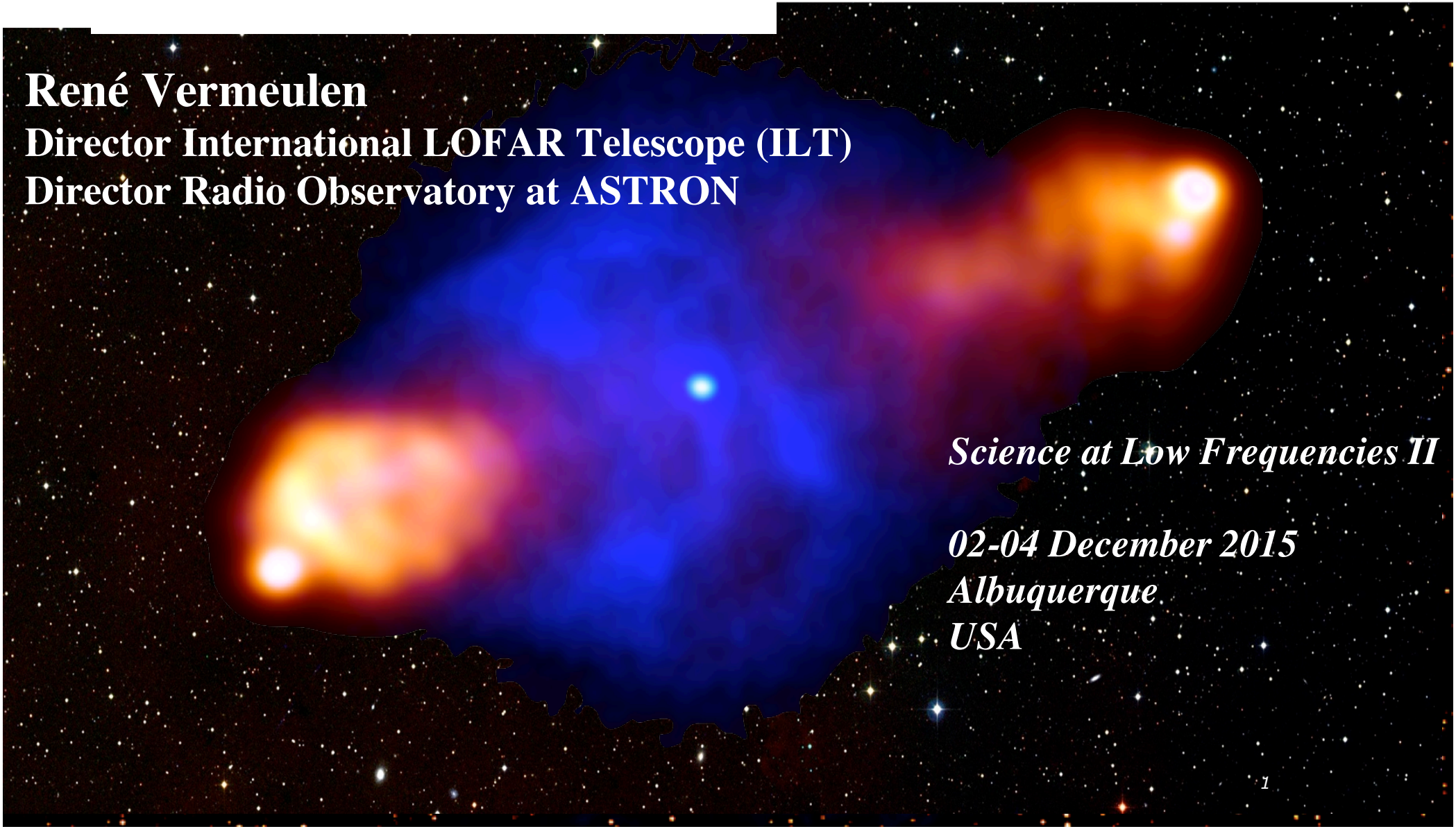
# The Expanding International LOFAR Telescope



**René Vermeulen**
**Director International LOFAR Telescope (ILT)**
**Director Radio Observatory at ASTRON**

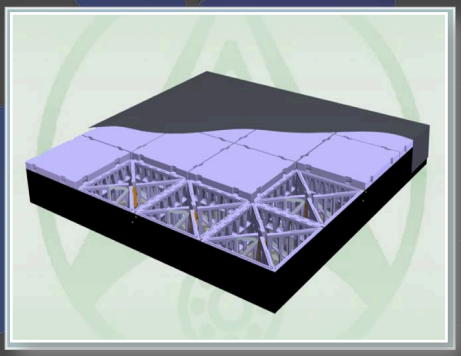
***Science at Low Frequencies II***

***02-04 December 2015***
***Albuquerque***
***USA***


LOFAR Core

# LOFAR antenna stations in Europe

10-80 MHz



120-240 MHz

Onsala

Dutch stations

Norderstedt

Chilbolton

LOFAR Core (NL)

