The LOFAR Super Station concept : an input for discussion

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LOFAR context

- "Rescope plan" : redefinition of the number of stations, distribution of antennas, performances of backend…
- Increasing effective participation throughout Europe : several stations in Germany[1], UK[2], soon a French LOFAR station in Nançay[3], and further contacts in several other countries[4]

FLOW context

- Official decision for funding the French station taken by CNRS (with srong support from Observatoire de Paris), with today >50% of the funding secured; installation planned end 2009
- Funding beyond 1 station very difficult except if instrumental development

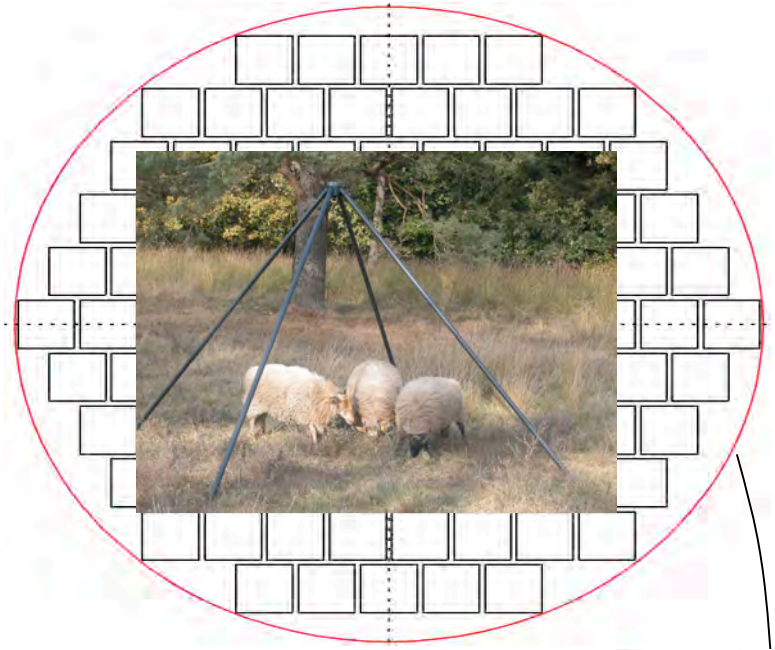
[1] http://lofar.mpa-garching.mpg.de/glow.html
[2] http://www.lofar-uk.org/
[3] http://www.lesia.obspm.fr/plasma/LOFAR2006/FLOW_Science_Case.pdf
[4] http://www.lofar.org/workshop/

LOFAR station

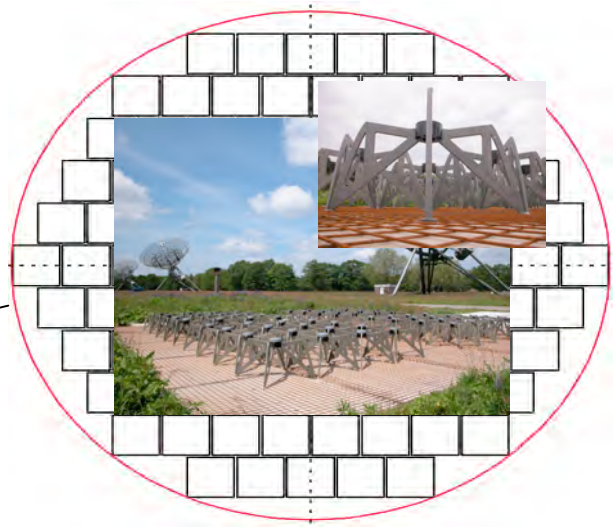
- One set of LBH = low-band-high antennas 30-80 MHz (existing)
- One set of HBA = high-band antenna tiles 120-240 MHz (near-future)
- LBL = low-band-low antennas 10-30 MHz (abandoned option)
- Connected to receiver units (RCU) that digitize and process the signals
- LOFAR77 design (before Rescope)
    - 77 stations in the Netherlands
    - 96 dual-polarization antennas (tiles) per set
    - Connected to 96 pairs of RCU[5]
    - Back-end cabinet - containing the RCU, clocks, power supplies…
    - Connected via a Gbit network link (1 to 10 Gb/s - tbd) to the central processor (Blue Gene, in Groningen, The Netherlands).
    - Each RCU switches between 3 input "channels" : LBL, LBH and HBA, that differ only by their input filters (same for LBL & LBH = 10-90 MHz)
        → LBH or HBA measurements not simultaneous, must share time

