LOFAR observations of Cosmological Signals & Foregrounds

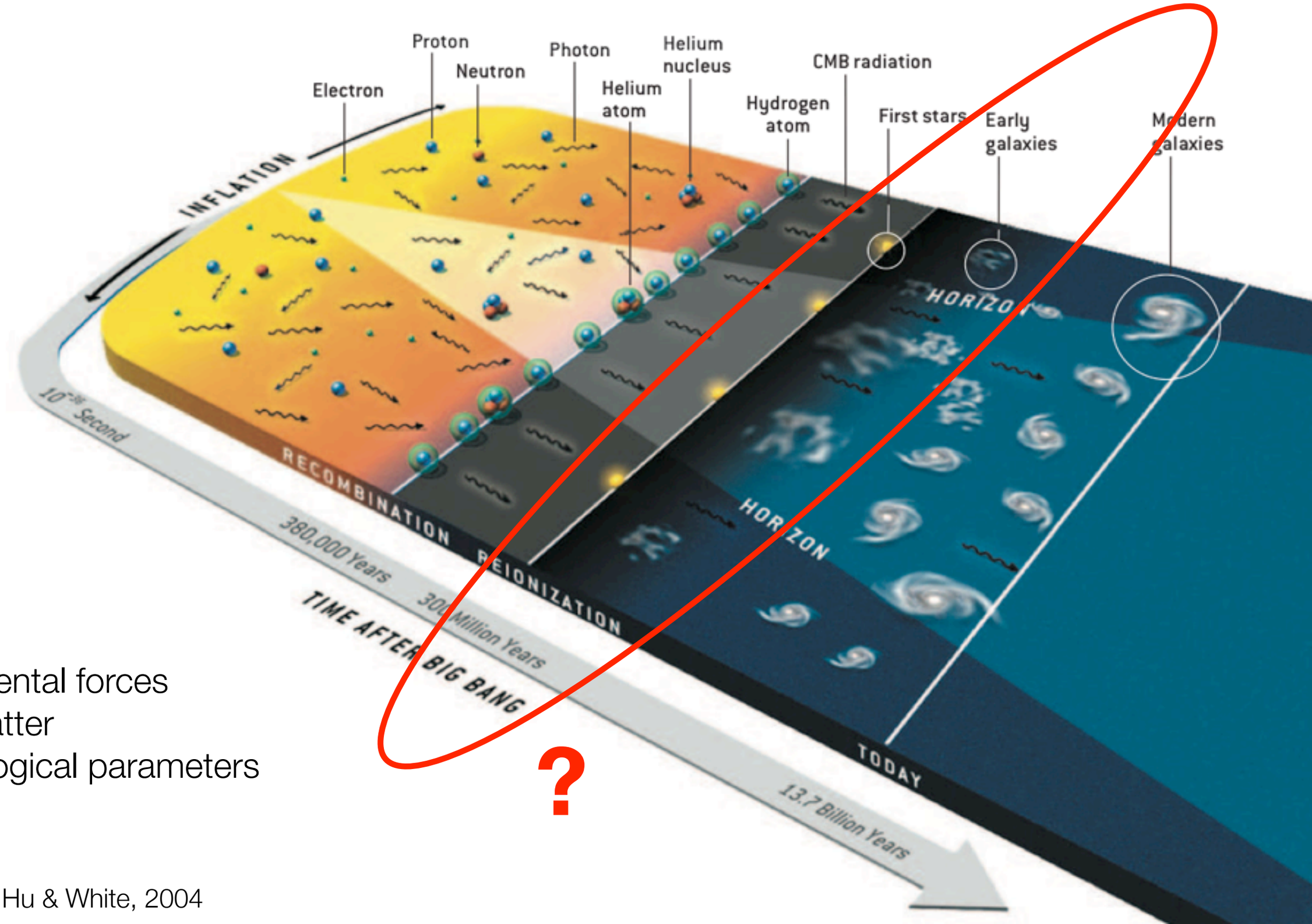
Philippe Zarka

LESIA

PCCP workshop, 23-24/5/2013

- EoR
- LOFAR
- Imaging
- Results
- Foregrounds
- Operations
- LSS/NenuFAR
- LSS /NenuFAR science

Large structures formation



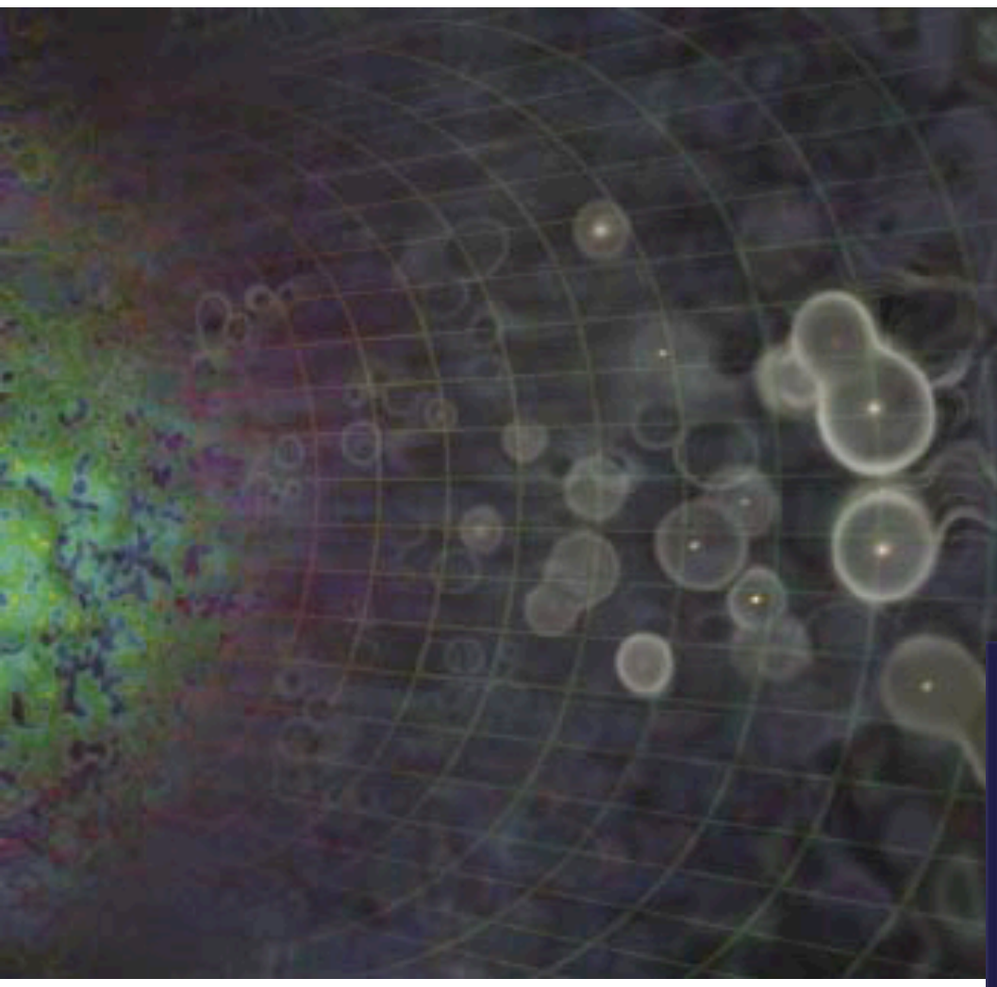
- fundamental forces
- dark matter
- cosmological parameters

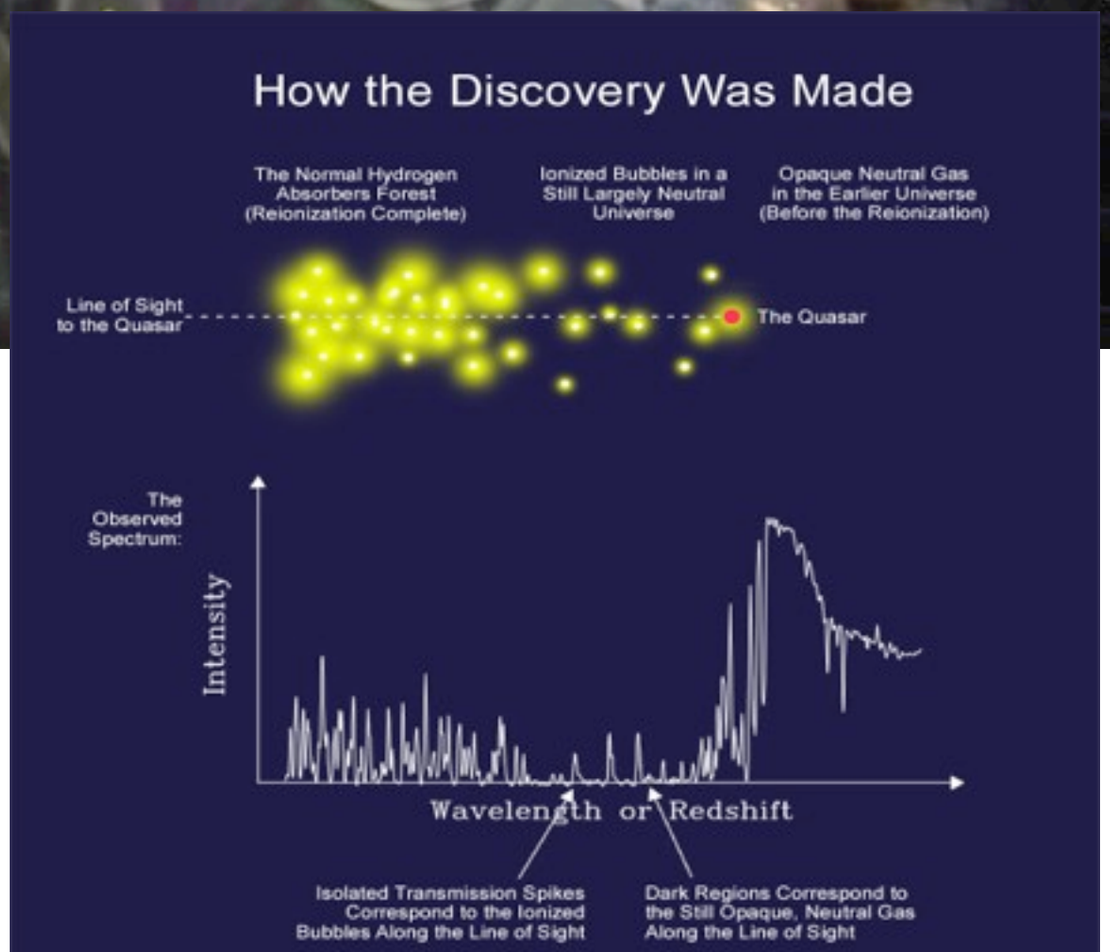
Hu & White, 2004

Reionization

dark ages

reionization





CMB

first sources (stars ? quasars ?)

first galaxies

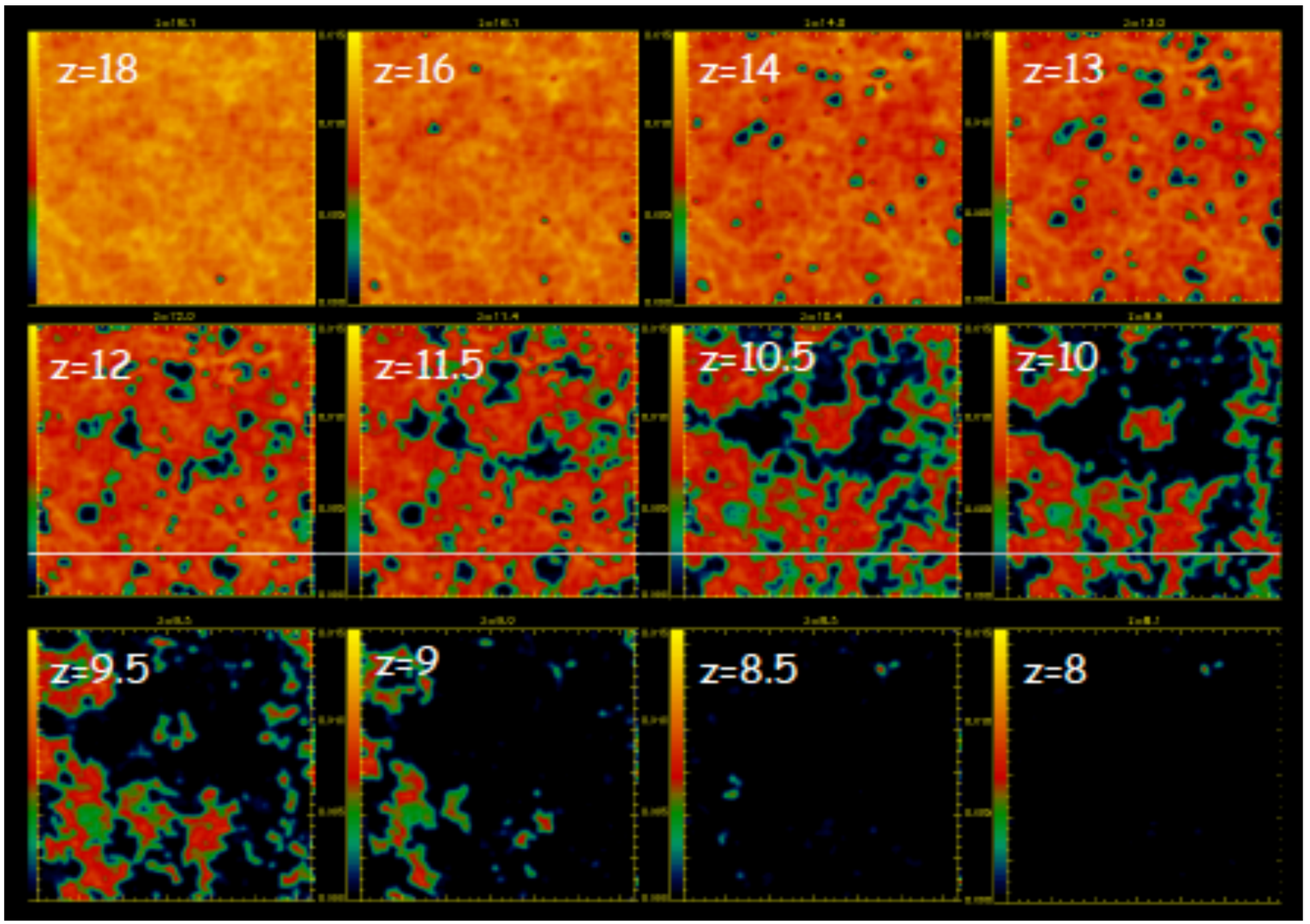
Loeb, 2006

Djorgovski, 2001

Simulations

- First sources ? Initial mass function ?
- Simulations of structures formation including dark matter + ionization sources + radiative transfer (assumption dependent scenario)

HI density



Ciardi et al., 2001, 2003, 2006

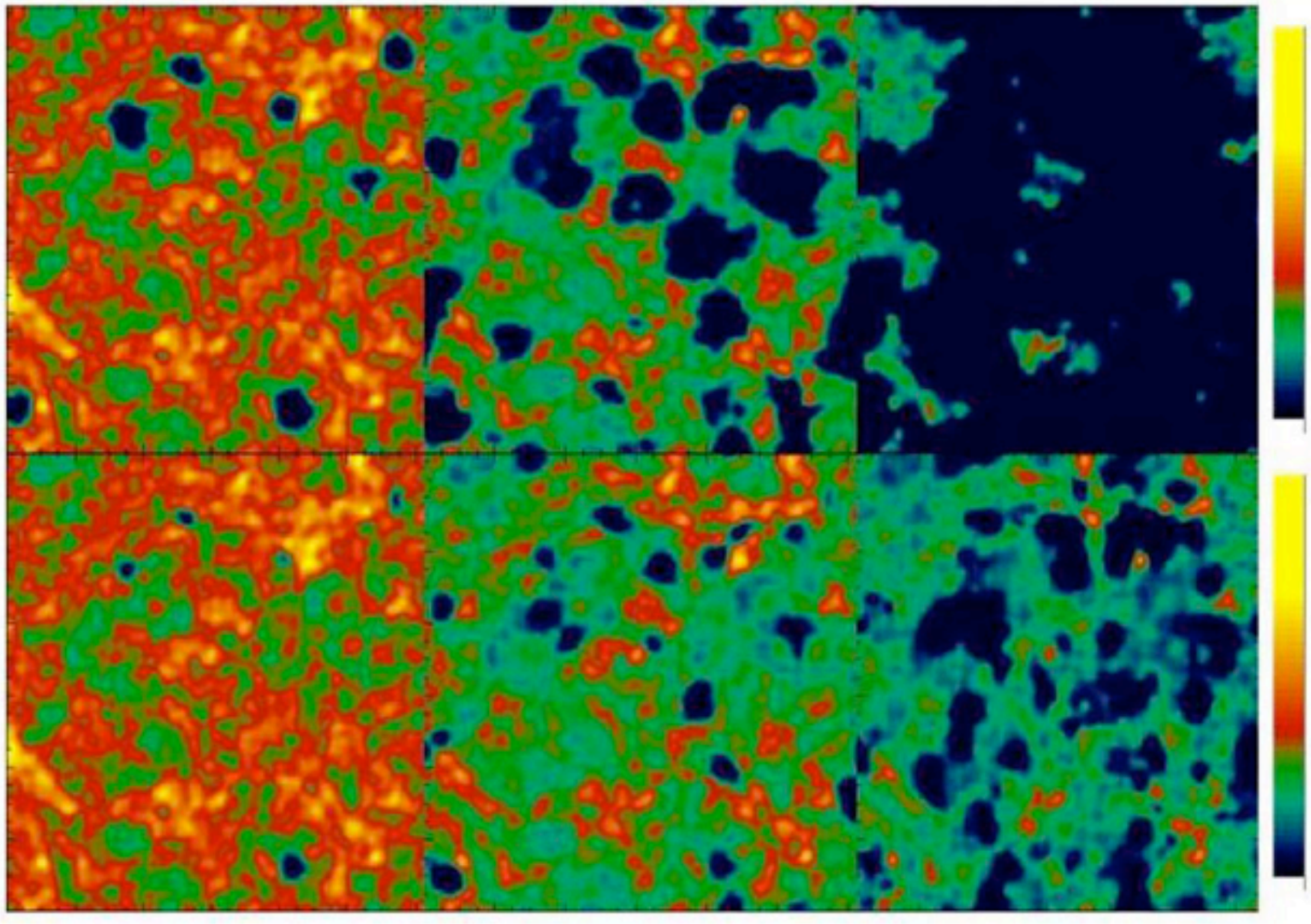
Simulations

- First sources ? Initial mass function ?
- Simulations of structures formation including dark matter + ionization sources + radiative transfer (assumption dependent scenario)

HI density

«heavy» IMF
Larson

«classical» IMF
Salpeter



Ciardi et al., 2001, 2003, 2006

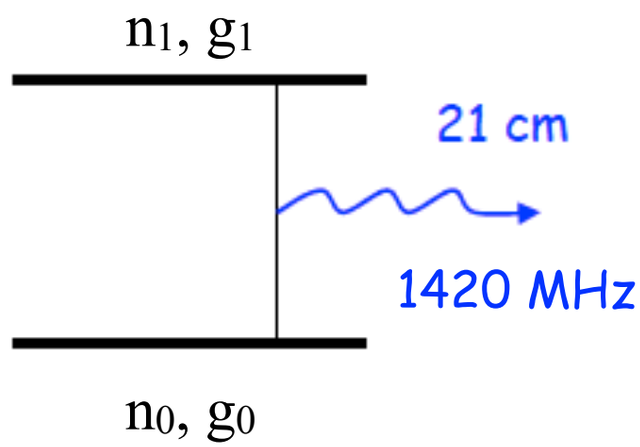
EoR Signal

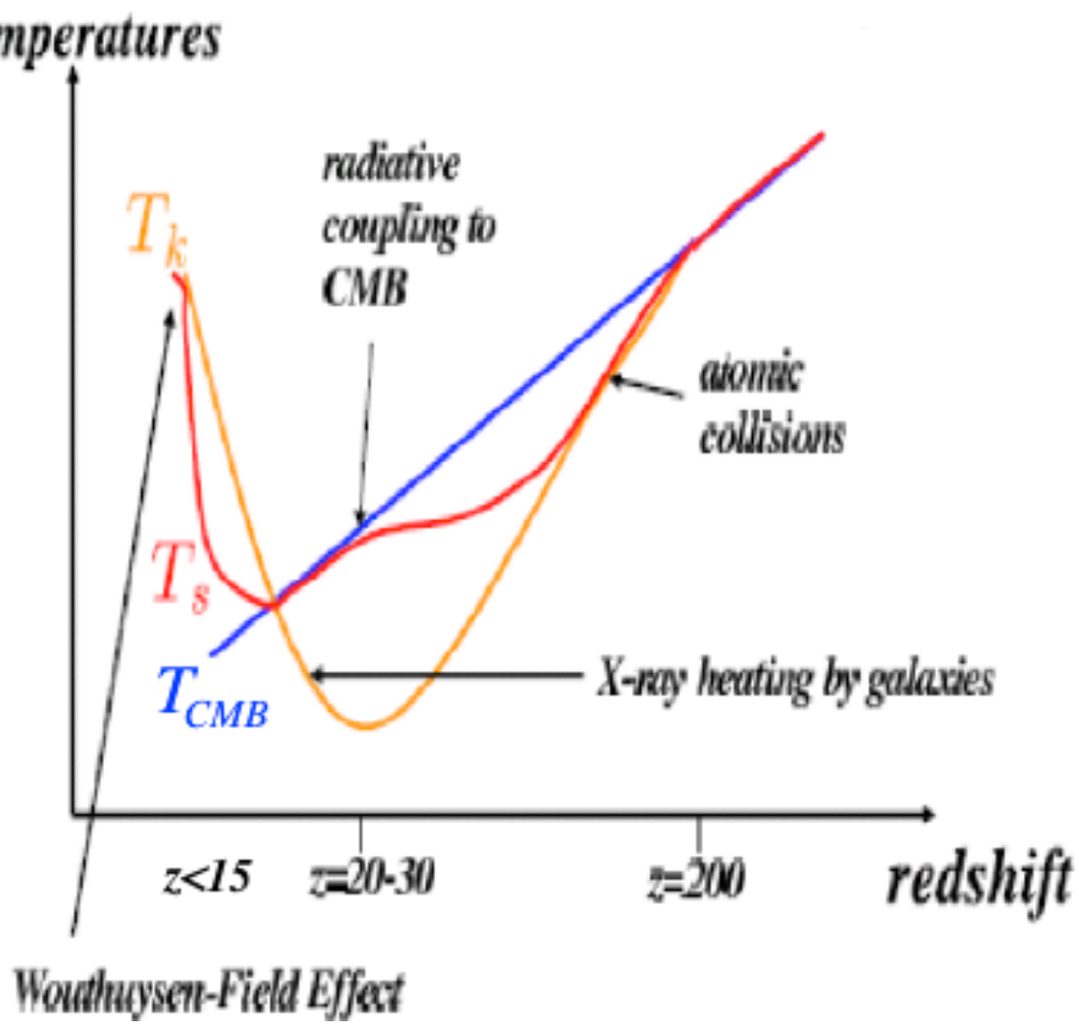
- HI ground state hyperfine transition : $n_1/n_0=g_1/g_0 \exp(-T_*/T_s)$

  with $T_* = 0.068K$ and spin temperature $T_S(T_{CMB}, T_k)$

  T_k = gas kinetic temperature → collisions, absorption/emission

  of Ly-α photons (Wouthuysen-Field effect)





Ciardi & Madau, 2003

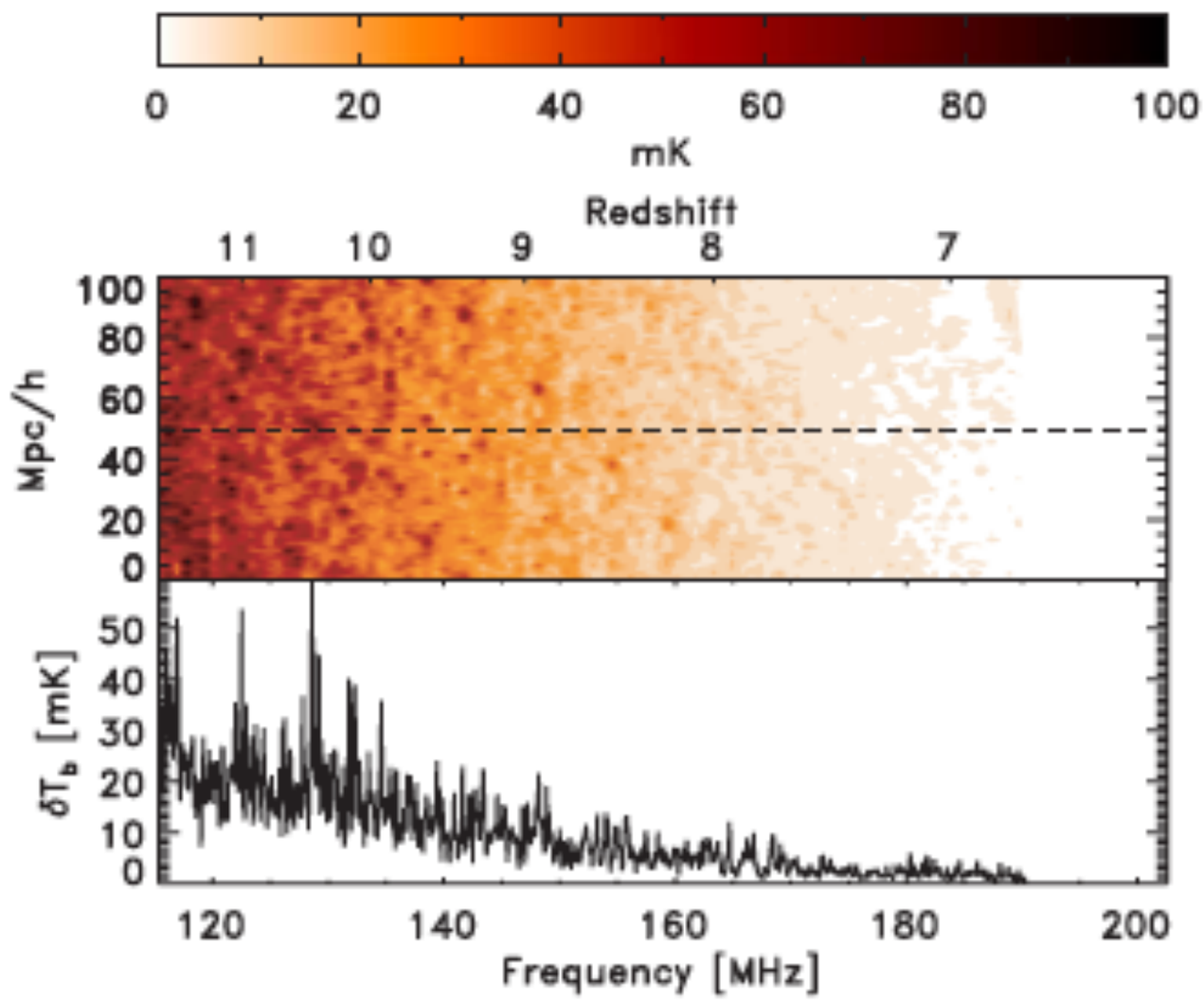
EoR Signal

$\delta T_b \sim (T_S - T_{CMB}).\tau / (1+z)$ $\Rightarrow$ ~10's of mJy, in emission or absorption

models $\Rightarrow$ evolution of T_S, T_{CMB}, τ with z

$\Rightarrow$ maps of δT_b vs z = IGM tomography

$\Rightarrow$ typical structure size ~ arcmin

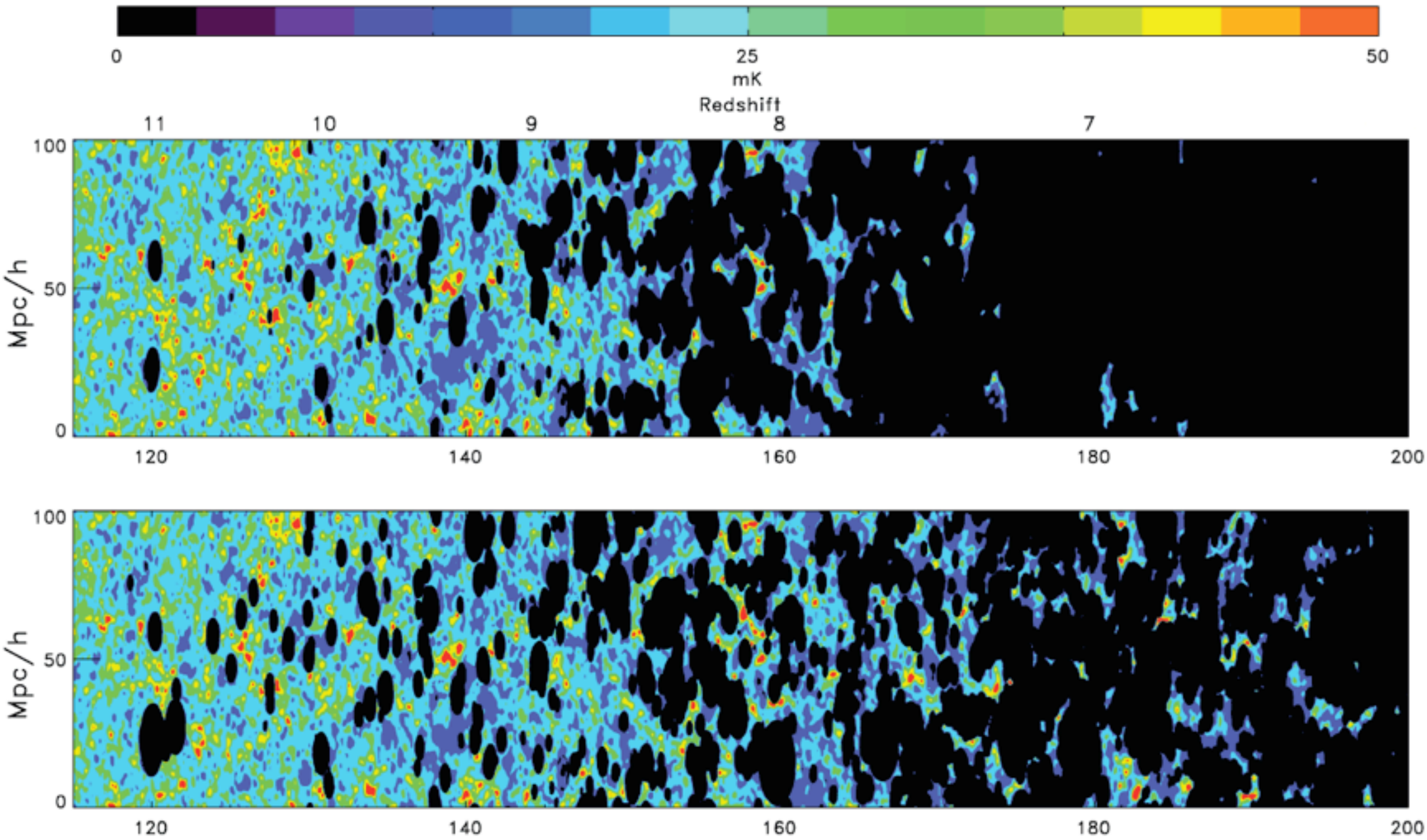


Jelic et al., 2008

EoR Signal

First sources = quasars

First sources = stars

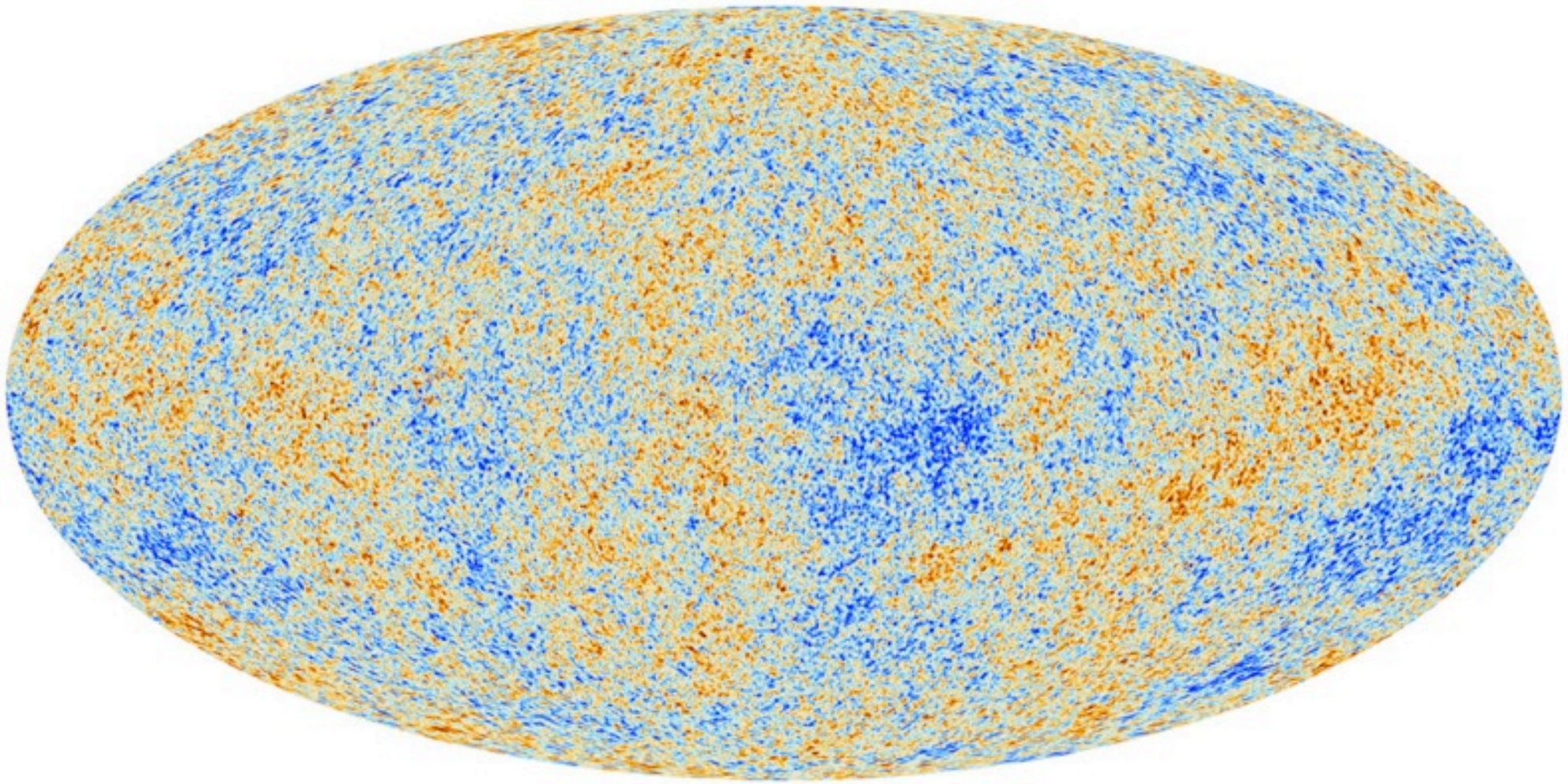


Thomas et al., 2009

Interest of EoR signal detection

- First sources ? Initial mass function ?
- Dark matter ? Super Massive Black Holes at high z ?
- Density power spectrum during dark ages
- Cross-correlation δT_b (21 cm) with CMB & Ly-α emitters maps
- Distribution & characteristic size of bubbles ?

