Focal L-band Array for the GBT (FLAG): Instrumentation Upgrades and Initial Commissioning results

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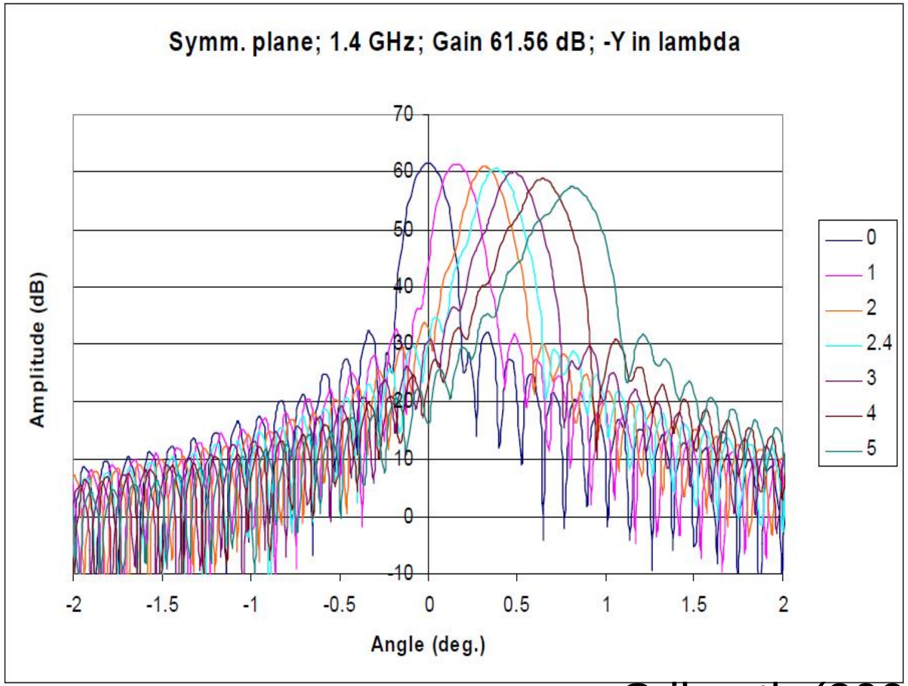
PAF Workshop, Aug 24, 2016

- Motivation to build FLAG, NRAO FLAG history
- Summary : 2015 Cyro-PAF system, GBT commissioning, NRAO PAF model development
- 2016: New Instrumentation development and Initial measurments on the GBT
- Future work

Field of View of GBT at L-band



Srikanth (2006)

Figure 2. GBT beams at 1.4 GHz for offsets (λ) in symmetric plane towards the feed arm

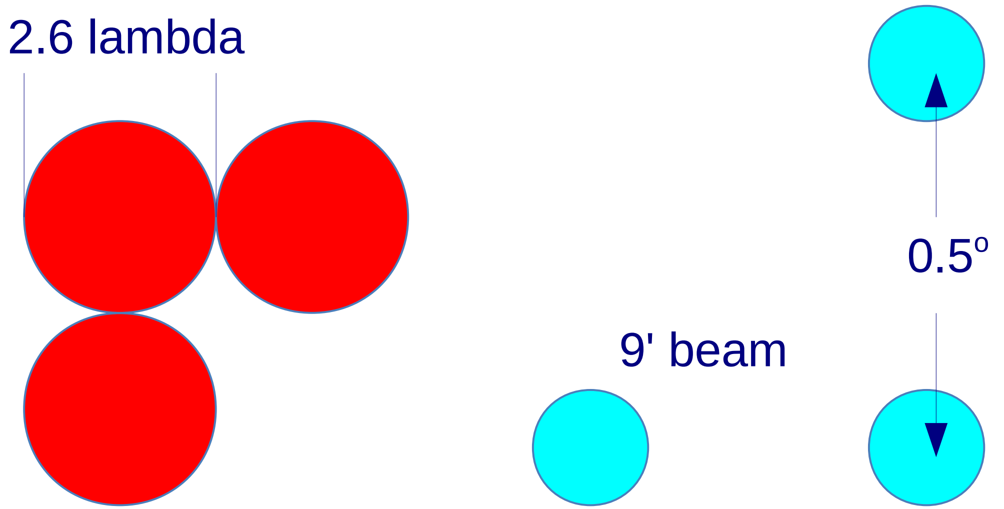
Green Bank Telescope (GBT); 100 m dia; ang resolution at 1.4 GHz is 9'

FOV – angular region where the beam aberration is within a specified tolerance. (for GBT ~ 1^o x 1^o for 1 dB loss in gain)

Focal Plane Array vs Phased Array Feed

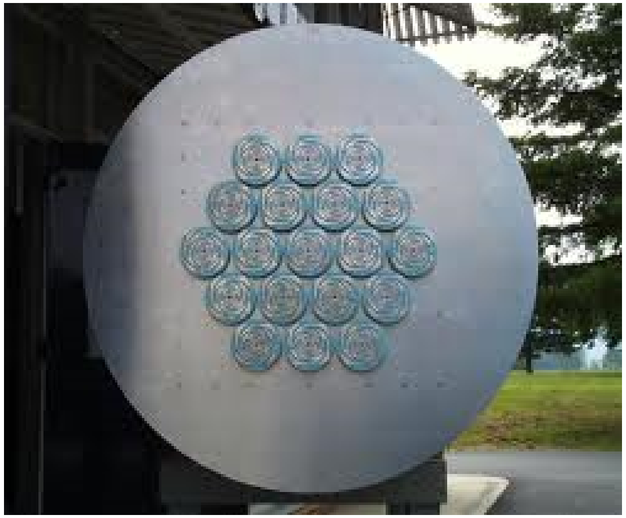
An example 1.4 GHz prime-focus
feed array for GBT

Beam ~ 9'
Feed size ~ 2.6 lambda ~ 55 cm

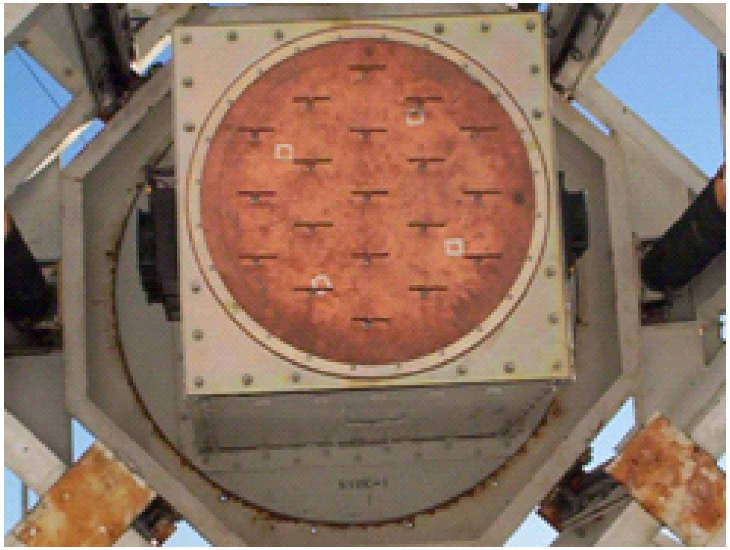


- Feed designed to maximize telescope gain and minimize spillover
- FPA with L-band feed – 9’ beam separated by 0.5˚
- Sky sampling not good for imaging
- Solution to overcome these difficulties – PAF

