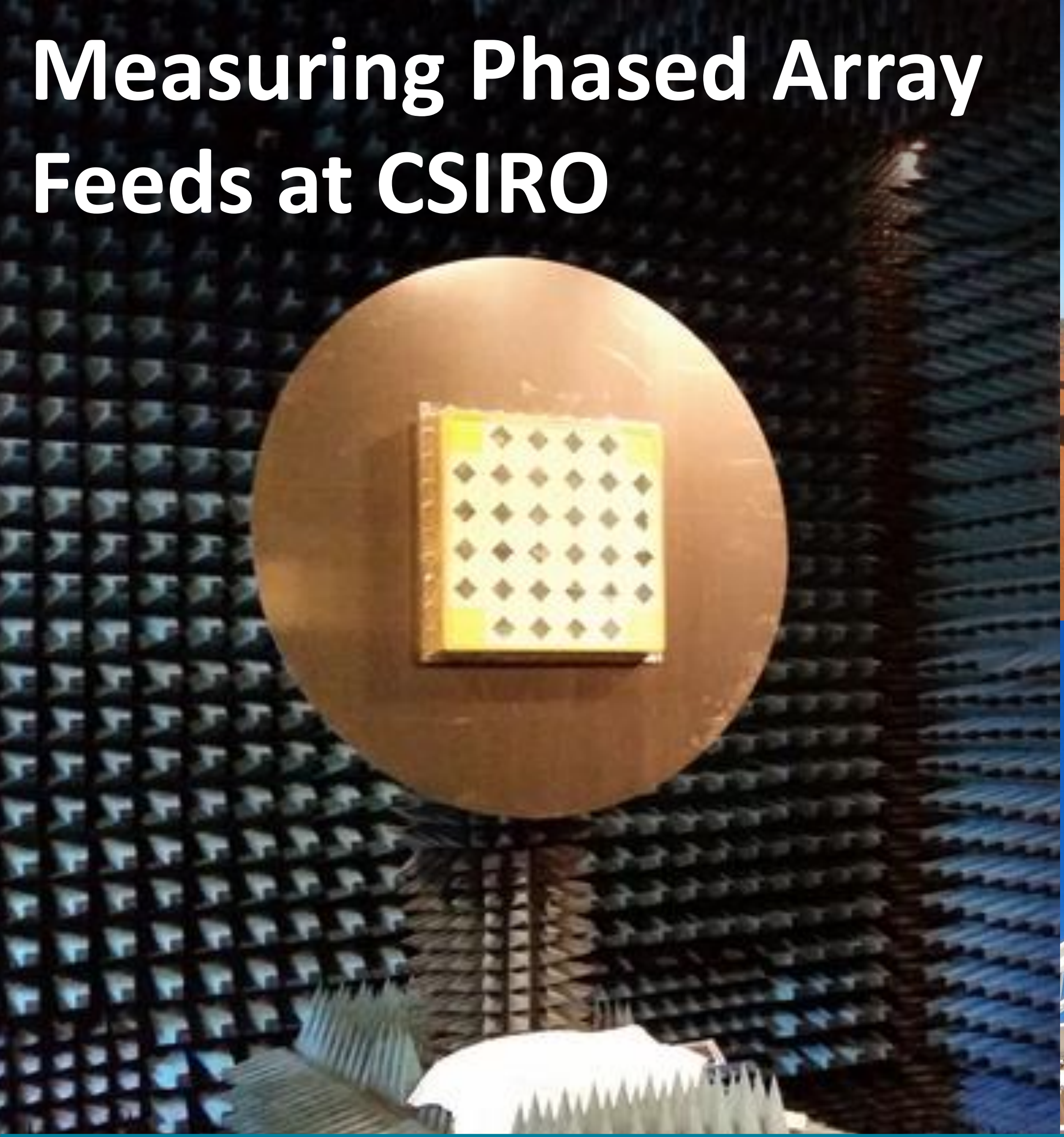
Measuring Phased Array Feeds at CSIRO



ASTRONOMY AND SPACE SCIENCE
www.csiro.au

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PAF Workshop
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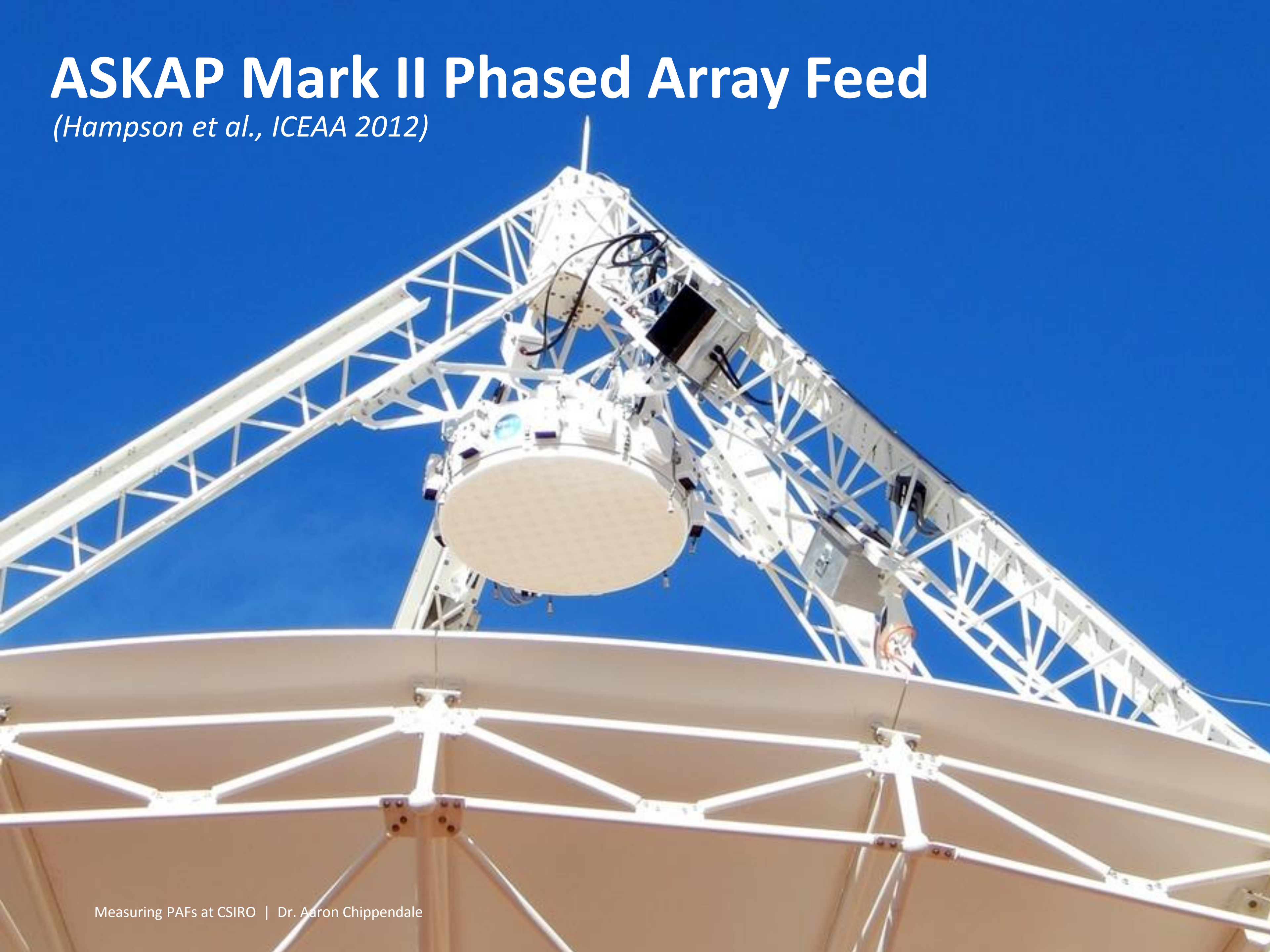
Summary

