Technical studies for a SKA-LF precursor:

Antennas & Mini-arrays

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Large instruments

LWA 256 dipoles
Large instruments

LWA  256 dipoles

Large number of elements

- sensitivity ++
- imaging ++

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Large instruments

LWA 256 dipoles

Large number of elements vs. Hardware/software effort

- sensitivity ++
- imaging ++

- signal acquisition
- computational load and tractability
- cost...
Large instruments

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⇒ Hierarchical instrumentation

ex: HBA field  96 x (4x4 dipoles)
Large instruments

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➡ Hierarchical instrumentation

ex:HBA field 96 x (4x4 dipoles)
NenuFAR (LSS)

Receivers

HBA  
LBA  

LOFAR FR606
NenuFAR (LSS)

Receivers

LBA
HBA

LOFAR FR606
NenuFAR (LSS)

- 96 LF tiles phased in analog (≥16 antennas / tiles)
- diameter ~ 400 m
- frequency band ⊆ LOFAR LBA
- LSS = Big phased array and interferometer

Receivers

LSS

LBA

HBA

LOFAR FR606

Phasing
LSS project (ANR 2009-2012)

Problematic: x 96

~

LOFAR HBA tile

4x4 antenna tile x 96
LSS project (ANR 2009-2012)

Problematic: x 96

LOFAR HBA tile

4x4 antenna tile x 96

→ Which elementary antenna?
LSS project (ANR 2009-2012)

Problematic:

\[ \sim \]

4x4 antenna tile \times 96

→ Which elementary antenna?

→ What topology for Mini-Arrays?

phasing strategy?
LSS project (ANR 2009-2012)

→ Which elementary antenna?

→ What topology for Mini-Arrays?
   phasing strategy?

→ Which global MA distribution?
LSS Elementary antenna

Specifications

● Large FOV & Smooth antenna pattern - quasi-isotropic $\geq 20^\circ$ elevation
  - rapidly decreasing $\leq 20^\circ$ elevation
● Broadband electrical properties in 15-80 MHz
● Simple & cost-effective design
LSS Elementary antenna

Specifications

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Studies

● EM simulations using NEC (Numerical Electromagnetics Code, NRL)
  → Effect of the antenna geometry of the antenna (parametric study)
  → Effect of the environment (ground, losses ...)
LSS Elementary antenna

- Study relevant existing antenna designs
LSS Elementary antenna

- Study relevant existing antenna designs
LSS Elementary antenna

- Definition of the optimal antenna (radiator ~ LWA + grid)
  - Antenna impedance
  - Beam smoothness

[Girard, et al., CRAS, 2012]

<table>
<thead>
<tr>
<th>L</th>
<th>1.42</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>1.5 m</td>
</tr>
<tr>
<td>(\alpha)</td>
<td>45°</td>
</tr>
<tr>
<td>(\beta)</td>
<td>14.8°</td>
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</table>
LSS Elementary antenna

Resulting antenna pattern in its principal planes

HPBW E/H = 90°/92° @ 20 MHz & 180°/118° @ 80 MHz
Antenna preamplifier (ASIC)

- Wideband
- Stable
- Gain of >10 dB over the sky

GURT design
Nançay design
Subatech design
Antenna preamplifier (ASIC)

- wideband
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Nançay design
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GURT design
Nançay design
Subatech design

Drift scan of the sky compared to LFmap

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Sensitivity to the galactic background with the LSS antenna (LSS-LONAMOS output)

- The system noise is calculated from measured LONAMOS characteristics and simulated parameters of the LSS antenna.
- The galactic noise is calculated from typical minimum galactic temperature, simulated parameters of the LSS antenna and measured parameters of LONAMOS.
- The low cut-off frequency can be decreased or increased.

