LOFAR: CURRENT STATUS, ACHIEVEMENTS, SCIENCE, AND FUTURE PLANS

R. F. Pizzo

ASTRON

Pasadena, December 7th 2016

LOFAR

THE LOW FREQUENCY ARRAY – KEY FACTS

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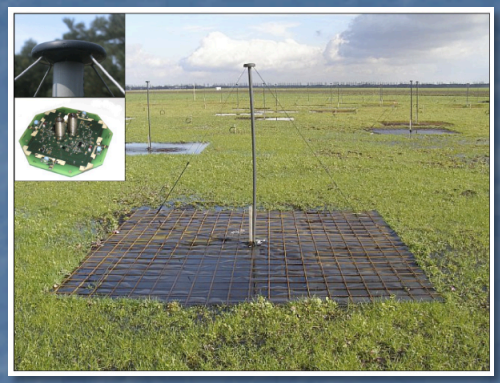
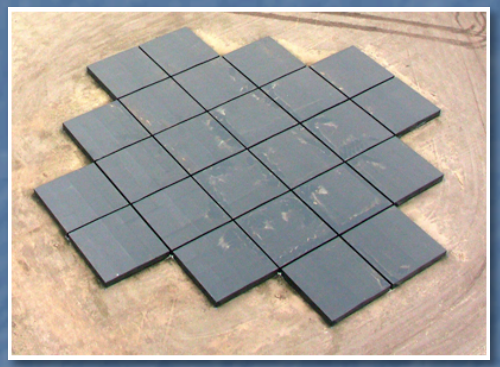
- The International LOFAR telescope (ILT) consists of an interferometric array of dipole antenna stations distributed throughout the Netherlands, Germany, France, UK, Sweden, Poland (~ 50Meuro construction + running costs)
- Operating frequency is 10-250 MHz
- Low band antenna (LBA; 4800 dipole pairs, 96 LBA per station, Area ~ 75200 m^2; 10-90 MHz)
- High Band Antenna (HBA; 47616 dipole pairs, 48/96 tiles per station in NL/EU, Area ~ 57000 m^2; 110-250 MHz)
- Several observing modes (imaging, BF, BF+IM, TBB)
- 96 MHz bandwidth (can be split to perform simultaneous beamforming in different directions)





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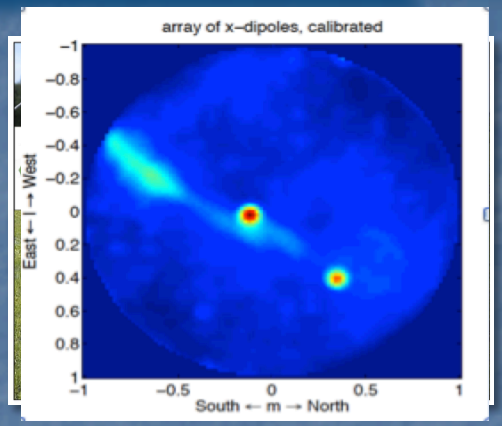

THE LOFAR SYSTEM: DATA FLOW

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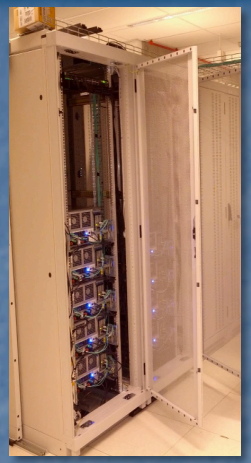
Station signals collected in the station cabinets



Signal sent to COBALT for correlation

CEP4
(IM and BF pipelines)

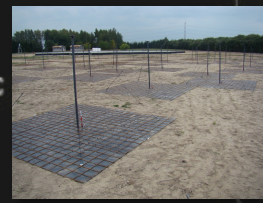
Data sent to CEP4 for initial RO processing

Products sent to the long-term archive (3 sites: NL, D, PL)

AARTFAAC: real-time transient detector

- Data flow from all antennas combined: 1.7 Tbyte/s. To COBALT: 28 Gbyte/s. Data storage challenges: ~ 80 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

International LOFAR Telescope (ILT)



Birr

Onsala

Dutch stations

Chilbolton

Norderstedt

LOFAR Core (NL)

Potsdam

Bałdy

Borówiec

Jülich

Effelsberg

Tautenburg

Łazy

Unterweilenbach

Nançay

- ***Most distant stations 1000 miles apart***
- ***1 new station funded – it will be built in Ireland (IE613) -> 1300 miles across***

NenuFAR: See P. Zarka's talk

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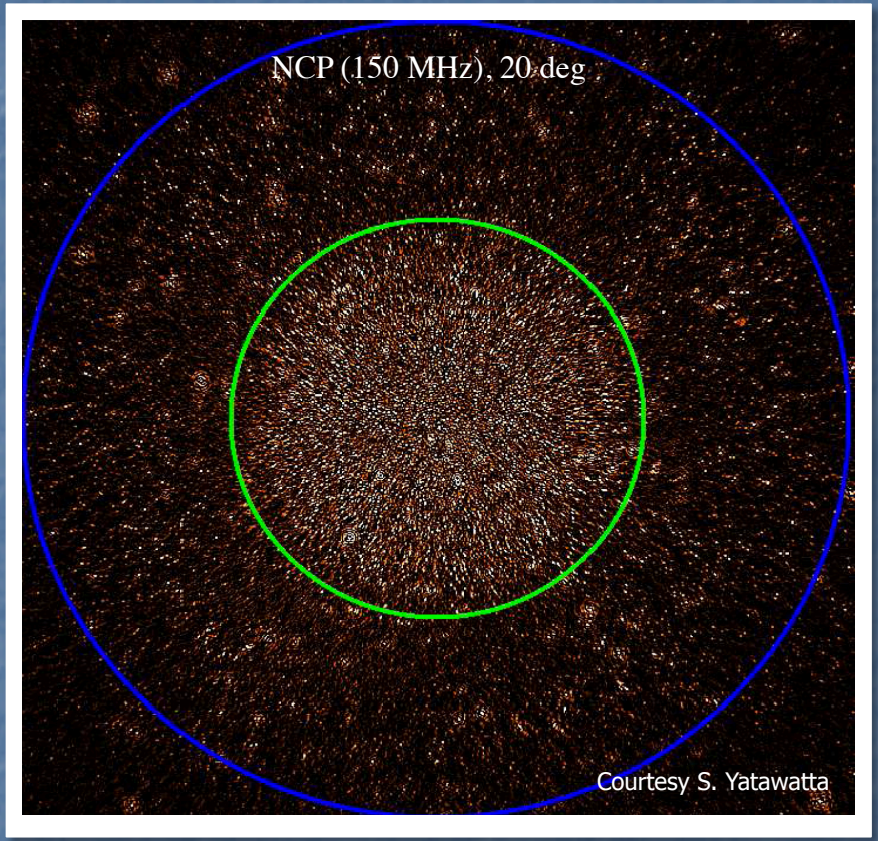
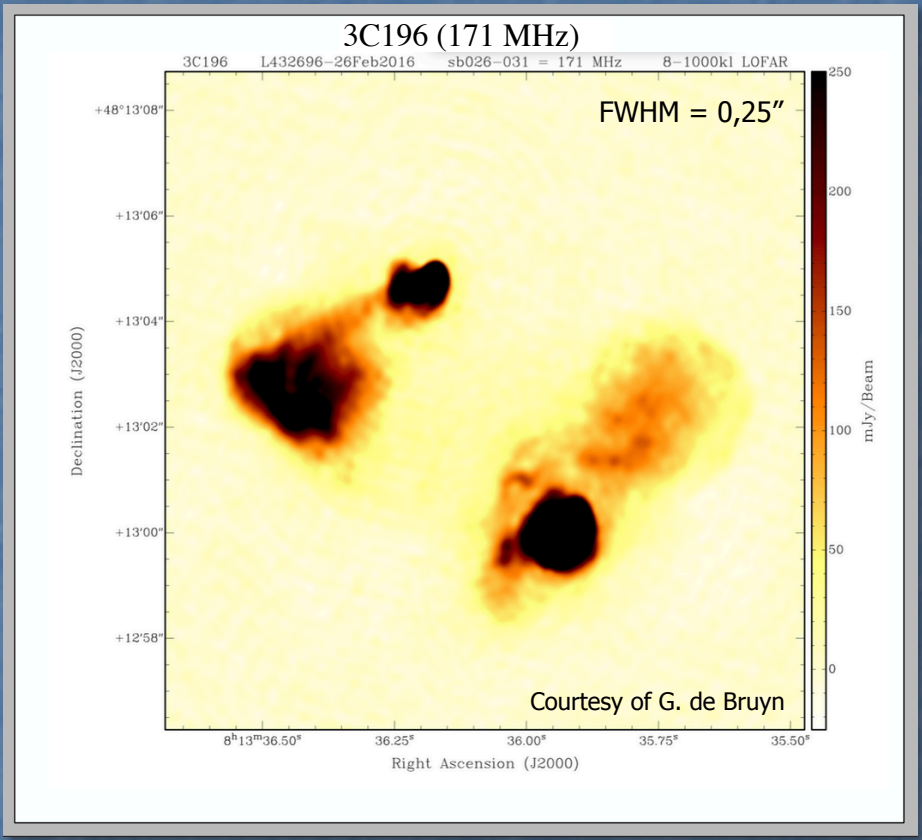
Netherlands Institute for Radio Astronomy

