Precision Primary Beam Mapping with ECHO

Daniel Jacobs
NSF Fellow — ASU

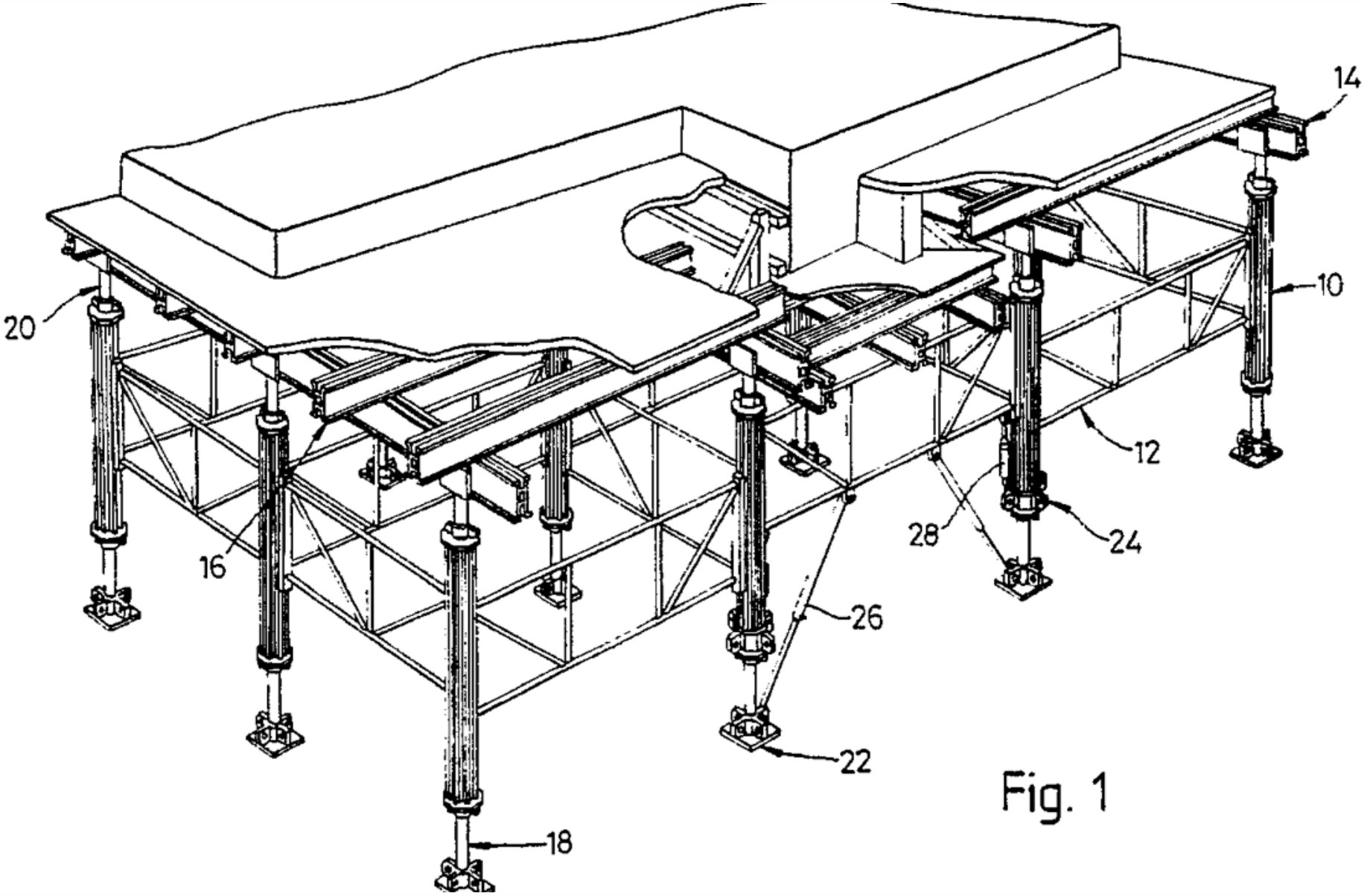
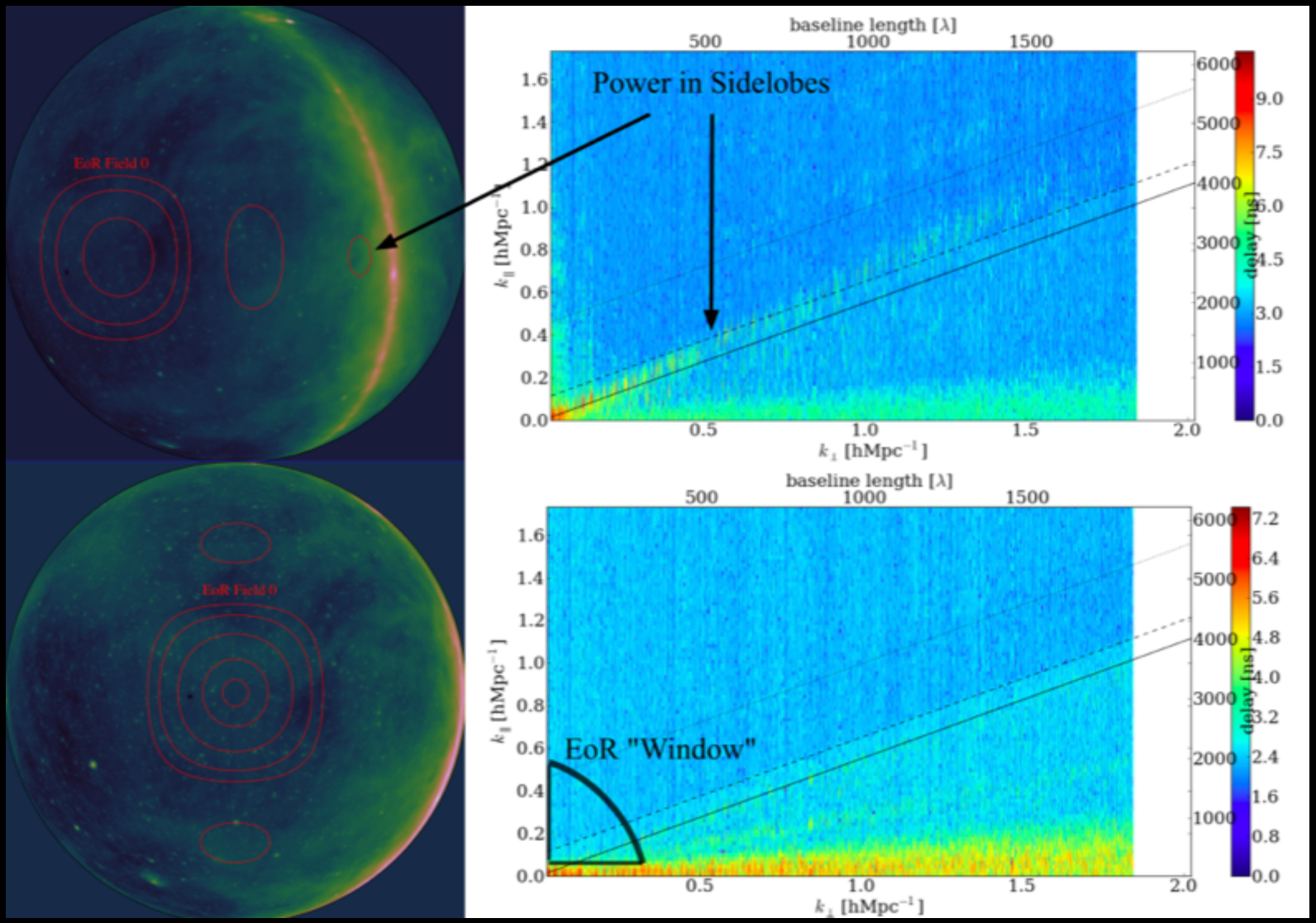


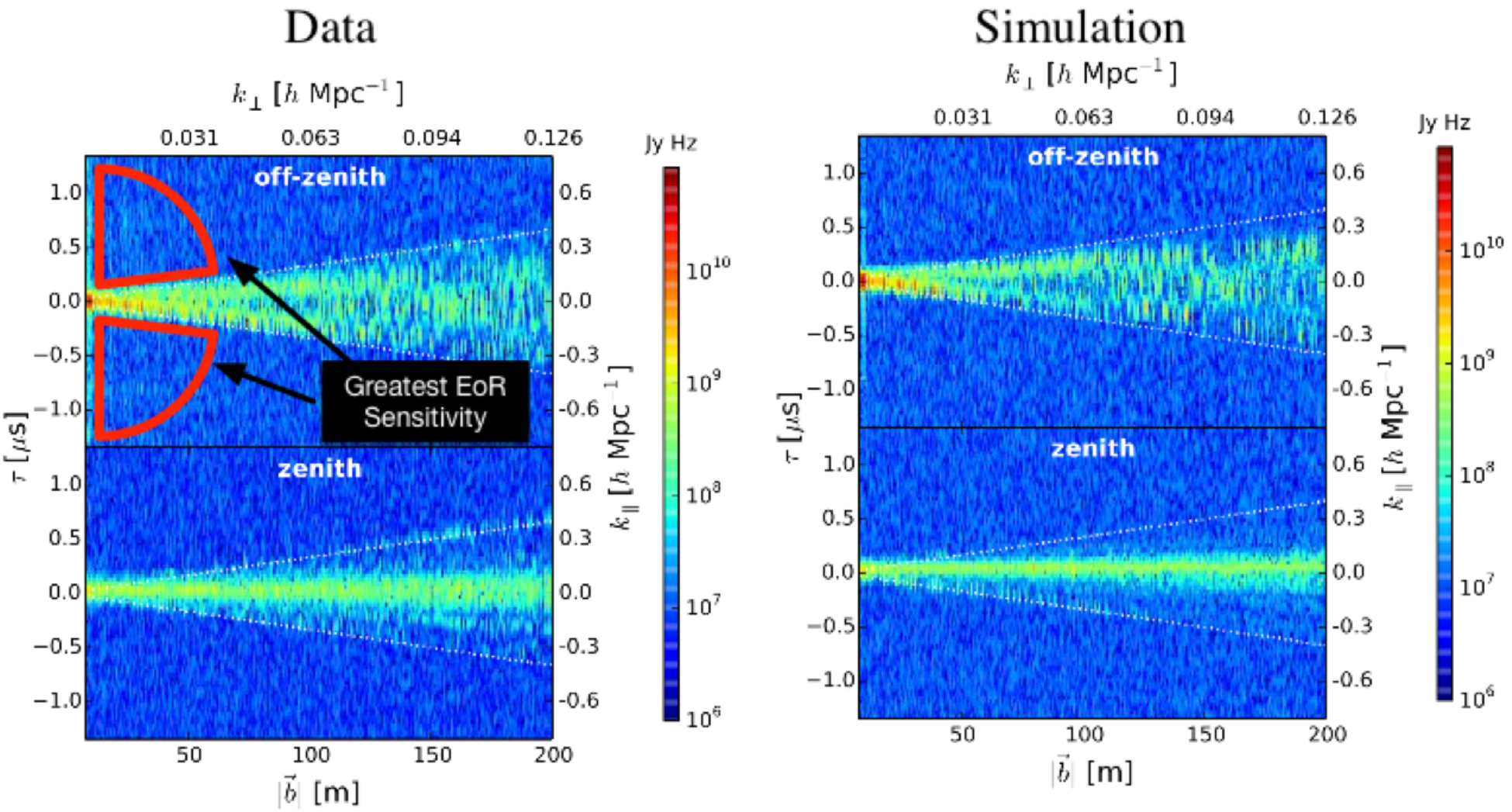
Fig. 1

THE EXTERNAL CALIBRATOR FOR HYDROGEN OBSERVATORIES

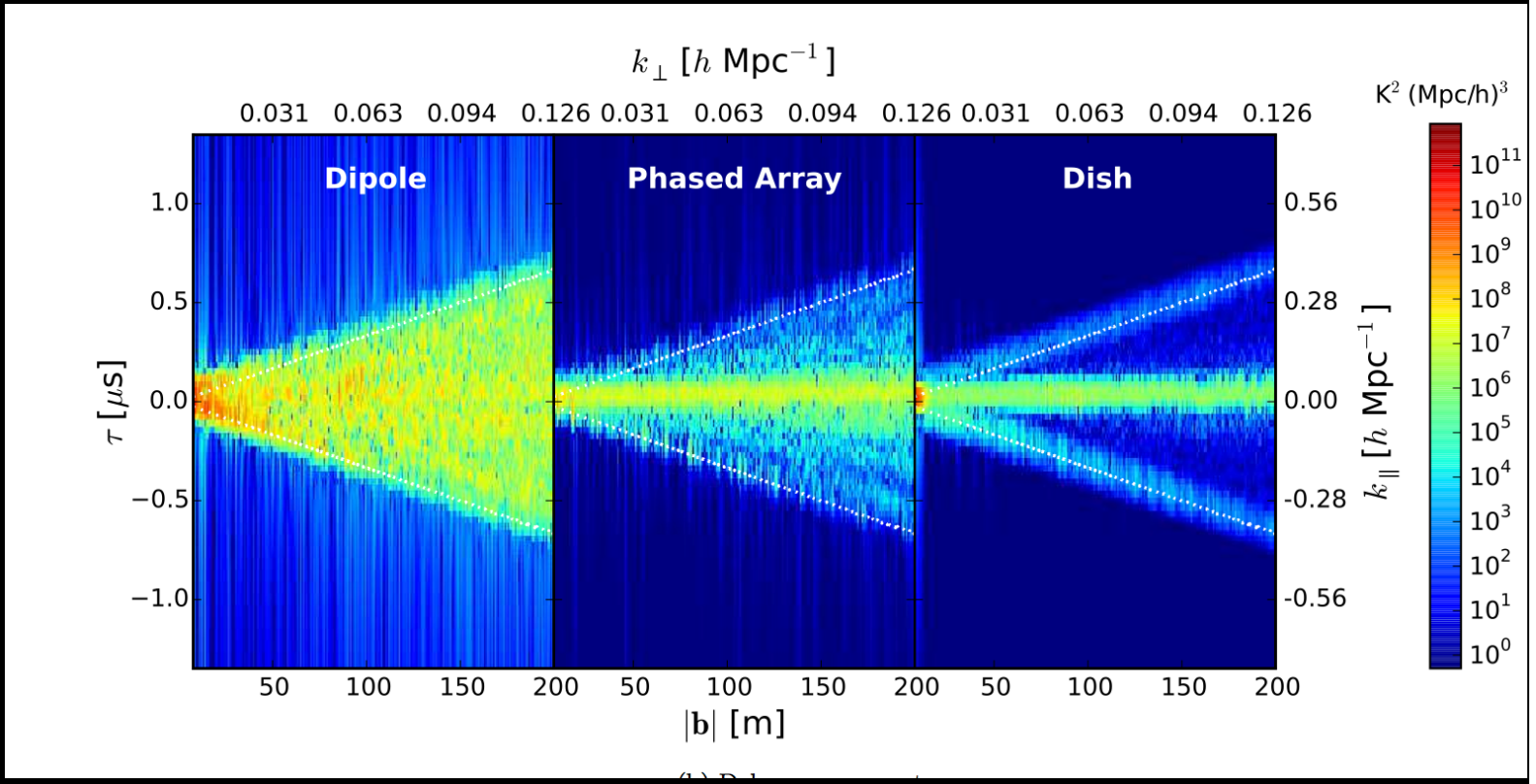
ASU: D.Jacobs, J. Bowman
J. Burba, L. Turner, B. Stinnett, M. Busch, M. Leatham, V. Serrano, M. Denney, D. Nelson
MIT: A. Neben

