

STATUS UPDATE ON THE HYDROGEN EPOCH OF REIONIZATION ARRAY (HERA) AND FUTURE PROSPECTS

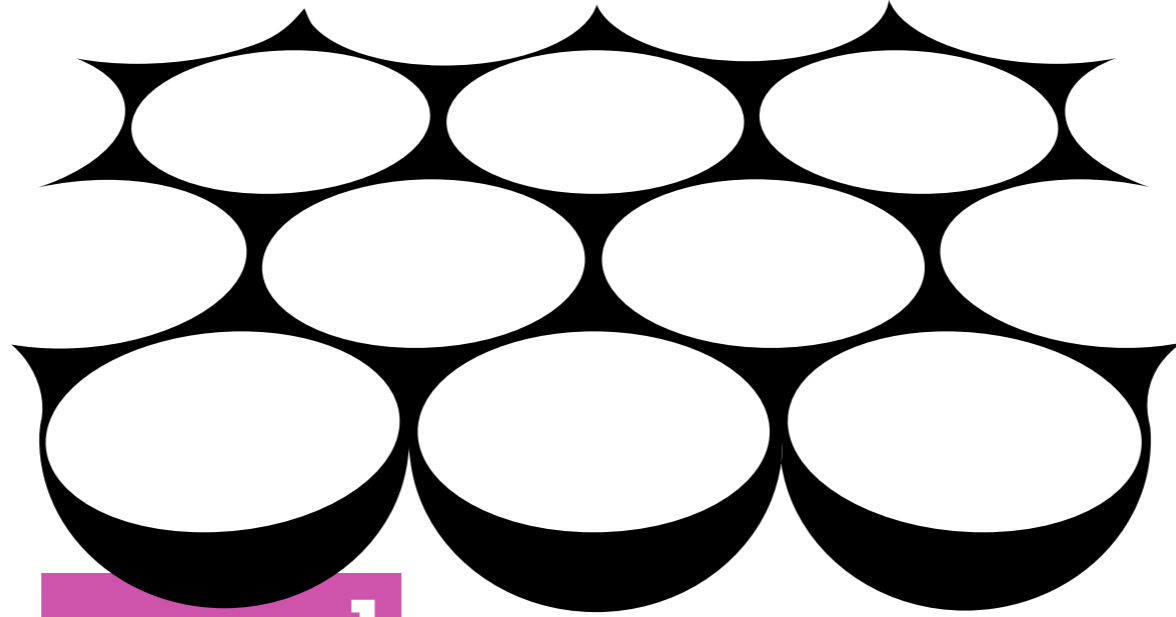
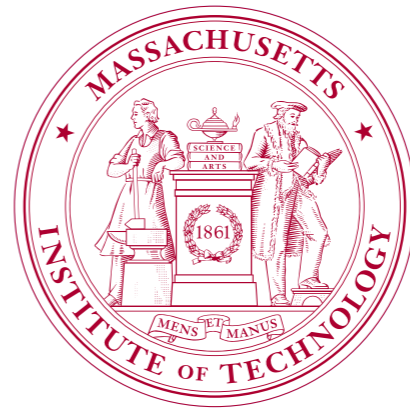


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McGill



ERA



UNIVERSITY of the WESTERN CAPE



SKA AFRICA SQUARE KILOMETRE ARRAY



McGill



Queen Mary University of London

Vision

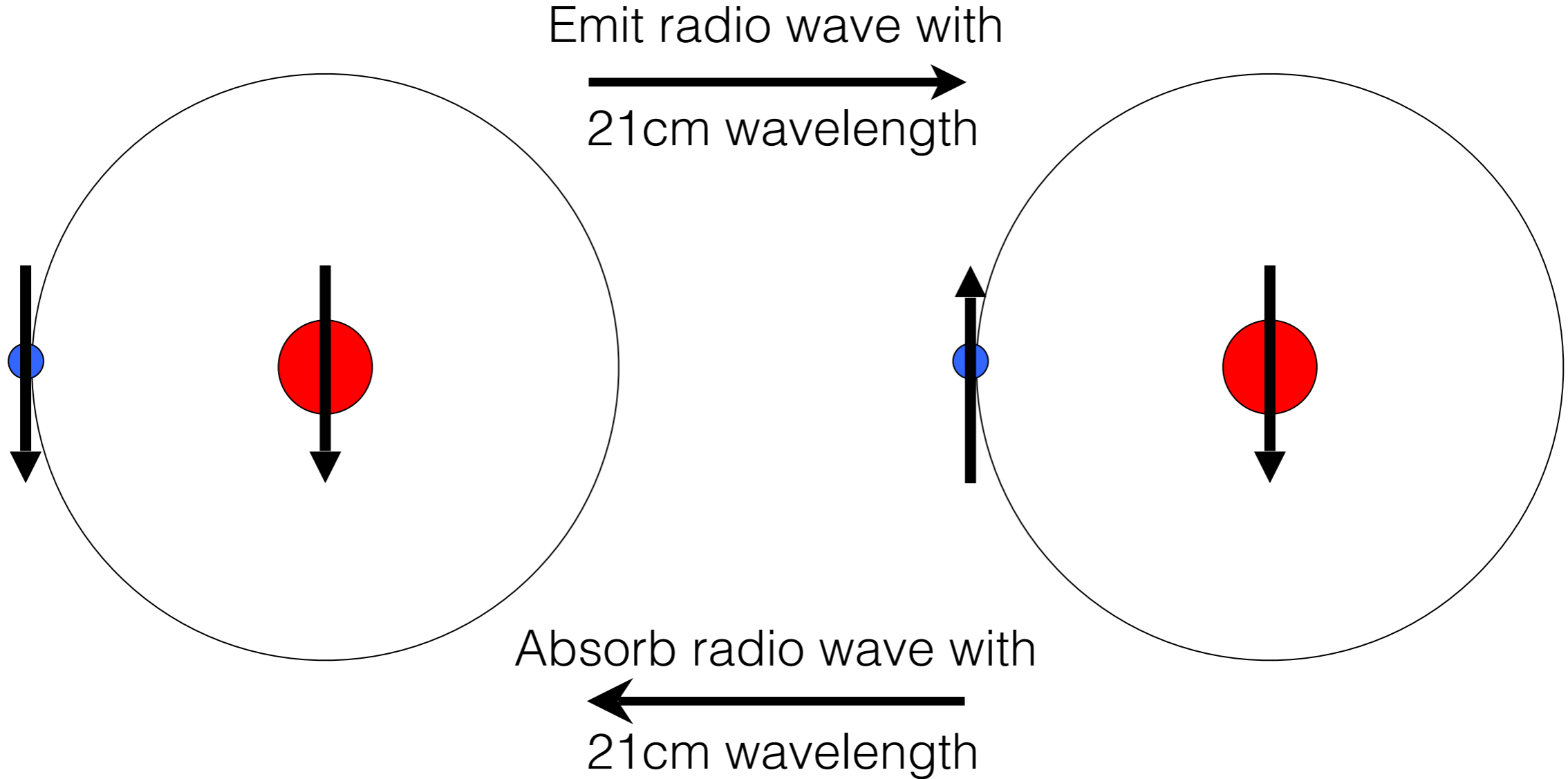
We wish to directly observe Cosmic Dawn and Reionization because it's a

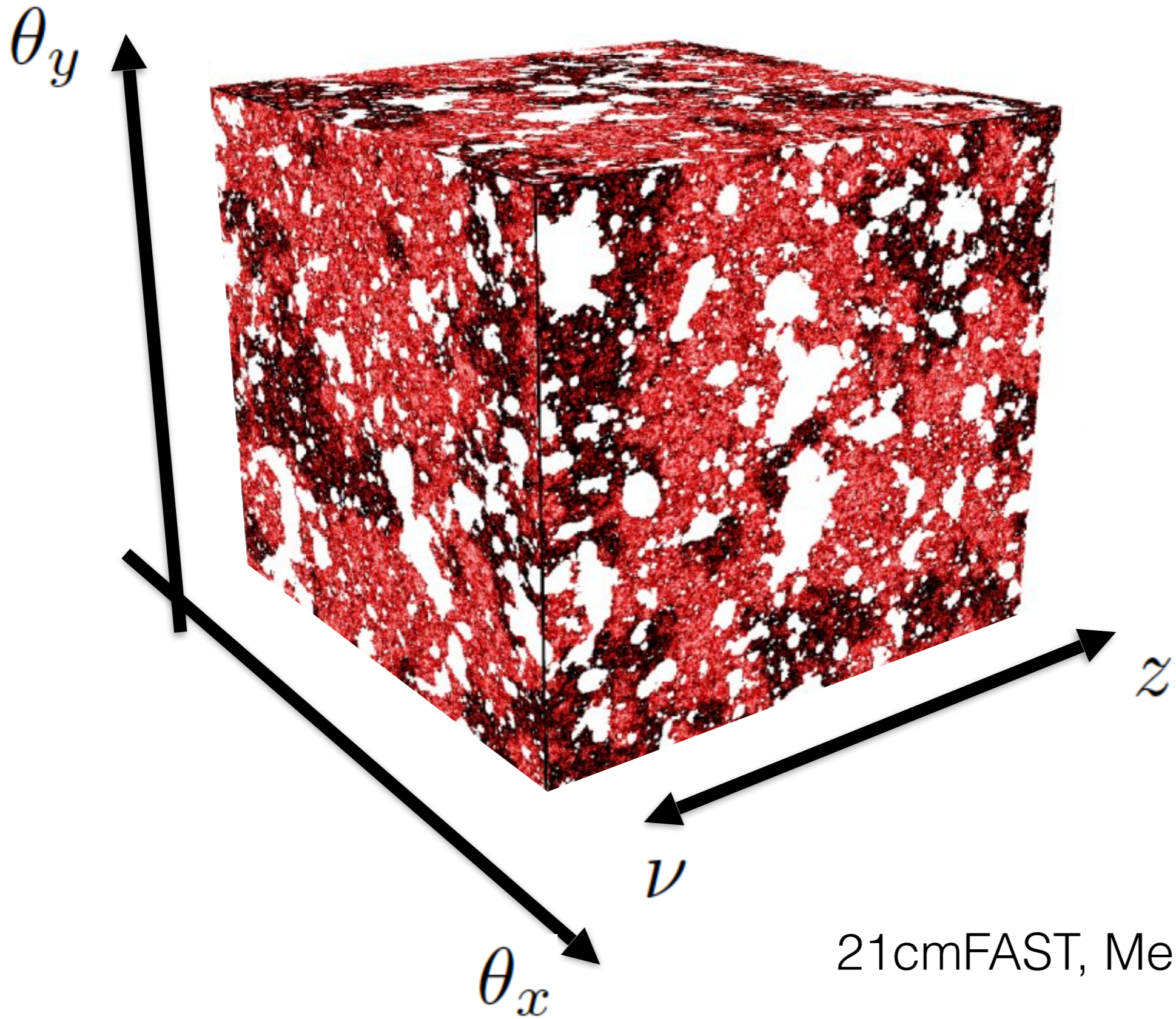
crucially unexplored portion of our cosmic history

that has implications for both

**cosmology and galaxy formation
astrophysics**

Hydrogen is everywhere, and the 21cm line allows us to trace hydrogen

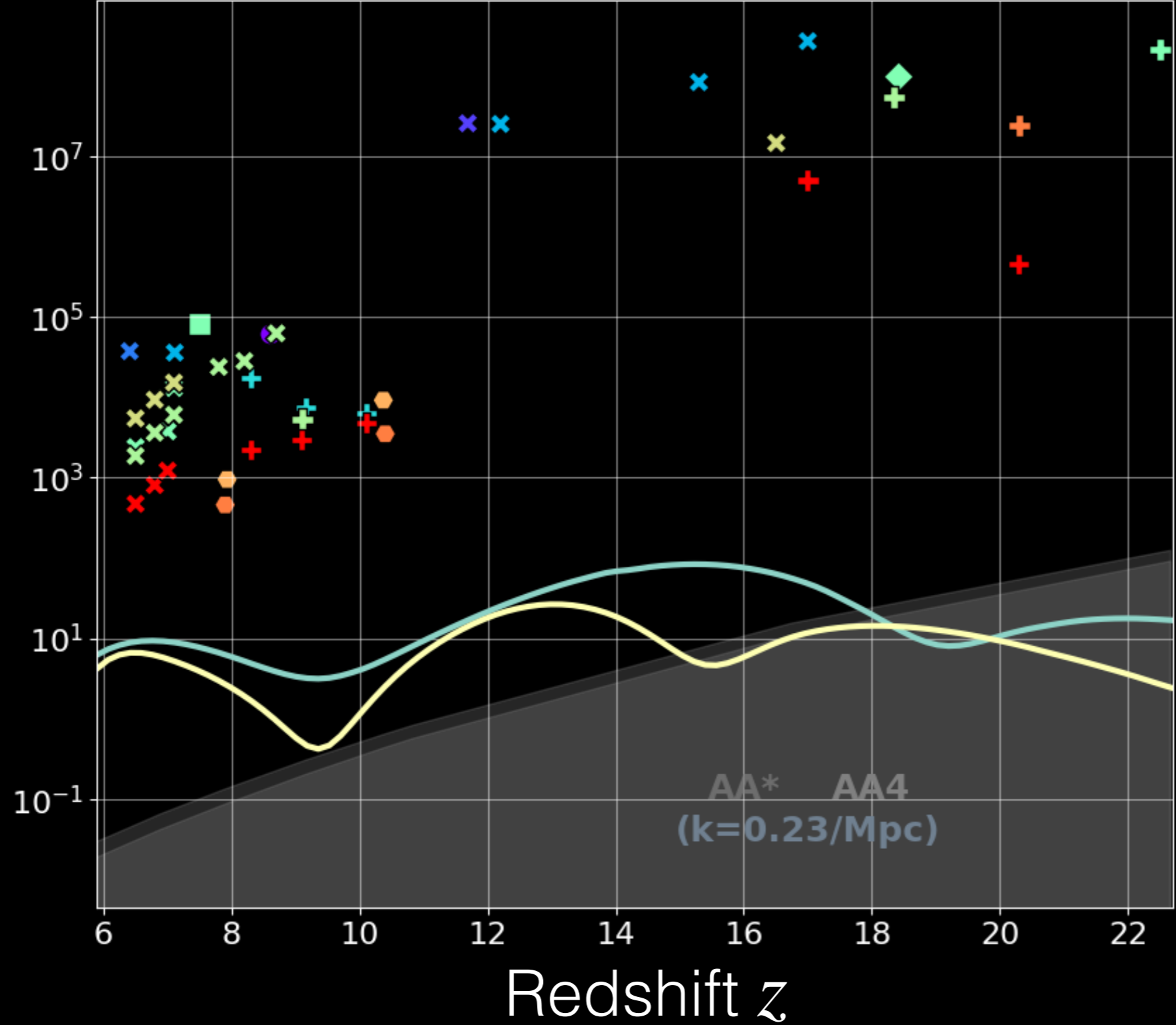




21cmFAST, Mesinger et al.

All Upper Limits to Date ($k = 0.04 - 0.57$)

Fluctuation Strength Δ^2 [mK^2]



- GMRT (Paciga, 2013)
 - × MWA (Dillon, 2014)
 - × MWA (Dillon, 2015)
 - × MWA (Ewall-Wice, 2016)
 - × MWA (Beardsley, 2016)
 - + LOFAR (Patil, 2017)
 - × MWA (Barry, 2019)
 - + LOFAR-LBA (Gehlot, 2019)
 - PAPER (Kolopanis, 2019)
 - × MWA (Li, 2019)
 - ◆ LWA (Eastwood, 2019)
 - + LOFAR (Mertens, 2020)
 - × MWA (Trott, 2020)
 - + AARTFAAC (Gehlot, 2020)
 - × MWA (Yoshiura, 2021)
 - × MWA (Rahimi, 2021)
 - HERA (HERA, 2022)
 - HERA (HERA, 2023)
 - + NenuFAR (Munshi, 2023)
 - + LOFAR (Mertens, 2025)
 - × MWA (Trott, 2025)
 - + NenuFAR (Munshi, 2025)
- Theories ($k=0.23/\text{Mpc}$)
- Muñoz+2021, Optimistic
 - Muñoz+2021, AllGalaxies

Today:

HERA's new upper limits

on reionization

HERA collaboration (2023), ApJ **945**, 124

HERA collaboration (2025), ApJ **998**, 33

What is the Hydrogen
Epoch of Reionization
Array (HERA)?

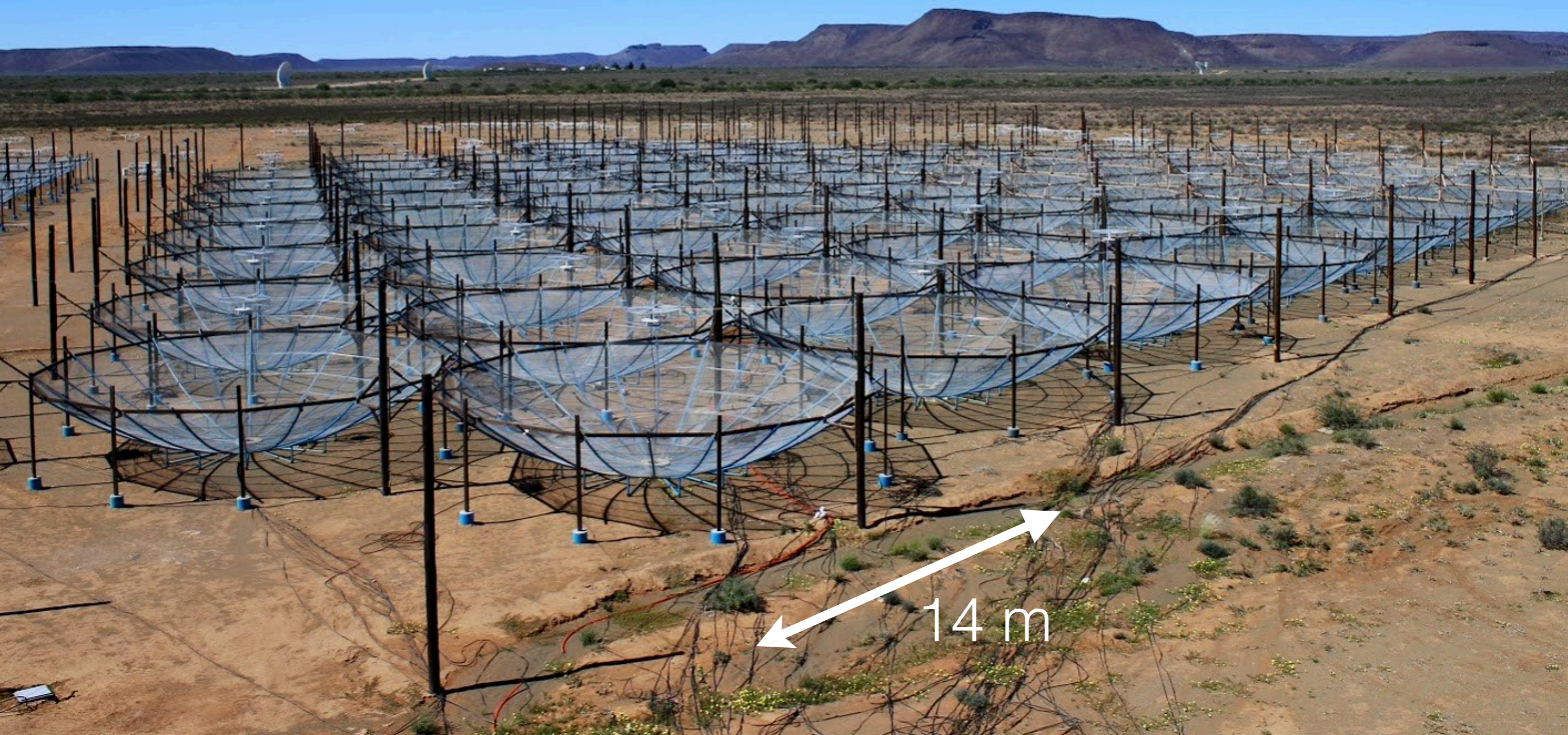
HERA is...

...located in the South African Karoo Desert



HERA is...

...a radio interferometer



14 m

HERA is...

