Results from LWA1 Commissioning: Sensitivity, Beam Characteristics, & Calibration

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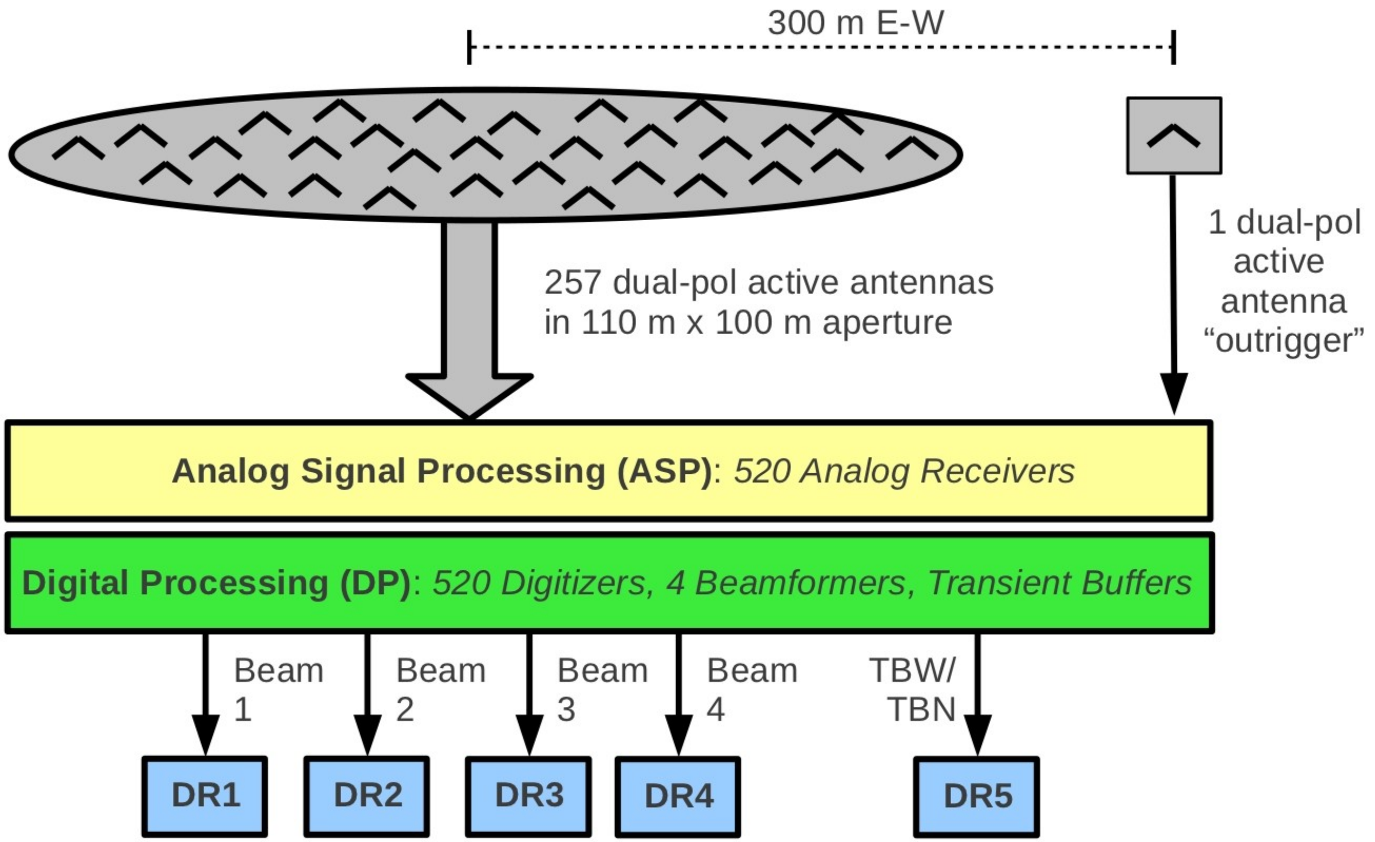
LWA1

10-88 MHz usable, Galactic noise-dominated (>4:1) 24-87 MHz
4 independent beams x 2 pol. x 2 tunings each ~16 MHz bandwidth

Beam SEFD ~[3,17] kJy for Z=[0°,65°],
~ independent of freq; but somewhat dependent on {RA,δ}
Main lobe FWHM ≈ 2.2° ((74 MHz)/ν) sec^2 Z
Sidelobe levels highly variable; typically ~ 10-15 dB at maxima

What this talk is about:
How do we know this?
How is the instrument calibrated? (Mutual coupling? Confusion?)

