Broadband, wide-field polarimetry with ASKAP

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CSIRO ASTRONOMY AND SPACE SCIENCE, PERTH ASTROPHYSICS GROUP
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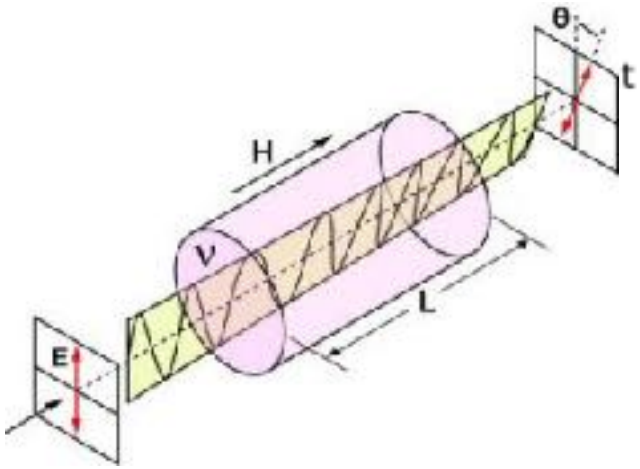
ASKAP as a broadband instrument

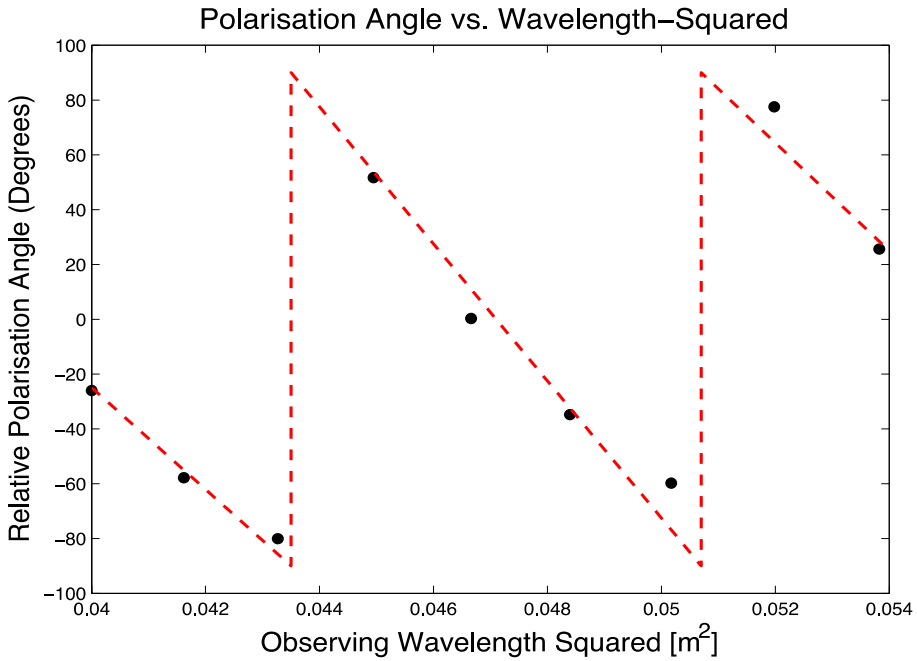
- ASKAP continuum surveys: 1.1—1.4 GHz
- 0.7—1.8 GHz actually observable with ASKAP (more or less)
- For some emerging topics in polarisation science…
  - ➢ the former band is inadequate
  - ➢ the latter band is particularly useful

Refresher: Faraday rotation



$$\theta = \theta_0 + \phi\lambda^2, \qquad (1)$$

$$\phi \propto \int_{source}^{telescope} n_e B \, dl \qquad (2)$$

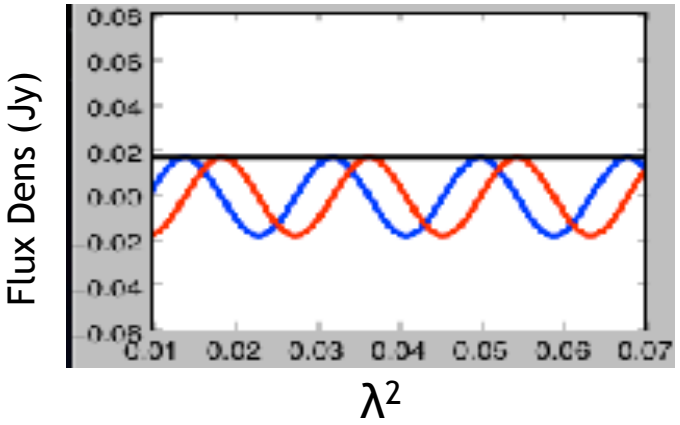


Faraday rotation

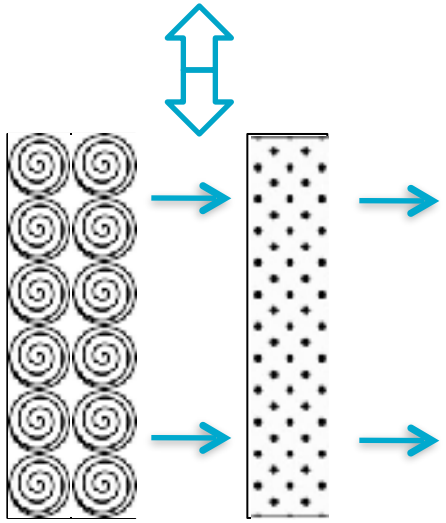
Stokes q

Stokes u

p



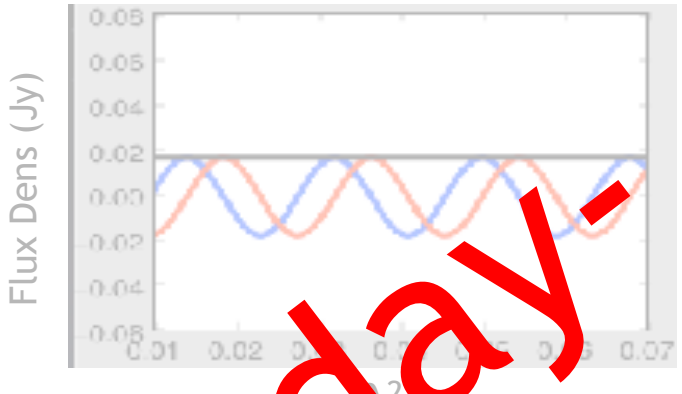
Corresponding physical arrangement:



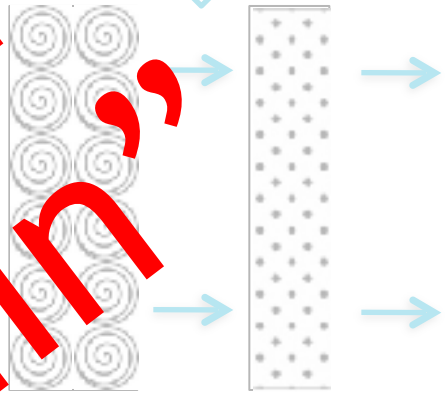
Synchrotron emitting medium

Faraday rotating medium

Faraday rotation



Corresponding physical arrangement:



"Faraday-thin"

Synchrotron emitting medium

Faraday rotating medium

Science in the Faraday-thin regime (i.e. full POSSUM)

- magneto-ionic structure of Milky Way on a range of scales
- magnetic properties of galaxies, clusters & IGM
- evolution of magnetic fields though cosmic time

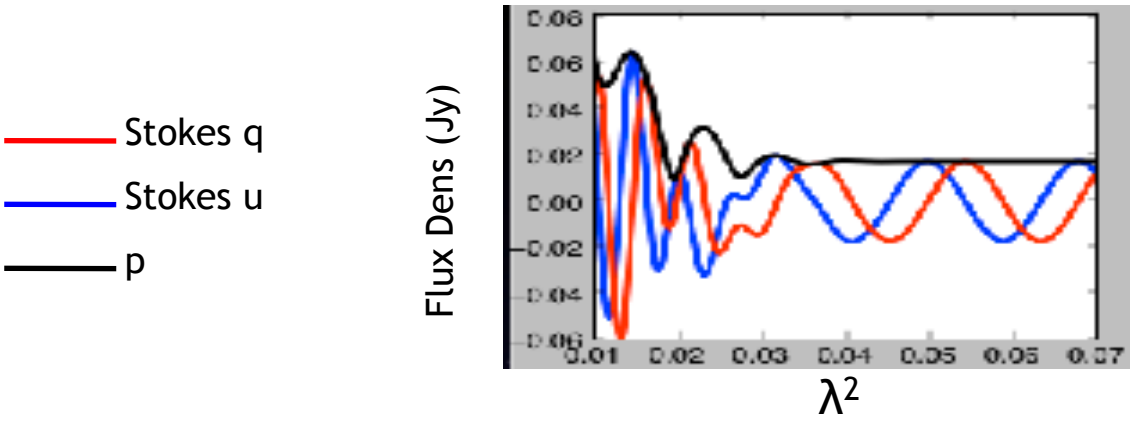
Science in the Faraday-thin regime (i.e. full POSSUM)

- magneto-ionic structure of Milky Way on a range of scales
- magnetic properties of galaxies, clusters & IGM
- evolution of magnetic fields though cosmic time

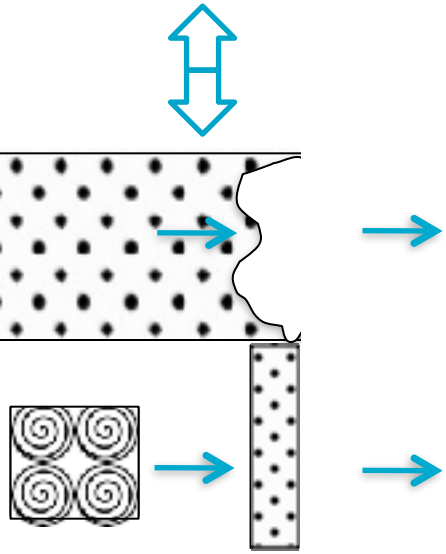
Underlying idea:

Use ensembles of radio sources to ‘back-illuminate’ regular magnetic field structures in the foreground

Faraday interference effects



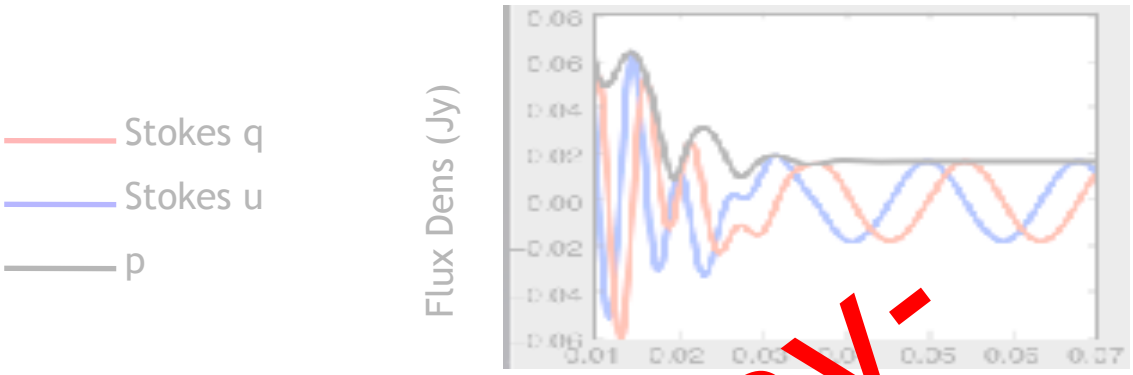
(One possible) corresponding physical arrangement:



Synchrotron emitting medium

Faraday rotating medium

Faraday interference effects



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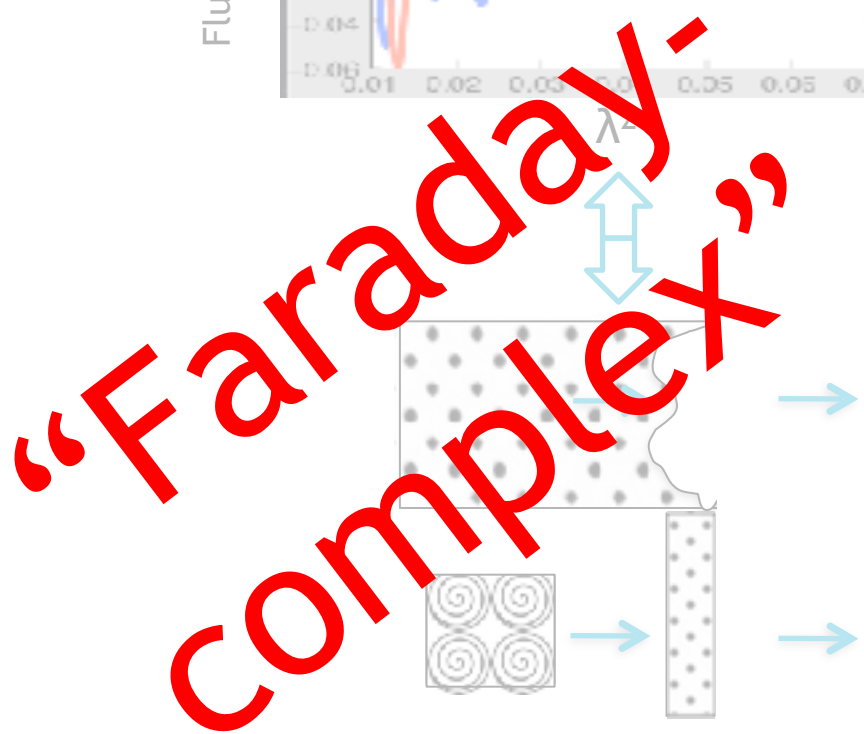
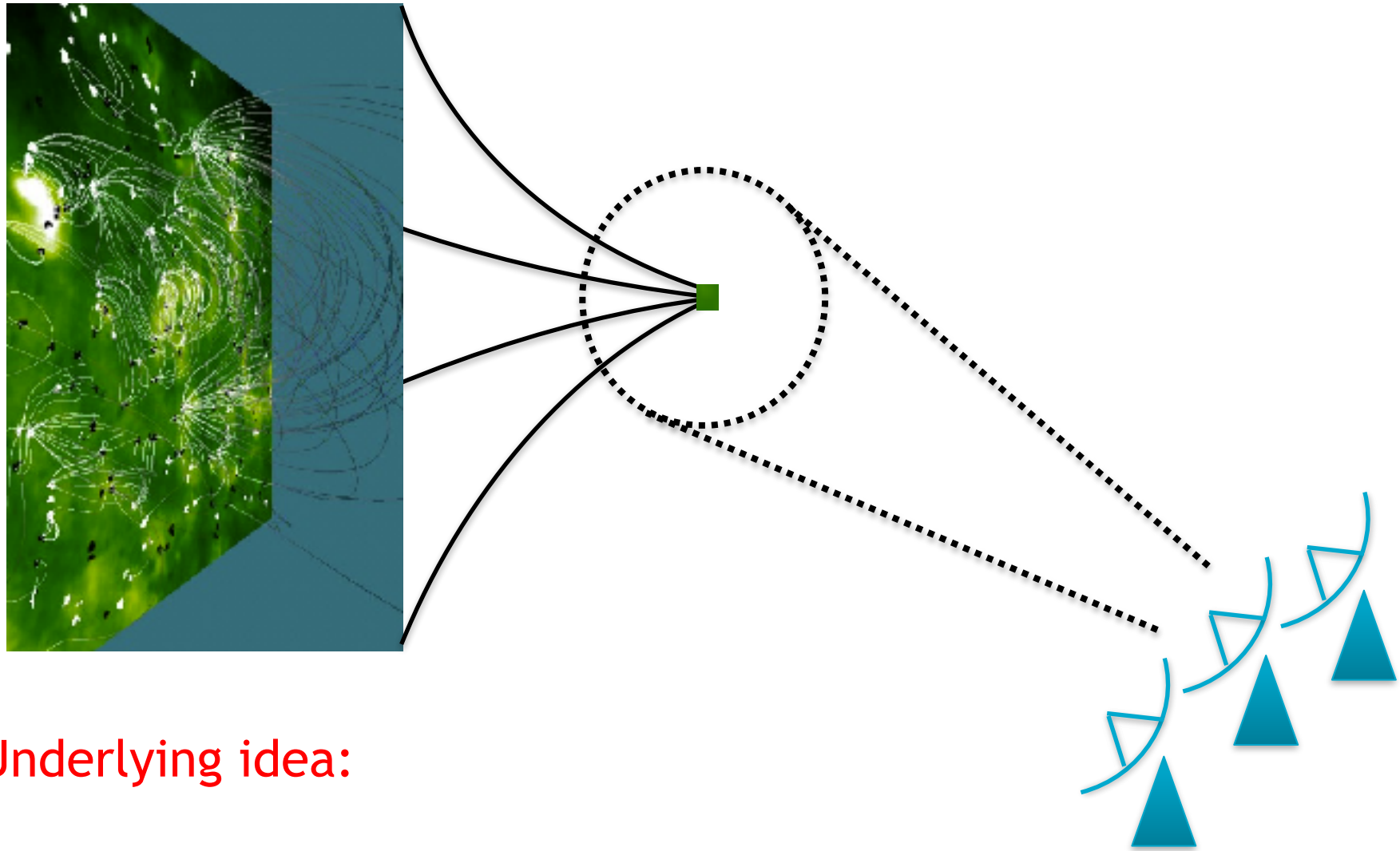


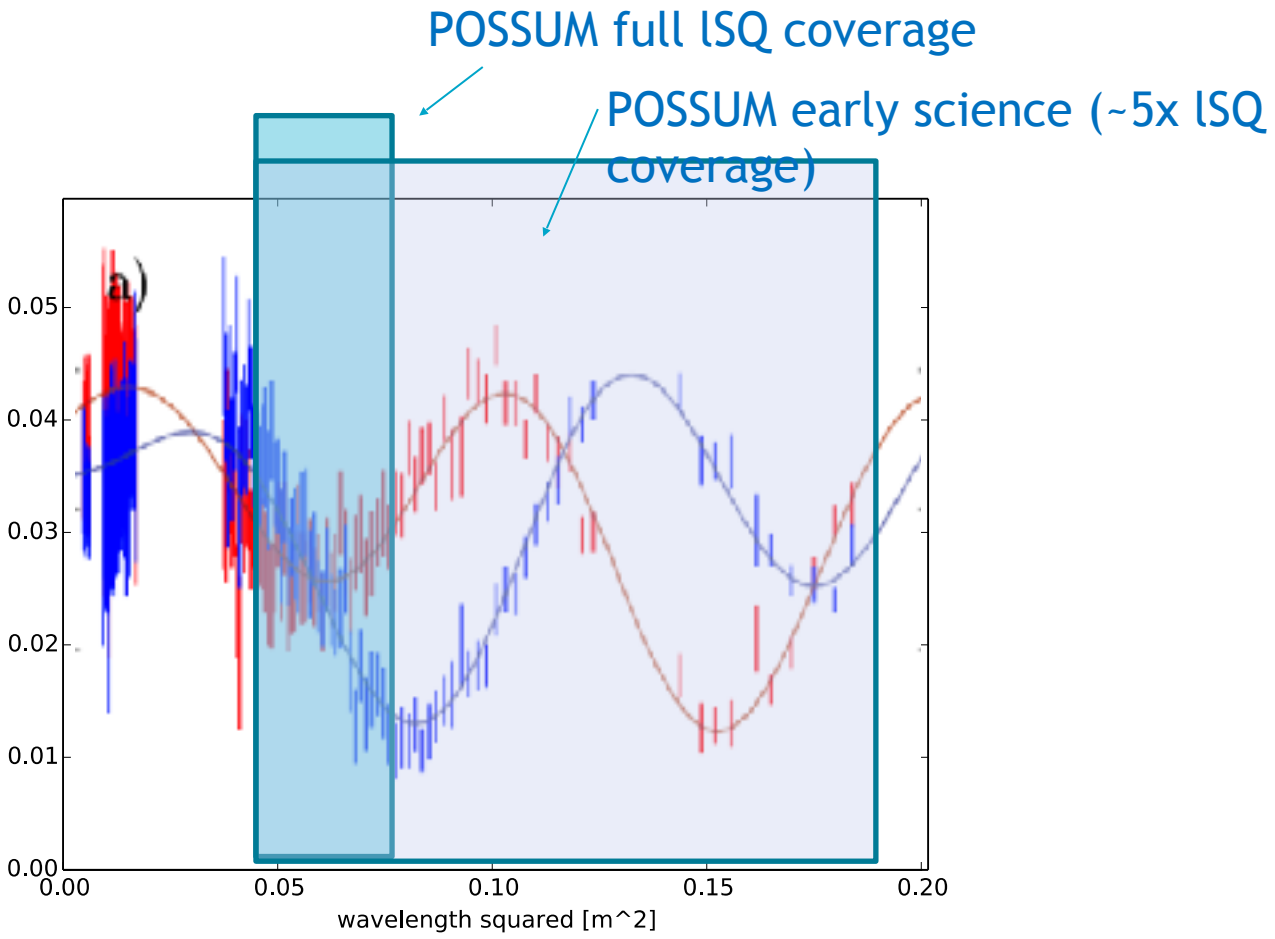
Faraday complexity



Underlying idea:

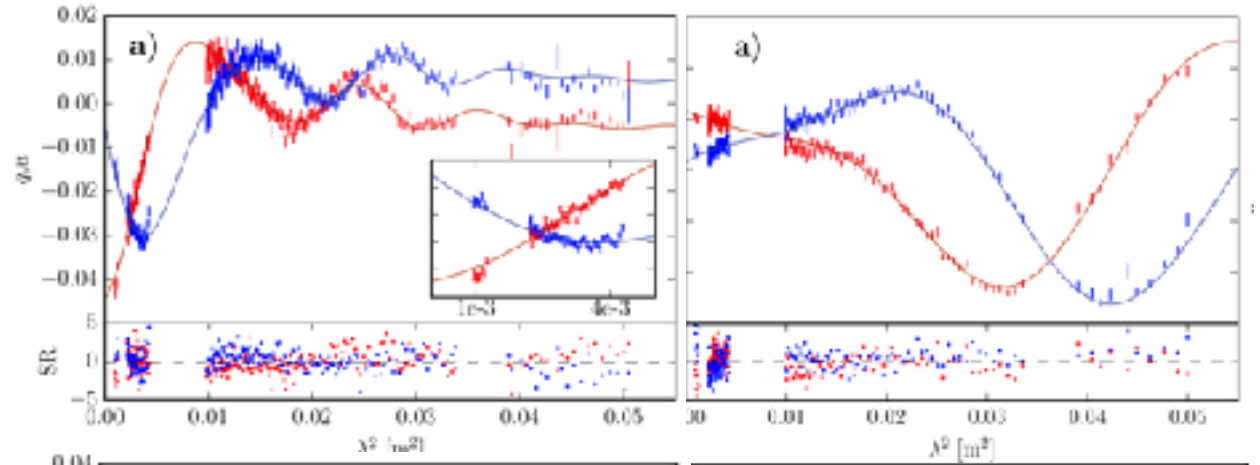
Constrain the fine-scale (sub-resolution) structure of magnetised plasmas along individual sight-lines

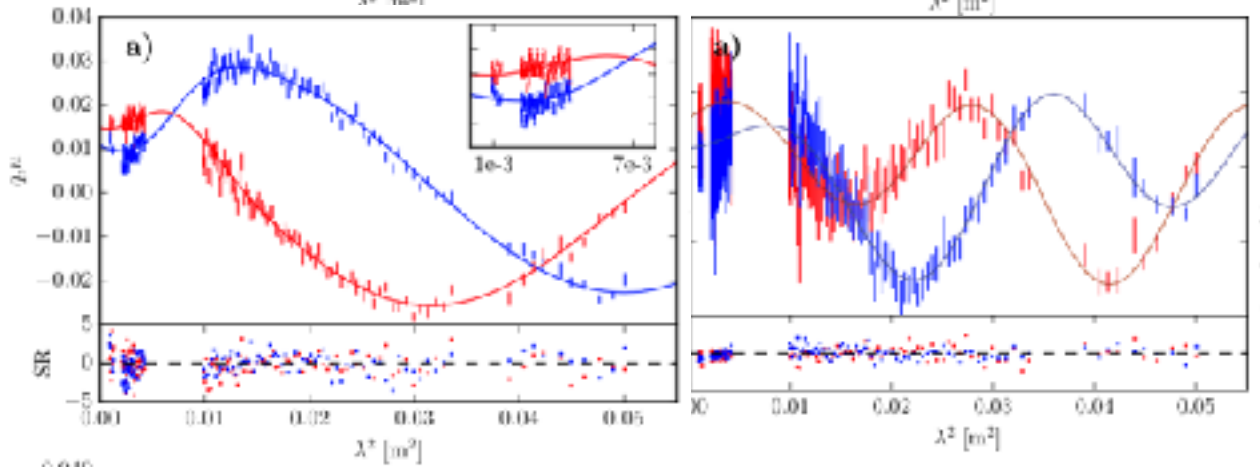
Faraday complexity

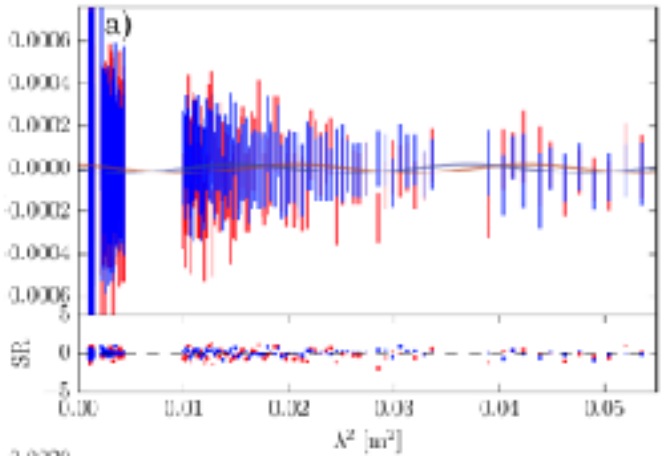


Broadband polarisation science

- Rich polarisation behaviours observed in individual sources



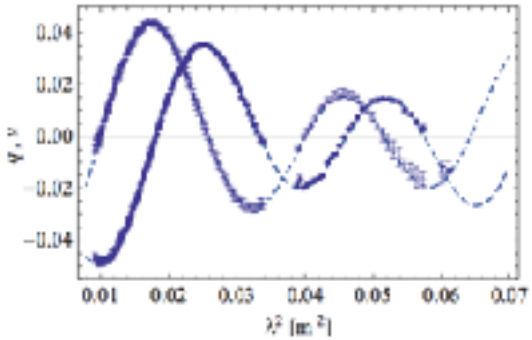




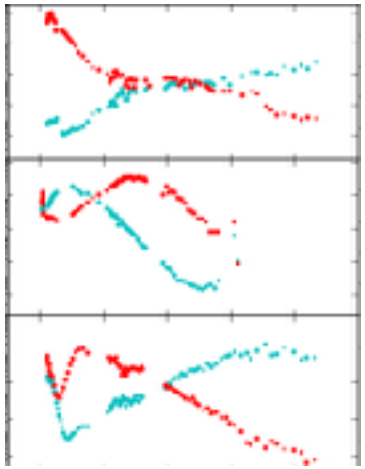
Anderson+ 2016

Broadband polarisation science

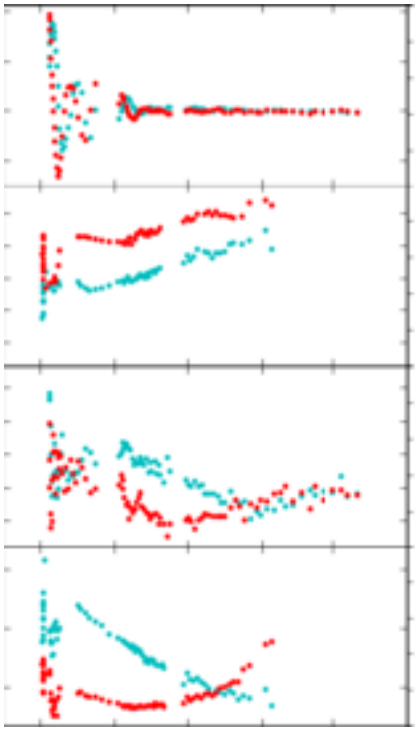
- Lest you think these are rare…

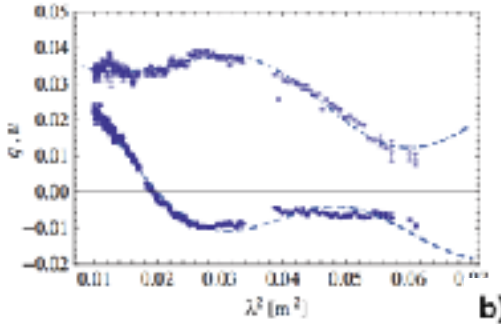


O'Sullivan+ 2012

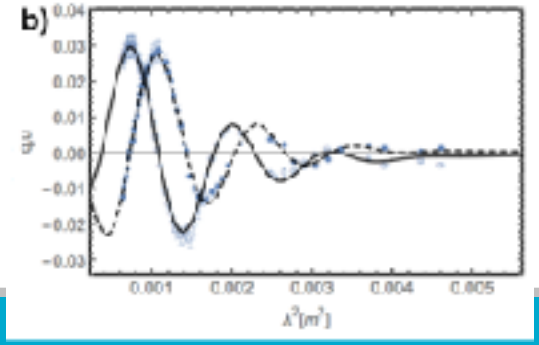


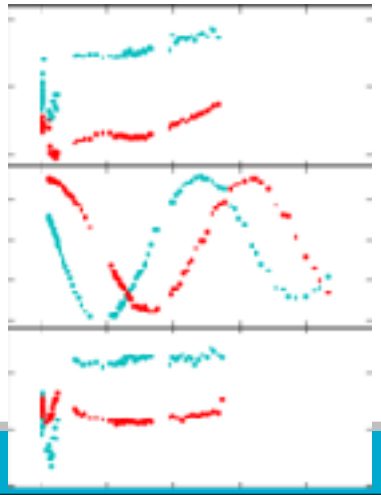
Kim+ 2016





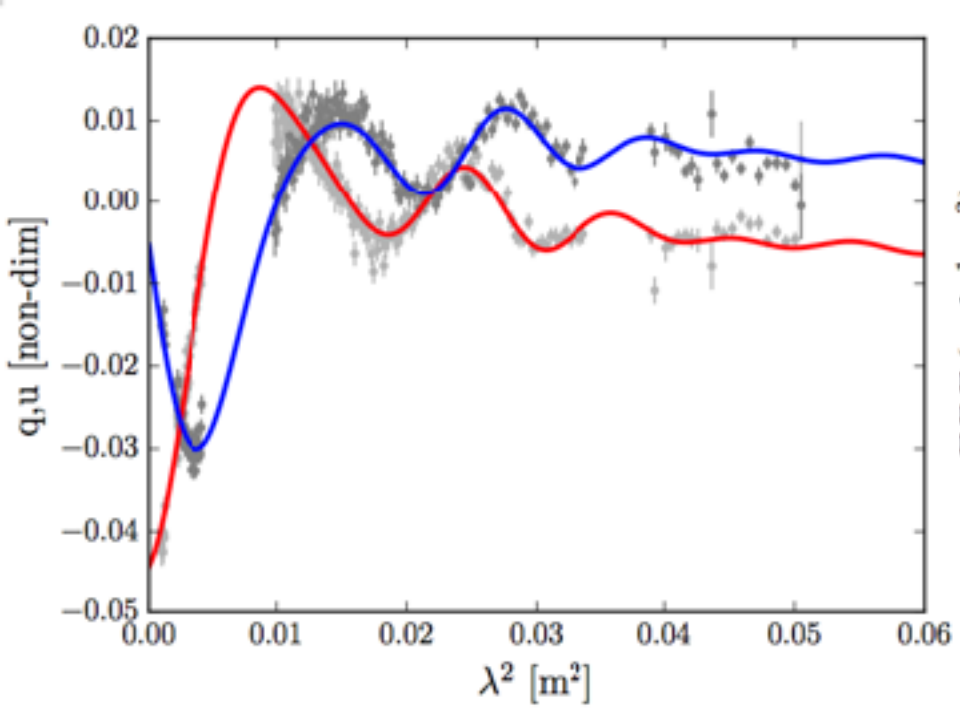
Pasetto+ in prep.

