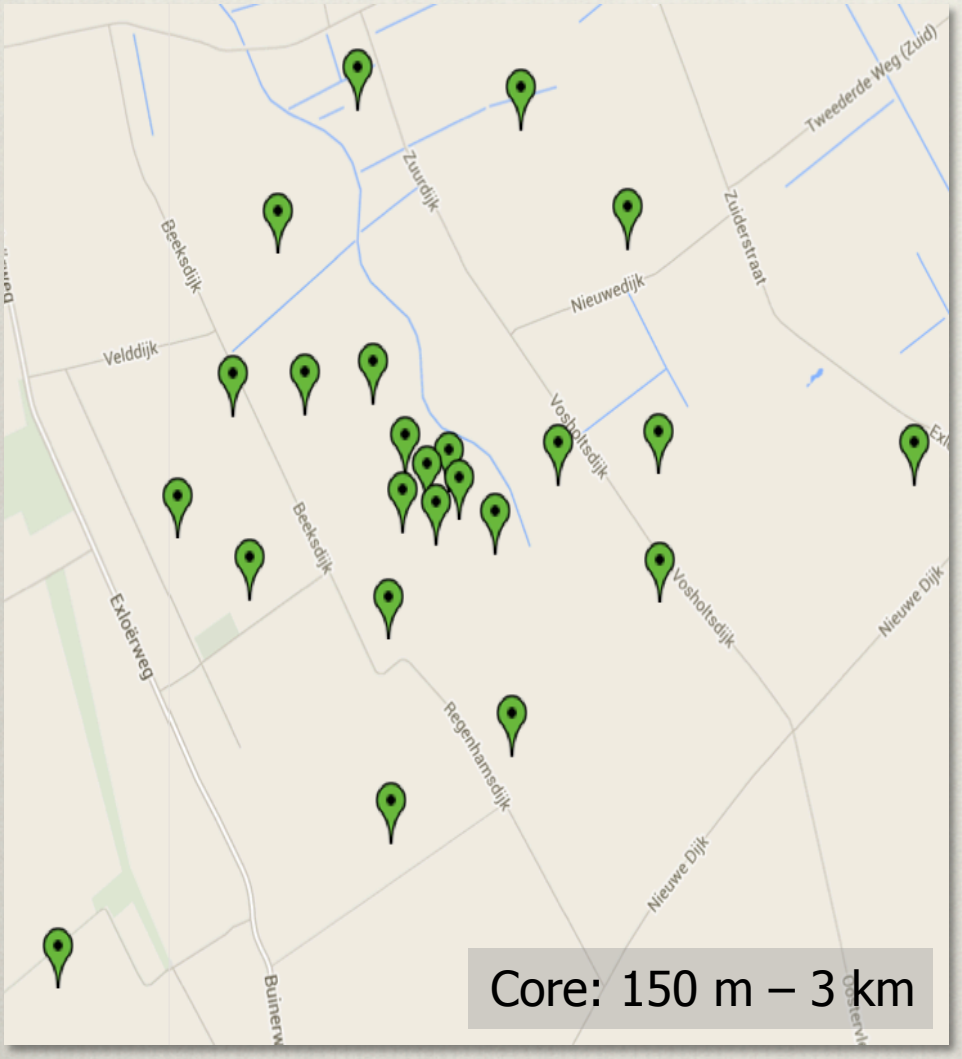

The Low Frequency Array
The telescope specs
Observing modes and processing capabilities
Science drivers & highlights
LOFAR
STATUS and UPDATE
Emanuela Orru'
Albuquerque, December 2nd 2015
ASTRON
LOFAR

DUTCH ARRAY



http://www.astron.nl/~heald/lofarStatusMap.html

International LOFAR Telescope (ILT)

Onsala

Dutch stations

Chilbolton

Norderstedt

LOFAR Core (NL)

Potsdam

Bałdy

Borówiec

Jülich

Effelsberg

Tautenburg

Łazy

- *300 – 1000 km*
- ~~*3 new stations coming in Poland*~~

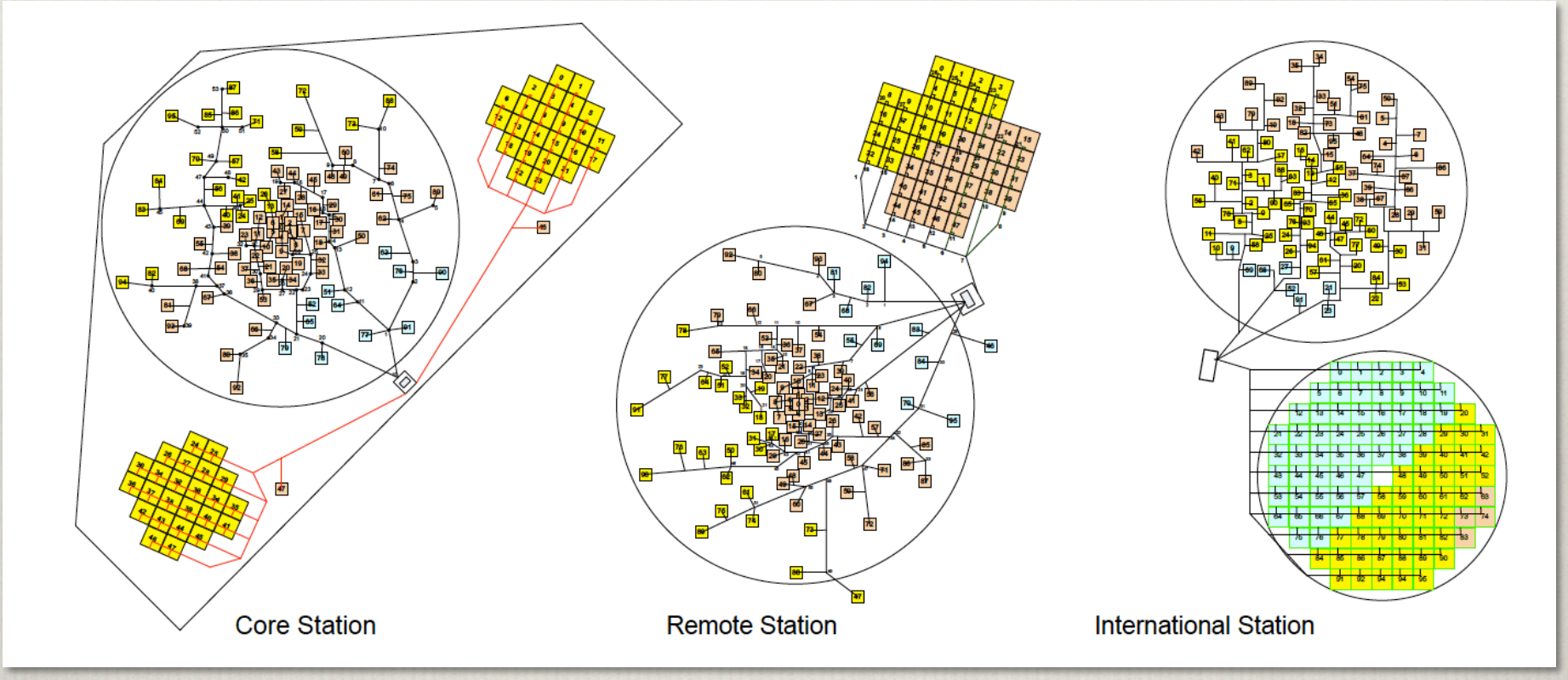
Unterweilenbach

Nançay

LOFAR

Netherlands Institute for Radio Astronomy

LOFAR STATIONS: CONFIGURATION

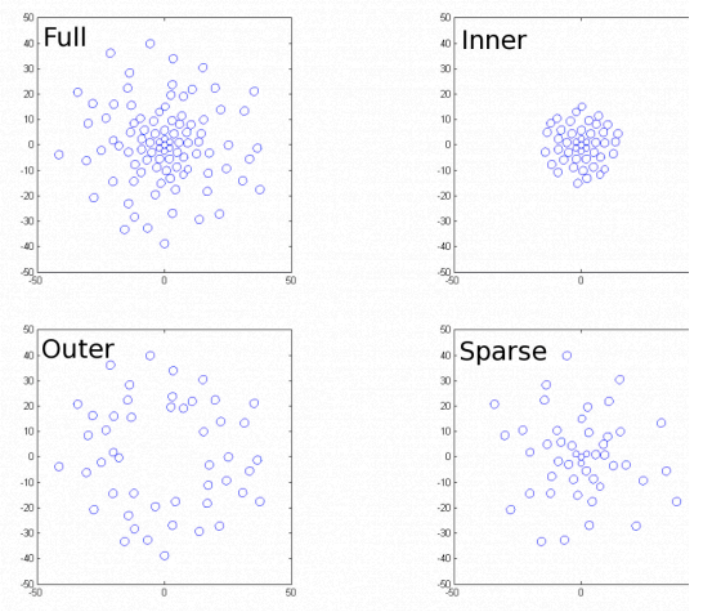


- Three types: Core (24), Remote (14) and International (9, but more to come!)
- Different beam shapes
- Different sensitivities

48 HBA tiles/96 LBA dipoles

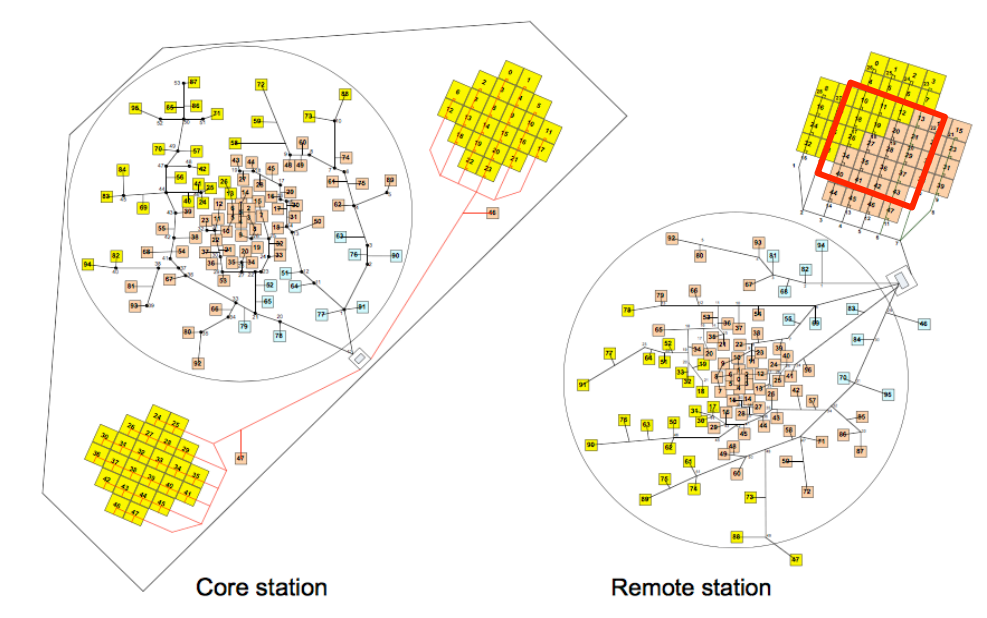
LBA

- 96 dipoles BUT 48 signal paths dual polarization
- Half of dipoles for NL stations can be used
- Inner – Outer - Sparse