- Measuring on-dish performance without the dish
- Referencing beam weights to a broadband calibration noise wave
- Separating noise and antenna efficiency
- Compactly summarising measured PAF performance

ASKAP Mark II Phased Array Feed

(Hampson et al., ICEAA 2012)



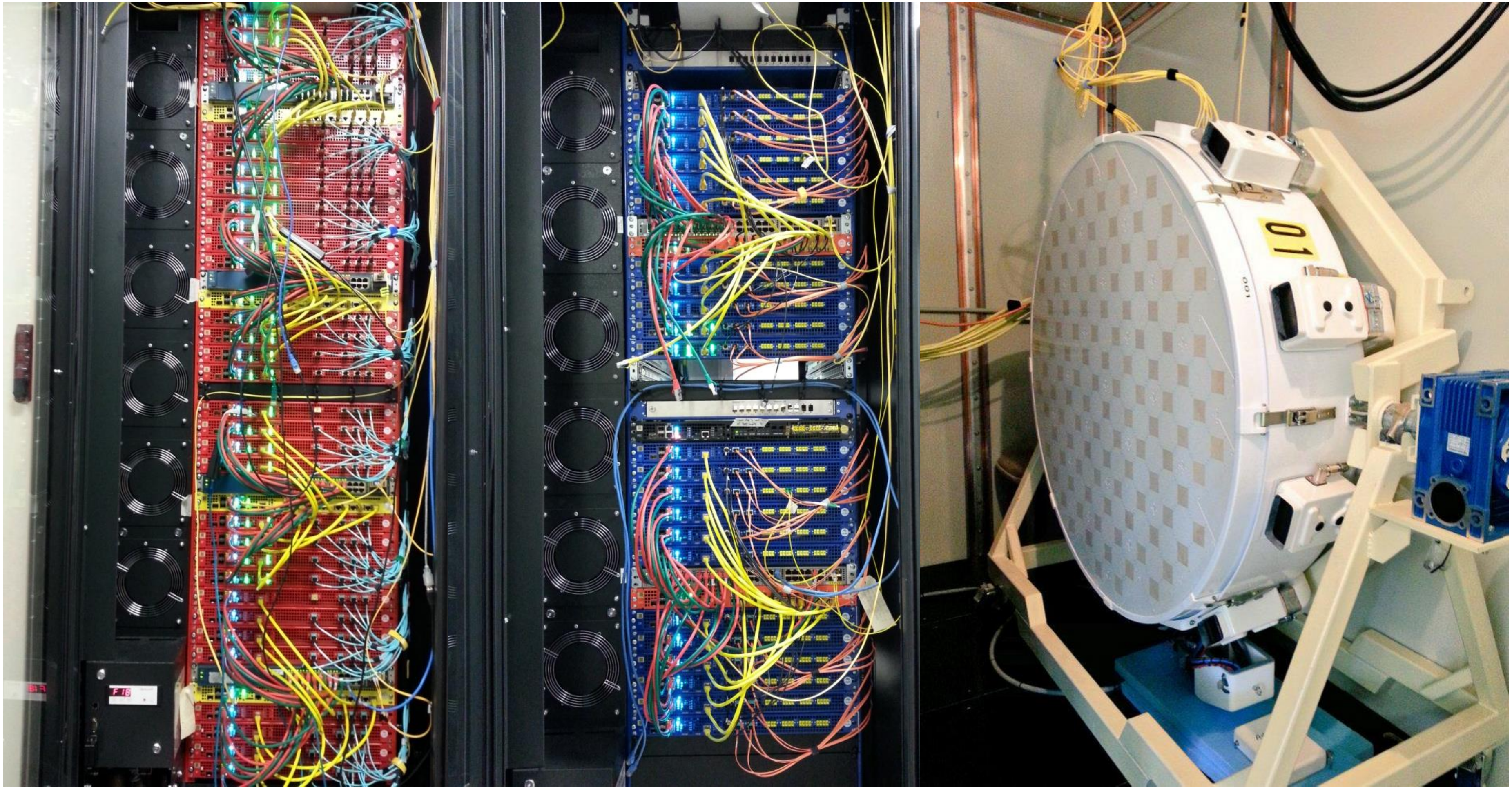
ASKAP

(Hotan et al., PASA 2014)
(DeBoer et al., Proc. IEEE 2009)

Australian SKA Pathfinder | 36 antennas | 0.7 – 1.8 GHz | 30 deg^2 FOV

CSIRO

ASKAP Mk II System *(Hampson et al., ICEAA 2012)*

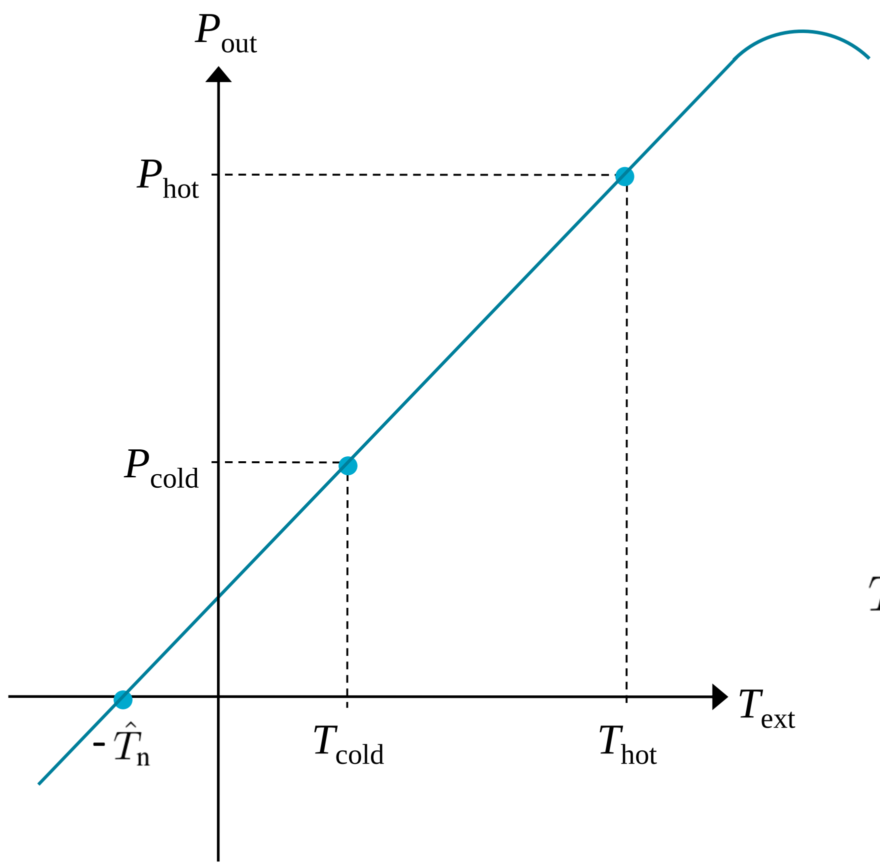


BW: 384 MHz 600 MHz 600 MHz (x 188 ports)

