Latest results from HERA

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Manchester/
UWC

Outline

- 21cm cosmology at high z
- Overview of the HERA survey
- HERA upper limits

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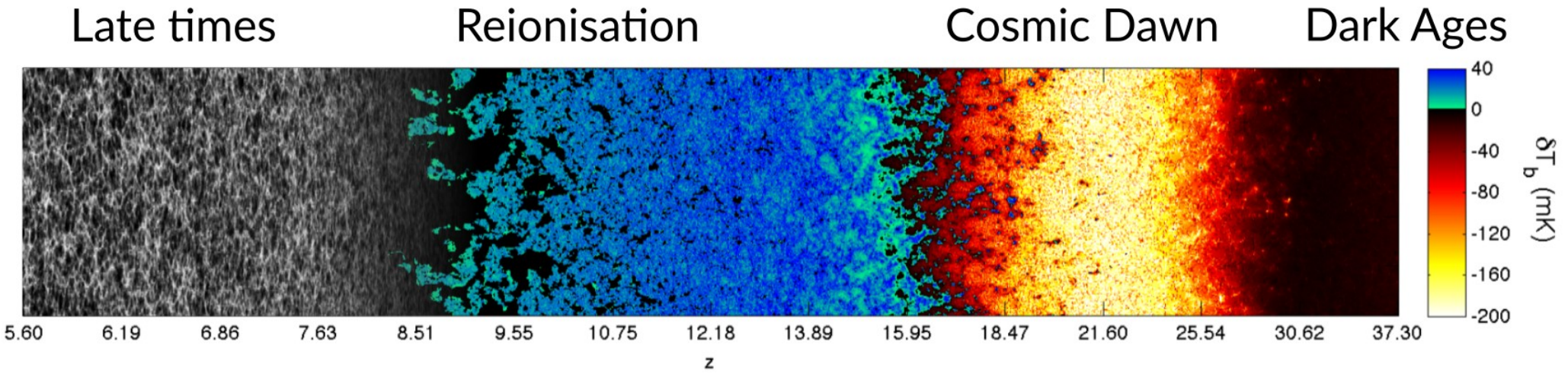
European Research Council
Established by the European Commission

Cosmology with the 21cm EoR power spectrum

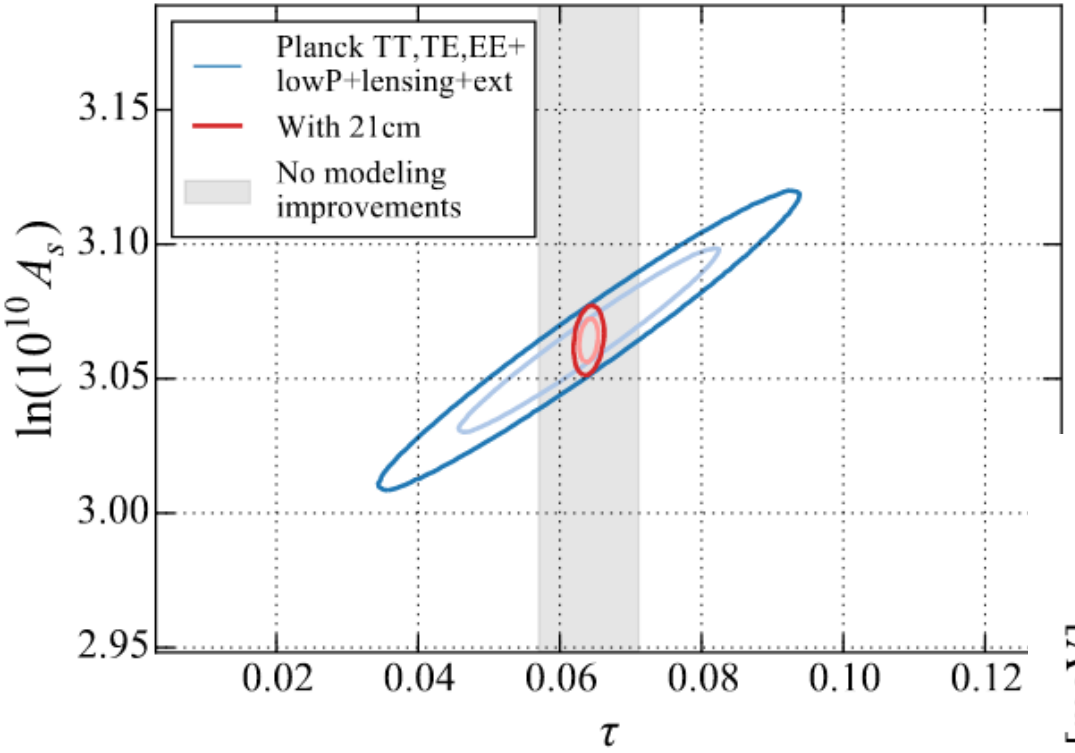
- EoR contributes to optical depth to the CMB, τ, which controls TT power spectrum amplitude, low-ℓ BB spectrum etc.
- Properties of early galaxies and galaxy formation/evolution models
- Sensitivity to energy injection (e.g. DM annihilation)
- Gateway to the Dark Ages!

