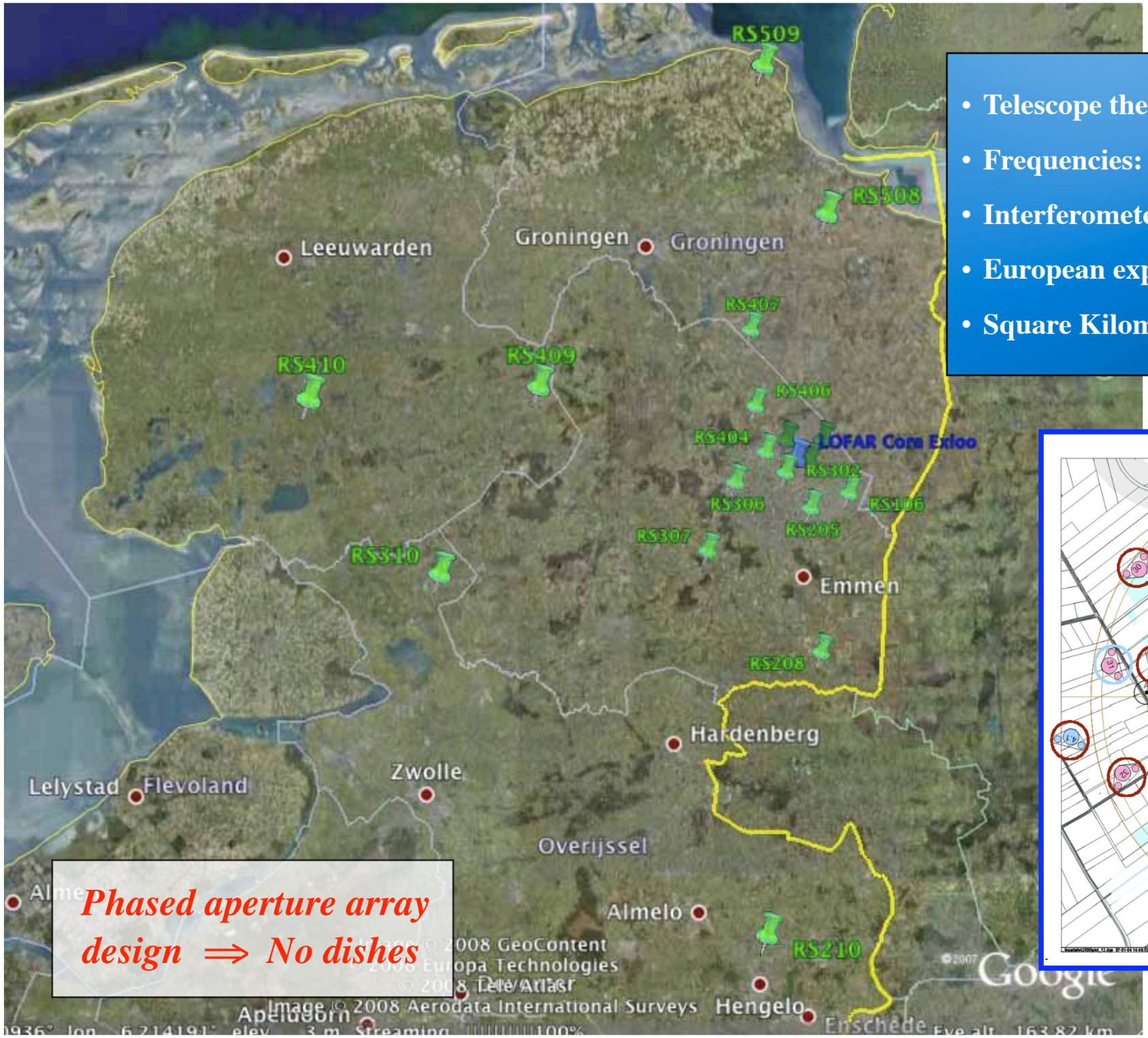
Solar Observations with LOFAR

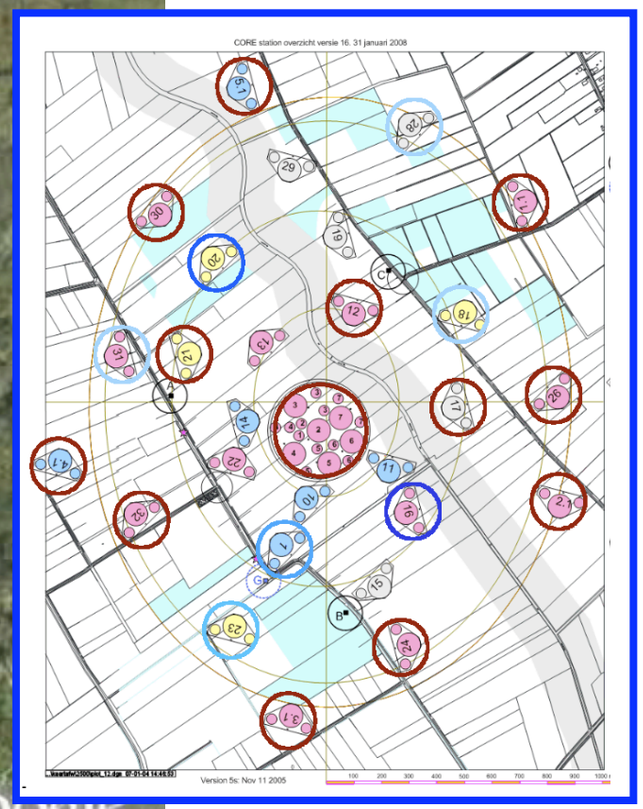
NRH Workshop
30 June 2009

Michael Wise
ASTRON RO / LOFAR / Univ. Amsterdam

LOFAR Radio Telescope



- **Telescope the size of the Netherlands-Europe**
- **Frequencies: 30 – 240 MHz**
- **Interferometer baselines ~100 km**
- **European expansion to 1000 km**
- **Square Kilometer Array (SKA) pathfinder**

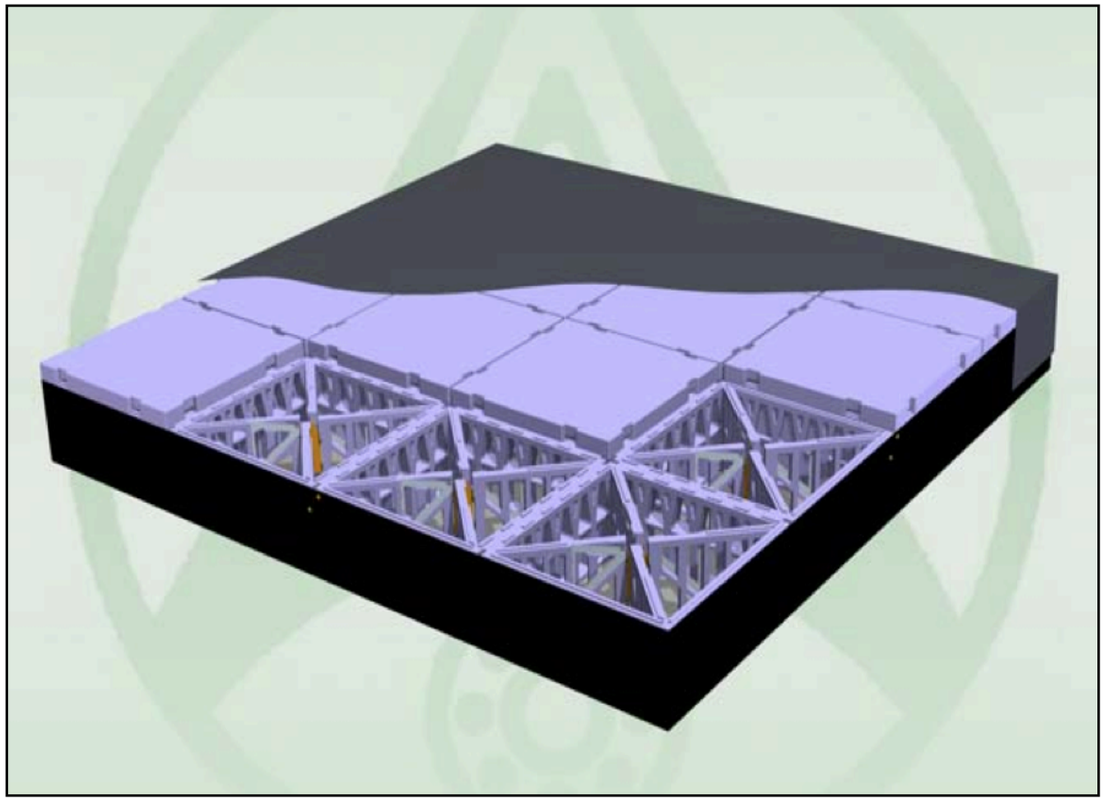


Phased aperture array design ⇒ No dishes

LOFAR Antennas

Low band antenna: 30 – 80 MHz
48/96 antennas per station

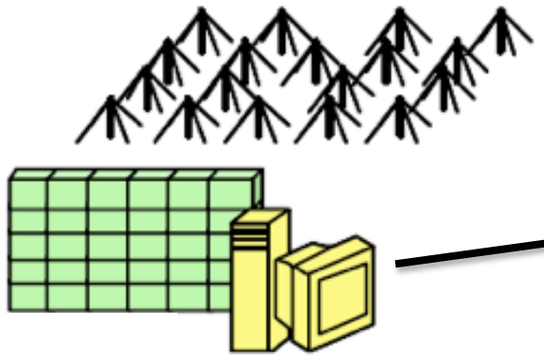
High band tiles:120 – 240 MHz
96 tiles/station, 4x4 antennas/tile



- 36 NL + 8 EU stations of dipoles
- Replace big dishes by many cheap dipoles
- No moving parts: electronic beam steering
- Flexible digital beam forming