CSIRO

Y-factor measurement

(Chippendale et al., PASA 2014)
(Hayman et al., EuCAP 2014)
(Warnick et al., Submission to IEEE Standard Test Procedures for Antennas, 2016)



$$Y = \frac{P_{\text{hot}}}{P_{\text{cold}}} = \frac{\mathbf{w}^H \mathbf{R}_{\text{hot}} \mathbf{w}}{\mathbf{w}^H \mathbf{R}_{\text{cold}} \mathbf{w}}$$

$$\hat{T}_{\text{n}} = \frac{T_{\text{n}}}{\eta_{\text{rad}}} = \frac{\alpha T_{\text{abs}} - Y T_{\text{ext,sky}(A)}}{Y - 1}$$

$$\hat{T}_{\text{n}} = T_{\text{ext,sky}(B)} + T_{\text{ext,gnd}} + (T_{\text{loss}} + T_{\text{rec}})/\eta_{\text{rad}}$$

Measurement contexts

Aperture array

(Chippendale et al., ISAP 2015)

- Receiver performance
- $M_1 = T_n / \eta_{rad}$

In-reflector

(Chippendale et al., ICEAA 2015)

- Deployed system performance
- $M_2 = T_{sys} / \eta_{rad} \eta_{ap}$

$$\eta_{ap} = (M_1 + T_{sky} + T_{stray}) / M_2$$

$$Y = \frac{P_{hot}}{P_{cold}} = \frac{\mathbf{w}^H \mathbf{R}_{hot} \mathbf{w}}{\mathbf{w}^H \mathbf{R}_{cold} \mathbf{w}}$$

Signal and noise depend on weights!

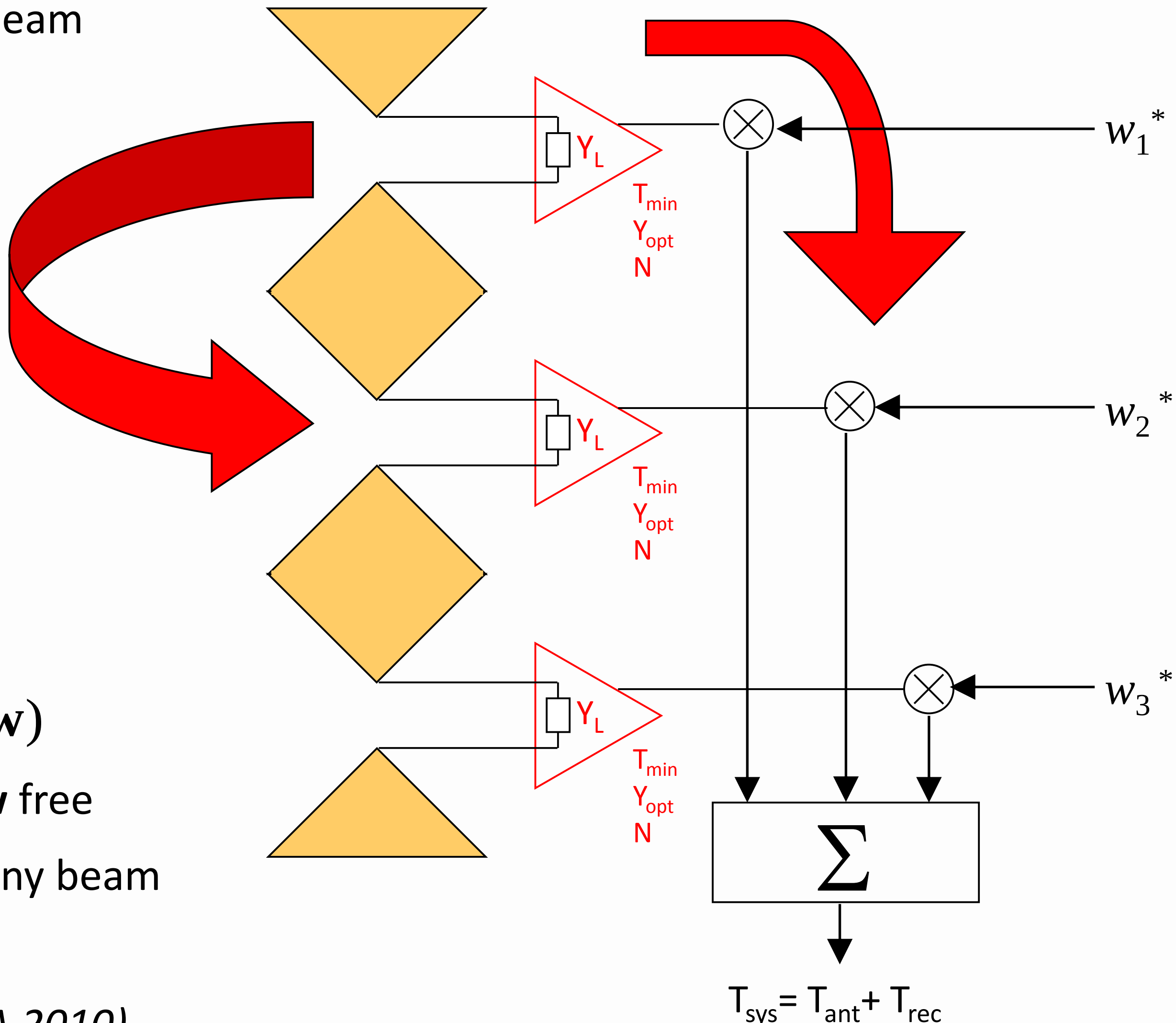
Measurement

Maximise SNR for boresight beam coupled to wave from from reference antenna

$$\mathbf{R} = \frac{1}{L}\sum_{n=1}^{L}\mathbf{x}(n)\mathbf{x}^H(n)$$

$$\mathbf{w} = \mathbf{R}_{\mathrm{cold}}^{-1}\mathbf{r}_{xd}$$

$$Y = \frac{P_{\mathrm{hot}}}{P_{\mathrm{cold}}} = \frac{\mathbf{w}^H\mathbf{R}_{\mathrm{hot}}\mathbf{w}}{\mathbf{w}^H\mathbf{R}_{\mathrm{cold}}\mathbf{w}}$$



