DANNY JACOBS
20 MARCH 2019

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DRONE BASED EXTERNAL CALIBRATION FOR LOW FREQUENCY OBSERVATORIES

hoto: Josh Dillon

SCHOOL OF EARTH & SPACE EXPLORATION
ARIZONA STATE UNIVERSITY

The Many Ages of Neutral Hydrogen

Pre-Reionization

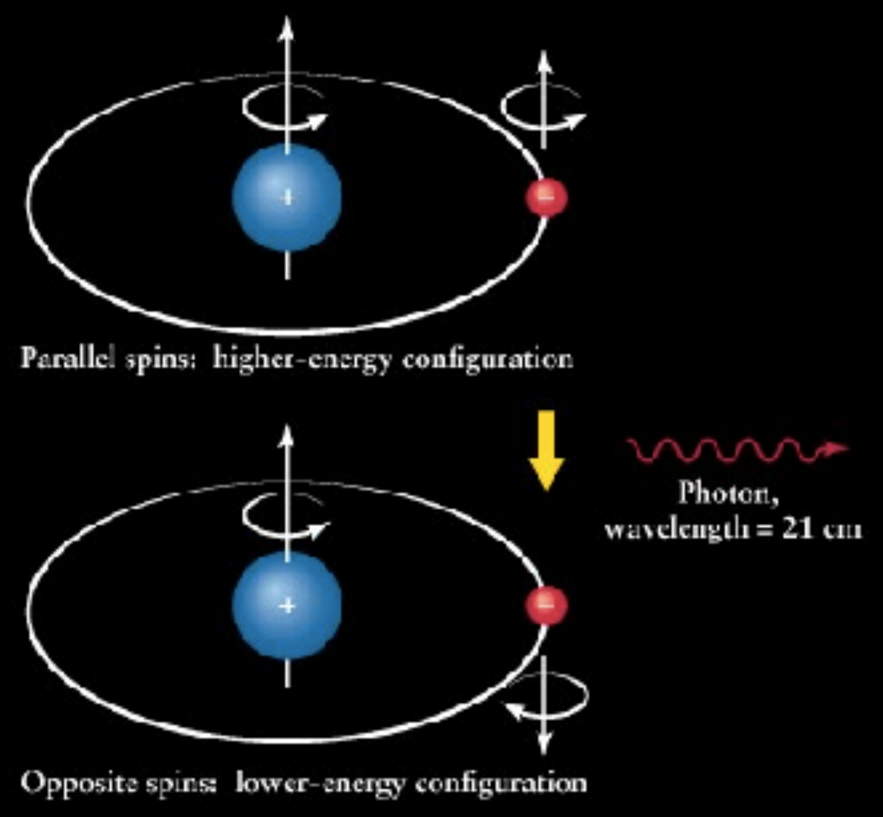
First stars activate 21cm line with Lyalpha
Visible in absorption

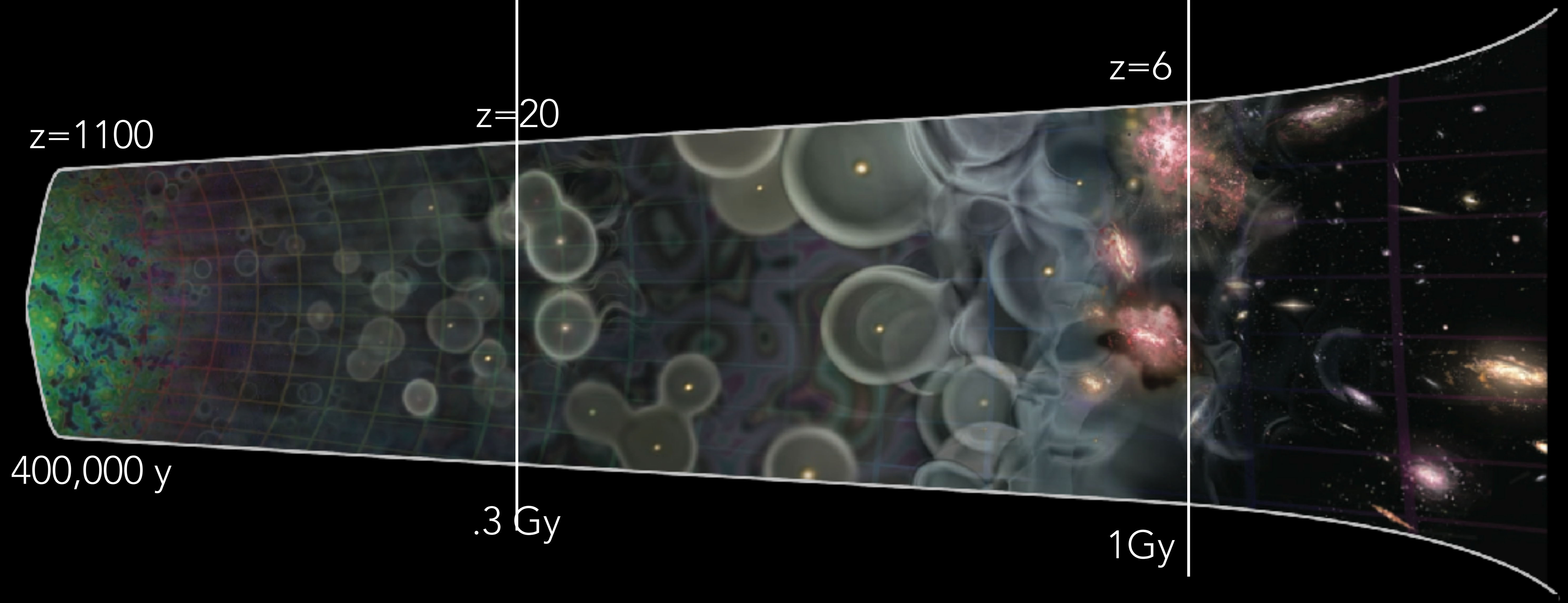
Reionization

Tau, As, $\sum m_\nu$,
first galaxies, supermassive blackholes

Post-Reionization

dark energy equation of state





Pre-Reionization

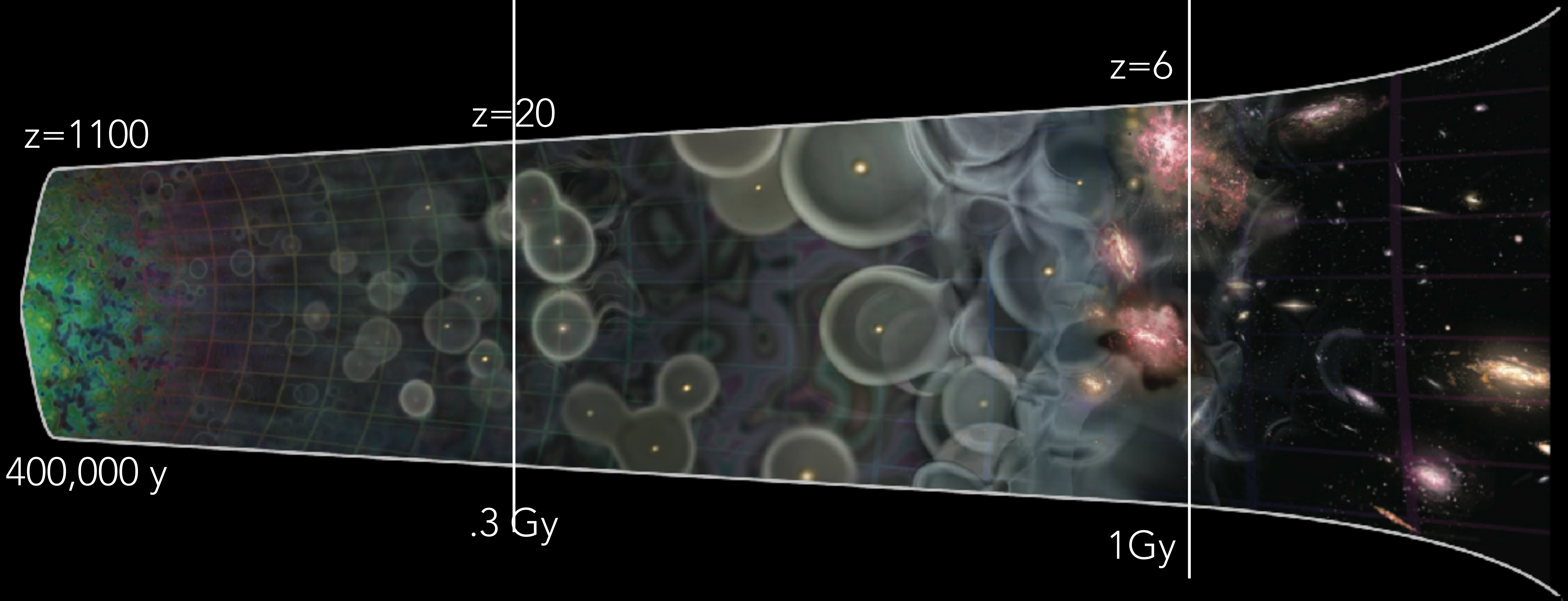
Inflation, exotic matter, first stars

Reionization

Tau, As, $\sum m_\nu$,
first galaxies, supermassive blackholes

Post-Reionization

dark energy equation of state



LWA, OVLWA, LOFAR

~50MHz

HERA, MWA, PAPER, LOFAR, EDGES

200MHz

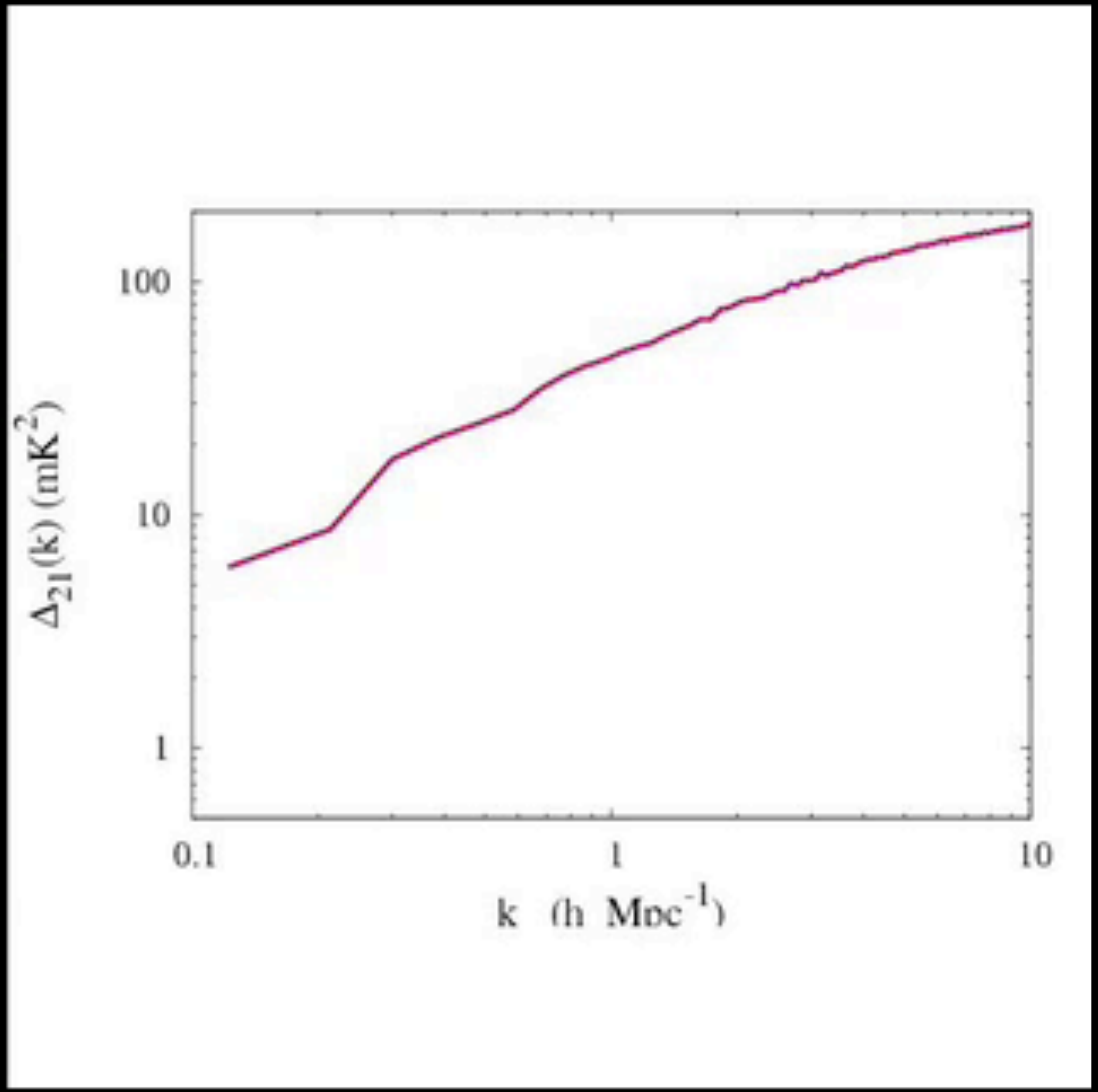
CHIME, Tienlai, Hirax

1421 MHz

Some 21cm instruments

DETECTING FLUCTUATIONS

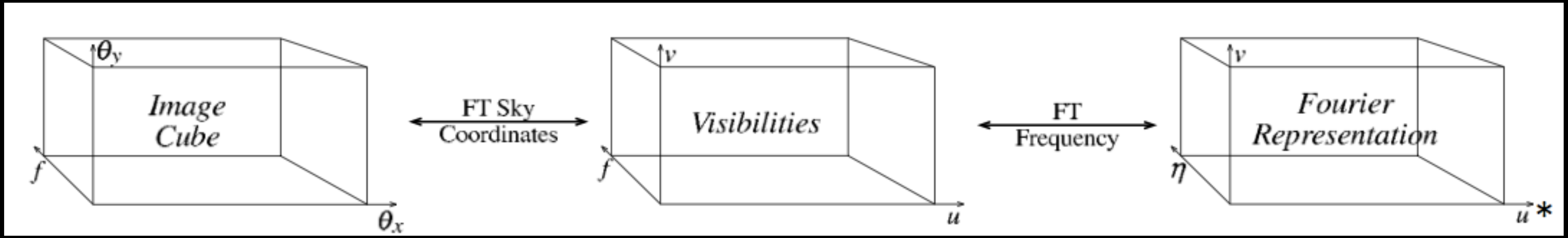
- Theoretical fluctuation size: 20mK
- First gen instruments: power spectrum sensitivity SNR~2
- Power spectrum evolves with redshift