...a massively redundant array
to increase sensitivity

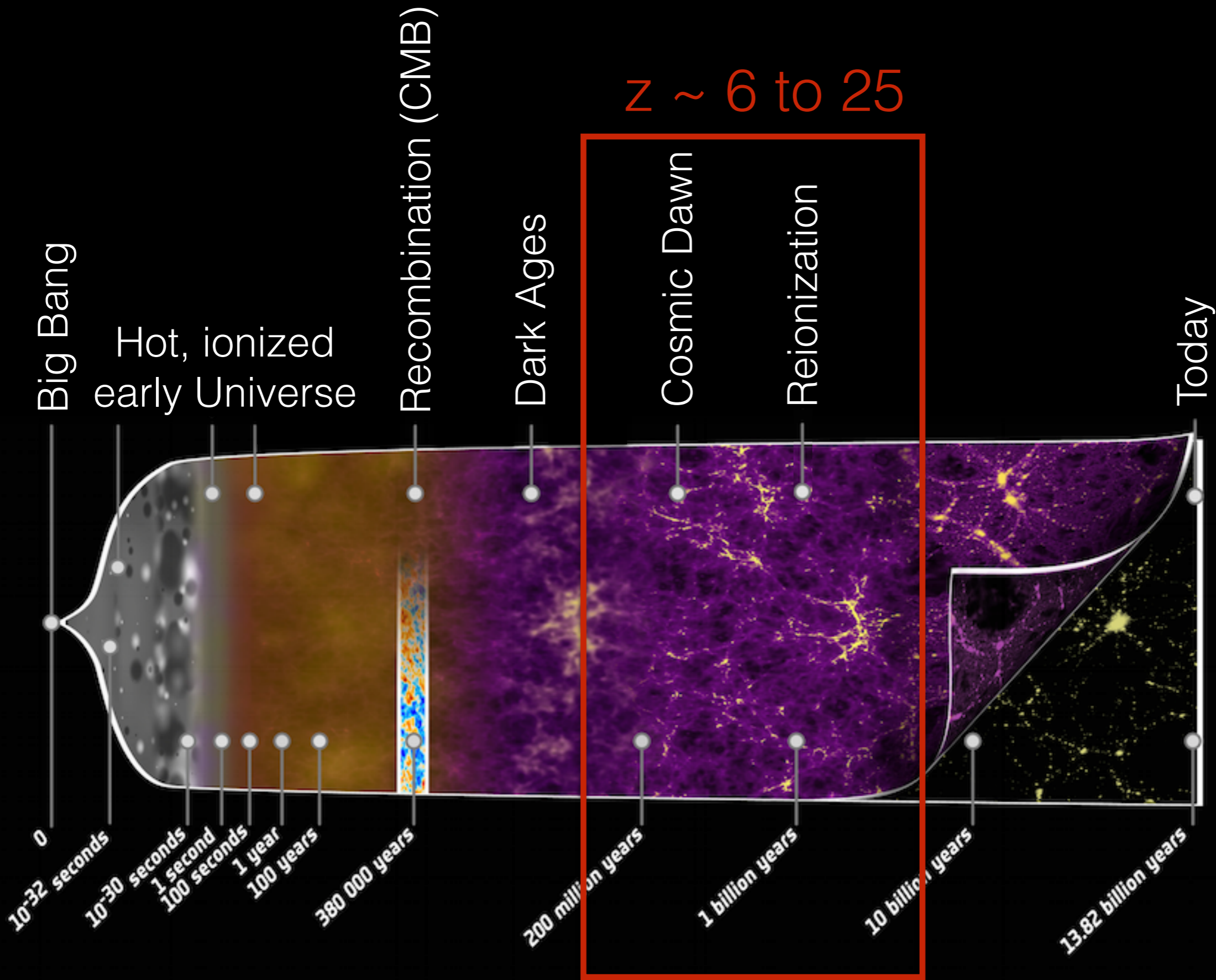


HERA is...

Wire mesh!

...a low-frequency
(~50 to 225 MHz)
instrument

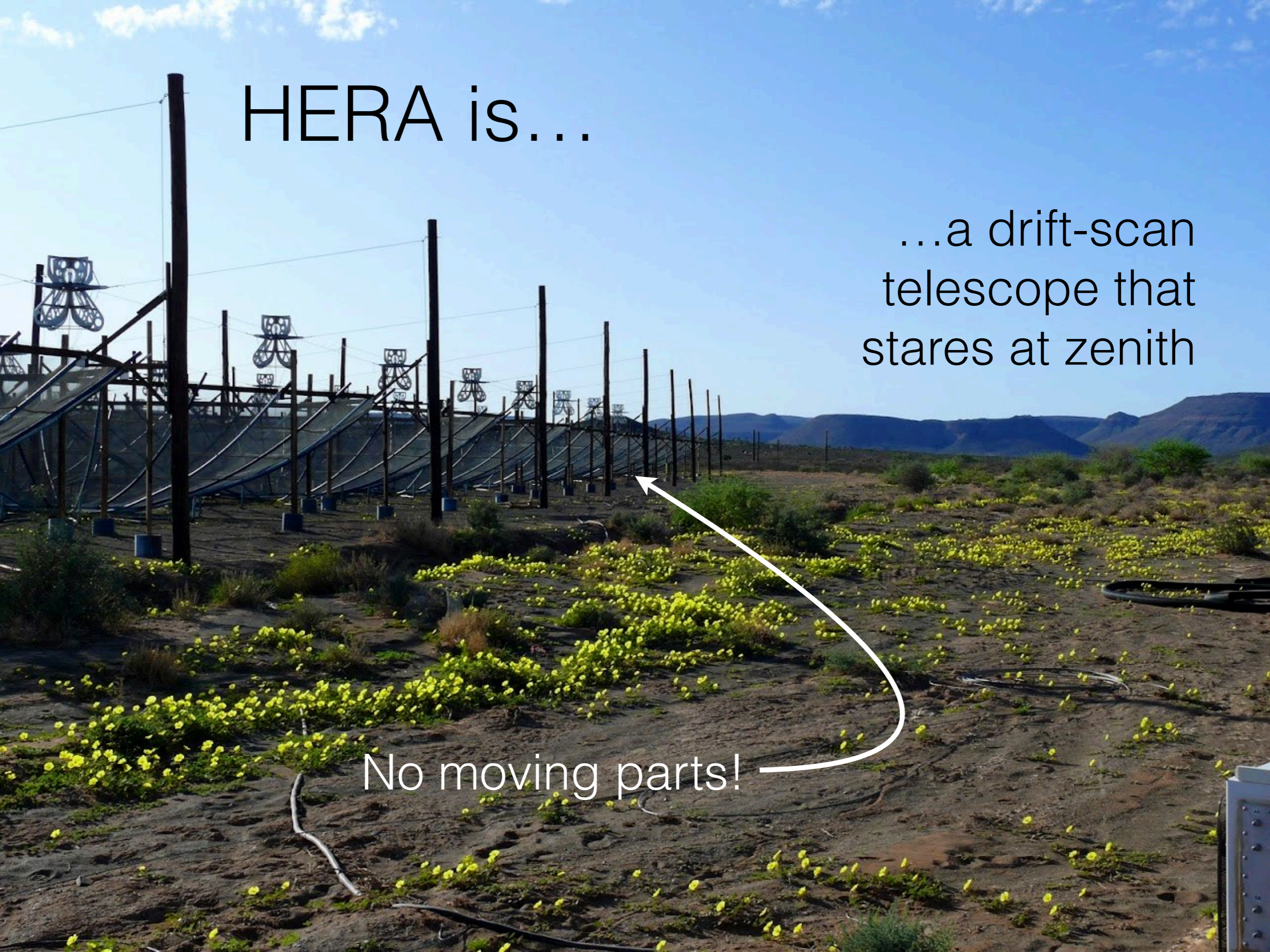




HERA is...

...a drift-scan
telescope that
stares at zenith

No moving parts!



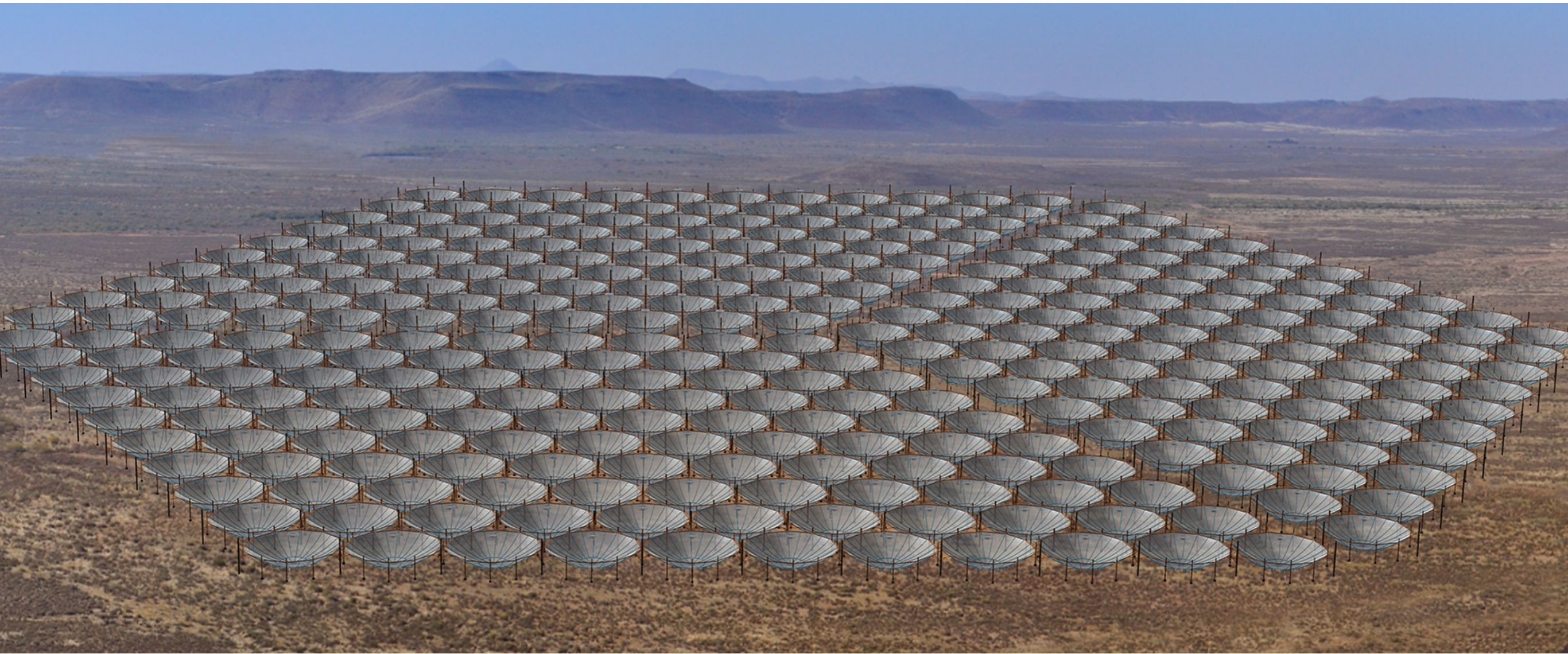
HERA is...



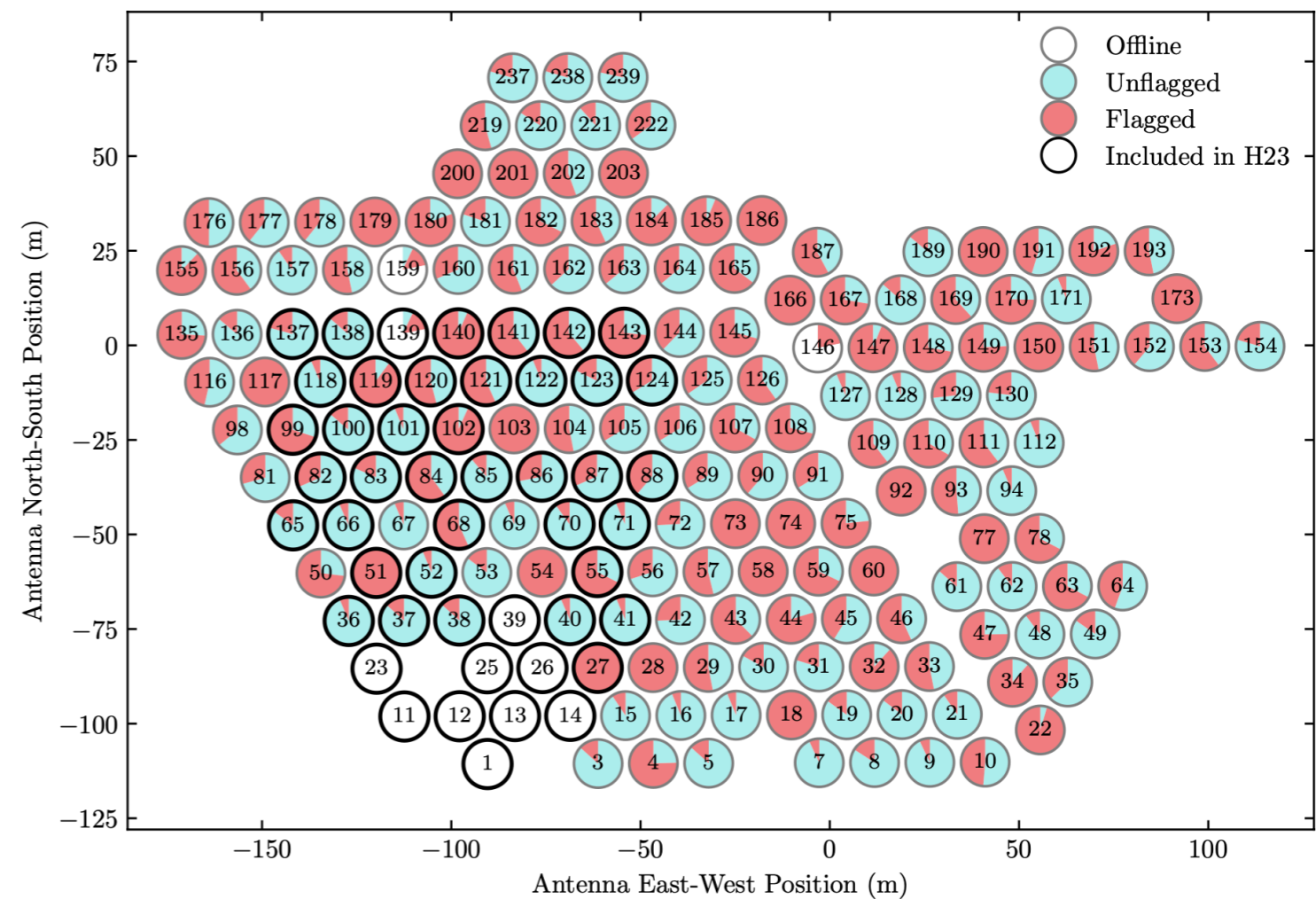
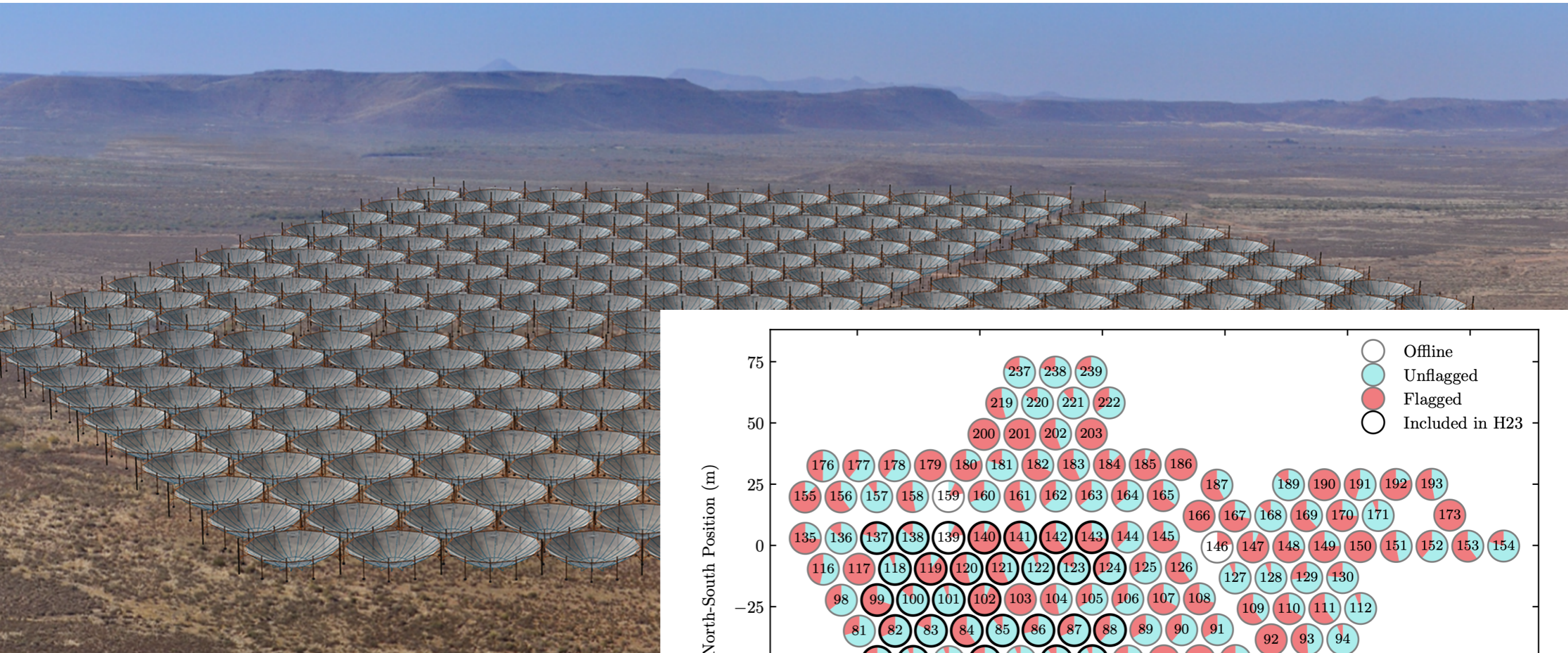
154 m

HERA Phase II Observational Campaign

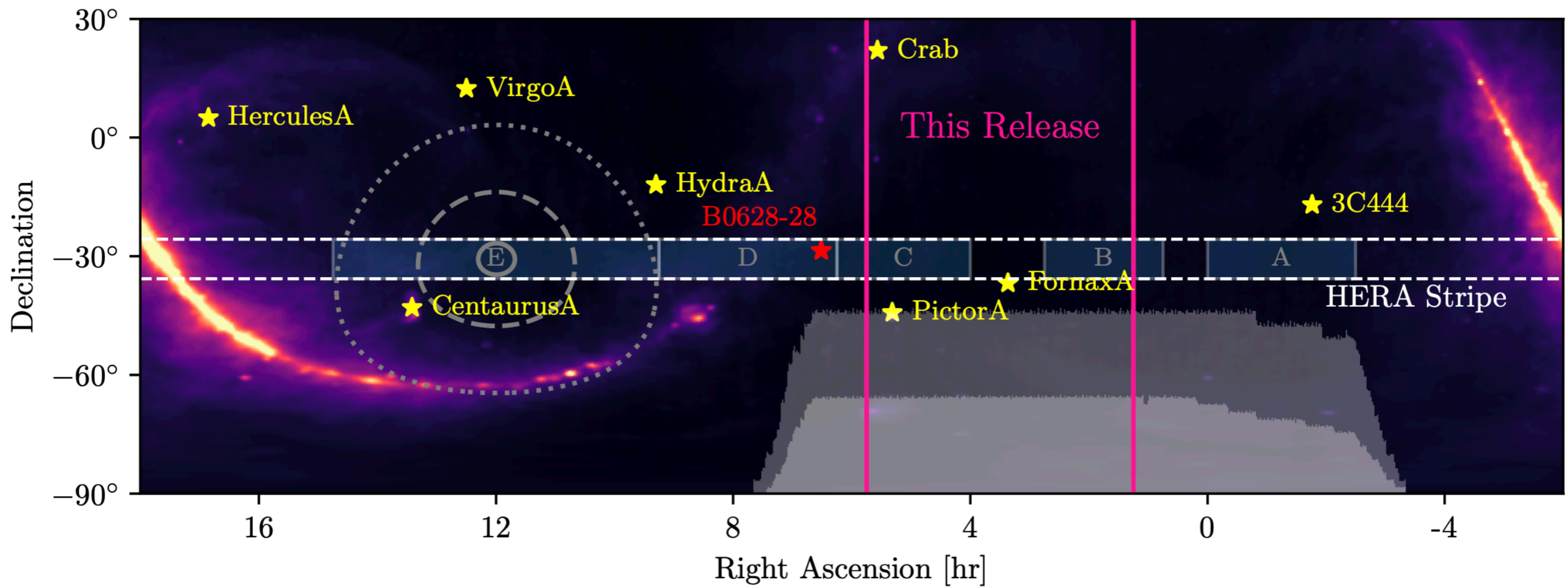
Not the full instrument!