Design

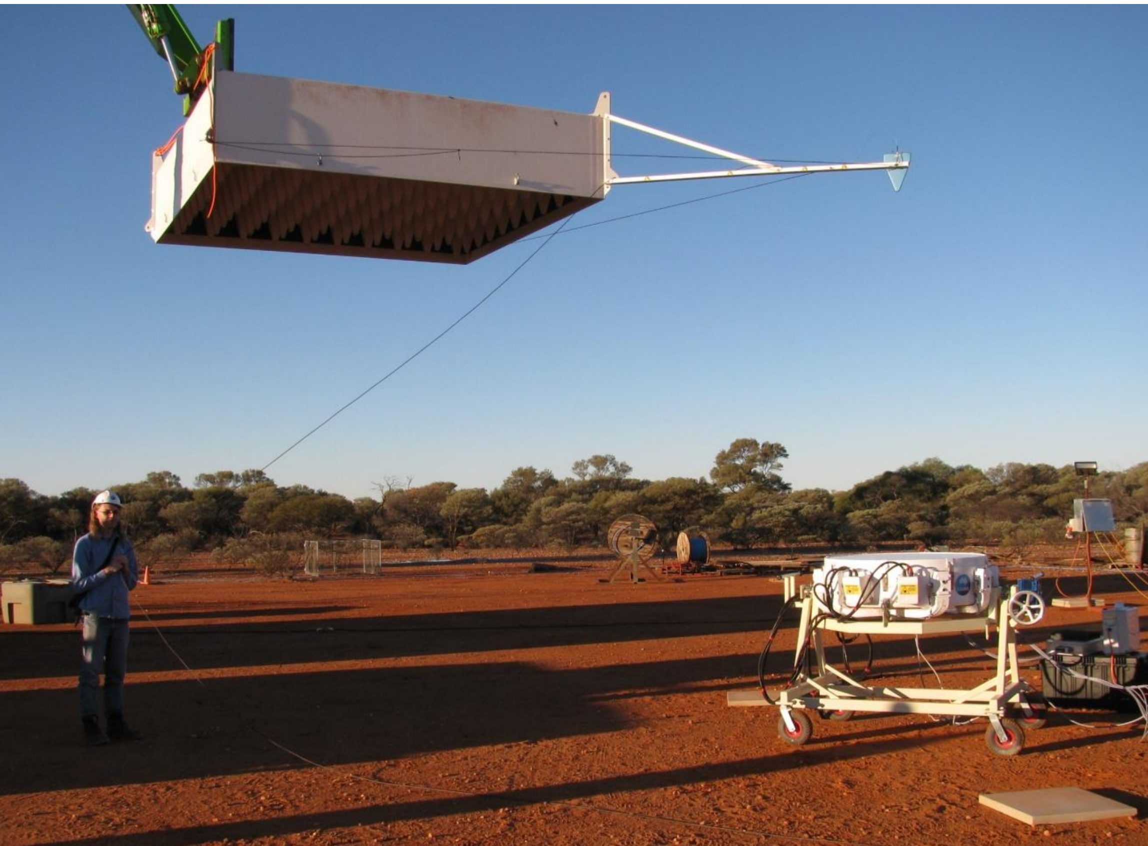
$$SNR = f(\mathbf{Y}_A, T_{\min}, Y_{opt}, N, \mathbf{w})$$

Maximise SNR with Y_{opt} and **w** free

Find global optimum over many beam directions in FOV

(Hay, IJMOT 5,6,2010 & ICEAA 2010)

Calibration source



Array calibration wrt. source

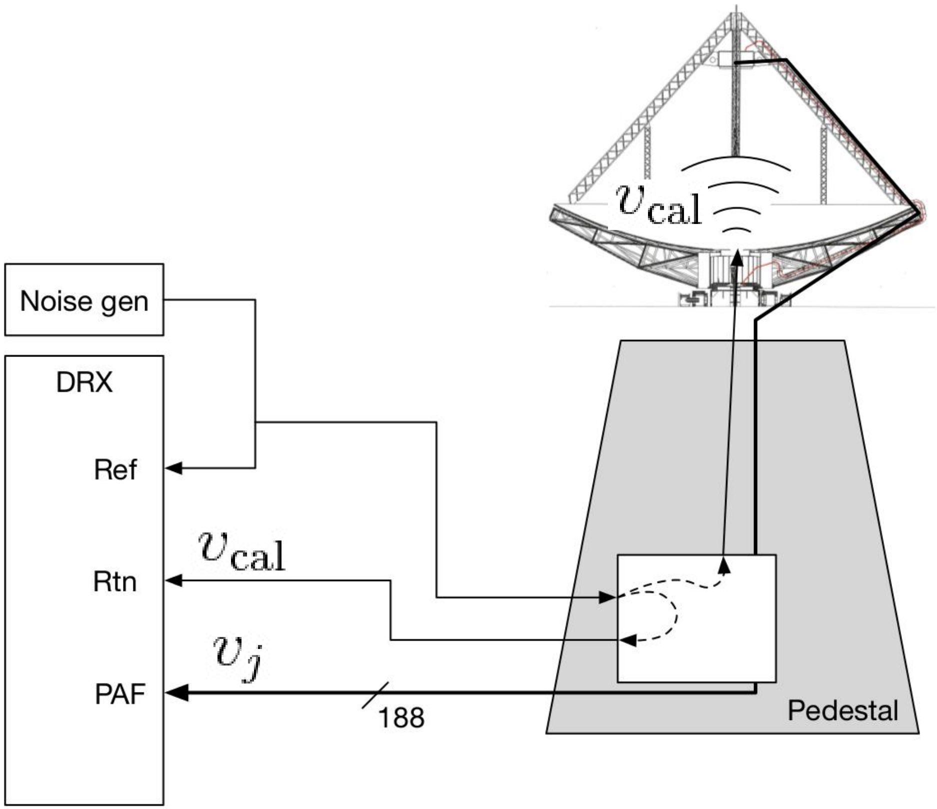
(Hayman et al., ICEAA 2010)
(Chippendale et al., EuCAP 2016)

$$d_j = \langle v_j \bar{v}_{\mathrm{cal}} \rangle \,/\, \langle v_* \bar{v}_{\mathrm{cal}} \rangle$$

$$\mathbf{D} = \mathrm{diag}(\mathbf{d})$$

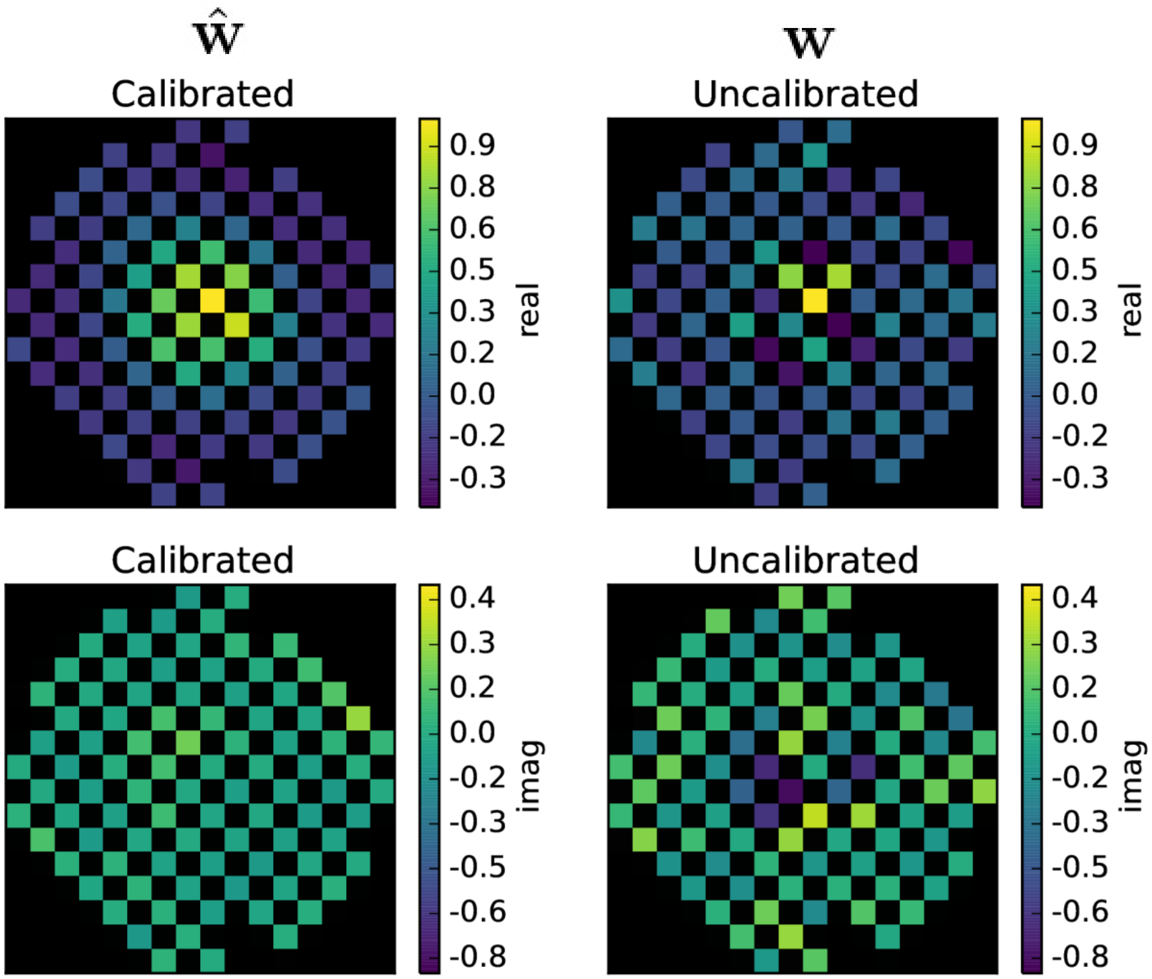
$$\hat{\mathbf{R}} = \mathbf{D}^{-1}\mathbf{R}\bar{\mathbf{D}}^{-1}$$

