LWA1 Beam Calibration

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Disclaimer

This presentation applies to the following modes of LWA1 observations:

- DRX beam-formed raw voltage data
- DRX beam-formed spectrometer data
- Custom beam-formed data such as beam-dipole or dipole-dipole

DRX gain for beam observations

- Did the DRX gain get set right?
  DRX gain compensates for bandwidth reduction

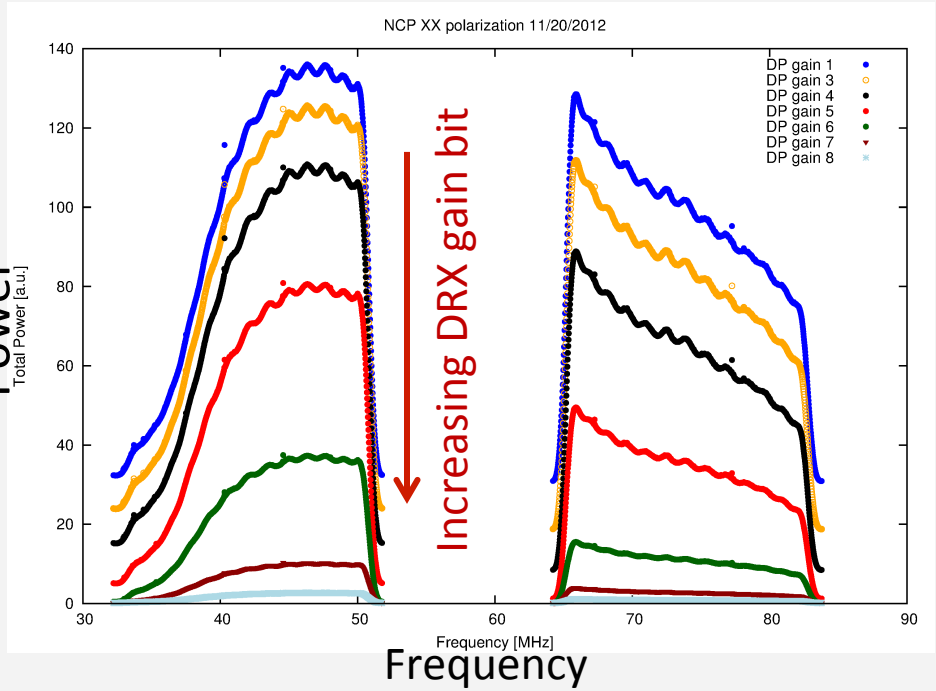
Target	Full Bandwidth AT1=13, AT2=13	Split Bandwidth AT1=08, AT2=06, ATS=15
Cyg A/Cas A	5 or 6	7 or 8
Vir A/Tau A	4 or 5	6 or 7

- Too low DRX gain can cause severe data clipping and skews the spectral response
- Too high DRX gain causes only few bits to toggle also skewing the spectral response

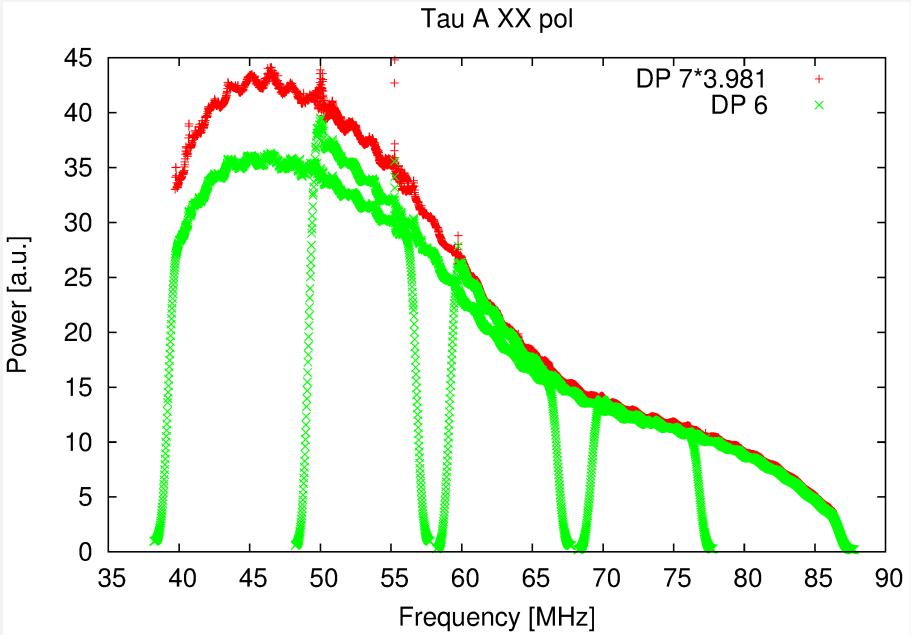
Scheduler and Operator might not know the intent of the observation thus cannot always know the right DP gain.

