Engineering Development Array (EDA)

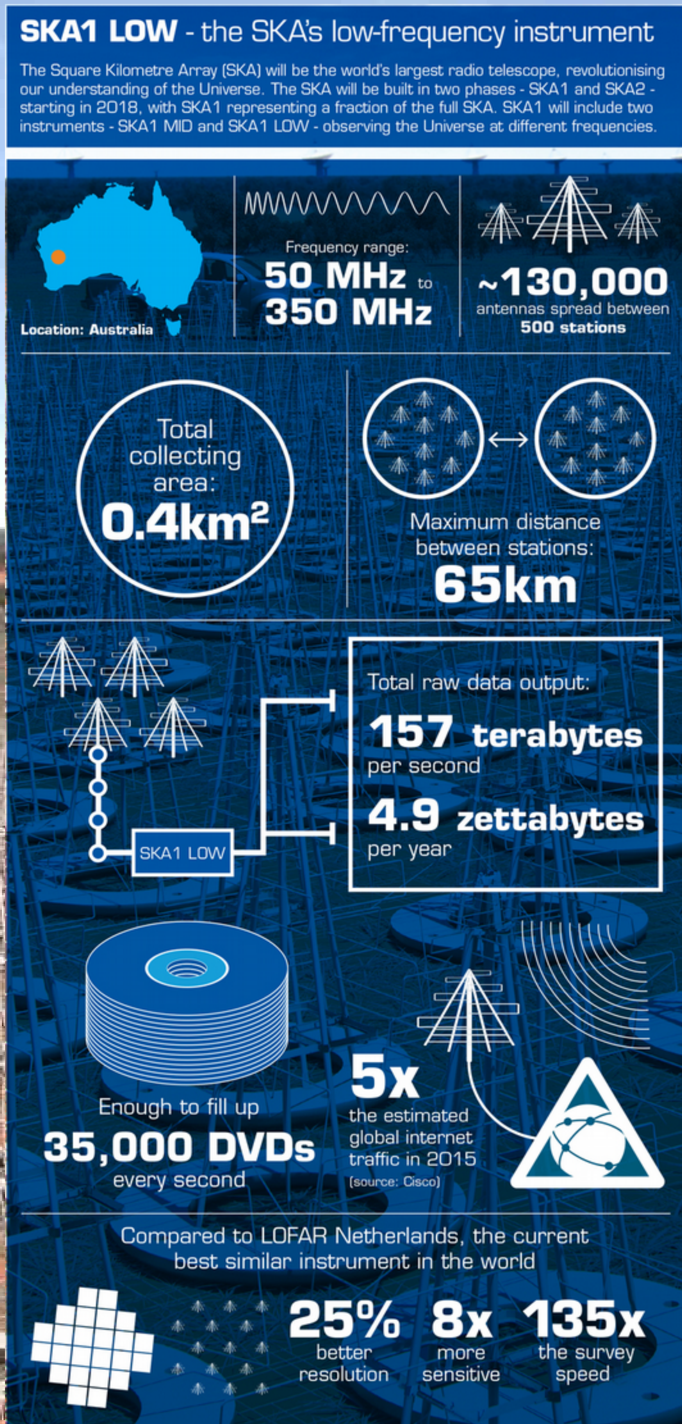
Image: Kim Steele

Marcin Sokołowski, ICRAR-Curtin

on behalf of the EDA team : Tom Booler, Brian Crosse, David Emrich, Peter Hall, Luke Horsley, Budi Juswardy, David Kenney, Kim Steele, Adrian Sutinjo, Daniel Ung, Steven Tingay, Cath Trott, Mia Walker, Randall Wayth, Andrew Williams and others

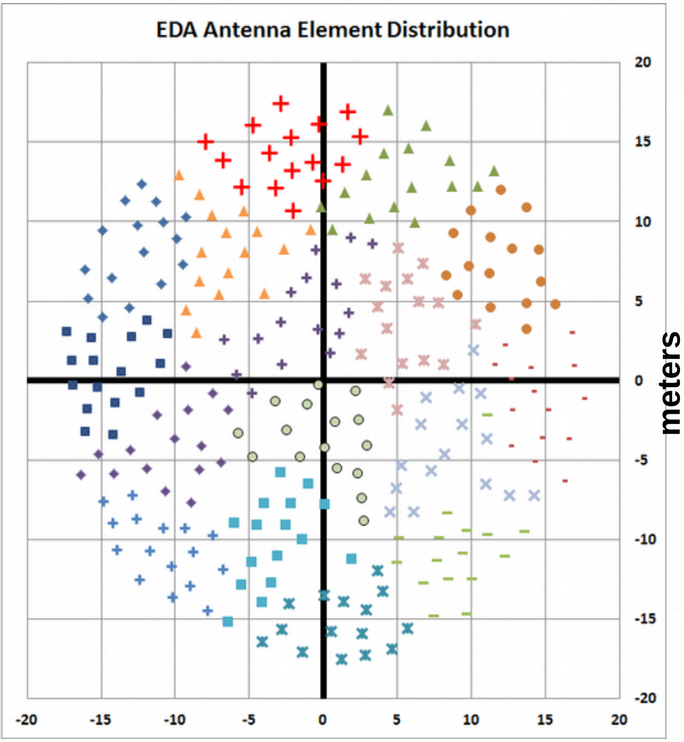
International Centre for Radio Astronomy Research

Motivation for EDA driven by SKA-low



- Collect further SKA-low precursor experience using "MWA technology"
- Test different options in the context of cost reduction process :
  - analogue (MWA style) beamforming
  - MWA Bow-Tie dipole antenna
- Test EDA / AAVS correlation with the MWA and find any unknowns / issues
- Identify any other unknowns and unexpected problems at early stages
- Continue to provide important contributions of the MWA Epoch of Reionisation community to the SKA-low design specifications

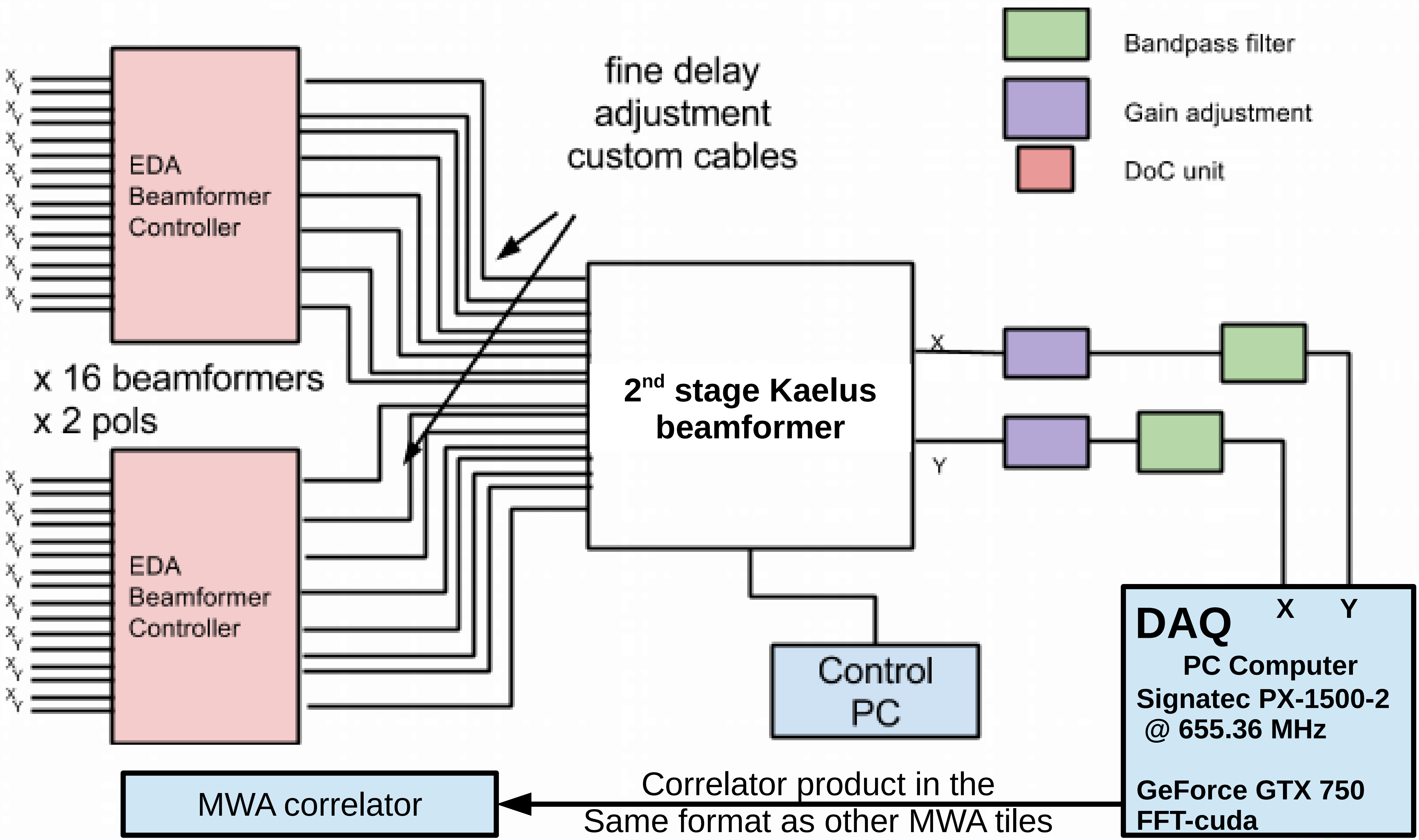
EDA deployed in the field in 2016



- The same pseudo-random layout as AAVS station with different antenna
- Diameter 35 meters
- 256 MWA Bow-Tie dipoles, clustered in groups of 16 connected to MWA beamformer
- Outputs of 16 beamformers connected to 2nd stage Kaelus beamformer

