Planetary studies with LOFAR and contribution to the development of a LOFAR Super-Station

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LOFAR

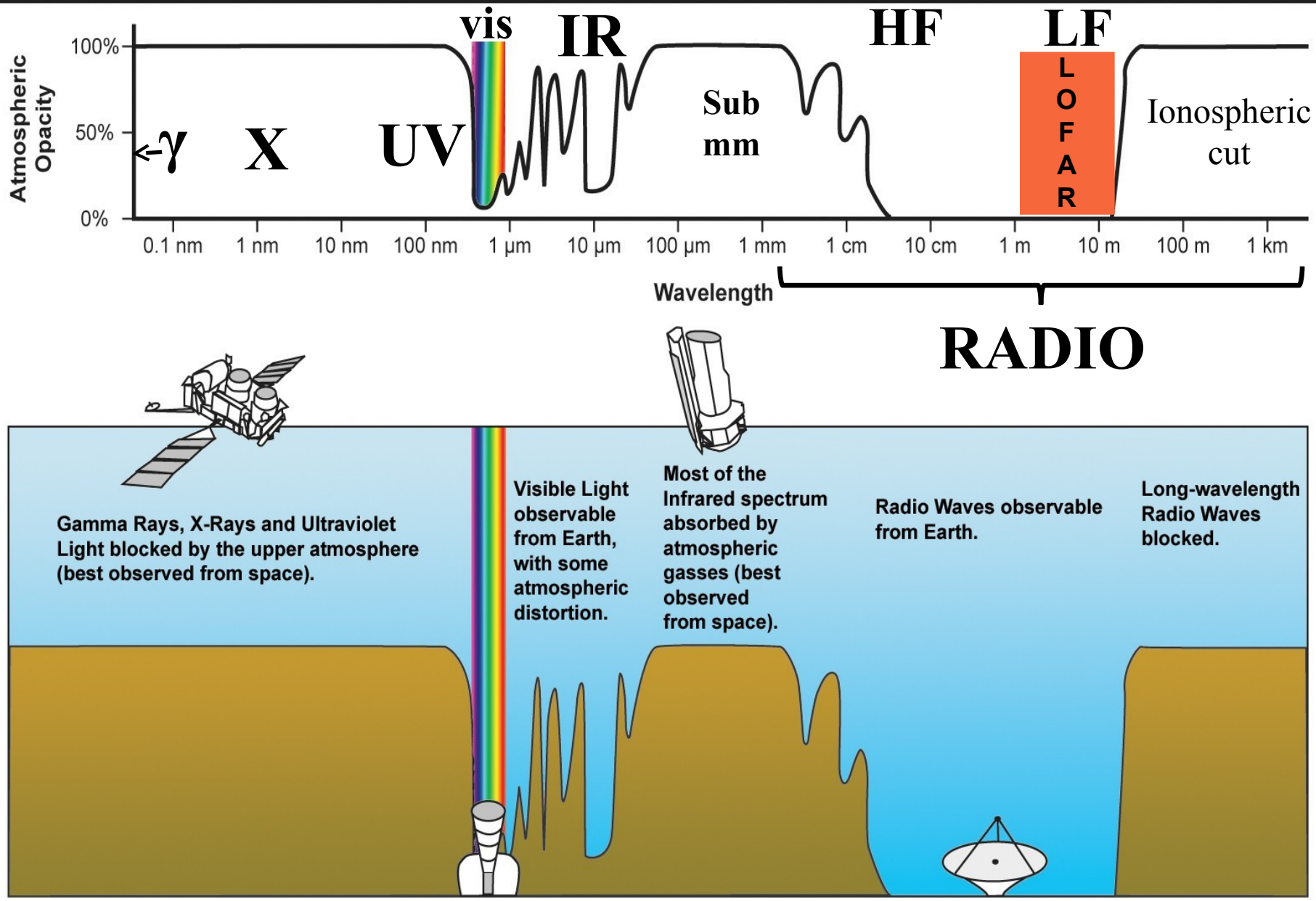
Outline

I. **The LOFAR instrument**

I. Planet observations
   1. Jupiter DAM
   2. Saturn SED

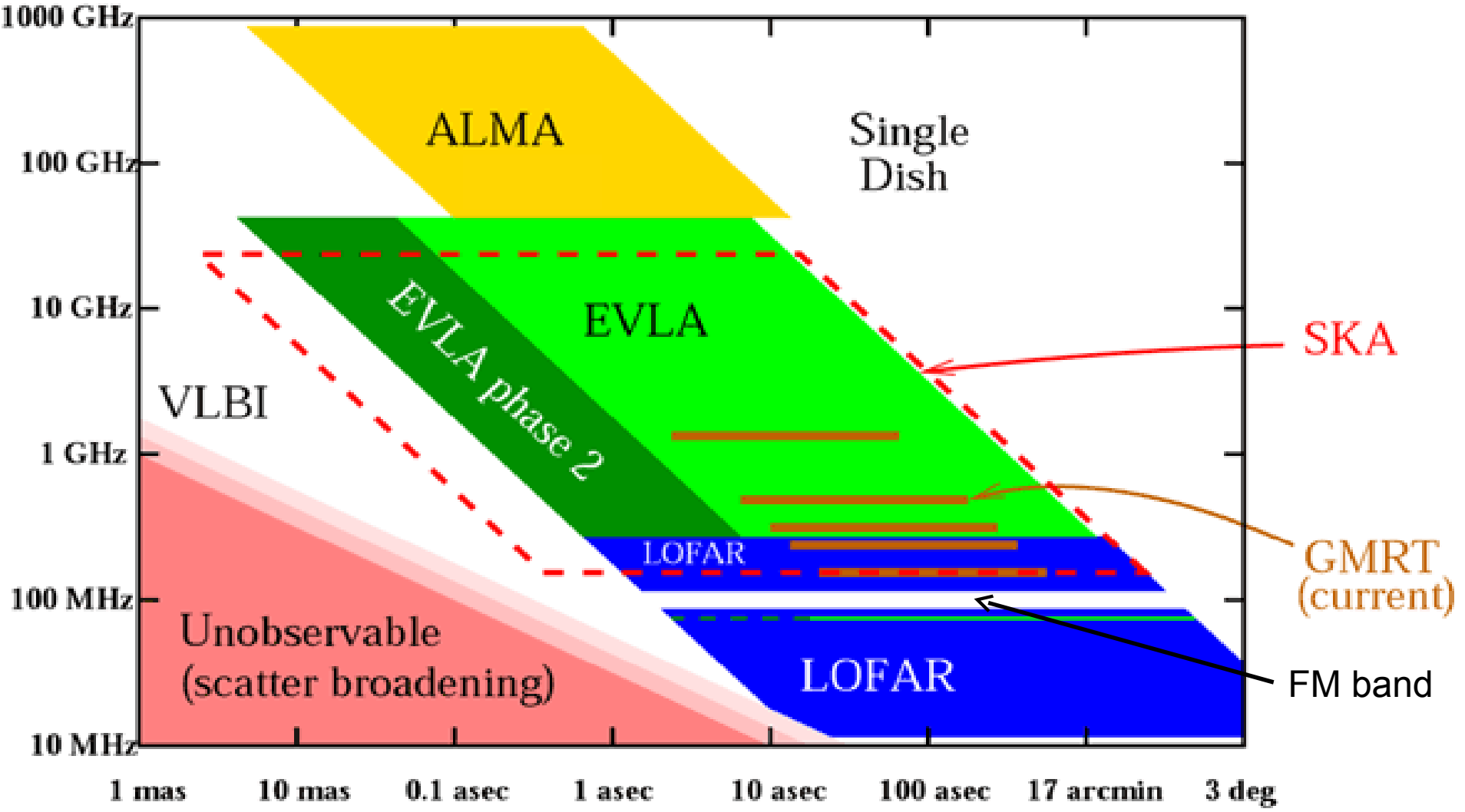
I. The LOFAR Super-Station Concept

EM window


Atmospheric Opacity
100%
50%
0%
←γ
X
UV
vis
IR
Sub mm
HF
LF
LOFAR
Ionospheric cut
0.1 nm
1 nm
10 nm
100 nm
1 μm
10 μm
100 μm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength
RADIO
Gamma Rays, X-Rays and Ultraviolet Light blocked by the upper atmosphere (best observed from space).
Visible Light observable from Earth, with some atmospheric distortion.
Most of the Infrared spectrum absorbed by atmospheric gasses (best observed from space).
Radio Waves observable from Earth.
Long-wavelength Radio Waves blocked.

