Credit: E. Lenc

Primary Beams
2018 ICRAR/CASS Radio School

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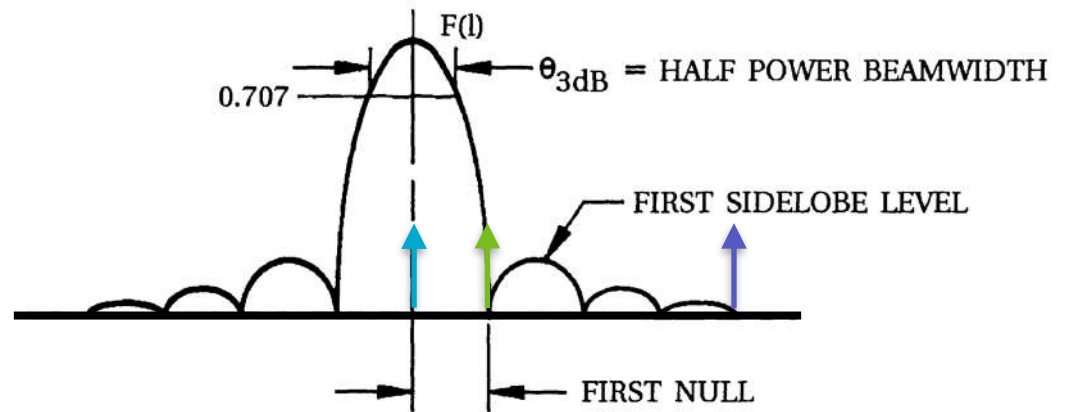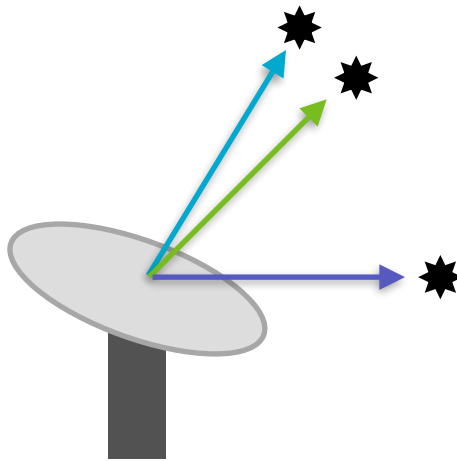03 October 2018

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Primary Beams

- What are they?
- Why do we to understand them?
- How do we determine them?
- What affects the beam?
- How do we improve the beam?
- How do we minimise beam-related effects?
- Fun tricks with beams

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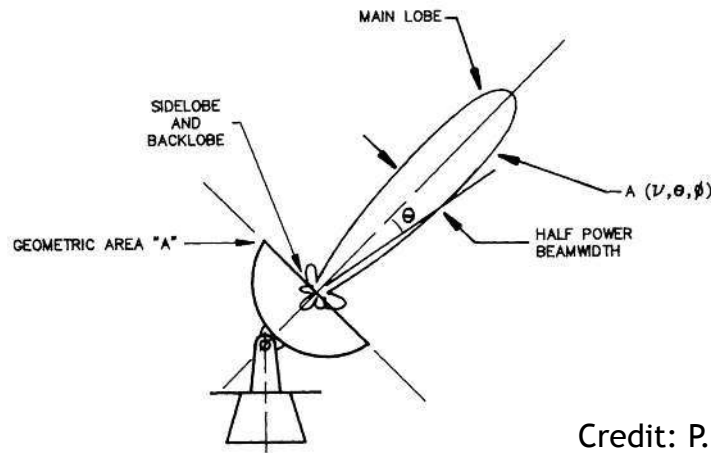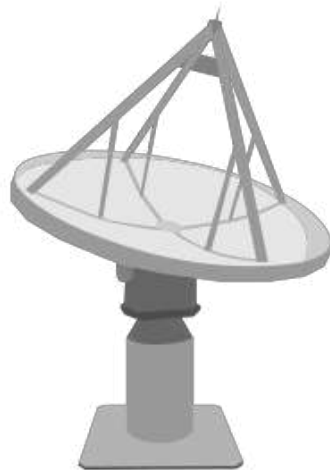# What is the primary beam?

Credit: P.J. Napier

Antenna Illumination Pattern - Fourier transform of Aperture

For typical parabolic antenna: Half Power Beamwidth $\sim 1.02\lambda/D$

First Null $\sim 1.22\lambda/D$

What is the primary beam?

Credit: P.J. Napier

- Beams can be very complex in shape!
- They can be challenging to model accurately.
- Sometimes you have greater sensitivity away from where you are pointing (see Daniel's talk).

Why do we want to know the beam shape?

- The beam shape is important for calibration (bandpass and flux).

- Beam needed to correct for beam attenuation during imaging and mosaicking - to ensure flux scale is correct (direction independent).

- Especially important for polarisation calibration.

- Poor understanding of beam leads to false polarisation i.e. Q = XX-YY

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Why do we want to know the beam shape?

