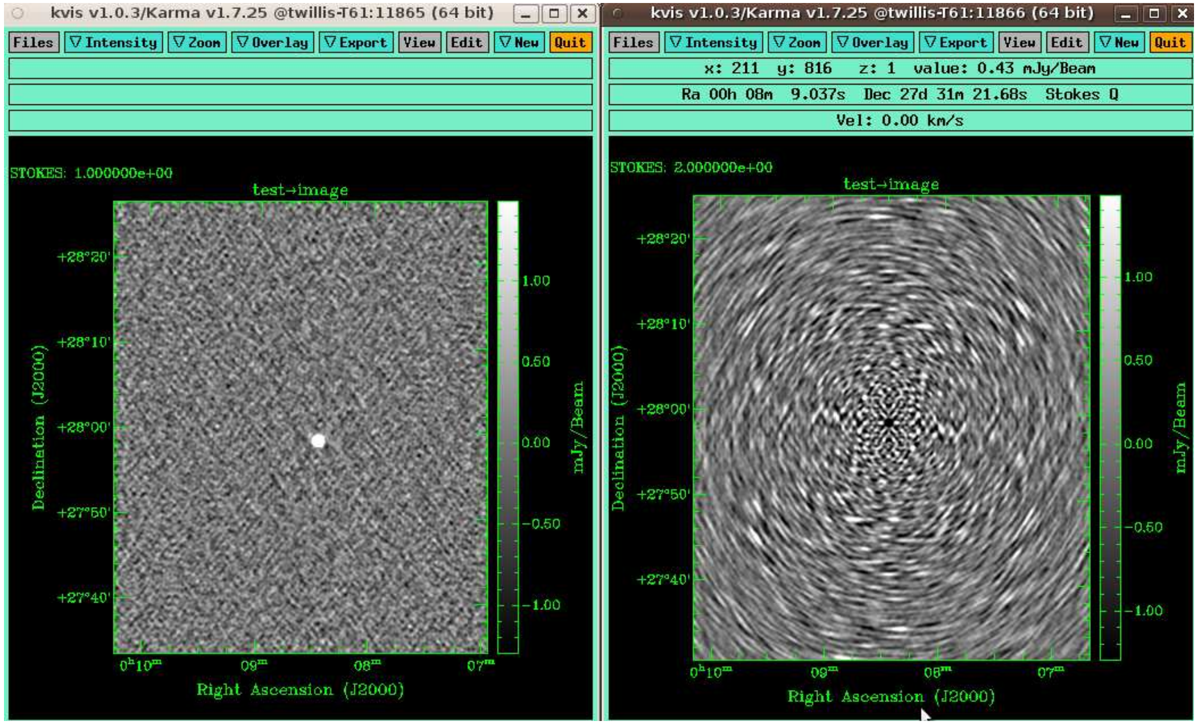
Phase Conjugate Weighted Beam at Larger Distance

- 3 hour track of source offset 0.75 x FWHM centred on transit
- upper plot gives I, bottom gives corresponding Q



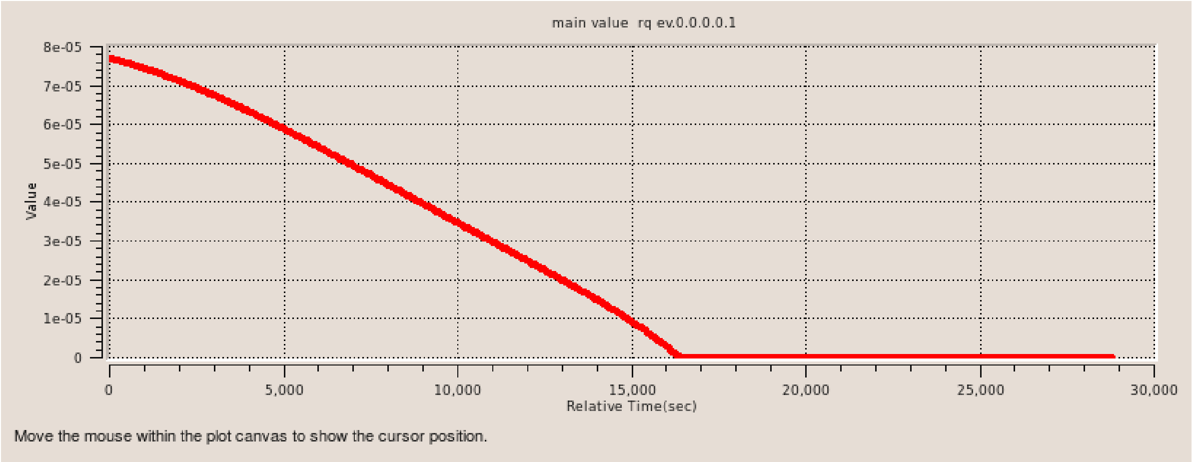
Why a Sky (de)Rotator is a 'Good Thing'

- The (de)Rotator eliminates time-variable instrumental polarization
- The figure shows the result of a SKA simulation where a field on the sky is tracked by adjusting the weights of the FPA beams as a function of time
- Left - Stokes I for a point source at the half-power point of the phased-up primary beam
- Right - the corresponding instrumental Stokes Q. As it is time-variable, the synthesized beam response cannot be deconvolved by simple CLEANing.

