NenuFAR Cosmic Dawn project Current status
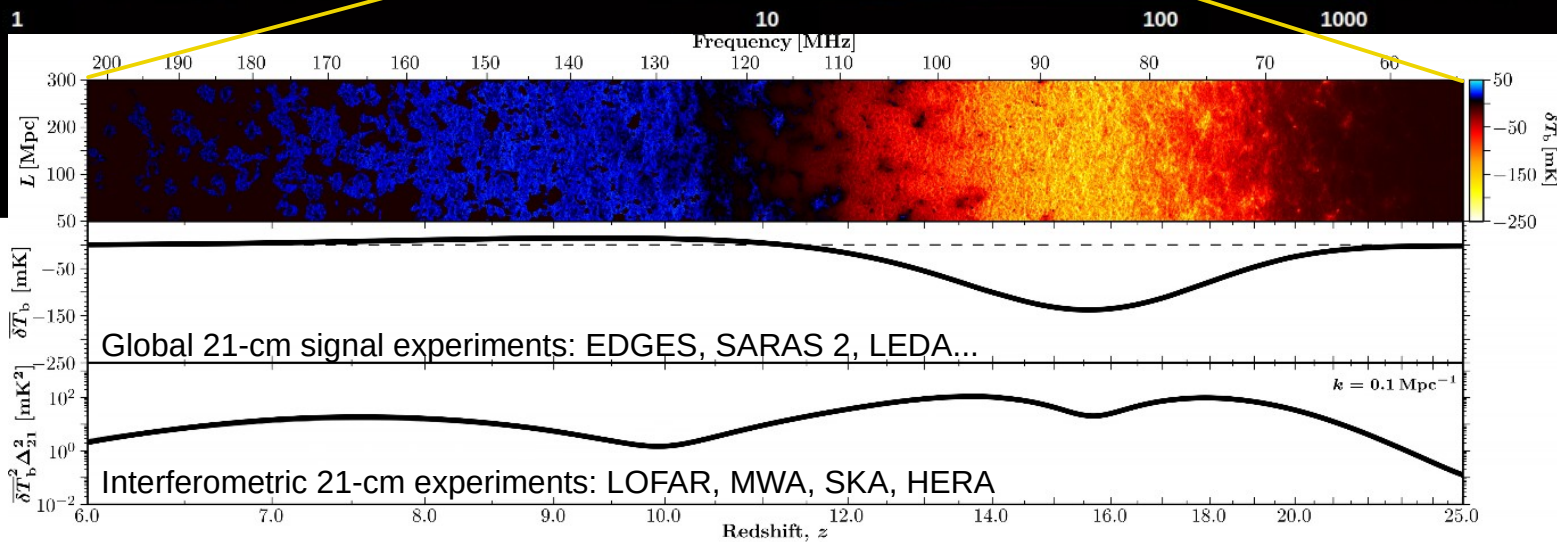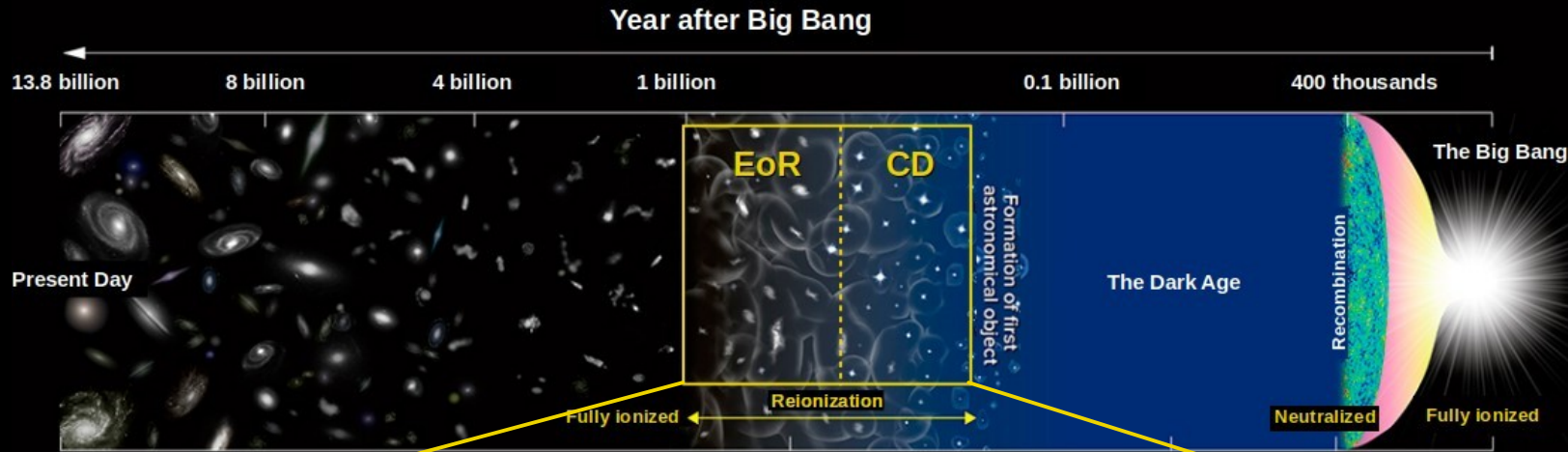
Florent Mertens (LERMA)
NenuFAR User meeting – 17/11/2021

The NenuFAR Cosmic Dawn team:
Leon Koopmans (PI), Benoit Semelin (PI), F. Mertens (co-PI), D. Aubert, R. Barkana,
J. Bobin, F. Boulanger, B. Cecconi, J. Chardin, A. Doussot, A. Fialkov, H. Gan,
S. Gazagnes, B. Gehlot, N. Gillet, J. Girard, V. Jelic, F. Levrier, M. Mevius, P. Ocvrik,
A. Offringa, P. Vishambhar, M. Pommier, C. Tasse, H. Vedantham, P. Zarka, S. Zaroubi
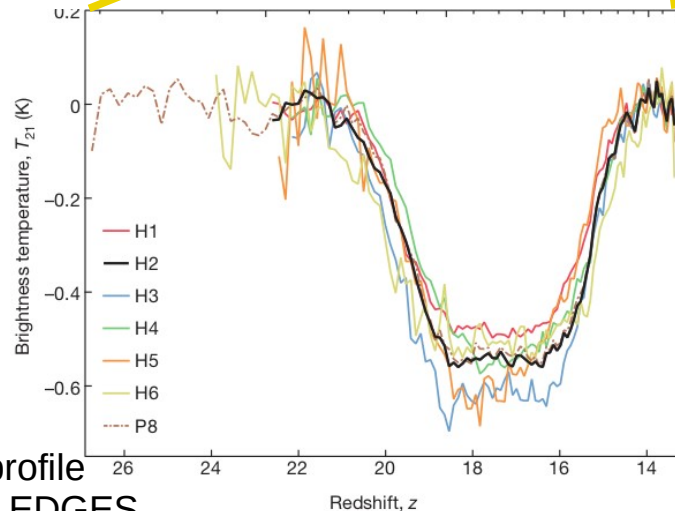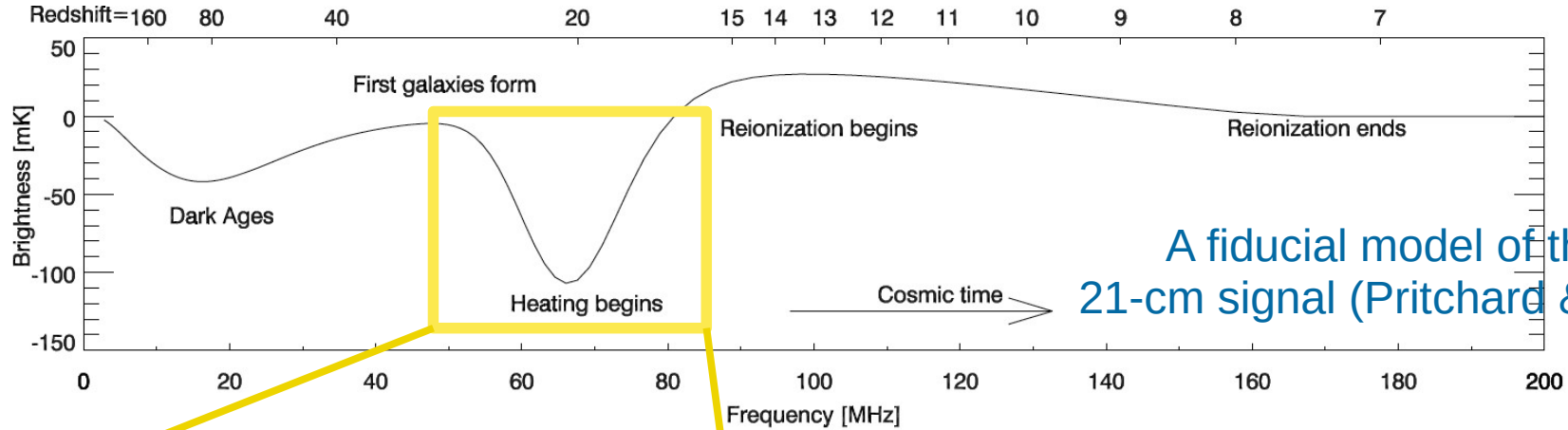
Cosmic Dawn / Epoch of Reionization