Zaroubi, 2008



Planck map, 2013

Required instrument

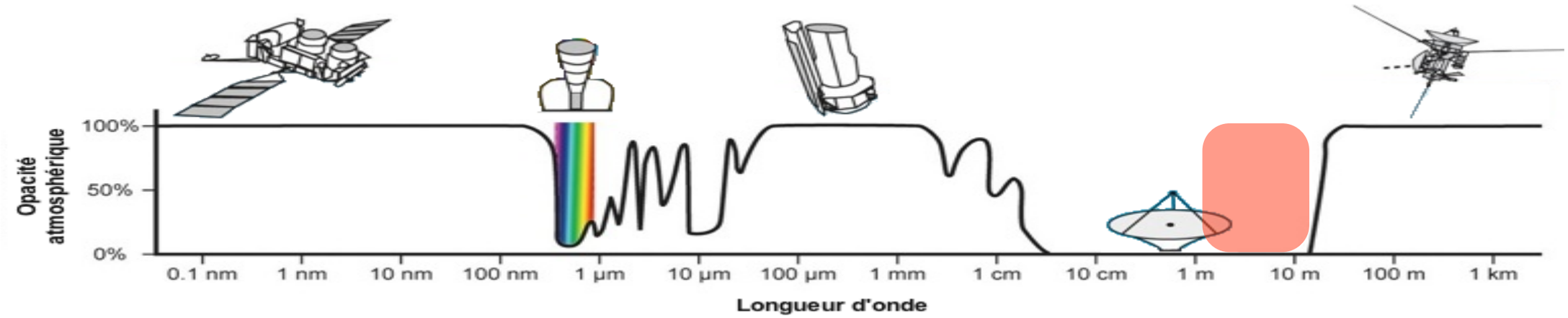
- maps of δT_b (redshifted 21 cm) vs z = IGM tomography with sensitivity ~ 10s of mJy & arcmin resolution

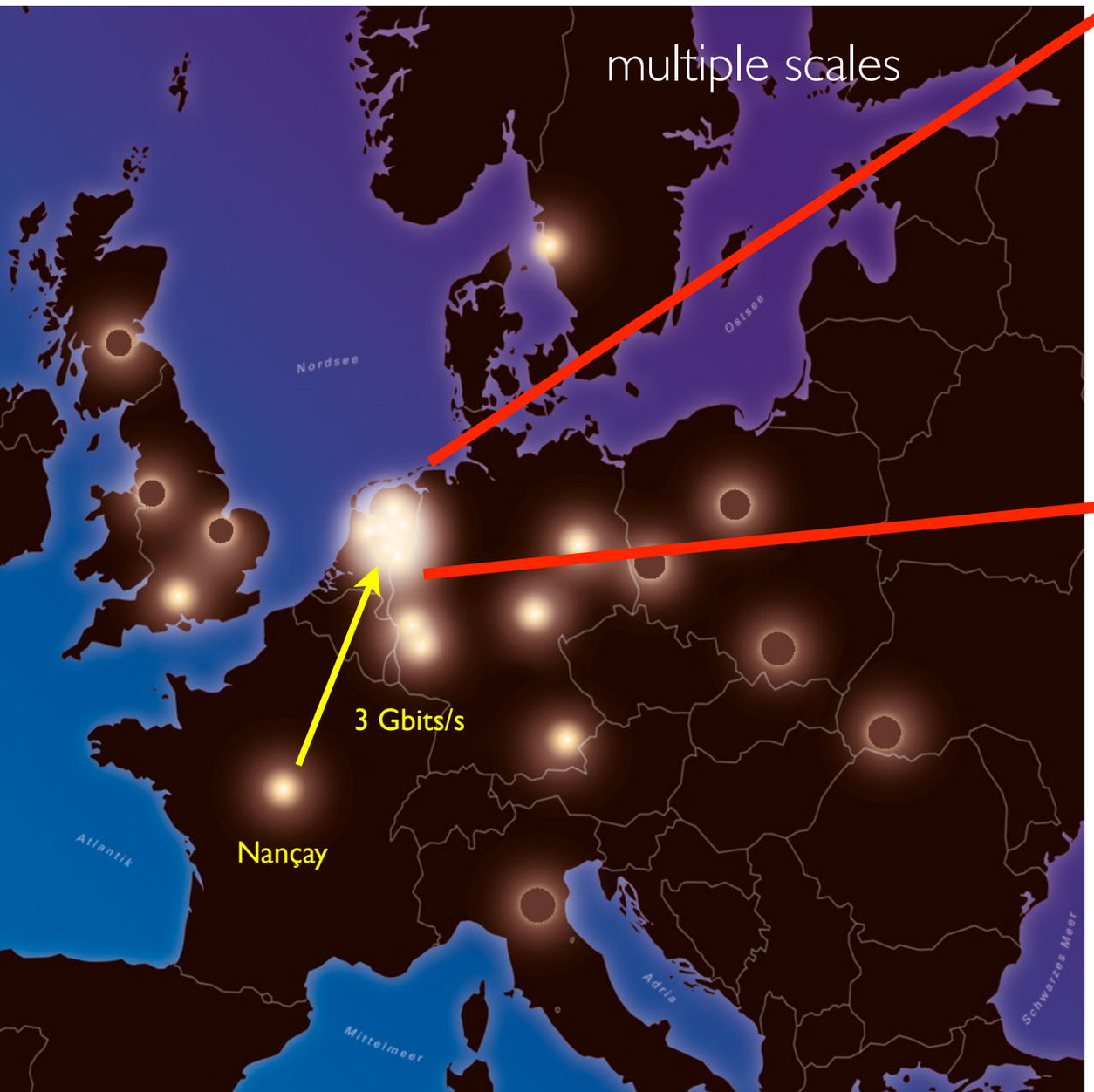
- z = 6 - 12 ⇒ ν = 110 - 240 MHz , λ = 1.2 - 2.7 m

⇒ LOFAR , the LOw Frequency ARray

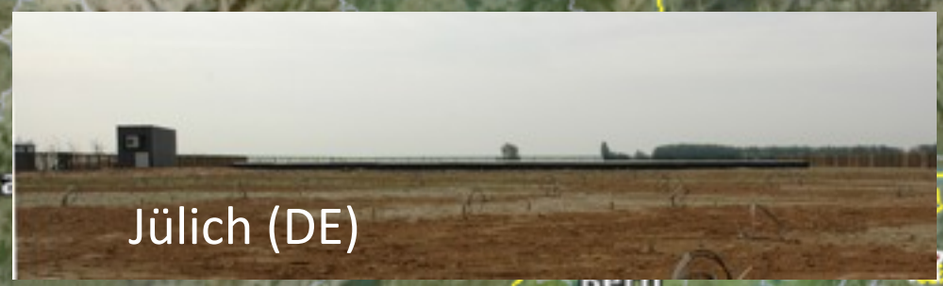
- EoR
- LOFAR
- Imaging
- Results
- Foregrounds
- Operations
- LSS/NenuFAR
- LSS /NenuFAR science

LOFAR : phased-array + interferometer

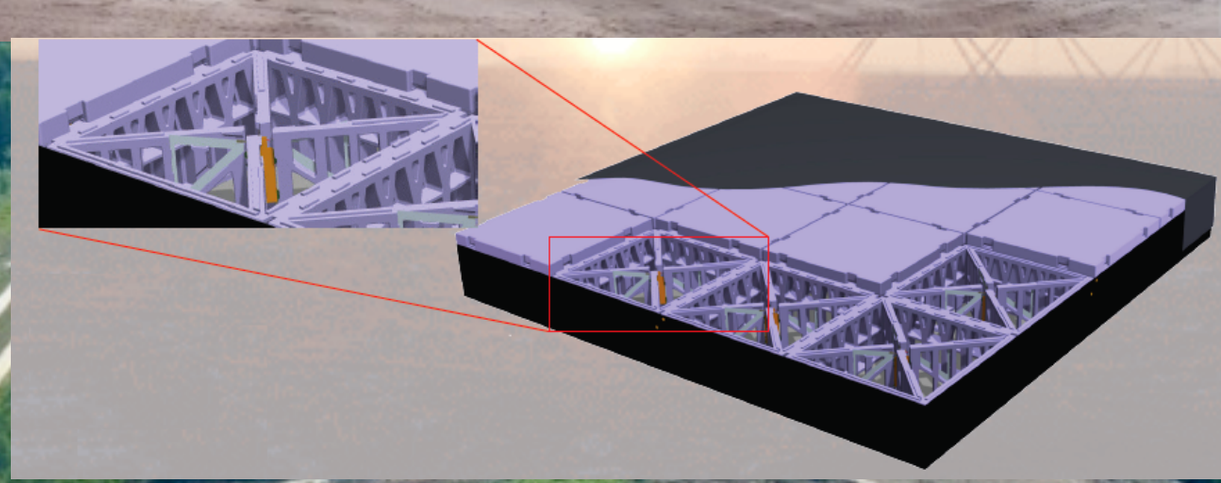




The LOFAR telescope



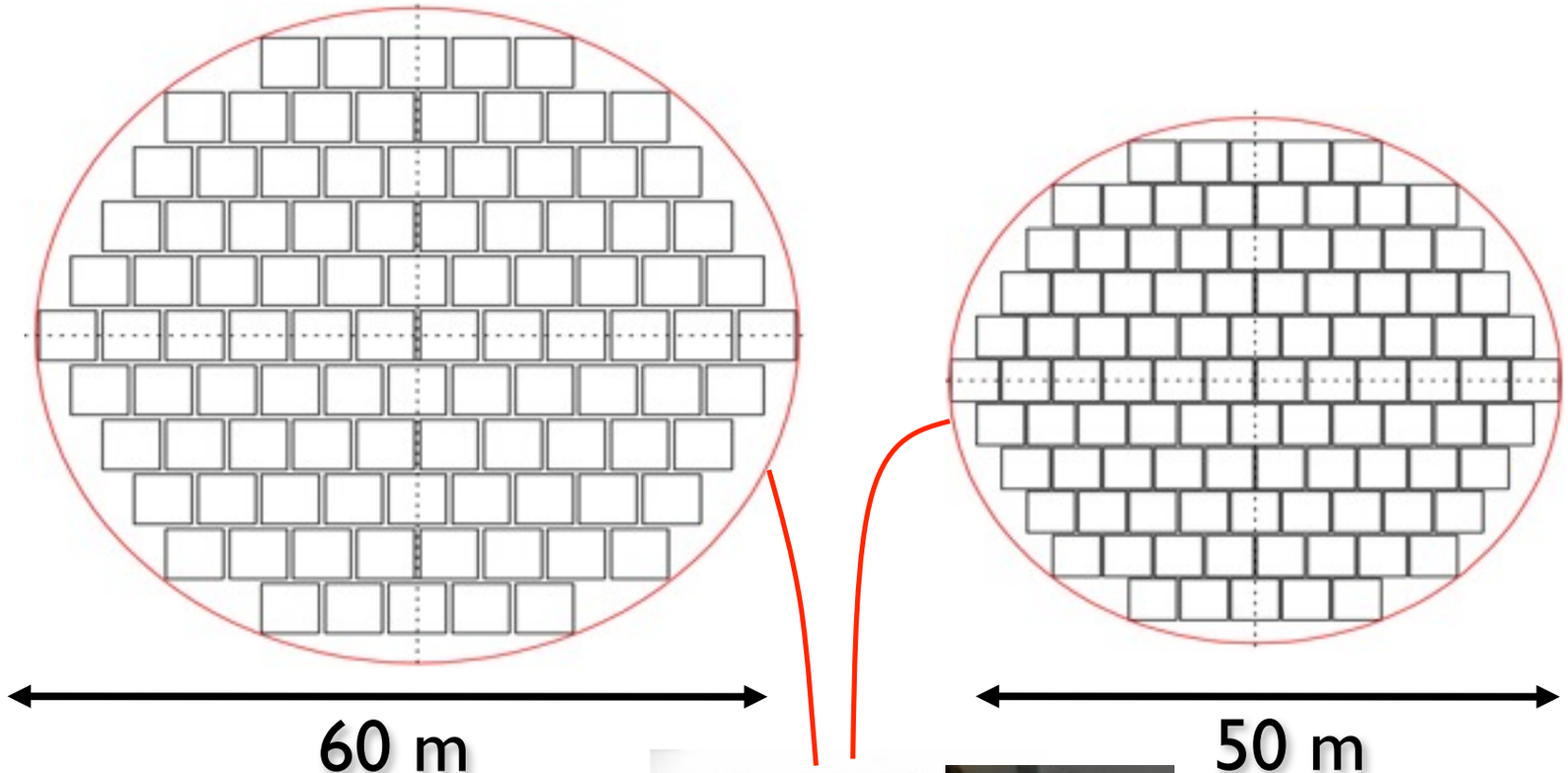
FR606, the Nançay LOFAR station



LOFAR station : 2 phased arrays + backends

Low frequencies : LBA
(30-80 MHz)

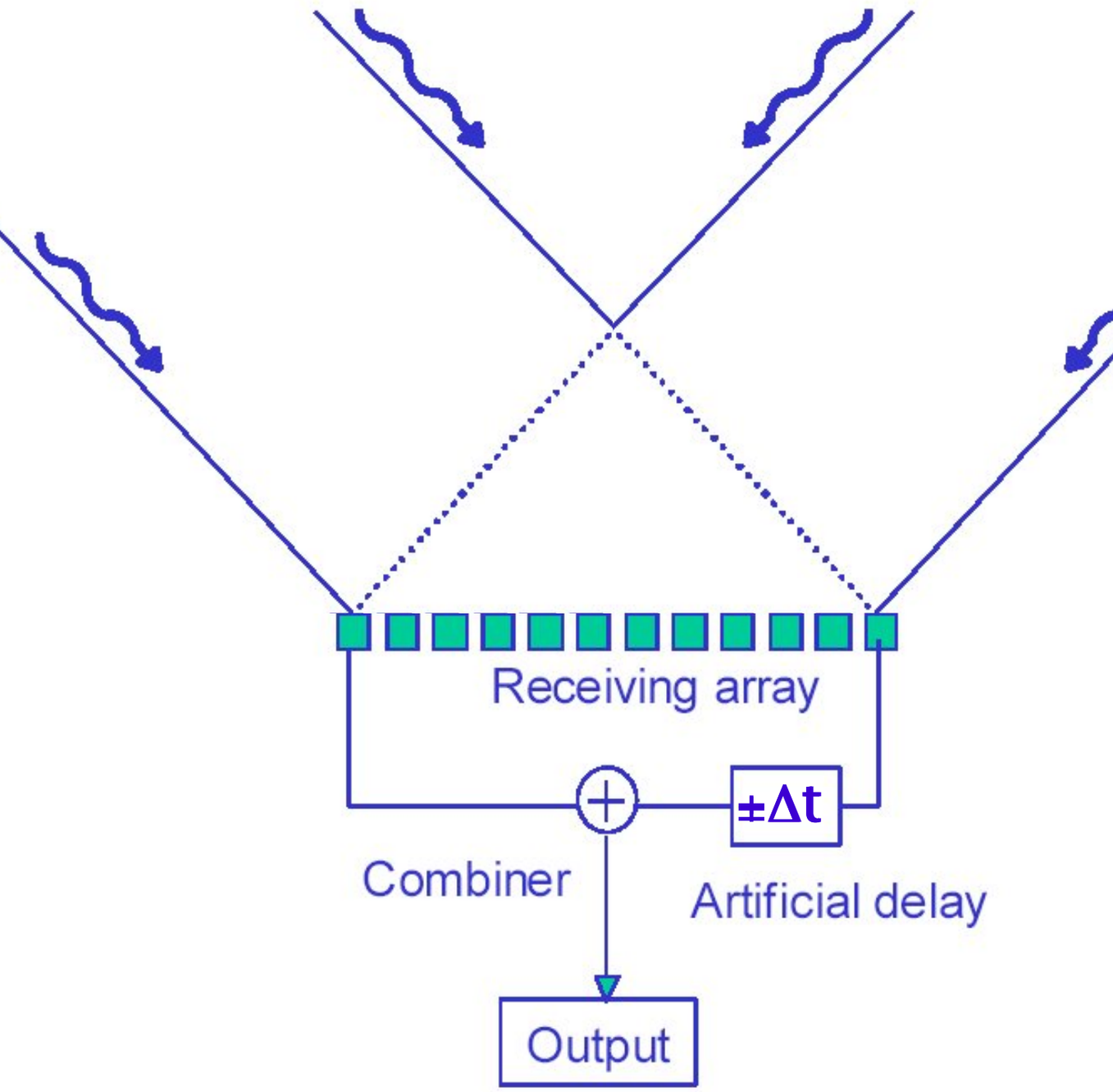
High frequencies : HBA
(110-250 MHz)

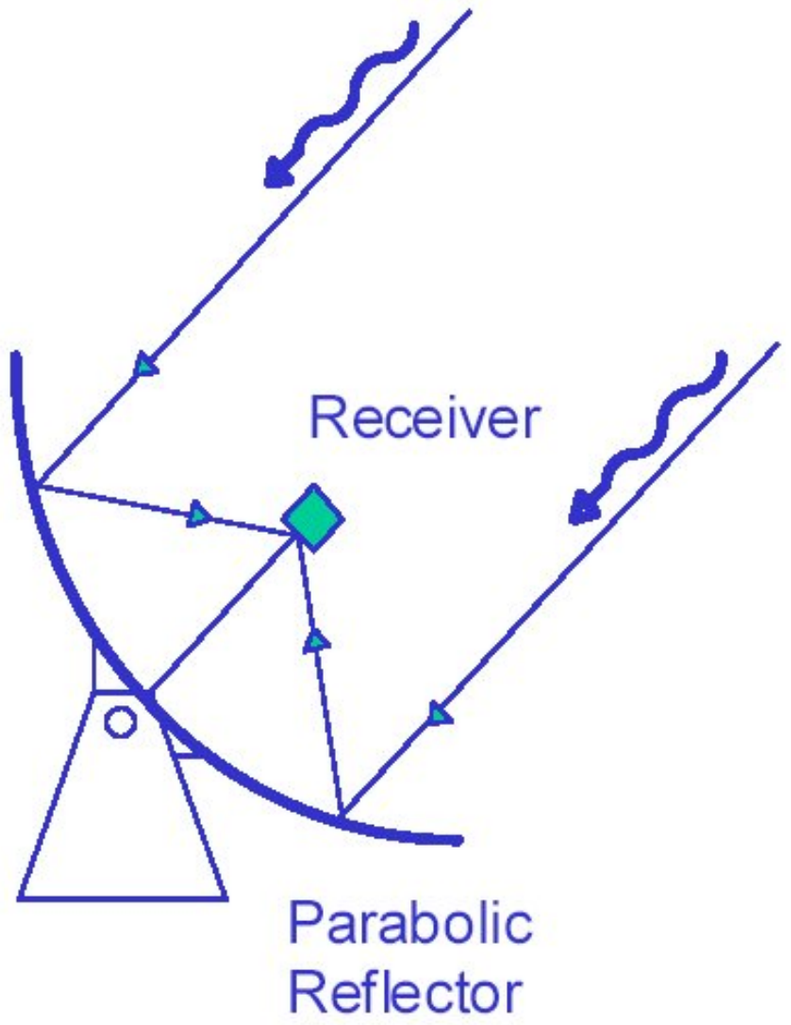


3+ Gbit/sec link

Superordinateur Blue Gene

Phased Array Detectors

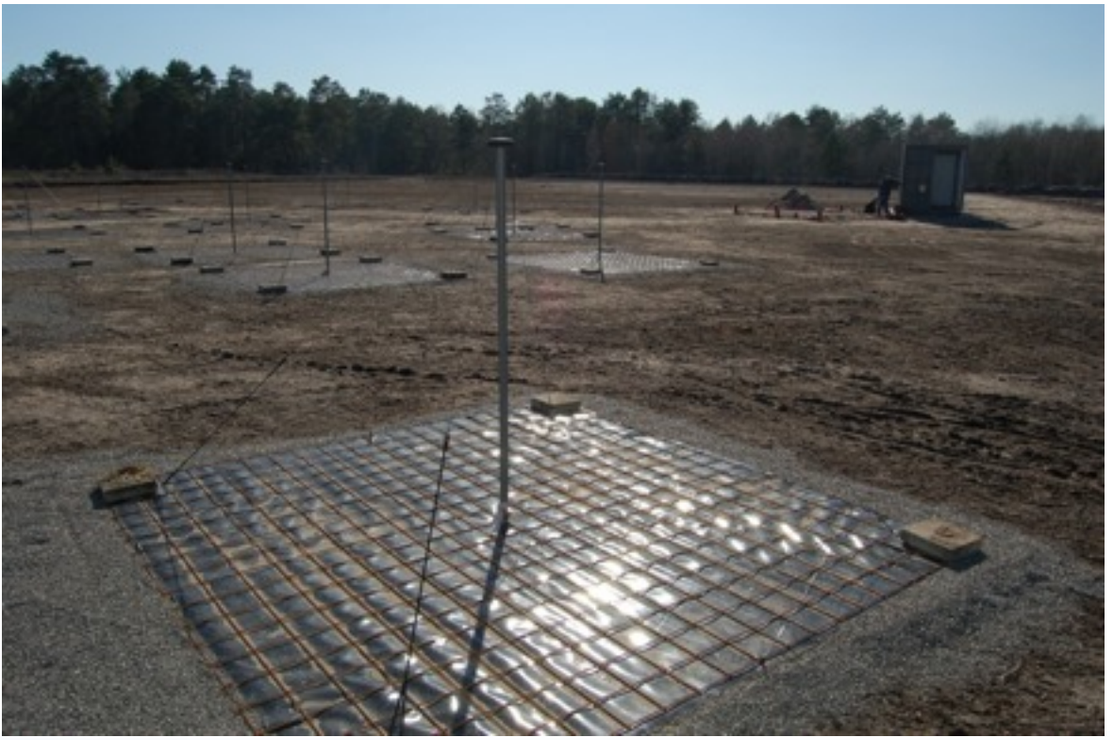


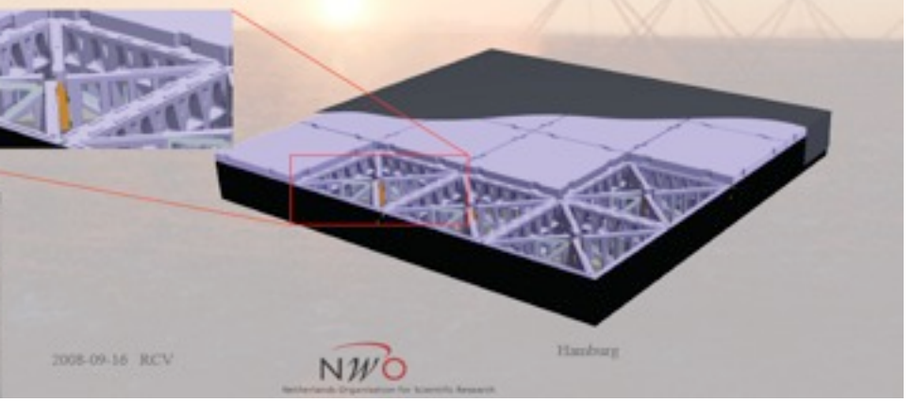


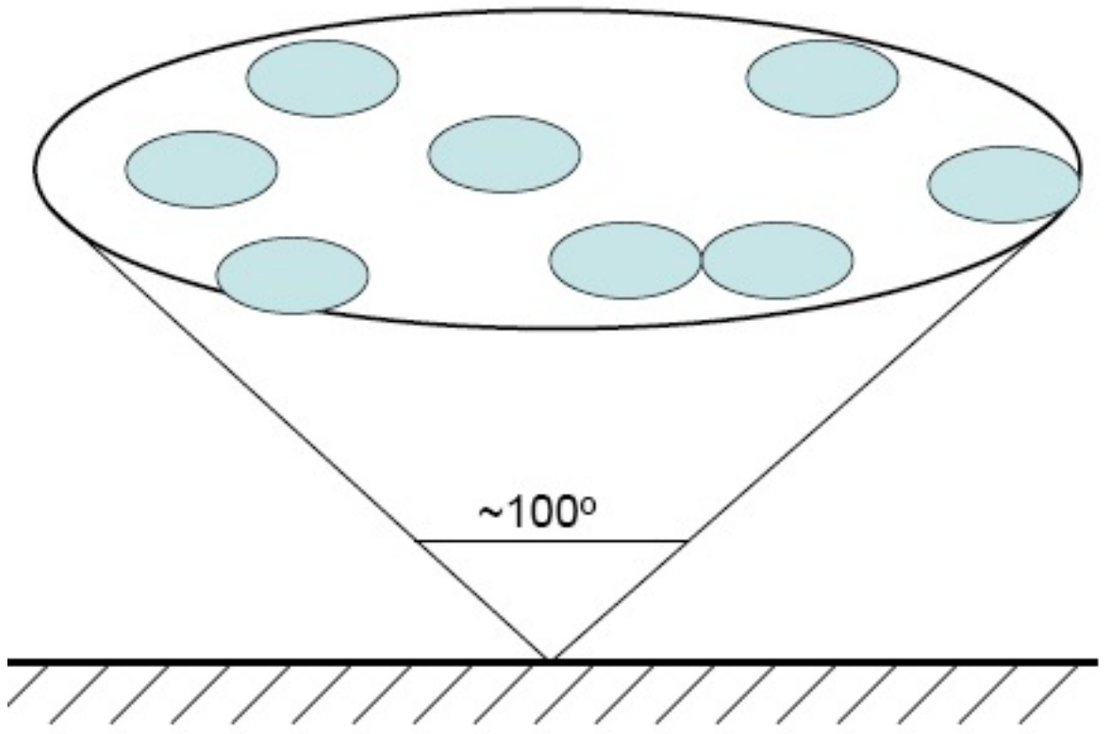
Electronic beam steering

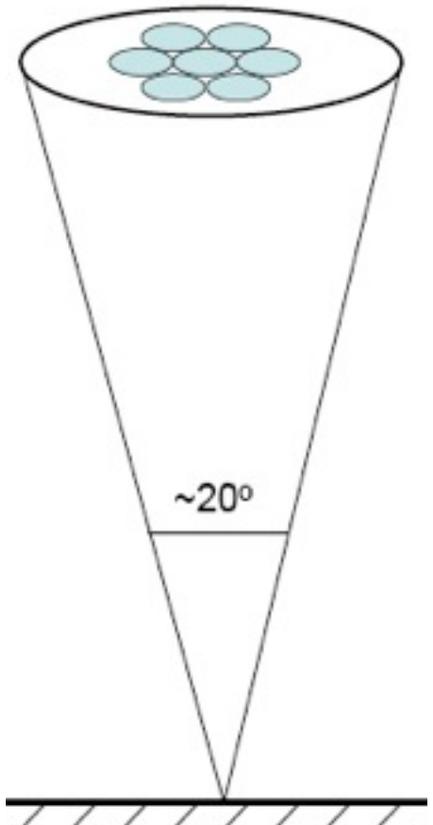
- Parallel observations
- Fast re-configuration
- Rapid response

LBA & HBA antennas & FoV

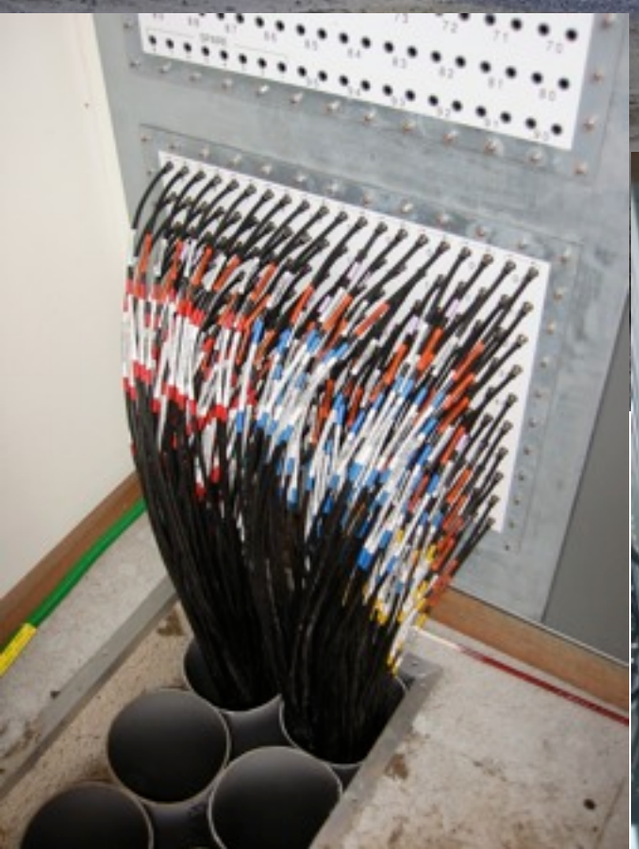






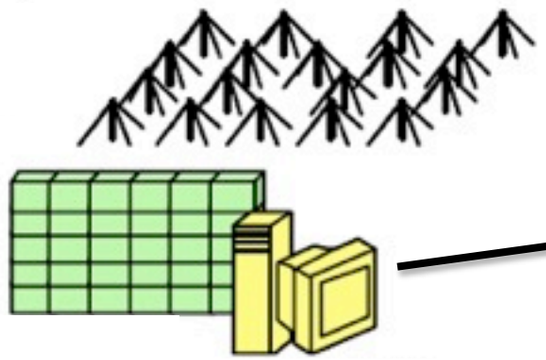


FR606 Backends



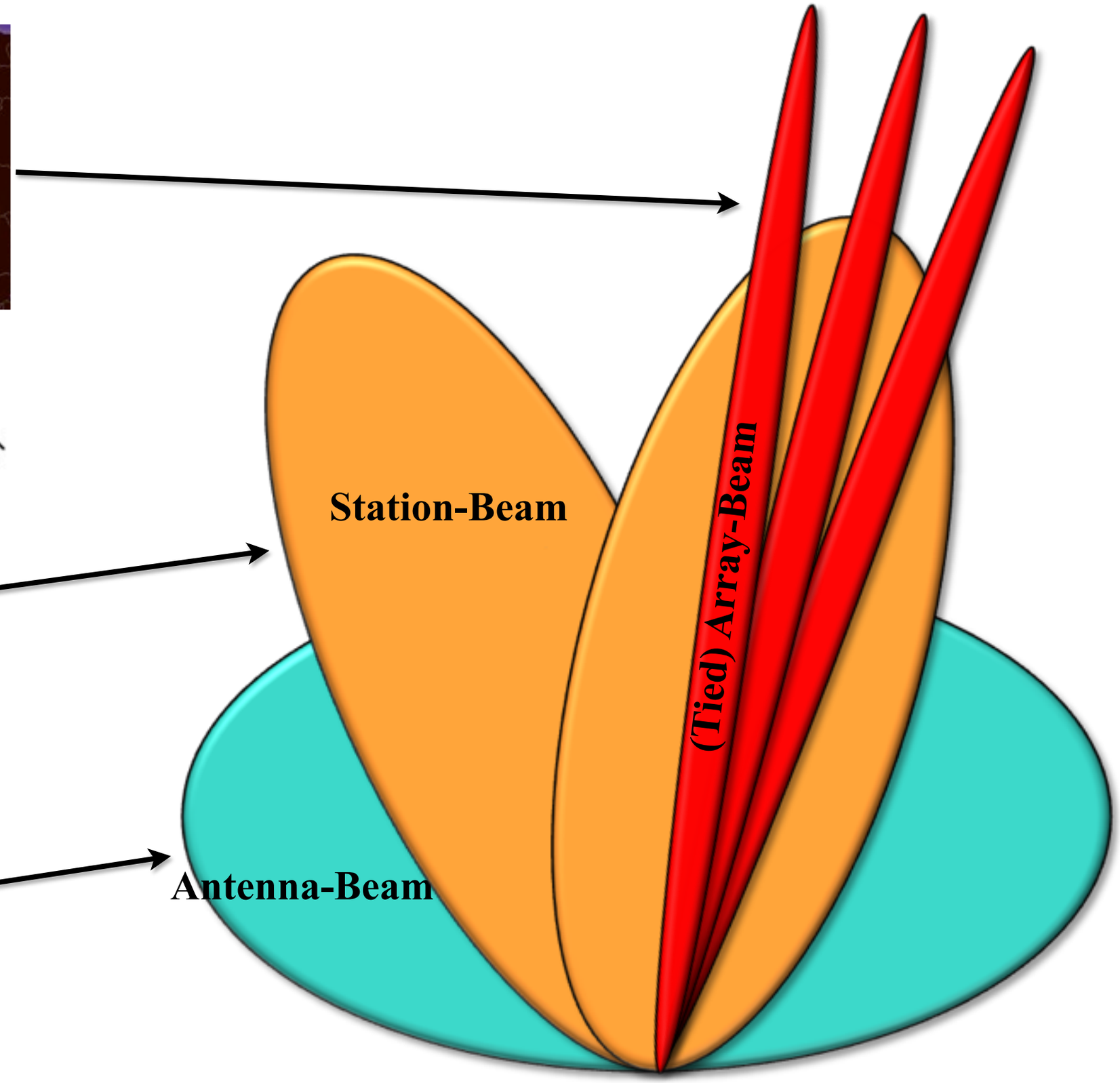
Digital beamforming

Array



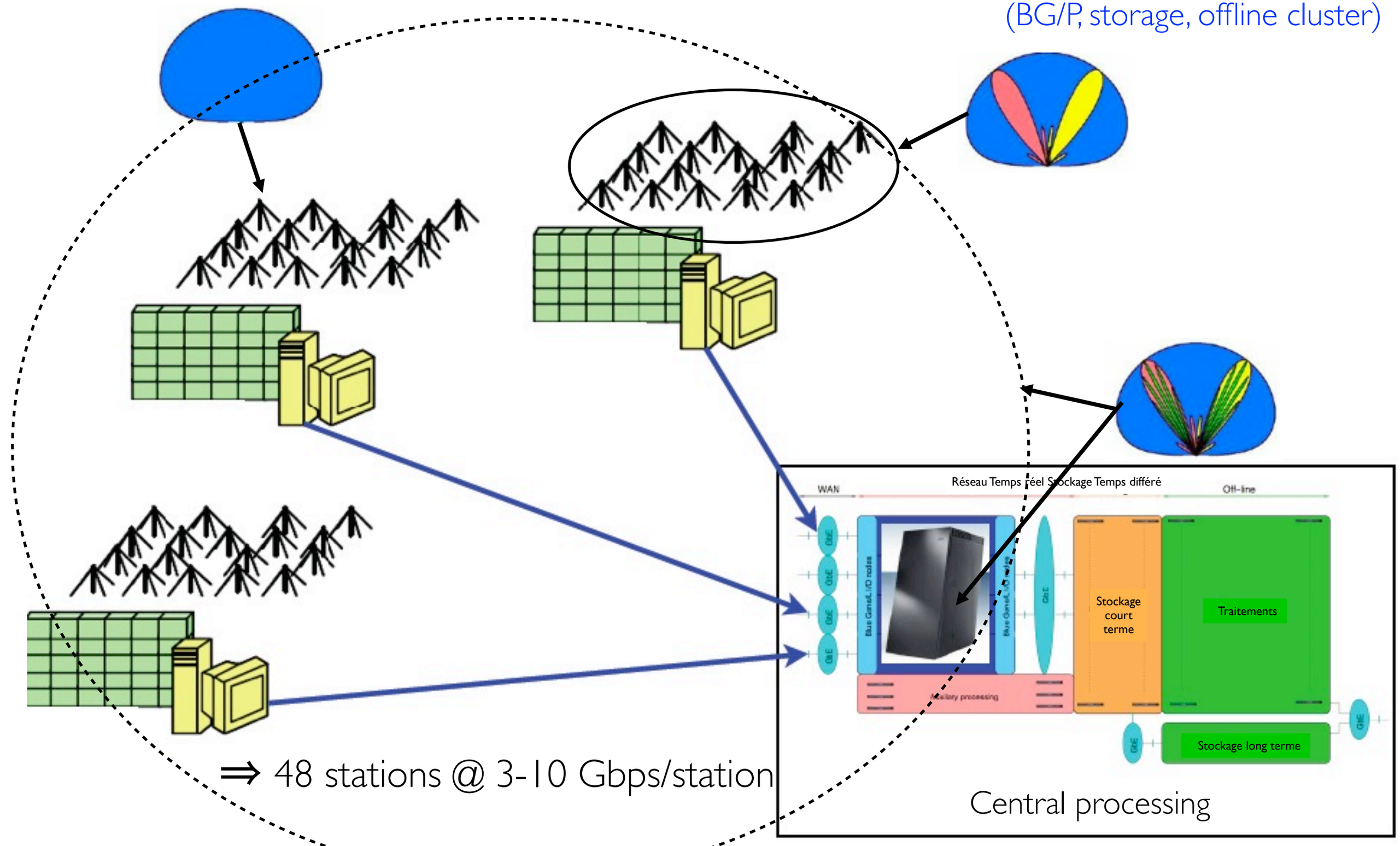
Station

Dipole



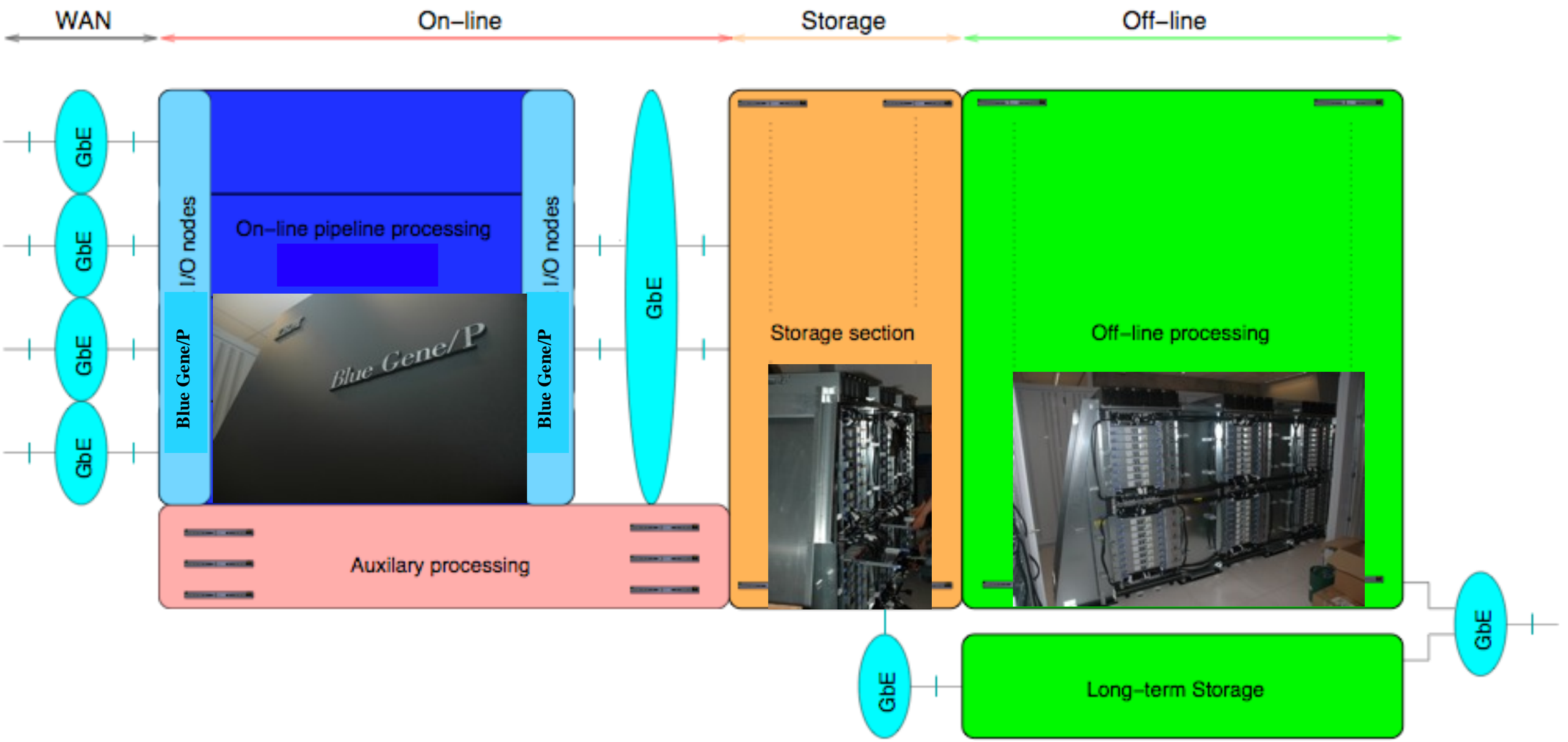
The LOFAR array

- Station level processing : amplification, digitization, filtering, beam-forming, transient ram buffers (TBB)
- Central processing : delay compensation, correlation or summation, calibration, science pipelines (BG/P, storage, offline cluster)