THE BEAM IN 21CM POWER SPECTRA





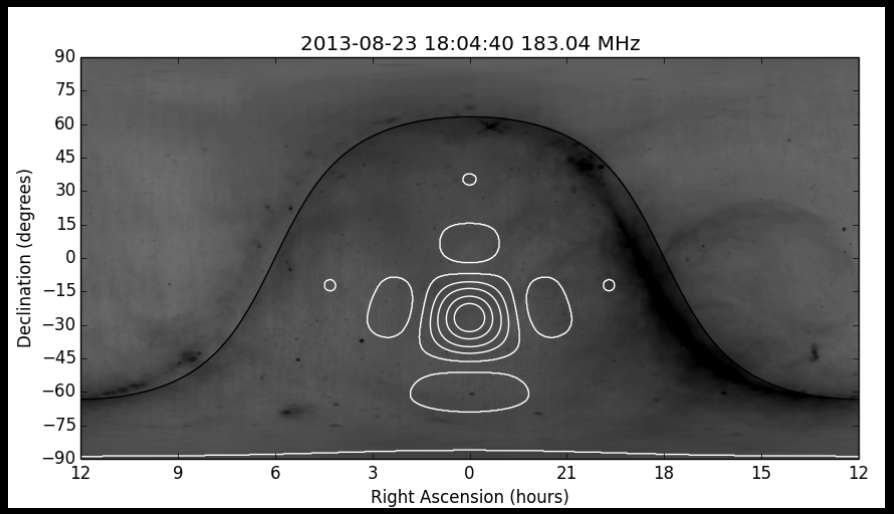
Thyagarajan et al (2015)

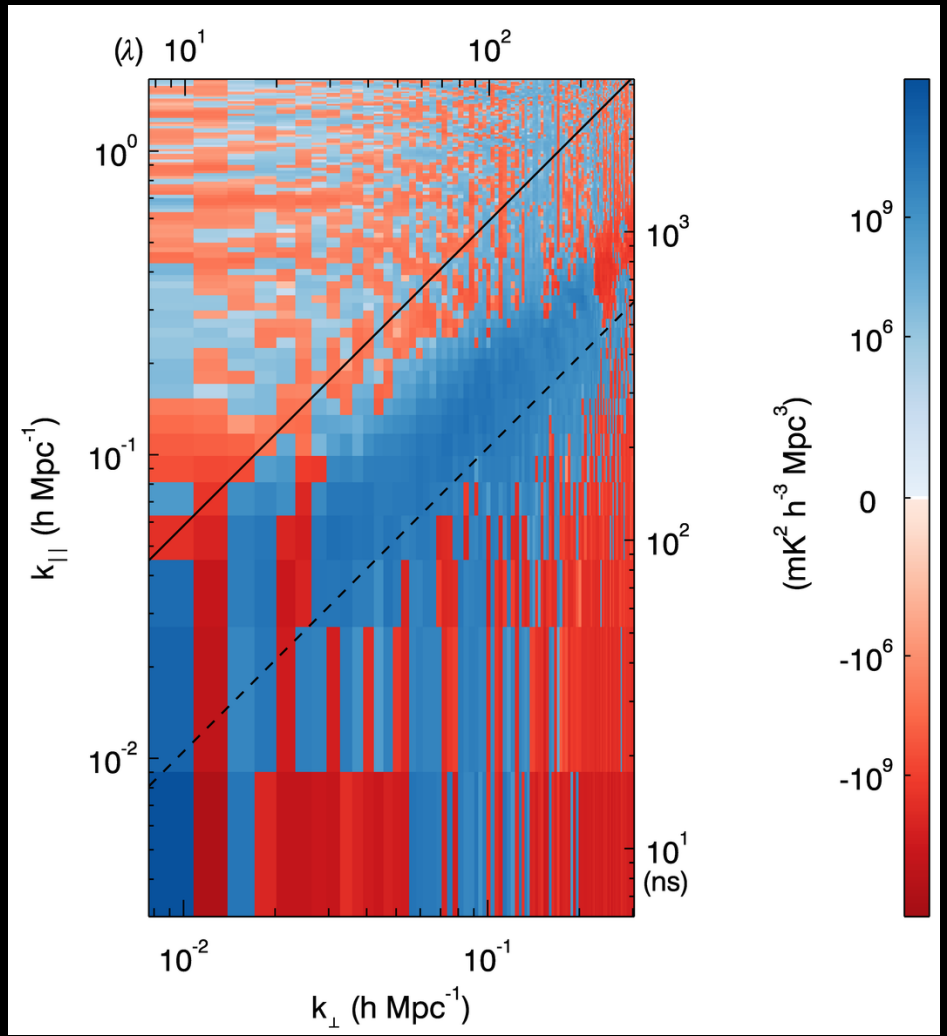


Thyagarajan et al (2015)

BEAM PRECISION LIMITS SUBTRACTION

- Sidelobe sources bleed higher in $k_{\parallel}$

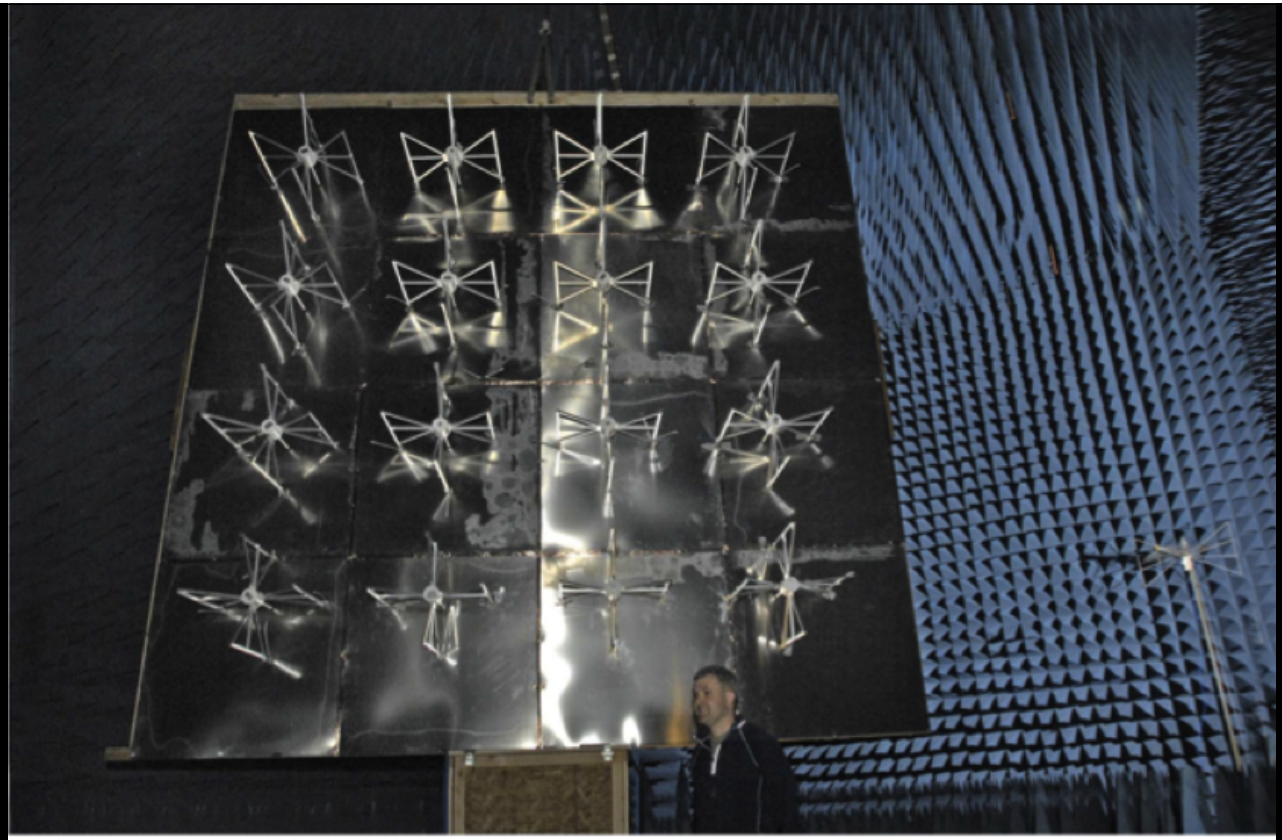


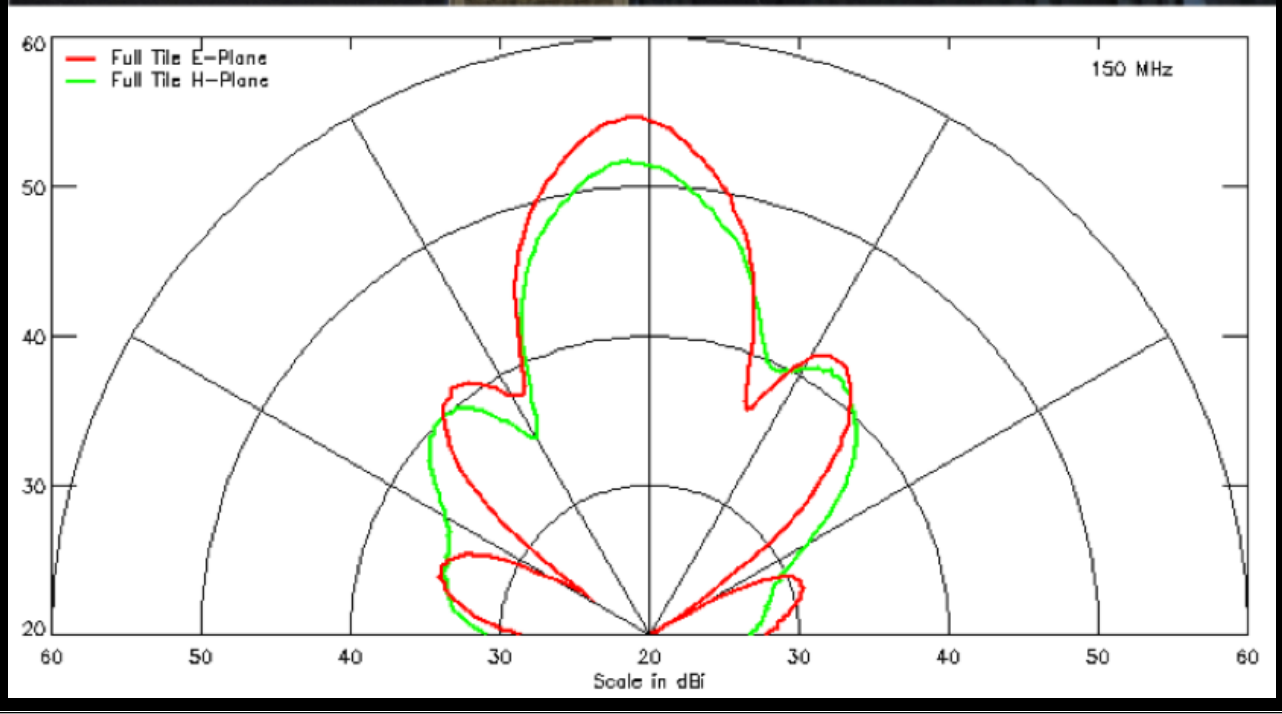


Pober et al., in review

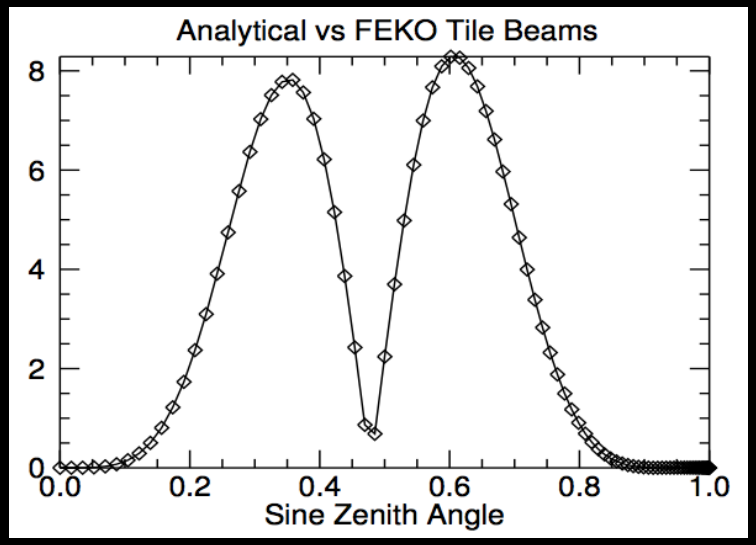
EOR BEAM REQUIREMENTS

- accuracy for model subtraction
  preliminary spec 1% at -40dB (pending more modeling)
  —> this is likely below the known manufacturing tolerance, implying a requirement to measure the "as-built system"
- similar requirement on precision (ie as built, beam to beam variation) to understand limits of redundancy
- horizon to horizon response (regardless of FoV)




