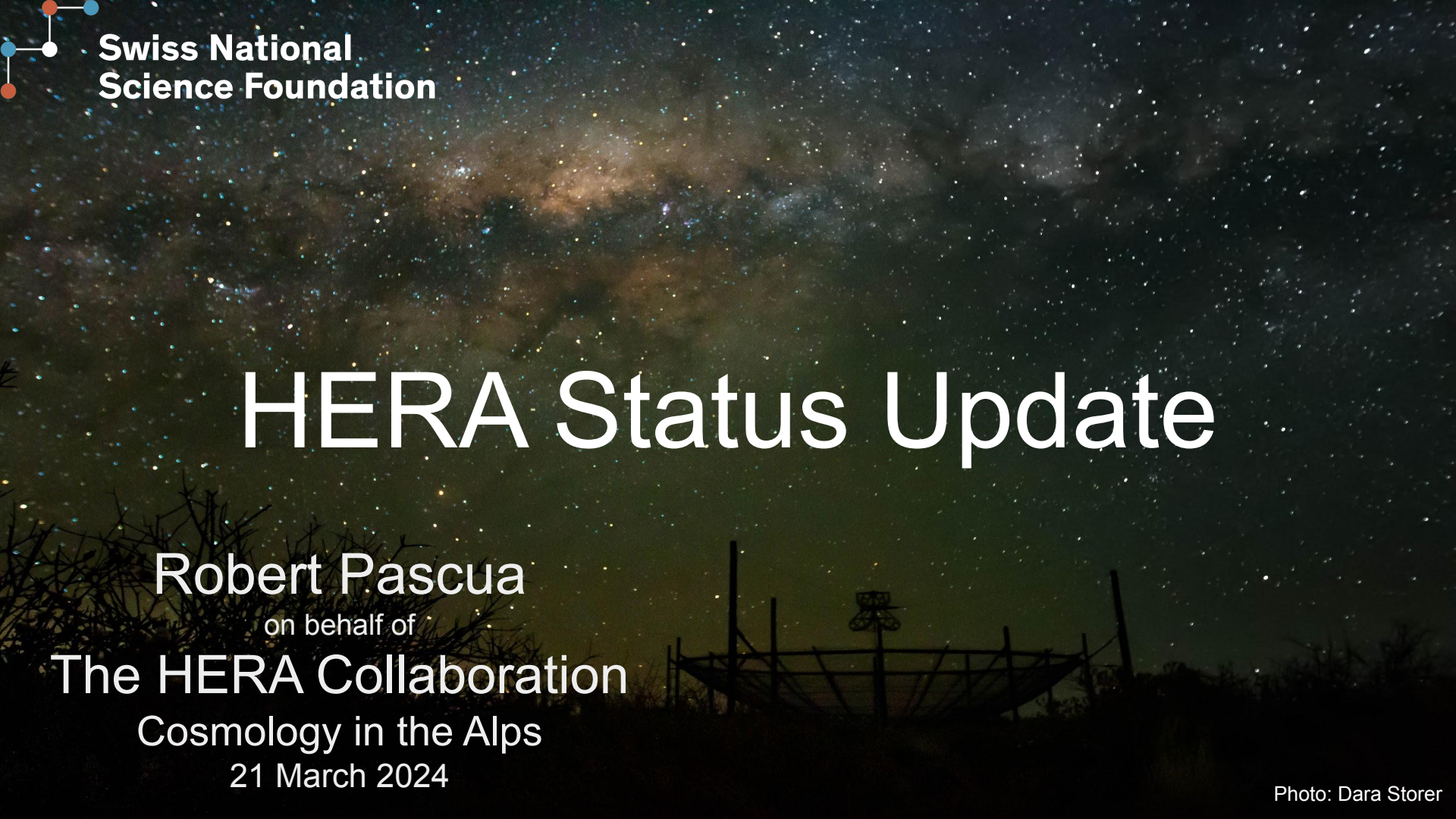


HERA Status Update

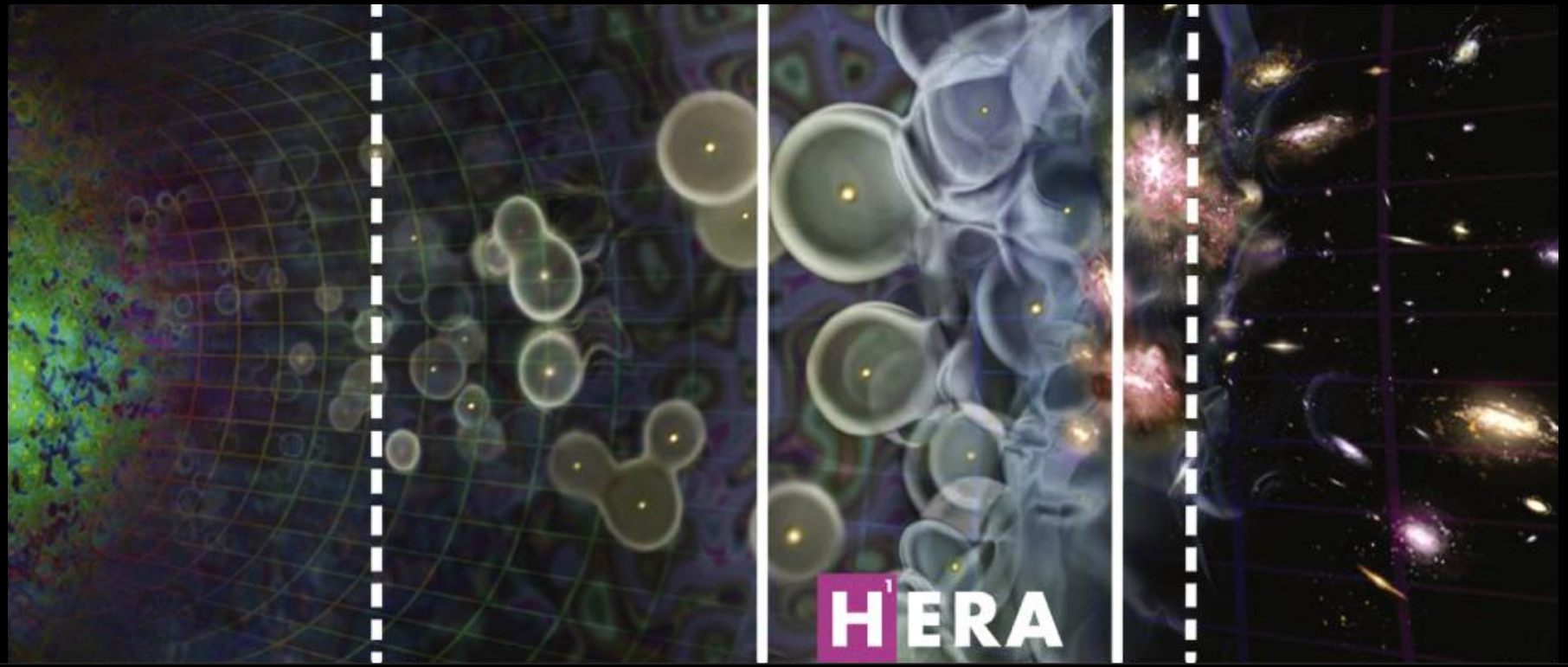
Robert Pascua
on behalf of
The HERA Collaboration

Cosmology in the Alps
21 March 2024

Photo: Dara Storer

Science Case

adapted from DeBoer+ 2017;
adapted from Loeb 2006
doi: 10.1088/1538-3873/129/974/045001



Science Case

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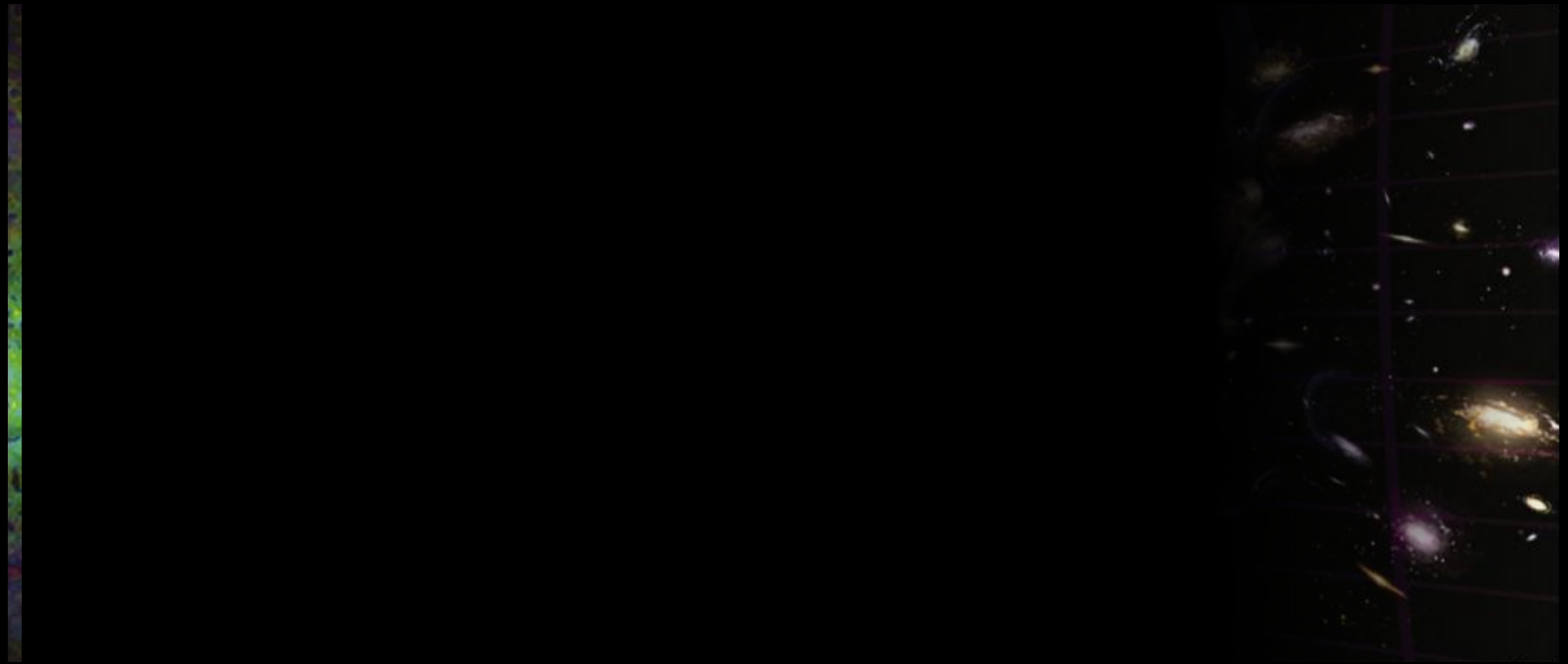


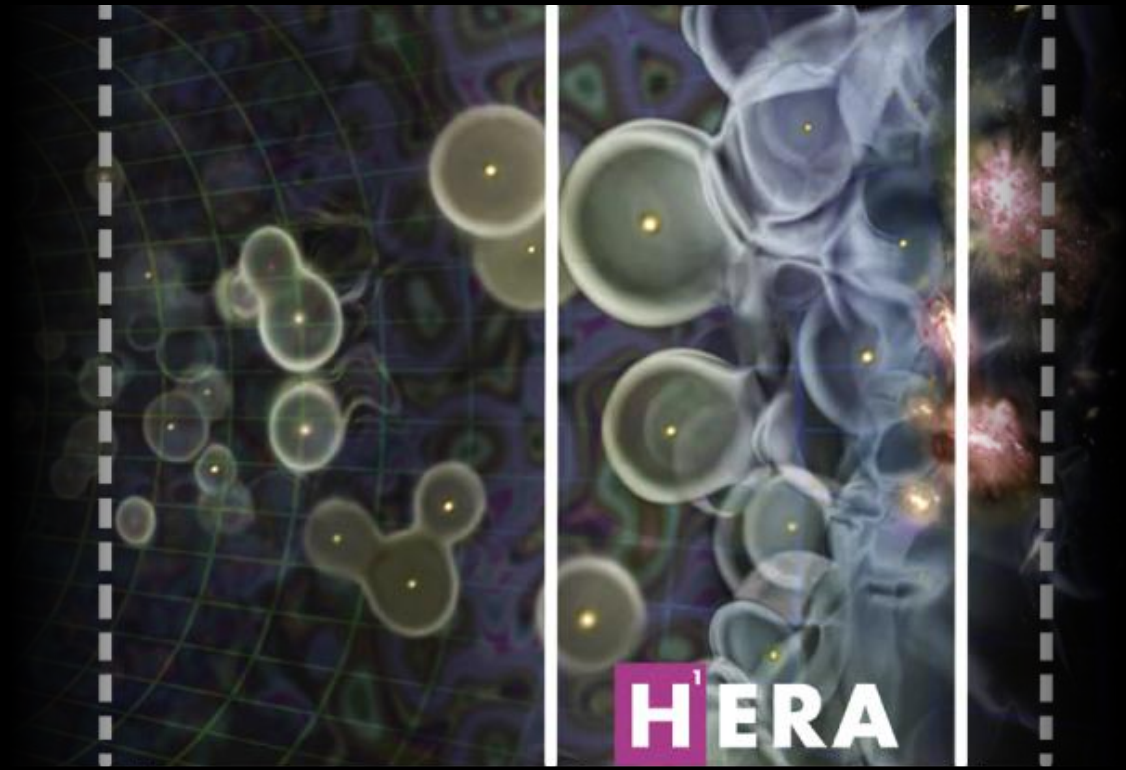
z ~ 1100
400,000

z ~ 0
13 Billion

Time since the Big Bang in years →

Science Case

adapted from DeBoer+ 2017;
adapted from Loeb 2006
doi: 10.1088/1538-3873/129/974/045001



The Goal

Measure the statistics of fluctuations in the cosmologically-redshifted 21-cm signal.

Science Case

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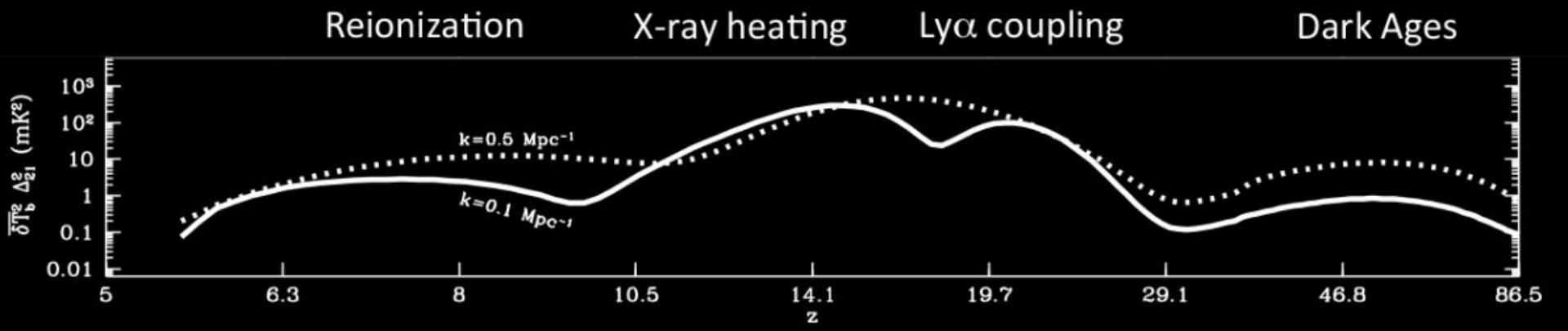
Measure the statistics of fluctuations in the cosmologically-redshifted 21-cm signal.

$$\langle \tilde{T}(\boldsymbol{k})\tilde{T}(\boldsymbol{k}')^* \rangle = (2\pi)^3 \delta^D(\boldsymbol{k}-\boldsymbol{k}')P(\boldsymbol{k})$$