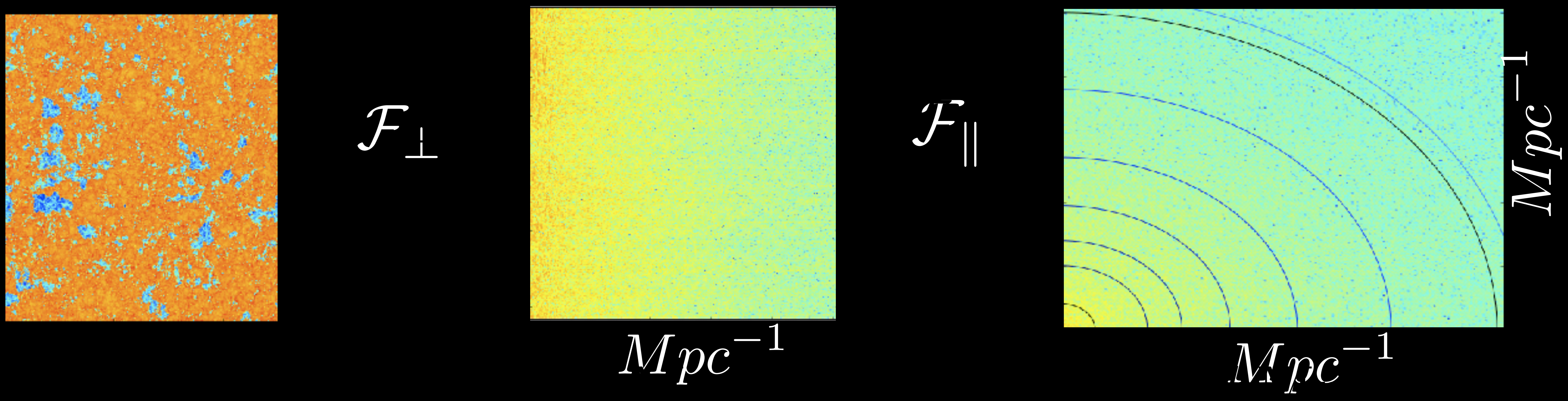


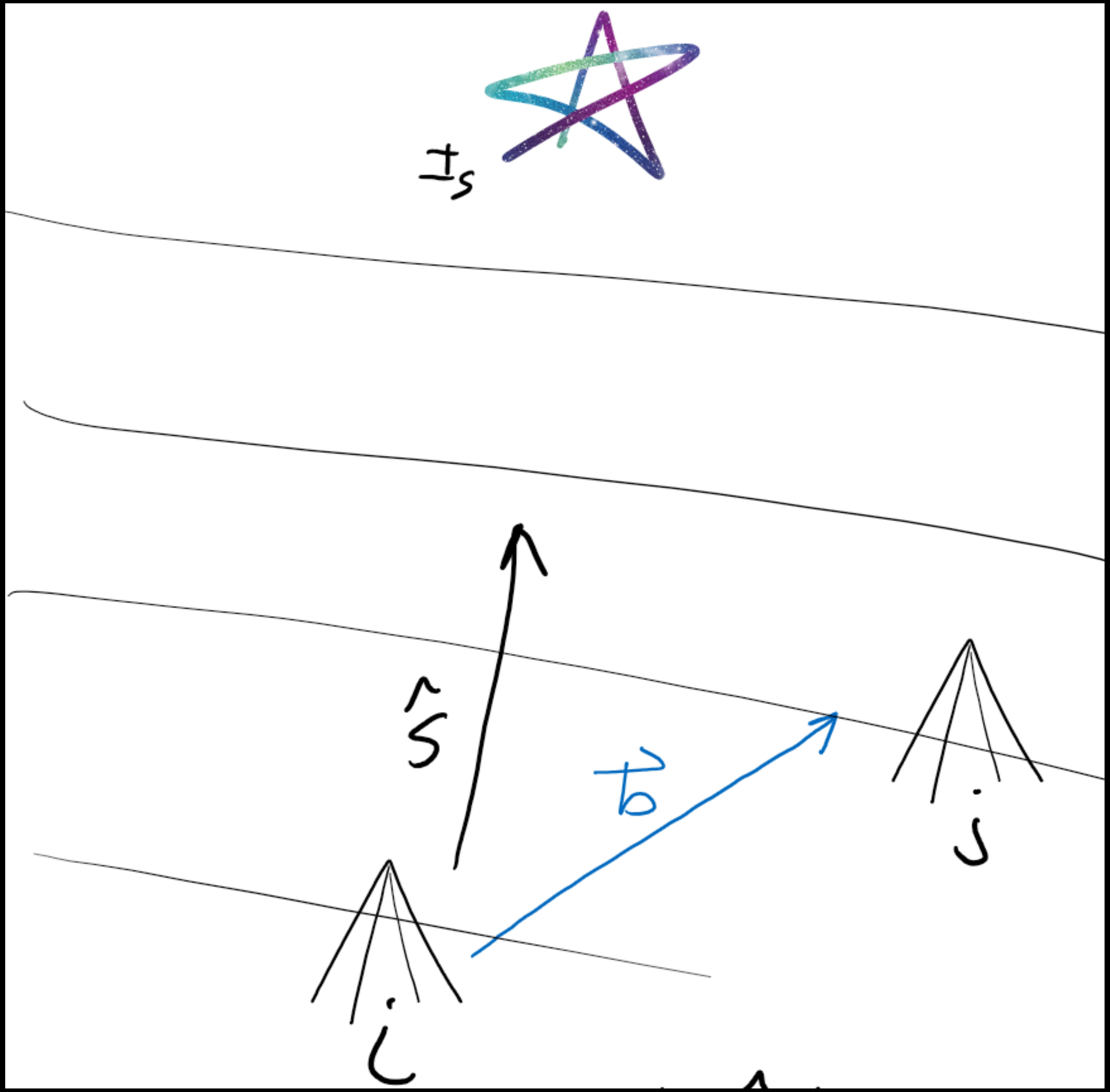
McQuinn

POWER SPECTRUM ANALYSIS WITH AN INTERFEROMETER

Image Cube | Native Interferometer | 3D Power spectrum



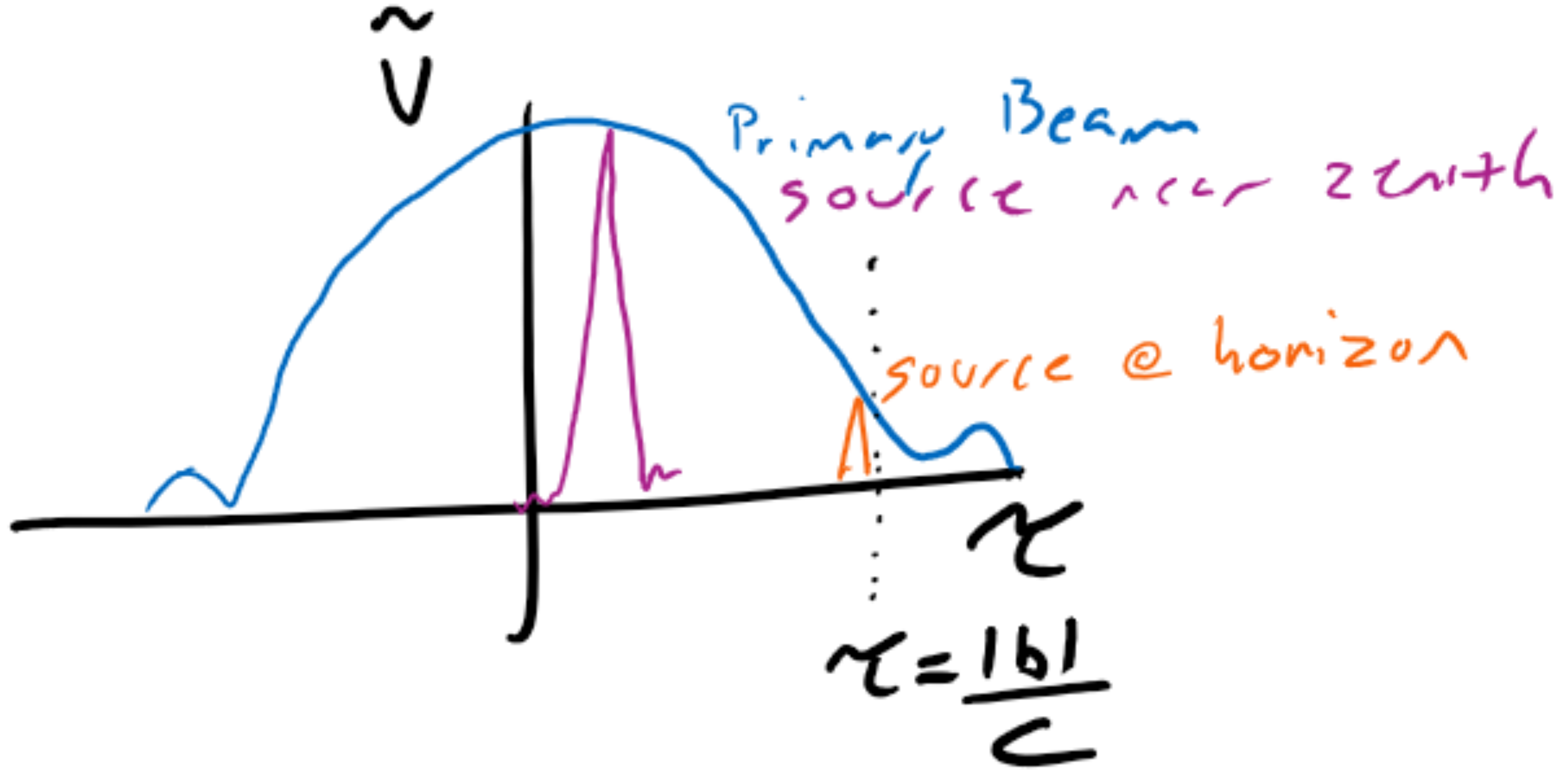




$$V_{ij}(f) = I_s e^{-i 2\pi \vec{b}\cdot\hat{s}/\lambda}$$

$$\Big\downarrow \text{FT}$$

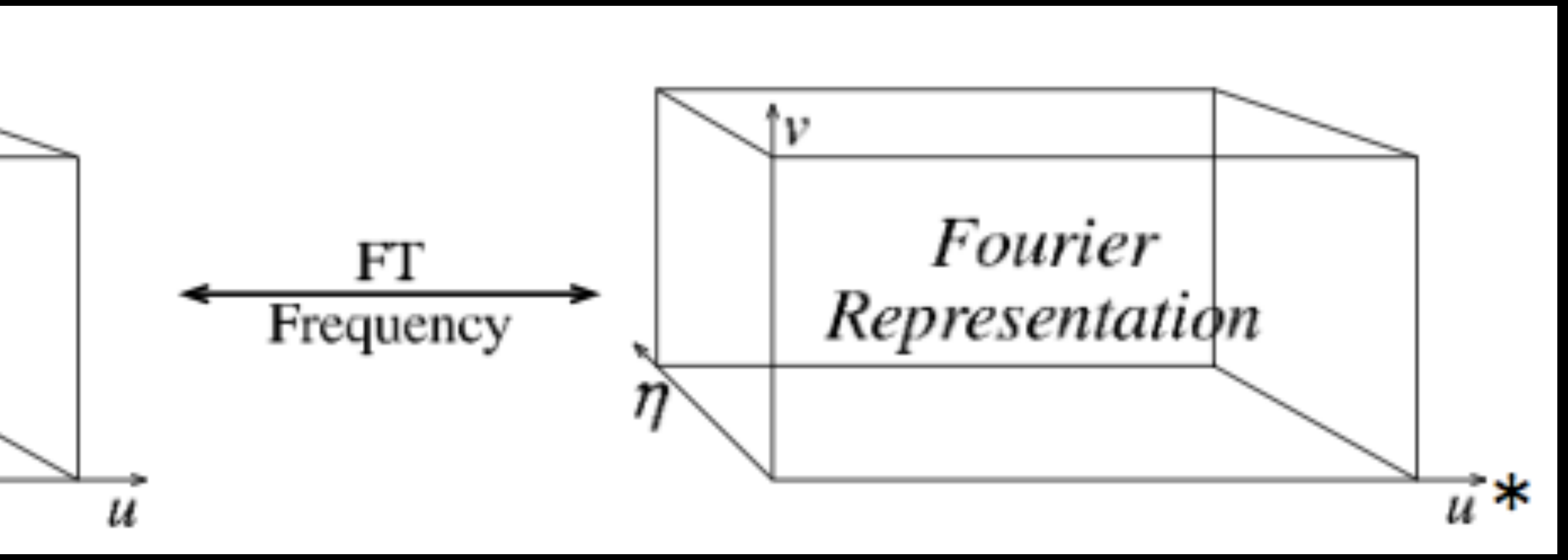
$$\tilde{V}_{ij}(\tau) = I_s\,\delta\left(\frac{\vec{b}\cdot\hat{s}}{\lambda} - \tau\right)$$

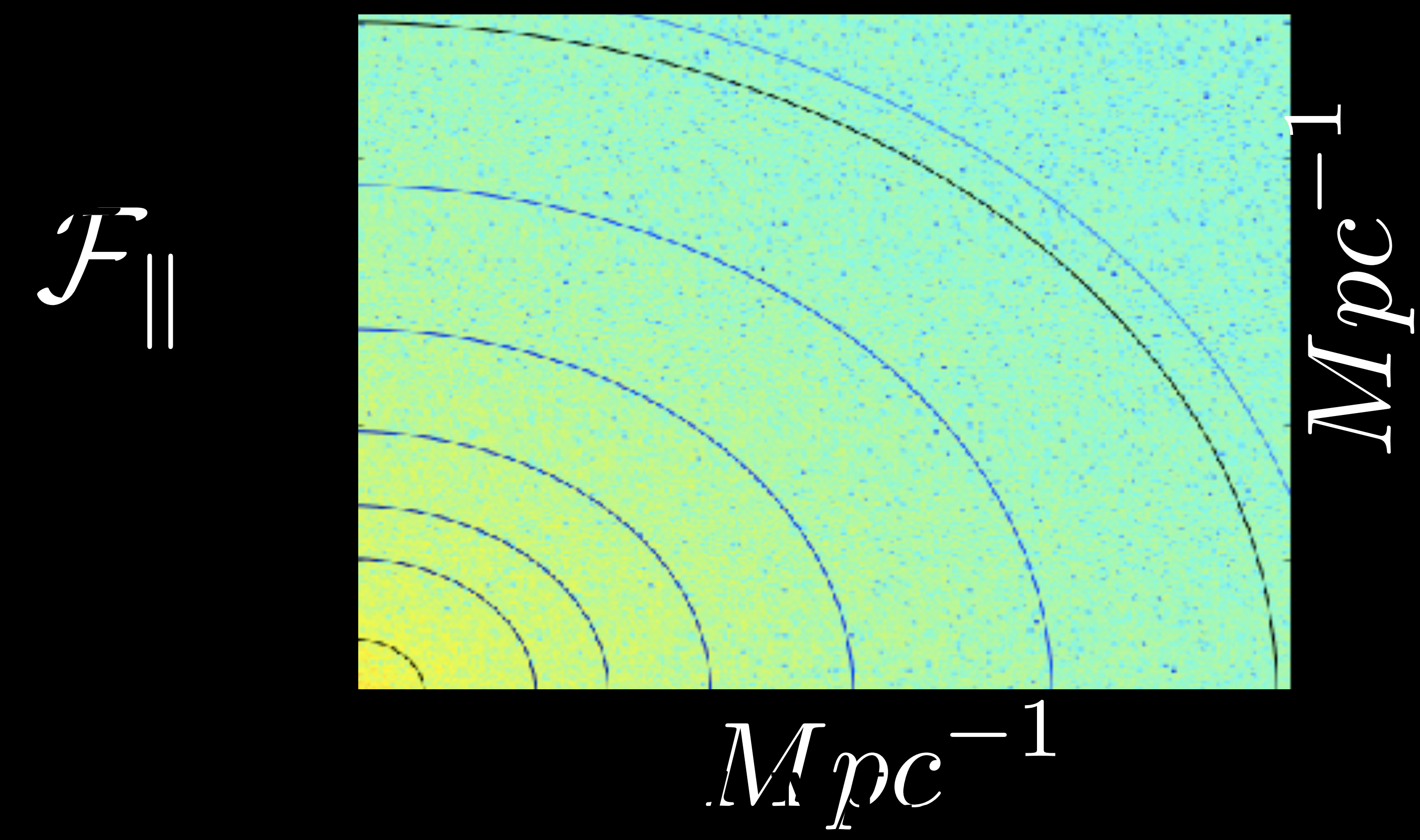


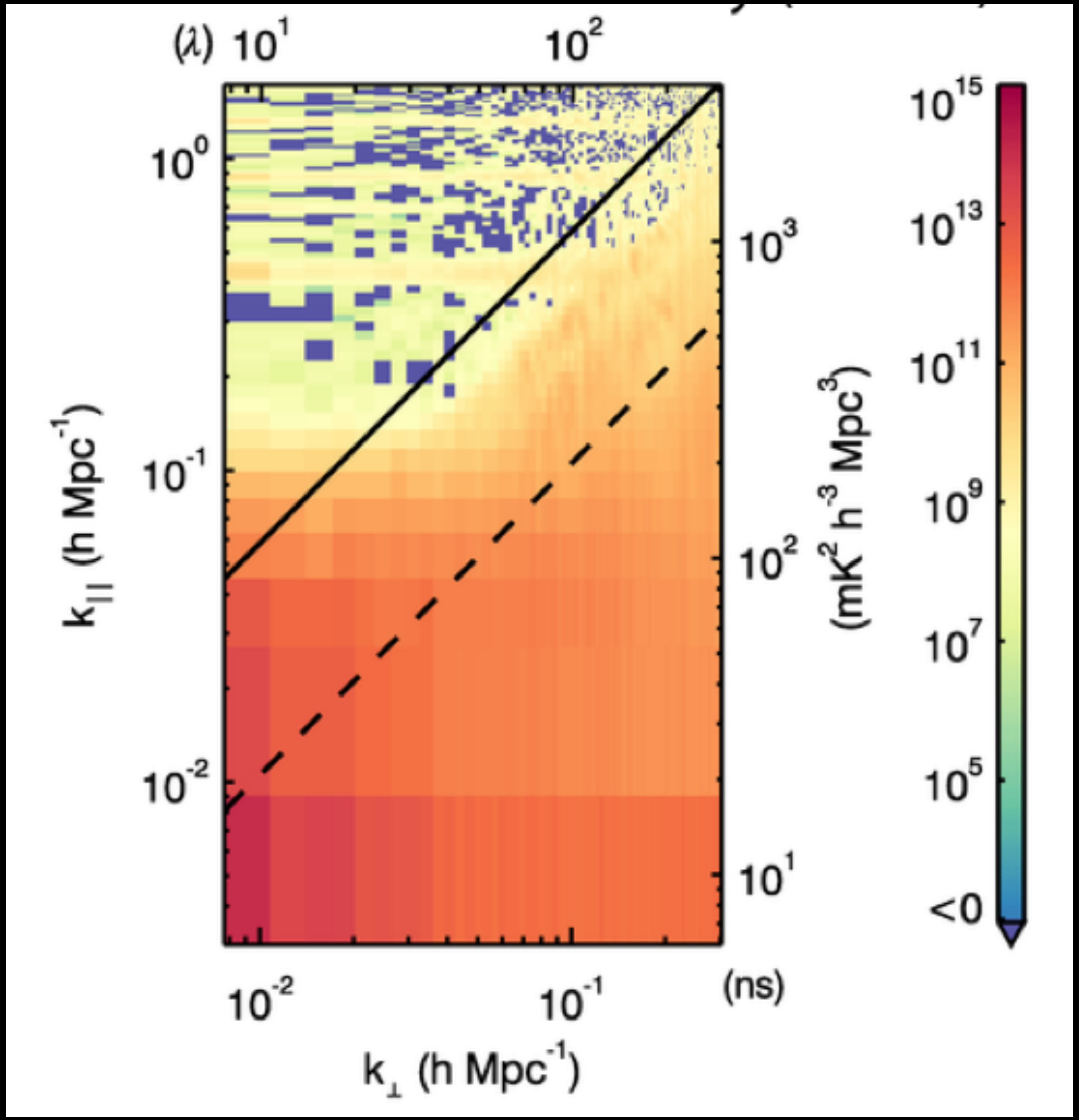
When we do this.

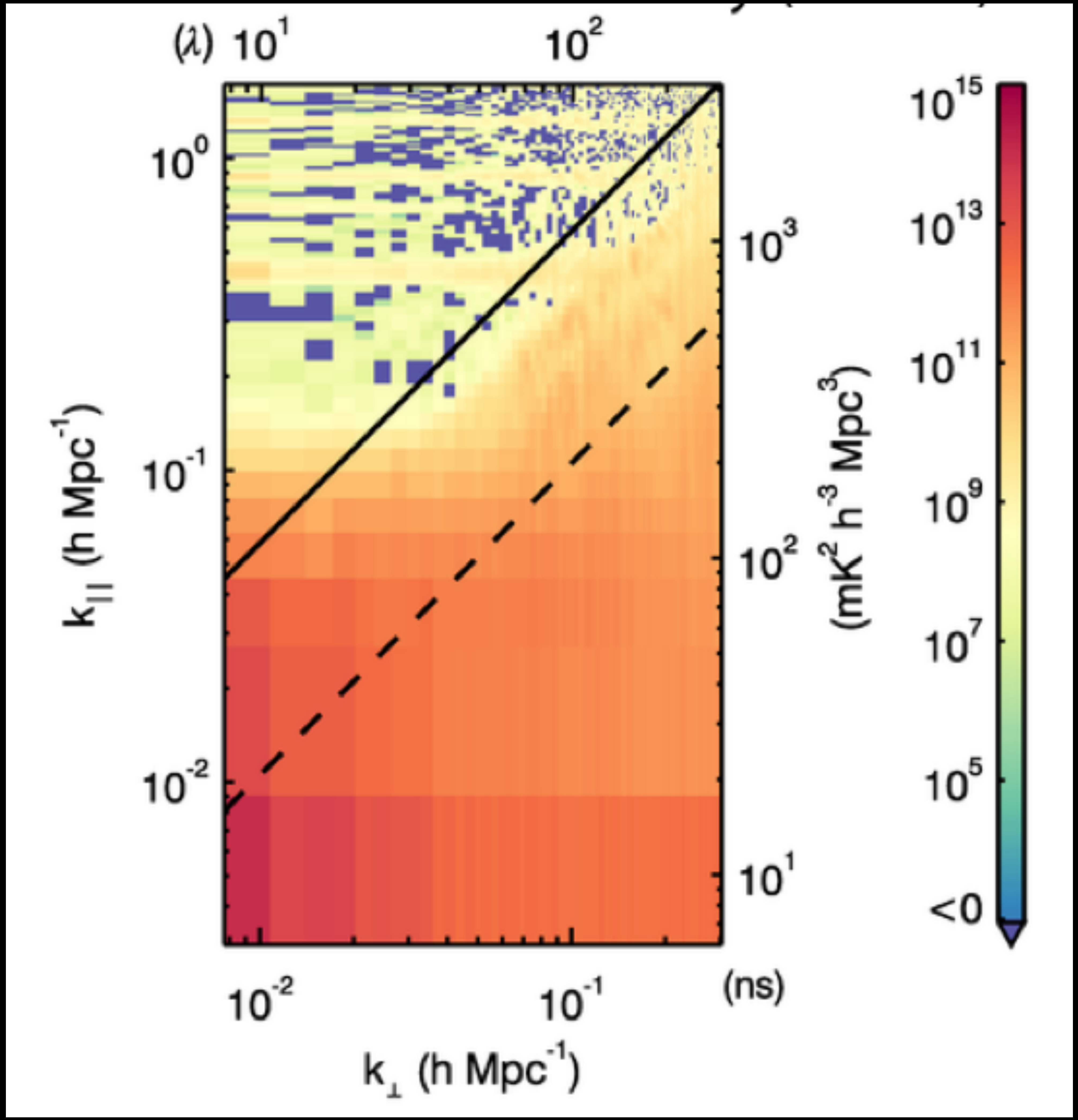
We get this!