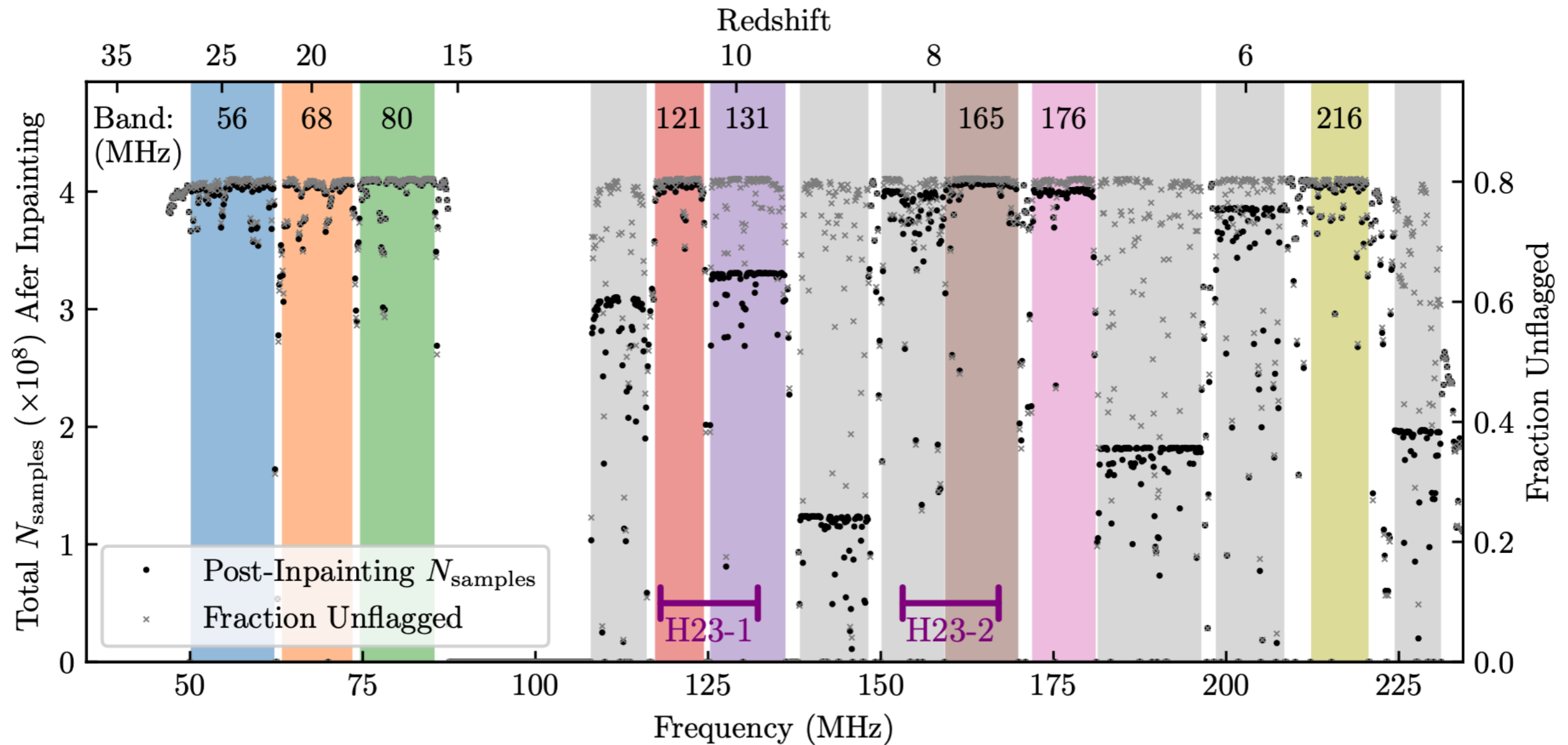
Not the full instrument!



Not the full sky (or even the full stripe!)



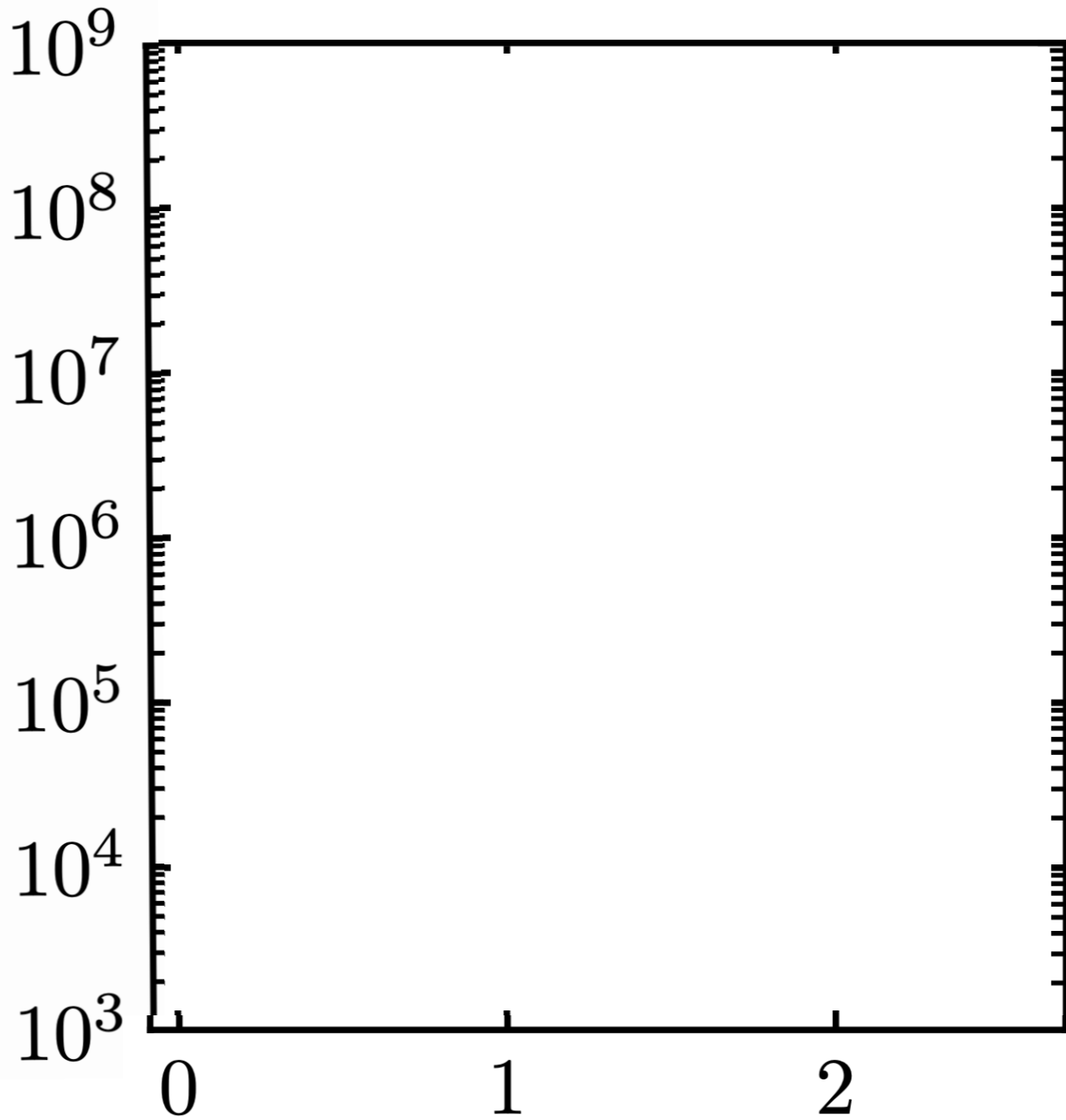
We are going above $z \sim 10$ for the first time with our instrument!



The upper limits on the
21 cm power spectrum

Fluctuation Signal
Strength

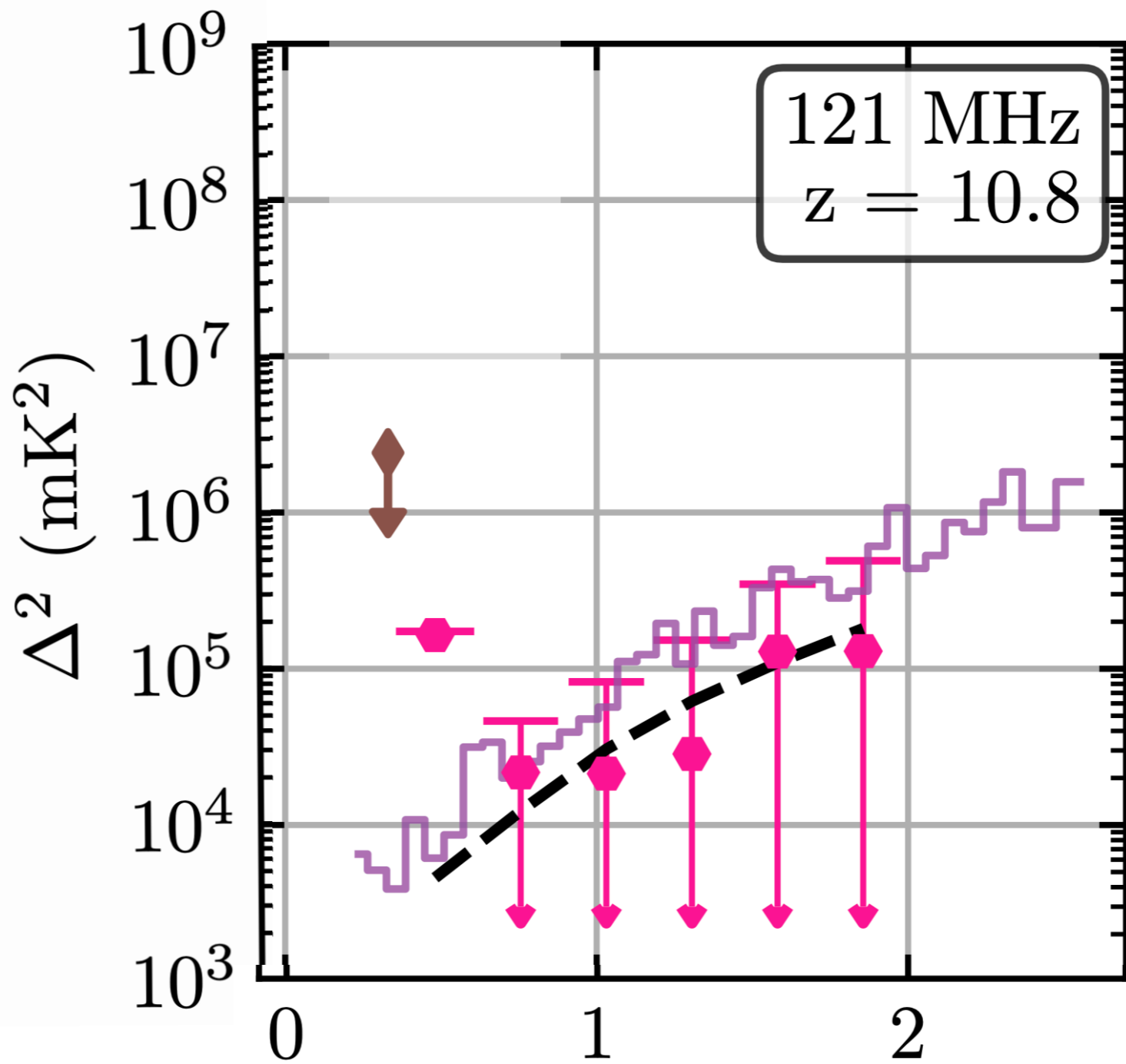
Δ^2 (mK²)



k (hMpc⁻¹)

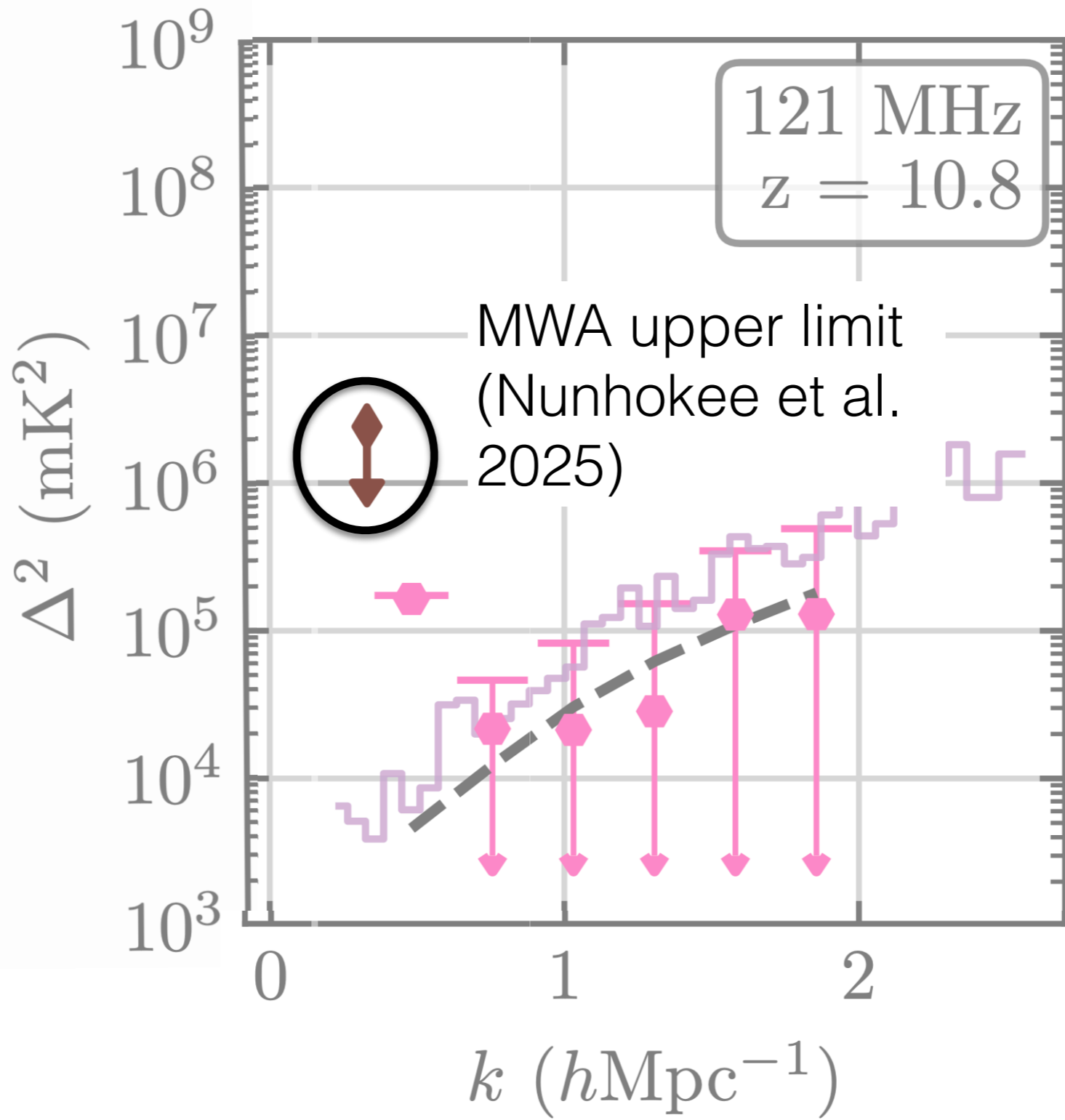
Spatial scale

Fluctuation Signal
Strength



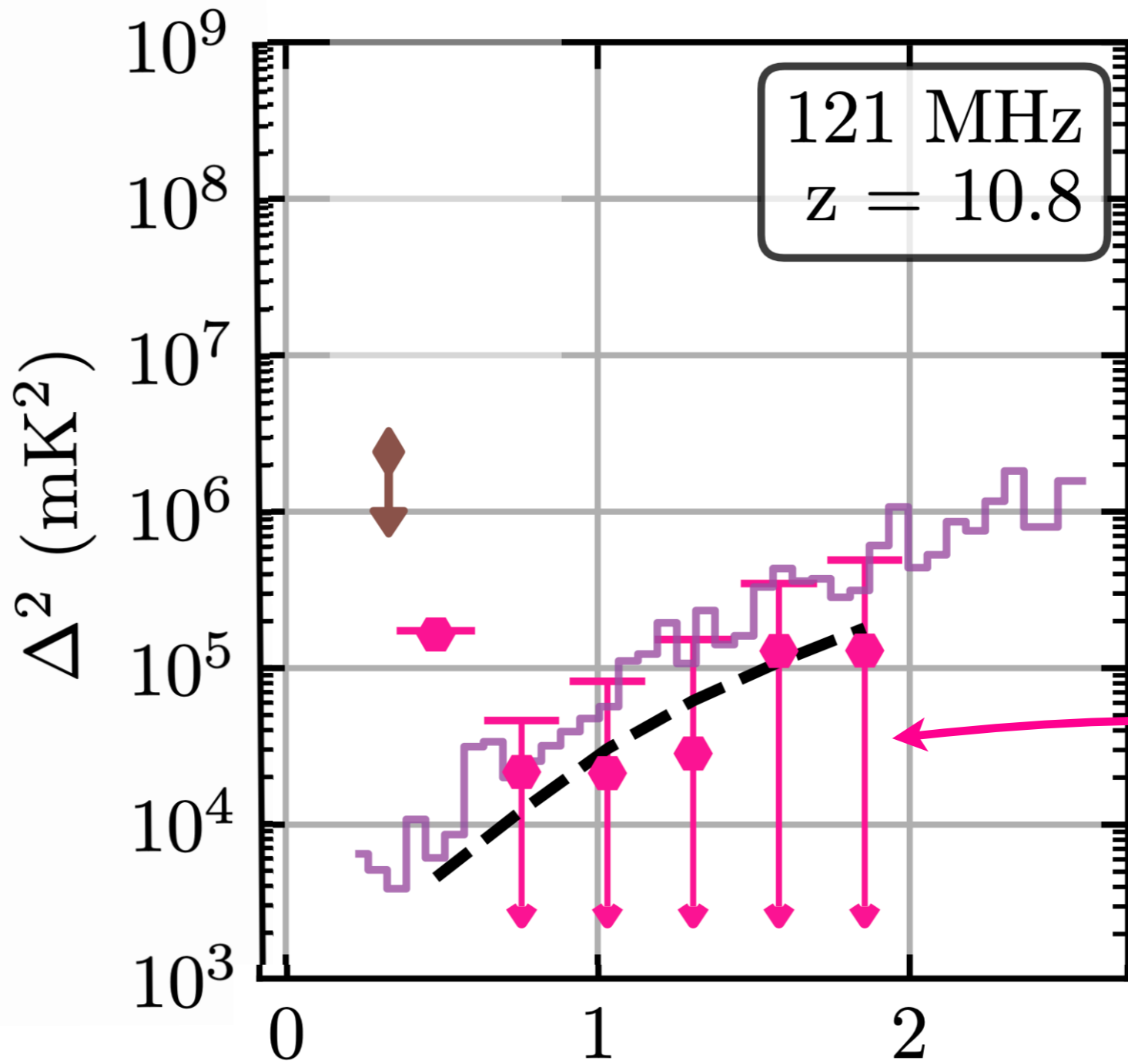
k ($h\text{Mpc}^{-1}$)
Spatial scale

Fluctuation Signal
Strength



Spatial scale

Fluctuation Signal
Strength

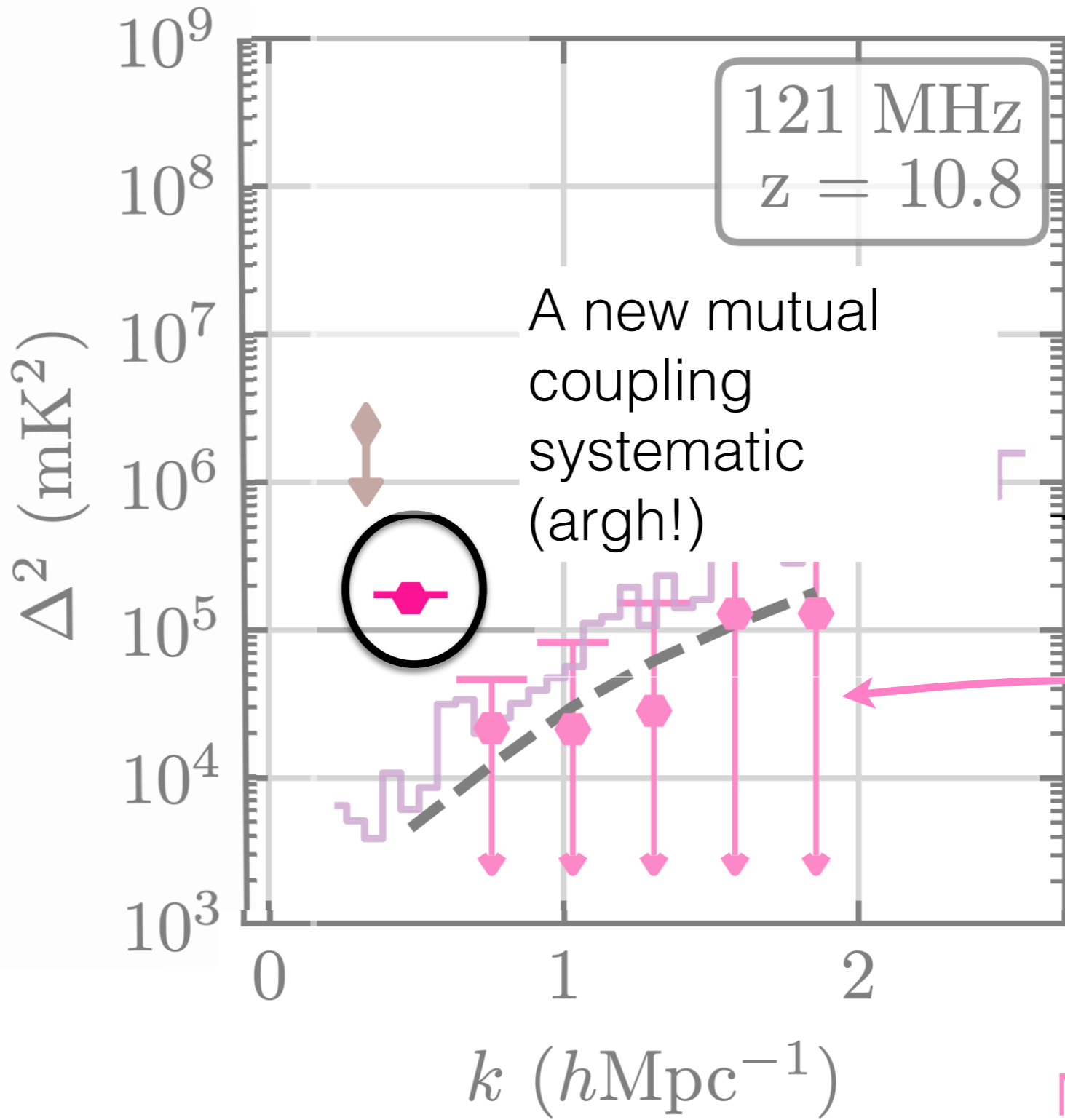


k ($h\text{Mpc}^{-1}$)
Spatial scale

← Previous
Phase I
limits

Most points
consistent with zero
(i.e., noise-limited)