Mesinger, Greig, Sobacchi 2016
doi: 10.1093/mnras/stw831

Science Case

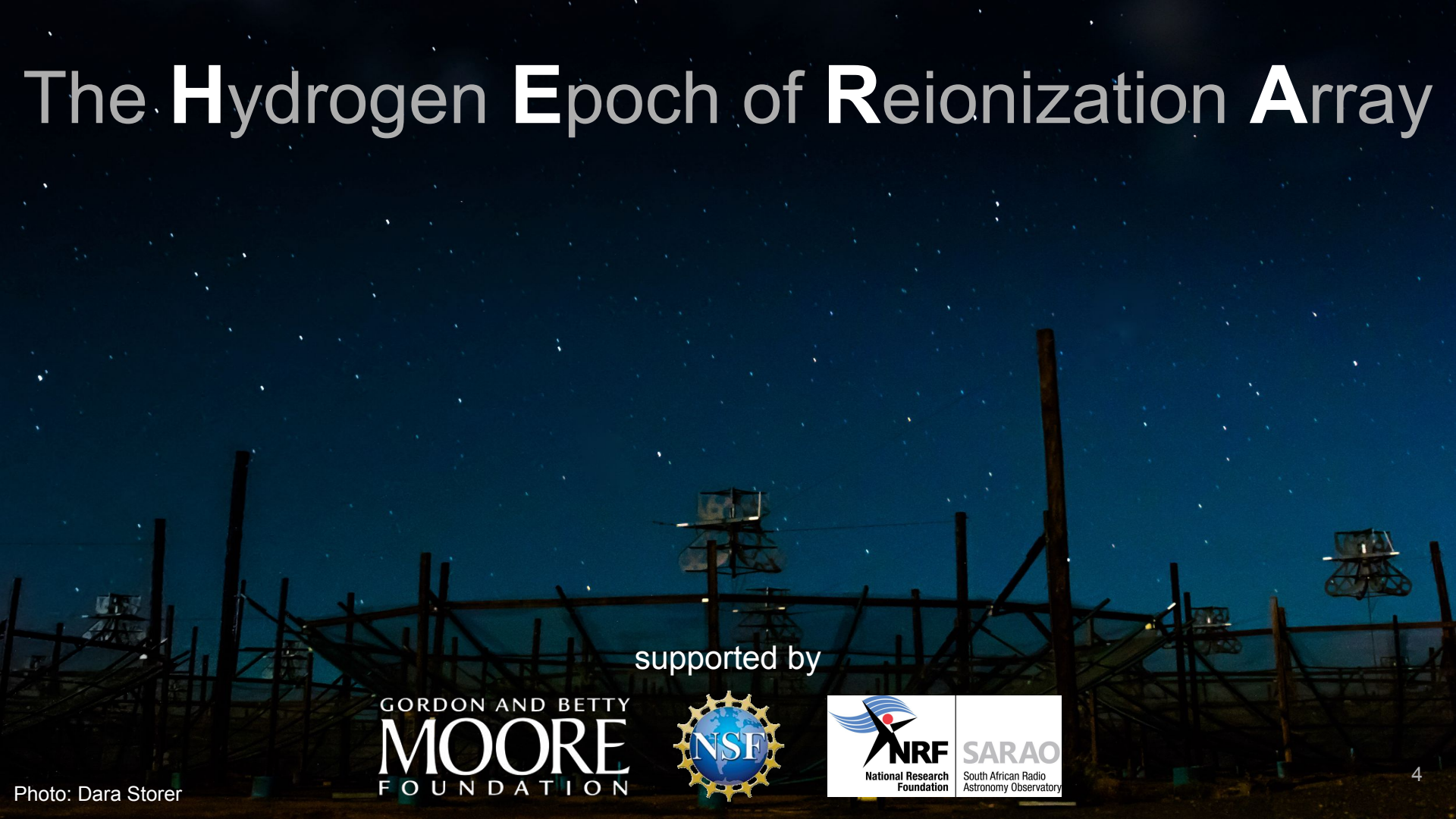
What were the first stars and galaxies like?

Science Case

What were the first stars and galaxies like?

How did Reionization unfold?

The **H**ydrogen **E**poch of **R**eionization **A**rray



supported by

GORDON AND BETTY MOORE FOUNDATION

NSF

NRF National Research Foundation | SARAO South African Radio Astronomy Observatory

Photo: Dara Storer


UNIVERSITY OF KWAZULU-NATAL
VE RI TAS HARVARD
TSI
NRAO
SKA
SKA AFRICA
SQUARE KILOMETRE ARRAY
RESPICE PROSPICE
UNIVERSITY of the WESTERN CAPE
BROWN
Penn
UNIVERSITY OF CAMBRIDGE
SCUOLA NORMALE SUPERIORE
CAL POLY POMONA
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
ARIZONA STATE UNIVERSITY
1885
THE UNIVERSITY OF CALIFORNIA
UCLA
THE UNIVERSITY OF CALIFORNIA BERKELEY
1868
UNIVERSITY OF WASHINGTON
1861
MANCHESTER
1824
The University of Manchester


