HERA (and MWA) Update

Adam Beardsley

21cm Cosmology Workshop
21 October, 2019

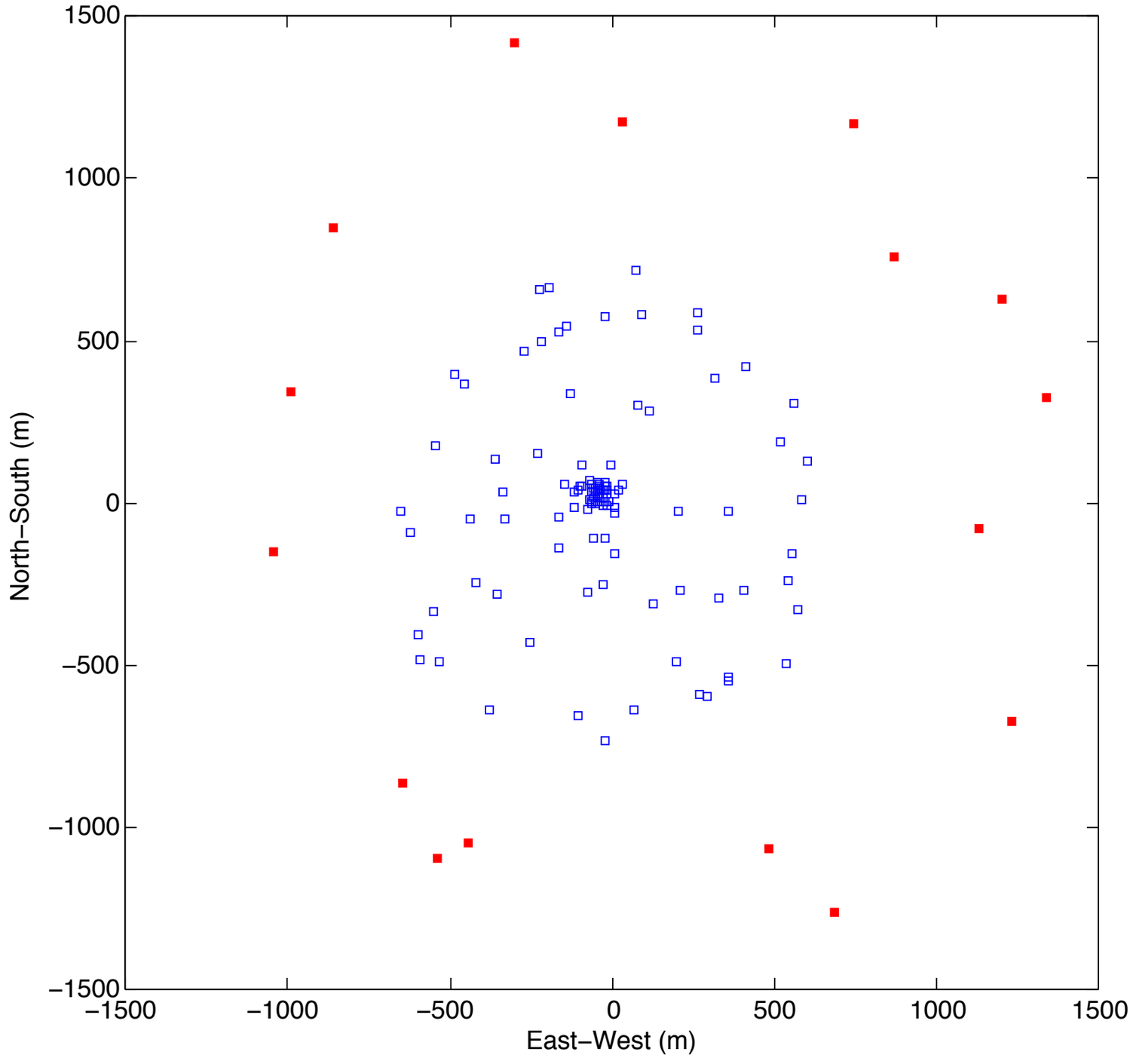
Murchison Widefield Array

Observing since August, 2013. ~ 30 PB of data!

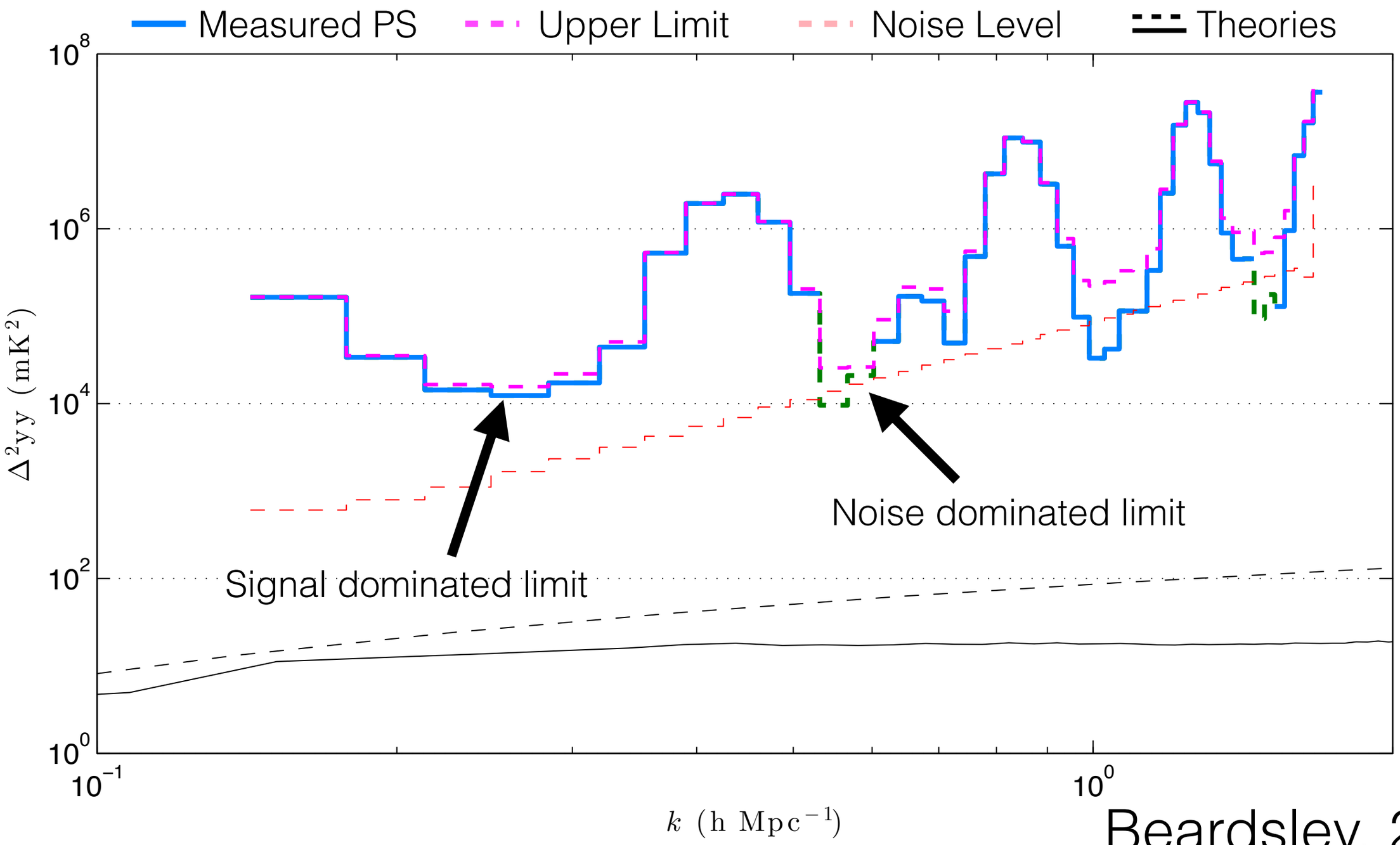
Versatile observing, including voltage capture

