PHASED ARRAY ANTENNA SYSTEMS FOR RADIO ASTRONOMY
Brigham Young University, Provo UT May 3-5, 2010

Simulated Response of a 19 Element PAF for the Arecibo Radio Telescope PAF Feasibility Study

G. Cortes-Medellin, K. F. Warnick and B. D. Jeffs

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Cornell University
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Collaborators
AO PAF Feasibility Study

- Karl F. Warnick and Brian D. Jeffs (BYU)
- David Smith (MERLAB)
- Ganesh Rajagopalan, Phil Perilat,

  Dana Whitlow, and AO tech Staff. (AO)

Overview

- Introduction:
- Arecibo’s Shaped Optics and FOV
- Arecibo’s PAF Feasibility Study
- Simulations and Preliminary Results
- Conclusions

Introduction

- Most Sensitive Single Dish L-Band Radio telescope in the World.
- Main Spherical Reflector is 305 m in diameter

Introduction

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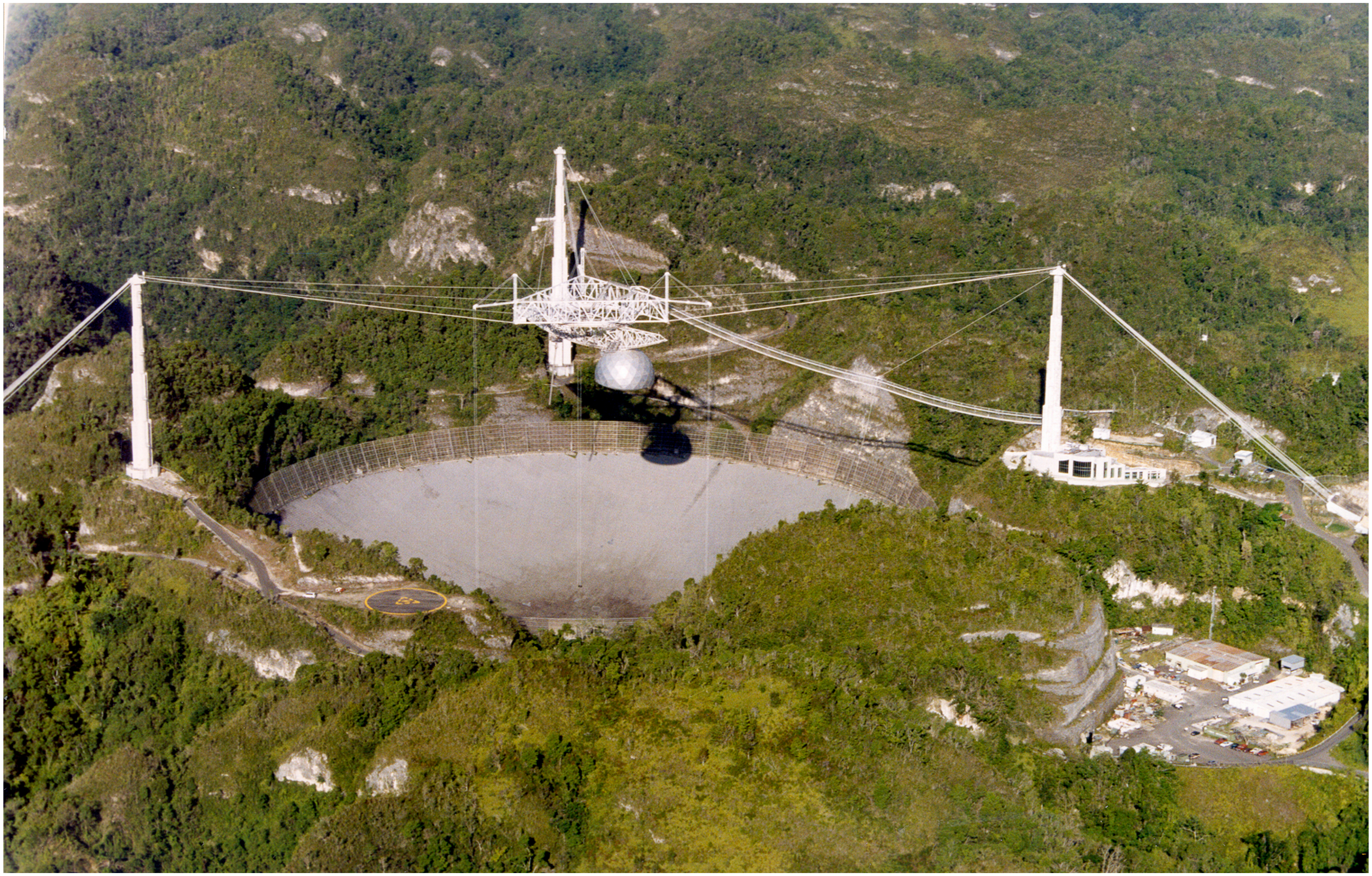
Introduction



Introduction

- Most Sensitive Single Dish L-Band Radio telescope in the World.
- Main Spherical Reflector is 305 m in diameter
- Maximum scanning angle with respect to zenith: ±15°

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Arecibo Gregorian Corrector

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Arecibo Gregorian Corrector

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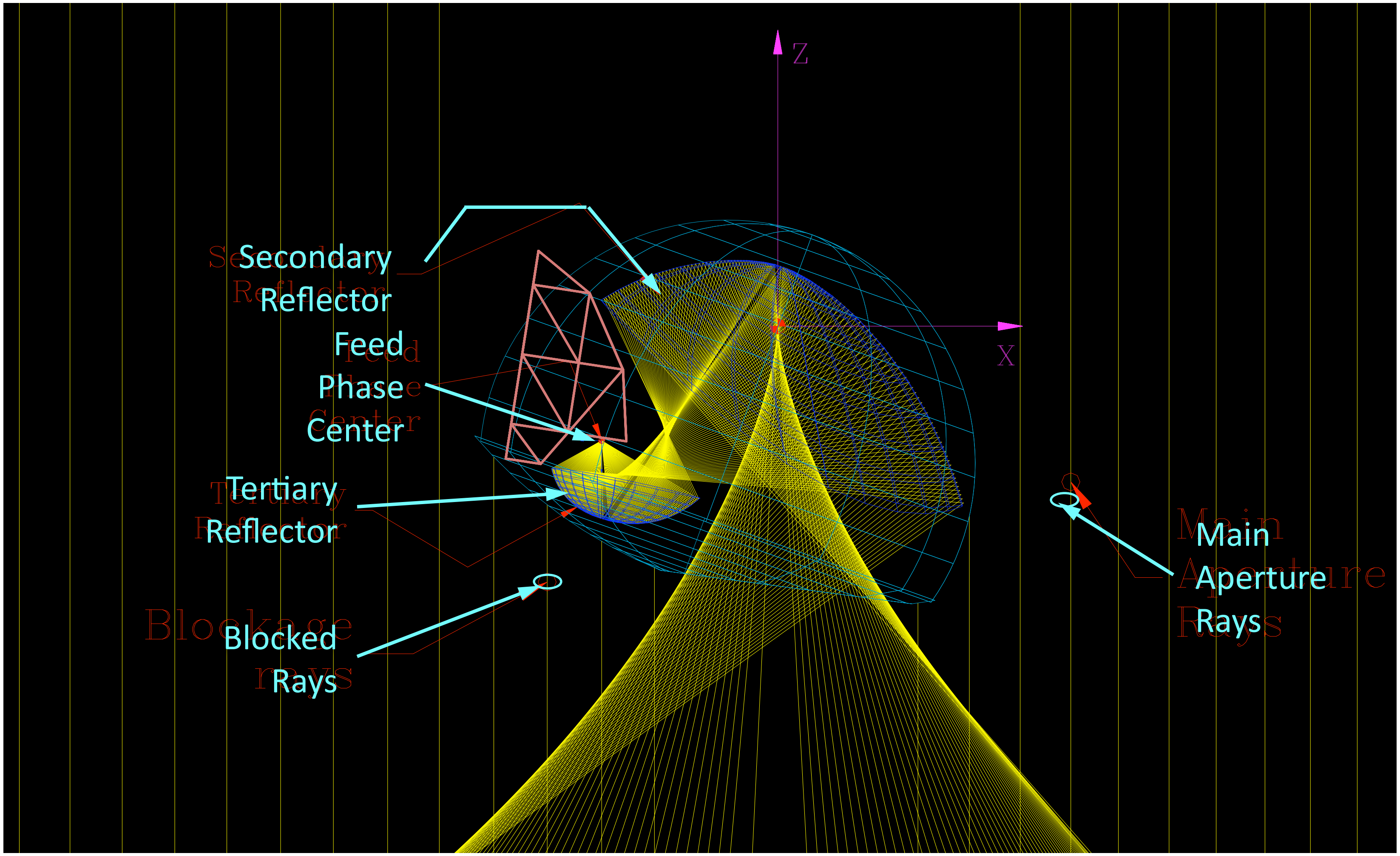
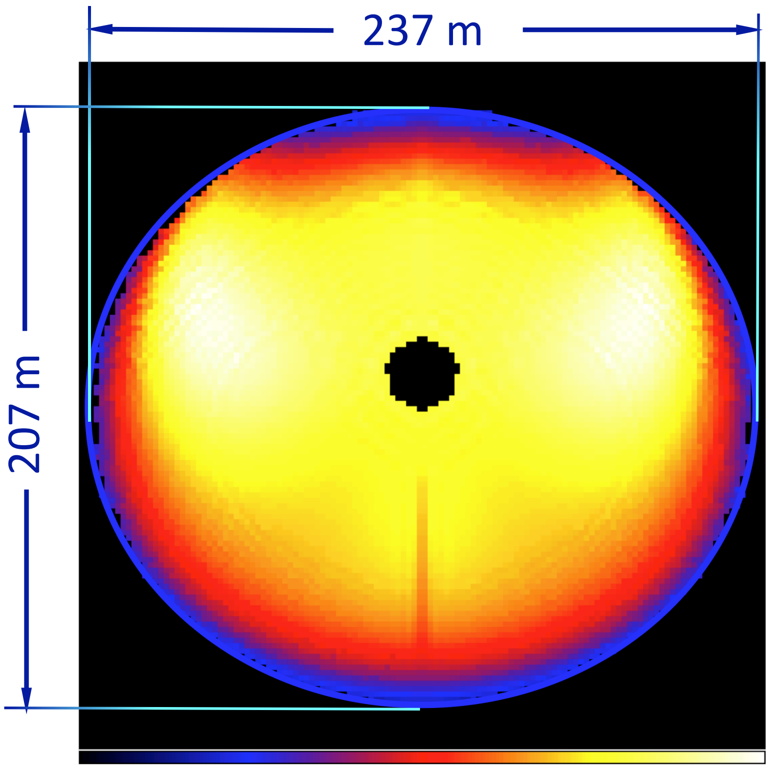


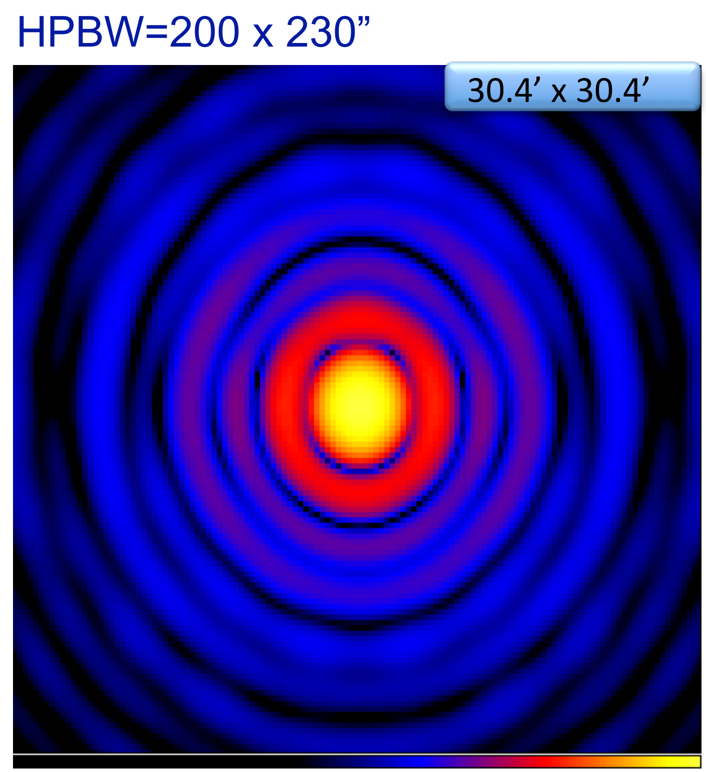
Introduction

- Most Sensitive Single Dish L-Band Radio telescope in the World.
- Main Spherical Reflector is 305 m in diameter
- Maximum scanning angle with respect to zenith: ±15°
- Arecibo Gregorian Corrector: Dual shaped Reflector System to correct for spherical aberration and produces a uniform aperture Illumination.
- Effective Elliptical Illumination of 237 x 207 m

Aperture Illumination and Radiation Pattern L-Band @ 1.375 GHz



Aperture illumination



Far Field Radiation Pattern [dB]

ALFA
Arecibo L-Band Feed Array

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ALFA

Total Incoherent Multi Beam Pattern

TE11 Mode Horn ∅25.0 cm x 26.0 cm c-c

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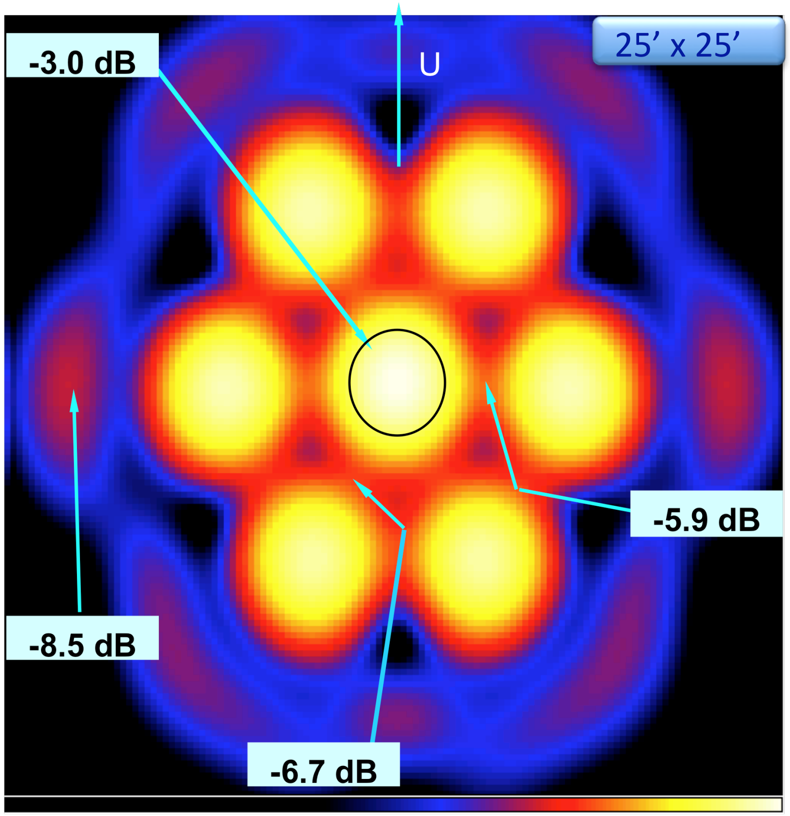
Calculated Beam Pattern



Measured Beam Pattern

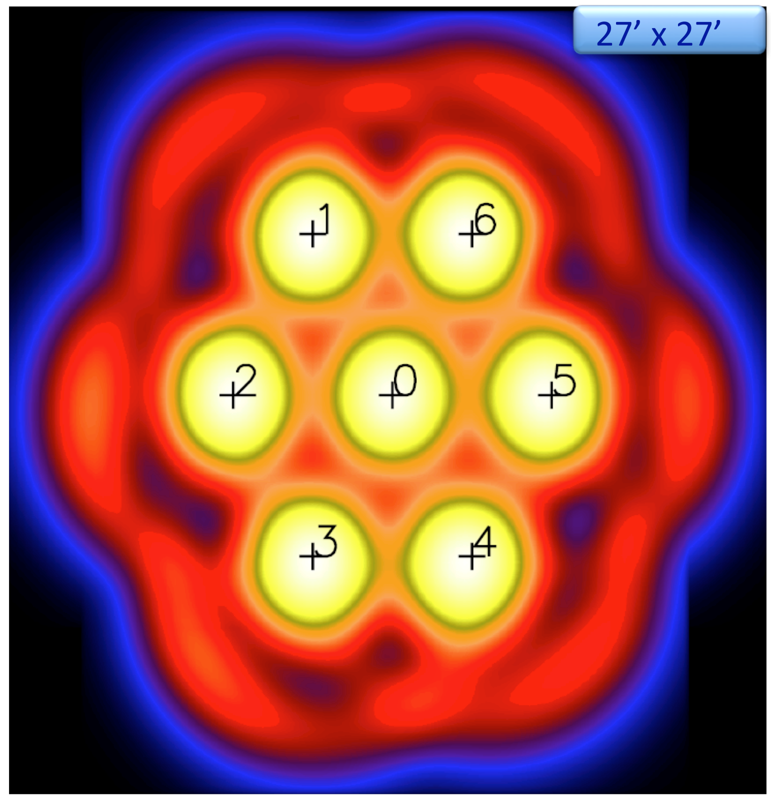
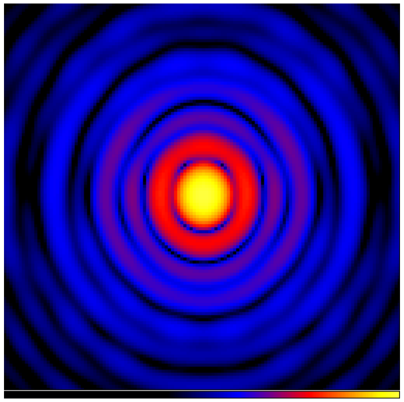


Image by Carl Heilis, Dec 2004

Beyond ALFA

Beyond ALFA

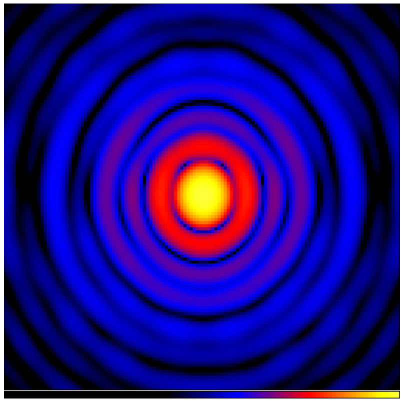
HPBW=200” x 230”



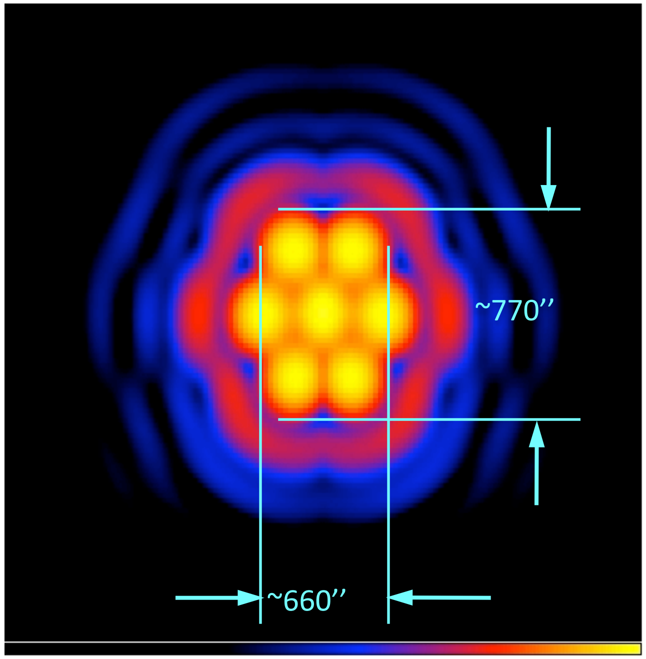
AO

Beyond ALFA

HPBW=200" x 230"



AO



ALFA

Beyond ALFA

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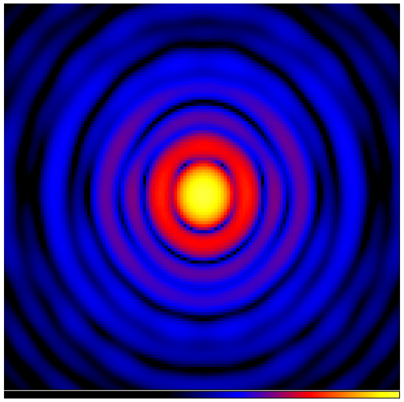
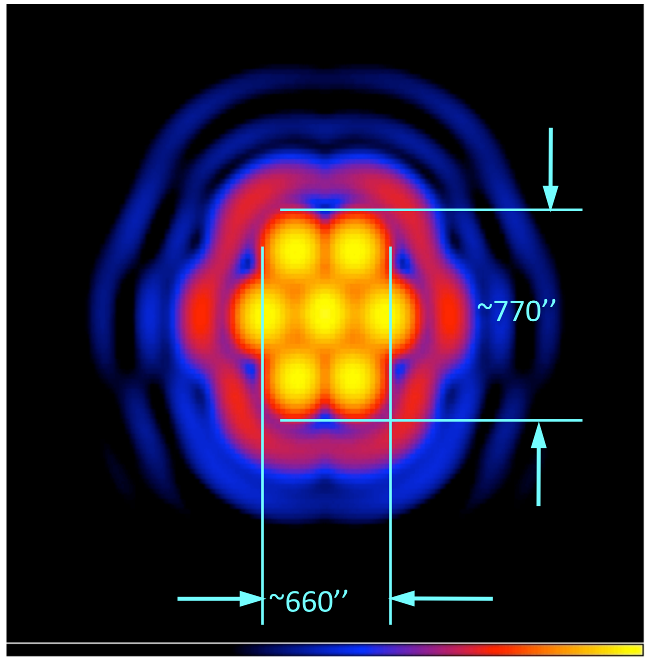
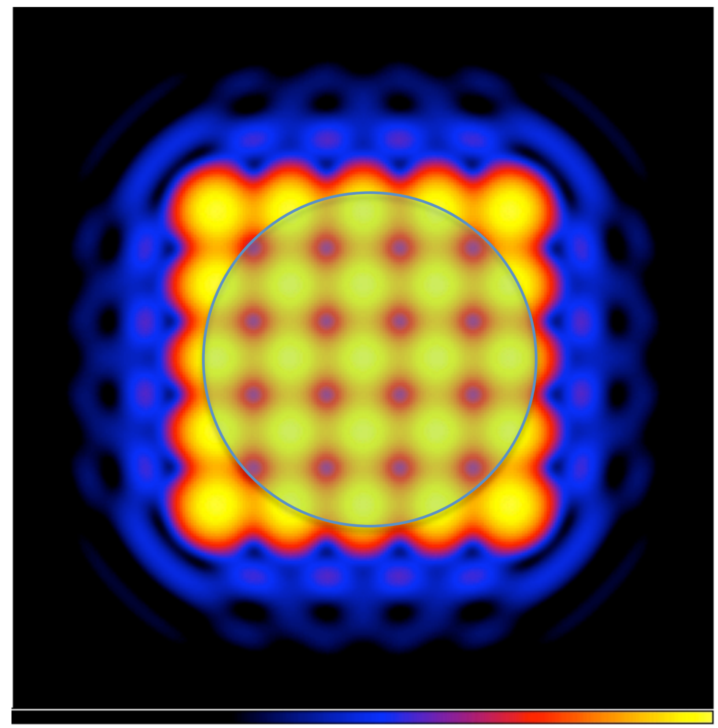


AO



ALFA



AO PAF

Survey Speed:

$$\mathrm{SVS} \;=\; N_{\mathrm{b}}\,\Omega_{\mathrm{b}}\,BW\;\left(A_{\mathrm{eff}}/T_{\mathrm{sys}}\right)^{2}$$

Survey Speed:

$$\mathrm{SVS} = \overbrace{N_{\mathrm{b}}}^{\text{\# of beams}}\, \underbrace{\Omega_{\mathrm{b}}}_{\text{Beam Solid Angle}}\, \overbrace{BW}^{\text{Bandwidth}}\, \left(A_{\mathrm{eff}}/T_{\mathrm{sys}}\right)^2$$

Survey Speed: Enter AO PAF

# of beams

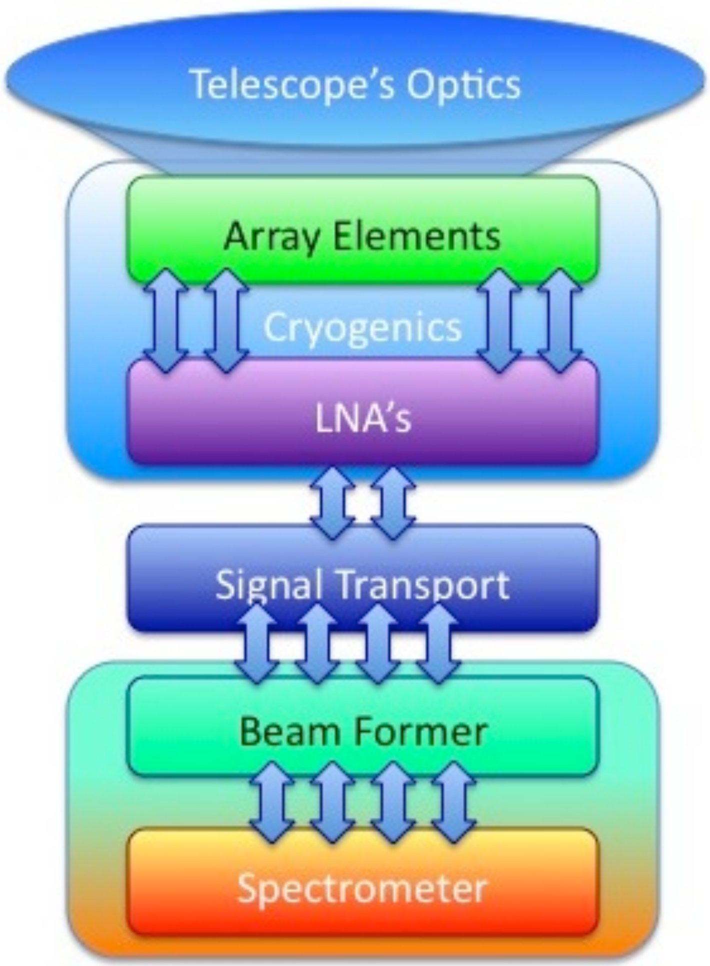
Bandwidth

$$\mathrm{SVS} = N_\mathrm{b}\,\Omega_\mathrm{b}\,BW\,\left(A_\mathrm{eff}/T_\mathrm{sys}\right)^2$$

Beam Solid Angle

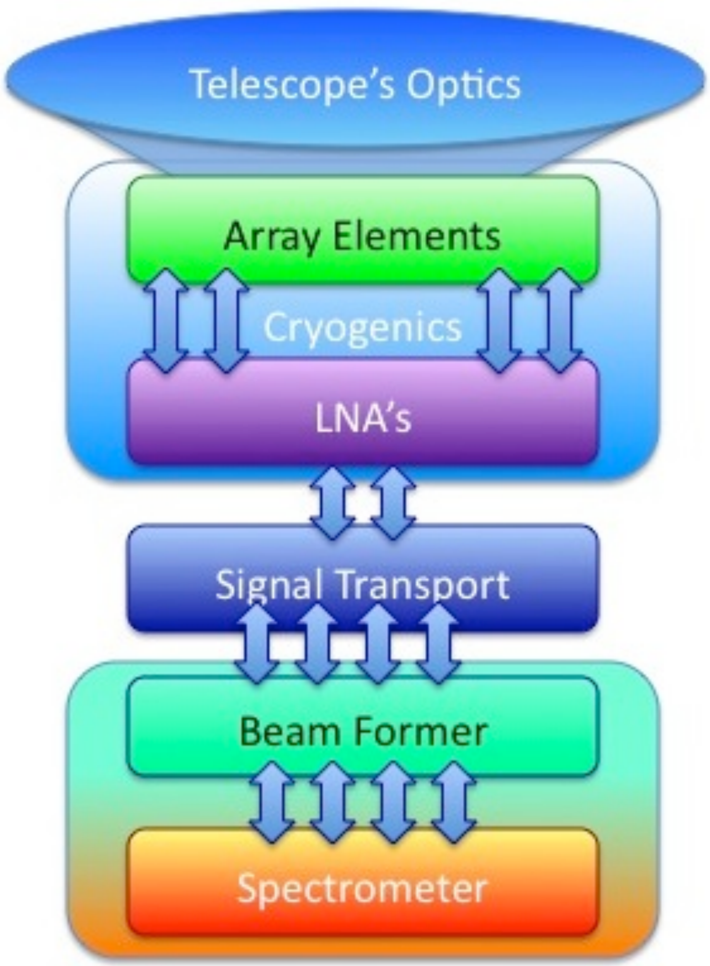
L-Band	N_b	Ω_b	BW	A_{eff}	T_{SYS}	A_{EFF}/T_{SYS}	SVS/ AO_{SVS}
		[deg²]	[MHz]	[m²]	[K]	[m²/K]	
AO	1	0.0028	300	32750	27	1213	1
ALFA	7	0.0028	300	32750	27	1213	7
AO FPA	40	0.0028	300	32750	35	936	23.8