DRX gain examples

Example: NCP XX pol. Split bandwidth



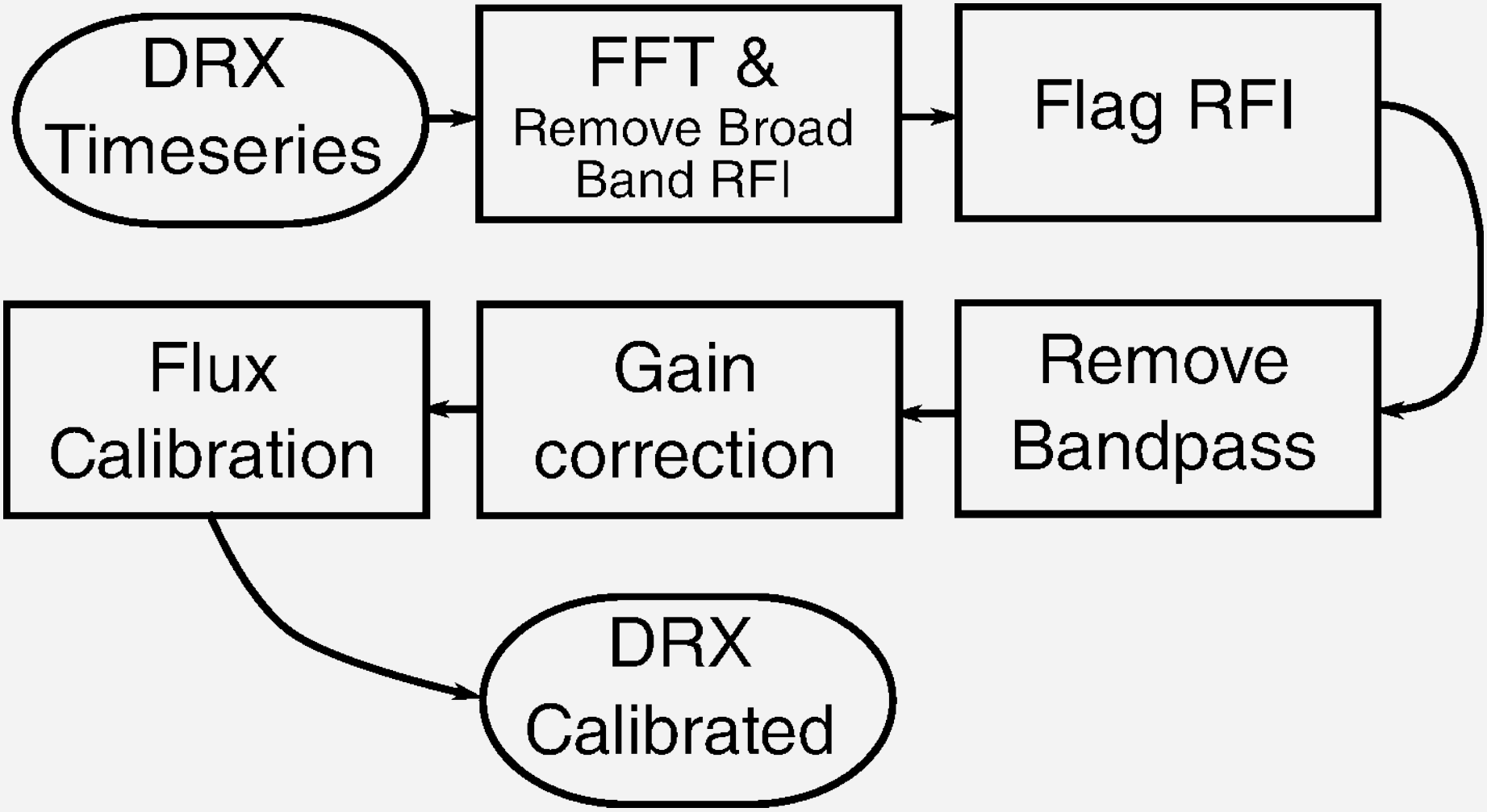
Example: Tau A good and bad gain



Here optimal gain for NCP is 5 or 4; optimal gain for Tau A is 7

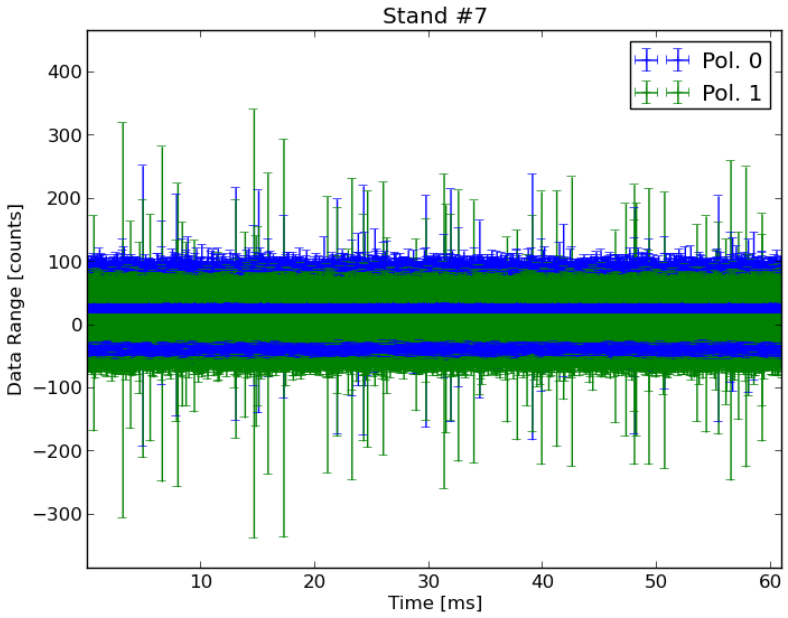
Difference in 1 digit of DRX gain corresponds to 6 dB (power ratio ~4)