Fluctuation Signal
Strength



Most points consistent with zero (i.e., noise-limited)

Mutual coupling between dishes

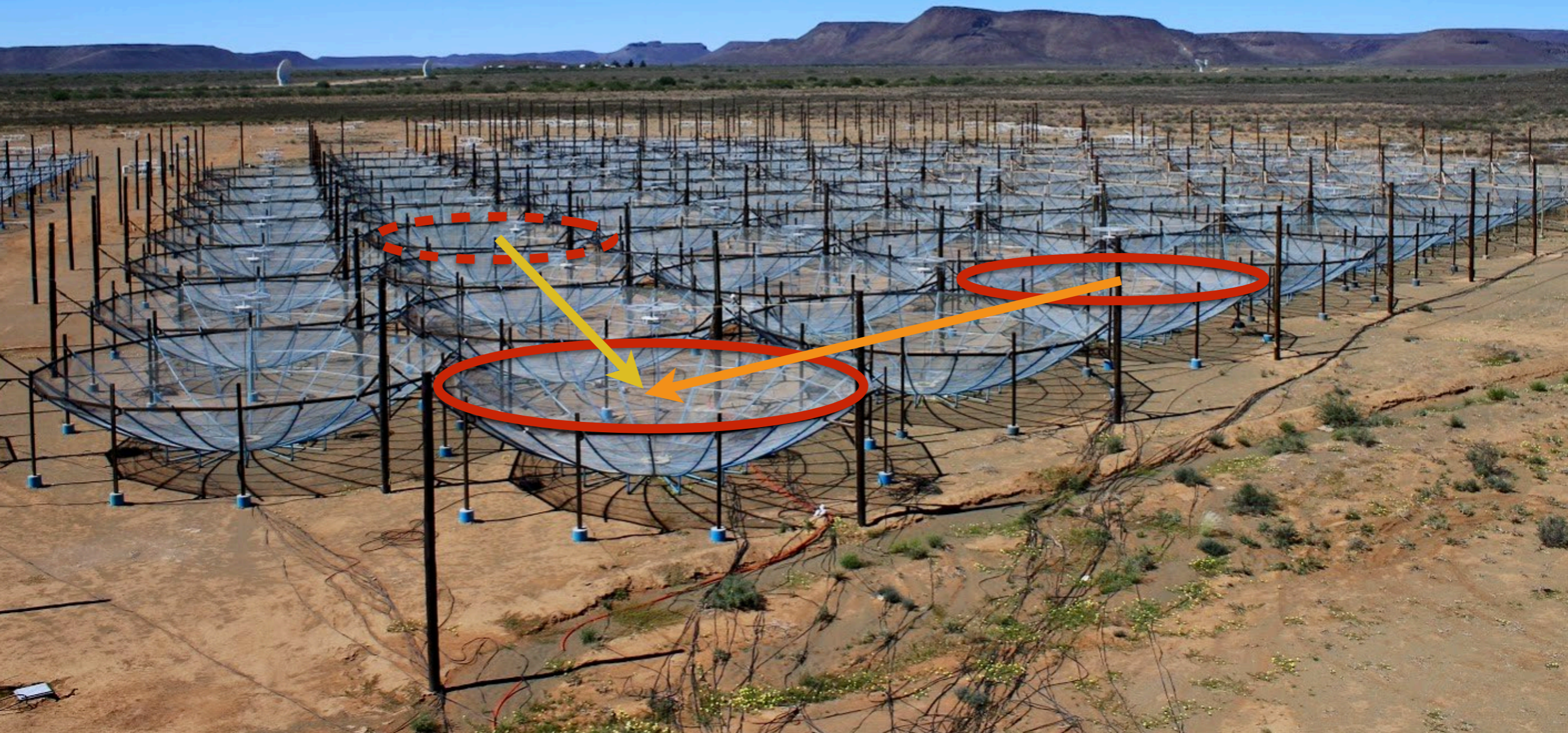
is now believed to be a

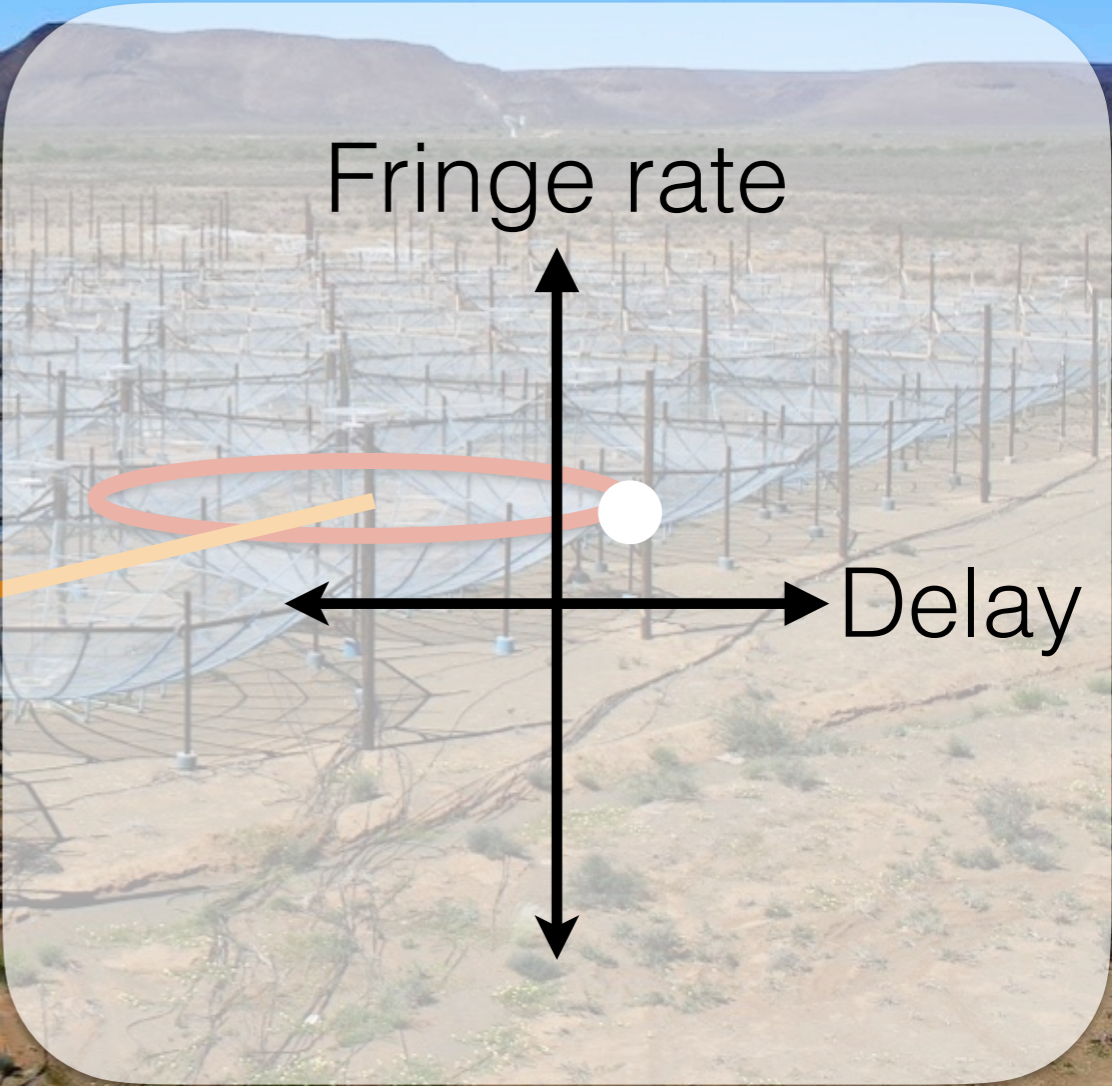
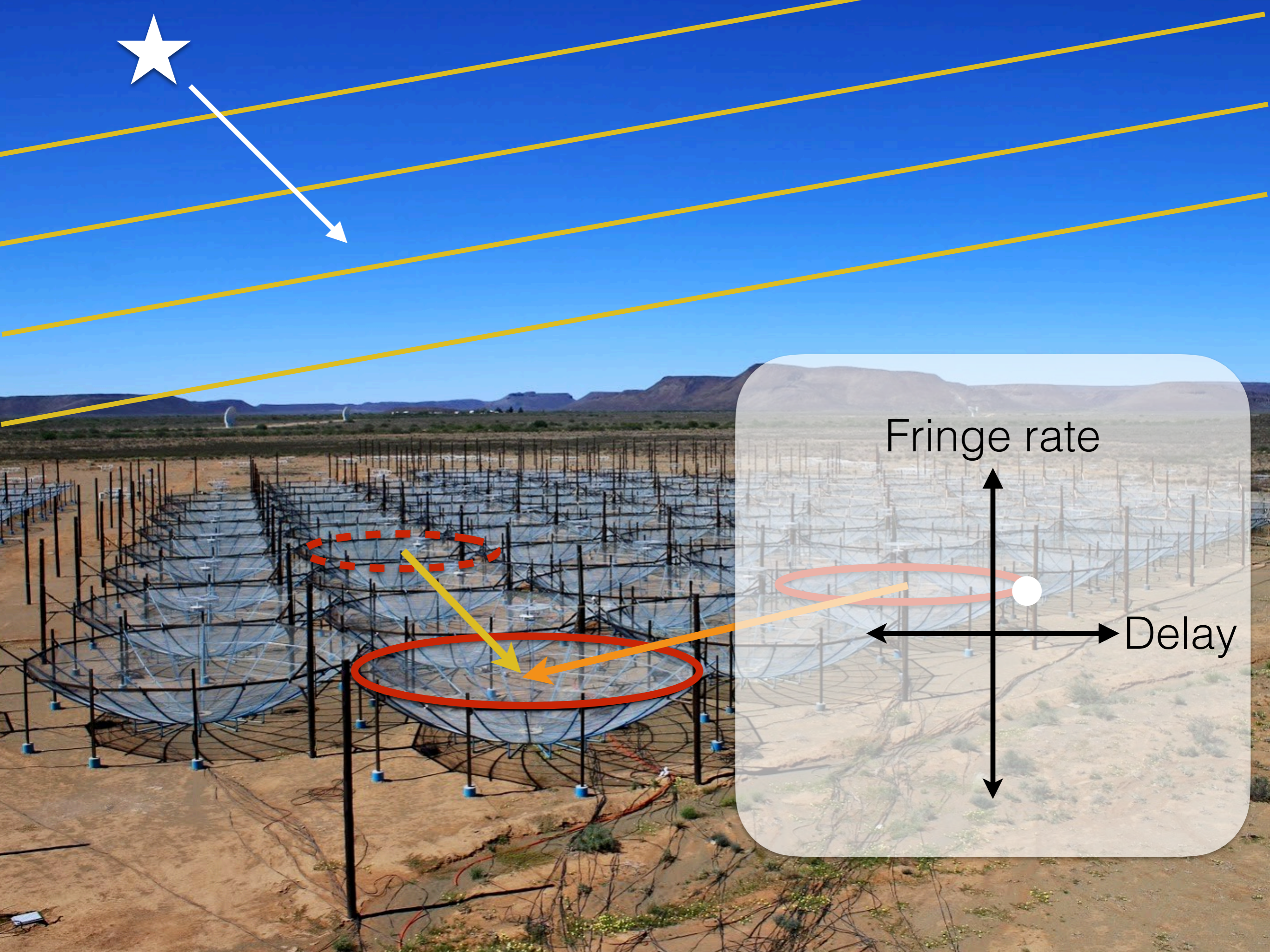
**strong systematic for
HERA at low k**

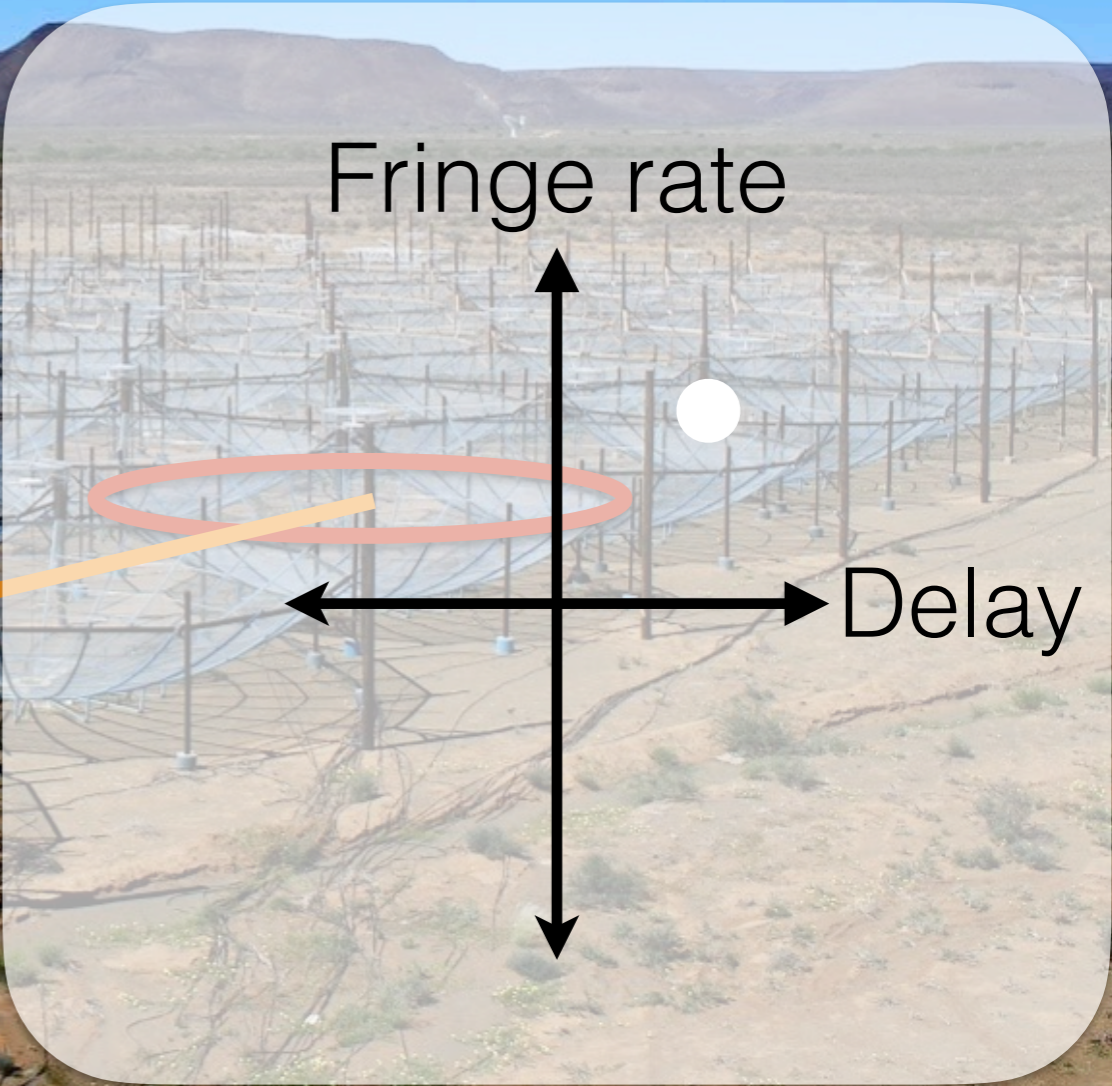
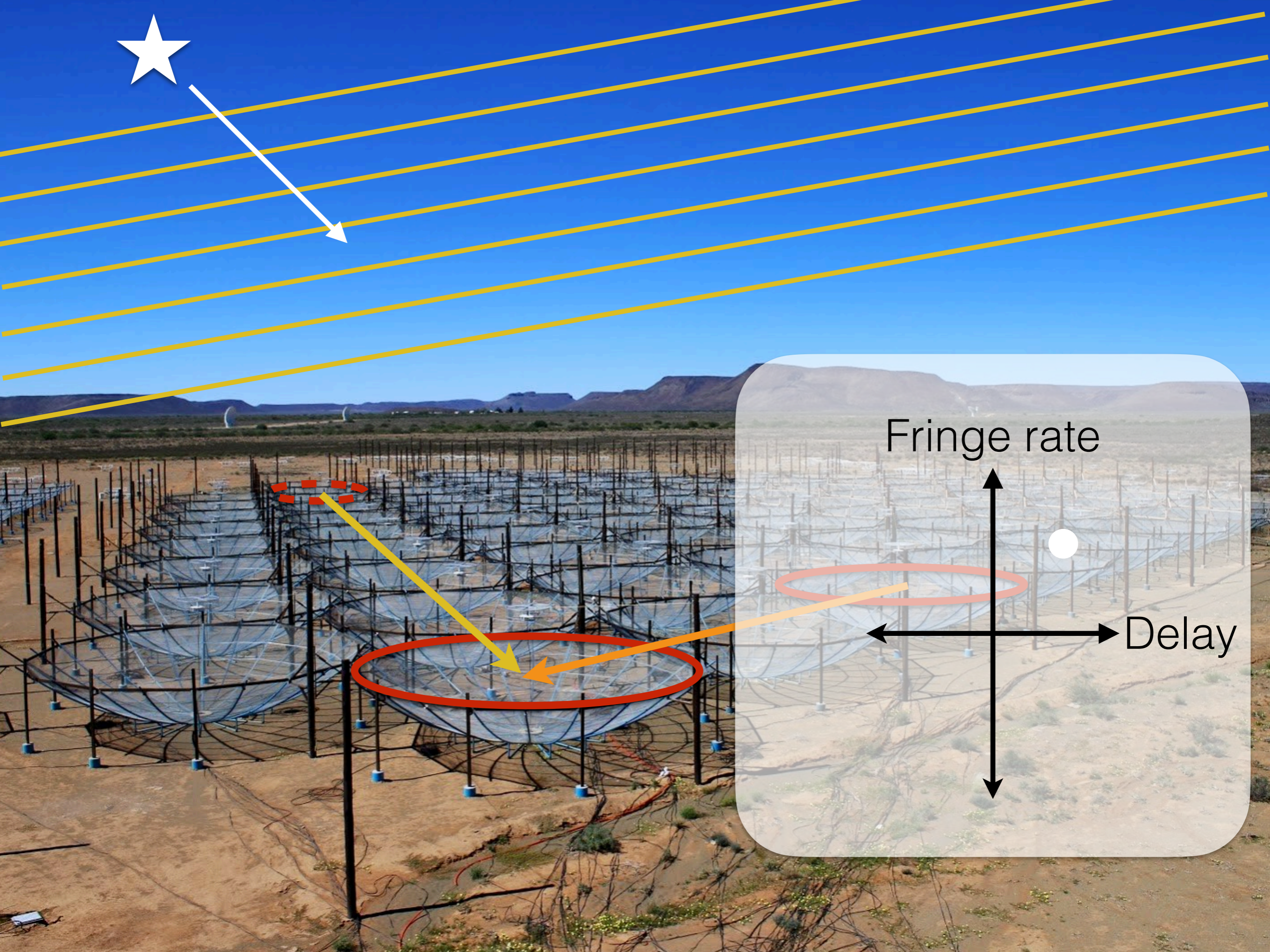
Mutual coupling: reflection/re-emission of sky signal from one antenna into surrounding antennas

