# Application of Radio Phase Modes to Modification and Remote Sensing of the Atmosphere and Space

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Dynamical Processes in Space Plasmas
Ein Bokek, Israel, 10-17 April 2010
http://physics.bgu.ac.il/~gedalin/Isradynamics2010/

## Radio phase modes

Photon orbital angular momentum (OAM)
- intrinsic property of photons
- complement to photon spin angular momentum (polarization)
- long studied in optics

Transmission from existing radio antenna arrays
- remote sensing
- communication

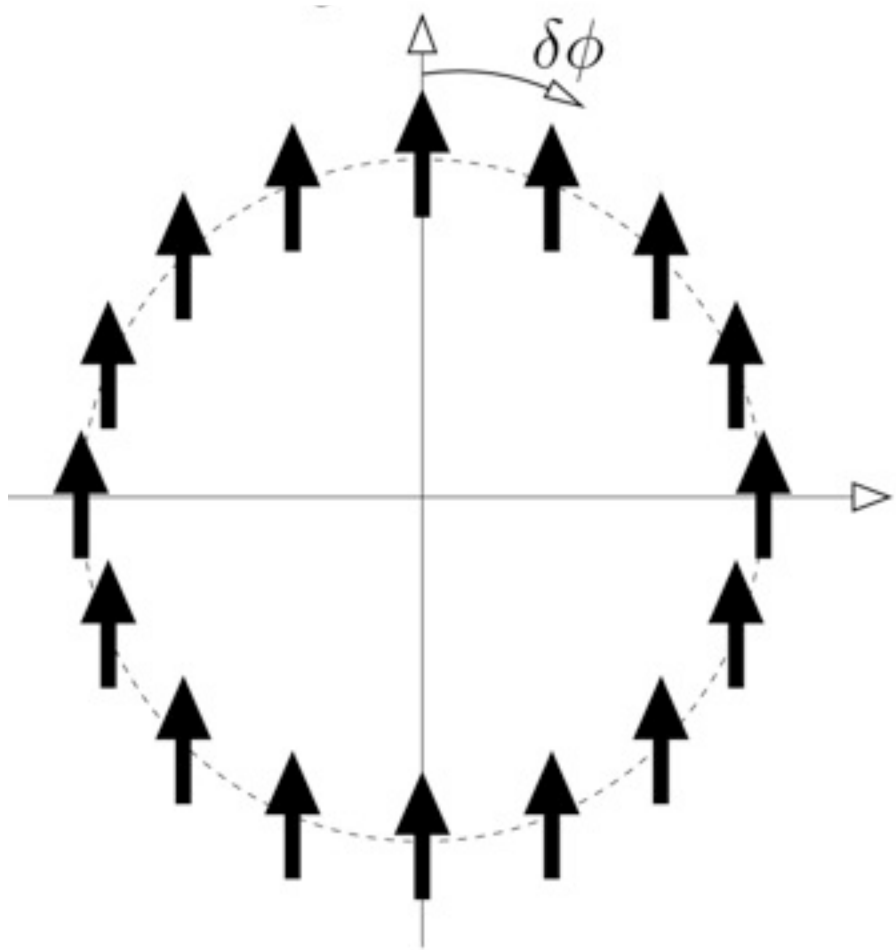
Detection
- phase gradient
- full polarization (crossed dipole arrays may be insufficient)

Potential space and astrophysical sources
- space plasma turbulence?

Other potential applications

# Transmission of radio phase modes

$$n\,\delta\phi = 2\pi\,l$$



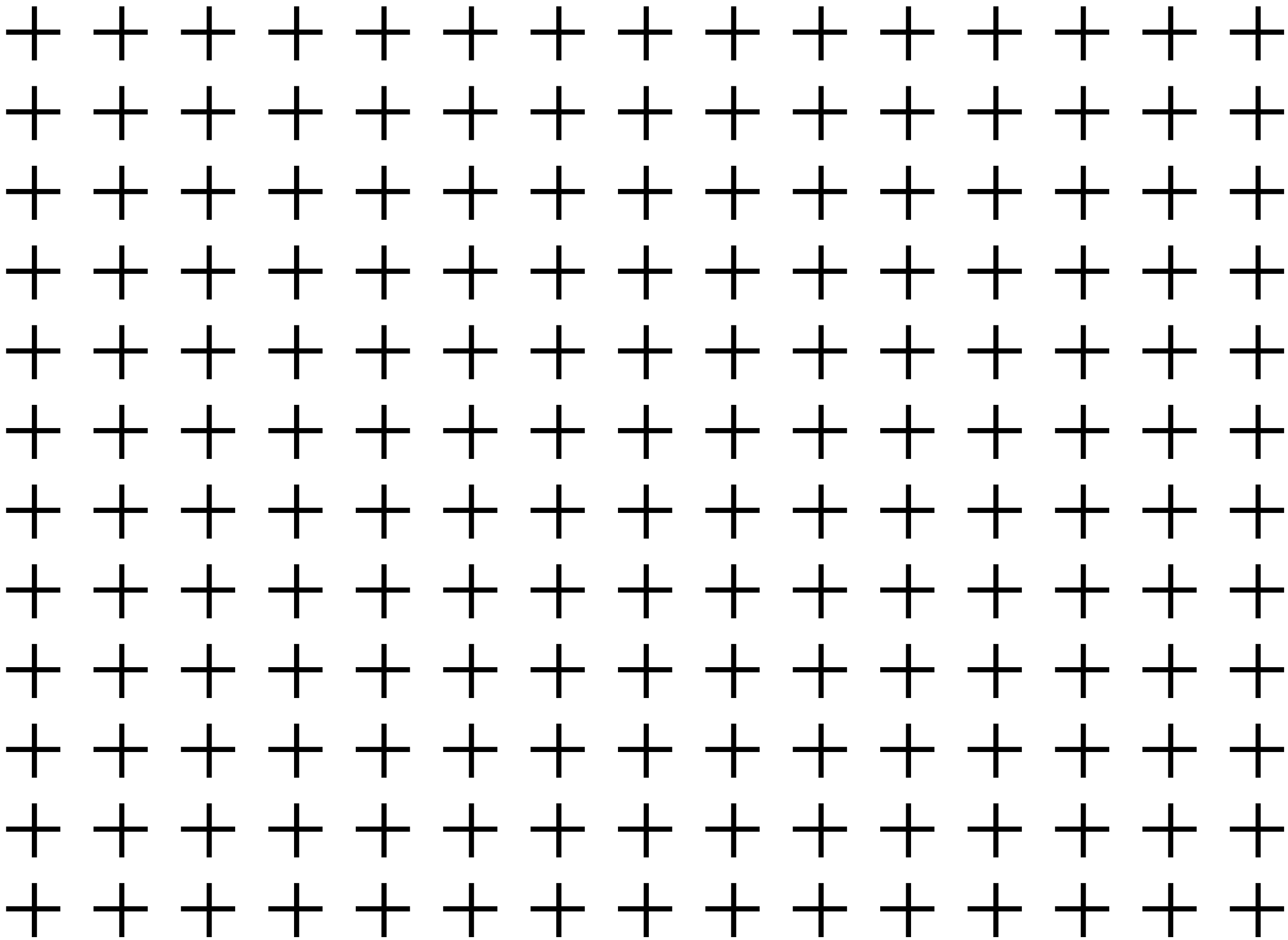

$n$ antennas

$l$ = OAM mode

Mohammadi et al. (2010)

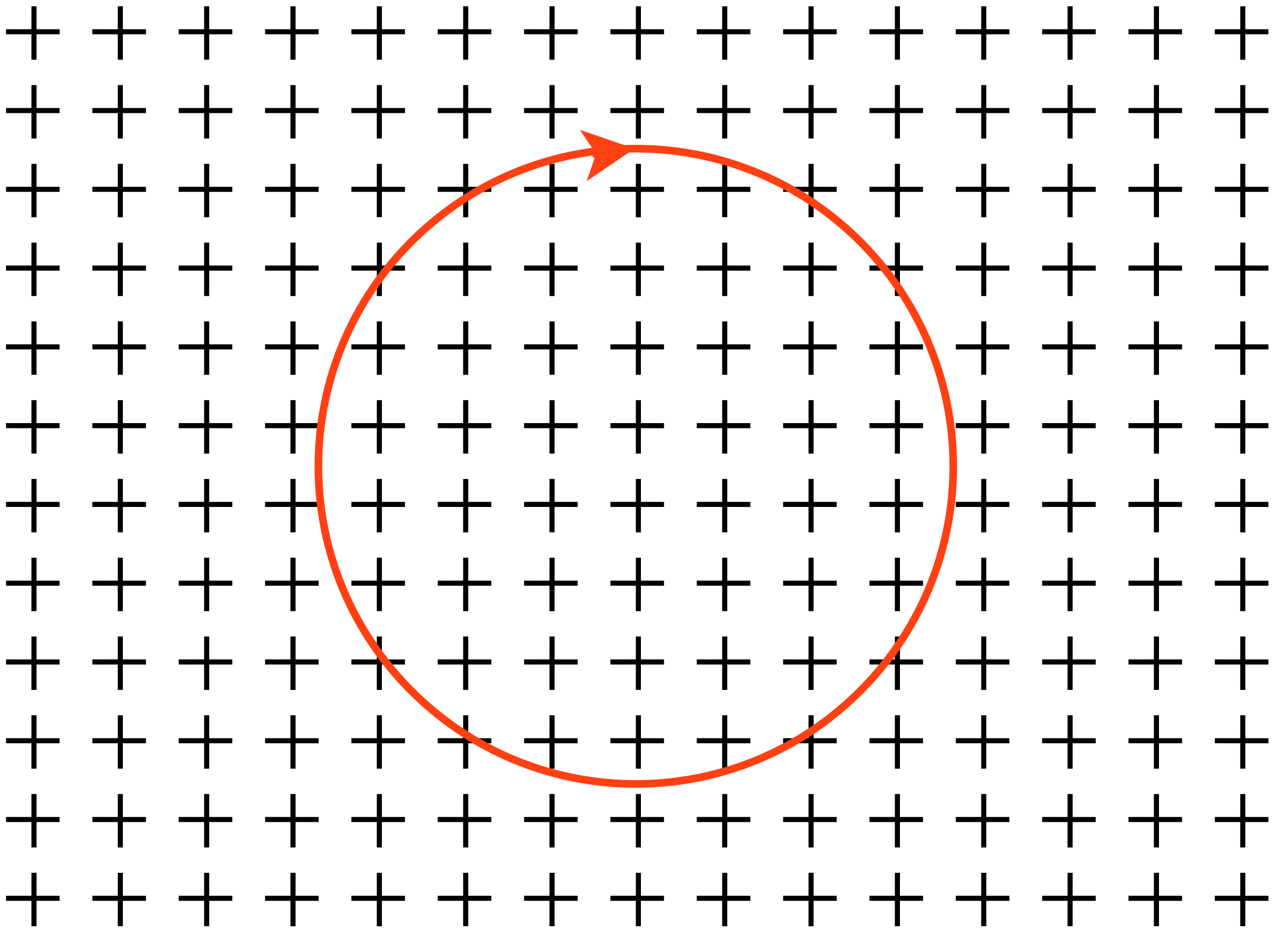
# High Frequency Active Auroral Research Program (HAARP)