Calibration Strategy



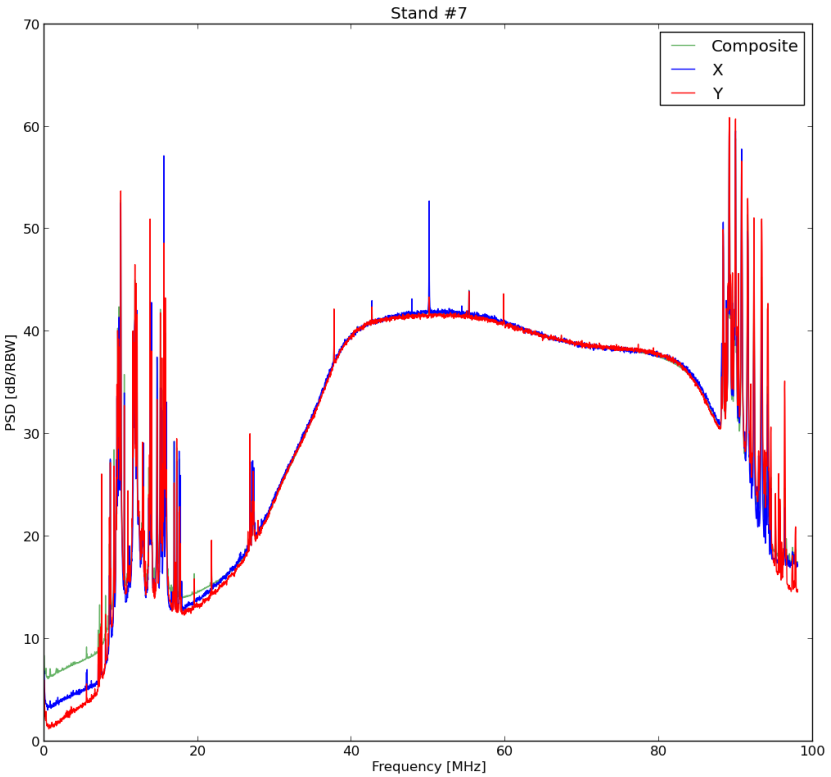
Radio Frequency Interference

Timeseries



Powerline RFI

Spectrum



TV carriers, Amateur Radio, AM, FM, etc.