Global 21-cm signal experiments: EDGES, SARAS 2, LEDA...

Interferometric 21-cm experiments: LOFAR, MWA, SKA, HERA

Credit:
Mesinger & Greig

Global experiment: a first Detection (?)

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

Profile is largely consistent with expectations, however absorption about 2.5 x deeper than most extreme models!

Detection passed through numerous hardware and processing tests, also still controversial.

Need "exotic" model to be explained:
- Additional cooling mechanism (e.g. baryons dark-matter scattering) (e.g. Barkana et al .2018 and many more)
- Excess radio background (e.g. SMBH, Sne) (e.g. Fialkov et al. 2019 and many more)

Absorption profile observed by EDGES (Bowman et al., Nature, 2018)

Need to be confirmed by other experiments !

Interferometric experiments:
Current 21-cm upper limits and sensitivity
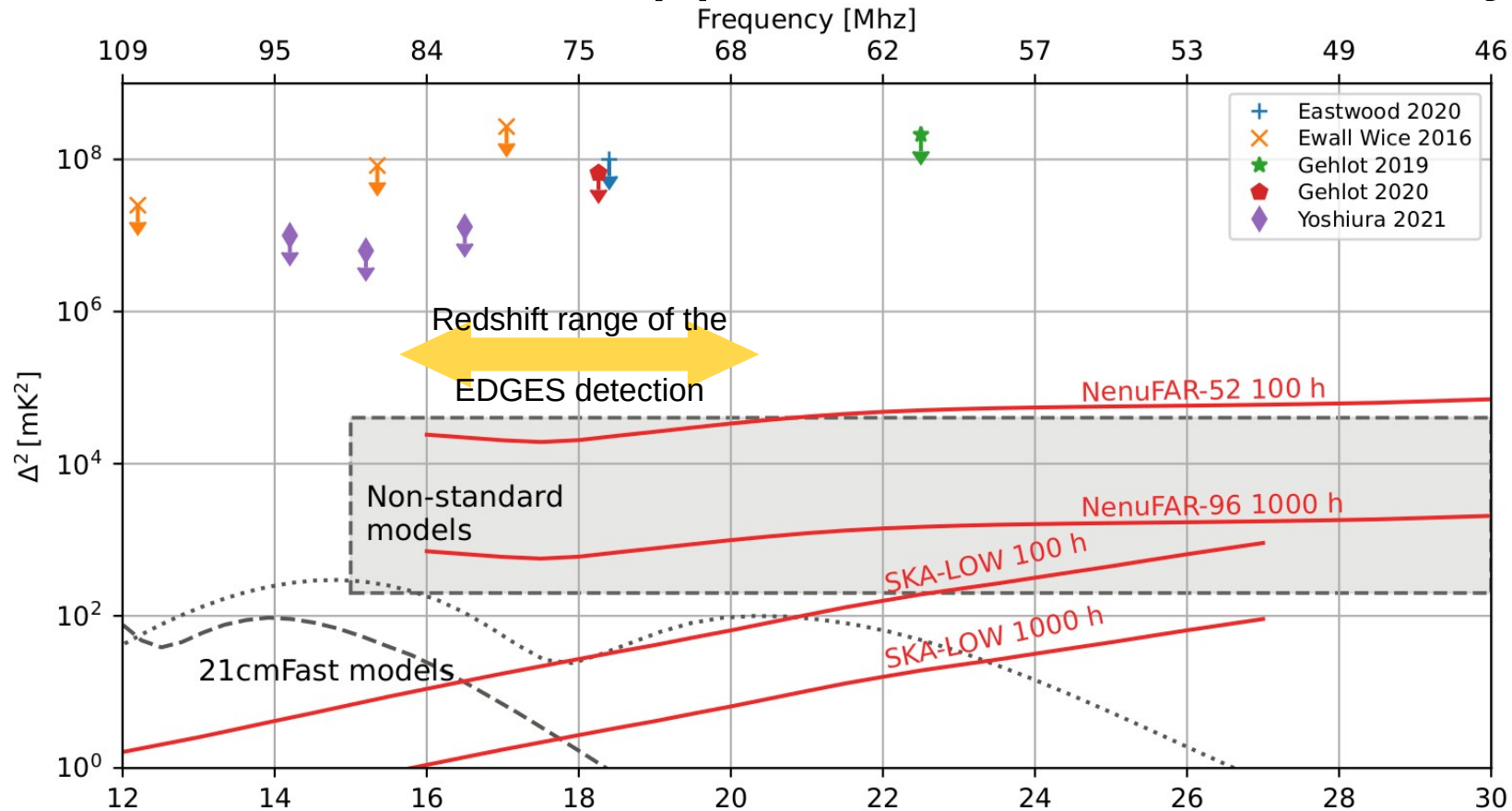
New: SARAS3 (global) experiments presented recently new results discarding the presence of the features observed by EDGES. Still needs to be confirmed.

