MSSS (MS^3)

or

a calibration survey for LOFAR

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(LOFAR calibration PS & PM)

Dwingeloo, 19Mar08 + 21Aug08

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Outline

- CS-1 results (LBA/HBA) and lessons learned
- LOFAR20/34 configuration choice
- Station configuration (see also Ronald's talk)
- Rollout activities and planning

- Main and secondary goals of MS^3
- Proposed observational/technical specifications
- Issues underlying the proposed choices
- Issues to be discussed / investigated

Confusion limited CS-1 image at ~ 50 MHz

16 dipoles (only ~70 baselines)

Sarod Yatawatta

3 x 24h

38 - 59 MHz (B=6 MHz)

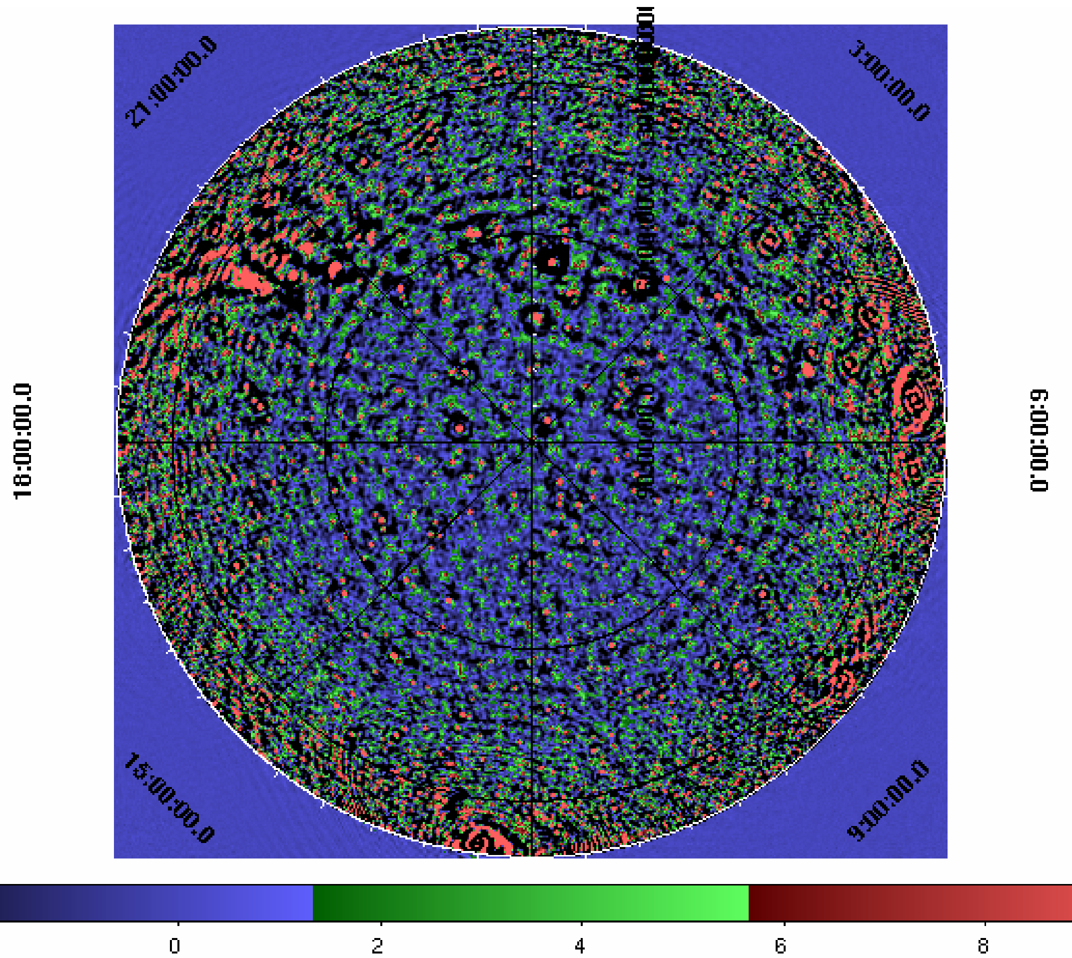
~ 800 sources !

PSF ~ 0.5º

noise ~ 0.5 - 1 Jy

CasA/CygA (~20,000 Jy) subtracted

- dipole beam corrected
- no deconvolution



Deep HBA image : 10’ PSF , sub-Jy noise

36 subbands:

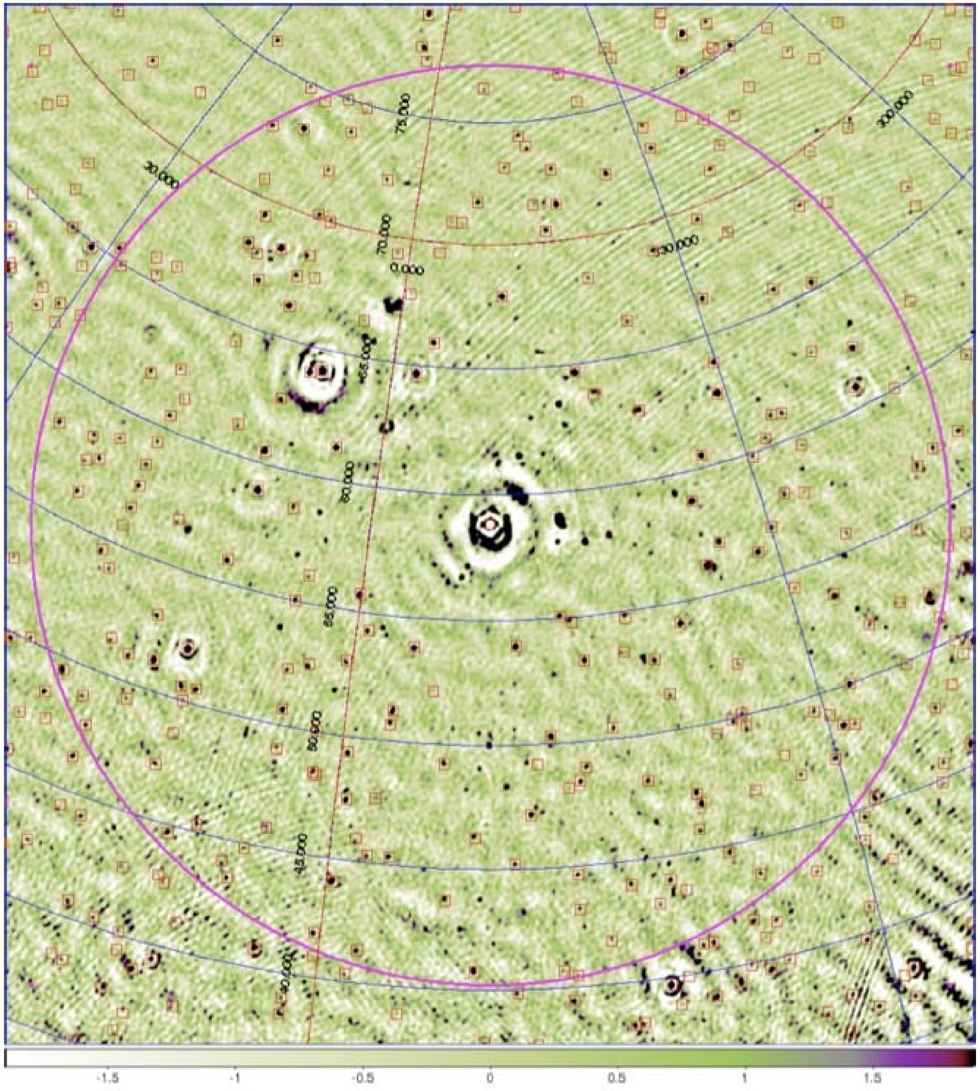
MFS from 125 - 175 MHz

24h integration using

20 dipoles +

4 tiles (tracking CasA)