Full Tile E-Plane
Full Tile H-Plane
150 MHz
60
50
40
30
20
60
50
40
30
20
30
40
50
60
Scale in dBi

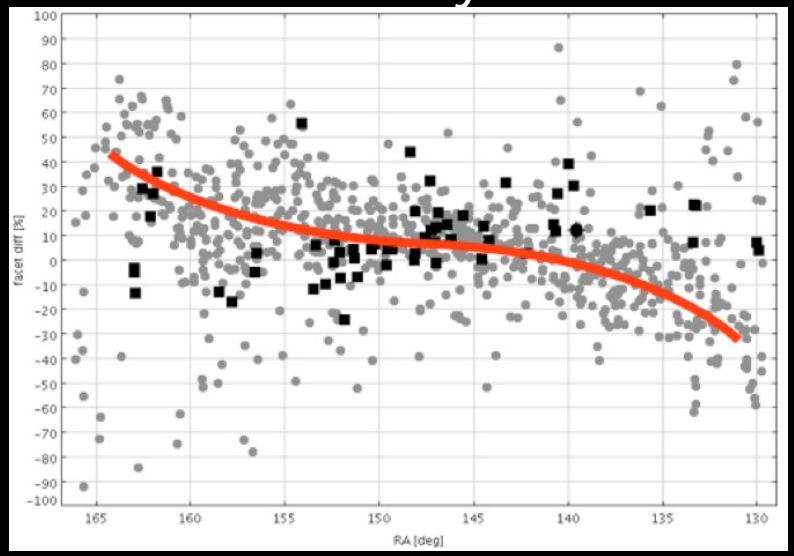
Model Variance



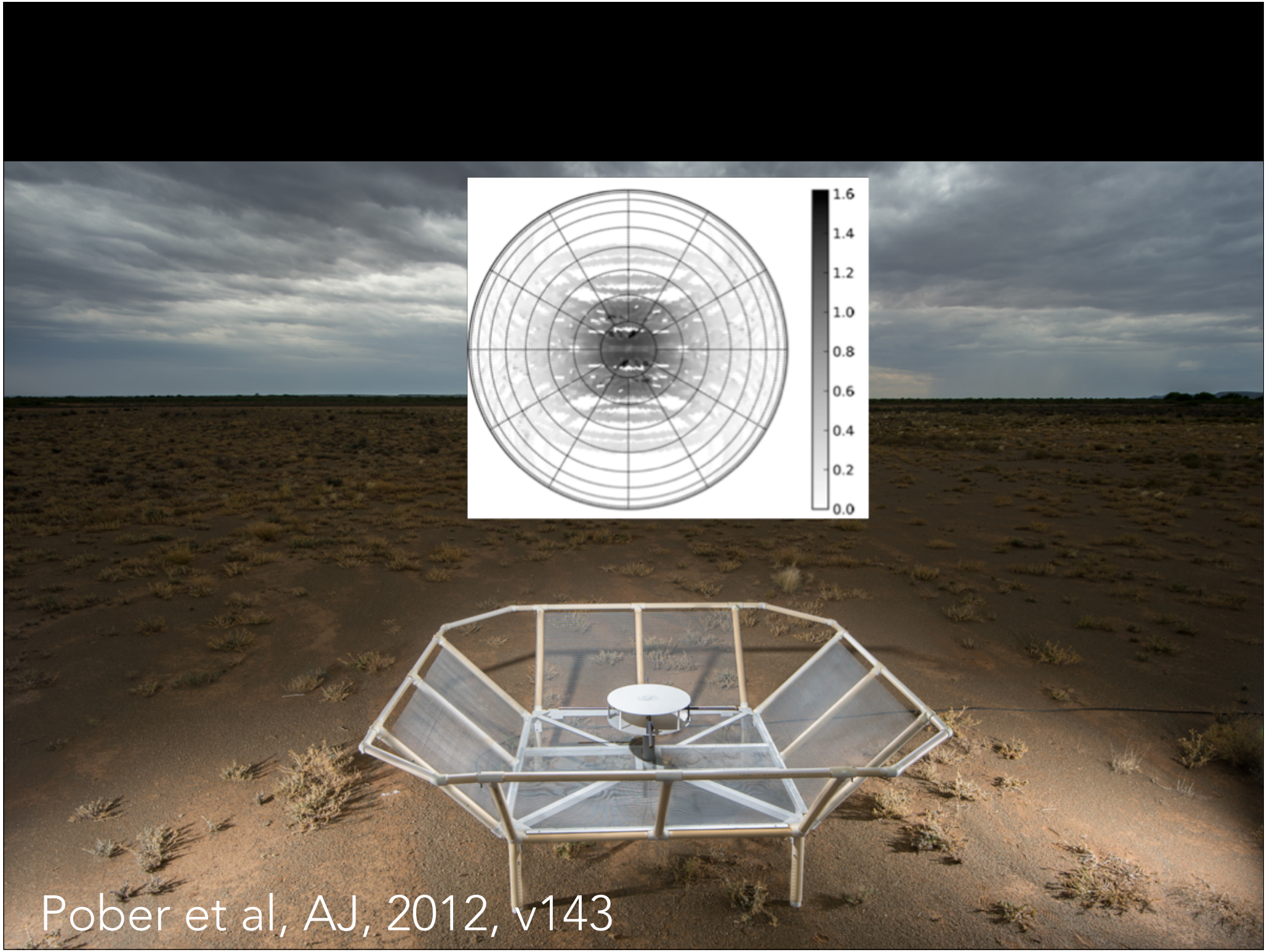
Analysis by Ben McKinley et al

see also Sutinjo et al, Rad Sci, 2015

Flux uncertainty



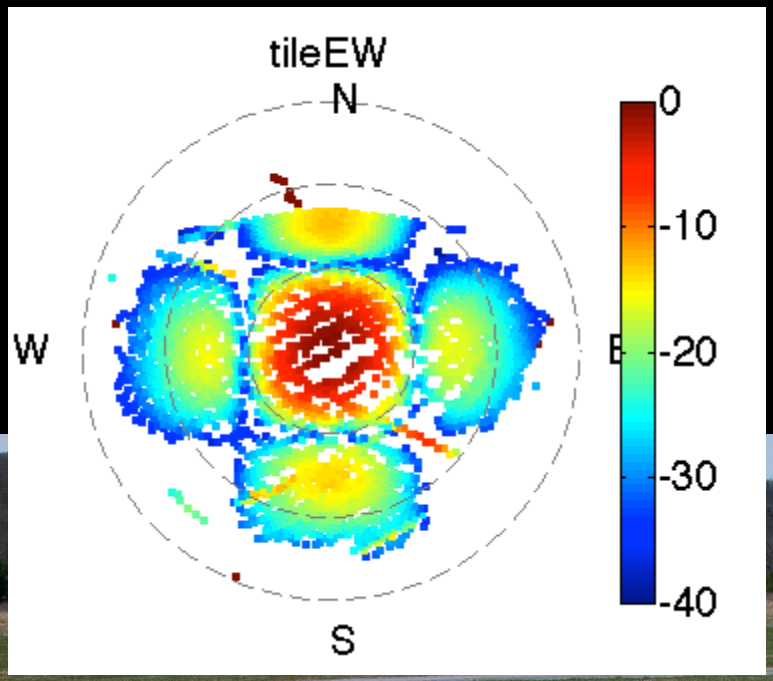
Jacobs et al 2013



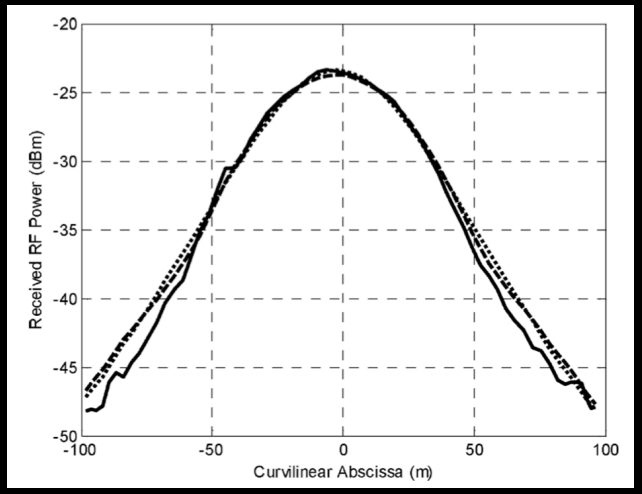
Pober et al, AJ, 2012, v143

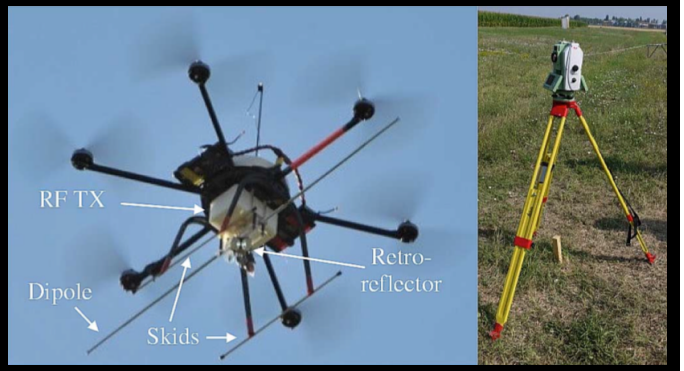
Using ORBCOMM

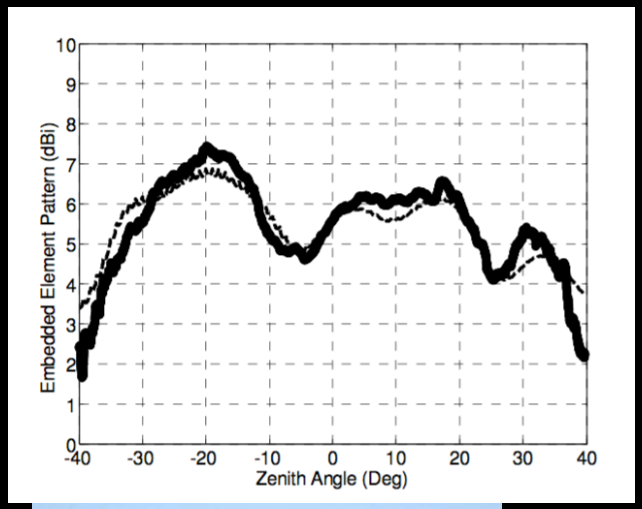
Neben et al Radio Science, 2015, vol 50



SKA Aperture Array Verification Program



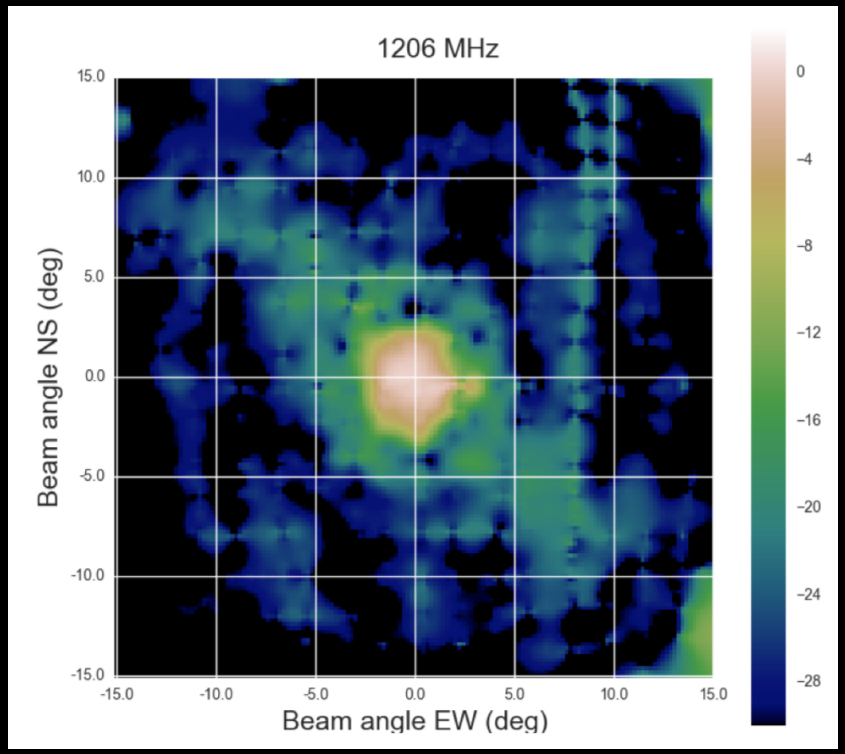




virone et al IEEE AWPL, 2014

virone et al APS IEEE, 2014

Chang et al arxiv:1505.05885
~1GHz

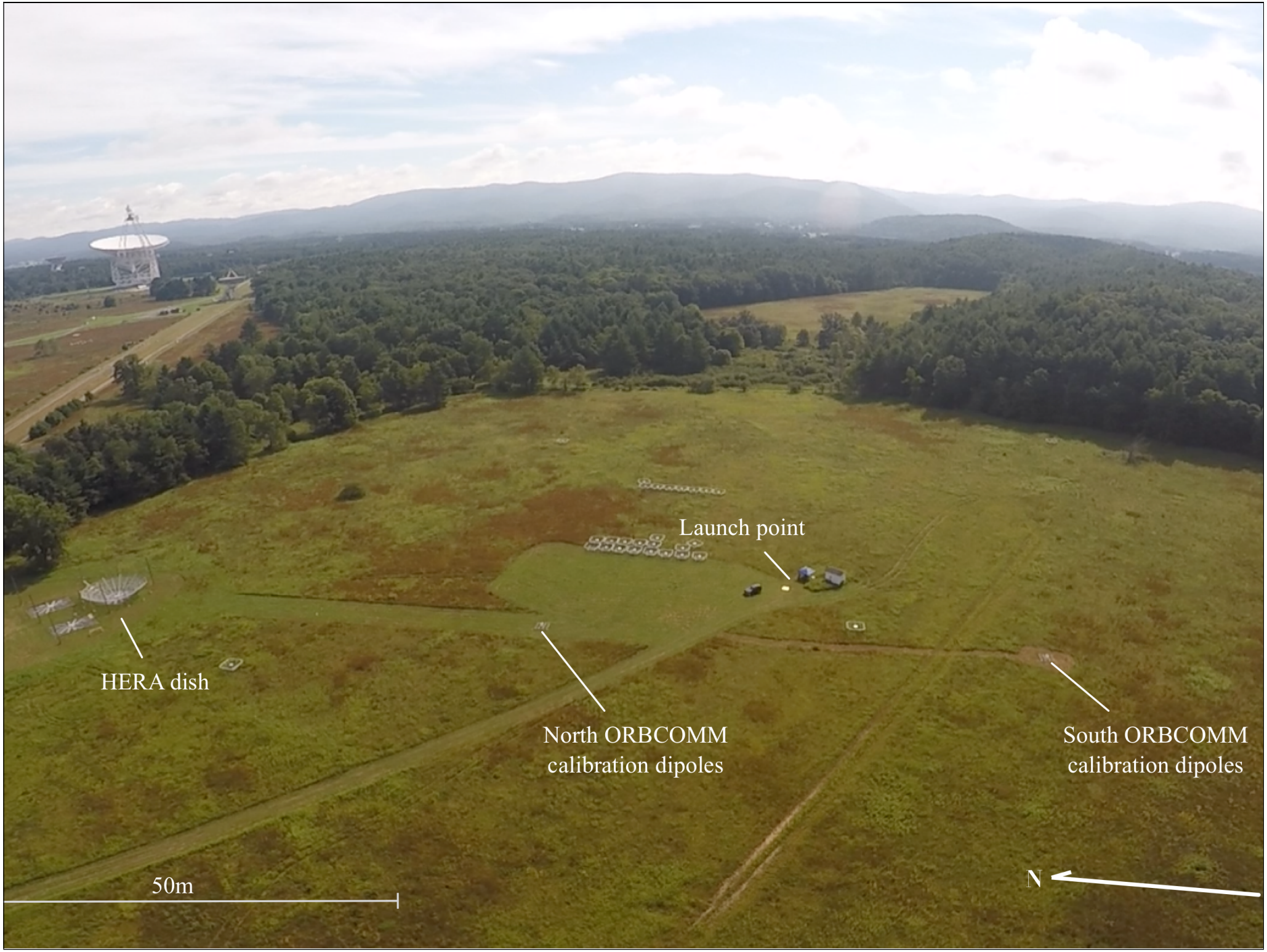


EXTERNAL CALIBRATOR FOR HYDROGEN OBSERVATORIES

Source: VCO synthesizer
(137-2GHz)

Drone: 3DR X8

Antenna: Bicolog bowtie
100-2Ghz

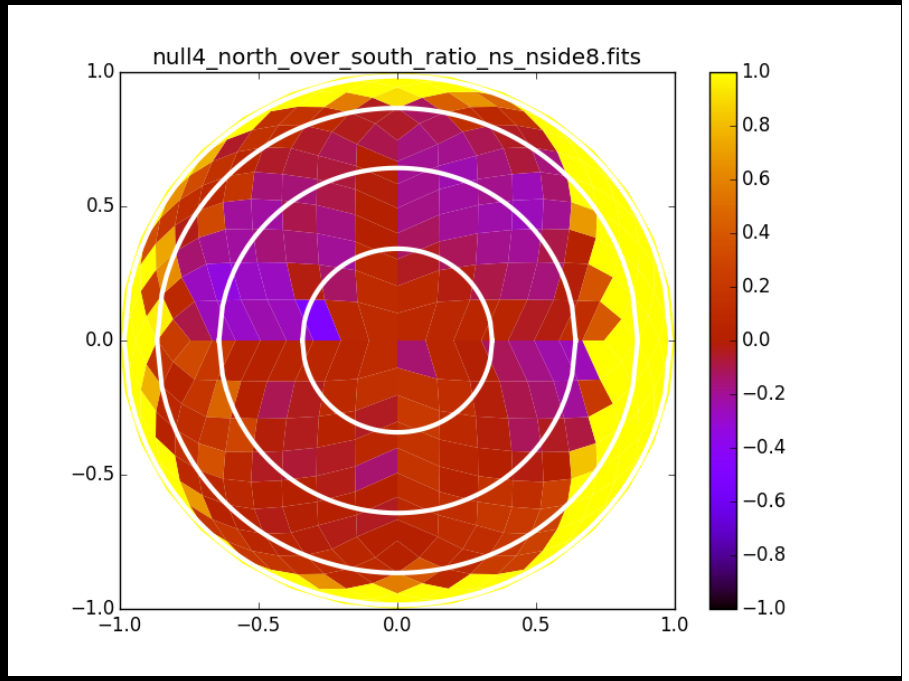

Launch point
HERA dish
North ORBCOMM
calibration dipoles
South ORBCOMM
calibration dipoles
50m
N

