# HERA Data Analysis Part II:
## Calibration and Imaging


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# Lesson Overview:

1. Calibration (~1.5 hour)
   a. Calibration overview
   b. HERA calibration exploration

**Break (10 min)**

2. HERA Imaging (~1 hour)
   a. HERA imaging overview
   b. HERA imaging demo

# Learning Objectives

A. Gain a basic understanding of what calibration is, and explore applying calibration to real data

B. Become familiar with HERA's imaging capabilities

C. Learn how to perform basic imaging of HERA data

# *1. HERA Calibration*

# All Instruments Need to be Calibrated

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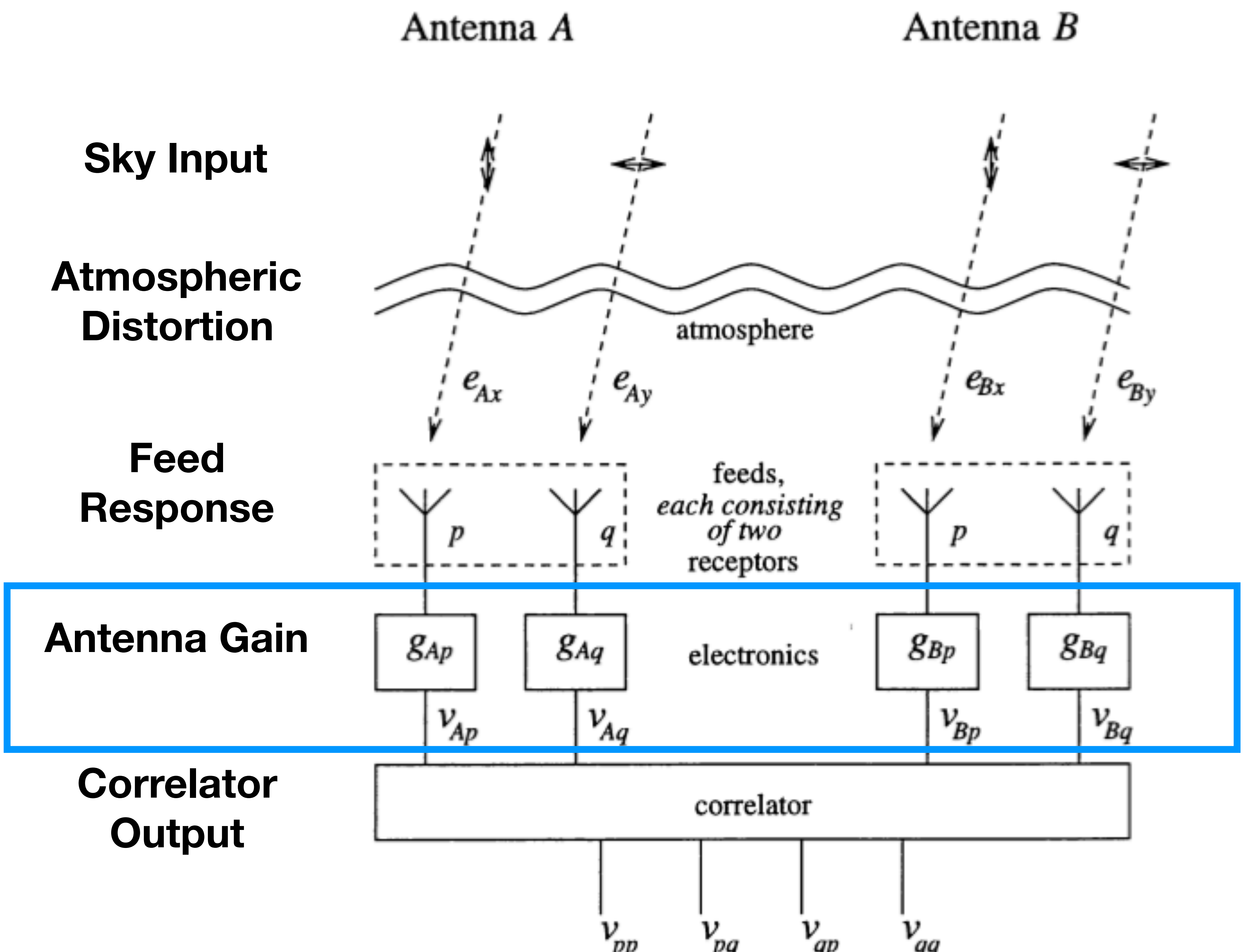



