

ASTRON



LOFAR

Netherlands Institute for Radio Astronomy

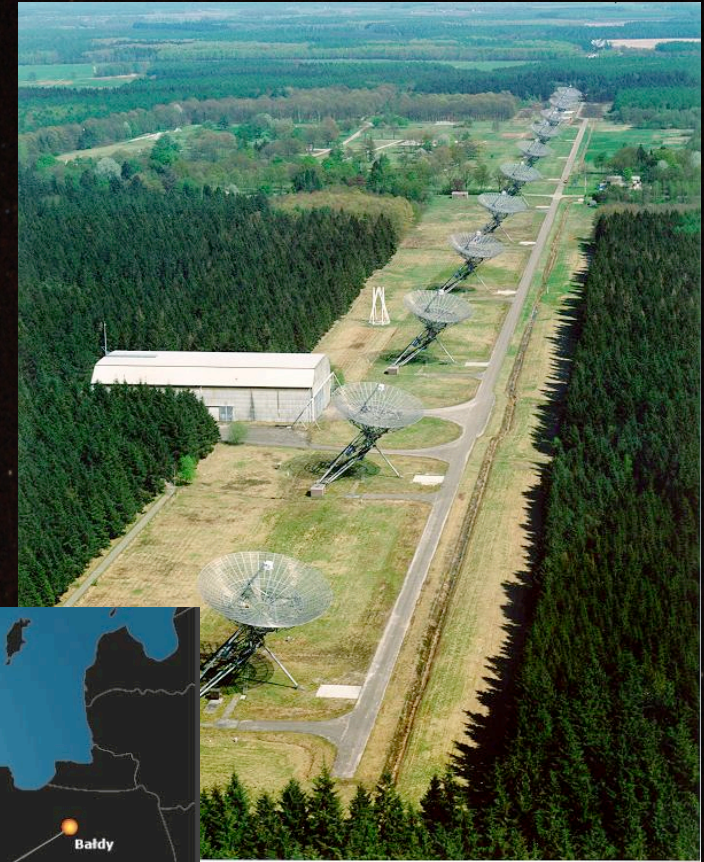
LOFAR data formats and the Virtual Observatory

Adriaan Renting
ASTERICS Data Providers Workshop
26-29 June 2018

ASTRON is part of the Netherlands Organisation for Scientific Research (NWO)

Overview

- LOFAR
 - Introduction to LOFAR
 - Services
 - Data Models
 - Data Types and Data Formats
- LOFAR in the Virtual Observatory
 - VO modeling
 - Technical issues
 - Current efforts and future plans
- WSRT



LOFAR introduction



LOFAR

ASTRON

International LOFAR Telescope

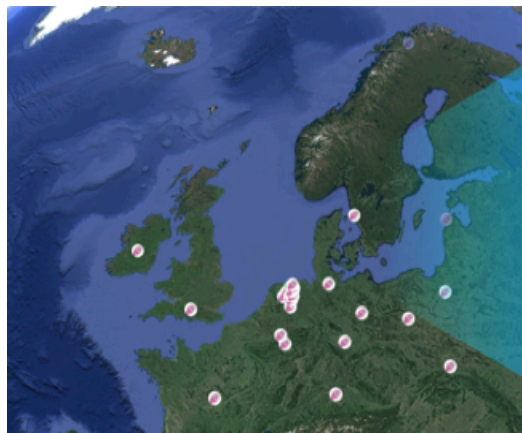
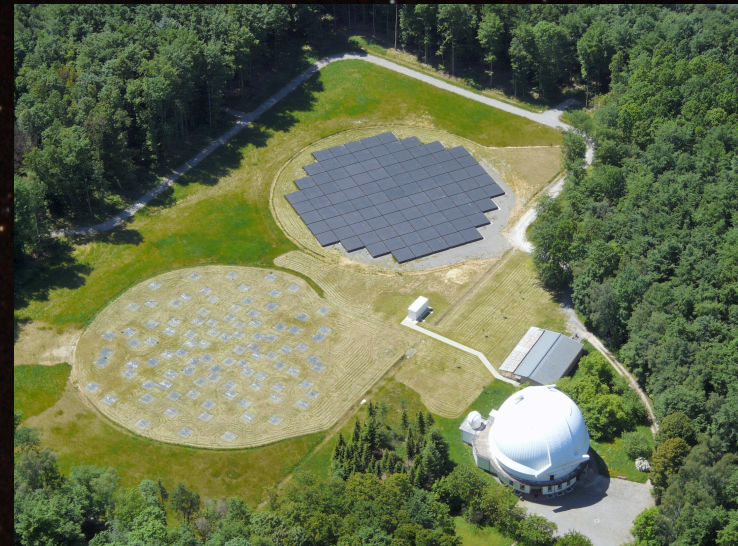
7 countries

51 Stations

107,712 Antennas

Opened 12 June 2010

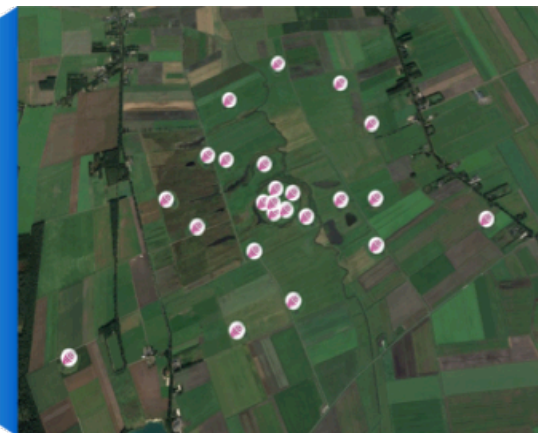
Fully operational 2012



Europe



Netherlands



Core

LOFAR introduction



LOFAR

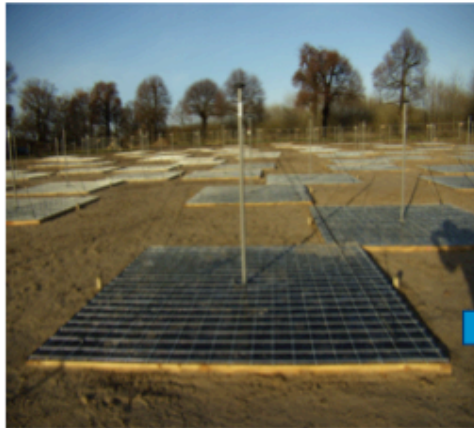
ASTRON

Low Band Antennas

- 10-90 MHz
- 96 per station

High Band Antennas

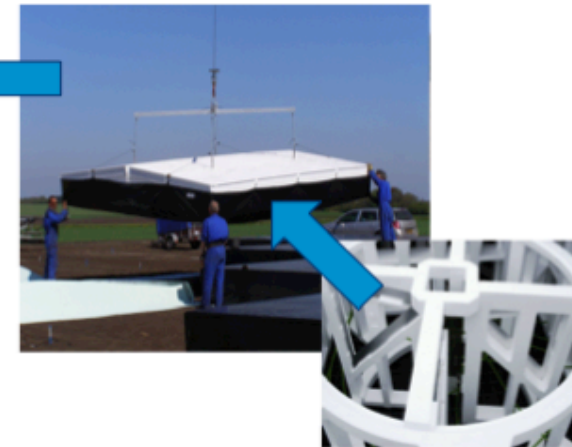
- 110-250 MHz
- up to 96 tiles of 16



LBA



Station



HBA



Three main modes:

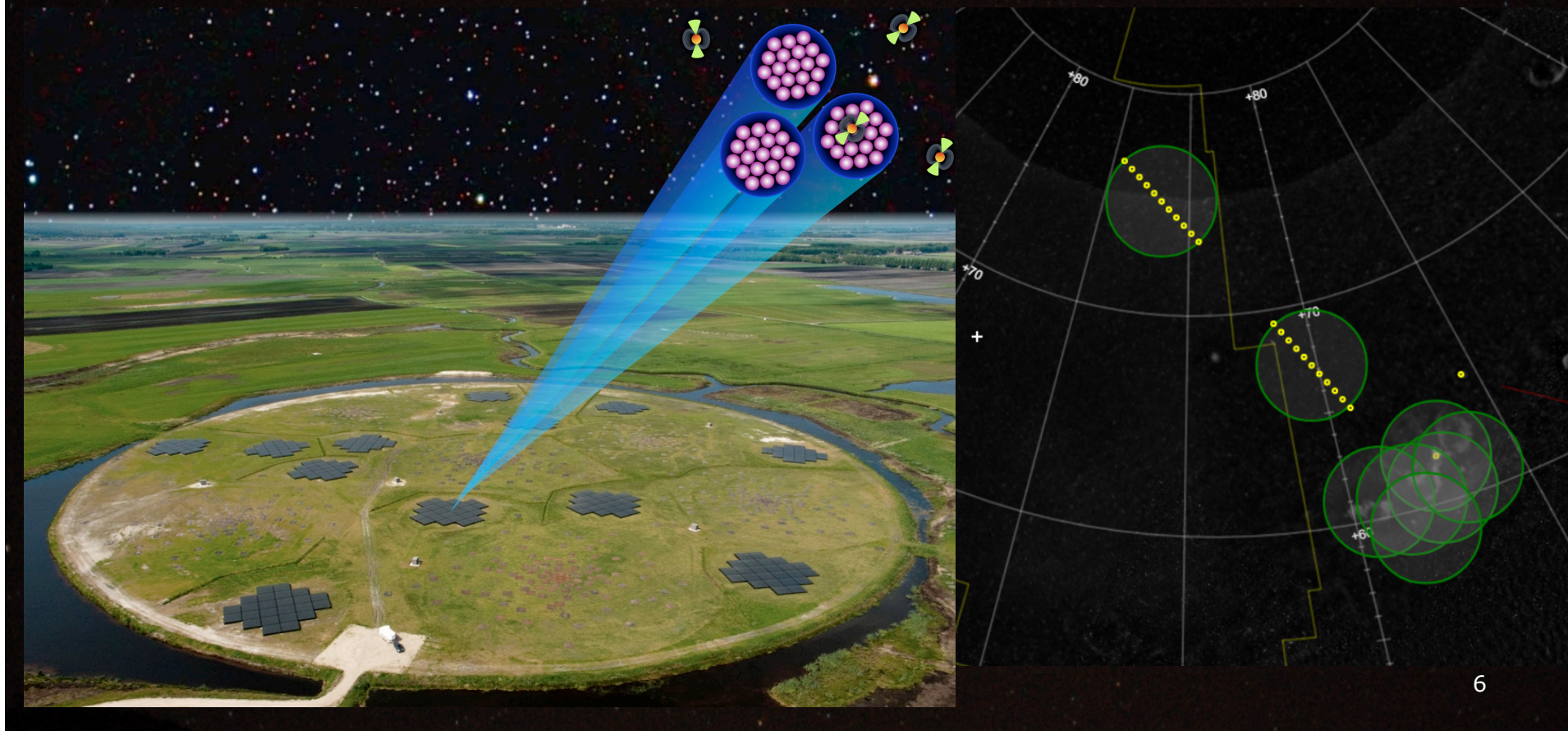
- Interferometry: low time resolution
- Tied Array: low spatial resolution
- Transient Buffer: limited time window

Mode	Time	Spatial	Spectral	Sensitivity (1s)
Interferometer	0.5s	0.13 arcsec	610 Hz	2.5 mJy
Tied Array	5 μ s	2 arcmin	610 Hz	51 mJy
Transient Buffer	5 ns	1m/20m	1 Hz	10^{17} eV

- 400+ beams on the sky
- Response time in seconds
- 76 MHz bandwidth continuous or 192 kHz segments across multiple beams and frequencies

LOFAR Flexibility

- Multiple modes at the same time
- Large field of View and high detail



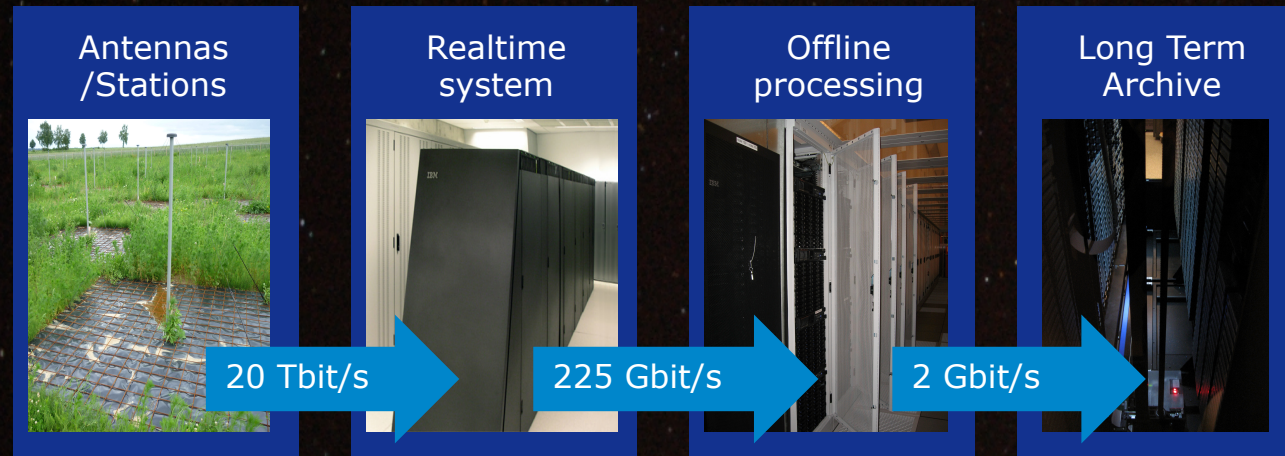
LOFAR Processing



LOFAR

ASTRON

- 10,000 Observations/year (5min – 48hr)
- 25,000 pipelines/year
- 100's dataproducts per task
- Raw data only stored for a short time (PB/week)



20 Tbit/s

225 Gbit/s

92 TFLOP

96 TFLOP and 3.6 PB offline processing and storage

2 Gbit/s

raw data rate

real time data stream to central processing

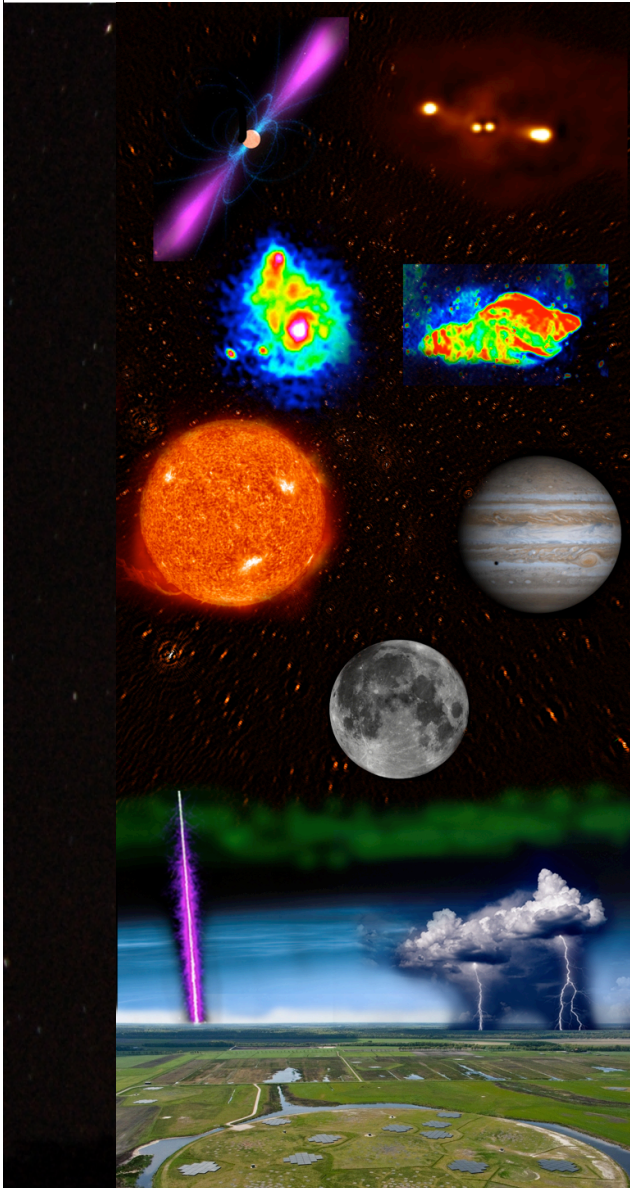
real time processing

to Long Term Archive, total 34 PB stored



Wide range of science applications

- Low frequency sky surveys
- Epoch of Reionization
- Galaxies, AGNs
- Pulsars
- FRB, Gravitational Waves
- Interstellar medium
- The Sun, Moon, (Exo)planets
- Cosmic Rays
- Ionosphere
- Lightning
- Earthquakes
- Etc.