Arecibo's AO FPA Architecture Components



1. Gregorian Optics
2. Array Elements
3. LNA's
4. Cryogenics
5. Signal Transport
6. Beam Former
7. Spectrometer

Arecibo's AO FPA Architecture Challenges



FOV

Tsys

Bandwidth

Available Field of View with Arecibo's a Shaped Optics

FOV in the Gregorian Focal Plane

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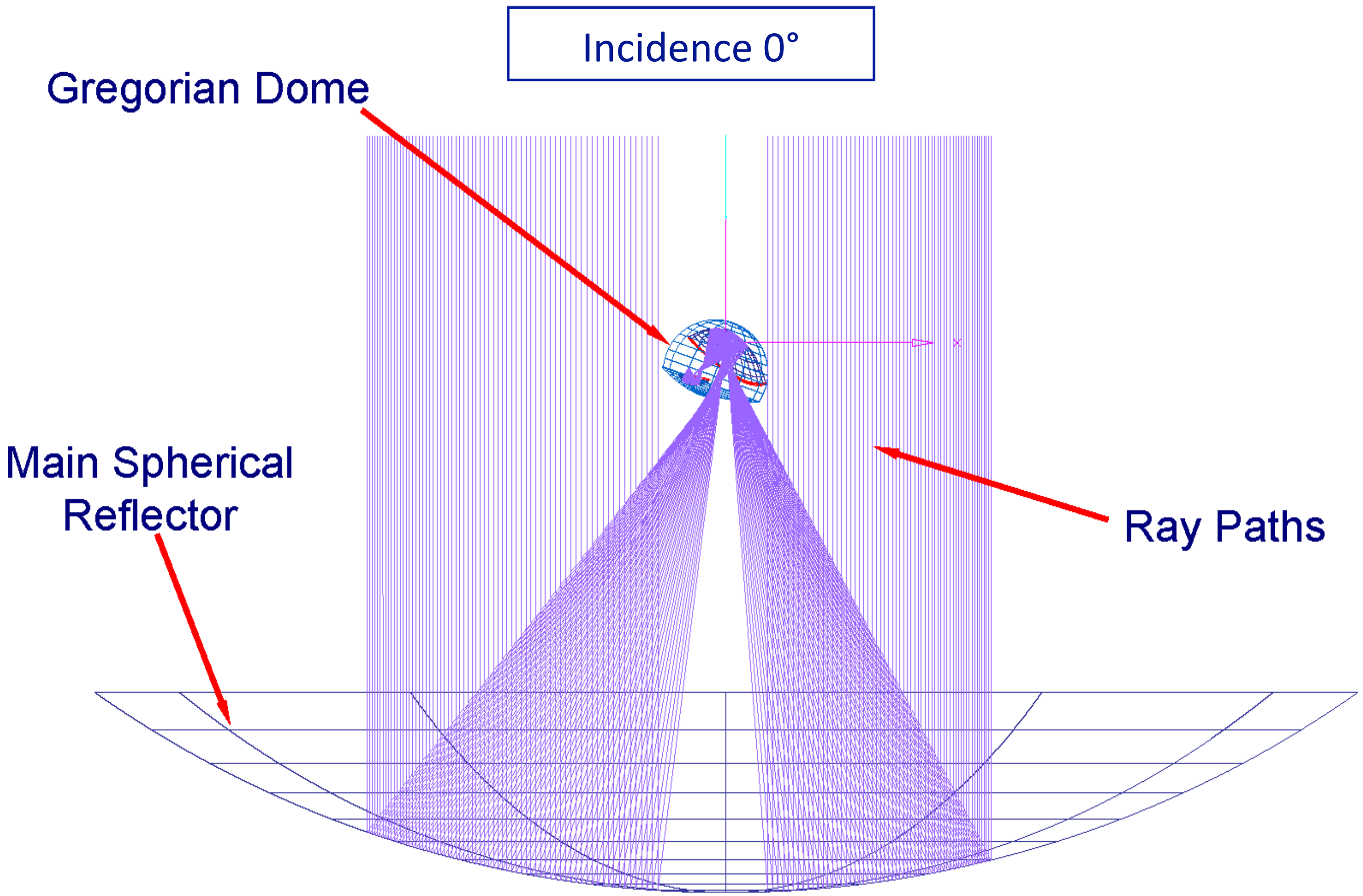

FOV in the Gregorian Focal Plane

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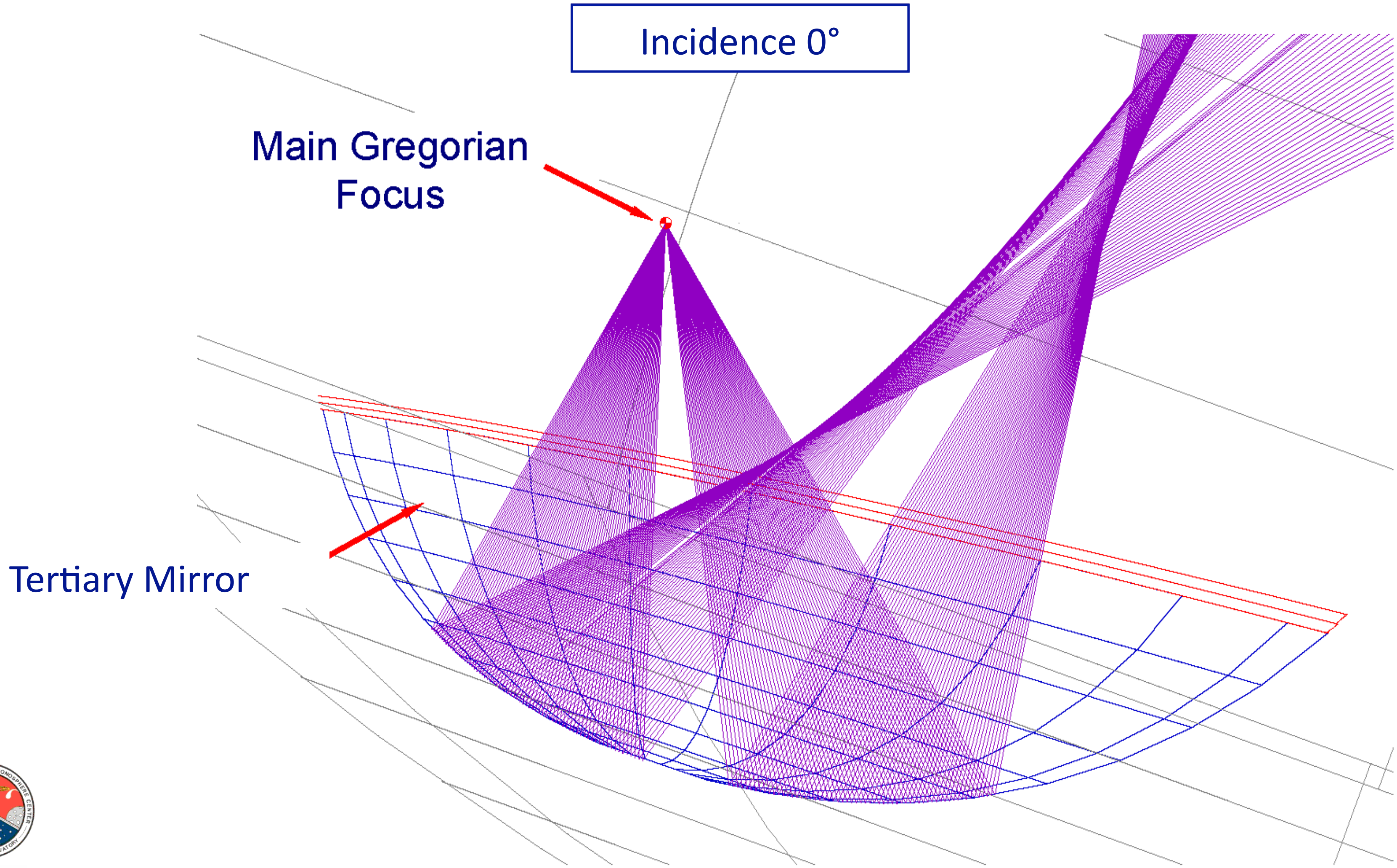

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FOV in the Gregorian Focal Plane

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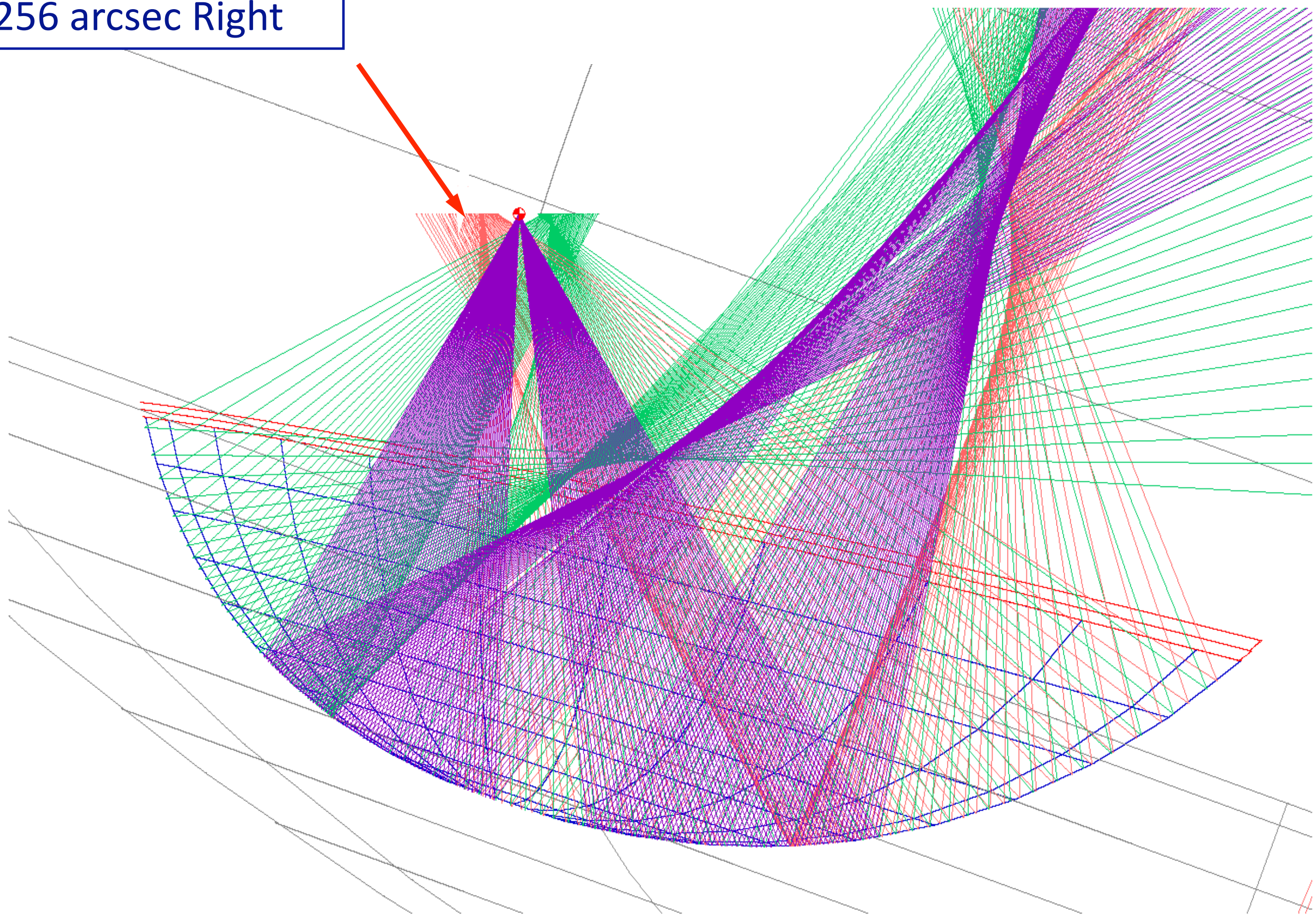
256 arcsec Right



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FOV in the Gregorian Focal Plane

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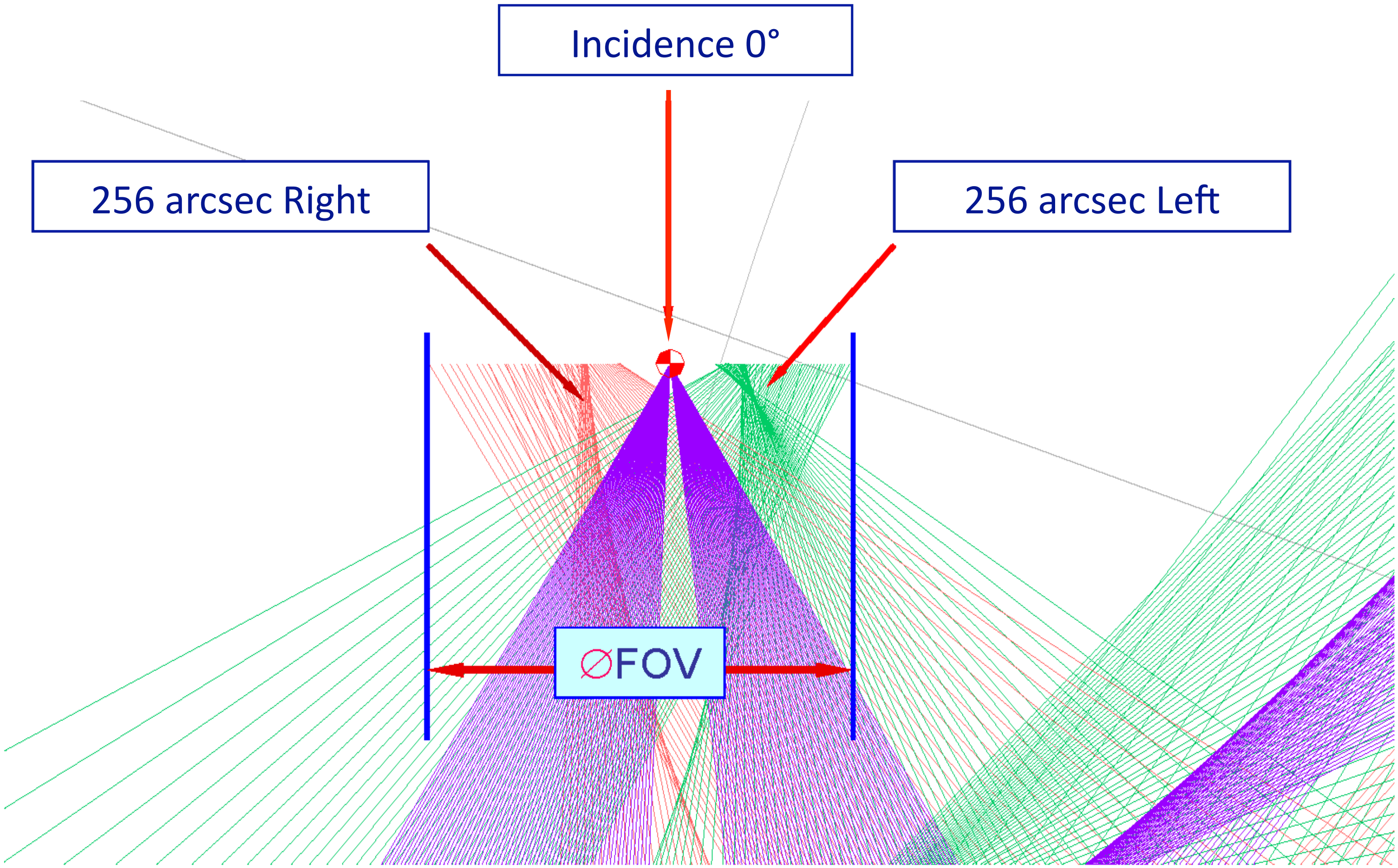
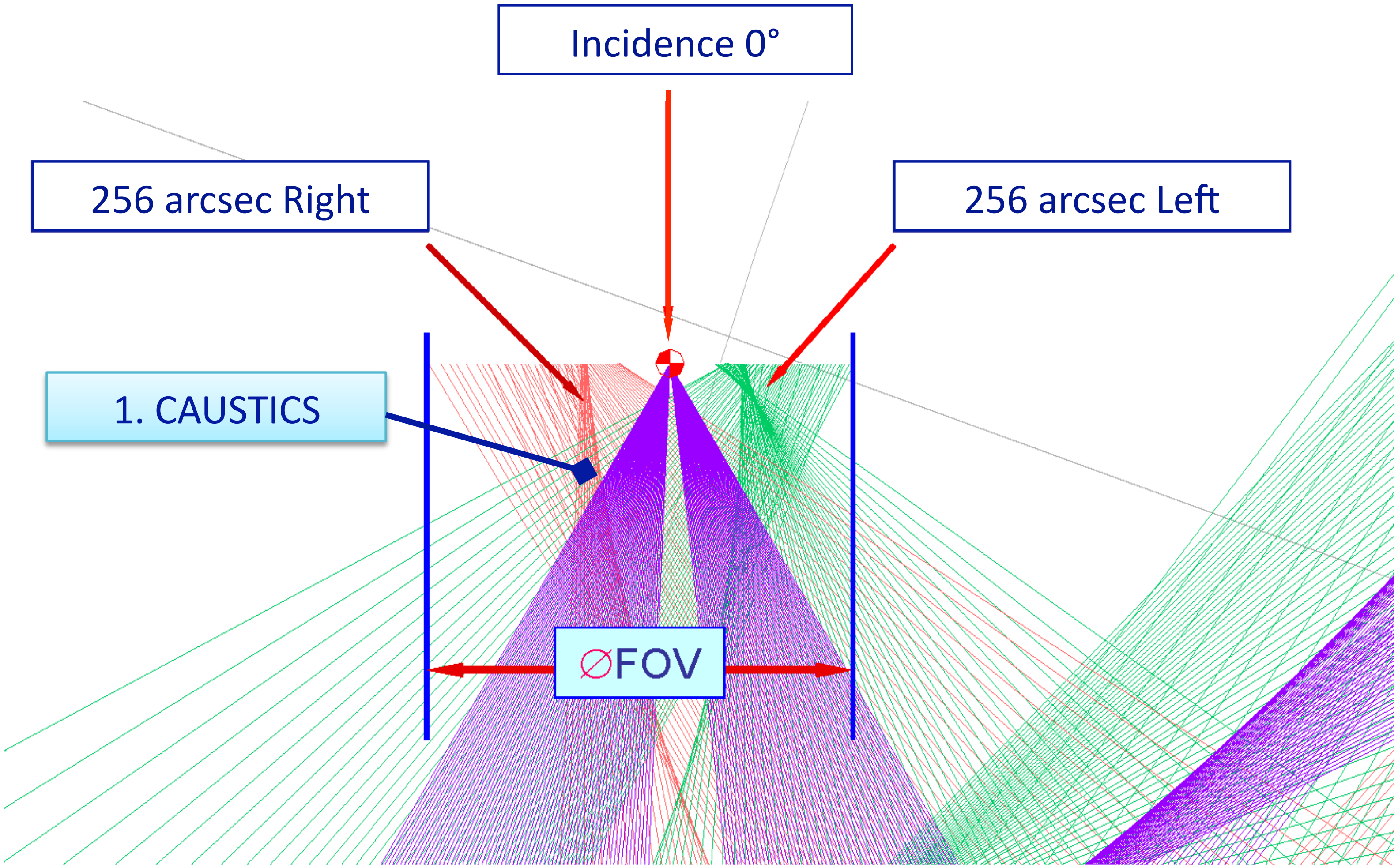


FOV in the Gregorian Focal Plane



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AO Gregorian FOV: Scanning Losses

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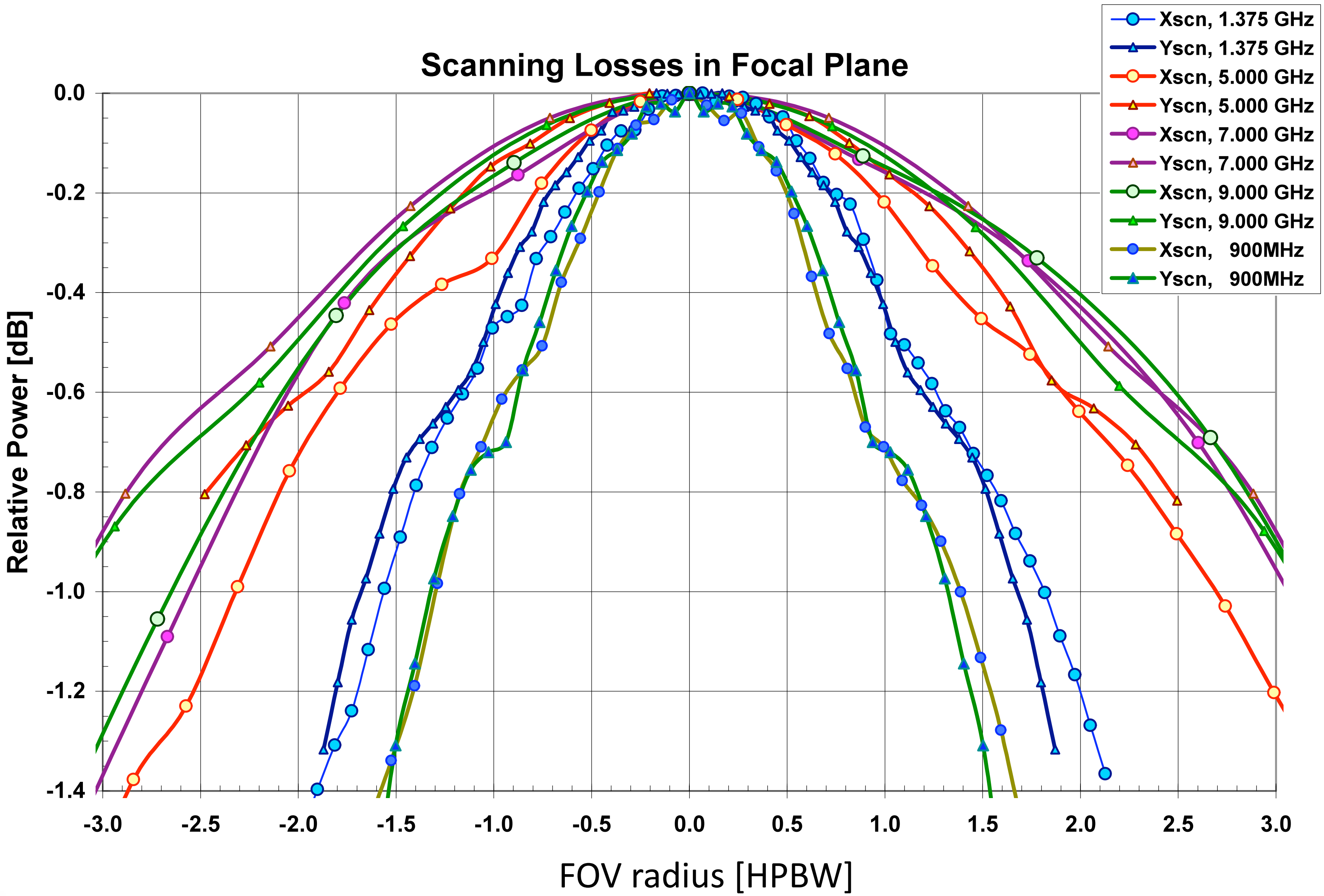
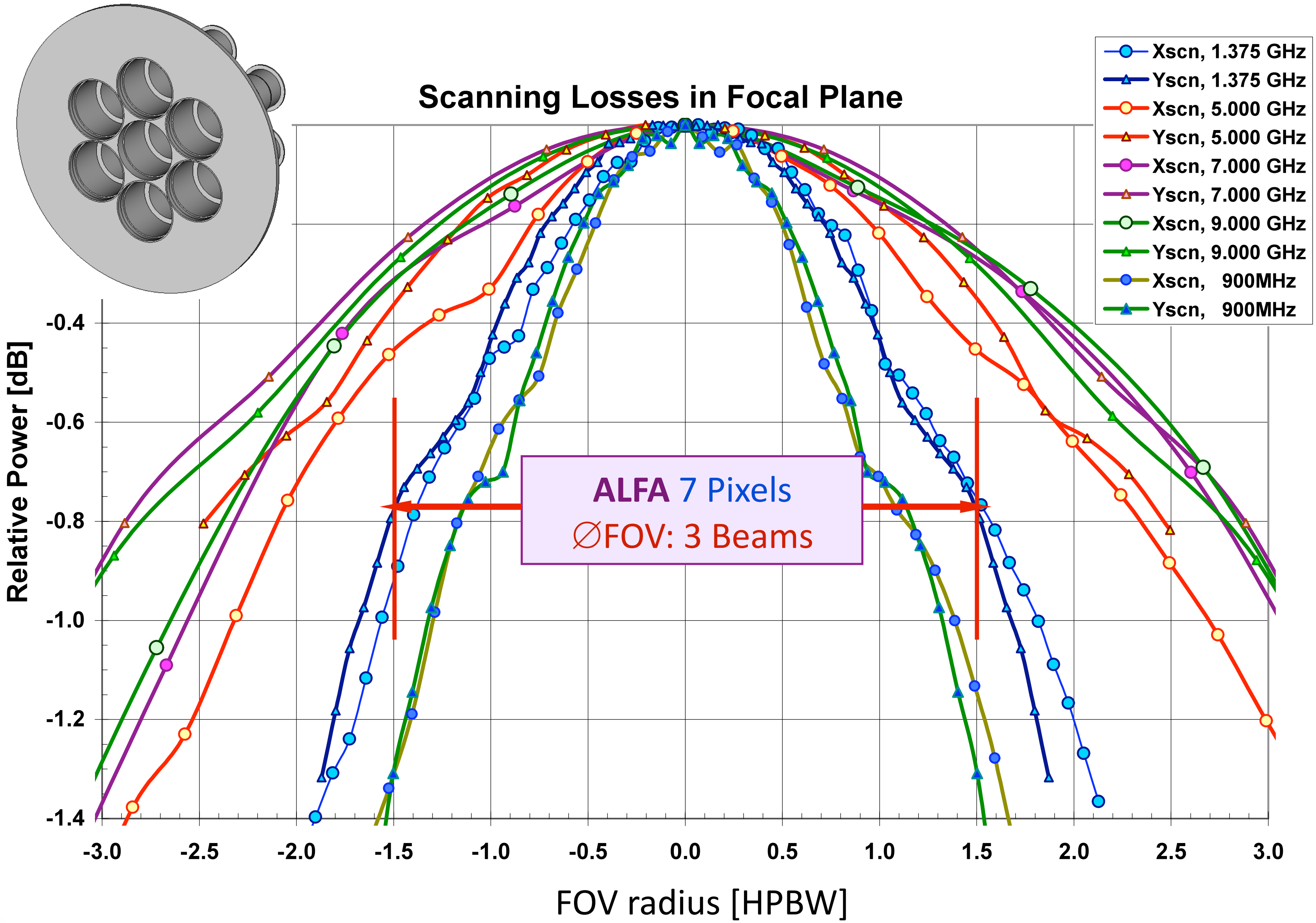
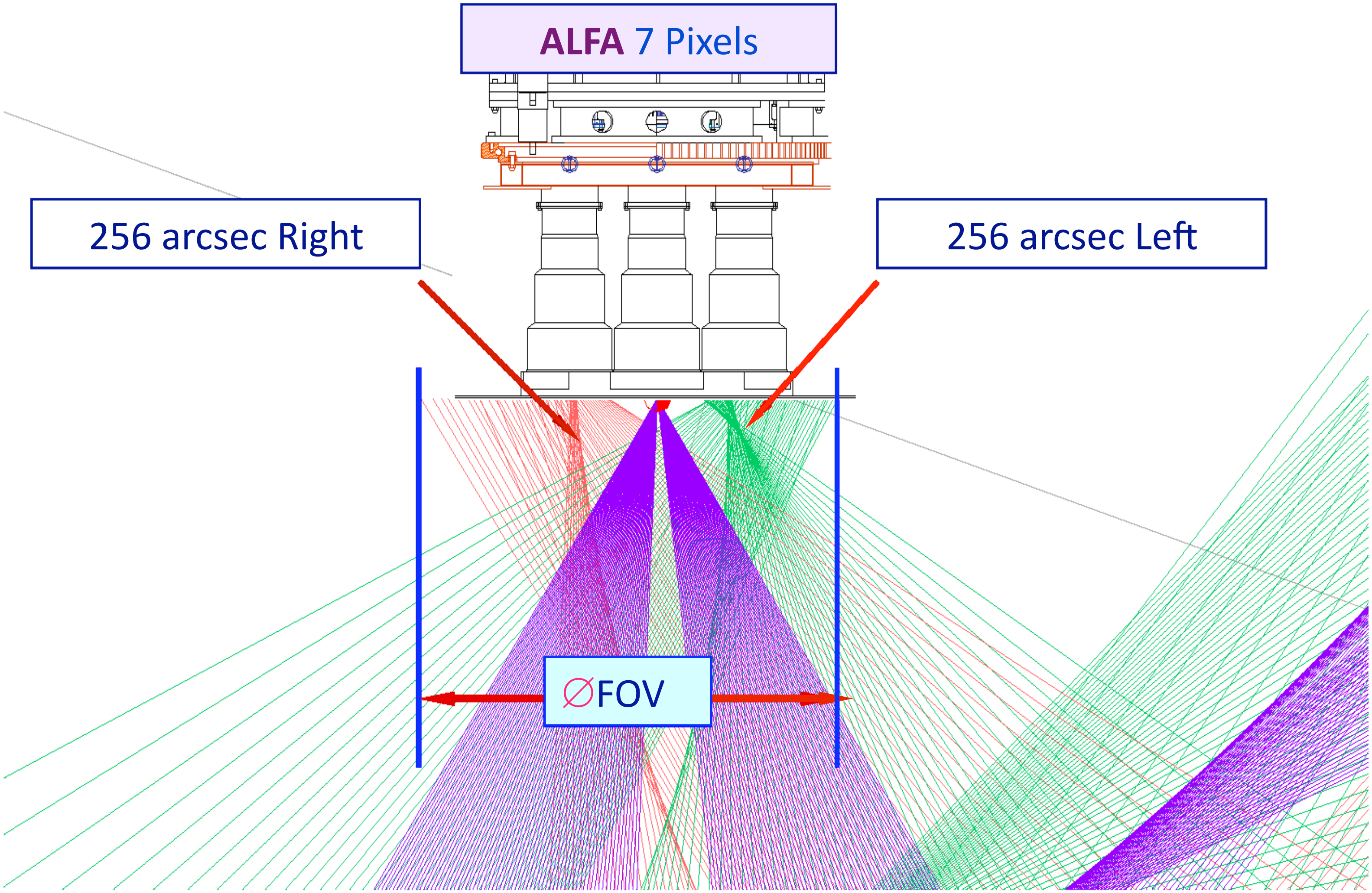