NRAO PAF History



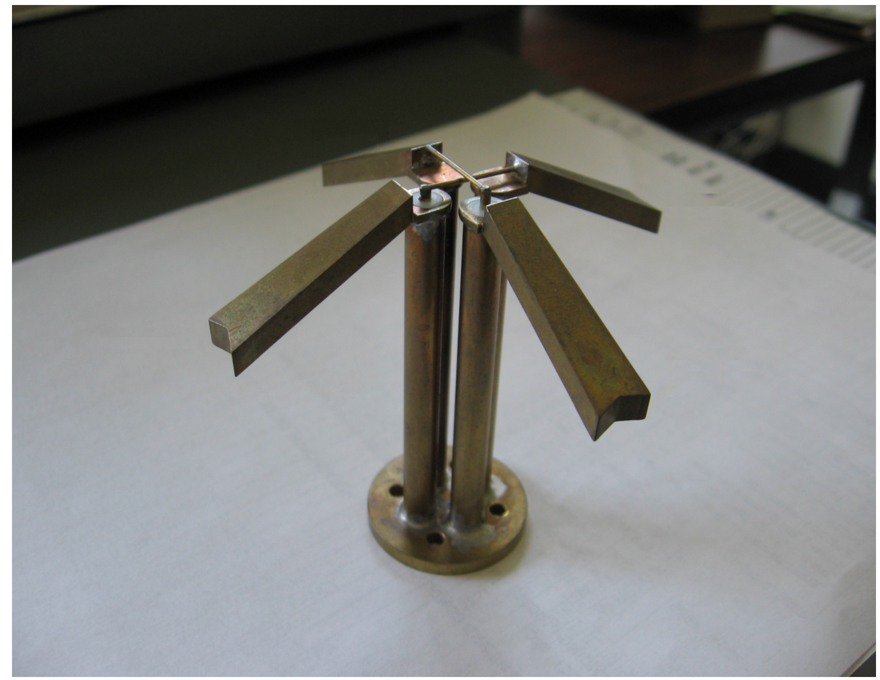
Sinuous element
140 ft 1996



Thin Dipoles
20-m 2007

Thick, impedance-optimized dipoles, 20-meter,2010

Cryo-PAF used for 2015 commissioning

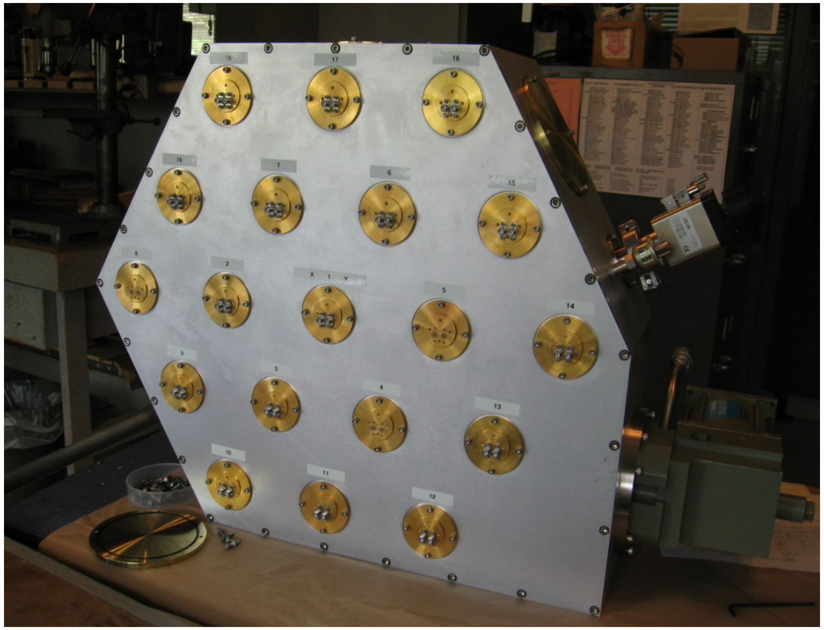


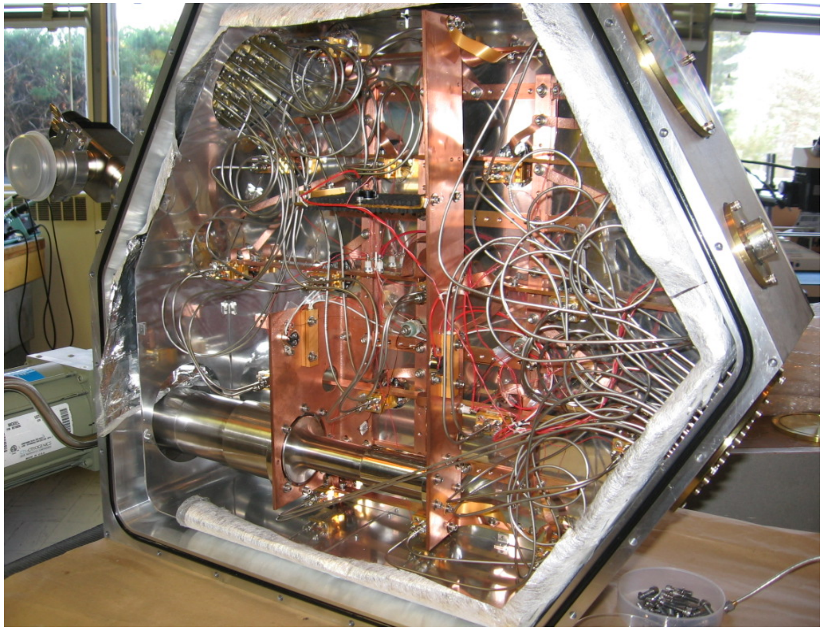
19 element dual polarized Kite Array

Kite Dipole

Weinreb SiGe LNAs

2015 Cryostat for 19 element PAF



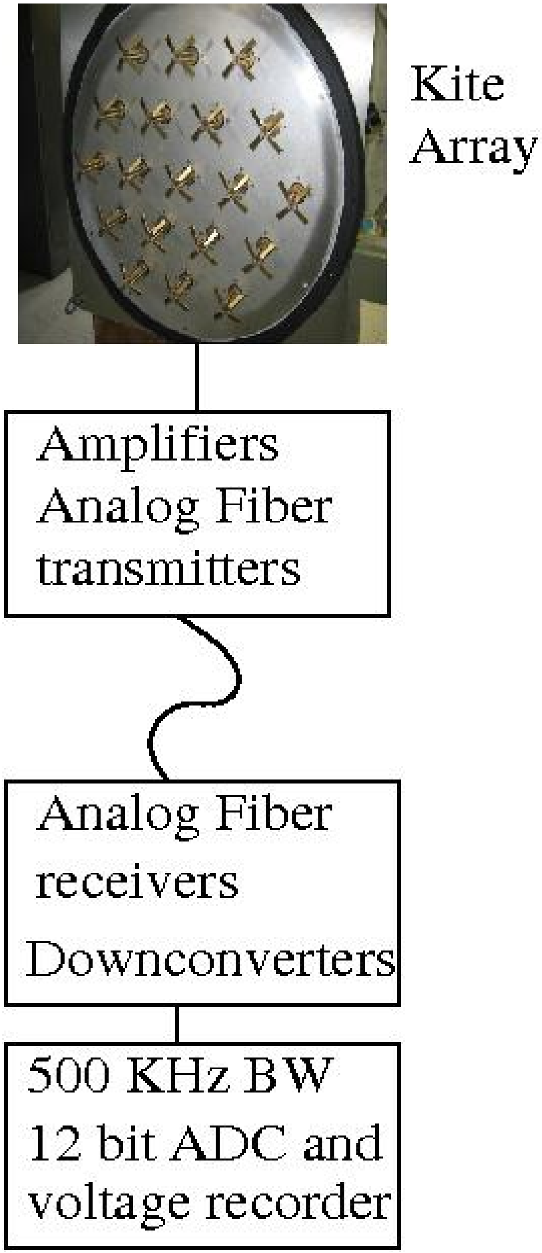


Cooled LNA receiver-Dewar;

2-stage GM cooler; Cooled to 15 K

Developed by Roger Norrod at NRAO.

2015 PAF system and Signal Processing



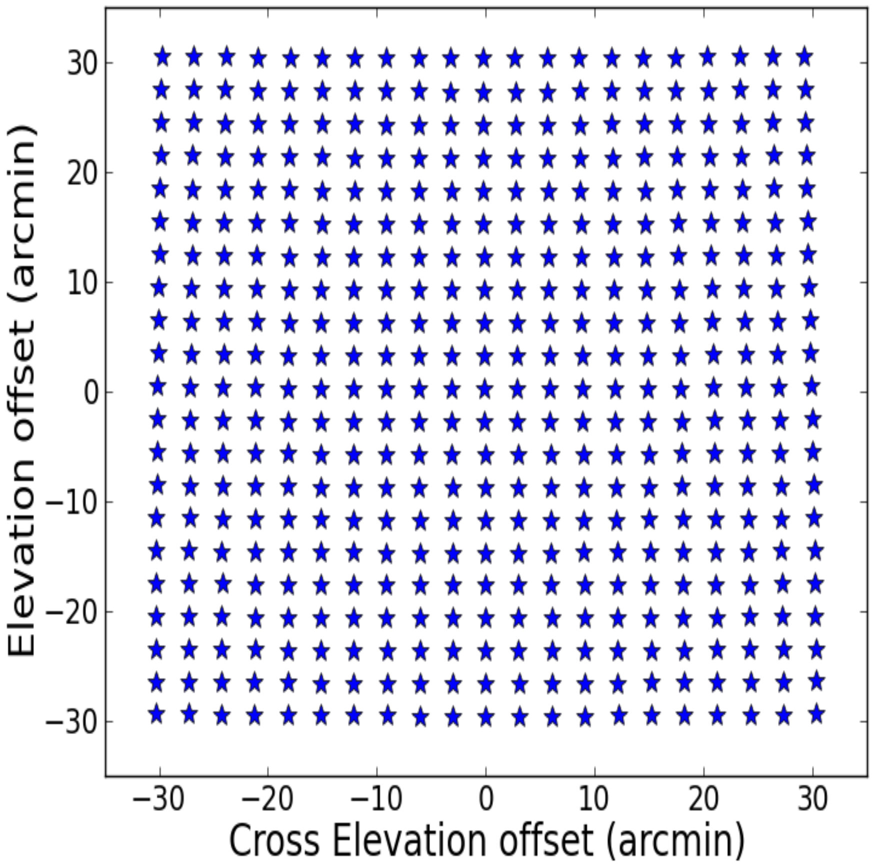
- Receiver connected to backend through analog fiber links
- Digitize (12 bits) and record voltage
- Process data off-line

$v_{out} = \mathbf{w}^T\mathbf{V}$; **w** is beamformer weights

$\langle v_{out} v_{out}^* \rangle = \mathbf{w}^H\mathbf{R}\mathbf{w}$

$\mathbf{R} = \langle \mathbf{V}\mathbf{V}^H \rangle$; Correlation of output voltages

2015:Observations with the GBT



Grid Obs :

- GBT beam at 1.7 GHz ~ 7', Grid pos ~ 3'
- Observed radio galaxy Virgo A
- Freq of obs 1700 MHz

Freq Scan Obs :

- Made On-Off observations on Calibrators
- Freq scanned from 1250 to 1800 MHz in steps of 50 MHz

Max SNR Beamforming

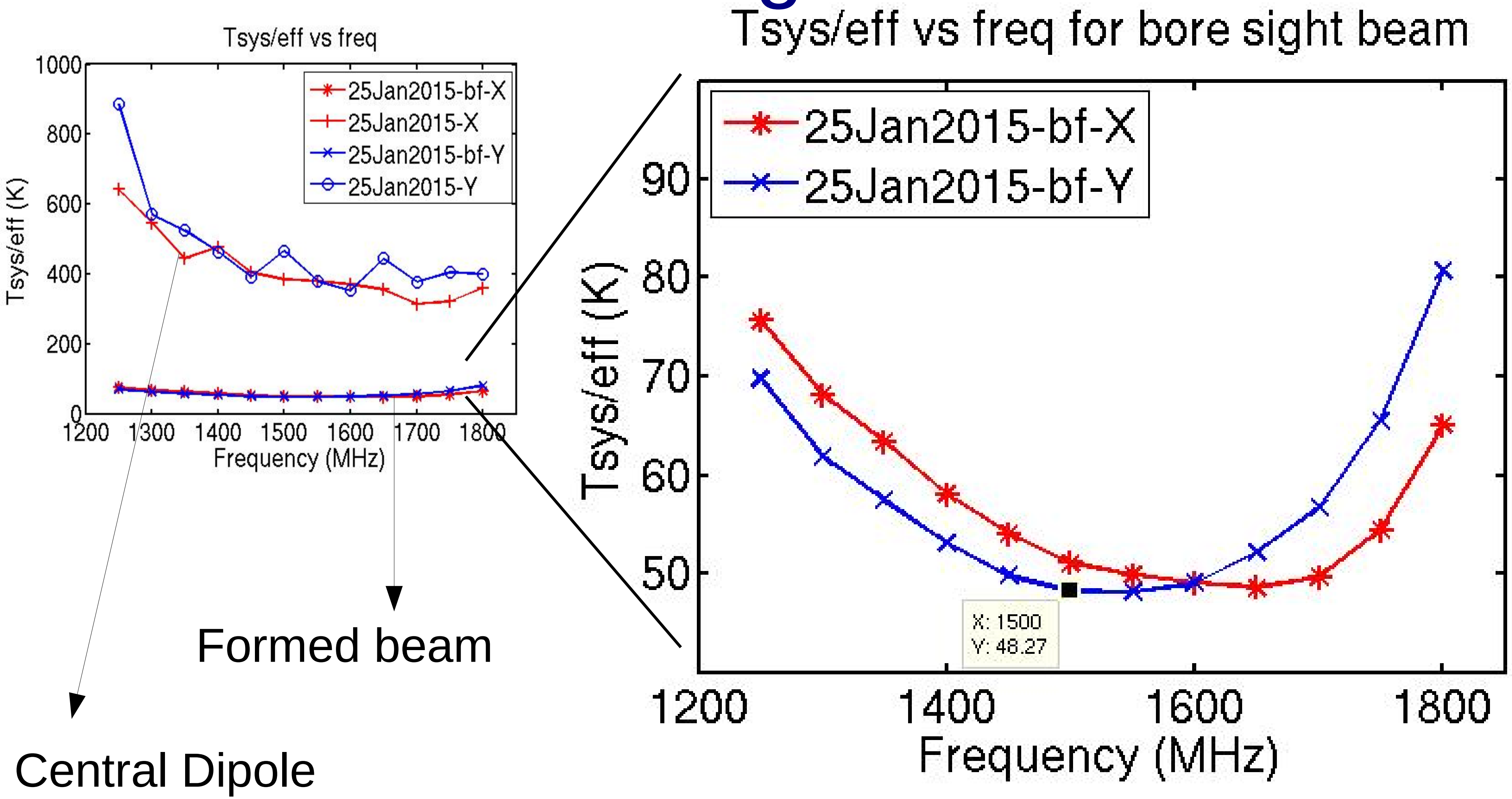
- Using On-Off data on calibrator

  $\mathbf{R}_{on}$, $\mathbf{R}_{off}$ – On & Off correlation matrix, **w** is beamformer weights