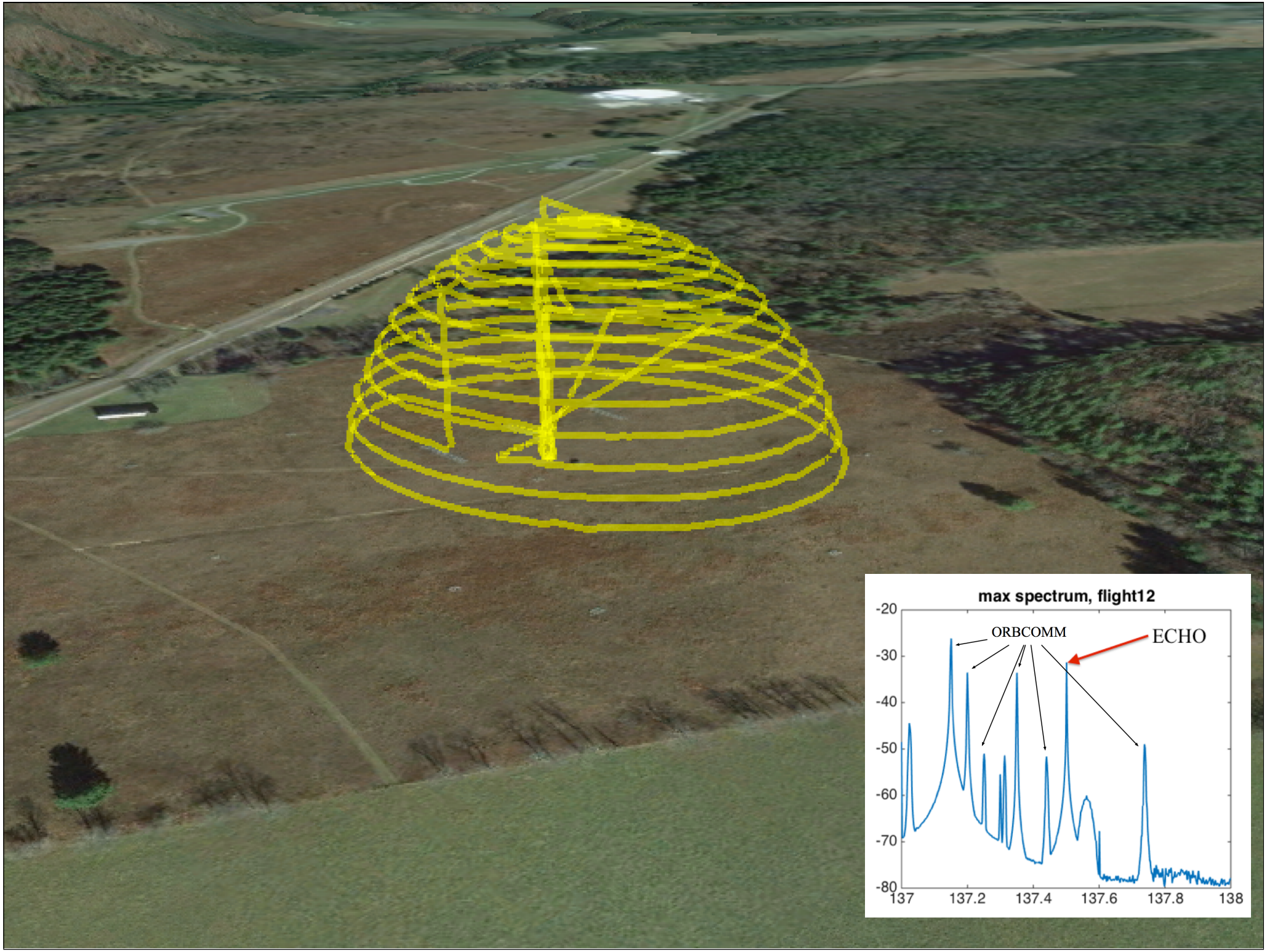
ORBCOMM NULL CALIBRATION

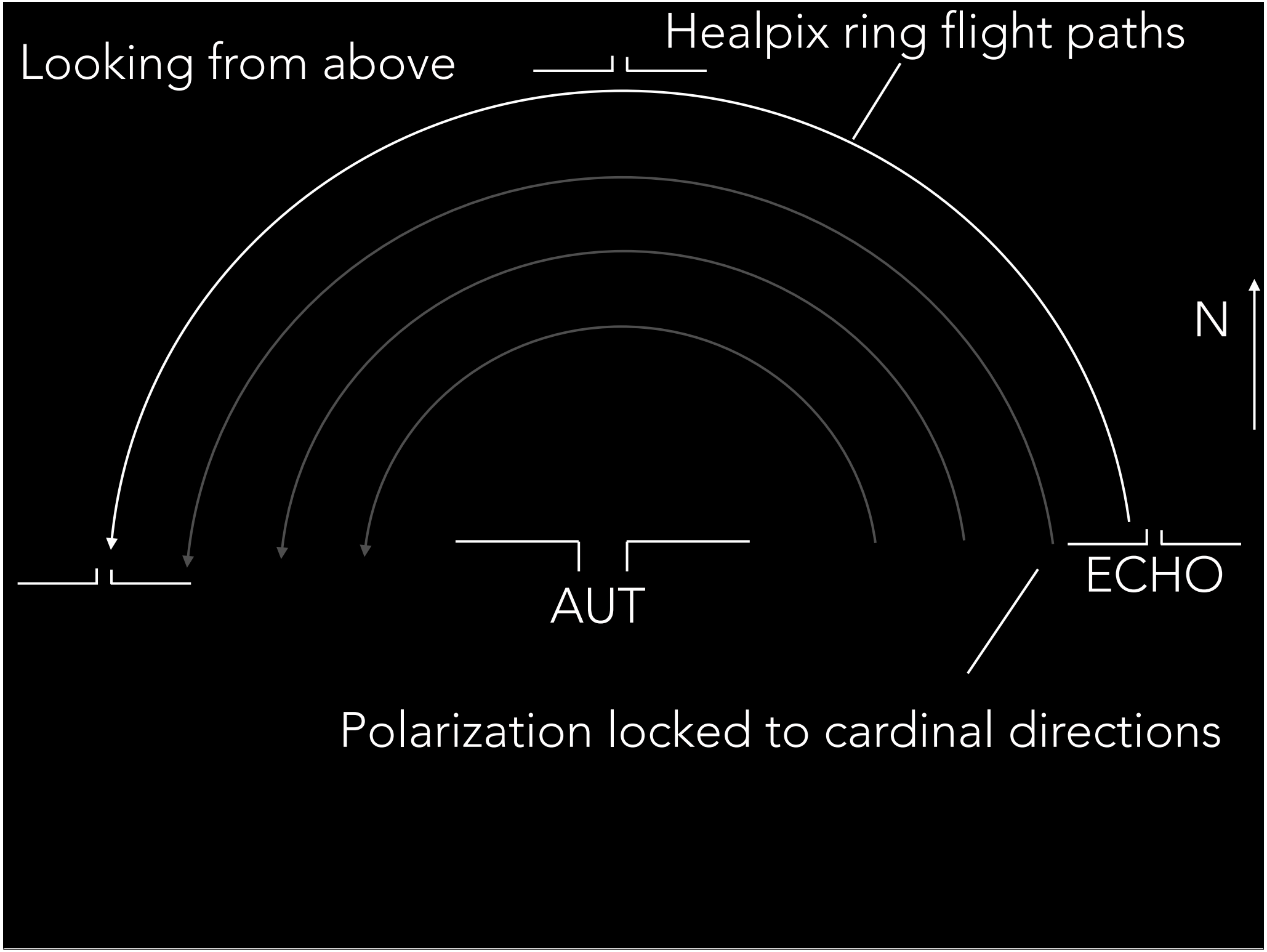
N

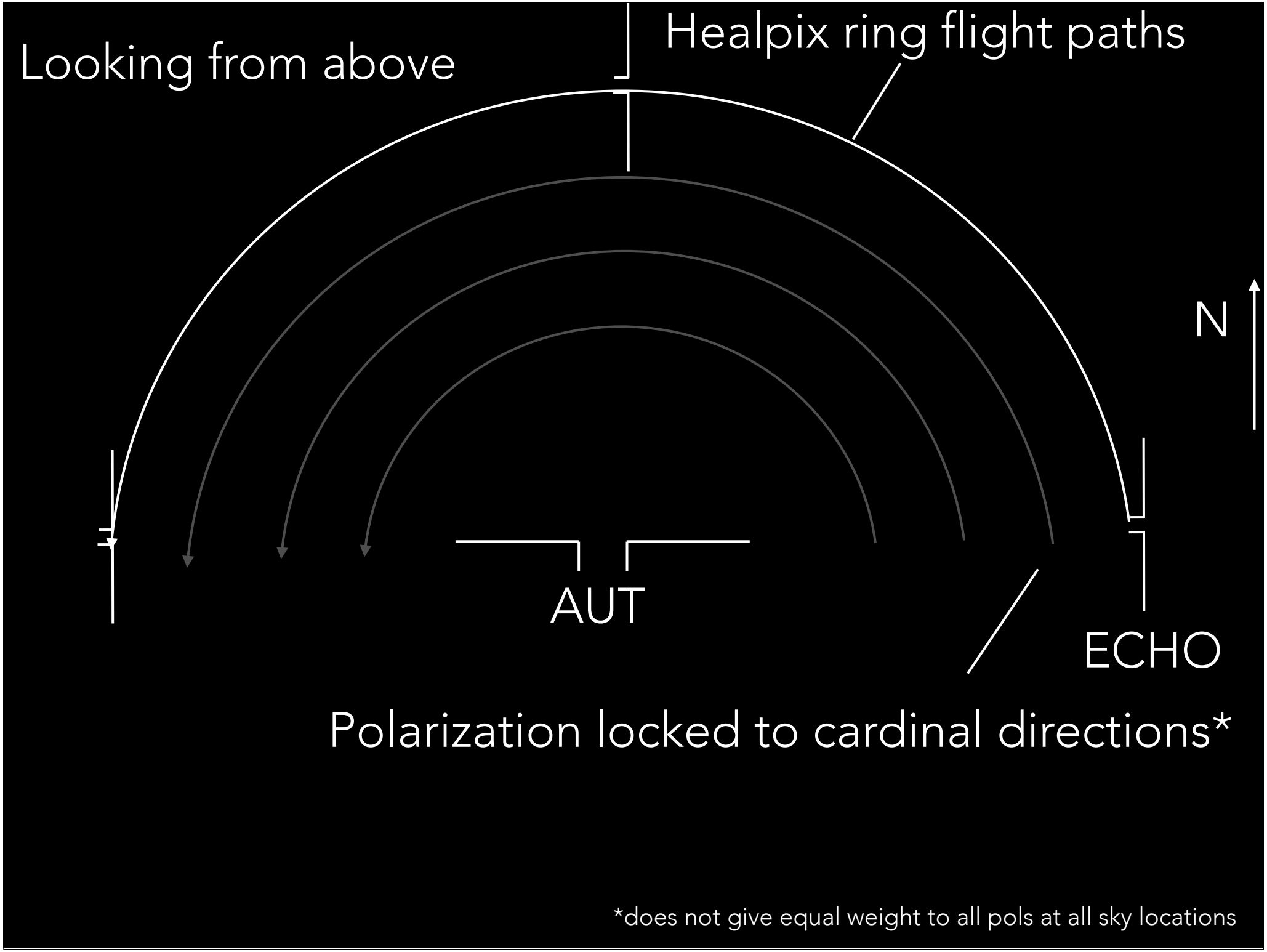
S

÷

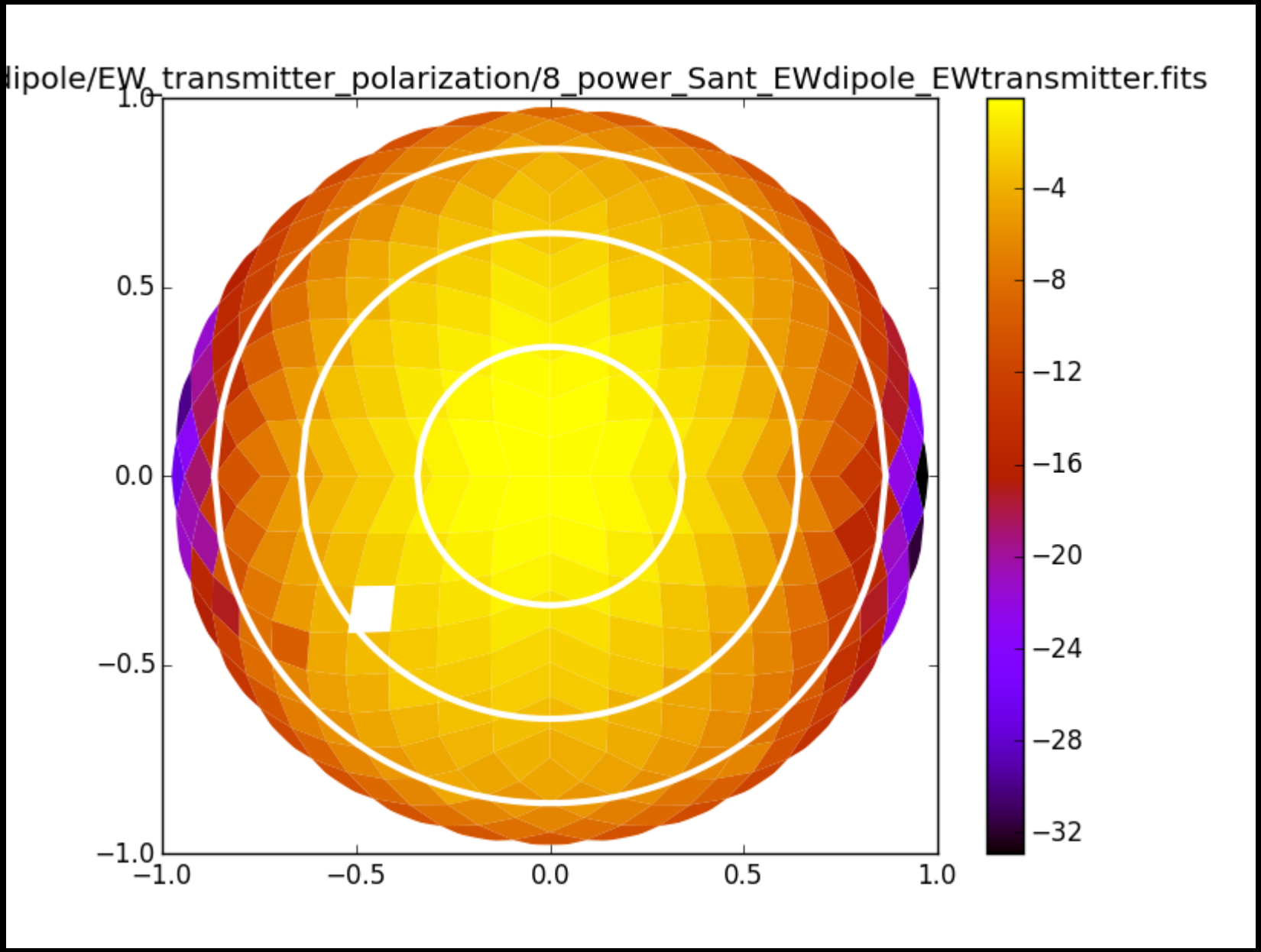



max spectrum, flight12
ORBCOMM
ECHO
-20
-30
-40
-50
-60
-70
-80
137
137.2
137.4
137.6
137.8
138