Ground-based Instrumental context

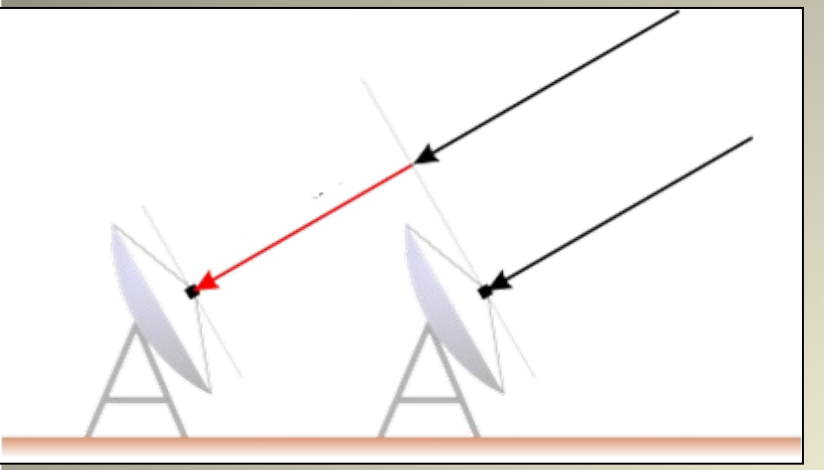
Frequency



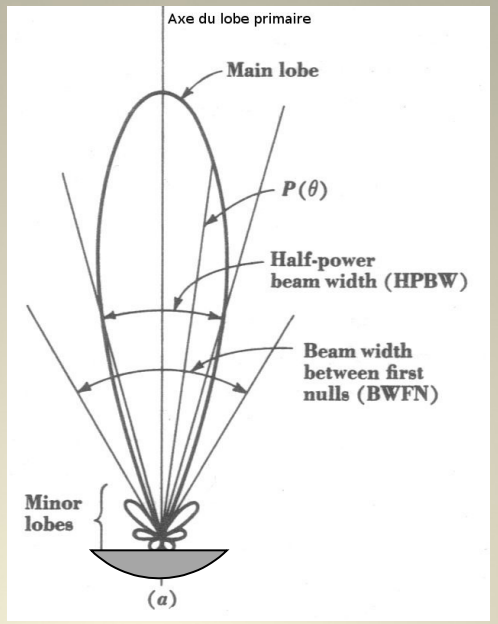
Radio (LF) → antennas in arrays
(↗ resolution et ↗ sensitivity)

Angular resolution

Antennas in arrays

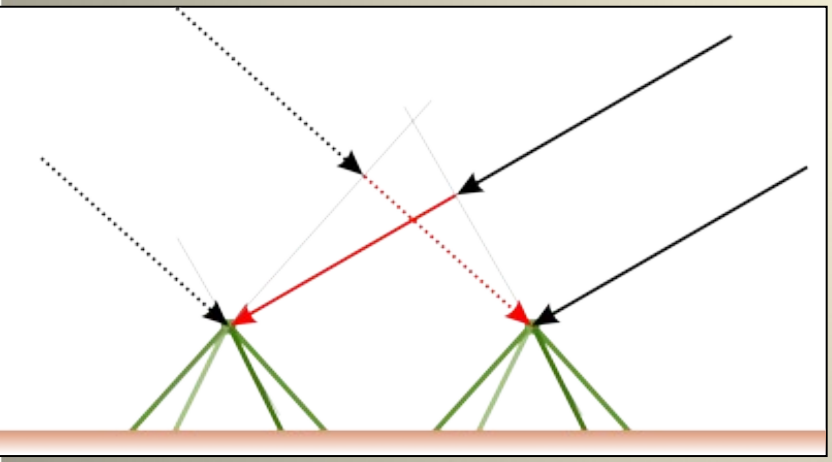


Dish antennas

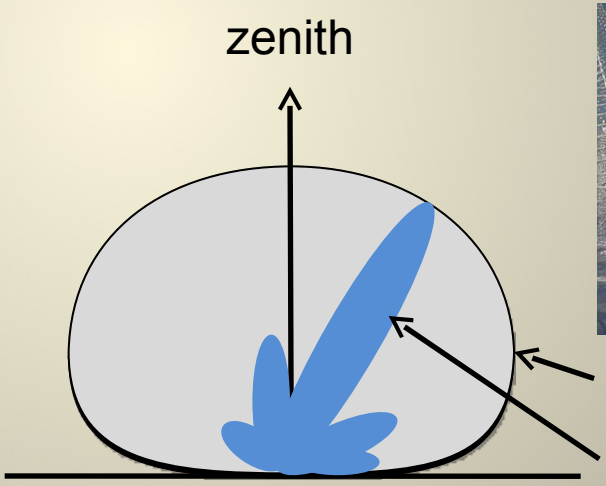


Directive antennas

Mechanically steerable



Dipole antennas



~ isotropic antennas

Electronically steerable in array

Arrays

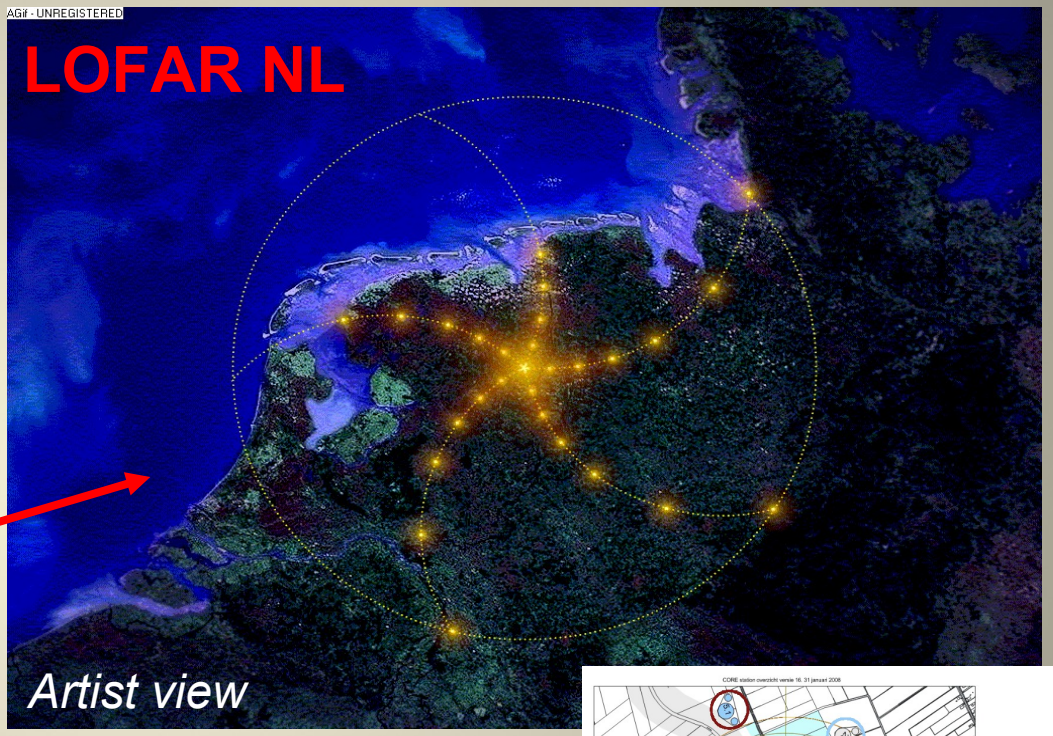
- Interferometer: 'product' of each antenna pairs
- Phased Array: 'sum' in phase of each antennas