Hamaker et al. 1996

# Measurement Equation

**Ideal Scenario**

$$V_{ij}^{\mathrm{model}} = I \cdot e^{-2\pi i \vec{b} \cdot \hat{s} / \lambda}$$

**Practical Scenario**

$$V_{ij}^{\mathrm{measured}} = g_i g_j^* \cdot I \cdot e^{-2\pi i \vec{b} \cdot \hat{s} / \lambda}$$

$$\boxed{V_{ij}^{\mathrm{measured}} = g_i g_j^* V_{ij}^{\mathrm{model}}}$$

***Antenna-Based Calibration Equation***

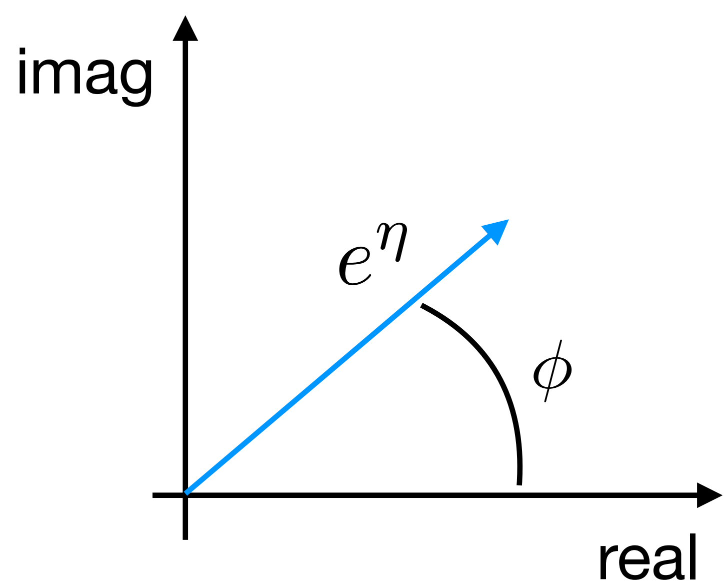
# Breaking down Antenna Gains

Antenna gain is a complex quantity, defined by an amplitude and phase

$$g_j = e^{\eta_j + i\phi_j}$$

$$\eta_j = \text{amplitude}$$

$$\phi_j = \text{phase}$$




Gains are also in principle **time and frequency** dependent:

$$g_j(t,\nu) = e^{\eta_j(t,\nu) + i\phi_j(t,\nu)}$$

# Solving for Gains

Given your measurements and your model, setup a system of equations!

We won’t go into the details of ***how*** to solve this system of equations, but if you are curious ask me after class!