LWA1 System Architecture

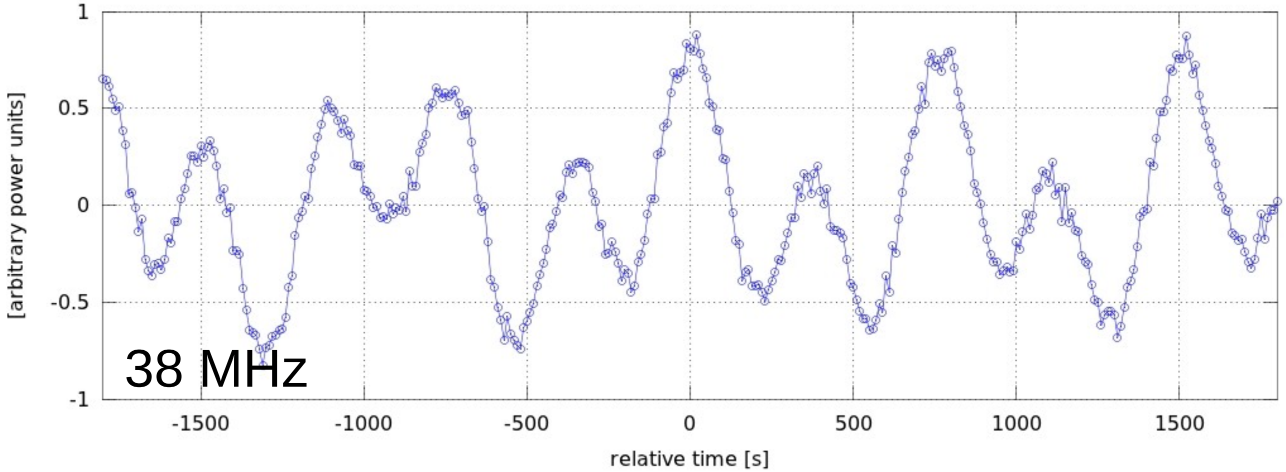


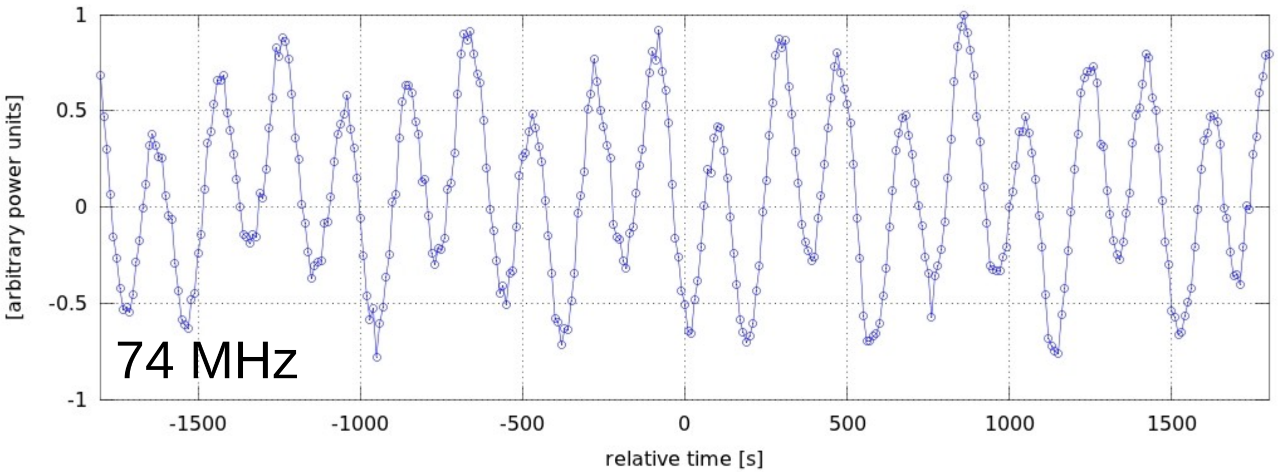
Three key features:

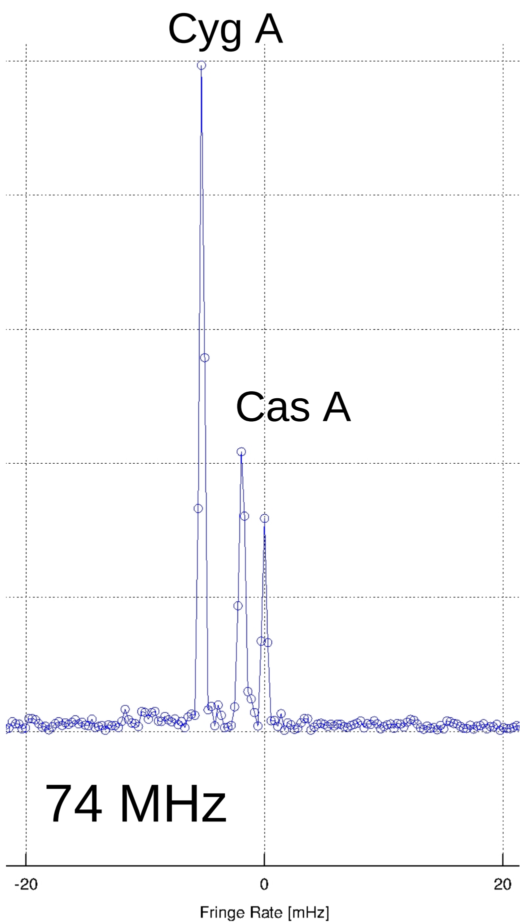
1. **We record *voltages* (no in-line spectrometer)**
2. **"TBN" mode provides all dipoles, coherently (~70 kHz BW)**
3. **Outrigger provides baselines ~[10,88]λ at [10,88] MHz**

LWA Long Wavelength Array

Use of Outrigger + TBN to Extract "Embedded" Dipole Response







Fringe Rate Spectrum

Fringes: Stand 248 * Outrigger (389 m E-W baseline)
~70 kHz bandwidth
10 s integrations with ~0.01% time domain blanking

Calibration Strategy

Select a source which is:

- Strong (e.g., Cas A, Cyg A, Tau A, 3C123)
- Produces a high fringe rate (to distinguish from background)
- Produces a fringe rate which is distinct from other strong sources

Cross-correlate every dipole with the outrigger for

- at least 1 fringe rotation period (preferably many)
- but not more ~3 h (so dipole pattern response is approx. constant)

Fringe rate filtering is useful to further suppress background and other strong sources

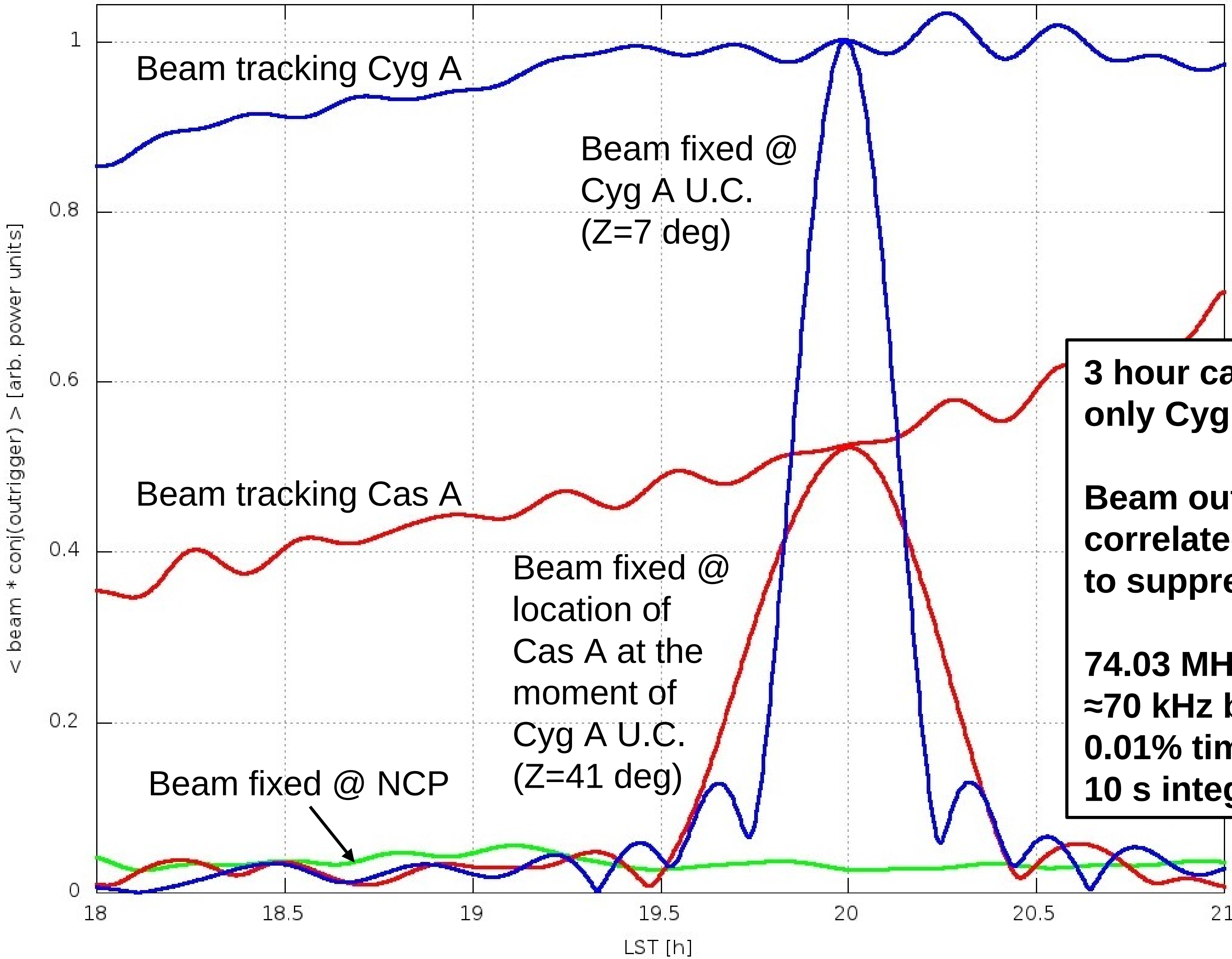
The resulting visibility is essentially the response to the selected source