HERA
HERA
ARDER
BETTER
ASTER
STRONGER

HERA Overview

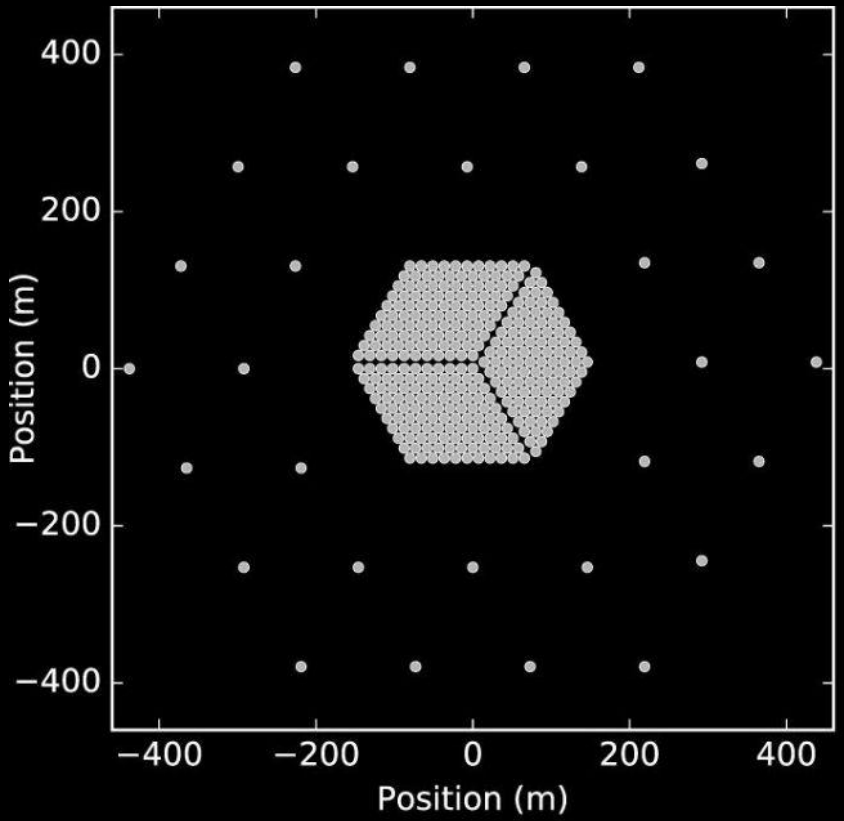
Google Maps

HERA Overview

Google Maps

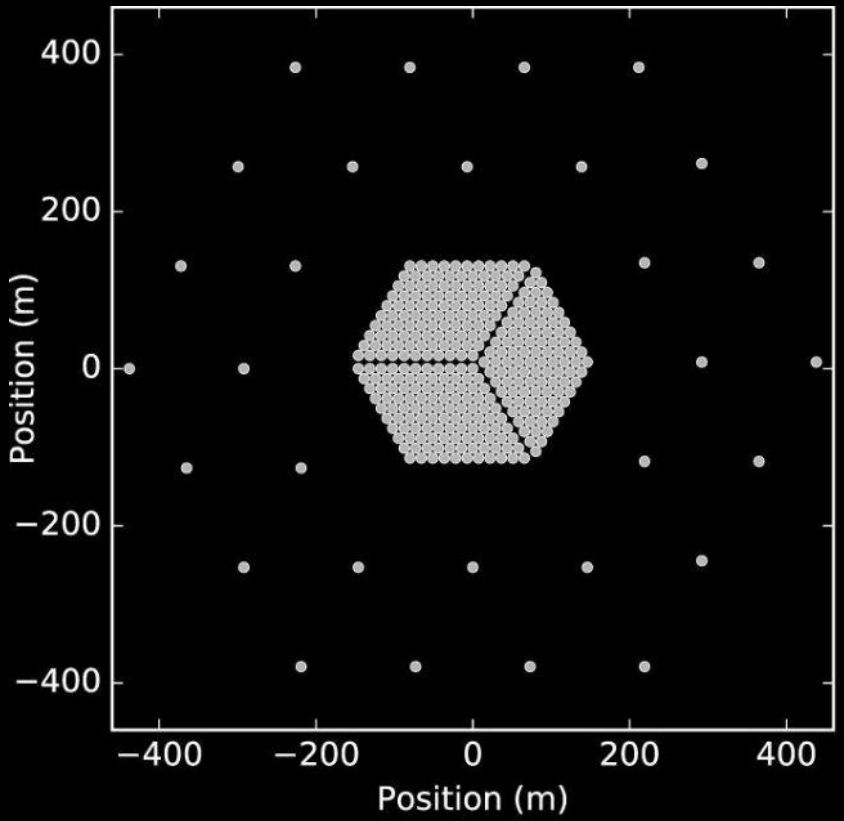
HERA Overview

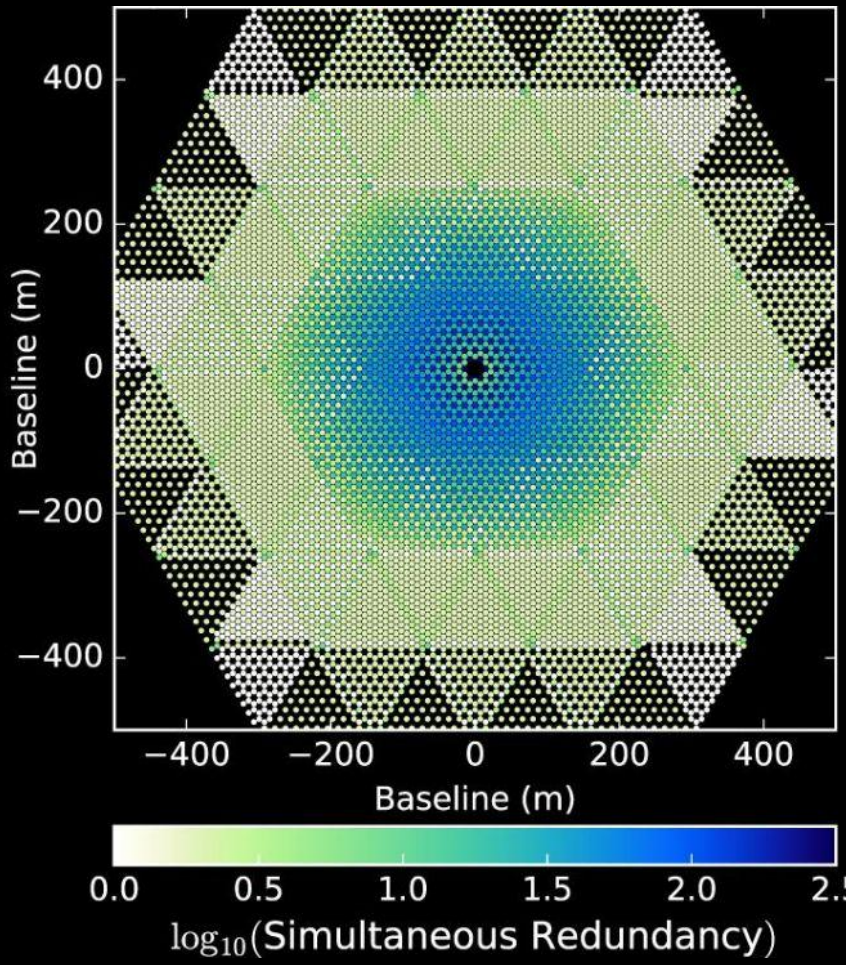
Observation Strategy



DeBoer+ 2017
doi: 10.1088/1538-3873/129/974/045001

Observation Strategy

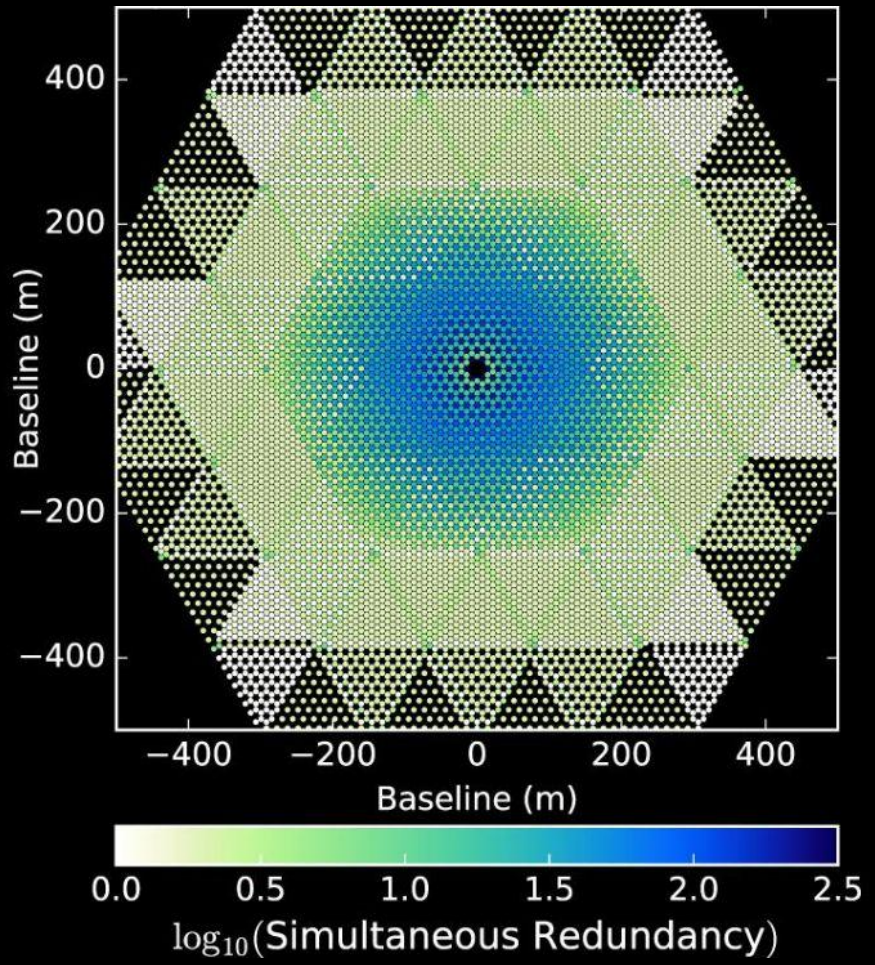




DeBoer+ 2017
doi: 10.1088/1538-3873/129/974/045001

Observation Strategy

Improve instantaneous sensitivity through redundancy



DeBoer+ 2017
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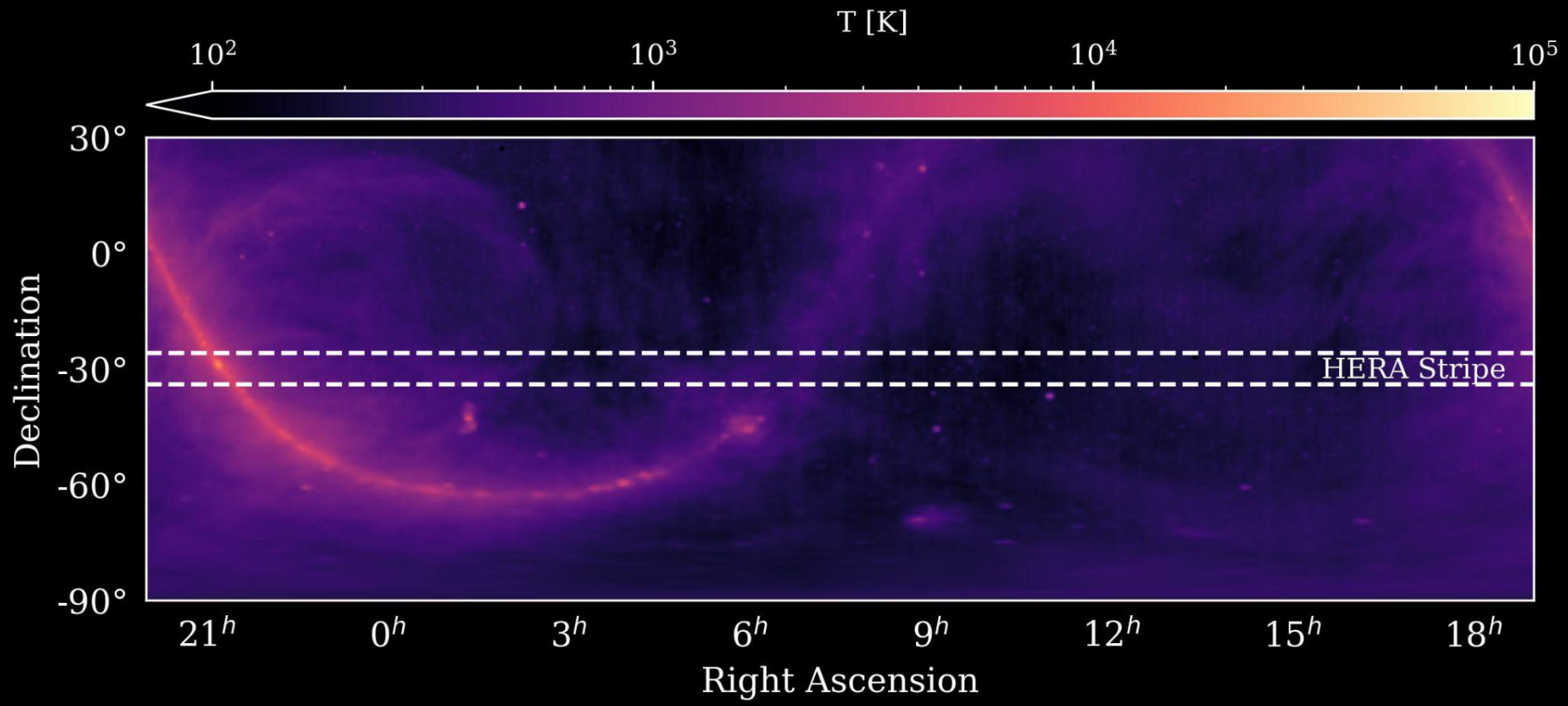
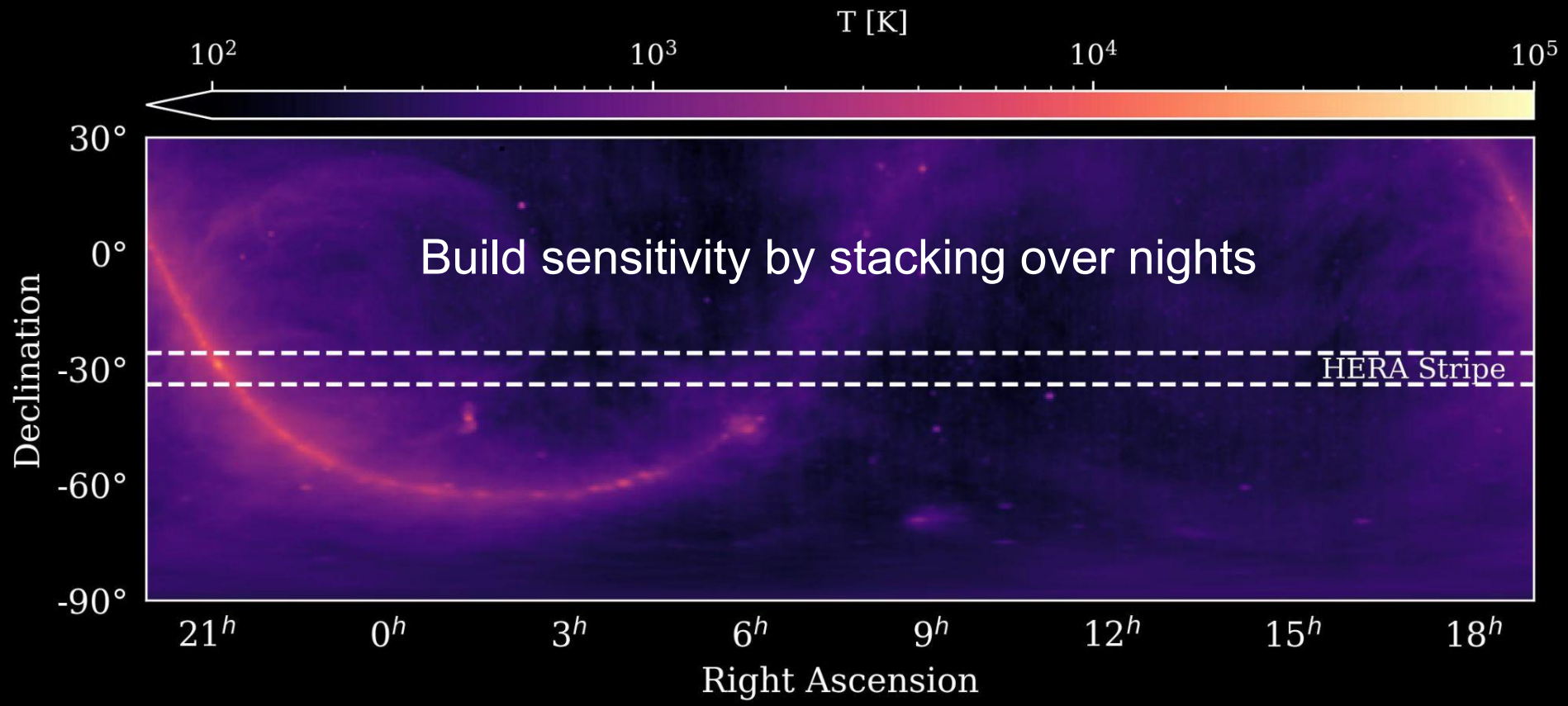
Observation Strategy

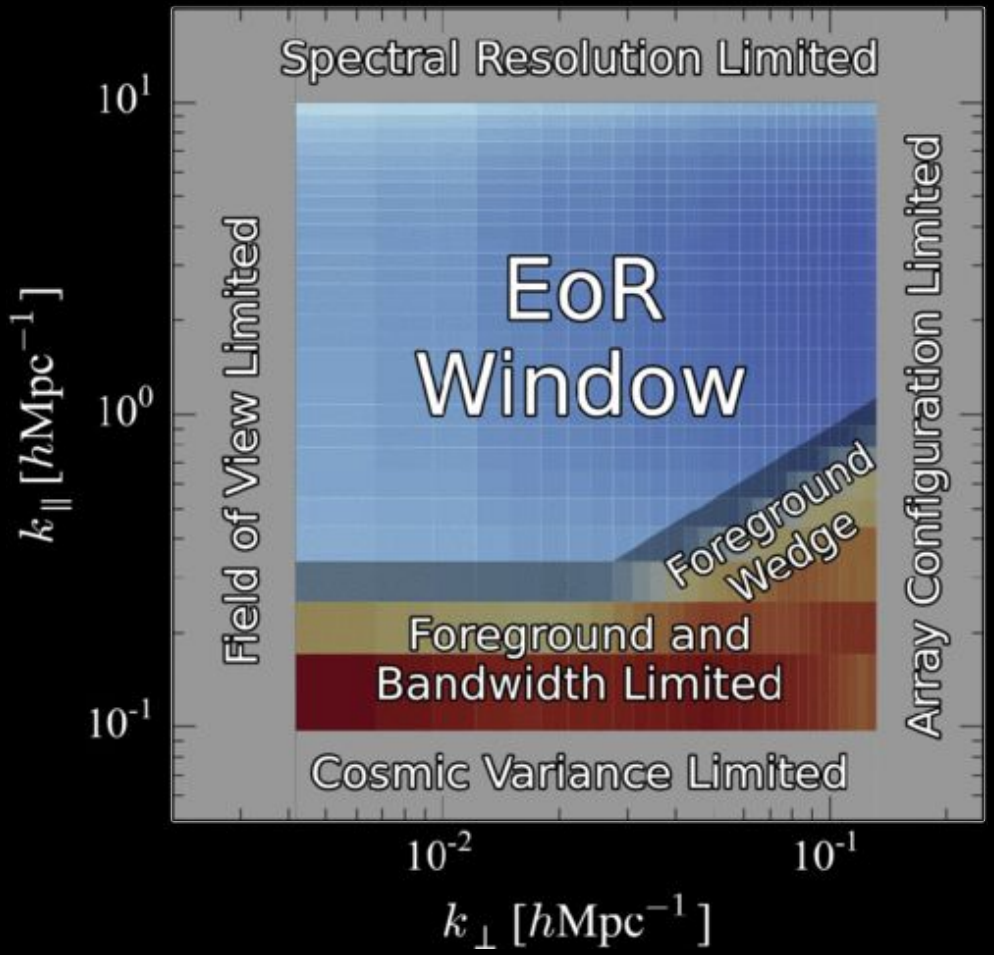


Observation Strategy



Observation Strategy

Liu, Parsons, Trott 2014
doi: 10.1103/PhysRevD.90.023018



Detect the 21-cm signal by avoiding the foregrounds in cosmological Fourier space

Later, we'll look at HERA's latest upper limits, but how are things looking now?

We’re analyzing two seasons of data in parallel…

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The 2020-2021 season was the first real test of the Phase II system.

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The 2022-2023 season brought with it a big increase in the number of antennas.

We’re analyzing two seasons of data in parallel…

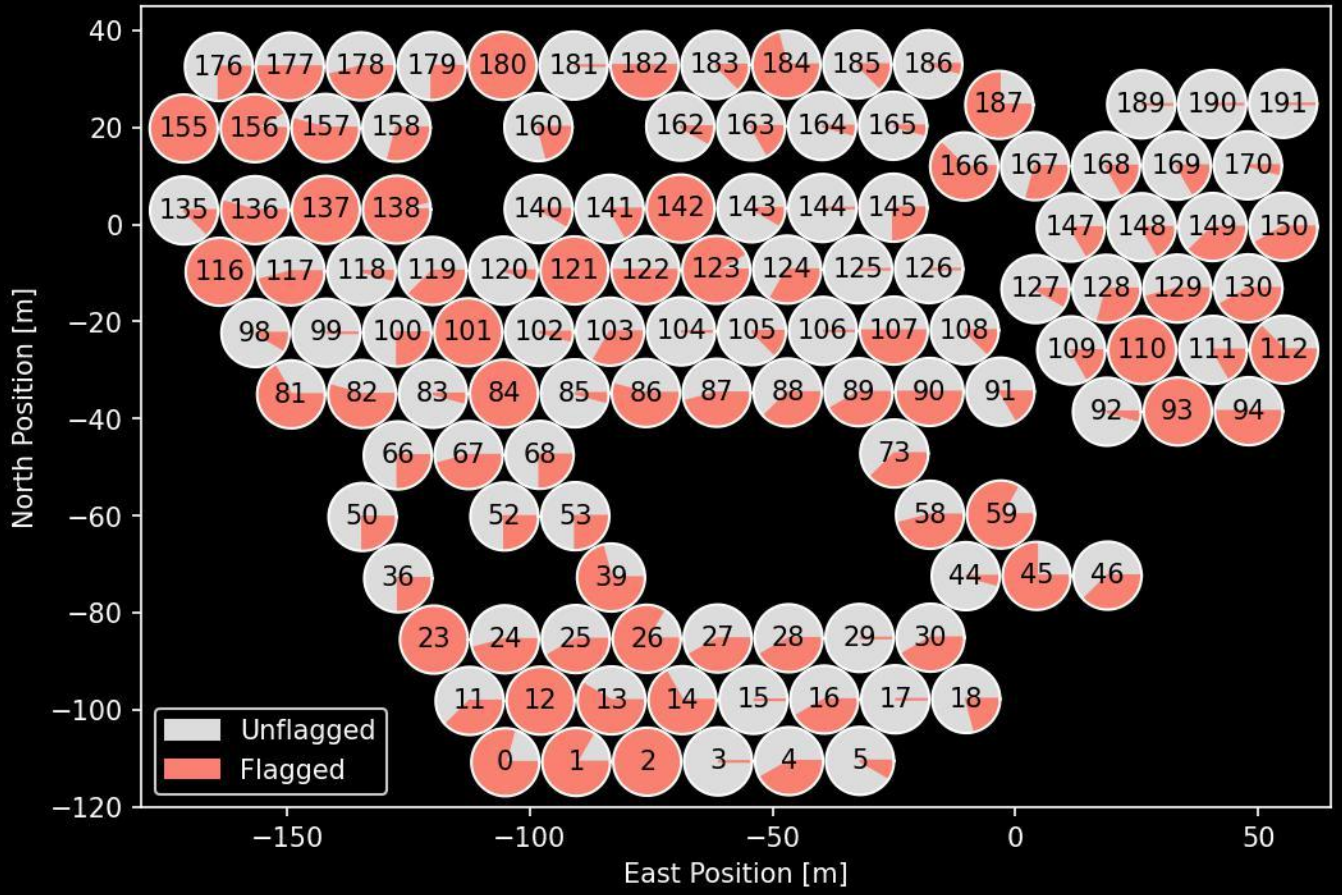
The 2020-2021 season was the first real test of the Phase II system.

The 2022-2023 season brought with it a big increase in the number of antennas.

What can we expect?

