the NenuFAR project

(New Extension in Nançay Upgrading LOFAR)

P. Zarka, M. Tagger, L. Denis, J. Girard

for the NenuFAR collaboration

why NenuFAR

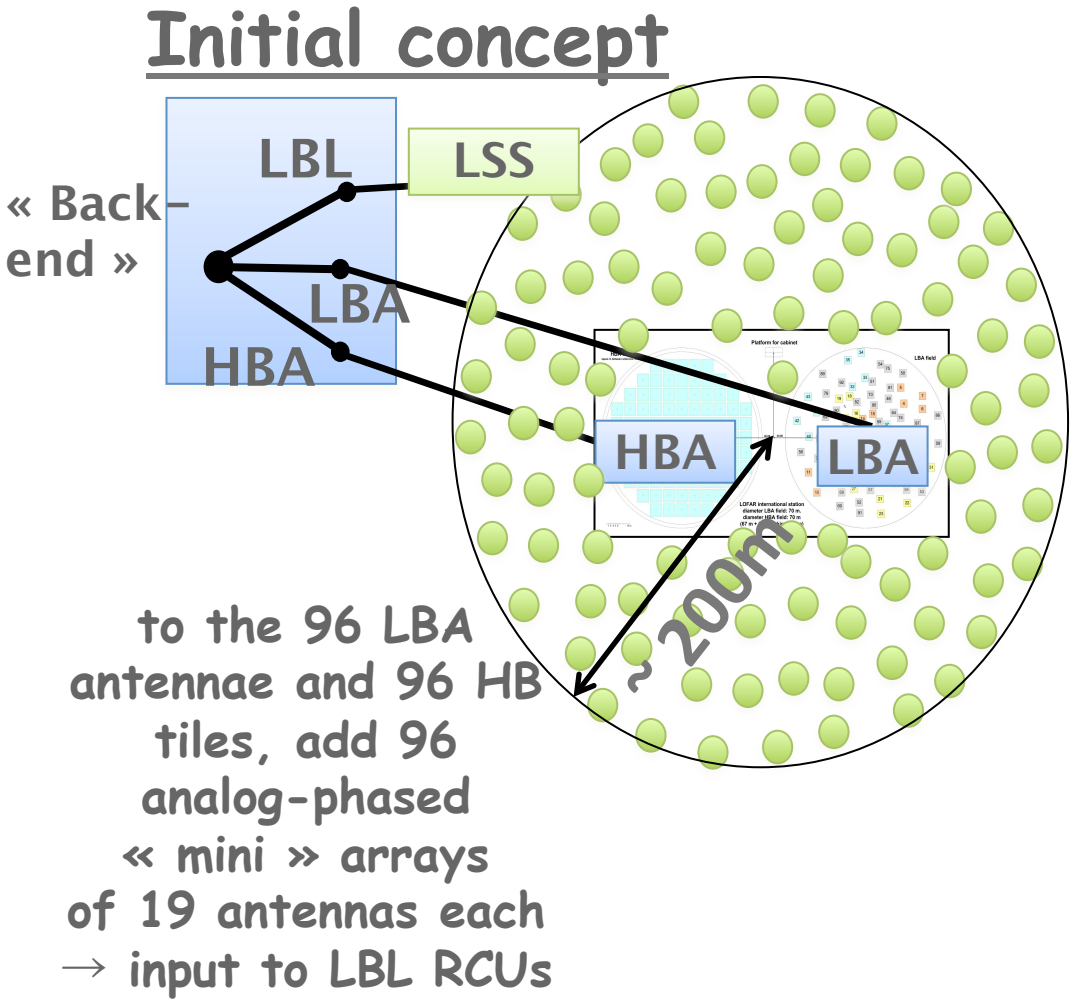
- 2006 -> LOFAR workshop, FLOW science case
- 2011 -> FR606 up and running
- two further goals
  - do more and better science
  - need to prepare a scientific community, ready for SKA
    - much broader than "traditional" LF radio
    - consolidate Nançay-Orléans-Paris as a world-visible reference
- very strong local, regional, national support for these goals

the next step

- FR606 -> we bought a LOFAR station, installed it in Nançay but
  - no use of local technical expertise
  - no specific visibility of the french community
- try to do better: rather than proposing to buy additional stations, develop an original instrument
- -> the LOFAR SuperStation (LSS) concept