A challenging experiment
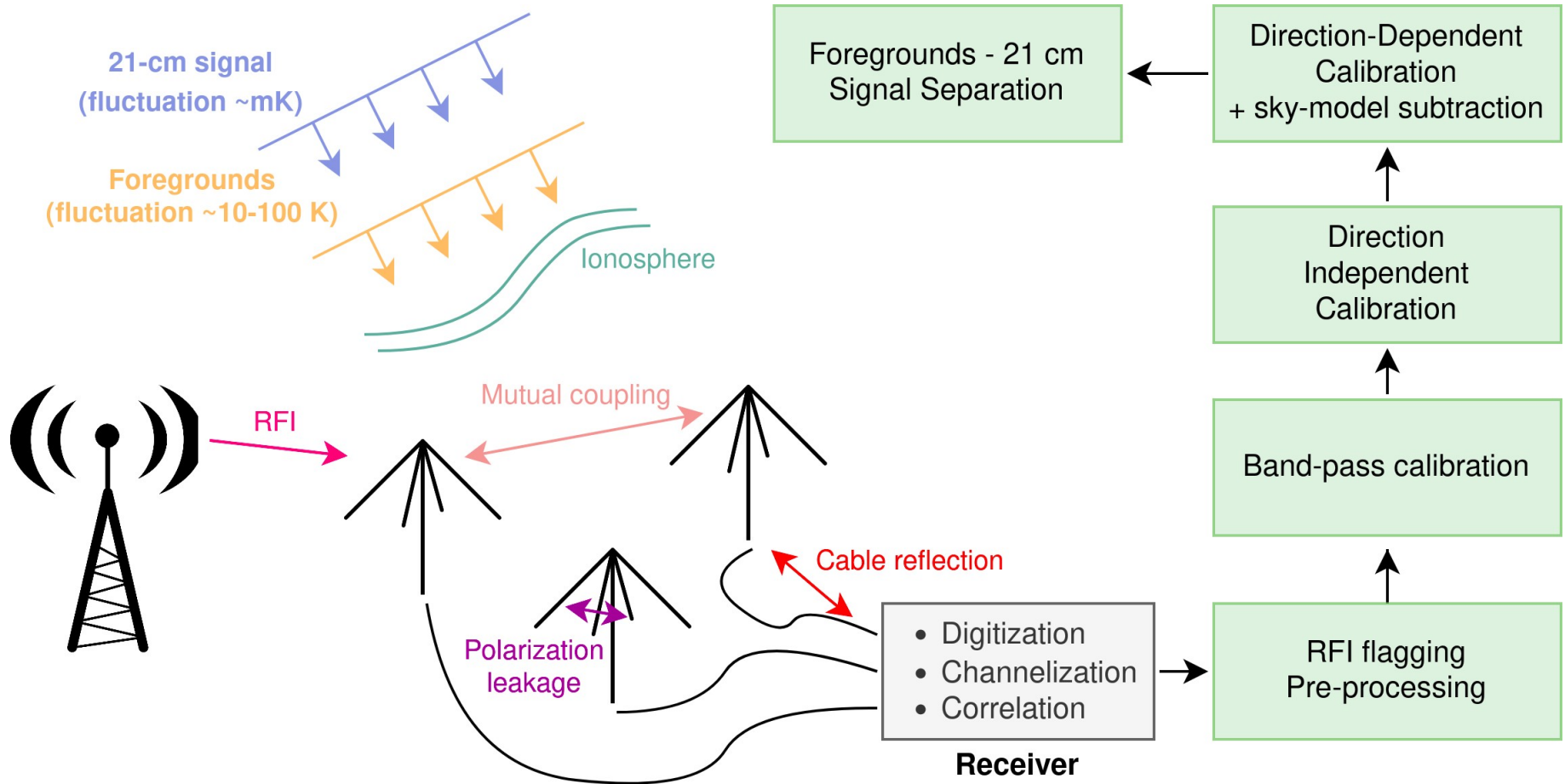
Status of the NenuFAR-CD project

Semester	Target	Time	Purpose
2019 S2	NCP	18h (324h)	Check systematics, check RFI Initial sky model of the NCP
2020 S1	3C196	1.7h (30h)	Polarized emission analysis
2020 S2	NCP	144h	Commissioning of the new correlator Start of the deep integration phase (09/20)
2021 S1	NCP	357h	Deep integration on the NCP field
	3C196 / ELAIS-N1	8h	Polarized emission analysis Comparison with NCP field
2021 S2	NCP	268h	Deep integration on the NCP field
2022 S1+S2	NCP	TBD	Deep integration on the NCP field