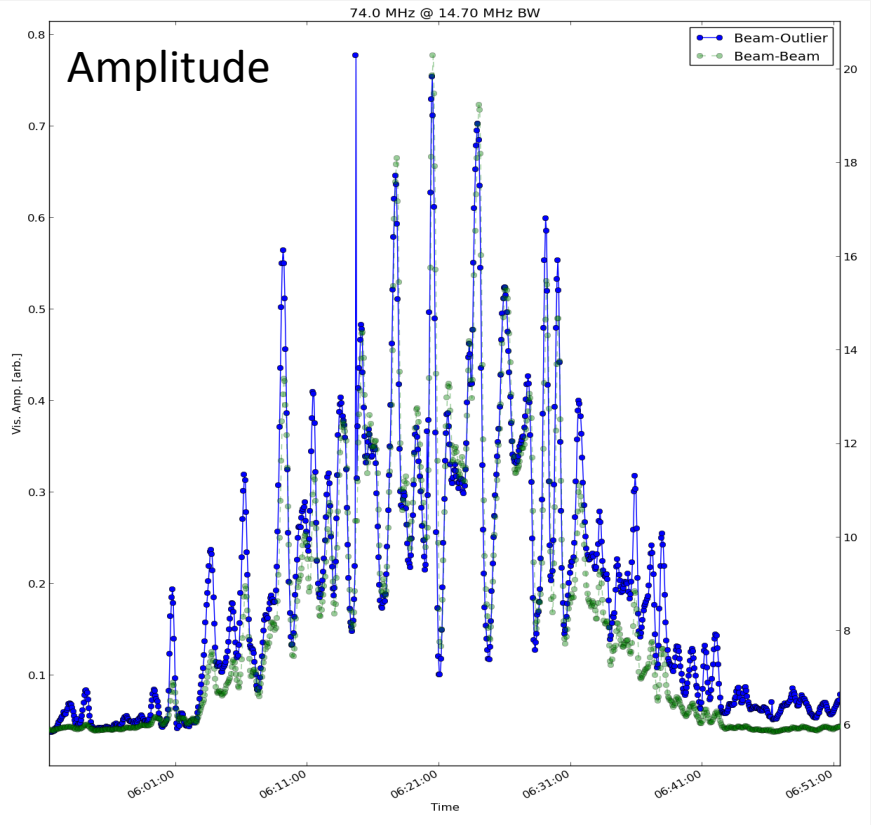
Post-correlation Flagging Methods

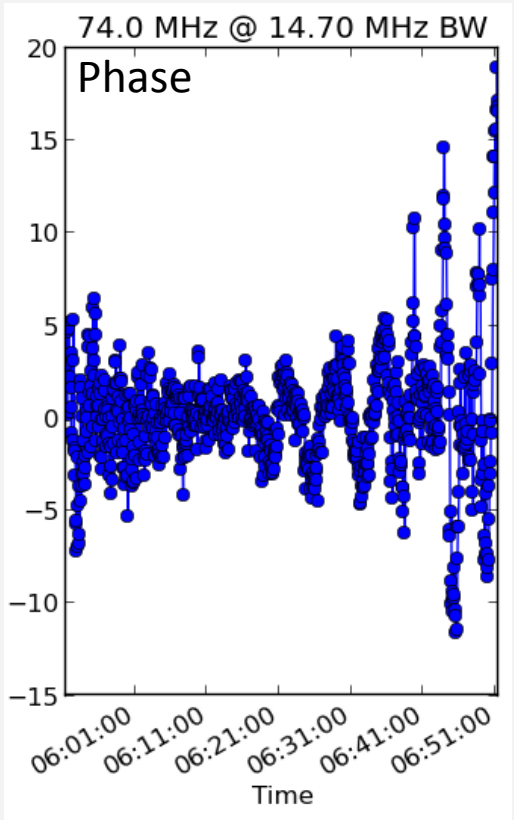
- Time domain:
  - Clipping levels can be used as a tool to remove strong broad-band bursts of RFI
  - Weak broad-band RFI?
- Frequency domain:
  - Post-correlation thresholding
  - Surface fitting and smoothing
  - Combinatorial thresholding
  - SumThresholding
  - Spectral Kurtosis (implemented in LSL: lsl.statistics.kurtosis)

Good references to start: LWA Memo #143, Nita & Gari PASP, 122, 595; Offringa et al., MNRAS 405, 155