- $$SNR = \frac{\mathbf{w}^H(\mathbf{R}_{on} - \mathbf{R}_{off})\mathbf{w}}{\mathbf{w}^H \mathbf{R}_{off} \mathbf{w}}$$

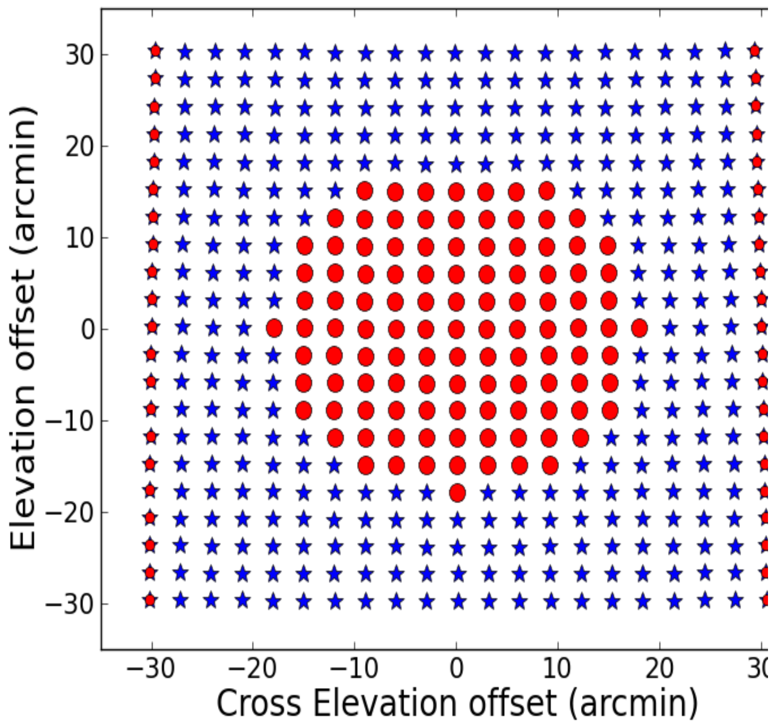
- Max (generalized) Rayleigh quotient gives the best SNR
- Eigenvector of the max Rayleigh quotient gives **w** for best SNR
- Performance – T_{sys}/η; ← $SNR = \frac{0.5\ S\ A\ \eta}{kT_{sys}}$

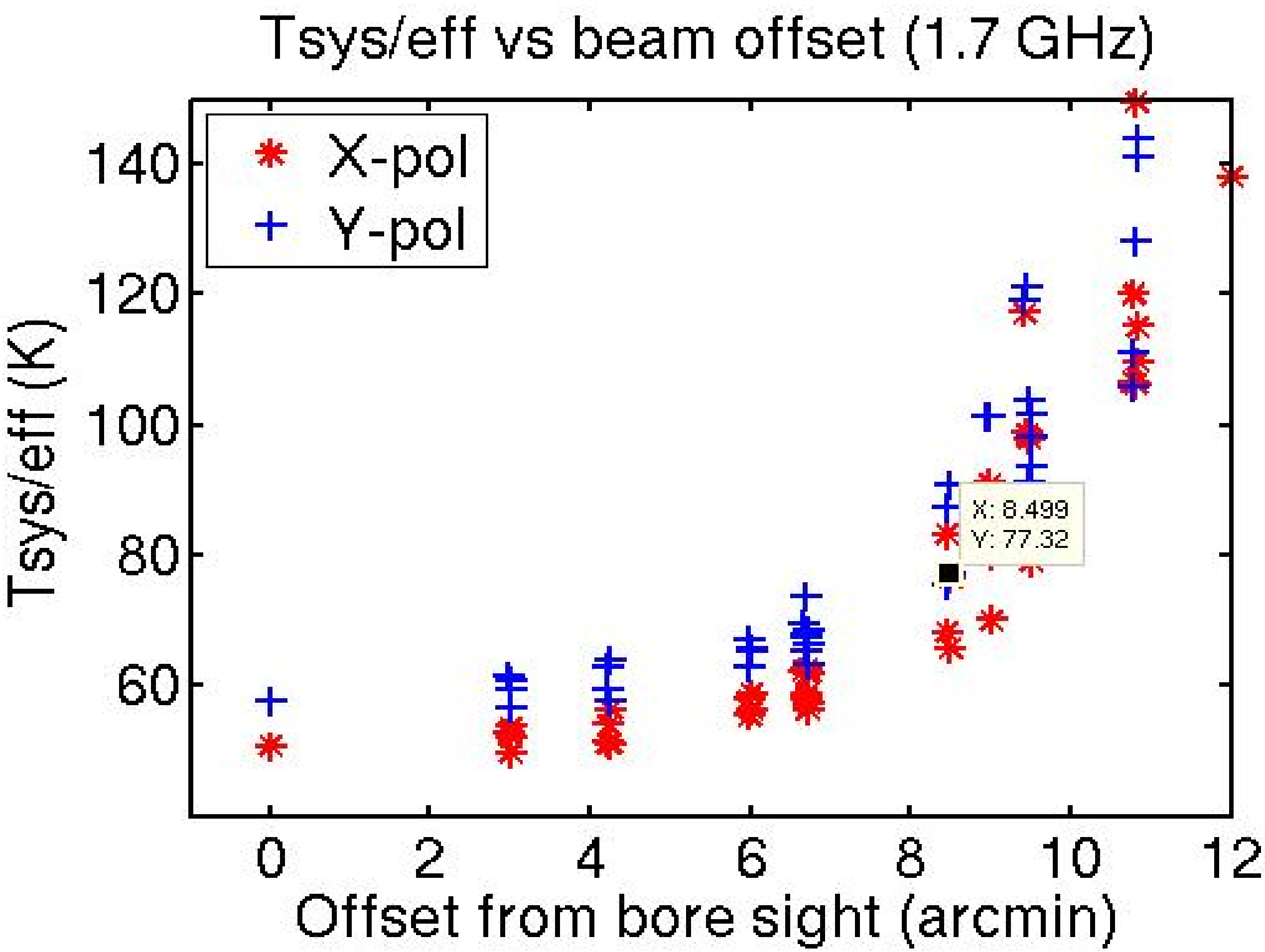
2015: Boresight beam T_{sys}/η on Virgo A



T_{sys}/η = 48.2 K @ 1550 MHz

2015:Off-boresight T_{sys}/η





- T_{sys}/η = 63 K @ 7'.2 (FWHM) @ 1.7 GHz
- Survey speed compared to GBT L-band feed : PAF is 20% better

NRAO PAF model

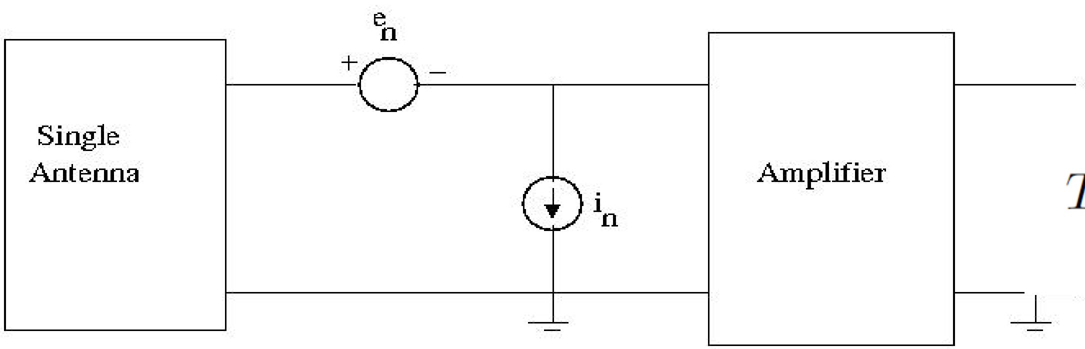
Question: For a PAF installed on a telescope what is the best (spectral) T_{sys}/η that can be obtained when observing a source at some angle (θ_s, φ_s) from the boresight direction ?

Answer:

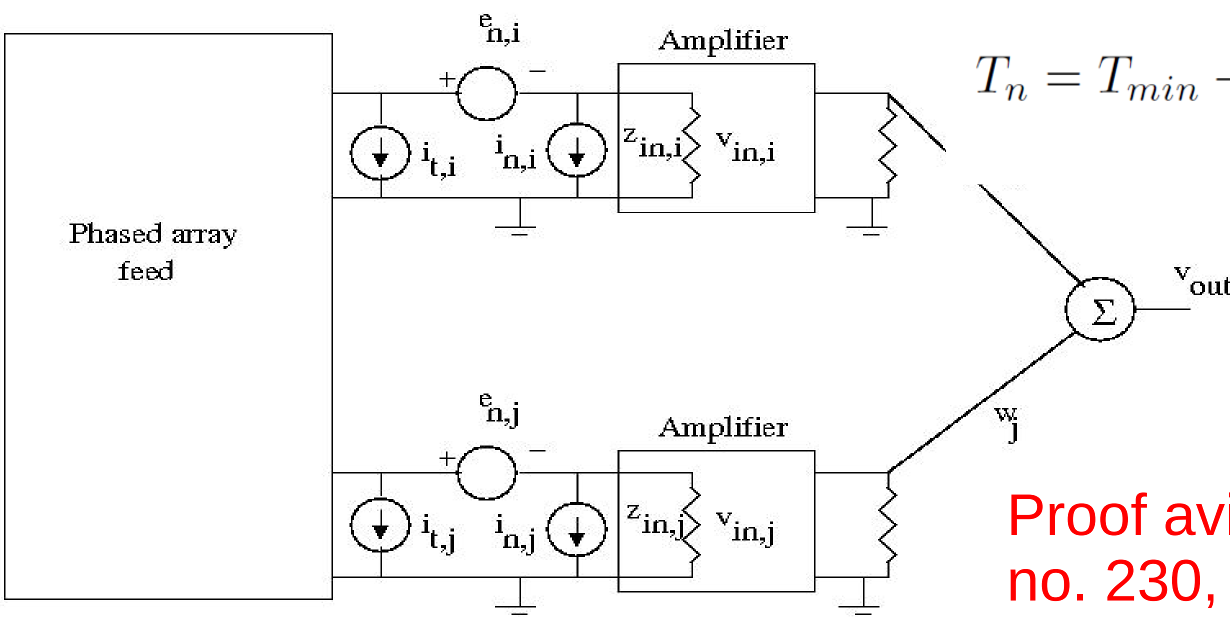
Theorem: Given (spectral) **Z** , $\mathbf{E}_i$ (θ, φ), amplifier noise parameters (R_n, g_n, ρ) and given the telescope geometry and source position, one can construct a characteristic matrix **M** for the *system*. Then, the best signal-to-noise ratio on the source is the maximum eigenvalue, e_{max}, of **M.**