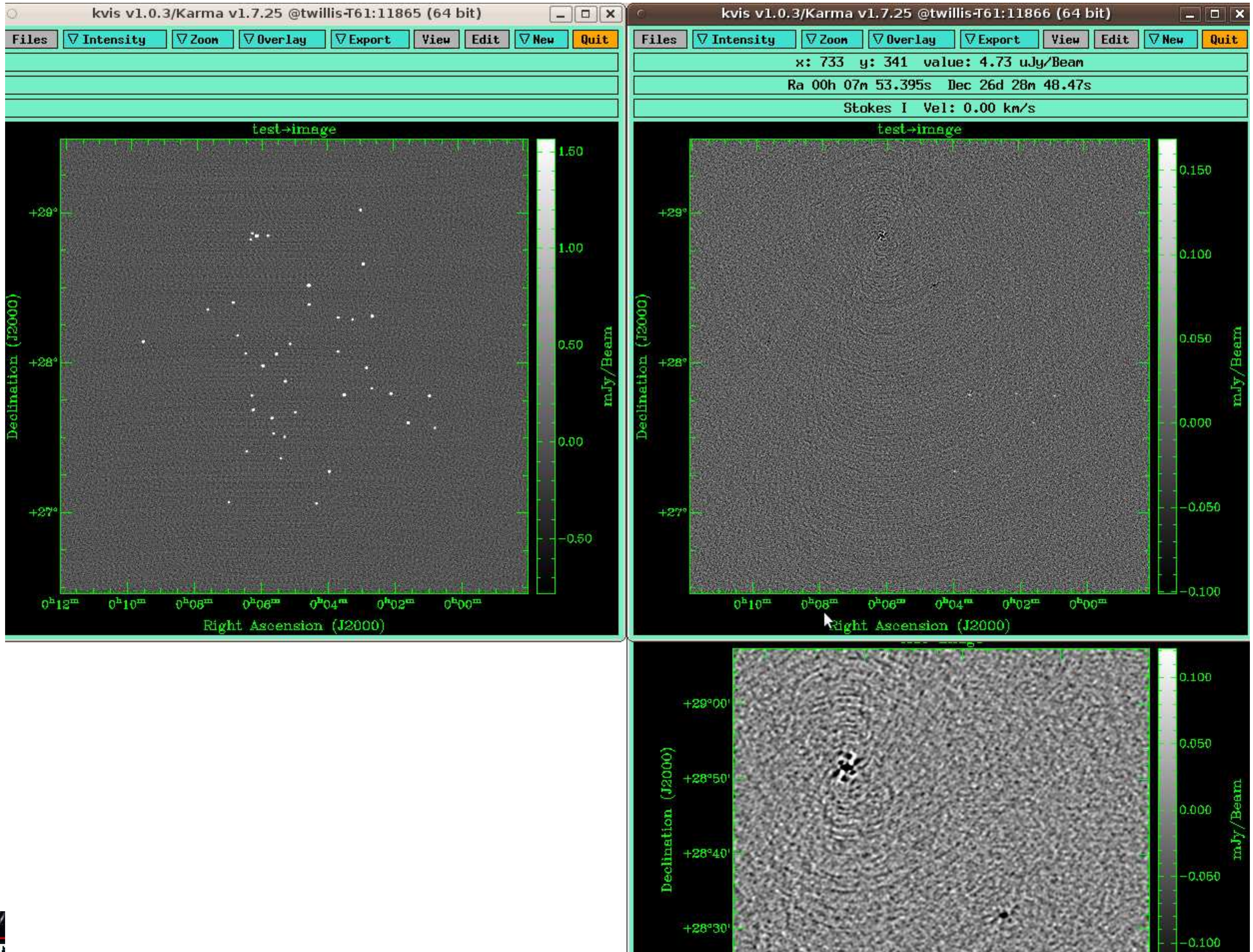


ASKAP Pointing Test

- Observe a field at RA 0h 5m, DEC +28d for 8 hours centred on transit on Jan 1, 2010
- Antennas are assumed to have RMS pointing errors of 24 arcsec on ‘short’ timescale
  - This is less than 1/100 of a beam - the limit recommended in SKA Memo 114
- BUT what would happen if antennas had an uncorrected thermal offset that is a function of sine(solar elevation) and sine(delta azimuth)
  - delta azimuth is the difference between the azimuth angle of the Sun and the azimuth angle of the observed field centre. We expect maximum thermal effects when the difference is 90 deg. We set maximum allowable thermal deflection to be 45 arcsec
- Observe a Stil model sky - cut off when attenuated flux density is less than 10 mJy
- actual maximum thermal deflection found is about 16 arcsec - see below - deflection is given in radians