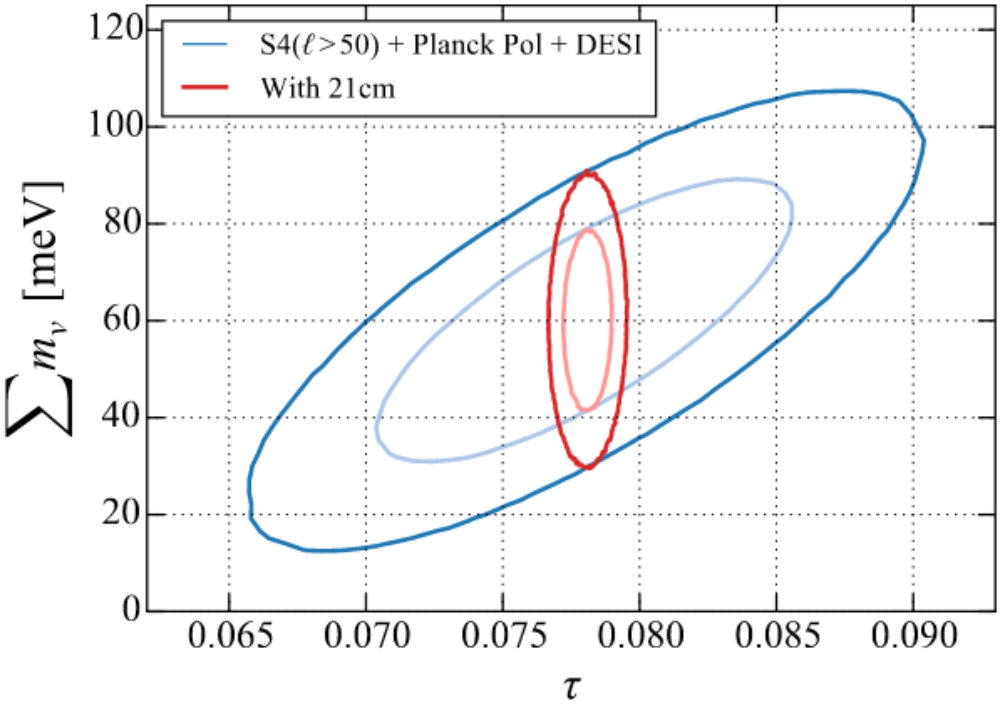


A. Mesinger (adapted)

Impact of 21cm constraints on parameters

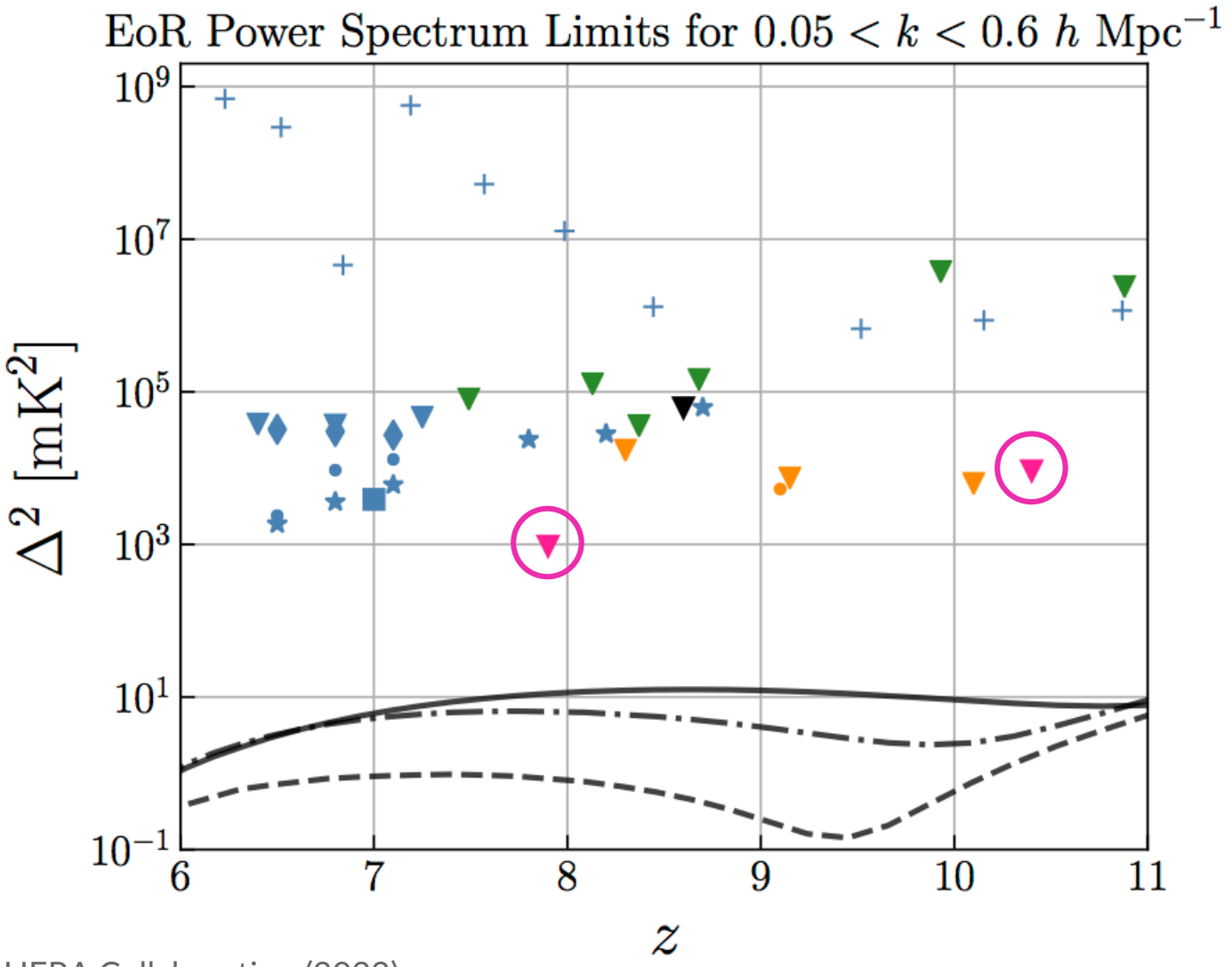
Optical depth is probably the biggest deal in the short-term