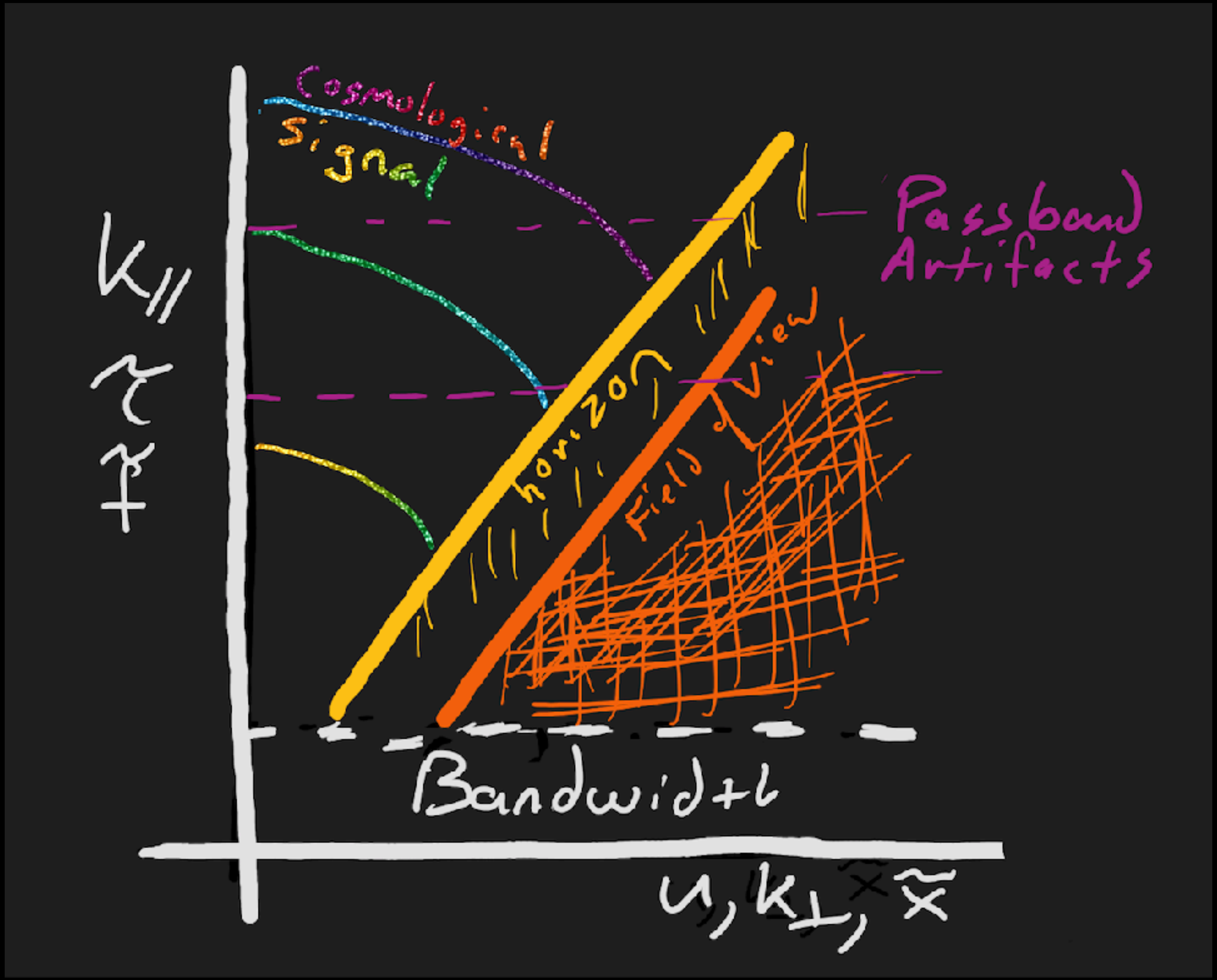
3D Power spectrum



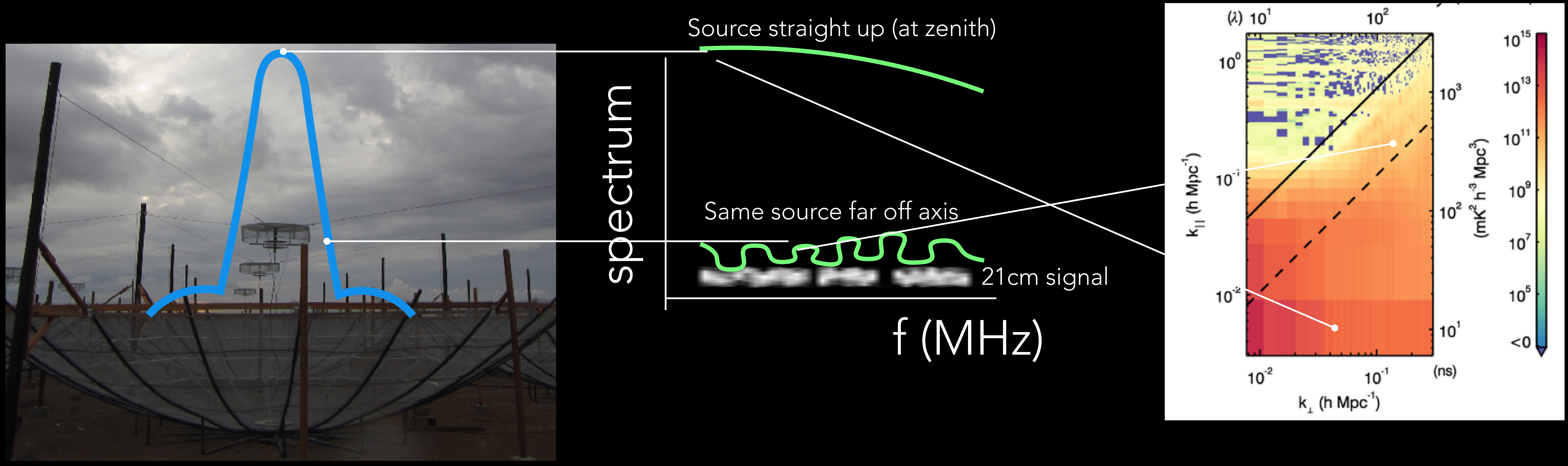




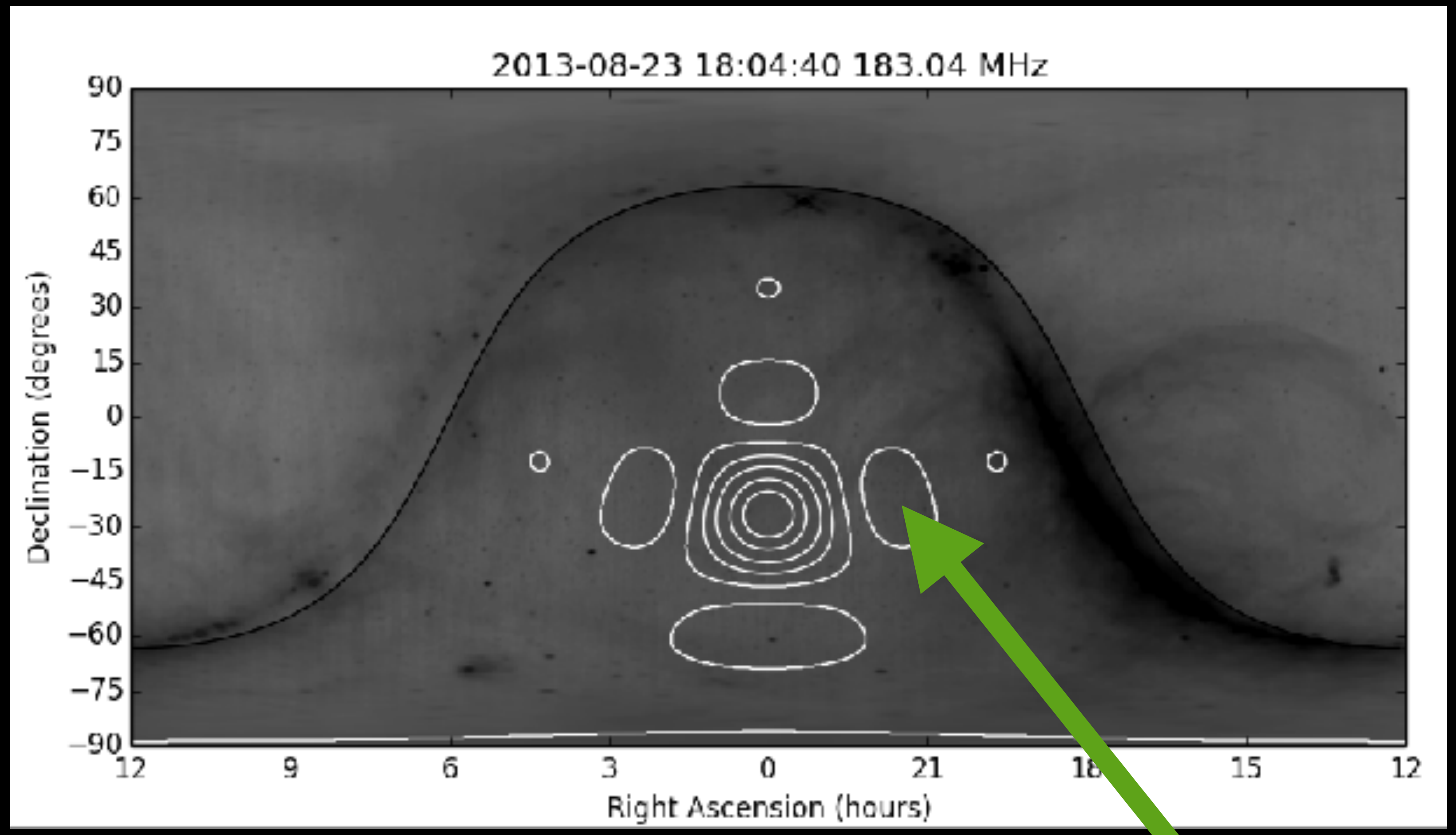

(λ) 10^1 10^2
10^0
10^-1
10^-2
10^3
10^2
10^1
k∥ (h Mpc^-1)
(mK^2 h^-3 Mpc^3)
10^15
10^13
10^11
10^9
10^7
10^5
<0
10^-2 10^-1 (ns)
k⊥ (h Mpc^-1)

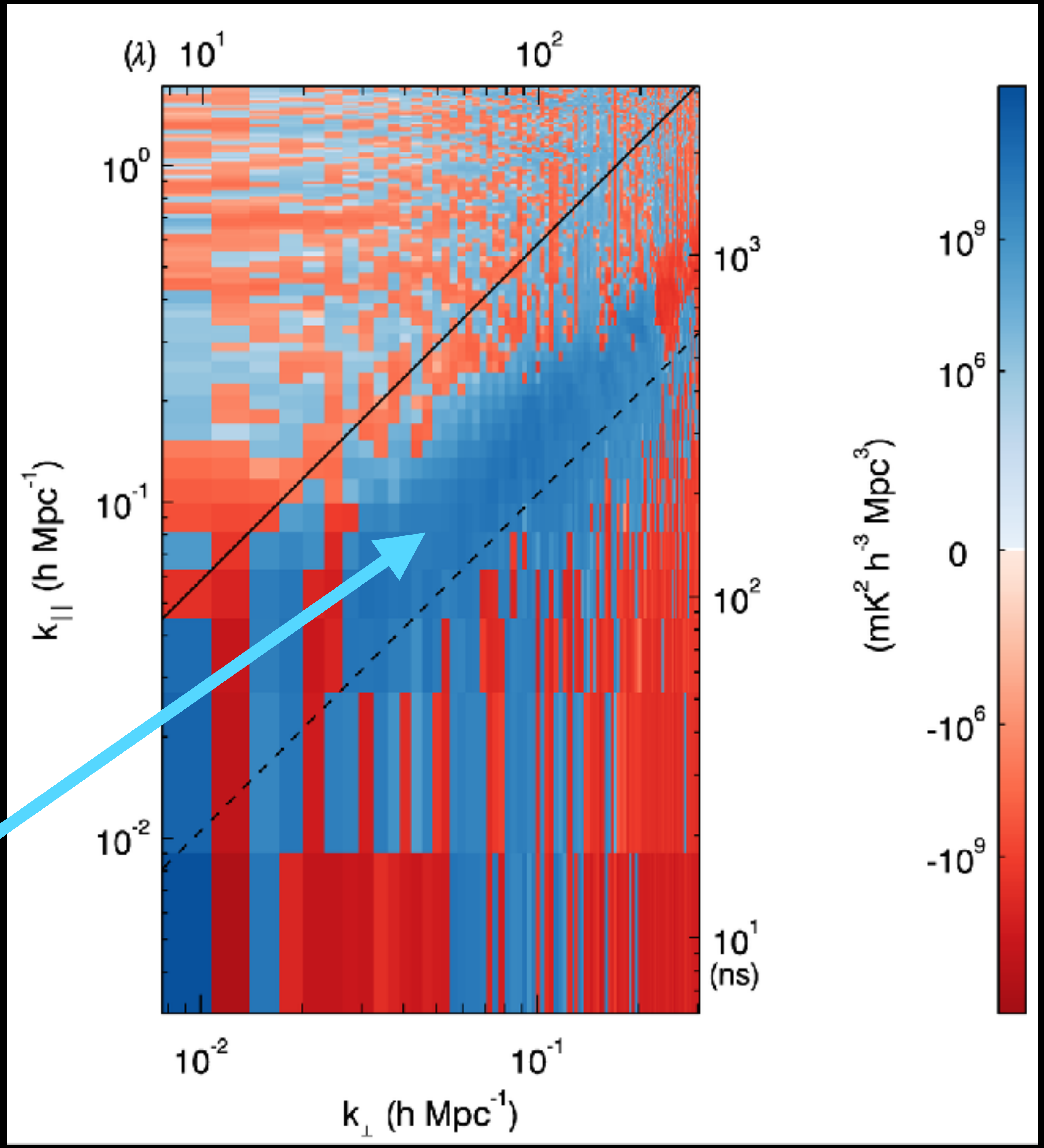

Cosmological
Signal
Passband
Artifacts
horizon
Field of View
Bandwidth
k∥
τ
u, k⊥, x̃

Beam Maps necessary for foreground subtraction



IF WE HAVE PRECISION BEAM MAPS WE CAN DO BETTER!

