

The LOFAR Two-metre Sky Survey (LoTSS)

Timothy Shimwell and the LoTSS team

Leiden University



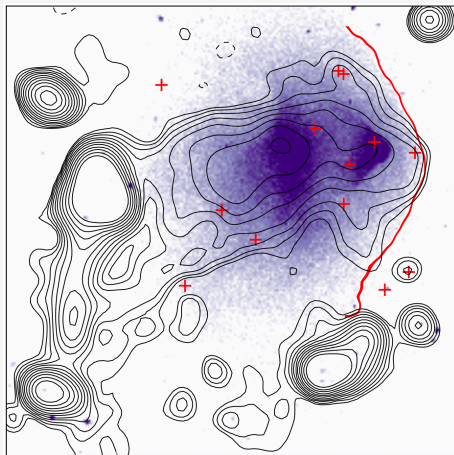
Outline

- 1 Radio emission associated with galaxy clusters
- 2 The LOFAR Two-metre Sky Survey (LoTSS)
- 3 Clusters in LoTSS
- 4 Conclusions

Radio emission from galaxy clusters – radio halos

Diffuse radio emission is confirmed in ≈ 70 merging clusters implying relativistic electrons and magnetic fields distributed on Mpc-scales.

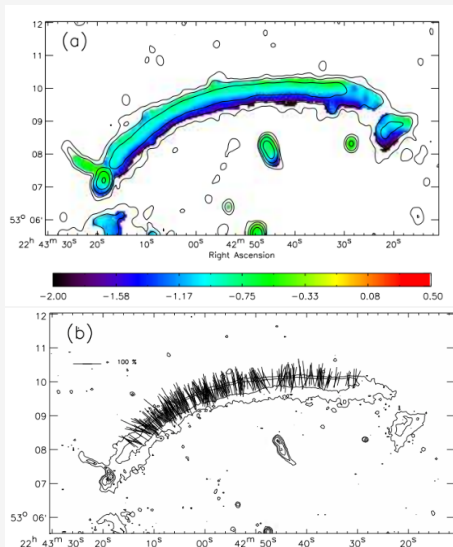
- shocks and turbulence cause cluster wide (re)acceleration of electrons.
- the injection of relativistic electrons from collisions between relativistic and thermal protons.



The bullet cluster radio halo overlaid on X-ray emission – Shimwell et al. 2014.

Radio emission from galaxy clusters

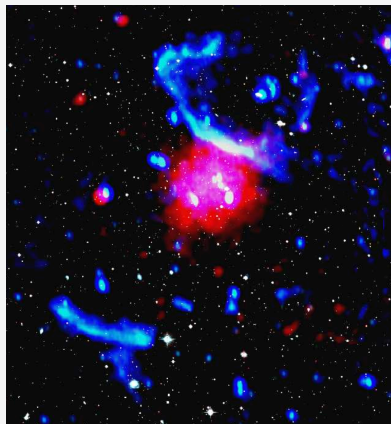
- Diffuse emission at the outskirts of a cluster is known as a radio relic.
- Relics have been confirmed in ≈ 50 clusters.
- They are thought to be formed by shocks accelerating particles and compressing the cluster magnetic field.



The Sausage relic – van Weeren et al. 2010

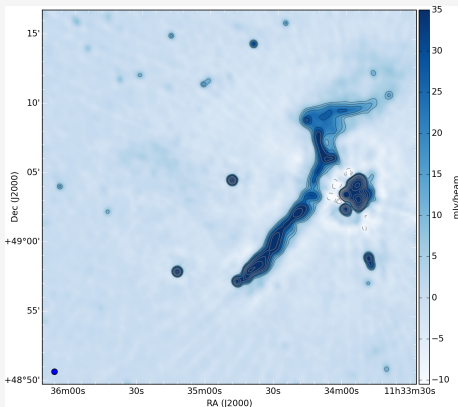
Radio emission from galaxy clusters: some unusual properties

