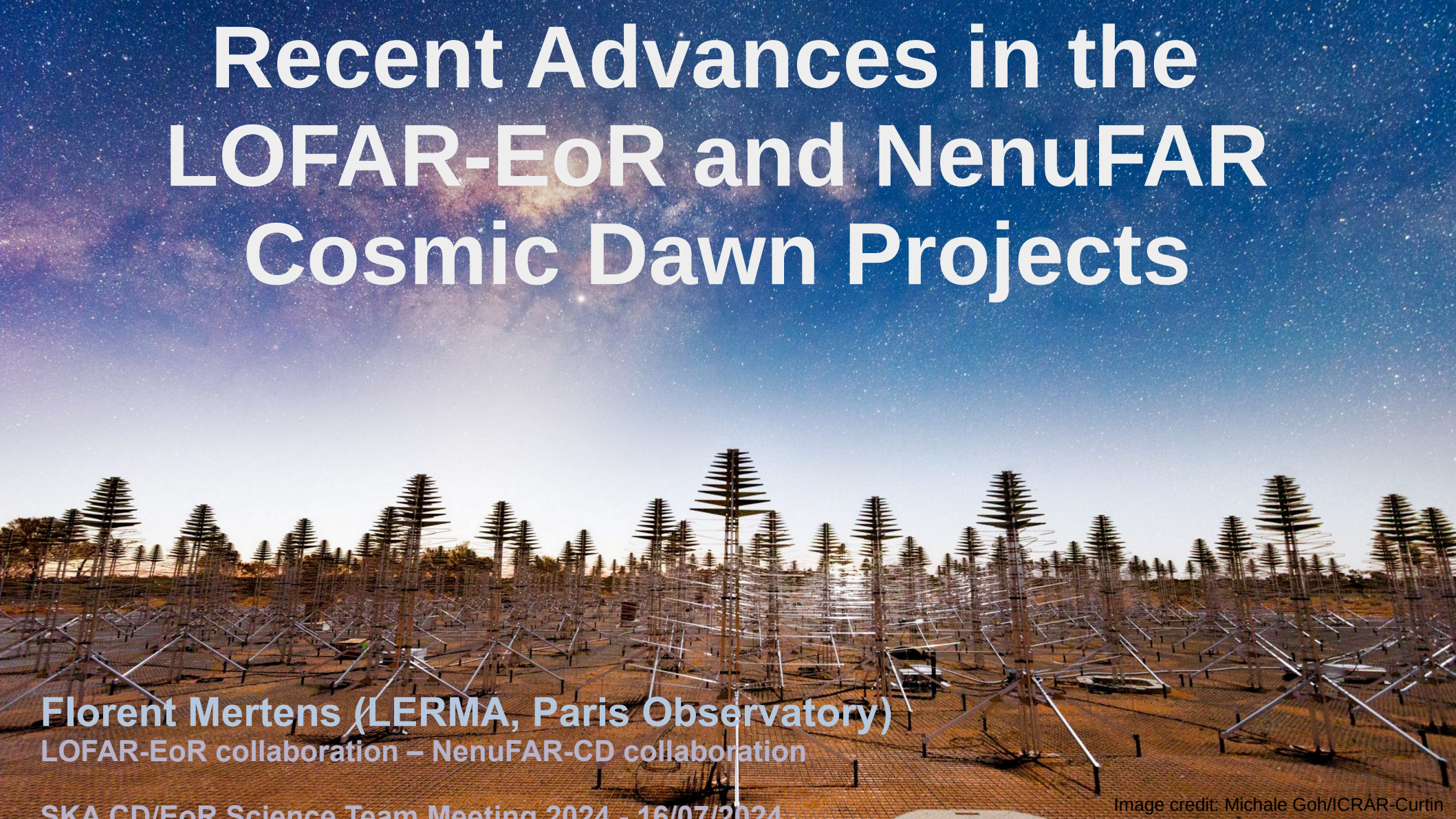
Recent Advances in the LOFAR-EoR and NenuFAR Cosmic Dawn Projects



Florent Mertens (LERMA, Paris Observatory)
LOFAR-EoR collaboration – NenuFAR-CD collaboration

SKA CD/EoR Science Team Meeting 2024 - 16/07/2024

Image credit: Michale Goh/ICRAR-Curtin

The LOFAR-EoR and NenuFAR Cosmic Dawn experiments

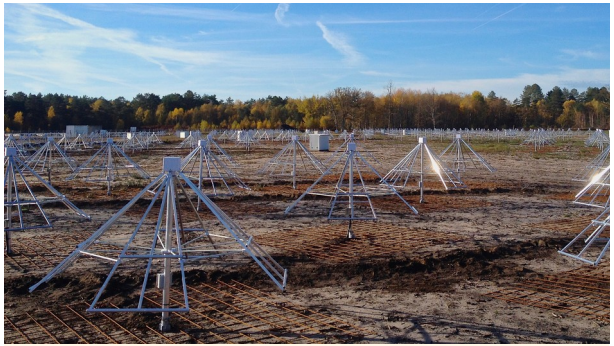
LOFAR-EoR

Observation started in 2012

+ 2000 h observed

➔ Properties of the IGM and ionising sources.

➔ History of reionization.



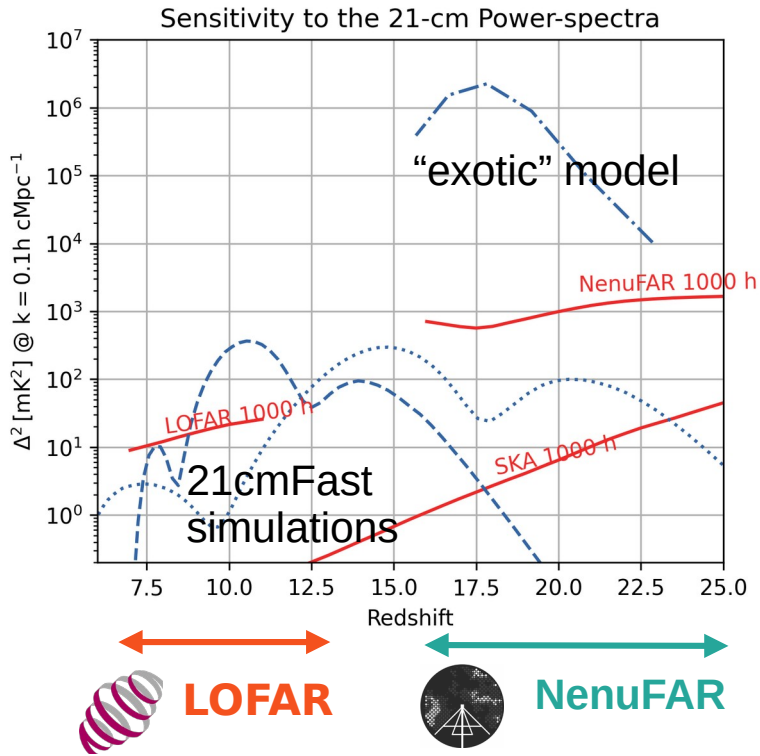
NenuFAR Cosmic Dawn

Observation started in 2019

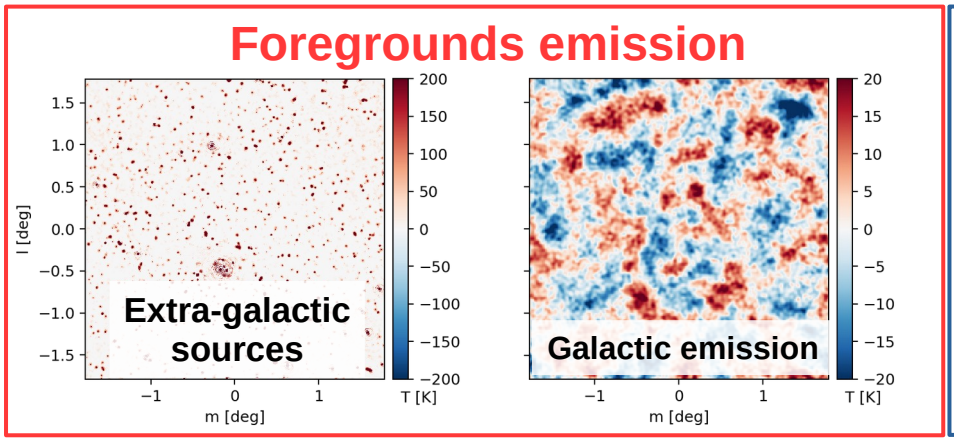
+ 1000 h observed

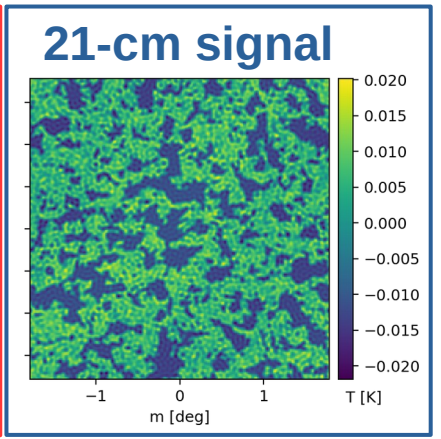
➔ Testing of non-standard models.