Proof avilable in NRAO EDIR 2016, no. 230, Roshi & Fisher

PAF model: Receiver Temperature



$$T_n = T_{min} + NT_0 \frac{(Z_s - Z_{opt})(Z_s - Z_{opt})^*}{\mathrm{Re}\{Z_s\}\,\mathrm{Re}\{Z_{opt}\}}$$

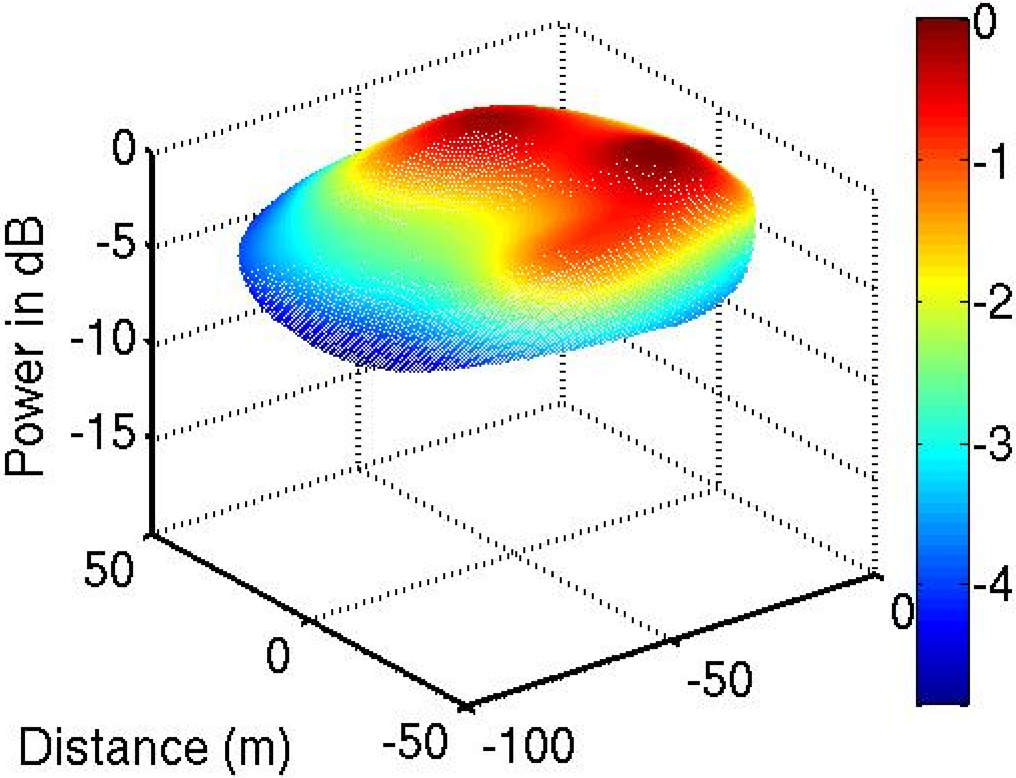


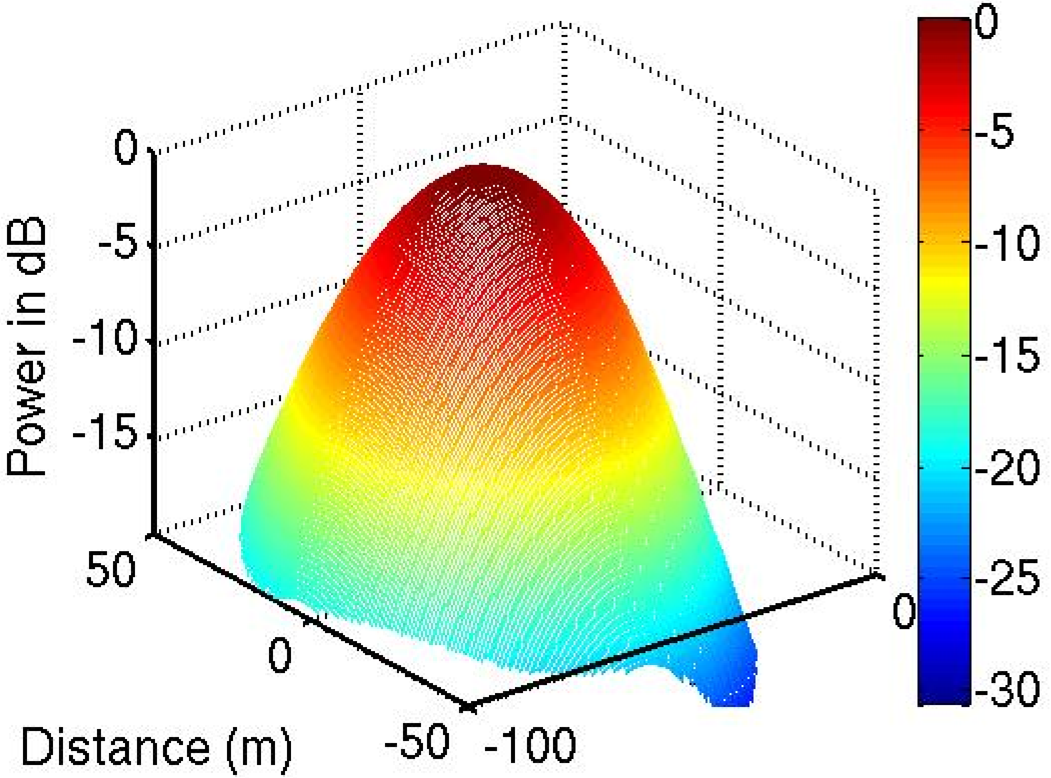
$$T_n = T_{min} + NT_0 \frac{\boldsymbol{w}_1^H(\boldsymbol{Z} - Z_{opt}\boldsymbol{I})(\boldsymbol{Z} - Z_{opt}\boldsymbol{I})^H \boldsymbol{w}_1}{\mathrm{Re}\{Z_{opt}\}\ \frac{1}{2}\boldsymbol{w}_1^H(\boldsymbol{Z} + \boldsymbol{Z}^H)\boldsymbol{w}_1}$$

(for identical amplifiers)