Potsdam

Jülich

Effelsberg

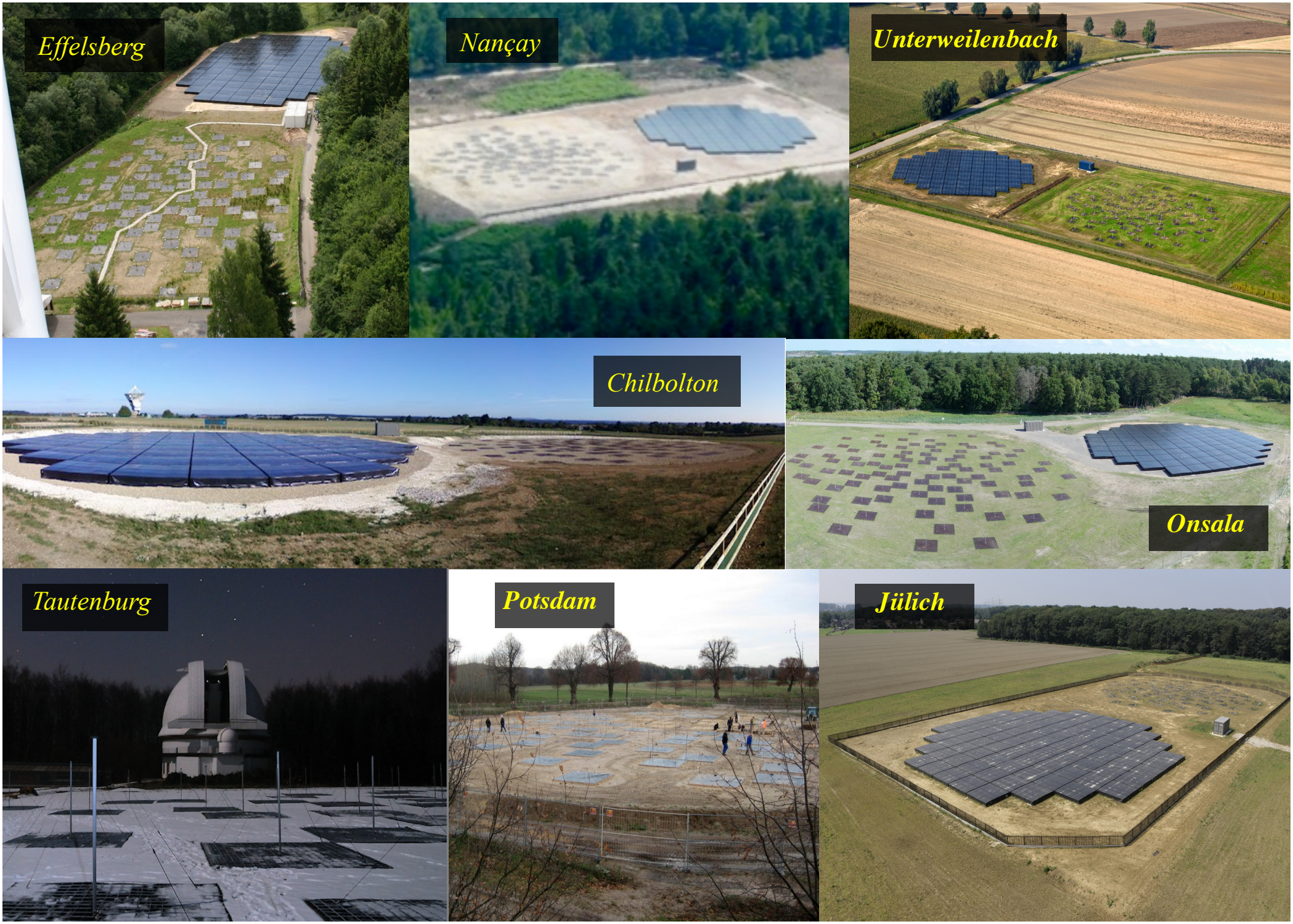
Tautenburg

Nançay

Unterweilenbach

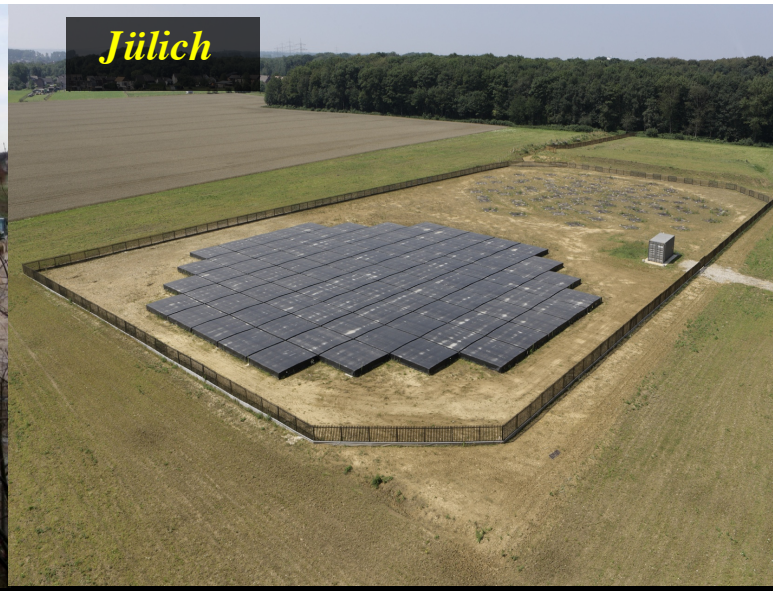
ASTRON

Netherlands Institute for Radio Astronomy


Effelsberg
Nançay
Unterweilenbach
Chilbolton
Onsala
Tautenburg
Potsdam
Jülich

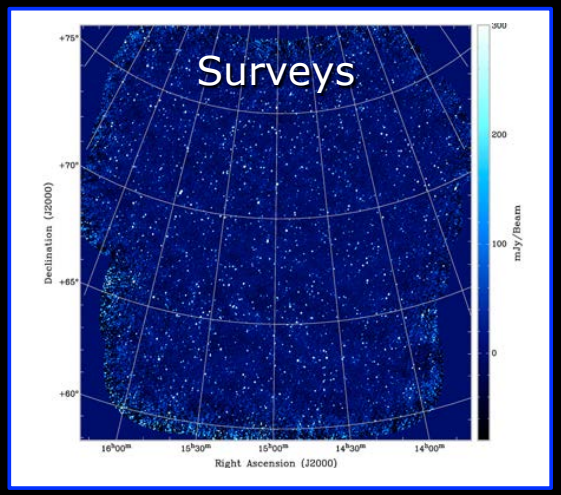

Tautenburg

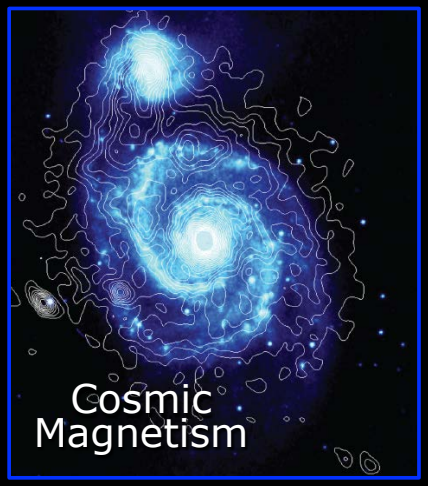

Potsdam

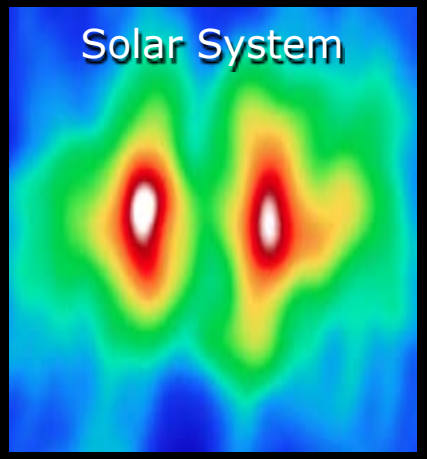

Jülich

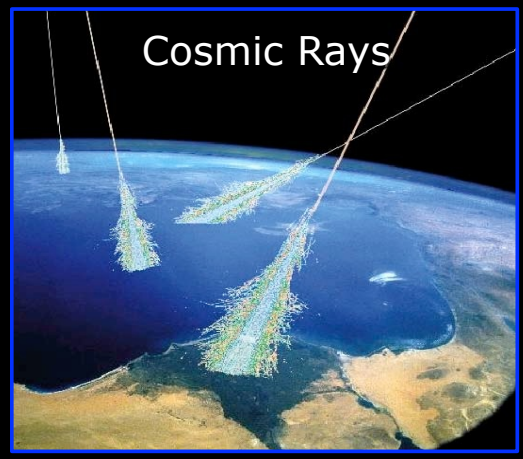

*Operating since 1-1-2015*

# LOFAR Key Science Projects

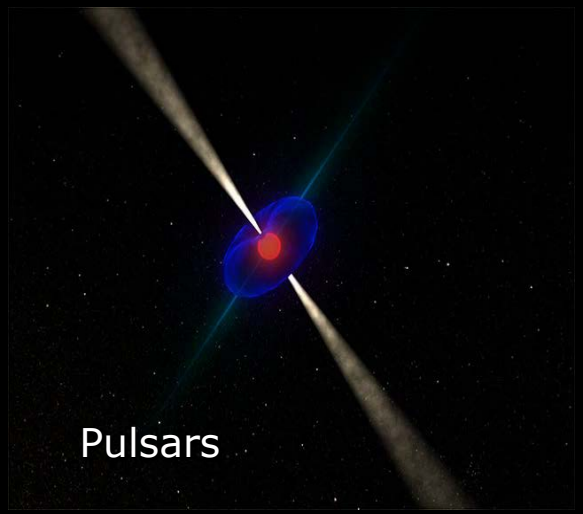


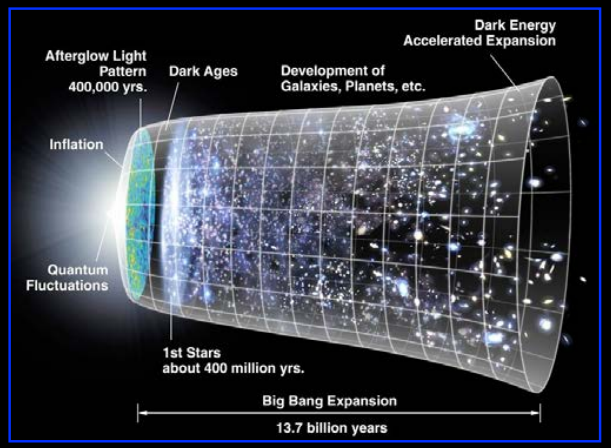





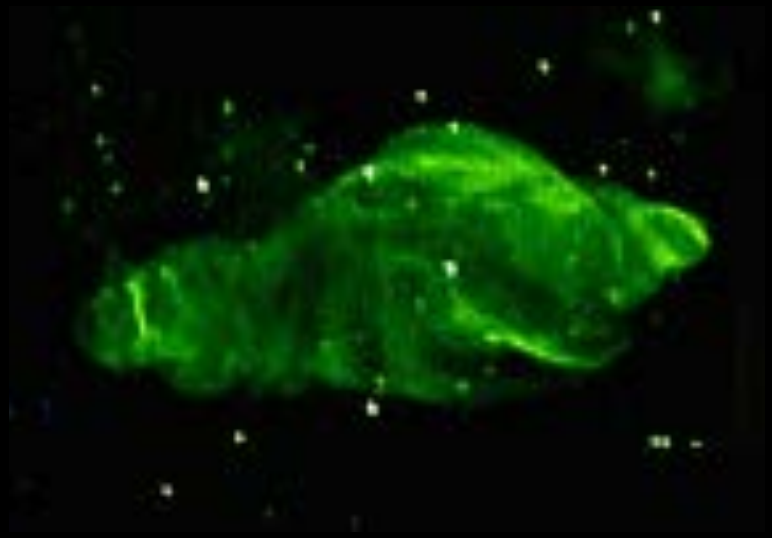


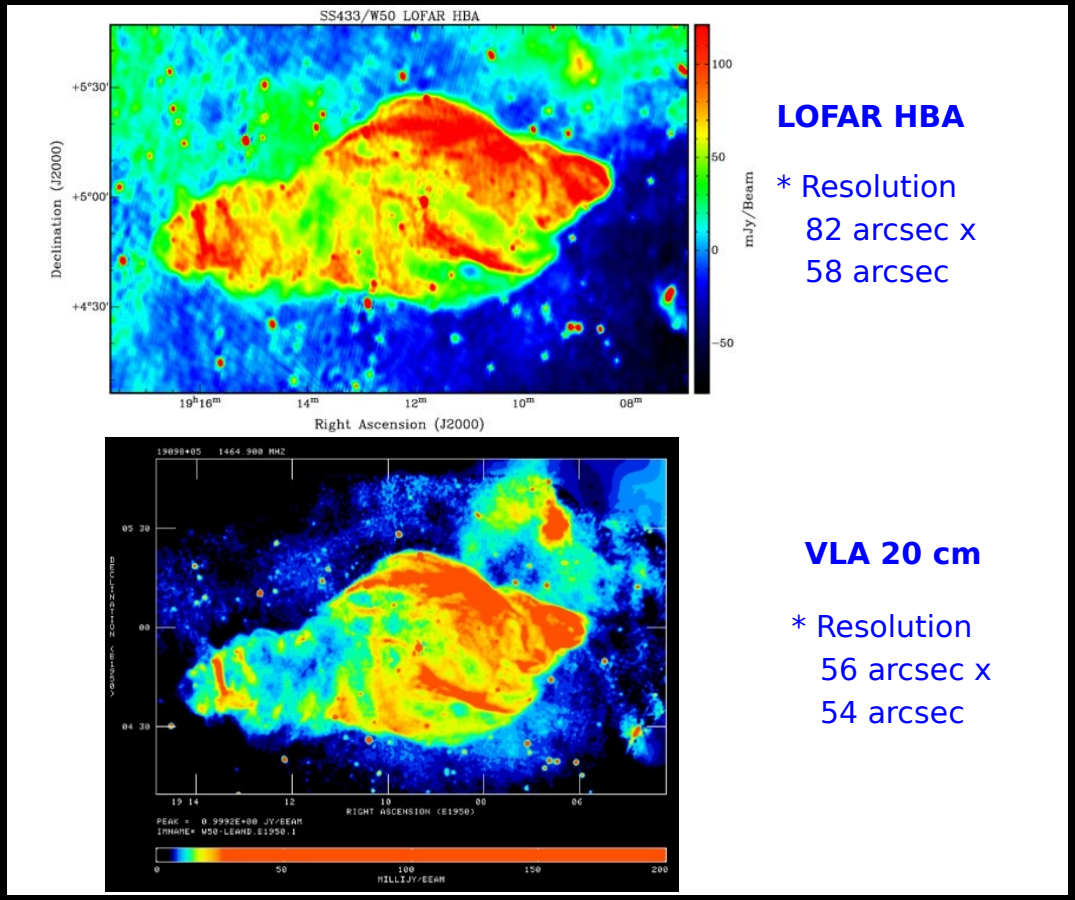

Epoch of Reionization

# High Fidelity LOFAR Imaging

*SS433 and W50*



Broderick et al. 2015




**LOFAR HBA**

* Resolution
  82 arcsec x
  58 arcsec

**VLA 20 cm**

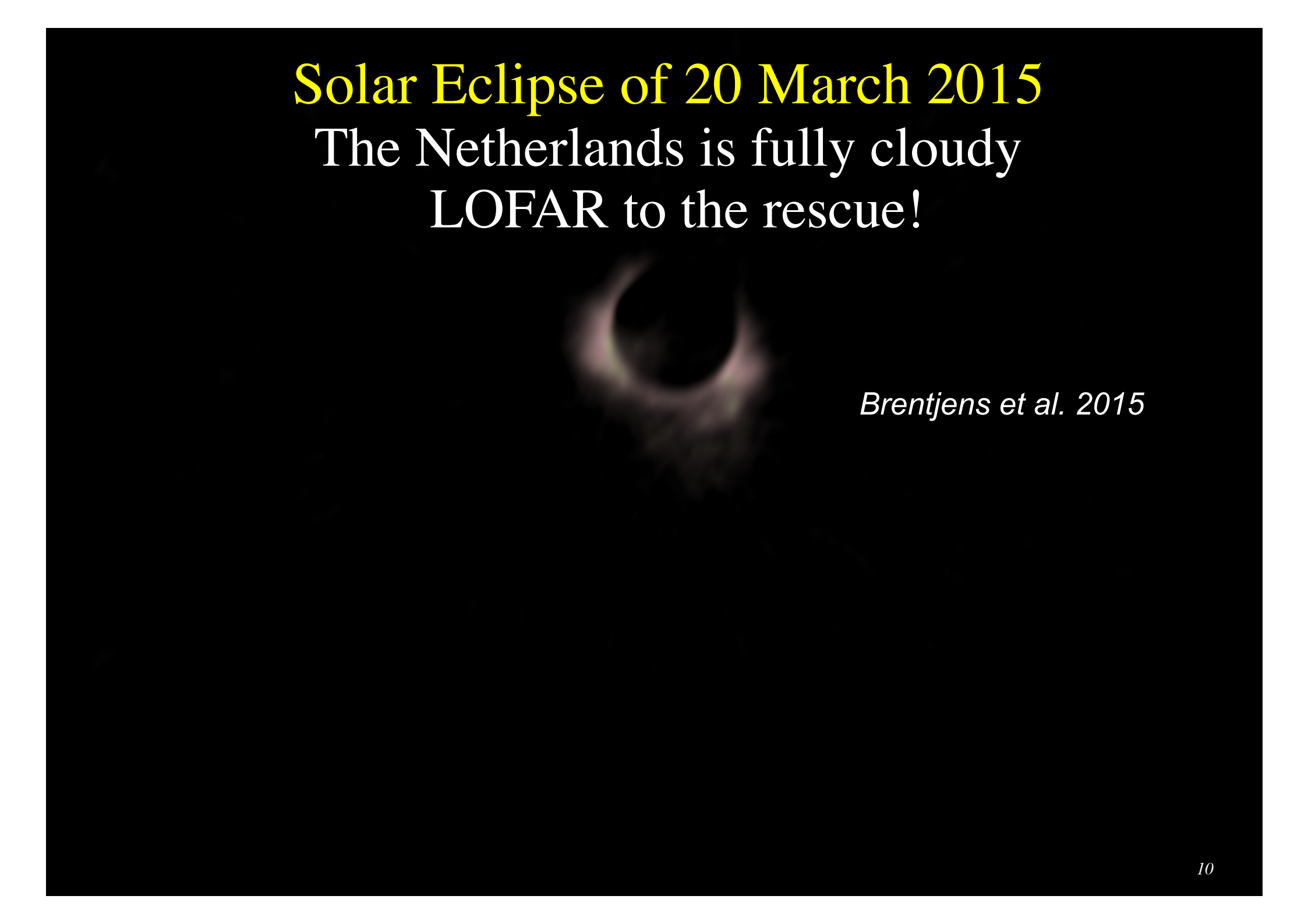