[5] in the following, we simply write "antennas" and "RCU" for "dual-polarization antennas" and "pairs of RCU"

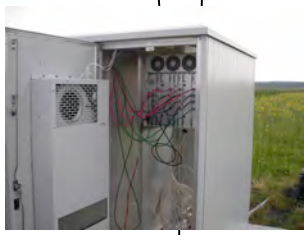
LOFAR station



Low Band Antennas (30-80 MHz)



High Band antennas (120-240 MHz)



60 m

50 m

+ 3 Gbit/sec link

Modes of operation

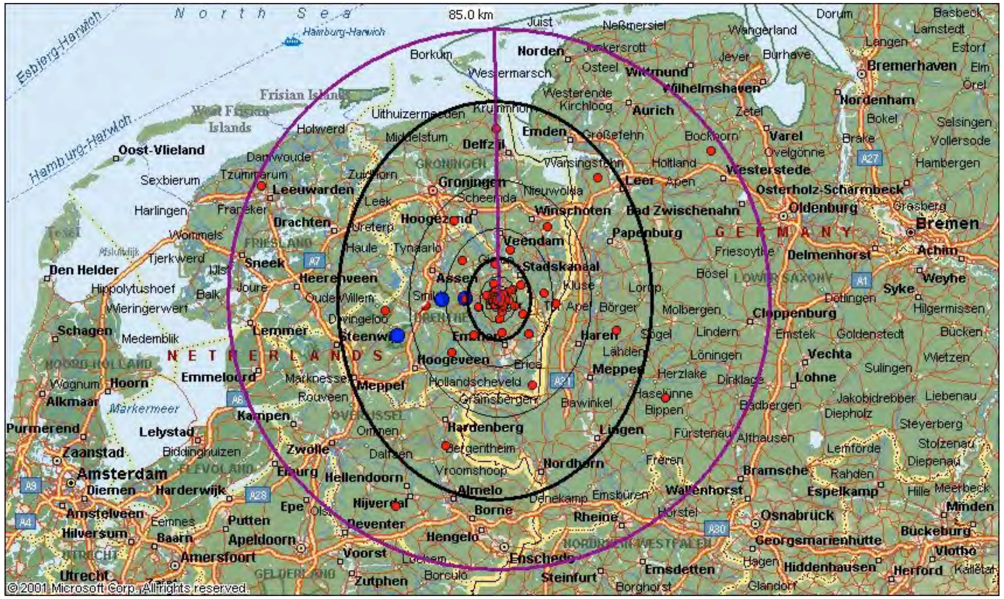
- In LOFAR77 design[6] :
  - All stations identical
  - 32 grouped in a central area a few km in diameter (the core)
  - 45 distributed in rings up to 100 km from the core (outer stations)
  - Core stations can be used with or without outer stations

- Core Stations used alone (Radio Sky Monitor mode)

  → multibeam survey of the whole sky with moderate angular resolution (a few arcmin.), over a maximum bandwidth of 120 MHz

  → heavy use for the EoR (Epoch of Reionization) key project

[6] The ongoing LOFAR rescope will lead to a reduced number of Dutch stations and fewer antennas per core station.