tilebeam ~ 25°

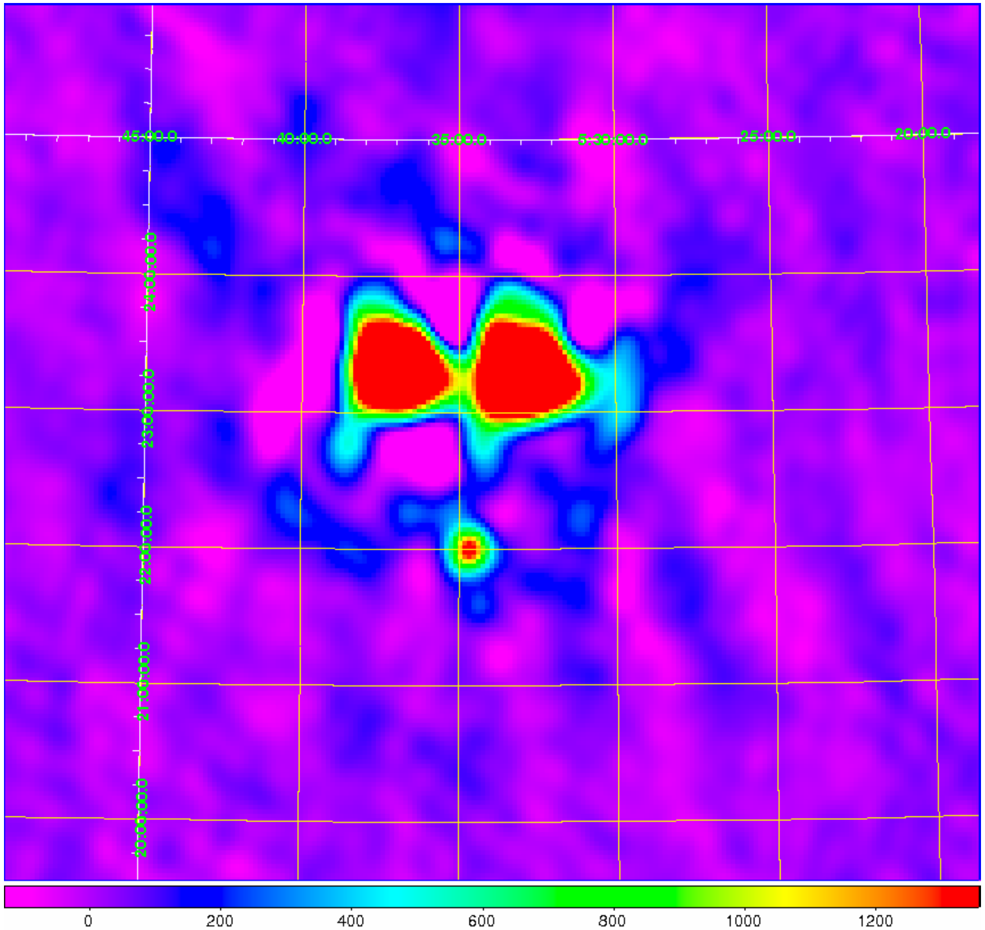


Sun and TauA conjunction on 14+15Jun08

~12h syntheses

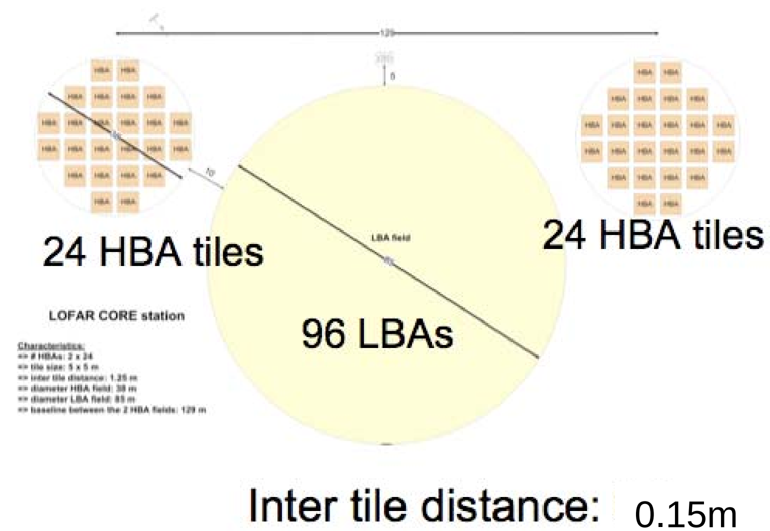
~ 150 MHz

~ 10’ PSF

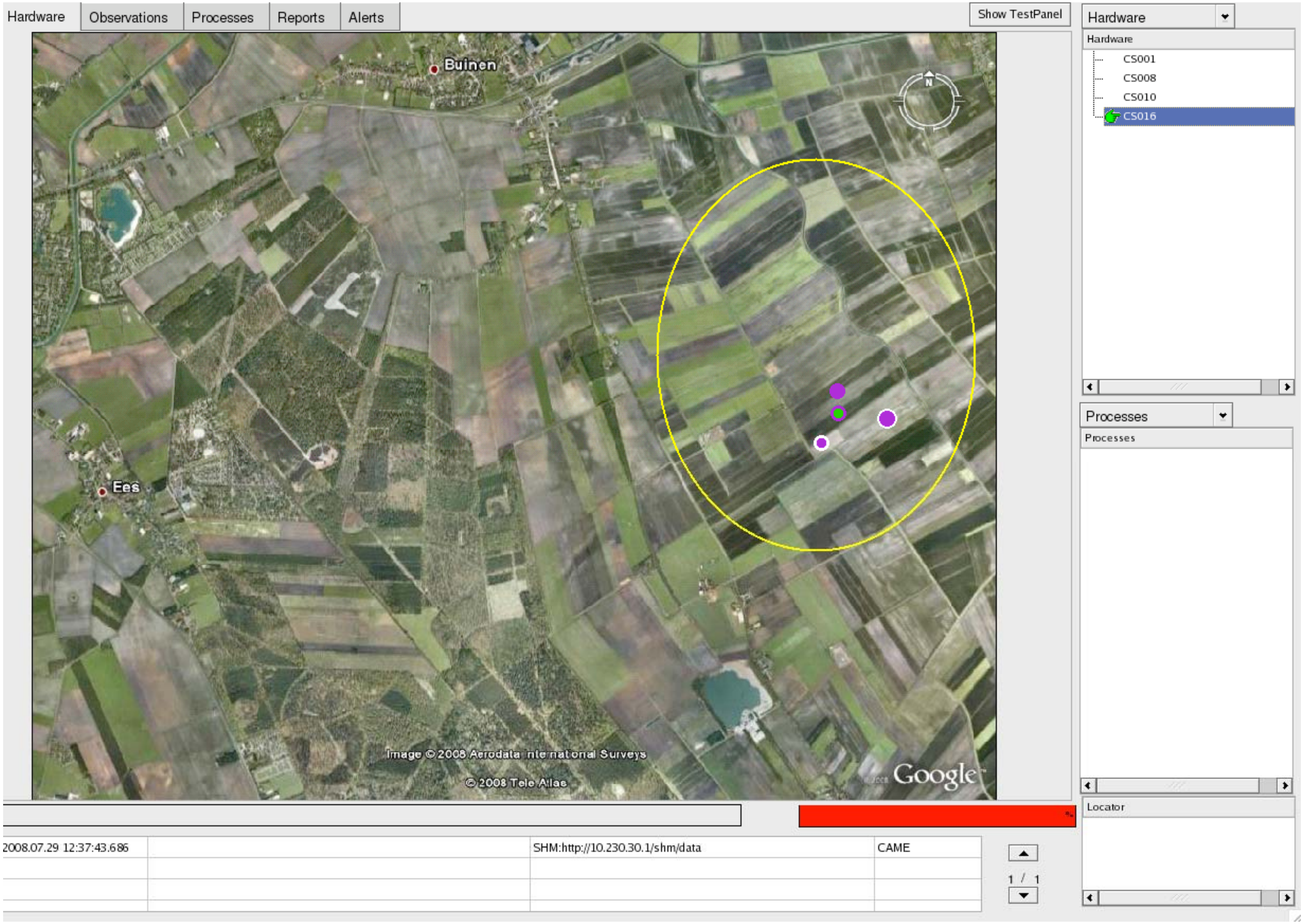


Yatawatta & Brentjens, AJDI, 10Aug08

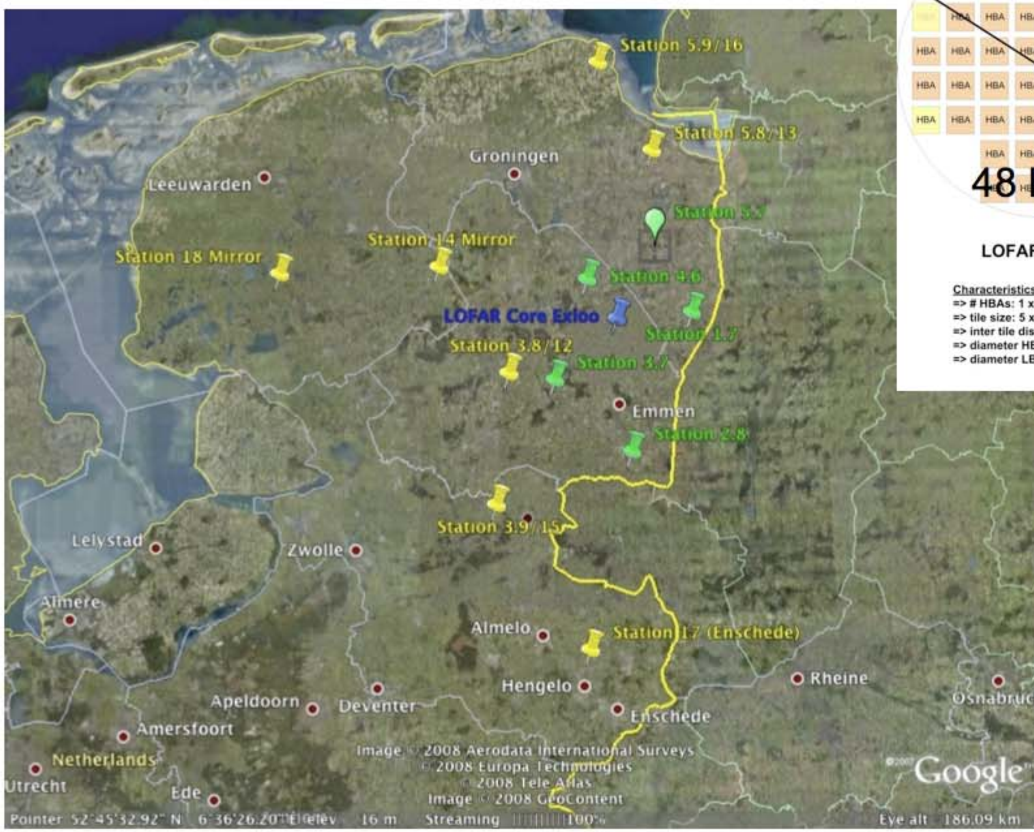
LOFAR core configuration

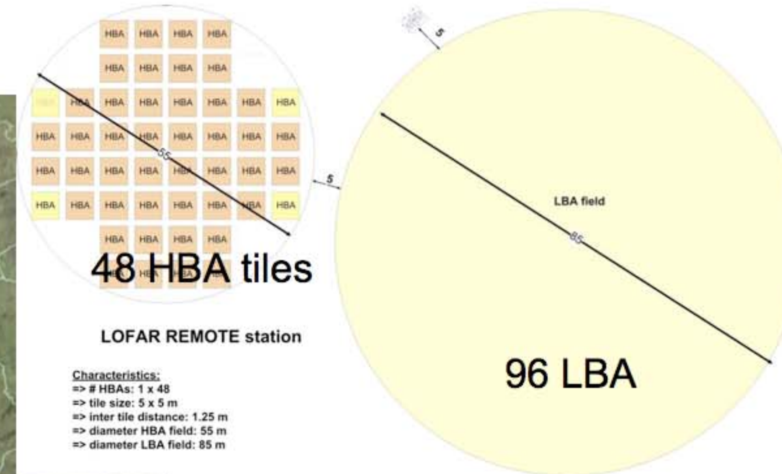


Navigator control panel & Google earth



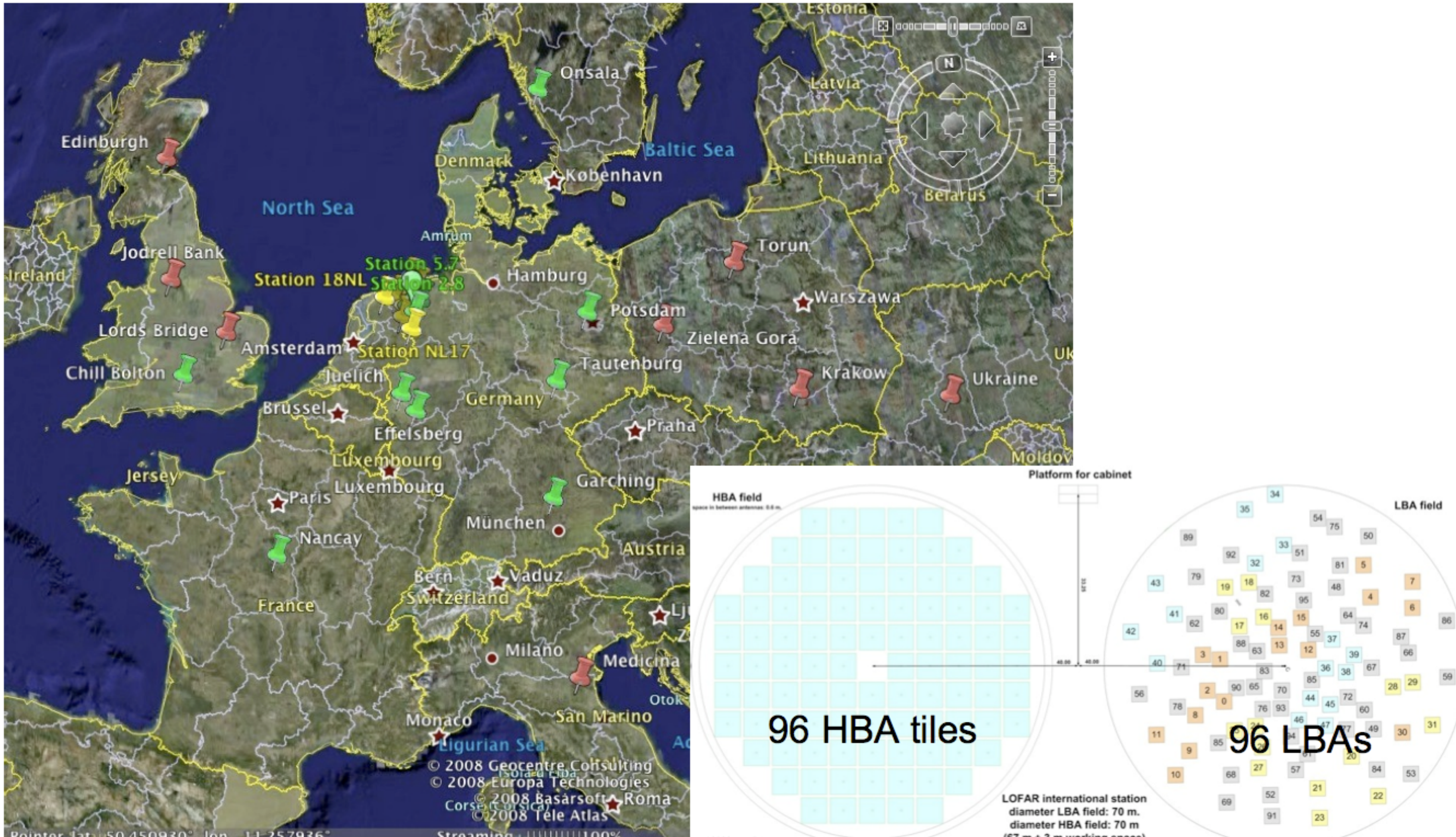