Liu et al. [1509.08463]

Previous upper limits on the EoR power spectrum



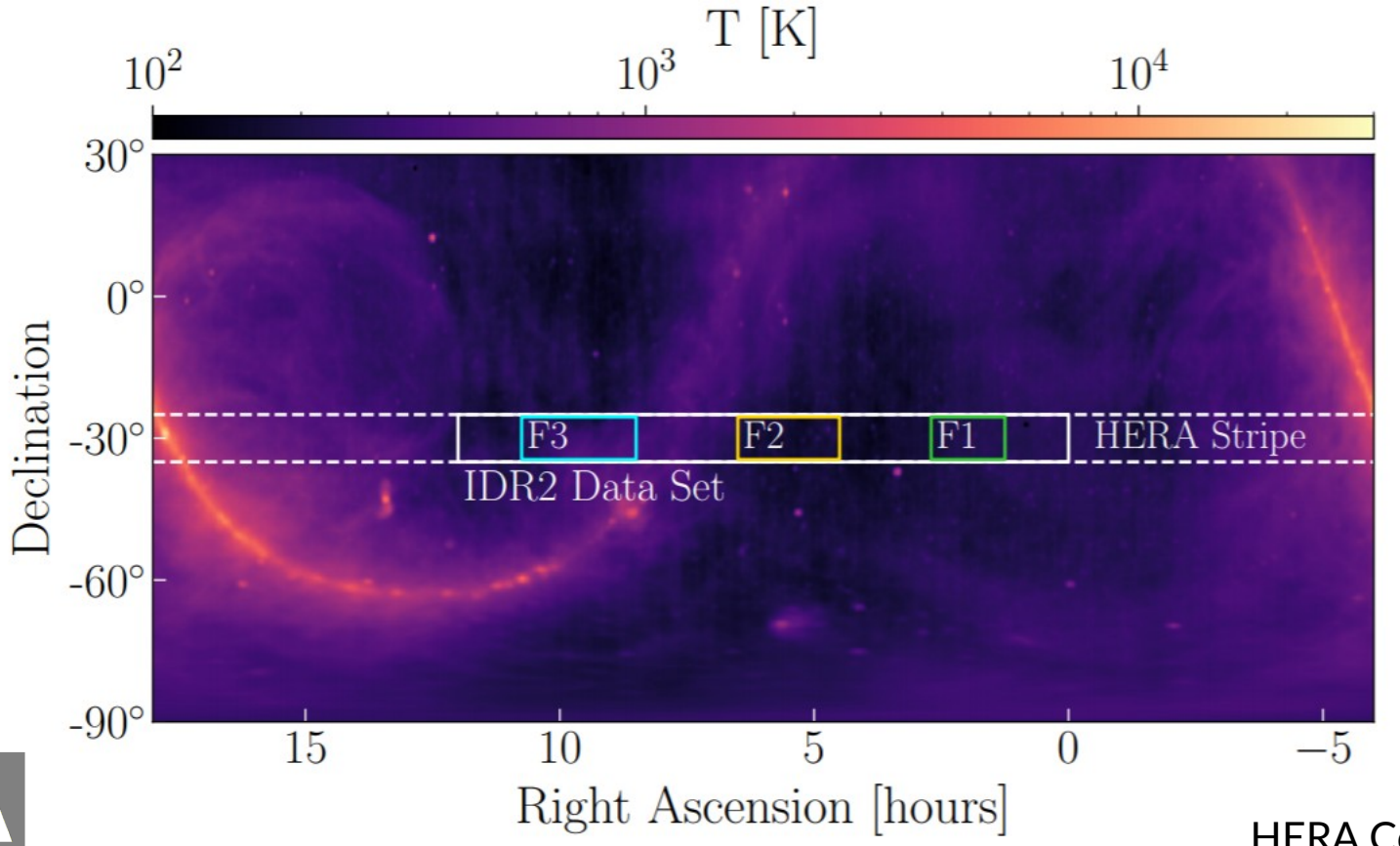
HERA Collaboration (2022)

HERA Collab. [2108.02263]

Hydrogen Epoch of Reionization Array

Built on SKA site in South Africa, run from UC Berkeley/NRAO

- Eventually: Approx. 350 dishes with dual-pol. receivers (50 – 220 MHz)
- 14m dishes, 14.6m minimum baseline length in hexagonal layout
- Drift scan telescope – it just points up!
- Redundant array – many copies of the same baseline



HERA Collab. [2108.02263]