R. Wayth et al. PASA, 2017

EDA architecture inside the hut

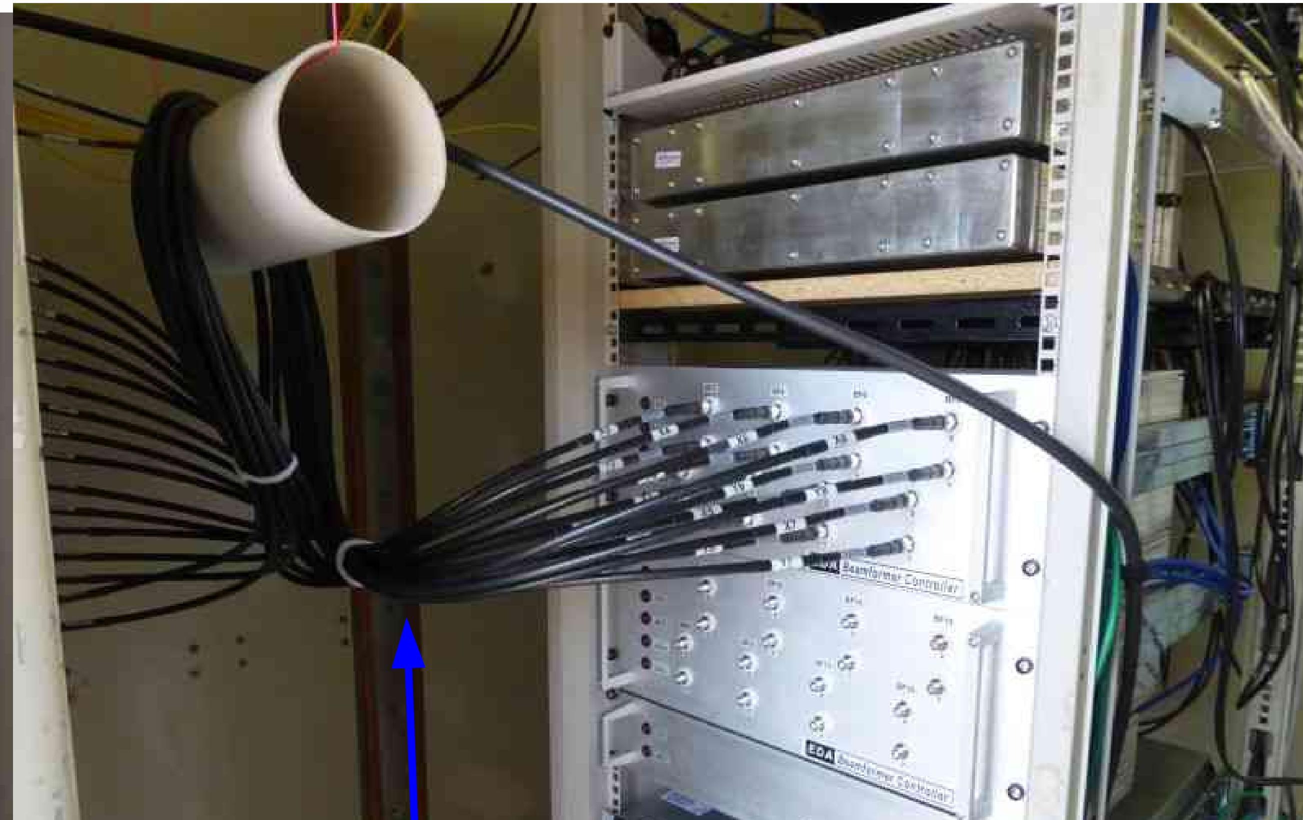


EDA inside the Telstra hut

Data acquisition computer with digitiser card and GPU

Signatec PX-1500

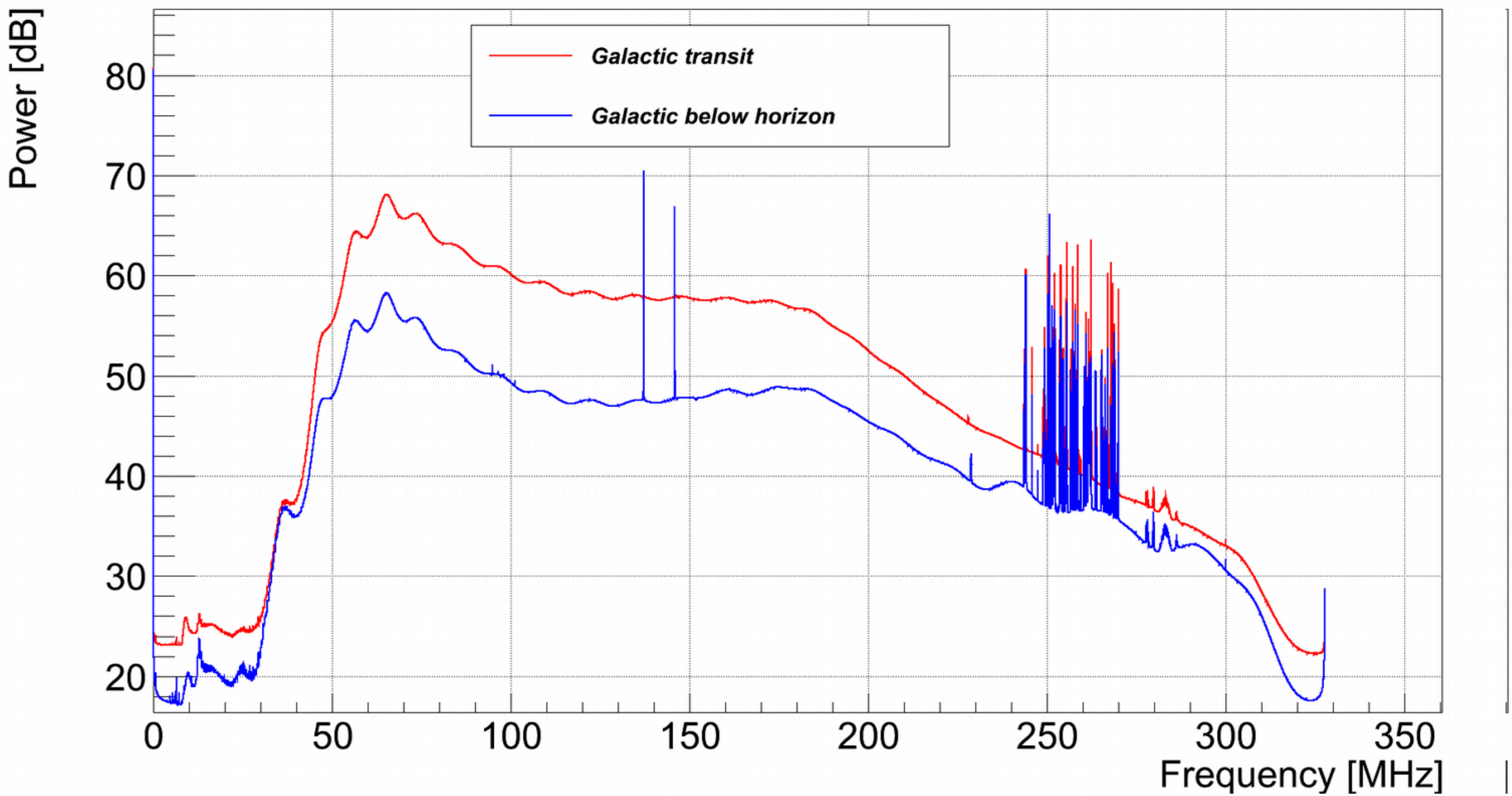
GTX 750



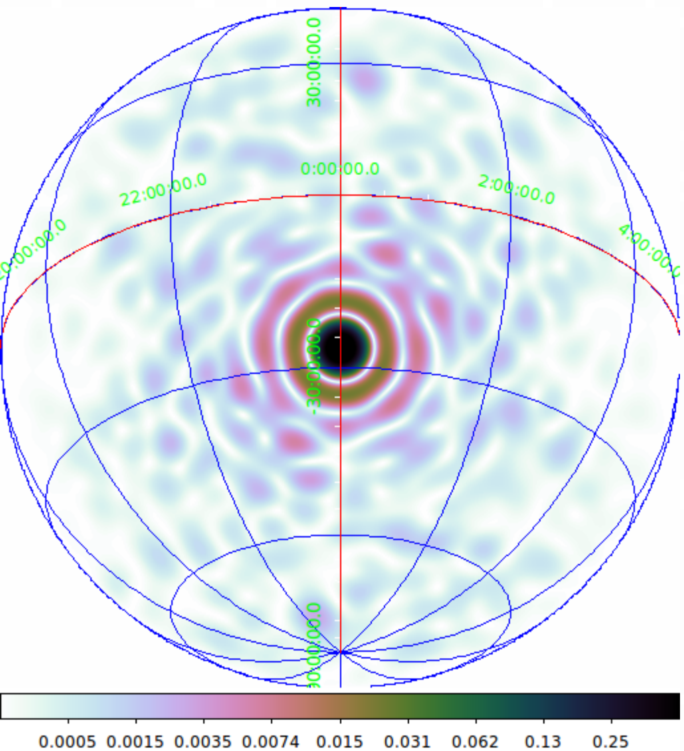
Delay matching cables phase-equalised in the LAB, but required further adjustments based on sky measurements

Images: David Kenney

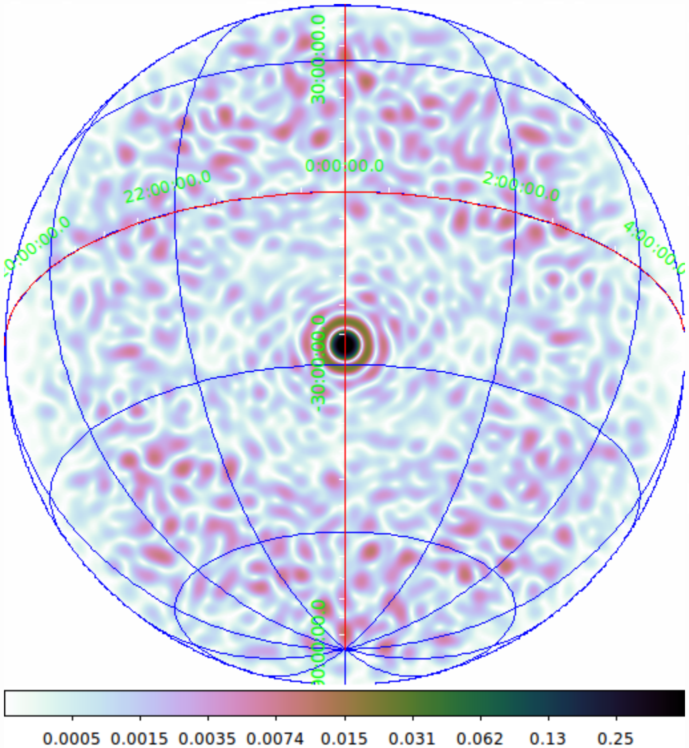
EDA not-the-first light spectrum



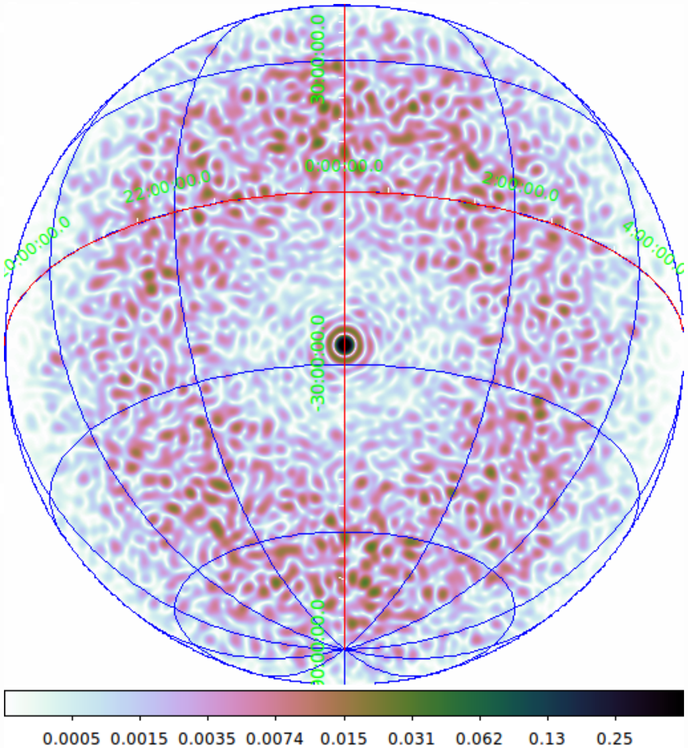
EDA beam simulations



100 MHz



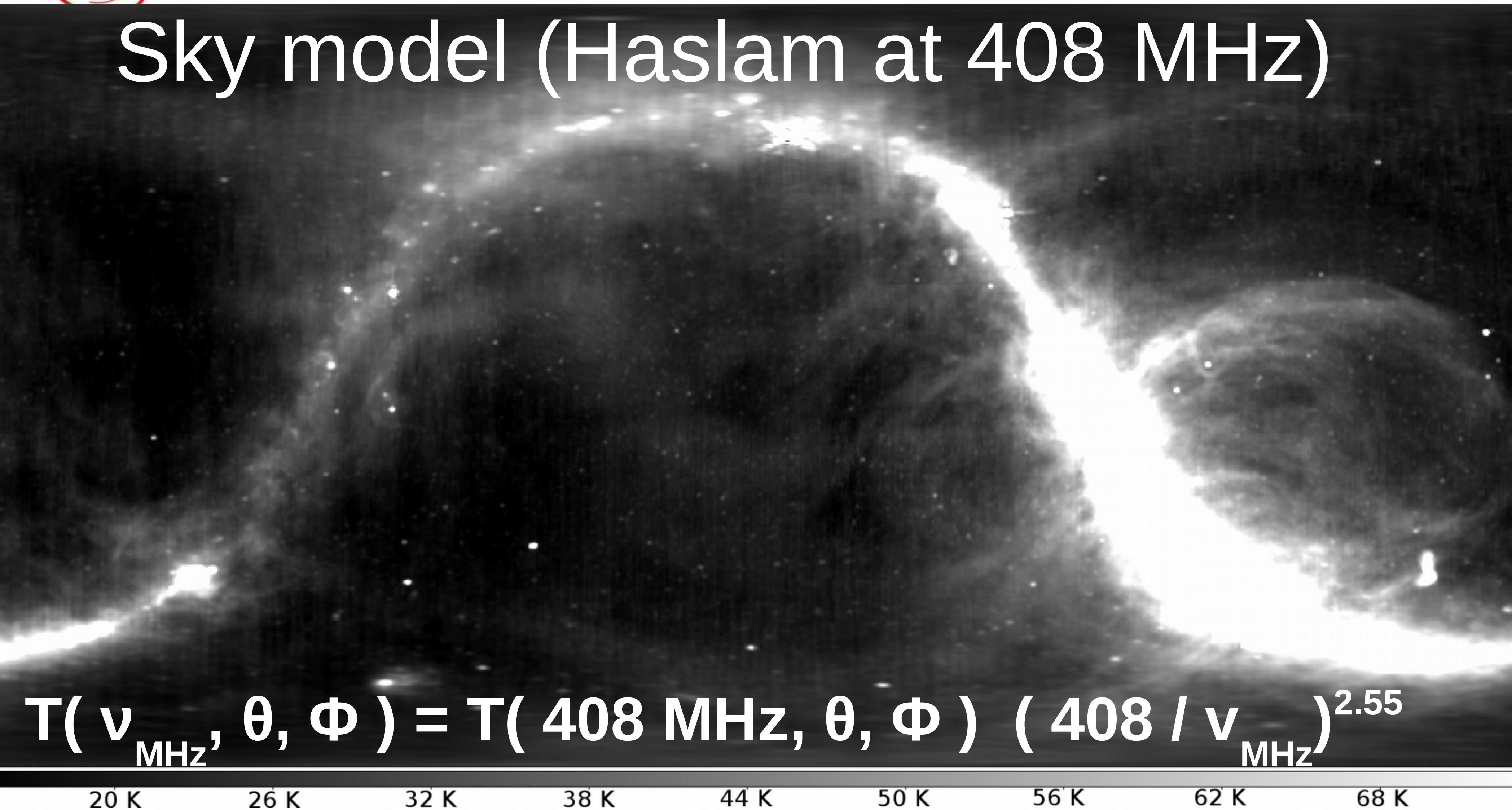
200 MHz



300 MHz

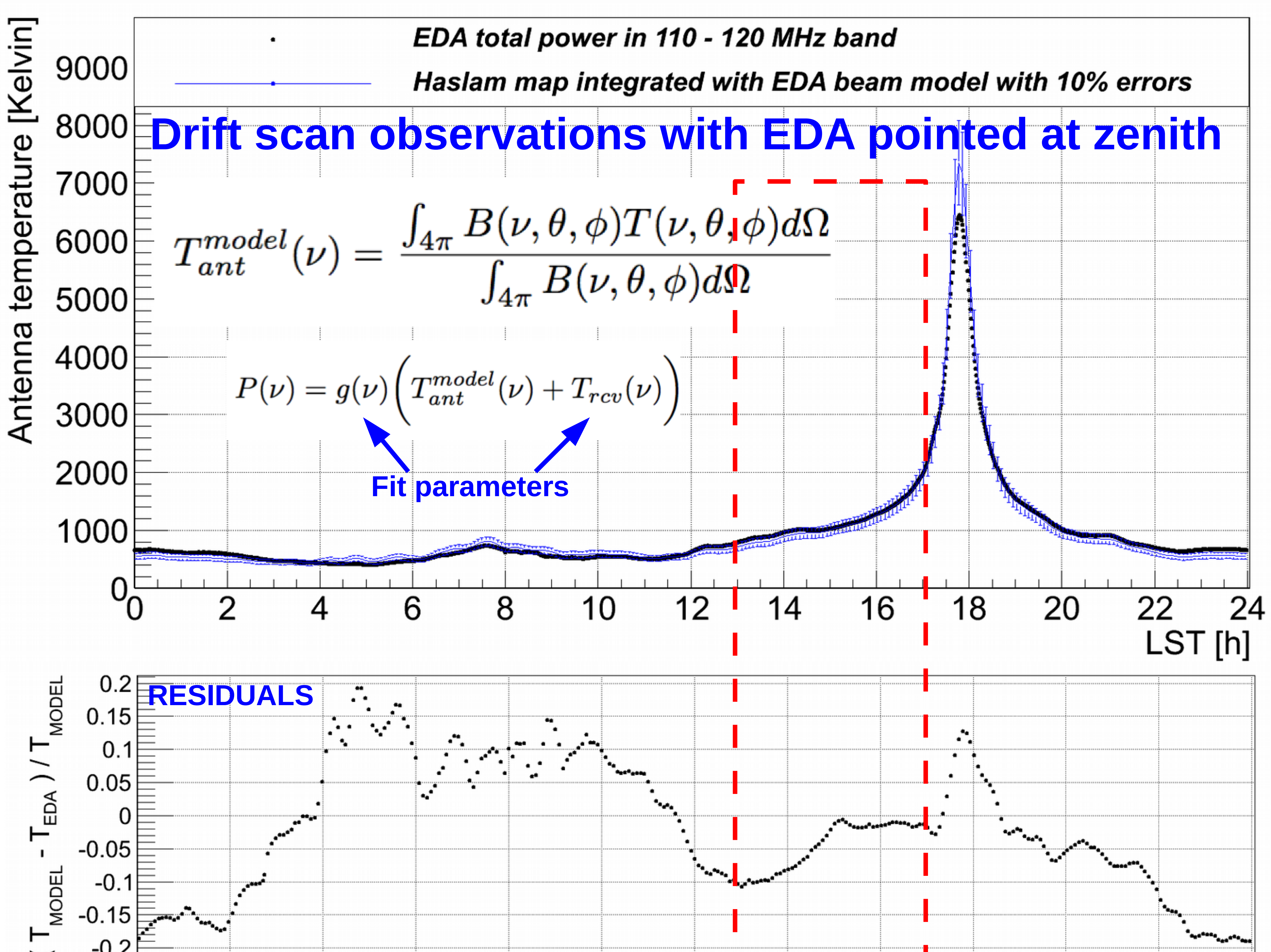
Sensitivity = Effective Area / (antenna temperature + receiver temperature)

Sky model (Haslam at 408 MHz)



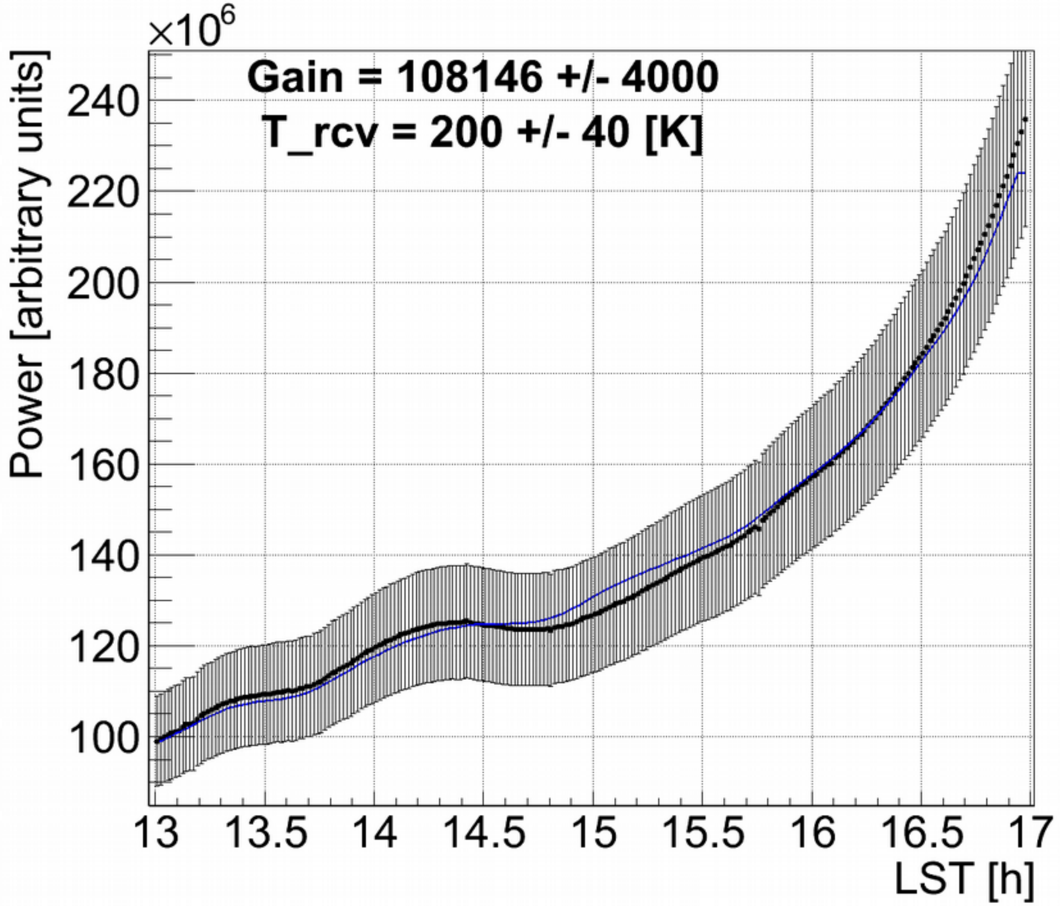
$$T(\nu_{MHz}, \theta, \Phi) = T(408\ \mathrm{MHz}, \theta, \Phi)\ (408 / \nu_{MHz})^{2.55}$$