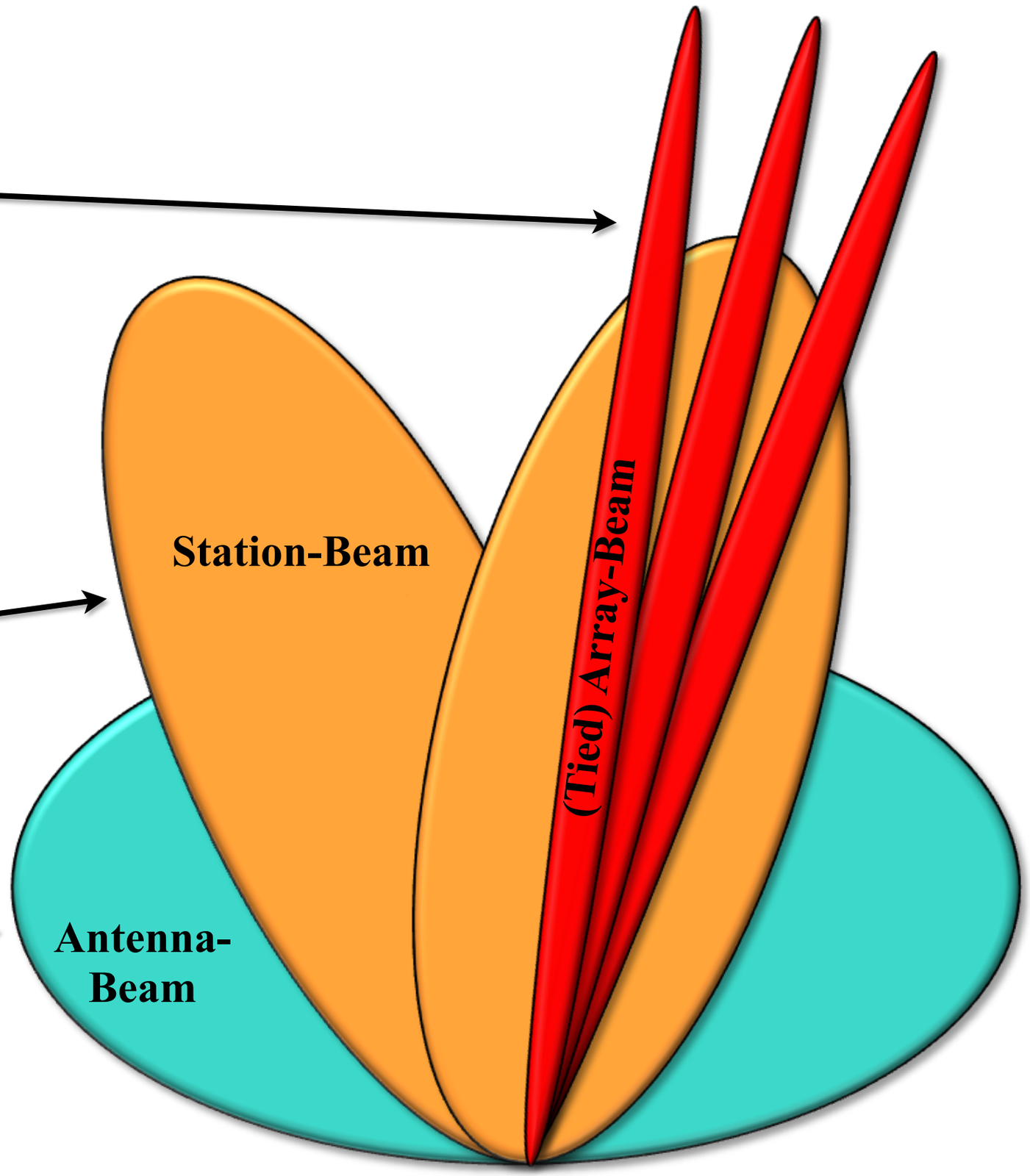
Digital Beam-Forming

Array

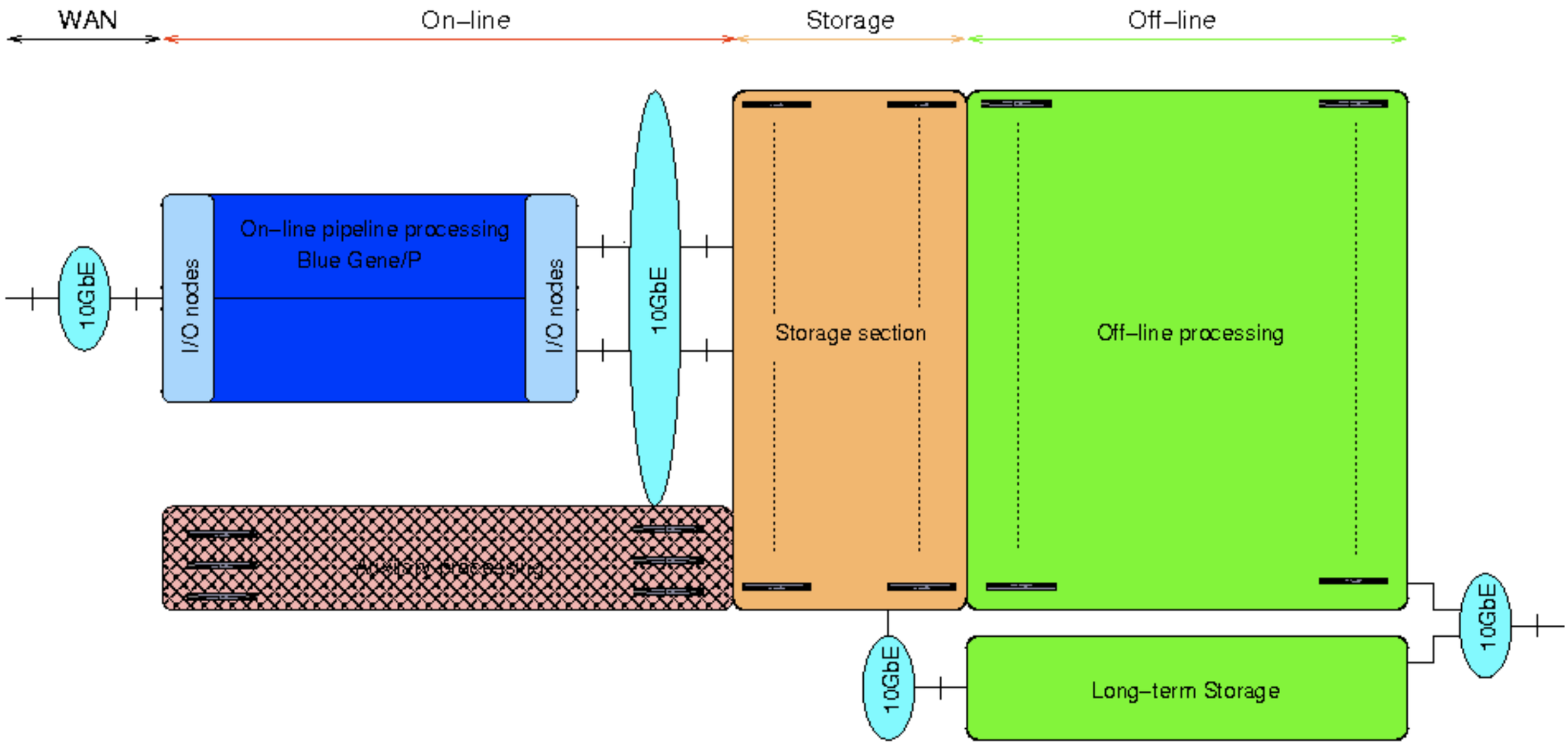


Station

Dipole

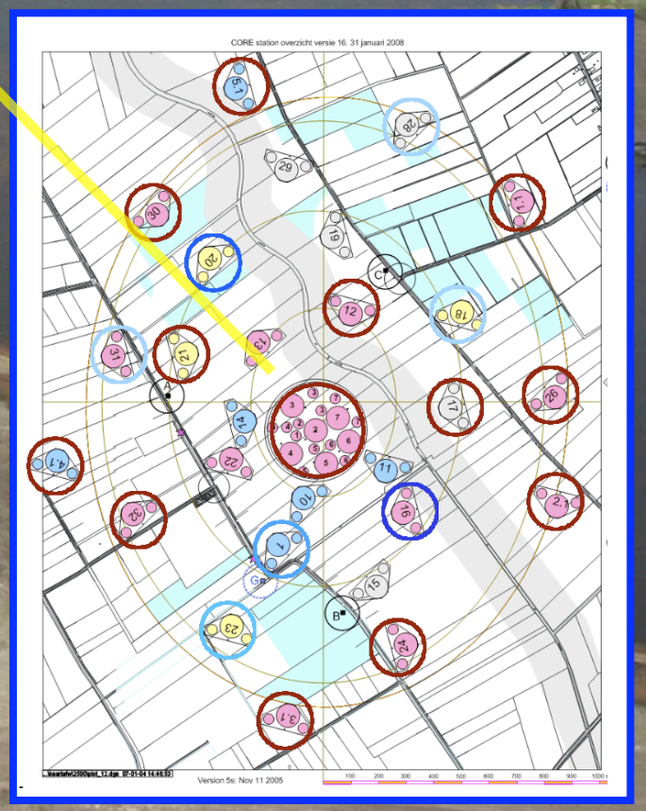


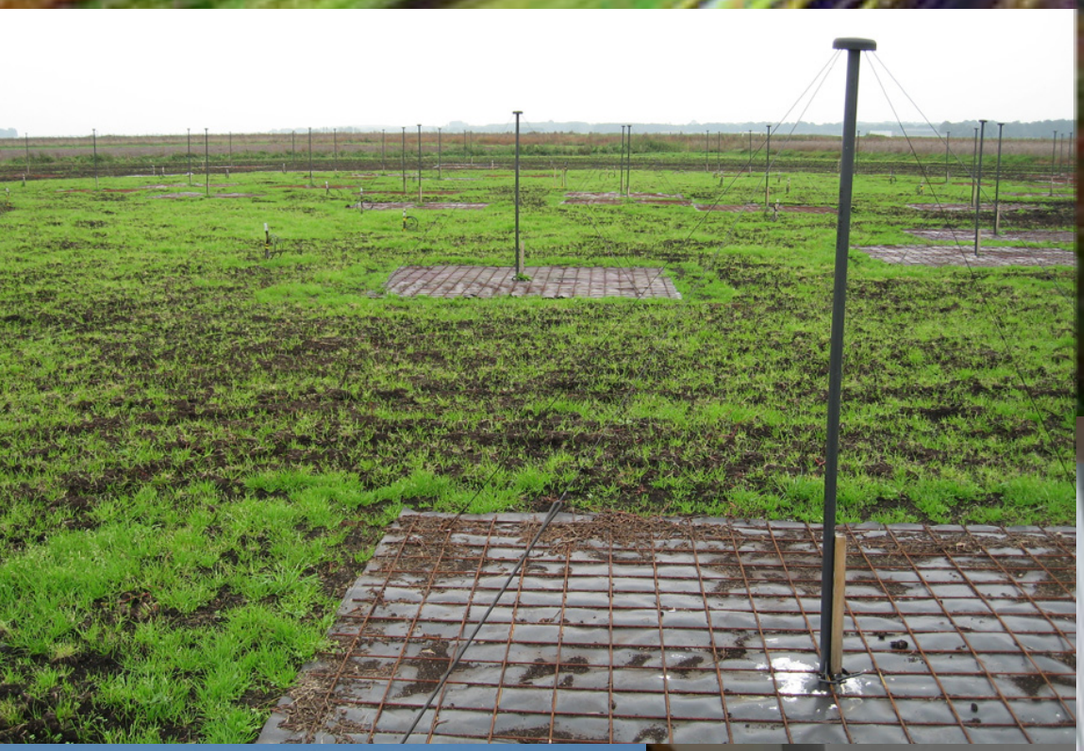
Central Processing



- BG/P *Data reception, transpose, correlation, beam-forming, 41. 8 TFLOPS, 6TB memory*
  - Storage system *Short term storage of data, ~2 PByte, 50-100 Gbps I/O*
    - Offline cluster *Calibration, data products, off-line analysis, ~10 TFLOPS*

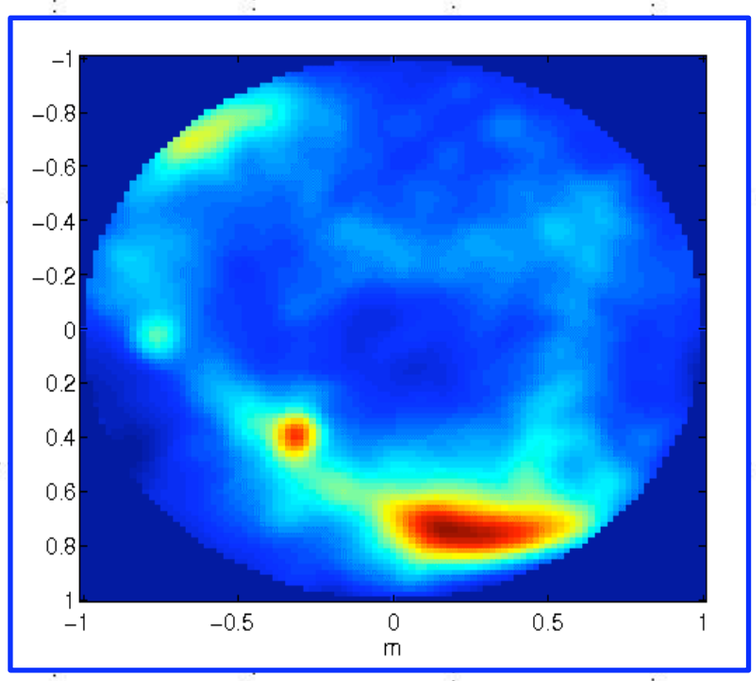
LOFAR “Superterp”





