LOFAR
Short and Long Baselines

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LOFAR sensor network

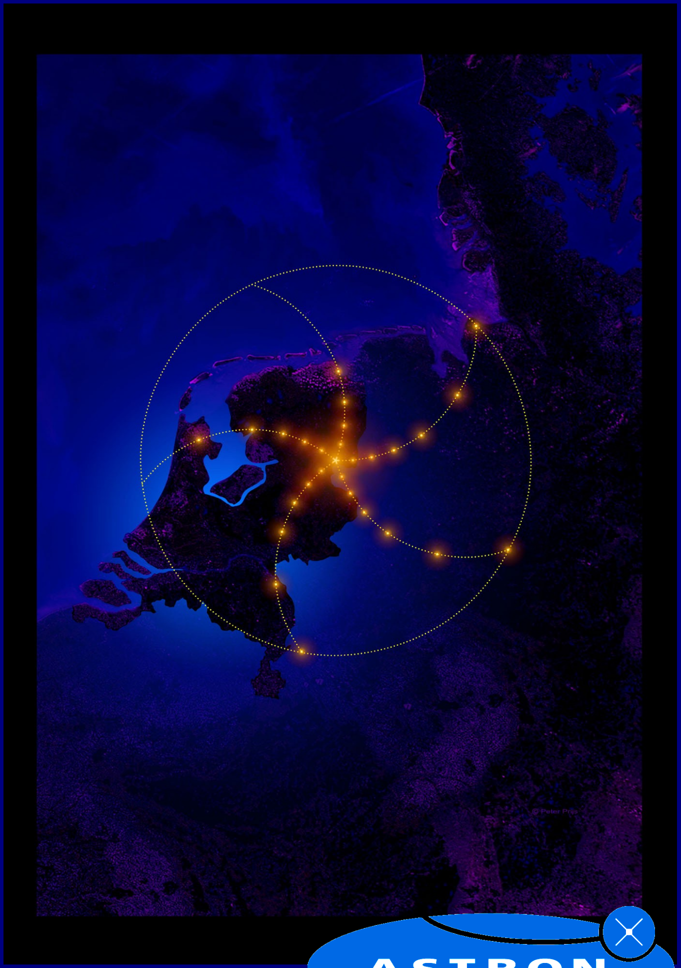
radio antennas

geophones

agriculture

LOFAR network - Radio astronomy

LOFAR - phased array telescope

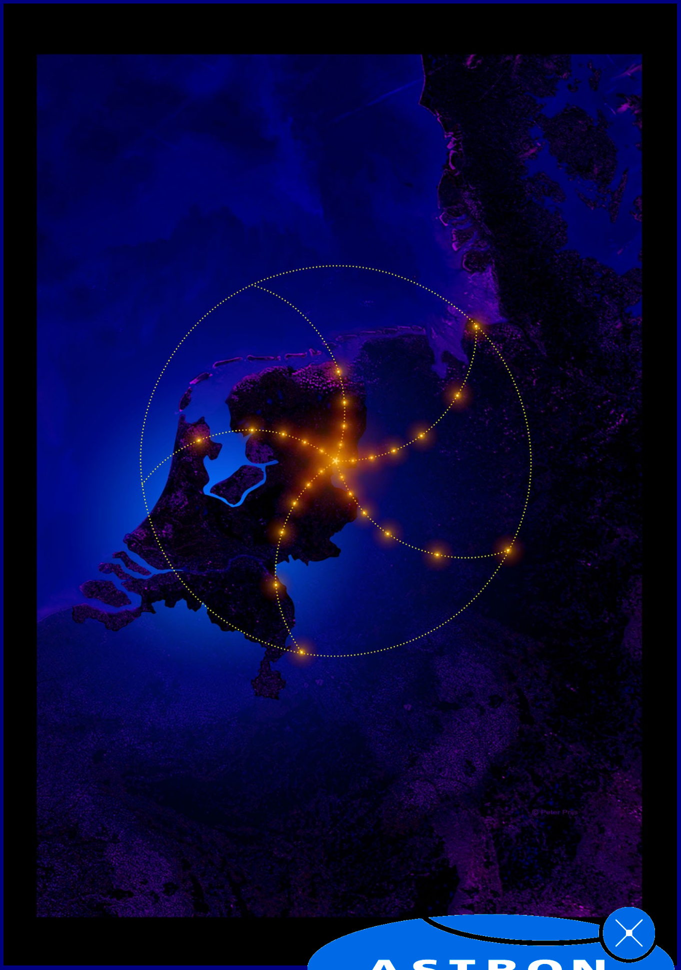


- Telescope the size of the Netherlands
- Frequencies: (10) – 30 – 240 MHz
- 10% Square Kilometer Array (SKA) prototype at low-frequencies
- Interferometer baselines: 100 km
- European Expansion to 1000 km

LOFAR network - Radio astronomy

- Aperture array: Replace big dishes by many cheap dipoles
  - 77 stations of dipoles antenna + extra sensors (geo+agro)
  - No moving parts: electronic beam steering
  - supercomputer synthesizes giant dish
- Current Funding: 74 M€
- Two orders of magnitude improvement in resolution and sensitivity
- Lots of science applications to be done as we will discuss