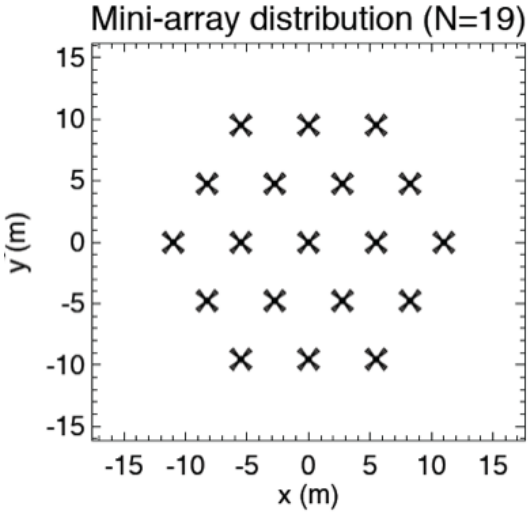
LOFAR SuperStation, initial concept

- use existing LOFAR infrastructure and multiply the number of antennae
- use available "Low-Band Low" back-end input
- 96 mini-arrays of n (=19) analog-phased antennae
- optimized for 10 – 85 MHz
- can be used by LOFAR as a non-standard LBA field



LOFAR SuperStation, ANR study

- antenna optimization -> LWA concept
- Mini-Array design -> 19 antennae/MA
- optimal distribution of the MAs
- ASIC preamplifier
- dedicated receiver
- prototype: 3 MAs
- dedicated science case
- much help from foreign colleagues!

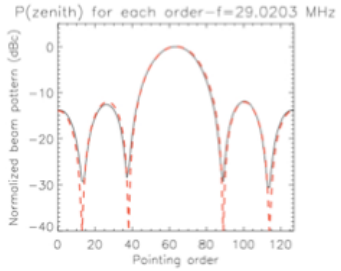


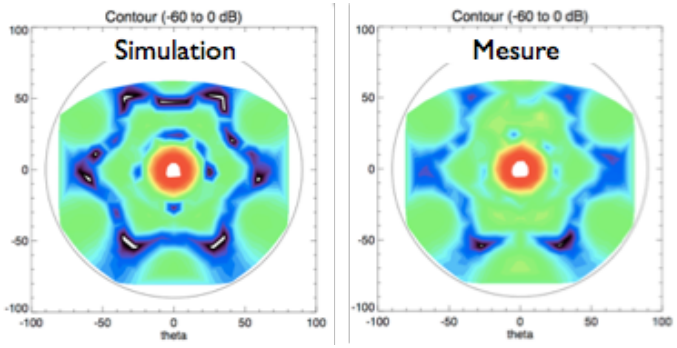
Pointing by mutualization of 7 bits analog delay lines in two directions (x & y)

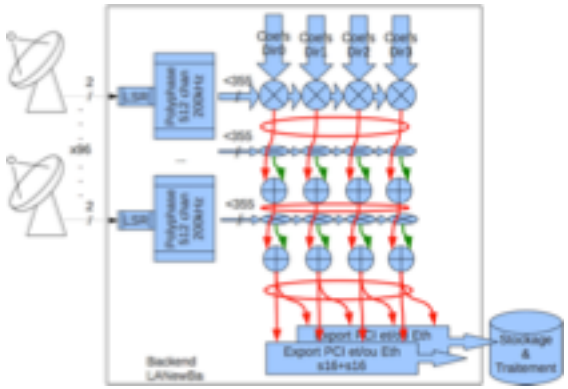
Relative gain variation between two pointing directions ≤10%