Proof avilable in NRAO EDIR 2016, no. 230, Roshi & Fisher

PAF model: GBT Aperture Field Pattern



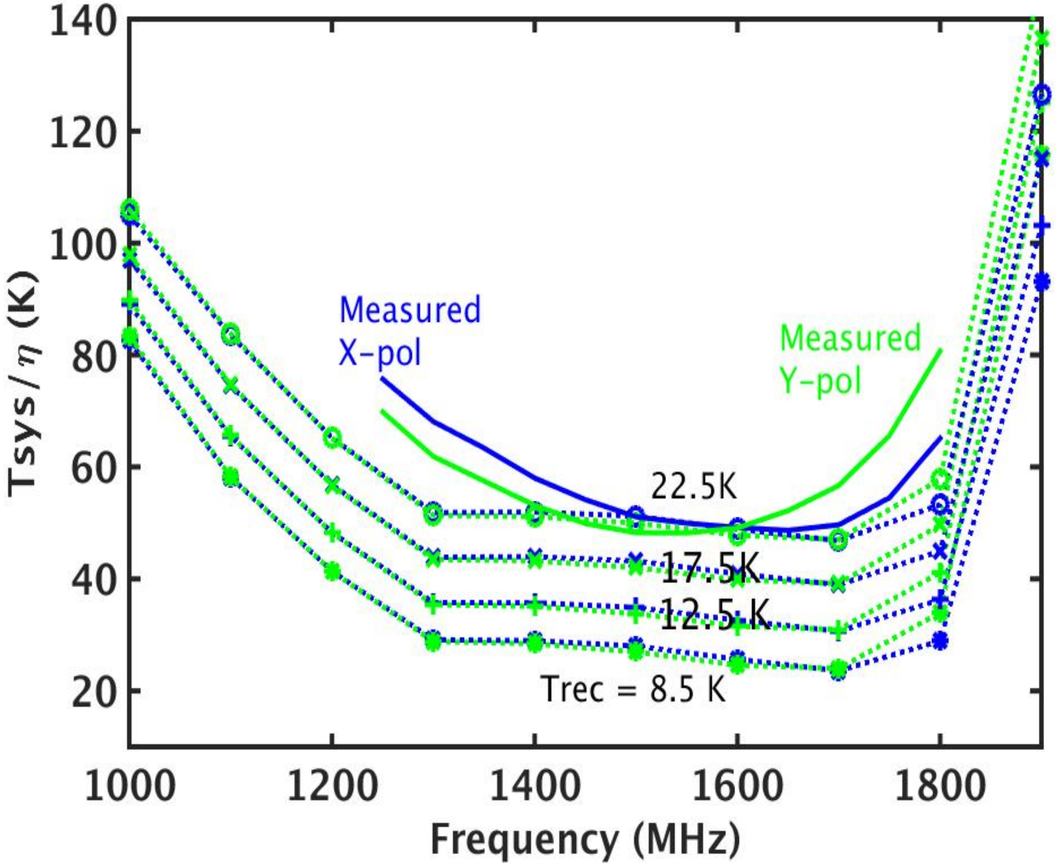


Dipole 1, X-pol

Max SNR wt-ed X-pol field

NRAO PAF model vs 2015 obs

Boresight beam



Thermal transition	4 K
Replacement transistor	5 K
Excess needed	5 K

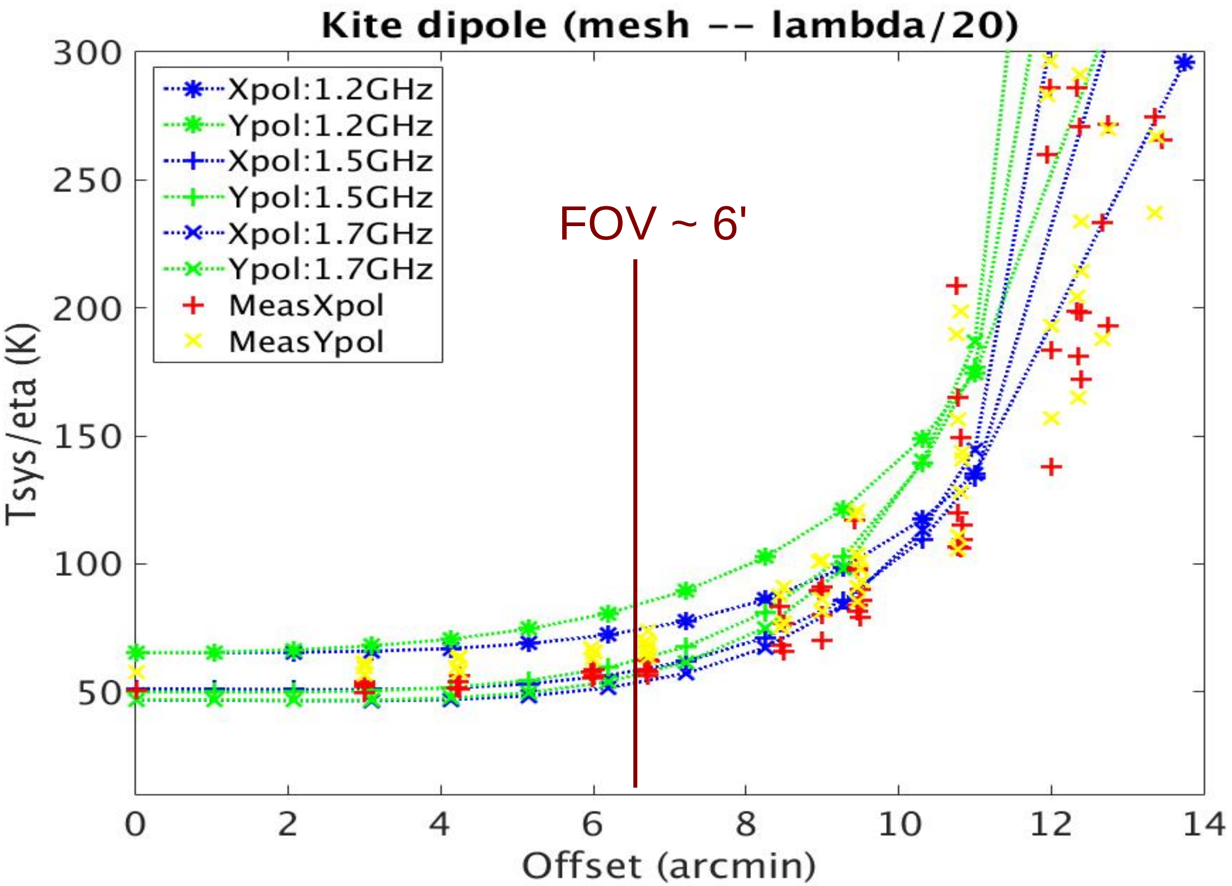
Antenna Loss	?
Excess noise in Down converter	4 K

Trec ~ 22 K for model to match measurement

Trec is 5 K above what can be accounted for

NRAO PAF model vs 2015 obs

Off-boresight beam

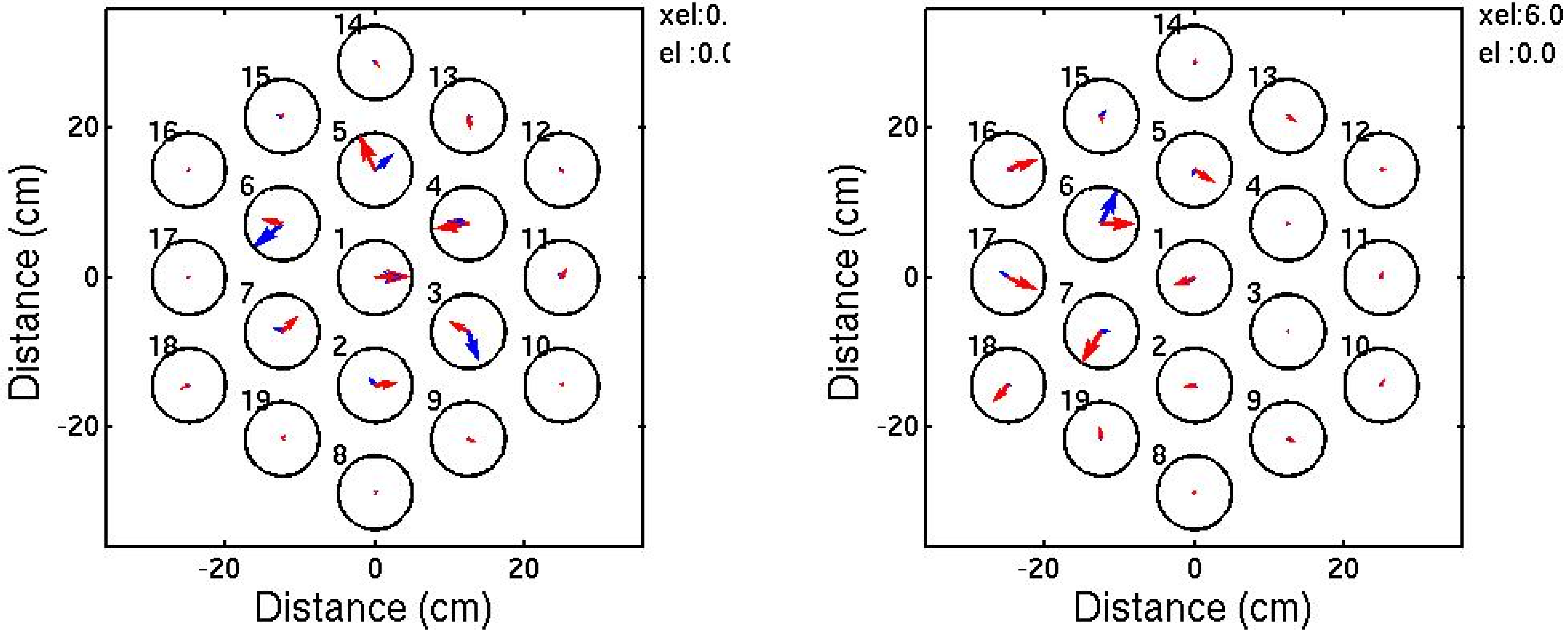


Model results match well with measurements for Trec ~ 22 K

Spillover efficiency – 97 % for Trec ~ 22 K

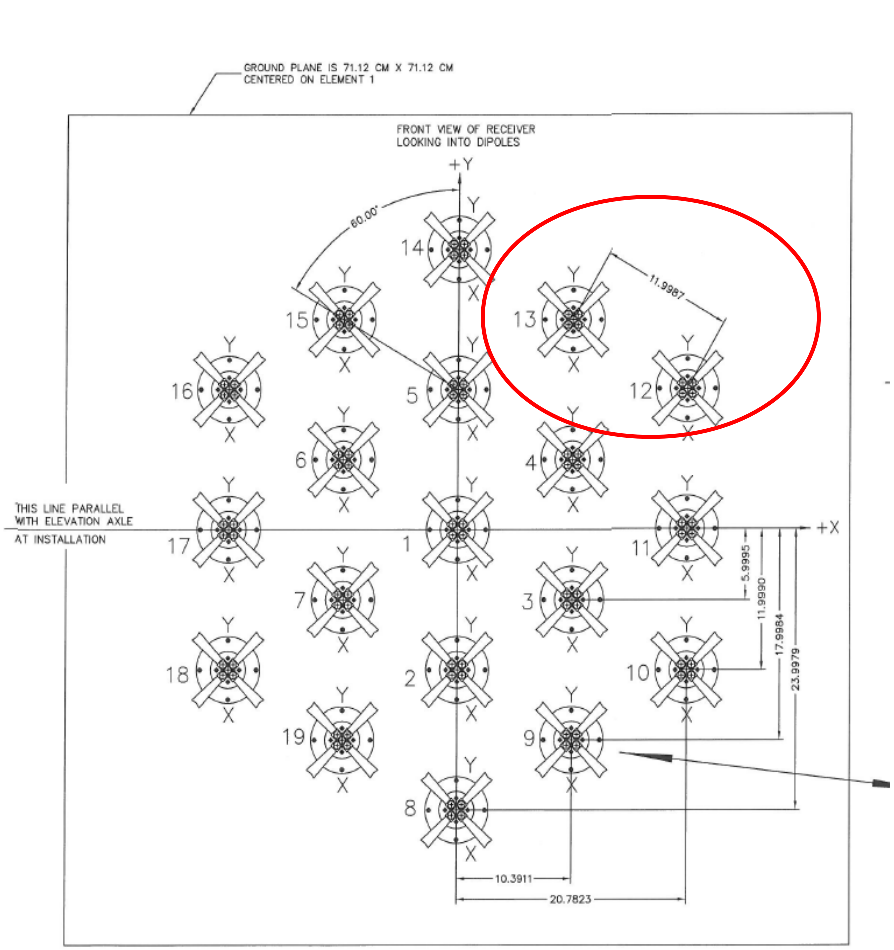
Aperture efficiency – 65 % for Trec ~ 22 K

