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 Specs
    b. Miriad to MS file conversion
    c. 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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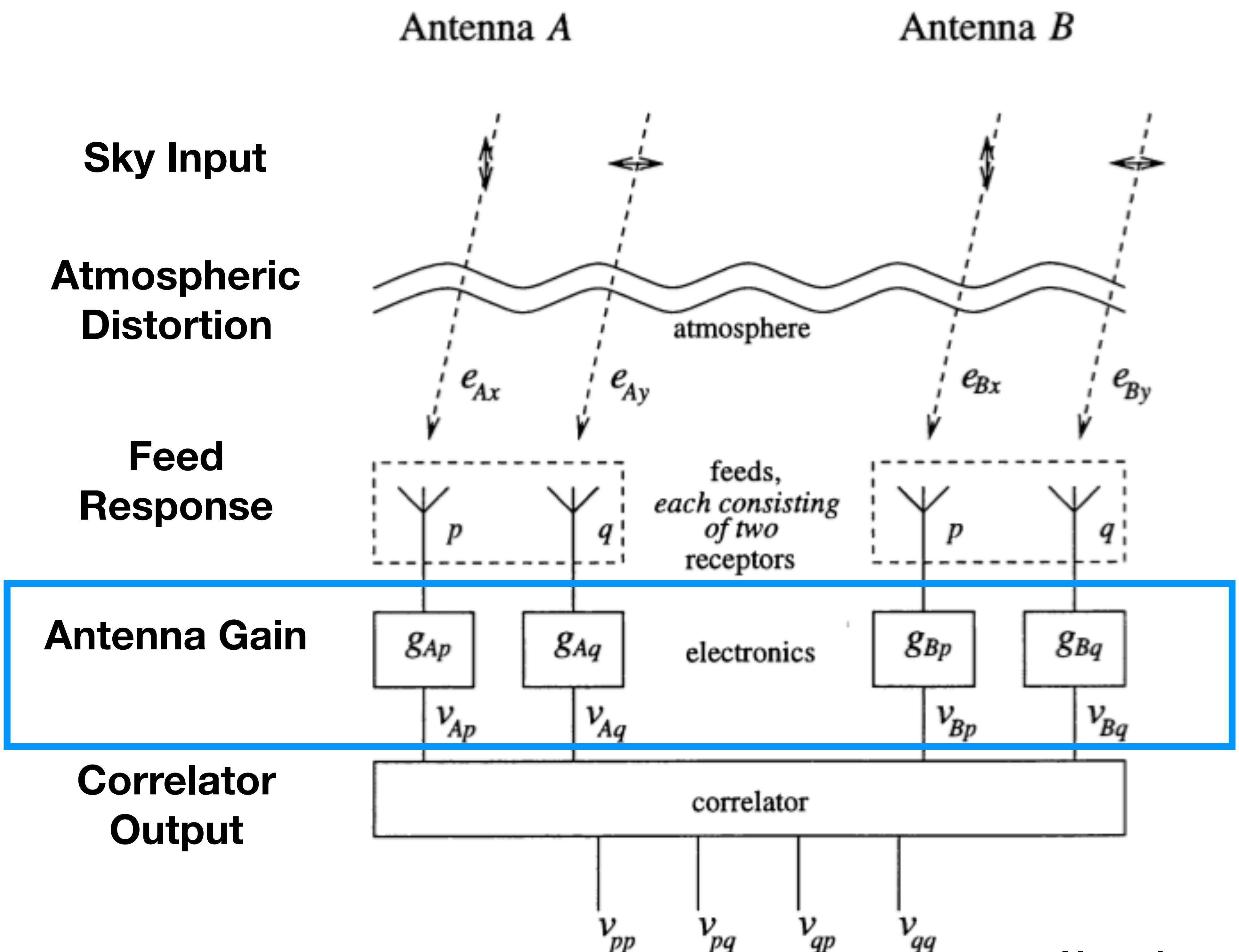