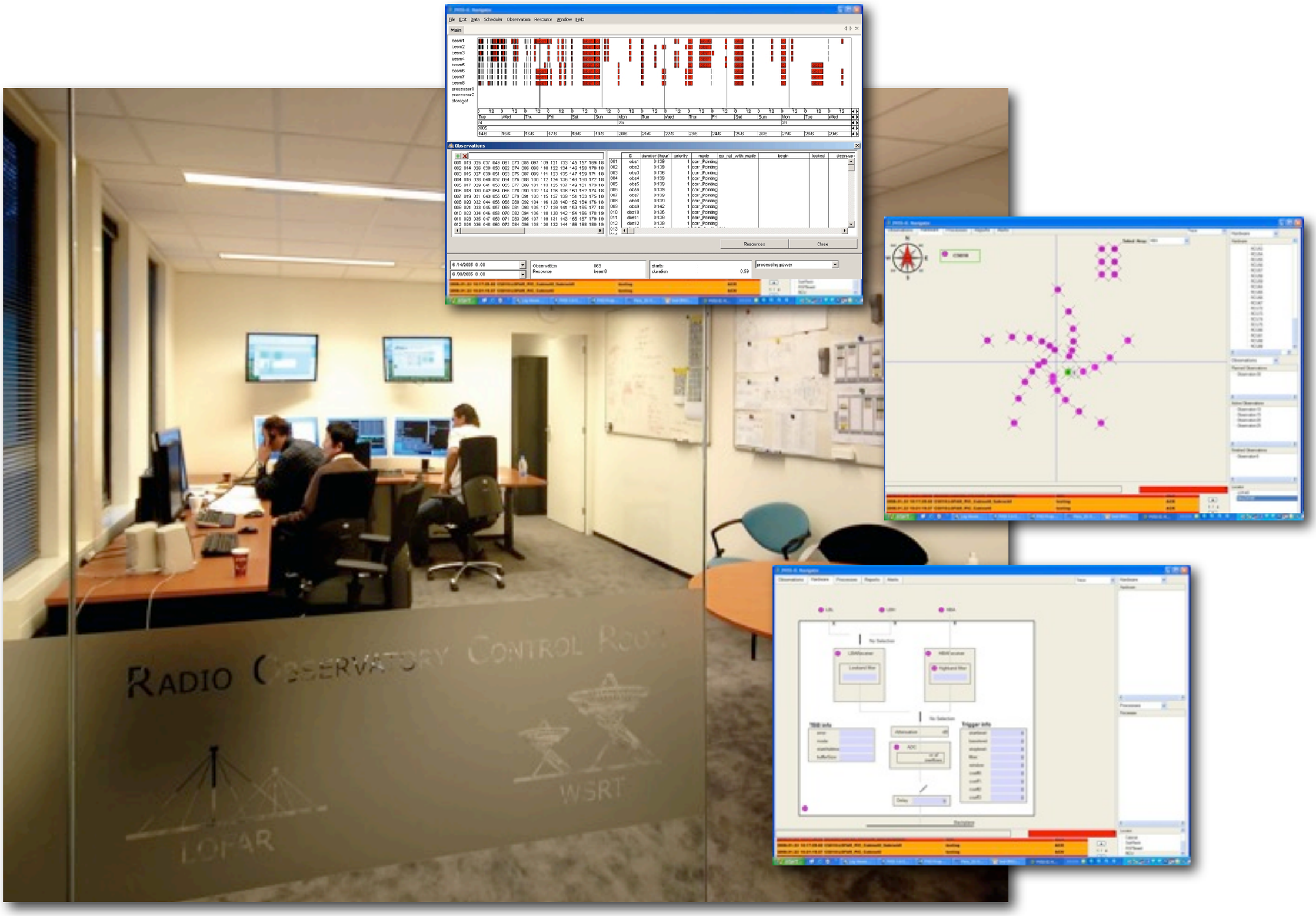
⇒ 48 stations @ 3-10 Gbps/station

Central Processing

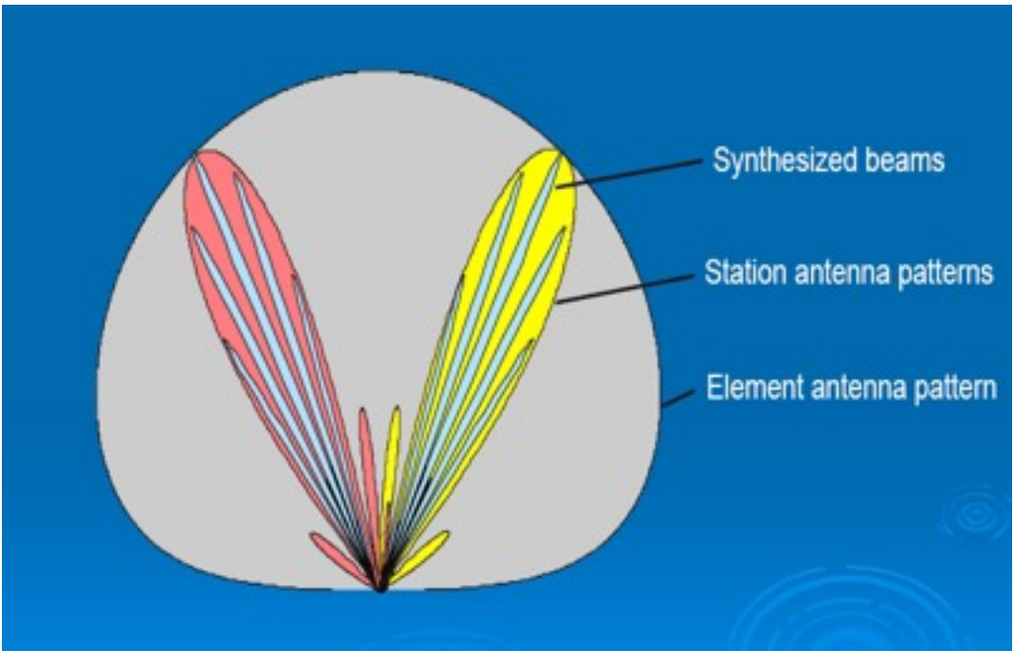


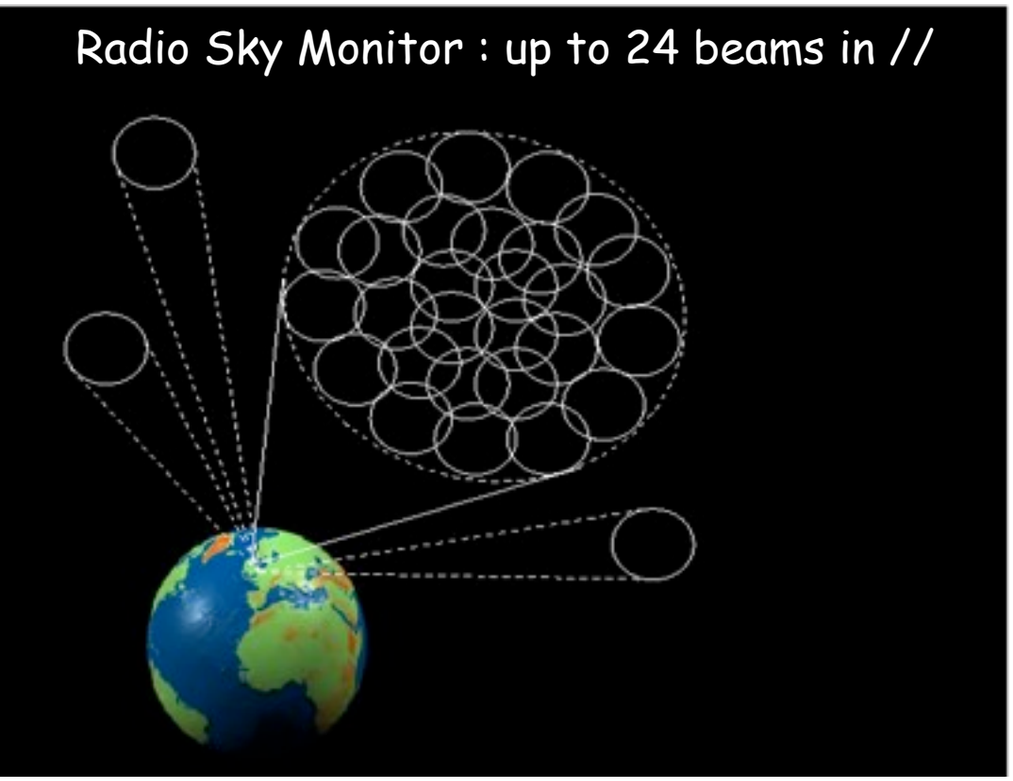
- BG/P : Data reception, transpose, correlation, beam-forming, de-dispersion, 45 TFLOPS
- Storage system : Short term storage of data, ~2 PByte, ~100Gbps I/O
- Offline cluster : Pipelines, data products, off-line analysis, ~20 TFLOPS

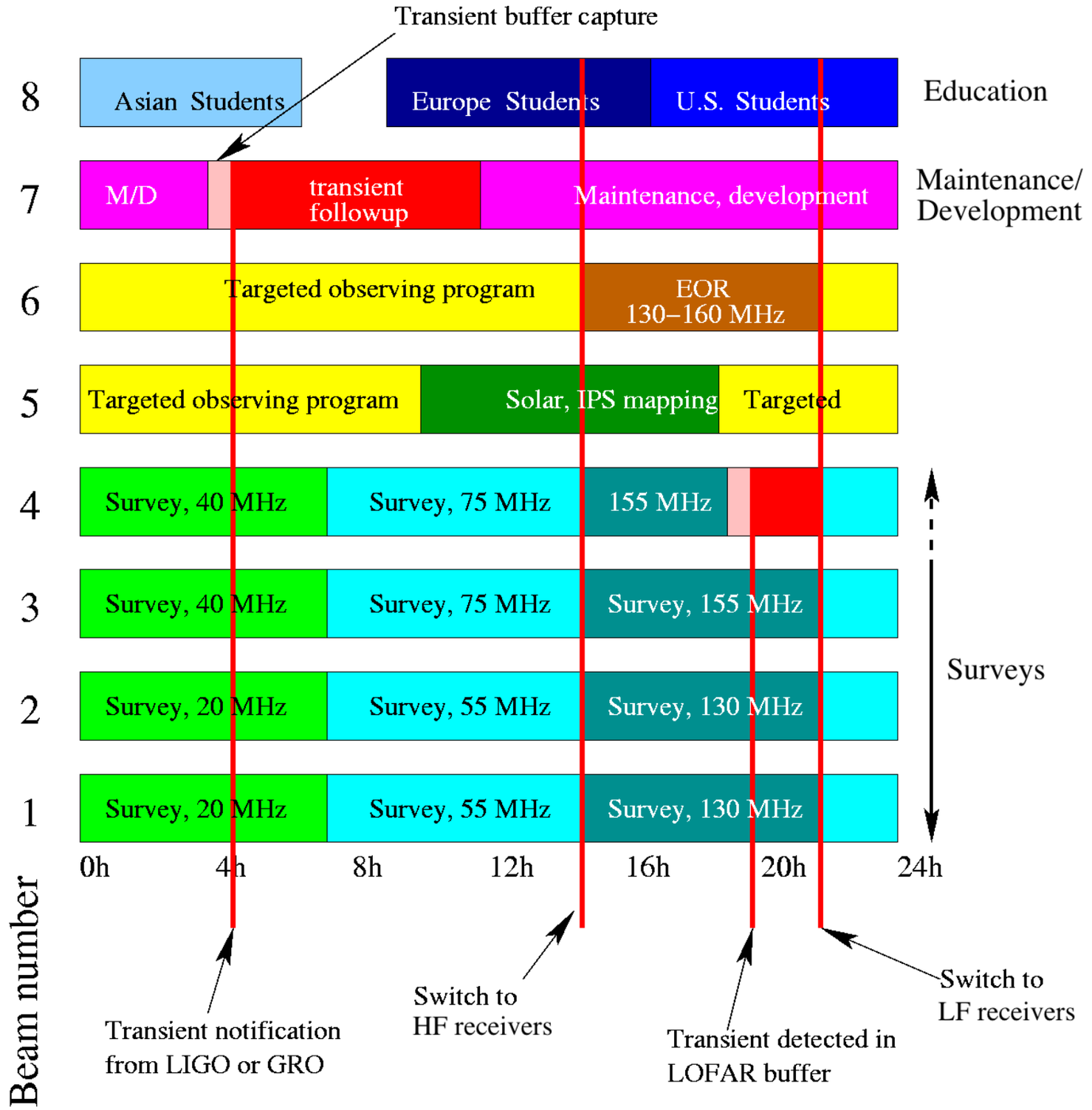
Remote Operation



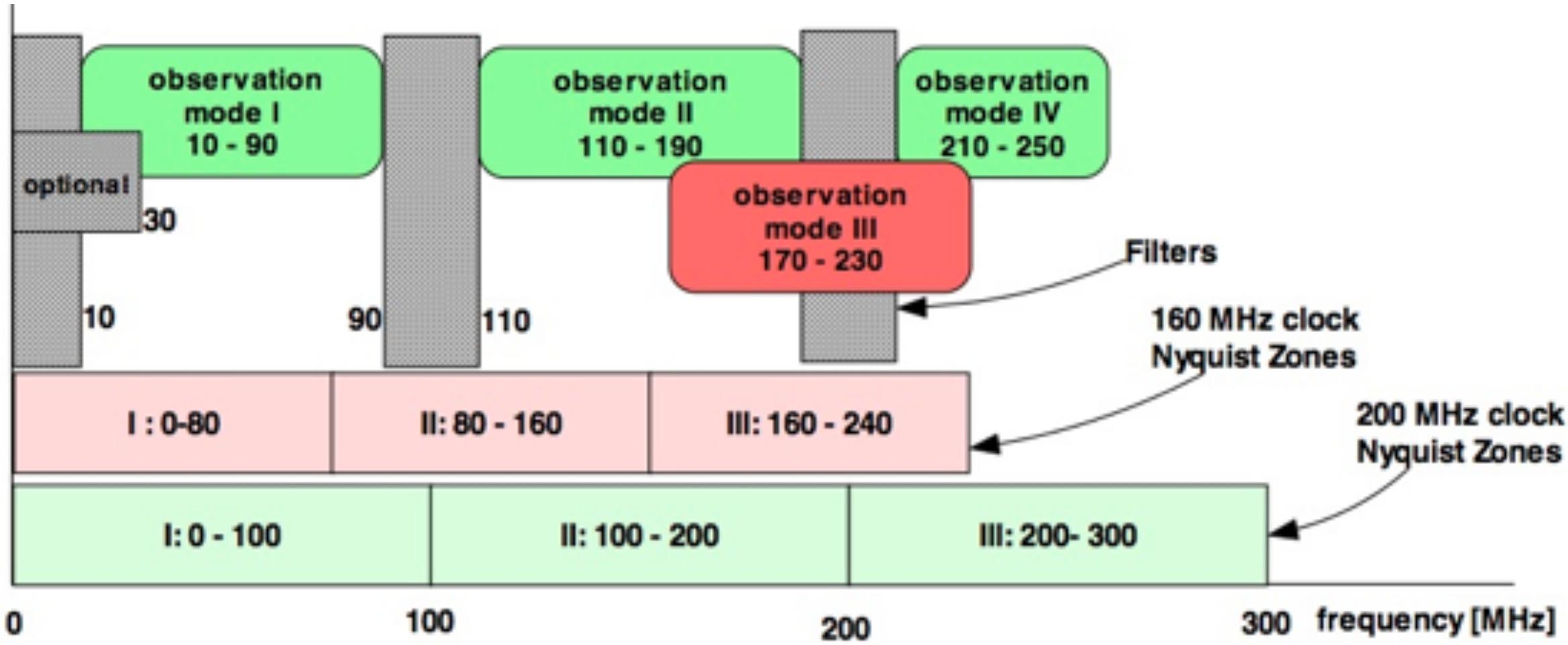
Multi-beam Multi-programs telescope







Frequency ranges



Summary of technical characteristics

- European « Interferometer » of « Phased arrays »
- 24 stations «core» + 16 remote + 8 international
- Diameter ~100 km (NL) → 1500 km (Europe)
- Effective area ~ 100 000 m^2 ($\propto\lambda^2$)
- Frequency ranges = 30-80 & 110-250 MHz (λ=1.2-10m)
- Operation Modes = imaging, tied-array beams, waveform capture
- Resolution ~ 0.1 " - 10 ", large FoV (~10°)
- Sensitivity < mJy (10^{-29} $Wm^{-2}Hz^{-1}$)
- Resolutions → 1 msec × 1 kHz, Full polarization
- RFI mitigation, ionospheric « adaptive optics »
- First Low-Frequency « all-purpose » spectro-imager
- 1st SKA precursor

RADIO OBSERVATORY

LOFAR

(Observing Proposals
(Observing Capabilities
(Cycle 0 schedule
(Weekly schedule
(Commissioning Period & the LCCG
(LOFAR MSSS
(Station Status
(LOFAR Science
(Publications and Authorship Policy
(Roll-out status
(LOFAR Wiki
(LOFAR Users Forum

WSRT

(Astronomers
(Weekly schedule
(Observation status
(Apertif
(Apertif - EOIs

GENERAL

(PC pages

Home » Radio Observatory » Observing Capabilities

(search

(Summary
(In depth Technical Information
(LOFAR in its initial operations phase
(Lofar Cookbooks

LOFAR OBSERVING CAPABILITIES FOR ASTRONOMERS

LOFAR

LOFAR the Low Frequency Array is a next-generation electronically steered phased array radio telescope. LOFAR's capabilities are revolutionising the astronomical capabilities in the 10-240 MHz range. LOFAR, has been designed and constructed by ASTRON. Fourty LOFAR stations are placed in the Netherlands, as well as 5 stations in the Germany (3) and one each in France, Sweden and the UK.

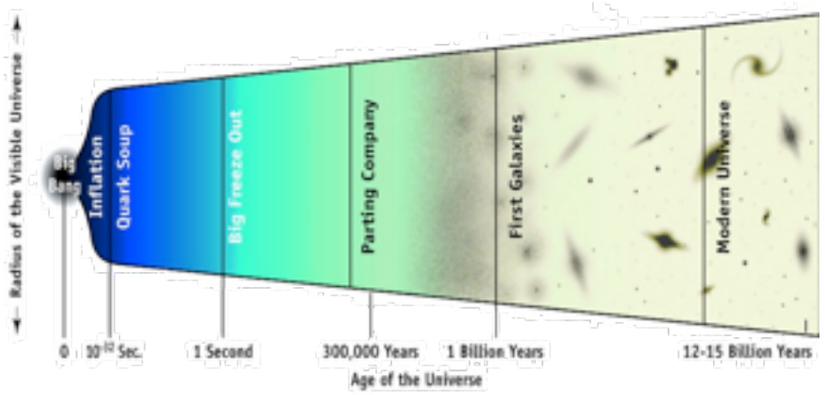
LOFAR is jointly operated by the International LOFAR Telescope (ILT) foundation, as an observatory open to the astronomical community.

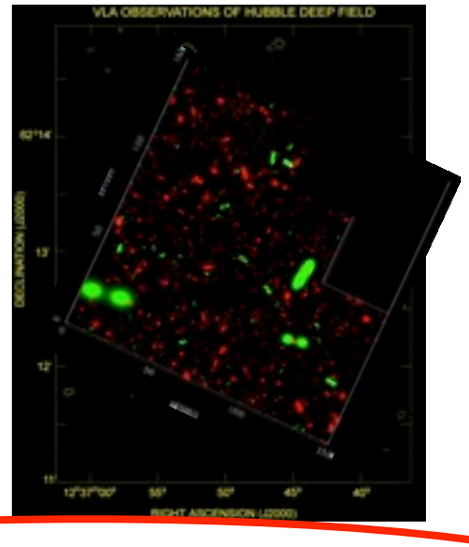
LOFAR entered its first operational cycle in December 2012, following a period of commissioning.

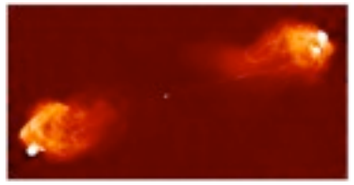
The following web pages describe the LOFAR's observing capabilities, major observing modes and analysis pipelines:

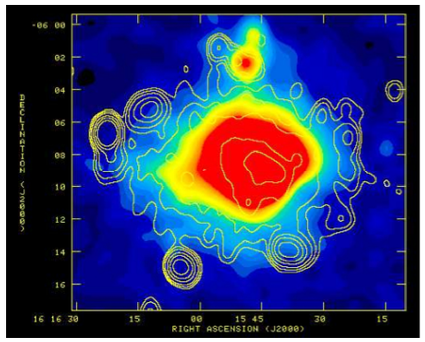
- Summary
- LOFAR in its initial operational phase
- In-depth technical information
- Cookbooks

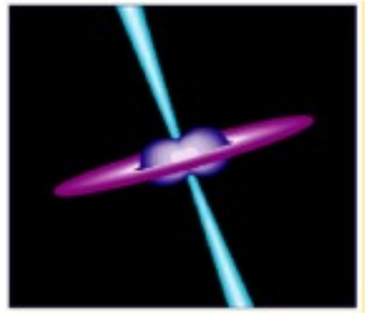
LOFAR Science : Key Scientific Projects

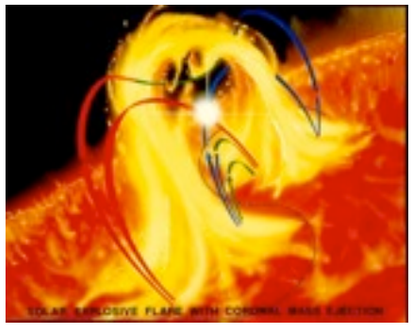




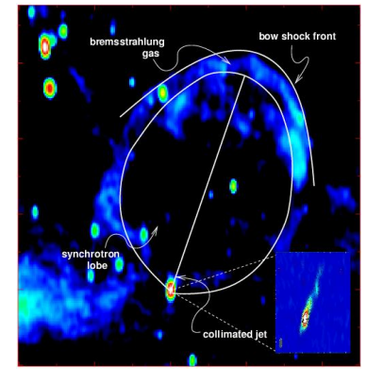




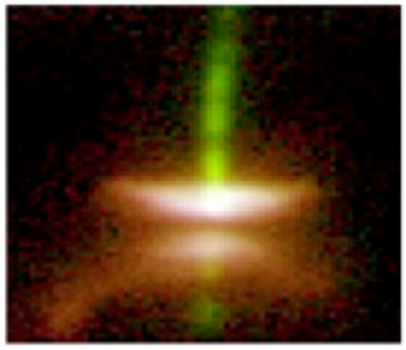


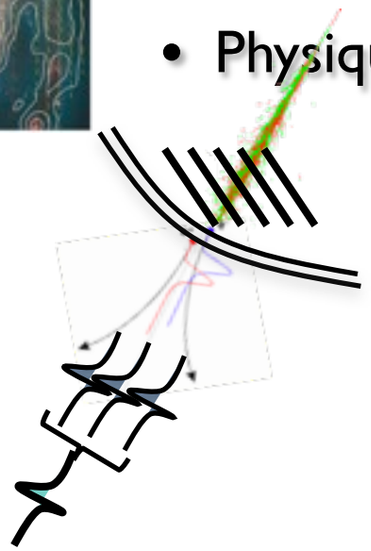


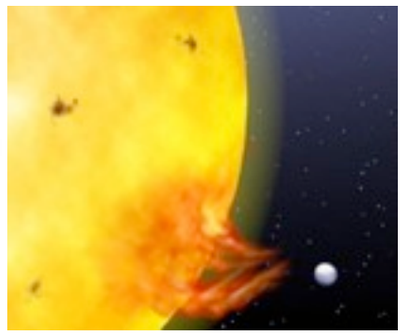
- Cosmologie, Réionisation *(Groningen)* **EoR**
- Cartographie, Formation stellaire, NAG, amas… *(Leiden)*

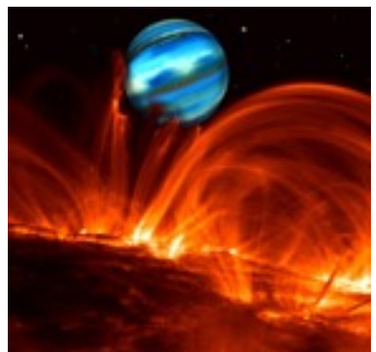


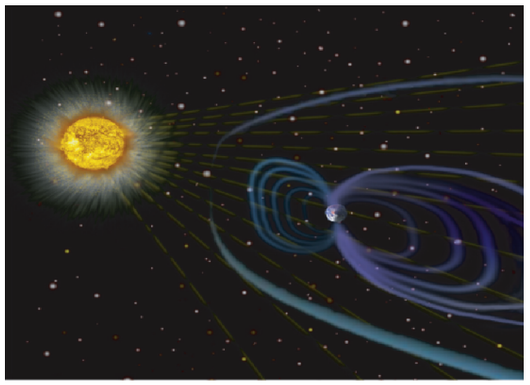
- Transitoires *(Amsterdam / Manchester / NRAO / Obs. Paris)*
- Rayons Cosmiques, Neutrinos sur la Lune *(Nijmegen)*
- Magnétisme Galactique *(Bonn)*
- Physique Solaire et Spatiale *(Potsdam)*

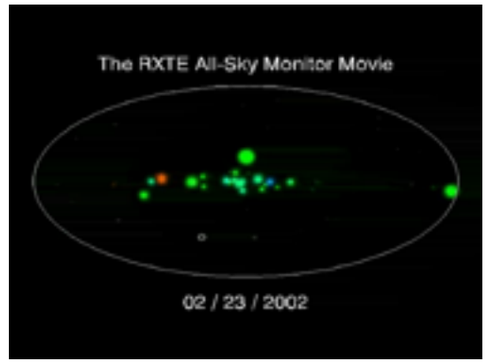












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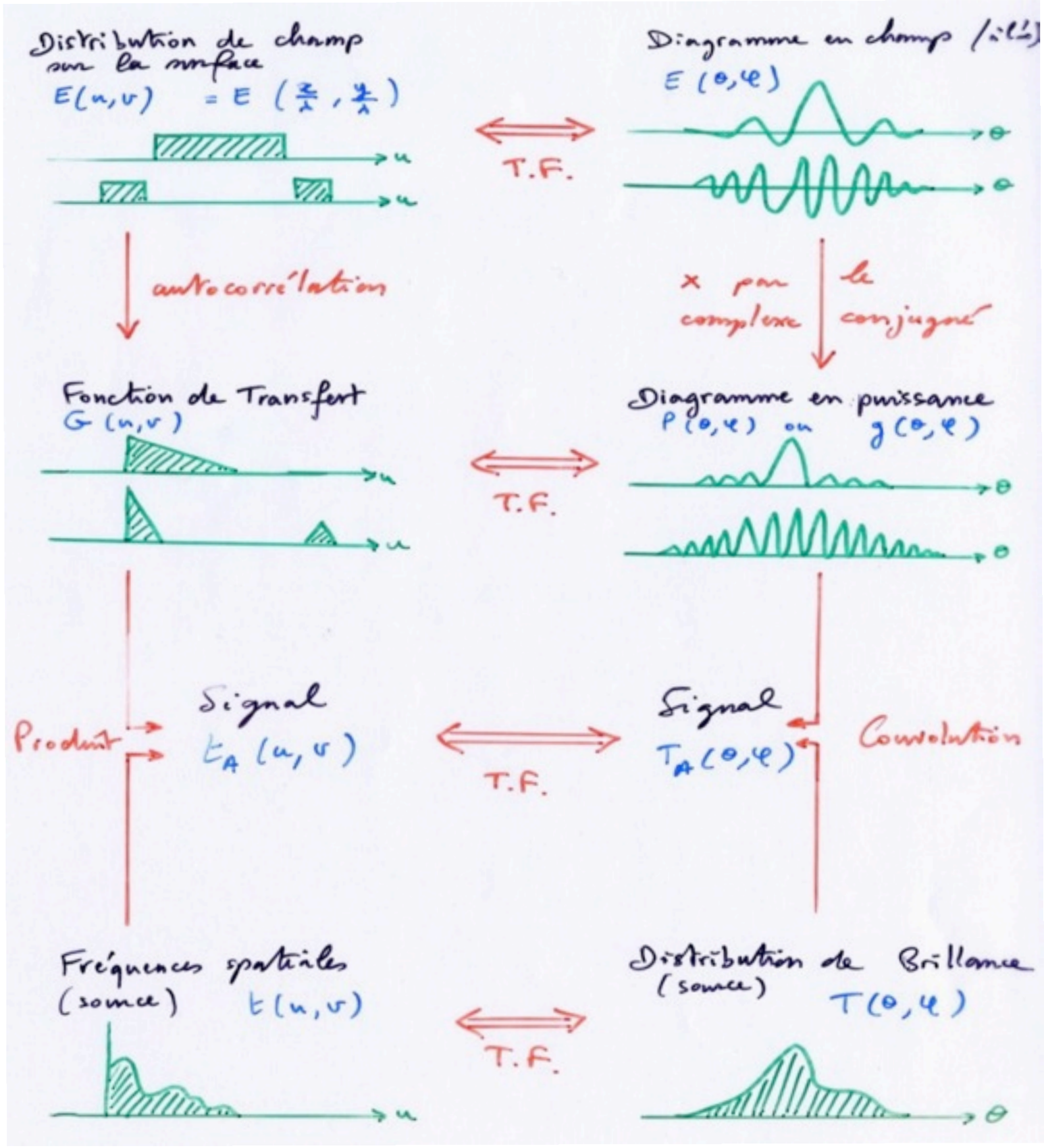
- LSS /NenuFAR science

Instrument response



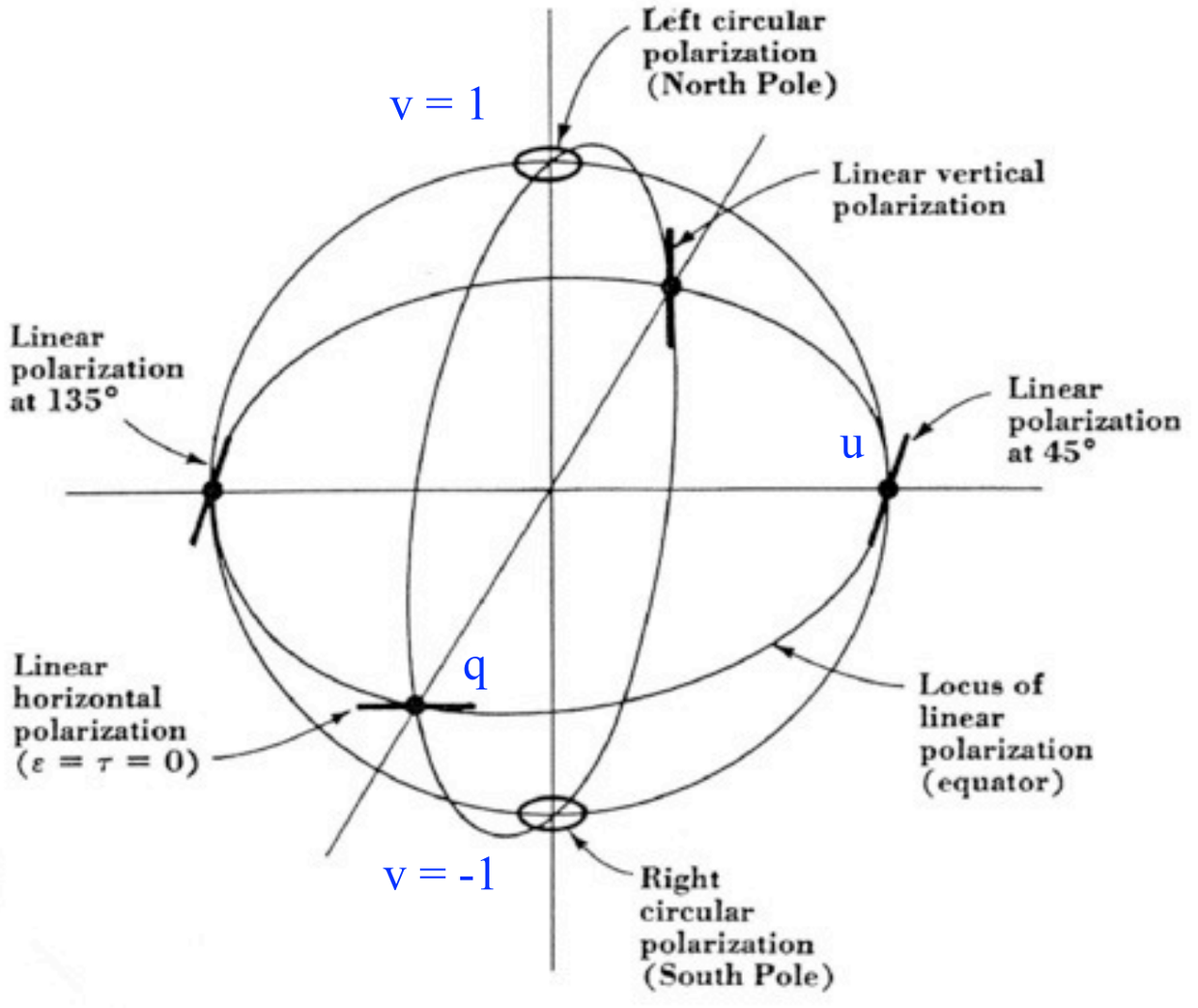
Wave Polarization

$$\mathbf{E} = \begin{bmatrix} E_x \\ E_y \end{bmatrix} = \begin{bmatrix} A_x e^{i(\omega t + \phi_x)} \\ A_y e^{i(\omega t + \phi_y)} \end{bmatrix} = e^{i\omega t} \begin{bmatrix} A_x e^{i\phi_x} \\ A_y e^{i\phi_y} \end{bmatrix}$$

Stokes parameters : S (or I), Q, U, V

normalized: q=Q/S, u=U/S, v=V/S

$S = < A_x^2 + A_y^2 > / 2Z_o$
$Q = < A_x^2 - A_y^2 > / 2Z_o$
$U = < A_x A_y \cos(\phi_x - \phi_y) > / Z_o$
$V = < A_x A_2 \sin(\phi_x - \phi_y) > / Z_o$



Polarization at cardinal points of Poincaré sphere.