Photo Credit: Peter Wheeler, ICRAR

MWA Phase I Layout

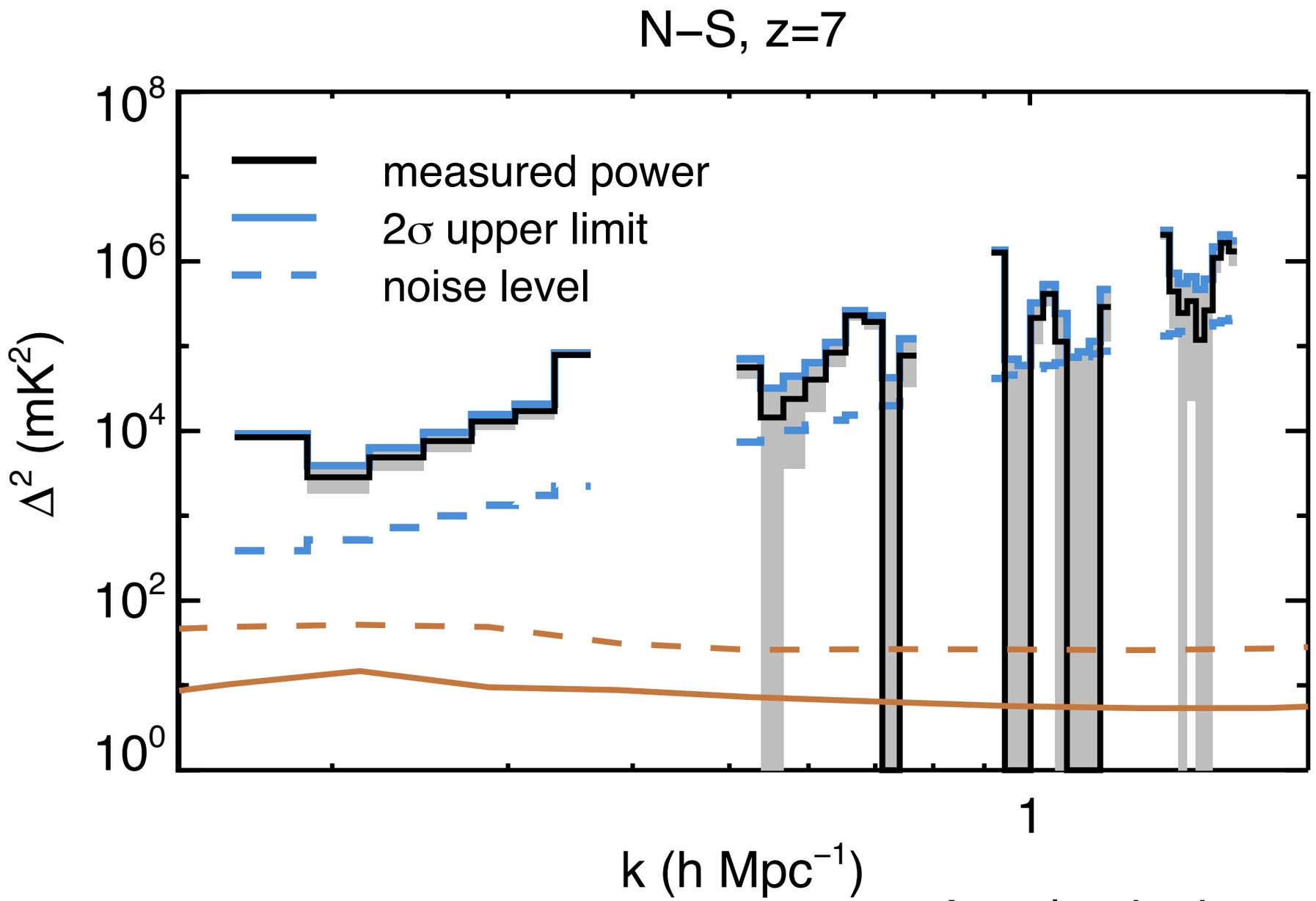


MWA Phase I EoR Results



Beardsley, 2016

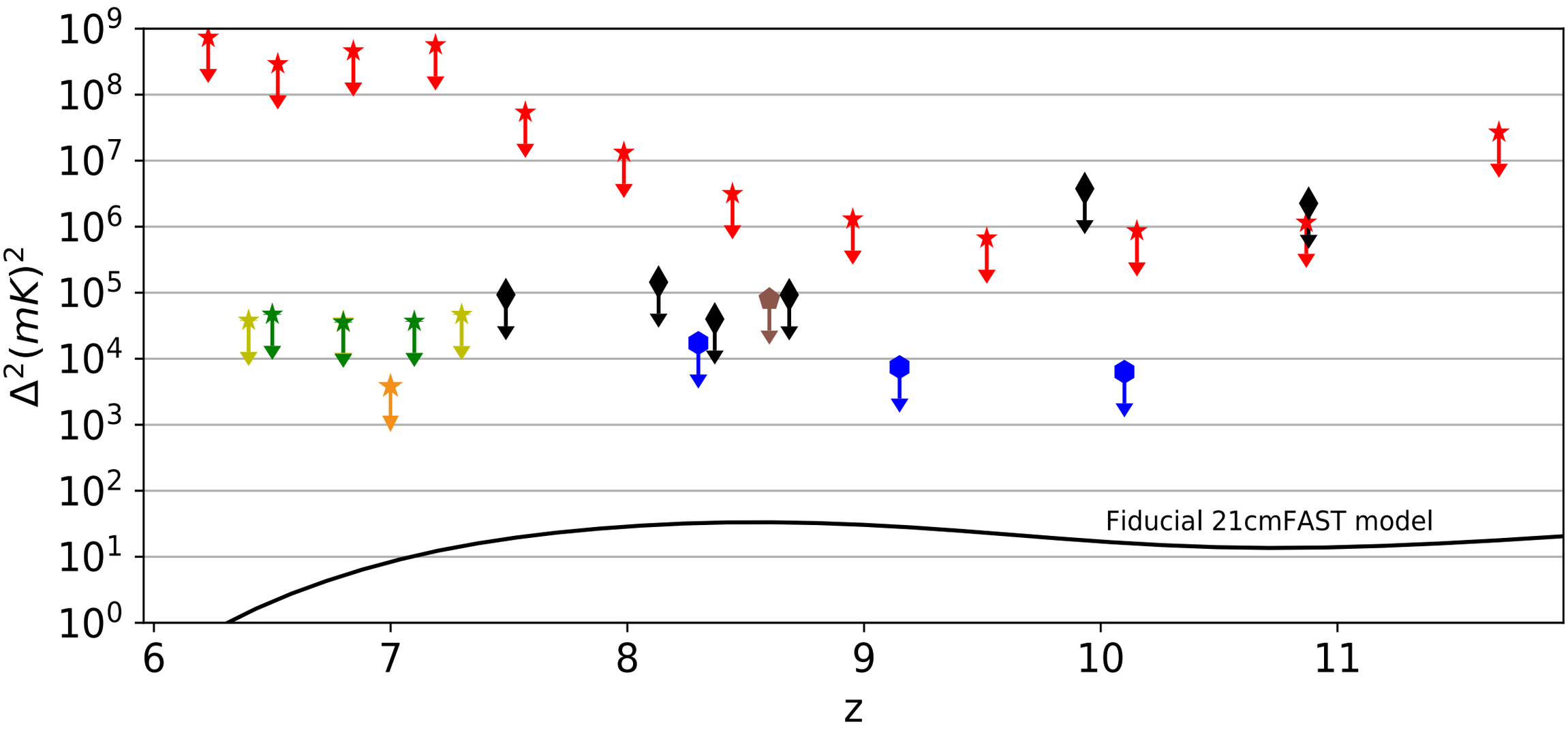
MWA Phase I EoR Results



Barry et al, 2019

Analysis improvements
Data quality cuts

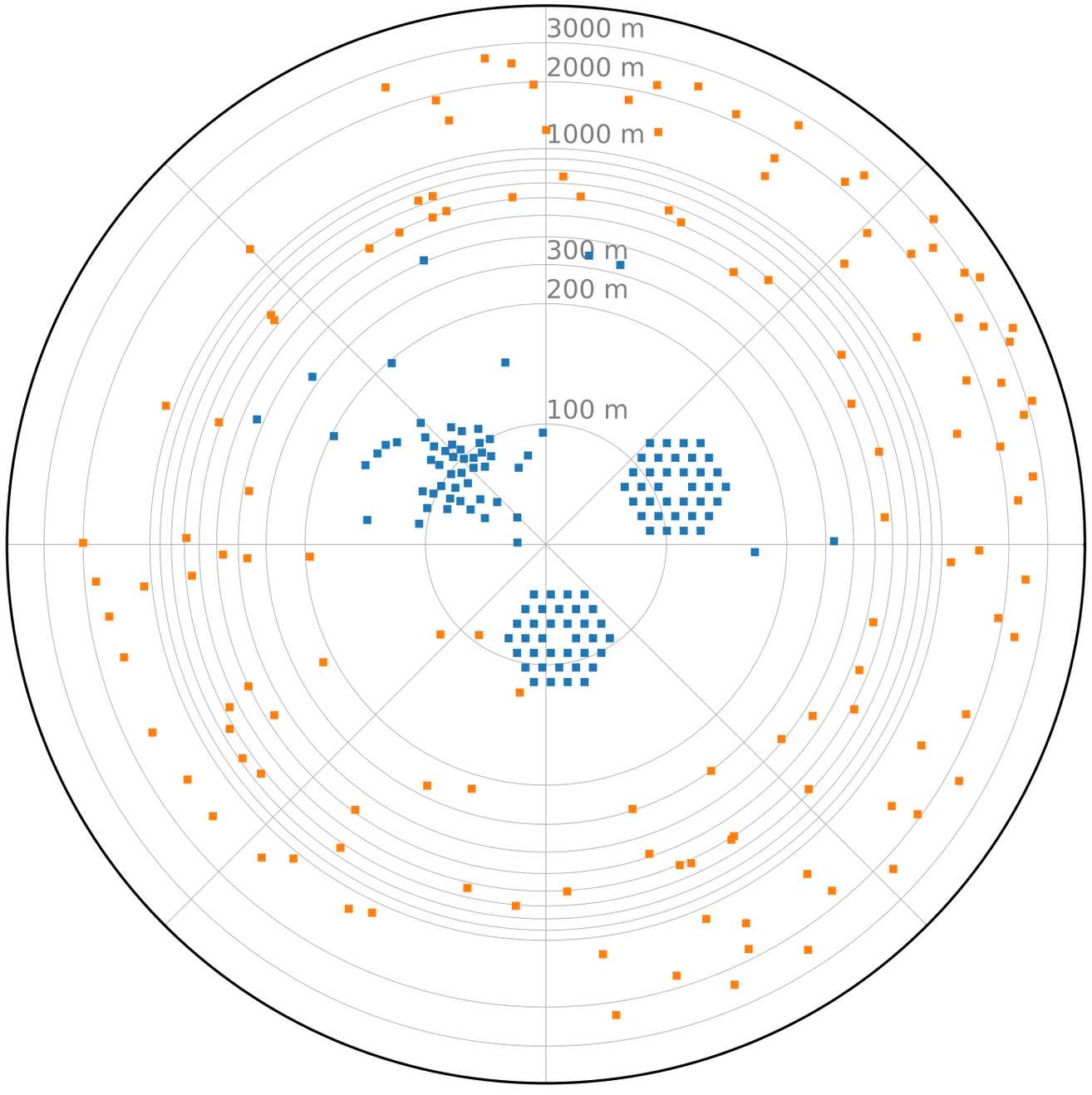
EoR Best Limits



MWA Upgrades: Phase II

- New antennas
  - Compact & Extended configurations
- Digital back-ends
- Rapid-response Triggering