Hamaker et al. 1996

Measurement Equation

Ideal Scenario

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

Practical Scenario

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

$$\downarrow$$

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

Antenna-Based Calibration Equation

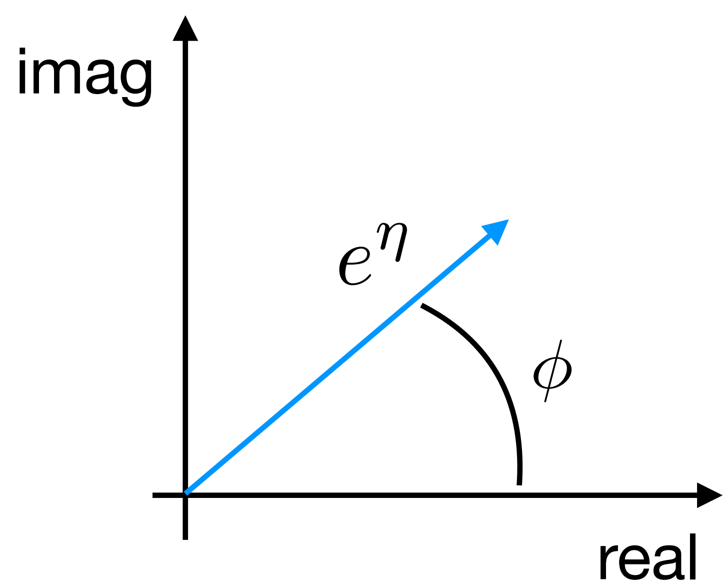
Breaking down Antenna Gains

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:

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

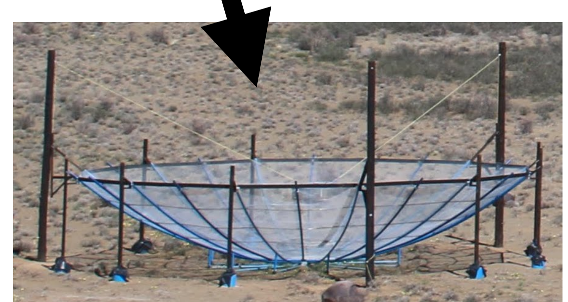
Solving for Gains

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!

