ASKAP and its phased array feeds

Innovation and Discovery in Radio Astronomy, 13-17th September, Queenstown, NZ

DAVID MCCONNELL, CSIRO
www.csiro.au

2016 SEPT 13

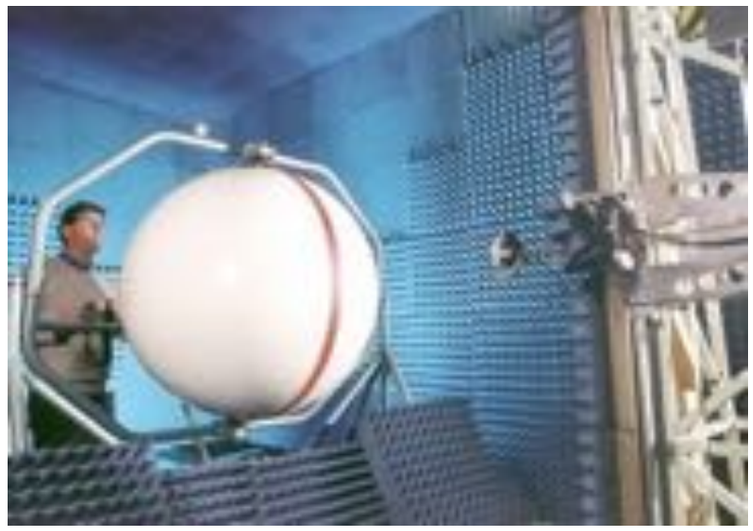
History - pre 2004

- SKA - search for technology
  - to get cheap collecting area
  - more specifically, to optimise survey speed/dollar

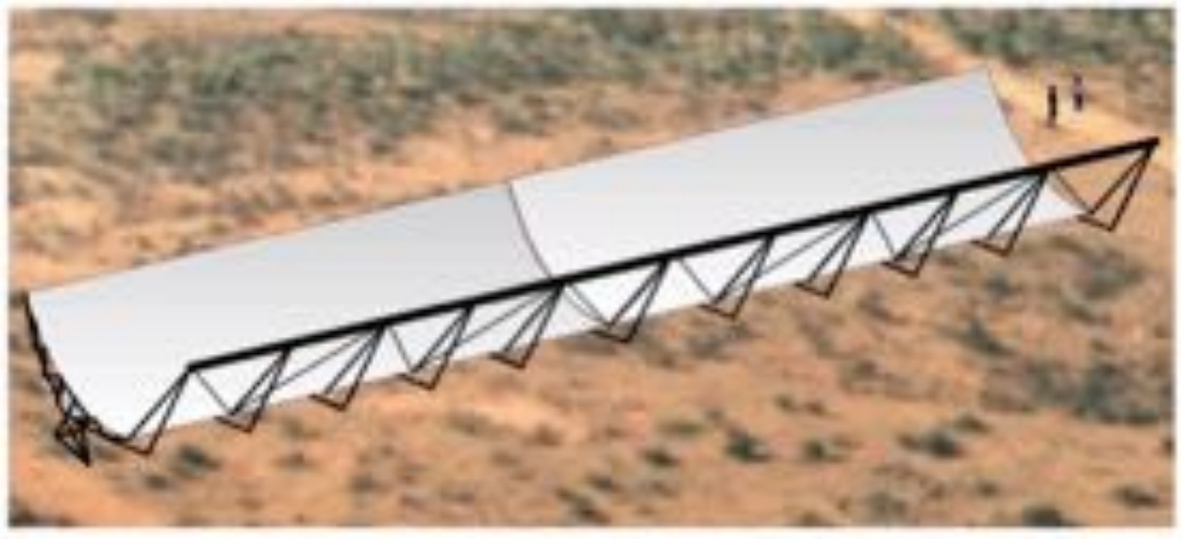
$$SS \propto \mathrm{FoV}\left(\frac{A_{\mathrm{eff}}}{T_{sys}}\right)^2$$