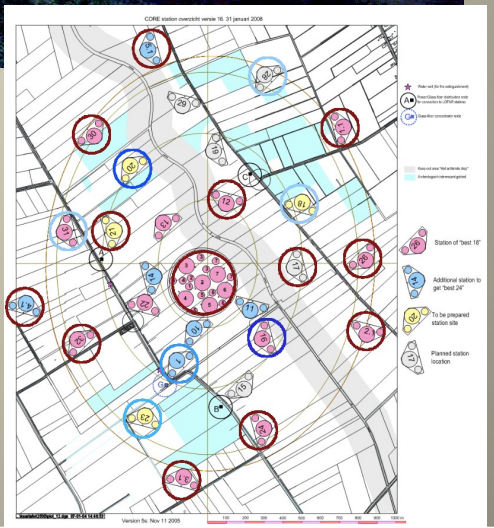
LOFAR ("Low Frequency ARray")

Interferometer of | **phased arrays** at low frequencies **30-250 MHz**
« stations »

40 stations in NL
- 20 'core' stations
- 20 'remote' stations

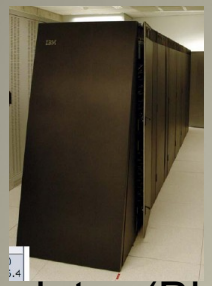
~10 international stations





Nançay station (built 06/2010)

The LOFAR station



Correlator (Blue Gene /P)

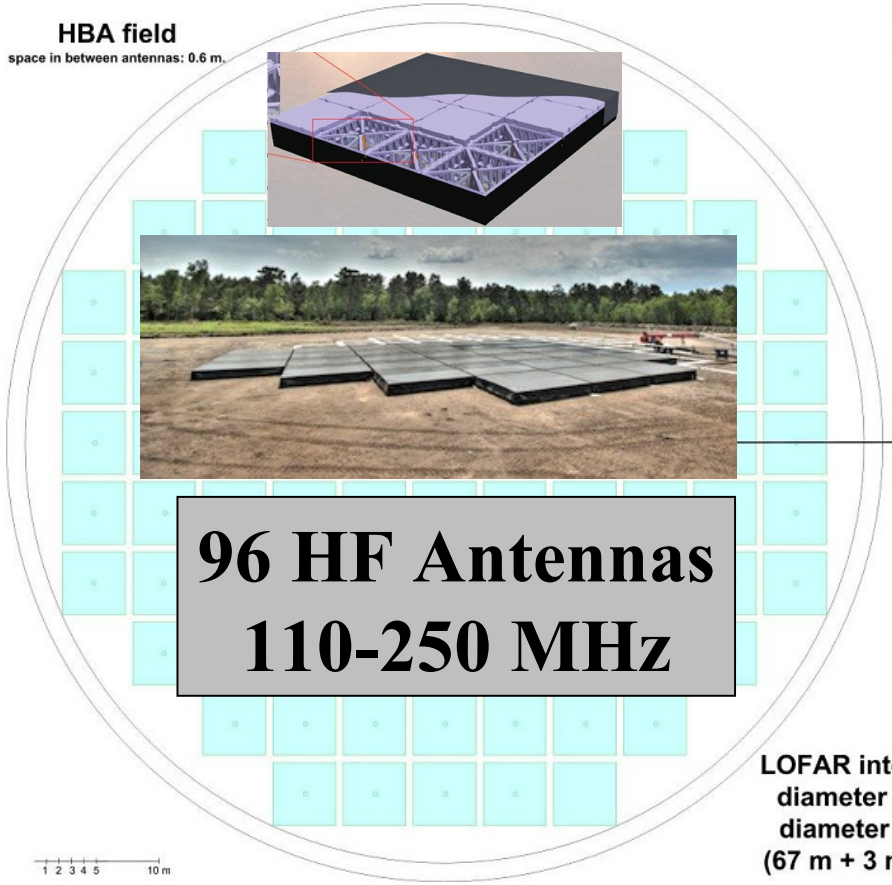
Other stations

3 Gbit/sec

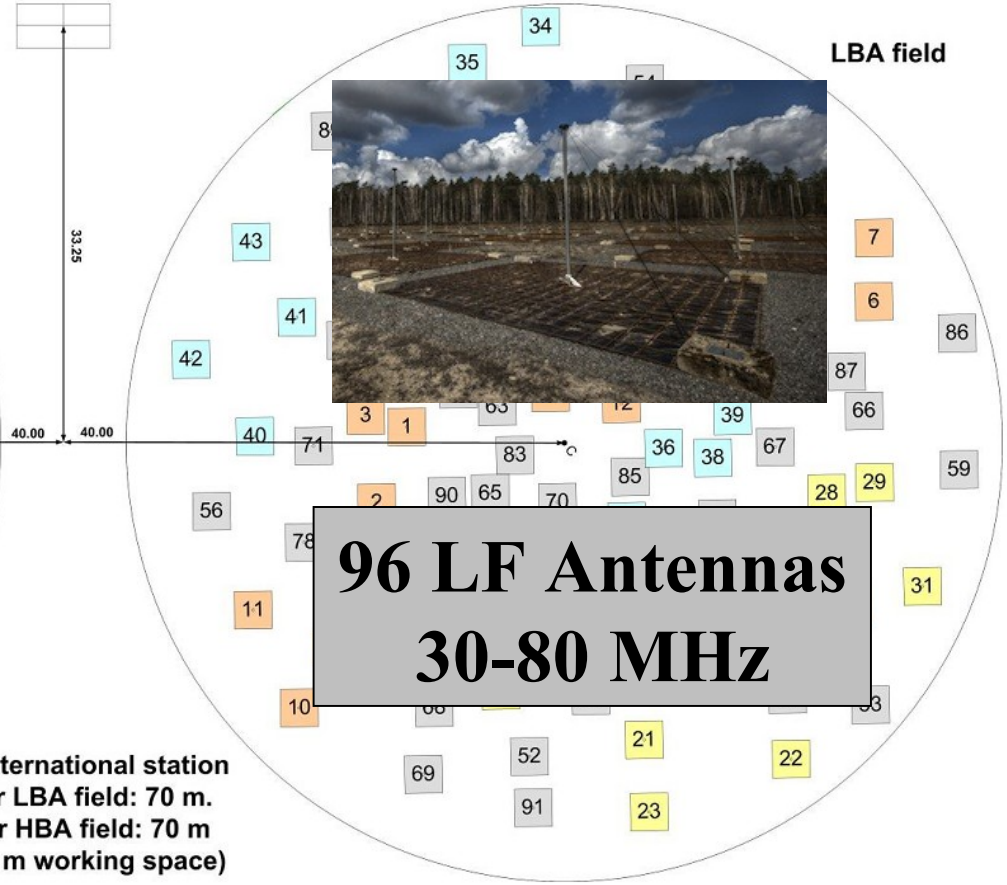
« Back-end »

Two switchable phased arrays

- HF array
- BF array
- **free inputs (96 inputs)**



96 HF Antennas
110-250 MHz



96 LF Antennas
30-80 MHz

LOFAR international station
diameter LBA field: 70 m.
diameter HBA field: 70 m
(67 m + 3 m working space)

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Planetary observations during commissionning phase

Within the LOFAR « Transients » Key Science Project

The **Imaging** mode of LOFAR is almost ready (data definition and pipeline)

The **Tied Array Beam** (TAB) mode not yet ready.