LOFAR stations within the Netherlands





Inter-tile distance : 0.15m

LOFAR stations in Europe

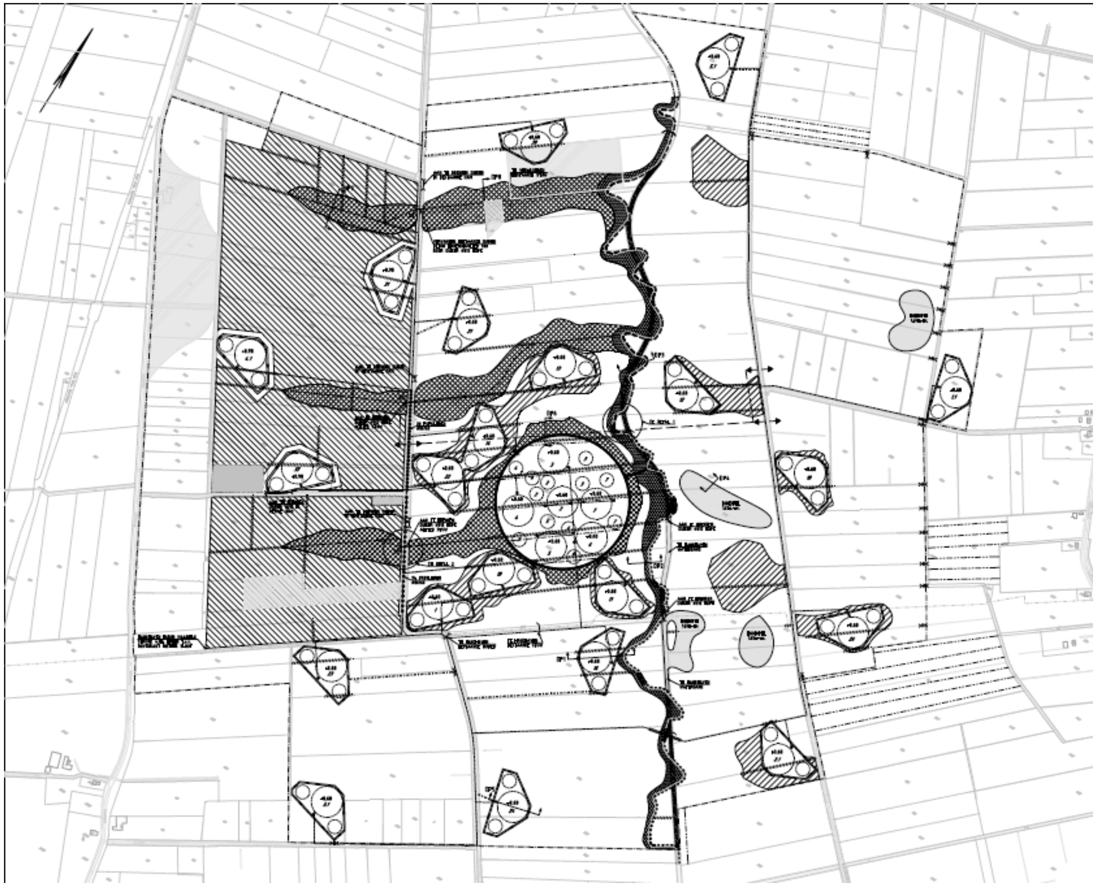


Inter-tile distance: 0.15m

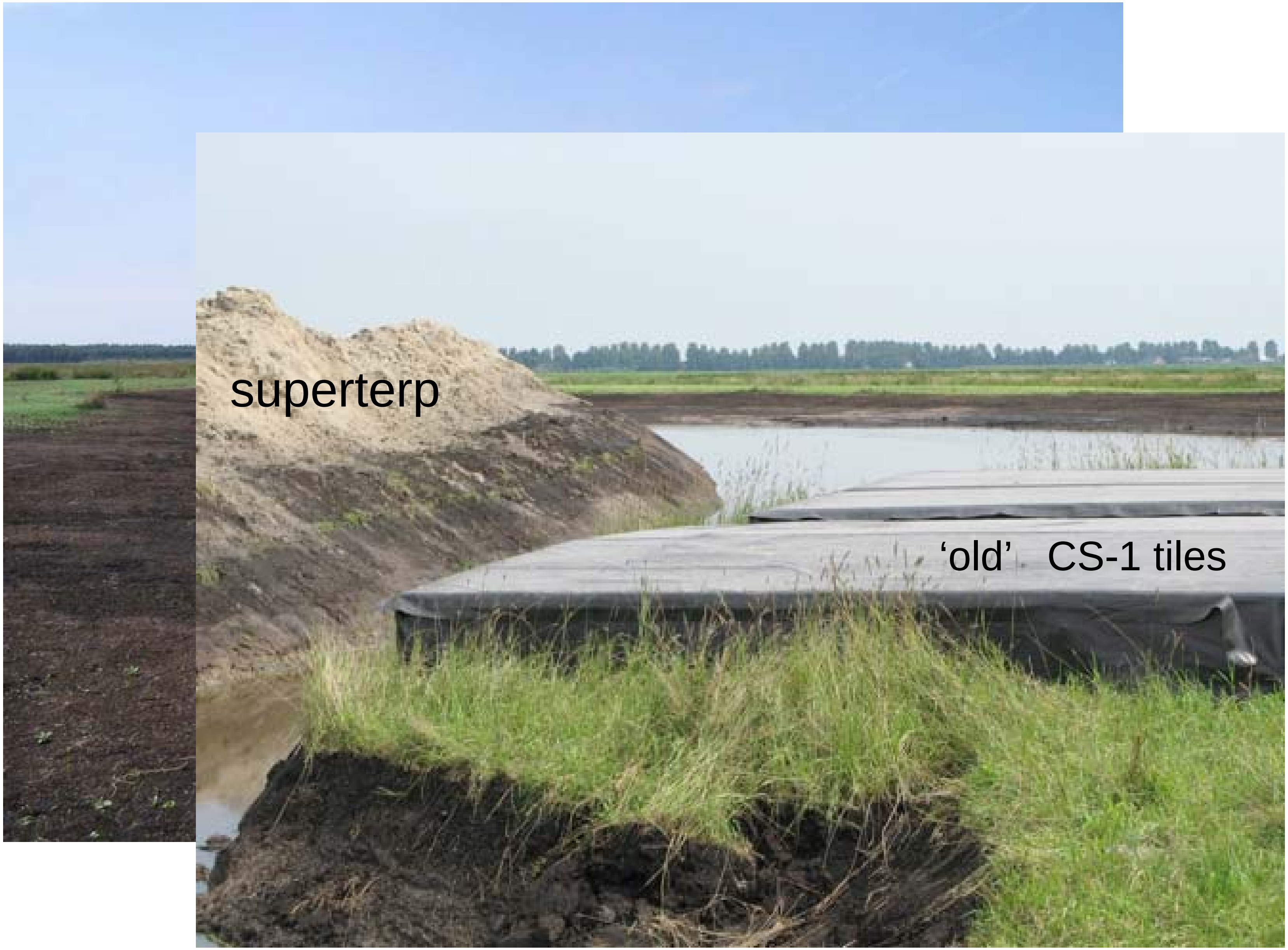
Nature development in LOFAR core (Exloo)

Rather soggy in rainy season ⇒ station fields raised 60cm

other areas go down by 60cm !



Raising and lowering land in the core (~1 Aug08)



Also people in Garching have been busy...