# HAARP HF (2-8 MHz) antenna array



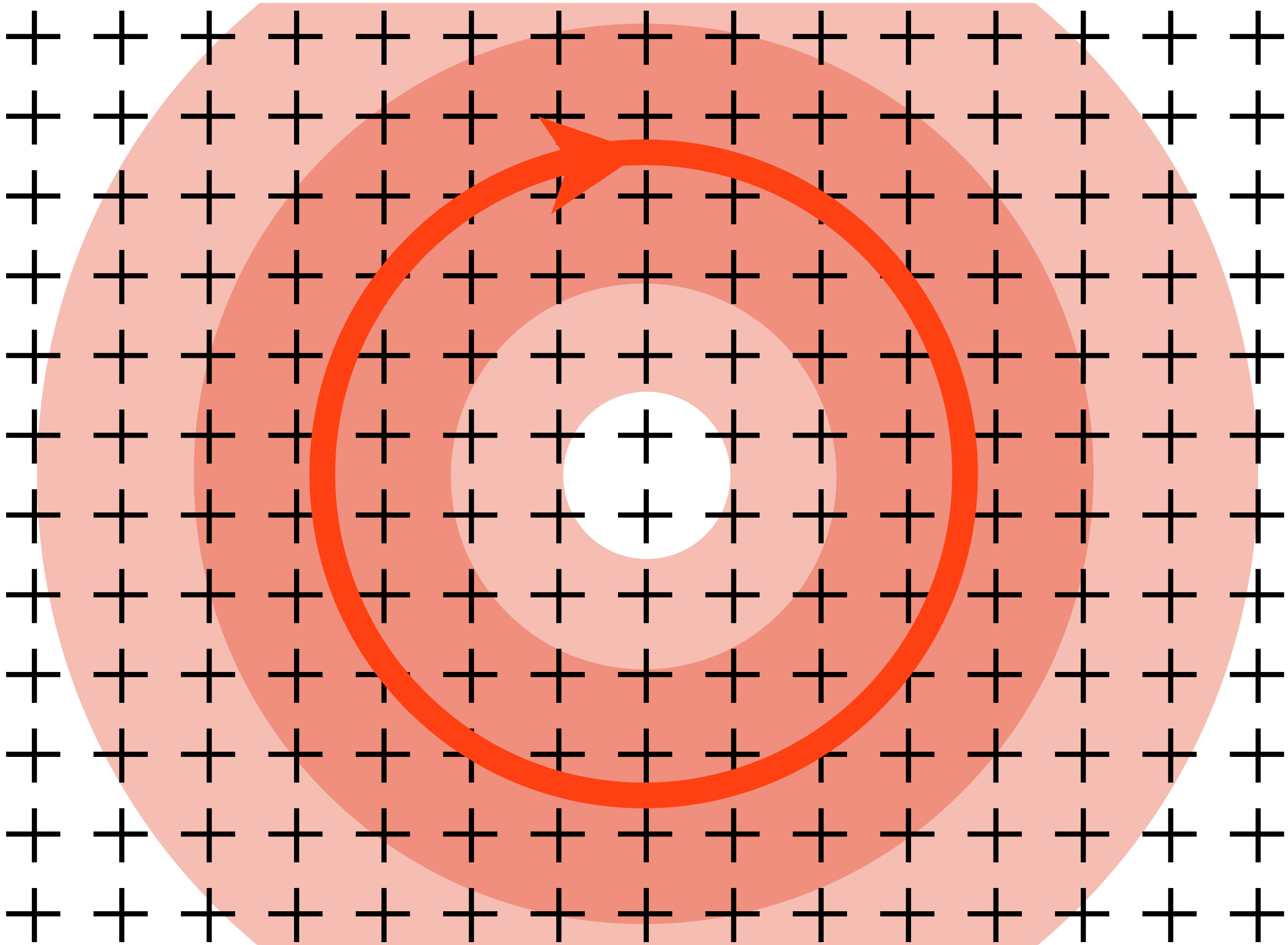
# HAARP HF (2-8 MHz) antenna array

Generation of radio OAM

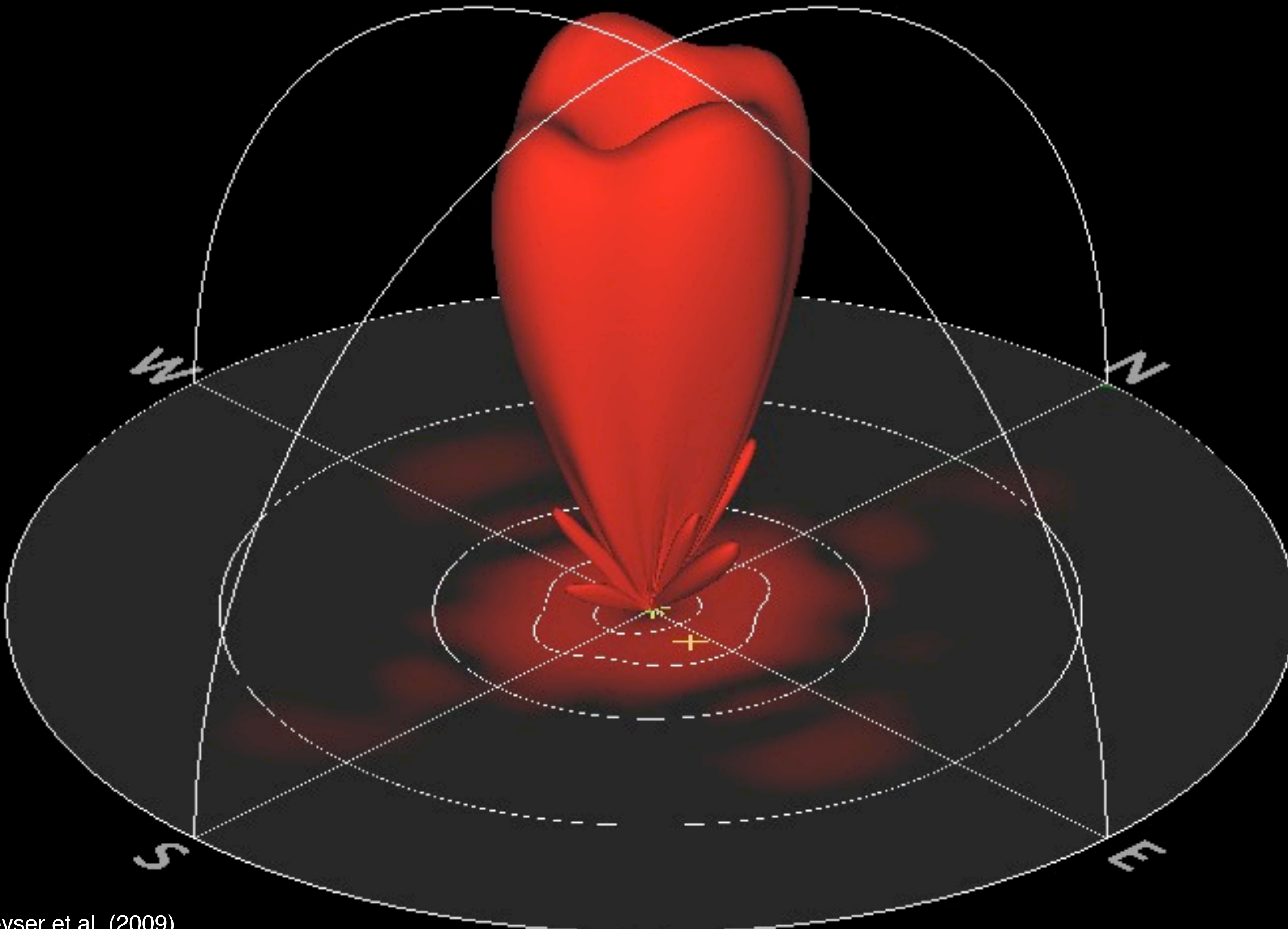


# HAARP HF (2-8 MHz) antenna array

Generation of radio OAM:  Tapered beam

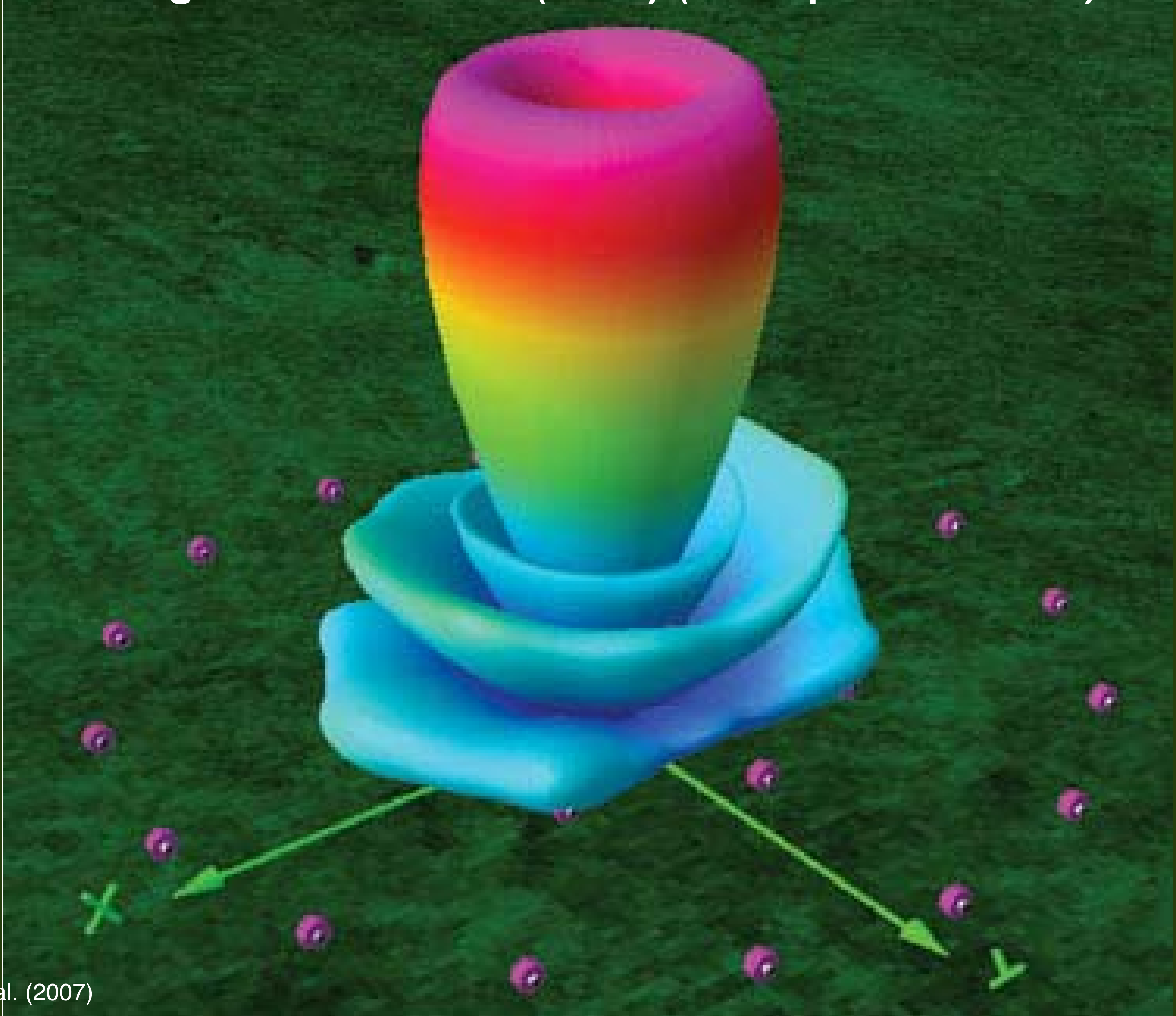


# Orbital angular momentum (OAM) (radio phase modes) at HAARP




Leyser et al. (2009)