Station CS302

d:\LOFAR\dataCS302\\20090516_123406_sst_rcu094.dat time=2



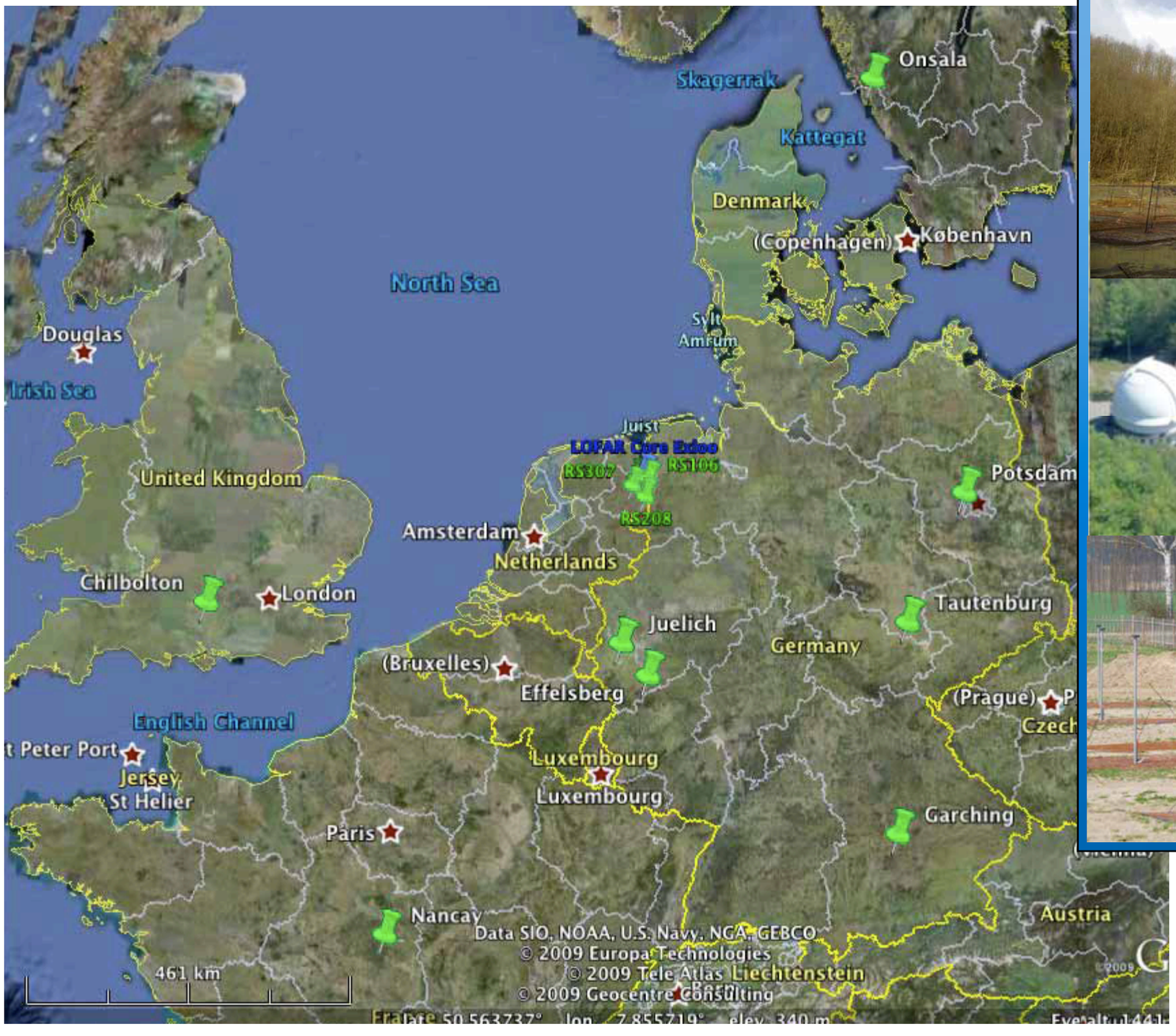
Power (dB)

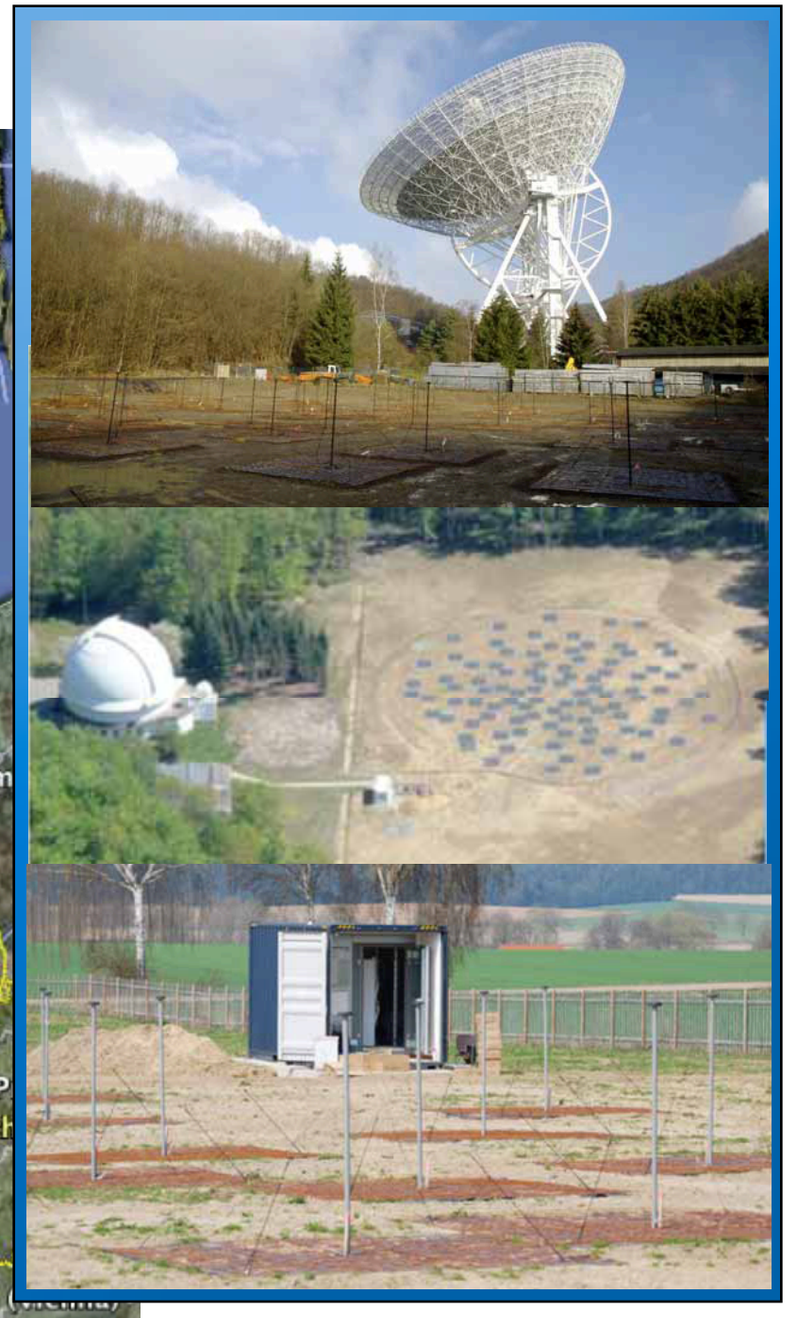
-50
-60
-70
-80
-90
-100
-110

0
10
20
30
40
50
60
70
80
90
100

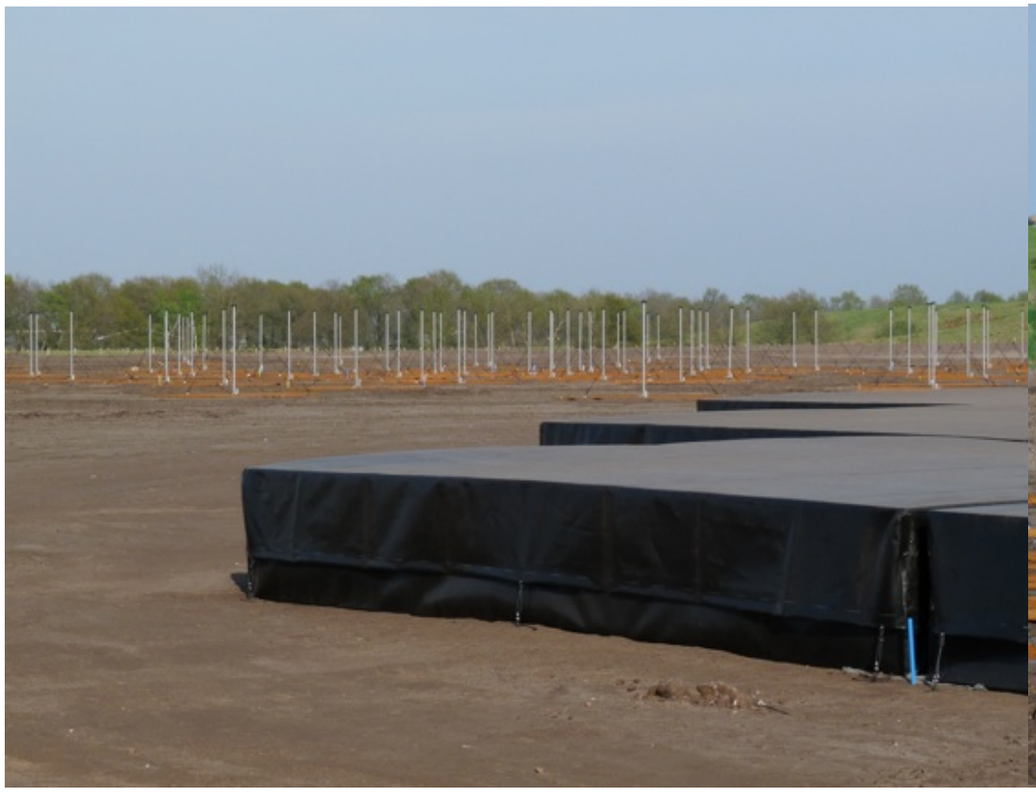
Frequency (MHz)

International LOFAR





Station Rollout



Current rollout schedule:

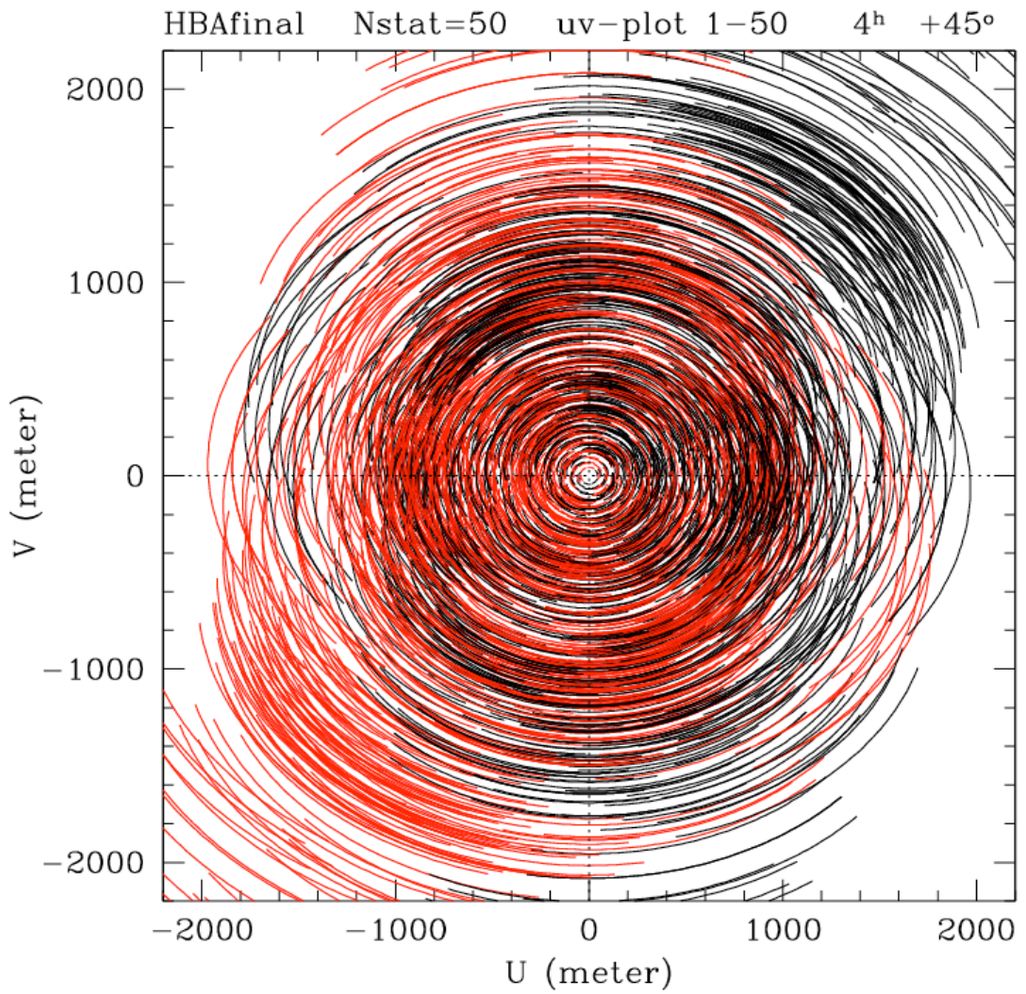
- Jun-Oct 2009 — 1 ⇒ 20NL stations + 4 EU stations
- Nov-Jan 2010 — 20 NL stations + 6 EU stations
- Jan-Aug 2010 — 36 NL + 8-11 EU stations