North Sea
85.0 km
Esbjerg-Harwich
Hamburg-Harwich
Frisian Islands
West Frisian Islands
Oost-Vlieland
Leeuwarden
Groningen
Emden
Wilhelmshaven
Bremerhaven
Oldenburg
Bremen
Assen
Emmen
Veendam
Stadskanaal
Hoogeveen
Meppel
Zwolle
Amsterdam
Almelo
Enschede
Deventer
Apeldoorn
Amersfoort
Utrecht
Osnabrück
Lingen
Papenburg
Leer
Cloppenburg
Nordhorn
NETHERLANDS
GERMANY
LOWER SAXONY
FRIESLAND
GRONINGEN
DRENTHE
OVERIJSSEL
FLEVOLAND
GELDERLAND
NORDRHEIN-WESTFALEN
NOORD-HOLLAND
Markermeer
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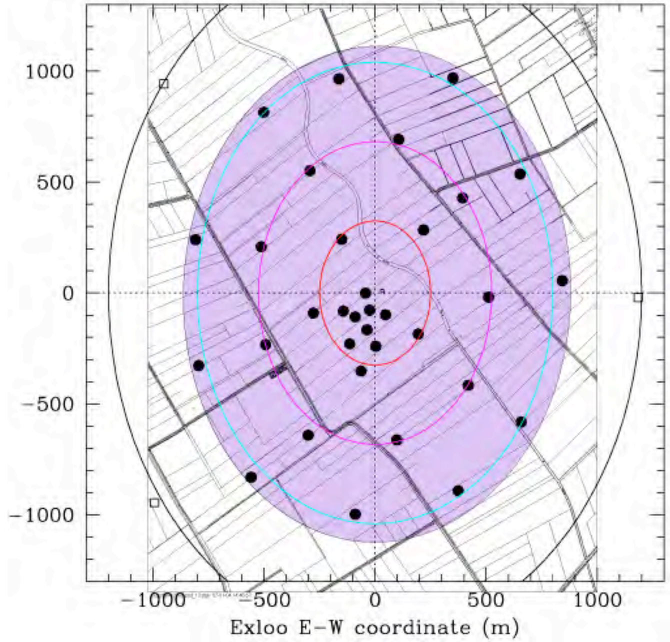
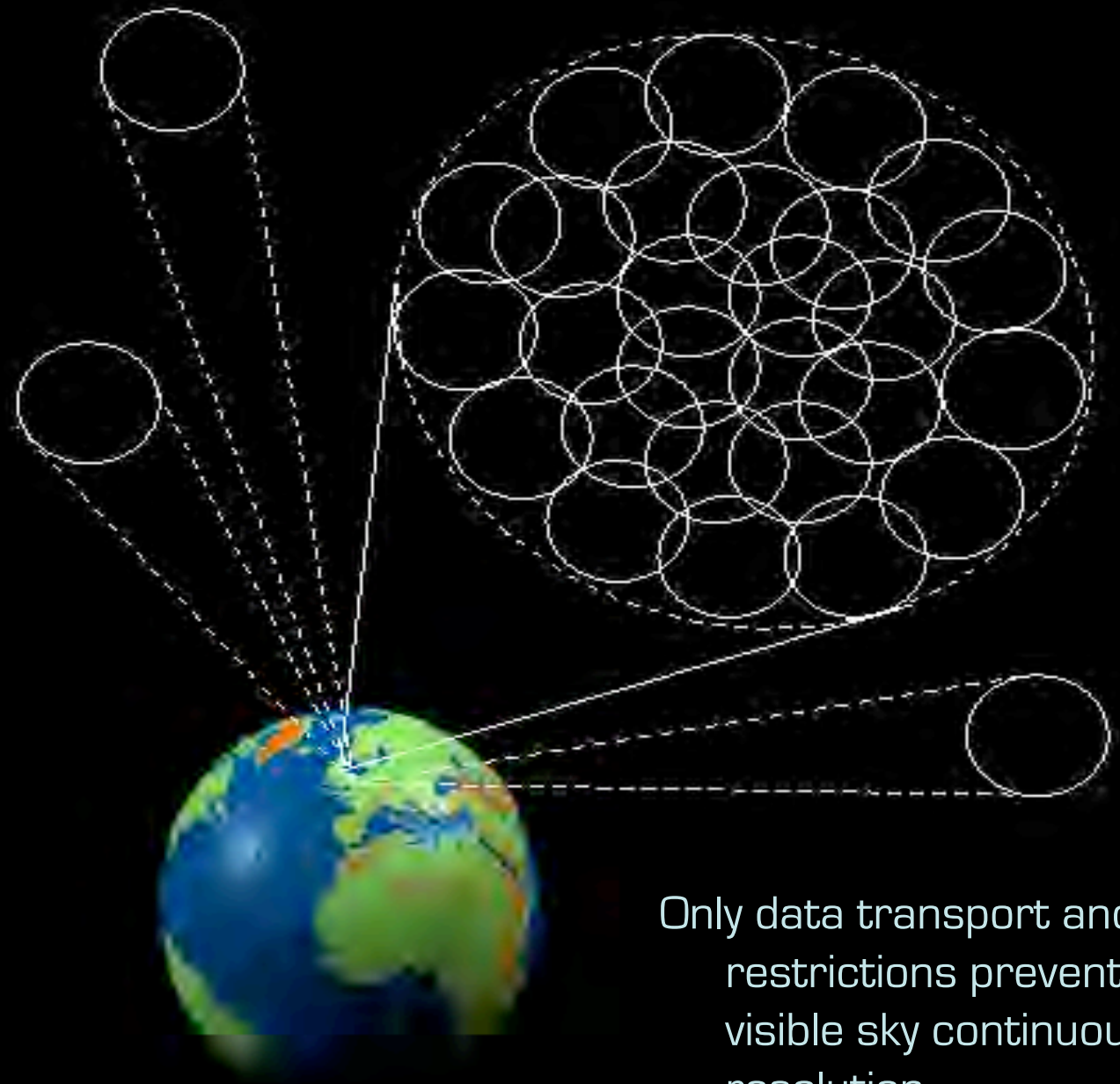