LOFAR - phased array telescope



LOFAR Radio antennas

Low band antenna: 30 – 80 MHz

96 antennas per station

High band antenna:120 – 240 MHz

96 tiles per station

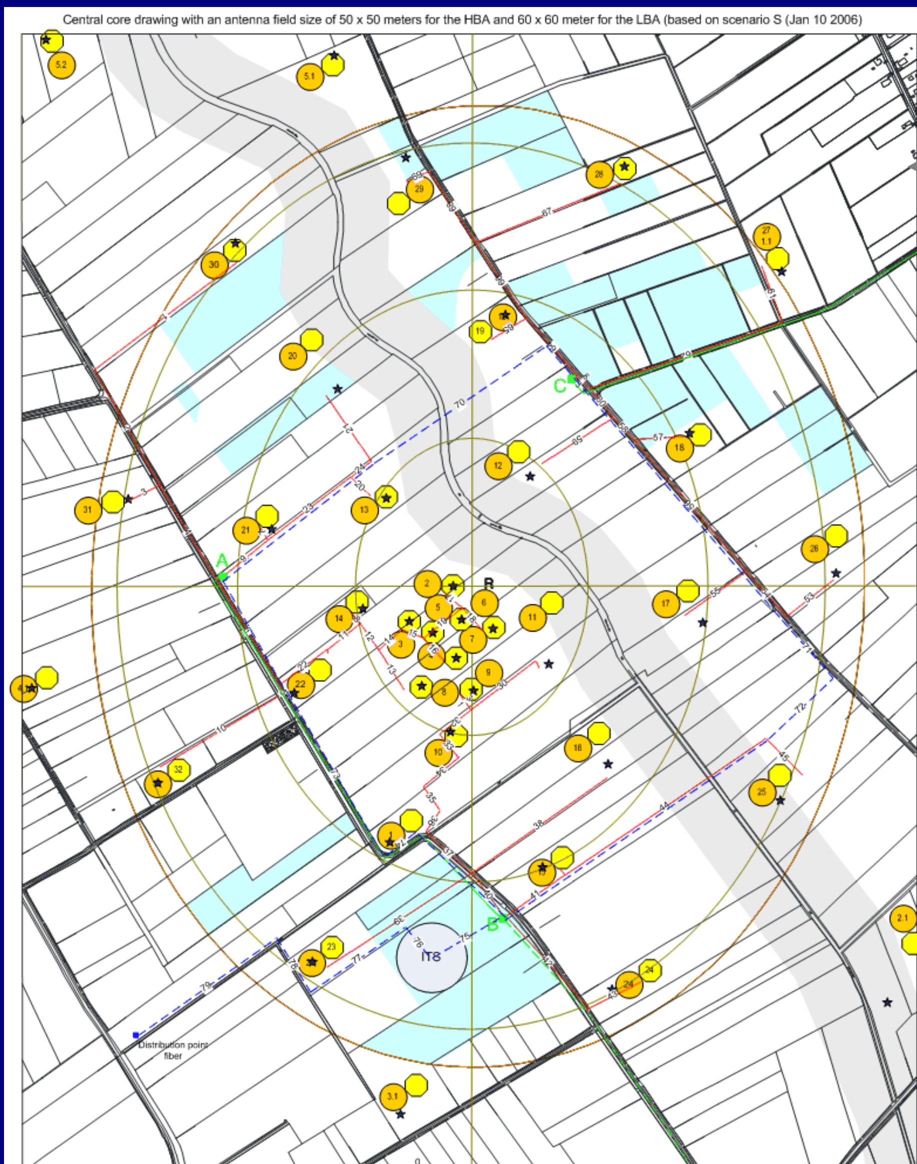
4x4 antennas per tile

LOFAR Science Drivers

- Epoch of Reionization - Groningen
  - PI: Ger de Bruyn
- Extragalactic Surveys - Leiden
  - PI: Huub Röttgering
- Transients and Pulsars - Amsterdam
  - PI's: Rob Fender, Ralph Wijers, Ben Stappers
- Cosmic Rays - Nijmegen
  - PI: Heino Falcke, Jan Kuijpers

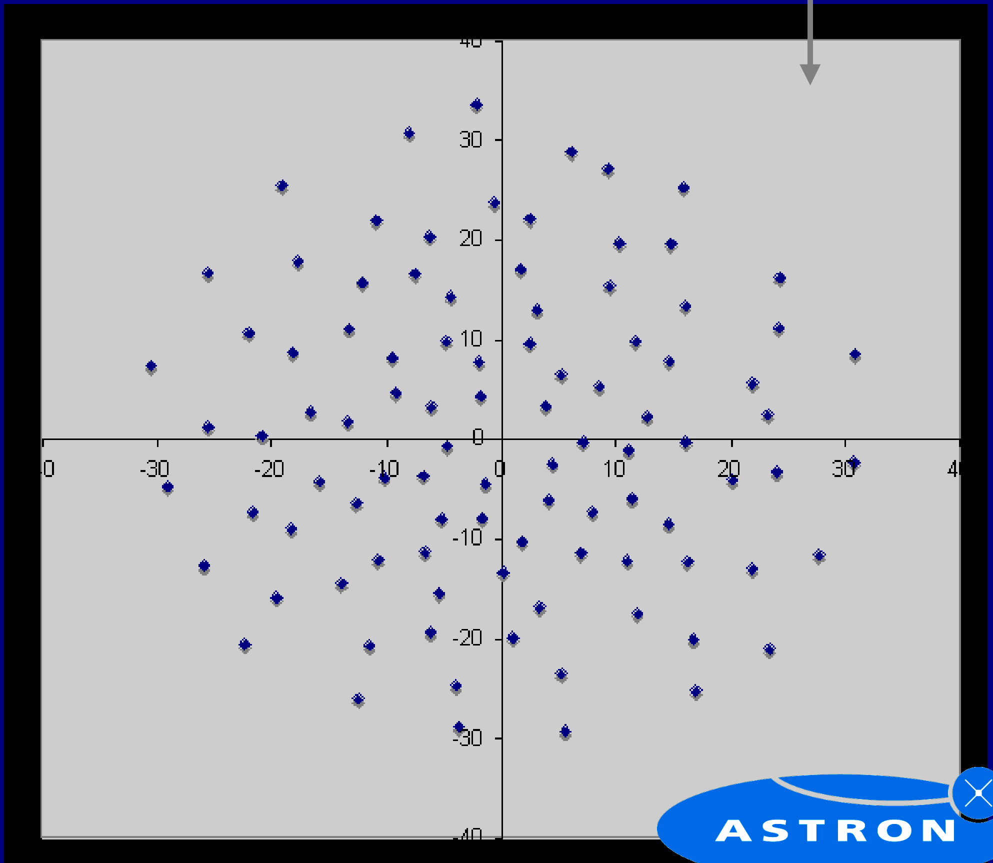
LOFAR Configuration (I)

LOFAR Configuration (II)

