Recherche de transitoires radio associés à des ondes gravitationnelles avec LOFAR

Search of radio transient counterparts for gravitational waves with LOFAR

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LESIA

IVème Ecole de Physique des Astroparticules "Ondes gravitationnelles et Multi-Messagers", OHP, 2013

- RADIO COUNTERPARTS TO GW EVENTS
- RADIO PROPAGATION
- TRANSIENT RADIO SKY
- LOFAR TELESCOPE & OPERATING MODES
- LOFAR EARLY RESULTS
- TRANSIENT SURVEYS & SEARCH STRATEGY
- ALERTS MANAGEMENT
- ORGANISATION
- SOME CONCLUSIONS
- REFERENCES

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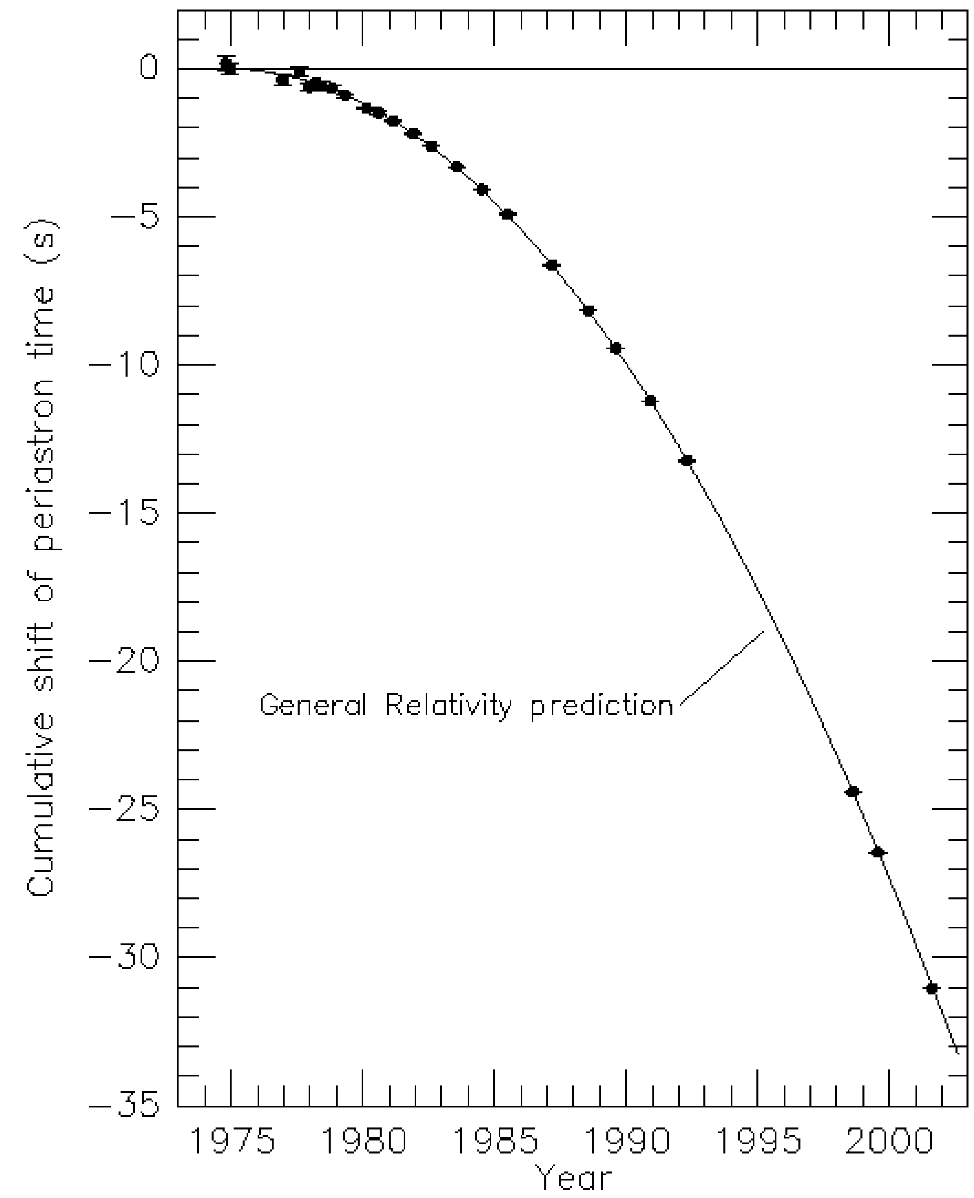
RADIO COUNTERPARTS TO GW EVENTS

- Binary Pulsar → Taylor & Hulse, Nobel Prize 1993



- GW searches via known pulsars timing (upper limit on Crab, correlated to glitches ?) [Predoi, 2010]

- **Two classes of radio transients possibly associated to GW**

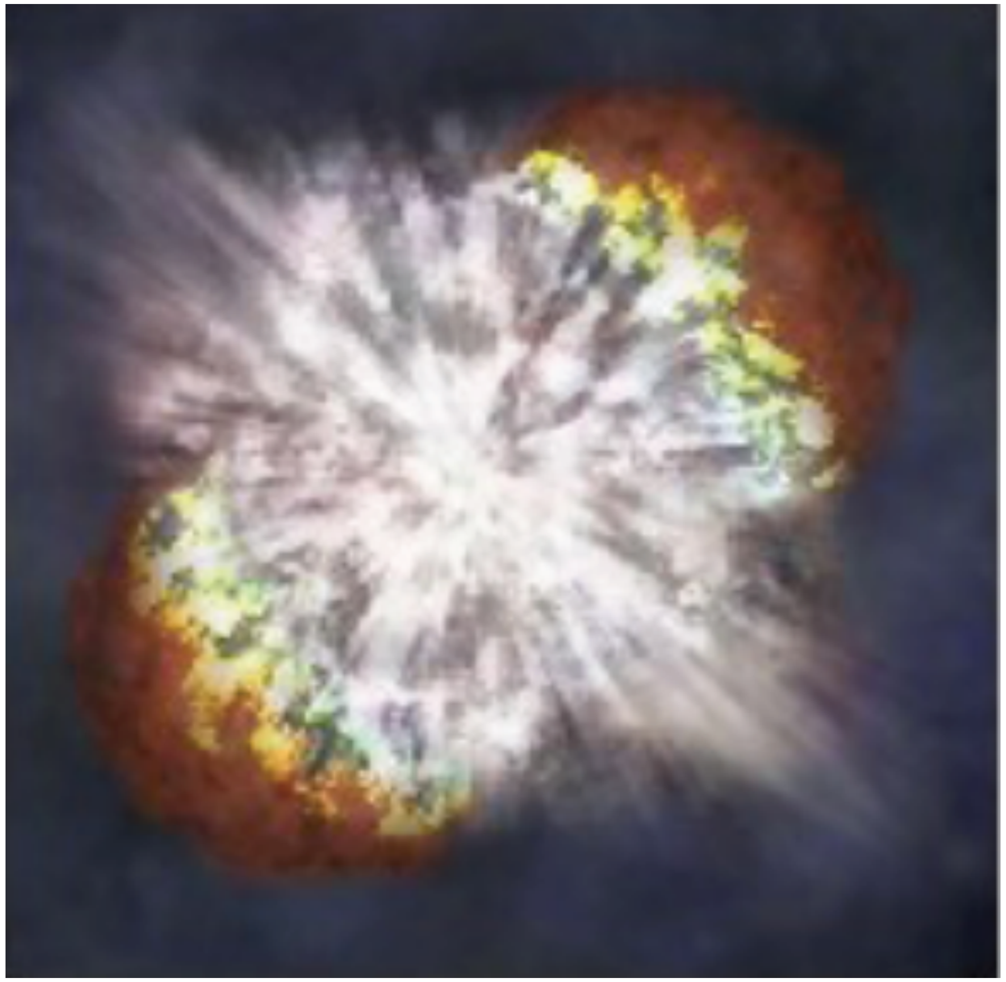
RADIO COUNTERPARTS TO GW EVENTS

- **Incoherent** (robust) [Van Eerten et al., 2010; Nakar et al., 2011; Frail, 2011; Frail et al., 2012]

    - Synchrotron emission produced by all explosive phenomena, that accelerate particles (e^-, e^+) and «amplify» B field :

      Relativistic jets from X binaries (microquasars) & from AGN, SN, magnetars giant bursts …

      Galactic binary sources/mergers (NS, BH), SHB/GRB afterglow



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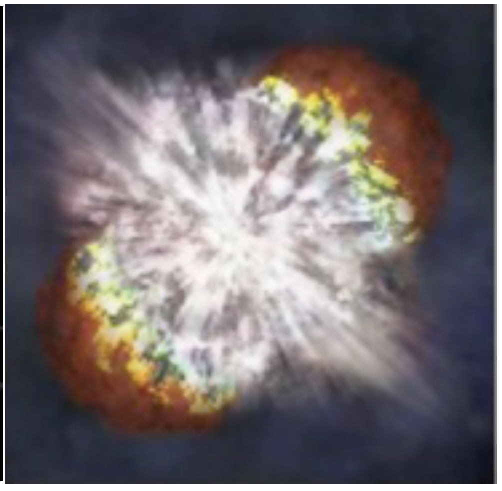
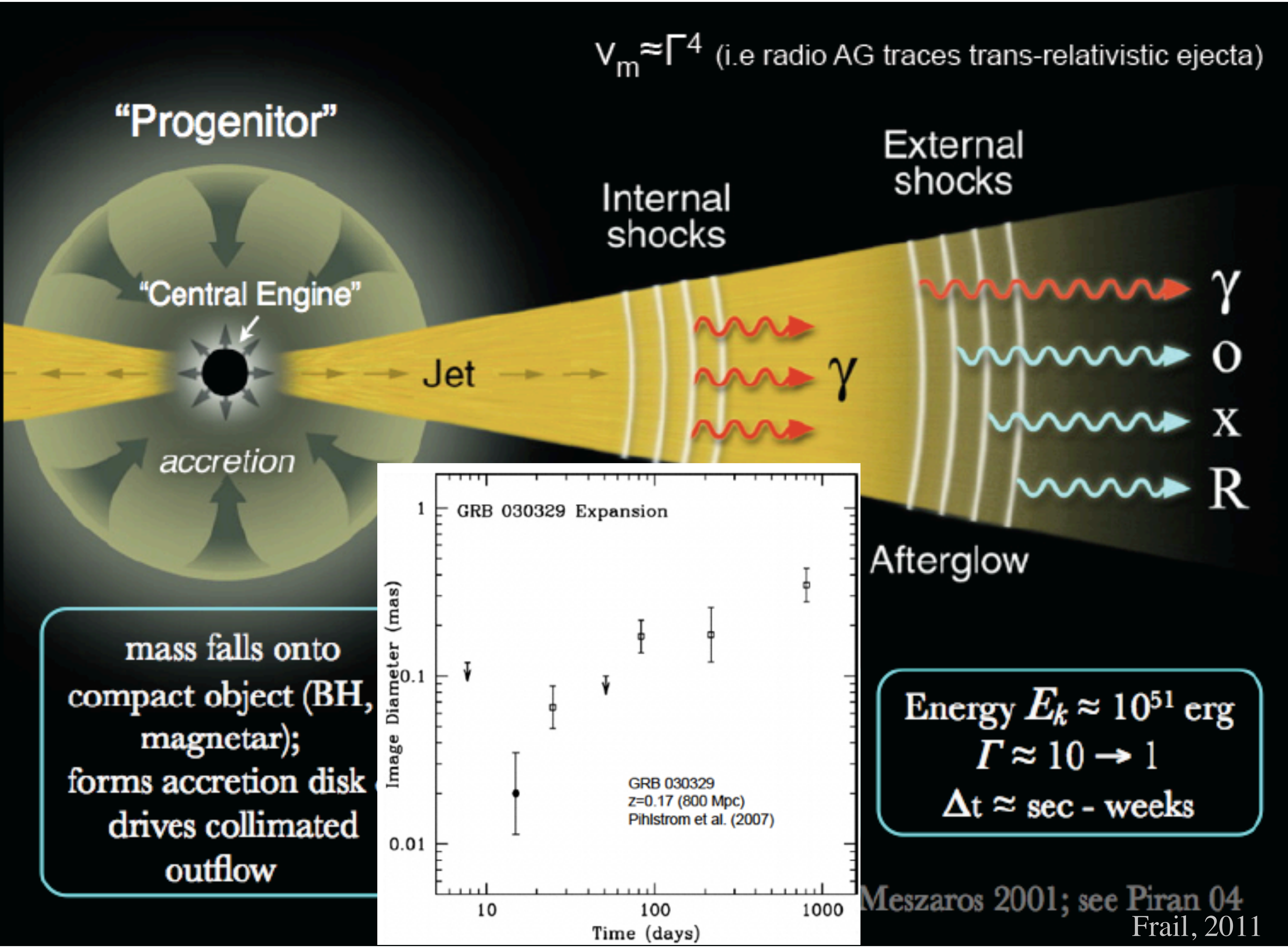
  - $\nu \propto \Gamma^4$, radio emitted farther from central object → Γ~1-10 (moderately relativistic particles)



$\nu_m \approx \Gamma^4$ (i.e radio AG traces trans-relativistic ejecta)
"Progenitor"
"Central Engine"
accretion
Jet
Internal shocks
External shocks
γ
γ
o
x
R
Afterglow
mass falls onto compact object (BH, magnetar); forms accretion disk drives collimated outflow
GRB 030329 Expansion
Image Diameter (mas)
1
0.1
0.01
10
100
1000
Time (days)
GRB 030329
z=0.17 (800 Mpc)
Pihlstrom et al. (2007)
Energy $E_k \approx 10^{51}$ erg
$\Gamma \approx 10 \rightarrow 1$
$\Delta t \approx$ sec - weeks
Meszaros 2001; see Piran 04
Frail, 2011

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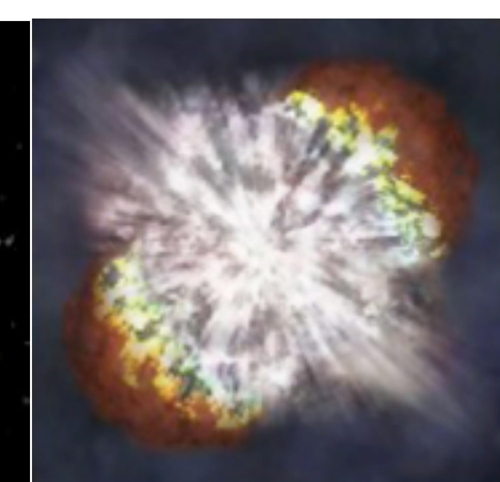
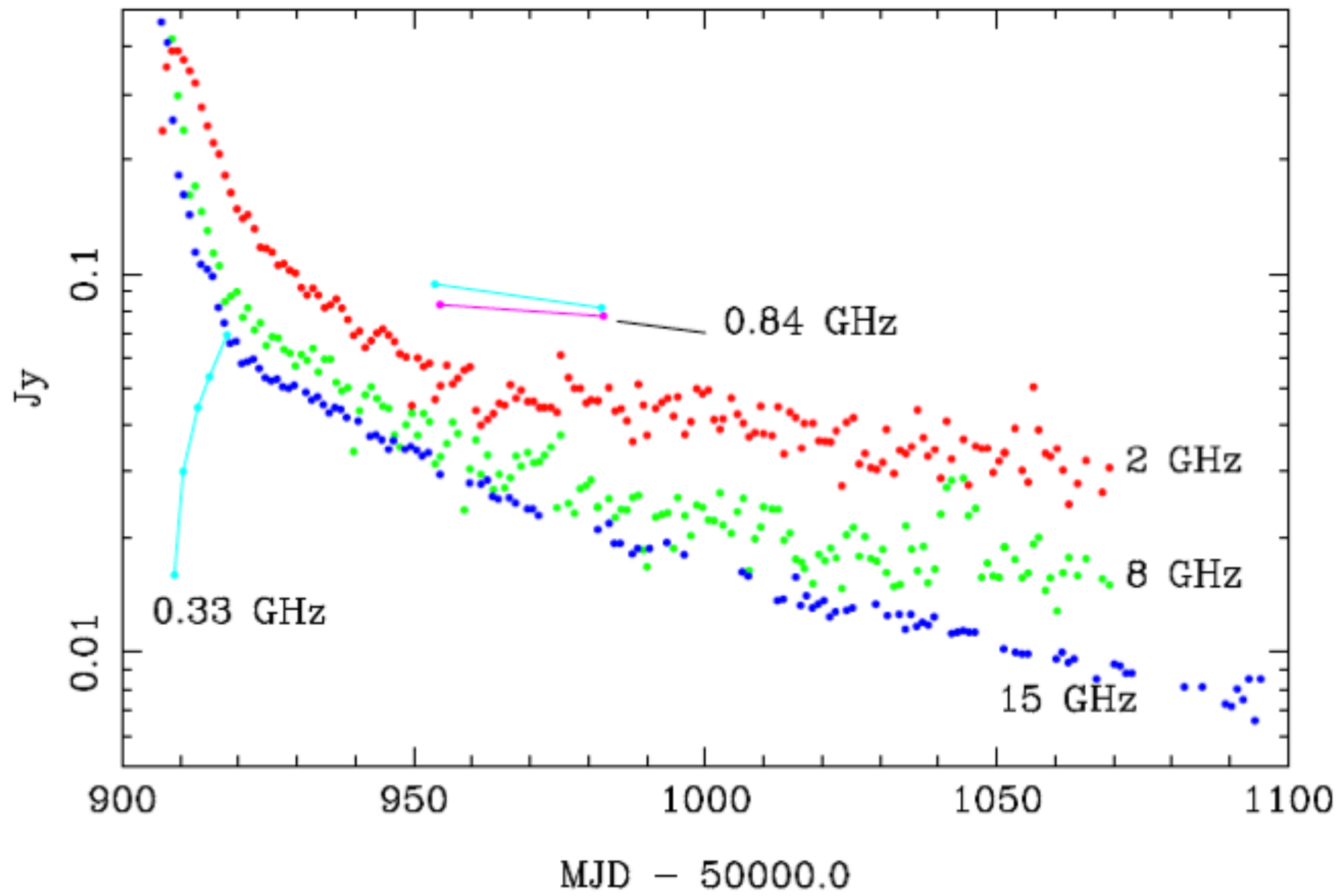
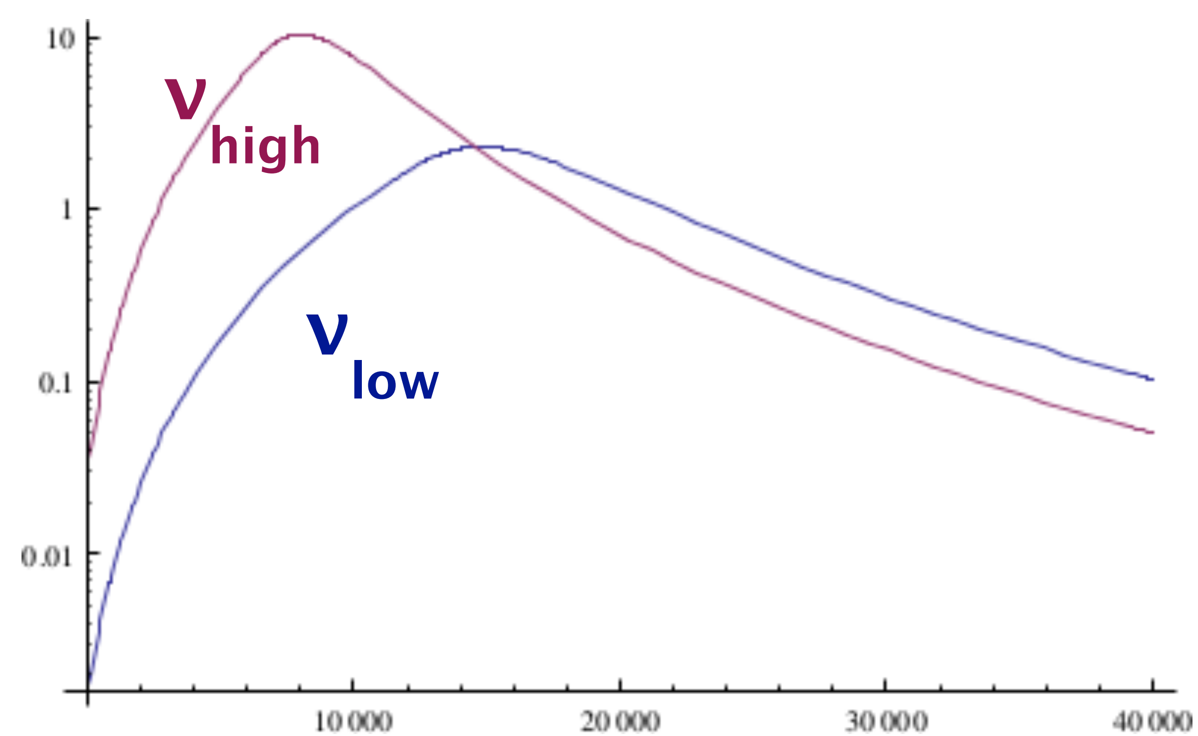
  - $\nu \propto \Gamma^4$, radio emitted farther from central object → $\Gamma \sim 1\text{-}10$ (moderately relativistic particles)
  - Slow variability : observations of weak radio signals hours or days (up to months) after the GRB



Binary transient outburst



Lower frequencies peak later and lower

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  - $\nu \propto \Gamma^4$, radio emitted farther from central object → Γ~1-10 (moderately relativistic particles)
  - Slow variability : observations of weak radio signals hours or days (up to months) after the GRB
  - Expected brightness/Flux density : T_B up to 10^{12} K

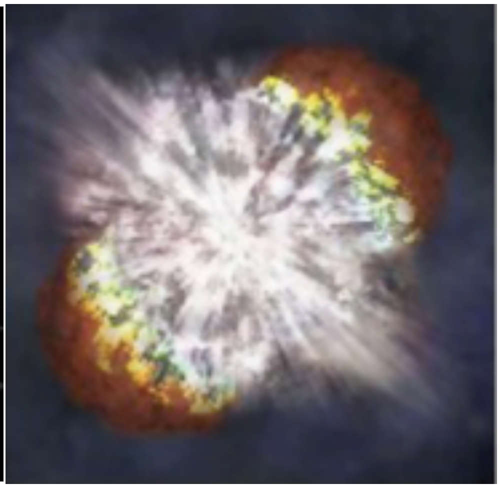
  Predictions for "Early radio emission" (hours to weeks) :

  10's mJy at 1-10 GHz for d=200 Mpc ; beamed on axis

  Predictions for "Late radio emission" (~months) : outflow expands and becomes non-relativistic :

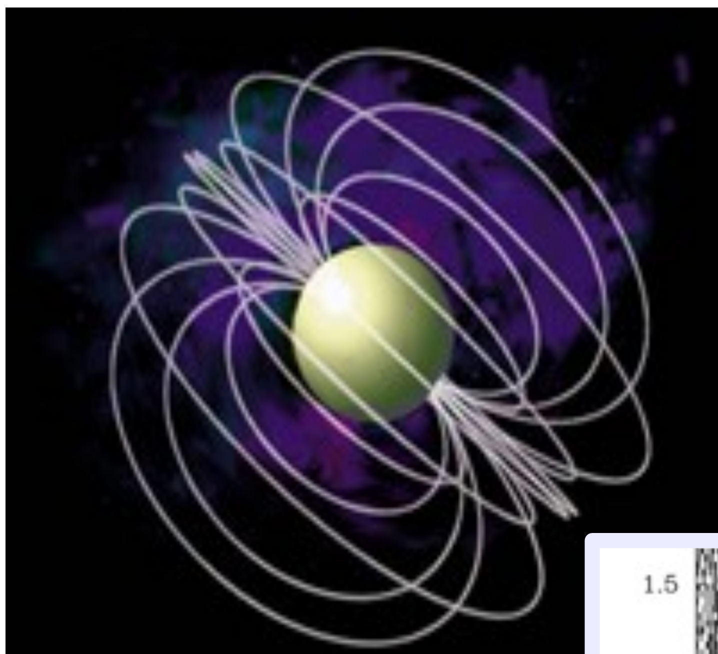
  @ t=30 days, <1 mJy at 1 GHz at 300 Mpc ; ~ isotropic

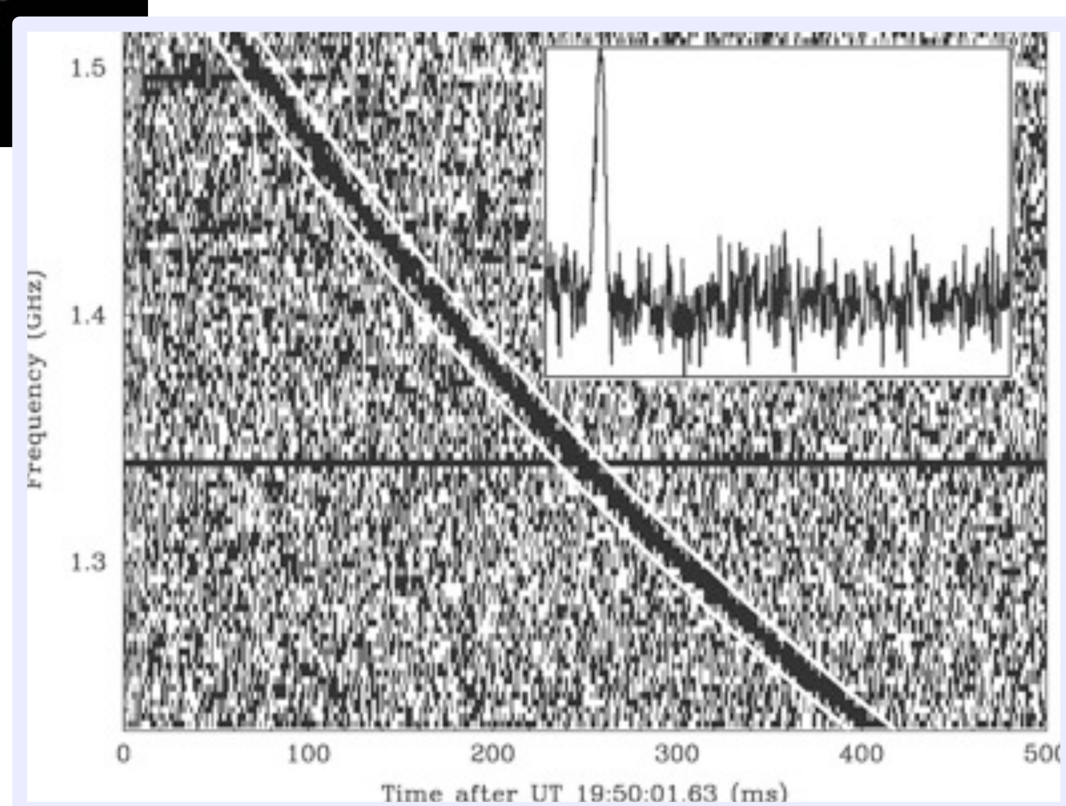
➢ Detection via Imaging



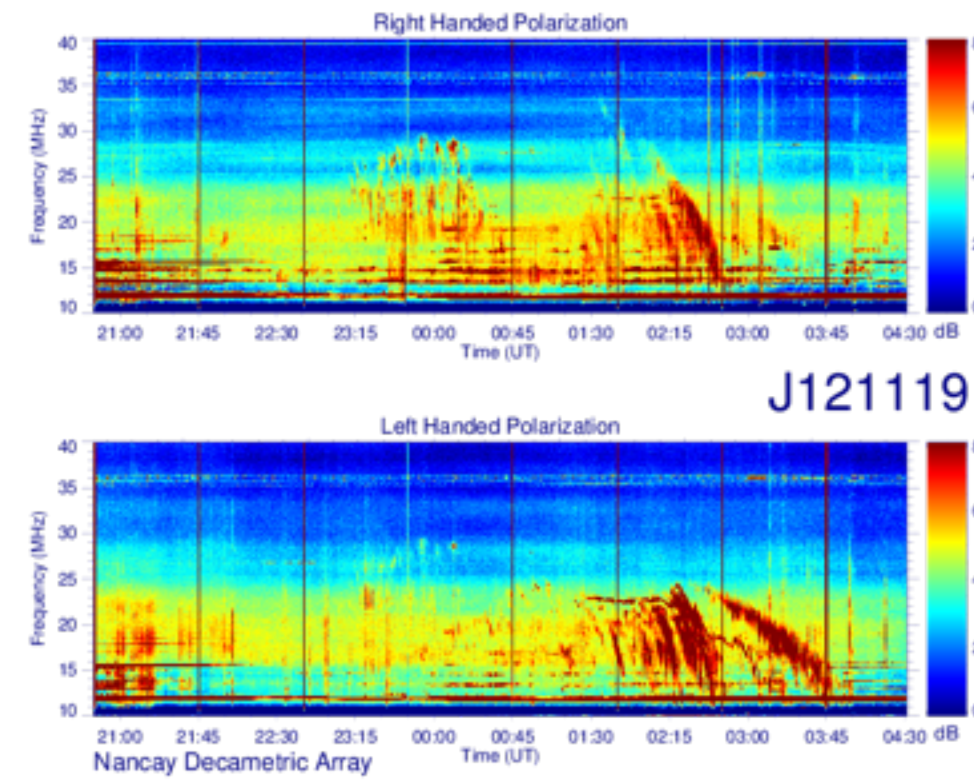
RADIO COUNTERPARTS TO GW EVENTS

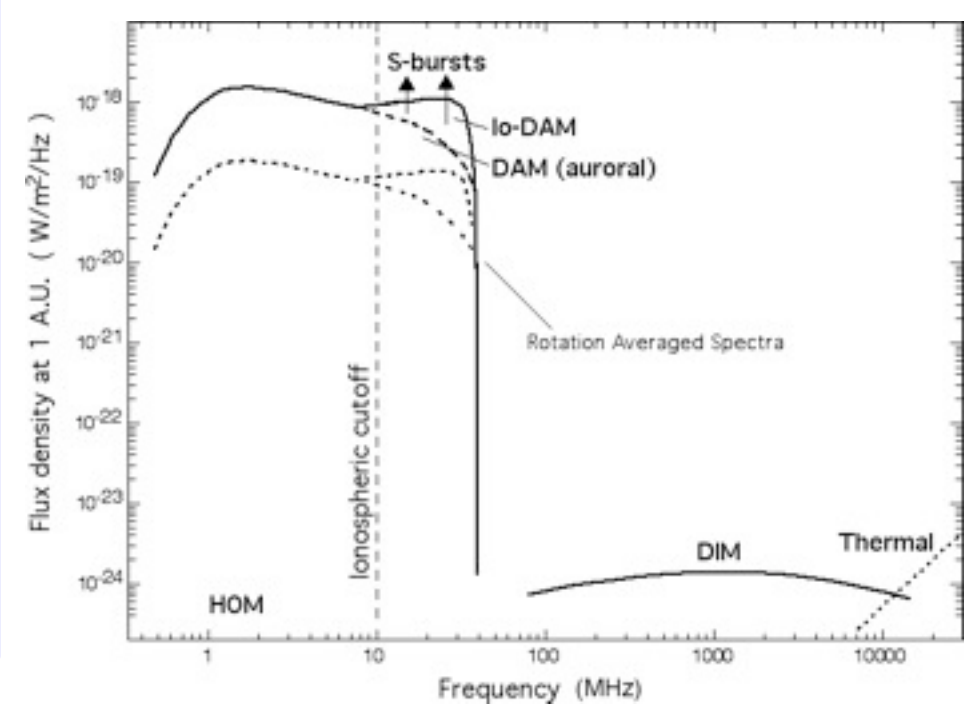
- **Coherent** (uncertain)
  - ○ Cyclotron-Maser ? Plasma? Curvature radiation ? … due to accelerated elecron bunches / unstable populations in strong B field
    - Pulsars, RRATs, Lorimer, Flare stars, (exo)planets …





Lorimer et al., 2007





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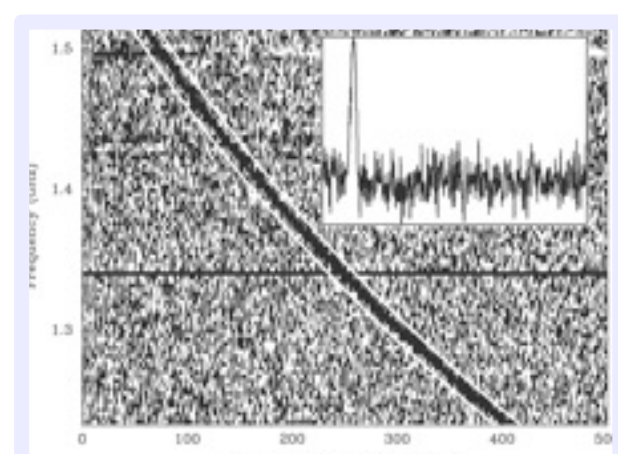
      before merging: interaction of conductive NS body with B-field ~10^{2-15} G → strong PSR-magnetosphere-like emission ($S \propto B^{2/3}\, a^{-5/2}$) [Hansen & Lyutikov, 2000]

      → Predictions of 1 mJy at 400 MHz for d=200 Mpc

      after merging: excitation of MHD modes by strong GW → conversion to radio ? [Moortgat & Kuijpers, 2004 ; Postnov & Pshirkov, 2009]

      → Predictions from ~10 kJy at 100 MHz to 50 Mjy at 30 MHz (at 200 Mpc)

      (~10^{-6} of SHB/GRB energy in prompt radio signal)



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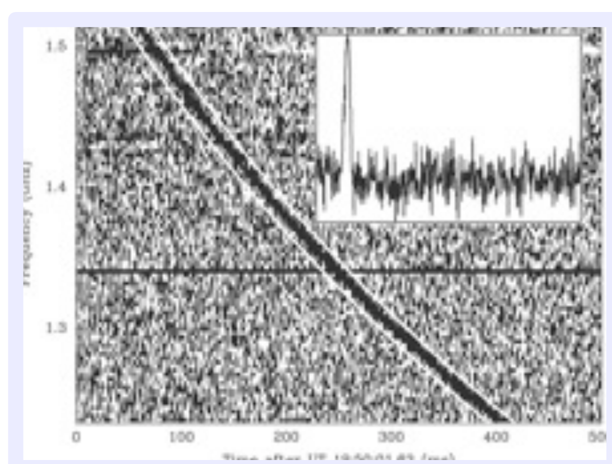
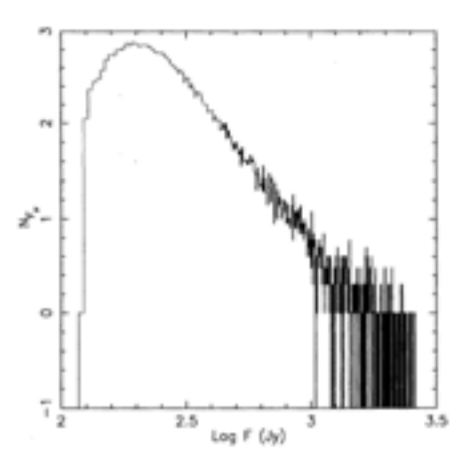
  - Fast variability: msec to sec (up to minutes)
  - Tb >> 10^{12} K (up to 10^{35} K ; >10^{30} K necessary for detecting a neutron star at 10 kpc, and pulsar giant pulses do exist!)

    often polarized, steep spectrum,

    less self-absorption by the source



Lorimer et al., 2007



Lundgren et al., 1995

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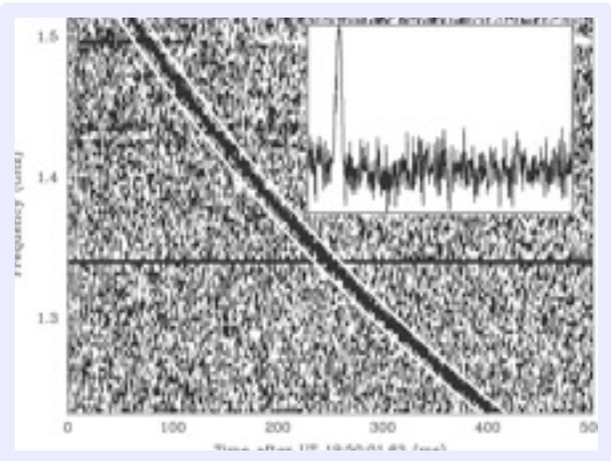
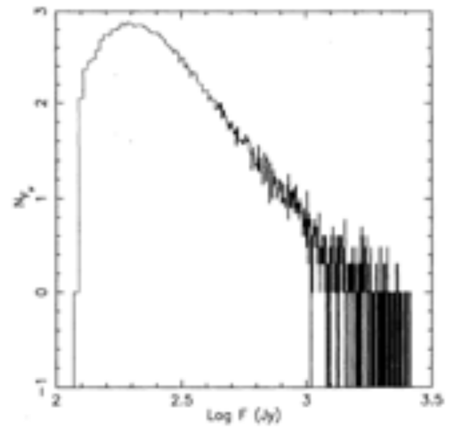
➢ Detection via Time series



Lorimer et al., 2007



Lundgren et al., 1995

RADIO COUNTERPARTS TO GW EVENTS

- Flux density :

$$S\ [\mathrm{Wm^{-2}Hz^{-1}}] = 2kT_b(\omega/\Omega)/A = 2kT_b\omega/\lambda^2$$
$$= (2kT_b/\lambda^2)\ (D^2/d^2)$$

$1\ \mathrm{Jy} = 10^{-26}\ \mathrm{Wm^{-2}Hz^{-1}}$

- Interest of radio signal :
  - little extinction
  - steep spectrum ?
  - accurate localization
  - emission produced later (in expanding region)

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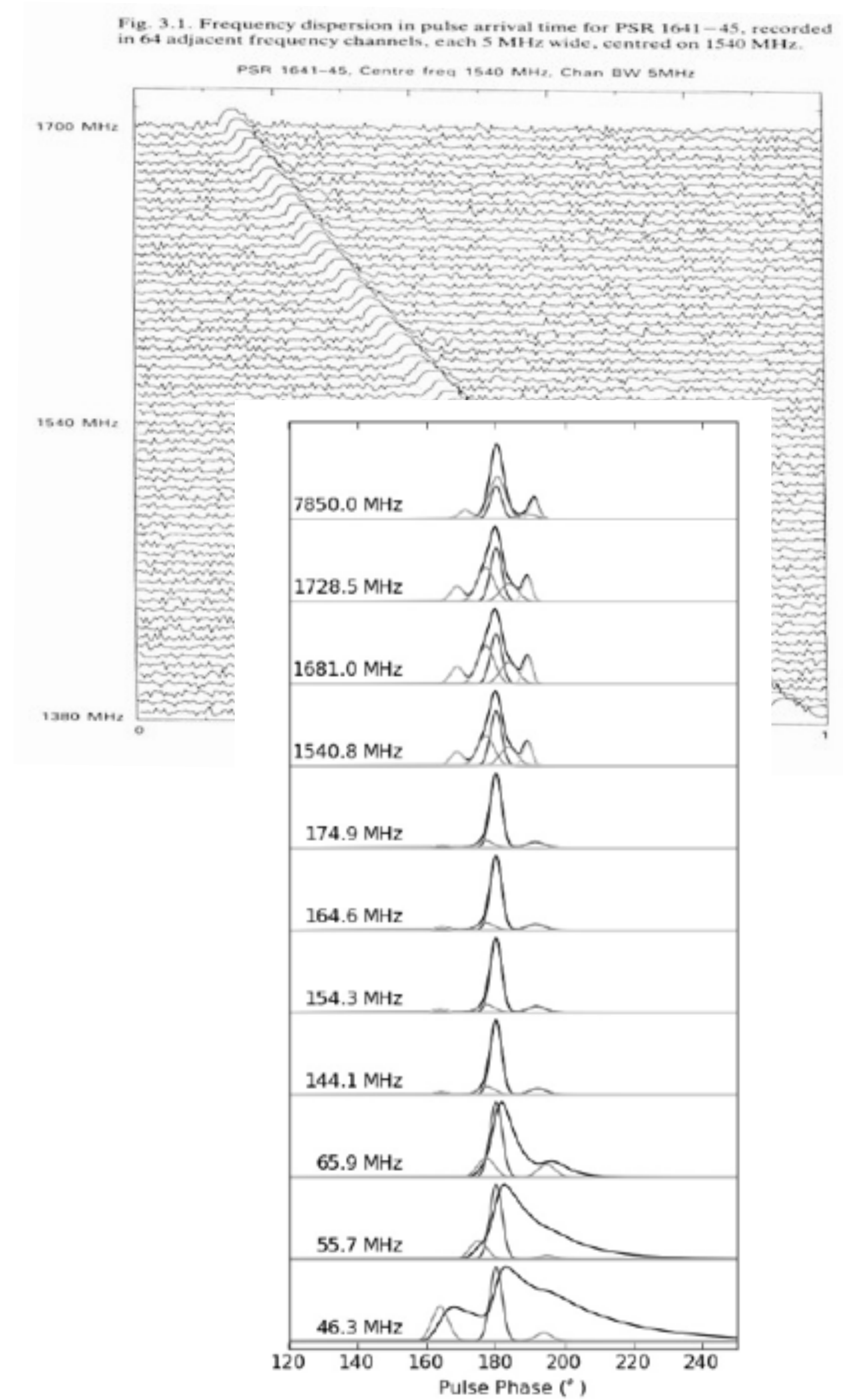
RADIO PROPAGATION