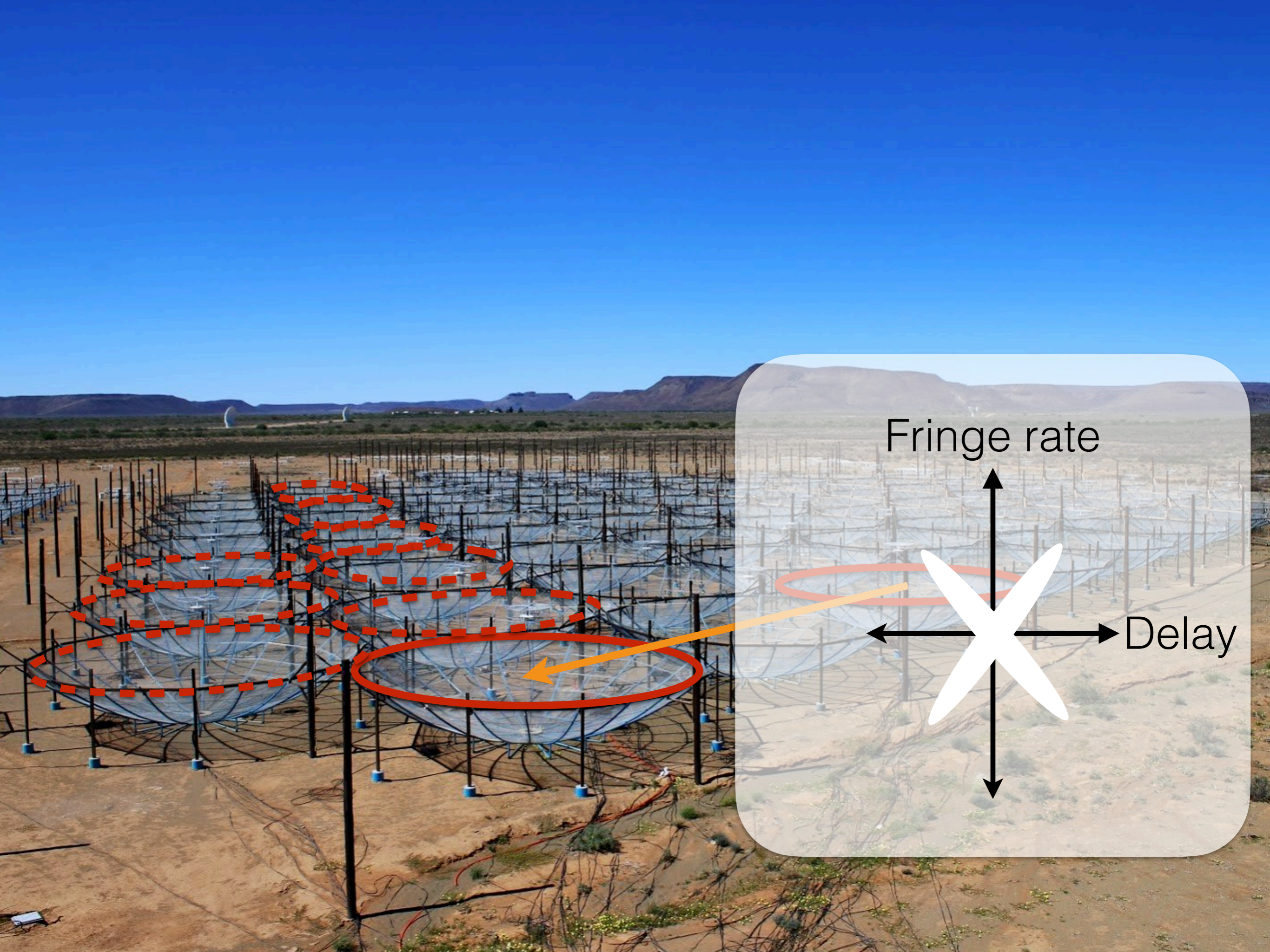


Mutual coupling: reflection/re-emission of sky signal from one antenna into surrounding antennas





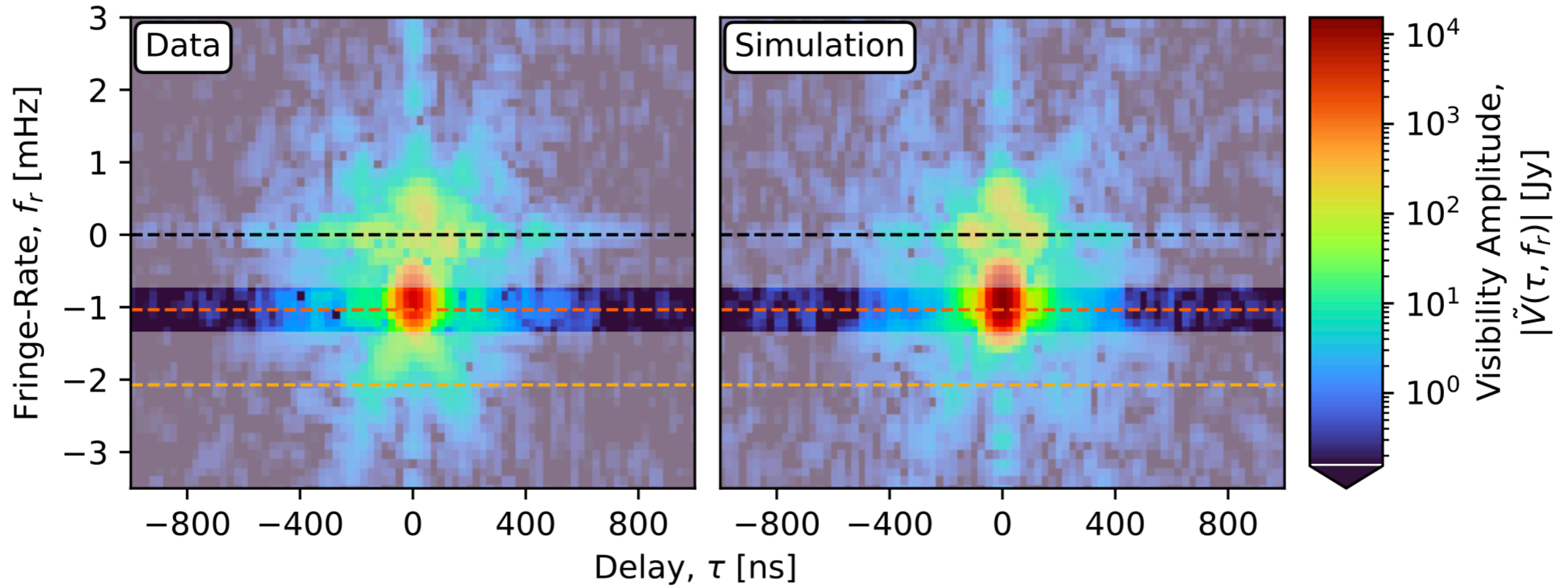




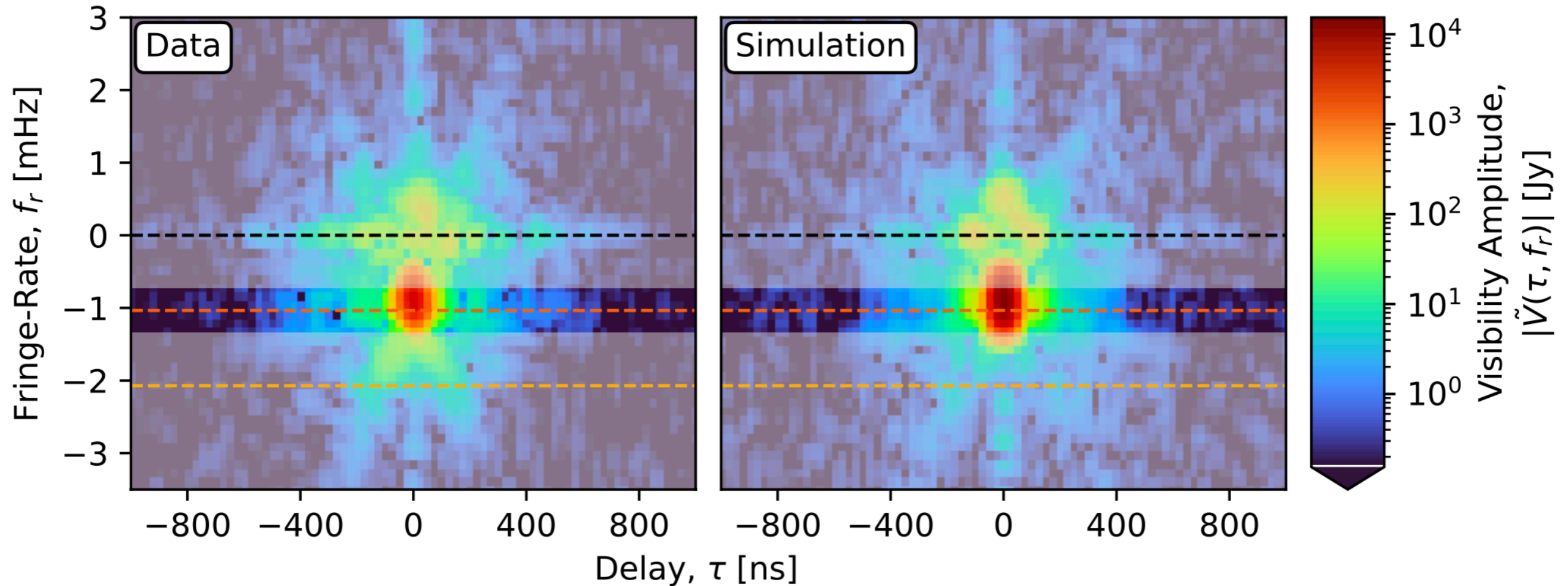
Fringe rate

Delay

Data and simulations agree qualitatively...



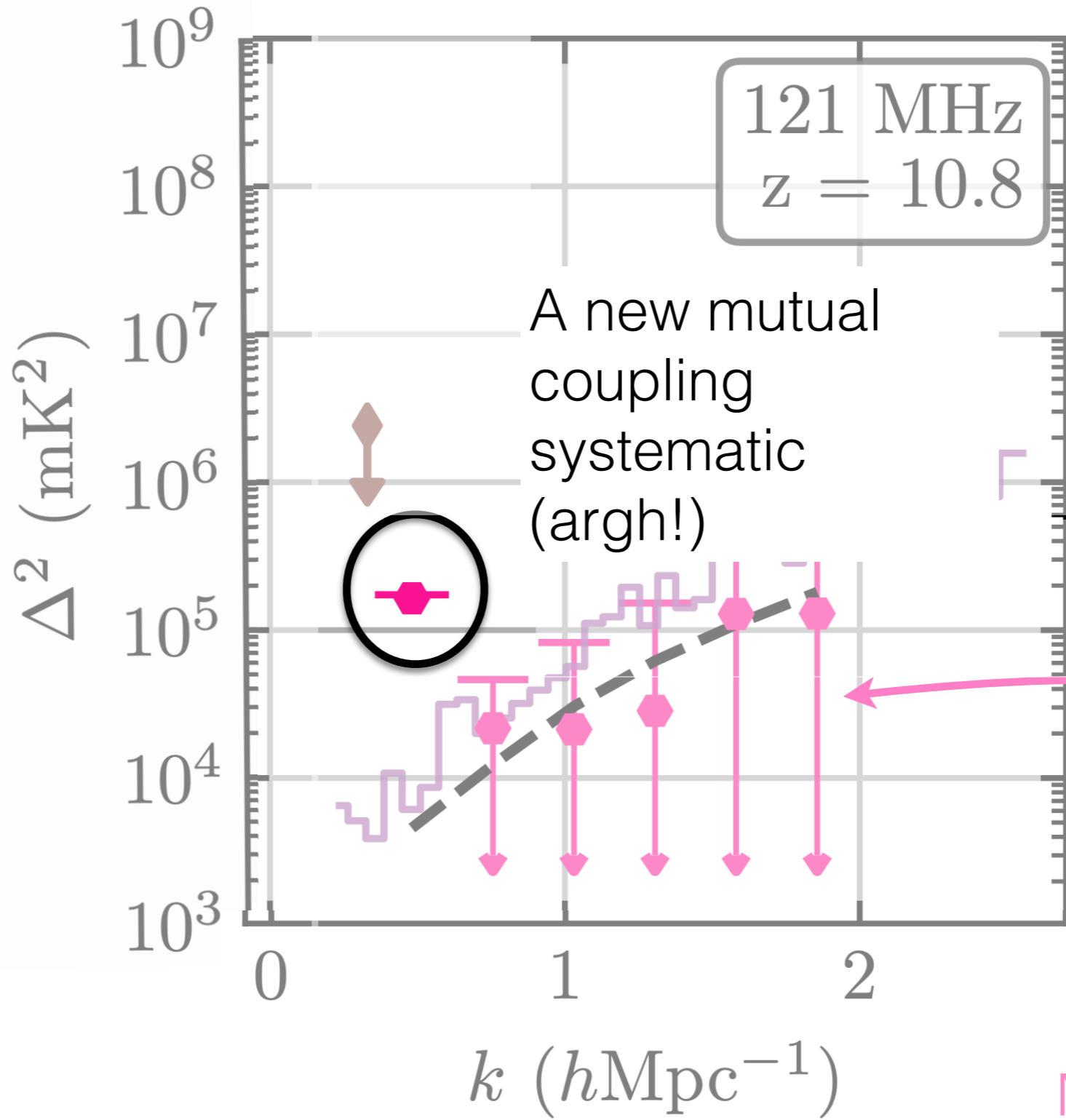
Data and simulations agree qualitatively...



...but not quantitatively, so we use broad filters rather than direct subtraction

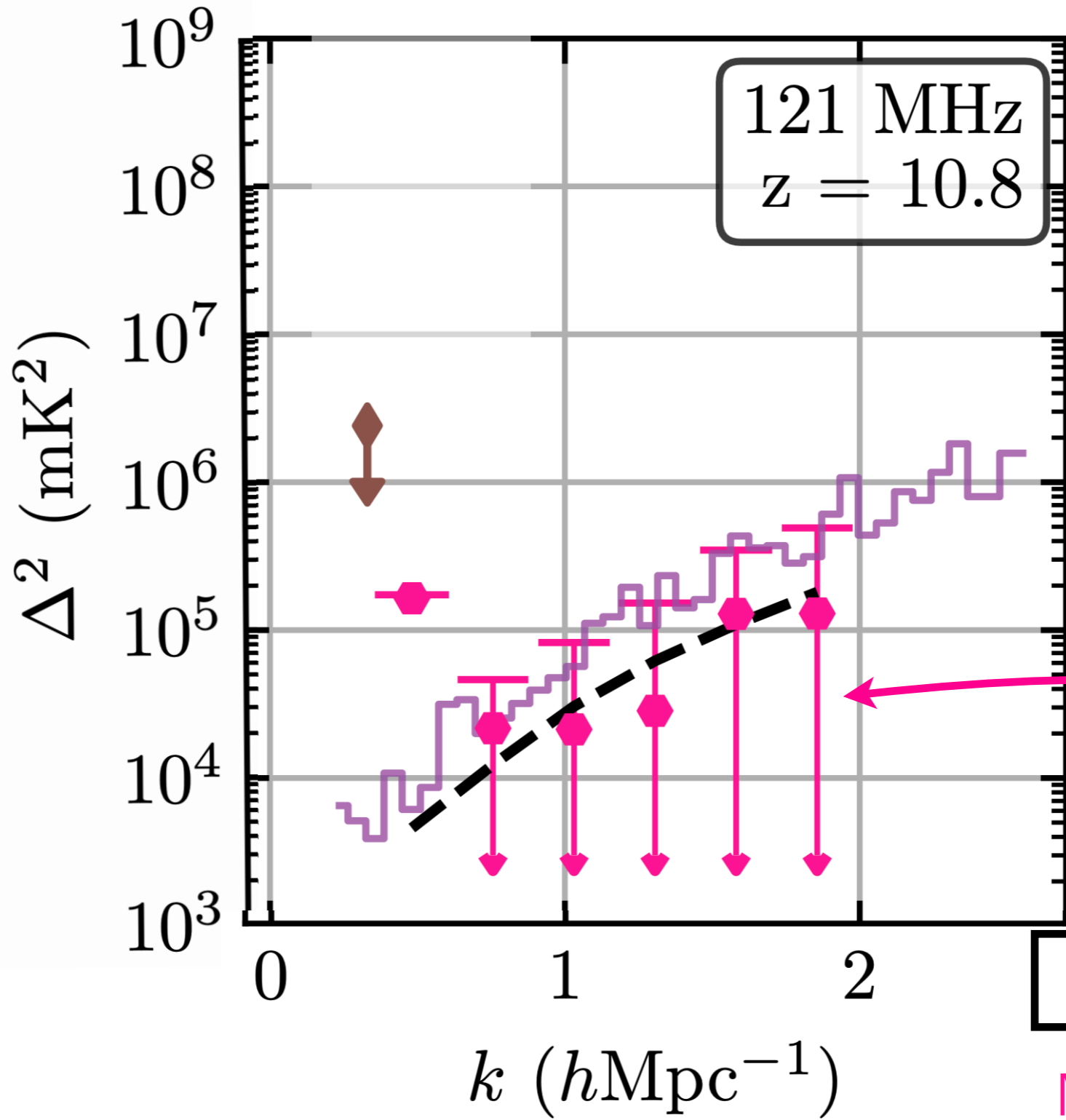
See also Rath, Pascua et al. (2025), MNRAS **541**, 1125
and Pascua et al. (2025), ApJ **985**, 127

Fluctuation Signal
Strength



Most points consistent with zero (i.e., noise-limited)

Fluctuation Signal
Strength



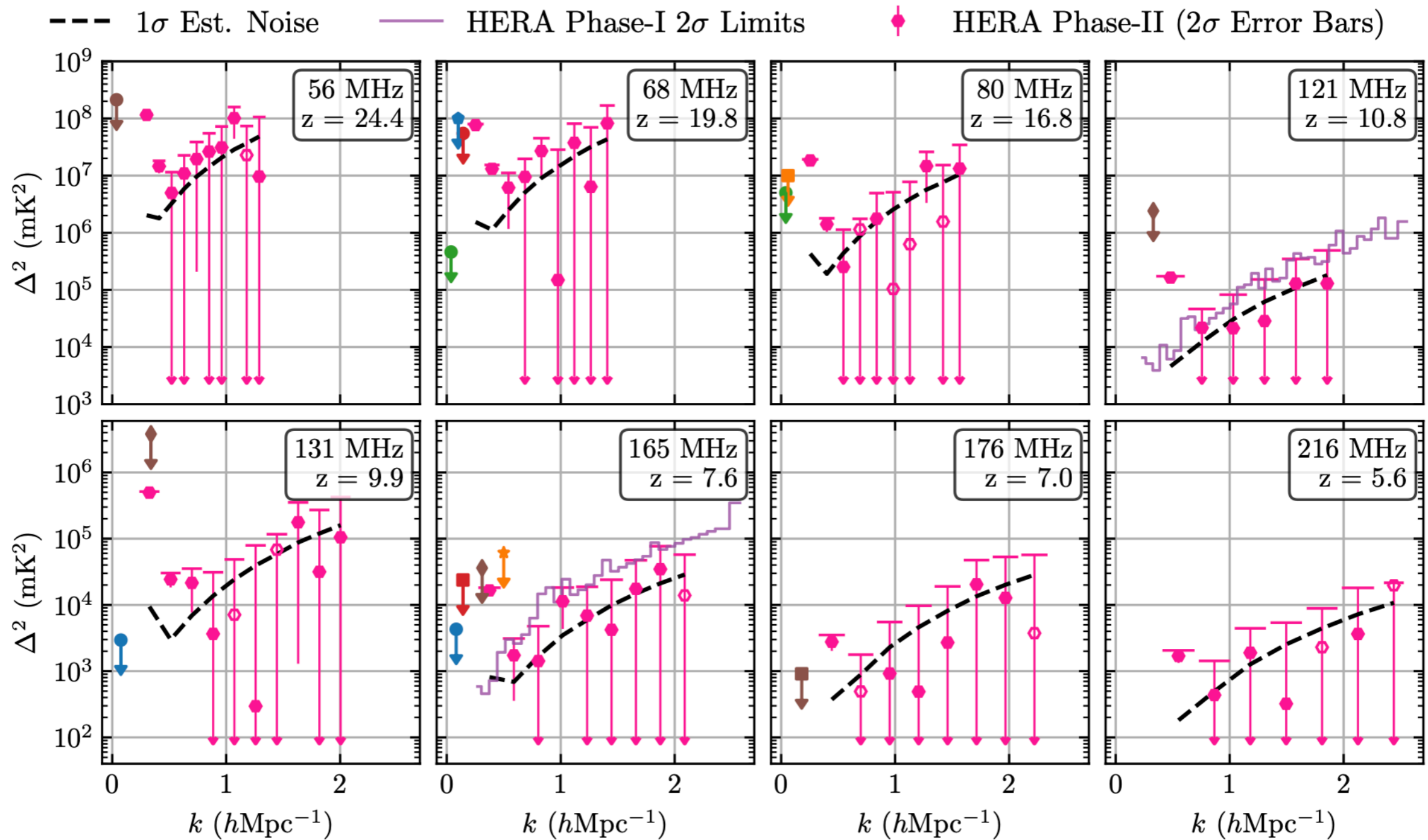
94 nights!

