

Ultra Steep Spectrum (USS) Sources In Galaxy Clusters

Soumyajit Mandal
PhD Student, Leiden Observatory

H. Intema, T. Shimwell, F. de Gasperin, R. van Weeren, A. Botteon,
H. Rottgering, H. Akamatsu, G. Brunetti, T. W. Jones, F Mernier

Diffuse Synchrotron Emission in Clusters of Galaxies
Leiden 25th October, 2017



Abell 2744

Radio: cosmic rays + magnetic fields



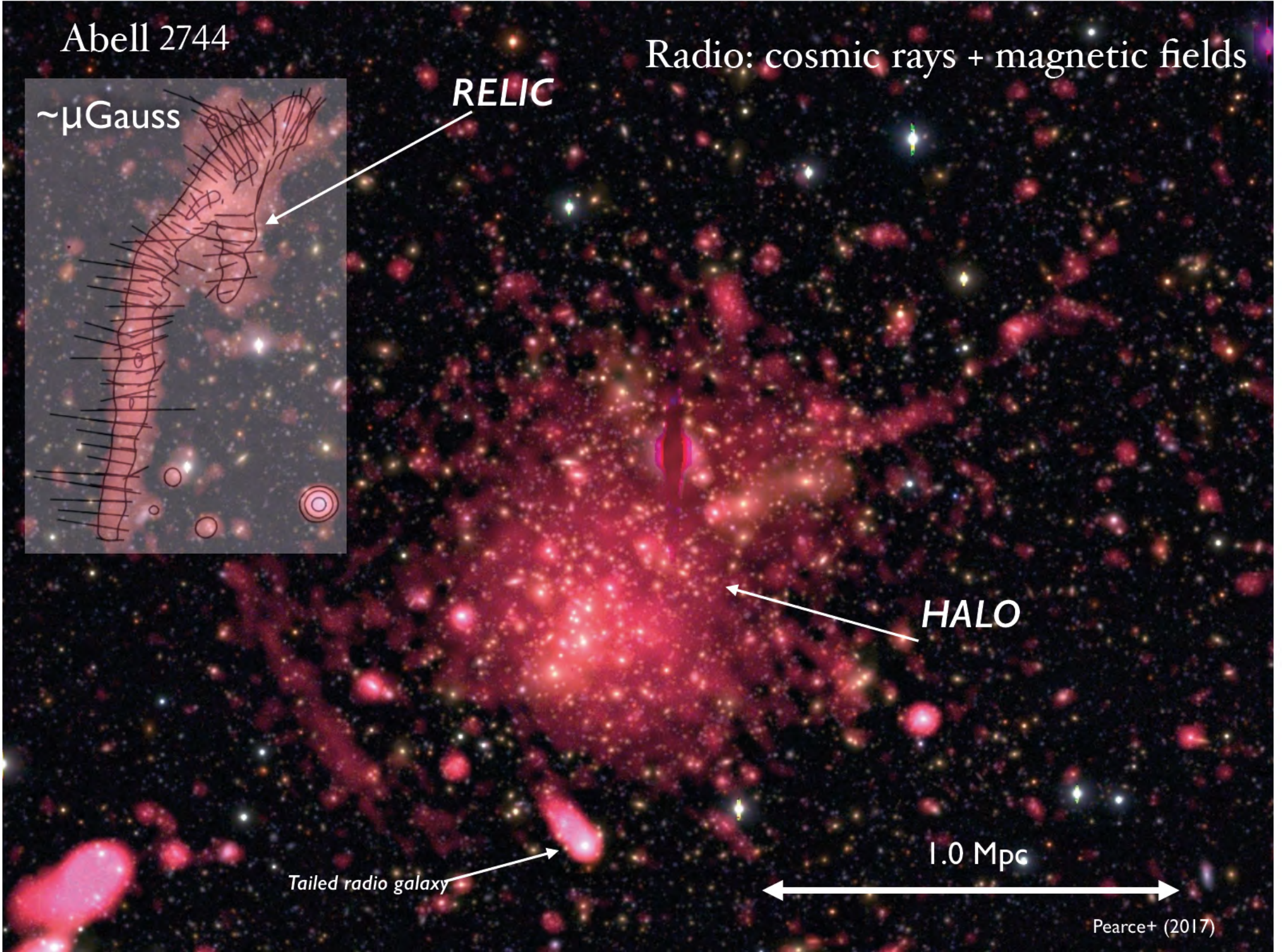
RELIC

HALO

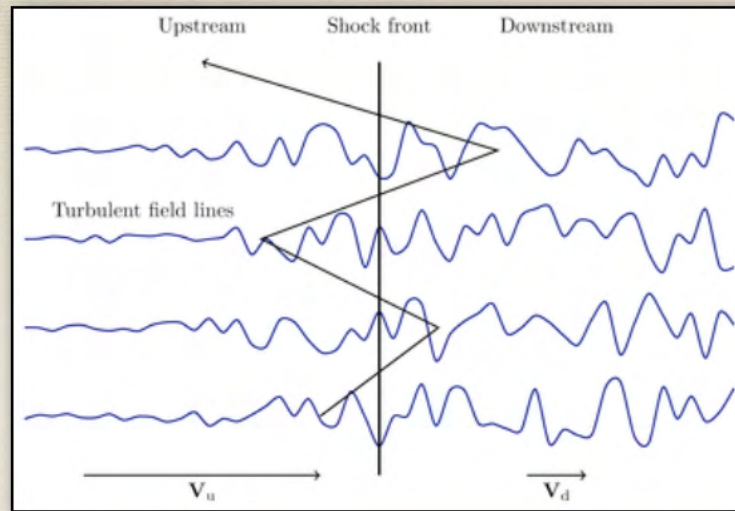
Tailed radio galaxy

1.0 Mpc

Pearce+ (2017)



Questions



Diffusive
Shock
Acceleration

How are particles accelerated in the ICM?

