Peering in to the Cosmic Dawn with NenuFar

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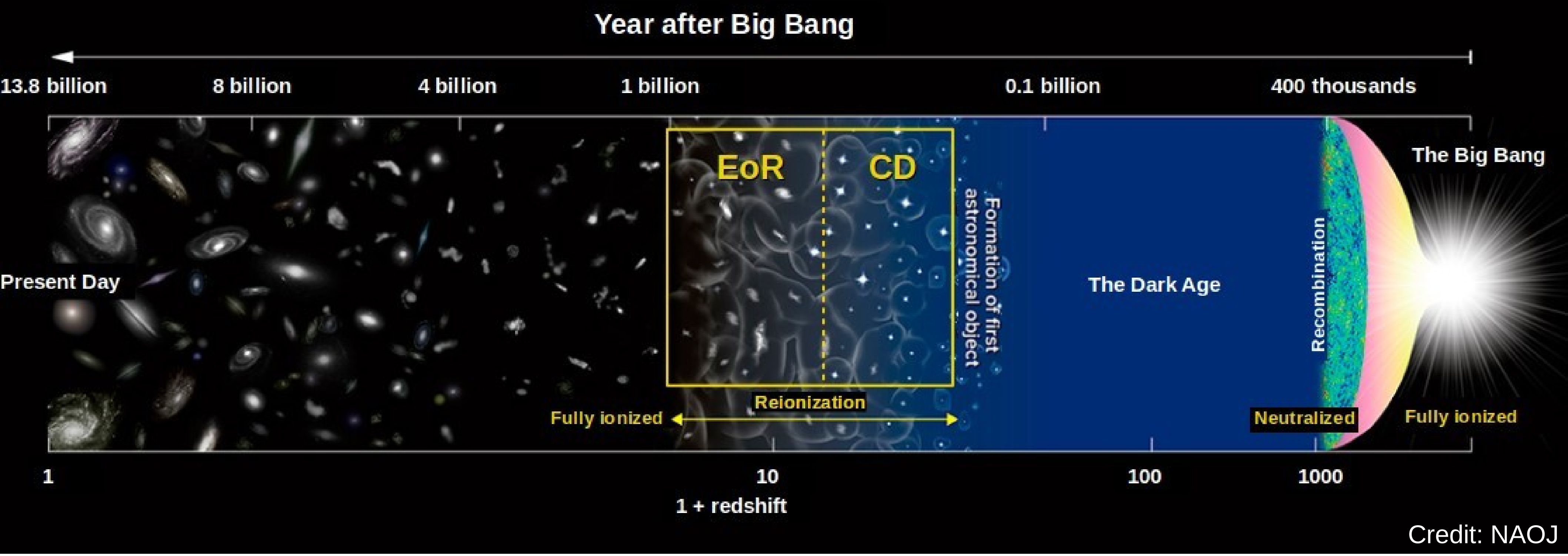
Cosmic Dawn / Epoch of Reionization



Epoch of Reionization

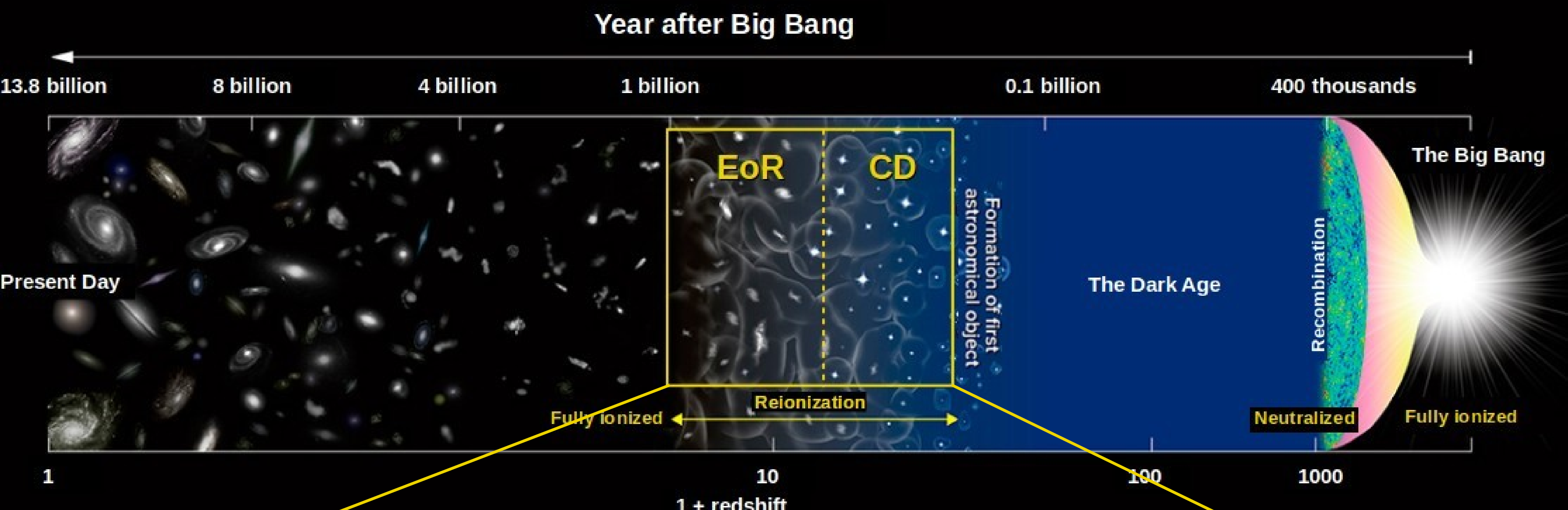
- Reionization by stars & mini-quasars
- IGM feedback (e.g. metals)
- PopIII - PopII transition
- Emergence of the visible universe

