

The project NenuFAR*

* New Extension in Nançay Upgrading LOFAR

**P. Zarka¹, M. Tagger², L. Denis³, J. Girard^{1,4},
& the NenuFAR-France team⁵**

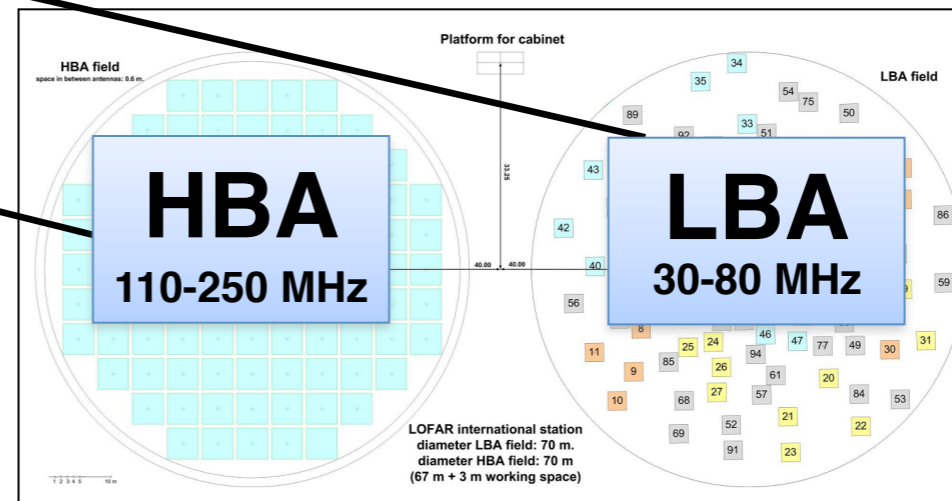
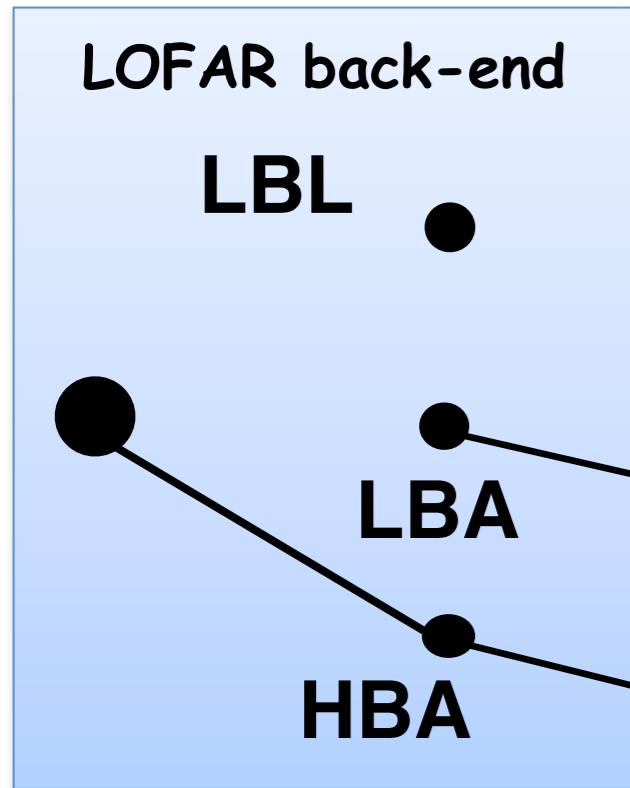
¹LESIA-OP, ²LPC2E-Orléans, ³USN-OP, ⁴CEA-Saclay,

⁵Everywhere in France especially in Nançay

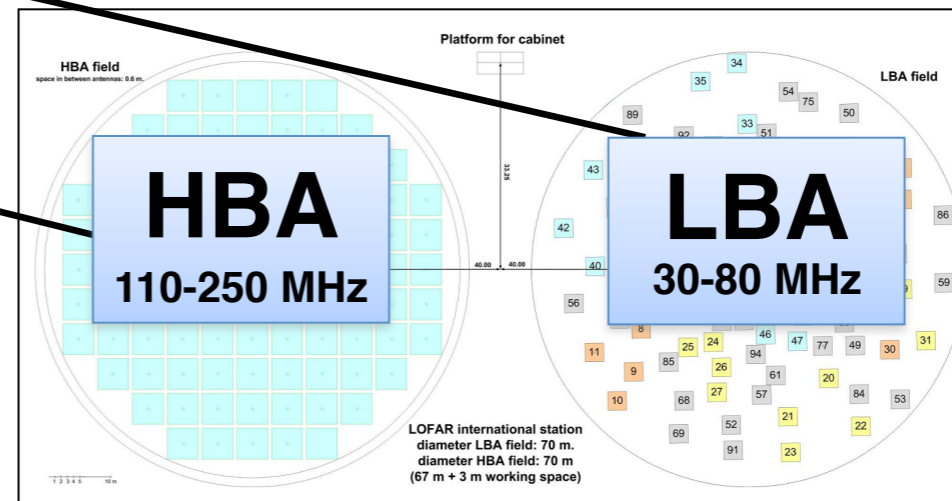
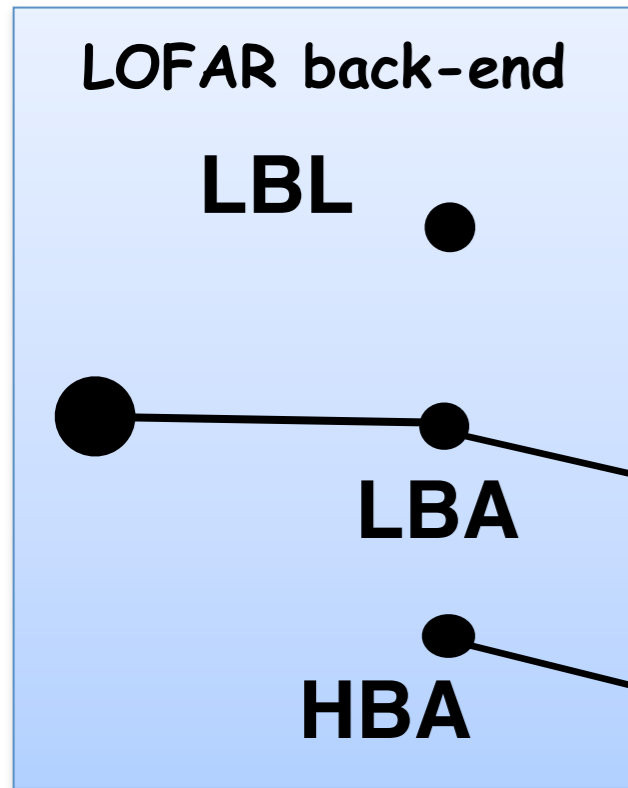
LOFAR station in Nançay : FR606



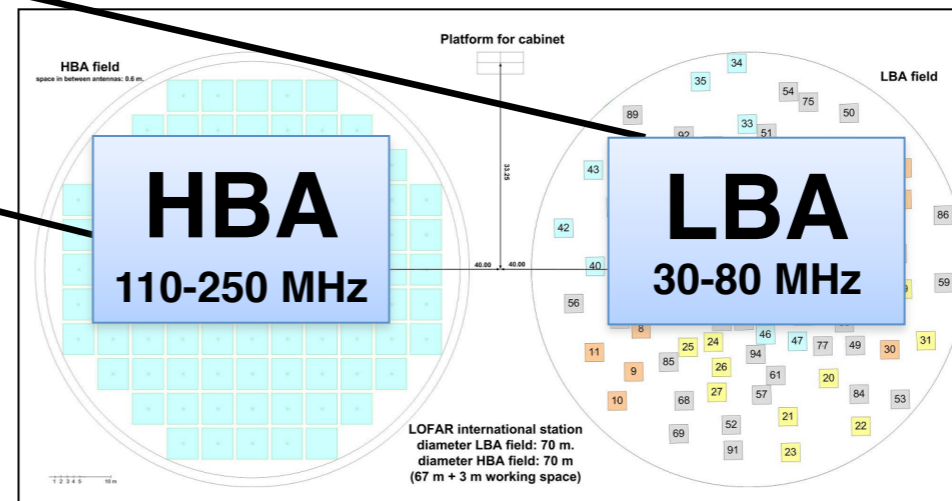
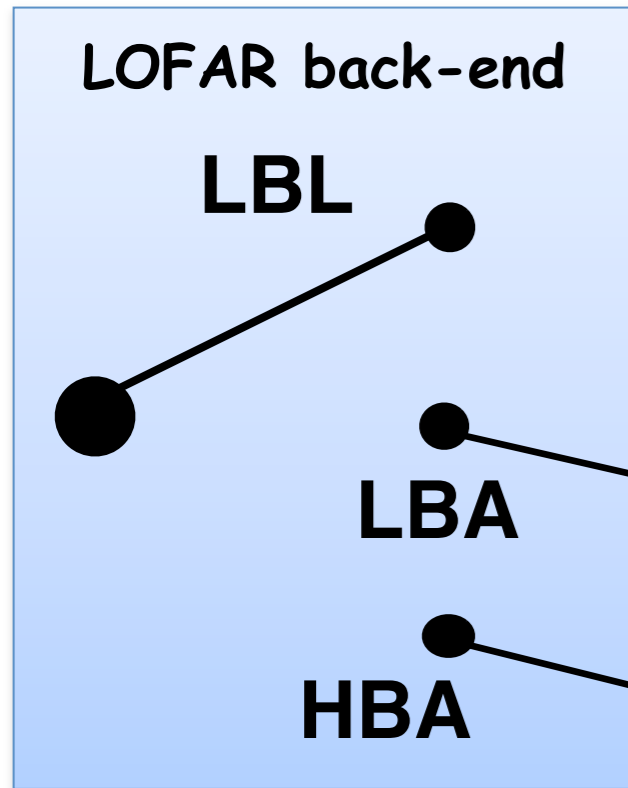
The LOFAR Super Station (LSS) concept : giant local phased array + interferometer



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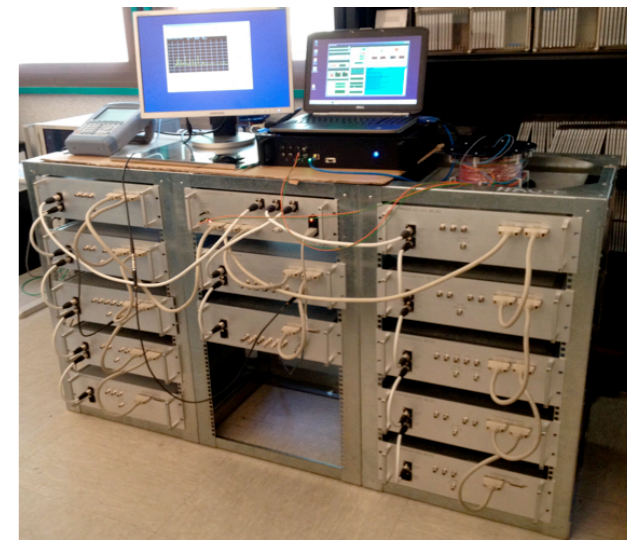
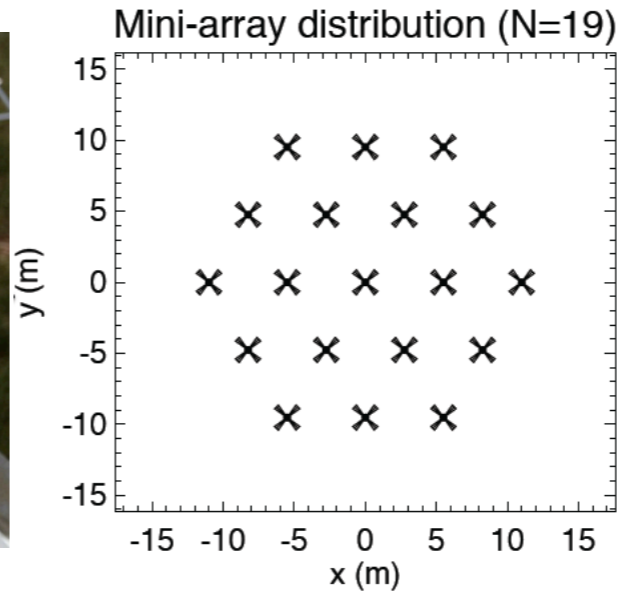
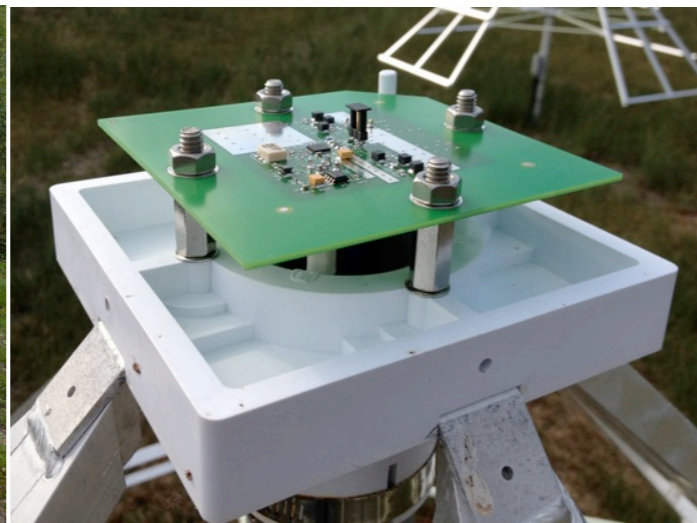


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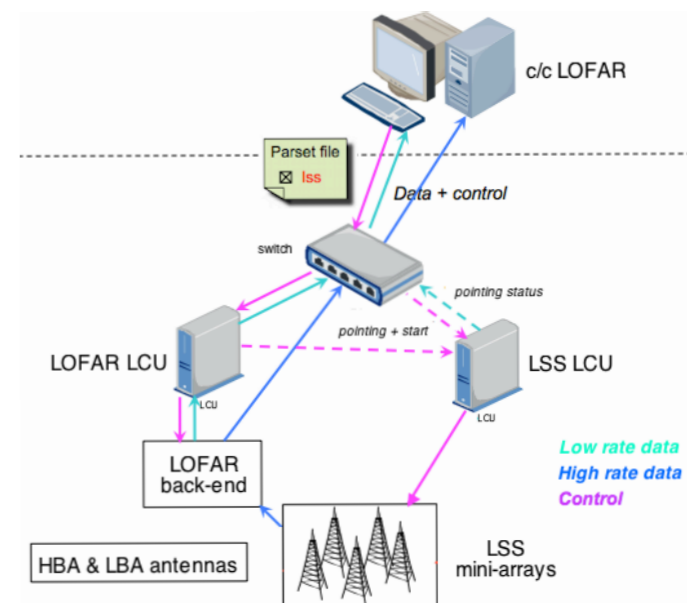
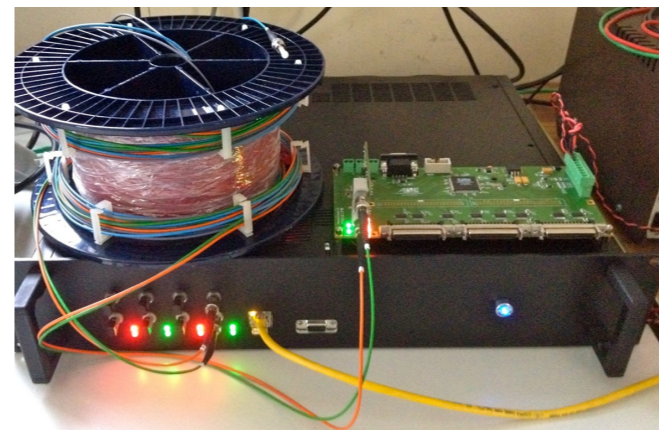
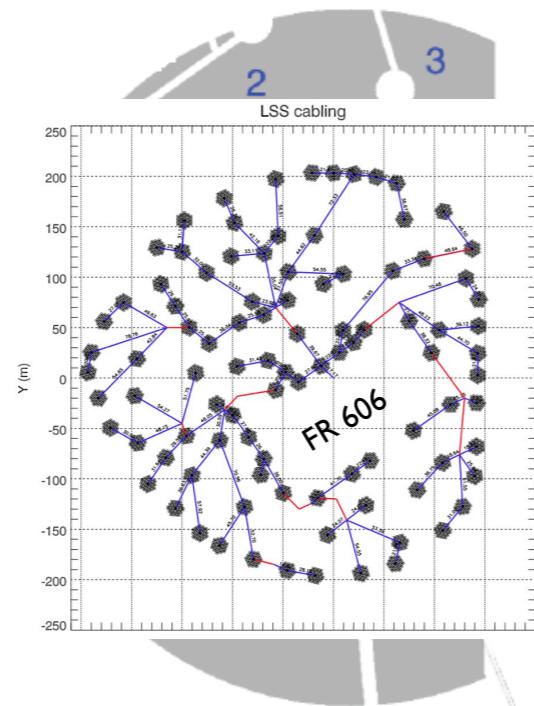
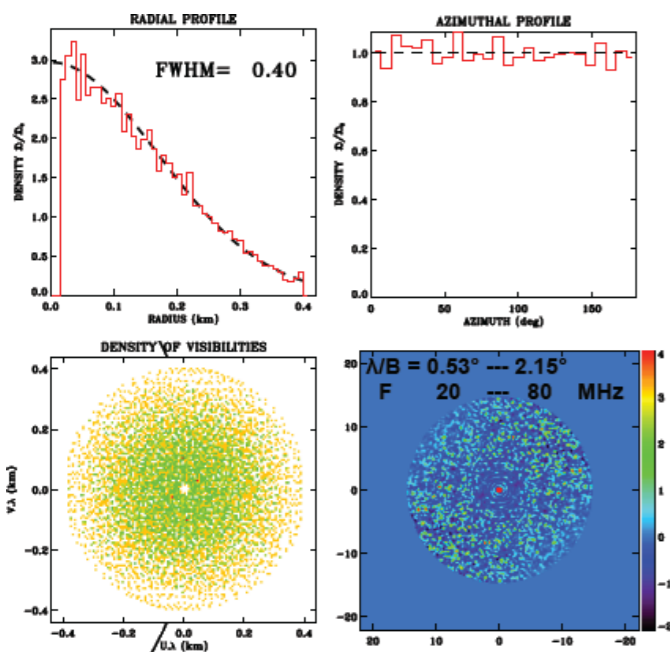