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

antenna 1

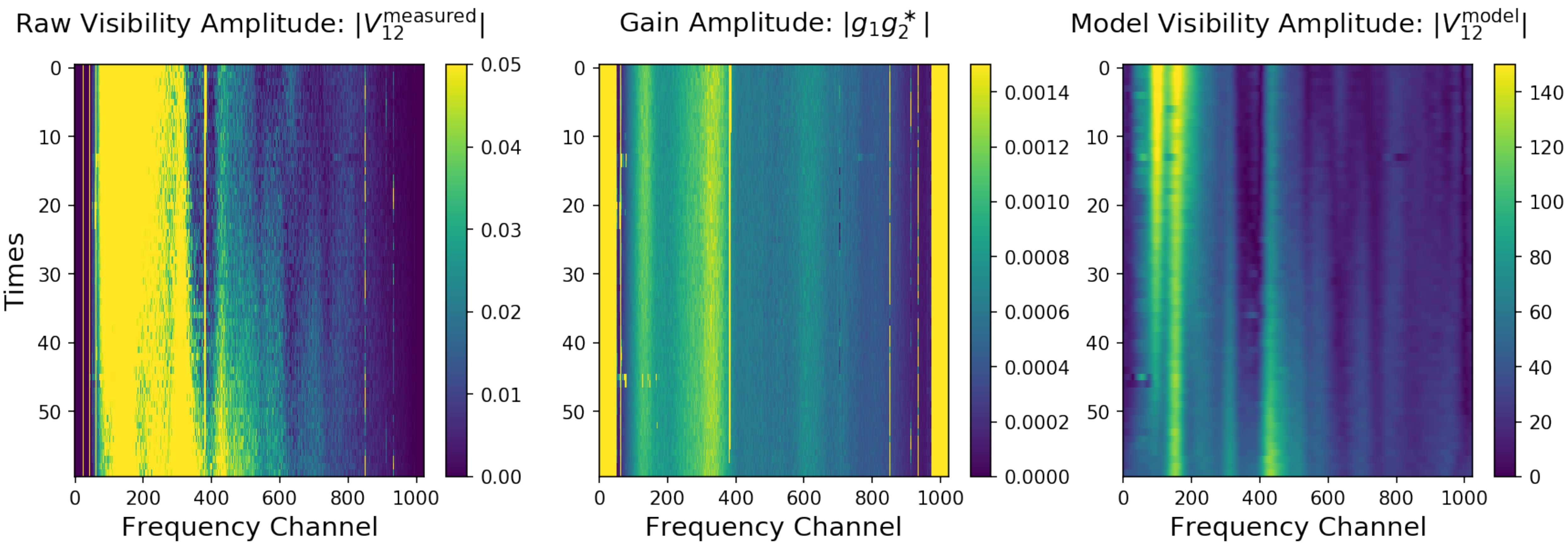


antenna 2

antenna 3

Applying Calibration

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

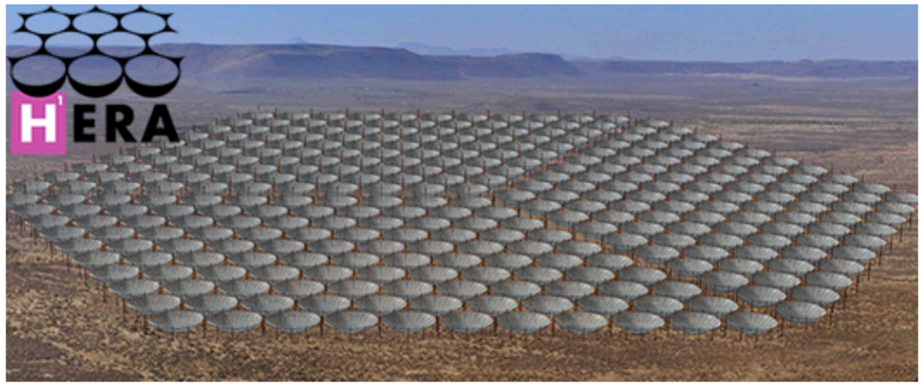