- No shock at relic in ZcCL 2341.1+000 – Ogrean et al. 2014
- Links with relics and radio sources – Ensslin et al. 1998, Bonafeda et al. 2014 and Shimwell et al. 2015
- In Cl1821+643 giant halo in cool core cluster – Bonafeda et al. 2014
- In Abell 2146 clear merging cluster with no detected halo – Russell et al. 2011



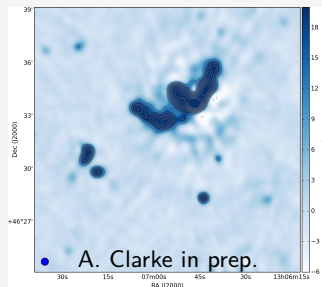
Reacceleration at a relic? – Bonafede et al. 2014

Beyond relics and halos



LoTSS image of the tailed galaxy in Abell 1314

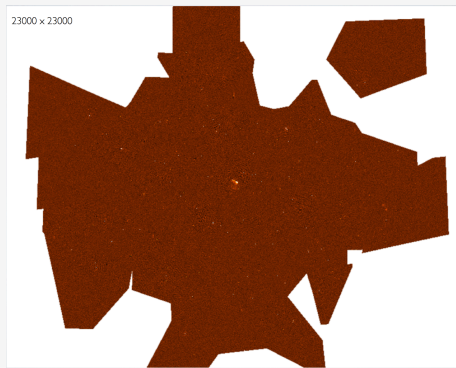
- Constrain dark matter annihilation (Storm et al. 2016)
- Reacceleration of fossil particles.
- Discovering clusters via tailed radio galaxies (Blanton et al.)



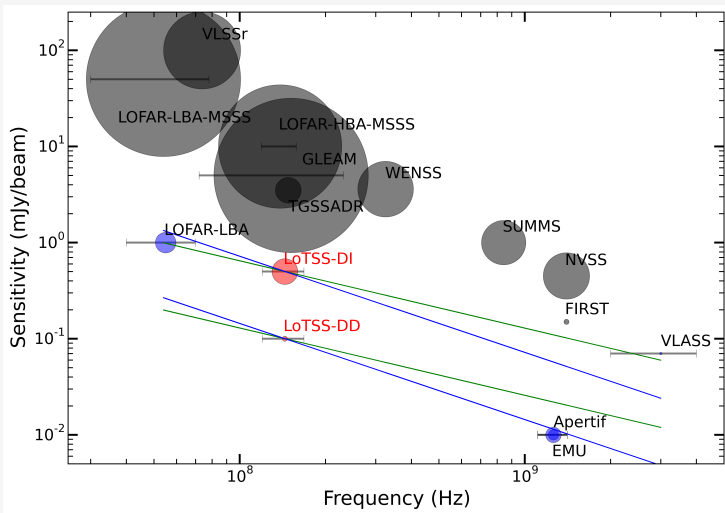
LoTSS image of Abell 1682

The LOFAR Two-metre Sky Survey (LoTSS)

- $\approx 5''$ resolution
- $\approx 100 \mu\text{Jy}/\text{beam}$ sensitivity at most declinations
- 48 MHz bandwidth (from 120 MHz to 168 MHz)
- 3170 8hr pointings to cover the northern sky ($\sim 14,000$ hrs)
- Over 10% of observations now complete (primarily within the FIRST coverage)



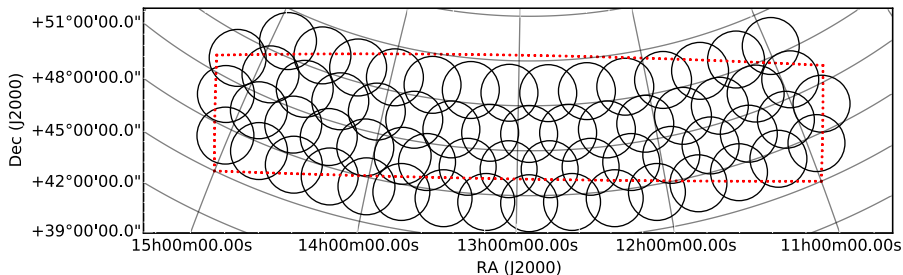
Demonstrating the LOFAR capabilities with a 10 hr observation of a cluster field. The image noise level is $100 \mu\text{Jy}/\text{beam}$ and the resolution is $5''$ (by Reinout van Weeren).



