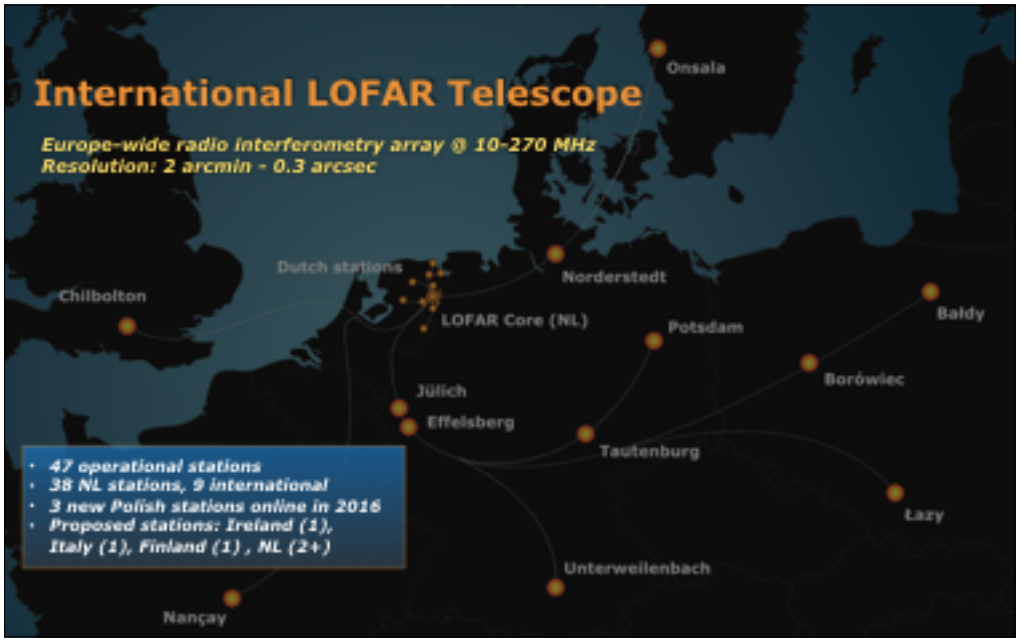
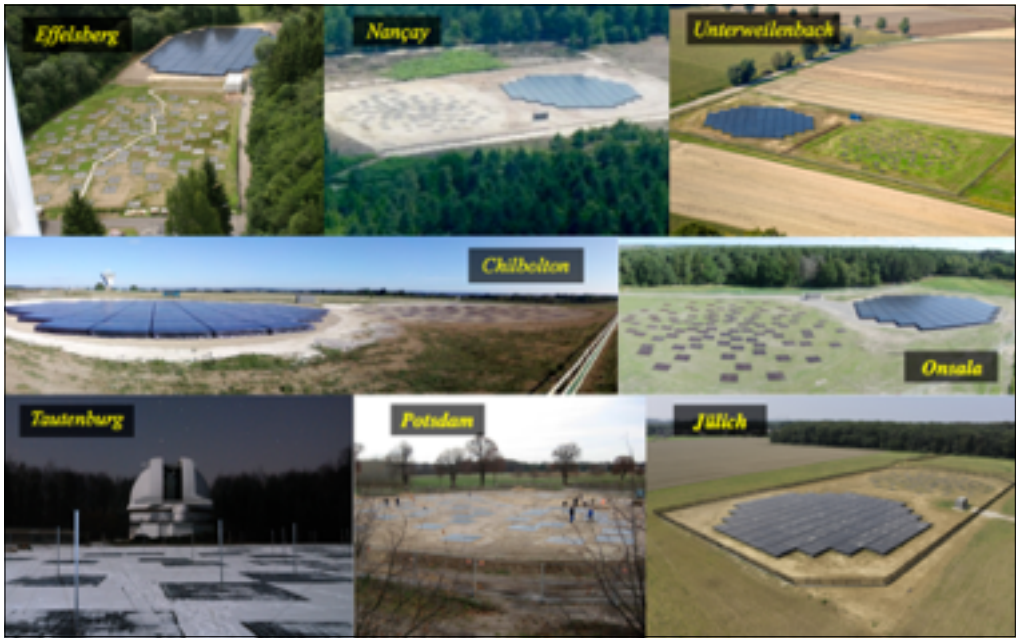