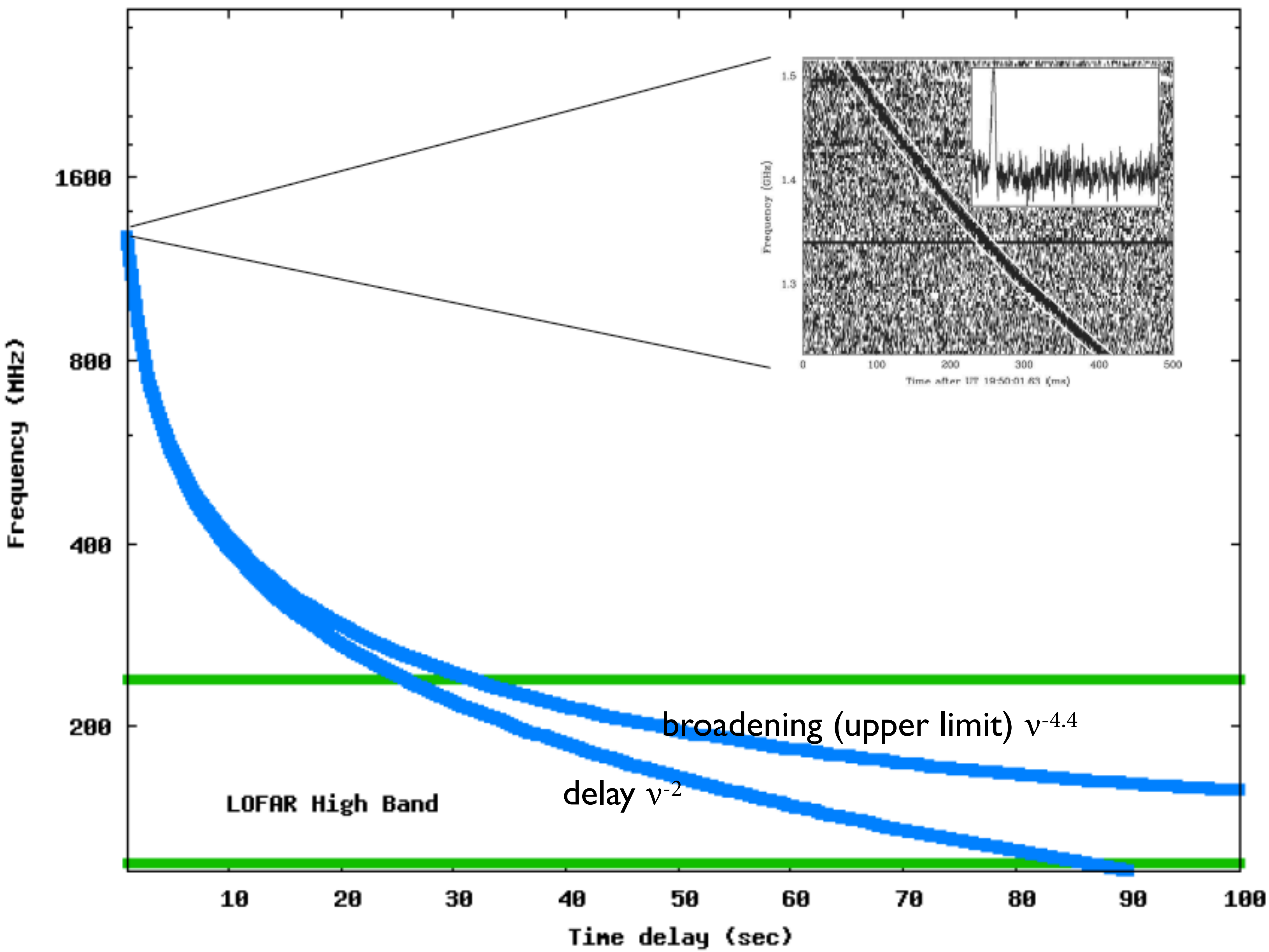
- Dispersion delay :
  $\Delta t \text{ (sec)} = 4.15\times10^3 \text{ DM} / f^2$
  $\text{DM} = \int N_e \, dl$ in pc.cm^{-3}



- Temporal broadening caused by scattering on free electrons :
  $\tau_b \propto \nu^{-4.4}$

(+ self-absorption in ionized material surrounding the source)

→ will affect prompt signal


1600
800
400
200
Frequency (MHz)
10
20
30
40
50
60
70
80
90
100
Time delay (sec)
LOFAR High Band
delay ν-2
broadening (upper limit) ν-4.4
1.5
1.4
1.3
Frequency (GHz)
0
100
200
300
400
500

RADIO PROPAGATION

- Sources of dispersive delay:
  - Our Galaxy (ISM) : 10 kpc × 0.03 cm^{-3} ~ 300 pc.cm^{-3}
  - IGM : low N_e, large distances → ~ 100 pc.cm^{-3}
  - Host galaxy and circumburst medium ~ ISM

    → expected total ~ 1000 pc.cm^{-3}

    (delays of 13 minutes at 75 MHz)

- Scattering effects (due to turbulence) more difficult to estimate :

  ~ 0.1 sec to 4 sec at 75 MHz

- Important question = time delay between gravitational wave and radio emission (unknown)

  → model + DM of propagation medium

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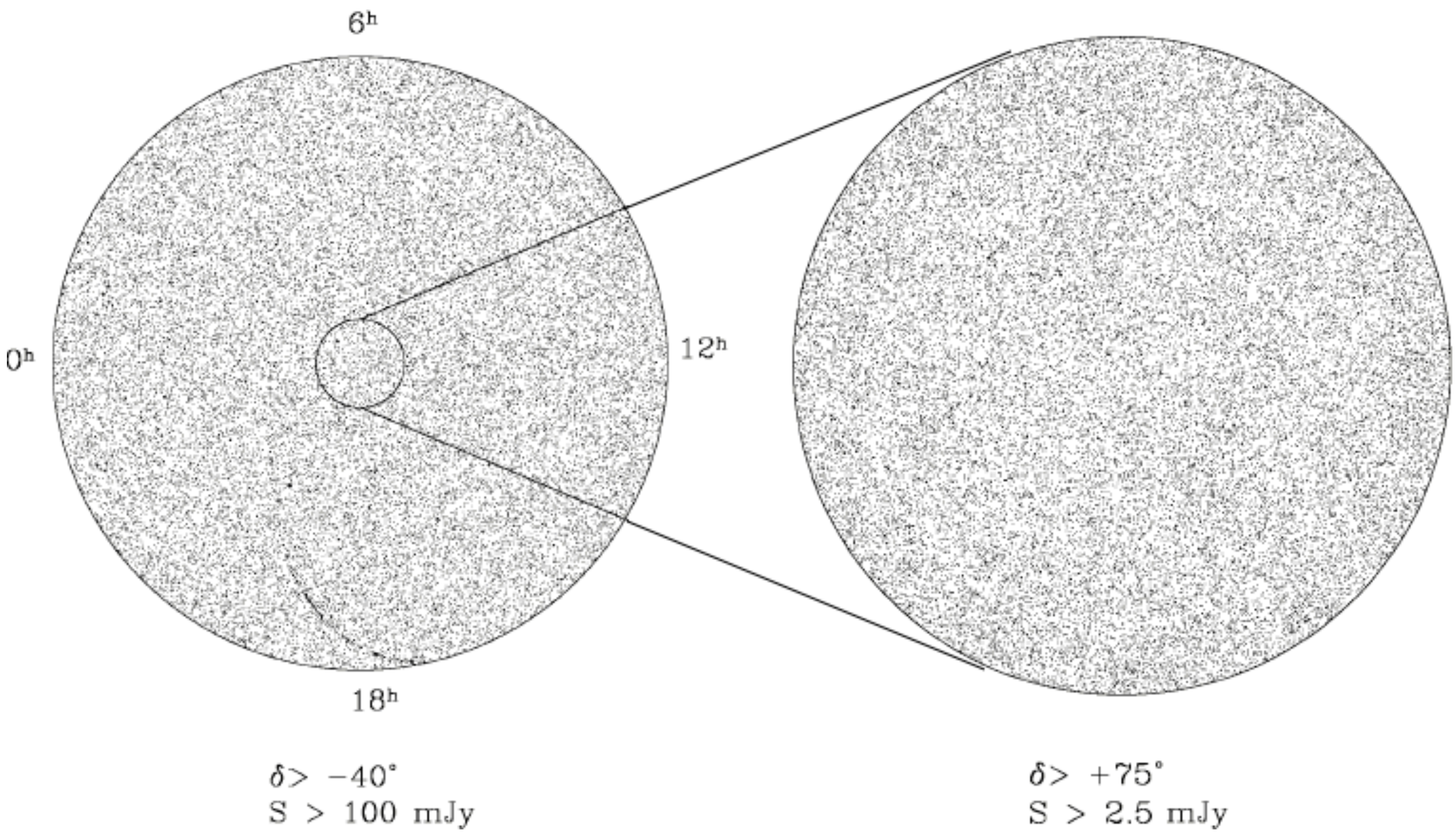
TRANSIENT RADIO SKY

Radio sources distribution ~isotropic on the sky

- ≥ 1 mJy AGN dominate source populations
- ≤ 1 mJy star-formation galaxies start to emerge



Condon, from Frail, 2011

TRANSIENT RADIO SKY

Transient Searches [Fender & Bell, 2011]

- Dedicated surveys (variable sources studies, sky drifts searching for transients …)
- Multi-wavelength triggered detections
- Searches in Archives
- Serendipitous discoveries & Commensal

TRANSIENT RADIO SKY

- Dedicated surveys (variable sources studies, sky drifts searching for transients …)

$\rightarrow$ not many radio transient found, mostly > GHz

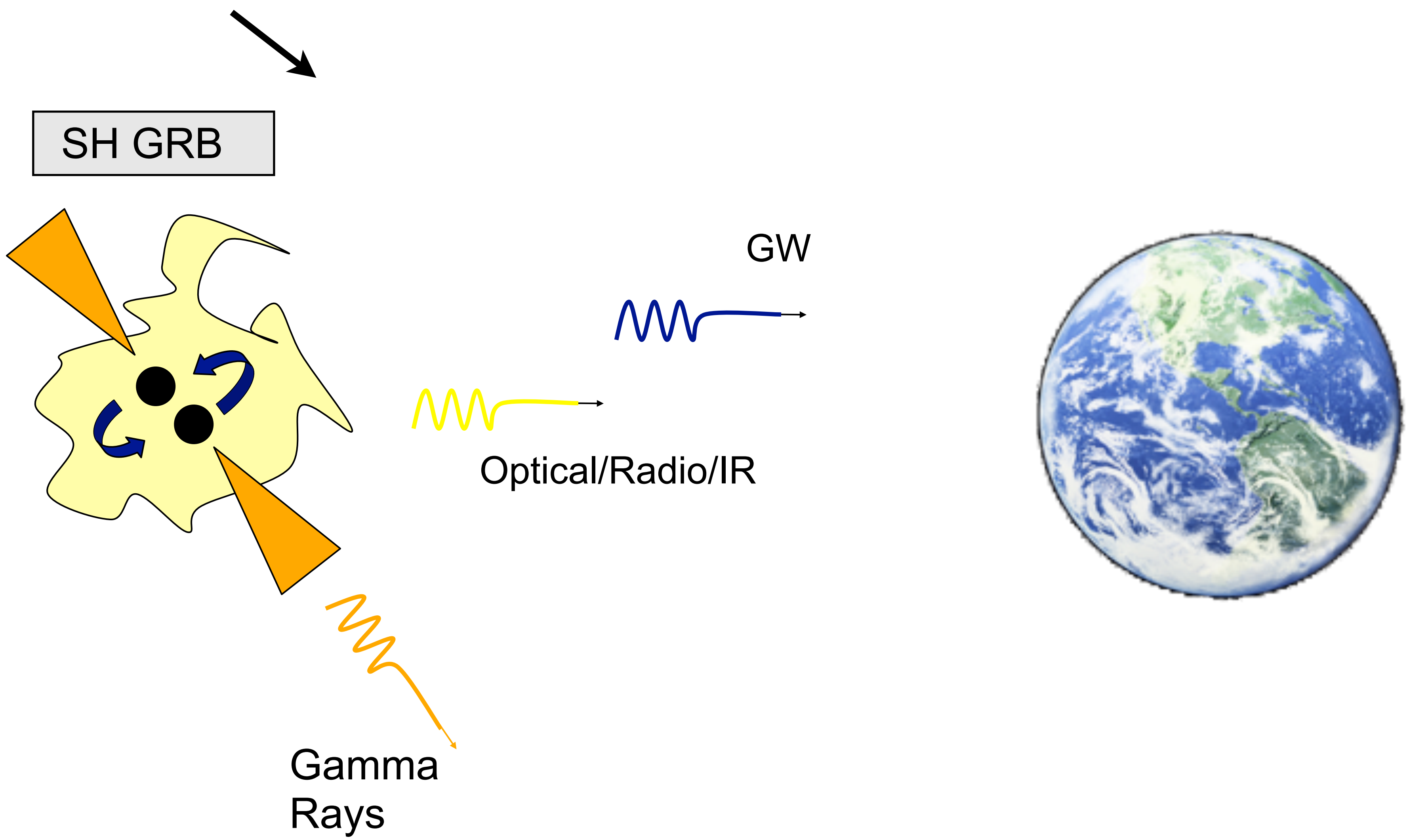
cf. refs in [Fender & Bell, 2011]

TRANSIENT RADIO SKY

- Multi-wavelength triggered detections

  Radio counterparts of GRBs, Soft Gamma Repeaters,
  BH X-binary outbursts

  <u>NB</u>: no high-energy counterpart for radio detected XDINs (X dim isolated neutron stars) & "orphan" GRB afterglows



TRANSIENT RADIO SKY

- Searches in Archives [Predoi et al., 2010]

Radio → GW

- radio transient triggers reduce time interval and position of search for GW
- relative timing ?
- interesting only if time window < a few hours → models + take into account DM
- start from list of radio transients : time duration, burst energy, DM, sky location

GW → Radio (less effective)

- too many GW candidates
- poor localization
- limited storage of high-resolution radio data

TRANSIENT RADIO SKY

- Searches in Archives [Predoi et al., 2010]

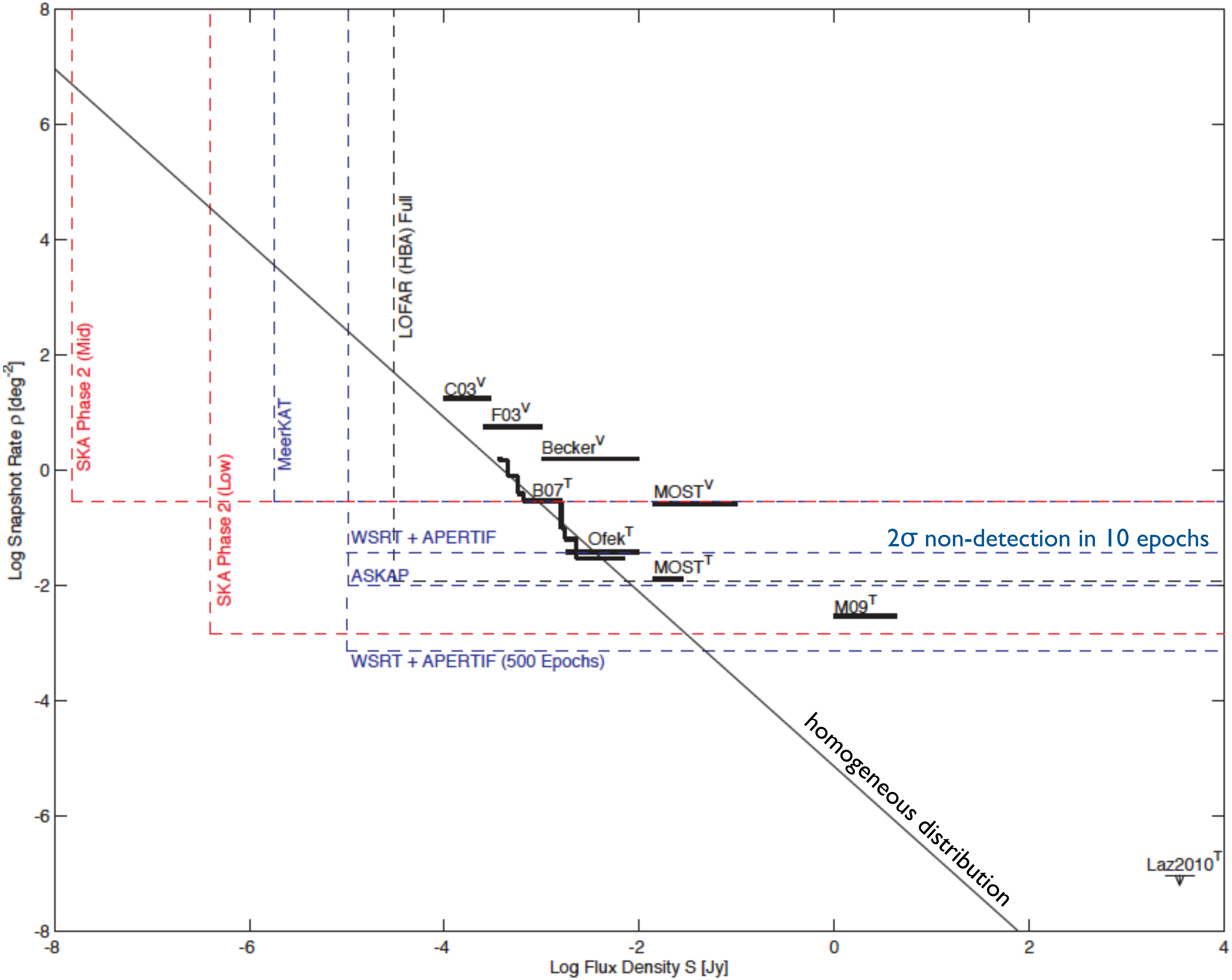
100's of events found in NVSS (northern sky, 1.4 GHz), FIRST (1.4 GHZ, rms~0.15 mJy, resolution 5") … catalogs

(few multi-wavelength counterparts due to relative observation timing)

[Bower et al. 2007] : 944 epochs of VLA 4.8 & 8.4 GHz over 22 years → 10 transients reported (timescale ~ weeks)

4 identified in host galaxies, 2 detected in follow-up X-ray observations

[Bannister et al. 2011] : 15 transients found in 22 years at Molonglo observatory (MOST, 843 MHz, Australia)



SKA Phase 2 (Mid)
SKA Phase 2 (Low)
MeerKAT
LOFAR (HBA) Full
C03V
F03V
BeckerV
B07T
MOSTV
WSRT + APERTIF
OfekT
MOSTT
ASKAP
M09T
WSRT + APERTIF (500 Epochs)
2σ non-detection in 10 epochs
homogeneous distribution
Laz2010T
Log Snapshot Rate ρ [deg-2]
Log Flux Density S [Jy]

TRANSIENT RADIO SKY

- Serendipitous discoveries & Commensal (= Piggyback)

  → VLA calibrator fields
  [Bower & Saul, 2011 ; Bell et al. 2011]
  → Molonglo calibrator fields
  [Gaensler & Hunstead, 2000]
  → LWA [Lazio et al., 2010]
  → LOFAR +++

TRANSIENT RADIO SKY

- Radio transients are relatively rare
- Transients are 10^{-3} to 10^{-4} of quiescent population [Levinson et al. 2002 ; Ofek et al. 2010]
- Radio-GW false detection rate will be small (<0.1 deg^{-2} at 1 mJy at frequencies ~ GHz) [Frail, 2011]

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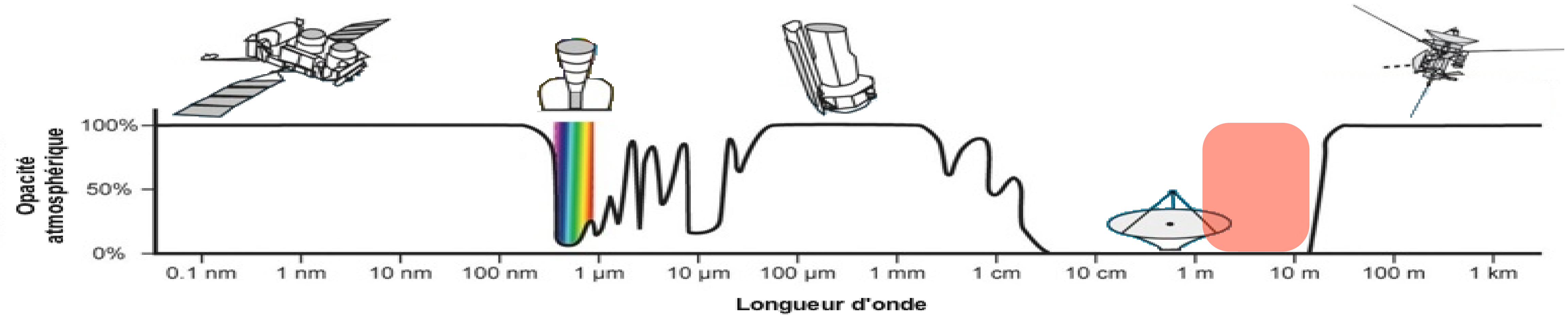
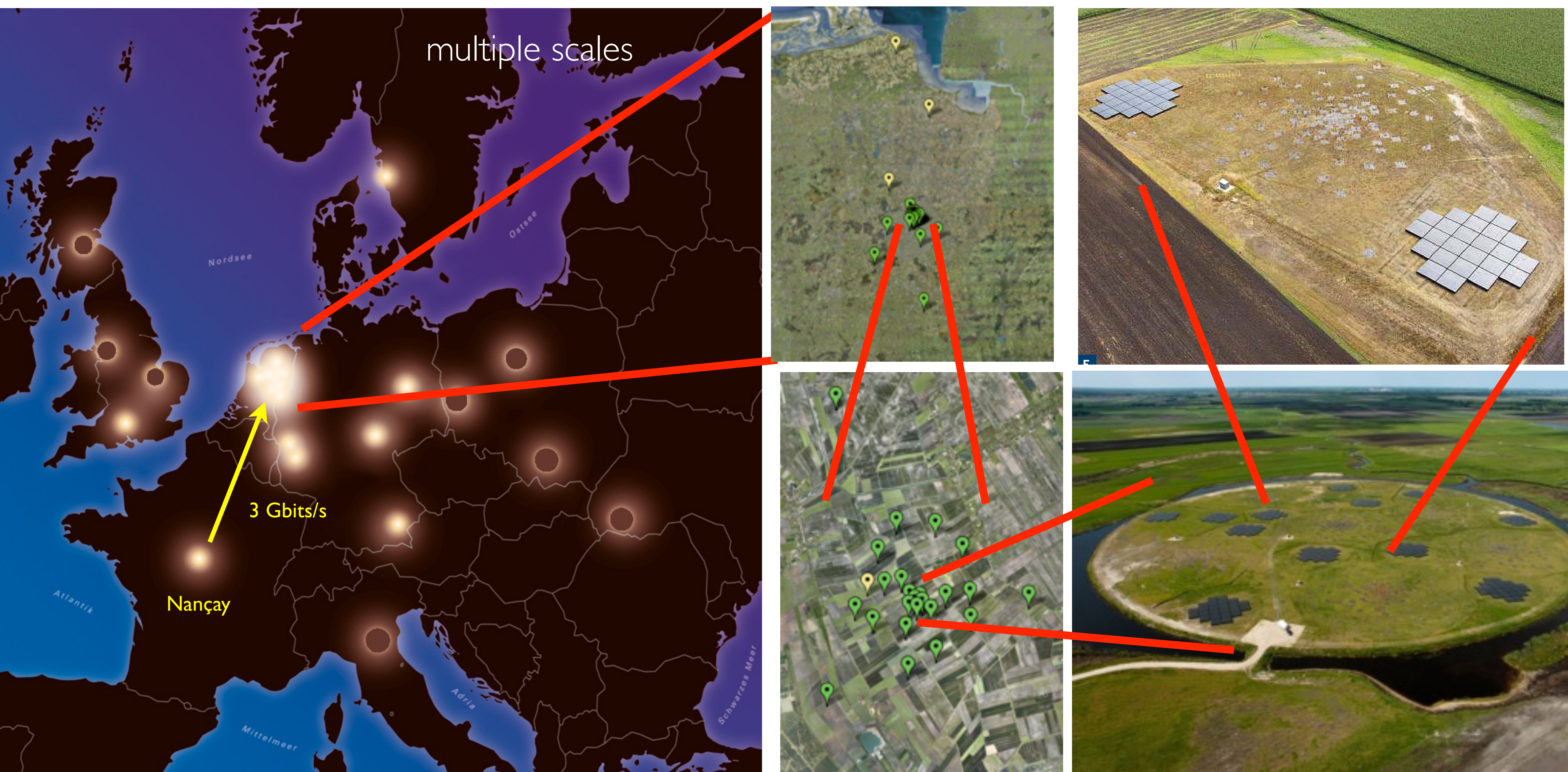
LOFAR TELESCOPE & OPERATING MODES





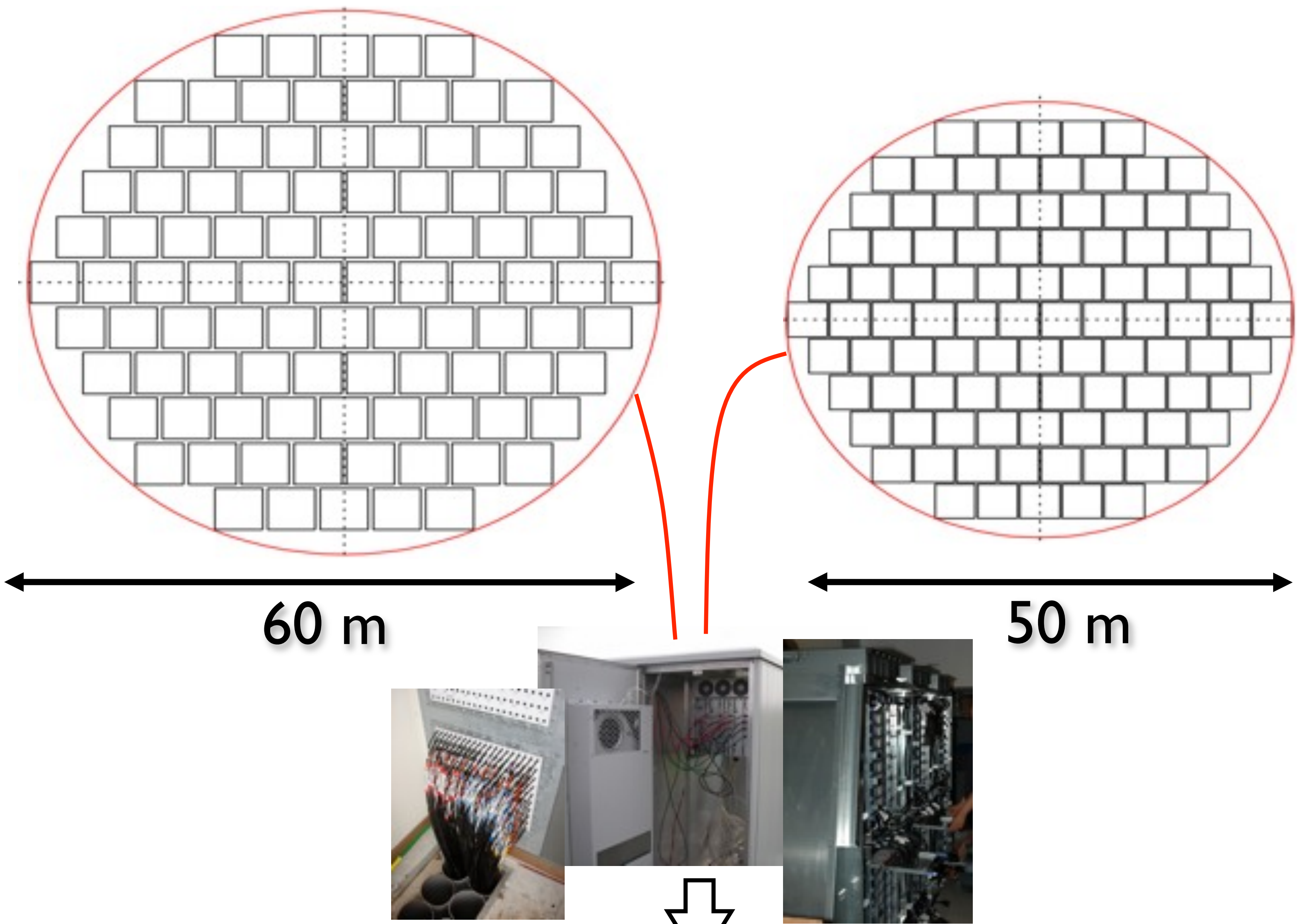
The LOFAR telescope

FR606, the Nançay LOFAR station

LOFAR station : 2 phased arrays + backends

Low frequencies : LBA
(30-80 MHz)

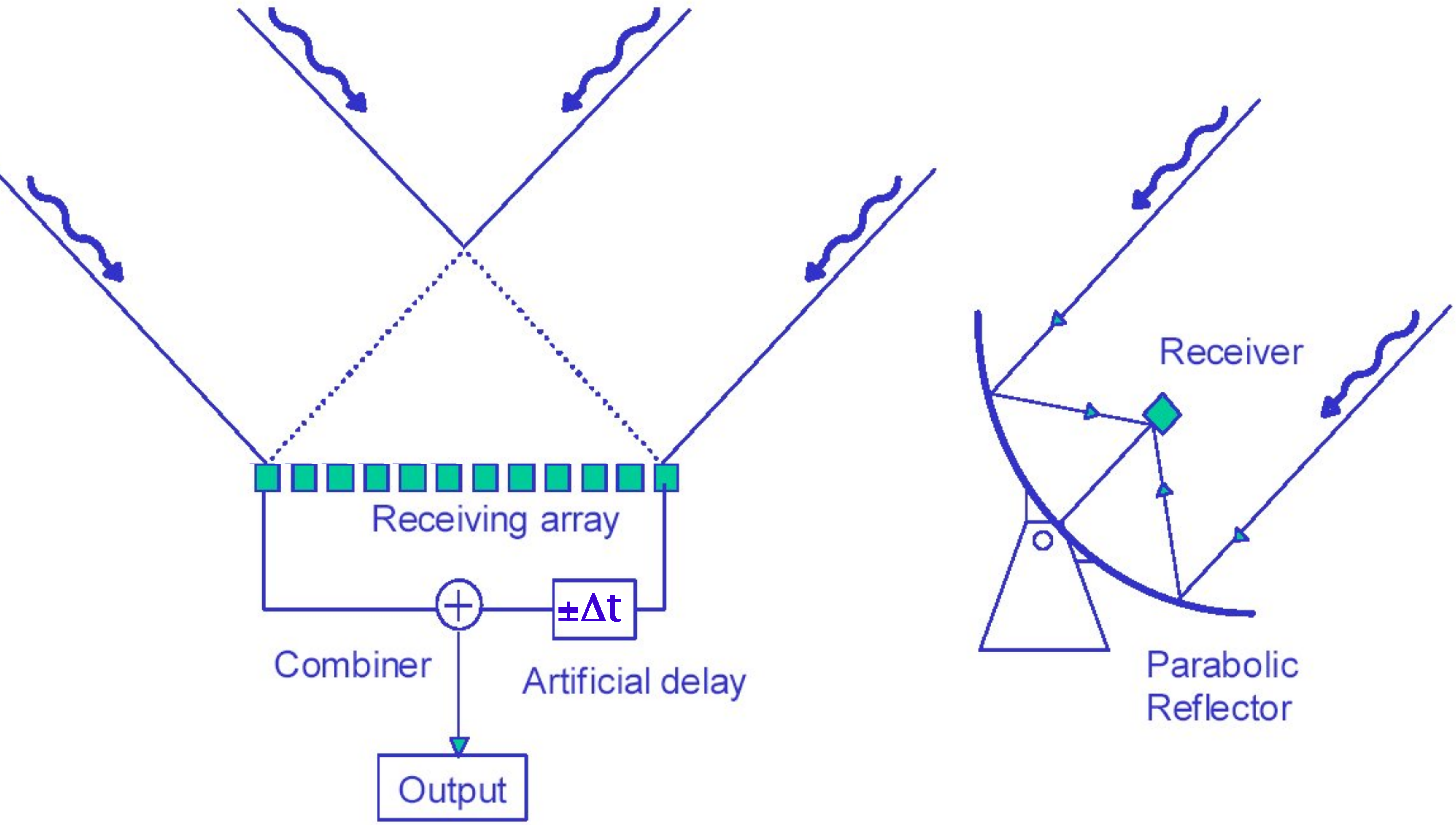
High frequencies : HBA
(110-250 MHz)