ANGULAR RESOLUTION AND FOV



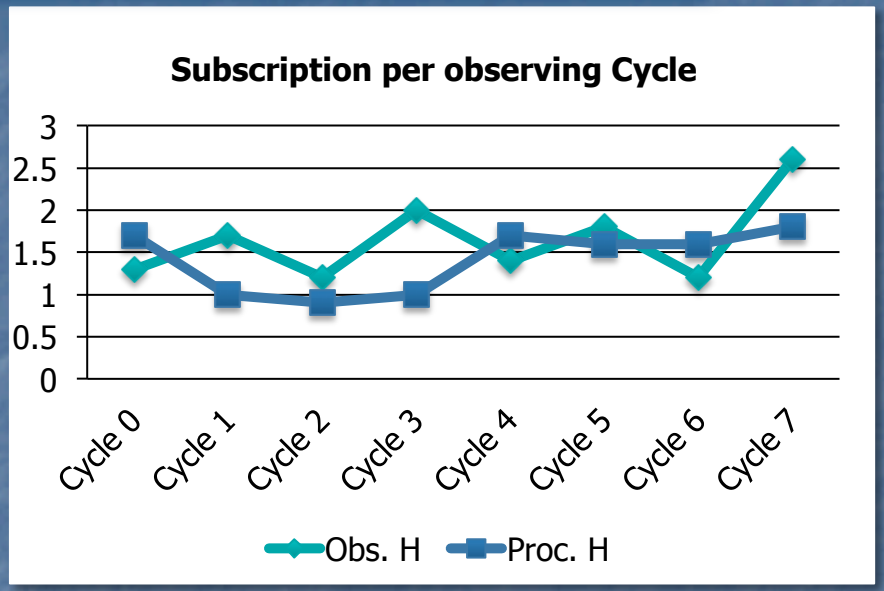


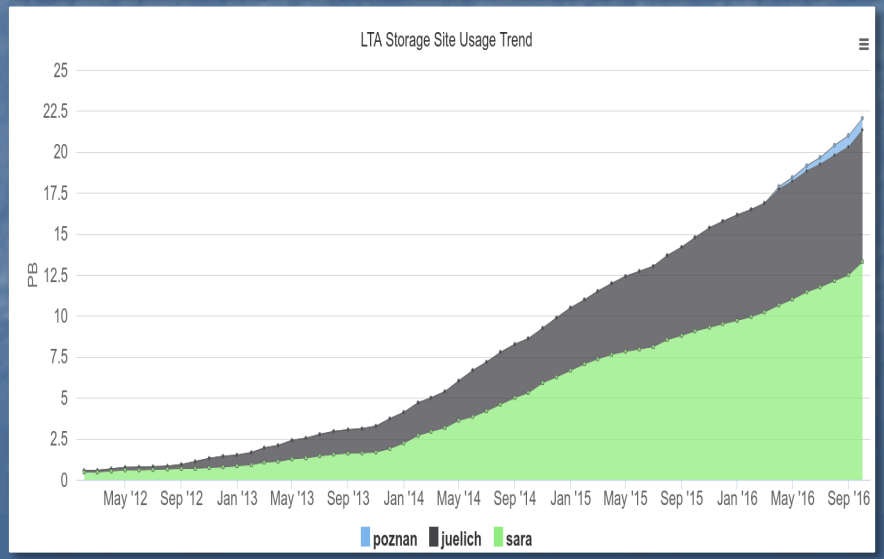
ACHIEVEMENTS

ACHIEVEMENTS…SO FAR

ASTRON

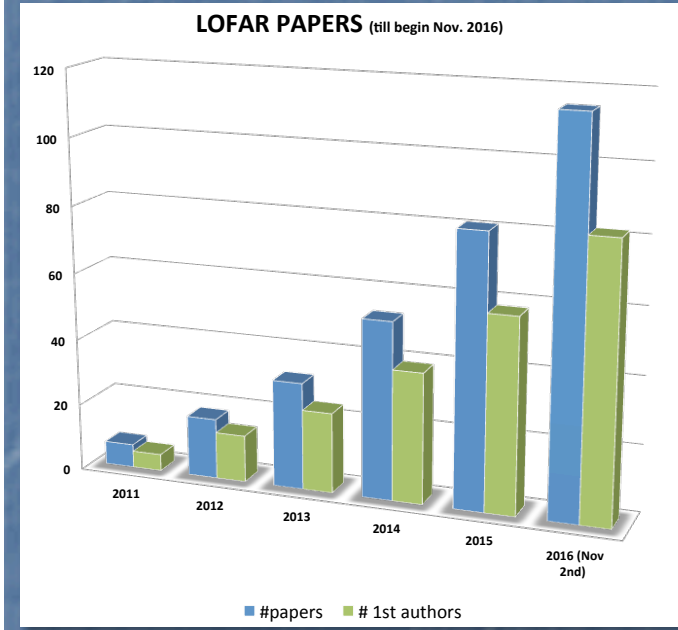
- Completed the 7th operational Cycle
- 13000 hours successfully observed in support to 233 projects
- Ingested > 26 PB (!) of data in the Long-term archive (visibilities, images and BF data) - yearly growth 7 PB/year
- Replaced two operational clusters and a correlator
- Grown the array with more stations, hardware and capabilities
- Brought the instrument closer to our users:
  - LOFAR Schools (200+ participants)
  - 60 Busy Weeks