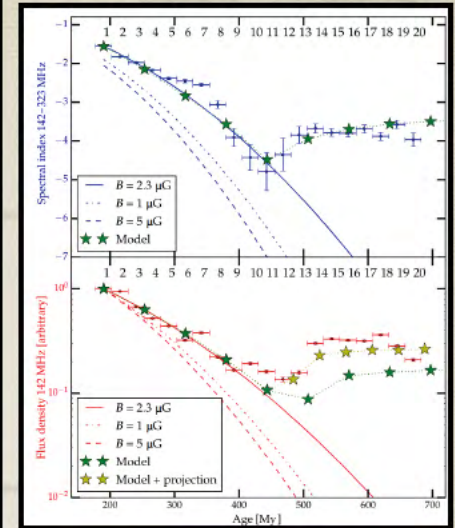
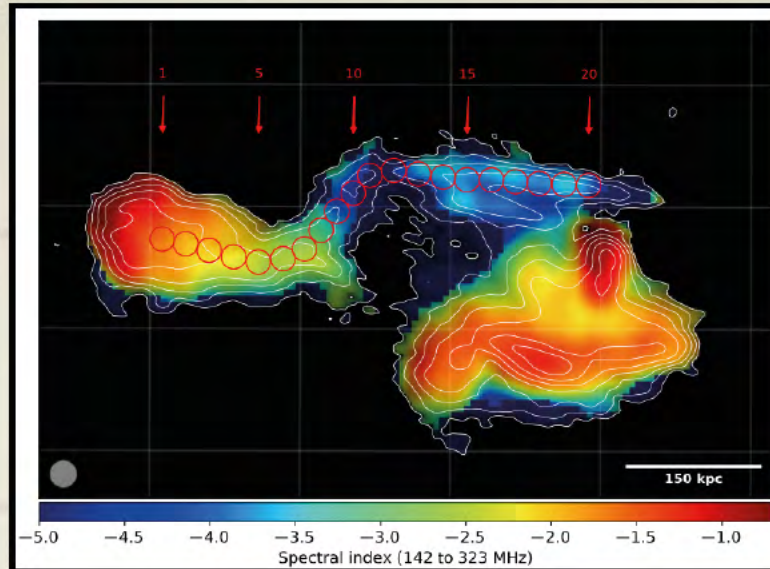
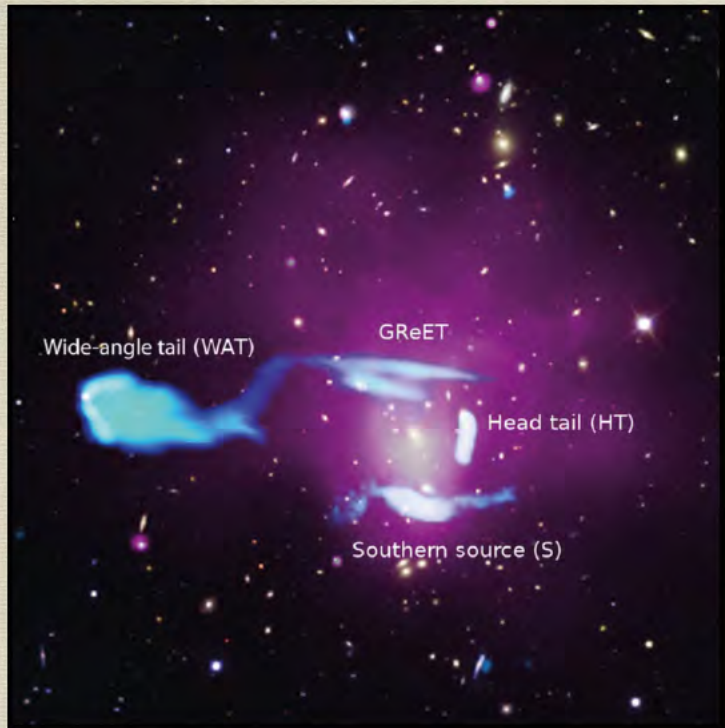
1. Via Shocks? Turbulence?
2. Acceleration Efficiency? Maximum CRe energy?
3. Seed population and role of radio galaxies?

Fossil Plasma Sources

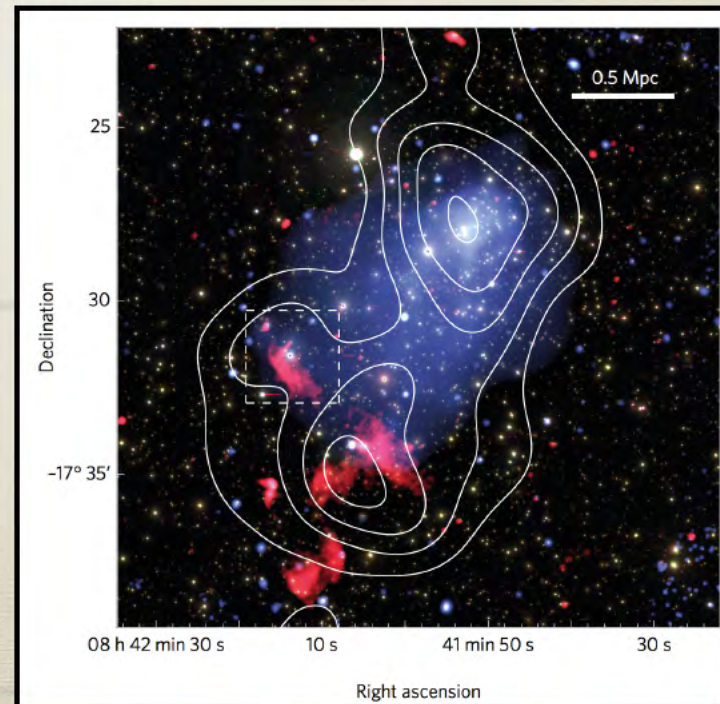
- A poorly studied, class of object
- Ultra-steep spectral indices
- Adiabatically compressed fossil plasma (Radio Phoenixes) (Ensslin & Gopal-Krishna, 2001)
- Old AGN lobes: (re)-accelerated by shocks

Recent Results

de Gasperin et al. 2017 *Science Advances*



van Weeren et al. 2017
Nature Astronomy



Our Search for Fossil Plasma sources

- USS sources have been seen sporadically in clusters in the past (examples: Slee et al. 2001, van Weeren et al. 2009/2011, de Gasperin et al. 2015)
- With improved sensitivity at the lowest radio frequencies, we start to see many more; may be very common in clusters
- Morphologically diverse group, so not easy to categorise
- Most likely explanation is shock compression of aged plasma
- Need to grow known sample & study in more detail to get a better handle on their general properties and test old plasma compression theory

Why Low-Frequency Radio Surveys?