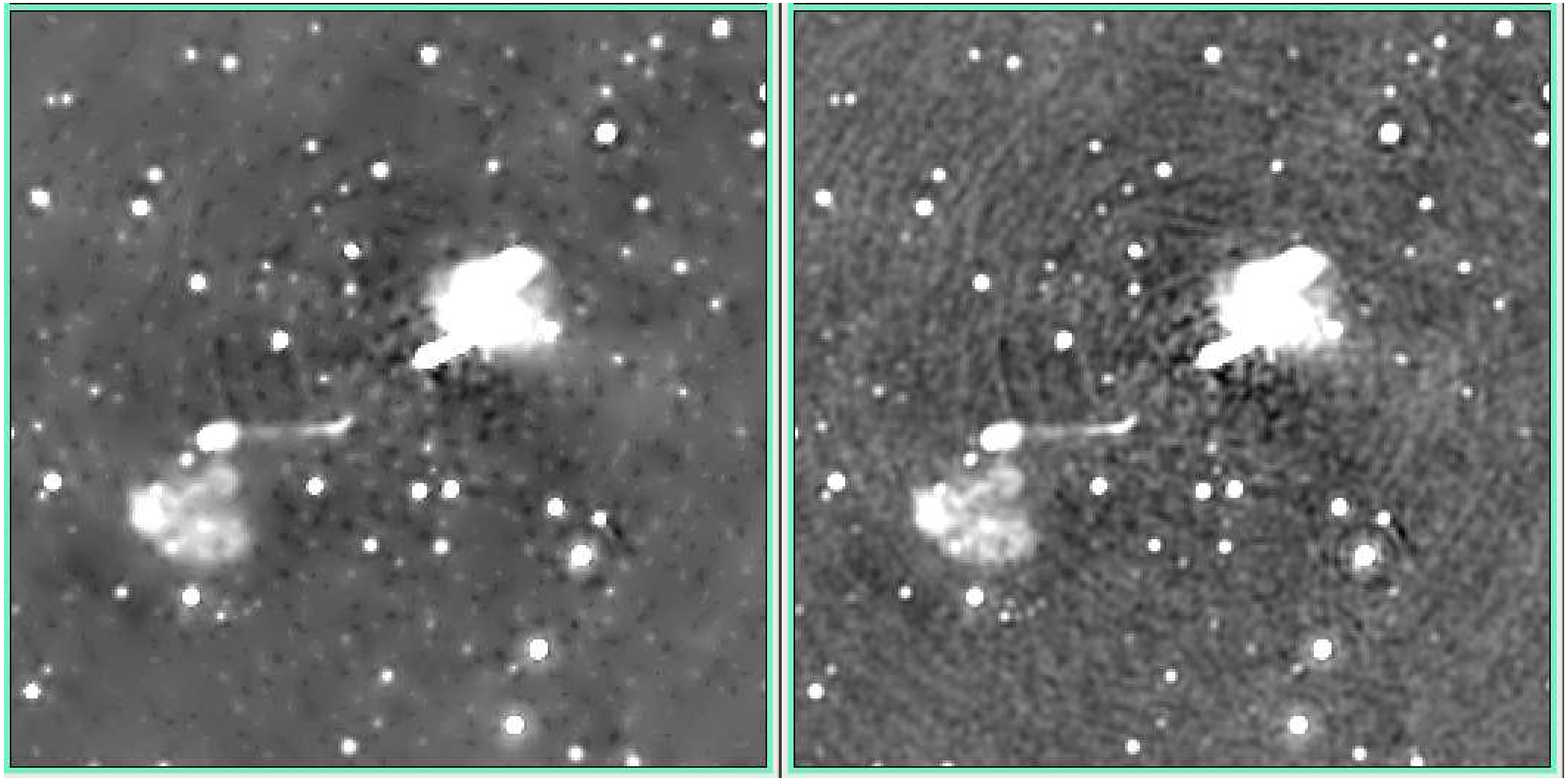


Pointing Result



The Short Spacing Issue

- SKA needs a dedicated short spacings facility. Some reasons ...
  - model constraints - see Urvashi Rau talk
  - high dynamic range calibration - see Sarod Yatawatta talk
  - proper polarization analysis - shown here Stokes I