ASTRON
Netherlands Institute for Radio Astronomy
LOFAR: Low Frequency Array
Michiel van Haarlem
ASTRON
SKA Engineering Meeting
Penticton, 11 November 2015
ASTRON is part of the Netherlands Organisation for Scientific Research (NWO)
LOFAR

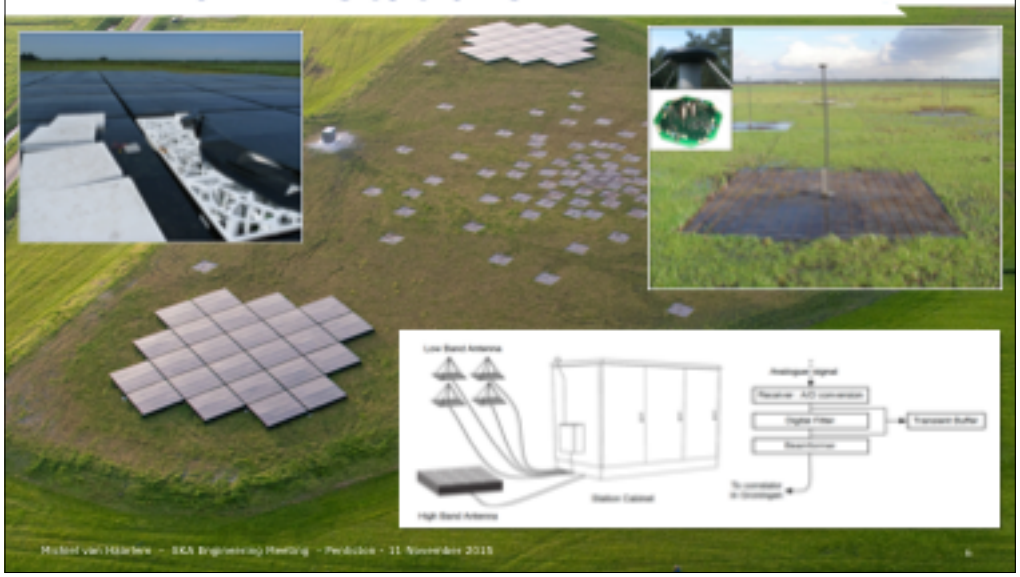

International LOFAR Telescope
Europe-wide radio interferometry array @ 10-270 MHz
Resolution: 2 arcmin - 0.3 arcsec
Onsala
Dutch stations
Norderstedt
Chilbolton
LOFAR Core (NL)
Potsdam
Baldy
Borówiec
Jülich
Effelsberg
Tautenburg
Łazy
Unterweilenbach
Nançay


International LOFAR Telescope
Europe-wide radio interferometry array @ 10-270 MHz
Resolution: 2 arcmin - 0.3 arcsec
Onsala
Dutch stations
Norderstedt
Chilbolton
LOFAR Core (NL)
Potsdam
Baldy
Borówiec
Jülich
Effelsberg
Tautenburg
Łazy
Unterweilenbach
Nançay
47 operational stations
38 NL stations, 9 international
3 new Polish stations online in 2016
Proposed stations: Ireland (1), Italy (1), Finland (1) , NL (2+)


Effelsberg
Nançay
Unterweilenbach
Chilbolton
Onsala
Tautenburg
Potsdam
Jülich

Construction of 6th German station & 3 in Poland

LOFAR Stations



LOFAR System Data Flow

Station signals collected in the station cabinets

Signals sent to COBALT for correlation

Data sent to CEP2 for initial post-processing

CEP2

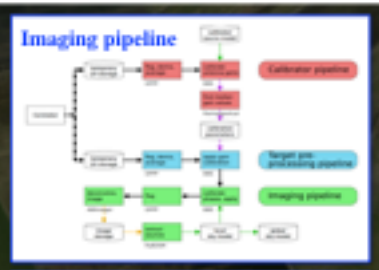
CEP3

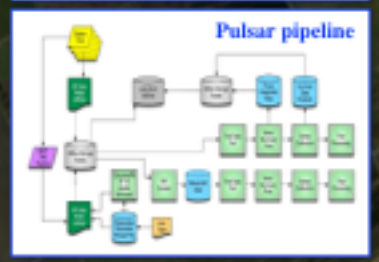
CEP3 cluster available for additional user processing