Cosmic Dawn

- Appearance of first stars/BHs (PopIII?)
- Ly-α radiation field
- Impact of Baryonic Bulk Flows
- First X-ray heating sources

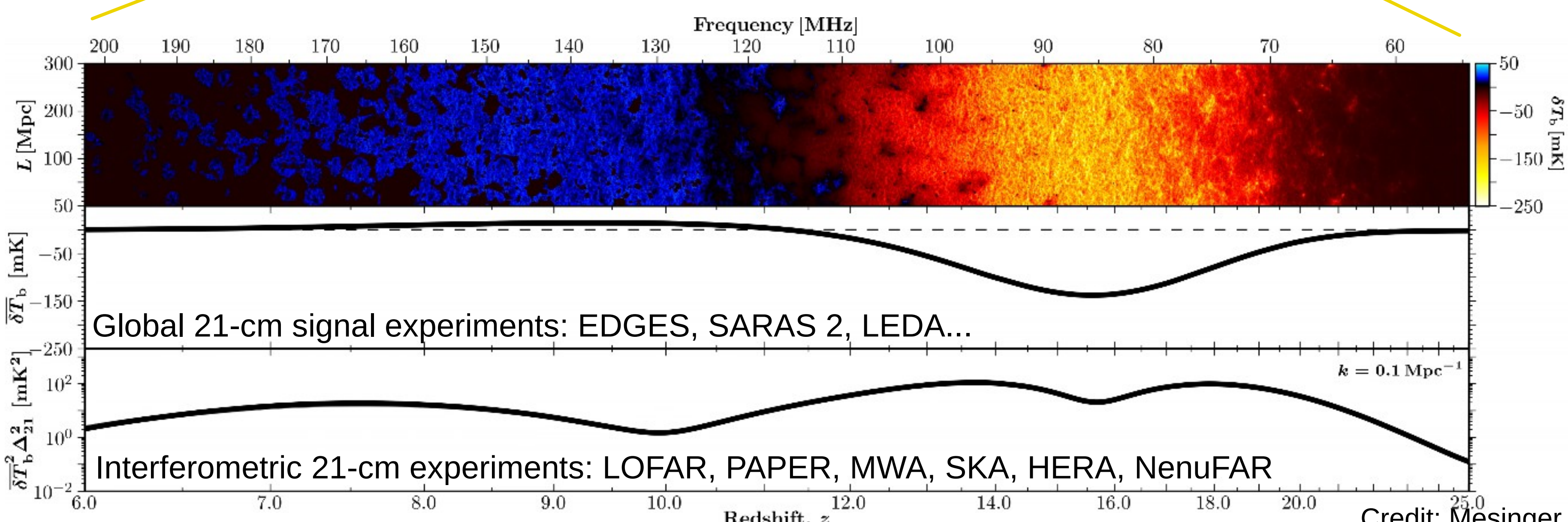
- When did the first galaxies/stars/black hole form?
- How did reionization proceed?
- How do galaxies form and evolve?

Cosmic Dawn / Epoch of Reionization



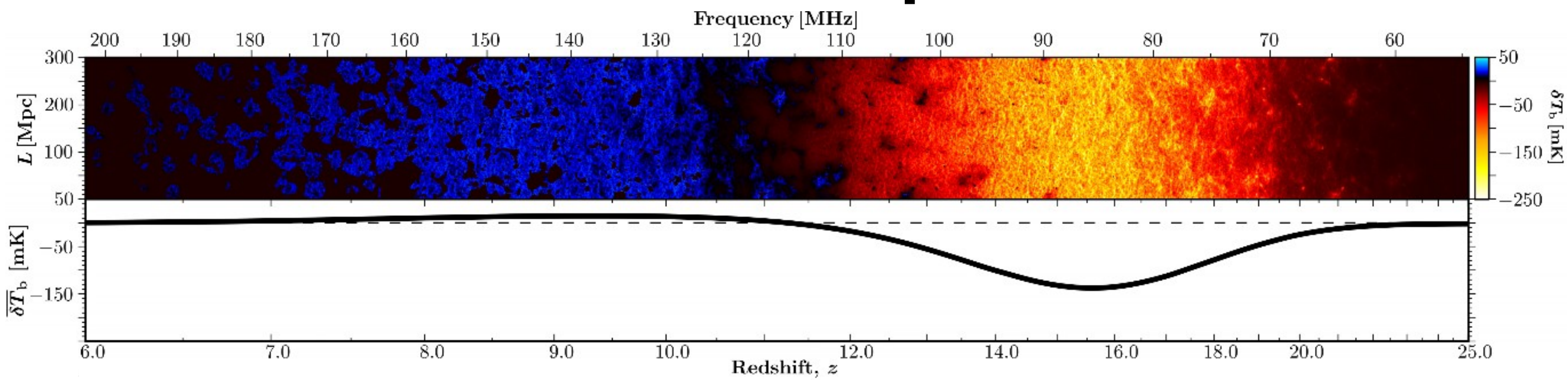
High-z HI 21-cm signal unique probe of the CD/EoR