HBA

- All for NL stations can be used
- Core stations: joined or dual
- Remote stations Inner or Outer



UV COVERAGE, ANGULAR RESOLUTION AND FOV

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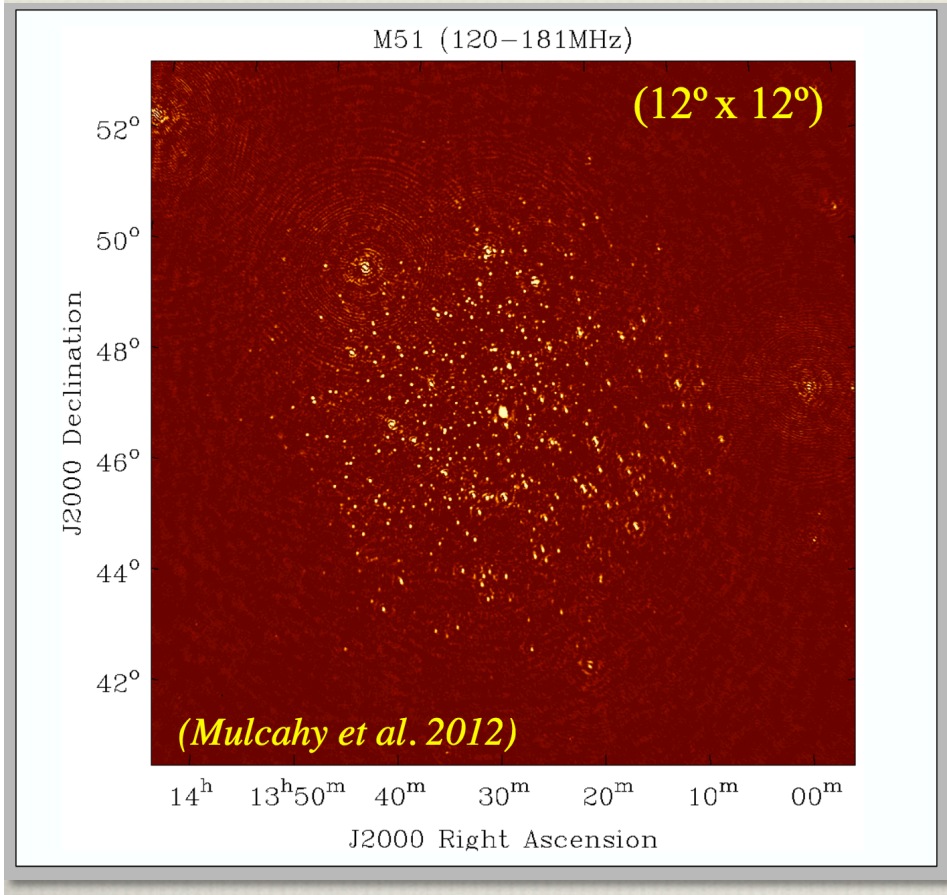

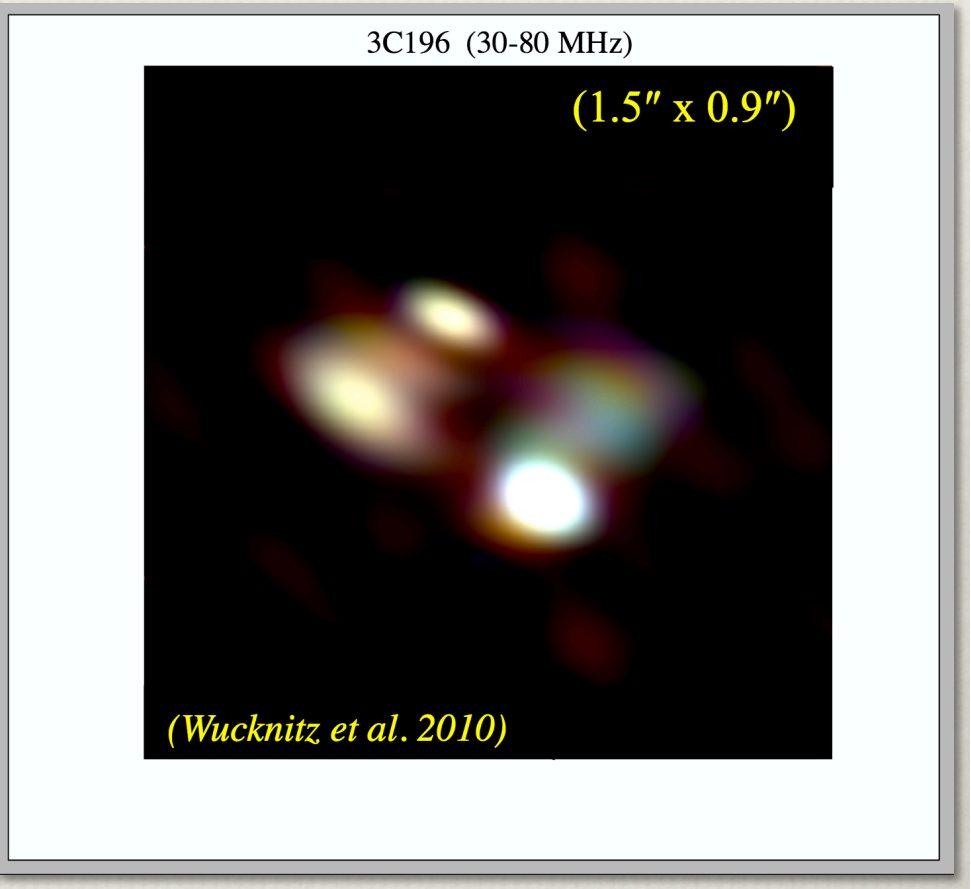

- One of the transformational aspects of LOFAR is the unprecedented range of angular scales that are achievable at low observing frequencies.

LOW BAND ANTENNA - LBA

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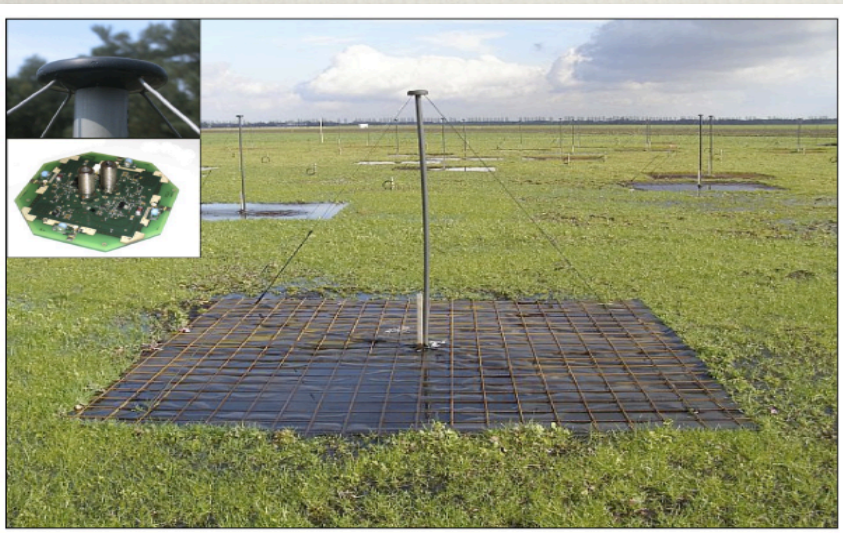
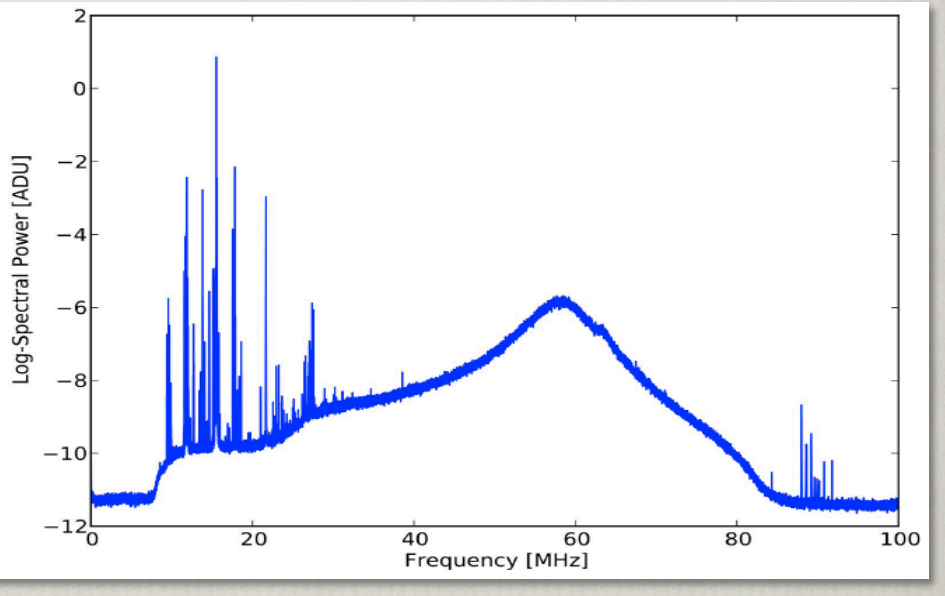
- LBA antennas: Cap containing the low noise amplifiers (LNAs), copper wires receive two orthogonal linear polarisations, ground plate
- Arms are 1.38 m long with the resonance frequency 52 MHz: the response curve is ~ 58 MHz.
- Filters 10-90 MHz or 30-90 MHz Area ~ 75200 m^2;