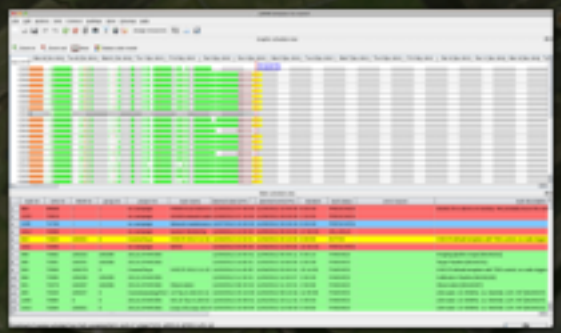
Products sent to the long-term archive

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

LOFAR Data Processing





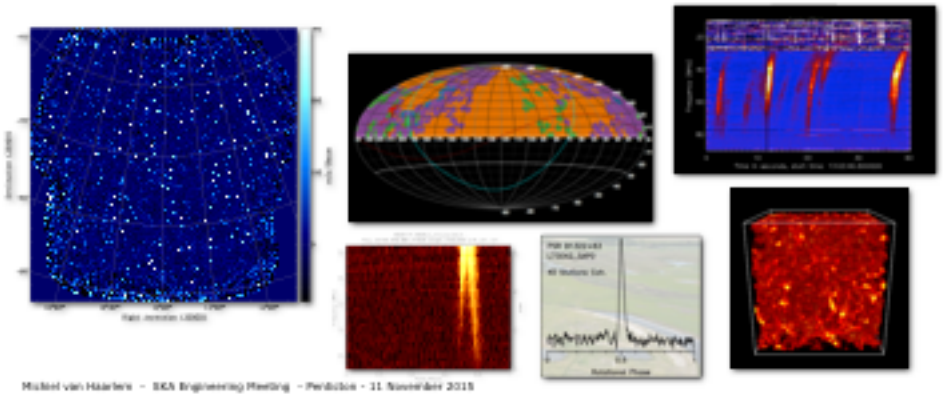


- Supports multiple data pipelines for different science products
- Scheduler oversees the entire end-to-end processing
- Maintains overview of the storage and computational resources
- Dynamic scheduling system currently under development

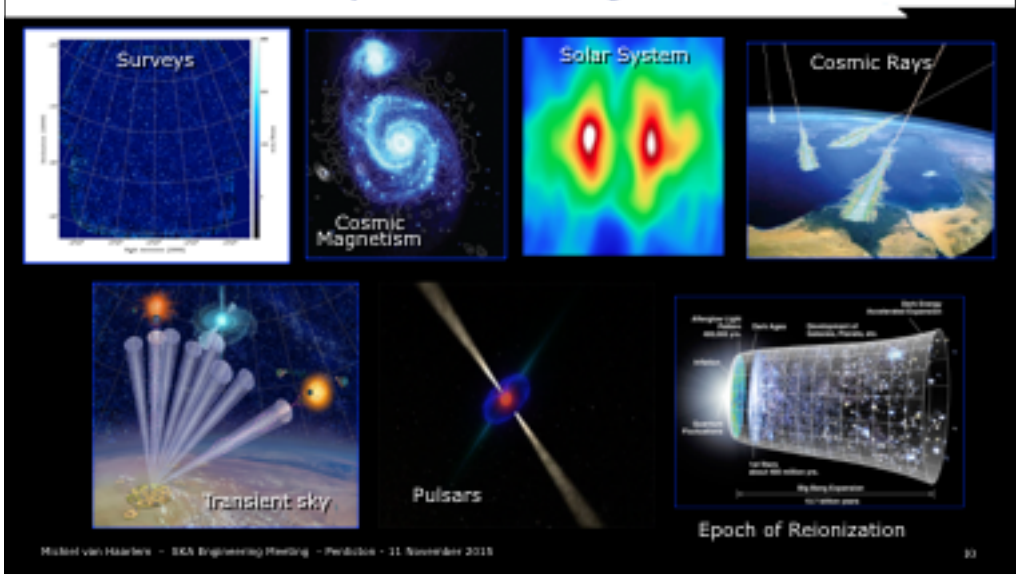
New flexible pipeline framework coming!