* Resolution
  56 arcsec x
  54 arcsec


Artist's rendition

*Lightning & Cosmic Rays: Astroparticlegeophysics*

# Solar Eclipse of 20 March 2015

## The Netherlands is fully cloudy
## LOFAR to the rescue!

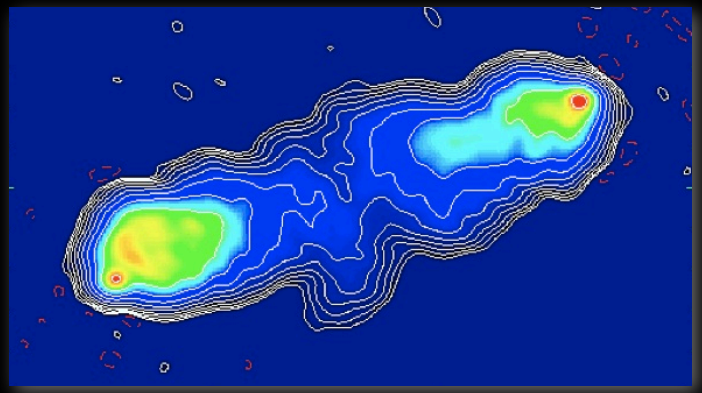


*Brentjens et al. 2015*

# LOFAR was opened on 12 June 2010 by H.M. queen Beatrix

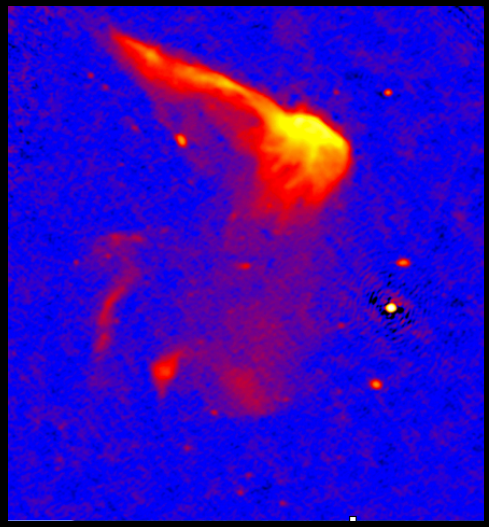
*Attendance of the Chairmen of the (inter)national LOFAR consortia*

# International LOFAR Telescope



- ILT is foundation under NL law
  - Annual central operations budget ~ 4.4 M€
- Constitution prescribes:
  - Participants are National Consortia (+ASTRON)
  - Highest authority: Board (supervisory) + Director (executive)
  - Board sets overall policies (incl. time shares, budgets, contributions)
  - Separate ownership of resources (≥ 10% station time retained for owner)