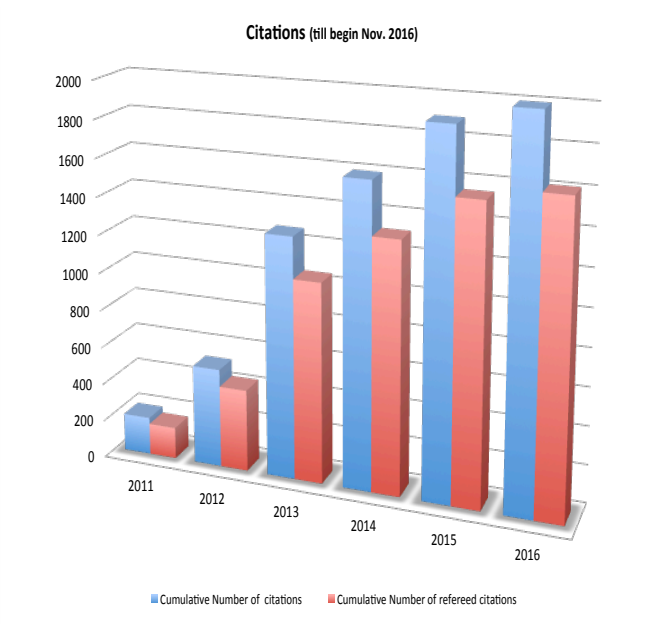


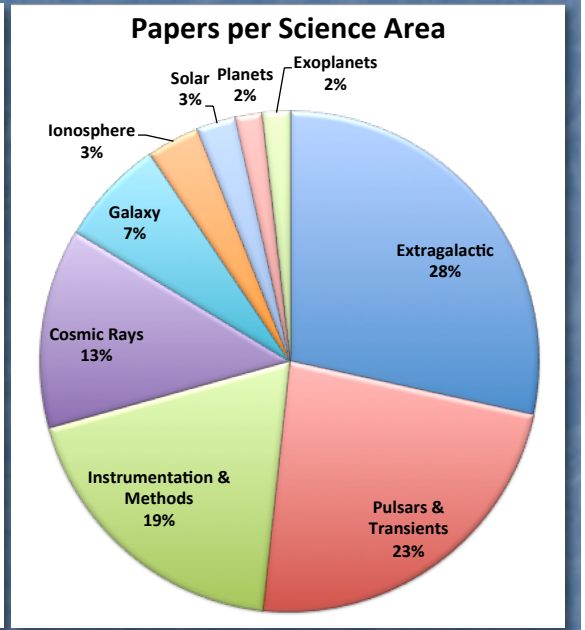


LOFAR SCIENCE OUTPUT

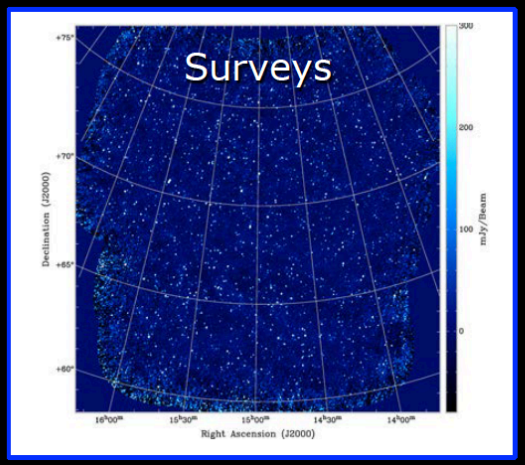
- 115 refereed papers to date

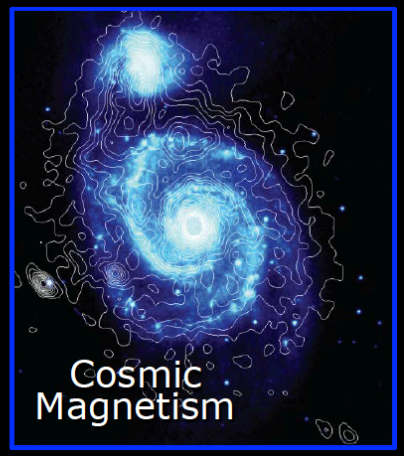


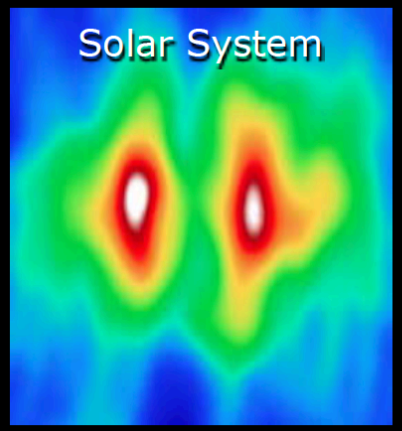


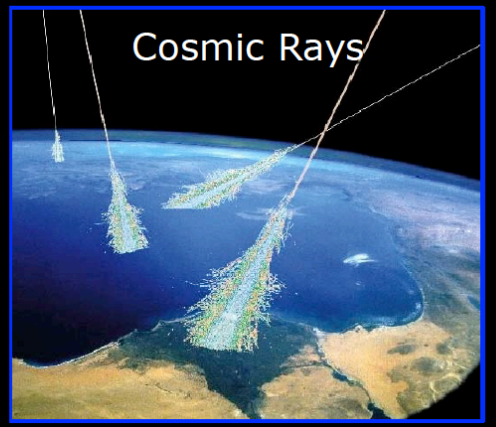


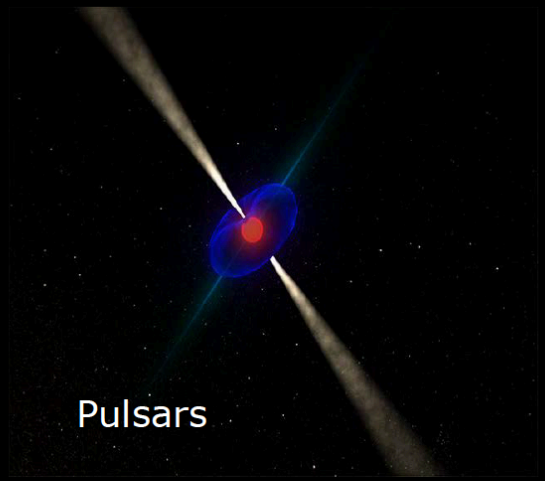
LOFAR KEY SCIENCE PROJECTS

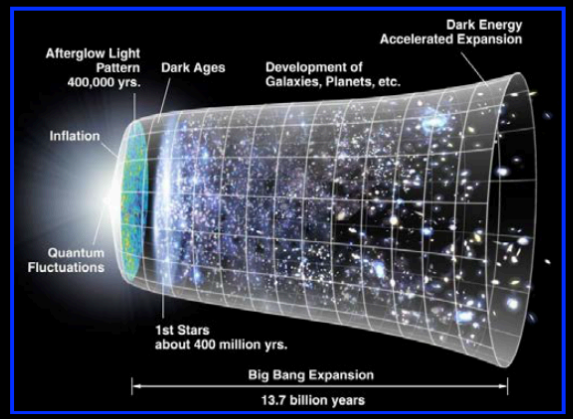






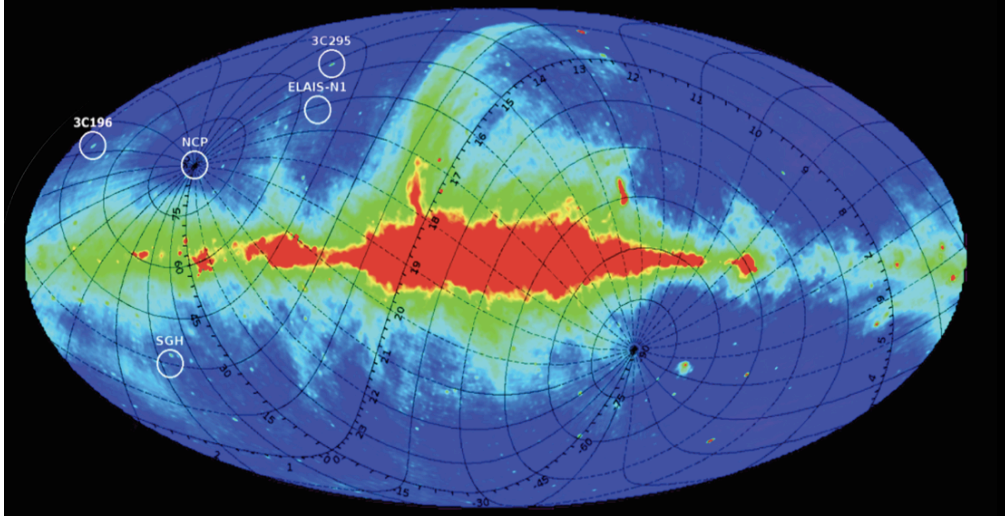


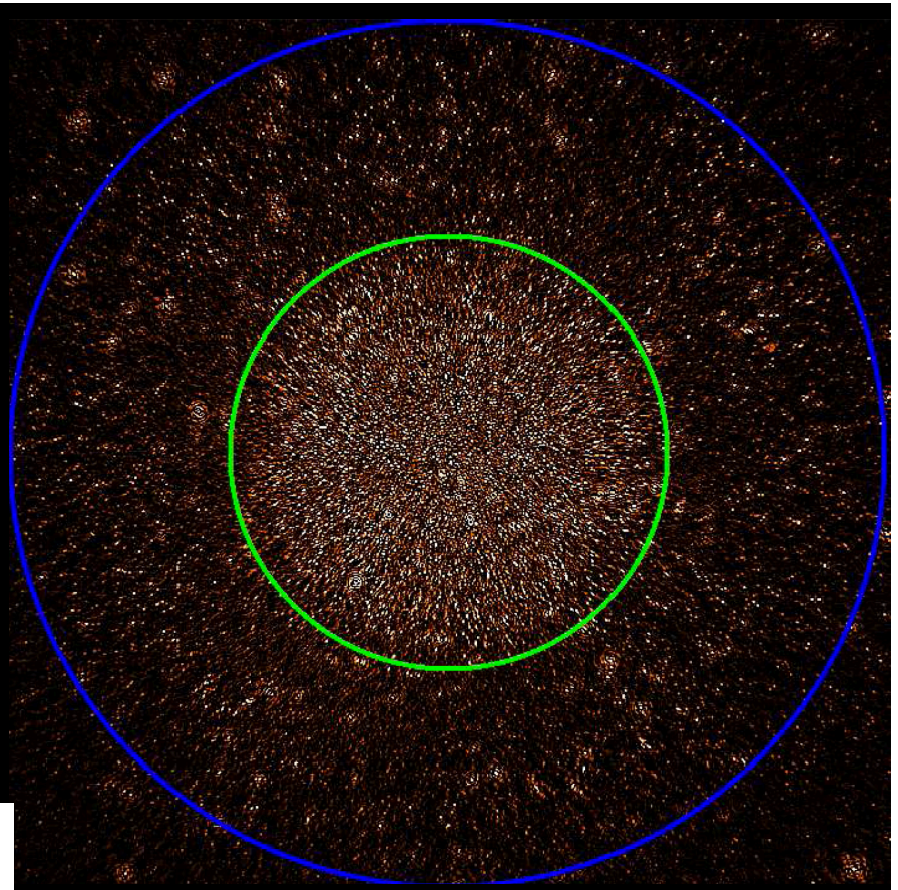




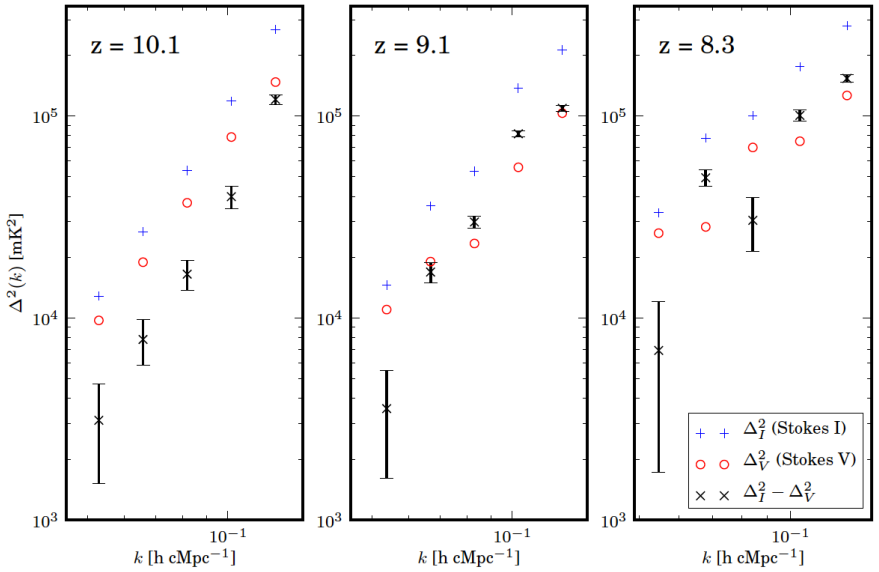
Epoch of Reionization

EOR KSP





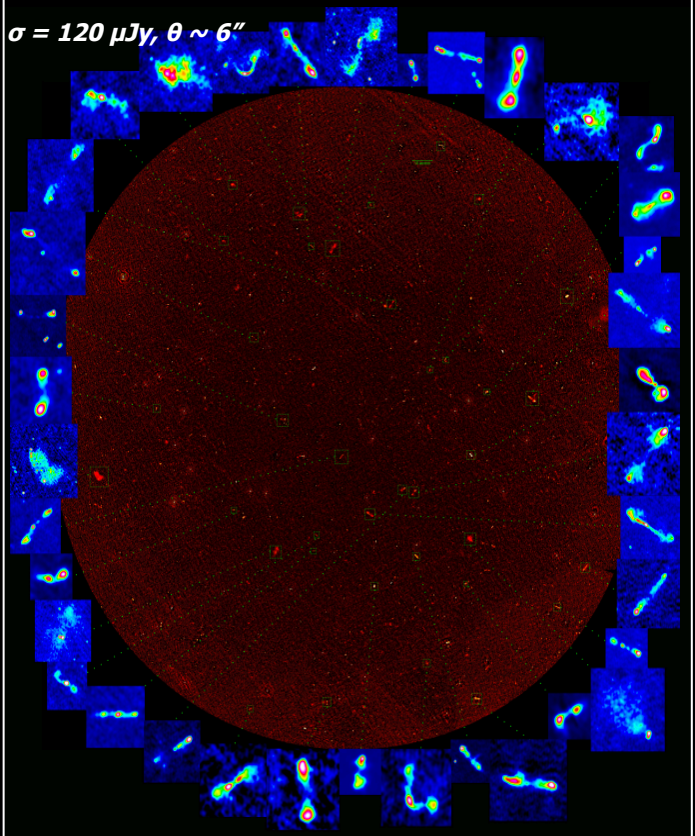
Patil et al. 2016



- Total 2000+ hours allocated
- Focus on 2 distinct fields
- Custom processing on EoR clusters
- Current upper limits based on a 13h NCP night