AO Gregorian FOV: Scanning Losses



FOV in the Gregorian Focal Plane



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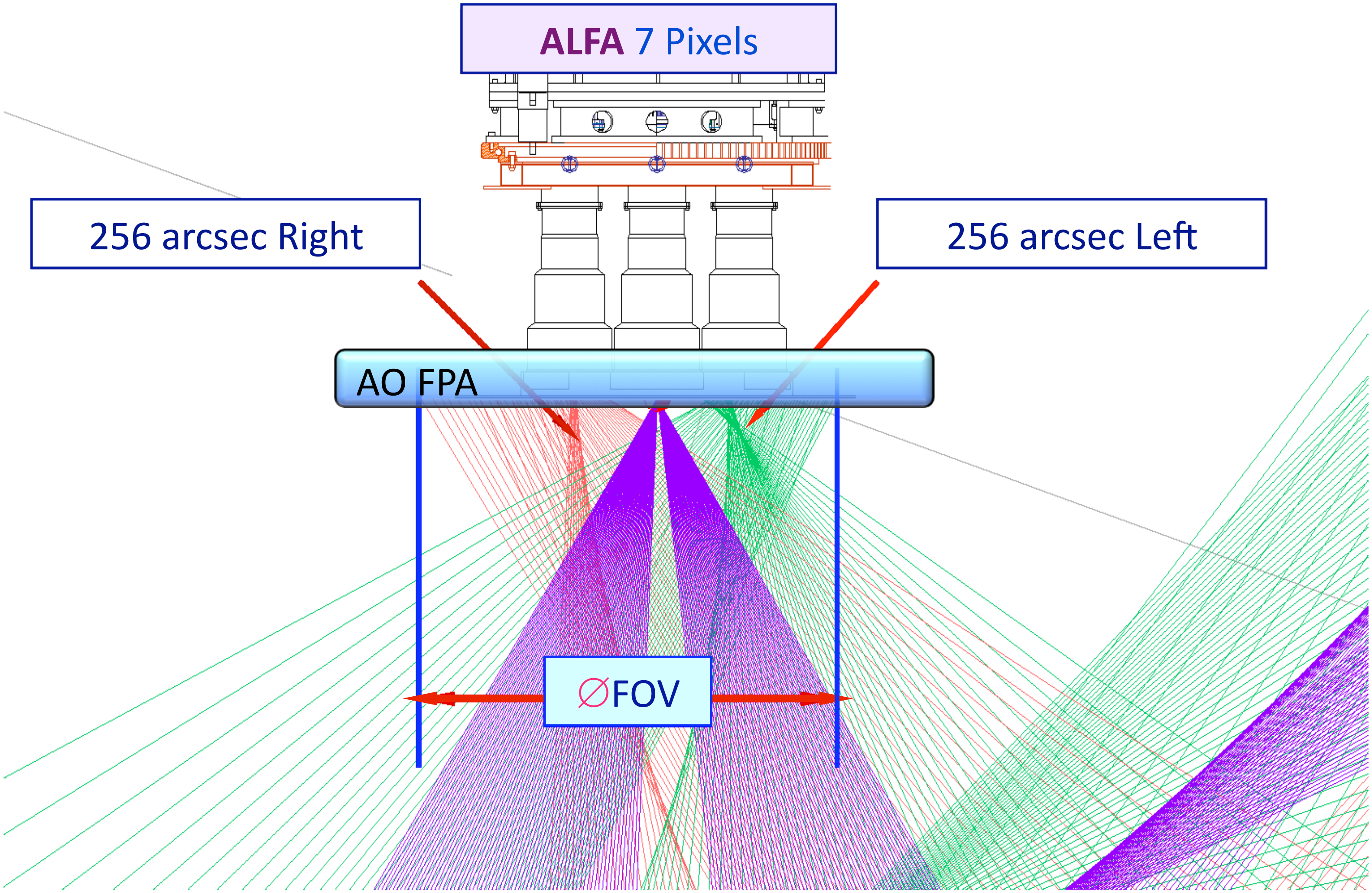
FOV in the Gregorian Focal Plane



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AO Focal Plane Field Distribution
from PO: On Axis, Wavelength: 21 cm

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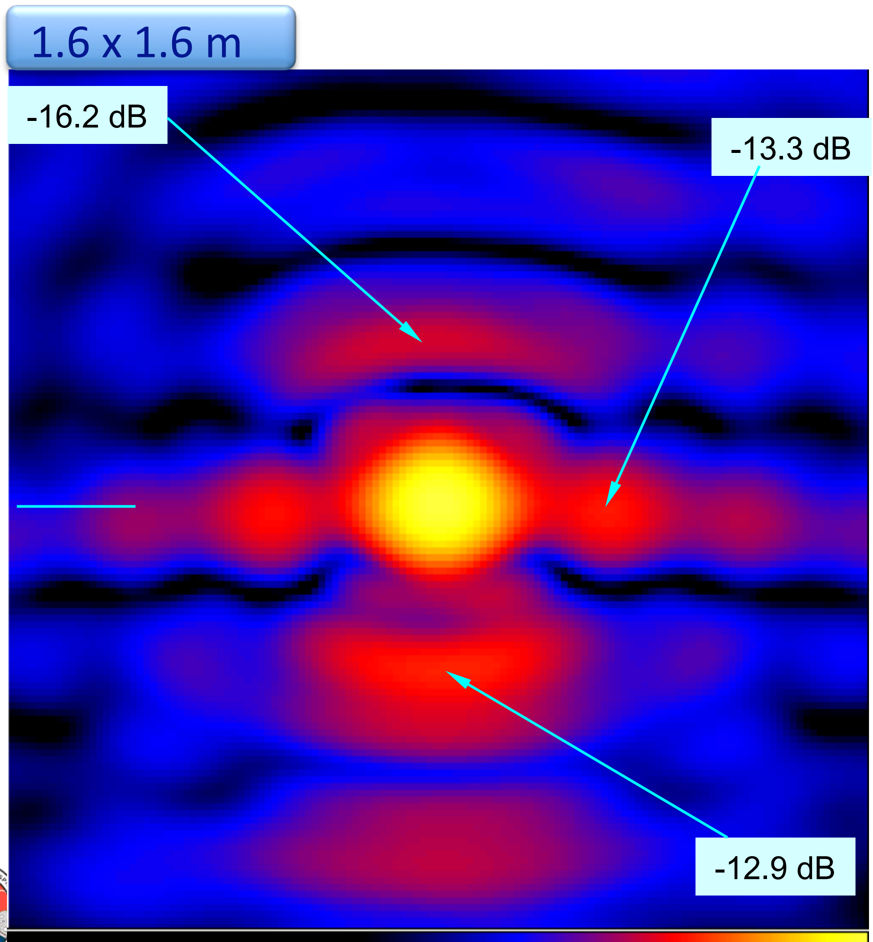
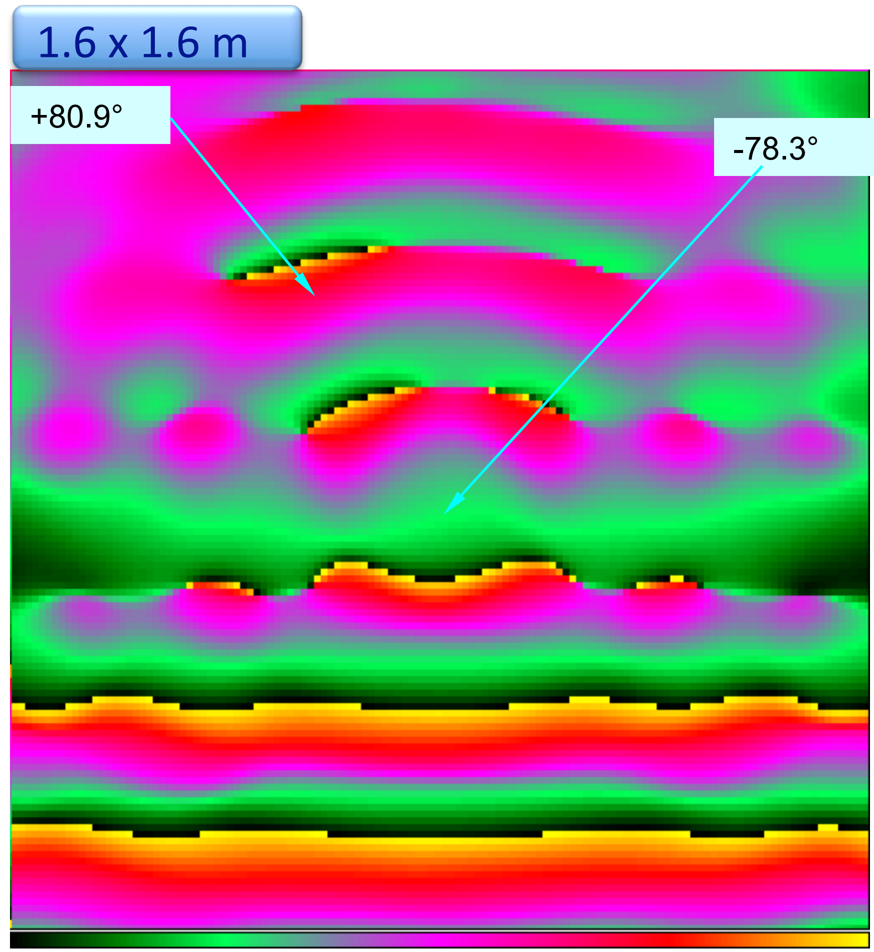
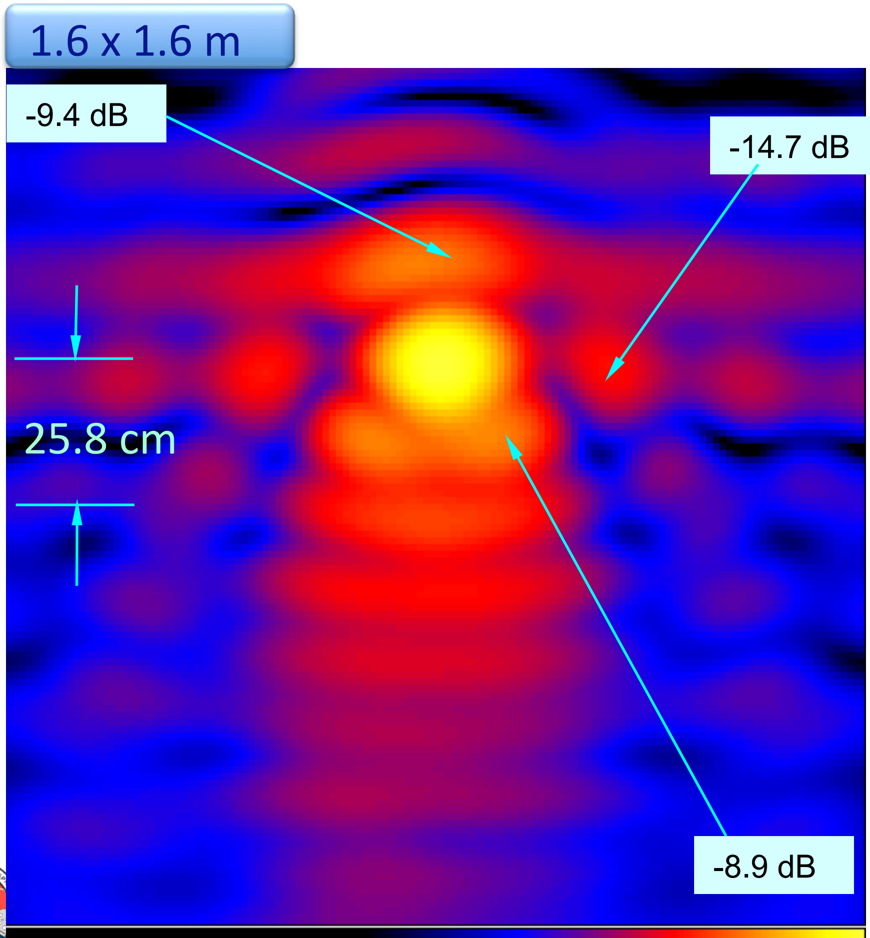


Co-Polar Intensity [dB]

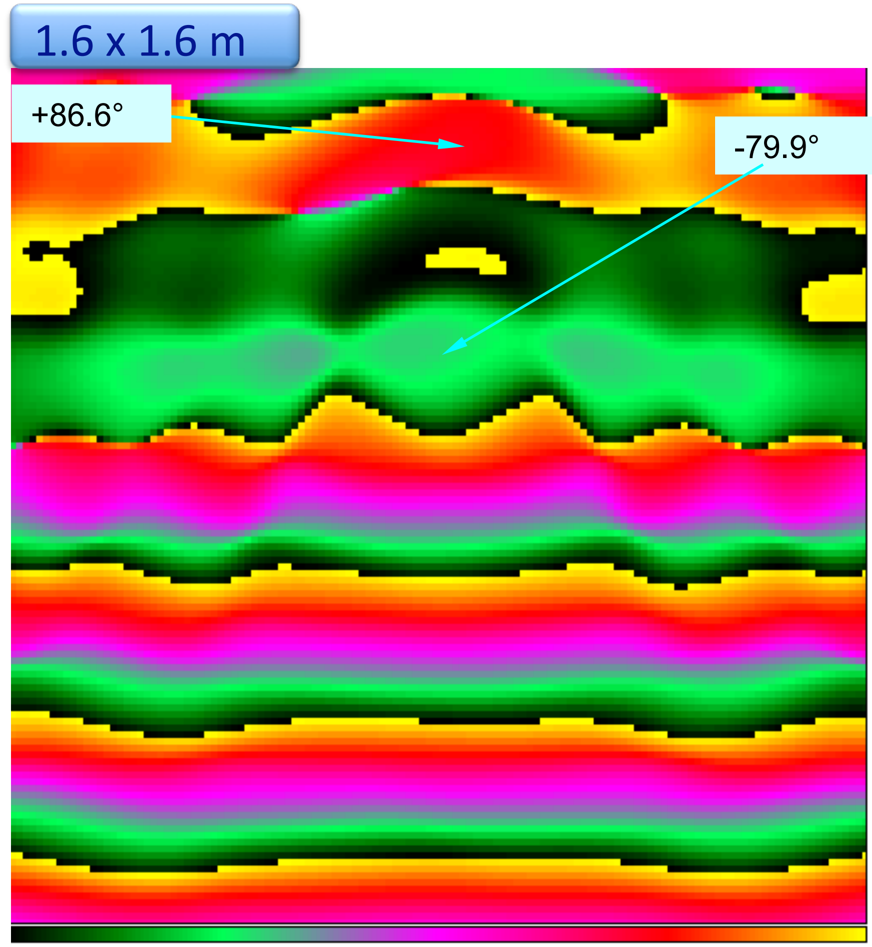


Co-Polar Phase Distribution

AO Focal Plane Field Distribution from PO: 430 arcsec, Wavelength: 21 cm



Co-Polar Intensity [dB]



Co-Polar Phase Distribution

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Exploring the Available:
FOV at AO Gregorian using PAF’s

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AO PAF Feasibility Study

Exploring AO FOV with 19 BYU dipole PAF

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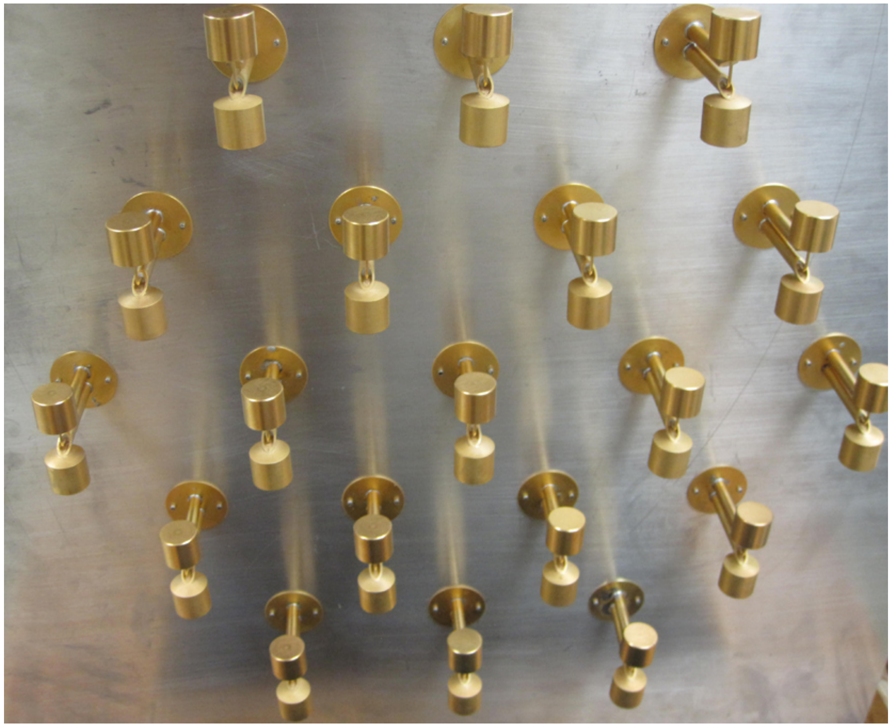
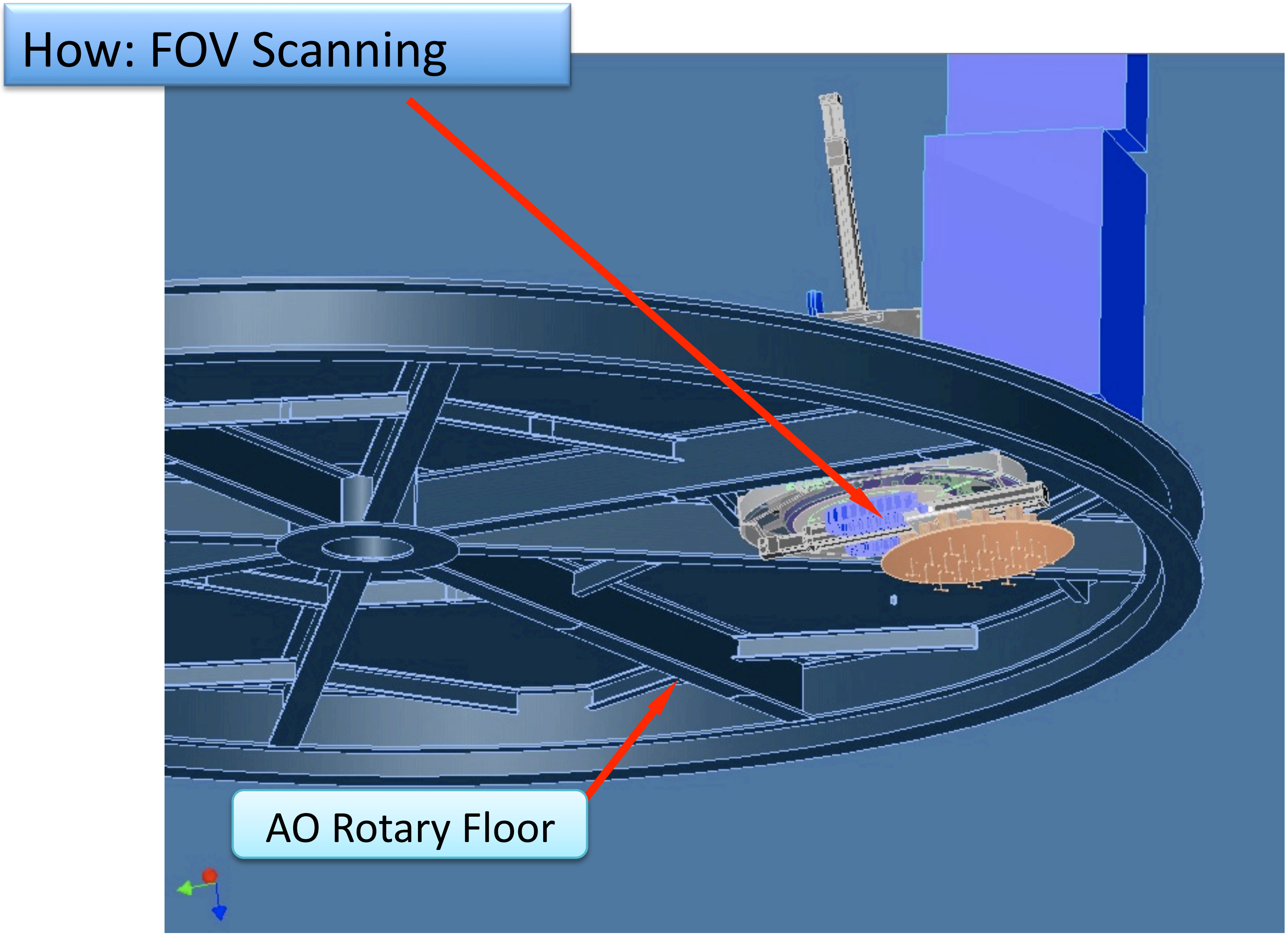
The PAF:



Single Polarization 19 BYU Dipole PAF

AO PAF Feasibility Study

Exploring AO FOV with 19 BYU dipole PAF



AO PAF Feasibility Study

Exploring AO FOV with 19 BYU dipole PAF

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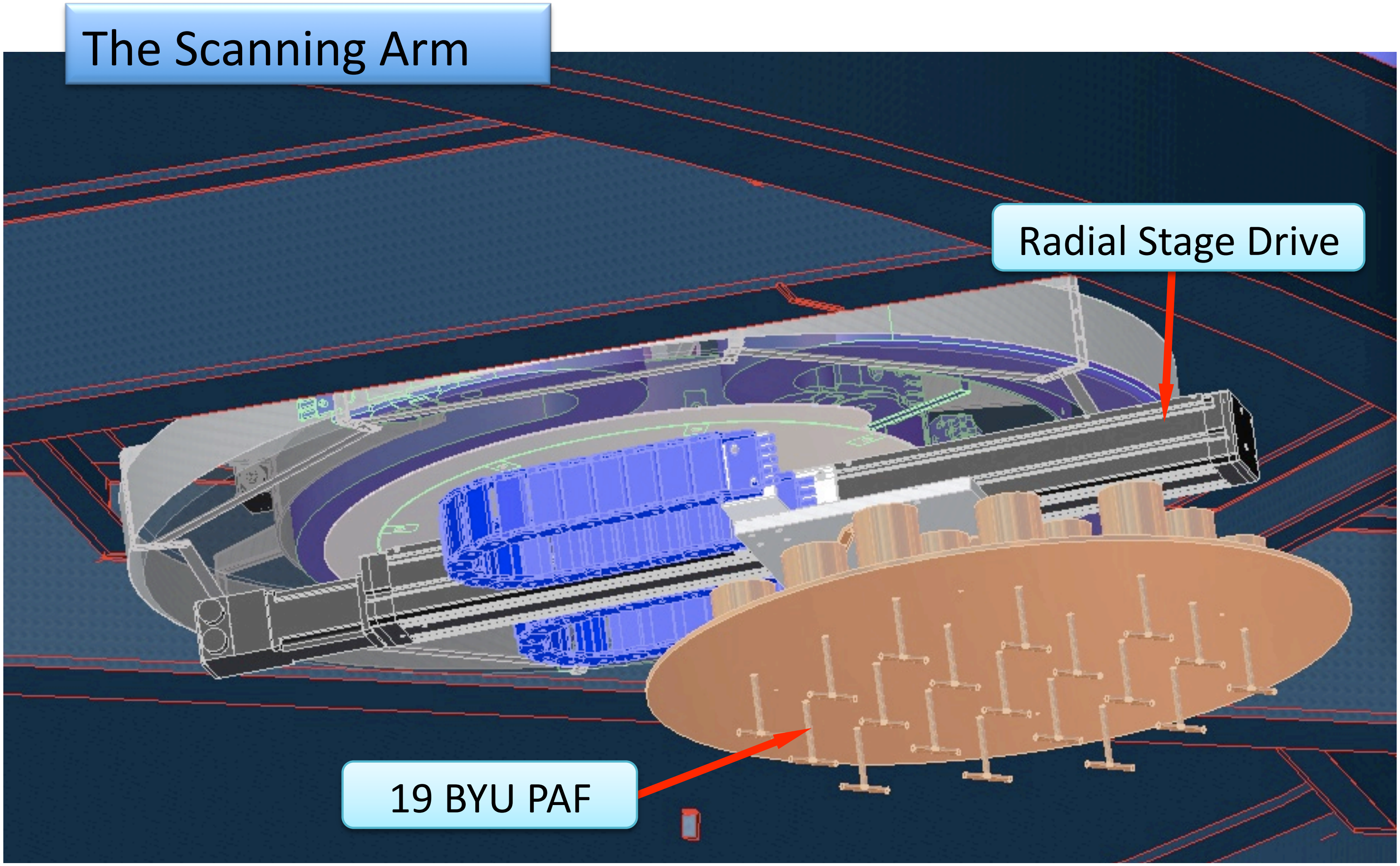
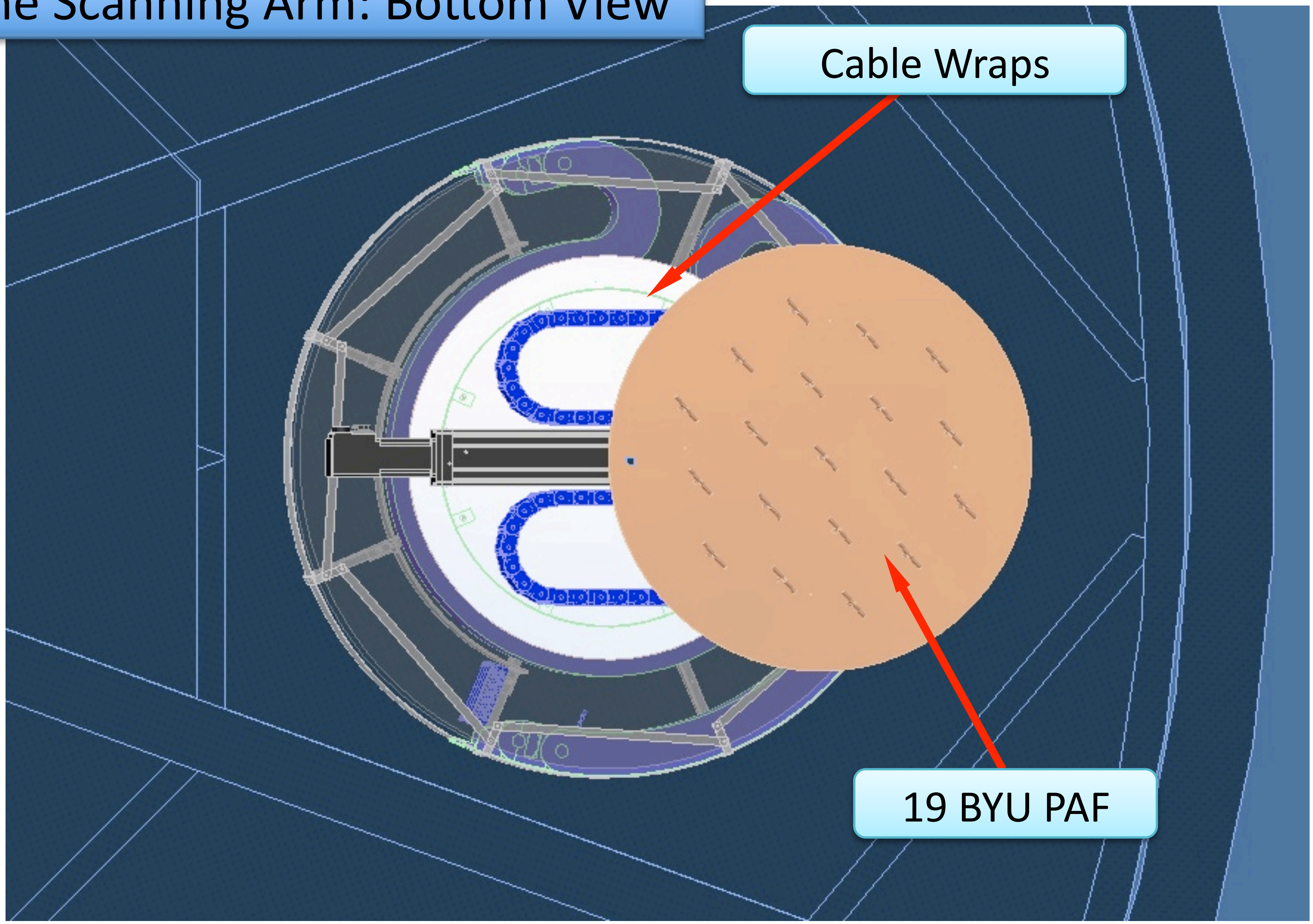