  - Participants contribute annually to central ILT operations

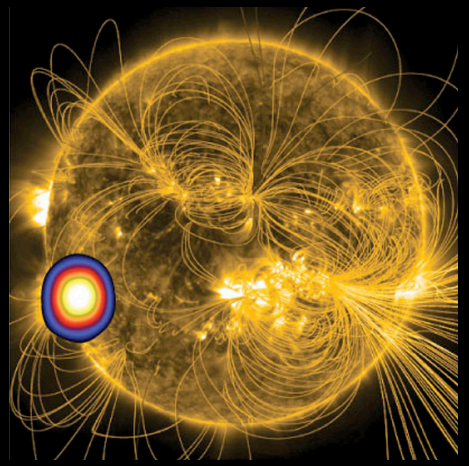
# ILT Observatory Model



- Individual user groups
  - Focus on their own research topics
  - Collaborate in styles to fit science and taste
  - Propose for observing & processing time
- (Inter)national Consortia and institutions organise
  - Operations: stations, networks, processors, archives
  - Science policies
  - Review & allocation of user proposals for time
- ASTRON coordinates
  - Central Observatory & Staff

# ILT Observatory

*sciencesupport@astron.nl*



- Cycle 5 now; Open skies fraction 45%
- Next proposal deadline 9 March 2016
- Next LOFAR data processing school September 2016

Station signals collected in the station cabinets

DragNet

COBALT

Signals sent to COBALT for correlation

AARTFAAC

Entire process is overseen by Observatory operators, Science Support, and Software development groups