$$V_{ij}^{\text{measured}} = g_i g_j^* V_{ij}^{\text{model}}$$

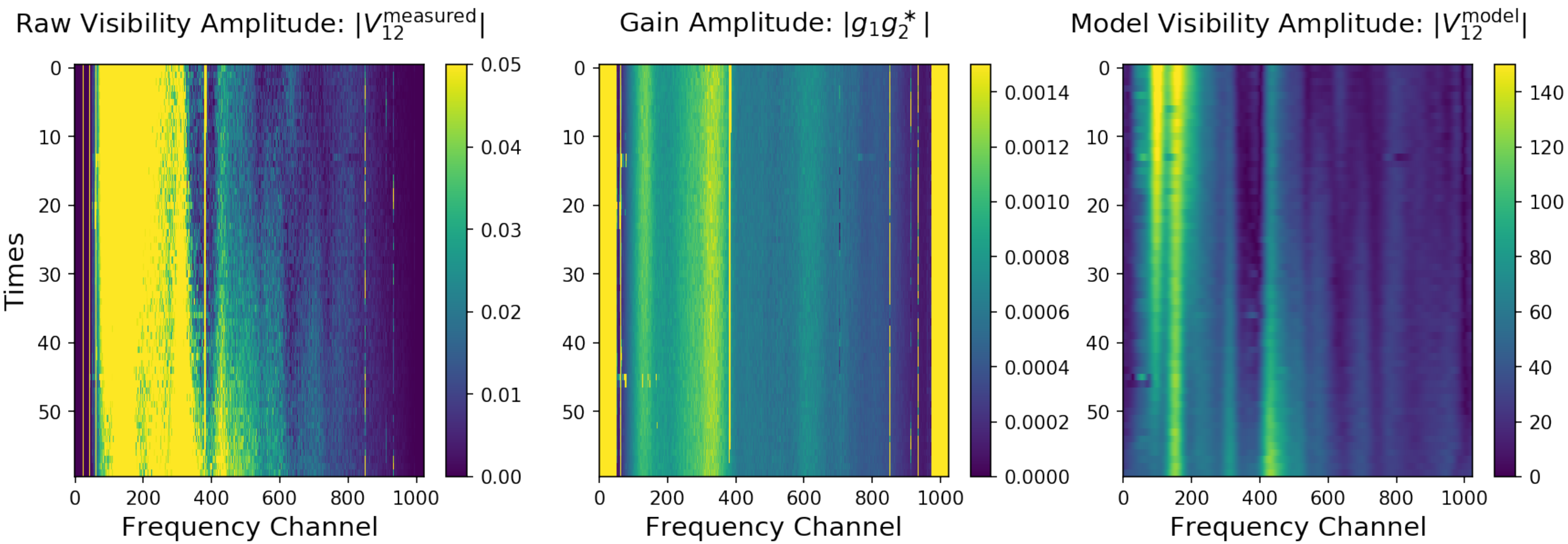
**antenna 1**

**antenna 2**

**antenna 3**

# Applying Calibration

$$V_{ij}^{\text{updated}} = V_{ij}^{\text{measured}} / (g_i g_j^*)$$

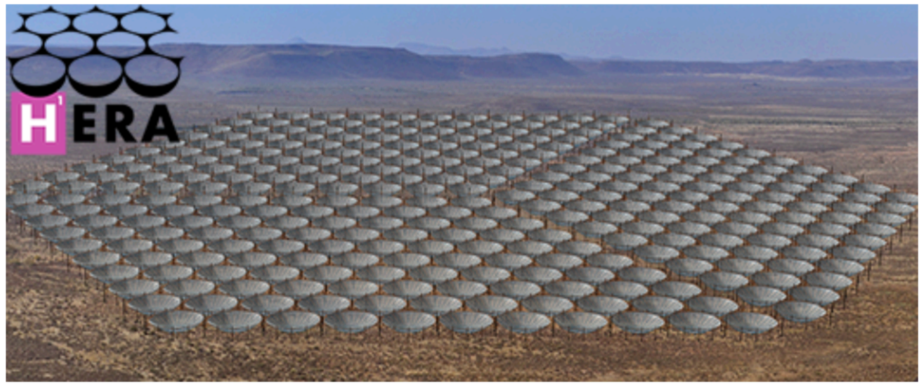


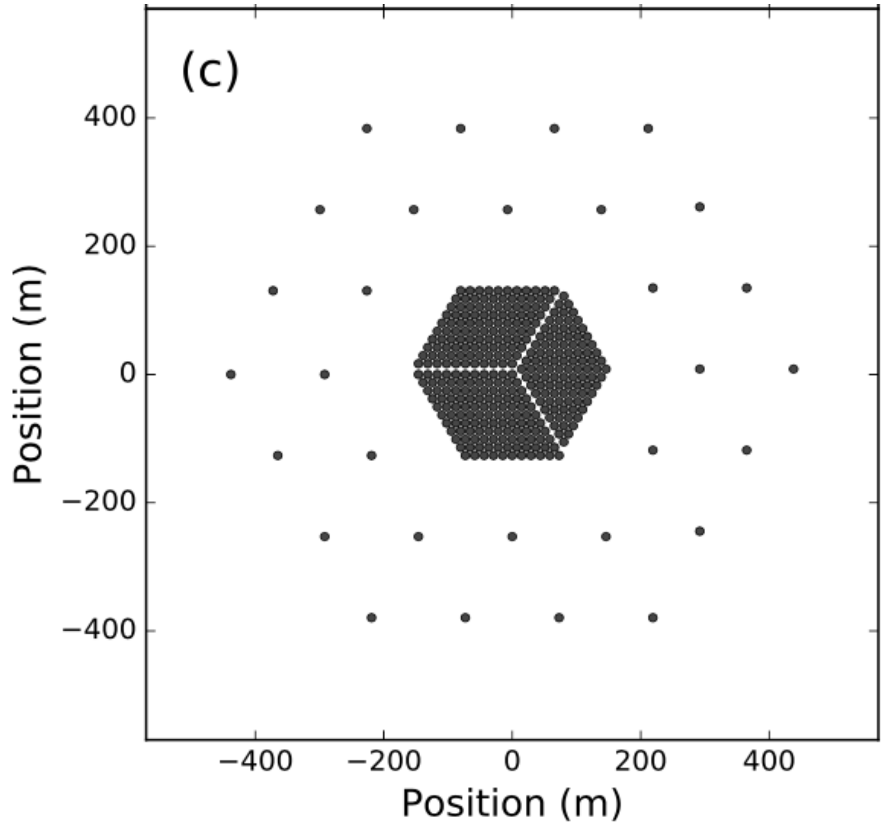
# HERA Calibration Exploration

# 2. HERA Imaging Specs

# HERA Imaging Specs

| Design Spec | Performance |
| --- | --- |
| **Frequency Coverage:**<br><br>100 - 200 MHz<br>[50 - 250 MHz] | **Redshift Coverage:**<br><br>6 < z < 13<br>[5 < z < 27] |
| **Longest Baseline:**<br><br>Core: 292 m<br>Outrigger: 876 m | **Angular Resolution:**<br><br>Core: 25 arcmin<br>Outrigger: 11 arcmin |