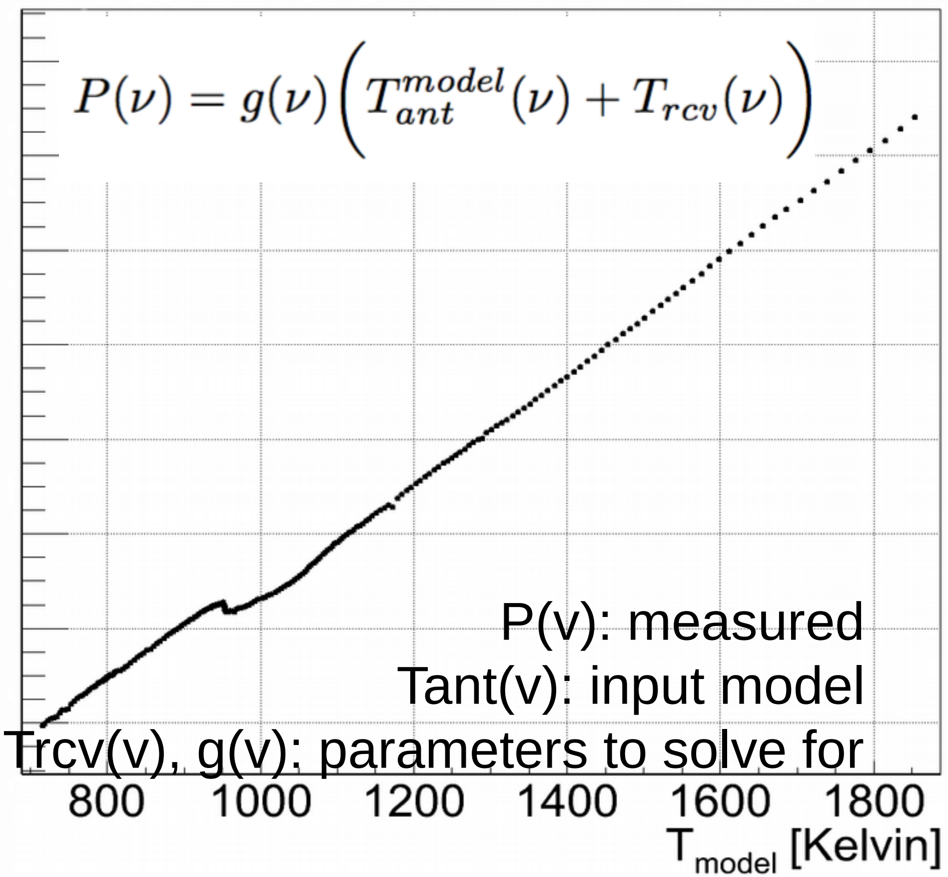
$$T_{ant}^{model}(\nu) = \frac{\int_{4\pi} B(\nu,\theta,\phi) T(\nu,\theta,\phi) d\Omega}{\int_{4\pi} B(\nu,\theta,\phi) d\Omega}$$



EDA total power in 110 - 120 MHz band
Haslam map integrated with EDA beam model with 10% errors
Drift scan observations with EDA pointed at zenith
$$T_{ant}^{model}(\nu) = \frac{\int_{4\pi} B(\nu,\theta,\phi)T(\nu,\theta,\phi)d\Omega}{\int_{4\pi} B(\nu,\theta,\phi)d\Omega}$$
$$P(\nu) = g(\nu)\left(T_{ant}^{model}(\nu) + T_{rcv}(\nu)\right)$$
Fit parameters
Antenna temperature [Kelvin]
LST [h]
RESIDUALS
$(T_{MODEL} - T_{EDA}) / T_{MODEL}$

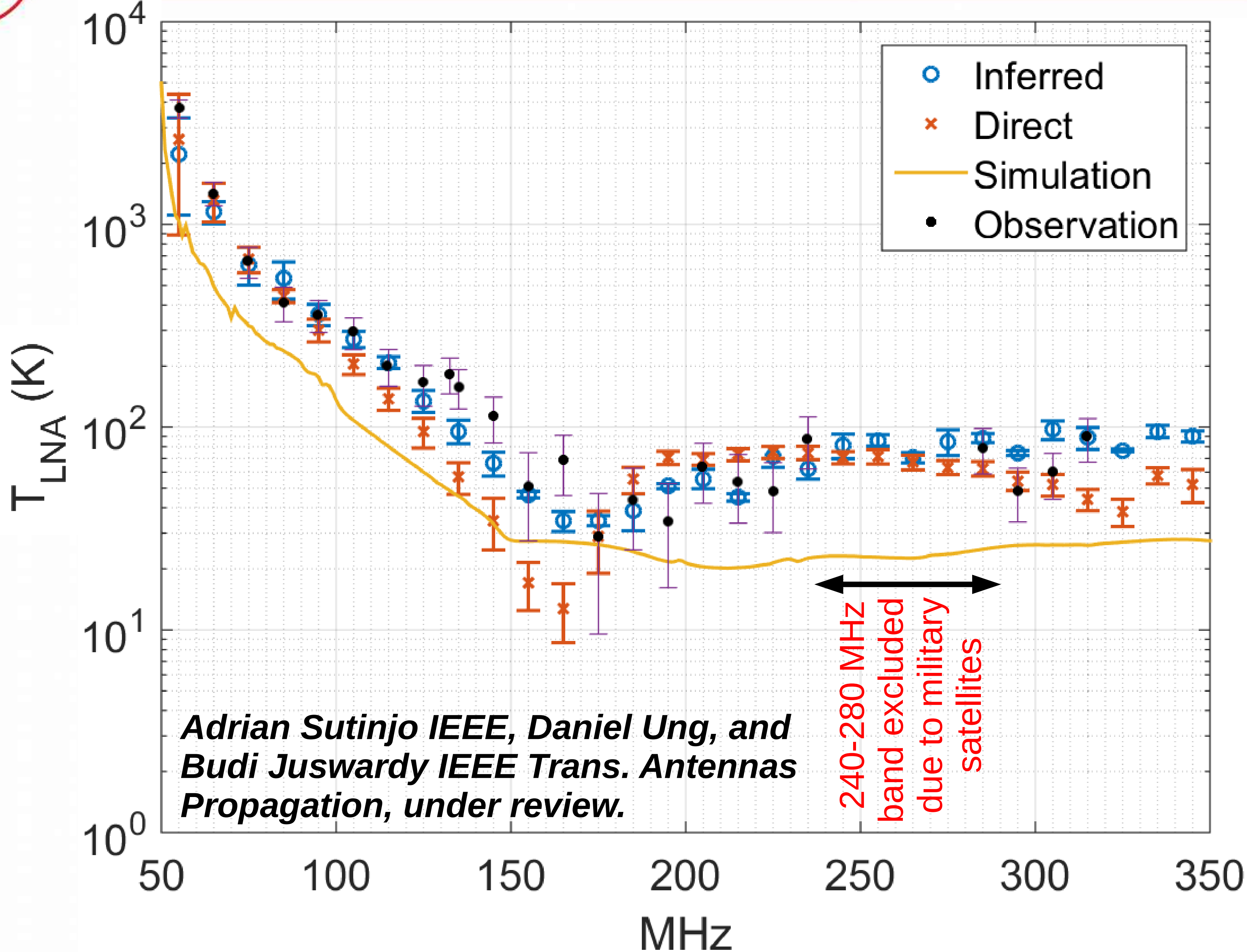
EDA receiver temperature in 110-120 MHz band derived from sky model in 13-17 hours LST range



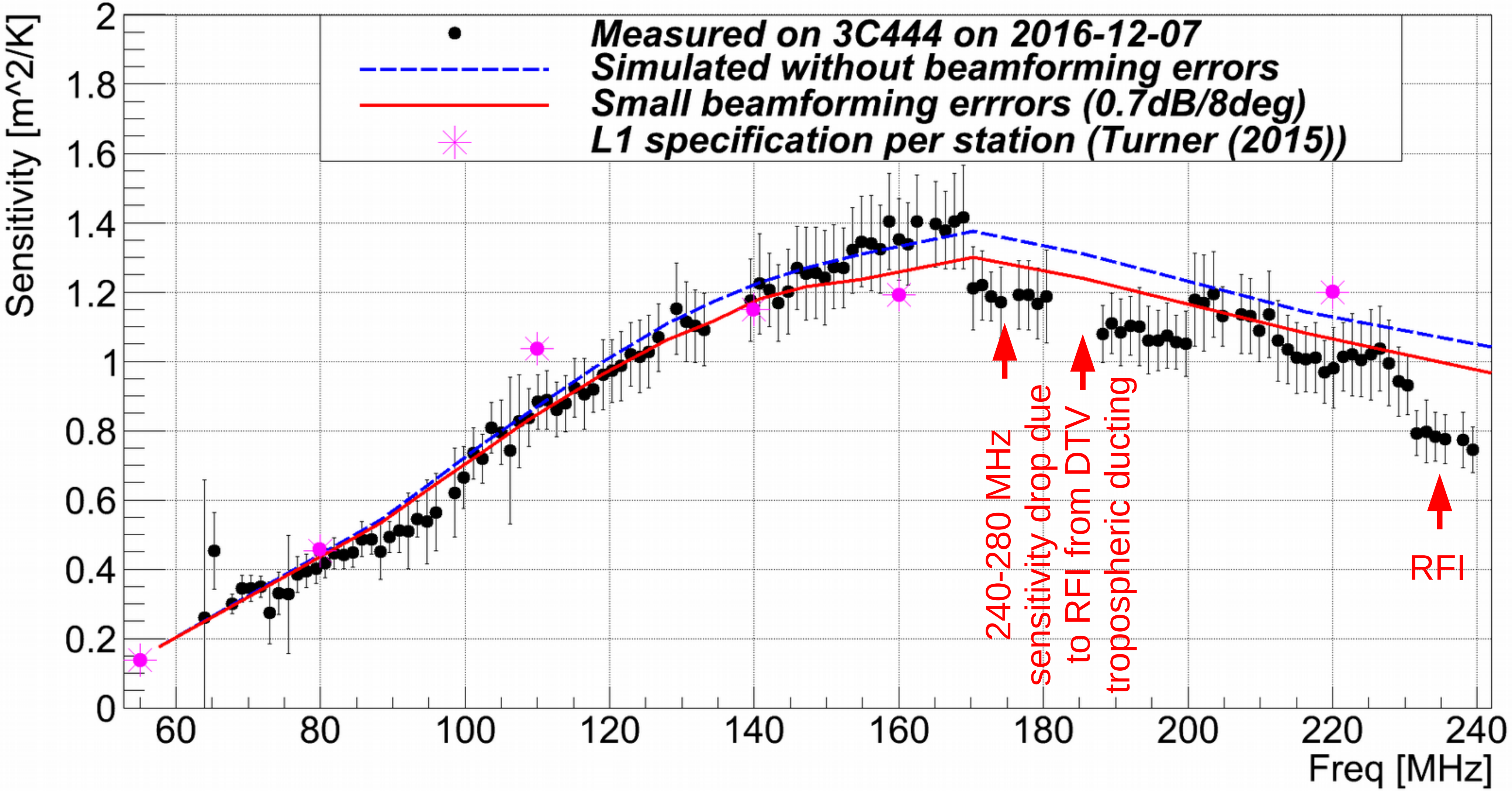


Like a hot/cold method where the changing sky gives hot/cold
Error dominated by systematic error due to sky model uncertainty

EDA receiver temperature from the sky model in LST range 13-17 h agrees with LAB measurements