Previous
Phase I
limits

14 nights!

Most points
consistent with zero
(i.e., noise-limited)

We now go from $z \sim 5.5$ to $z \sim 25$



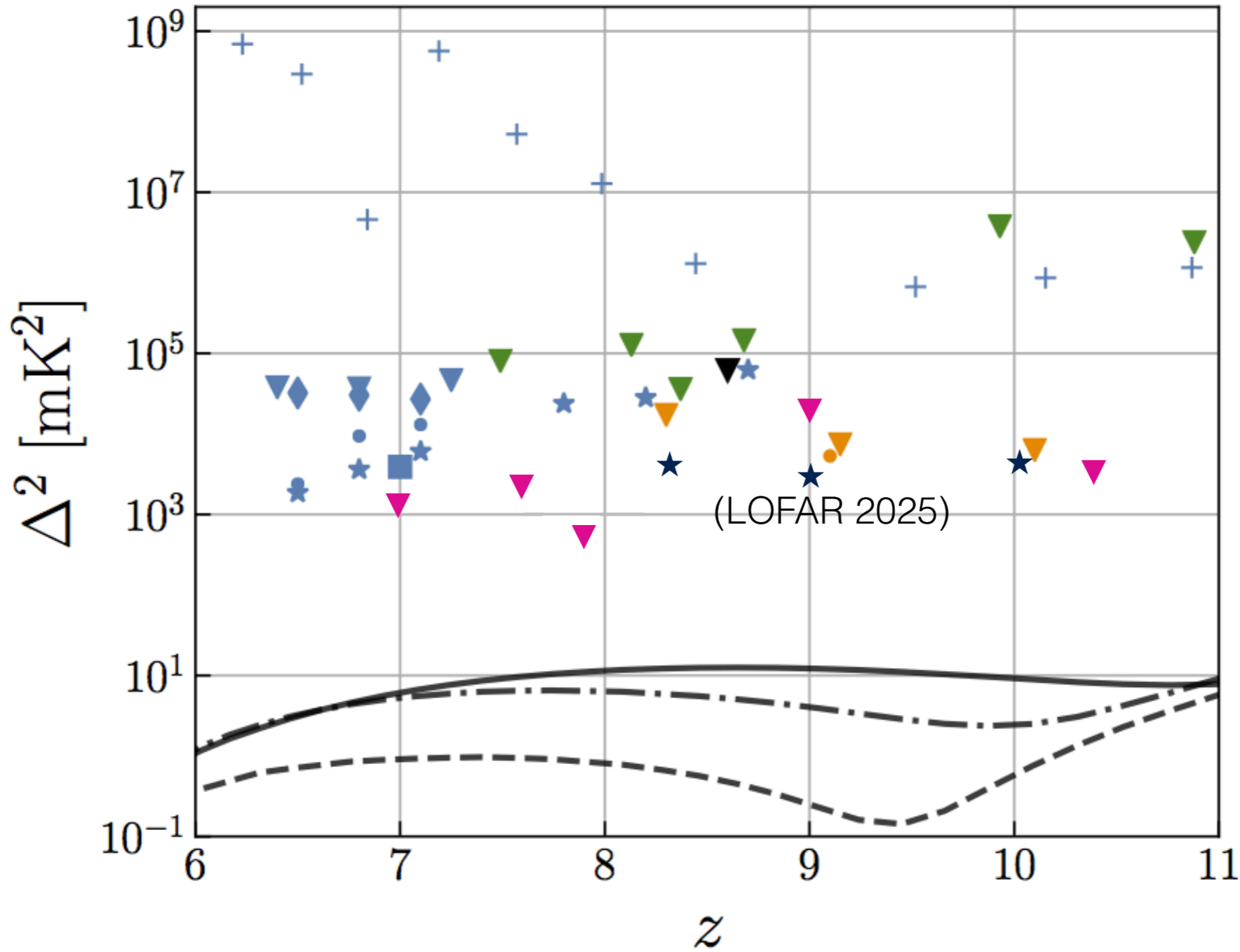
With the HERA Phase II instrument,
at high k we get the

**same sensitivity with just 14
nights of data (versus 94 nights)**

and our broadband feeds mean that we now set limits

from $z \sim 5.5$ to $z \sim 25$

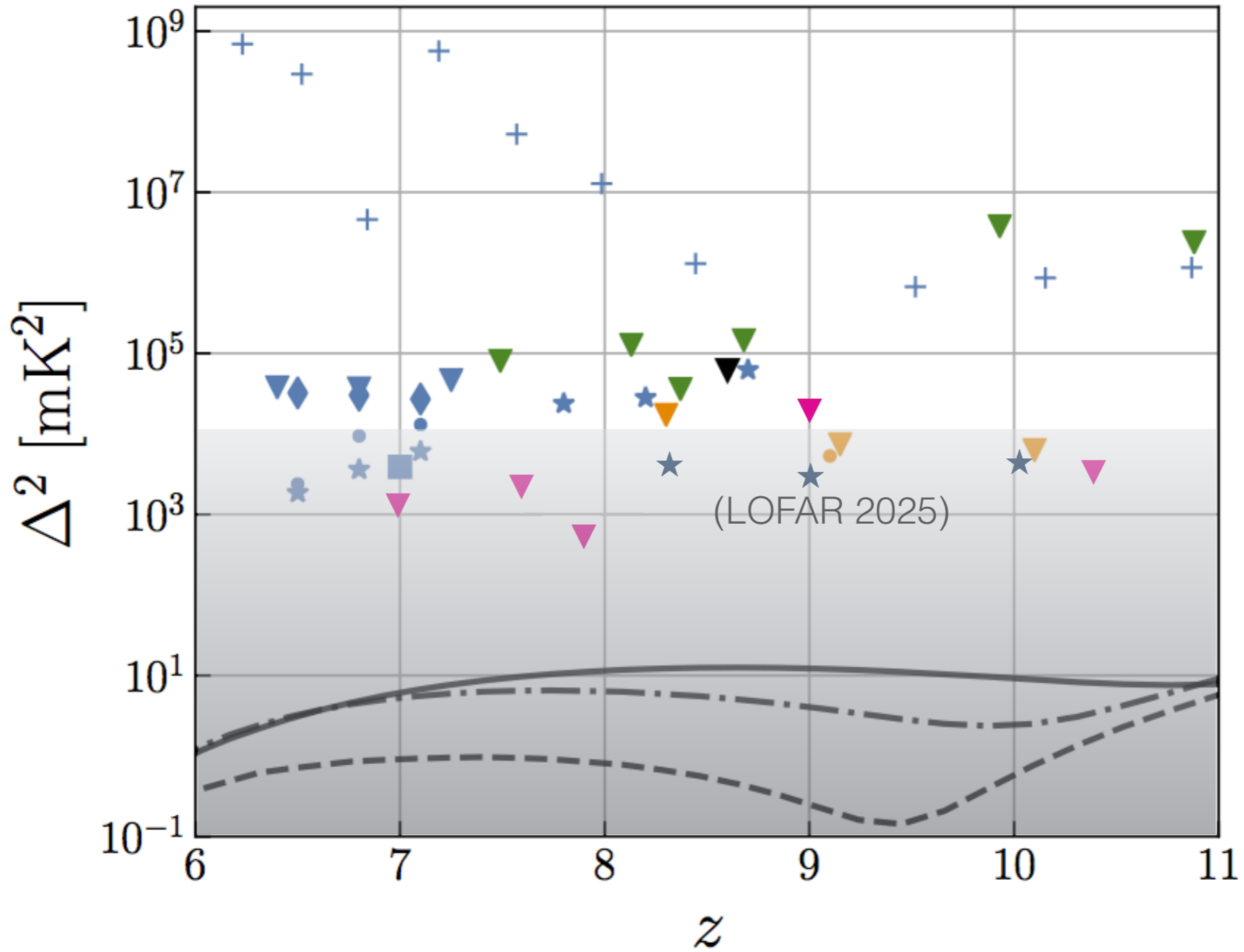
EoR Power Spectrum Limits for $0.05 < k < 0.6 h \text{ Mpc}^{-1}$



▼ Our current limits

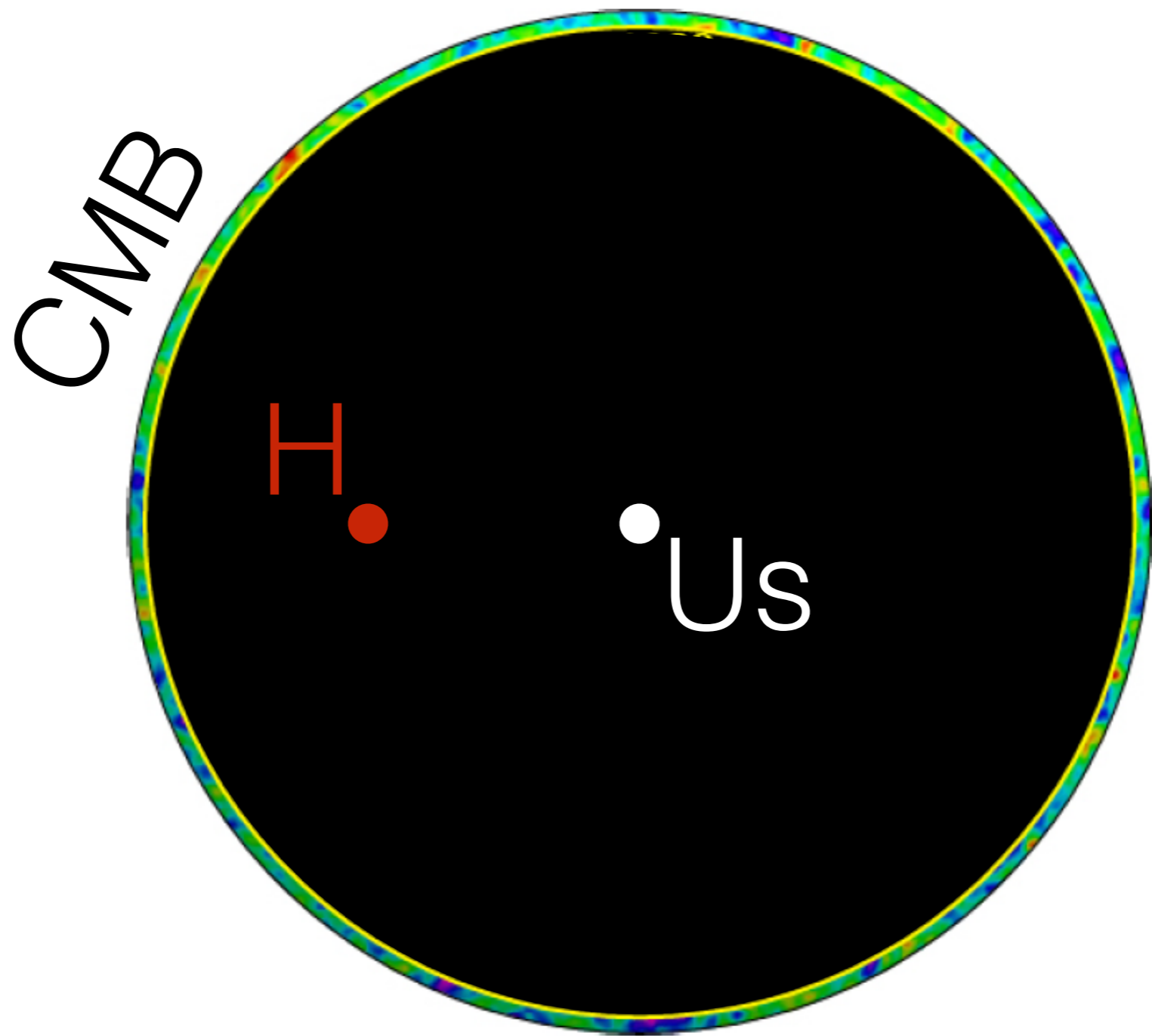
- | | | | |
|---|------------------------|-------|------------------------------|
| ▼ | MWA (Dillon+2015) | ▼ | LOFAR (Patil+2017) |
| • | MWA (Li+2019) | • | LOFAR (Mertens+2020) |
| ■ | MWA (Barry+2019) | ▼ | GMRT (Paciga+2013) |
| + | MWA (Dillon+2014) | ▼ | HERA (HERA+2021) |
| ◆ | MWA (Beardsley+2016) | - - · | Mesinger+2016 ($k = 0.05$) |
| ★ | MWA (Trott+2020) | - · · | Mesinger+2016 ($k = 0.2$) |
| ▼ | PAPER (Kolopanis+2019) | — | Mesinger+2016 ($k = 0.5$) |

EoR Power Spectrum Limits for $0.05 < k < 0.6 h \text{ Mpc}^{-1}$



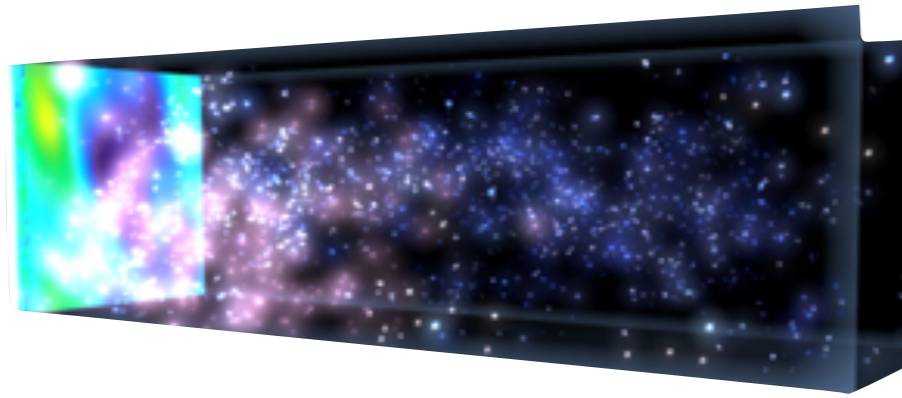
- | | | | |
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| ▼ | PAPER (Kolopanis+2019) | — | Mesinger+2016 ($k = 0.5$) |

What science can we
do with these limits?