LOFAR Science Products

- Velocity *(Raw data rates of ~13 Tbits/s, correlated ~10 TB/hr)*
- Volume *(100 TB visibilities, 1 TB cubes, 1 PB catalogues)*
- Variety *(raw telemetry, uv data, beam-formed data, 2D-3D-4D-5D cubes, RM cubes, light-curves, catalogues, etc.)*



LOFAR Key Science Projects



MSSS: LOFAR's first imaging survey

Goals: obtain broadband sky model, shakedown LOFAR operations

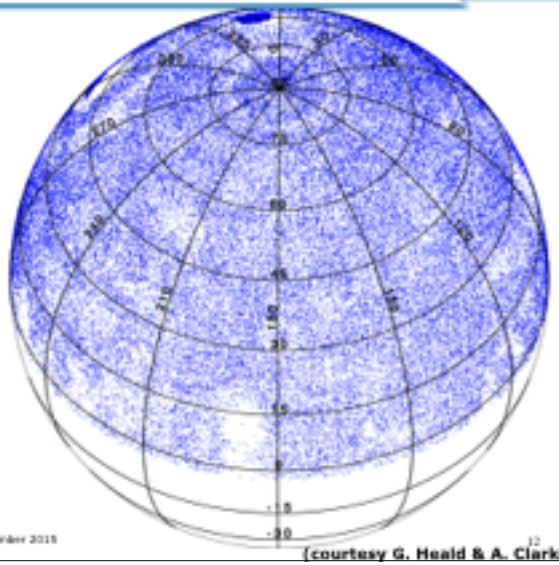
MSSS-LBA	MSSS-HBA
	
Frequency: 30-75 MHz (8 x 2 MHz bands)	Frequency: 120-160 MHz (8 x 2 MHz bands)
Resolution: ≤100 arcsec	Resolution: ≤120 arcsec
Sensitivity: ≤15 mJy/beam	Sensitivity: ≤5 mJy/beam
Area: 20,000 square degrees	Area: 20,000 square degrees
Number of Fields: 660	**Number of Fields: 3616**
Simultaneous ~10° beams: 5	Simultaneous ~4° beams: 6
Test observations resuming	Observations 100% complete

MSSS Source Catalog

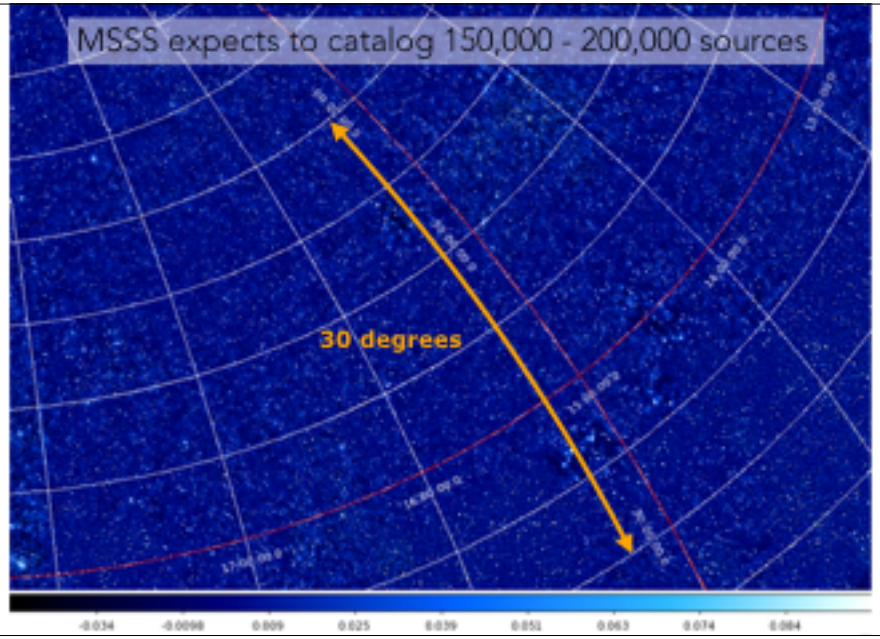
MSSS-HBA V0 catalog

- ~140,000 sources
- Average ~ 400 sources/mosaic
- MSSS products will be available through custom VO image and catalog server
- Expected release: soon

http://msss.astron.nl



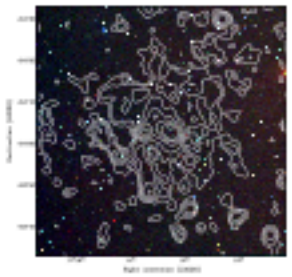
(courtesy G. Heald & A. Clarke)