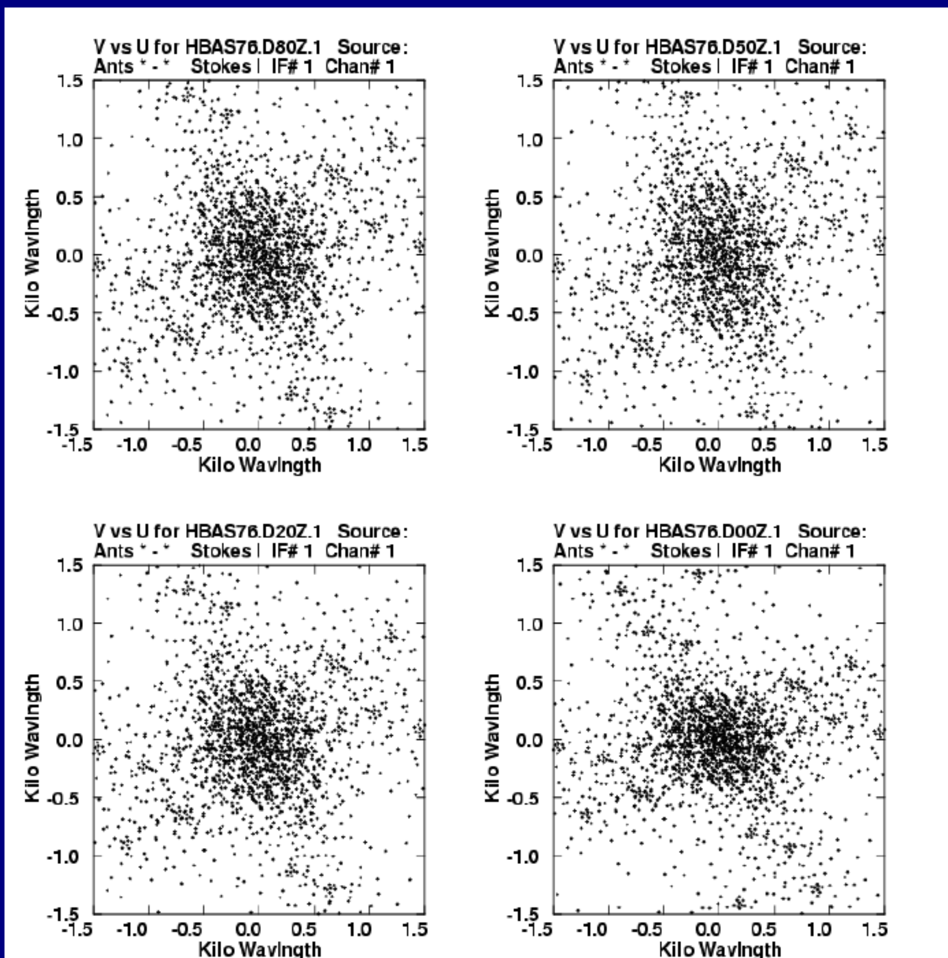


Core Station Lay-Out

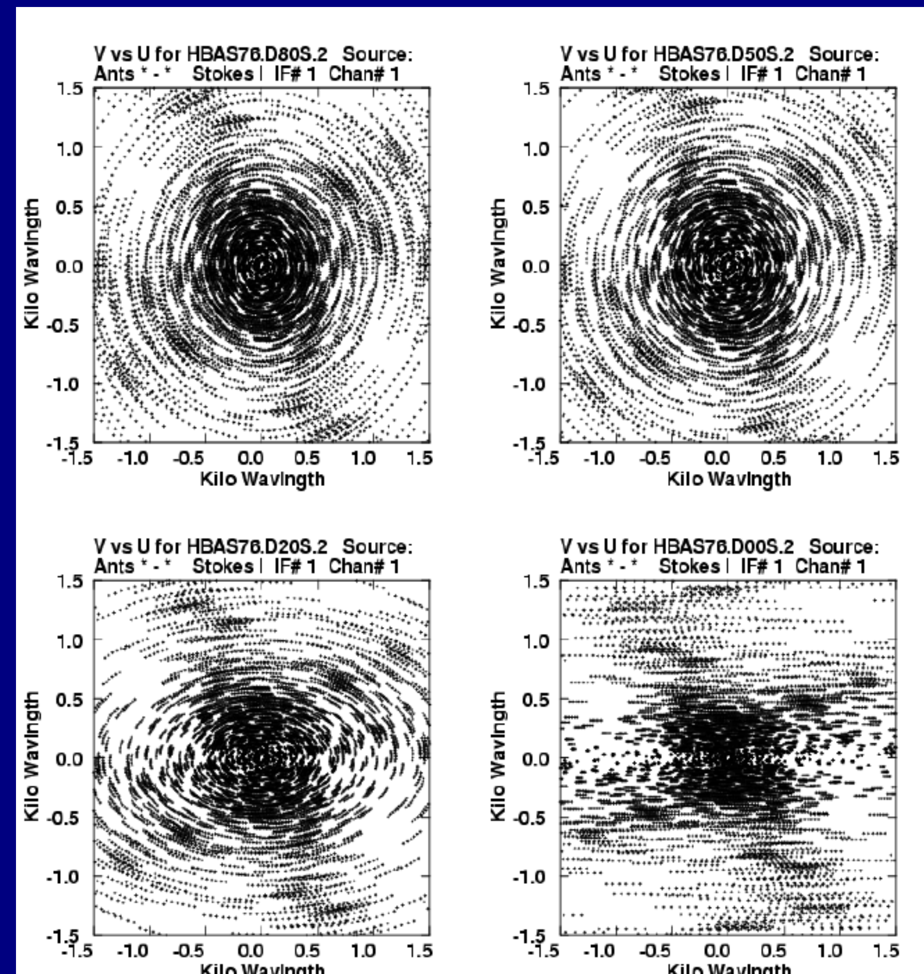
LBA Antenna Lay-Out



LOFAR UV coverage



Snapshot



-0.5 – +0.5 hrs

LOFAR Summary

System parameters		Value
Frequency range		30 – 80 MHz (low band) 120 – 240 MHz (high band)
Polarisations		2
Bandwidth		32 MHz
Spectral channels		42240 52736 (with 160 MHz Sample Rate)
Stations		32 in compact core 45 remote
Baseline length		100m to 100 km
Baselines		2926 Full stokes
Simultaneous digital beams (full array)	Full array	Configurable between 1 beam of 32 MHz and 8 beams of 4 MHz
	Central Core	24 beams of 32 MHz
Digital signal paths		14784 (2 pol x 96 channels per station)
Sample bit depth		12 bit
Correlator capacity		399 10^9 Correlations/sec
Tied array beamformer capacity		128 beams (full array)
Storage capacity		5 days raw data 1 month reduced data
Data export capacity		20 Gbit/s = 200 TByte/day
Spectral resolution		0.76 kHz 0.61 kHz (with 160 MHz Sample Rate)
Correlator dump time		1 second

Imaging Performance

ν/MHz	*λ/m*	***Beam Size***		***Effective collecting area***		T_{rec}/K
		Core	***Full Array***	***Core***	***Full Array***	
30	10	21'	25"	$8.0\cdot10^4$ m^2	$1.9\cdot10^5$ m^2	max 20% T_{sky}
75	4	8.3'	10"	$1.2\cdot10^4$ m^2	$2.9\cdot10^4$ m^2	max 20% T_{sky}
120	2.5	5.2'	6.0"	$8.6\cdot10^4$ m^2	$2.0\cdot10^5$ m^2	130
200	1.5	3.1'	3.5"	$6.6\cdot10^4$ m^2	$1.6\cdot10^5$ m^2	190

ν/MHz	*λ/m*	***Point Source Sensitivity***		***Primary Beam (50 m station)***
		Core	***Full Array***	
30	10	4.8 mJy	2.0 mJy	11.5º
75	4	3.3 mJy	1.3 mJy	4.6º
120	2.5	0.19 mJy	0.07 mJy	2.9º
200	1.5	0.07 mJy	0.03 mJy	1.7º