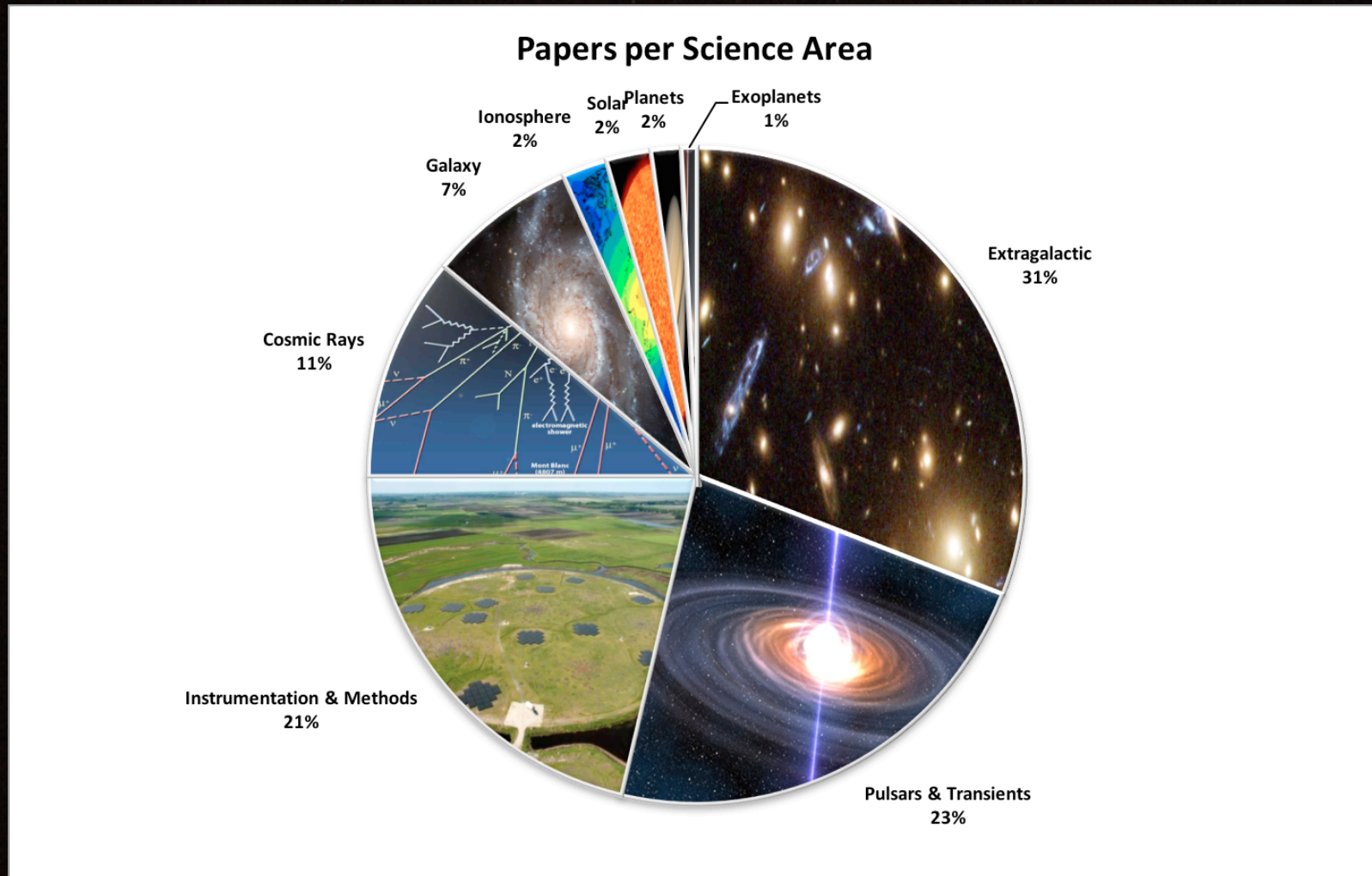
LOFAR Publications



LOFAR

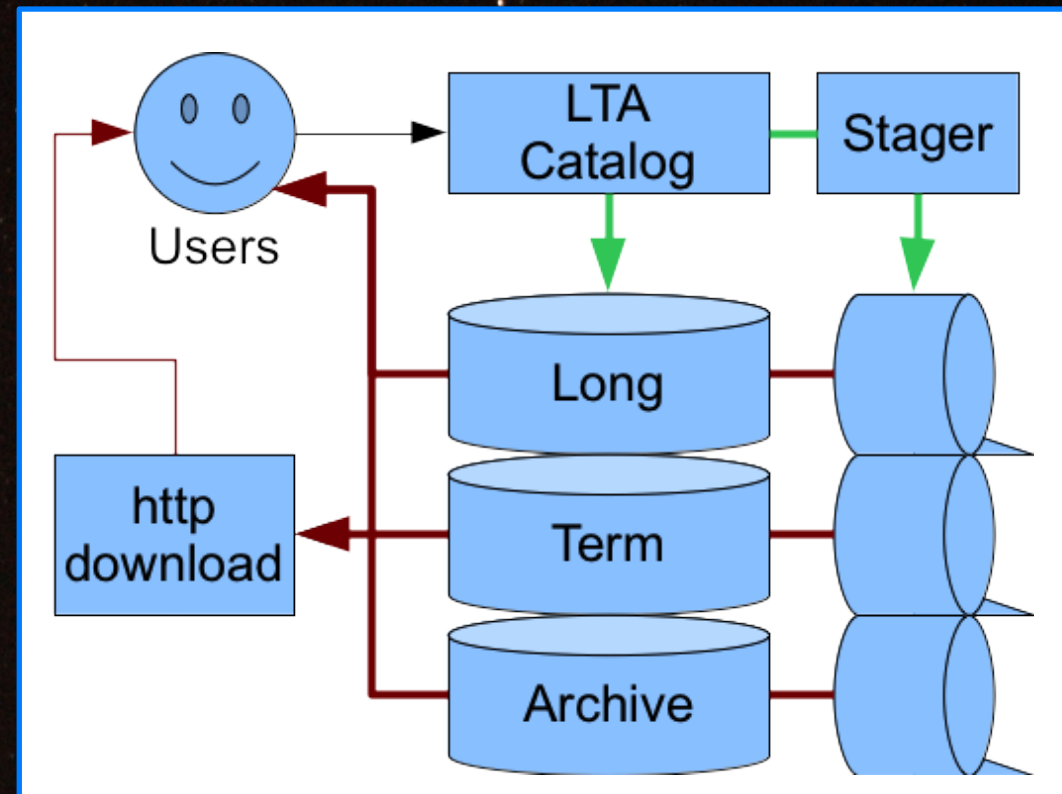
ASTRON

www.astron.nl/radio-observatory/lofar-science/lofar-papers/lofar-papers



LOFAR Services: LTA

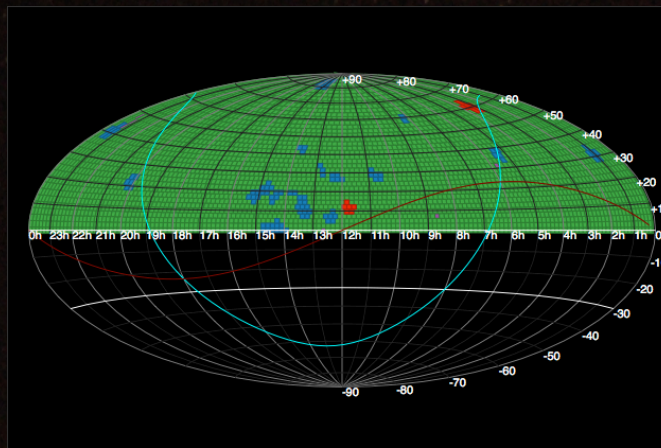
- Long Term Archive
 - All data is public after embargo period
 - Projects/ users also provide data
 - Not all LOFAR data (yet?)
- LTA Manual/Howto on LOFAR wiki
- Webinterface
 - LTA Catalog
 - Advanced interface
- Storage sites
 - SARA (NL)
 - FZJ/Jülich (DE)
 - POZNAN (PL)
- Staging
 - webinterface or tools
- Download
 - HTTP (easy, slow)
 - GRID (hard, fast)
- Processing



Services: Other



- LOFAR Survey VO services
 - LoTSS
 - MSSS



The LOFAR Two-metre Sky Survey (LoTSS)

Description

Performing increasingly sensitive surveys is a fundamental endeavour of astronomy. Over the past 60 years, the depth, fidelity, and resolution of radio surveys has continuously improved. However, new, upgraded and planned instruments are capable of revolutionising this area of research. The International Low-Frequency Array (LOFAR) is one such instrument. LOFAR offers a transformational increase in radio survey speed compared to existing radio telescopes. It also opens up a poorly explored low-frequency region of the electromagnetic spectrum. An important goal that has driven the development of LOFAR since its inception is to conduct wide and deep surveys in order to advance our understanding of the formation and evolution of galaxies, clusters, and active galactic nuclei (AGN). The LOFAR Surveys Key Science Project is conducting a survey with three tiers of observations: Tier-1 is the widest tier and includes low-band antenna (LBA) and high-band antenna (HBA) observations across the whole Northern sky; deeper Tier-2 and Tier-3 observations are focussing on smaller areas with high quality multi-wavelength datasets.

The ongoing LOFAR HBA 120-168MHz Tier-1 survey is hereafter referred to as the LOFAR Two-metre Sky Survey (LoTSS) and is described in Shimwell et al. 2017. This is the second northern hemisphere survey that is being conducted with the LOFAR HBA and is significantly deeper and higher resolution than the first, the Multifrequency Snapshot Sky Survey (MSSS; Heald et al. 2015).