LSS-LONAMOS specifications, Didier Charrier, Subatech/CNRS, February 2013
The LSS-LONAMOS board

The LSS-Lonamos board is a dual polarization LNA designed by the Nançay observatory for the LSS active antenna. It uses a dedicated micro chip circuit called 'LONAMOS' and designed at the Subatech laboratory.
LSS Elementary antenna

Nançay Decameter Array

Decameter emission from Jupiter (intense, <40 MHz)

prototype LSS antenna

LSS Elementar antenna

Decameter emission from Jupiter (intense, <40 MHz)

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LSS Elementary antenna

Nançay Decameter Array

Decimeter emission from Jupiter
(intense, <40 MHz)

- 1 LSS antenna detect jovian decameter emission down to ~10 MHz
- Measured gain consistent with EM simulations (NEC = 5.5 dB)
LSS Mini-array

Specifications

• **Sensitivity** of the MA (should detect main radiosources: CygA, CasA)
• **FOV**: Large primary lobe, low side lobe levels
• **Broadband** characteristics \( \frac{f_{\text{max}}}{f_{\text{min}}} > 5 \)
• «Fine» pointing
• **Analog** phasing system
LSS Mini-array

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Studies

- Optimal number of antennas in MA
- Distribution of antennas in MA
- Phasing system design
LSS Mini-array: topology

Generalized study of the optimal free positioning of MA

- **Deterministic algorithm**: Kogan algorithm
- **Non deterministic algorithm**: Simulated annealing

![Optimal distributions Prop.](image)

- **Compacts**
- **Irregular**
- **with ~ axial symmetry**

- SSL=-176.55 dB
- SSL=-172.09 dB
- SSL=-181.29 dB
- SSL=-162.52 dB
- SSL=-166.68 dB
- SSL=-165.25 dB
- SSL=-30.62 dB
- SSL=-164.03 dB
- SSL=-31.03 dB
- SSL=-31.14 dB
- SSL=-33.74 dB
- SSL=-33.22 dB
- SSL=-31.19 dB
- SSL=-30.20 dB
- SSL=-31.30 dB
- SSL=-28.96 dB
- SSL=-30.06 dB
- SSL=-31.12 dB

\[N=5 \quad N=6 \quad N=7 \quad N=8 \quad N=9 \quad N=10 \quad N=11 \quad N=12 \quad N=13 \quad N=14 \quad N=15 \quad N=16 \quad N=17 \quad N=18 \quad N=19 \quad N=20\]
LSS Mini-array: topology

Optimal solutions exist \((N \geq 16\) antennas\)

Irregular phased array \(\rightarrow\) Analog phasing very complex
very expensive
LSS Mini-array: topology

Optimal solutions exist (N ≥ 16 antennas)

Irregular phased array → Analog phasing very complex
very expensive

Compromise between
Radiation pattern and regular topology → hexagonal MA
of 19 antennas

\[ D_{\text{inter-antennes}} = 5.5 \text{ m} \rightarrow \text{Compromise between } A_{\text{eff}} \text{ and radiation pattern quality} \]
Primary lobe: 9° at 80 MHz
33° at 20 MHz

[Girard, et al., CRAS, 2012]
Primary lobe: 9° at 80 MHz
33° at 20 MHz

Hexagonal MA
- Less grating lobes
- Lower energy lost in side lobes

[Girard, et al., CRAS, 2012]
Compensating from positive/negative time delays
Compensating from positive/negative time delays
LSS Mini-array: Phasing

Lines phase centers

1st stage of phasing
= 8 delay lines

2nd stage of phasing
= 2 delay lines

In total, 10 delay lines /pol /MA (same number as for a 4x4 array)

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LSS Mini-array: Phasing

Pointing direction map: ~1° accuracy subject to $\frac{\Delta \text{Gain}}{\text{Gain}} \leq 10\%$

2-D sky sampling

With isotropic antennas

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LSS Mini-array: Phasing

Pointing direction map: ~1° accuracy subject to \( \frac{\Delta \text{Gain}}{\text{Gain}} \leq 10\% \)

2-D sky sampling

With isotropic antennas

with LSS antenna pattern
\( \Rightarrow \) beam squint at low elevation

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LSS Mini-array: Phasing

Prototype phasing system (MR N°1)
LSS Mini-array: Phasing

Lab tests compared to simulations
- source at the zenith, ~400 pointing directions
- agreement <<1 dB (except minima, < 5 dB)

41 MHz

Radiation pattern

79 MHz
LSS Mini-array: Phasing

Lab tests compared to simulations
- source at the zenith, ~400 pointing directions
- agreement <<1 dB (except minima, < 5 dB)

41 MHz

Radiation pattern  Simulations  Measures  1D profiles

79 MHz
LSS Mini-array: Phasing

Phasing system in the MA container →

Galaxy transit with one MA ↓
LSS Mini-array: Phasing (Future?)