Large area, low frequency radio surveys below 300 MHz have great potential in this area

- VLA Low Frequency Radio Survey (VLSS; Cohen et al. 2007)
- Galactic and Extra-galactic All-sky Murchison Wide Field Array Survey (GLEAM; Wayth et al. 2015)
- LOFAR Multifrequency Snapshot Sky Survey (MSSS; Heald et al. 2015)

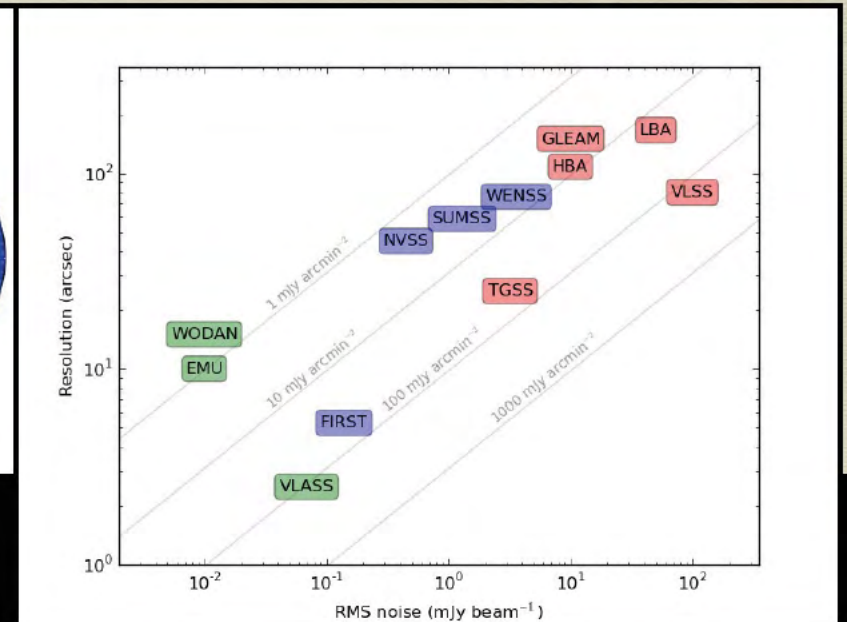
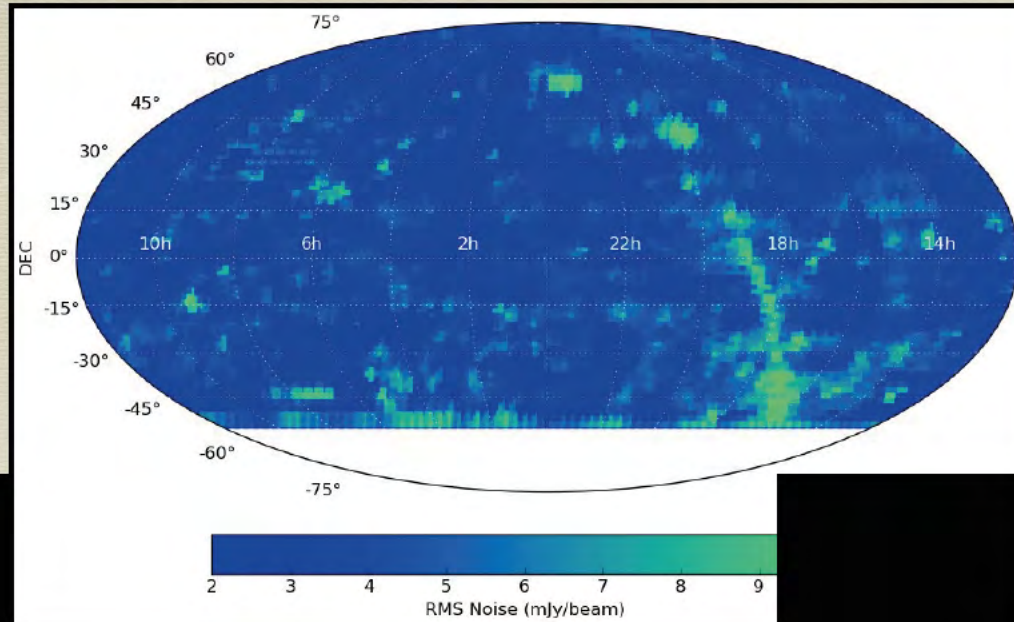
Why Low-Frequency Radio Surveys?

Large area, low frequency radio surveys below 300 MHz have great potential in this area

- VLA Low Frequency Radio Survey (**VLSS**; Cohen et al. 2007)
- Galactic and Extra-galactic All-sky Murchison Wide Field Array Survey (**GLEAM**; Wayth et al. 2015)
- LOFAR Multifrequency Snapshot Sky Survey (**MSSS**; Heald et al. 2015)