Survey Products

[LoTSS Preliminary Data Release](#)

Survey Progress

Table of Contents

- The LOFAR Two-metre Sky Survey (LoTSS)
 - Description
 - Survey Products
 - Survey Progress
 - Coobserving with LoTSS



The VO @ ASTRON

Welcome to the ASTRON VO data center.

In addition to the services listed below, on this site you probably can access [numerous tables](#) using [TAP](#) or [form-based ADQL](#).

Please check out our [site help](#).

Services available here

By Title By Subject

L...

- [LBCS Calibrator Search](#) [i](#) [Q](#)
LBCS Calibrator Search
- [LOFARTIER 1 Image Archive](#) [i](#) [Q](#)
The LOFAR HBA Tier-1 preliminary data release contains images and catalogs that characterise the low-frequency radio emission in the region of the HETDEX Spring Field. In excess of 40,000 sources are detected in the images that cover an area of over 350 square degrees, have a resolution of 25 arcsec, and typical noise levels of less than 0.5 mJy/beam.
- [LOFARTIER 1 Image Cutout Service](#) [i](#) [Q](#)
- [LOFARTIER 1 Source Catalogue](#) [i](#) [Q](#)
The LOFAR HBA Tier-1 preliminary data release contains images and catalogs that characterise the low-frequency radio emission in the region of the HETDEX Spring Field. In excess of 40,000 sources are detected in the images that cover an area of over 350 square degrees, have a resolution of 25 arcsec, and typical noise levels of less than 0.5 mJy/beam.

M...

- [\[P\] MSSS catalogue](#) [i](#) [Q](#)
The Multifrequency Snapshot Sky Survey (MSSS) is the first major observing program to be carried out with LOFAR during its ongoing commissioning phase. This service queries the unified source catalogue database for the MSSS survey.
- [\[P\] MSSS Image Archive](#) [i](#) [Q](#)
The Multifrequency Snapshot Sky Survey (MSSS) is the first major observing program to be carried out with LOFAR during its ongoing commissioning phase. This service queries the archive of both LBA and HBA images.
- [MSSS Verification Field Images](#) [i](#) [Q](#)
The Multifrequency Snapshot Sky Survey (MSSS) is the first major observing program to be carried out with LOFAR during its ongoing commissioning phase. This service queries the archive of both LBA and HBA images.
- [MSSS Verification Field Sources](#) [i](#) [Q](#)
The Multifrequency Snapshot Sky Survey (MSSS) is the first major observing program to be carried out with LOFAR during its ongoing commissioning phase. This service queries the unified source catalogue database for the MSSS survey.

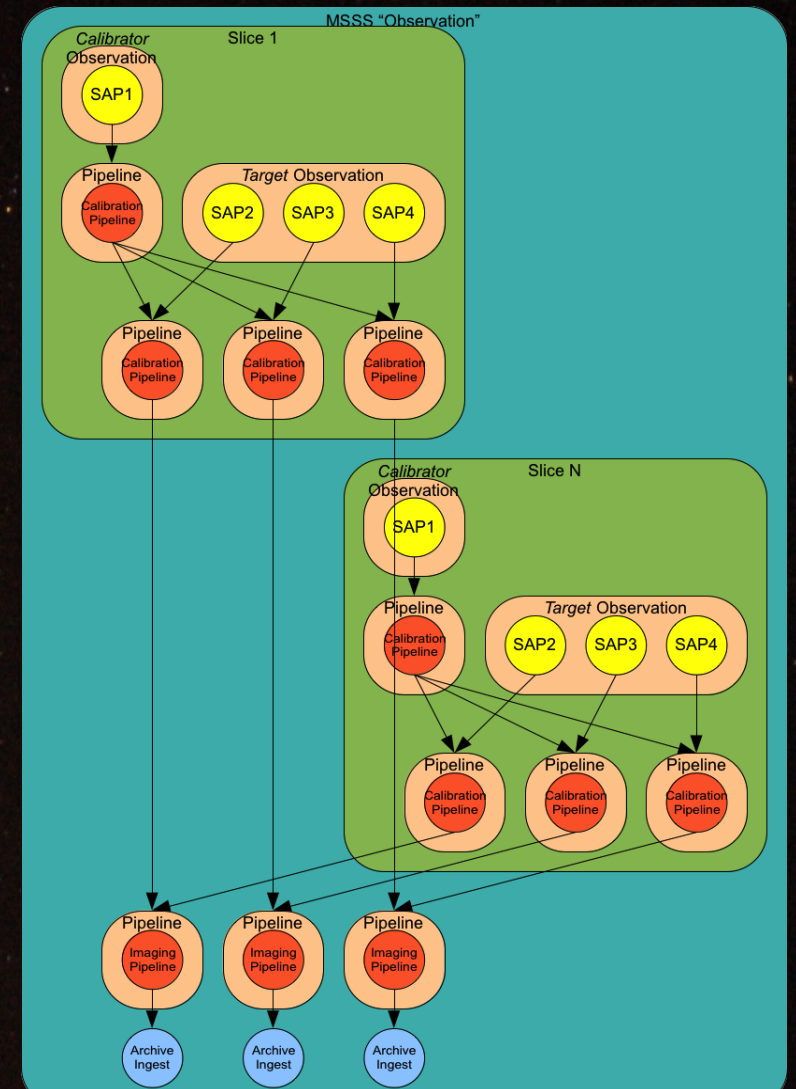
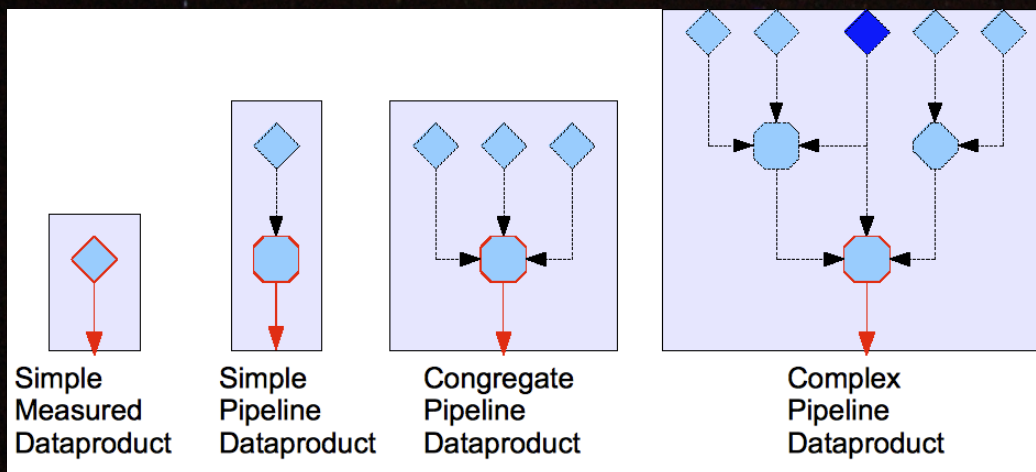
T...

- [TGSSADR Image Archive](#) [i](#) [Q](#)
Download the TGSS Alternative Data Release mosaic images (5 deg sq degree mosaics).

LOFAR LTA Data Model



- Usually not storing raw data
- Heavy averaging in time and frequency
- Demixing of bright sources
- Dedispersion
- Instrumental and Ionosphere correction
- Full provenance very important



Data Types and Availability

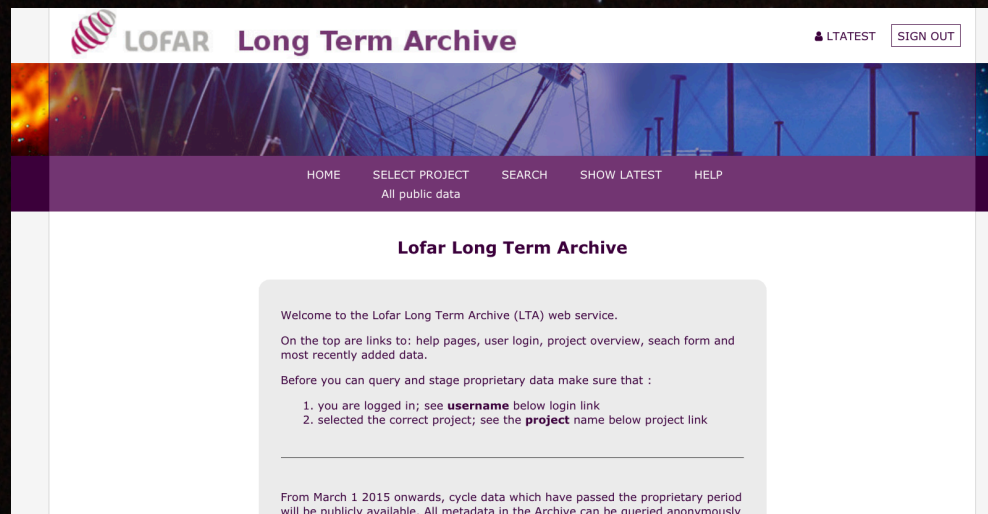


LOFAR	LTA	VO
Visibilities	Green	Orange
Sky Images	Green	Dark Red *
Tied Array Coherent beamformed data	Green	Dark Red
Tied Array Incoherent beamformed data	Green	Dark Red
Station Coherent beamformed data (Fly's Eye)	Green	Dark Red
Transient Buffer Board Data	Yellow	Dark Red
Pulsar Profiles	Green	Dark Red
Dedispersed Pulsar time series	Green	Dark Red
Dynamic Spectra	Yellow	Dark Red
Instrument Models	Yellow	Dark Red
Sky Models	Dark Red	Dark Red
Ionosphere Models	Dark Red	Dark Red
Source Lists	Dark Red	Dark Red *
Rotation Measure Cubes	Dark Red	Dark Red