ATCA

ASKAP

14 Jy Bandpass calibrator
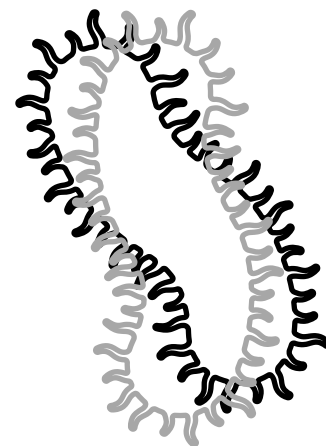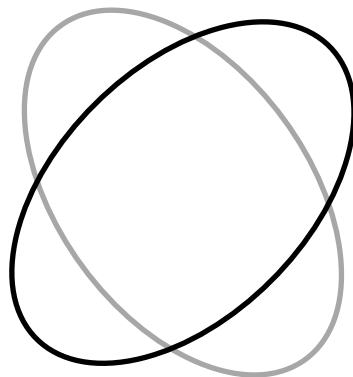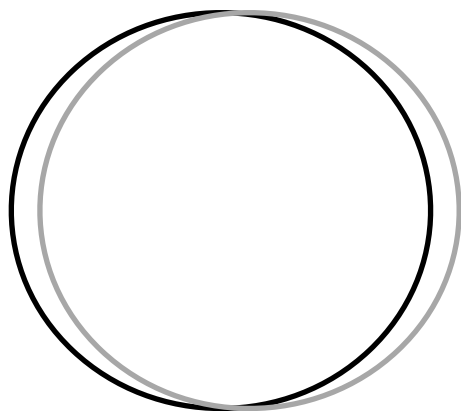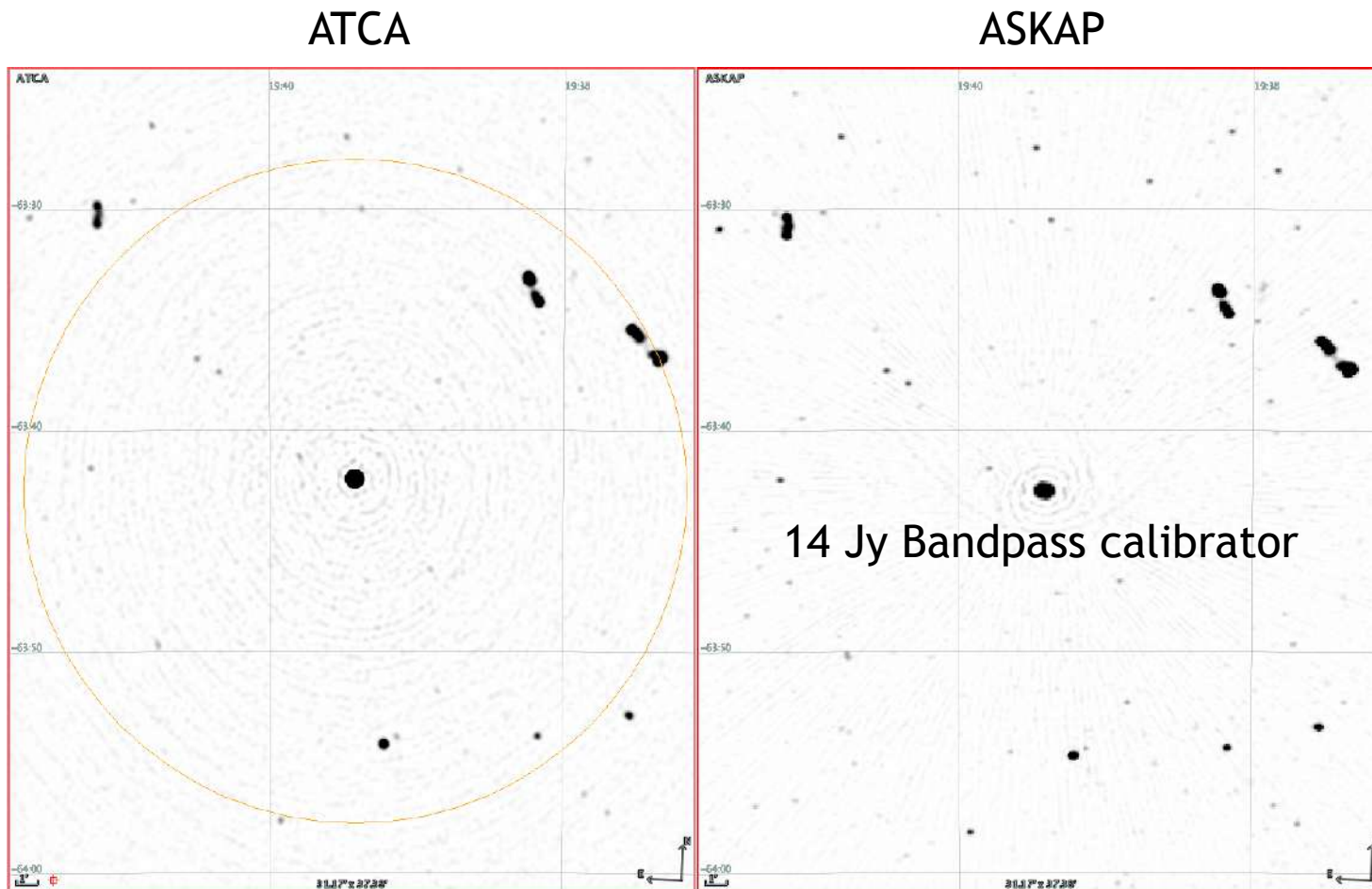
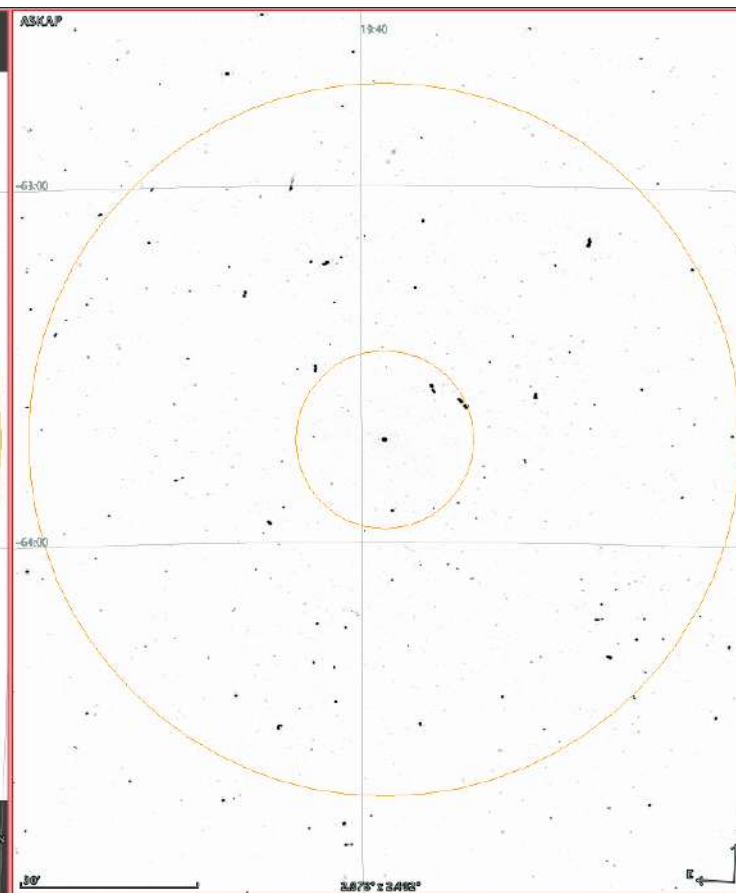For high-dynamic range we need to know how to calibrate what is in the beam.
Frequency-dependent beam attenuation can cause unusual spectral curvature on edge sources.