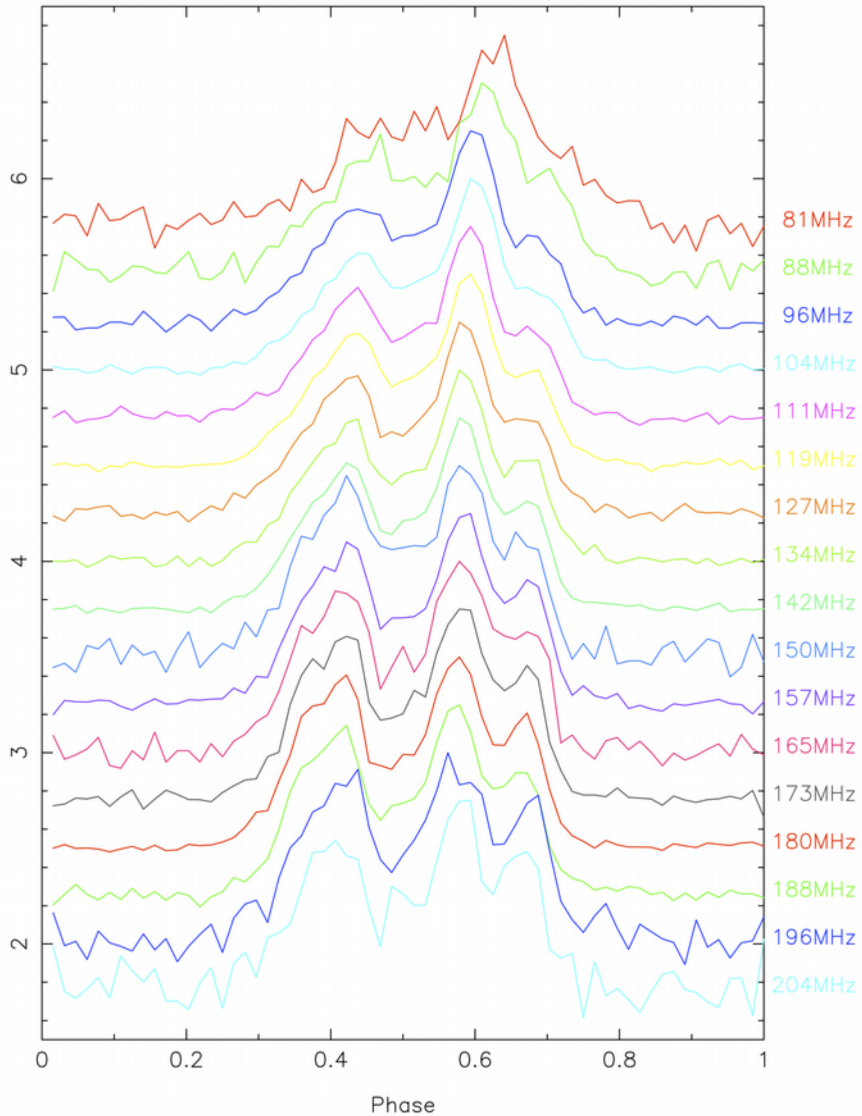
Sensitivity vs. SKA specifications



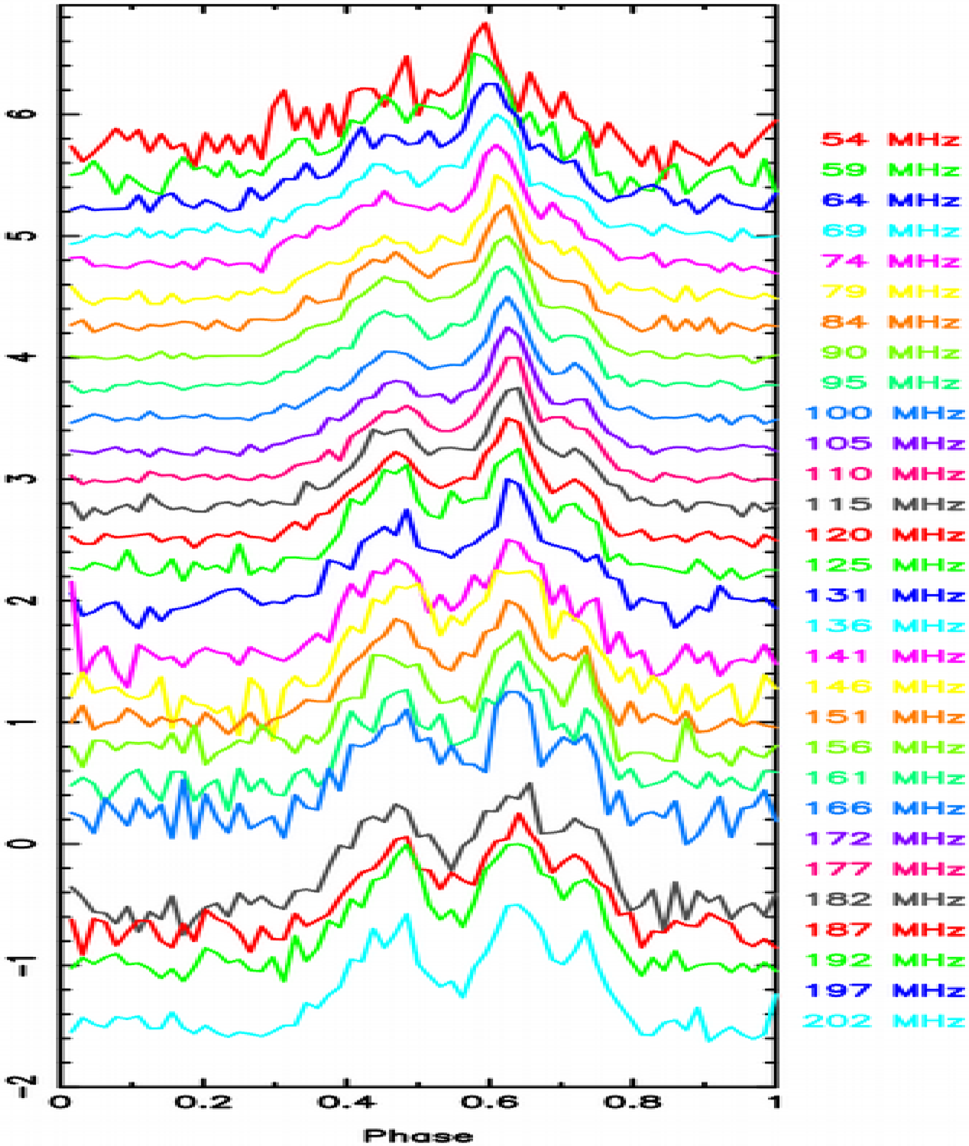
Sensitivity = Effective Area / System temperature = 2k/SEFD, where SEFD was measured from standard deviations of calibrated visibilities collected on calibrator source (HydA or 3C444)

Observations of milisecond pulsars 0437-4715

MWA VCS : ~80 – 200 MHz

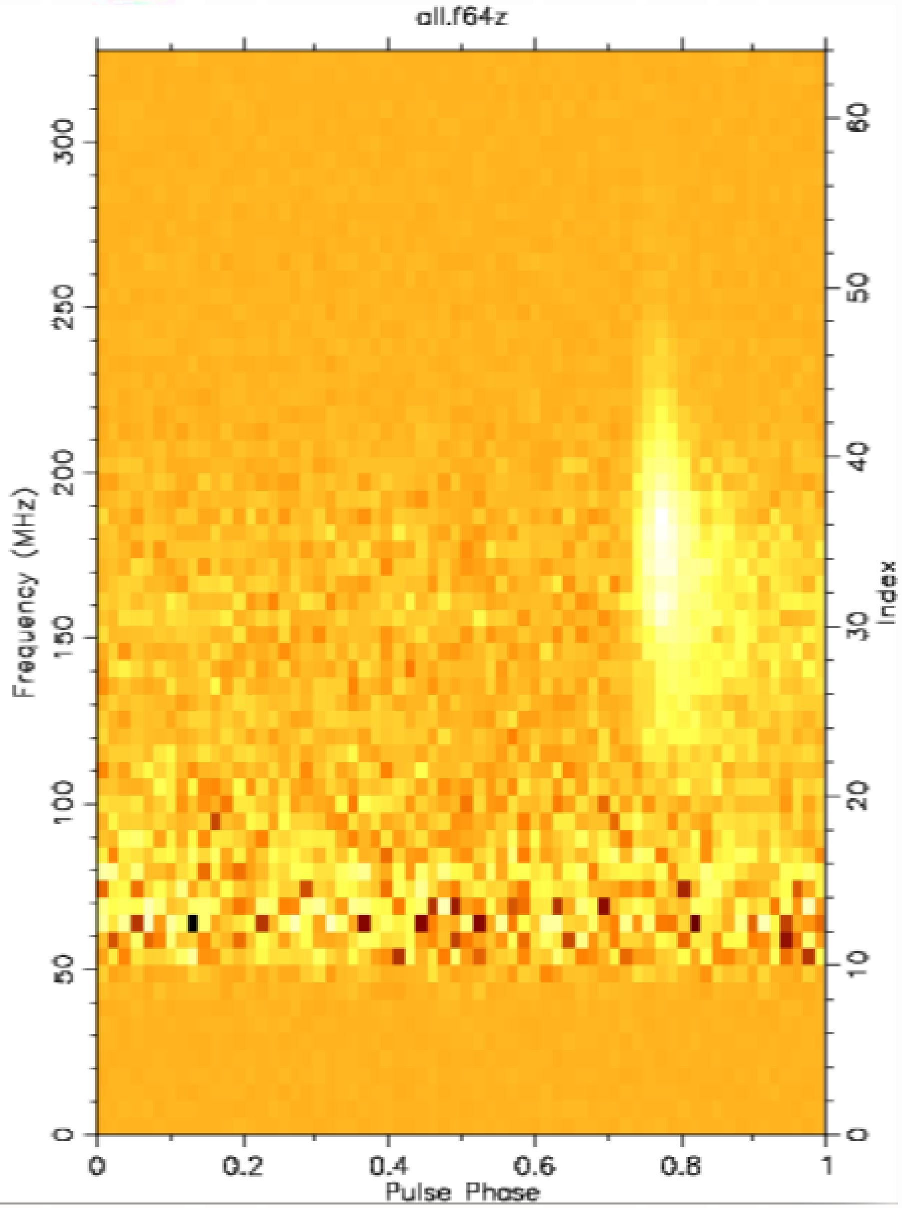


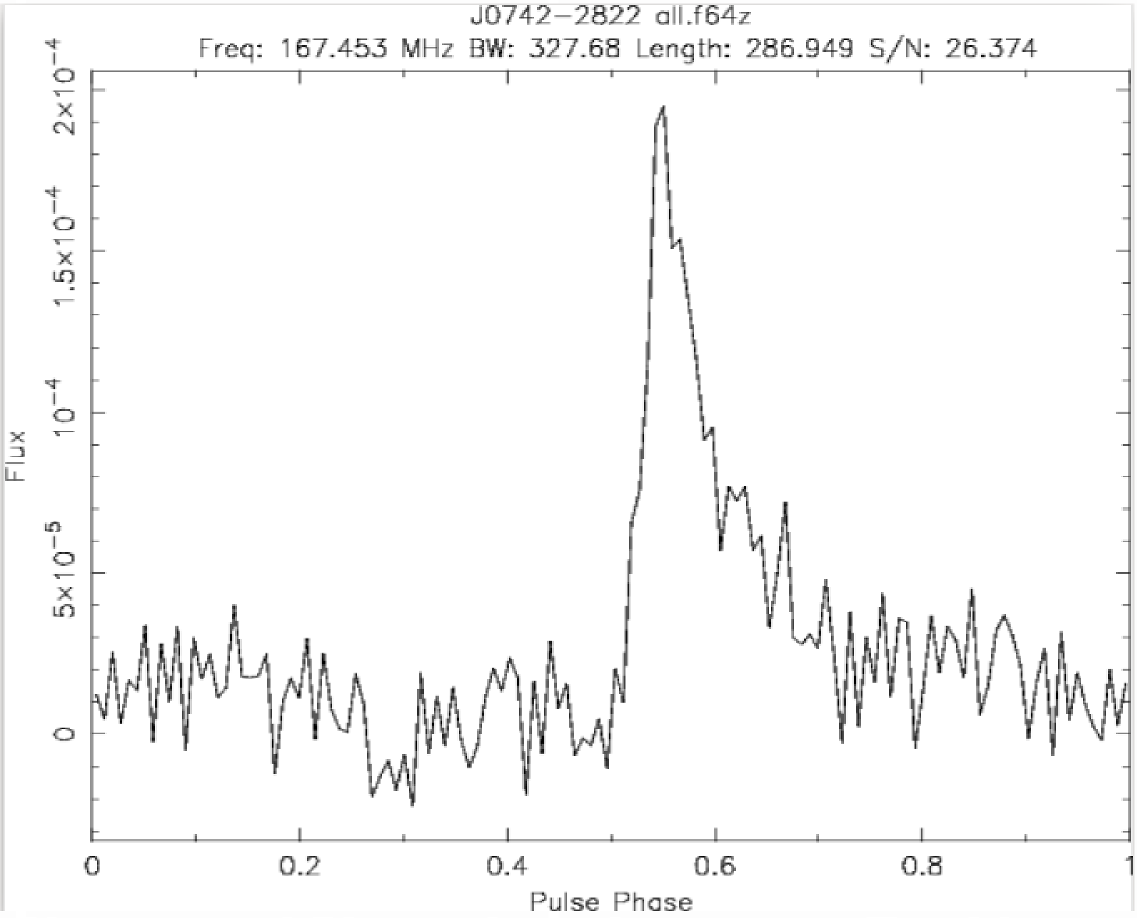
EDA : ~50 – 200 MHz



Ramesh Bhat et al. in prep.

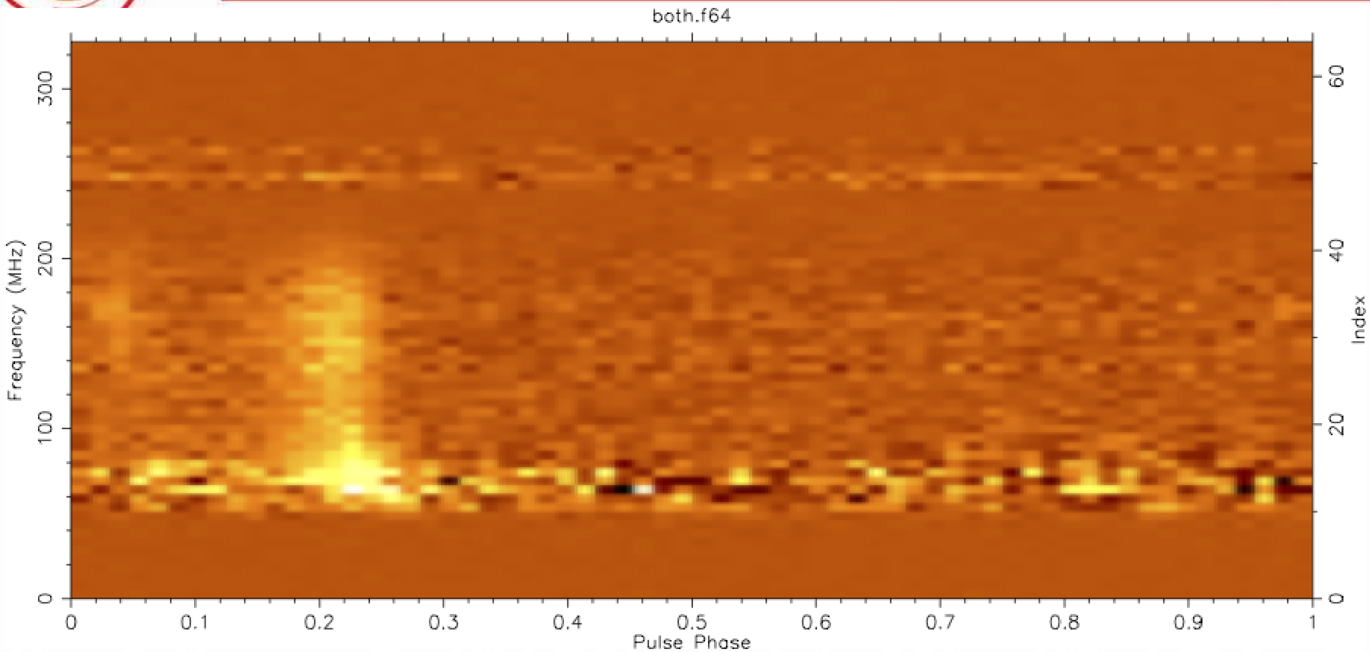
Observations of milisecond pulsars J0742-2822

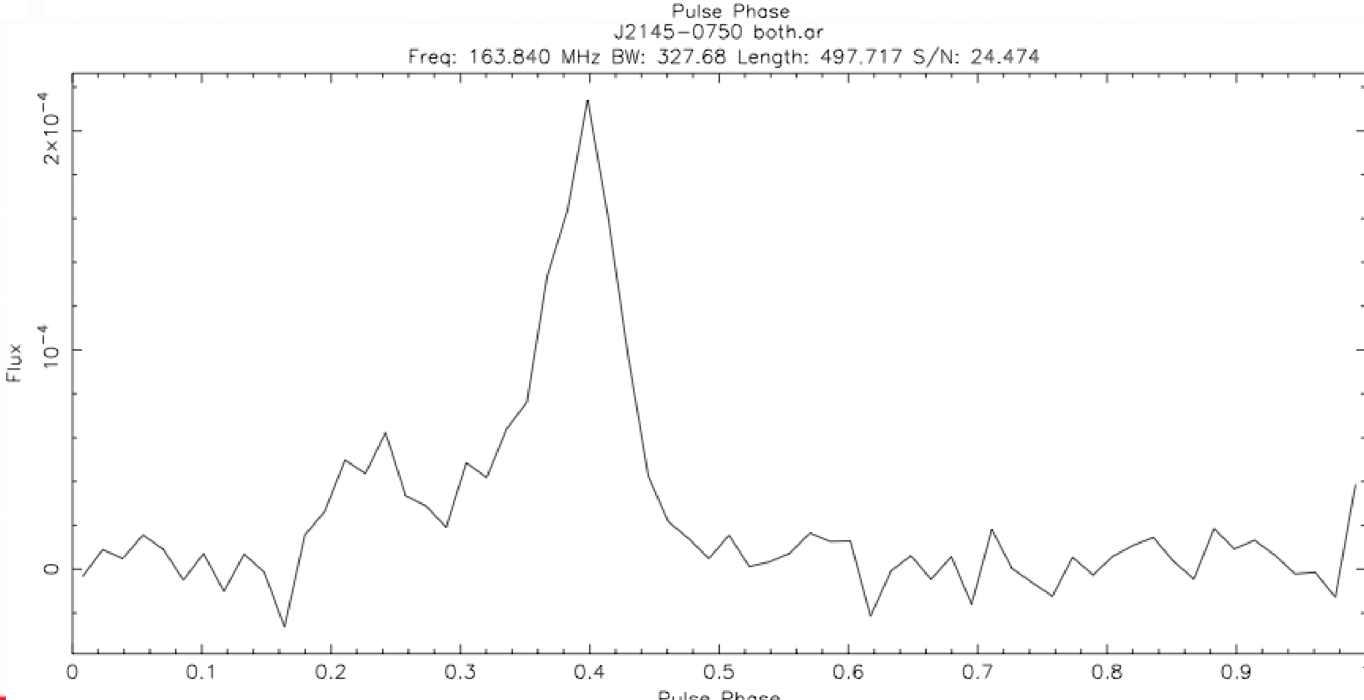


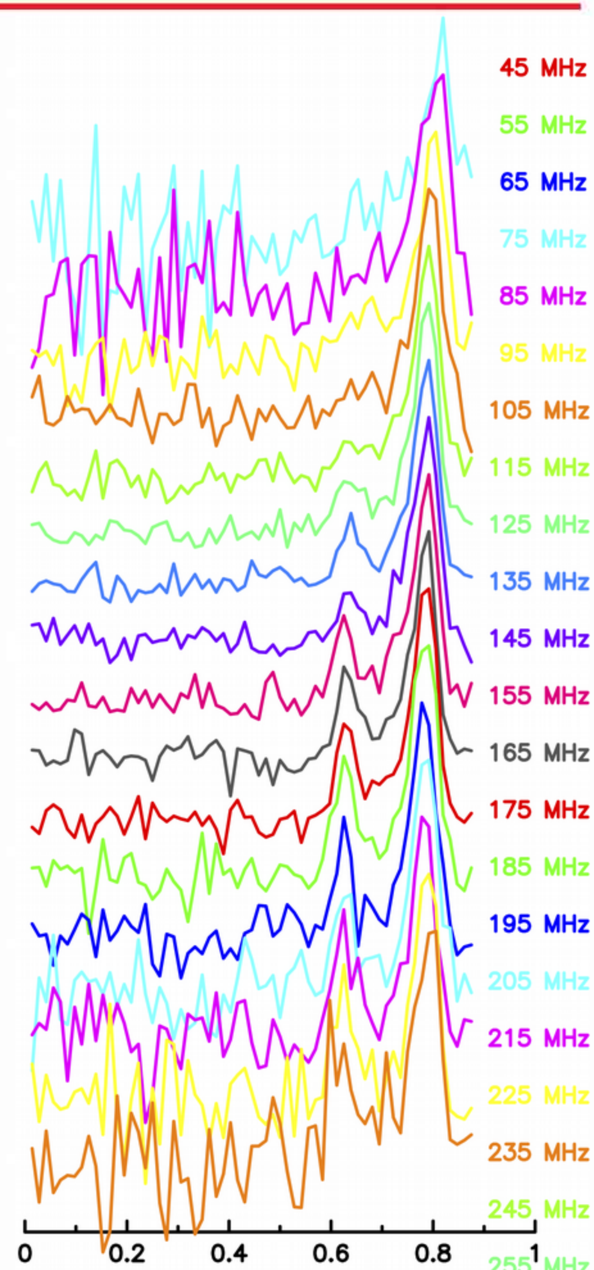


Ramesh Bhat et al. in prep.