- within CSIRO, a number of technologies were explored

Luneburg Lenses



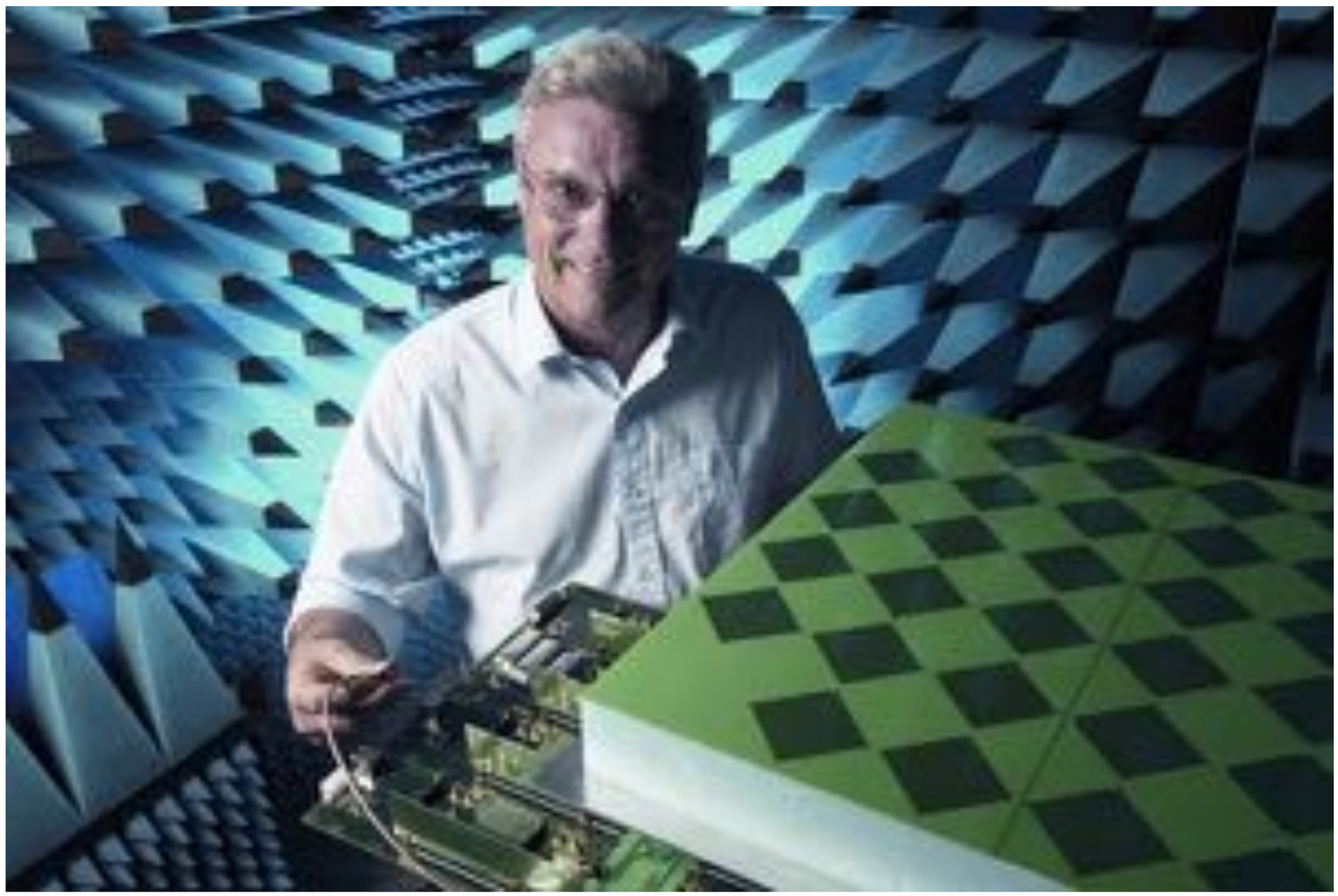
Cylindrical reflectors



Phased arrays at the focal plane of paraboloids

and the winner was …

Phased arrays at the focal plane of paraboloids



John O’Sullivan with prototype chequerboard

History - names!

? 2003 ?

NGRT

(HIFAR)

From 2004

Up to 2007

NTD

xNTD

MIRA

PAFs

2007 May

MIRANdA

2007 Nov

Australian SKA Pathfinder

ASKAP

ASKAP

Antennas :	36 x 12m diameter
Longest baseline :	6440 m
Frequency range :	700 - 1800 MHz
Instantaneous bandwidth:	300 MHz
Spectral channels :	16416

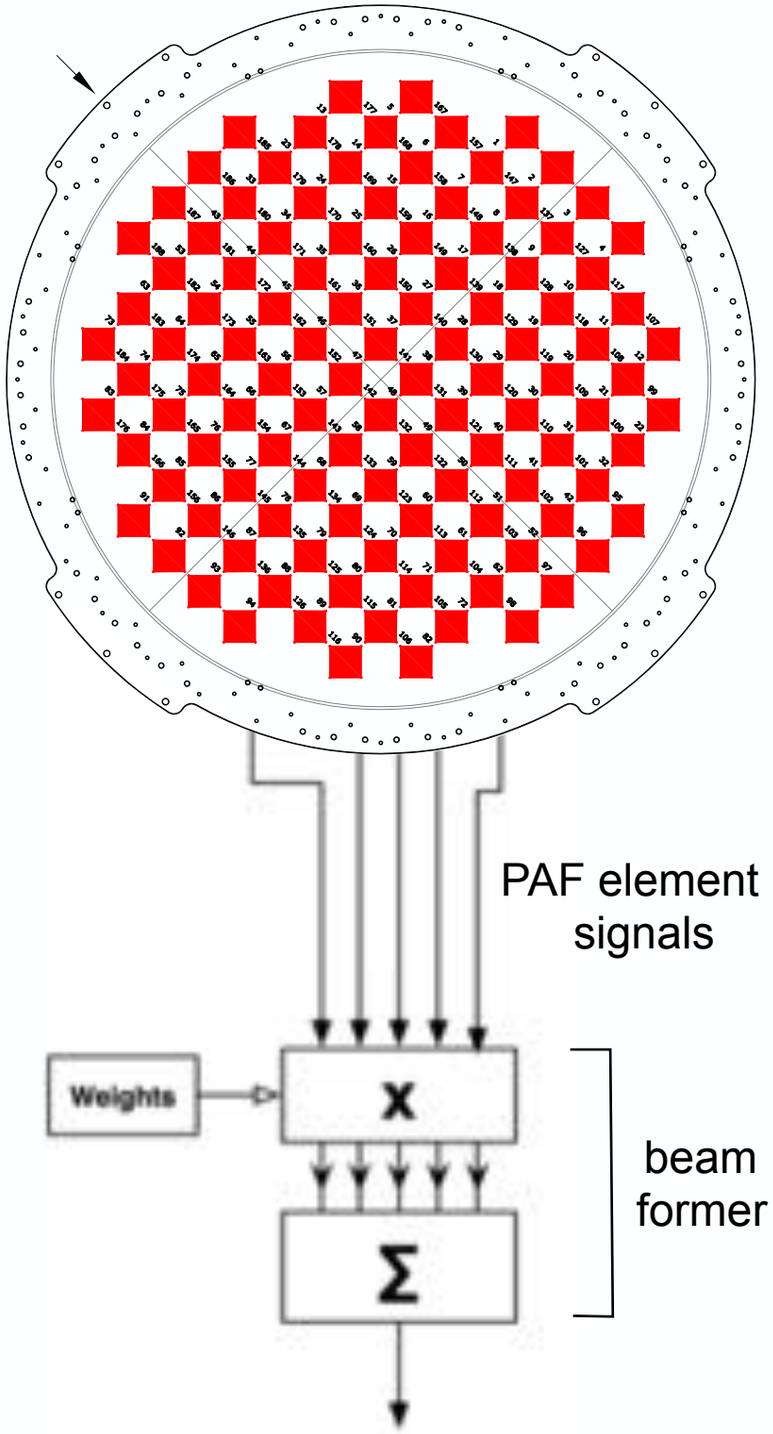
Phased array feed

PAF

Chequerboard array of 188 sensors
Two interleaved sets of 94 X and 94Y polarised elements

Field of view : 5.5 x 5.5 = 30 square degrees

PAF and beamformer



ASKAP

	BETA	ASKAP-12	ASKAP
Antennas :	6	12	36
Longest baseline :	916 m	2304 m	6440 m
PAF :	Mark I	Mark II	Mark II
Beams :	9 x 2	36 x 2	36 x 2

BETA (Boolardy Engineering Test Array) operated from 2014 March - 2016 February

ASKAP-12 is currently operating over a fixed 48MHz band.

What determines survey speed, image sensitivity?

$$\frac{\mathrm{SS}}{\sigma^2} = B n_p N_a^2 F \left(\frac{A_{\mathrm{eff}}}{2kT_{\mathrm{sys}}}\right)^2$$

$$= B n_p N_a^2 \int_{\mathrm{FoV}} \left(\frac{A_{\mathrm{eff}}}{2kT_{\mathrm{sys}}}\right)^2 d\Omega$$

$$= B n_p N_a^2 \int_{\mathrm{FoV}} \left(\frac{1}{\mathrm{SEFD}}\right)^2 d\Omega$$

- Footprint sensitivity
- Primary beam shape (variability/knowledge of)
- Interferometer calibration
- RFI
- etc

Primary beam shapes

Maximum Sensitivity Beamforming

- The output of a beamformer is:

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

PAF element outputs at time *i*

Beam *k* output at time *i*

Weight vector for beam *k*

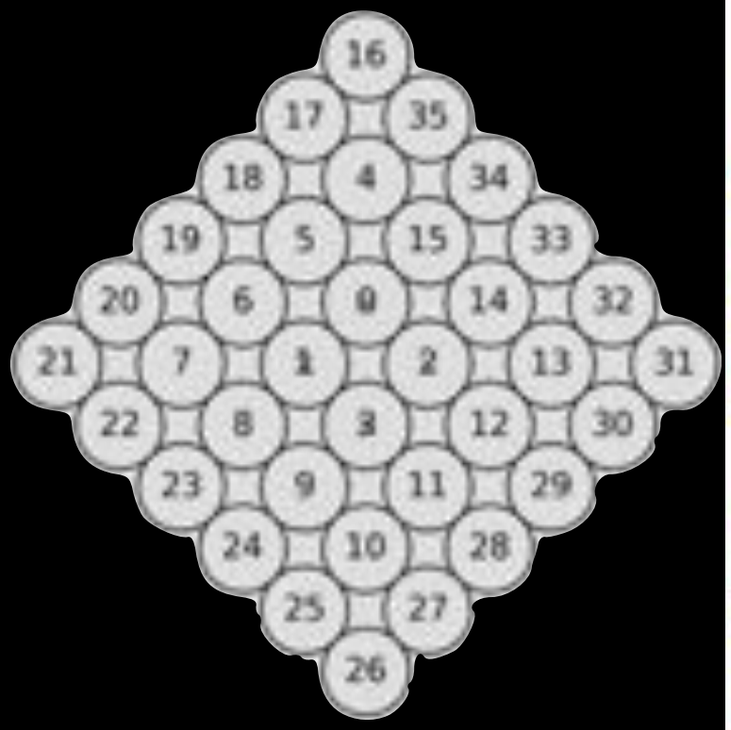
- We determine weights that define the “maximum sensitivity” beam (Applebaum (1976)):

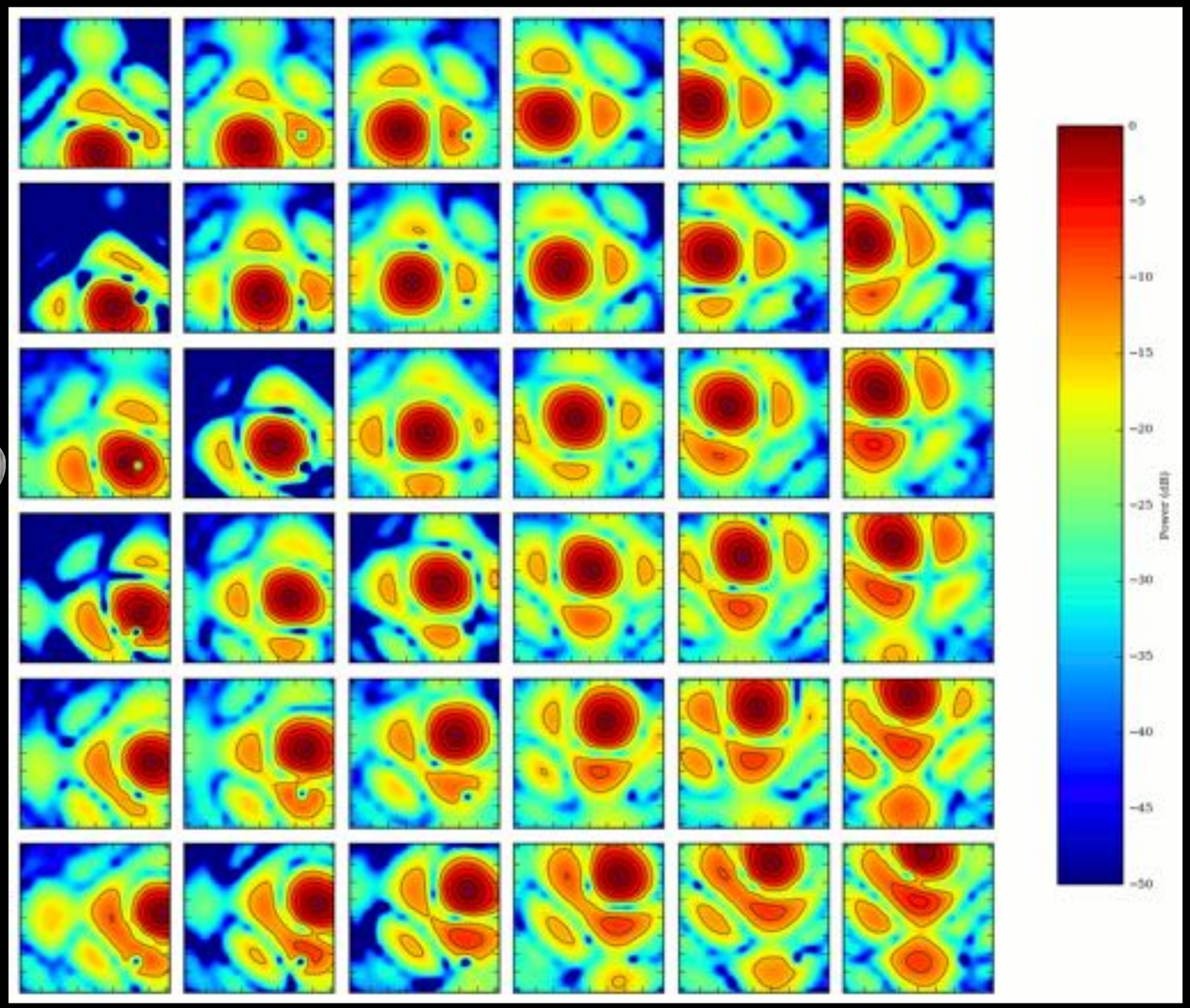
$$\mathbf{w}_k = \hat{\mathbf{R}}_n^{-1} \hat{\mathbf{v}}_k$$