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Why do we want to know the beam shape?
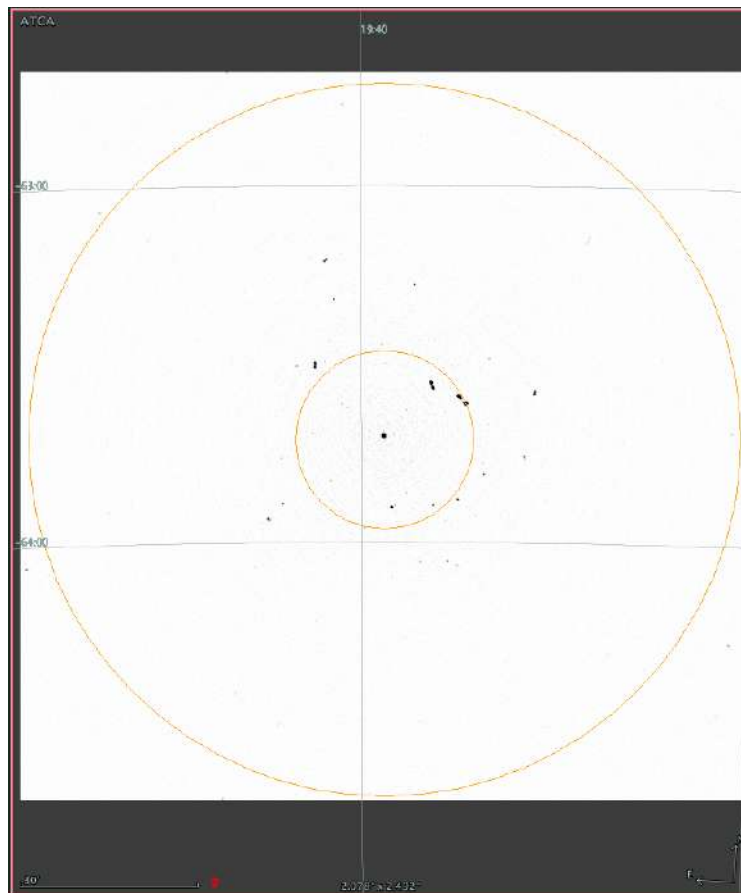
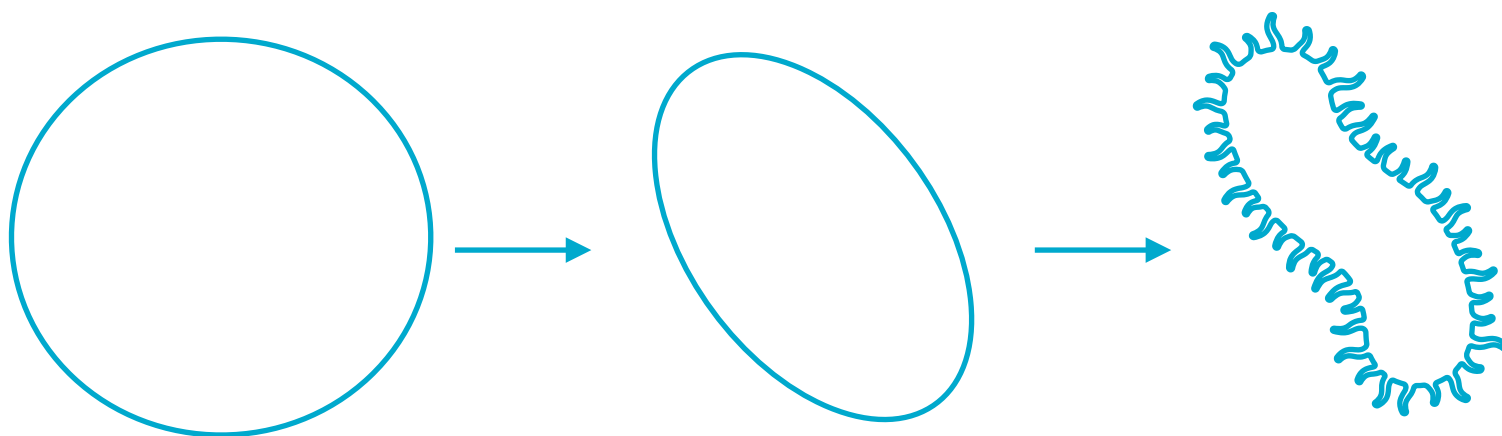ATCA   ASKAP

The beam null is not entirely obvious because this is a wide-band image and the null occurs at different locations for different frequencies.

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Why do we want to know the beam shape?

- How does the beam change with frequency?

- Are the beams consistent across antennas?

- Is the beam stable with time?

- Is the beam stable with pointing direction?

# How do we measure the primary beam?
Holography with astrophysical source

Use signals between reference antenna and remaining antennas to determine response for each antenna by using known model of astronomical source.