# Orbital angular momentum (OAM) (radio phase modes): $l = 1$



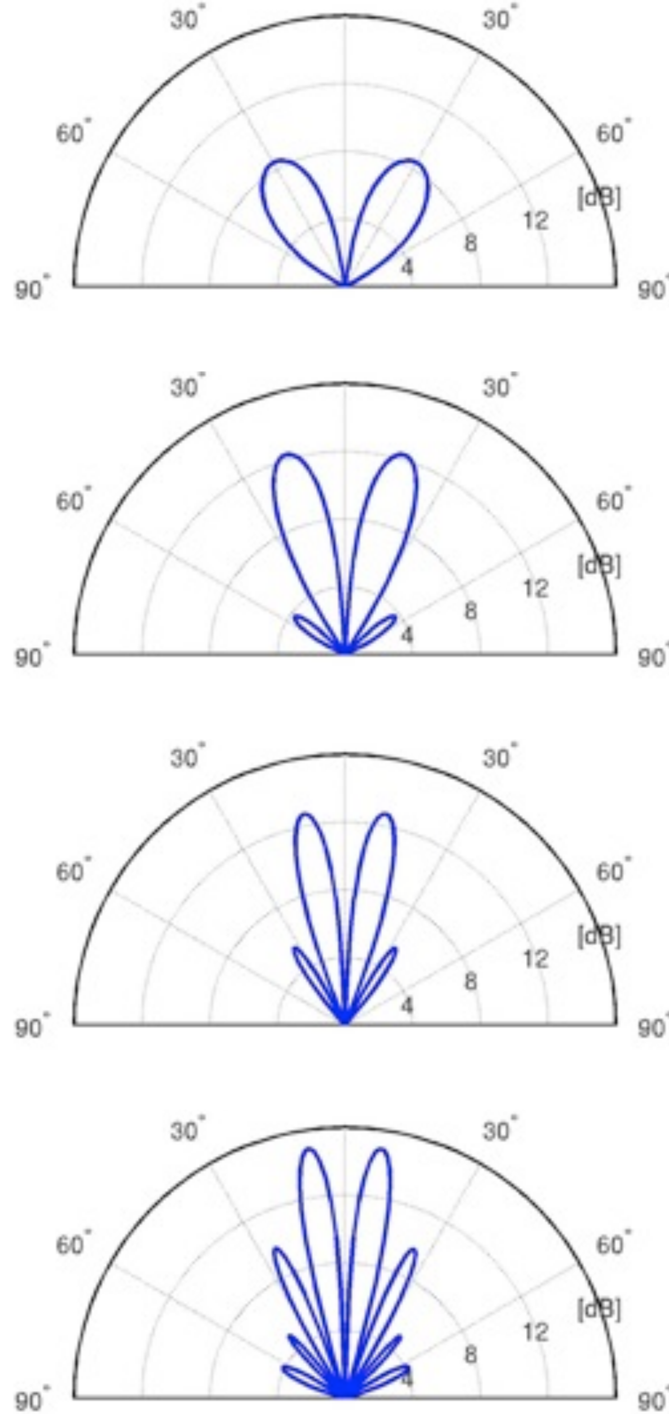

Thidé et al. (2007)

**Transmission of radio phase modes**

OAM number $l = 1$

$D$ = array diameter

$\lambda$ = wavelength




$\lambda = D$

$\lambda = D/2$

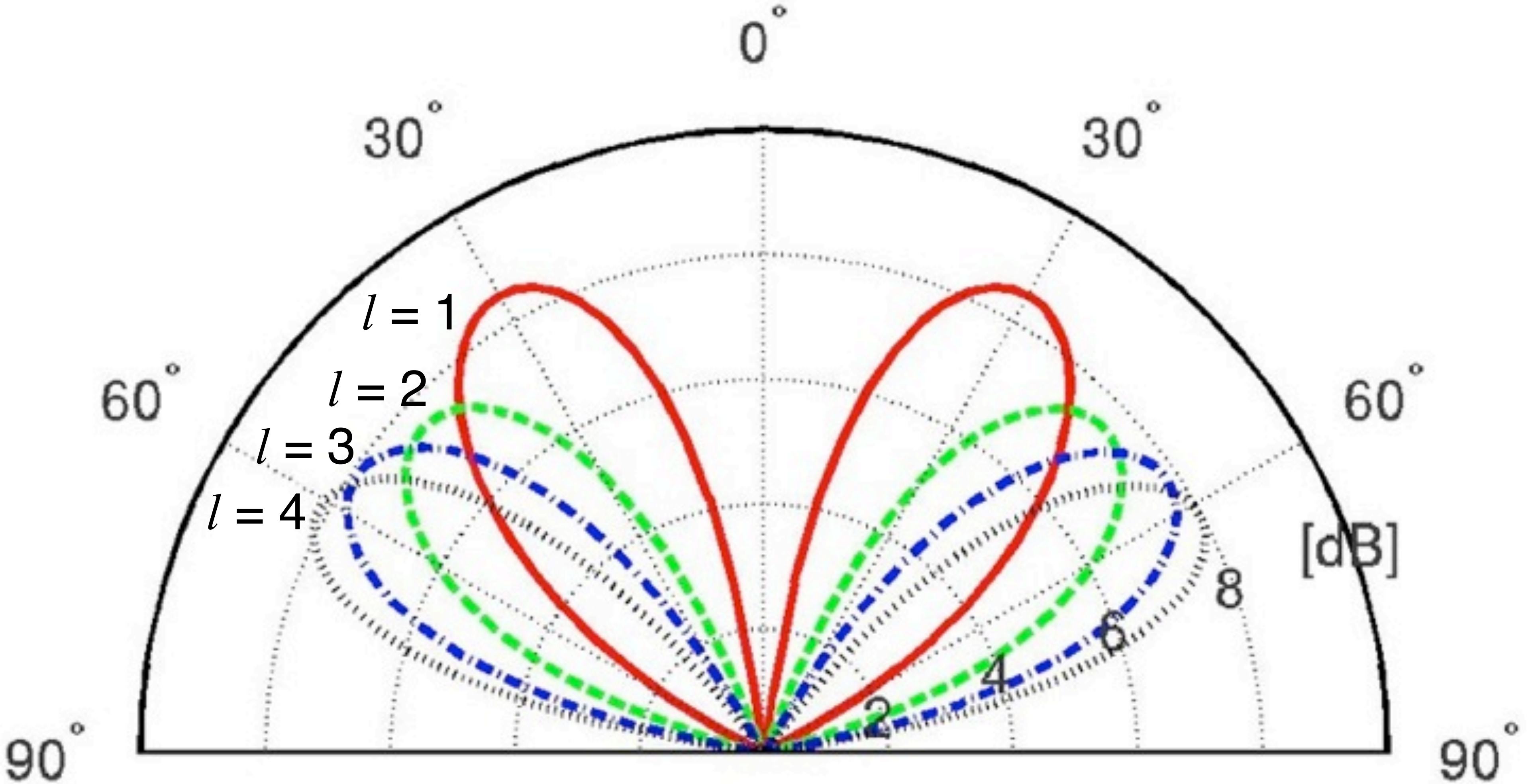
$\lambda = D/3$

$\lambda = D/4$

Mohammadi et al. (2010)

# Transmission of radio phase modes

(wavelength = array diameter)




Mohammadi et al. (2010)

## HAARP HF array: Summary

Objectives:

- generate plasma turbulence using a high-power HF OAM beam
- identify differences between OAM and non-OAM turbulence

Methods:

- transmit OAM 1
- receive stimulated radio backscatter (SEE)
- compare to standard radio emissions (using OAM 0)

Results:

- OAM 1 generated
- radio emissions measured (one receiver, one polarization)
- data are inconclusive

Future possibilities:

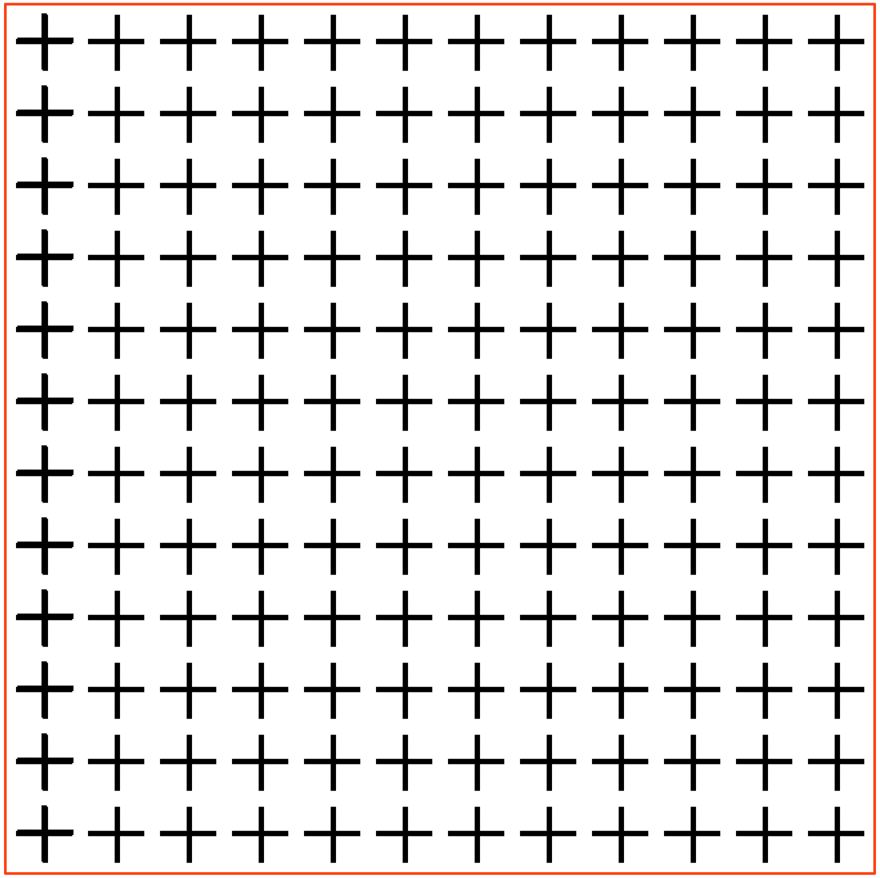
- add additional diagnostics (radar, optics)
- receive using OAM-sensitive (full-polarization) radio techniques
- verify transmitted OAM

# Jicamarca Radio Observatory (JRO) 50-MHz antenna array

# Jicamarca radio antenna – one subarray

12 x 12 (144)
crossed dipoles
per subarray

8 x 8 (64)
subarrays



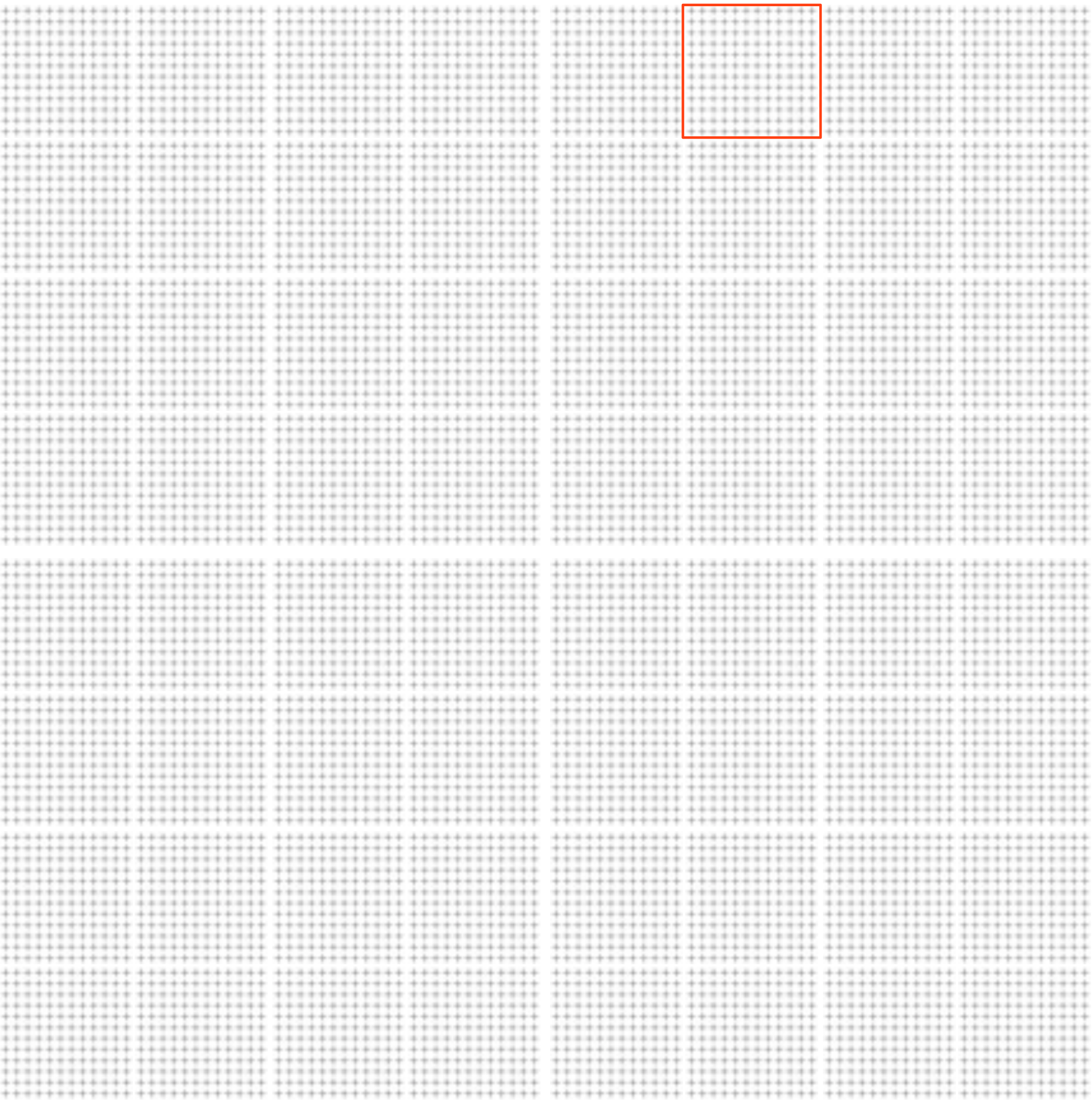
# Jicamarca radio antenna – 64 subarrays