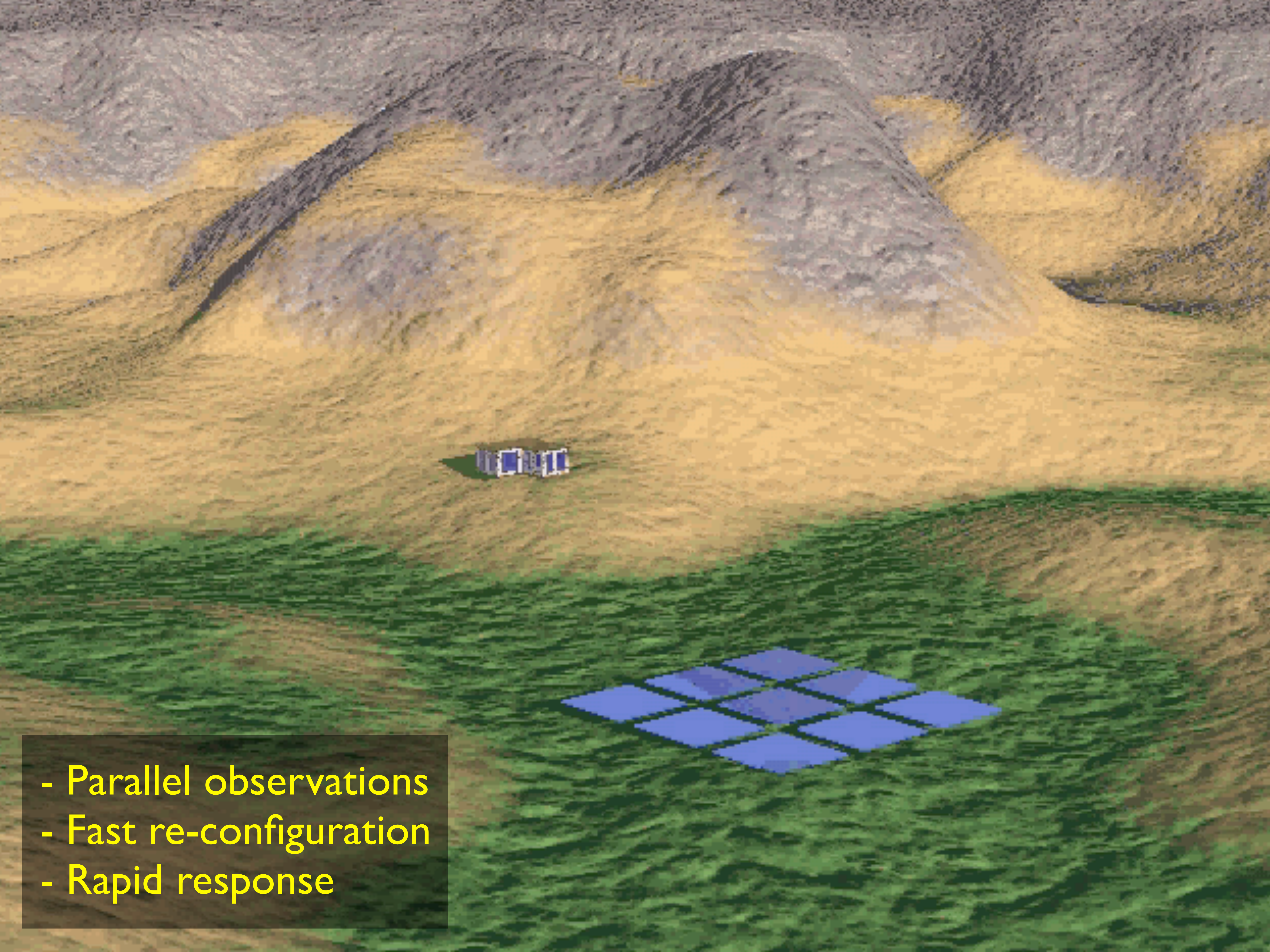
3+ Gbit/sec link

Superordinateur Blue Gene

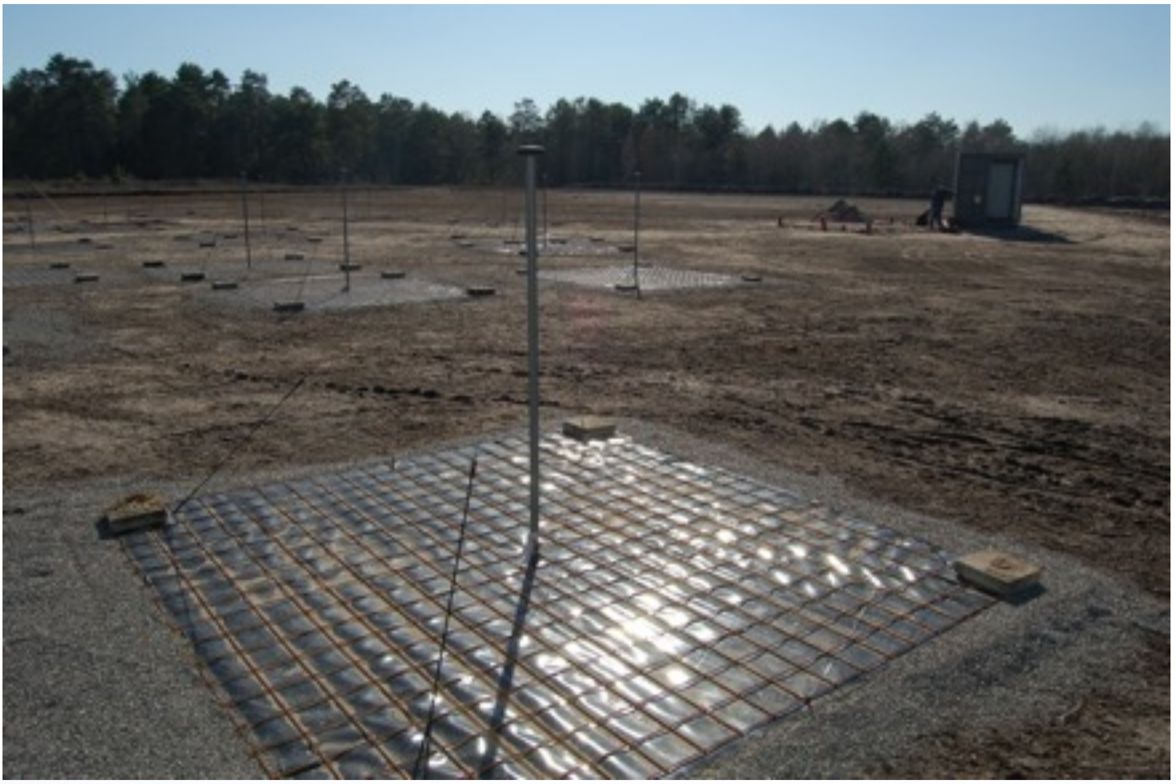
Phased Array Detectors

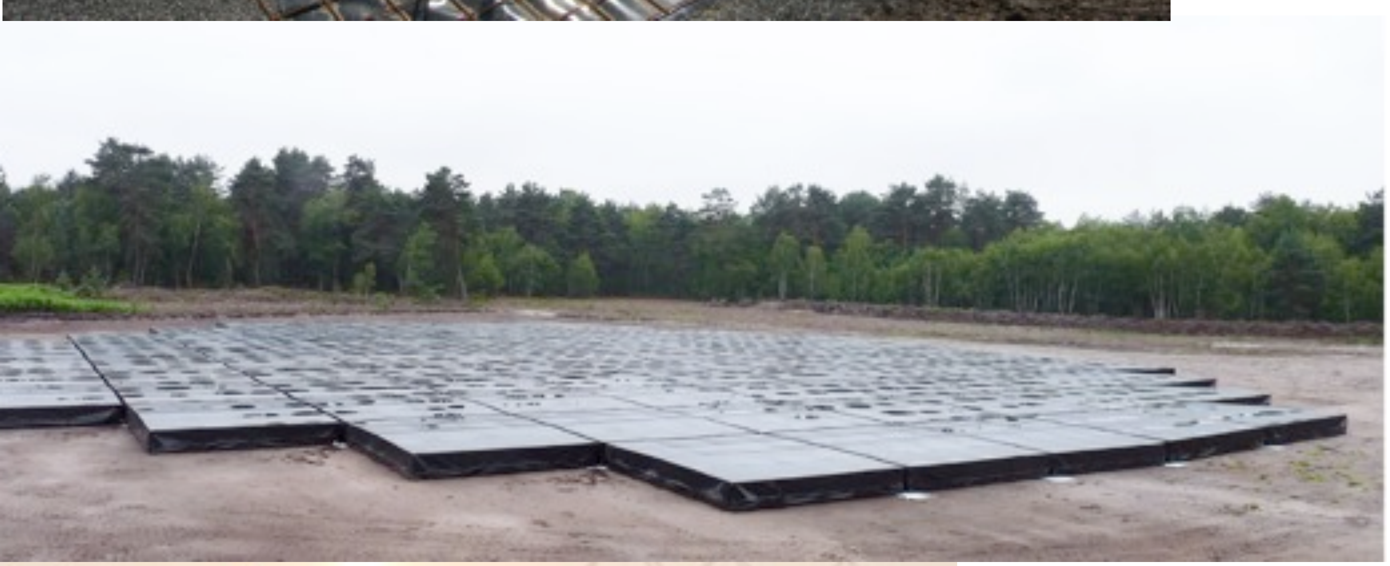


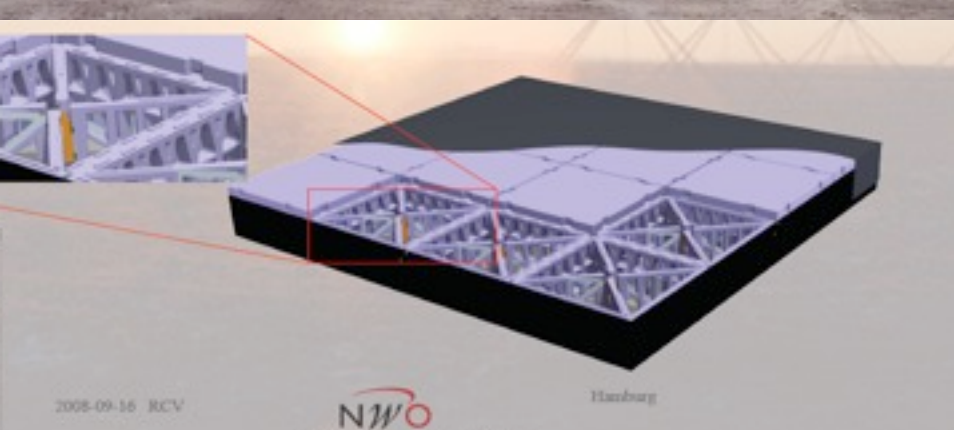
Electronic beam steering

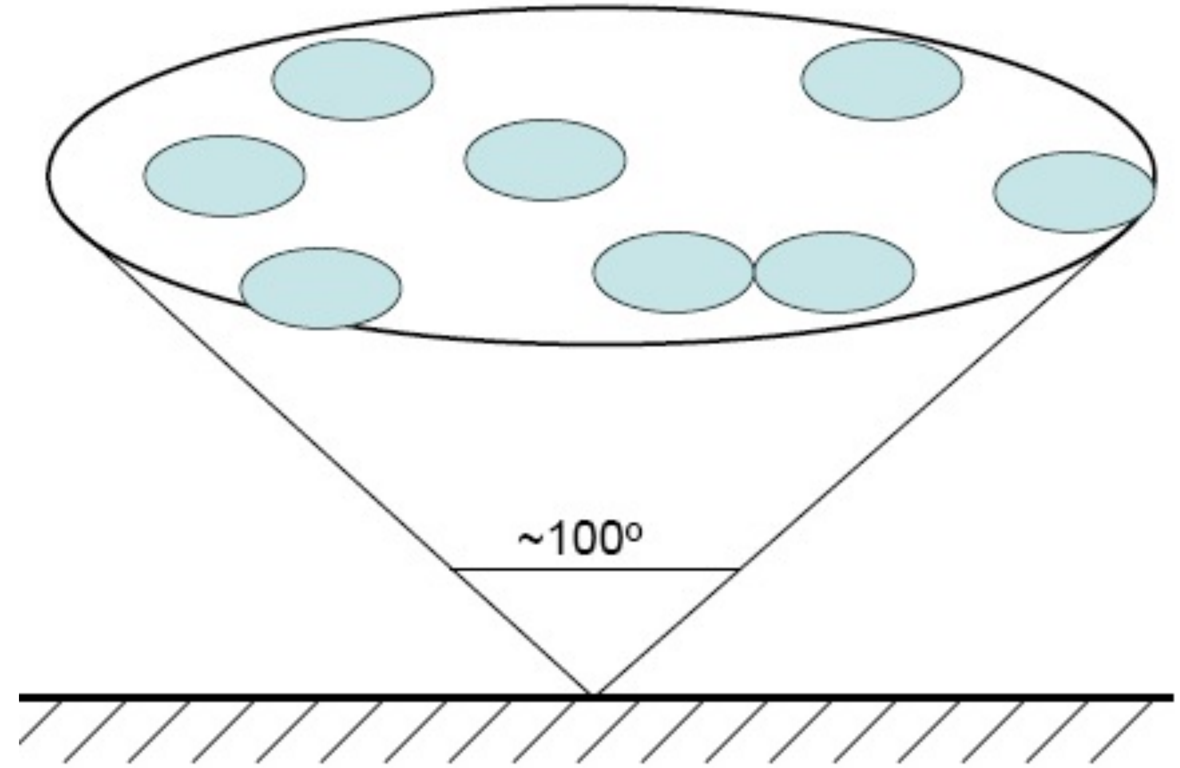

- Parallel observations
- Fast re-configuration
- Rapid response

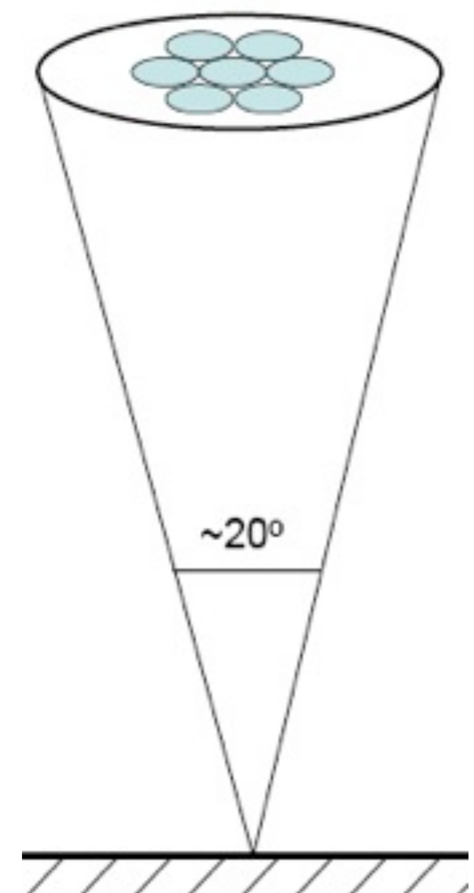
LBA & HBA antennas & FoV



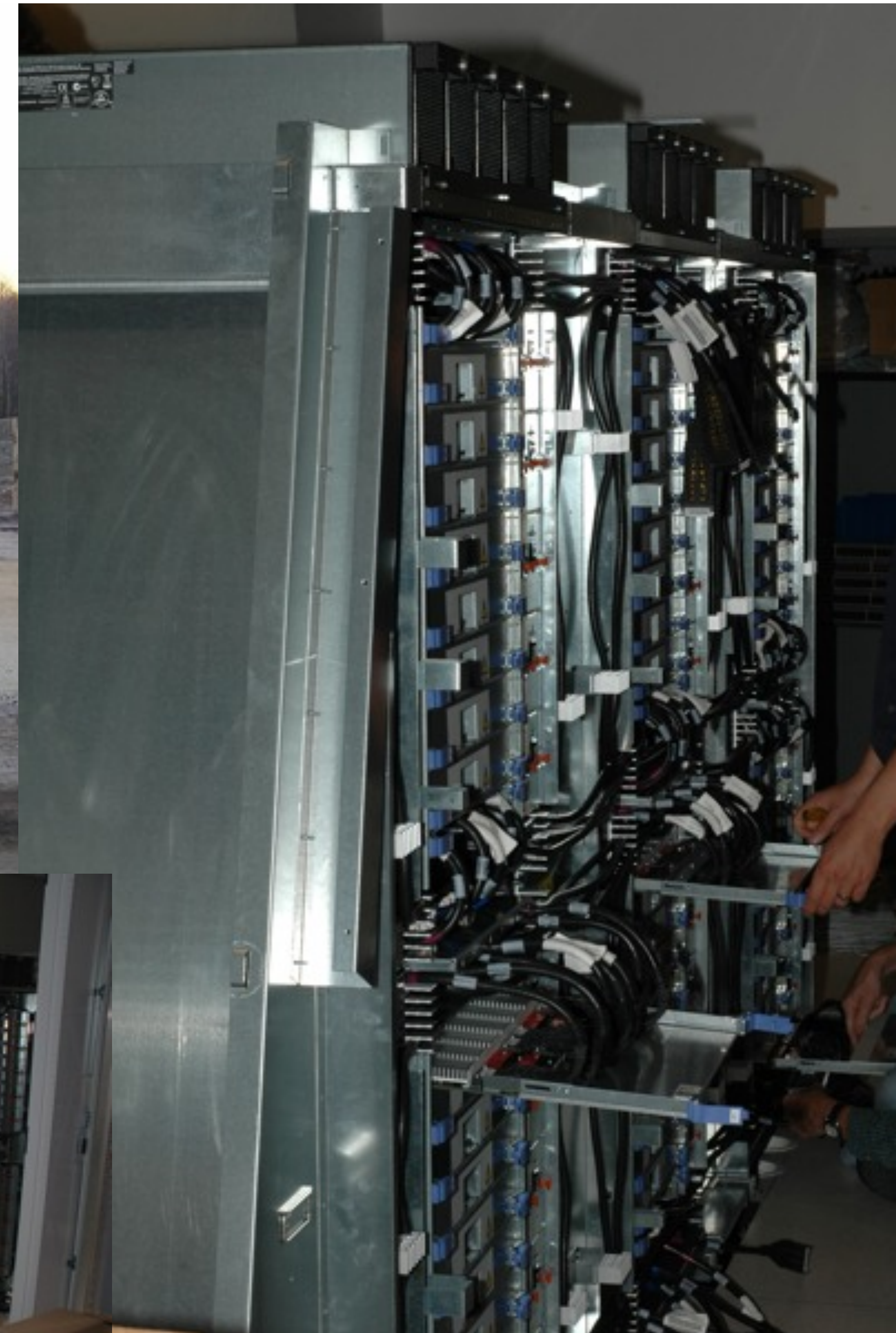




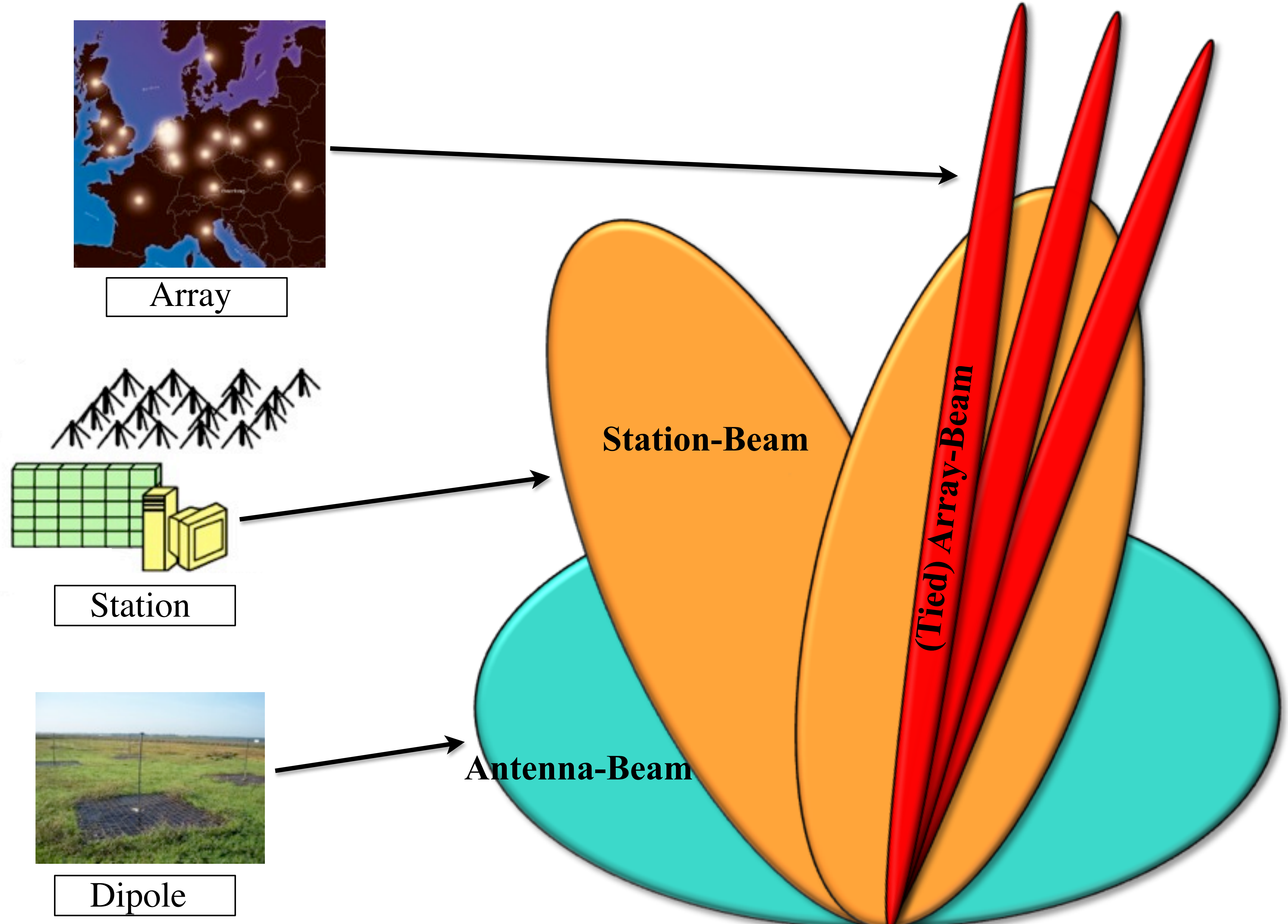




FR606 Backends

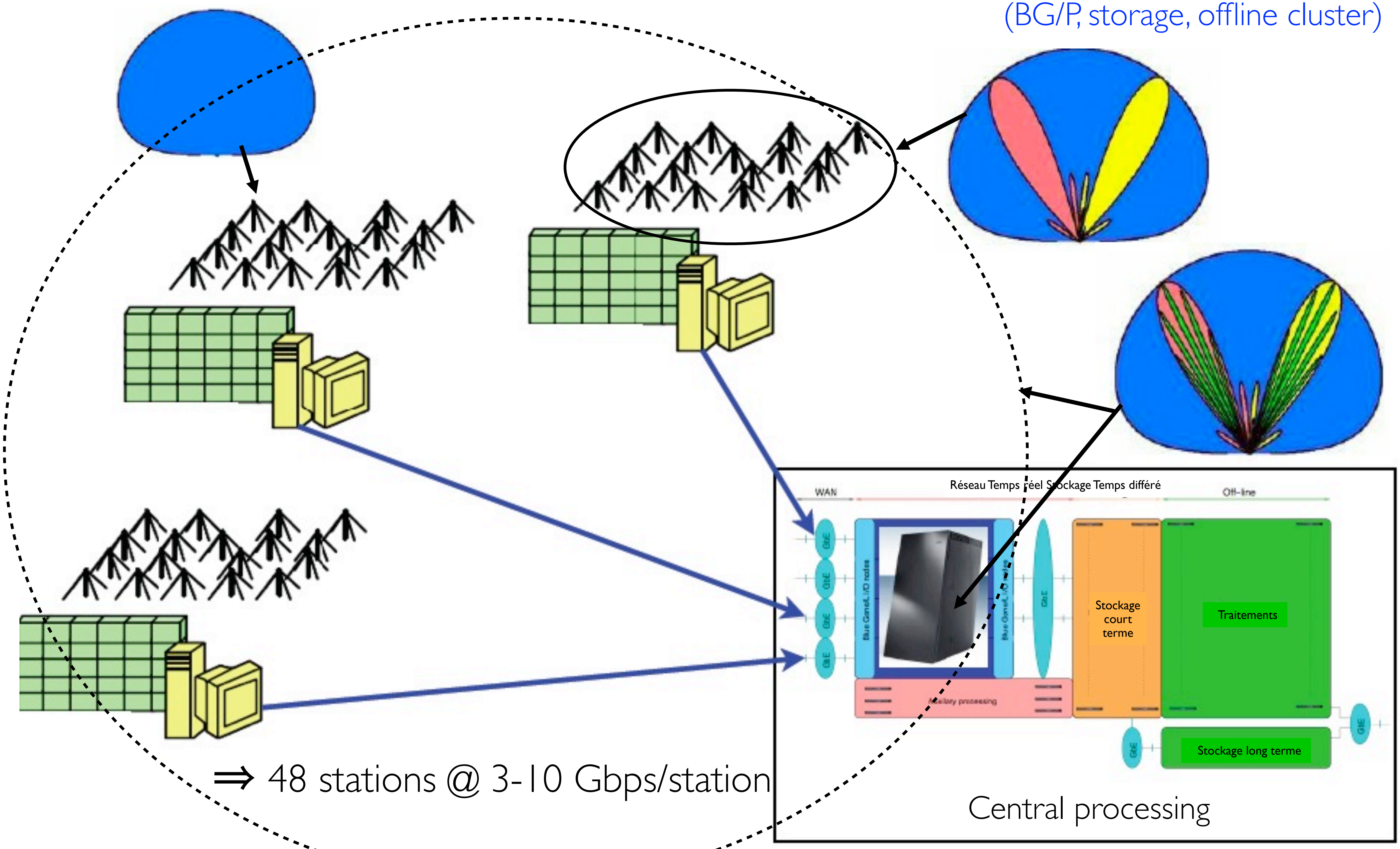


Digital beamforming

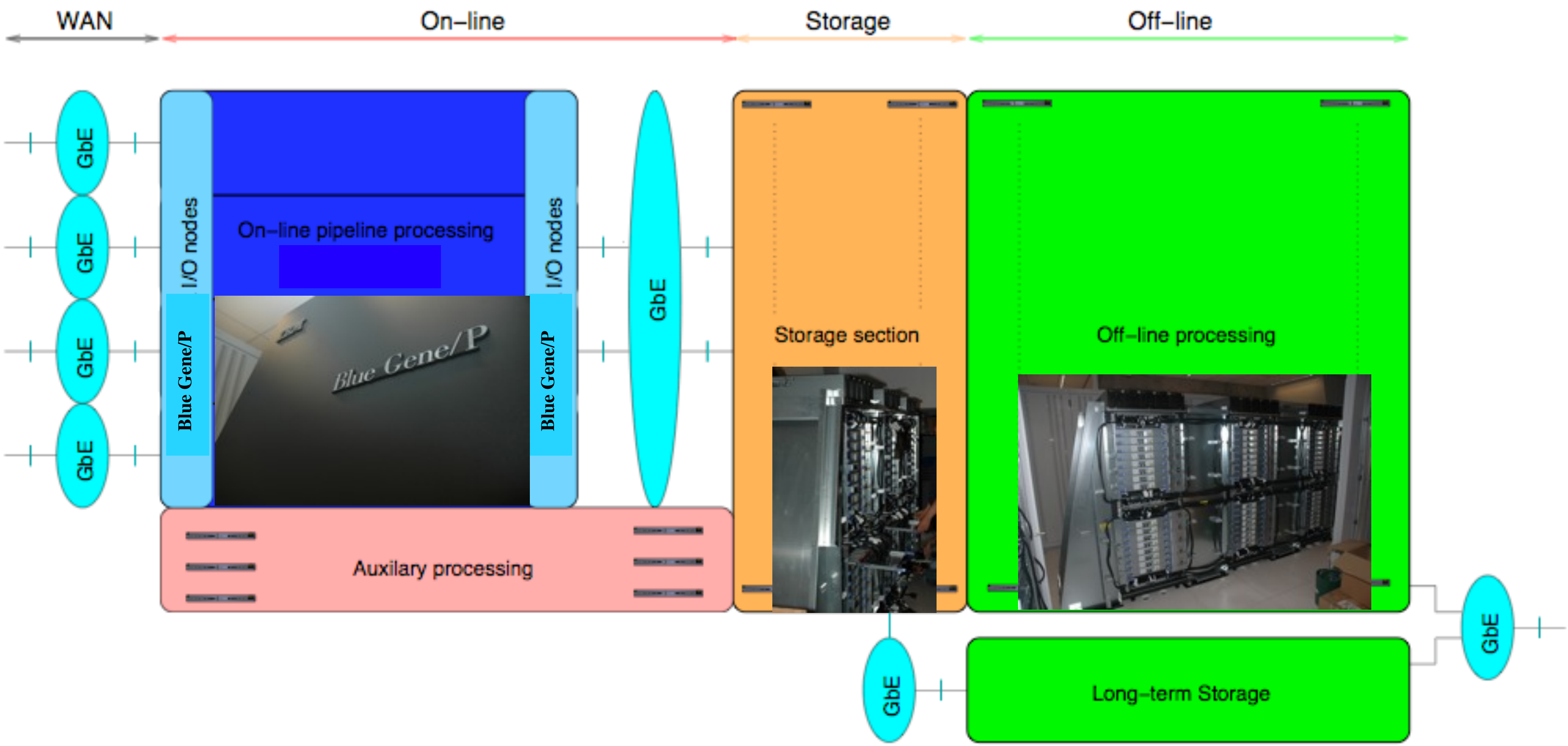


The LOFAR array

- 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)



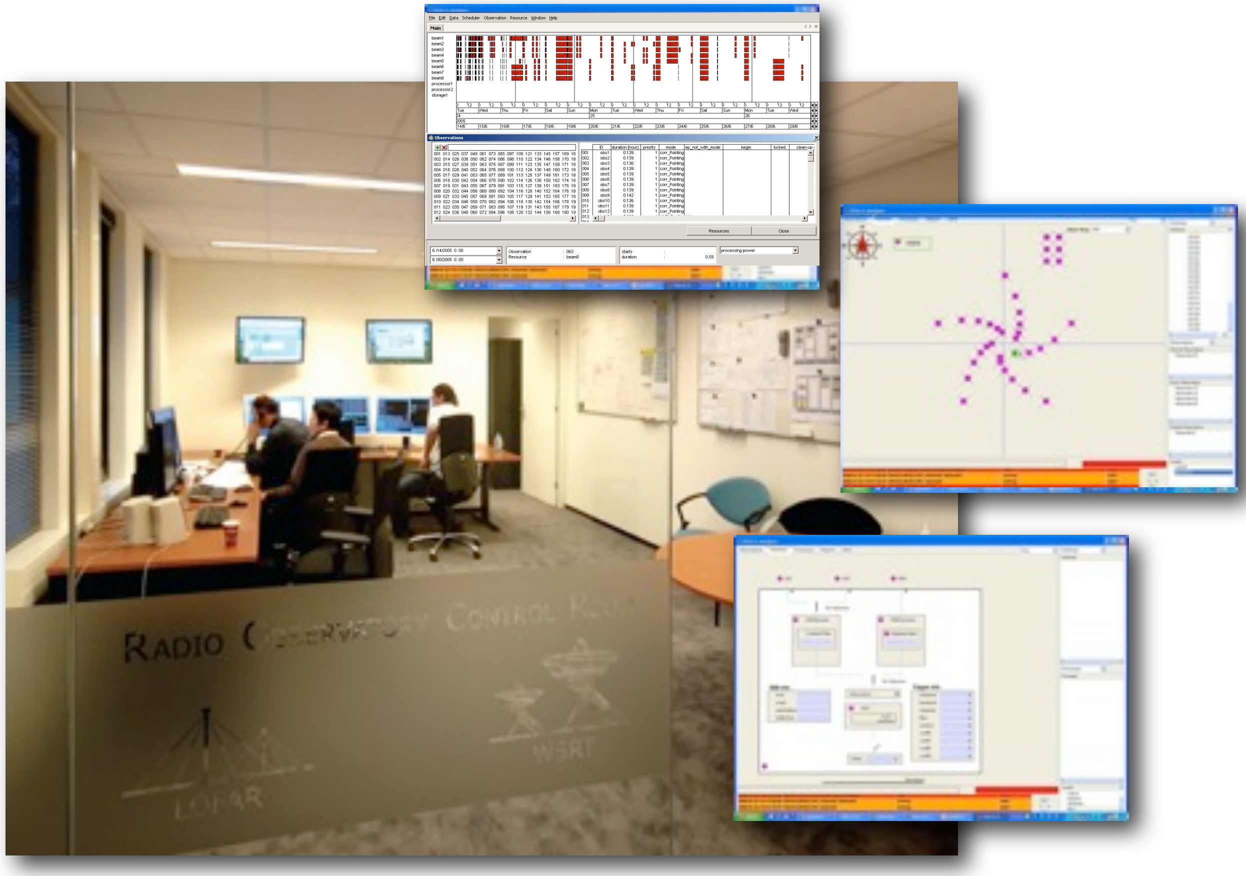
Central Processing



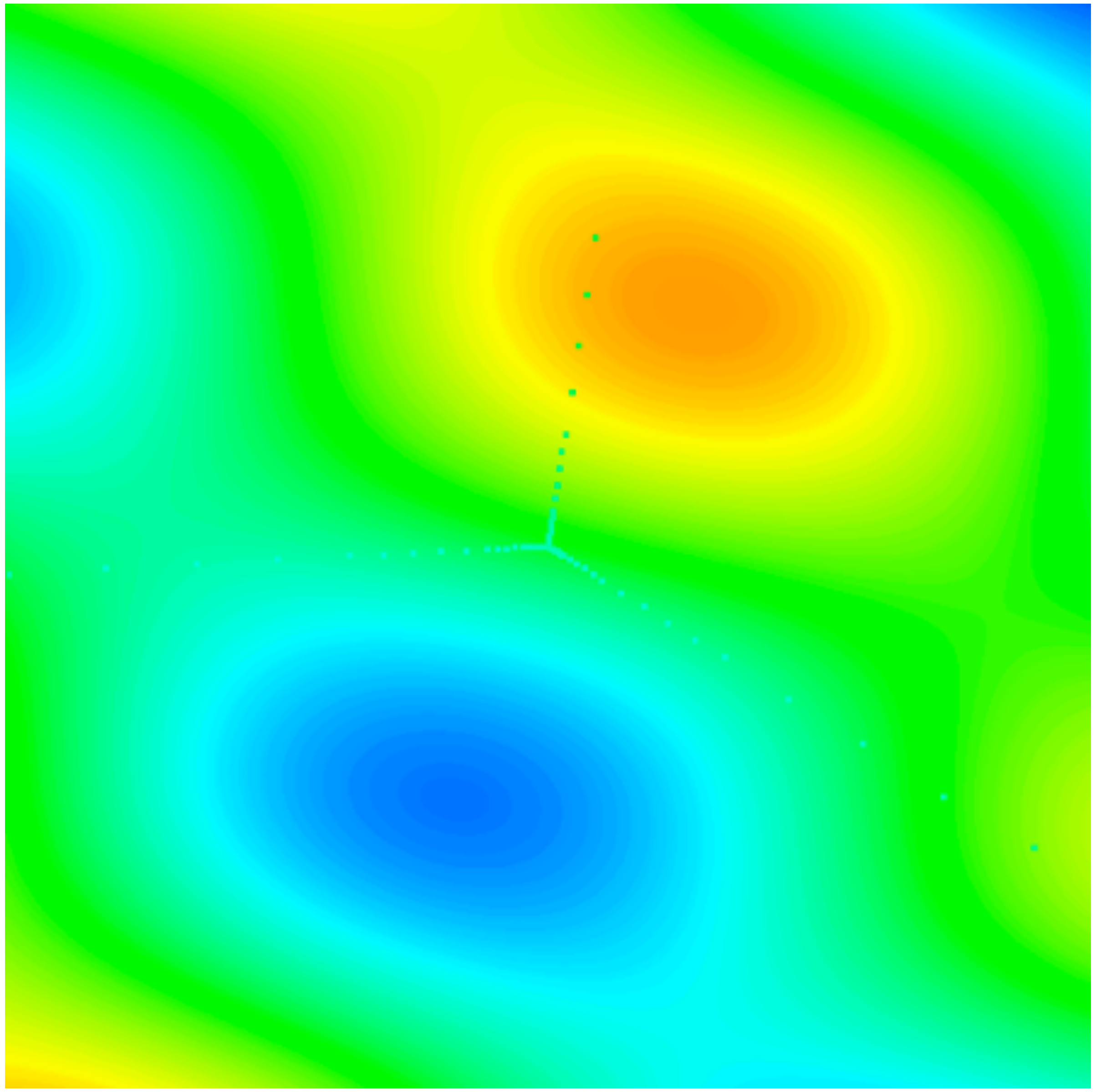
- BG/P : Data reception, transpose, correlation, beam-forming, de-dispersion, 45 TFLOPS
- Storage system : Short term storage of data, ~2 PByte, ~100Gbps I/O
- Offline cluster : Pipelines, data products, off-line analysis, ~20 TFLOPS

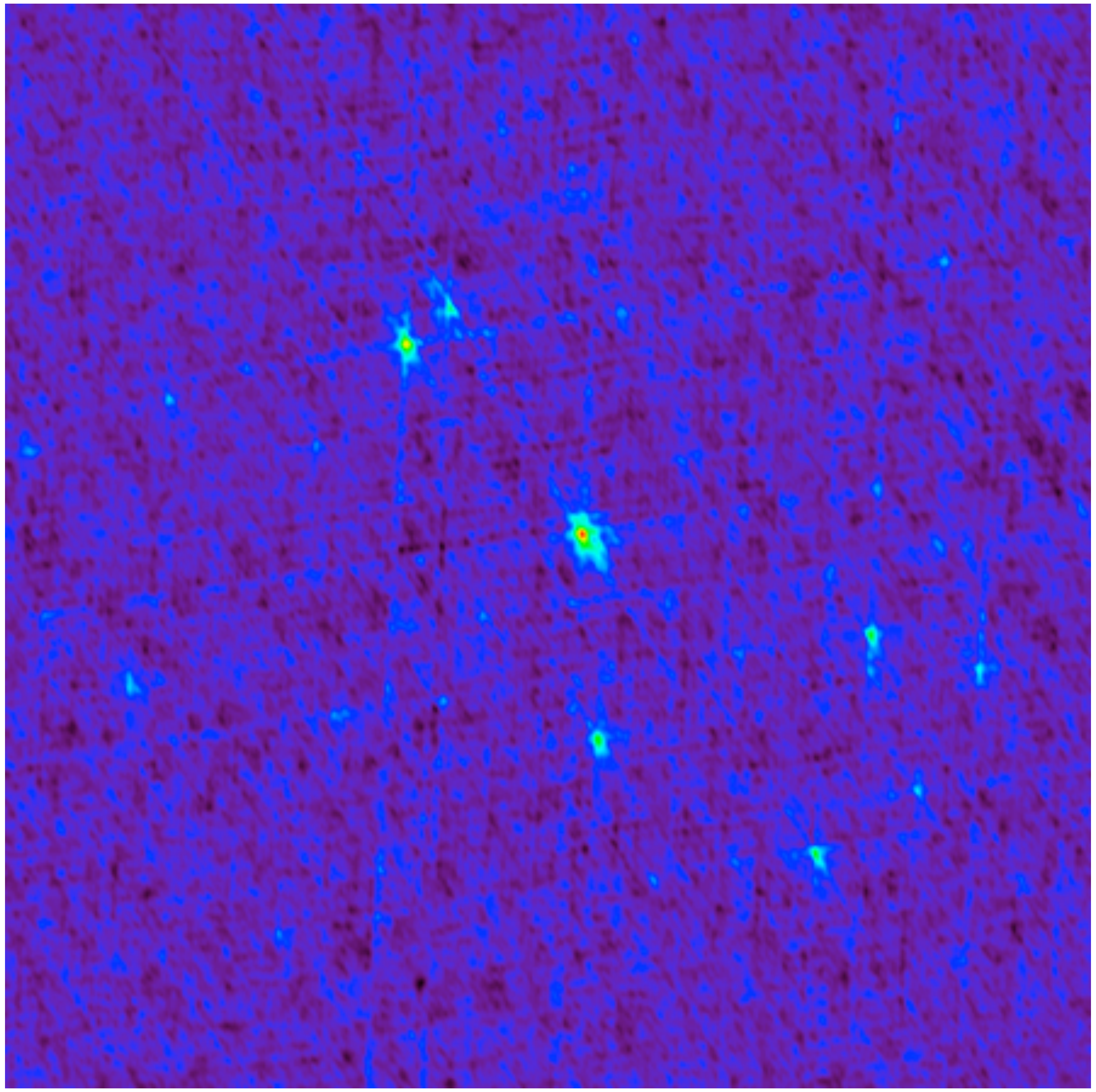
LOFAR observing modes

- Interferometric Imaging



Modelling the ionosphere





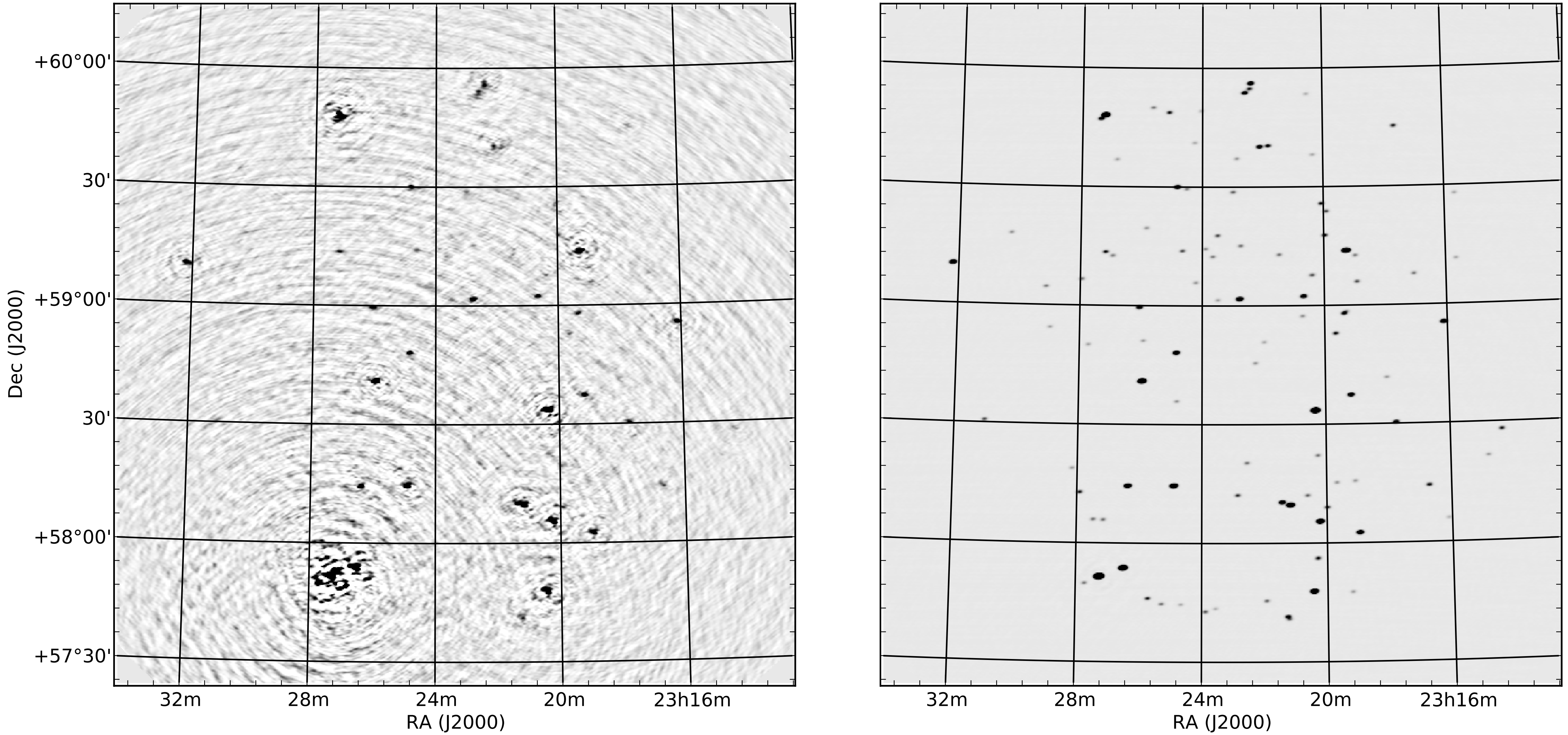
Need of many sources / beam for proper calibration

The AWI Imager

Tasse et al., 2013

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

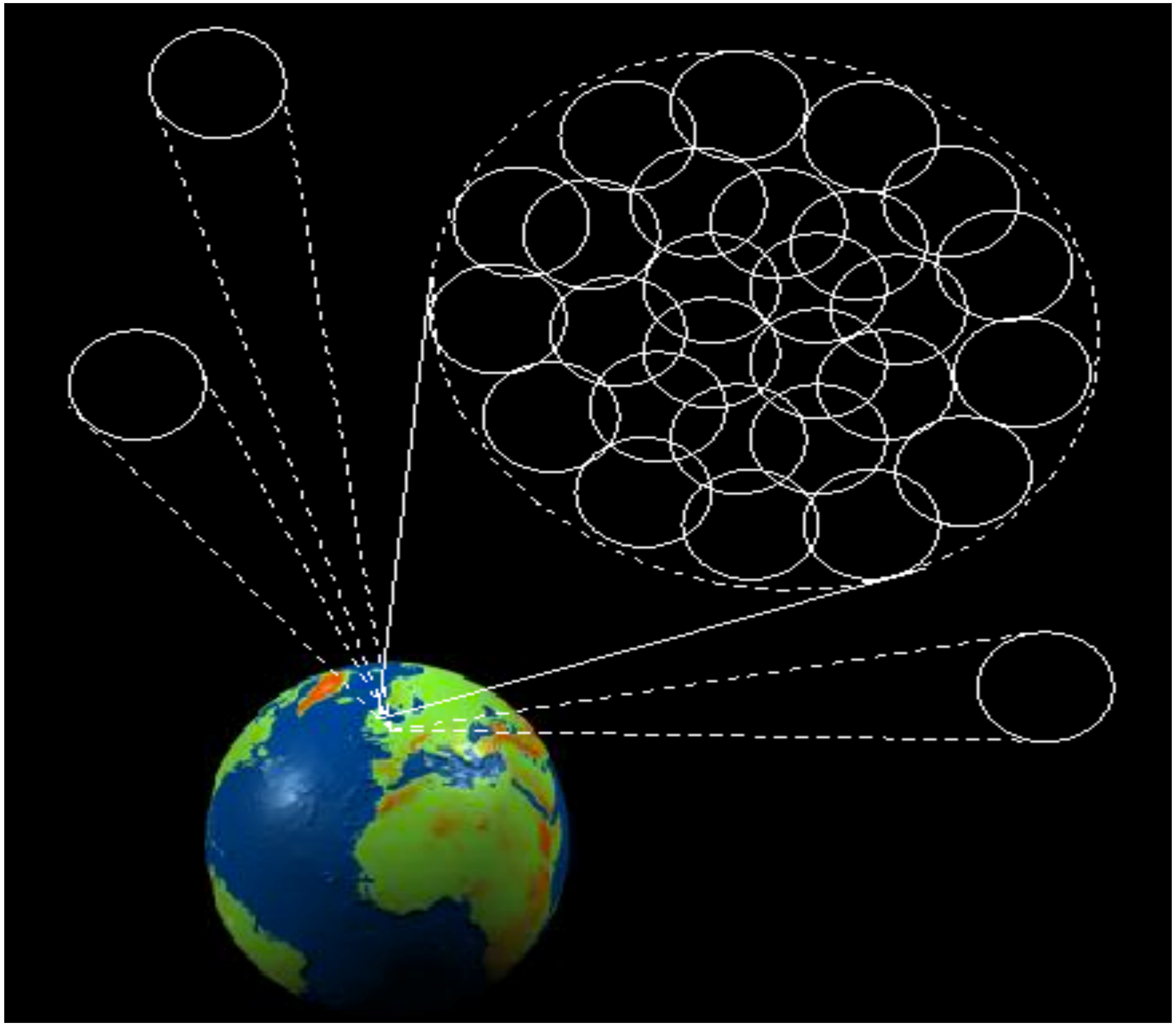
C. Tasse[1,2,3], B. van der Tol[4], J. van Zwieten[5], Ger van Diepen[5], and S. Bhatnagar[6]