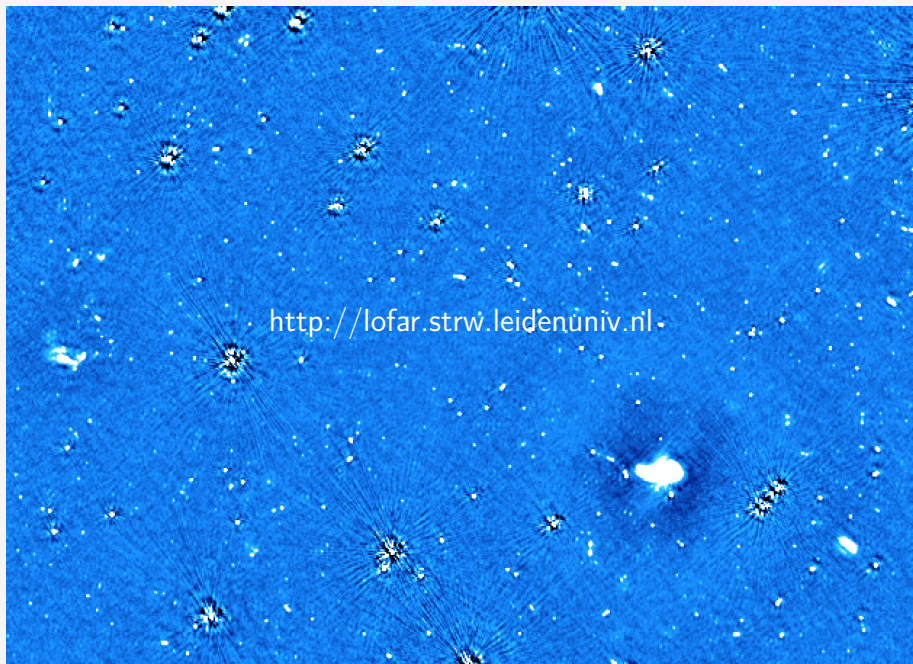
Green $\alpha = -0.7$. Blue $\alpha = -1.0$.

LoTSS – preliminary data release

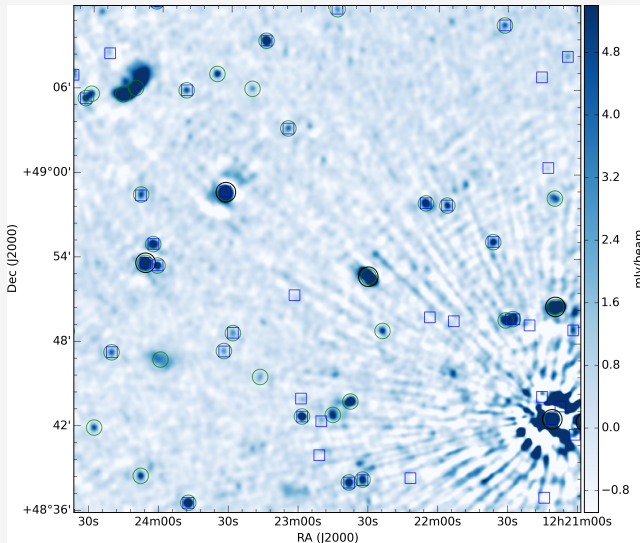
A release of 25" resolution images and catalogues made from 63 direction independent calibrated datasets. The area covered is 381 square degrees in the region of the HETDEX Spring Field and the catalogue contains 44,500 sources.