System response other than dipole is independent of direction, so:

Extrapolate to other directions using a parametric model of "standalone" dipole pattern fit to the above result (LWA Memo 178)

This approach captures the effect of mutual coupling in the measured direction, but neglects it in the extrapolation to other directions

Beam Pointing & Tracking Demo



3 hour calibration using only Cyg A

Beam output cross-correlated with outrigger to suppress confusion

74.03 MHz center
≈70 kHz bandwidth
0.01% time blanking
10 s integrations

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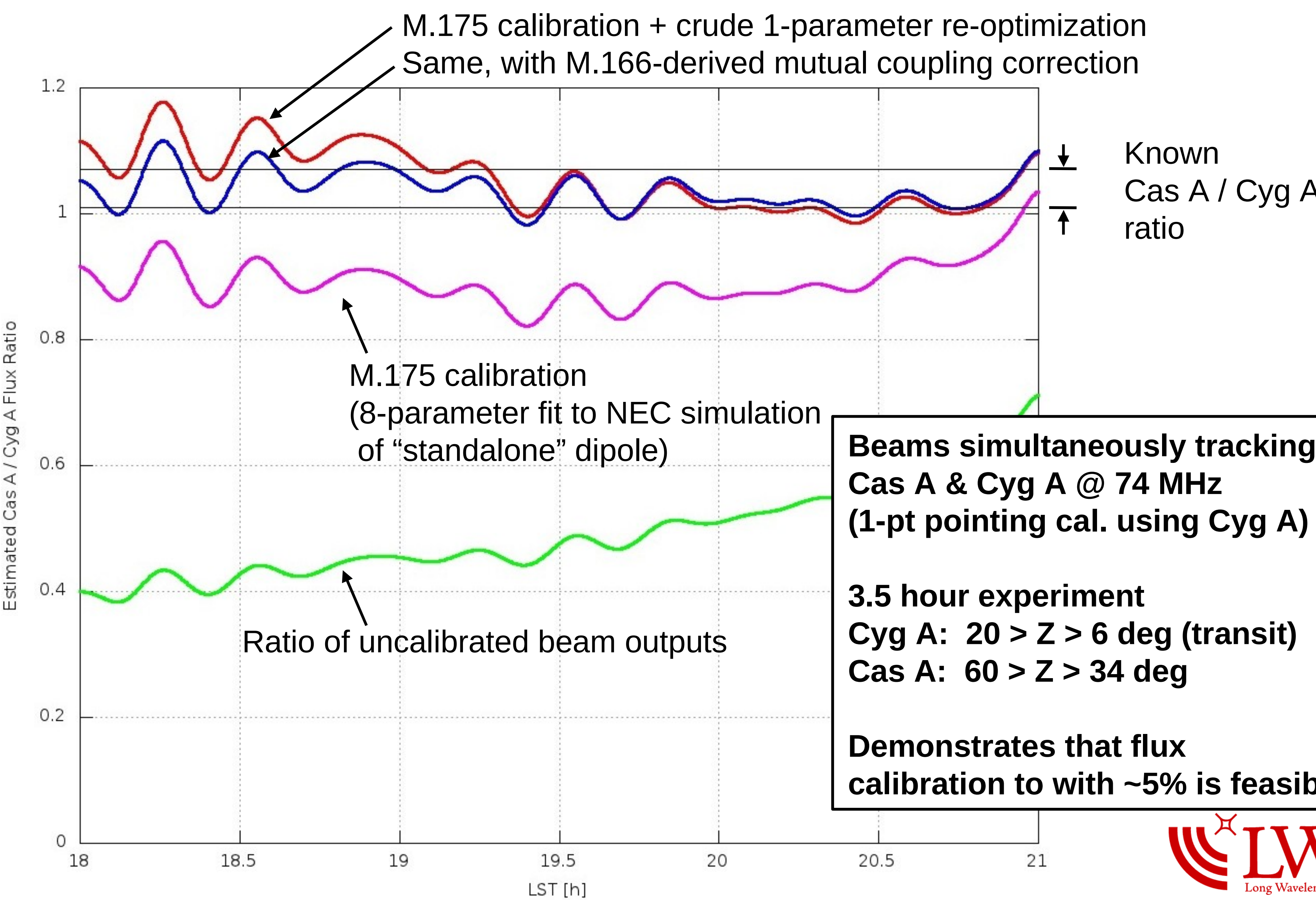
Beam Flux Calibratibility

(Cas A – Cyg A Flux Ratio)



Beams simultaneously tracking Cas A & Cyg A @ 74 MHz (1-pt pointing cal. using Cyg A)