LOFAR back-end will then beamform within this « pre-pointed » antenna beam

LOFAR SuperStation, 3 prototype MAs



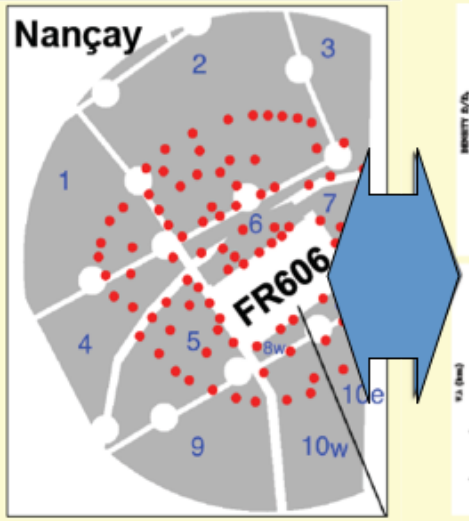




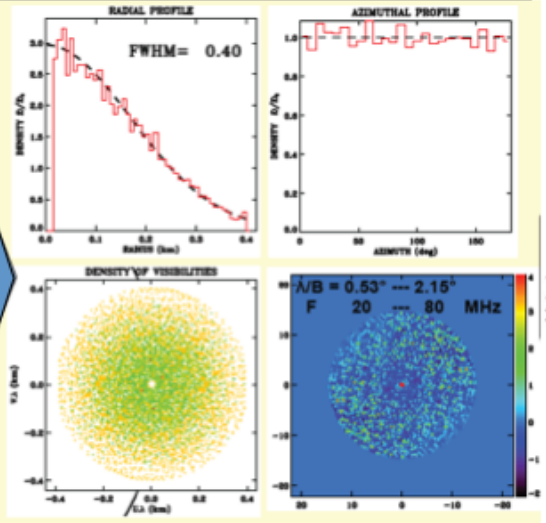
- Construction of 3 mini-arrays (x 2 polarizations)
- Definition of a **standalone dedicated NenuFAR receiver** (Nançay/ALSE)
  ⇒ "duty-cycle" ~100% in the analog mini-array beam (~30° @ 30 MHz)
- Industrialization studies, site study (ONF), costing, sub-contracting, schedule

Station layout & cabling (near-final)

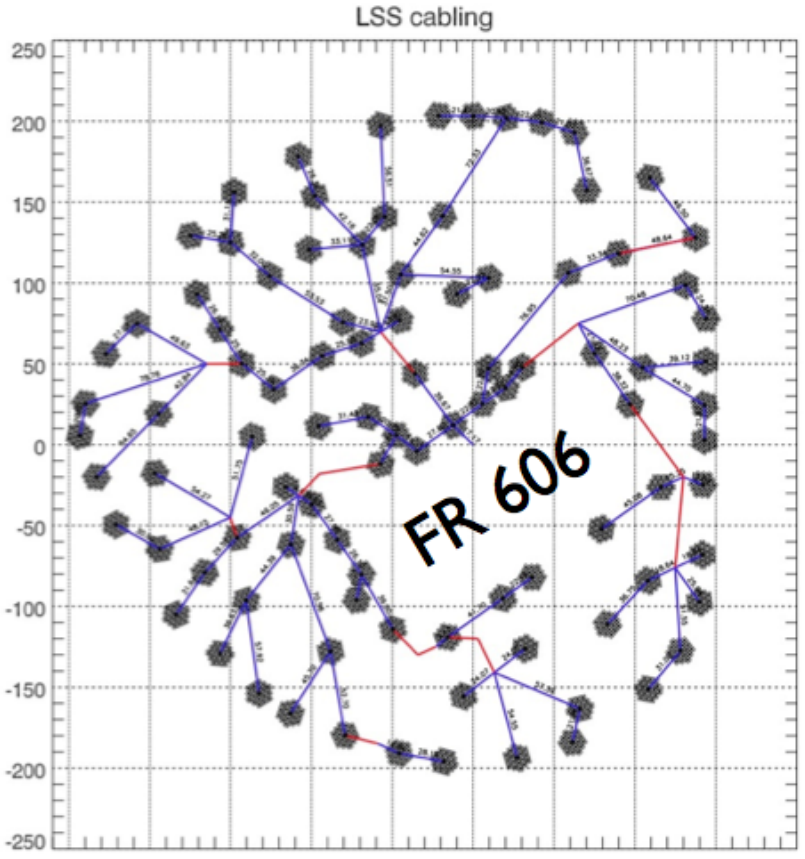
Scale	Layout	Phasing
Mini-array (10-20 elements)	A_{eff} & beam optimized	Analog (using cable delays)
LSS (96 MA)	(u,v) optimized	Digital (using station back-end)