1000
500
0
−500
−1000
−1000
−500
0
500
1000
Exloo E−W coordinate (m)

A NEW TOOL: Multiple (up to 24) station beams tile out a significant fraction of the entire compound element beam – and/or up to eight full array beams



This is the

Radio Sky Monitor

mode

Only data transport and processing power restrictions prevents monitoring the entire visible sky continuously at full sensitivity and resolution

- Core+outer stations used together
  - → maximal angular resolution (10") and sensitivity
  - → visibility (u,v) maps
  - → images sky patches, over a maximum bandwidth of 32 MHz

- Other possible modes of operation:
  - Core stations + possibly some outer stations as a single phased array, coherently synthesizing an instantaneous pencil beam (maximum bandwidth of 32 to 120 MHz)
  - Incoherent addition of the same stations to synthesize a broad instantaneous beam (maximum bandwidth of 32 to 120 MHz)

European distant stations

- European additional LOFAR stations (Extended LOFAR) at distances up to ~1000 km (or more) from the core

  → add longer baselines to the (u,v) plane (but with limited coverage)

  → eventually increasing by a factor ~10 the angular resolution in interferometric mode[7]

- In France, one LOFAR station in Nançay (fall 2009 ?), ~700 km from the Dutch core
- Standard European distant stations → moderate increase of LOFAR array sensitivity
- Significant increase of sensitivity would imply to multiply the number of stations