3.5 hour experiment
Cyg A: 20 > Z > 6 deg (transit)
Cas A: 60 > Z > 34 deg

Demonstrates that flux calibration to with ~5% is feasible

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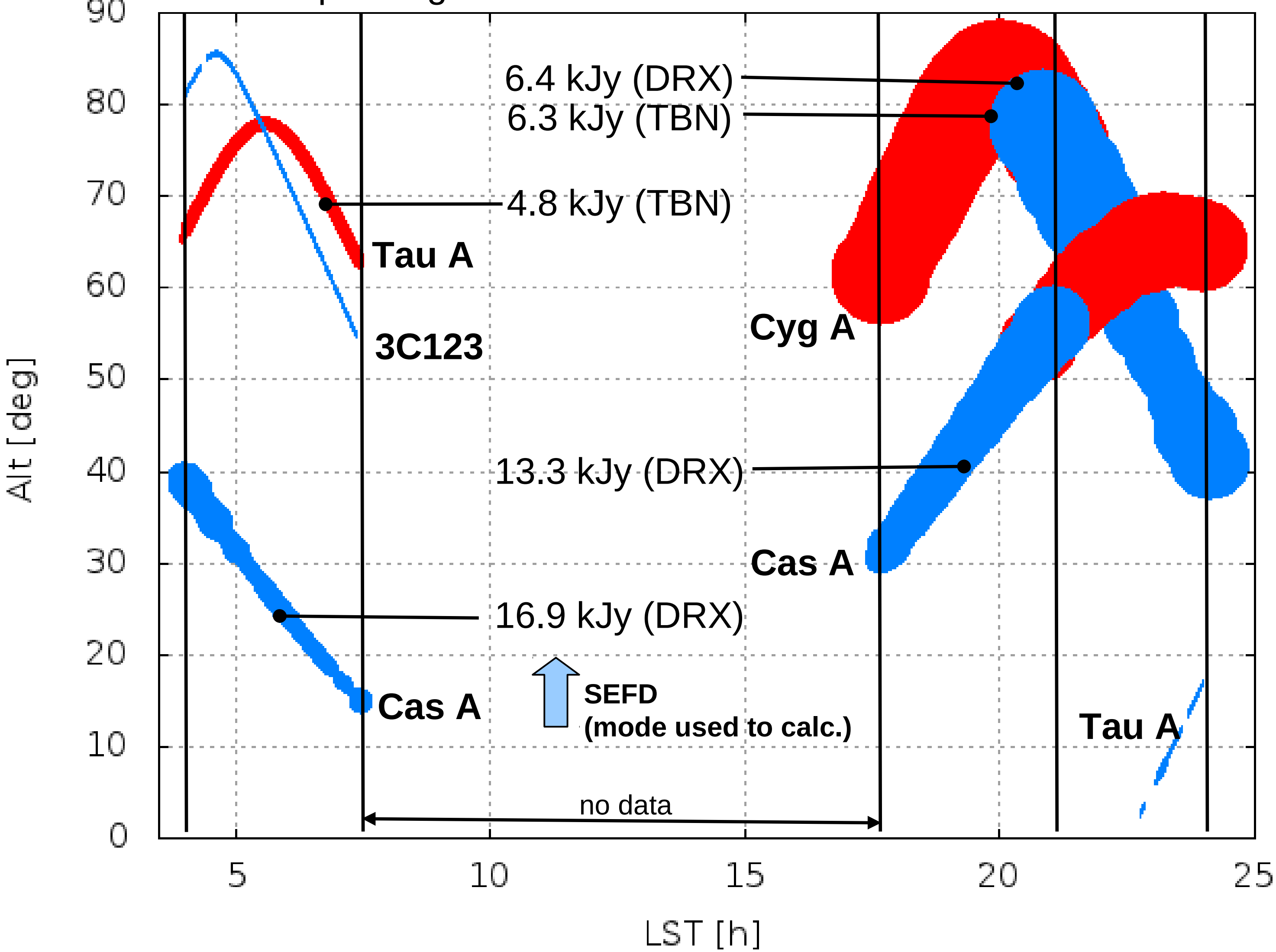
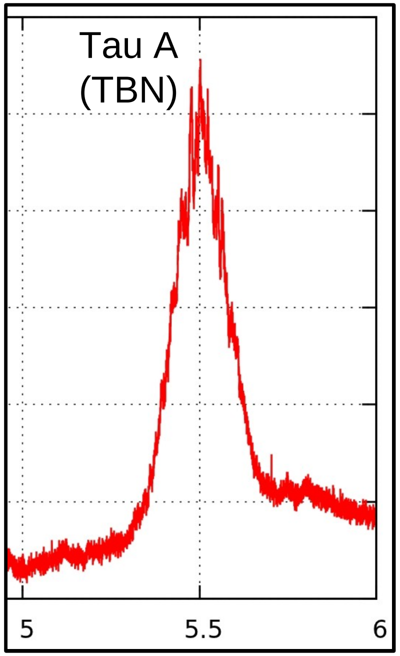
Source Tracking & SEFD Estimates

Line width indicates <u>uncalibrated</u> beam output power
Beam pointing calibrator for each time interval indicated in red