+ specialized software

LOFAR observing modes

- Interferometric Imaging
  - Radio Sky Monitor, tiling

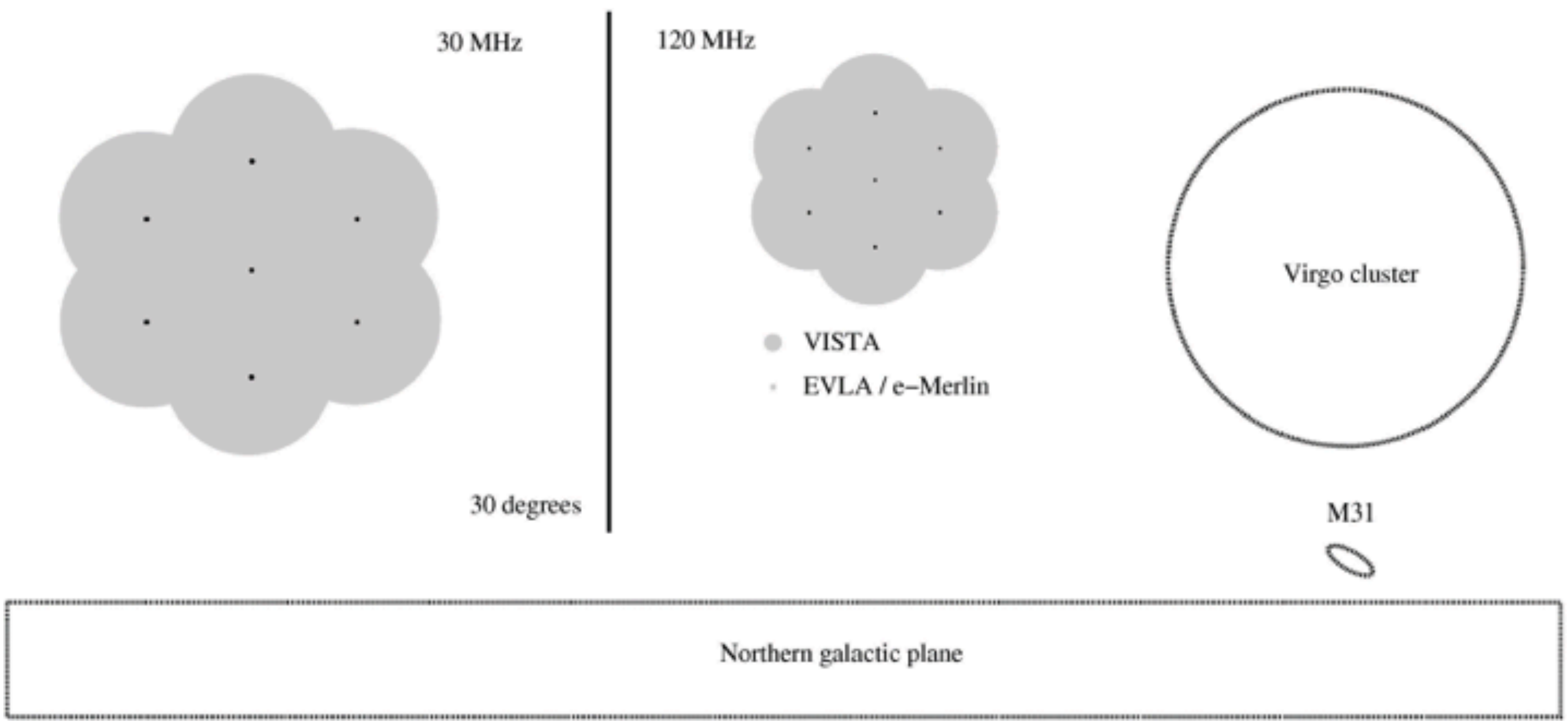


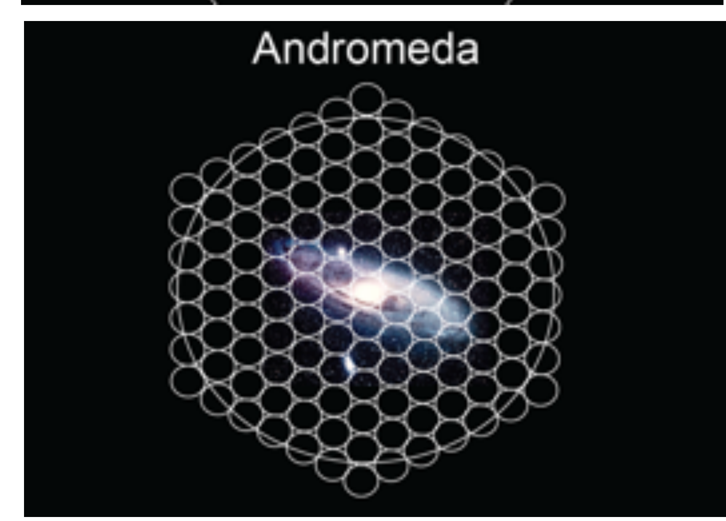
Up to 24 beams in //

The Radio Sky Monitor

- Multiple large beams on sky, can be tiled or spread across sky over ~1000 deg^2
- Instantaneous field of view with 8 beams ~800 deg^2 (LBA) ~200 deg^2 (HBA)

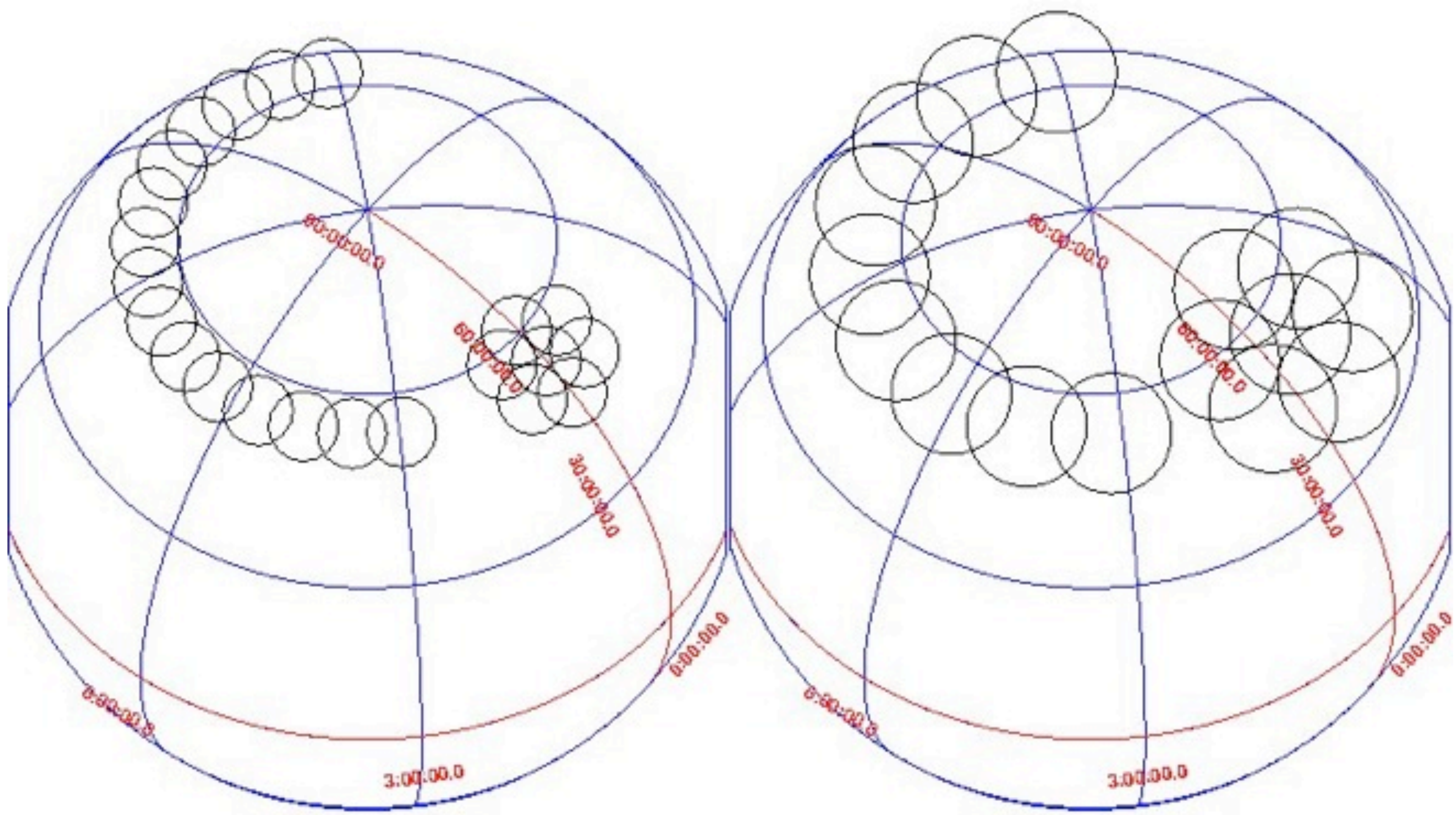
- Large collecting area × large FoV × multi-beam → very high speed surveys (with good angular resolution)
- All-sky transient searches with $\tau \geq 1$ sec.





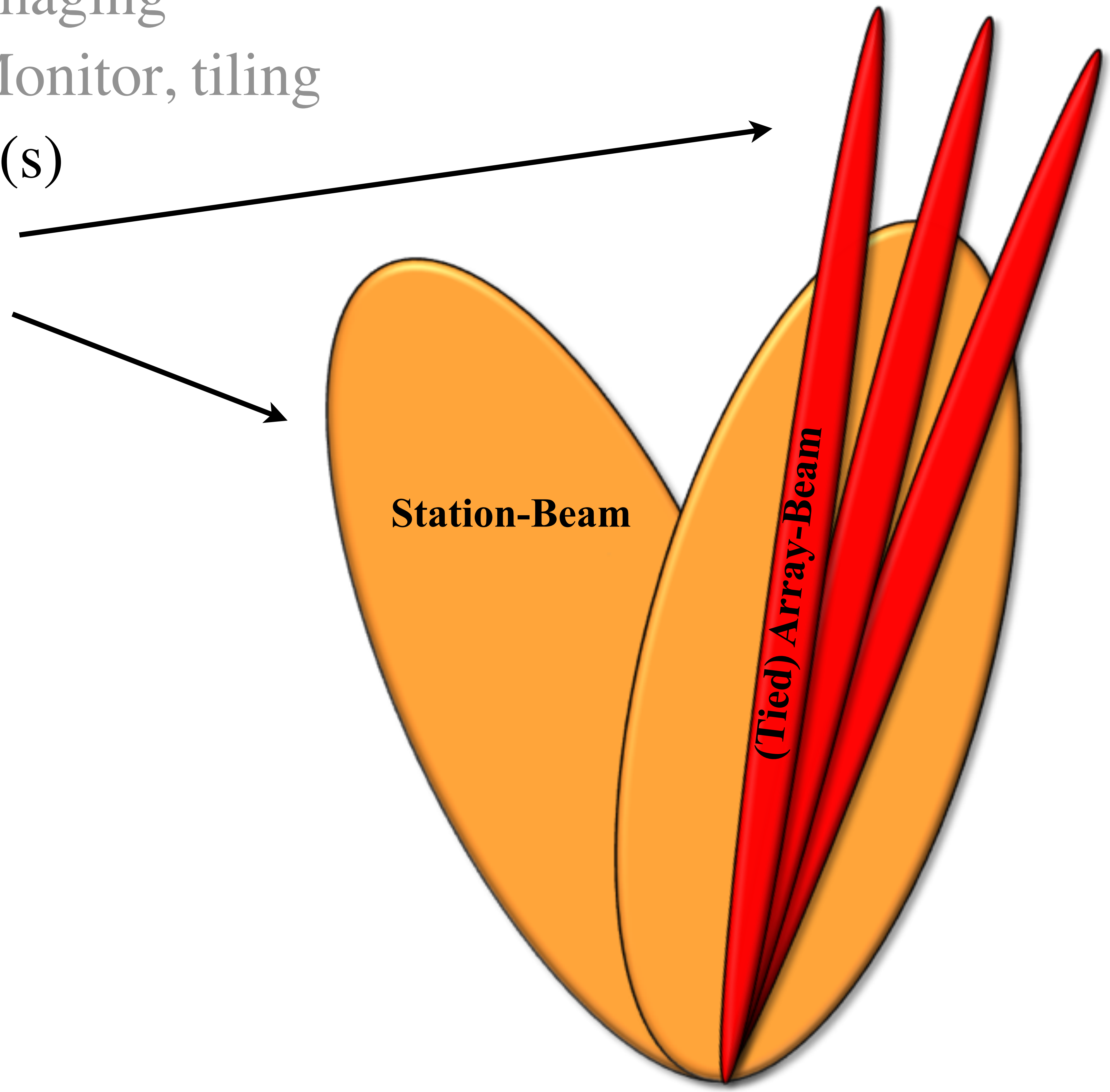
The Radio Sky Monitor

- Image plane searches: Zenith Monitoring Program
- Eight 7-beam tiles in LBAs tiles out entire zenith strip (~1800 deg^2)
- Sixteen 7-beam tiles in HBAs does the same (~1000 deg^2)
- Done monthly → daily with ~mJy sensitivity → // GW



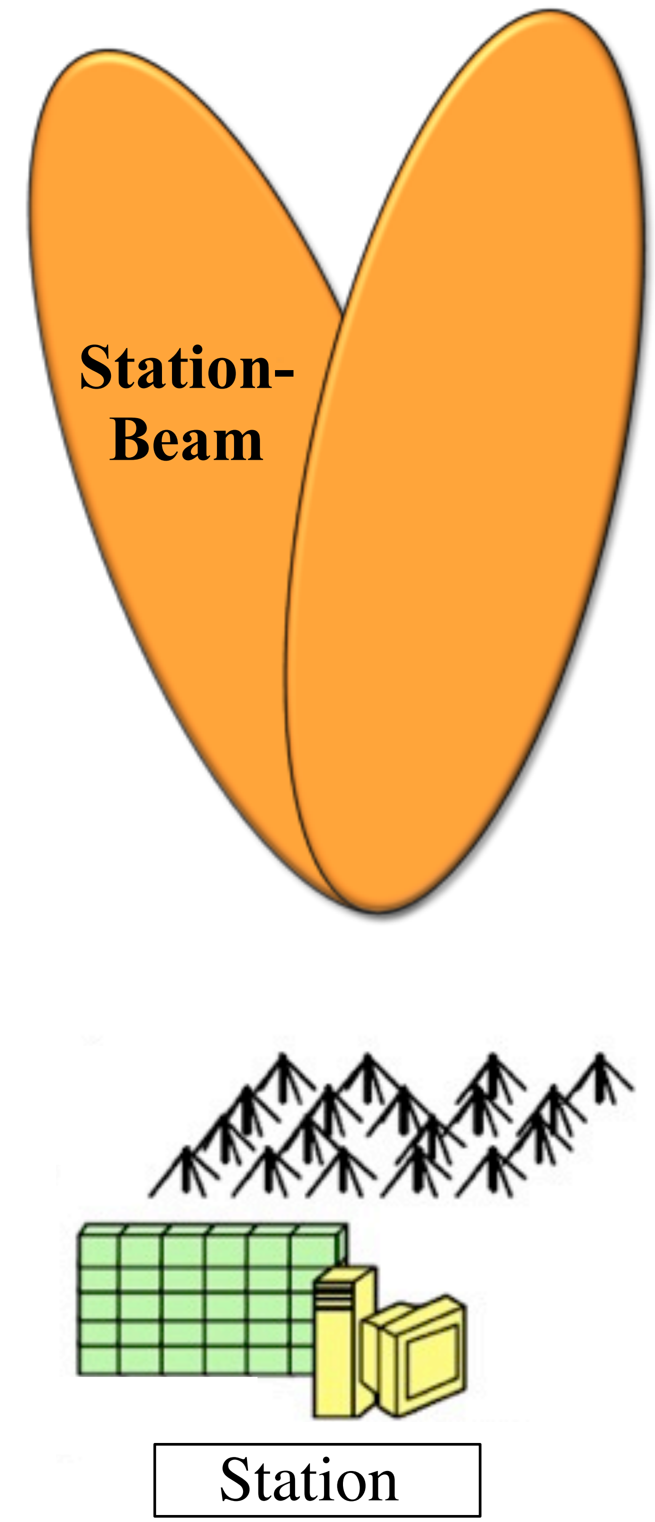
LOFAR observing modes

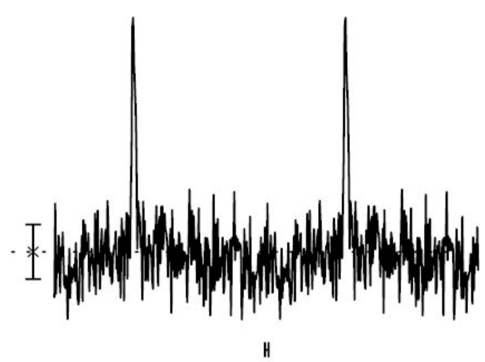
- Interferometric Imaging
  - Radio Sky Monitor, tiling
- Tied Array Beam(s)
  - coherent
  - incoherent



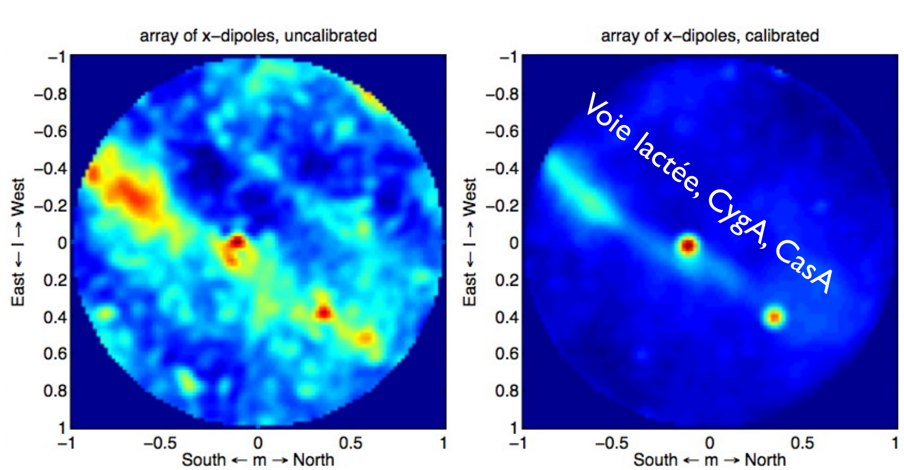
LOFAR observing modes

- Interferometric Imaging
  - Radio Sky Monitor, tiling
- Tied Array Beam(s)
  - coherent
  - incoherent
- **Single Station**
  - ILT





1st light in Nançay
PSR 1919+21, 1.337s
@ 42-53 MHz

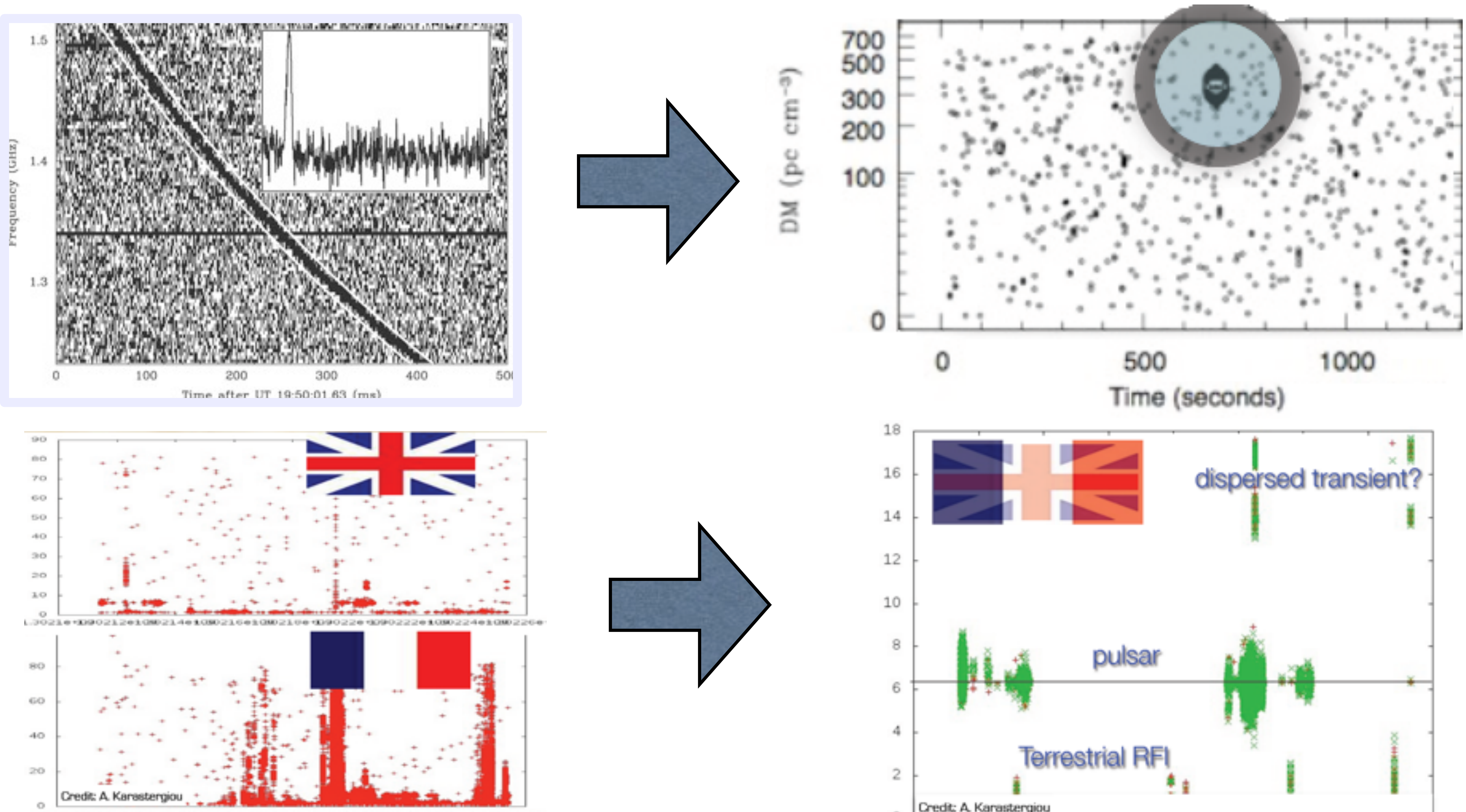


1st sky map in Nançay
200 kHz x 20 sec
@ 60 MHz

LOFAR observing modes

- Interferometric Imaging
  - Radio Sky Monitor, tiling
- Tied Array Beam(s)
  - coherent
  - incoherent
- Single Station
  - ILT
  - ARTEMIS

Karastergiou et al., 2012



LOFAR observing modes

- Interferometric Imaging
  - Radio Sky Monitor, tiling
- Tied Array Beam(s)
  - coherent
  - incoherent
- Single Station
  - ILT
  - ARTEMIS
- Waveform storage (TBB dumps)
  - FRATs (incoherent (broad) beam + trigger → TBB imaging = all sky survey + arcseconds resolution)

Transient Buffer Boards

RAM Ring buffer for each LBA/HBA element

Data stored, stopped, dumped to disk.

Reproduce any LOFAR signal; Also your data!

Limited memory => limited time

Beamsize:
LBA: All-sky (30000 sq. degr)
HBA: 500 sq. degr.

Falcke, Ter Veen et al.

- 1.3 → 5.2 sec of full bandwidth data, 52 sec at 10% bandwidth

- TBBs can be frozen and fed to correlator for re-imaging of sky in a different direction to that which was being observed at the time
- + full time resolution time series data

LOFAR observing modes

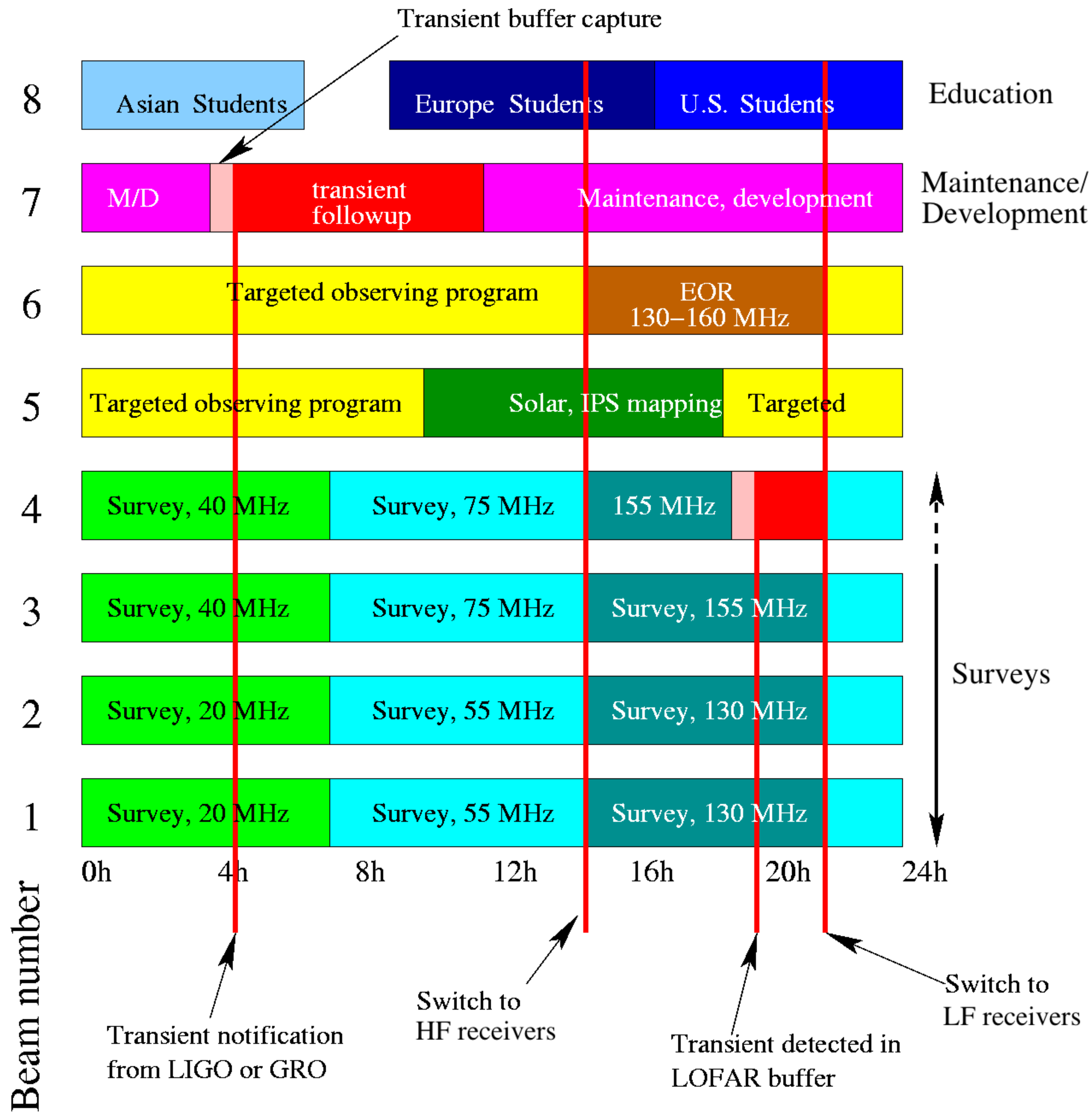
- Interferometric Imaging
  - Radio Sky Monitor, tiling
- Tied Array Beam(s)
  - coherent
  - incoherent
- Single Station
  - ILT
  - ARTEMIS
- Waveform storage (TBB dumps)
  - FRATs (incoherent (broad) beam + trigger → TBB imaging = all sky survey + arcseconds resolution)
- Superterp AARTFAC (all sky low sensitivity survey commensal to LOFAR observations)

Amsterdam-ASTRON Radio Transients Facility and Analysis Centre

Low Band	Field of view	~10000 sq. deg.
	RMS	1 Jy (1 s)
	Resolution	40 ′
High Band	Field of view	~300 sq. deg.
	RMS	0.05 Jy (1 s)
	Resolution	16 ′

Swinbank, Wijers et al., 2012

Multi-beam Multi-programs telescope



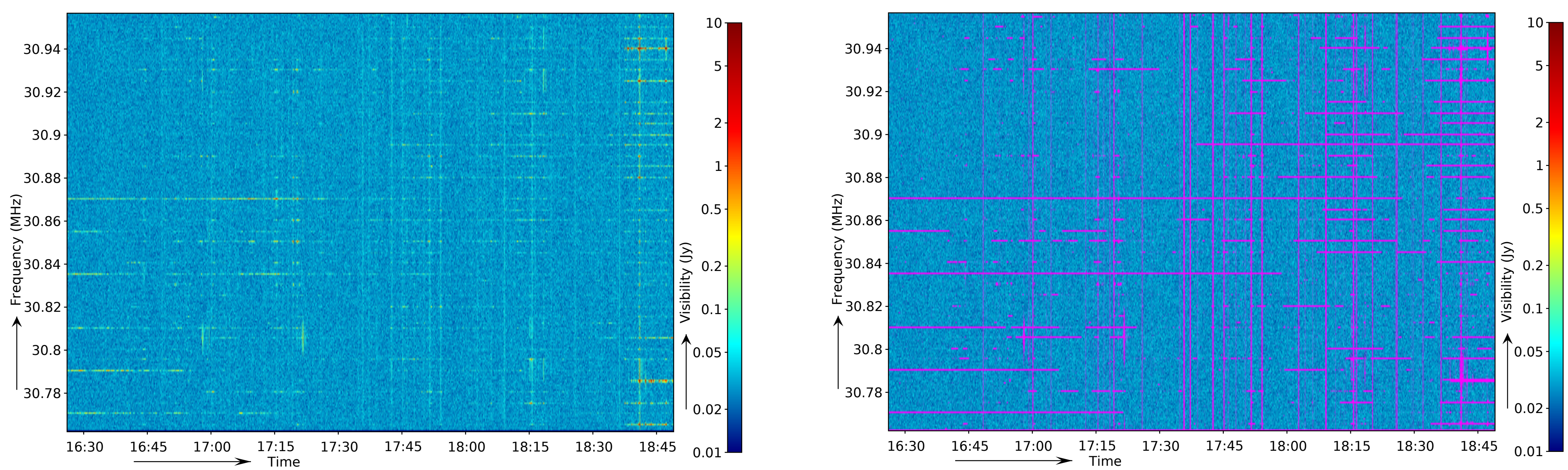
LOFAR TELESCOPE & OPERATING MODES

- LF Radio sky is sky noise (galactic background) limited :

Noise (1 σ) = $2kT_{sky}/(A\,(\delta f.\delta t)^{1/2})$

with $T_{sky} \sim 1.15\times10^{8}/\nu^{2.5}$ (~420 K at 150 MHz)

- RFI



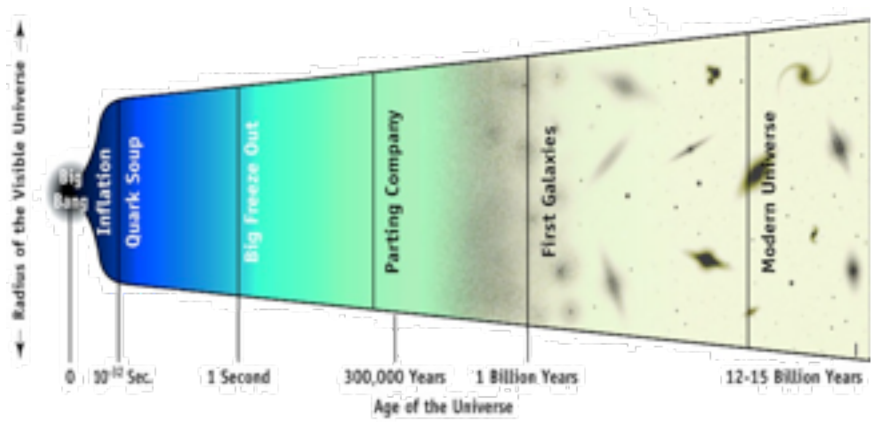
Offringa et al. 2013

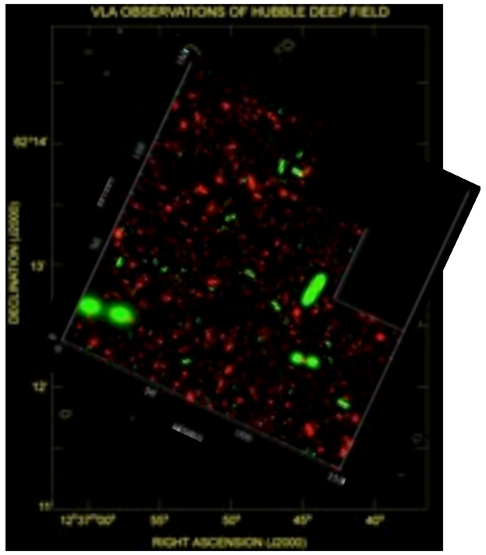
Summary of technical characteristics

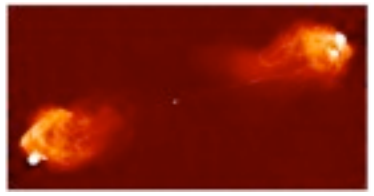
- European « Interferometer » of « Phased arrays »
- 24 stations «core» + 16 remote + 8 international
- Diameter ~100 km (NL) → 1500 km (Europe)
- Effective area ~ 100 000 m^2 ($\propto \lambda^2$)
- Frequency ranges = 30-80 & 110-250 MHz (λ=1.2-10m)
- Operation Modes = imaging, tied-array beams, waveform capture ...
- Resolution ~ 0.1 " - 10 ", large FoV (~10°-30° → 50-500 deg^2)
- 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

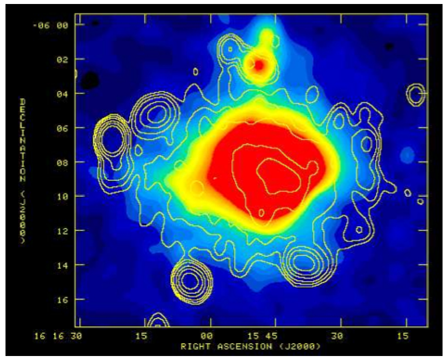
http://www.astron.nl/radio-observatory/astronomers/lofar-astronomers
http://www.lofar.org/operations/doku.php

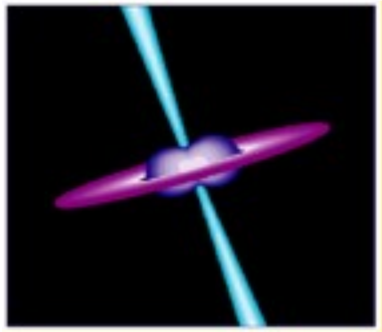
LOFAR Science : Key Scientific Projects

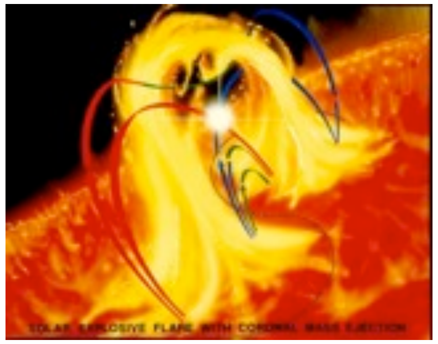


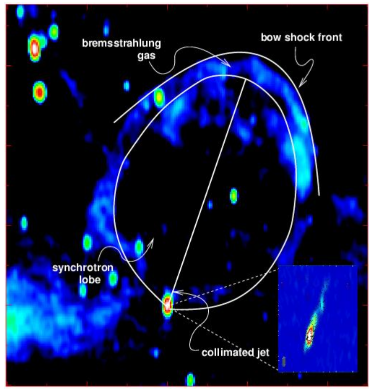




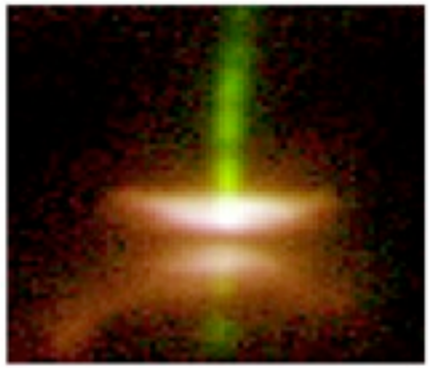


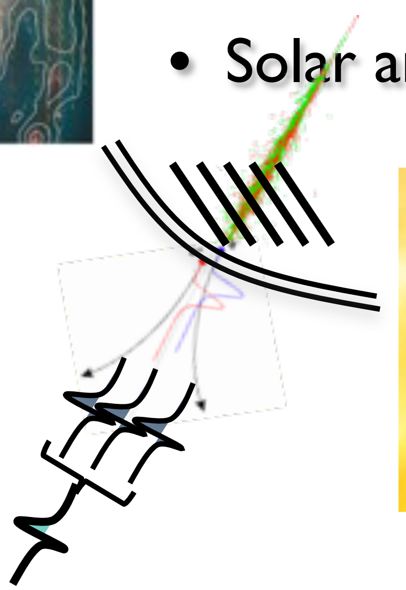


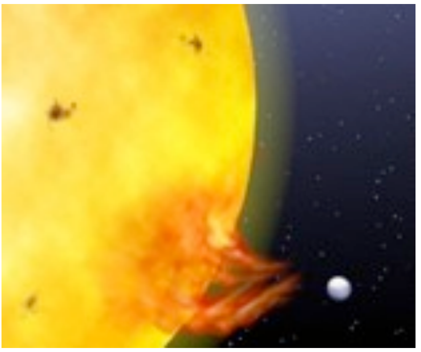


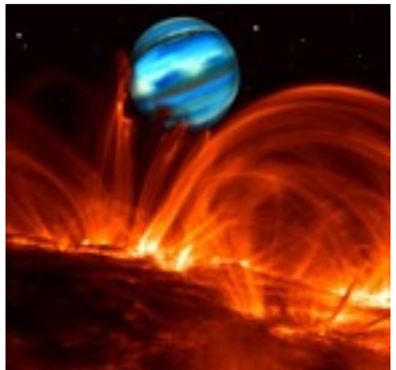


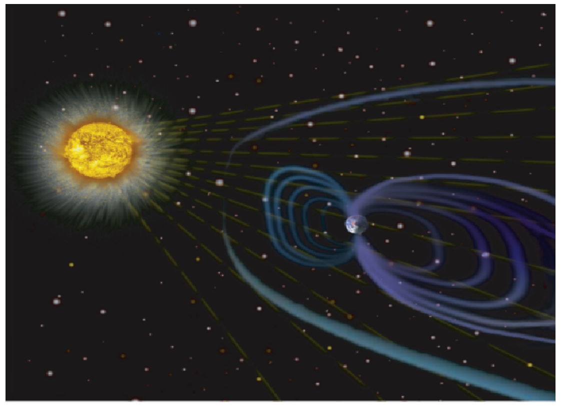
- Cosmology, Reionization *(Groningen)*
- Surveyx, Star Formation, NAG, clusters… *(Leiden)*
- Transients *(Amsterdam / Manchester / NRAO / Obs. Paris)*
- Cosmic Rays, Neutrinos on the Moon *(Nijmegen)*
- Galactic Magnetisme *(Bonn)*
- Solar and Space Physics *(Potsdam)*