HIGH BAND ANTENNA - HBA

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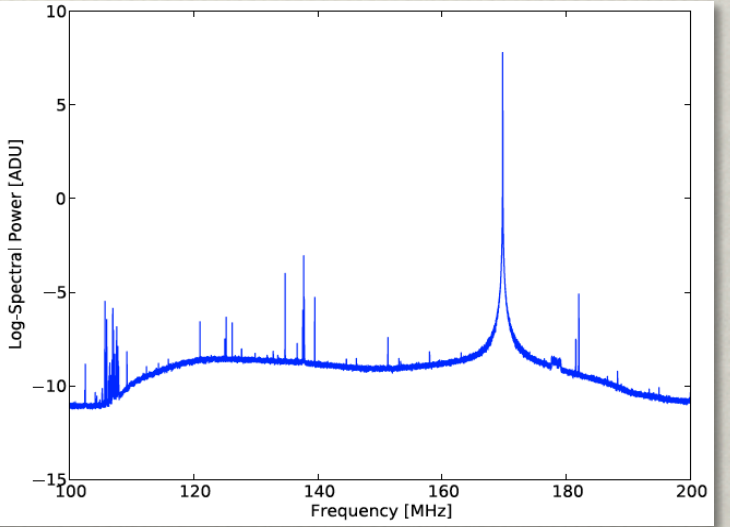
- HBA antennas: cluster 16 antenna elements together into 'tiles' that include initial analog amplification and digital beamforming – single 'tile-beam' formed
- Each tile consists of 4 x 4 dual linear polarisation aluminum dipoles, housed in a polystyrene structure, covered by polystyrene sheets
- Filters: 110-190 MHz and 210-250 MHz (200 MHz clock) - 170-230 MHz (160 Mhz clock)
- Area ~ 57000 m^2



- The response curve: there is a smoother response over the main HBA observing band - peak near 170 MHz corresponding to an emergency pager signal

CENTRAL CABINETS

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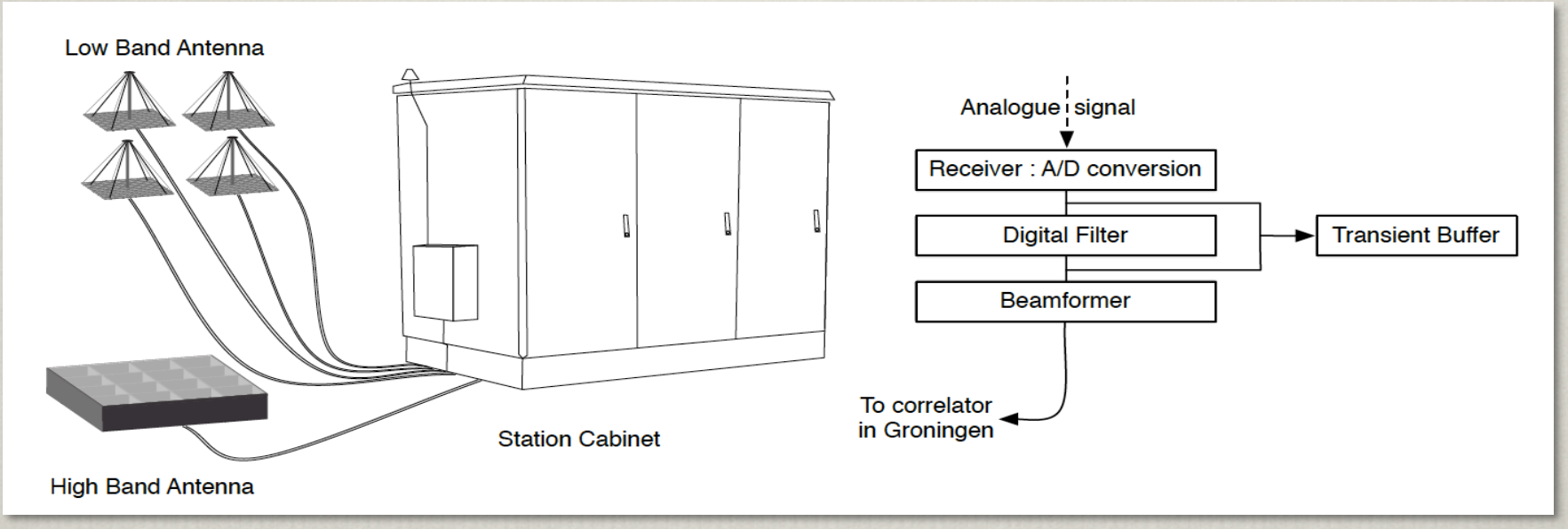
- **Receiver Control Units (RCU)**: input antenna voltages are converted to base-band frequencies, amplified, filtered, and digitised
- **Remote Station Processing (RSP)**: separate the signal into 512 sub bands of 156 or 195 kHz (clock dependent) by a PPF
- Carries out phase-rotations based beam-forming by multiplying with a set of complex weights that correspond to the geometrical delay for pointing



BEAM-FORMING – PARALLEL OBSERVATIONS

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- Unlike standard telescopes, LOFAR has no moving parts
- Pointing is achieved by combining the beams from each individual element (antenna or tile), at the station level, using different complex weights
- <488 beams can be formed, increasing survey speed, efficiency, calibration

THE LOFAR SYSTEM: DATA FLOW

Station signals collected in the station cabinets

Signal sent to COBALT for correlation

CEP2

CEP3

Data sent to CEP2 for initial RO processing – products might get copied to CEP3

Products sent to the long-term archive

- Large data transport rates ➔ data storage challenges (35 TB /h)
- LOFAR is the first of a number of new astronomical facilities dealing with the transport, processing and storage of these large amounts of data and therefore represents an important technological pathfinder for the SKA

Observing modes

- Imaging (COBALT)
- Beam formed (COBALT)
- Beam formed + imaging (COBALT)
- TBB (station level)
- AARTFAC (separate correlator)
- Parallel observations (COBALT): experimental not supported

LOW BAND ANTENNA - LBA

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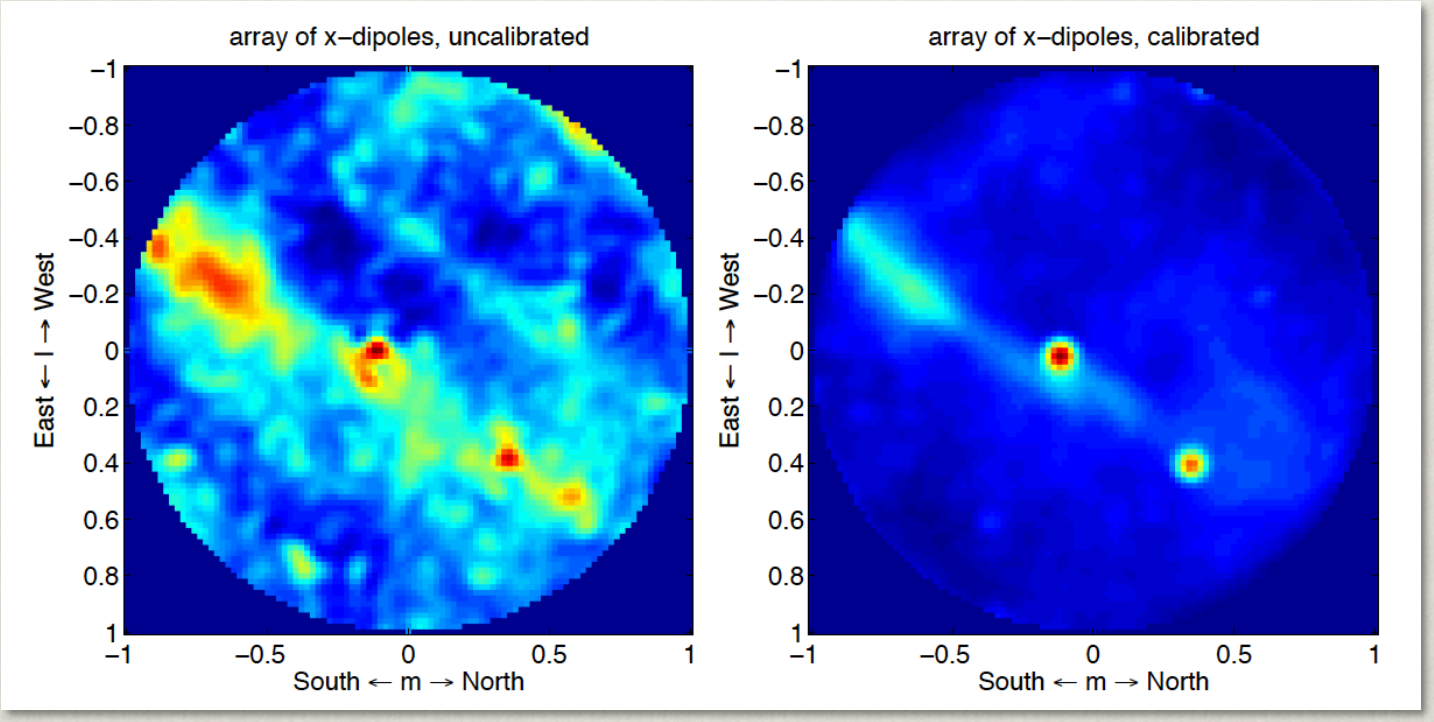
- Despite the simple design, the LOFAR LBA dipole provides a powerful detection system at low frequencies. In particular, the omnidirectional response of the LBA antennas allows for the simultaneous monitoring of the entire visible sky



- Studies of the large scale Galactic emission from the Milky Way and all-sky monitoring for radio transients

(see Y. Cendes talk)

Processing

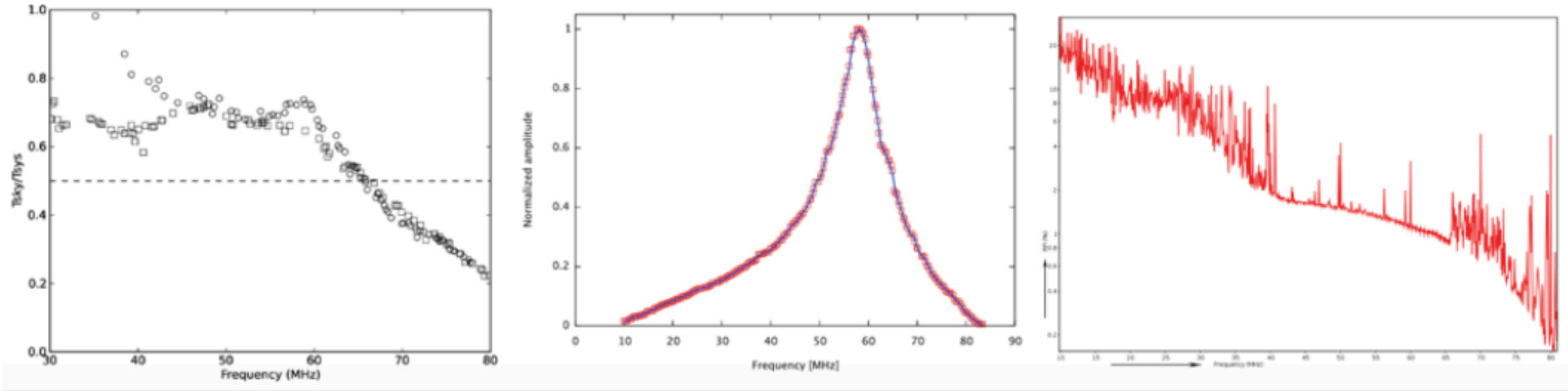
- Imaging pipelines (pre-processing – standard imaging pipeline – long baseline pipeline
- PSR pipeline
- Commissioning processing cluster CEP3
- Transient pipeline and solar pipeline have been developed and are used by the KSPs.