Noise covariance matrix

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

Primary beam shapes: measurement

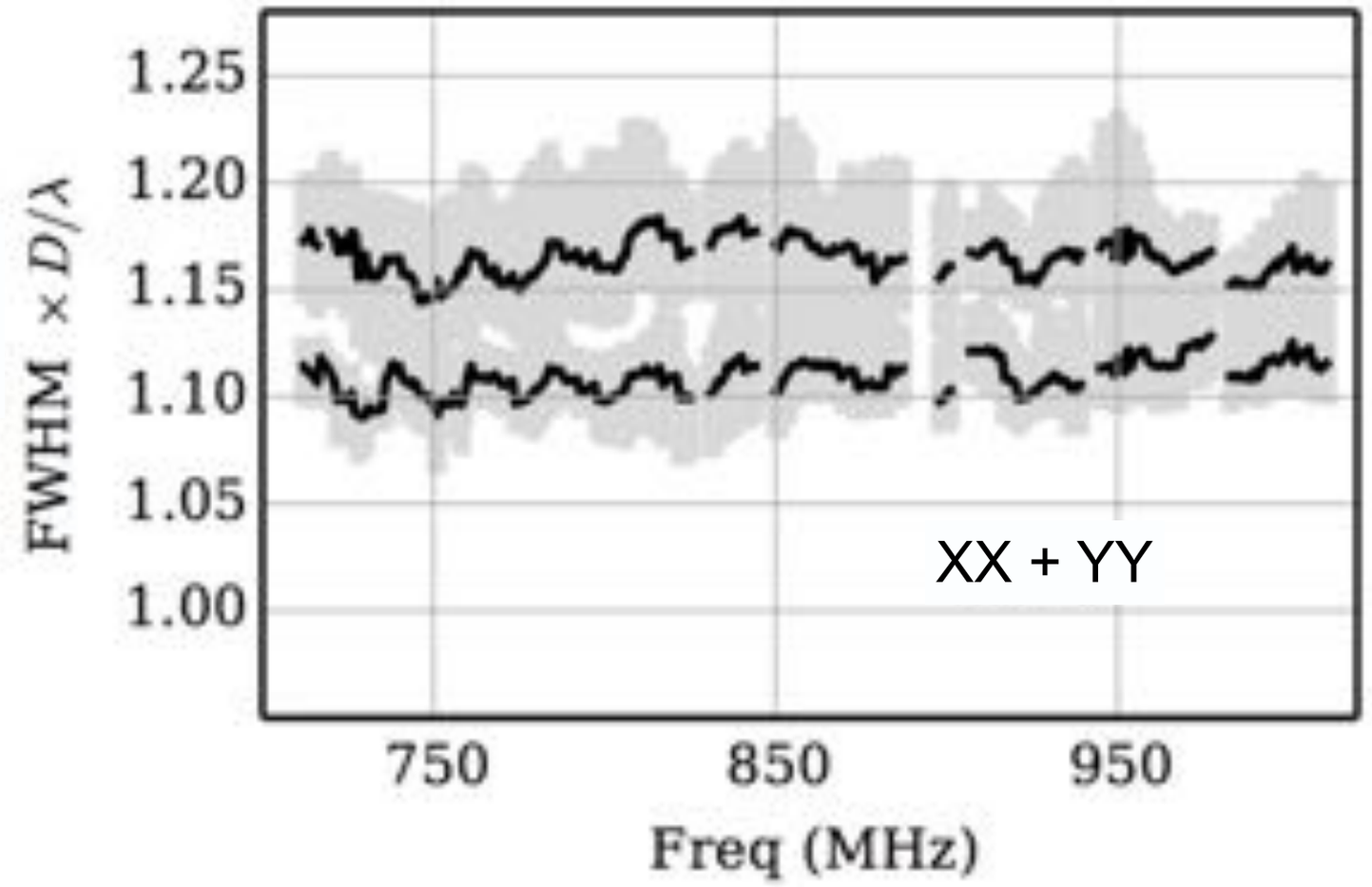




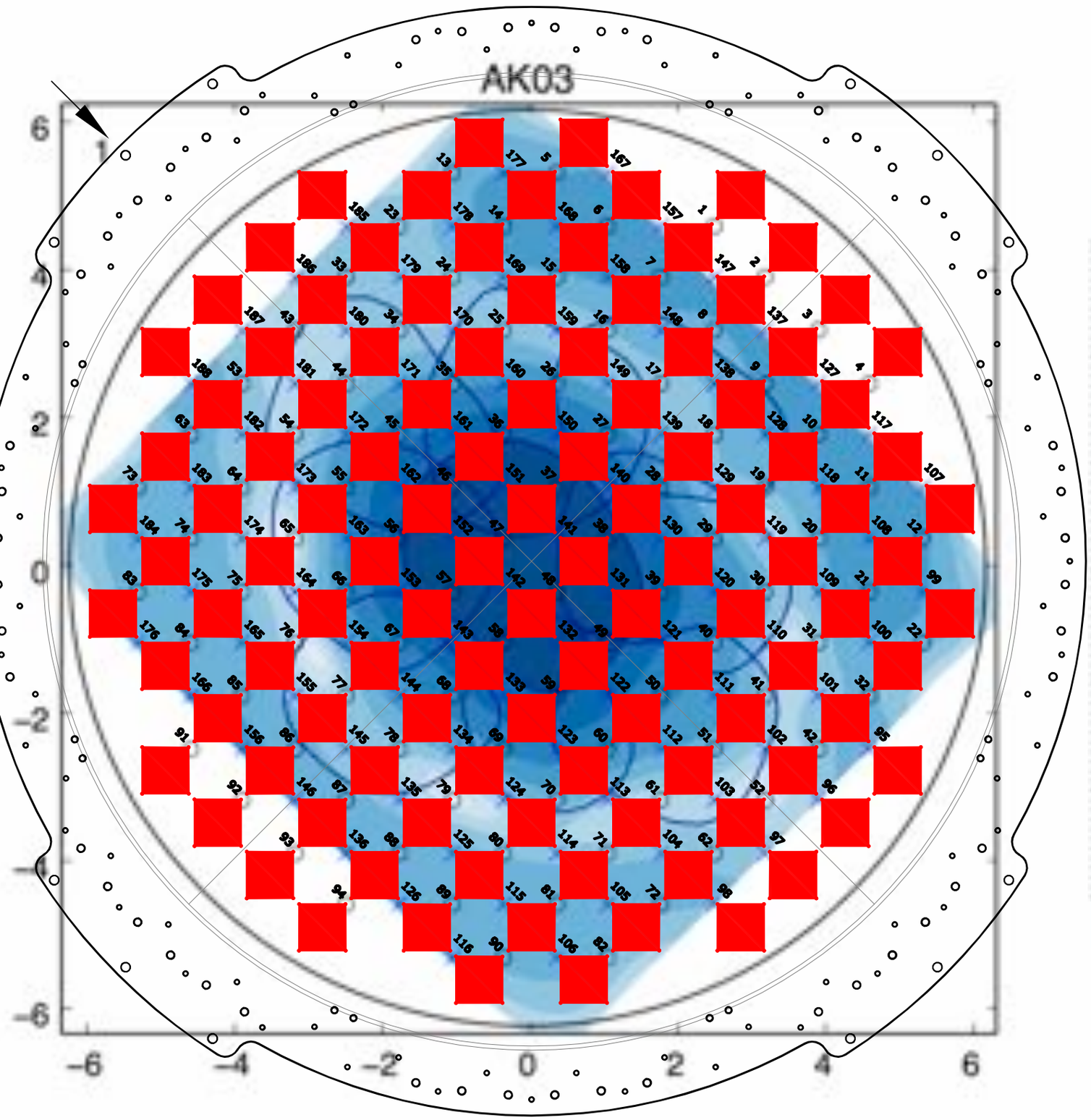
by Aidan Hotan

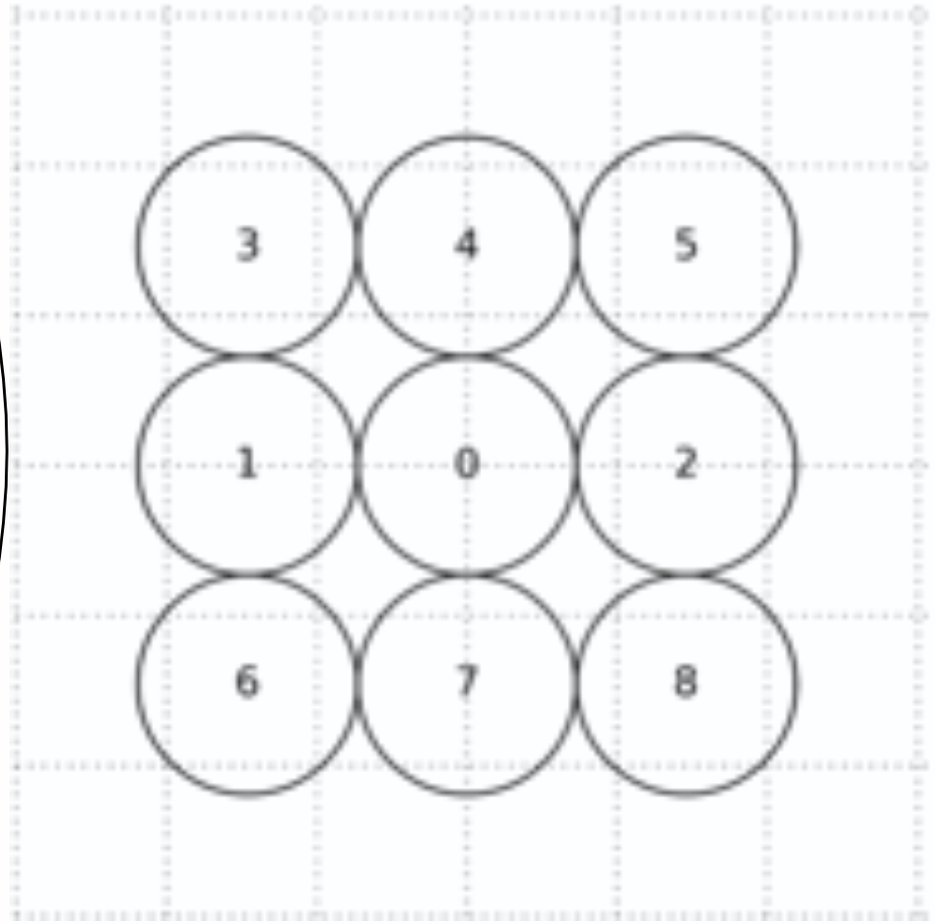
Primary beam shapes: variation

Boresight beams measured on BETA