Phase 1

Phase 2

← Official start of the early science phase

← Availability of the new correlator

← First remote station

← 2nd and 3rd remote station + many more core stations

← 4th remote station

NenuFAR processing pipeline
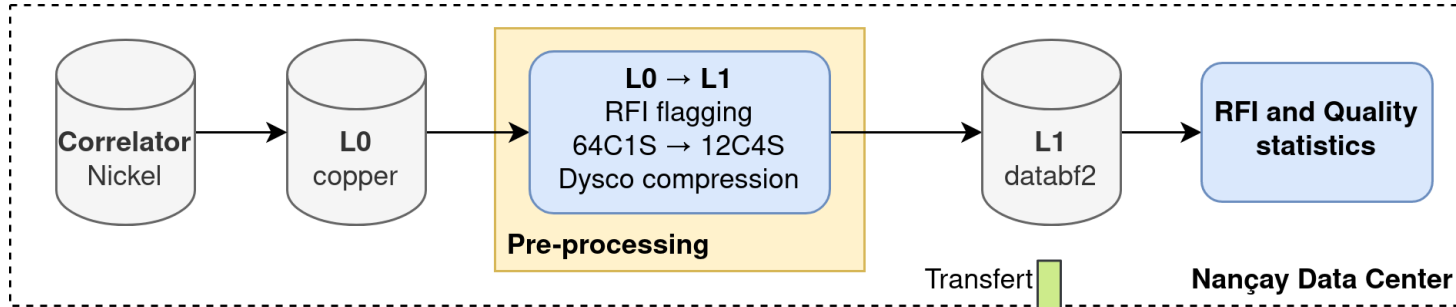
Pre-processing pipeline
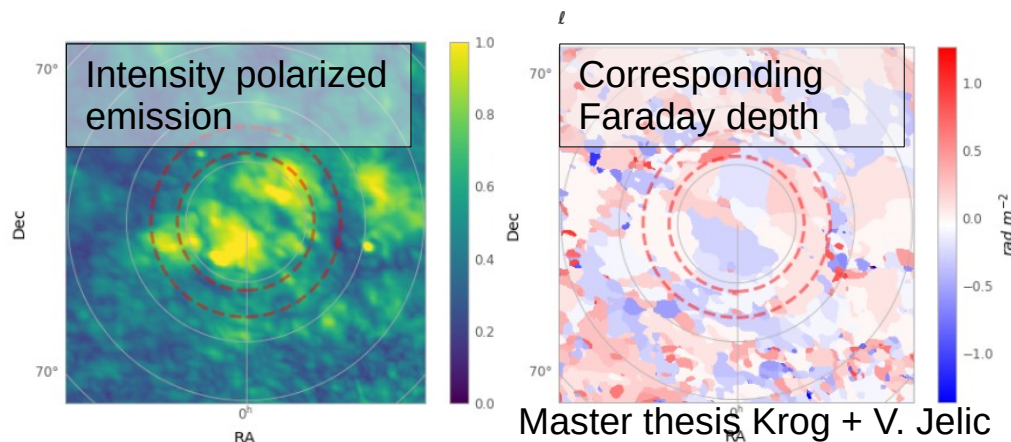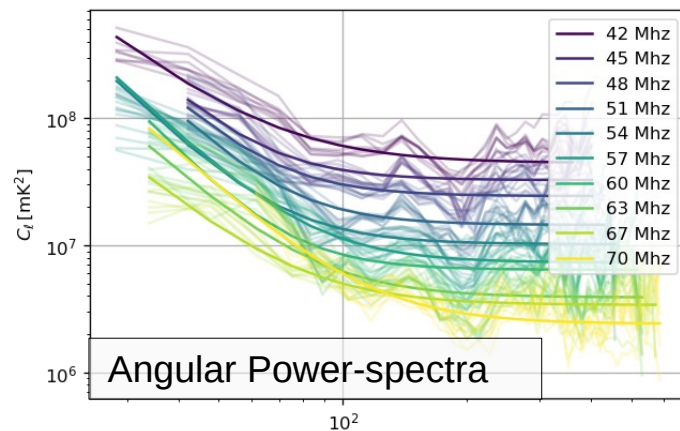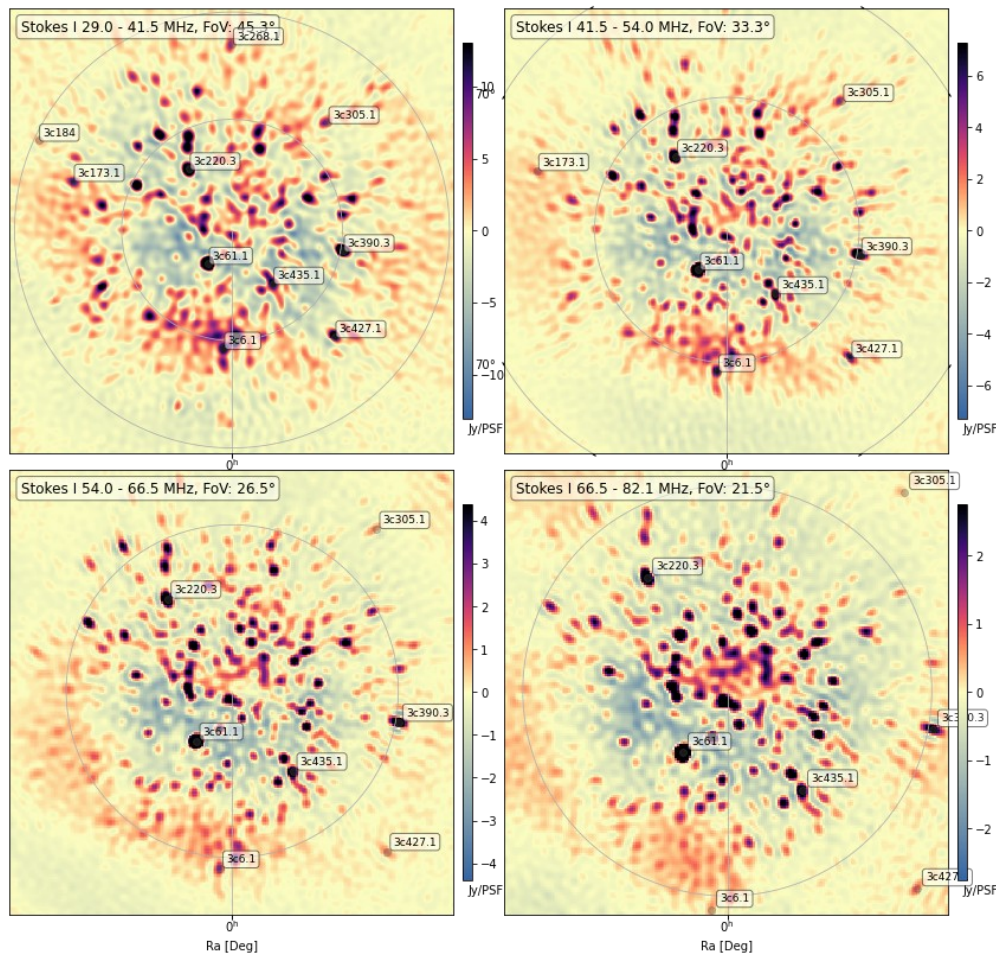- Being automatized
- ~ 30h for 8h obs on 4 copper nodes
