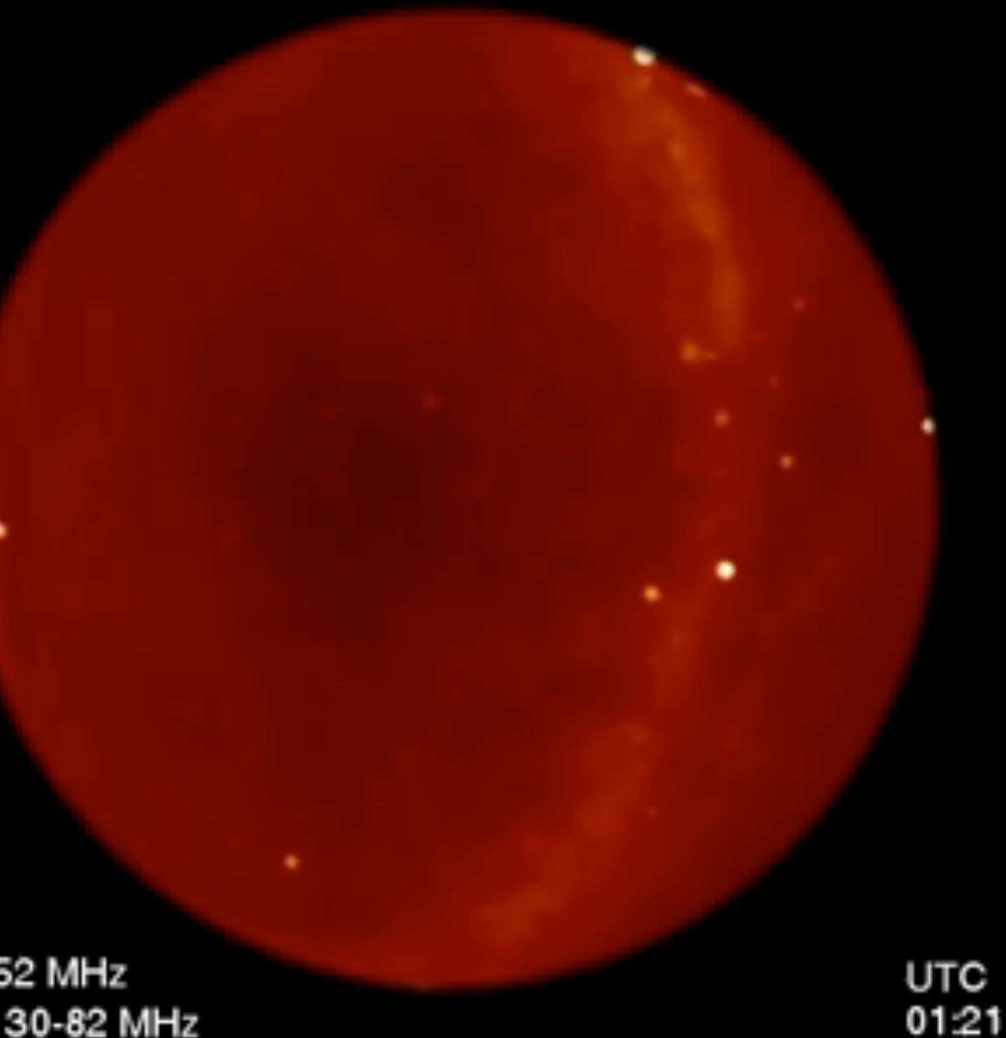
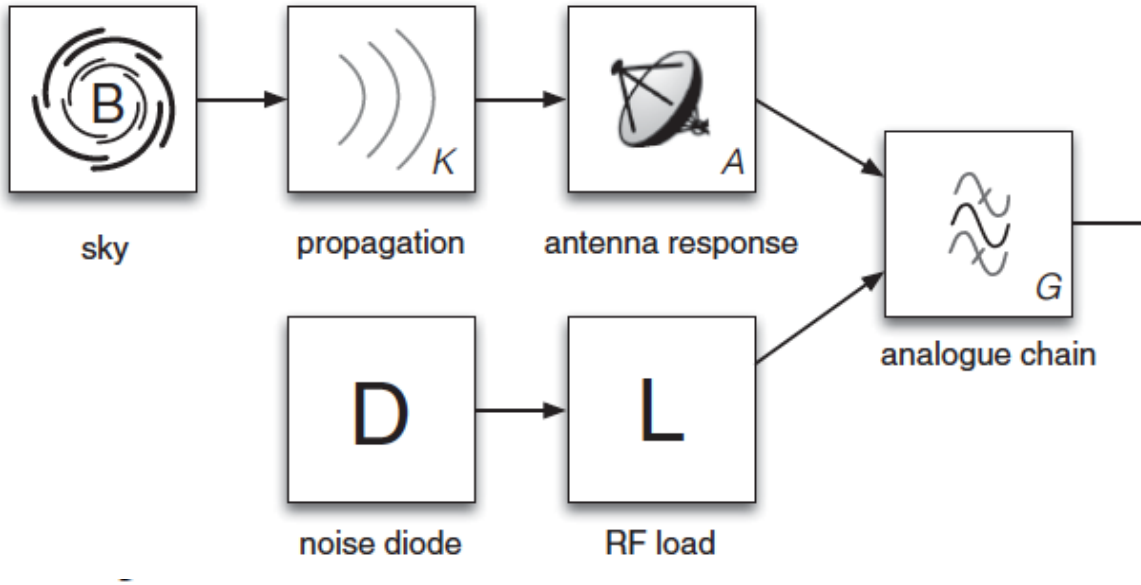
LEDA: Status update and future outlook

Danny
Science at Low Freq
4 Decem



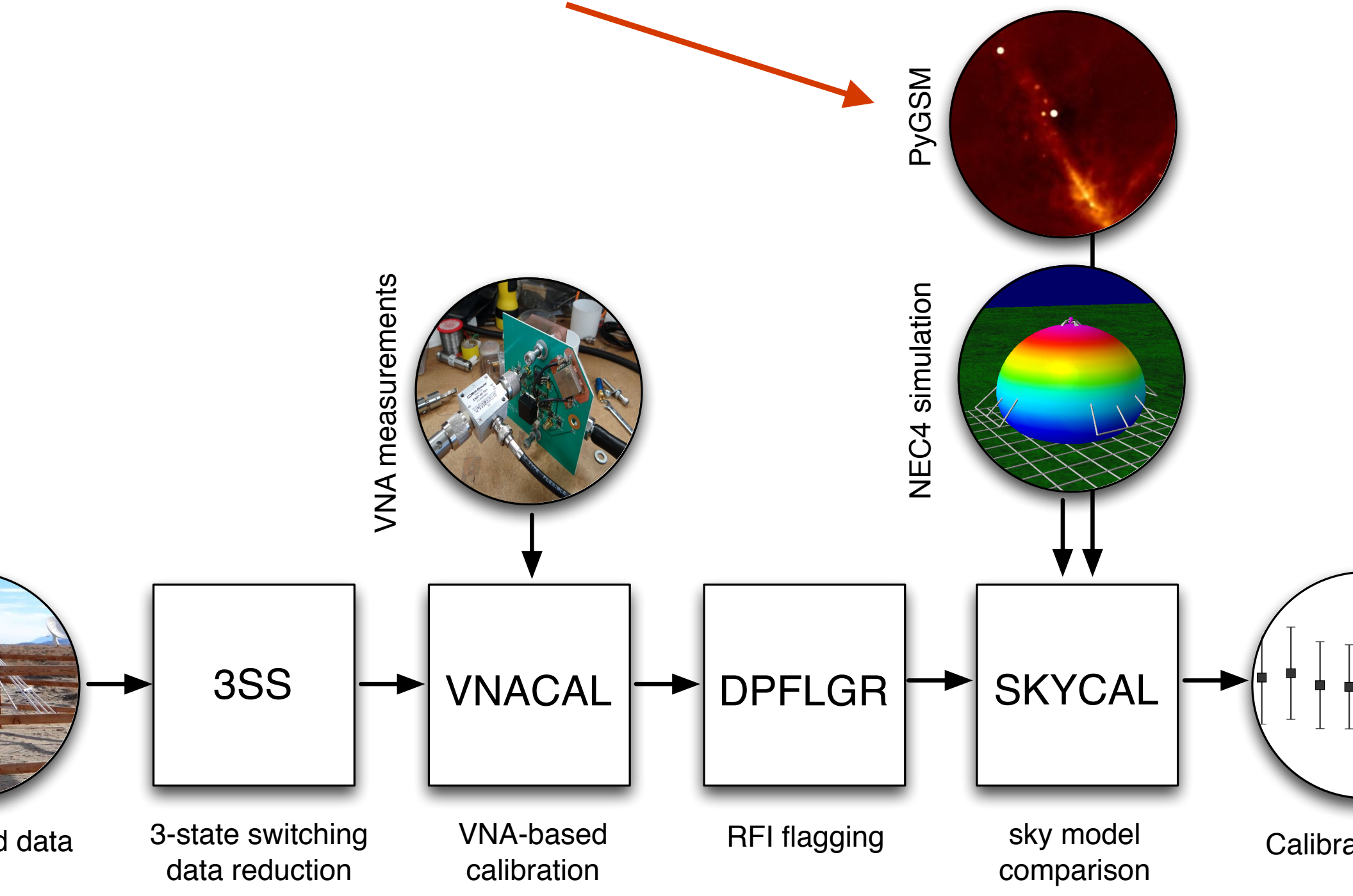
- LEDA is a hybrid experiment, consisting of 5 precision radio antennas that are cross-corre against 251 antennas in a den core.
- We can use this to monitor the ionosphere, measure the gain of the antennas, and monitor to improve our sky model.
- That is: this movie is **only of in for calibration** via the visibilitie

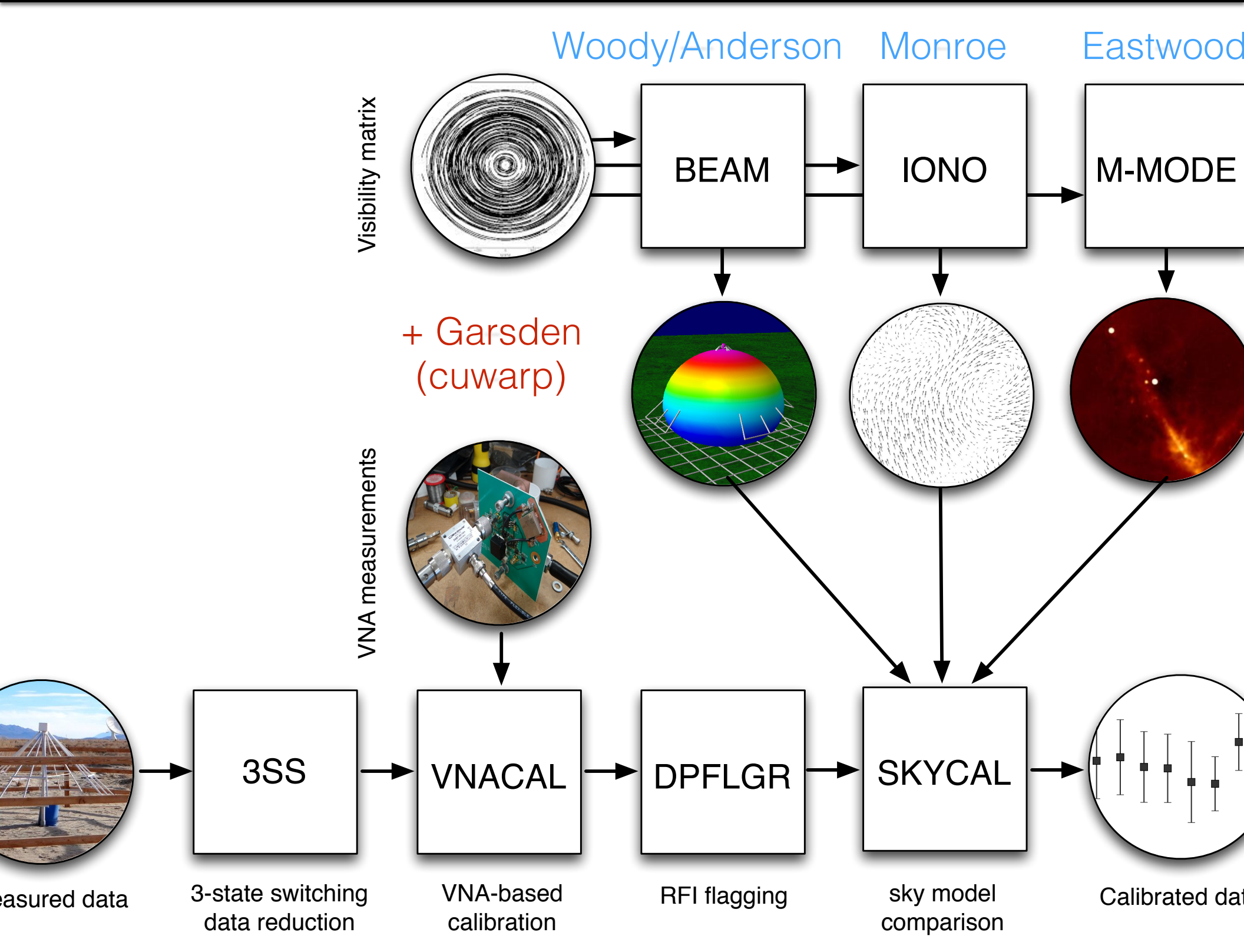
- Three-state frontend board (FEE) switc between antenna, load and noise diode (ala Rogers & Bowman 2012)
- Switching triggered by PPS, or can be controlled remotely