Research continues on shape-constrained beamforming.
There remains much to be learnt about beamforming.



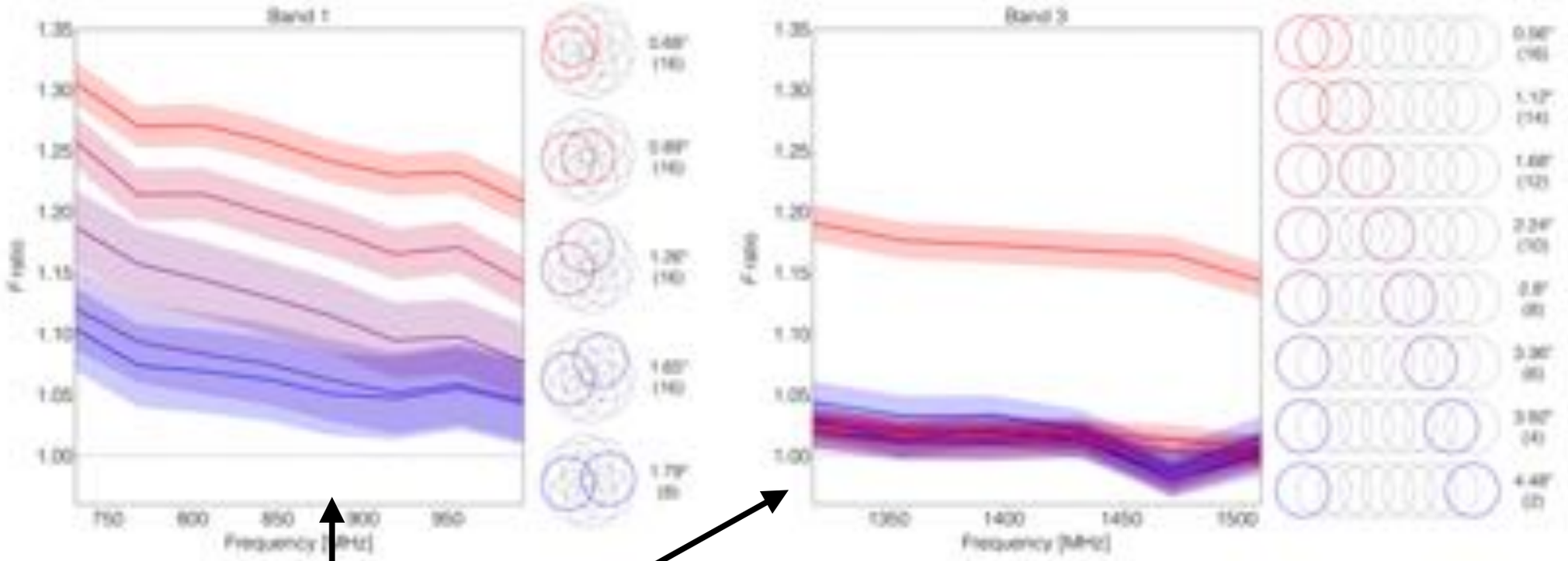


QUA

Footprint sensitivity

- Noise in adjacent beams is not independent, they share PAF elements
- This affects the noise amplitude in the mosaiced image