LOFAR frequency selection aspects

Two 12-bit sampling modes: 160 or 200 MHz clock
Frequency filtering done in two (PPF) stages:
- at station ⇒ 512 subbands (of 156 or 195 kHz)
- at CEP (BG/P) ⇒ 256 channels for ~ 200 subbands

~ 50,000 channels of 0.6 - 0.8 kHz !!

(NB: ~ 1 kHz is required for both RFI excision and very wide-field imaging)

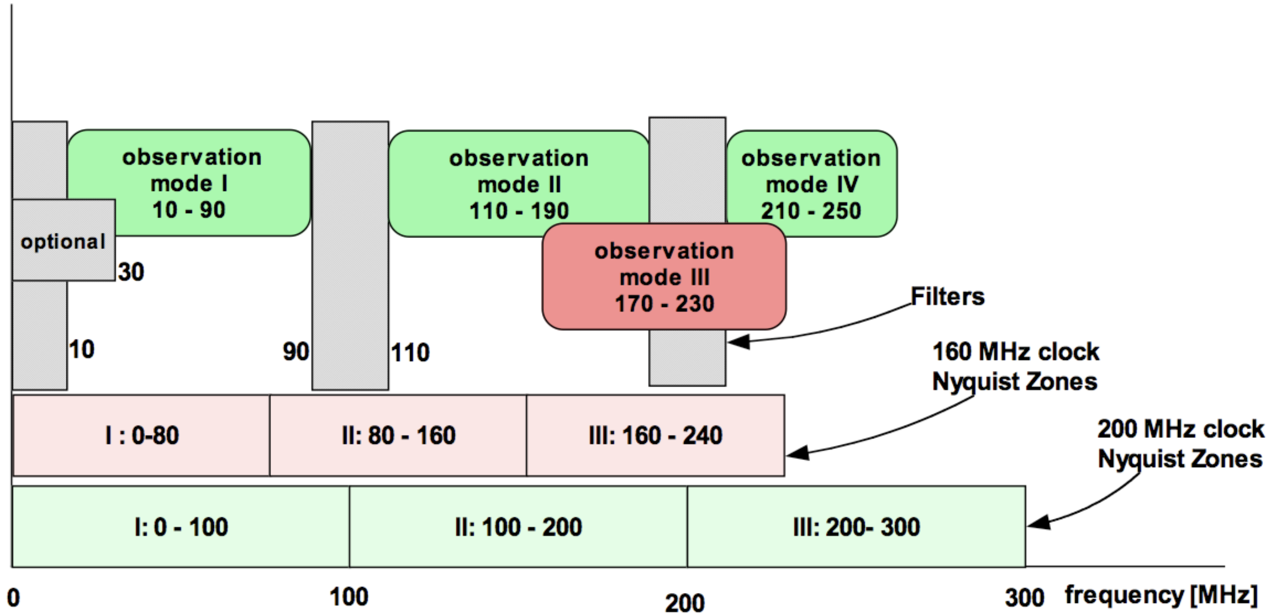
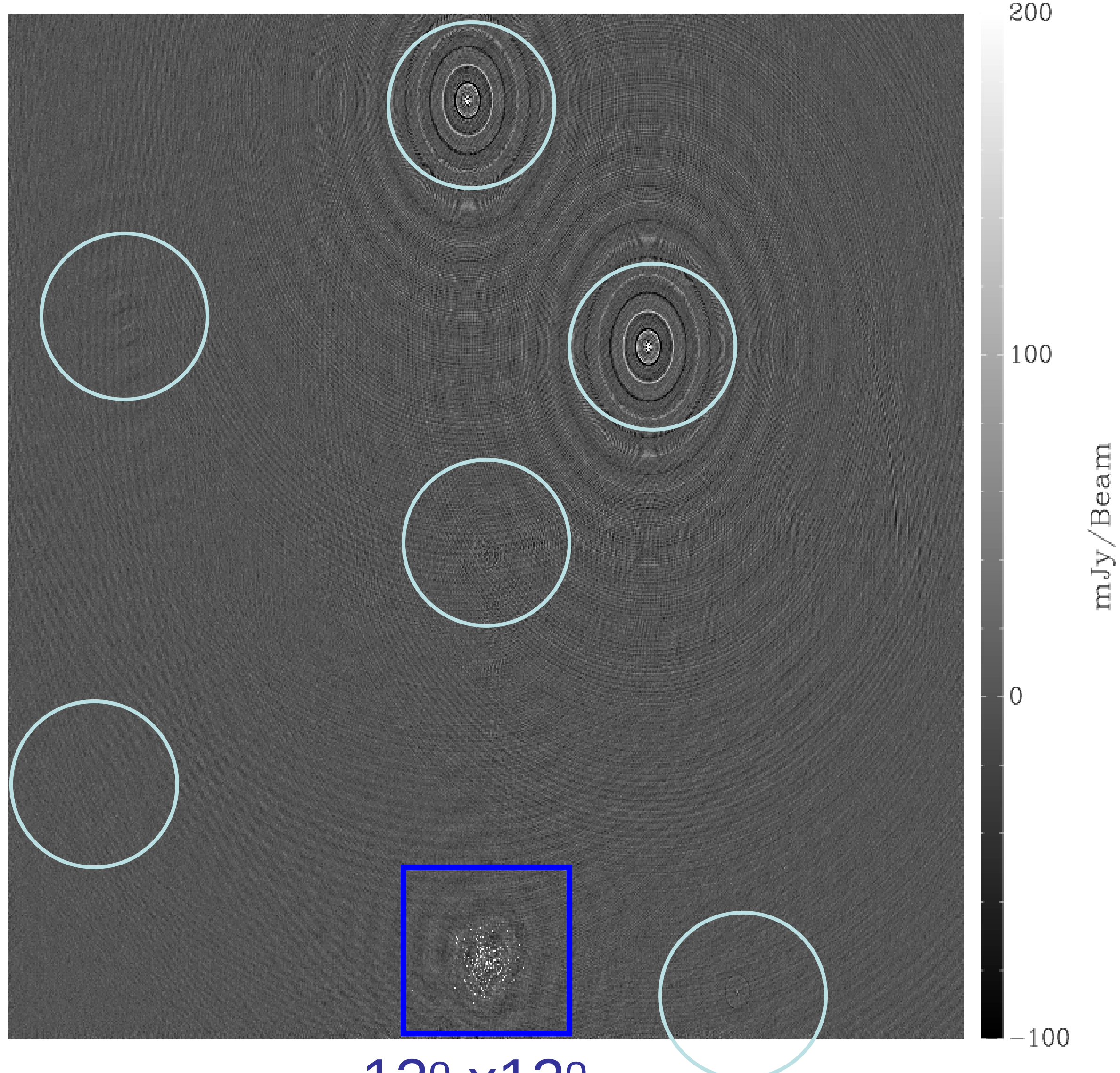
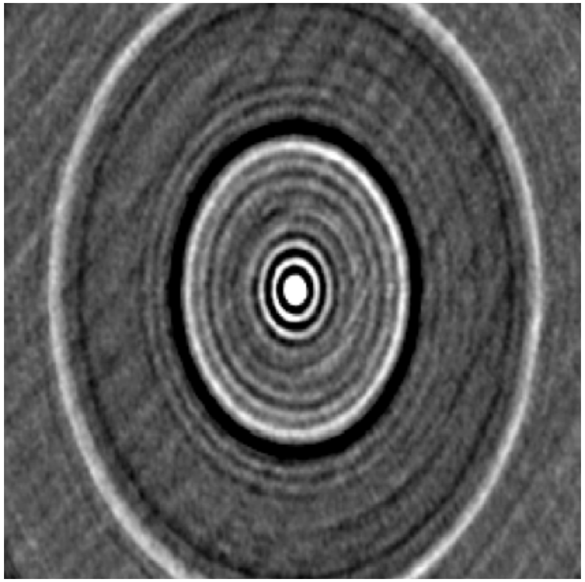