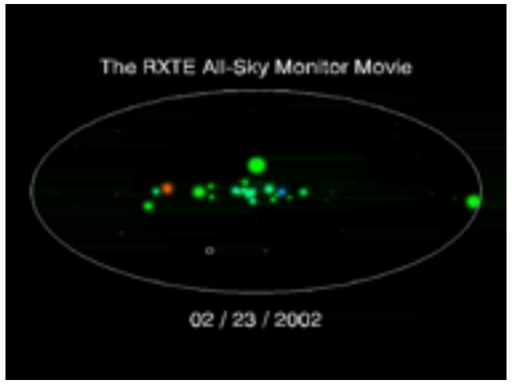




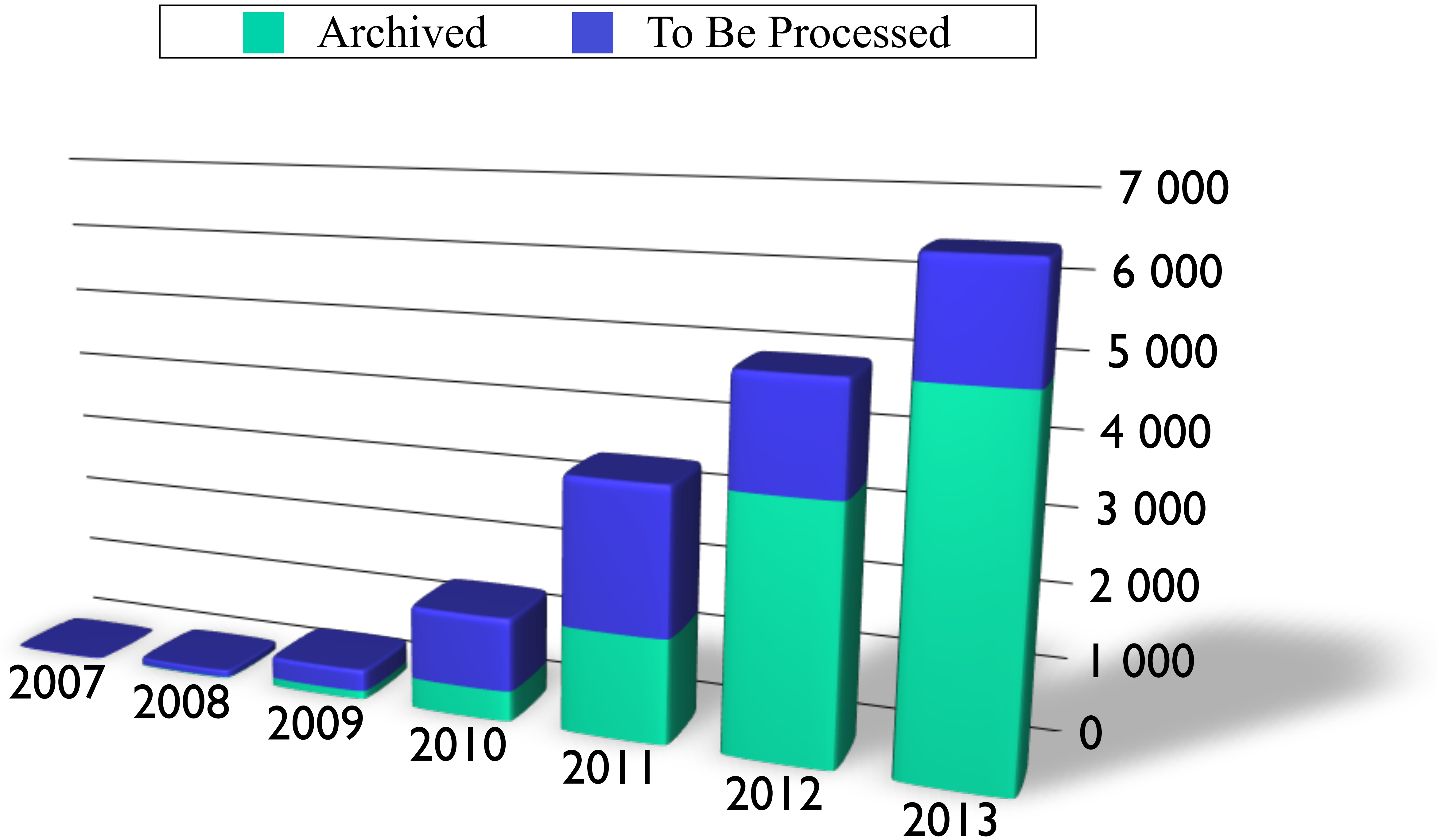








LOFAR archive growth



Estimated growth rate ~ 2.5 Pb/yr

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]	[illegible]	Determining the origin and (magnetic) substructure of the Fermi bubbles	[illegible]	[illegible]

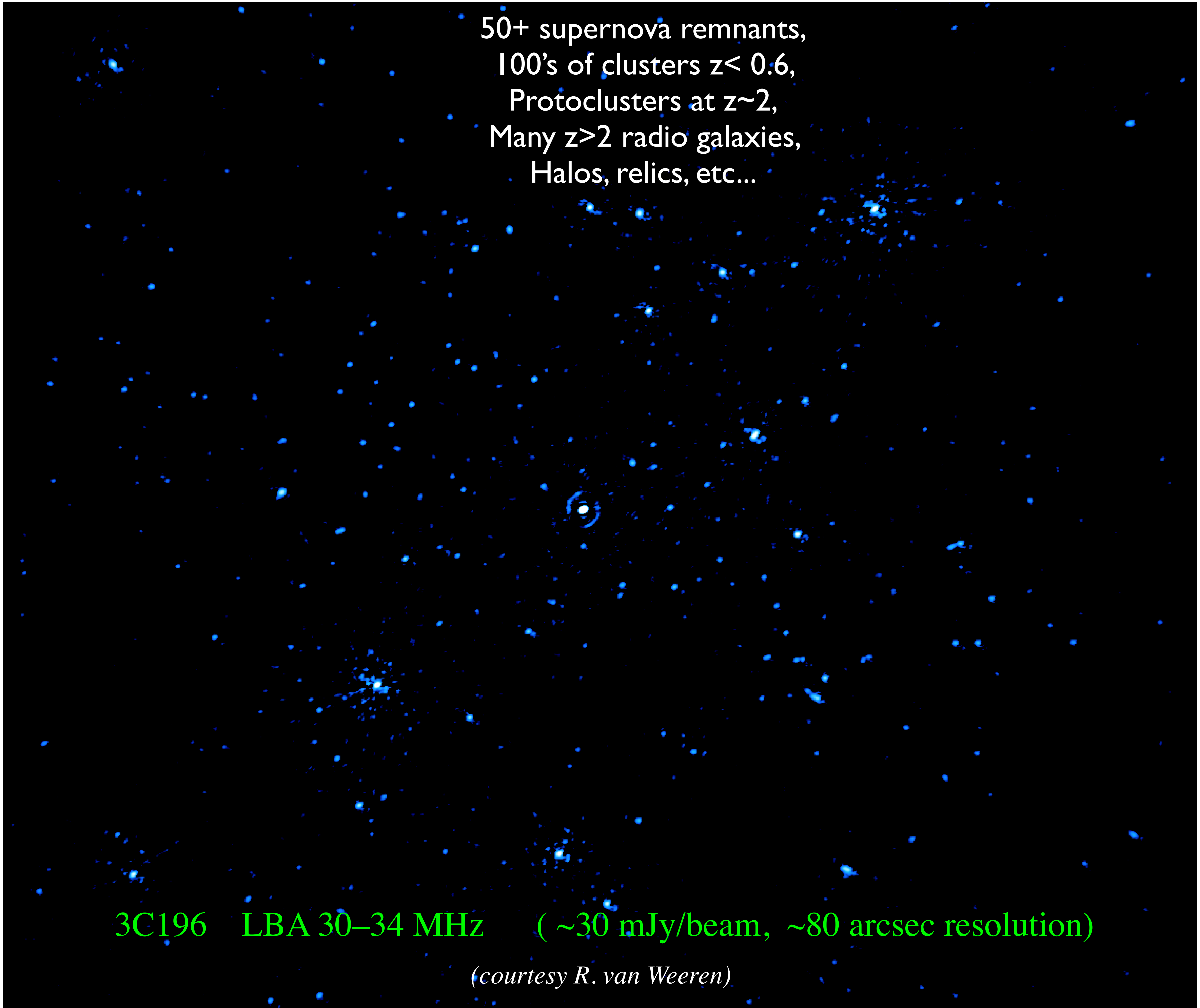
Week number	week day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
21, 20th May	Mon	LC0_003 - Zenith fields - 24 hrs												Stress system runs + TBB runs	LC0_031 - MS0735.6 - 6hrs						LC0_019 (EoR)				
	Tue	LC0_019 (EoR)						Investigation week-end failures; Stress system runs; TBB 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

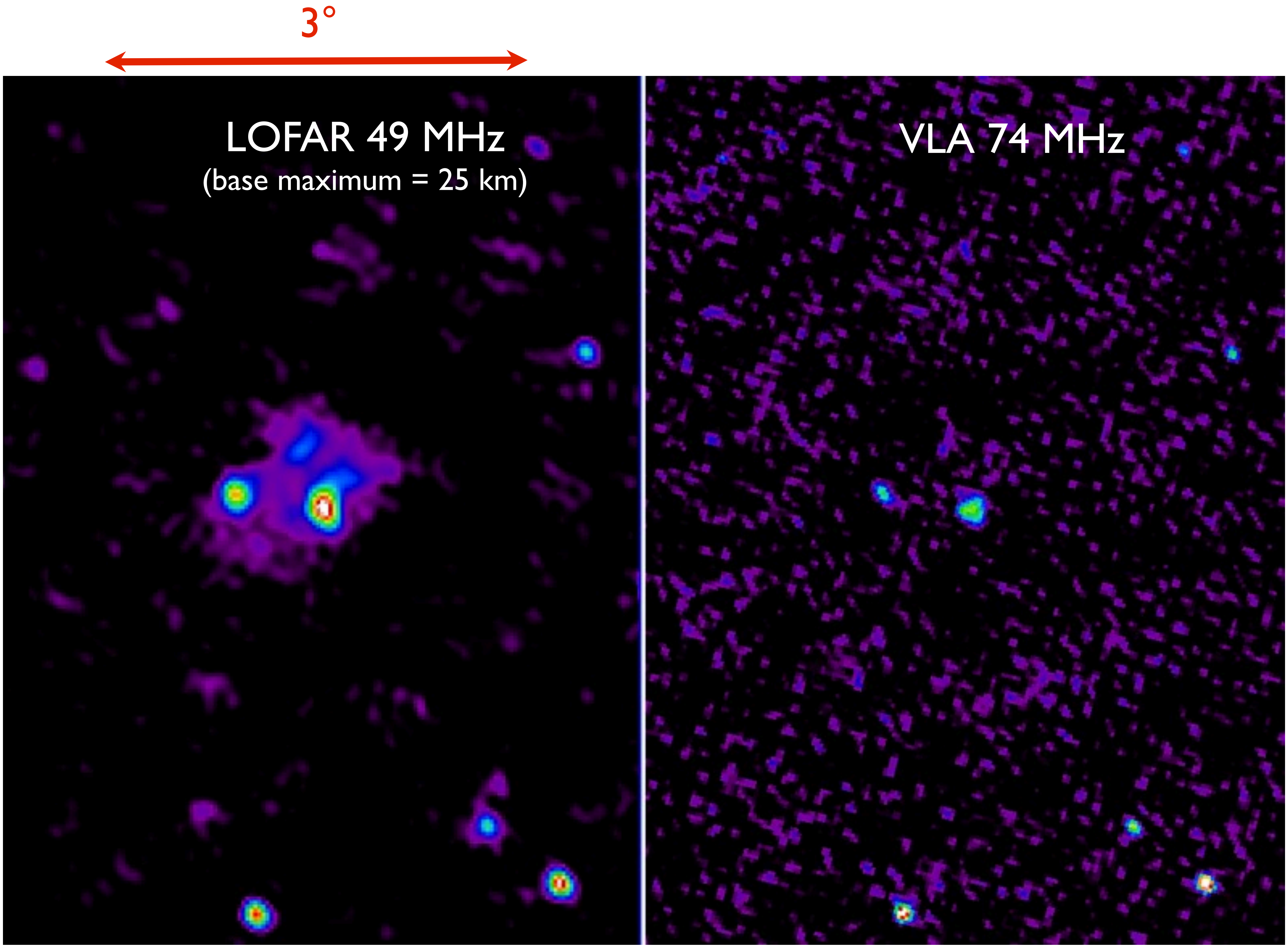
- Cycle 0 will run until 2013 November 14
- Cycle 1 will run from 2013 November 15 to 2014 May 14
- The proposal (issued in June) will have a deadline at 2013 September 6
- 10% open time on 1st year → 65% on 5th year
  + complement under KSP «umbrellas»
  + commissionning / development LOFAR v2.0
- Proposals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

- RADIO COUNTERPARTS TO GW EVENTS
- RADIO PROPAGATION
- TRANSIENT RADIO SKY
- LOFAR TELESCOPE & OPERATING MODES
- LOFAR EARLY RESULTS
- TRANSIENT SURVEYS & SEARCH STRATEGY
- ALERTS MANAGEMENT
- ORGANISATION
- SOME CONCLUSIONS
- REFERENCES

All-sky Surveys with LOFAR

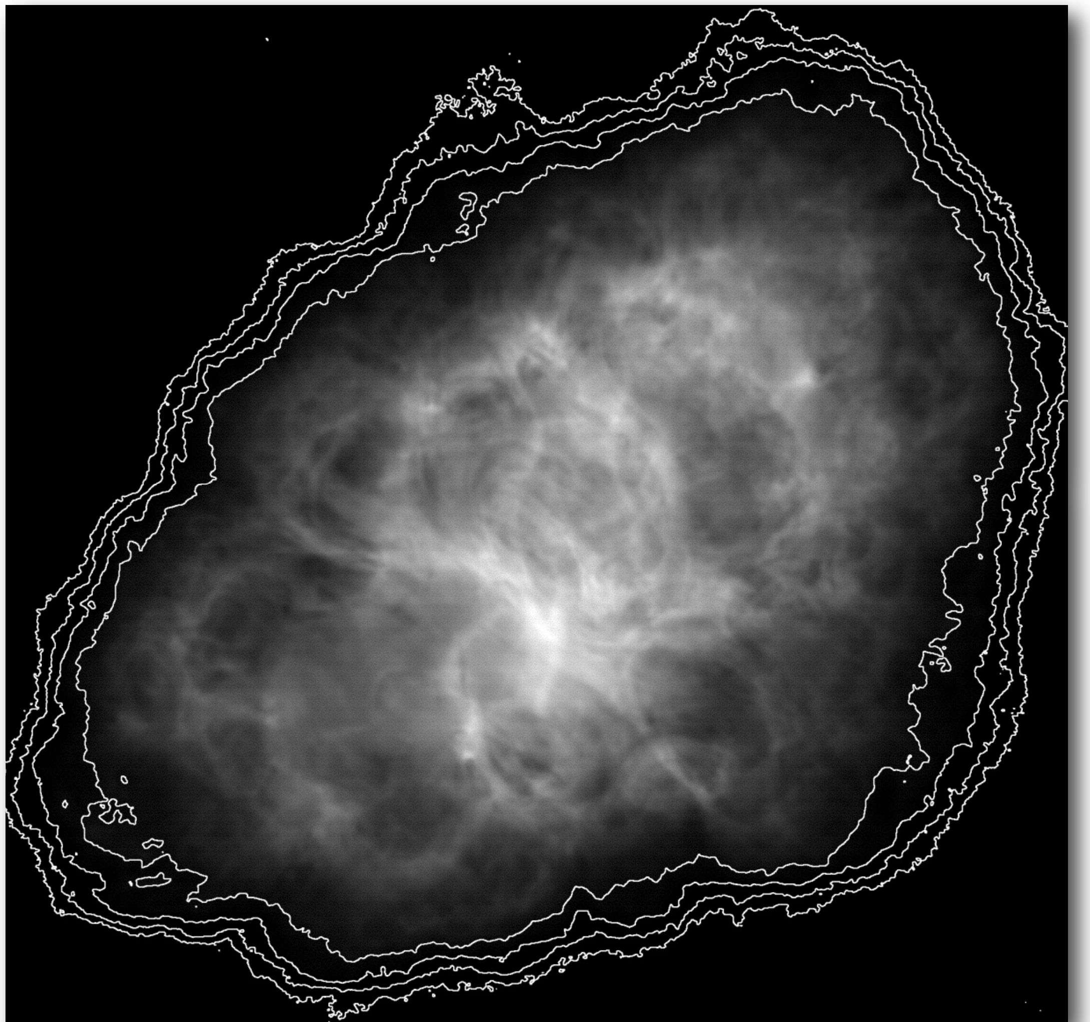


Extended / diffuse emissions



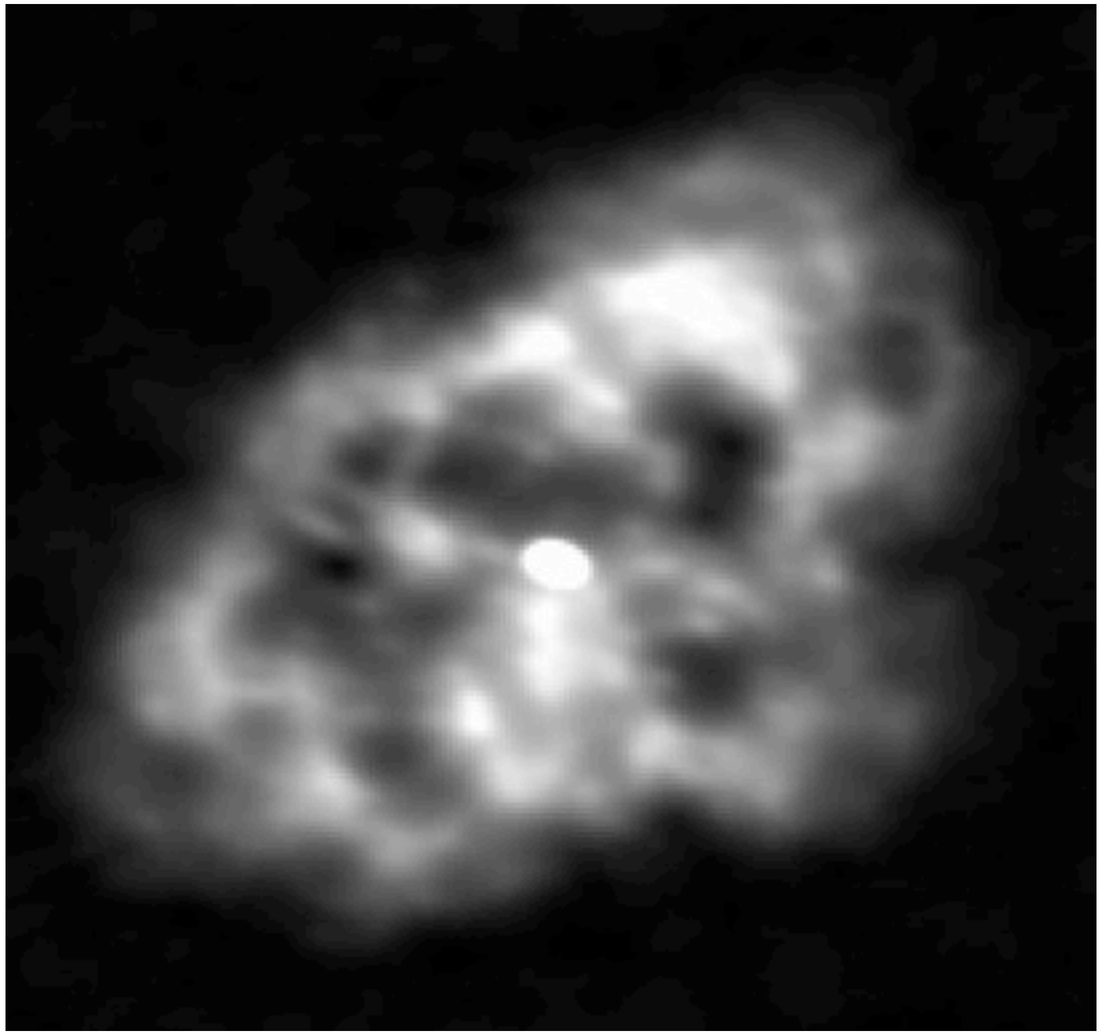
Crab Nebula (Taurus A) with international baselines

VLA 5 GHz



Bietenholz et al., 2004

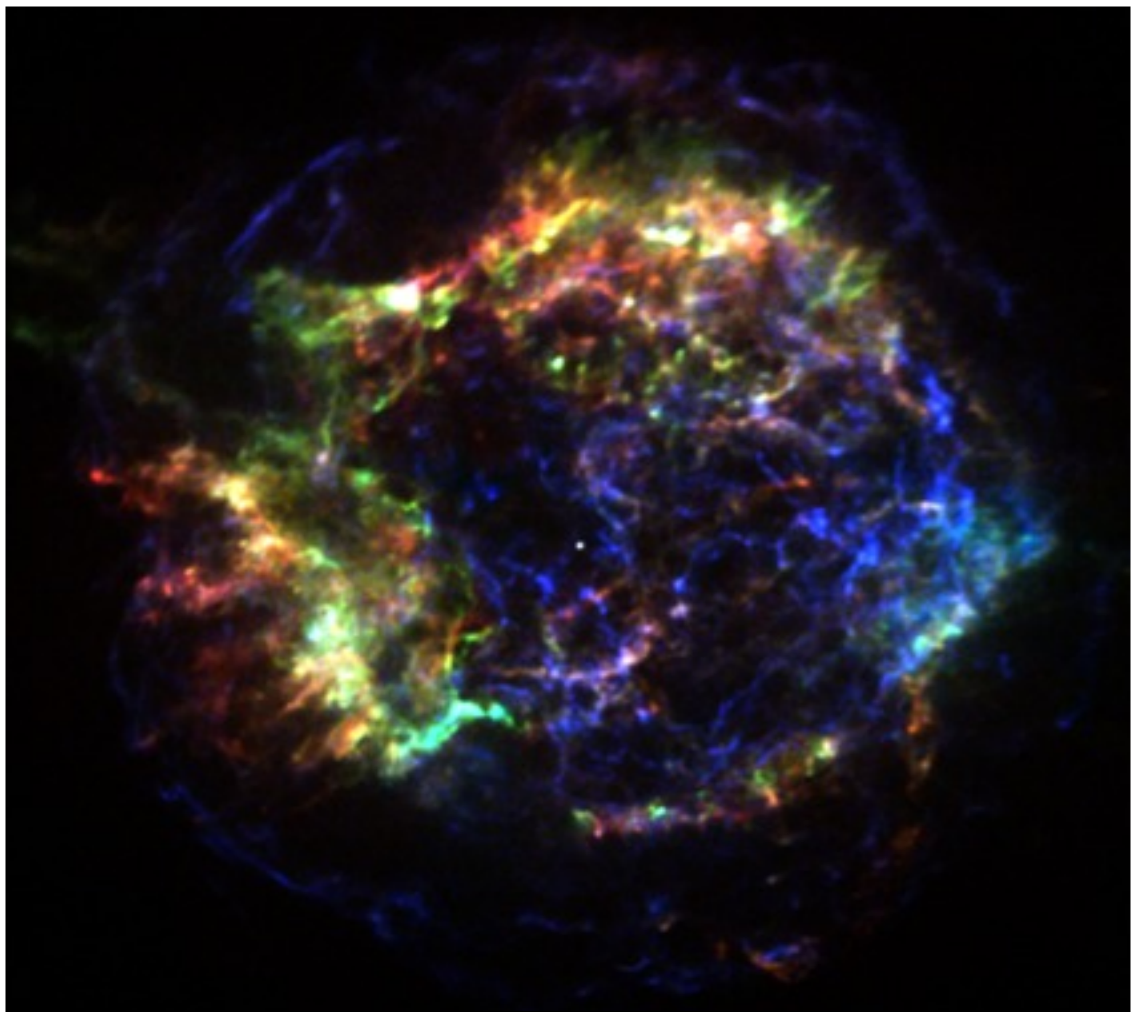
LOFAR 250 MHz



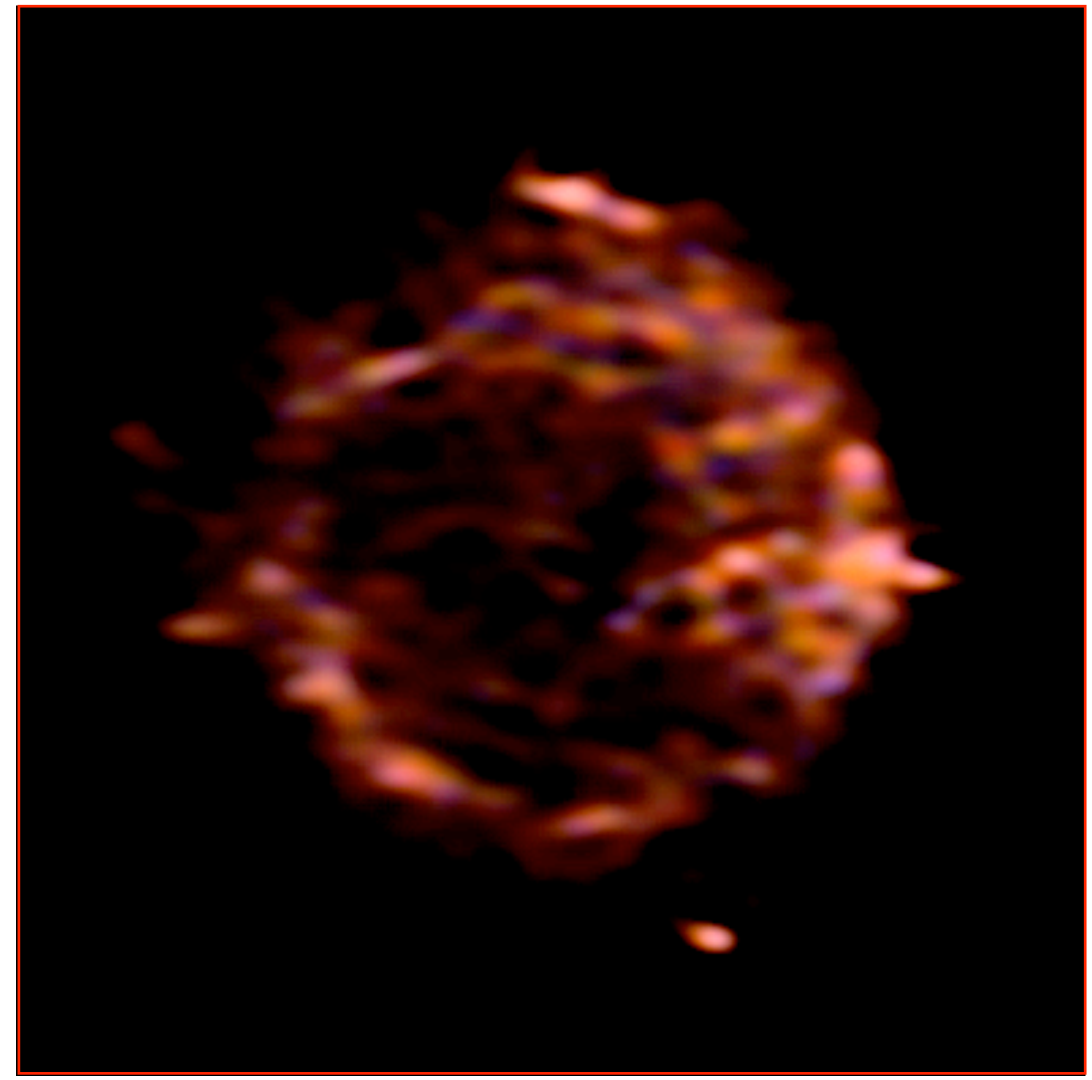
Wucknitz et al., 2011

Cassiopeia A

Chandra



LOFAR



Brentjens et al., 2011

M 87

commissioning data

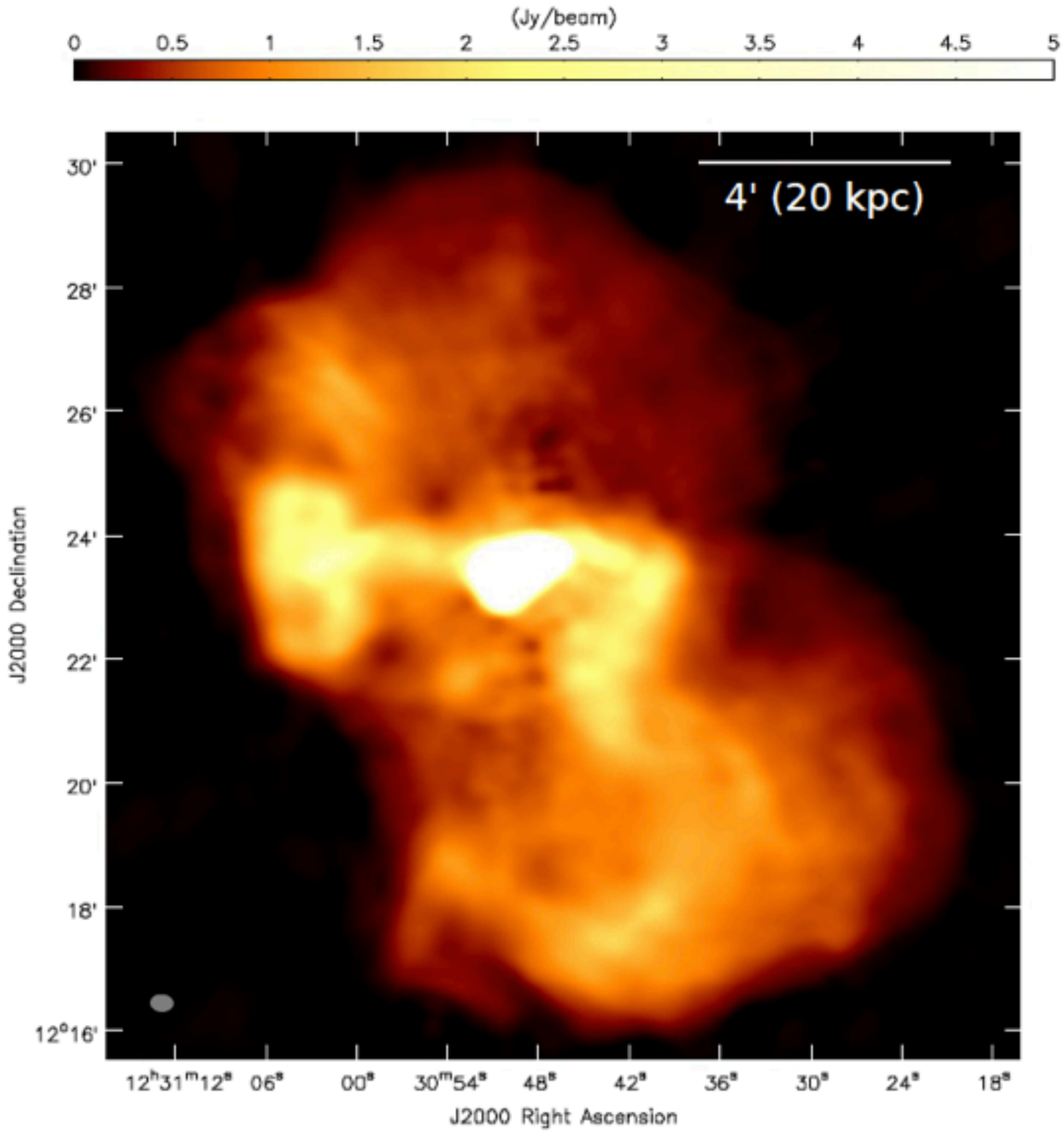


Fig. 5. LOFAR-HBA image of Virgo A at 140 MHz. The rms noise level is σ = 20 mJy/beam, the flux peak is 101 Jy/beam and the beam size is 21″ × 15″ (ellipse in the bottom-left corner). Some deconvolution errors are visible as small holes slightly above and below the bright core.

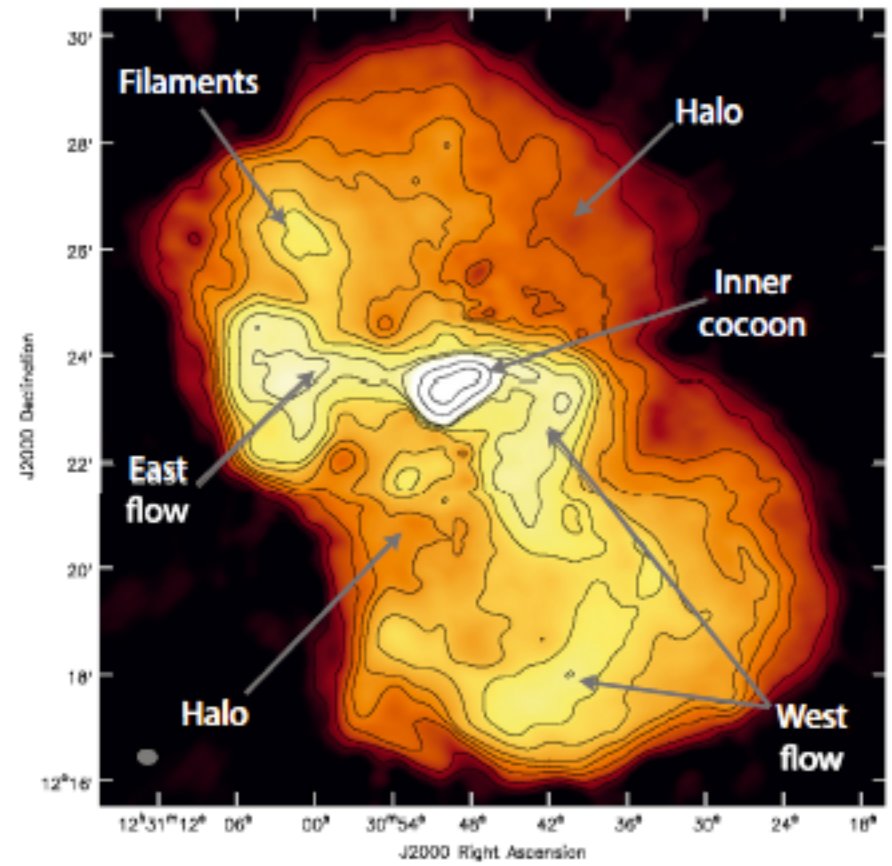
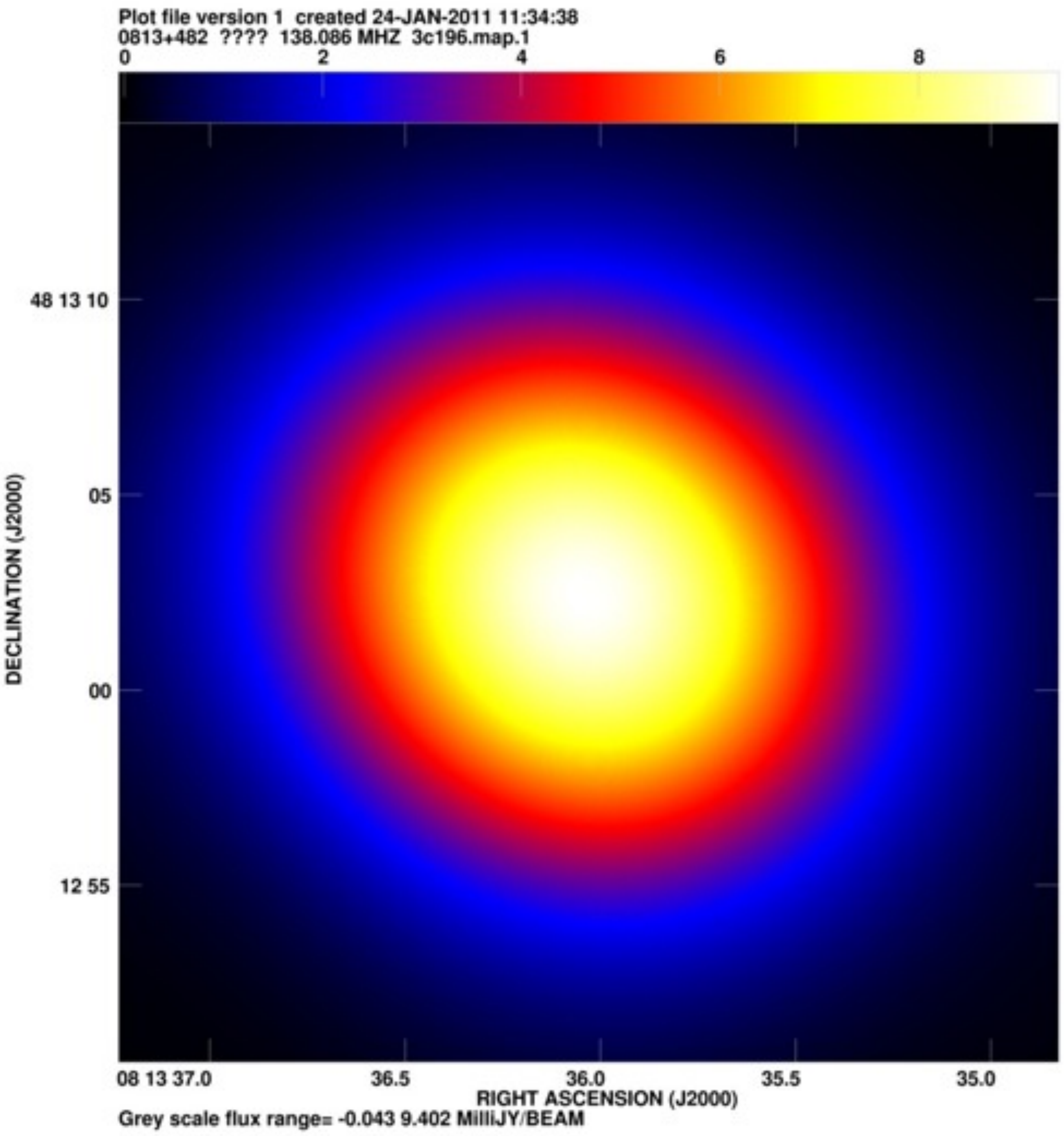


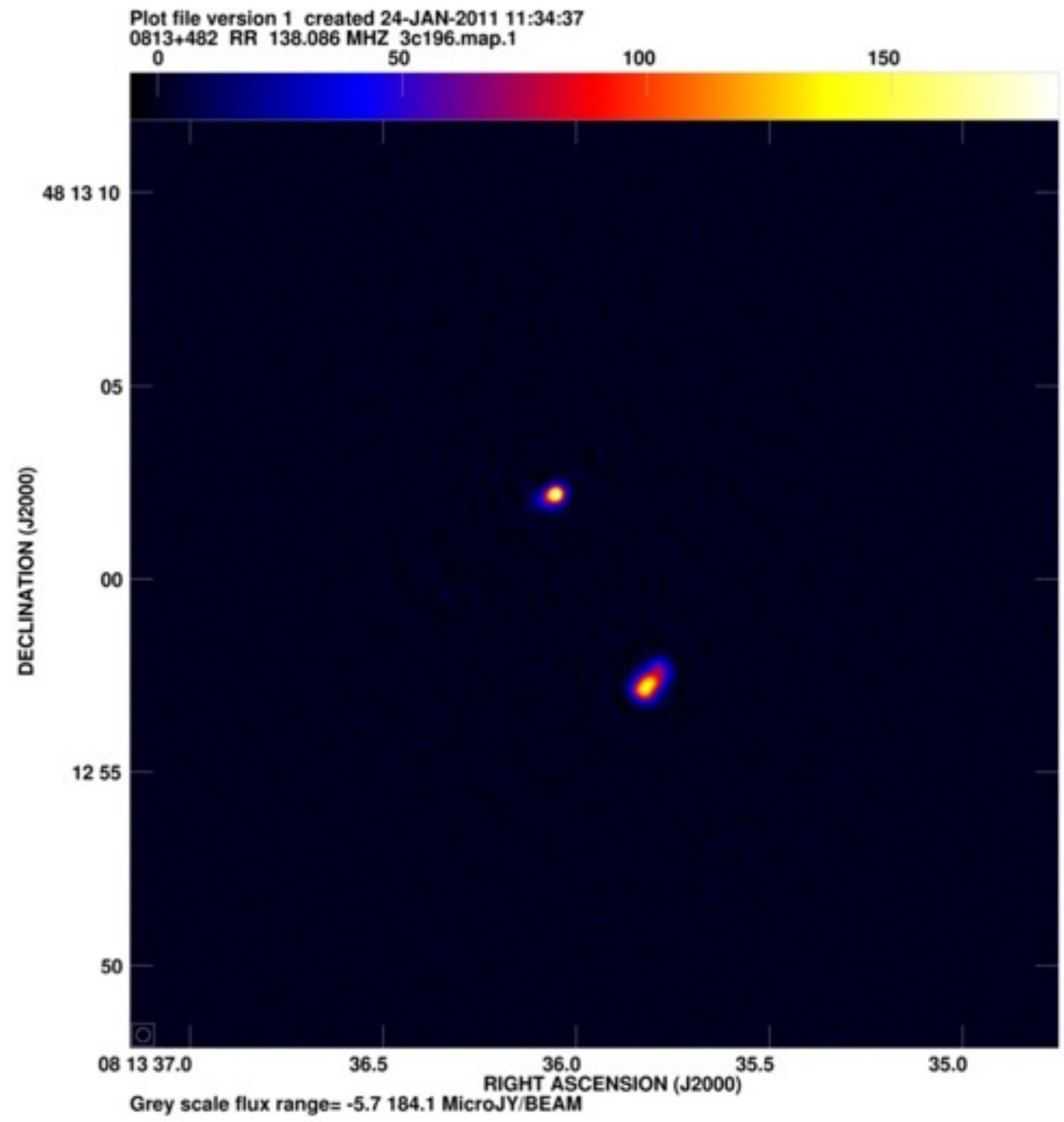
Fig. 8. Same as Fig. 5 with most prominent features described in the text labelled. Contour lines are at (1, 2.5, 5, 7.5, 10, 15, 20, 25, 30, 35, 45, 250, 1000) × 3σ.