Designing + Prototyping the LSS

ANR program 9/2009 → 2/2013

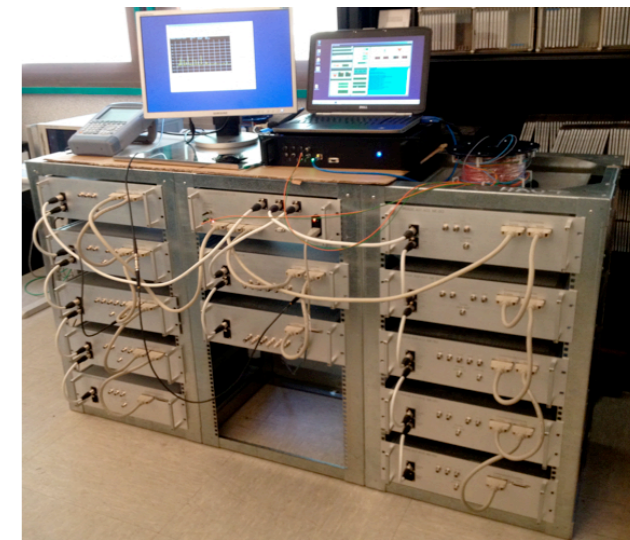
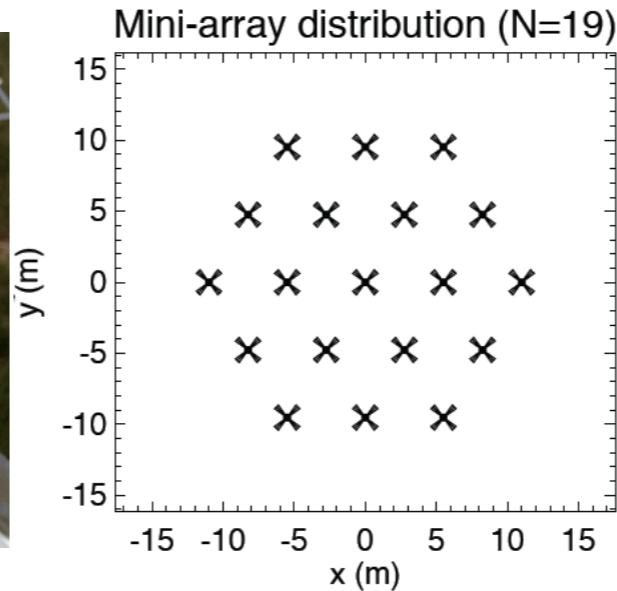
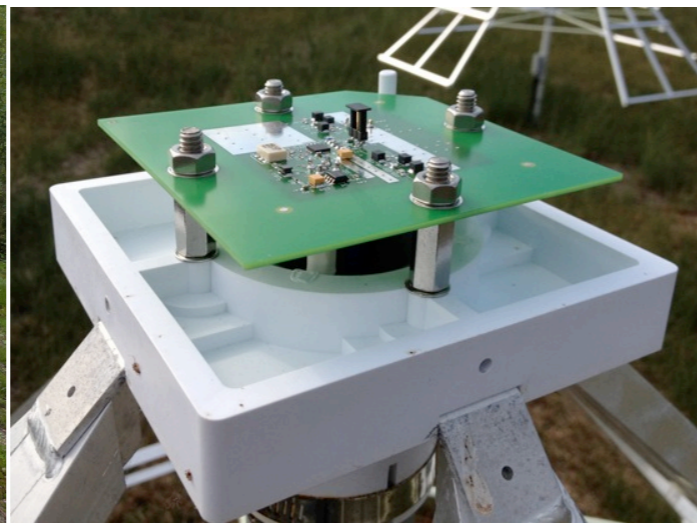


- Study of all aspects of the project : antenna, preamp., distribution mini-arrays & global, phasing, cabling/trenches, silent control/command, dialog with LOFAR

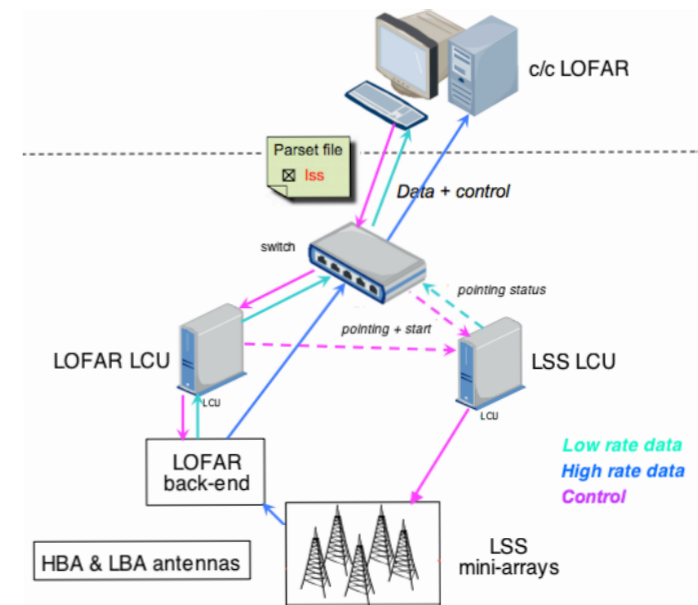
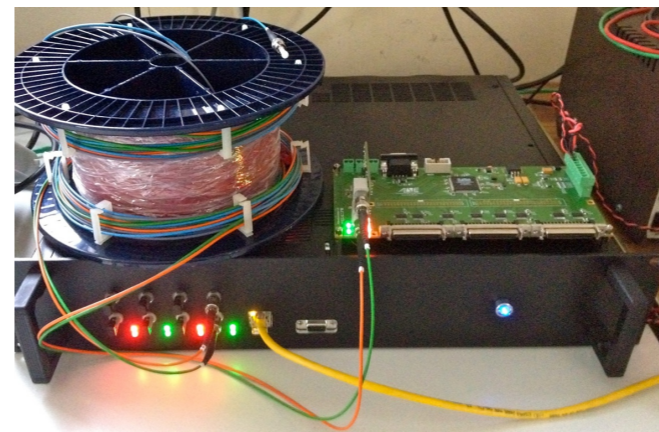
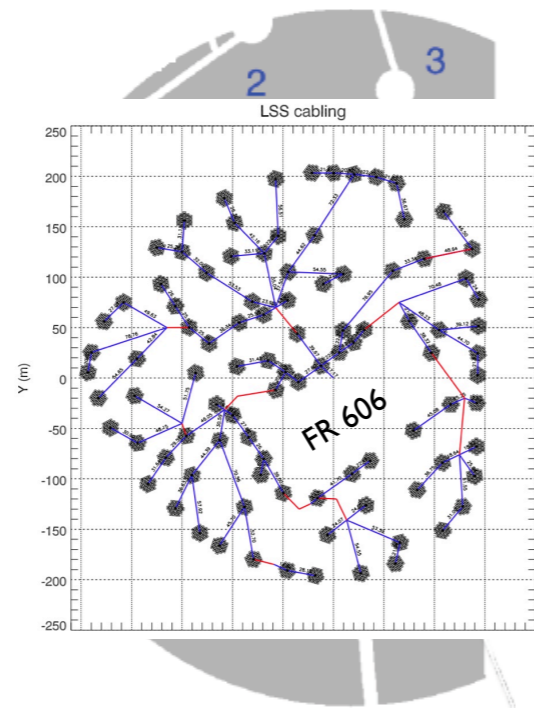
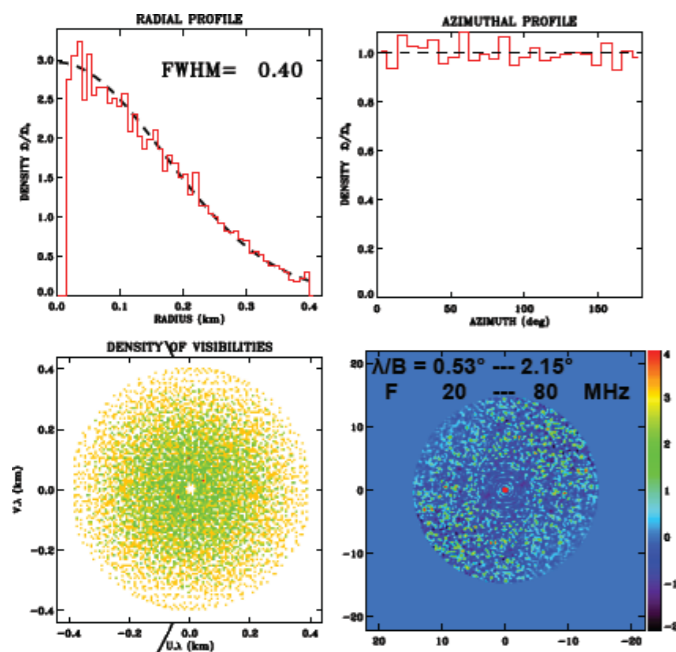


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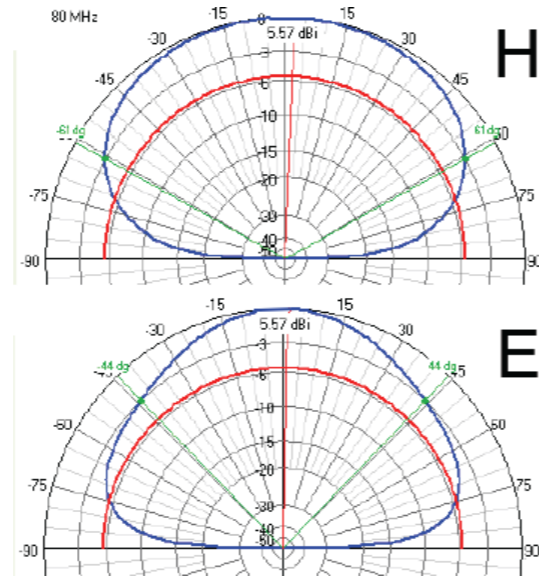
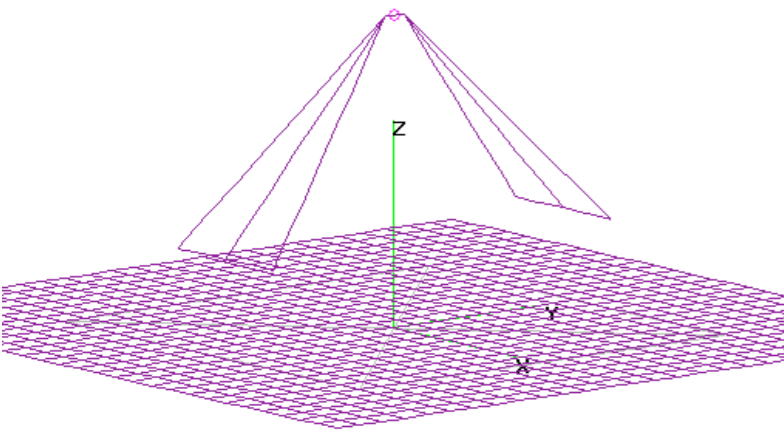
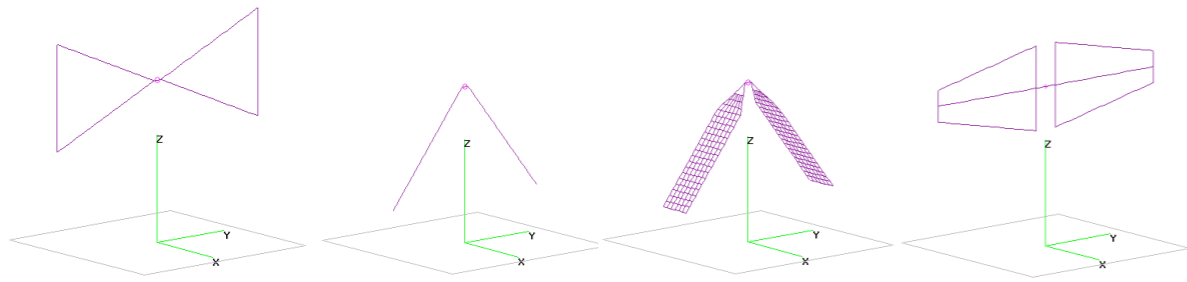


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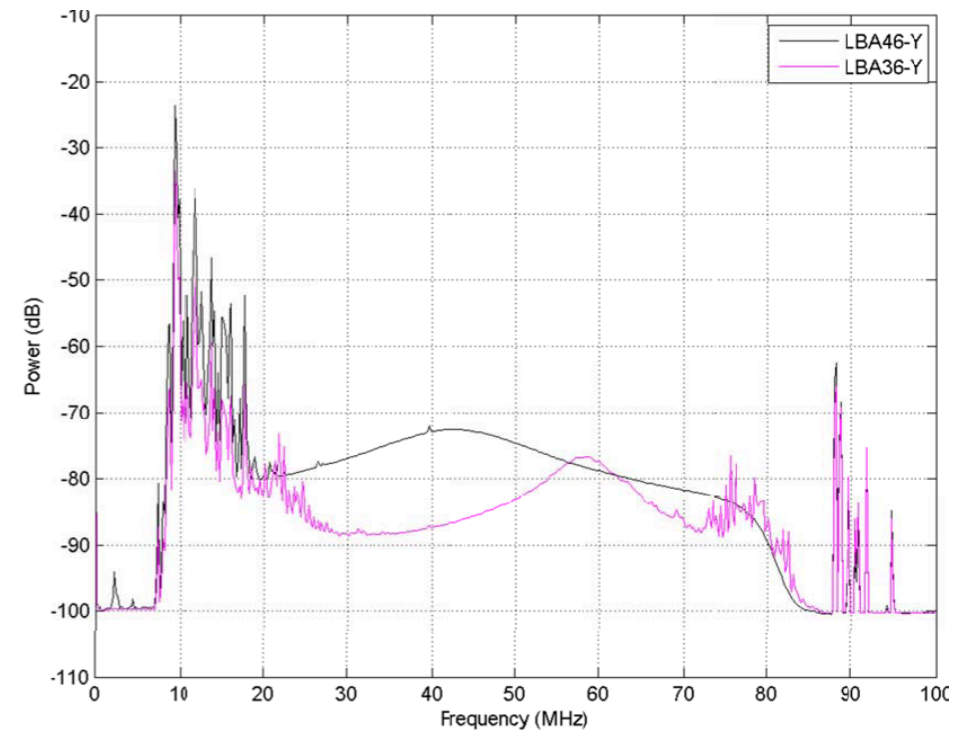
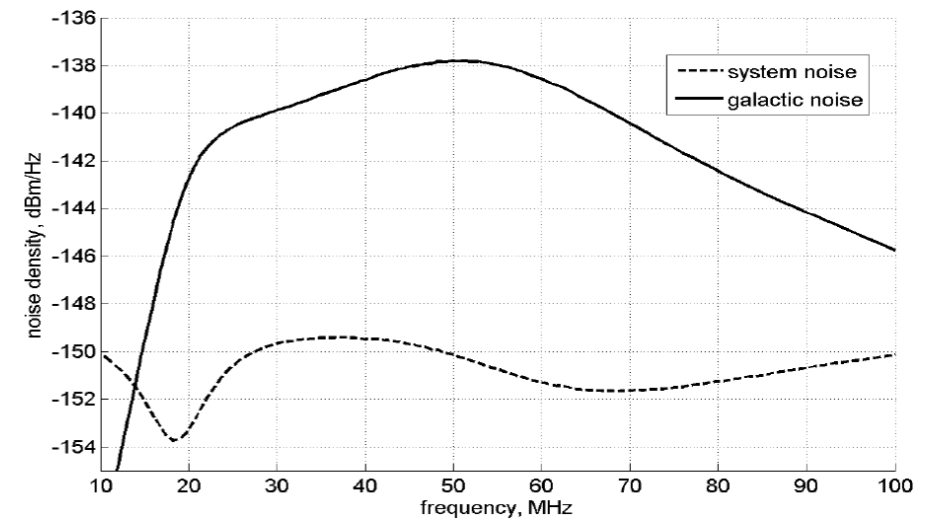
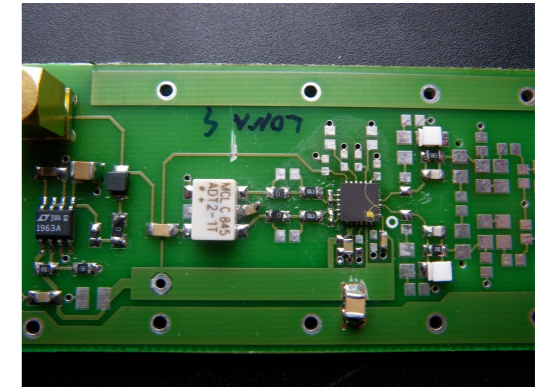
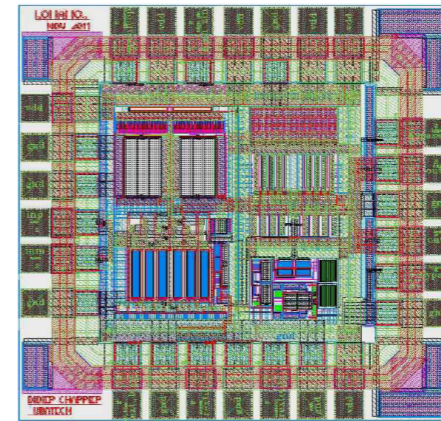
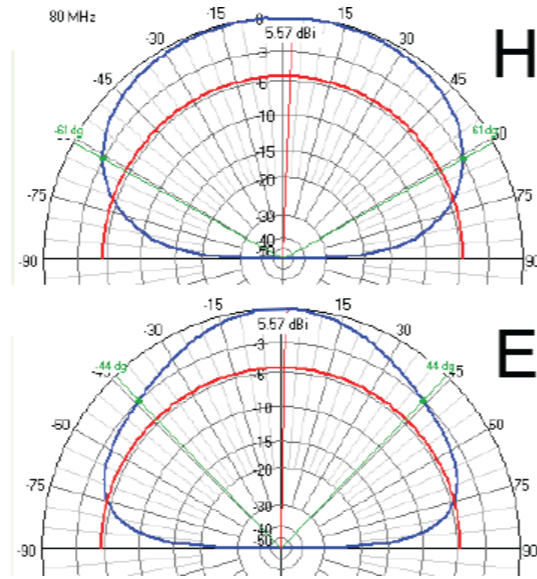
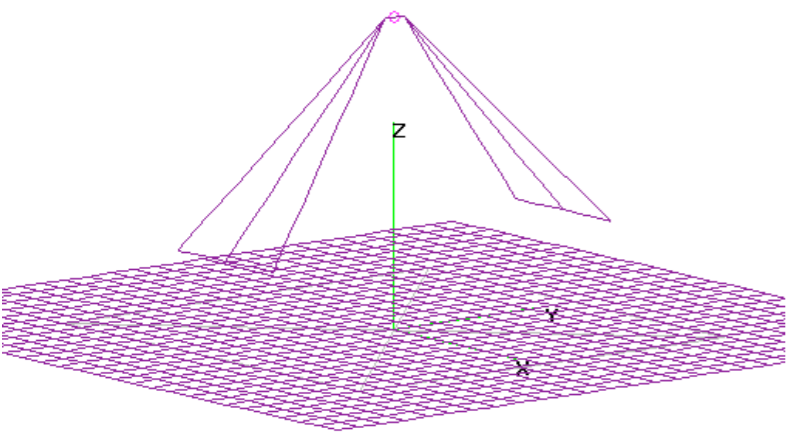
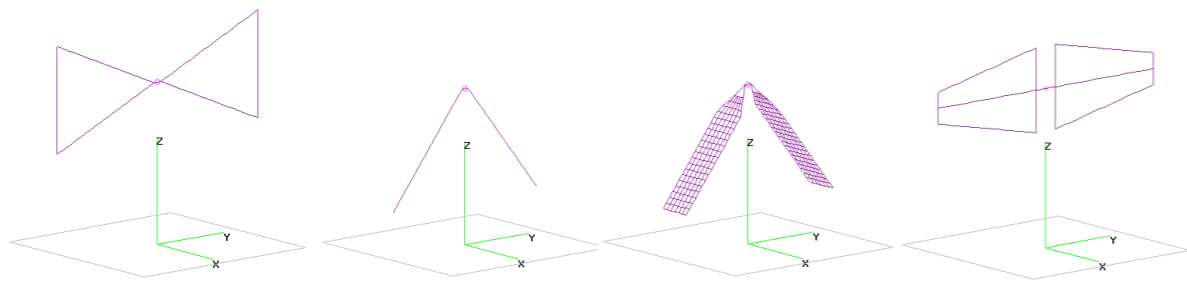