- Obtained at angular scales of 30–60 arcmin
- In between the upper limits from PAPER (at z=8.4) and MWA (at z=7)
- Detection expected by combining 200 nigths

Bootes field 150 MHz

σ = 120 μJy, θ ~ 6″

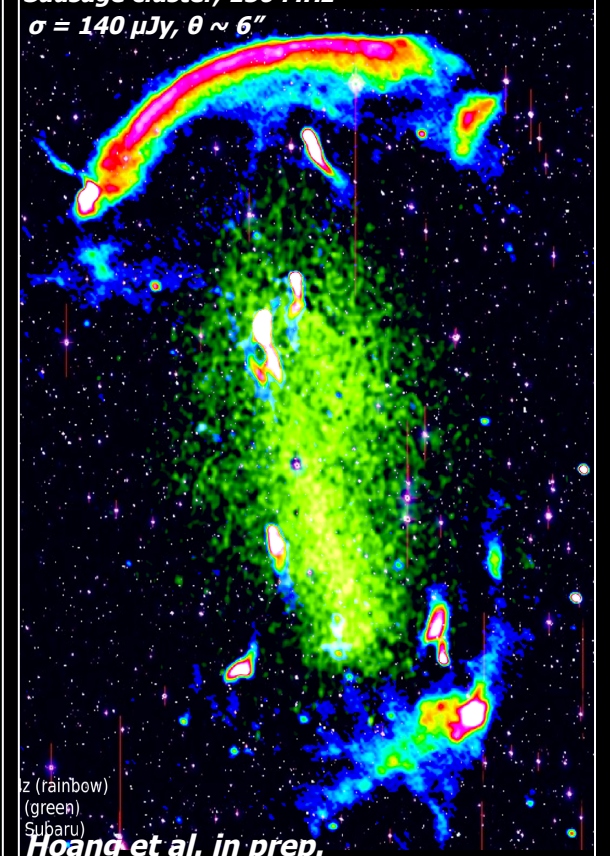


Williams et al. 2016

- *Differential source counts reaching an order of magnitude deeper in flux density than previous studies*

Sausage cluster, 150 MHz

σ = 140 μJy, θ ~ 6″

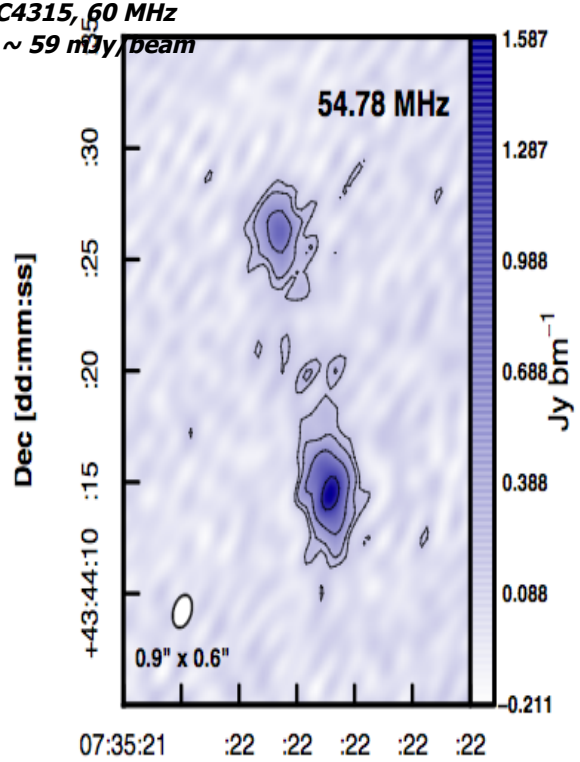


Hoang et al. in prep.

- *Double radio relics*
- *Enables the most precise characterization of a cluster shock ever*

4C4315, 60 MHz

σ ~ 59 mJy/beam

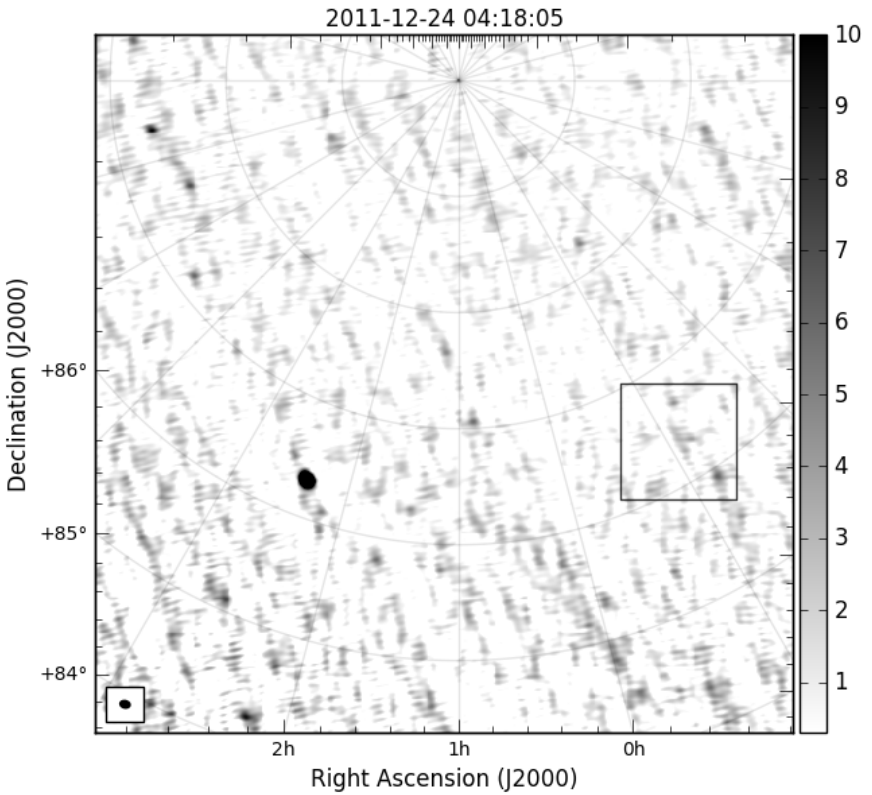


Morabito et al. 2016

- *First spatially resolved studies at frequencies below 100 MHz of high-z radiogalaxy 4C4315*