Ionosphere

Example Cas A

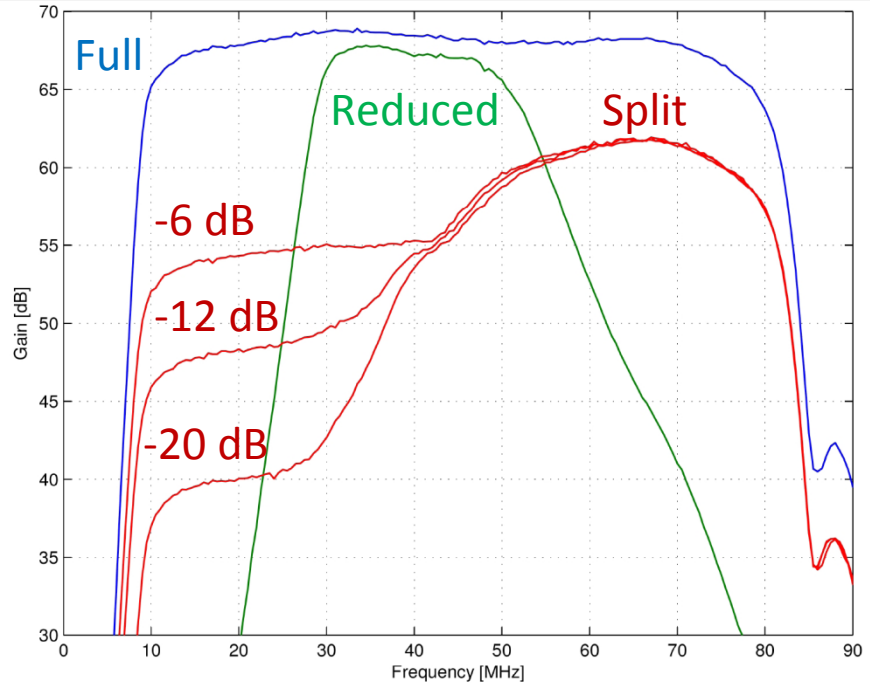




Pretty much a lost cause unless interested in Ionospheric scintillation

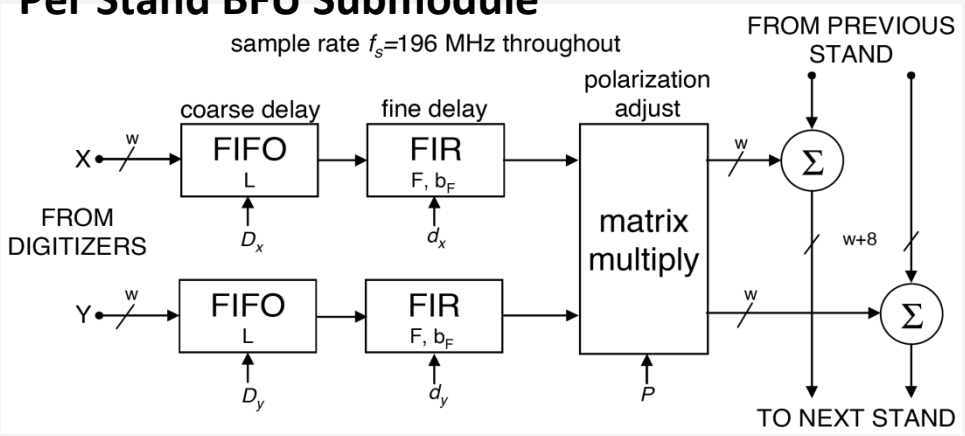
Bandpass

1. ARX filter configuration

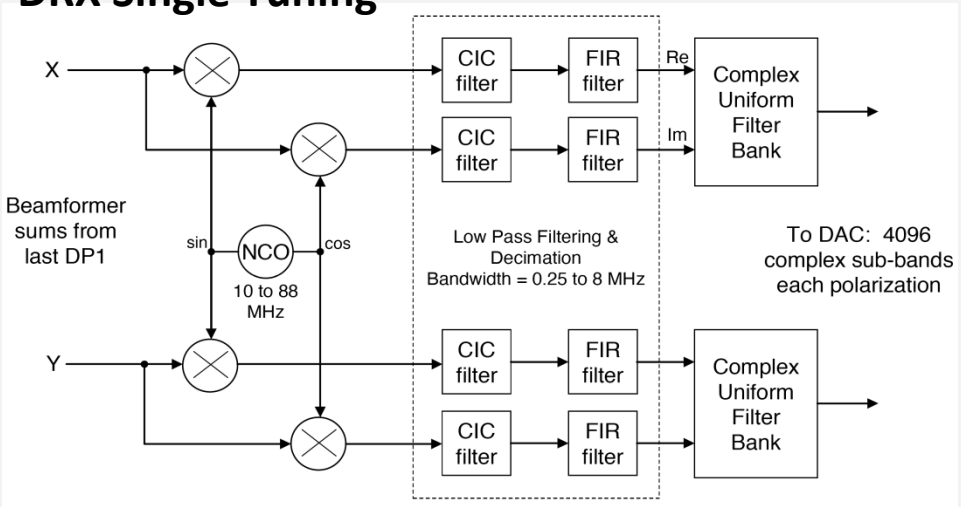


2. Digital filter

Per Stand BFU Submodule



DRX Single Tuning



3. Antenna & cable response, ground losses, etc.

References: LWA Memos #161, #154

Off-source calibration

Approaches tried:

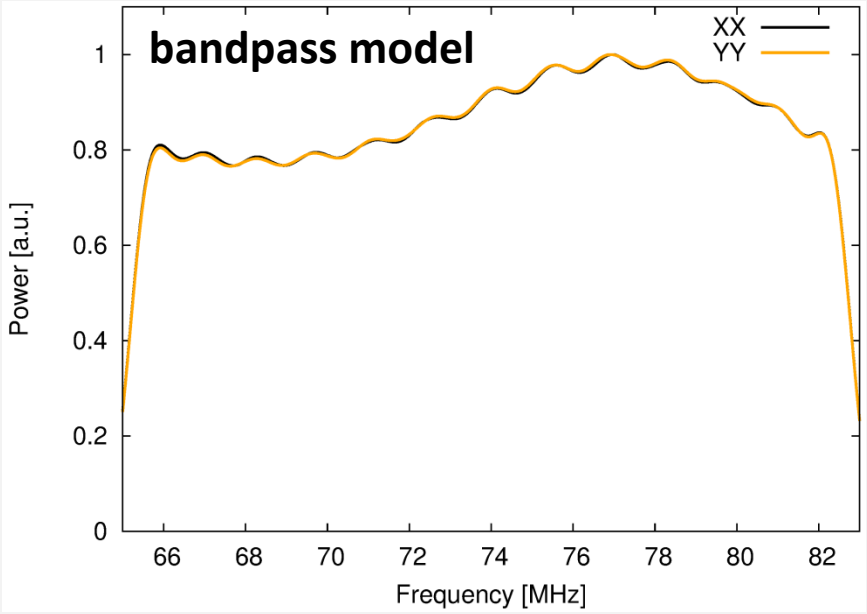
- **'empty' sky off-source**
  caveat: pick-up sidelobes from target or nearby sources etc.
- **NCP as 'empty' sky reference**
  caveat: large beam, picking-up a lot of other stuff
- **Strong calibrator**
  caveat: spectral properties at <60 MHz not well known, beam confusion not well known

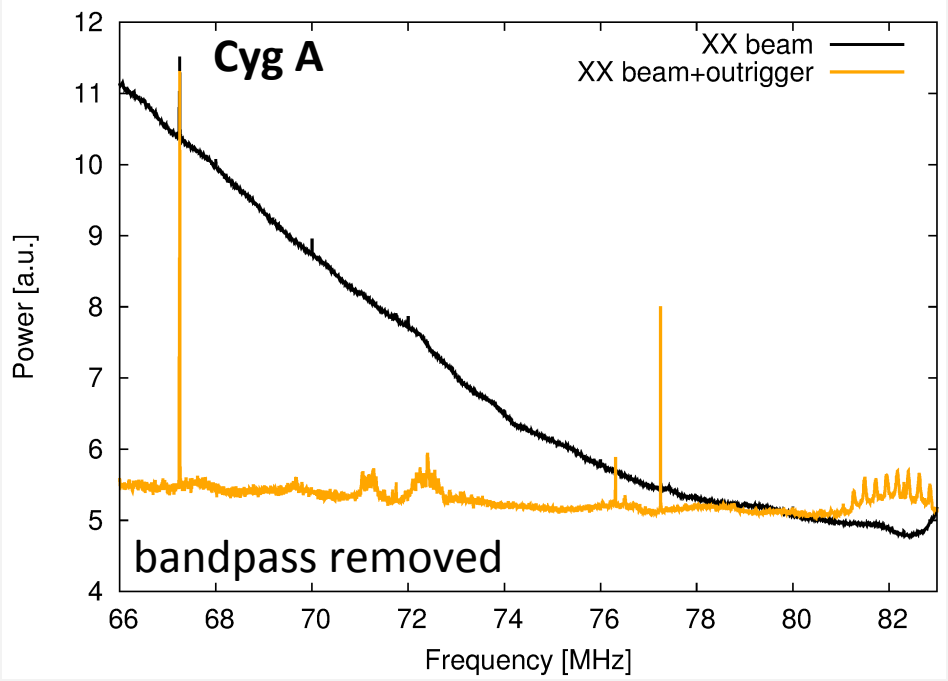
All this did not work reliably in a broad range of applications, some might get away with it.