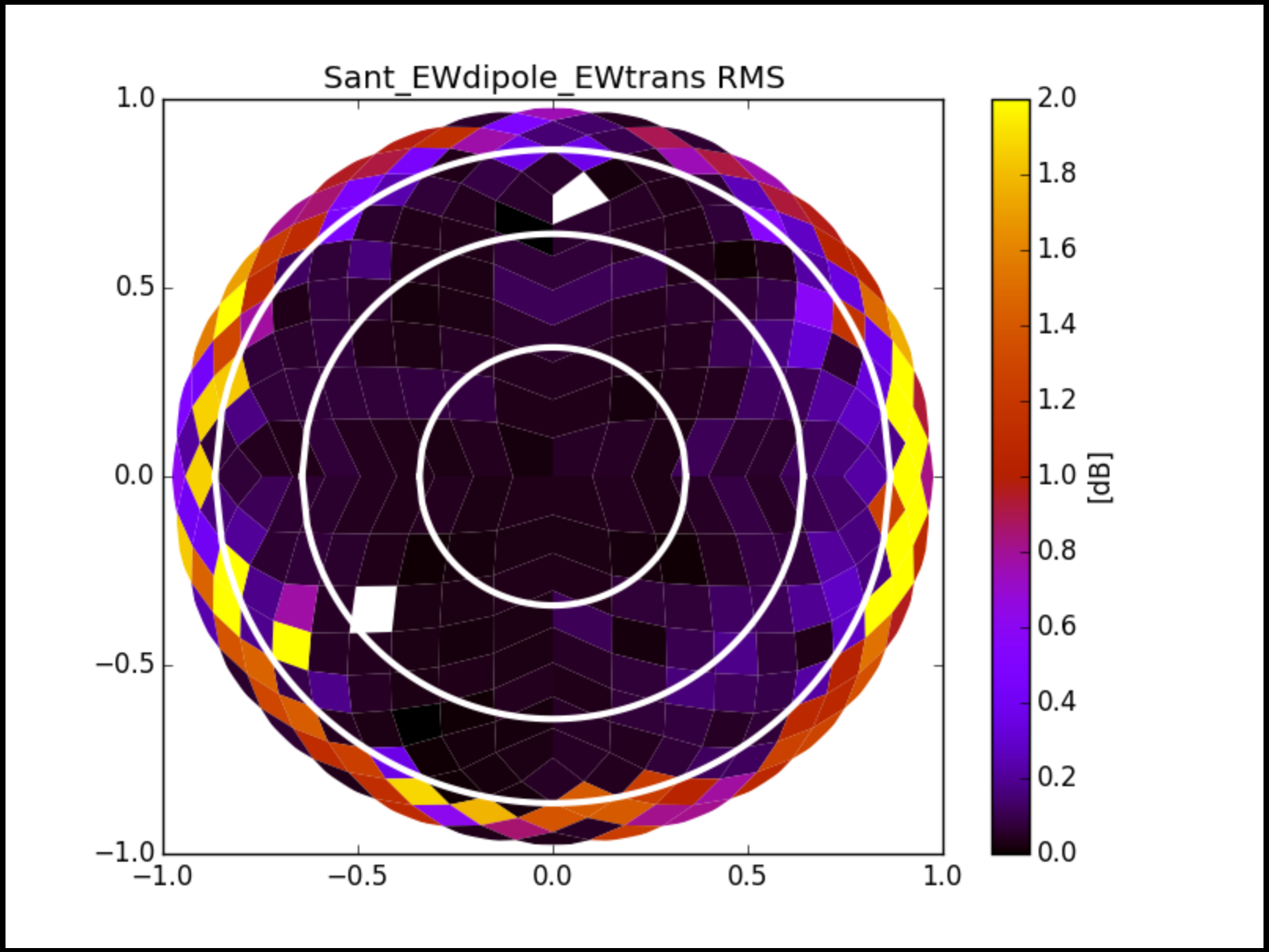

Looking from above
Healpix ring flight paths
N
AUT
ECHO
Polarization locked to cardinal directions


Looking from above
Healpix ring flight paths
N
AUT
ECHO
Polarization locked to cardinal directions*
*does not give equal weight to all pols at all sky locations