Compact & Extended Configurations



MWA Phase II - Hexes

Wayth et al, 2018; Beardsley et al, 2019

HERA

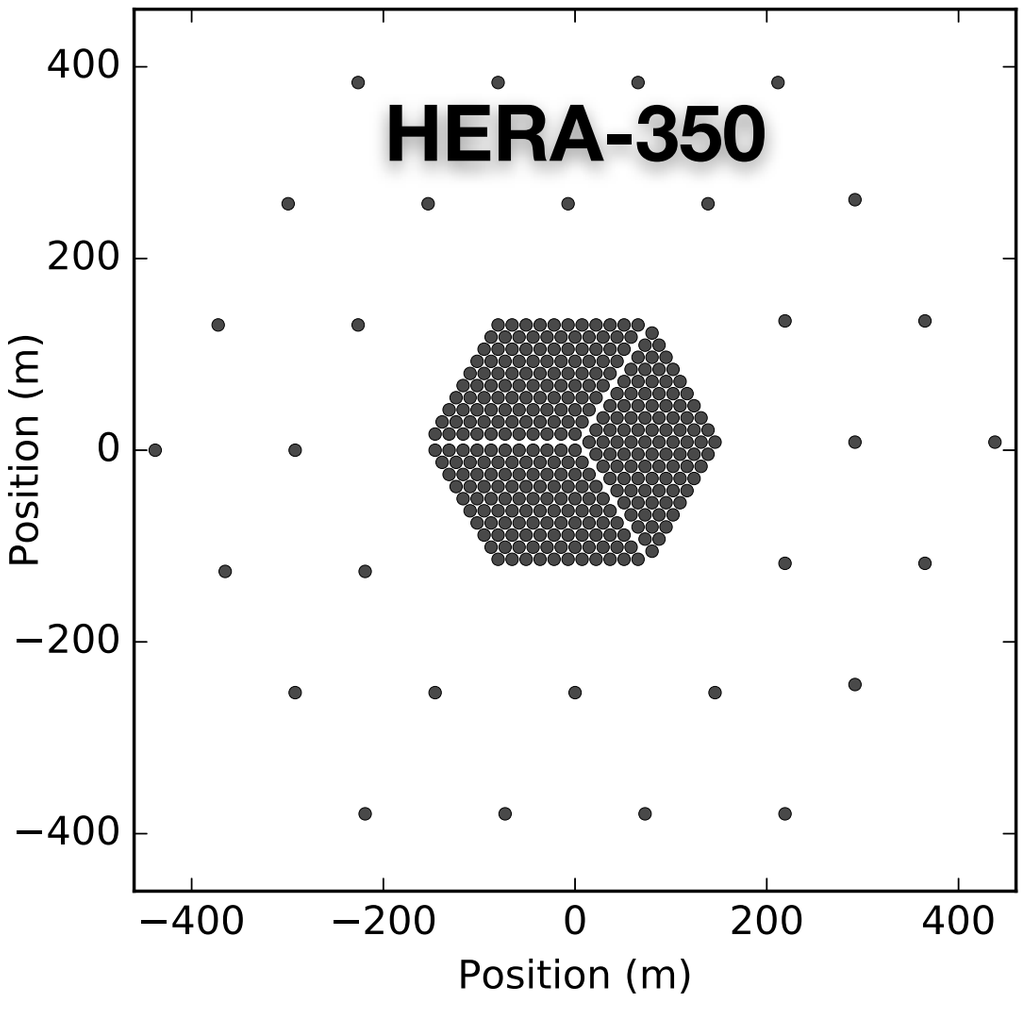
Purpose-driven experiment

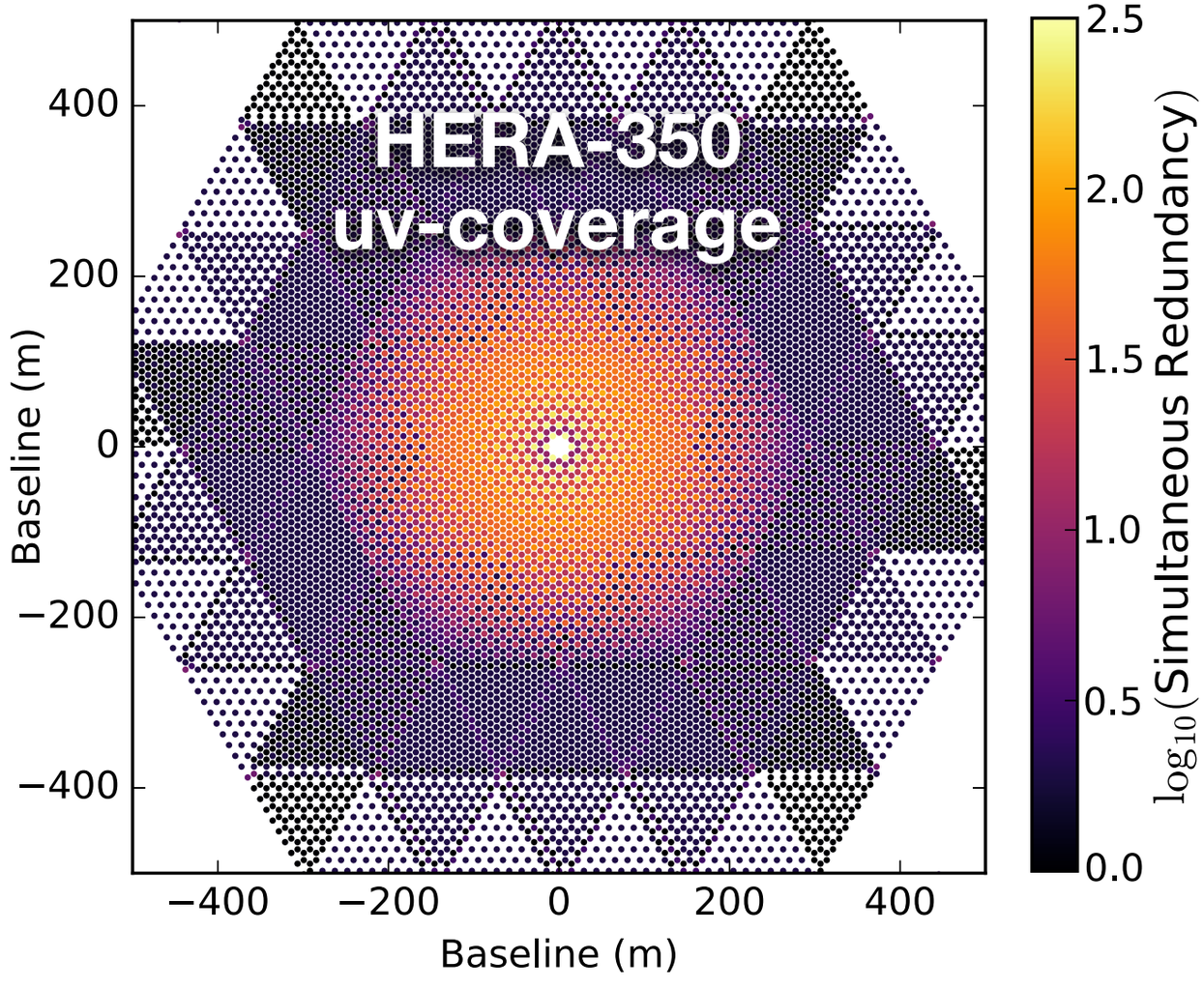
South African Karoo Desert

350 14m dishes by 2020

Highly redundant

Highly Redundant



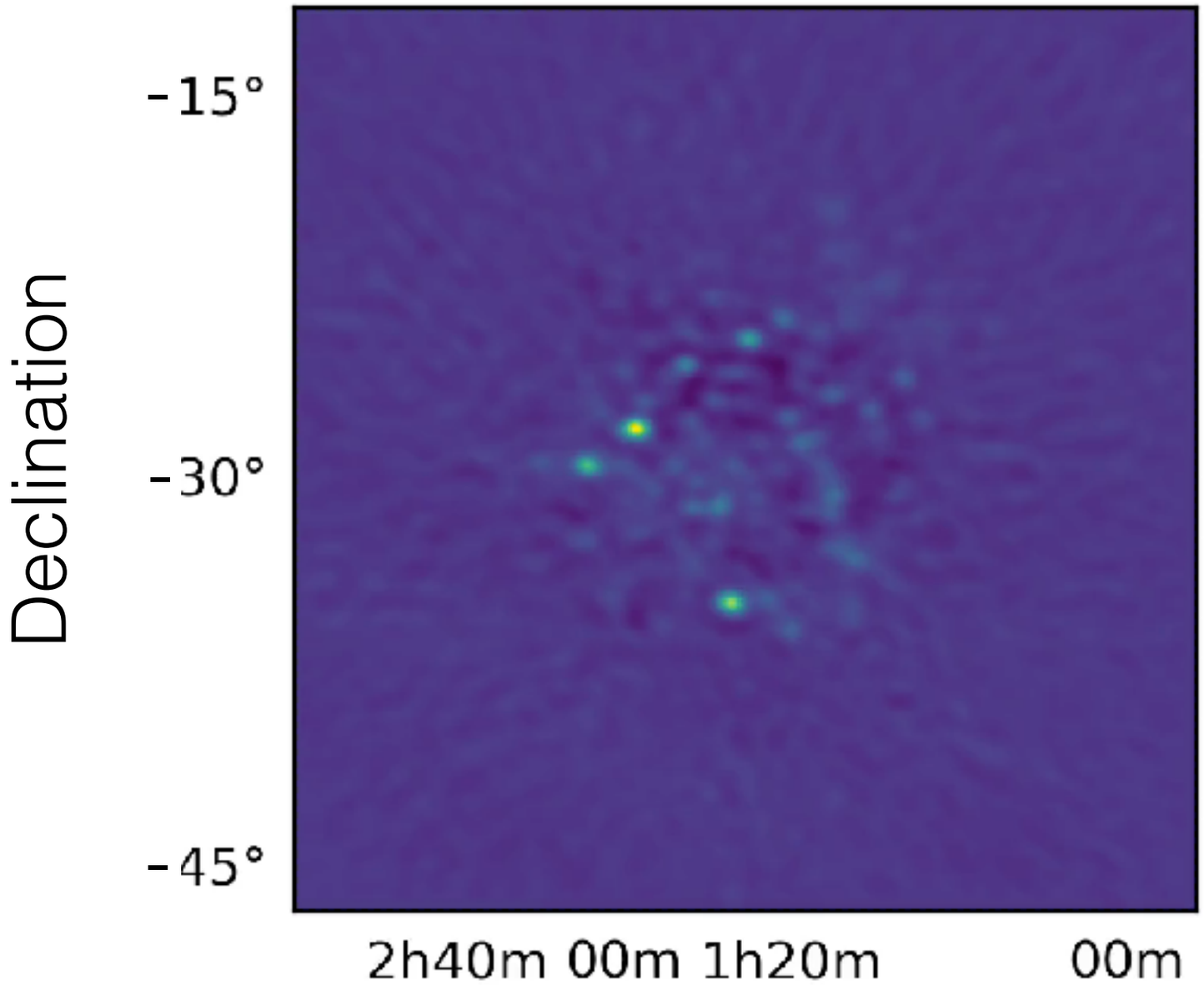


Under Construction

First Season - reuse PAPER

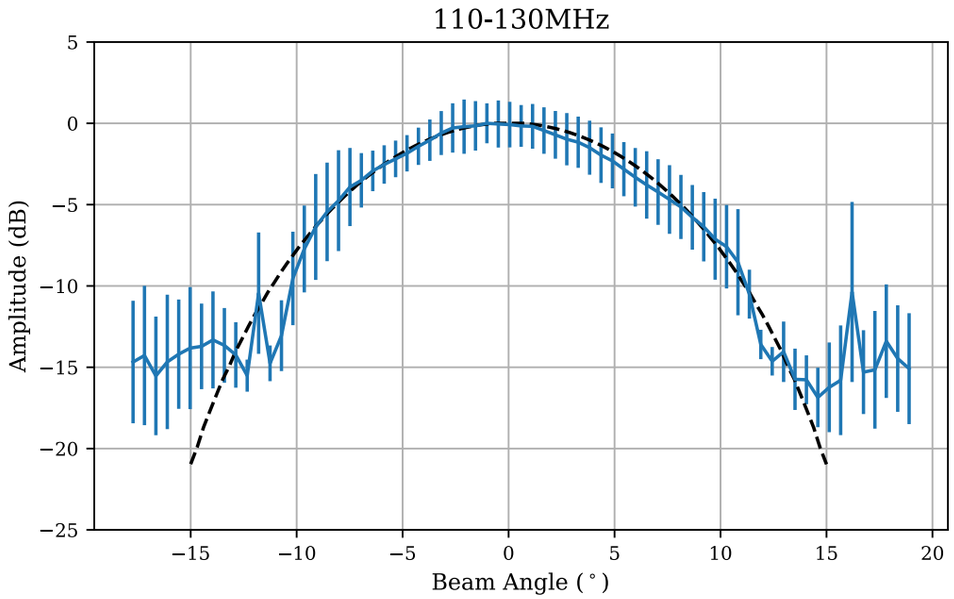
First Season - reuse PAPER

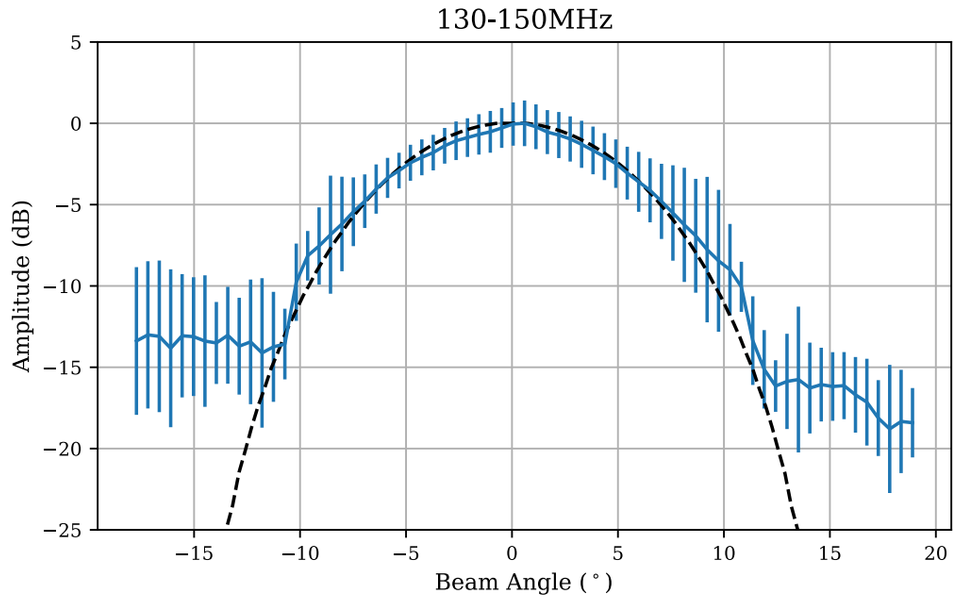
Imaging with HERA - Year 1

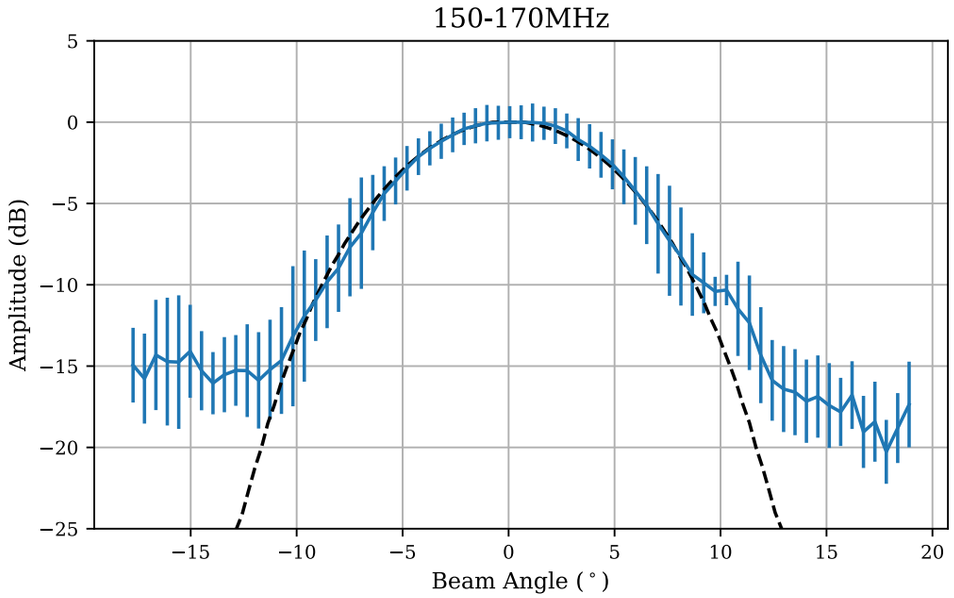


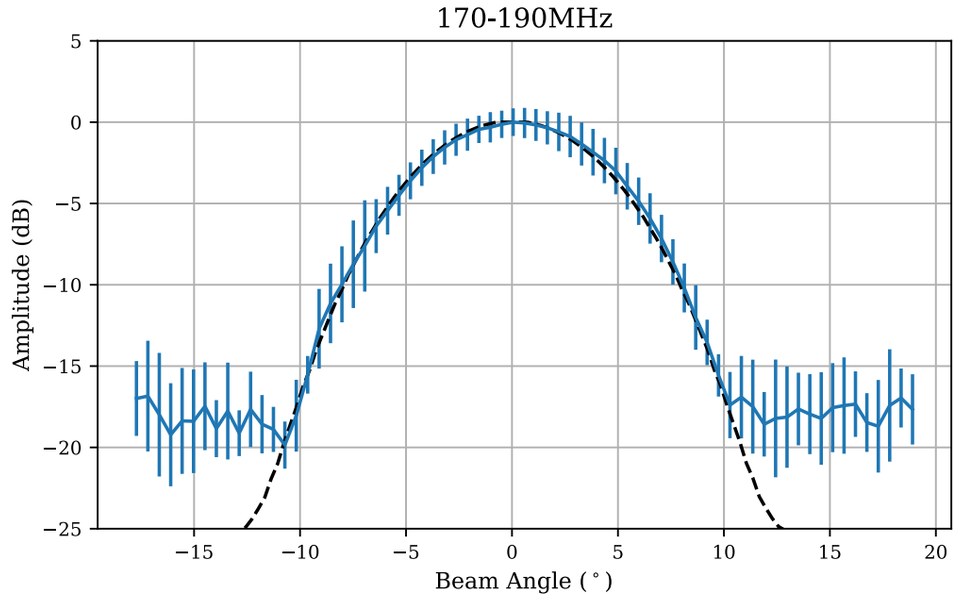
Credit ASU HERA undergrads

Beam Measurement





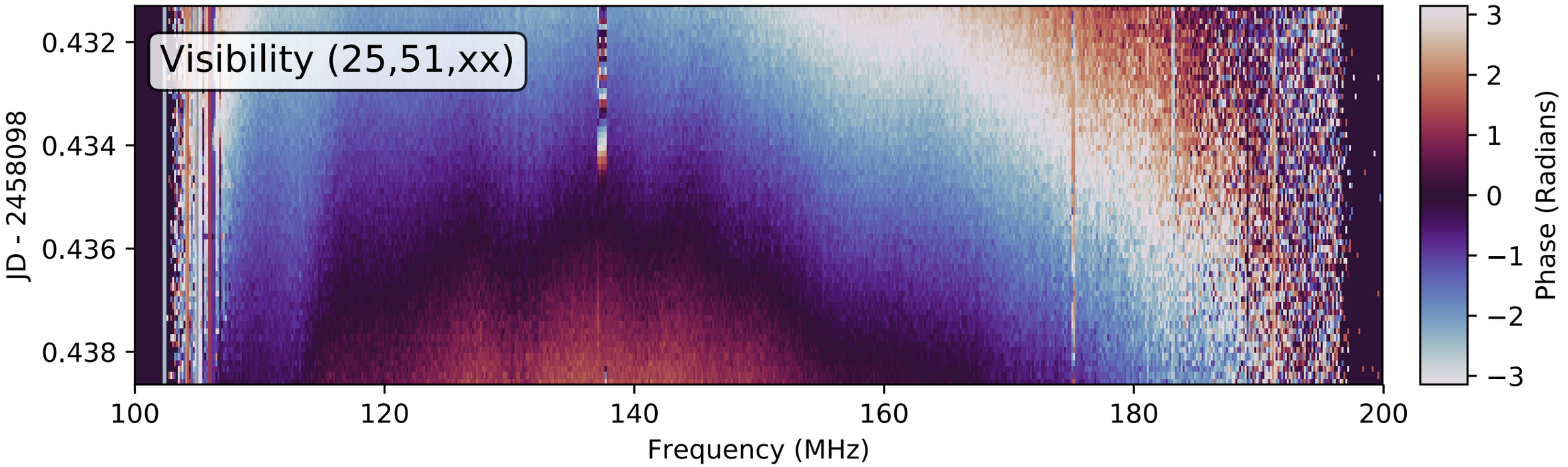




Credit ASU HERA undergrads, especially Tyler Cox

Year 1 “Analysis”