AO PAF Feasibility Study

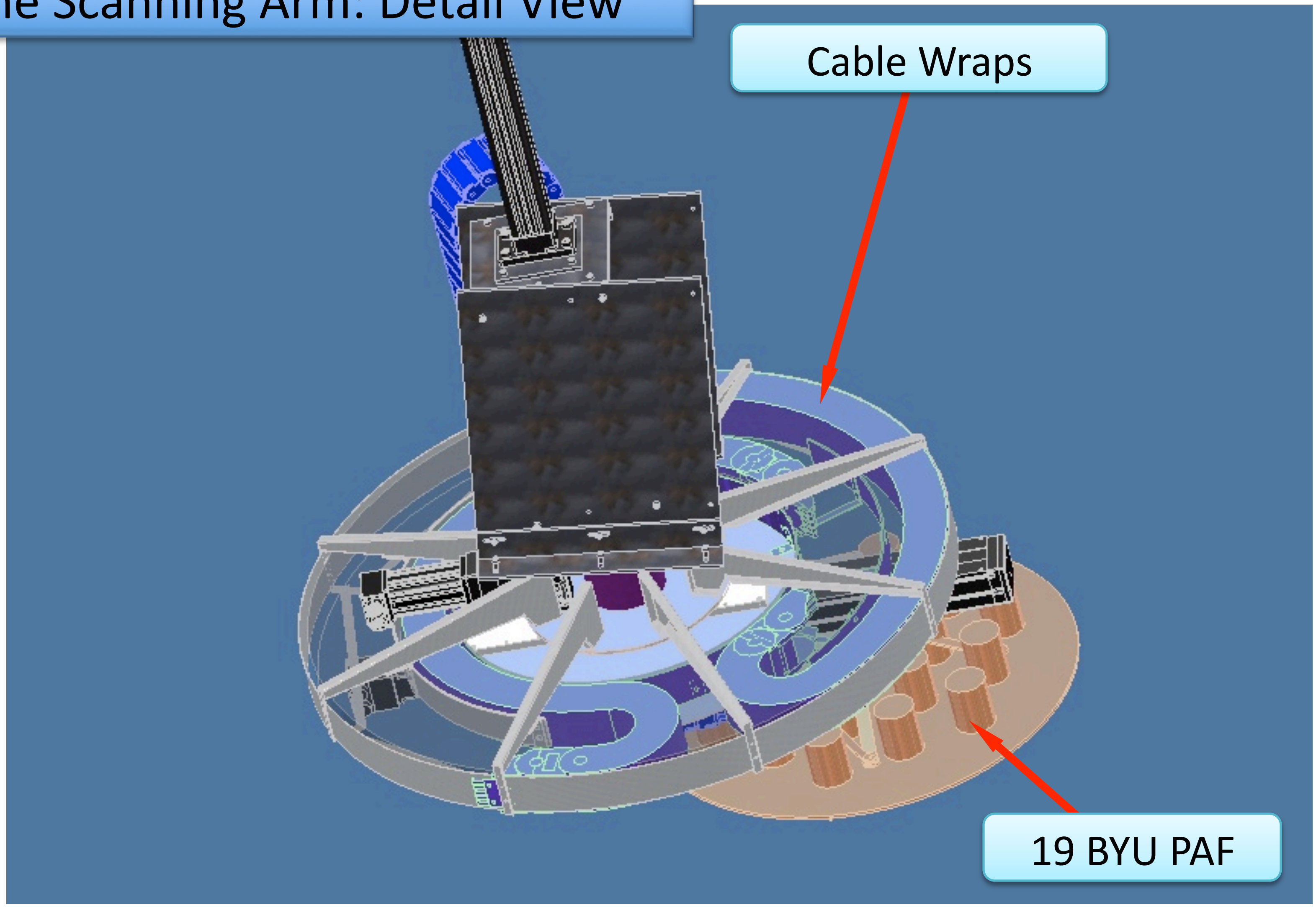
Exploring AO FOV with 19 BYU dipole PAF

The Scanning Arm: Bottom View



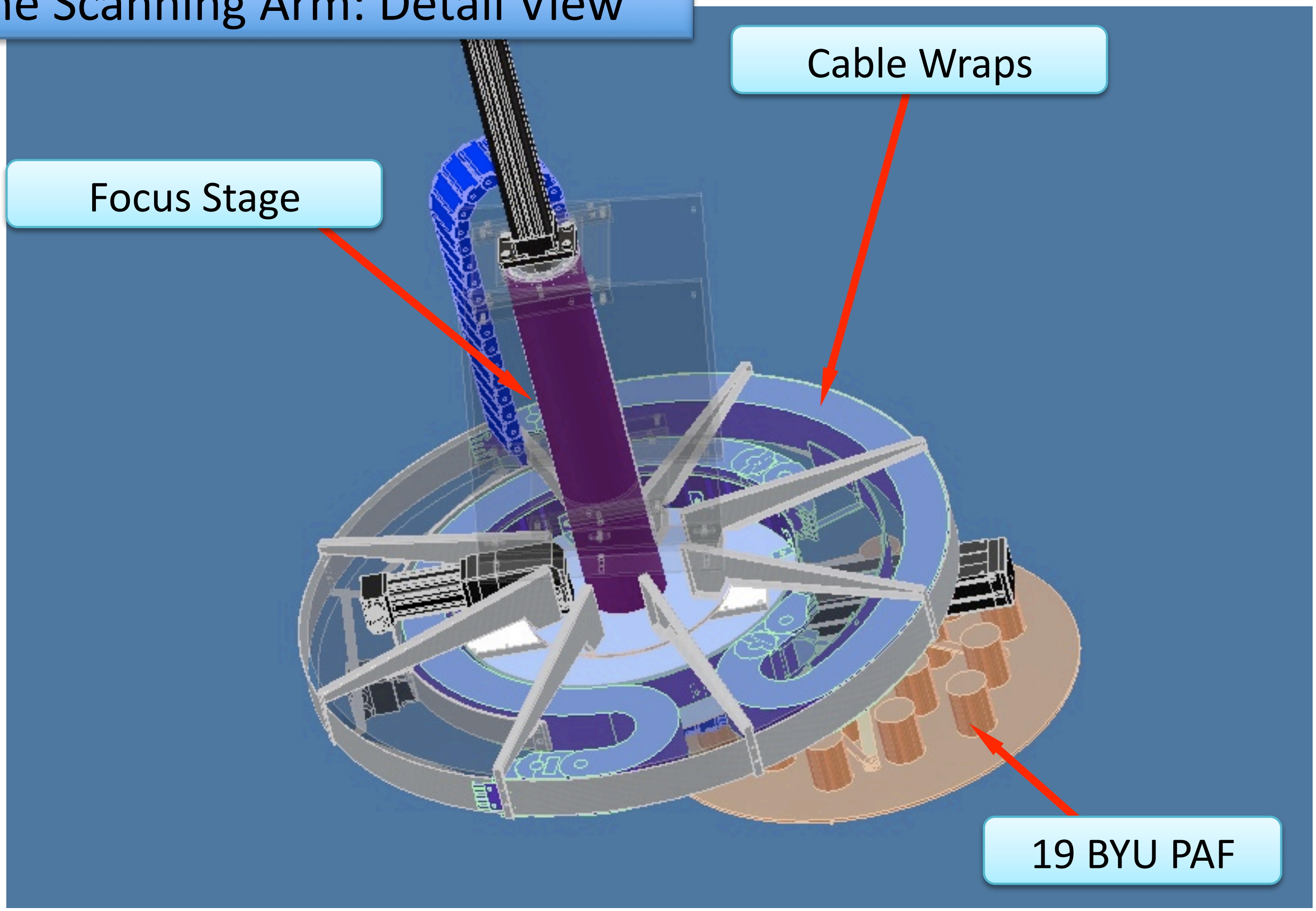
PAF Positioner/Scanning Arm

The Scanning Arm: Detail View



PAF Positioner Scanning Arm

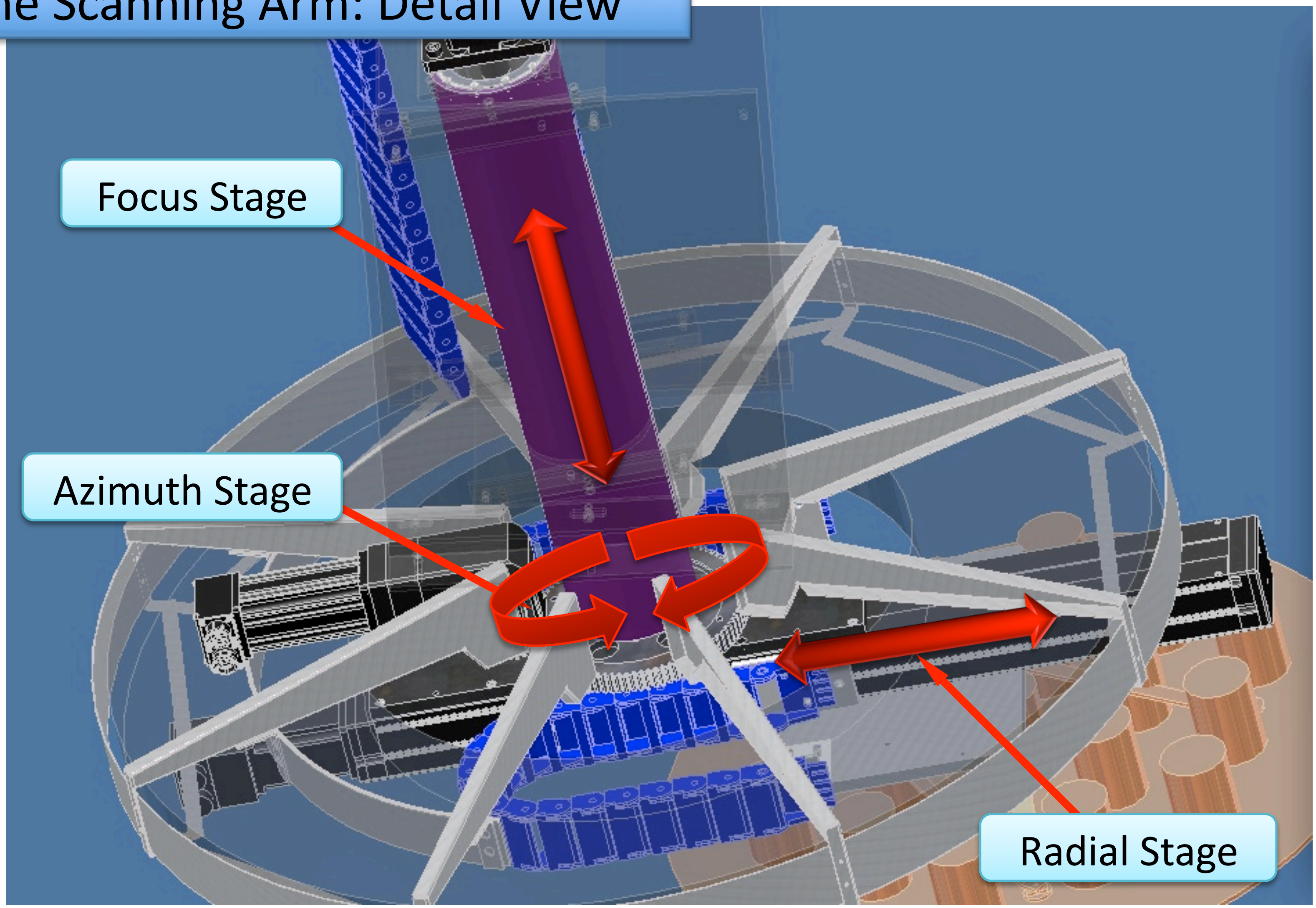
The Scanning Arm: Detail View



AO PAF Feasibility Study

PAF Positioner/Scanning Arm

The Scanning Arm: Detail View

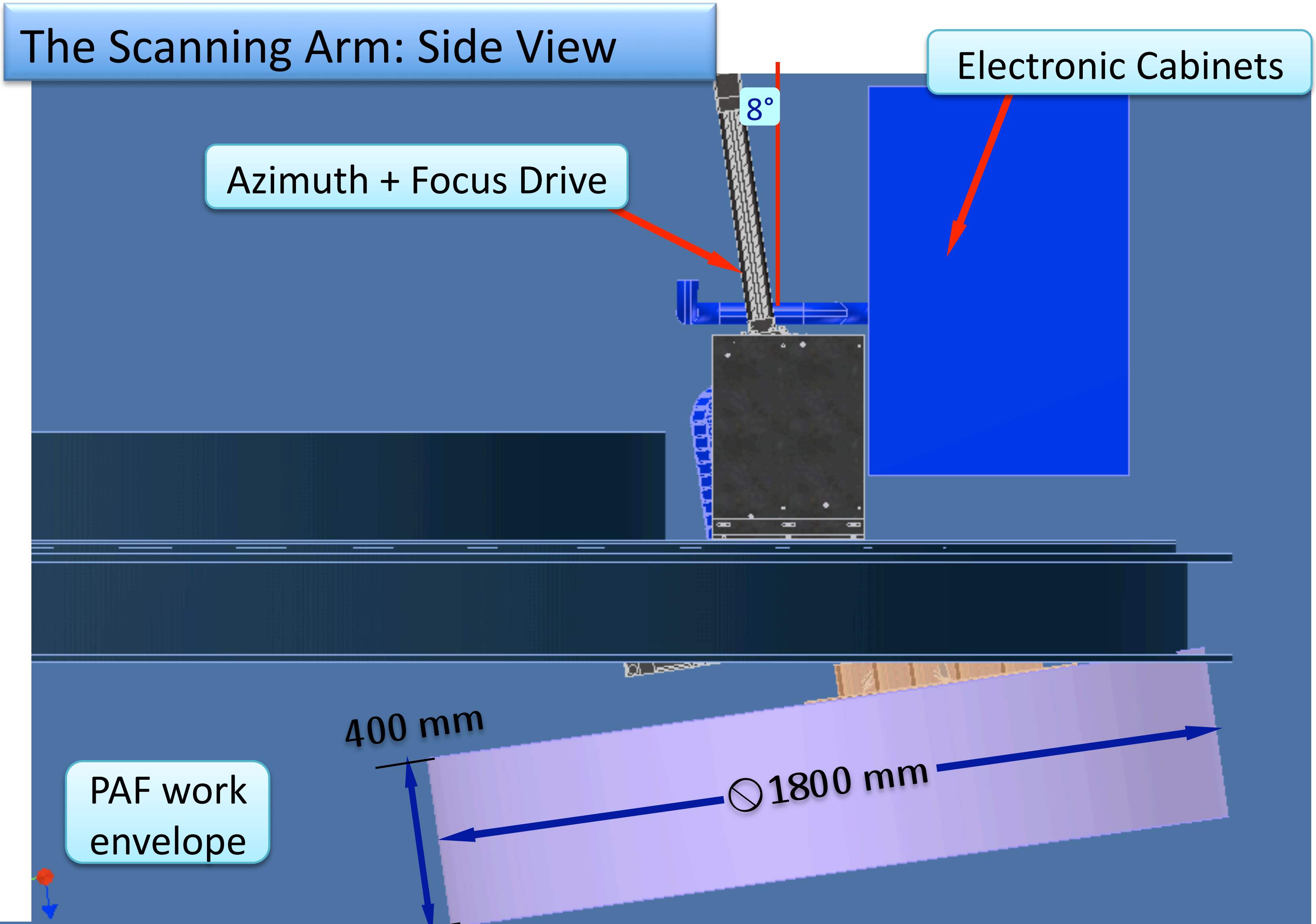


PAF Positioner/Scanning Arm

- Design by Dr. David Smith
- 3 degrees of Freedom
- Radial Stage Range: 600 mm (+PAF Diam/2)
- Azimuth: +/- 180 degrees
- Focus Stage: -100 mm to +300 mm
- Weight: ~50 Kg

AO PAF Feasibility Study

PAF Positioner Arm Work Envelope



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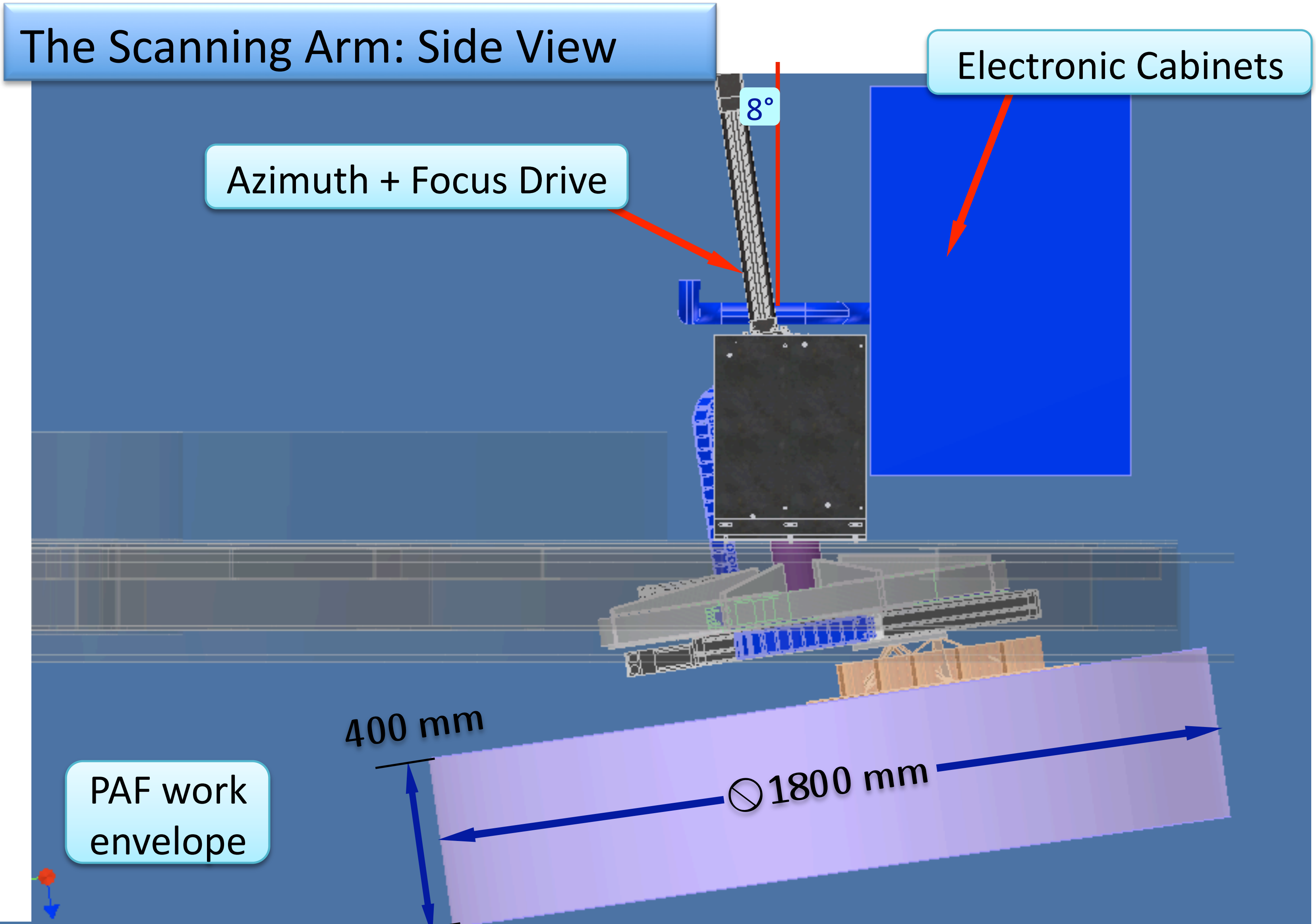
AO PAF Feasibility Study

PAF Positioner Arm Work Envelope



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Exploring the Available FOV at AO using PAF's: Simulations I

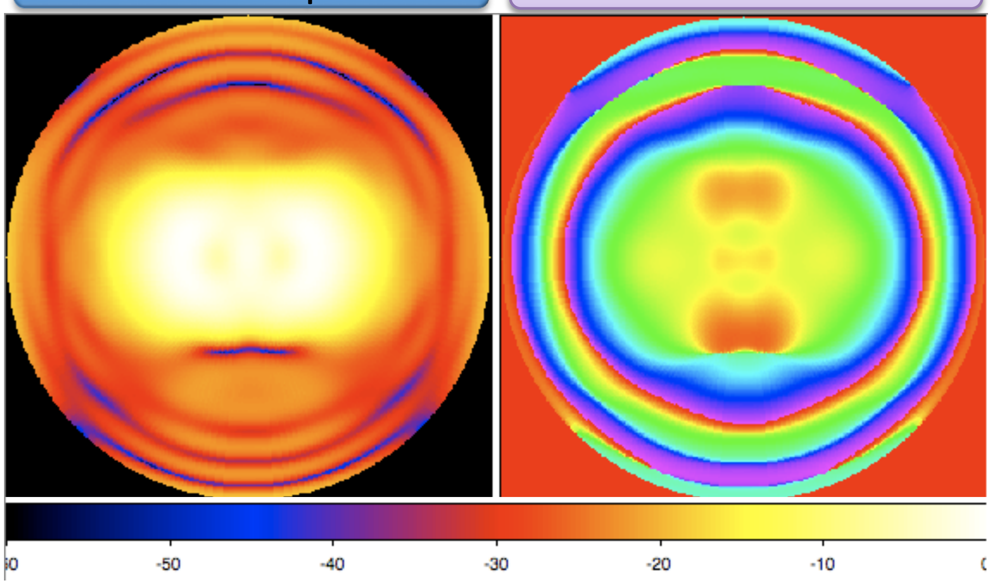
Methodology

For each individual Dipole:

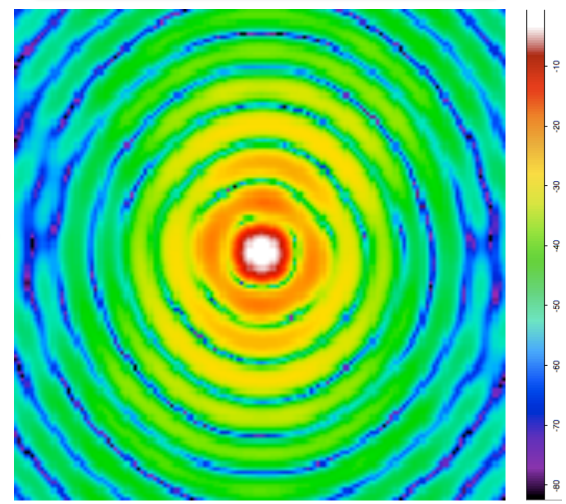
- Embeded Dipole Radiation Pattern
- Far Field Antenna Pattern Through AO Optics

Co-Polar Amplitude

Co-Polar Phase



AO Far Field Pattern



Methodology

For each individual Dipole:

- Embeded Dipole Radiation Pattern
- Far Field Antenna Pattern Through AO Optics

PAF Beam Forming

- Mutual Coupling
- Noise model

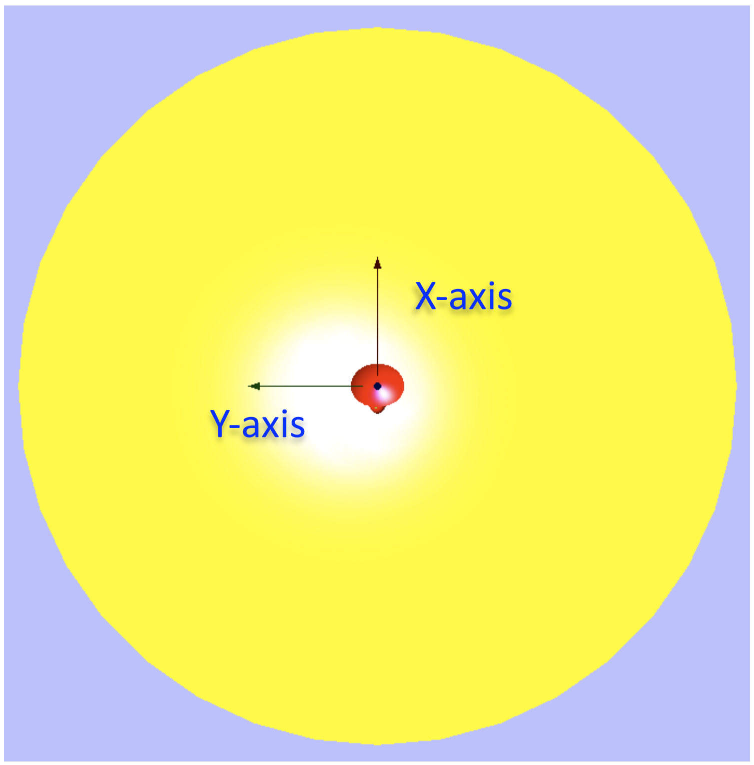
Coordinates,

Coordinates,

Coordinates…

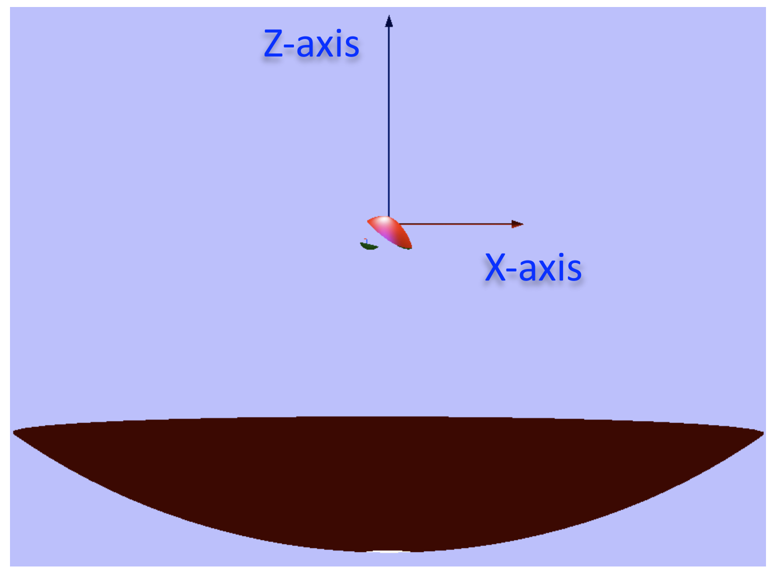
Arecibo Telescope Coordinates

AO Top View
(Gregorian Dome Removed)



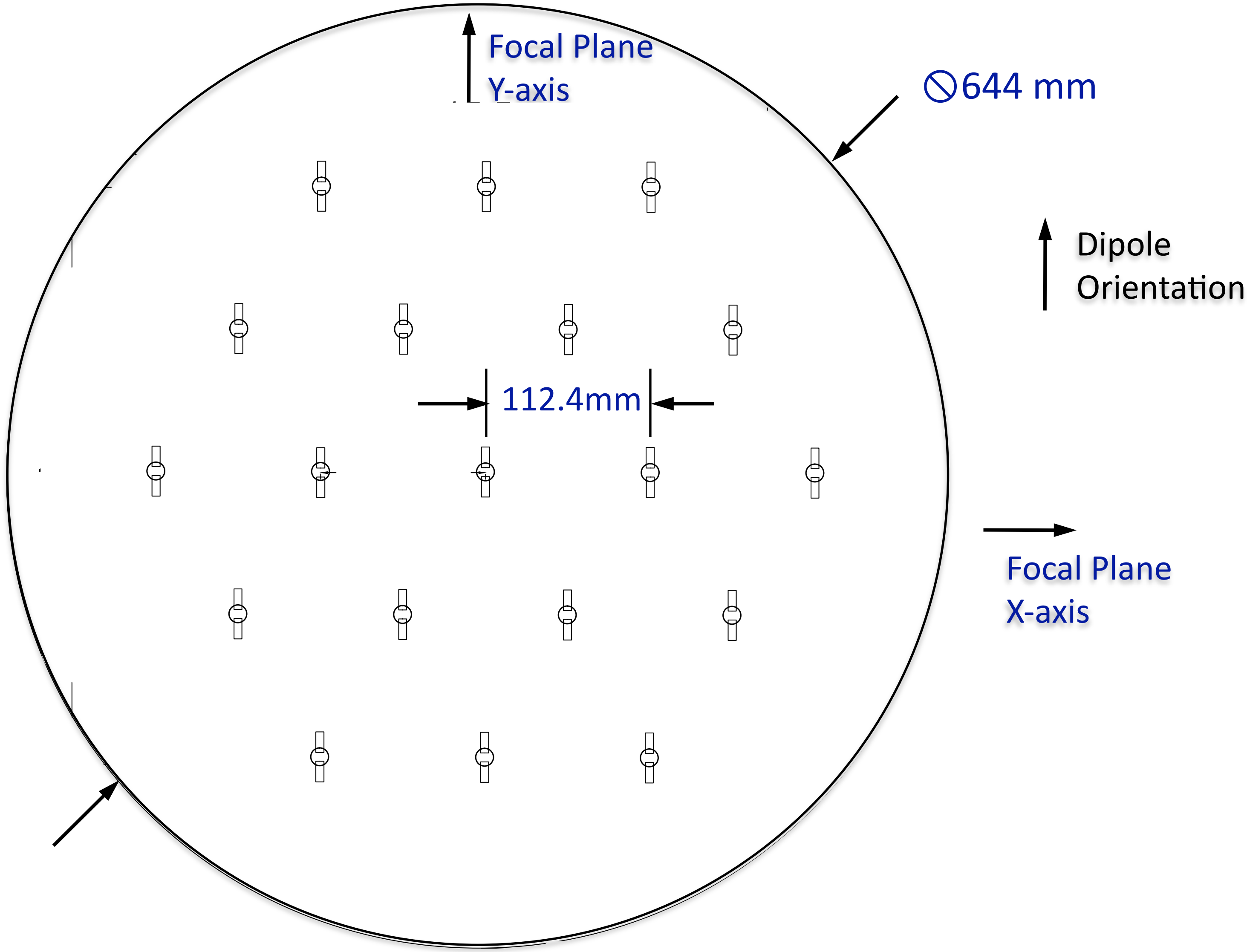
AO Side View
(Gregorian Dome Removed)

Plane of Symmetry: Z-X



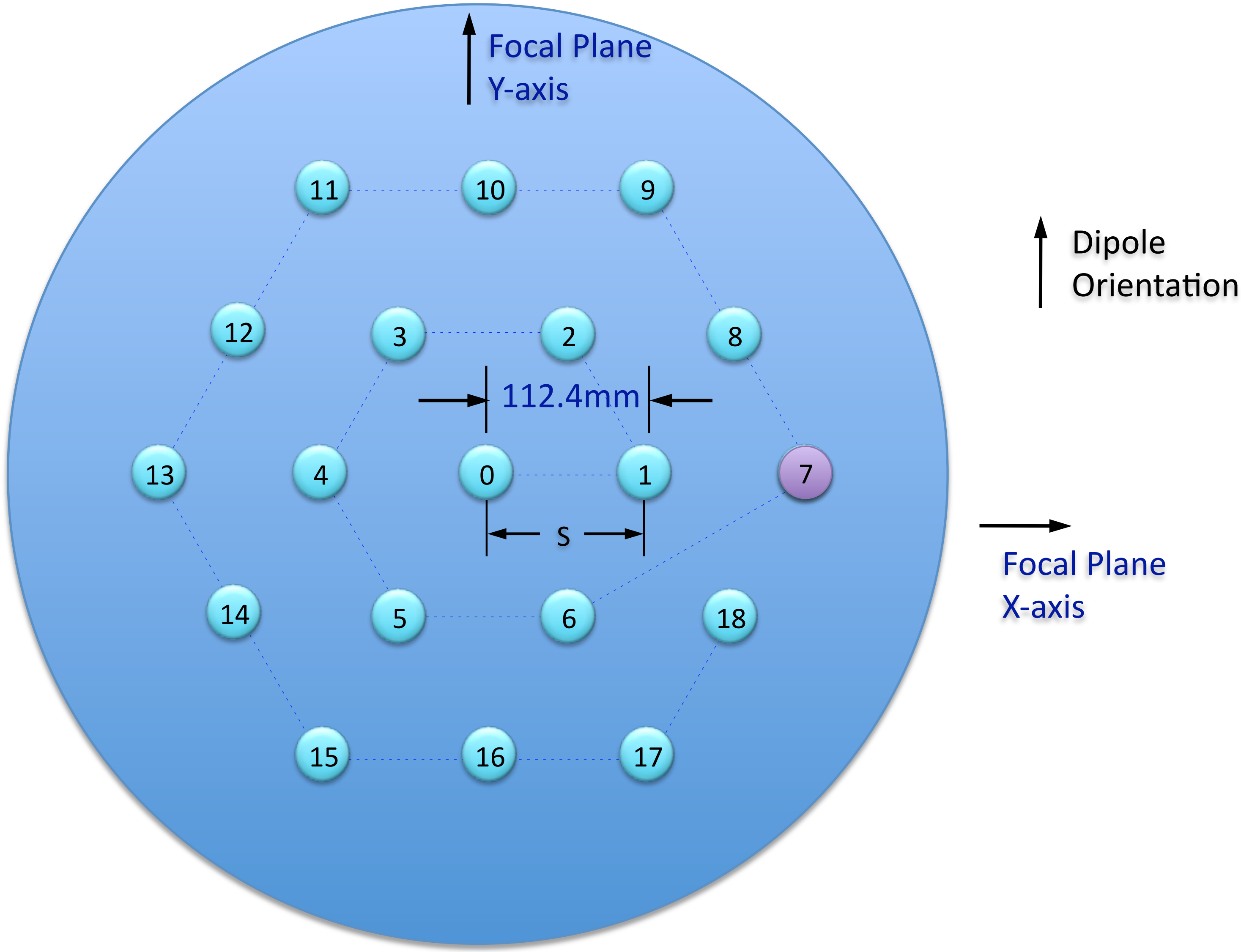
Array’s Coordinate System in Focal Plane