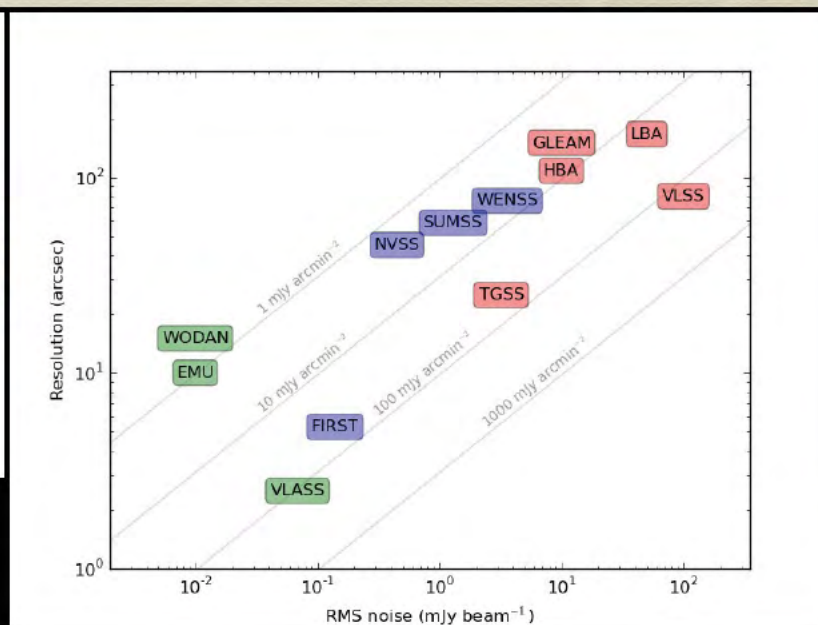
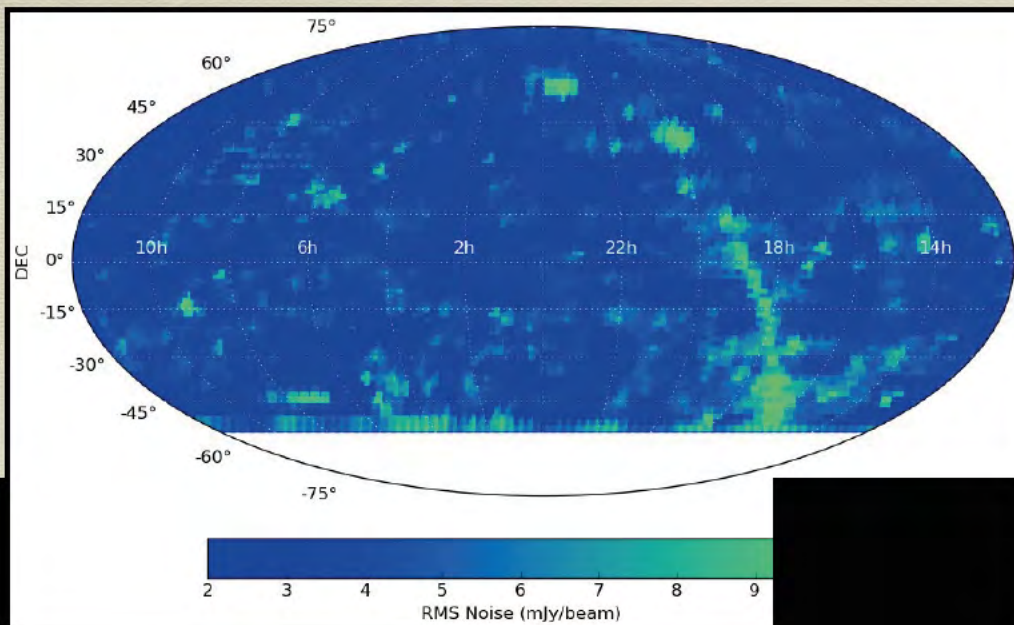
Confusion Limited, Low resolution => hard to distinguish between halo/relic emission and emission from individual galaxies

TGSS ADR (TIFR GMRT Sky Survey Alternate Data Release) (Intema et al. 2016)



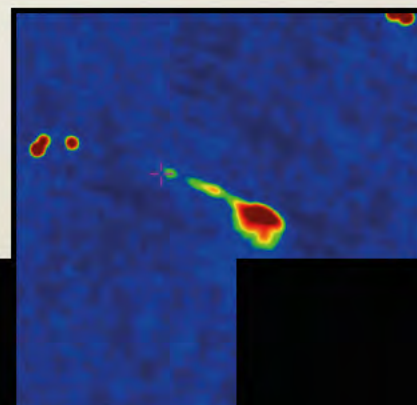
- 150 MHz sky survey at 25" by the Giant Meterwave Radio Telescope (GMRT)
- Covers 90% of the sky (+90 Dec till -55 Dec)
- Samples the radio sky in both few arc-seconds and tens of arc minute scale simultaneously.
- Rms noise: 3-5 mJy/beam
- A powerful tool to look for diffuse emission in clusters

TGSS ADR (TIFR GMRT Sky Survey Alternate Data Release) (Intema et al. 2016)

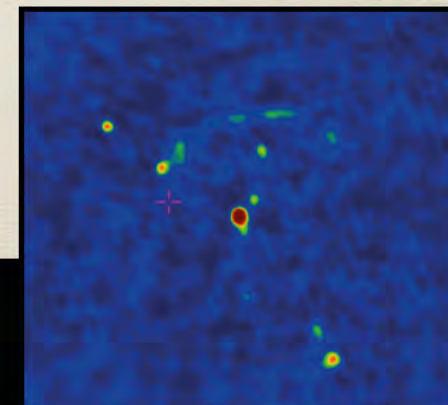


- 150 MHz sky survey at 25" by the Giant Meterwave Radio Telescope (GMRT)
- Covers 90% of the sky (+90 Dec till -55 Dec)
- Samples the radio sky in both few arc-seconds and tens of arc minute scale simultaneously.
- Rms noise: 3-5 mJy/beam
- A powerful tool to look for diffuse emission in clus