12 x 12 (144) crossed dipoles per subarray

8 x 8 (64) subarrays

9216 crossed dipoles

18432 dipoles



# Jicamarca radio antenna

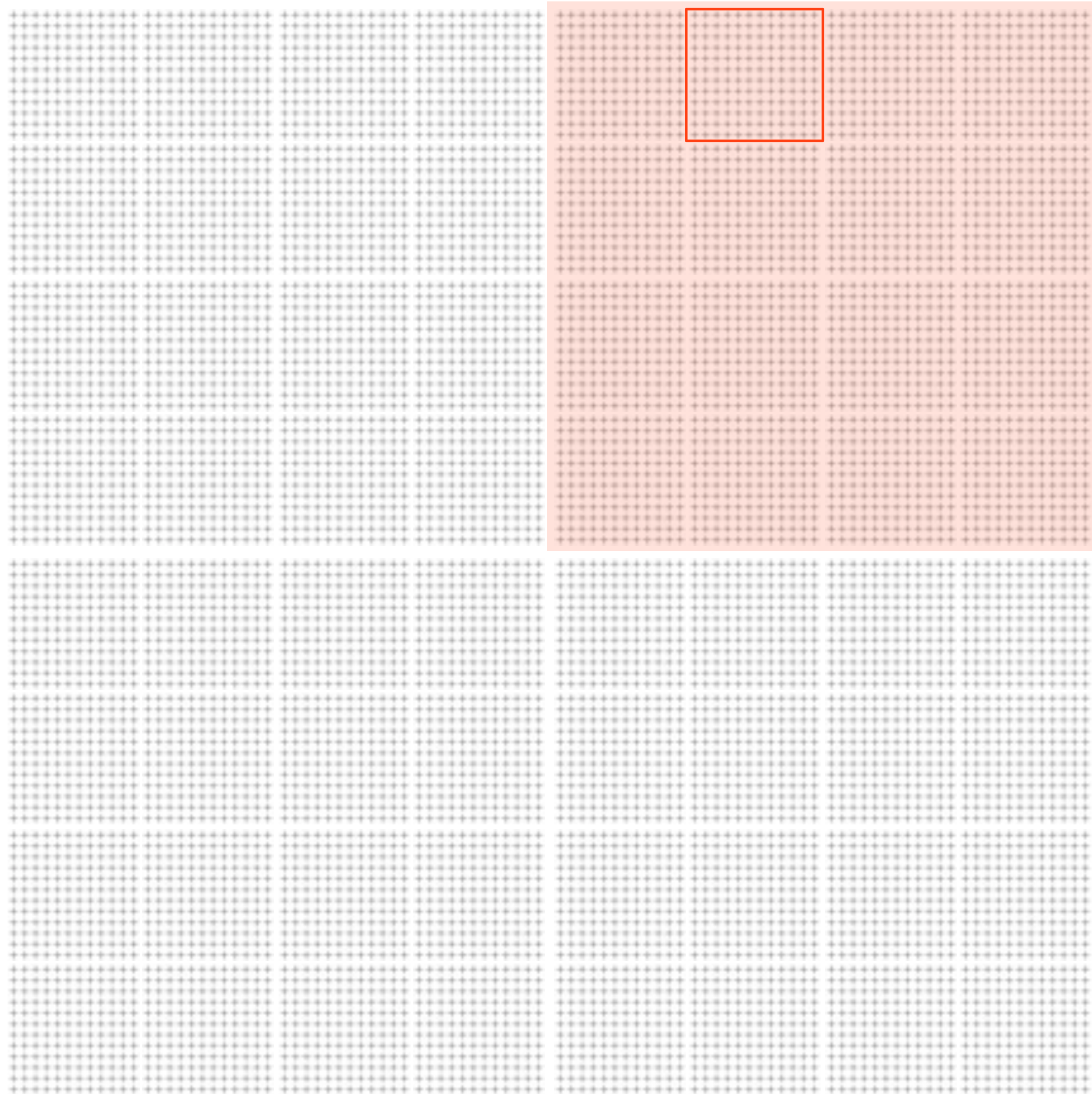
12 x 12 (144) crossed dipoles per subarray