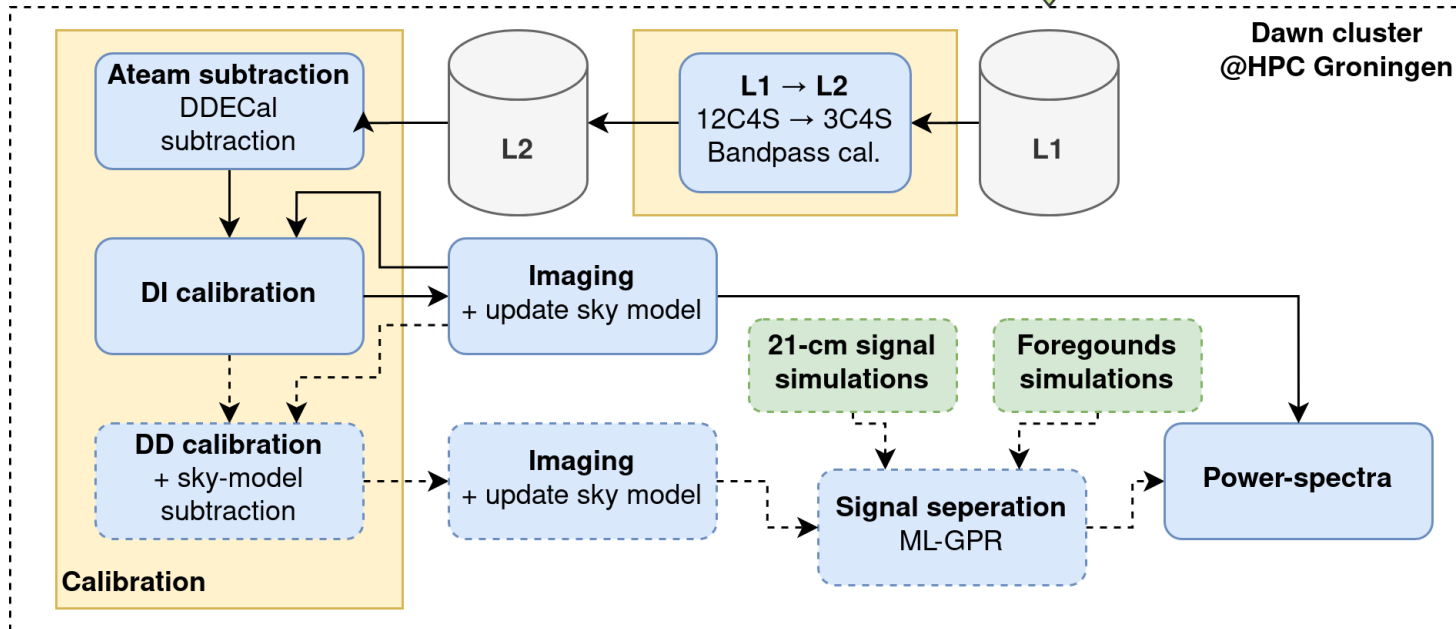
Calibration pipeline
- Calibration tools public: https://gitlab.com/flomertens/nenucal-cd
- Catalog sky model is being replaced now that we have 3 remote stations.
- DD-calibration possible when we have 4 remote stations
- ML-GPR is being developed for LOFAR-EoR.
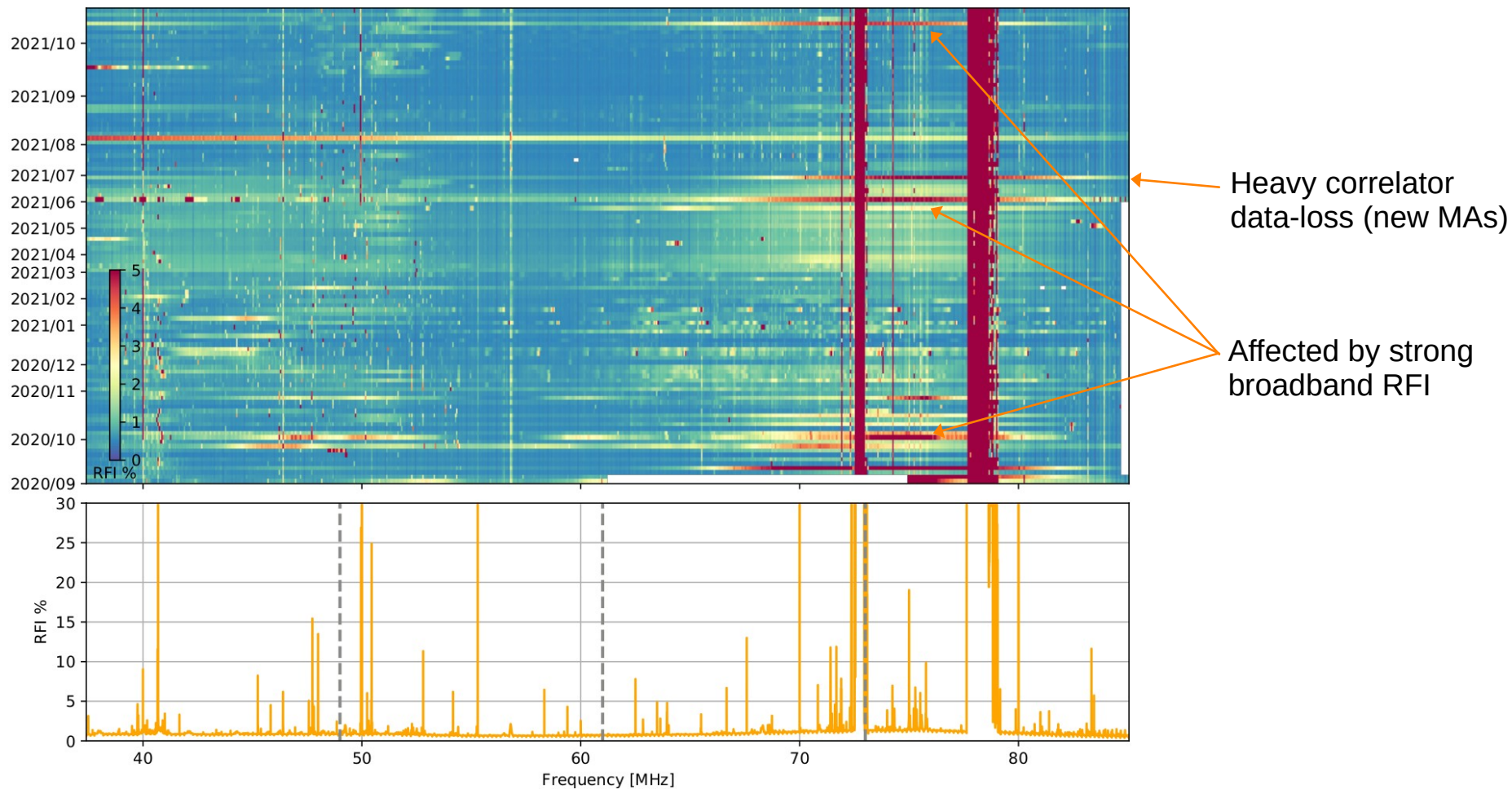
Phase 1 results: diffuse emission
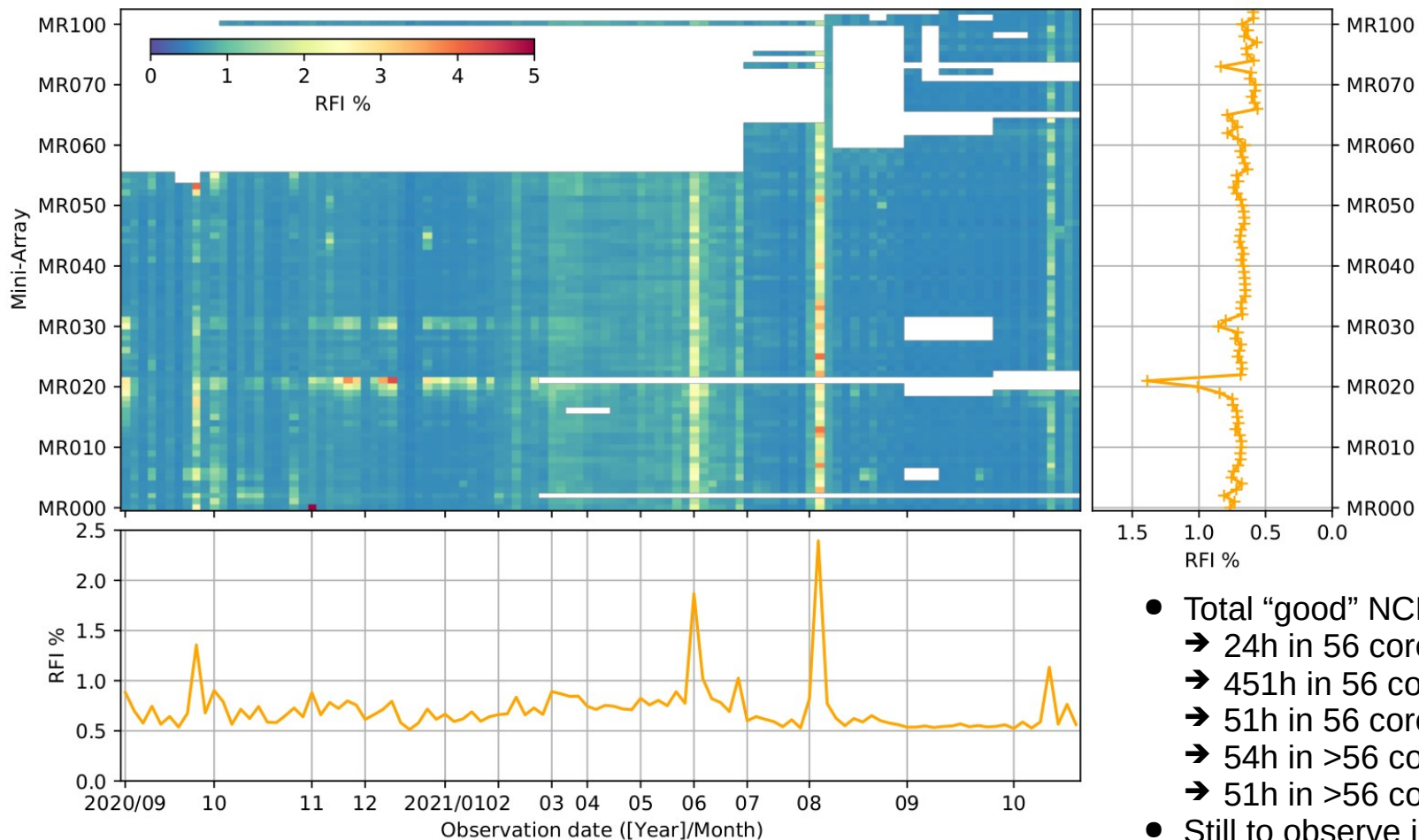
North Celestial Pole – NenuFAR