Toothbrush Cluster



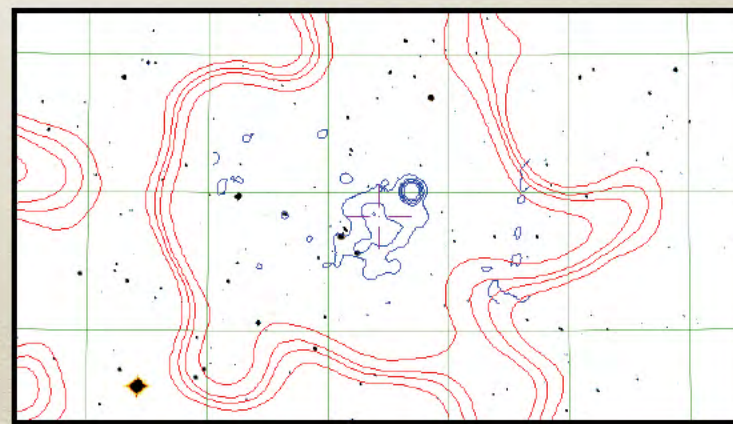
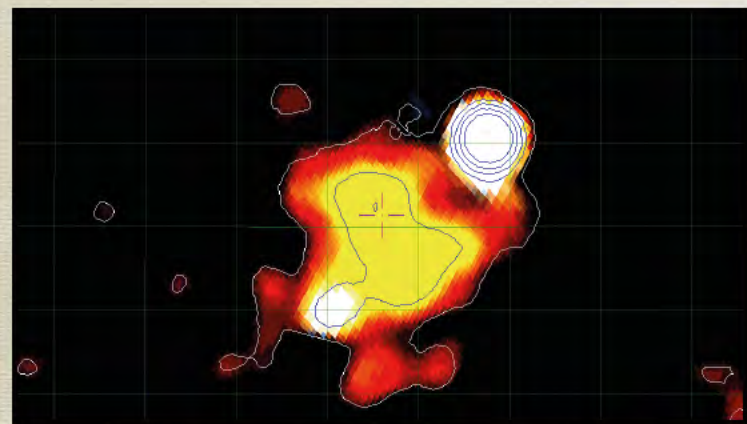
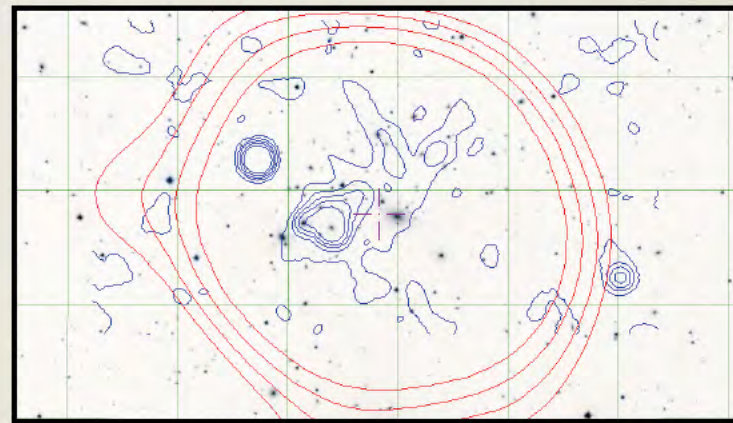
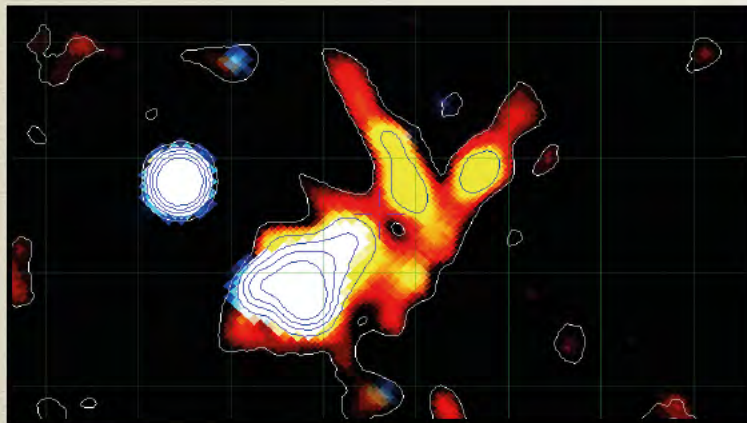
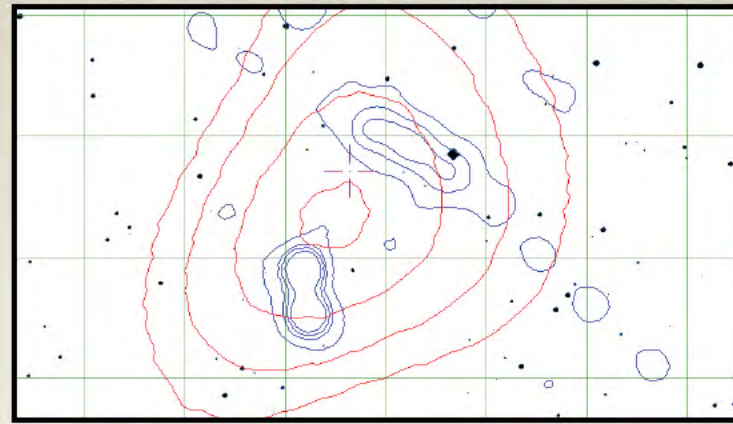
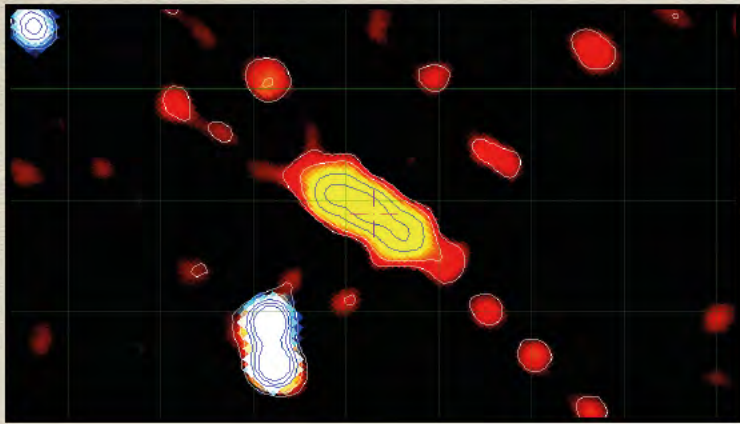
Sausage Cluster



Selection Criteria

- Systematic search: Convolution of TGSS to NVSS resolution and looking up steep-spectrum diffused emission. $\alpha < -2$
 - 150 MHz TGSS flux ≥ 30 mJy (10 sigma detection)
 - A morphology compatible with Mpc-scale cluster emission
 - No clear optical counterpart in DSS / SDSS
 - Apparent disturbed X-ray morphology in the ROSAT all sky survey
 - All candidates above DEC 0 (allowing LOFAR follow ups)
- =>Finally we chose 10 candidates for follow up observation.