8 x 8 (64) subarrays

9216 crossed dipoles

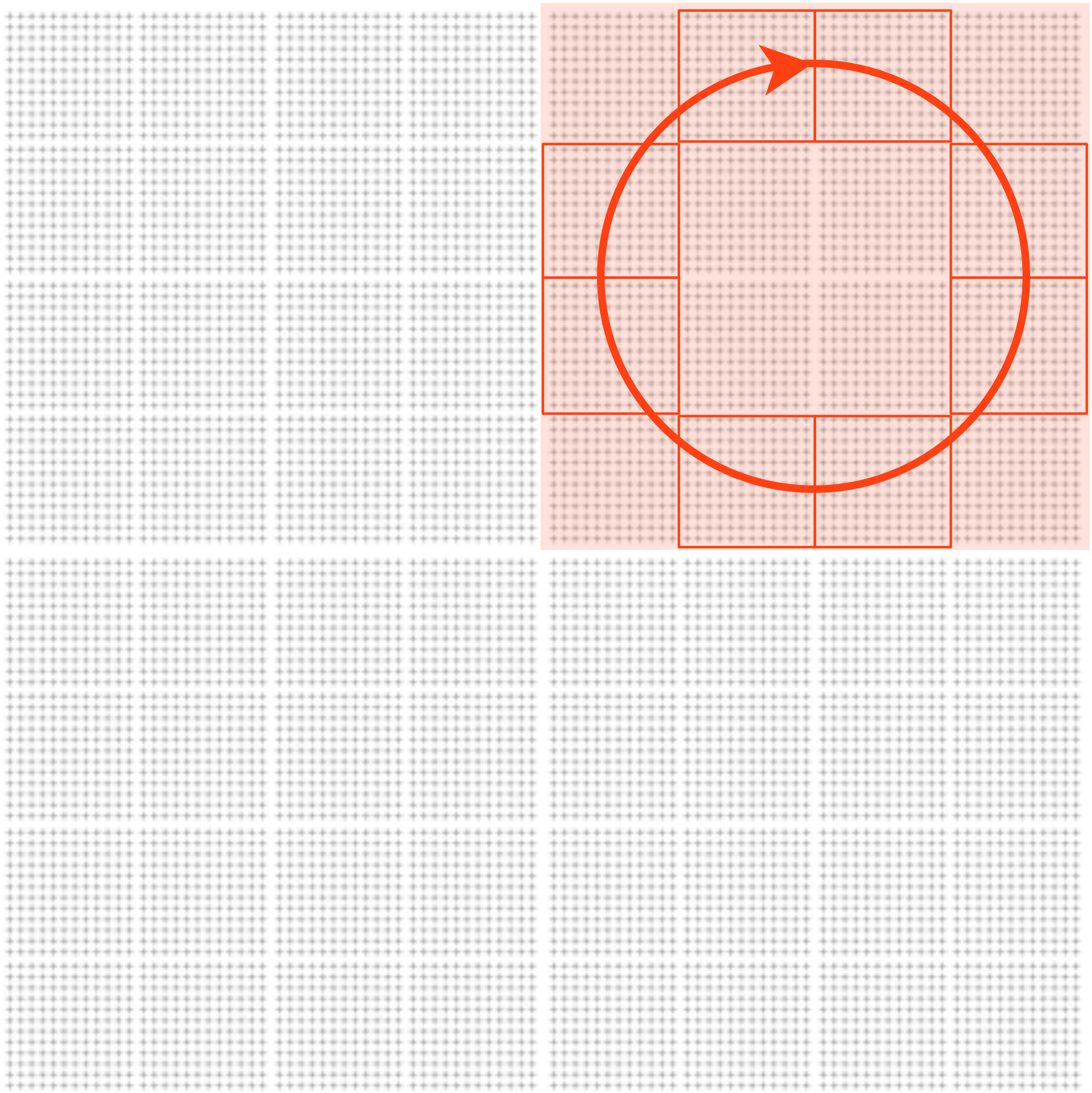
18432 dipoles

four quarters each with 4 x 4 (16) subarrays



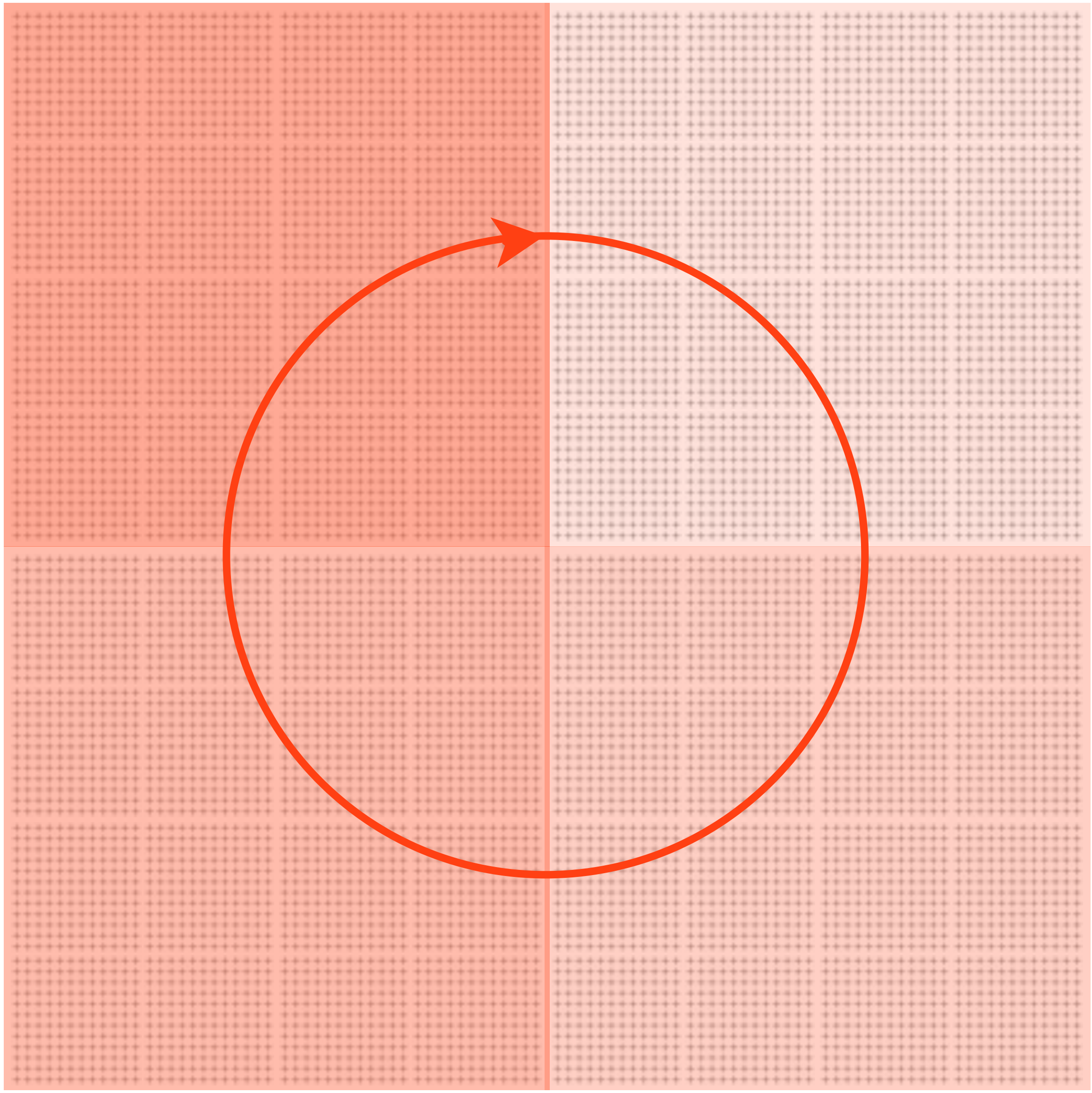
# Jicamarca radio antenna

## OAM 1 generated using subarrays



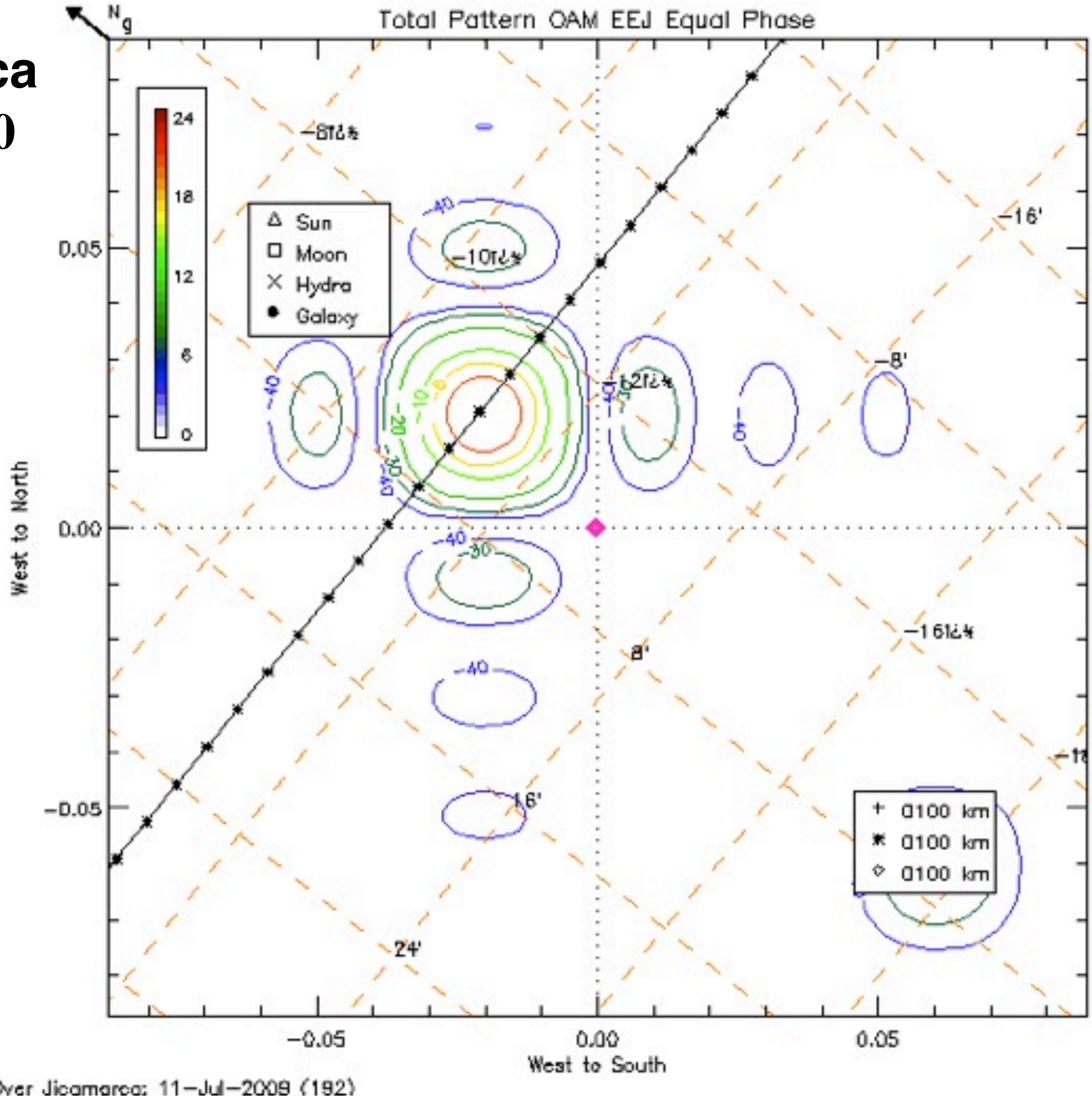
# Jicamarca radio antenna

## OAM 1 generated using quarters



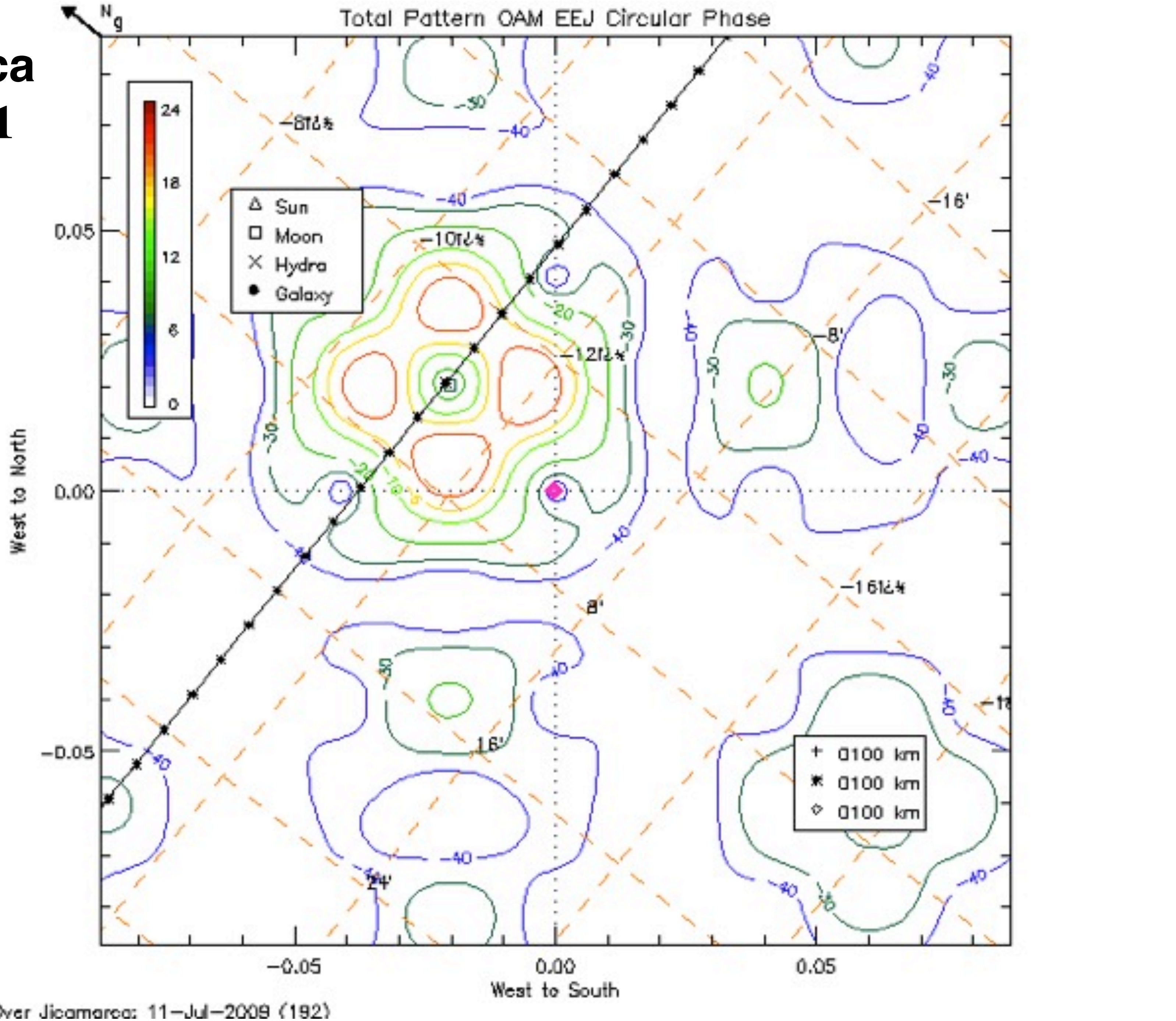
**Jicamarca OAM $l = 0$ beam pattern**

using quarters

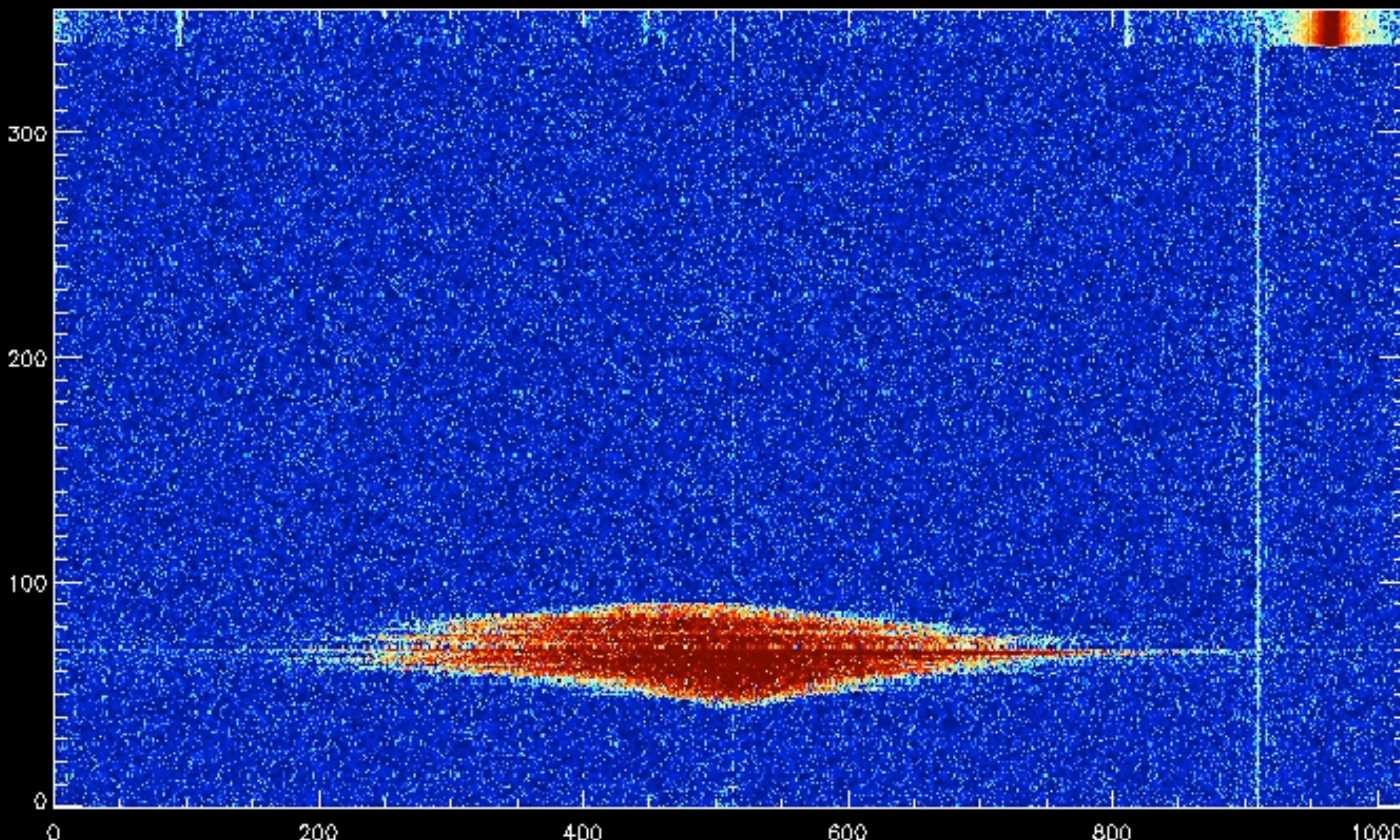


# Jicamarca OAM $l = 1$ beam pattern

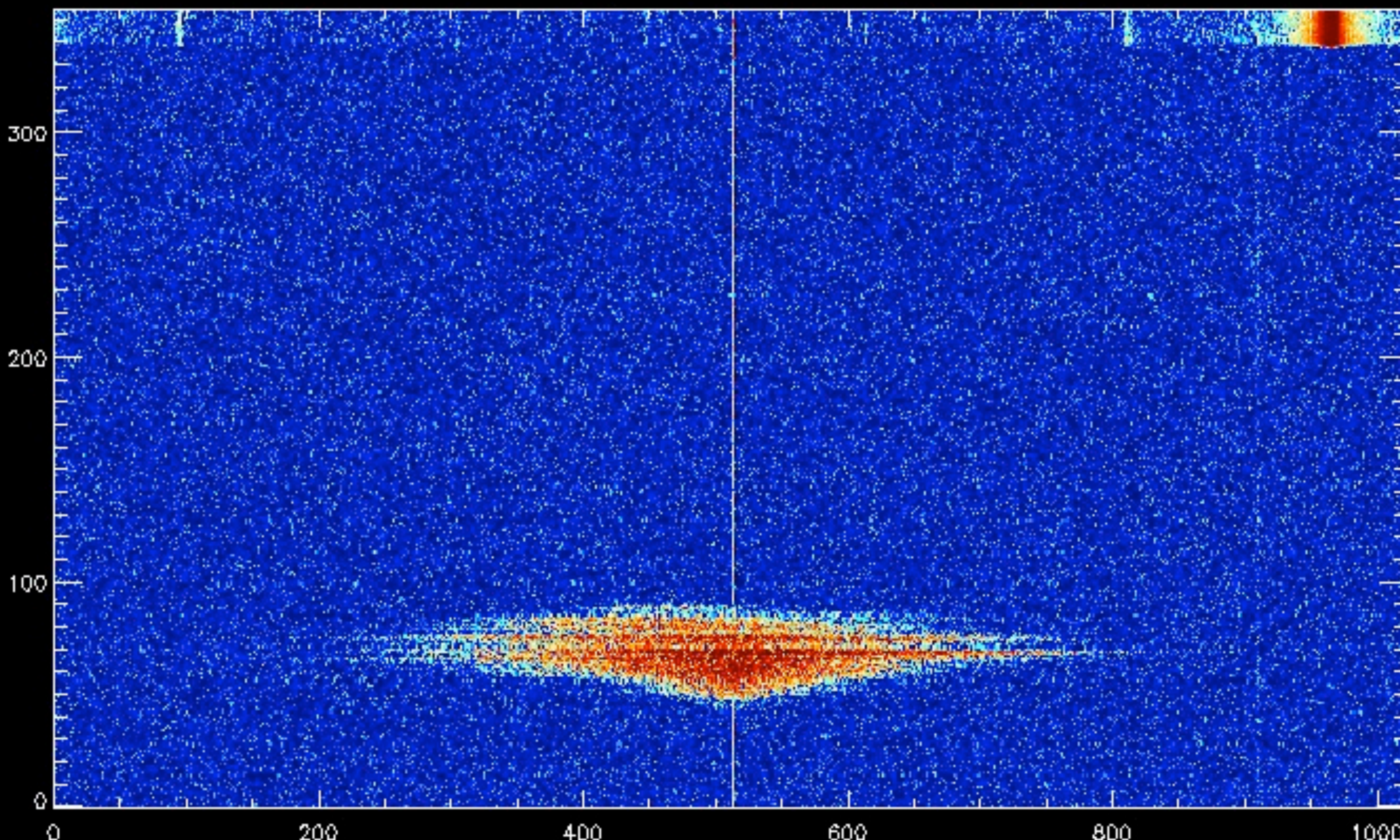
using quarters



# Equatorial electrojet observed using OAM $l = 0$ transmission



# Equatorial electrojet observed using OAM $l = 1$ transmission



## Jicamarca 50-MHz radar: Summary

Objectives:

- use OAM as an active radio remote sensing technique