The Measurement Equation

Hamaker et al., 1996

$$\mathbf{E} = \begin{bmatrix} E_x \\ E_y \end{bmatrix} = \begin{bmatrix} A_x e^{i(\omega t + \phi_x)} \\ A_y e^{i(\omega t + \phi_y)} \end{bmatrix} = e^{i\omega t} \begin{bmatrix} A_x e^{i\phi_x} \\ A_y e^{i\phi_y} \end{bmatrix}$$

$$\mathbf{J} = \begin{bmatrix} A_x e^{i\phi_x} \\ A_y e^{i\phi_y} \end{bmatrix}$$

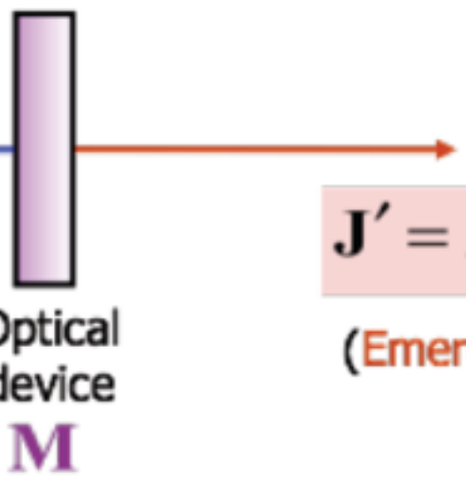
Jones vector

$$C = \langle E\, {}^{t}E^{*} \rangle_{|\Delta t >> 1/\nu} = \begin{bmatrix} \langle E_x E_x^{*} \rangle & \langle E_x E_y^{*} \rangle \\ \langle E_y E_x^{*} \rangle & \langle E_y E_y^{*} \rangle \end{bmatrix} = \frac{1}{2} \begin{bmatrix} S+Q & U+iV \\ U-iV & S-Q \end{bmatrix}$$

Coherency matrix

$\mathbf{J} = E_x \mathbf{i} + E_y \mathbf{j}$

(Incident beam)



$\mathbf{J}' = E'_x \mathbf{i} + E'_y \mathbf{j}$

(Emergent beam)

Application to interferometric imaging

Bregman et al., 1996, Sault et al., 1996

Measured visibility : $\mathbf{V = J\ E} = (V_x\ ,\ V_y)$ = complex voltages from each polarized antenna element

Visibility matrix for each interferometer baseline :

$$\mathbf{V_{ij}} = \langle V_i\ {}^tV_j^* \rangle = \begin{bmatrix} \langle V_{ix}V_{jx}^* \rangle & \langle V_{ix}V_{jy}^* \rangle \\ \langle V_{iy}V_{jx}^* \rangle & \langle V_{iy}V_{jy}^* \rangle \end{bmatrix} = \langle \mathbf{J_i\ E\ {}^t(J_j\ E)^*} \rangle = \mathbf{J_i} \langle E\ {}^tE^* \rangle\ {}^t\mathbf{J_j}^* = \mathbf{J_i\ C\ {}^tJ_j}^*$$

Signal transformations : $J_i = B_i\ G_i\ D_i\ E_i\ P_i\ T_i\ F_i$

$$V_{ij} = \sum_{sky} B_i\ G_i\ D_i\ E_i\ P_i\ T_i\ F_i \quad \frac{1}{2} \begin{bmatrix} S+Q & U+iV \\ U-iV & S-Q \end{bmatrix} {}^tF_j^*\ {}^tT_j^*\ {}^tP_j^*\ {}^tE_j^*\ {}^tD_j^*\ {}^tG_j^*\ {}^tB_j^* + n$$

$$V_{ij} = J_i\ \ C\ {}^tJ_j^*\ \ + n$$

- *F* = ionospheric Faraday rotation
- *(T* = tropospheric effects)
- *P* = parallactic angle
- *E* = antenna voltage pattern
- *D* = polarization leakage
- *G* = electronic gain
- *B* = bandpass response

(Self)-Calibration:

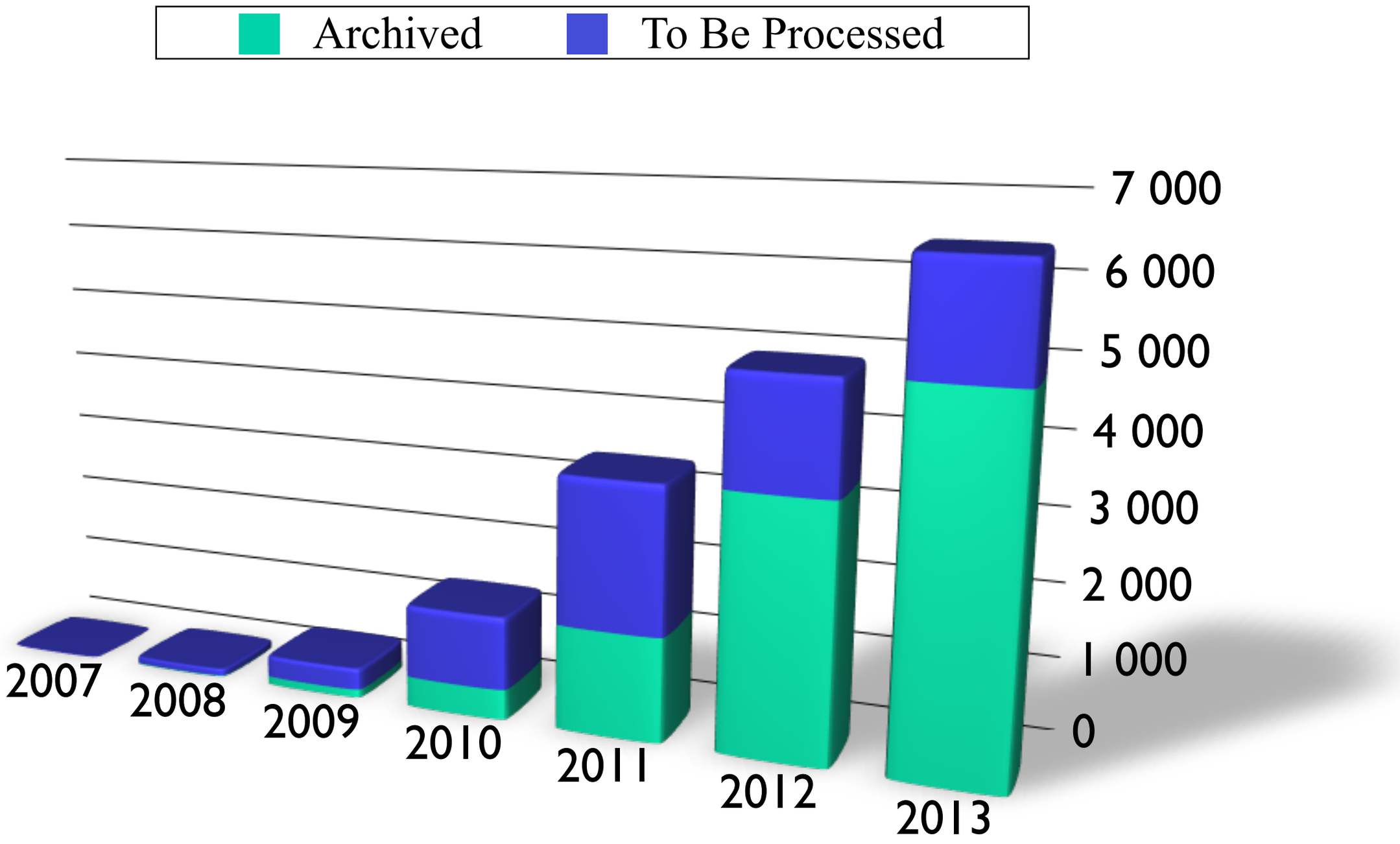
Sky Model : $\sum_{sky} C \Rightarrow V_{ij\text{-model}}$

Residuals : $V_{ij\text{-measured}} - V_{ij\text{-model}}$

Corrected residuals : $J_i^{-1} (V_{ij\text{-measured}} - V_{ij\text{-model}})\ {}^tJ_j^{-1*}$ $\Rightarrow$ minimize, iterate

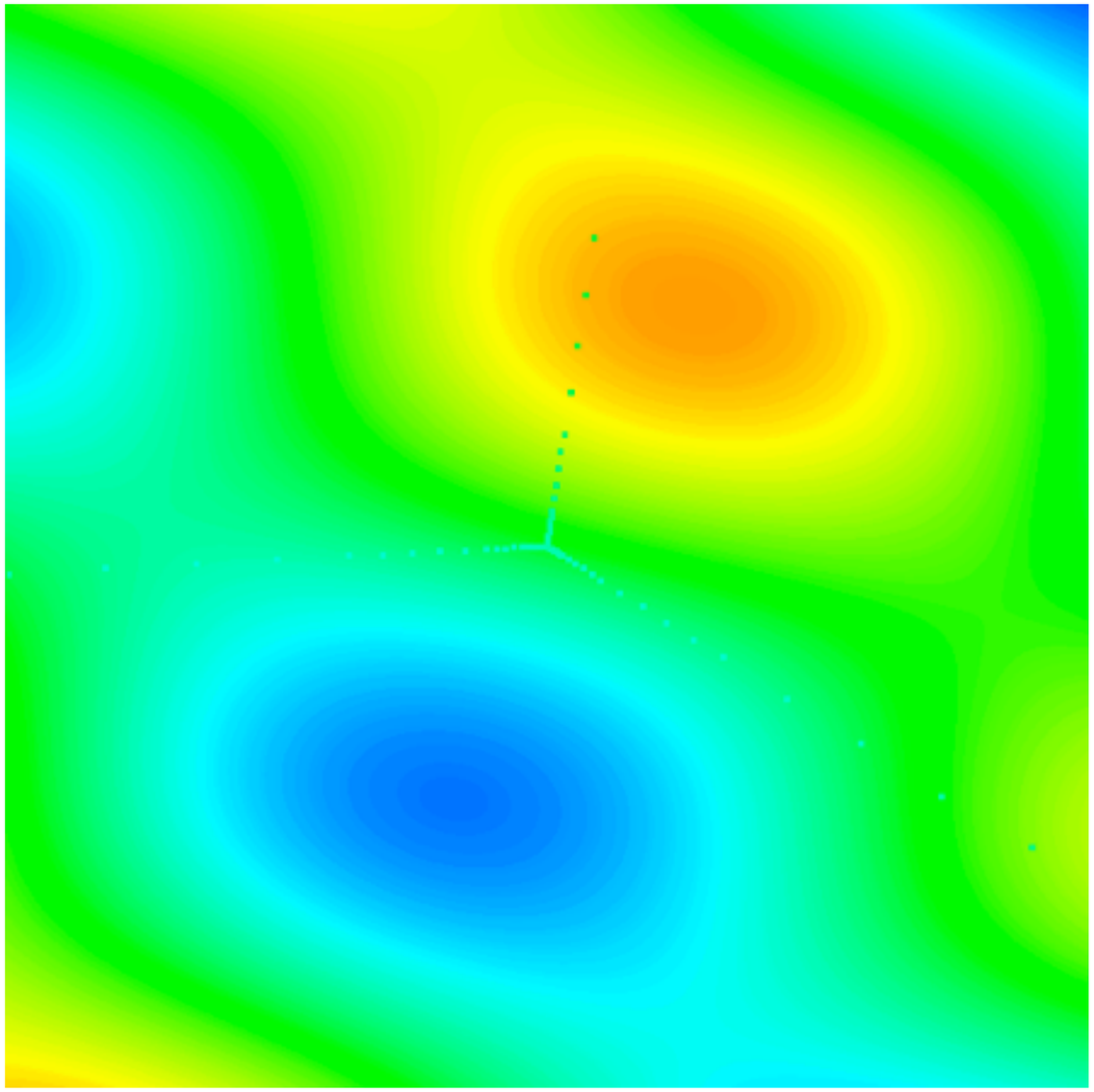
(computationally expensive)

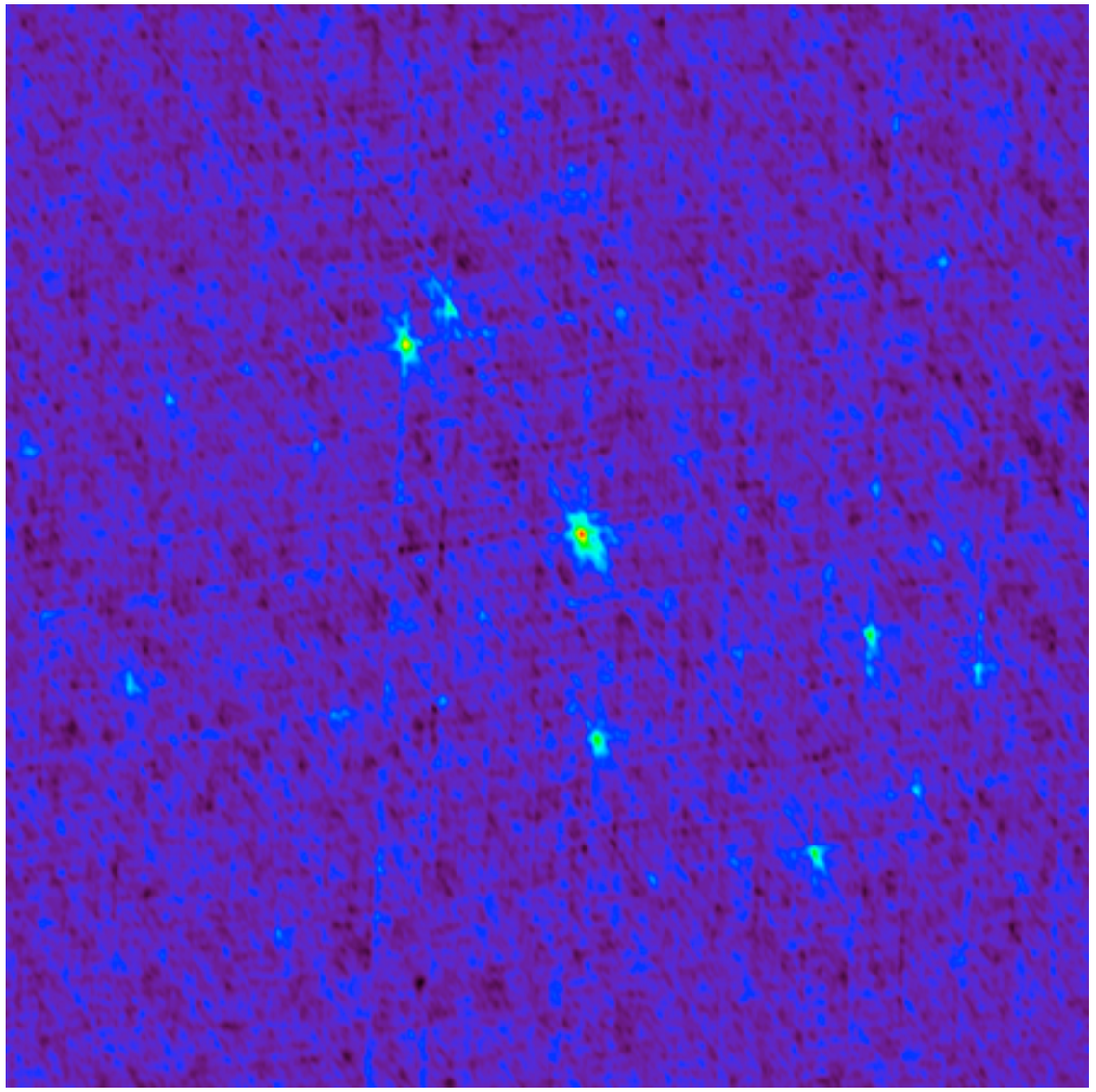
LOFAR archive growth



Estimated growth rate ~ 2.5 Pb/yr

Modelling the ionosphere





Need of many sources / beam for proper calibration

The AWI Imager

Tasse et al., 2013

Applying full polarization A-Projection to very wide field of view instruments: An imager for LOFAR

C. Tasse[1,2,3], B. van der Tol[4], J. van Zwieten[5], Ger van Diepen[5], and S. Bhatnagar[6]

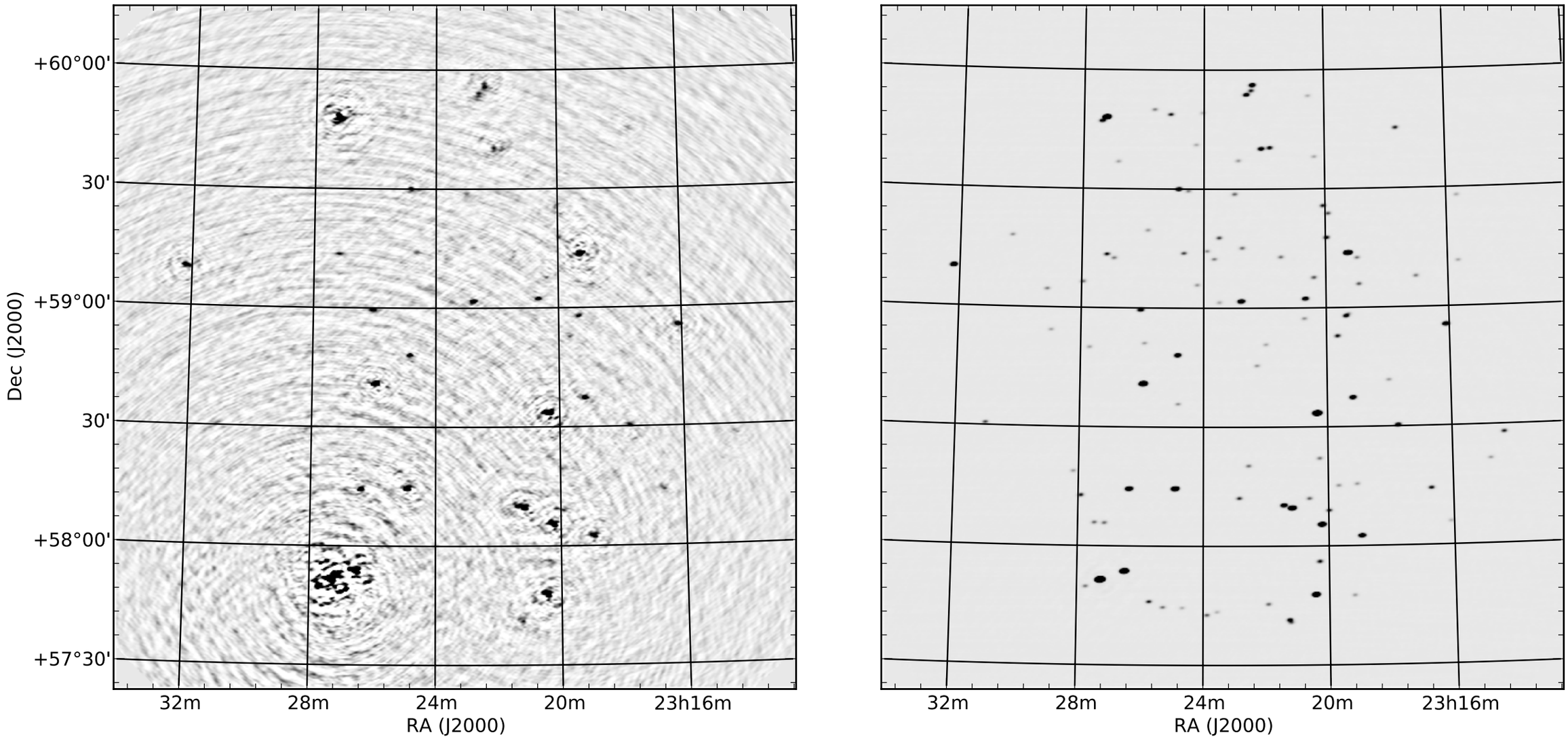


Fig. 6. This figure shows the deconvolved image synthesized from the simulated dataset described in Sec. 4.2.2. In the left panel, the ionospheric effects are not taken into account, and our deconvolution scheme naturally produces severe artifacts and high residuals in the reconstructed sky. The deconvolved image shown in the right panel has been estimated using our implementation of A-Projection with the time-dependent ionospheric phase screen.

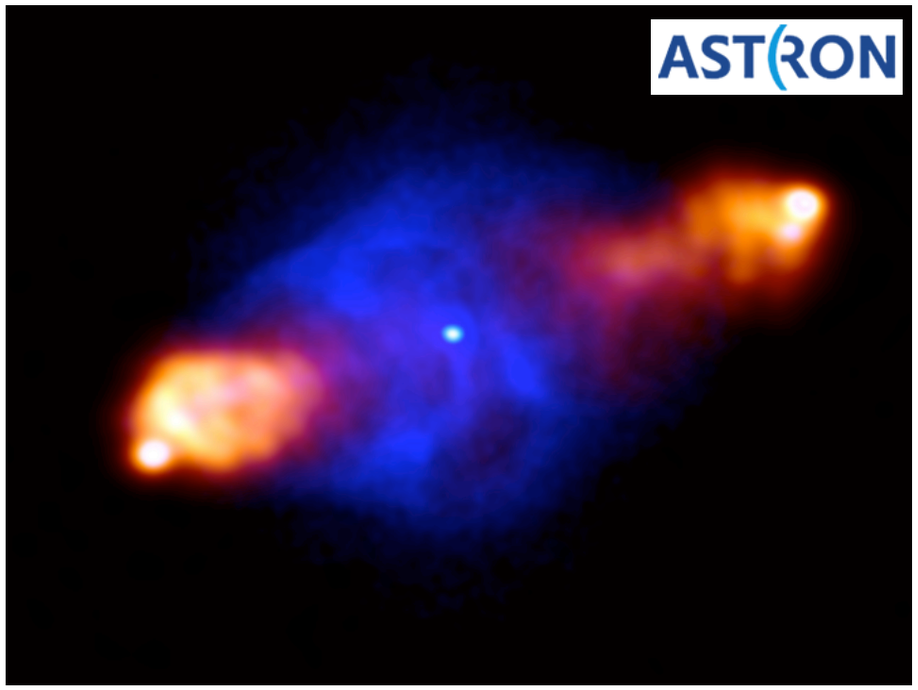
The LOFAR Imaging cookbook

THE LOFAR IMAGING COOKBOOK:

Manual data reduction with the imaging pipeline

Version 12.0

October 25, 2012



Edited by Roberto F. Pizzo

& other LOFAR cookbooks

LOFAR Beamformed-Data Pipeline Cookbook - v1.2

Ashish Asgekar [1]

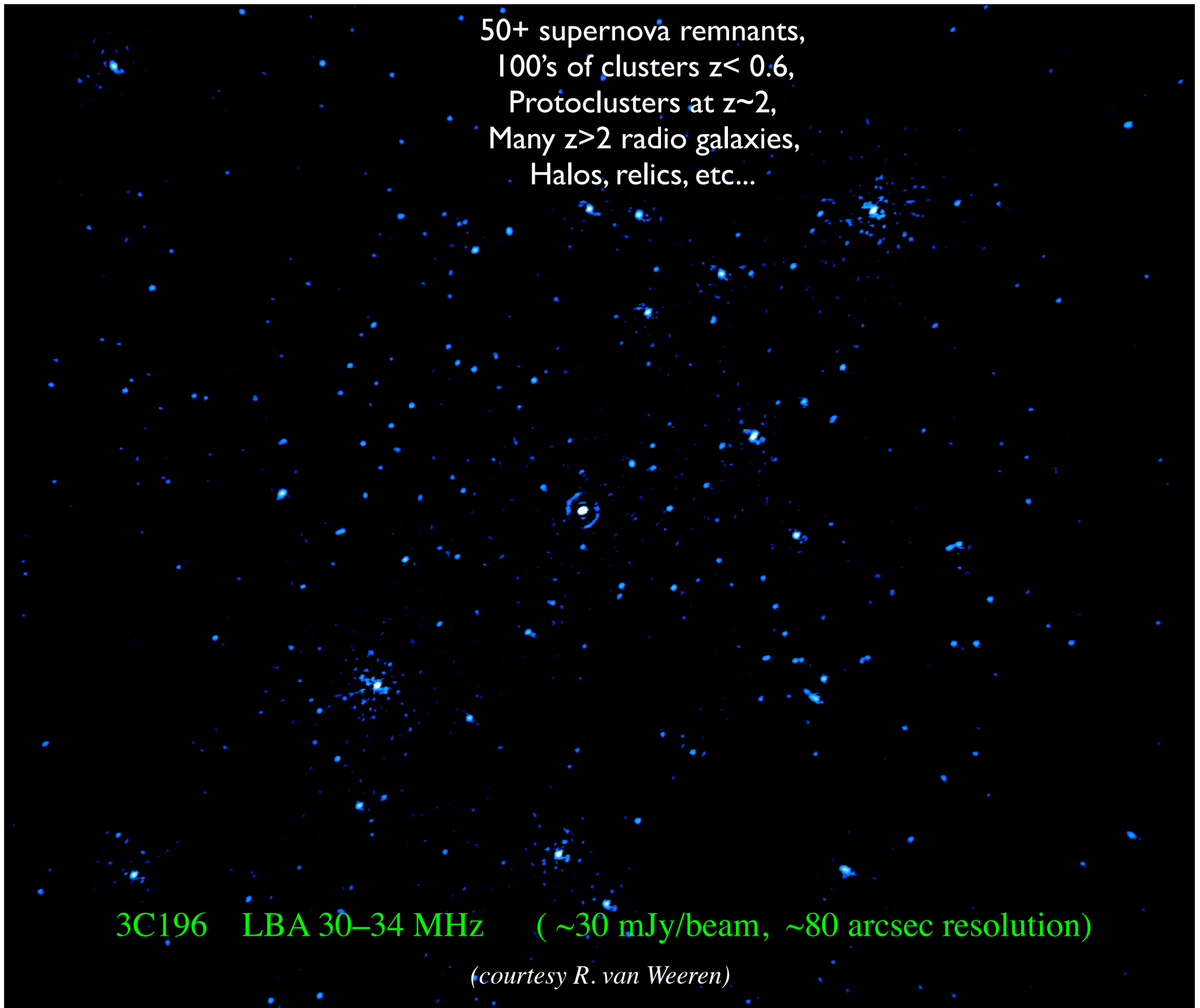
on behalf of **LOFAR Pulsar Pipeline Working Group**[2]

Long Baseline Workgroup Data Pipeline Recipe

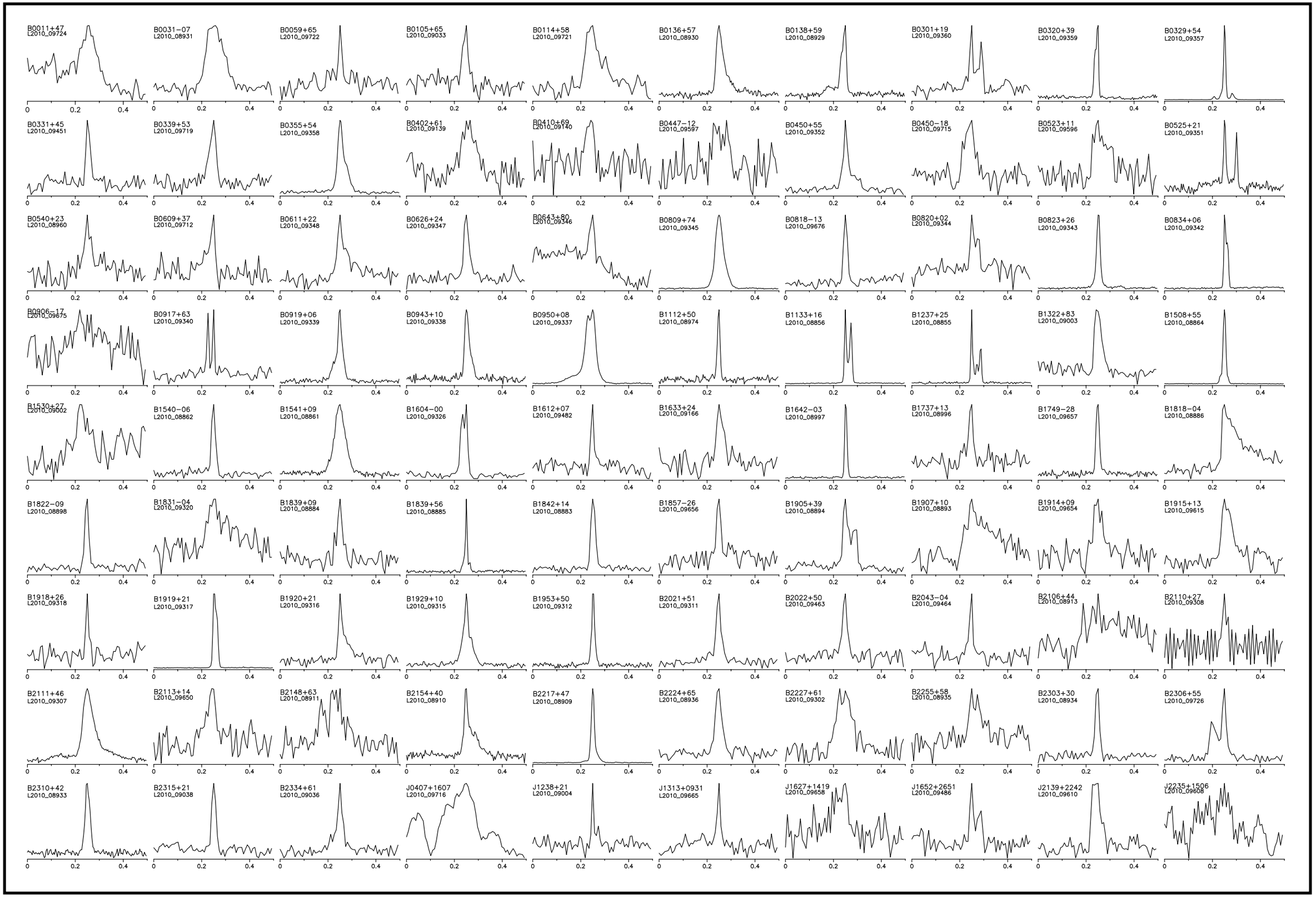
Tobia Carozzi 2012-02-20

- EoR
- LOFAR
- Imaging
- Results
- Foregrounds
- Operations
- LSS/NenuFAR
- LSS /NenuFAR science