Reference antenna(s)

Antennas for which beam is to be mapped

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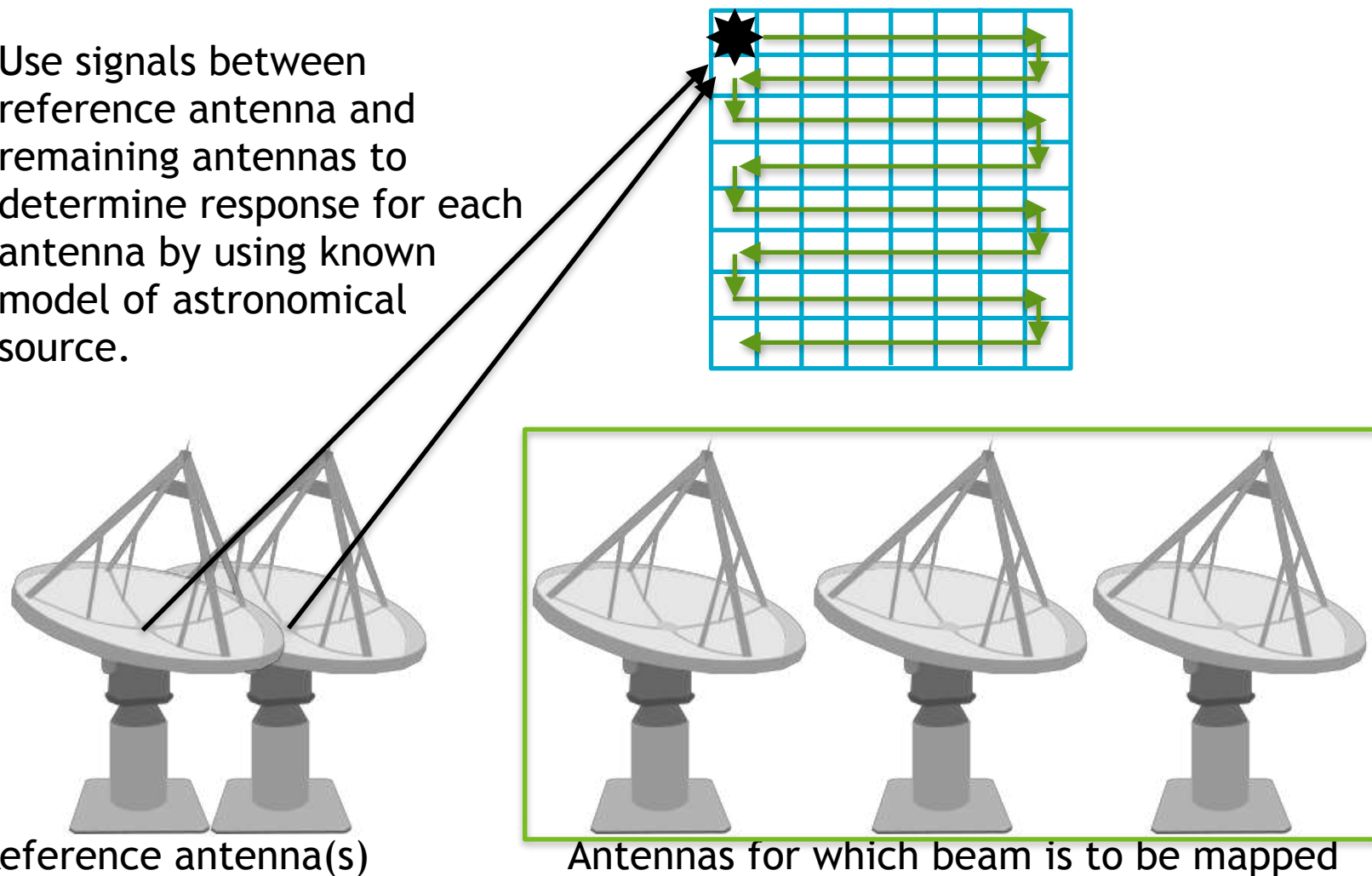
How do we measure the primary beam?
Holography with artificial source

- Artificial source (satellite) provides a line of sight probe.
- Measure satellite emission as it passes through the beam.
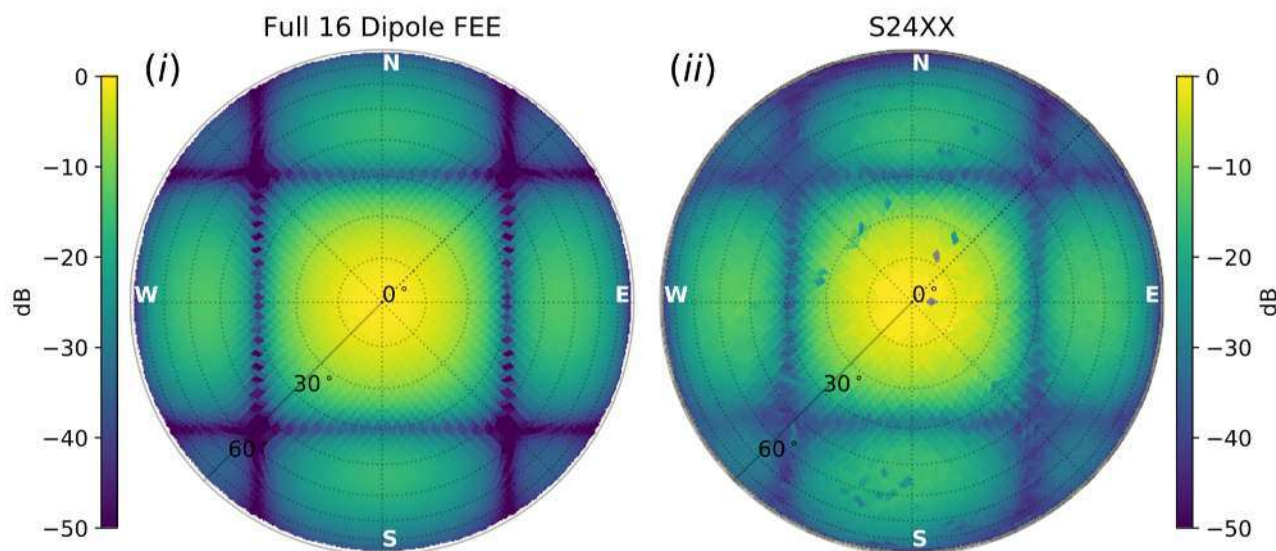
Line et al. (2018)

- Obtain a good indication of a beam shape at a frequency you probably can't practically observe at.
- Gives an indication of how well your beam model performs at that frequency (see Daniel's talk - beam is pointing and frequency dependent)