Observations of milisecond pulsars J2145-0750

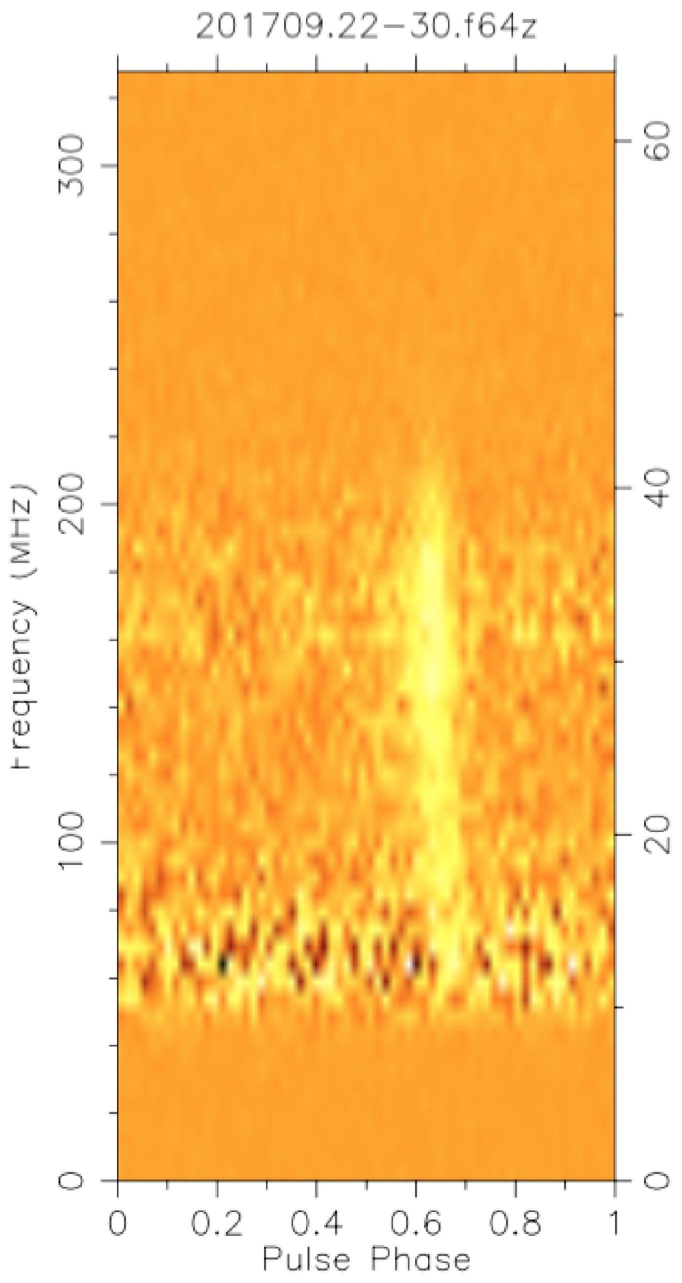


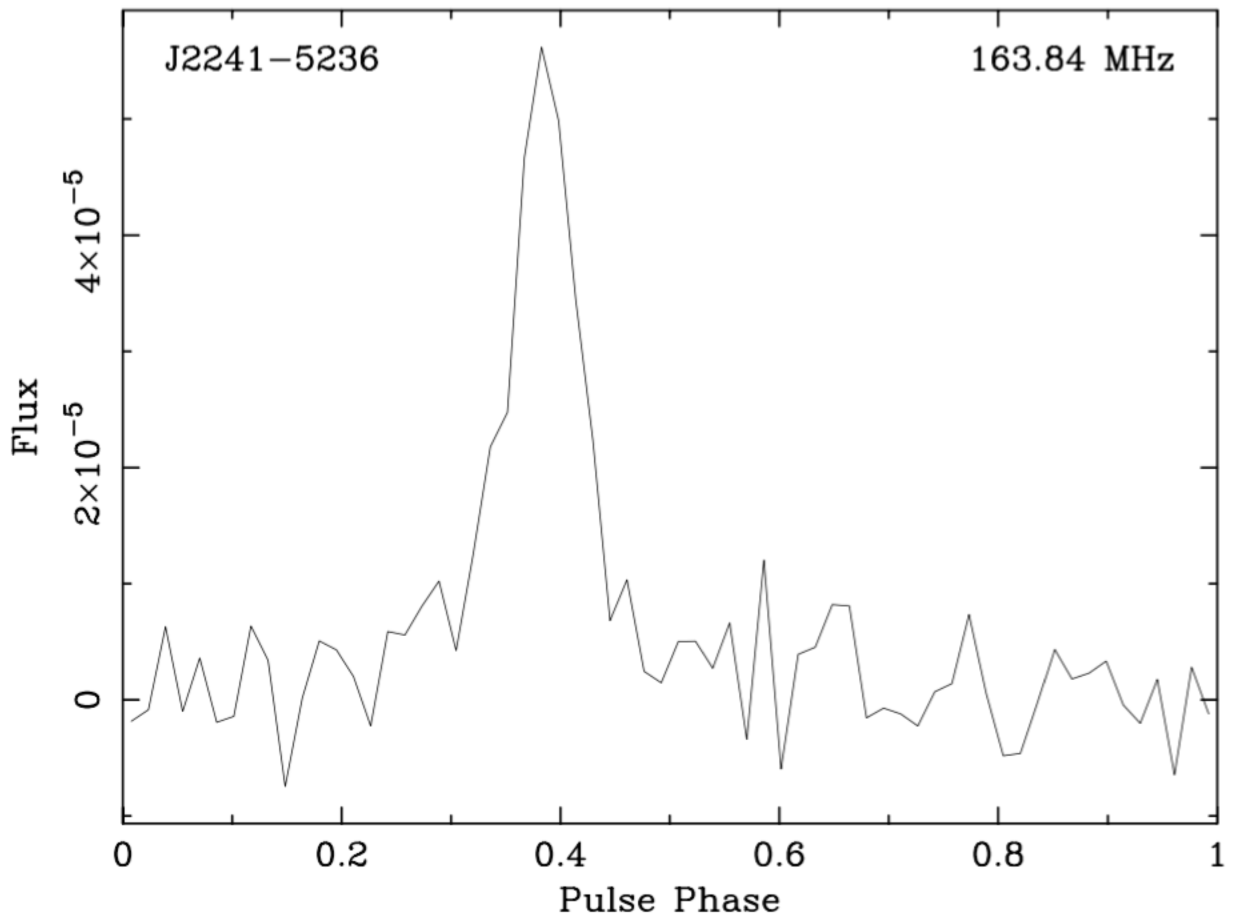




Ramesh Bhat et al. in prep.

Observations of milisecond pulsars J2241-5236



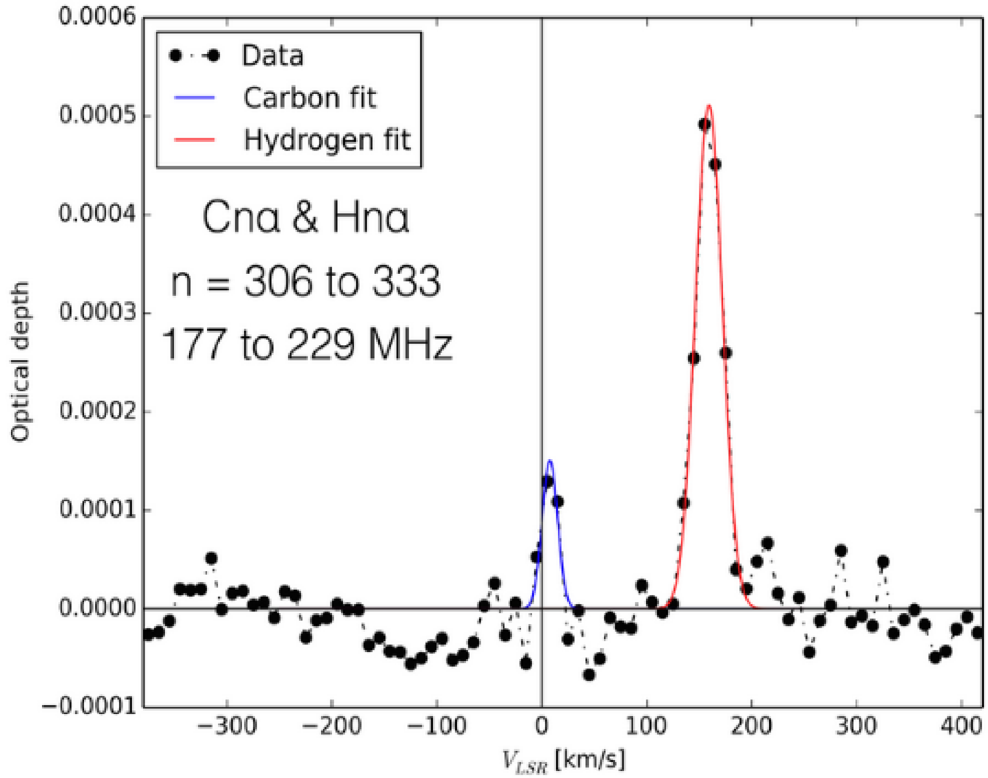


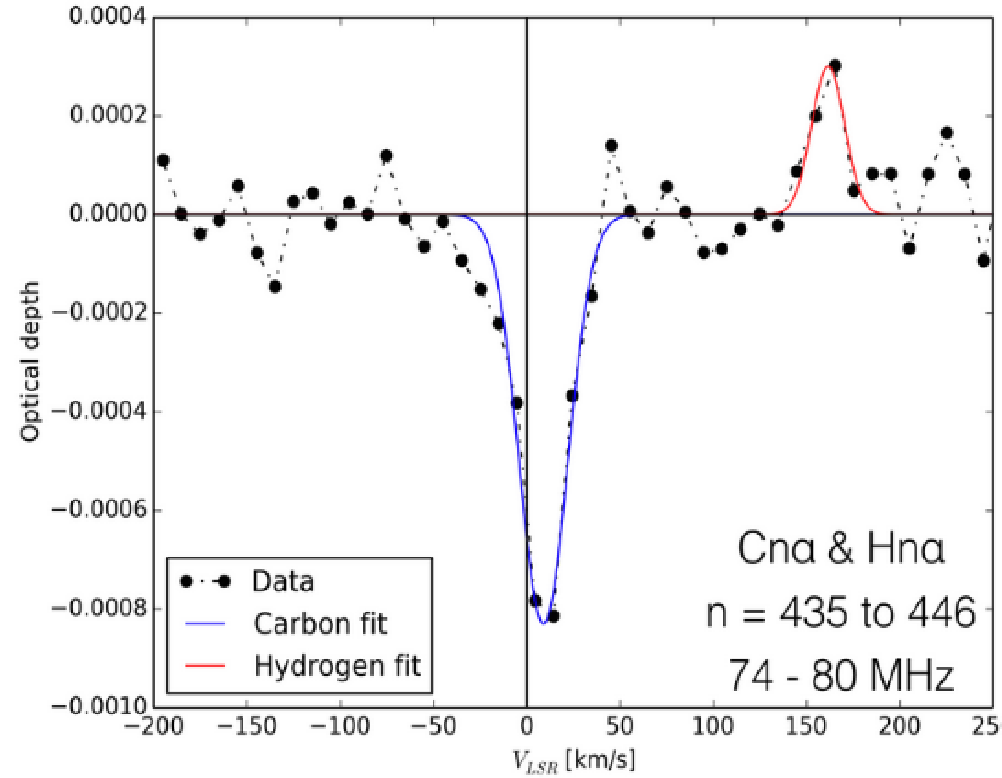
EDA baseband data enables coherent de-dispersion and improves sharpnes of the profiles comparing to MWA

Ramesh Bhat et al. in prep.

Low-frequency radio recombination lines towards the Galactic Centre

ASTRON





* 200-min observation on 2017 June 13 (in 1.25 kHz resolution).

* CRRL properties broadly consistent with previous studies.

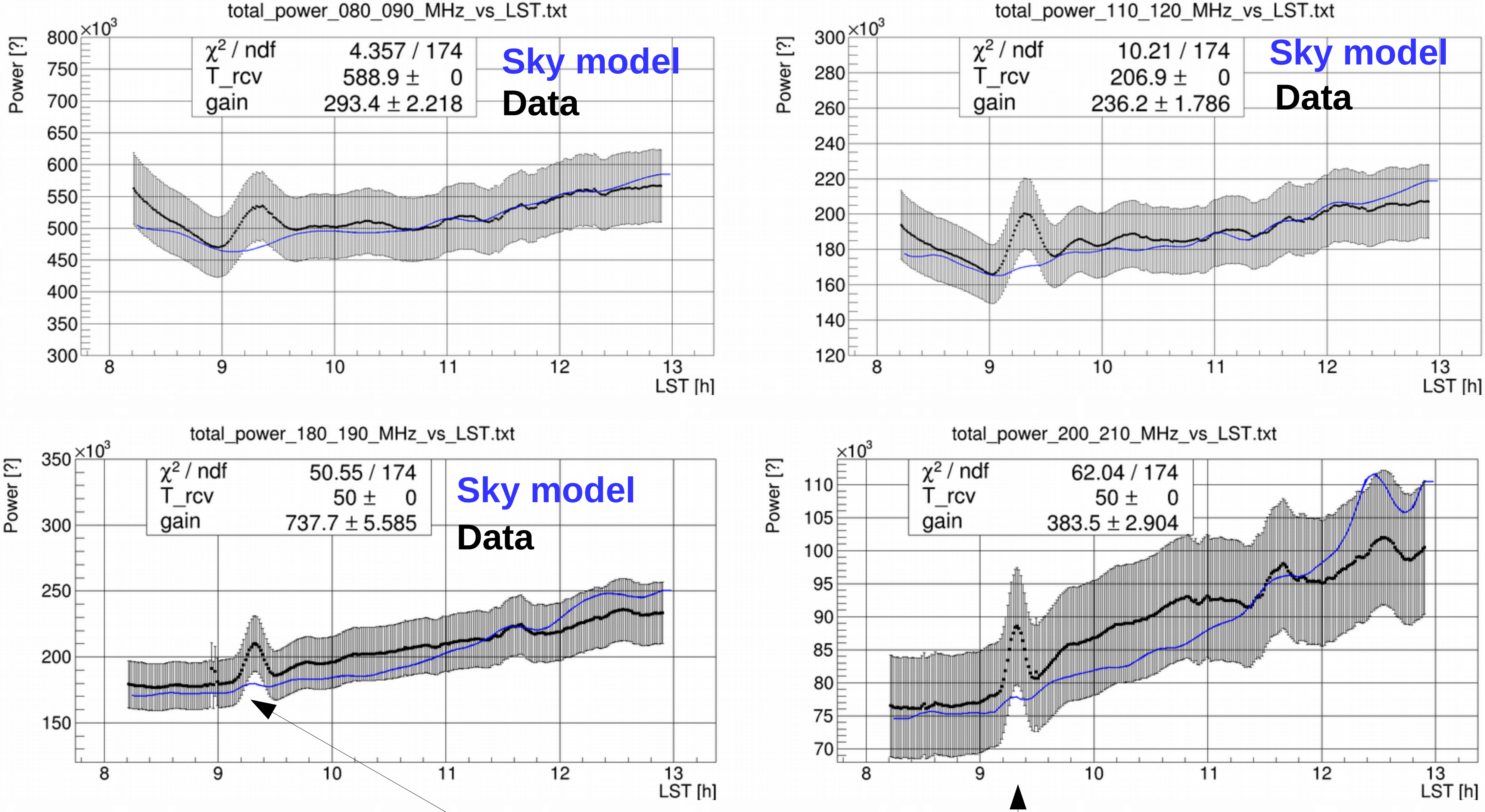
* Ongoing work in calibrating the data. Encouraging result as a proof of concept!