All-sky Surveys with LOFAR

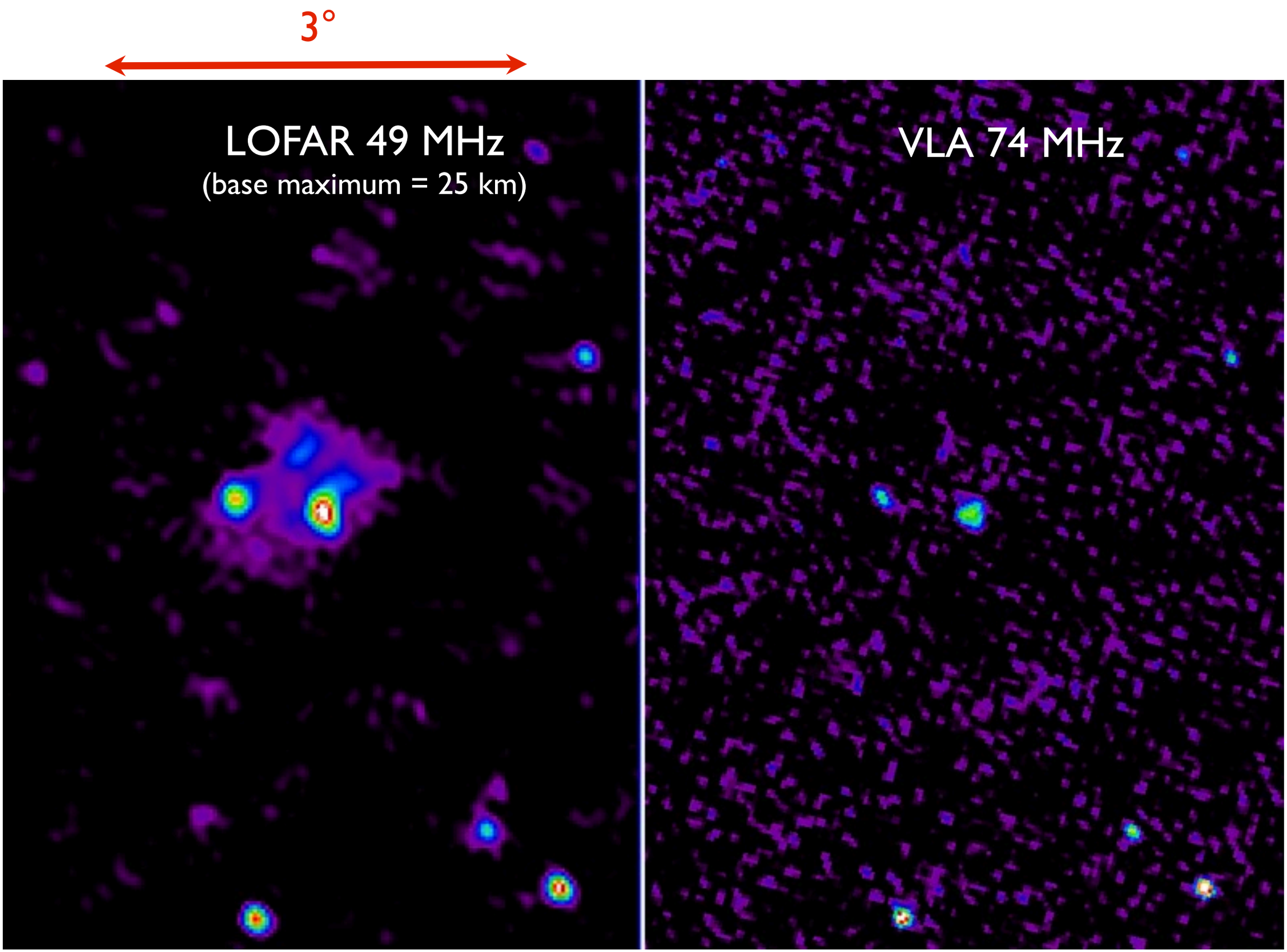


100+ Pulsars detected with LOFAR



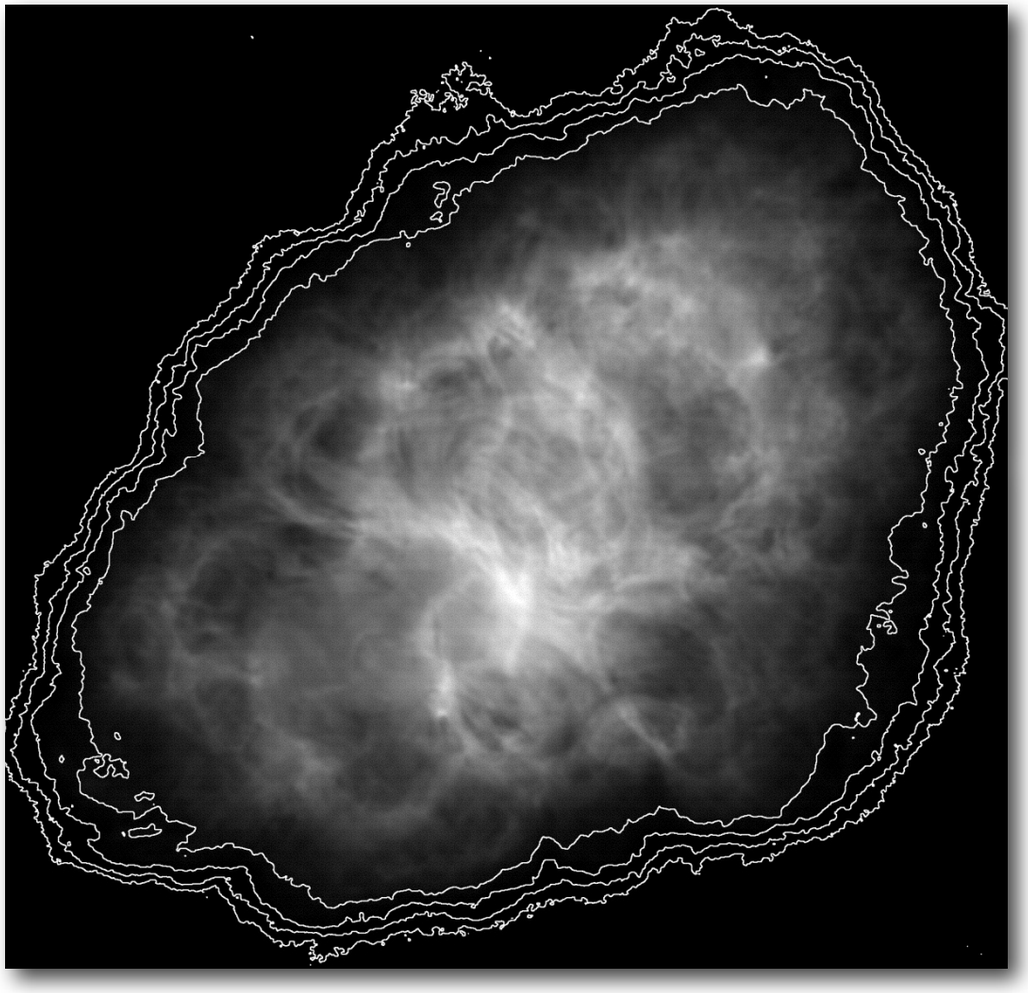
courtesy: J. Hessels & Pulsars WG

Extended / diffuse emissions



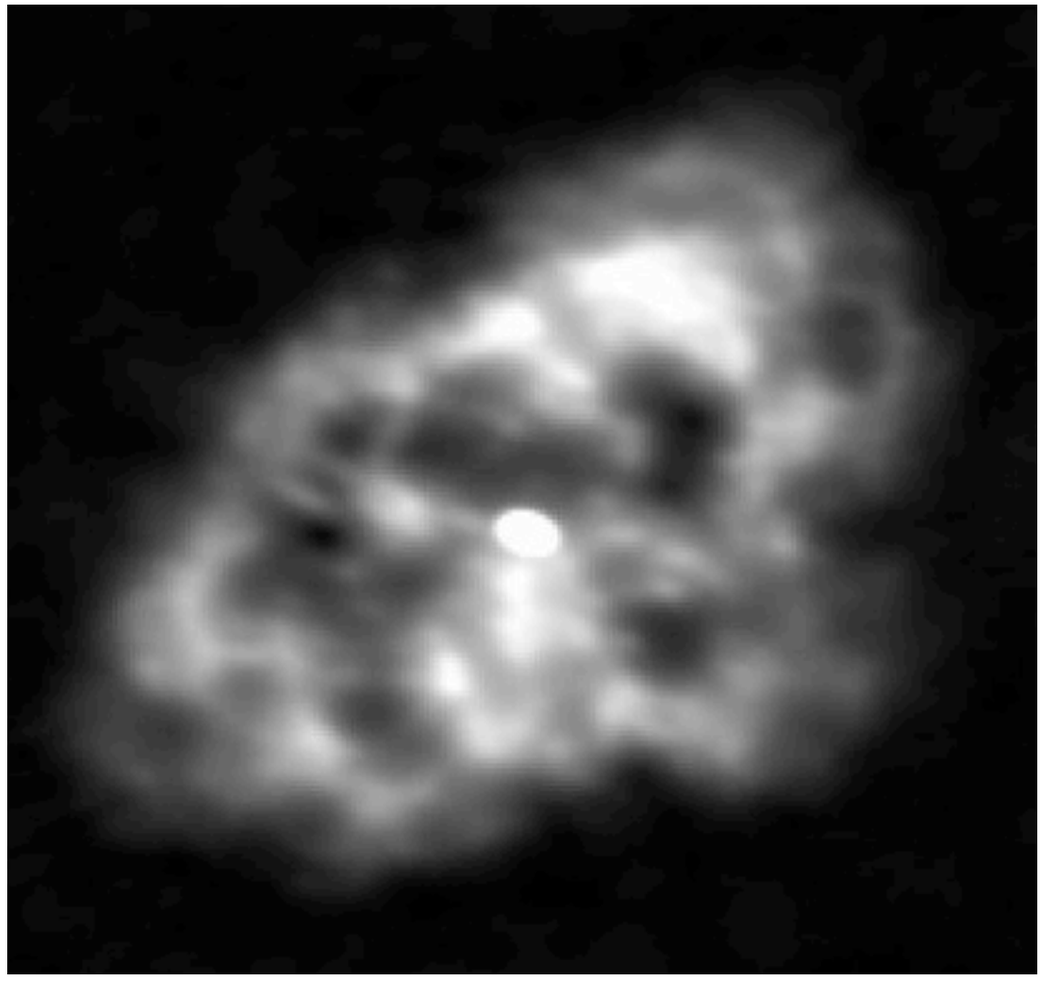
Crab Nebula (Taurus A) with international baselines

VLA 5 GHz



Bietenholz et al., 2004

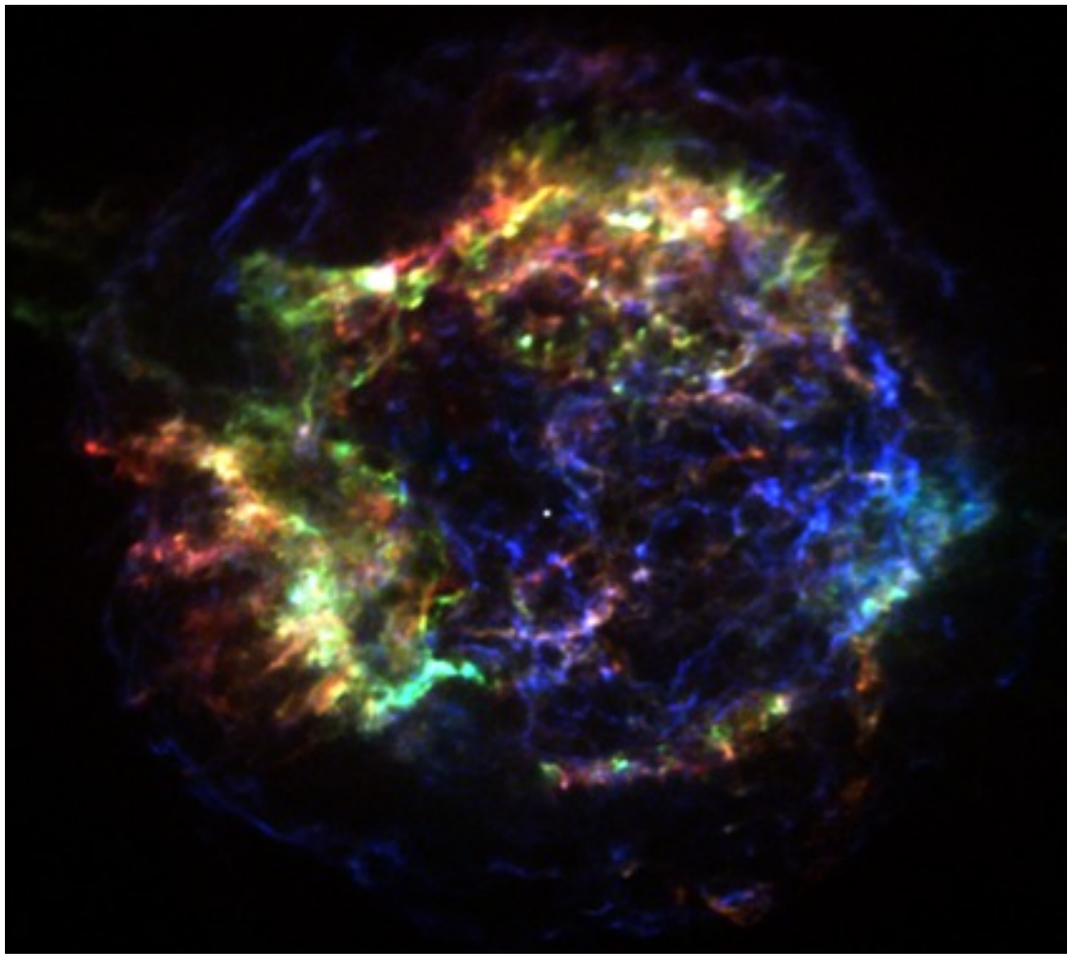
LOFAR 250 MHz



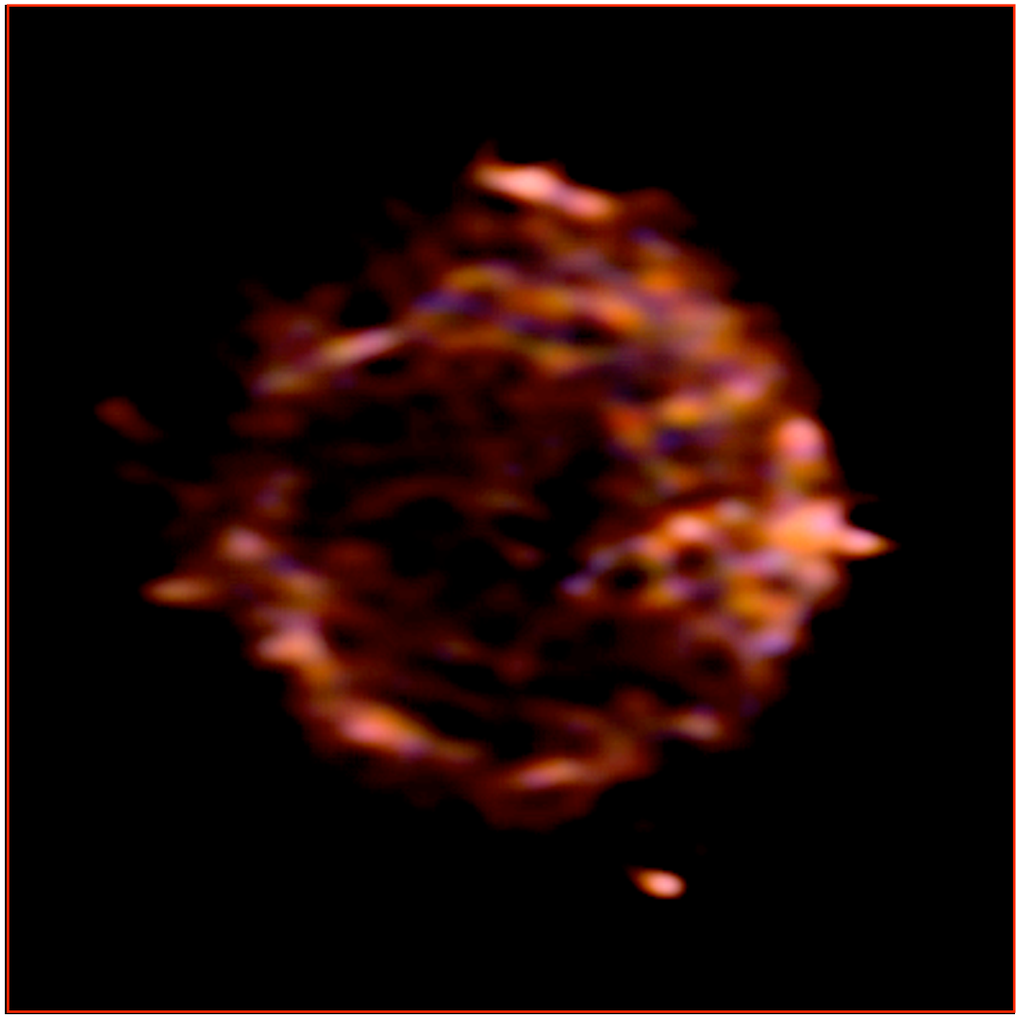
Wucknitz et al., 2011

Cassiopeia A

Chandra



LOFAR



Brentjens et al., 2011

M 87

commissioning data

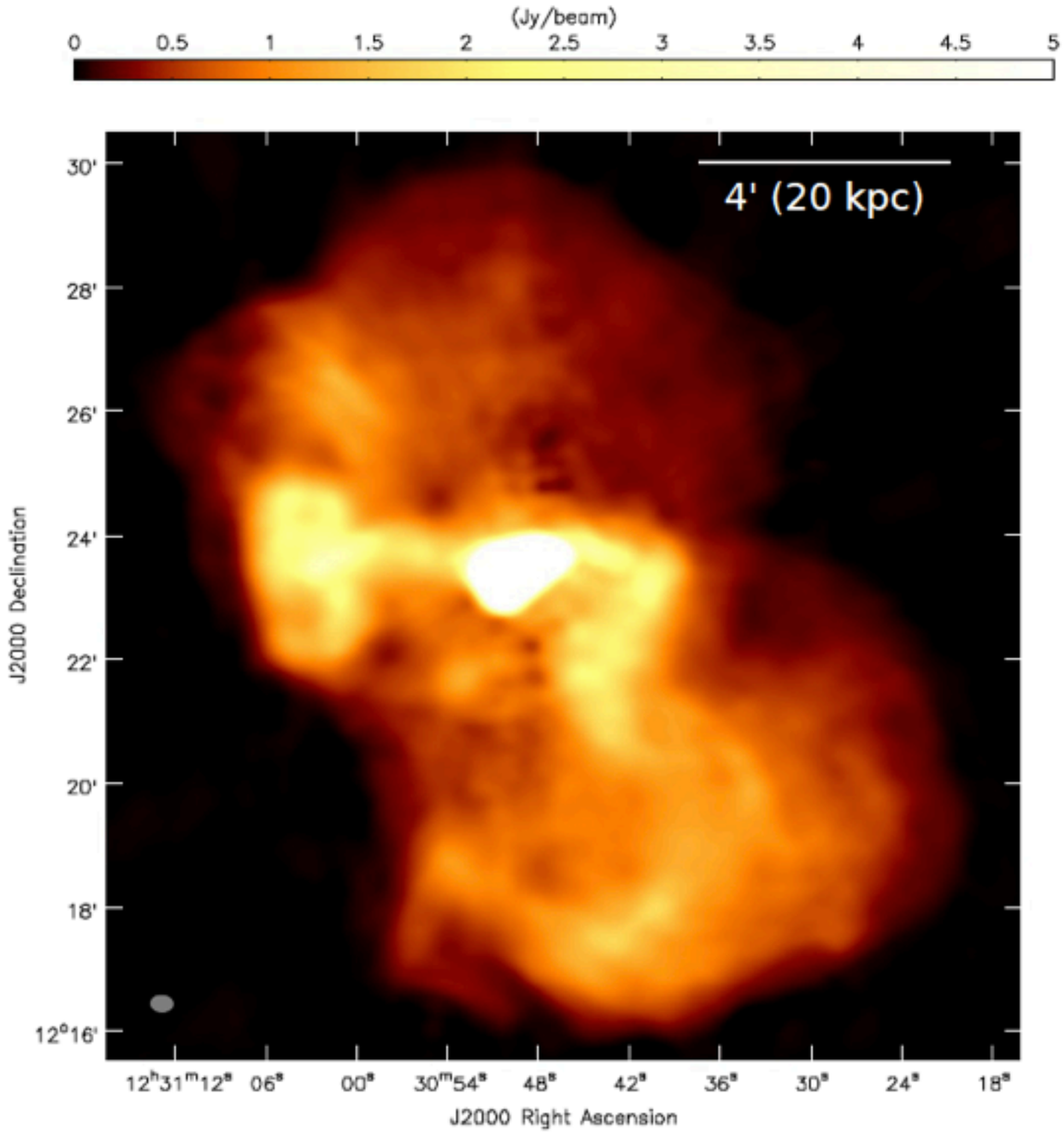


Fig. 5. LOFAR-HBA image of Virgo A at 140 MHz. The rms noise level is σ = 20 mJy/beam, the flux peak is 101 Jy/beam and the beam size is 21″ × 15″ (ellipse in the bottom-left corner). Some deconvolution errors are visible as small holes slightly above and below the bright core.

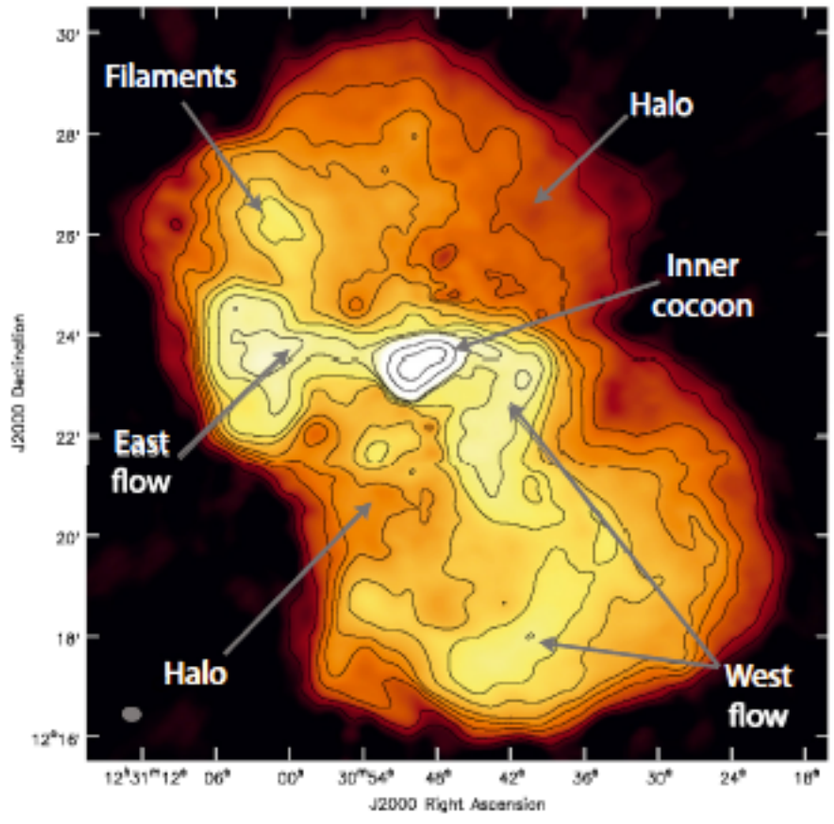
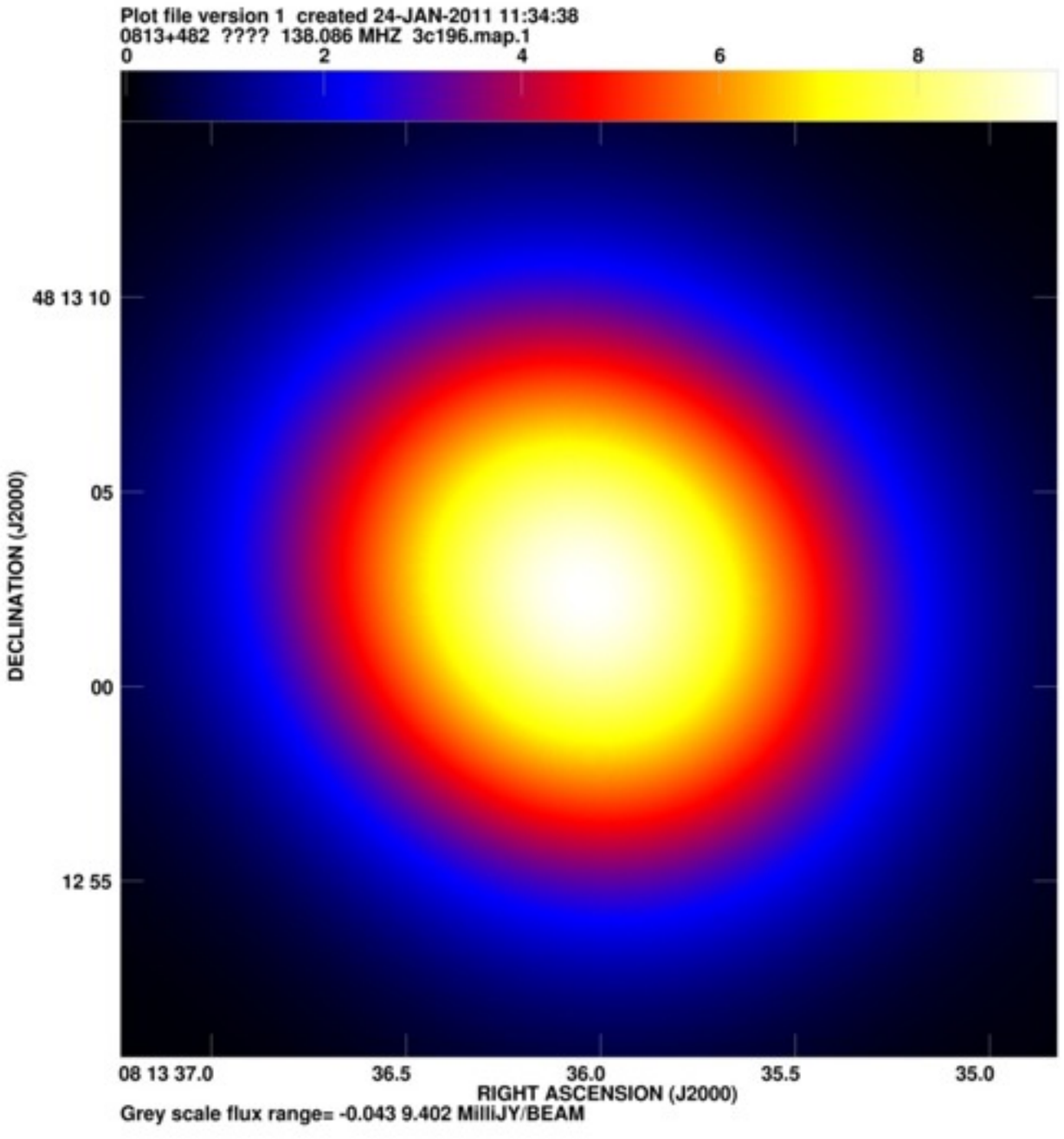


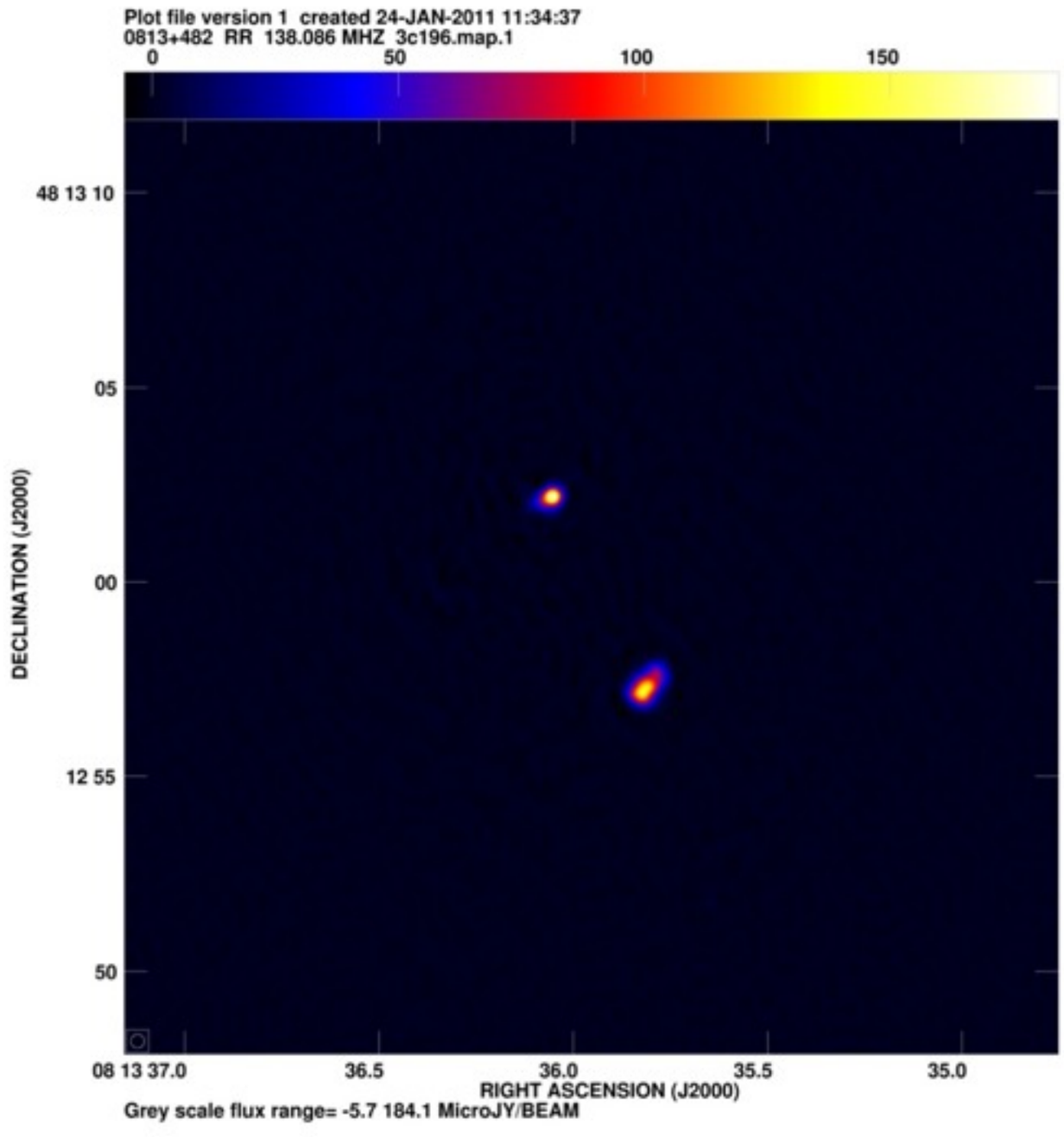
Fig. 8. Same as Fig. 5 with most prominent features described in the text labelled. Contour lines are at (1, 2.5, 5, 7.5, 10, 15, 20, 25, 30, 35, 45, 250, 1000) × 3σ.

de Gasperin et al., 2012

3C 196

commissioning data





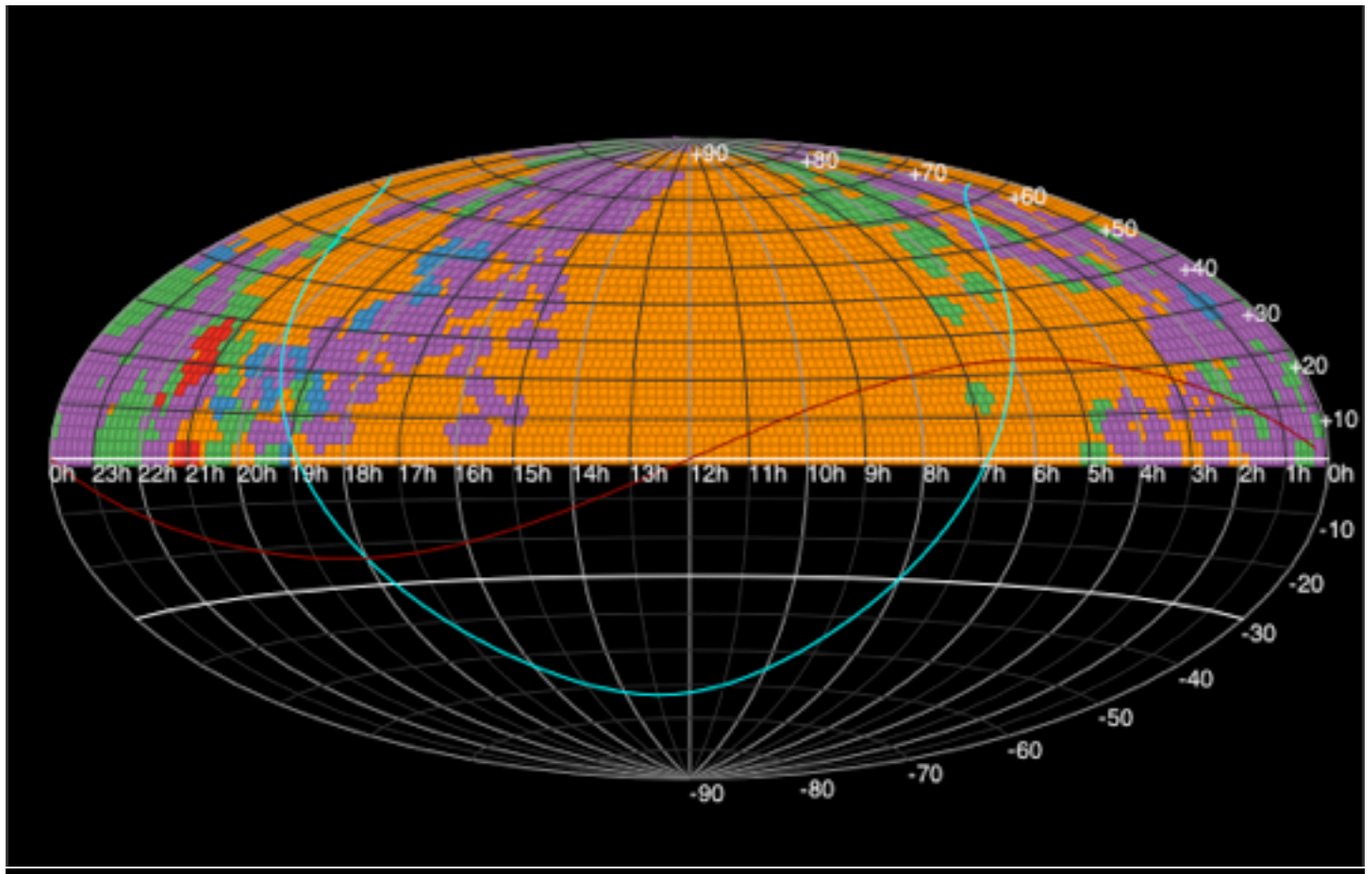
courtesy O. Wucknitz

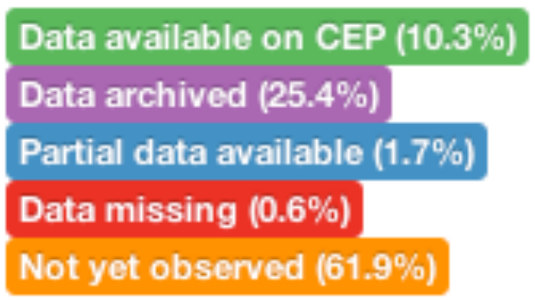
DE, UK, and FR stations ~0.2 arcsec resolution ⇒ Highest resolution image ever