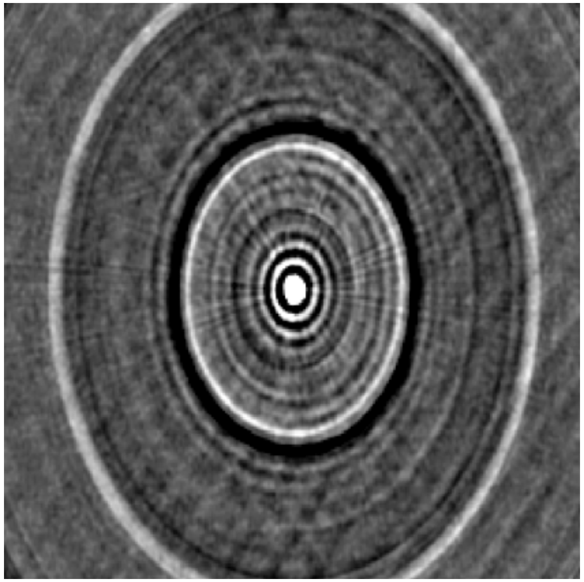
Figure 10 *Selection of Nyquist zones is used to select the observed band in the station.*

WSRT 150 MHz image of 3C196: 'all-sky imaging needed !'



The A-team magnified

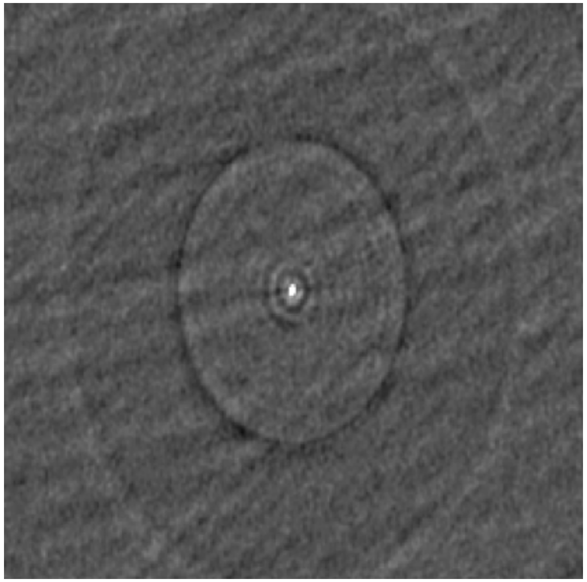


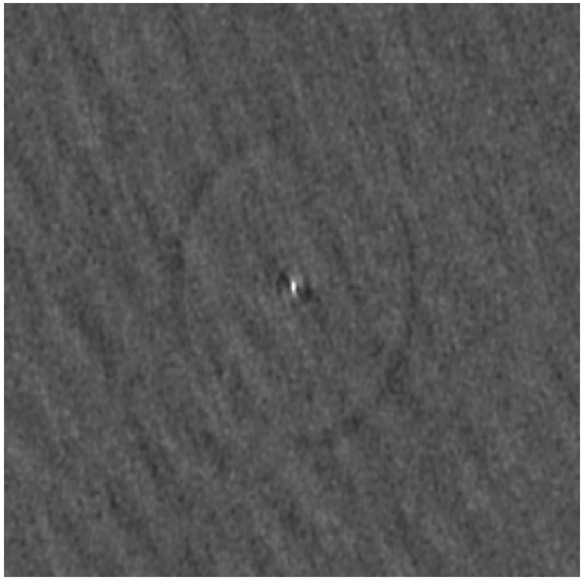


~5' PSF

CasA CygA

~ 10 Jy peakflux





~ 1Jy peakflux

TauA VirA

Why do a MS^3 ?

LOFAR20 needs a ***Global Sky Model (GSM)*** for the northern sky (~ 21,000 □°) in an early phase and which:

— has a proper flux scale

— has validated (initial) source parameters (spectrum, structure, ..)

— is astrometrically correct to better than 0.5”

— interfaces efficiently to calibration & imaging pipeline (LSM)

Carrying out MS^3 will also

— create a ***joint focus for activities***

— allows integration of scheduling, monitoring, processing, calibration & imaging

— provide realistic estimates for storage and processing resource needs

— provide the conditions for a rehearsal of full LOFAR operations

How to do MS^3 :   an initial proposal

Observations:

- 20 NL stations (13+7) => 3-9 snapshots for decent uv-coverage
- limit to two (broad?) frequency ranges: 60 MHz & 150 MHz
- complete in < 3 months (30% efficiency) & 'real-time' processing
- 2 beams of ~15 MHz (+ CasA beam, ~1 MHz)

Products:

- ~ 1 million sources, of which ~ 100,000 will be high S/N (I.e. ~ 5 / □°)
- spectral indices for the ~ 100,000 sources seen in both bands
- structural information: ~20-60" resolution, i.e. comparable/better than VLSS/WENSS/NVSS (= initial reference catalogue)
- fully tested pipelines

How to do MS^3 ? - continued

remaining observational issues:

- use of VERY wide bandwidth synthesis (BWS): calibration/deconvolution ?
- 16 - 8 - 4 bit transport options:

  more beams => faster => better uv-coverage BUT lower SNR for calibration
- polarization (RM-synthesis) processing in both HBA and LBA (?)
- participation of European stations: 3 - 8 ? => afternoon discussion

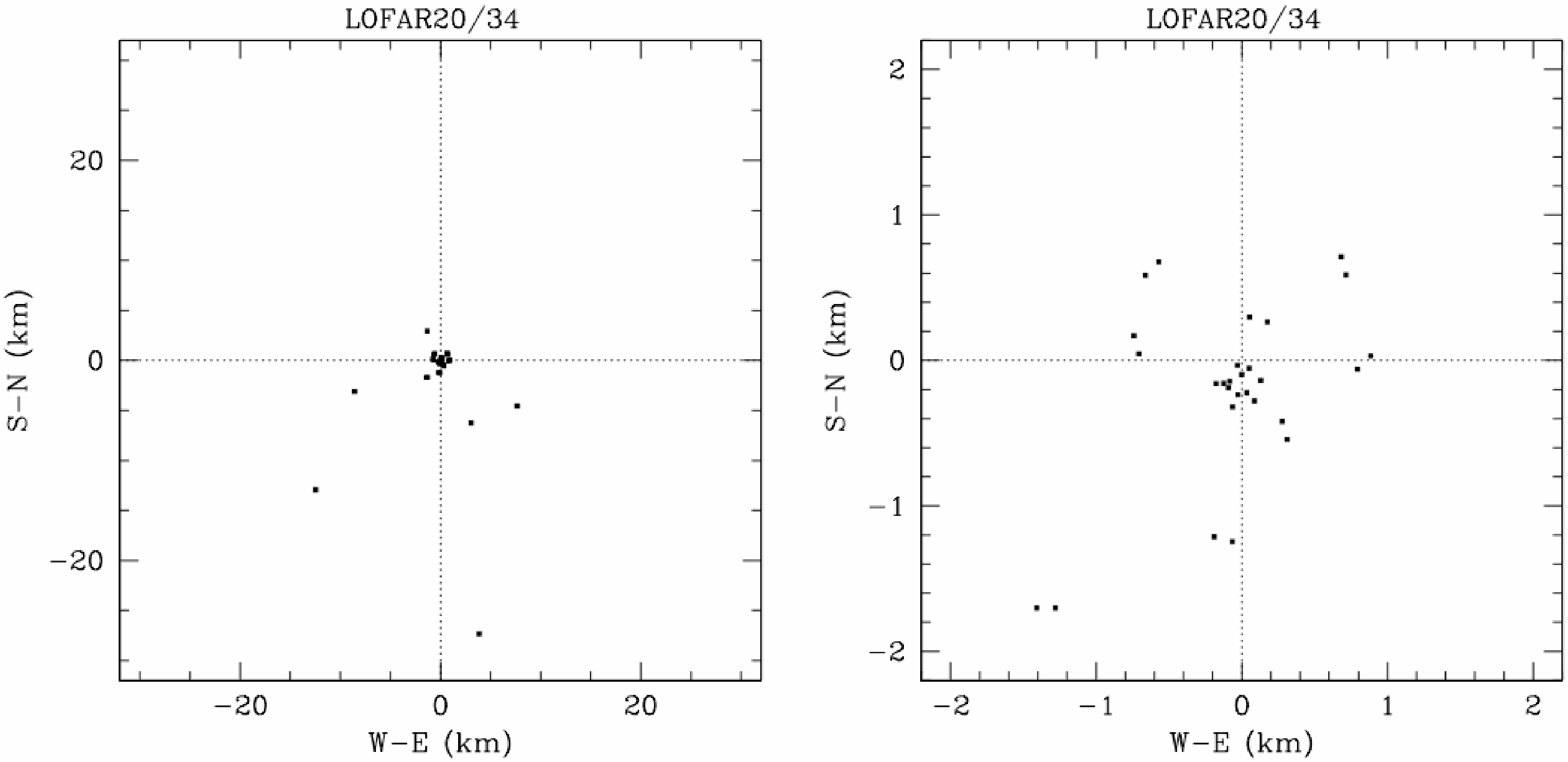
Should we try to include simultaneously other KSP-specific commissioning issues ?