Shimwell et al., A&A (arXiv:1611.02700) <http://lofar.strw.leidenuniv.nl>

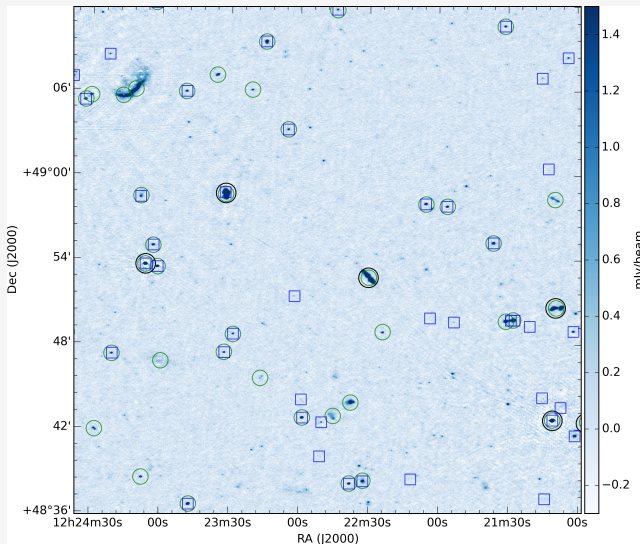


Beyond the LoTSS preliminary data release



25'' and 300-600 μ Jy/beam – direction independent

Beyond the LoTSS preliminary data release



5 – 8'' and $\sim 100 - 120 \mu\text{Jy/beam}$ – direction dependent.

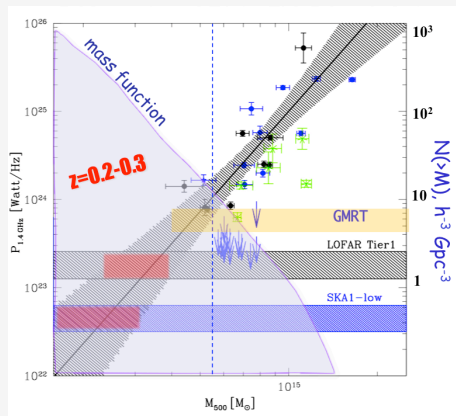
Clusters in LoTSS

Marcus Bruggen, Gianfranco Brunetti

Monique Arnaud, Philip Best, Michiel Brentjens, Laura Birzan, Annalisa Bonafede, Rossella Cassano, Krzysztof Chyzy, Judith Croston, Alastair Edge, Torsten Ensslin, Luigina Feretti, Chiara Ferrari, Francesco de Gasperin, Susanne Heidenreich, Mike Hogan, Matthias Hoeft, Duy Hoang, Cathy Horellou, Huib Intema, Henrik Junkelwitz, Matt Lazell, Soumyajit Mandal, George Miley, Emanuela Orru, Roberto Pizzo, David Rafferty, Somak Raychaudhury, Huub Rottgering, Federica Savini, Timothy Shimwell, Andra Stroe, Ed Valentijn, Amanda Wilber, Reinout van Weeren.