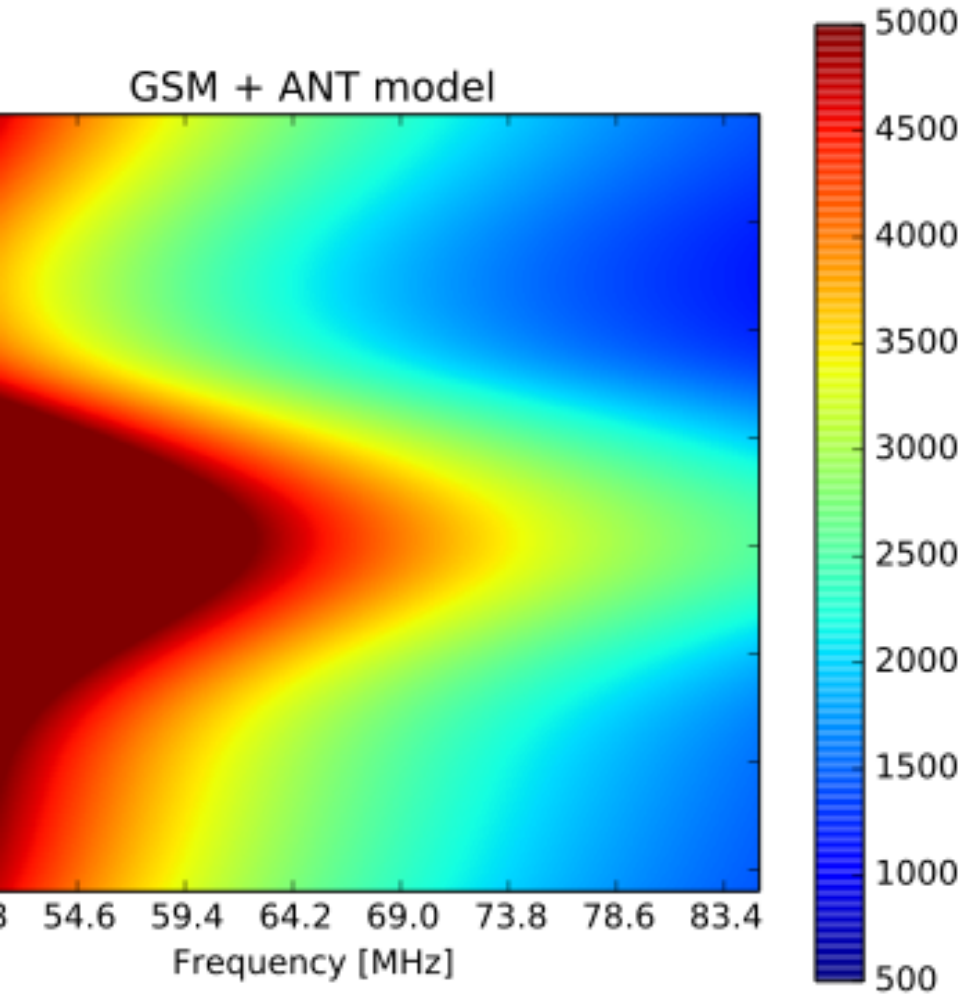


$$T_{ant} = T_{diode} \frac{P_{ant} - P_{load}}{P_{diode} - P_{load}} + T_{lo}$$

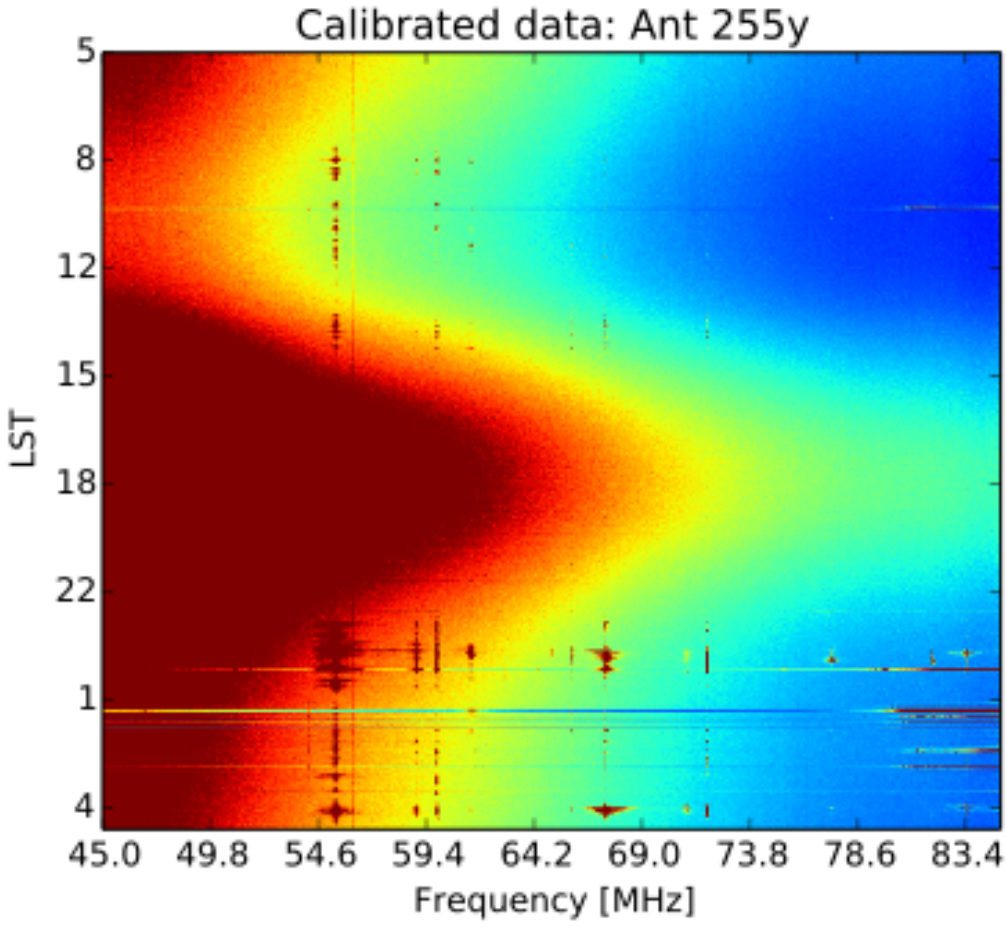
github.com/telegraphic/pygsm

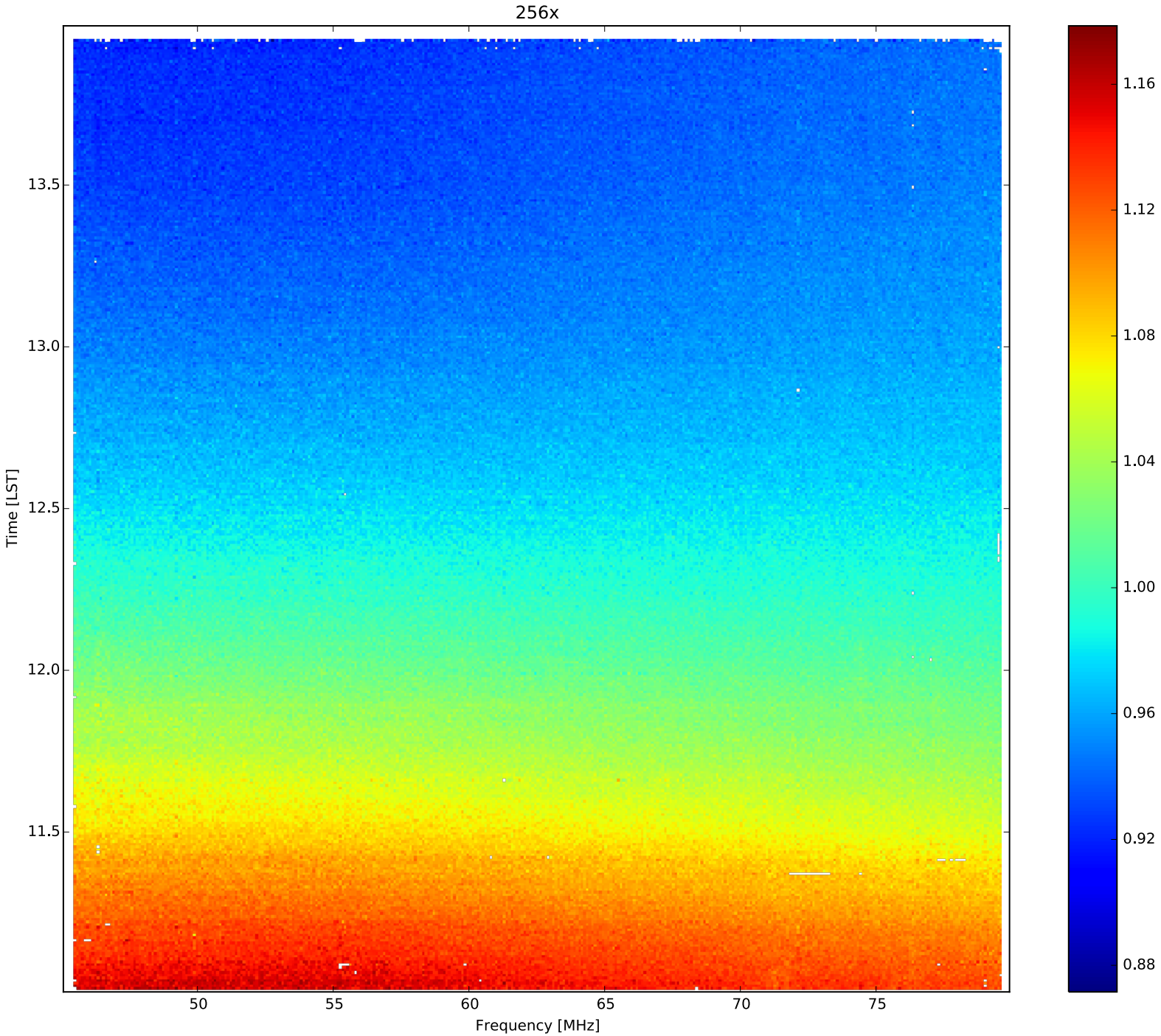



Woody/Anderson
Monroe
Eastwood
Visibility matrix
BEAM
IONO
M-MODE
+ Garsden
(cuwarp)
VNA measurements
3SS
VNACAL
DPFLGR
SKYCAL
easured data
3-state switching
data reduction
VNA-based
calibration
RFI flagging
sky model
comparison
Calibrated dat

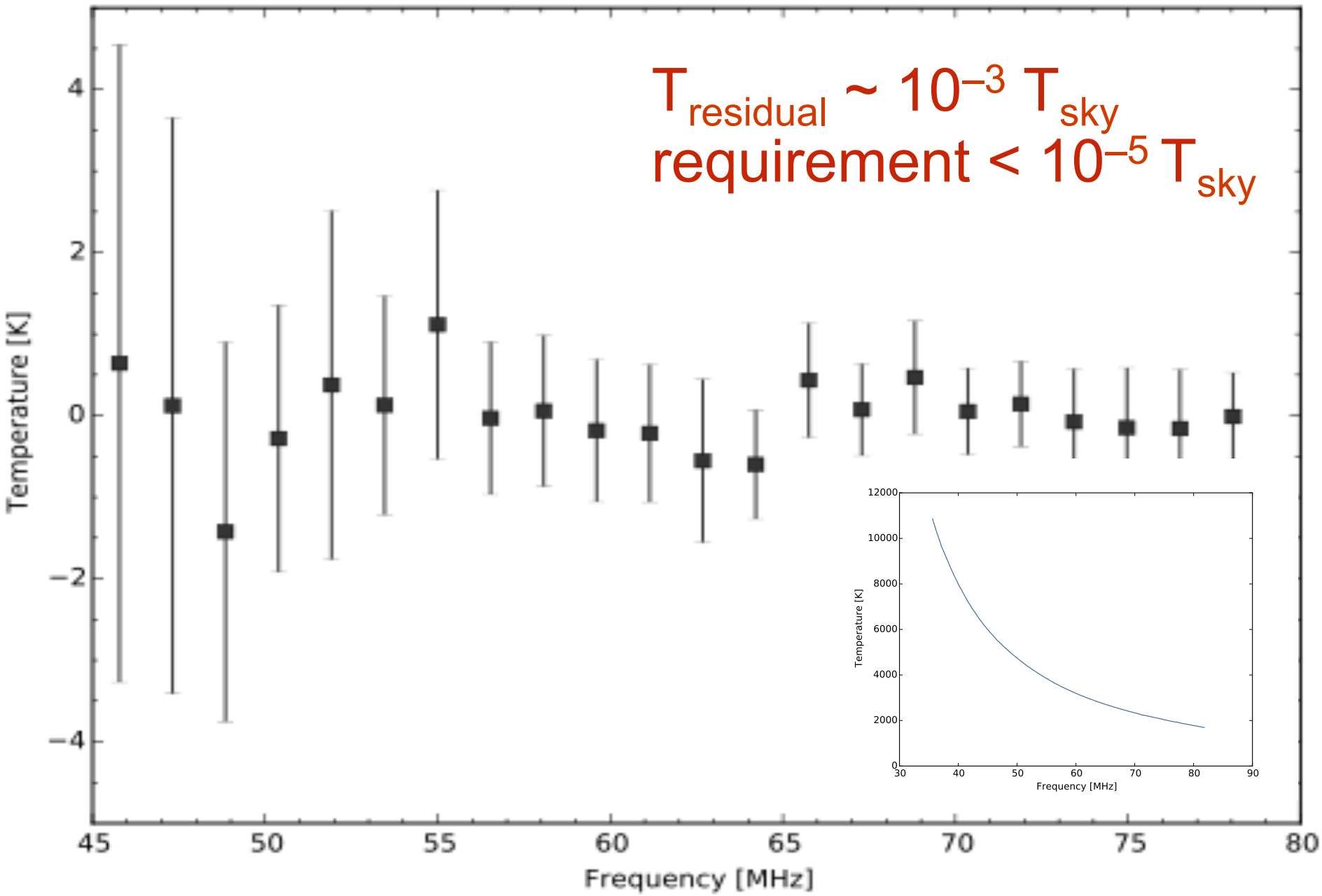

GSM + ANT model
54.6
59.4
64.2
69.0
73.8
78.6
83.4
Frequency [MHz]

5000
4500
4000
3500
3000
2500
2000
1500
1000
500


Calibrated data: Ant 255y
LST
5
8
12
15
18
22
1
4
45.0
49.8
54.6
59.4
64.2
69.0
73.8
78.6
83.4
Frequency [MHz]

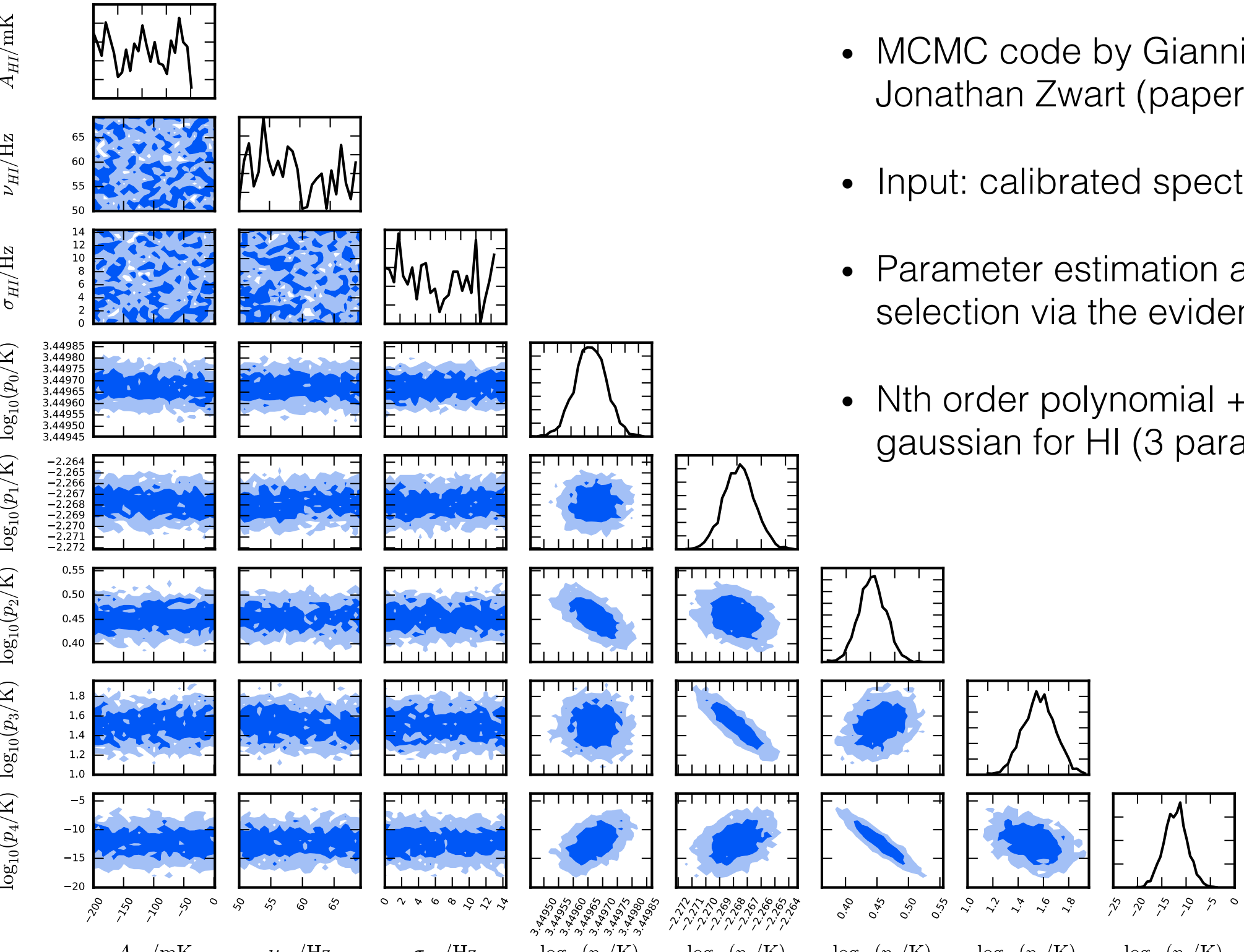


Single antenna (252X), median bandpass over frequency axis removed. Data from Dec 26 2014