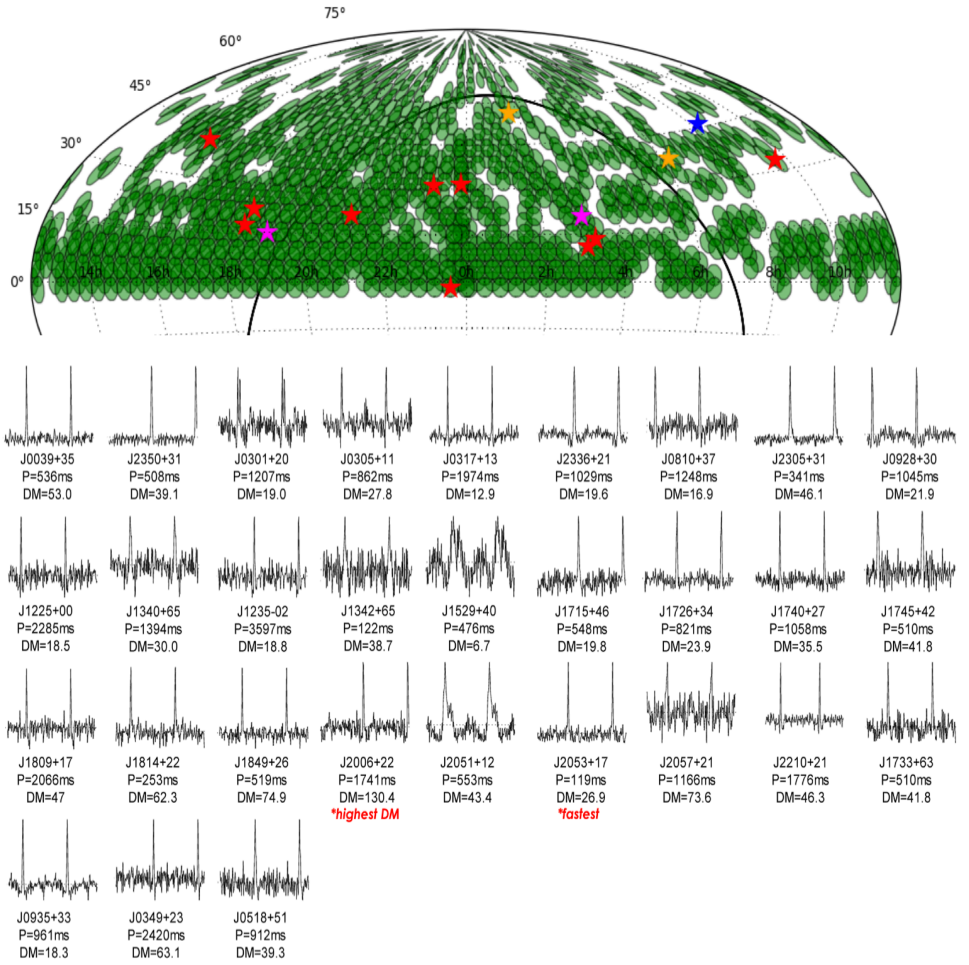
SURVEYS KSP

See talks by H. Rottgering, W. Williams, T. Shimwell, F. de Gasperin,



Stewart et al. 2016

- **Detection of first LOFAR transient event (LBA)**



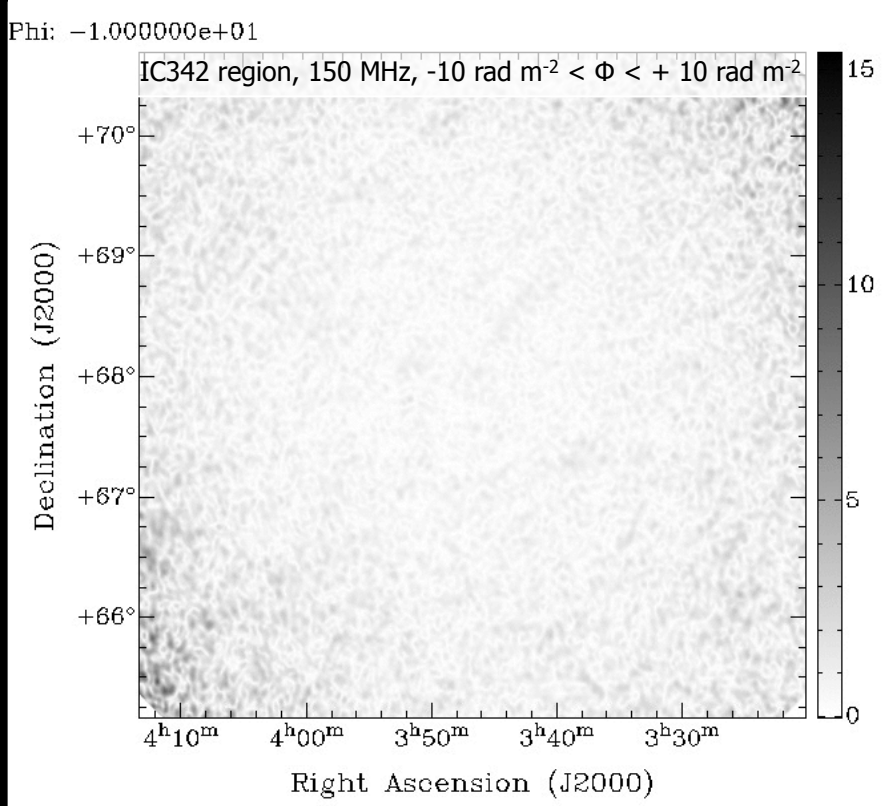
Coenen et al. 2014, Bassa et al. submitted, Hessels et al. in prep, etc…

TRANSIENTS & PULSARS KSP

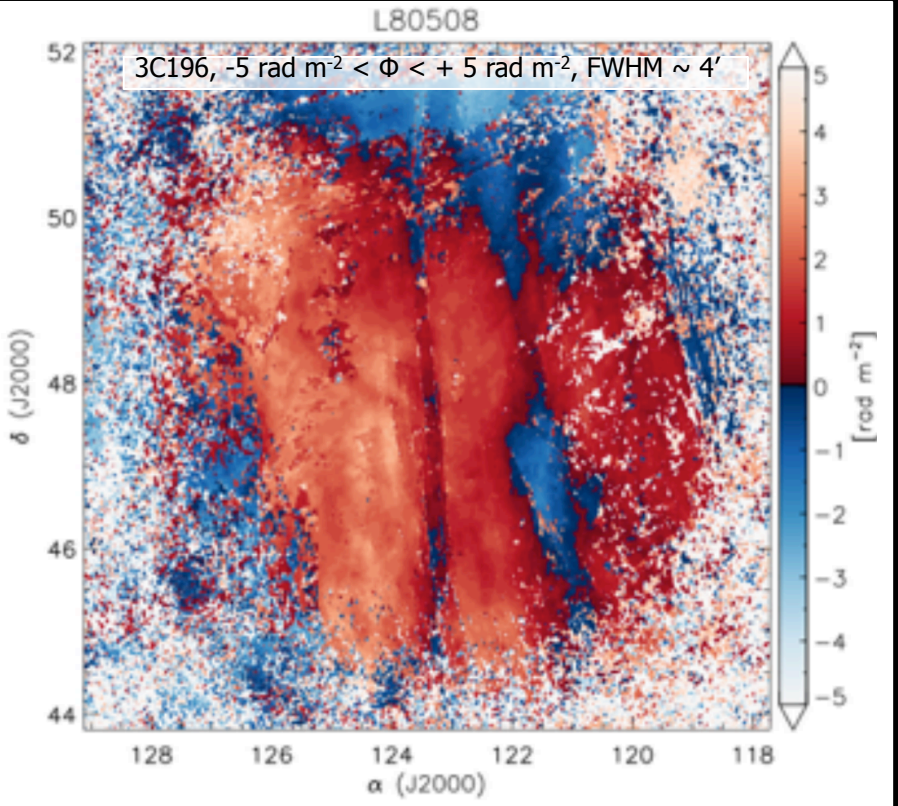
See talks V. Kondratiev, A. Rowlinson

- **LOTAAS – LOFAR Tied Array All-Sky Survey**
- **Deepest low frequency pulsars survey ever performed**
- **49 Pulsars discovered so far**
- **Already the most successful very-low-frequency pulsars survey since the 1970s and has potential to become the most successful of all times**

MAGNETISM KSP



Van Eck et al. in prep.