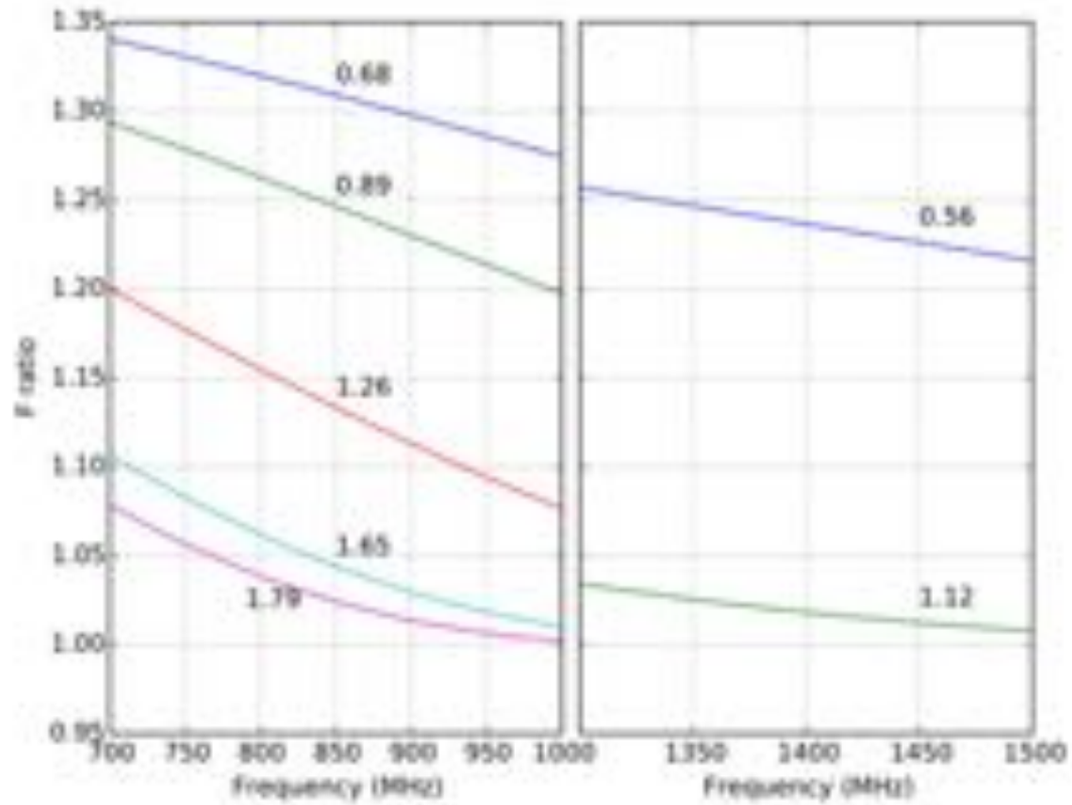
- We can measure and model the effect



Measurements

(by Ian Heywood)

Model predictions



F ratio

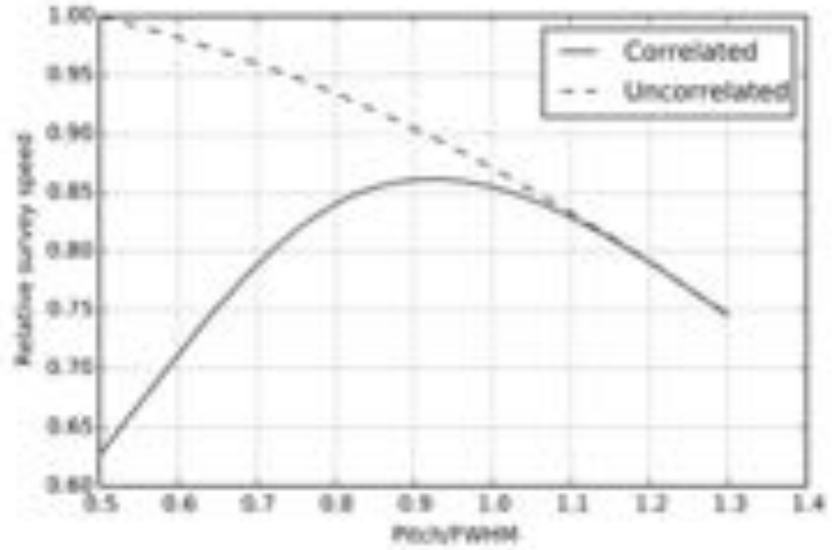
$$F = \sqrt{1 + R_{AB}}$$

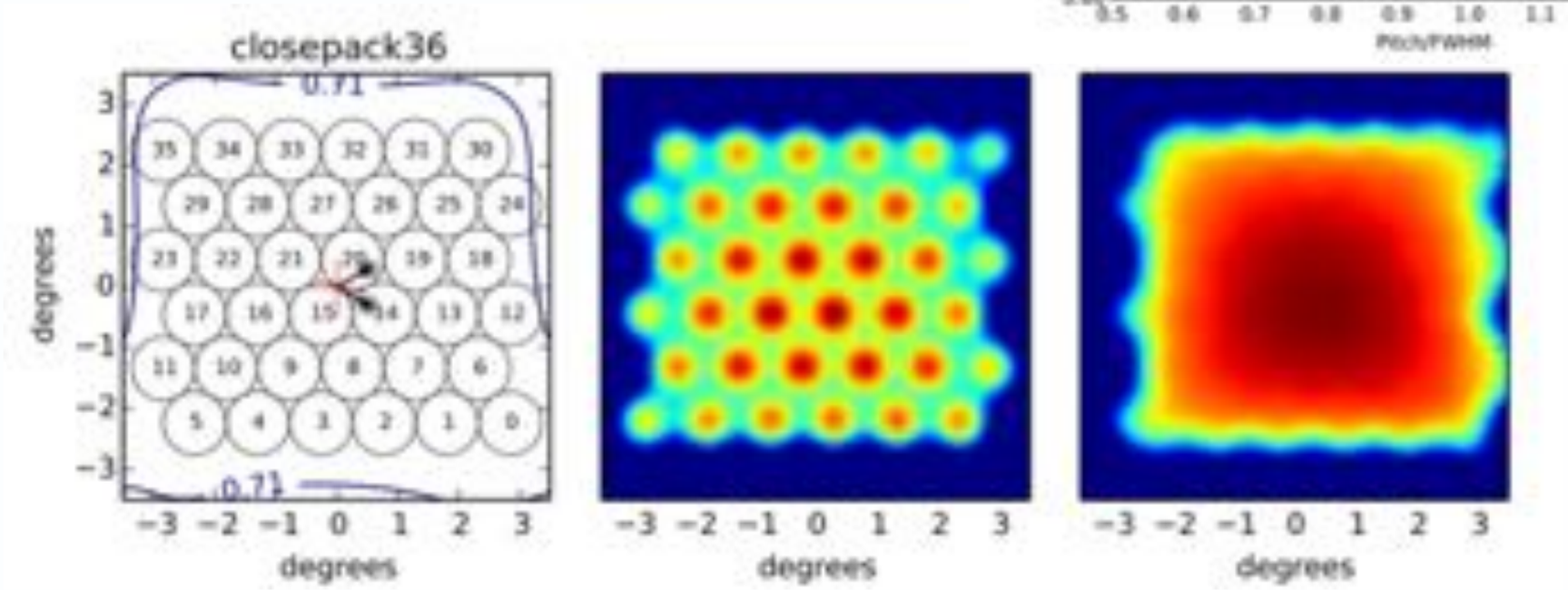
Footprint sensitivity

- Noise in adjacent beams is not independent, they share PAF elements
- This affects the noise amplitude in the mosaiced image