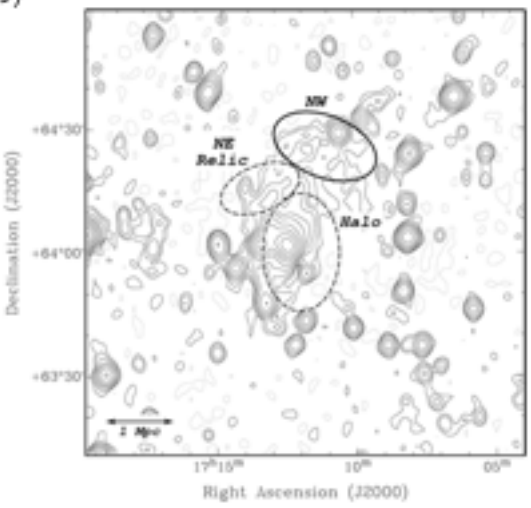
MSSS-HBA: Abell 2255

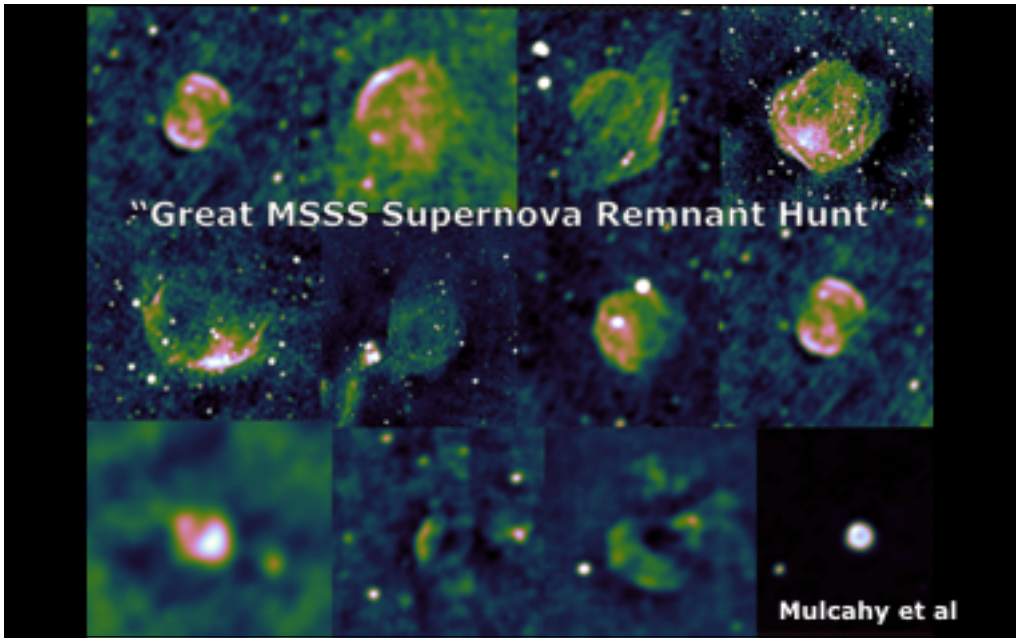
ASTRON

- cf Pizzo & de Bruyn (2009)
  WSRT, 150 MHz (5x12h)

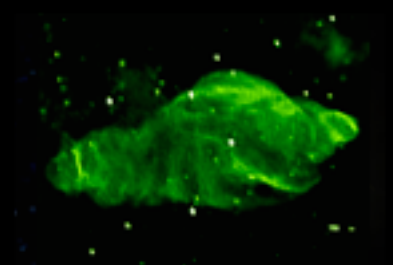


MSSS-HBA: 14 min!