$\hat{\mathbf{w}} = \hat{\mathbf{R}}^{-1}\hat{\mathbf{s}}$ where $\hat{\mathbf{s}}$ is the dominant eigenvector of $\hat{\mathbf{R}}_{\mathrm{on}} - \hat{\mathbf{R}}_{\mathrm{off}}$



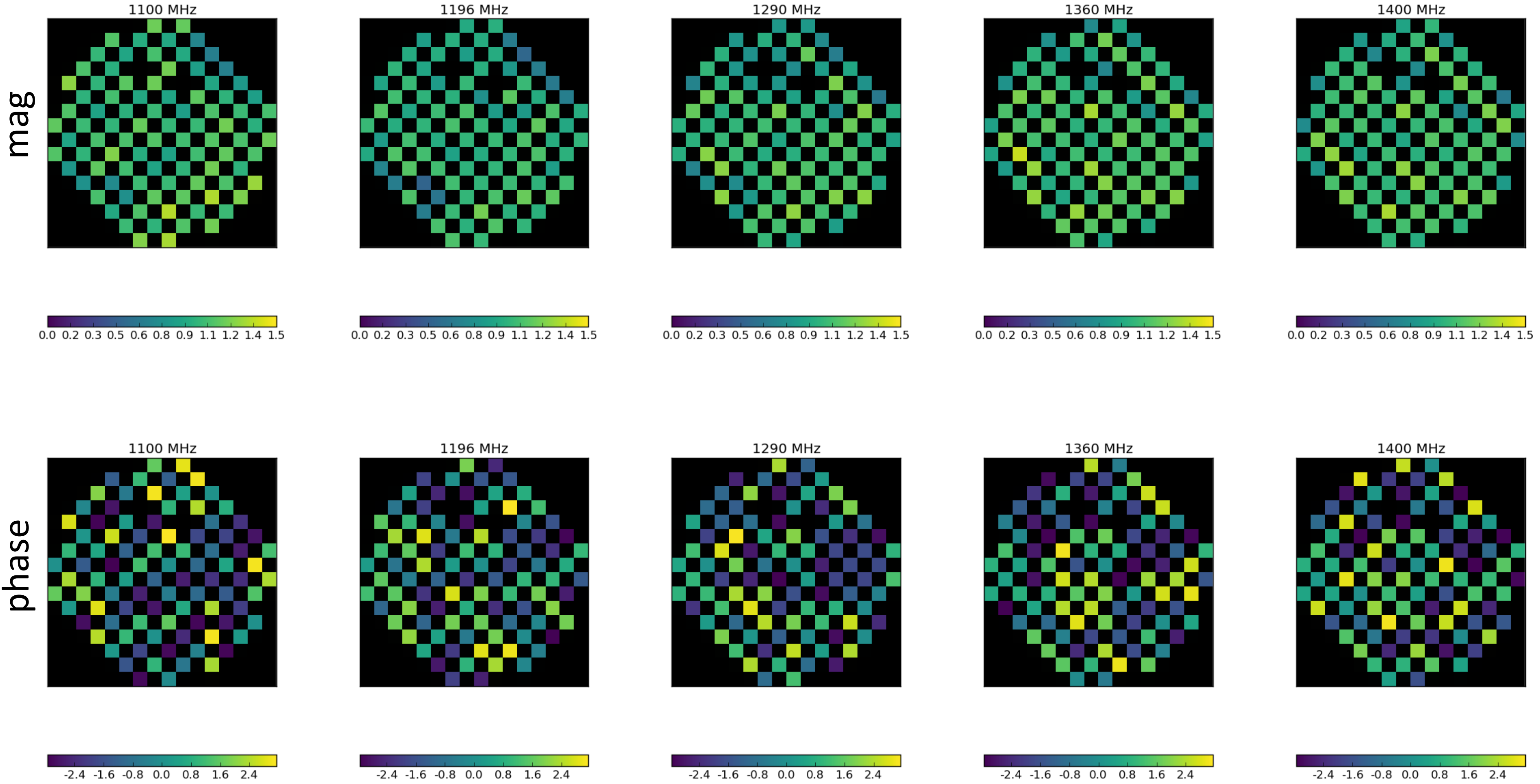
* is a reference PAF port

MaxSNR PAF beam at 835 MHz

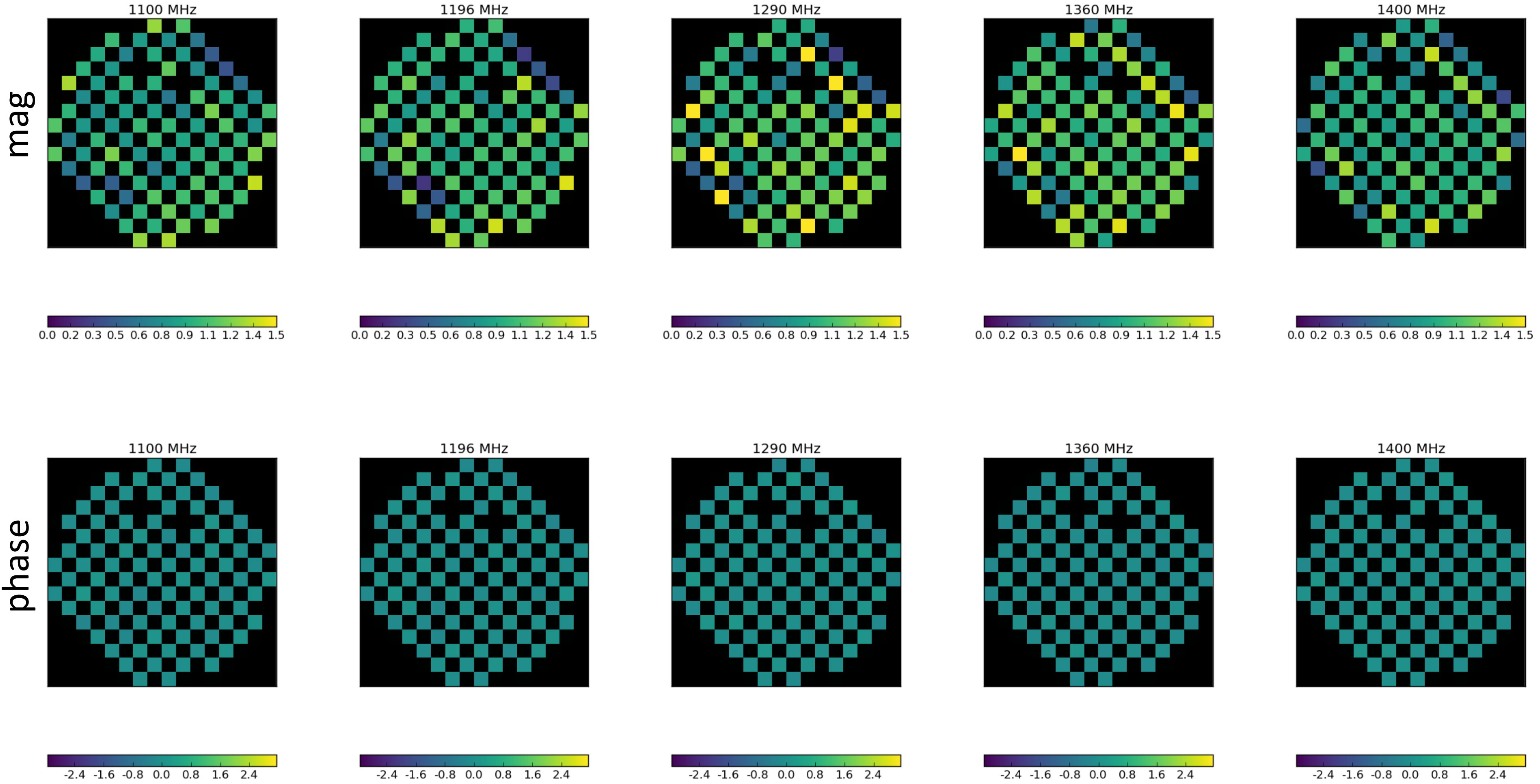


(Chippendale et al., EuCAP 2016)