Data sent to CEP2 for initial post-processing

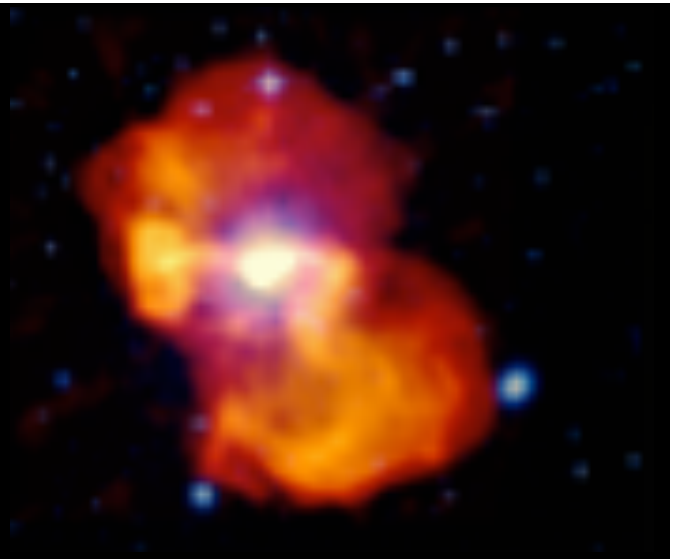
CEP4

CEP3

CEP3 cluster available for additional user processing

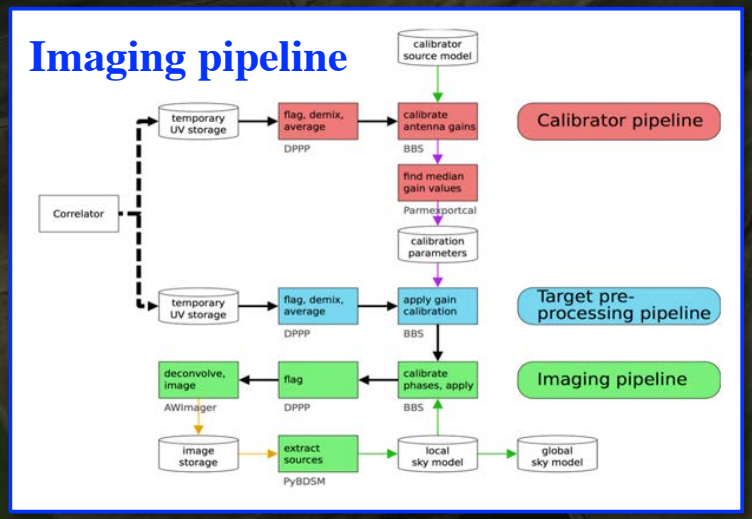

Products sent to the long-term archive

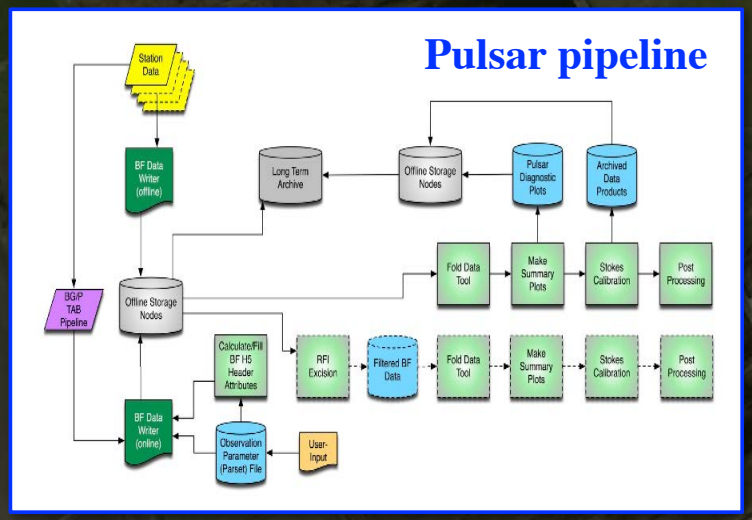
# CEP4

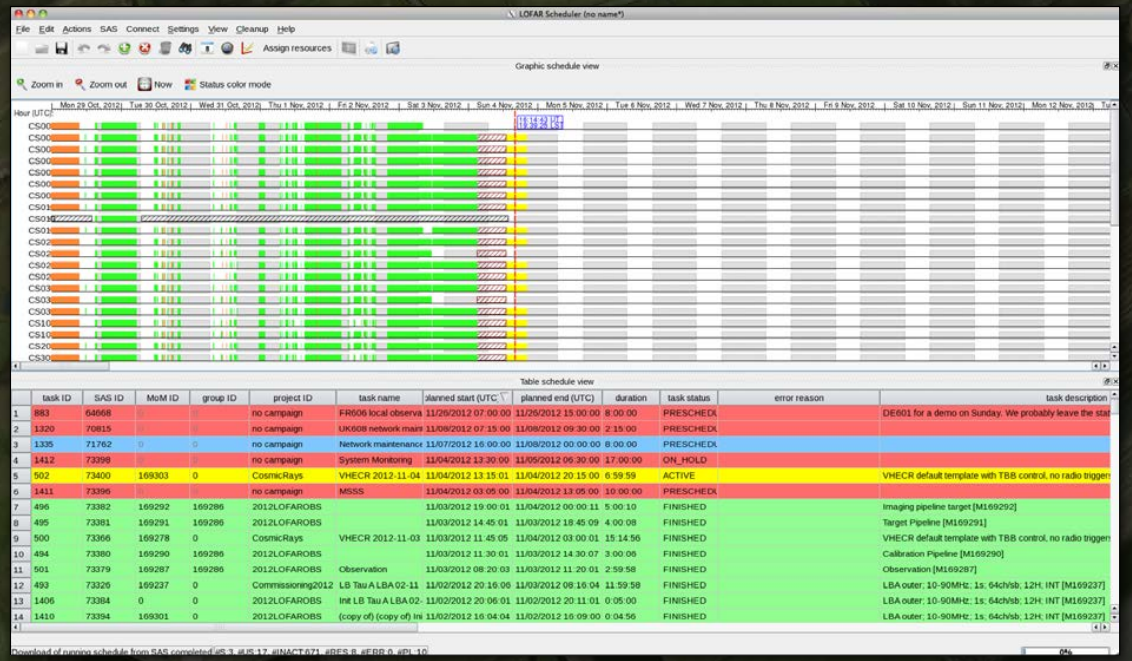


- 50 compute nodes, 256 GB memory
- 4 GPU nodes, 320 GB memory
  Tesla K40C GPU (each 2880 cores;
  4.3 Tflops single, 1.4 Tflops double precision)
  2x6 TB internal storage
- Lustre file system
  18x storage server + 18x storage array,
  60x4 TB each, total usable capacity 3 PB