Till then:

➔ Raw outputs of polyphase filters (~FT of waveform) of separated stations
➔ Incoherent sum of any subset of stations (corrected of geometric delays)

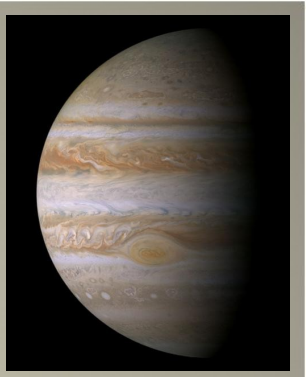
Target	Date	Duration	Band	Nb of stations	Data type
Jupiter	27/11/09	56min	20-32 MHz	5	Raw PF output
	02/04/10	20min	20-39 MHz	4	Raw PF output
	03/06/10	30min	30-90 MHz	5	Raw PF output & Incoherent sum
Saturn	08/04/10	3h	30-90 MHz	10	Incoherent sum

- Comparisons of station responses (Core, Remote and International stations)
- Correlation between stations (to follow ionospheric effects)
- Polarization (4 Stokes available)
- Check Incoherent sum mode

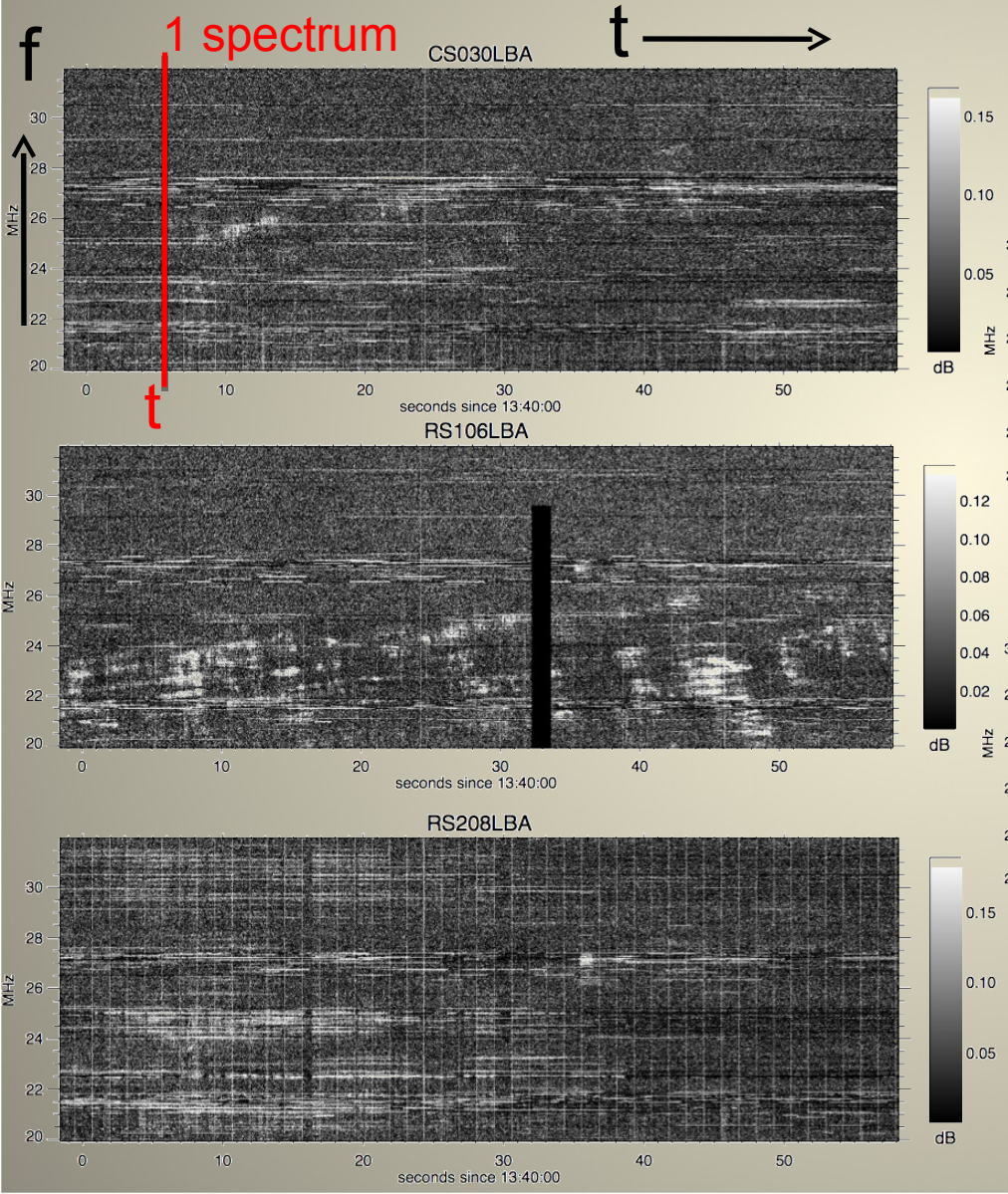
Work in progress !

Jupiter Decameter emissions

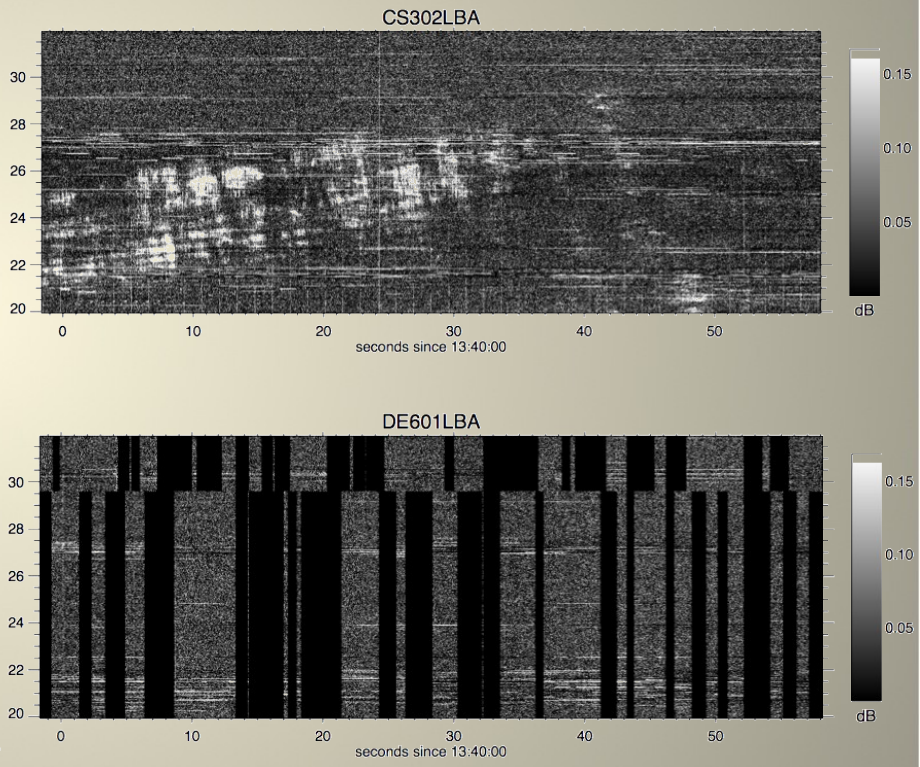
(Io-DAM: 10 - 40 MHz) (Zarka 1998)



5 LOFAR stations (2 core (NL), 2 Remote (NL), 1 Int. (DE))



128 sub-bands [20-32 MHz]