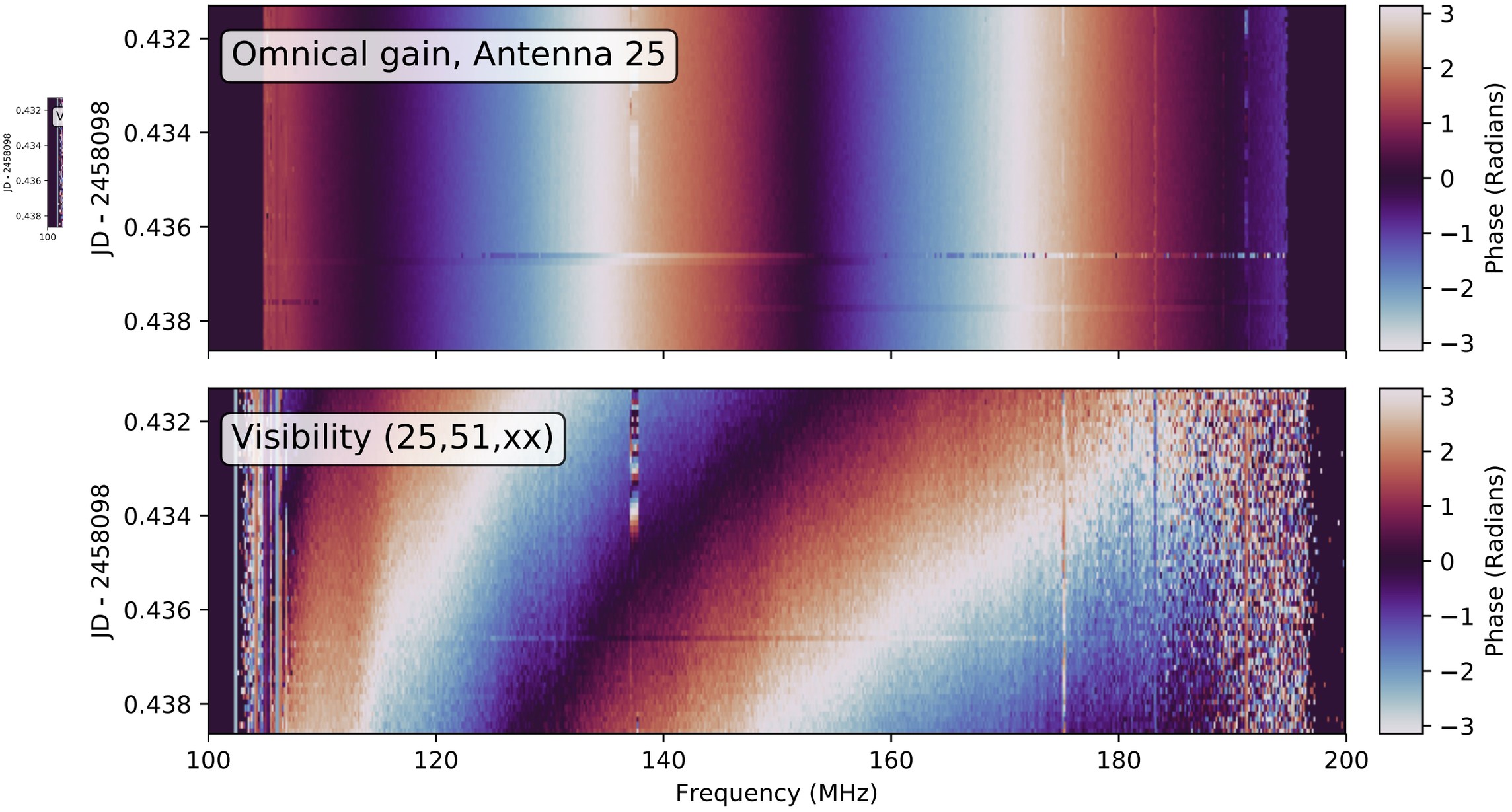
Raw Data



HERA Memo #69

Year 1 “Analysis”

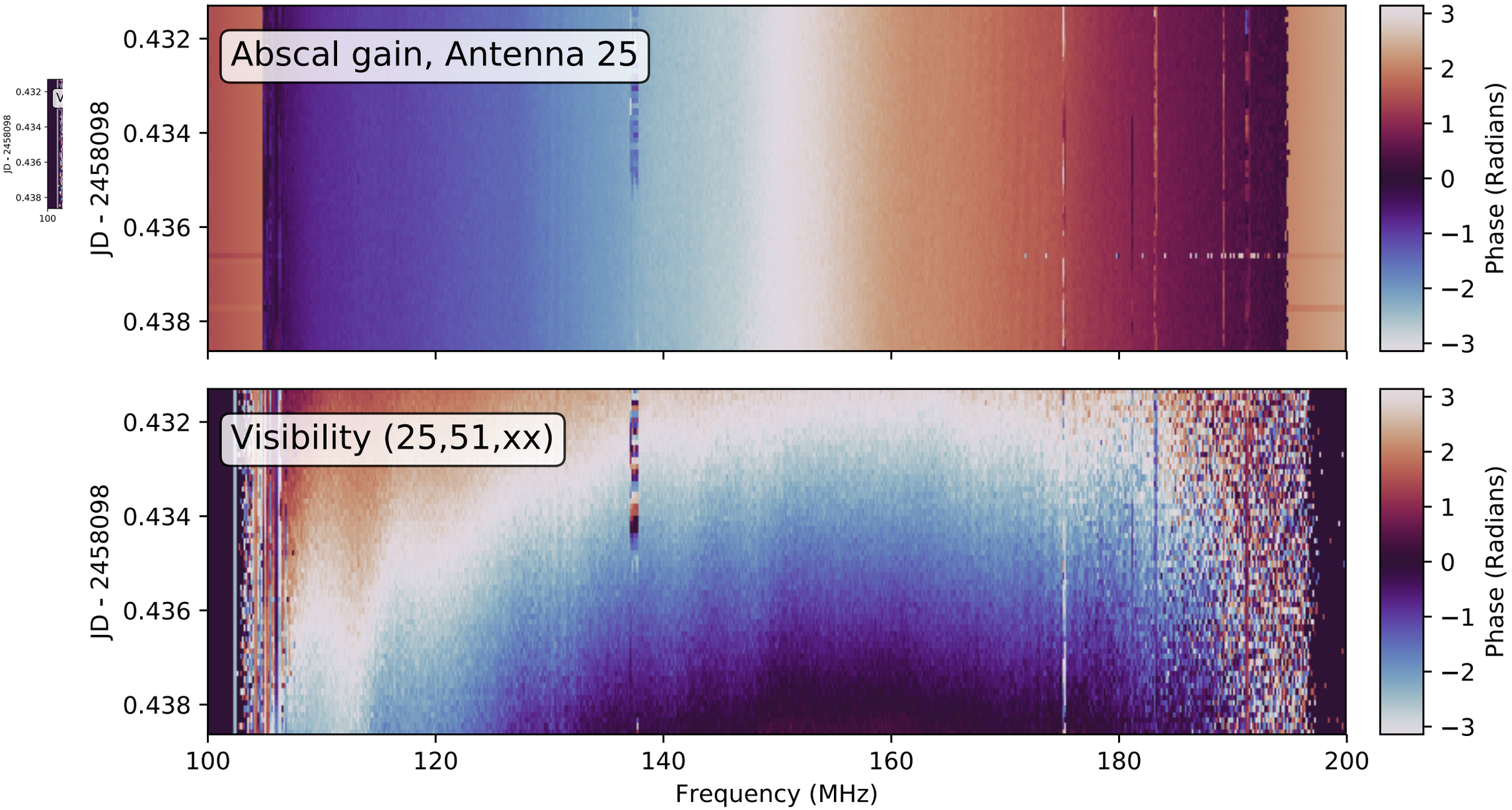
Redcal



HERA Memo #69

Year 1 “Analysis”

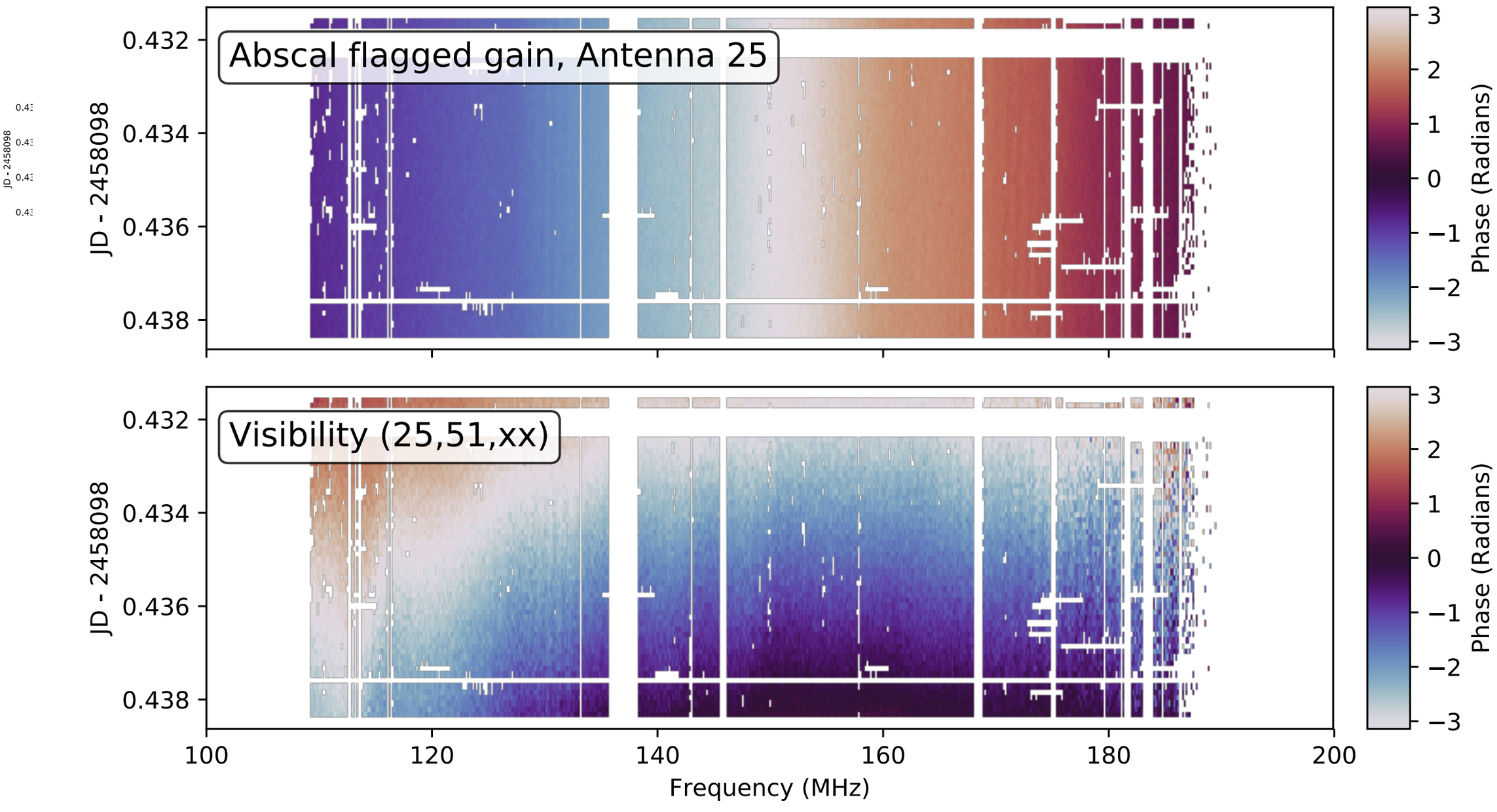
Abscal



HERA Memo #69

Year 1 “Analysis”

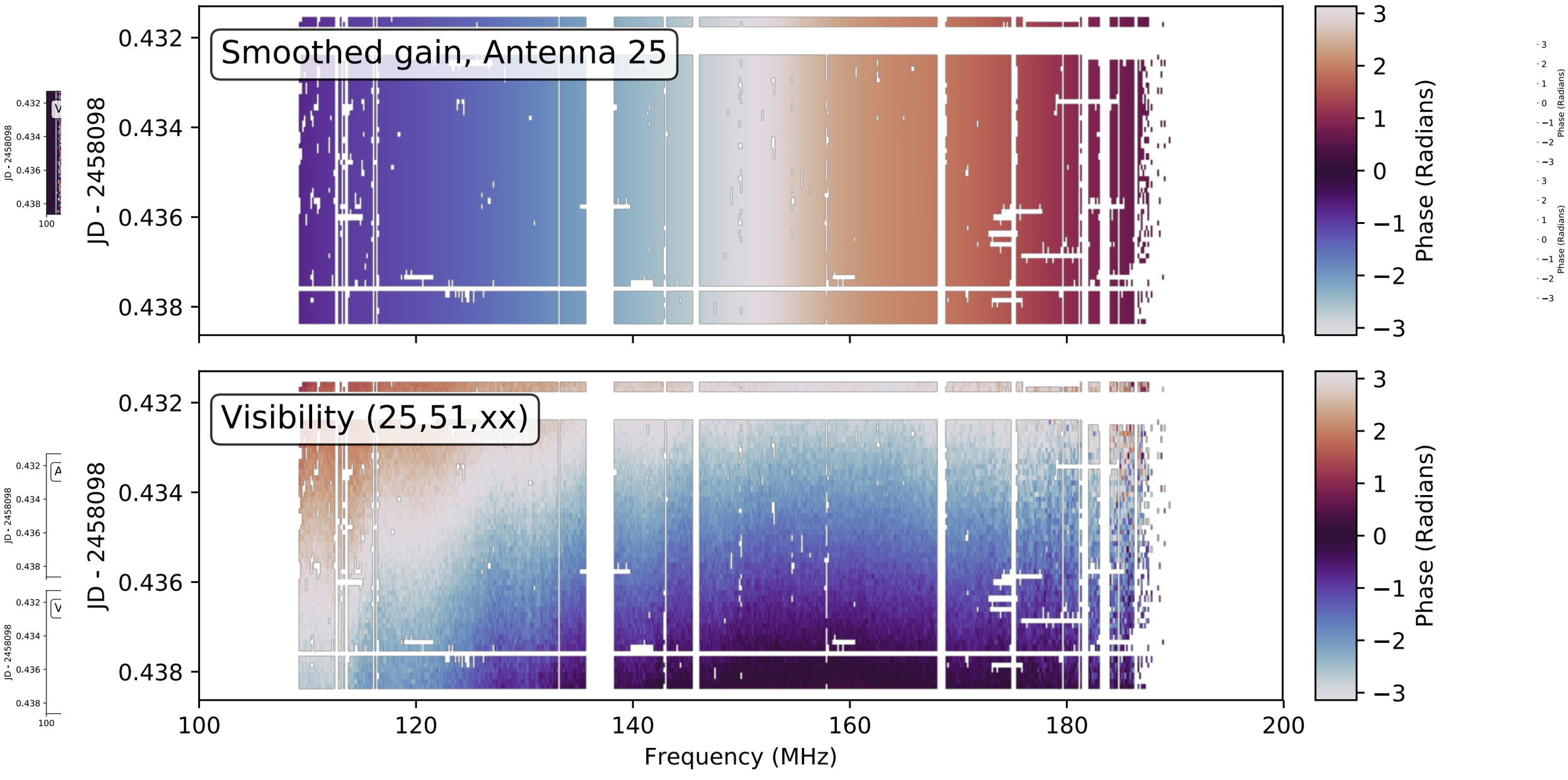
XRFI



HERA Memo #69

Year 1 “Analysis”