Angular Power-spectra

Intensity polarized emission

Corresponding Faraday depth

Master thesis Krog + V. Jelic

+ results on the impact of RFIs and ionospheric disturbance to be published in Mertens et al. (in prep)
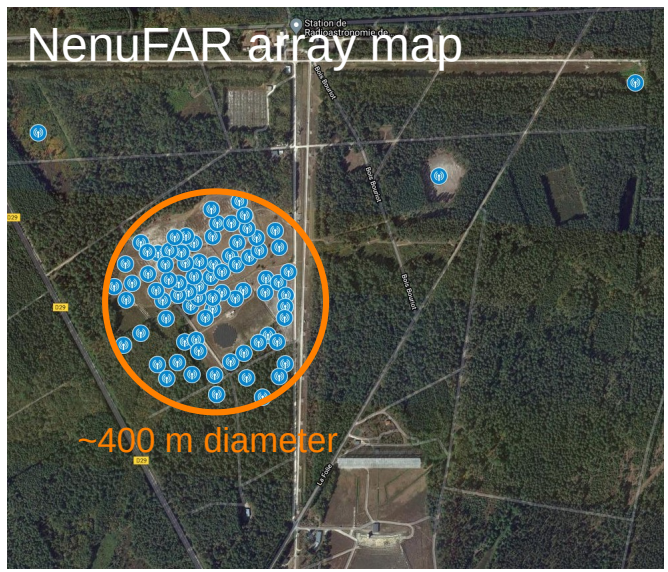
Phase 2: data quality check
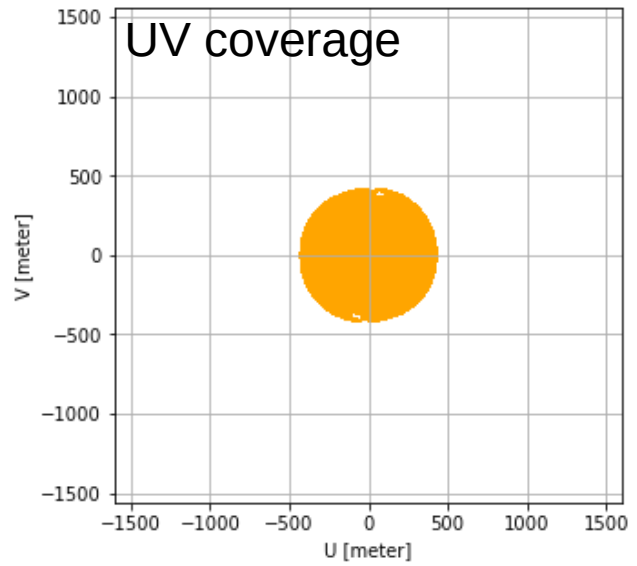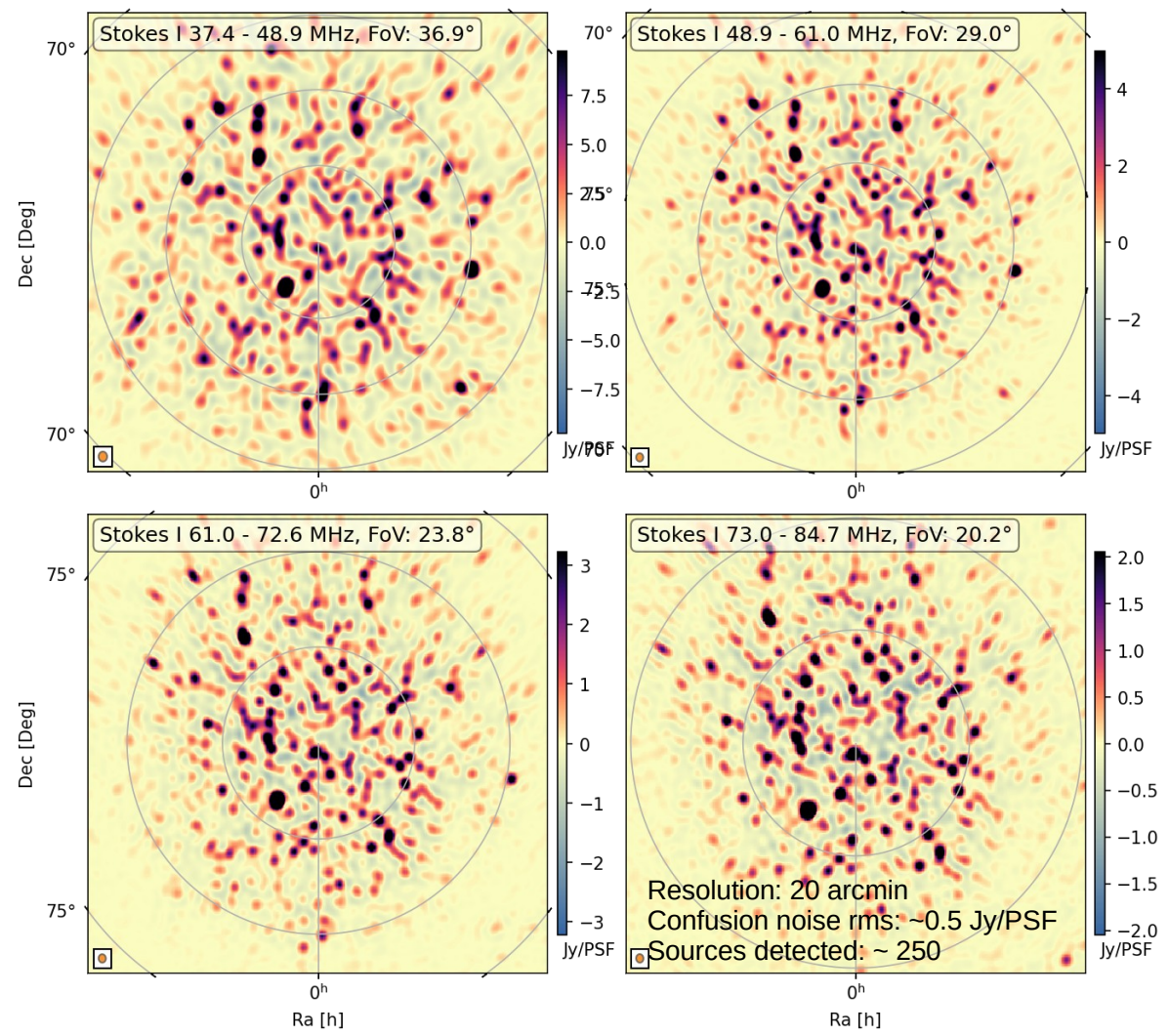
Phase 2: data quality check

- Total "good" NCP data: 630 hours
  - ➜ 24h in 56 core MAs config
  - ➜ 451h in 56 core + 1 remote
  - ➜ 51h in 56 core + 1 remote
  - ➜ 54h in >56 core + 2 remotes
  - ➜ 51h in >56 core + 3 remotes
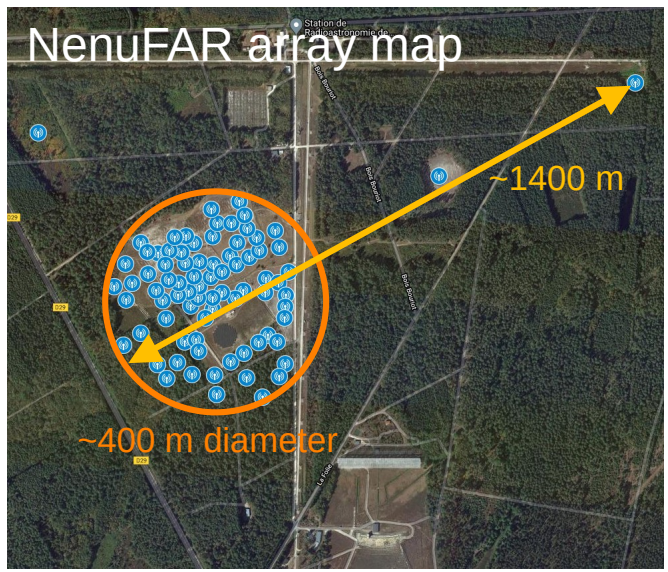- Still to observe in S4: 45 hours