Few examples from the TGSS

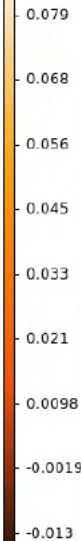


Red:
ROSAT
contours
Blue:
TGSS
contours

Few examples from the TGSS

GMRT @ 325 MHz

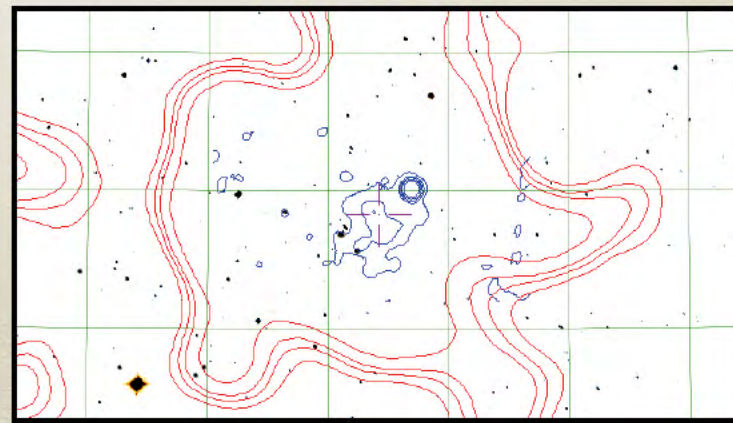
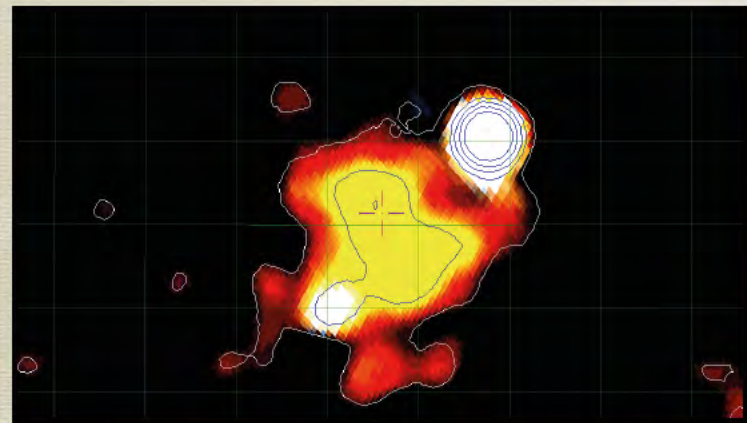
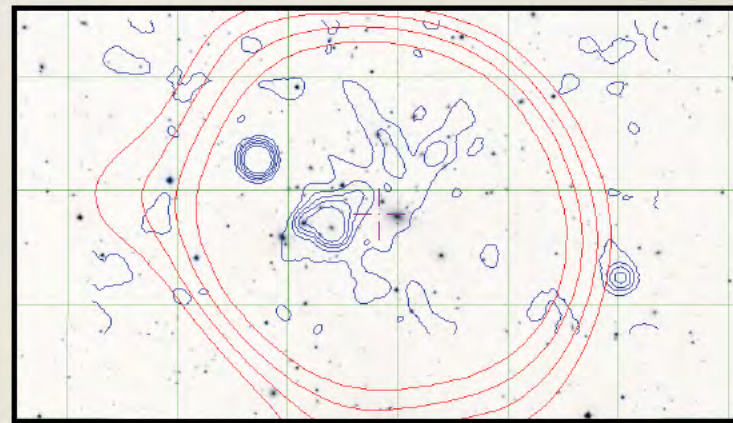
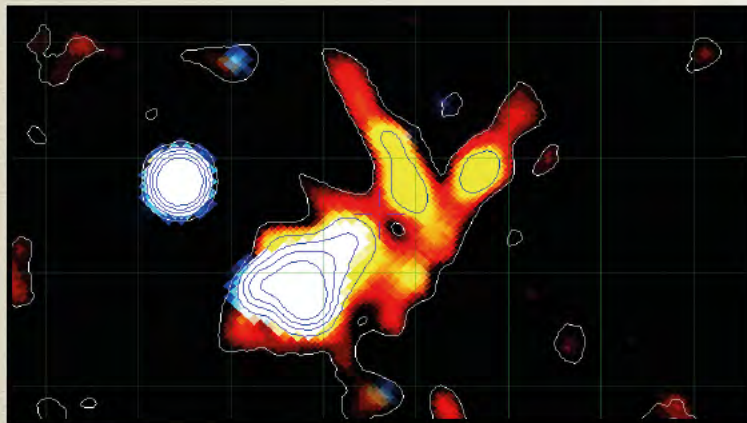
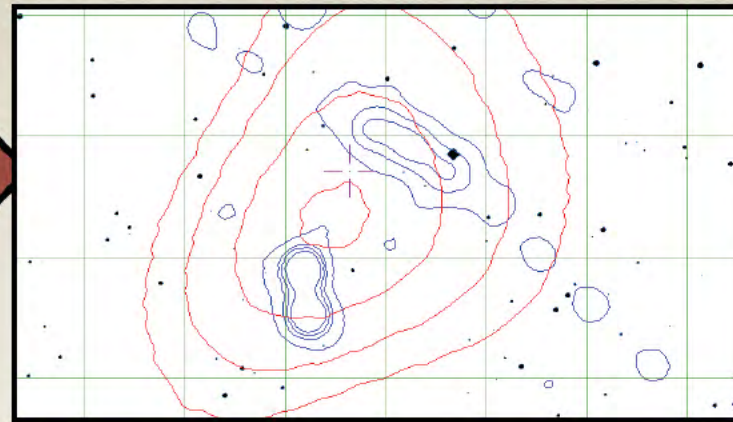
TGSS @ 150 MHz