$$z = 1.42 \times 10^9/\nu - 1$$

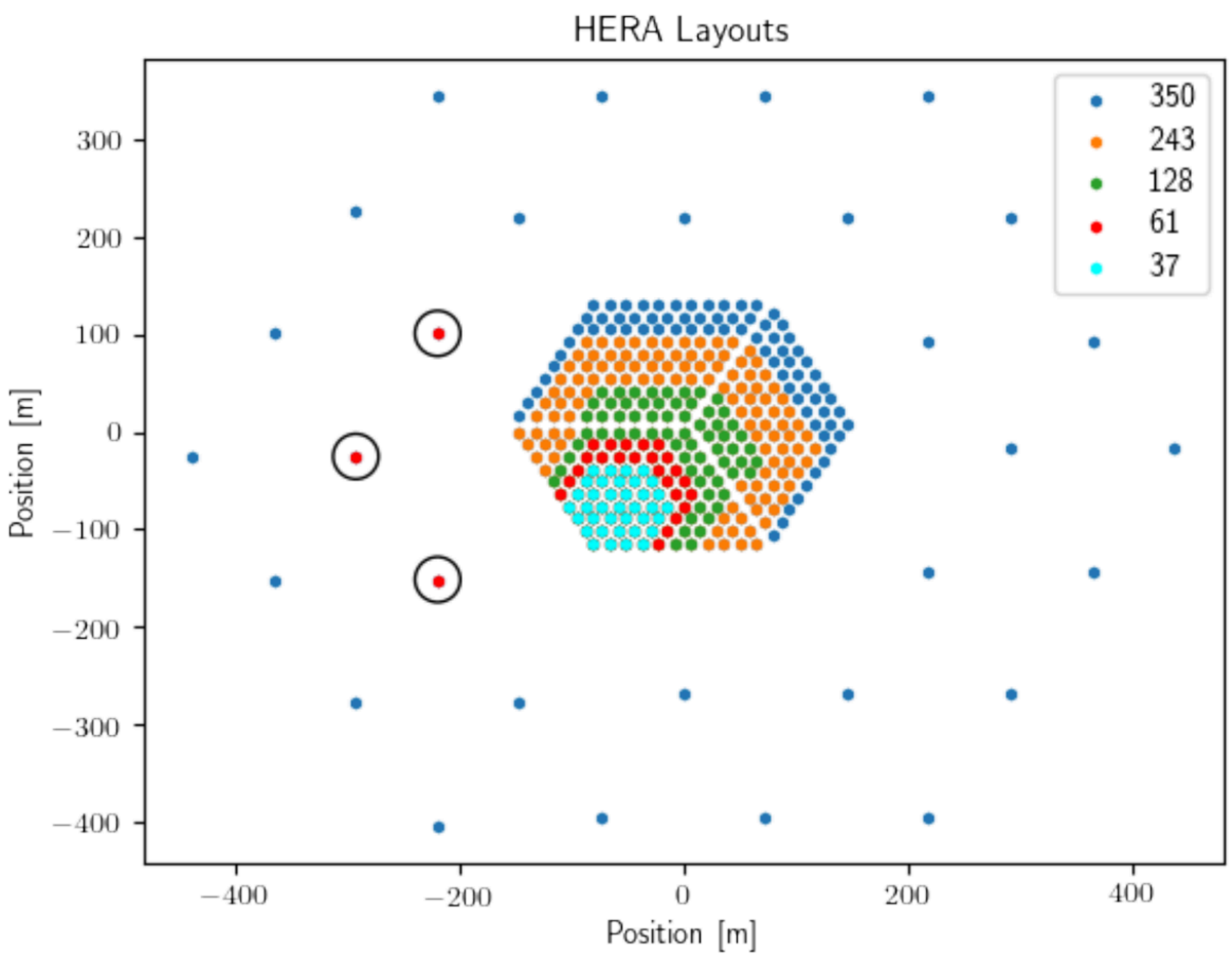
$$\theta = \lambda/D$$

**DeBoer et al. 2016**

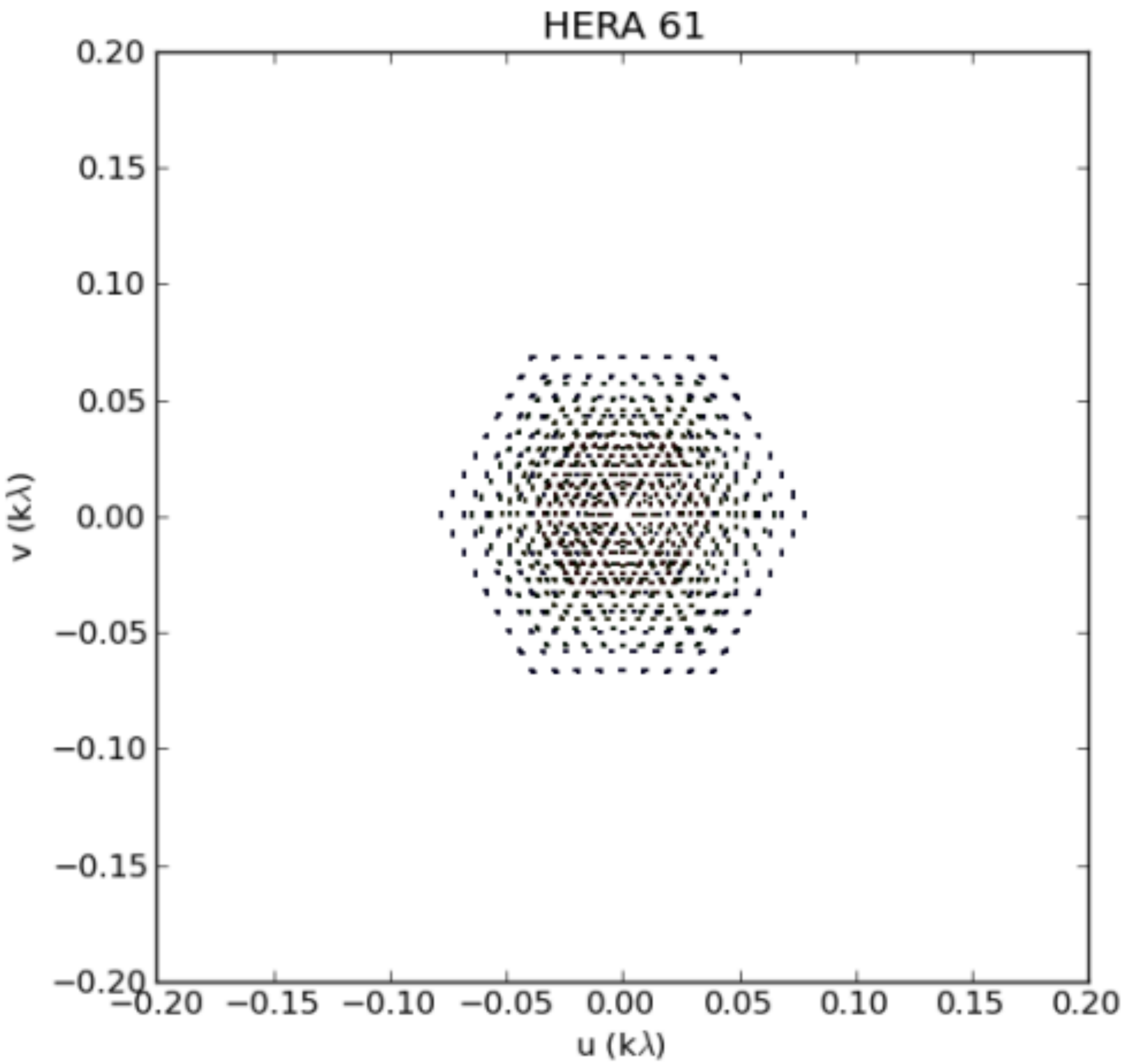