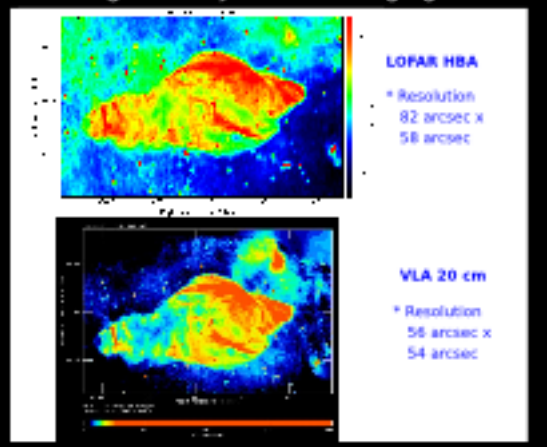


SS433/W50 Exploding Star



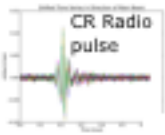
Broderick et al. 2015

High Fidelity LOFAR Imaging

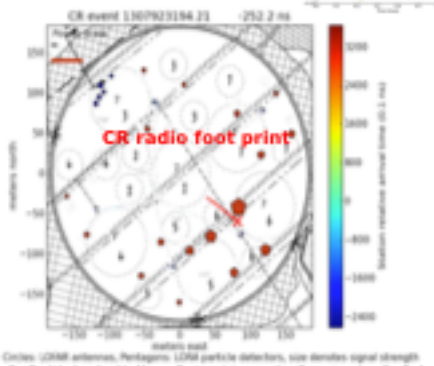


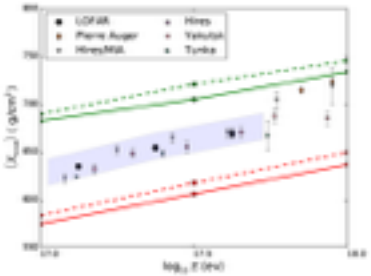
Cosmic rays in radio: most precise (and accurate) measurements

ASTRON — Radboud University Nijmegen



Average shower depth with current experiments (proxy for particle type)





LOFAR: smallest errors!
Indicates a strong proton component beyond "second knee"

S. Buitink, A. Nelles, S. ter Veen, A. Corstanje, P. Schellart, J. Hörandel, O. Scholten, H. Falcke et al.

Lightning & Cosmic Rays: Astroparticlegeophysics

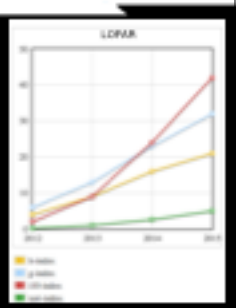
Artist's rendition

Schellart et al. (2015, PRL), Tran et al. (in prep.)

LOFAR Publications

LOFAR — ASTRON

- LOFAR Publication output is increasing
  - expect ~40 refereed publications in 2015
  - compared with 22 in 2014



Radio Telescope Premier Division (Season 2012-2015)

Data from NASA/ADS - metrics summary (2012-2015) with facility name and abbreviation in abstract.

Facility h-index = the largest number H, such that H publications using this facility have at least H citations.

Very Long Baseline Array	20
Pierre Auger	20
Arecibo	20
Parkes	21
Green Bank Telescope	21
LOFAR	21
JVLA	20
WSRT	18
GMRT	15
European VLBI Network	15
JCMT	15
Effelsberg	13
Nancay	10
MWA	8
Onsala	8
Lovell	8
Allen Telescope Array	8
Medicina	3

Michiel van Haarlem - SKA Engineering Meeting - Perdiscao - 11 November 2015

Ongoing Development

LOFAR — ASTRON

- Calibration and Imaging Tiger Team (CITT)
  - Awimager
  - Calibration
  - Self calibration
  - Facet calibration

CITT2 - from October 2015
- More focus on integration
- Generic pipeline
- Focus on directional calibration
- Focused on LBA calibration

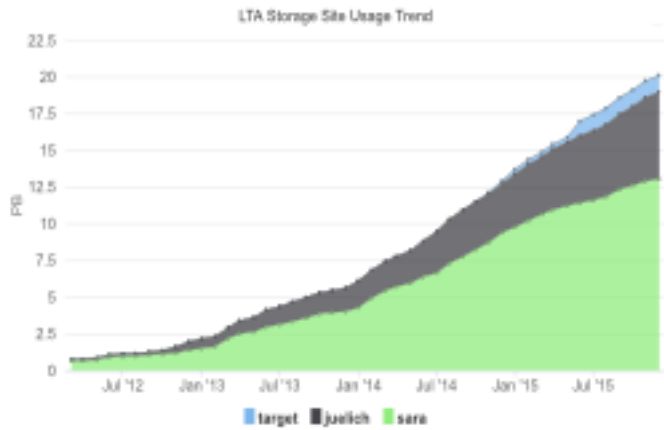
- 3R Tiger Team
  - Robustness
    - Software to be maintainable and robust against component failures
    - Design for minimal effort required to incorporate (future) changes
  - Responsiveness
    - The system is to support triggers and dynamic behavior
    - System performance to match requirements from operational processes and science cases
  - Reliability
    - Software to truthfully and consistently maintain and present state
    - Minimize need for users to check for and act on unexpected behavior