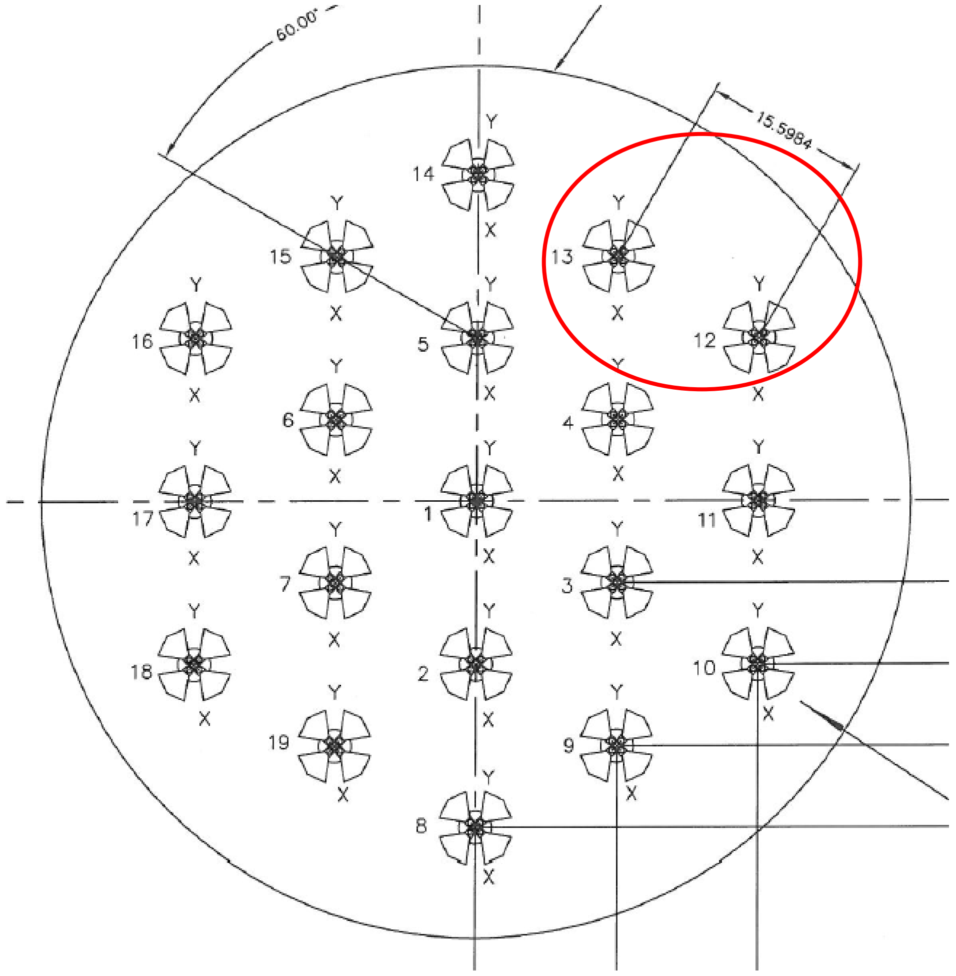
2015: Weights vs offset from boresight



FOV is limited by the array size to ~ 6'

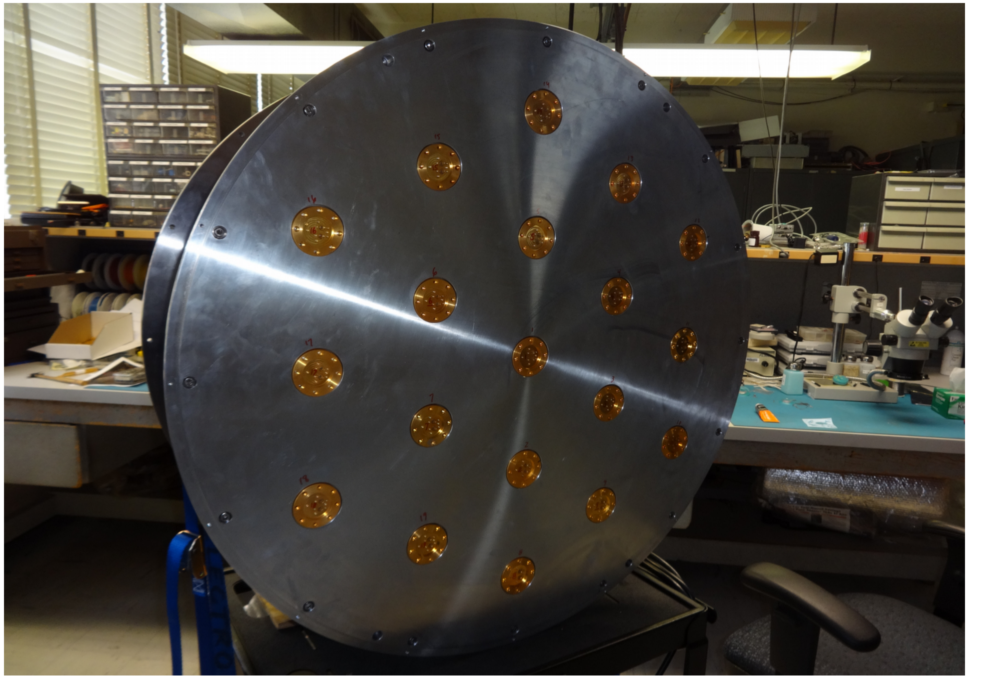
2016: Increase FOV





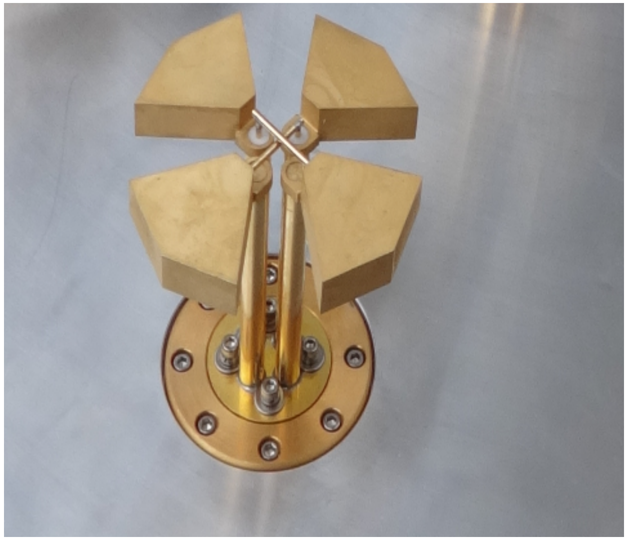
Increase the dipole spacing by ~ 30 %

2016: New Cryo-stat



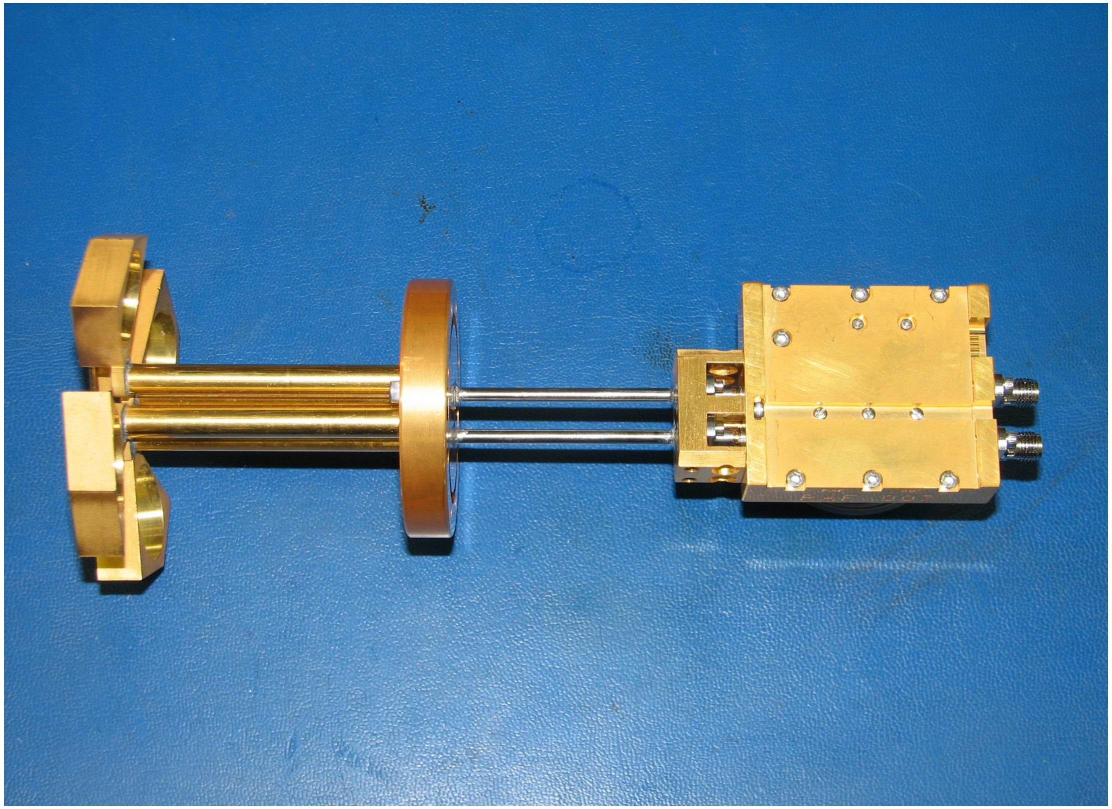
B. Simon, NRAO

2016: New Dipole (GBT2 dipole) and LNA



GBT2 Dipole designed by BYU

Better optimized for the increase FOV

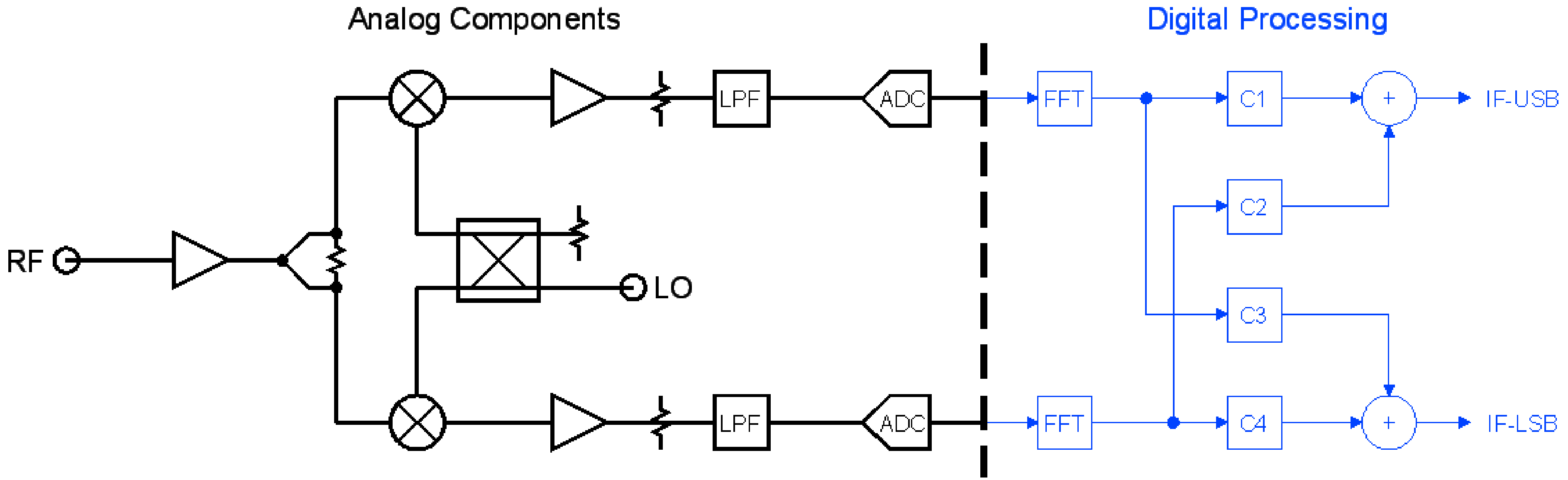


New thermal transition (B. Simon, NRAO)