Calibration Imaging Tiger Team

- A team of astronomers, developers and signal processing experts focused on developing new calibration algorithms and recipes.
- The ultimate goal is to integrate these products into the Radio Observatory processing pipelines

Calibration and imaging

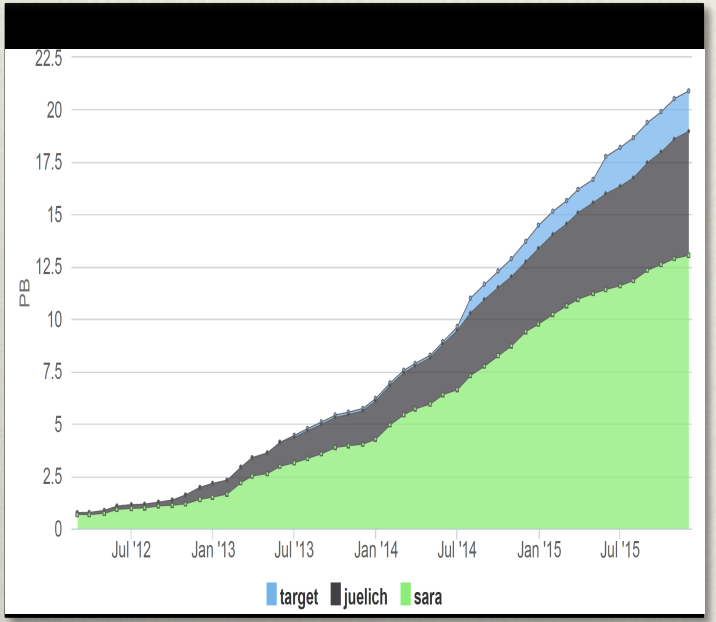
- **Beam:** unlike in other tracking telescopes, the beam varies with time and frequency: NEED develop of non standard software to

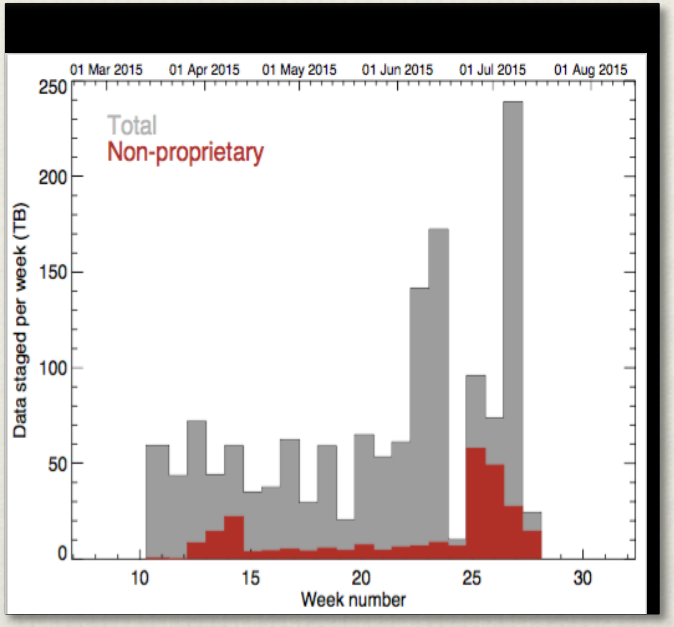


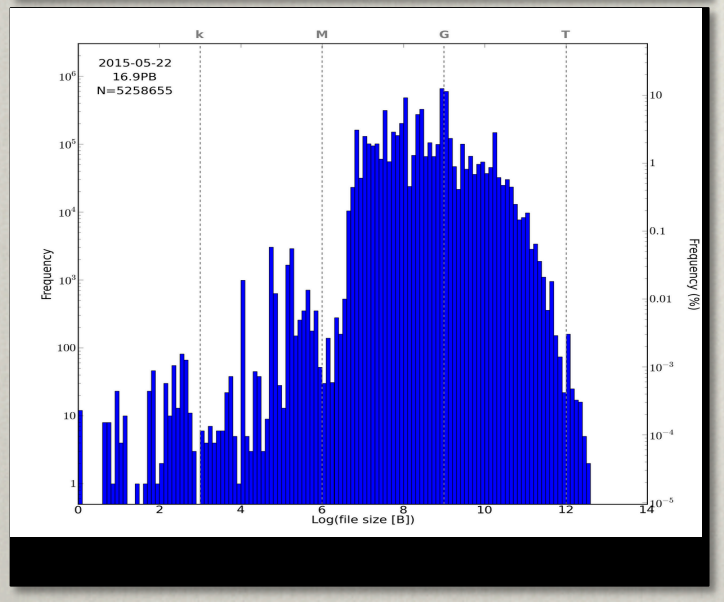
- **LBA** is our next goal: sky noise ionosphere RFI

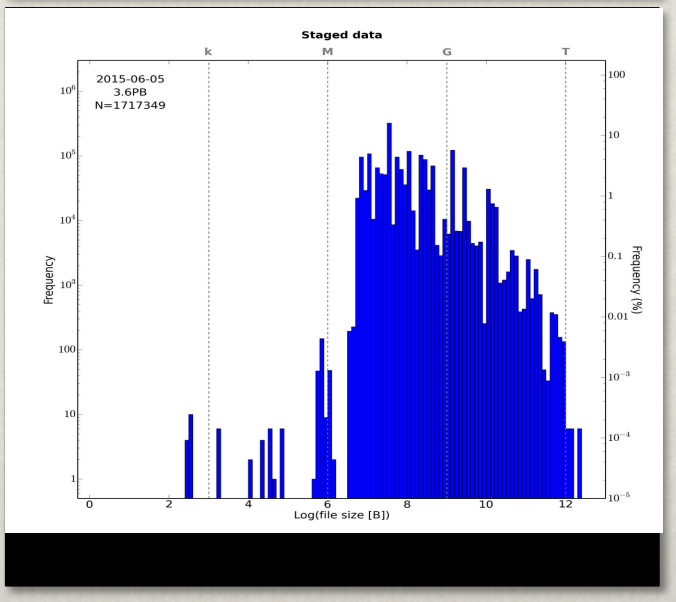
*Direction Dependent Calibration

DATA AT THE LTA









- Operations started in December 2012
- 5 Cycles successfully completed – a new one started yesterday
- ~ 8200 hours of good data delivered to the PI's of 180 projects!
- Exceeded 20 PB of data in the LTA!
- Current growth per year: 6 PB (and increasing!!)
- 5.5 million data products
- > 1 billion files

Courtesy of LOFAR LTA team: L. Cerrigone, J. Schaap, H. Holties, W. J. Vriend, Y. Grange

LOFAR SCIENCE DRIVERS

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Key Science Projects

Epoch of Reionization

Surveys and Distant Universe

Transients and Pulsars

High Energy Cosmic Rays

Cosmic Magnetism

Solar Physics and Space Weather

Other projects

Radio Recombination lines (see R. Oonk & K. Emig talks)

Ionosphere monitoring

Moon occultation (see H. Vedantham talk), ***Exoplanets, SETI etc***.

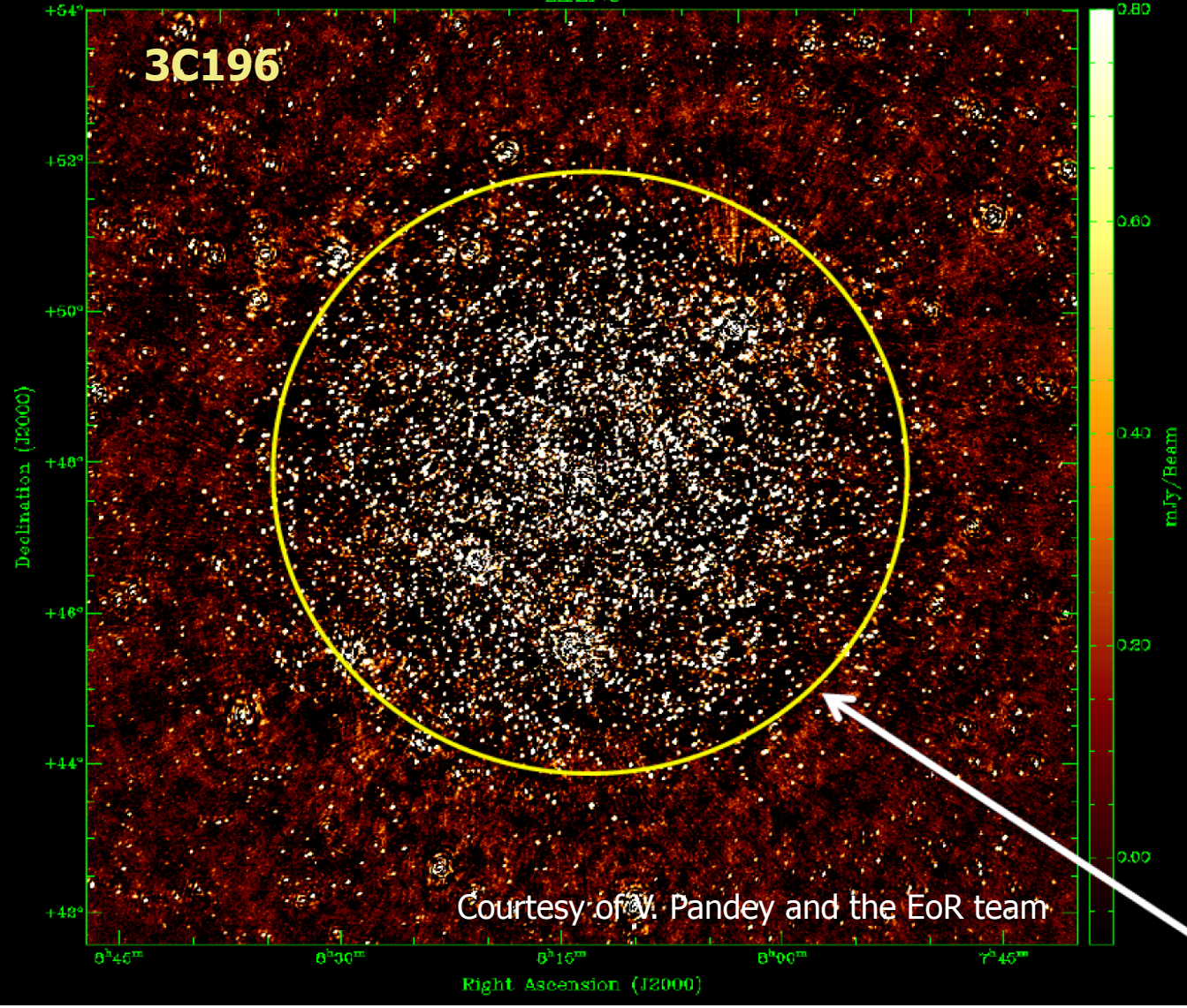
International membership from countries all over the World