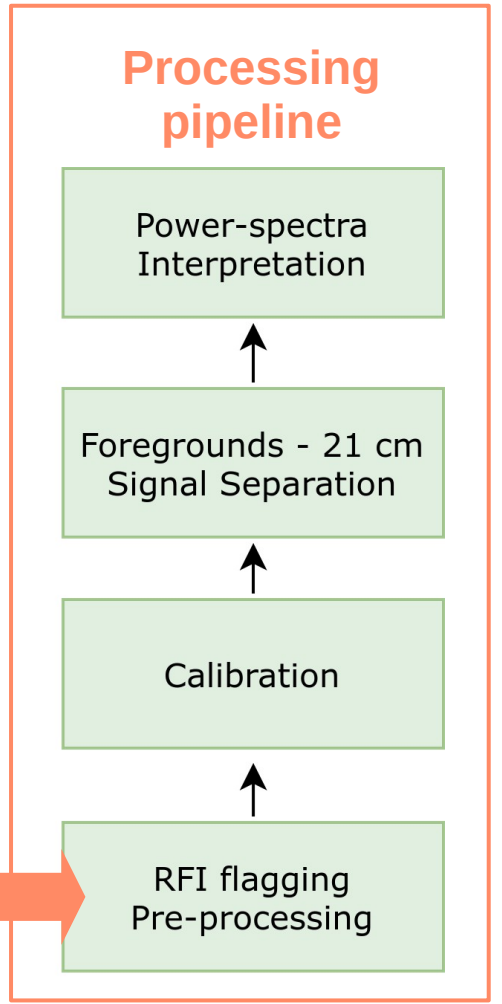
➔ First constraints on the properties of the first stars and on the physics at that time.

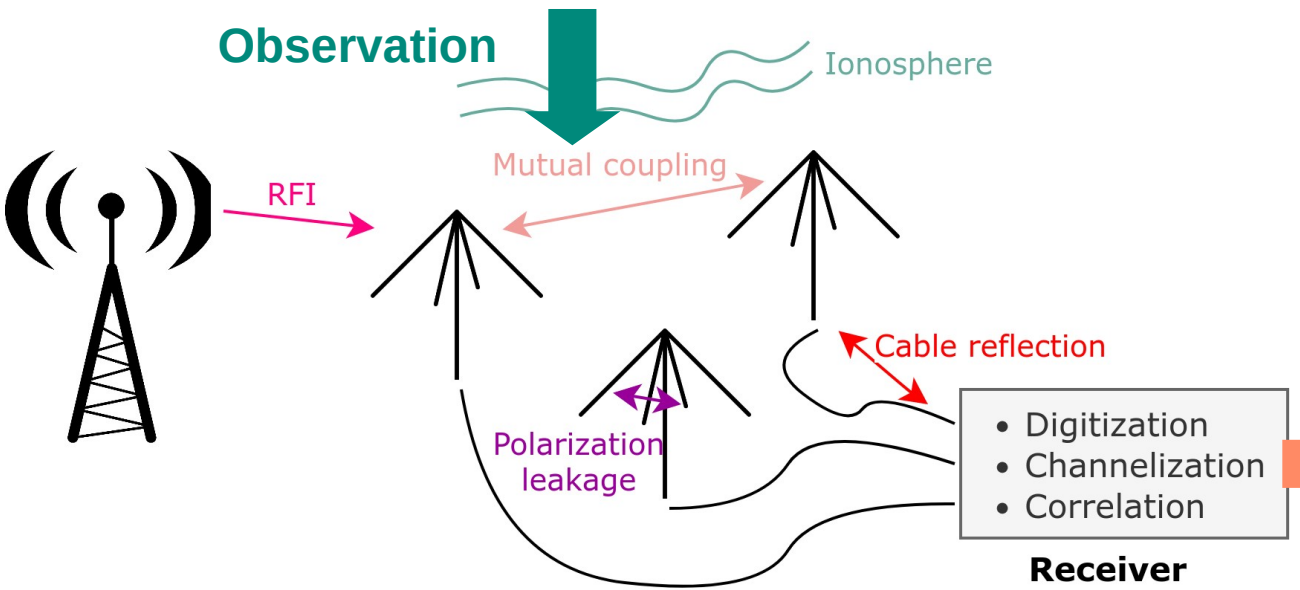


A challenging experiment









The Epoch of Reionization with LOFAR

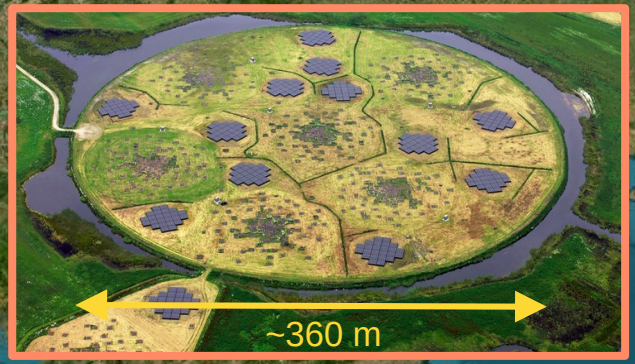
LOFAR-EoR plenary 2019 - Groningen

LOFAR-EoR plenary 2022 - Paris

The Low Frequency Array

13 International stations
14 (NL) remote stations
24 core stations

110 – 240 MHz (HBA)
30 – 80 MHZ (LBA)

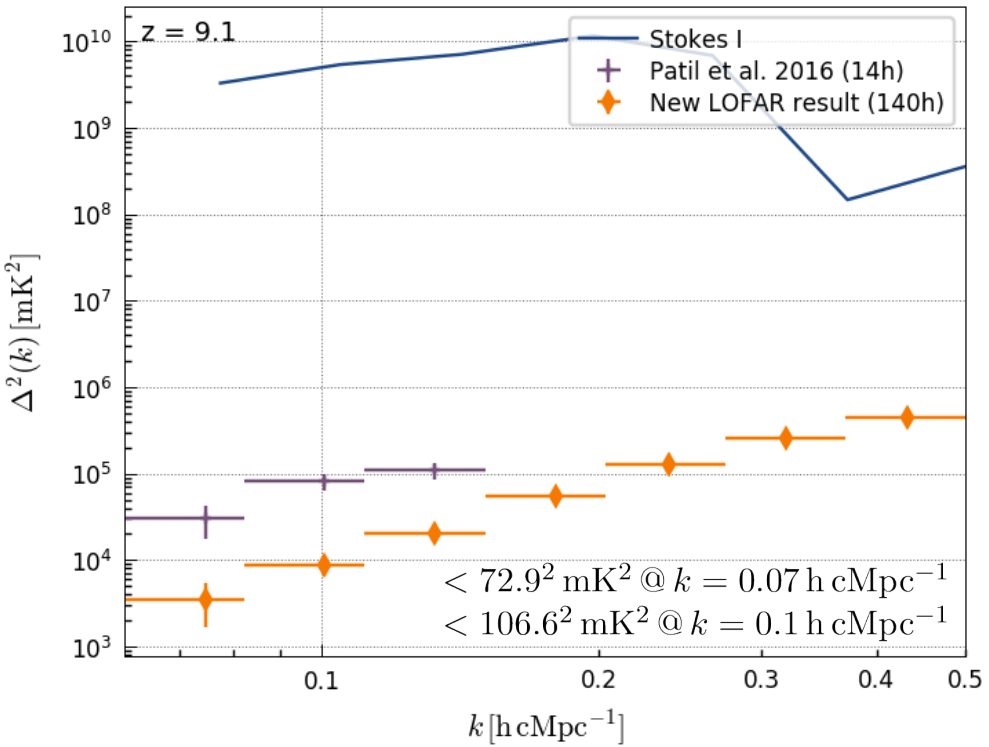


The « superterp »