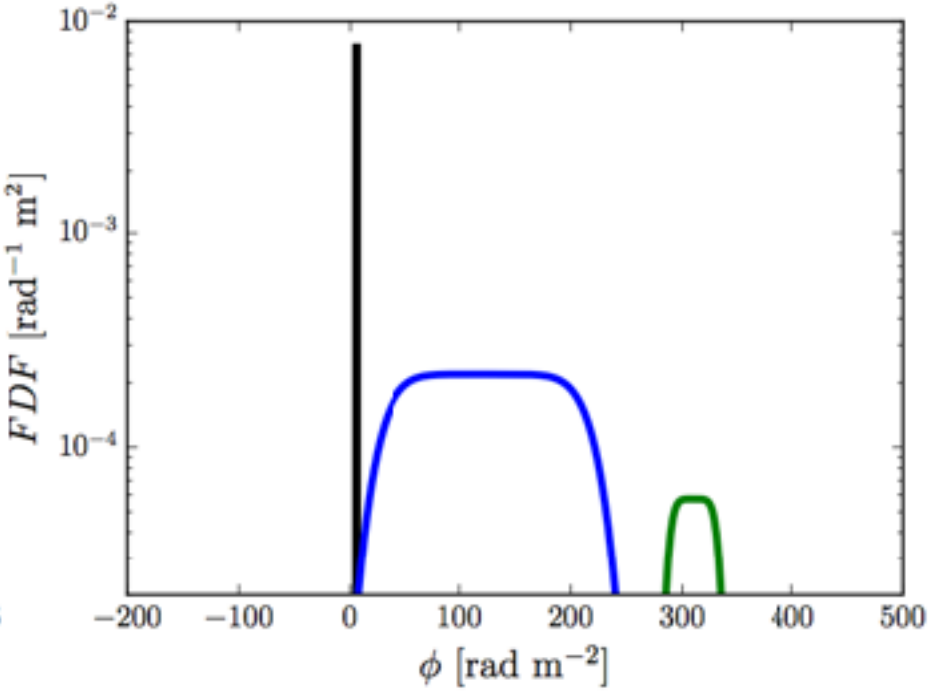




Broadband polarisation science

- Constraining global magnetised and ionised gas structure of environments of jets and AGN

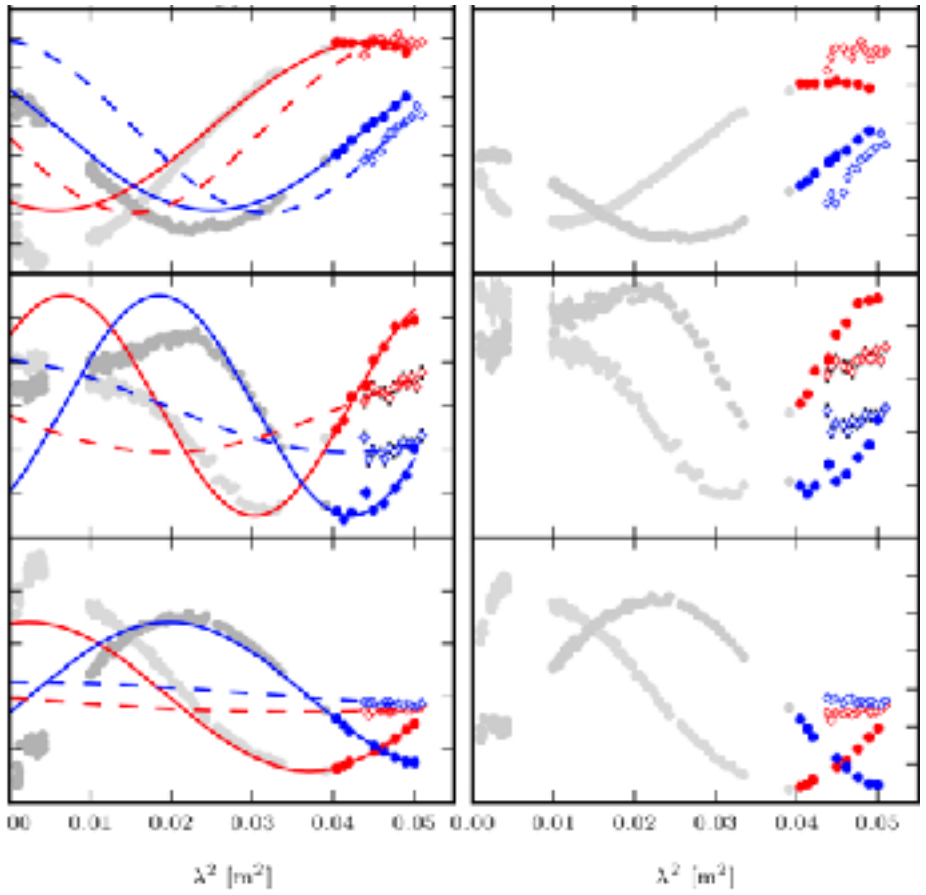




Anderson+ 2016

Broadband polarisation science

- Taking it into the time-domain



Anderson+ 2016

Broadband polarisation science

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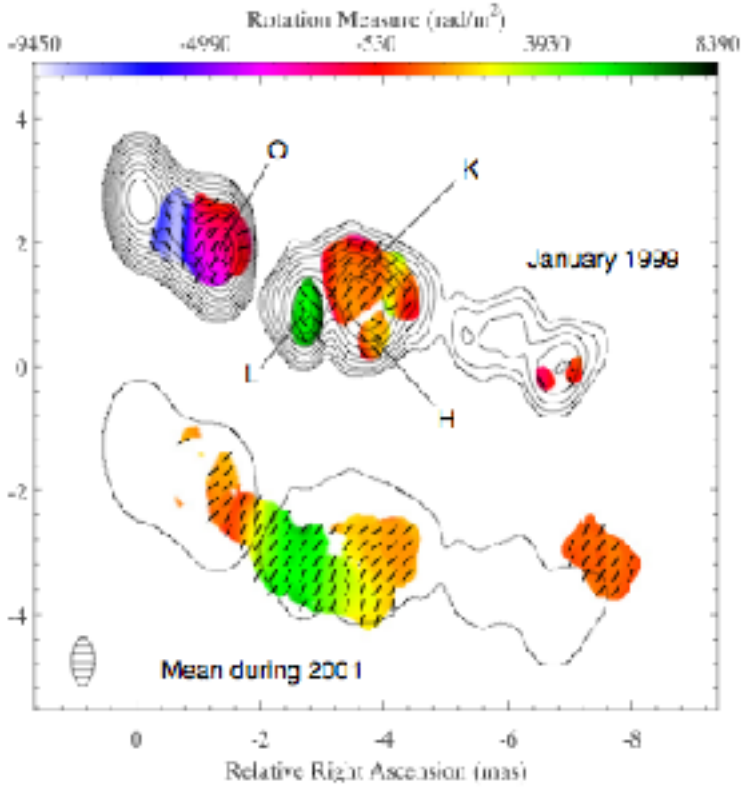
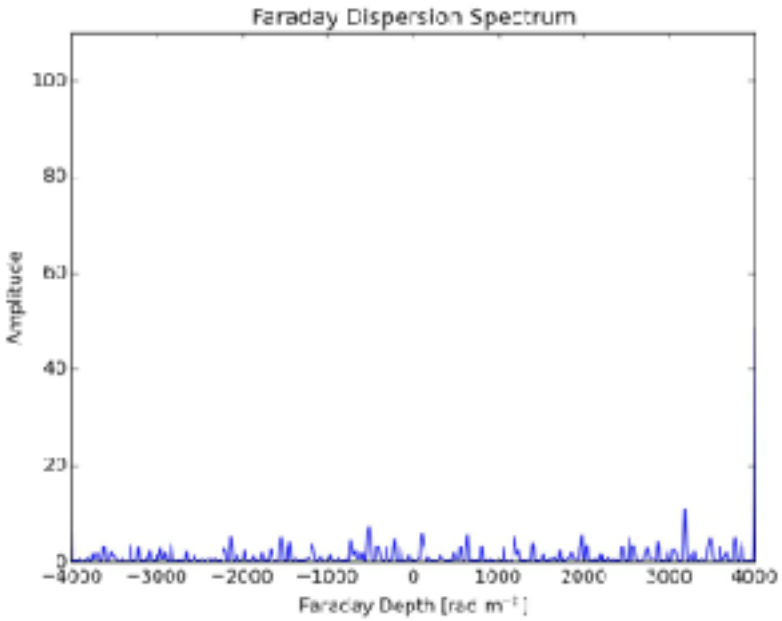
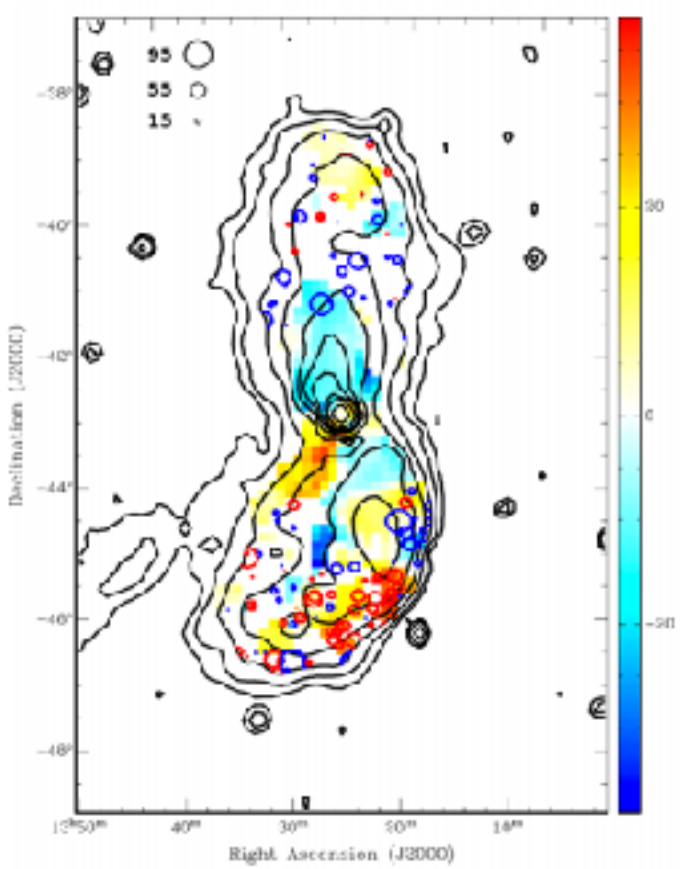