- search for differences between OAM and non-OAM backscatter

Methods:

- transmit OAM 0 and 1 using four antenna quarters
- receive using standard methods
- compare radar backscatter

Results:

- OAM 1 generated
- backscatter received
- data being analyzed

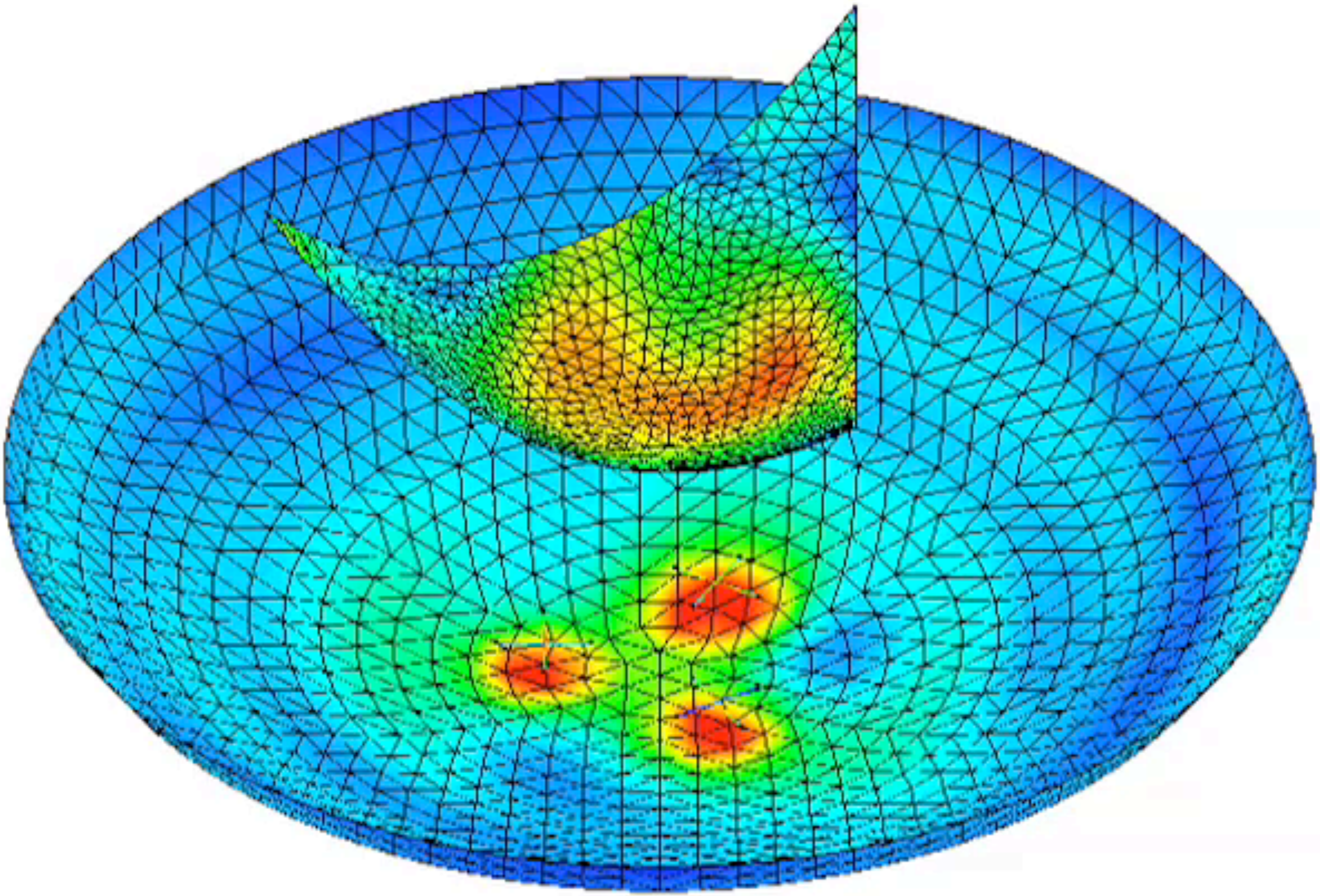
Future possibilities:

- generate OAM using eight antenna subarrays
- receive using OAM-sensitive (full-polarization) radio techniques
- verify transmitted OAM


Arecibo
Observatory
305-meter antenna

# Orbital angular momentum (OAM) (radio phase modes) at Arecibo

HF (5 and 8 MHz) transmission using three crossed dipoles



Breakall and Sulzer

# Orbital angular momentum (OAM) (radio phase modes) at Arecibo

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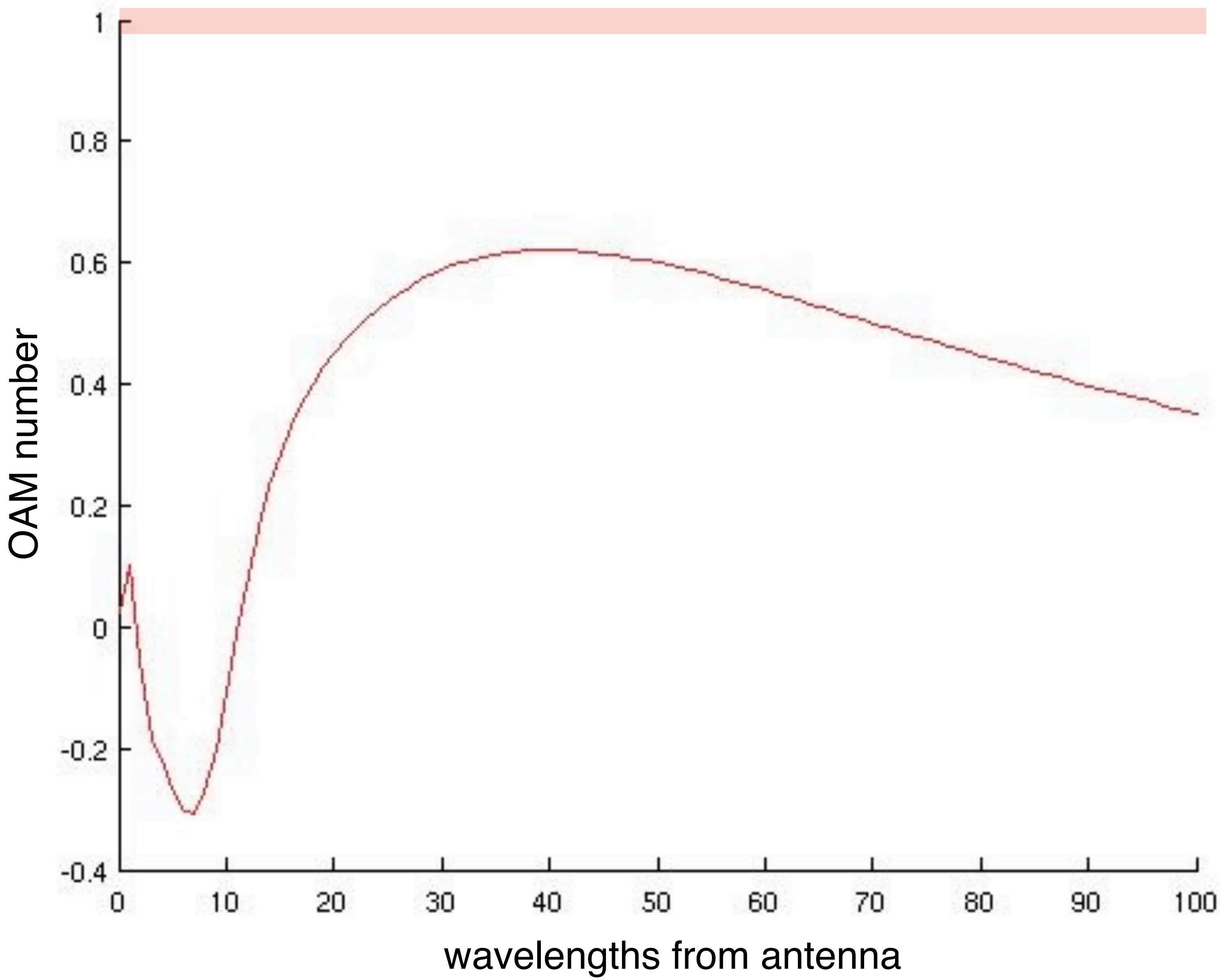
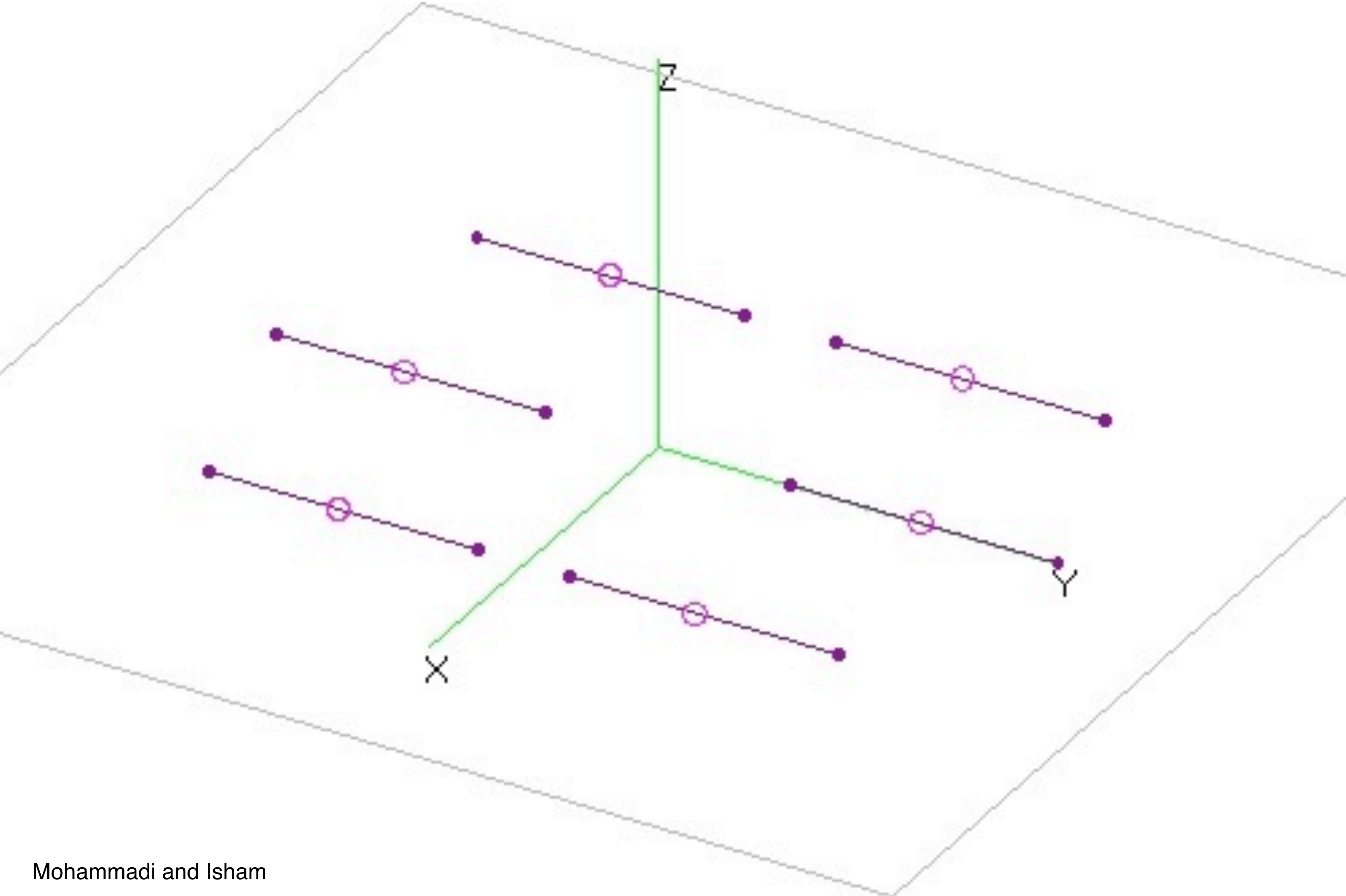