Dipoles **Out of** the page



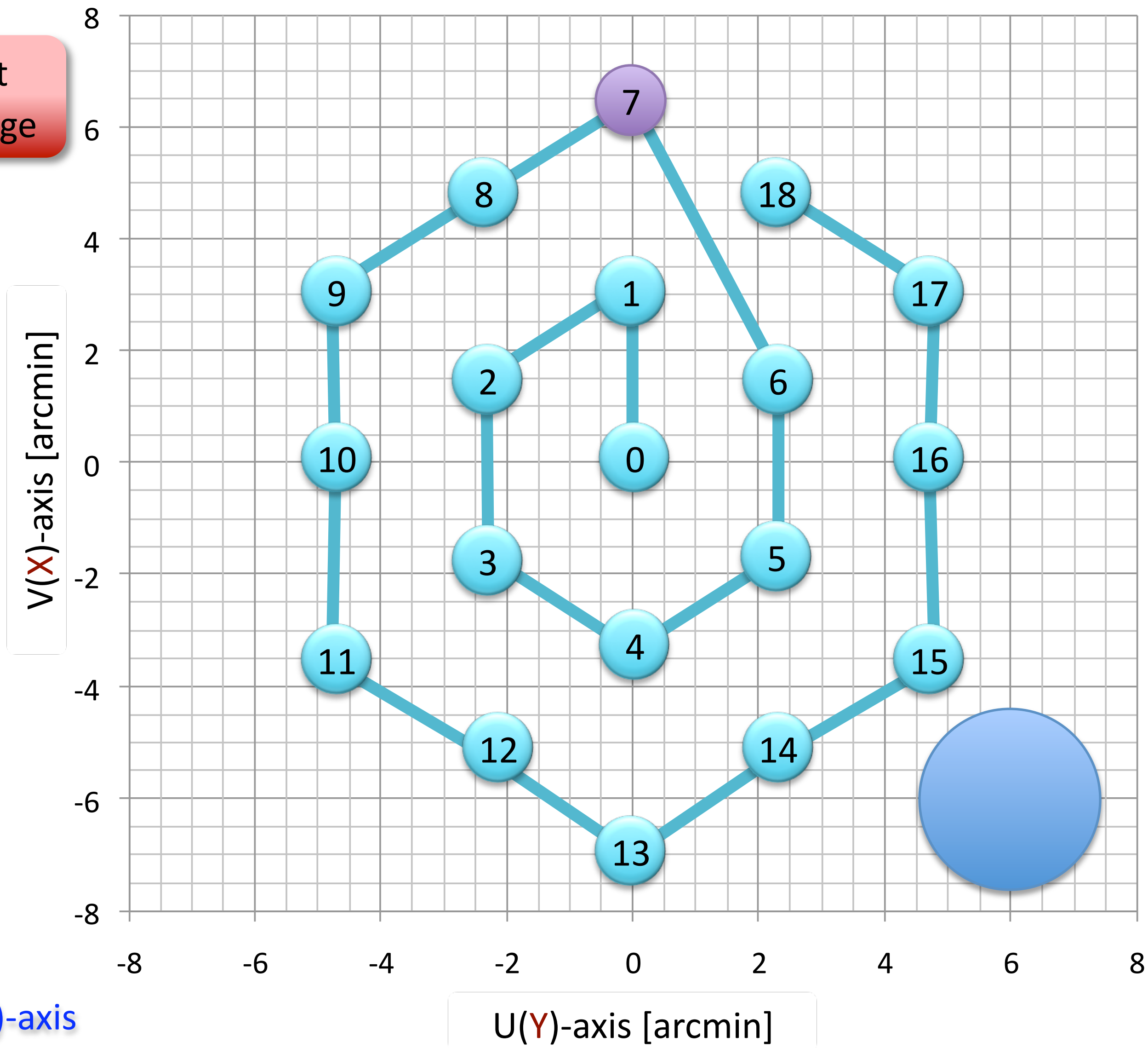
Array's Coordinate System in Focal Plane

Dipoles **Out of** the page



PAF Sky Beam Pointing: Case B0

Bore-sight **into** the page



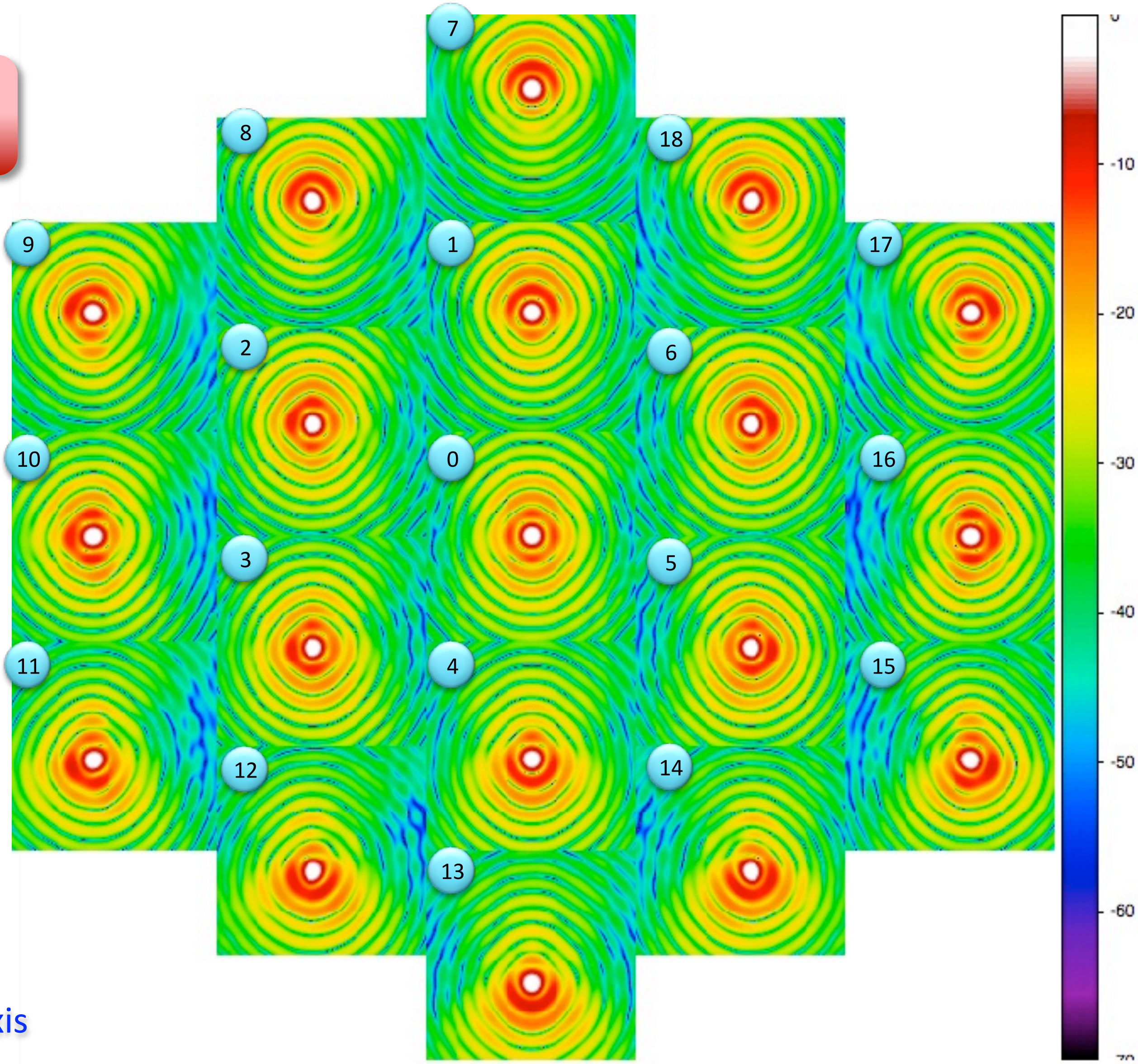
V(X)-axis

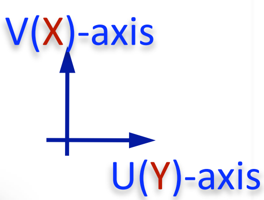
U(Y)-axis

Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Mosaic: Case B0

Bore-sight **into** the page





PAF Sky Beam Mosaic: Case B0

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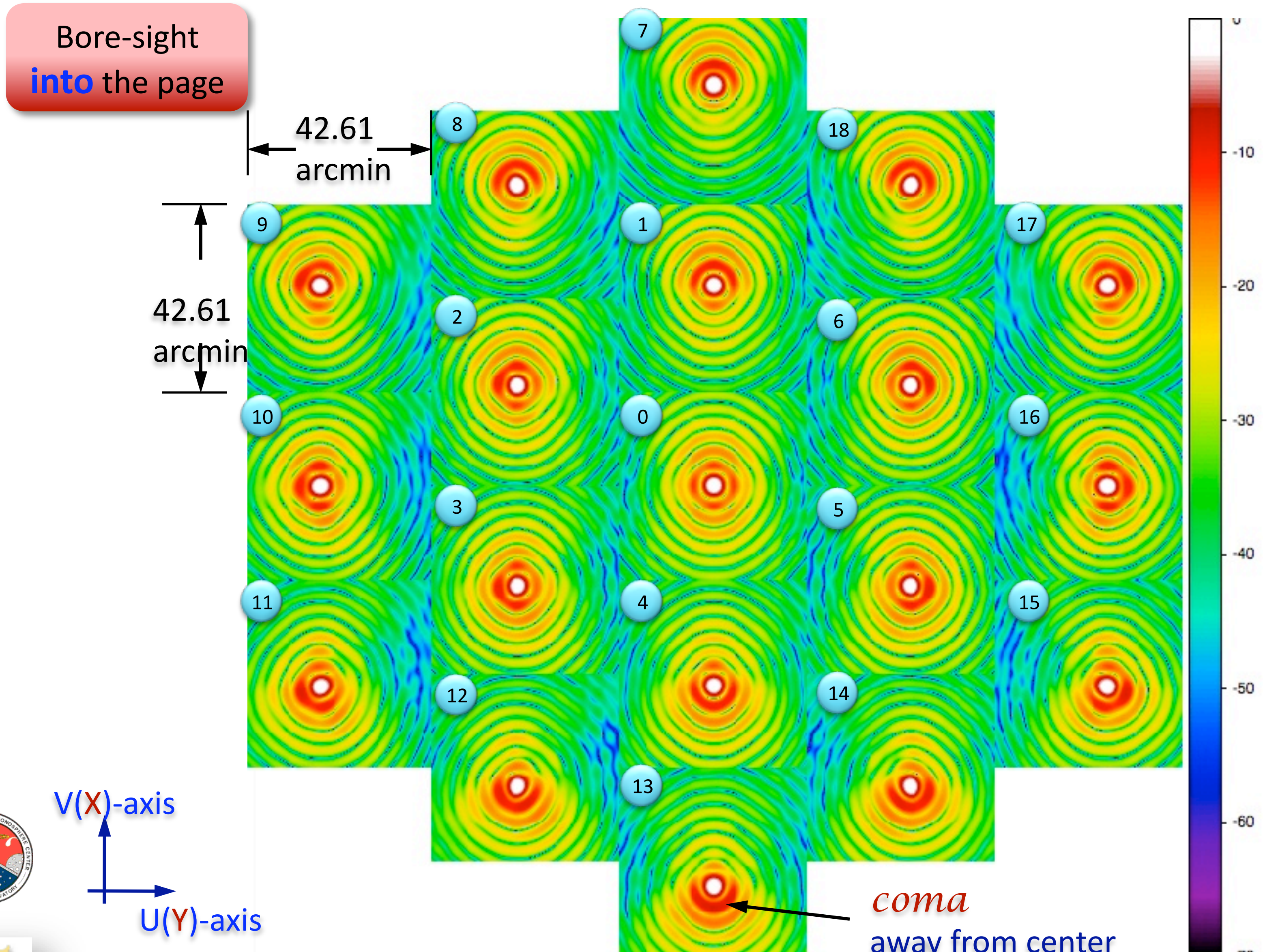

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Exploring the Available FOV at AO using PAF's: Simulations II

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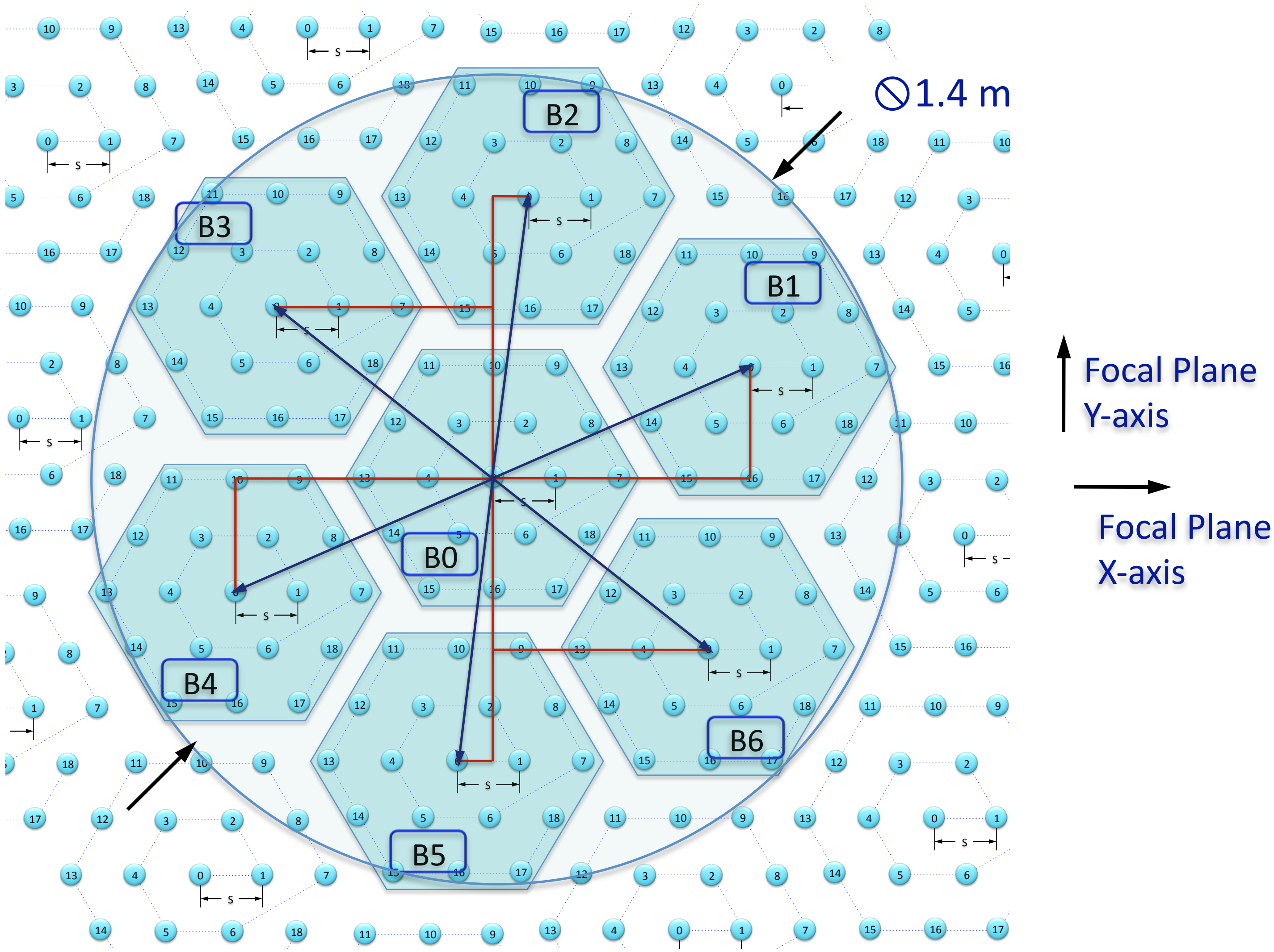
Arecibo Focal Phased Array Feasibility Study

PAF No Overlapping Positions in Focal Plane: Cases B0 to B6



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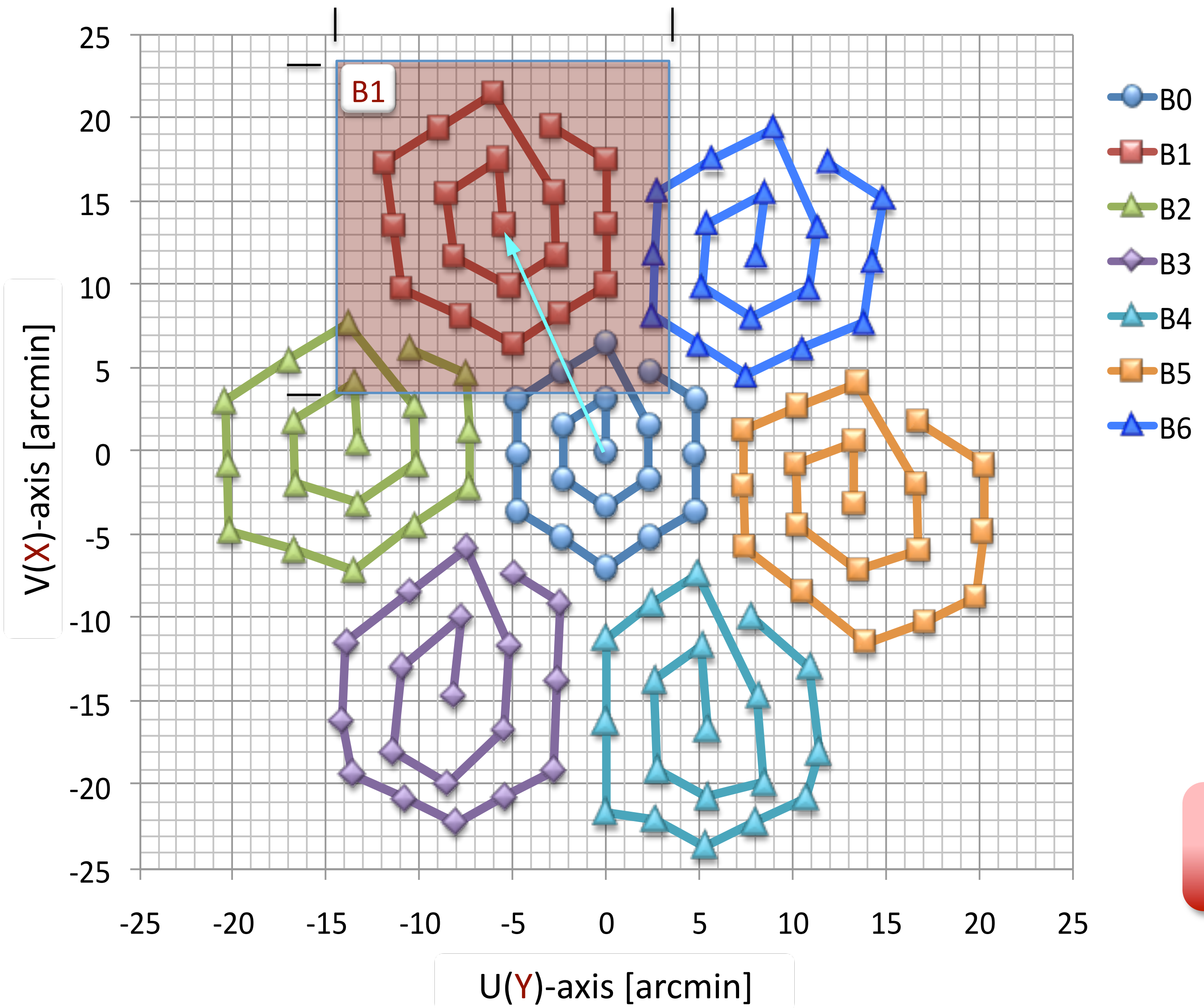
PAF Sky Beam Directions: Cases B0 to B6



Bore-sight **into** the page

Arecibo Focal Phased Array Feasibility Study

PAF Maps in the Sky: Cases B0 to B6

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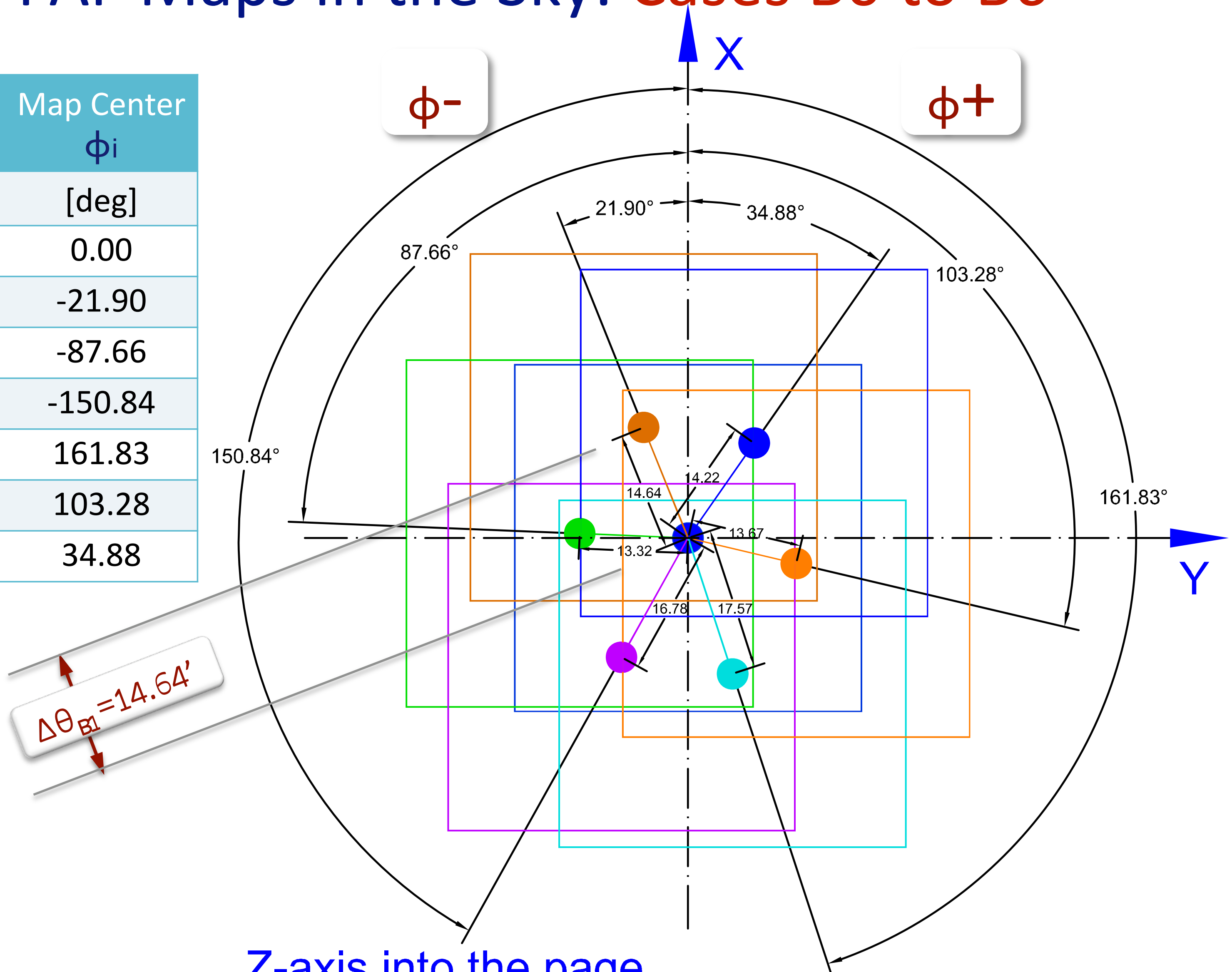
Case	Map Center $\Delta\theta_i$	Map Center ϕ_i
	[arcmin]	[deg]
B0	0.00	0.00
B1	14.64	-21.90
B2	13.32	-87.66
B3	16.78	-150.84
B4	17.57	161.83
B5	13.67	103.28
B6	14.22	34.88



Z-axis into the page

German Cortes Feb-2010

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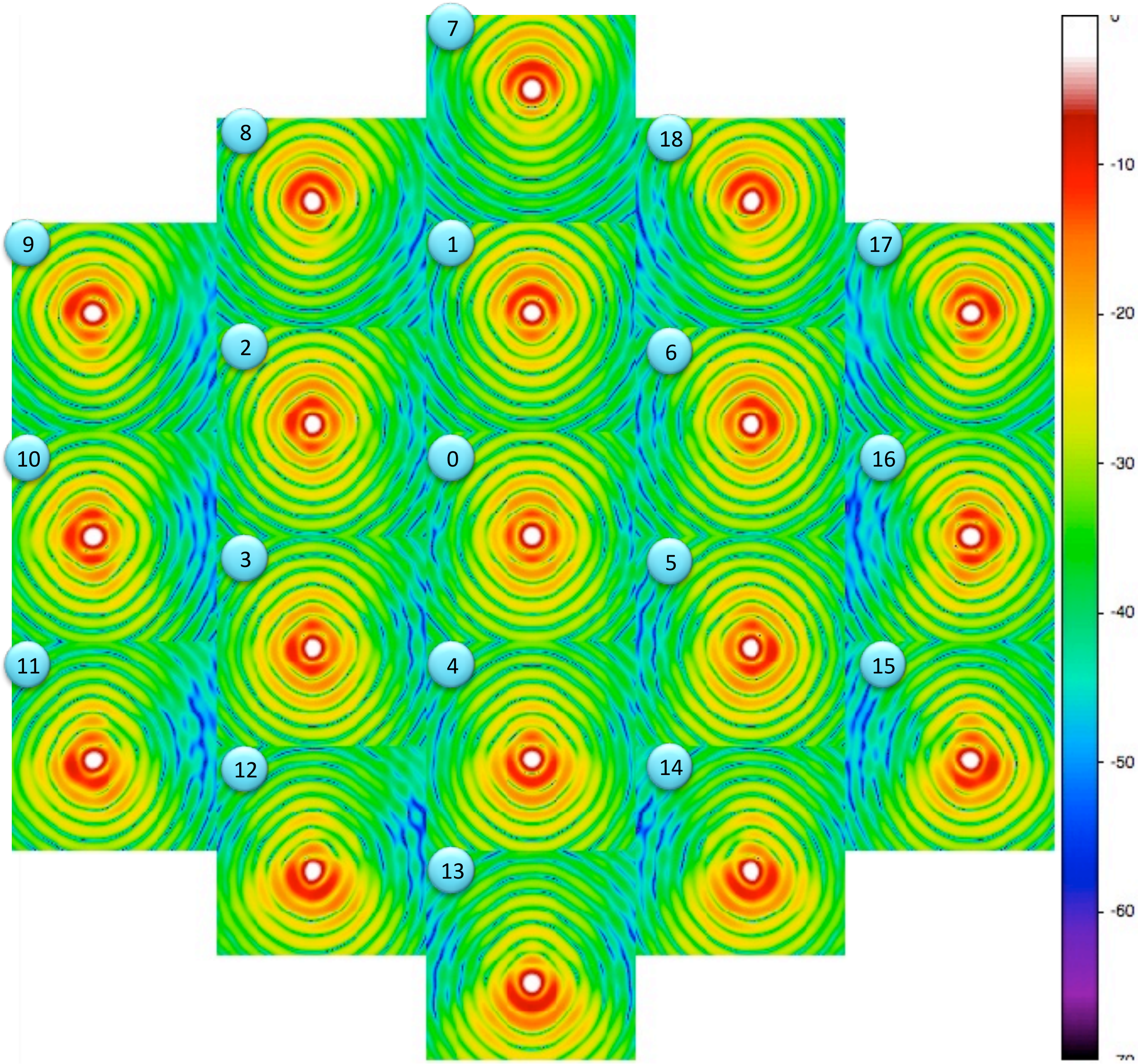
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Mosaic: Case B0



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PAF Sky Beam Mosaic: Case B1

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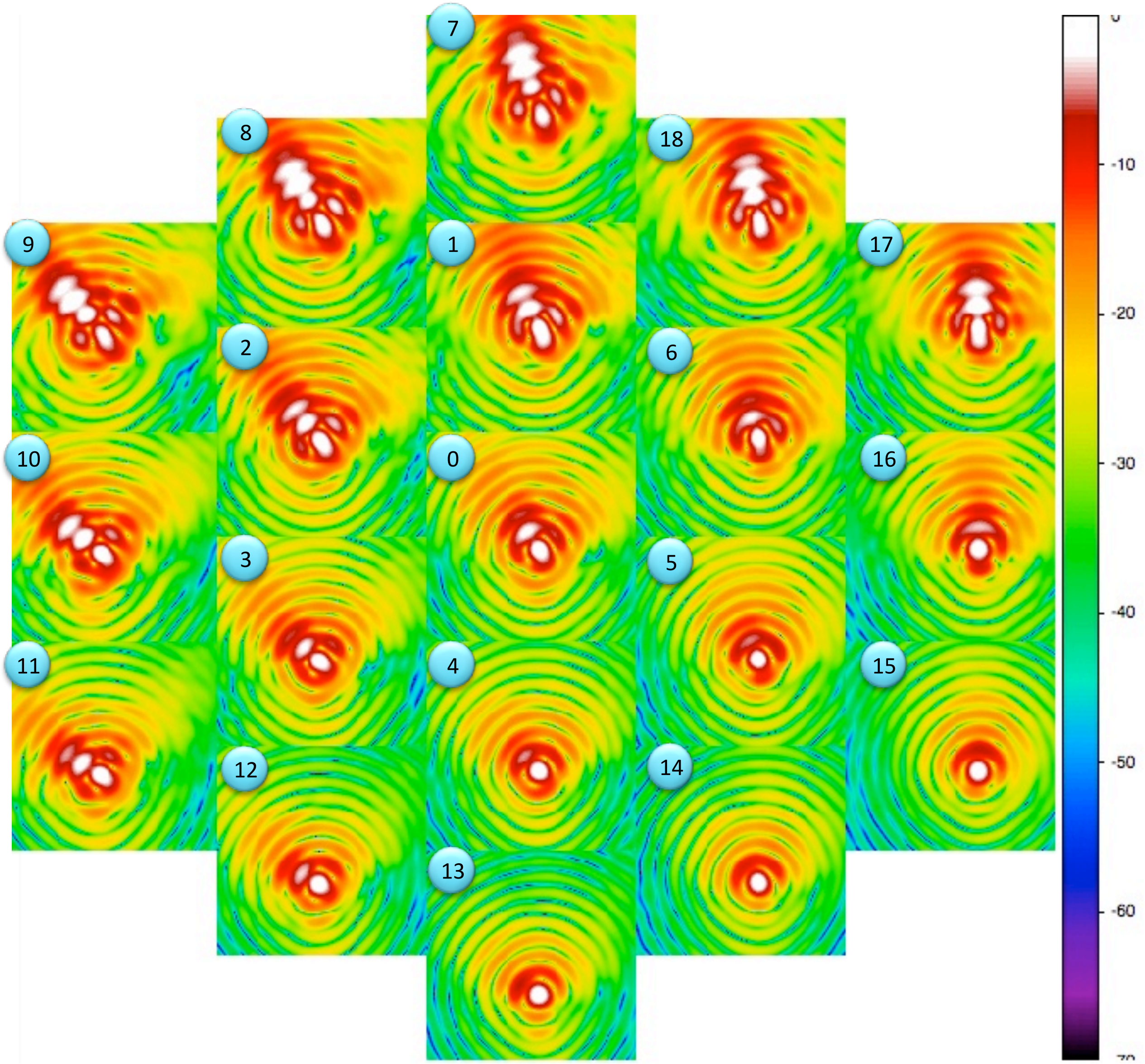
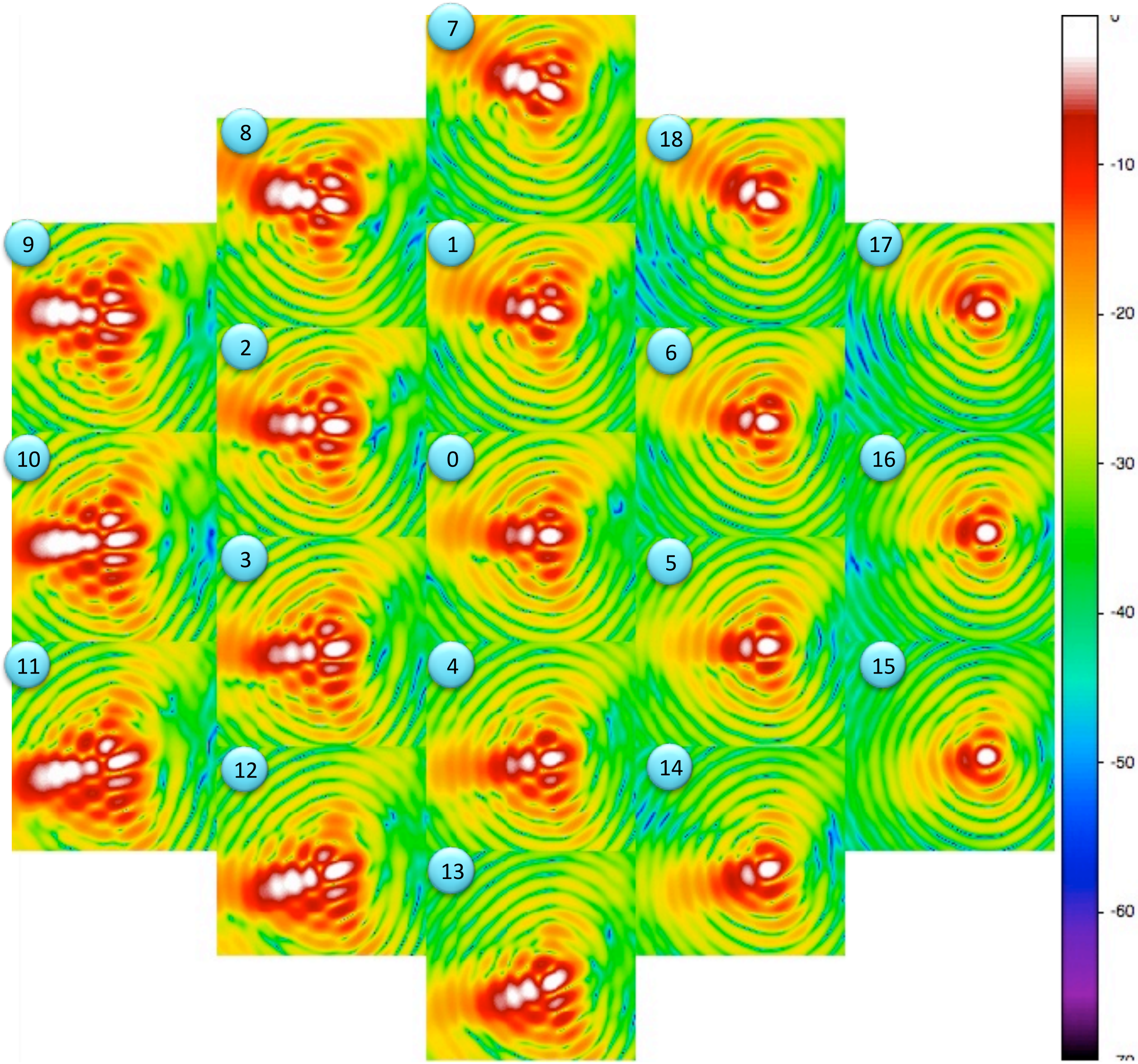


Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Mosaic: Case B2



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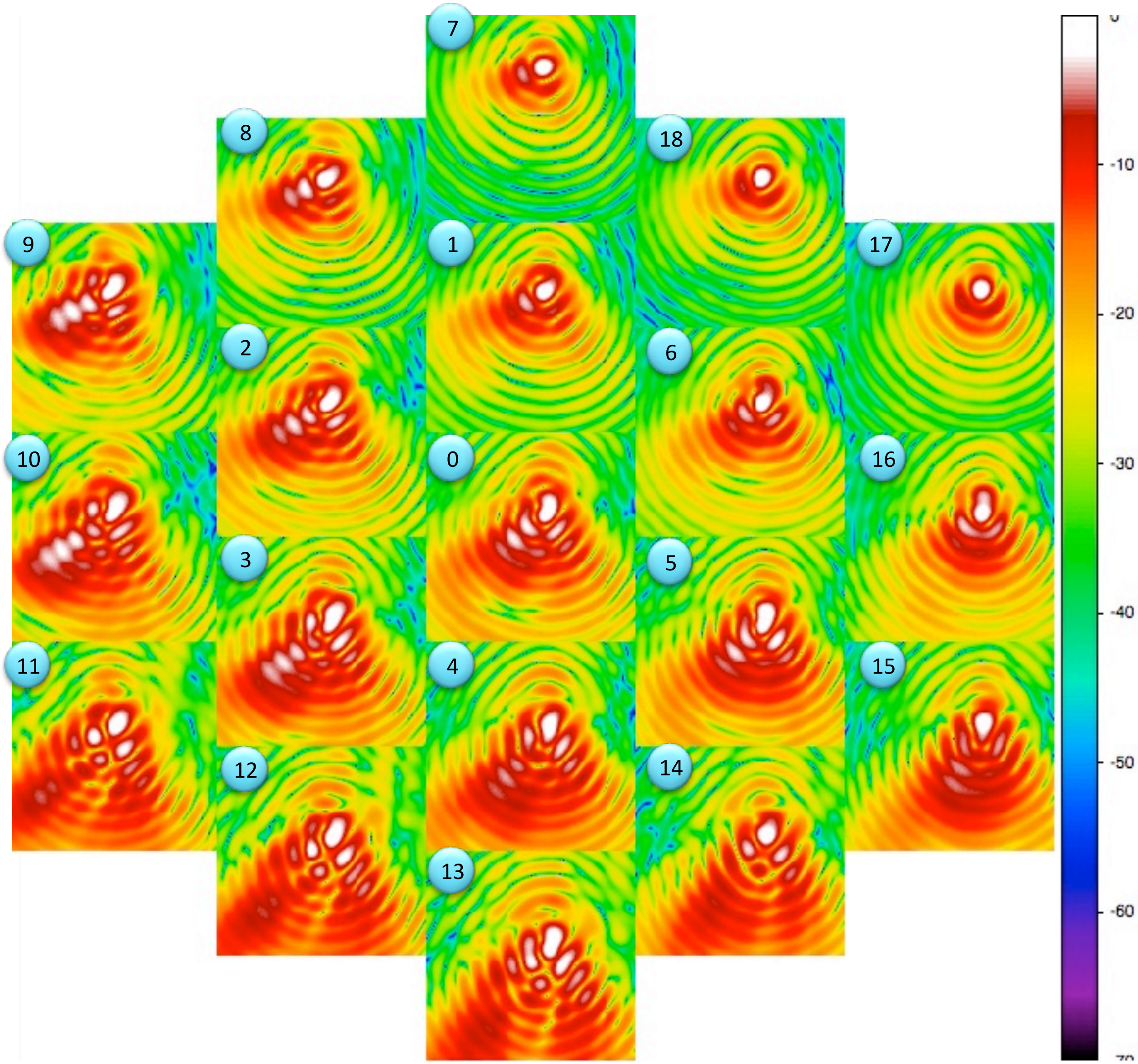
Arecibo Focal Phased Array Feasibility Study

BYU BRIGHAM YOUNG UNIVERSITY

PAF Sky Beam Mosaic: Case B3

National Astronomy and Ionosphere Center



PHASED ARRAY ANTENNA SYSTEMS FOR RADIO ASTRONOMY
Brigham Young University, Provo UT May 3-5, 2010

Germán Cortés M May, 2010

Rev. -

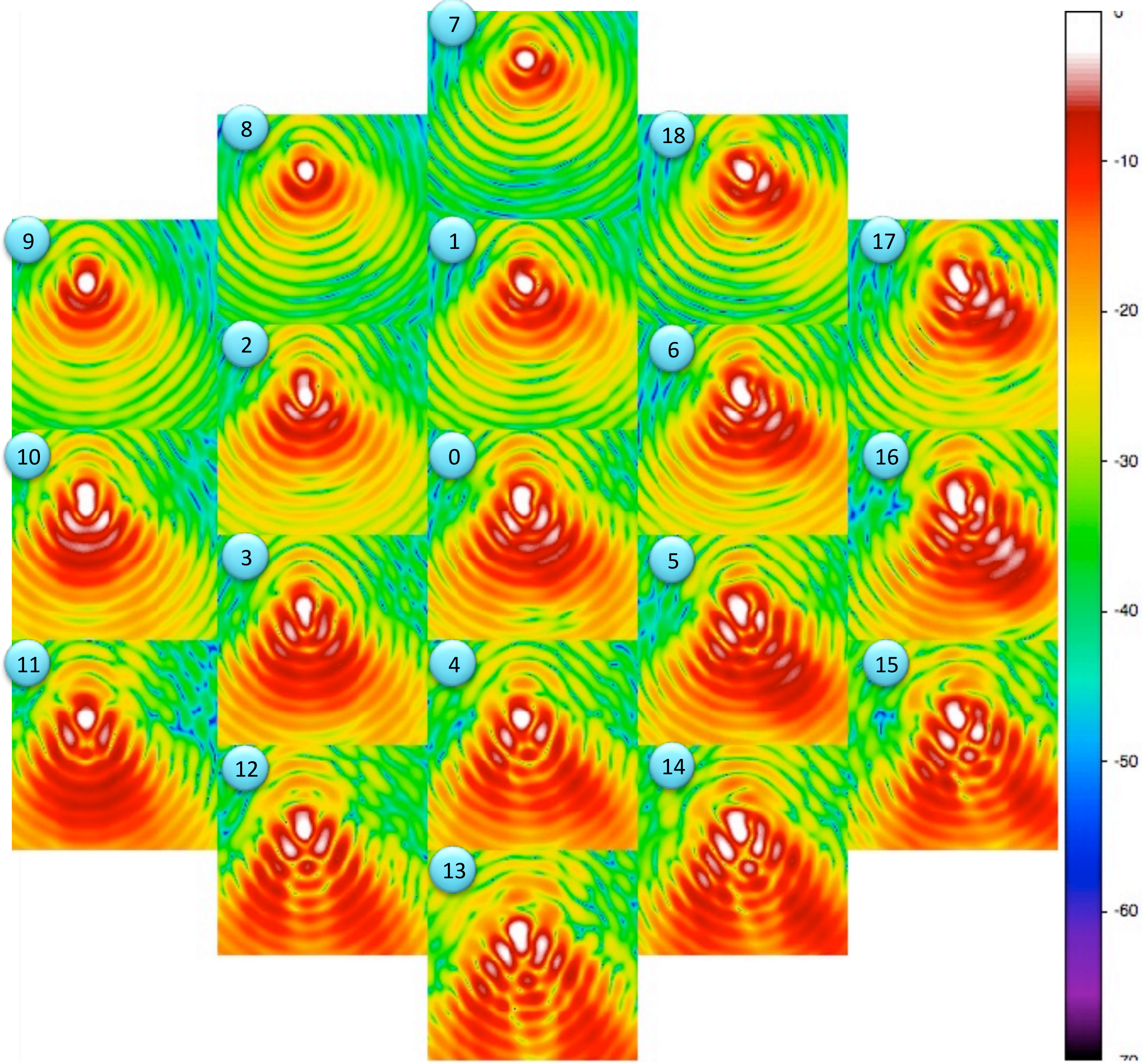
Cornell University

Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Mosaic: Case B4

BYU BRIGHAM YOUNG UNIVERSITY

National Astronomy and Ionosphere Center



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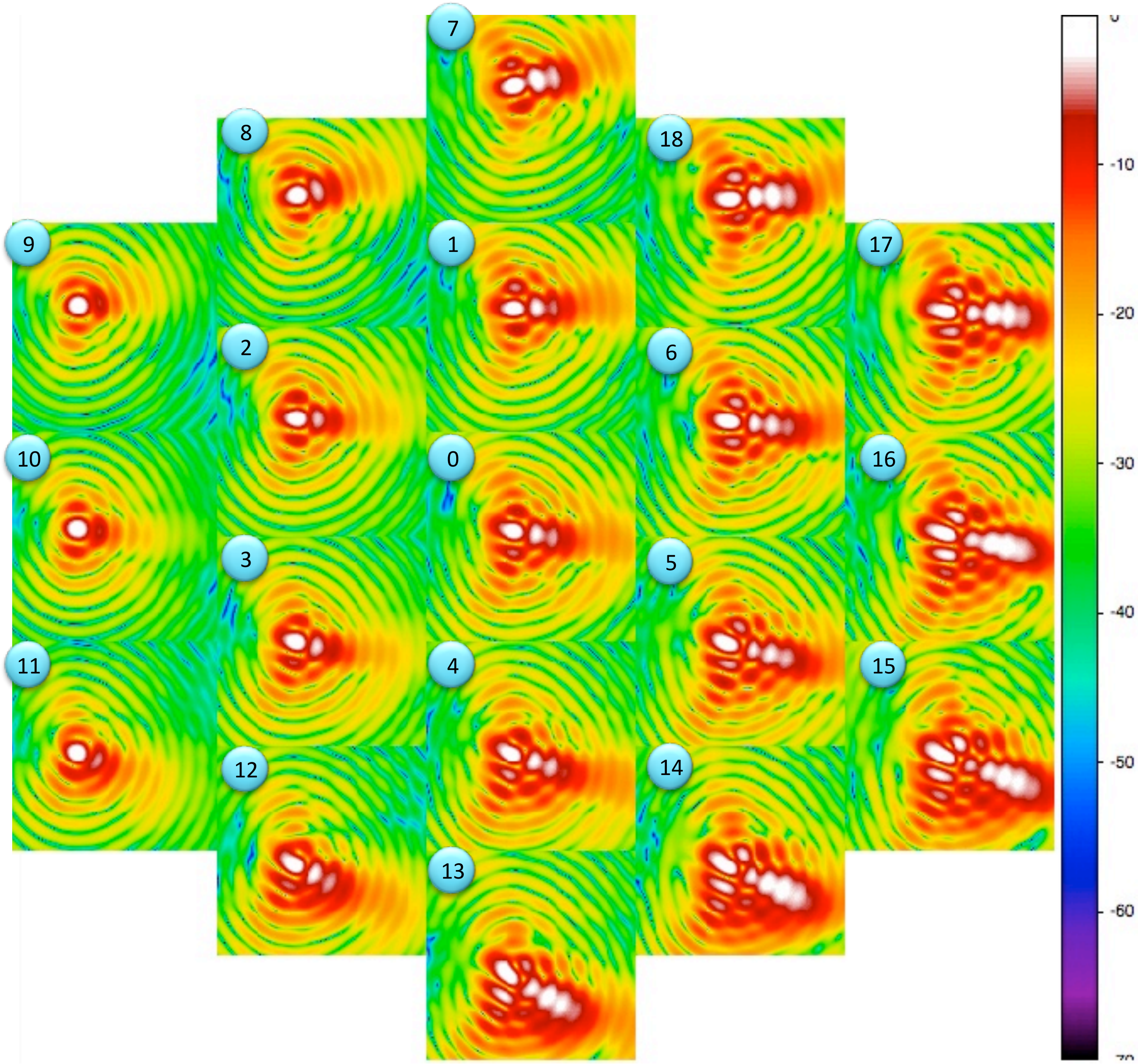
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Mosaic: Case B5

National Astronomy and Ionosphere Center



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PHASED ARRAY ANTENNA SYSTEMS FOR RADIO ASTRONOMY
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Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Mosaic: Case B6

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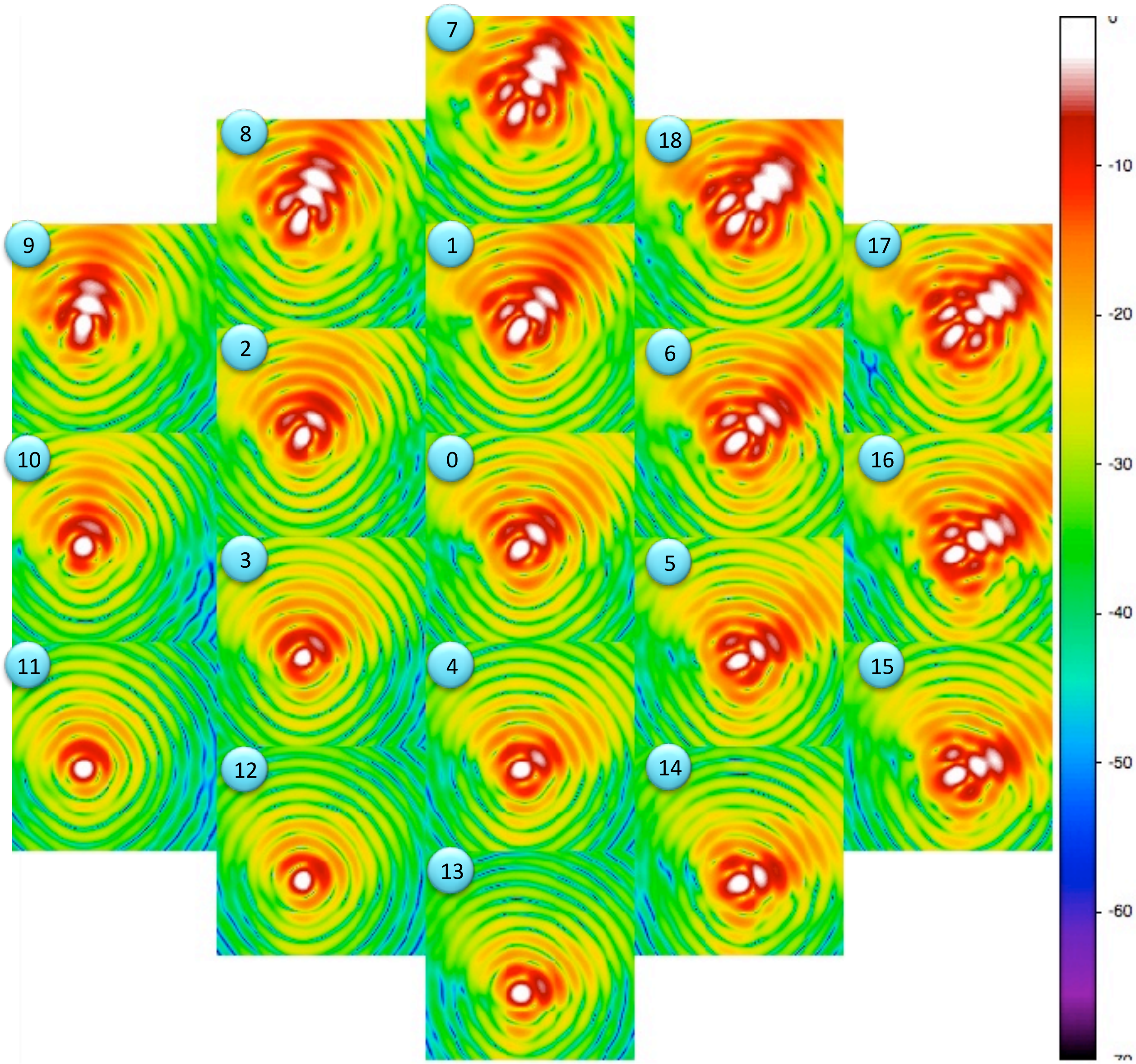
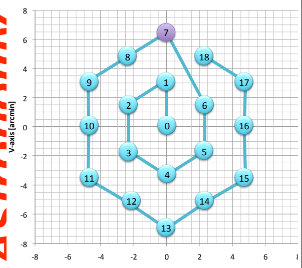
National Astronomy and Ionosphere Center

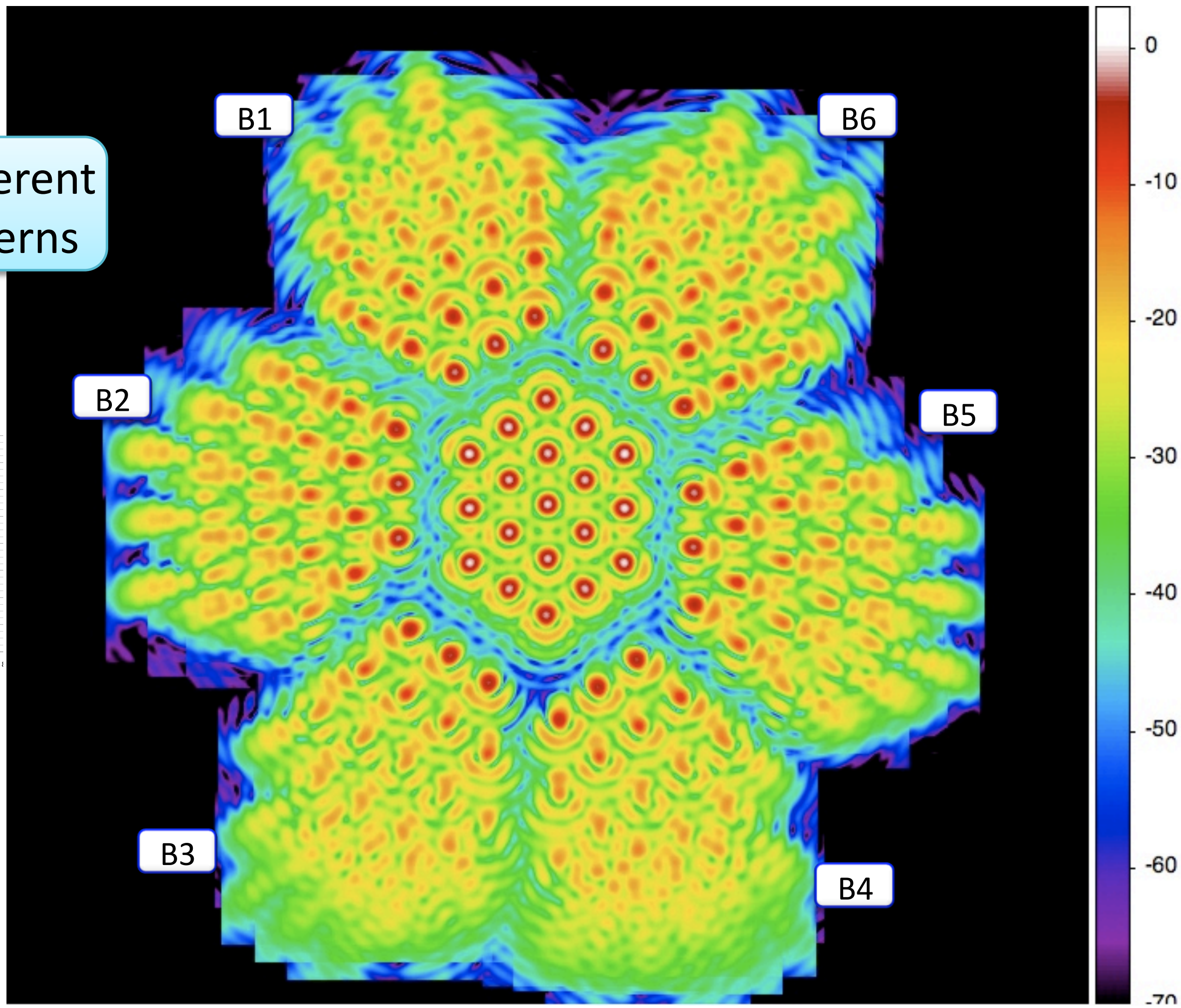


PAF Sky Beam Patterns: Cases B0 to B6

Separation x3.5

Total Incoherent Beam Patterns



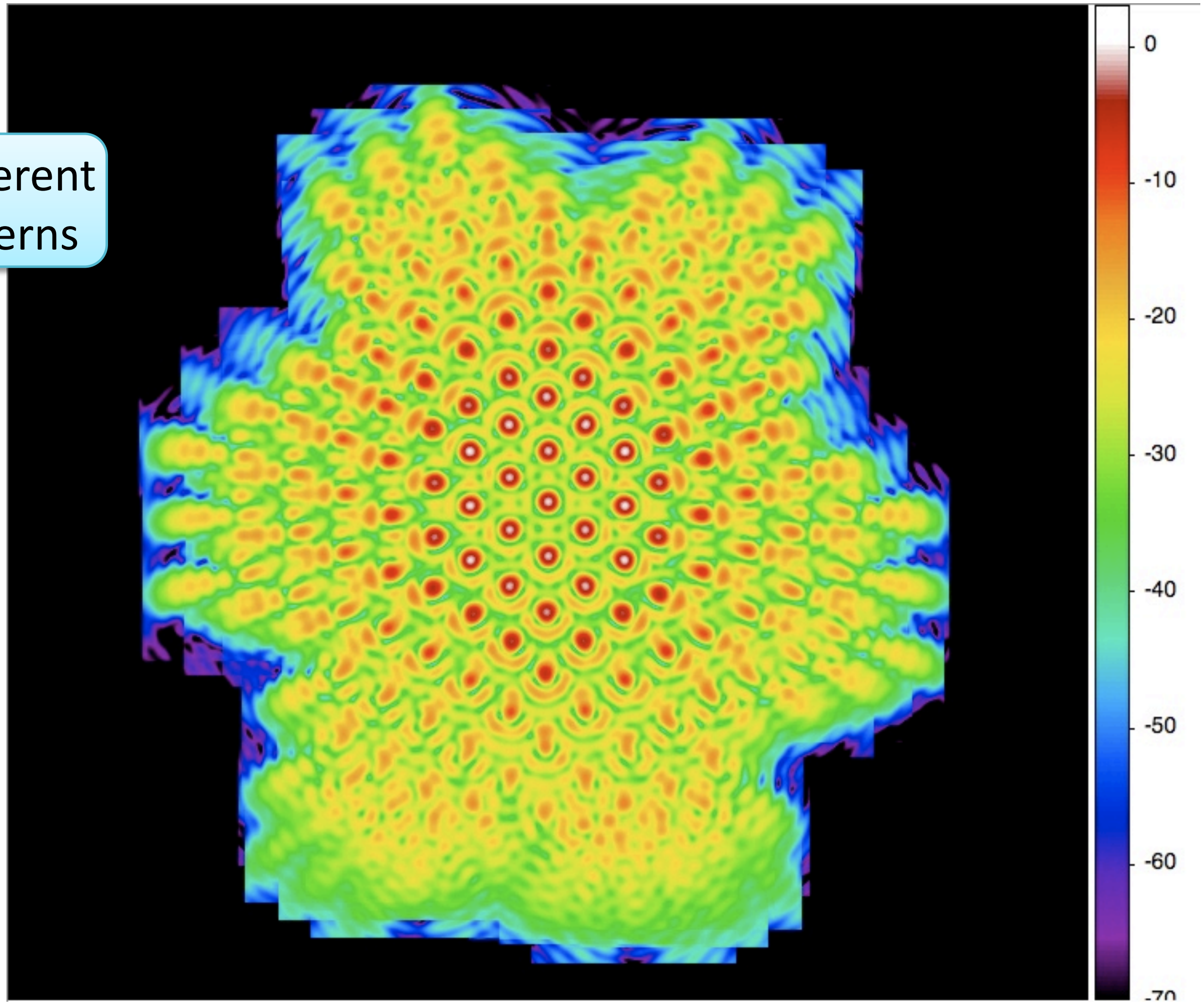


Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Patterns: Cases B0 to B6

Separation x3.5

Total Incoherent Beam Patterns



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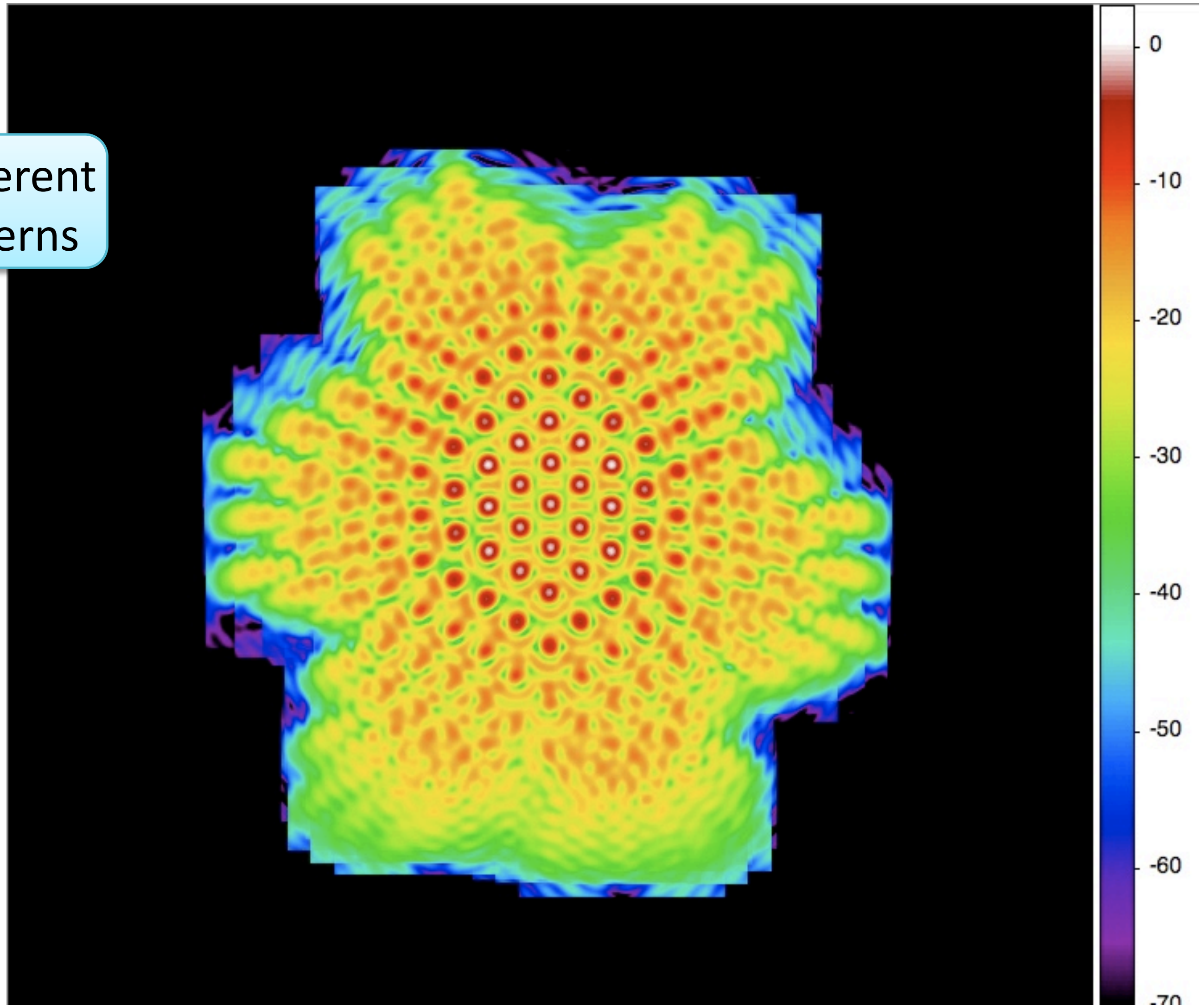
PAF Sky Beam Patterns: Cases B0 to B6