Current Status

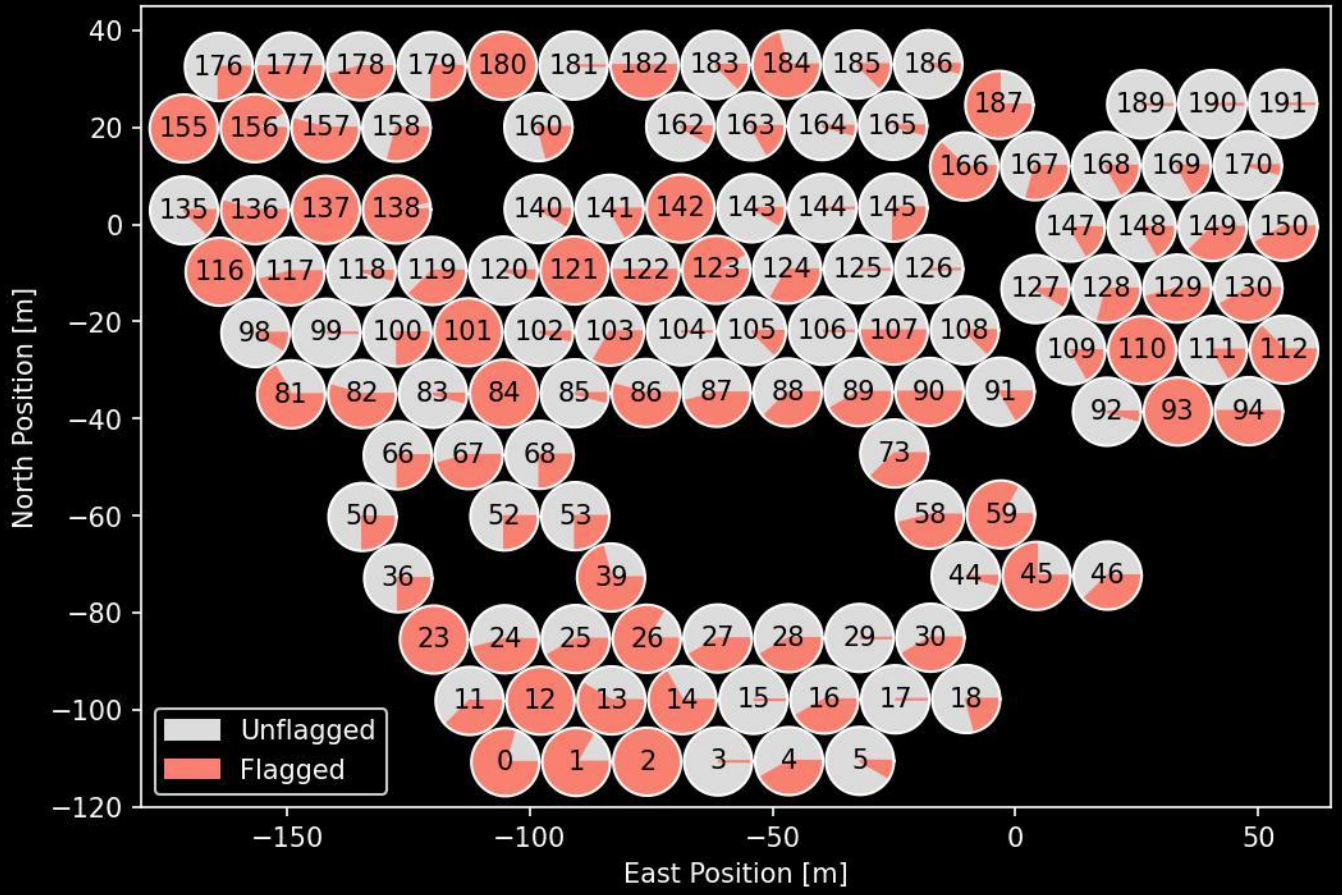
2020-2021 Season



Current Status

2020-2021 Season

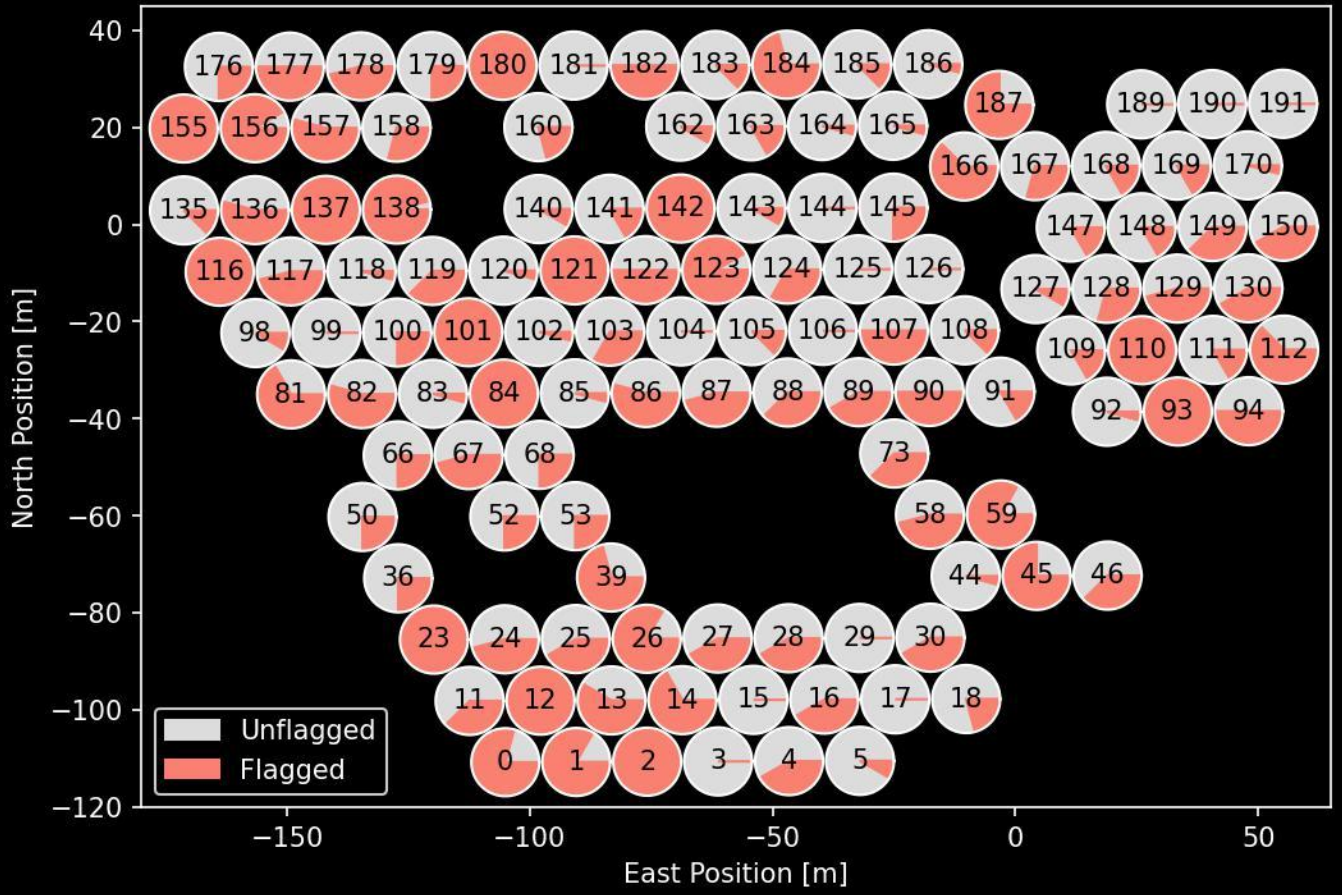
- 24 nights of data



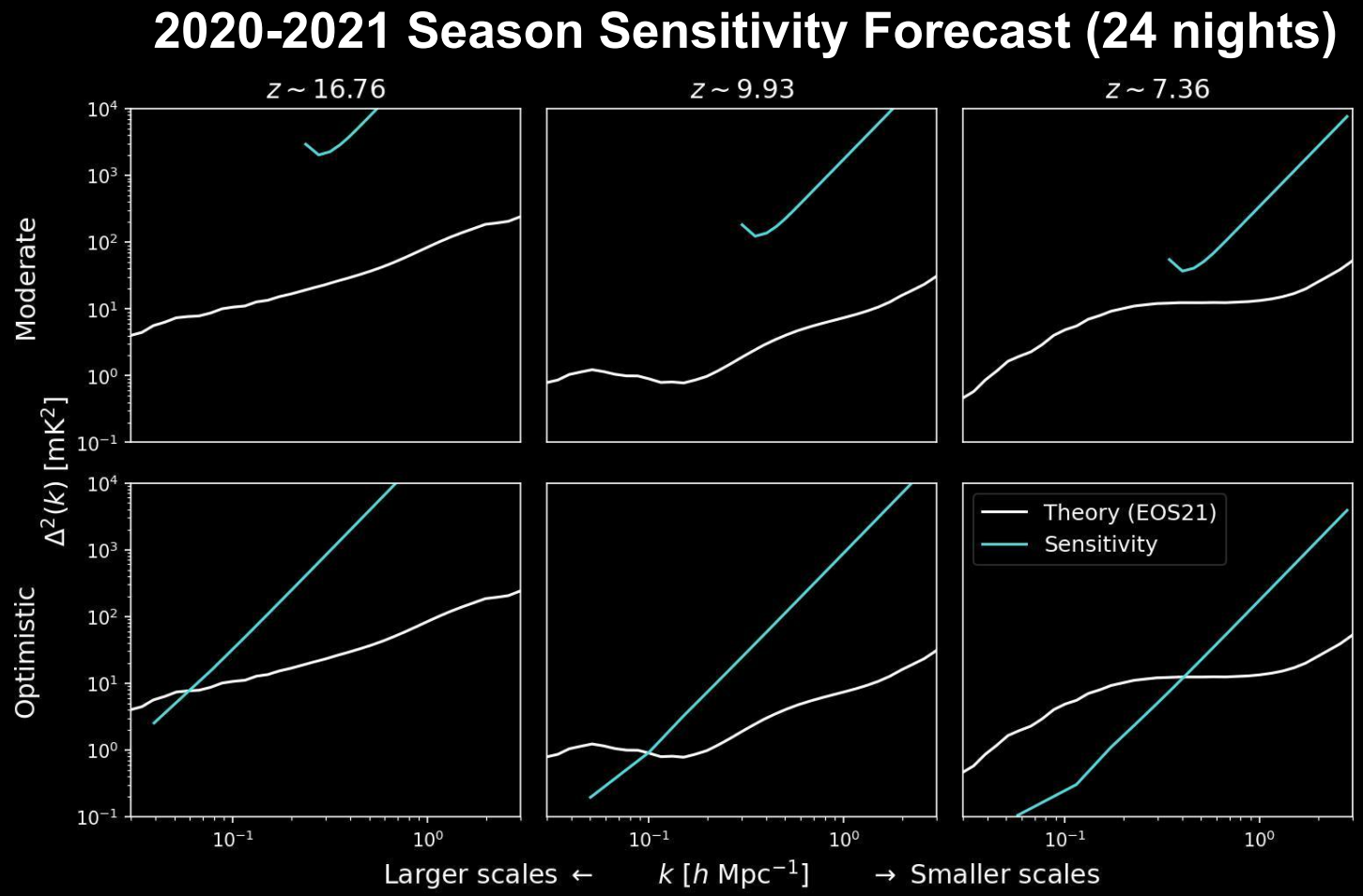
Current Status

2020-2021 Season

- 24 nights of data
- Up to ~84 antennas with good data each night

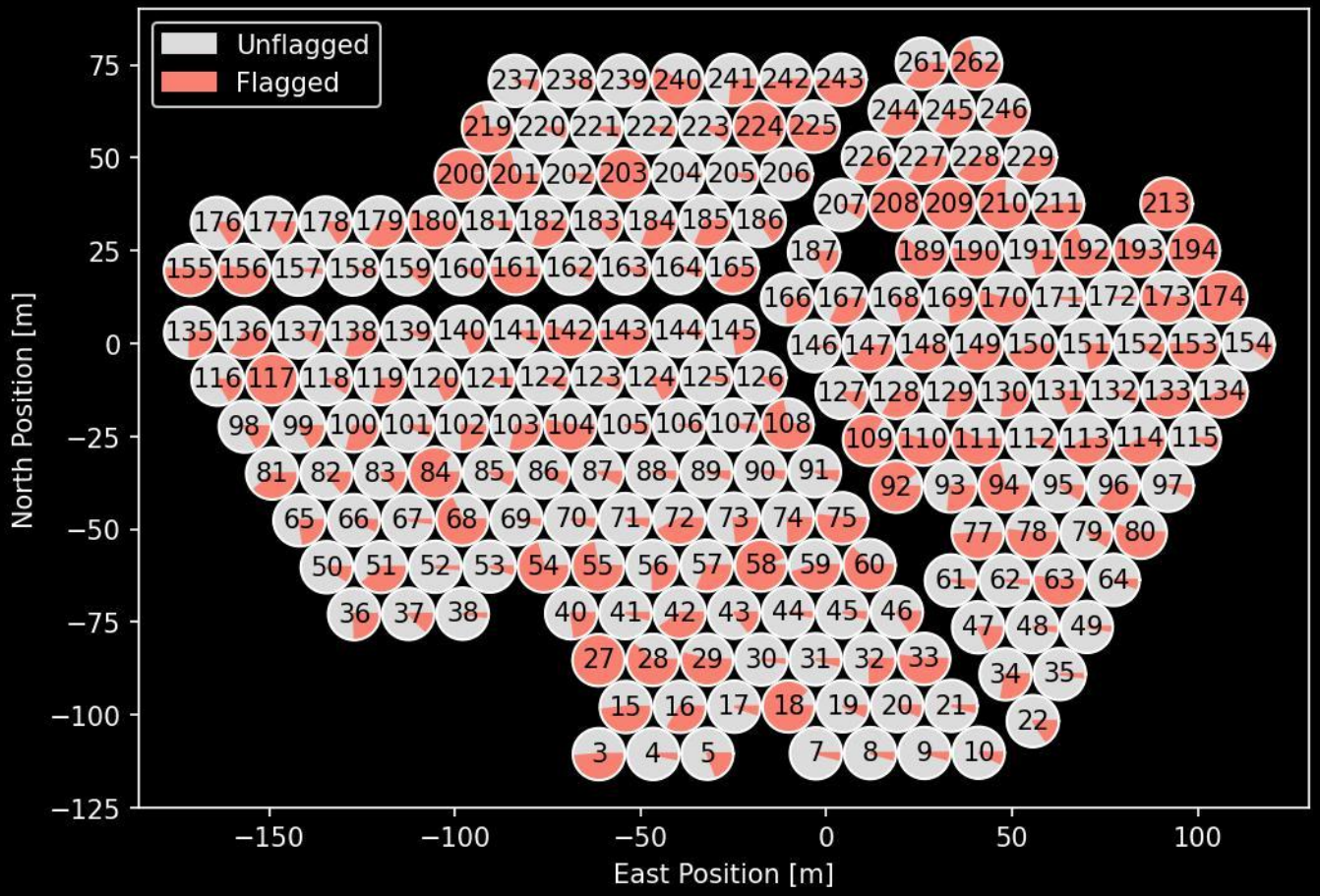


Current Status



Current Status

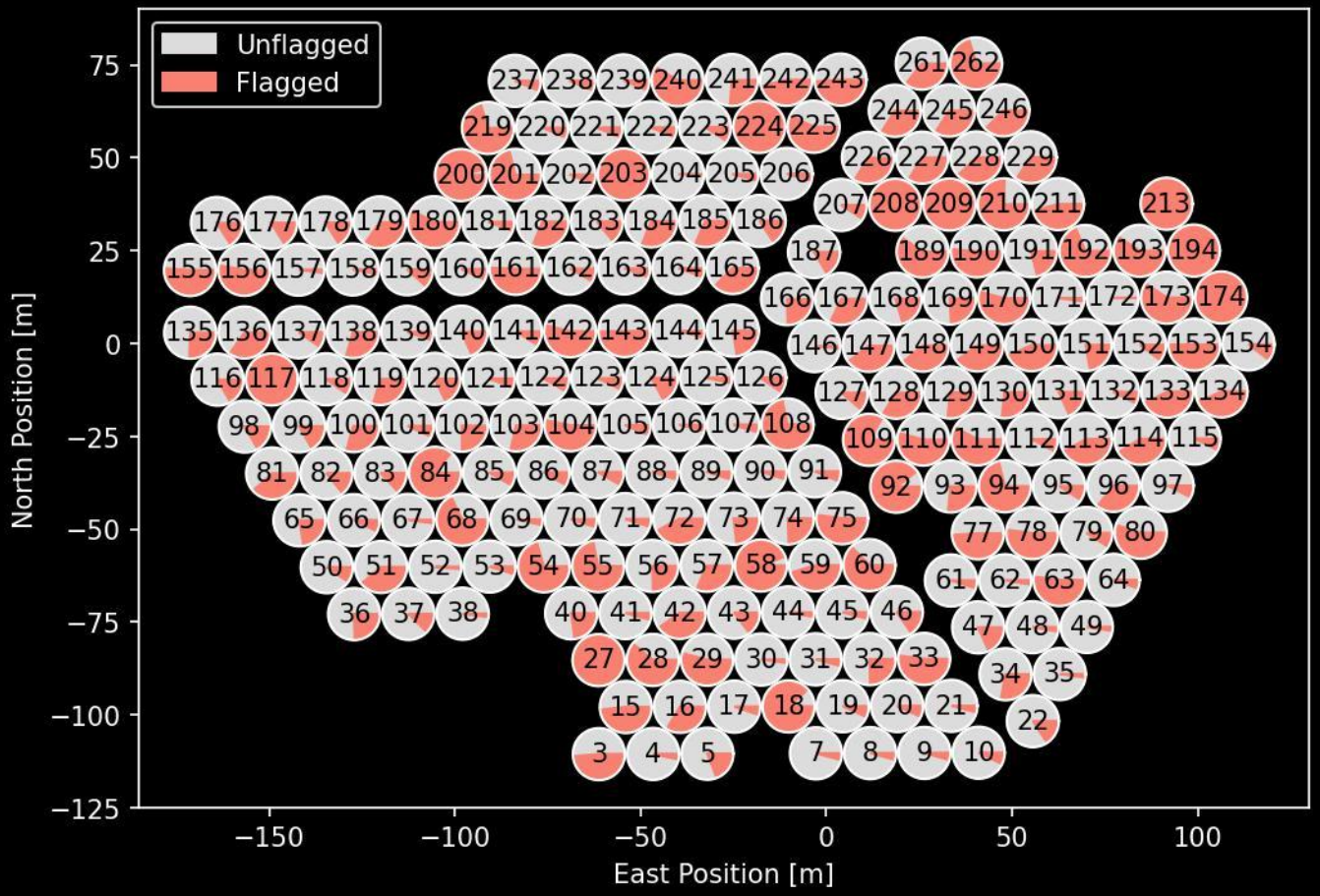
2022-2023 Season



Current Status

2022-2023 Season

- Up to ~140 nights (~1300 hours) of data