- Industrialization studies, site study (ONF), costing, sub-contracting, schedule

Antenna radiator & preamplifier

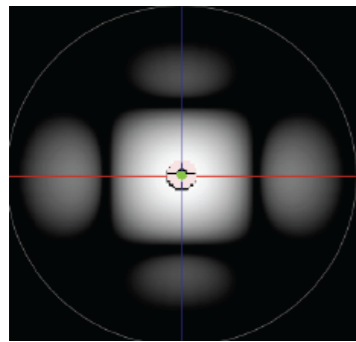
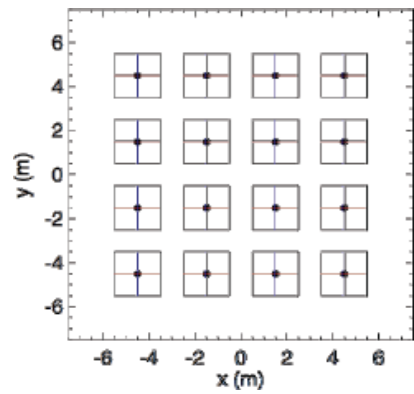


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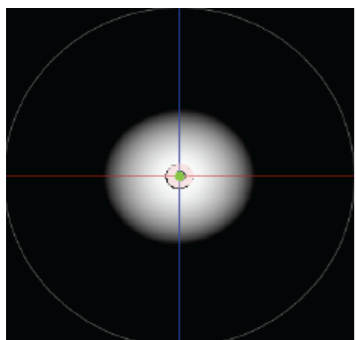
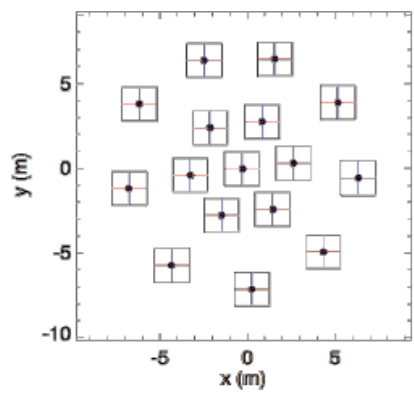


Antenna distribution within Mini-Arrays

40 MHz



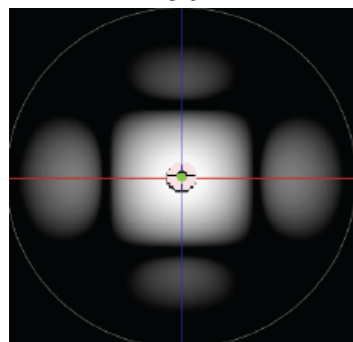
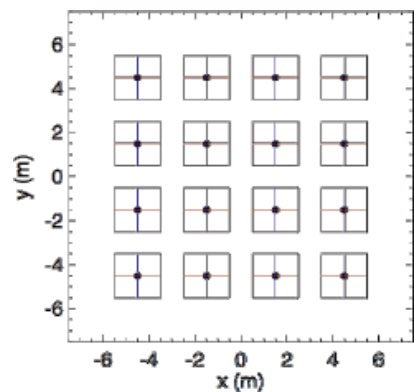
-15 dB sidelobes



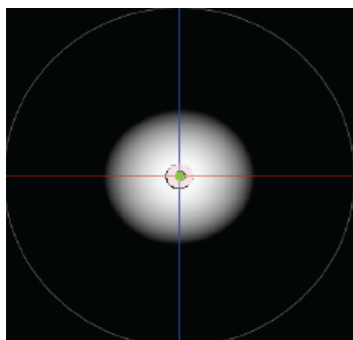
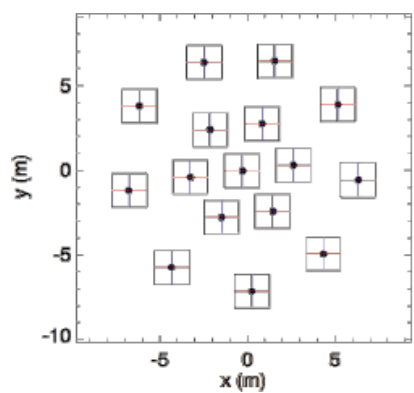
-32 dB sidelobes

Antenna distribution within Mini-Arrays

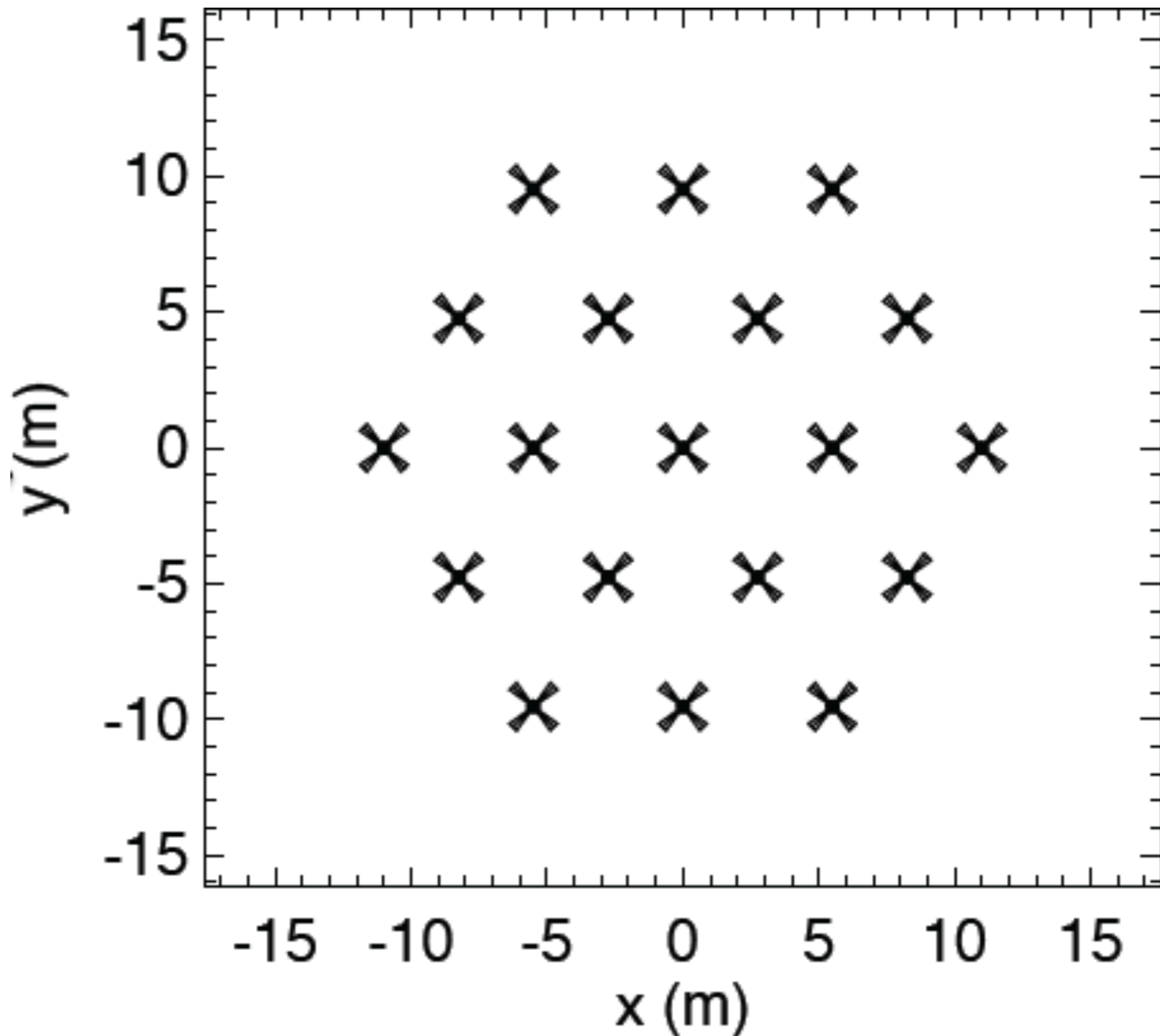
40 MHz



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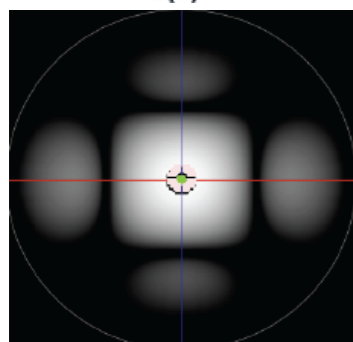
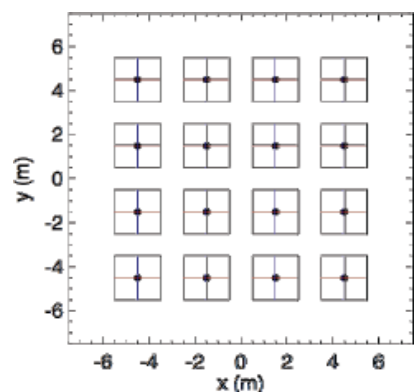


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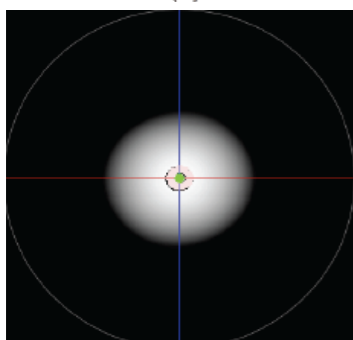
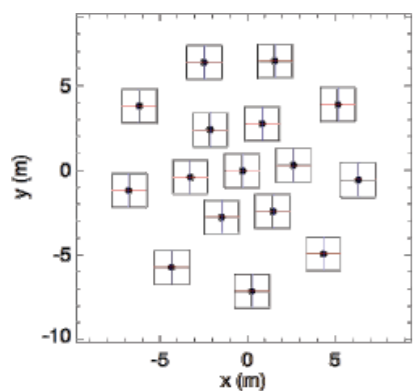


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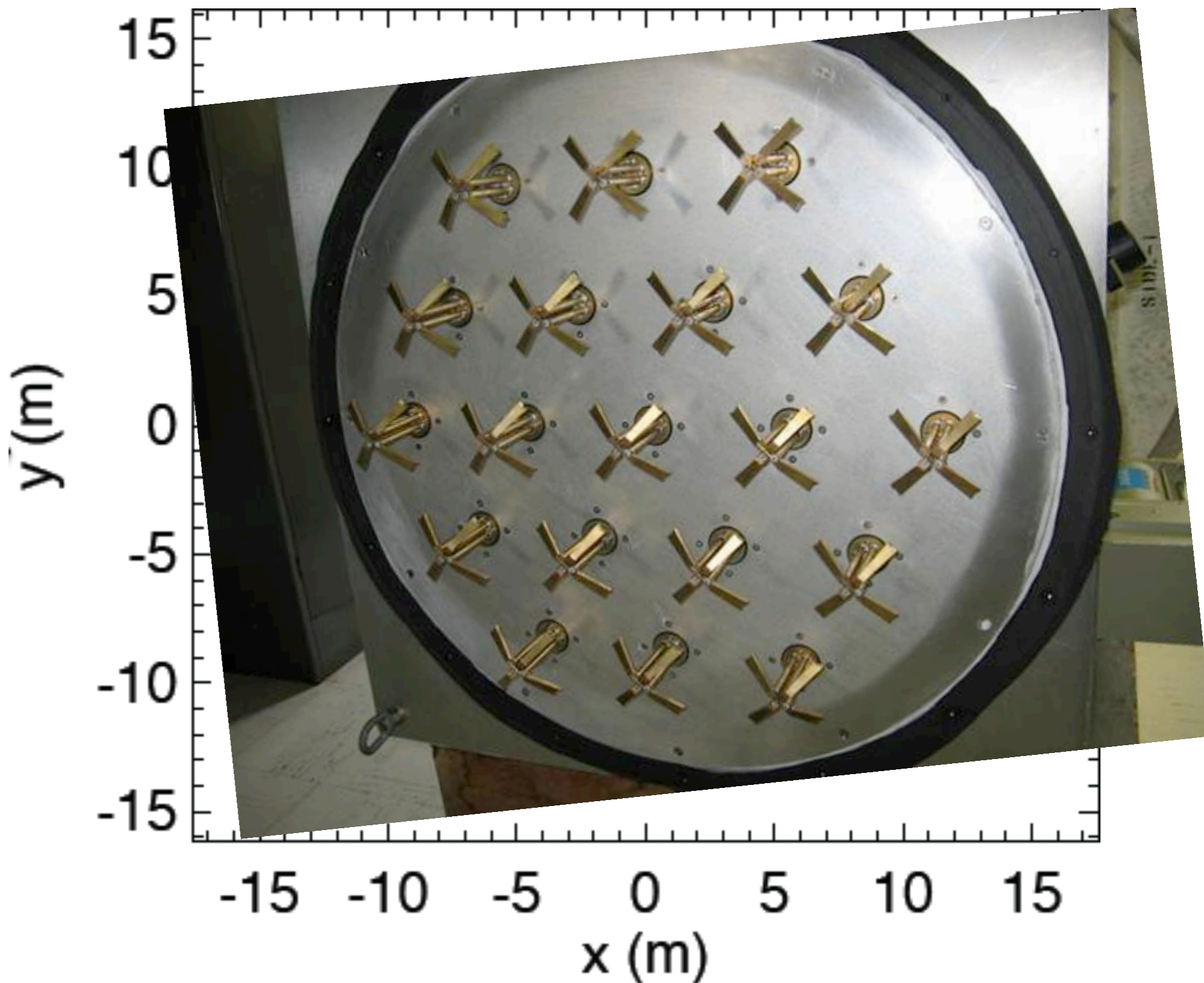
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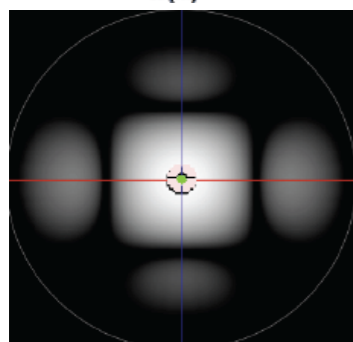
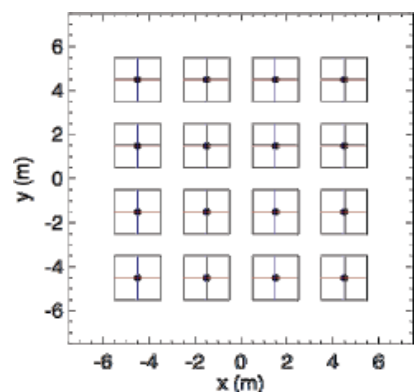


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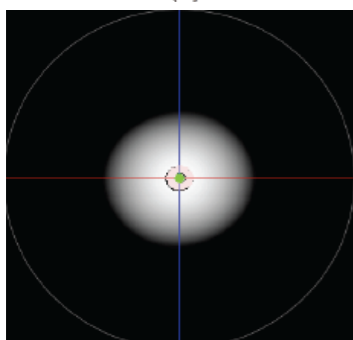
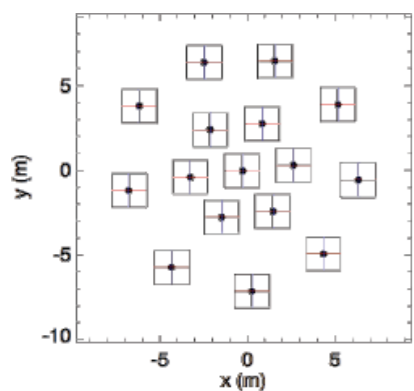