(u,v) optimization given a site mask

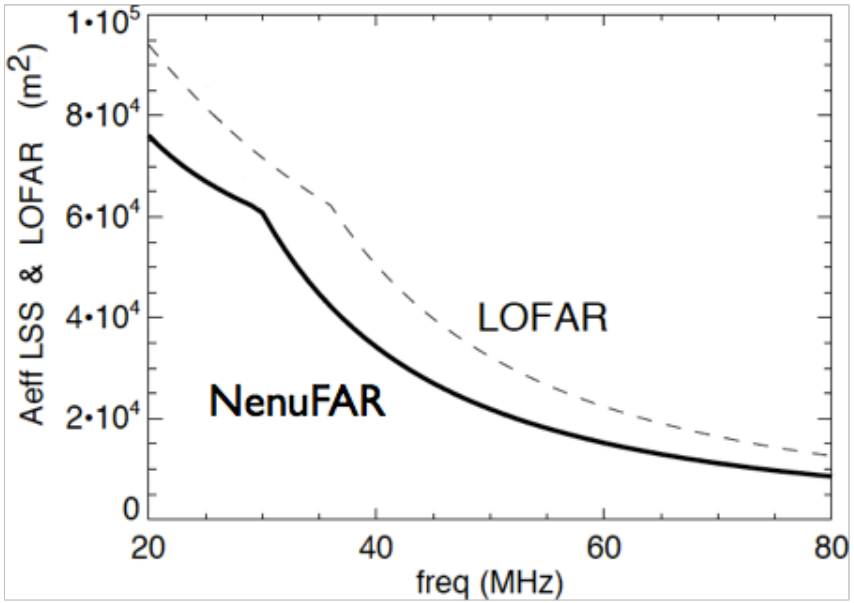


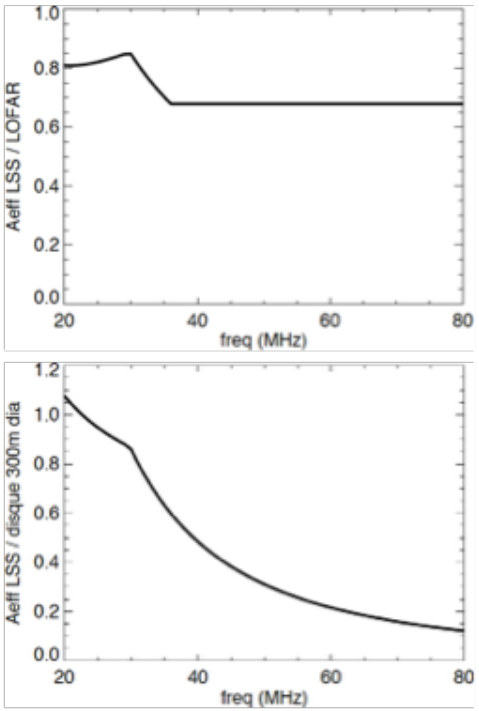
(u,v) density and PSF



Optimized (u,v) coverage (gaussian) using pressure-driven Boone algorithm
Relative rotations of Mini Arrays to temper grating/side lobes (but keeping all antennas //)
Optimized infrastructure costs : Cable-Trench problem (total cable length ~20 km)

What will bring LSS/NenuFAR ?