Few examples from the TGSS

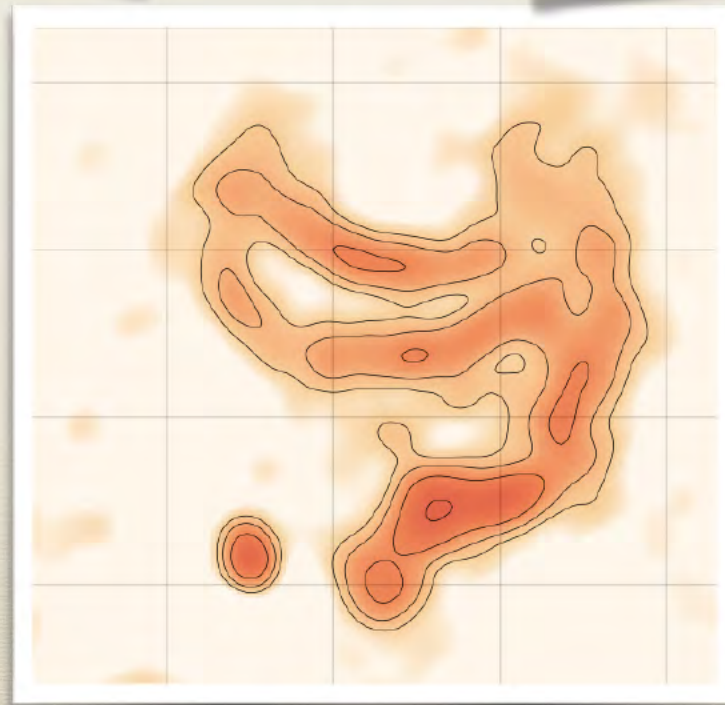
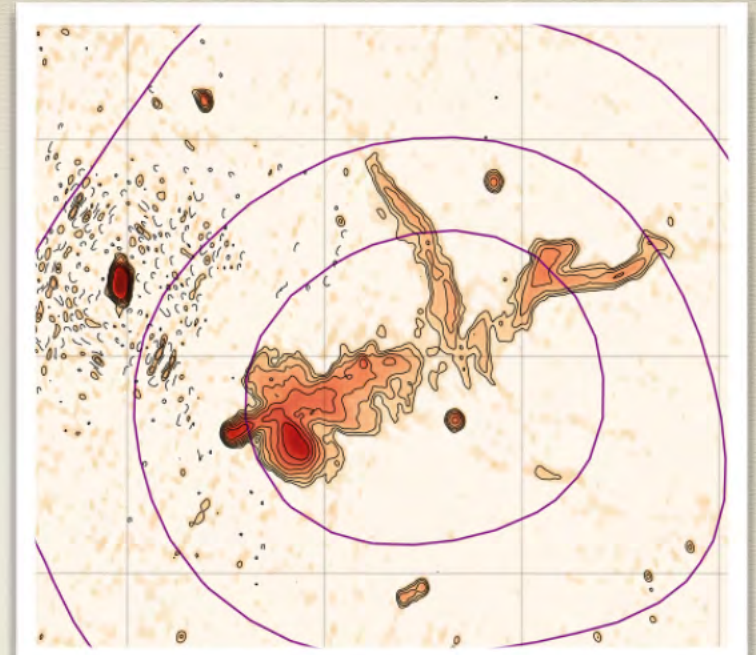
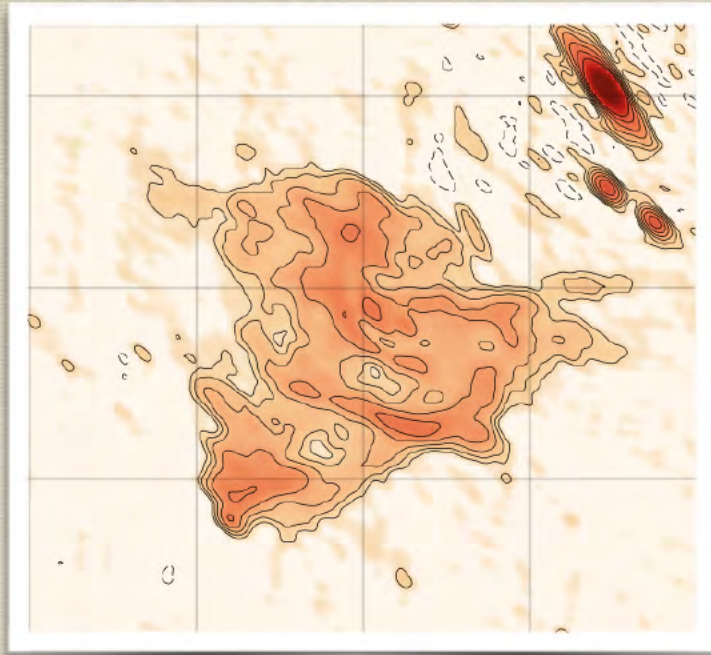


JUPITER!!