EoR/SRV ‘deep’ fields + TRA + UHECR + MagKSP + Solar System

additional products:

- arcsecond images of ~ 4,000 (?) European-LOFAR calibrator sources
- lists of polarized calibration sources for ionospheric RM monitoring

Adopted LOFAR20/34 configurations



Some assumptions and their consequences

- < 3 months total (e.g. April-June, May-July, June-August) combined with 24h RA coverage $\Rightarrow$ mostly daytime observations !
  => vulnerable to Solar flares, scintillation (IPS), ionospheric TID waves

- required uv-coverage and (relative) sensitivity
  $\Rightarrow$ at least 3 x 5m (HBA) and 9 x 5m (LBA)

NB: if multiple snapshot AND multi-beam => considerable complexity in processing !

- FOV for ~ 30m stations (core/remote NL, space tapered)
  $\Rightarrow$ grid of 2.5^o (150 MHz) and 6^o (60 MHz)

- Only one longish baseline (28 km) => imaging with ~ 10 km tapered array

Some basic numbers for MS^3

Some numbers

The numbers below are based on 9 times 5 minute observations in the LBA and 3 times 5 minute observations in the HBA using 1 beam of 32 MHz (and 1 calibration beam of a single subband). In order to improve the UV – coverage and PSF we might trade BW for beams. In this way we can observe more fields at the same time and, hence, integrate longer on the same field. This goes at the expense of a smaller BW, but the sensitivity and total data size on that field remain the same.

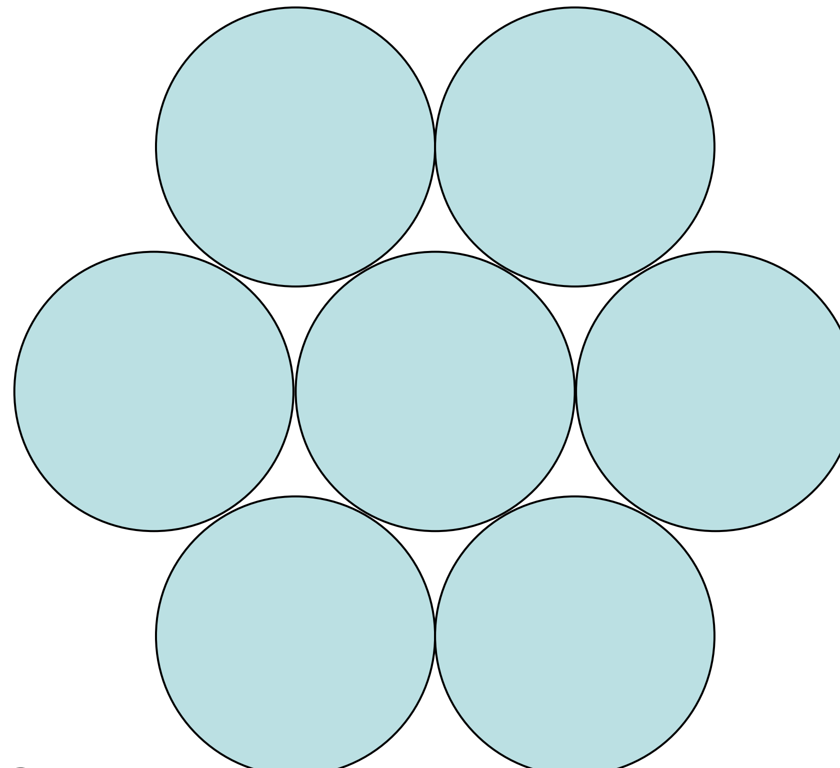
	60 MHz	150 MHz
Observing time per FoV	9 times 5 minutes	3 times 5 minutes
FoV	121 deg^2	19.4 deg^2
FWHM	12.4 deg	4.97 deg
PSF resolution (10 km)	82.5 arcsec	33.0 arcsec
Correlator time resolution	1 s	1 s
Correlator freq resolution	0.76 kHz	0.76 kHz
Uv data size	760 Gbyte	680 Gbyte
Post DP^3 time res.	5 s	5 s
Post DP^3 freq res.	21.3 kHz	42.6 kHz
Post DP^3 uv data size	~ 5.43 Gbyte	~ 2.43 Gbyte
# channels per image cube	Tbd	Tbd
# pixels per image plane	Tbd	Tbd
Total image size	Tbd	Tbd

Table 1: Specifications per pointing / FoV

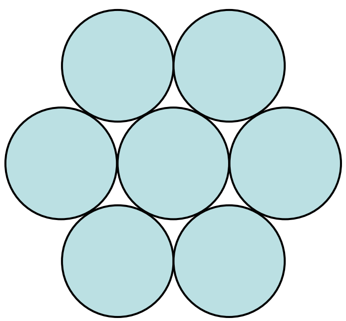
Gridpatterns, mozaicing and multi-beam issues

We assume 30m stations for both HBA-150MHz and LBA-60MHz

60 MHz: HPBW=12.5^{o} => 6.25^{o} grid in RA



150 MHz: HPBW =5.0^{o} => 2.5^{o} grid in RA



Question:

Should we conduct MS^{3} in a 7-beam observing mode?

Beams, bandwidth, effciency and MS^3 duration

We have 8 beams (assuming 16-bit signals)

Note that one beam (1-2 MHz) always on CasA to get clock (+ ionosphere) but only in core (CasA resolved at ~ 2 km - 5 km). What to do for NL clocks ?

Broadband (120 -1 80 MHz) data might allow separation of clock ($\phi \propto \nu$) and ionosphere ($\phi \propto \nu^{-1}$) delays.

Choice of observing mode depends on efficiency:

— 100% 1 beam x 30 MHz => 7.5 weeks

— 60% 1 beam x 30 MHz => 13 weeks = 3 months

— 30% 2 beams x 15 MHz => 13 weeks

— 30% 4 beams x 7.5 MHz => 7 weeks

(Assuming last mode applies we could add more snapshots in HBA)

Calibratability of MS^3

Important assumption: still 16-bit transport (⇒ 2 x 15 MHz beams)

If the 16 => 8 => 4 bit option is available => more beams possible , better uv-coverage but reduced SNR !

Calibratibility

In order to say something about the calibratibility of LOFAR20 the number of sources visible in the FoV in 10 s of data is computed. If we want to trade BW for beams in order to improve the UV – coverage and PSF, this will reduce the available BW for the calibration.

	100 σ; 60 MHz	100 σ; 150 MHz	30 σ; 60 MHz	30 σ; 150 MHz
1 beam; 30 MHz	17	44	94	140
3 beams; 10 MHz	6.9	24	45	84
5 beams; 6 MHz	4.4	17	31	66
7 beams; 4.29 MHz	3.3	14	24	56

sources in FoV in 10 s integration time.

It is currently expected that at 150 MHz there will be enough sources (> 10) in the FoV per 10 s for LOFAR20 to be calibratable. At 60 MHz the situation is much harder, especially in the daytime. Peeling large number of sources and using the phase information to model an ionospheric screen will have to be high on the agenda in the next 6 months.