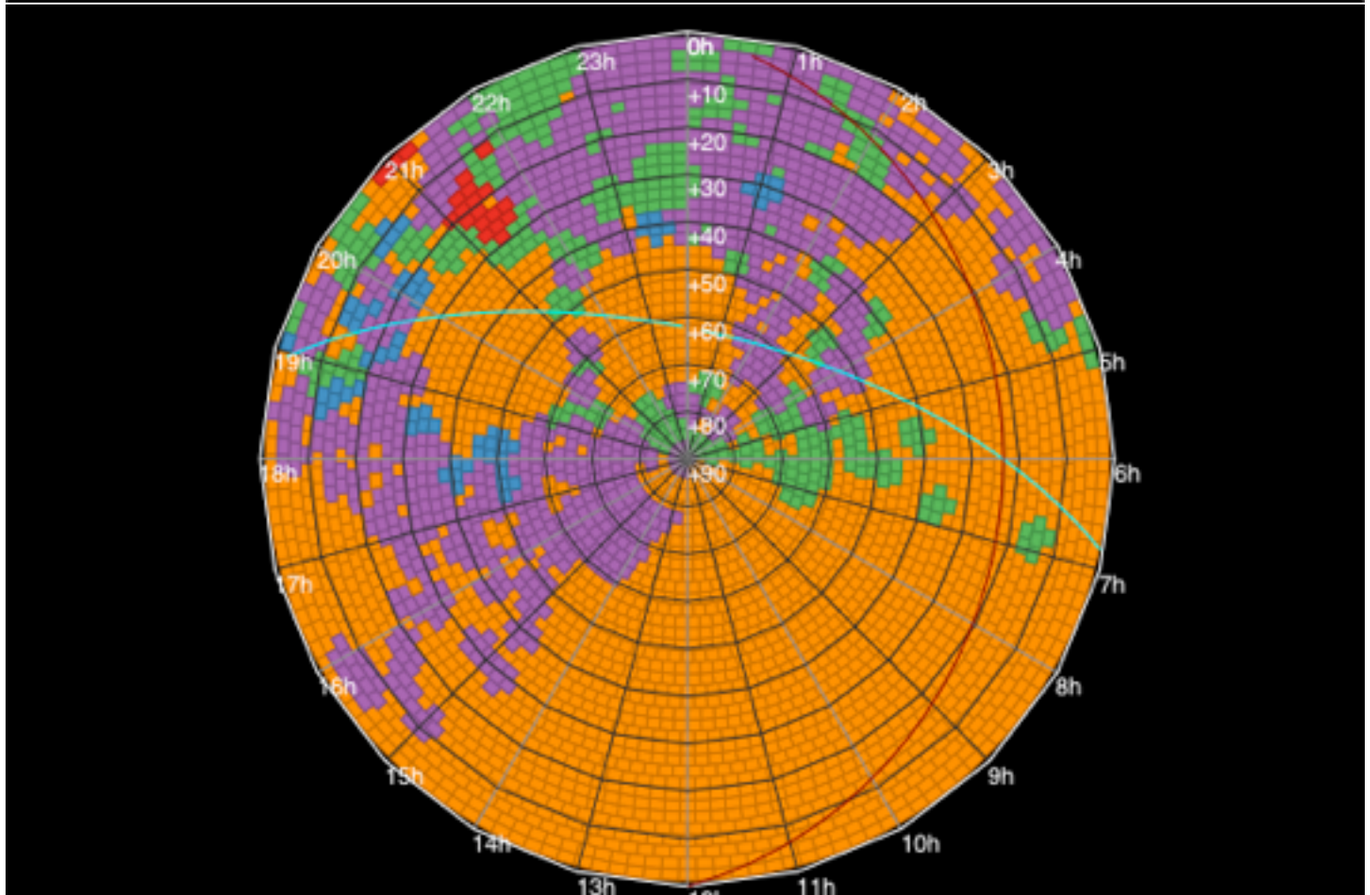
MSSS

MSSS HBA

Number of Targets	3616
Number of Calibrators	8
Start Date	8 Feb. 2013
Stop Date	17 May 2013
Completed Fields	1291 (35.7%)
Information collected	21 May 2013

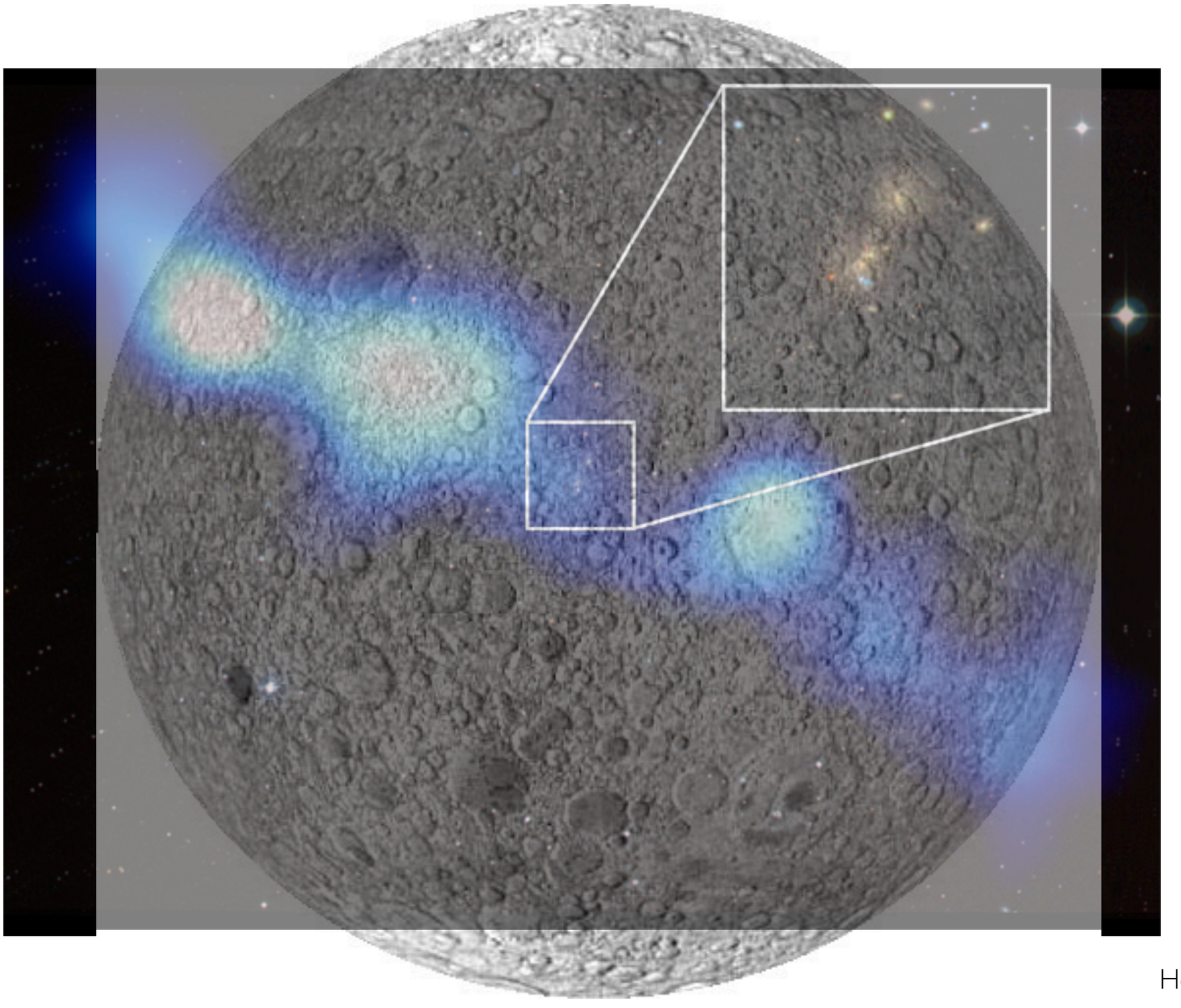






MSSS observations ⇒ giant radio galaxy

around triplet UGC 09555

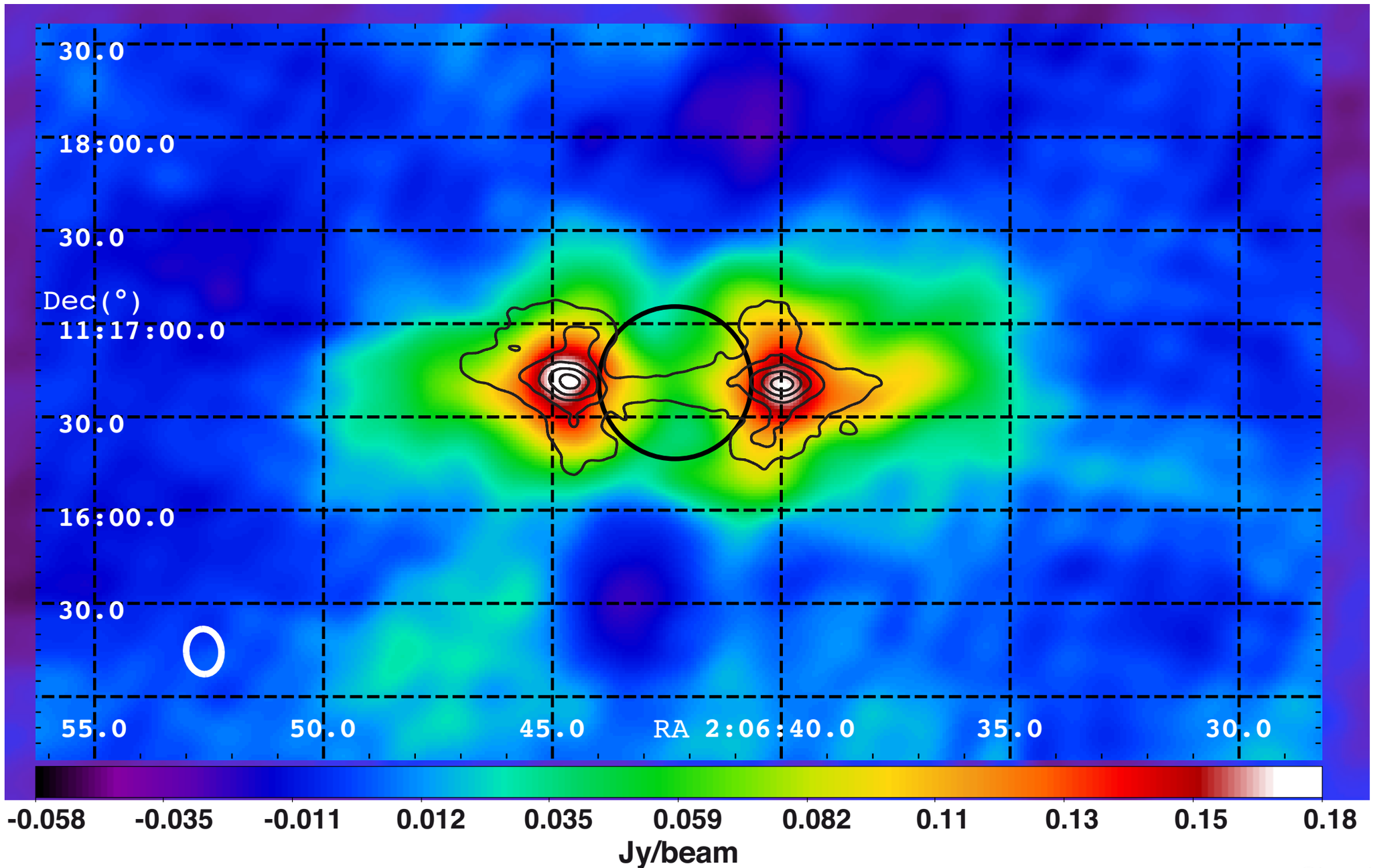


Heald et al., 2013

Jupiter's radiation belts

LOFAR : Δf = 127-172 MHz), Δt = 7h, Beam = 17.8"x15.5", Pixel = 1", Jupiter disk = 49"

Contours @ 15 GHz [de Pater & Dunn, 2003]



Girard et al., 2013

Initial deep LOFAR observations of Epoch of Reionization windows: I. The North Celestial Pole

FoV 10°x10°, Δt=6h, Δf=115-163 MHz, 25 stations

⇒ sensitivity 0.1 mJy achieved (≤1.5 x thermal noise), using SageCal

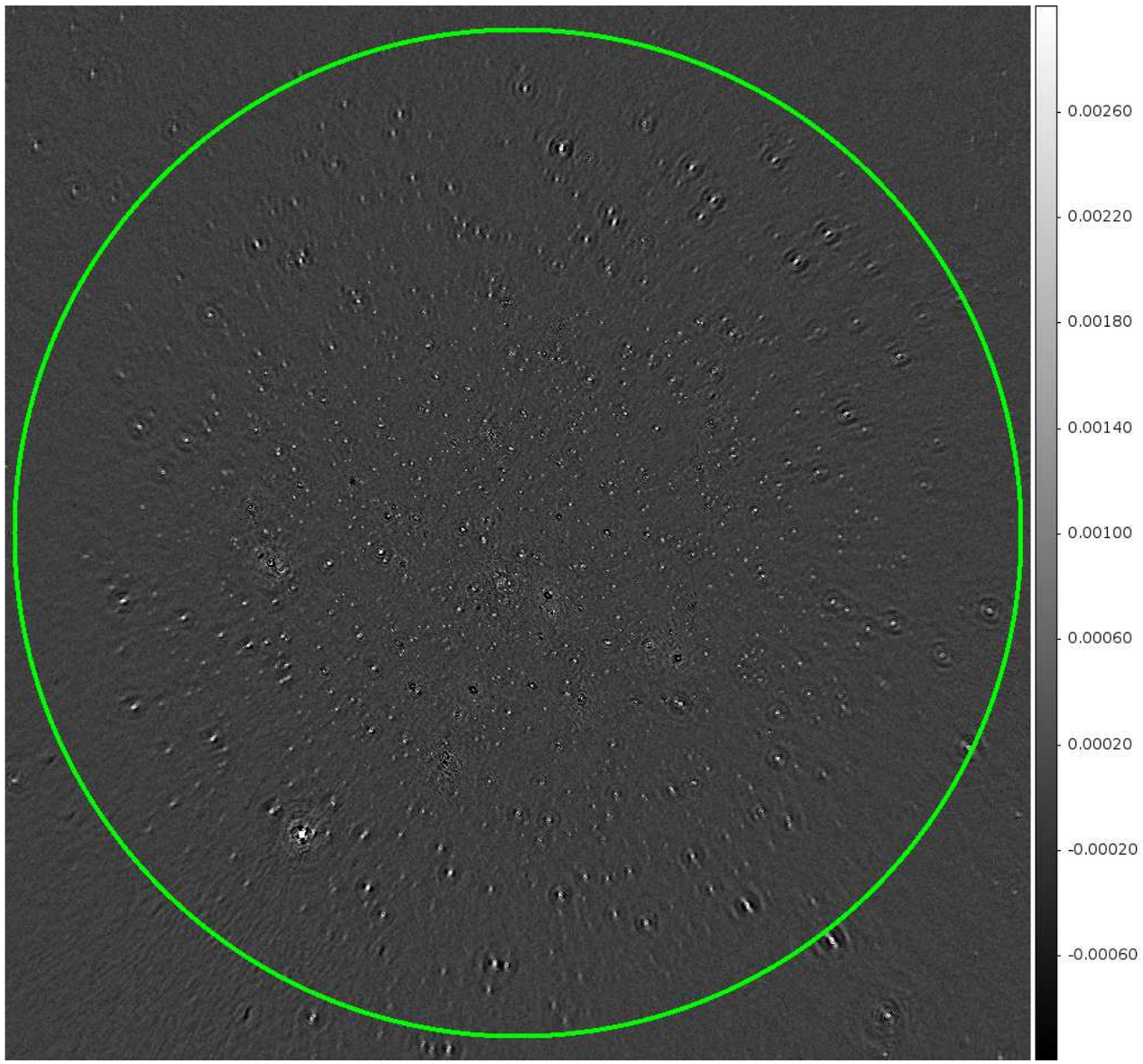


Fig. 9. The NCP image after multi-directional calibration and source subtraction using `SAGECal`. After a shallow deconvolution using CASA (mainly to estimate the PSF), the skymodel is restored onto the image. The circle indicates an area of diameter 10 degrees. The image has 12000 × 12000 pixels of size 4″ with a PSF of 12″ and the noise level is about 100 μJy/PSF. Due to the fact that RS and CS beam shapes have different FOVs the sources at the edge of the image are distorted. In addition, due to frequency smearing, the sources at the edge of the image appear 'attracted' towards the center. The colourbar units are in Jy/PSF.

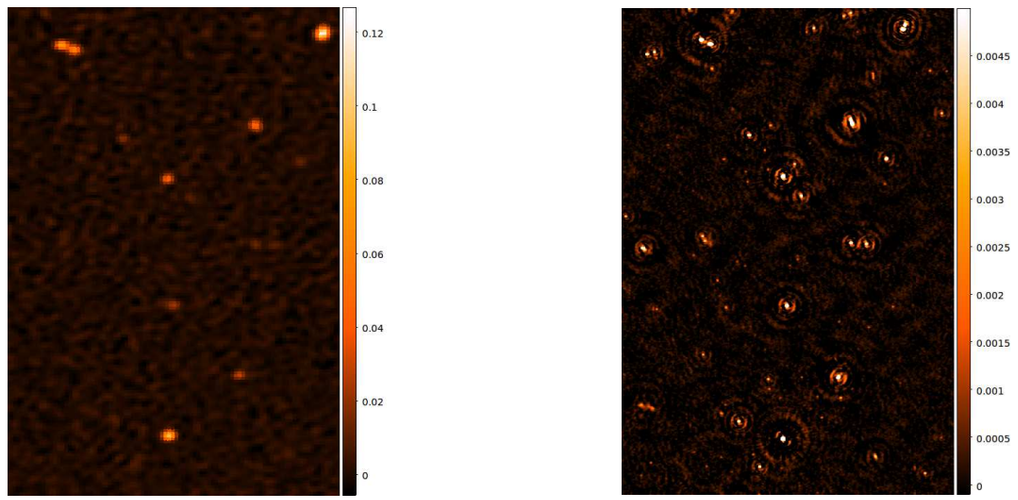


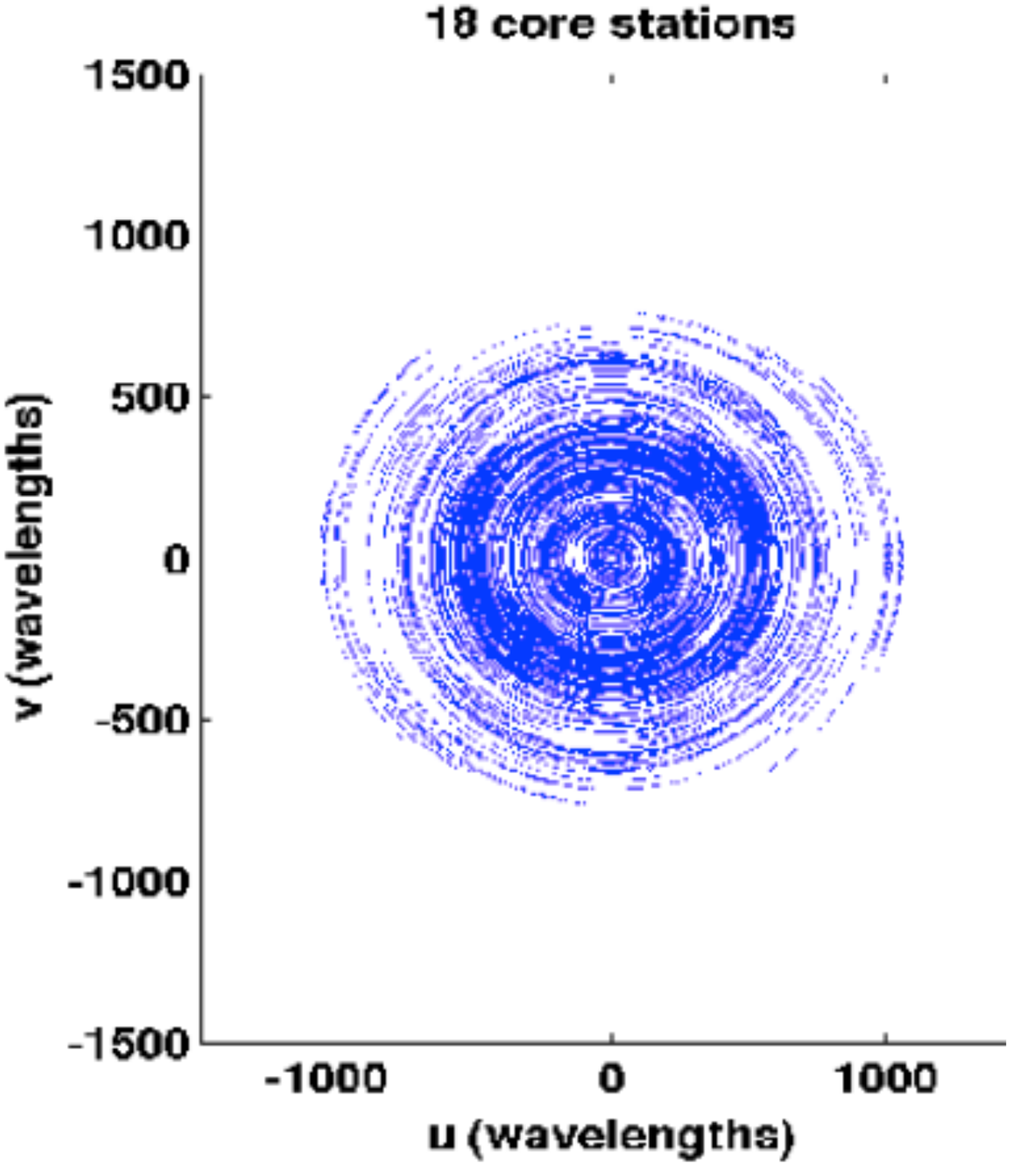
Fig. 11. Comparison of a small area of the NCP image, size 0.6 × 1.0 degrees with WENSS. The left panel shows the image from WENSS (PSF 60″) while the right panel shows the equivalent image made using LOFAR (PSF 12″). The colourbar units are in Jy/PSF. Many more sources, at much higher angular resolution can be detected.

Yatawatta et al., 2013

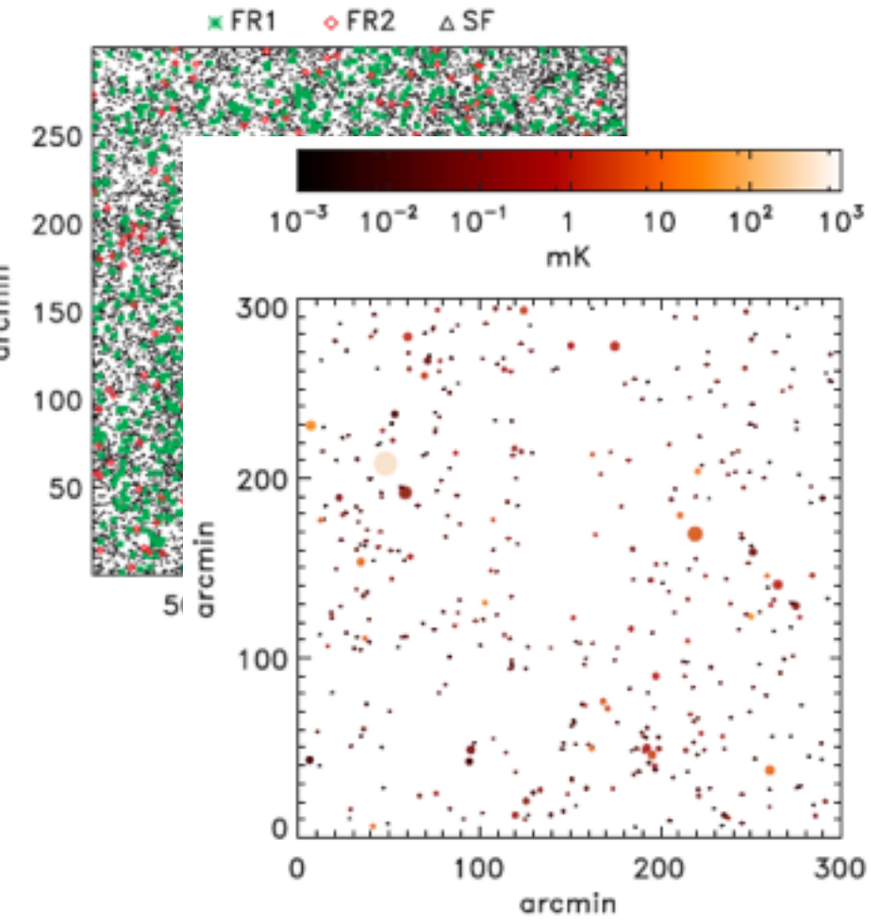
- EoR
- LOFAR
- Imaging
- Results
- Foregrounds
- Operations
- LSS/NenuFAR
- LSS /NenuFAR science

EoR Observation strategy

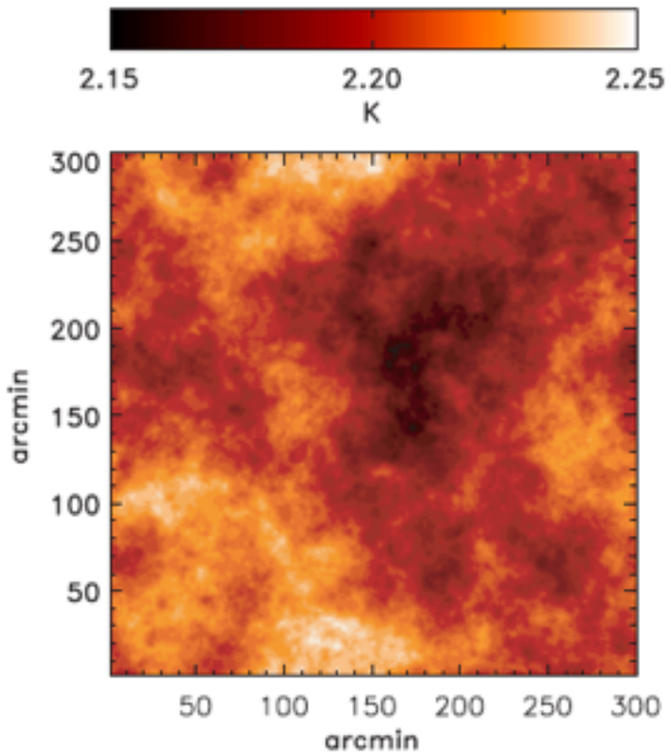
- LOFAR core (24 x 2 HBA)
- good u,v coverage required (1128 baselines)
- 115-190 MHz
- arcmin resolution
- 5 windows of 5° FoV (with low polarization)
- 10 kHz x 10 sec data
- 100s hours



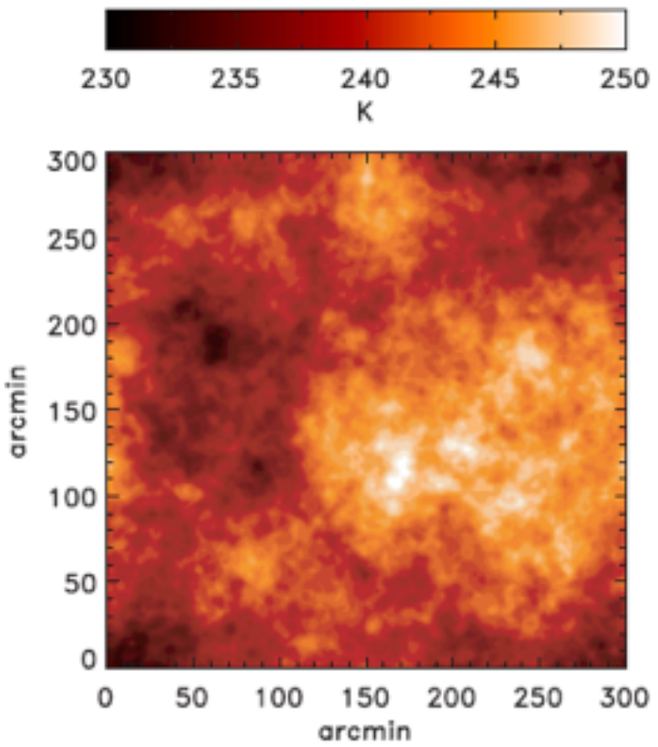
Foregrounds : simulations



galaxies & clusters



galactic free-free

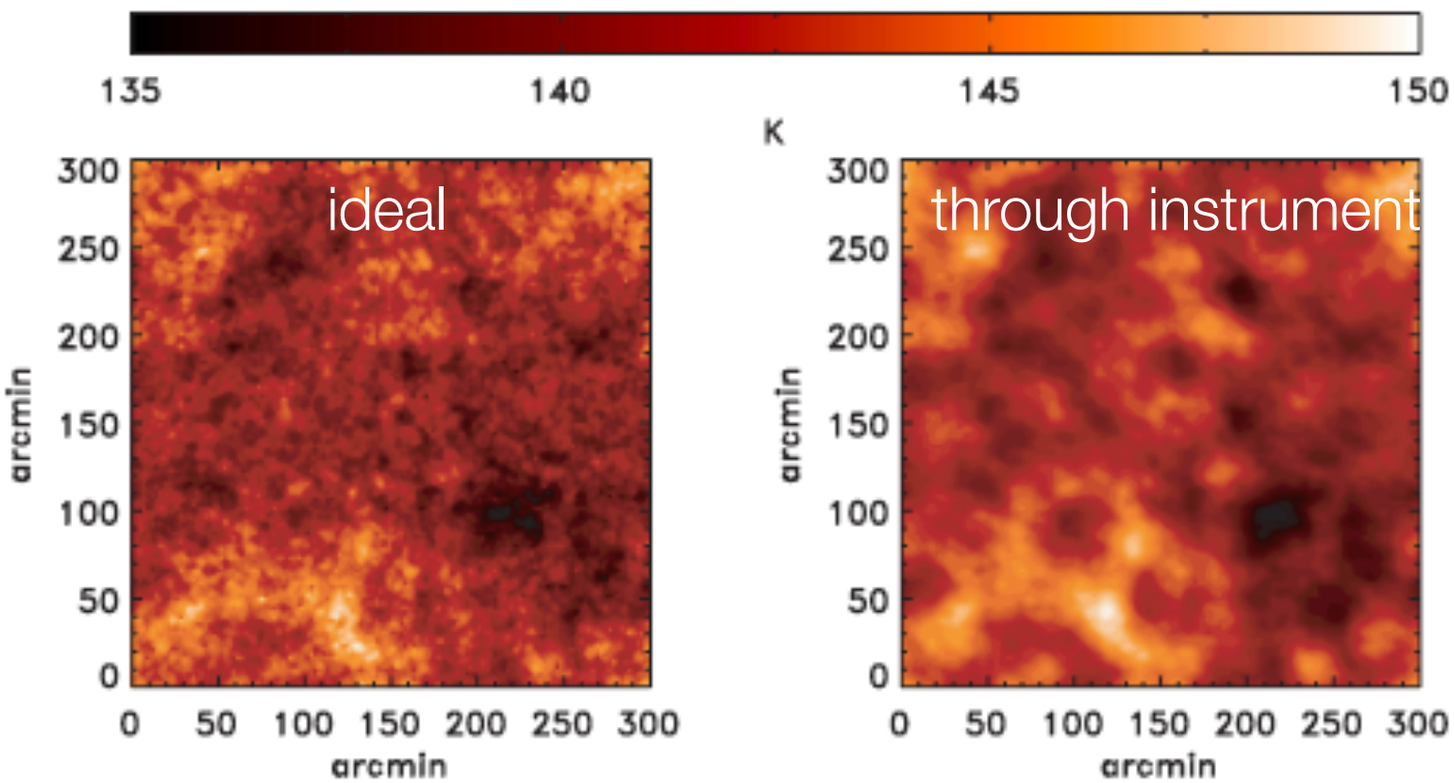


galactic synchrotron

⇒ Simulated FG maps

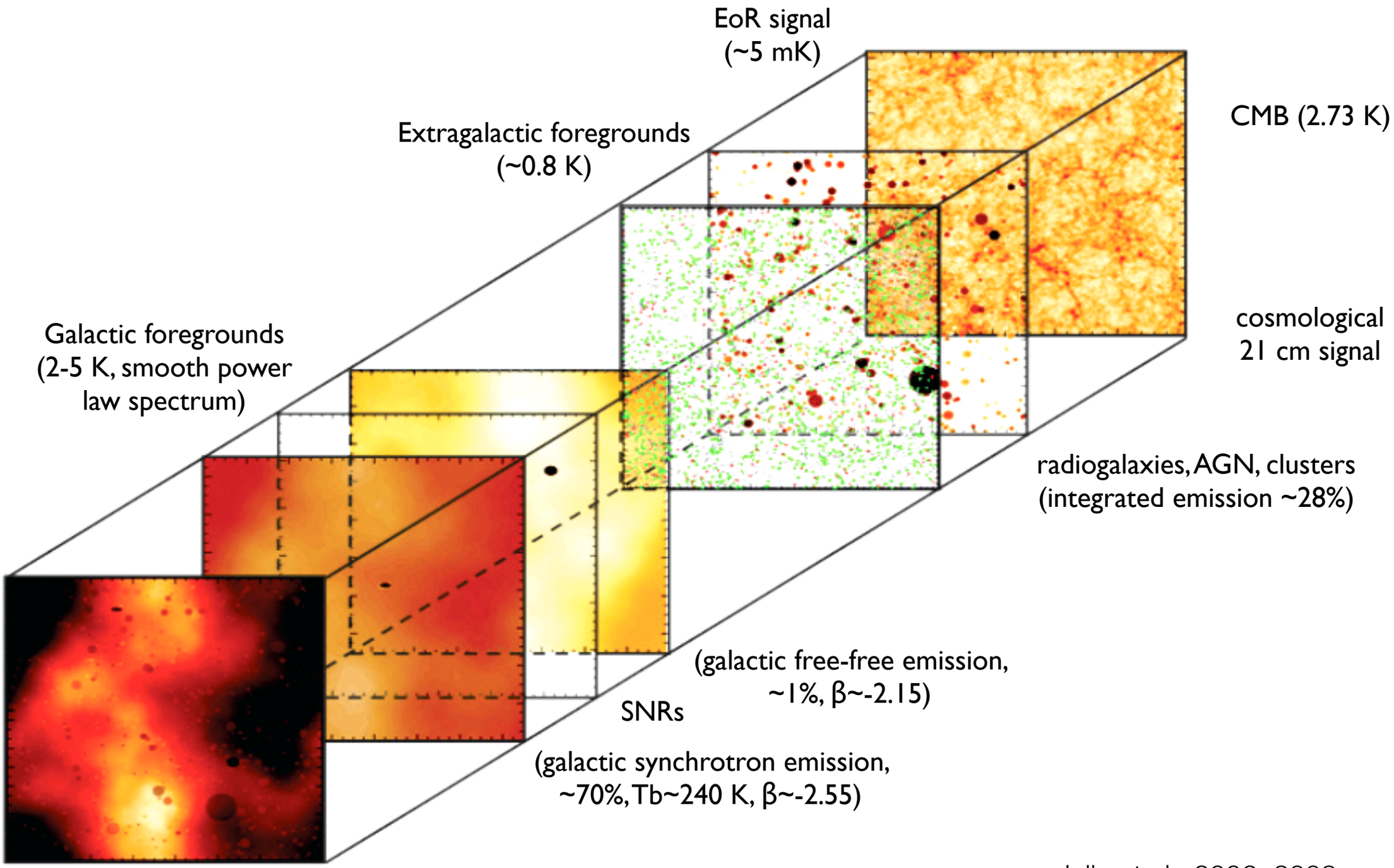
- Pointing to zenith
- 150 MHz
- Δt=400 h
- 100s averaging