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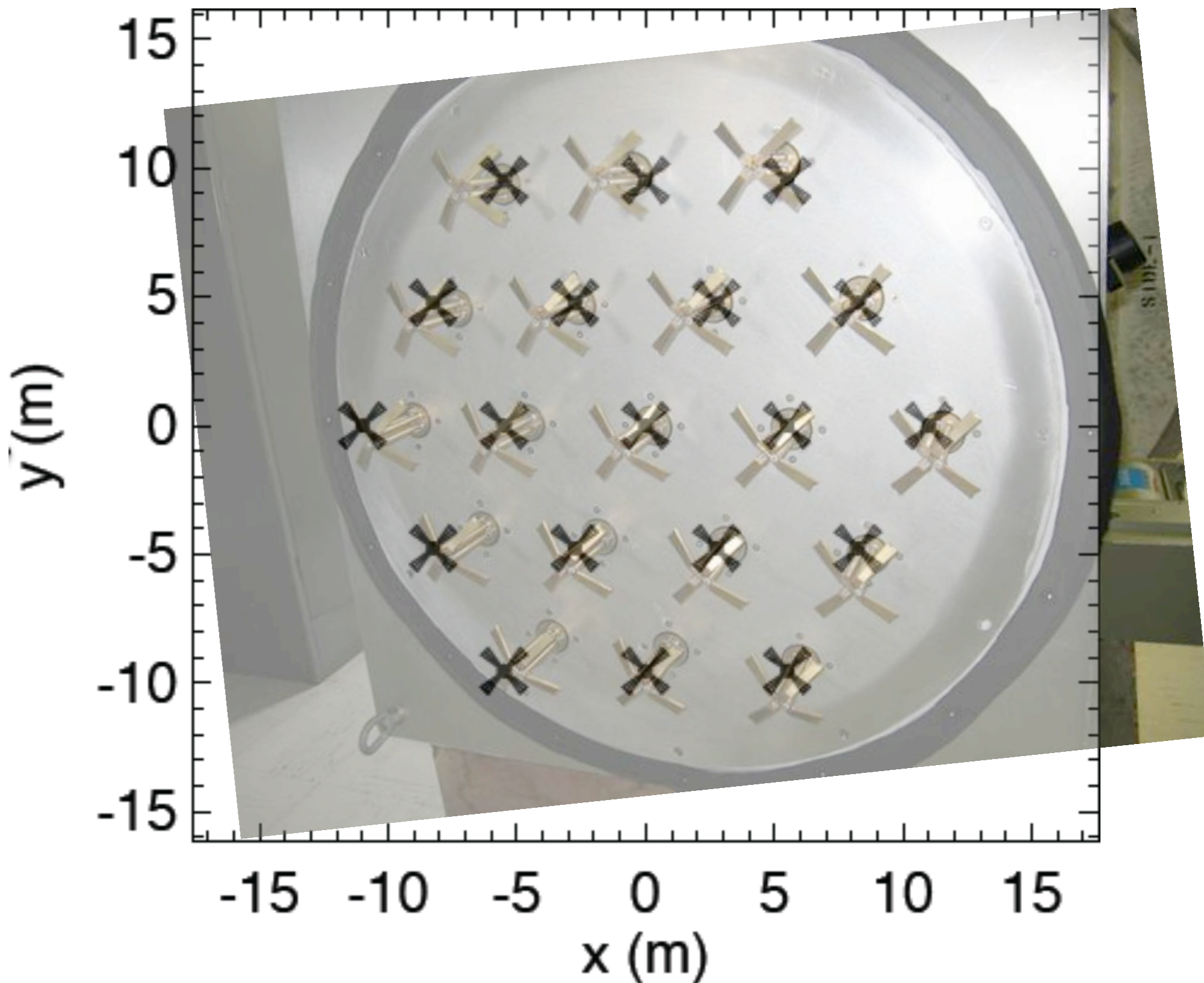
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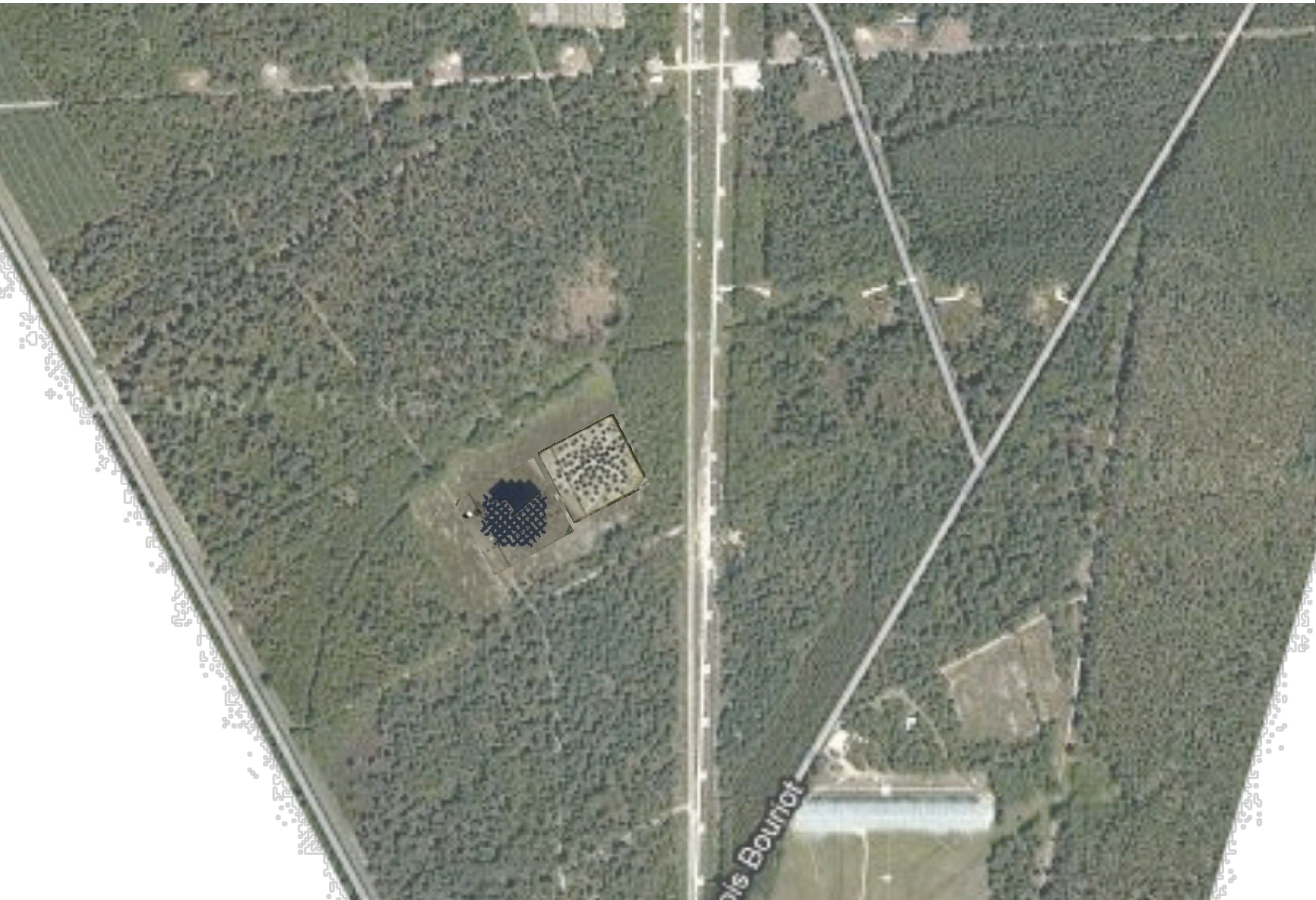
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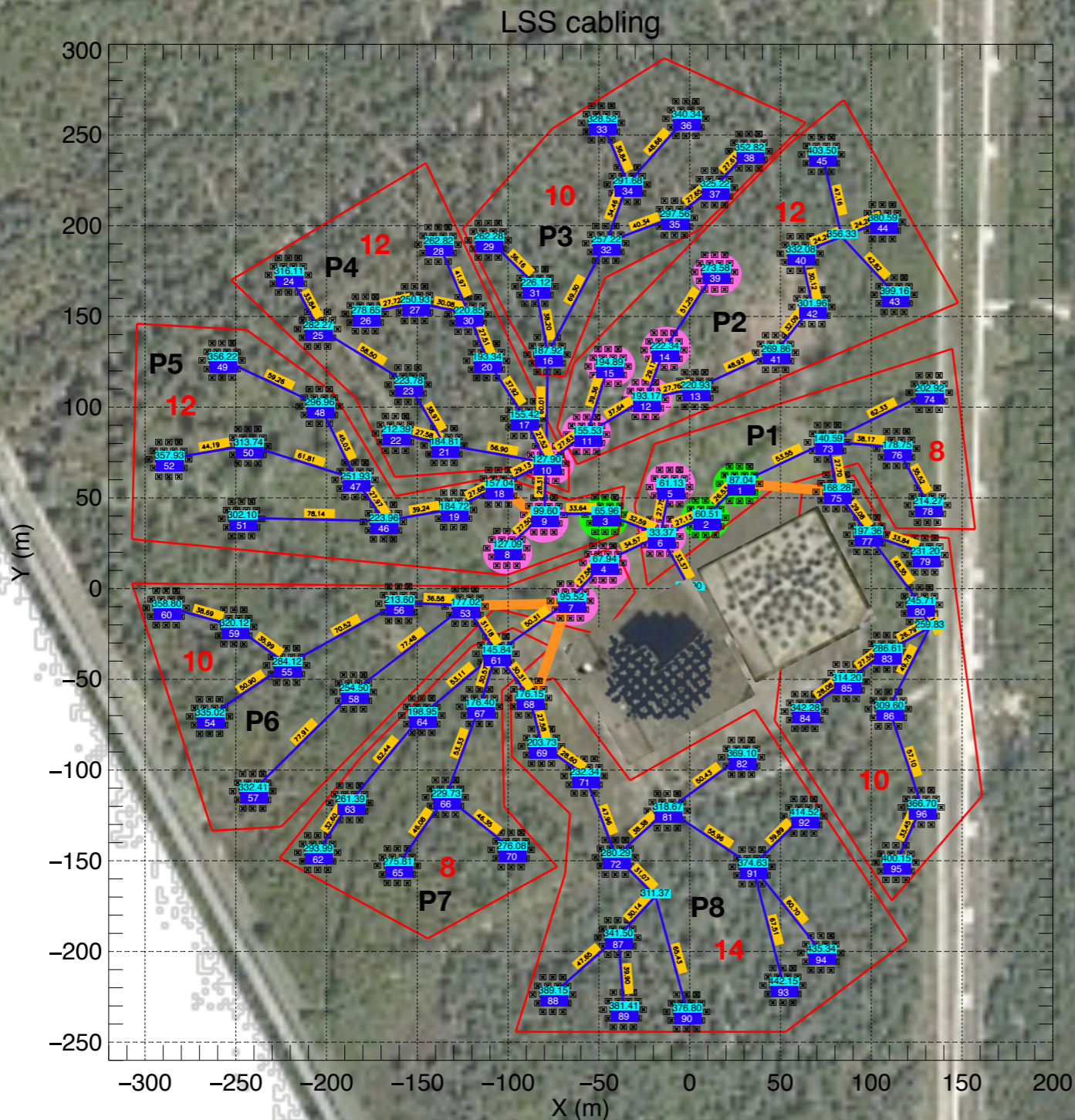


Mini-Array distribution within LSS (& cabling)



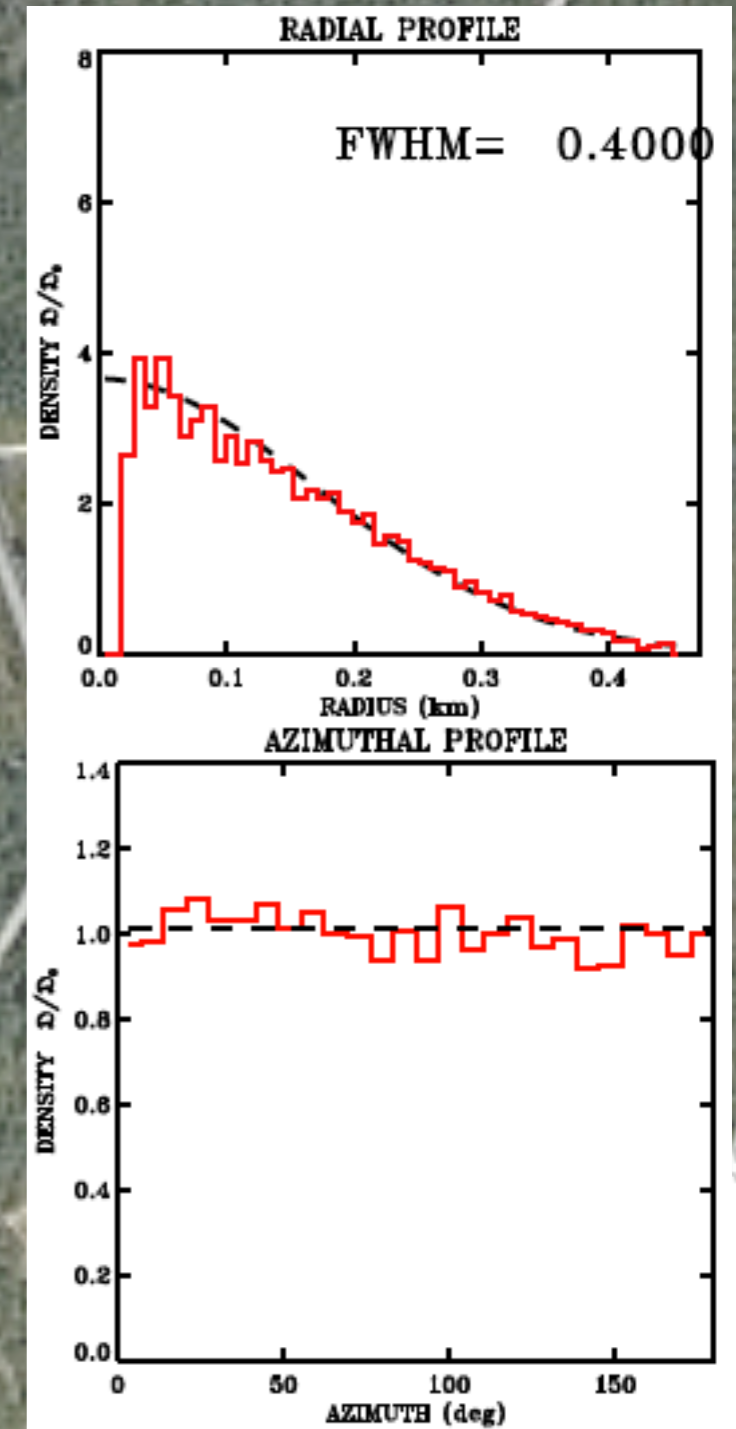
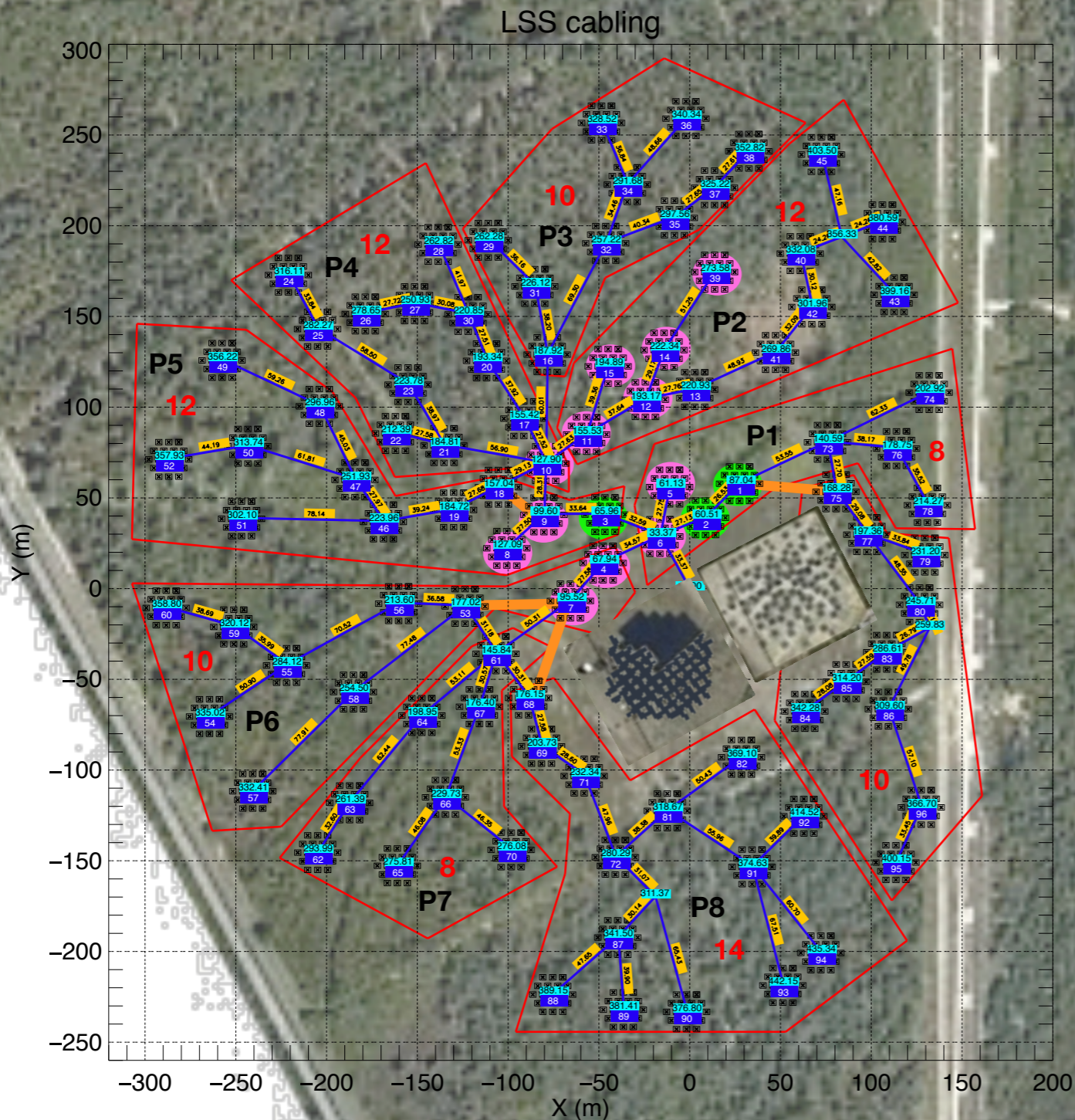
Mini-Array distribution within LSS (& cabling)