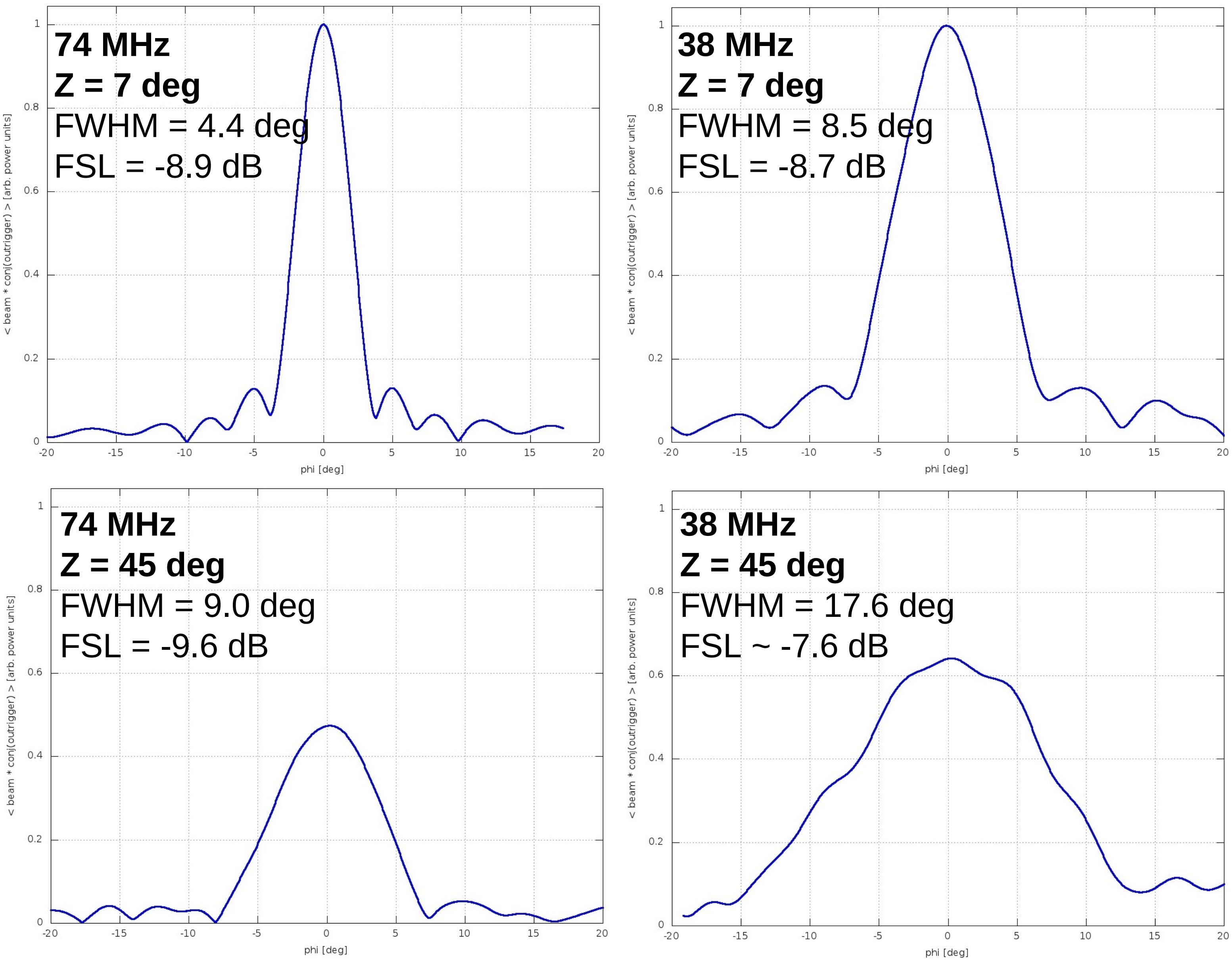


Tracks:
TBN (70 kHz BW)
74.03 MHz
10 s integrations
0.1% time blanking

Drift scans used to
Calculate SEFD; e.g.:



Main Lobe Characterization



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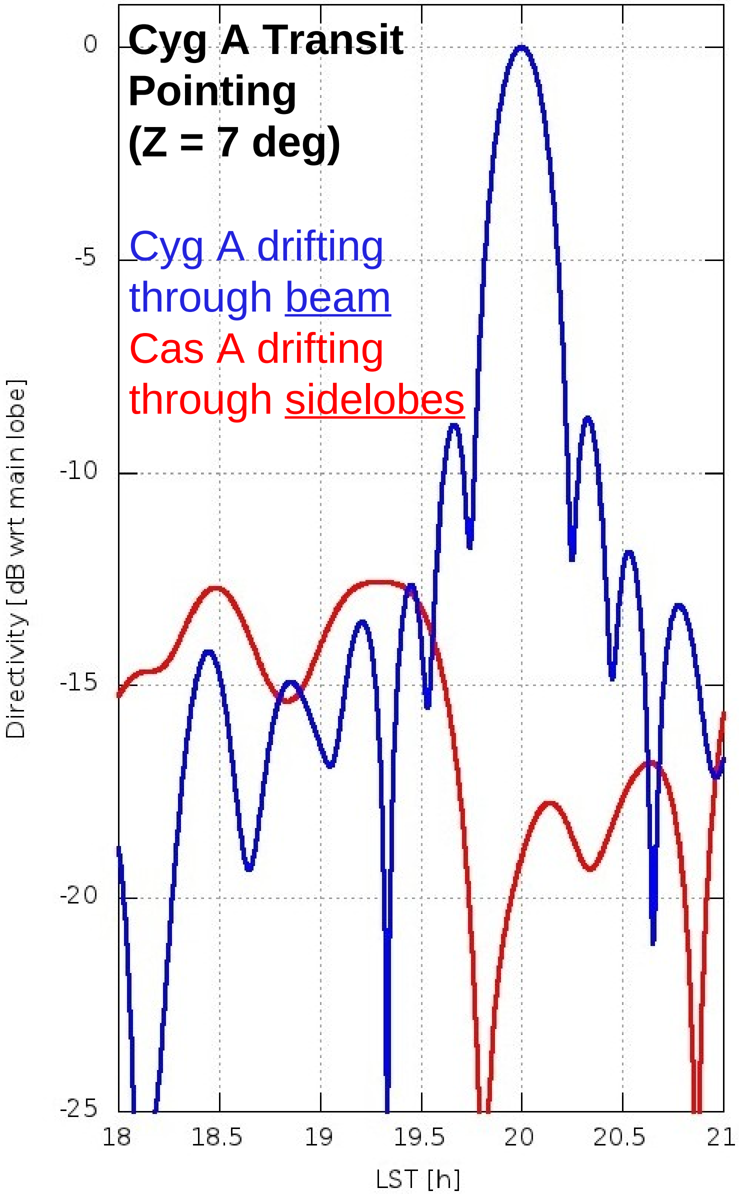
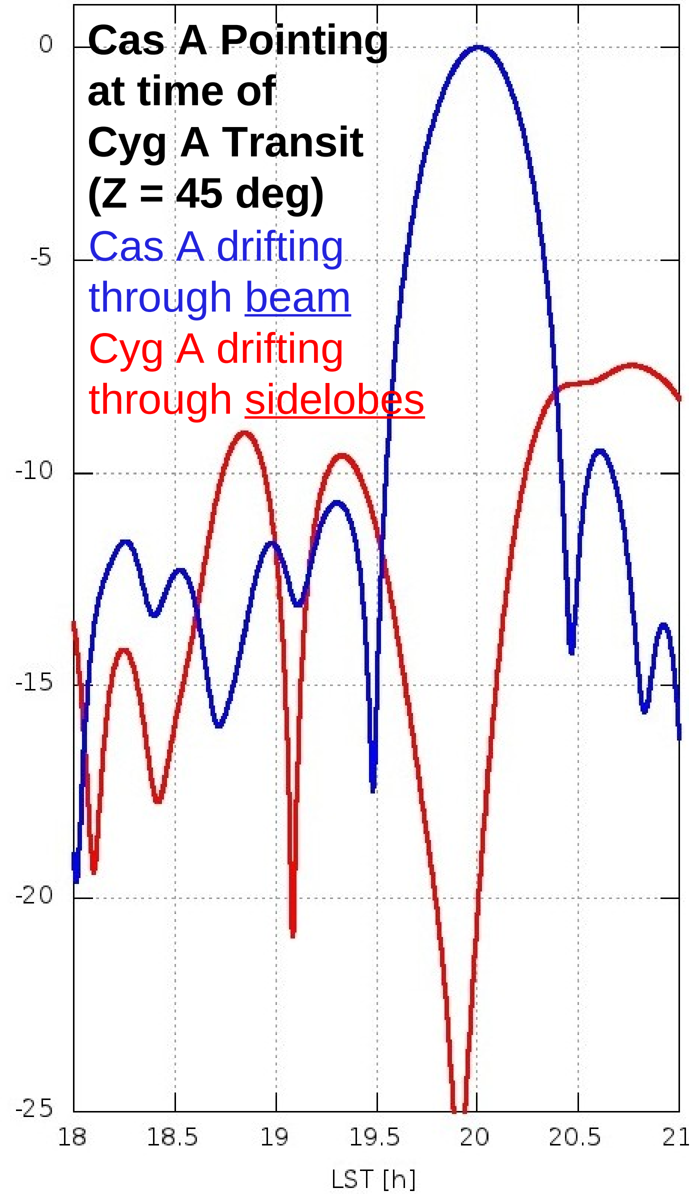
Sidelobe Characterization