Cold hydrogen
gas

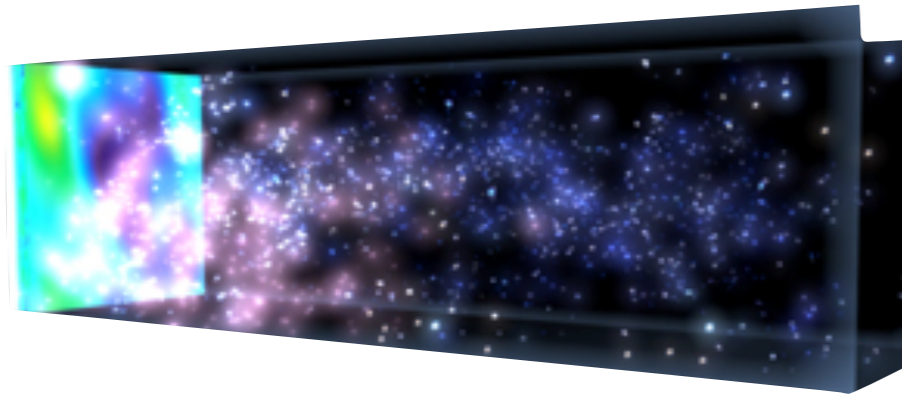


(Relatively)
hot CMB



Cold hydrogen
gas





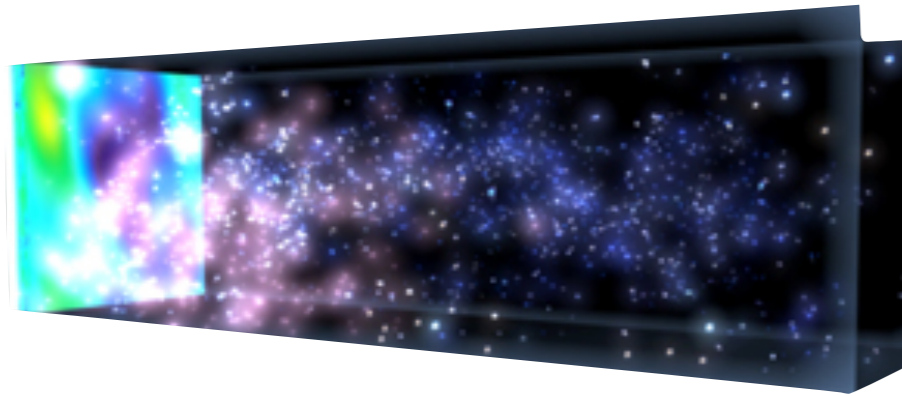
(Relatively)
hot CMB



Cold hydrogen
gas

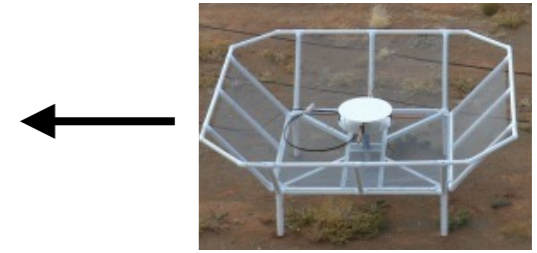


BIG
contrast,
large signal

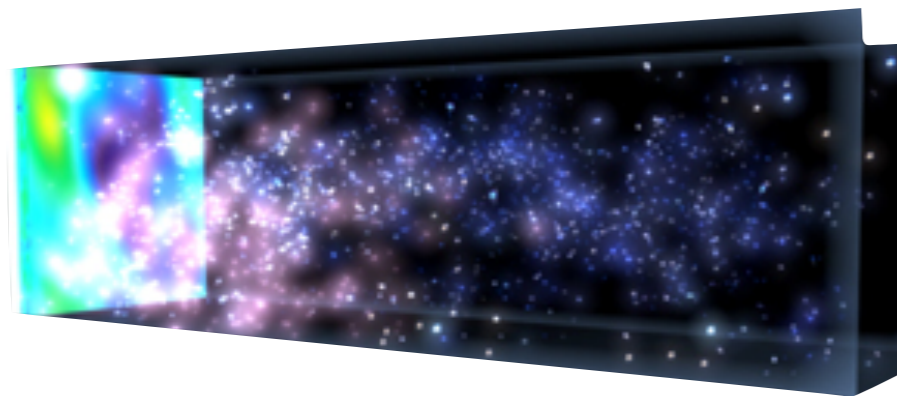


(Relatively)
hot CMB

Cold hydrogen
gas

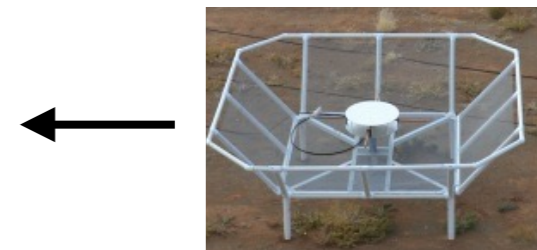


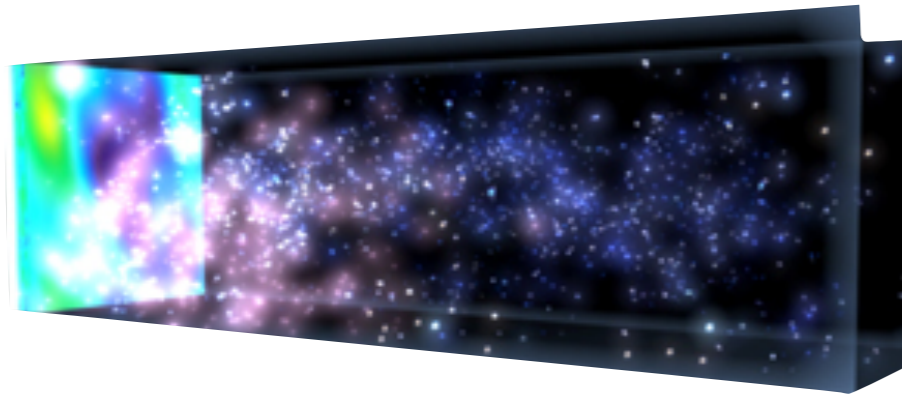
BIG
contrast,
large signal



(Relatively)
hot CMB


Warm
hydrogen gas

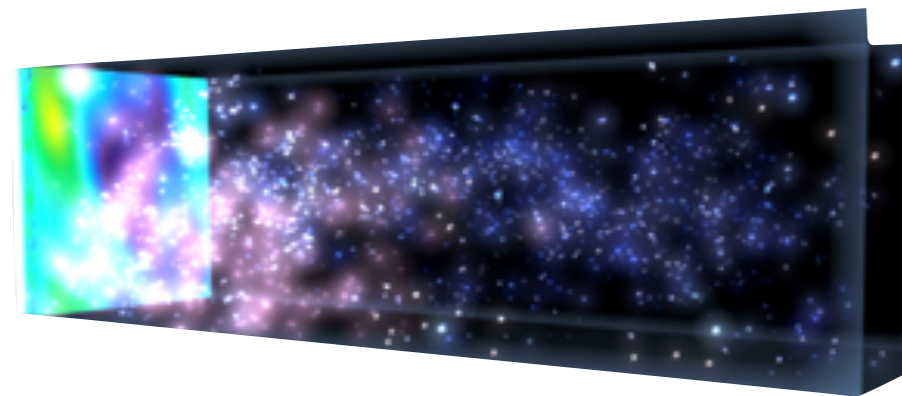




(Relatively)
hot CMB


Cold hydrogen
gas

← 
BIG
contrast,
large signal



(Relatively)
hot CMB

Warm
hydrogen gas

← 
Small contrast, small signal

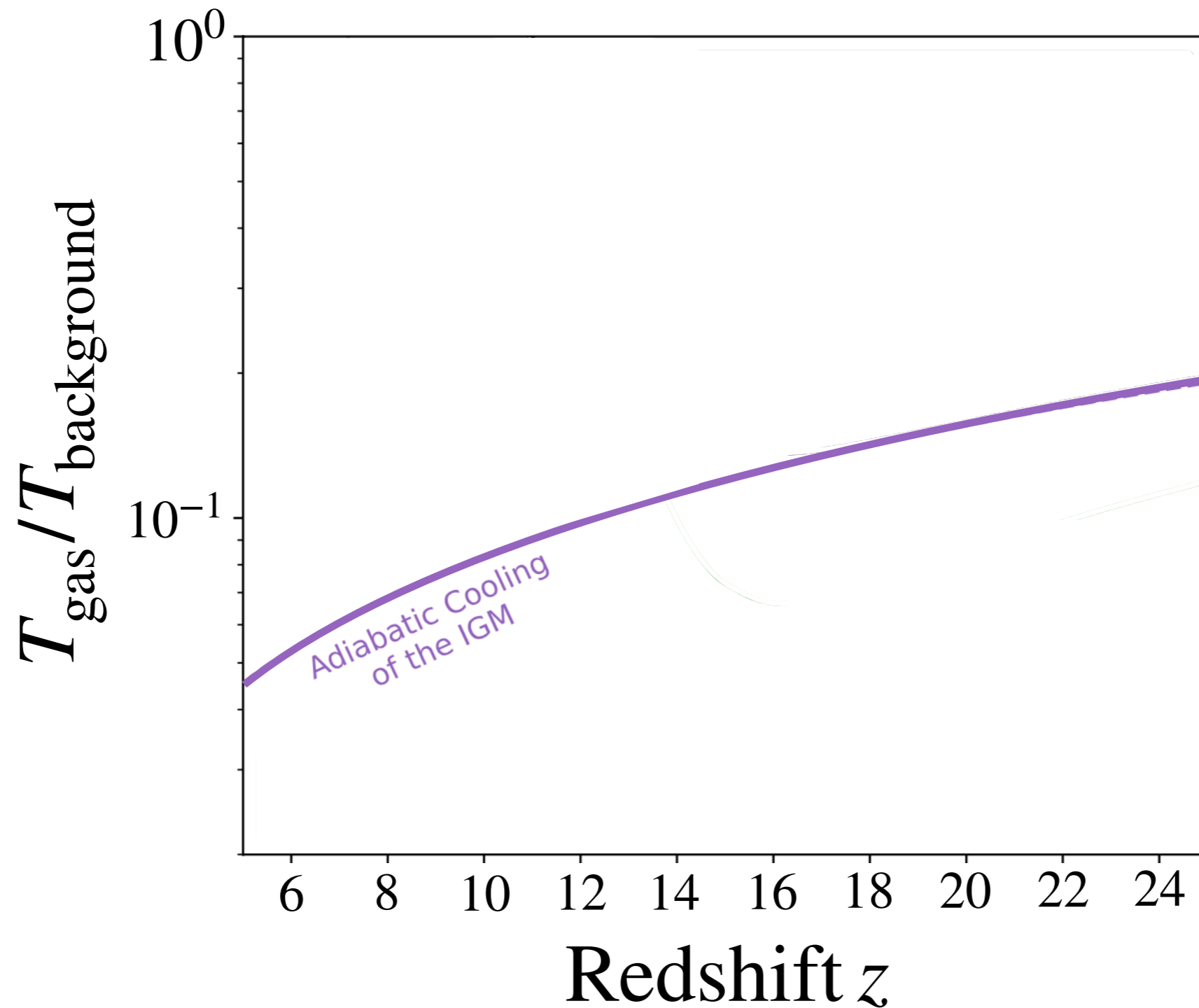
Current limits

**rule out an extremely cold,
adiabatically cooled IGM**

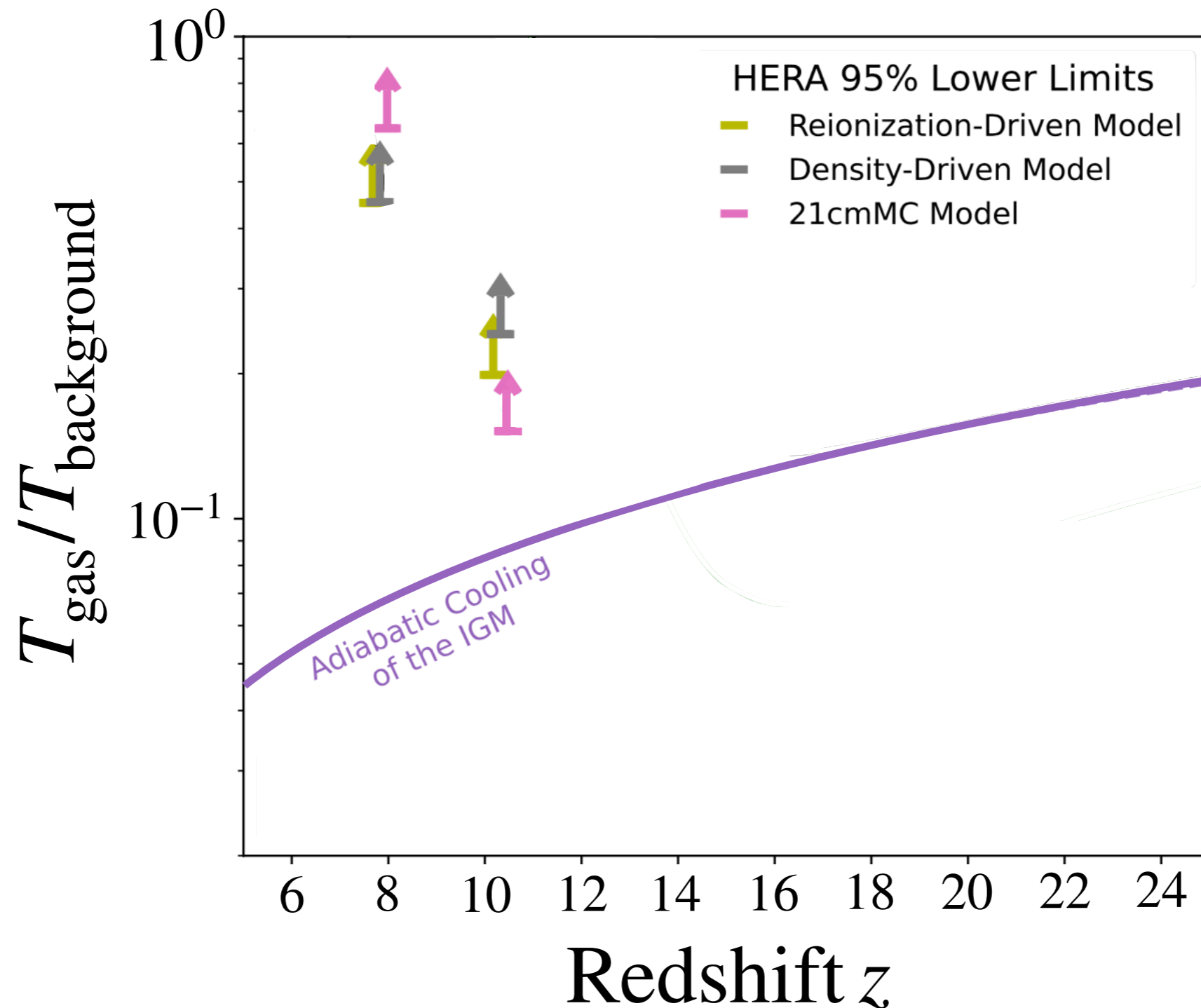
at relevant redshifts and these in turn

**constrain the X-ray luminosity of
galaxies responsible for heating**

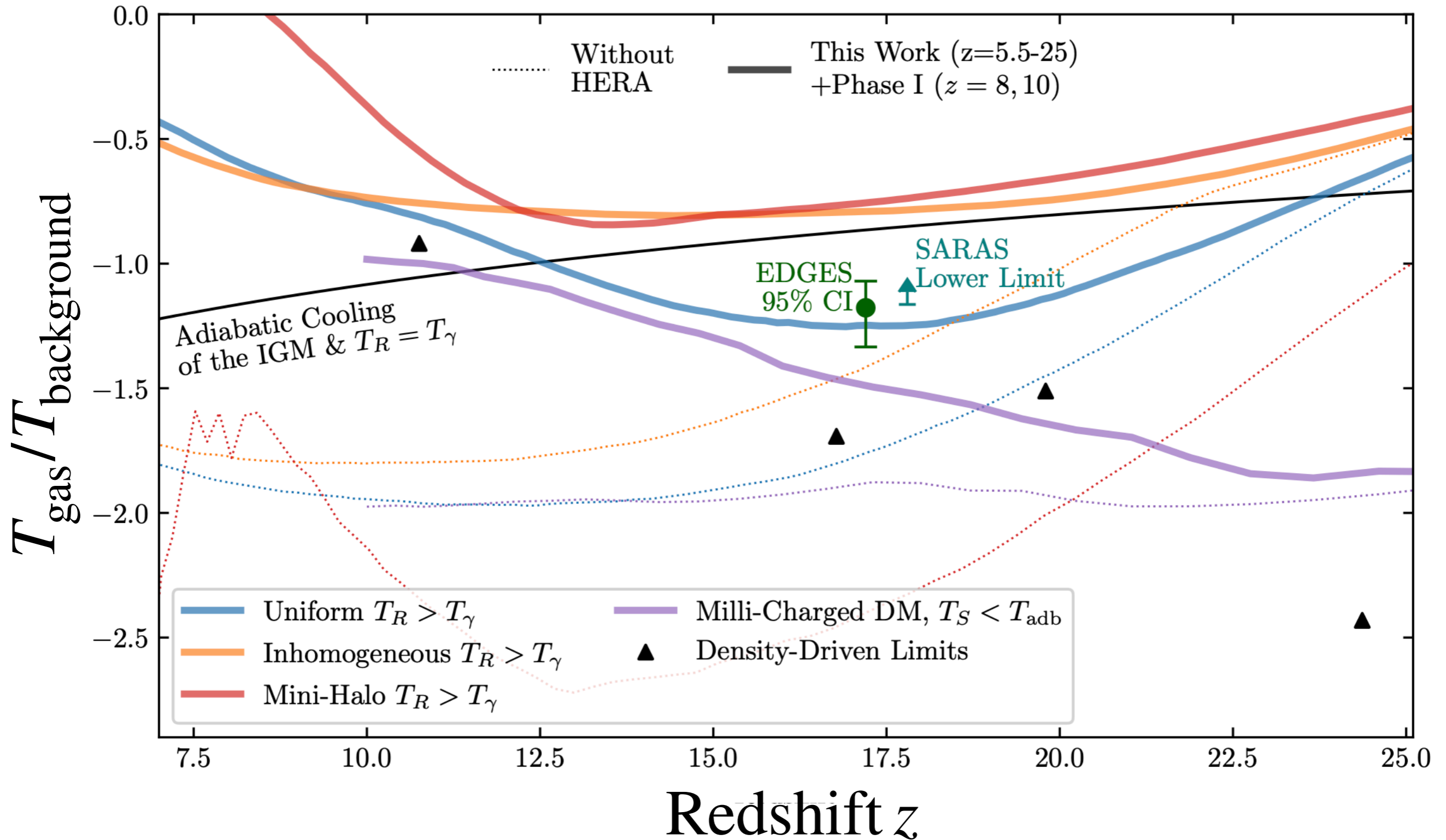
HERA rules out an adiabatically cooled IGM



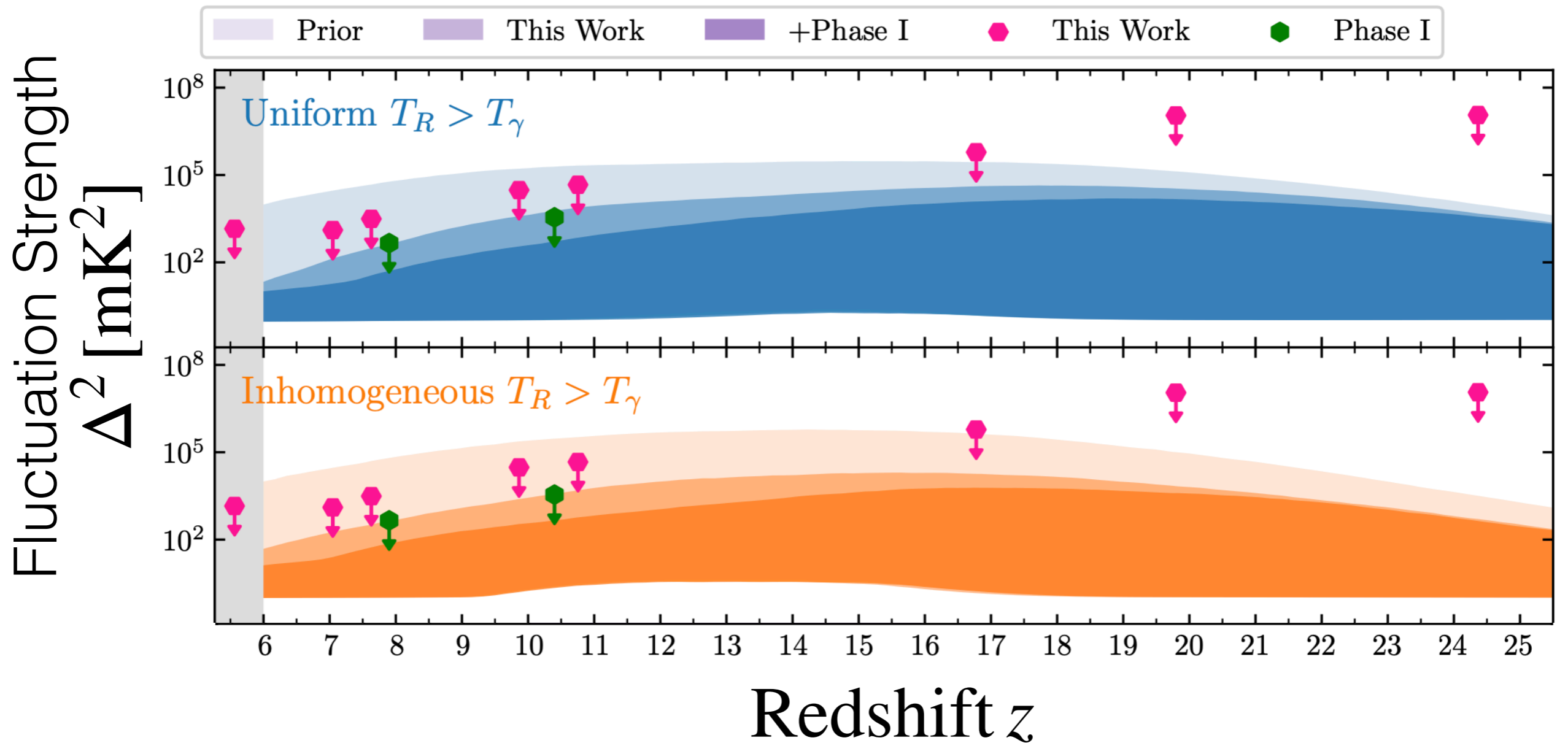
HERA rules out an adiabatically cooled IGM



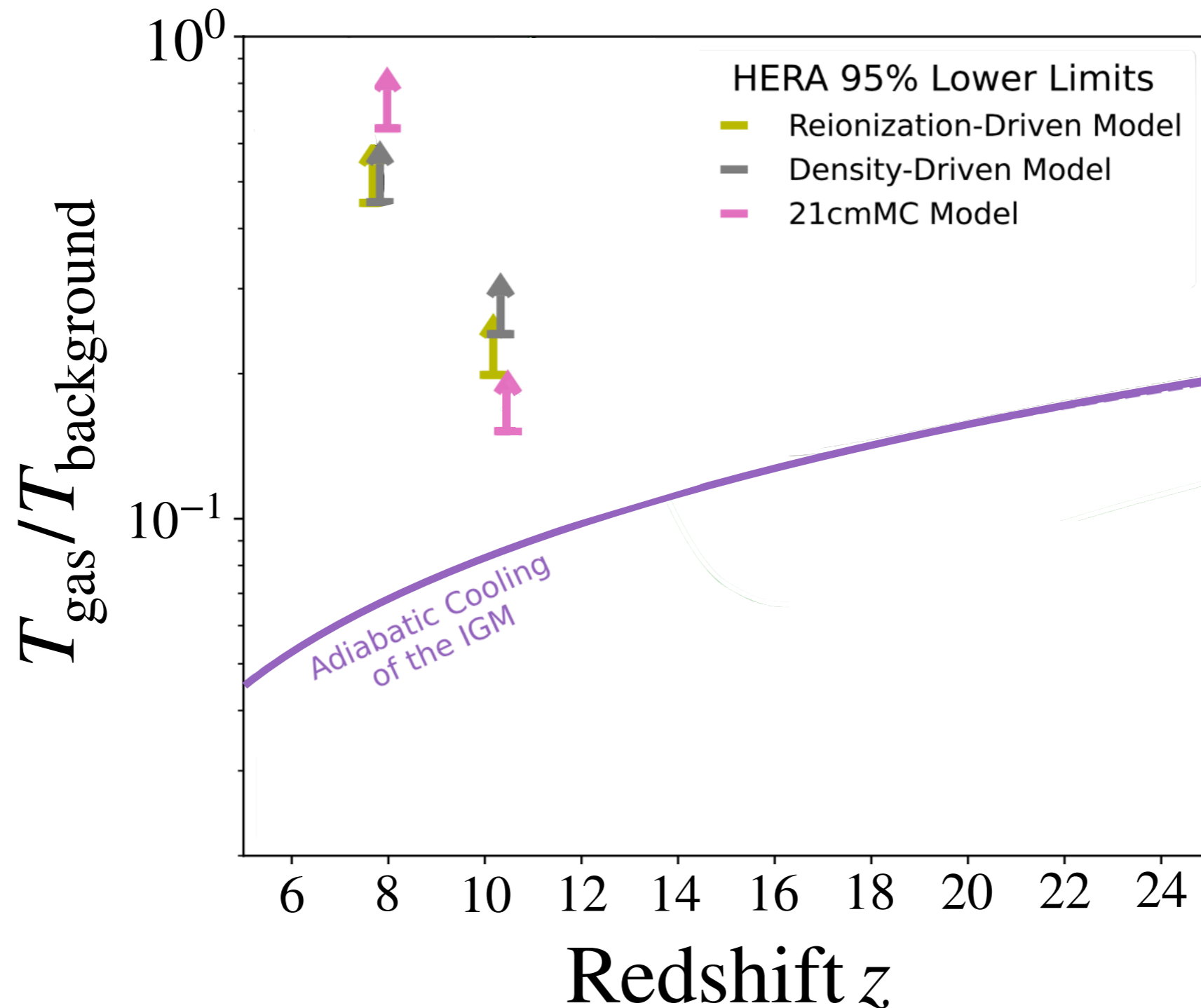
Do we rule out EDGES? Not directly...