REFERENCE: E X_L93=639085,5940443 m Y_L93=6697605,2239016 m

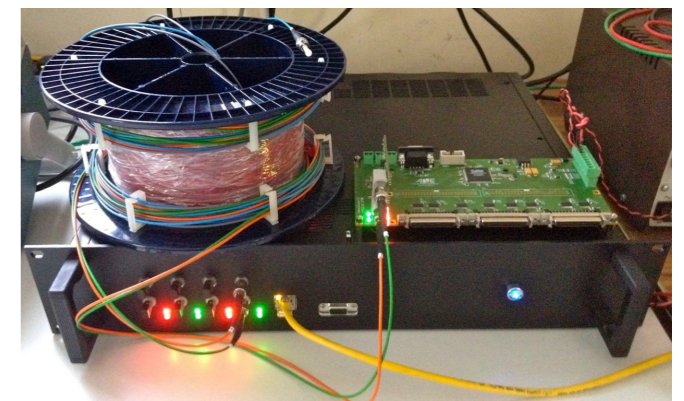
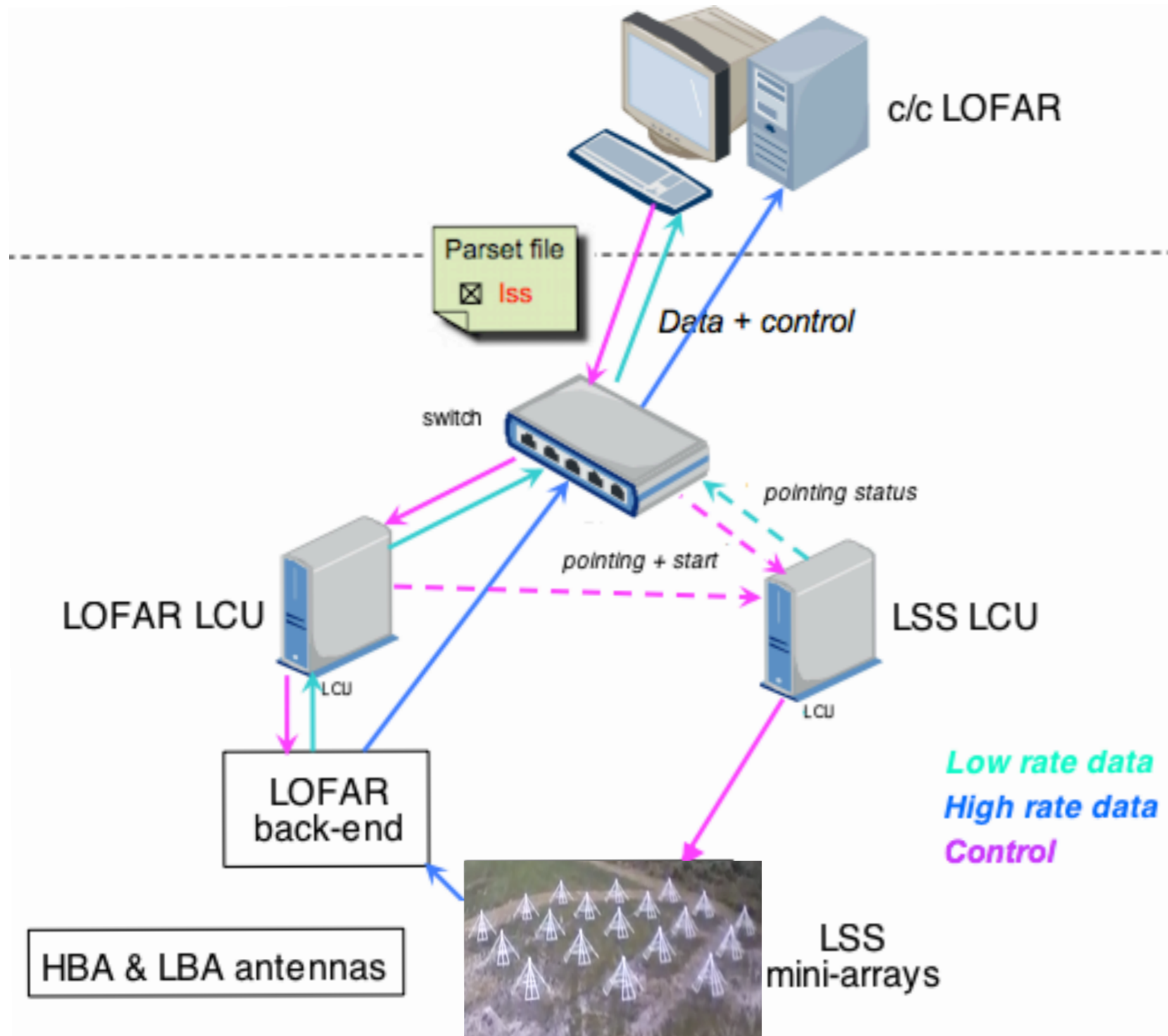


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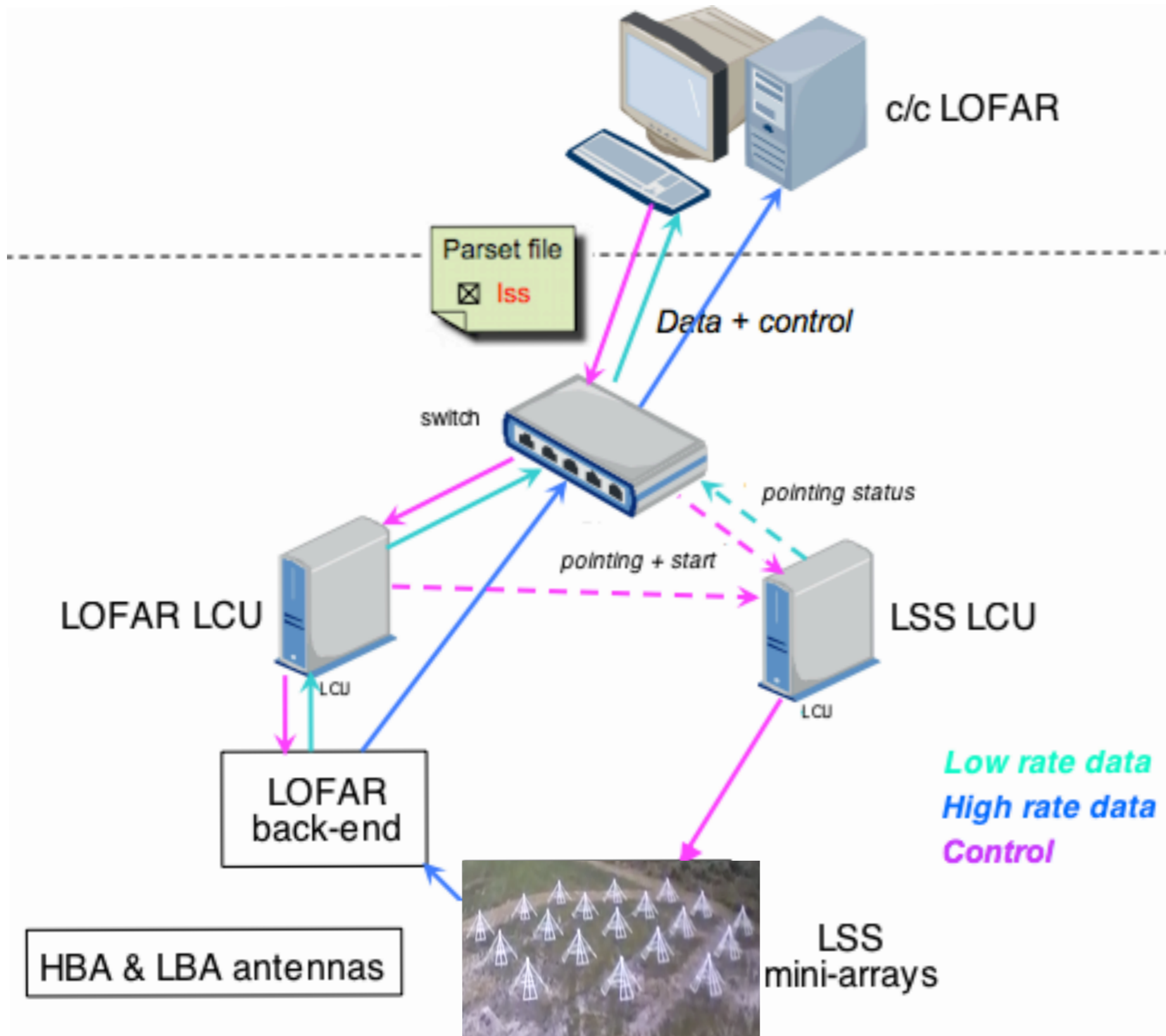


Control/command system & protocol

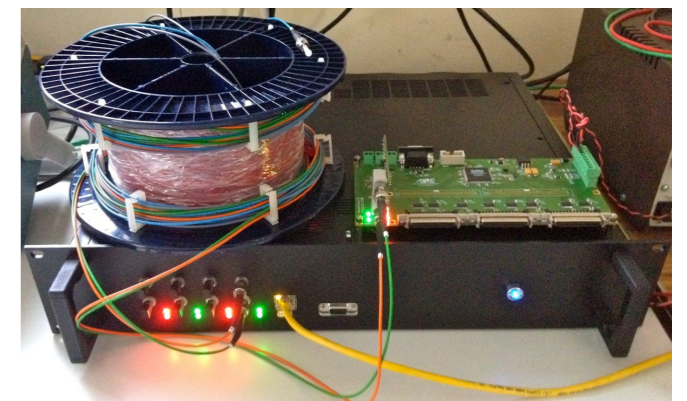


silent c/c system

Control/command system & protocol



We need support from ASTRON!



silent c/c system

Building & testing the LSS

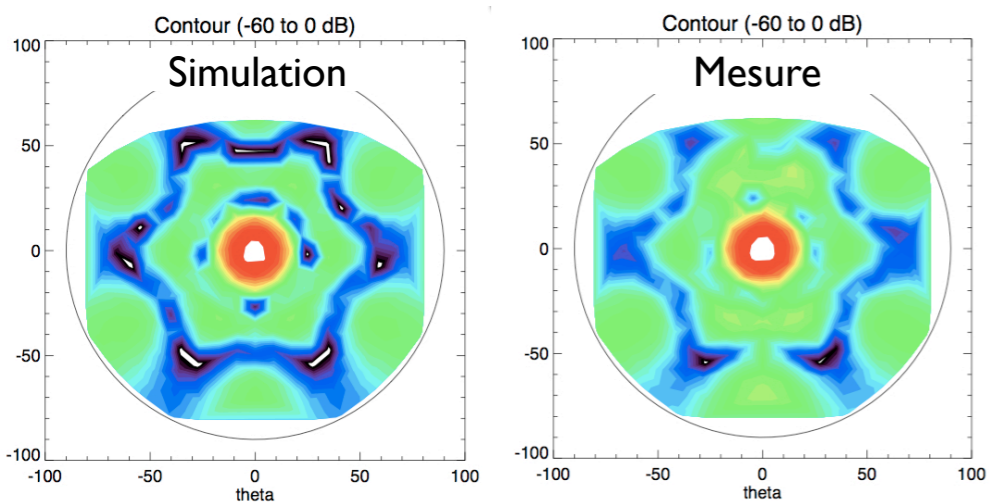
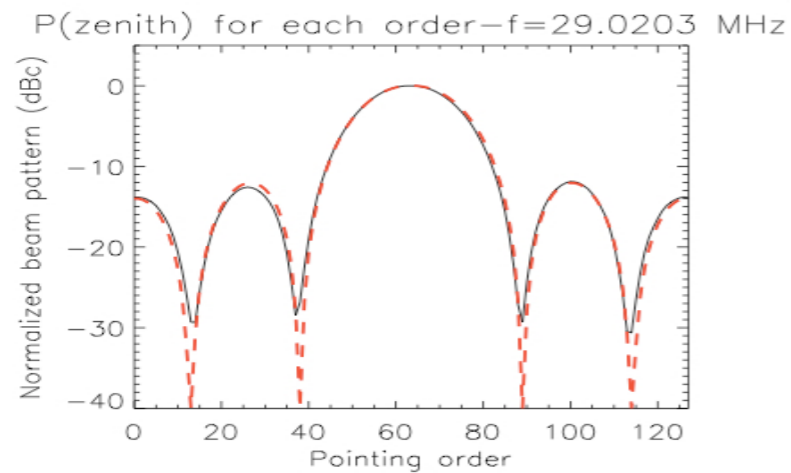


- Construction & test of 3 mini-arrays (x 2 polarizations) with a dedicated receiver