  → cost and data volume to be processed ↑

[7] http://www.lofar.org/conference_meetings/LOFAR_LOBAS_Science.pdf

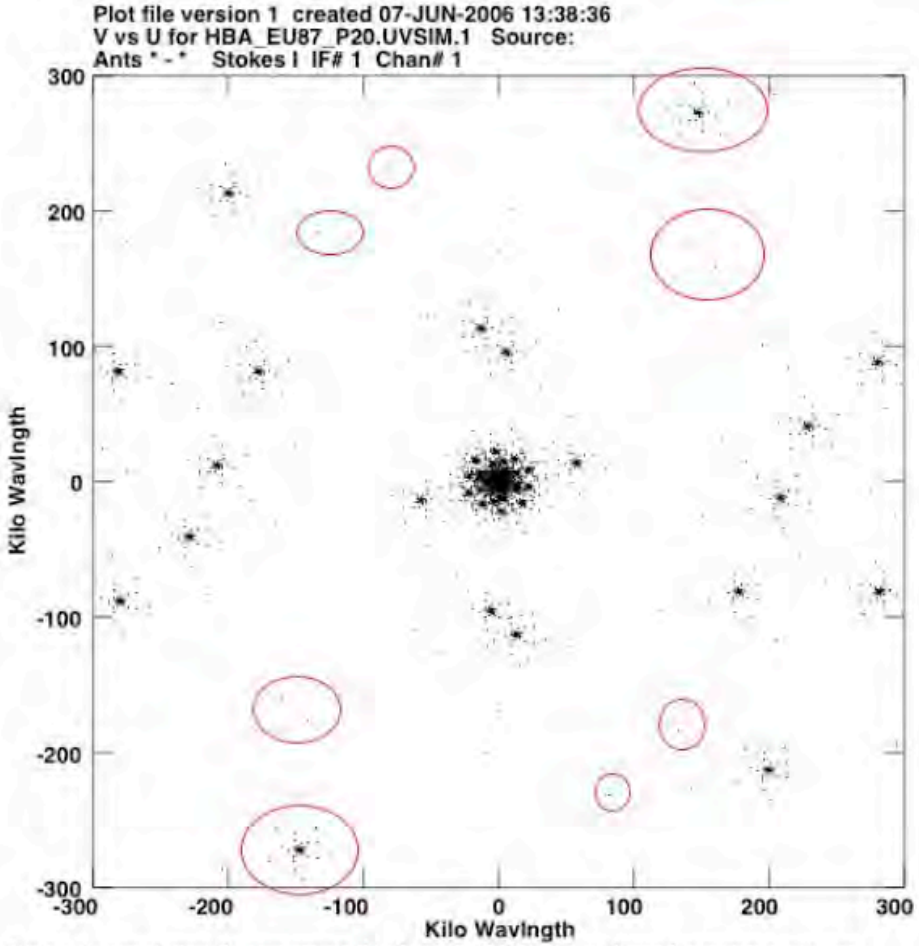


Figure 4 : simulation de couverture du plan u-v de LOFAR incluant les stations prévues en Allemagne et au Royaume-Uni. En rouge l'apport de la station de Nançay. Par intégration sur plusieurs heures, et grâce à la rotation terrestre la synthèse améliore encore la couverture du plan. Couverture instantanée pour H.A.=0 (limitée à une élévation de 45°) pour une déclinaison de 20° à 150 MHz.