# LOFAR Data Processing



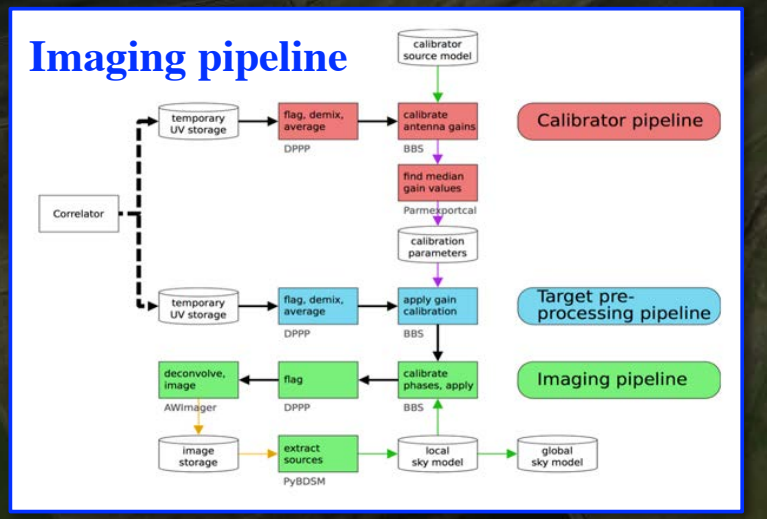



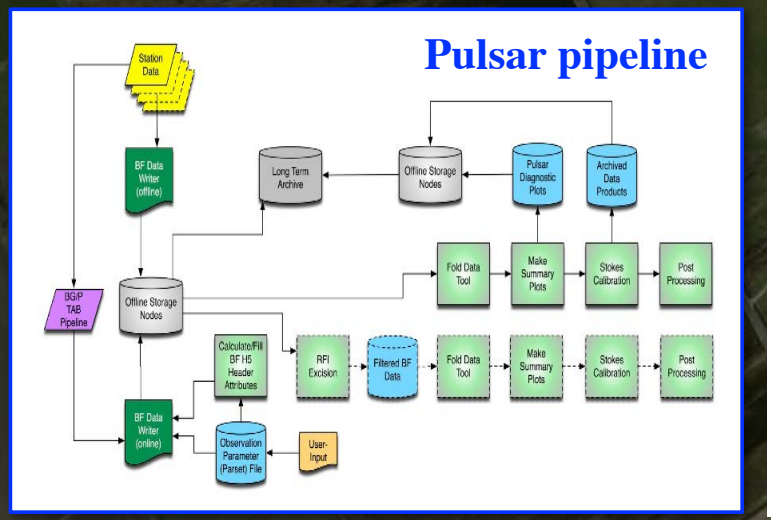




- **Supports multiple data pipelines for different science products**
- **Scheduler oversees the entire end-to-end processing**
- **Maintains overview of the storage and computational resources**
- **Dynamic scheduling system currently under development**

***New flexible pipeline framework coming!***

# LOFAR Data Processing




- Supports multiple data pipelines for different science data products
- Scheduler oversees end-to-end observing and processing resources, including stations, compute, storage

- New flexible pipeline framework coming
- Dynamic scheduling under development

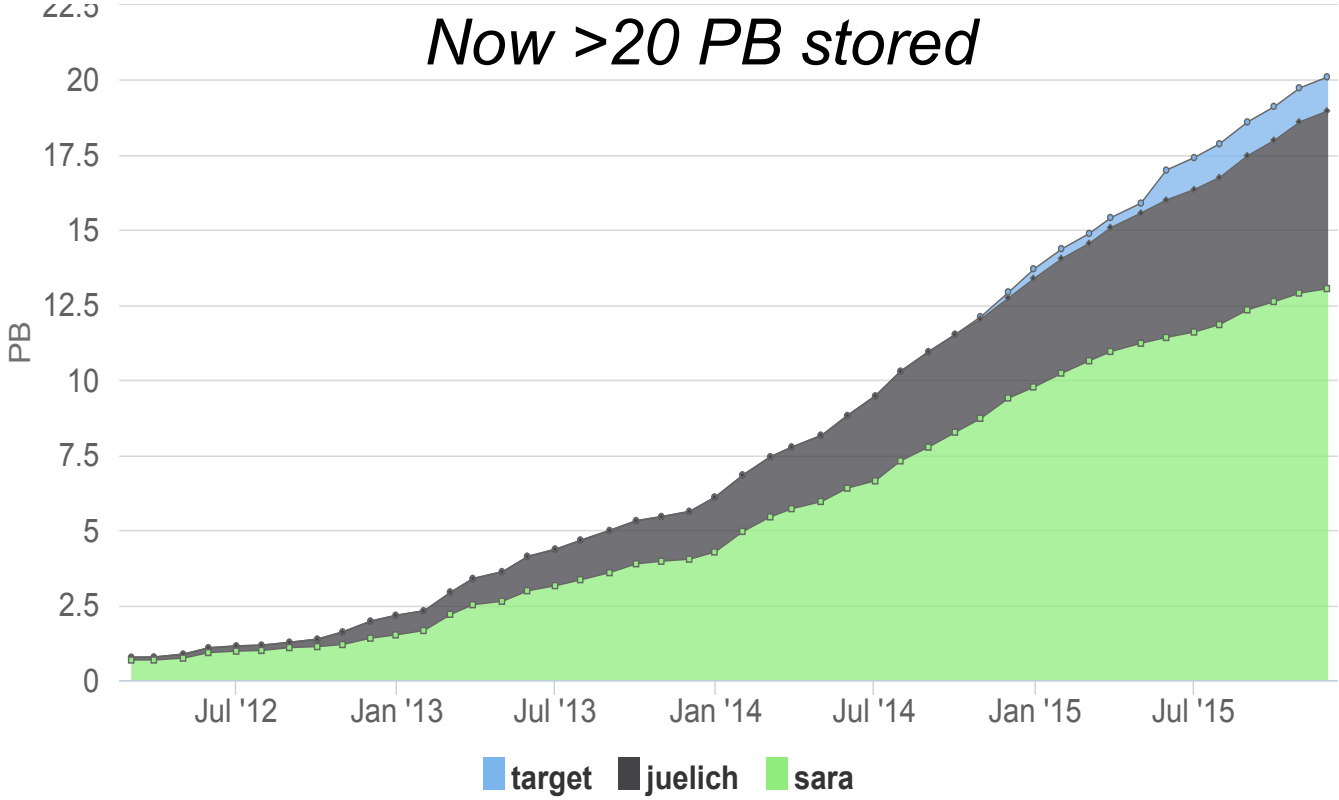
- Expertise & experience will leverage formation of Science Data Centre (LOFAR, Apertif, SKA)

# LTA Data Accumulation

**Poznan Supercomputing and Networking Centre (PSNC) involved as of 1-1-2016 adding to Target (Groningen, NL), Sara (Amsterdam, NL), FZ Jülich (DE)**

- Data Storage
  - *20.1 Petabytes*
  - *6 PB/yr growth*
  - *3 sites, 2 countries*
  - *300 TB/month ingest*
  - *100 TB/month staged*

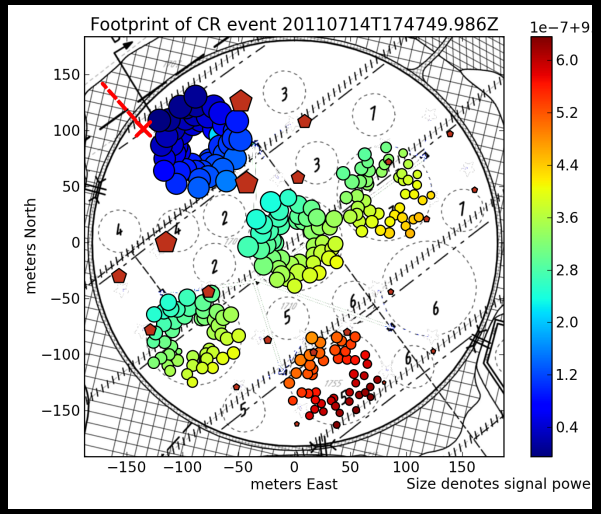
- Contents
  - *Over 5x10$^6$ products*
  - *10$^9$ individual files*
  - *Visibilities, images, and BF data*
  - *Does not include raw visibilities*