Constribute development and commissioning resources

EoR KSP

Goal: Detect cosmological 21 cm signal (z~ 6-10)

see talks by G. de Bruyn & A. Offringa



Courtesy of V. Pandey and the EoR team

0.8 mJy

- 145 MHz (~2m)
- 60MHz continuum
- 6 powers of 10

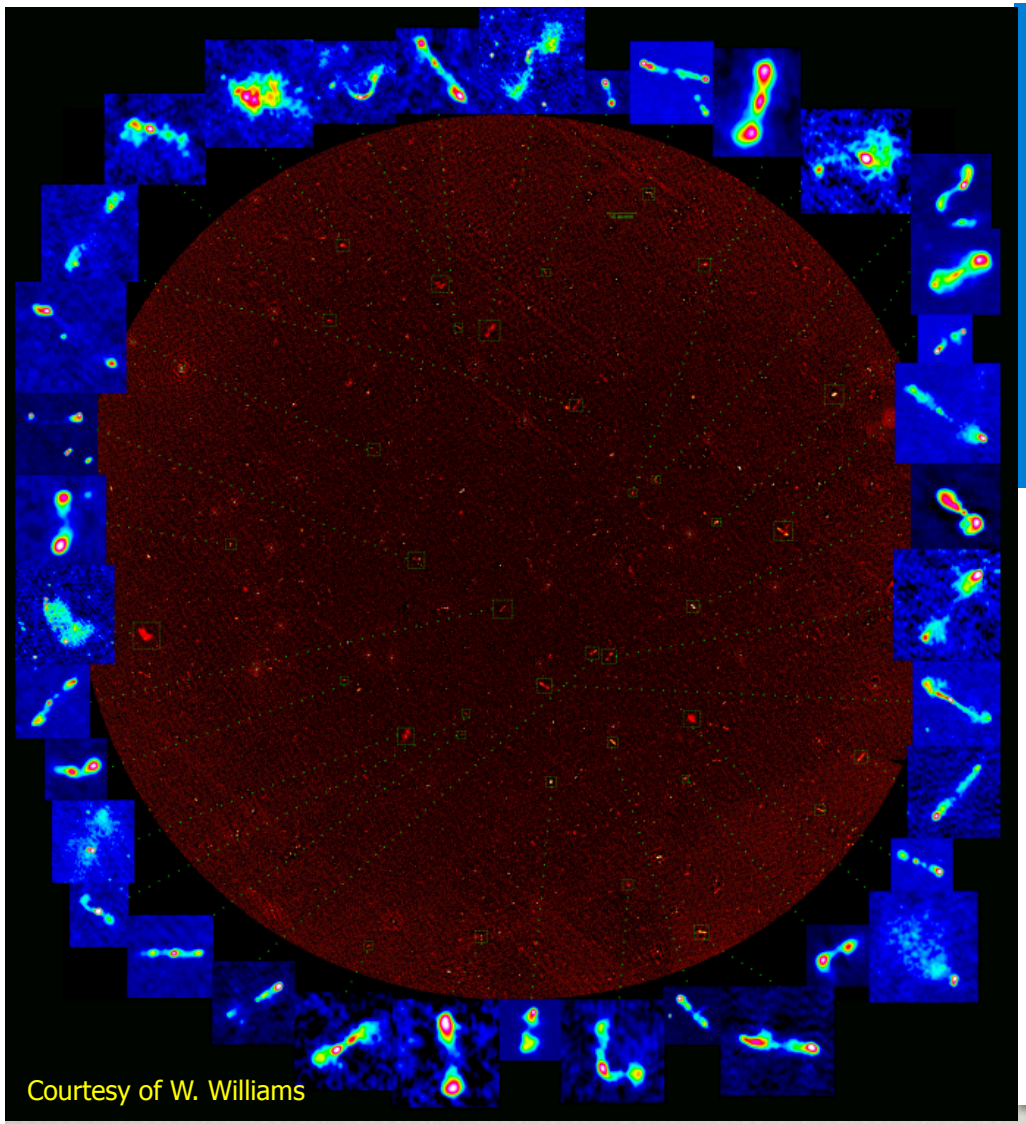
- 32 hours on 3C196 (8 hrs x 4 days)
- Dec 21,12-Feb08,13
- 30λ - 5000λ
- Resolution - 50”
- 12^0 x 12^0 Image

- ‘Noise’ < 75 μJy
- 3C196 - 79.97 Jy
- DR: ~ 10^6:1

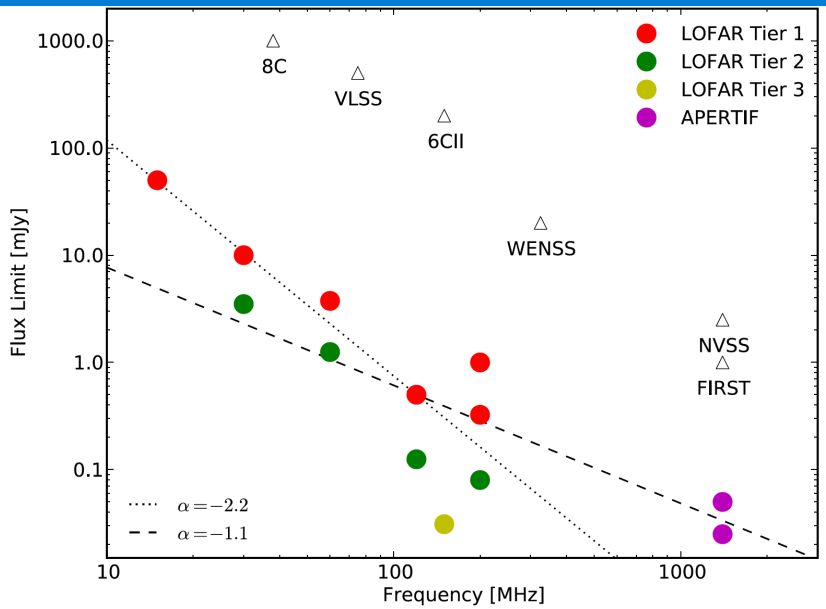
Station beam (~8^0)

SURVEYS KSP - DEEP SURVEYS

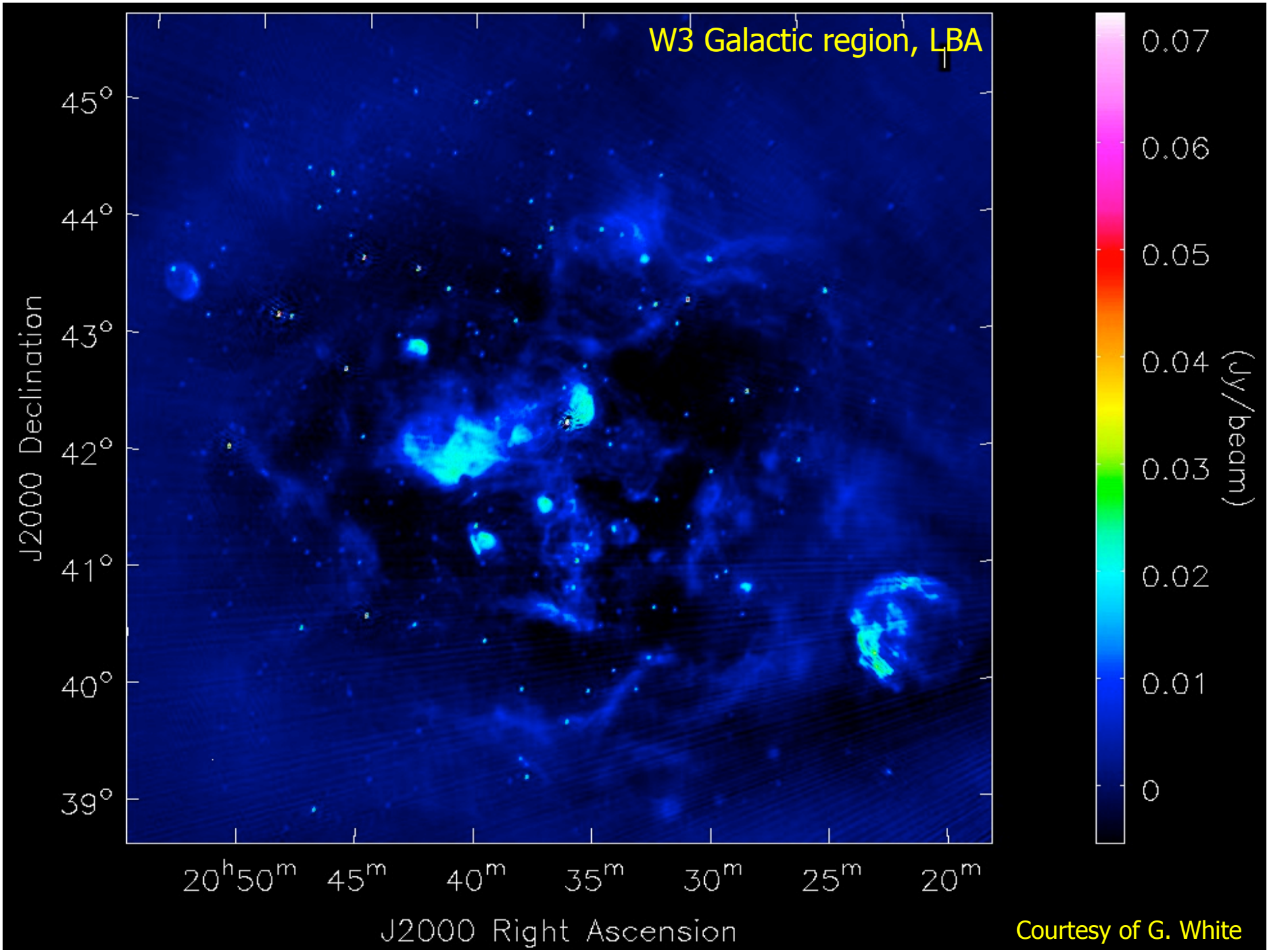
Goal: High-redshift radio galaxies, Galaxy clusters, star-formation, new parameter space for serendipitous discovery