How do we measure the primary beam?
Drift Scans – Useful for dipole instruments
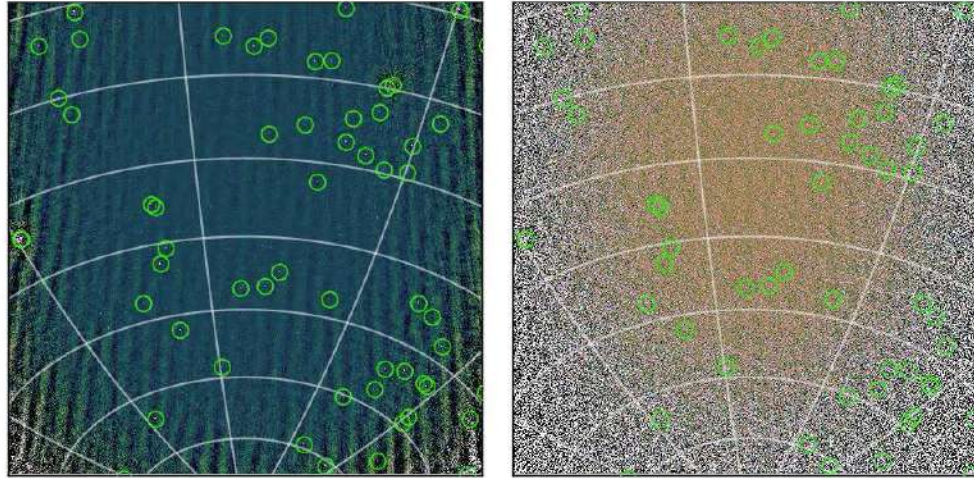
- Keep beam fixed
- Measure sources as they drift through the beam
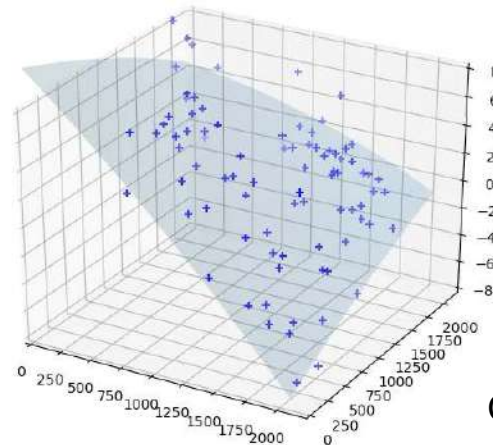
Credit: Lenc et al. (2018)

Holography with multiple beams (ASKAP)
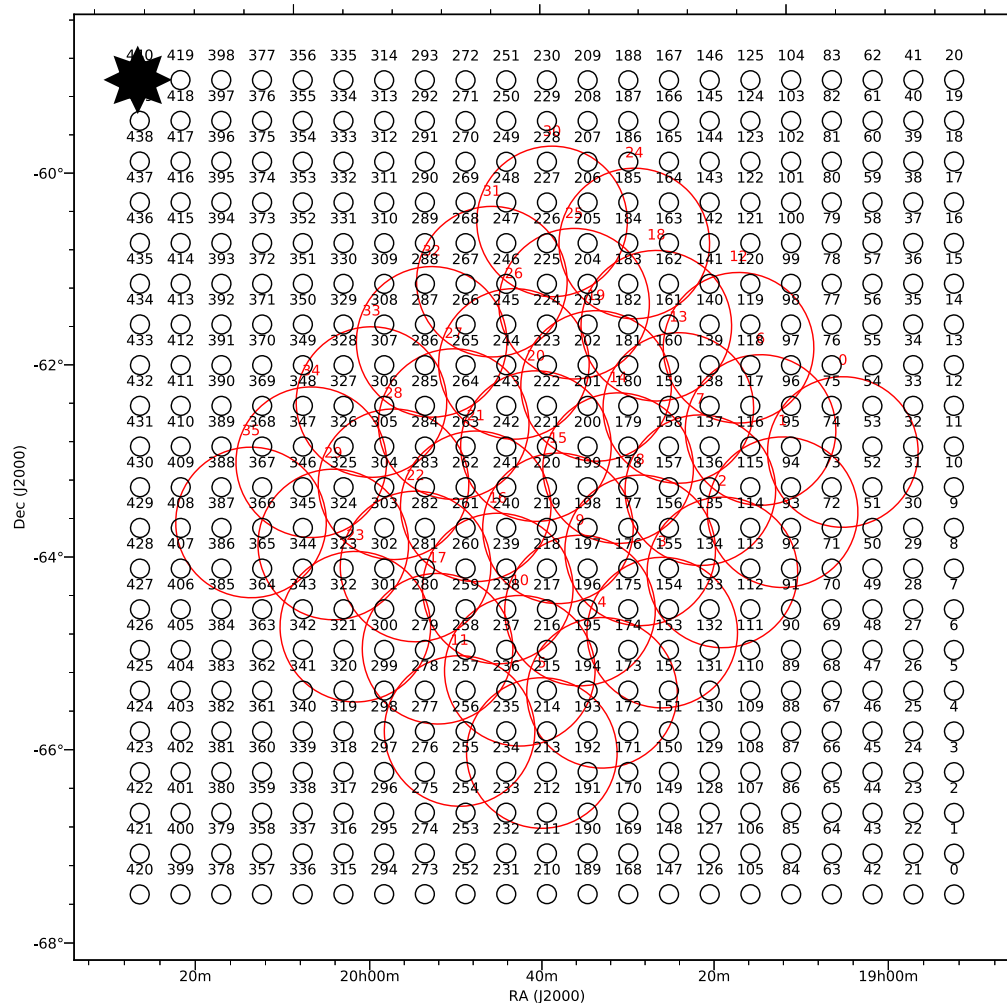
ASKAP Holography