⇒ ***Regular LOFAR observing to begin in mid to late 2010***

Performance Estimates

Freq. (MHz)	λ (m)	Resolution L = 2 km (arcsec)	Resolution L = 10 km (arcsec)	Resolution L = 80 km (arcsec)
15	20.0	1650	330	41.3
30	10.0	825	165	20.6
45	6.67	550	110	13.8
60	5.00	413	82.5	10.3
75	4.00	330	66.0	8.25
120	2.50	206	41.3	5.16
150	2.00	165	33.0	4.13
180	1.67	138	27.5	3.44
210	1.43	118	23.6	2.95
240	1.25	103	20.6	2.58

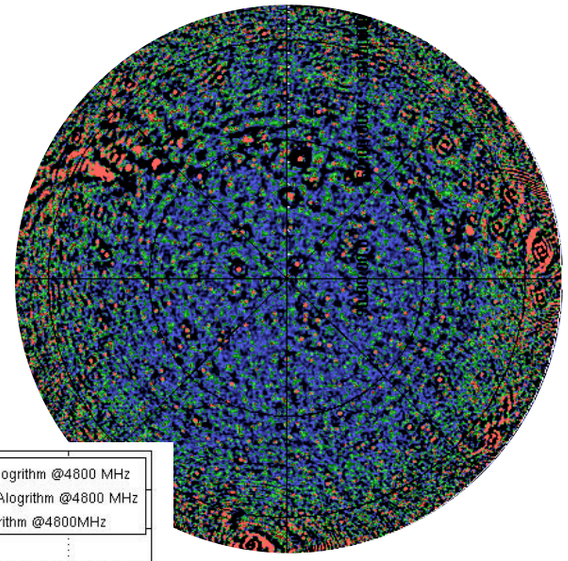
Freq. (MHz)	λ (m)	ΔS_{13+7} (mJy)	ΔS_{13+7} Tapered (mJy)	ΔS_{18+18} (mJy)	ΔS_{25+25} (mJy)
15	20.0	201		110	79
30	10.0	37		20	15
45	6.67	20		11	7.8
60	5.00	13		7.2	5.2
75	4.00	21		12	8.4
120	2.50	0.74	0.89	0.41	0.29
150	2.00	0.58	0.71	0.32	0.23
180	1.67	0.67	0.81	0.37	0.26
210	1.43	0.76	0.91	0.42	0.30
240	1.25	0.84	1.0	0.46	0.33

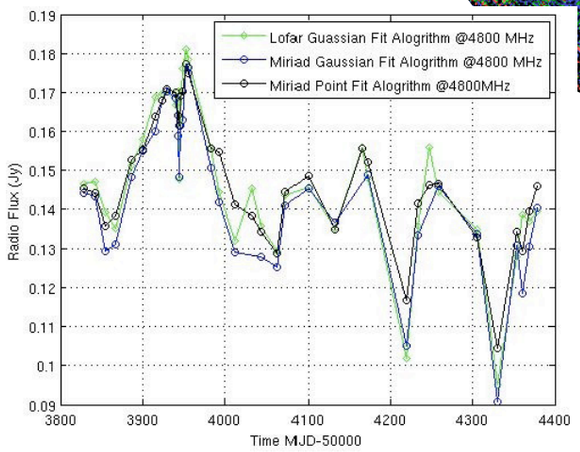


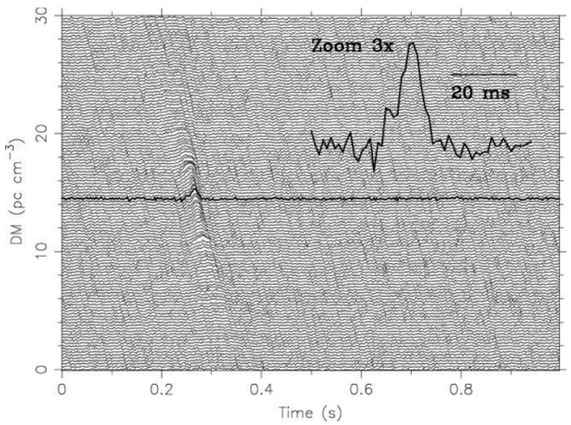
⇒ ***Initial all-sky survey begins Oct. 2009!***

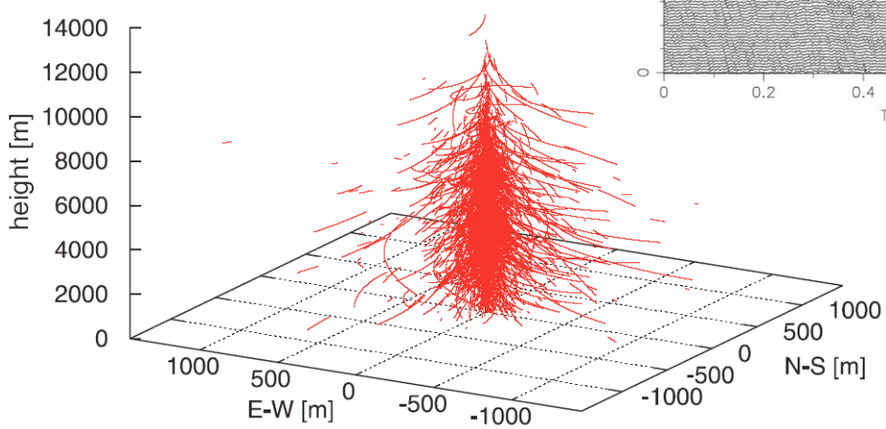
Observing Modes

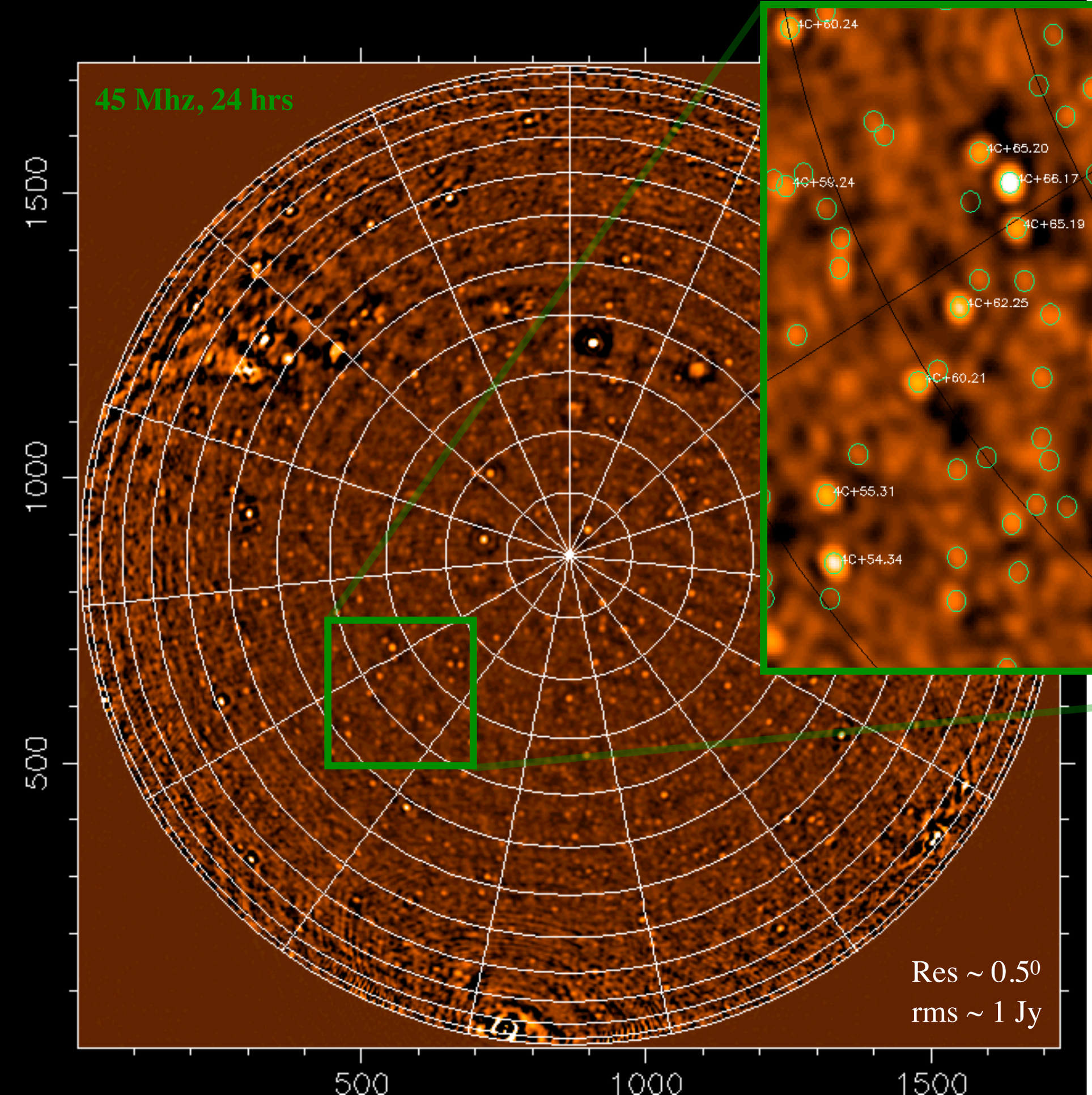
- Synthesis Imaging
  - Pointed observations and surveys
  - Standard Data Products: uv data, image cubes
- Transient Detection
  - Radio all-sky monitor
  - Detect transients on ~1 sec scales
- Tied Array Beam-forming
  - Support coherent and incoherent beam-forming
  - Useful for surveys of pulsars, solar spectra, etc.
- Antenna-based Buffering
  - 1 sec at full, digitized bandwidth
  - Detection/triggering for CR