Bandpass Model

Create a model bandpass from ARX, DRX, and antenna responses (impedance mismatch)

lsl: arx.response/dp.drxFilter (also see memo #191)

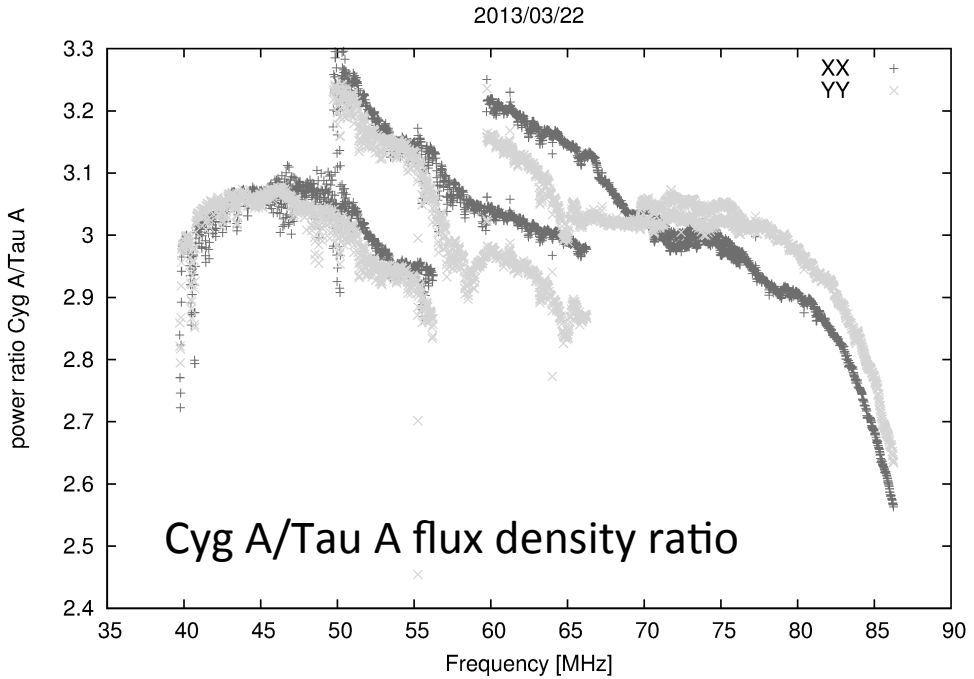


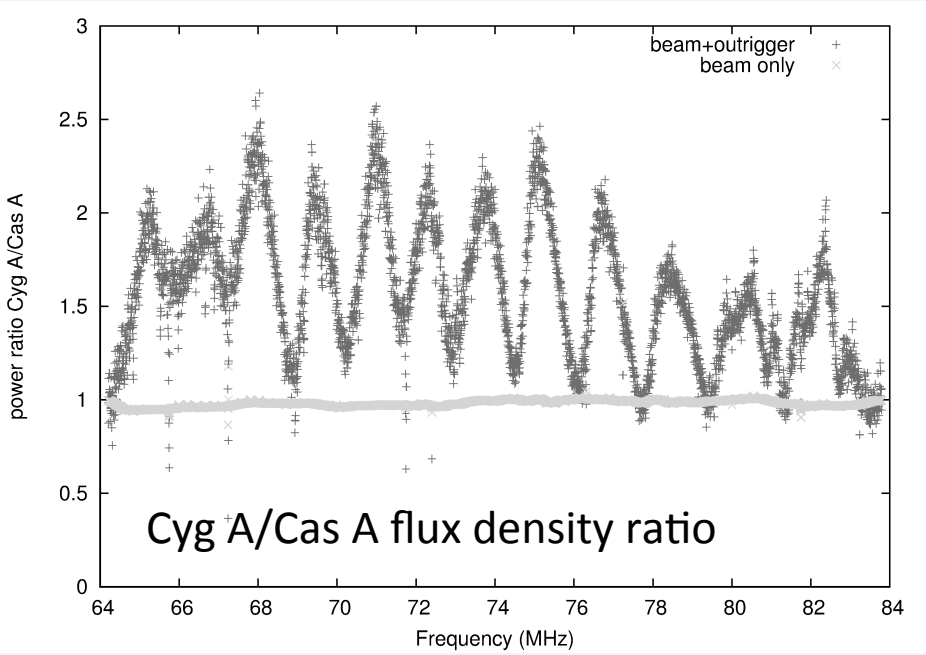


Works pretty well for beam-formed data, antenna impedance mismatch is most likely the biggest unknown at the moment.

Primary Beam Confusion

Cyg A/Cas A vs Tau A/Vir A, expected flux ratio is ~10, but LWA1 (beam-only) measured is ~3