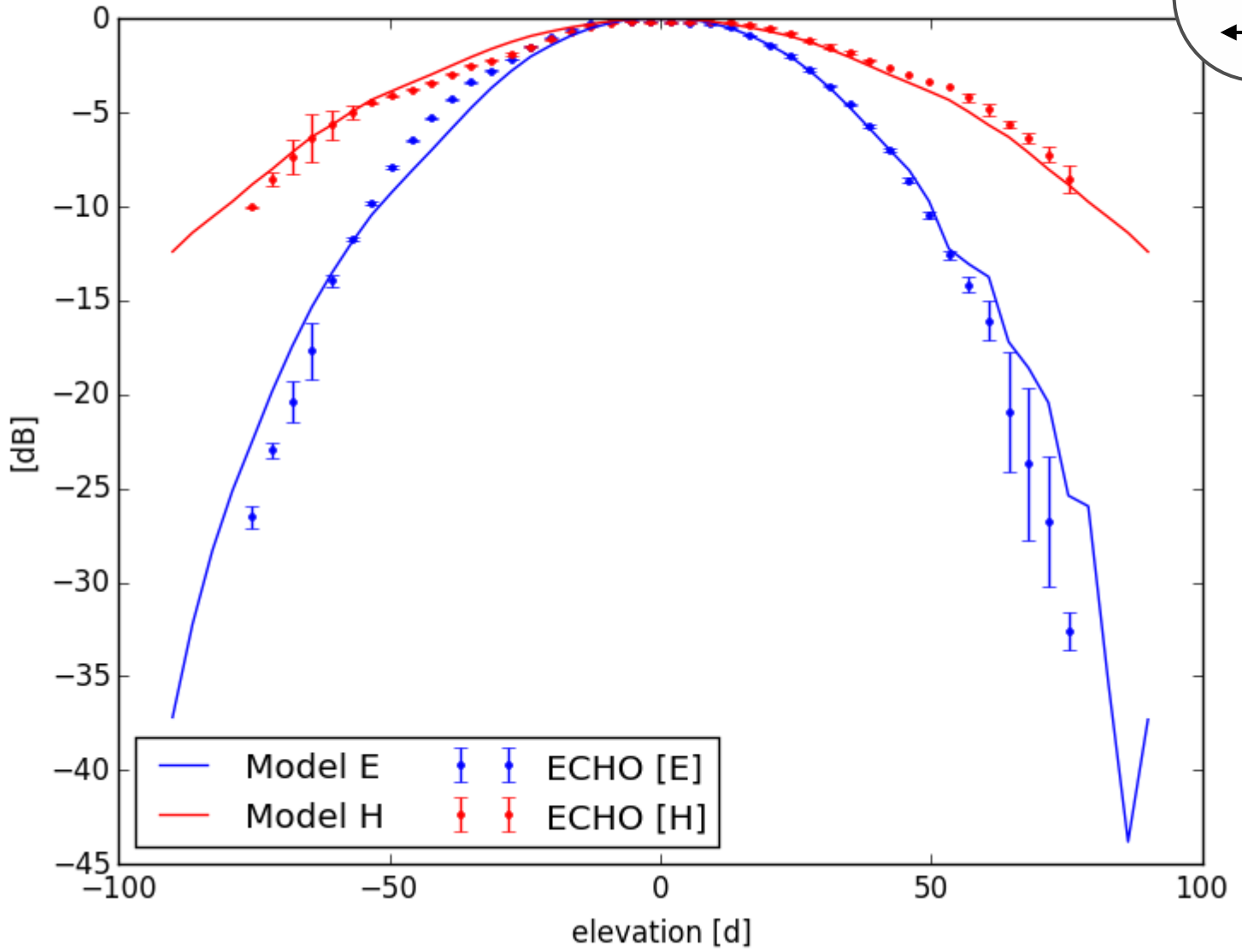
EXAMPLE MAP

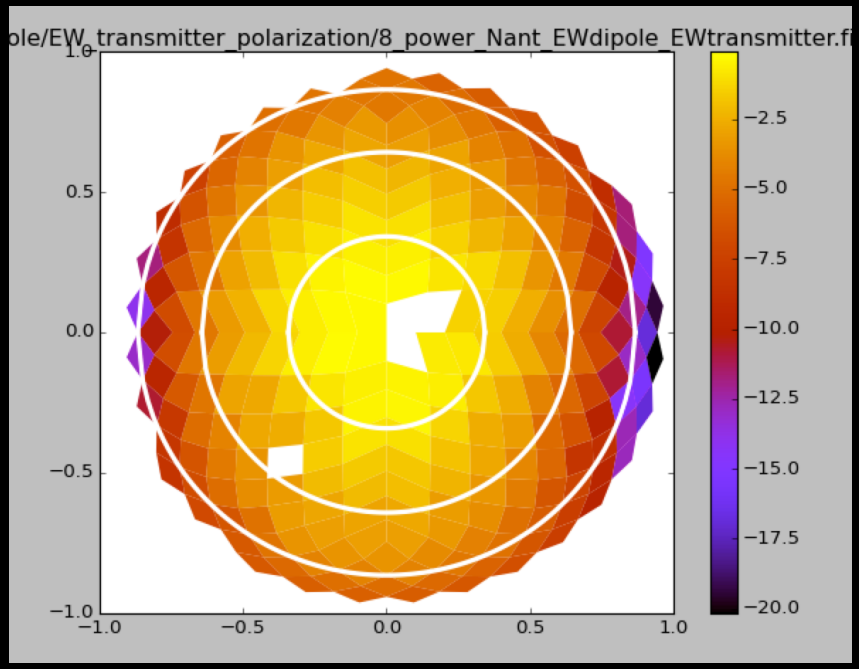

ipole/EW_transmitter_polarization/8_power_Sant_EWdipole_EWtransmitter.fits
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
−4
−8
−12
−16
−20
−24
−28
−32