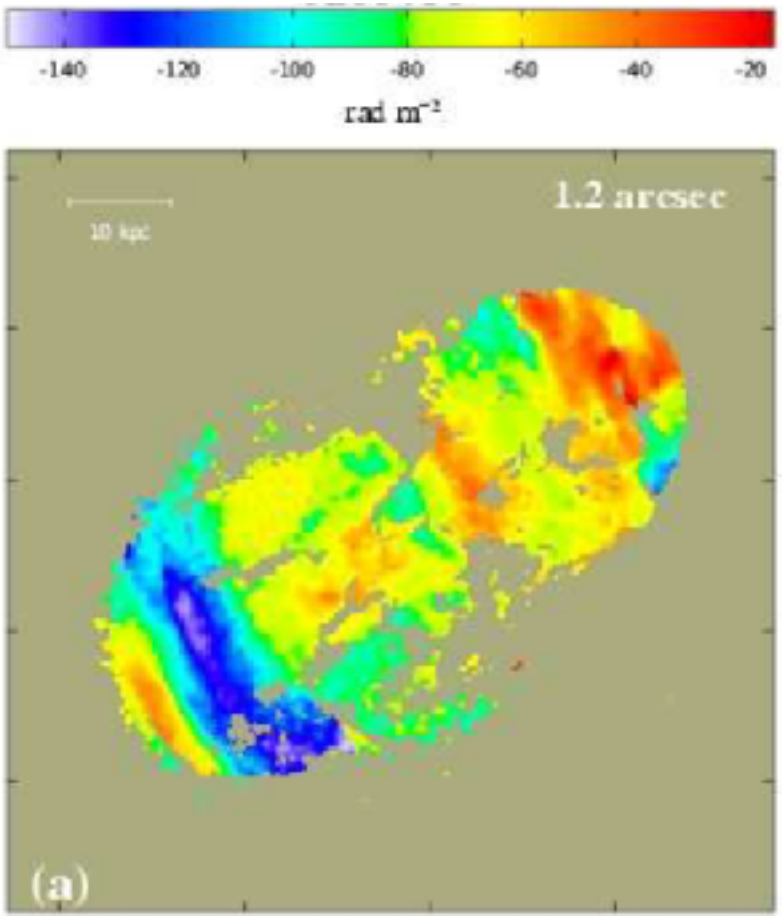
Gomez+ 2011

Broadband polarisation science

- Radio lobe structure



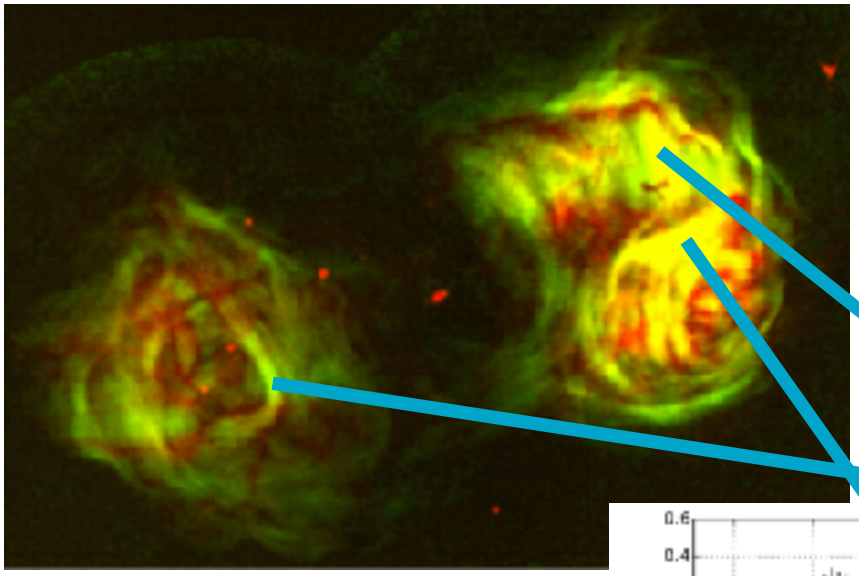
O'Sullivan+ 2013



Guidetti+ 2012

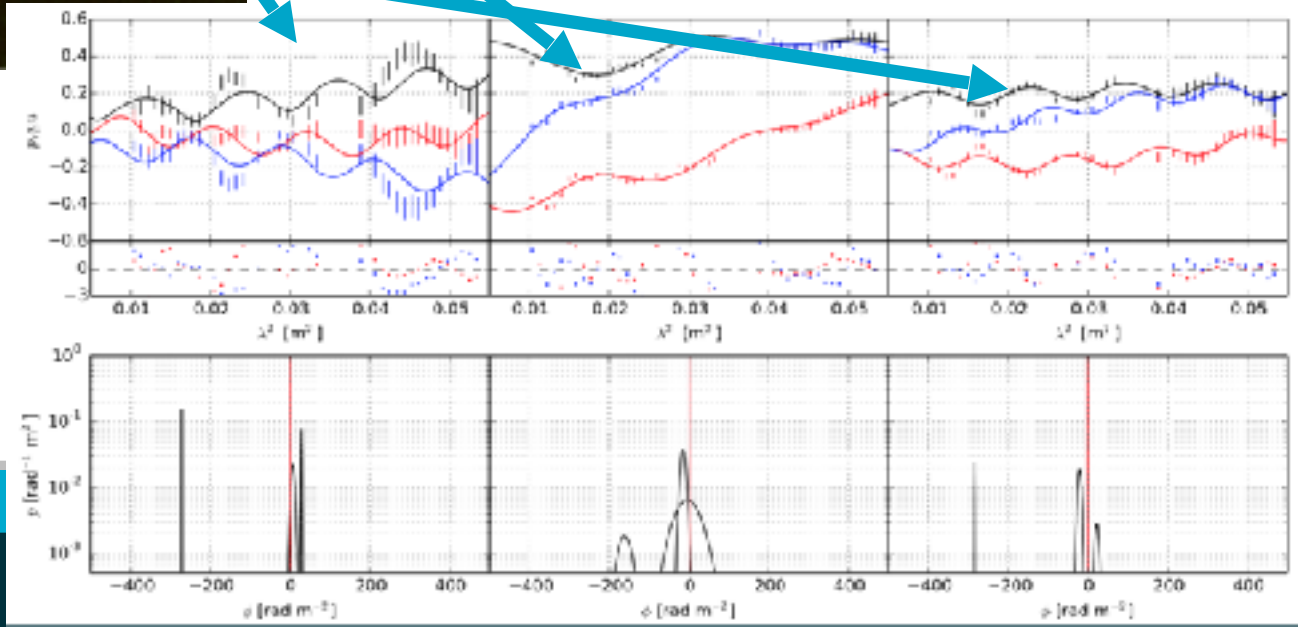
Broadband polarisation science

- Radio lobe structure

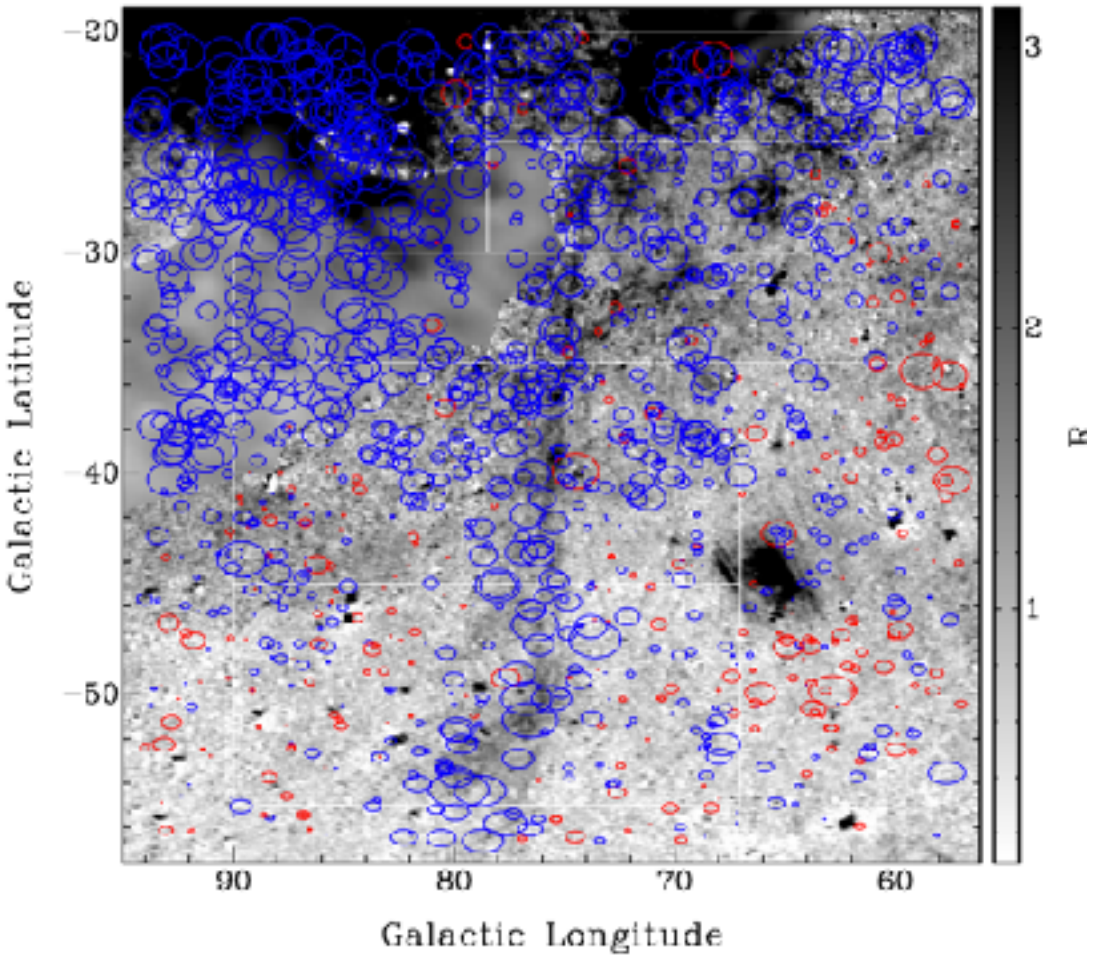


Fomalont+ 1989

Anderson+ in prep.