Building & testing the LSS



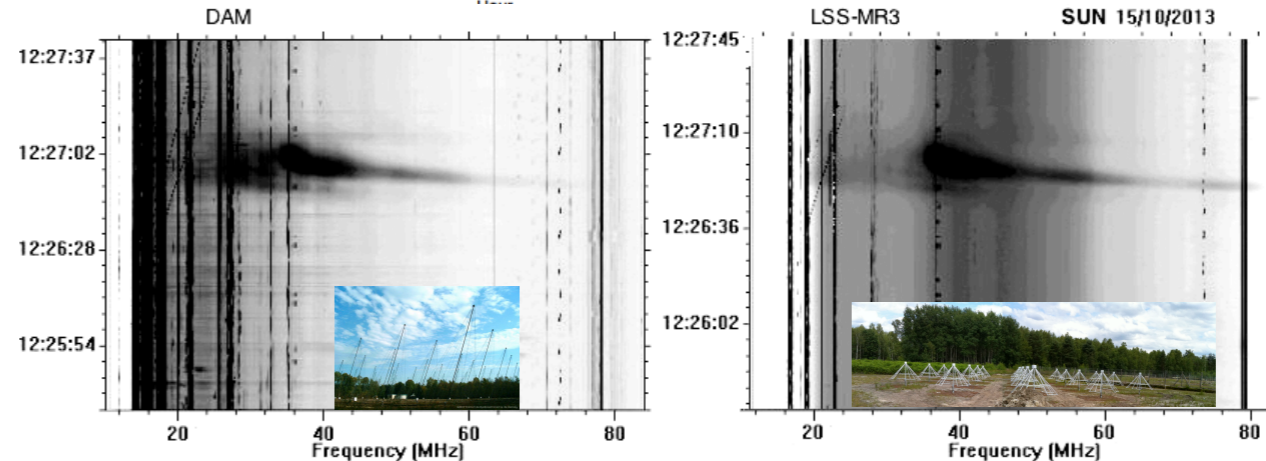
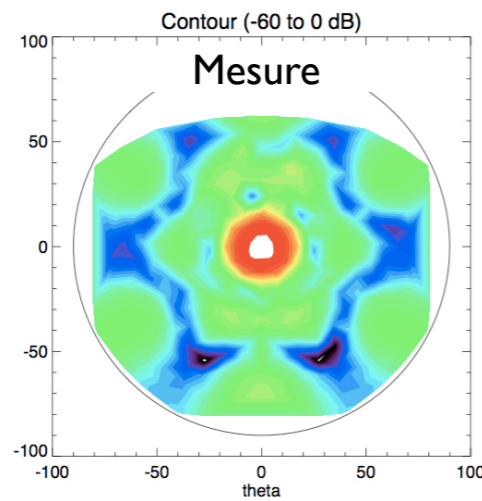
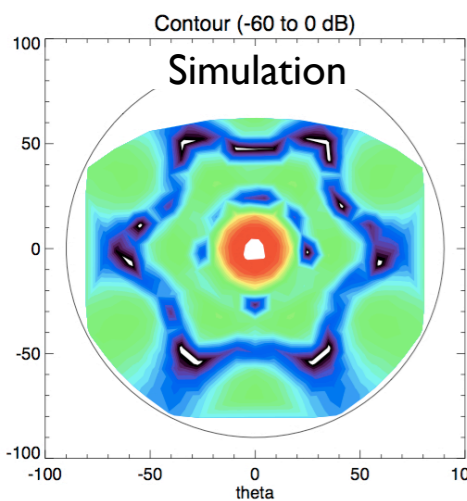
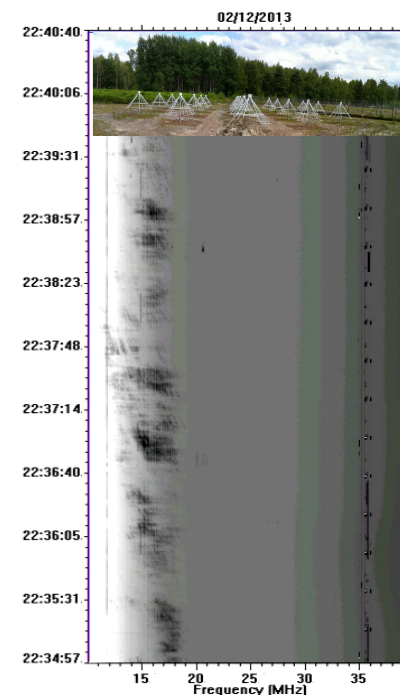
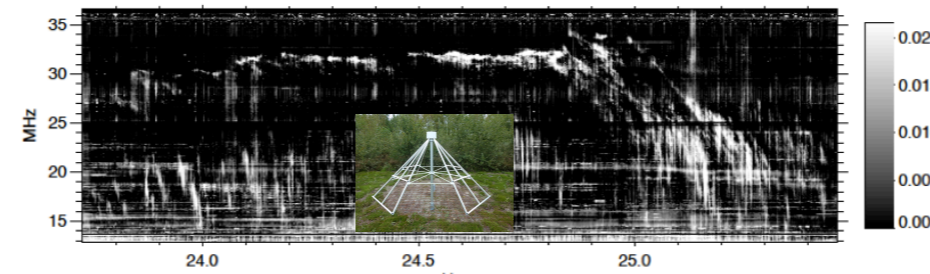
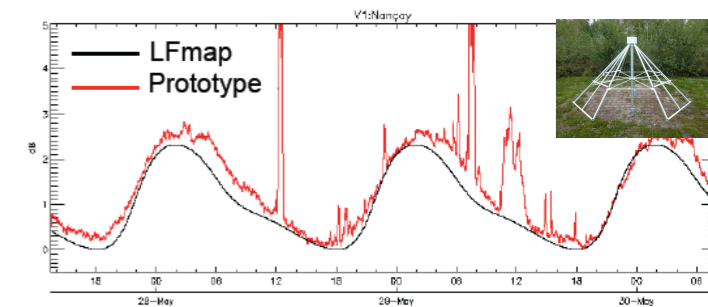
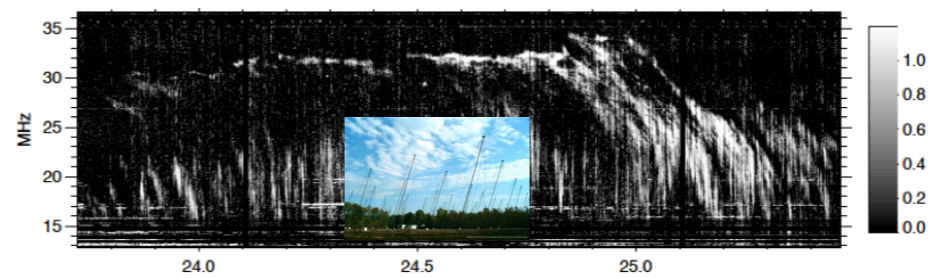
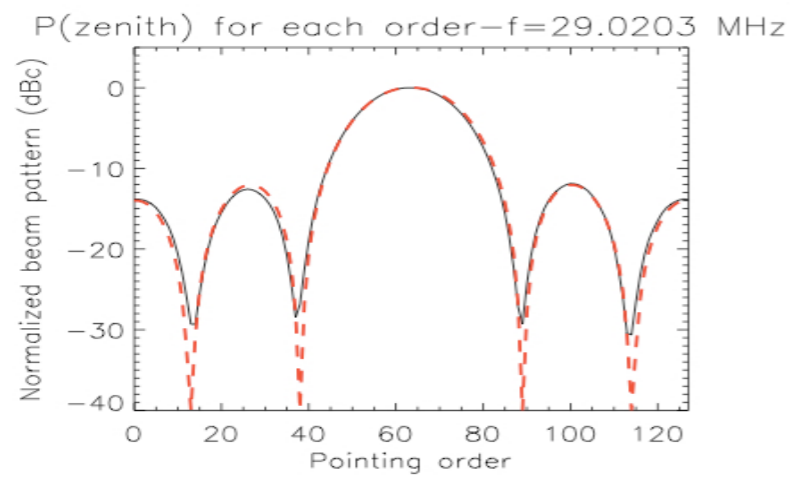
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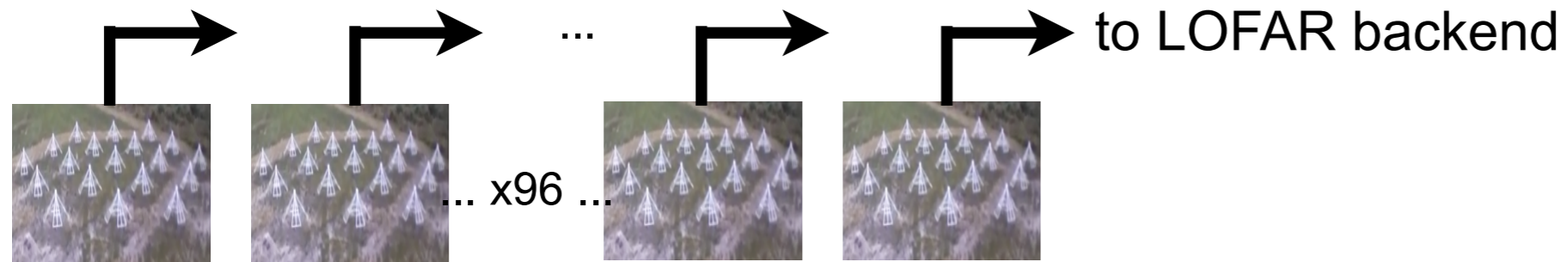
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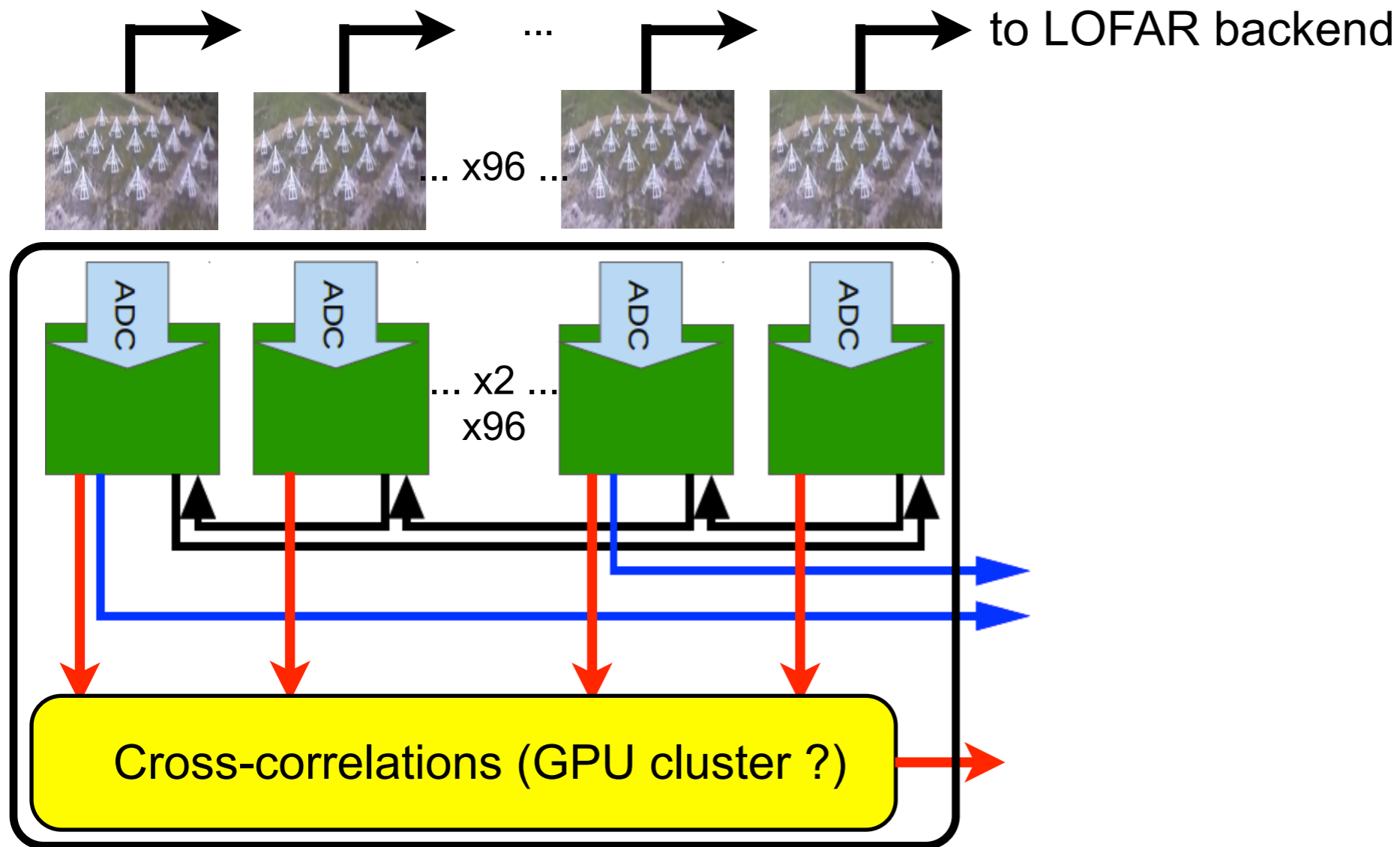
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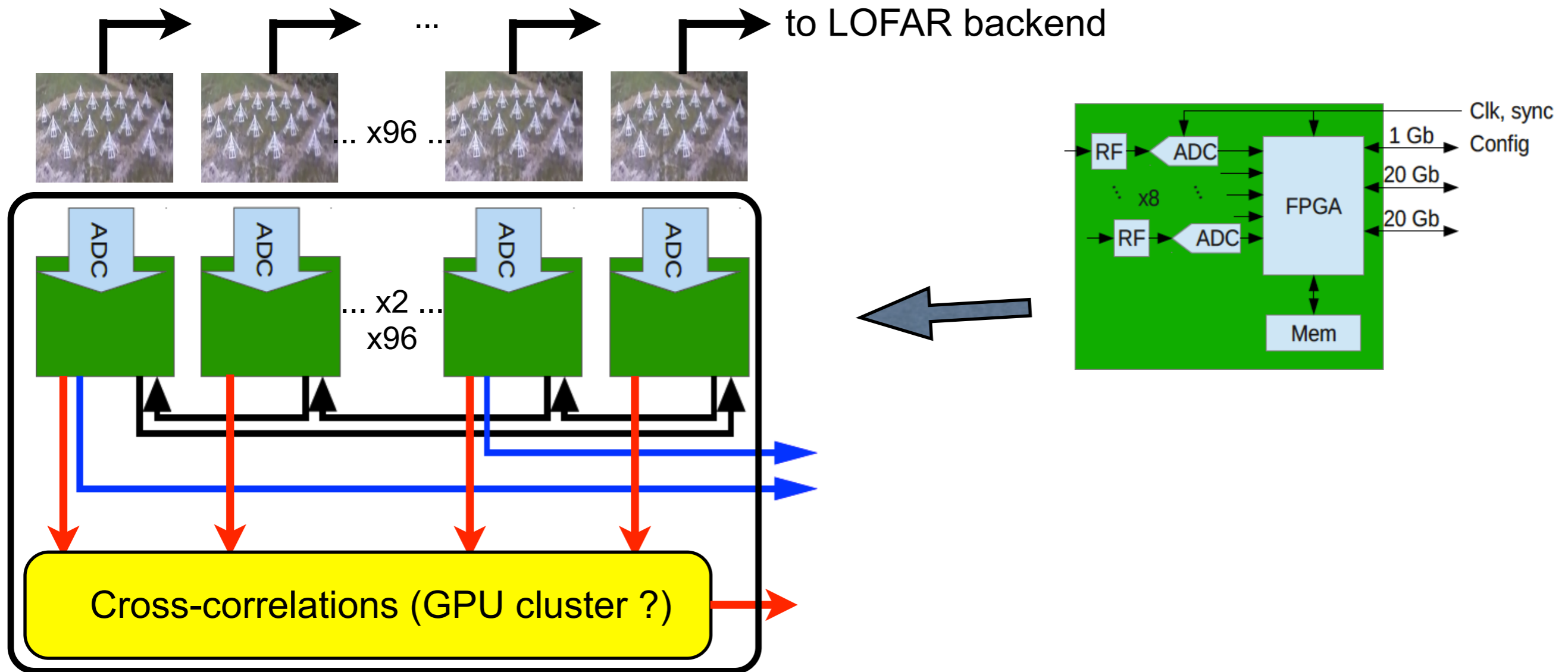
From the LSS to NenuFAR



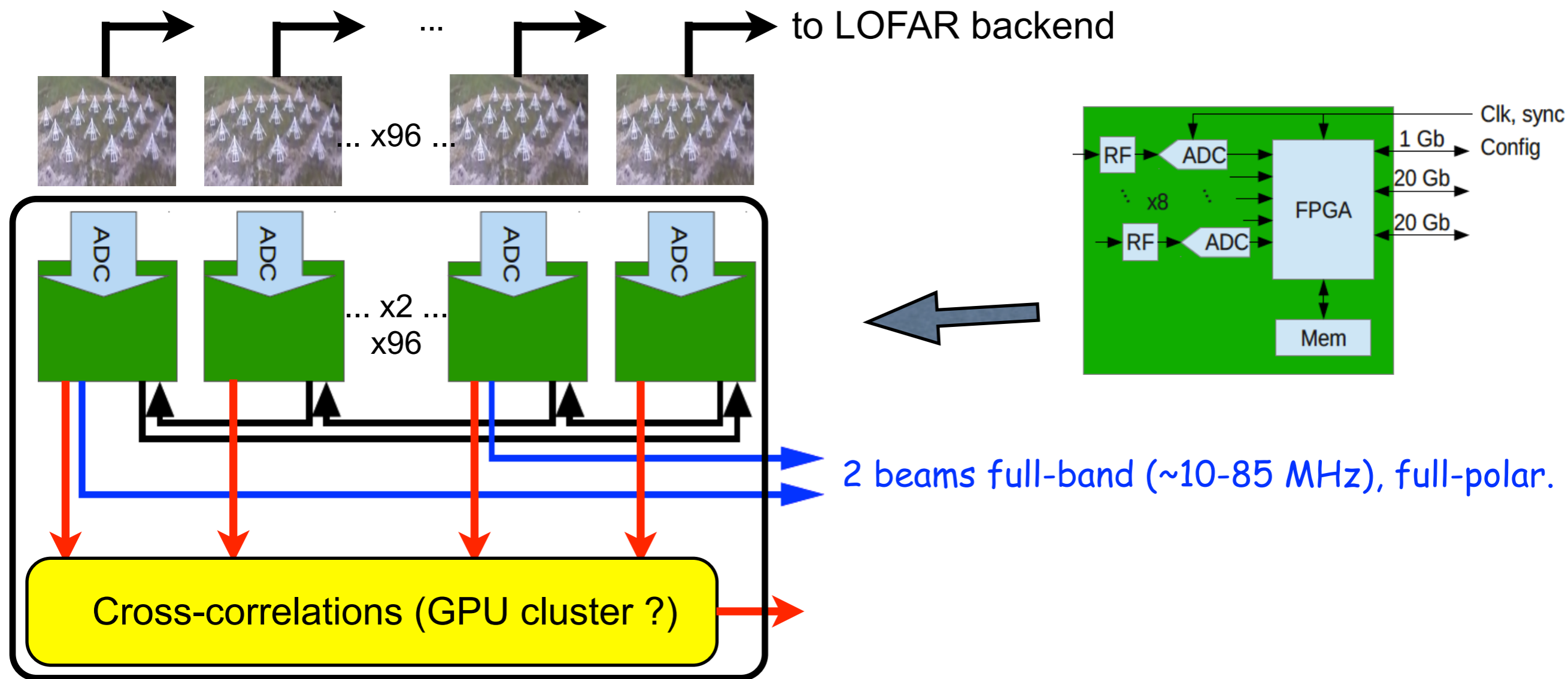
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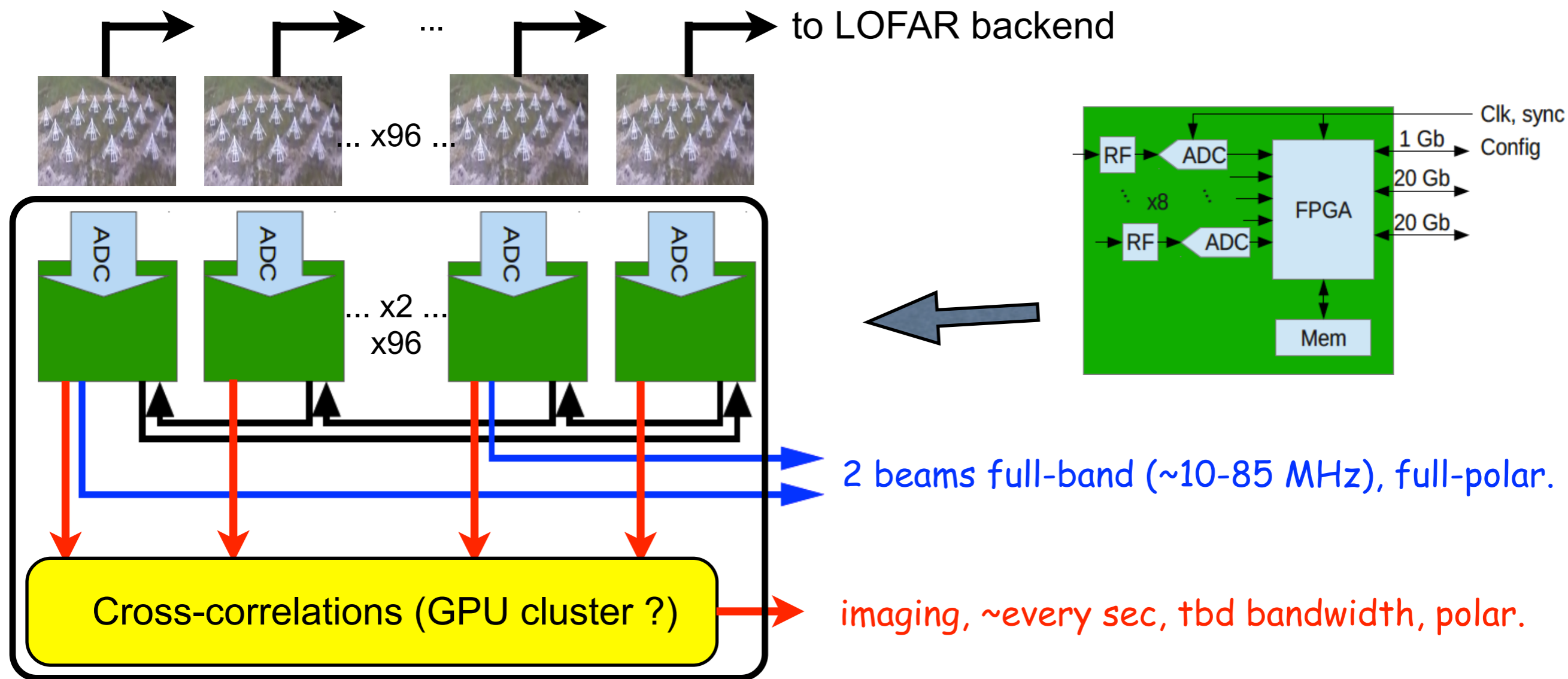
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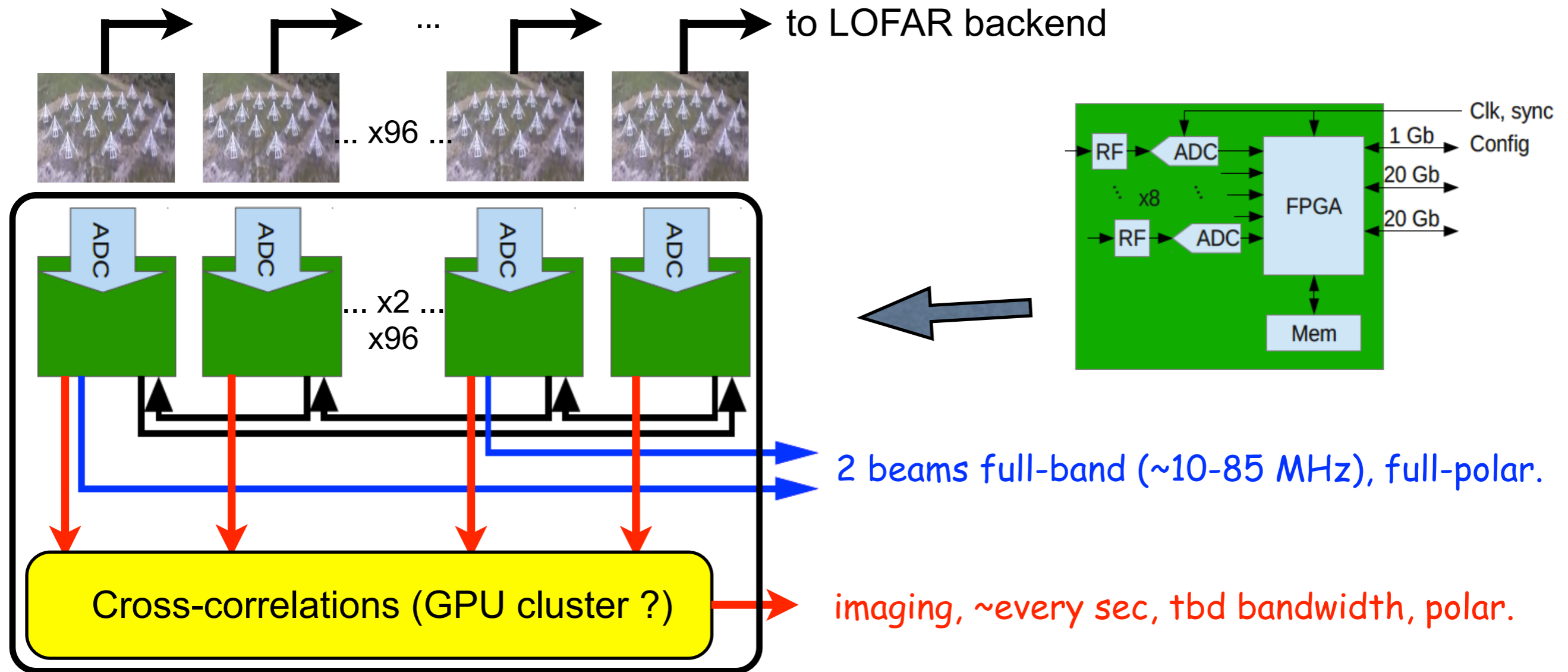
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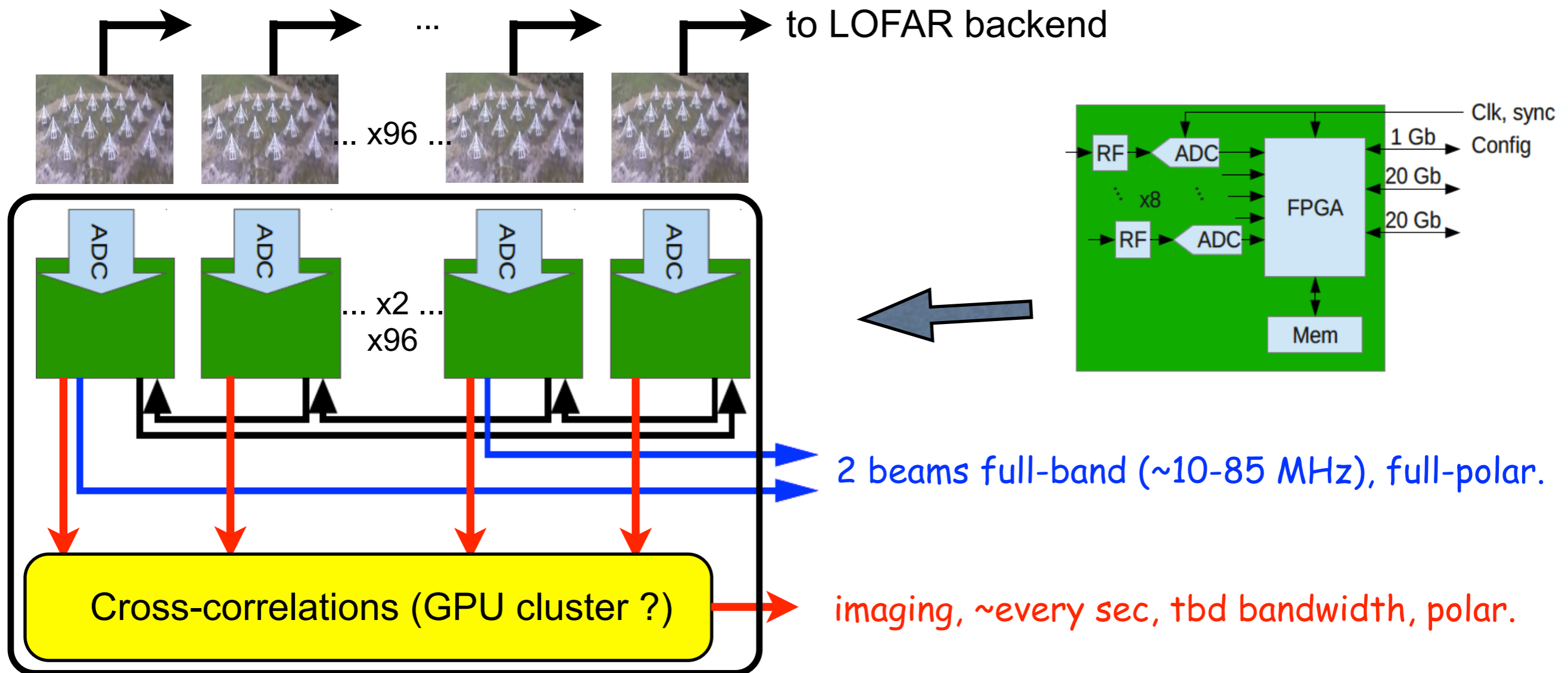