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2022-2023 Season

- Up to ~140 nights (~1300 hours) of data
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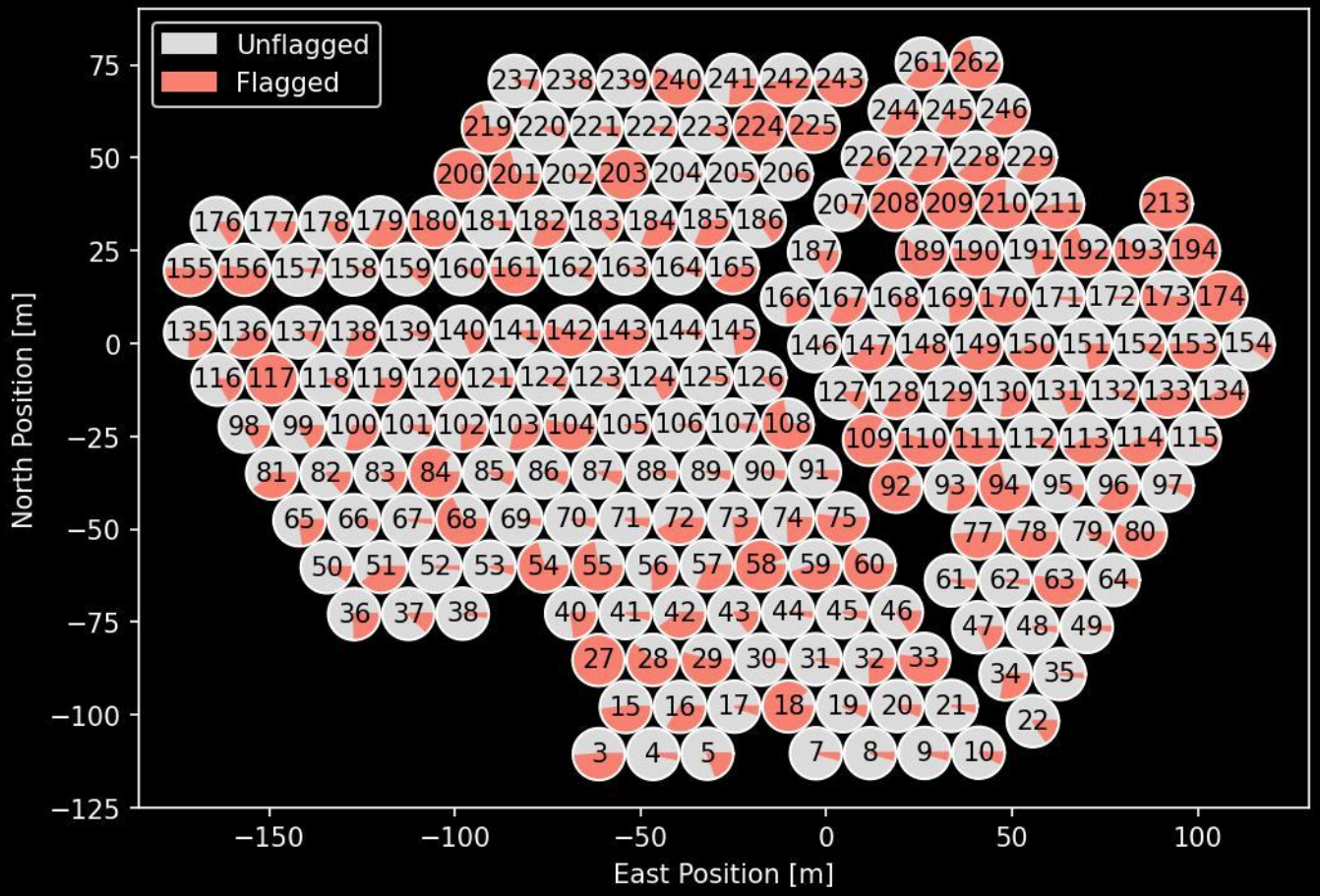
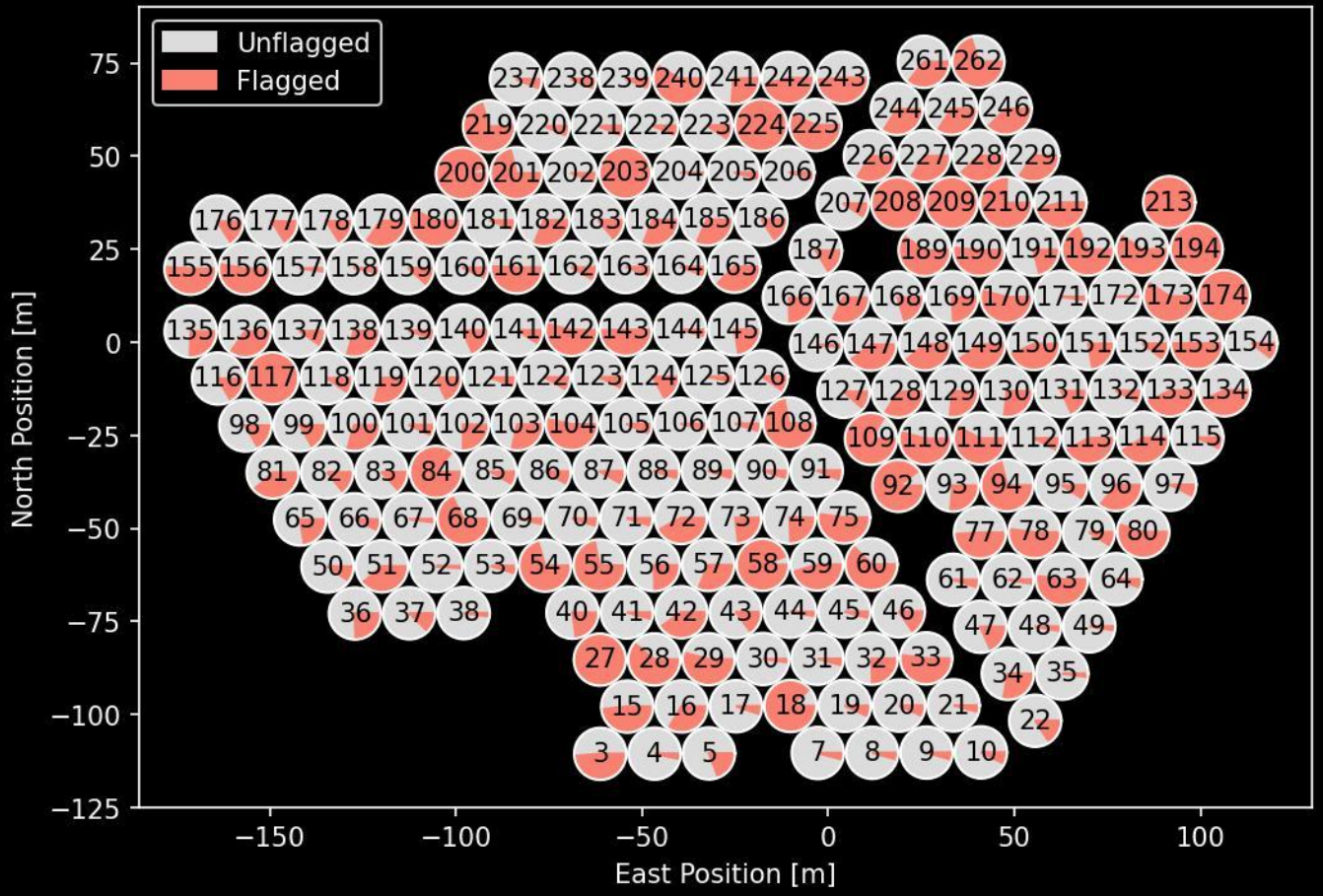


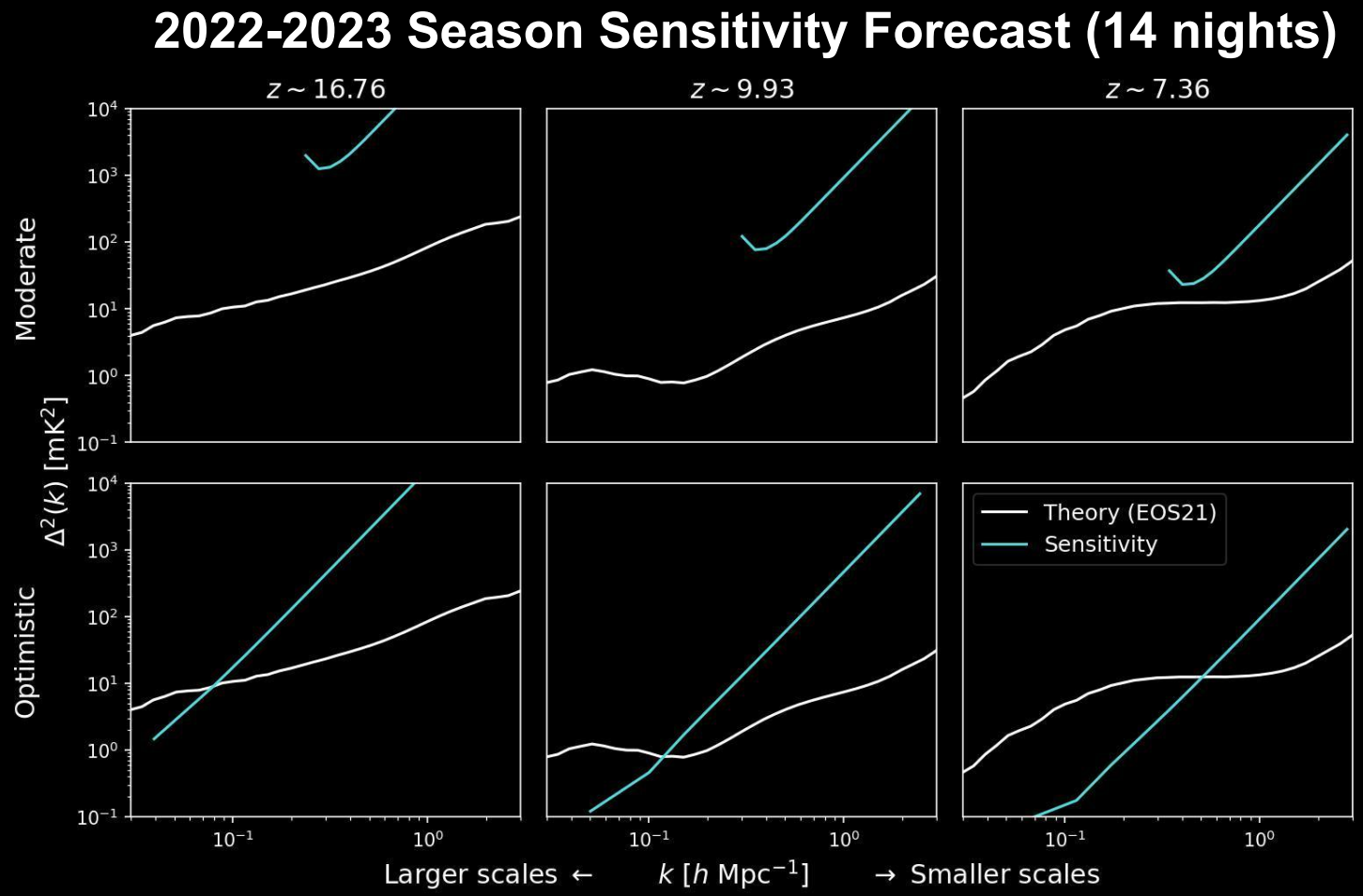
Current Status

2022-2023 Season

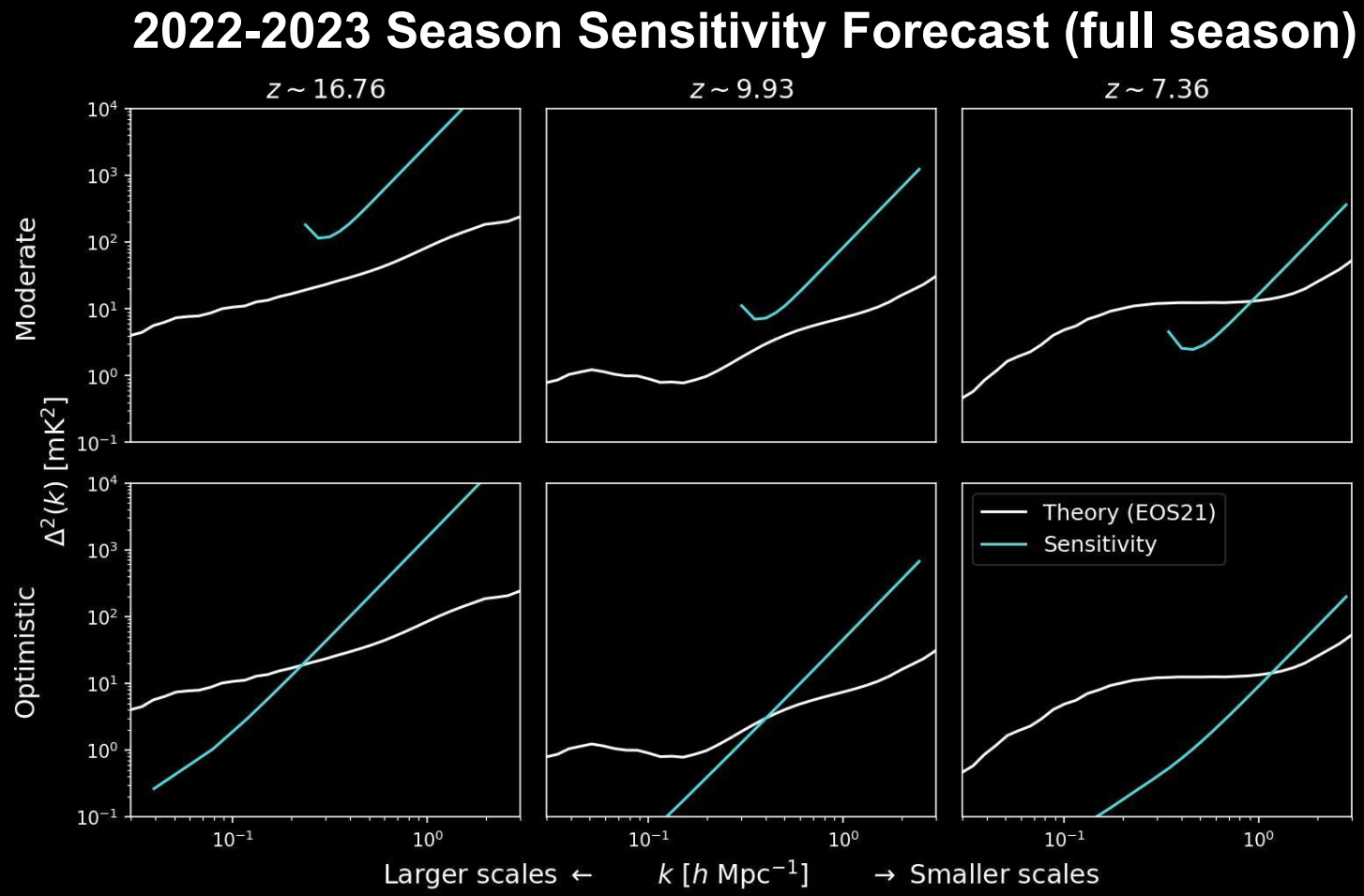
- Up to ~140 nights (~1300 hours) of data
- Up to ~140 antennas with good data each night
- Currently analyzing 14 nights of data