74 MHz





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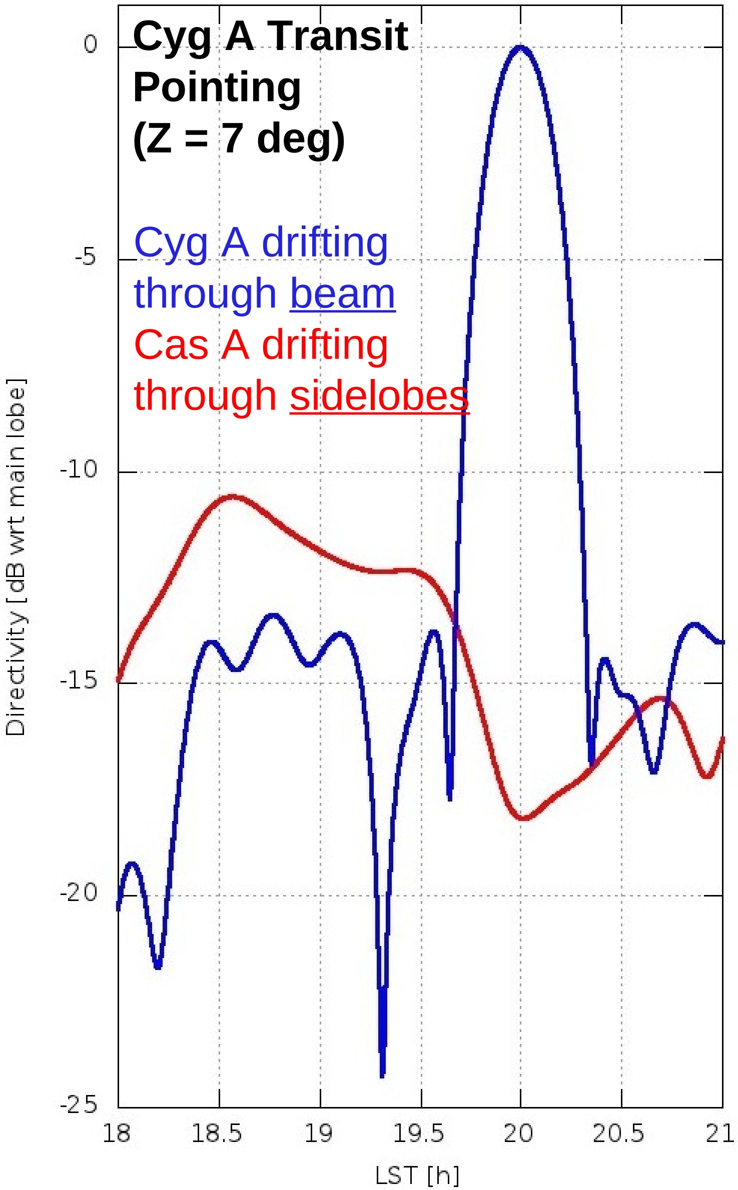
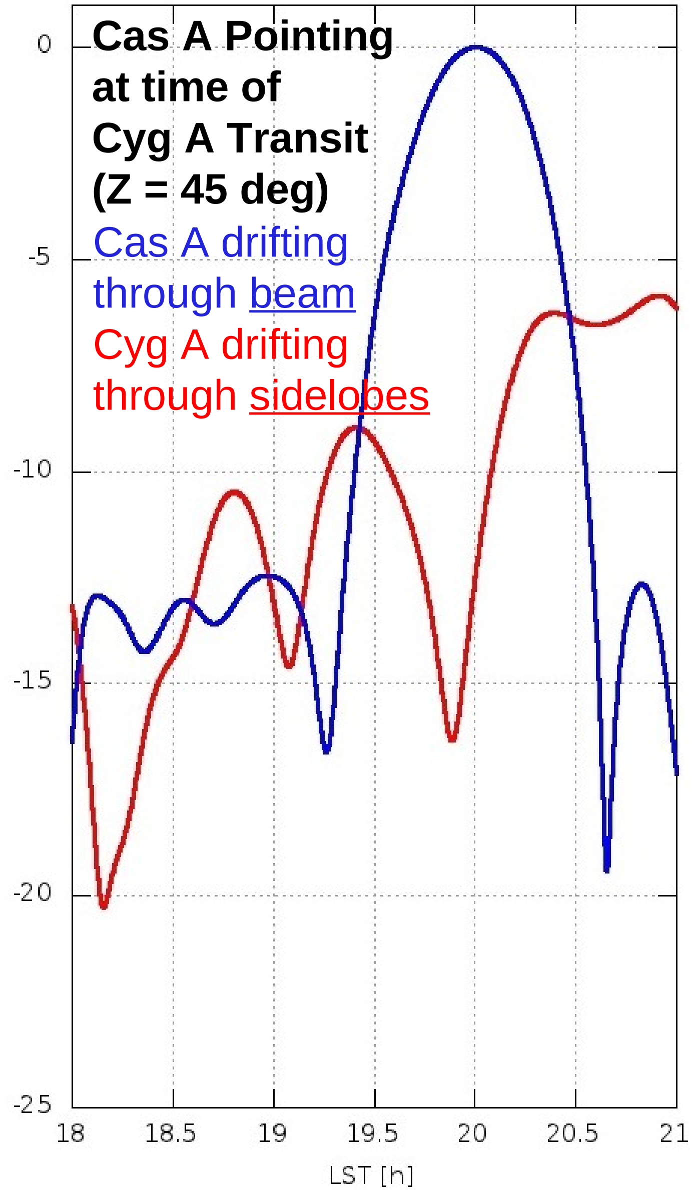
Sidelobe Characterization





74 MHz

“Conical” Windowing

Effects of Mutual Coupling

A concern for arrays of closely-spaced low-gain antennas

What we know (in the context of LWA1):

– **<u>Dipole patterns</u>: Variations on the order of a couple dB (M.166)**

– **<u>Beam main lobe</u>: Small but perceptible effect on pointing & FWHM (Pretty good results are possible by ignoring mutual coupling)**

– **<u>Beam sensitivity</u>: Variations up to about 30% depending on RA/Dec and zenith angle (M.166)**

– **<u>Beam sidelobes</u>: Much higher than would be predicted in the absense of mutual coupling**

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Additional Comments

LWA1 delay-and-sum (“DRX”) beamformers are current calibrated by fitting delay to narrowband response sampled over tuning range of instrument

Optimum (“max-SNR”; LWA M.166) beamforming in development
- Simulations predict gains ~50% in sensitivity, esp. for high Z

Precision control of beam shape & polarization in development
- Important for Dark Ages cosmology, RRLs

Spatial nulling:
- Not needed (but possibly useful) for RFI mitigation
- Useful for mitigating confusion from discrete strong sources
- LWA1 is uniquely well-suited to development of nulling techniques (esp. streaming per-dipole voltages)