Jelic et al, 2008



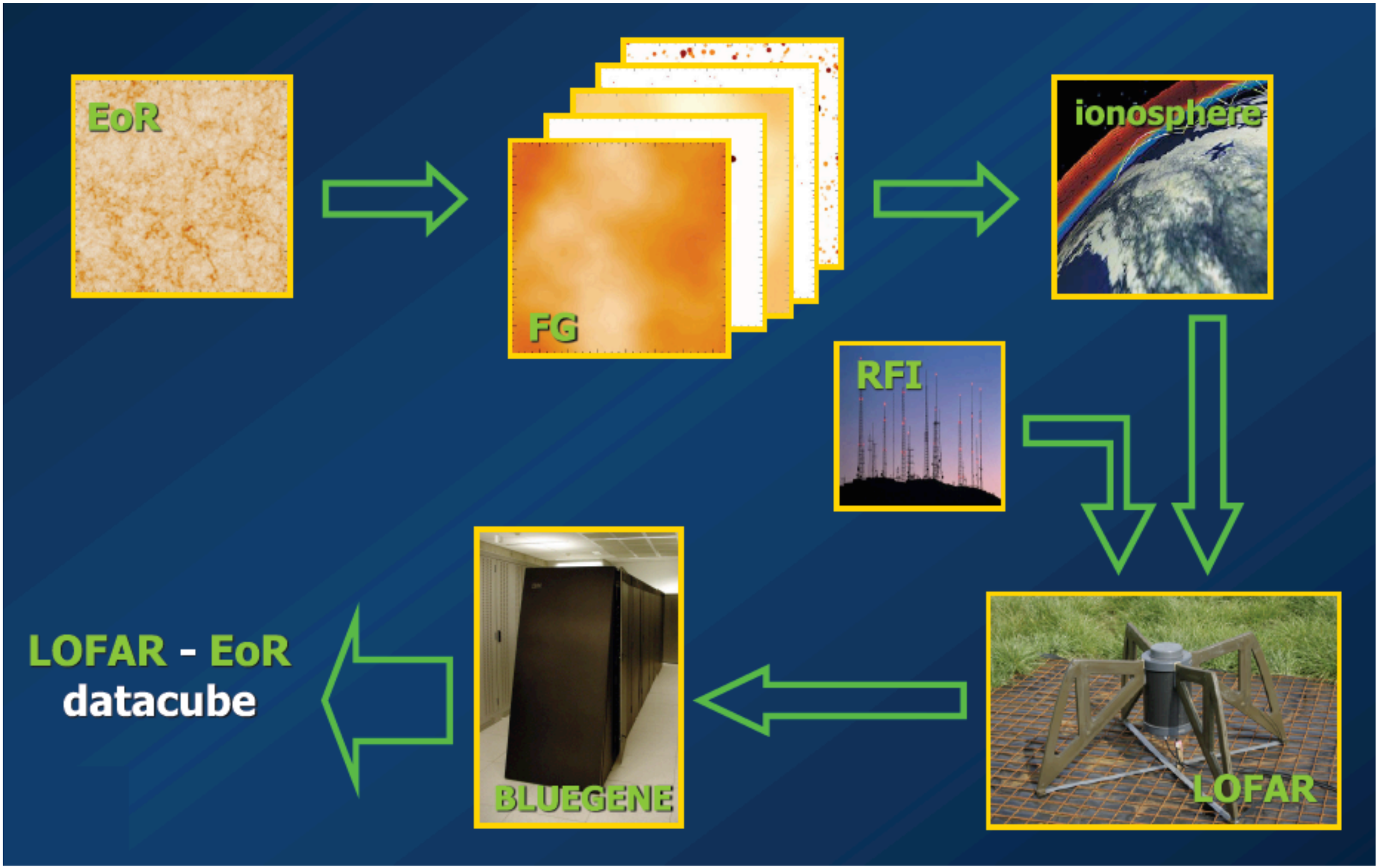
Foregrounds

5°x5° FoV, ~0.6' resolution, 115-180 MHz (here 120 MHz)

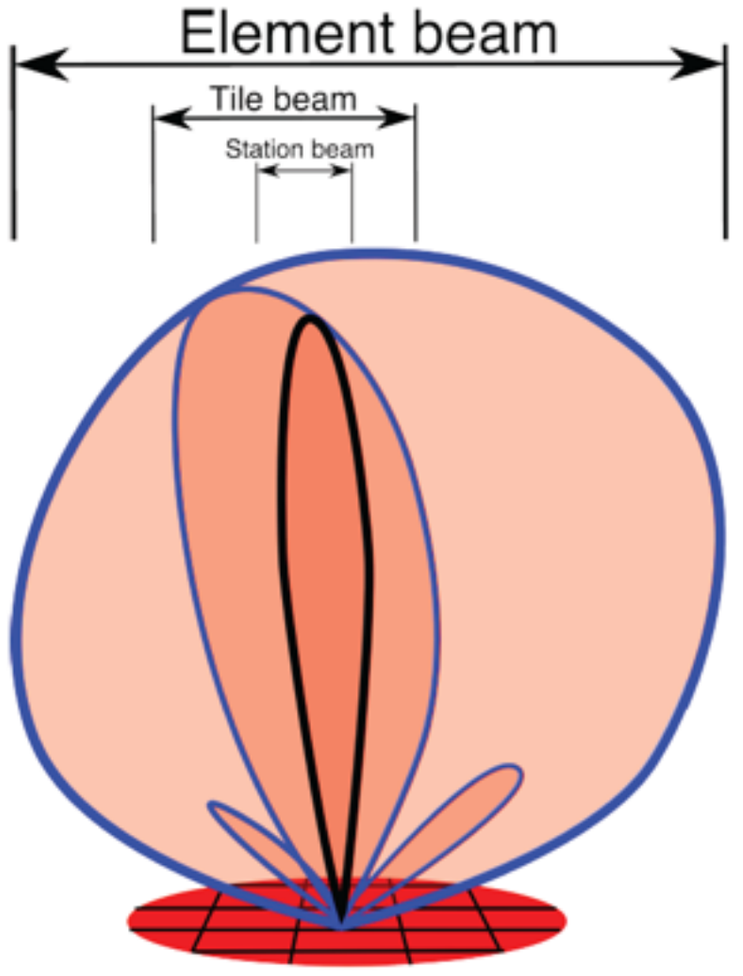


Jelic et al., 2006, 2008

Effect of Foregrounds

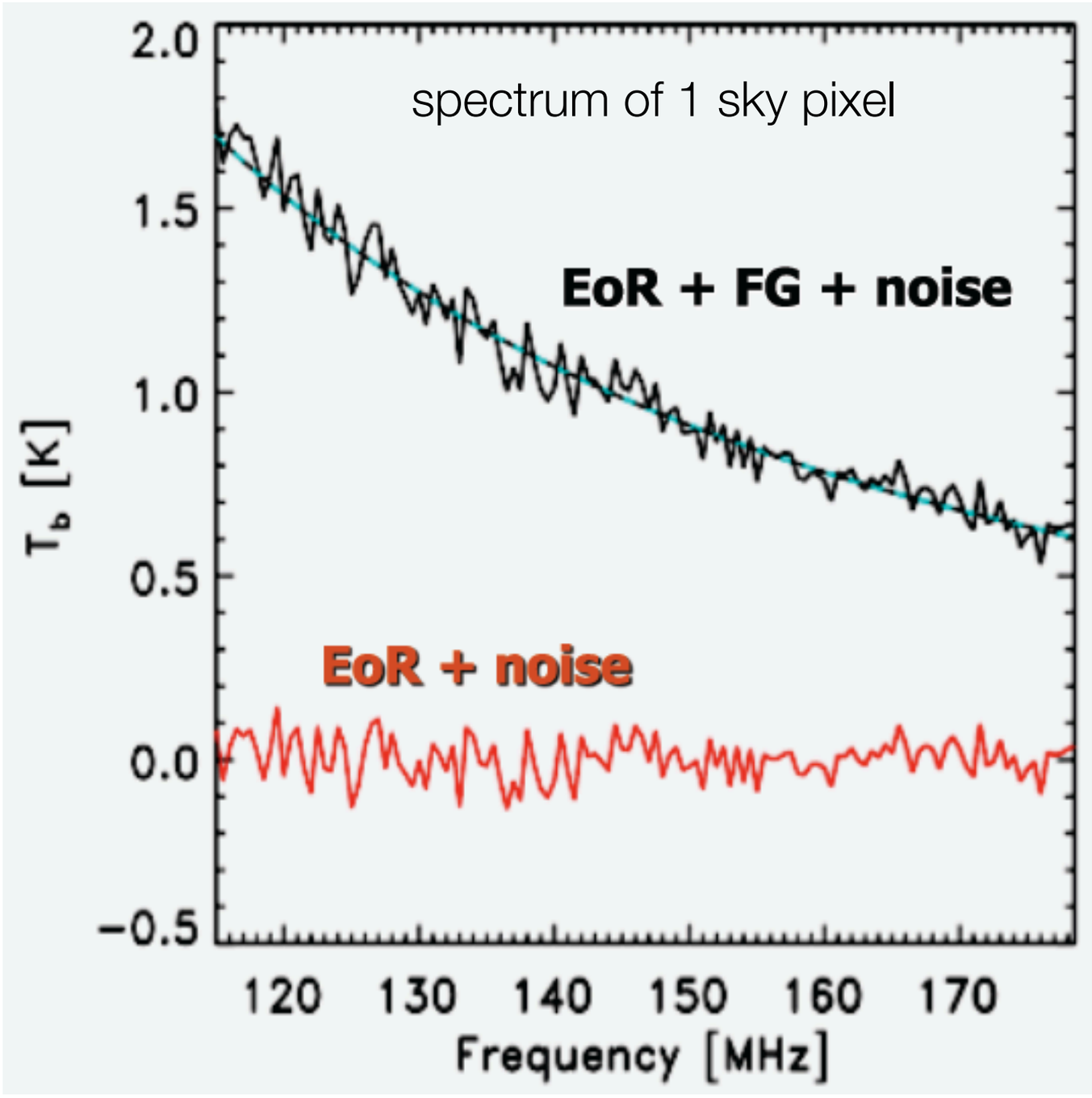


Analysis strategy



- Calibration +++ necessary (incl. ionosphere and beam model)
  - → deep images (10^6 dyn. range)
- fit+filter foreground (smooth vs frequency per sky pixel)
- model residual noise
- extract sky (EoR) shifted 21 cm signal (unpolarized)

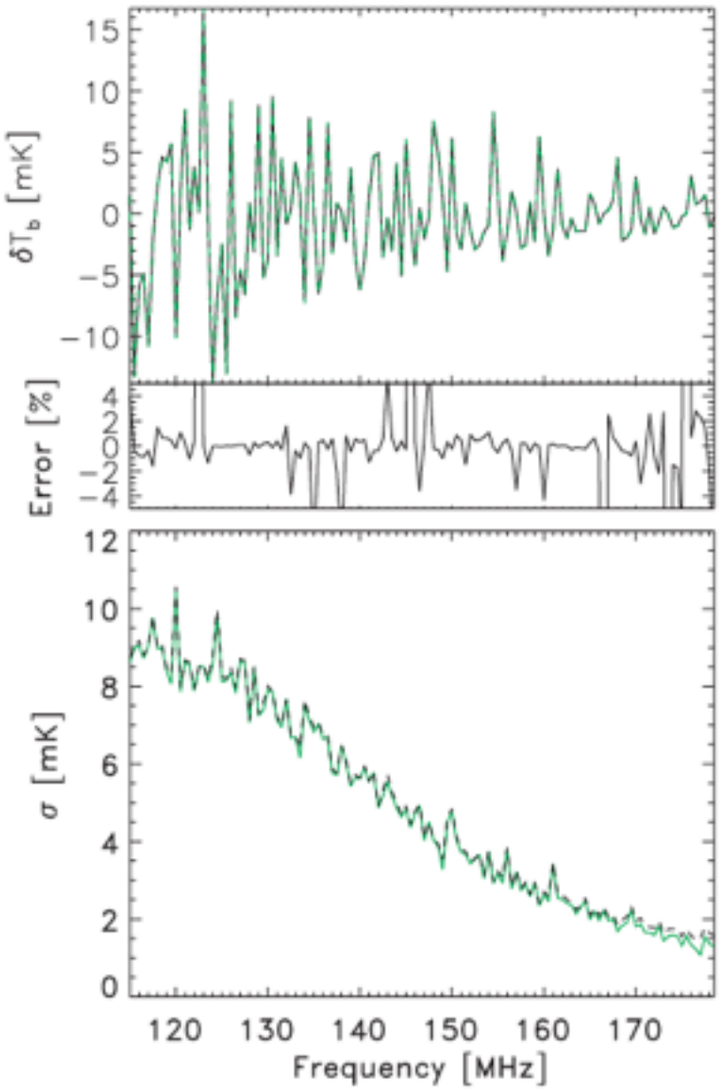
Statistical detection of EoR signal



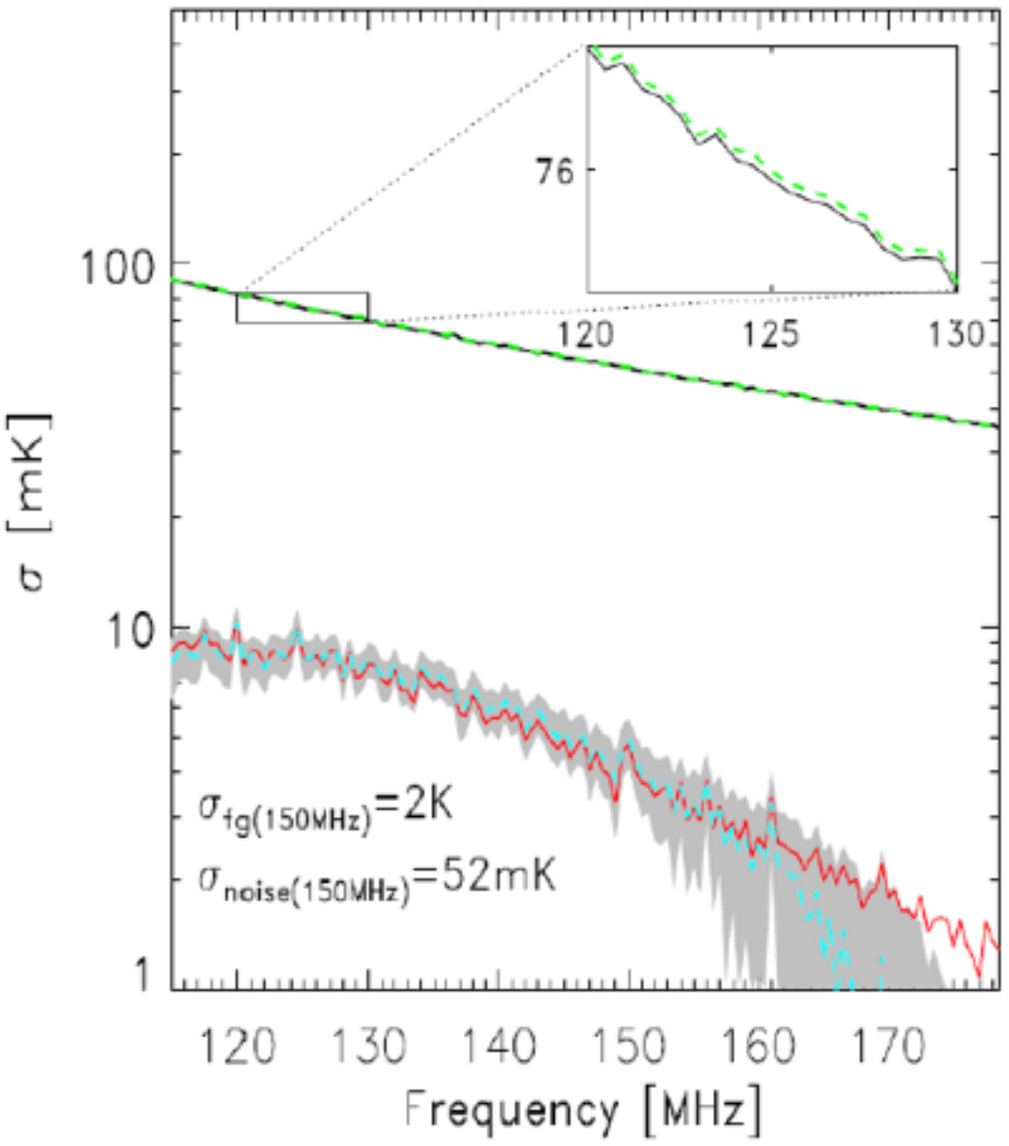
Jelic et al., 2008

- At 150 MHz: T_{EoR} ~5 mK, T_{FG} ~2 K, T_{noise} ~50 mK
- Hypotheses : diffuse FGs only in total intensity, perfect instrument & calibration

Statistical detection of EoR signal

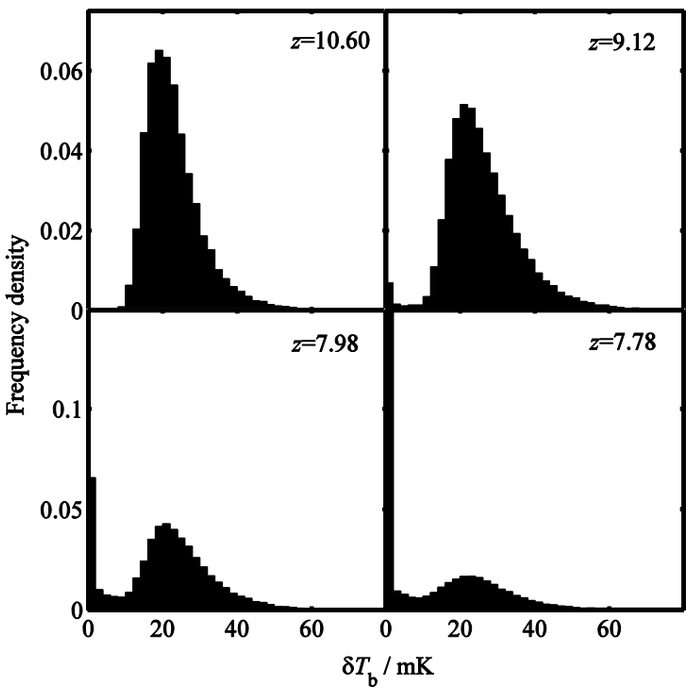


- Modelled EoR signal for 1 pixel & sigma over map



- Noise modelling
- EoR signal extraction (input EoR signal = red, retrieved = gray, avg = blue)
- Possible use of skewness

Jelic et al., 2008



Harker et al., 2008

The LOFAR KSP EoR

Homepage — LofarEor

http://www.astro.rug.nl/eor

Google

Meudon – Pr...Ressources ▾ Conferences ...rs – Ecoles ▾ LOFAR ▾ Cassini ▾ Missions Spatiales ▾ Bases de données ▾ Ephémérides ▾ Musique ▾

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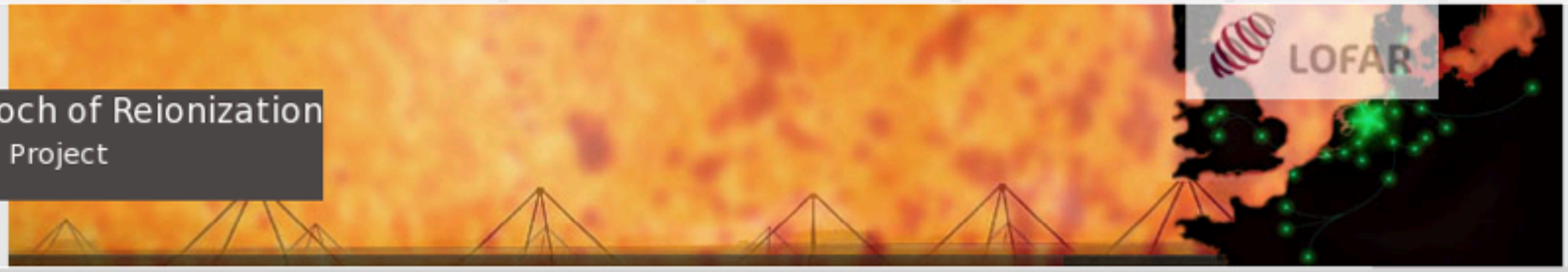

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Homepage

WELCOME TO THE LOFAR EoR KSP

Also available in presentation mode.

LOFAR, the LOw Frequency ARray ra … in the Universe as a function of redshift, through the hydrogen hyp… ject that will carry out this very challenging observation and analyz… f fields of view with arc-minute resolution. Each field will contain ab… 1.5-6.5).

The EoR measurement is very challe…

1. The signal will be contaminated …
2. The sky signal goes through an ever changing ionosphere that can severely distort the signal.
3. Given the nature of the LOFAR instrument, modeling the telescope with time will be very challenging.
4. The thermal noise per resolution element, even after hundreds of hours of observation will dominate over the signal.

All these issues have to overcome before a reliable detection of the EoR could be claimed.

Kapteyn Astronomical Institute, RUG

ASTRON

Management team, Core & Associated members
3 WG:
- Signal modelling & extraction,
- Instrument design, observational strategies
- Calibration & (re-)processing
French Members : Aghanim, Langer, Douspis ...

- EoR
- LOFAR
- Imaging
- Results
- Foregrounds
- Operations
- LSS/NenuFAR
- LSS /NenuFAR science

LOFAR Operations

- Cycle 0 will run until 2013 November 14 (LOFAR v1.0)

Proposal Code	PI	Proposal title	Total observing hours	Total processing hours
LC0_002	Olaf Wucknitz	Location and motion of sources of Jupiter's magnetospheric/auroral decameter emissions	9	9
LC0_003	Rob Fender	Wide field searches for image-plane radio transients	196	249,5
LC0_004	Neal Jackson	Gravitational lenses at low frequencies	30	15
LC0_005	Regis Courtin	A determination of the abundance of water in Saturn's deep atmosphere with LOFAR	10	70
LC0_006	Imke de Pater	LOFAR Observations of Jupiter's Synchrotron Radiation	11,5	35
LC0_007	Philippe Zarka	Exoplanet radio search and characterization	30	167
LC0_008	Ben Stappers	LOFAR studies of pulsars, fast transients and the interstellar medium	85	8
LC0_009	George Miley	Particle acceleration and cold gas in high-redshift radio sources - long baseline and recombination line studies	36	27
LC0_010*	Aris Karastergiou	ARTEMIS on LOFAR: real-time searches for fast transients with international LOFAR stations	260	0
LC0_011	Joris Verbiest	Pulsar timing with LOFAR	36,5	5
LC0_012	Raffaella Morganti	Using LOFAR for detailed studies of AGN, and AGN physics	210	373
LC0_013	Rachel Osten	Stellar Radio Astronomy with LOFAR	12	2,5
LC0_014*	Maciej Serylak	Studying pulsars and the interstellar medium using International LOFAR stations	364	0
LC0_015	Philip Best	A deep and wide extragalactic survey at low frequencies: AGN evolution, star formation, and cosmology	129	292
LC0_016	Ewan OSullivan	Stephan's Quintet: the role of shocks in the formation of the hot intragroup medium	8	20
LC0_017	Joseph Lazio	A Search for radio emissions from HD 80606b near planetary periastron	30	75
LC0_019	A G de Bruyn	Studying the Epoch of Reionization and cosmic dawn of the Universe	640	0
[illegible]	David Jones	Determining the origin and (magnetic) substructure of the Fermi bubbles	[illegible]	[illegible]

Week number	week day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
21, 20th May	Mon	LC0_003 - Zenith fields - 24 hrs												Stress system runs + TBB runs	LC0_031 - MS0735.6 - 6hrs						LC0_019 (EoR)				
	Tue	LC0_019 (EoR)							Investigation week-end failures; Stress system runs; TBB runs			LC0_002 - Jupiter - 10:20 to 13:20 UT			Commissioning OH test				Stress system runs + TBB runs		LC0_005 - Saturn - 5hrs			
	Wed	Pulsars								DE601, DE602, DE603, DE605, FR606, SE607, UK608 switched to local mode at 9 UTC; FE monitoring runs; beam tests											Pulsars	LC0_005 - Saturn - 5hrs			
	Thu	Stress system runs + TBB runs		LC0_039: SS433		Stress system runs + TBB runs			Station test runs; Stress system runs; TBB runs						LC0_012 - 3C223 - 10hrs									Stress system runs + TBB runs	
	Fri	MSSS - HBA - 16 hrs																	Stress system runs + TBB runs		LC0_019 (EoR)				
	Sat	LC0_019 (EoR)							Pulsars								Stress system runs + TBB runs				LC0_012 - VLSS1431 - 8hrs				
	Sun	LC0_012 - VLSS1431 - 8hrs			Obsevations for system characterization + TBB runs																LC0_019 (EoR)				

LOFAR Operations

- Cycle 0 will run until 2013 November 14
- Cycle 1 will run from 2013 November 15 to 2014 May 14
- The proposal (issued in June) will have a deadline at 2013 September 6
- 10% open time on 1st year → 65% on 5th year
  + complement under KSP «umbrellas»
  + commissionning / development LOFAR v2.0
- Proposals via NorthStar online tool
  https://lofar.astron.nl/useradministration/user/forward.do?forward=http://lofar.astron.nl/proposal/setUpProposalList.do

- EoR
- LOFAR
- Imaging
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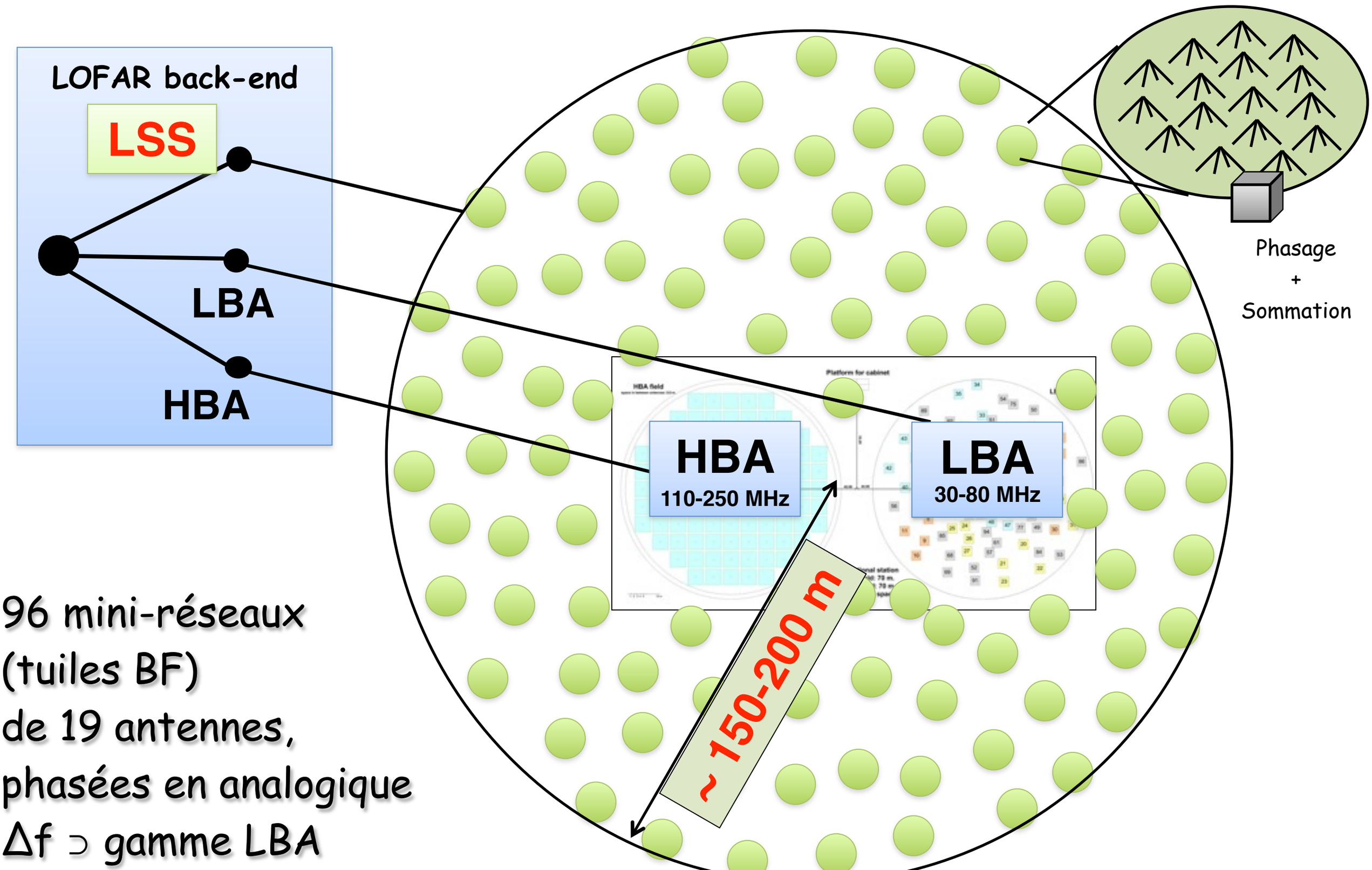
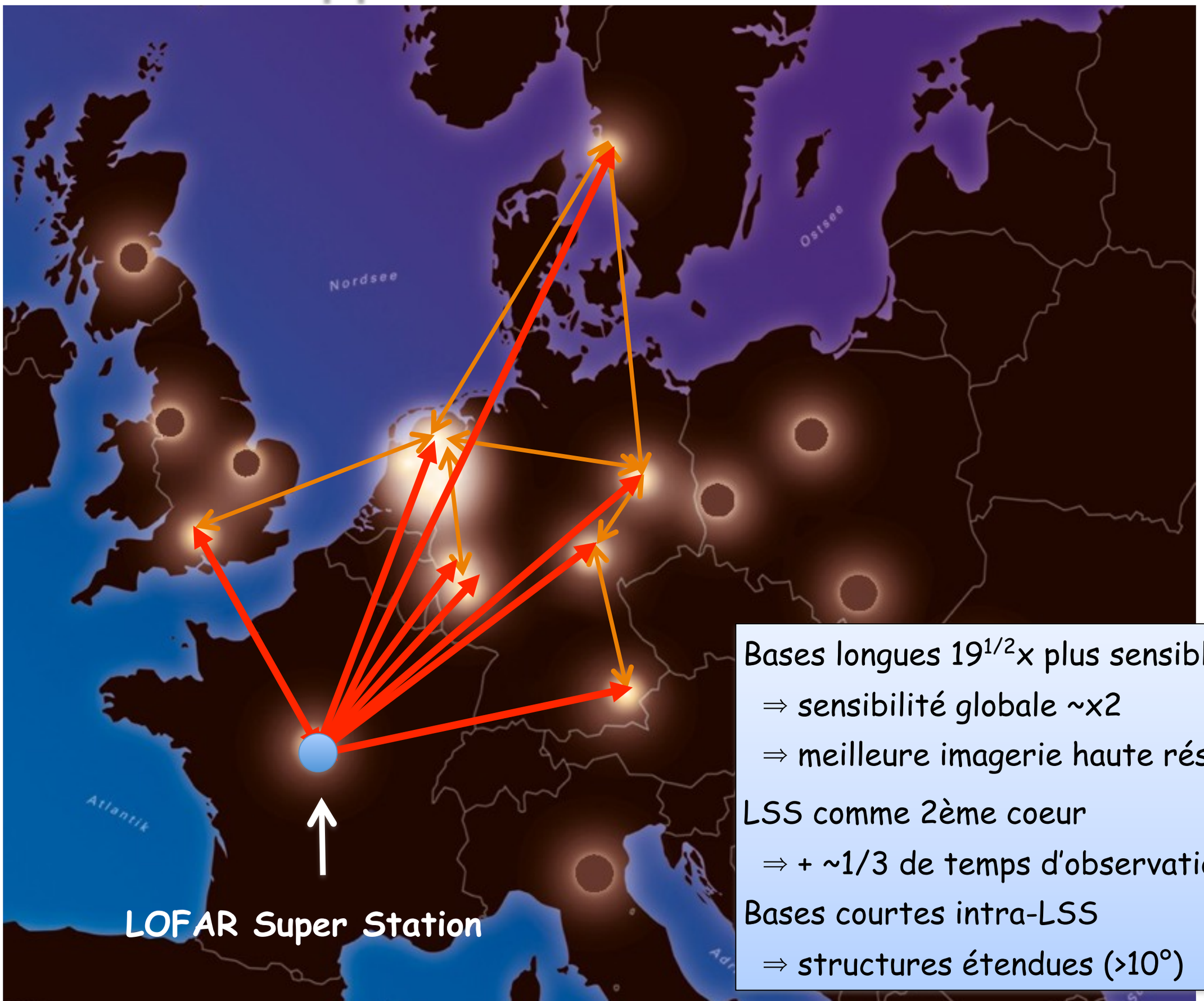
- LSS /NenuFAR science

Le concept de Super Station LOFAR : réseau phasé + interféromètre géant à Nançay



96 mini-réseaux
(tuiles BF)
de 19 antennes,
phasées en analogique
$\Delta f \supset$ gamme LBA

Les apports de la LSS/NenuFAR



Bases longues $19^{1/2}$x plus sensibles

⇒ sensibilité globale ~x2

⇒ meilleure imagerie haute résolution

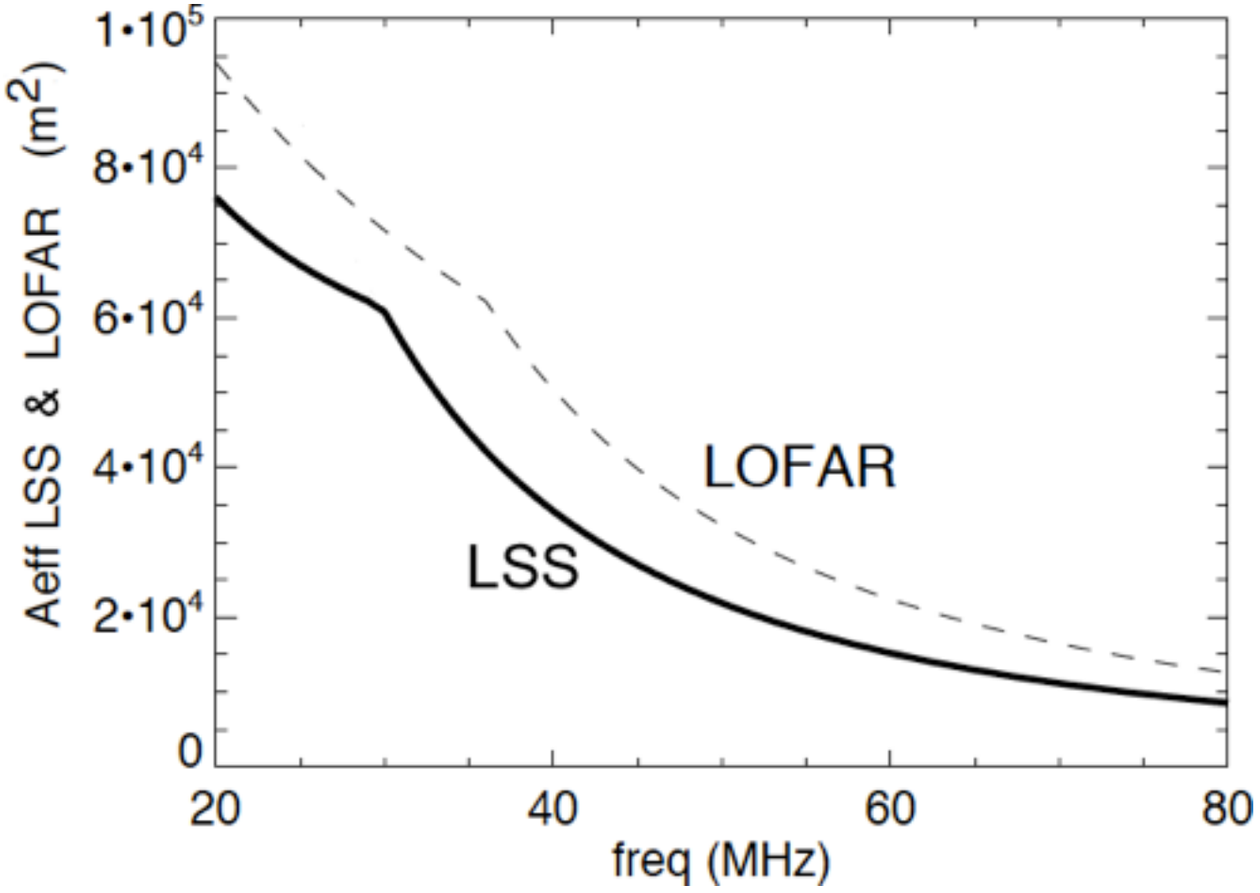
LSS comme 2ème coeur

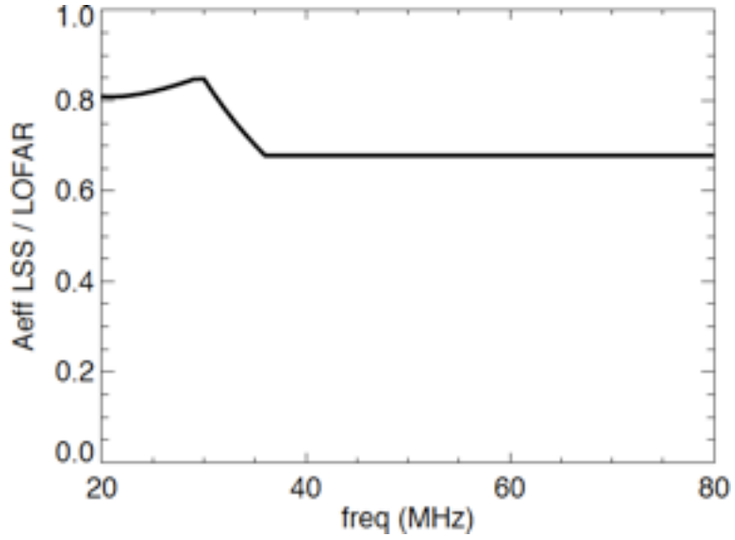
⇒ + ~1/3 de temps d'observation

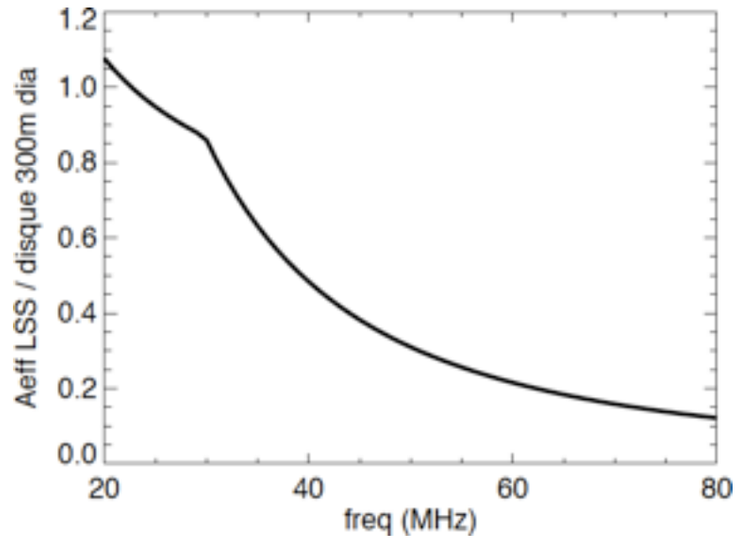
Bases courtes intra-LSS

⇒ structures étendues (>10°)