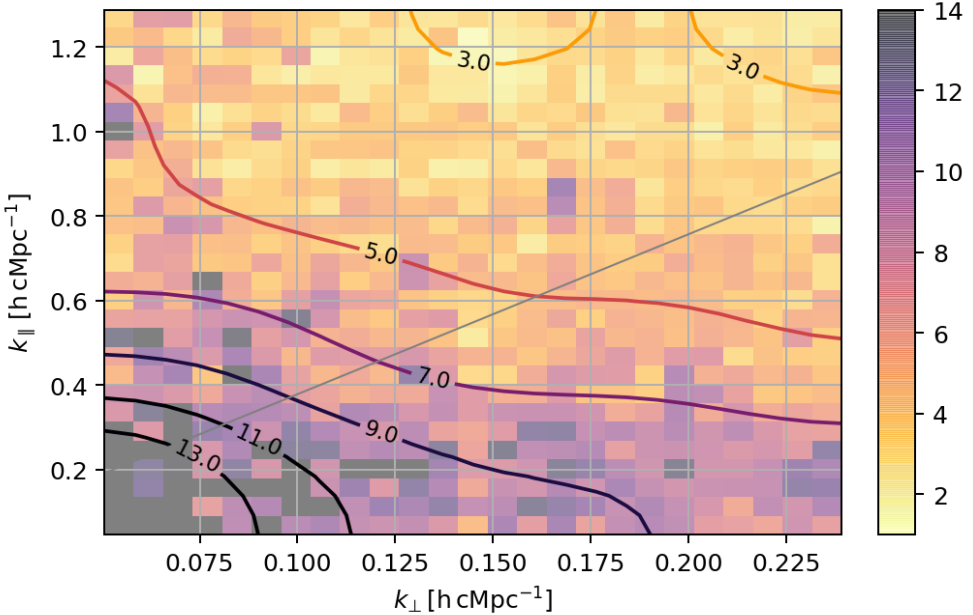
Super-terp:
Densely packed “elevated” area of 6 (12) core stations.

Current LOFAR upper limit at z~9

NCP field, 140 hours, 134-146 MHz, z ~ 9.1



PS ratio Stokes I residual / thermal noise

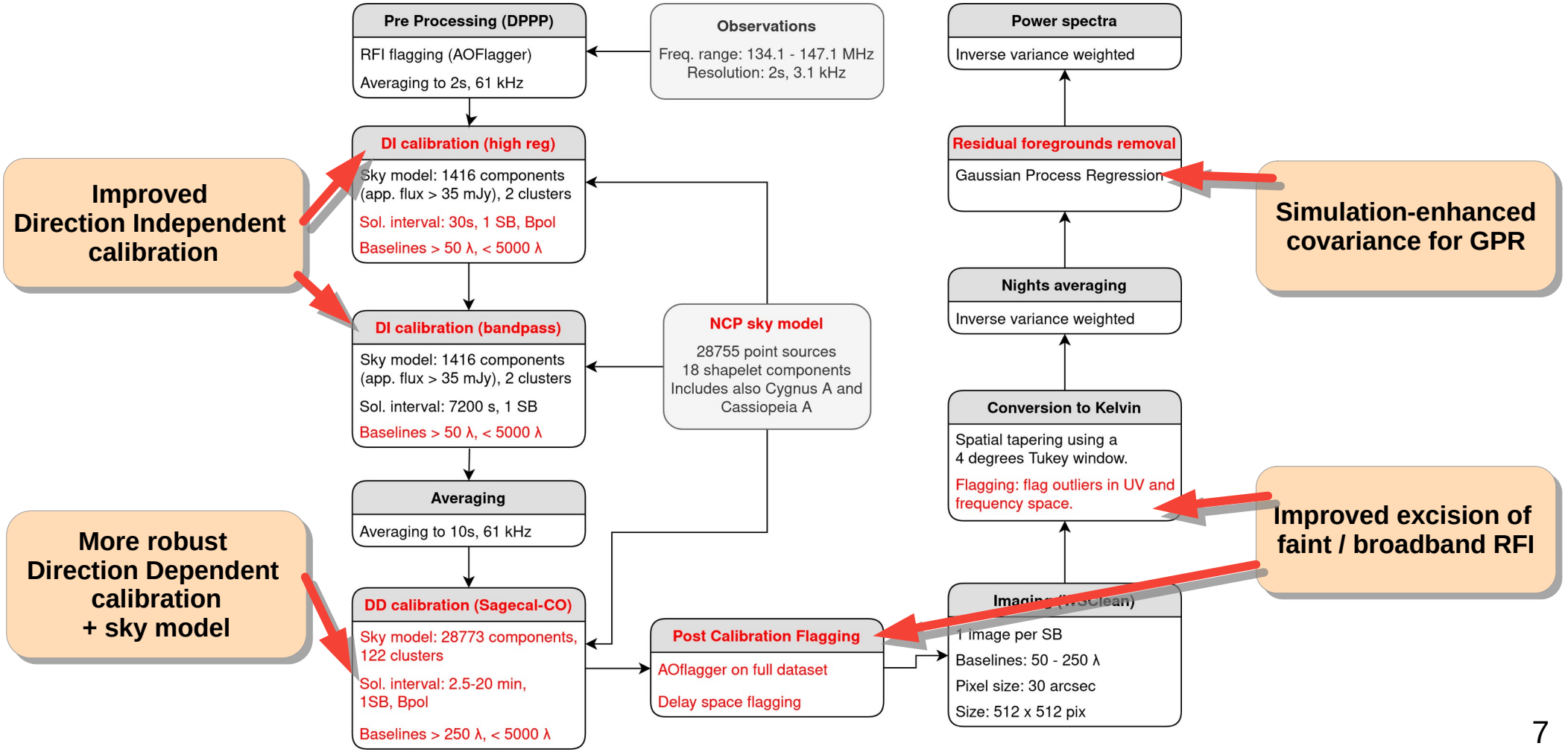


A reduction by a factor ~ 10 compared to our 2017 upper limit, the deepest at z ~ 9 ...