1 hr, 2 pol., 4 MHz

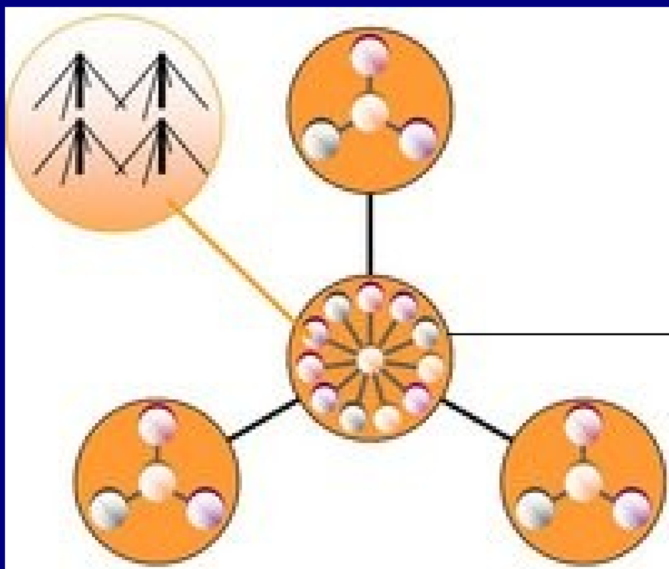
Observing Modes

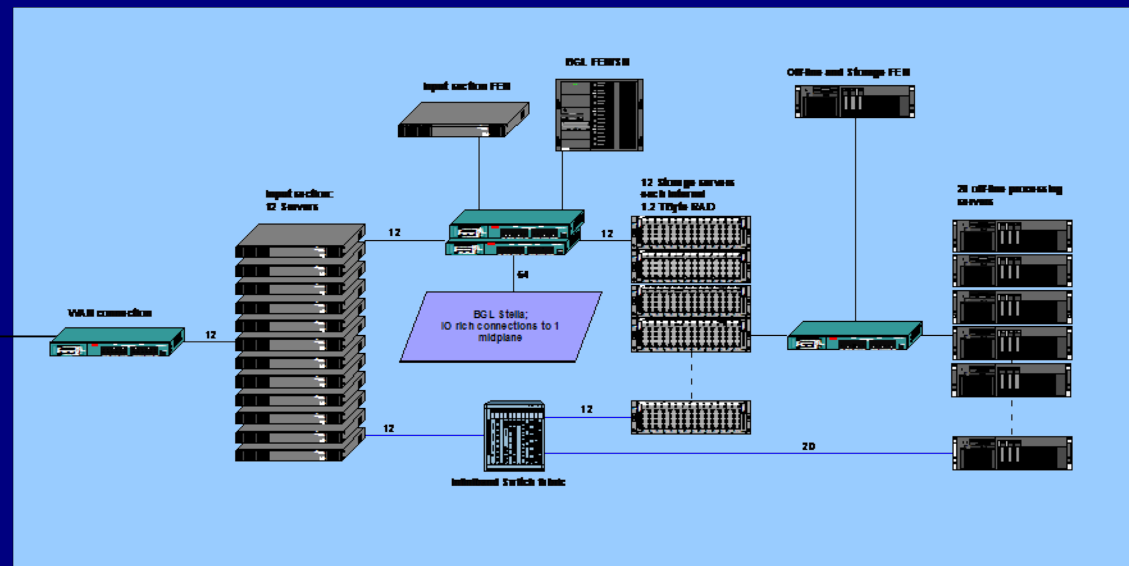
- Synthesis Imaging
  - Standard Data Products: uv-data; image cubes
  - Complication: station beams not constant
- Transient Detection
  - Based on snap-shots for the shortest periods
  - Sub-Band data can also be buffered
- Tied Array beamforming
  - Incoherent
  - Coherent
- Antenna-based Buffering
  - 1 sec at full-digitised bandwidth
  - detection/triggering for CR

Purpose of CS1

- Procurement Process
- Roll-out of a station (cost/time/planning)
  - digging trenches
  - laying fibres
  - installing hardware
  - tests
- Engineering Tests
- Scientific Tests

CS1

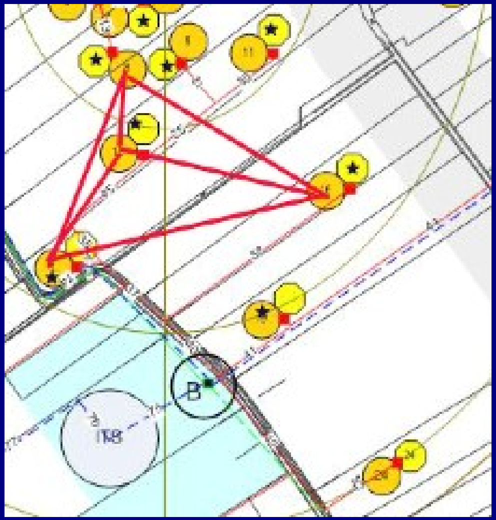




- Hardware of 1 station
- Distributed over 4 station locations
- 12 Gbps connection to Groningen
- Downscaled Central Processing installation

CS1

- Operational Autumn 2006 with final prototype hardware
- 96 dual-dipole antennas:
  - grouped in 4 clusters
  - one cluster with 48 dipoles
  - three clusters of 16 dipoles
  - distributed over ~ 500m.
  - with 24 microstation in total
  - of 4 dipoles each



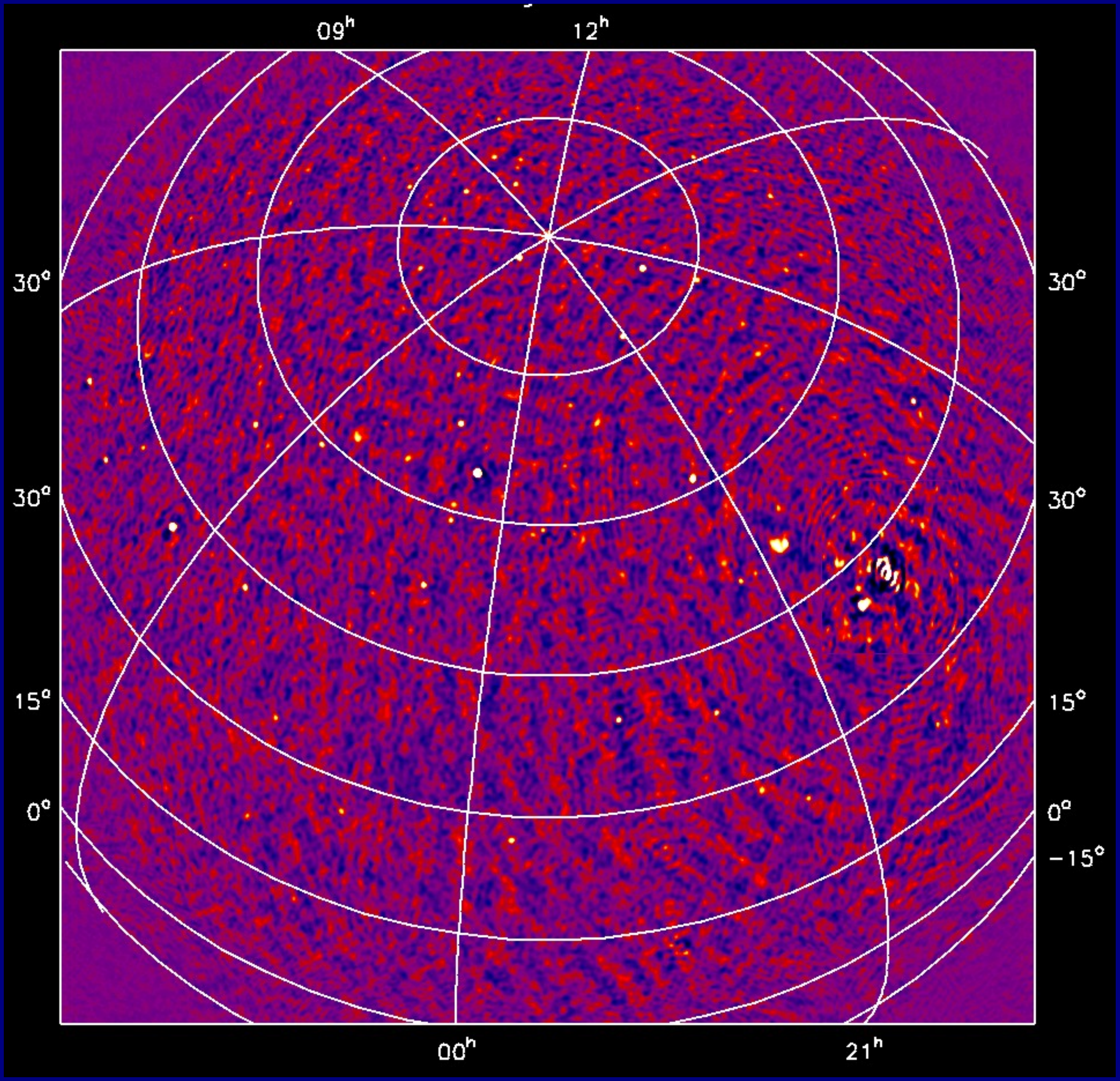
- Goal: Emulate LOFAR with 24 micro-stations at reduced bandwidth or act as a single station at full BW
- TBB & HBA will follow later
- Conclude CDR Based on CS-1 Results