Les apports de la LSS/NenuFAR







Grand instrument autonome : « Arecibo à Nançay »

⇒ ~19x la sensibilité d'une station internationale en LBA

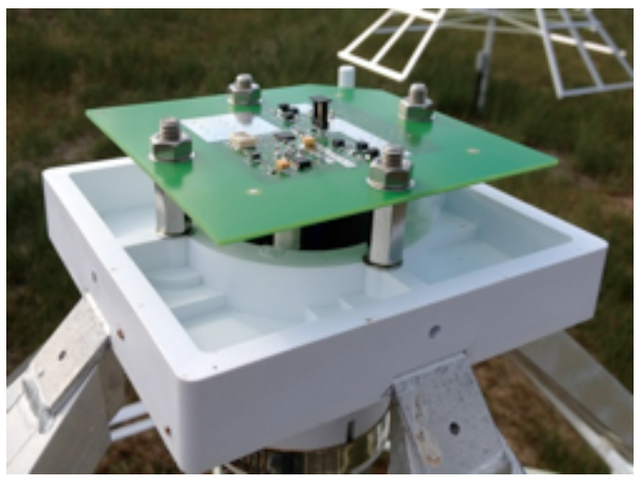
⇒ A_{eff} = 70-80% x A_{eff} LOFAR LBA = 190% x A_{eff} Coeur LOFAR LBA

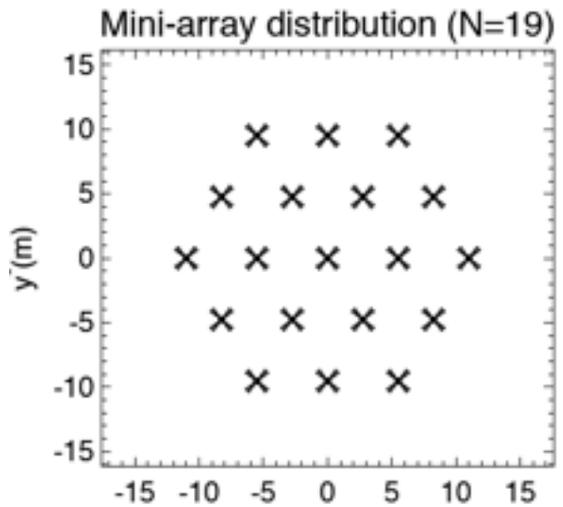
(mode faisceau cohérent > 2x+ efficace que LOFAR)

Accès aux TBF (15-80 MHz)

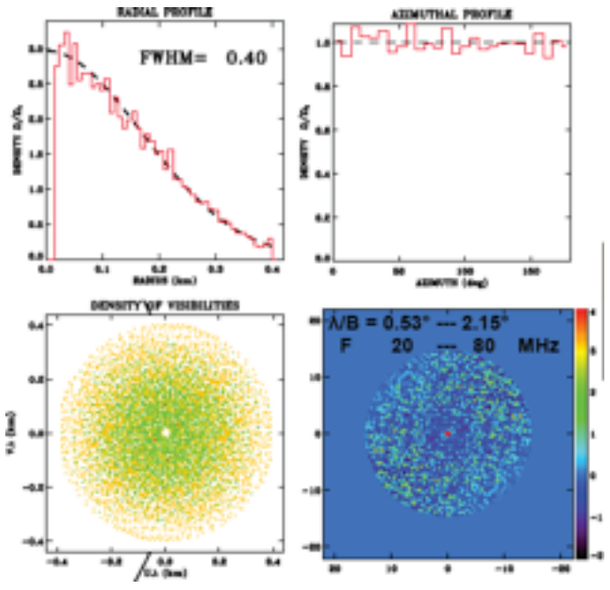
Design + Prototype de la LSS/NenuFAR

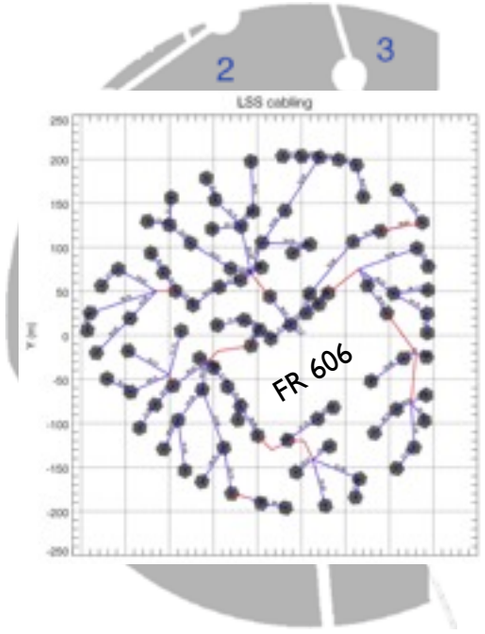
programme ANR 9/2009 - 2/2013 - 500 k€
http://www.obs-nancay.fr/lss/

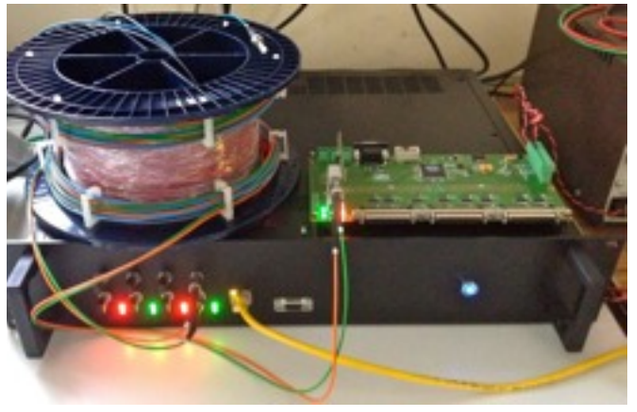




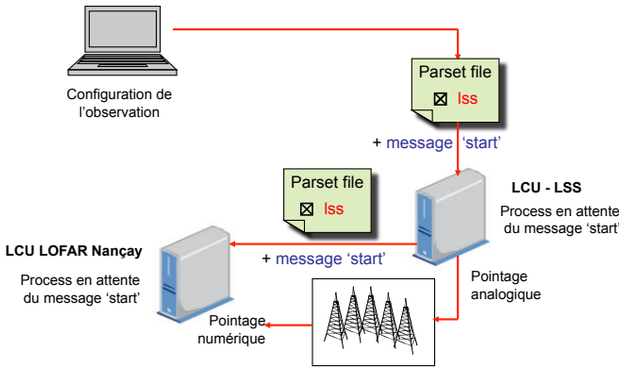
- Etude de tous les aspects du projet : antenne, préampli, distribution mini-réseau & globale, phasage, câblage/tranchées, contrôle/commande silencieux, dialogue/LOFAR





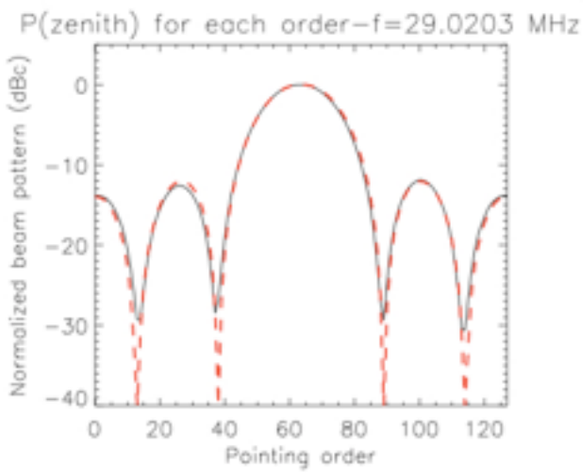


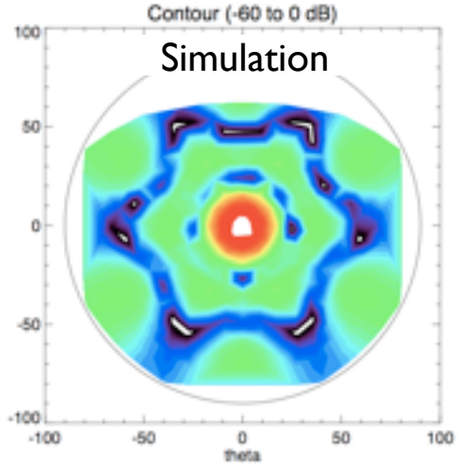
Mode standalone

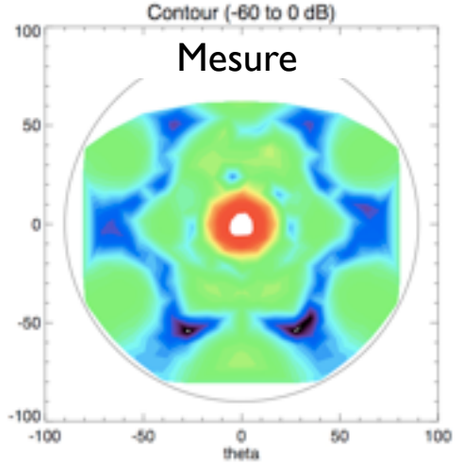


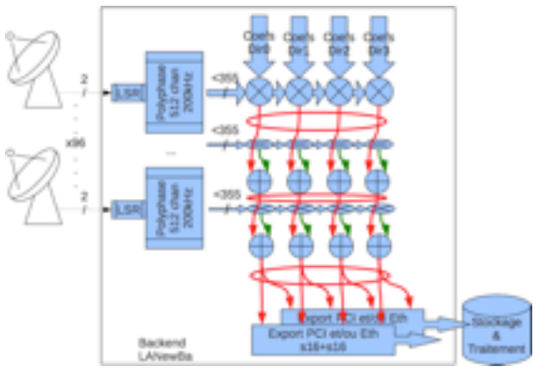
Design + Prototype de la LSS/NenuFAR

programme ANR 9/2009 - 2/2013 - 500 k€
http://www.obs-nancay.fr/lss/









- Construction de 3 mini-réseaux (x 2 polarisations) + récepteur de test dédié
- Définition d'un récepteur autonome dédié (Nançay/ALSE)
  ⇒ "duty-cycle" ~100% dans le faisceau analogique mini-réseau (~30° @ 30 MHz)
- Études industrialisation, site (ONF), chiffrage, sous-traitance, calendrier

LSS/NenuFAR dans le contexte national & international

Equipe LSS-France : ~ 25 chercheurs + 15-20 ITA

Laboratoires impliqués dans la réalisation : Nançay, LESIA, GEPI, LERMA, LPC2E, Prisme, Subatech, IRA Kharkov, SRI Graz (soutien OP, ESEP) ⇒ Axe Paris(Meudon)-Orléans-Nançay, en vue de SKA

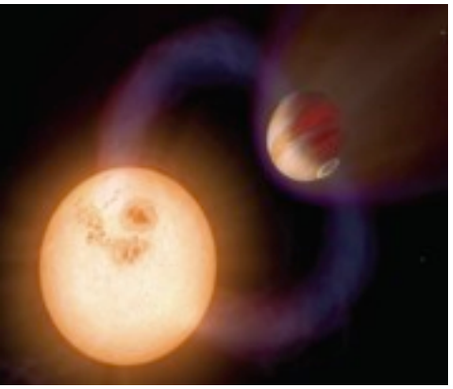
(LSS = précurseur scientifique et technique de SKA)

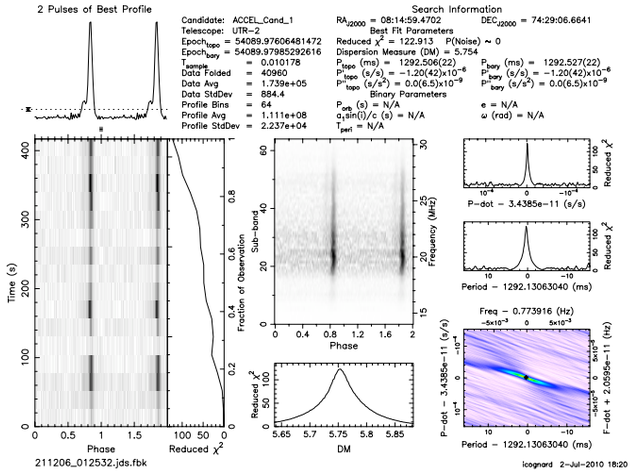
Laboratoires utilisateurs : OP (LESIA, GEPI, LERMA, LUTh), CEA/Sap-DASE-AIM, IAS, IAP, E. Polytechnique, ENS/LRA, APC, IN2P3, LPC2E, Nançay, OCA, IRAP ...

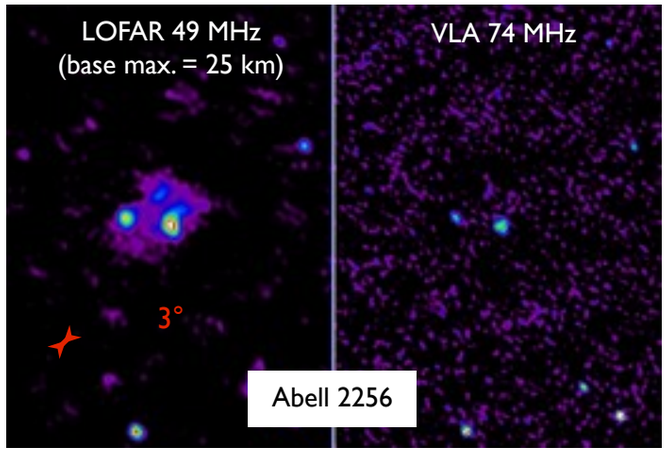
UTR-2	2040 dipoles	143000 m^2	8-32 MHz	0.5°	5 faisceaux	1 polar. lin.
VLA	27 paraboles x 25 m	~2000 m^2	73-74.5 MHz	0.5'	1 faisceau	4 Stokes
LWA	256 Xdipoles	8000 m^2 @ 20 MHz	10-88 MHz	9° 20 MHz	4 faisceaux x 20 MHz	4 Stokes
LOFAR (LBA)	2688 Xdipoles	72000 m^2 @ 30 MHz	30-80 MHz	2" @ 30 MHz	8+ faisceaux x 4- MHz	4 Stokes
LSS autonome	1824 Xdipoles	62000 m^2 @ 30 MHz	15-80 MHz	3° @ 30 MHz	4 faisceaux x 65 MHz	4 Stokes
LSS+LOFAR	4512 Xdipoles	134000 m^2 @ 30 MHz	30-80 MHz	2" @ 30 MHz	8+ faisceaux x 4- MHz	4 Stokes
SKA	??	1 000 000 m^2	100+ MHz	0.2" @ 100 MHz	nombreux faisceaux	4 Stokes

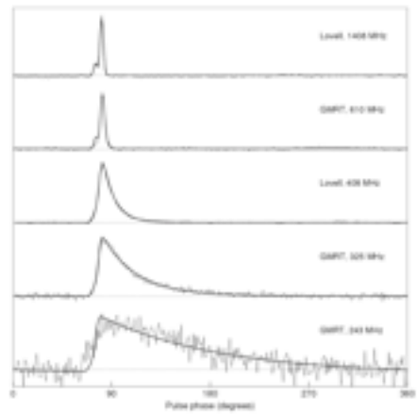
- EoR
- LOFAR
- Imaging
- Results
- Foregrounds
- Operations
- LSS/NenuFAR
- LSS /NenuFAR science

Les apports scientifiques de la LSS/NenuFAR



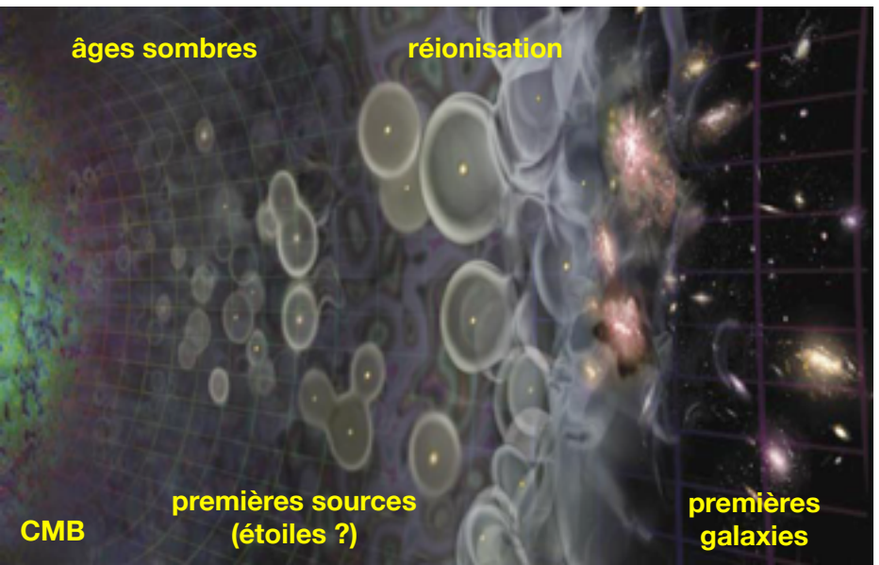






- Étoiles Binaires/Éruptives & Exoplanètes
- Pulsars & Rotating radio transients (RRATs)
- Structure du Milieu InterStellaire Galactique
- Cosmologie et Formation des galaxies
- L'Univers impulsionnel
- Les flashes lumineux dans les atmosphères Terrestre et planétaires

⇒ LSS autonome, LSS+LOFAR, LSS//LOFAR



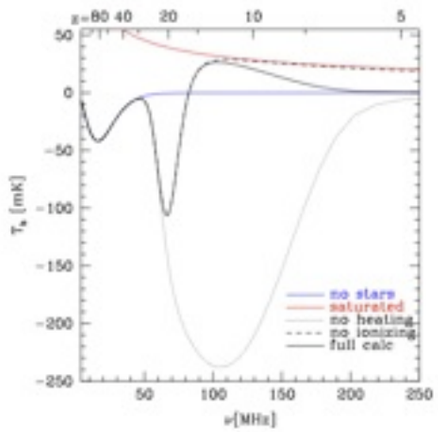
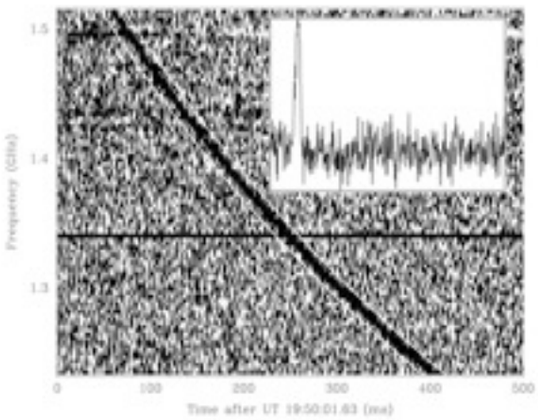
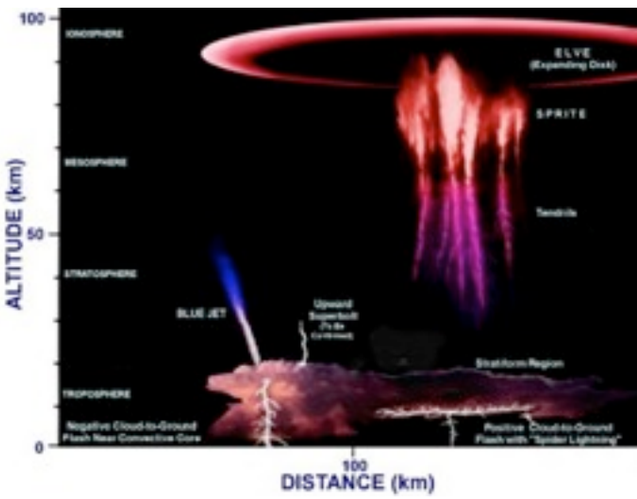
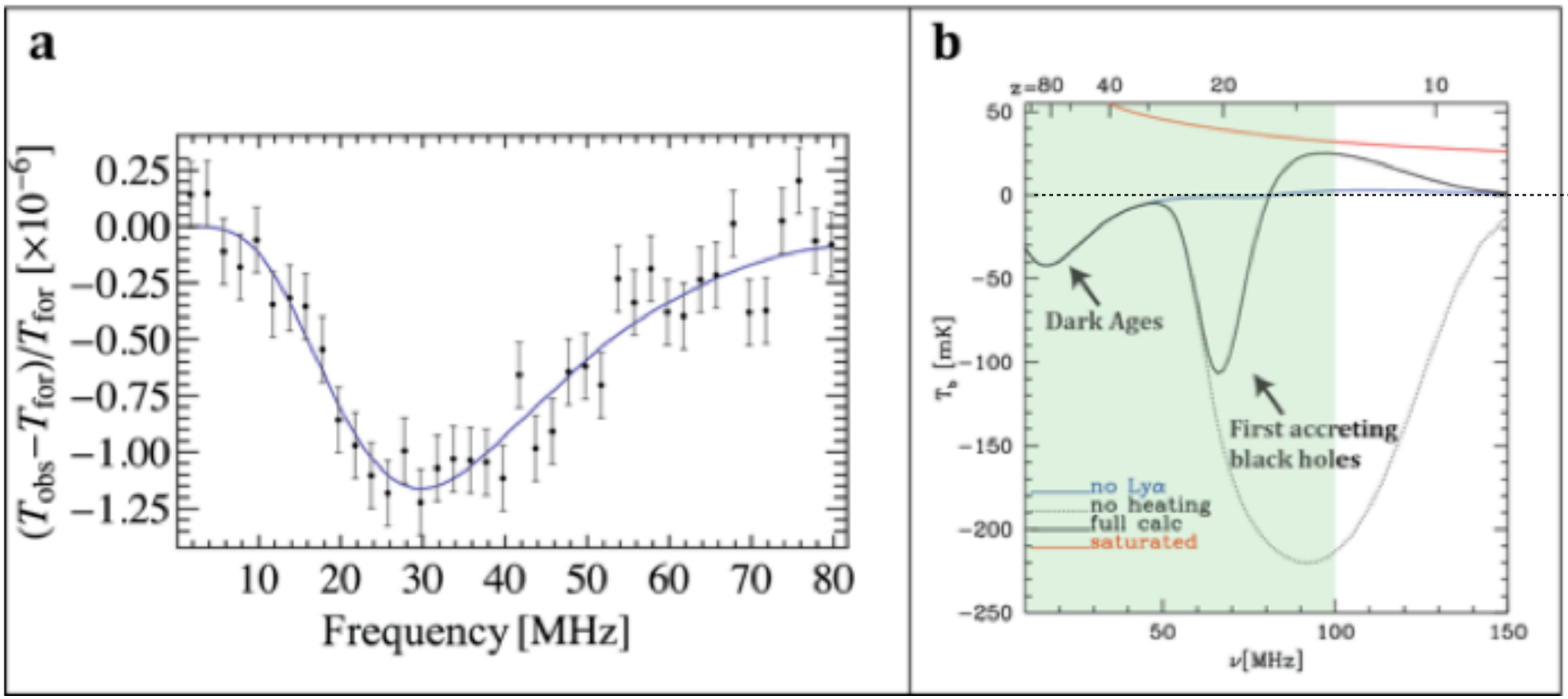


FIG. 1 (color online). Evolution of the 21 cm global signal for different scenarios. *Solid blue curve:* no stars; *solid red curve:* $T_S \gg T_\gamma$ and $x_H = 1$; *black dotted curve:* no heating; *black dashed curve:* no ionization; *black solid curve:* full calculation.





LSS/NenuFAR & Late Dark Ages



emission/CMB

absorption/CMB

Pritchard & Loeb, 2008, 2010

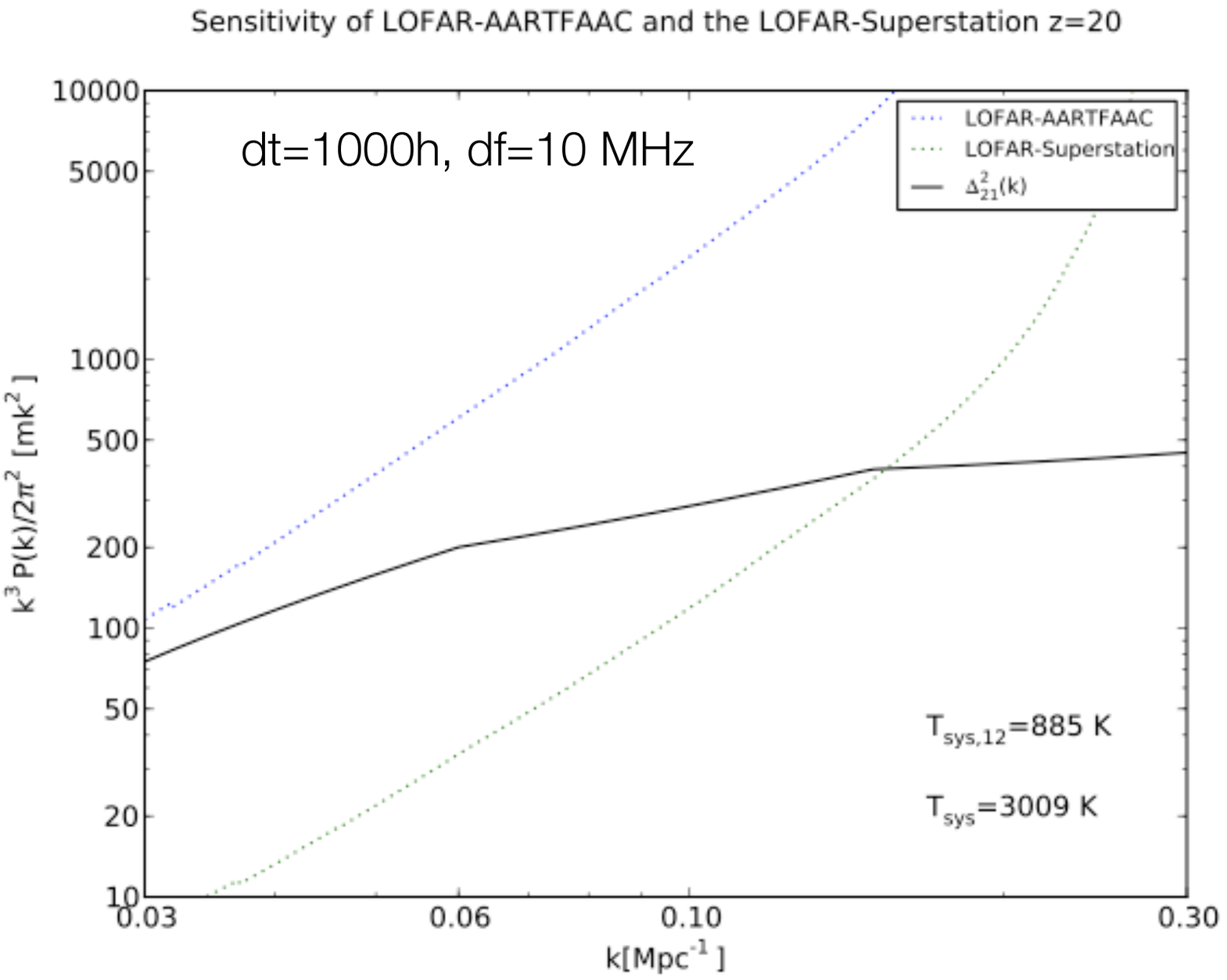
- Total (all-sky) intensity H_I for $z \geq 12$-20 (Late Dark Ages) : δT_b up to (-)100 mJy in LBA range

  ⇒ detectable in hours with a phased array (station)

- But requires accurate bandpass calibration (at 10^{-6} level), via measurement of auto- & cross-correlations on noise source (laboratory or A team)

⇒ **LSS Standalone !**

LSS/NenuFAR & Late Dark Ages



Visbal et al., 2012
McQuinn et al., 2012

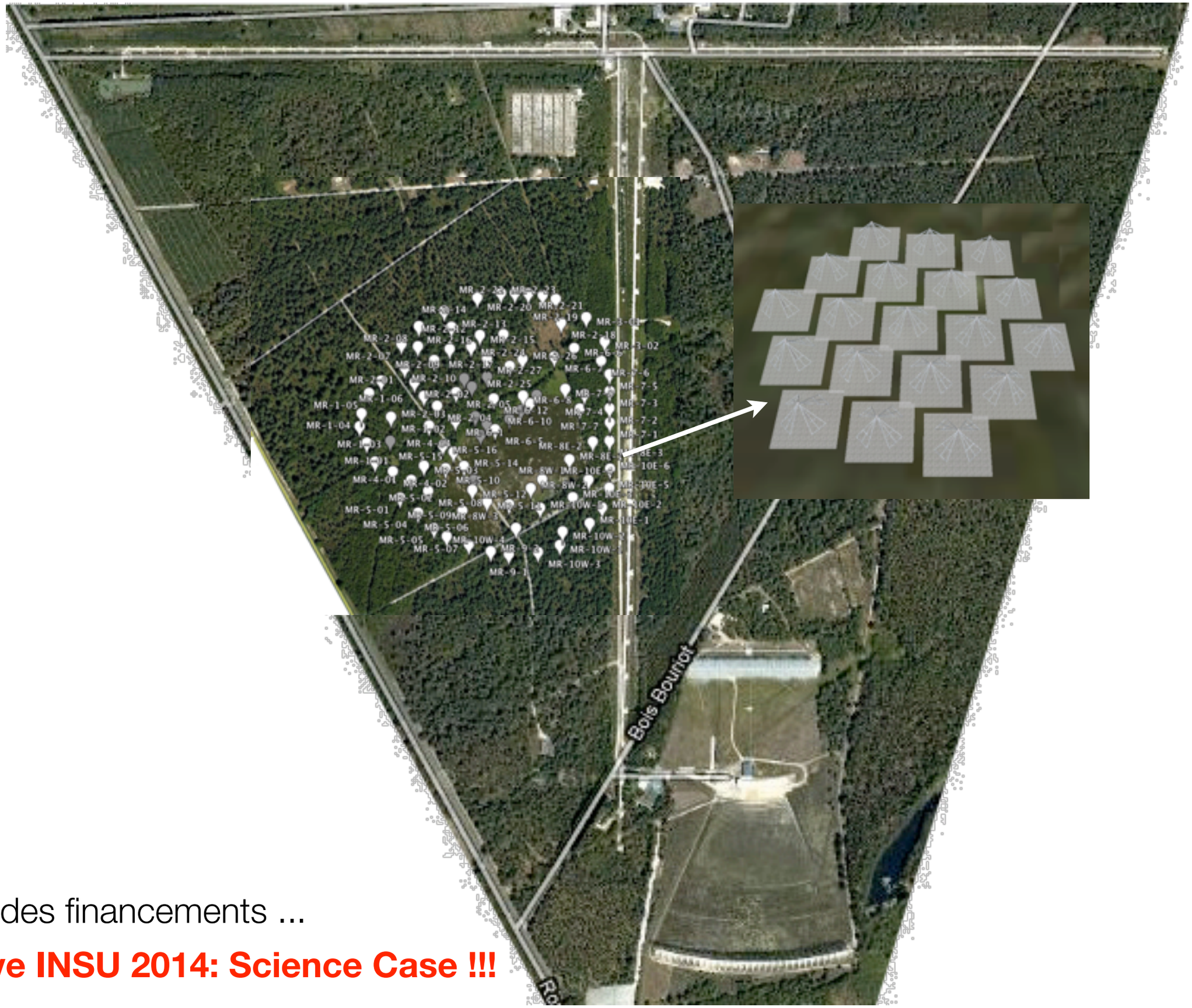
courtesy L. Koopmans

$$\Delta^2_{\rm Noise} = \left(\frac{2}{\pi}\right) k^{3/2} \left[D_c^2 \Delta D_c \times \Omega_{\rm FoV}\right]^{1/2} \left(\frac{T_{\rm sys}}{\sqrt{B t_{\rm int}}}\right)^2 \left(\frac{A_{\rm core} A_{\rm eff}}{A^2_{\rm coll}}\right)$$

- Spatial fluctuations of H_I at z~20 possibly larger than previously thought

  ⇒ **Possibly detectable with LSS due to large collecting area**

Demain la LSS/NenuFAR ?

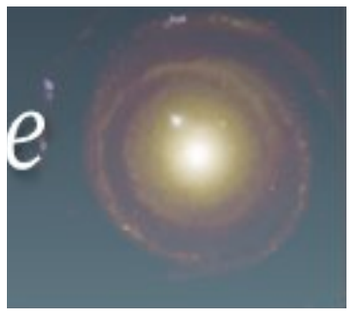


Recherche des financements ...

Prospective INSU 2014: Science Case !!!

LOFAR - LSS/NenuFAR in France

FLOW : Tagger, Zarka, Theureau et al.

Action Spécifique SKA-LOFAR : Corbel, Charlot, Zarka et al.

	Mardi 4 Juin
14h00-14h30	Mickael Wise (Invité): LOFAR's First Year of Operations: A Gallery of First Science
14h30-14h50	Jean-Mathias Griessmeier: Low frequency pulsar observations with LOFAR
14h50-15h10	Philippe Zarka: LOFAR imaging issues and first extragalactic observations
15h10-15h30	Giulia Macario: The LOFAR's view of galaxy clusters
15h30-15h50	Julien Girard: Jupiter's synchrotron emission: a practical example of science and data reduction with LOFAR
15h50-16h00	Jean-Mathias Griessmeier:Observing with LOFAR in local and in international mode
16h-16h30	***Pause café***
16h30-17h00	Thijs van Der Hulst (Invité): Probing cosmology and galaxy evolution with HI using SKA and SKA Pathfinders
17h00-17h20	Steve Torchinsky: Results from EMBRACE@Nancay
17h20-17h40	Dominique Aubert: Simulation of the BAO 21 cm signal during the epoch of reionization
17h40-18h00	Yannick Libert: High-resolution imaging of circumstellar environments around AGB stars at 21 cm
18h00-18h15	Mamta Pommier: Low Frequency Radio observations in galaxy clusters