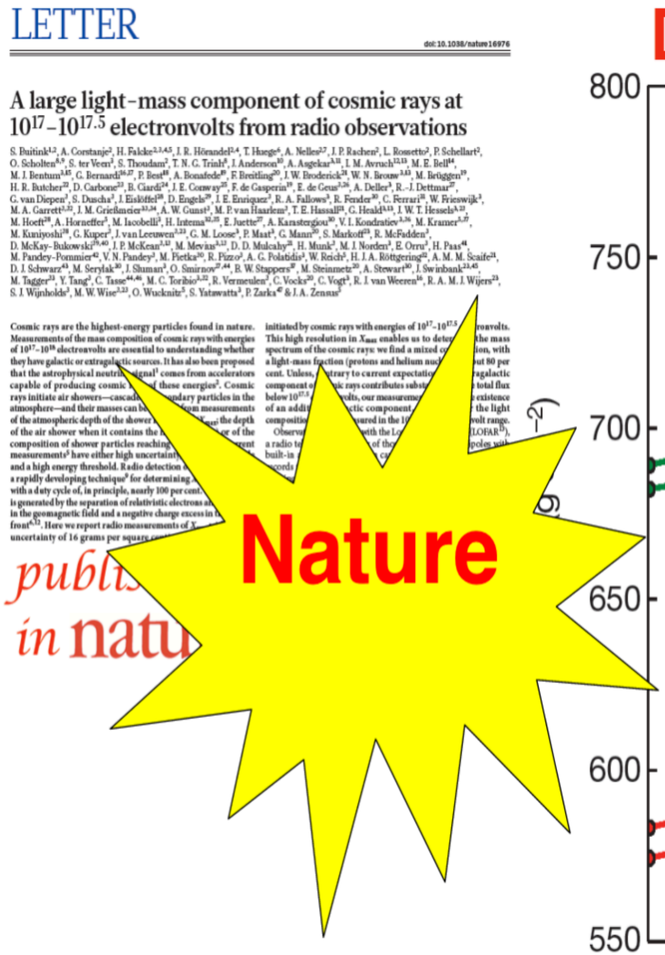


Jelic et al. 2016

- ***Rich morphology of polarized emission detected with LOFAR HBA (115 - 175 MHz)***
- ***Discovery of many filamentary structures and linear depolarization canals (thermal instabilities with anisotropic conduction; trails of stars,...)***
- ***Probed ISM mostly close by (<200 pc), within the Local Bubble***