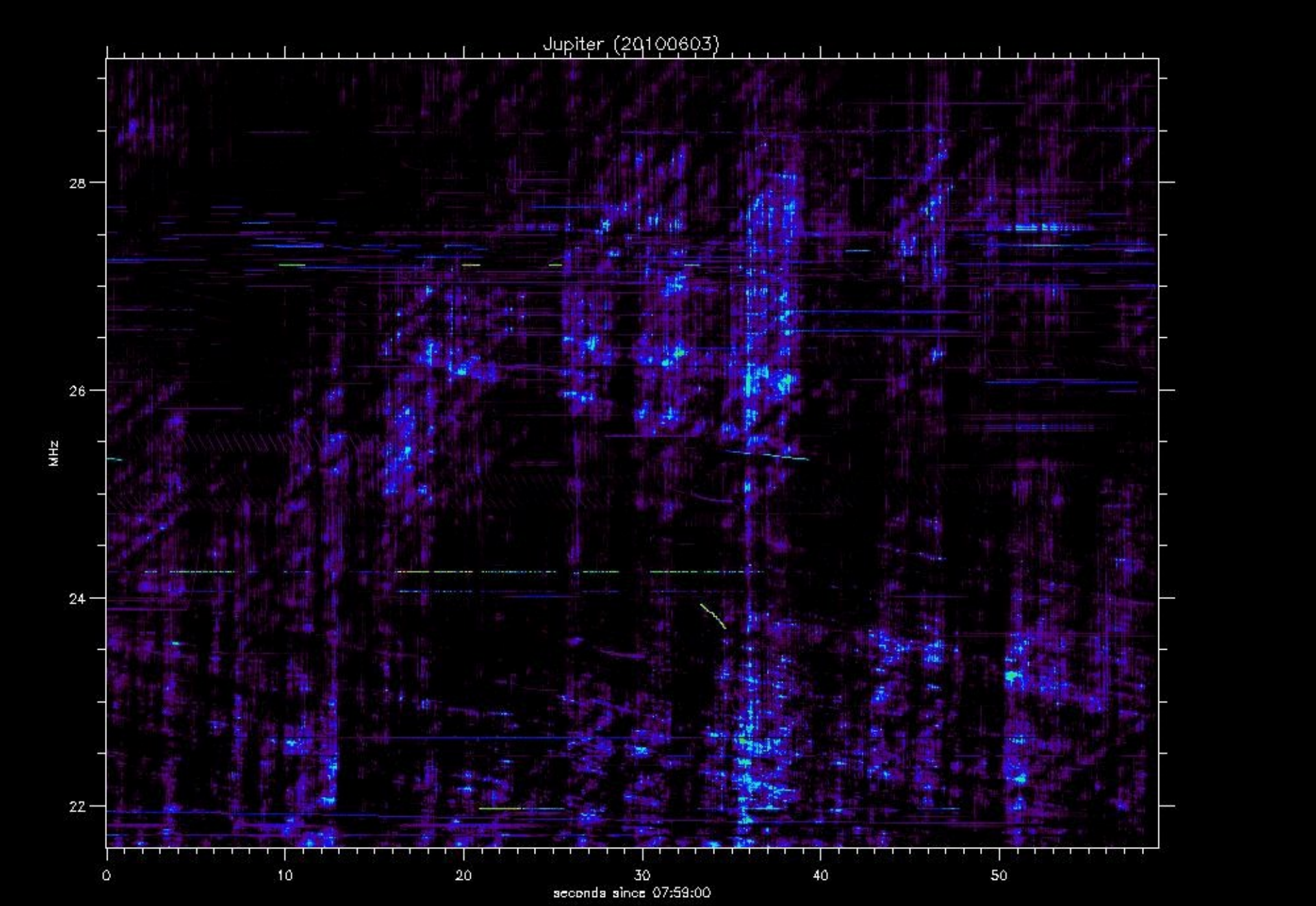


Data inspection:

Data losses

Sensitivity of each station

RFI environment



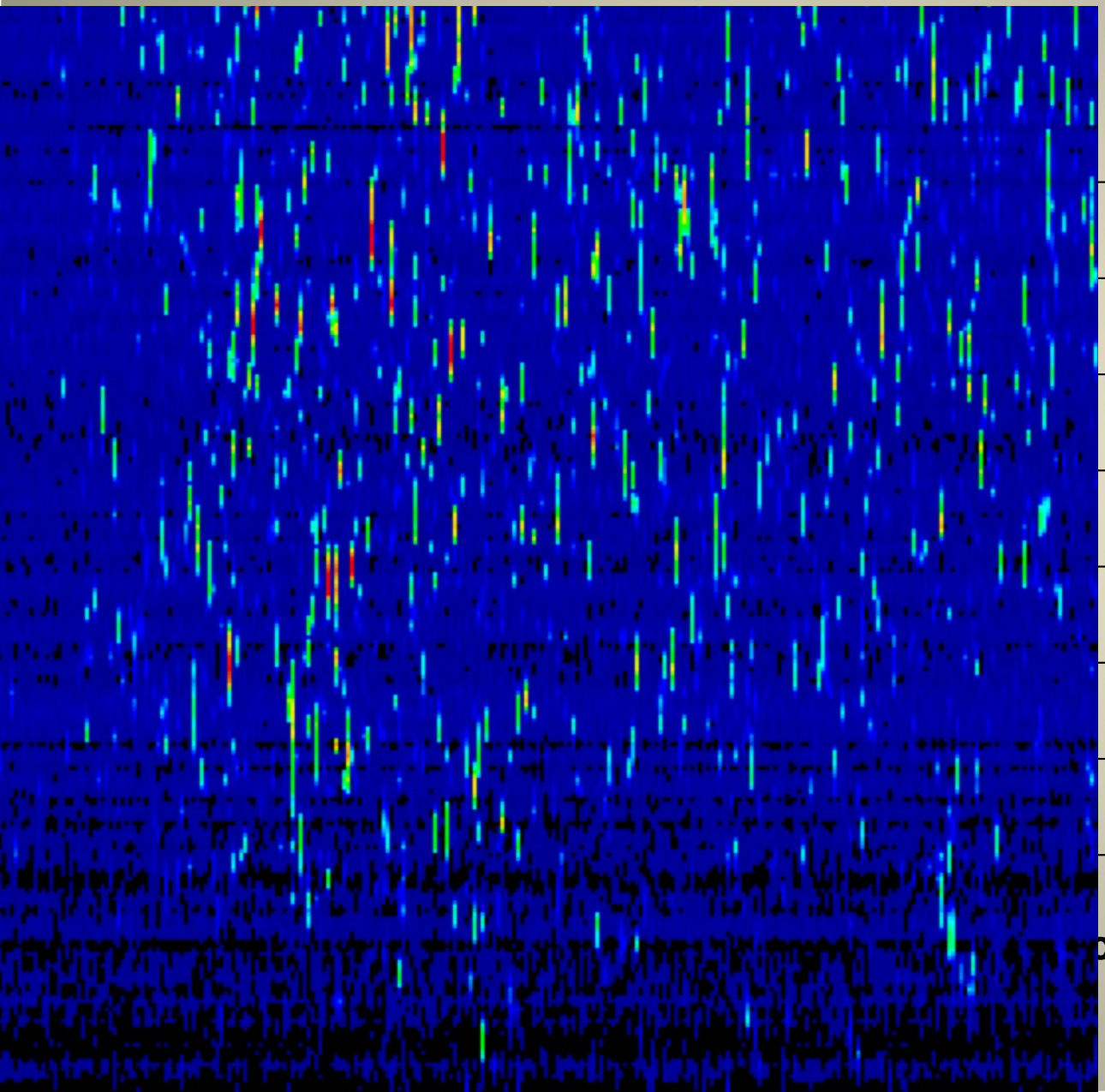
RS306, RS307, DE601 incoherent sum

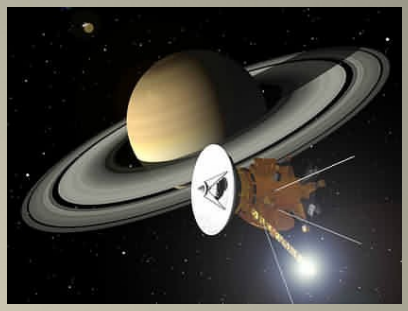
J. M. Griessmeier

Saturn's Electrostatic Discharges (SED)

(See Christina's talk @ 16:20 !)