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Summary

Confirmed LWA1 beamforming performance:

Beam SEFD ~[3,17] kJy for Z=[0^o,65^o],
~ independent of freq; but somewhat dependent on {RA,δ}

Main lobe FWHM ≈ 2.2^o ((74 MHz)/ν) sec^2 Z

Sidelobe levels highly variable; typically ~ 10-15 dB at maxima

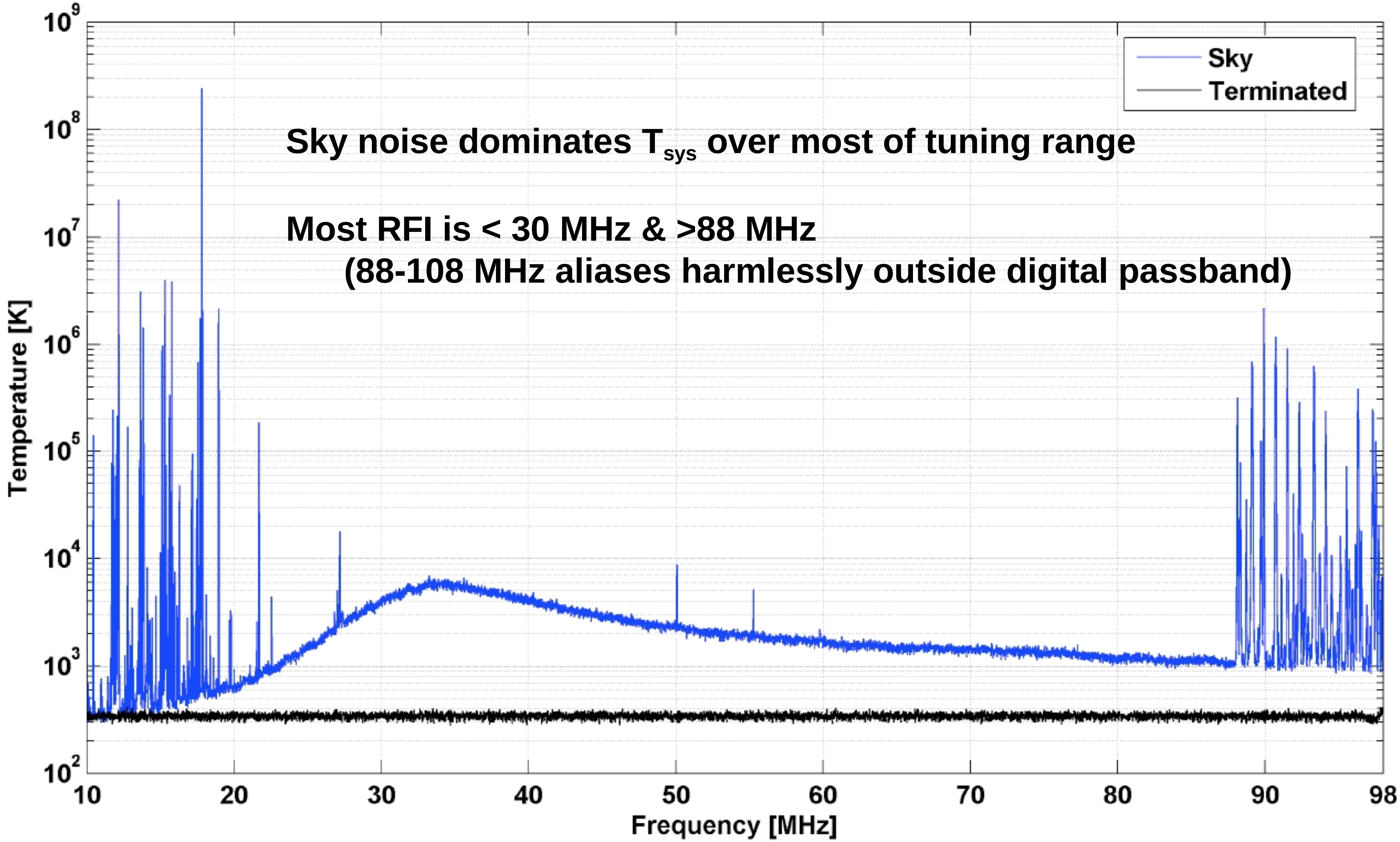
A useful path to calibration of large, wide FOV, low freq. beamforming arrays is:

Orthogonally-oriented long baselines
(strong sources at high fringe rates)

Access to individual dipole signals, or at least cross-correlation of every dipole against each outrigger

Backup Slides

Active Dipole Output Spectrum



Antenna through digitizer (12 bits @ 196 MSPS)
10 s integration, early afternoon local time
6 kHz spectral resolution

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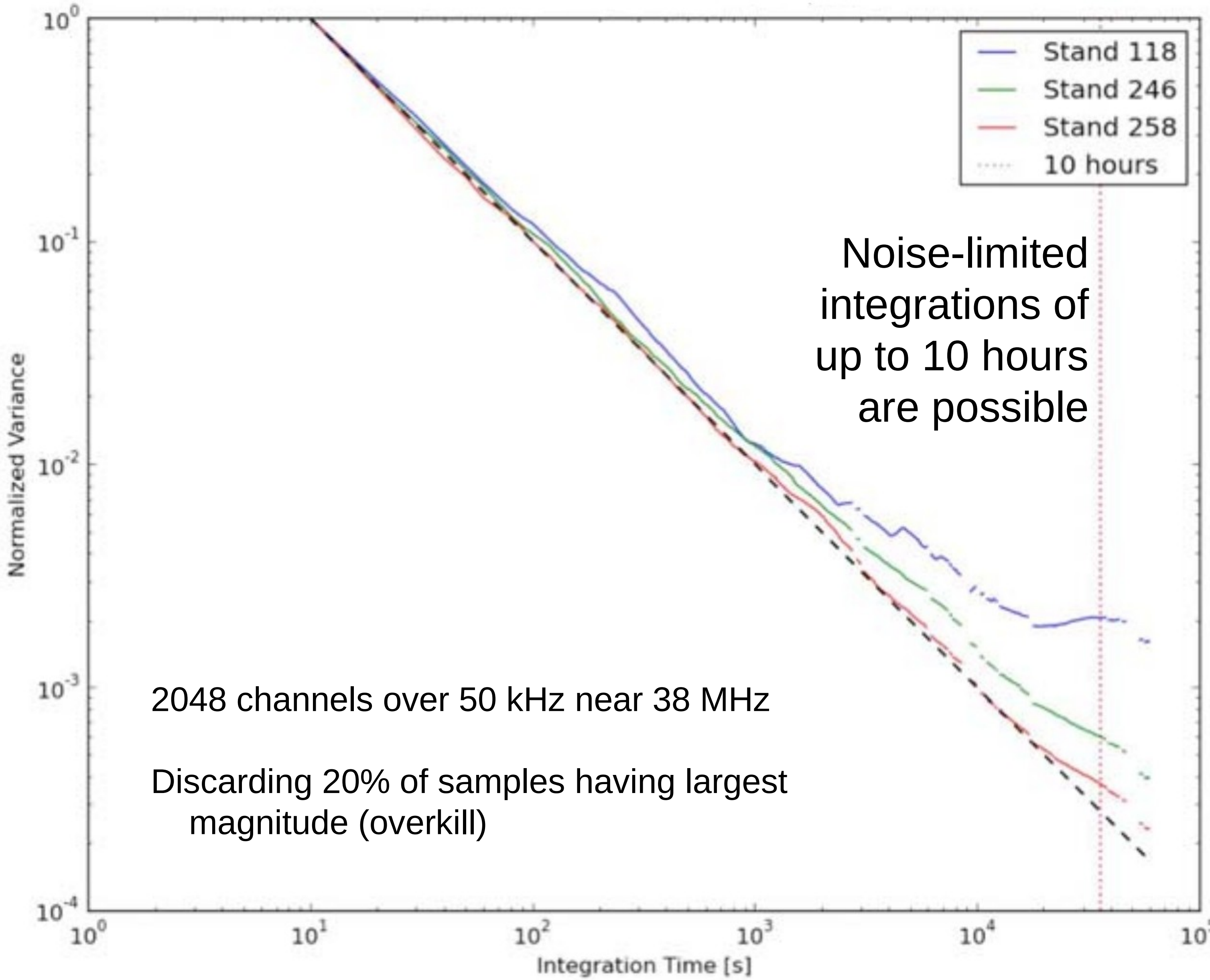
Radiometric Stability