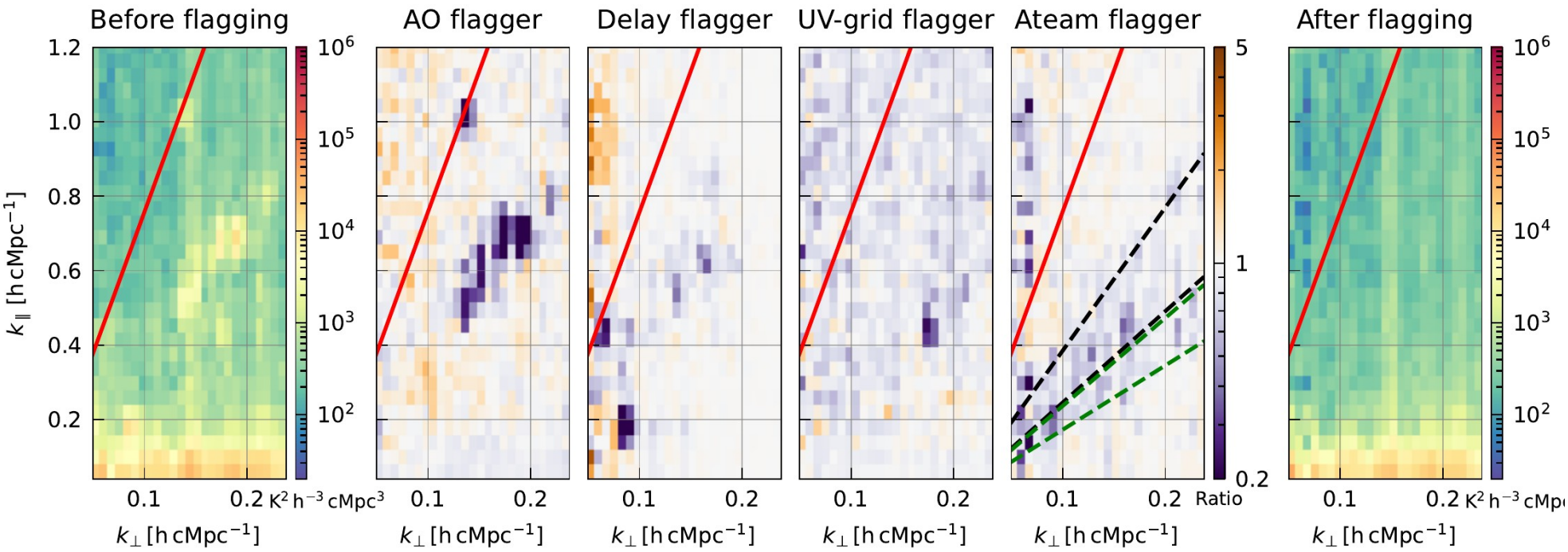
… but still affected by large **excess power**.

(Mertens et al. 2020)

Mitigating the excess



LOFAR RFI flagging



A combination of AO flagger, delay-space space, and gridded-visibility flagger reduce contamination in the EoR window