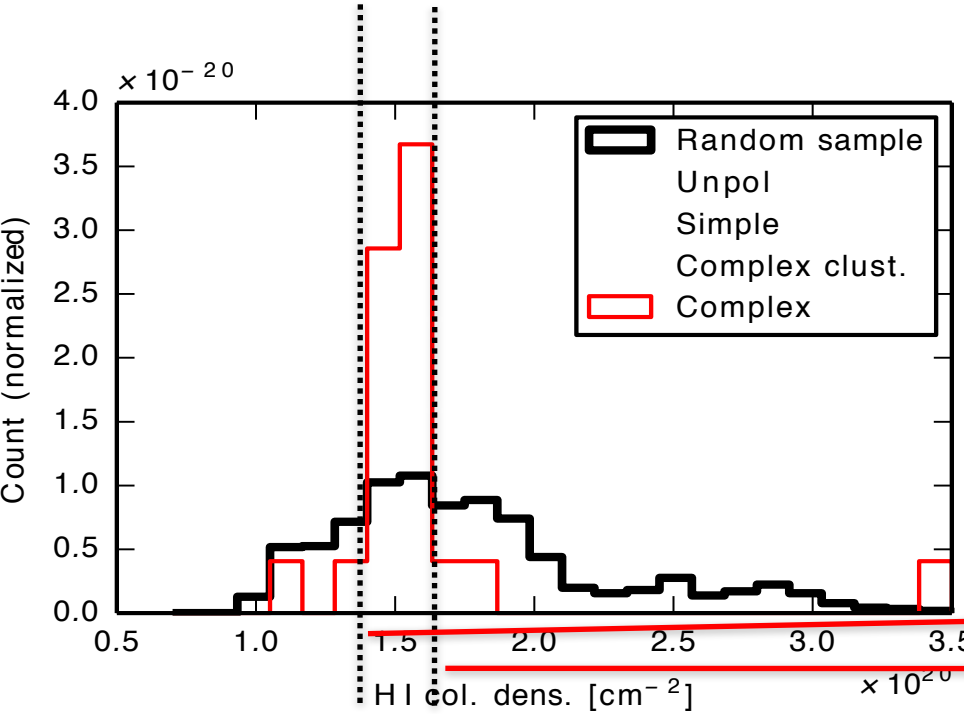
Broadband polarisation science

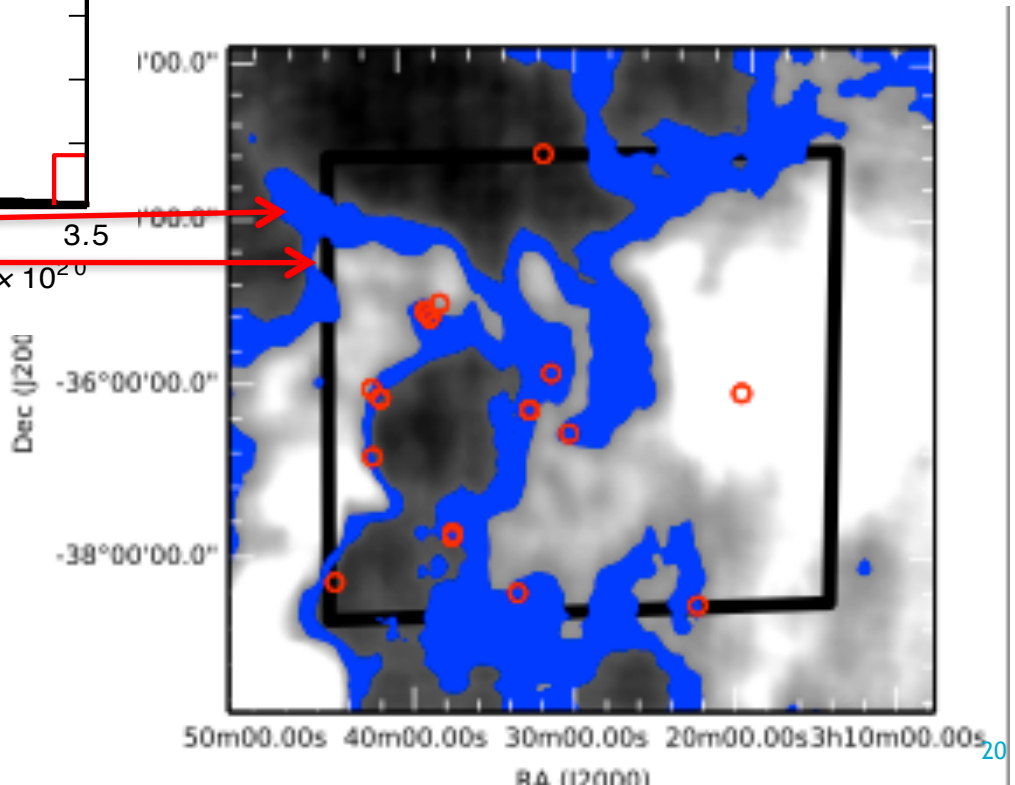


Stil & Hryhoriw 2016

Broadband polarisation science

- Ensembles of sources for ‘depolarisation grids’





Anderson+ 2015

A broadband, wide-field survey

- Broadband polarisation signals still contain degeneracies
- Need large samples to gain statistical purchase, facilitate multi-wavelength comparison

-> Has helped motivate a broadband ‘early science’ survey on ASKAP:

- ➢ ~8000 polarised sources
- ➢ 0.7—1.8 GHz
- ➢ generally fields w/ good multi-wavelength coverage

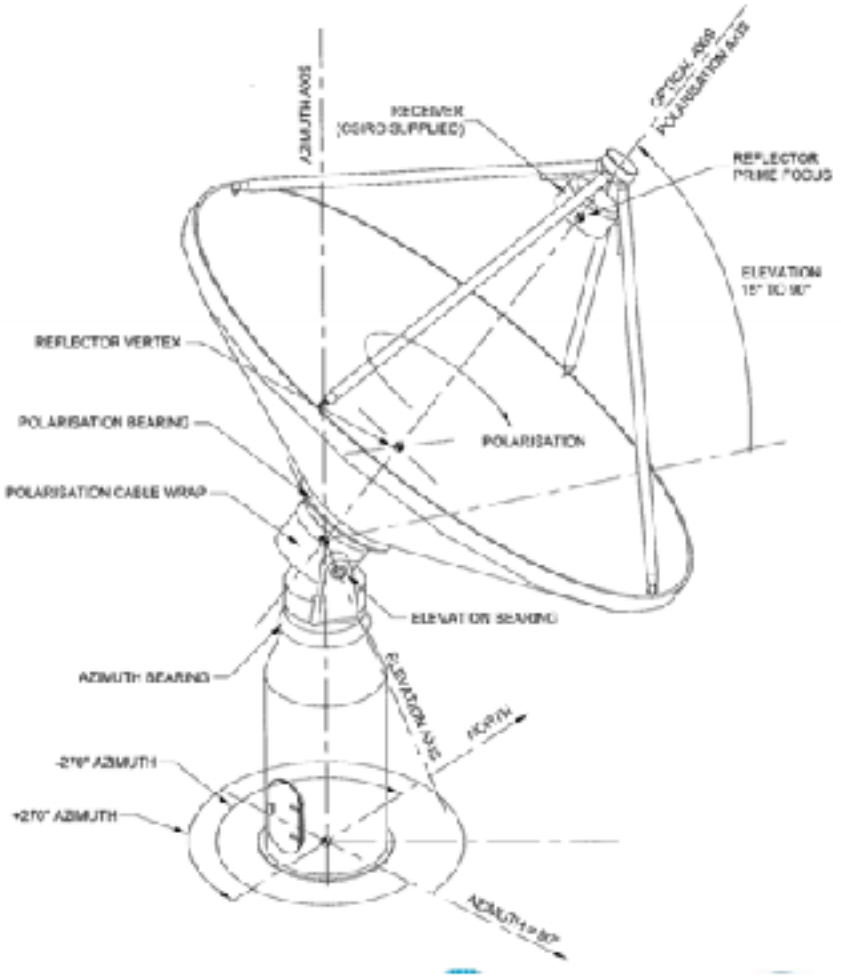
ASKAP in polarisation: Towards early science

Acknowledgements

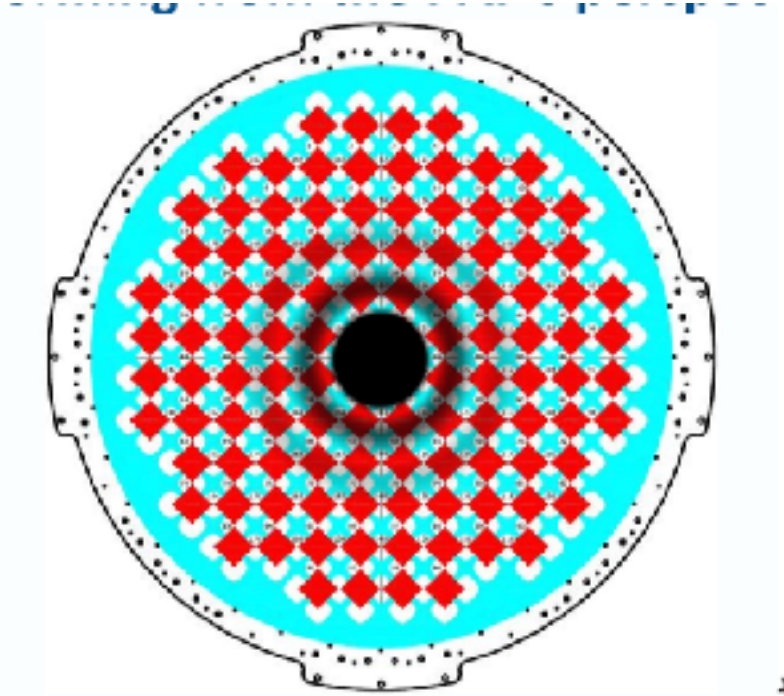
The ACES team, especially:

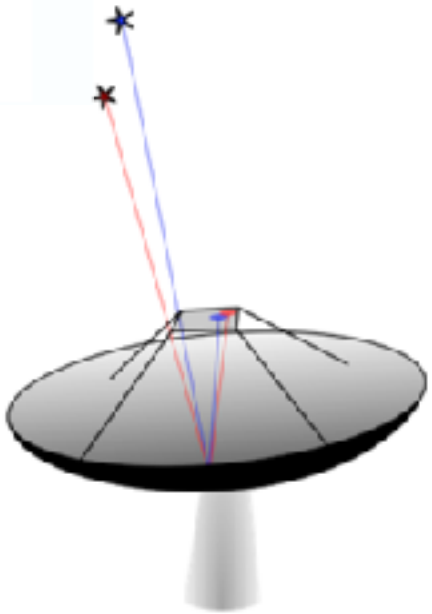
Wasim Raja
Sarah Hegarty
Bob Sault
Daniel Mitchell
Aidan Hotan
Dave McConnell
George Heald
Aaron Chippendale