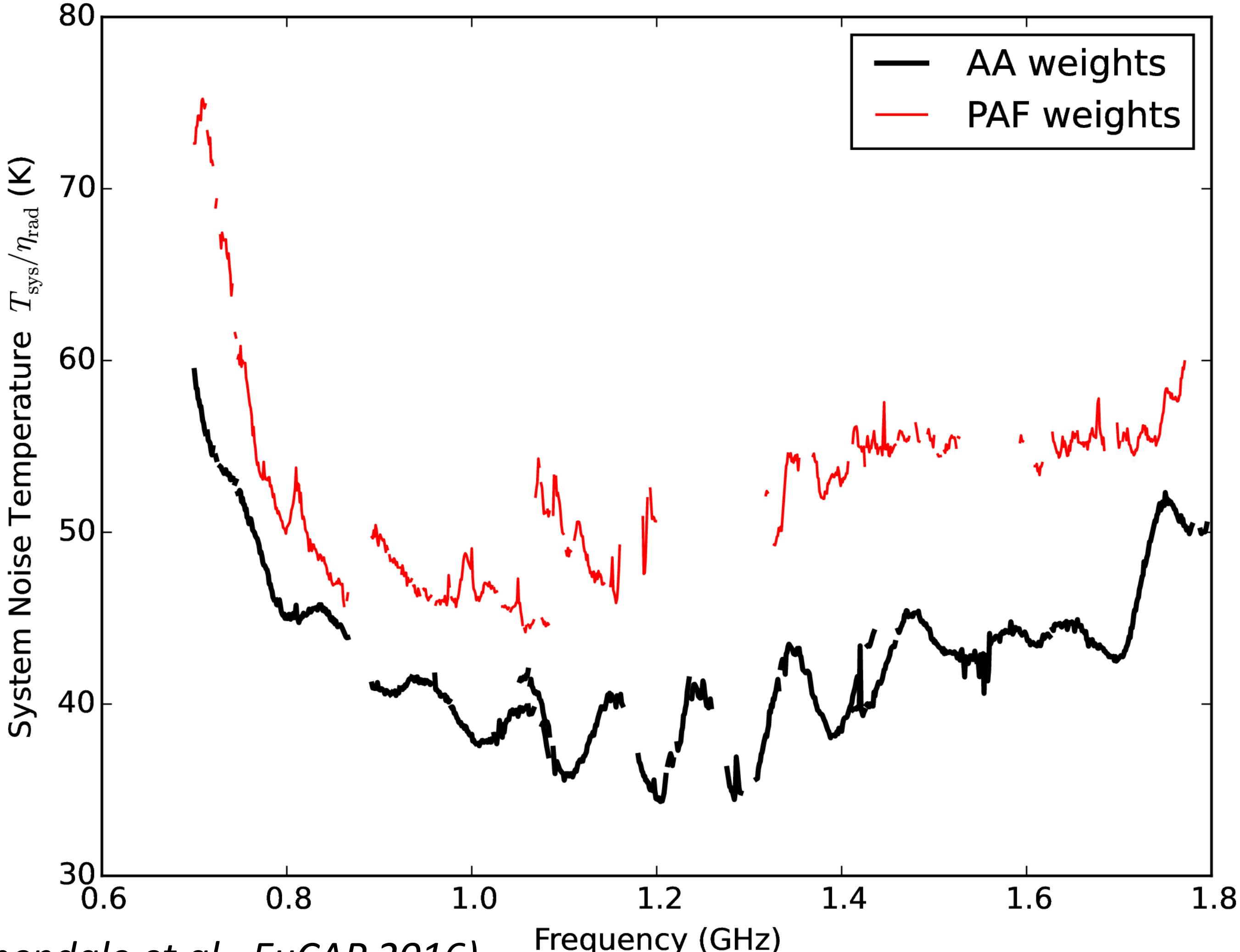
MaxSNR AA beam (uncalibrated)



MaxSNR AA beam (calibrated)



System temperature (AA weights via dish)

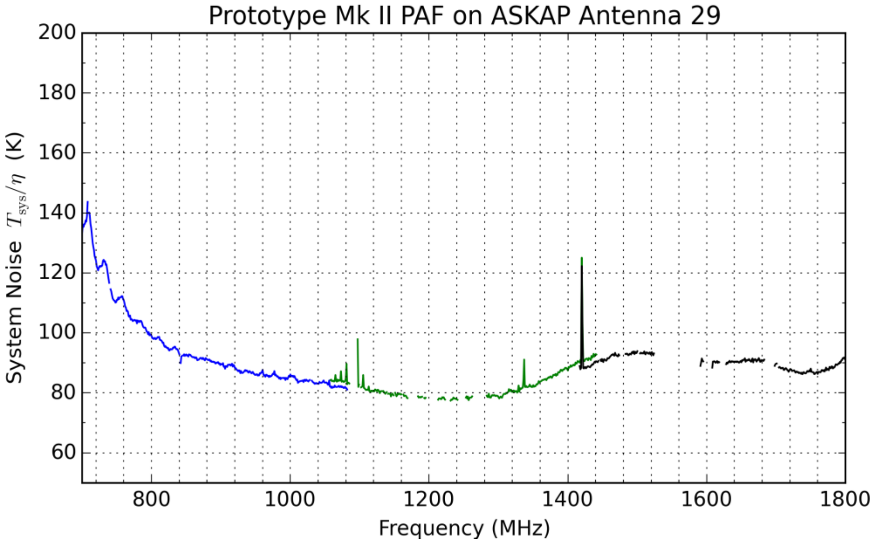


$$y = \frac{\hat{\mathbf{w}}^H \hat{\mathbf{R}}_{\mathrm{on}} \hat{\mathbf{w}}}{\hat{\mathbf{w}}^H \hat{\mathbf{R}}_{\mathrm{off}} \hat{\mathbf{w}}}$$