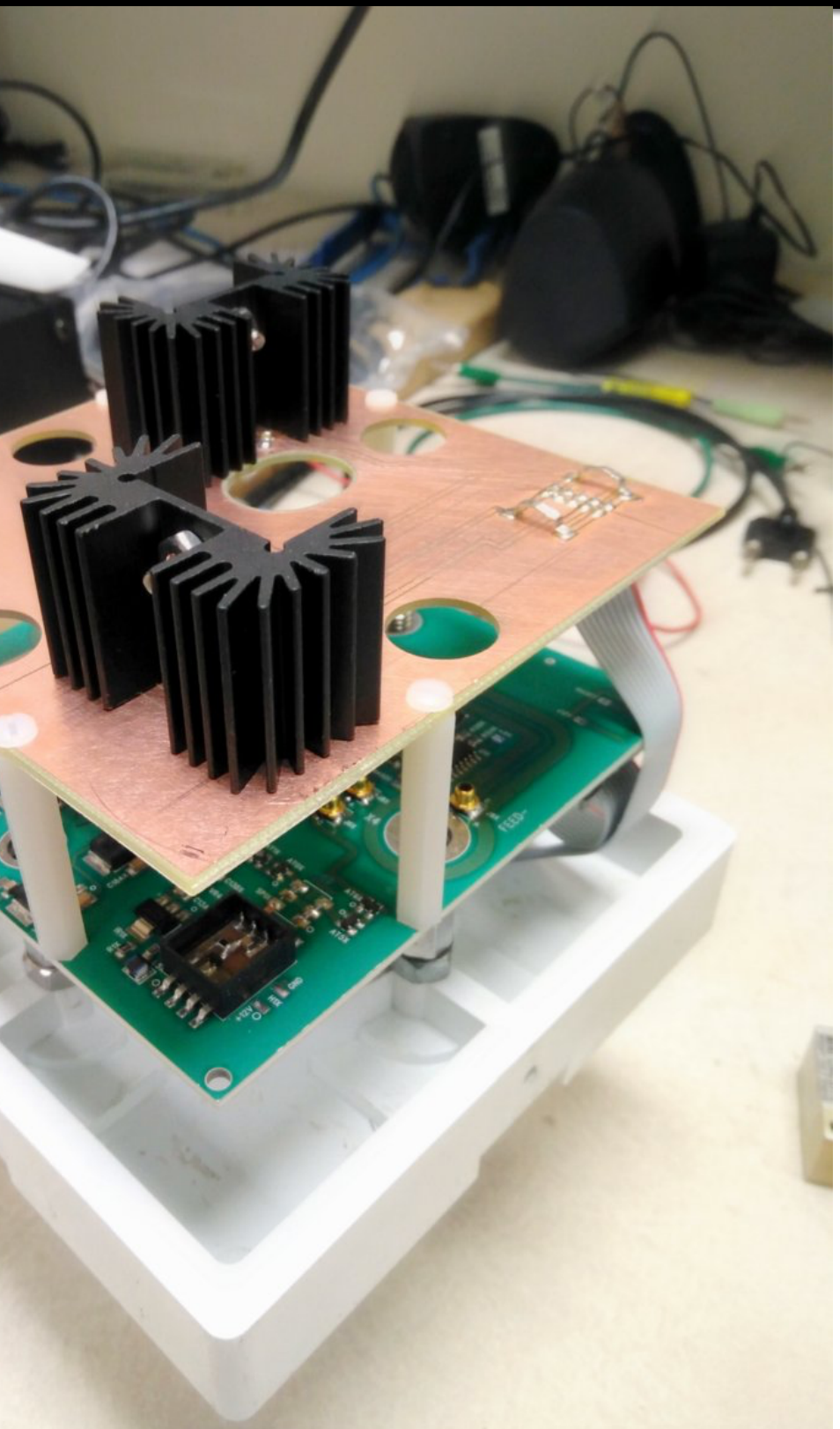


11-14 hrs LST, single antenna, 26-29 Dec 2014

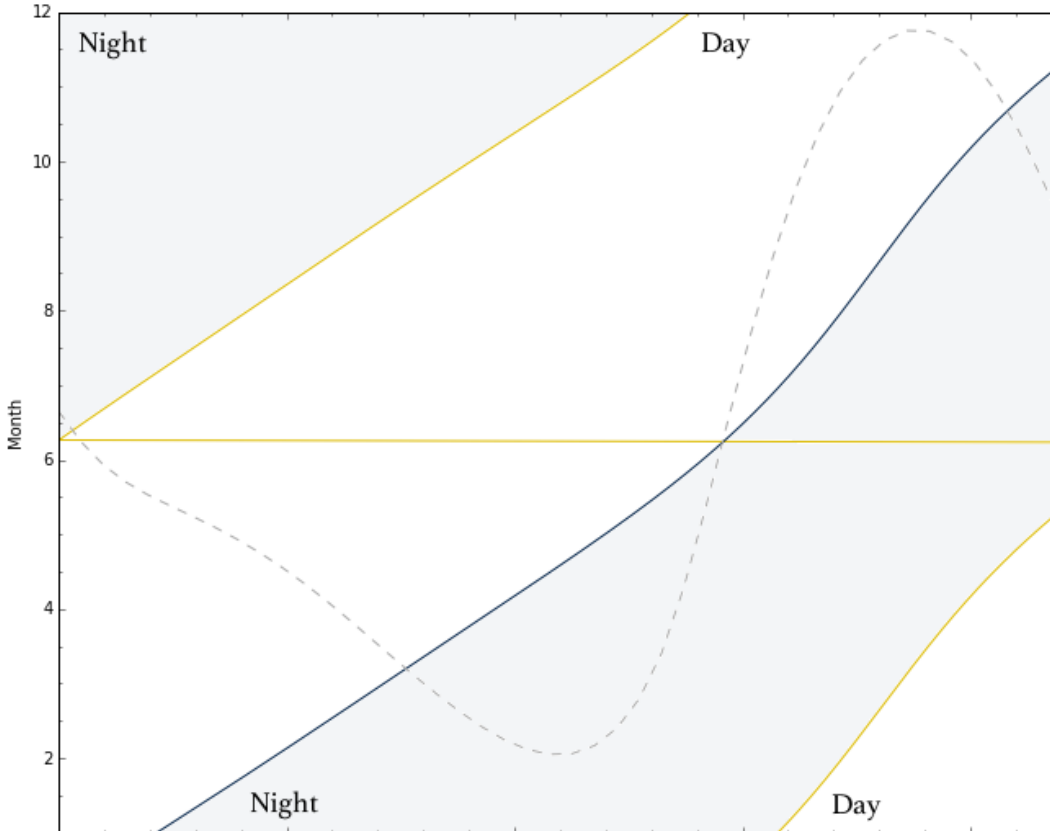
5 order polynomial removed

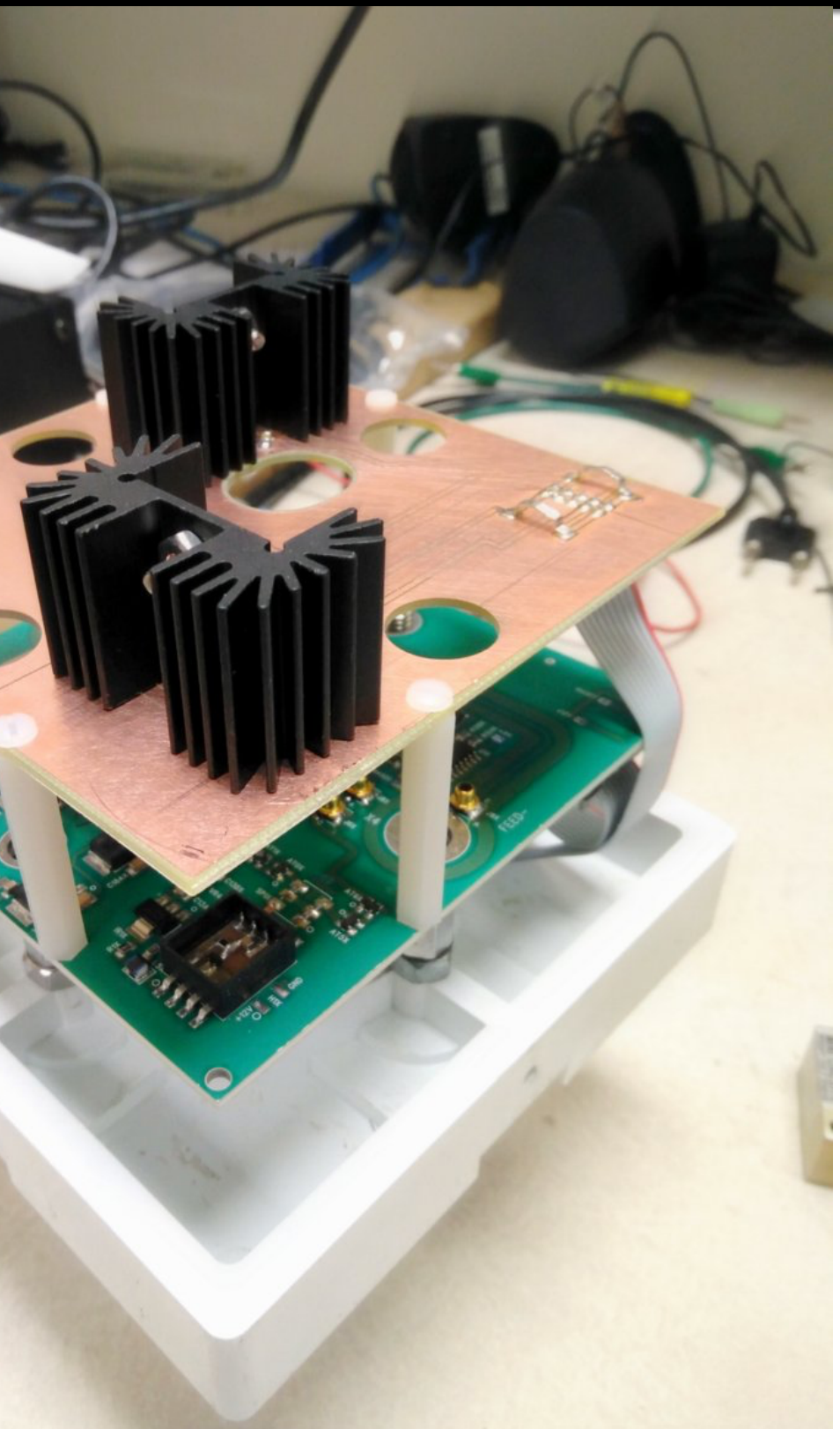


- MCMC code by Gianni Ber
  Jonathan Zwart (paper in p
- Input: calibrated spectrum
- Parameter estimation and m
  selection via the evidence
- Nth order polynomial + inv
  gaussian for HI (3 paramet



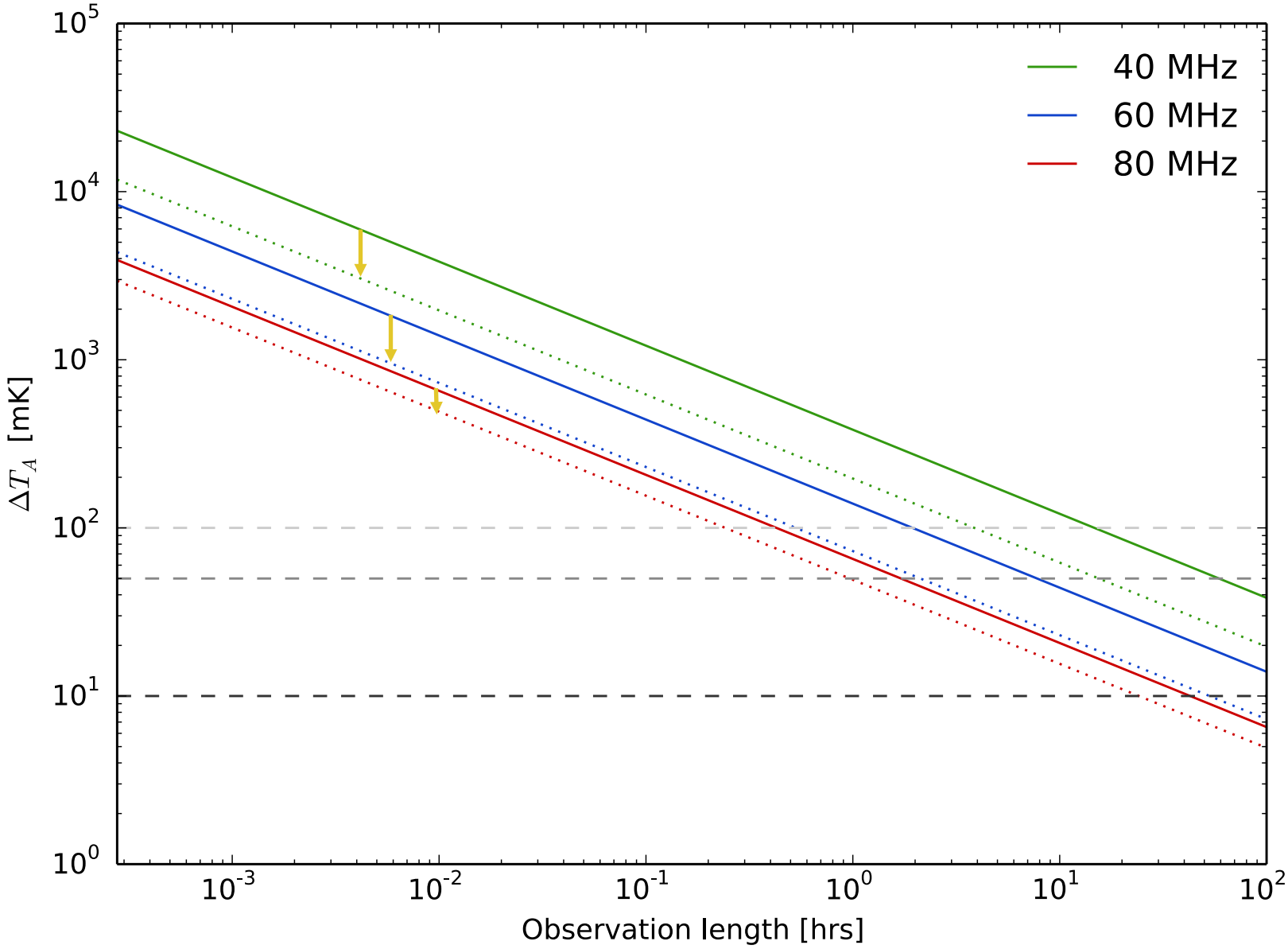
- March-November 2015: developm testing of new radiometer receiver
- 16-20 December 2015: site visit ar instrument upgrades.
- January-April 2016: science obser



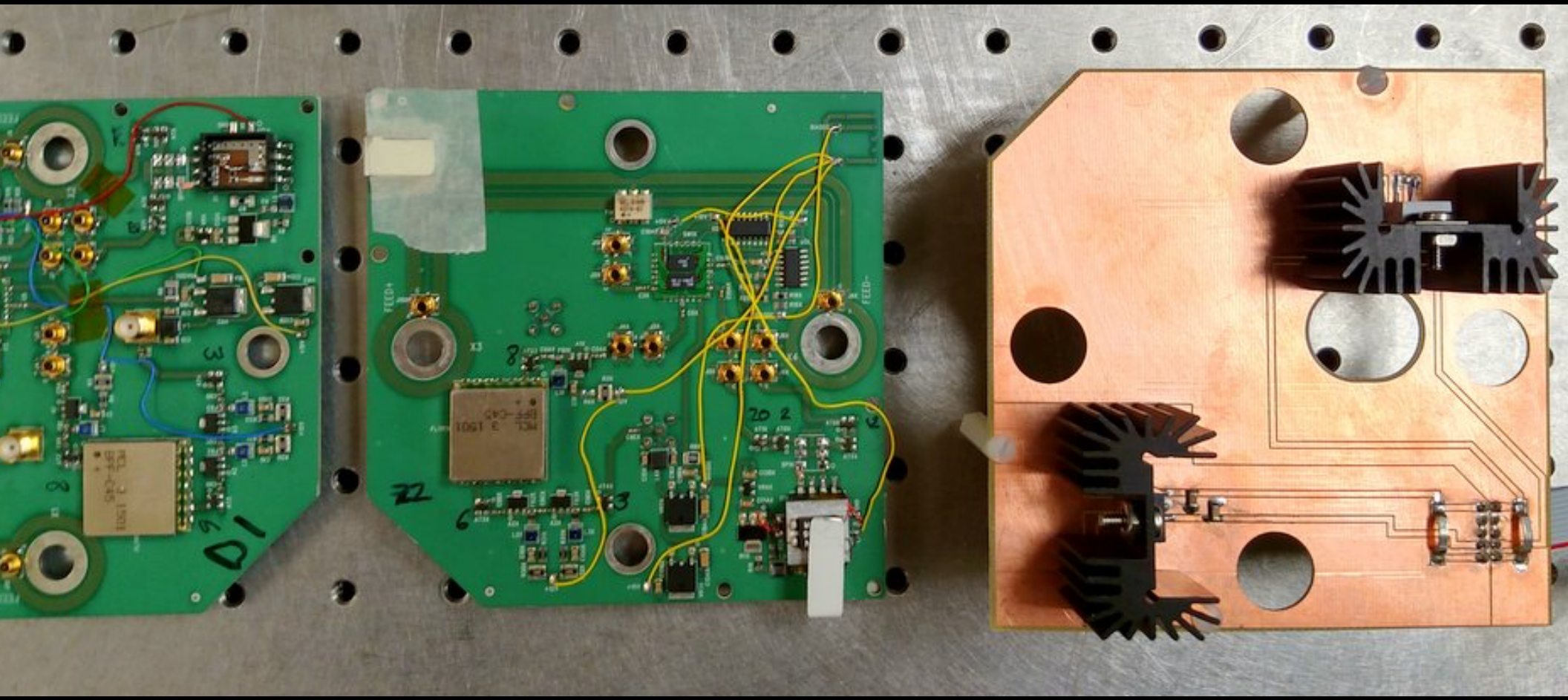


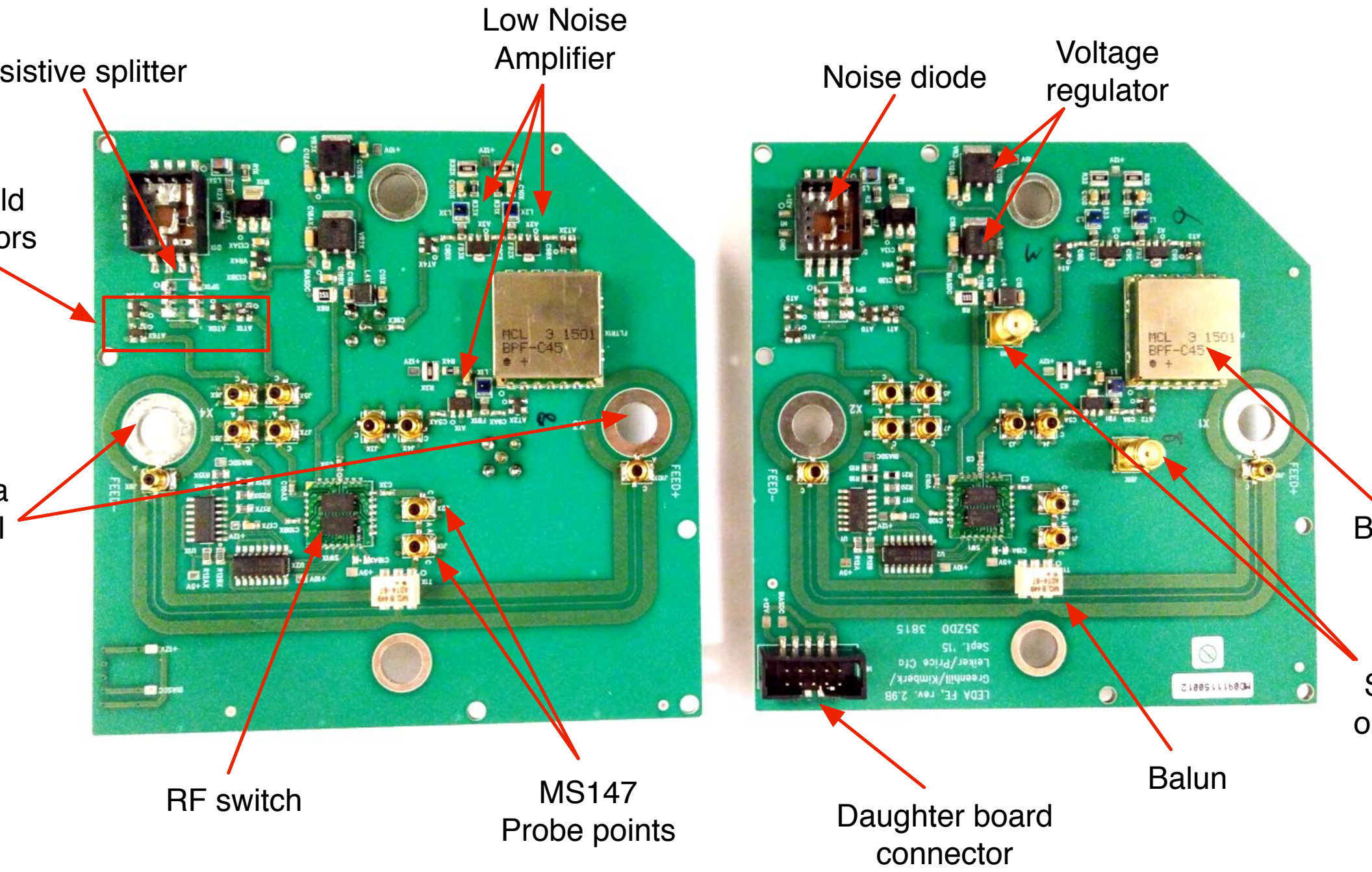
- Hirose MS147 test ports added for measurement of S-parameters (ref coefficients) in the field.
- Swapped low-pass filter for bandpa
- Dual-diode calibration instead of d load (load is << sky temp)
- Improved attenuation between amp stages for better reflection charact
- Well characterized in labs, S-paran measured, thermal stability and alla variance tested & performing admi

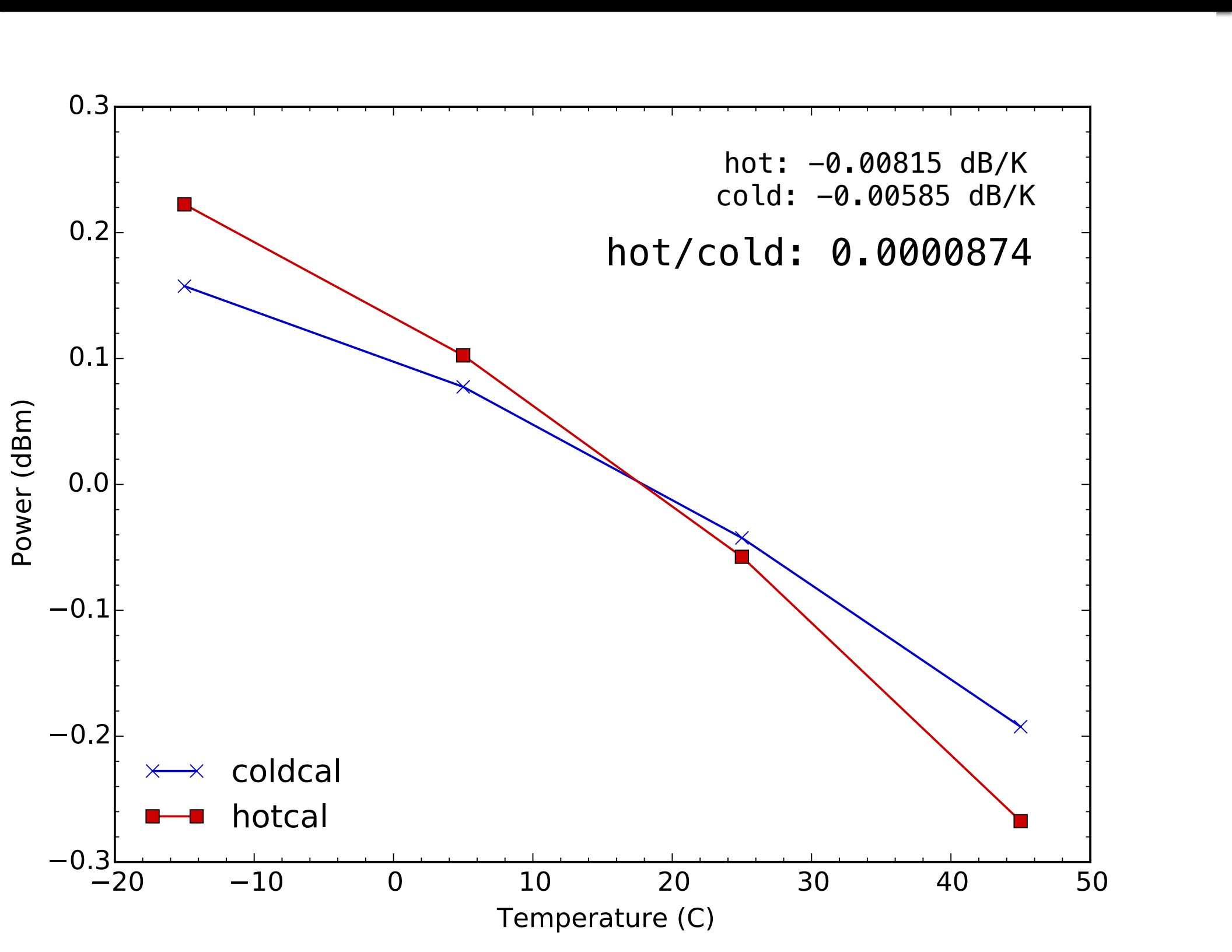
$$dT_A = \frac{T_D}{P_{DLR} - P_{LR}} \sqrt{(dP_{AR}(\nu))^2 + \left(\frac{P_{AR}(\nu) - P_{LR}}{P_{DLR} - P_{LR}}\right)^2 (dP_{DLR})^2 + \left(\frac{P_{AR}(\nu) - P_{DR}}{P_{DLR} - P_{LR}}\right)^2 (dP_{LR})^2}$$