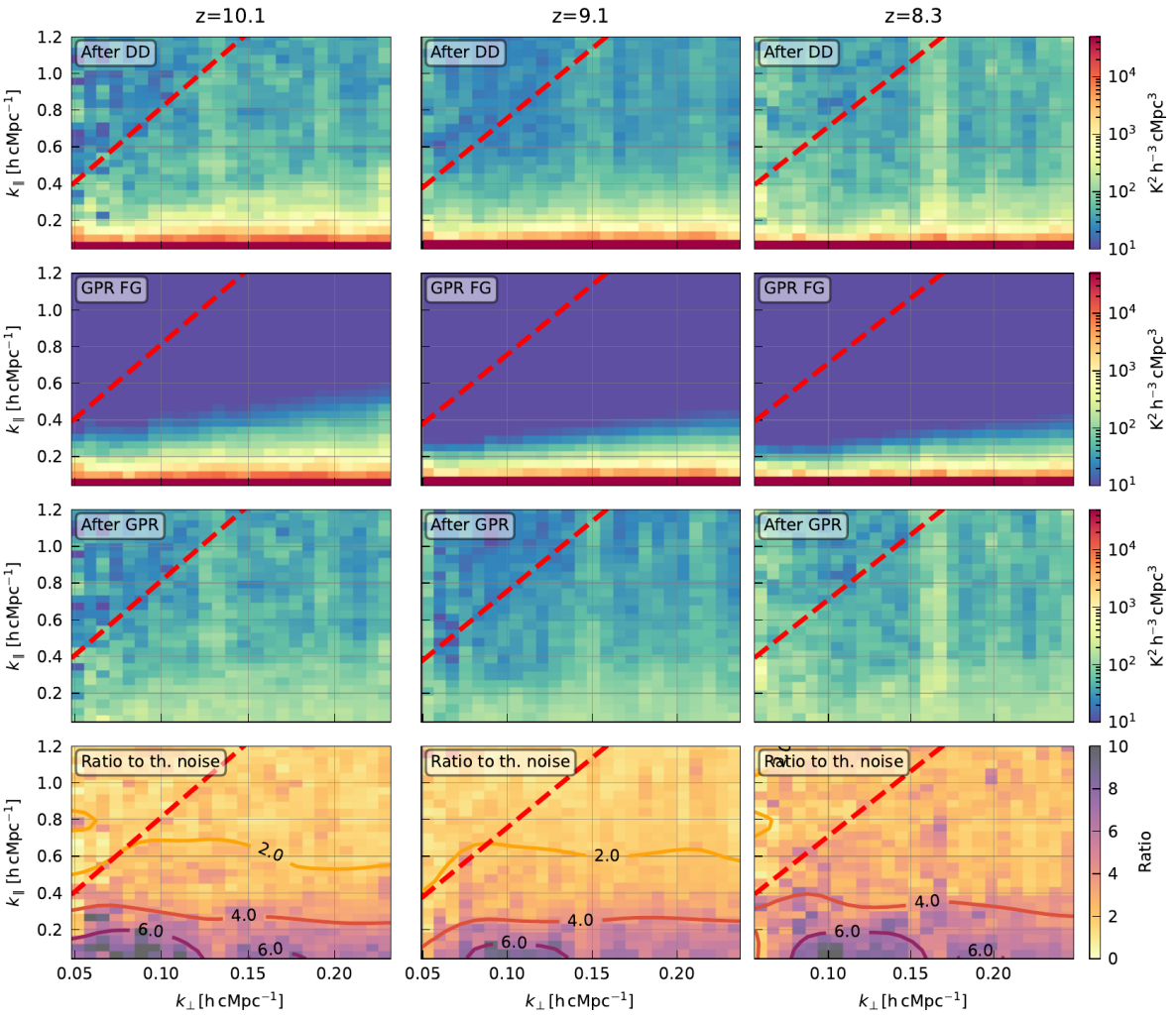
Foregrounds removal

Before Foregrounds removal

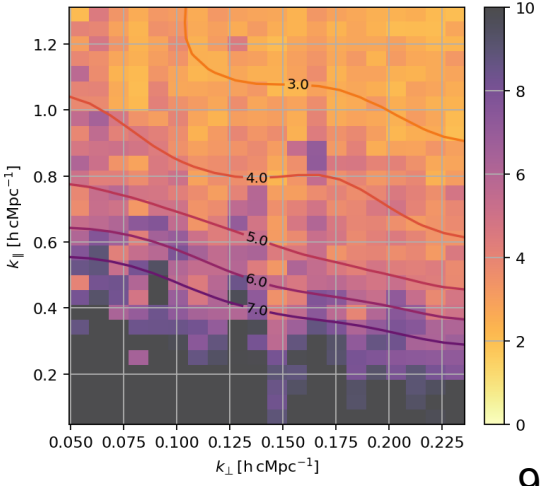
Foregrounds component

Residual

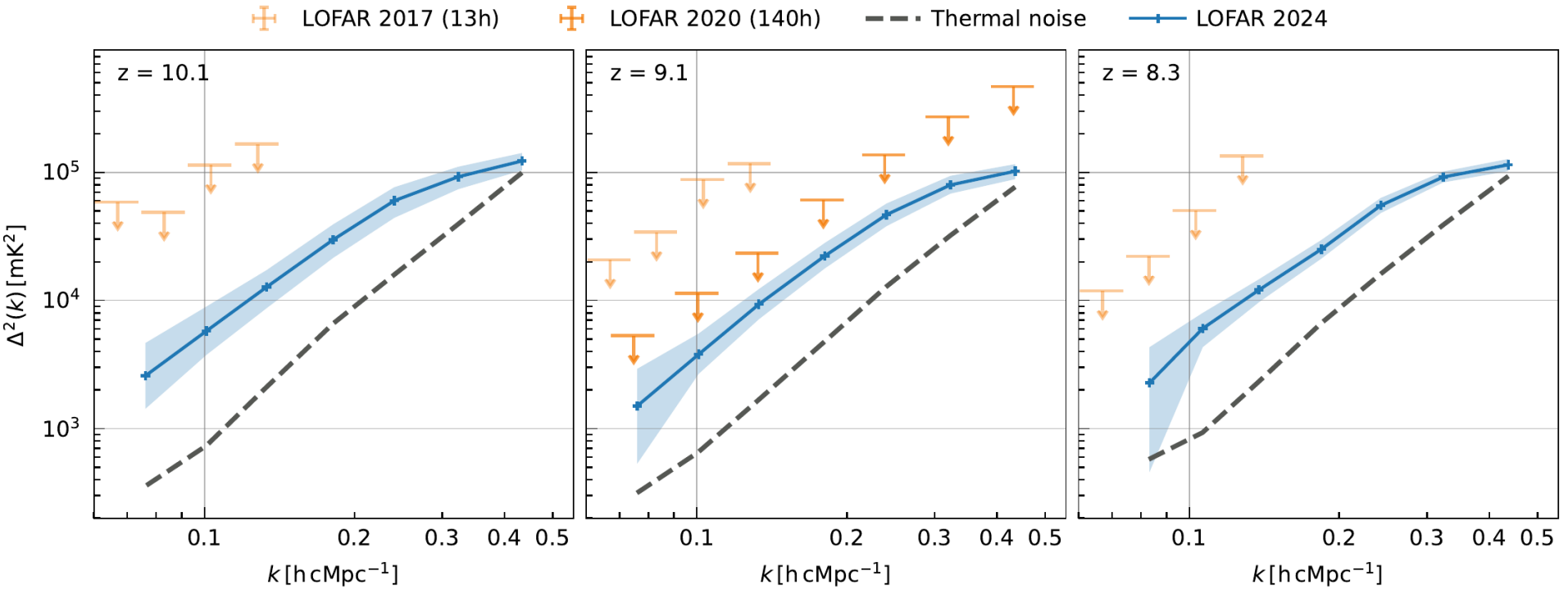
Residual ratio to thermal noise



LOFAR 2020
Residual to thermal noise for comparison



New LOFAR results



➔ A reduction in upper limits by a factor ~2 to 10 for the three LOFAR redshifts (Mertens, Mevius, et al. in prep.)

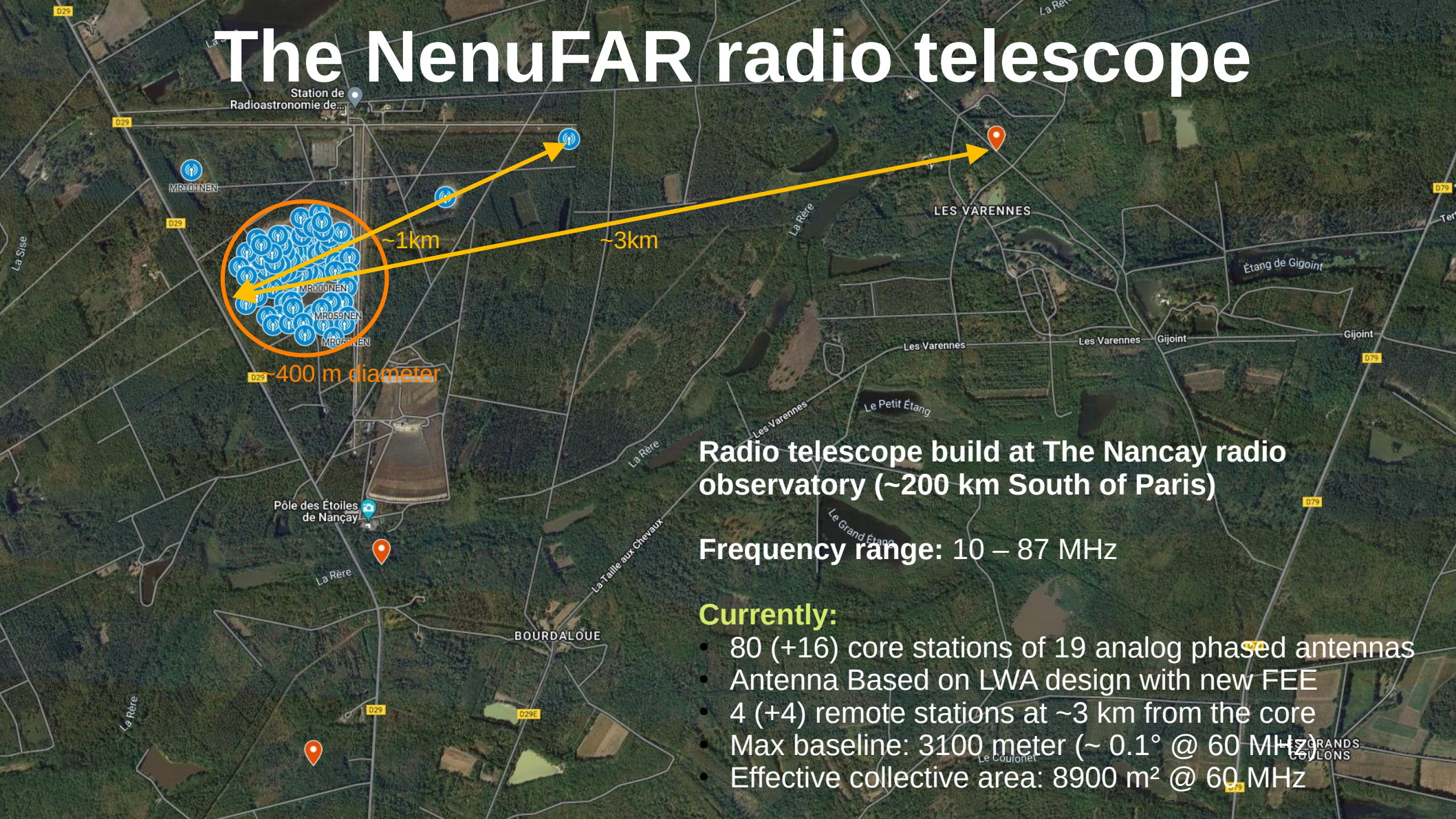
➔ An improvement by a factor ~2 to 5 at redshit 9.1 **with the same data** !

Probing the Cosmic Dawn with NenuFAR

NenuFAR CD plenary 2021 - Paris

NenuFAR CD plenary 2023 - Groningen

The NenuFAR radio telescope



Radio telescope build at The Nancay radio observatory (~200 km South of Paris)

Frequency range: 10 – 87 MHz

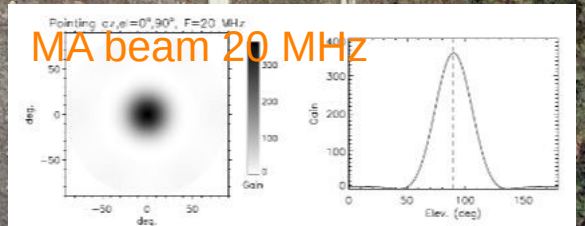
Currently:

- 80 (+16) core stations of 19 analog phased antennas
- Antenna Based on LWA design with new FEE
- 4 (+4) remote stations at ~3 km from the core
- Max baseline: 3100 meter (~ 0.1° @ 60 MHz)
- Effective collective area: 8900 m² @ 60 MHz

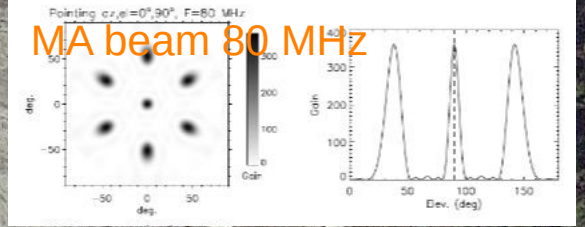
The NenuFAR radio telescope

MR012NEN
MR054NEN
MR052NEN
MR053NEN
MR009NEN
MR032NEN
MR005NEN
Mini-Array
MR008NEN
MR001NEN
MR007NEN
MR004NEN
LOFAR LBA
MR058NEN
LOFAR HBA
MR072NEN
MR067NEN
MR061NEN