de Gasperin et al., 2012

3C 196

commissioning data





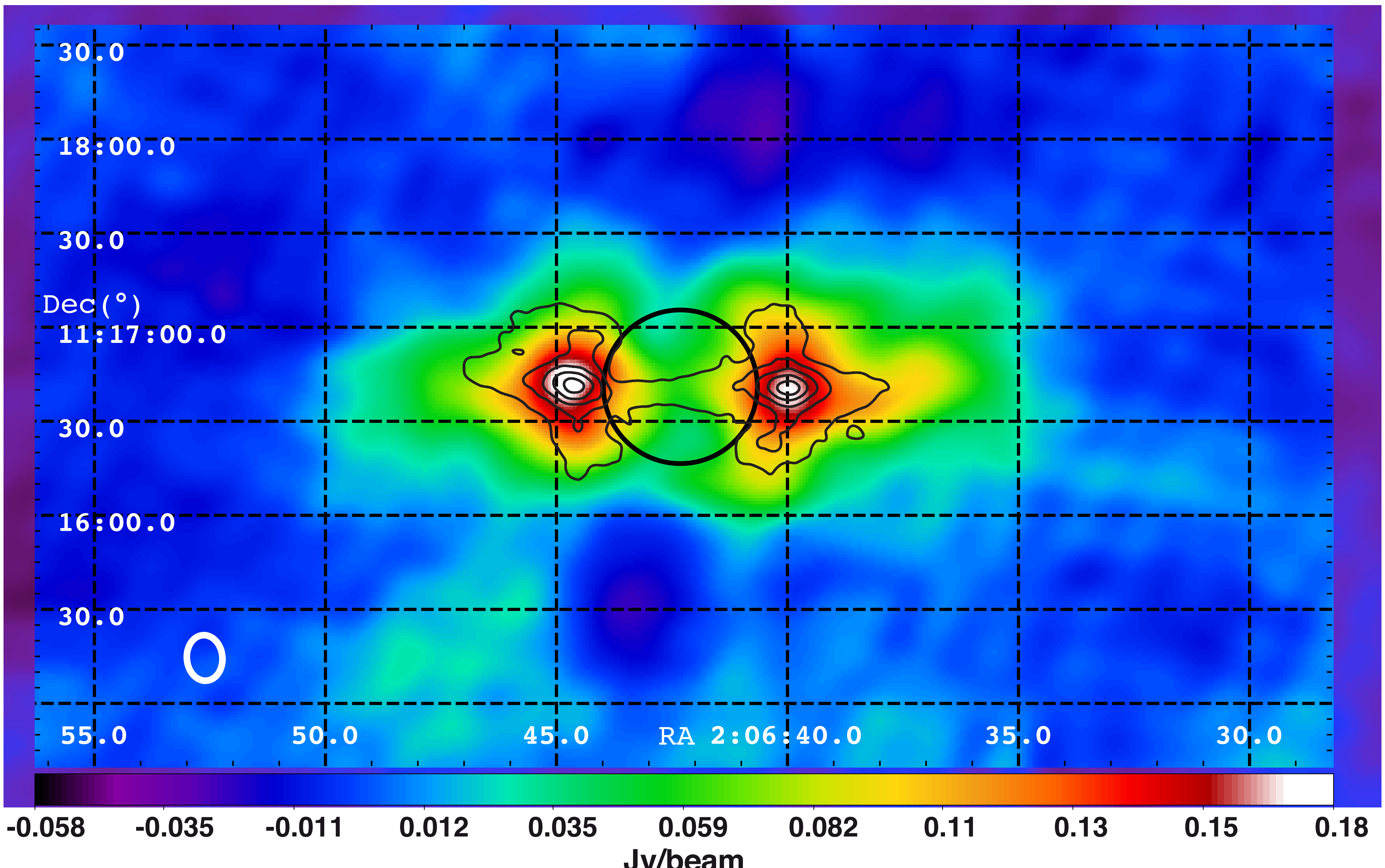
courtesy O. Wucknitz

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

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

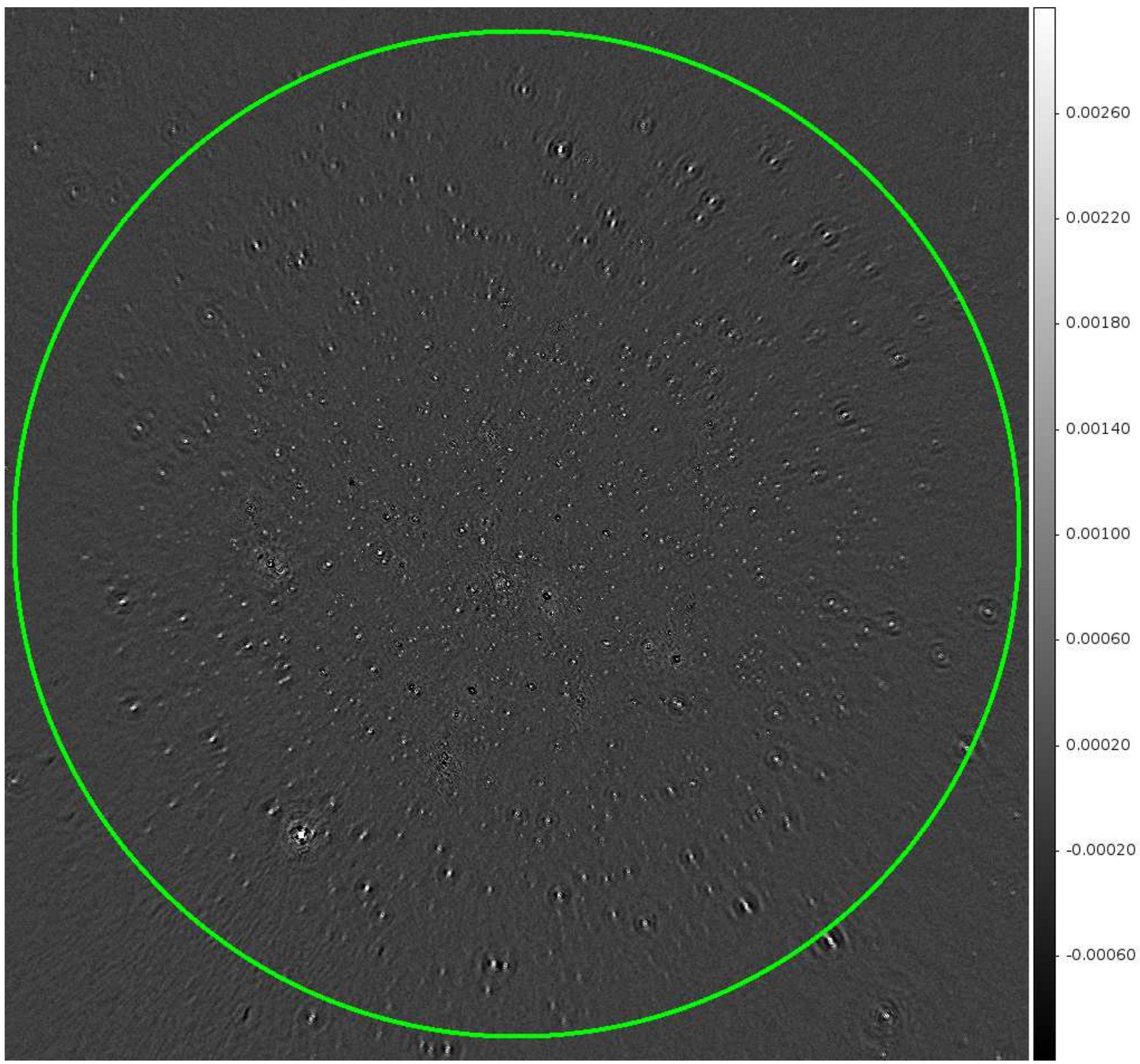


Fig. 9. The NCP image after multi-directional calibration and source subtraction using SAGECal. After a shallow deconvolution using CASA (mainly to estimate the PSF), the skymodel is restored onto the image. The circle indicates an area of diameter 10 degrees. The image has 12000 × 12000 pixels of size 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.

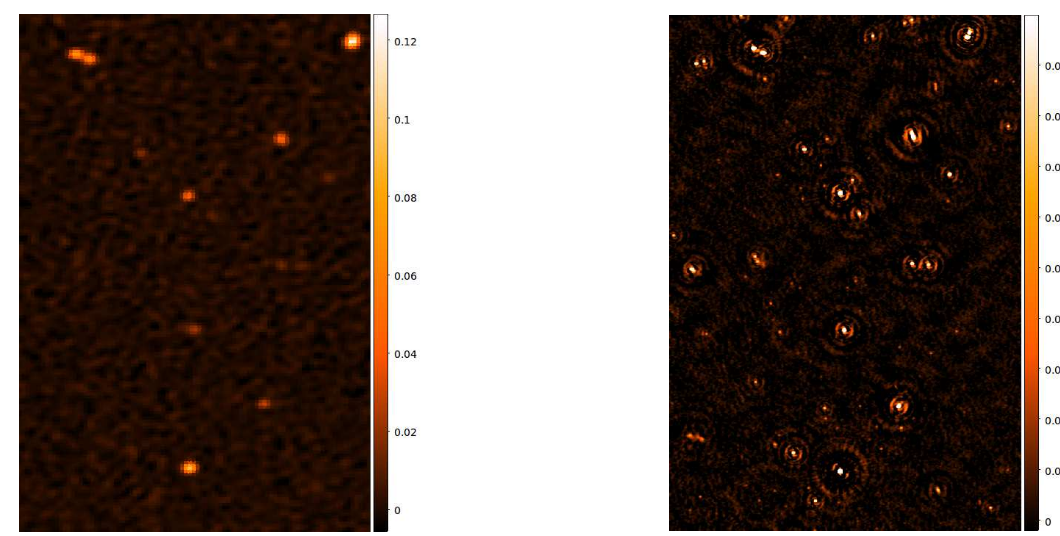
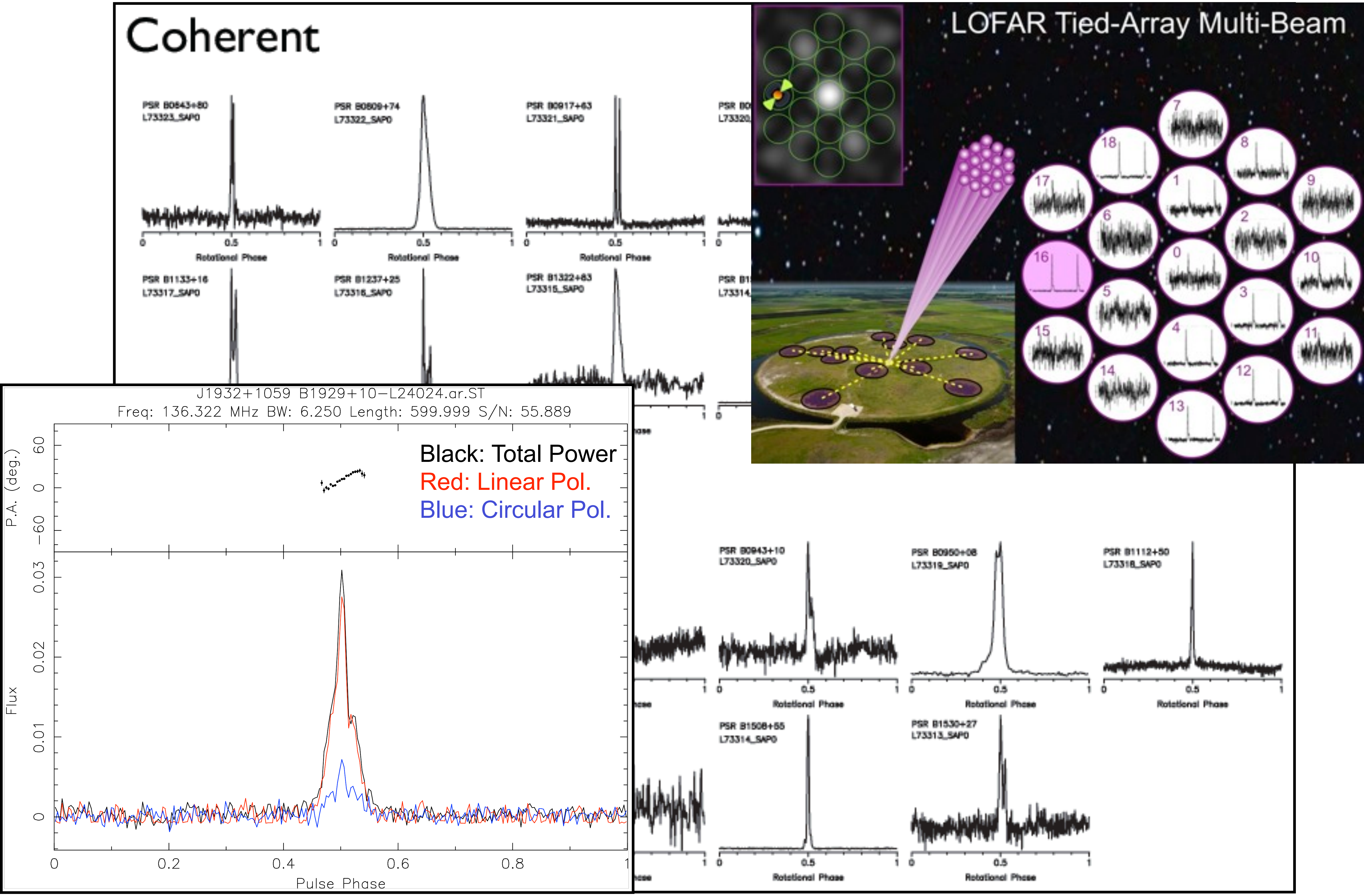


Fig. 11. Comparison of a small area of the NCP image, size 0.6 × 1.0 degrees with WENSS. The left panel shows the image from WENSS (PSF 60″) while the right panel shows the equivalent image made using LOFAR (PSF 12″). The colourbar units are in Jy/PSF. Many more sources, at much higher angular resolution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

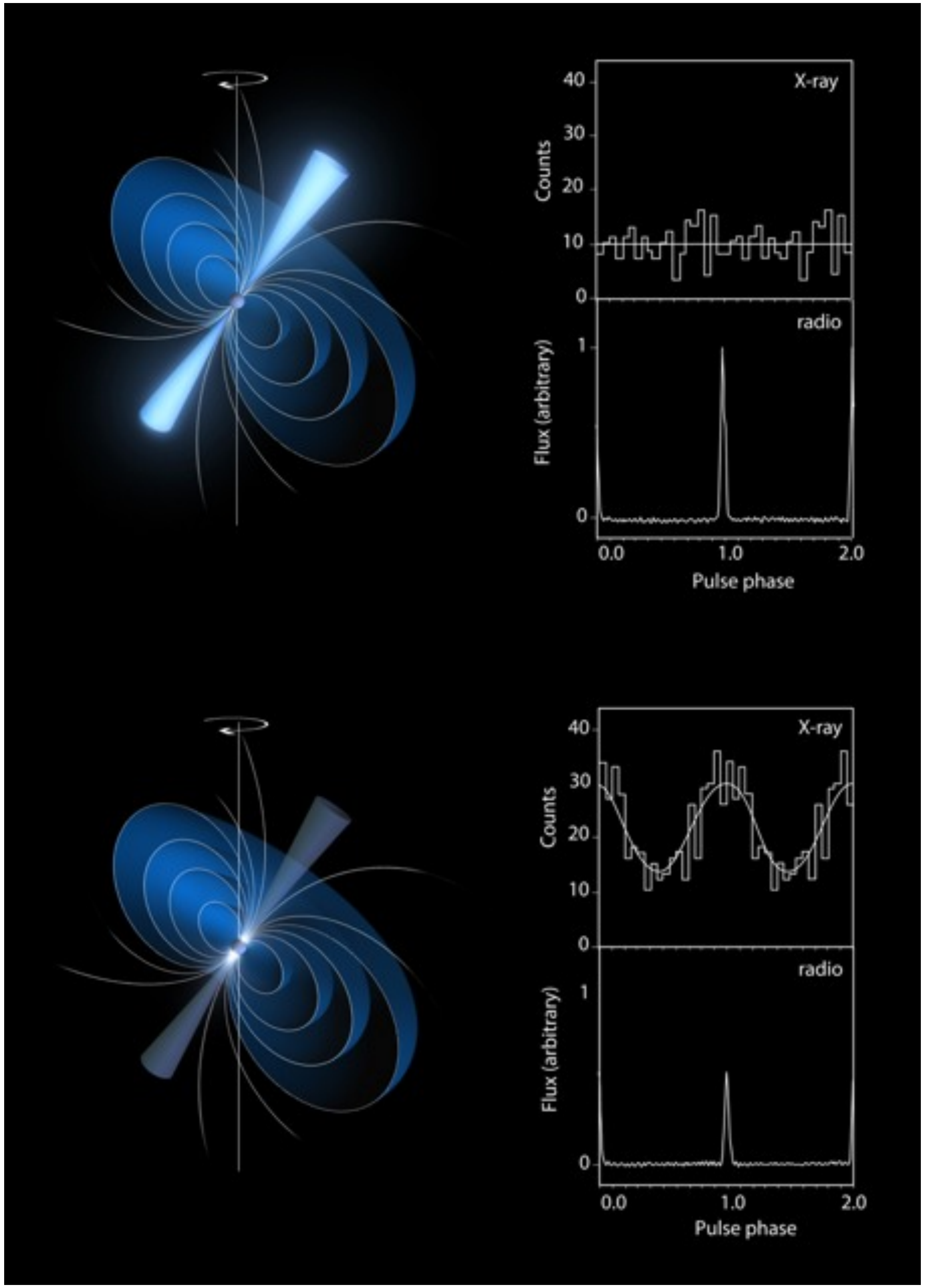
Yatawatta et al., 2013

100+ Pulsars detected with LOFAR



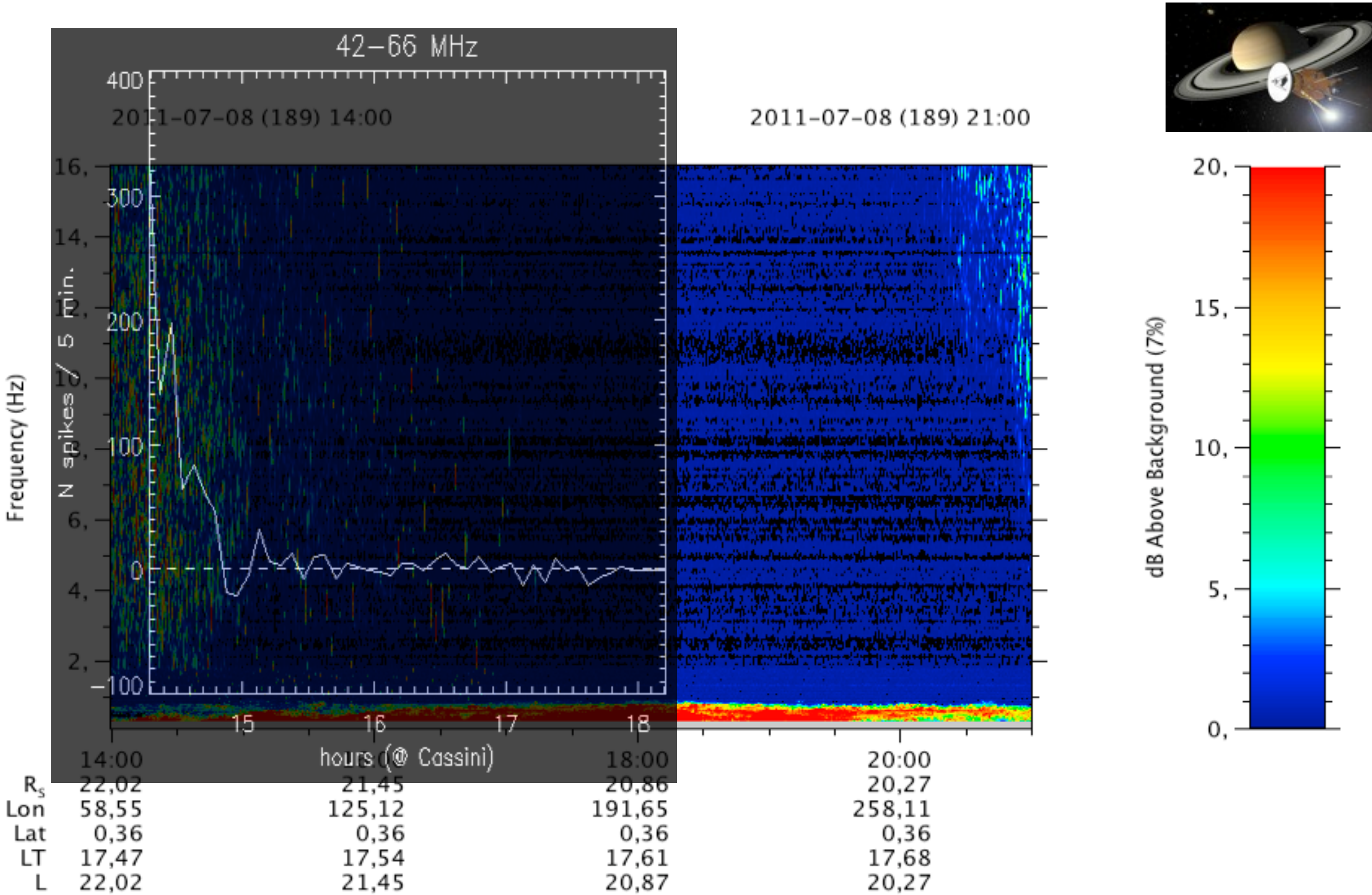
J. Hessels & Pulsars WG

Synchronous X-ray and Radio Mode Switches: a Rapid Global Transformation of the Pulsar Magnetosphere



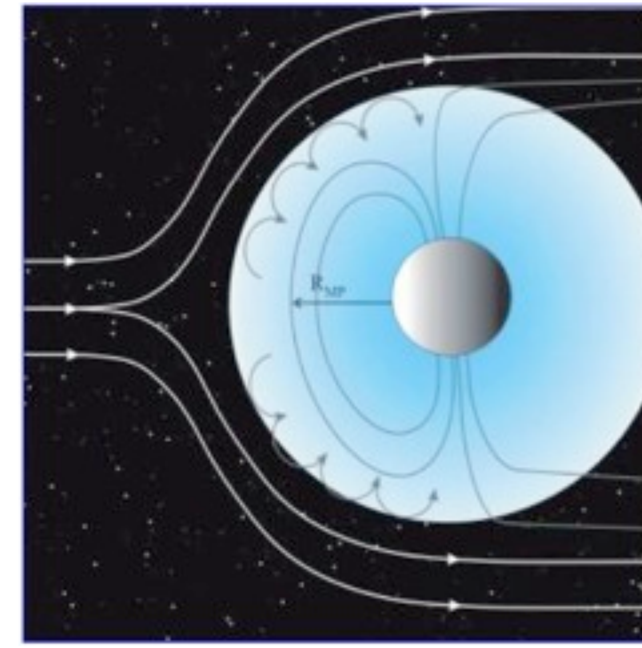
Hermsen et al., 2012

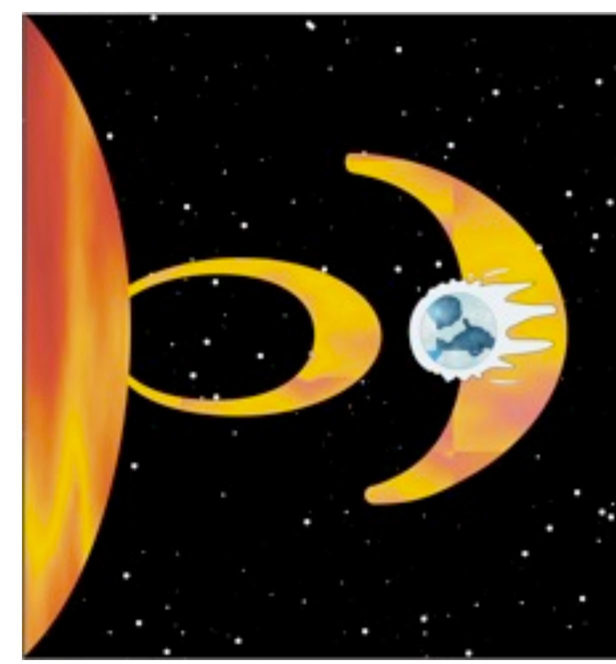
Radio signatures from Saturn's lightning



Zarka et al., 2012

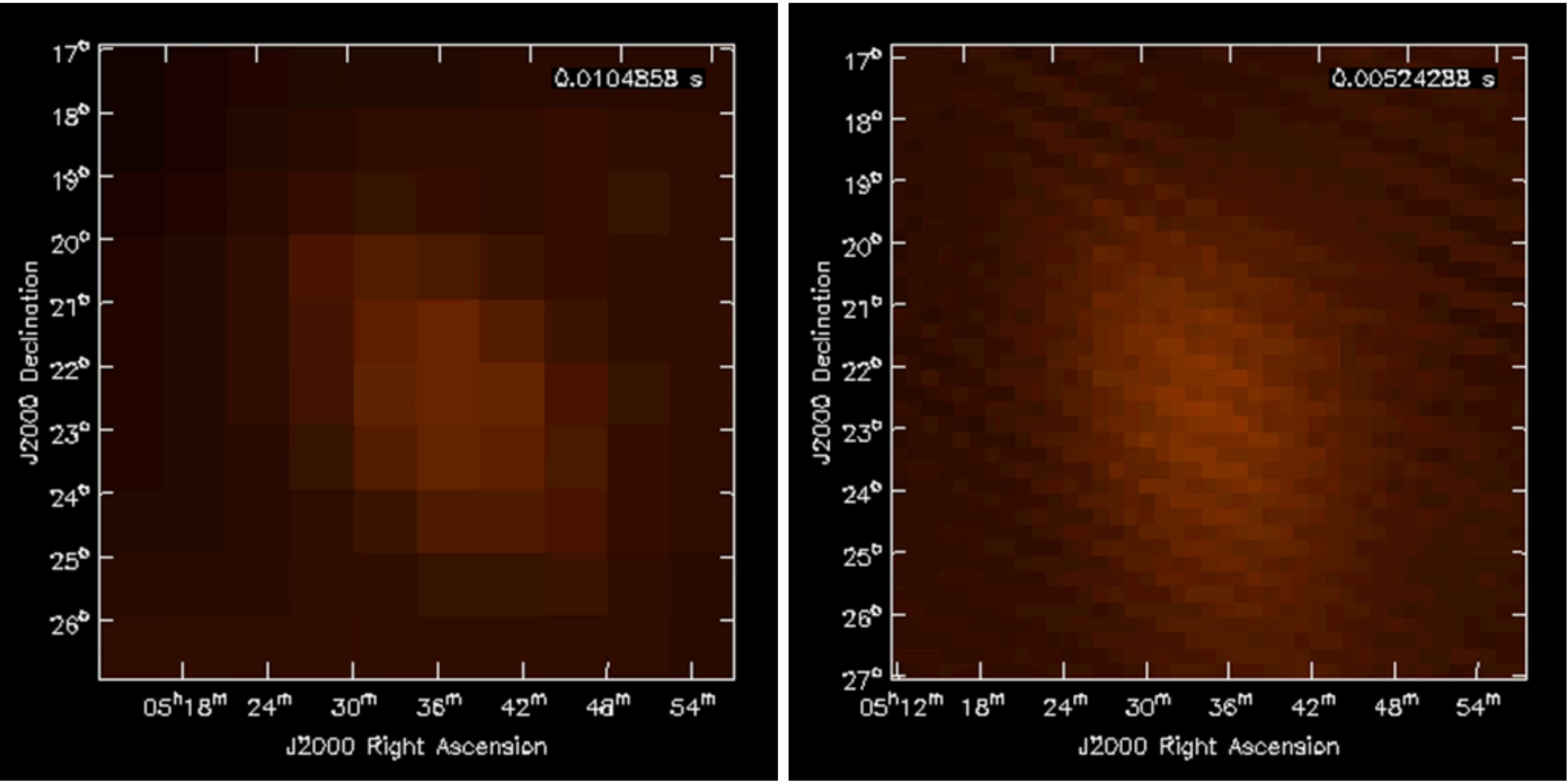
Coherent radio emissions from exoplanets ?





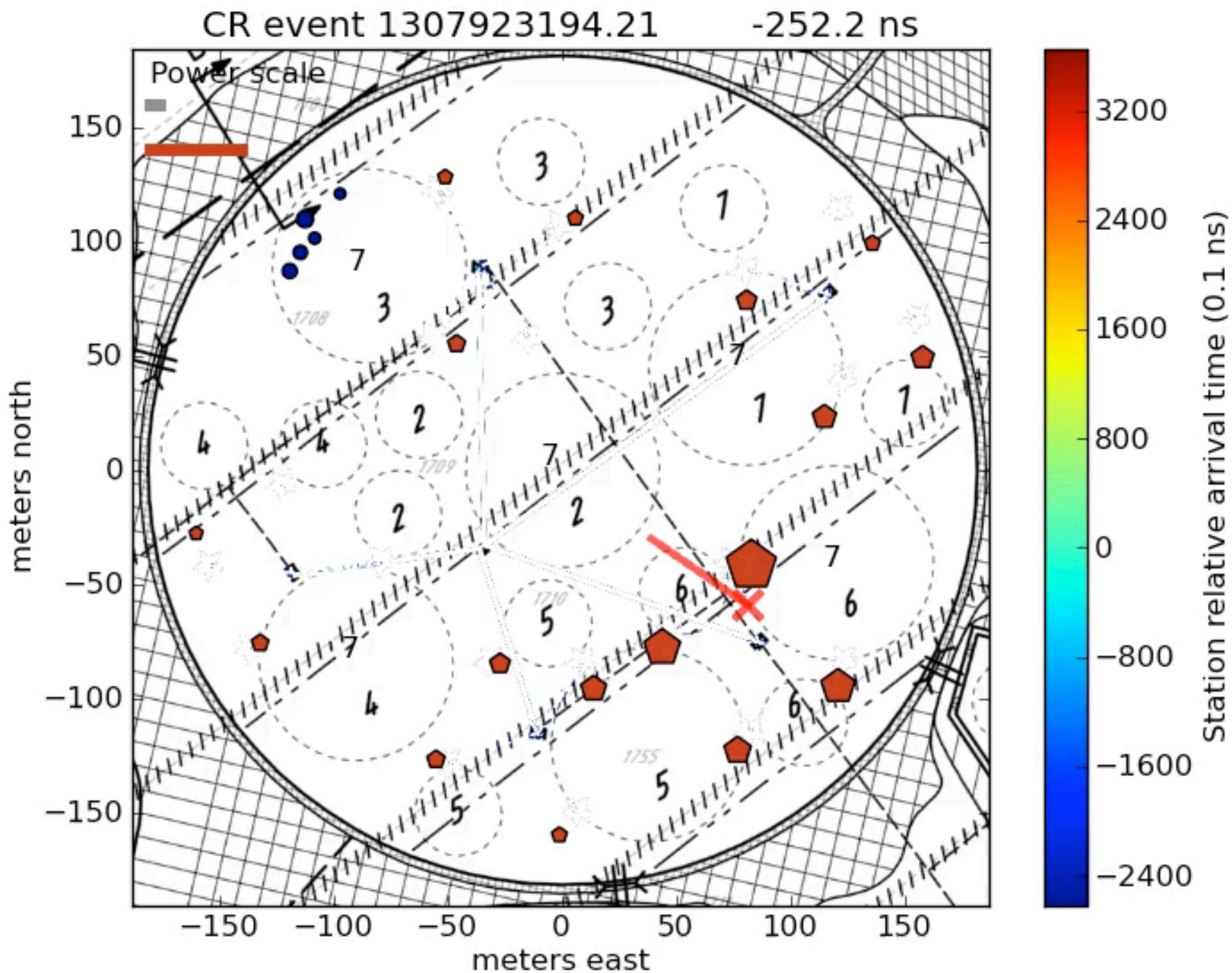
Zarka et al., in progress

Giant Pulses from Crab Pulsar (TBB imaging)



ter Veen et al., 2011

Cosmic Rays



Circles: LOFAR antennas, Pentagons: LORA particle detectors, size denotes signal strength

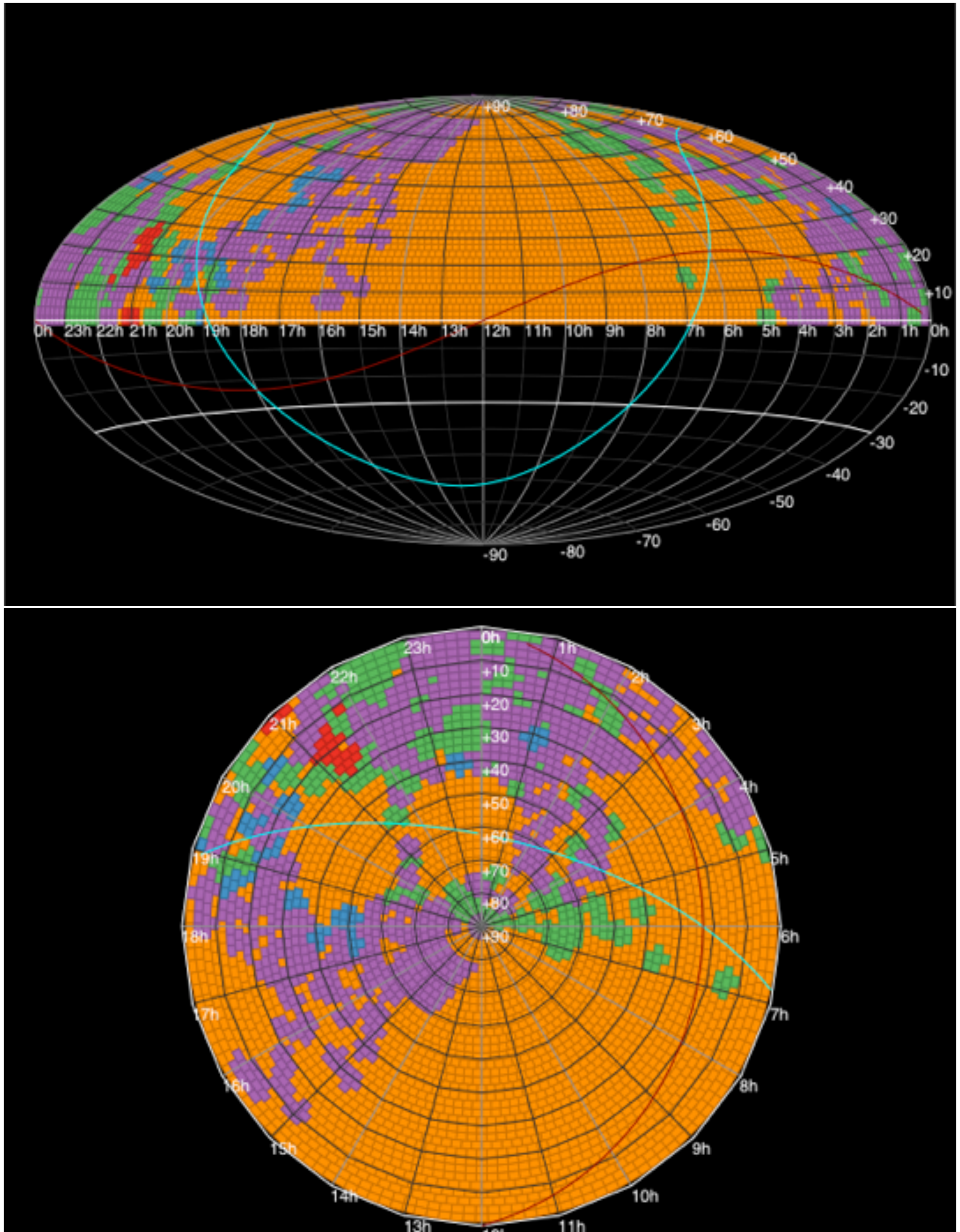
courtesy: H. Falcke & CR WG

MSSS

MSSS HBA

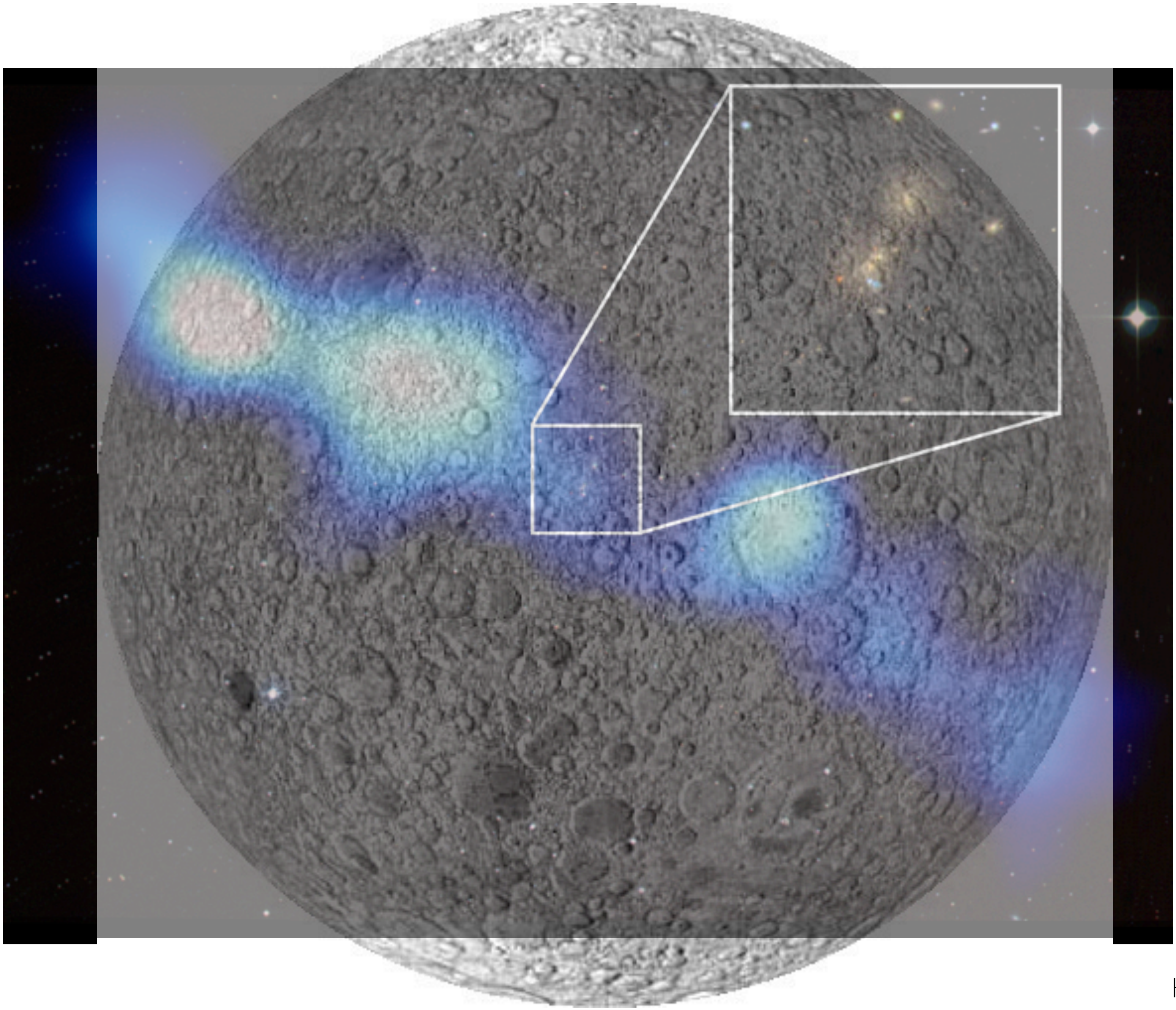
Number of Targets	3616
Number of Calibrators	8
Start Date	8 Feb. 2013
Stop Date	17 May 2013
Completed Fields	1291 (35.7%)
Information collected	21 May 2013

- Data available on CEP (10.3%)
- Data archived (25.4%)
- Partial data available (1.7%)
- Data missing (0.6%)
- Not yet observed (61.9%)



MSSS observations ⇒ giant radio galaxy

around triplet UGC 09555



Heald et al., 2013

- RADIO COUNTERPARTS TO GW EVENTS
- RADIO PROPAGATION
- TRANSIENT RADIO SKY
- LOFAR TELESCOPE & OPERATING MODES
- LOFAR EARLY RESULTS
- TRANSIENT SURVEYS & SEARCH STRATEGY
- ALERTS MANAGEMENT
- ORGANISATION
- SOME CONCLUSIONS
- REFERENCES