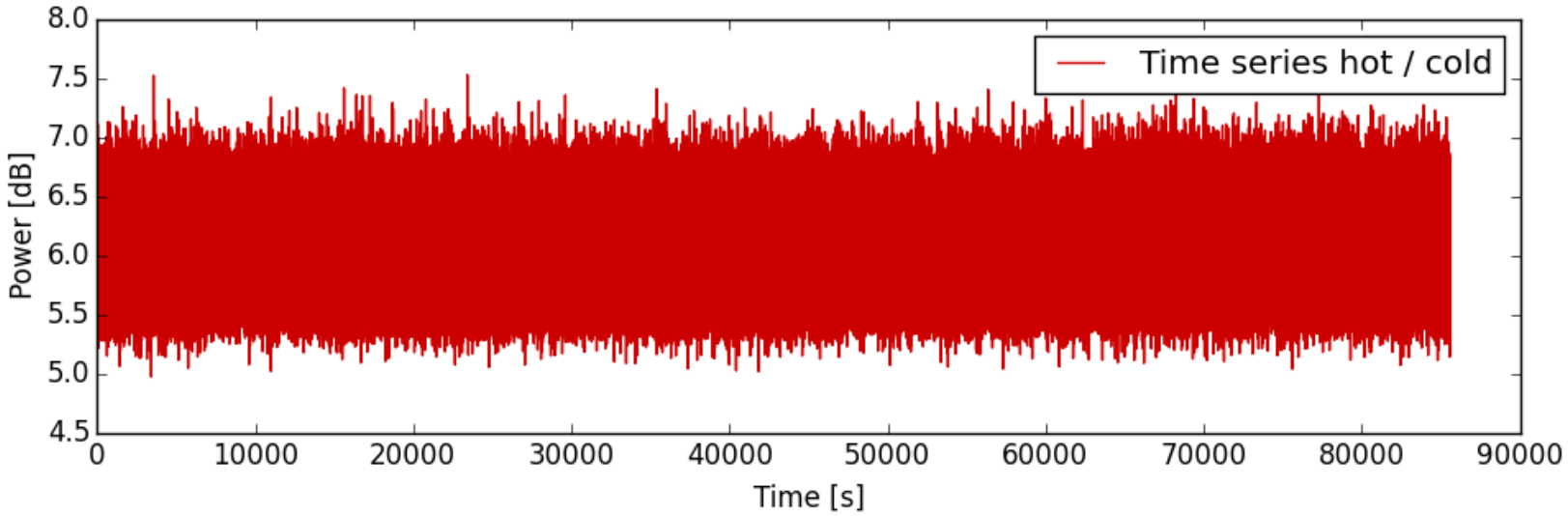


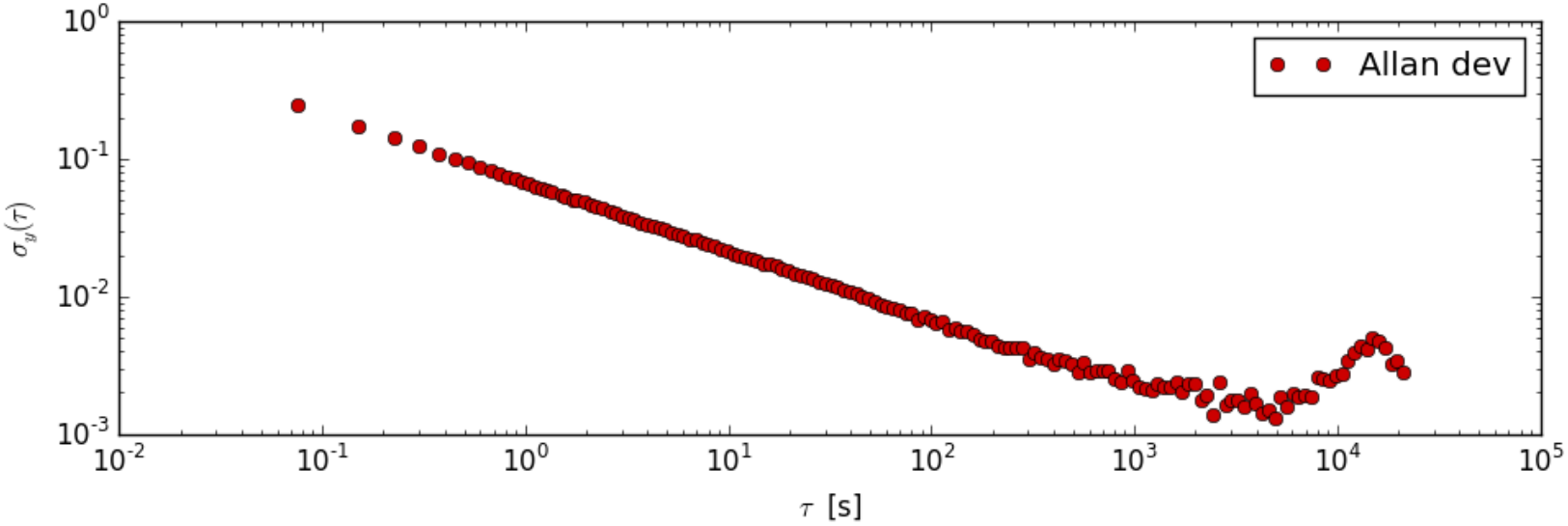
Increasing hot and cold load power increases sensitivity of 3-state calibrated data

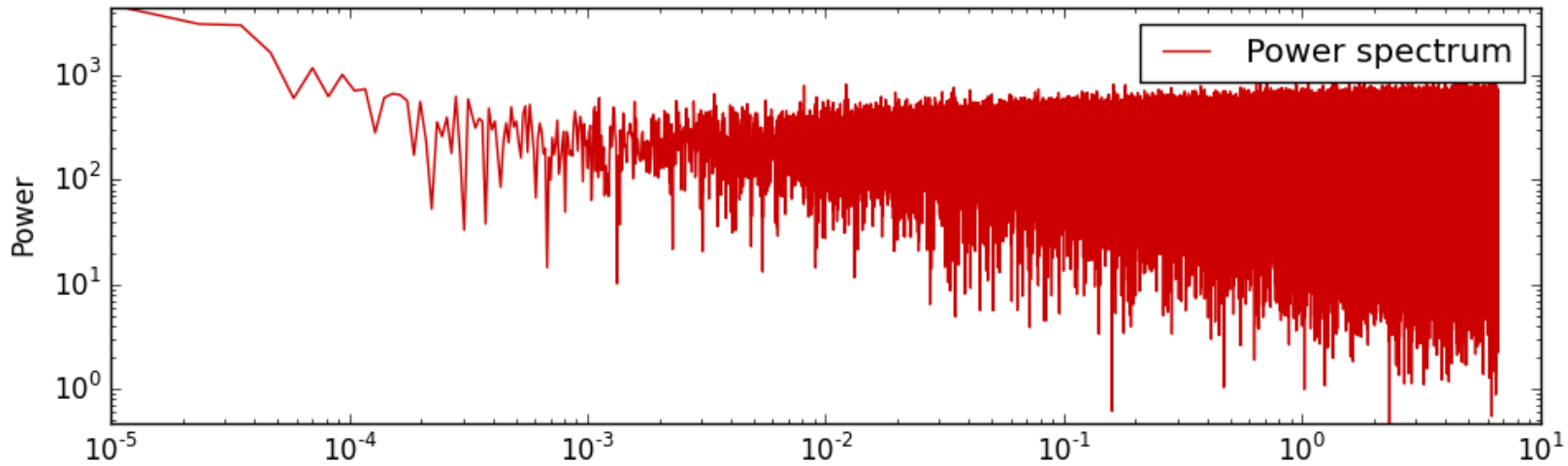

FEED+
FEED-

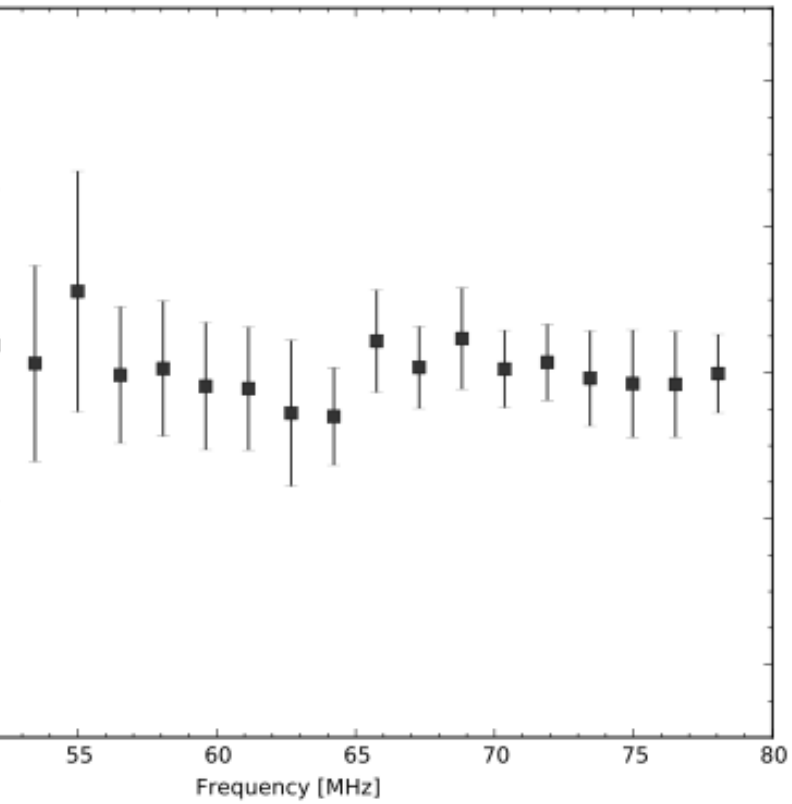

sistive splitter
ld
ors
a
l
Low Noise
Amplifier
Noise diode
Voltage
regulator
B
RF switch
MS147
Probe points
Daughter board
connector
Balun


hot: −0.00815 dB/K
cold: −0.00585 dB/K
hot/cold: 0.0000874
coldcal
hotcal
Power (dBm)
Temperature (C)
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−20
−10
0
10
20
30
40
50


Time series hot / cold
Power [dB]
Time [s]
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
0
10000
20000
30000
40000
50000
60000
70000
80000
90000


Allan dev
$\sigma_y(\tau)$
τ [s]
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
10^4
10^5


Power spectrum
Power
10^3
10^2
10^1
10^0
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1



- Full calibration pipeline for single-anten complete, including MCMC parameter extraction.
- Work under way on next-generation cali pipeline (multi-antenna, ionosphere & b modelling).
- New receiver boards tested, characteriz ready for deployment in a few weeks.
- Winter science observations begin Jan
- Calibration pipeline paper should be co out soon.
- Ask me about post-correlation beamforr

Backup slides

Beamformer / single dish approach

(intensity mapping)

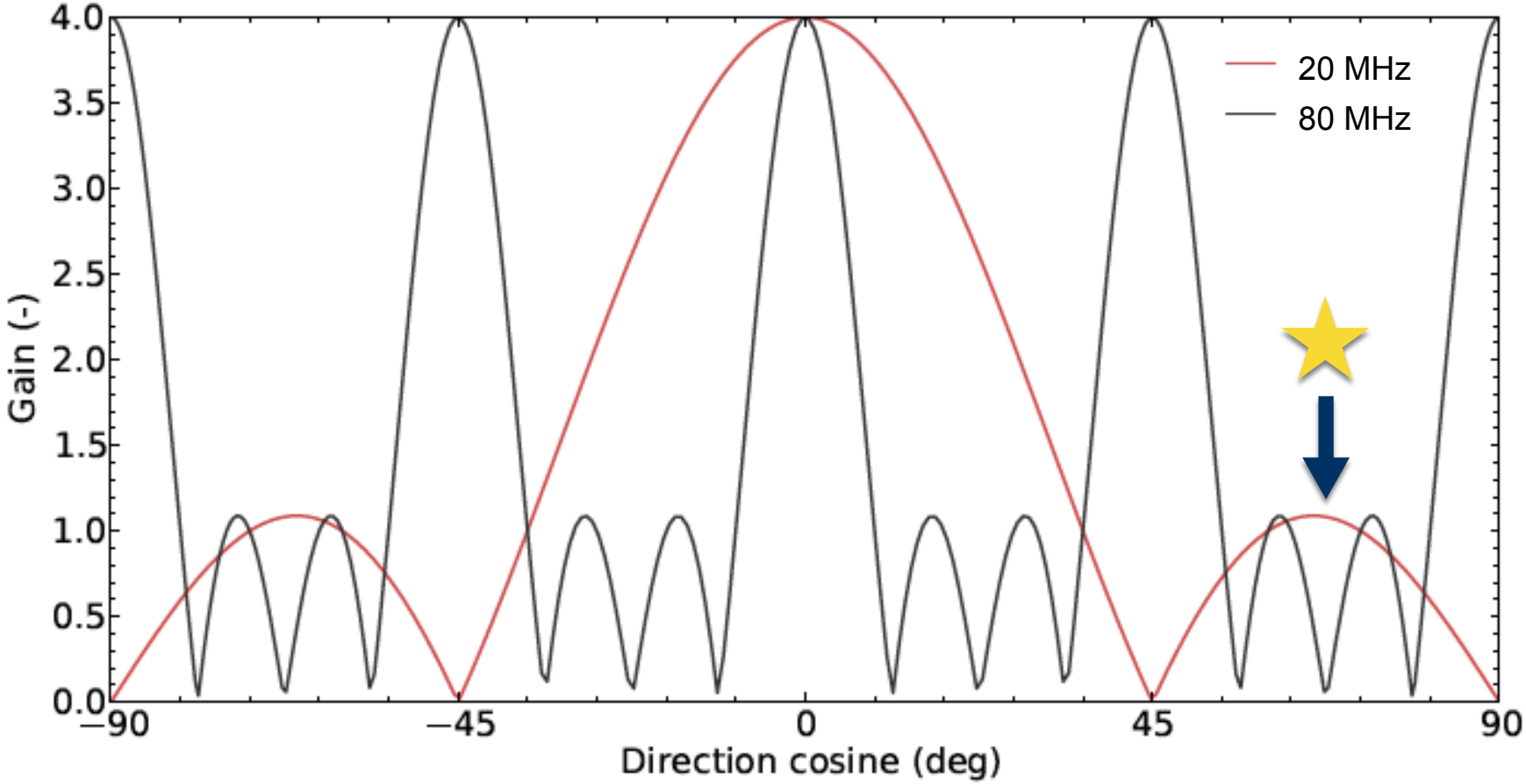
- Instruments *with* angular resolution
  also be used.
  - Single dishes with low-f feeds
    (e.g. Parkes, GBT, Effelsberg, Jodrell)
  - Beamformed low-f arrays
    (LWA, LOFAR, LEDA)

- This approach **is equivalent** to int
  mapping, as proposed for 21cm E
  at lower redshift (e.g. *Pen et. al. 2*

- Collecting area **does not** increase
  thermal sensitivity.

- Angular information is nonetheless
  useful for foreground subtraction.