Credit: NAOJ



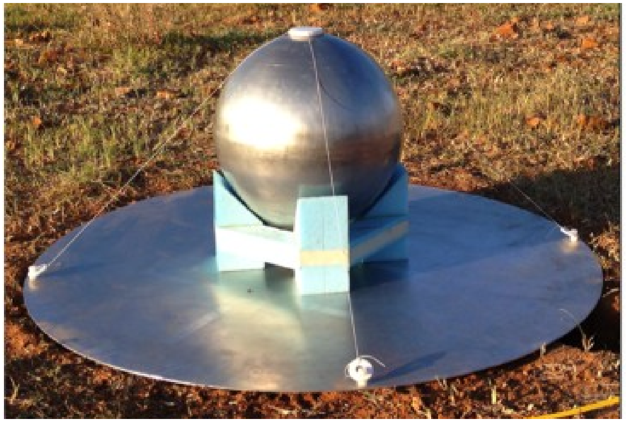
Credit: Mesinger & Greig

The Global experiments



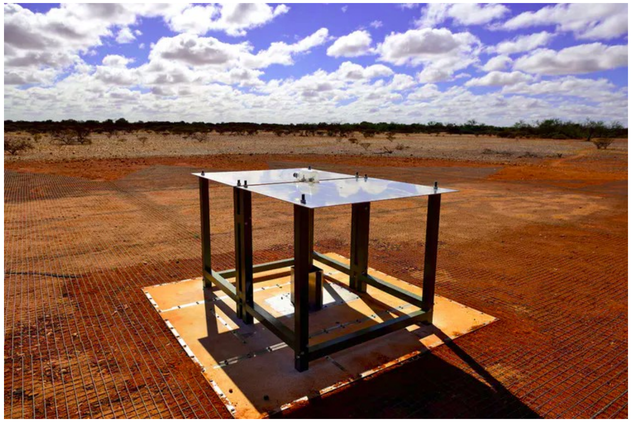
PRIZM
30-200 MHz
Marion Island

Peterson, Sievers, Chiang ++



SARAS
50-100, 100-200 MHz
India (Himalayas)

Singh et al. 2017

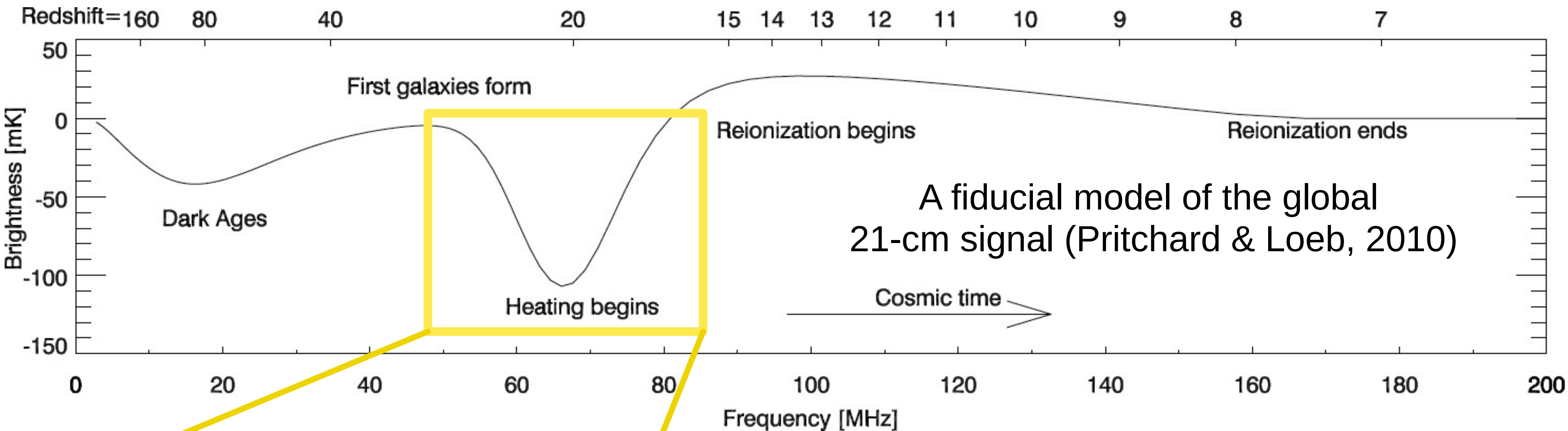


EDGES
50-100, 100-200 MHz
Western Australia

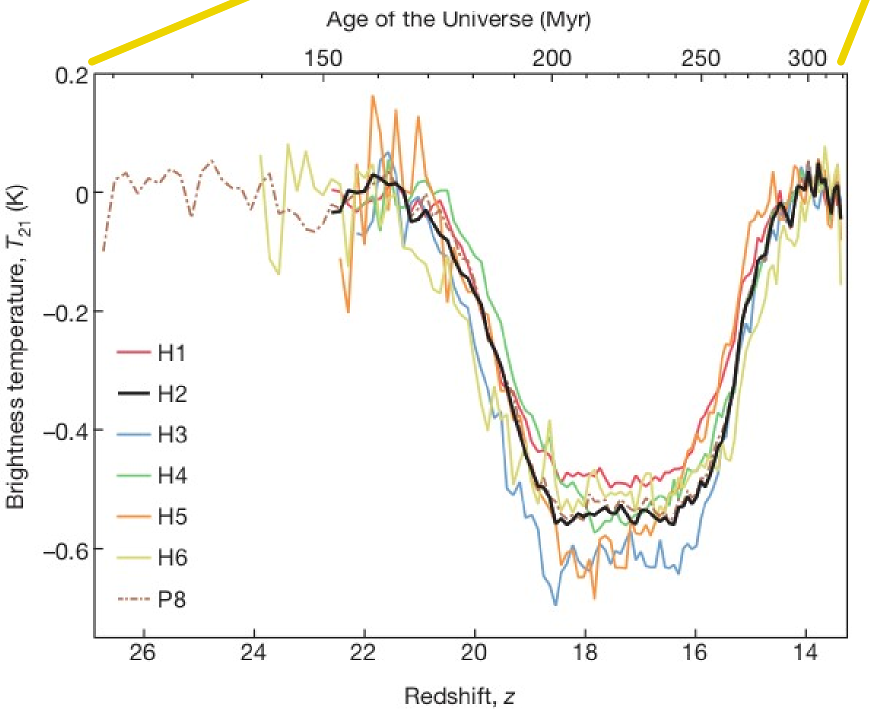
Rogers & Bowman 2008, 2012;
Bowman et al 2018

+ Many more

EDGES detection (?)