Current Status

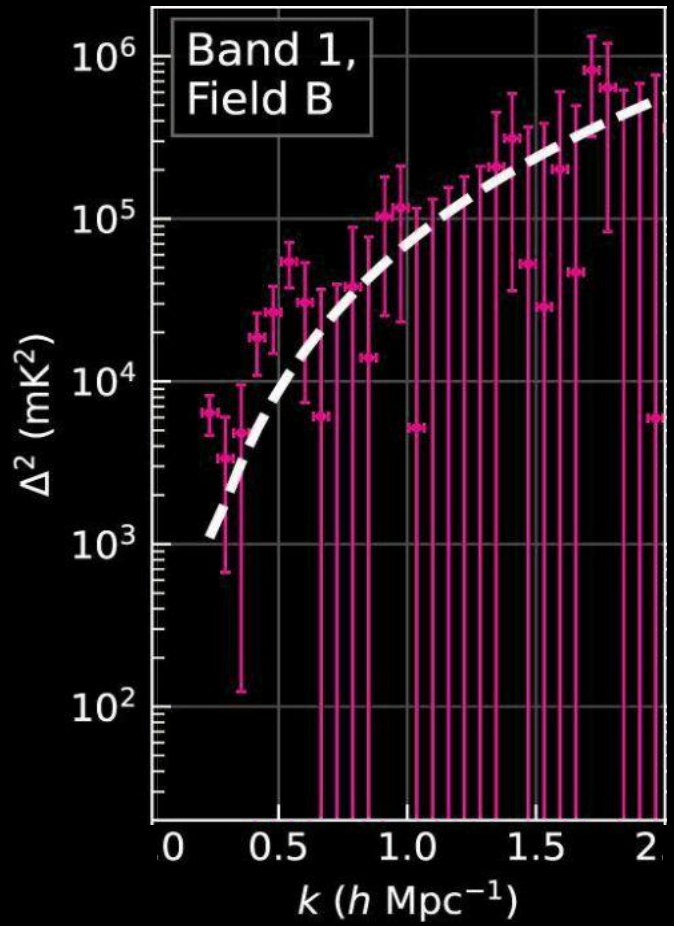


Current Status

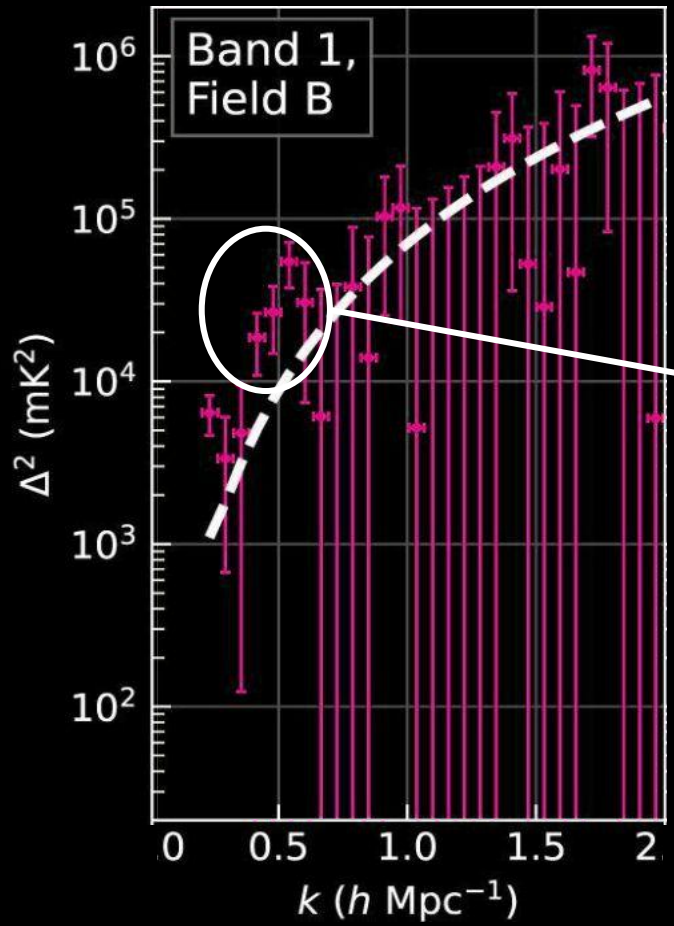


Recent Challenges

Challenges



Challenges

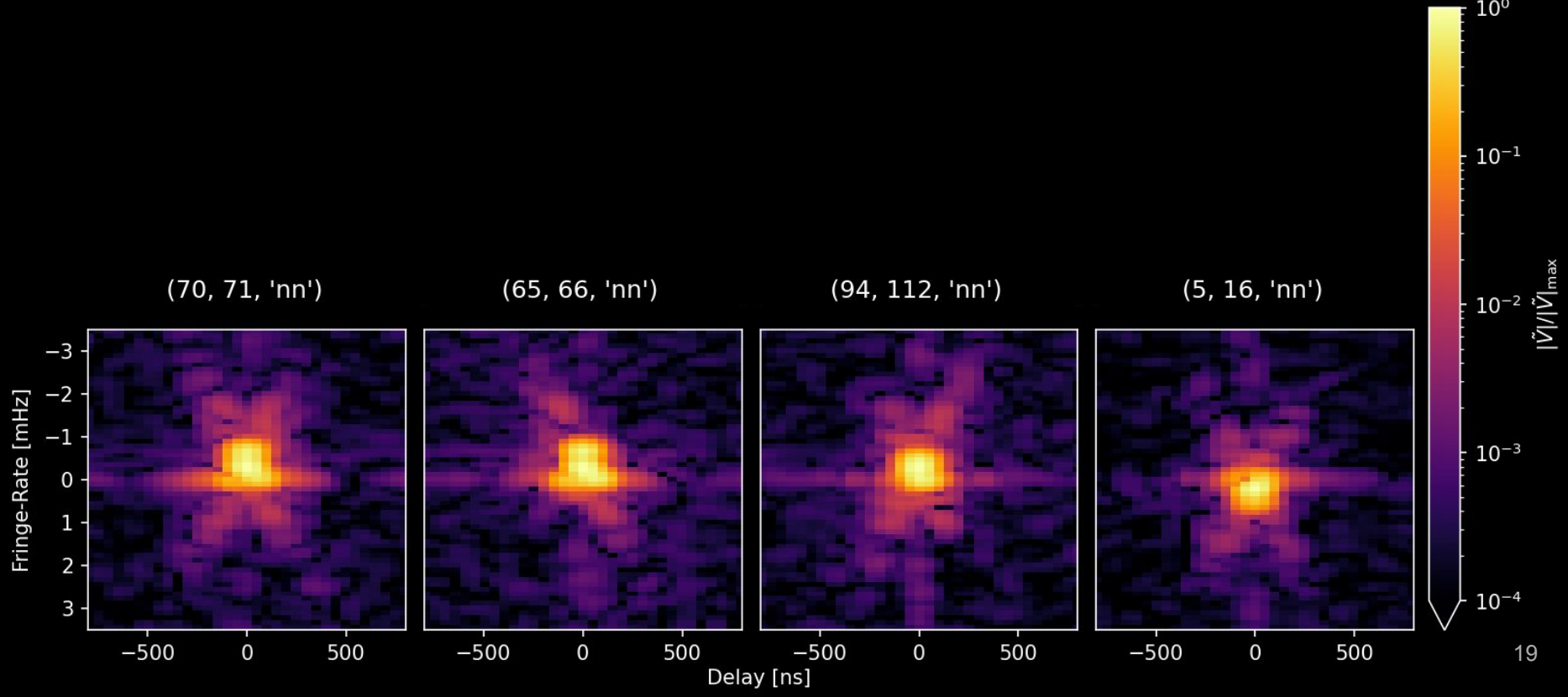


Similar to other experiments, we see excess power at some *k* modes.

What's causing this?

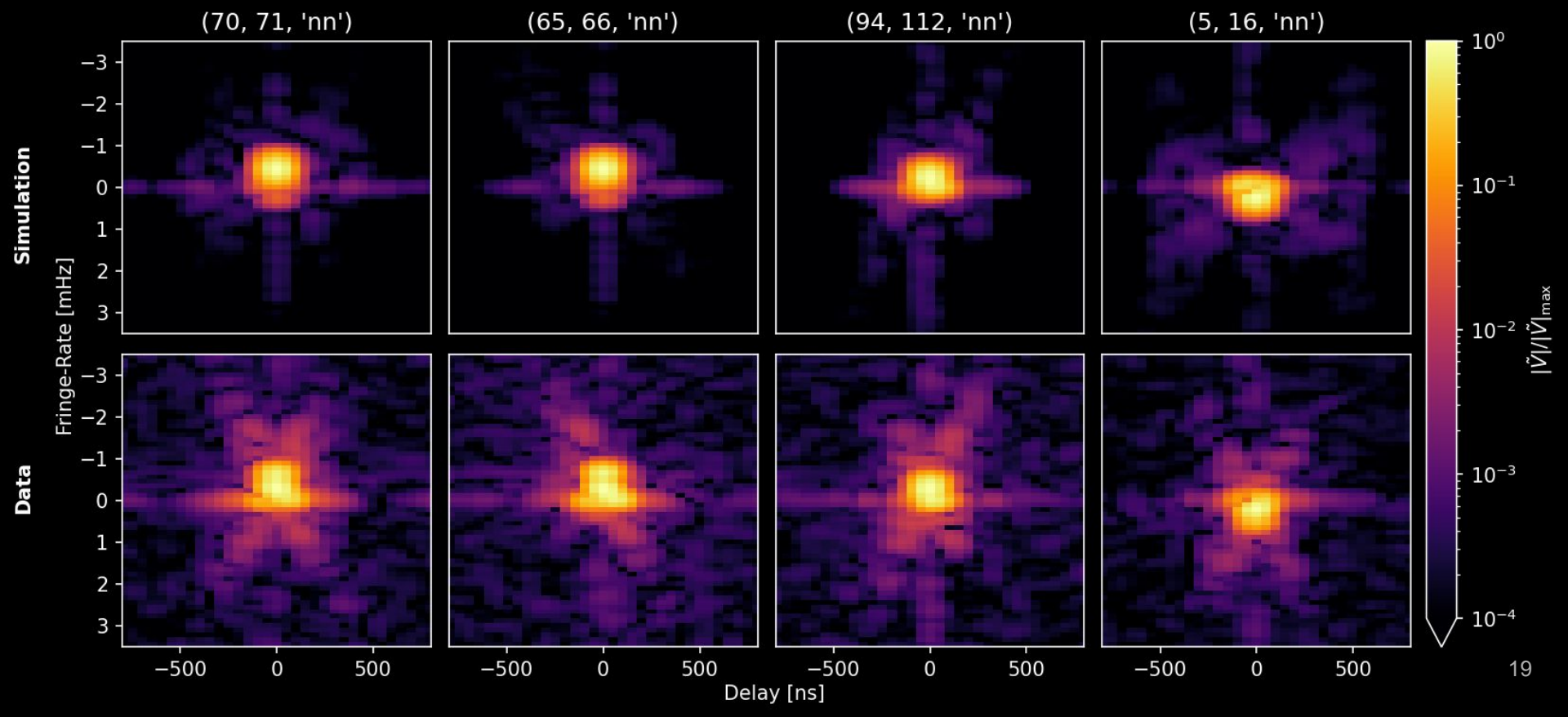
Challenges

We see excess structure in the visibilities…



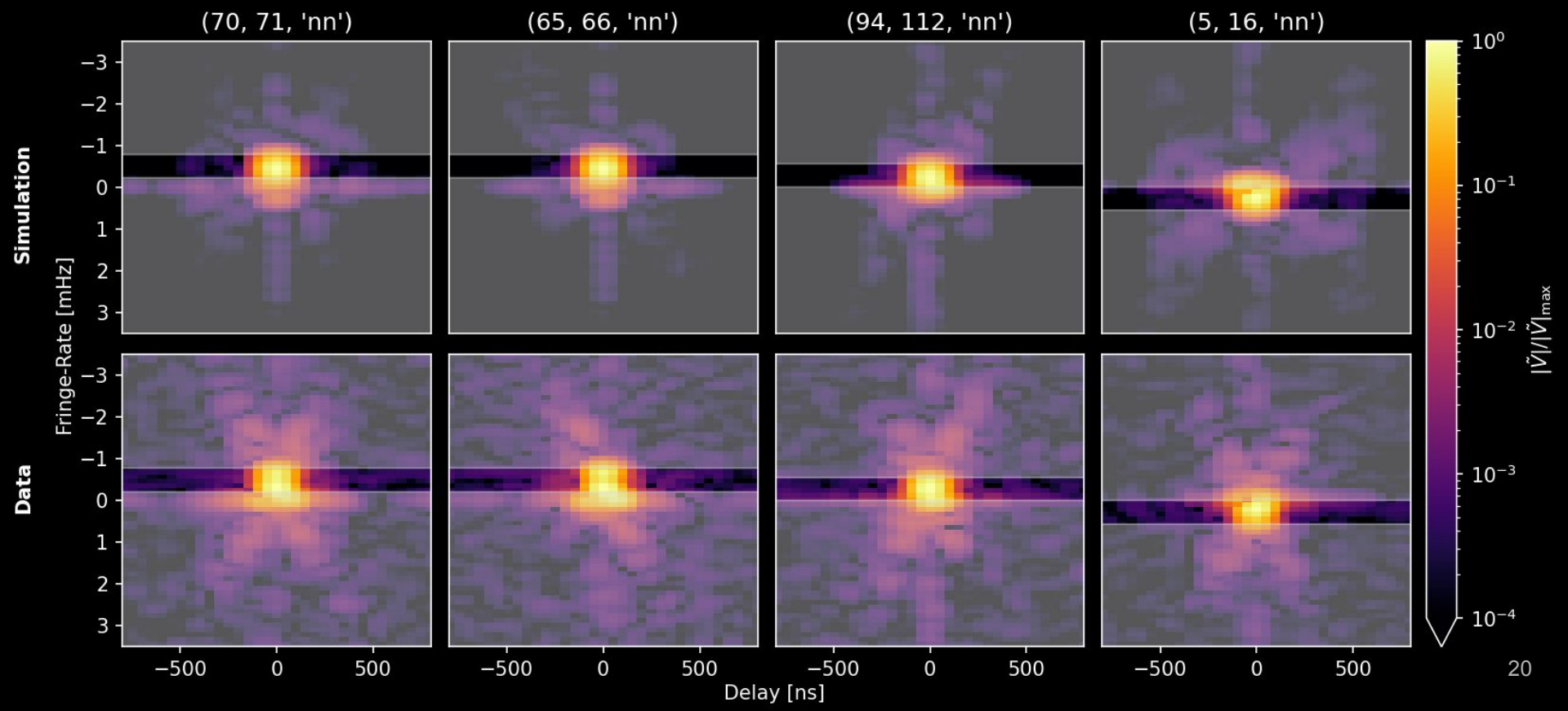
Challenges

…which we can reproduce with mutual coupling simulations. (Rath & **Pascua**+ 2024)

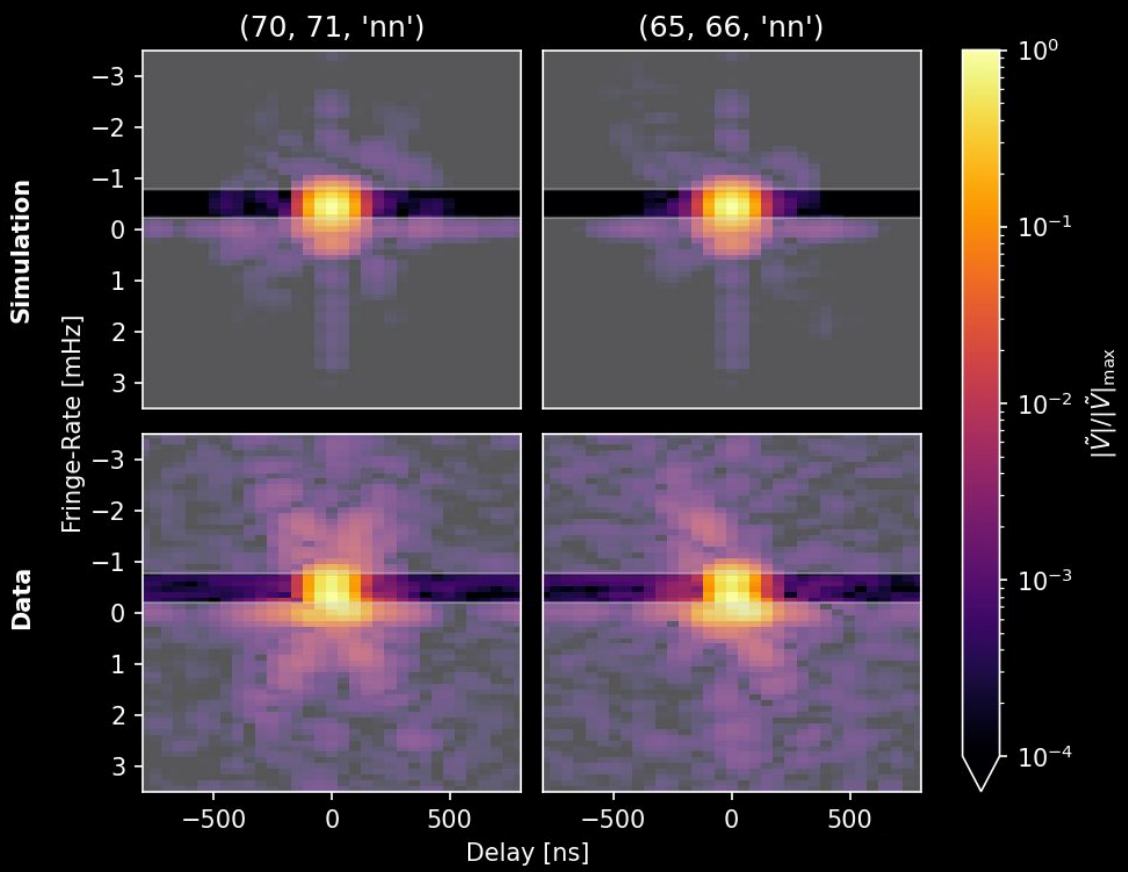


Challenges

We can mitigate these features with the help of fringe-rate filters.

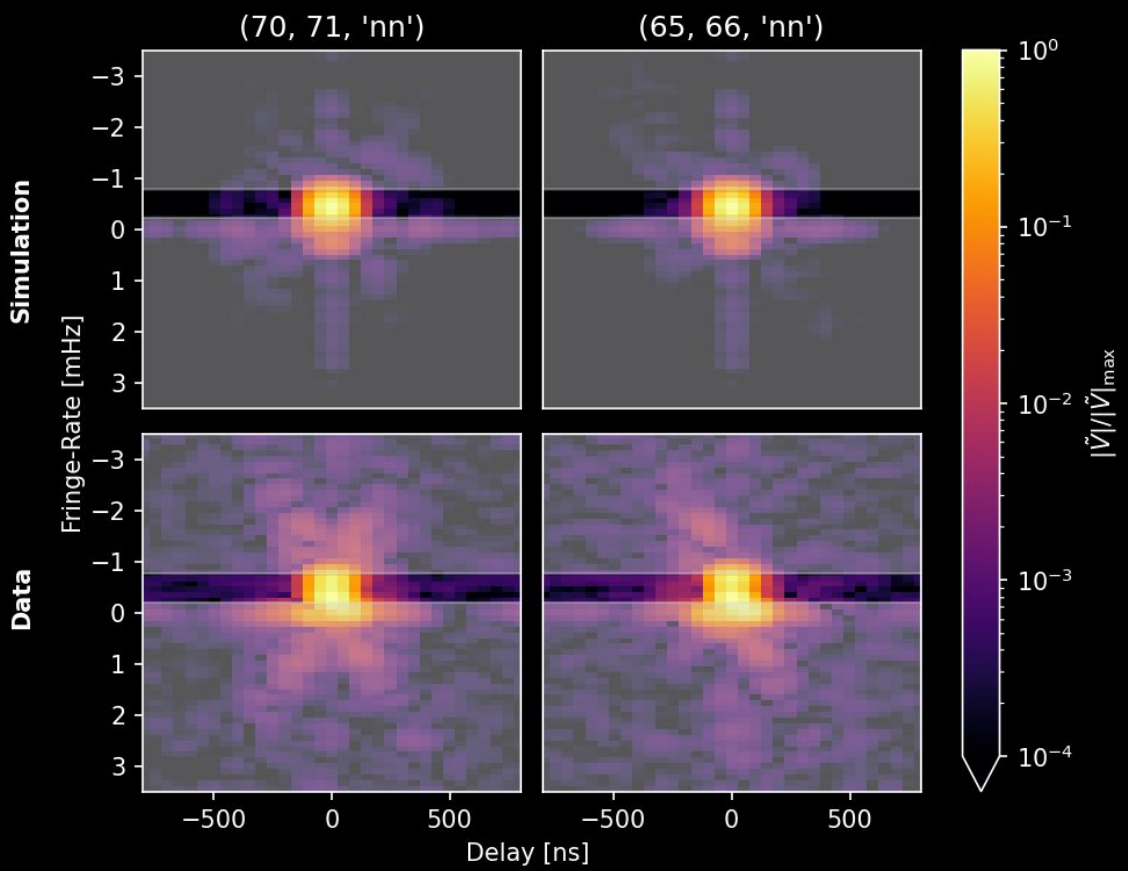


Challenges



We see evidence of mutual coupling in the data.