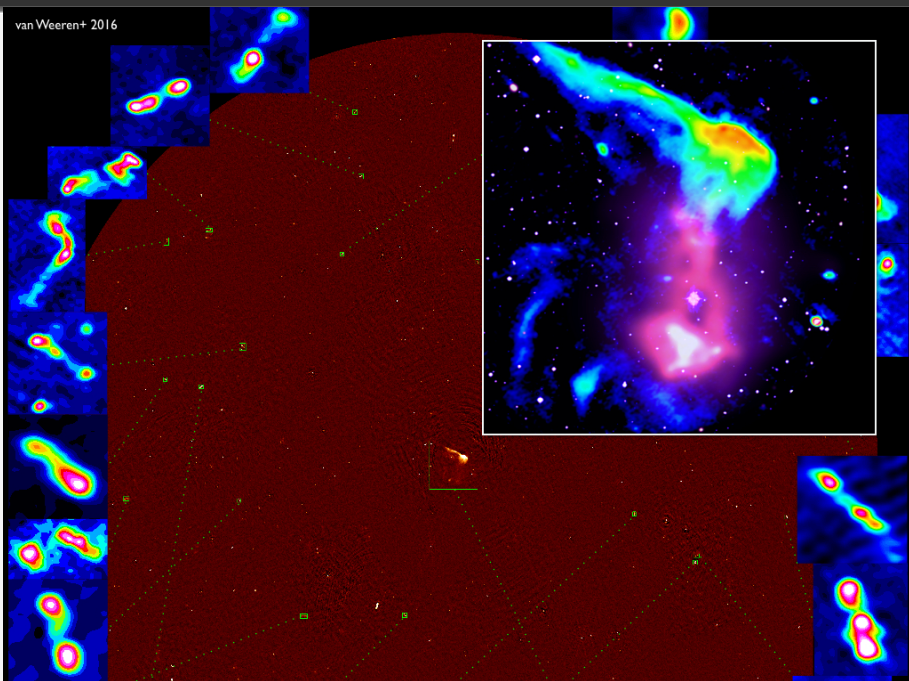
Why do cluster science with LoTSS

- Low frequency very sensitive to steep spectrum, allows for older particles to be detected.
- Excellent surface brightness sensitivity from dense core
- High resolution (5") to distinguish contaminating sources
- An anticipated detection of hundreds of clusters with radio emission from the ICM and tens of thousands of resolved tailed radio galaxies.

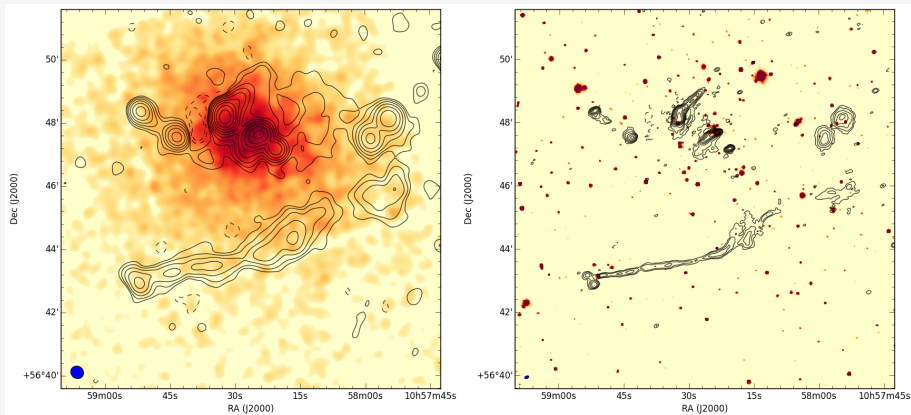


Massive clusters are rare but the radio emission correlates with the cluster mass.