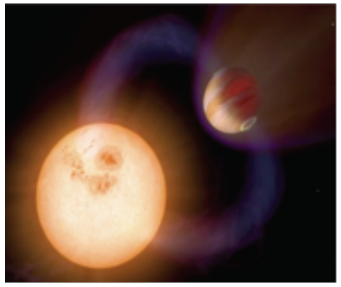
Large standalone instrument with high instantaneous sensitivity

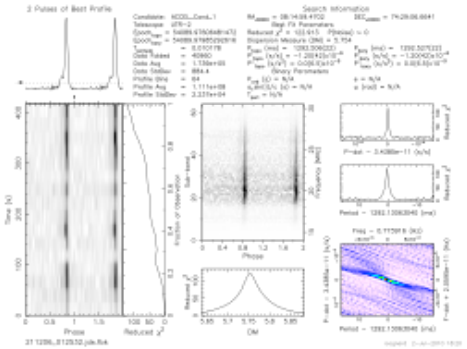
- ~19x the sensitivity of an international LOFAR station in LBA range
- A_{eff} = 70-80% x A_{eff} LOFAR LBA = 190% x A_{eff} LOFAR core LBA
- Access to VLF (15-80 MHz)
- 2 full-band (70 MHz) full-polarization simultaneous coherent tied-array beams

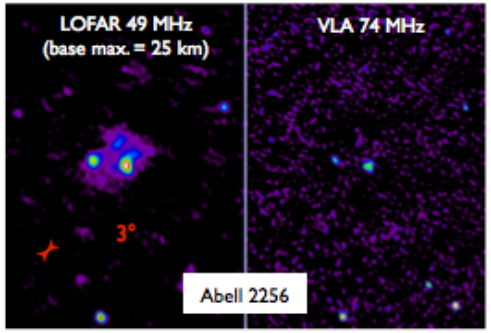
⇒ coherent TAB mode > 2x more efficient than LOFAR

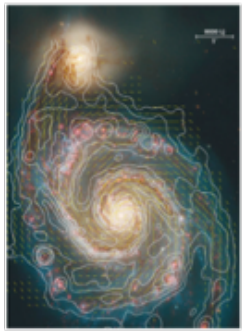
⇒ Instantaneous polarized imaging with 256 pixels in 8°-45° FoV within TBD bandwidth