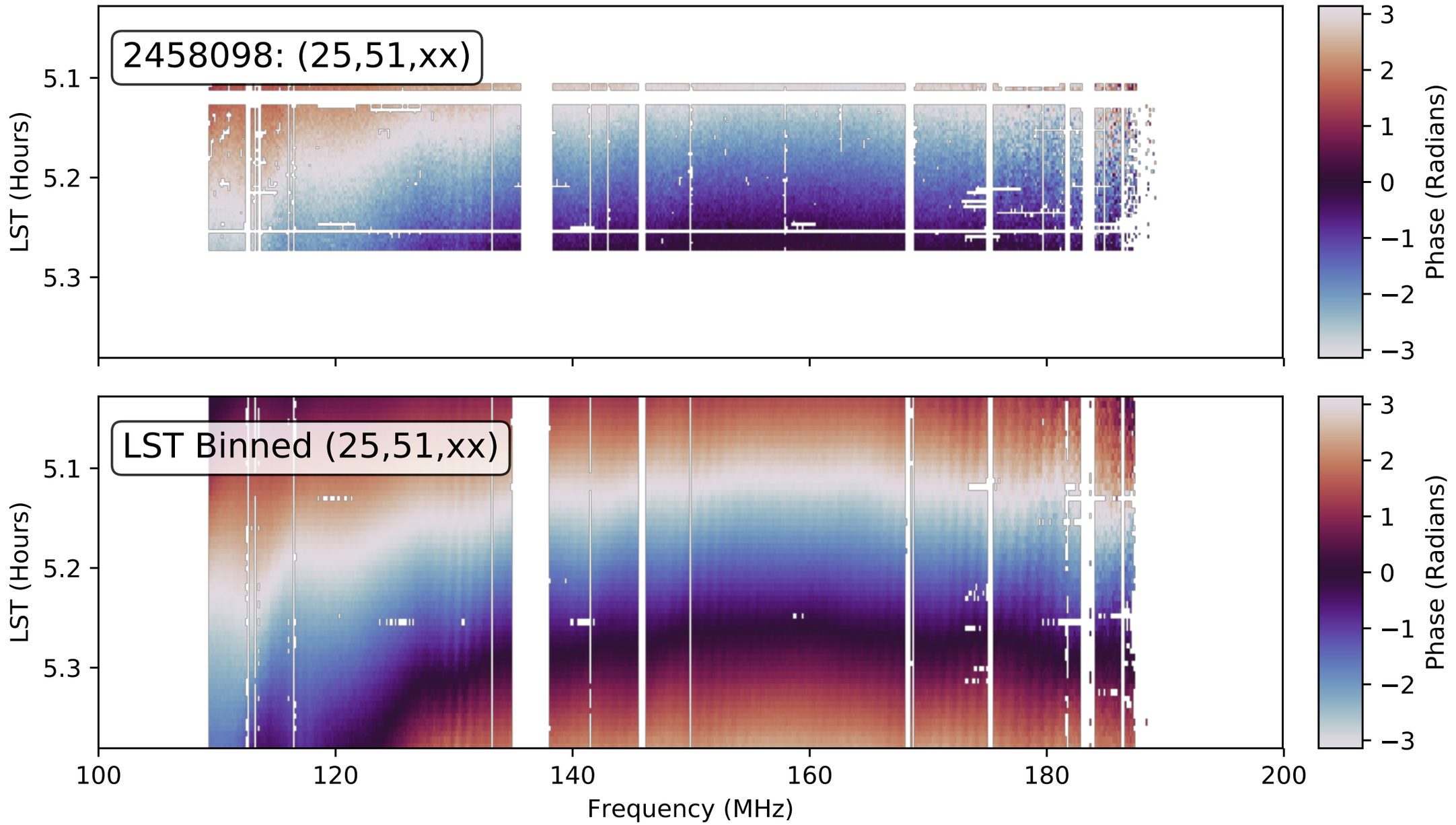
Smoothcal



HERA Memo #69

Year 1 “Analysis”

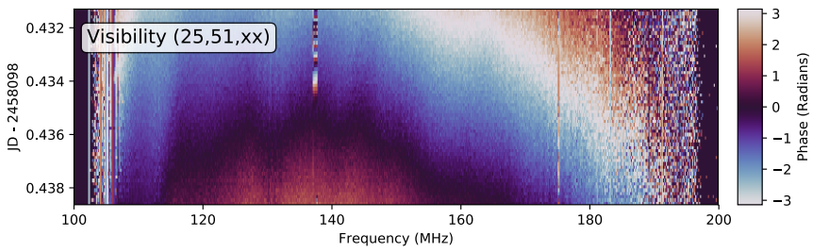
LST Binning



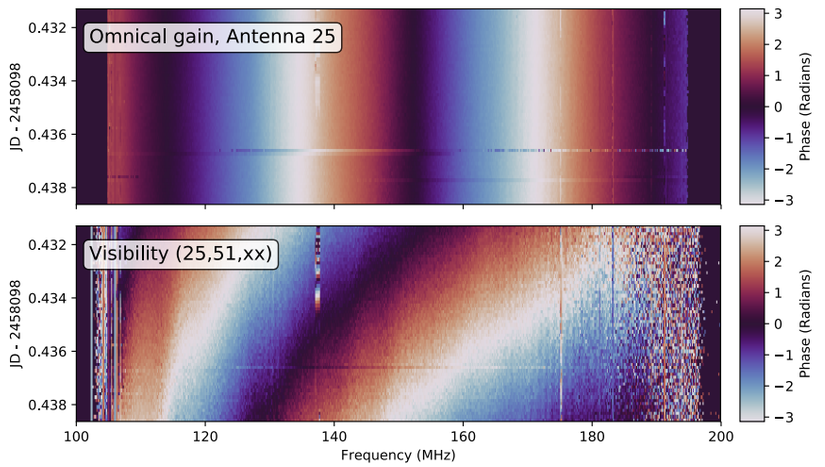
HERA Memo #69

Year 1 “Analysis”