From the LSS to NenuFAR



- Definition of a standalone dedicated receiver : beamformer + spectro-imager
 - ⇒ ~100 kHz spectral resolution
 - ⇒ fully parallel use to LSS mode
 - ⇒ "duty-cycle" ~100% in the analog mini-array beam

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- Definition of a standalone dedicated receiver : beamformer + spectro-imager
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 - ⇒ "duty-cycle" ~100% in the analog mini-array beam
- LSS + Standalone = **NenuFAR** (2 instruments in 1)

Technical characteristics of NenuFAR

<https://nenufar.obs-nancay.fr/>

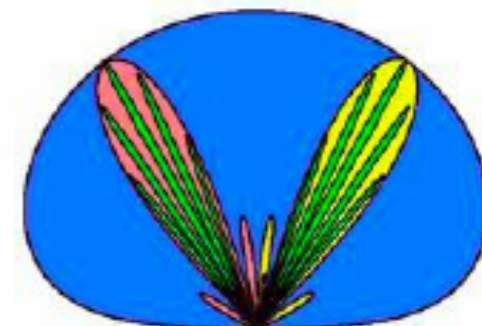
- Giant LOFAR-compatible phased array & interferometer
- 1824 antennas : 96 mini-arrays of 19 antennas each
- Diameter ~400 m
- Collective area ~ 62 000 m² @ 30 MHz ($\propto \lambda^2$)
- Frequency range = 10-85 MHz ($\lambda=3.5-30\text{m}$)
- Broad FoV (8°-60°), pointing -23° → +90°
- Resolution ~ 1° (Standalone) - 0.1 " (LSS)
- Resolutions <1 msec × 1-100 kHz, Full polarization (4 Stokes)
- Sensitivity <10 mJy (10^{-28} Wm⁻²Hz⁻¹) [+confusion]
- SKA-Low pathfinder

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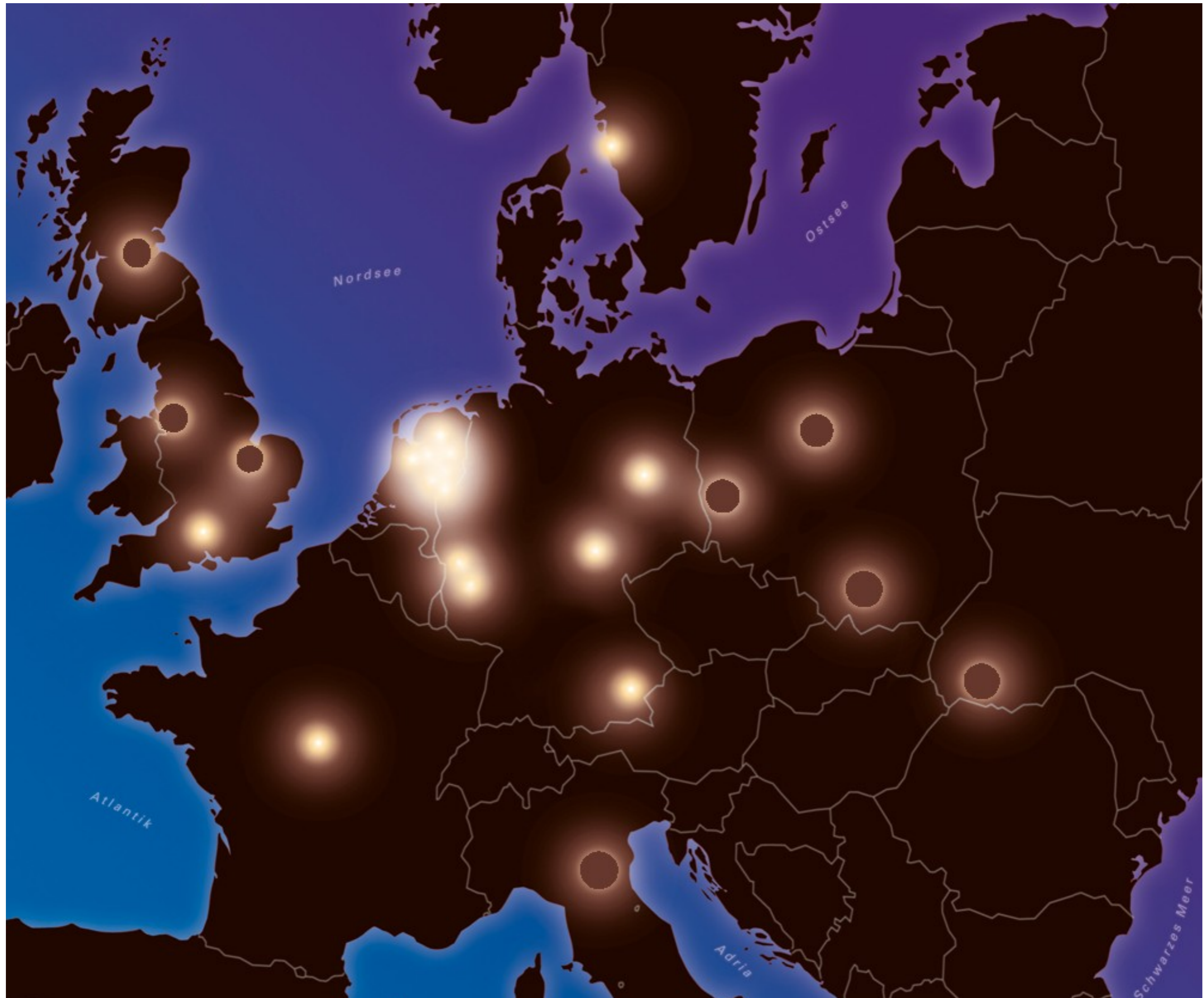
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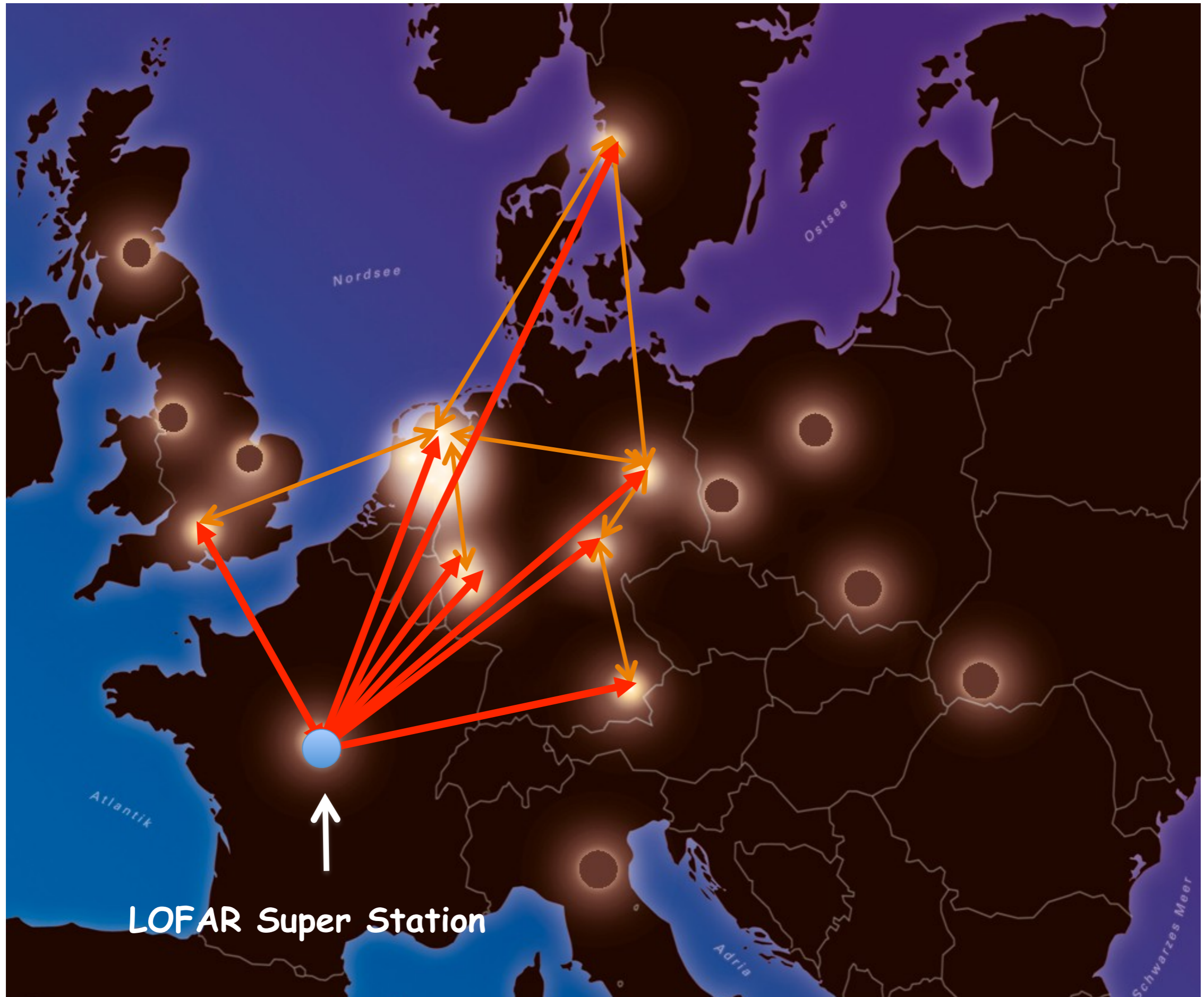
• Phasing / scale :	antenna	Mini-Array	NenuFAR
• Beaming :	~2 π	8° - 60°	0.5° - 4°



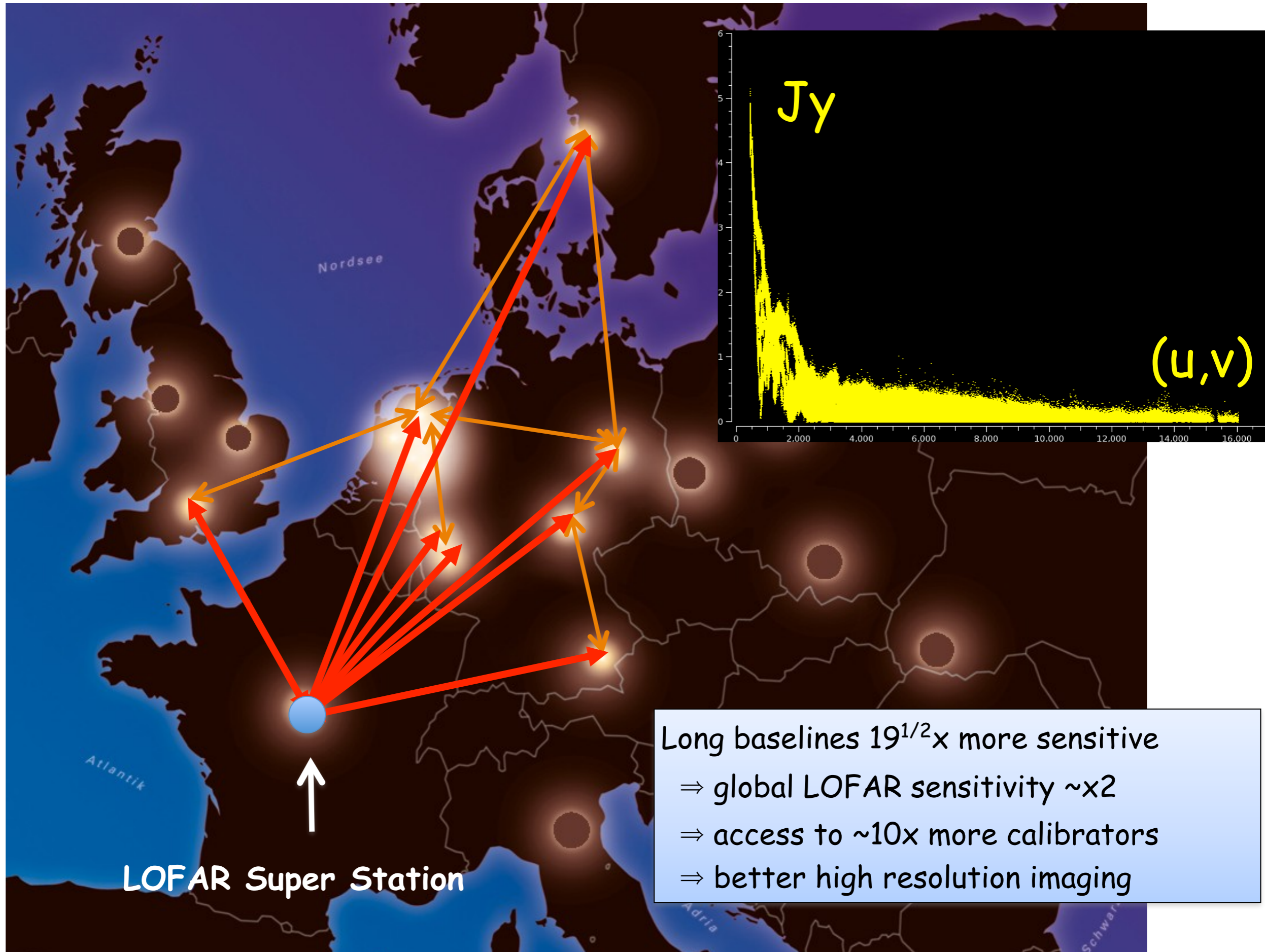
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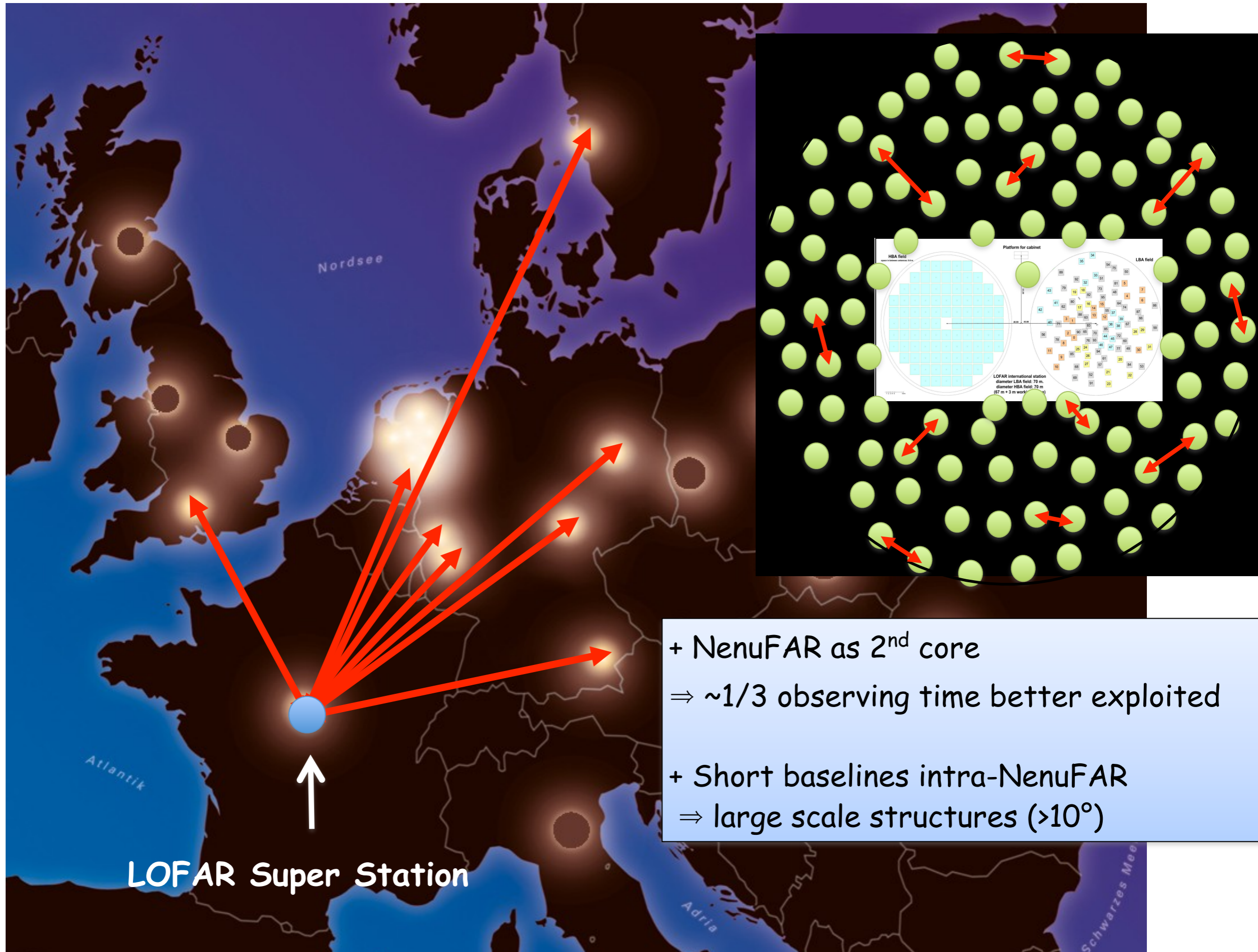
What NenuFAR will bring ?