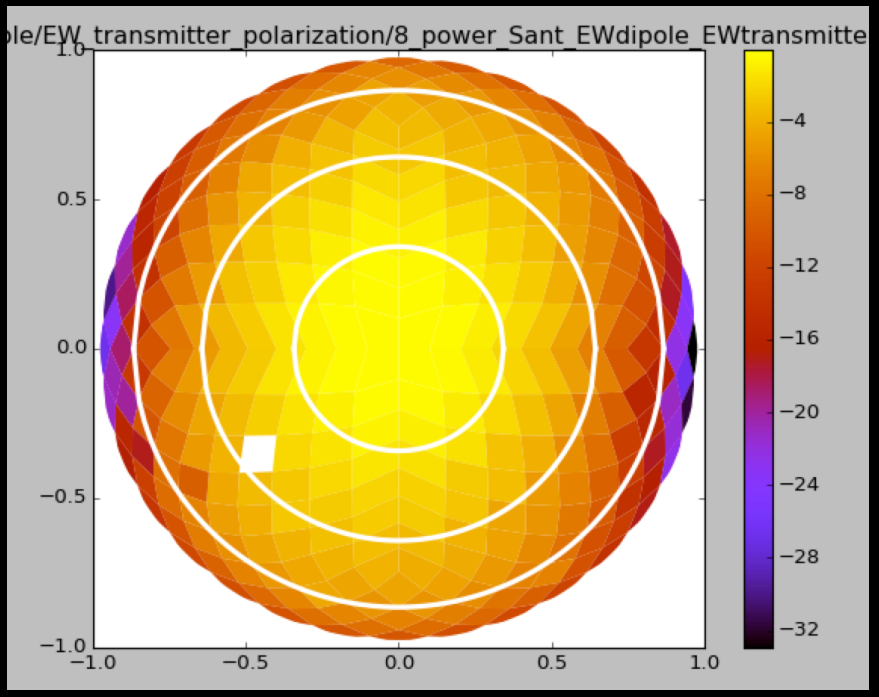
MEASUREMENT PRECISION

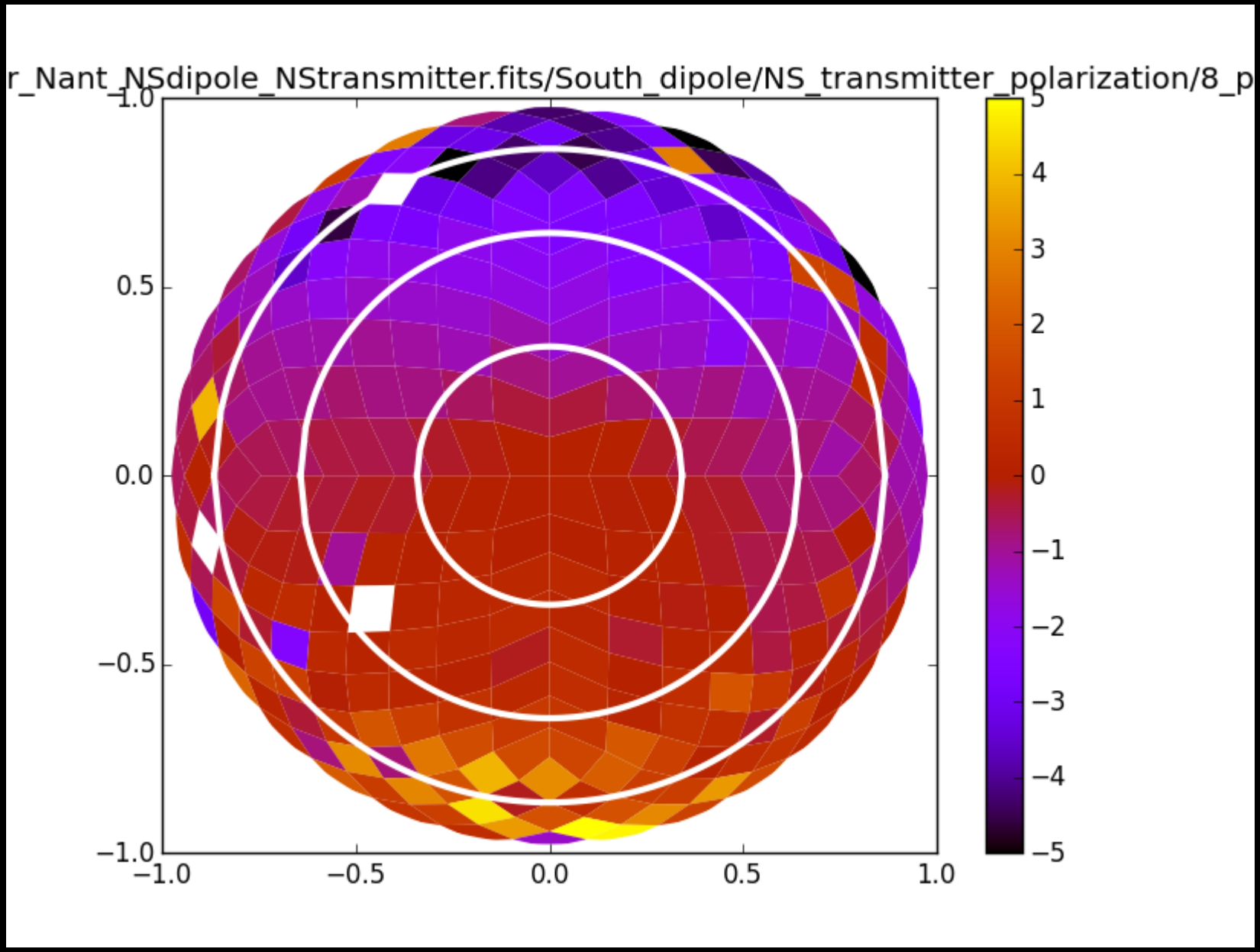


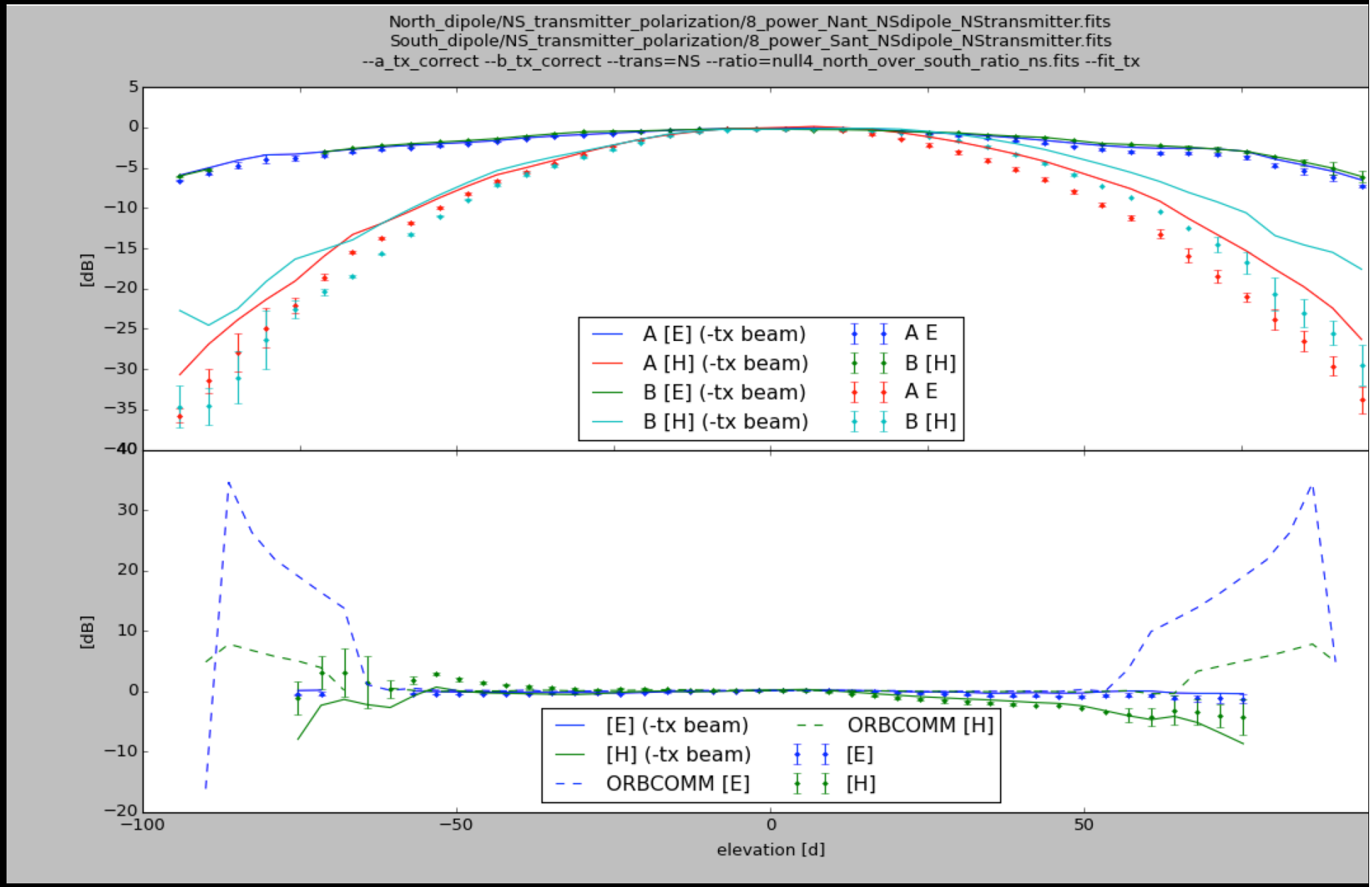
BEAM CUT

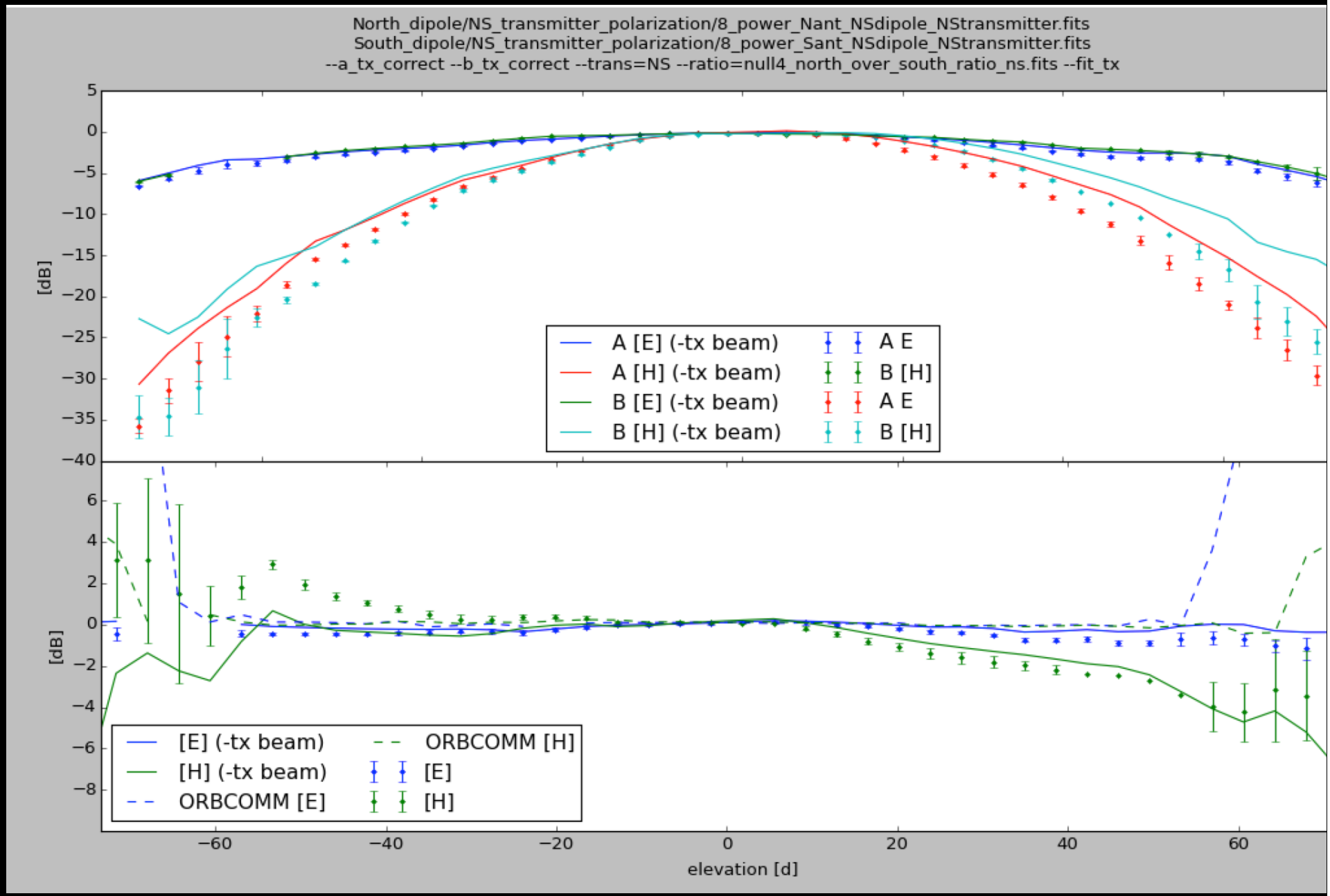

ant
0
−5
−10
−15
−20
−25
−30
−35
−40
−45
[dB]
−100
−50
0
50
100
elevation [d]
Model E
Model H
ECHO [E]
ECHO [H]


ole/EW_transmitter_polarization/8_power_Nant_EWdipole_EWtransmitter.fi
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
−2.5
−5.0
−7.5
−10.0
−12.5
−15.0
−17.5
−20.0


ole/EW_transmitter_polarization/8_power_Sant_EWdipole_EWtransmitte
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
−4
−8
−12
−16
−20
−24
−28
−32


r_Nant_NSdipole_NStransmitter.fits/South_dipole/NS_transmitter_polarization/8_p
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
5
4
3
2
1
0
−1
−2
−3
−4
−5


North_dipole/NS_transmitter_polarization/8_power_Nant_NSdipole_NStransmitter.fits
South_dipole/NS_transmitter_polarization/8_power_Sant_NSdipole_NStransmitter.fits
--a_tx_correct --b_tx_correct --trans=NS --ratio=null4_north_over_south_ratio_ns.fits --fit_tx
[dB]
A [E] (-tx beam)
A [H] (-tx beam)
B [E] (-tx beam)
B [H] (-tx beam)
A E
B [H]
A E
B [H]
[dB]
[E] (-tx beam)
[H] (-tx beam)
ORBCOMM [E]
ORBCOMM [H]
[E]
[H]
elevation [d]


North_dipole/NS_transmitter_polarization/8_power_Nant_NSdipole_NStransmitter.fits
South_dipole/NS_transmitter_polarization/8_power_Sant_NSdipole_NStransmitter.fits
--a_tx_correct --b_tx_correct --trans=NS --ratio=null4_north_over_south_ratio_ns.fits --fit_tx
[dB]
A [E] (-tx beam)
A [H] (-tx beam)
B [E] (-tx beam)
B [H] (-tx beam)
A E
B [H]
A E
B [H]
[dB]
[E] (-tx beam)
[H] (-tx beam)
ORBCOMM [E]
ORBCOMM [H]
[E]
[H]
elevation [d]

FIRST TEST CONCLUSIONS

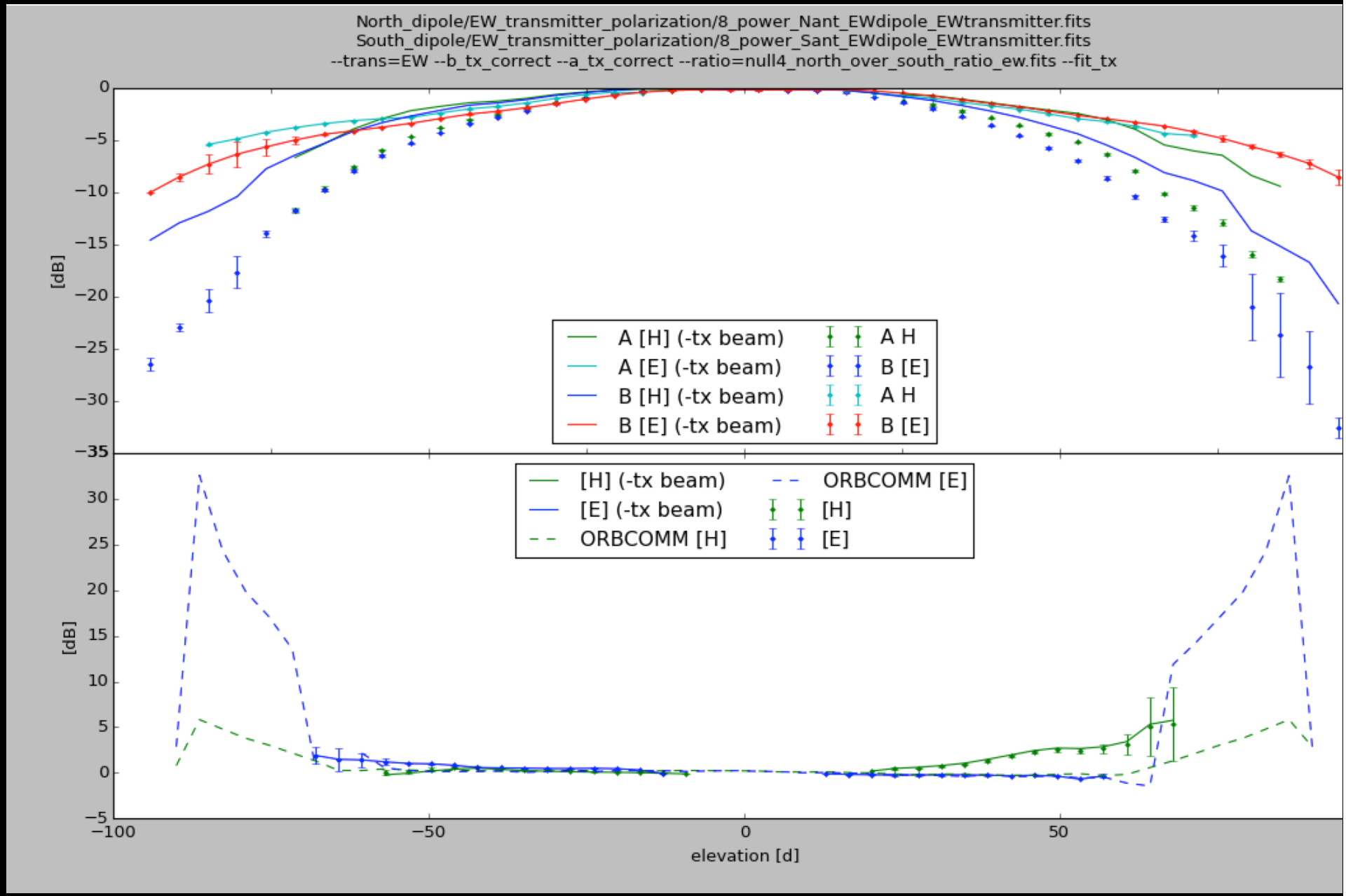
- Most places much better than 0.1dB (2%) precision on each map
- Accuracy can be much better then 1dB (25%) but is subject to systematics
-