**Dillon et al. 2016**

# HERA-60 Images: Simulated

array layout

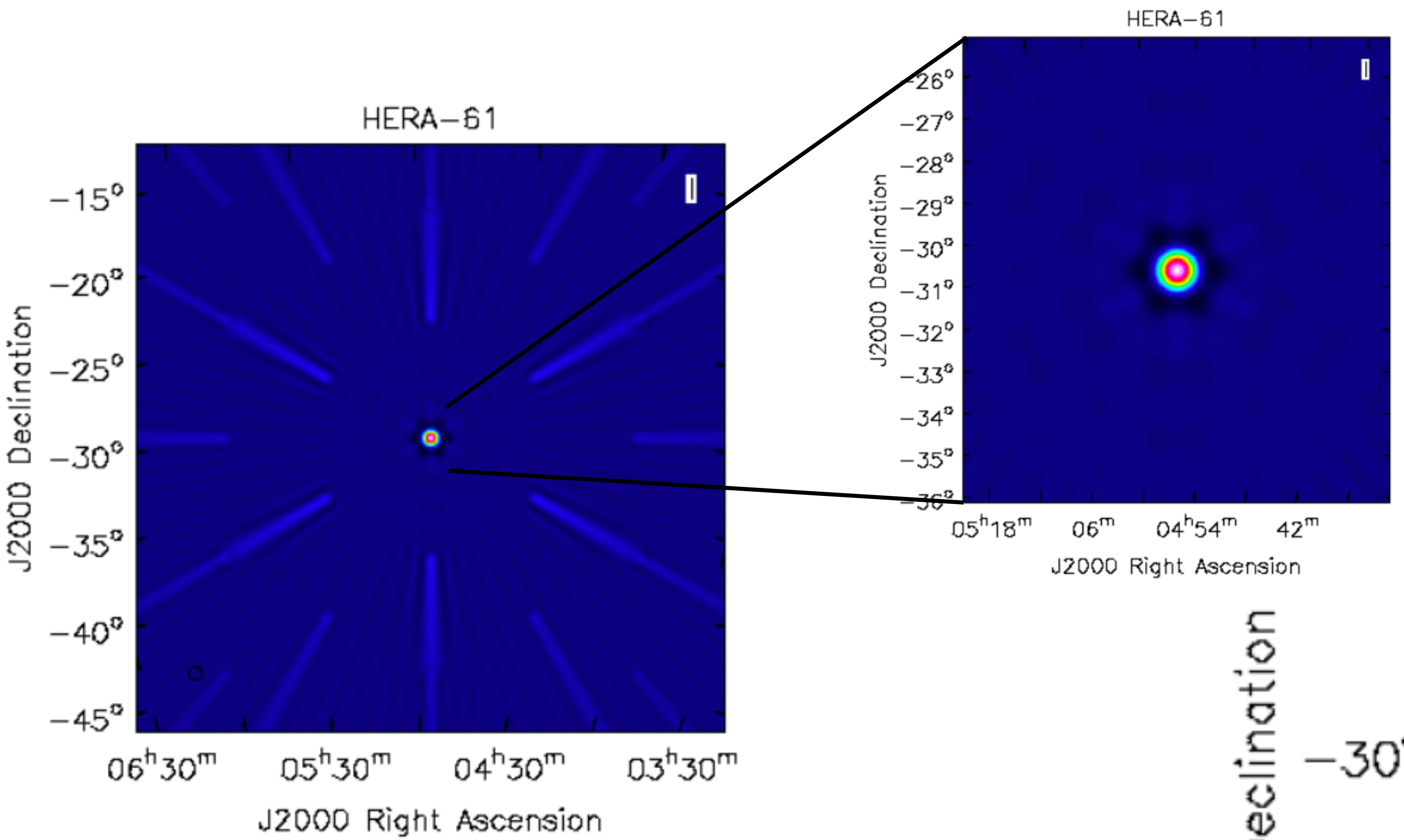



uv coverage