TRANSIENT SURVEYS & SEARCH STRATEGY

- Targets of searches :
  - Prompt signal : mJy to MJy (i.e. highly uncertain)
  - Early (afterglow) radio emission : beamed on-axis, ~10 mJy, timescale ~ days
  - Late (afterglow) radio emission : ~isotropic, 0.1 – 1 mJy, timescale ~ month
- Signal will be dispersively delayed

TRANSIENT SURVEYS & SEARCH STRATEGY

- Key parameters of transient surveys :
  - Sensitivity (needs $S < 0.1$ mJy)
  - FoV (Ω as large as possible)

- New Generation Radiotelescopes have large FoV (~ present X & γ telescopes that have found many transients)

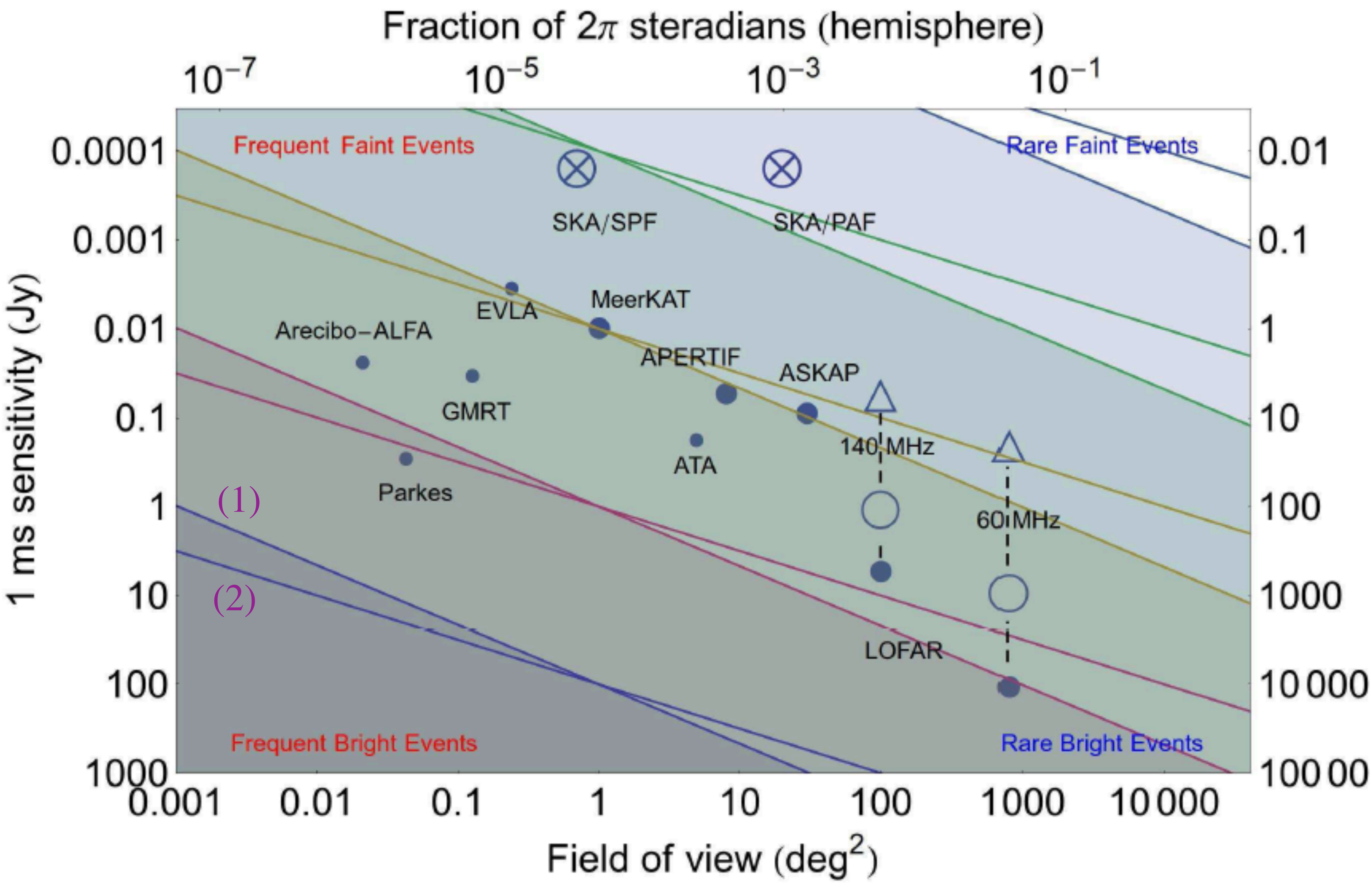
- A key science goal for LOFAR is to detect radio transients : extremely wide FOV

Radio Facility	Observing Freq.	Field of View	1 hr rms	Beam	Start Date
ASKAP	1.4 GHz	30 deg^2	30 uJy	20”	2013
Apertif	1.4 GHz	8 deg^2	50 uJy	15”	2013
MeerKAT	1.4 GHz	1.5 deg^2	35 uJy	15”	2013
EVLA	1.4 GHz	0.25 deg^2	7 uJy	1.3-45”	2010
EVLA	327 MHz	5 deg^2	2 mJy	5-18”	2011
LOFAR	110-240 MHz	50 deg^2	1 mJy	5”	2011
EVLA	74 MHz	100 deg^2	50 mJy	25-80”	2011
MWA	80-300 MHz	1000 deg^2	8 mJy	300”	2011+
LOFAR	15-80 MHz	500 deg^2	8 mJy	120”	2011

TRANSIENT SURVEYS & SEARCH STRATEGY

(1) $N \propto \Omega\, d^3 \propto \Omega\, S^{-3/2}$ for transients (N = constant for $S \propto \Omega^{2/3}$)

(2) $N \propto \Omega / \delta t \propto \Omega\, S^{-2}$ for surveys (N = constant for $S \propto \Omega^{1/2}$)



TRANSIENT SURVEYS & SEARCH STRATEGY

→ All NG insruments have comparable survey speeds

- LOFAR in good place, trade-off Ω - S possible

- For steep spectra, LOFAR will be a powerful transients detector (world leading for coherent emission of index -2)

- N transients with LOFAR will depends on spectral index, time characteristics of transients, direction of observation, propagation …

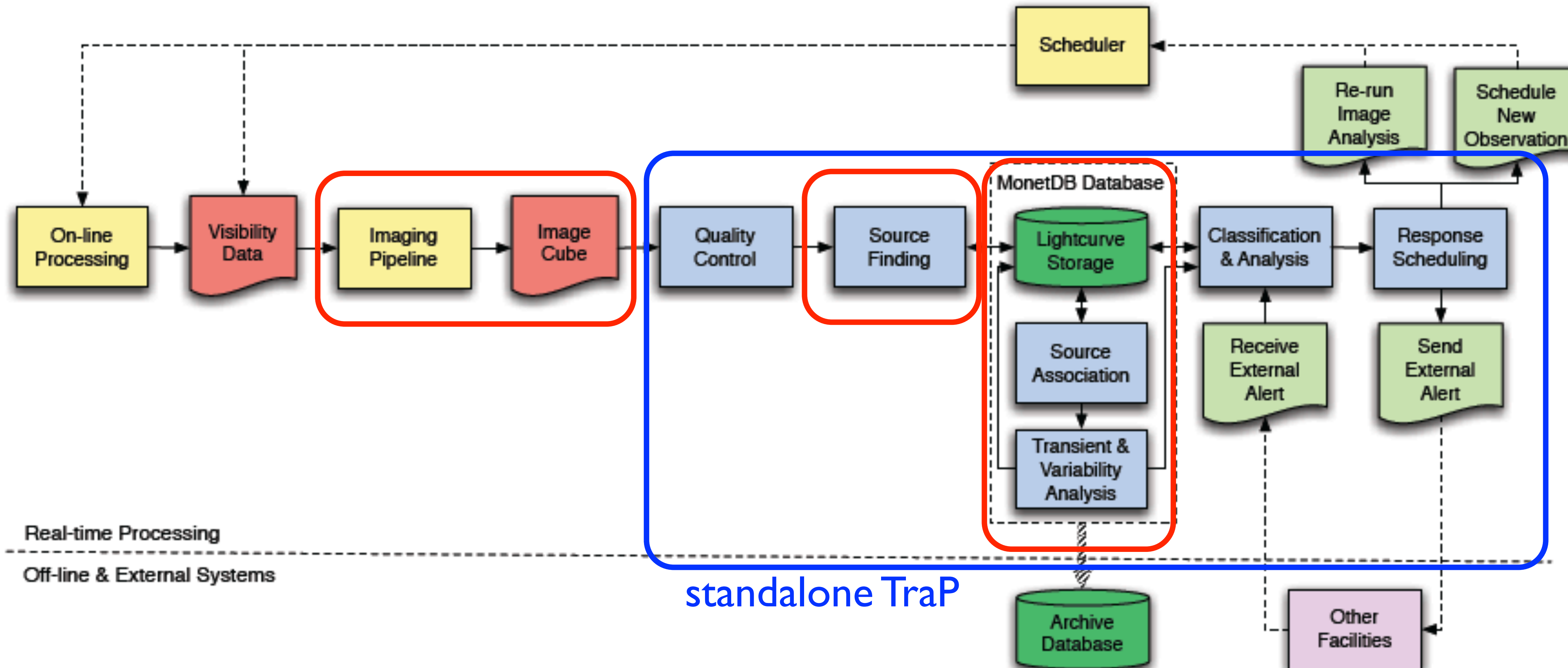
TRANSIENT SURVEYS & SEARCH STRATEGY

LOFAR strategies

- Monitoring of known transient/variable sources
- Radio Sky Monitor
- Commensal transient searches in all observations (1 sec resolution)

  → TraP (TKP's Transients Pipeline)

The Trap



Swinbank et al., 2012

TRANSIENT SURVEYS & SEARCH STRATEGY

- Expected transient rates (uncertain)

	N / °^{2} week	N / °^{2} year	N in FoV / year
Instrument	Snapshot rate (deg^{-2})	Rate per year ($deg^{-2}\ yr^{-1}$)	Yield (yr^{-1})
SKA Phase 2 (Mid)	9.7×10^5	5.0×10^7	5.0×10^7
SKA Phase 2 (Low)	6.7×10^3	3.5×10^5	7.0×10^7
MeerKAT	6.9×10^2	3.6×10^4	3.6×10^4
WSRT + APERTIF	5.0×10^1	2.6×10^3	2.0×10^4
ASKAP	5.0×10^1	2.6×10^3	7.8×10^4
LOFAR (HBA) Full	9.8	5.0×10^2	1.2×10^4
LOFAR (HBA) Full ($\alpha = -0.7$)	1.0×10^2	5.3×10^3	1.3×10^5
LOFAR (HBA) Full ($\alpha = -2$)	8.9×10^3	4.6×10^5	1.2×10^7
SKA Phase 2 (Low)($\alpha = -0.7$)	5.5×10^4	2.8×10^6	5.7×10^8
SKA Phase 2 (Low)($\alpha = -2$)	2.4×10^6	1.2×10^8	2.5×10^{10}

Fender & Bell, BASI, 2011

TRANSIENT SURVEYS & SEARCH STRATEGY

LOFAR strategies

- Monitoring of known transient/variable sources
- Radio Sky Monitor
- Commensal transient searches in all observations (1 sec resolution)
  → TraP (TKP's Transients Pipeline)
- Follow-up on external or internal trigger alerts
  → Instant imaging → precise source localization
- Playback in time via TBB (see below)

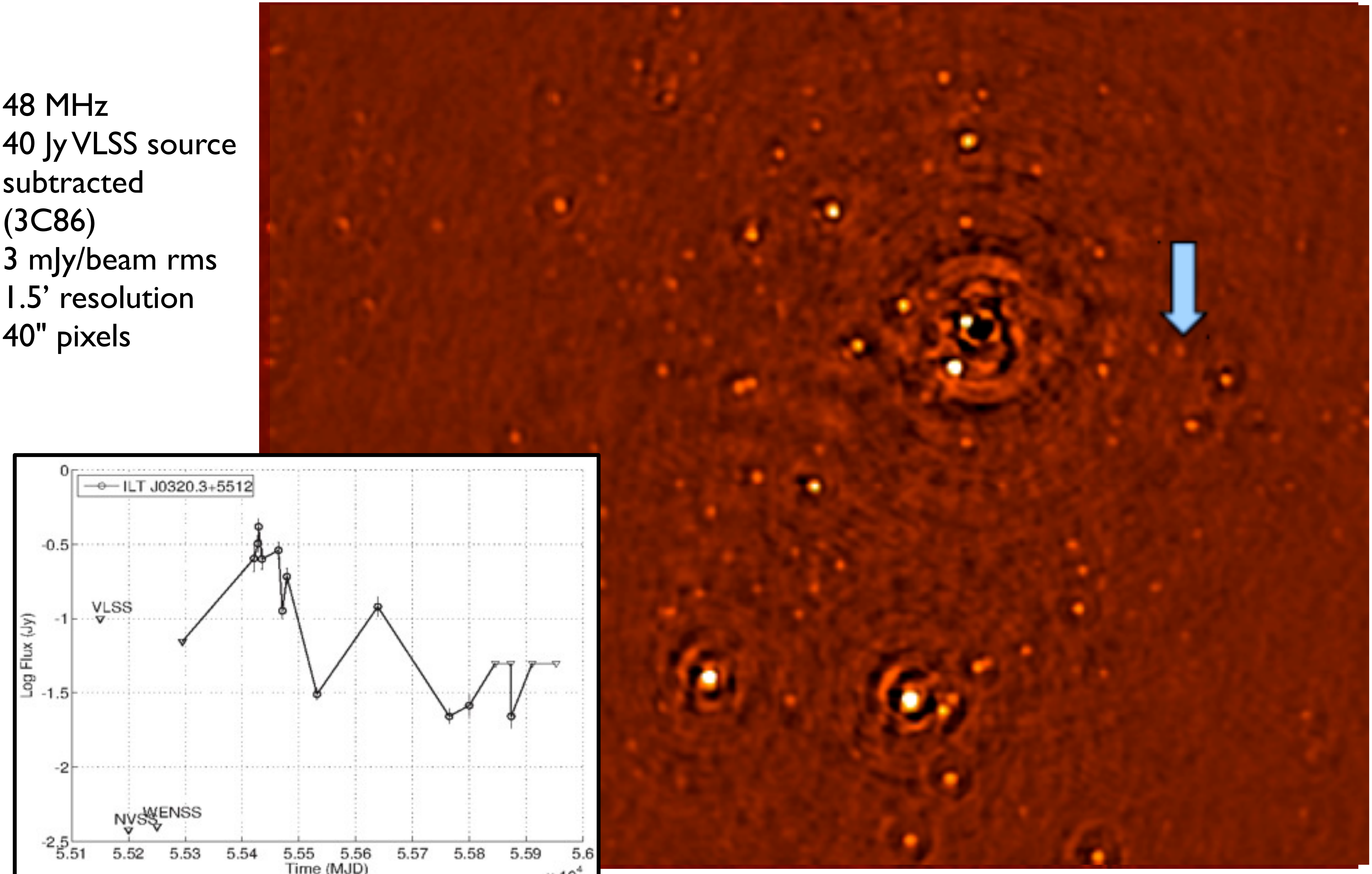
TRANSIENT SURVEYS & SEARCH STRATEGY

Today's status of transients detections

- ILT J0320.3+5512 (Bell#1) in LOFAR zenith field images 2010-2012 [Broderick et al., 2012]

ILT J0320.3+5512 (Bell#1) in LOFAR zenith field images 2010-2012

48 MHz
40 Jy VLSS source subtracted
(3C86)
3 mJy/beam rms
1.5’ resolution
40" pixels



TRANSIENT SURVEYS & SEARCH STRATEGY

Today's status of transients detections

- ILT J0320.3+5512 (Bell#1) in LOFAR zenith field images 2010-2012 → real or artefact ? [Broderick et al., 2012]

TRANSIENT SURVEYS & SEARCH STRATEGY

Today's status of transients detections

- ILT J0320.3+5512 (Bell#1) in LOFAR zenith field images 2010-2012 → real or artefact ? [Broderick et al., 2012]

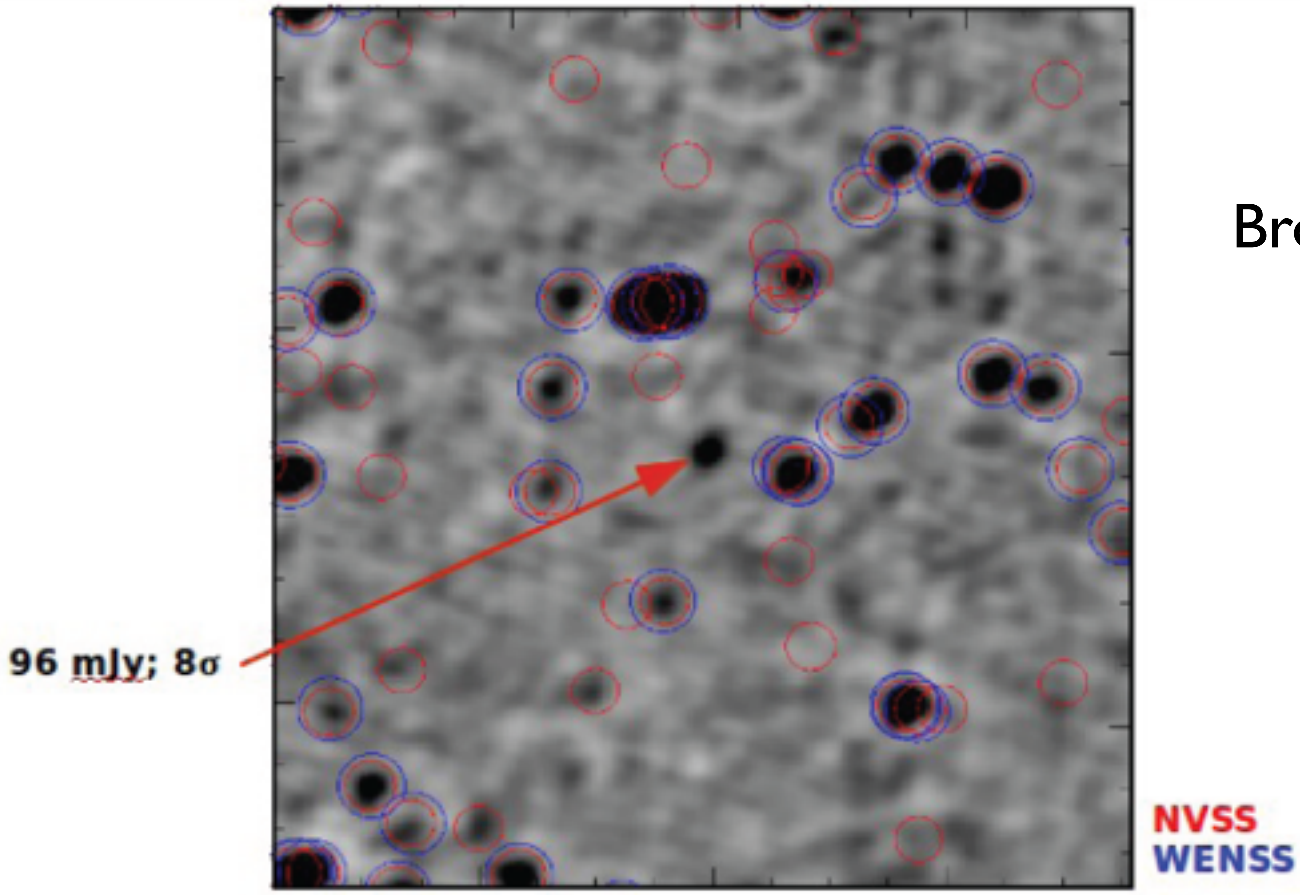
- Searches in NCP images → no confirmed transient yet [Stewart et al., 2012]

- TraP reports ~800 transient candidates from the first two ~1500 deg^2 zenith scans

  → many spurious likely, calibration errors.. .

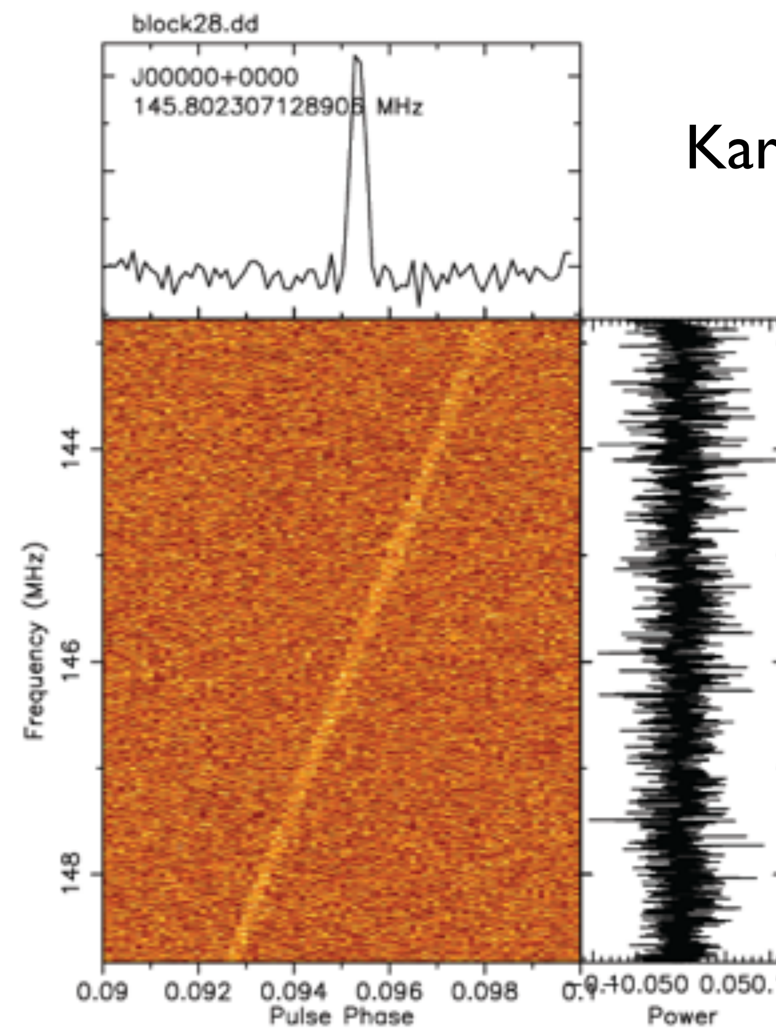
  → no 100% certain radio transient yet

- New bright sources not in previous catalogues (WENSS, NVSS), 2 new pulsars discovered



* Transient or ultra-steep spectrum source? (α < -1.6)

Broderick, Fender et al.



Karastergiou et al., 2012

Unknown sources at DM 0.9, observed simultaneously at Chilbolton and Nancay

- RADIO COUNTERPARTS TO GW EVENTS
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ALERTS MANAGEMENT

- LF arrays such as LOFAR (+MWA …) electronically steered → fast response to GW trigger

- TBB allow to play the radio signal (dedispersed time series & imaging) back in time up to ~ -20 sec

- Real-time pipeline + internal (in development) & external trigger alerts

- LOFAR's UK station triggered within 1 min of Fermi & Swift alerts (with pre-defined setup) [Breton et al., 2012]

- In progress : dynamic control and observing setup, multi-station triggering, TBBs

ALERTS MANAGEMENT

- LOFAR transients detected → alert issued : optical follow up, automatic/robotic Cambridge Arcmin. μK Imager (15 GHz response in <30 min. from event) …

- There are observing scenarios with VIRGO (MoU) & LIGO
  → Exchange of informations, not control of telescope

- How to manage transients (especially if very many) ?
  → VO events …

Transient Notifications

Outside
GCN
IAUCs

Other
MacOS: Dashboard Widget

The Astronomer's Telegram
for reporting and commenting on new astronomical observations
Post a New Telegram | Search | Information | Mirror Software
Telegram Index
Register To Post | Email and RSS Subscriptions | Forgot your password?

Present Time: 15 Jun 2009; 15:20 UT

RSS
XML Top
XML Supernovae
XML Transients
XML SGRs
XML Gamma Ray Bursts
XML Comets

[Previous | Next]

Related
2080 Archival Chandra

Discovery of a new transient radio source in the central region of M82

ATel #2073; *T. W. B. Muxlow, R. J. Beswick, A. Pedlar (JBCA, Manchester), D. Fenech (UCL), M. K. Argo (Curtin University), M. J. Ward (Durham), A. Zezas (Harvard-Smithsonian CfA)*
on 9 Jun 2009; 16:46 UT
Distributed as an Instant Email Notice (Transients)
Password Certification: Rob Beswick (Robert.Beswick@manchester.ac.uk)

Subjects: Radio, Binaries, Novae, Soft Gamma-ray Repeaters, Supernovae, Transients
Referred to by ATel #: 2078, 2080

We report the discovery of a new compact transient radio source in the central region of the starburst galaxy M82 with MERLIN at 4994MHz. The position measured for the transient source is (J2000) 09 55 52.5083, +69 40 45.420, with an astrometric error of 5mas each coordinate. The source was discovered in continuous monitoring observations mad between 1st and 5th May 2009 with a flux density of 720+/-50microJy. This source was n detected one week earlier (from monitoring observations between 24th-27th April 2009) a 3 sigma limit of <180microJy/beam. Subsequent MERLIN monitoring observations on

```
TITLE:   GCN CIRCULAR
NUMBER:  9509
SUBJECT: GRB 090610C: Fermi GBM detection
DATE:    09/06/12 16:29:53 GMT
FROM:    Adam Goldstein at Fermi-GBM/UAH  <adam.m.goldstein@msfc.nasa.gov>

A. Goldstein (UAH) reports on behalf of the Fermi GBM Team:

"At 21:12:07.73 UT on 10 June 2009, the Fermi Gamma-Ray Burst Monitor
triggered and located GRB 090610C (trigger 266361129 / 090610883).

The on-ground calculated location, using the GBM trigger
data, is RA = 70.4, DEC = +30.3 (J2000 degrees,
equivalent to 04h 42m, 30d 18'), with an uncertainty
of 8.2 degrees (radius, 1-sigma containment,
statistical only; there is additionally a systematic
error which is currently estimated to be 2 to 3 degrees).
The angle from the Fermi LAT boresight is 104 degrees.

The GBM light curve consists of a single pulse
with a duration (T90) of about 18.1 s (8-1000 keV).
The time-averaged spectrum from T0-4.1 s to T0+8.2 s is
best fit by a simple power law function with index -1.62 +/- 0.08
(chi squared 341.6 for 362 d.o.f.).

The event fluence (8-1000 keV) in this time interval is
(8.54 +/- 0.38)E-07 erg/cm^2. The 1-sec peak photon flux
measured starting from T0-0.51 s in the 8-1000 keV band
is 1.12 +/- 0.11 ph/s/cm^2.

The spectral analysis results presented above are preliminary;
final results will be published in the GBM GRB Catalog."
```

Swinbank et al., 2012

VOEvent

XML

Who?

What?

When?

How?

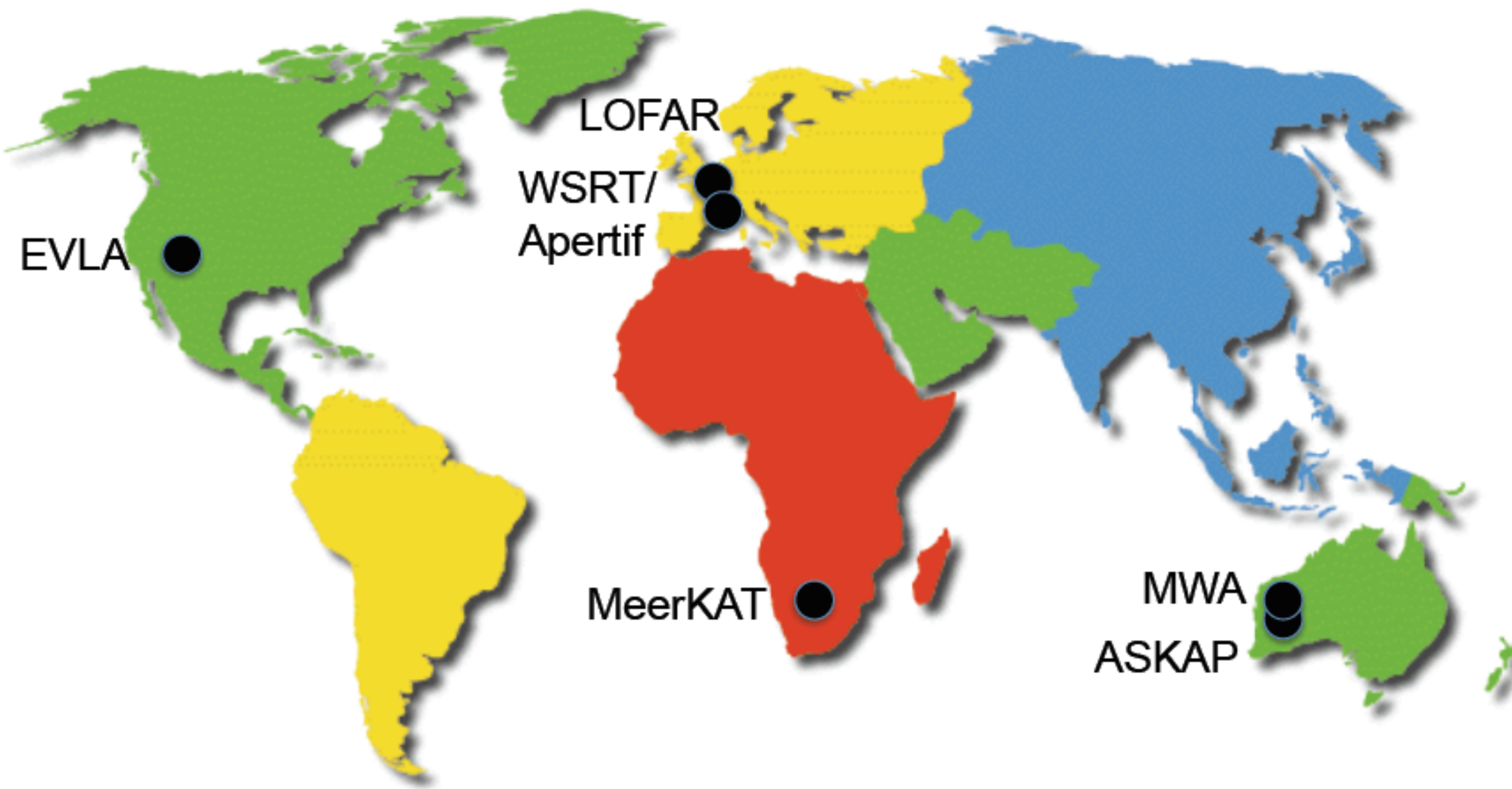
So what?


```
<?xml version = '1.0' encoding = 'UTF-8'?>
<voe:VOEvent
    ivorn="ivo://nasa.gsfc.gcn/Fermi#GBM_Alert_2012-11-28T05:05:50.96_375771953_1-351"
  <Who>
    <Author>
      <shortName>Fermi (via VO-GCN)</shortName>
    </Author>
    <Date>2012-11-28T05:05:57</Date>
    <Description>This VOEvent message was created with GCN VOE version: 1.11 02aug12</Description>
    <Param name="TrigID"          value="375771953" ucd="meta.id" />
    <Param name="Trig_Signif"     value="5.5" unit="sigma" ucd="stat.snr" />
    <Param name="Trig_Dur"        value="0.512" unit="sec" ucd="time.interval" />
    <Description>A heads-up alert that the Fermi-GBM instrument found a transient.</Description>
[...]
  </What>
[...]
        <Time unit="s">
          <TimeInstant>
            <ISOTime>2012-11-28T05:05:50.96</ISOTime>
          </TimeInstant>
        </Time>
[...]
    <Description>The RA,Dec coordinates are of the type: unavailable/inappropriate.</Description>
  </WhereWhen>
    <Description>Fermi Satellite, GBM Instrument</Description>
  </How>
    <Inference probability="0.5">
      <Concept>process.variation.burst;em.gamma</Concept>
    </Inference>
  </Why>
  <Description>
  </Description>
</voe:VOEvent>
```


Swinbank et al., 2012

ALERTS MANAGEMENT

- Other current and future radio facilities:
  ASKAP, Apertif/WSRT, MeerKAT, EVLA, MWA … SKA



ALERTS MANAGEMENT

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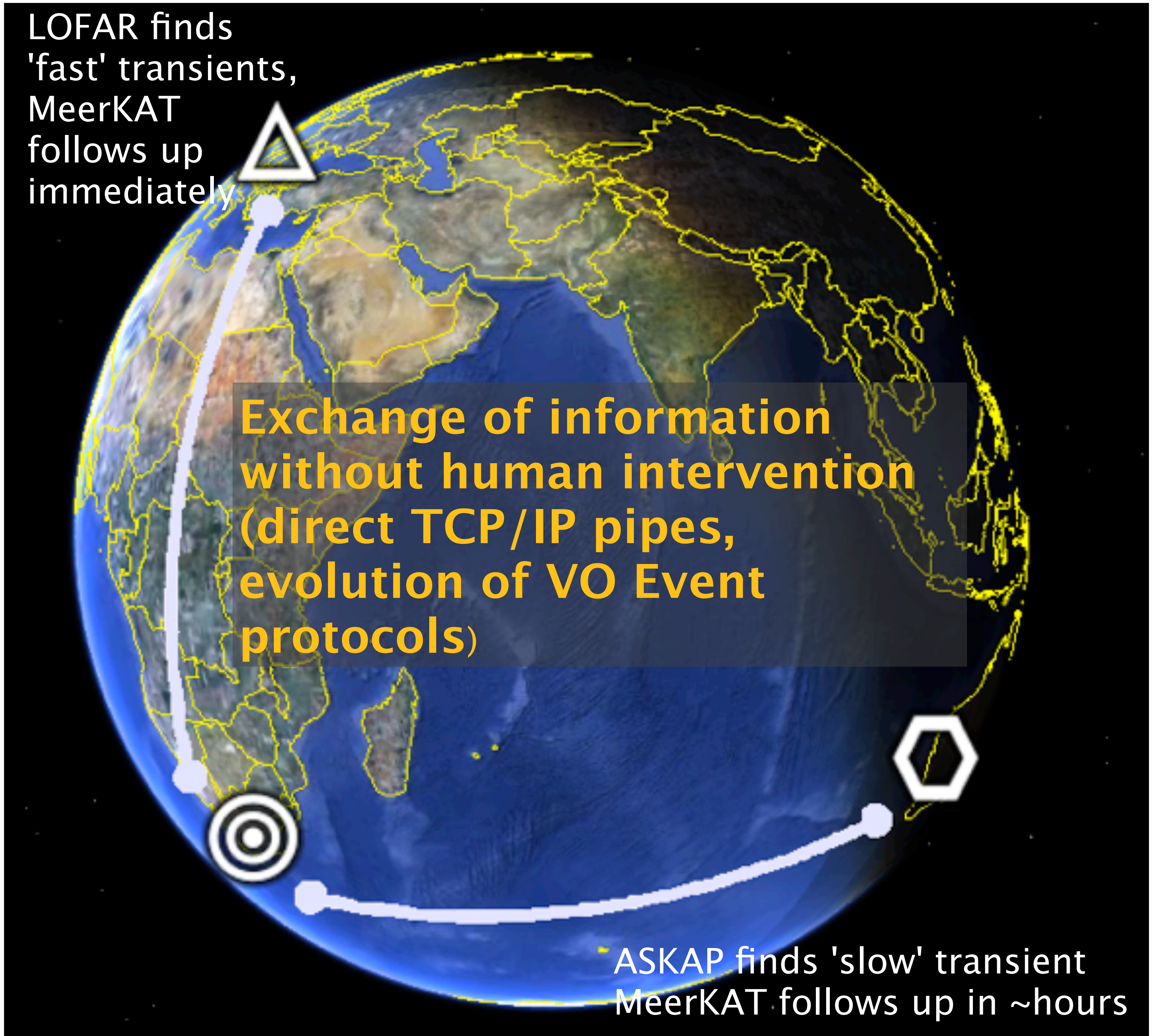
MeerKAT	1.4 GHz	1.5 deg^2 FPA	35 uJy	15″	2013
EVLA	1.4 GHz	0.25 deg^2	7 uJy	1.3-45″	2010
EVLA	327 MHz	5 deg^2	2 mJy	5-18″	2011
LOFAR	110-240 MHz	50 deg^2	1 mJy	5″	2011
EVLA	74 MHz	100 deg^2	50 mJy	25-80″	2011
MWA	80-300 MHz	1000 deg^2	8 mJy	300″	2011+
LOFAR	15-80 MHz	500 deg^2	8 mJy	120″	2011






ALERTS MANAGEMENT

- Fender's 4π project : LOFAR + MeerKAT + ASKAP + ...
  → rapid response to triggers (e.g. Swift ... in 30 sec)
  → TBBs allow to image from -22 sec of the Swift trigger



Courtesy R. Fender

- RADIO COUNTERPARTS TO GW EVENTS
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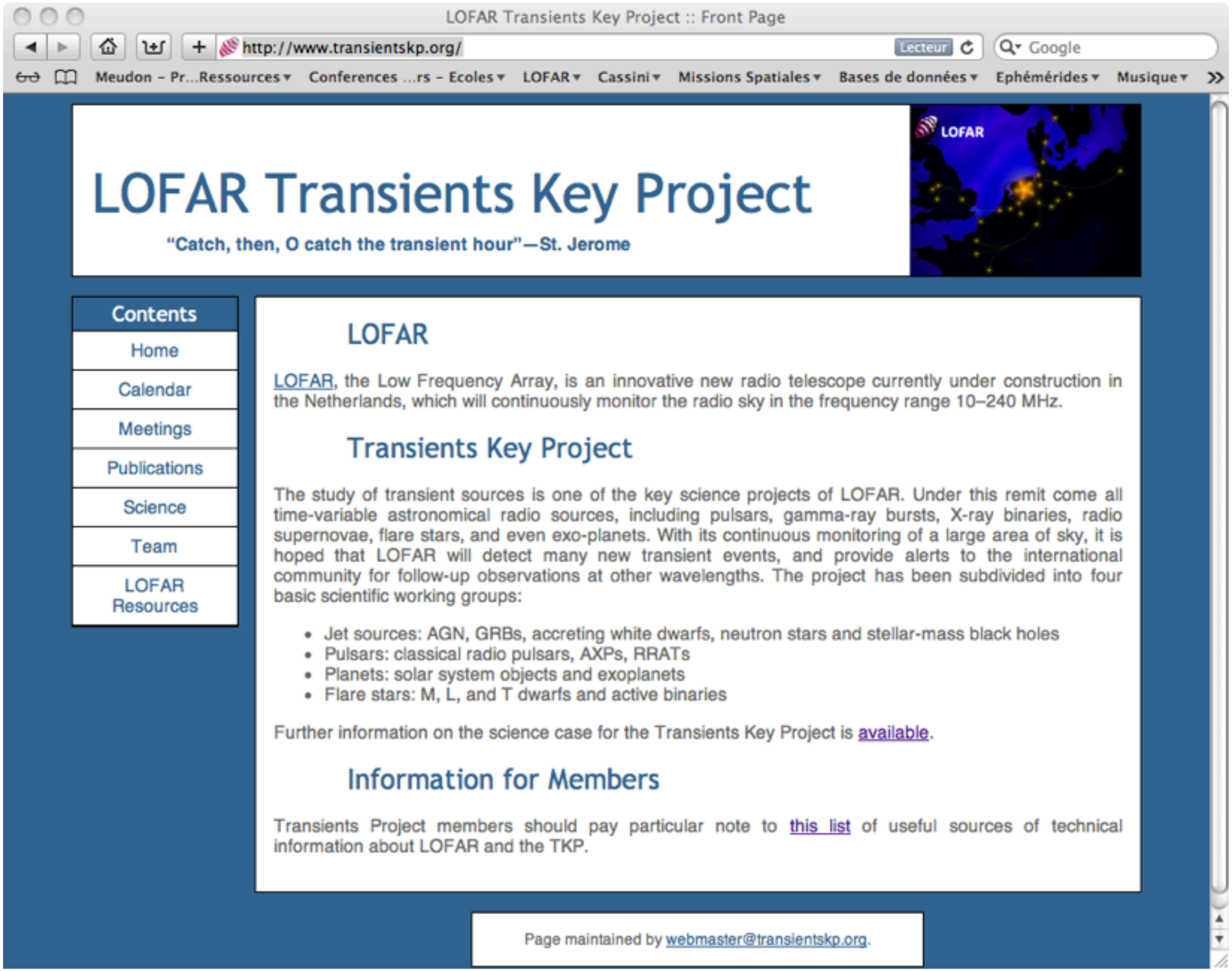
ORGANISATION

http://www.transientskp.org/


LOFAR Transients Key Project :: Front Page

http://www.transientskp.org/

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

LOFAR Transients Key Project

"Catch, then, O catch the transient hour"—St. Jerome

LOFAR

Contents

- Home
- Calendar
- Meetings
- Publications
- Science
- Team
- LOFAR Resources

LOFAR

LOFAR, the Low Frequency Array, is an innovative new radio telescope currently under construction in the Netherlands, which will continuously monitor the radio sky in the frequency range 10–240 MHz.