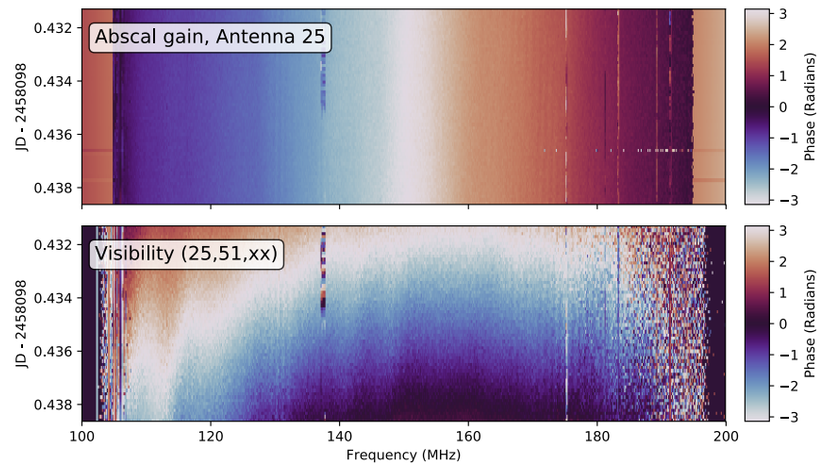
Raw Data



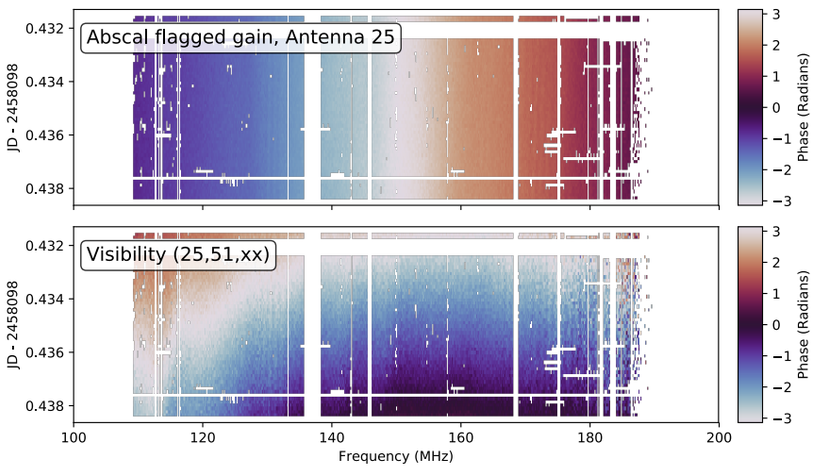
Redcal



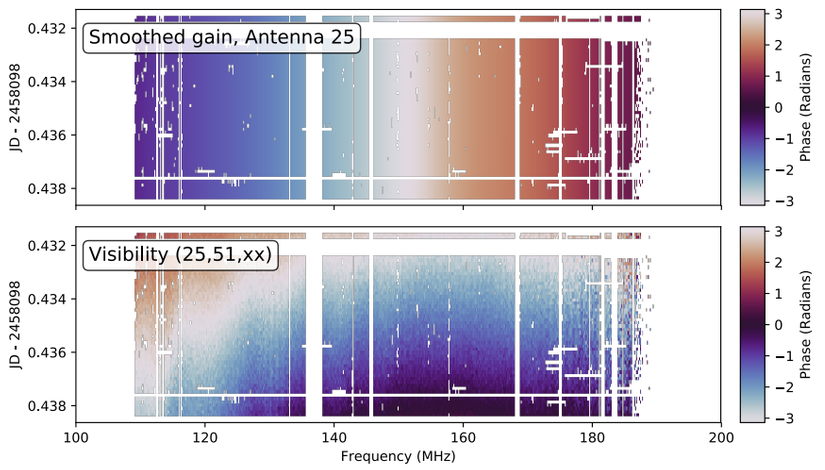
Abscal



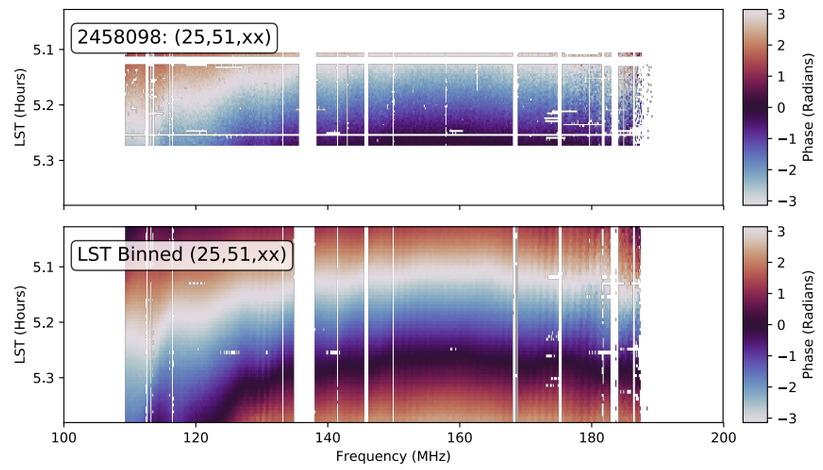
XRFI



Smoothcal

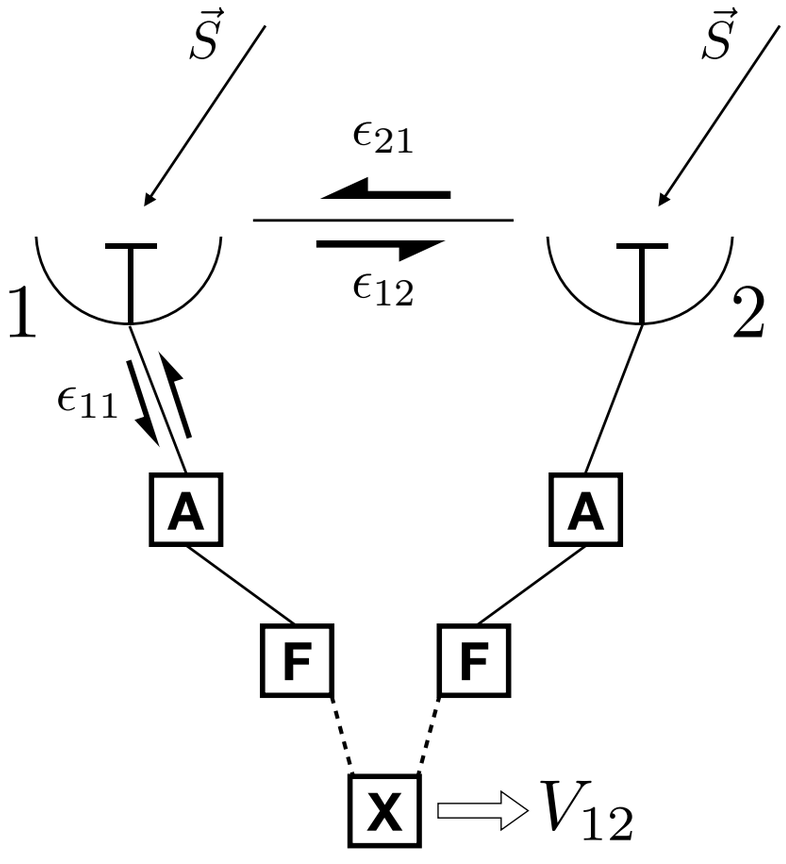


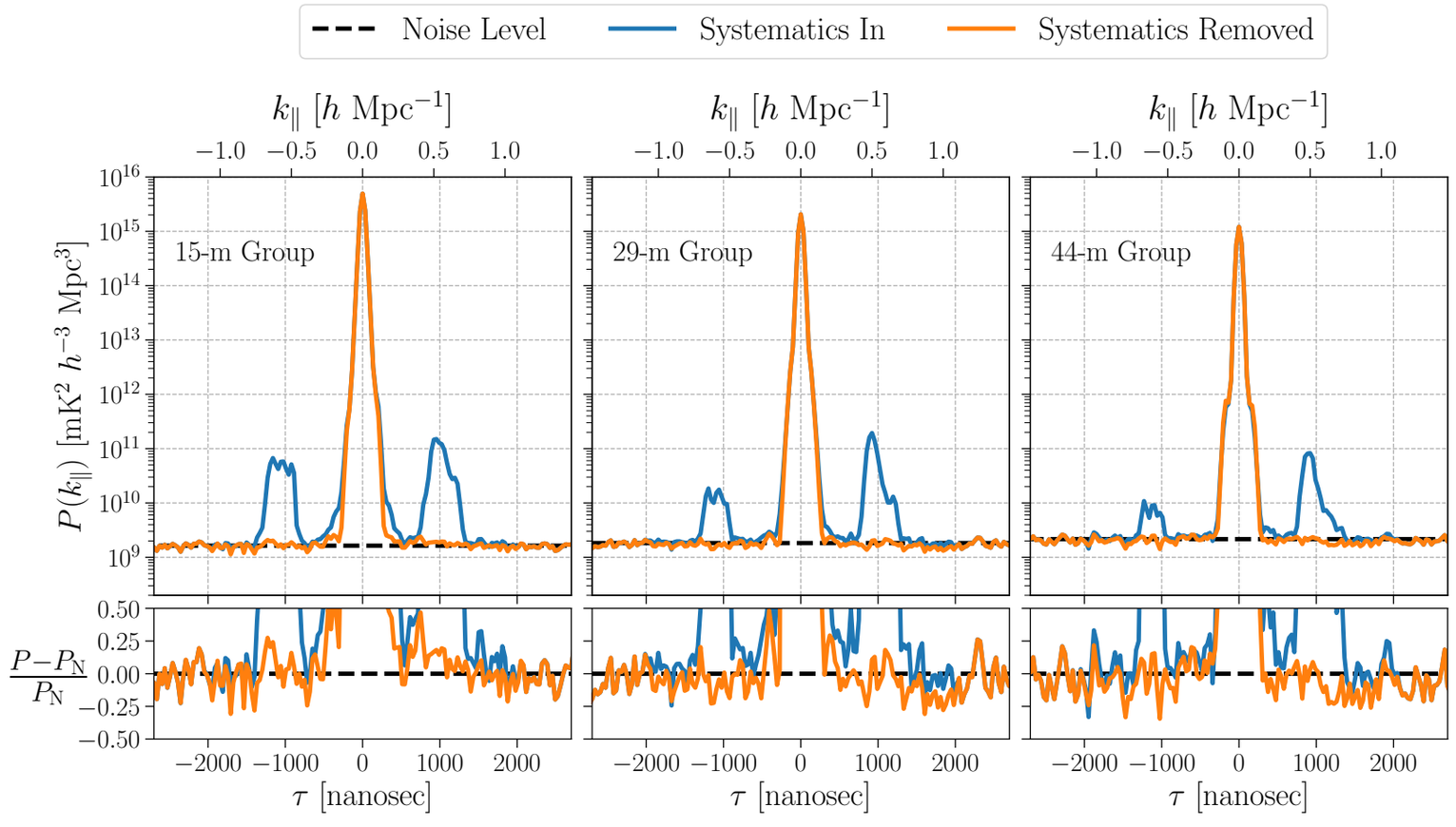
LST Binning



HERA Memo #69

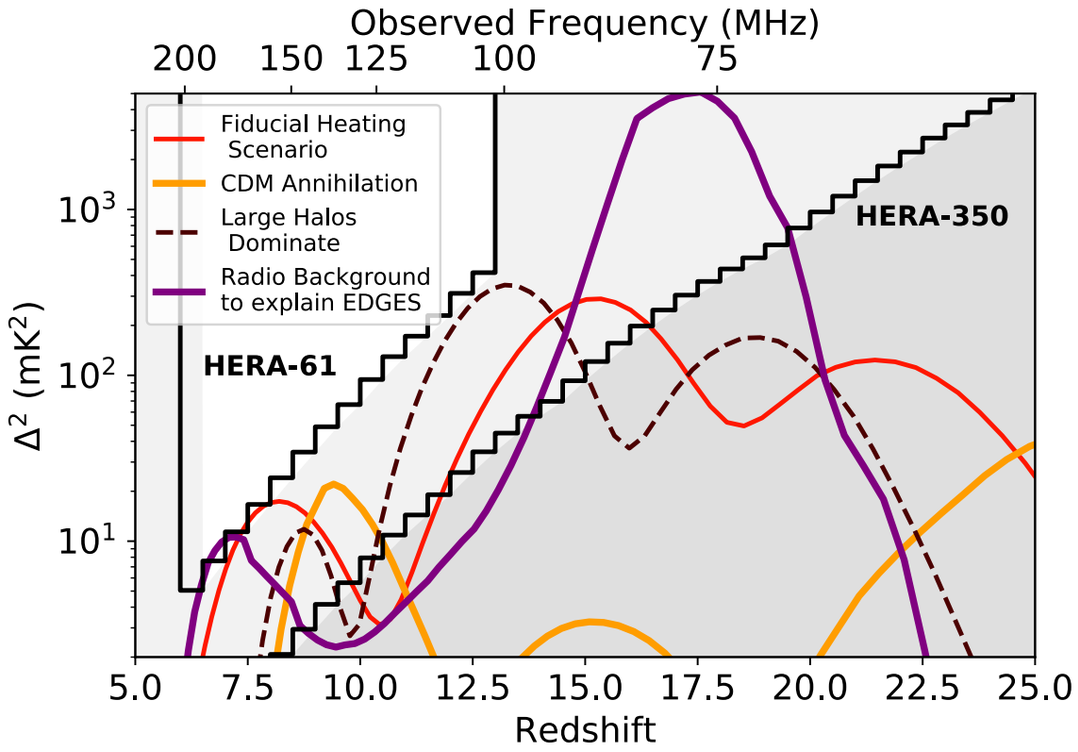
Systematics Removal





Kern, 2019a,b

HERA Upgrades

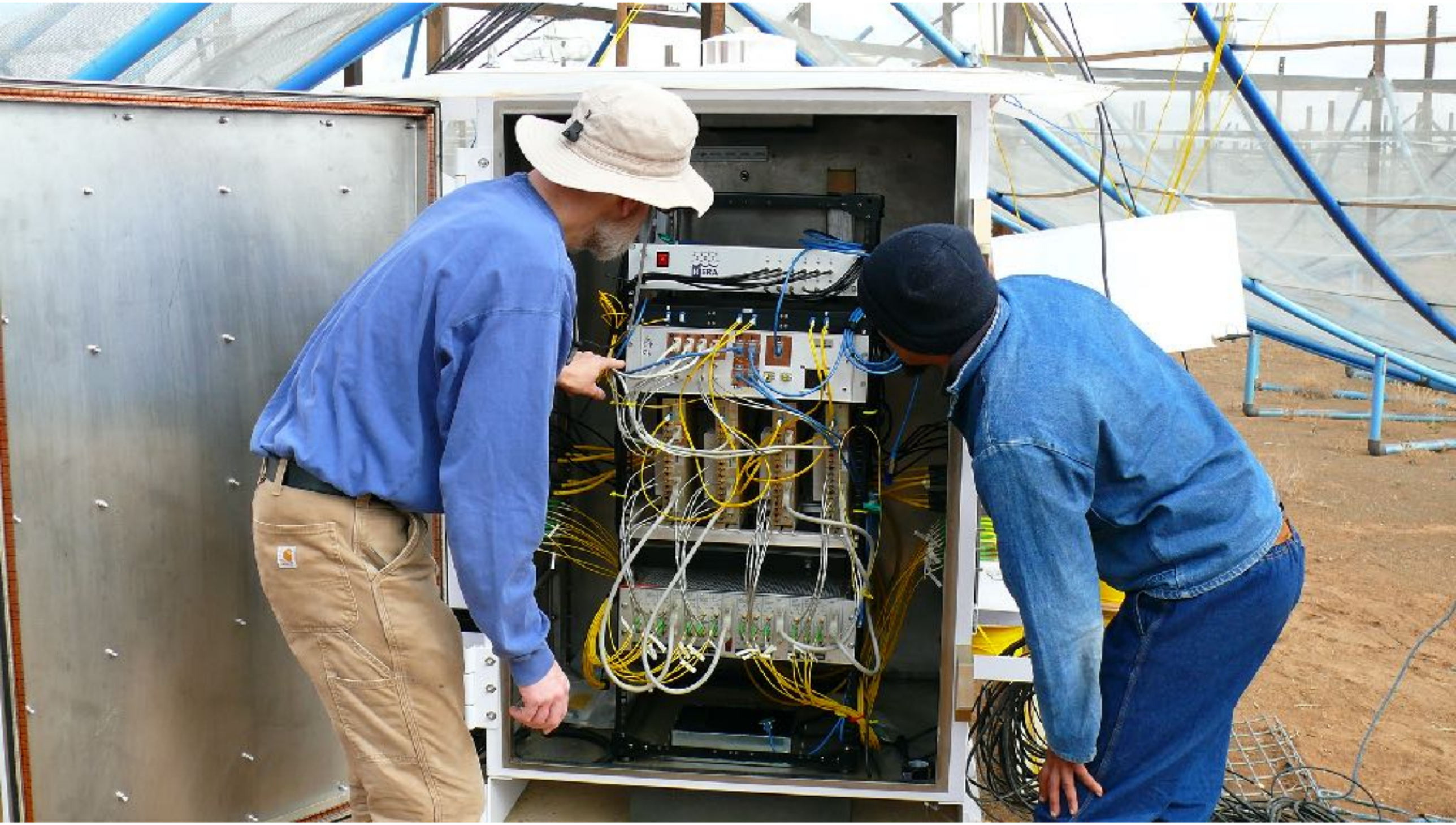


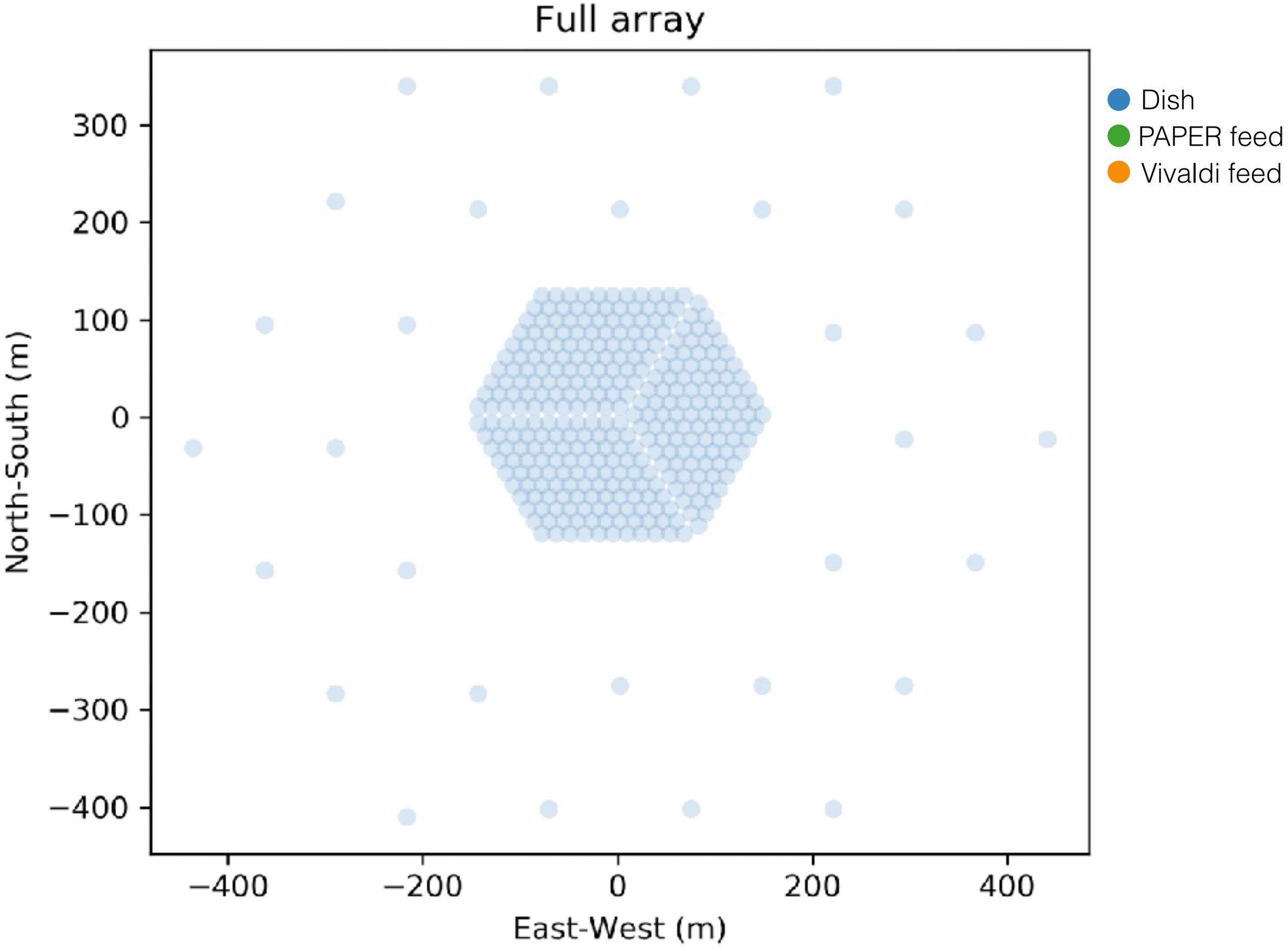
→ Go low!