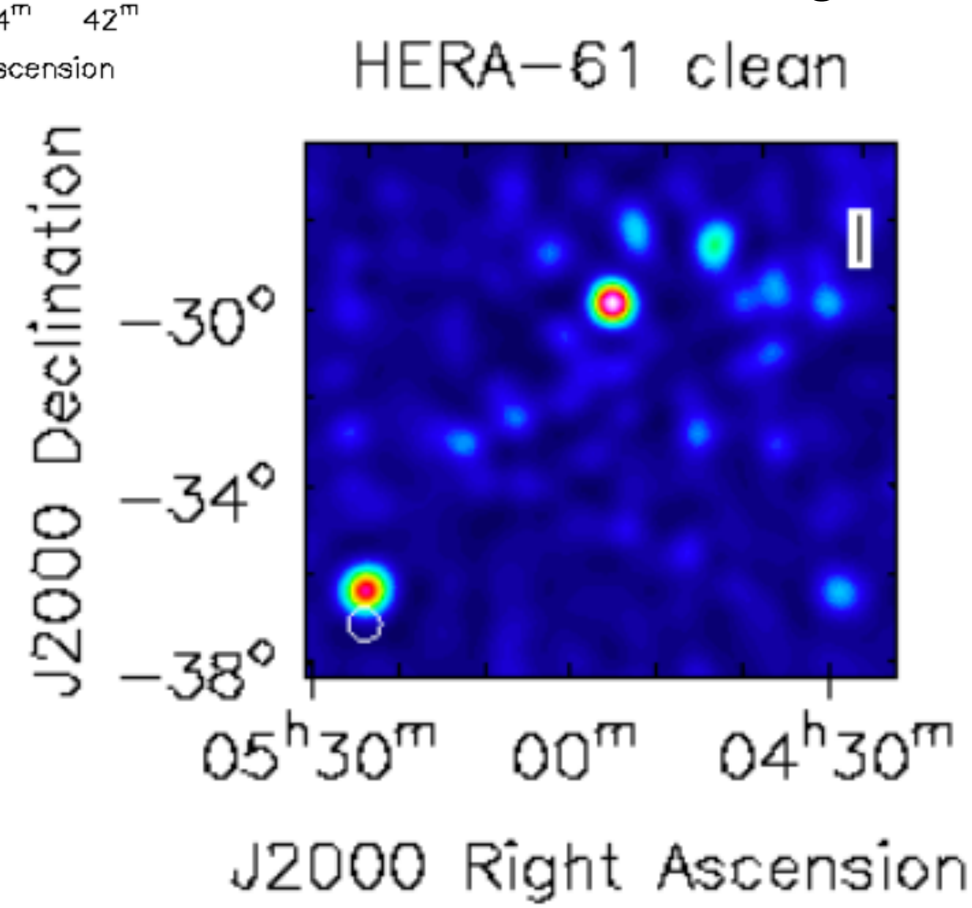

**HERA Memo #28**
**Kolopanis et al. 2017**

# HERA-60 Images: Simulated




point spread function

simulated image