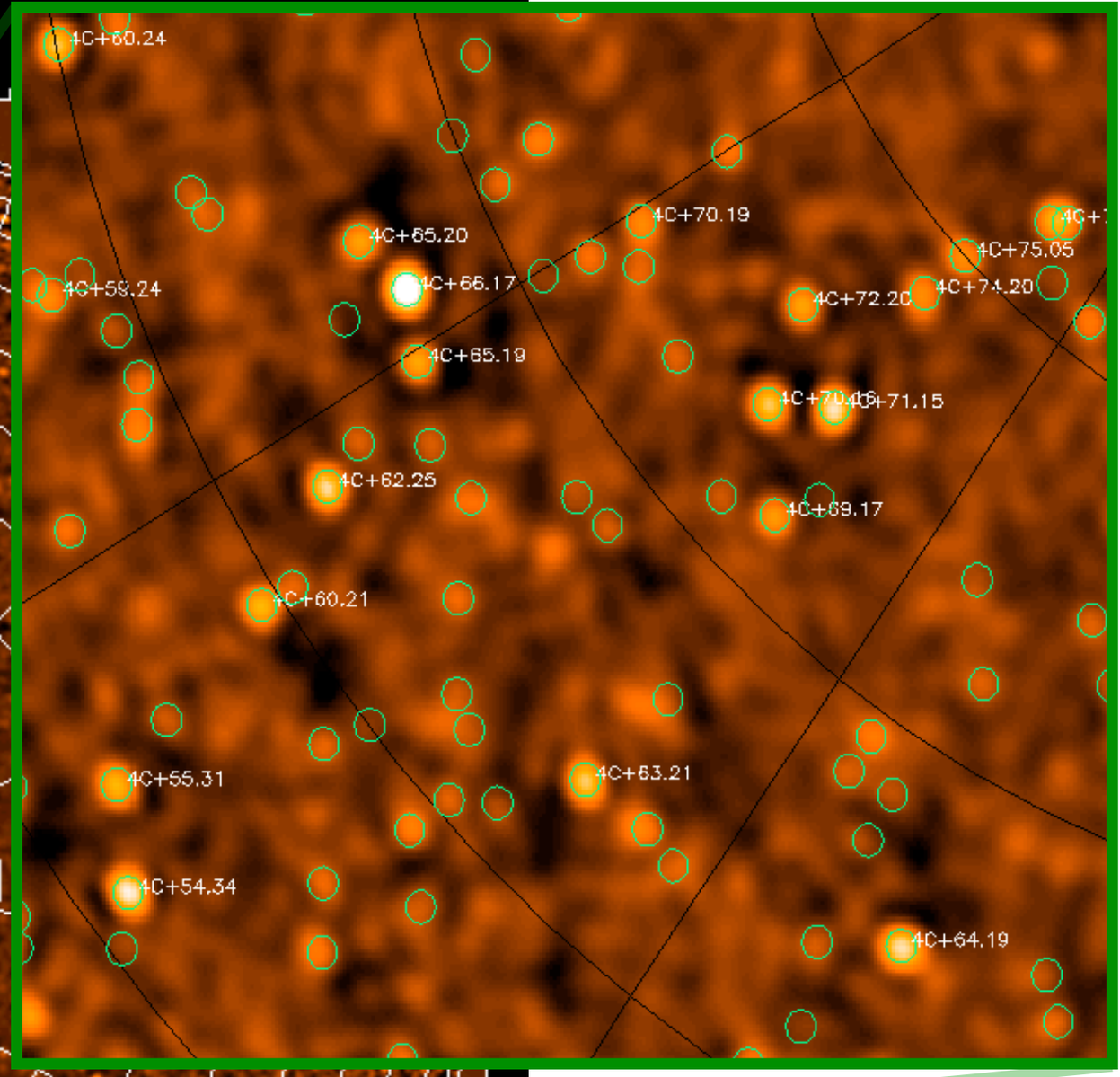








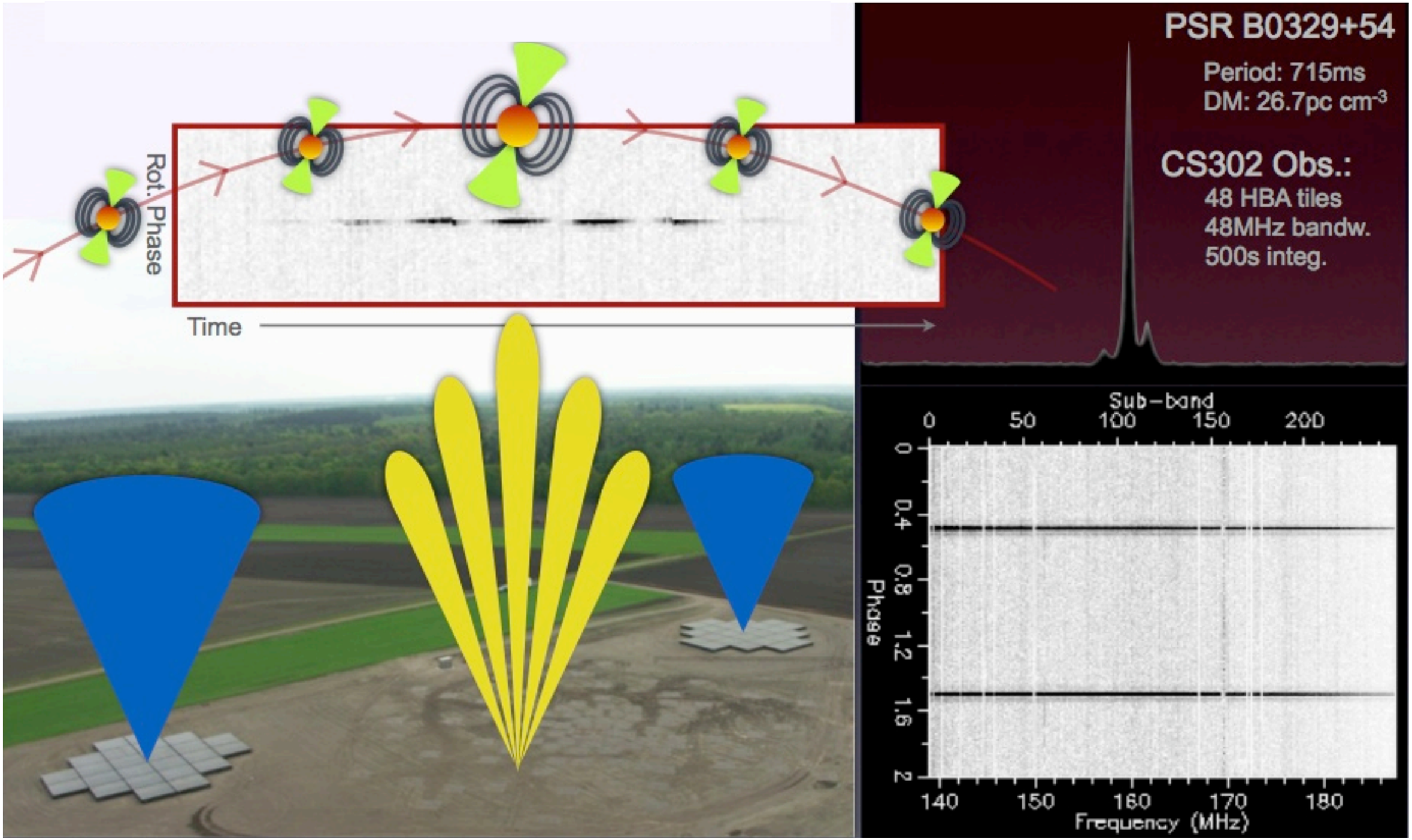




Recent LOFAR imaging results

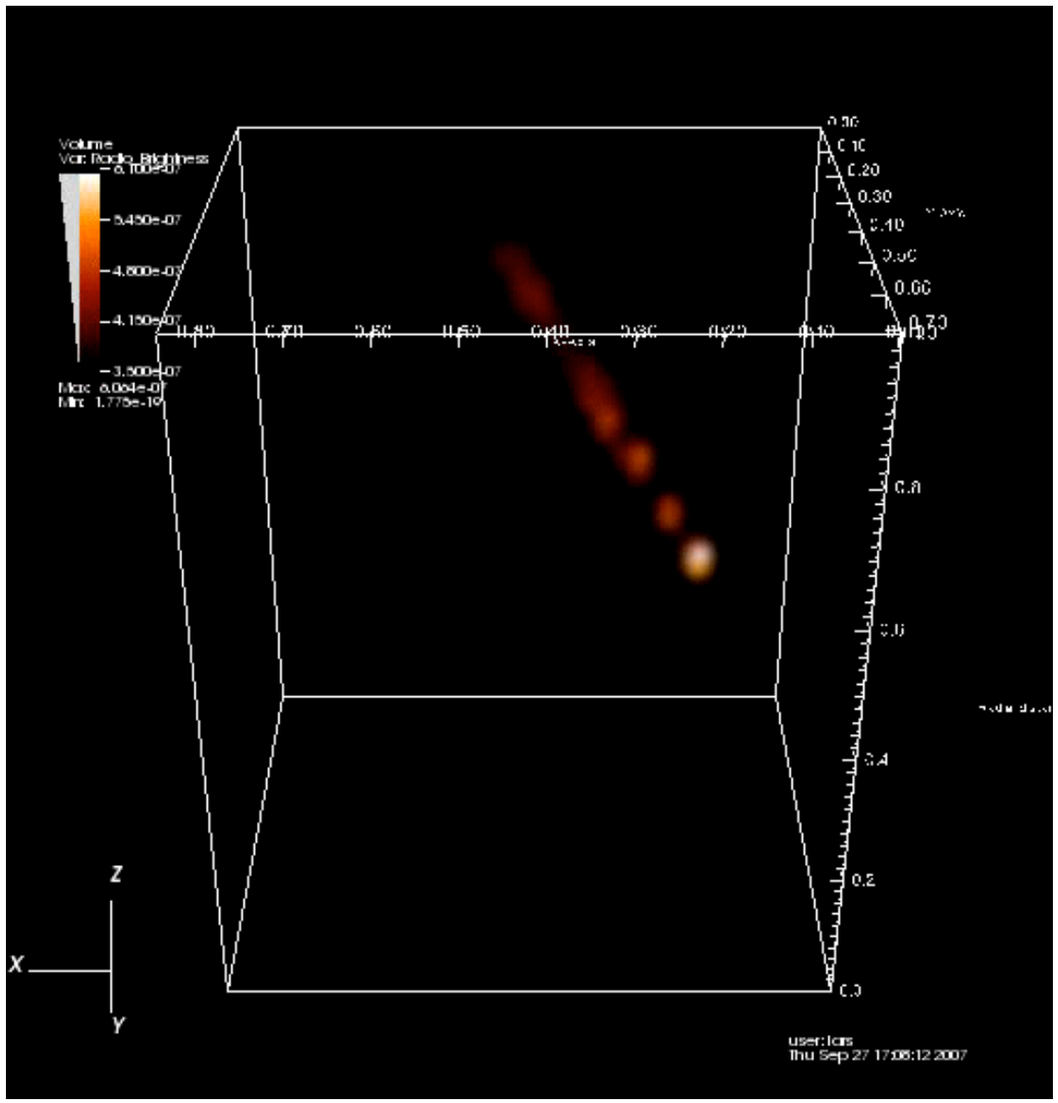
50+ supernova remnants,
Many z>2 radio galaxies,
A2255, A2256, M82 ...