National Astronomy and Ionosphere Center

Separation x2.8

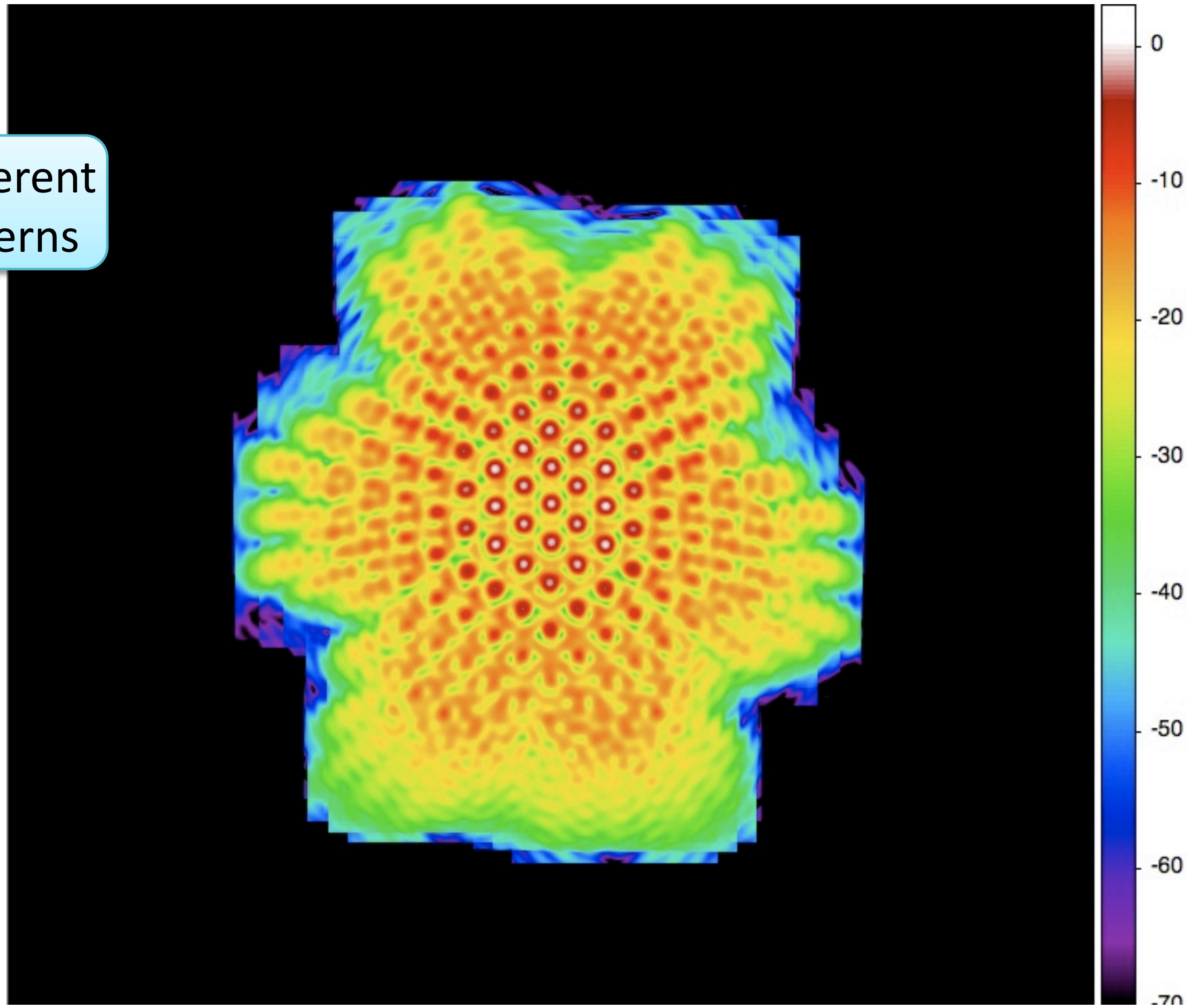
Total Incoherent Beam Patterns



PAF Sky Beam Patterns: Cases B0 to B6

Separation x2.5

Total Incoherent Beam Patterns



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PAF Sky Beam Patterns: Cases B0 to B6

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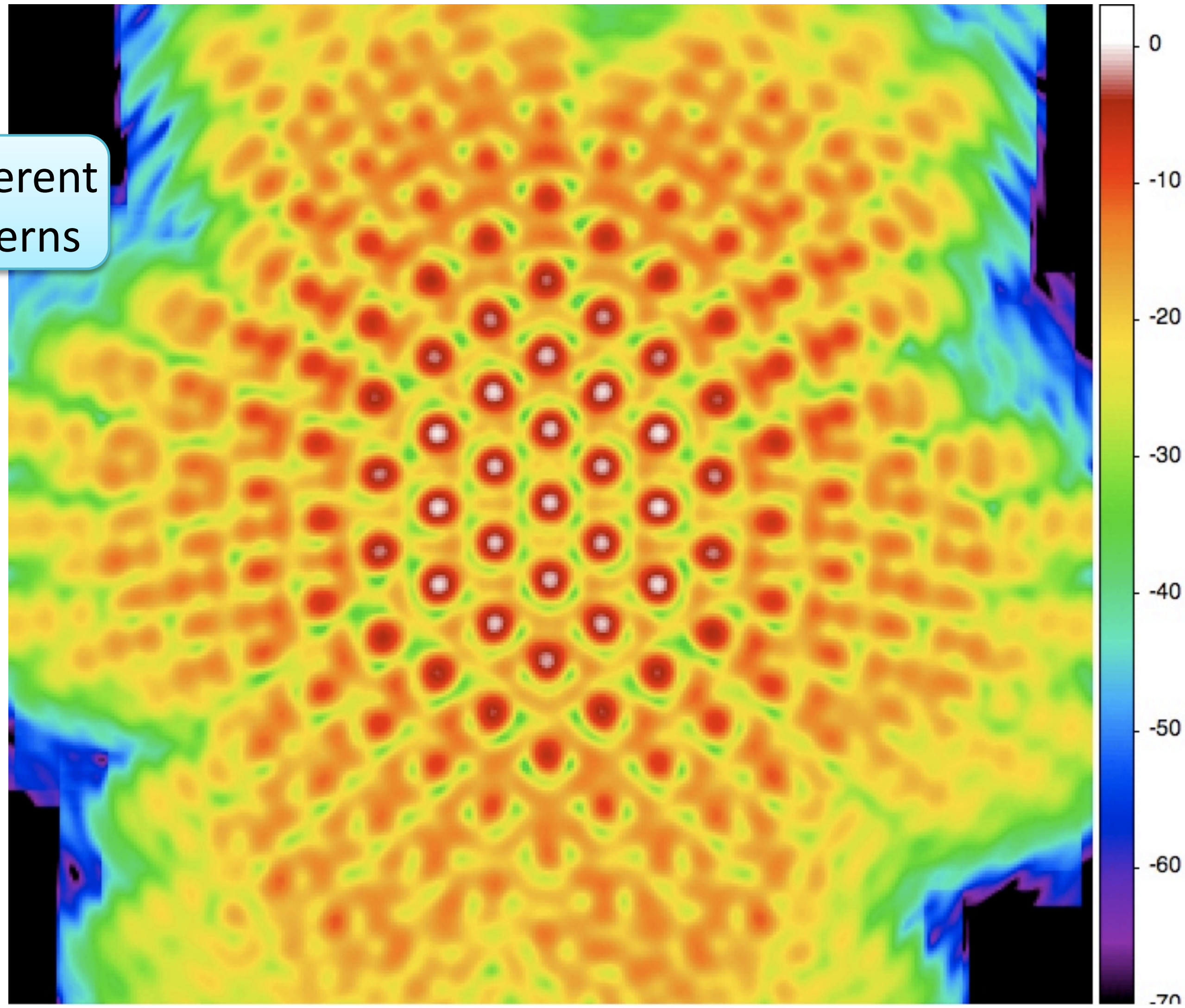
Separation x2.5

Total Incoherent Beam Patterns



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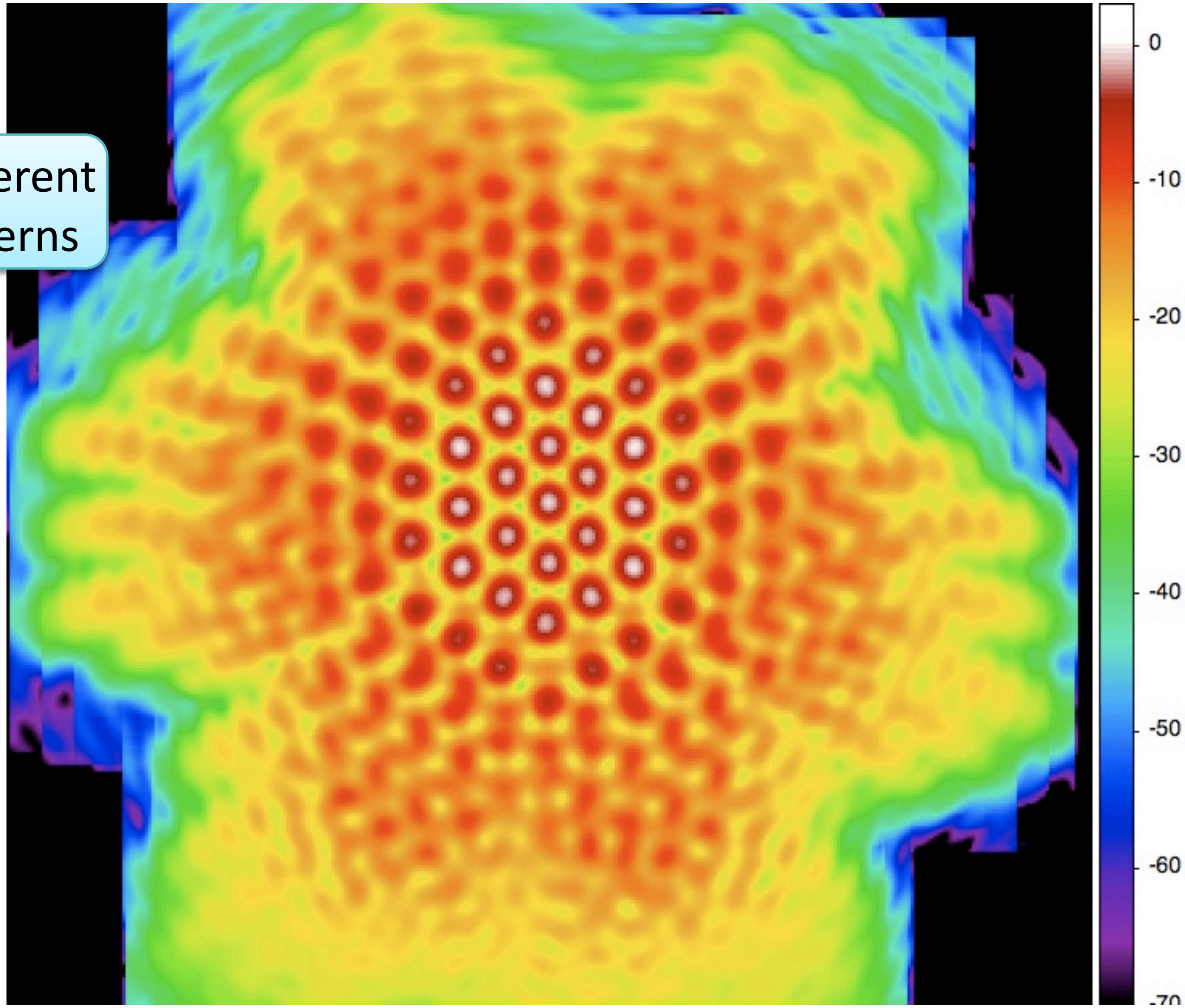
PAF Sky Beam Patterns: Cases B0 to B6

Separation x2.0

National Astronomy and Ionosphere Center

Total Incoherent Beam Patterns



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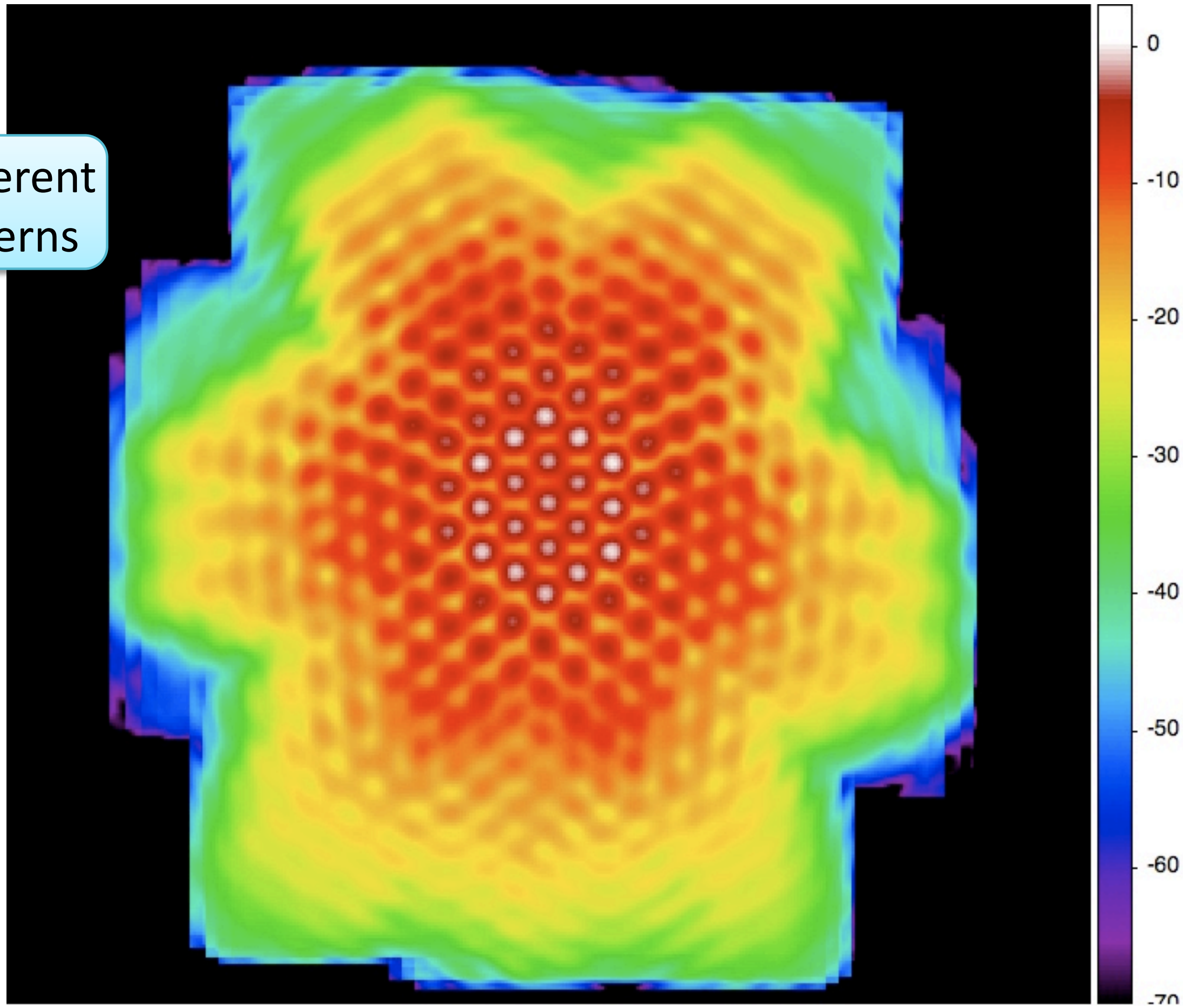
PAF Sky Beam Patterns: Cases B0 to B6

Separation x1.5

Total Incoherent Beam Patterns

National Astronomy and Ionosphere Center

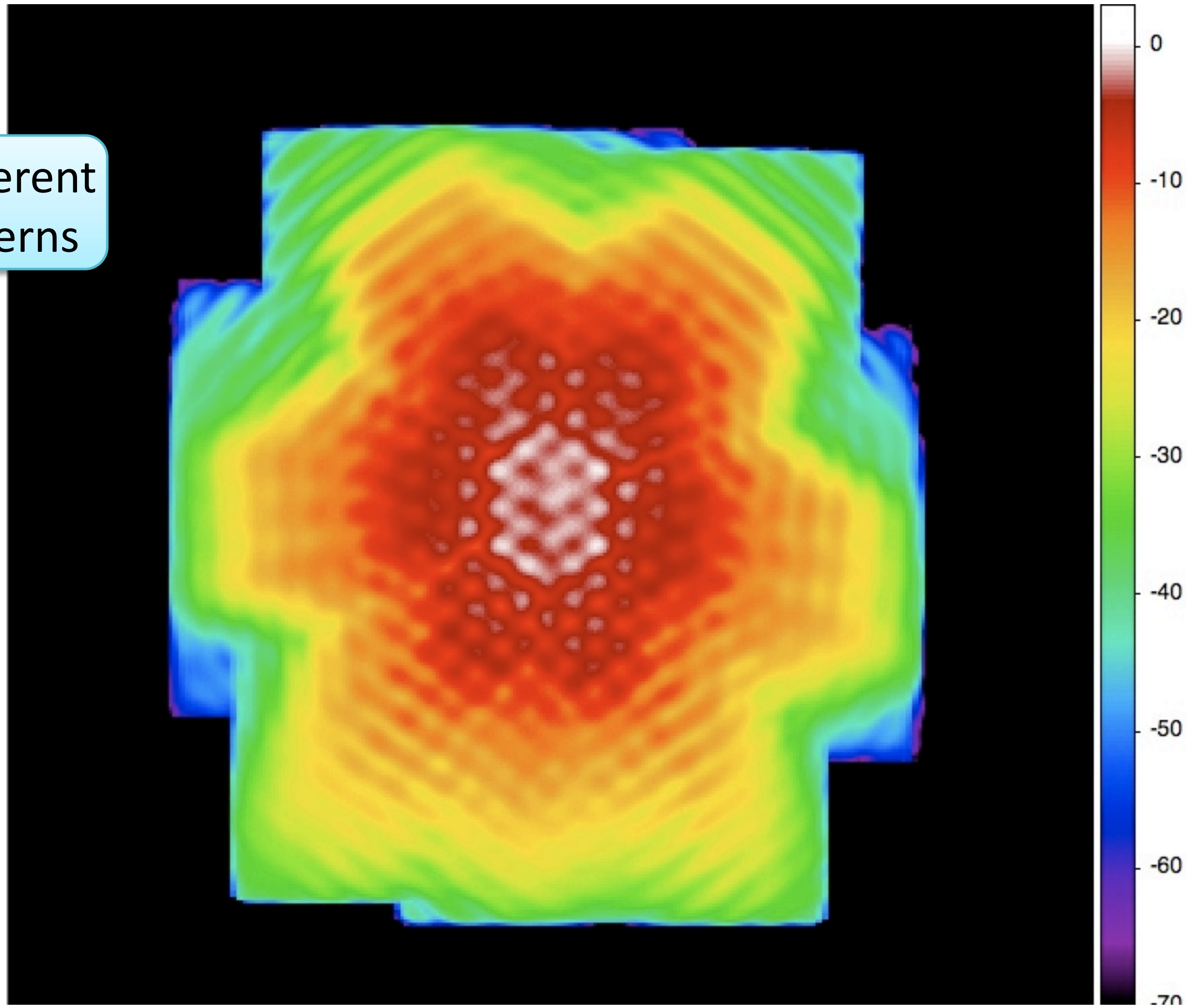


Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Patterns: Cases B0 to B6

Separation x1.2

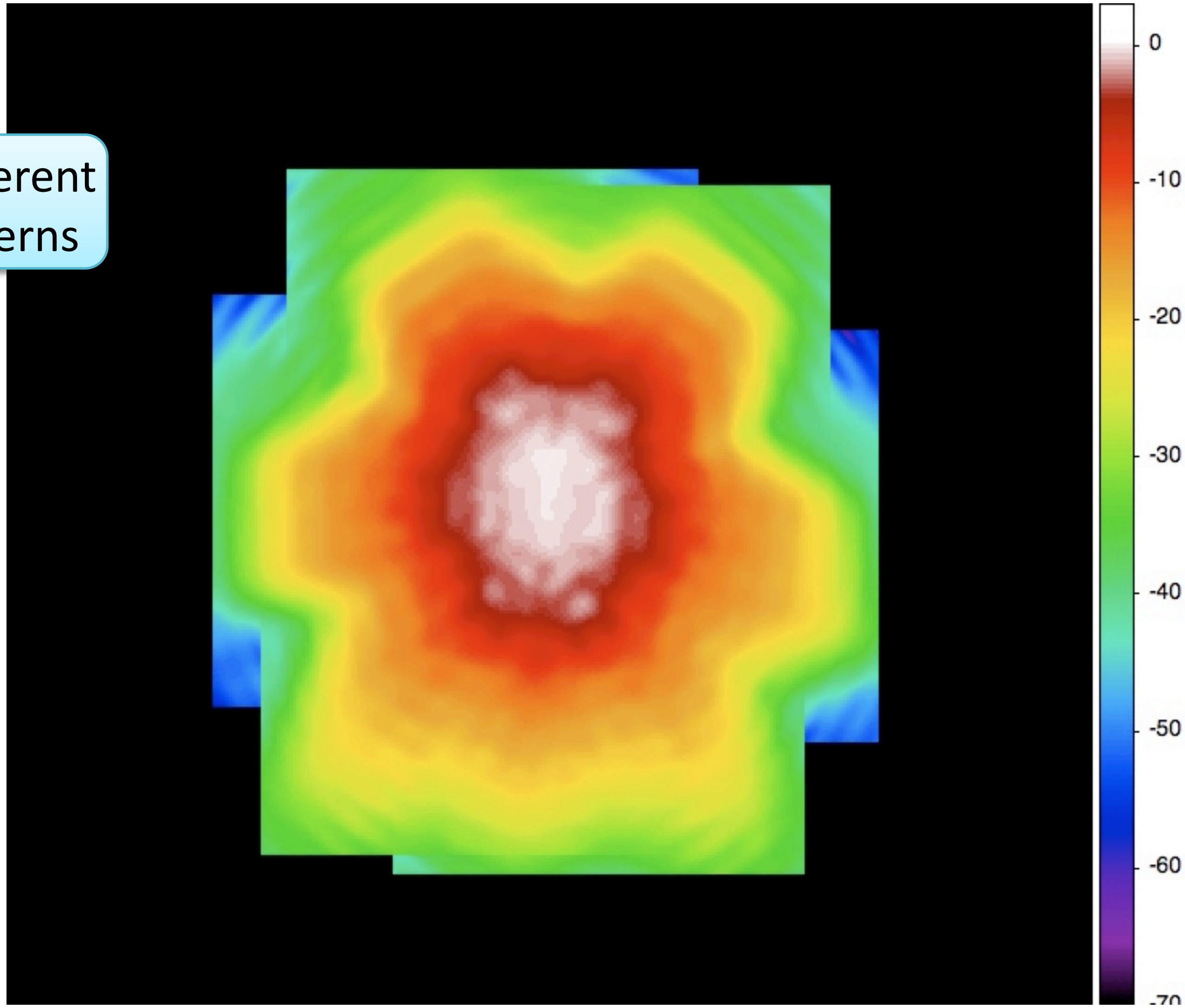
Total Incoherent Beam Patterns



PAF Sky Beam Patterns: Cases B0 to B6

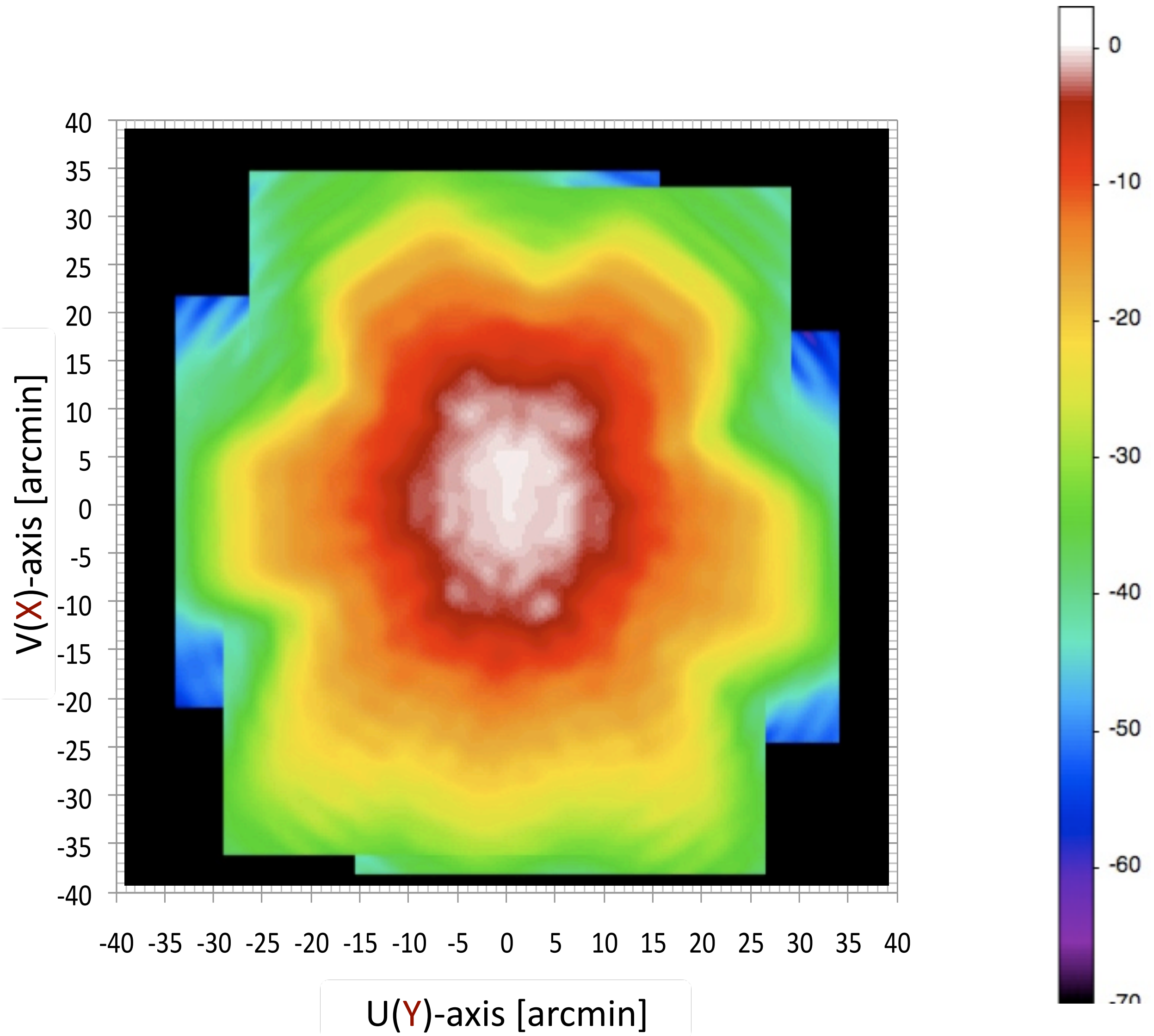
Separation x1.0

Total Incoherent Beam Patterns



PAF Sky Beam Patterns: Cases B0 to B6

Separation x1.0



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PAF Sky Beam Patterns: Cases B0 to B6

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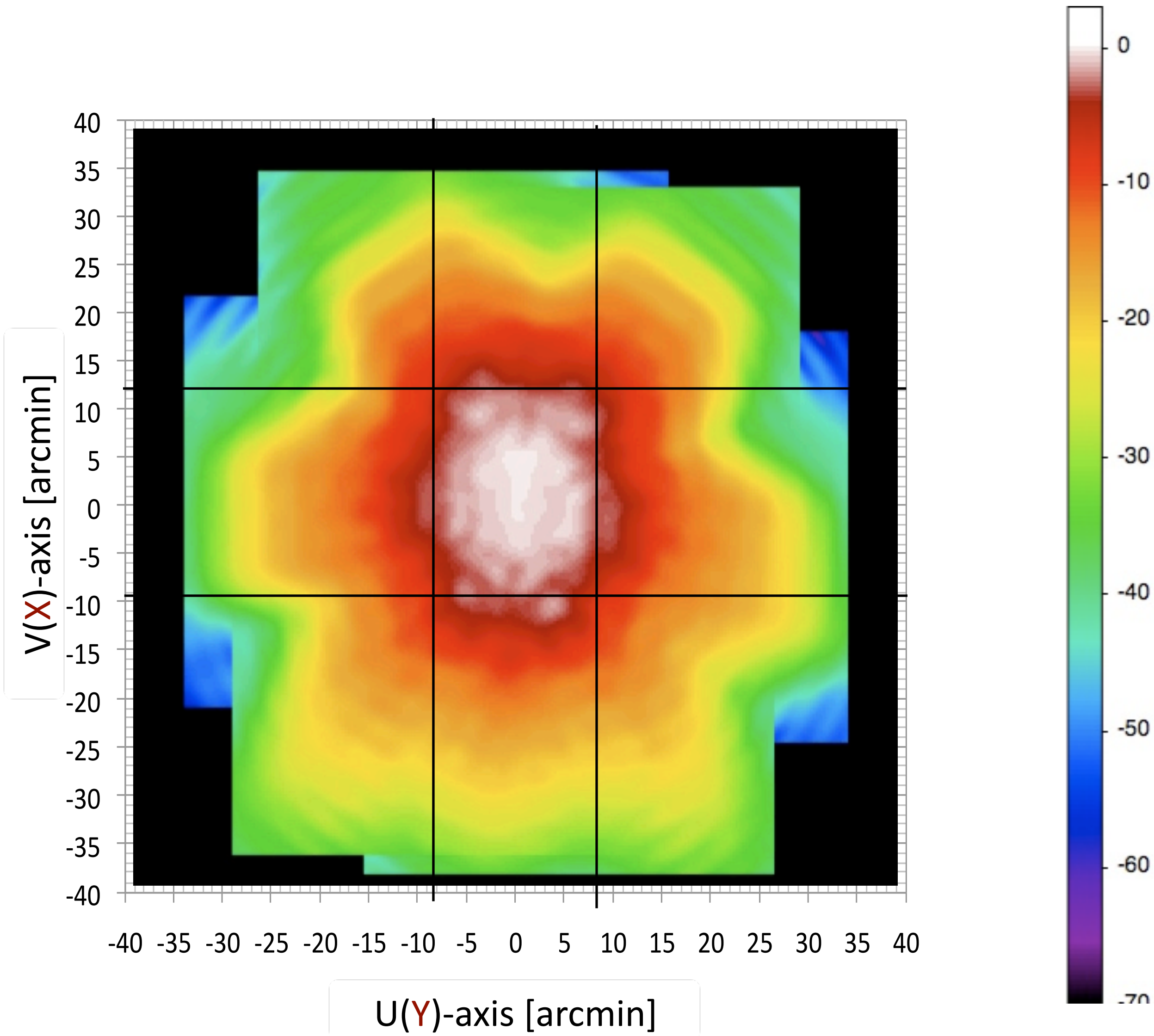
Separation x1.0