LOFAR
CS-8
CS-10
CS-1
CS-16
ASTRON

LOFAR

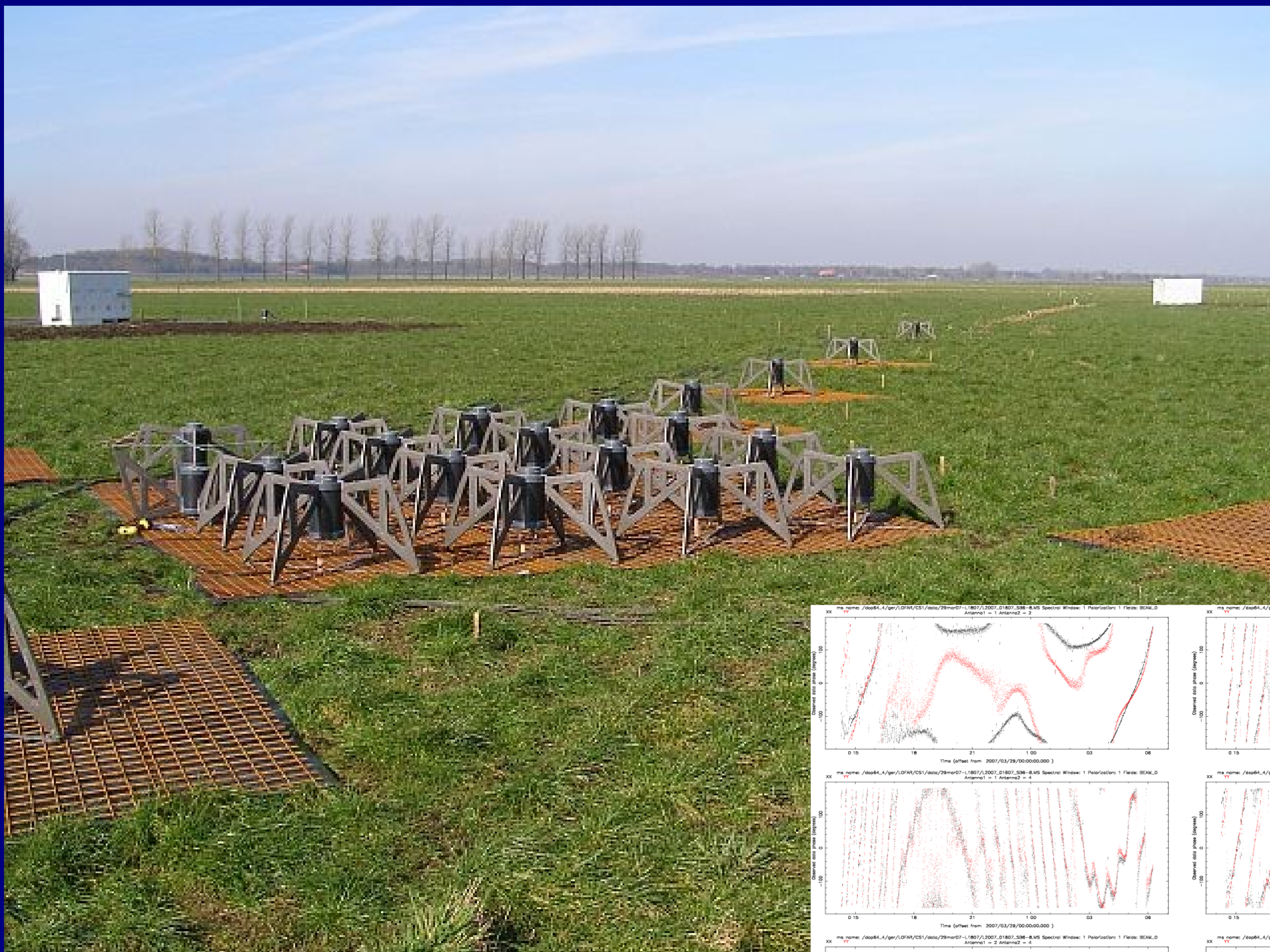
ASTRON

Finally: A CS1 Image

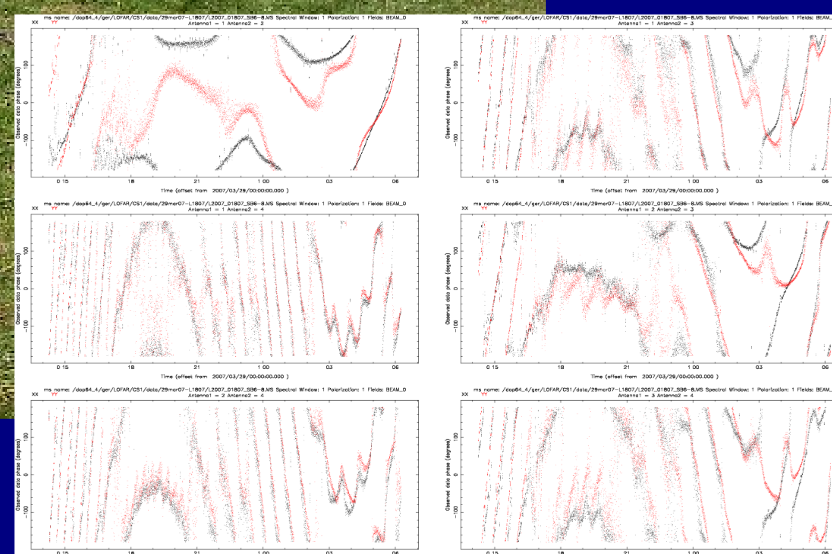


50MHz, (Sarod Yatawatta)

HBA antennas in Exloo



First interferometric fringes between 4 HBA antennas on 5, 8, 13(2x), 21 and 26m baselines (225 MHz)
29 March 2007