Pulsar Observations

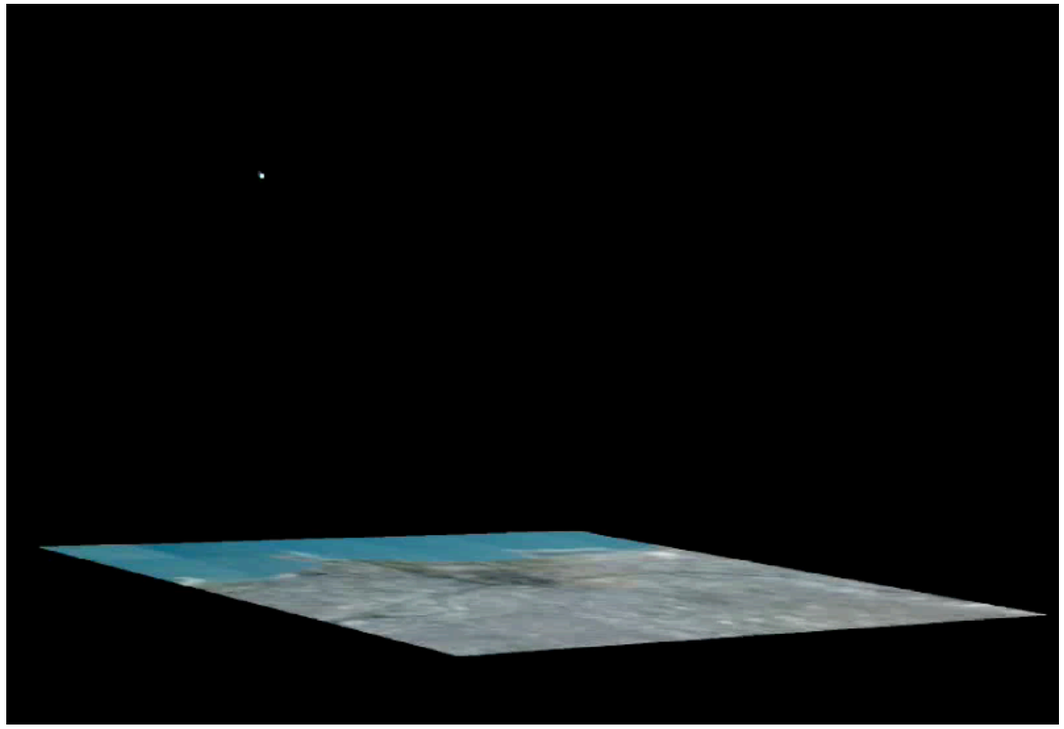


Radio Emission from CRs

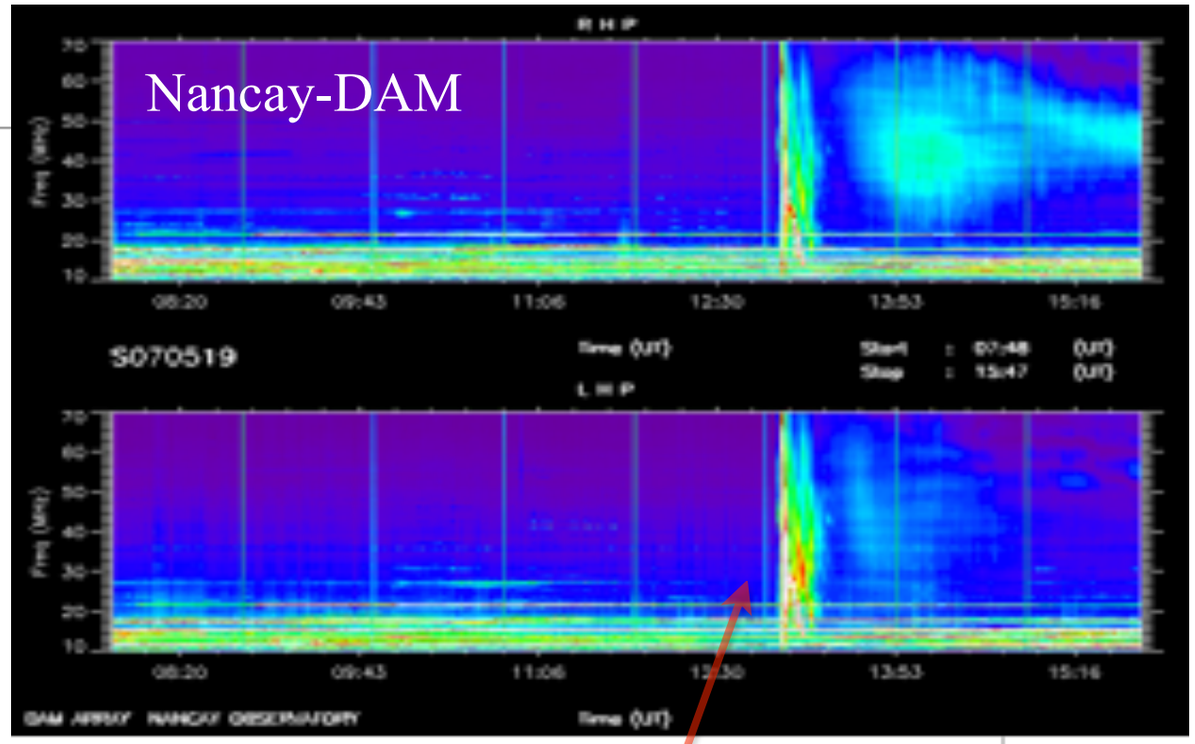
- Cosmic Ray Air Showers produce radio pulses as liberated electrons spiral in the earth's magnetic field (geosynchrotron emission)
- This pulse is detectable for showers with energies above ~10^{17} eV



Near-field imaging



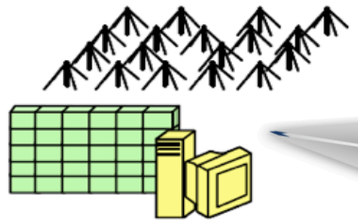
Solar Monitoring



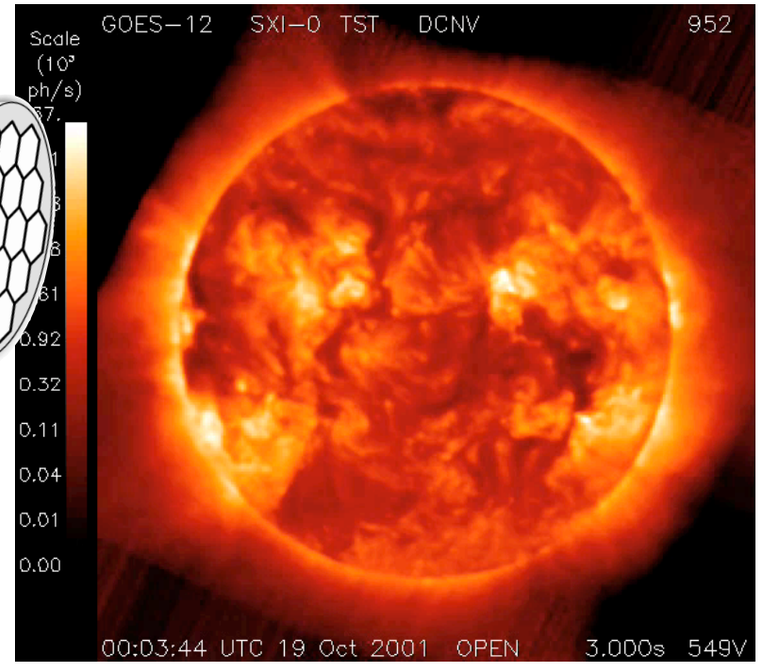
Solar flare detection (50 Mhz, 19May07)