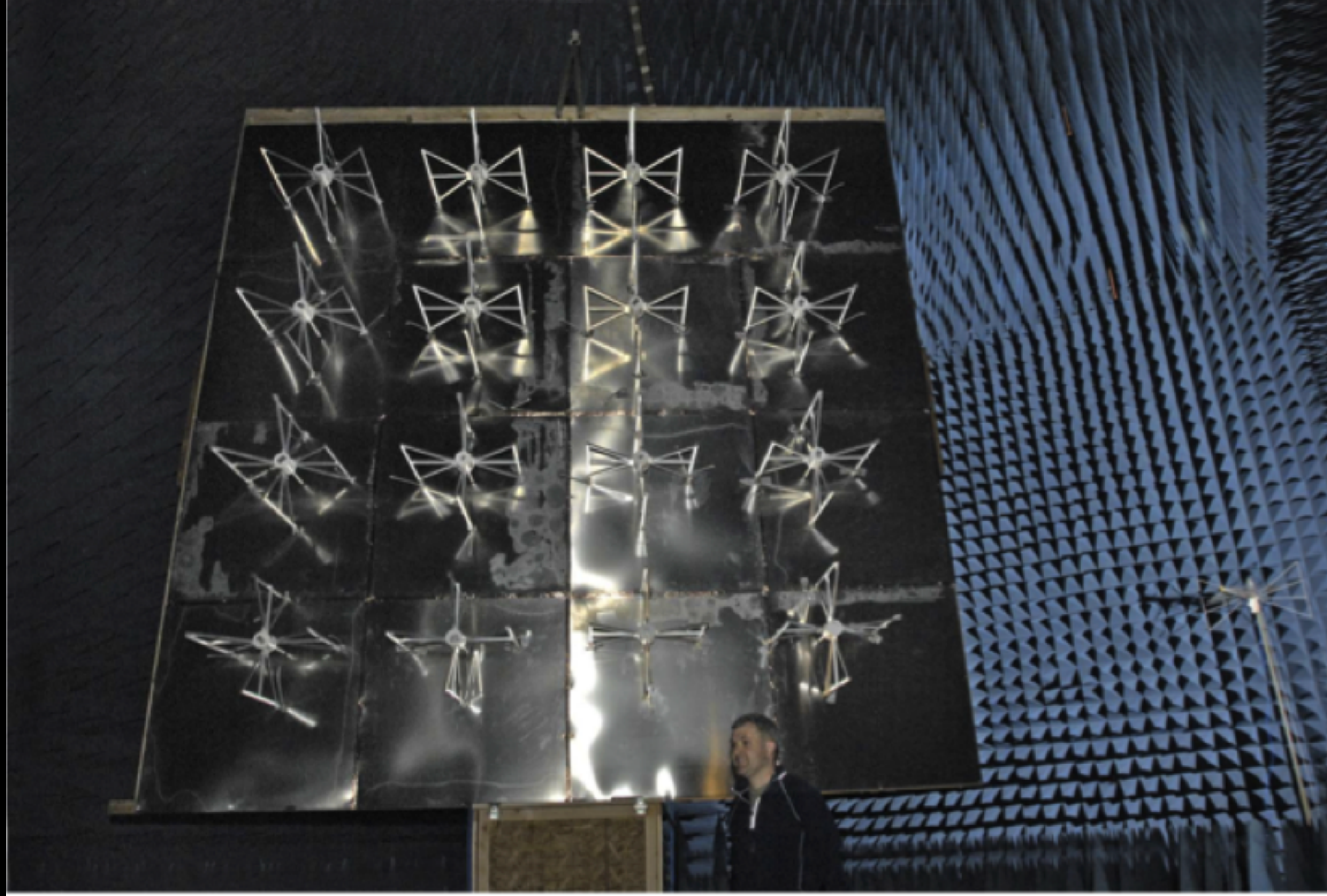


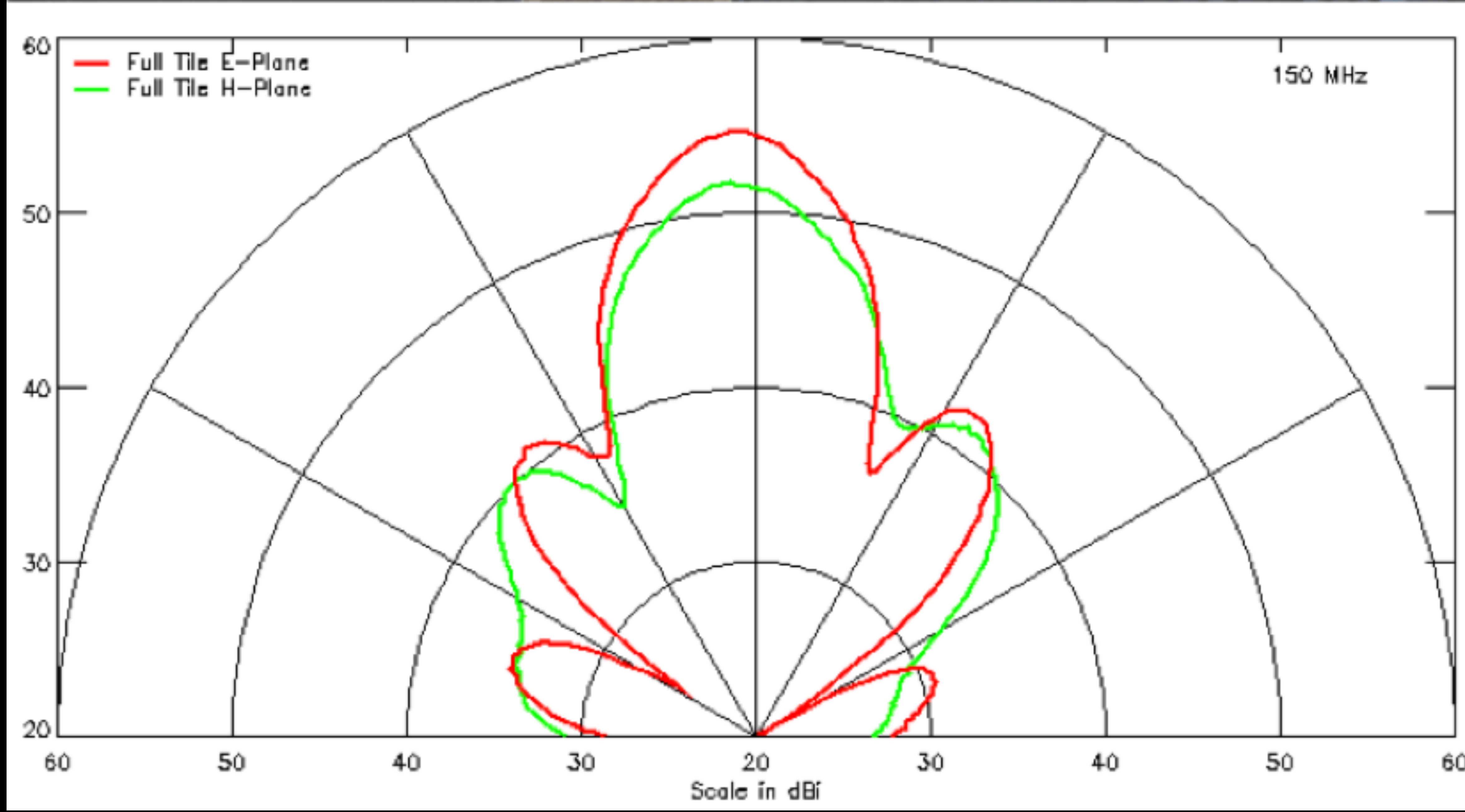


Subtracting sources in **sidelobes** reduces power in **wedge**

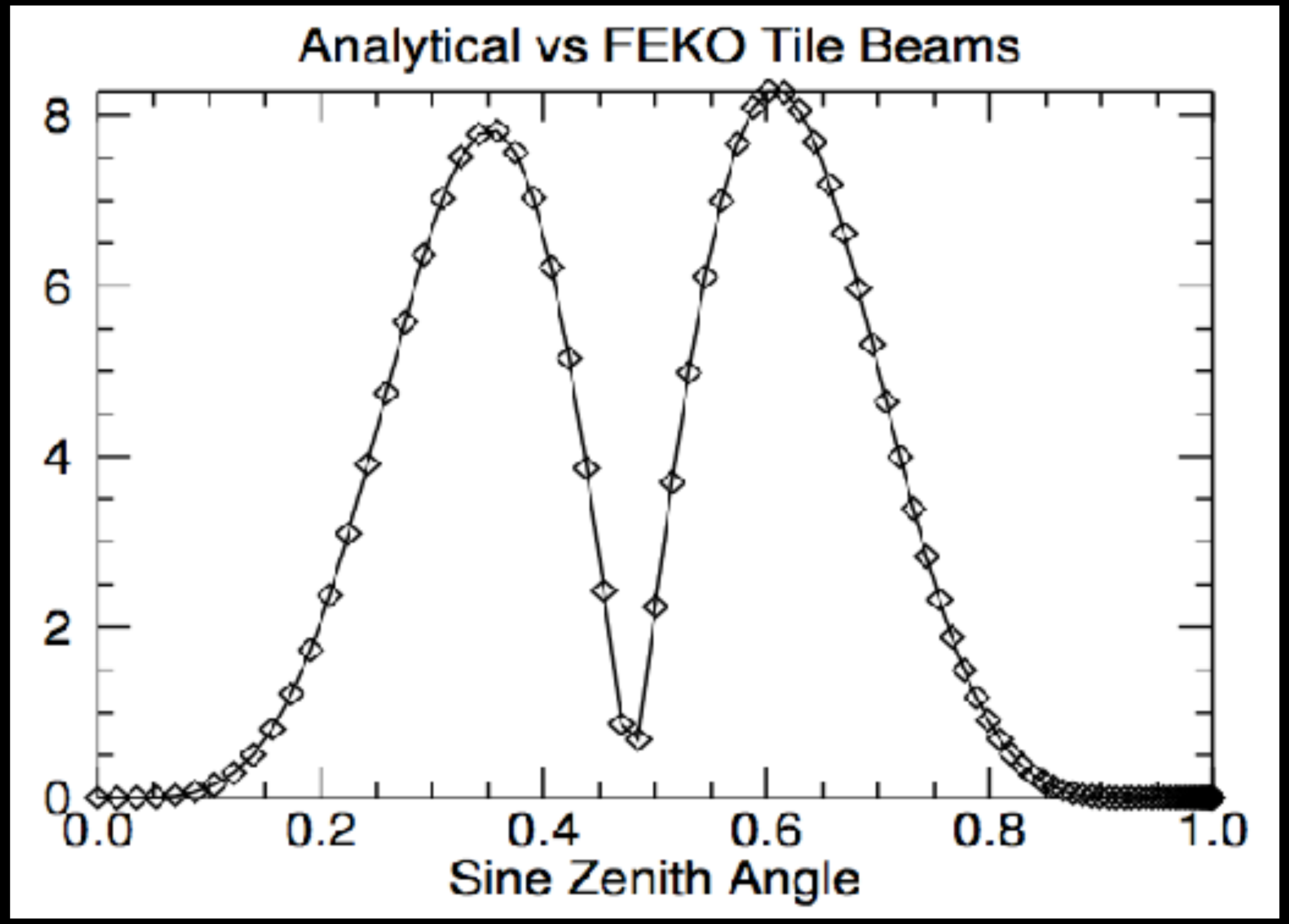
Pober et al. 2015

ANECHOIC CHAMBER MEASUREMENTS OF MWA TILE



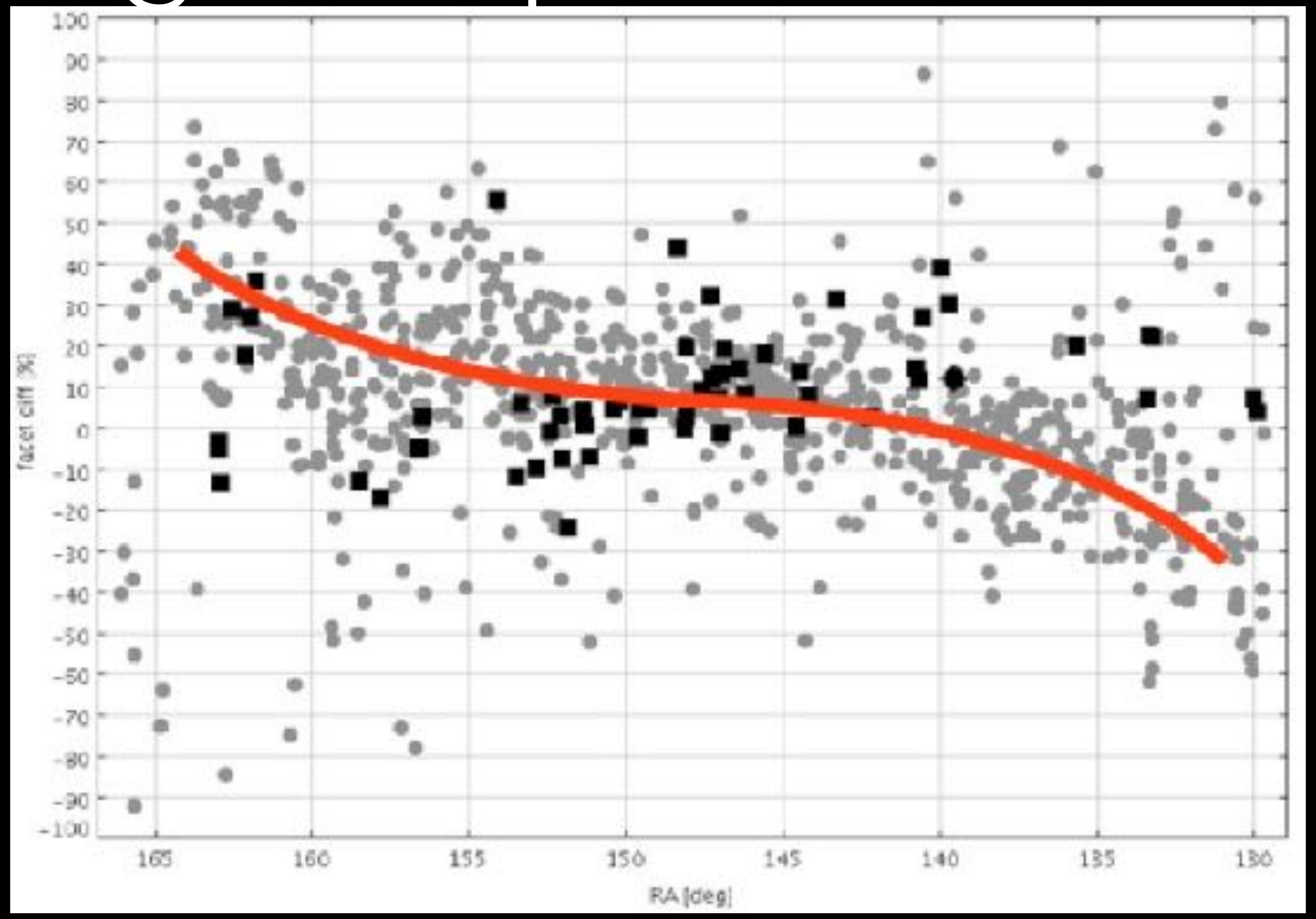


Model Variance



Analysis by Ben McKinley et al

Catalog Comparison

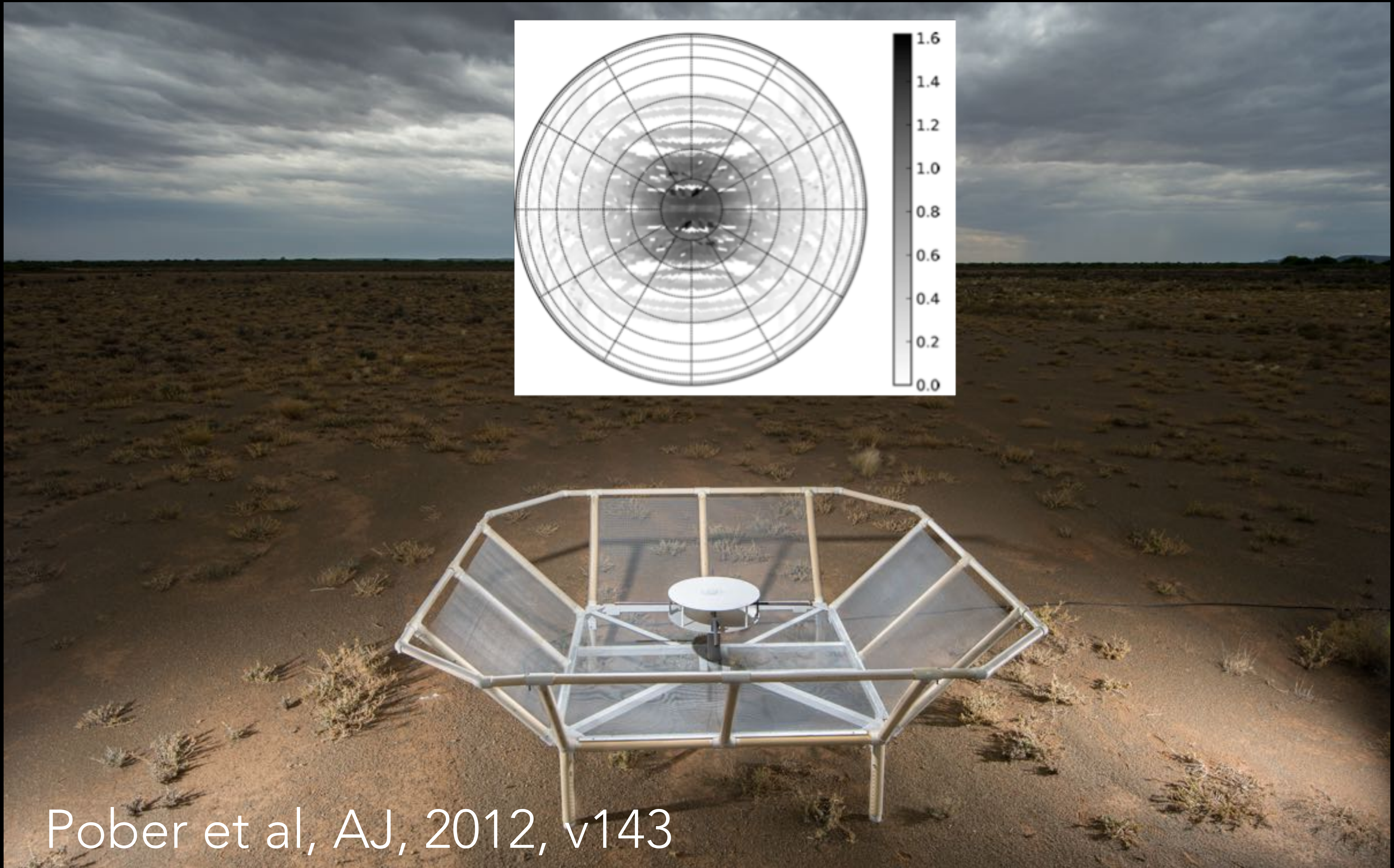


Beam Error

Jacobs et al 2013

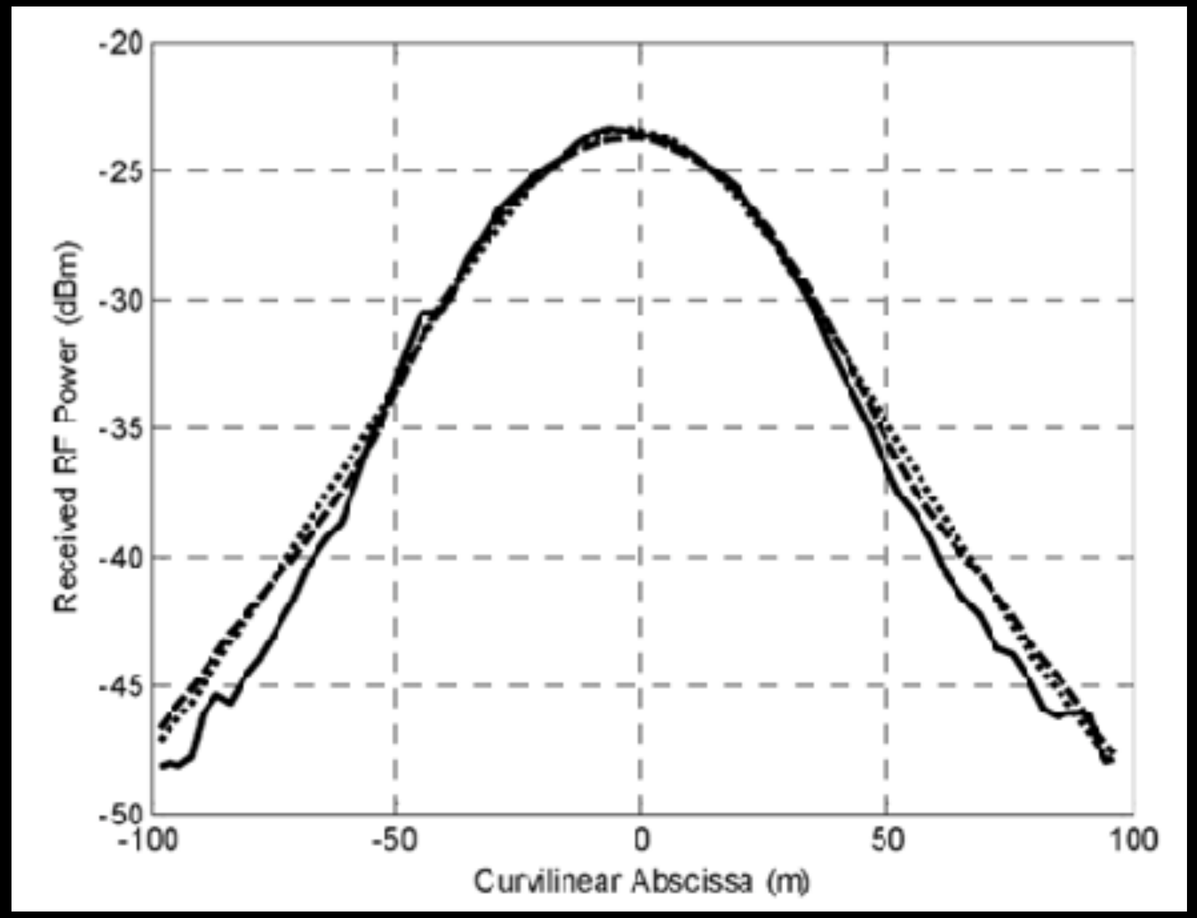
see also Sutinjo et al, Rad Sci, 2015

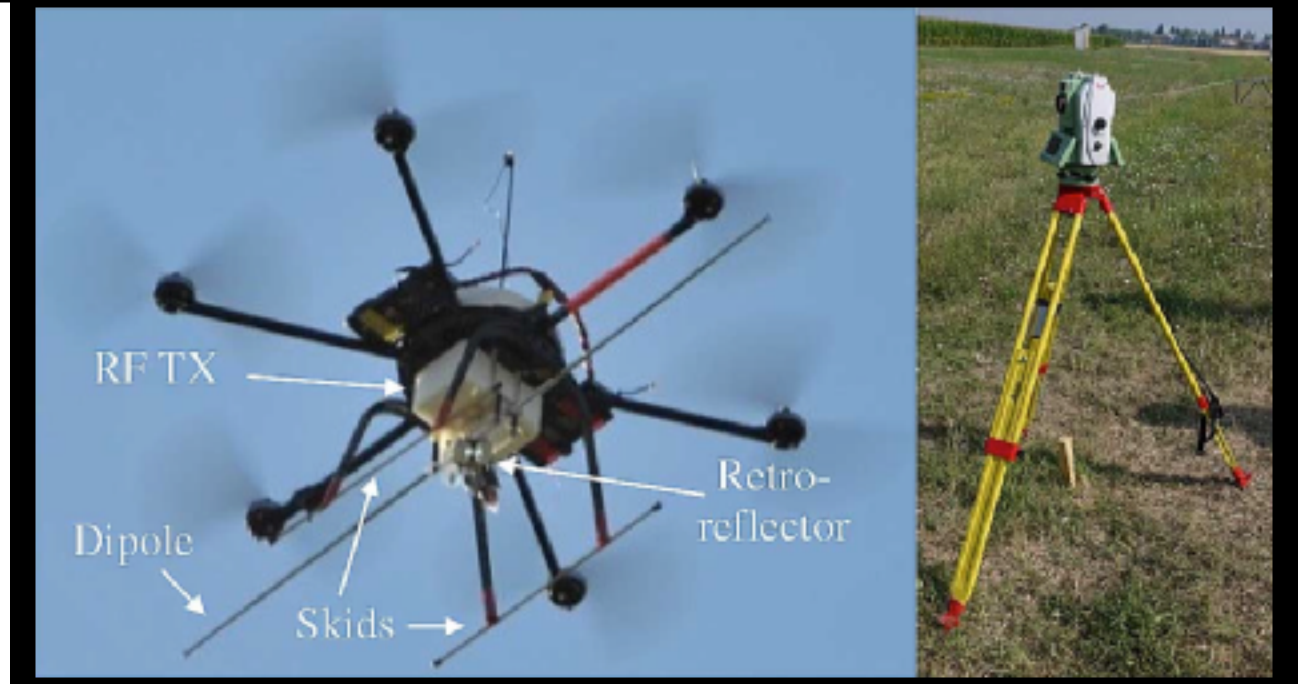
USING SKY SOURCES - LIMITED BY EAST-WEST SYMMETRY

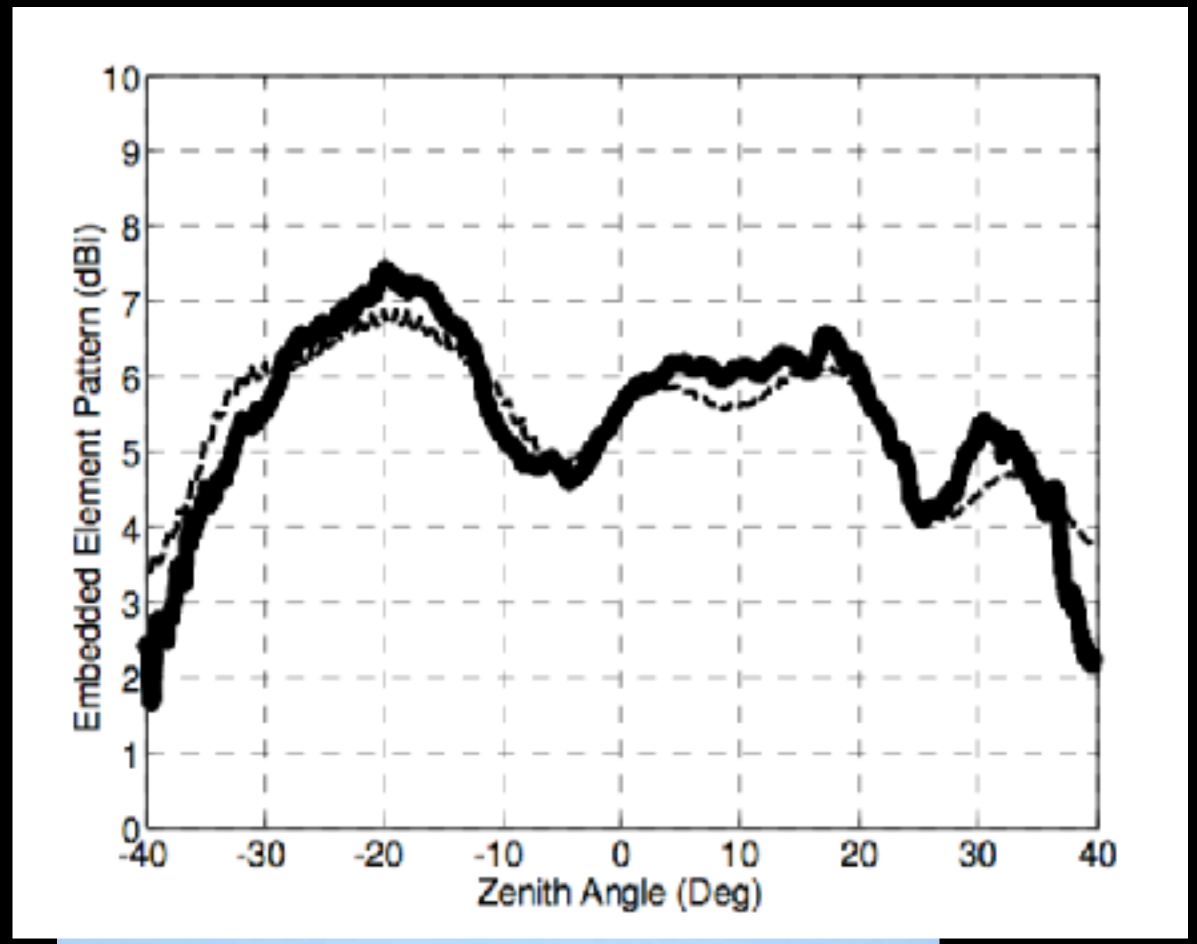