A fiducial model of the global 21-cm signal (Pritchard & Loeb, 2010)



21-cm absorption profile observed by EDGES (Bowman et al., Nature, 2018)

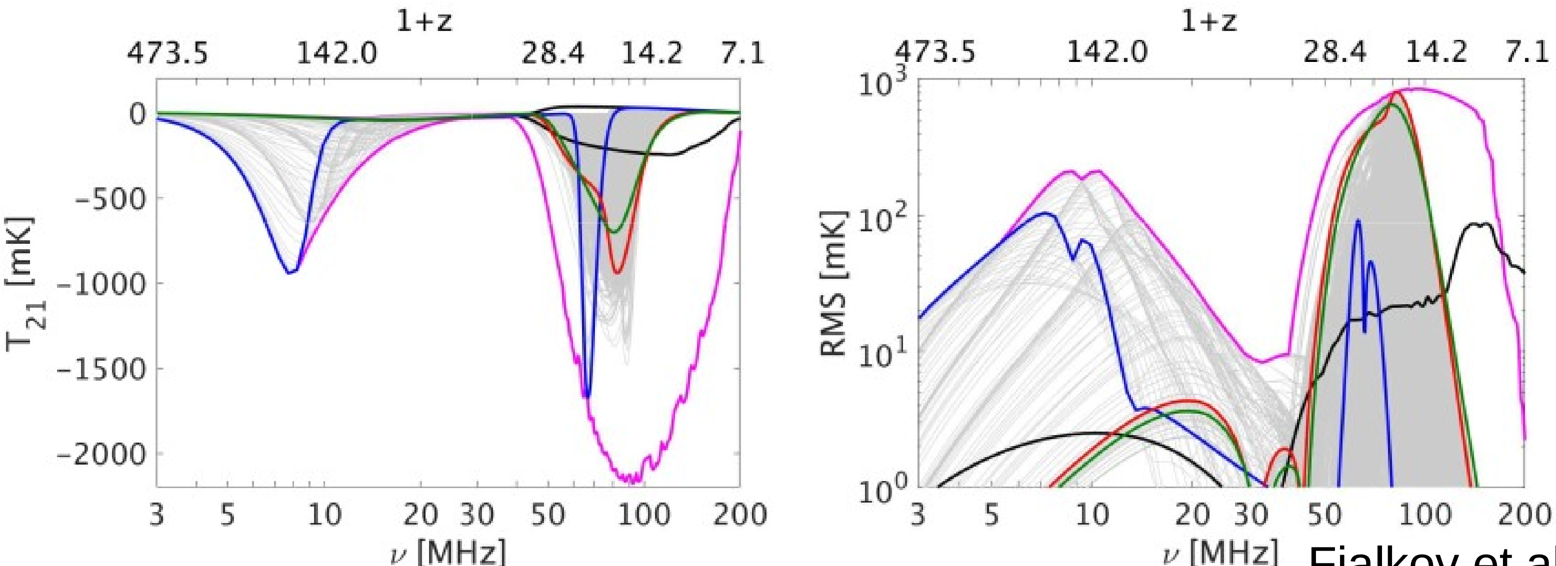
Observation passed through numerous hardware and processing tests: 2 independent antennas, different hardware configurations, calibrations, fitting methods...

Profile is largely consistent with expectations, however absorption about 2.5 x deeper than most extreme models ! (and peculiar profile !)

Need to be confirmed by other experiments !

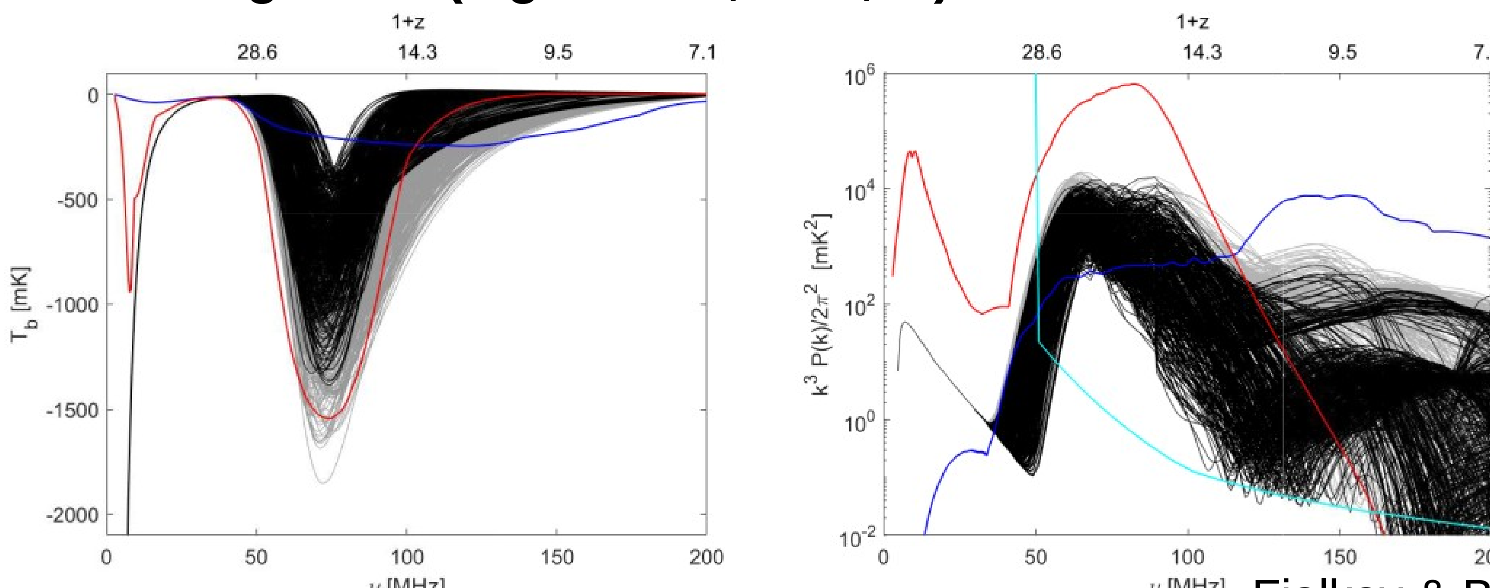
Explaining the EDGES results

Additional cooling mechanism (e.g. baryons dark-matter scattering)