- Tier 1: 'large area' 2π steradian surveys – HBA (σ = 0.07 mJy) + LBA (σ = 1-2 mJy)
- Tier 2: the 'deep' surveys – HBA (500 deg^2, σ = 15 μJy)+ LBA (1000 deg^2, σ = 0.3 mJy)
- Tier 3: the 'ultra-deep' survey – HBA -> σ = 7μJy -> detect 50 proto-clusters at z>2



See talks by A. Shulevsky, F. de Gasperin, R. v. Weeren, I. Polderman, C. Riseley, A. Clarke


W3 Galactic region, LBA
45°
44°
43°
42°
41°
40°
39°
J2000 Declination
20h50m
45m
40m
35m
30m
25m
20m
J2000 Right Ascension
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
(Jy/beam)
Courtesy of G. White

IMAGING WITH THE INTERNATIOANL STATIONS

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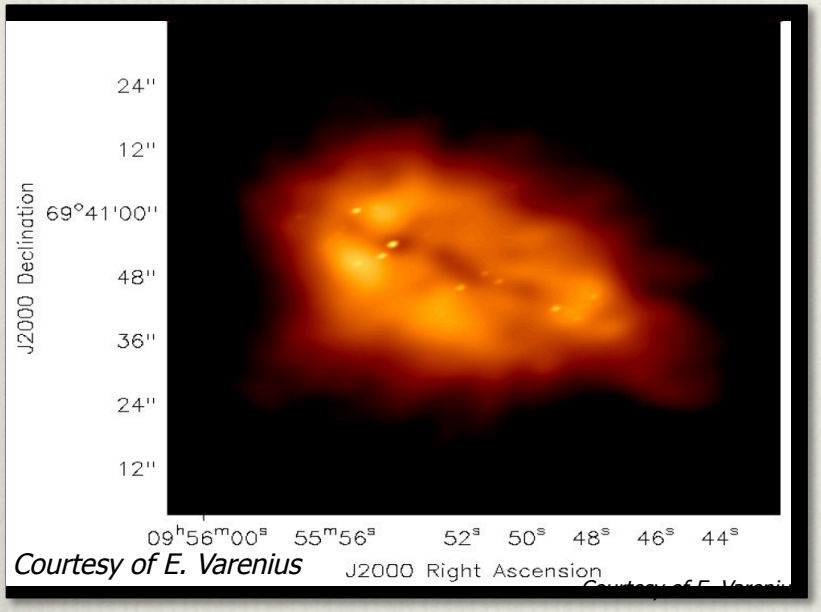
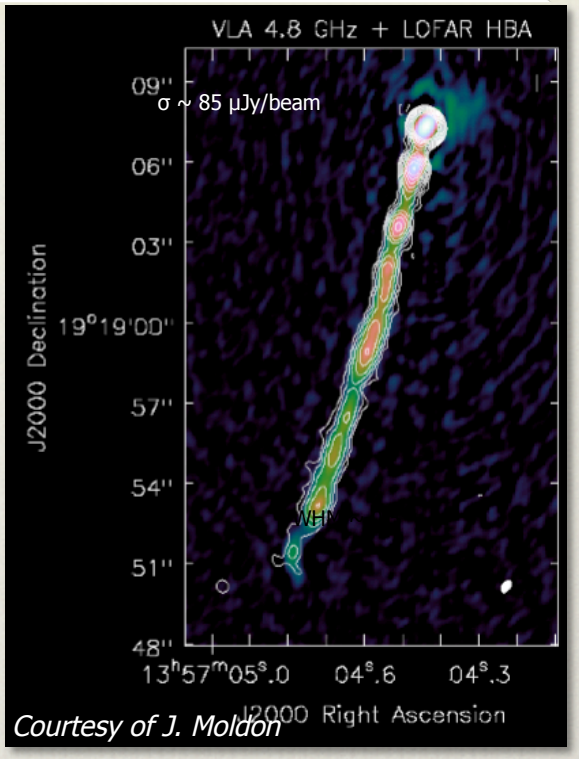


Courtesy of E. Varenius

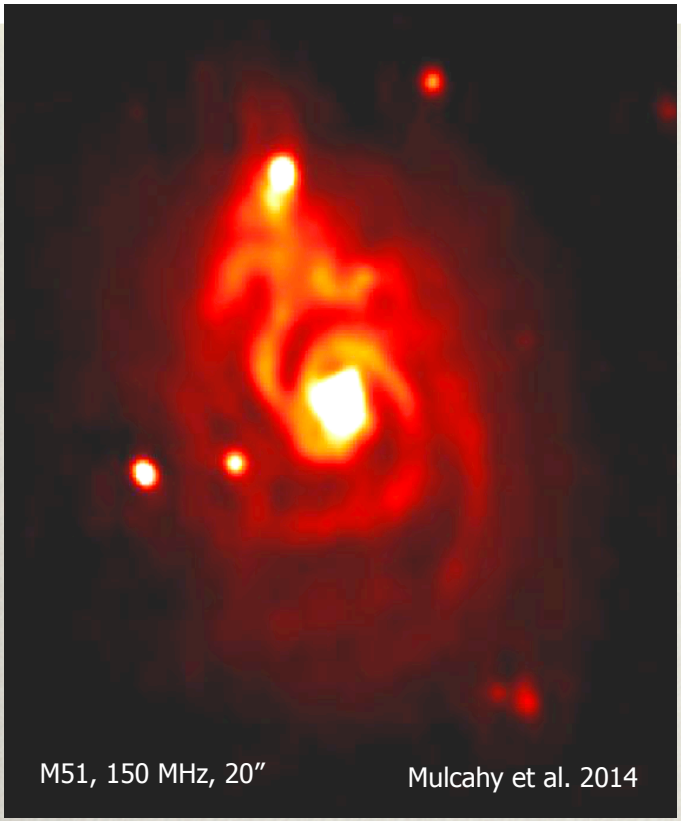
- M82: population of compact Supernova Remnants embedded in diffuse emission
- First weak extended object to be imaged by the full European wide network of LOFAR stations; the resulting image is a new record in terms of image resolution at low frequencies



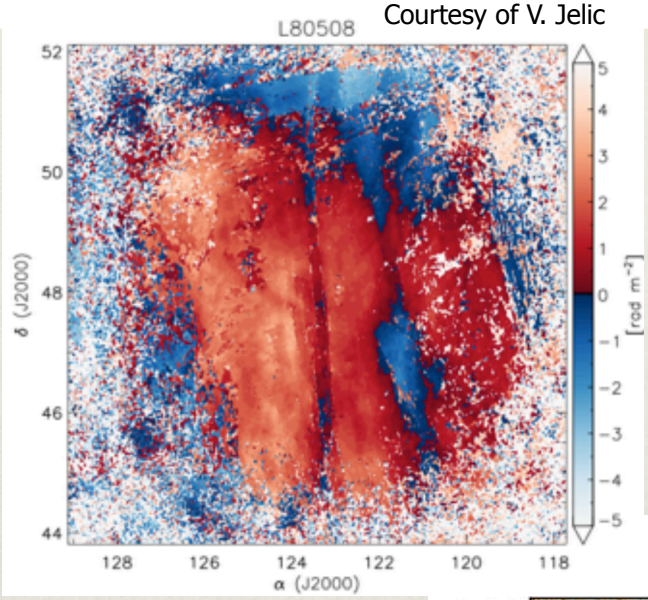
Courtesy of J. Moldon

- 4C19.44: understand the origin of the X-ray emission from quasar jets
- Compatible with a low-energy population of electrons capable of producing the X-ray emission through IC/CMB