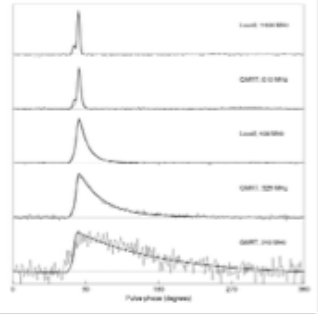
Science case of LSS/NenuFAR

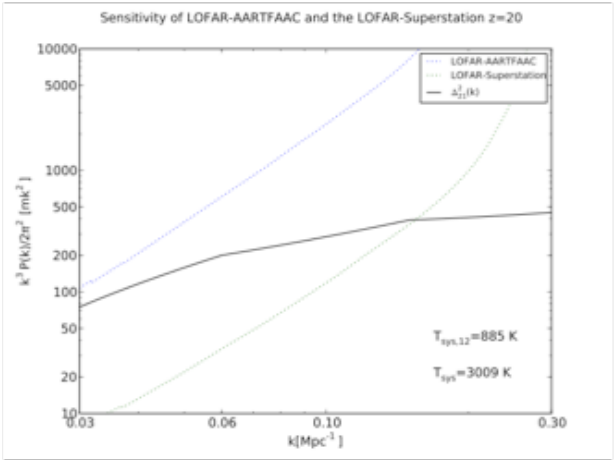






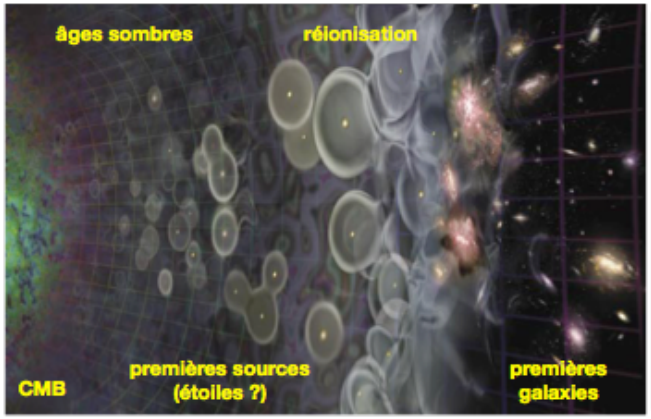






- Cosmology (dark ages) and galaxy formation
- Structure of Galactic Interstellar Medium
- Pulsars & Rotating radio transients (RRATs)
- Binary/flaring stars & Exoplanets
- The Transient Universe
- Light flashes in Terrestrial and Planetary atmospheres

⇒ LSS standalone, LSS+LOFAR, LSS//LOFAR



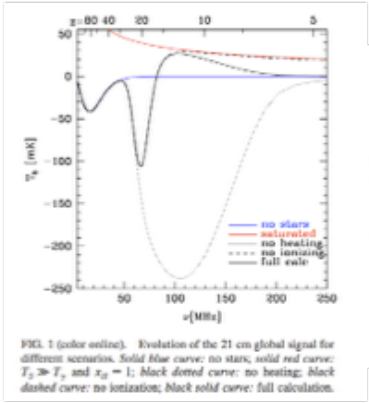
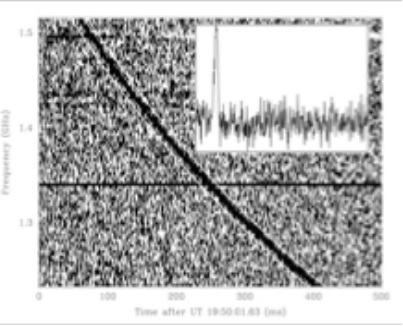
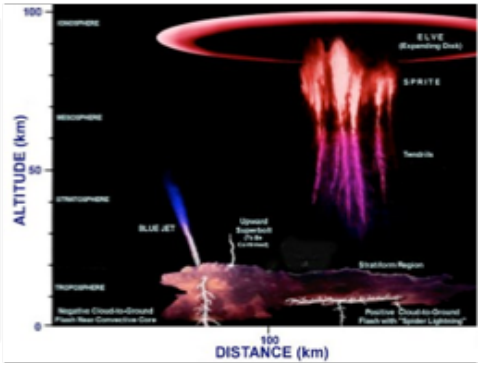


FIG. 1 (color online). Evolution of the 21 cm global signal for different scenarios. *Solid blue curve:* no stars; *solid red curve:* $T_S \gg T_\gamma$ and $x_{\mathrm{H\,I}} = 1$; *black dotted curve:* no heating; *black dashed curve:* no ionization; *black solid curve:* full calculation.