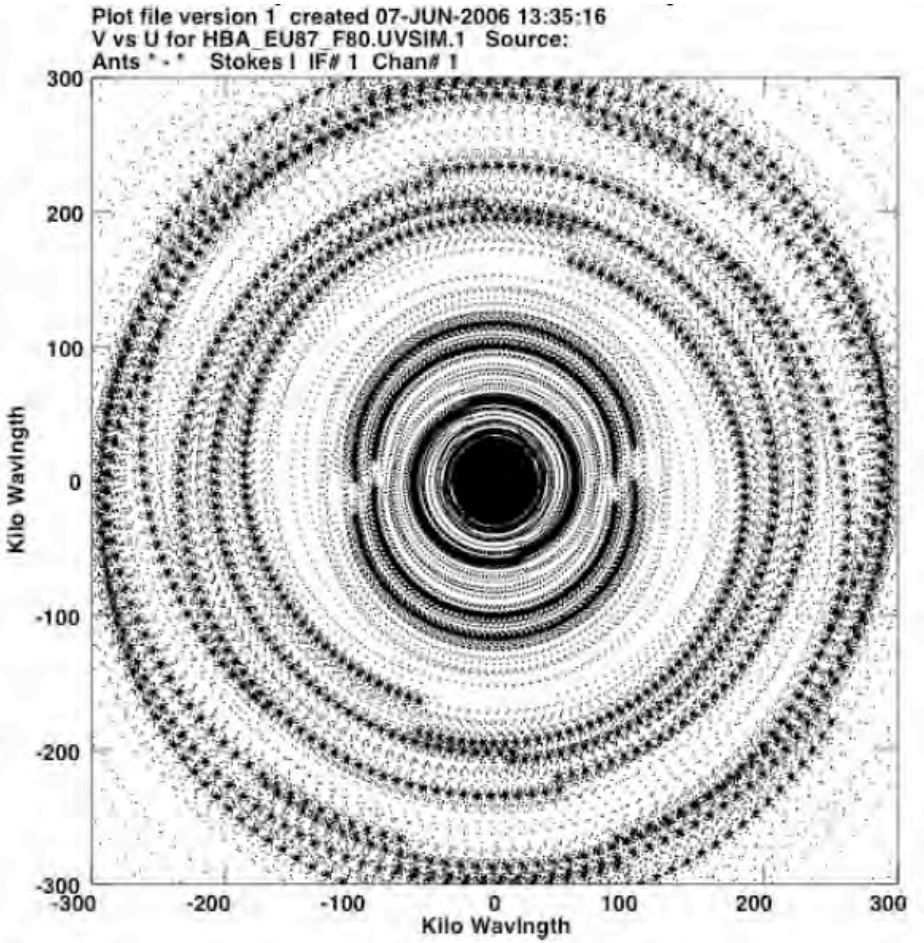


Figure 5 : Couverture du plan u-v pour une déclinaison de 80°, utilisant la rotation de la Terre pour une intégration pendant 8 heures.

LOFAR "Super" station (LSS) concept

Aim :

- Increase significantly the station sensitivity (thus its "weight" in the correlation with other stations) by ~1 order of magnitude
- Without increasing much its cost (by a factor <2)

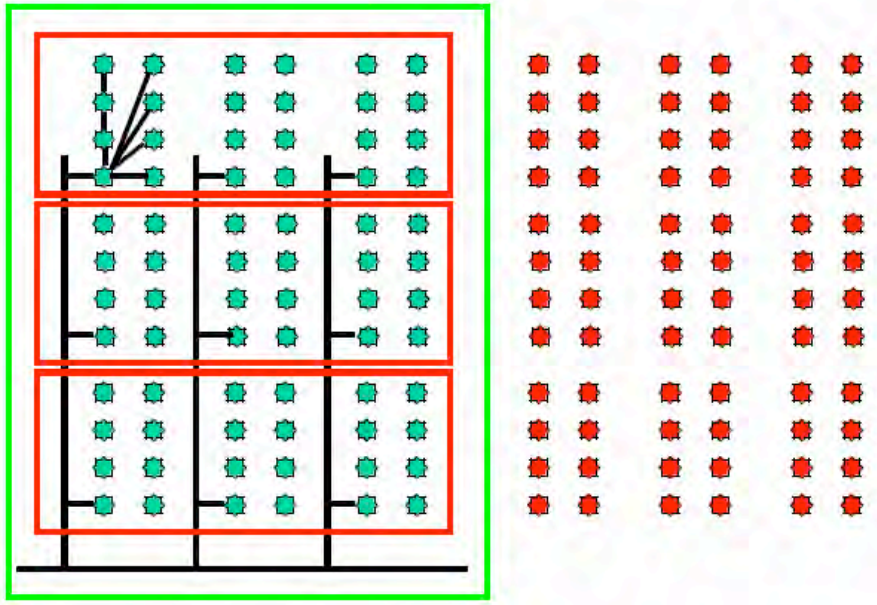
Basic idea :

- Add to a standard LOFAR station a set of 96 antennas, that will feed the 96 RCU
- Each antenna is a mini-phased array of N elementary antennas (N~10)
- Analog phasing of these mini-arrays (delay lines or other tbd method)
- Each one connected to one RCU input (LBL channel)

  → LSS sensitivity increased by a factor ~N

  → at cost of the new set of antennas + their adaptation to RCU, phasing (and control/command) system

NDA



- Standard RCU switches between standard LBH / HBA (standard station mode) to mini phased-arrays (LSS mode)
- LSS will include all the functionalities of a standard (distant) station when switched to LBA or HBA antennas
- ~ Same data flux as standard station (at zero order)

LSS operation (preliminary)