New amplifiers (W. Groves, Matt, NRAO)
Tamp = 5 K ; (blind mate connectors)

Integrated Unformatted Digital Link

Concept (Matt & Rick Fisher)



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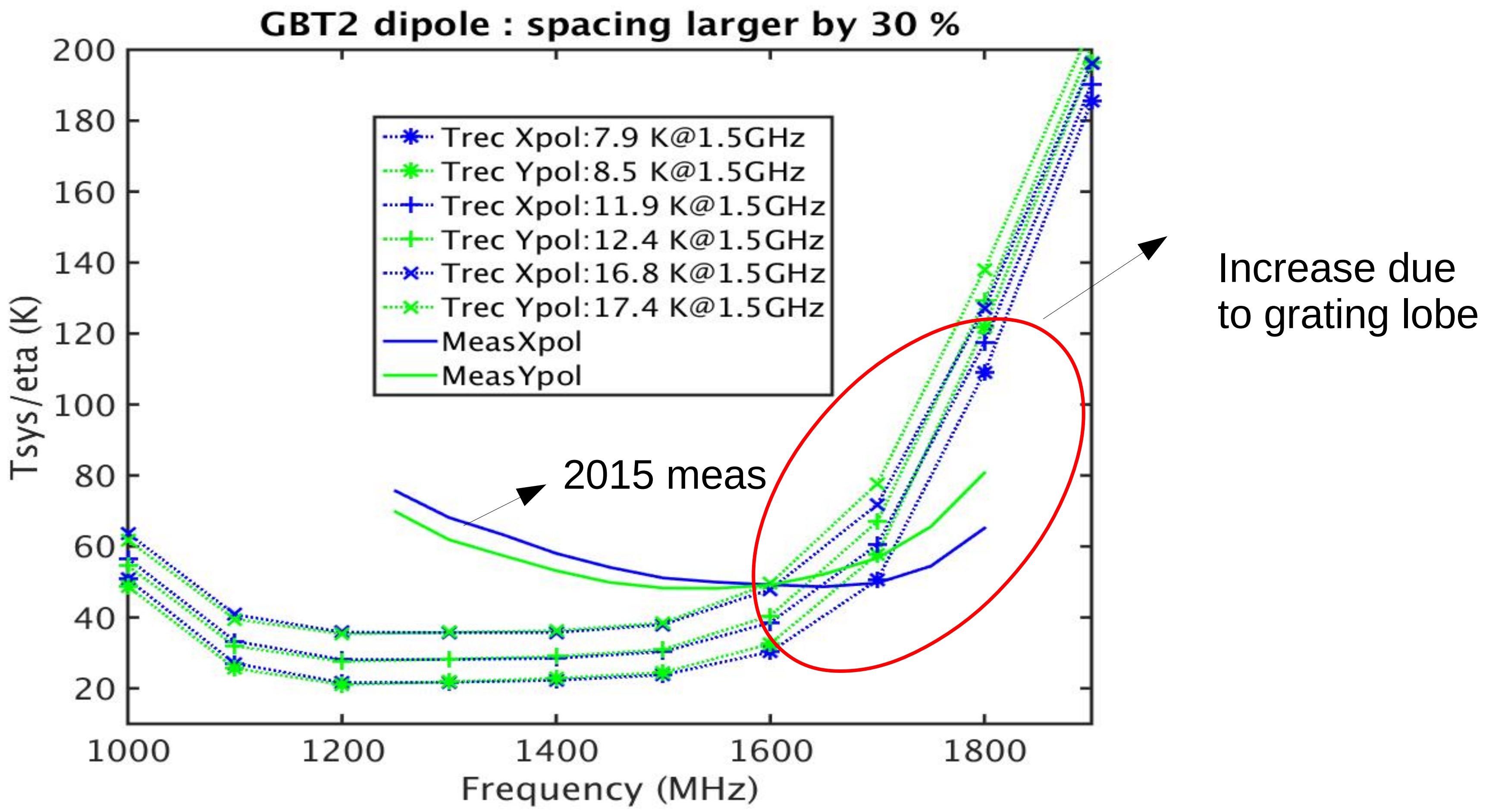
Bandwidth = 150 MHz (Digital downconverter; remove the excess noise from 2015 downconveters)

- M. Morgan and J. Fisher, "Statistical Word Boundary Detection in Serialized Data Streams," U.S. Patent No. 8,688,617, April 1, 2014.
- M.Morgan, J. Fisher, and J. Castro, "Unformatted Digital Fiber-Optic Data Transmission for Radio Astronomy Front Ends," Publications of the Astronomical Society of the Pacific, vol. 125, no. 928, pp. 695-704, June 2013.
- M. Morgan and J. Fisher, "Experiments With Digital Sideband-Separating Downconversion," Publications of the Astronomical Society of the Pacific, vol. 122, no. 889, pp. 326-335, March 2010

2016: NRAO PAF model prediction

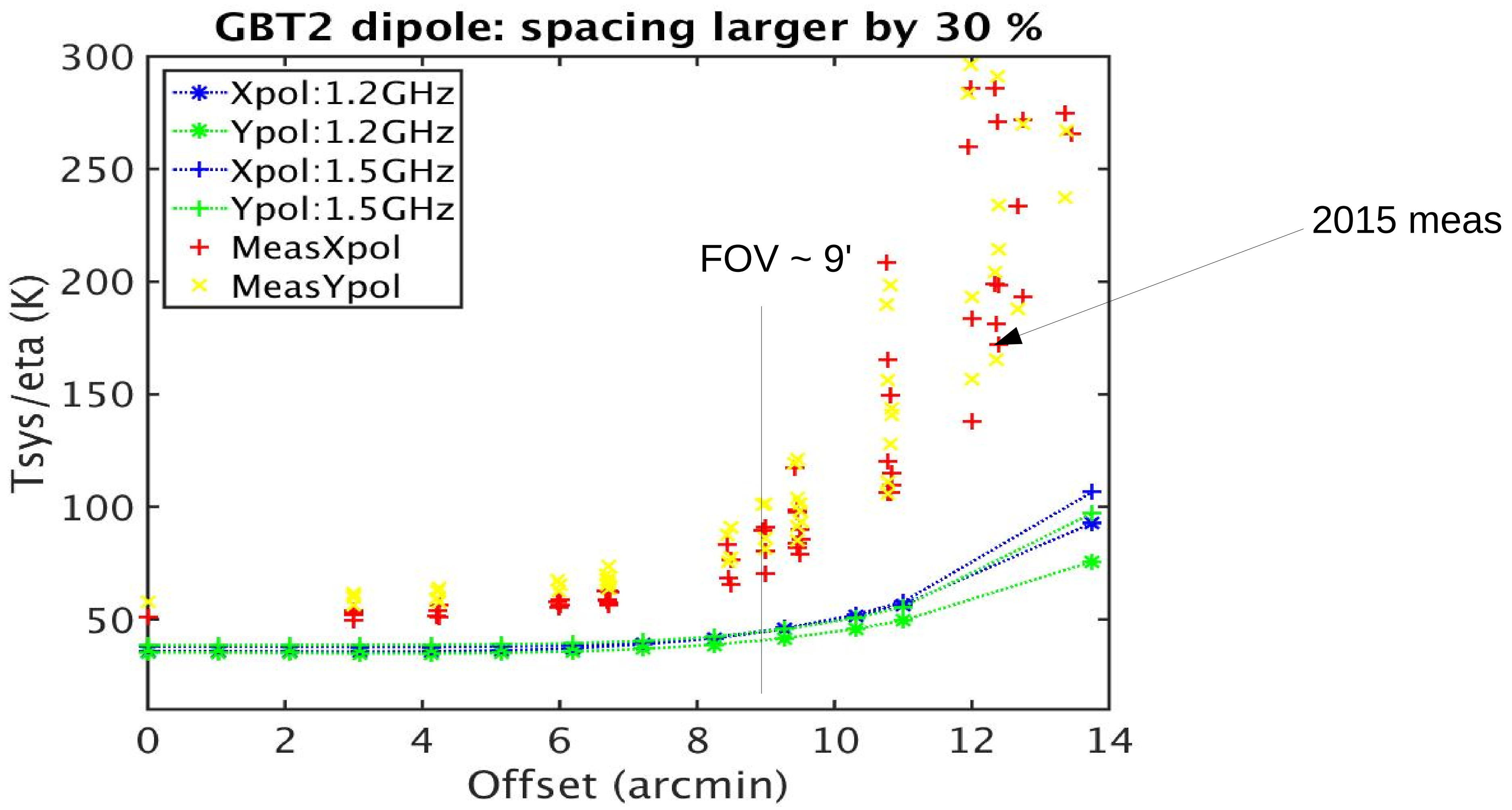
Boresight beam



Expected Tsys/eta – better than 40 K (depending on the Trec)

2016: NRAO PAF model prediction

Field of View



Expected FOV @ 1.4 GHz – better than 9' (Trec ~ 17 K)

2016 PAF test system and Signal Processing

2015 system

Kite Array

Amplifiers
Analog Fiber transmitters

Analog Fiber receivers
Downconverters

500 KHz BW
12 bit ADC and voltage recorder

Firmware

V. van Tonder
J. Ford et al.
NRAO

GBT2 Array

Cryo LNA

BYU dipoles

Amplifiers
Integrate unformated
Digital link

ROACH2

Digital Fiber receiver
PFB

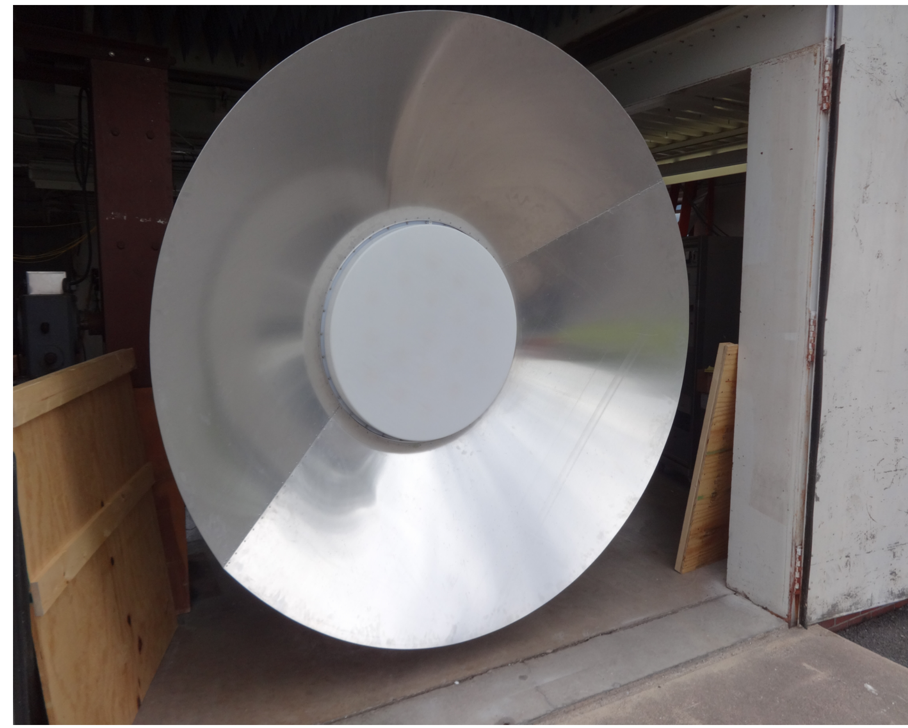
ROACH2 hardware (BYU, WVU grant)