MA beam 20 MHz

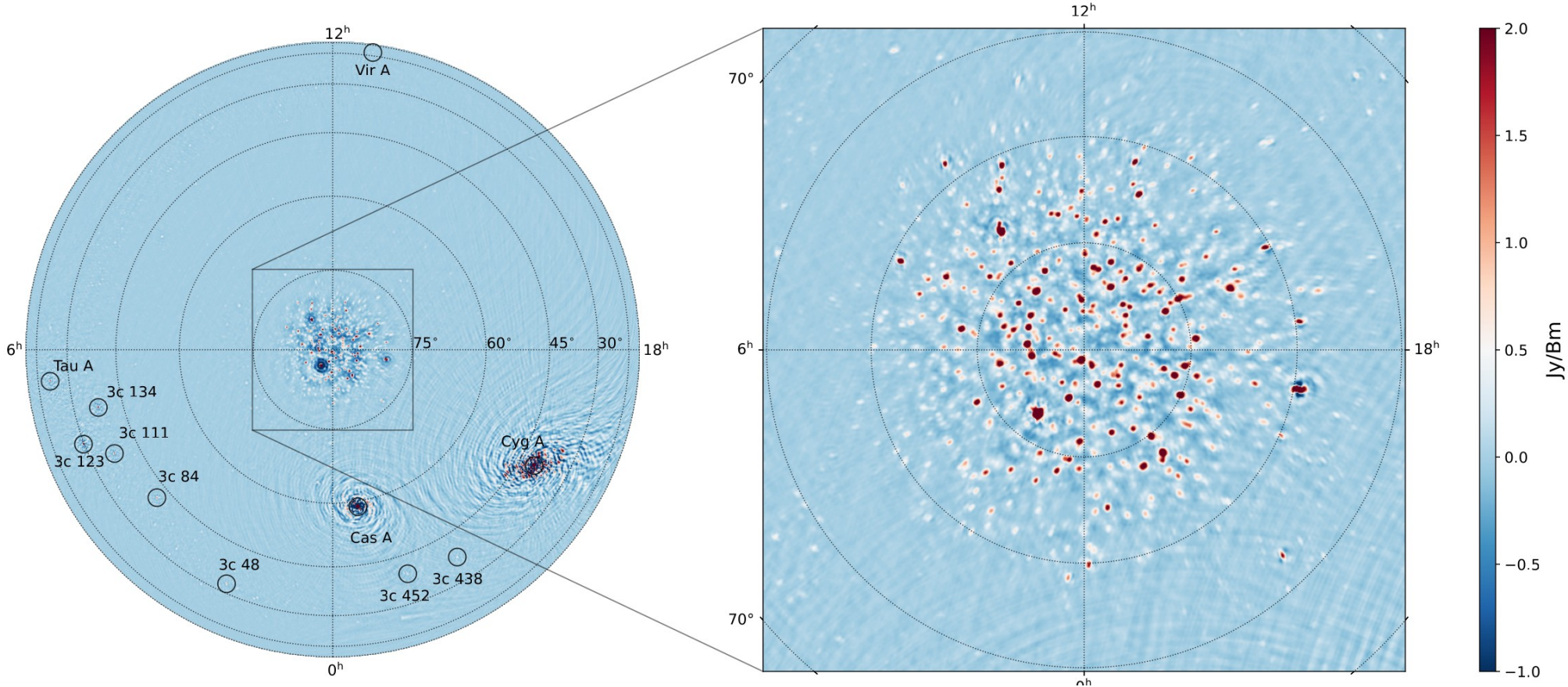


MA beam 80 MHz



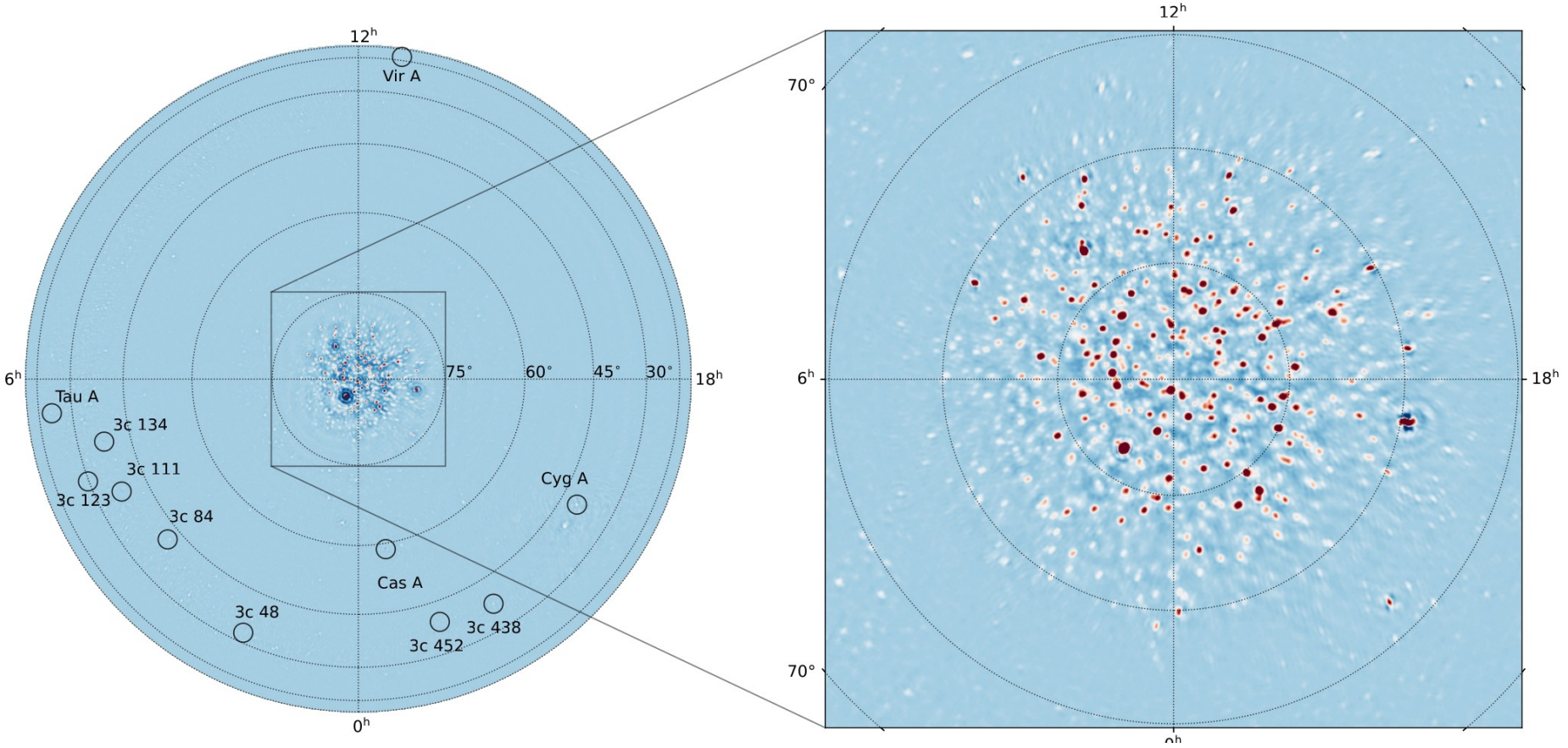
First NenuFAR upper limit

NCP observation from the 12/12/2022 | z~20 (61-72.5 MHz)