Transients Key Project

The study of transient sources is one of the key science projects of LOFAR. Under this remit come all time-variable astronomical radio sources, including pulsars, gamma-ray bursts, X-ray binaries, radio supernovae, flare stars, and even exo-planets. With its continuous monitoring of a large area of sky, it is hoped that LOFAR will detect many new transient events, and provide alerts to the international community for follow-up observations at other wavelengths. The project has been subdivided into four basic scientific working groups:

- Jet sources: AGN, GRBs, accreting white dwarfs, neutron stars and stellar-mass black holes
- Pulsars: classical radio pulsars, AXPs, RRATs
- Planets: solar system objects and exoplanets
- Flare stars: M, L, and T dwarfs and active binaries

Further information on the science case for the Transients Key Project is available.

Information for Members

Transients Project members should pay particular note to this list of useful sources of technical information about LOFAR and the TKP.

Page maintained by webmaster@transientskp.org.

ORGANISATION

http://www.transientskp.org/

LOFAR Transients Key Project :: Team

http://www.transientskp.org/team/

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

LOFAR Transients Key Project

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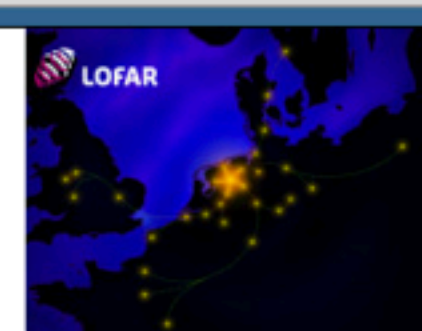


Contents

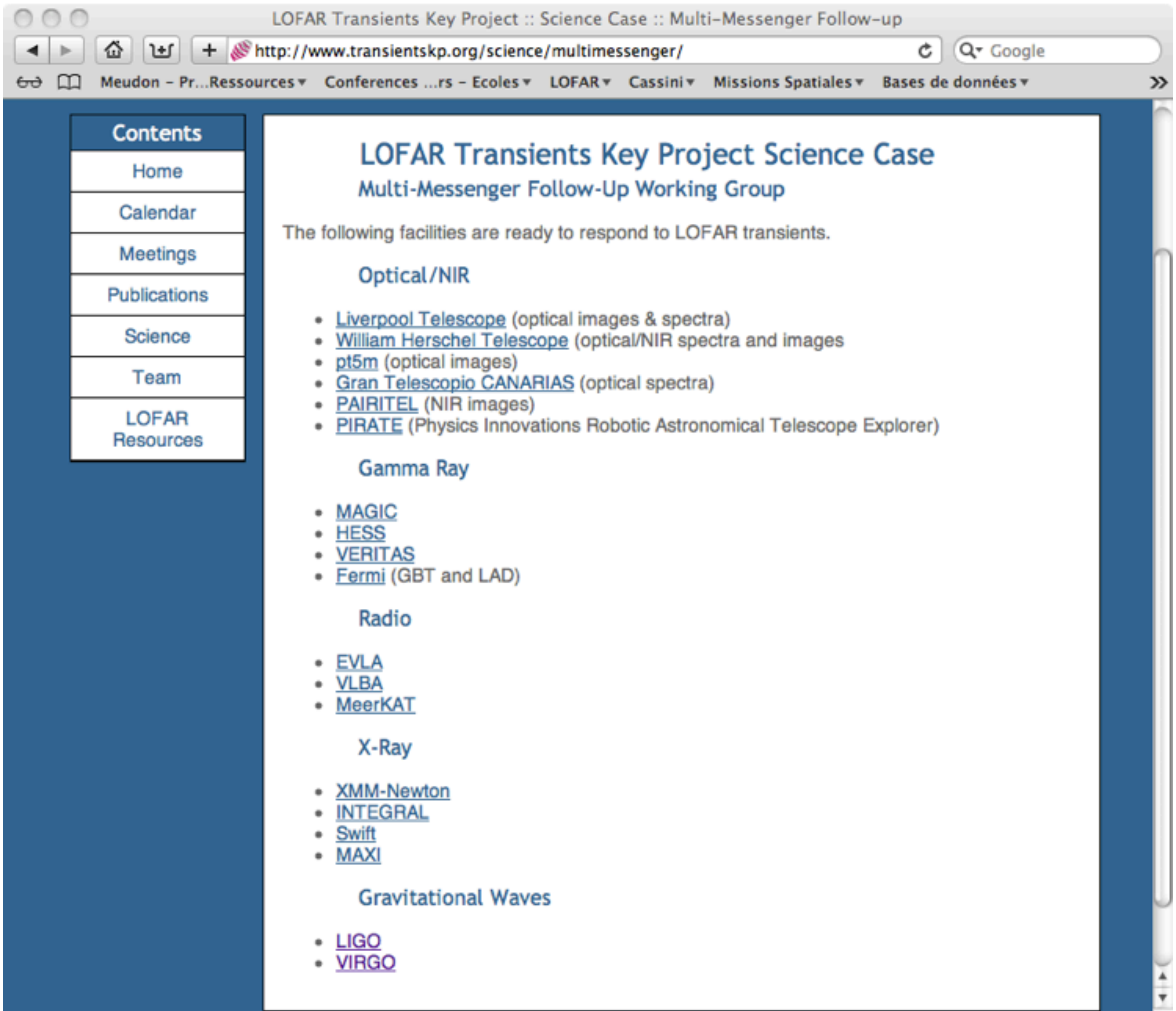
The Team

Multi-Messenger Follow-Up

- **Peter Jonker** (Co-leader; SRON, Netherlands Institute for Space Research, Harvard-Smithsonian CfA & Radboud University Nijmegen)
- **Rudy Wijnands** (Co-leader; University of Amsterdam)
- **David Bersier** (Liverpool John Moores University)
- **Catherine Brocksopp** (Mullard Space Science Laboratory)
- **Stéphane Corbel** (University Paris Diderot & CEA Saclay)
- **Ed Daw** (University of Sheffield)
- **Vik Dhillon** (University of Sheffield)
- **Alexander van der Horst** (University of Amsterdam)
- **Lucien Kuiper** (SRON)
- **Casey Law** (University of California, Berkeley)
- **Sera Markoff** (University of Amsterdam)
- **James Miller-Jones** (Curtin Institute of Radio Astronomy)
- **Teo Muñoz-Darias** (University of Southampton)
- **Paul O'Brien** (University of Leicester)
- **Anthony Rushton** (ESO & Onsala Space Observatory)
- **Adam Stewart** (University of Southampton)
- **Valeriu Tudose** (Romanian Institute of Space Science)
- **Anna Watts** (University of Amsterdam)
- **Patrick Woudt** (University of Cape Town)

ORGANISATION

http://www.transientskp.org/



ORGANISATION

- LOFAR France (FLOW) : Tagger, Zarka, Theureau et al.
- Station FR606 : INSU + OP + Univ. Orléans, THD, Centre de Données Nançay
- AS SKA-LOFAR : Corbel, Charlot, Zarka et al.

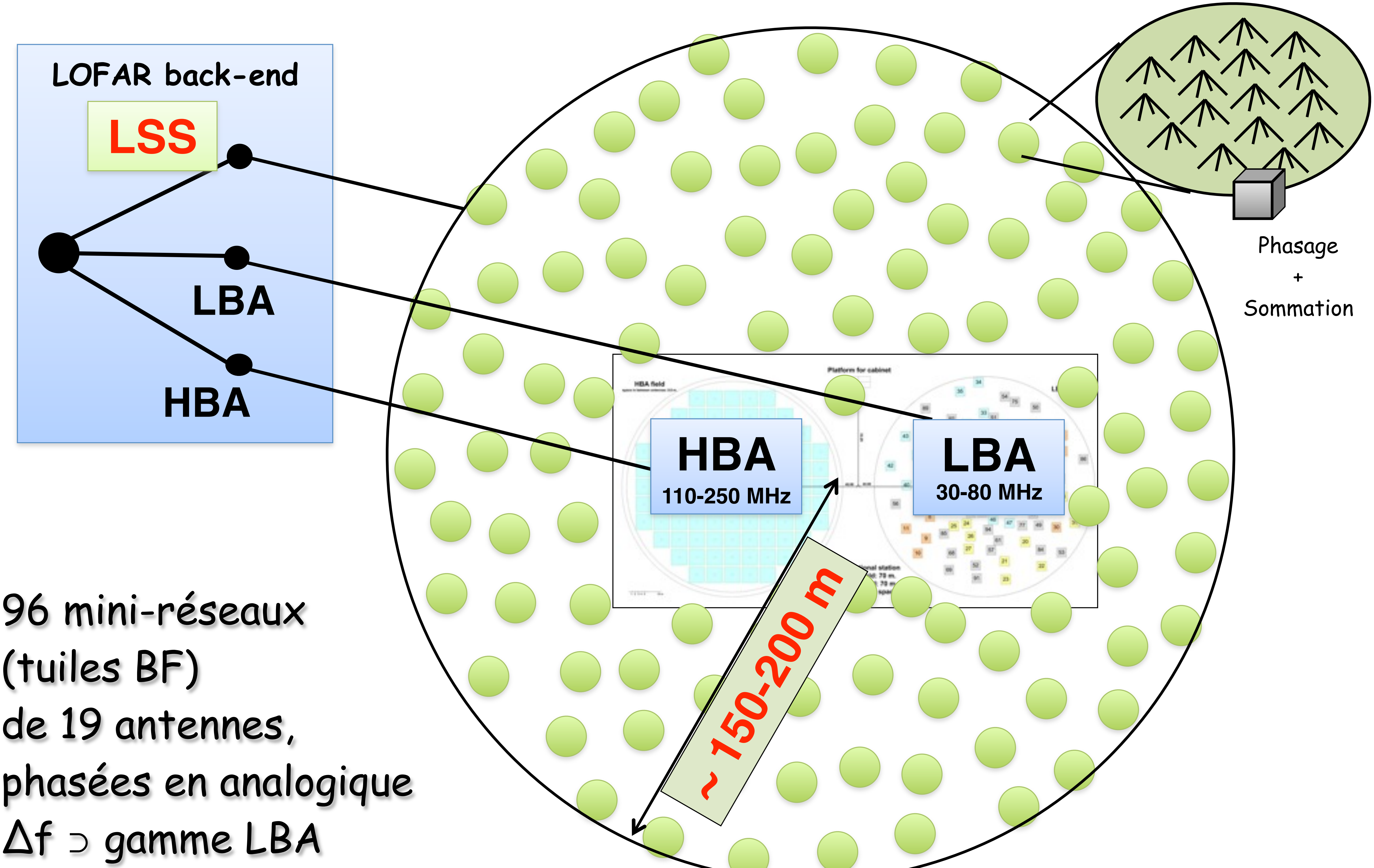
Semaine de l'Astrophysique Française

SF2A

	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

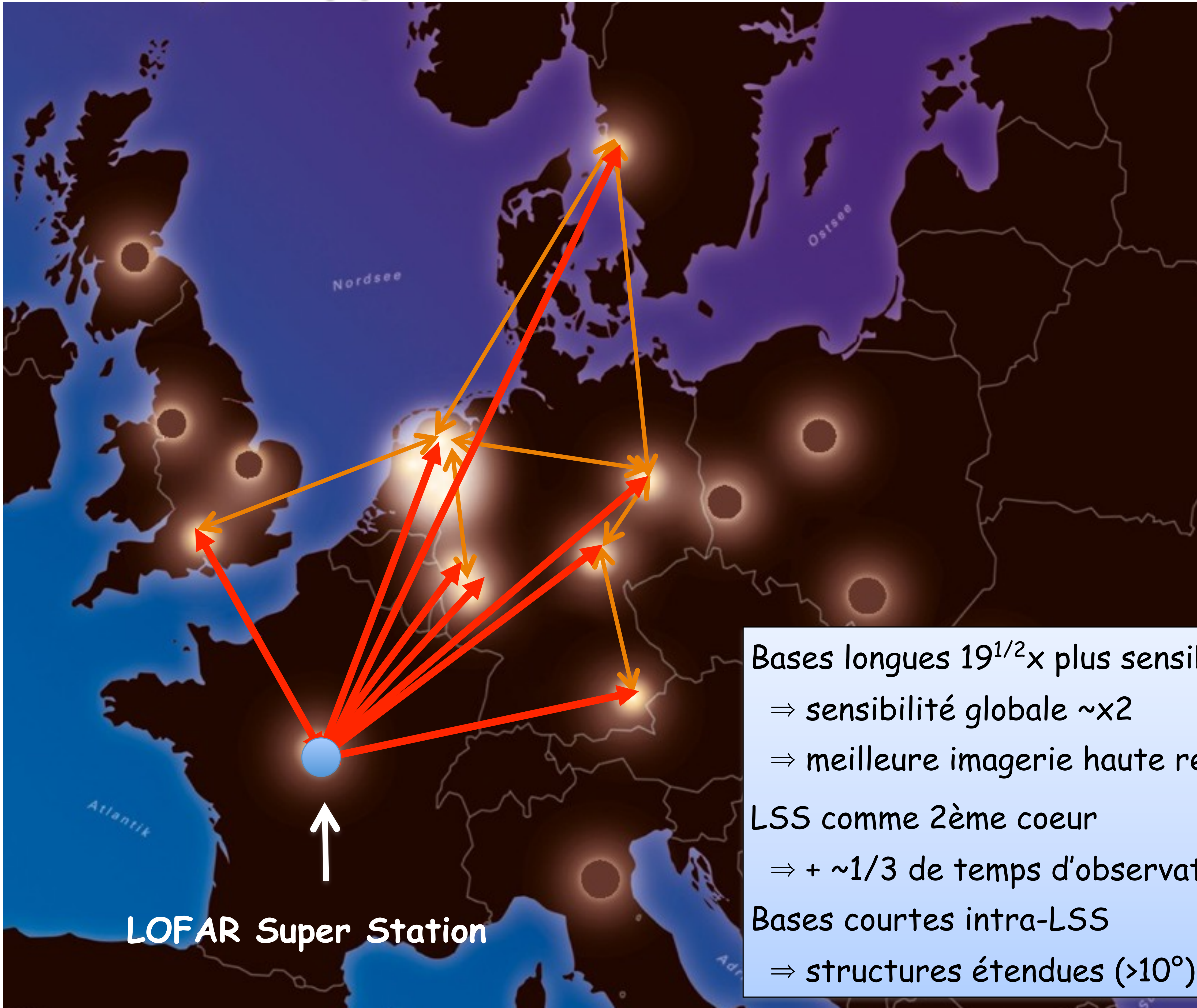
- LSS/NenuFAR

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



96 mini-réseaux
(tuiles BF)
de 19 antennes,
phasées en analogique
Δf ⊃ gamme LBA

Les apports de la LSS/NenuFAR



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

⇒ sensibilité globale ~x2

⇒ meilleure imagerie haute résolution

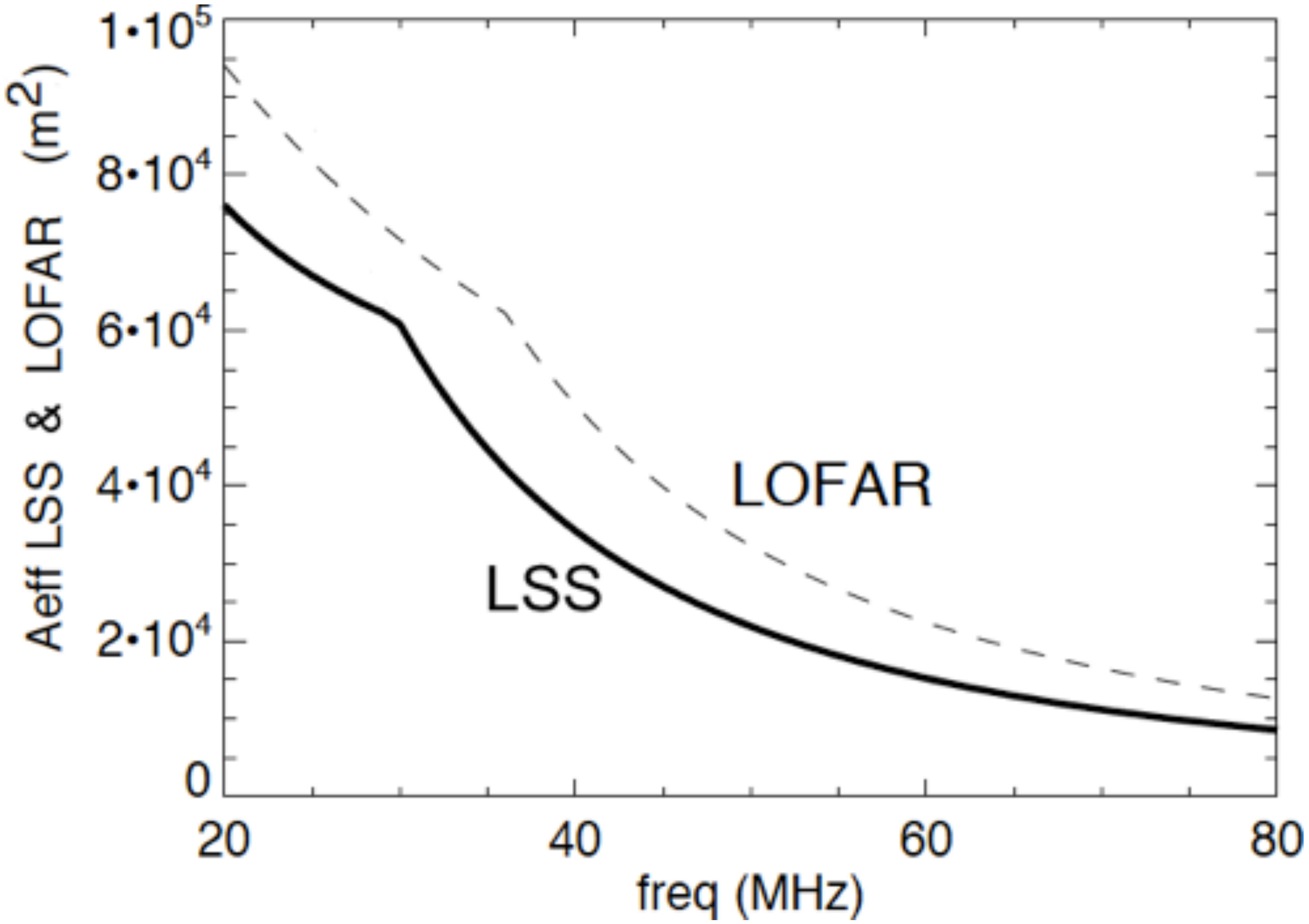
LSS comme 2ème coeur

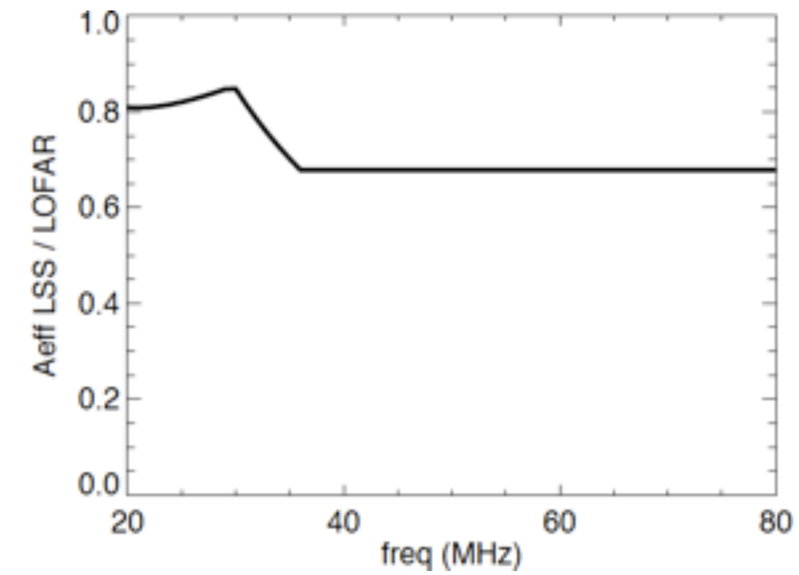
⇒ + ~1/3 de temps d'observation

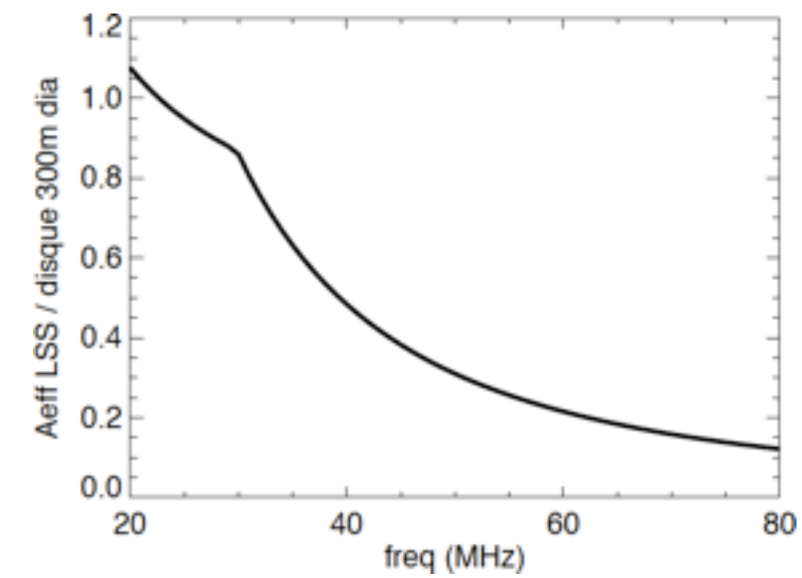
Bases courtes intra-LSS

⇒ structures étendues (>10°)

Les apports de la LSS/NenuFAR







Grand instrument autonome : « Arecibo à Nançay »

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

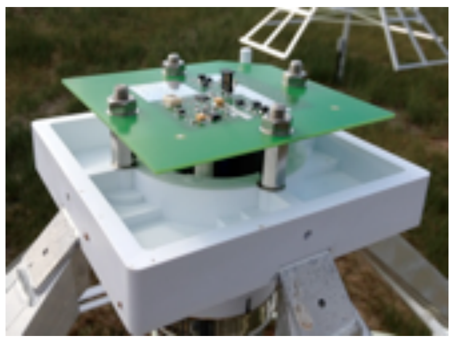
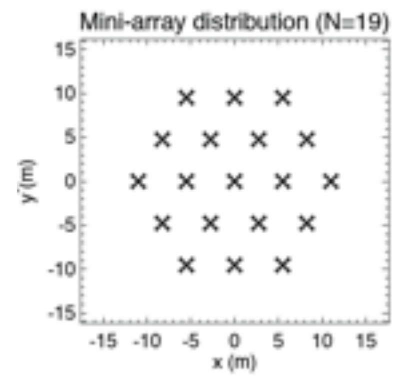
⇒ A_{eff} = 70-80% x A_{eff} LOFAR LBA = 190% x A_{eff} Coeur LOFAR LBA

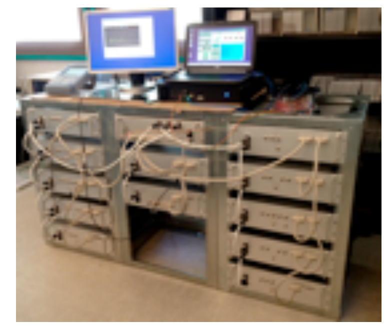
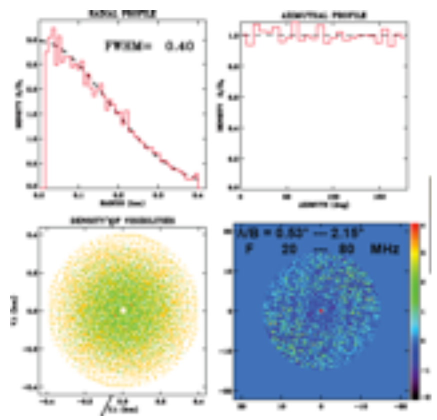
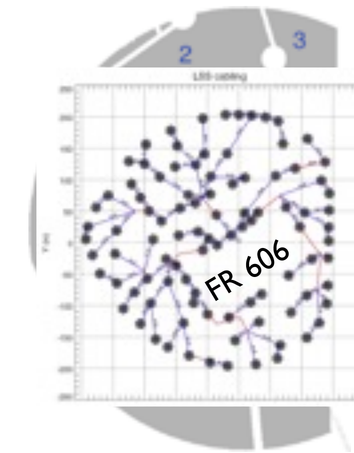
(mode faisceau cohérent > 2x+ efficace que LOFAR)

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

- Construction de 3 mini-réseaux (x 2 polarisations)
- 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

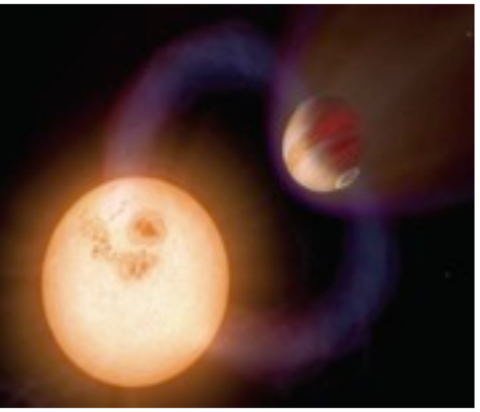
<u>Equipe LSS-France</u> : ~ 25 chercheurs + 15-20 ITA
<u>Laboratoires impliqués dans la réalisation</u> : Nançay, LESIA, GEPI, LERMA, LPC2E, Prisme, Subatech, IRA Kharkov, SRI Graz (soutien OP, ESEP) ⇒ Axe Paris(Meudon)-Orléans-Nançay, en vue de SKA

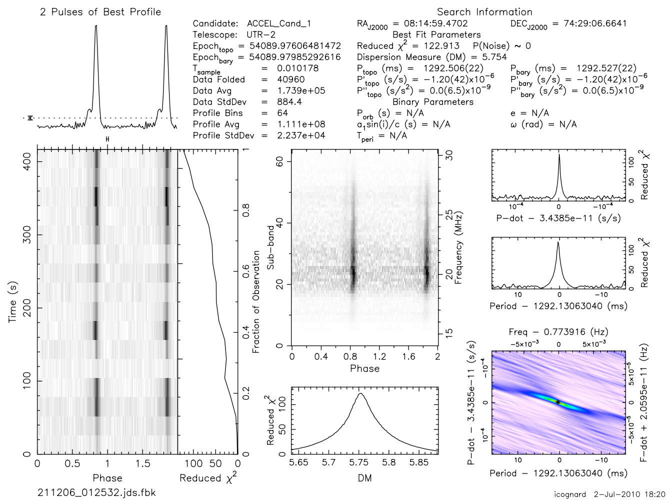
(LSS = précurseur scientifique et technique de SKA)

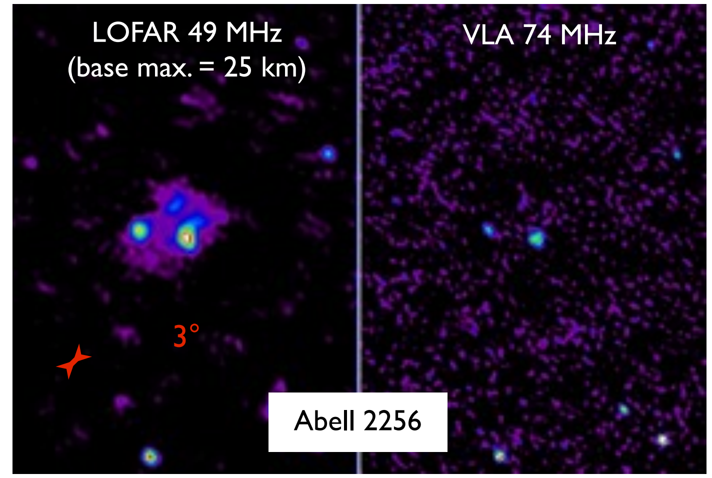
<u>Laboratoires utilisateurs</u> : OP (LESIA, GEPI, LERMA, LUTh), CEA/Sap-DASE-AIM, IAS, IAP, E. Polytechnique, ENS/LRA, APC, IN2P3, LPC2E, Nançay, OCA, IRAP ...

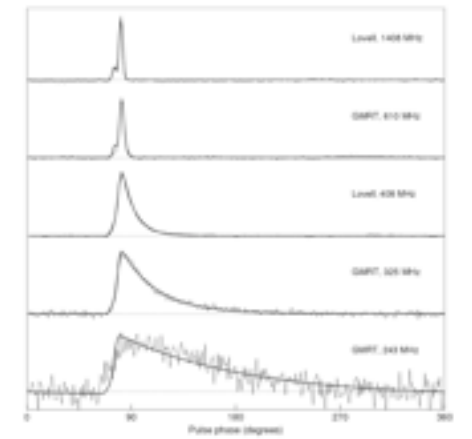
UTR-2	2040 dipoles	143000 m²	8-32 MHz	0.5°	5 faisceaux	1 polar. lin.
VLA	27 paraboles x 25 m	~2000 m²	73-74.5 MHz	0.5'	1 faisceau	4 Stokes
LWA	256 Xdipoles	8000 m² @ 20 MHz	10-88 MHz	9° 20 MHz	4 faisceaux x 20 MHz	4 Stokes
LOFAR (LBA)	2688 Xdipoles	72000 m² @ 30 MHz	30-80 MHz	2" @ 30 MHz	8+ faisceaux x 4- MHz	4 Stokes
LSS autonome	1824 Xdipoles	62000 m² @ 30 MHz	15-80 MHz	3° @ 30 MHz	4 faisceaux x 65 MHz	4 Stokes
LSS+LOFAR	4512 Xdipoles	134000 m² @ 30 MHz	30-80 MHz	2" @ 30 MHz	8+ faisceaux x 4- MHz	4 Stokes
SKA	??	1 000 000 m²	100+ MHz	0.2" @ 100 MHz	nombreux faisceaux	4 Stokes

Les apports scientifiques de la LSS/NenuFAR





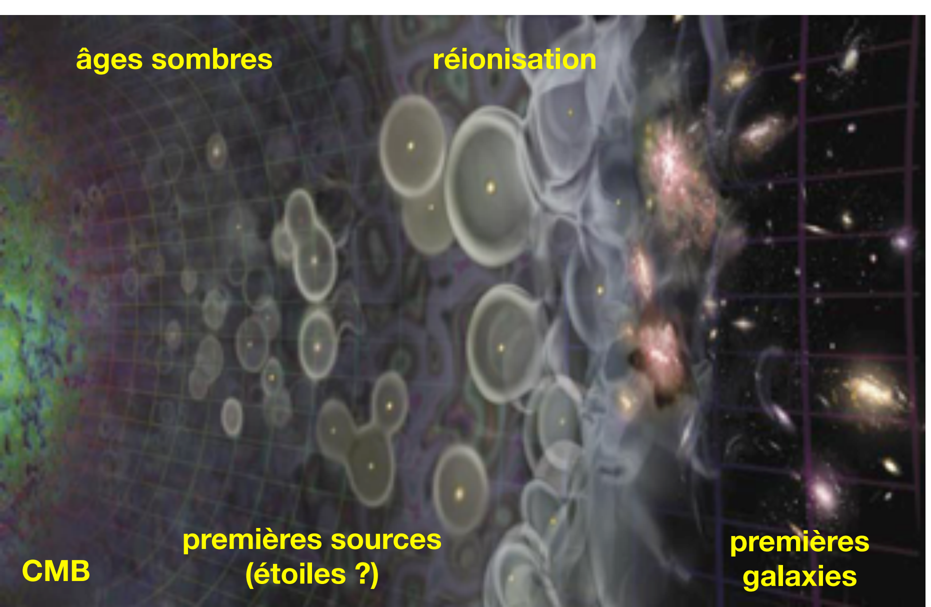




- Étoiles Binaires/Éruptives & Exoplanètes
- Pulsars & Rotating radio transients (RRATs)
- Structure du Milieu InterStellaire Galactique
- Cosmologie et Formation des galaxies
- L'Univers impulsionnel
- Les flashes lumineux dans les atmosphères Terres[...]

⇒ LSS autonome, LSS+LOFAR, LSS//LOFAR

GW ?



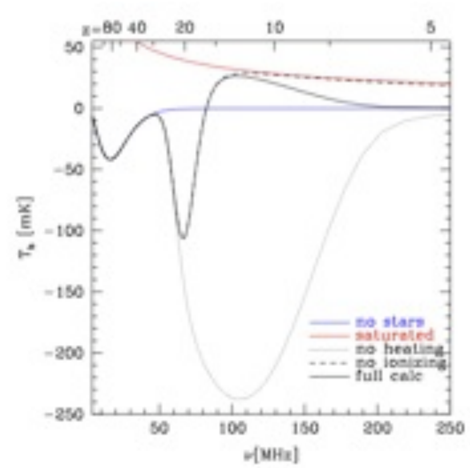
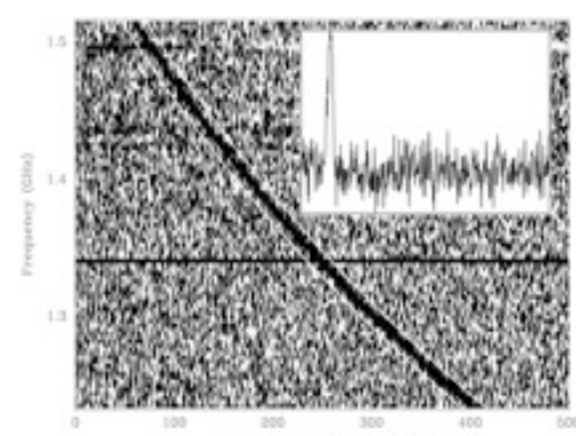
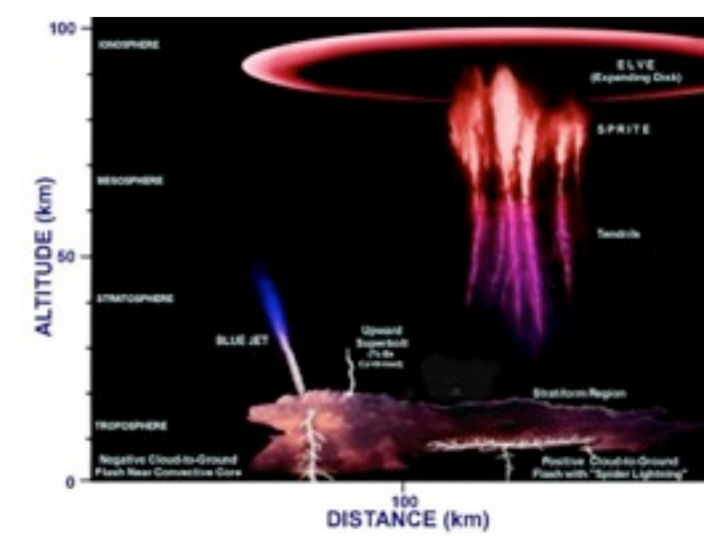
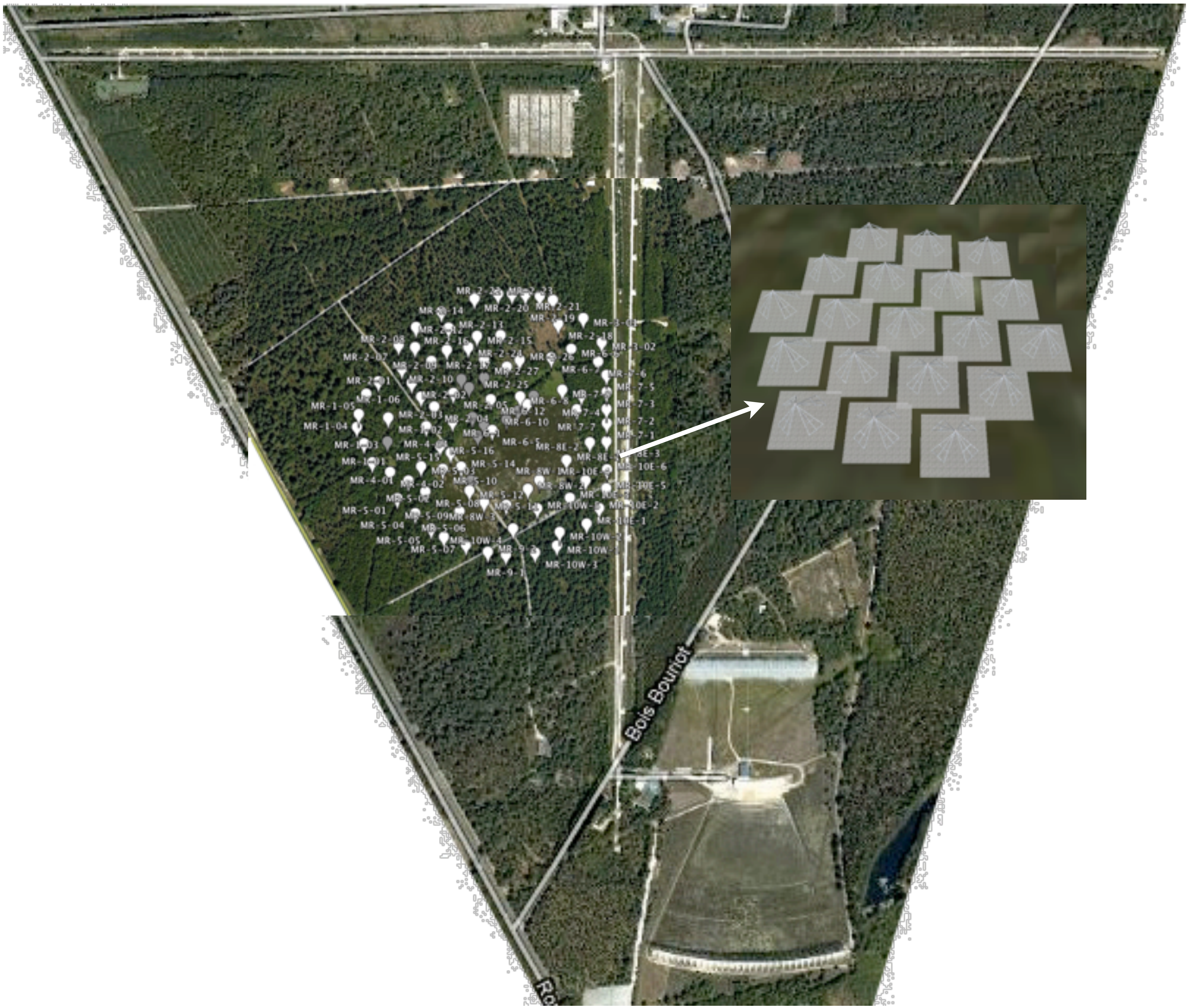


FIG. 1 (color online). Evolution of the 21 cm global signal for different scenarios. Solid blue curve: no stars; solid red curve: $T_S \gg T_\gamma$ and $x_H = 1$; black dotted curve: no heating; black dashed curve: no ionization; black solid curve: full calculation.





Demain la LSS/NenuFAR ?



- RADIO COUNTERPARTS TO GW EVENTS
- RADIO PROPAGATION
- TRANSIENT RADIO SKY
- LOFAR TELESCOPE & OPERATING MODES
- LOFAR EARLY RESULTS
- TRANSIENT SURVEYS & SEARCH STRATEGY
- ALERTS MANAGEMENT
- ORGANISATION
- SOME CONCLUSIONS
- REFERENCES

SOME CONCLUSIONS

- Radio counterpart searches are a powerful tool (sensitivity, beaming, duration, low false >0 rate)

- Powerful NG arrays start operations (+ VLBI imaging at HF with sub-milliarcsecond resolution ?)

- Direct Radio - GRB (GW) correlation ? Statistics ?

- Comparing MHz & GHz studies (one key TKP target)

- Improve multi-spectral modelling (energies, circumburst N_e, characteristic times → T_b, S, delays, …)

MHz surveys (LOFAR, LWA, MWA):

Much larger field of view: GW follow-up in one shot
Software steered → very rapid response
Preferentially detect coherent sources
Dispersion, scattering, synchrotron optical depth delays much larger

MHz or GHz ?

GHz surveys (APERTIF, ASKAP, MeerKAT, EVLA):

Much smaller field of view: GW follow-up = small survey
Mechanically steered → slower
Preferentially detect synchrotron sources
Dispersion, scattering, synchrotron optical depth delays much smaller

Courtesy R. Fender

- RADIO COUNTERPARTS TO GW EVENTS
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