  See Liu, A., Pritchard, J., Tegmark, M., Loeb, A. (
  Global 21cm signal experiments: a designer's gu
  Phys. Rev. D 87, 043002



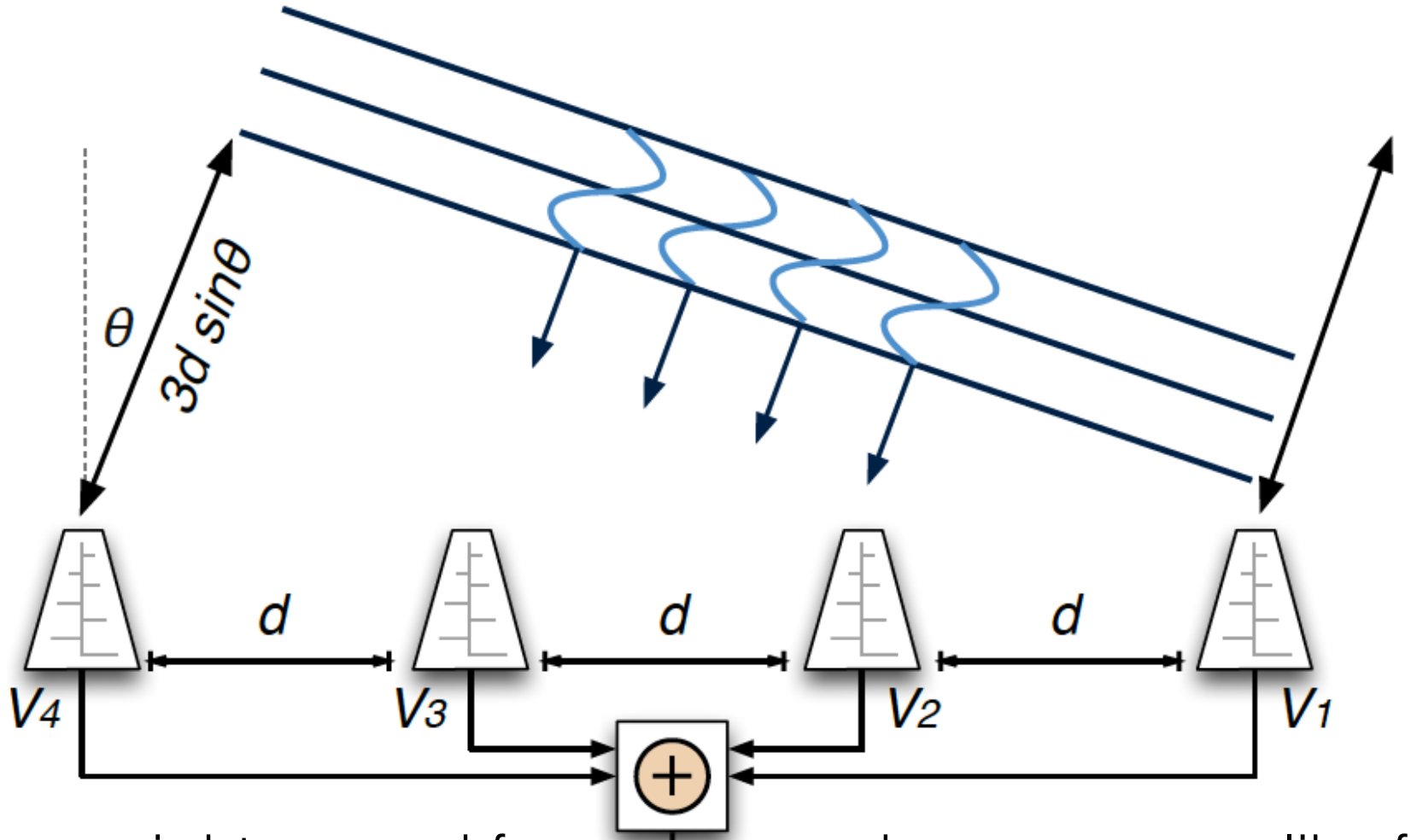
Disadvantage #1: Beam sidelobes are frequency-dependent

Disadvantage #2: Antenna/beam pattern may be harder to model as system is necessarily far more complicated

Disadvantage #3: Large dishes at low-f may have alt-az dependent response (K. Bannister, personal comm.)

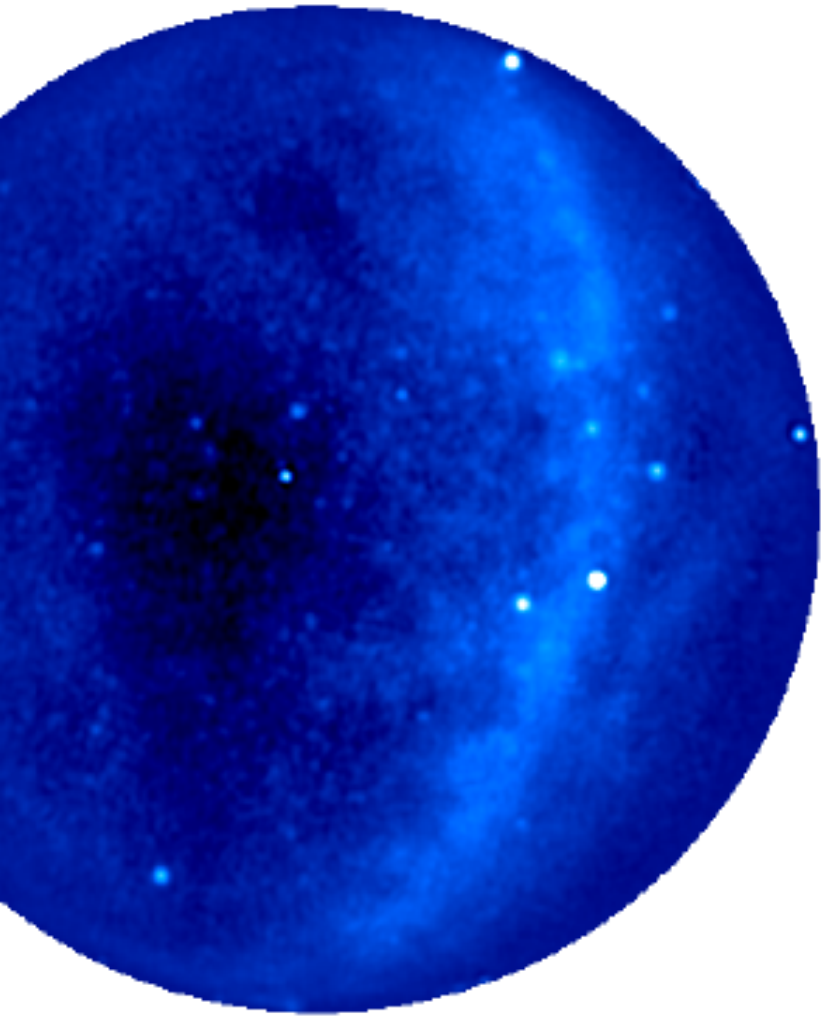
A voltage beam is given by:

$$b(t) = \mathbf{w}^H \mathbf{v}(t)$$

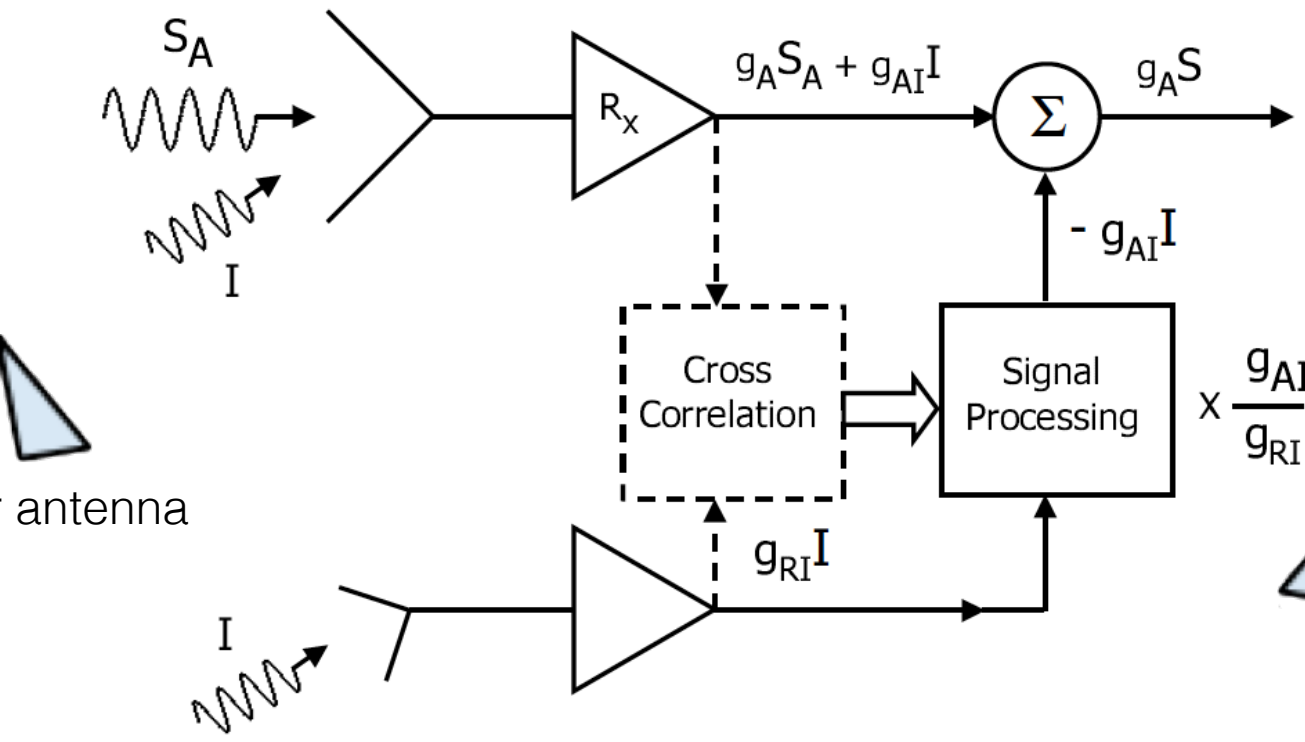


Choose weights **w** and form as many beams as you like from **V**

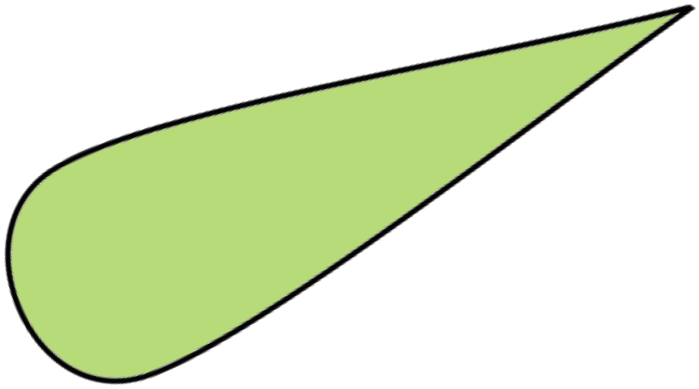
$$w_1V_1 + w_2V_2 + w_3V_3 + w_4V_4$$

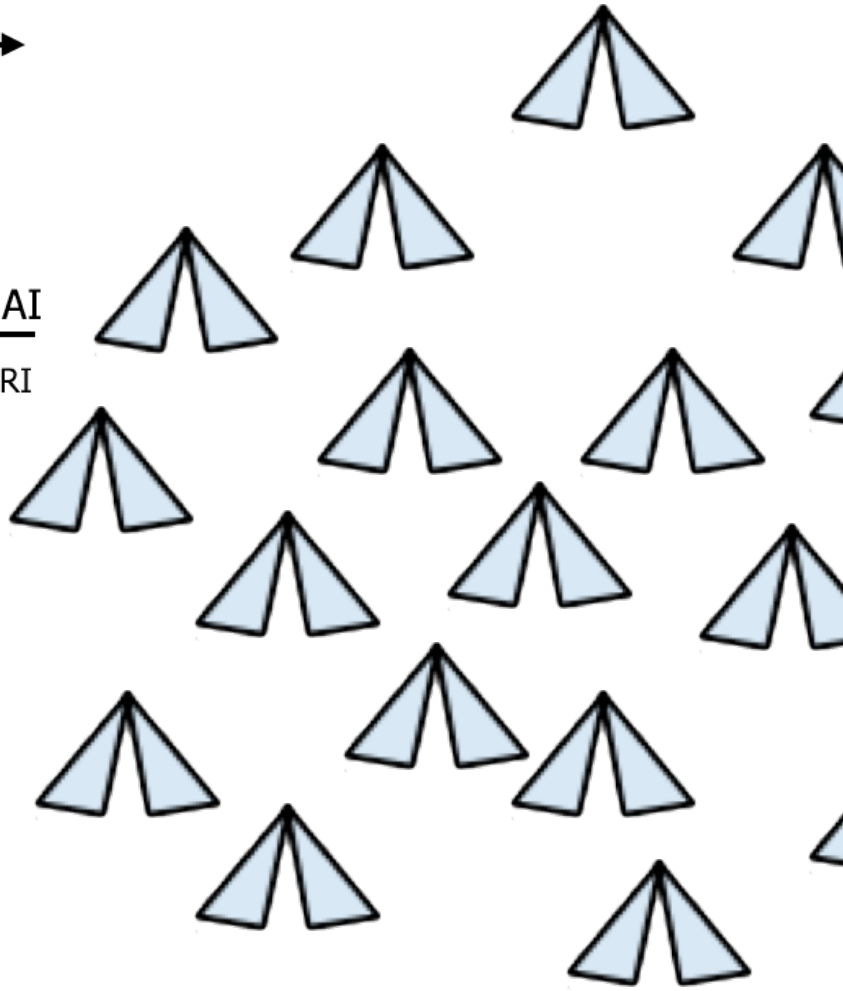


- A post-correlation beamformer may form multiple beams on the sk
- If regularly gridded, the beams for an image.
- This approach may provide good calibration via continuous compari known sources (e.g. Cas A, Cyg A
- We are investigating this as an alternative approach for LEDA



antenna





antenna core

Interferometric approach

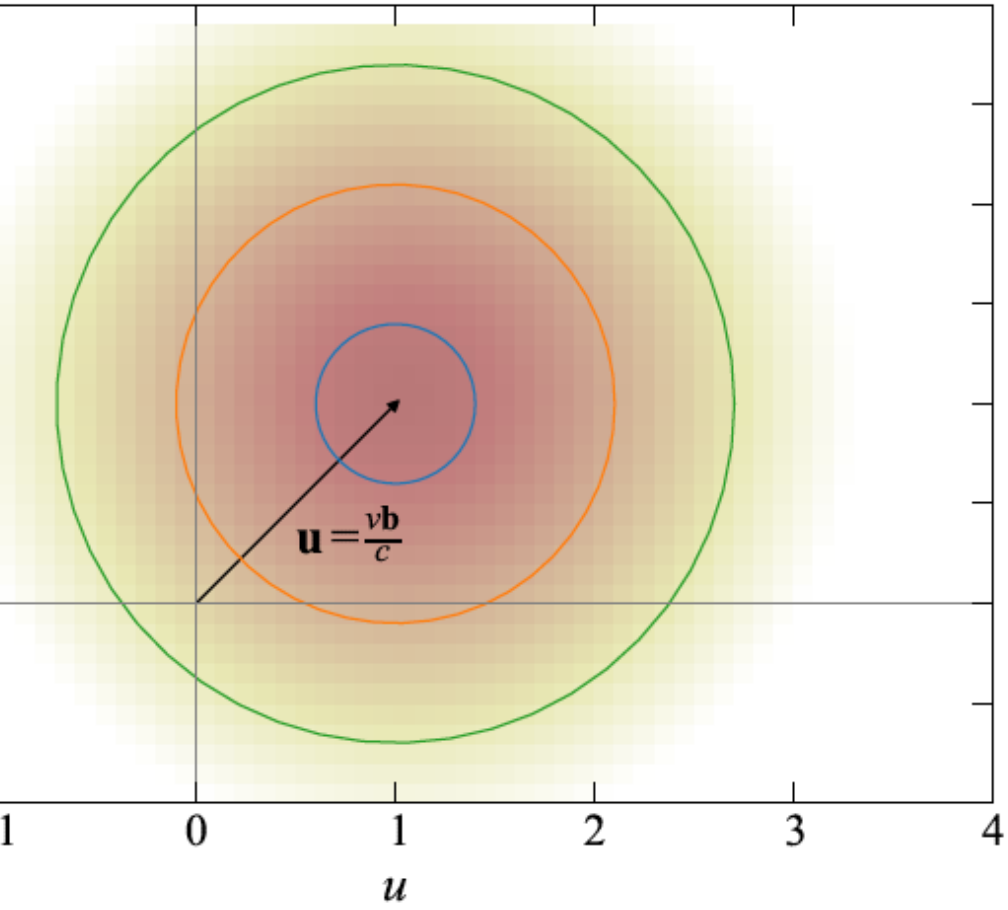
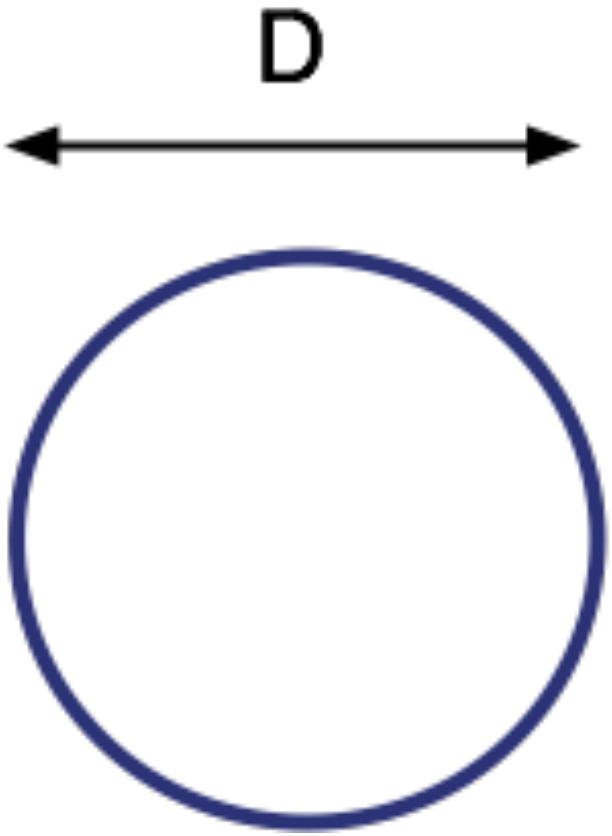


Image: Presley et. al. (2015)

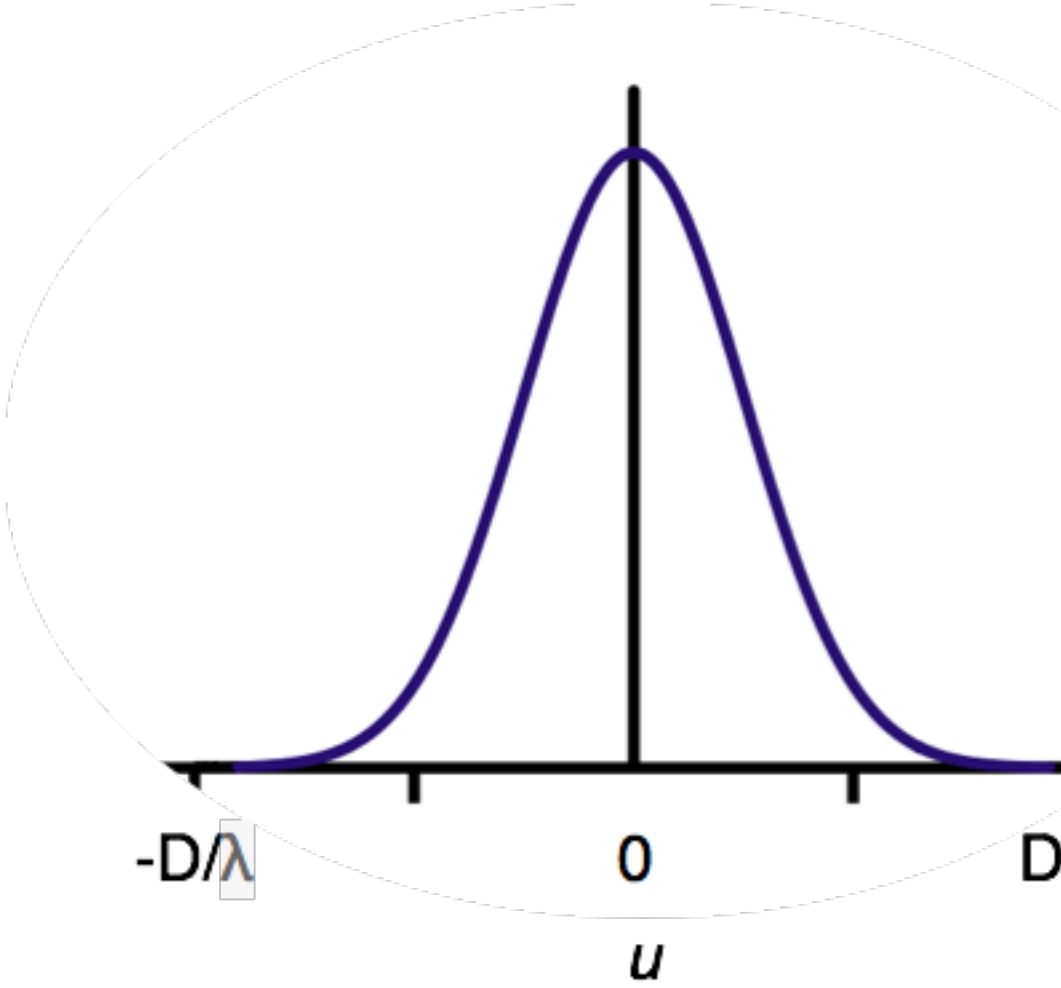
- Presley et. al. (2015) suggest tha densely-packed interferometers sensitive to the monopole signal
  M. Presley, A. Liu, and A. Parsons, "Measuri Cosmological 21 cm Monopole with an Interferometer," submitted to ApJ.