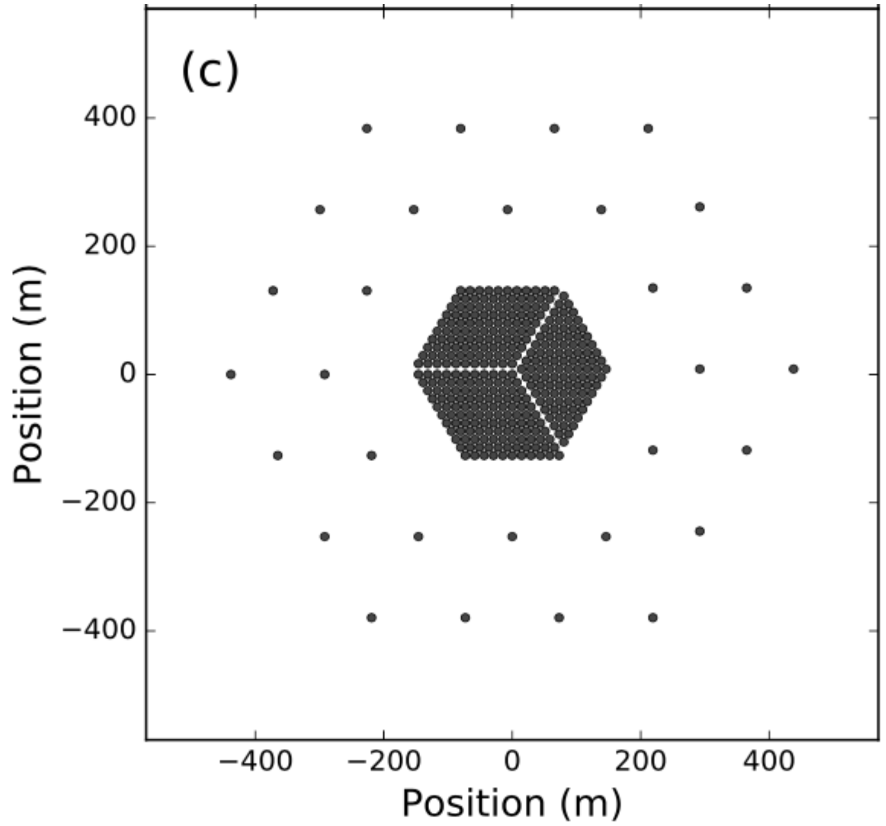
HERA Calibration Exploration

2. HERA Imaging Specs

HERA Imaging Specs

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





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

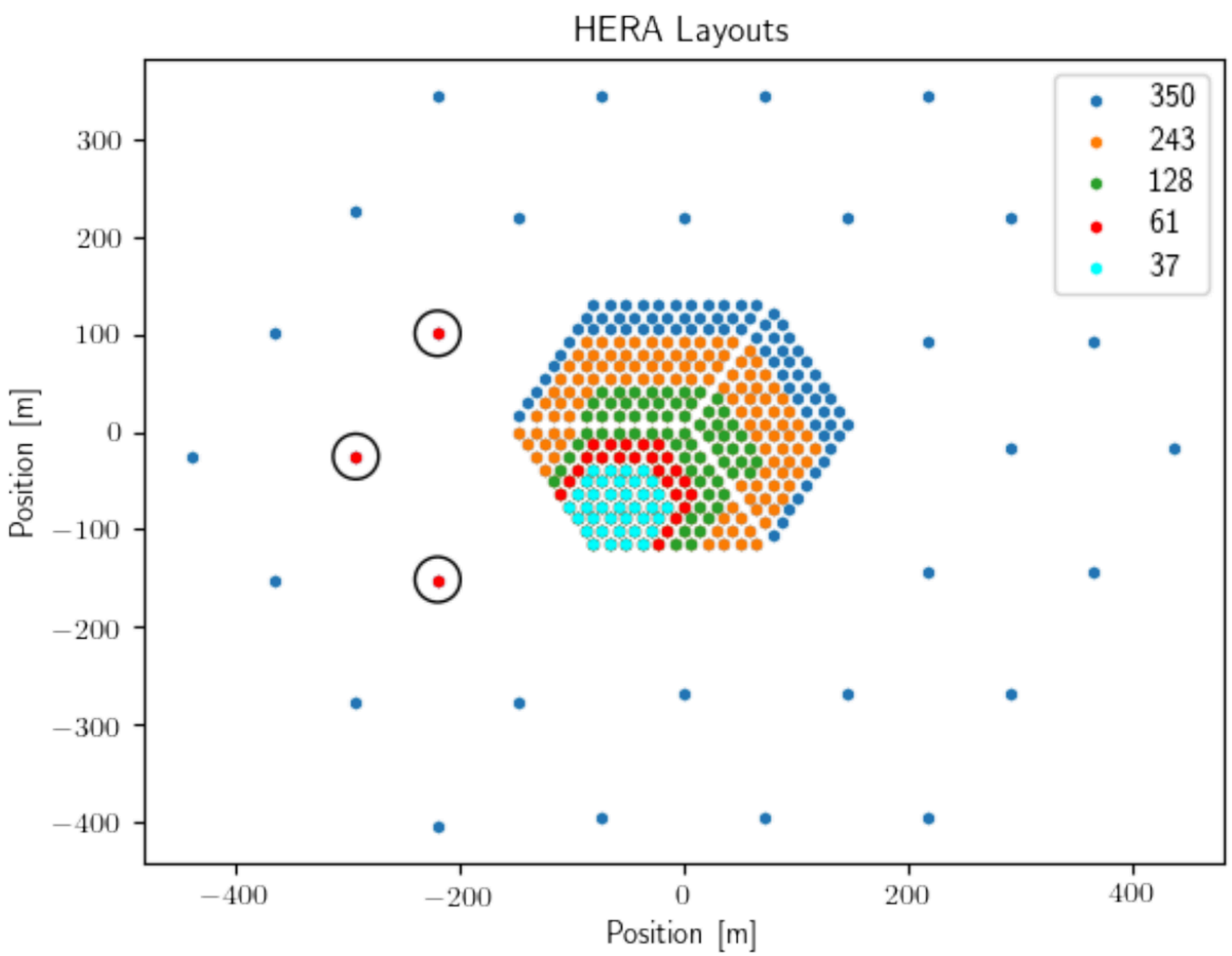