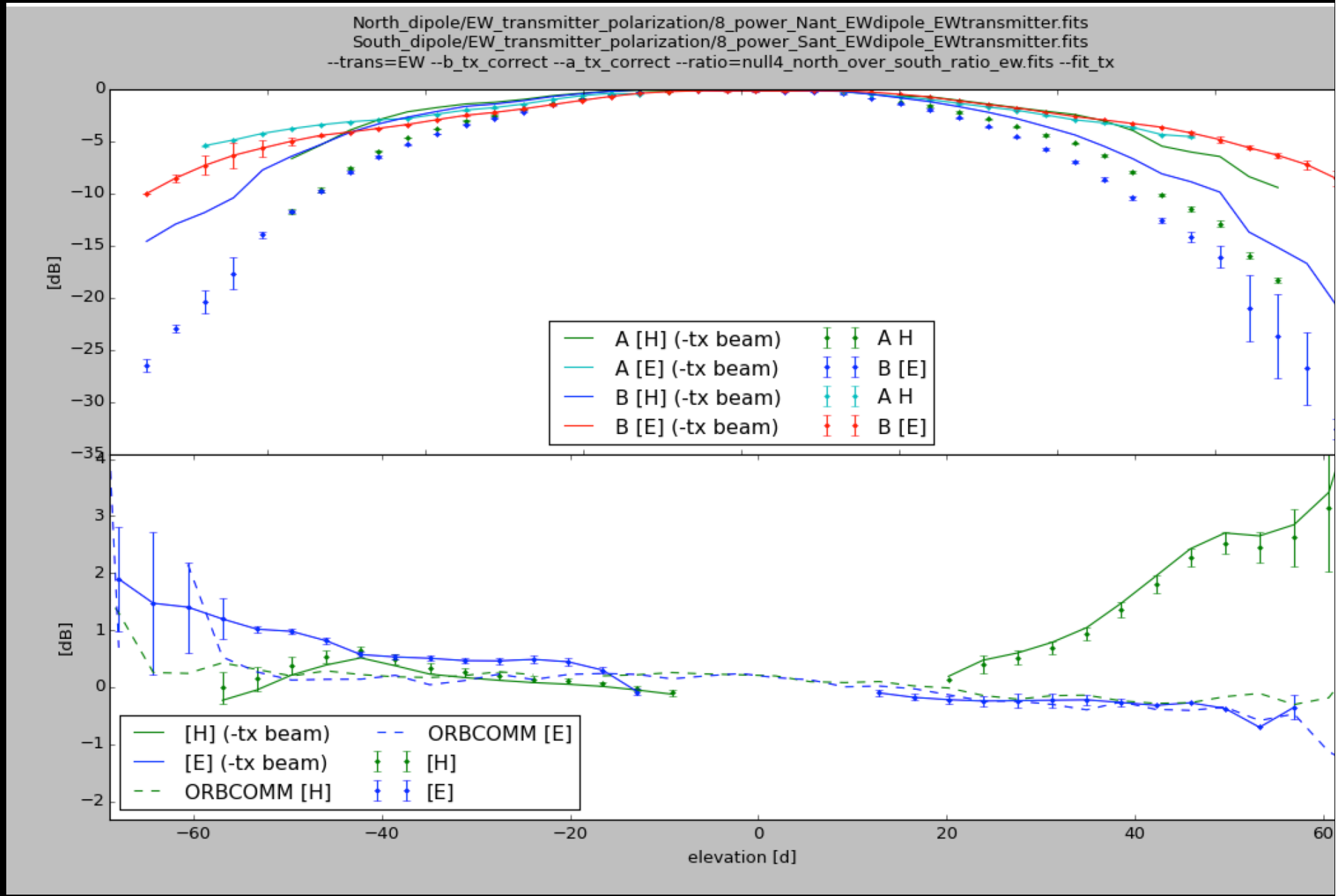
CURRENT\FUTURE WORK

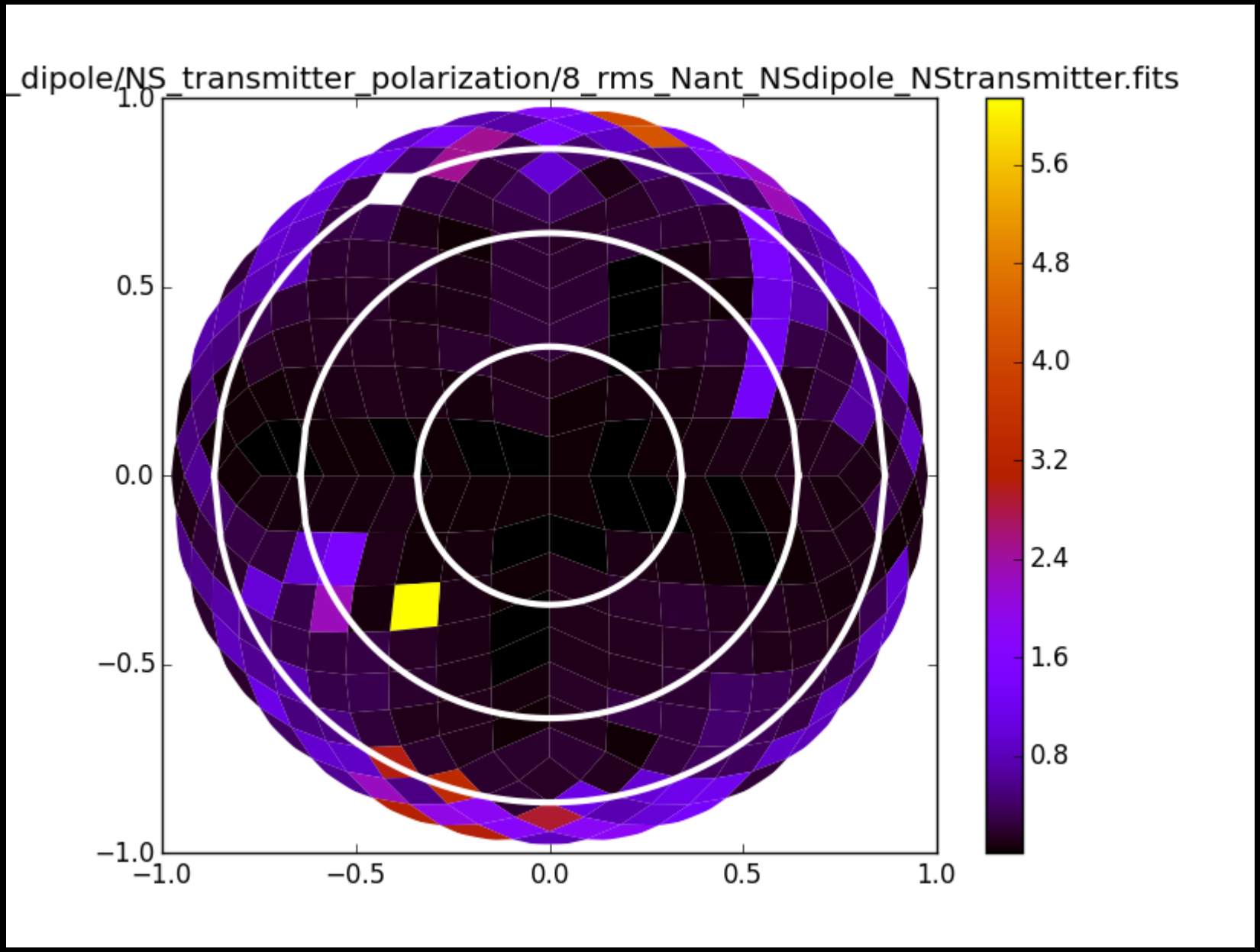
- **Mapping HERA dishes/MWA tiles/[insert your favorite telescope here]**
- Systematic modeling
- real time mapping
- platform stability
- guest instruments
- full polarization coverage
- Site coordination

- EM simulation and anechoic chamber mapping of calibration source
- Identify systematics “as they happen”
- RTK GPS positioning and attitude, longer duration flight time, better EM isolation
- Measure reflections in time domain.
- Add vertical transmitter dipole?
- Goal: routine operation on radio quiet sites


The ECHO Team


North_dipole/EW_transmitter_polarization/8_power_Nant_EWdipole_EWtransmitter.fits
South_dipole/EW_transmitter_polarization/8_power_Sant_EWdipole_EWtransmitter.fits
--trans=EW --b_tx_correct --a_tx_correct --ratio=null4_north_over_south_ratio_ew.fits --fit_tx
[dB]
A [H] (-tx beam)
A [E] (-tx beam)
B [H] (-tx beam)
B [E] (-tx beam)
A H
B [E]
A H
B [E]
[H] (-tx beam)
[E] (-tx beam)
ORBCOMM [H]
ORBCOMM [E]
[H]
[E]
[dB]
elevation [d]


North_dipole/EW_transmitter_polarization/8_power_Nant_EWdipole_EWtransmitter.fits
South_dipole/EW_transmitter_polarization/8_power_Sant_EWdipole_EWtransmitter.fits
--trans=EW --b_tx_correct --a_tx_correct --ratio=null4_north_over_south_ratio_ew.fits --fit_tx
[dB]
A [H] (-tx beam)
A [E] (-tx beam)
B [H] (-tx beam)
B [E] (-tx beam)
A H
B [E]
A H
B [E]
[dB]
[H] (-tx beam)
[E] (-tx beam)
ORBCOMM [H]
ORBCOMM [E]
[H]
[E]
elevation [d]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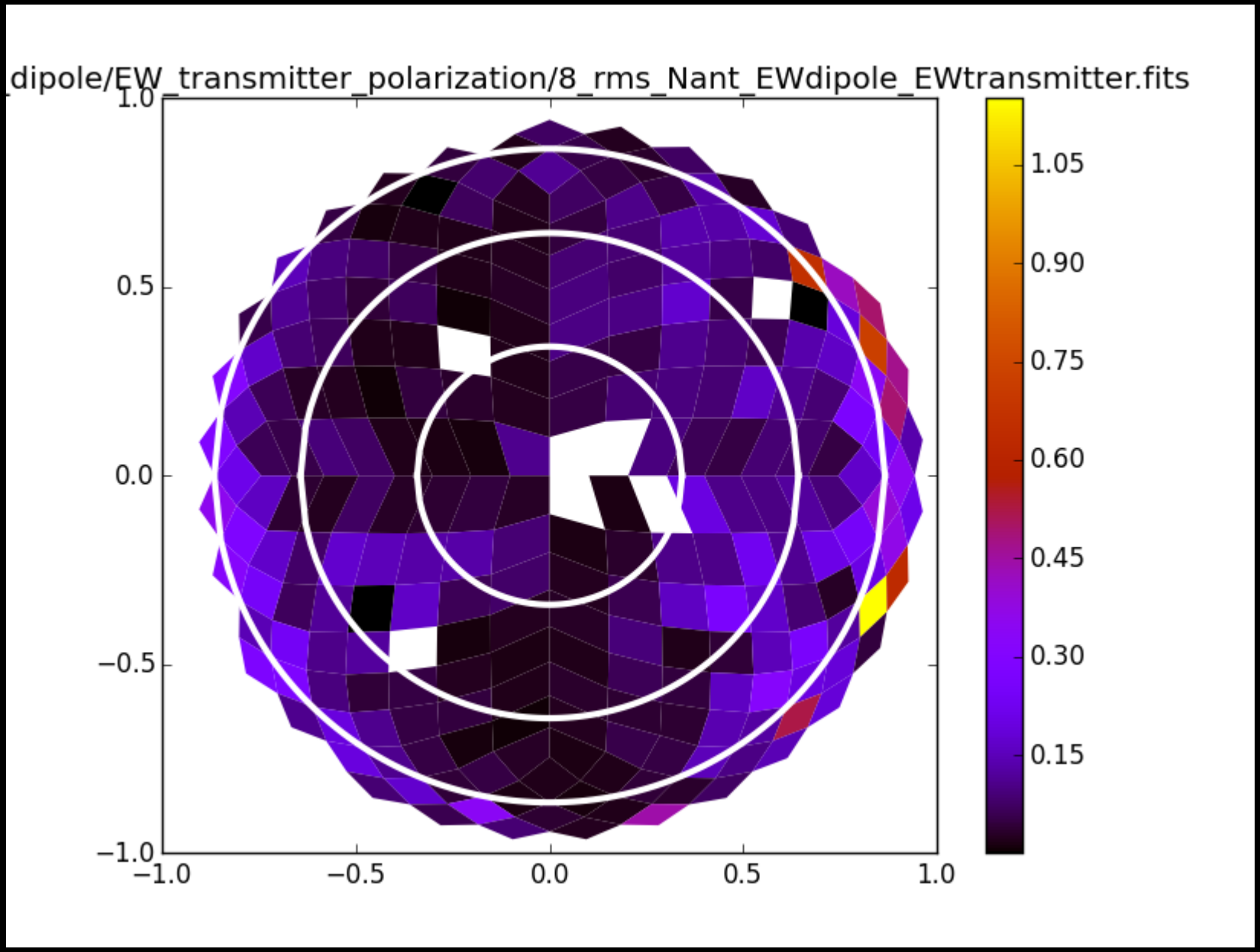
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
5.6
4.8
4.0
3.2
2.4
1.6
0.8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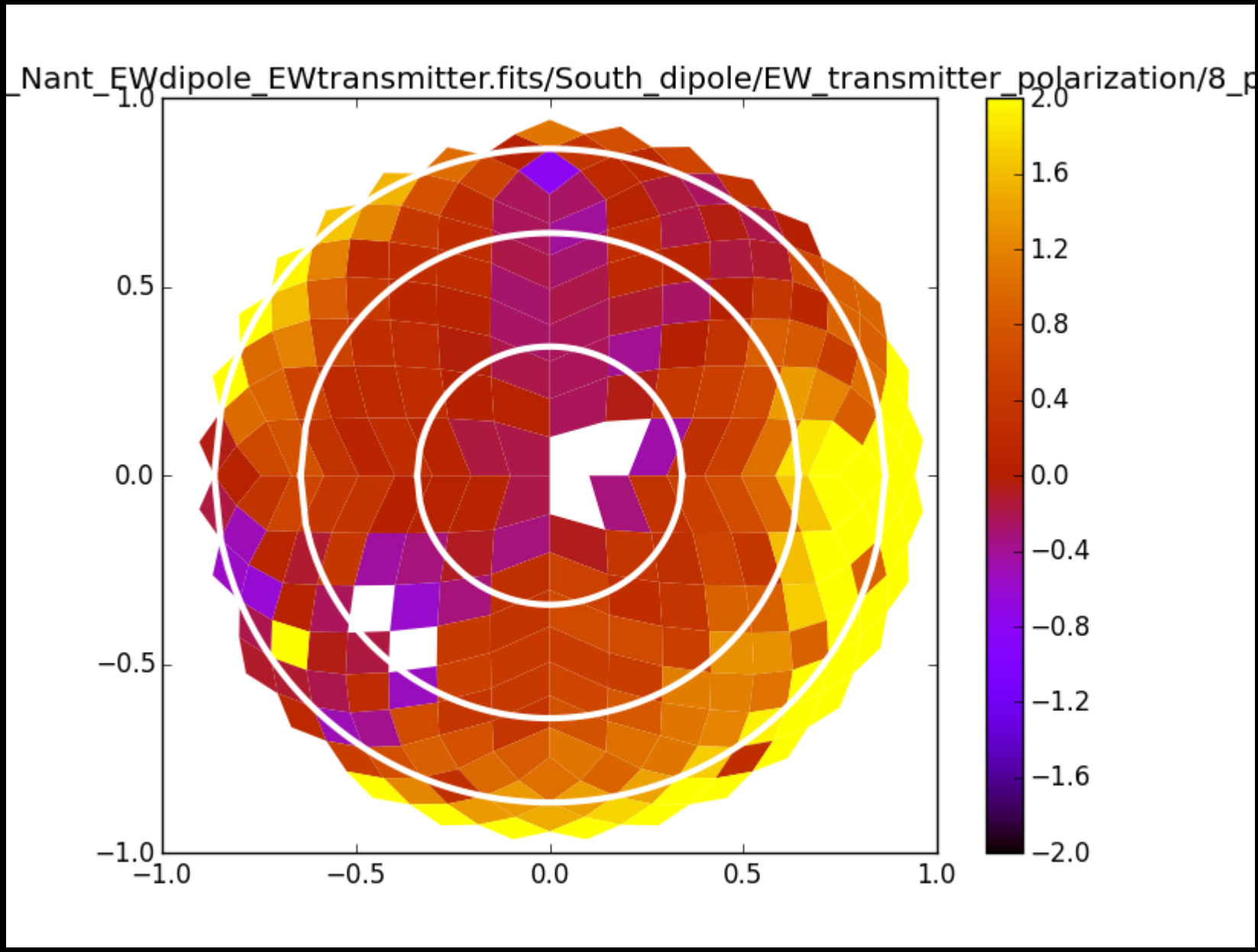
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
1.05
0.90
0.75
0.60
0.45
0.30
0.15


_Nant_EWdipole_EWtransmitter.fits/South_dipole/EW_transmitter_polarization/8_p
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
2.0
1.6
1.2
0.8
0.4
0.0
−0.4
−0.8
−1.2
−1.6
−2.0