(Chippendale et al., EuCAP 2016)

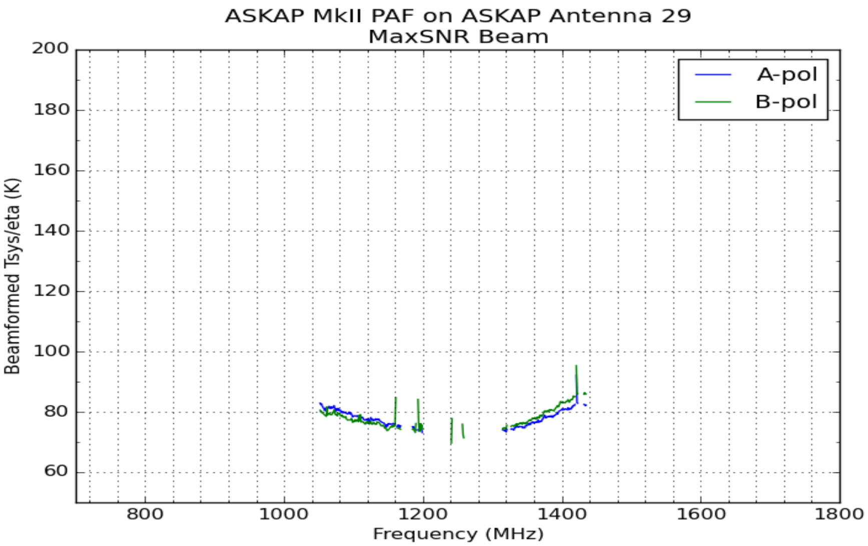
T_{sys}/η on ASKAP antenna 29 (prototype)

no calibration



(Chippendale et al., ICEAA 2015)

calibrated w.r.t. noise



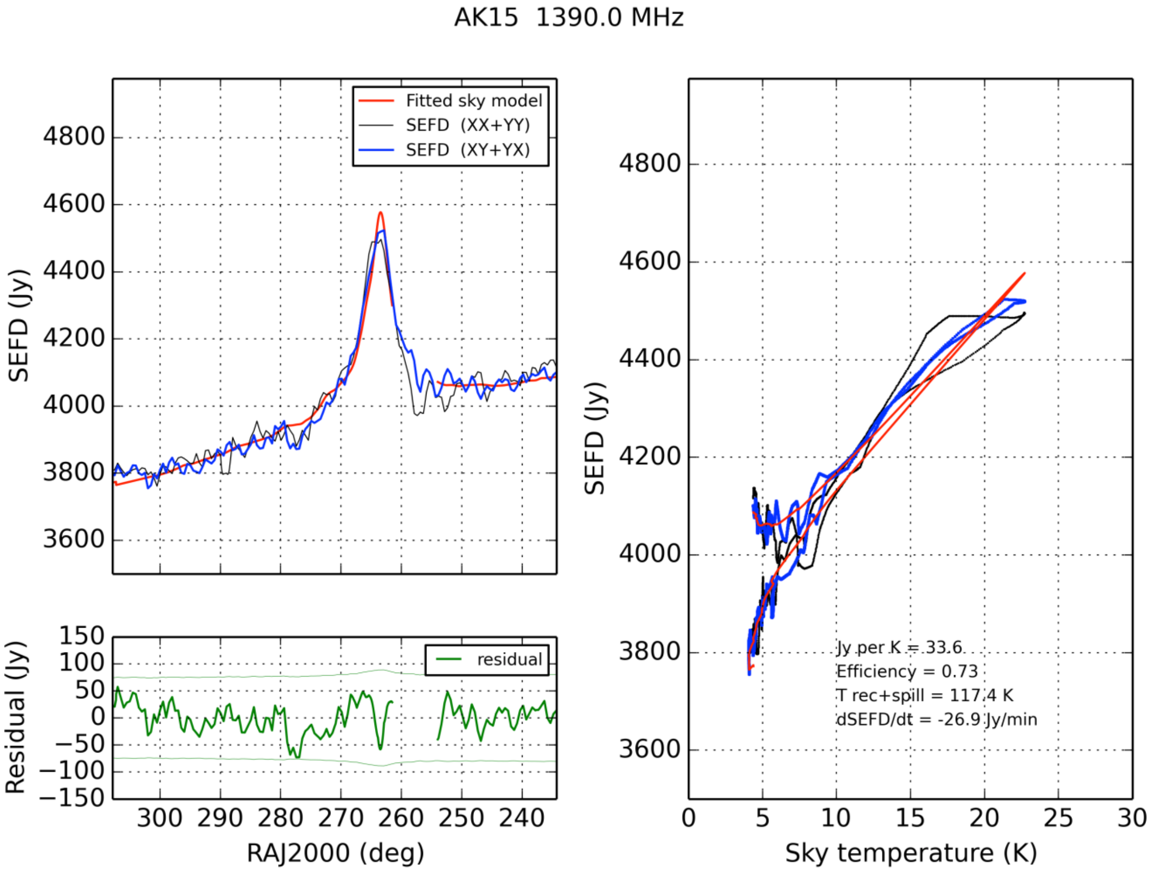
Note: calibrated and uncalibrated measurements made at different epochs

Separating noise and efficiency: Mk I PAF at 1390 MHz

(McConnell et al., ACES Memo 5, 2015) http://www.atnf.csiro.au/projects/askap/ACES-memos

(McConnell et al., PASA 2016)

(Chippendale et al., EuCAP 2016)



$$\text{SEFD} = \frac{2k}{\eta A}(T_{\text{rec}} + T_{\text{spill}} + T_{\text{sky}})$$

$$\text{SEFD} = aT_{\text{sky}} + b$$

Invert for all baselines and decompose per antenna

$$T_{\text{sys}} = 111 \pm 7\ \text{K}$$

$$\eta = 70 \pm 4\ \%$$

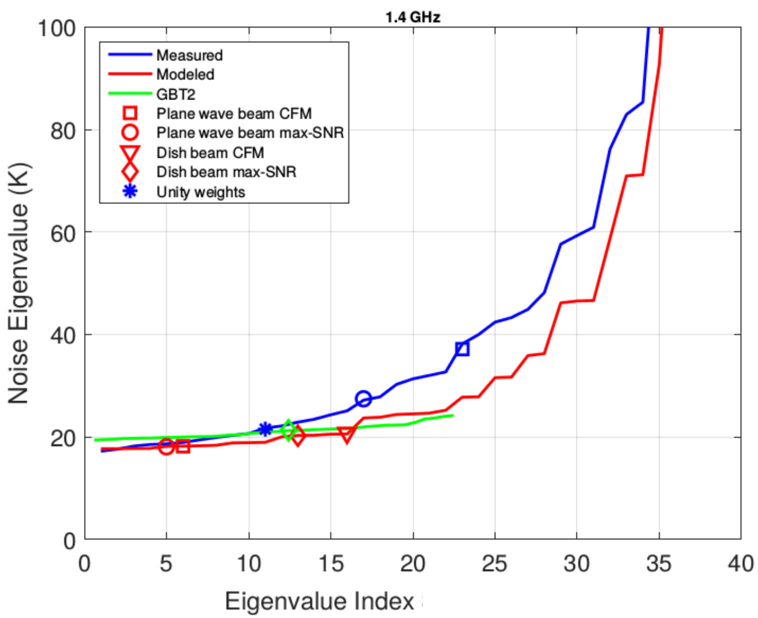
Neglected loss variation with ambient temp.