Emma Alexander (ASTRON summer student 2017), Jess Broderick, Raymond Oonk, Randall Wayth, Marcin Sokolowski

EDA calibration options

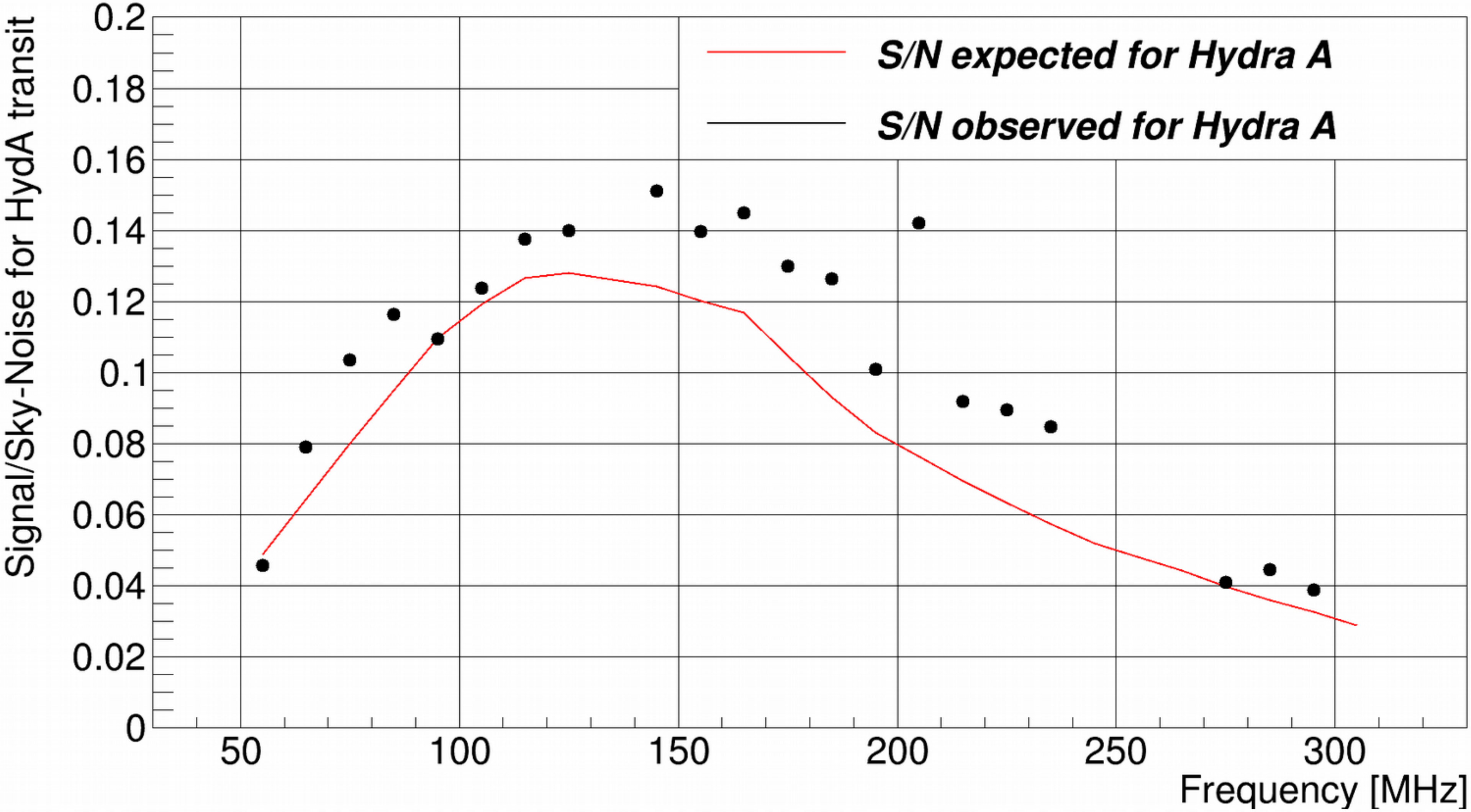
- Pulsar observations were successfuly calibrated using SEFD calculated from sky, beam model, receiver temperature and observed standard deviation (RMS_{obs}) of the noise (gain = (RMS_{obs}/ SEFD)* sqrt(Bτ)).
- Standard way: switching between all 256 antennas and reference (50 Ohm resistor) not possible for EDA, but increases the cost and introduces “dead time” when we “observe” reference source
- **We can observe bright calibrator source (HydA) in drift scan mode**
- **Real time absolute calibration and flux measurements of calibratiors using additional well characterised and absolutely calibrated radiometer system (BIGHORNS log-spiral conical antenna in this case)**

Total power from Hydra A drift scan

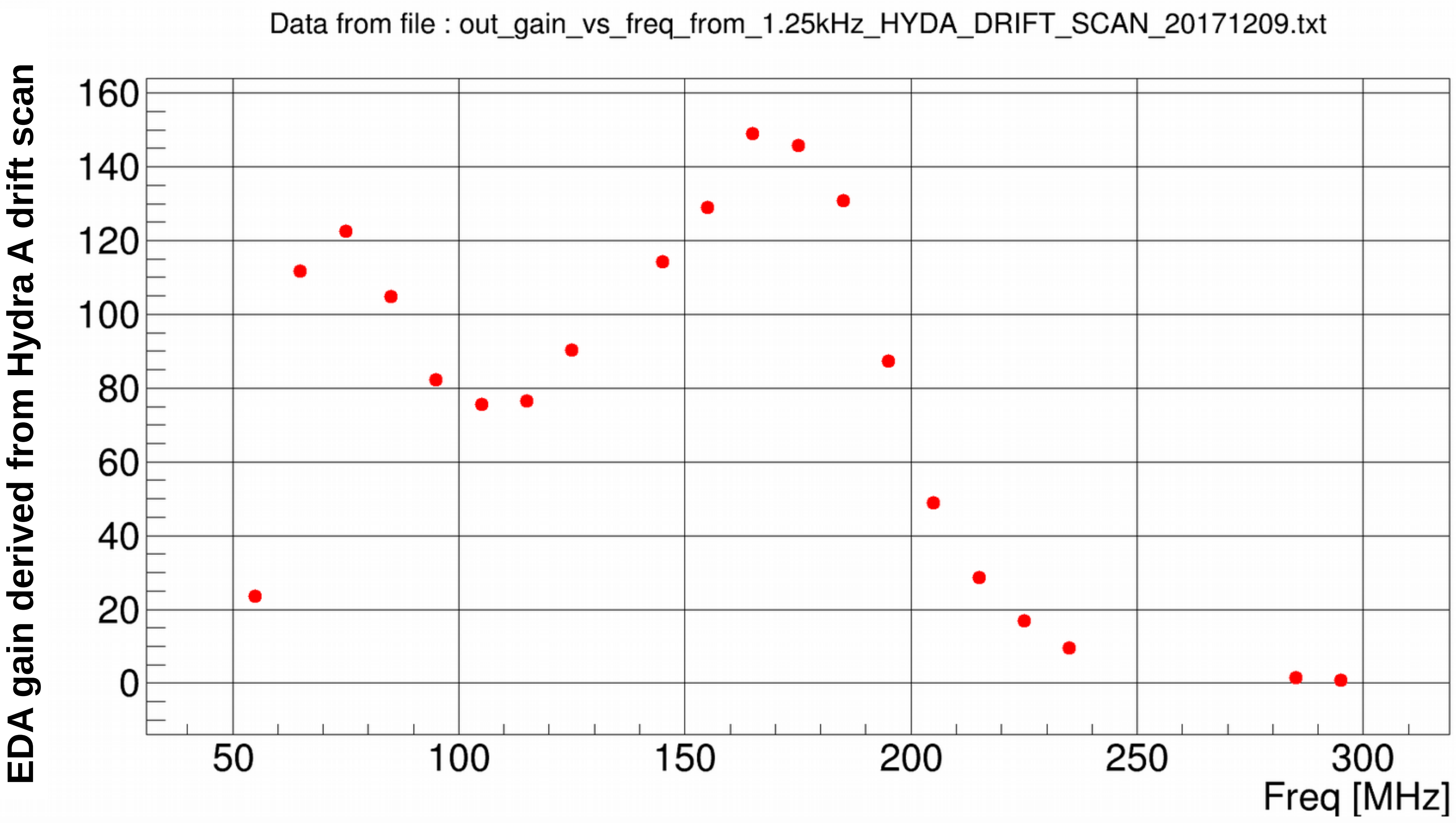


Hydra A transit at LST ~9.30 hours

SNR expected for Hydra A



Calibration constant derived from Hydra A flux and drift scan data is in reasonable agreement with SEFD calibration



Absolute flux calibration for EDA

Correlation of EDA and BIGHORNS

Total powerwith the EDA:
P_eda = Flux * (G_eda * A_eda)

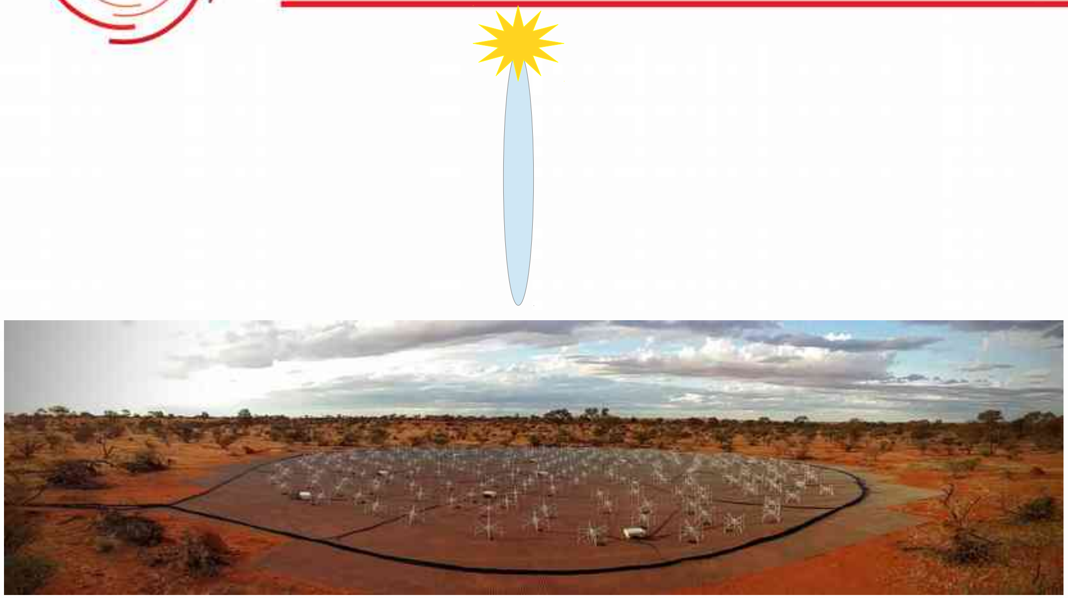
Observed in total power 10 MHz bins (SEFD_eda ~ 2800 Jy)

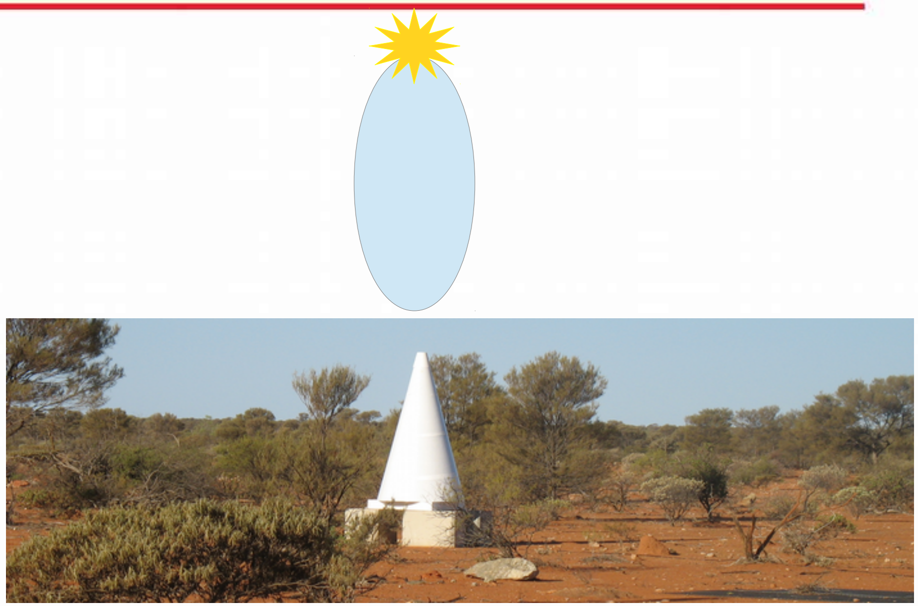
P_corr = Flux *
[(G_eda*A_eda) * (G_b*A_b)]^1/2

BIGHORNS total power :
P_b = Flux * (G_b * A_b)

cannot be observed
SEFD_bighorns ~ 500000 Jy

Absolute flux calibration for EDA





Correlation of EDA and BIGHORNS

Unknowns in red

Knowns in blue

Total powerwith the EDA:

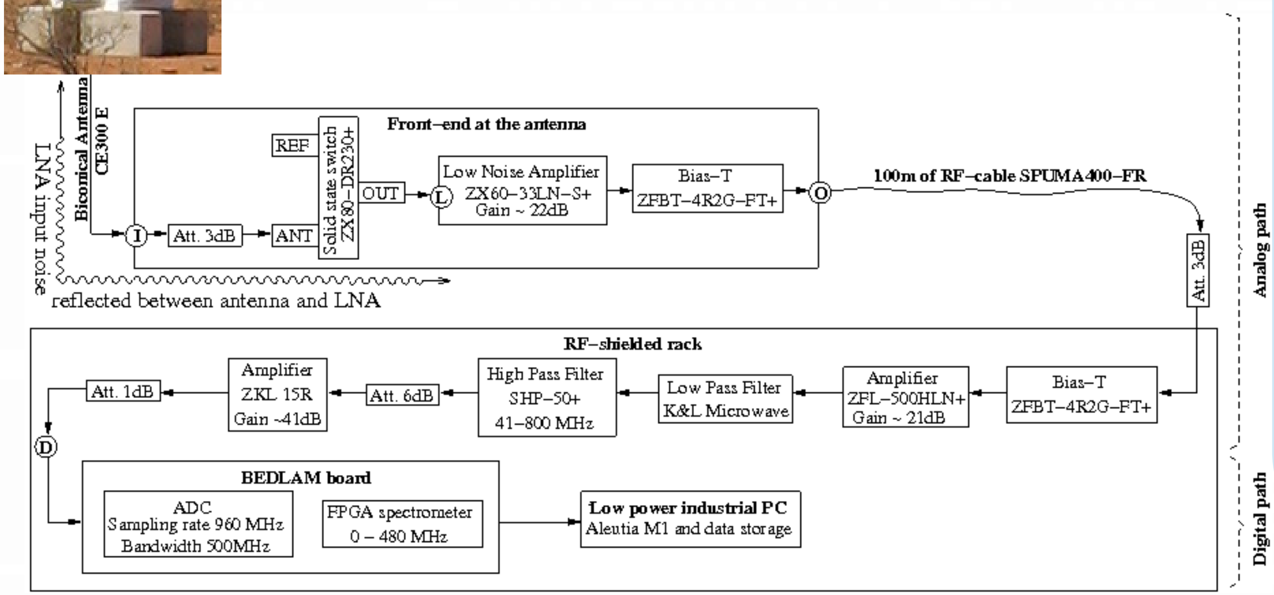
$P_{eda} = Flux * (G_{eda} * A_{eda})$

$P_{corr} = Flux * [(G_{eda} * A_{eda}) * (G_b * A_b)]^{1/2}$

Unknowns in red

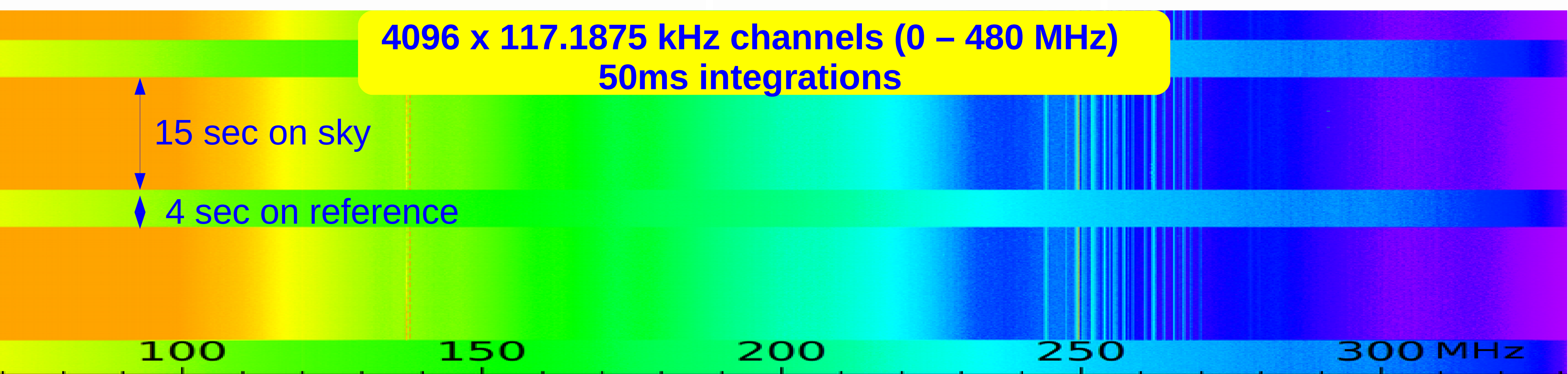
Knowns from BIGHORNS calibration and simulation. Their knowledge determes final calibration error.

BIGHORNS total power radiometer

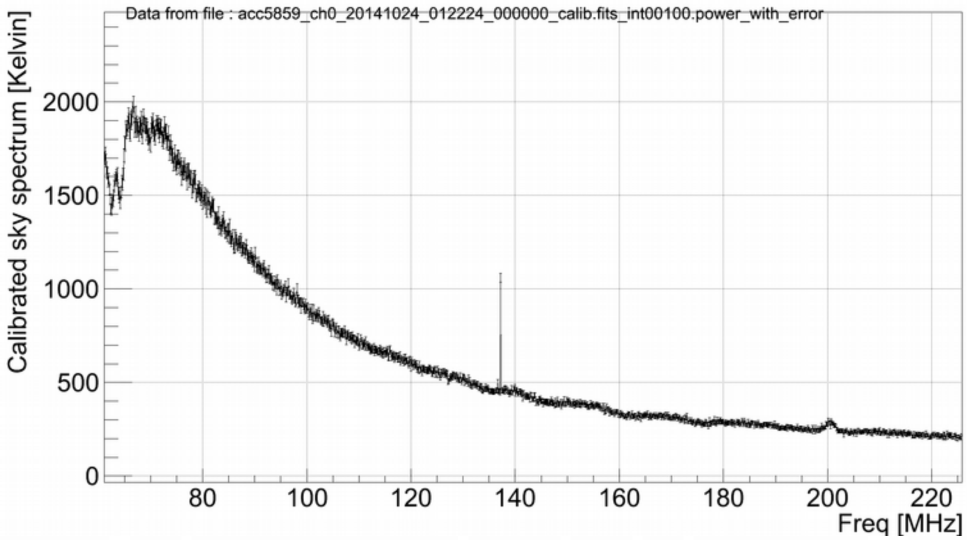


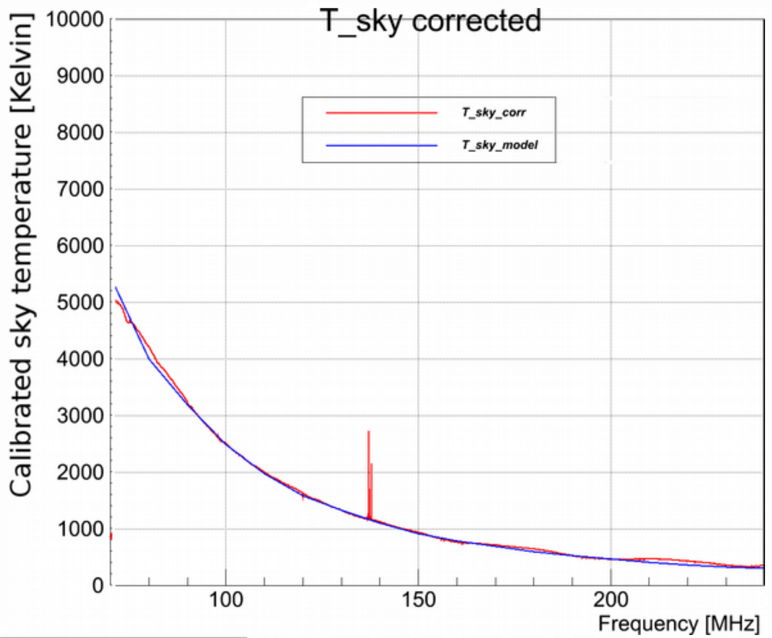
- Conical log-spiral antenna (built at Curtin University) - very well matched to 50 Ohm (almost no reflections)
- Switching between antenna and calibrator

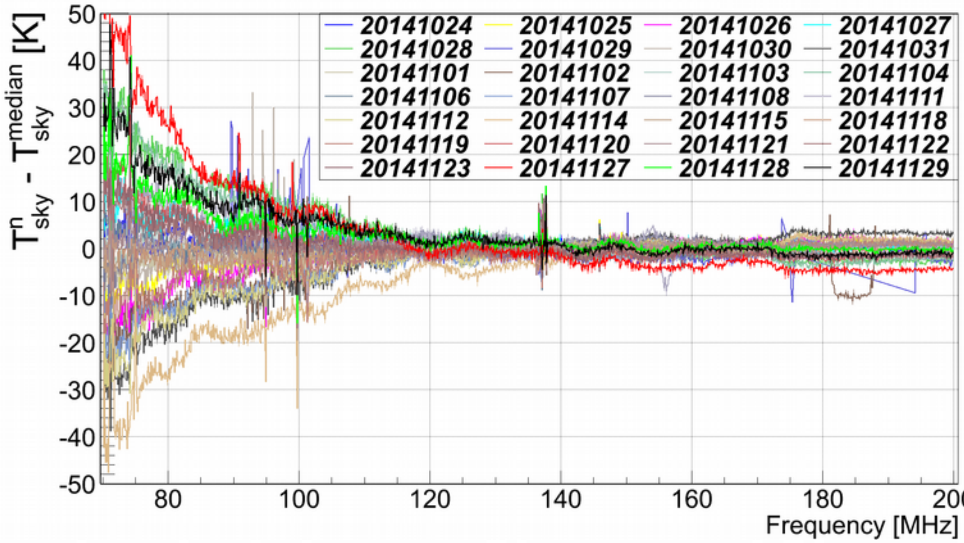
Sokolowski et al, PASA (2015)



BIGHORNS calibration ~ 1 %

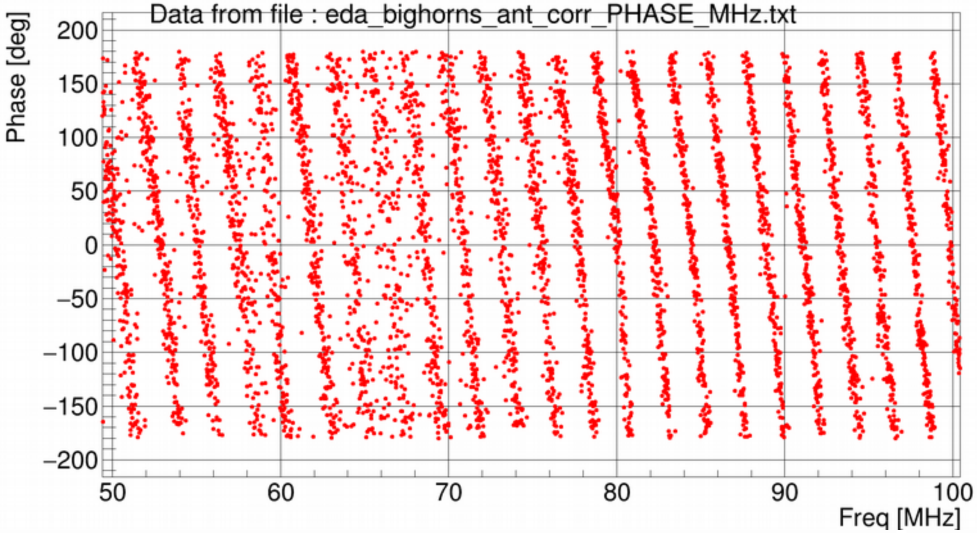


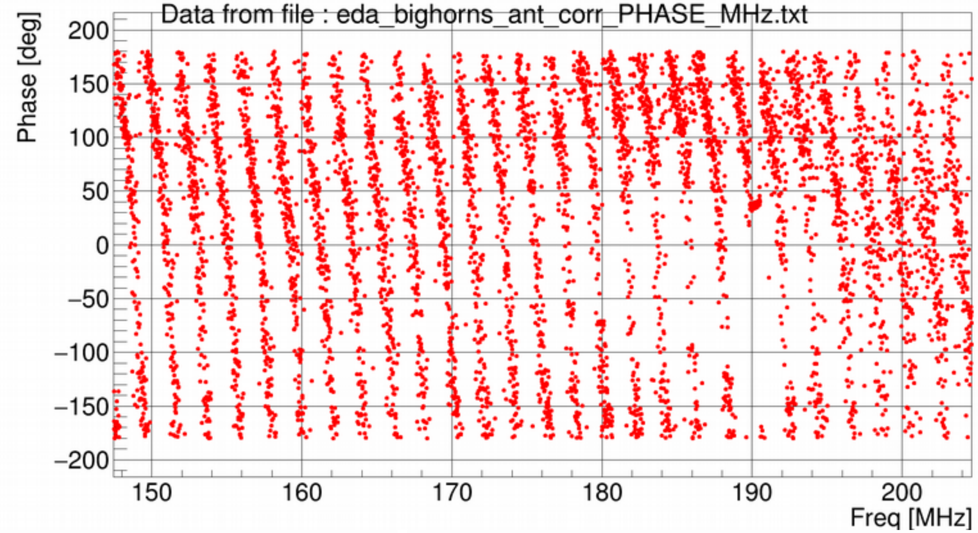


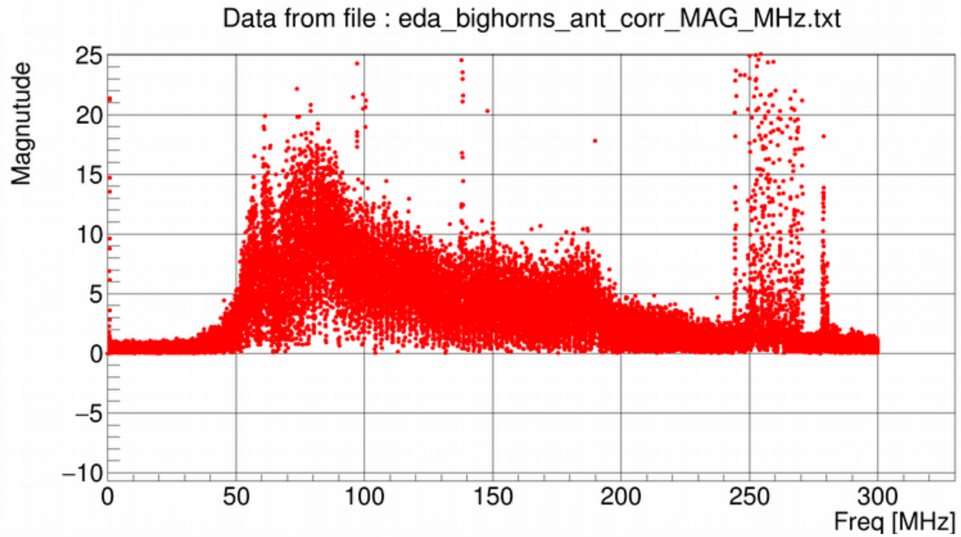


Sokolowski, et al, ApJ, (2015)

Absolute calibration of EDA with BIGHORNS



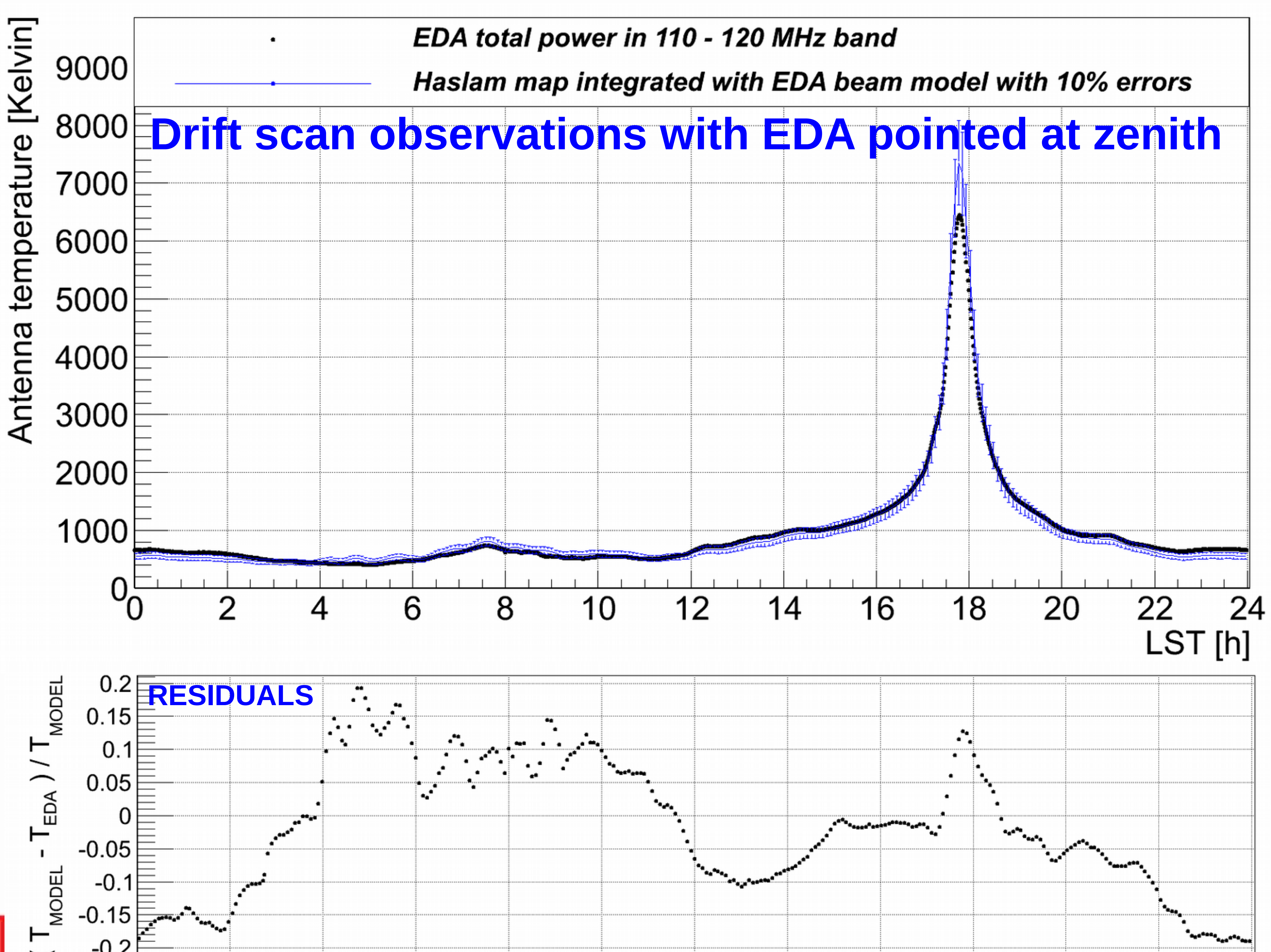




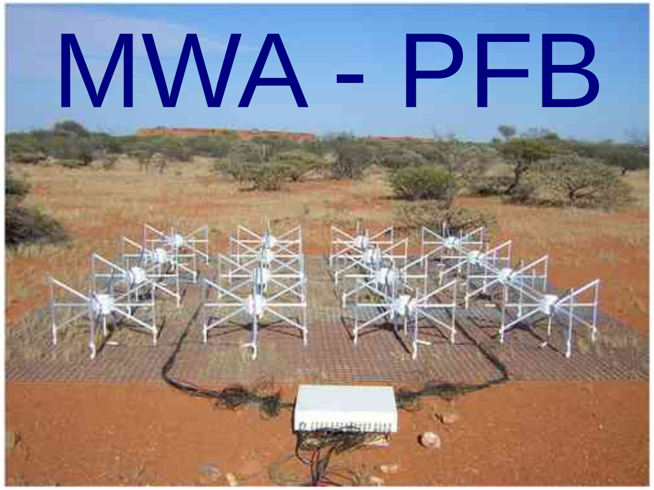
Absolute calibration pipeline still work in progress with Hydra A flux still a bit off