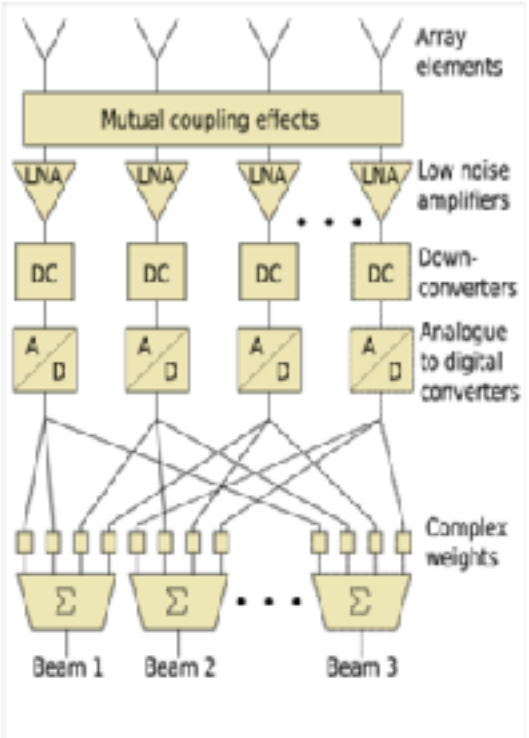
Antenna design



Antenna design - PAFs and beams

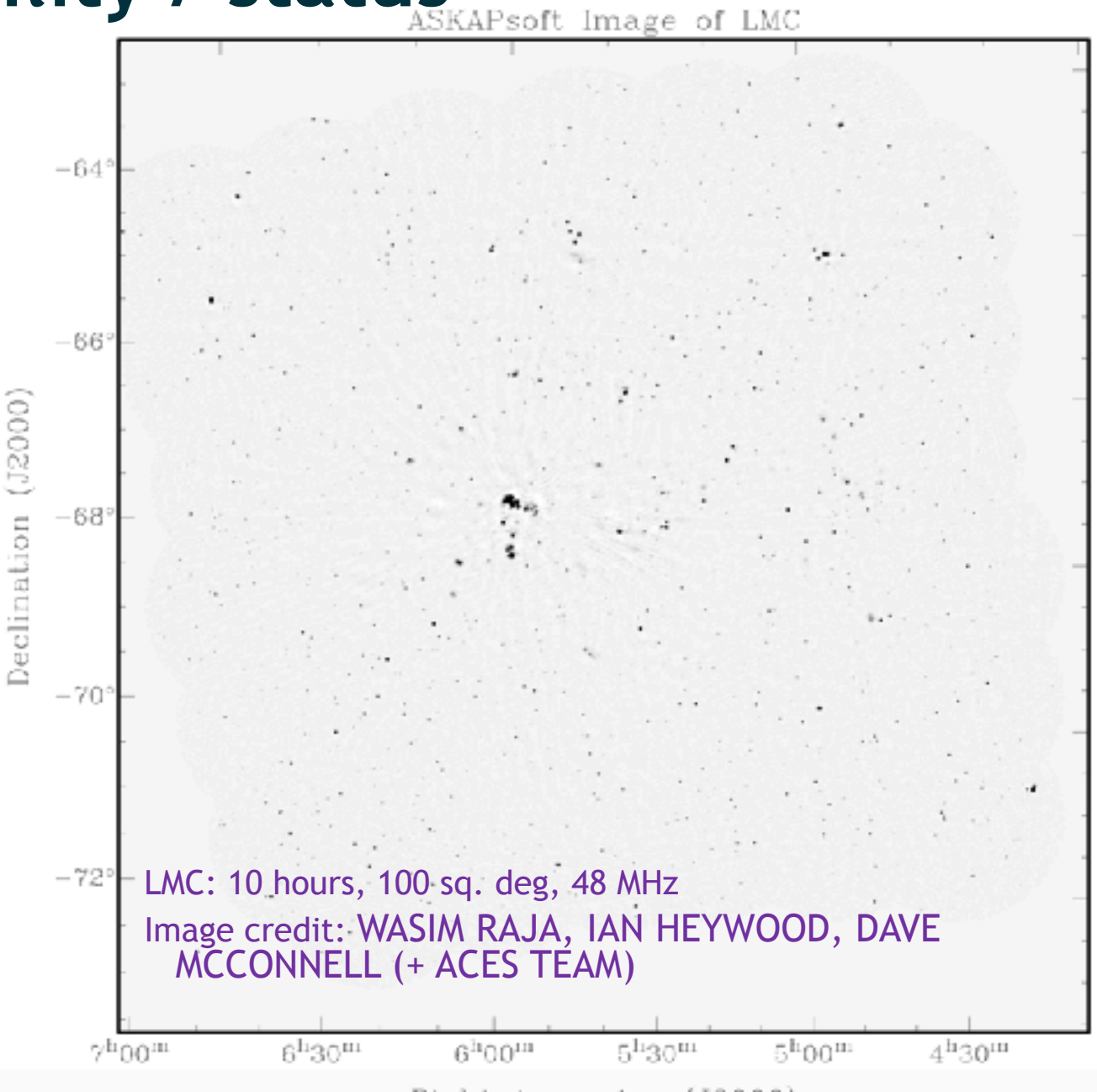






Array capability / status

- 30 square-degree instantaneous FOV
- More-or-less routine imaging w/ 36 beams now. BW now multi-~200 MHz, increasing constantly.
- Changing focus:
  low-level commissioning work + basic imaging --> pipeline optimisation, early science, adding capabilities



LMC: 10 hours, 100 sq. deg, 48 MHz

Image credit: WASIM RAJA, IAN HEYWOOD, DAVE MCCONNELL (+ ACES TEAM)

On-axis polarimetry, current status

- On-axis leakages <1%, approximately constant over 300 MHz band, relatively stable over ~weeks

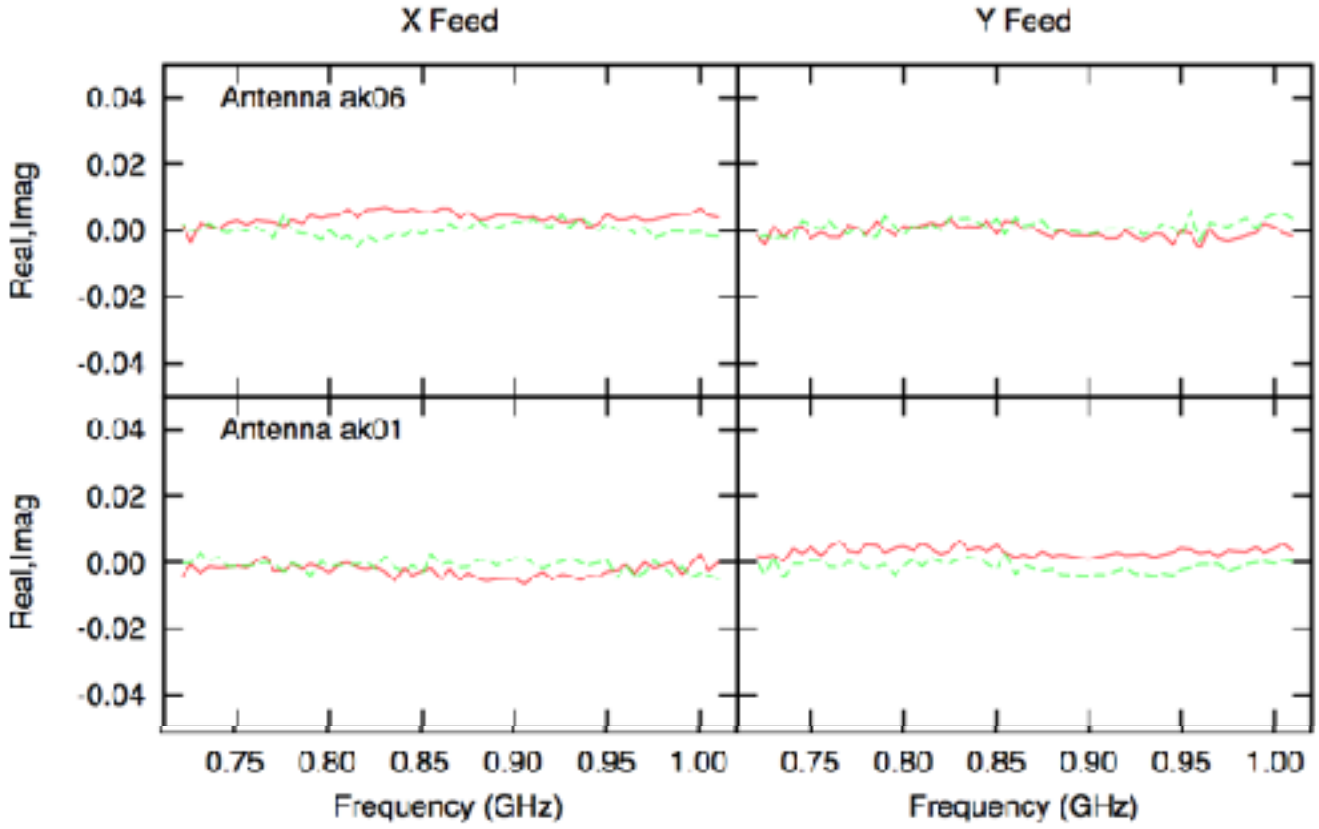


Image credit: BOB SAULT

On-axis polarimetry, current status

- Spectral data is clean, largely artefact-free after bandpass and phase self-cal

1921-293

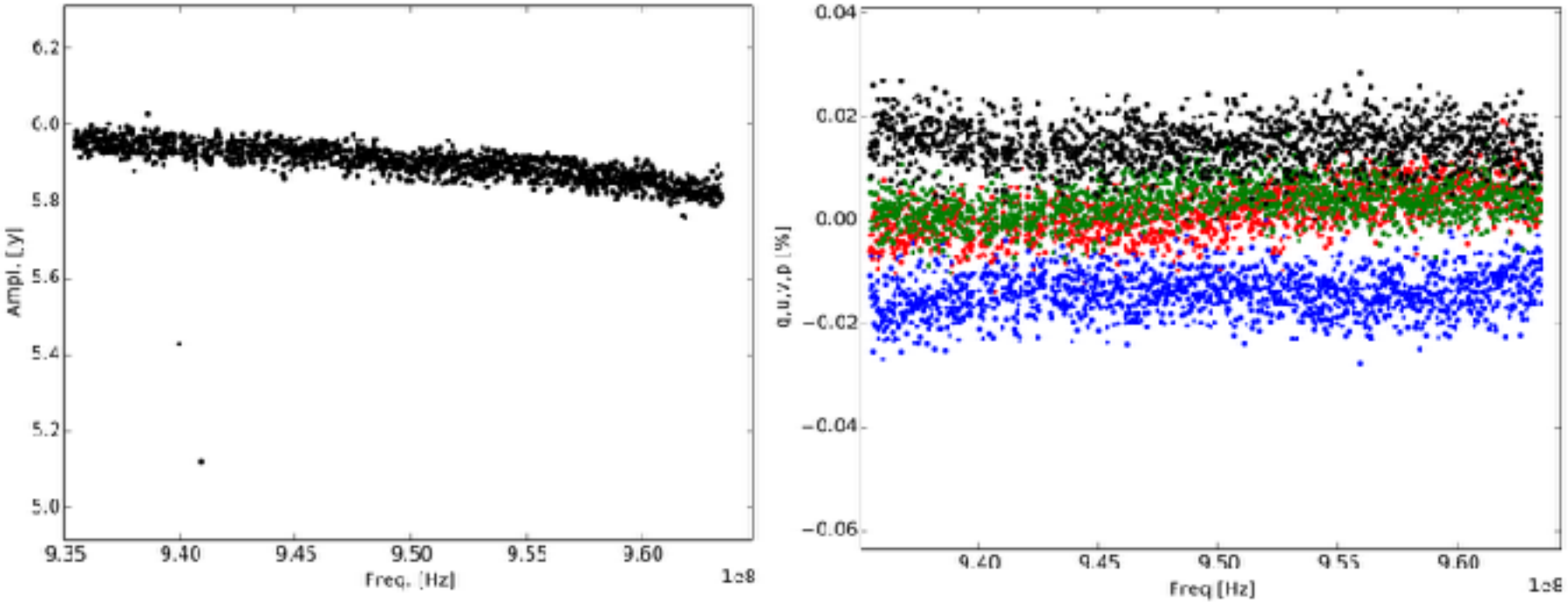


Image credit: CRAIG ANDERSON

On-axis polarimetry, current status

- Known RMs are reproducible

(though ionospheric correction is currently ‘by hand’ only)