- Snaps → More bandwidth (Cosmic Dawn + FGs)
- RFoF → Mitigate reflections
- Switchable noise sources → Improved calibration
- Baseline dependent averaging → Compress data

Broadband feeds

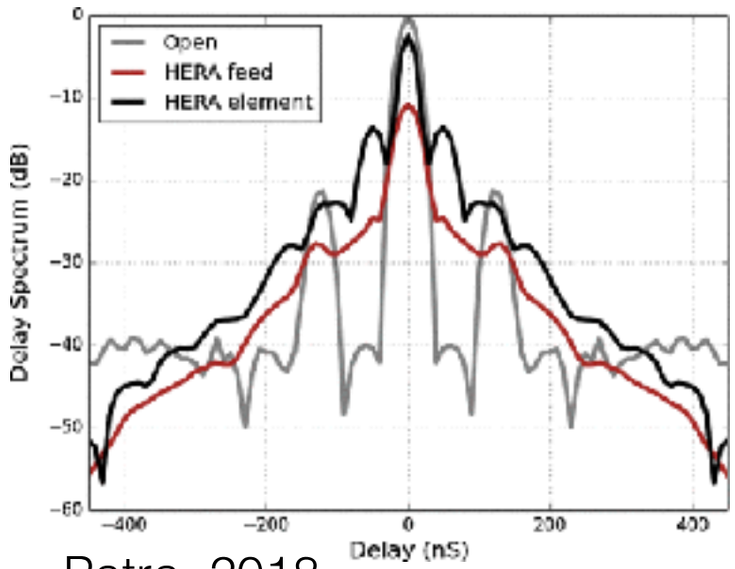
50 - 250 MHz — Includes EDGES band


MERA

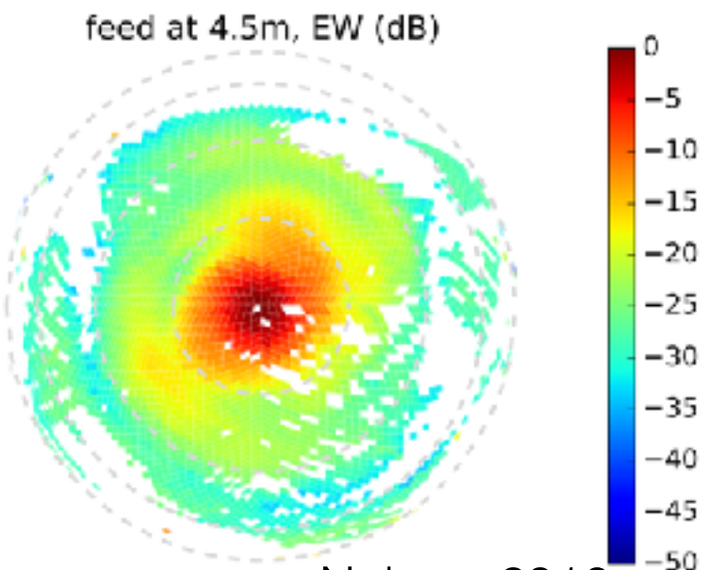

Full array
Dish
PAPER feed
Vivaldi feed
North-South (m)
300
200
100
0
−100
−200
−300
−400
−400
−200
0
200
400
East-West (m)

Beam Characterization

Measurements

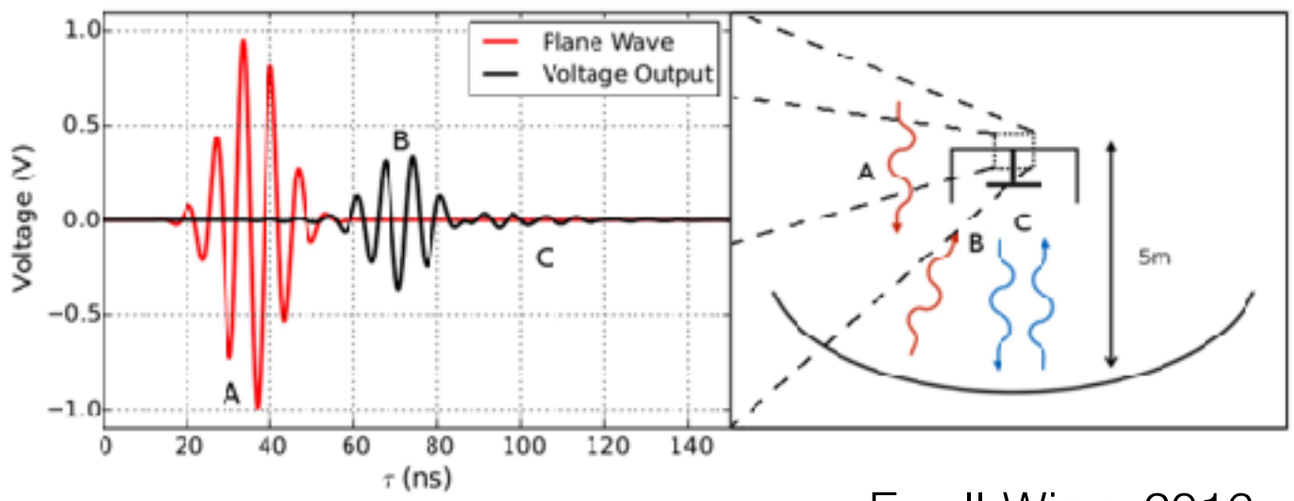


Patra, 2018

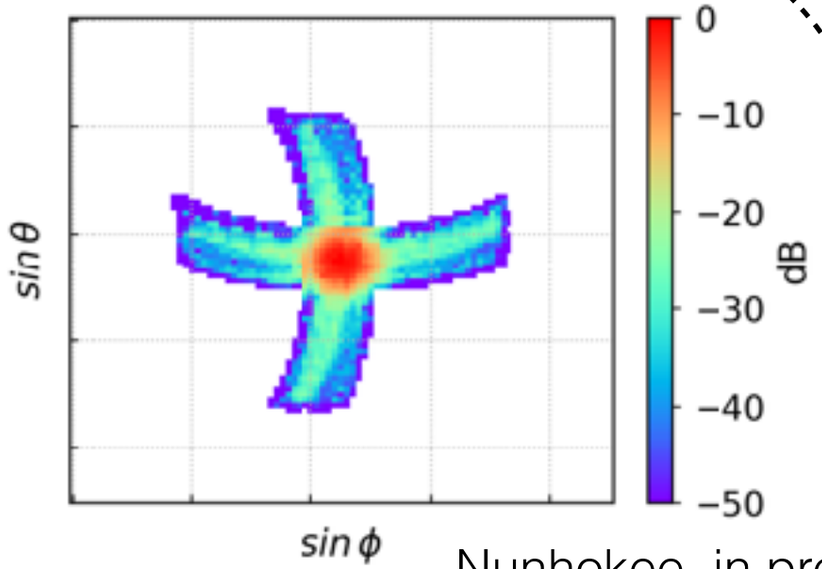


Neben, 2016

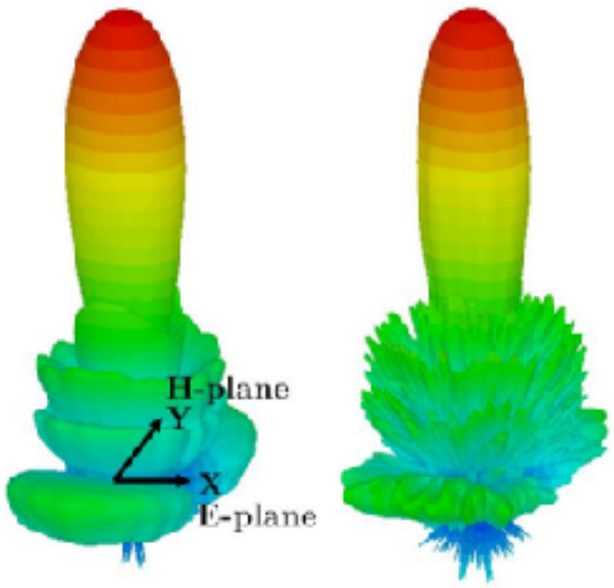
Simulations



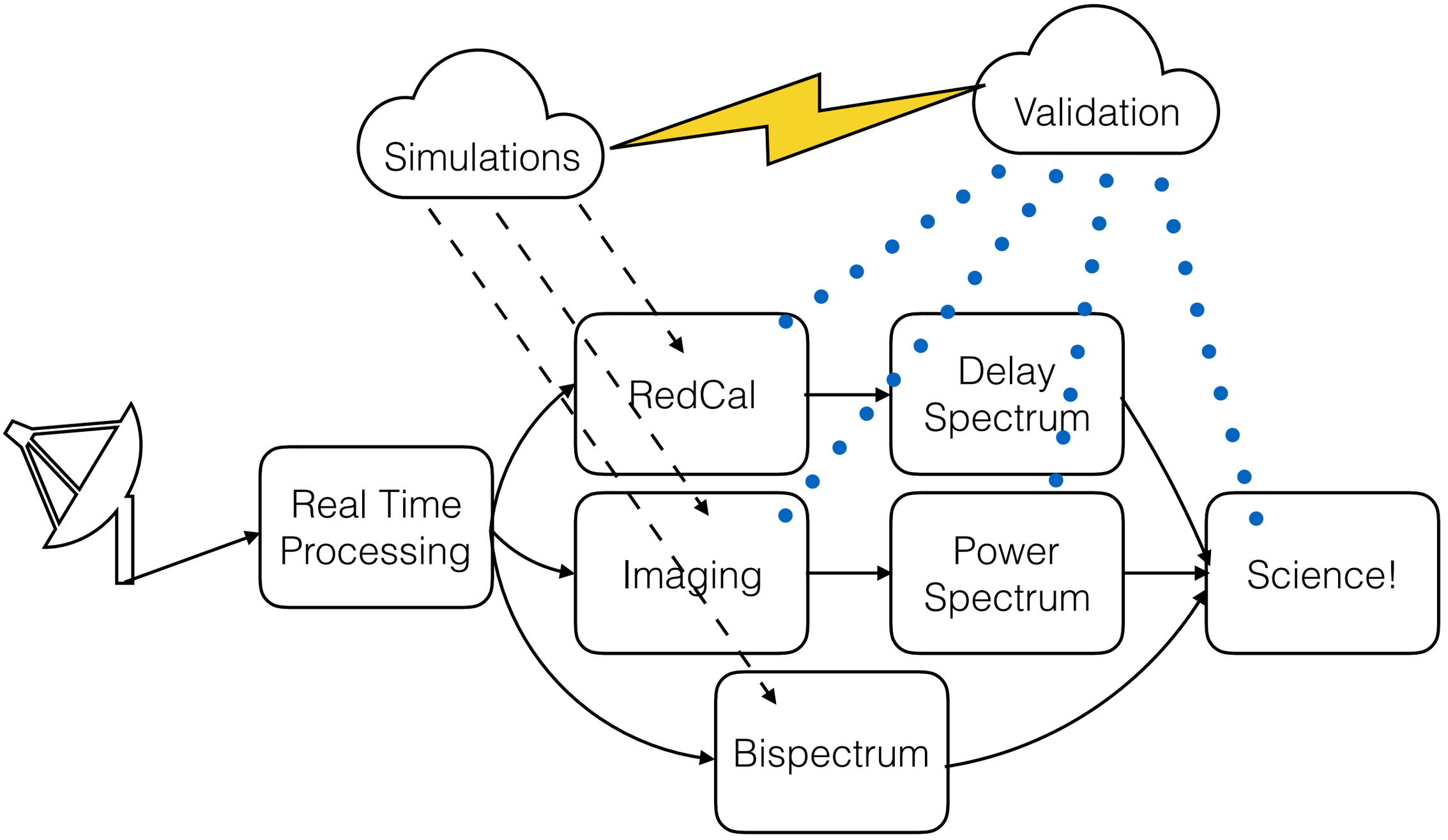
Ewall-Wice, 2016



Nunhokee, in prep



Fagnoni, in review


Simulations
Validation
RedCal
Delay Spectrum
Real Time Processing
Imaging
Power Spectrum
Science!
Bispectrum