$$\theta = \lambda/D$$

DeBoer et al. 2016

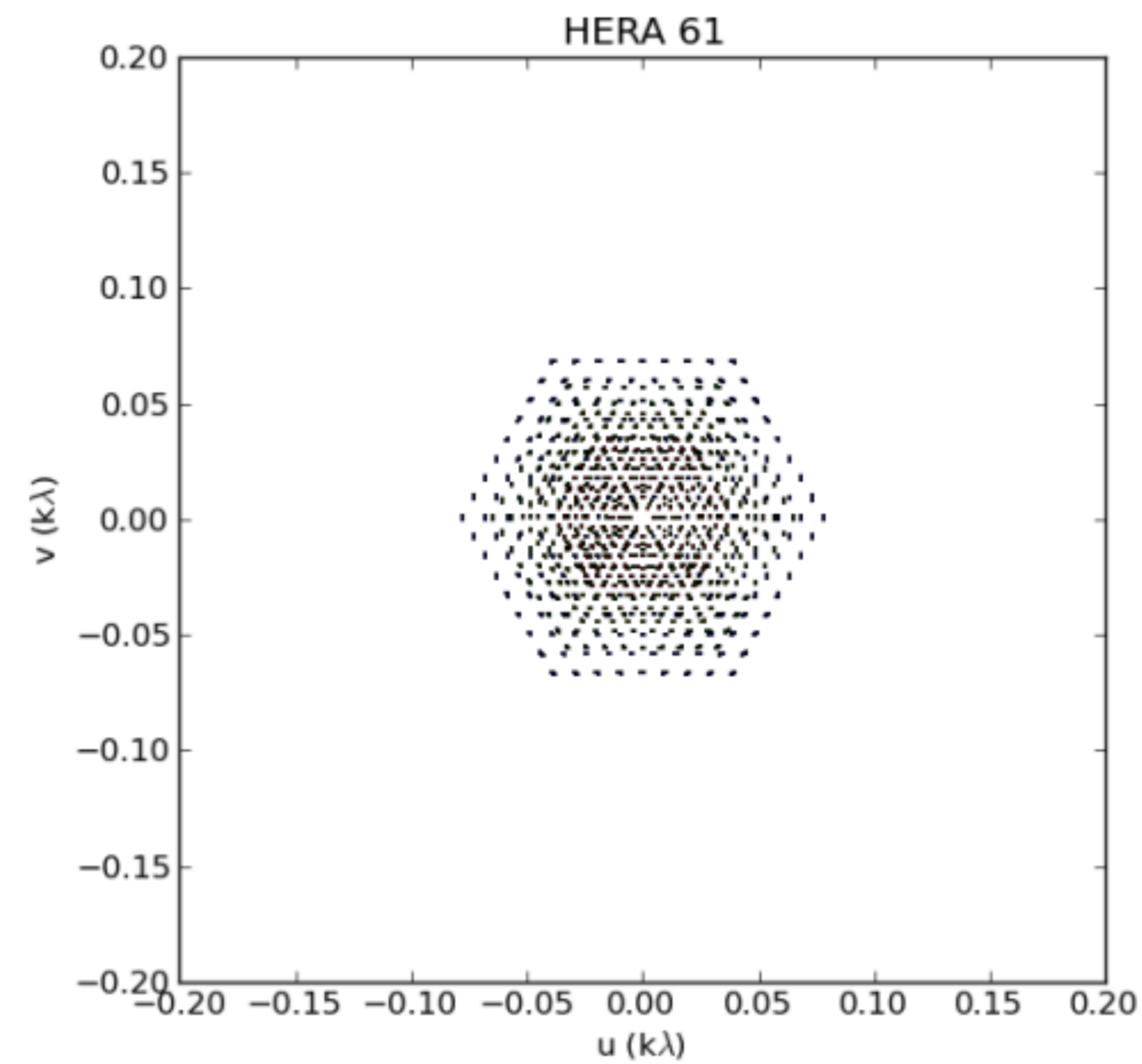
Dillon et al. 2016

HERA-60 Images: Simulated

array layout

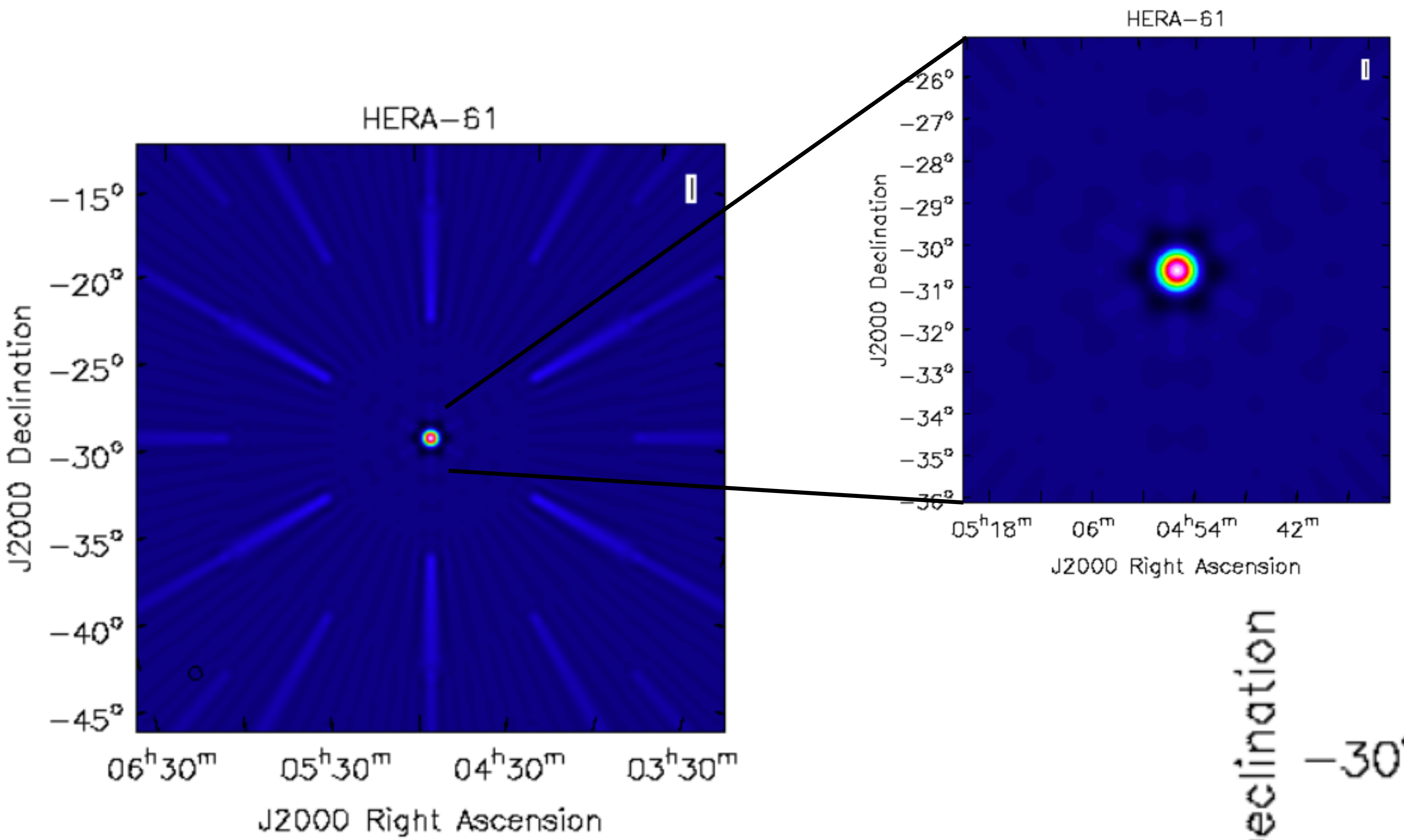


uv coverage



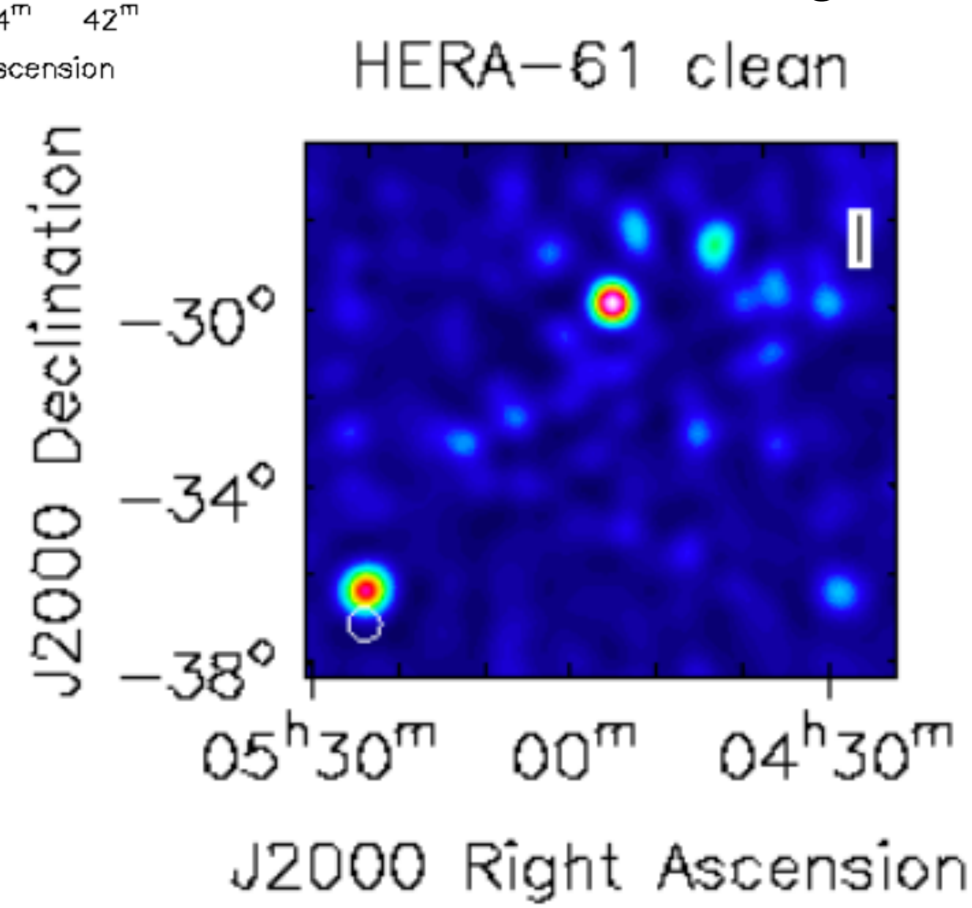
HERA Memo #28