van Weeren+ 2016

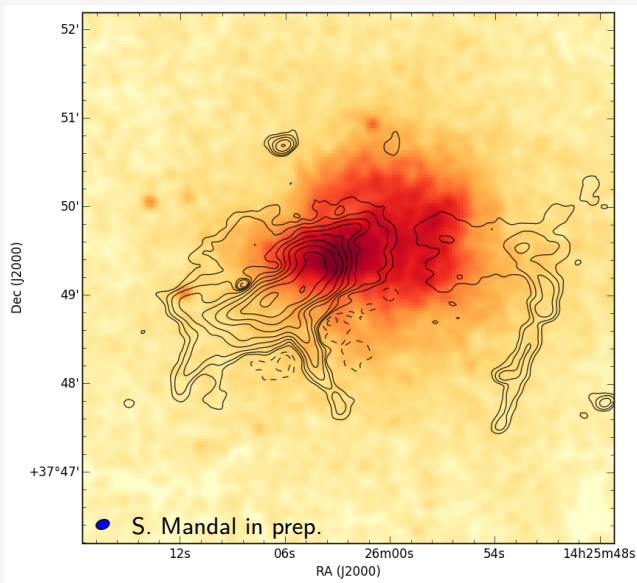


Abell 1132

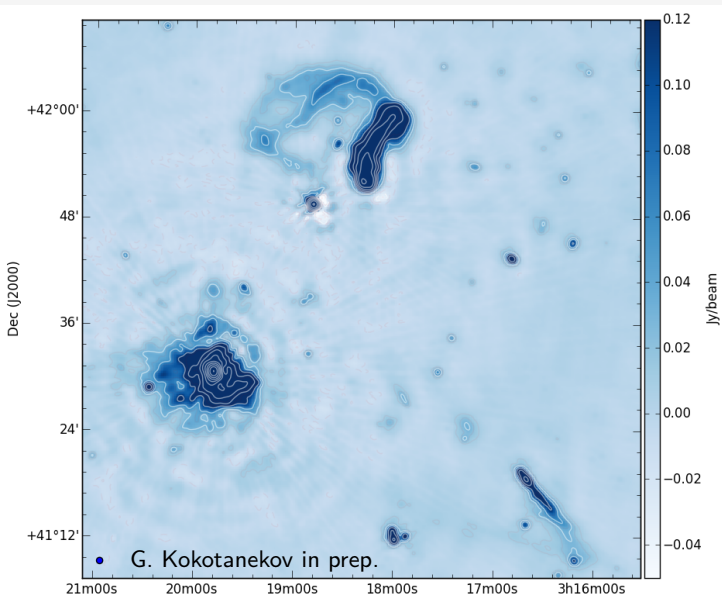


1.3 Mpc tailed radio galaxy and radio halo
 A. Wilber et al. in prep.

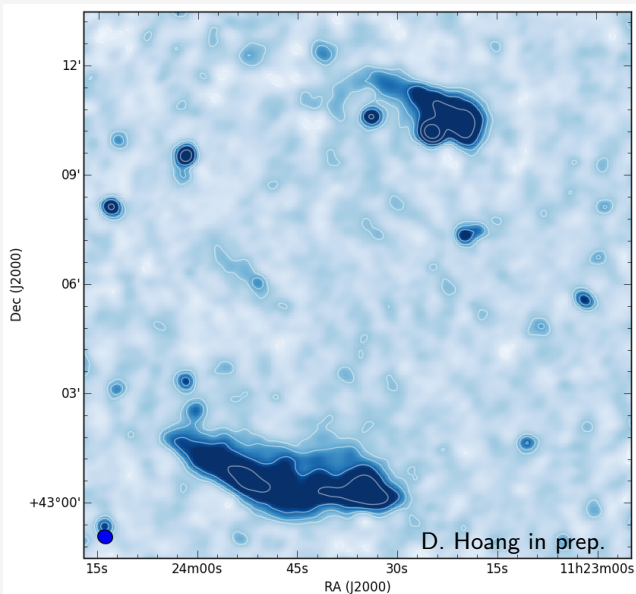
Abell 1914



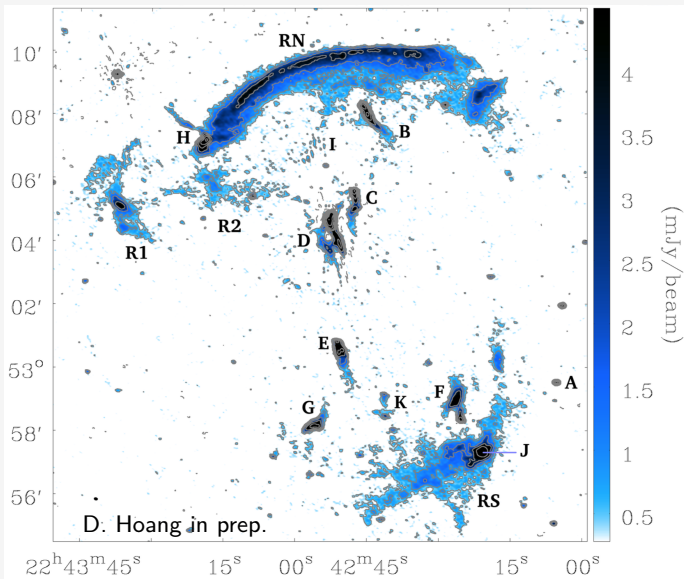
Perseus



Abell 1240

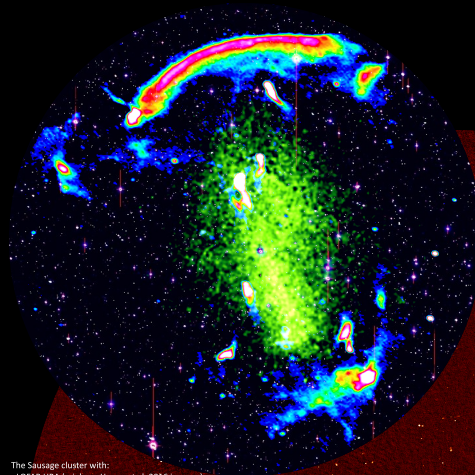


Sausage cluster



Deep LOFAR HBA observations of the Sausage cluster

D. Hoang, T. Shimwell, H. Röttgering
Leiden Observatory, Netherlands

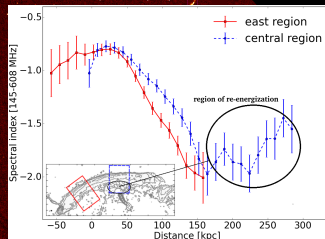


The Sausage cluster with:

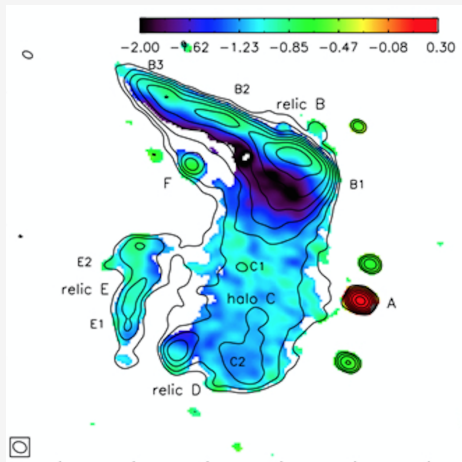
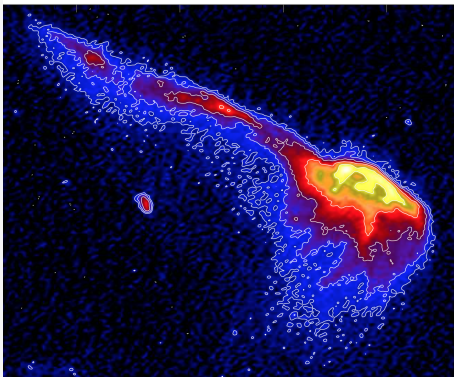
- LOFAR HBA (rainbow, Hoang et al. 2016 in prep.)
- Chandra X-ray (green, O'gorman et al. 2014)
- Subaru & CFHT optical (background, Stroe et al. 2015)