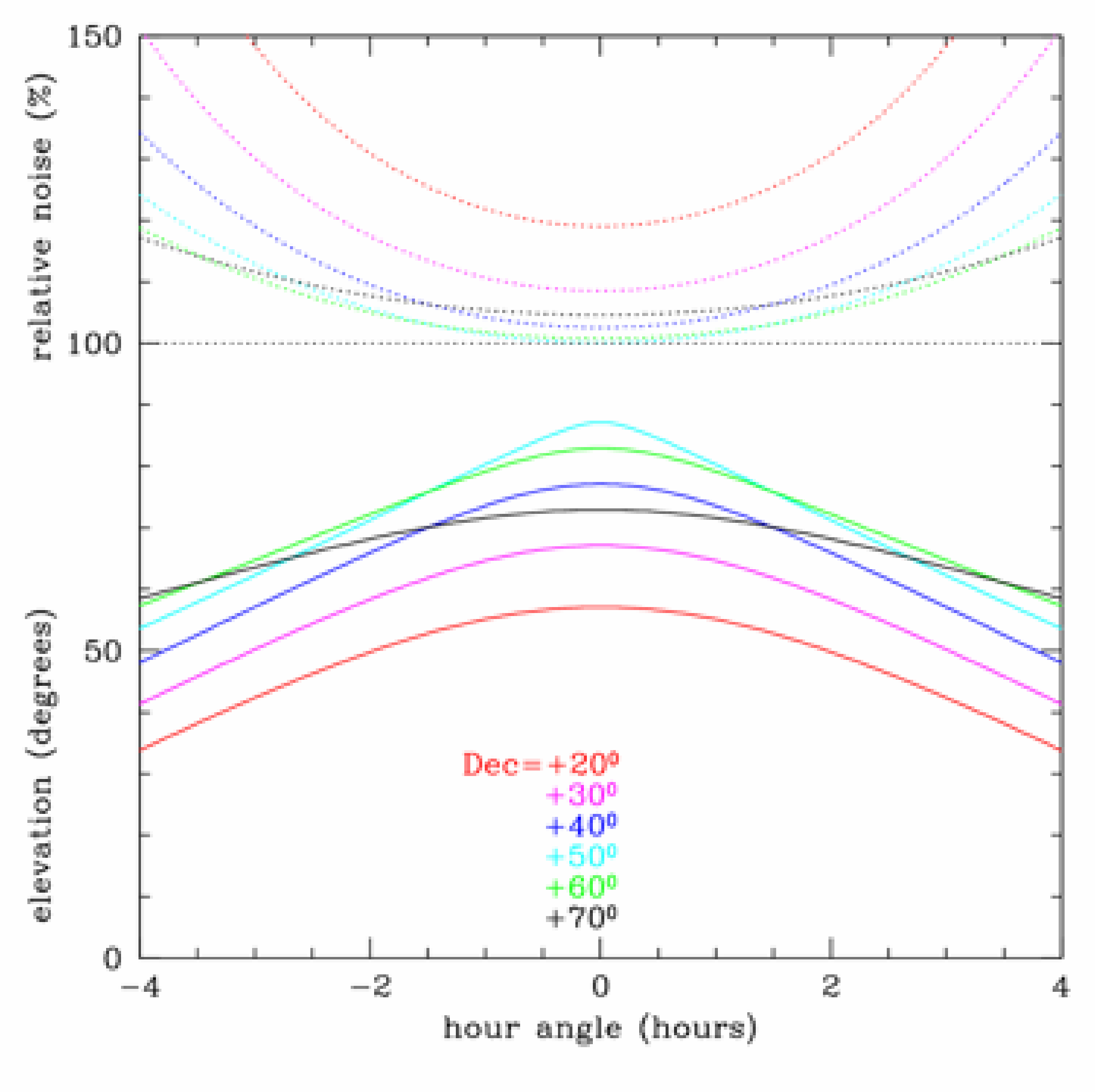
Elevation, uv-coverage and projection issues

Ideally we would like to have snapshots at many widely separated hour angles,

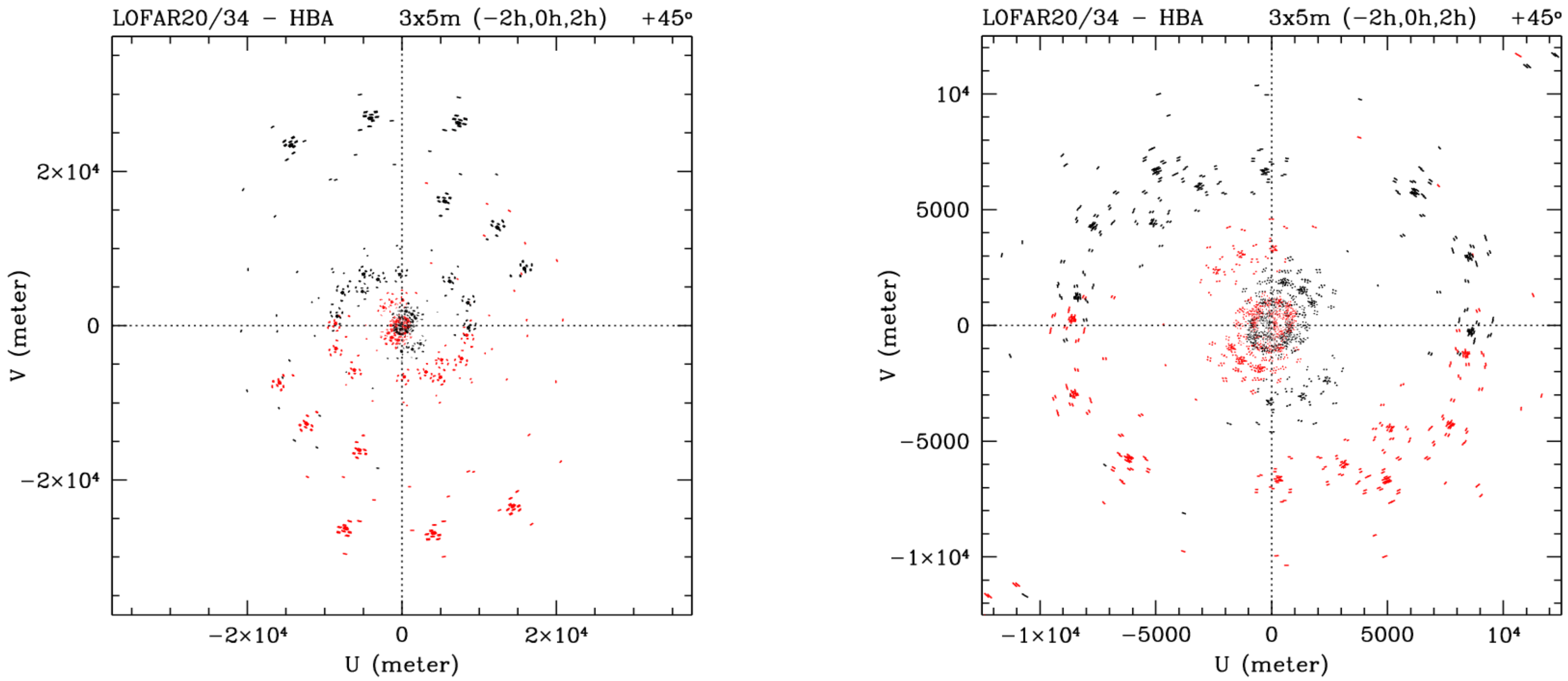
BUT

for declinations below about +20º the sensitivity losses for large hour angles will outweigh the uv-coverage improvements