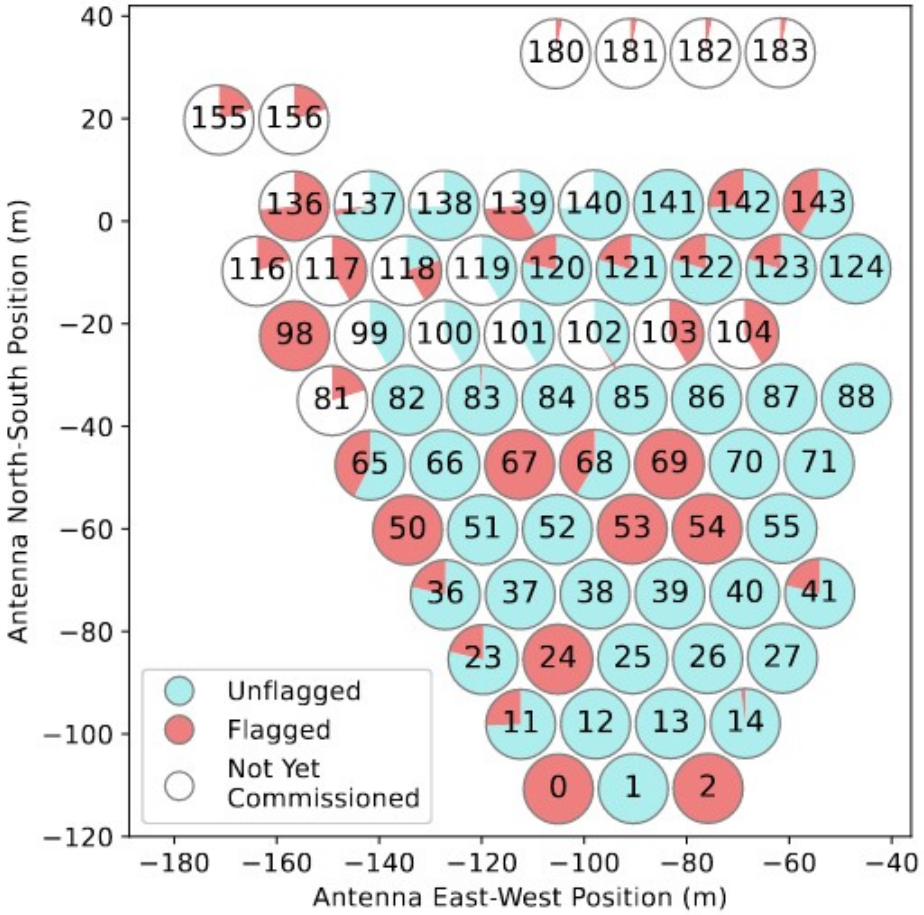

MeerKAT
HERA


Dara Storer

HERA Phase I array

Data from between 35-41 good antennas (out of 47-71)

- 94 nights of good data (out of 182) between 29th Sep. 2017 - 31st Mar. 2018
- Using the old PAPER receivers (100 – 200 MHz, 1024 channels)
- Focused on 5 “clean” fields, 2 sub-bands



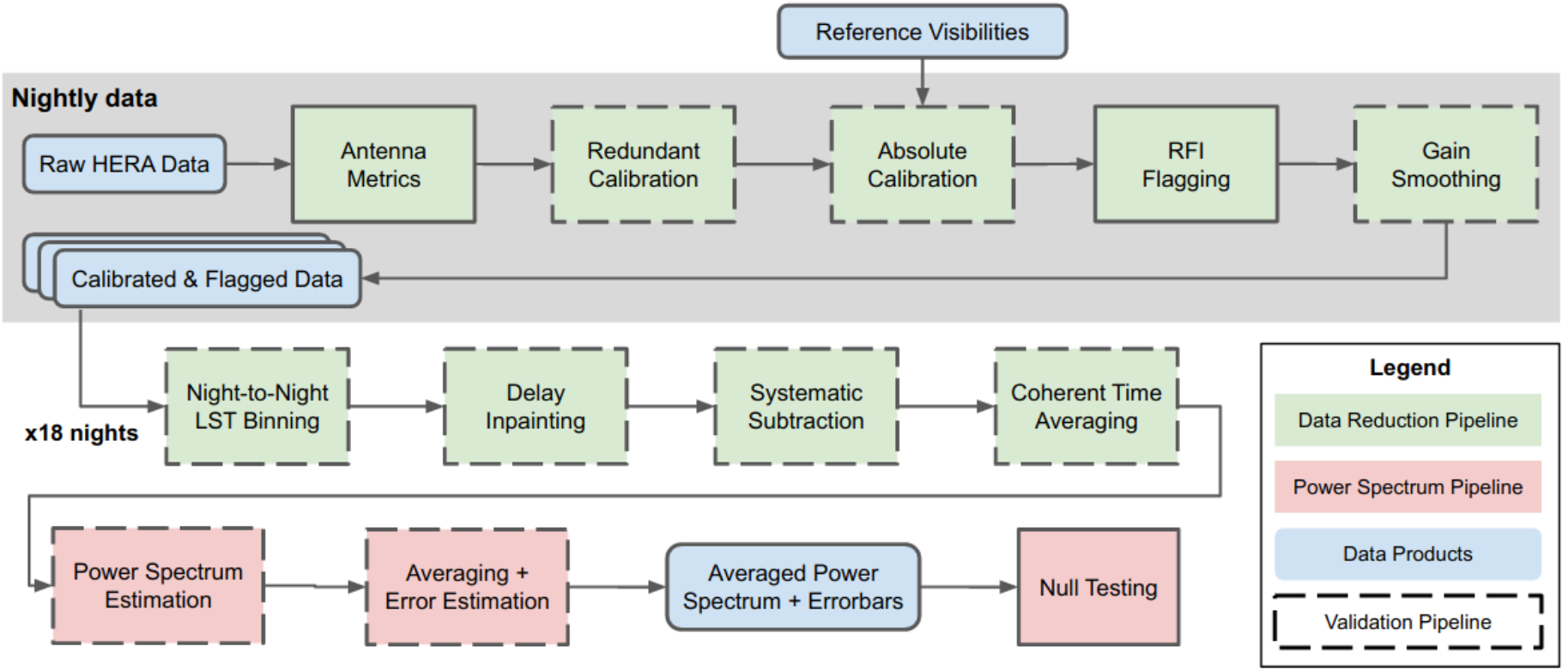
- Full redundant calibration
- Partial absolute calibration
- Smoothing of gains
- Reflection and cross-talk subtraction
- Foreground avoidance