Challenges



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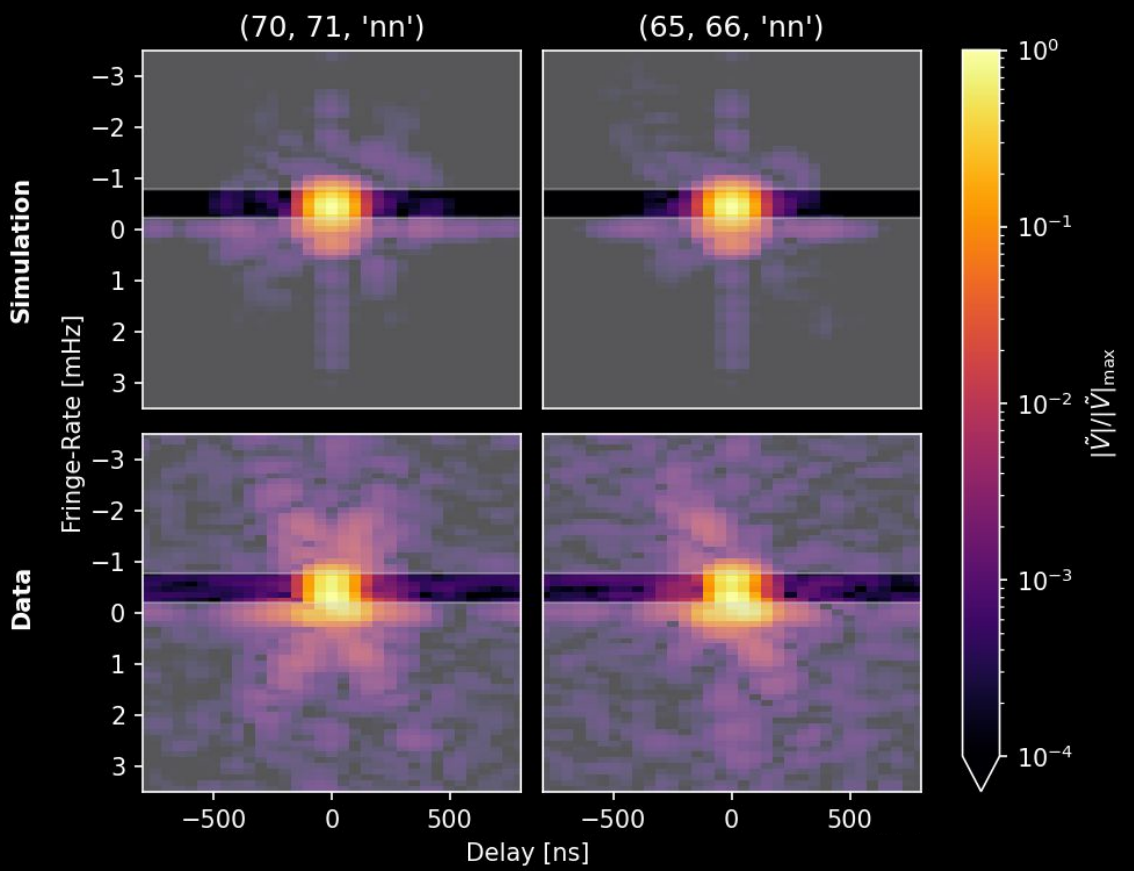
Challenges

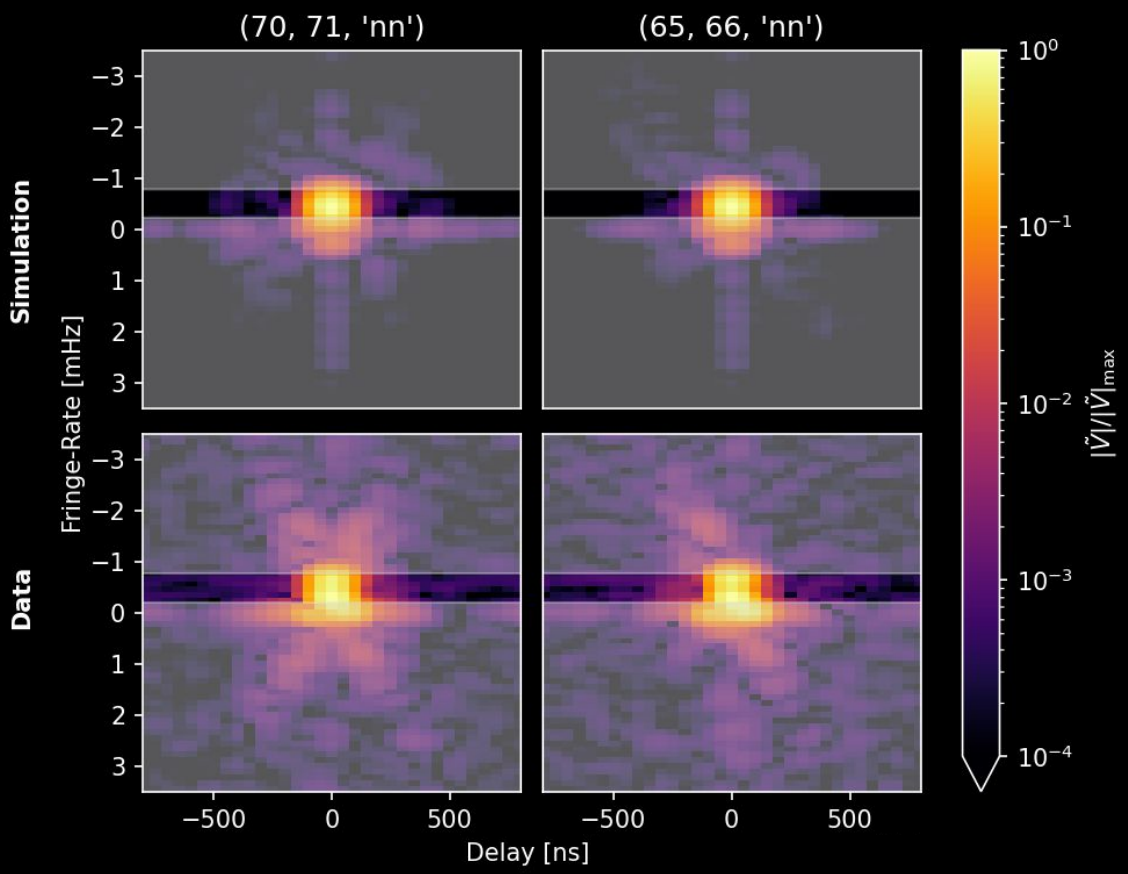


We see evidence of mutual coupling in the data.

We can mitigate it with fringe-rate filters.

We've carefully studied the effects of these filters on power spectra. (**Pascua**+ 2024)

Challenges



We see evidence of mutual coupling in the data.

We can mitigate it with fringe-rate filters.

We've carefully studied the effects of these filters on power spectra. (**Pascua+** 2024)

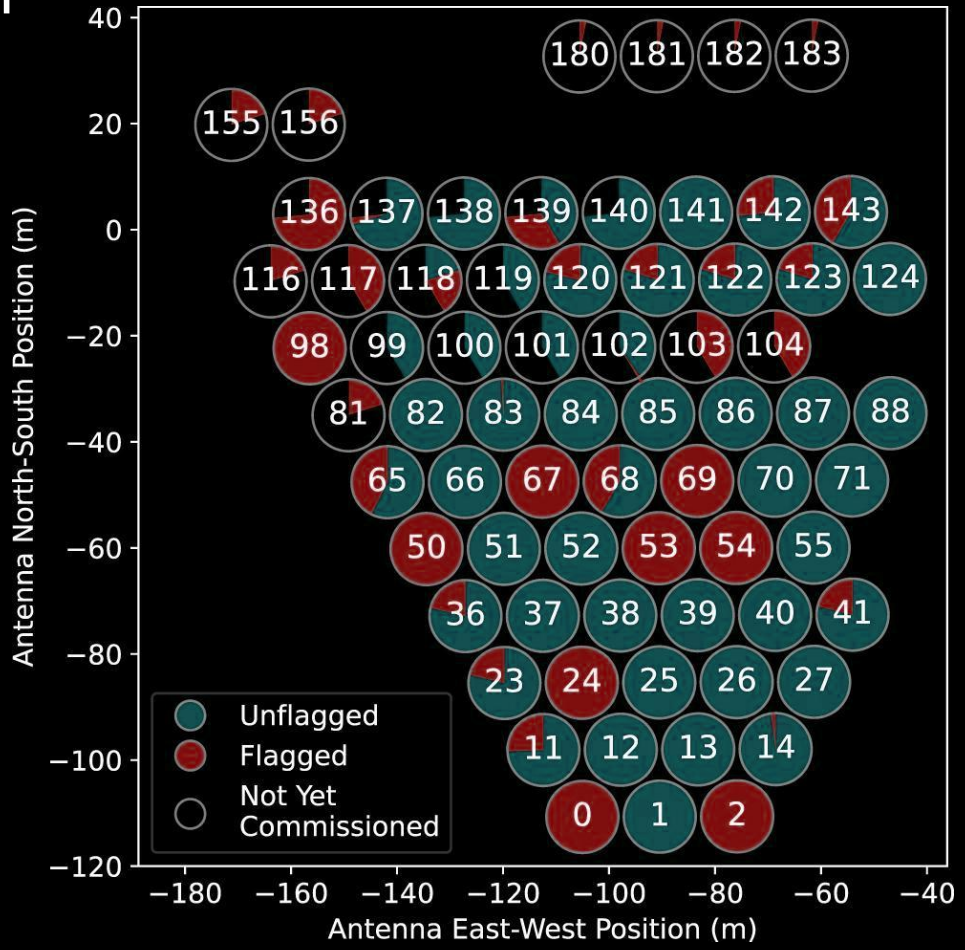
We're actively investigating improved mitigation techniques.

Latest Results

(HERA 2023)