⇒for low declination we aim for snapshots at -2h, 0, +2h

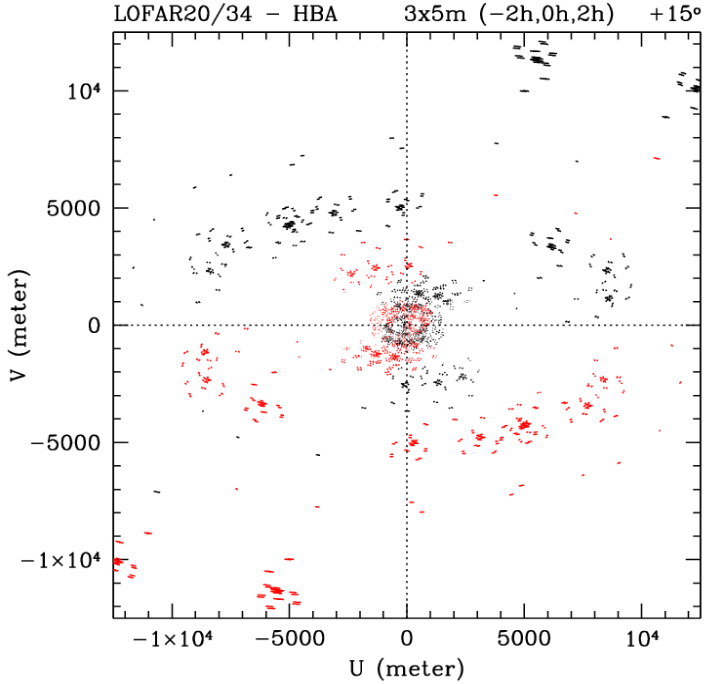


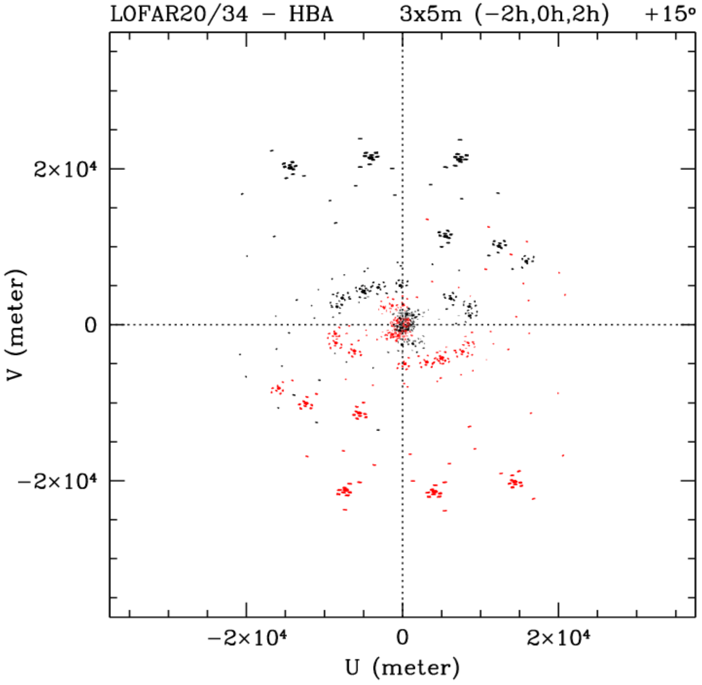
monochromatic 3x5min +45°



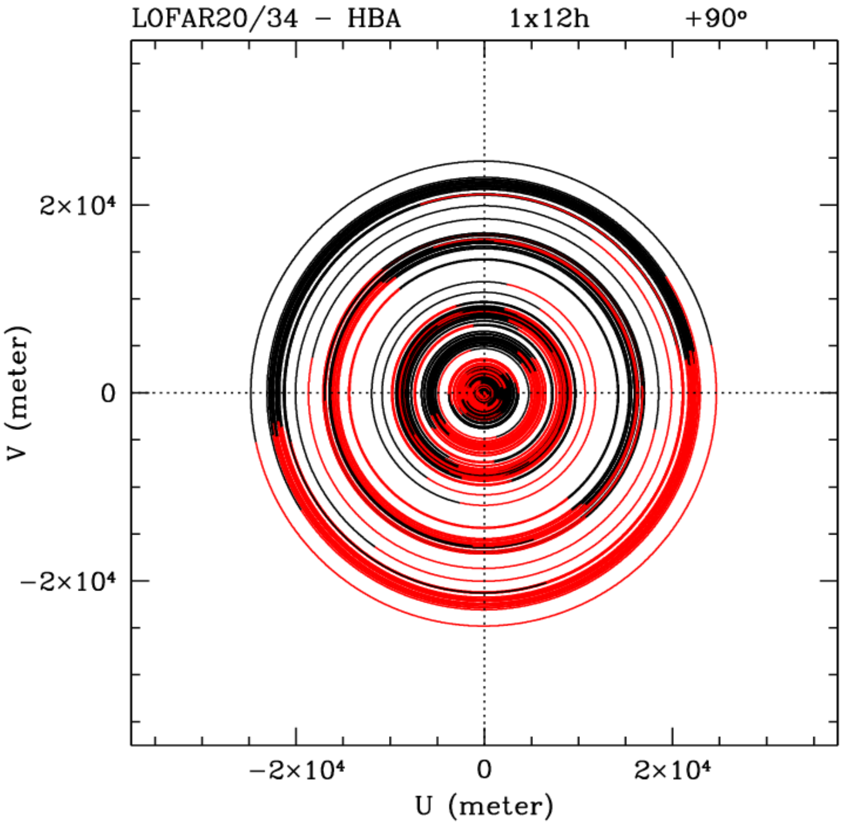
LOFAR20/34 HBA uv-coverages

monochromatic 3x5min +15°

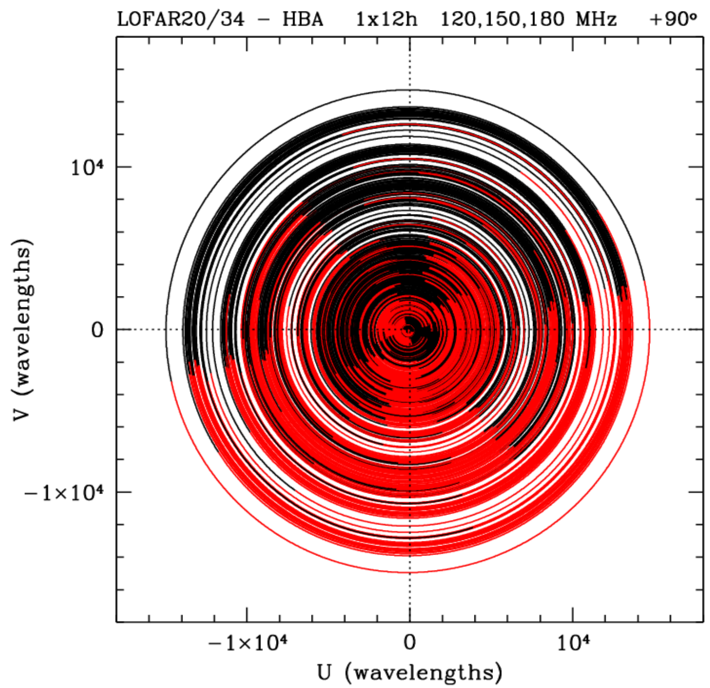


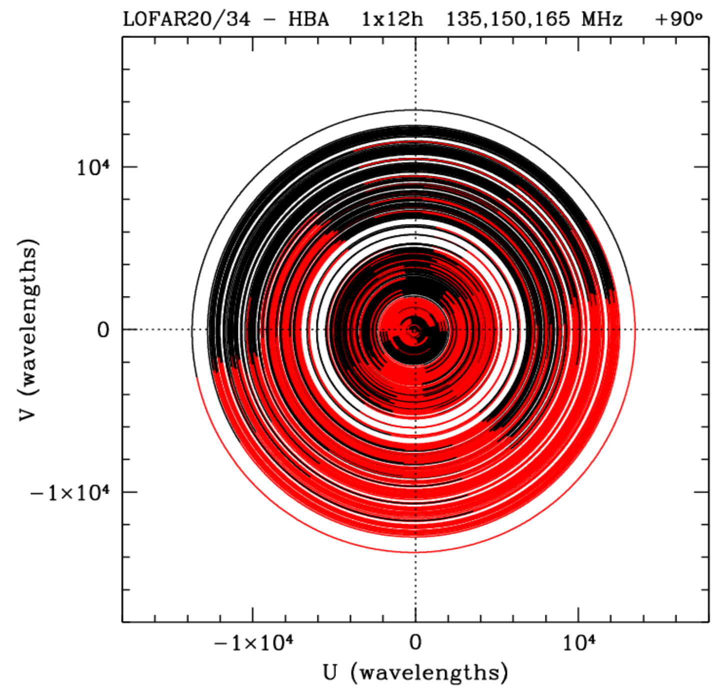


monochromatic 12h +90°

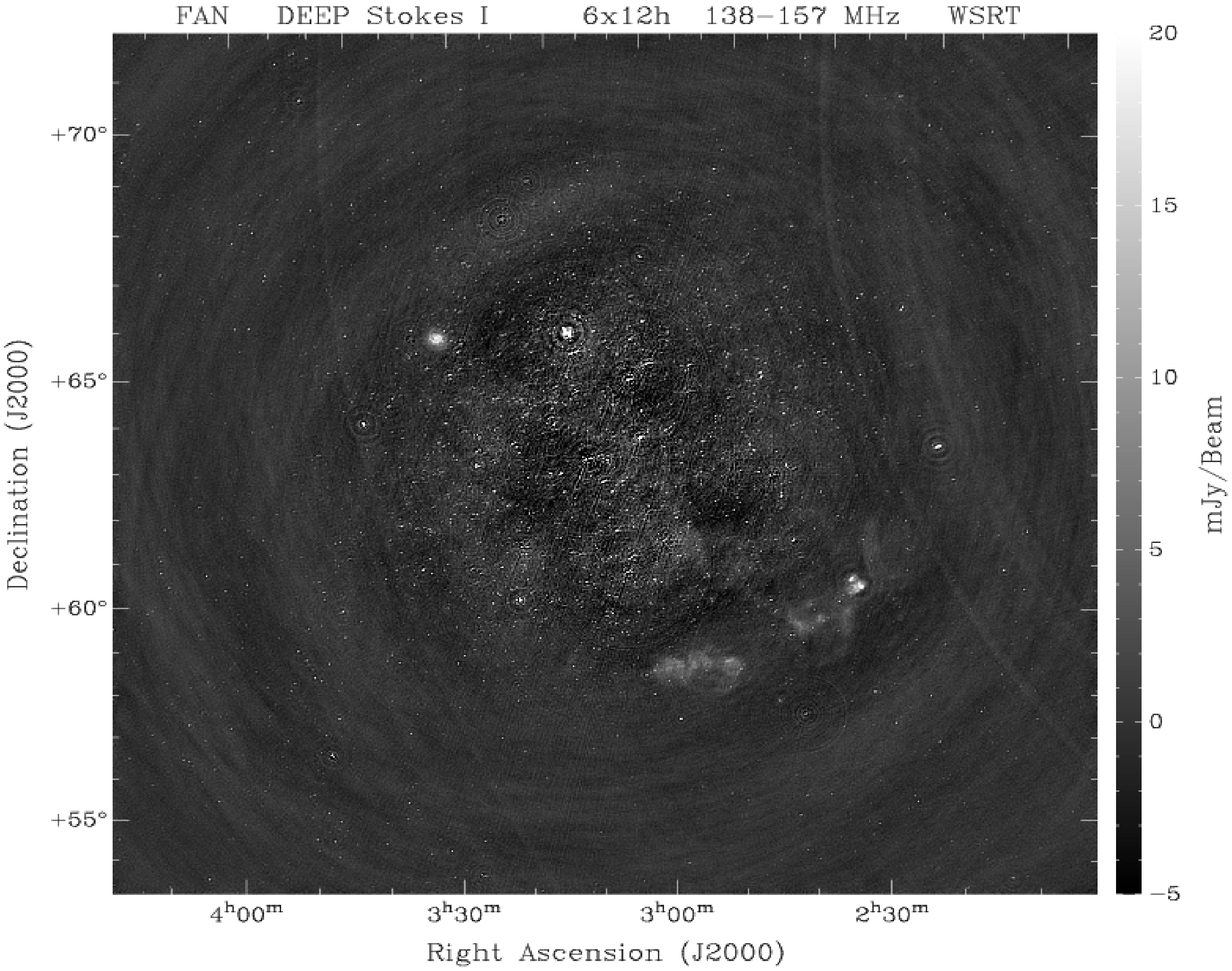


broadband/MFS 12h +90°





The deepest 150 MHz WSRT image



Bernardi et al, in prep)