Extract of Cassini observation of 7th April 2010





➔ Visibility effect due to storm & S/C relative position

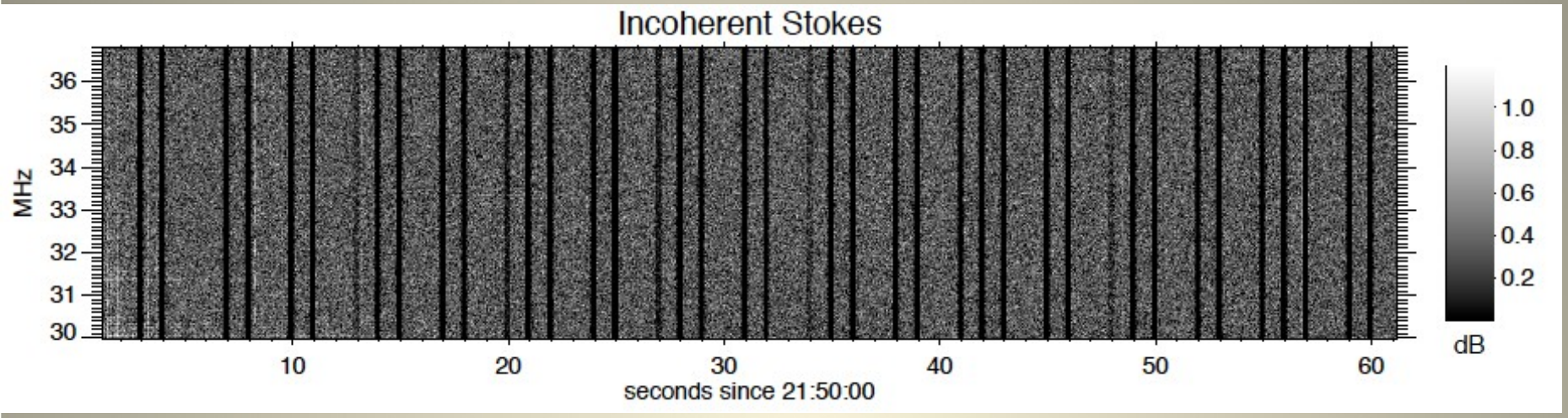
➔ SED events

- Intense bursts
- Artificially narrow-band
- Randomly distributed

c cut

Saturn's Electrostatic Discharges (SED)

Detection of Saturn Electrostatic Discharges (SED) with LOFAR



@ Earth, SED are mostly hidden in the background

➔ need to play with time & freq integration

SED level ~ 200-1000 Jy and $\sigma_{sky} = \frac{2k_b T_{sky}}{A\sqrt{b\tau}}$ with $T_{sky} \approx \frac{1,15.10^8}{f^{2.5}}$ K

for 10 ≤ f (MHz) ≤ 100

$A_{\text{one LOFAR Station}} \sim 48/3\lambda^2$

(1 Jy = 10^{-26} W.m^{-2}.Hz^{-1})

van Haarlem et al., 2001

Nb of Stations	f	b	τ	σ_{sky}
1 station	30 MHz	200 kHz	82µs	10^4 Jy
10 stations	30 MHz	200 kHz	82µs	3.10^3 Jy
10 stations	30 MHz	6 MHz	20ms	37 Jy

➔ ok

SED duration

$$N = N_0 e^{-\frac{D}{D_0}}$$

D = 30 – 400 ms

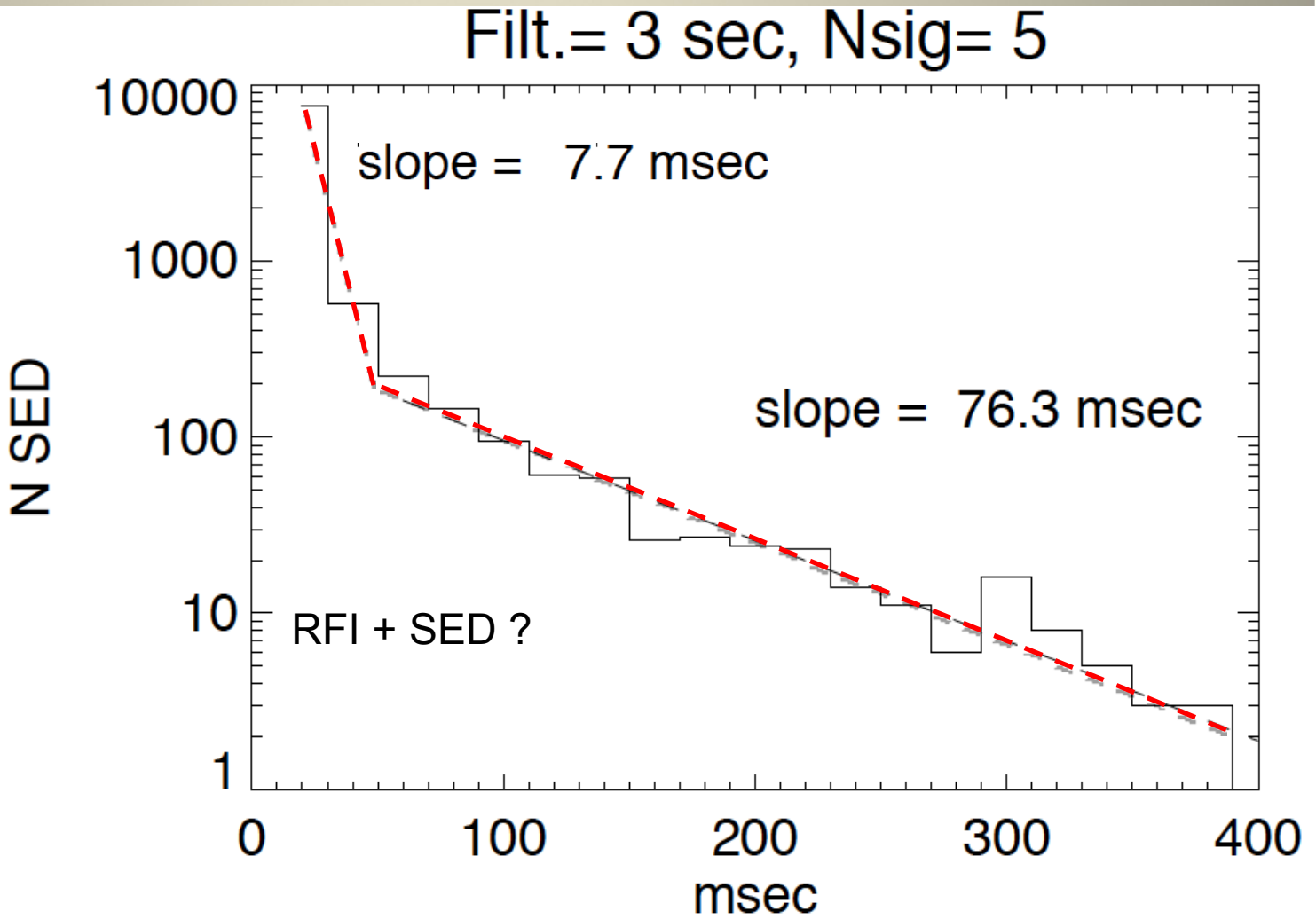
D_0 e-folding time

D_0~ 50 ms (as seen by Voyager I & II & Cassini)

(Zarka et al. Planetary Radio Emission VI)