Pober et al, AJ, 2012, v143

SKA Aperture Array Verification Program





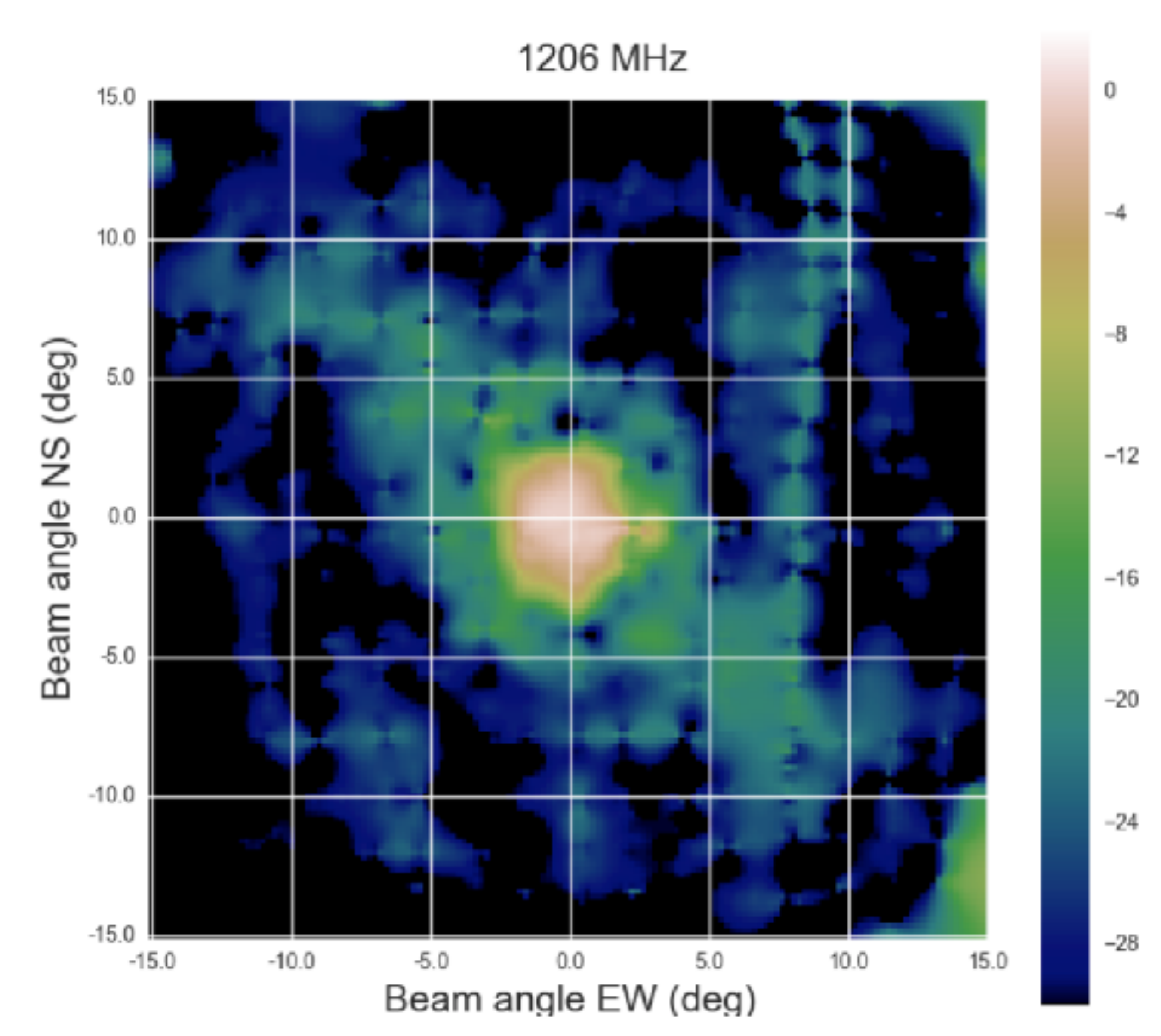


virone et al IEEE AWPL, 2014

virone et al APS IEEE, 2014

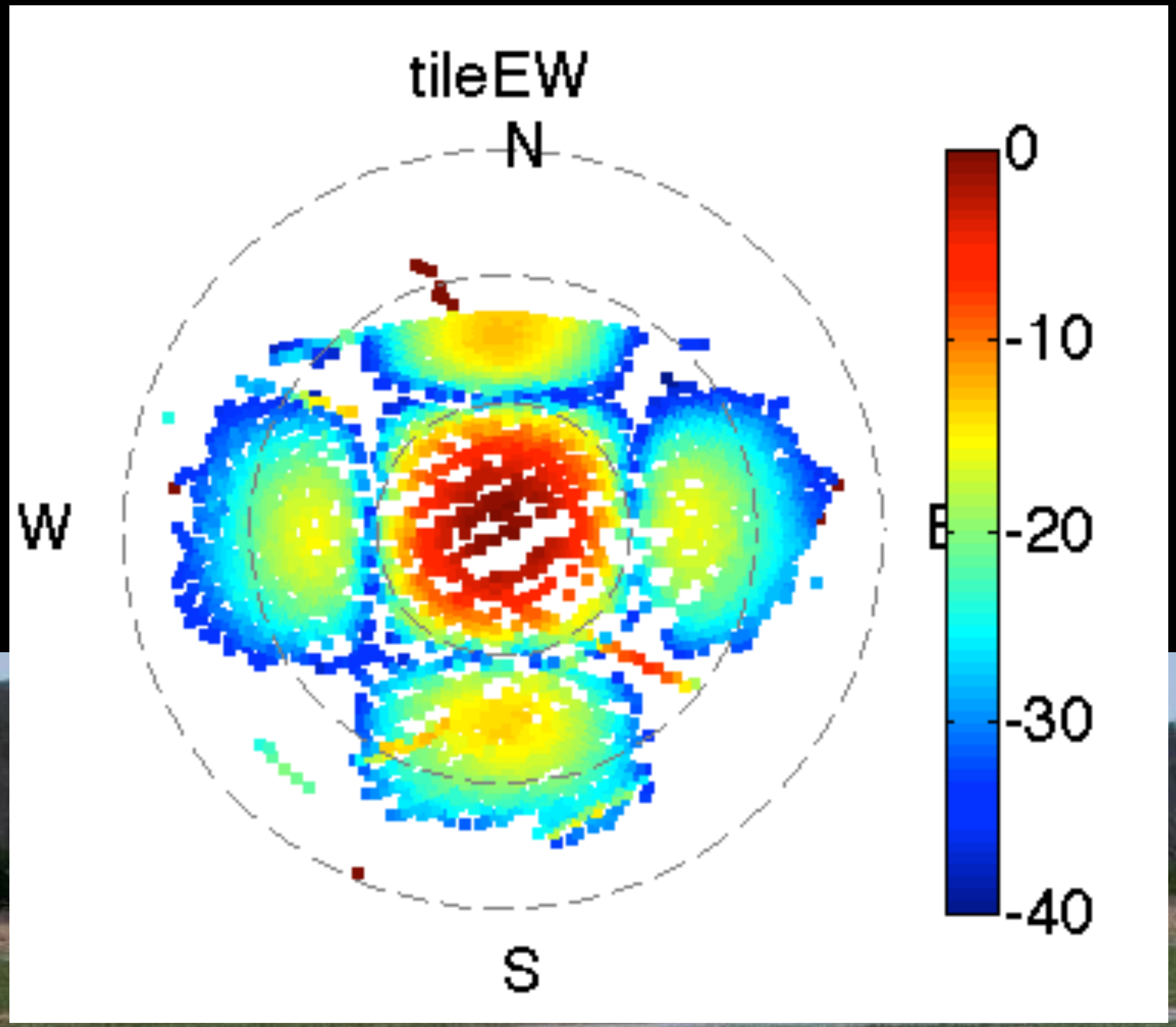
Chang et al arxiv:1505.05885

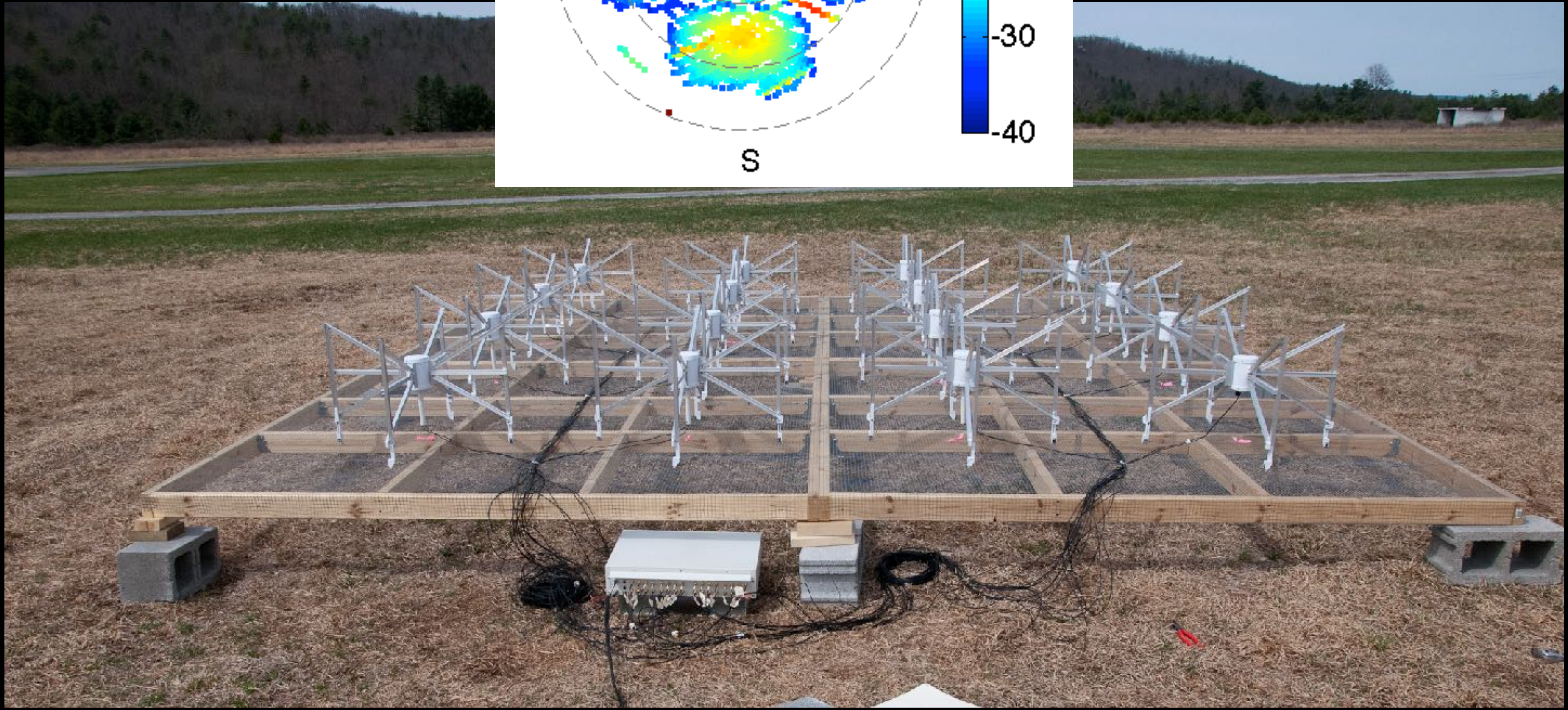
~1GHz



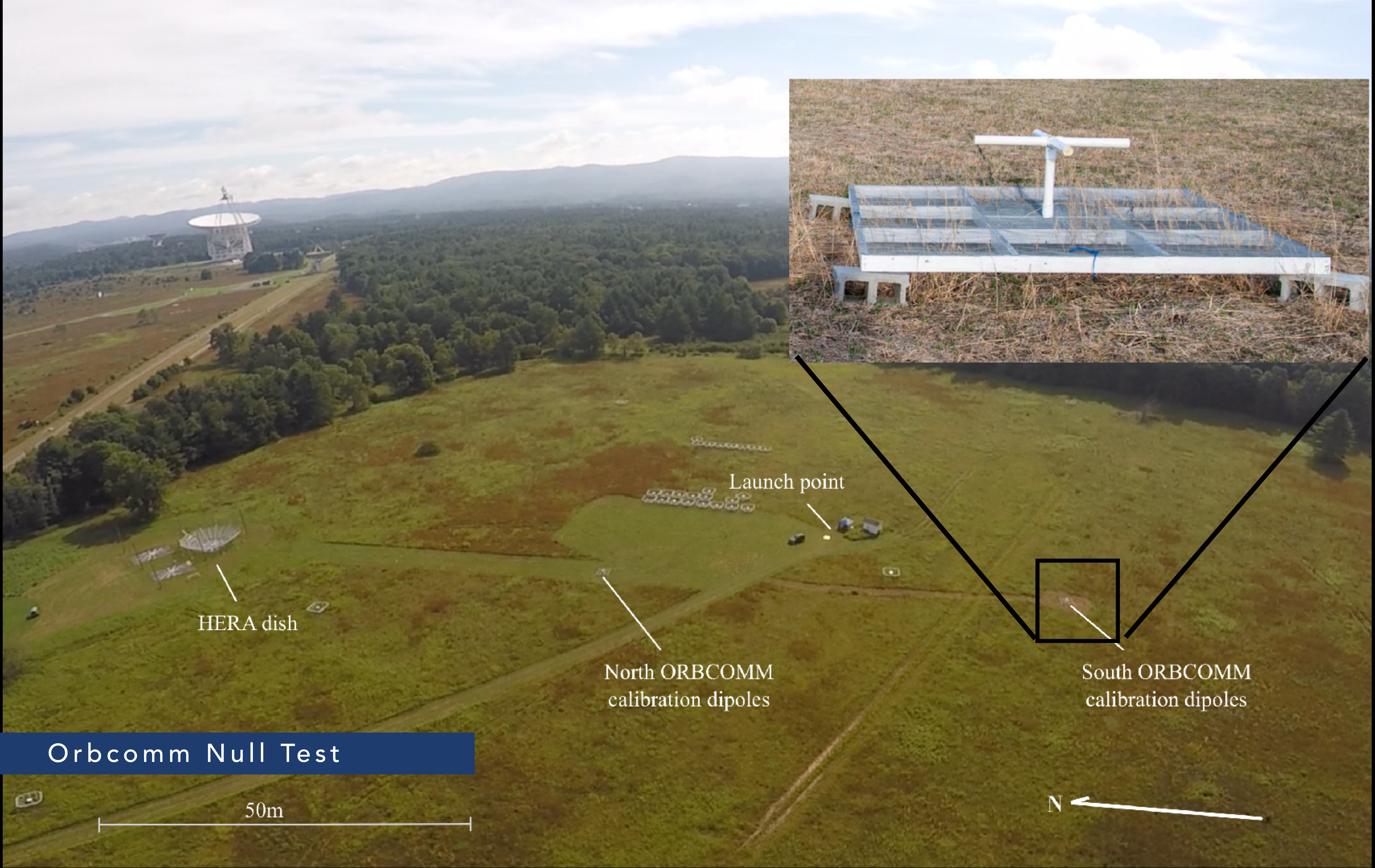
Using ORBCOMM

Neben et al Radio Science, 2015, vol 50

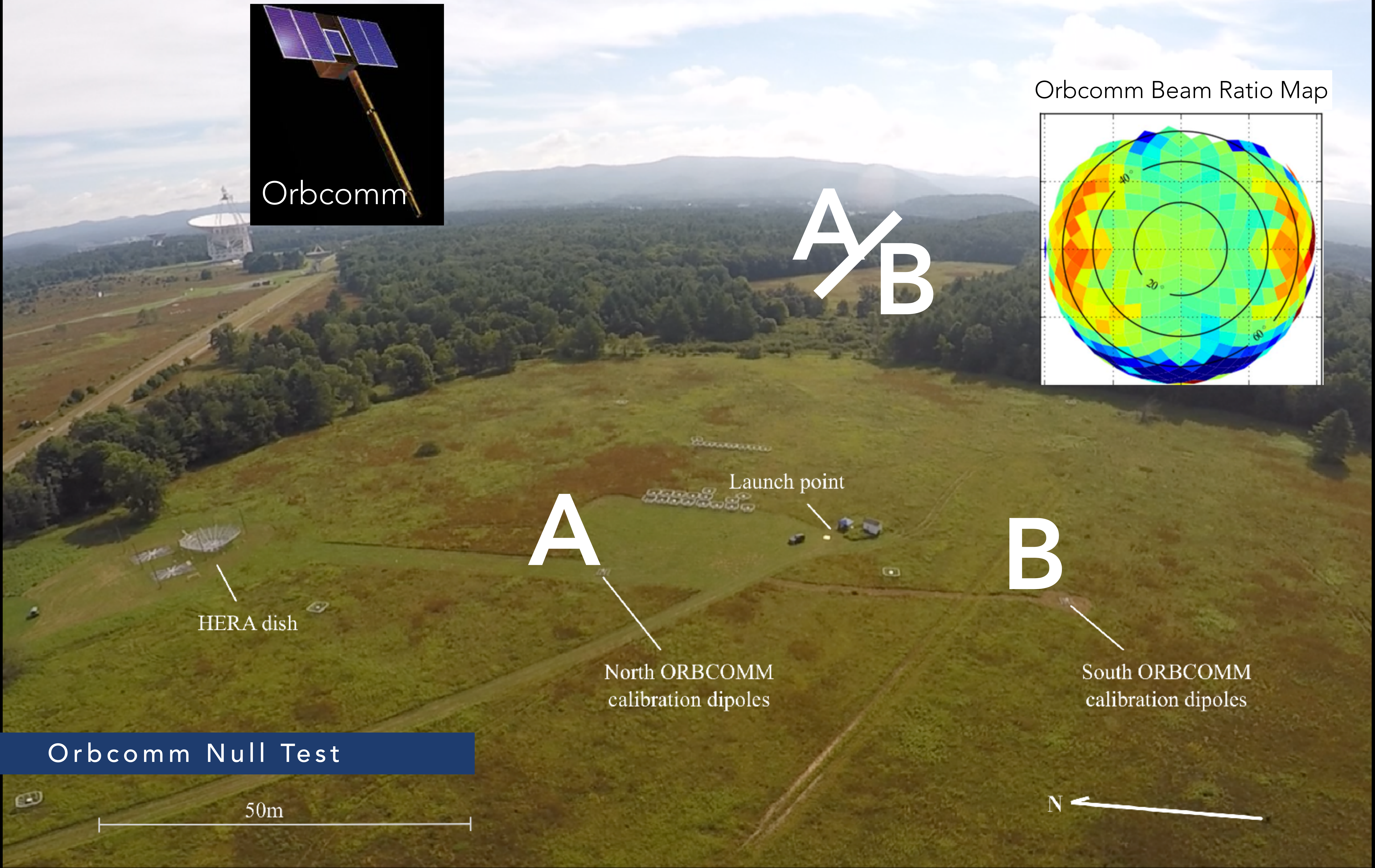




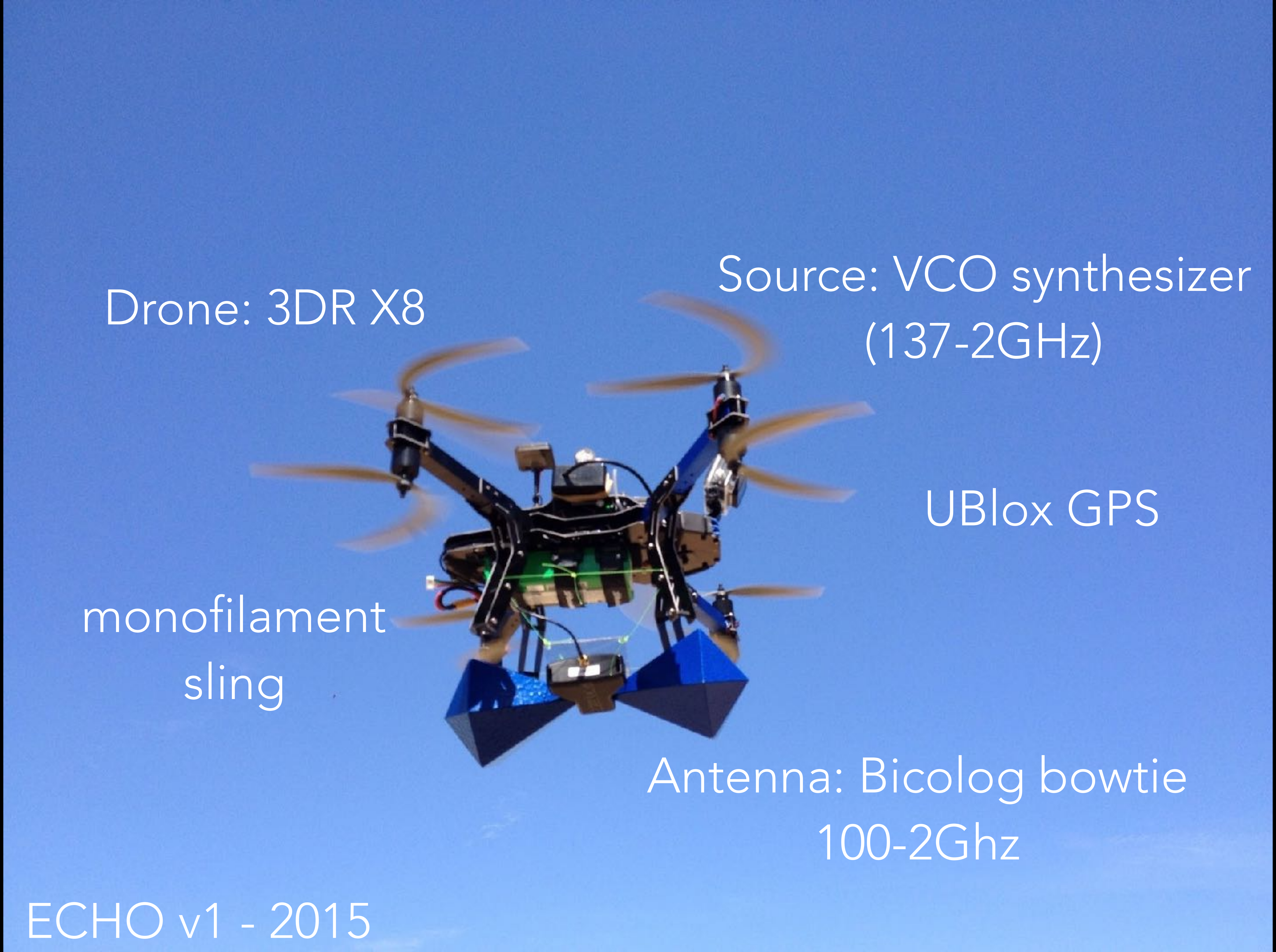
Orbcomm Null Test

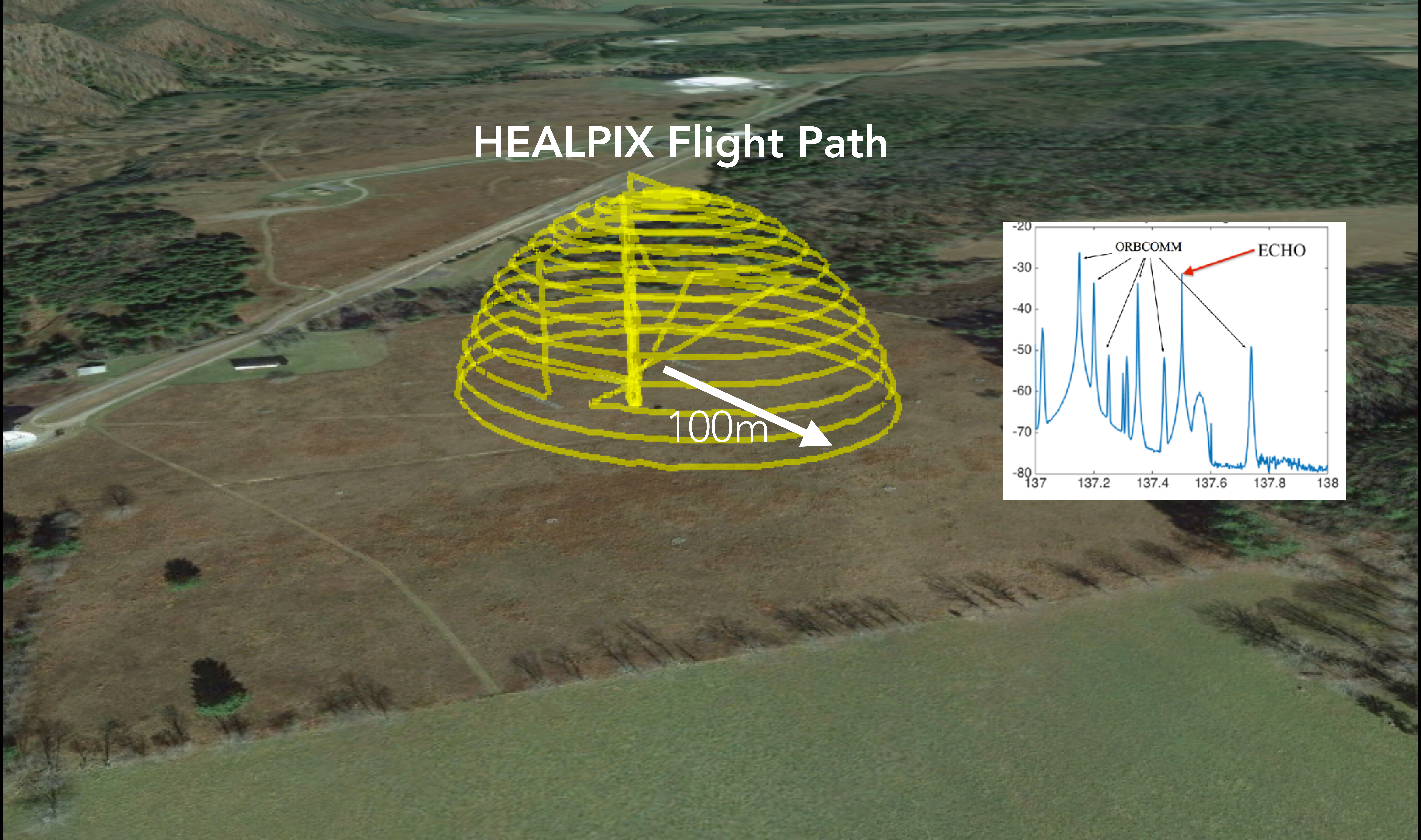


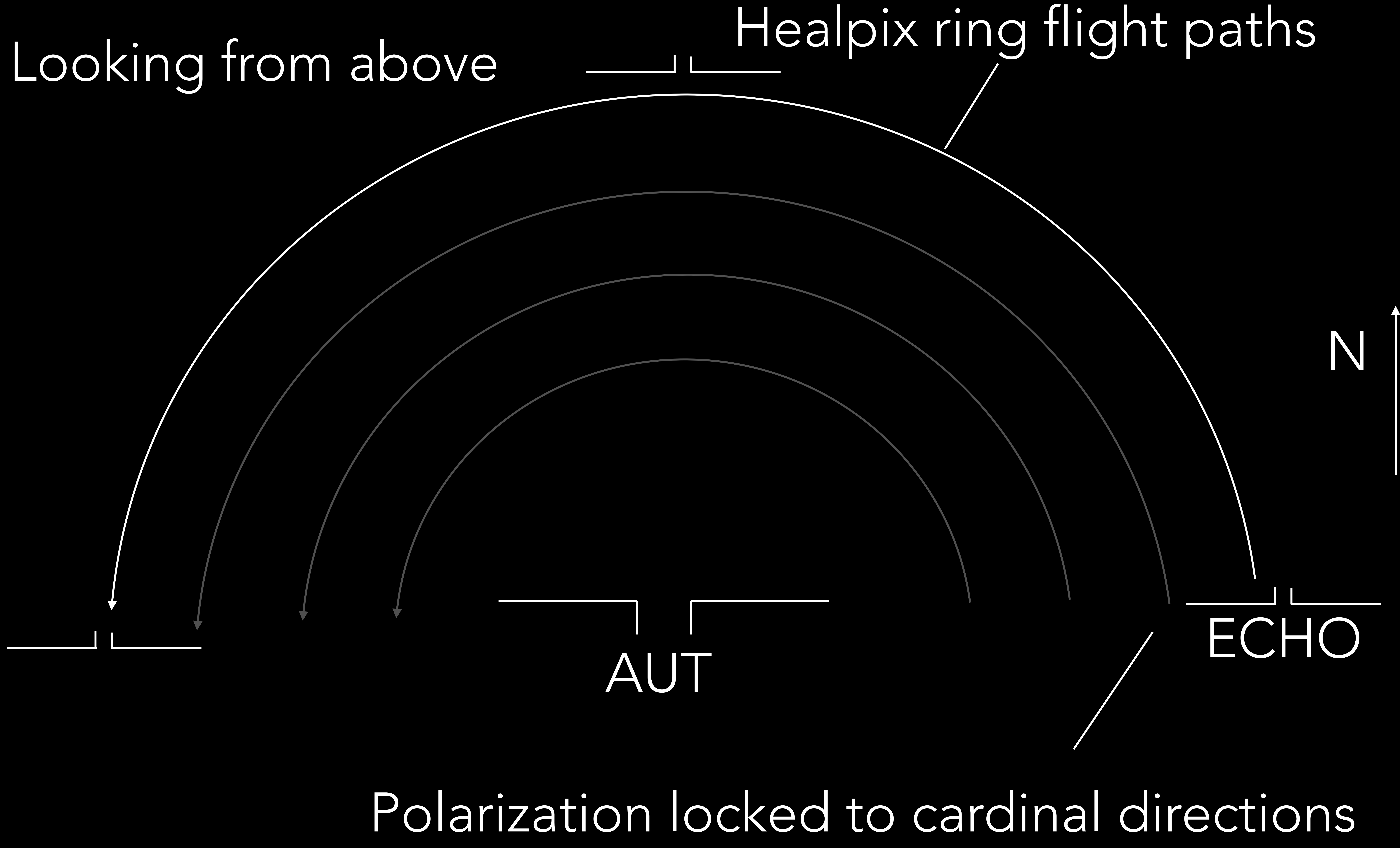
Orbcomm Null Test



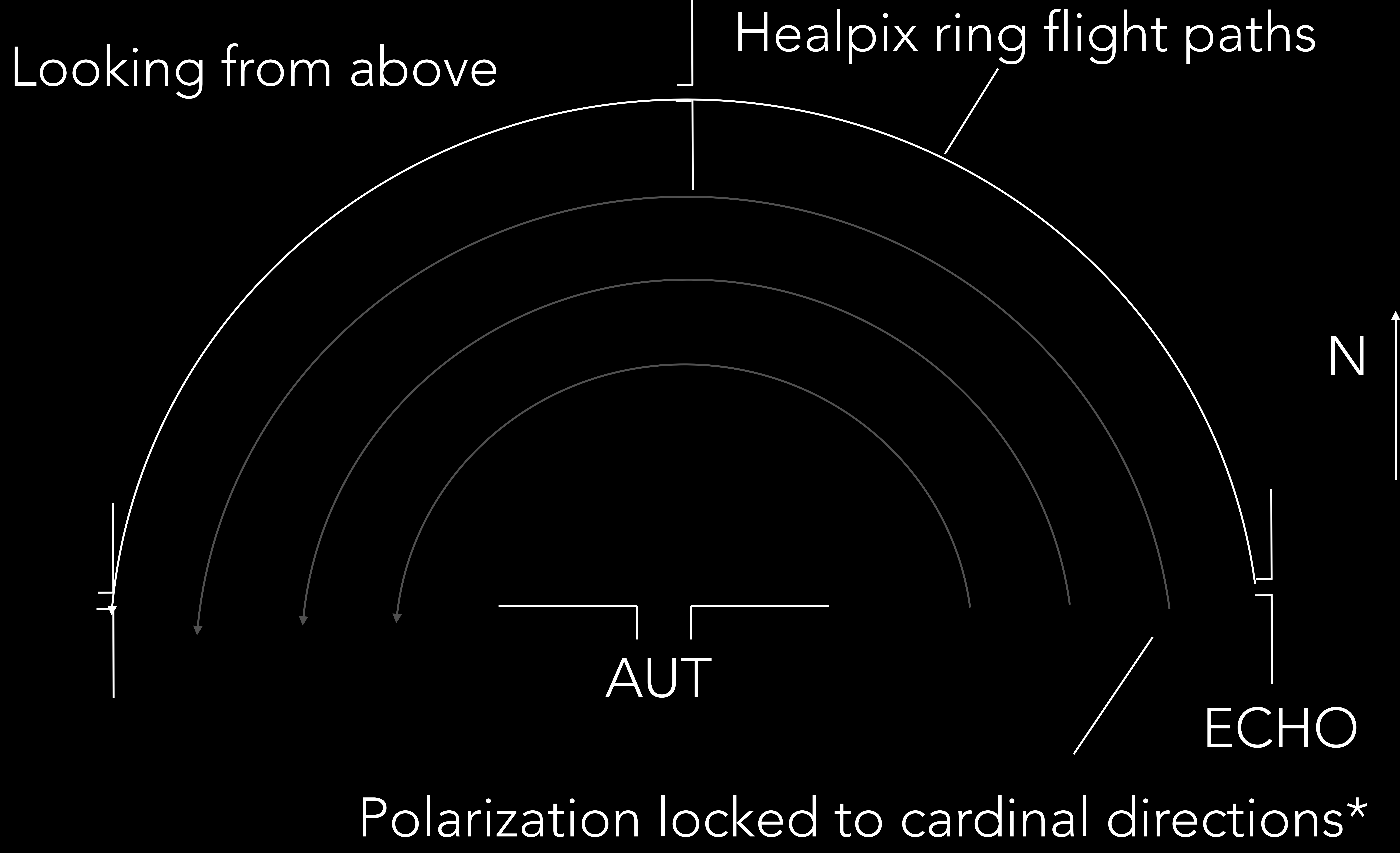
Orbcomm Null Test


Drone: 3DR X8