1st International Station Effelsberg - MPIfR

- Start Roll in Nov/Dec 2006
- First Light in March 2007

- First on-line correlation with Exloo expected autumn 2007

International Stations
Long baselines

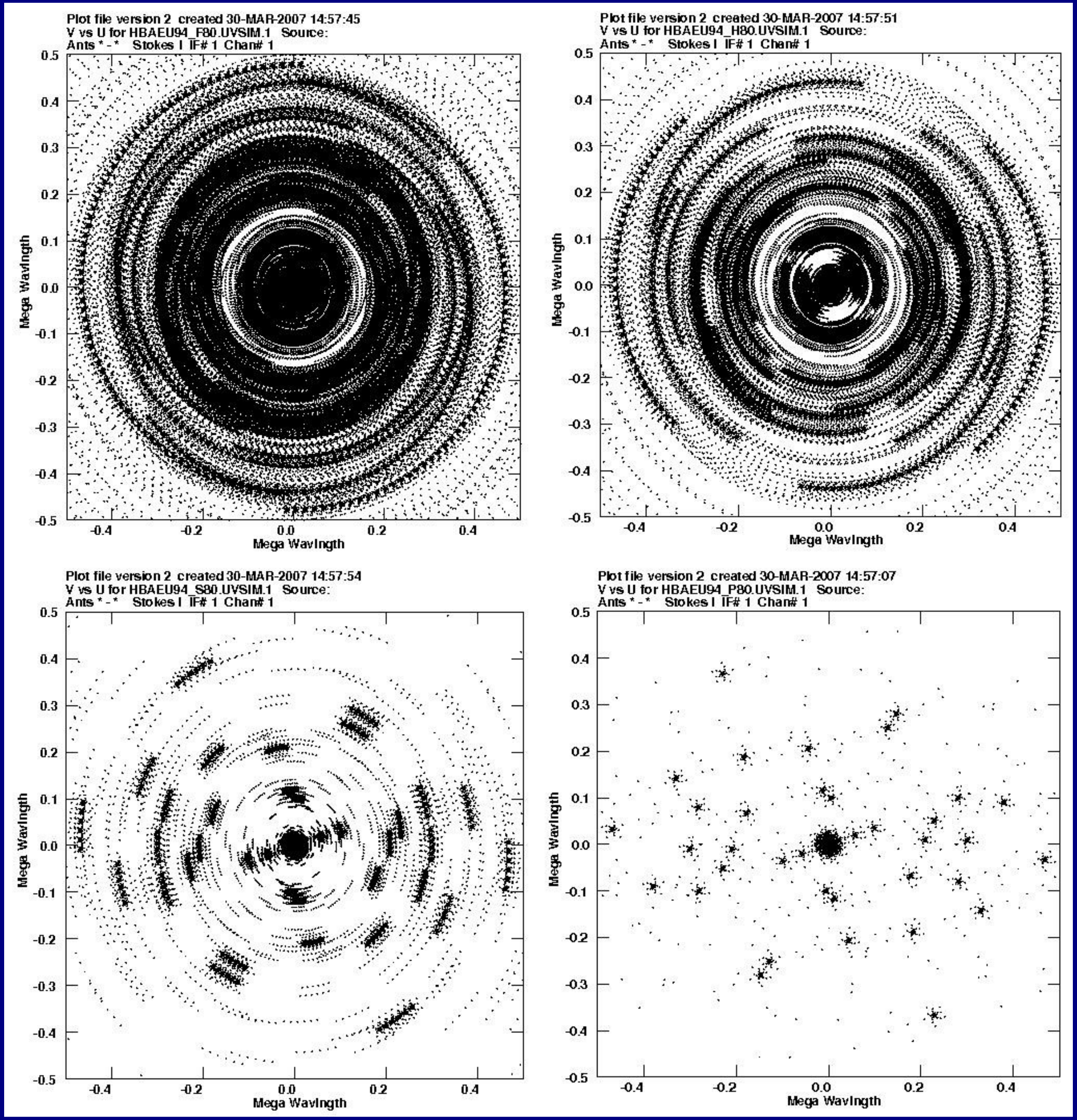
Activities towards an E-LOFAR in:

- Germany
- UK
- France
- Sweden
- Italy
- Poland

E-LOFAR

Stockholm
Oslo
Tallinn
ESTONIA
Stavanger
Aberdeen
Göteborg
Riga
Glasgow
Edinburgh
North
Sea
UNITED
KINGDOM
DENMARK
Copenhagen
Malmö
LITHUANIA
Vilnius
Kaliningrad
Belfast
Gdańsk
Leeds
Manchester
Liverpool
Hamburg
Bremen
Berlin
Warsaw
Poznan
POLAND
Łódź
Wroclaw
Birmingham
Amsterdam
Rotterdam
Cardiff
Essen
Cologne
Leipzig
Brussels
Lille
GERMANY
Prague
Kraków
Frankfurt am Main
Luxembourg
CZECH REPUBLIC
Brno
SLOVAKIA
Bratislava
Guernsey (U.K.)
Jersey (U.K.)
Paris
Stuttgart
Strasbourg
Vienna
Budapest
Nantes
AUSTRIA
HUNGARY
Zurich
Bern
Vaduz
FRANCE
Geneva
Ljubljana
Zagreb
Bay of Biscay
SLOVENIA
Lyon
Milan
Venice
Turin
Bordeaux
MASSIF CENTRAL
BOSNIA AND HERZEGOVINA
Belgrade
Bilbao
Genoa
CROATIA
Toulouse
MONACO
Sarajevo
SERBIA AND MONTENEGRO
Andorra la Vella
Marseille
Florence
PYRENEES
ITALY
Adriatic Sea
Zaragoza
ANDORRA
Corsica
Rome
Tirana
Barcelona
VATICAN CITY
ALB.
Naples
Valencia
Sardinia
Tyrrhenian

E-LOFAR: uv-coverages



E-LOFAR

Table 1.2: Resolutions achievable with a LOFAR extended to station separations of 150, 500, 1000km.