NenuFAR array map

~400 m diameter

UV coverage

Phase 2: new remote stations - **Before**

Stokes I 37.4 - 48.9 MHz, FoV: 36.9°

Stokes I 48.9 - 61.0 MHz, FoV: 29.0°

Stokes I 61.0 - 72.6 MHz, FoV: 23.8°

Stokes I 73.0 - 84.7 MHz, FoV: 20.2°

Resolution: 20 arcmin
Confusion noise rms: ~0.5 Jy/PSF
Sources detected: ~ 250

NenuFAR array map

~1400 m

~400 m diameter

UV coverage

Phase 2: new remote stations - **After**

Stokes I 37.4 - 48.9 MHz, FoV: 36.9°

Stokes I 48.9 - 61.0 MHz, FoV: 29.0°

Stokes I 61.0 - 72.6 MHz, FoV: 23.8°

Stokes I 73.0 - 84.7 MHz, FoV: 20.2°

Resolution: 10 arcmin
Confusion noise rms: ~0.15 Jy/PSF
Sources detected: ~ 700

Obs: 16/09/2021
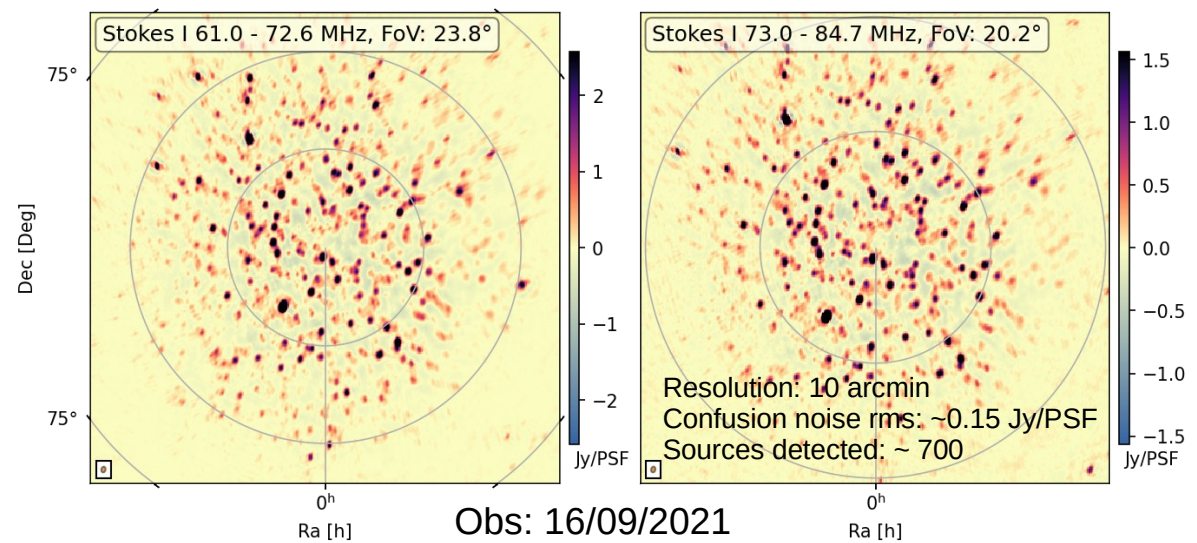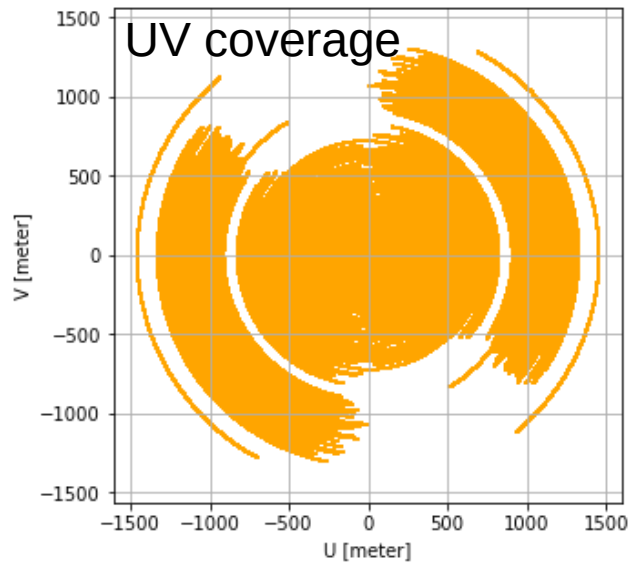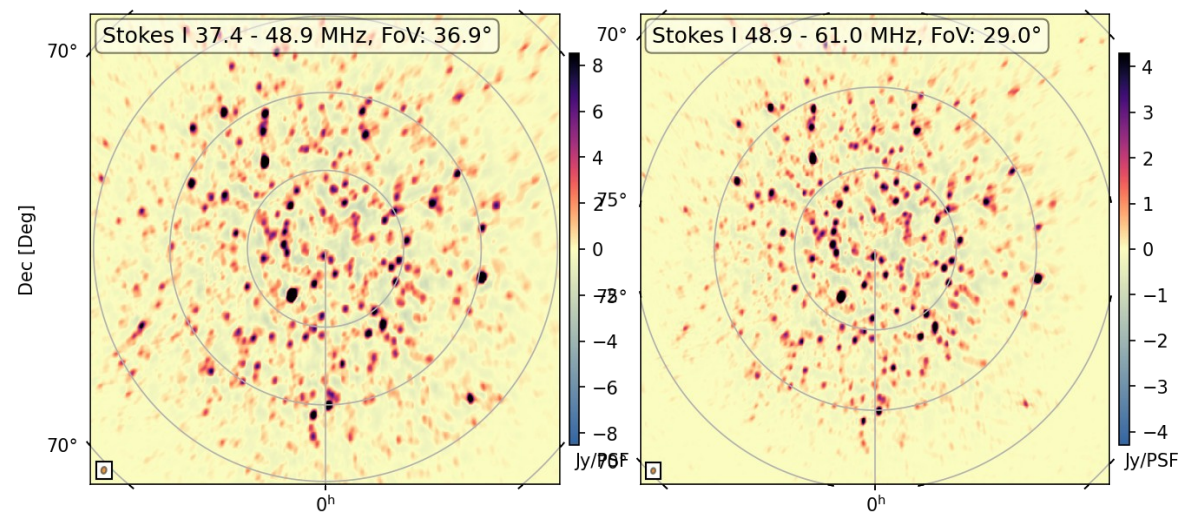
Impact of remote MAs on calibration

Rendered sky-model: catalog vs build using core-only vs core+3 remotes images
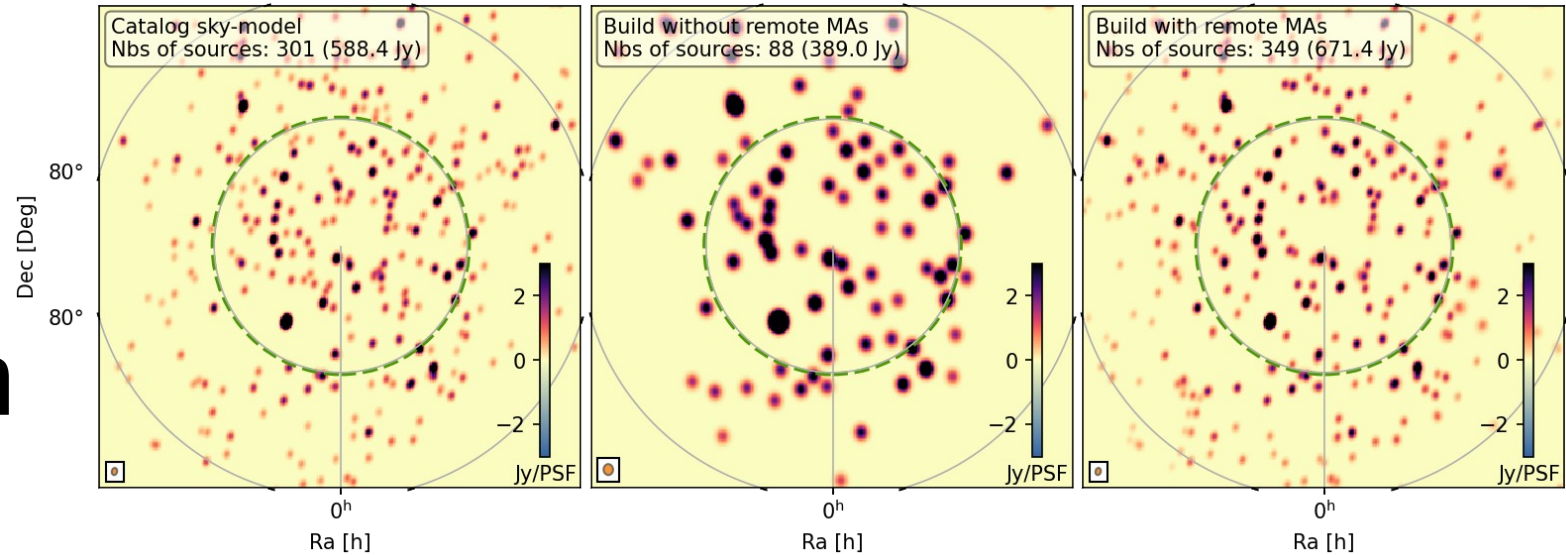
Longer baselines:

➜ higher angular resolution
➜ lower confusion noise.
➜ more detectable sources.
➜ deeper sky-model.
➜ more constraint in calibration both because of the deeper sky model & the extra (long) baselines.
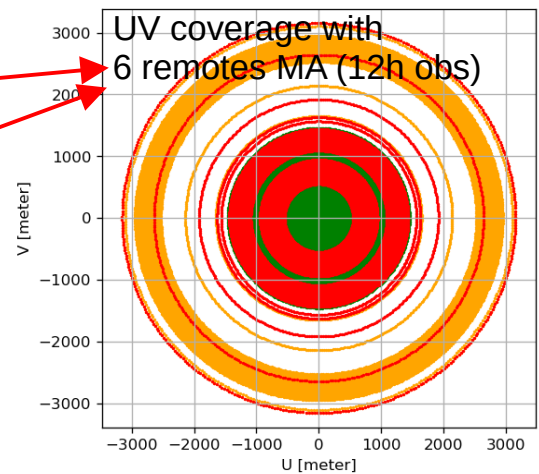➜ Can calibrate in more directions.
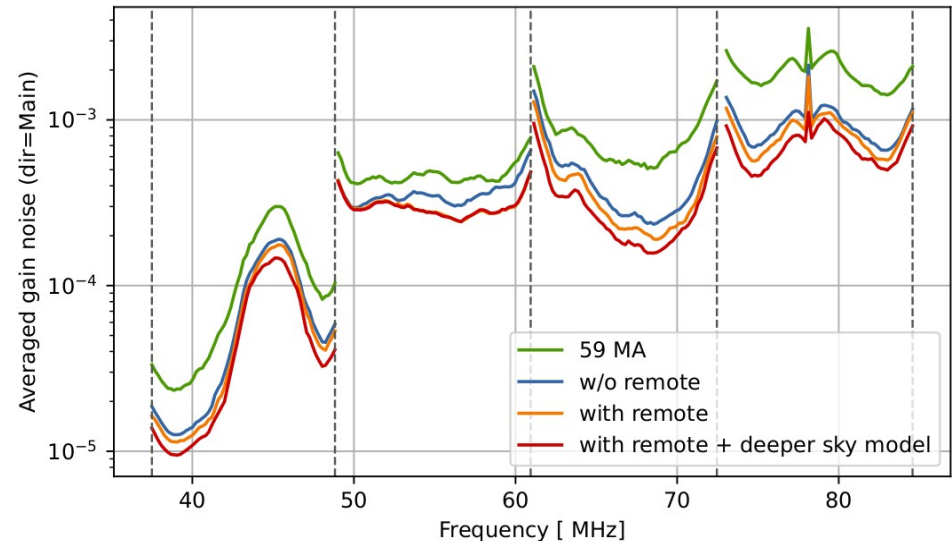
Upcoming remote stations

MR103
(end of 2022)

~3000 m

MR104
(later)

MR105
(later)

UV coverage with
4 remotes MA (12h obs)
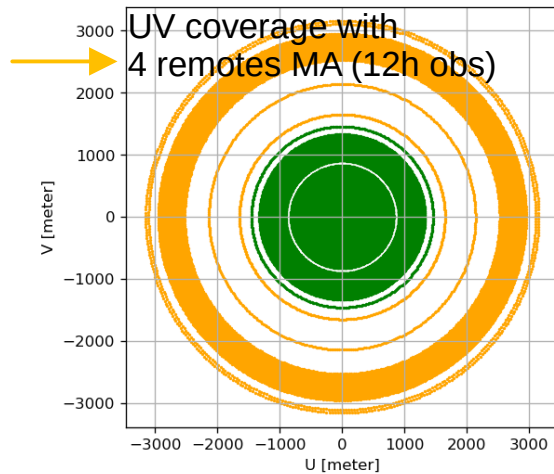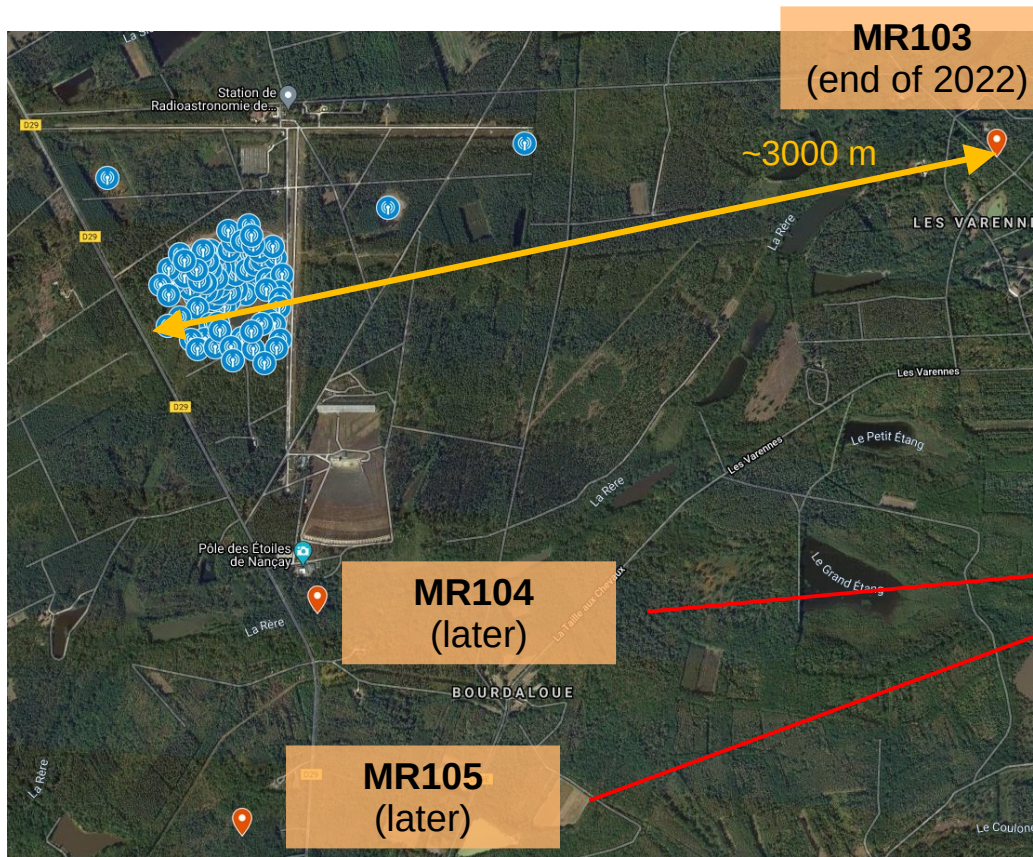
At 80 MHz
Resolution: 4 arcmin
Conf. Noise ~ 40mJy/PSF

At 60 MHz
Resolution: 5.4 arcmin
Conf. Noise ~ 85mJy/PSF

UV coverage with
6 remotes MA (12h obs)

No major improvement in
baseline length

Better uv-coverage
especially for shorter
observation (or lower dec).

Done, current and next steps

Phase 1:

- **Done:**
  - Total intensity and polarized dffuse emission analysis of the NCP field.
  - Ionospheric analysis.
  - RFI analysis (near-field imaging).

Phase 2:

- **Done:**
  - Pre-processing & calibration pipeline.
  - First images with 1-3 remote stations.

- **Ongoing:**
  - Deeper NCP sky model (with Satyapan).
  - Check systematics in power-spectra and data selection criteria.
  - Polarized emission analysis of NCP, 3C196 and ELAIS-N1 fields (with V.Jelic).

- **Next:**
  - DD-calibration (with Satyapan).
  - Have the the primary beam in DPPP !!
  - Adapt ML-GPR for NenuFAR data.
  - Investigate other calibration technique.