- Find the sweet spot

- and interleave for uniformity





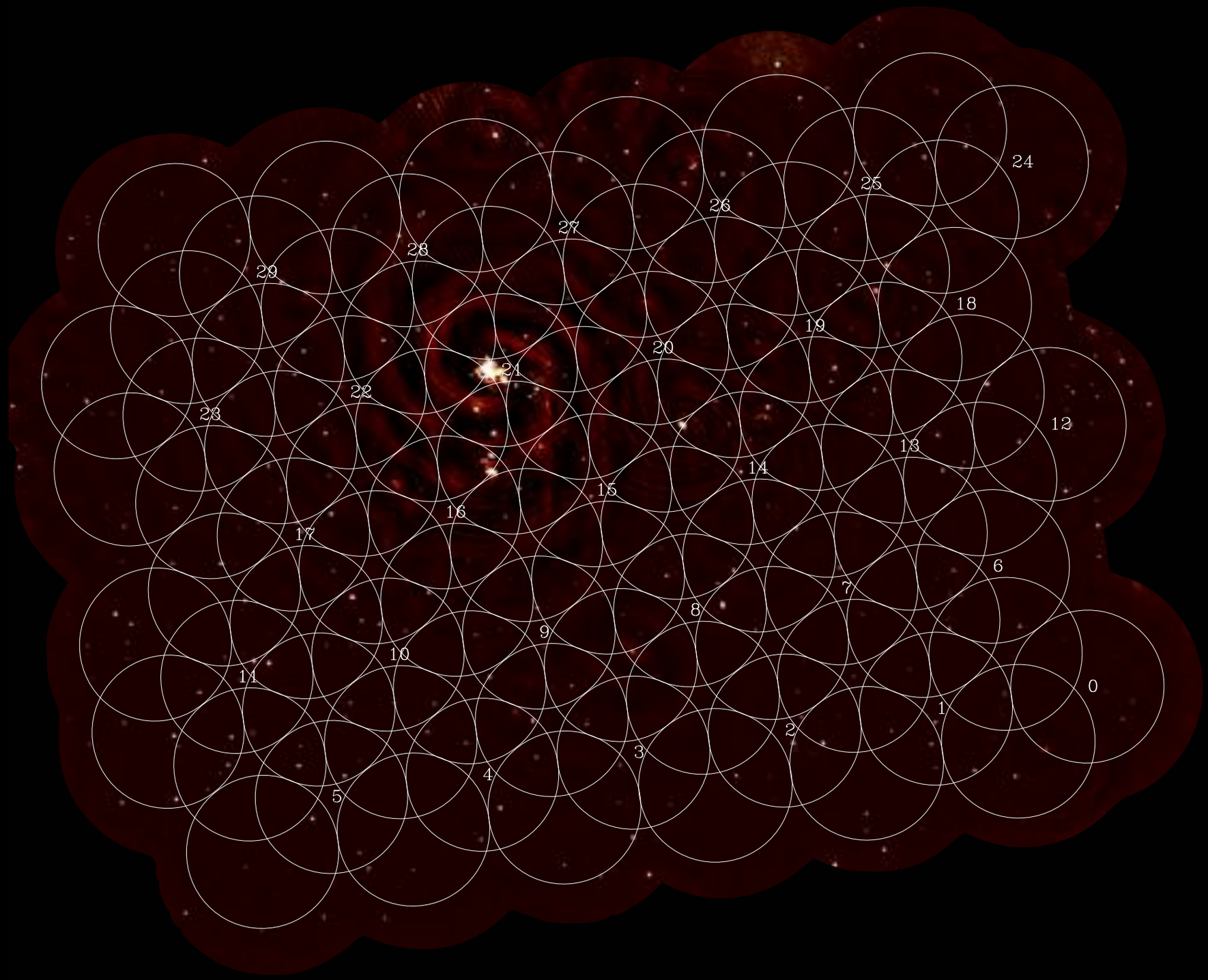
Wide Fields Fast!

- 150 deg^2
- 12 hours per observation
- noise 1σ < 1 mJy
- 2,000 sources > 5σ
- 3 × 12 hr observations in RGB

This demonstration with:

- Just 6 of 36 antennas
- Just 9 of 36 beams

Credit: Keith Bannister (observations), Ian Heywood (calibration & Imaging), ACES/ASKAP team.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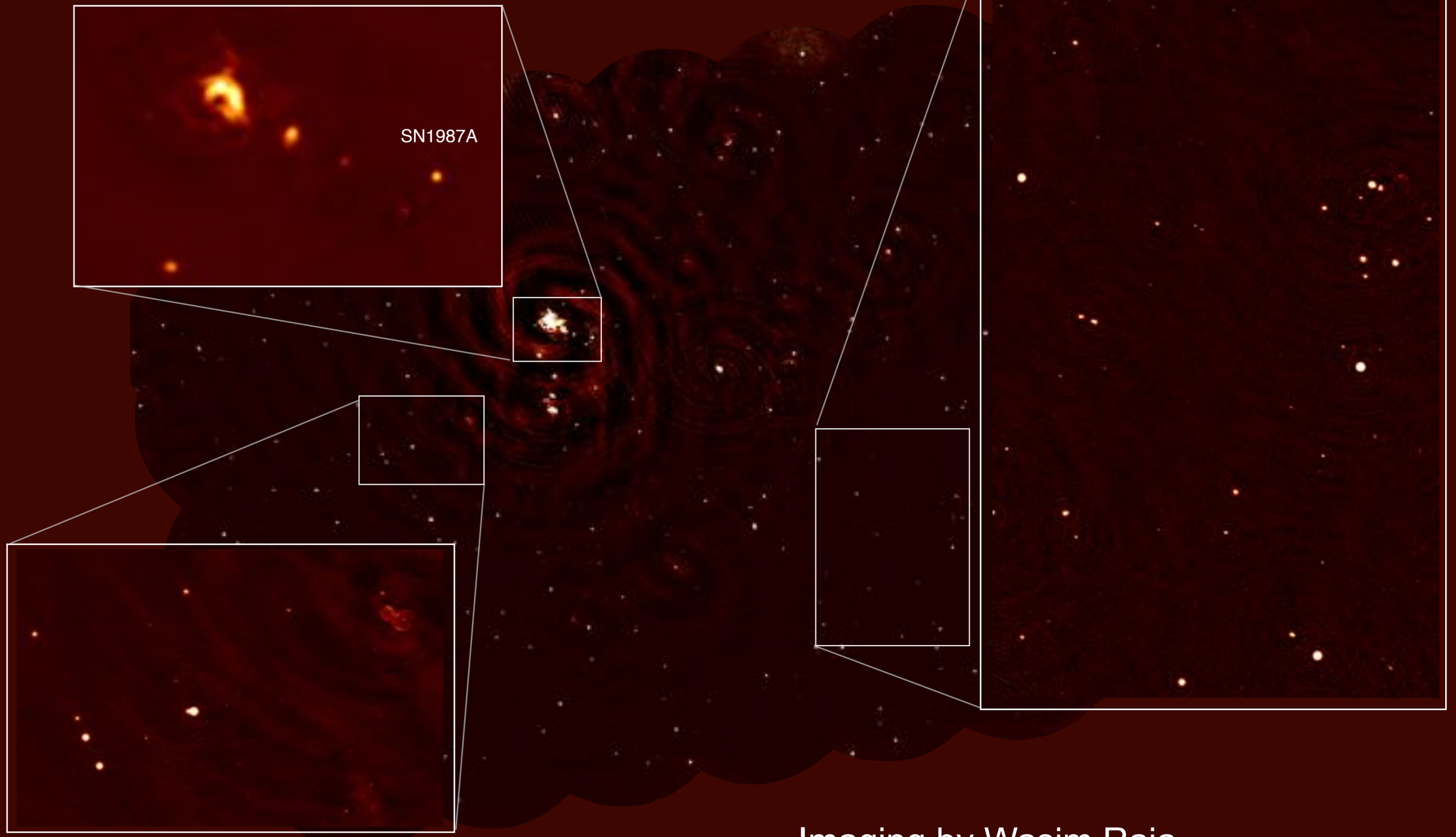