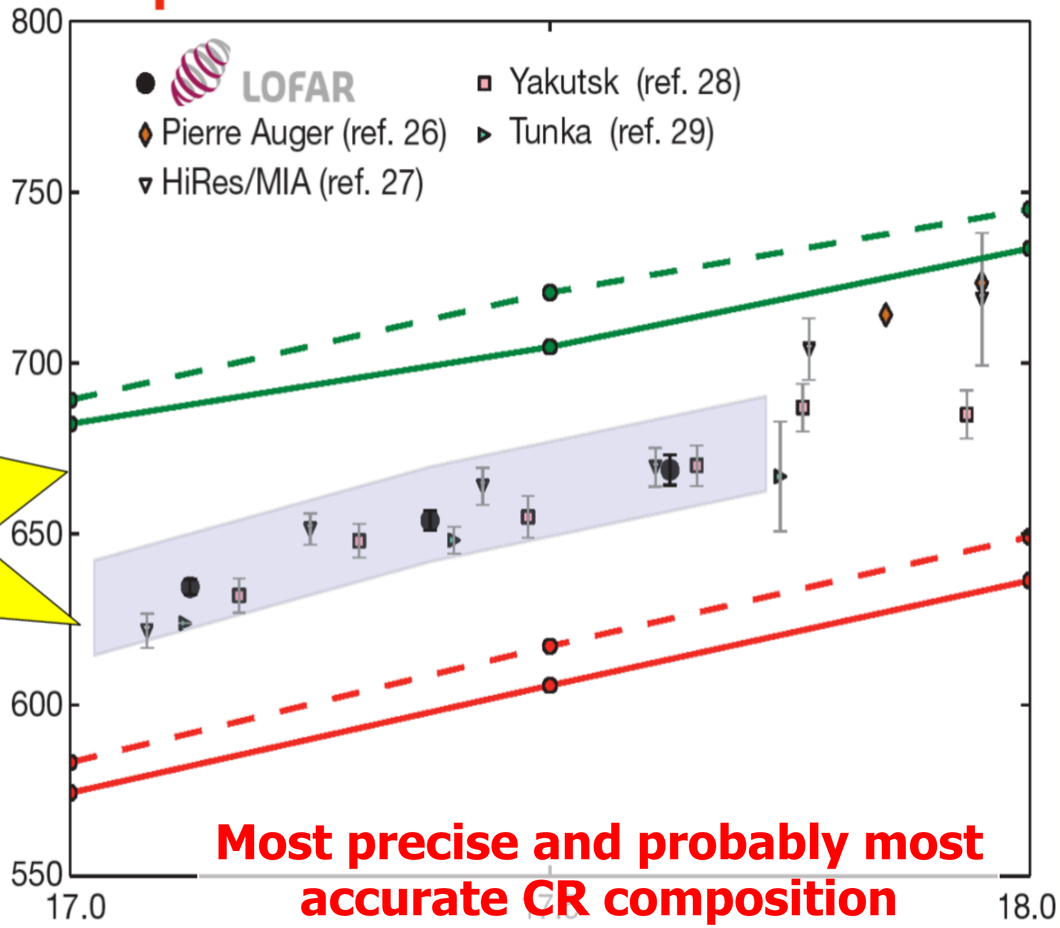
See talk by D. Mulcahy

Detection of Particle Showers from Cosmic Rays



S. Buitink et al., Nature (2016)

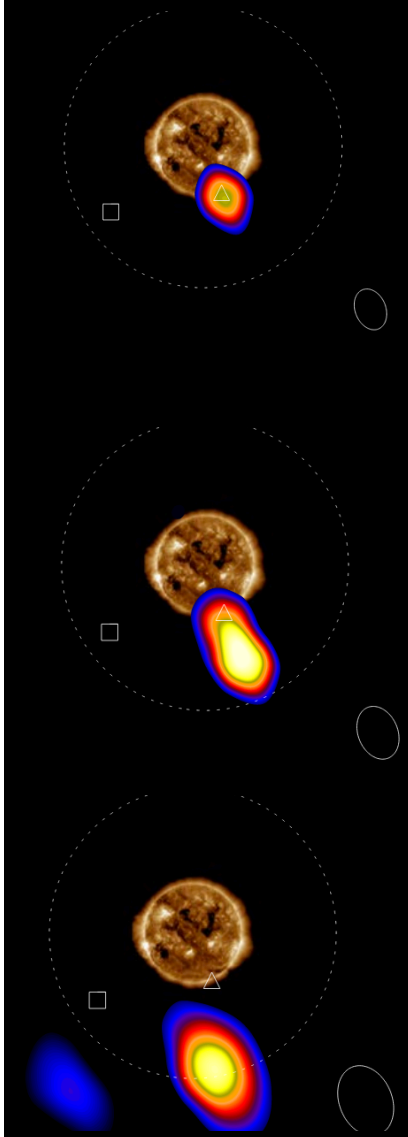
Depth of the shower maximum

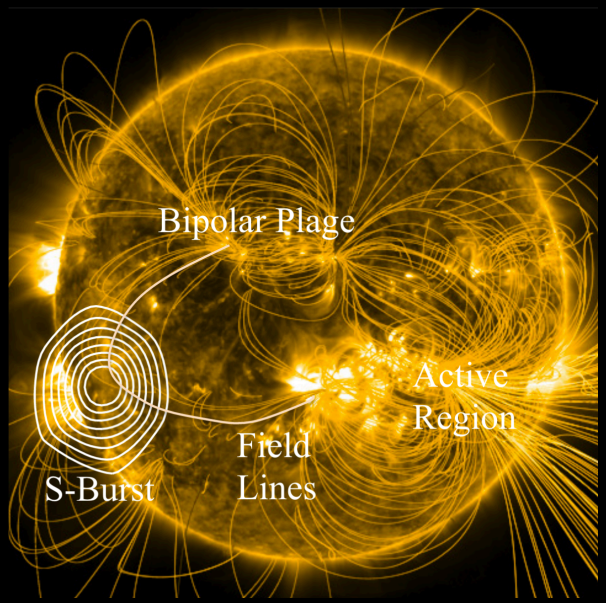


Most precise and probably most accurate CR composition measurements

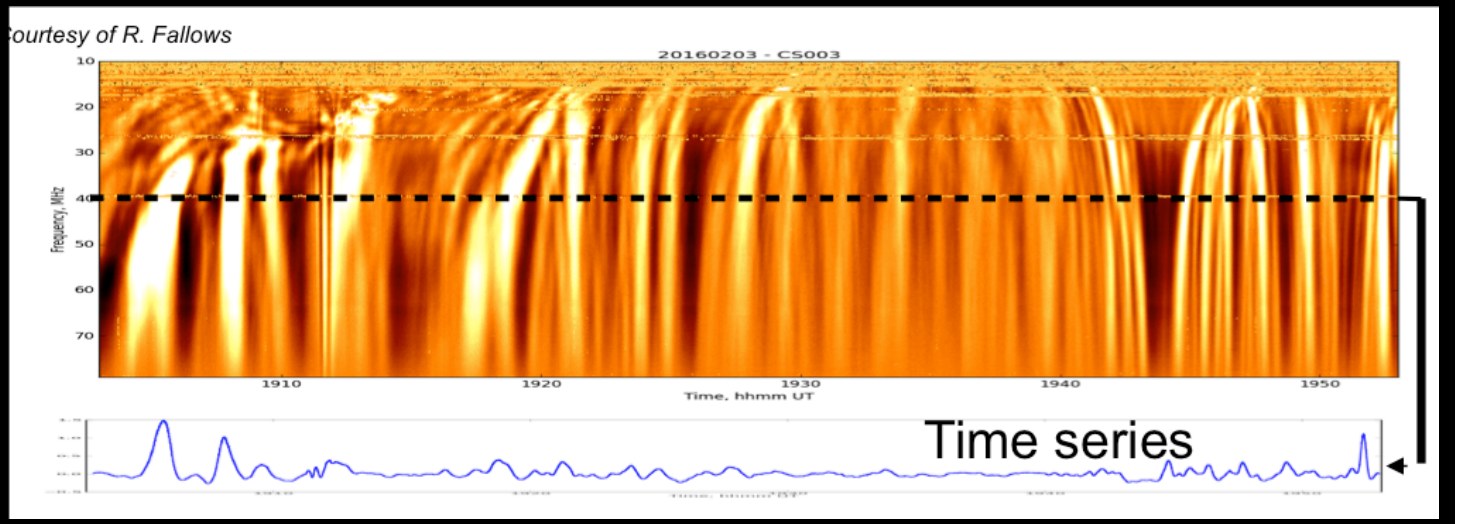
See talk by A. Nelles

SOLAR KSP



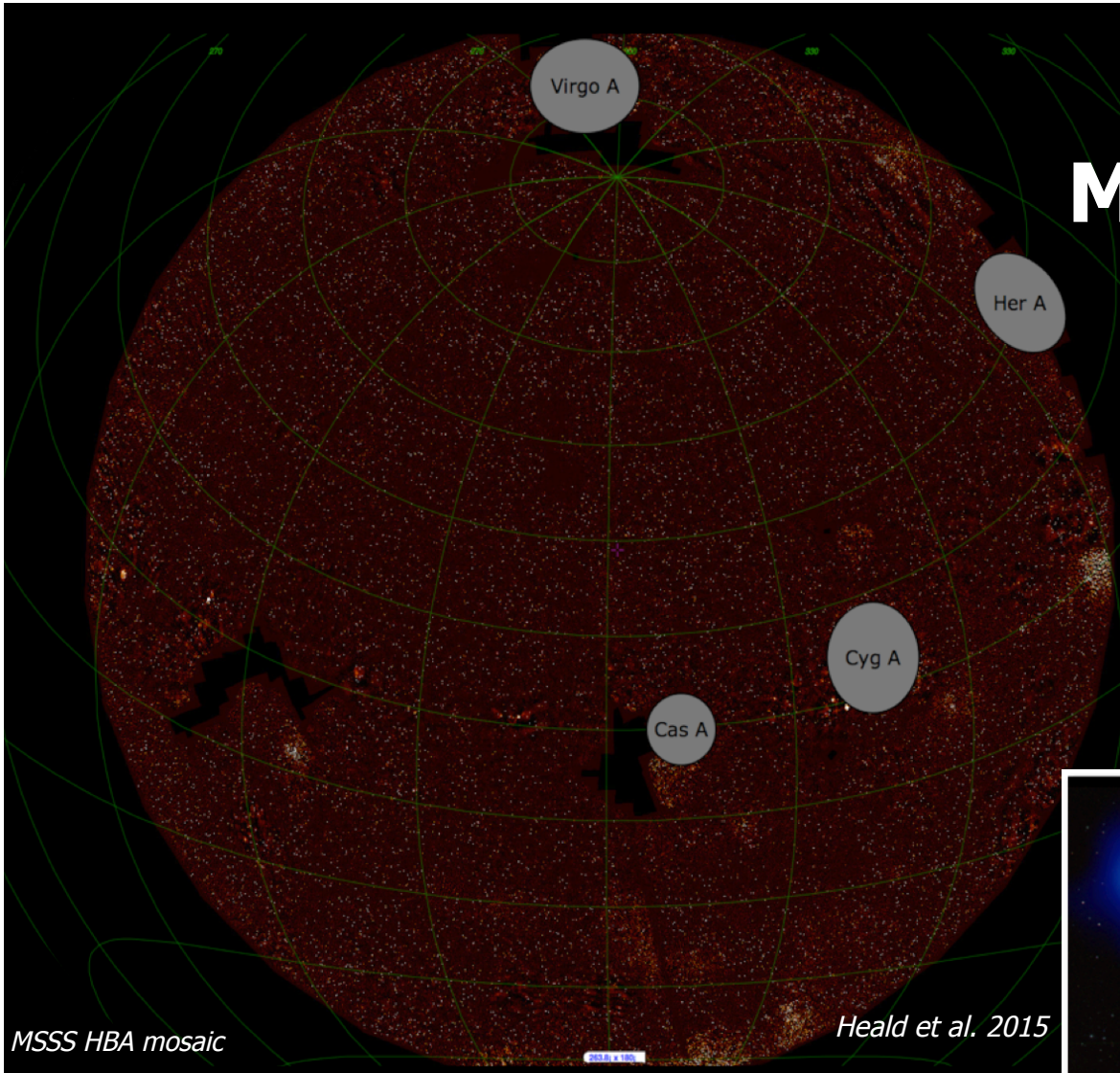


- Several type I-II-III radio bursts detected since 2011 (see e.g. Morosan et al. 2014)
- Solar Wind -> Interplanetary scintillation -> space weather!



Morosan et al. 2014

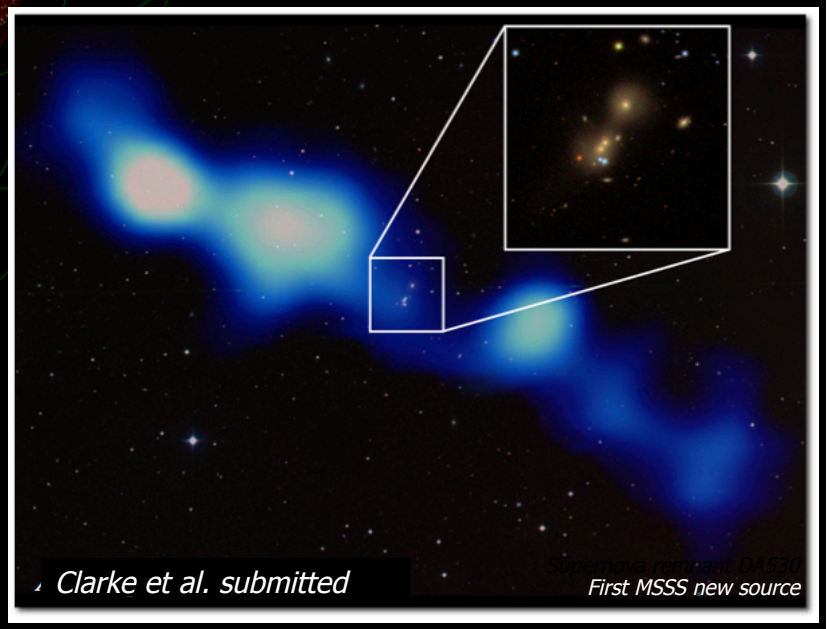
MSSS: MULTIFREQUENCY SNAPSHOT SKY SURVEY



MSSS HBA mosaic

Heald et al. 2015

- HBA completed
- Initial catalogue to be released soon



Clarke et al. submitted

See talks by G. Heald and A. Clarke

FUTURE: LOFAR 2.0

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Expand technical and scientific capabilities of LOFAR: discovering 'Cosmic Dawn' and characterizing 'EoR'; tracing galaxies through cosmic time; cosmic magnetism in nearby universe; serendipity.