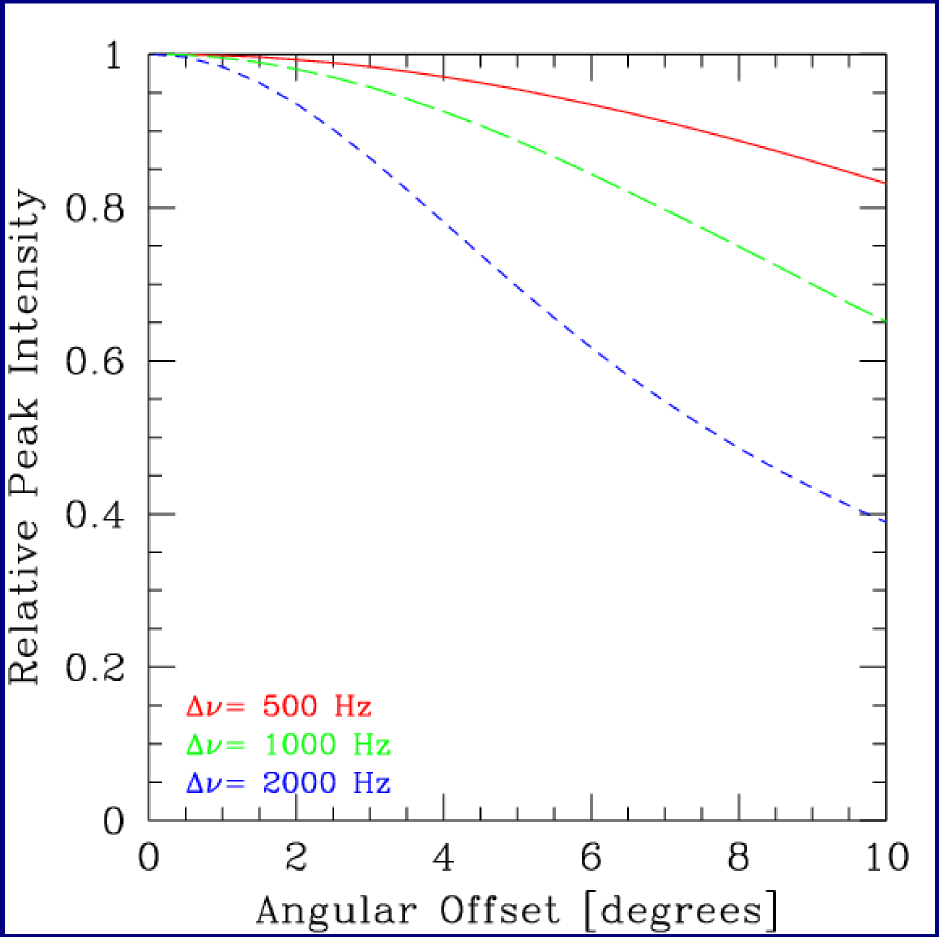
	$\nu = 30$ MHz $\lambda \sim 10$m	$\nu = 75$ MHz $\lambda \sim 4$m	$\nu = 120$ MHz $\lambda \sim 2.5$m	$\nu = 240$ MHz $\lambda \sim 1.25$m
150 km	17"	6.7"	4.2"	2.4"
500 km	5"	2"	1.2"	0.6"
1000 km	2.4"	1"	0.6"	0.3"

Science to be done:

- Low-energy tail of relativistic electrons contained in radio jets
- Study the history of radio sources in the Universe (Star forming galaxies)
- Study of lensed objects
- Map HII regions of Milky Way
- Exoplanet & Solar Science

E-LOFAR: Doable?

- Time average smearing ~ τ = 0.25s
- Bandwidth smearing $\Delta\nu$ = 1kHz



BlueGene is capable of that!

50MHz & τ=0.25s
Simulation by J.M. Anderson

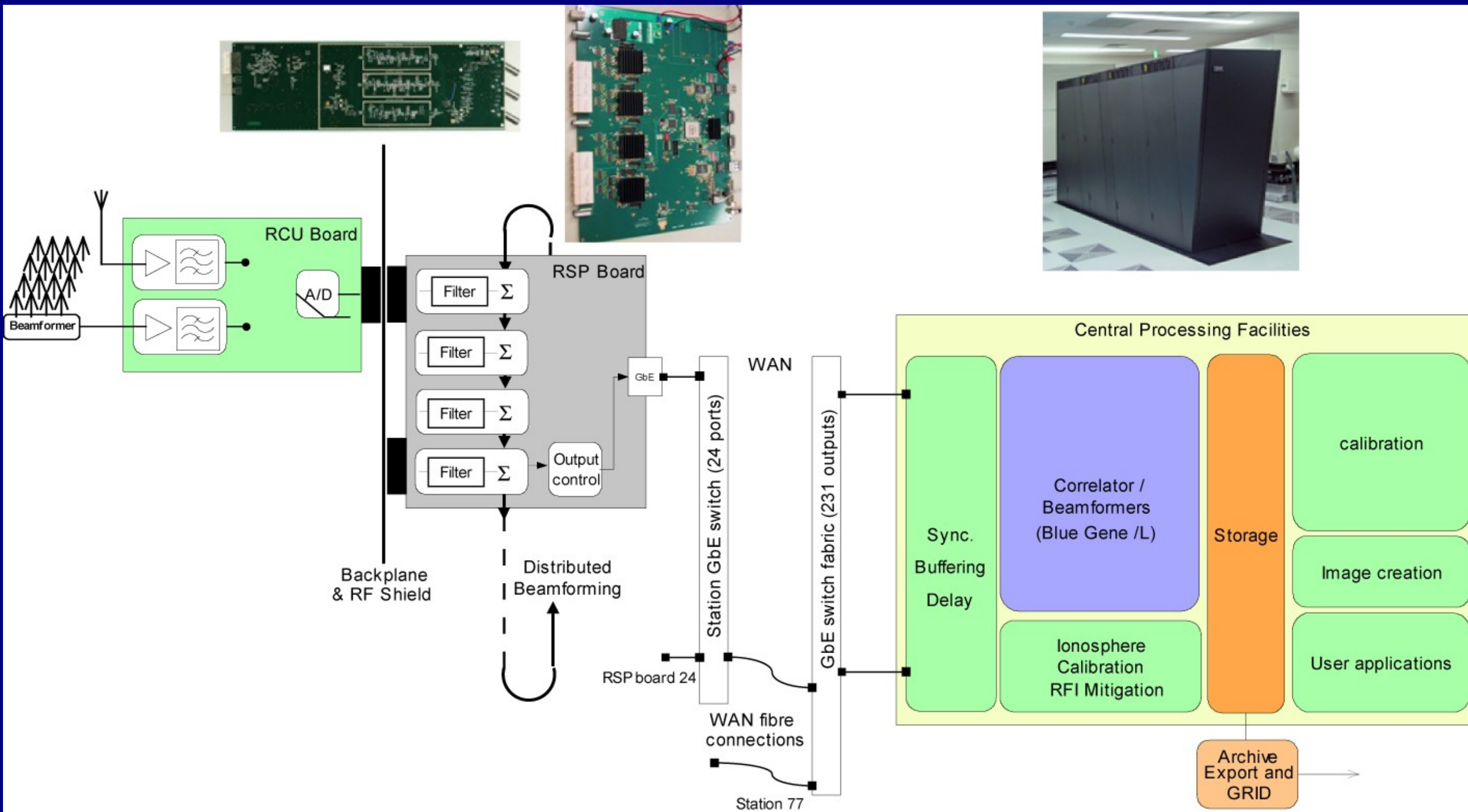
E-LOFAR: Calibratable?