HERA Collab. [2210.04912]

Analysis pipeline

We use ***redundant calibration***, a restricted ***absolute calibration***, and a ***delay power spectrum*** analysis.

- Absolute calibration (using a sky model) only operates on a degenerate subspace of the gain solutions, which are also smoothed.
- We don't do any imaging! Power spectra are per-baseline.

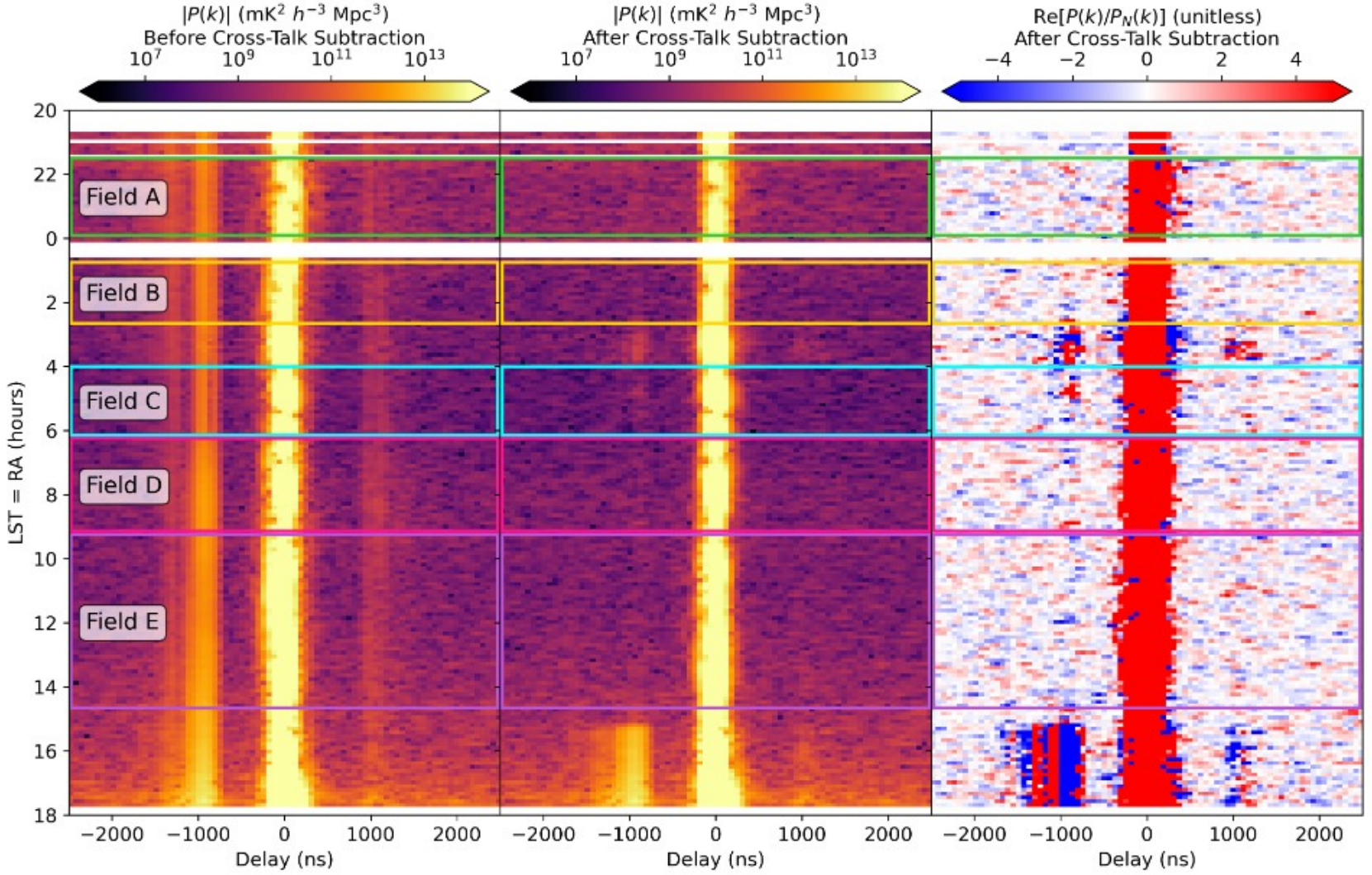


HERA Collab. [2108.02263]

Reflection and cross-talk systematics

Significant contamination detected outside the foreground wedge

- Mostly due to cable reflections and over-the-air crosstalk (Kern et al. 2020)
- Cross-talk can be fitted out using 35-term Fourier-space model