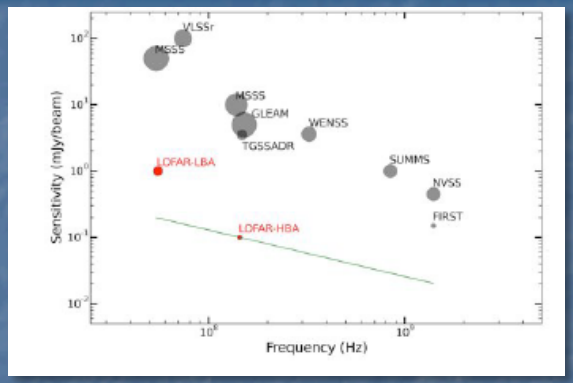
Several options being pursued for the coming 2-10 years – variety of funding sources may be sought

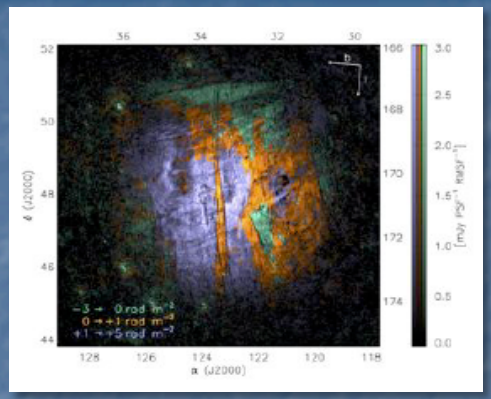
- Enhancement I: *Increase station electronics* -> use all 96 LBAs (for calibration), simultaneous LBA+HBA (for ionospheric calibration and on different fields)
- Enhancement II: *replace LBA dipoles with new design* -> achieve much better response at 30-50 MHz (*will secure LOFAR 2.0 preeminence as the world's best ultra-low-frequency telescope*)
- Enhancement III-IV: *increase the number of Dutch Stations + add international stations*
  - augment 10-100 km baselines – fill uv-holes for deep high dynamic range imaging
  - Fill in Superterp (EoR, extended emission, …)
  - augment 200-1000 km baselines for sub-arcsec imaging

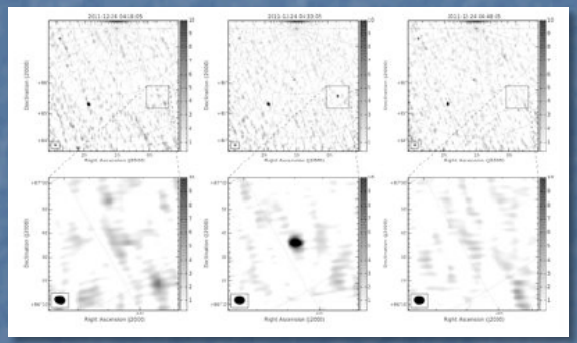
FUTURE: COBALT 2.0

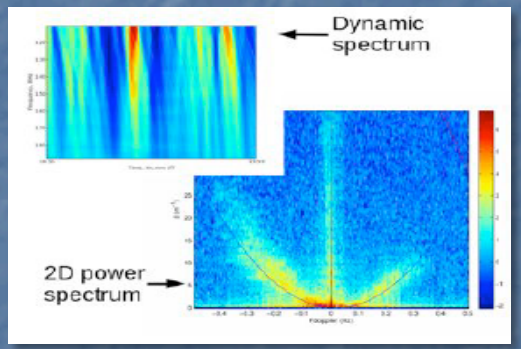
LOFAR

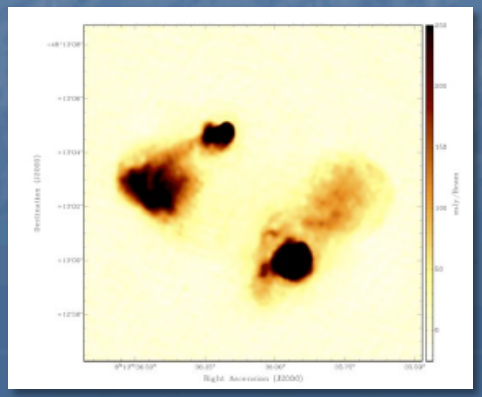
ASTRON

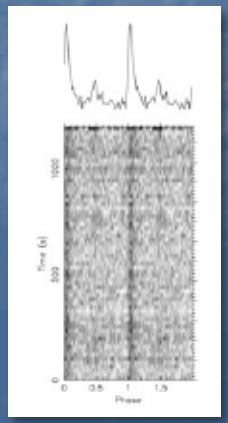












- NWO-M proposal submitted
- Enabling LOFAR Mega-Mode Science case – running IM + BF in parallel in order to get optimal data products for a range of science goals simultaneously
- After a potential go-ahead in February 2017, the new correlator and new mode could be available to scientific users for LC11 – November 2018

THE BROAD IMPACT OF LOW FREQUENCY OBSERVING

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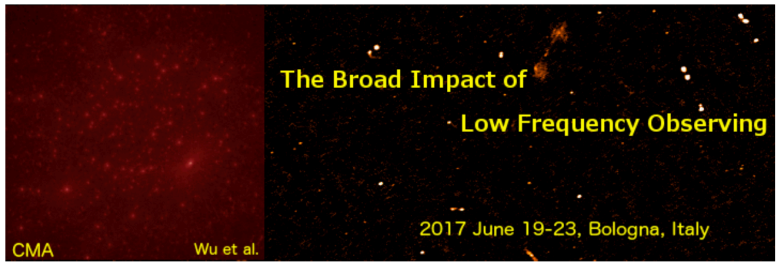

Organizing institutes

ASTRON

LOFAR

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

General information

LOFAR is a cutting-edge, low-frequency, multi-field aperture array telescope that is using transformational technologies and novel software approaches. LOFAR has entered its operational phase in December 2012, and since then is delivering to the WorldWide astronomical community scientific and unique data in the relatively unexplored spectral window below 200 MHz.
A host of other low-frequency facilities, including the MWA, LWA, GMRT, VLITE, PAPER, CHIME, and 21CMA, are also impacting a wide range of research fields. Intensive preparations are under way for the SKA-low.

It is now an appropriate time to review major recent achievements and results at low radio frequencies in their broader scientific context. From 19-23 June 2017, a conference on The Broad Impact of Low Frequency Observing will be held in the attractive Italian city of Bologna, hosted by INAF and in joint organization with support from the International LOFAR Telescope.

Science Conference, 19-23 June 2017

The science conference will explore relevant links to some of the main facilities complementary to LOFAR including ALMA, the VLA, and VLBI networks in the radio, as well as some of the worlds major observatories at other wavebands. There will be invited as well as contributed talks and posters. Participants will obtain a good overview of the versatility and state-of-the-art technical capabilities available at low frequencies, and of the planned upgrades to LOFAR and the other current facilities, looking ahead also to how these will complement the SKA-low in the years to come.

The fourth LOFAR Users Meeting, 23 June 2017

On Friday afternoon 23 June, staff from the ASTRON Radio Observatory will host the fourth LOFAR users meeting. This meeting is aimed at wide-ranging dialogue with the full LOFAR community, and is intended to bring together members of the Key Science Projects (KSPs), researchers with approved LOFAR projects, as well as any potential LOFAR users. ASTRON RO staff will demonstrate the current status of the LOFAR instrument and summarize plans for future development of software and procedures. For the users, this meeting represents an important forum for discussion, where they will have the opportunity to give their feedback on LOFAR operations and development, and highlight, when required, the need for improvement or change.

Attendance from all LOFAR users is highly encouraged. The meeting will take place on Friday 23 June from 14:00-18:30.

- 19 – 23 June 2017
- Bologna, Italy
- Explore relevant links to some of the main facilities complementary to LOFAR including ALMA, the VLA, and VLBI networks in the radio, as well as some of the worlds major observatories at other wavebands
- 2nd announcement soon

THANKS !