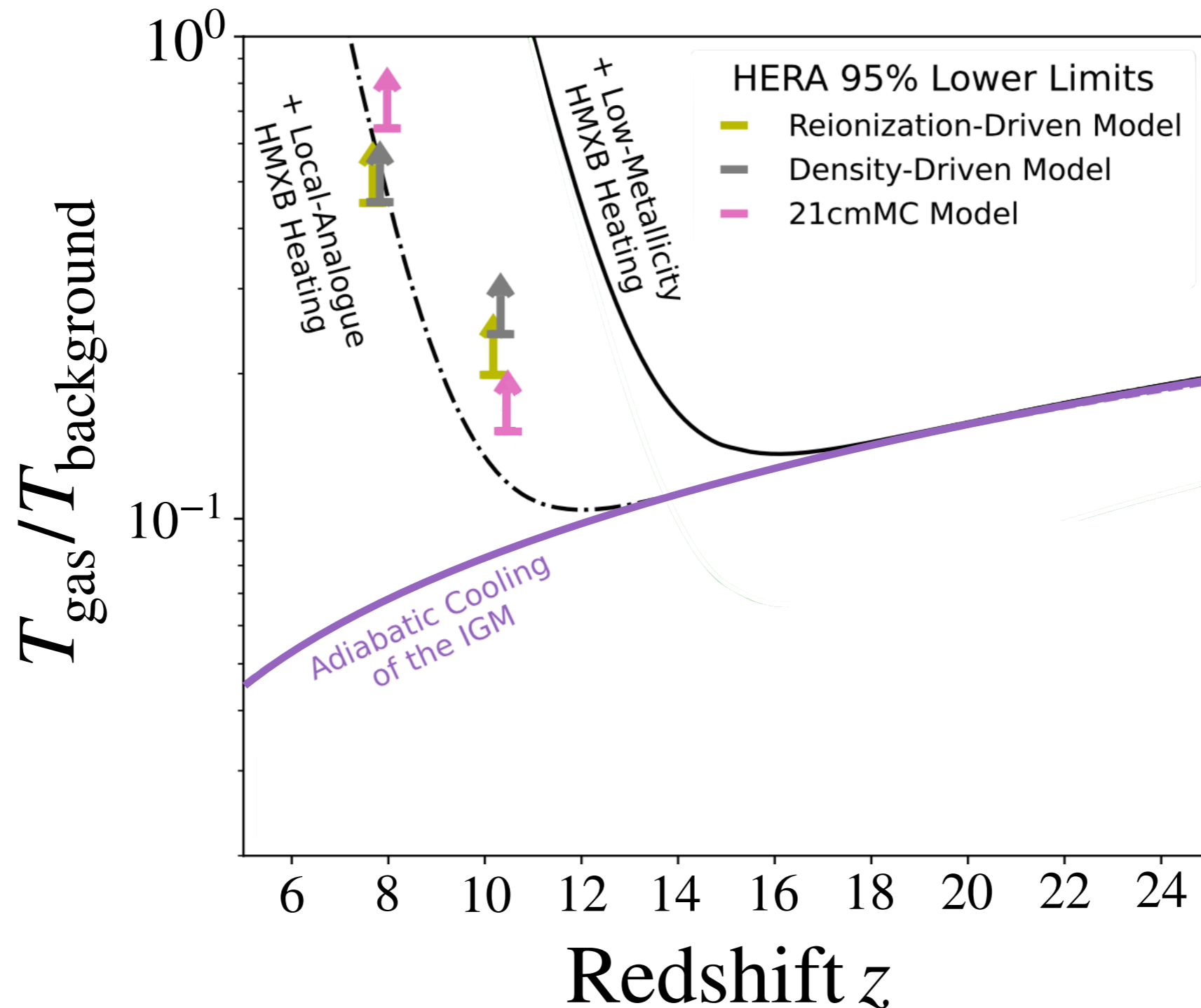
The constraints are driven by our low-redshift limits

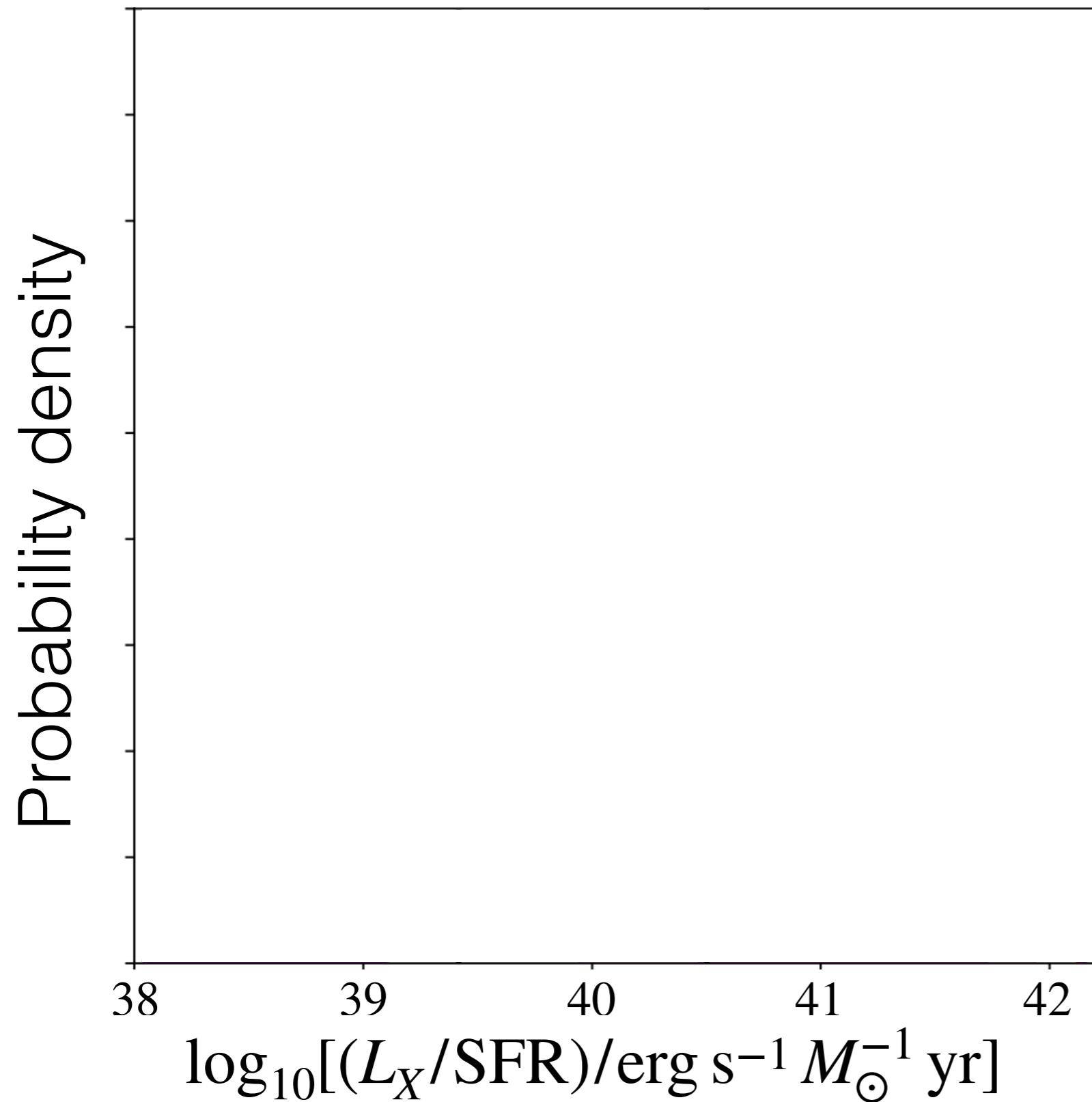


HERA rules out an adiabatically cooled IGM



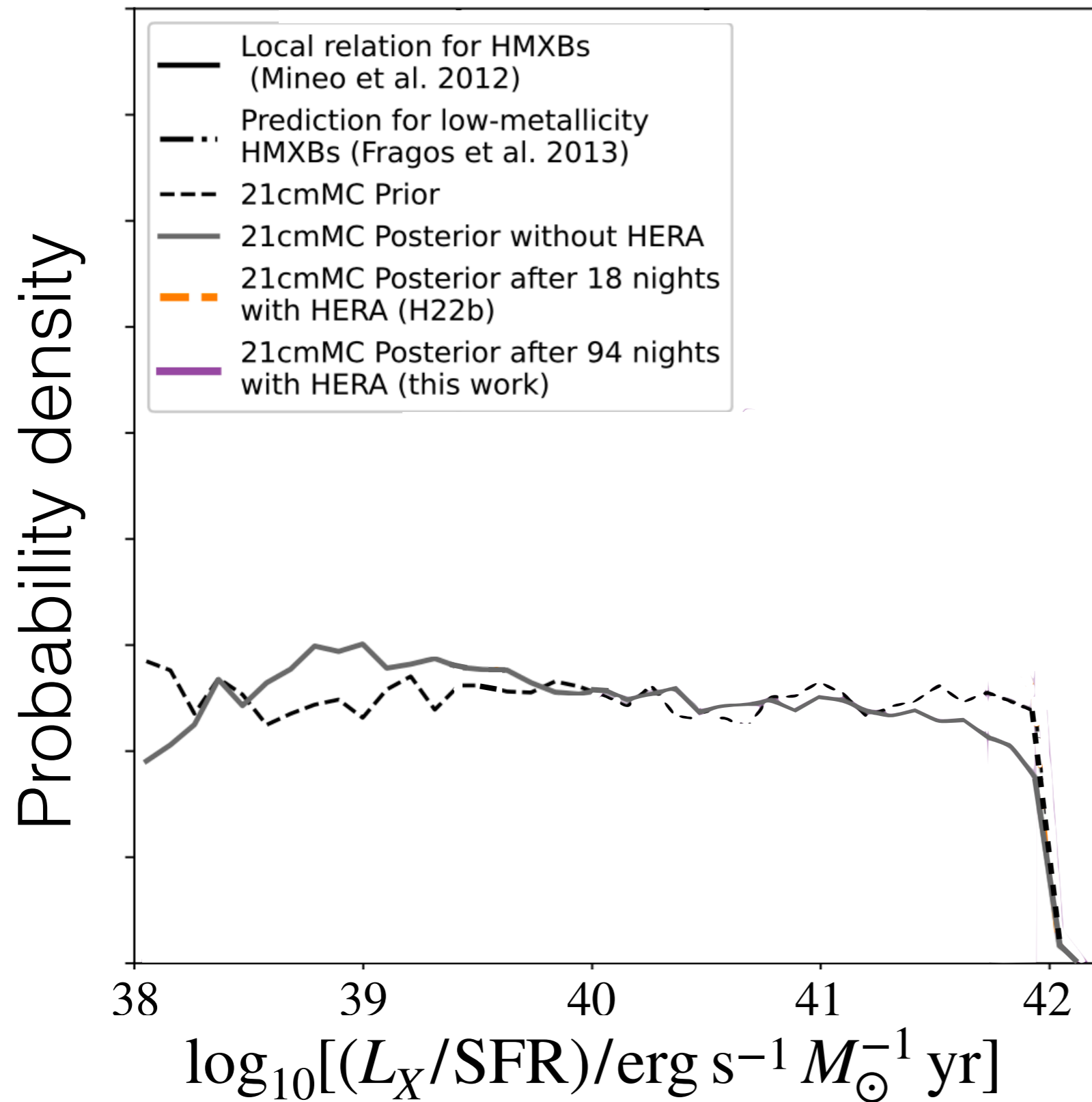
HERA rules out an adiabatically cooled IGM





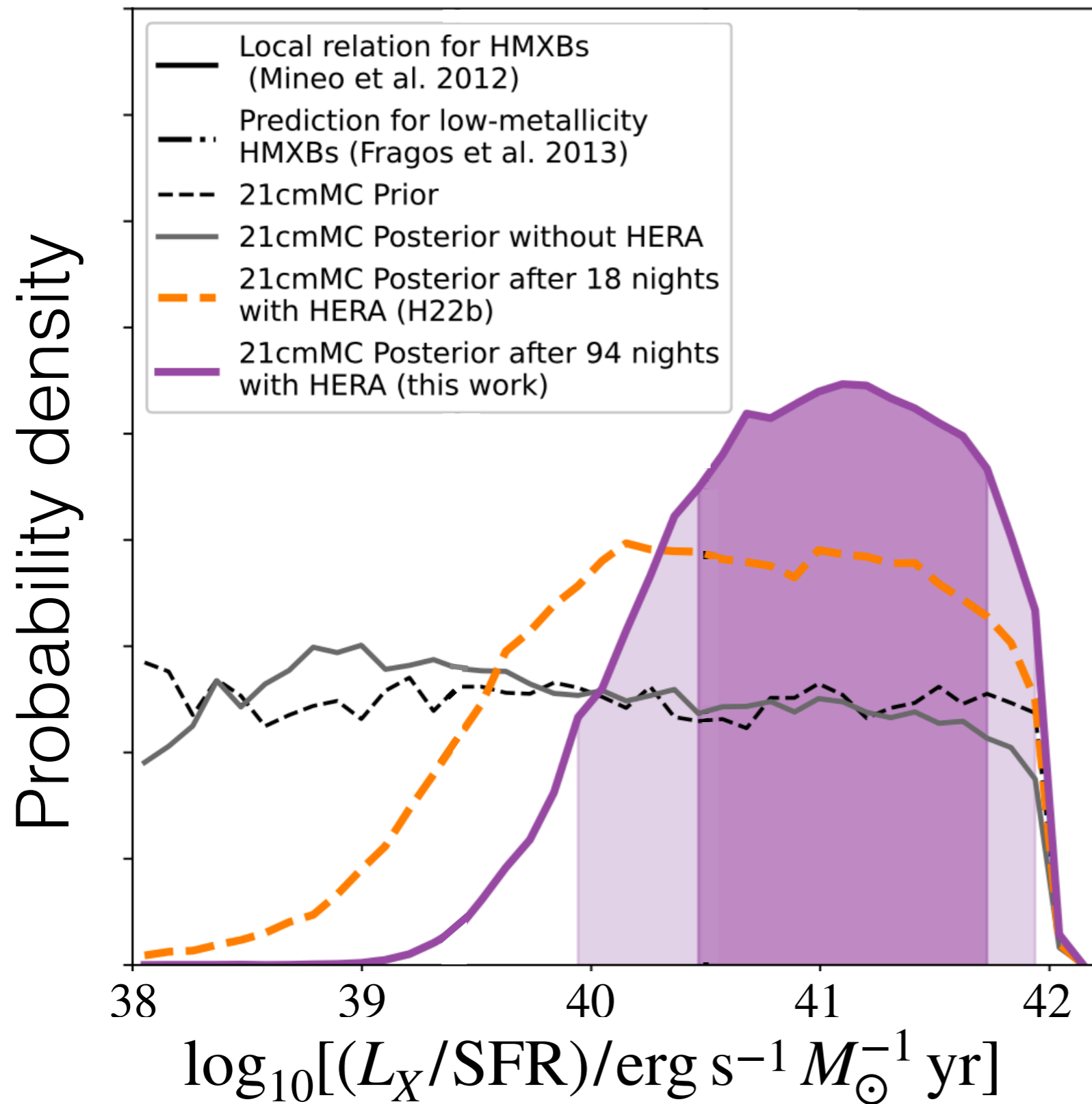
With modelling,
we place
constraints on
X-ray emission
from galaxies
responsible for
heating the IGM

X-ray luminosity per star formation rate



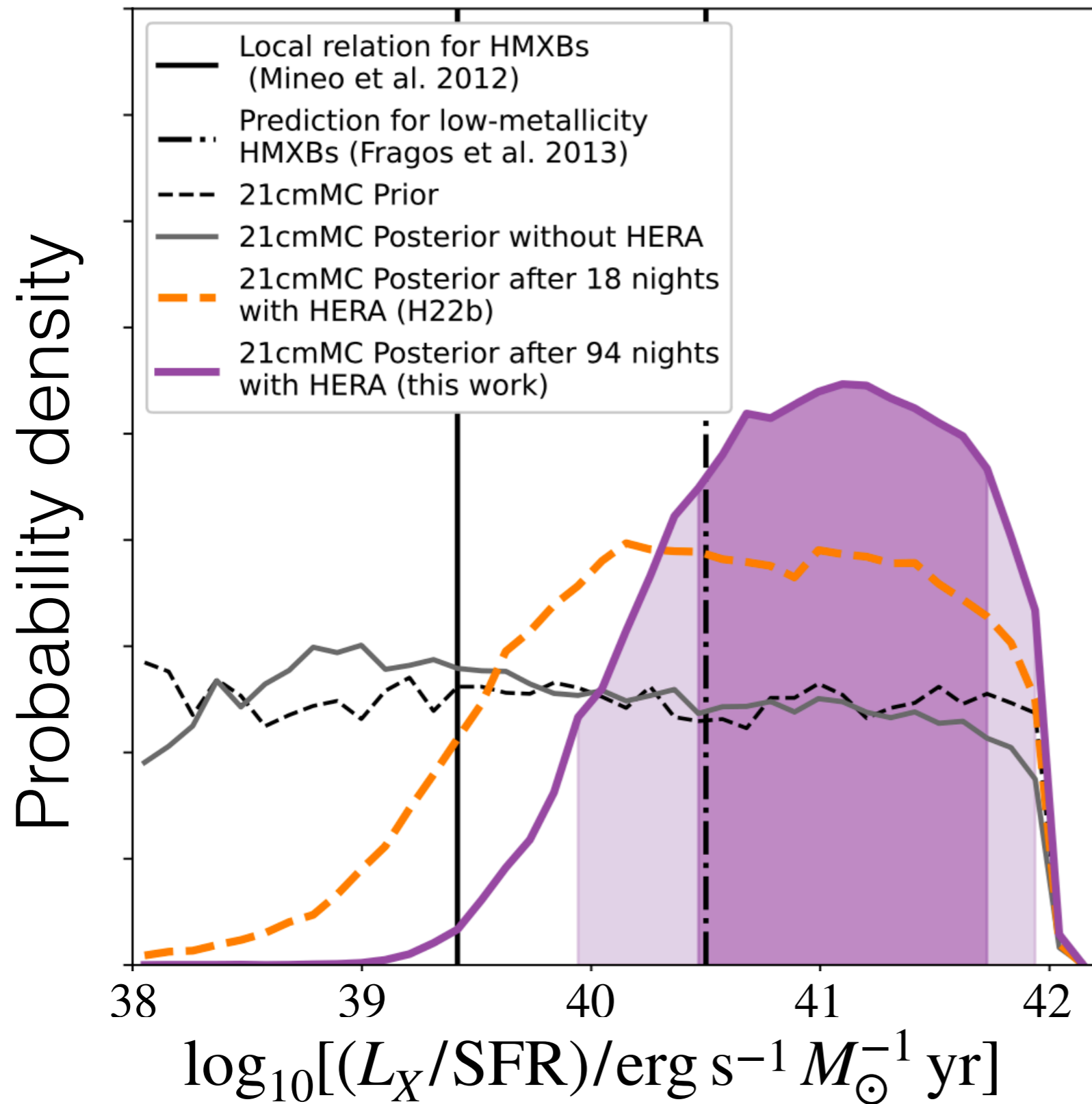
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X-ray luminosity per star formation rate



With modelling,
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X-ray emission
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heating the IGM







































X-ray luminosity per star formation rate



X-ray luminosity per star formation rate

With modelling,
 we place
 constraints on
 X-ray emission
 from galaxies
 responsible for
 heating the IGM

First Results from HERA Phase II

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Exciting Times are Ahead!

HERA has an upgraded system and initial data from this “Phase II” setup have produced upper limits on Cosmic Dawn and Reionization

The sensitivity of the Phase II array allows us to **match our previous 94-night sensitivity with just 14 nights of data**

There is evidence in the data of **mutual coupling at low k**

Our limits **rule out a very cold IGM** which in turn can be interpreted as **constraints on high- z galaxy X-ray emission**

	Here	Full Season
Array Location	-30.72°S, 21.43°E	
Avg. Antennas Connected	180	195
Avg. Antennas Unflagged	131	140
Shortest Baseline	14.6 m	14.6 m
Longest Avail. Baseline	280 m	755 m
Minimum Frequency	46.92 MHz	
Maximum Frequency	234.30 MHz	
Channels	1536	
Channel Width, $\Delta\nu$	122 kHz	
Integration Time, Δt	9.6 sec	
Per-Night Obs.	12 hr	
Total Nights Used	14	147
Unflagged Obs. Hours	129	1312
Raw Data Volume (Night)	2.7 TB	2.7 TB
Raw Data Volume (Full)	36 TB	~350 TB