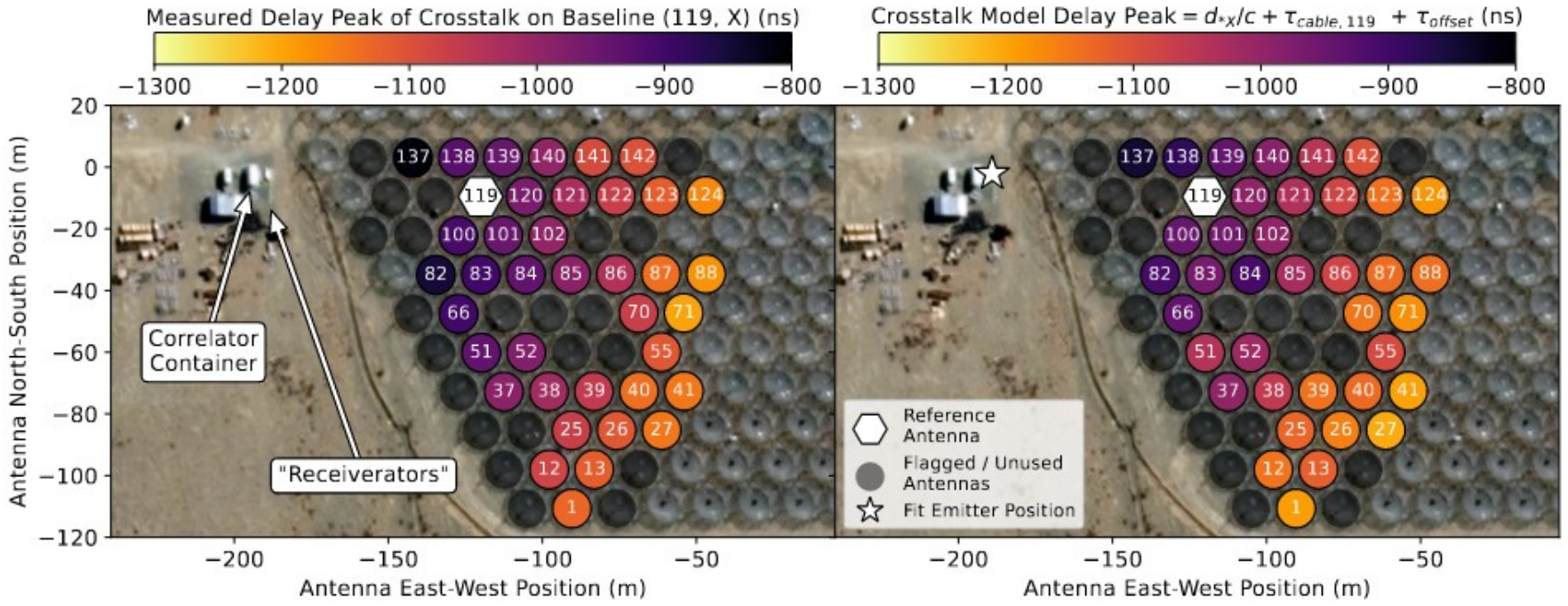


HERA Collab. [2210.04912]

Reflection and cross-talk systematics

Significant contamination detected outside the foreground wedge

- Mostly due to cable reflections and over-the-air crosstalk (Kern et al. 2020)
- Cross-talk can be fitted out using 35-term Fourier-space model
  - Stable for particular array layout, but changes as the array is extended
  - This allowed us to identify the source!