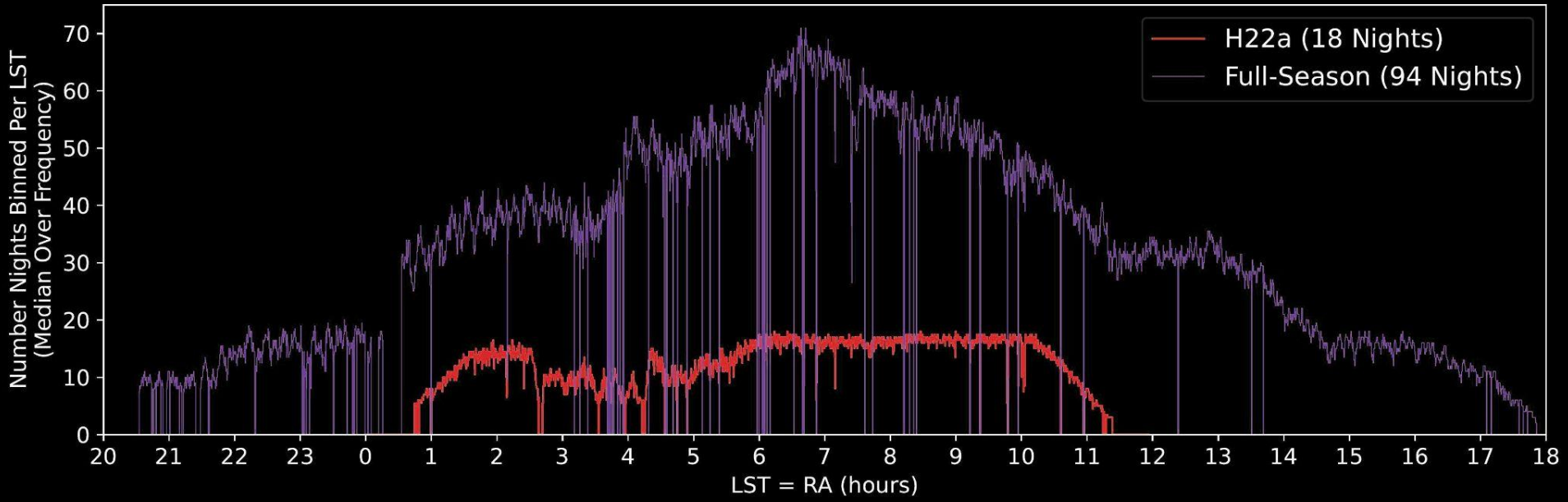
doi:10.3847/1538-4357/acaf50

Data Description



HERA 2023
doi: 10.3847/1538-4357/acaf50

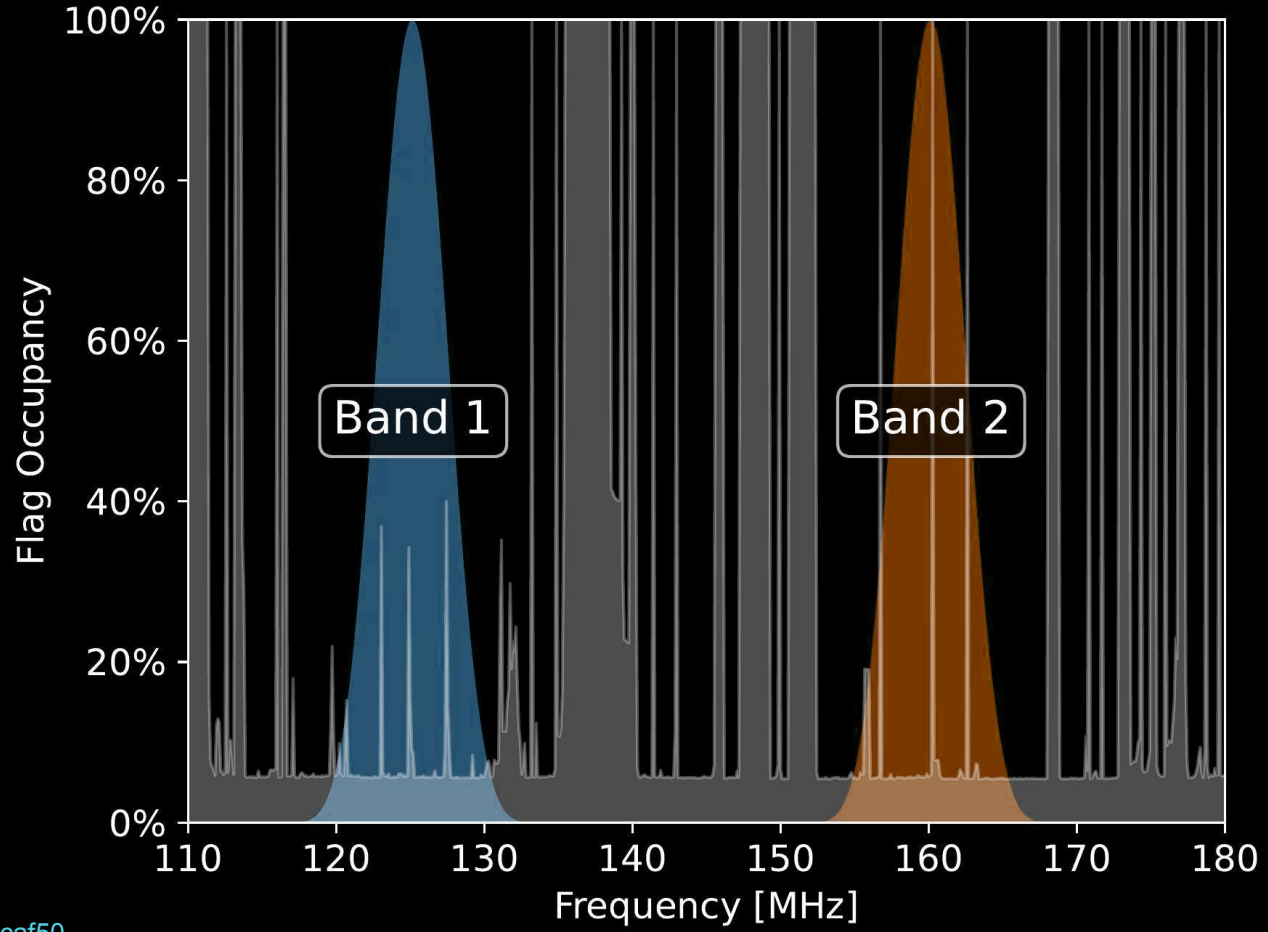
Data Description



HERA 2023
doi: 10.3847/1538-4357/acaf50

Data Description

$z \sim 10.4$ $z \sim 7.9$



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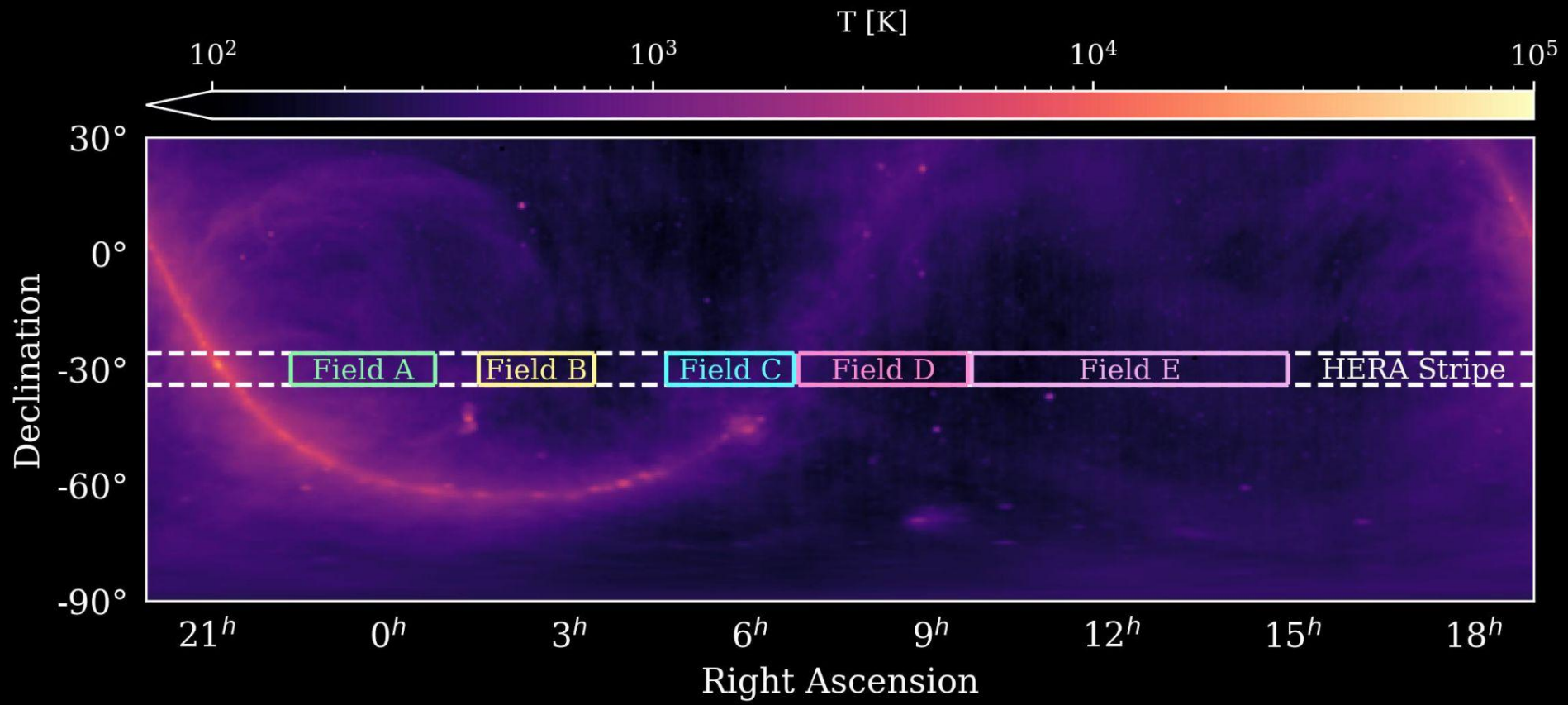
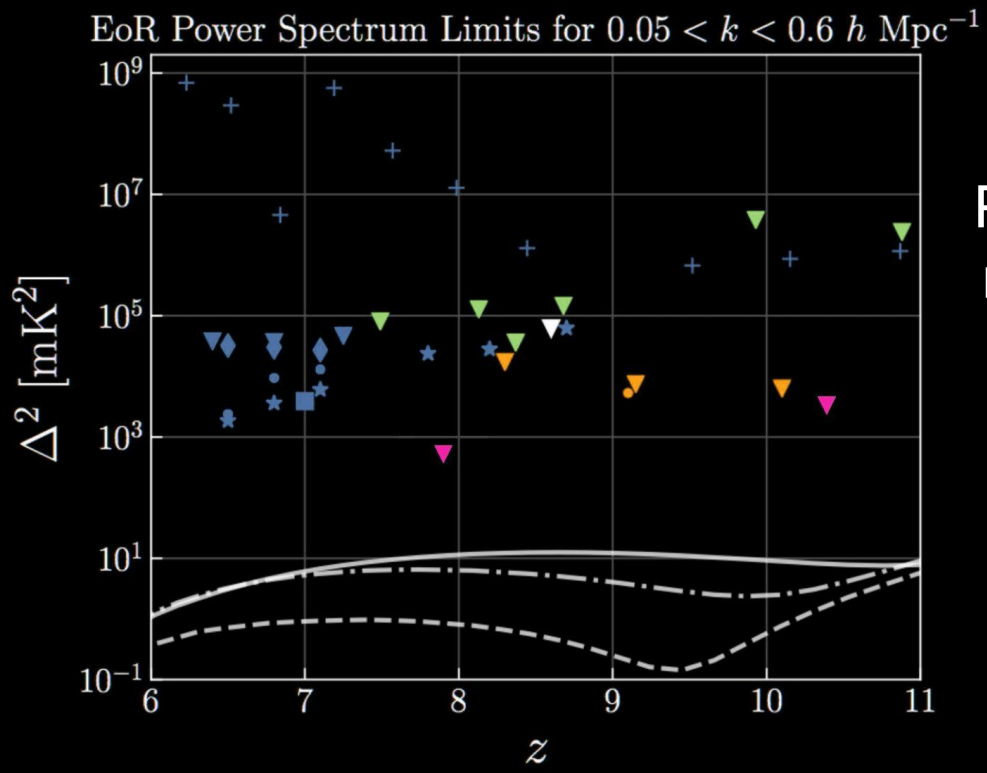


Upper Limits

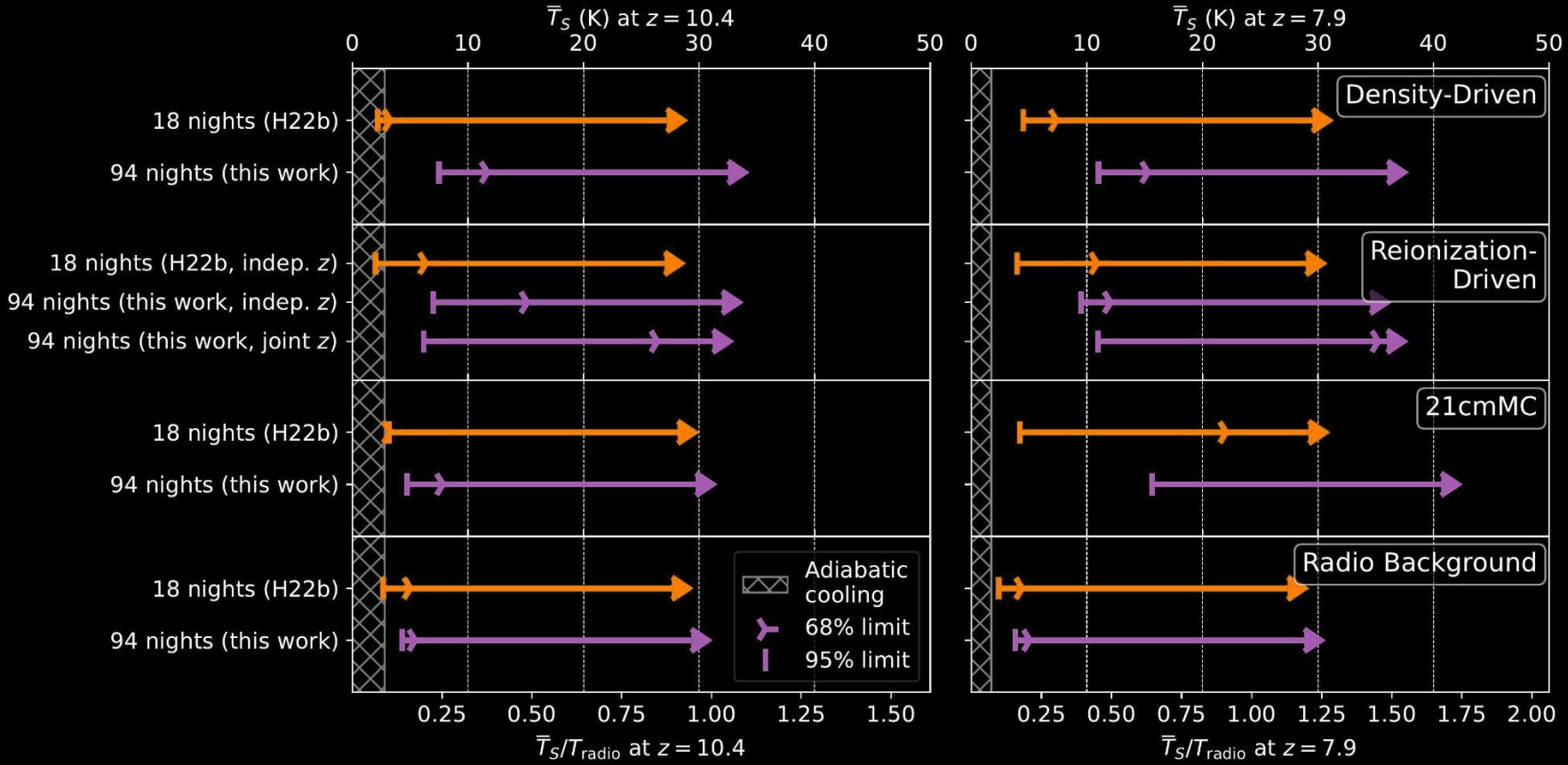
Adapted from HERA 2022
HERA Public Data Release



With 94 nights of data from the Phase I instrument, we've set the most stringent constraints on the 21-cm power spectrum to-date

MWA (Dillon+2015)
MWA (Li+2019)
MWA (Barry+2019)
MWA (Dillon+2014)
MWA (Beardsley+2016)
MWA (Trott+2020)
PAPER (Kolopanis+2019)
LOFAR (Patil+2017)
LOFAR (Mertens+2020)
GMRT (Paciga+2013)
HERA (HERA + 2023)
Mesinger+2016 ($k = 0.05$)
Mesinger+2016 ($k = 0.2$)
Mesinger+2016 ($k = 0.5$)

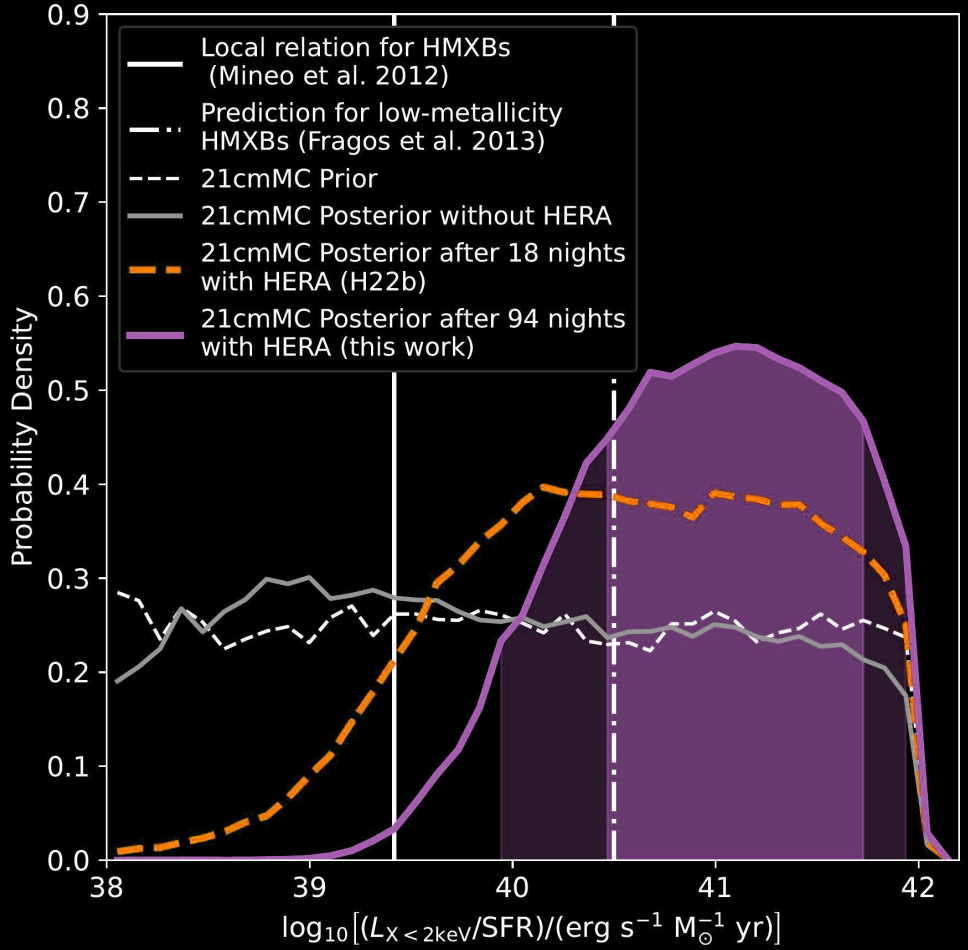
Astrophysical Constraints



HERA 2023
doi: [10.3847/1538-4357/acaf50](https://doi.org/10.3847/1538-4357/acaf50)

Astrophysical Constraints

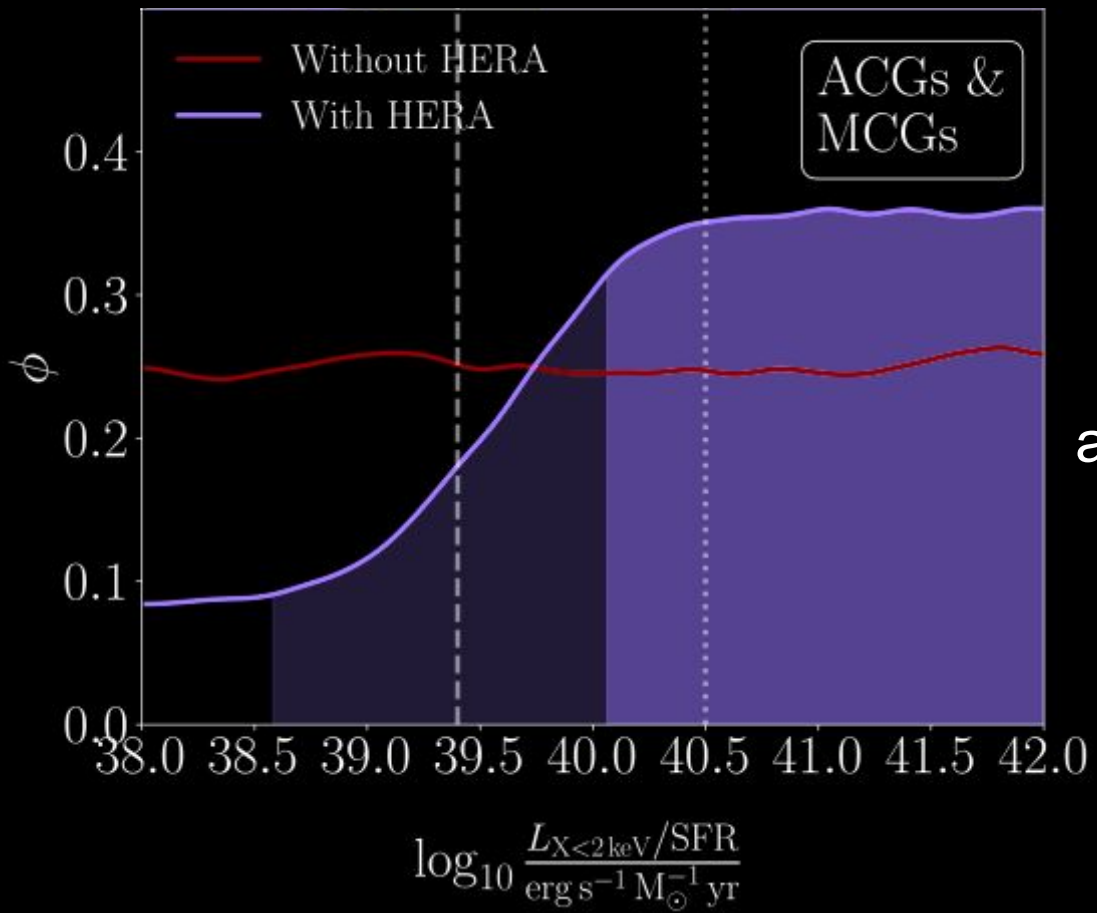
HERA 2023
doi: 10.3847/1538-4357/acaf50



Assuming the X-rays come from HMXBs in a single population of galaxies, X-rays were produced more efficiently in the past.

Astrophysical Constraints

Lazare+ 2024
doi: 10.1103/PhysRevD.109.043523



However, this constraint can be weakened by considering alternate heating mechanisms

With 94 nights of data from the Phase I instrument…

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We can say that the IGM *must* have been heated above the adiabatic cooling limit as early as redshift 10.4,

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and early galaxies were likely more efficient at producing X-rays than local galaxies.

With 94 nights of data from the Phase I instrument…

We can say that the IGM *must* have been heated above the adiabatic cooling limit as early as redshift 10.4,

and early galaxies were likely more efficient at producing X-rays than local galaxies.

We're currently working on obtaining even more sensitive upper limits, so keep an eye out for what's next!

Summary

- HERA aims to probe CD/EoR through statistical detections of fluctuations in the cosmic 21-cm signal
- We build the requisite sensitivity through redundant averaging and stacking observations over nights
- We deal with foregrounds by targeting the EoR window in our delay spectrum estimates
- We've already placed interesting constraints on the astrophysics of reionization
- Upcoming analyses could potentially be sensitive enough to detect the 21-cm signal around z ~ 7
- Check out our paper register: reionization.org/science/papers/