1 PFB channel
voltage recorder

(not BYU beamformer)

$\mathbf{R} = \langle \mathbf{V}\mathbf{V}^H \rangle$

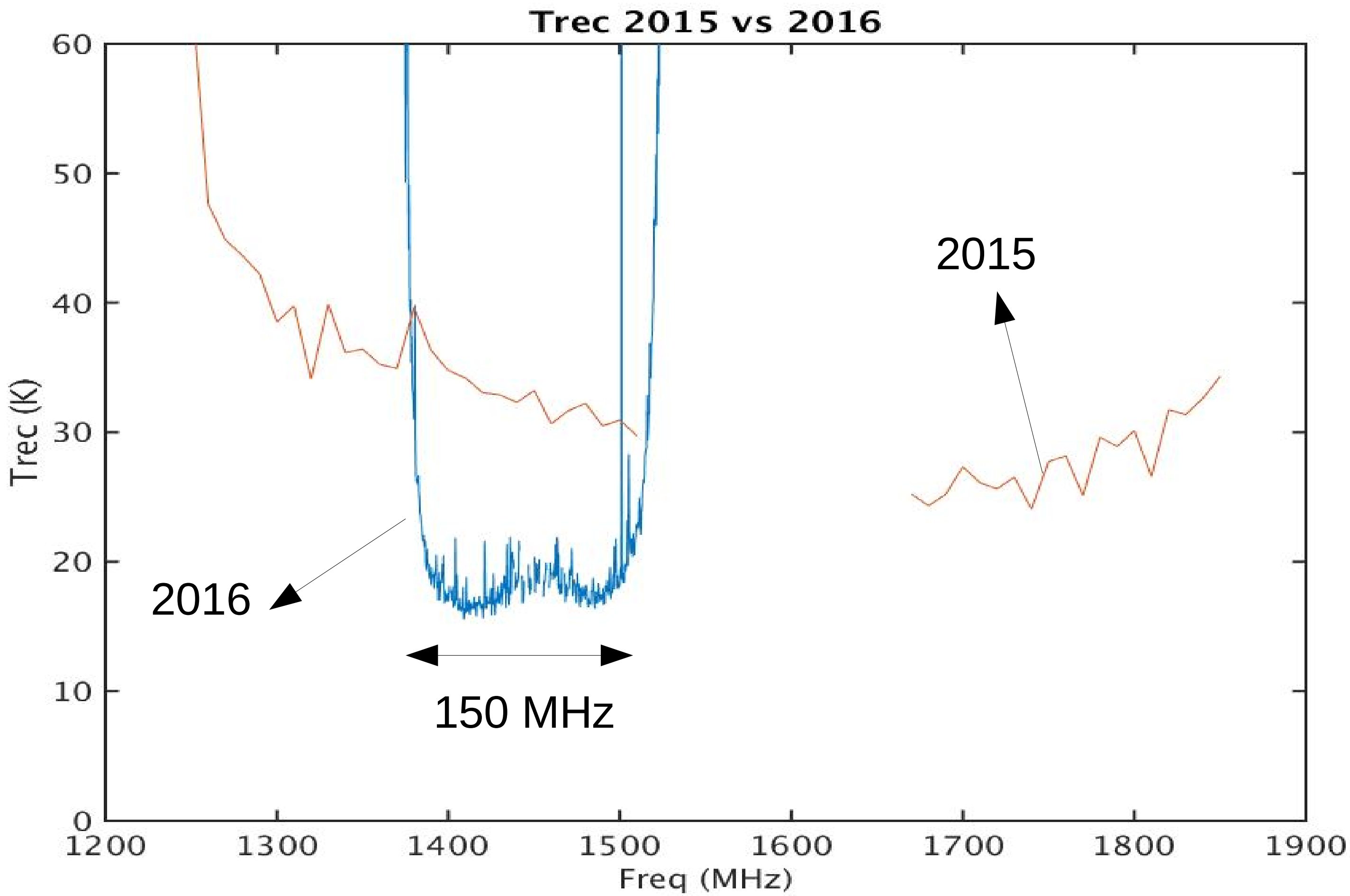
PAF Receiver Temperature Measurement



Outdoor test facility at NRAO, Green Bank

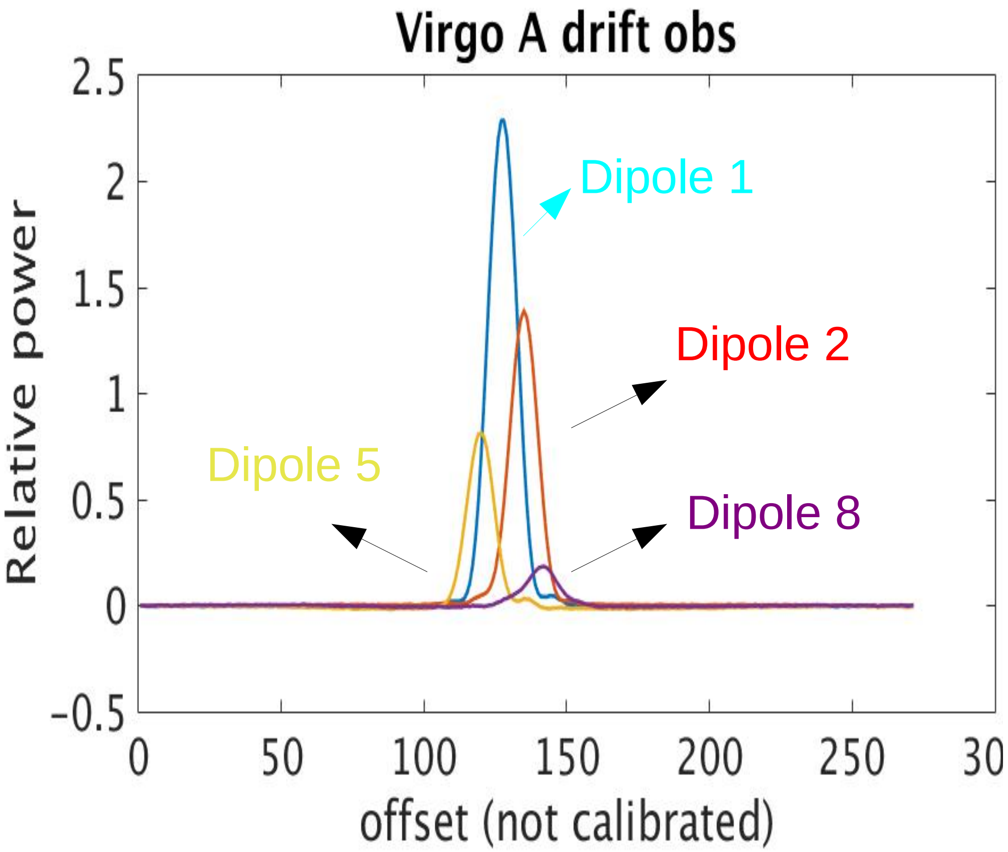
- Hot/Cold voltage correlation measurements → Y factor for a **w**

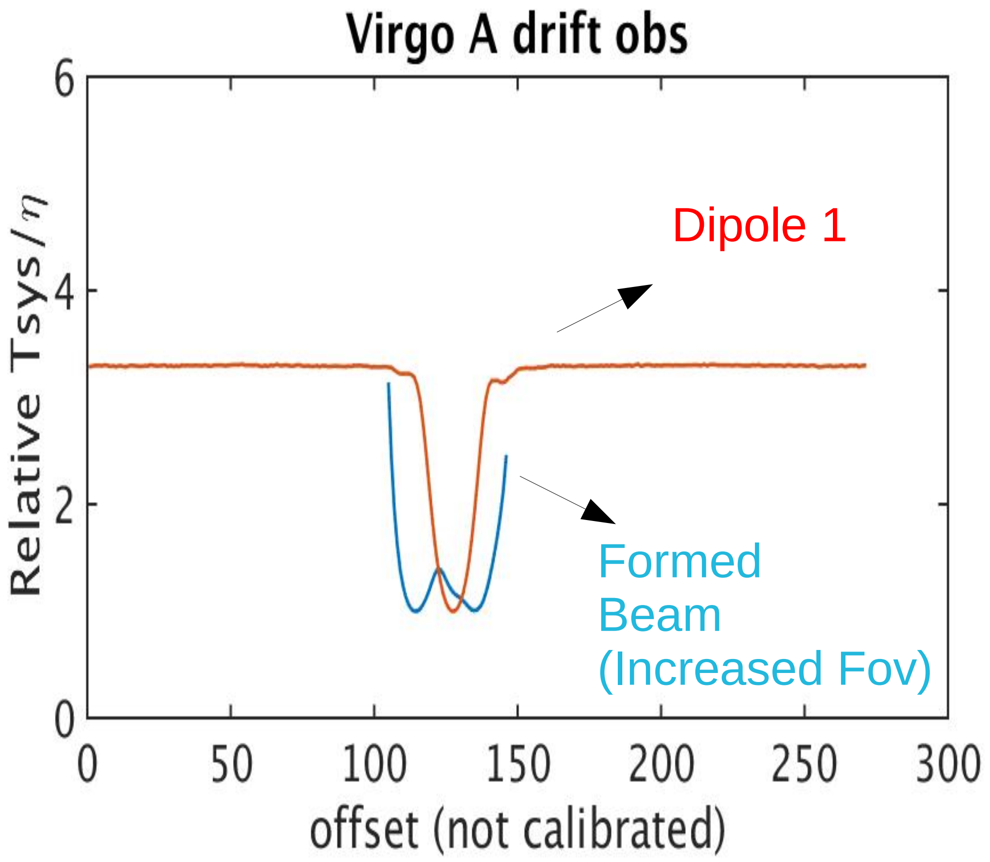
2016: PAF Receiver Temperature



- Median Trec (2016; Preliminary result) about 17 K
- 5 to 8 K better than the best trec with replacement transitors + thermal transition of 2015

2016: Virgo A Drift Scan





Need to fix the problem in the new instrument and redo the measurements …..

Thank You

Ack: J. D. Nelson, L. Jensen, S. Pan, Bob Dickman.