4880 AK03 959 MHz
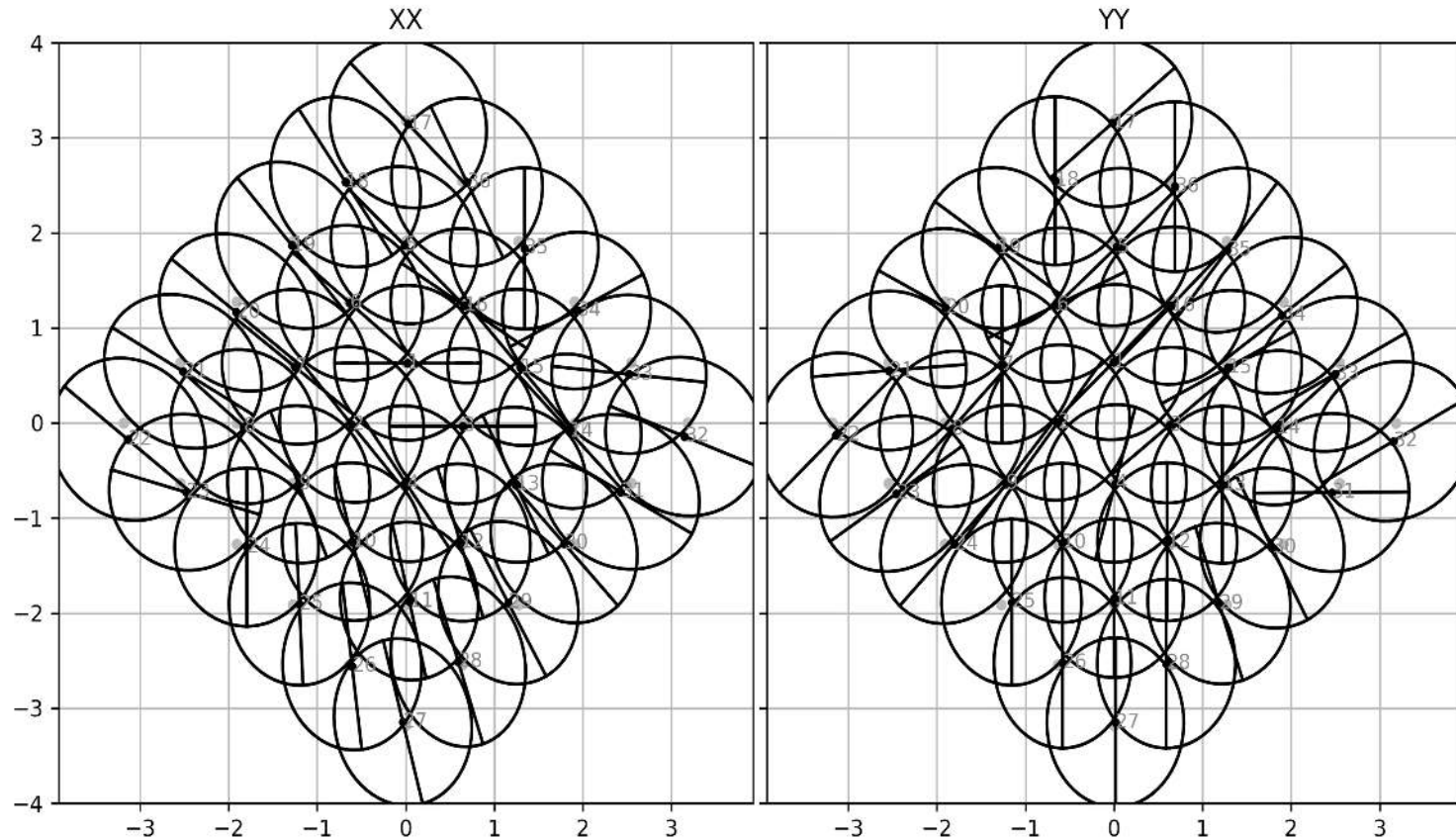
Credit: David McConnell

Factors affecting beam quality

Pointing errors

Obstructions

Deformation

Antenna Shadowing

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Factors affecting beam quality

- Dipole-based antennas:
  - Dipole orientation
  - Mutual coupling (beam shape depends on where dipole is within tile/station).
  - Faulty dipoles
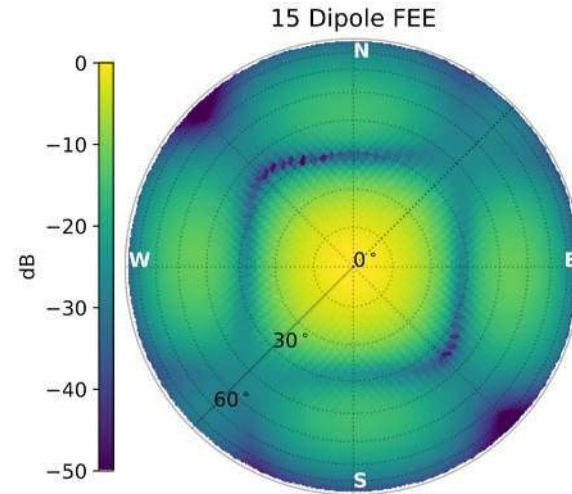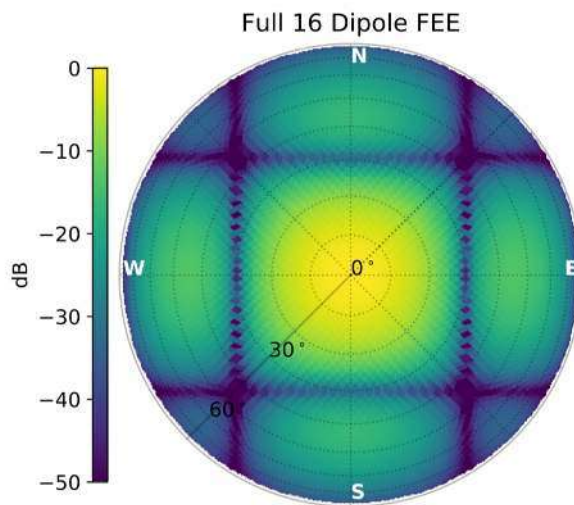
One faulty dipole
(note: not all faults are equal)

Factors affecting beam quality

- Phased Array Feeds (PAFs)