Validation Philosophy

The validation group seeks to…

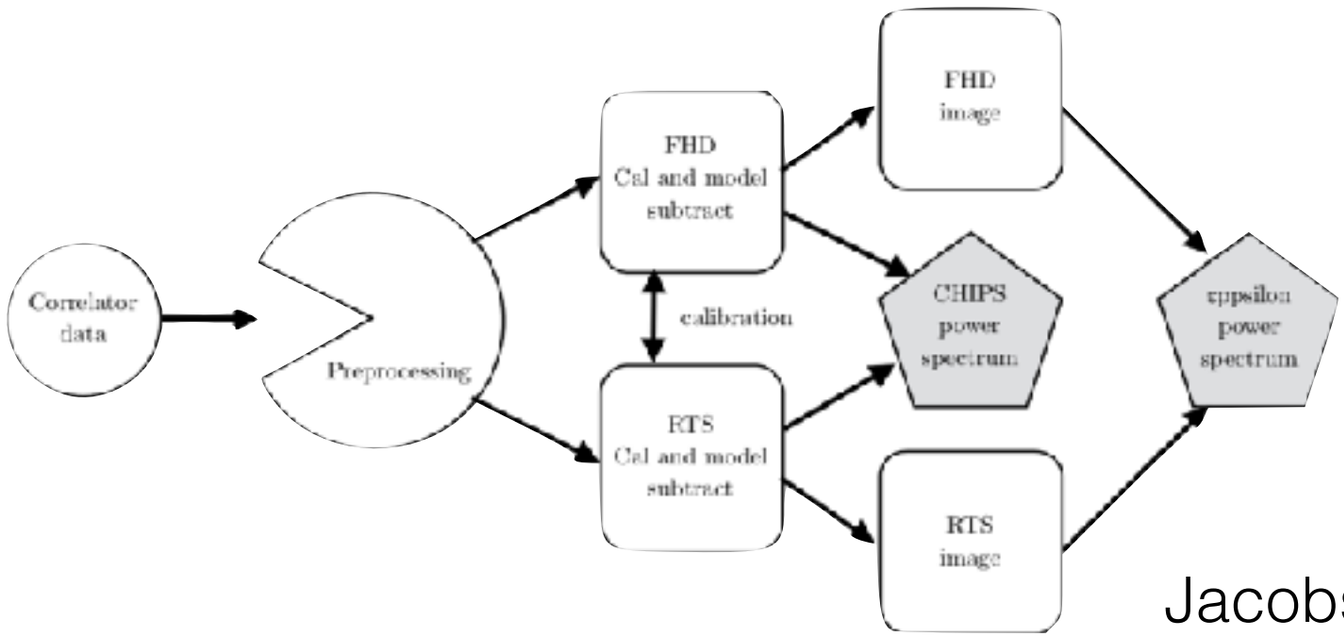
- validate the HERA data pipeline software and algorithms by testing the specific software against simulations where the expected output is well understood theoretically.

- develop and define increasingly sophisticated simulations on which to build an end-to-end test and validation of the HERA pipeline.

*HERA Validation mission statement

Pipeline Lessons

MWA pipeline(s)



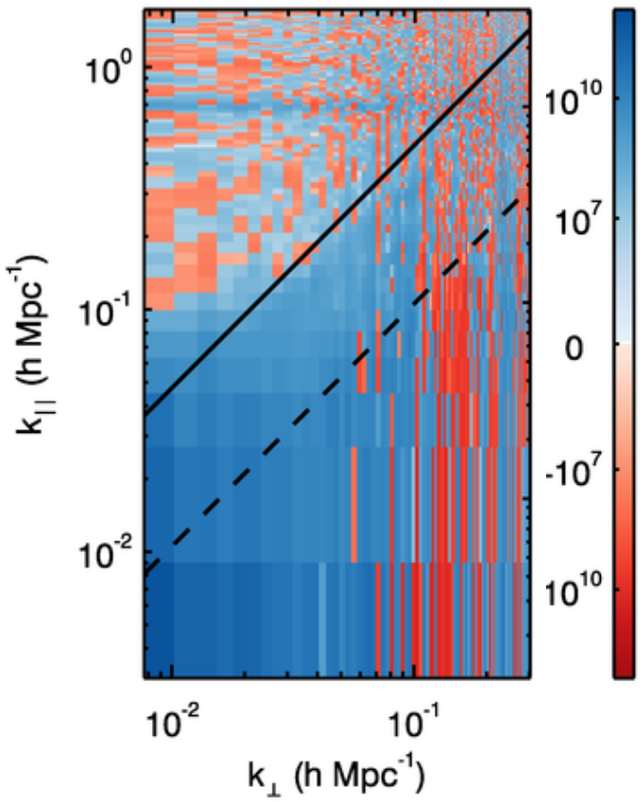
Jacobs, 2016

Parallel pipelines
with **exchangeable** data products

MWA pipeline(s)

2 fhd_core/fhd_struct_init_antenna.pro View

```
@@ -86,7 +86,7 @@ dec_use=dec_arr[valid_i]
86  86
87  87   ;NOTE: Eq2Hor REQUIRES Jdate to have the same number of elements as RA and Dec for precession!!
88  88   ;;NOTE: The NEW Eq2Hor REQUIRES Jdate to be a scalar! They created a new bug when they fixed the old one
89      -Eq2Hor,ra_use,dec_use,Jdate,alt_arr1,az_arr1,lat=obs.lat,lon=obs.lon,alt=obs.alt,precess=1
    89  +Eq2Hor,ra_use,dec_use,Jdate,alt_arr1,az_arr1,lat=obs.lat,lon=obs.lon,alt=obs.alt,precess=1,/nutate
90  90   za_arr=fltarr(psf_image_dim,psf_image_dim)+90. & za_arr[valid_i]=90.-alt_arr1
91  91   az_arr=fltarr(psf_image_dim,psf_image_dim) & az_arr[valid_i]=az_arr1
92  92
```

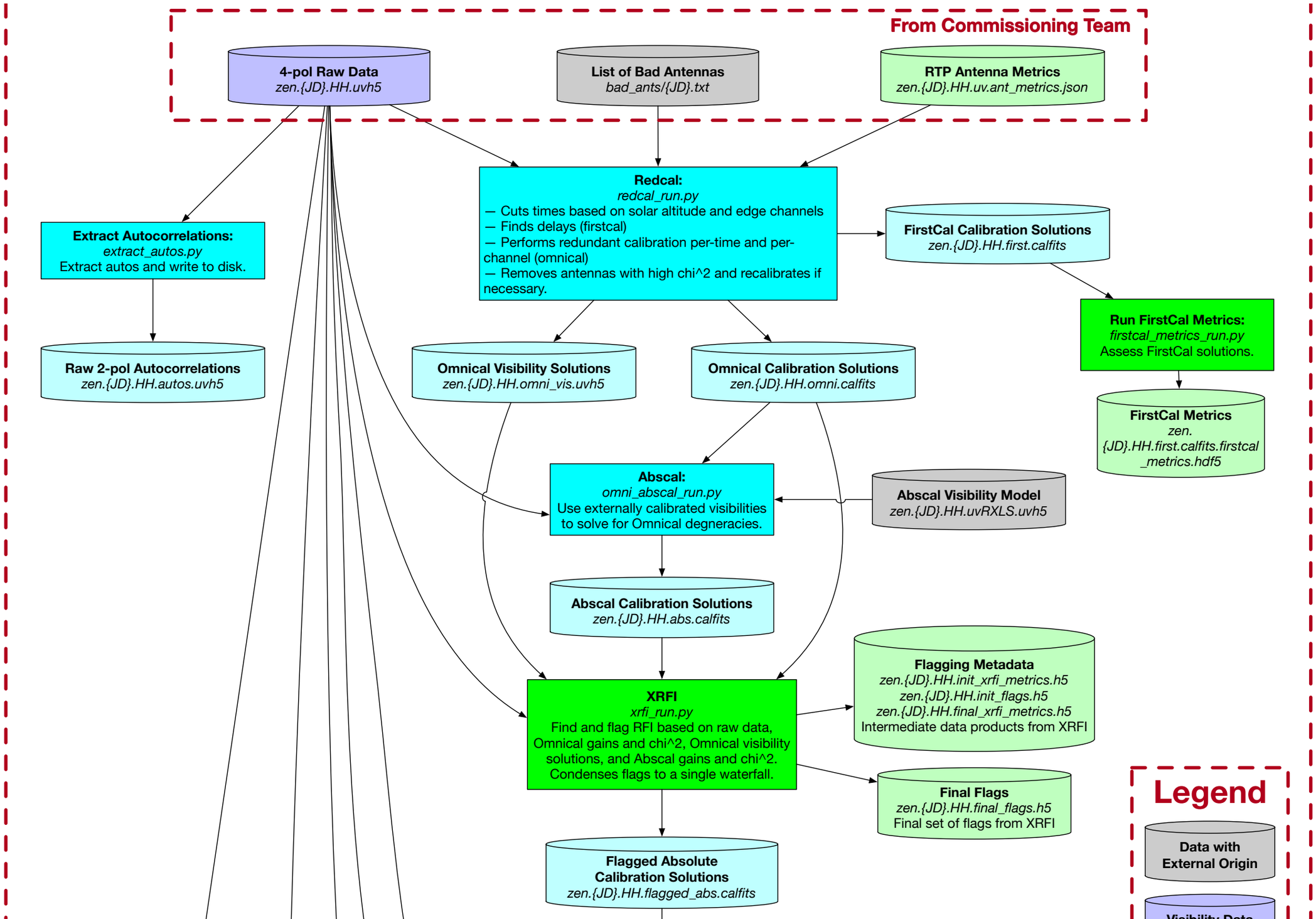


Regular integration tests

End-to-end simulations

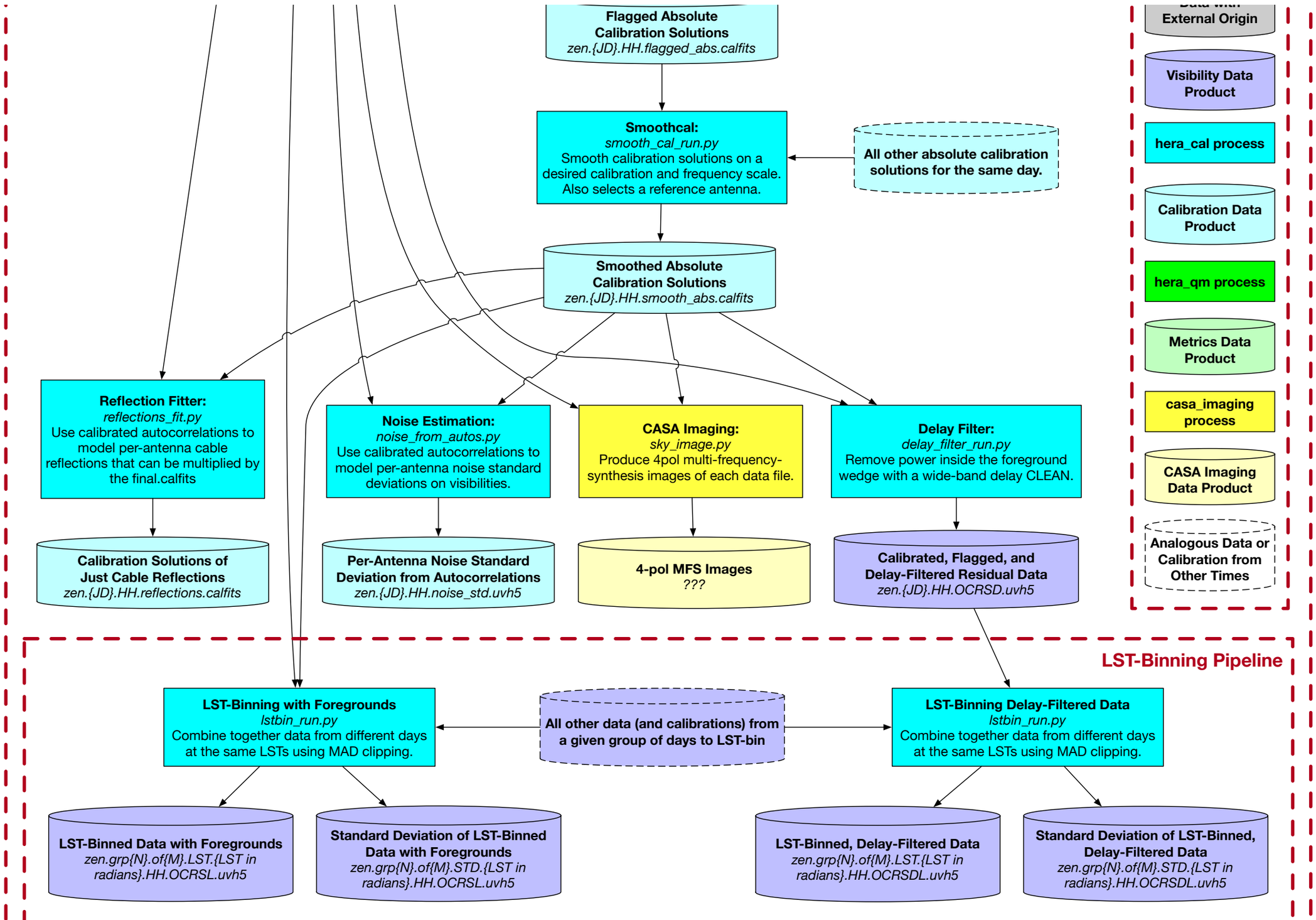
HERA Pipeline

HERA Memo #69



HERA Pipeline

HERA Memo #69



Software Standards

All “production software” must:

- Use continuous integration (travis, circle-ci)
  > 95% code coverage
- Be well documented
- Peer reviewed (every commit to master + design reviews)
- Define interfaces
  - pyuvdata!

Radio Astronomy Software Group (RASG)

github.com/RadioAstronomySoftwareGroup

- A home for software packages of broad use to the community (not telescope or analysis specific)
  - pyuvdata • pyuvsim • pygitversion •
- Community driven
- Repository/best practice templates

Adam Beardsley - adam.p.beardsley@gmail.com