COSMIC MAGNETISM

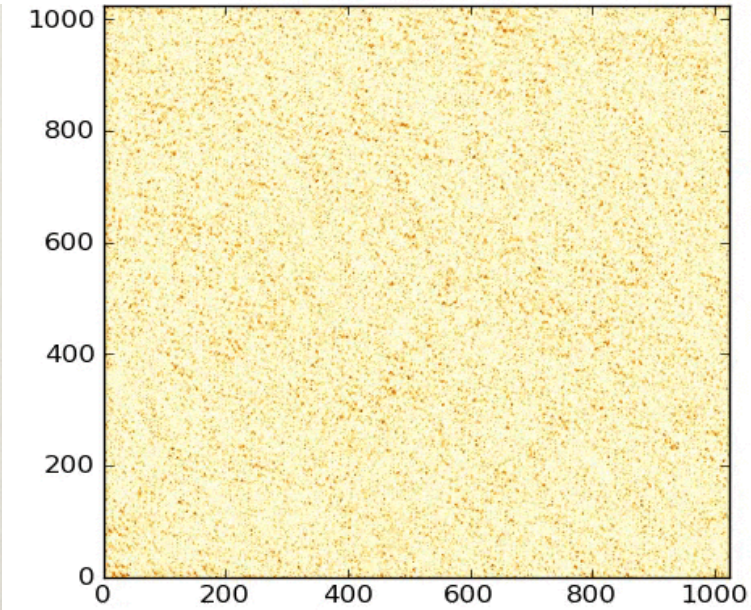


Courtesy of V. Jelic



See talks by
C. van Eck and V. Jelic

Courtesy of M. Iacobelli



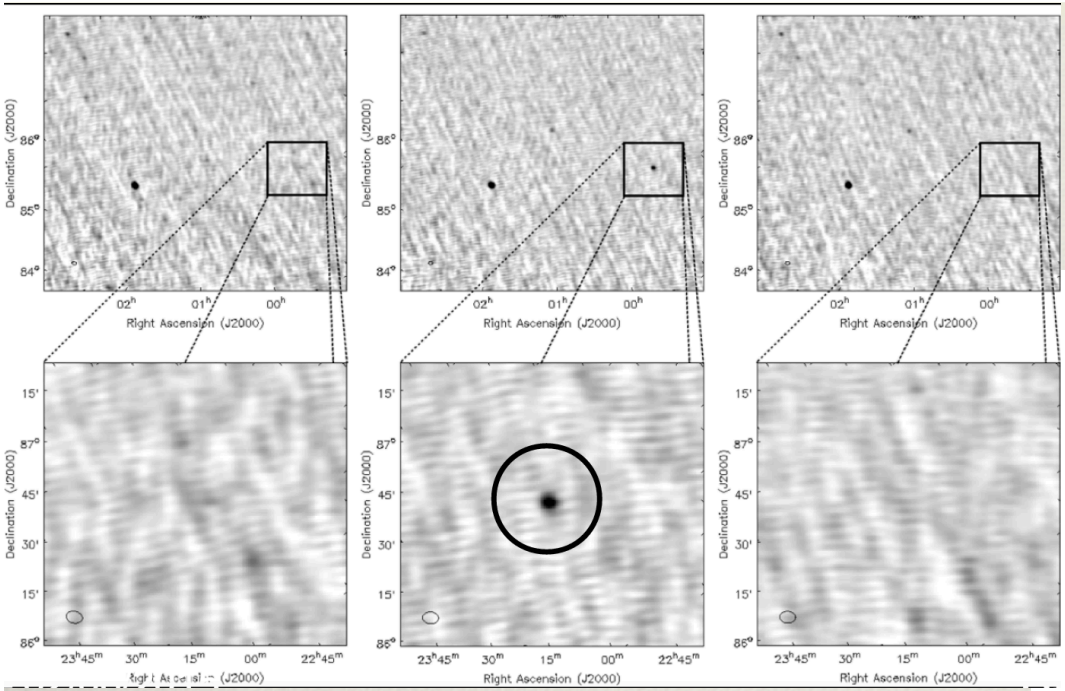
Due to its wide bandwidth at low frequency, LOFAR can:

- Provide info on spectral properties of the synchrotron radiation
- Trace electrons far away from their acceleration sites
- Trace weak magnetic fields through Faraday rotation studies (RM synthesis)

Transients KSP

LOFAR

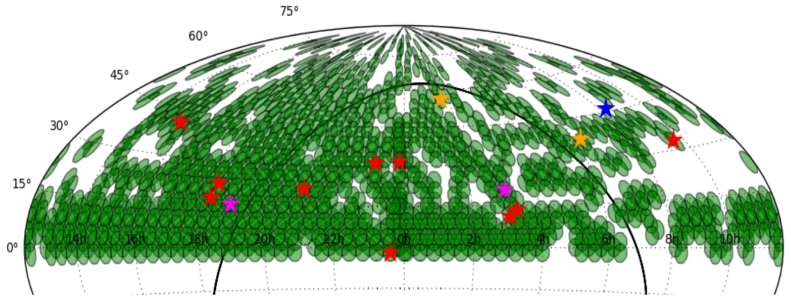
ASTRON

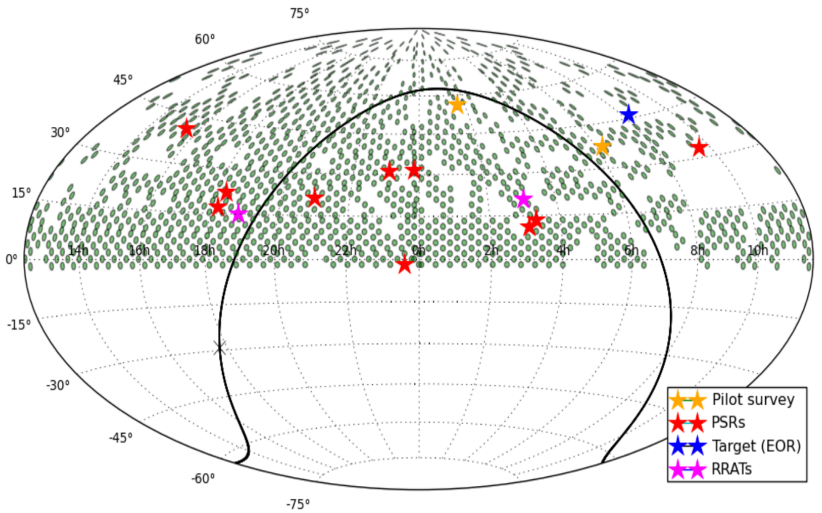


Stewart et al., submitted.

504 h observed

26 new pulsars discovered!





1. Discover exotic pulsar systems to use for testing gravity in the strong-field regime, constraining the physics of dense matter, and probing the pulsar emission mechanism

2. Characterize the low-frequency transient radio sky on sub-second timescales and determine what fraction of radio-emitting neutron stars are transient

See talks by V. Kondratiev, J. v. Leeuwen, D. Michilli, C. Sobey & Poster by S. Sanidas

COSMIC RAY PRECISION COMPOSITION MEASUREMENTS

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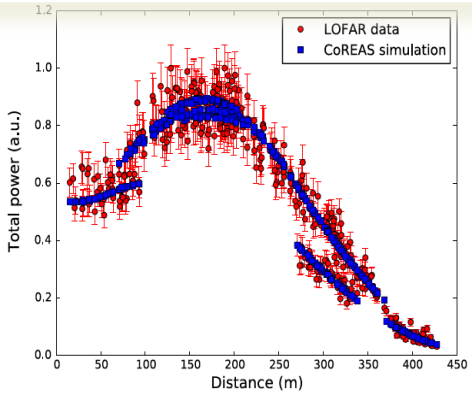
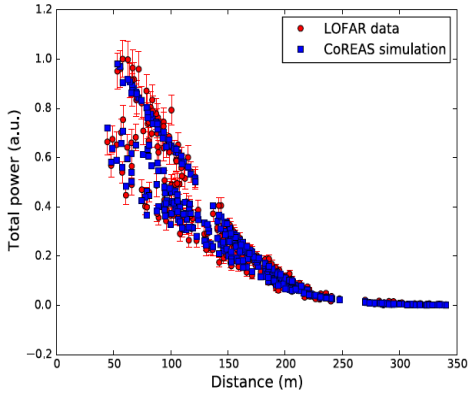
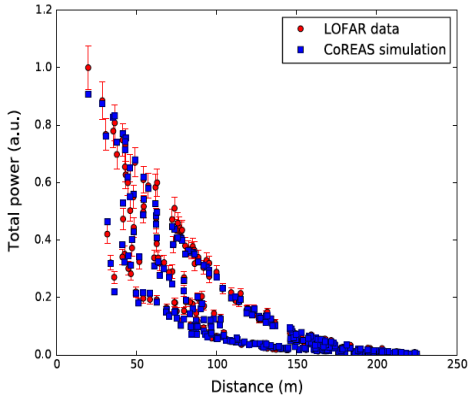
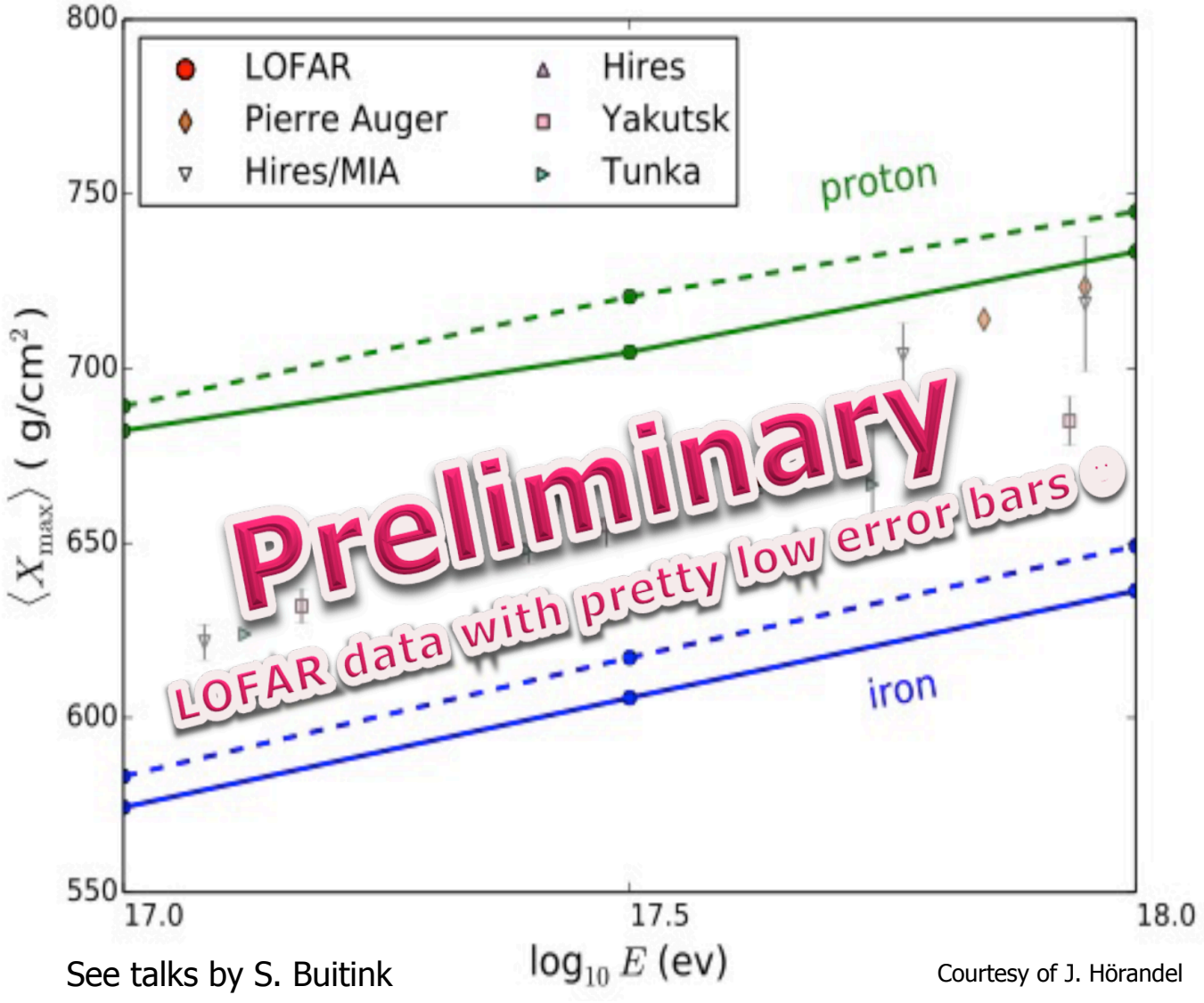