Data Types



- Most Data types have a detailed ICD available
 - Describes the data in sufficient detail for scientific use e.g. Broken antenna information
- Archive only designed for searching and selection
- Currently mostly Raw, Calibrated and some Derived data
- Few science ready products



LOFAR Data Format ICD TBB Time-Series Data

Document ID: LOFAR-USG-ICD-001

Version 2.02.12

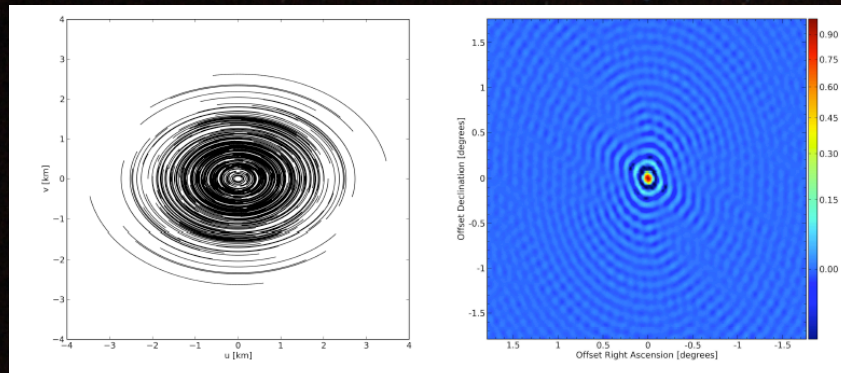
SVN Repository Revision: 9366

L. Bühren, K. Anderson, A. Corstanje, A. Horneffer, J. Masters

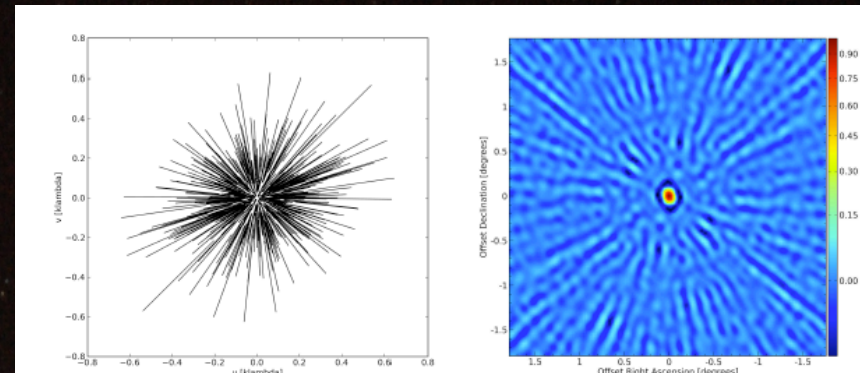
SVN Date: 2012-01-10

Data Types: Visibilities

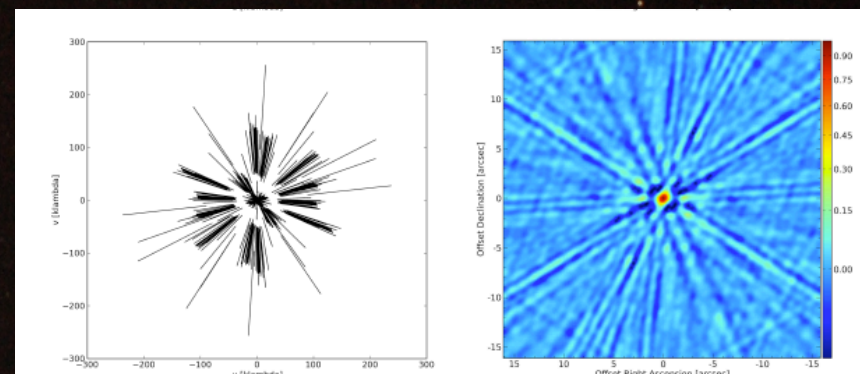
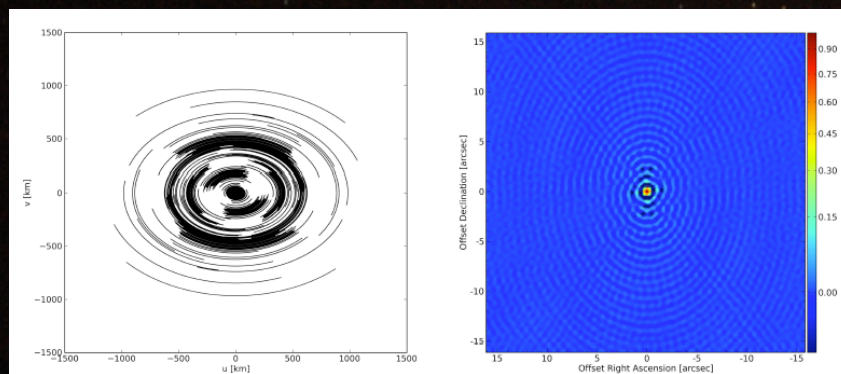
- Interferometer: Creating virtual aperture up to $\sim 2000\text{km}$ (λ/D)
- Incomplete coverage
- Typical use of Radio Telescopes: imaging depending on science
- LOFAR: Projection effects (No moving dish/mirror)