Abstract: The Sausage cluster (CIZA J2242.8+5301) is famous for its 'sausage'-like morphology of the northern relic that is caused by the ongoing major merger. The cluster merger generates large-scale (Mpc) shock waves that propagate outwards and are detected with radio telescopes. Also, the ICM plasma is heated up to extremely high temperature (keV) that is measured with X-ray satellites. Using our LOFAR observations at 150 MHz that have excellent surface brightness sensitivity coupled with high resolution, combined with other datasets (GMRT, WSRT, *Suzaku*), we can:

- study the re-energization in the post-shock region of the northern relic via its spectral properties.

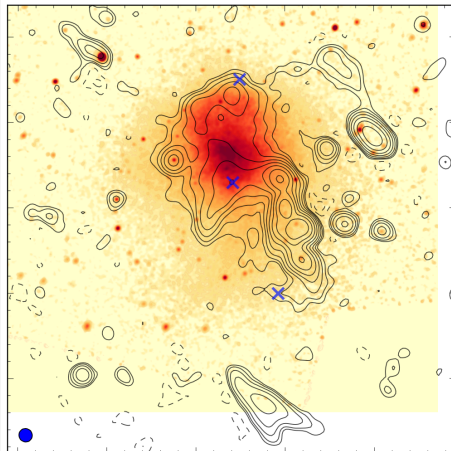
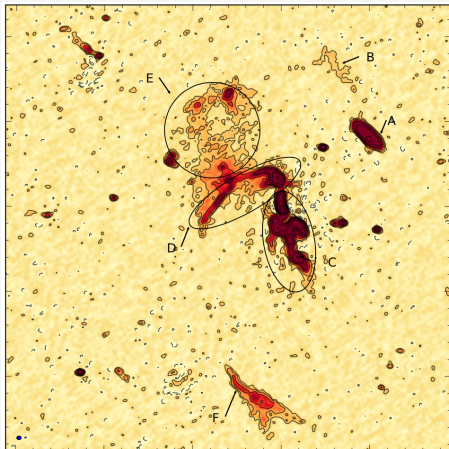