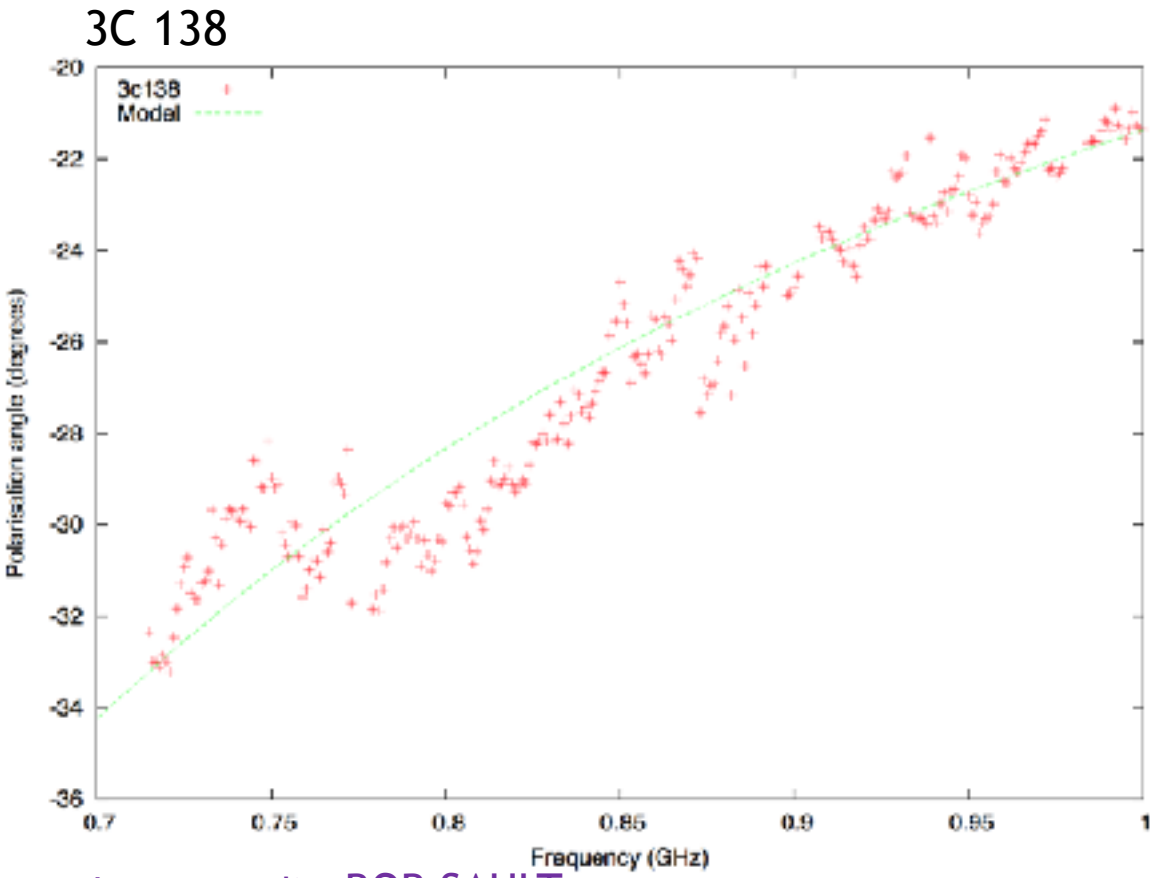


Image credit: BOB SAULT

On-axis polarimetry, current efforts

- Incorporation of ODCs (XY-phase bandpass, calibrating instrumental effects out of beamformer weights)

- Exact on-axis calibration approach still to be defined, but should be straight-forward

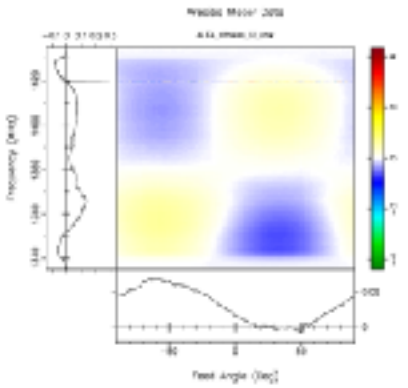
Instrumental Calibration using rotating feeds/dish

Work by Wasim Raja

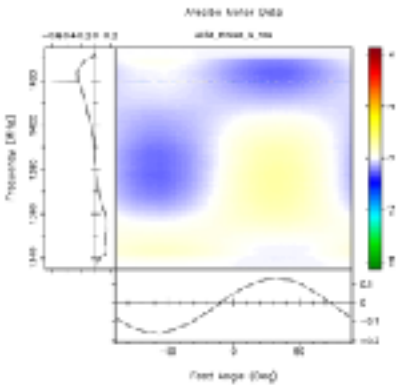
$$\begin{pmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{pmatrix}^{measured} = [\ M\ ]^{instrument}_{4x4} \begin{pmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{pmatrix}^{true} = [\ M\ ]_{4x4} \begin{pmatrix} I_0 \\ dp\ I_0\ \cos 2\chi \\ dp\ I_0\ \sin 2\chi \\ 0 \end{pmatrix}^{linearly\ polarised\ cal}$$

$$s_i^m(2\chi) = m_{i1} + m_{i2}\ dp\ \cos 2\chi + m_{i3}\ dp\ \sin 2\chi\ ;\ i = 1,2,3,4\ ;\ I_0 = 1$$

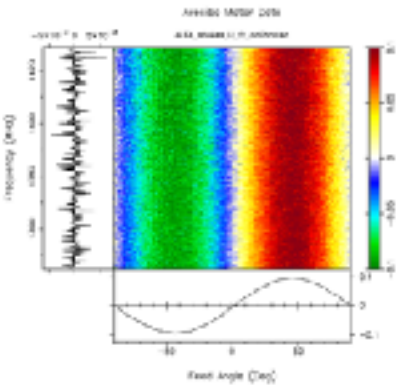
$$m_{i1} = \mathcal{S}_i^m(0); \quad m_{i2} = (2/dp)\ \Re\ [\mathcal{S}_i^m(1)]; \quad m_{i3} = (2/dp)\ \Im\ [\mathcal{S}_i^m(1)]$$



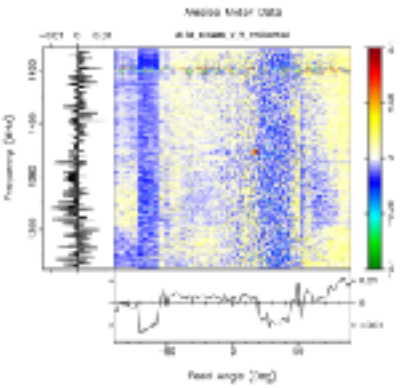
U(raw)



V(raw)



U(cal)

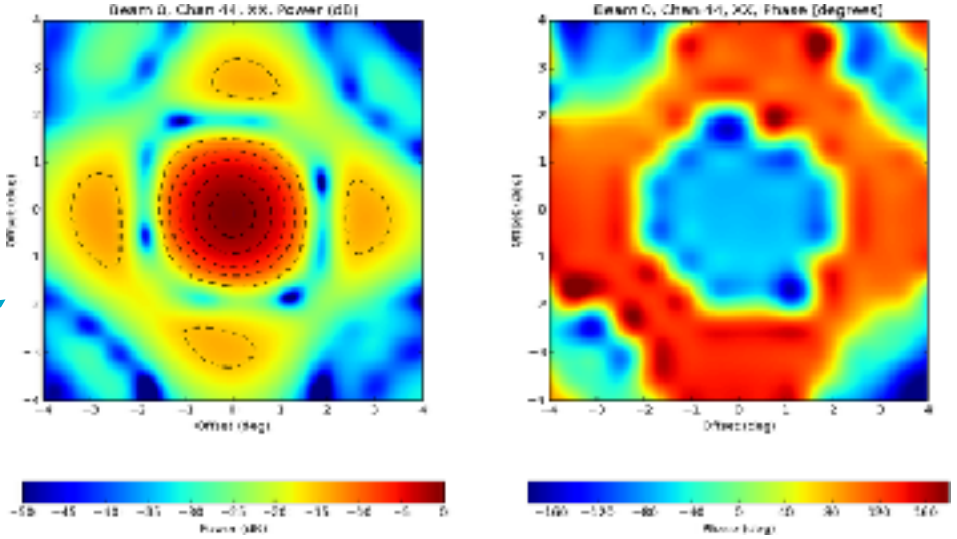


V(cal)

Off-axis polarimetry: beamforming

- Max SNR algorithm beamforming — ~3% difference in X and Y pol response

- One approach to dealing with this: Shape-constrained beamforming.



Amplitude

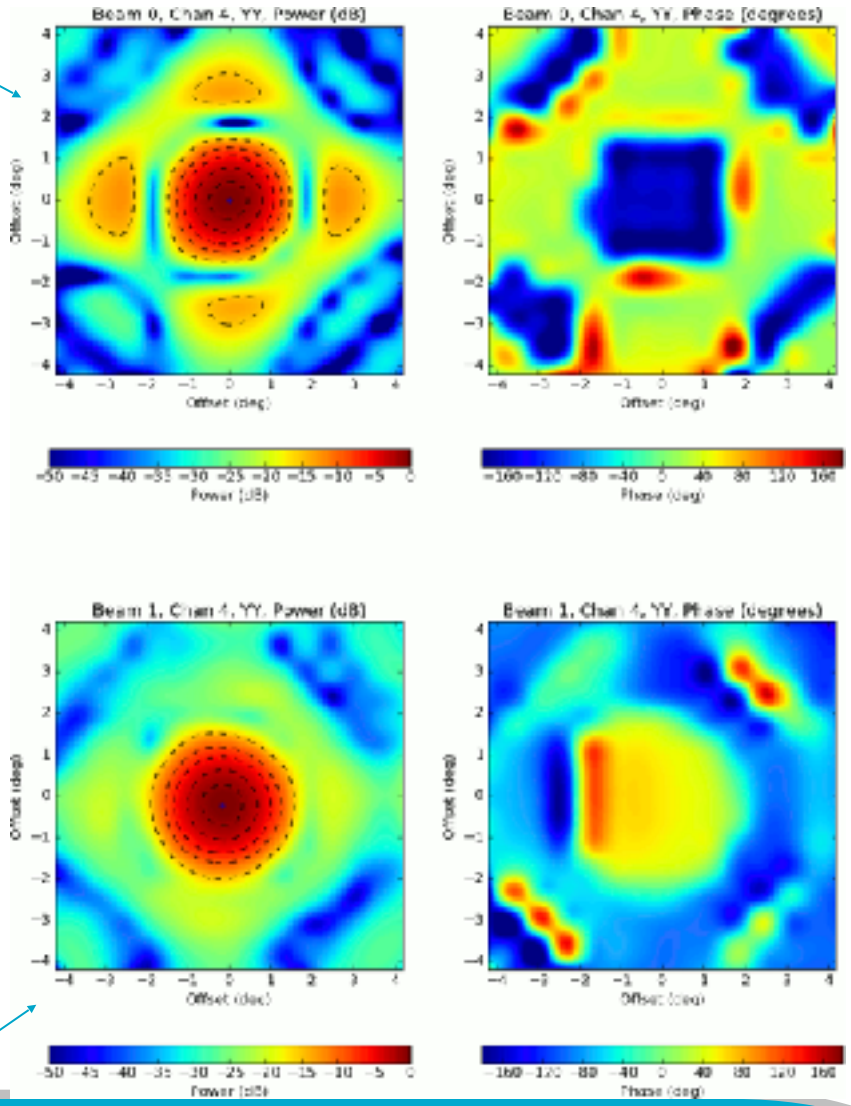
Phase

Asymmetry due to feed support structure

Work by: SARAH HEGARTY, AIDAN HOTAN

Beamforming is an active area of research

Max S/N



Work by:

SARAH HEGARTY, AIDAN HOTAN

Shape constrained

Credit: Sarah Hegarty and Aidan Hotan

The upshot

- Early science on ASKAP has begun, but not yet for polarisation
- ASKAP polarisation performance is ticking all the right boxes, but problems remain to be solved
- A dedicated team now working on polarisation-specific issues within ACES
- The array is producing, and things are starting to move quickly!

Extra slides