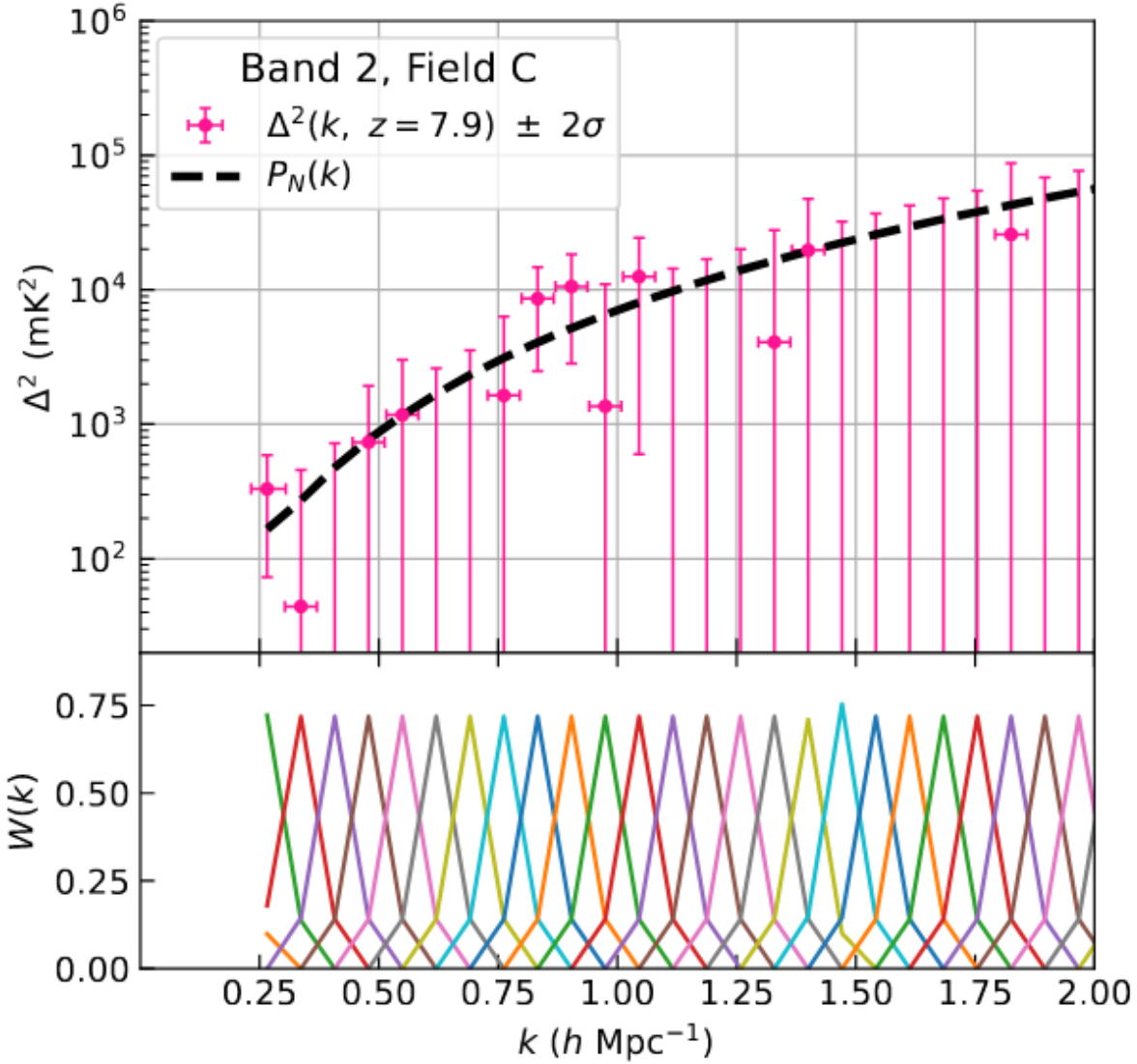


Antenna → 150m cable → amplifiers in receiverator → broadcast back to antennas

HERA Collab. [2210.04912]

Power spectrum upper limits

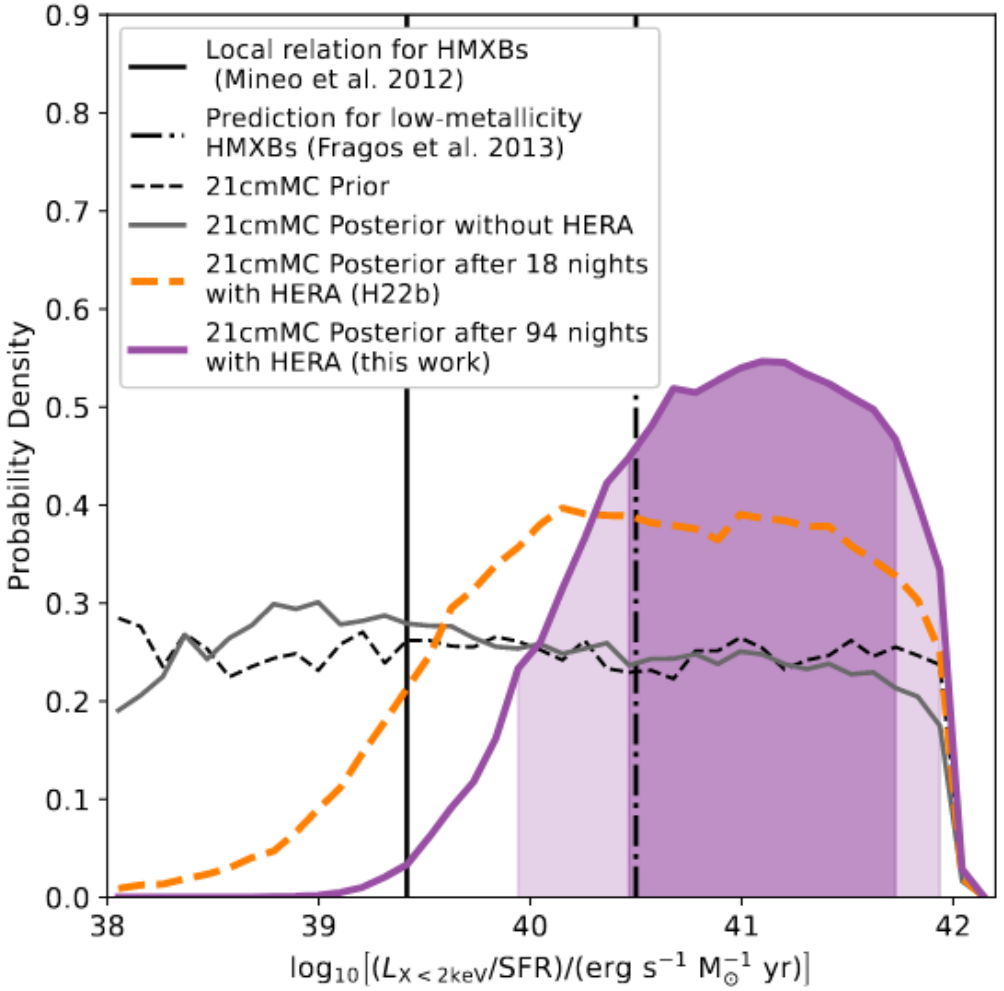
HERA Collab. [2210.04912]