Mohammadi and Isham

# Orbital angular momentum (OAM) (radio phase modes) at Arecibo

HF (5 and 8 MHz) transmission using six linear dipoles




Mohammadi and Isham

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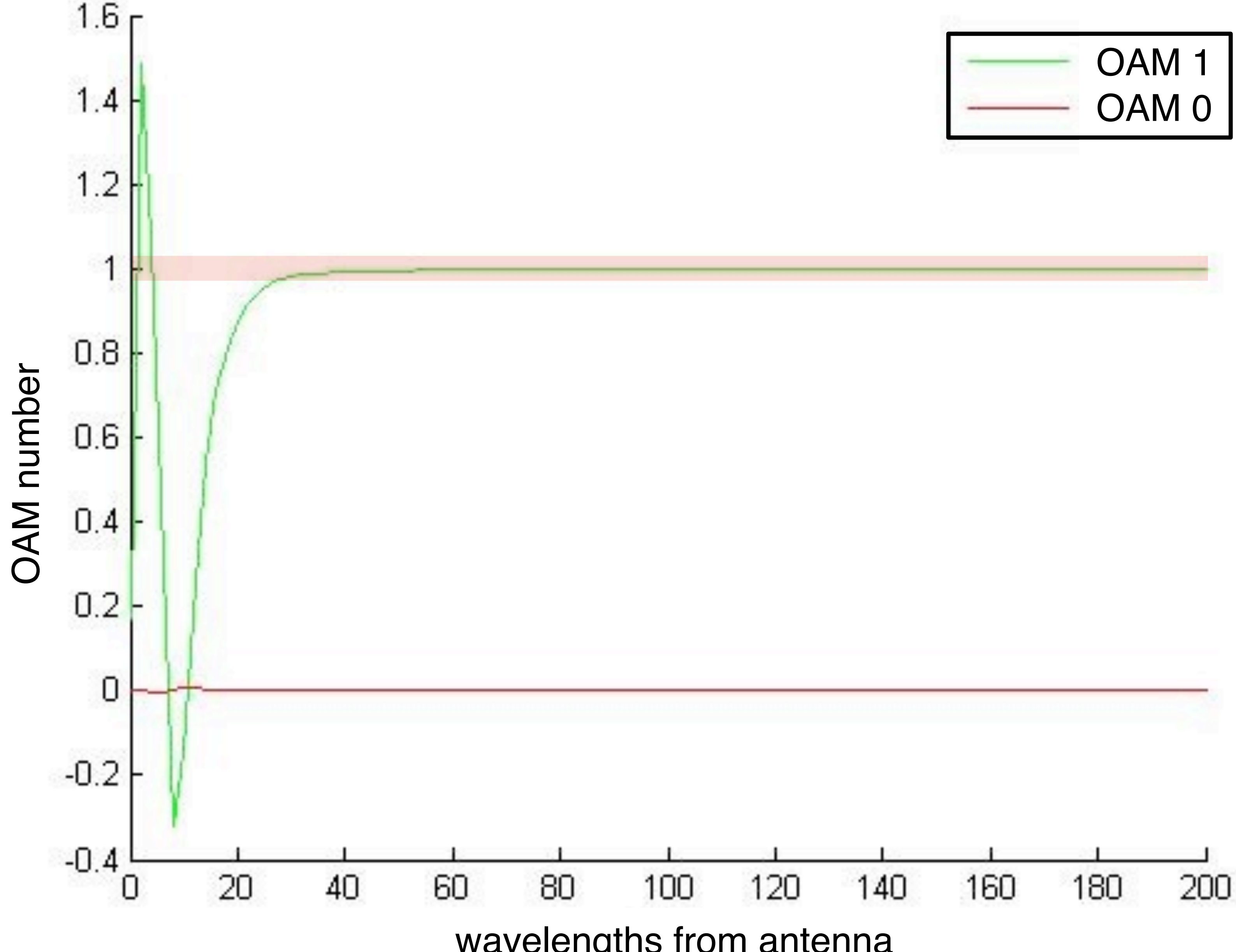



Mohammadi and Isham

# New Arecibo HF:  Summary

Objectives:

– determine if Arecibo can transmit a high-power HF OAM beam

Methods:

– calculate OAM for planned and possible dipole configurations

Results:

– pure OAM 1 cannot be generated with three crossed dipoles

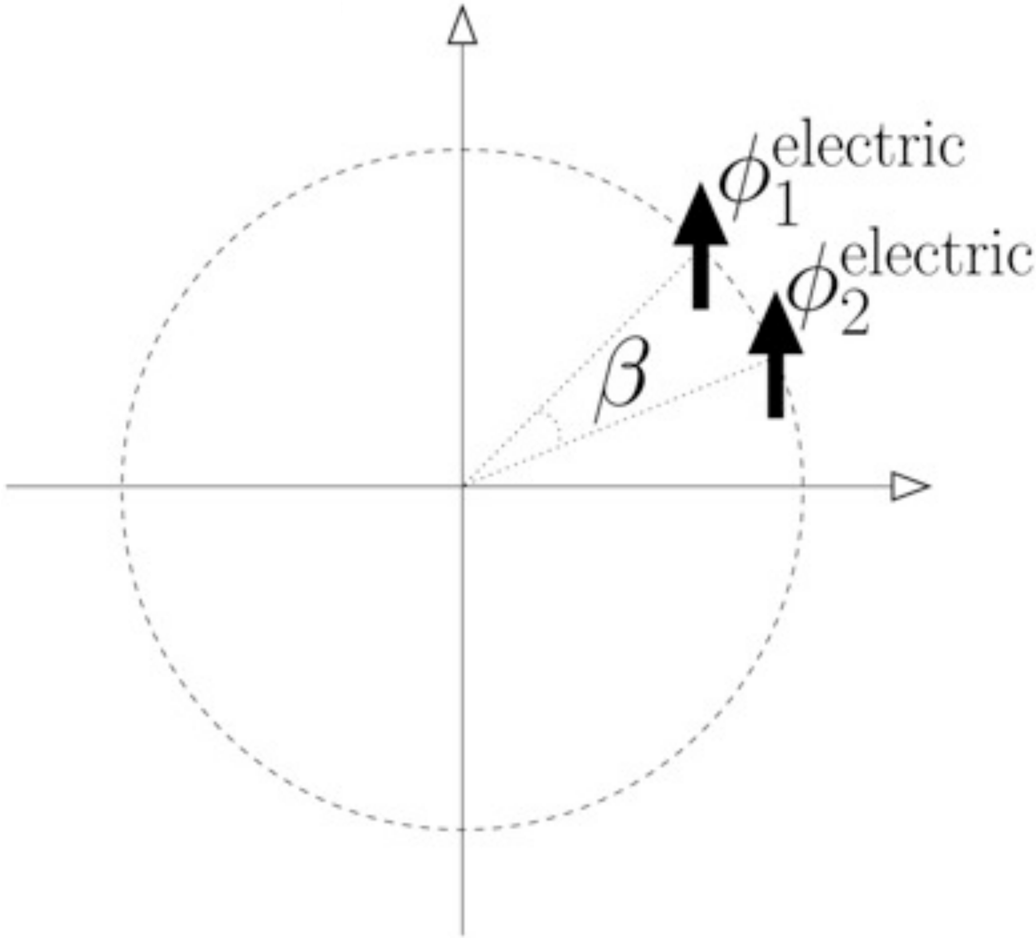
– pure OAM 1 can be generated with six linear dipoles

Future possibilities:

– account for Cassegrain and primary reflectors

# Reception of radio phase modes

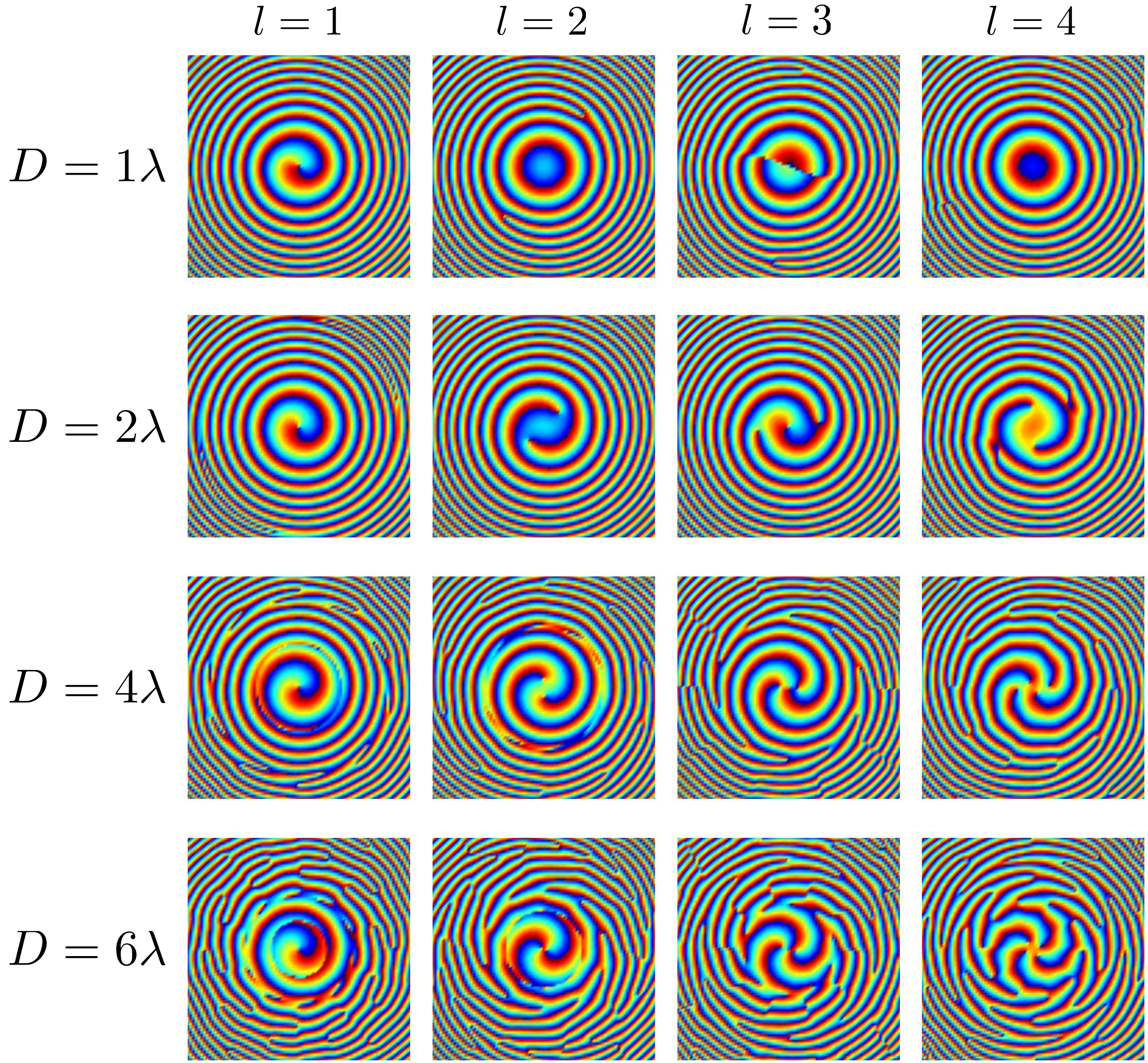
Phase gradient method




Mohammadi et al. (2010)

**Phase of $E_y$ at $R = 25\lambda$**

40-deg field of view

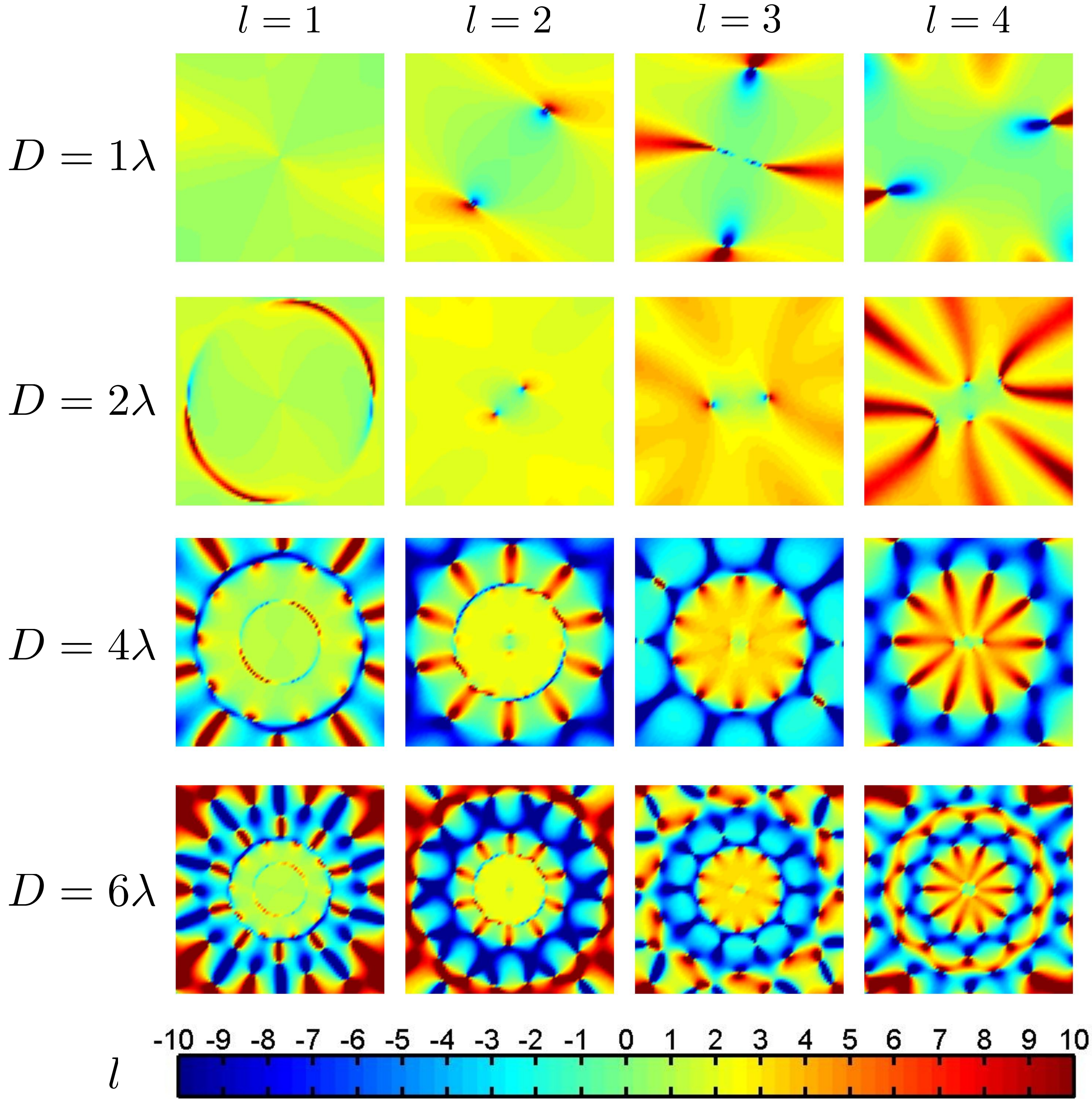



Mohammadi et al. (2010) figure 11

**Radio phase mode (OAM mode) number at**

$R = 25\lambda$

40-deg field of view




Mohammadi et al. (2010) figure 10

# Reception of radio phase modes

Longitudinal electric field method

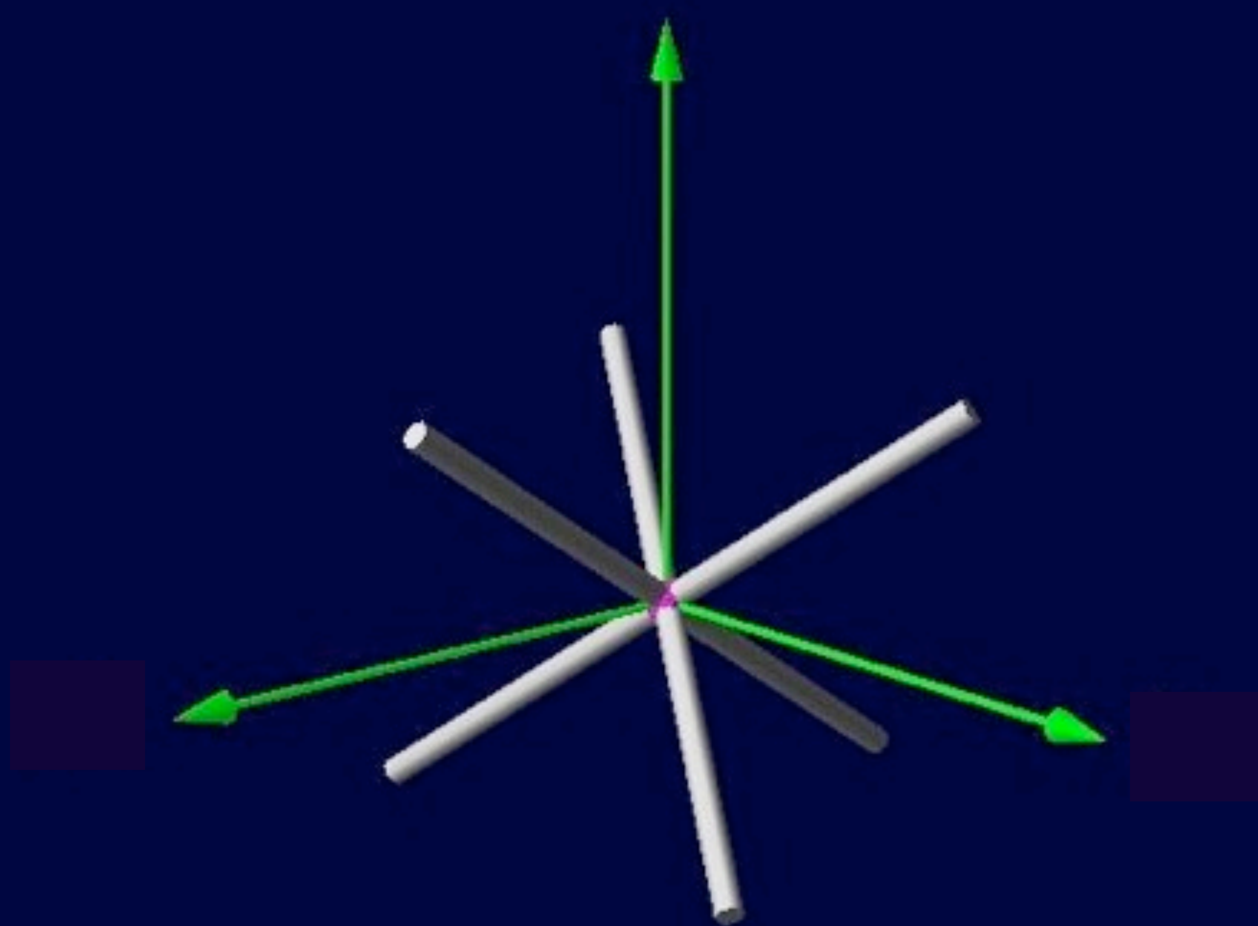
– Radio phase modes are not TEM modes

– *E* component along wave vector (**E** || **k**) exists in the far field

– Measurement using this method requires polarization purity

– Not possible with current crossed-dipole radio arrays

# Three-axis antennas



## A new digital radio receiving system

Multi-purpose
- spectra, polarization, direction angle
- imaging, orbital angular momentum
- pump wave “truth”, anomalous absorption, ionosonde radar receiver
- VHF/UHF satellite beacon scintillation receiver
- anomalous absorption and ionosonde radar receiver

Wide band
- clamped (radiowave pump)
- unclamped (natural)

Multi-channel (three-axis antennas)
- full polarization, polarization purity

Multiple and modular receivers
- swapable
- multiple sites
- coherent

Low maintenance
- easily configurable
- unattended operation
- remotely controllable

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# Three-axis antennas

Thidé, Bergman, Isham, et al.

# Three-axis antennas

Thidé, Bergman, Isham, et al.

## Three types of potential sources of photon OAM

Intrinsic

- "point" sources (pulsars, Kerr black holes)
- SETI

Structure

- maser diffracting on discontinuities in ISM
- cosmic microwave background

Pointing

- stellar coronagraph (detection of faint close companions)

In part from: Harwit (2003), Tamburini et al. (2006), Elias (2008)

## Other potential applications of radio OAM

Antenna pattern
- solar coronagraph
- nulling of strong unwanted source

Communications
- multiple channels at one frequency

Remote sensing (detection of OAM)
- radio and radar (reception)
- radar (transmission and reception)

Experiments (creation of OAM)
- radiowave pumping of high frequency turbulence

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## Space plasma turbulence

Intrinsic OAM?

Structure OAM?

## Radio phase modes: Conclusions

Photon orbital angular momentum (OAM)
- intrinsic property of photons
- complement to photon spin angular momentum (polarization)

Transmission from existing antenna arrays
- remote sensing
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Detection
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- full polarization (crossed dipole arrays may be insufficient)

Three types of OAM sources
- intrinsic
- structure
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## Radio phase modes:  Conclusions (continued)

Potential space and astrophysical sources

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– “point” sources (pulsars, Kerr black holes)
– maser diffracting on discontinuities in ISM
– cosmic microwave background
– SETI
– space plasma turbulence

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