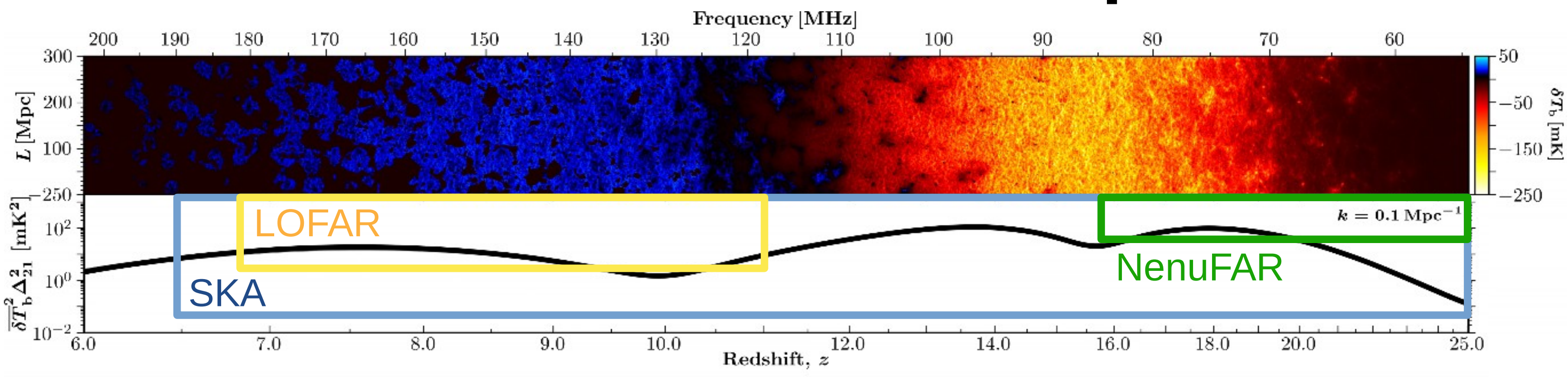
Fialkov et al. 2018

Excess radio background (e.g. SMBH, SNe, ...)



Fialkov & Barkana 2019

The Interferometric experiments



LOFAR-HBA
The Netherlands

z ~ 7 – 11
+ 2000h observed
13h published
Patil et al. 2017
140h in prep.

AARTFAAC (ACE)
The Netherlands

Target 1000h obs.
350h observed
z ~ 18

Gehlot et al. in prep.