- Vedantham (2014) used a lunar occultation trick with LOFAR, bu limited by systematics.
  H. K. Vedantham, L. V. E. Koopmans, A. G. Bruyn,et. al. *"Lunar occultation of the diffuse LOFAR measurements between 35 and 80 M* MNRAS, 450 2291-2305 2015.

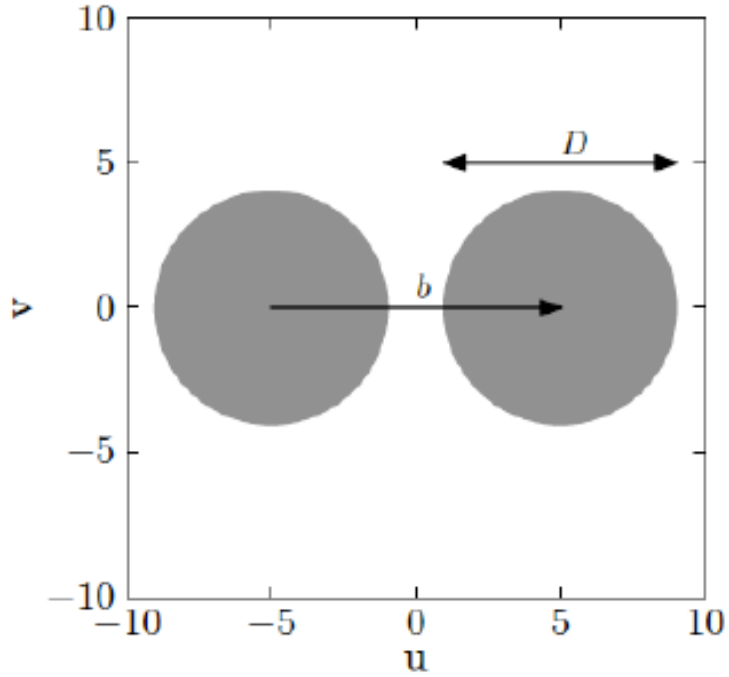
- LEDA has short baselines, so we be able to use the Presley et. al. technique.