- YES!
- LBA more challenging than HBA
- It has been done before
- Wide field imaging might be limited by processing power in the beginning

Exciting times ahead

- Soon prototype HBA tiles go to Exloo
- The Transient Buffer Boards are almost ready
- Station in Effelsberg soon on-line
- Q3-2007 – Q2-2008: build 20 stations + 2-3 German stations + 1 in UK
- Continuing software development (BBS)
- Complete the rest of array 2008/2009

LOFAR Top Level Architecture: Data Flow

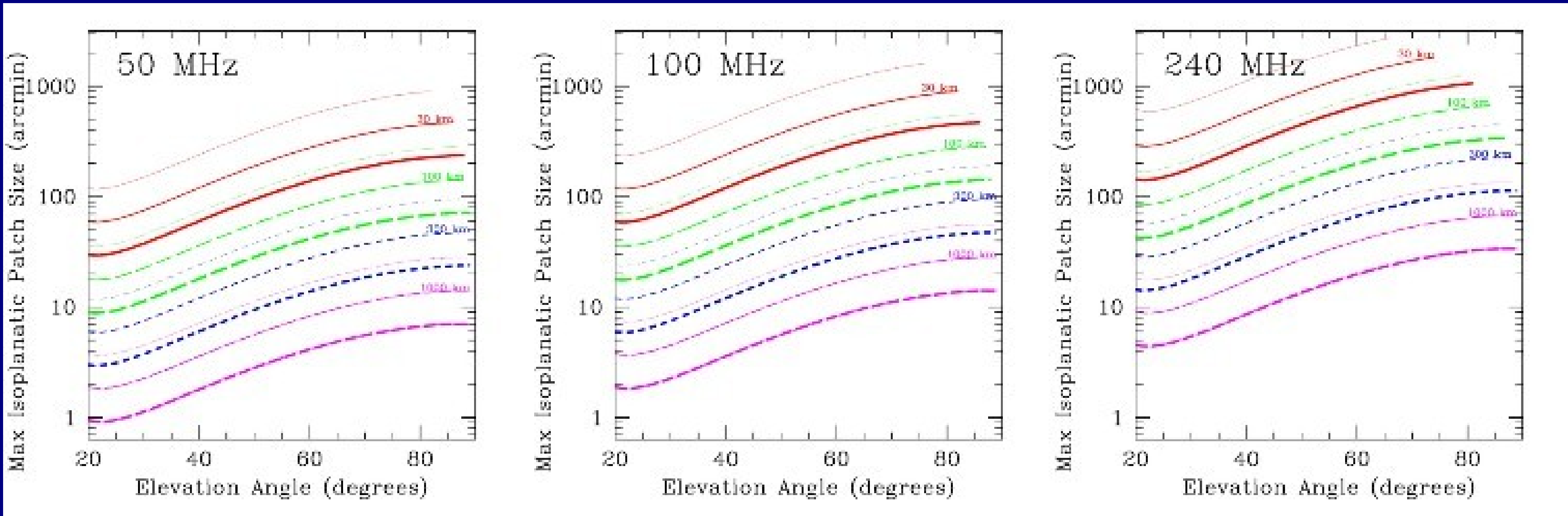


ASTRON

LOFAR History

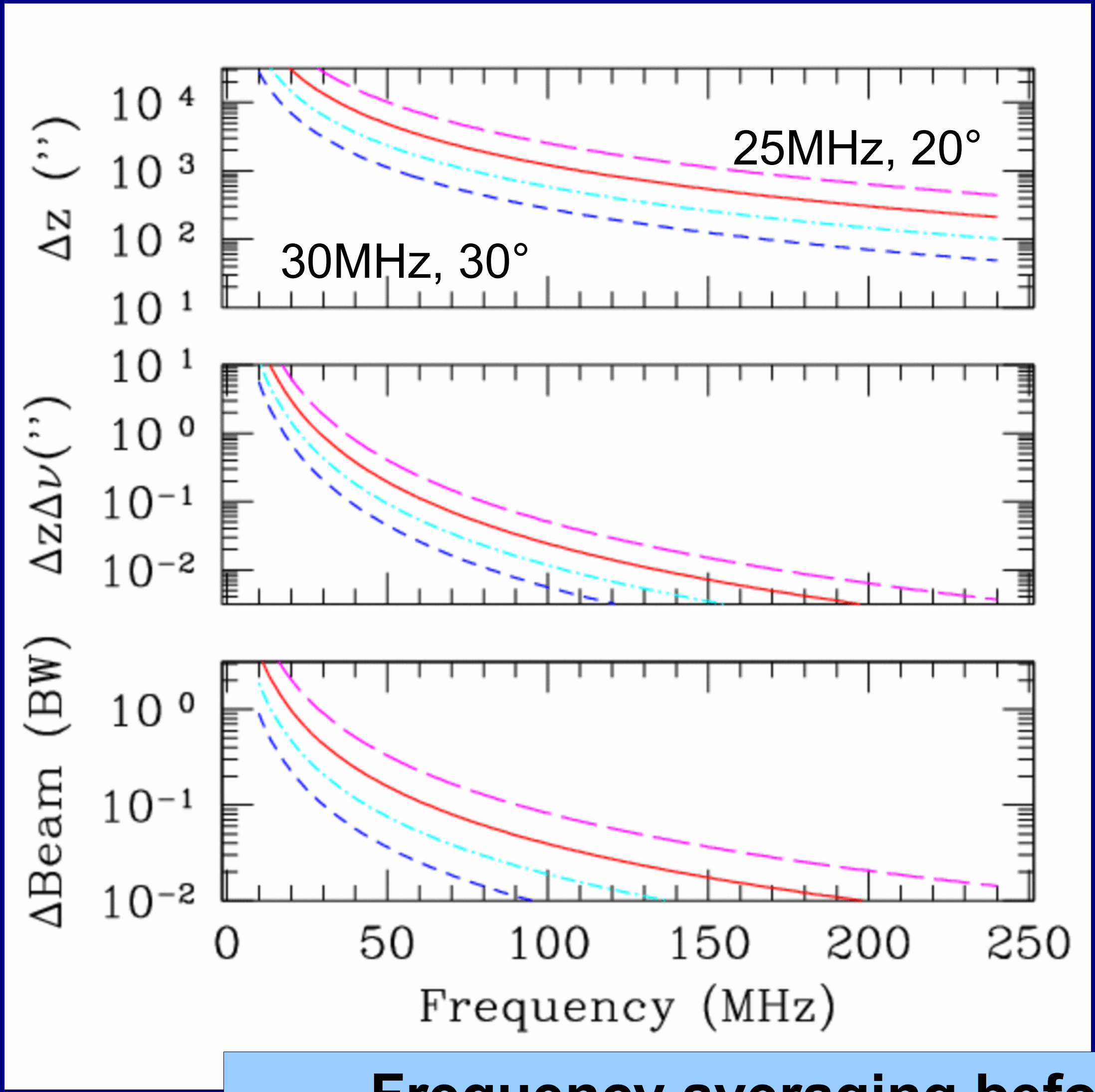
- Initial Design
- Funding decision
- Initial Test Station
- Sub-system Critical Design Reviews
- Roll-out of first station hardware – CS1

E-LOFAR: Calibratable?



Maximum isoplanatic patch size for different baseline lengths.

The Ionosphere - Scattering



Refraction of a source

Difference in refraction for two frequencies separated by 1kHz

Differential refraction of the middle plot as a function of synthesised beam width for a 1000km baseline

Frequency averaging before calibrating for the Ionosphere might not be advisable (at least for LBA)!

Observations at night