Toothbrush cluster



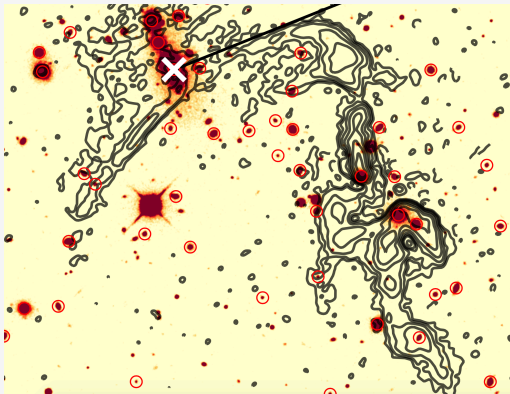
Remarkably uniform spectral index in a halo
van Weeren R. J., et al., 2016, ApJ, 818, 204

Abell 2034

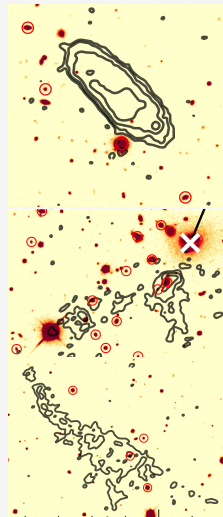


A plethora of diffuse steep spectrum emission
 Shimwell T. W., et al., 2016, MNRAS, 459, 277

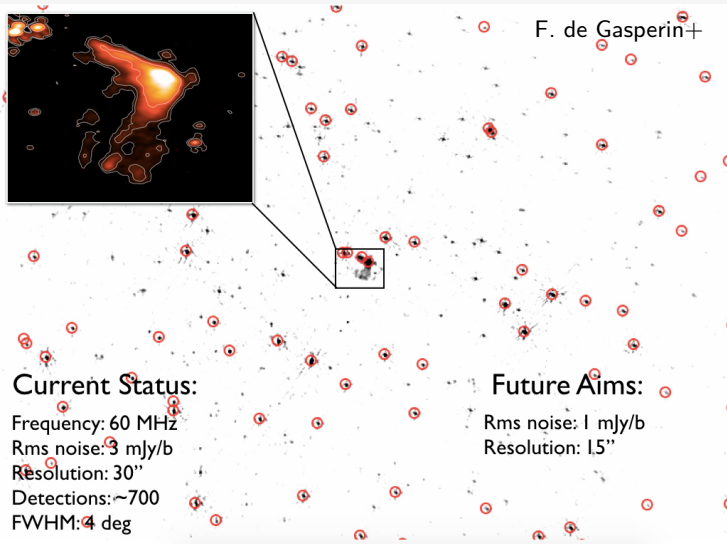
Abell 2034 – radio and optical



Tailed radio galaxies have clear optical companions in the cluster but there are no obvious optical counterparts for candidate relics or the filamentary structure.



Clusters at even lower frequencies – The LOFAR LBA Sky Survey (LoLSS)



Conclusions

- Over 10% of the LoTSS observations have been conducted.
- The LoTSS survey description and preliminary data release is now published (arXiv:1611.02700).
- We plan to produce $\approx 5''$ resolution images with a sensitivity of $\approx 100 \mu\text{Jy}/\text{beam}$ over a 500 square degree region with minimal manual interaction in a few months.
- Studies of individual clusters are demonstrating the significant contribution LoTSS will make in this field.
- We will soon begin statistical studies of clusters.

Co-observing with LoTSS

Observe with LOFAR:

- The LoTSS team will perform a direction independent calibration of your target data if you use 48MHz of bandwidth to place a beam on a LoTSS grid pointing.
- The LoTSS team will help you with the direction dependent calibration using publicly available pipelines.
- See <https://www.astron.nl/radio-observatory/observing-proposals/co-observing-surveys-ksp-team/co-observing-surveys-ksp-team> for details.