*LOFAR LTA team: H.A.Holties, G.A.Renting, Y. Grange, J. Schaap, N.Vermaas, W.J.Vriend*

# LOFAR 1.n … 2.0

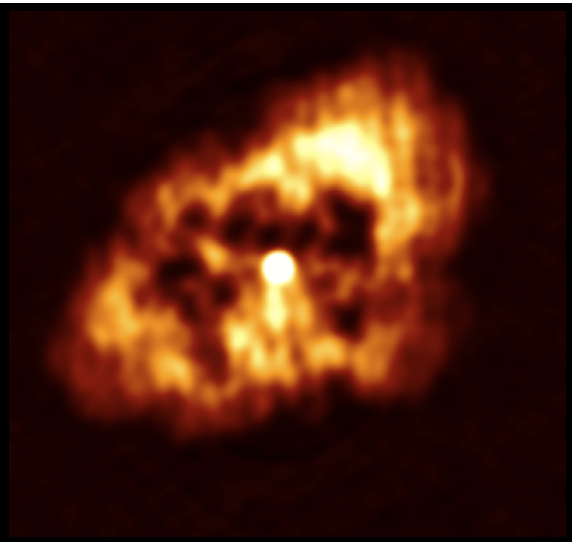
- Expand technical and scientific capabilities of LOFAR
  - Evolutionary process
  - Play to current strengths & future uniqueness
  - Leverage existing investments and infrastructure



# LOFAR 1.n … 2.0

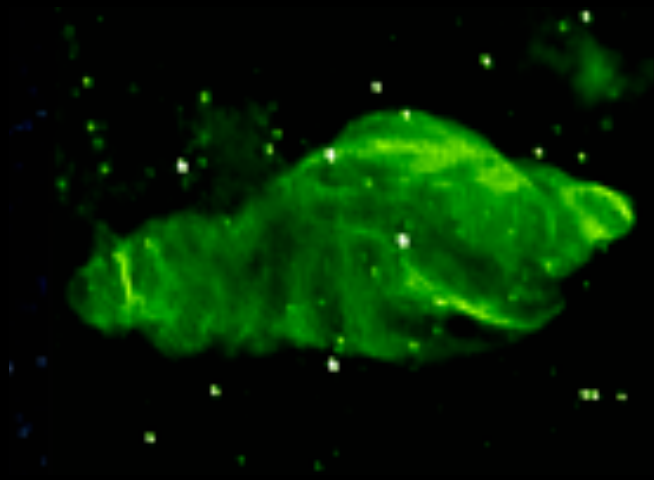
- Stress scientific impact, versatility
  - ✧ Inroads into “the Cosmic Dawn”
  - ✧ Tracing galaxies through cosmic time
  - ✧ Cosmic Magnetism in the nearby Universe
  - ✧ Characterizing the “Epoch of Reionization”
  - ✧ Transients
  - ✧ Serendipity

# LOFAR 1.n … 2.0



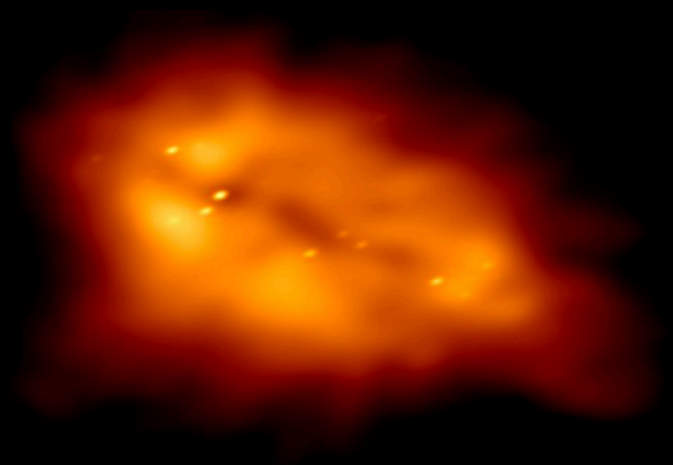
- Several possible options being pursued for next 3-10 years
  - Step-wise or combined development approach possible
  - Variety of funding sources may be sought

# LOFAR 1.n … 2.0



- Double or triple station electronics
  (e.g. with Uniboard$^2$)
  - Use all 96 LBAs; for calibration
  - Joint LBA + HBA observing; ionospheric calibration
  - Simultaneous LBA + HBA observing on different fields