Integration
τ=20ms
b=6MHz
Detection
Nσ=5
Time window=3s

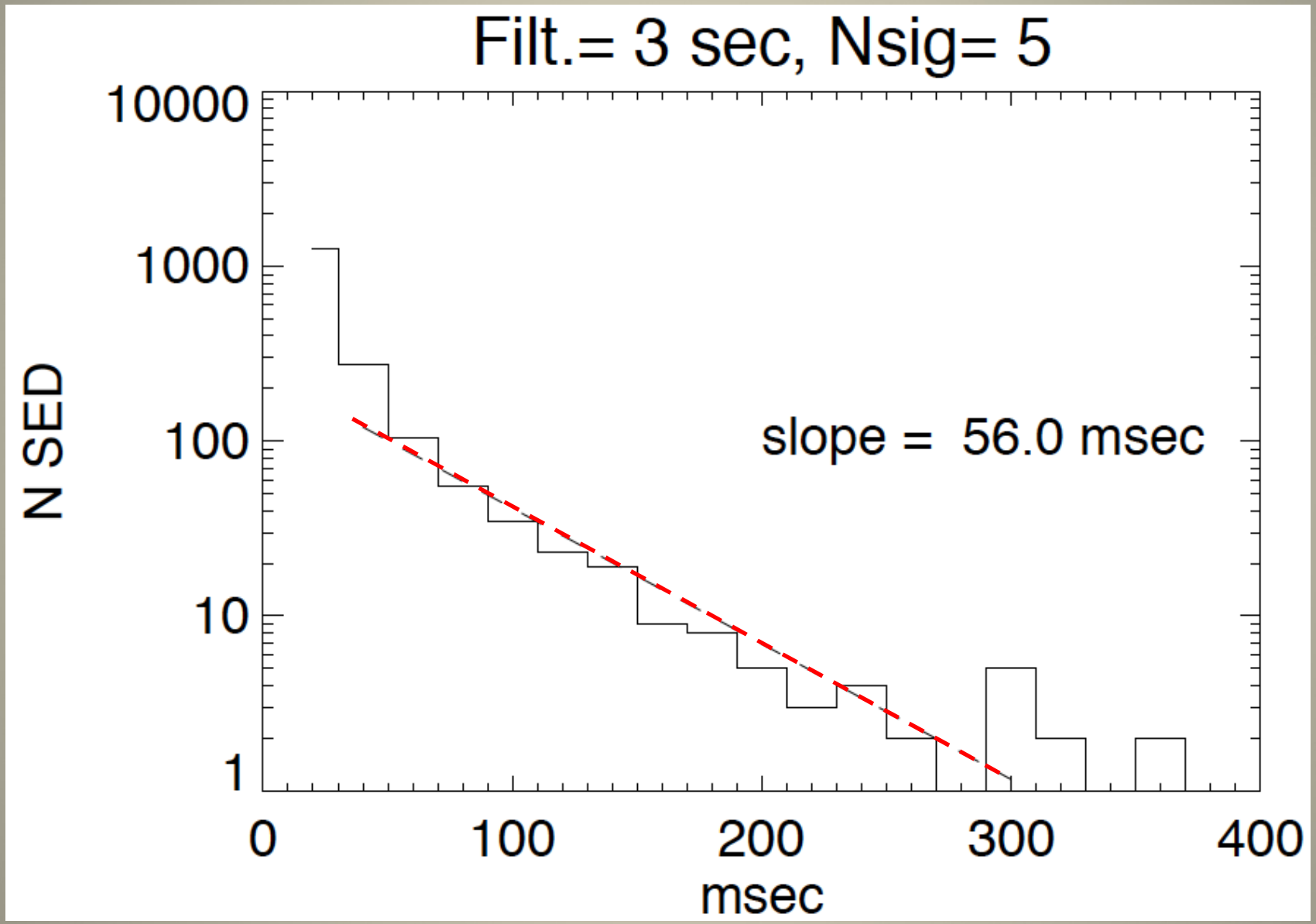
'Raw' data



SED duration

‘Cleaned’ data

RFI & ‘bad pixels’ treatment before integration



Work in progress !

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LOFAR Super-Station (LSS)

Principle:

➔ Use the 96 free inputs of the LOFAR Station to create a third mode

To plug 96 new ‘antennas’ Where ‘antenna’ = analog phased array of ~10-20 active elements

Key advantages:

- “Easy” and direct connection to the LOFAR system
- Higher sensitivity of long baselines involving the LSS
- New shorter baselines (< station diameter)
- Possible use as a new “standalone” interferometer & PA
- Aimed band ≤30 et ≥80 MHz

Super Station ~ 2nd core of LOFAR

Concept study and prototyping 2009-2011

LSS design studies

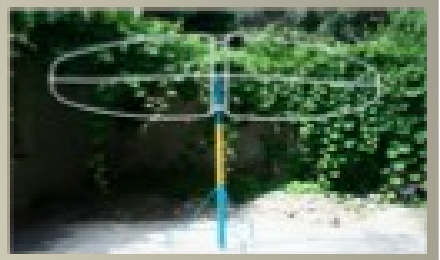
Array element Sky dominated at these frequencies

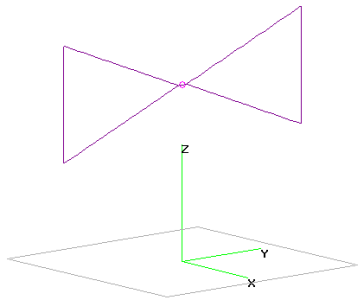
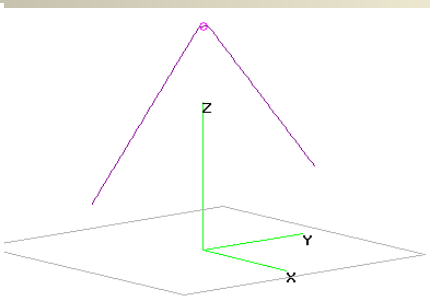
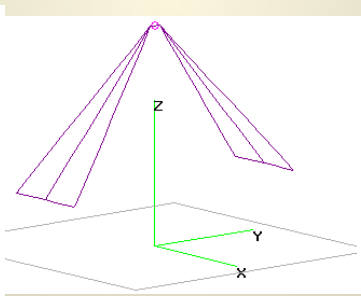
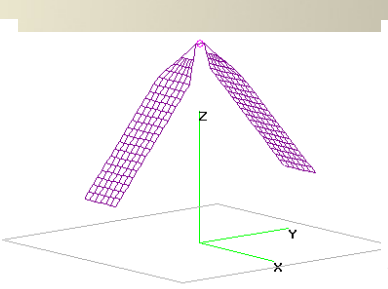
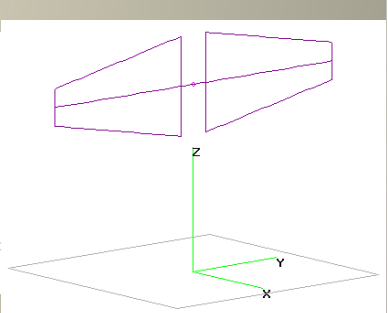
Benchmark of different antenna designs used in other projects (GURT, LWA, MWA, …)

➔Simulation (dependence of antenna geometry (height, « thickness », droop angle, …)
➔Tests on site (response to the galaxy, ground screen, real ground, …)