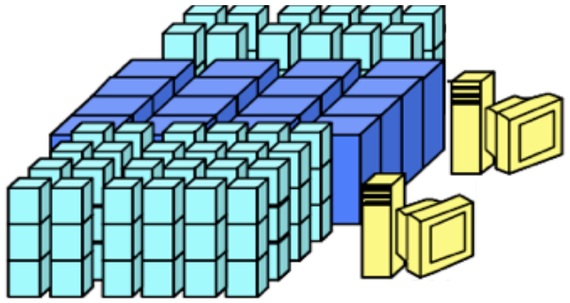
Solar Spectrometer mode

Station Data



LOFAR Station

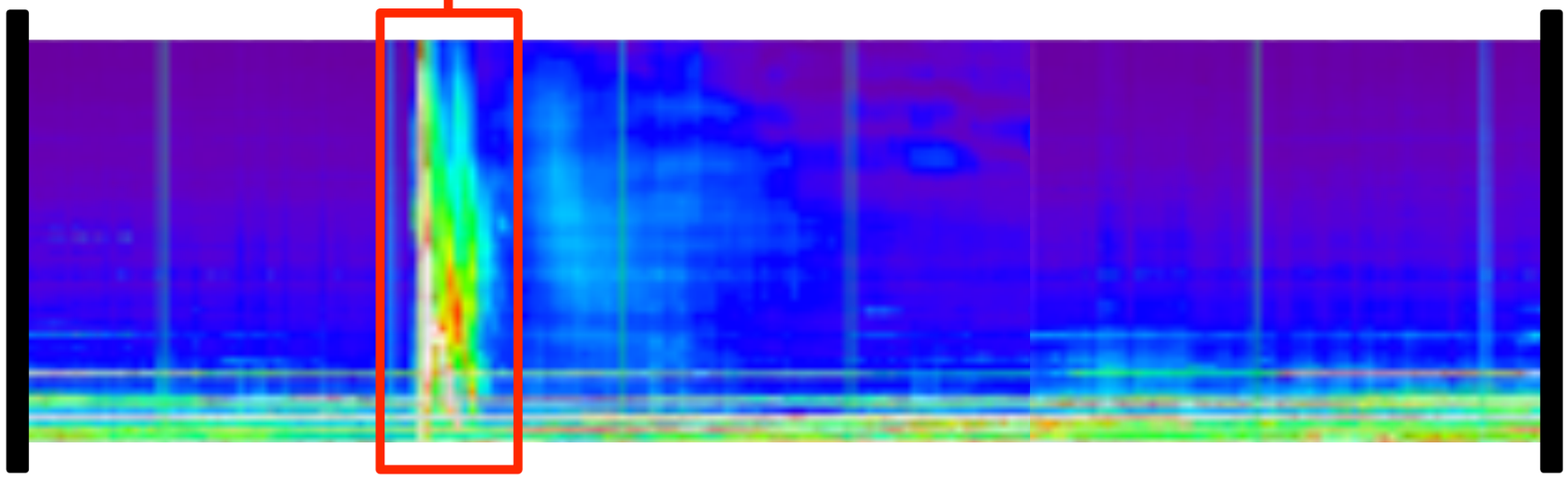




ocessing

Trigger generated

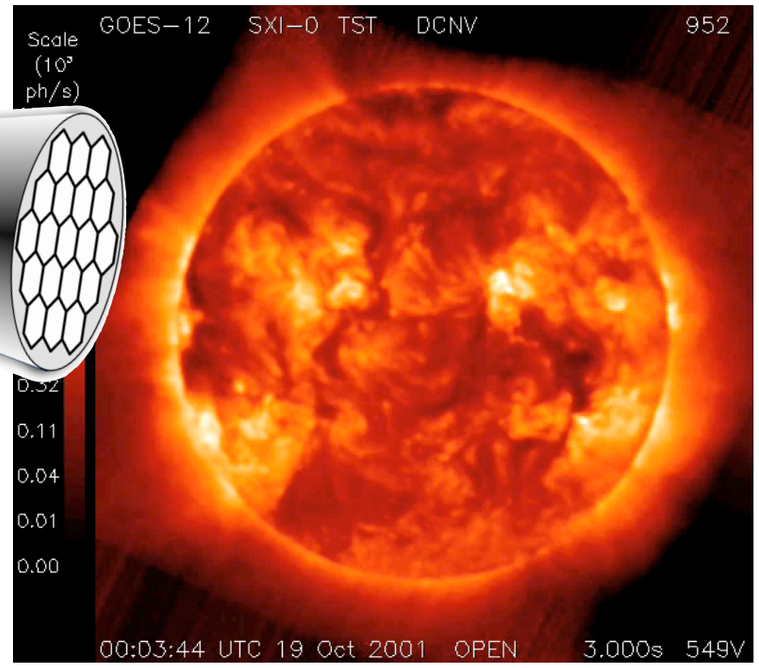
Dynamic Spectrum

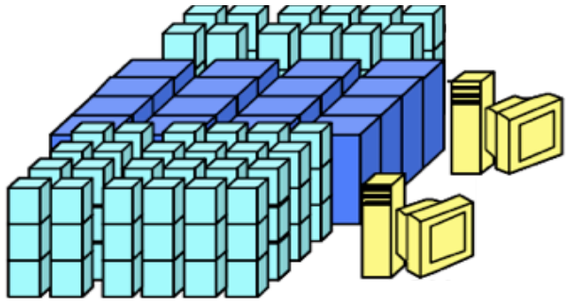


Solar Spectrometer mode

VOEvent Trigger

External Observatory

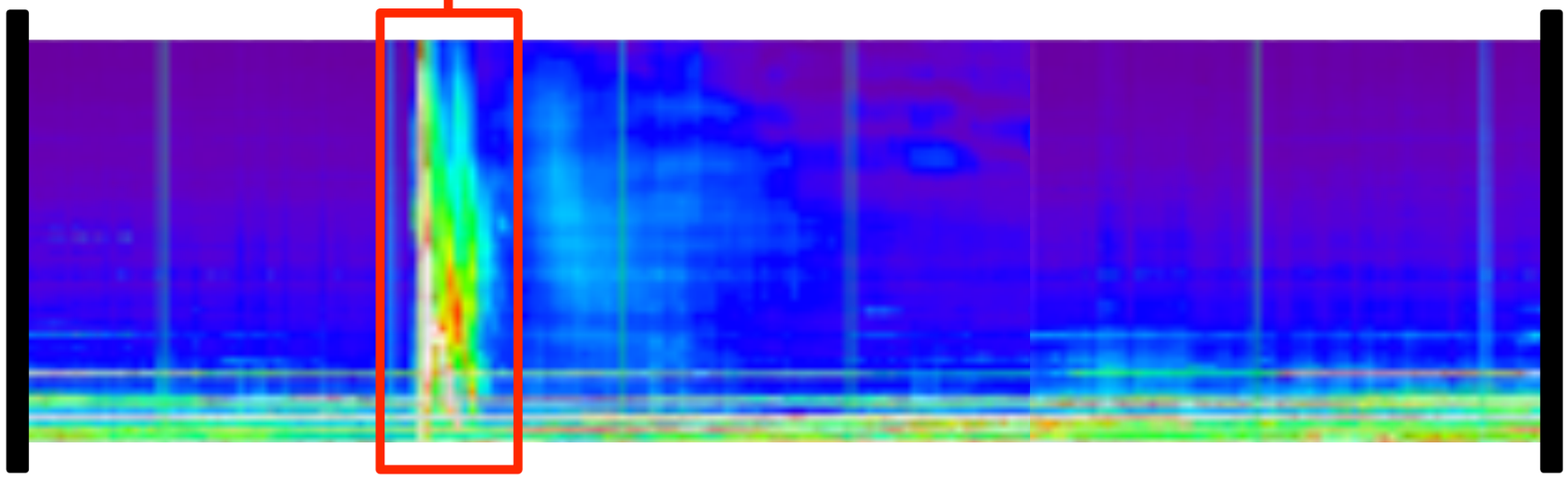




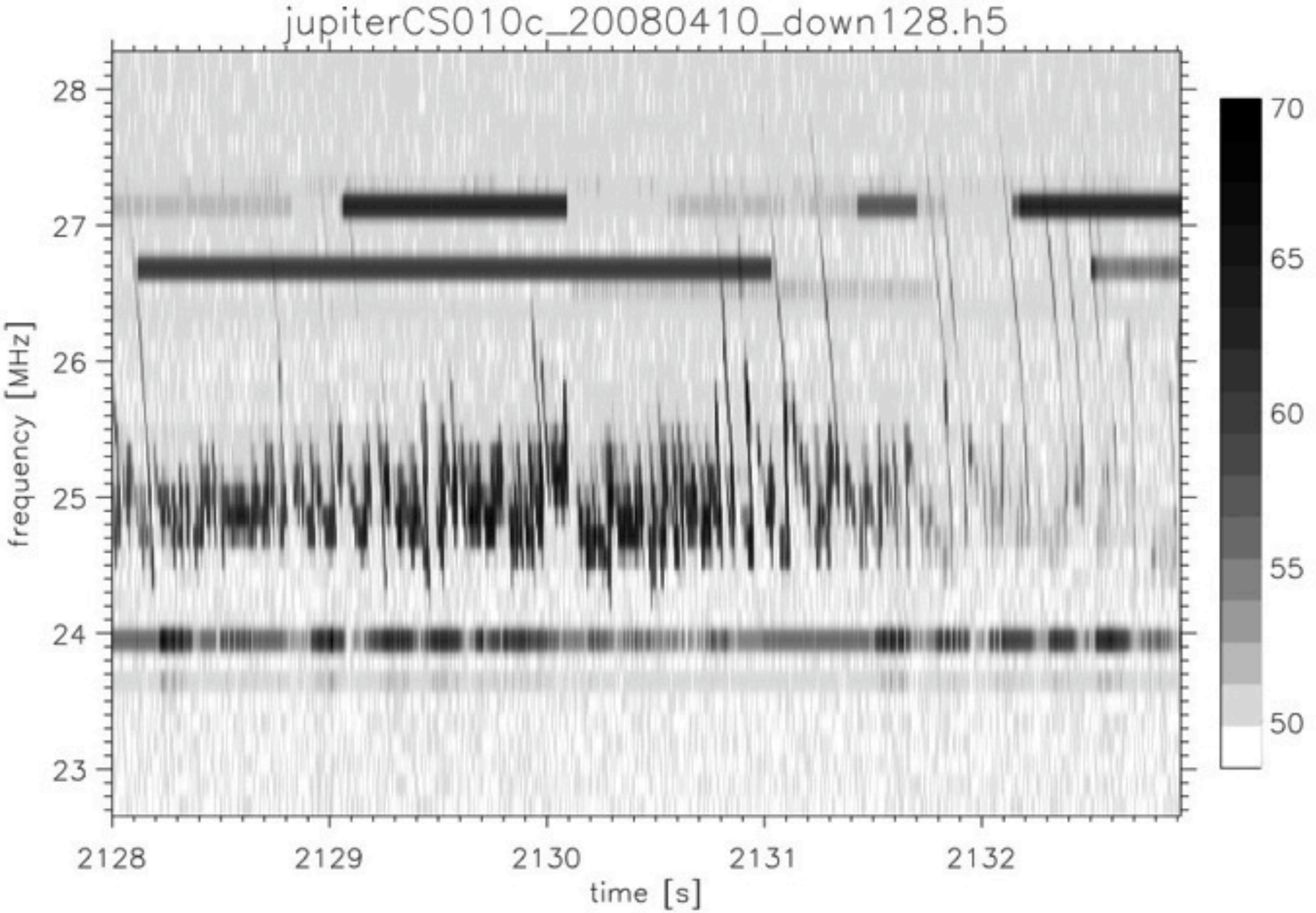
ocessing

Trigger generated

Dynamic Spectrum

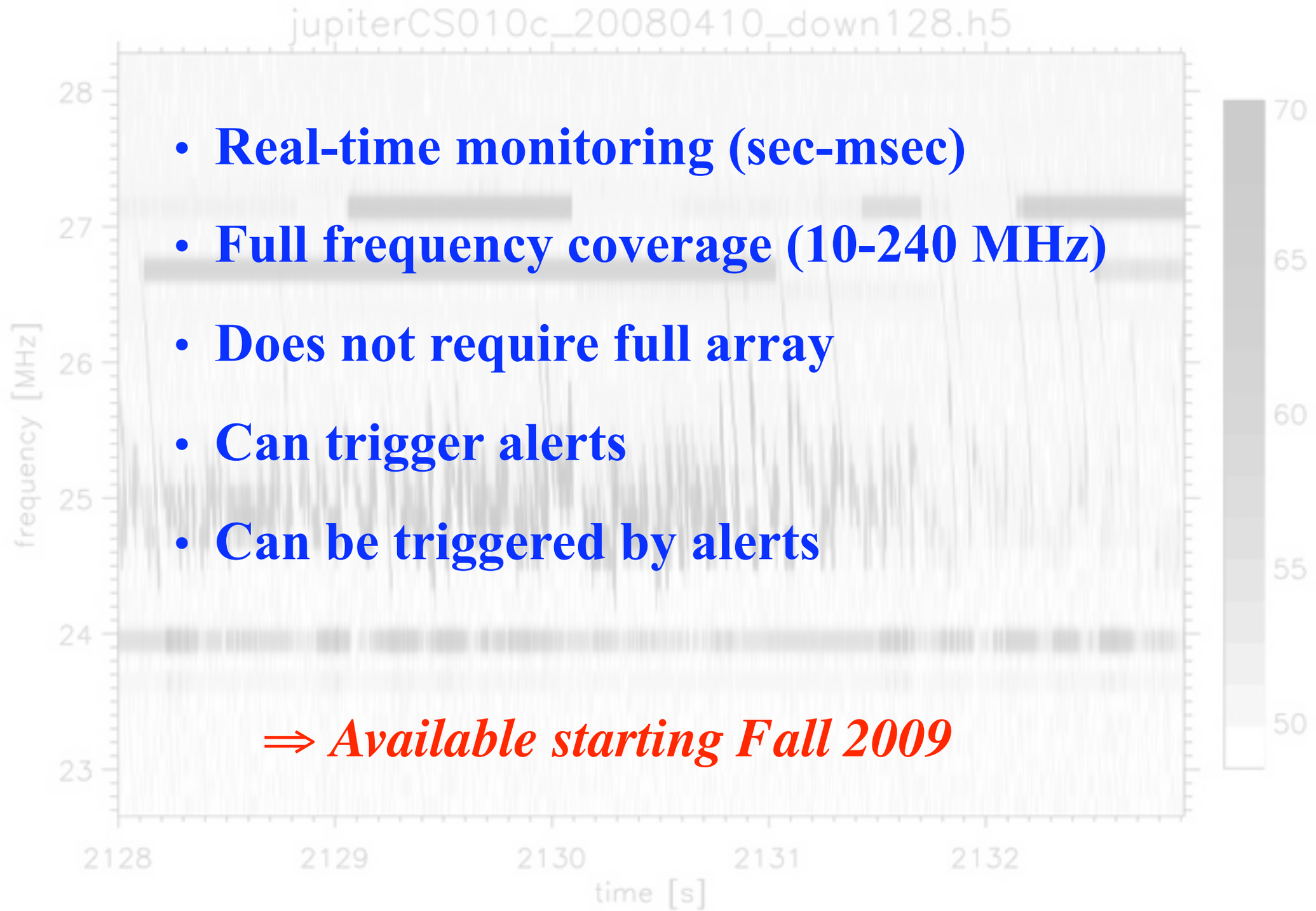


Dynamic Spectra



Jupiter bursts (courtesy J.-M. Grießmeier)

Dynamic Spectra



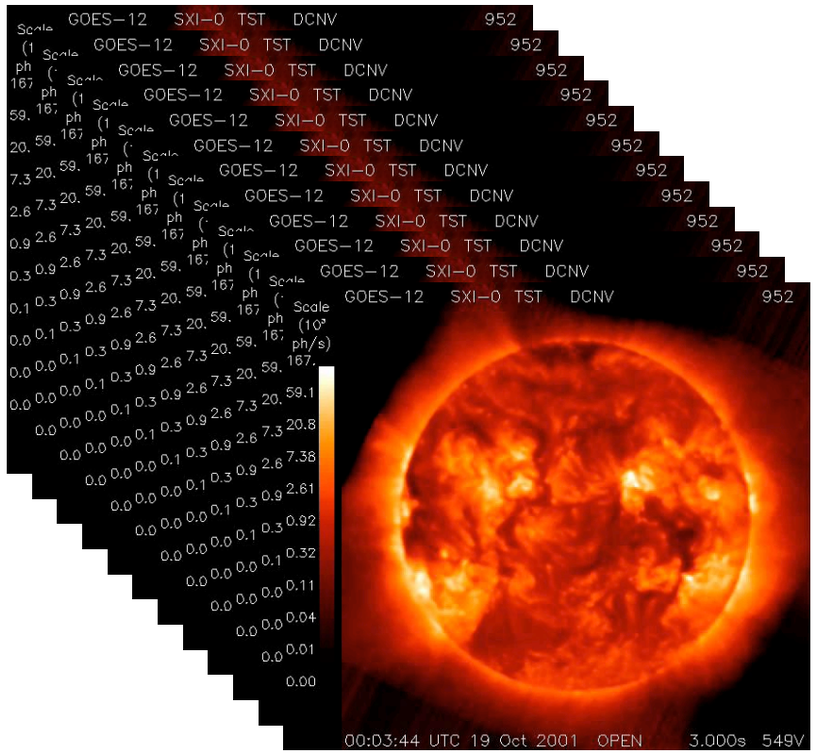
- **Real-time monitoring (sec-msec)**
- **Full frequency coverage (10-240 MHz)**
- **Does not require full array**
- **Can trigger alerts**
- **Can be triggered by alerts**

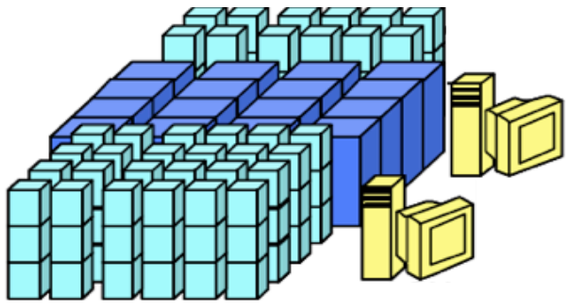
⇒ ***Available starting Fall 2009***

Jupiter bursts (courtesy J.-M. Grießmeier)