- In LSS mode : standard and non-standard use

Standard use : LSS as part of the LOFAR array

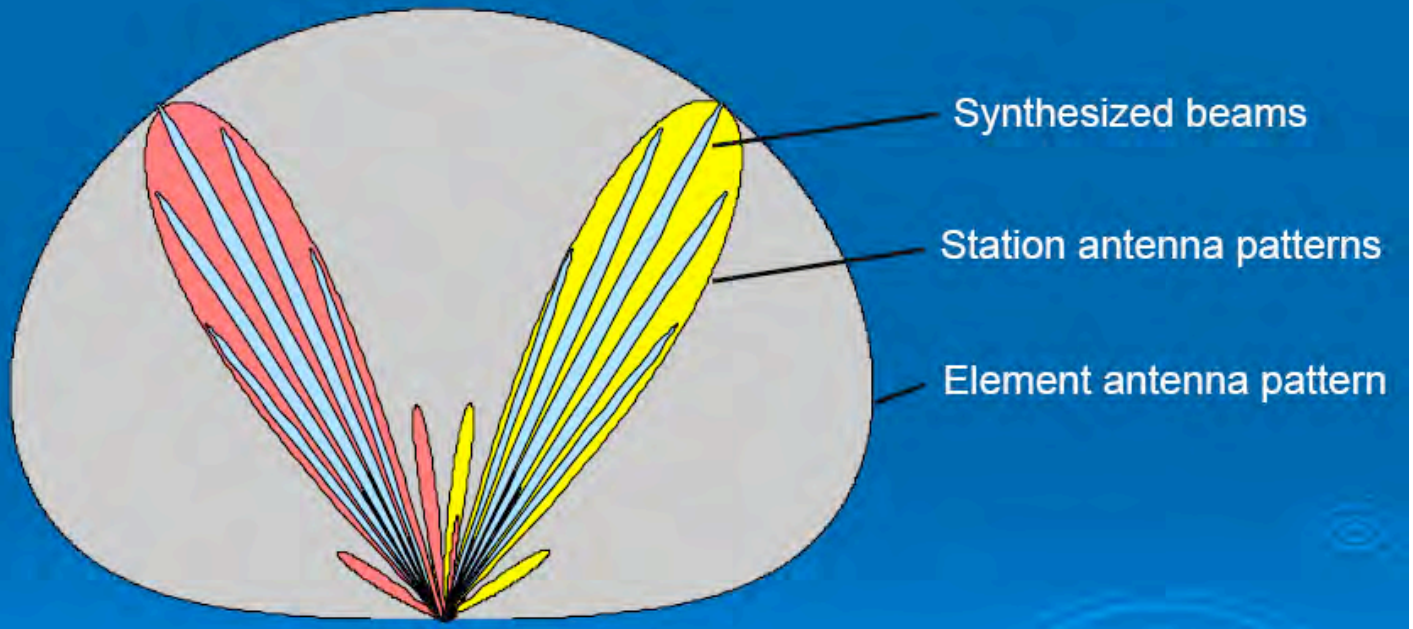
- LSS will provide high-sensitivity visibility measurements for long baselines in the (u,v) plane.
- LSS higher sensitivity → instantaneous detection of more faint point sources with higher S/N (albeit within a smaller FoV - tbd) → improves ionospheric calibration
- Better calibration at early stage in the project (first 2 years ?) when ionospheric calibration over the whole field (up to 1000 km from core) will not yet be possible ?
- If ionospheric conditions poor (and decorrelated above distant LOFAR stations) → correlation fringes drift fast → short integration times allowed by a more sensitive stations are better (in VLBI, large antennas remain usable when small ones are not)
- Possibly different antenna bandwidth, response, polarization, reduced FoV …

  → To be taken into account in the processing and correlation with all other LOFAR stations

  Correlation of signals from inhomogeneous stations (LSS / standard) done routinely in VLBI (& already necessary in rescoped LOFAR)

  → not a drawback ?

Aperture Array



But …

- Strong competition for the use of LOFAR observation time → since several modes of operation do not involve all stations, there may be a significant fraction of the time during which outer (and distant) stations can be used in non-standard mode

Non-standard use :

- When core used alone (e.g. EoR) → correlate together separately outer + distant stations (LSS providing core-like high-sensitivity visibility measurements for long baselines in the (u,v) plane)
- 2 core-like station (standard + LSS), or 2 synthezised large sub-arrays with comparable sensitivity → useful for coincidence observations of bursts (+ better transients detection efficiency and robustness) weak sources (e.g. exoplanets), thanks to decorrelated ionospheric perturbations, RFI, and instrumental effects at the 2 sub-arrays.
- Possibility for weak sources or transients, to correlate all stations together, and only process the subset of stations which were free of RFI or ionospheric decorrelation based on an examination of the data ?
- Various full array and sub-arrays schemes including a LSS may also improve high-resolution astrometry.