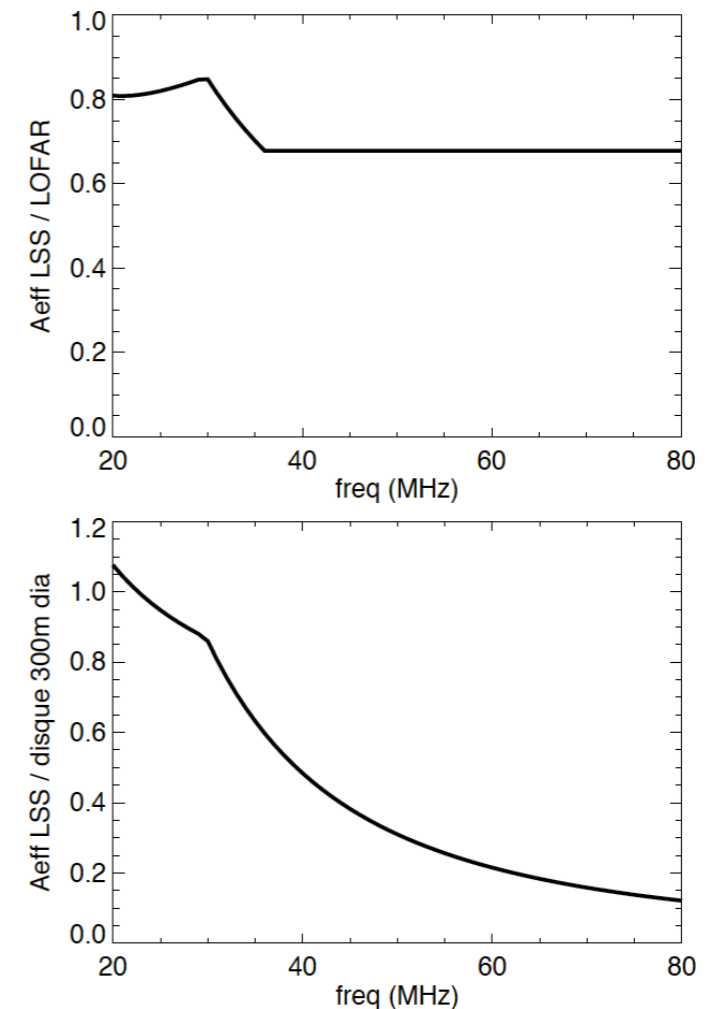
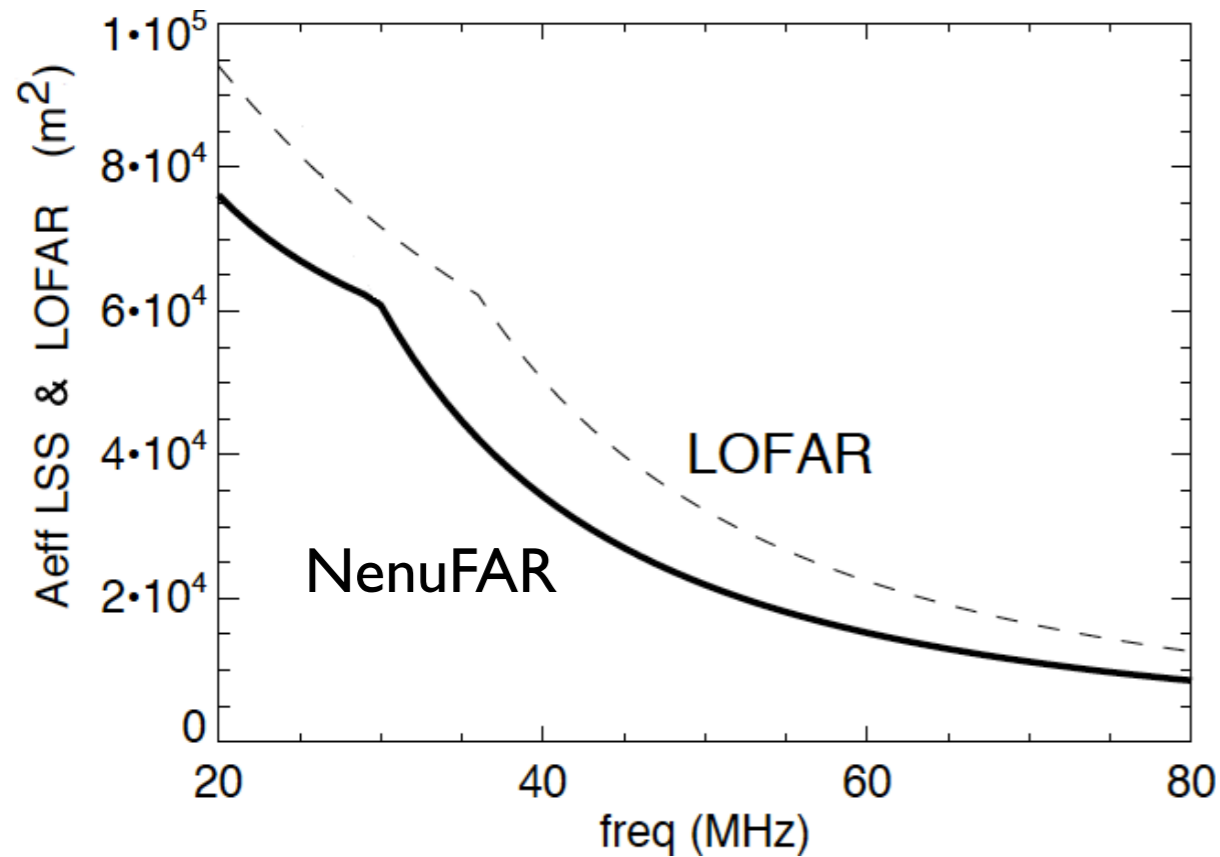
LOFAR Super Station

Long baselines $19^{1/2}$ x more sensitive
⇒ global LOFAR sensitivity \sim x2
⇒ access to \sim 10x more calibrators
⇒ better high resolution imaging

What NenuFAR will bring ?



What NenuFAR will bring ?



Large standalone instrument («LF Arecibo» in Nançay) with high instantaneous sensitivity

- ~19x the sensitivity of an international LOFAR station in LBA range
- Access to VLF (10-85 MHz)
- $A_{\text{eff}} = 70\text{-}80\% \times A_{\text{eff}} \text{ LOFAR LBA} \sim 1.6 \times A_{\text{eff}} \text{ LOFAR core LBA}$ (much more ≤ 30 MHz)
- 2 full-band (75 MHz) full-polarization simultaneous coherent tied-array beams
- Instantaneous polarized imaging with ~256 pixels in $8^\circ\text{-}60^\circ$ FoV within TBD bandwidth

NenuFAR Operating modes

- LOFAR-ILT (LSS) → high angular resolution
- LOFAR-single station → high spectral resolution
- Standalone (in // to above within Mini-Array analog FoV)
 - N(=2) beams, full band, with maximum time resolution
 - + ARTEMIS-like backend
 - ~256 pixels imaging within TBD bandwidth / a few sec
- Transient Buffer Boards (waveform)

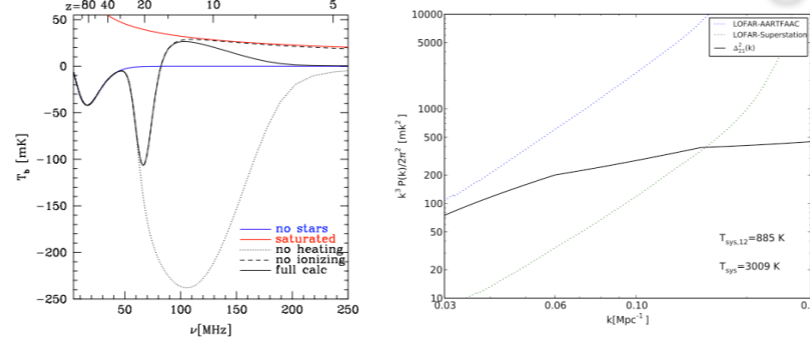
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- Data policy tbd with ILT : motivation = optimize scientific return
 - LSS mode via ILT, open use, builder's list ?
 - Standalone mode via FLOW PC ?
 - Sub arrays, Single station mode tbd

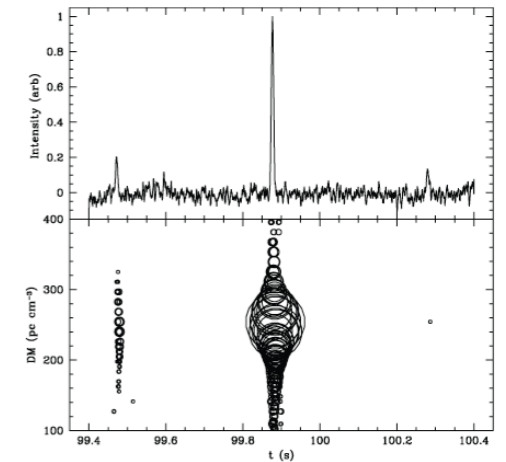
NenuFAR Science

- Standalone : all science topics requiring high-sensitivity & large FoV, no high angular resolution

dark ages



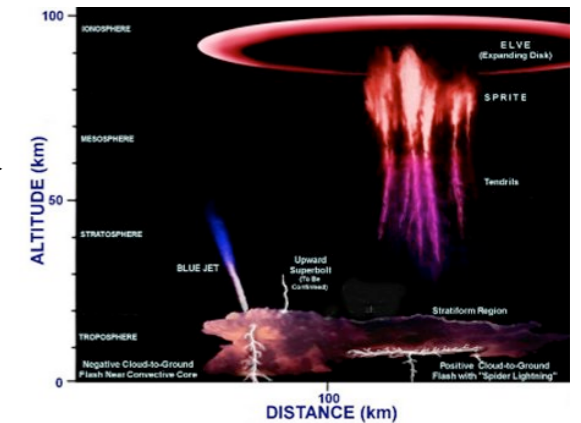
pulsars, RRATs



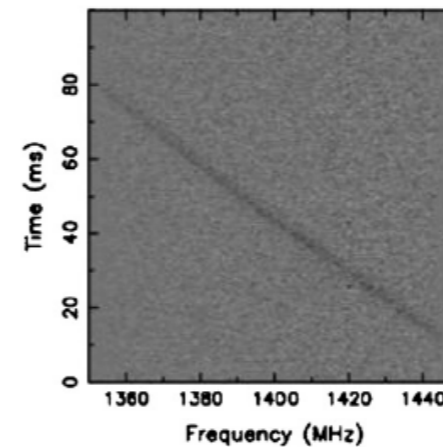
flaring/dwarf stars, exoplanets



SS planets - lightning/TLEs



blind transient searches



NenuFAR Science

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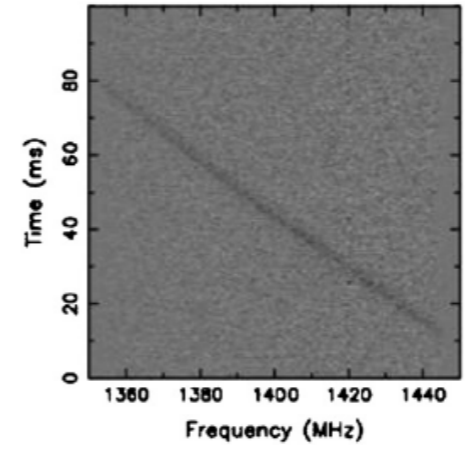
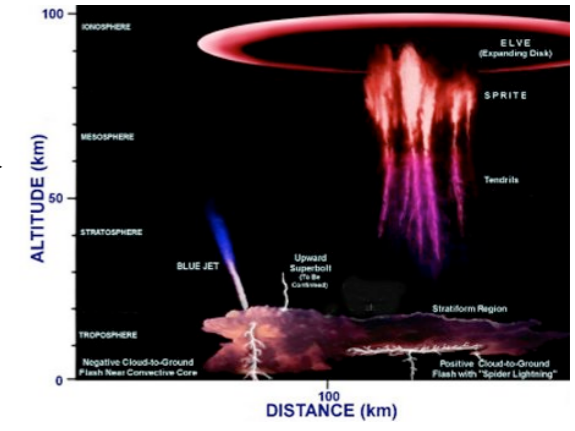
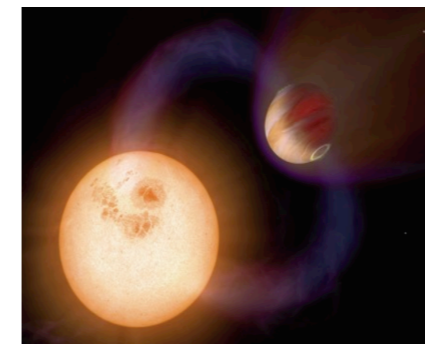
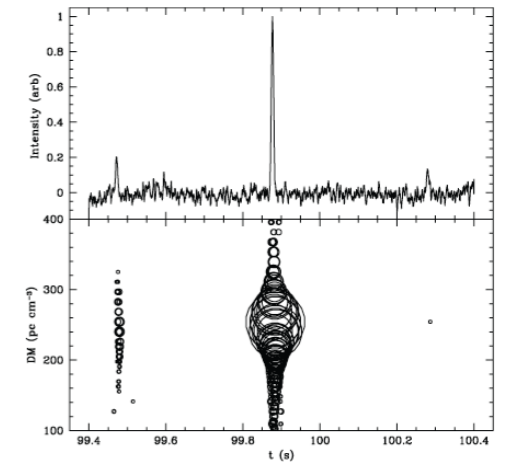
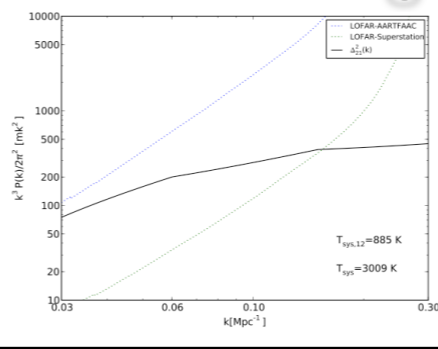
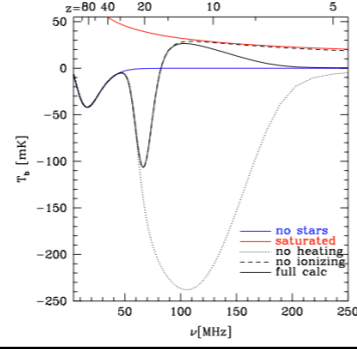
dark ages

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- LSS : high angular resolution imaging

Galaxy formation

ISM structure

small-scale B fields

NenuFAR status

<https://nenufar.obs-nancay.fr>

- Construction cost : ≤ 5 M€ (moderate operation cost)
- ~ 1/3 secured today + longer term plans ...
- Phase 1 started 15/11/2013
 - construction of ~24 mini-arrays started (456 antennas ; ≥ 4.7 LOFAR stations)
 - should be operational in 2015

- CNRS/INSU «Prospective» (fall 2014)
- Workshop "The science of NenuFAR", 2/2014, Paris
<http://nenufar.sciencesconf.org> (~50 participants)
 - updated science case in progress
- foreign participants welcome



The poster features a vertical timeline of three circular images: a radio telescope dish, a landscape with a radio telescope array, and a radio telescope dish. The background is a colorful nebula.

Journées Radio SKA-LOFAR
11-13 février 2014
IAP, Paris

Organisées par l'Action Spécifique SKA LOFAR en association avec les programmes nationaux de l'INSU (PCMI, PNCG, PNHE, PNST, PNP, PNPS)

Atelier NenuFAR
14 février 2014
IAP, Paris

<http://journées-radio.sciencesconf.org/>
Contact: journées-radio@sciencesconf.org

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NenuFAR-France : ~ 20 scientists + 15-20 technical staff
Laboratories involved in design & construction : Nançay, LESIA, GEPI, LERMA, LPC2E, Prisme, Subatech, IRA Kharkov, SRI Graz, OCA (support OP, ESEP)
Future users : same + LUTh, CEA/Sap, IAS, IAP, X, ENS/LRA, APC, IN2P3, IRAP ...

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