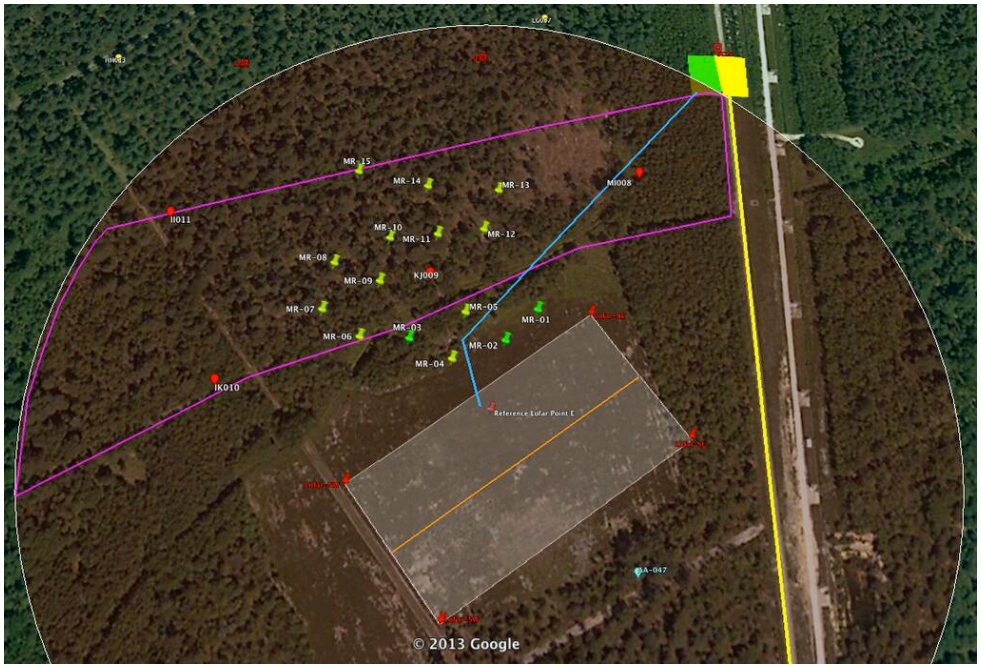


operating modes

- NenuFAR as a "super" LOFAR station LBA
  - short baselines -> extended objects (instantaneous "station" FoV ~10° @ 30 MHz)
  - $19^{1/2}$ times more sensitive long baselines
  - or as second core
- NenuFAR as a standalone instrument
  - down to 10 MHz
  - original science case
- dedicated receiver -> both modes can be used at the same time (within MA beam)

present status

- total cost ~ 4.5 M€ (plus Nançay staff)
- (nearly) already available 1.5 M€
- -> NenuFAR phase 1, ~ 25 mini-arrays (~ 2x LWA)+ receiver + some infrastructure for next stages
- convincing enough -> offocial go-ahead, Nov. 2013
- trees have been cut, phase 1 operational within ~ 1 year
- more MAs as funding comes in for phase 2



science and data policies
(our views, presented to the ILT)

- NenuFAR will appear to LOFAR as a "super" LBA field, can (doesn't have to) be used by LOFAR
- split data stream -> the dedicated receiver captures the signal before entering the LOFAR back-end
- thus NenuFAR can be used 100% of the time in stand-alone mode

even when used separately by LOFAR

- only constraint is the mini-array analog beam
- no use of LOFAR hardware in standalone use
- in that case LOFAR is commensal of NenuFAR…

science and data policies

(our baseline views, presented to the ILT)

main goal: optimize the scientific return of both LOFAR and NenuFAR; acknowledge help received while writing the science case

- NenuFAR will be added to LOFAR, and freely programmed by the LOFAR PC
  - no specific return asked for FLOW except a builder's list for the first few years (as in LOFAR)
- NenuFAR will also be used in stand-alone mode, programmed by a FLOW PC
  - a common-user facility, gradually opened to the community (as in LOFAR)
  - a member of LOFAR PC in FLOW PC ?

to be discussed within FLOW and with our authorities…

remaining questions

- sub-arrays (NenuFAR as second core)?
  - would follow LOFAR add-on policy
- single-station use?
  - is there really a need ? (competition with standalone mode)
  - we would rather avoid that, but smart ideas welcome!


NenuFAR
le projet est dans l'étang