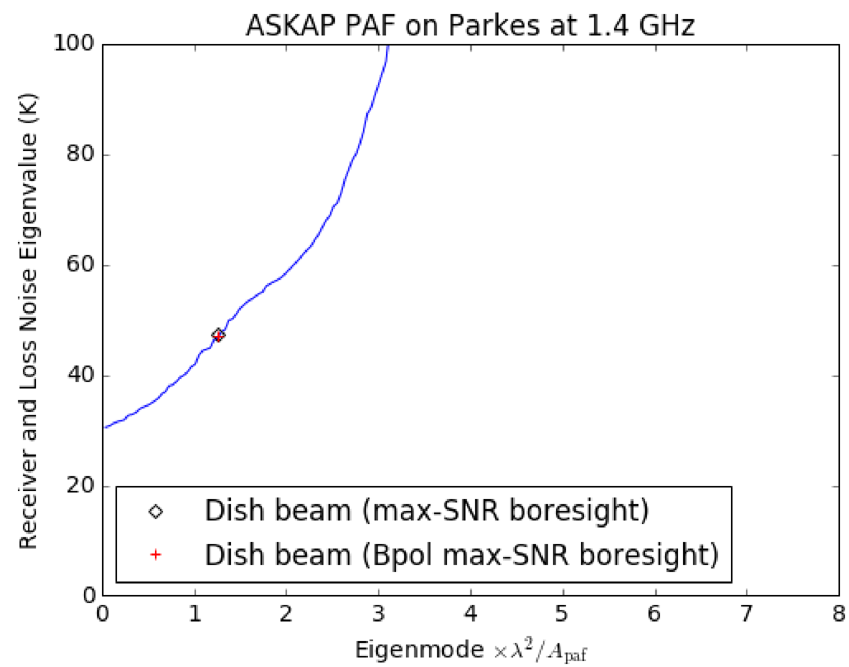
Evidence of temperature dependent gain and gain/calibration errors

Receiver noise eigenvalue spectrum:

Exploring receiver performance and design optimality

(Warnick, Chippendale, Hayman & Dunning, draft whitepaper 2016)

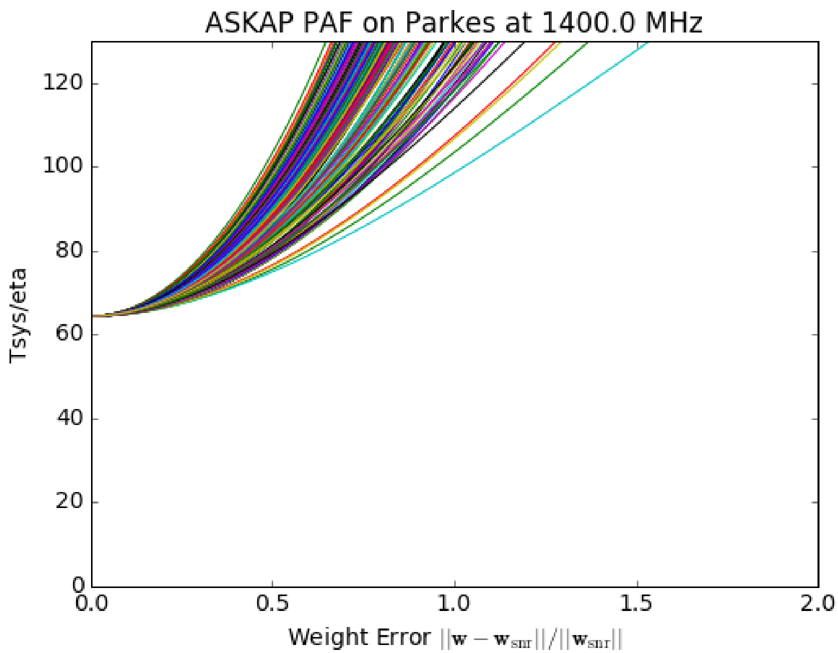


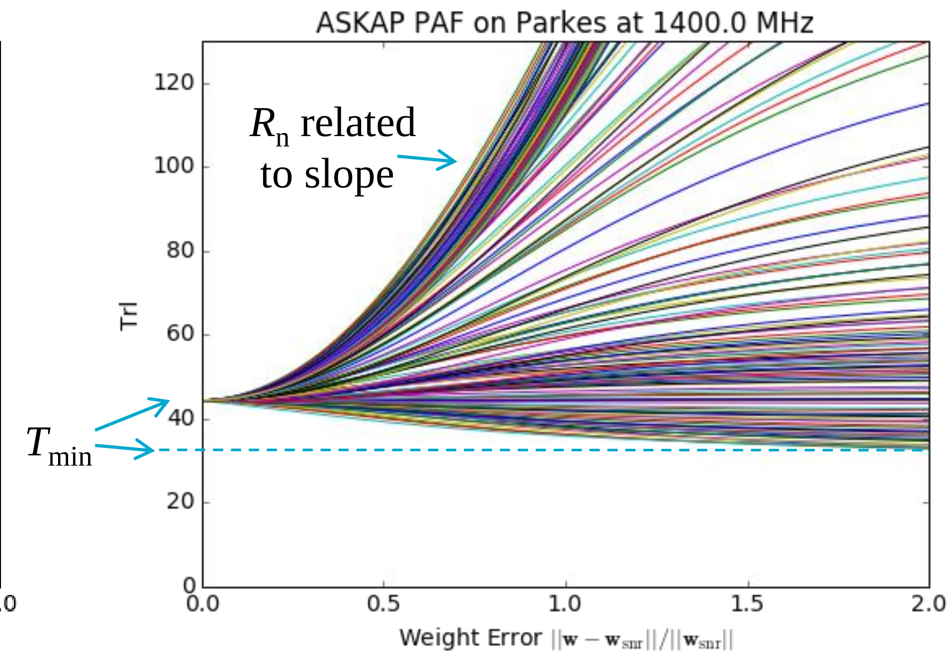


Performance trends towards noise eigenvectors

Seeking noise-parameter-like summary of PAF performance

(Warnick, Chippendale, Hayman & Dunning, draft whitepaper 2016)
(cf. Warnick et al., TAP 2010)





Related to distance $|Y\text{-}Y_{opt}|$ from optimum active admittance Y_{opt}

Conclusion

- ASKAP Mk II PAF noise temperature may be up to 10 K higher with in-reflector beam weights than with aperture-array weights.
  - need to quantify back-end noise contribution
  - need to make all measurements on a single array
  - include spillover change between in-dish and aperture array measurements
- Calibrating via a “plane-wave” gives weights physical meaning
  - makes weights smoother in frequency/space
  - simplifies weight interpolation
  - makes weights real-valued (sparser)
  - easier to apply a-priori knowledge (simulations or range measurements)
- Generating a nascent framework for comparing PAFs

Thank you

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