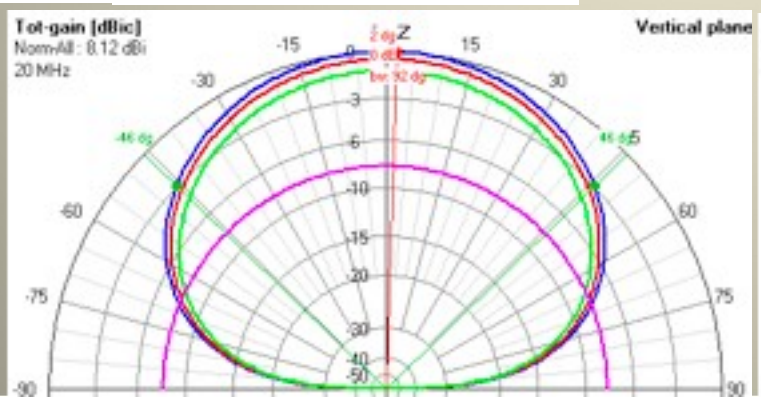


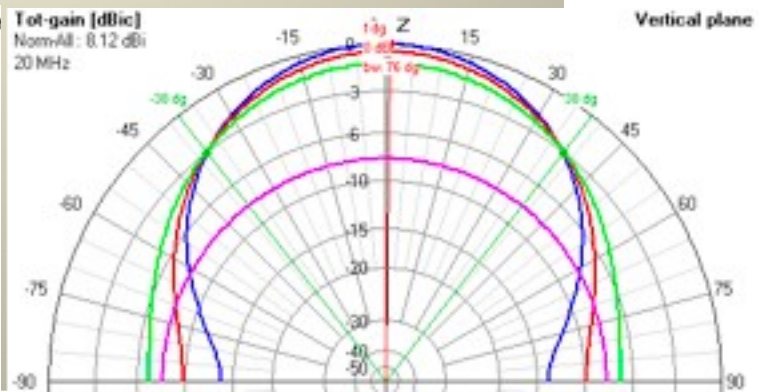




H-plane





E-plane

LSS design studies

Array configuration

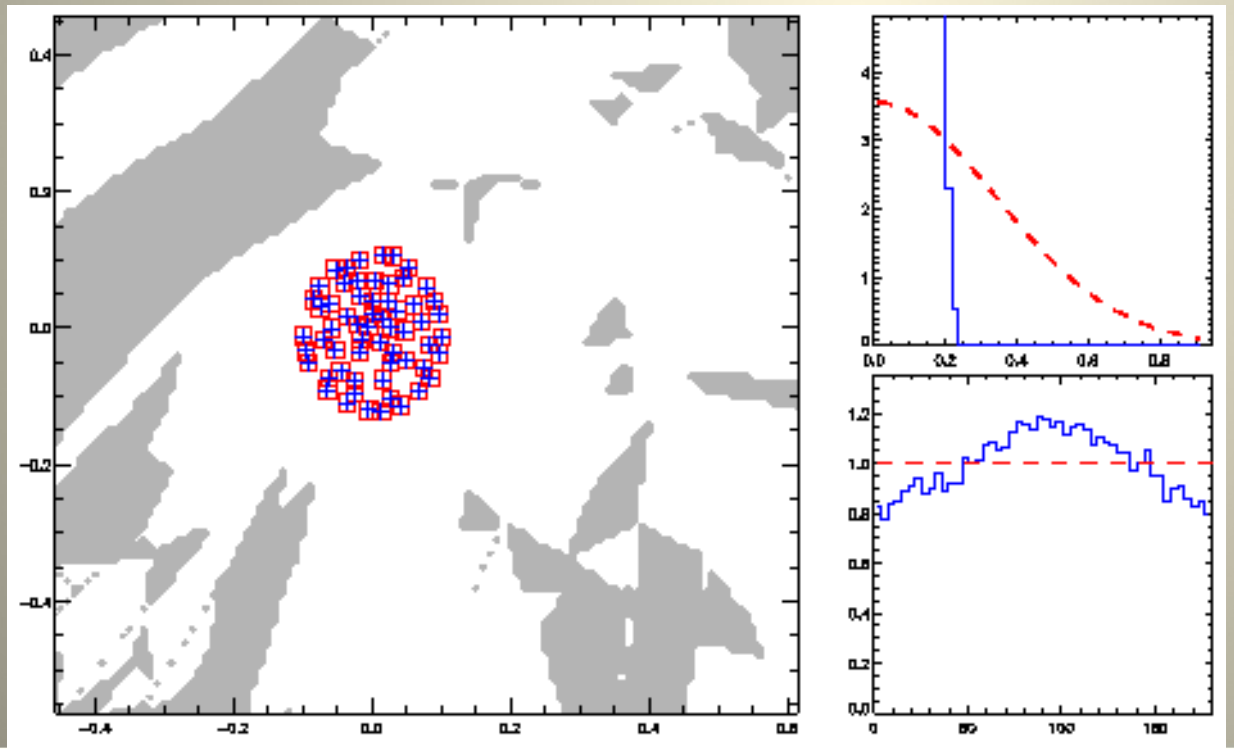
➔ Sub-array level (~10-20 active elements)

- Compromise between low sidelobes, effective area, coupling, …
- Analog phasing to allow broadband pointing
- Optimization algorithms used (Kogan, Simulated Annealing)

(Kogan, 2000, IEEE Trans. Ant. & Prop.) (Kirkpatrick, Gelatt, Vecchi, 1983, Science)

➔ Big array level (96 Analog Phased Arrays)

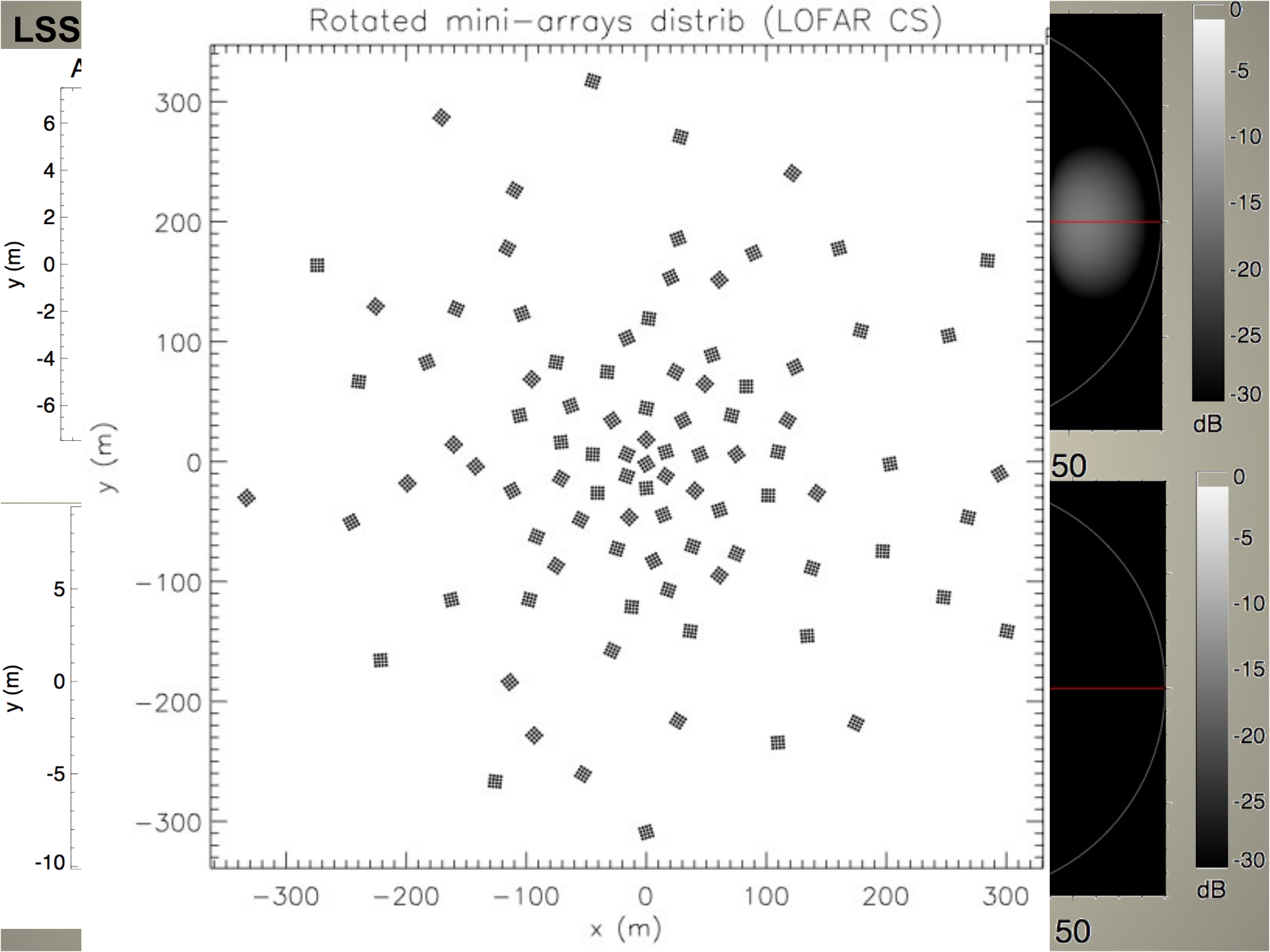
Compromise between phased array & interferometric needs ((u,v) coverage))



(Boone, A&A, 2001)

(u,v) radial distribution

Fitting residuals


LSS
Rotated mini-arrays distrib (LOFAR CS)
y (m)
x (m)
300
200
100
0
−100
−200
−300
−300
−200
−100
0
100
200
300
6
4
2
0
-2
-4
-6
5
0
-5
-10
0
-5
-10
-15
-20
-25
-30
dB
50
50

Thank you !