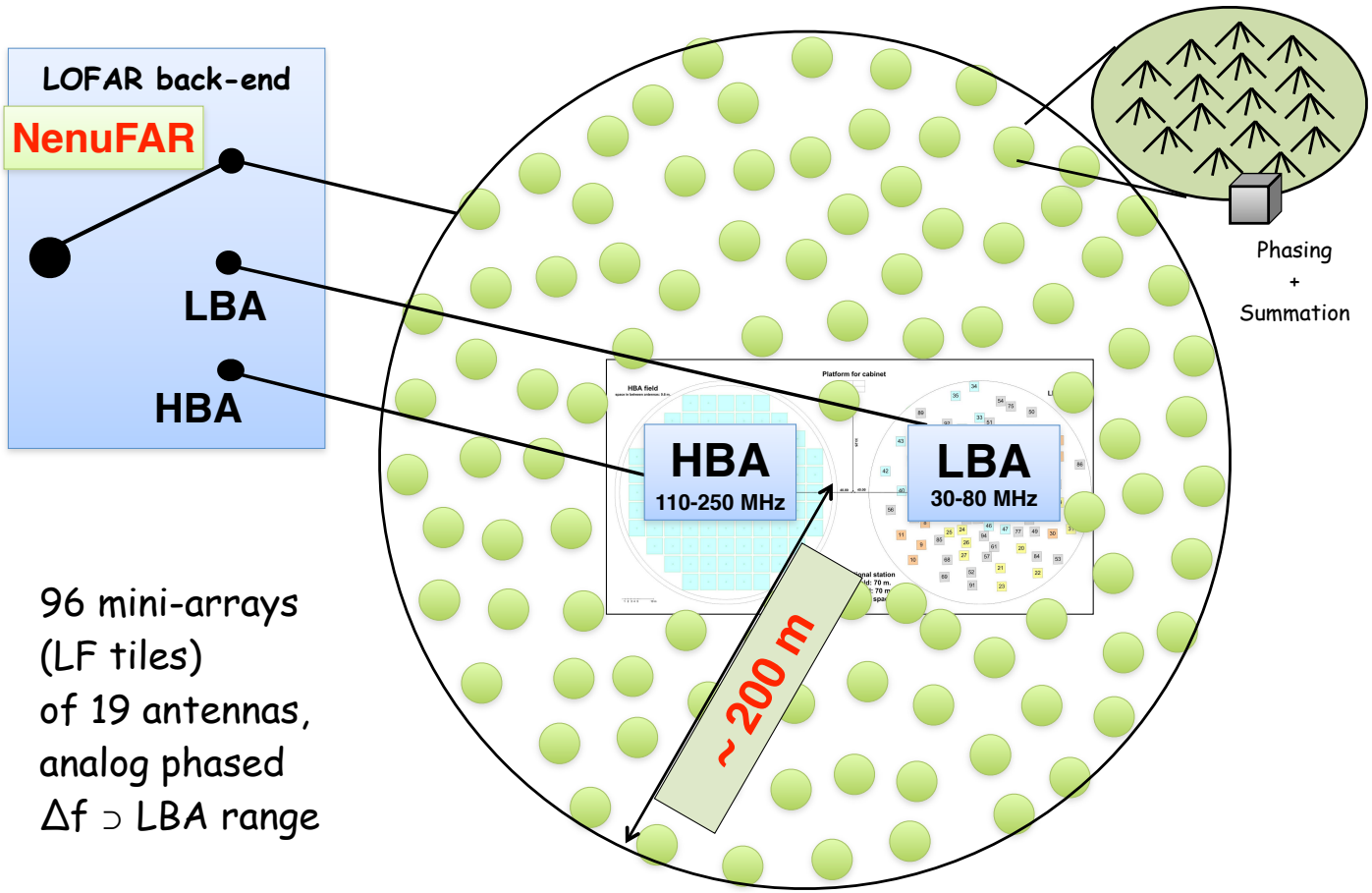
# LOFAR 1.n … 2.0



- Replace LBA dipoles with different design (e.g. Nenufar)
  - More broadband response 10-90 MHz
  - Optimized at 30-50 MHz

# Nenufar *New Extension in Nançay Upgrading loFAR*

giant local phased array + interferometer



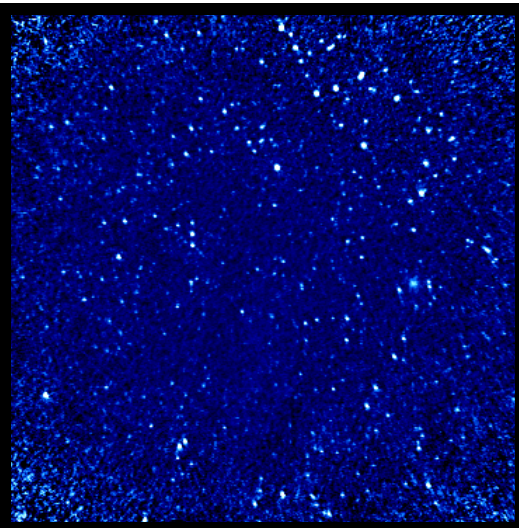

96 mini-arrays
(LF tiles)
of 19 antennas,
analog phased
Δf ⊃ LBA range

96 mini-arrays
of 19 antennas;

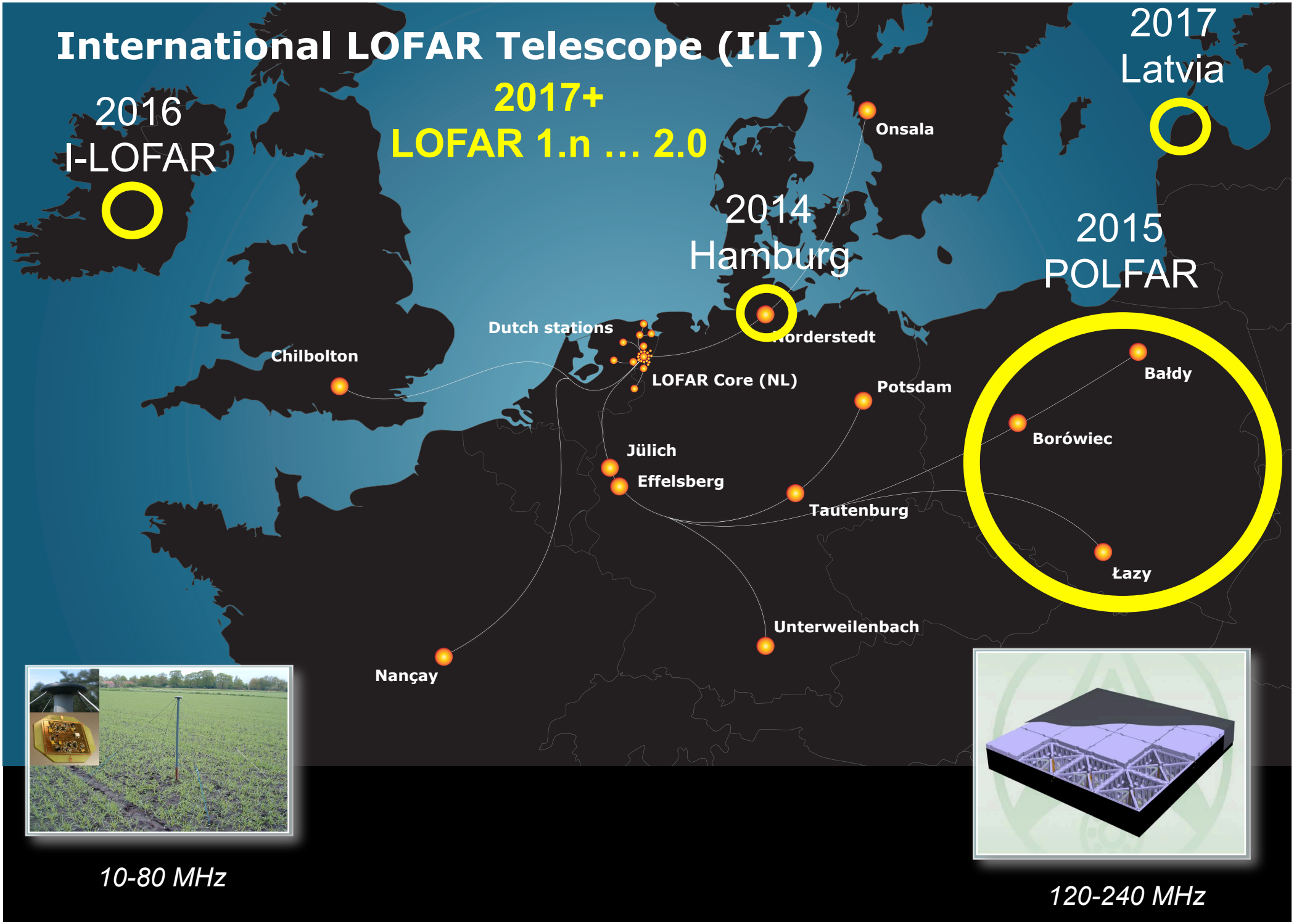
22 already built

Improved 30 MHz
performance

# LOFAR 2.0



- Strategically placed new stations
  - 10-300 km baselines, fill uv holes for deep high dynamic range imaging
  - 300-3000 km baselines for <1 arcsec imaging
  - Fill superterp as well (EoR, extended emission, complex fields)


International LOFAR Telescope (ILT)
2017+
LOFAR 1.n … 2.0
2016
I-LOFAR
2014
Hamburg
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POLFAR
2017
Latvia
Onsala
Dutch stations
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10-80 MHz
120-240 MHz


LOFAR