  → To be checked for a specific design and operating mode

  → Blue Gene (or its successor) should in principle be able to handle sub-arrays of stations from LOFAR

  → German LOFAR consortium is interested in doing correlations (possibly at Jülich) independent of Groningen at times.

Standalone mode ? (when not taking part in correlations with other LOFAR stations)

- LSS effective area 3-4 times that of the NDA
- Will have the sensitivity for detecting and studying strong radiosources such as Jupiter, the Sun, some pulsars, etc
- Adapted to user & student training purposes

  → requires the ability to extract locally the data output from the LOFAR back-end.

Technical issues

- Type of elementary antennas ?
  - Bandwidth (10 – X MHz ?)
  - Beam/FoV
  - Tests and calibration
  - cost, resources (size, power) …
- Mini-arrays and LSS configuration
  - mini-arrays all identical ?
  - compact/extended ?
- Phasing scheme / command
- Adaptation of mini-arrays to RCU input (specific filters …)
- Local products
  - switch Gbit link to local ?
  - storage + processing resources ? (TBB ?)

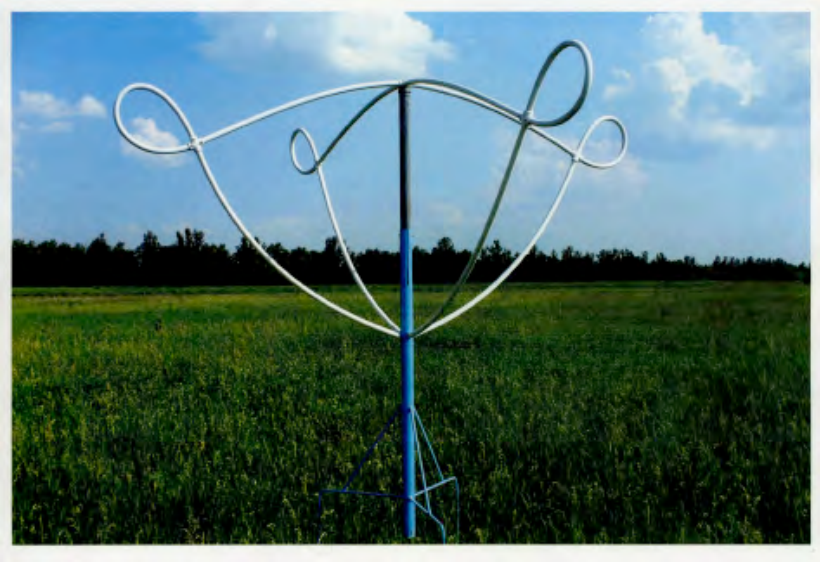
→ feasibility, cost + resources, instrument model/simulation, timeline ?

- Elementary antennas under evaluation for LSS
  - LOFAR LBH antennas (30-90 MHz)
  - NDA antennas (10-100 MHz)
  - Kharkov antennas (~10-60 MHz)
  - Short dipole (10->1000 MHz)
  - LWA antennas (20-80 MHz)
  - …

LWA

Codalema

Kharkov



Expected outcome of Worshop

- Scientific interest of LSS : impact for Key Science Projects ? for new KSPs *(e.g. LF polar without depolarization for KSP magnetism ; polarization calibration ; consequences on weighting the (u,v) sensitivity toward longer baselines → imaging easier ?)*

  Impact for high-resolution studies ? new scientific objectives ?

  → SCIENTIFIC CASE (why we want them at all ??)

- Start preliminary discussion of technical questions :
  - basic concept
  - advantages and inconvenience of LSS versus several colocated standard stations
  - antenna type, distribution, phasing … ?
  - products and standalone use
  - …
- Identify European collaborations :
  - Interest for several LSS in Europe ? (a few LSS operated together in a frequency range covering both LBL and LBA ranges might offer new perspectives) …

  → funding request to ANR ≤ 28/2/2008 ?

(expected 2 years development of full prototype from fall 2008 if successful)