Imaging by Wasim Raja
using ASKAPsoft

Realising the innovation

Hardware

Software

“Greyware”

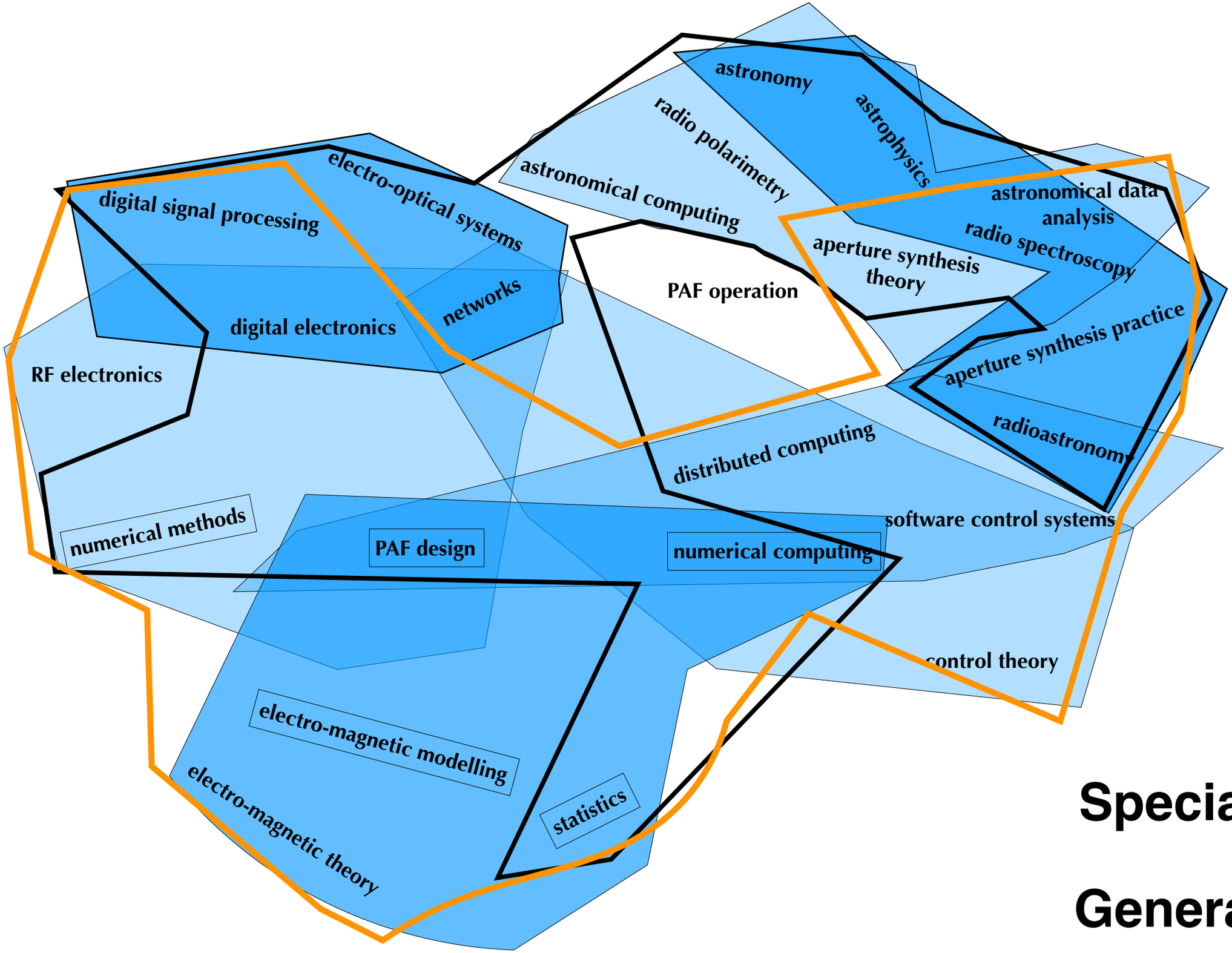
Publications of the Astronomical Society of Australia (PASA)

doi: 10.1017/pas.2016.Xx.

The Australian Square Kilometre Array Pathfinder: Performance of the Boolardy Engineering Test Array

D. McConnell[1], J.R. Allison[1], K. Bannister[1], M.E. Bell[1], B.E. Bignall[2,3], A.P. Chippendale[1], P.G. Edwards[1], L. Harvey-Smith[1], S. Hegarty[4], I. Heywood[1,5], A.W. Hotan[3], B.T. Indermuehle[1], E. Lenc[6,7], J. Marvil[1], A. Popping[8], W. Raja[1], J.E. Reynolds[1], R.J. Sault[1,9], P. Serra[1], M.A. Voronkov[1], M. Whiting[1], S.W. Amy[1], P. Antreas[1,10], L. Ball[1], T.J. Bateman[1], D.C.-J. Bock[1], R. Bolton[1], D. Brodrick[11,12], M. Brothers[1], A.J. Brown[1], J.D. Bunton[1], W. Cheng[1], T. Cornwell[1,13], D. DeBoer[1,14], I. Feain[1,15], R. Gough[1], N. Gupta[1,16], J.C. Guzman[1], G.A. Hampson[1], S. Hay[17], D.B. Haynes[1], S. Hoyle[18], B. Humphreys[1], C. Jacka[1], C.A. Jackson[1,3], S. Jackson[19], K. Jeganathan[1], J. Joseph[14], B.S. Koribalski[1], M. Leach[1], E.S. Lensson[1], A. MacLeod[1], S. Mackay[1], M. Marquarding[1], N.M. McClure-Griffiths[1,20], P. Mirtschin[14], D. Mitchell[1], S. Neuhold[1], A. Ng[1], R. Norris[1,21], S. Pearce[1], R.Y. Qiao[17,22], A.E.T. Schinckel[1], M. Shields[1], T.W. Shimwell[1,23], M. Storey[1], E. Troup[1], B. Turner[18,24], J. Tuthill[1], A. Tzioumis[1], R.M. Wark[1], T. Westmeier[1,8], C. Wilson[1], T. Wilson[19]

Realising the Innovation



Specialists

Generalists

Realising the Innovation

RON

Thanks

Thank you