Munshi, Mertens et al. 2024

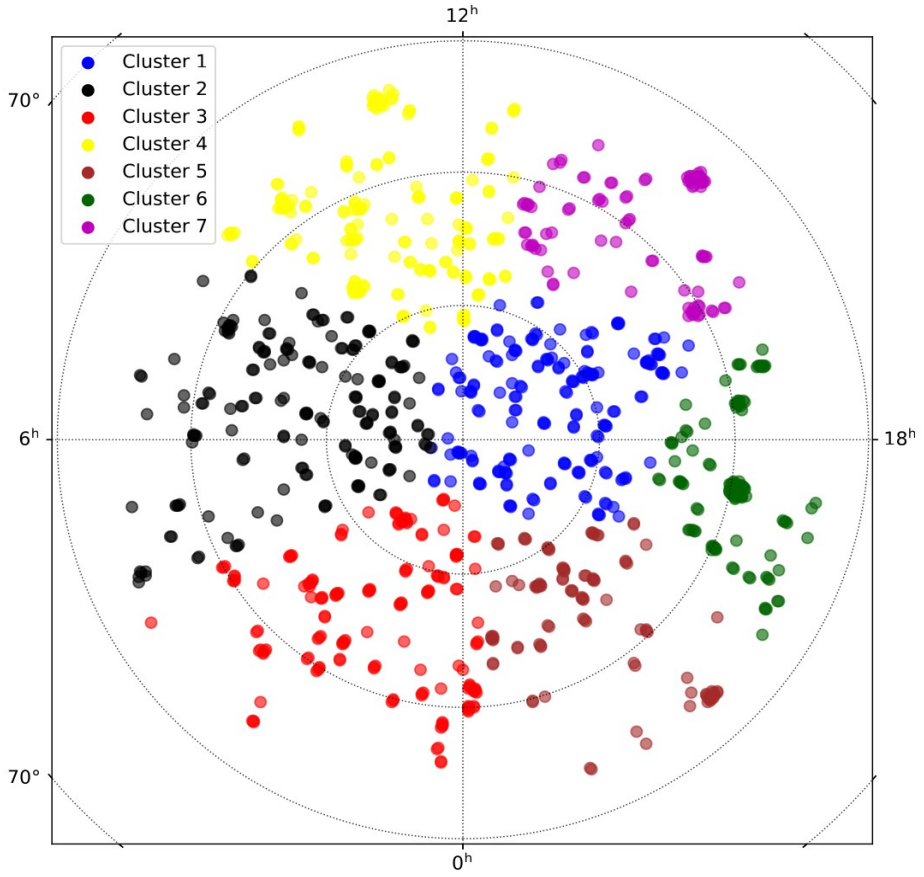
After A-team + 3C sources removed

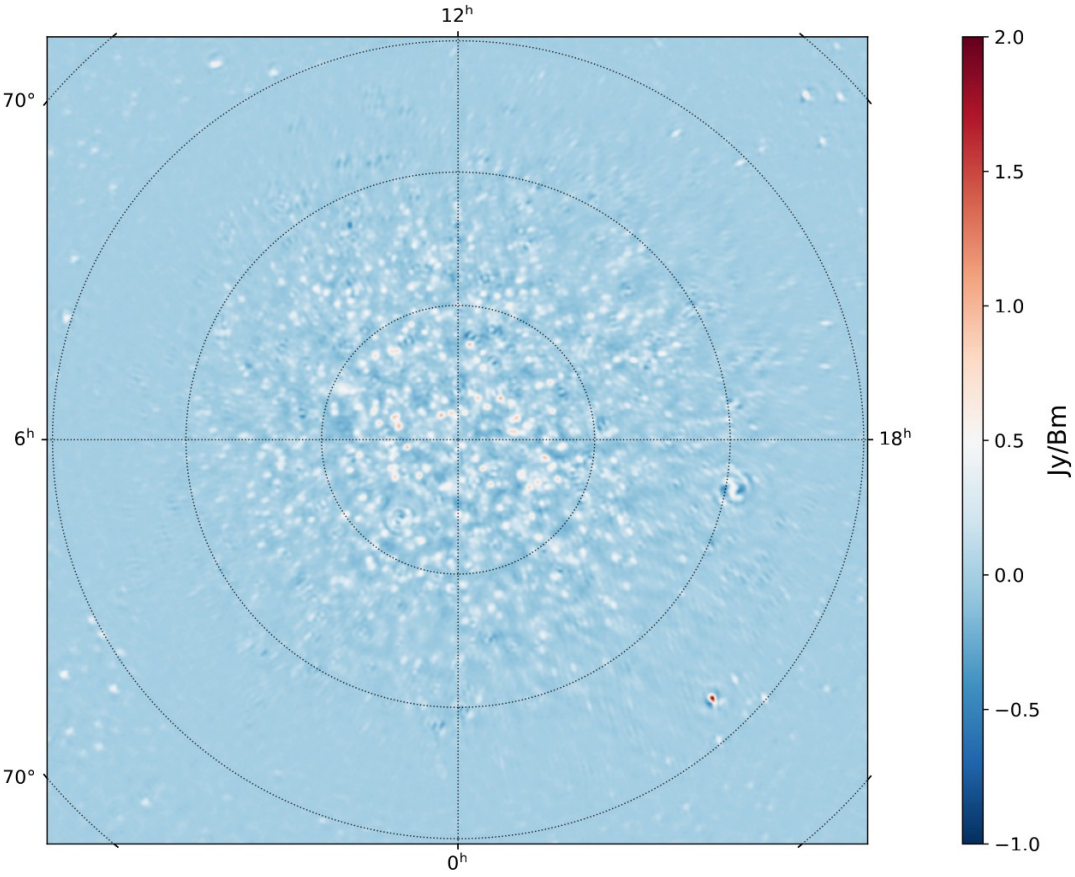


Munshi, Mertens et al. 2024

After sky-model point source removed

Sky model clusters

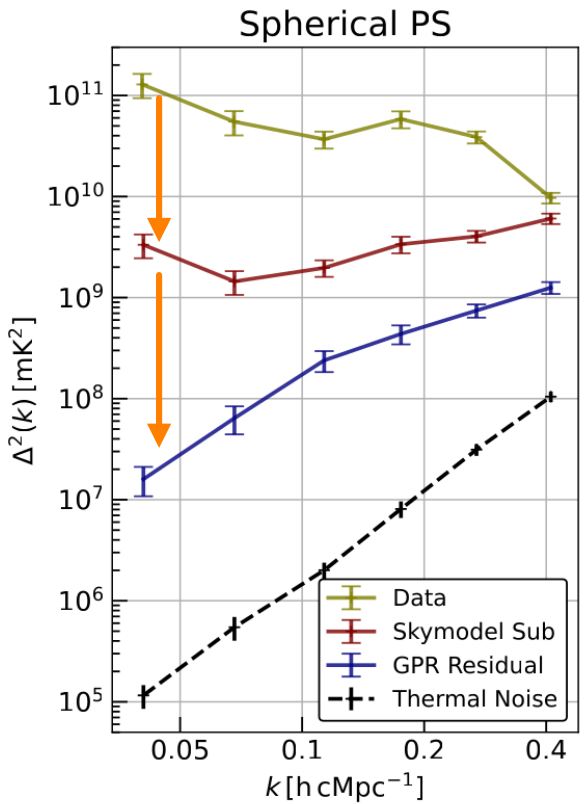


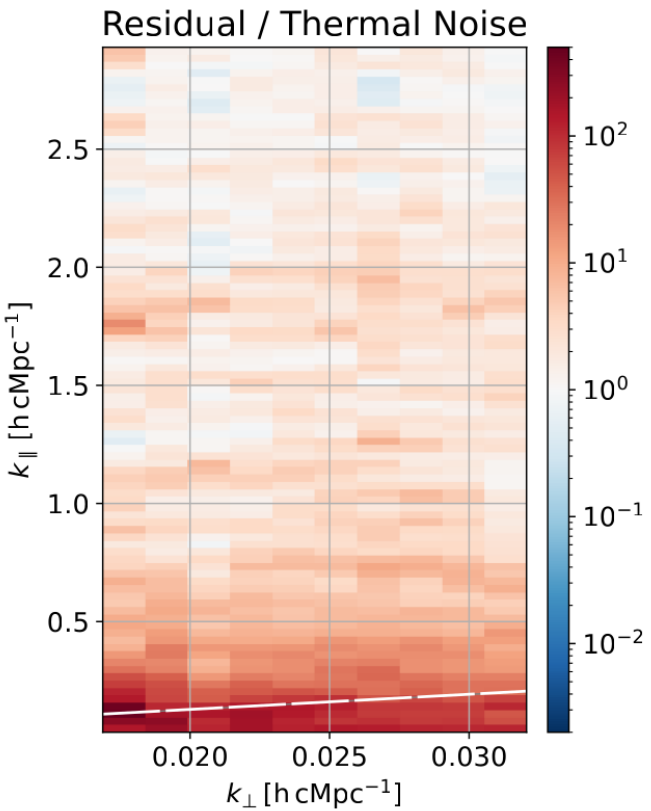


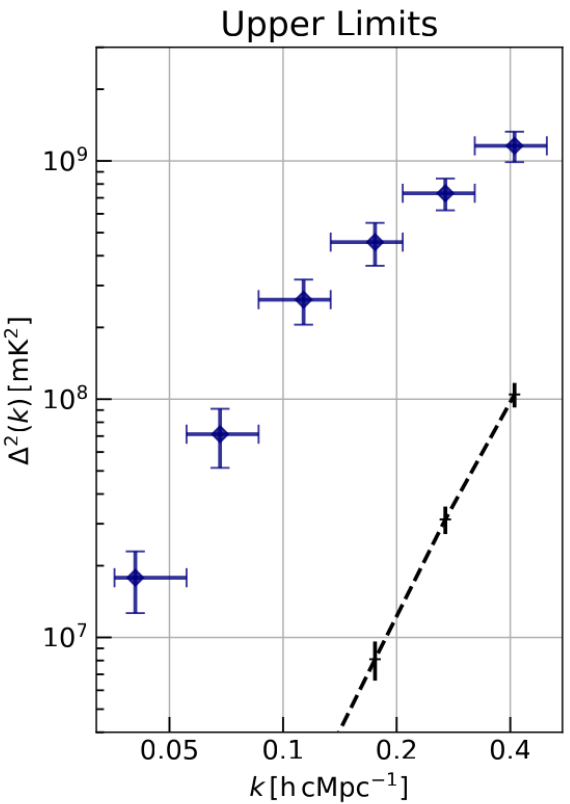
Munshi, Mertens et al. 2024

First NenuFAR upper limit

NCP field, 11.5 hours, 61-72.5 MHz, z ~ 20

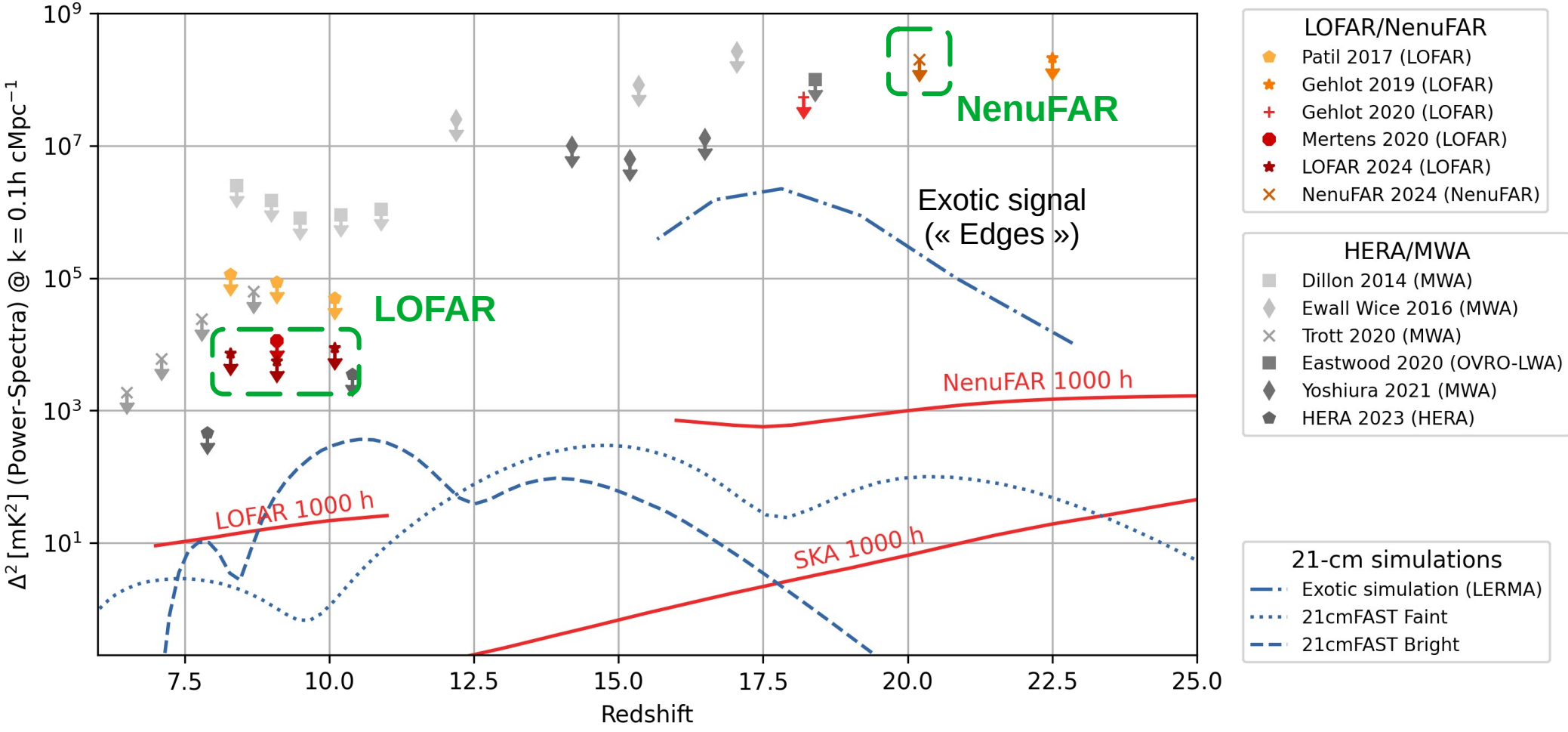






Munshi, Mertens et al. 2024

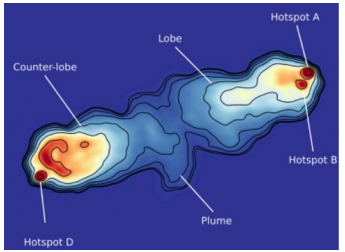
Progress toward a detection



Making a big leap towards a detection

Investigation and mitigation of the excess

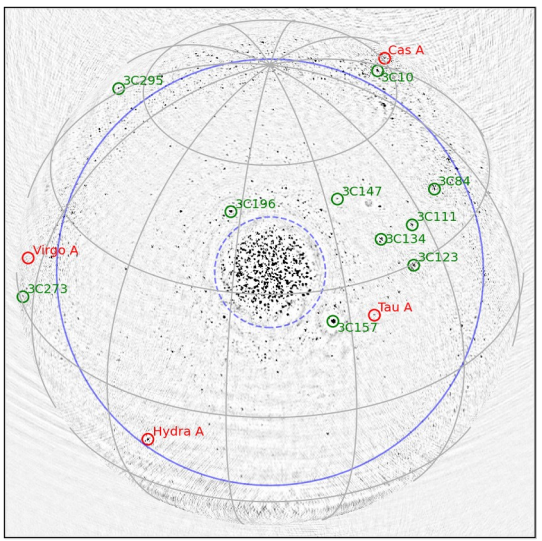
- ➔ Ionosphe impact analysis (Stefanie)
- ➔ Improved bright source model (Emilio)
- ➔ Filtering of local sources of RFI (Satyapan)



Improved Cygnus A model

New observing fields

- ➔ New “darker” NenuFAR deep field
- ➔ Analysis of the 3C196 field with LOFAR (Emilio)



New “darker” NenuFAR field

New end-to-end automated pipelines

- ➔ LOFAR EoR: NextLEAP (Kariuki)
- ➔ NenuFAR Cosmic Dawn: NenuFlow

- ➔ **Now ready for large batch processing**

Summary

- The 21-cm signal from the Cosmic Dawn and Epoch of Reionization promises a new and unique probe of the first billion year of the Universe, **but very challenging experiment.**
- Many challenges: **Foregrounds, Calibration, RFI**

- **Status of the LOFAR-EoR project:**
  - New multi-redshift upper-limits at z=8.3, 9.1 and 10.1, based on ~5% of LOFAR data
  - Deepest @ k=0.075 cMpc^{-1}, z ~ 9: **$\Delta^2 < (55\ \mathrm{mK})^2$**

- **Status of the NenuFAR Cosmic Dawn project:**
  - The NenuFAR Cosmic Dawn project aims at detecting the redshifted 21-cm signal from the Cosmic-Dawn in the redshift range **z ~ 15 – 31**.
  - **First upper limit at z ~ 20** published**.**

- **We are scaling up significantly!**