SKA-Low
Western Australia

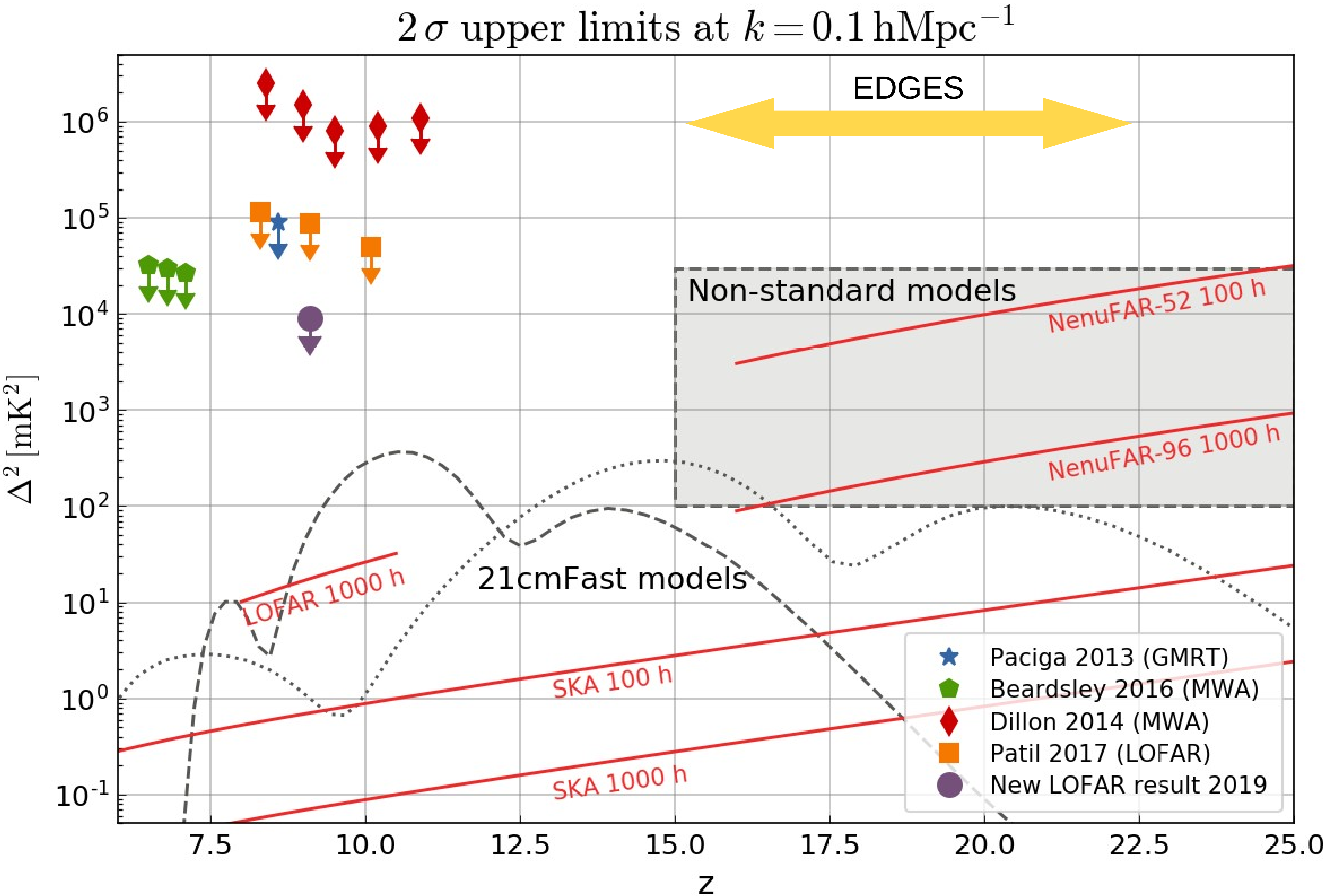
z ~ 6 – 25
2020-2025

NenuFAR
Nancay

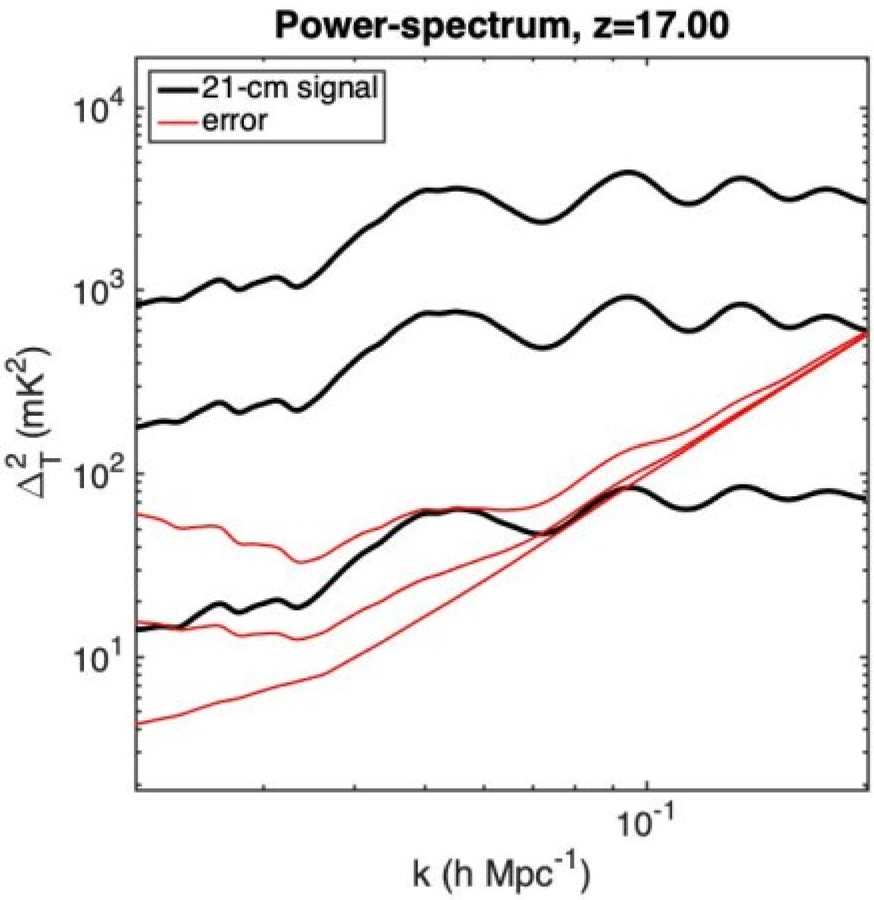
Target 1000h obs.
z ~ 16 - 27

+ Many more

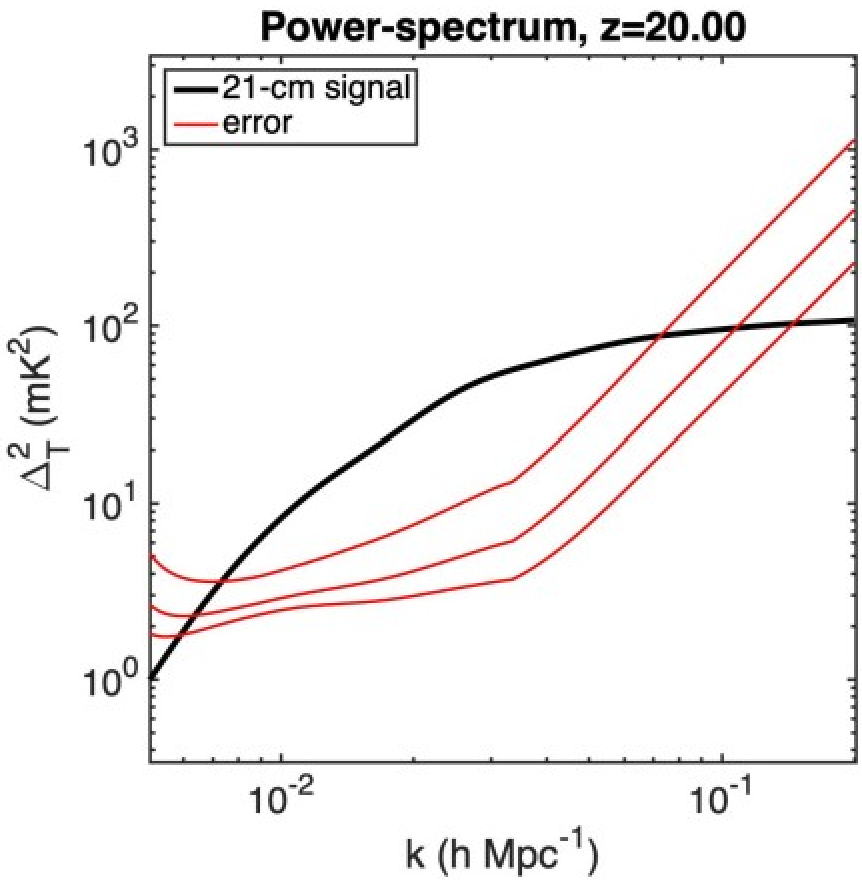
Where do we stand ?