  - Faulty elements

  - Temperature effect on gains

  - Radio interference during beam-forming

AK30 793 MHz
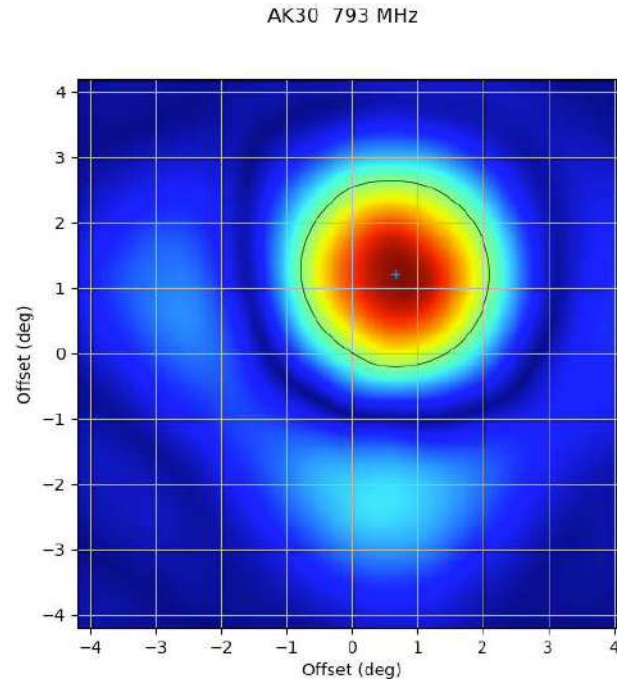
Improving the beam

Credit: Wikipedia

Phased array feed beam-forming
- Can sacrifice sensitivity for beam symmetry or a more well-defined beam.
- Can have many beams!
- Use beam-forming to null RFI source.
- Refer to Aaron Chippenale's talk for more details.

Improving the beam
Transparent Feed Legs

Credit: Wikipedia

Credit: Steve Barker

Now you see them   …   Now you don't?

Transparent feed legs are still under testing but it is anticipated they will improve the beam pattern and antenna efficiency by ~10%.

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Improving the beam

Roll axis (Third axis)
- Accounts for sky rotation in Alt-Az mount i.e. de-rotates beam.
- Can also be used to aid polarisation calibration.

Improving the beam

MeerKAT Antenna   Credit: Wikipedia

Offset Gregorian feed can be used to avoid blockage from receiver and feed legs.

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Mitigating Beam Effects

- When mosaicking place beams close together so that central part of beam contributes the most toward the final image.
- For wide-band observations, don't forget beams are smaller at the higher end of the band.
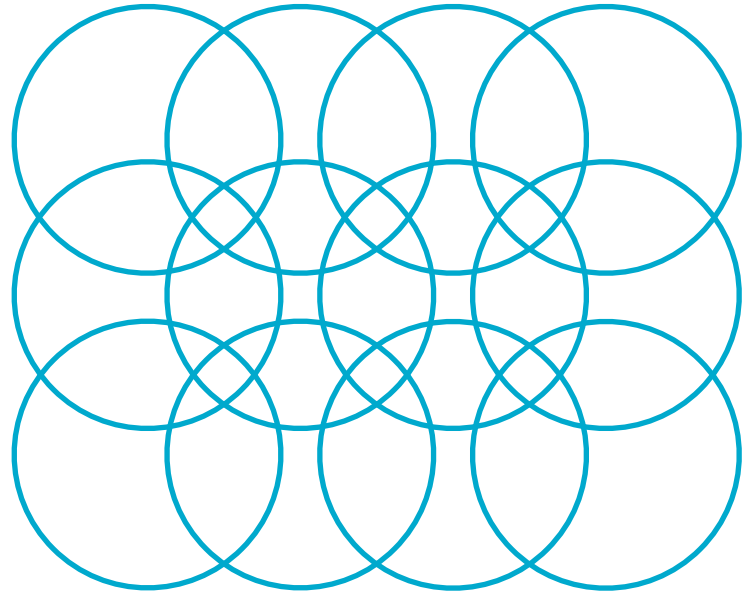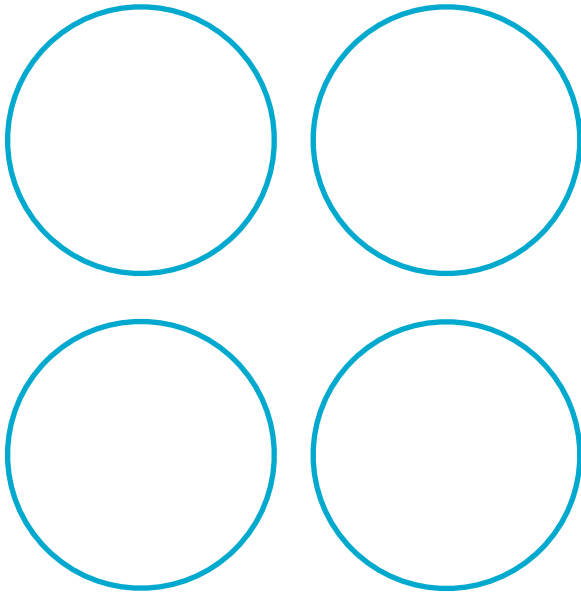
Mitigating Beam Effects