Summary / future

- EDA is the SKA-low station prototype at the MRO providing important inuput into the SKA-low design and cost reduction processes
- Satifies SKA-low sensitivity specifictions in 50-240 MHz band
- We derived EDA receiver noise temperature from sky and beam models
- Identified and investigated issues relevant to SKA-low : Correlation of heterogenous filterbank systems (EDA FFT and MWA PFB)
- We started to explore some SKA-low key science goals (RRL, Pulsars)
- Real-time absolute EDA calibration using BIGHORNS is being developed


EDA total power in 110 - 120 MHz band
Haslam map integrated with EDA beam model with 10% errors
Drift scan observations with EDA pointed at zenith
Antenna temperature [Kelvin]
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0
2
4
6
8
10
12
14
16
18
20
22
24
LST [h]
RESIDUALS
(T_MODEL - T_EDA) / T_MODEL
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2

Sensitivity measurements monsters : correlation of heterogenous filterbanks



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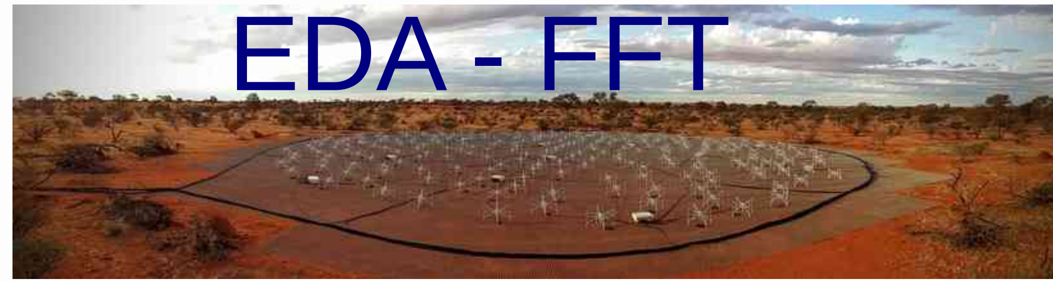
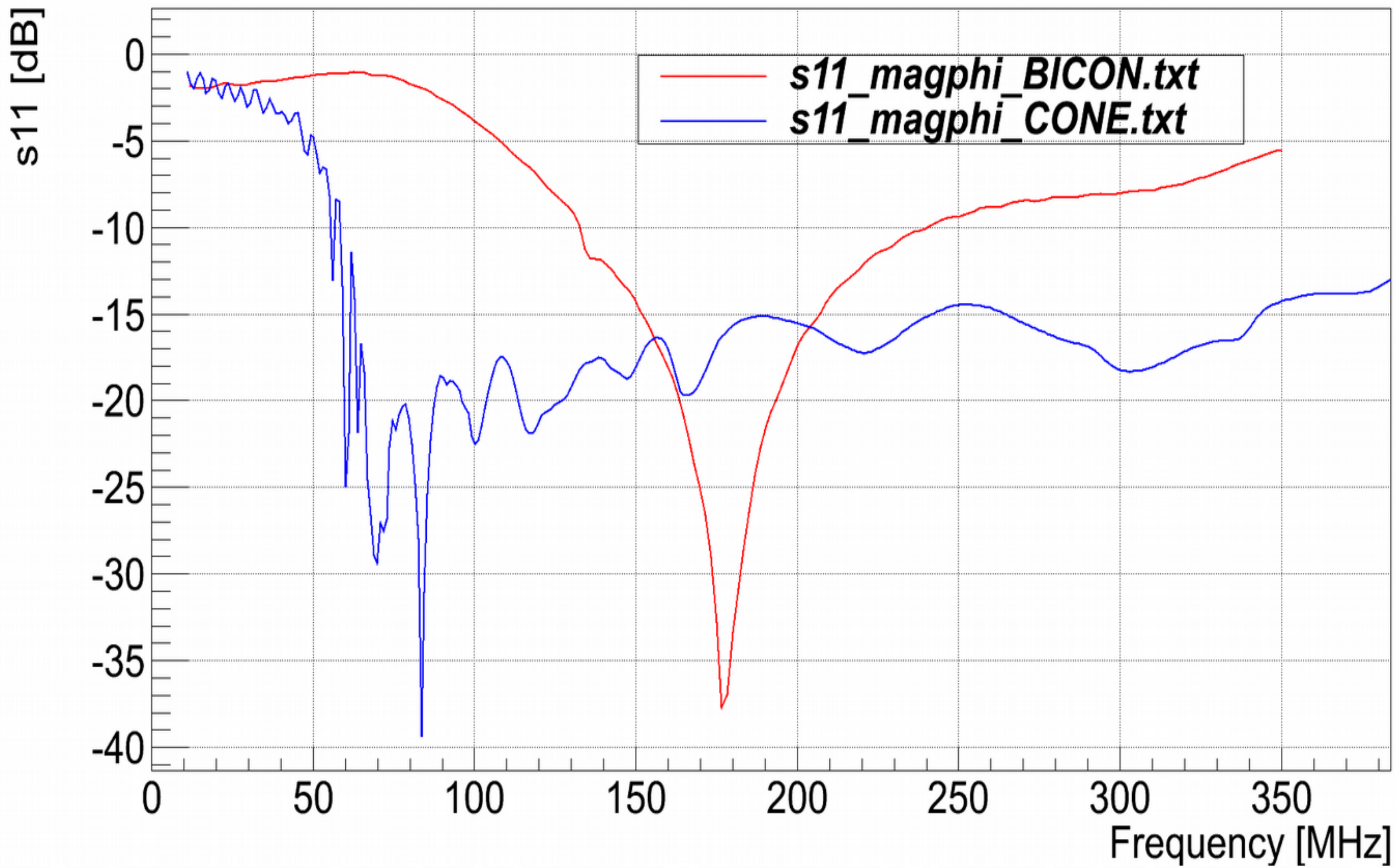


- Sample rate 655.36 Msamp/s
- 8-tap critically sampled polyphase filterbank (PFB) for coarse channels (1.28 MHz)
- 12-tap critically sampled PFB for fine channels (10kHz)

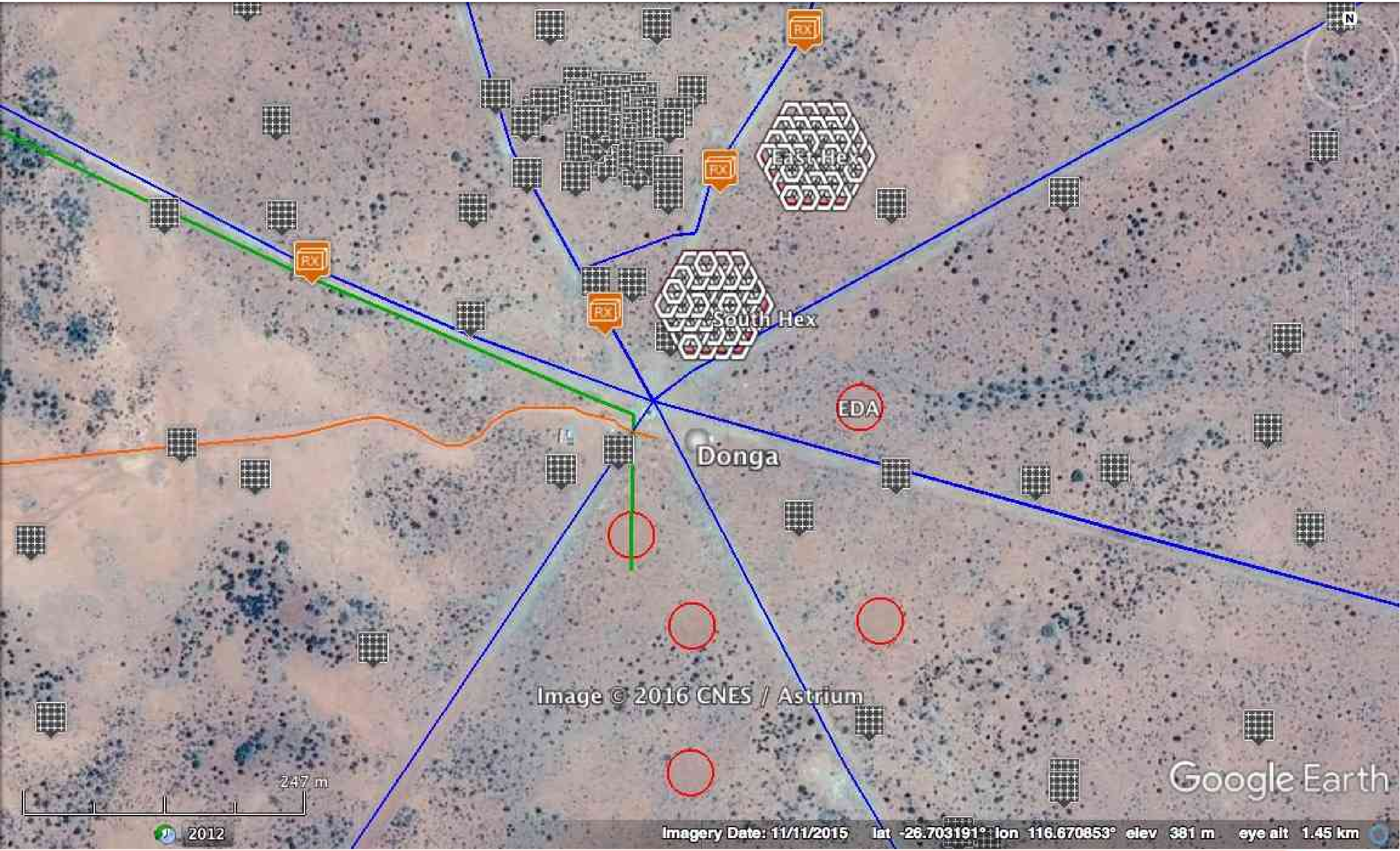
- Sample rate 655.36 Msamp/sec (from MWA clock)
- 65536 channels FFT directly gets 10 kHz channels (GPU FFTCUDA)

Lag of 5 or 6 samples (equally good) required for EDA samples to get fringes with MWA using MWA correlator and still sensitvity significantly (factor of >2) reduced !

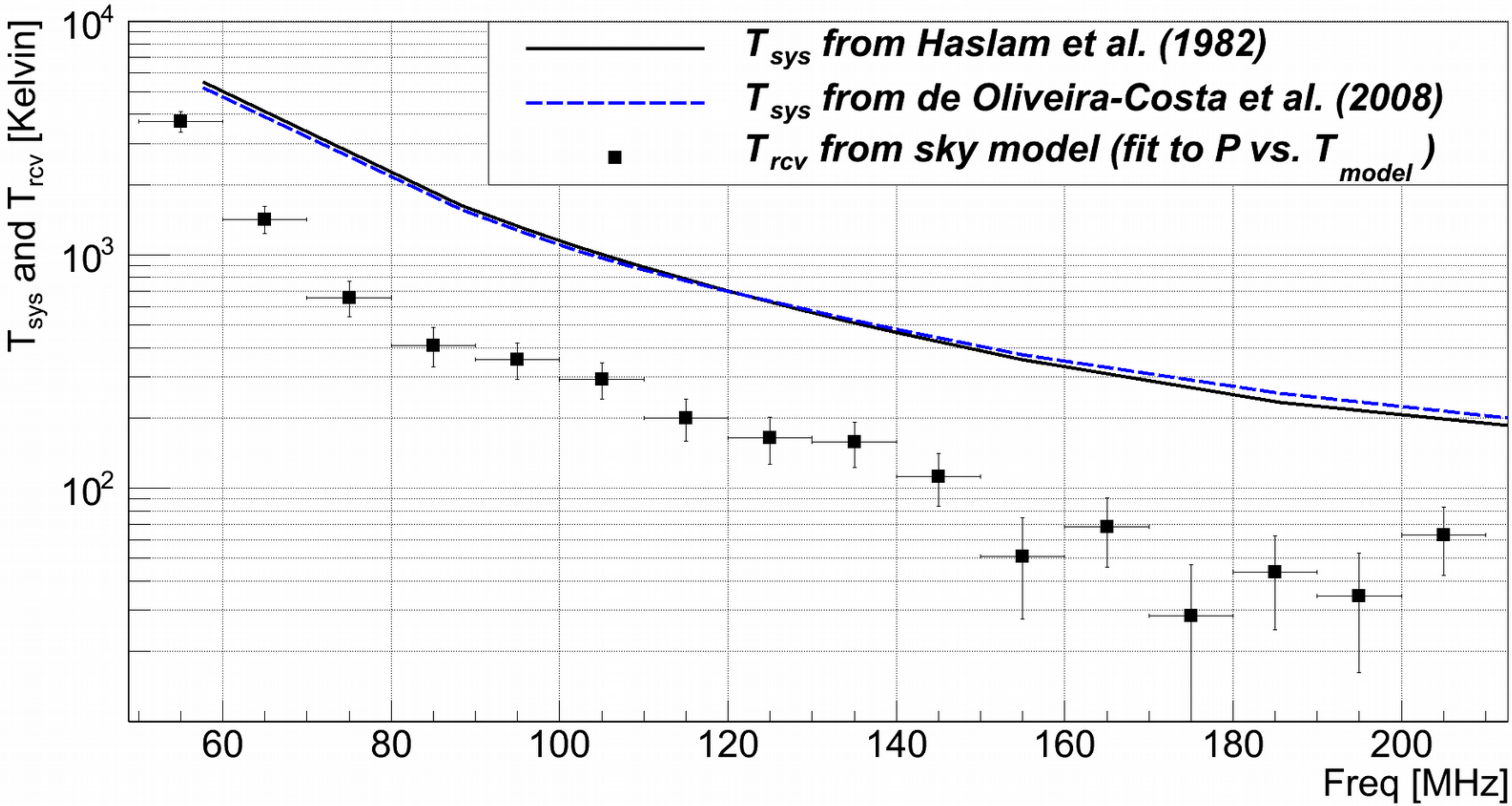
BIGHORNS cone s11



EDA location at the MRO



EDA receiver temperature derived from sky model in 13-17 hours LST range



Sky is a very precise and reasonably cheap Vector Network Analyser and can be even better once sky models are better