Observation strategy: sensitivity



1000 hrs, non-standard models



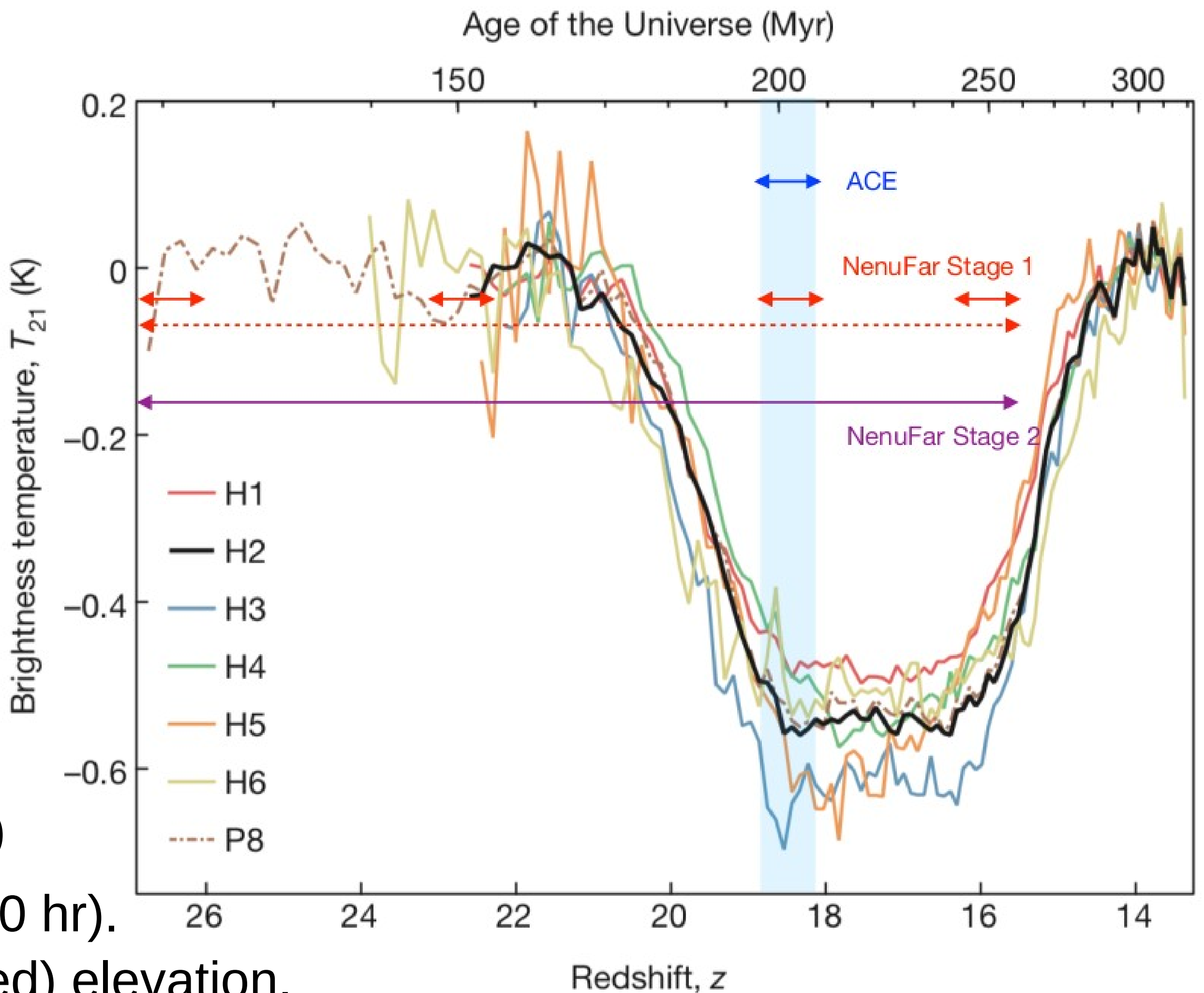
1000, 2500, 5000 hrs, standard models (21cmFast)

- ~ 1000 hrs of observations are required with NenuFAR for a detection at the 5-10-sigma level.
- More extreme models could be in range after few hundred hours.
- Standard model reachable after ~ 1000 hrs

Observation strategy

2 stages strategy envisioned:

- Stage 1: Before correlator, limited bandwidth (~ 3 MHz): 4 x 50 h on 4 frequencies combs.
- Stage 2: After correlator: deep 1000 hrs integration with 35 MHz bandwidth (z ~ 15.7 – 27).



Target: North Celestial Pole (NCP)

+ Main Lofar-EoR deep field (+2000 hr).
+ Visible all year round at high (fixed) elevation.
+ Avoid beam tracking.
+/- Relatively “cold” part of the sky.
+ No very bright source.
- No very bright source.