Most precise and probably most accurate CR composition measurements



See talks by S. Buitink

Courtesy of J. Hörandel

THE SUN WITH LOFAR

LOFAR

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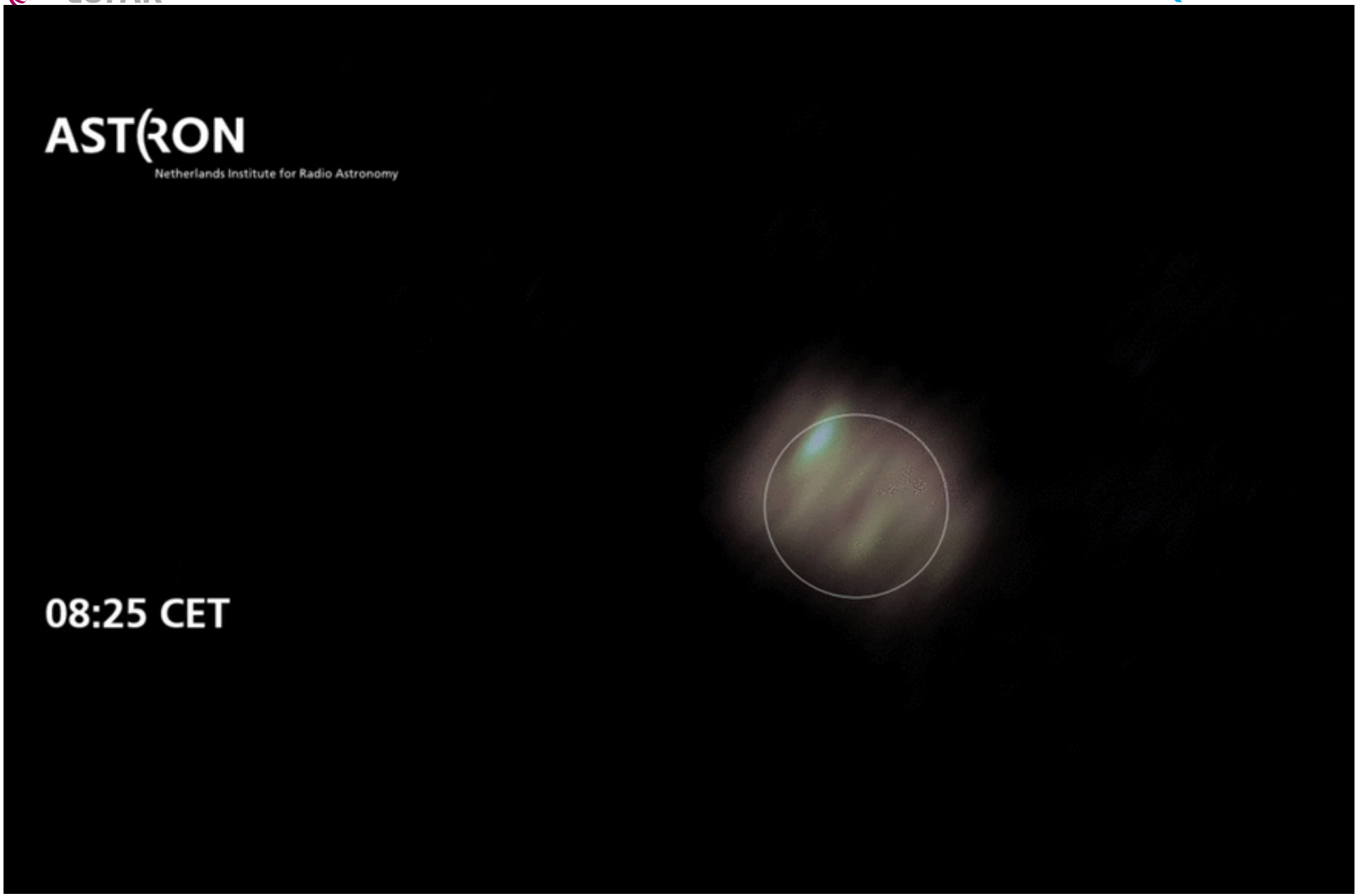

MULTIFREQUENCY SNAPSHOT SKY SURVEY: MSSS

LOFAR

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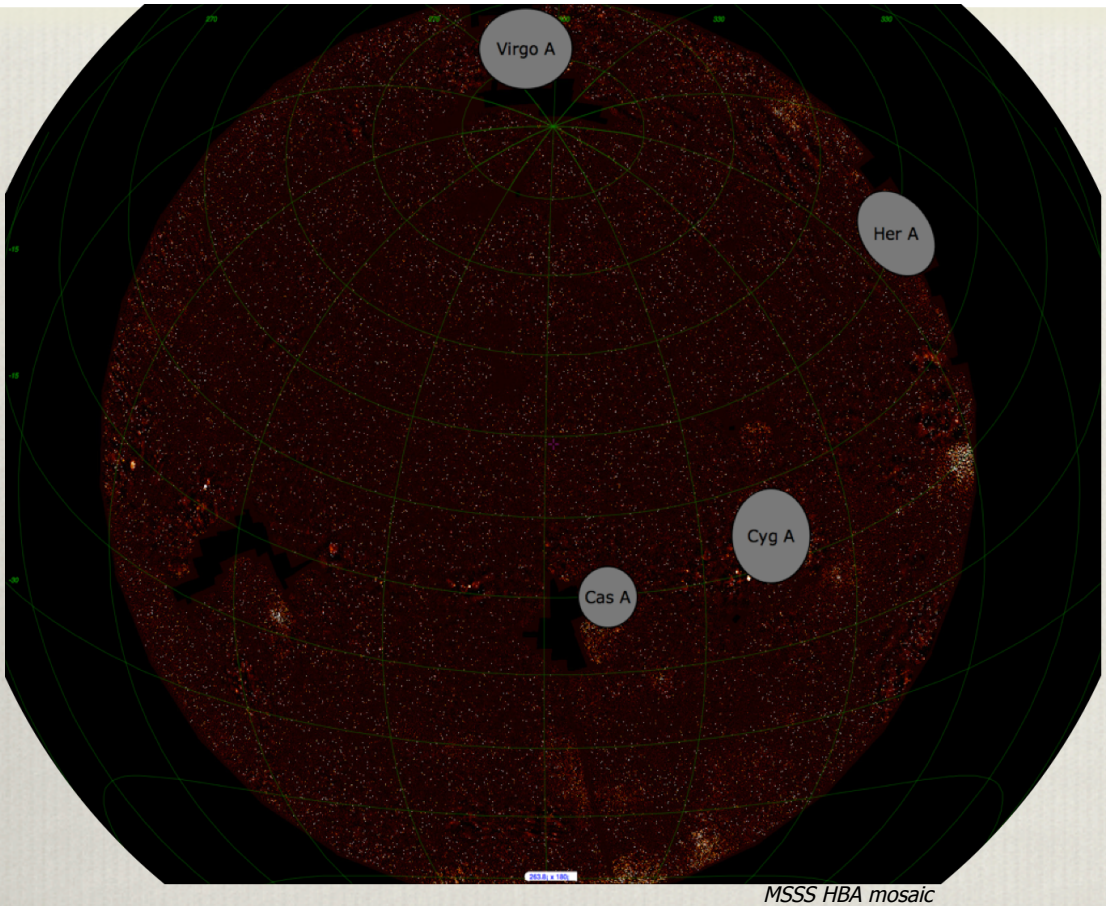
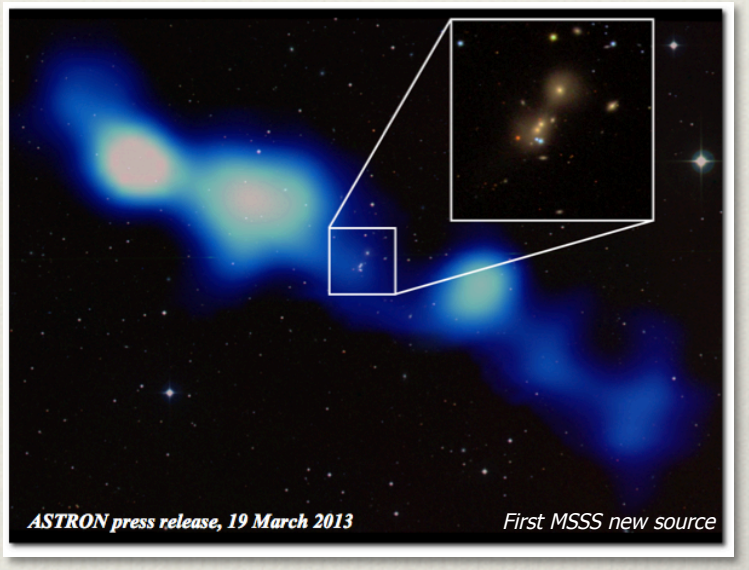
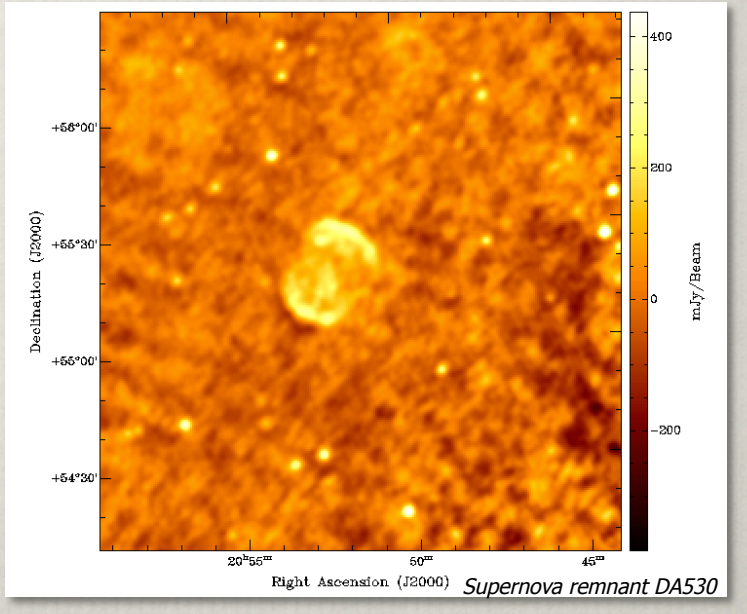


MSSS HBA mosaic





Supernova remnant DA530

- HBA completed
- Initial catalogue to be released soon
- MSSS LBA tests in progress

See talks by G. Heald

SUMMARY

- LOFAR is operational, PBs of data are in the LTA and new data can be continuously produced
- Hardware status of the LOFAR array is excellent
- LOFAR provides several unique scientific capabilities
- New discoveries are there to be made the unexplored territory in frequency and time resolution

LOFAR

The End