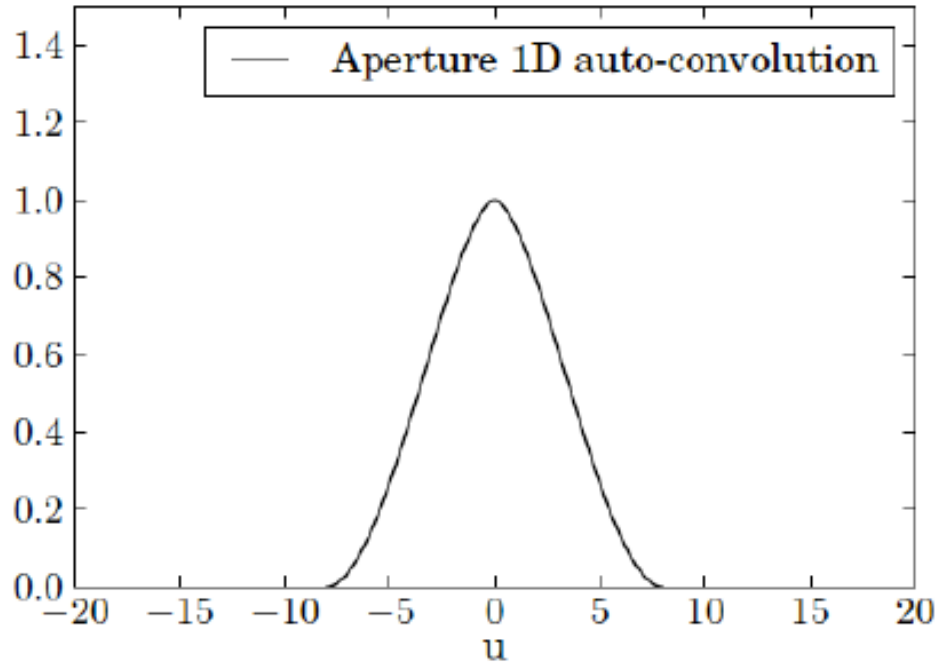


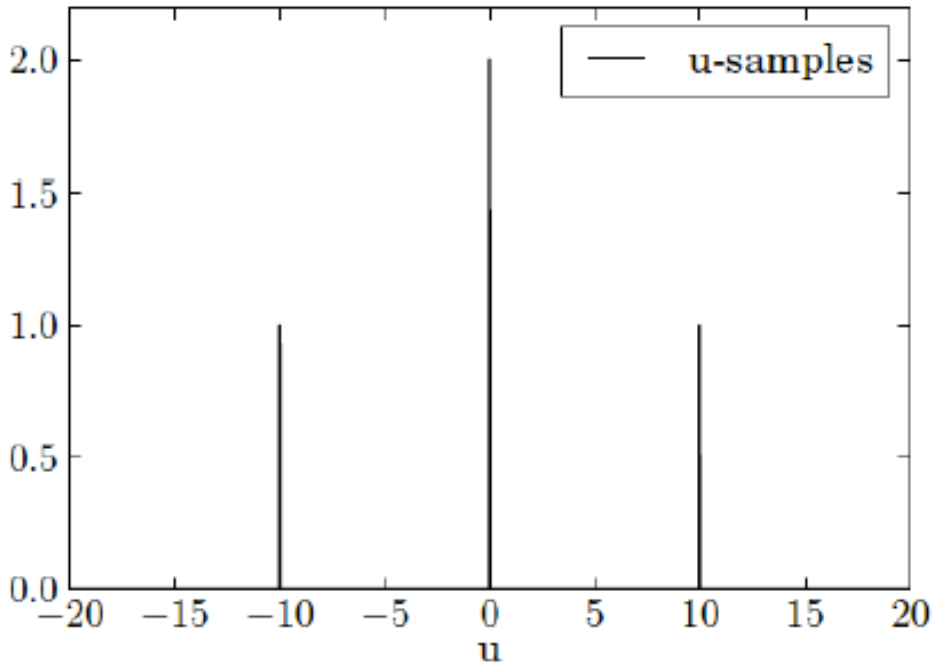
Antenna aperture



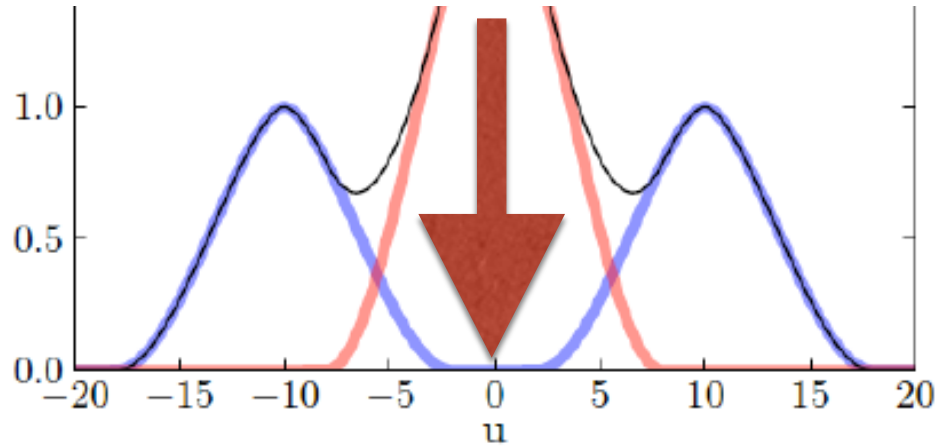
Window in Fourier spa



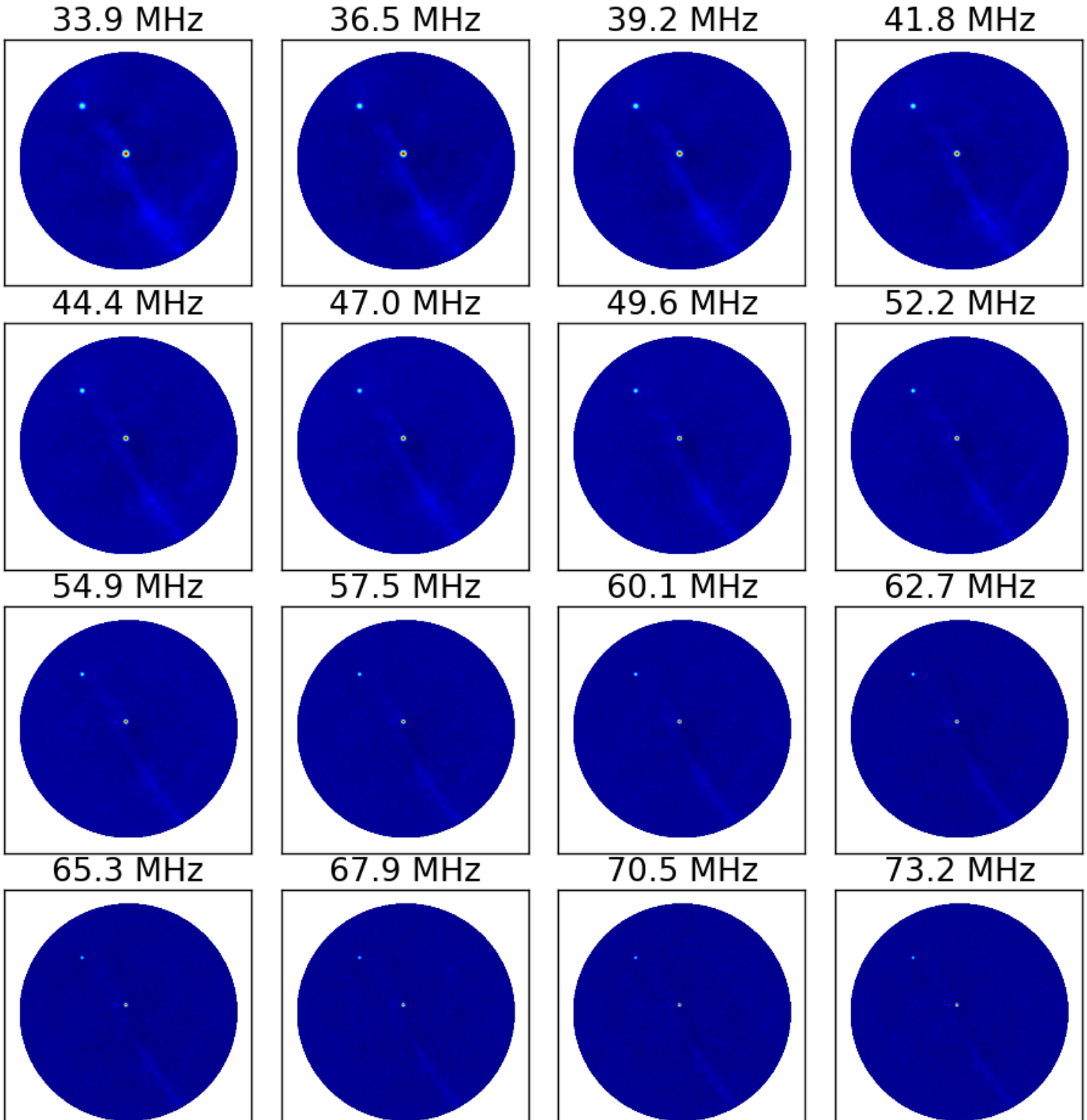


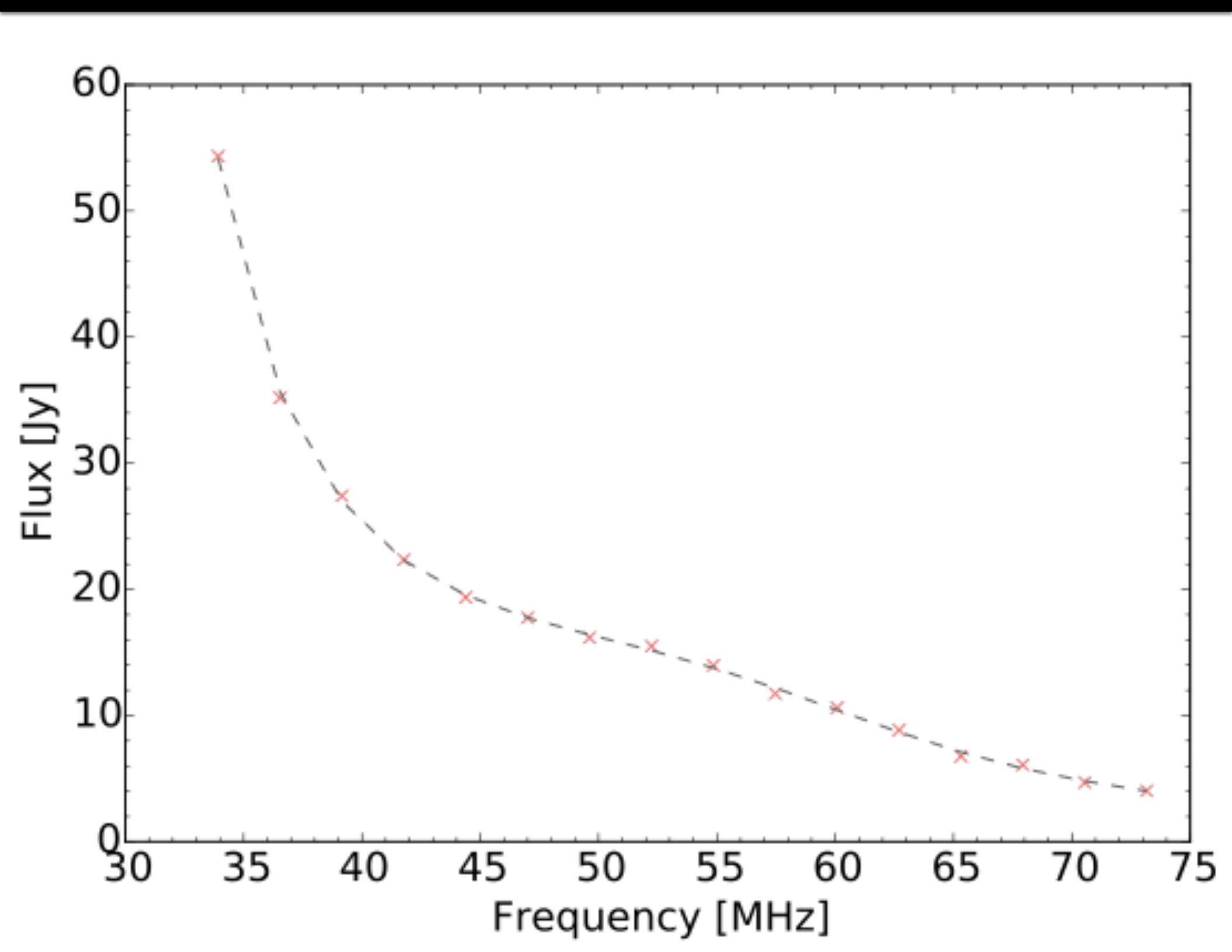


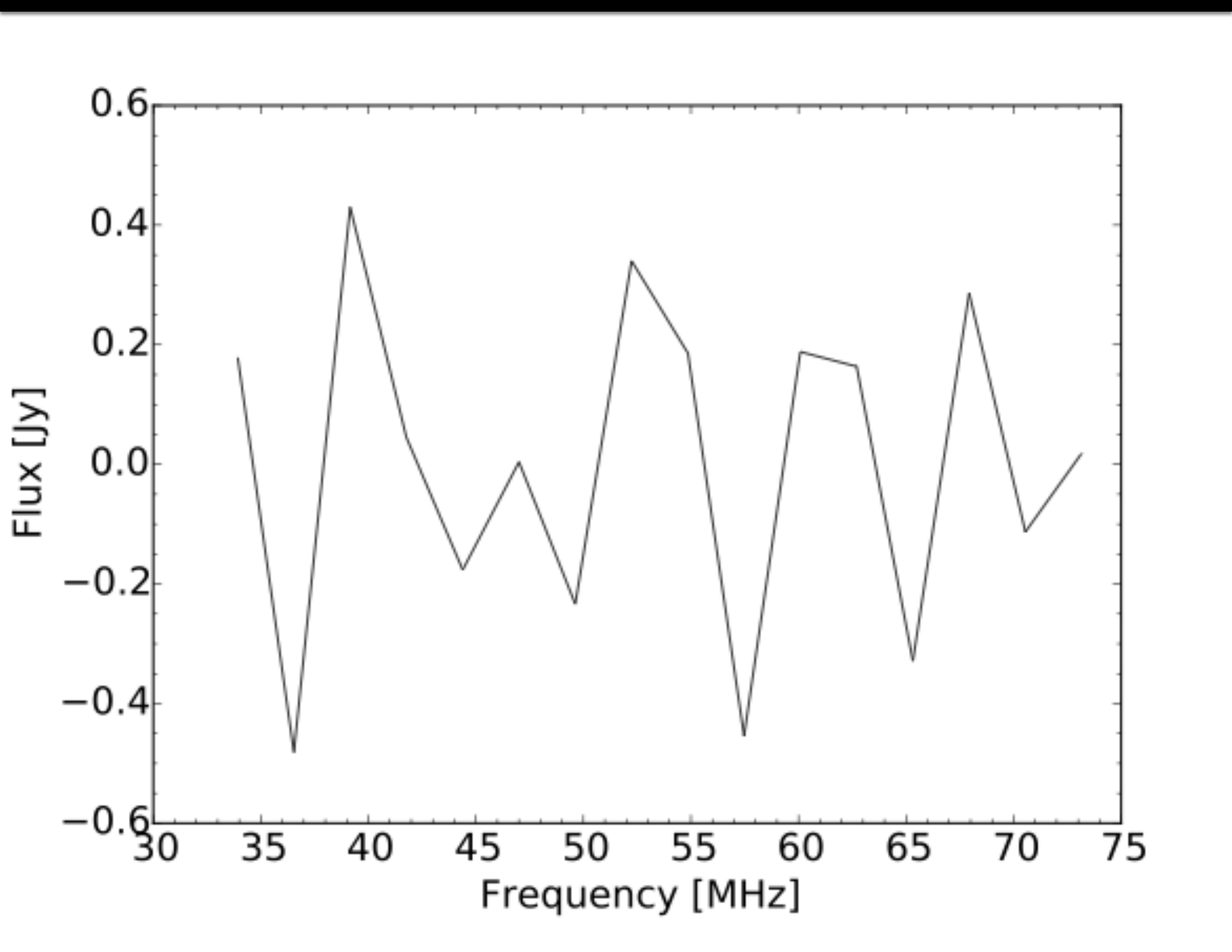
Q. Are the blue lines zero



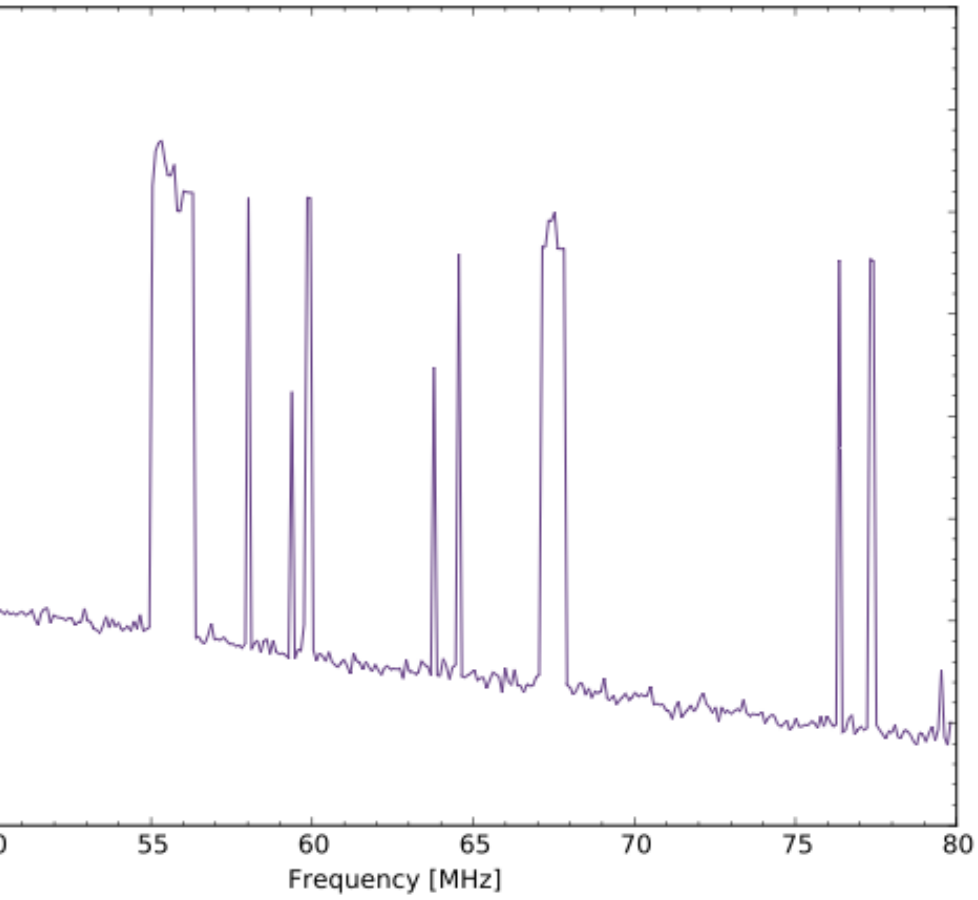
rice et. al., “Optimal Partitioning of SKA-Low Antenna Elements”, SKA Memo 150, 201

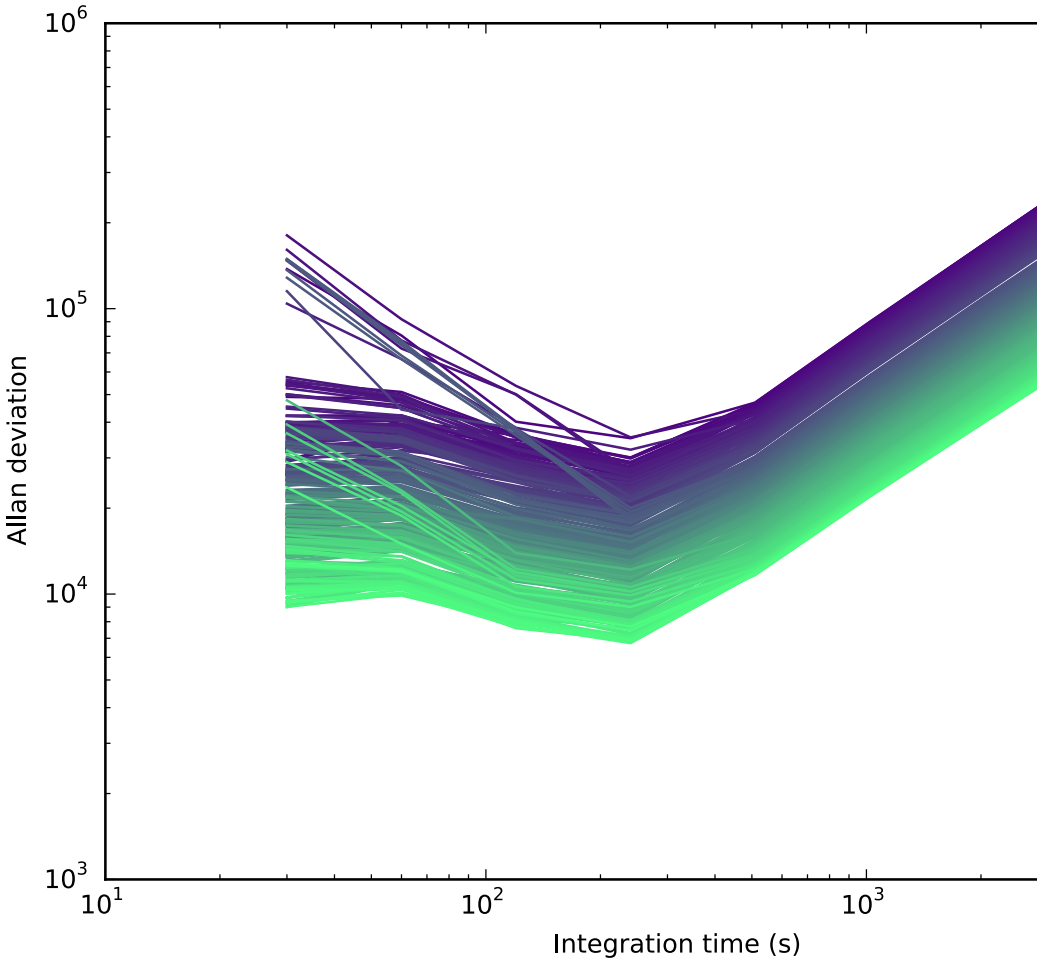

33.9 MHz
36.5 MHz
39.2 MHz
41.8 MHz
44.4 MHz
47.0 MHz
49.6 MHz
52.2 MHz
54.9 MHz
57.5 MHz
60.1 MHz
62.7 MHz
65.3 MHz
67.9 MHz
70.5 MHz
73.2 MHz

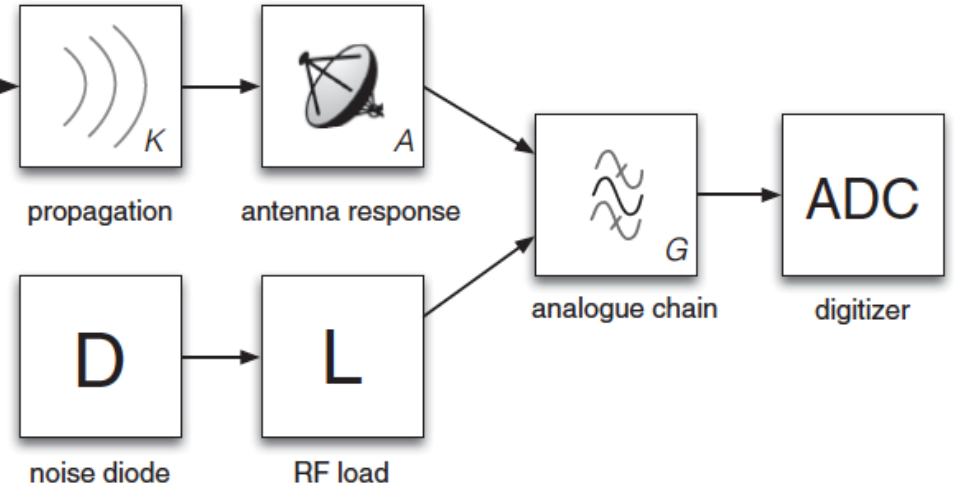

60
50
40
30
20
10
0
Flux [Jy]
30
35
40
45
50
55
60
65
70
75
Frequency [MHz]


0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Flux [Jy]
30
35
40
45
50
55
60
65
70
75
Frequency [MHz]

Calibration slides


55
60
65
70
75
80
Frequency [MHz]


10^6
10^5
10^4
10^3
Allan deviation
10^1
10^2
10^3
Integration time (s)



$$P_{ant} = Gk_B\Delta\nu(T_{ant} + T_{rx})$$

$$P_{load} = Gk_B\Delta\nu(T_{load} + T_{rx})$$

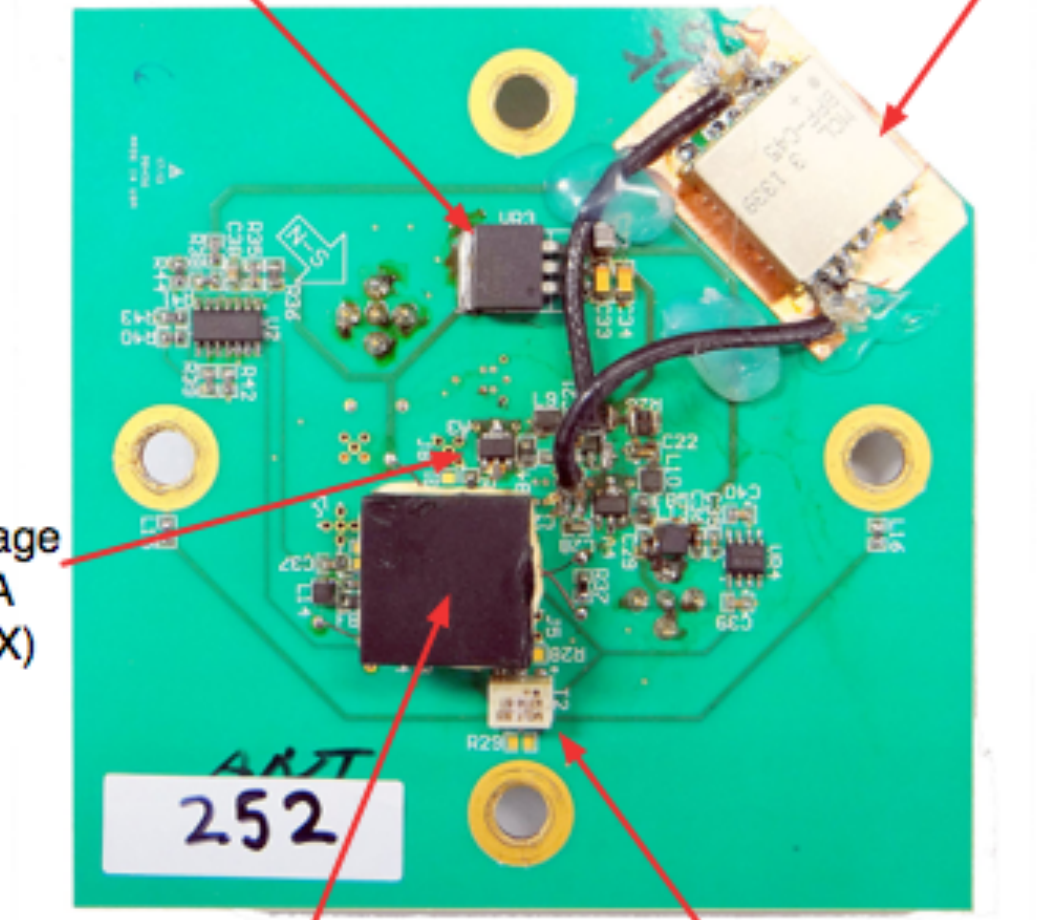
$$P_{diode} = Gk_B\Delta\nu(T_{diode} + T_{load}$$

Measure in lab

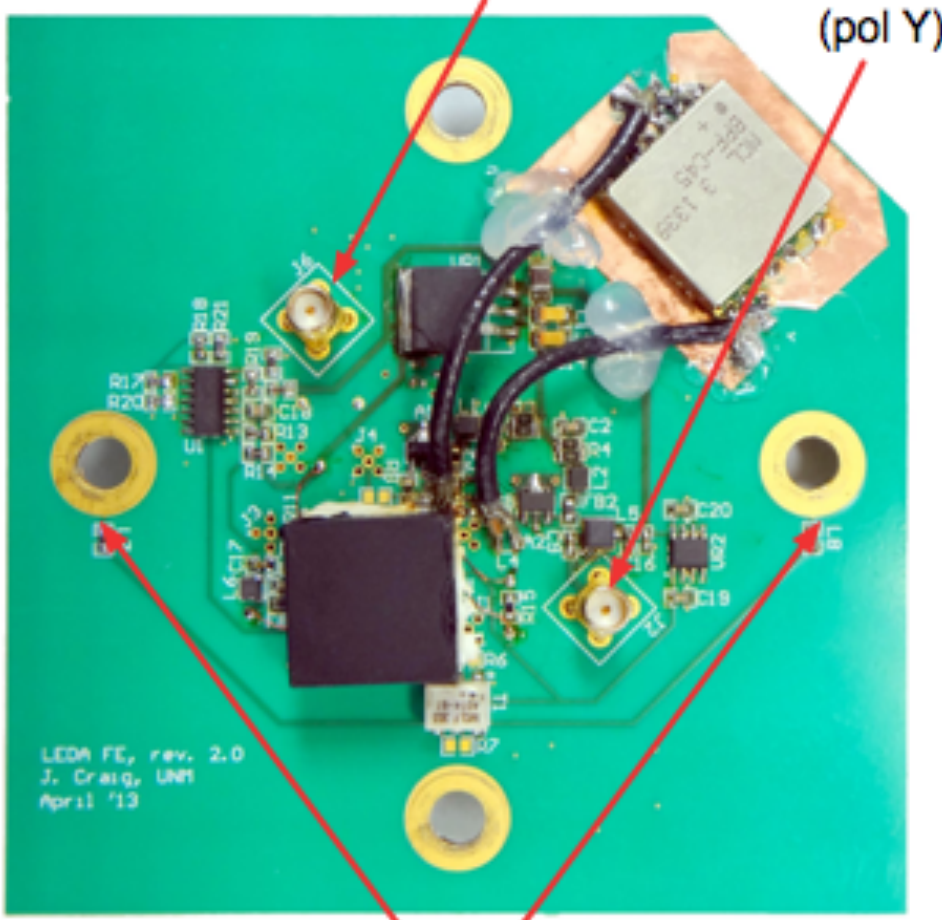
$$T_{ant} = T_{diode}\frac{P_{ant} - P_{load}}{P_{diode} - P_{load}} + T_{load}$$