Source: VCO synthesizer
(137-2GHz)
UBlox GPS
monofilament
sling
Antenna: Bicolog bowtie
100-2Ghz
ECHO v1 - 2015

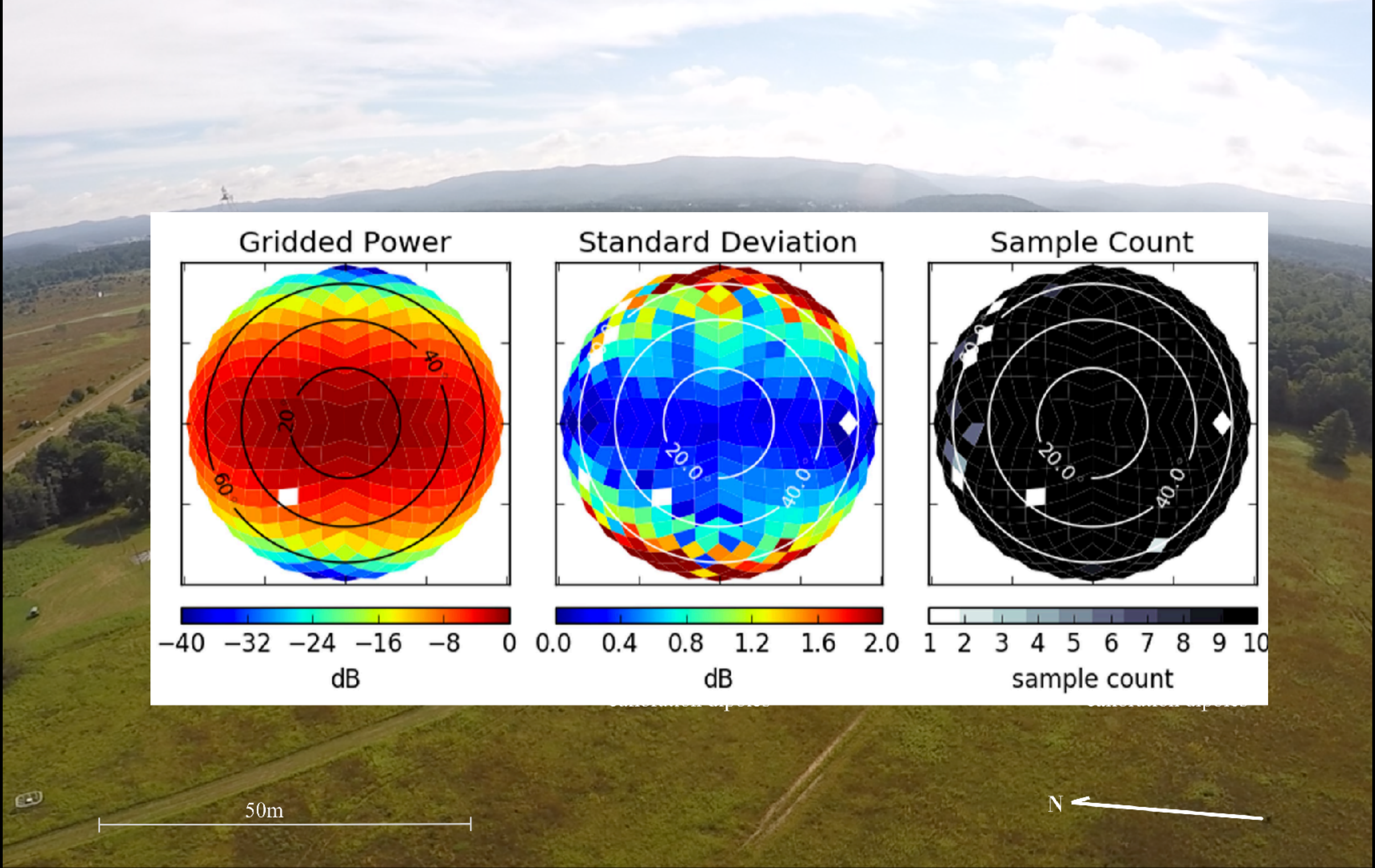

HEALPIX Flight Path
100m
ORBCOMM
ECHO
-20
-30
-40
-50
-60
-70
-80
137
137.2
137.4
137.6
137.8
138



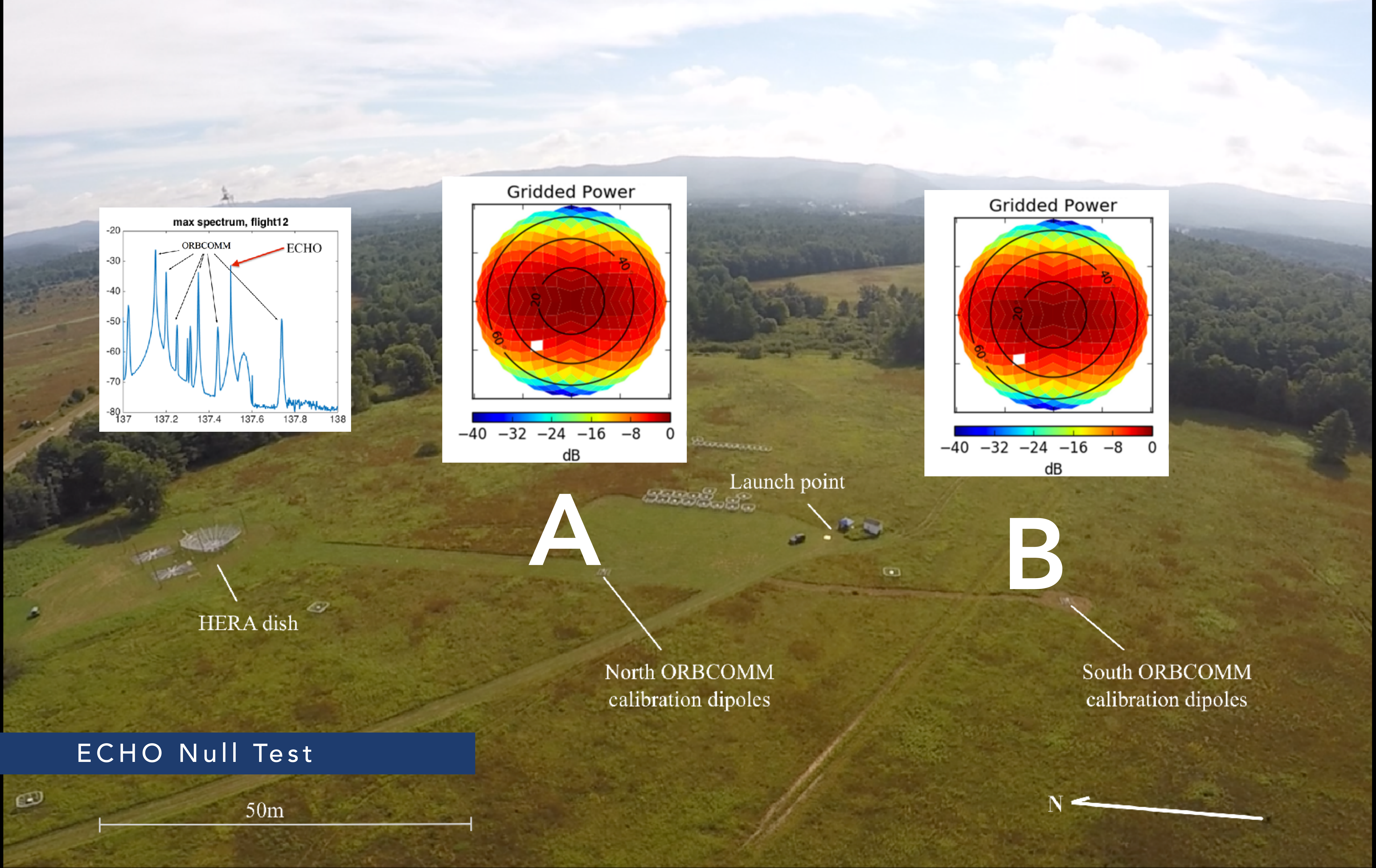
Healpix ring flight paths
Looking from above
N
AUT
ECHO
Polarization locked to cardinal directions



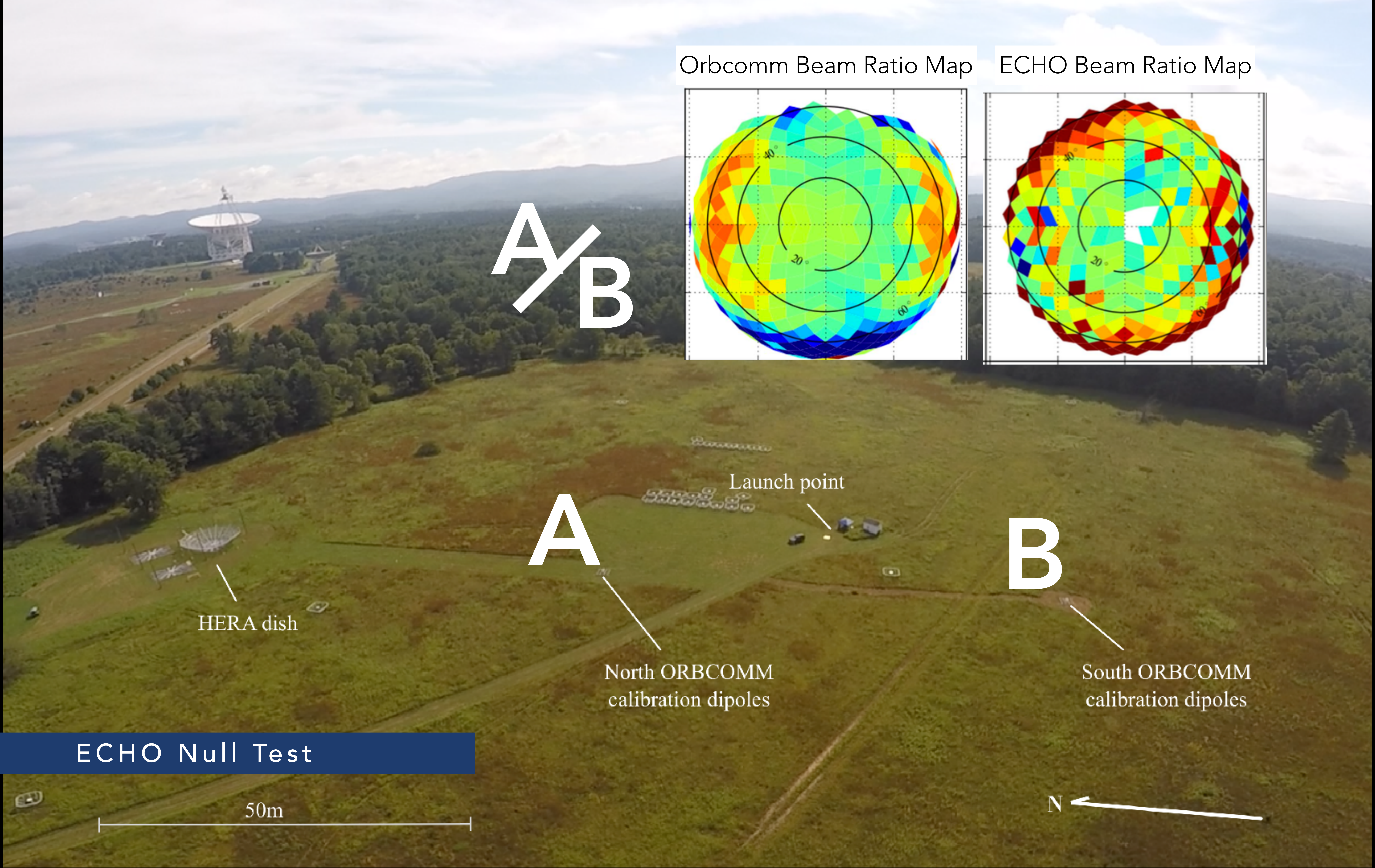
*does not give equal weight to all pols at all sky locations


Gridded Power
Standard Deviation
Sample Count
20
40
60
20.0°
40.0°
−40 −32 −24 −16 −8 0
dB
0.0 0.4 0.8 1.2 1.6 2.0
dB
1 2 3 4 5 6 7 8 9 10
sample count
50m
N