Kolopanis et al. 2017

HERA-60 Images: Simulated



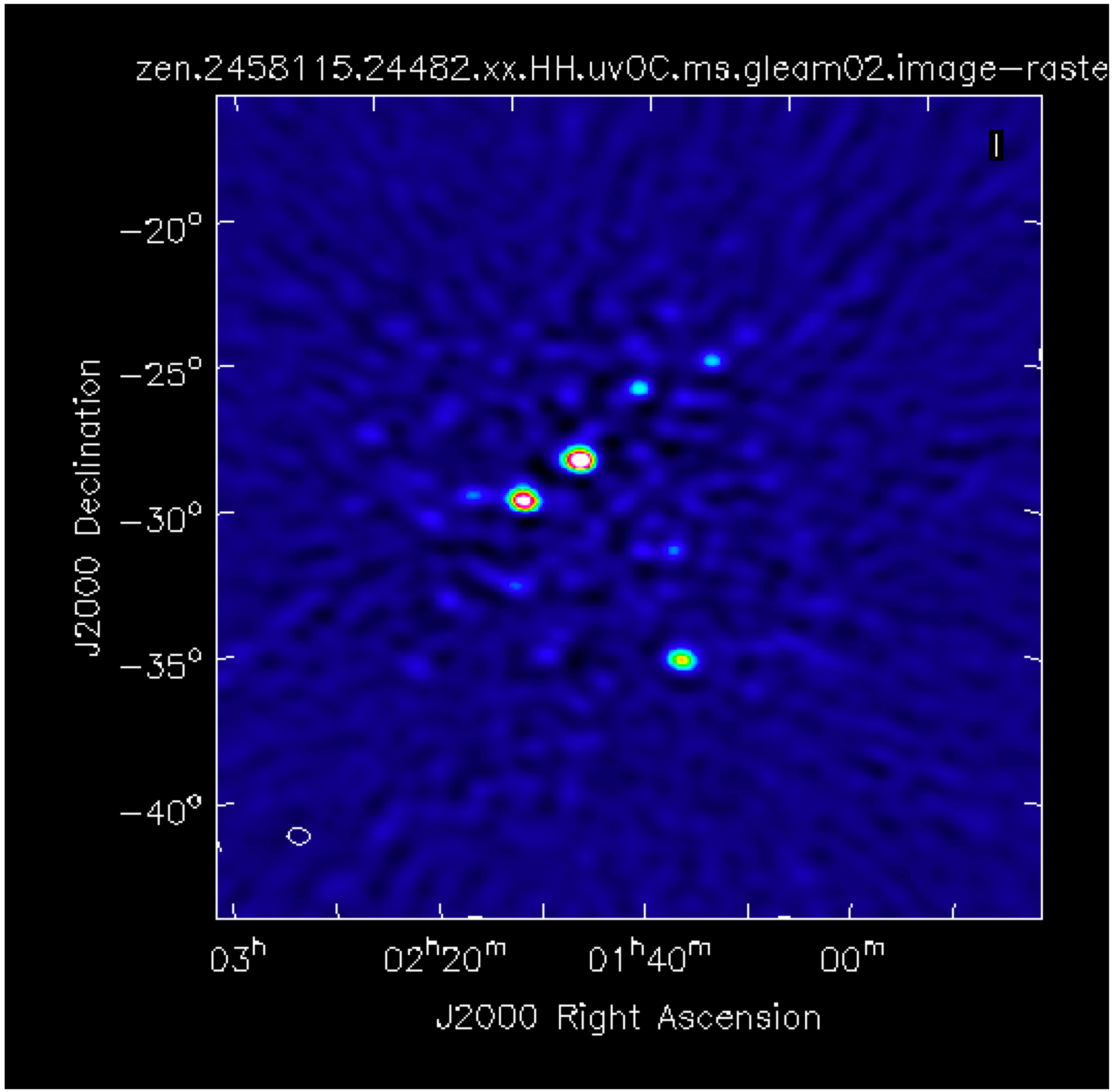
point spread function

simulated image



HERA Memo #28
Kolopanis et al. 2017

HERA-60 Images: Real



HERA Imaging Specs Takeaway

HERA is not designed to be particularly “good” at imaging

- Mediocre (and redundant) instantaneous uv-coverage

- Short baselines

- Drift scan

3. HERA Imaging

Preliminaries:
Miriad to MS File Conversion

In order to image our data with CASA, we need to convert our **Miriad** files to **Measurement Set** files.

We can do this from our command line using the **`pyuvdata`** tools and CASA.

Step 1: Miriad —> UVFITS

```
$ miriad_to_uvfits.py filename
```

Step 2: UVFITS —> MS

```
$ casa -c “importuvfits(filename.uvfits, filename.ms)”
```

Imaging Demo