- For drift scans this can generally only be done in Right Ascension and the bulk of the error is a function of declination and can be calibrated empirically, e.g. see Hurley-Walker, N. et al. (2017)
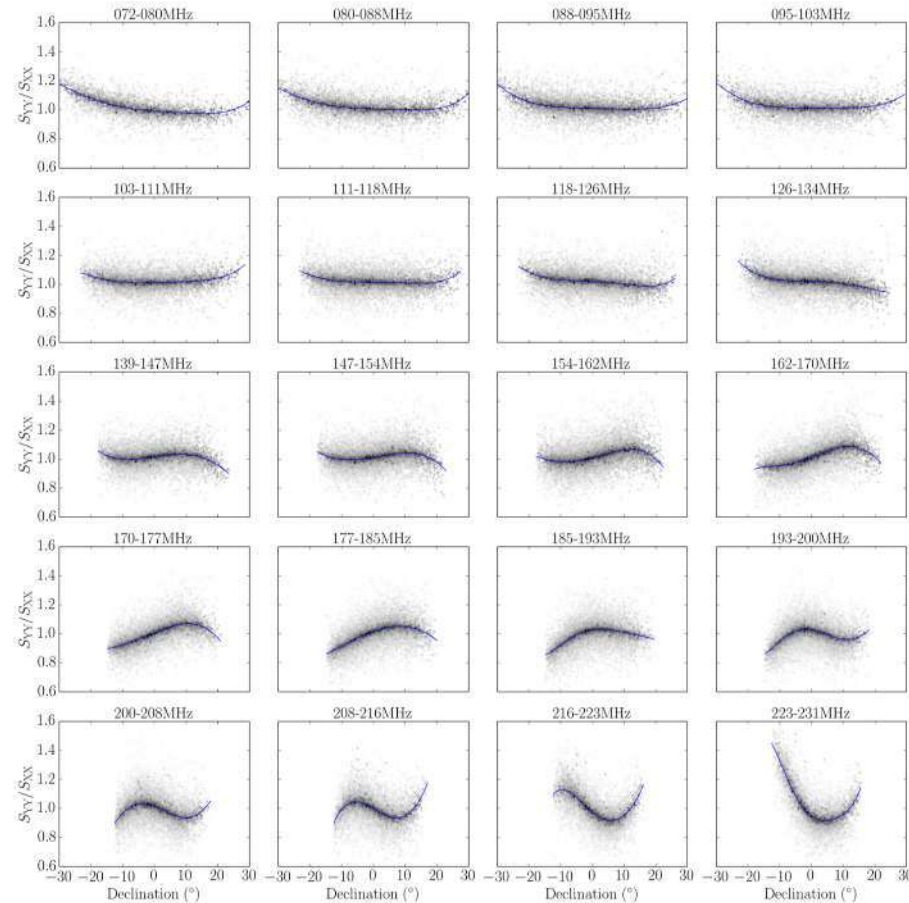
Fun Tricks with Beams

Credit: Kim Steele

Fly's eye mode
- Use 36 beams in each path
- Use 36 antennas pointing independently
- Effectively 36 x 36 = beams
- Powerful tool for finding fast transients

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Fun Tricks with Beams

Rotate the third axis slightly in one antenna to induce polarised signal for calibration purposes.

Reading Material

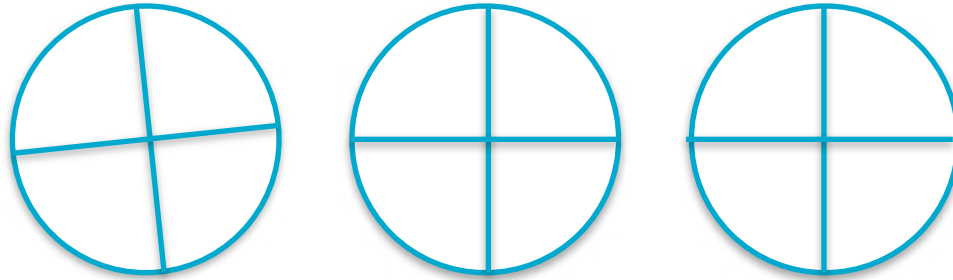- Napier, P.J., "The Primary Antenna Elements", Synthesis Imaging in Radio Astronomy II, 1999 : http://adsabs.harvard.edu/abs/1999ASPC..180...37N - basic introduction

- Wieringa, M, Kesteven, M.J., "Measurements of the ATCA primary beam", AT MEMO 39.2/010, 1992 : http://www.atnf.csiro.au/observers/memos/d96b7e~1.pdf - demonstration of how to measure the ATCA primary beam using a calibrator source

- Line, J. et al., "In situ measurement of MWA primary beam variation using ORBCOMM", PASA, accepted : http://adsabs.harvard.edu/abs/2018arXiv180804516L - demonstration of how to measure the MWA primary beam using satellites.

- Sutinjo, A. et al., "Understanding instrumental Stokes leakage in Murchison Widefield Array polarimetry", 2015, Radio Science, 50, 52 : http://adsabs.harvard.edu/abs/2015RaSc...50...52S - demonstration of beam modelling with simulations.

- Hurley-Walker et al., 2017, "GaLactic and Extragalactic All-sky Murchison Widefield Array (GLEAM) survey – I. A low-frequency extragalactic catalogue", MNRAS, 464, 1146 : http://adsabs.harvard.edu/abs/2017MNRAS.464.1146H - demonstration of empirical correction of beam uncertainties in MWA beam

- Lenc, E. et al., 2018, "An all-sky survey of circular polarization at 200 MHz", MNRAS, 478, 2835 : http://adsabs.harvard.edu/abs/2018MNRAS.478.2835L - demonstration of how to reduce the effects of Stokes I into V leakage as a result of poorly defined beams

- Riseley, C. et al., 2018, "The POlarised GLEAM Survey (POGS) I: First Results from a Low-Frequency Radio Linear Polarisation Survey of the Southern Sky", PASA, accepted : http://adsabs.harvard.edu/abs/2018arXiv180909327R - demonstration of how to reduce the effects of Stokes I leakage into Q/U as a result of poorly defined beams.

- McConnell, D., 2016, "The Australian Square Kilometre Array Pathfinder: Performance of the Boolardy Engineering Test Array", PASA, 33, 42 : http://adsabs.harvard.edu/doi/10.1017/pasa.2016.37 - PAF beam performance.

- Sault, R.J., 2014, "Initial characterisation of BETA polarimetric response", ASKAP MEMO : ftp://ftp.atnf.csiro.au/pub/people/sau078/memos/askap-1.pdf - example of using a beam rotation to calibrate polarisation.

See also earlier talks, Aaron's talk on PAFs, Daniel's talk on Aperture Arrays, Tim's talk on Wide-field imaging, Elizabeth's presentation on error recognition, Ian's talk on high-dynamic range imaging, my talk on polarimetry … and pretty much every other talk at the school.

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Thank you

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