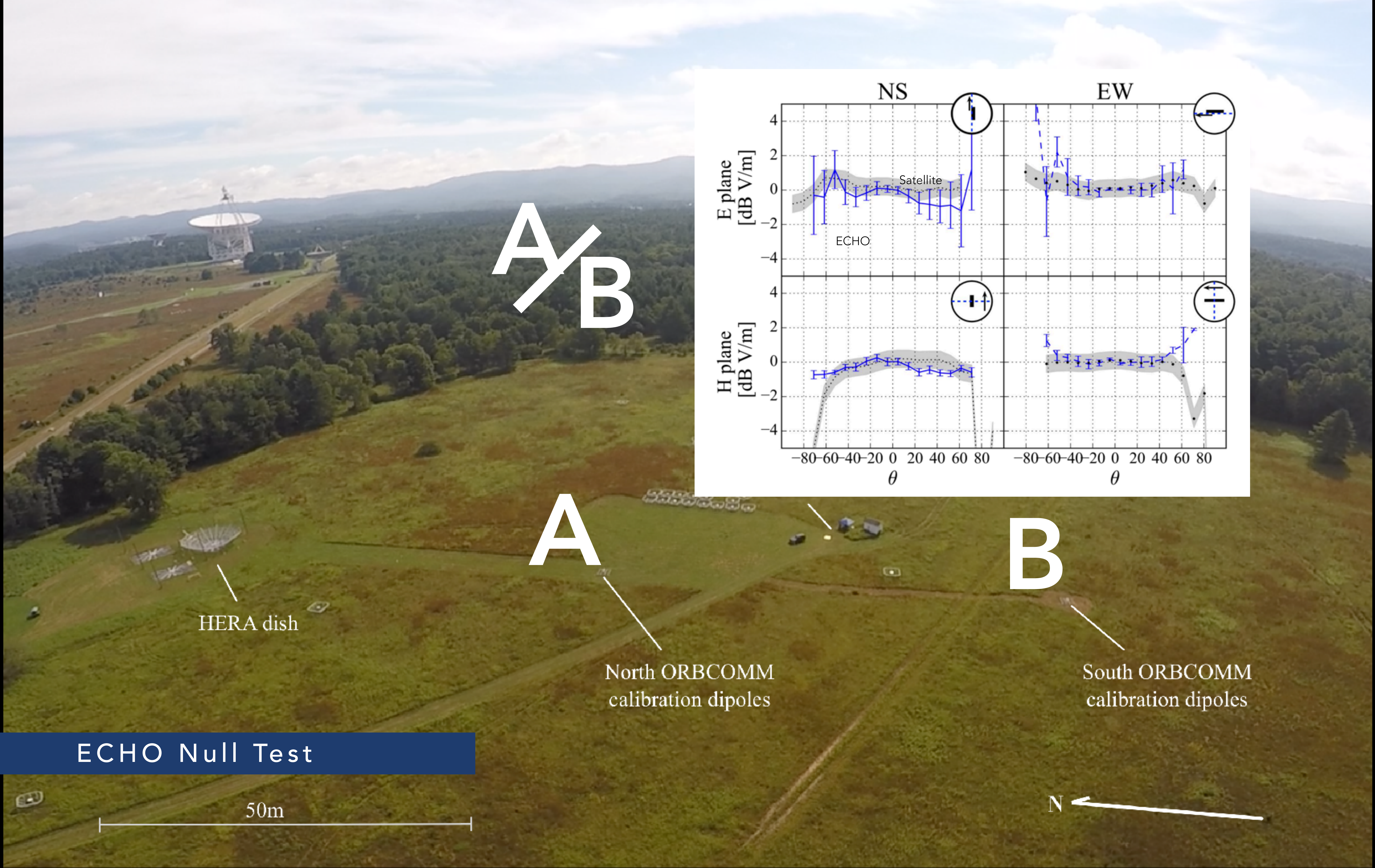
ECHO Null Test



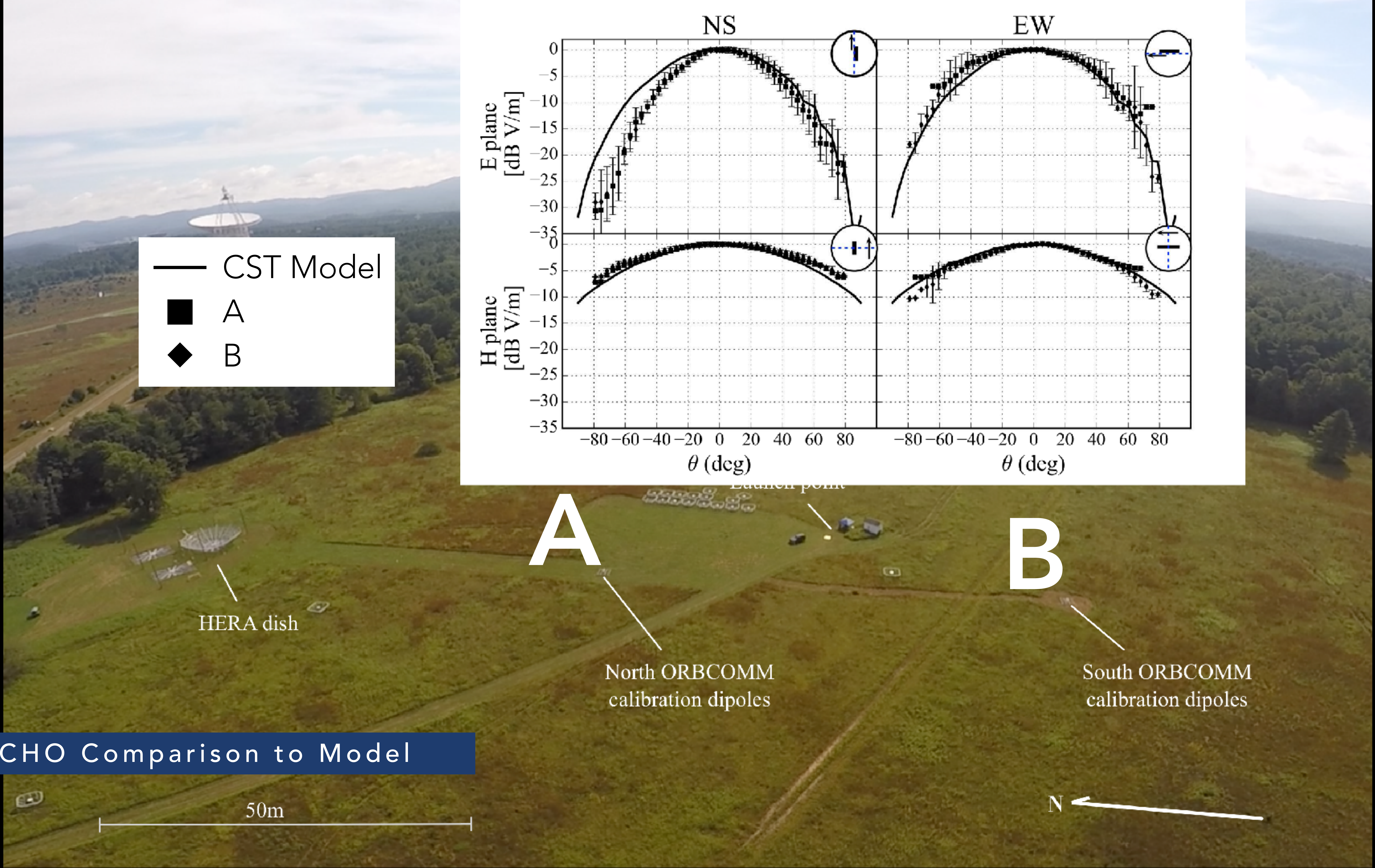
ECHO Null Test



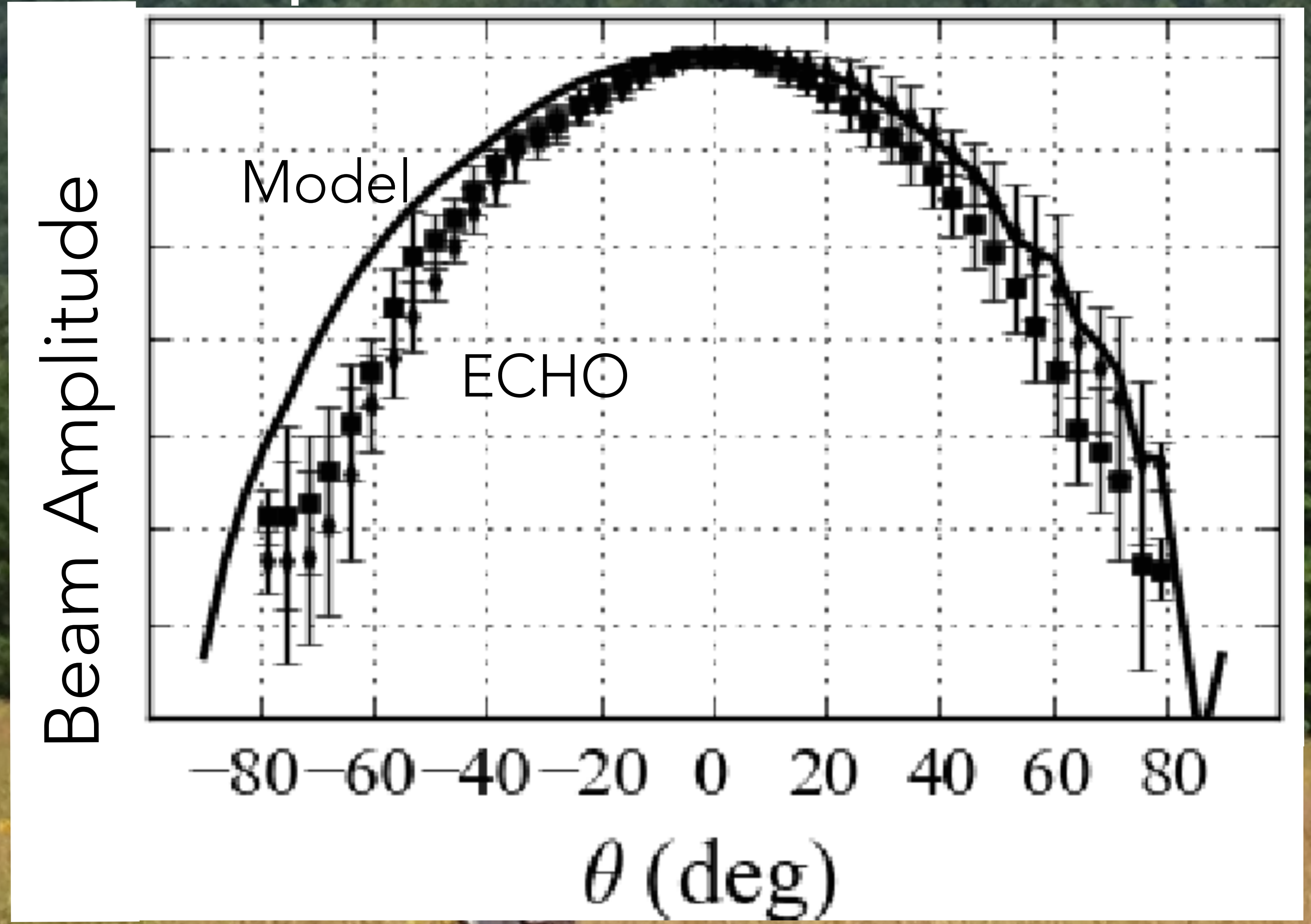
ECHO Null Test



ECHO Comparison to Model

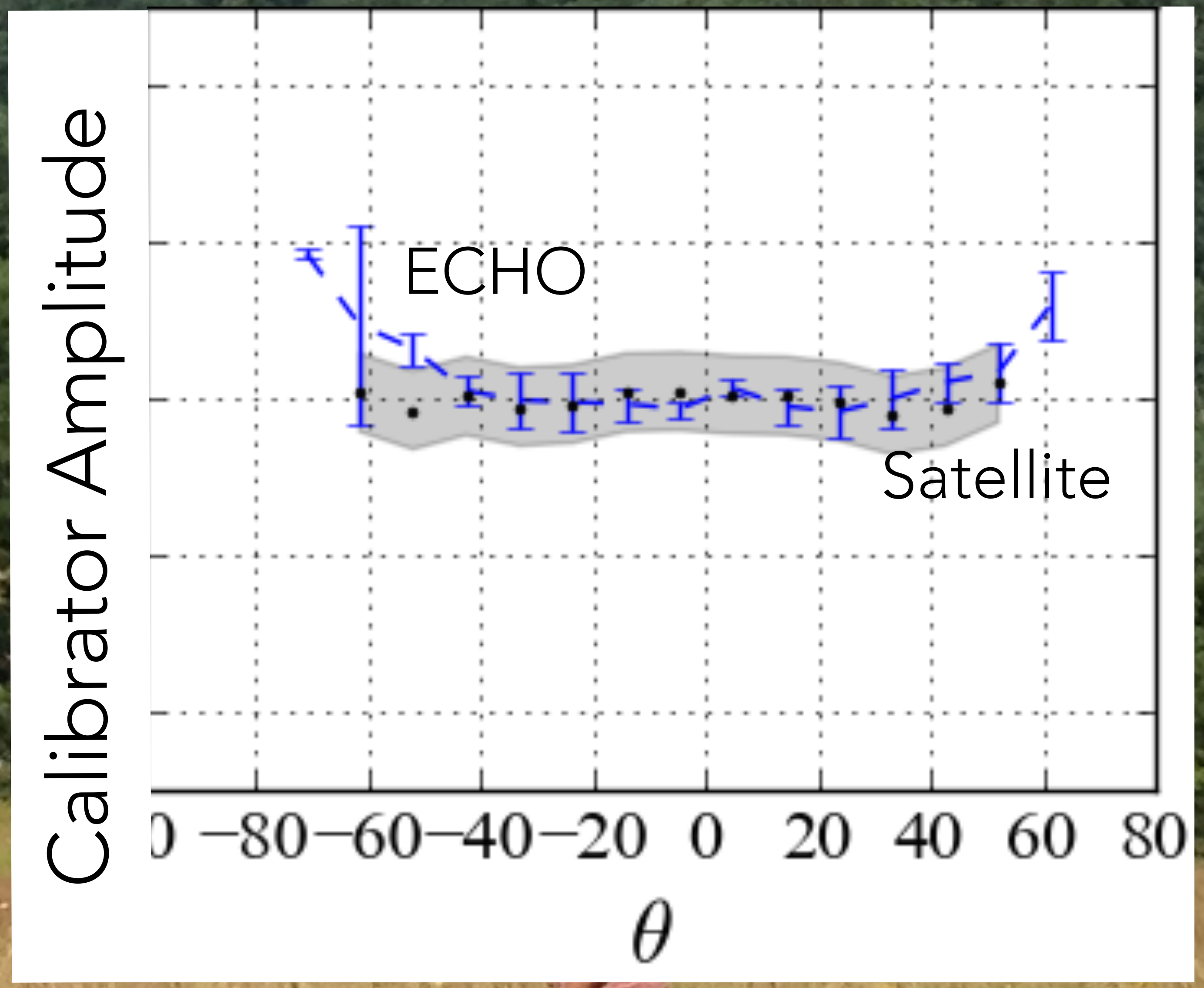


Comparison with Model

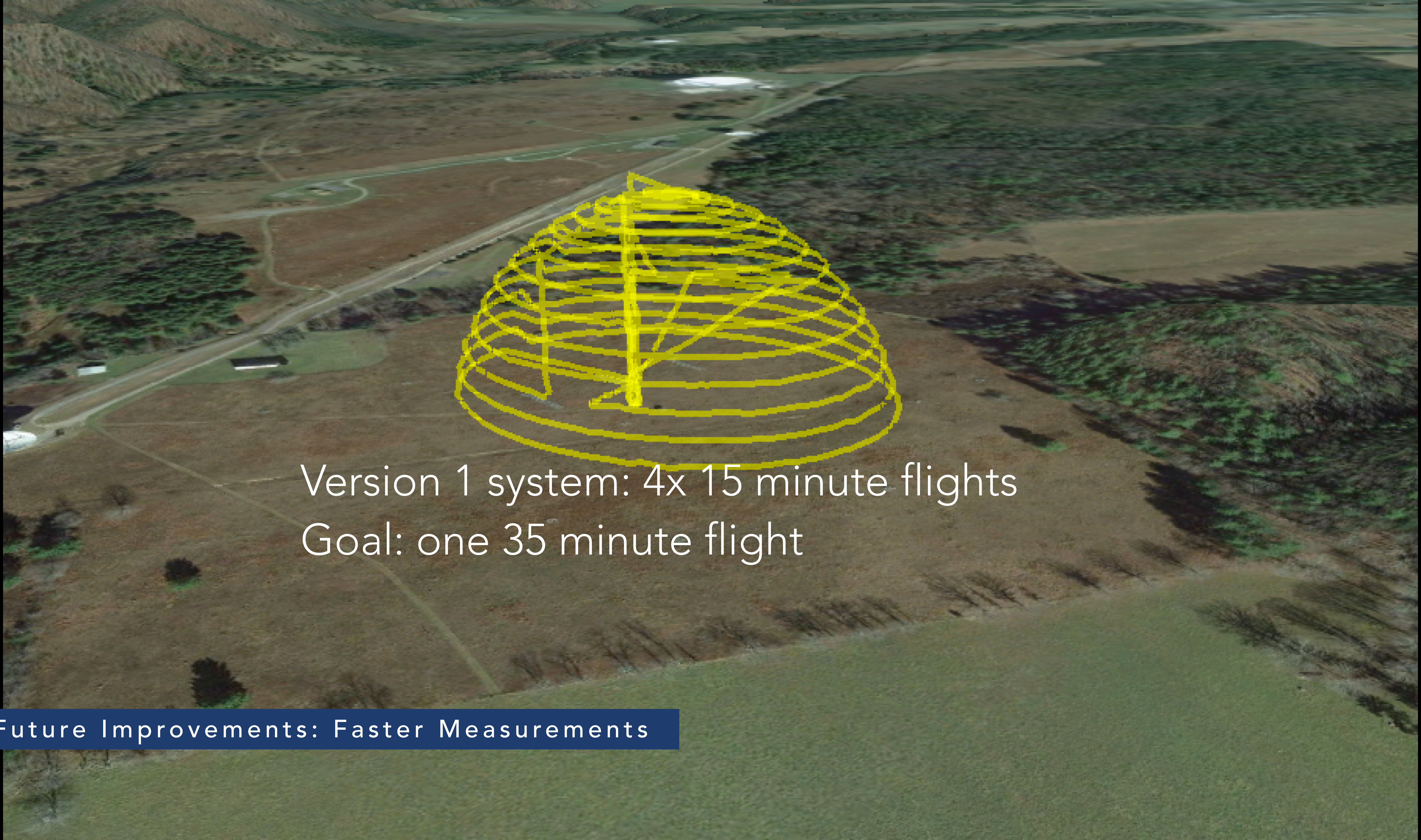


angle from zenith

Comparison with other data



angle from zenith



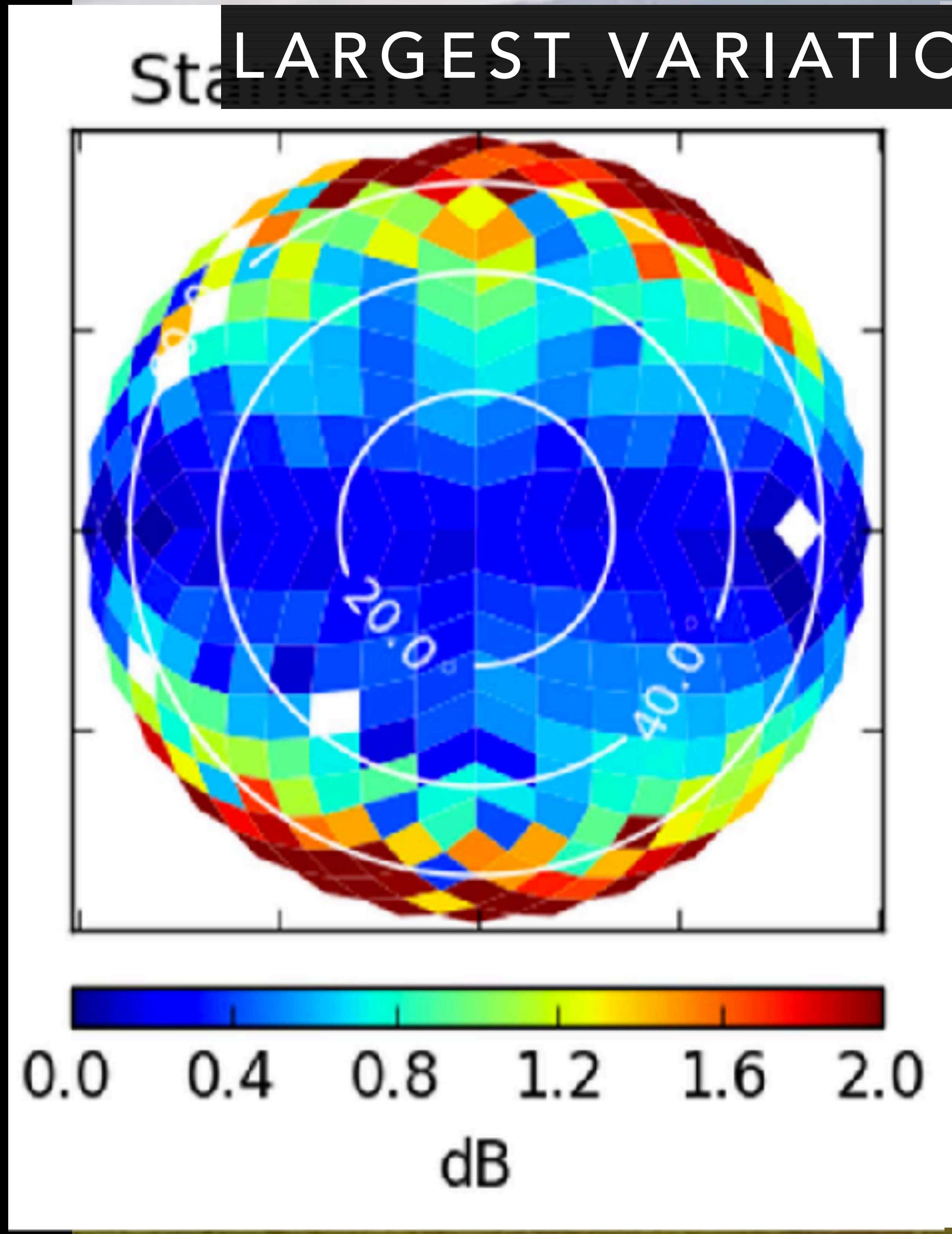
Version 1 system: 4x 15 minute flights

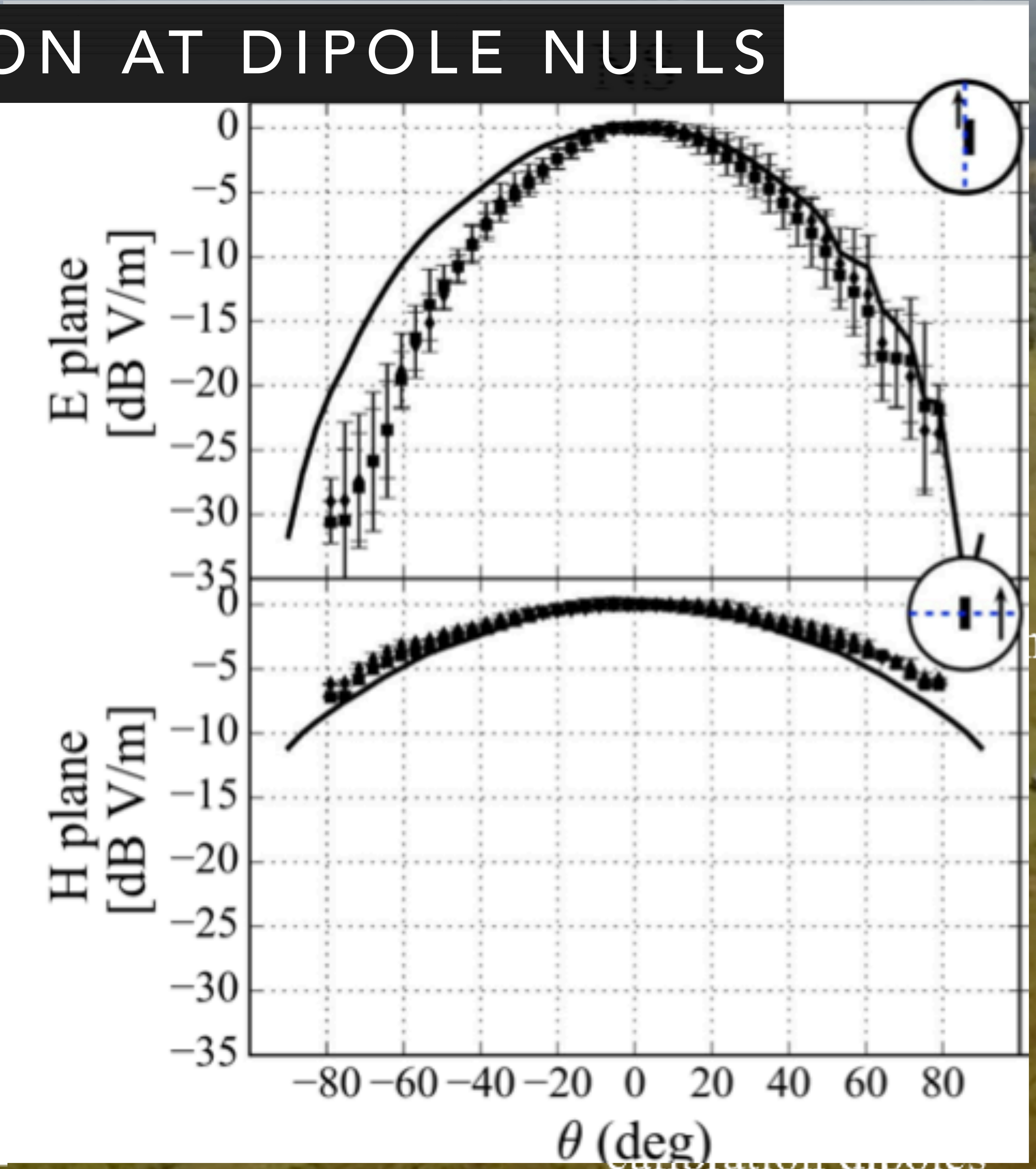
Goal: one 35 minute flight

Future Improvements: Faster Measurements

Future Improvements: Attitude Control

LARGEST VARIATION AT DIPOLE NULLS





STIFFER LIGHTWEIGHT MOUNT