Triggered Imaging

Fast Cadence Imaging

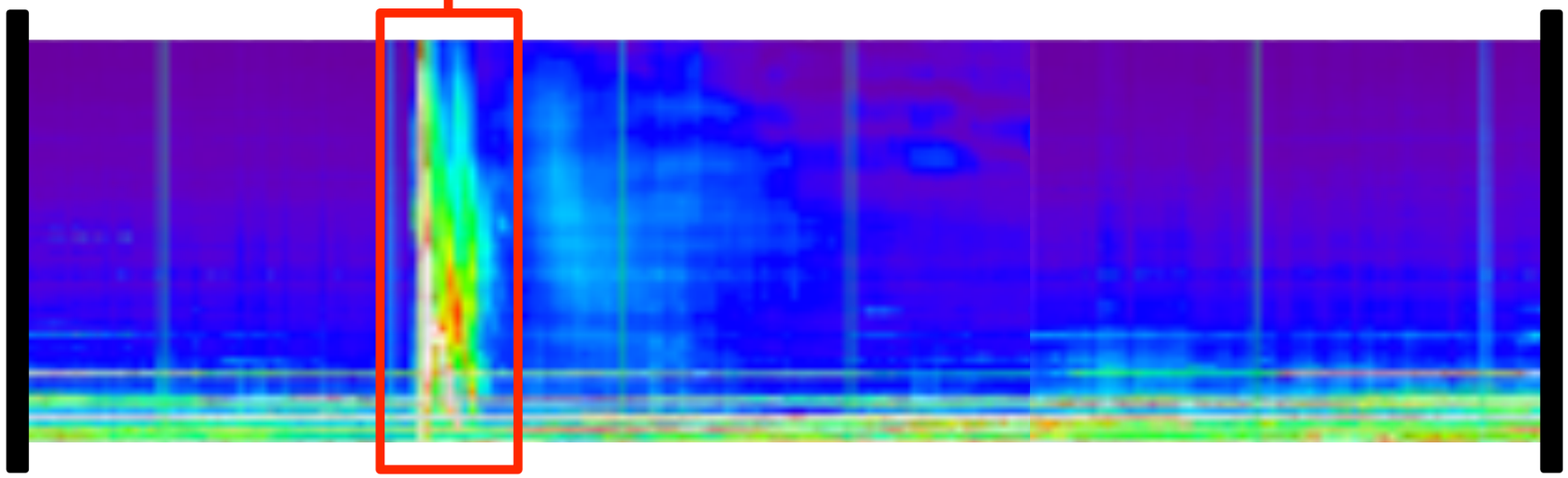




LOFAR Central Processing

Trigger generated

Dynamic Spectrum



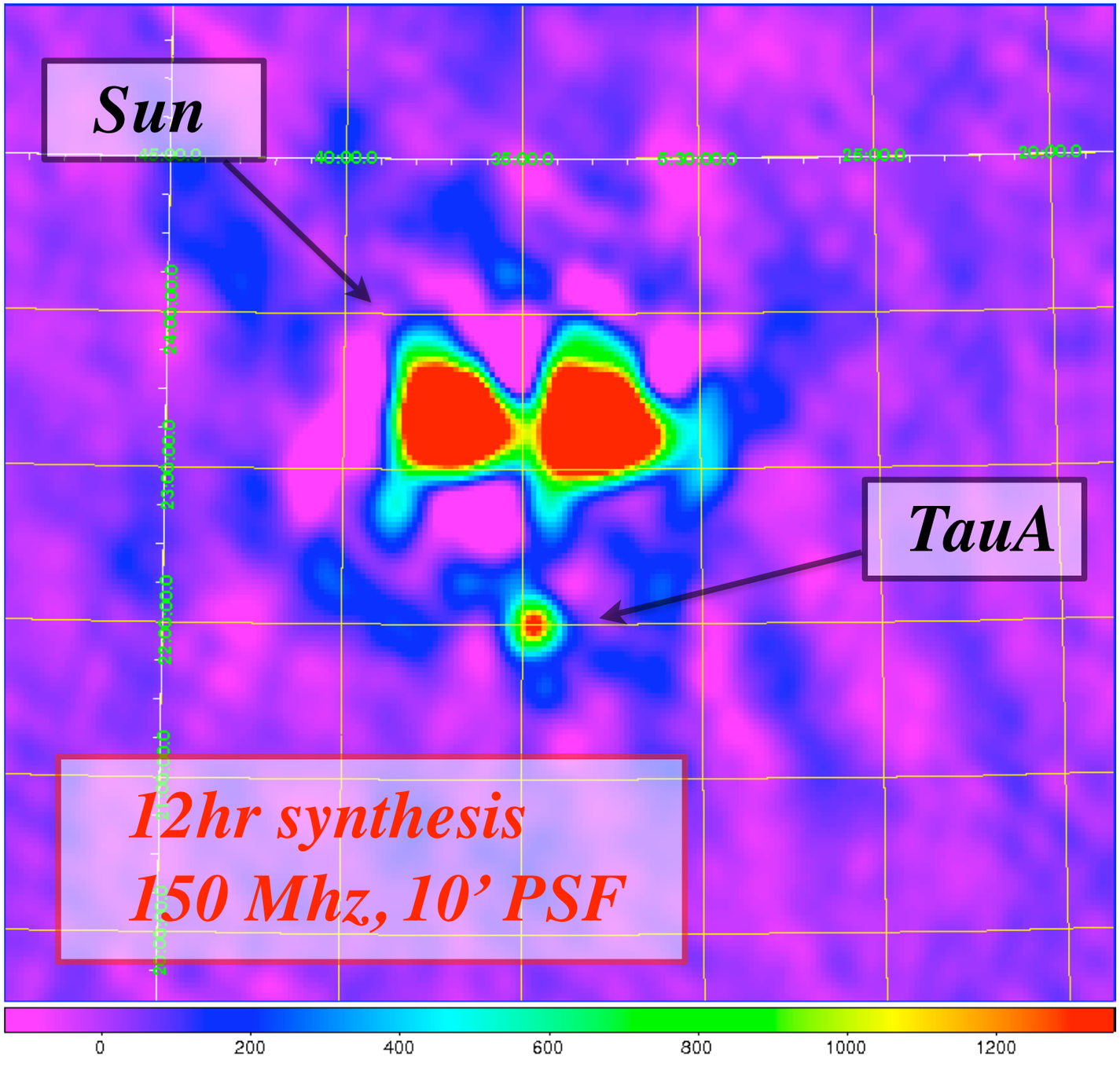
Solar Imaging

Performance

- Core resolutions (3-30')
- Full array (3-30'')
- Practical limit due to coronal scattering ~60"
- Image cadences (from minutes to hours)

Required Upgrades

- Solar tracking
- Calibration strategy
- System latency
- Overall performance

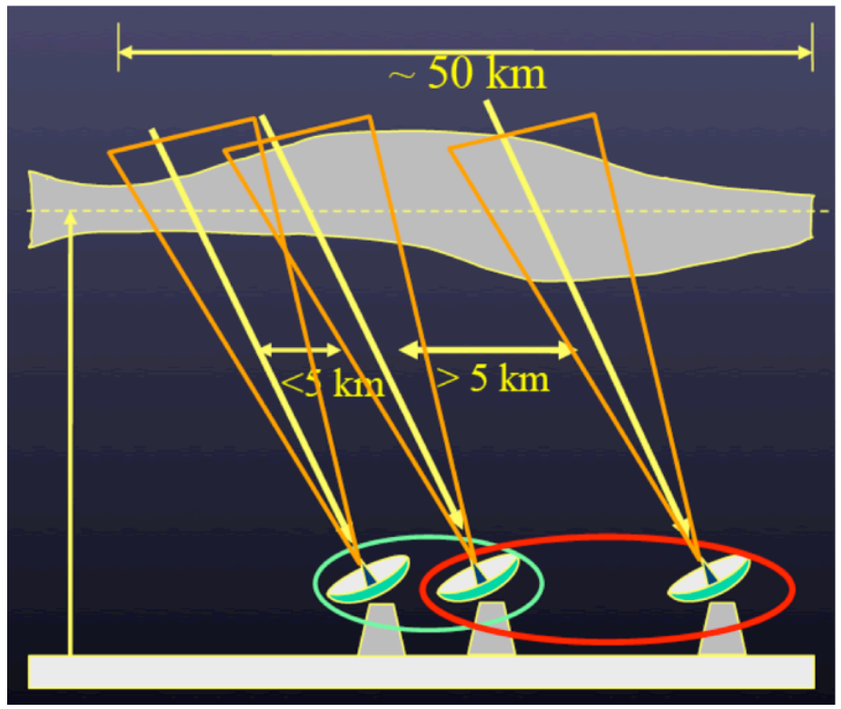


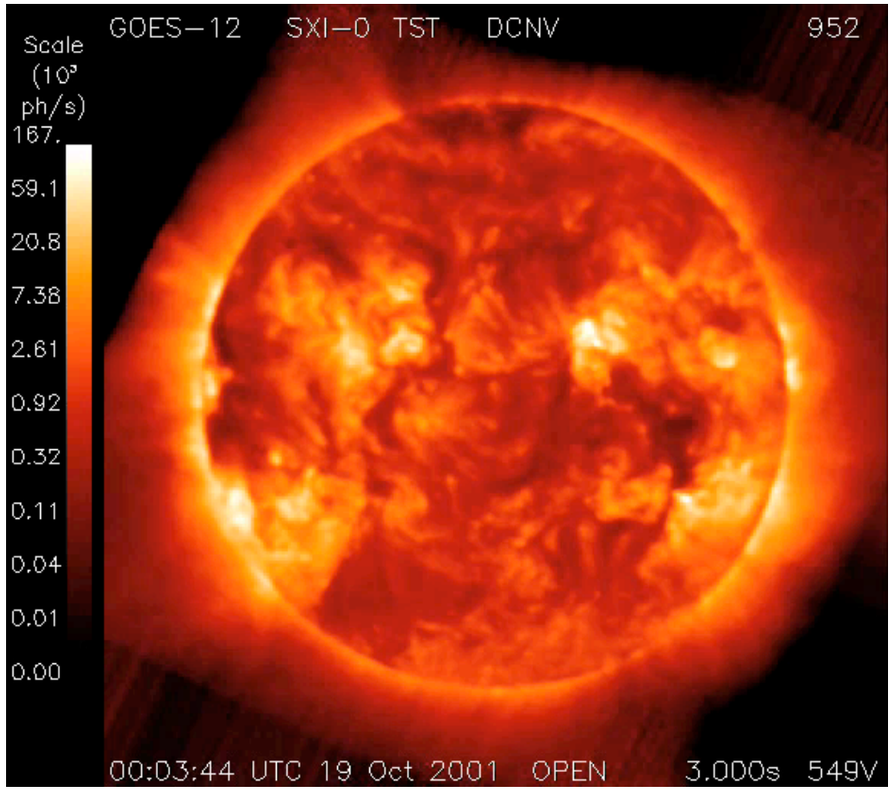
(courtesy S. Yatawatta & M. Brentjens)

Space Weather with LOFAR

Ionospheric Data

- Ionosphere affects image quality
- Integral part of LOFAR calibration
- Modeled on ~10 second timescales
- Potential community data product





Solar Observations

- Dynamic spectral monitoring
- High-time resolution (sec-msec)
- Flare detection and triggering
- Direct interferometric imaging

Key Science Project

Solar Physics and Space Weather

PI: Gottfried Mann (AIP, Germany)

Core members:
Alain Kerdraon (Obs. Paris-Meudon)
Alec McKinnon (Univ. Glasgow)
Bo Thide (Univ. Uppsala)
Christian Vocks (Project manager, AIP)

Regular members:
Henry Aurass (AIP)
Andy Breen (Univ. Aberystwyth)
Peter Gallagher (Dublin)
Jürgen Rendtel (AIP)
Alexander Warmuth (AIP)

Associated members:
Carsten Denker (AIP)
Arnold Hanslmeier (Univ. Graz)
Karl-Ludwig Klein (Obs. Paris-Meudon)
Wolfgang Otruba (Univ. Graz)
Helmut Rucker (IWF, Austria)
Joachim Voigt (Jacobs Univ. Bremen)
Alexander Warmuth (AIP)

AIP

- Based at Astrophysikalisches Institut Potsdam
- Plans to establish a Solar Data Center
- Local LOFAR station near Pottsdam
- Support local and full LOFAR array operations

⇒ *See Prof. Dr. Mann for details*

Timeline

Jun 09	Three NL stations operational
Jul 09	Partial CEP storage and offline cluster
Jul 09	First version of standard imaging pipeline
Aug 09	6-10 NL stations operational
Aug 09	First version known pulsar pipeline
Sept 09	VHECR pipeline working
Sept 09	Prototype solar spectrometer mode
Oct 09	20 NL + 3-4 EU stations completed
Oct 09	Global Sky Model survey begins
Dec 09	Second phase of CEP hardware ready
Jan 10	36 NL + 8 EU stations online

The End