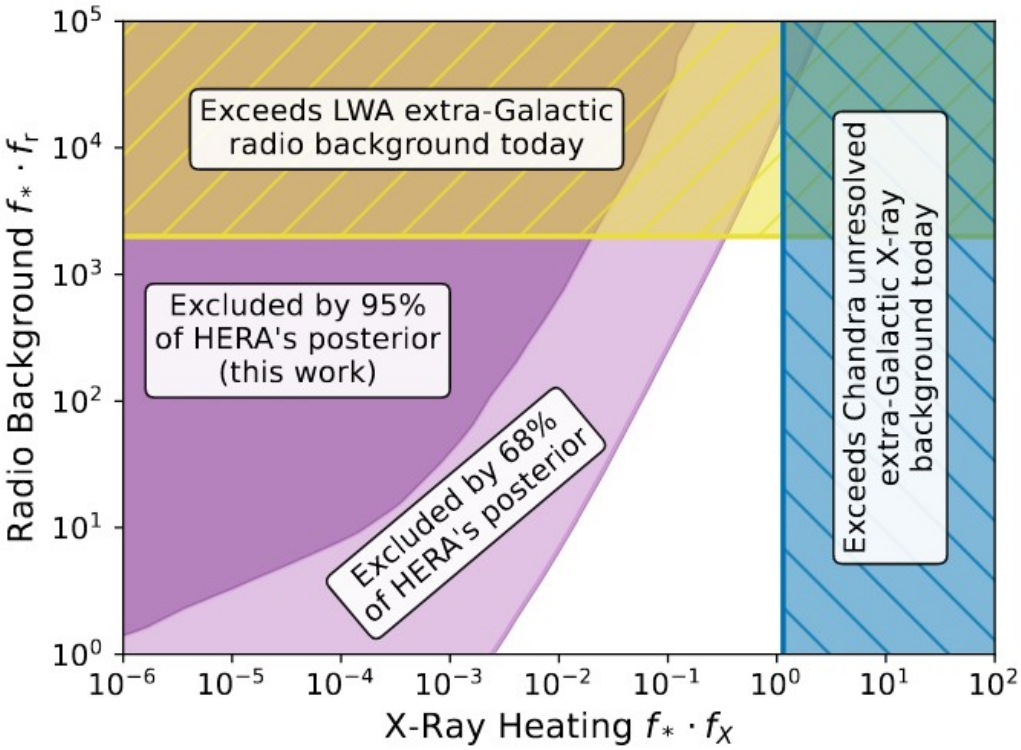


- Robust power spectrum upper limits
- Mostly consistent with being noise-dominated (confirmed by statistical tests; see Mike's talk)
- Conservative analysis with low signal loss (6-7%; confirmed by validation sims etc.)

Physical implications

HERA Collab. [2210.04912]

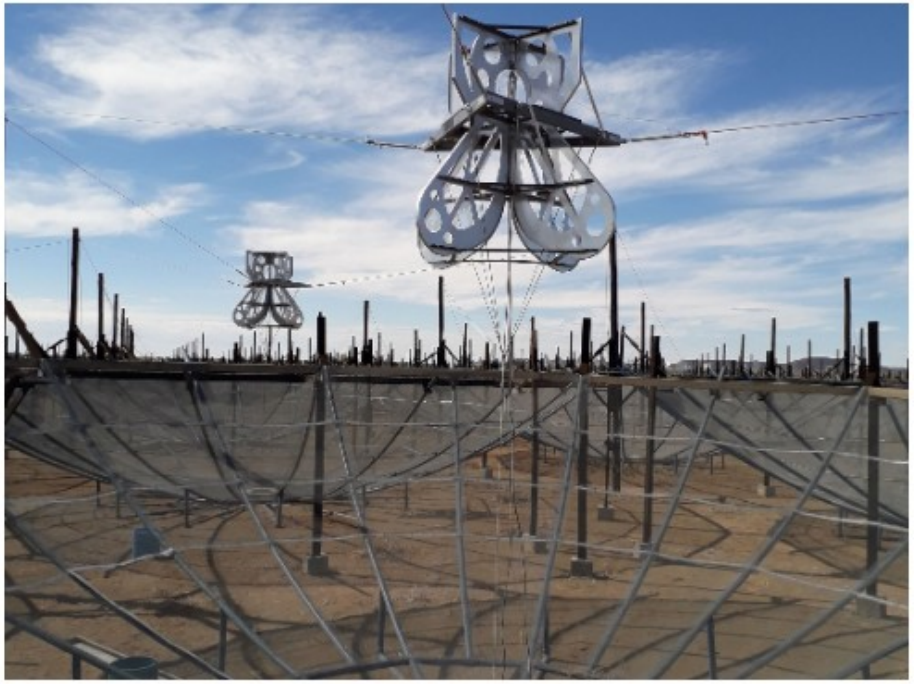




- Implies early galaxies had enhanced X-ray luminosity (for a given SFR)
- Disfavours unheated IGM at >99% level → heating definitely took place!
- Improved constraints on size of excess radio background

What's next?

Fagnoni et al. [2009.07939]



Phase II data

- Brand new Vivaldi feeds (50–220 MHz)
- Multiple new seasons of data with increasing number of dishes
- Fringe-rate filtering (see Hugh's talk)
- Lots of incremental improvements to analysis + new methods
- (Ask me about Hydra, our new Bayesian pipeline!)

The HERA pipeline

Almost all of our analysis pipeline is open source

- Redundant and partial absolute calibration: **hera_cal**
- Power spectrum estimation: **hera_pspec**
- Visibility simulators (with systematics etc): **hera_sim**
- Lots of other smaller utilities, RFI flagging etc.
- Very good unit test coverage, validation etc.

See **https://github.com/HERA-Team**