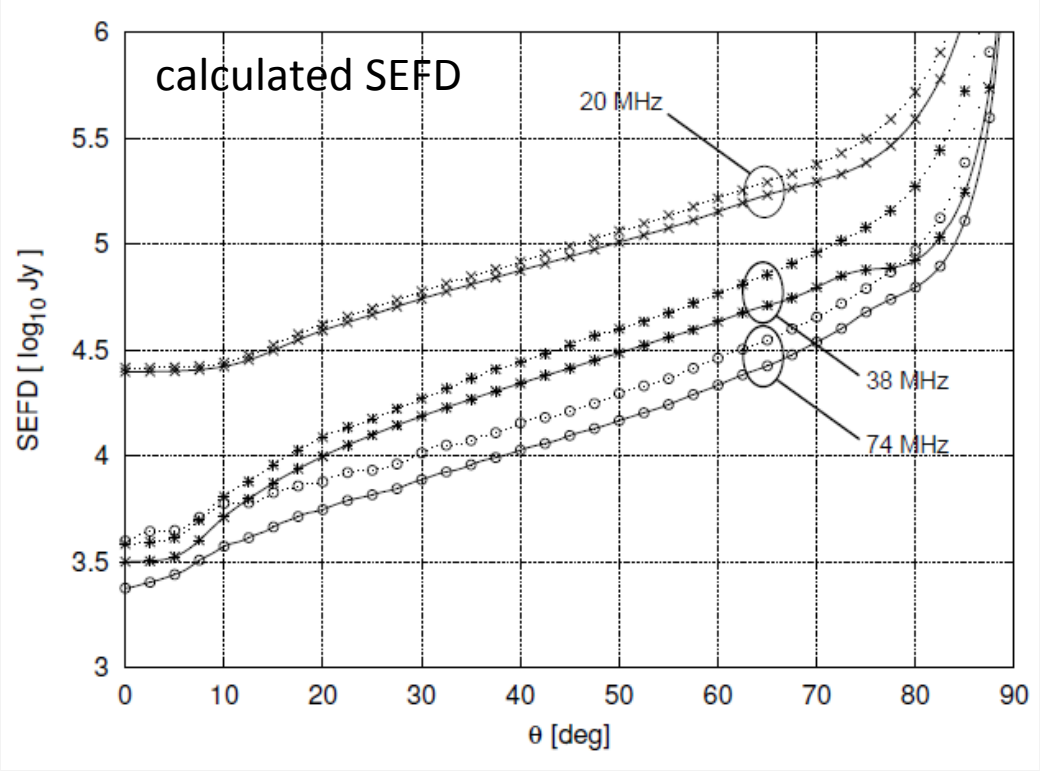
Need to apply a model for the beam pattern: source + off target sky contribution to determine the measured flux density

Gain calibration

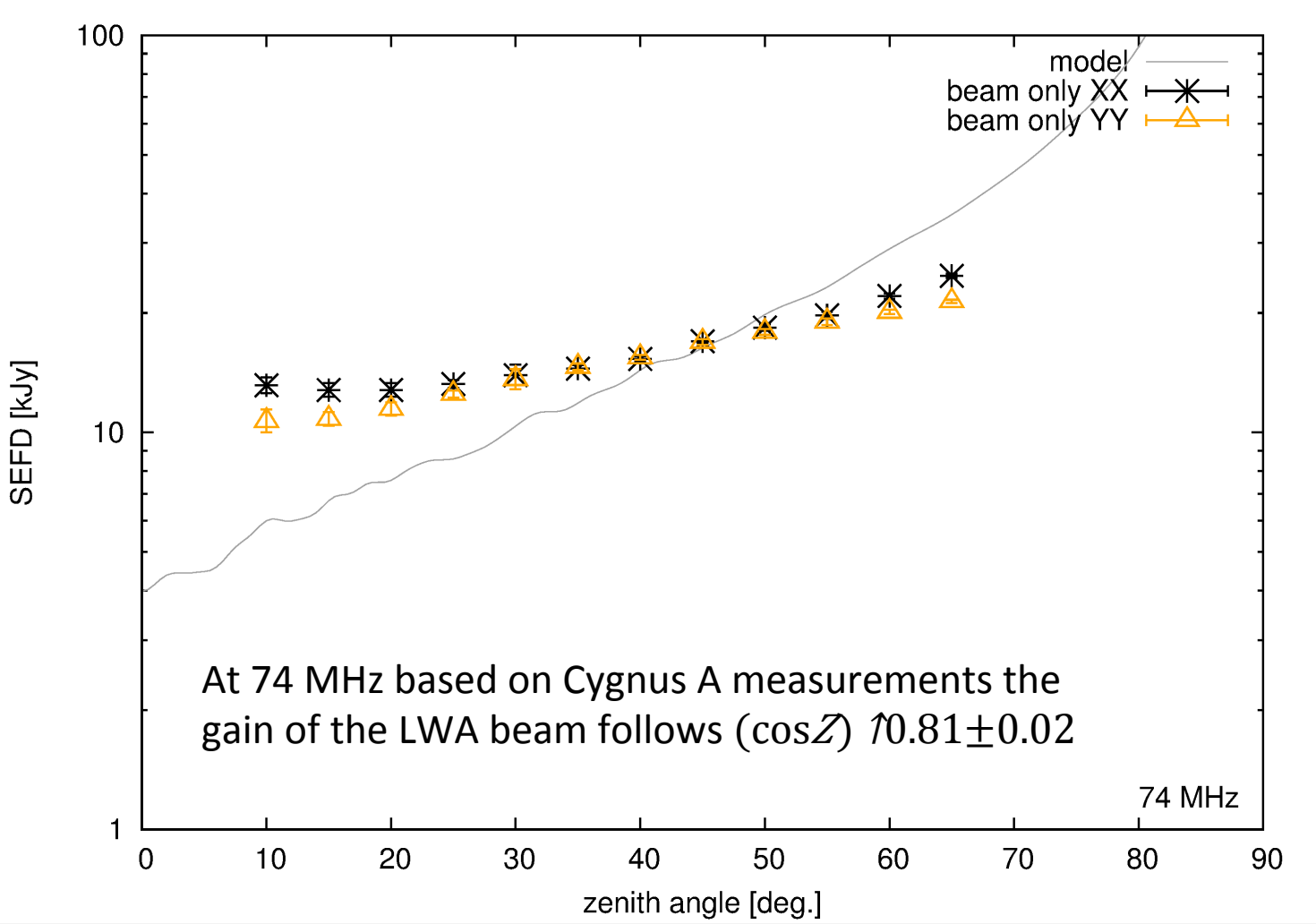
Gain variations introduced by changes in sensitivity as a function of frequency and zenith angle.