6 hours

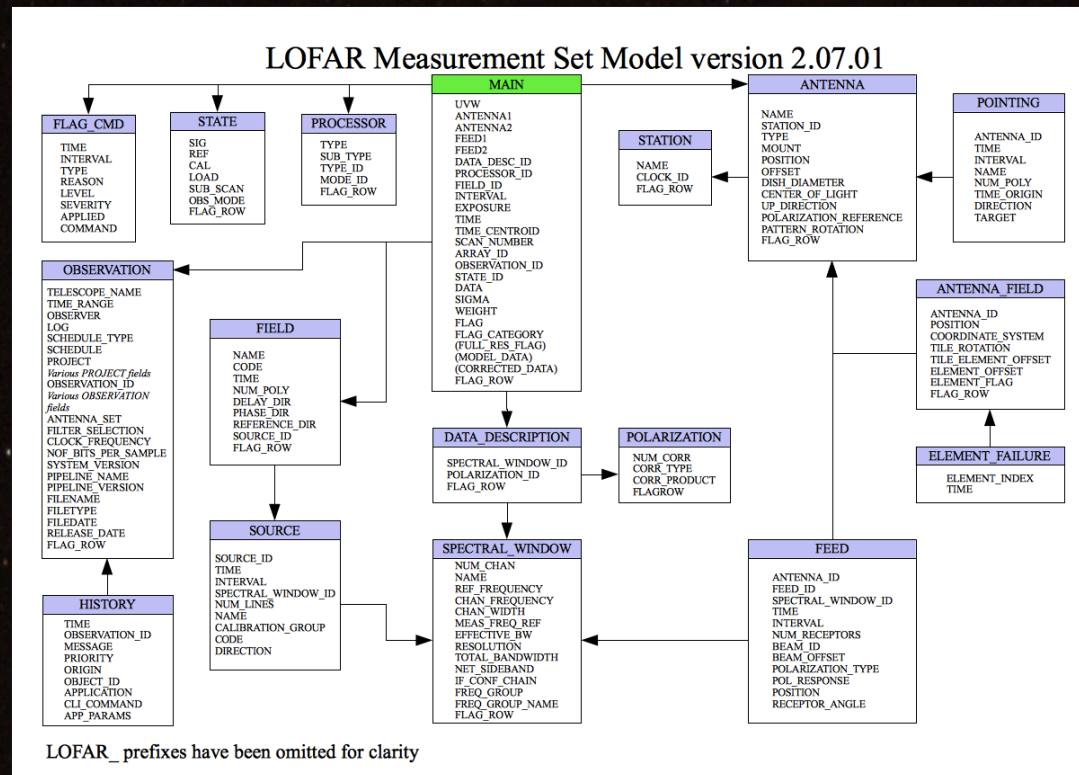


1 second



Data Types: Visibilities

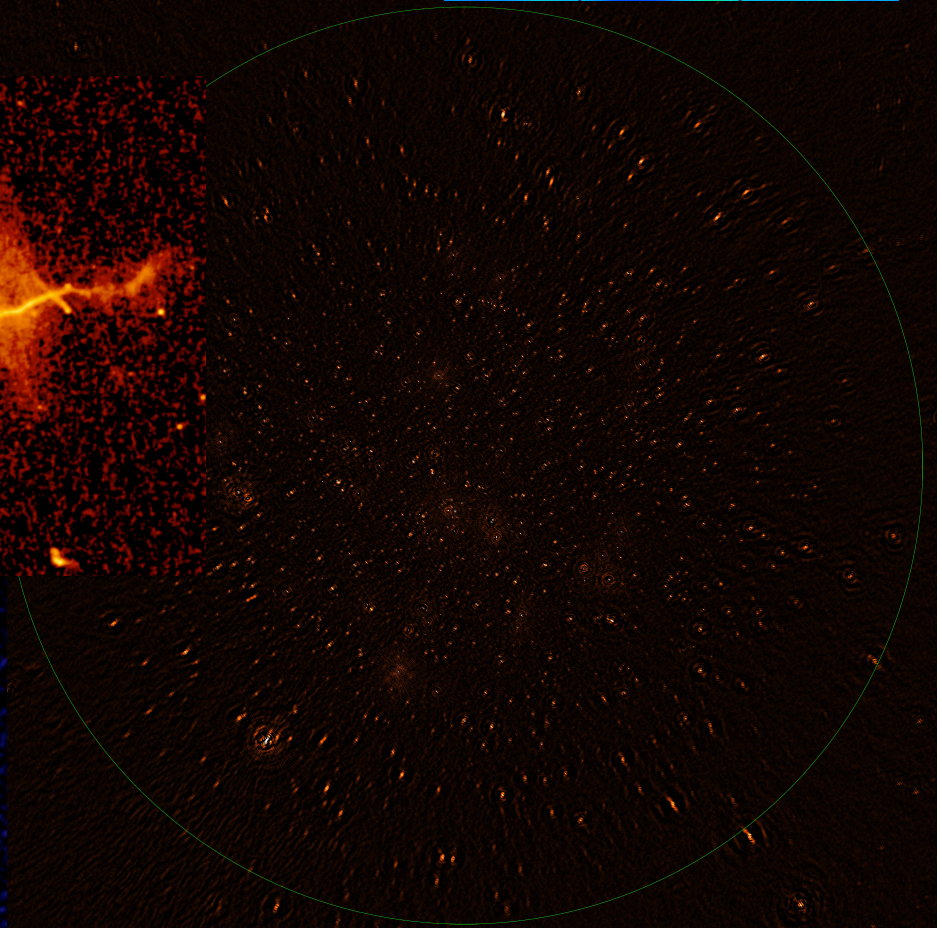
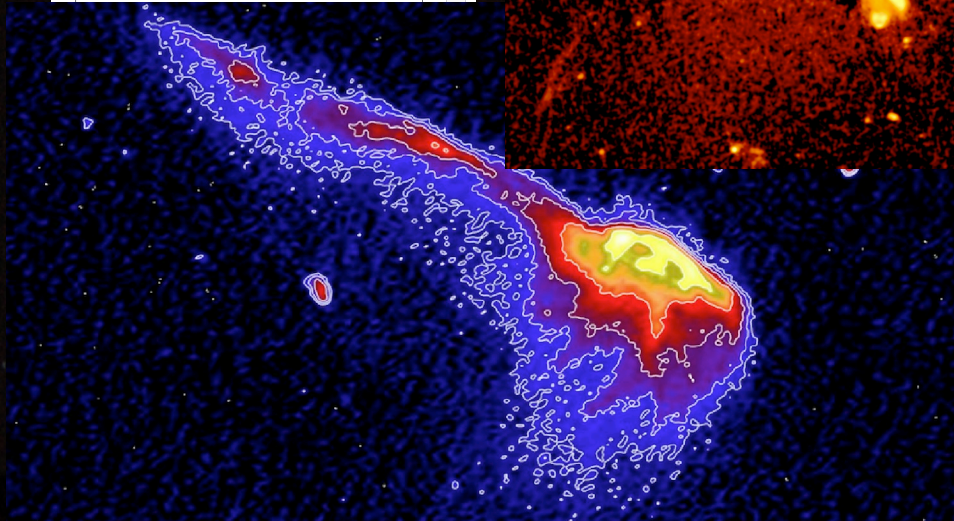
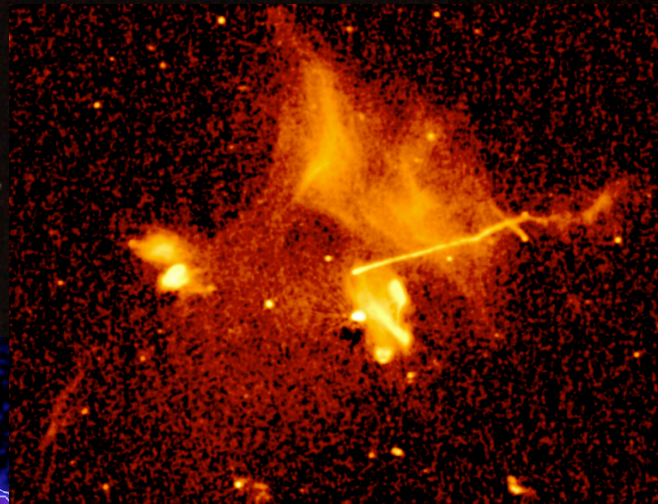
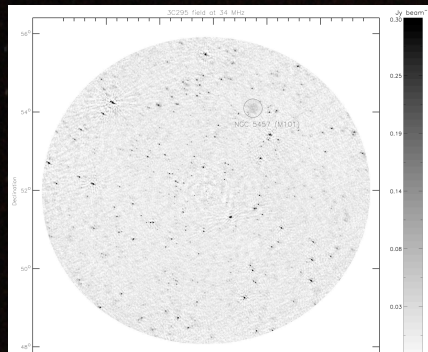
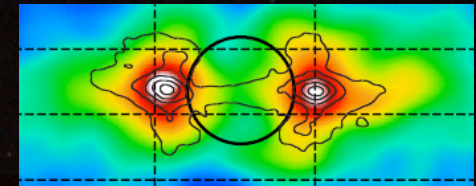
- Stored as CASA Measurement Sets
 - 10 MB - 100 GB in size, per 192 kHz frequency band
 - Usually 400-488 per observation
 - Relational structure
 - Each cell can have multiple dimensions (pol x freq)