LOFAR Long-Term Archive

- Tier 0 (LOFAR CEP)
  - *Short term storage*
  - *First iteration processing*
  - *After quality inspection move data to LTA Storage and metadata to LTA Catalog*
- Tier 1 (Groningen, SURFsara, Jülich)
  - *Long term storage*
  - *Further processing, custom user analysis*
  - *Catalog queries via prompt, web- and VO interfaces*
  - *Data made available via Download Service*
- Tier 2 (KSP Science Centers)
  - *User controlled*
  - *Includes university storage and processing systems*

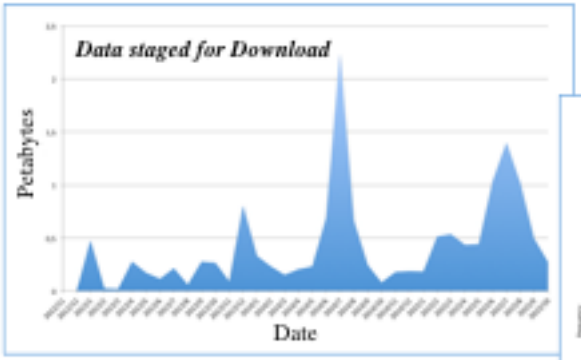
LTA Data Accumulation

- 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*



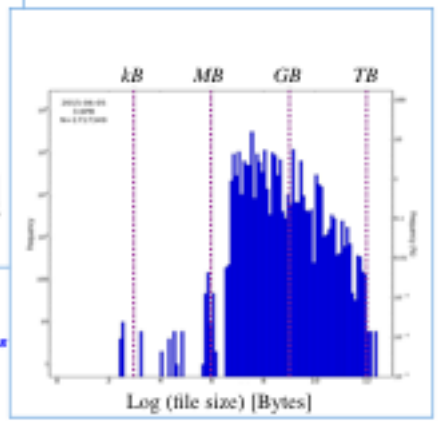
LOFAR LTA team: H.A.Holties, G.A.Renting, Y. Grange, J. Schaap, N.Vermaas, W.J.Vriend

Data Access Patterns



Typical data size is 10-100 Tb

Problematic for many researchers!

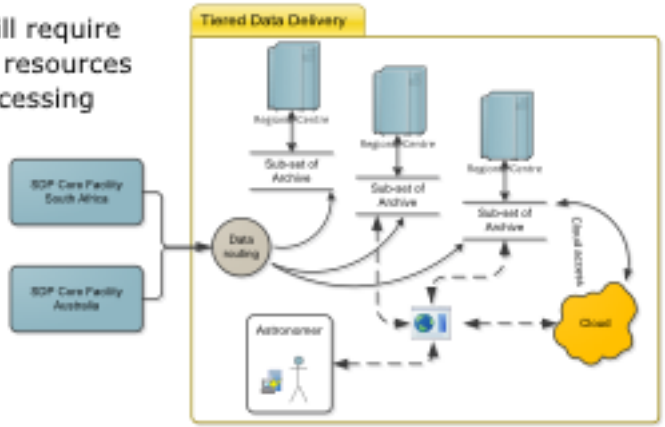


Typical 5 node clusters (320 Gb, 120 cores, 250 Tb) at individual research institutes are NO longer sufficient:

- ***Data transfer from archive to institutes too slow: ~ 10 Mb/s***
- ***Current P/O for a single observation too high: 10 - 100***

SKA Regional Science Data Centres

- Science extraction will require significant additional resources beyond standard processing
- Need for RSCs noted by SKAO board
- Likely there will be multiple RSCs to support community



RSCs will be the working surface for SKA science!

Regional Centres Capabilities

LOFAR ASTRON

Data oriented operations:

- Data archiving and curation
- Data management, discovery, and access
- Automated processing and reprocessing
- Generation and storage of science products
- Continued pipeline development

Science oriented operations:

- Portal-based data product access
- Interface to processing pipelines
- Interface to VO discovery and analysis tools
- Support for custom user analysis
- Development of new algorithms and tools
- End-to-end astronomer support
- Community education & outreach
- Face-to-face user support
- 24/7 help desk

Requires wide range of skill sets!

Summary

- ***LOFAR is up and running and generating great data***
- ***Long-term archive is large and growing fast***
- ***Computing resources to extract science are a bottleneck***
- ***ASTRON Science Data Centre division to attack this challenge***
- ***Excellent test bed for SKA Regional Science Data Centres***