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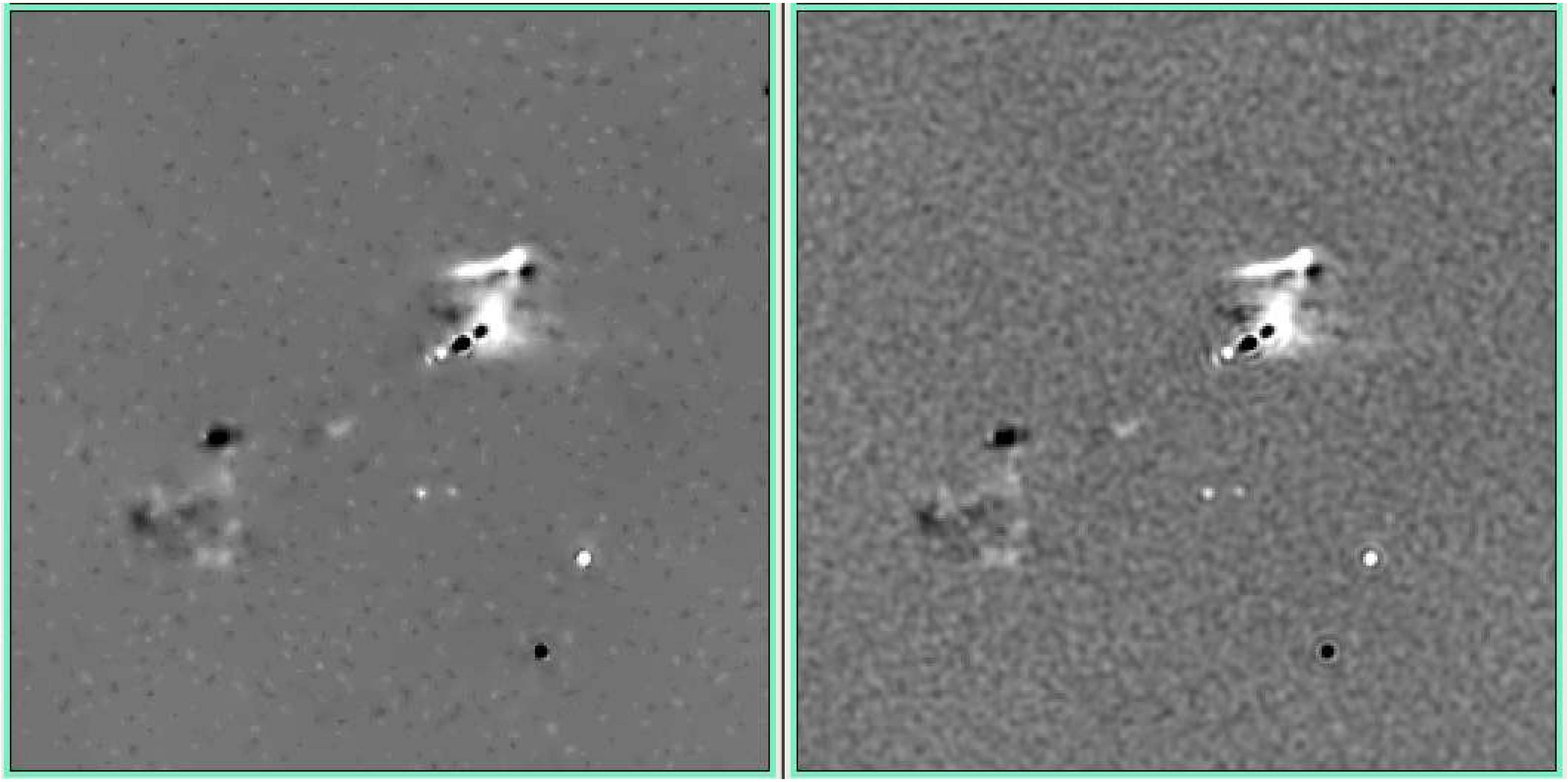

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Musings - Translated

- Those who cannot remember the past are condemned to repeat it. - George Santayana
- Its more important to look out the windshield than in the rear view mirror. - Warren Buffet
- Right from the start the array was designed with full polarization capabilities. One of the reasons to have the dishes equatorially mounted was to facilitate polarization observations: the sky would not rotate with respect to the telescopes. ... This was an important consideration in view of the limited speed and capabilities of electronic computers. - Ernst Raimond
- It's all just information theory - P.E. Dewdney

Thats All Folks!

- Thank you