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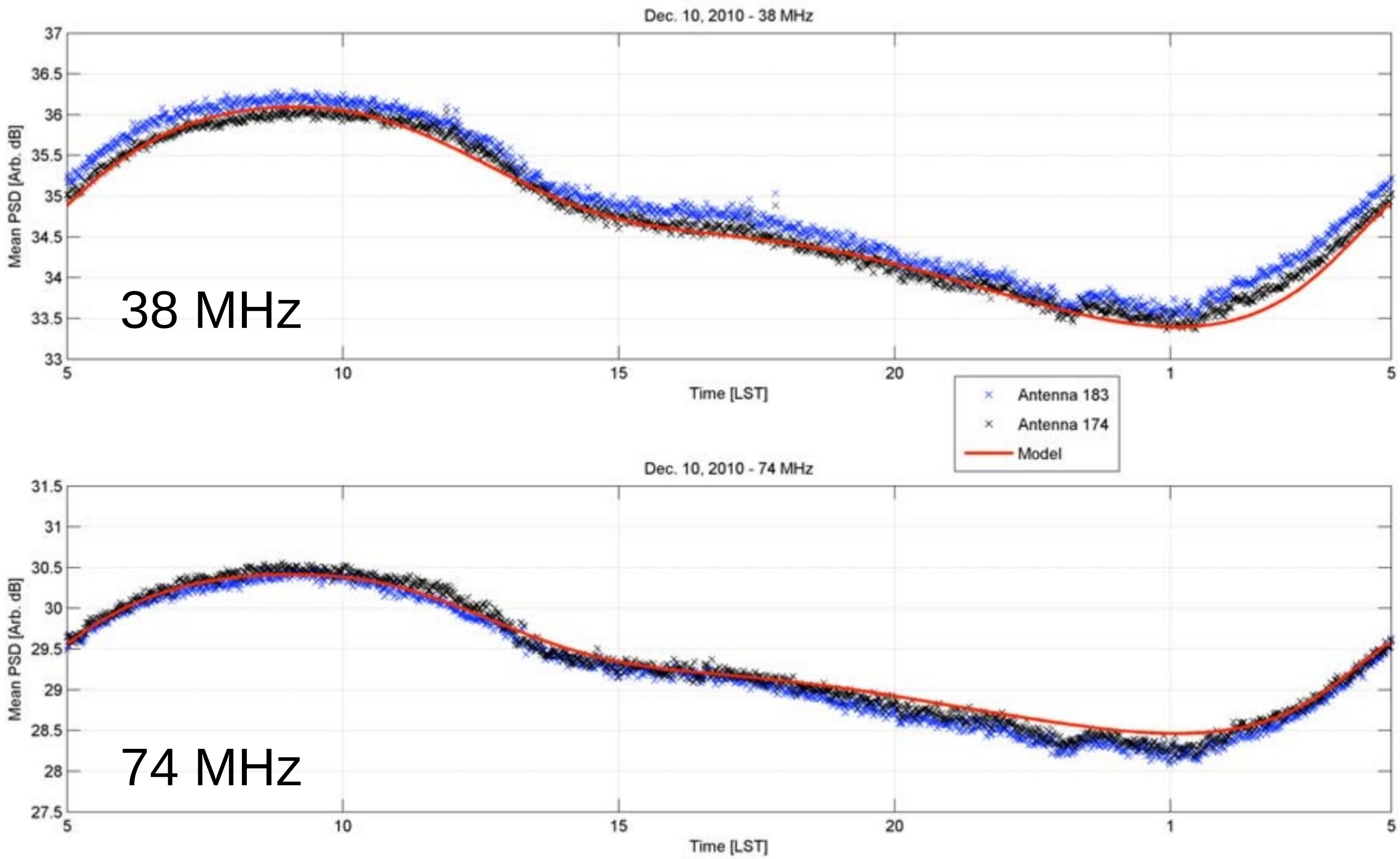
Confirmation of Galactic Noise-Dominated T_{sys}



Uncalibrated single-dipole total power drift scans

Close agreement to model – can even identify polarizations this way

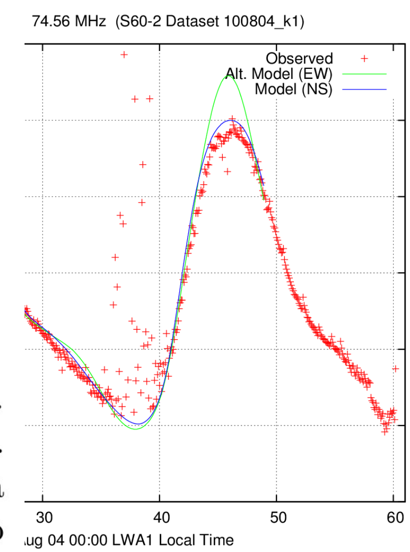


Figure 2: Dipole total power measurements (1 MHz bandwidth, 61 ms integration per point). Variation is due to the changing sky brightness temperature distribution as seen by the dipole. The solid red line is our prediction obtained by convolving the sky model of de Oliveira-Costa *et al.* (2008) with a model of the dipole pattern obtained from electromagnetic simulation. No RFI mitigation or editing has been applied.

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