LOFAR Data Types: Sky Images

ASTRON

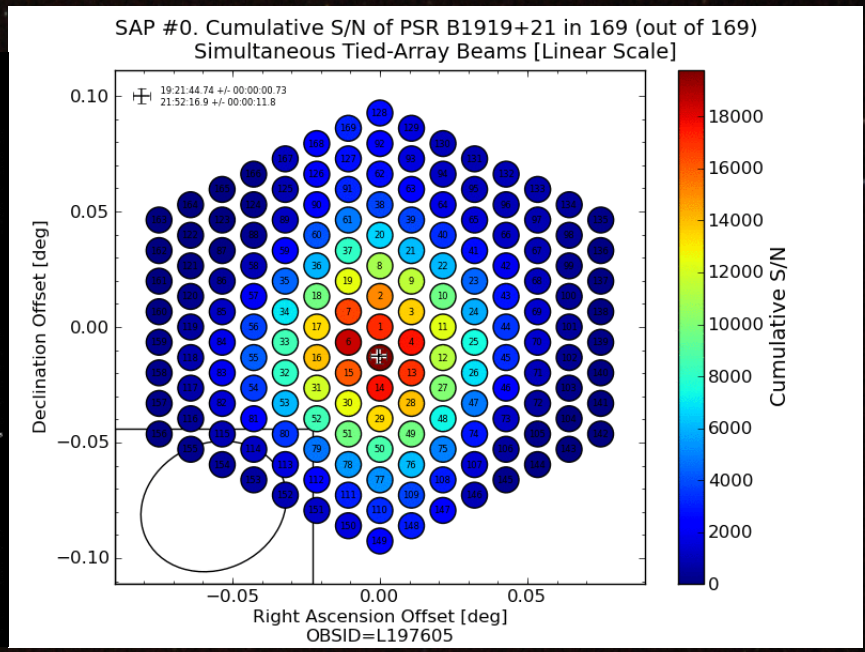
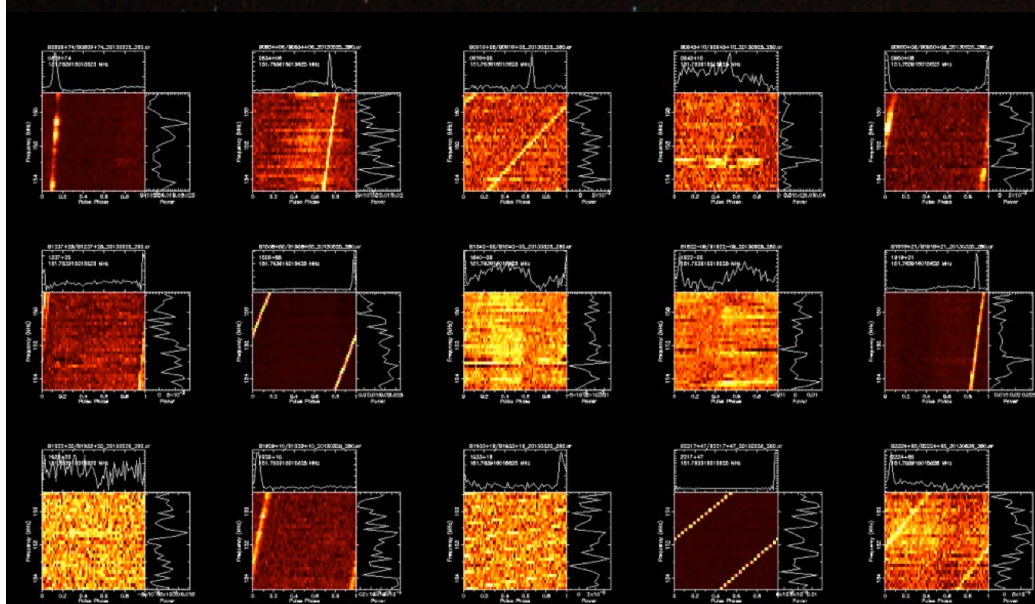
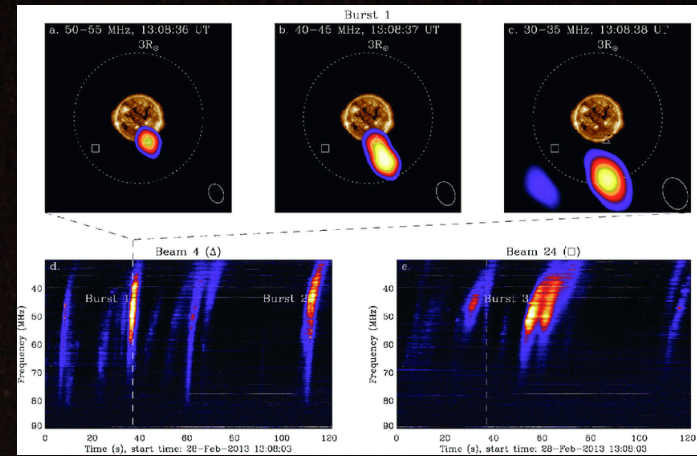
- FITS, CASA Images in *HDF5* and *CASA Tables*
- Only a few in LTA, users work with visibilities
- Can have frequency and polarization axis
- Surveys publish separately



Data Types: Tied Array

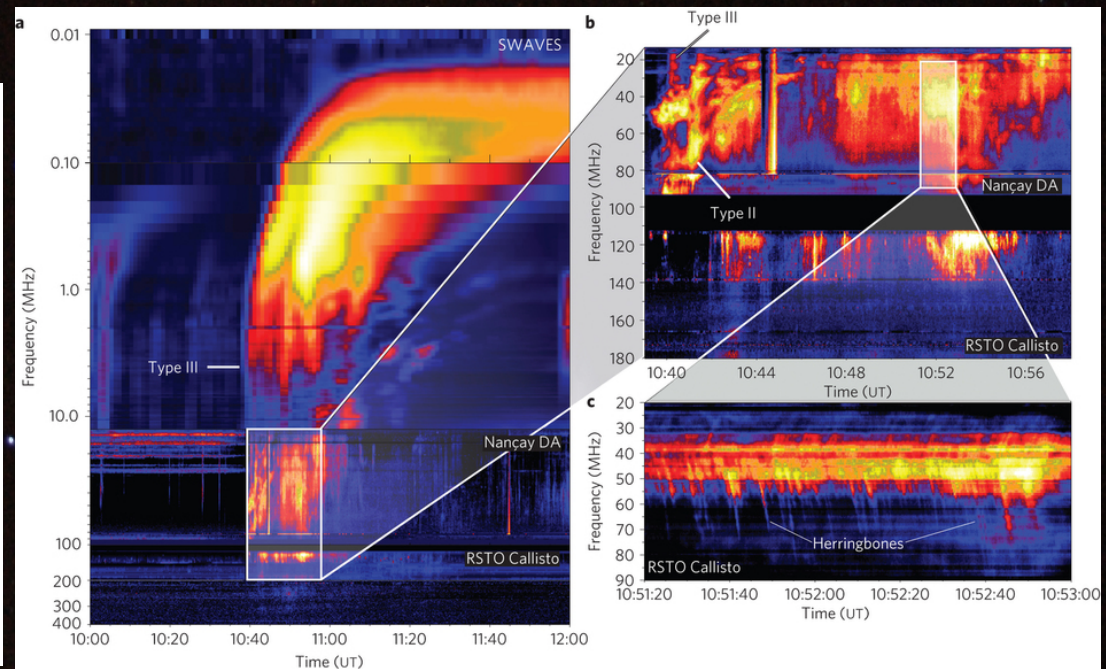
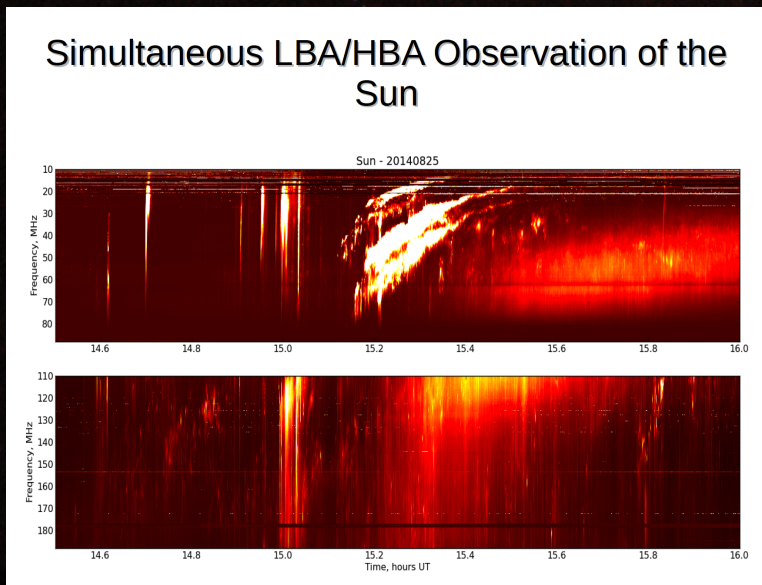


- Station beam forming
 - Coherent addition
 - Multiple Tied Array Beams
 - Incoherent addition
- Each station separately (Fly's Eye)
- High time resolution
- Stored in HDF5



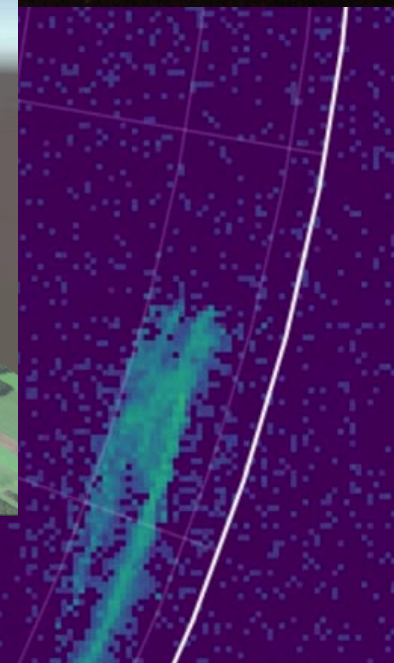
LOFAR Data Types: Dynamic Spectra

- Time-frequency Data in HDF5
- Single station and whole instrument
- Science: Sun, Solar wind, Northern Lights, Ionosphere, Planets
- Archived but not searchable
- Combined with other instruments (Nançay, Kaira)



Data Types: Transient Buffer Board (TBB)