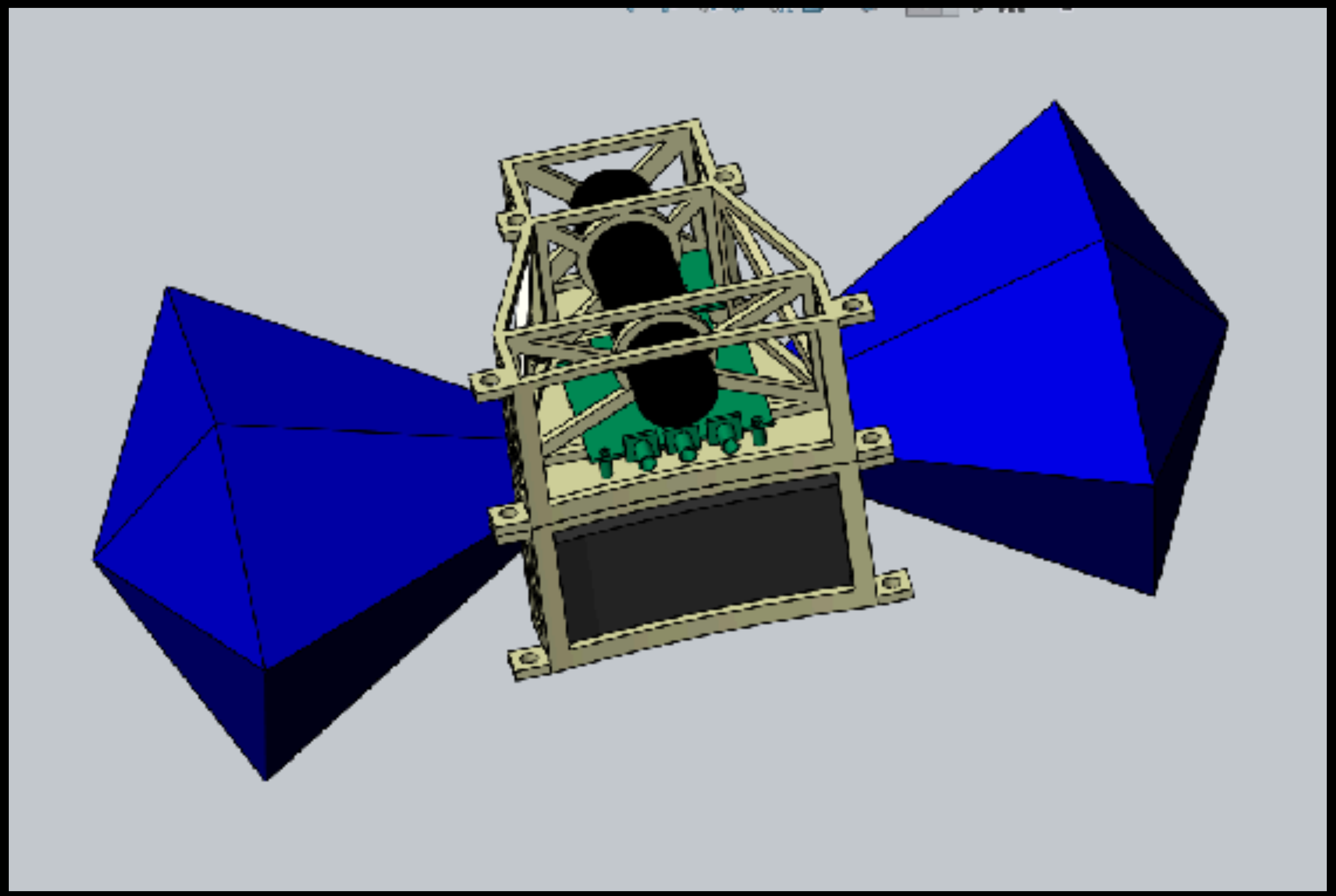
South ORBCOMM
calibration dipoles

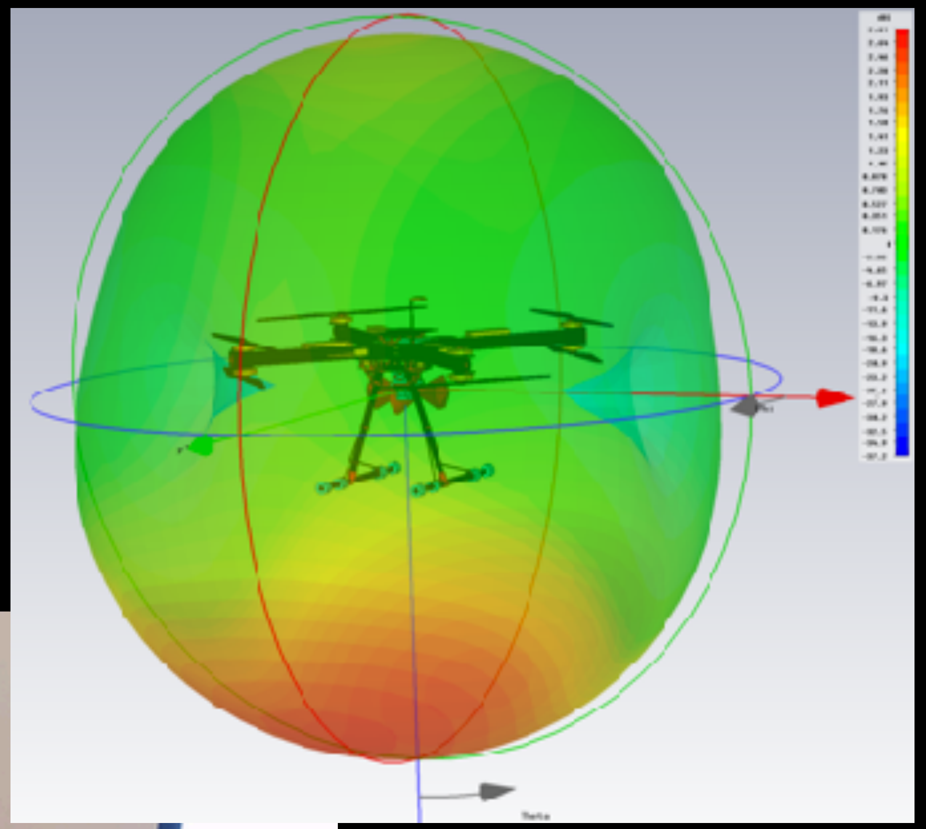
50m

N

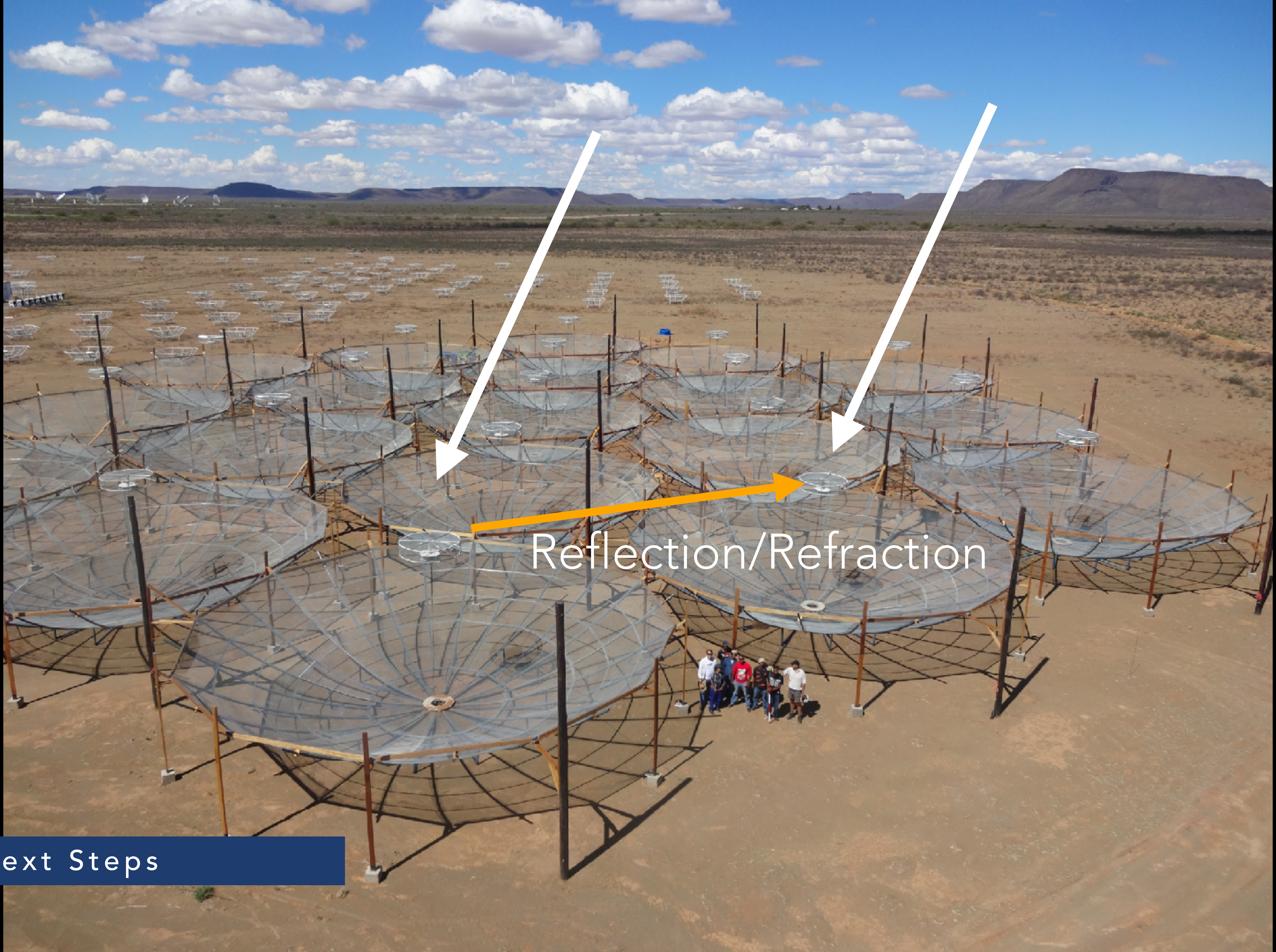
ECHO V2

Rigid mount

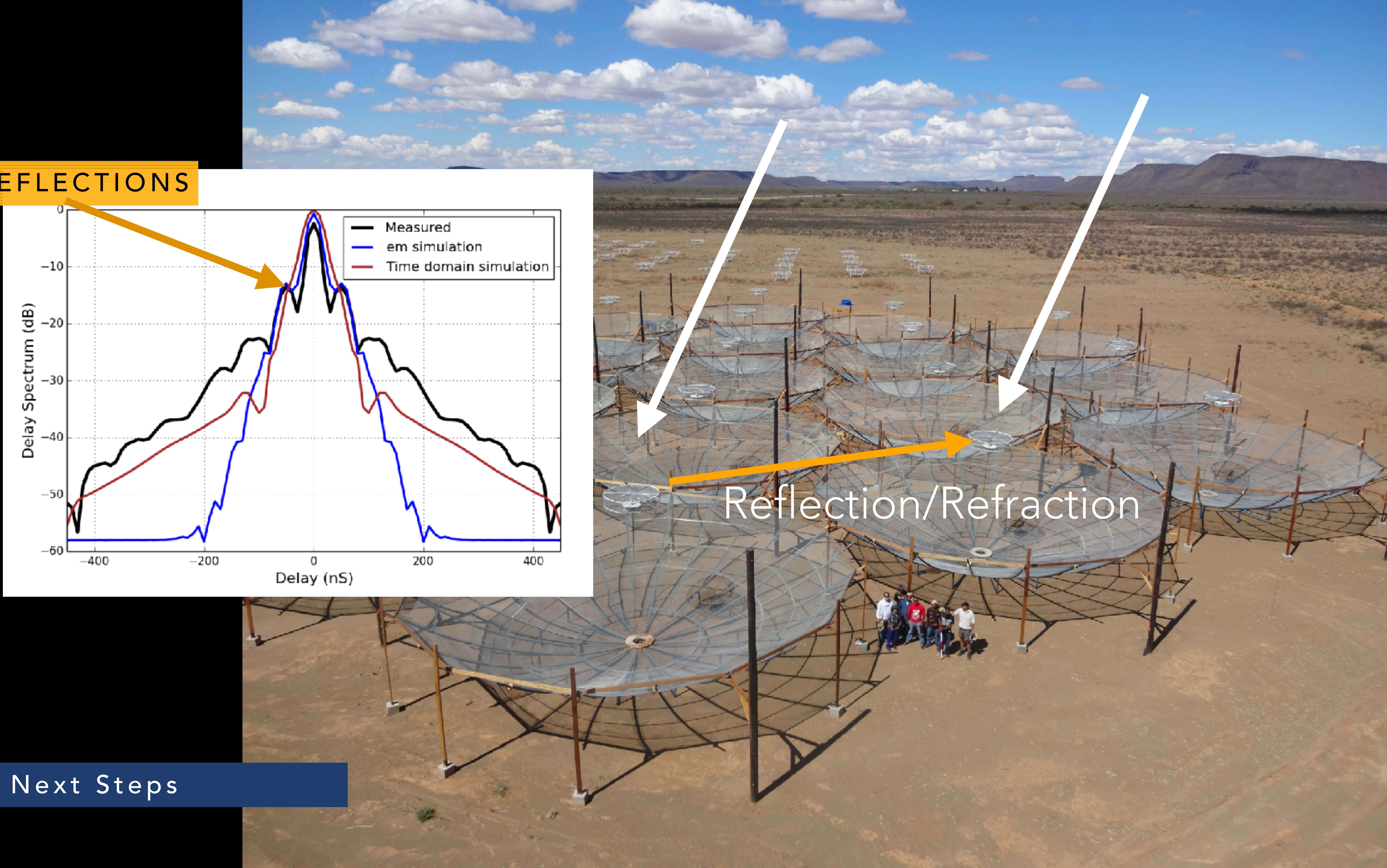




Larger platform, ~40min flight time, better attitude stability

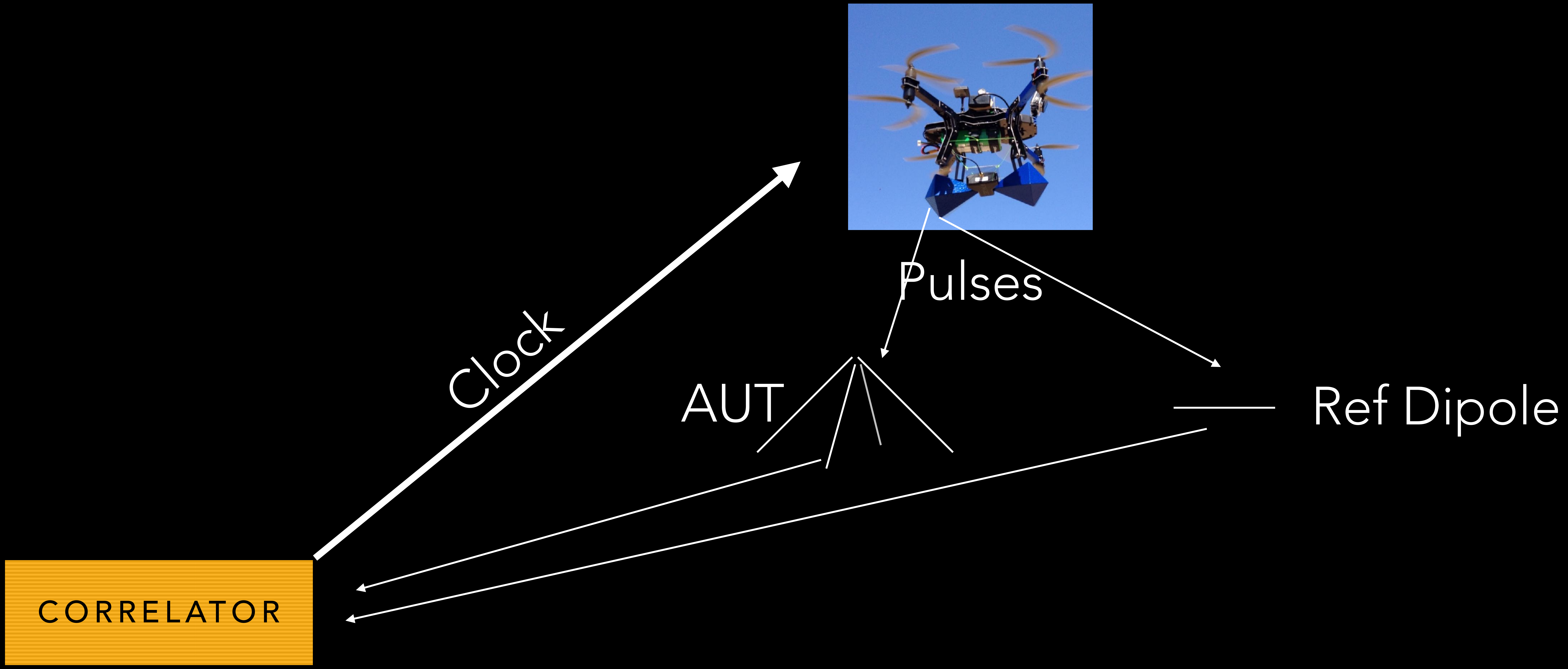


Next Steps


DISH REFLECTIONS
Measured
em simulation
Time domain simulation
Delay Spectrum (dB)
Delay (nS)
0
−10
−20
−30
−40
−50
−60
−400
−200
0
200
400
Reflection/Refraction

Next Steps

DELAY



Next Steps: Phase

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THANKS!

NSF

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