Observed in any block of time that exceeds ~4 hrs to ensure excellent uv coverage.

Observation strategy

Stage 1: Prepare for deep integration

Target	Total time	Frequency range	Total Bandwidth
NCP	4 x 50h	50-85 MHz	4 x 3.1 MHZ

Goals:

- Detailed spatial and spectral model of the NCP.
- Check systematic, adjust observation strategy if needed.
- Cross-validation with our AARTFAAC observation in the ACE program.

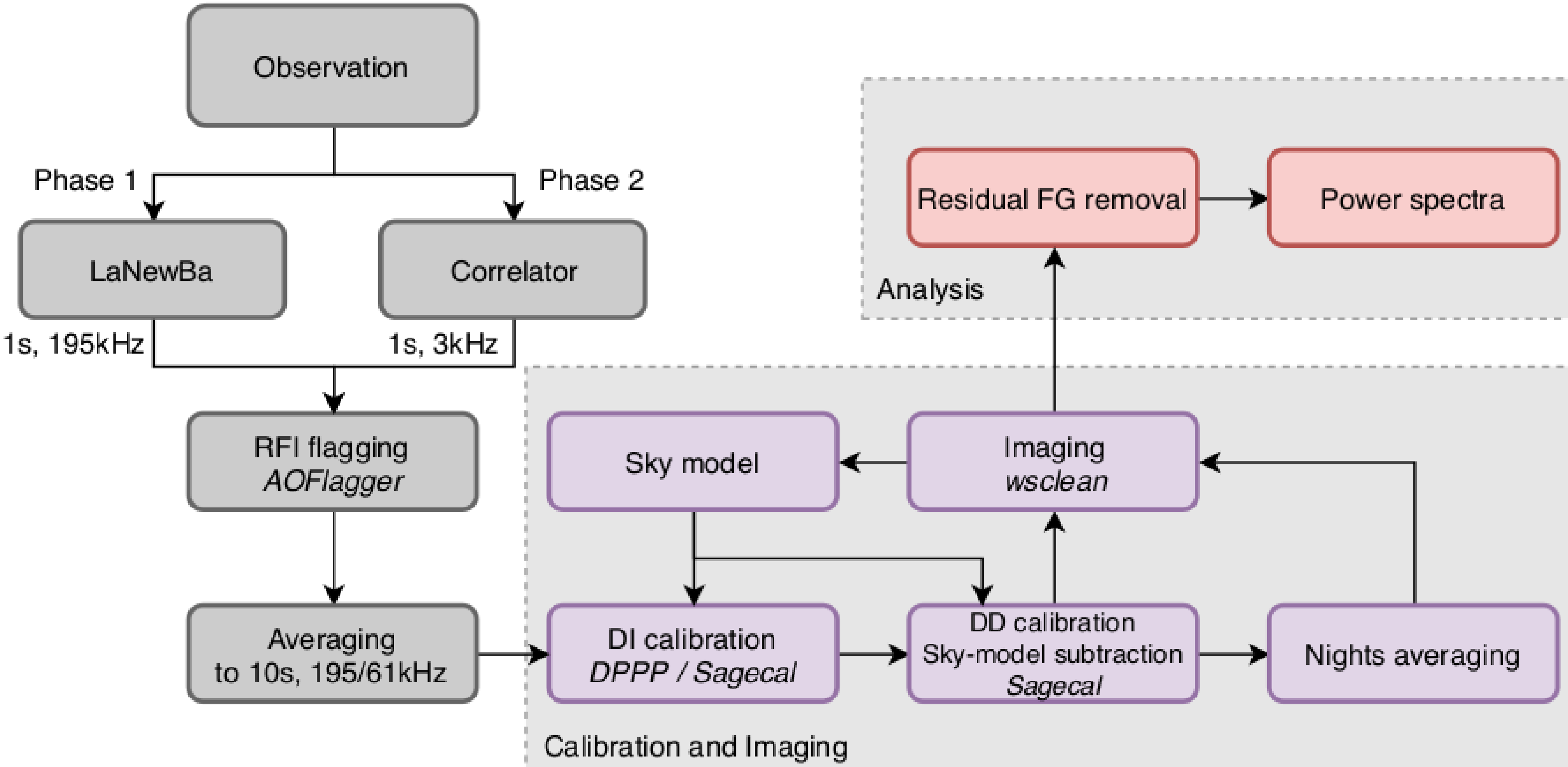
Stage 2: Deep integration

Target	Total time	Frequency range	Total Bandwidth
NCP	1000 h (TBC)	50-85 MHz	35 MHZ

Goals:

- 21-cm signal power-spectra in 3 redshift bins in the range z ~ 15.7 – 27
- Many other science cases (diffuse galactic emission, variable source, transients ...)

Data processing



After averaging, data would be transferred and stored to the Lofar-EoR cluster

- Phase 1: ~ 260 GB in 200 hours
- Phase 2: ~ 130 TB in 1000 hours

Summary

- The 21-cm signal from the Dark Ages, Cosmic Dawn and Reionization promises a new and unique probe of the first billion year of the Universe.
- Many ongoing/planned global and interferometric experiments, but very difficult experiments.
- NenuFAR’s compactness make it sensitive to the Cosmic Dawn 21-cm signal at 10-sigma level in about 1000 hours of observation.
- Most extreme non-conventional models triggered by EDGES claimed detection could even be probed in a few hundreds hours with high S/N.
- **2 stages plan:**
  - ➔ Before correlator, 4 x 50 h with 4 x 3.1 MHz bandwidth.
  - ➔ After correlator, deep 1000h integration at z ~ 15.7 – 27.
- 21-cosmology is driver but a lot of spin-off results (including in stage 1)
- Prepare for SKA, synergy with the ACE (AARTFAAC) project.