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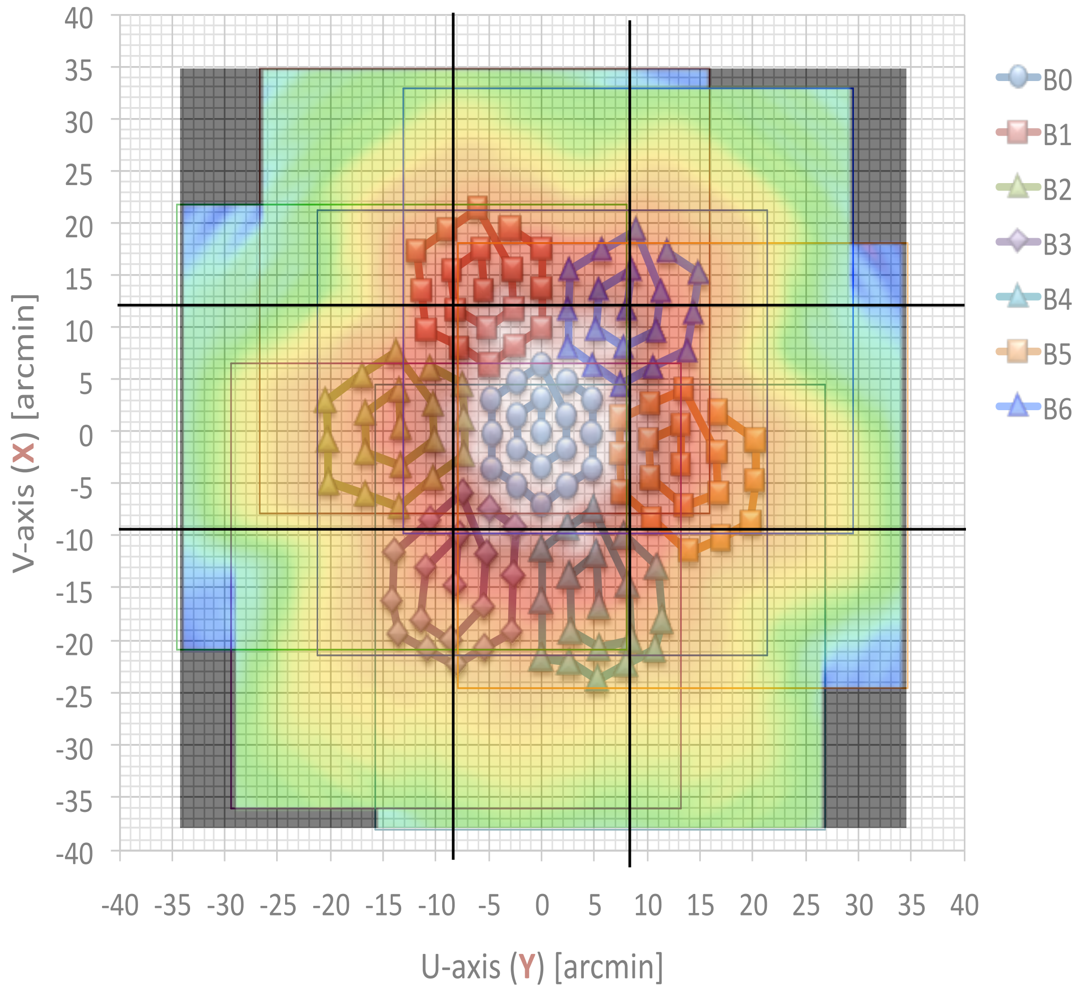
PAF Sky Beam Patterns: Cases B0 to B6

National Astronomy and Ionosphere Center



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PAF Sky Beam Patterns: Cases B0 to B6

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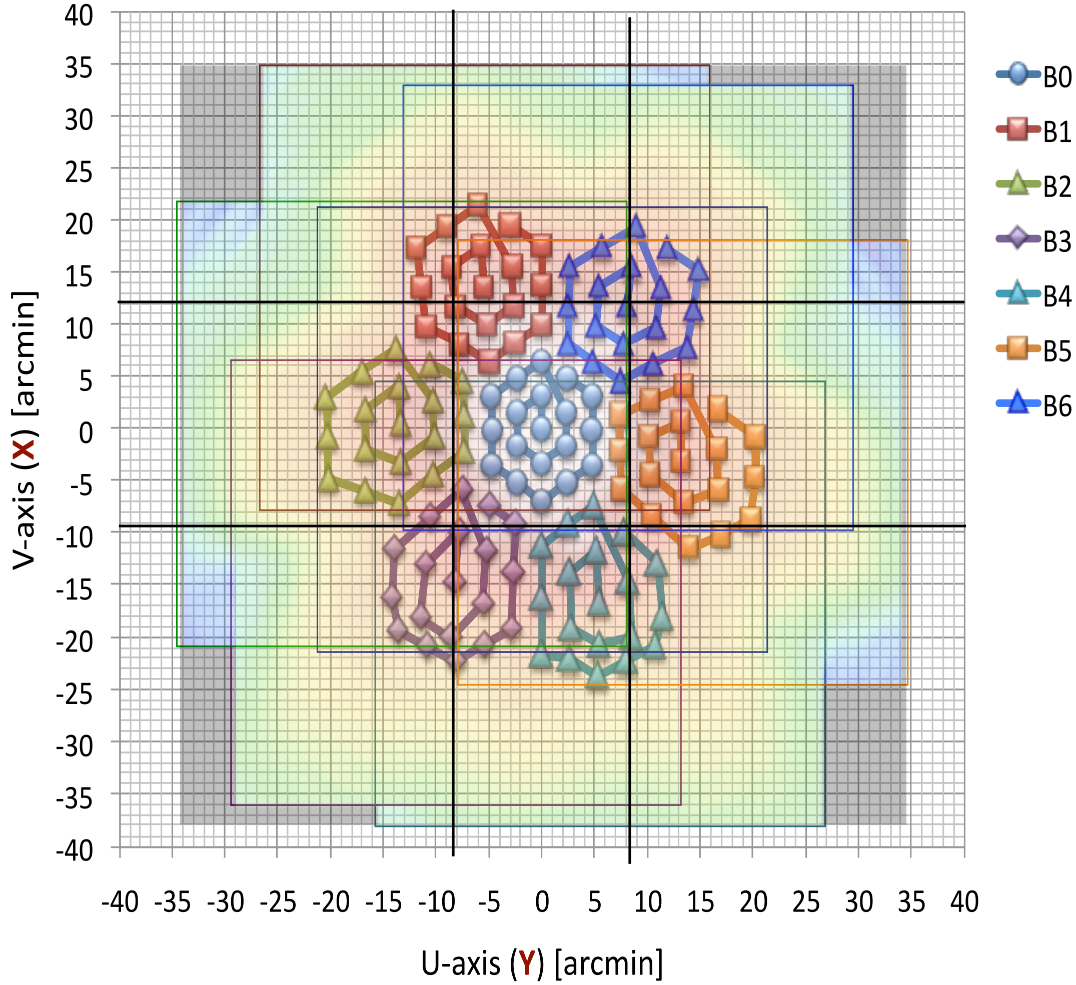

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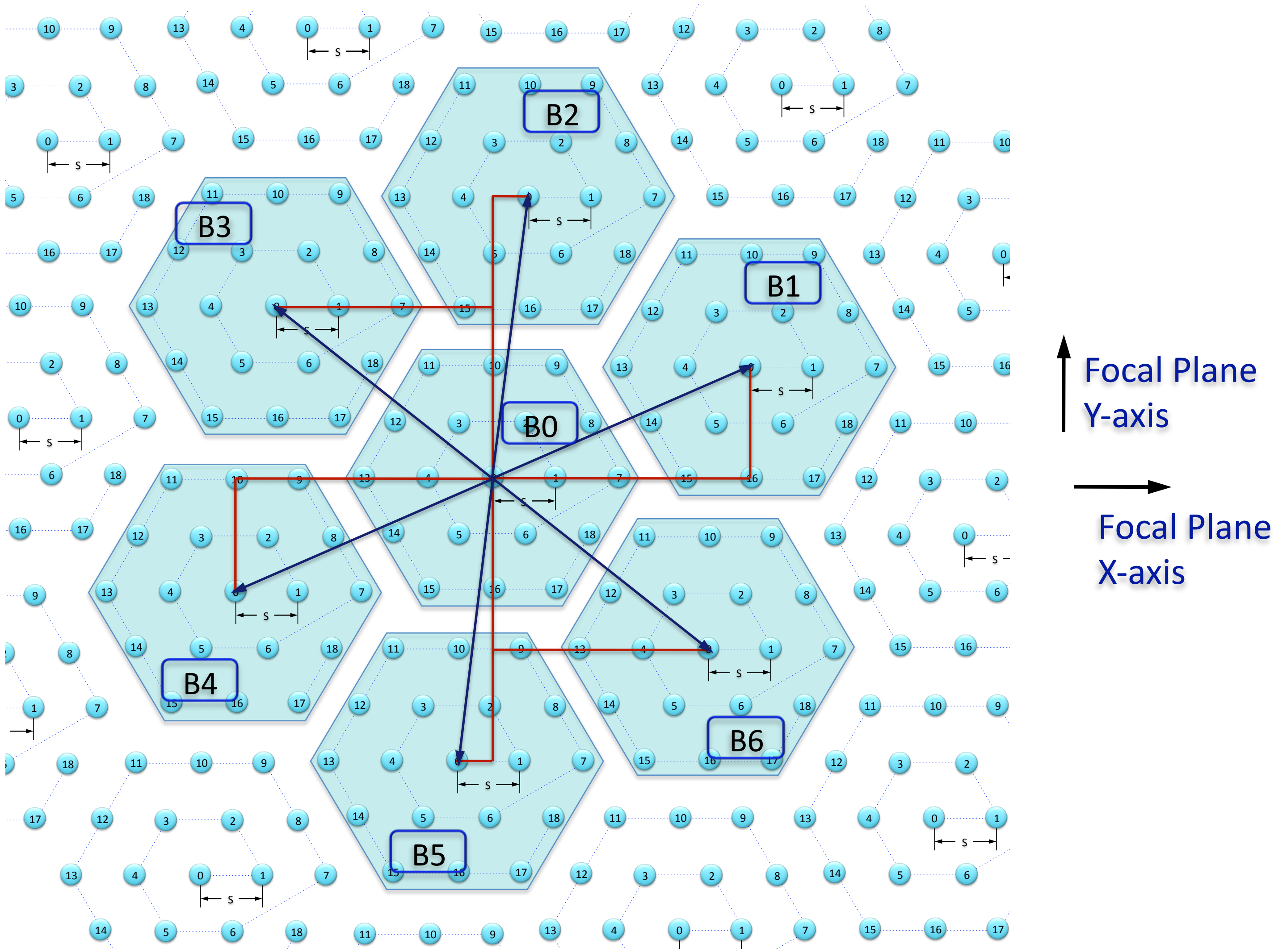
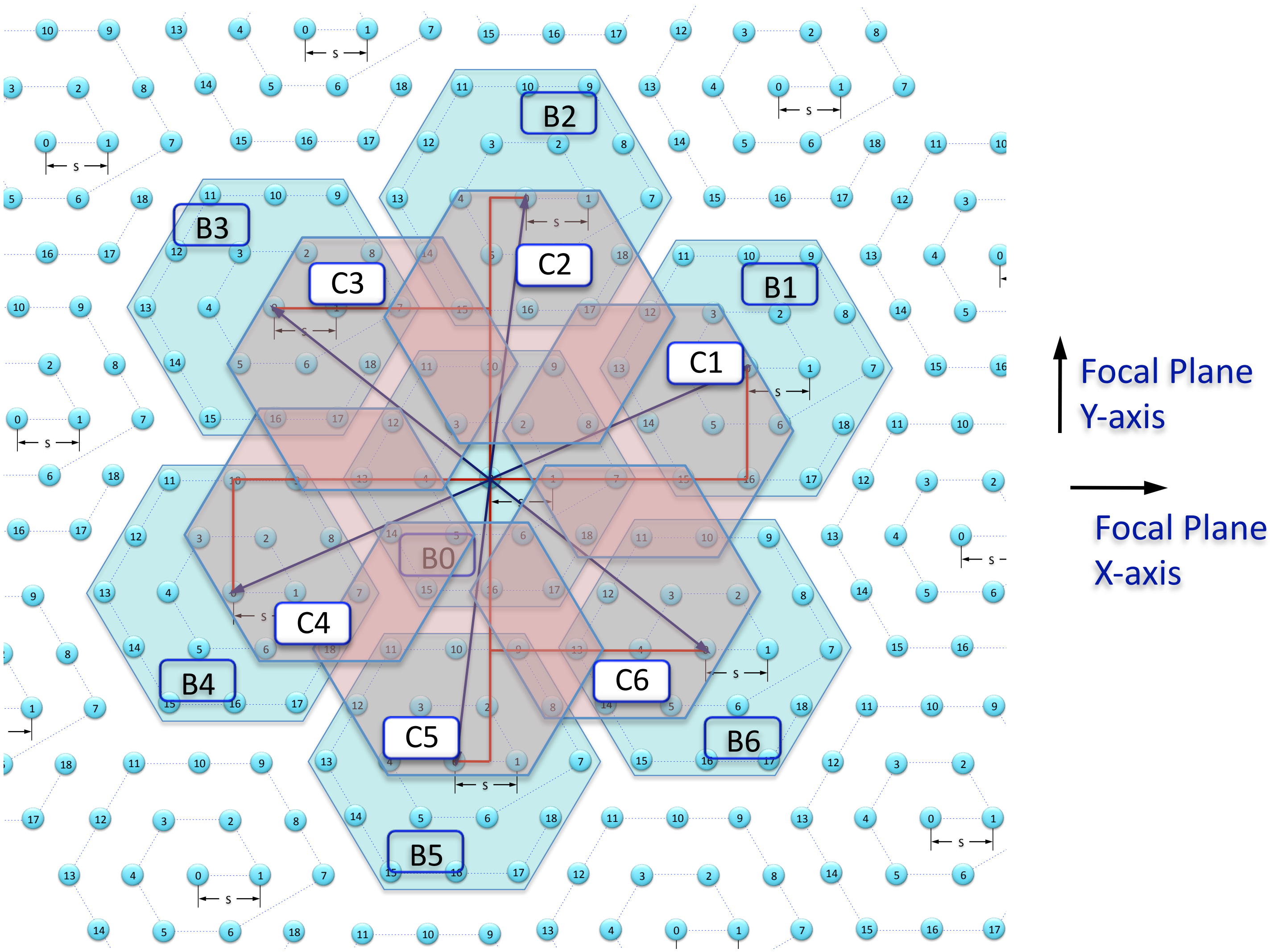
Beam Forming Simulation Preliminary Results

PAF NO Overlapping Positions in Focal Plane: Cases B0 to B6

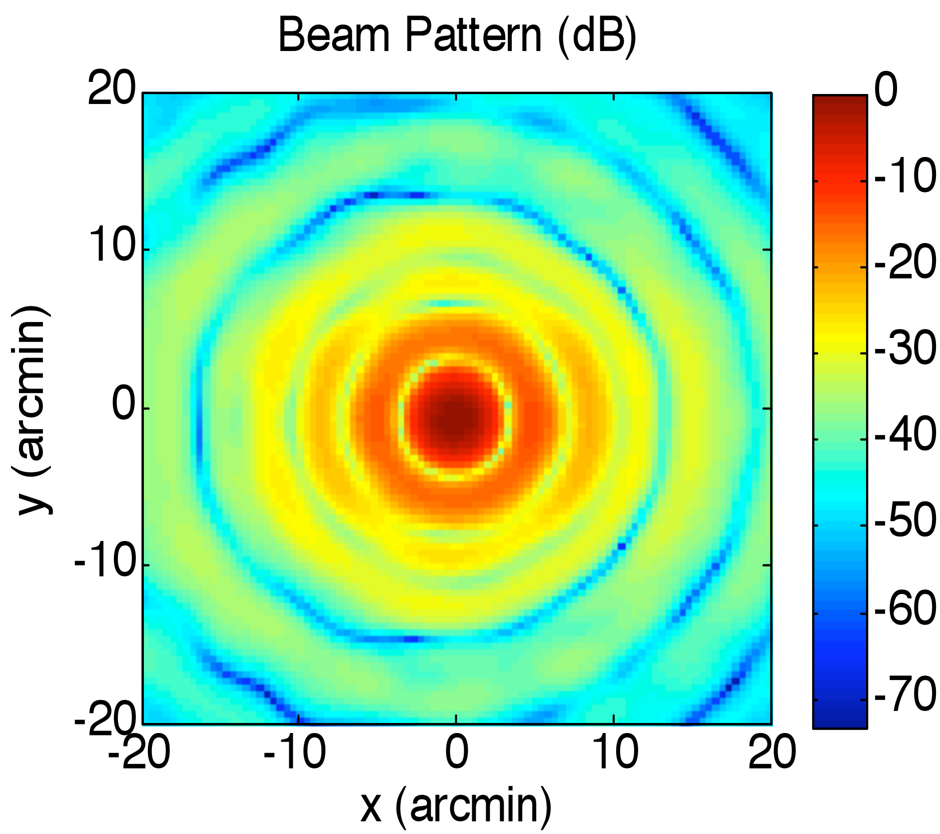


PAF Overlapping Positions in Focal Plane: Cases B0 to B6 + C1 to C6



Beam Formed PAF Pattern

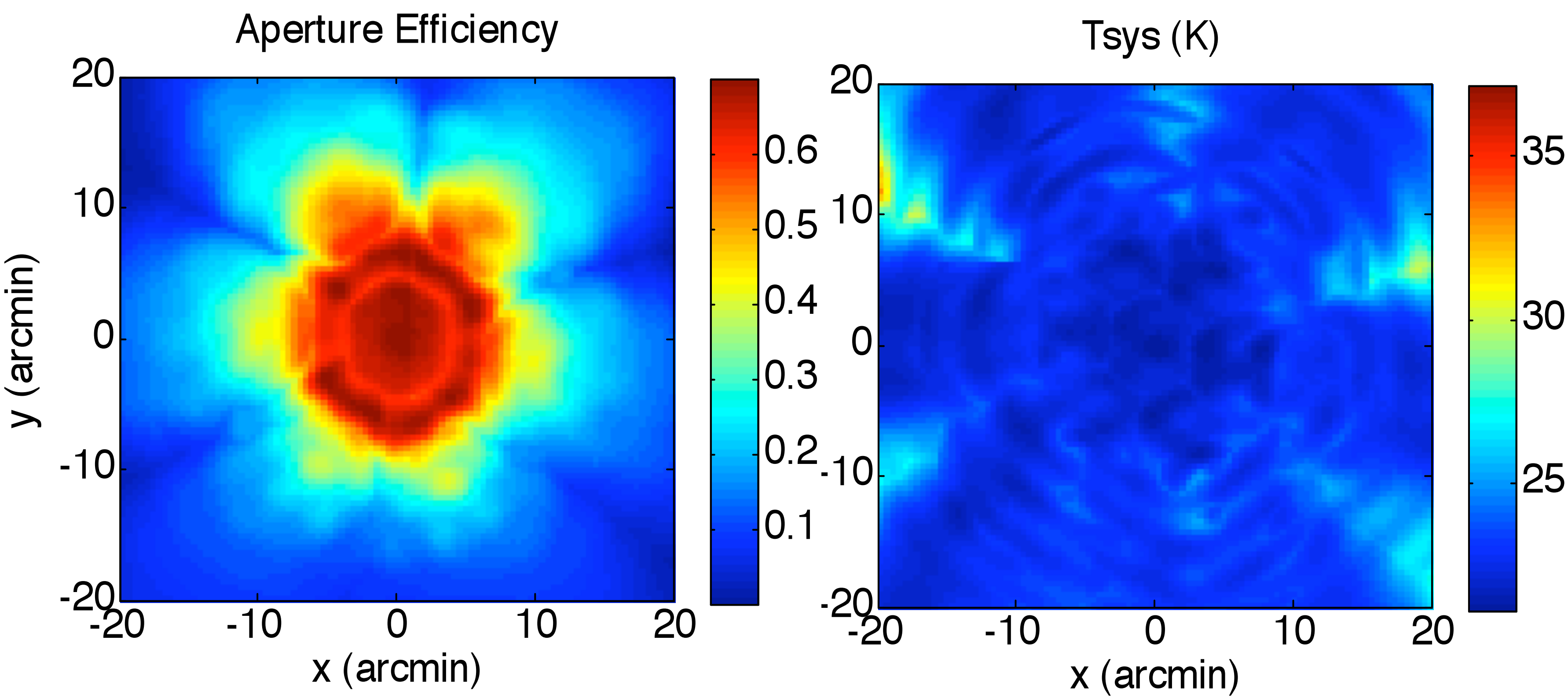
- Boresight beam pattern
- HPBW is 2.8 arcmin (ideally 2.9x3.3 arcmin)



BeamFormed η_A and Tsys over FOV

ΔZ= 0cm

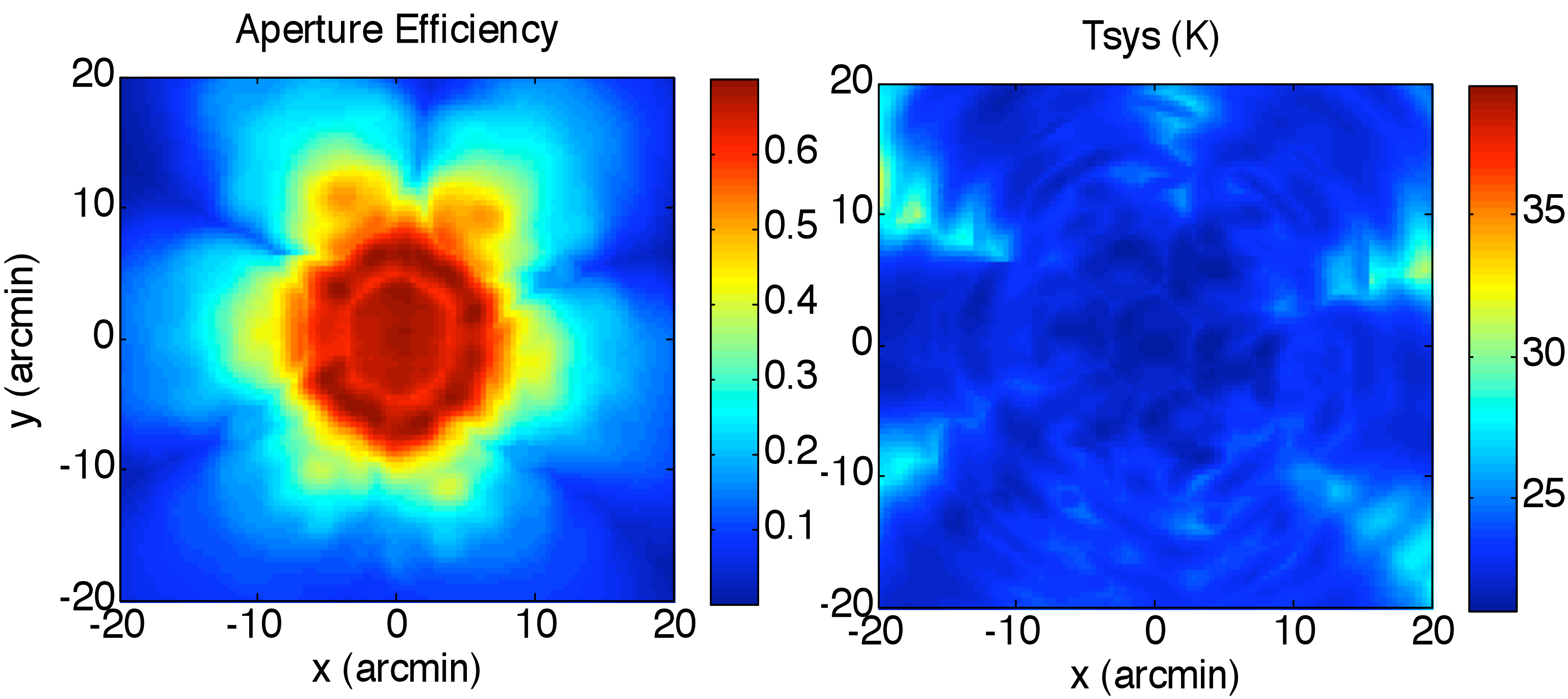
- Aperture Efficiency
- Modeled beam equivalent Tsys with 15 K LNA's



BeamFormed η_A and Tsys over FOV

ΔZ= +4cm

- Aperture Efficiency
- Modeled beam equivalent Tsys with 15 K LNA's



BeamFormed Aeff/Tsys over FOV

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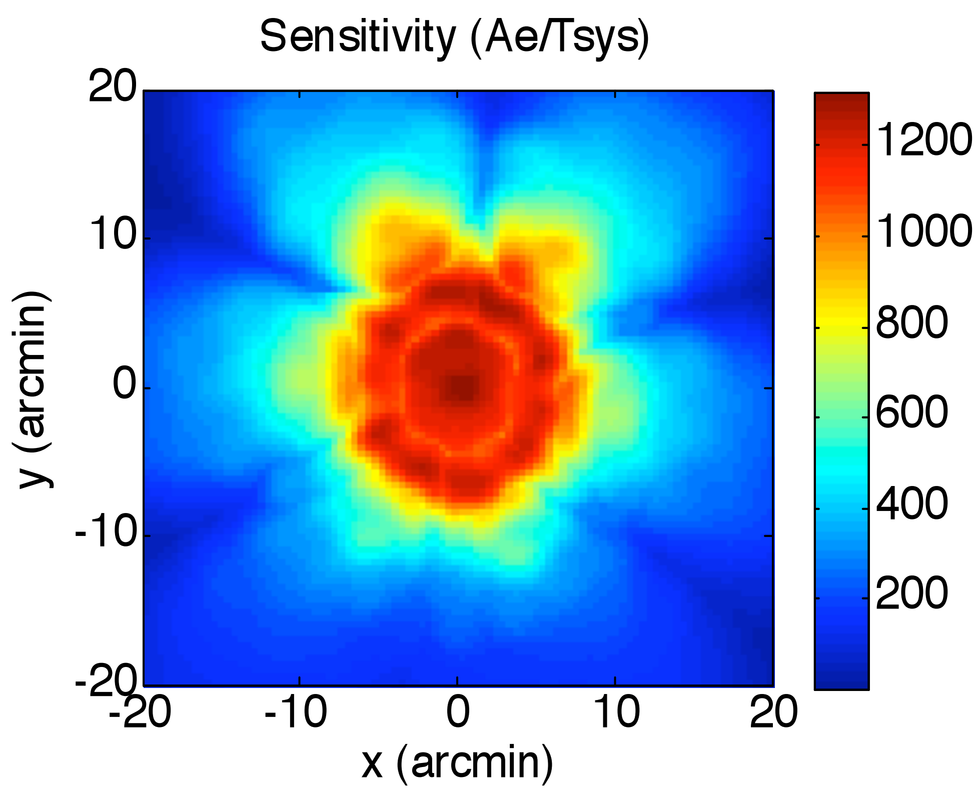
- Sensitivity as a function of beam steering angle
- Maximum value for each steering direction that is achieved over the 13 array positions

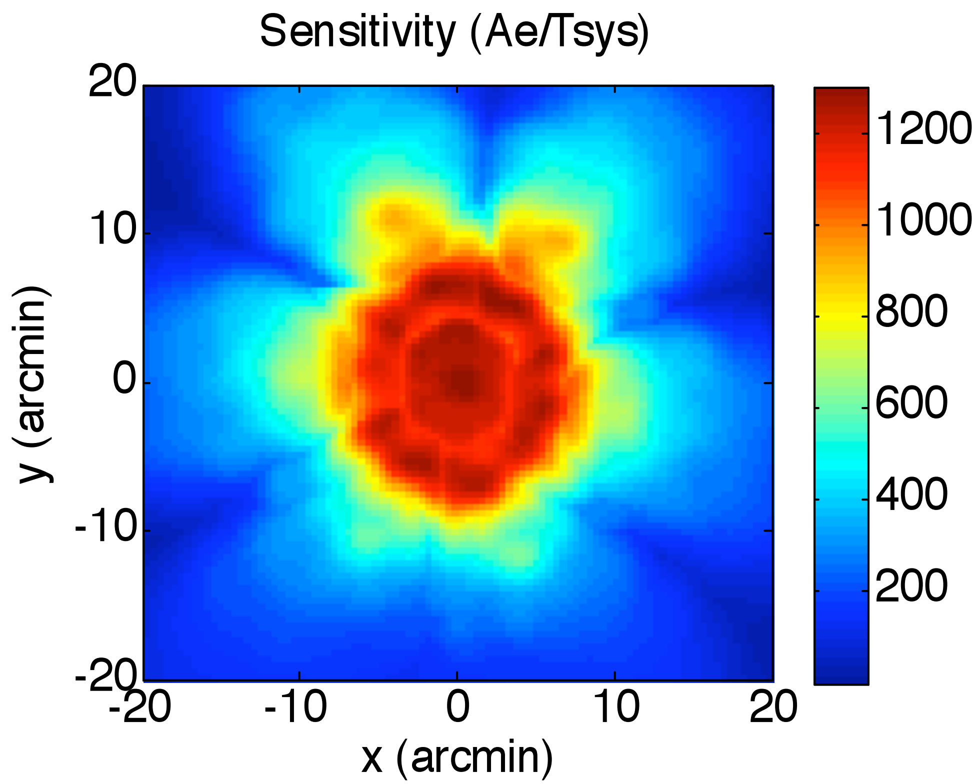
ΔZ= 0cm



BeamFormed Aeff/Tsys over FOV

- Sensitivity as a function of beam steering angle
- Maximum value for each steering direction that is achieved over the 13 array positions

ΔZ= +4cm



Conclusions

- We have started the PAF feasibility Study of AO Shaped Optics
- The PAF positioner is being fabricated, as well BYU's single/dual pol PAF.
- We have made a series of simulations to calculate the expected performance of BYU's 19 PAF at Arecibo's Focal plane, based on the simulated pattern calculations of each of the 19 BYU dipoles.
- We obtained far field pattern data for 133 no overlapping locations of dipoles in the focal plane
- From the sensitivity plot, the 1 dB FOV (80% of peak sensitivity) is roughly 16 arcmin in diameter
- Measuring campaign of a Shaped Optics with a PAF by mid June.