$$T_{ant} = T_{sky}(1 - |\Gamma|^2)$$

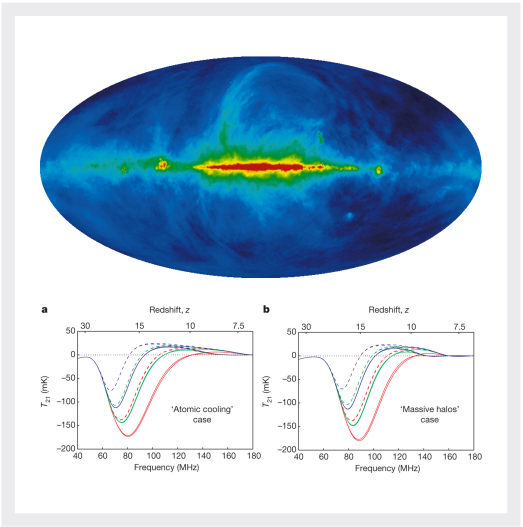
Top view



Bottom view

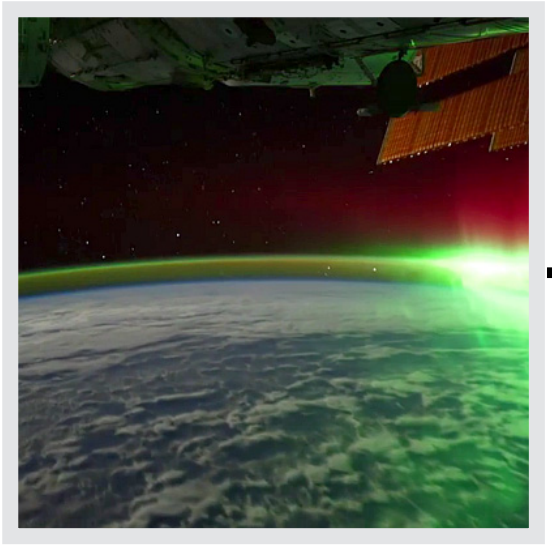


LEDA - Calibration strategy



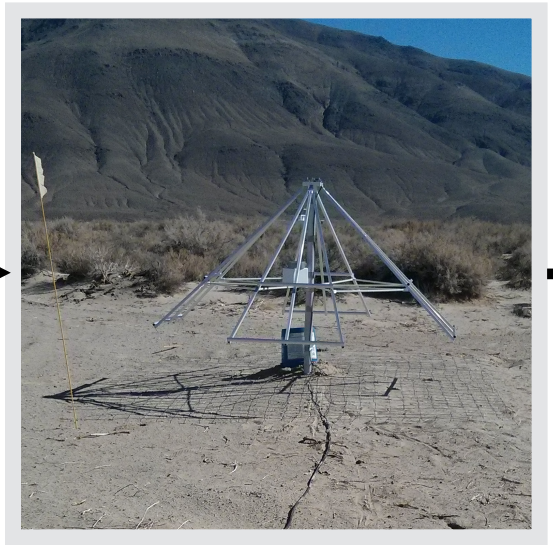
SKY

Sky brightness



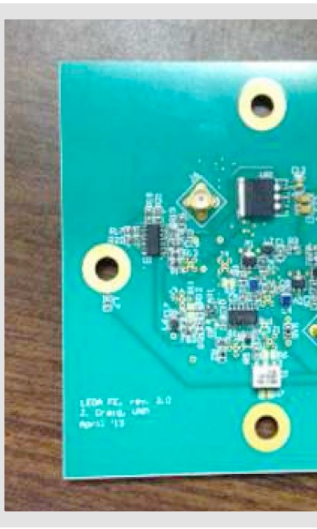
ION

Ionosphere



ANT

Antenna



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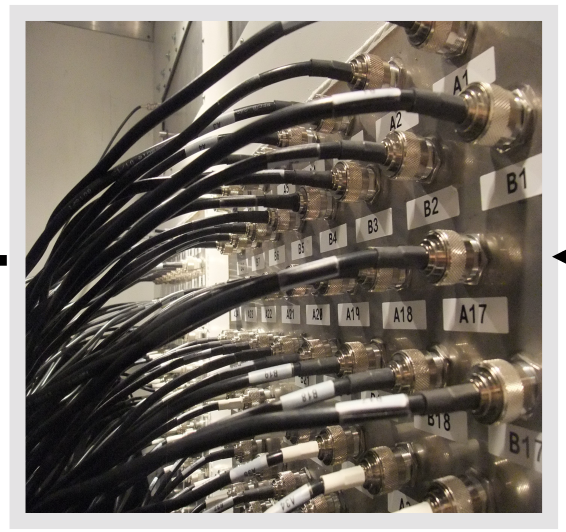
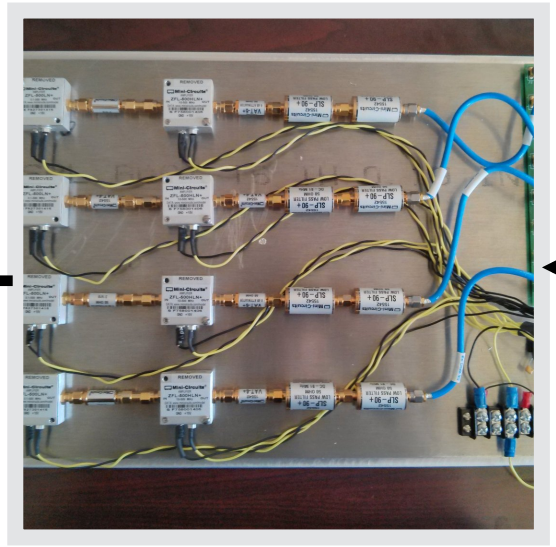
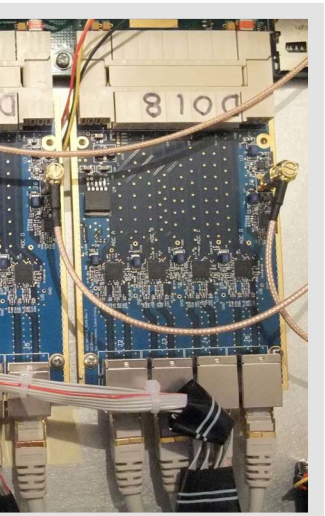


COAX

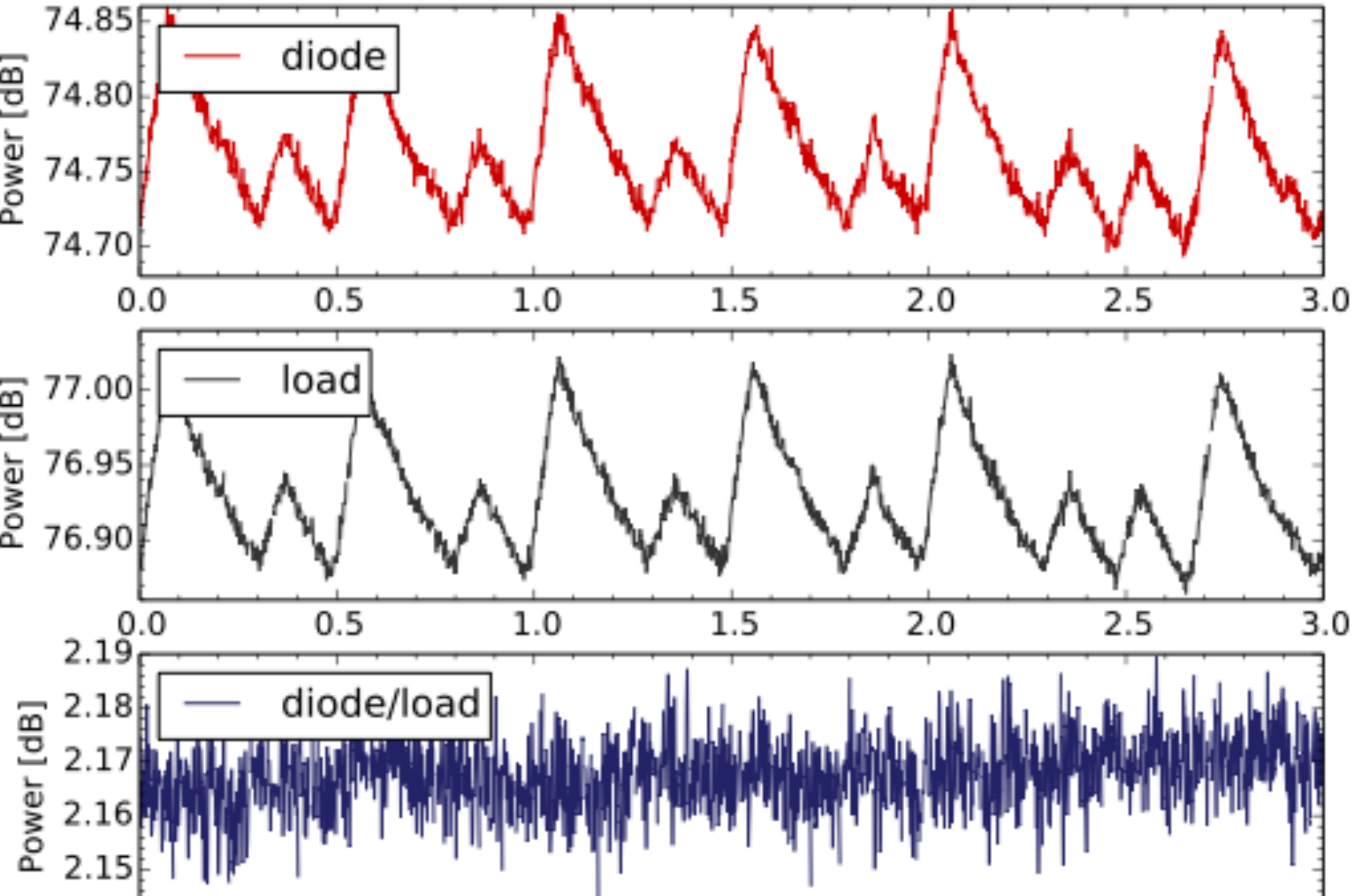


CRX



QC-16

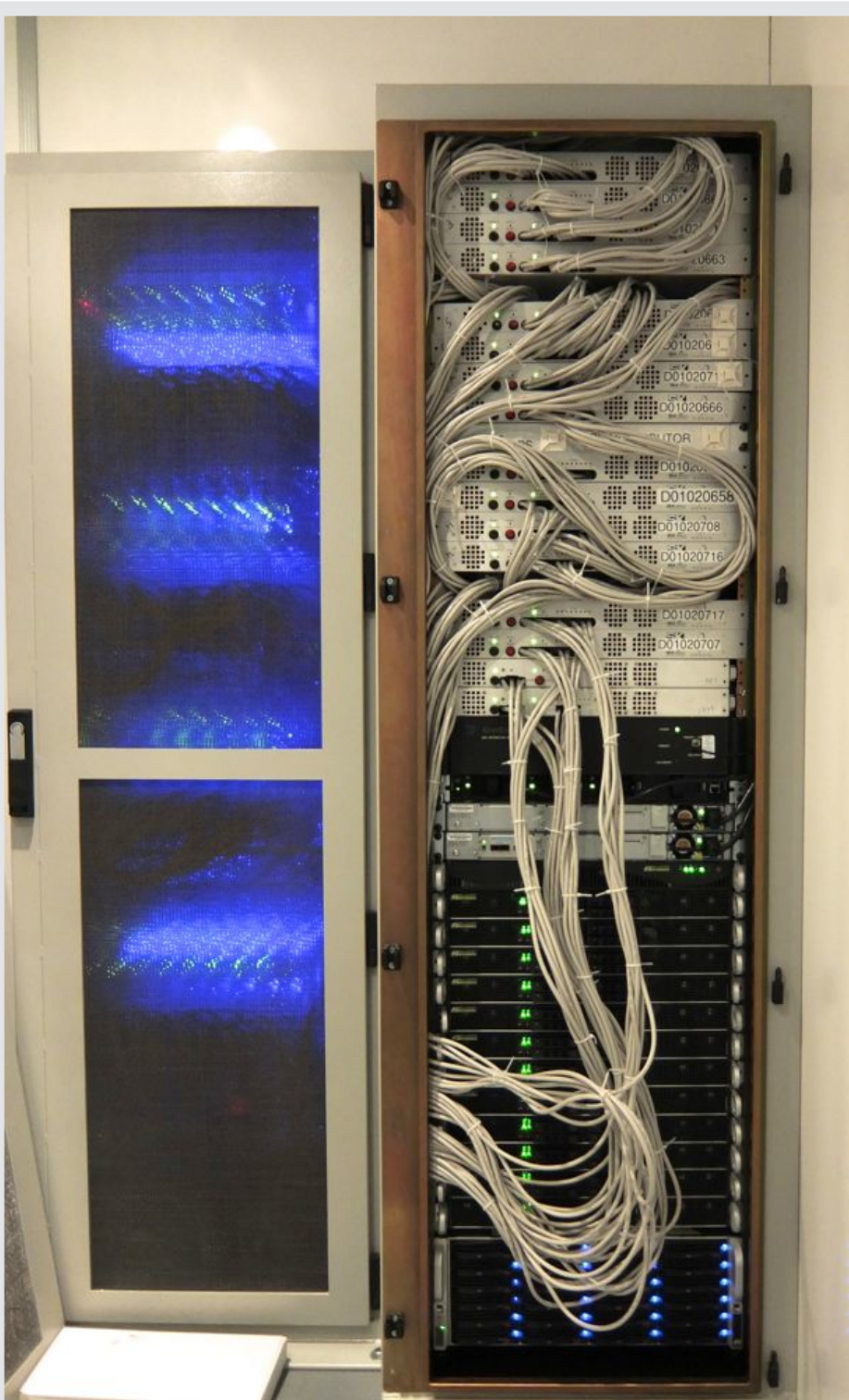
LEDA - Airconditioning switching



Correlator slides

LEDA-512 Correlator

orrelator	N	B (MHz)	N^2B (GHz)
ALMA	66	8000	34800
CHIME	256	400	26206
eVLA	27	8000	5830
LEDA	**288**	**58**	**4810**
CARMA	23	4000	2120
PAPER	128	30	819
MWA	128	30	492
SMA	8	32	256
pdBI	288	1	829
RTFAAC	288	1	829
LOFAR	48	32	737



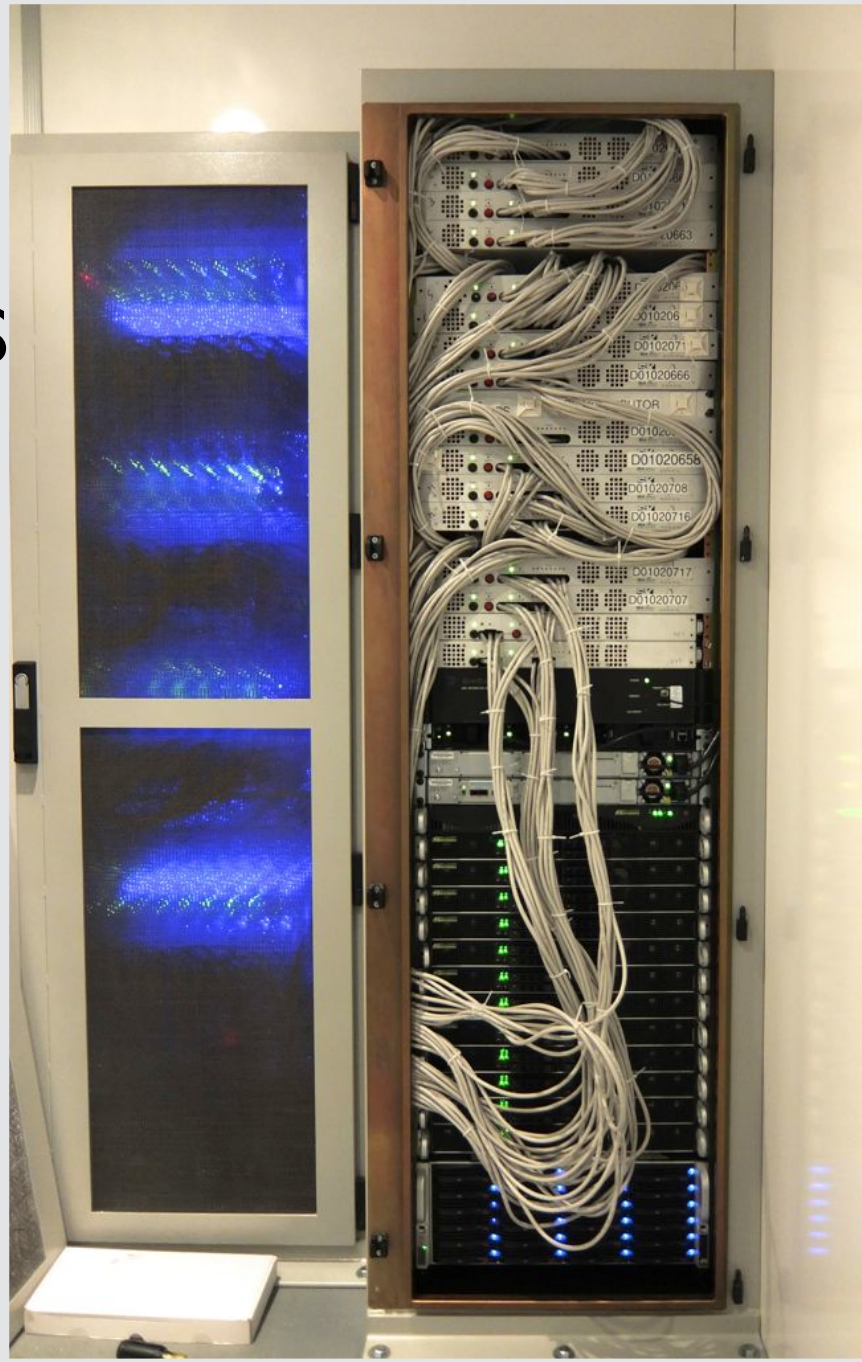
LEDA-512 Correlator

ELERATING RADIO ASTRONOMY
SS-CORRELATION WITH GRAPHICS
CESSING UNITS

LARK, P. C. LA PLANTE, L. J. GREENHILL
107.4264 [astro-ph]]

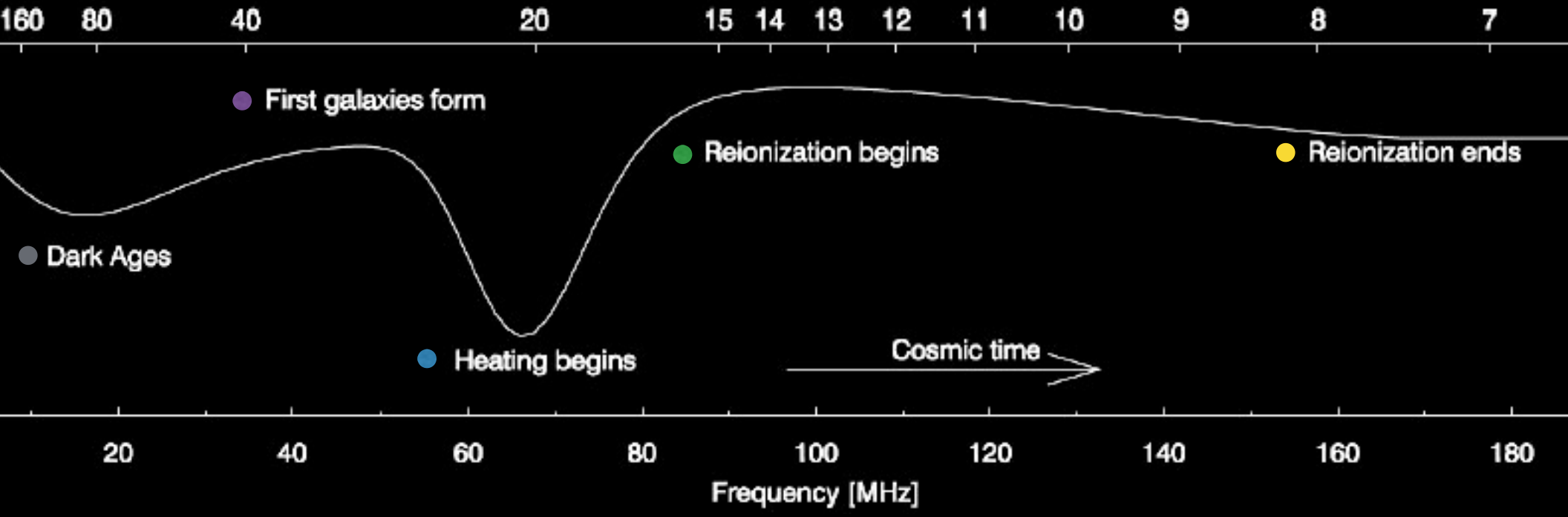
ALABLE HYBRID FPGA/GPU FX
RELATOR

Z, L. J. GREENHILL, B. R. BARSDELL, G. BERNARDI, A.
ON, M. A. CLARK, J. CRAIG, D. PRICE, G. B. TAYLOR, F.
ZEL, D. WERTHIMER
4)



- BIGHORNS
  - SARAS
  - ZEBRA
  - EDGES2 (hi)

- EDGES2 (low)
  - SCI-HI
  - LEDA



- DARE