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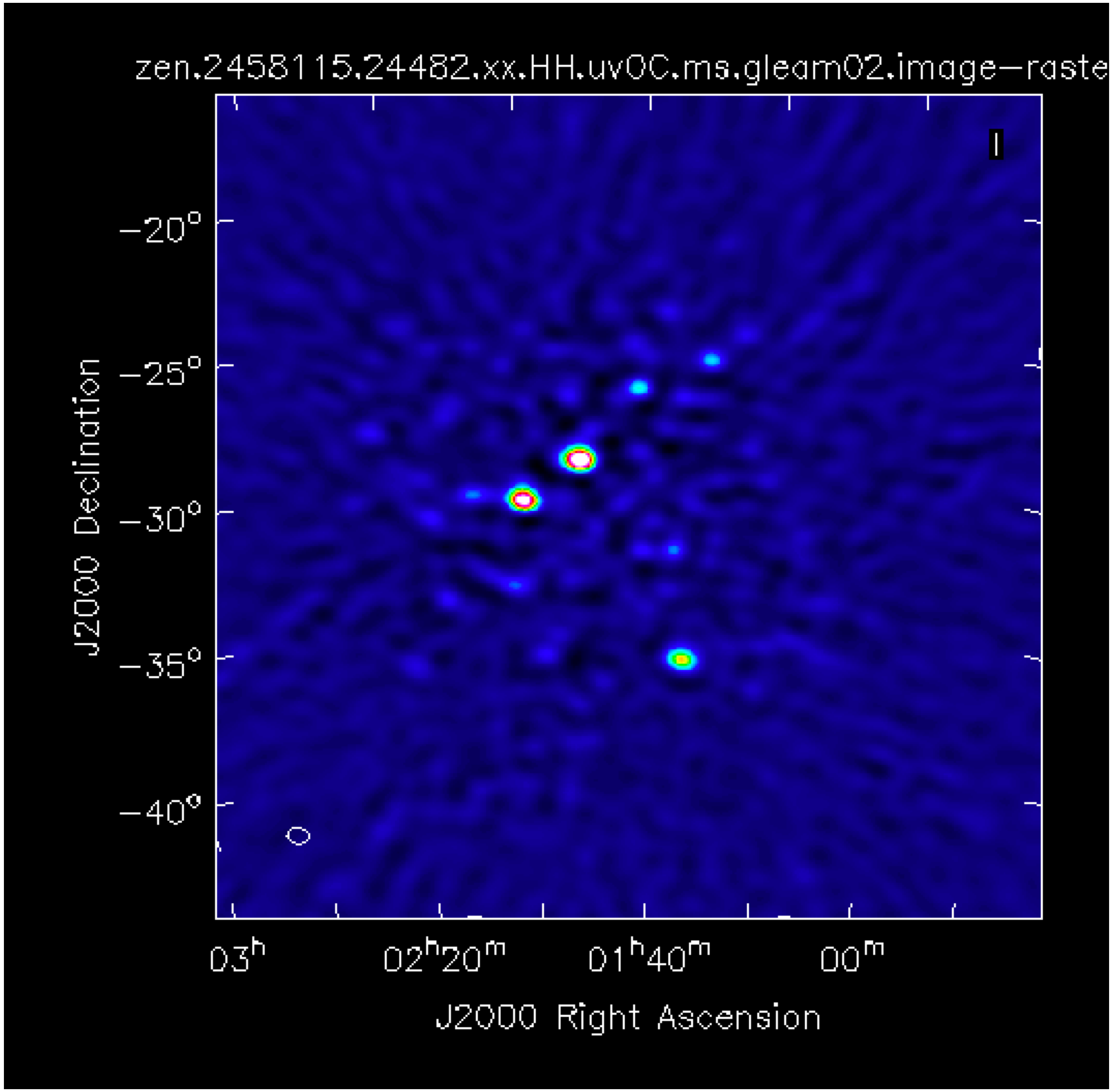
# HERA-60 Images: Real



# 3. HERA Imaging

# Imaging Demo