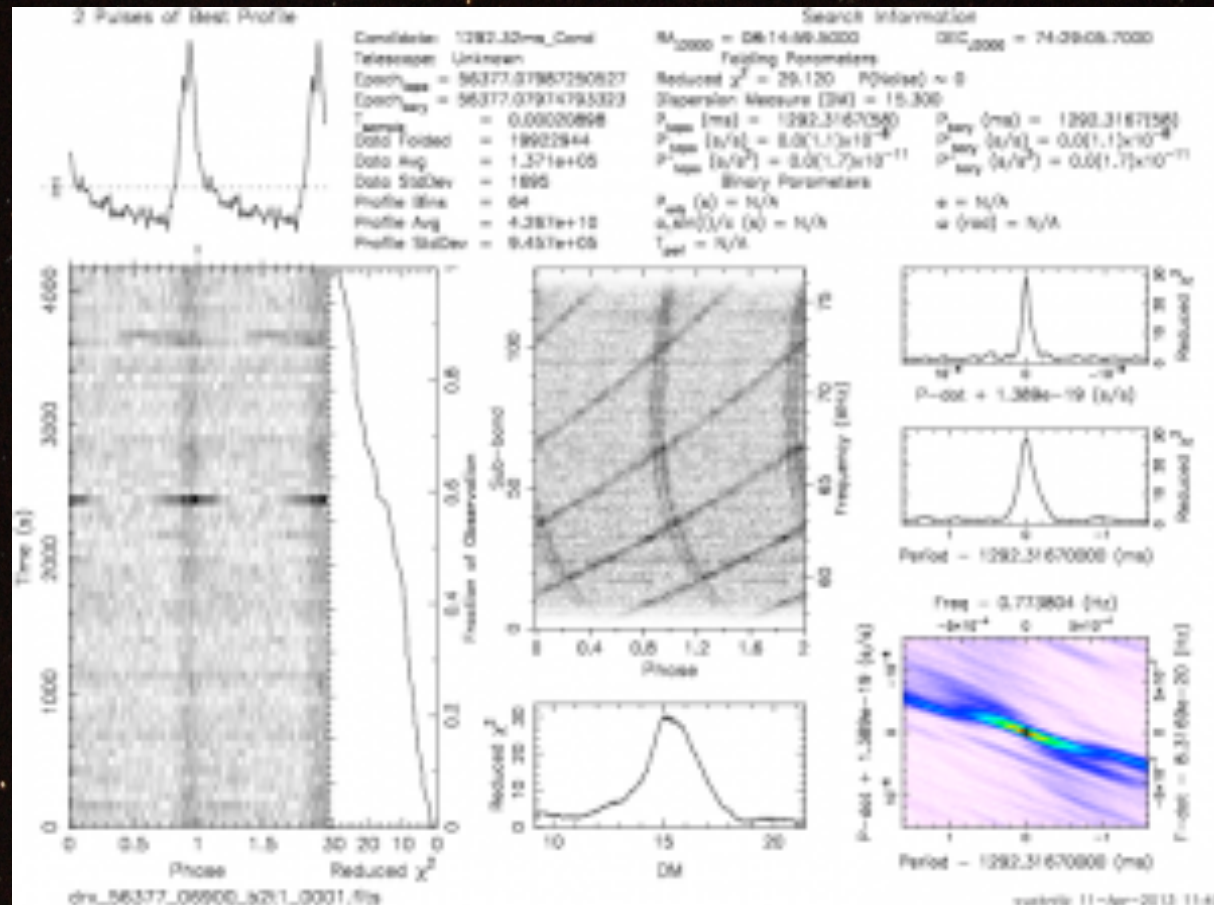
- Raw Complex Voltages captured from the antennas @ 5ns
- Triggered by Cosmic Ray detectors and Lightning
- After the fact (6 seconds buffer)
- 6D All sky data: Flux x Polarization x 3d Spacial x Time
- Archived but not searchable



Data Types: Pulsar Data

- Pulsar Profiles
- Dedispersed Pulsar time series
- Partially described and searchable

- PRESTO format not well described
- Combination of zipped files HDF5, FITS, ps, PRESTO, png



Data Types: Models and lists

- Instrument Models
- Sky Models
- Ionosphere Models
- Source Lists

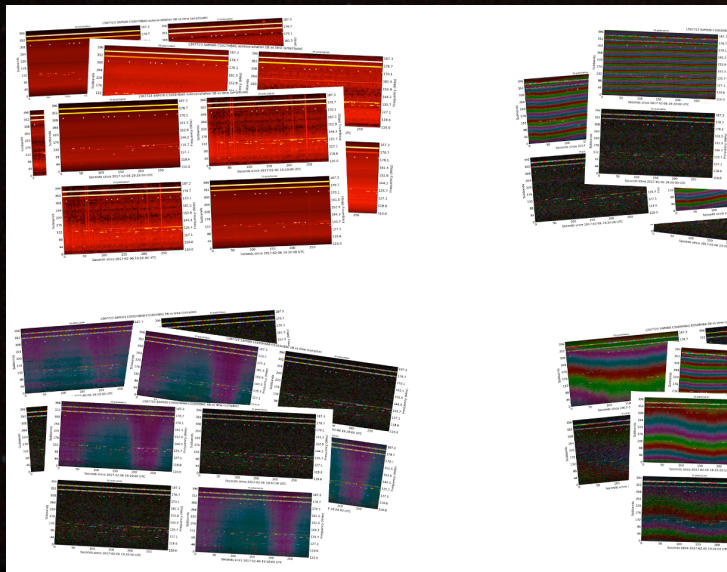
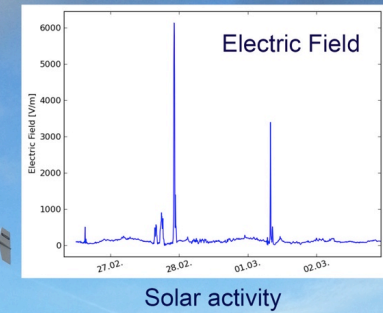
- Both science products and needed for understanding other data types
 - Calibrated data assume models
- Still in development as our understanding improves

Data types: Other



- Rotation Measure Cubes
- Quality Information
- Cosmic Ray detections
- Geophysics acoustic signals
- Meteorology

LOFAR Core, Exloo:
temperature: 10.4 degrees
barometric pressure: 1016 hPa
wind speed: 2.4 m/s
wind direction: SW
relative humidity: 86 %



- Multiple pointings per observation
- Processing Identifiers and provenance
- Resolution is processing dependent
- Field of View is not a constant
- All sky observations (and cone search)
- Dataset/Data collection identification as a shorthand for large numbers of dataproducts/DOIs/fragments
 - Maybe to standardize across data providers?

VO Technical issues

- Supported VO formats
 - Not easy to convert to FITS, VO Table (lossy, large)
 - Measurement Set
 - HDF5
 - PRESTO?
- Retrieval delay from tape
- Resource usage authorization (bandwidth, disk storage)
- VOspace and local user storage space
- Providing tooling to users
- User education
- Datalink provides a partial solution and a way forward

Current Efforts and Future Plans



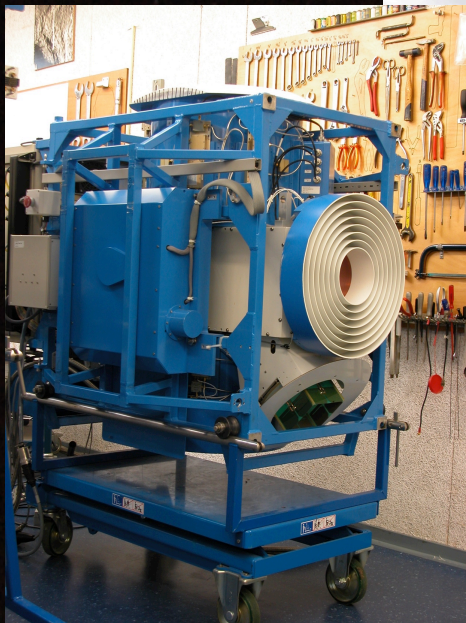
LOFAR:

- DaCHS installation for LOFAR Visibilities
 - Prototype installation almost working
 - Production installation planned
- Astron Data Portal (Marco Iacobelli's talk)
- Survey VO services
 - MSSS to be published this year
 - LoTSS to be updated
- Also: Responsive Telescope in CLEOPATRA
- Beyond ASTERICS:
 - Tied Array Data
 - Other types?
 - DOI

Current Efforts and Future Plans

Westerbork Radio Synthesis Telescope (WSRT)

- CAOM WSRT Legacy Archive (197?/1997 – 2015)
 - Prototype installation being worked on
- APERTIF Long Term Archive (2018-202?)



Thank you



LOFAR

Thank you
Vielen Dank



Questions?

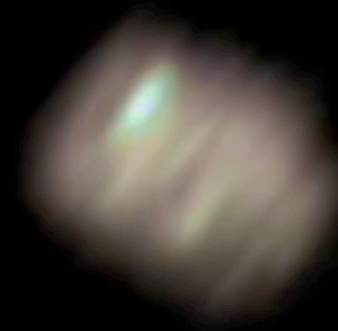


LOFAR

ASTRON

Real time observations of 2015 solar eclipse

ASTRON



International LOFAR Telescope