System Equivalent Flux Density can be estimated from drift scans.

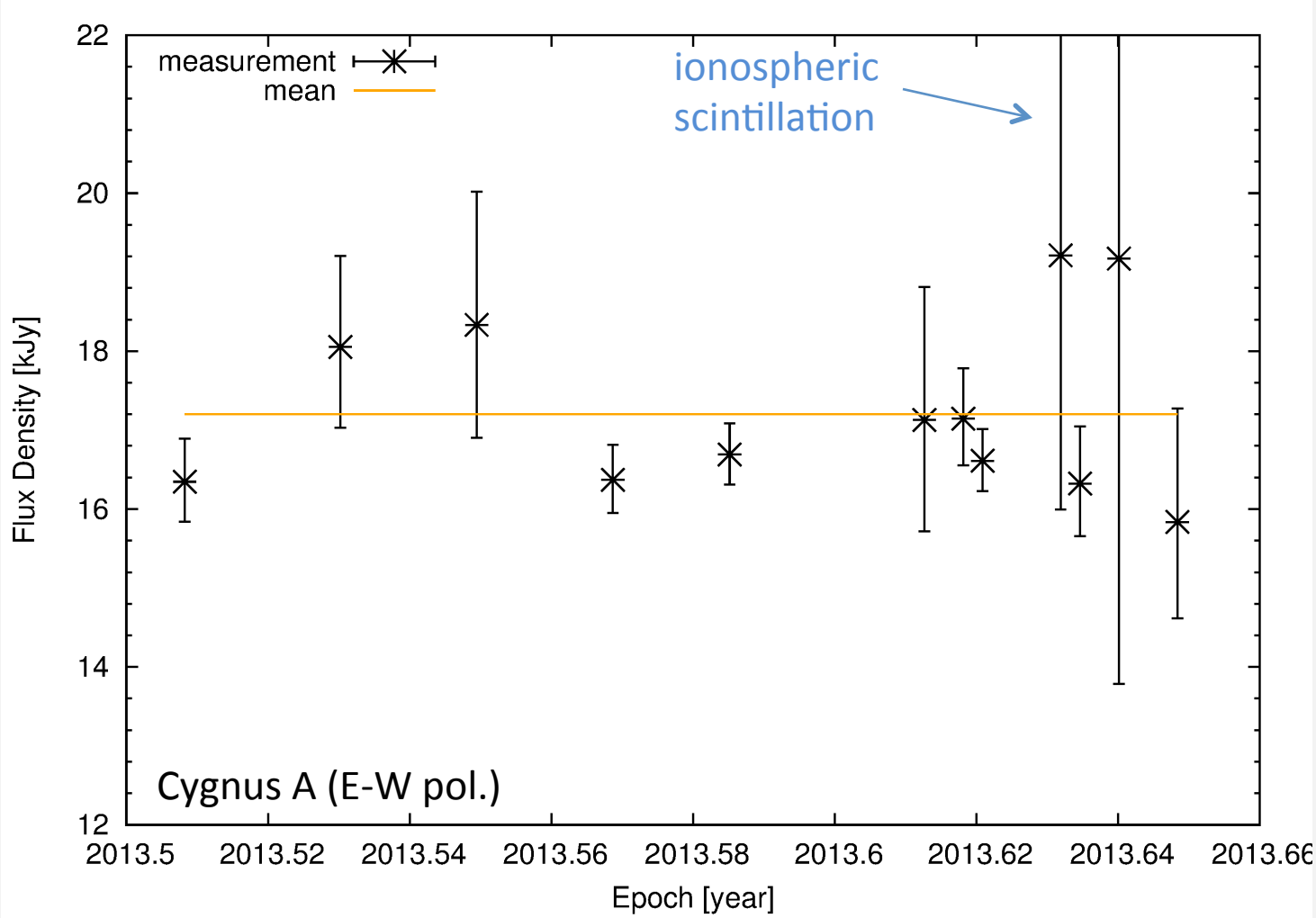
(see LWA memo #186, #166)



Gain calibration - measured



Day-to-day stability/Lightcurve



Flux Density Calibration

Translate total power measured by LWA1 station beam to an absolute flux density.

Challenges:

1. **Understanding the LWA1 beam**
   we are getting close
2. Knowledge of low frequency calibrators
   http://www.nrl.navy.mil/rsd/vlss/calspec/
   existing measurements are old and inconsistent
3. Good sky model for desired observing frequencies
   only crude sky models exist for the LWA1 frequency range

Summary

- Significant progress on beam calibration was made, although it remains challenging.
- Bandpass calibration works reasonably well applying a model.
- We have now a well sampled gain curve of LWA1 beam and beam+outrigger that allows to investigate and derive an empirical model.
- Still need to increase our understanding of beam confusion for absolute flux calibration.