(pers. com. Stéphane Bosse, Nançay)
NenuFAR toward SKA interest of physical miniaturization of delay lines

AAIR & MFAA projects knowledge of ASIC concept, phasing and integration of delay lines

AAIR = Aperture Array Integrated Receiver, MFAA = Middle Frequency Aperture Array
LSS Mini-array: Phasing (Future?)
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Electrical modeling of a time delay unit

- Using capacities & inductors
- With ASIC

ASIC = Application-Specific Integrated Circuit

Delay Coax
Cable of length
13 m

3 Delay Coax
Cable of length
3.2 m with 10 cm steps

4.5 cm à 14.1 cm selon les pertes admissibles

1.5 à 4 cm environ

4 cm max

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➔ Phasing 1 Mini-array, 1 pol = 20 x 20 cm rack bulk

➔ Analog (RF) Multi-Beam and direct digitization

➔ Multi-beam information carried on fiber links

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**Decrease of cost & volume**
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➔ Multi-beam information carried on fiber links


Decrease of cost & volume

Large scale NenuFAR at low cost (➔ SKA 3 ?)
Global NenuFAR distribution

Specifications

• « Good » \( I_{\text{Boone}} \) instantaneous \((u,v)\) distribution
• Maximum effective area in 15-80 MHz
• Ground constraints (natural, buildings)
Global NenuFAR distribution

Specifications

• « Good » |Boone instantaneous (u,v) distribution
• Maximum effective area in 15-80 MHz
• Ground constraints (natural, buildings)

Studies

• Constrained optimization of the MA positions
• Effect of relative rotation of MA
• Optimization of cabling MA
Global NenuFAR distribution

**Boone algorithm**: analogy between MA & gaz particles

→ enable iterative optimization of MA position toward a gaussian model

1 MA displacement is a consequence of the mean displacement imposed on the N-1 associated Fourier Measurements

[Boone, 2001, 2002]
Global NenuFAR distribution

- Taking obstacles into account → Mask derived from Nançay ground constraints (buried cables, natural obstacles, other instruments)

- GPS landmarking + topographic projection (Lambert 93)

- Authorized positioning areas
- Area for the 3 prototype MA

LOFAR FR606
Global NenuFAR distribution

Optimal distribution model: Gaussian with FWHM = 400 m  $B_{\text{max}} = 450$ m

MA distribution (u,v) distribution Radial (u,v) histogram Azimuthal (u,v) histogram

[BL1 = [ 0.000, 0.450 ] km HA1 = [ 0.000, 0.001 ] h]

[FWHM = 0.4000]

[Girard, et al., CRAS, 2012]
Global NenuFAR distribution

Optimal distribution model: Gaussian with FWHM = 400 m  \( B_{\text{max}} = 450 \text{ m} \)

MA distribution

(u,v) distribution

Radial (u,v) histogram

Azimuthal (u,v) histogram

\[ \text{BL1} = [0.000, 0.450] \text{ km} \quad \text{HA1} = [0.000, 0.001] \text{ h} \]

F=80 MHz — \( \theta \sim 0.5^\circ \)

F=20 MHz — \( \theta \sim 1.9^\circ \)

[\text{Girard, et al., CRAS, 2012}]
Global NenuFAR distribution
Global NenuFAR distribution

← MA radiation pattern

Nord

Φ=0°

Nord

Φ=50°

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Global NenuFAR distribution

MA radiation pattern

array of 96 MA ↓

\[ \Phi = 0^\circ \]

\[ \Phi = 50^\circ \]

Niveau = -13 dB

Sans rotation

Gain (dB)

Angle zénital (°)

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Global NenuFAR distribution

MA radiation pattern
array of 96 MA ↓

Niveau = -13 dB  Sans rotation  Niveau = -17 dB  Avec rotation

Gain (dB)

Angle zénital (°)

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Global NenuFAR distribution

- Minimizing cable and trench length → Need to find a compromise
Global NenuFAR distribution

- Minimizing cable and trench length → Need to find a compromise

→ Mathematical approach using graph theory: « Cable-Trench problem »
→ Integrating the ground constraints in Nançay

[Vasko, 2002]
Global NenuFAR distribution

- Minimizing cable and trench length → Need to find a compromise

Mathematical approach using graph theory: « Cable-Trench problem »
Integrating the ground constraints in Nançay

[Vasko, 2002]
Construction in phases

Prototype x 3

Phase 1 + 12

... + 5

... + 5

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