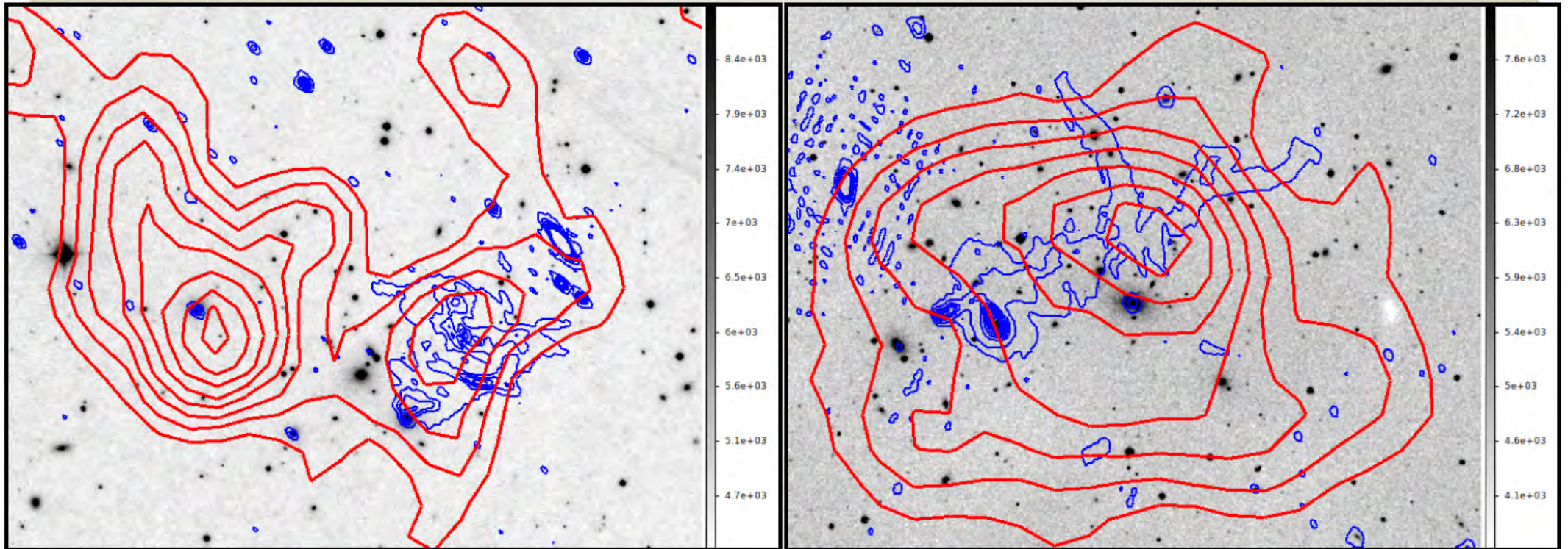


Red:
ROSAT
contours
Blue:
TGSS
contours

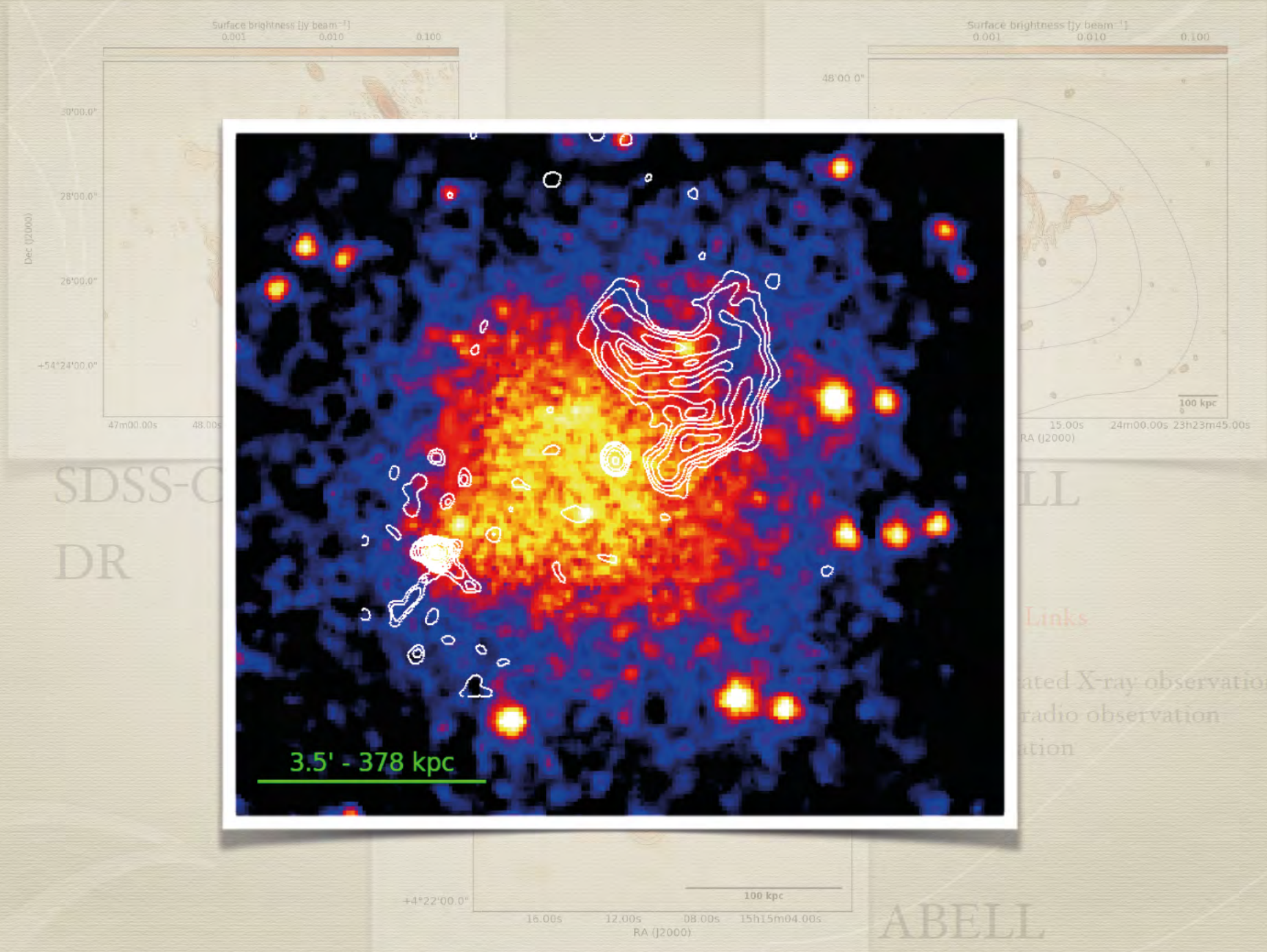
Results From Follow-up Observations (325 MHz)



Red: ROSAT X-ray contours
Blue: GMRT 325 MHz contours



Results From Follow-up Observations (325 MHz)



BUT.....

- Information about these sources are quite inadequate
- Most of them do not have dedicated X-ray observation
- Structures are very complicated to classify

With sufficient follow-ups we can address specific open questions

BUT.....

- Information about these sources are quite inadequate
- Most of them do not have dedicated X-ray observation
- Structures are very complicated to classify

With sufficient follow-ups we can address specific open questions



One such example: ABELL 1914

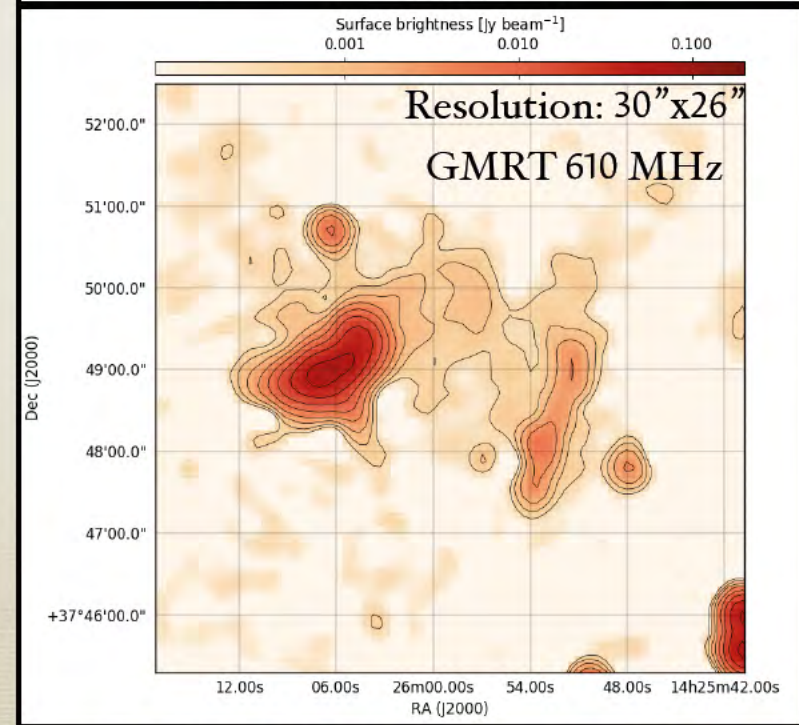
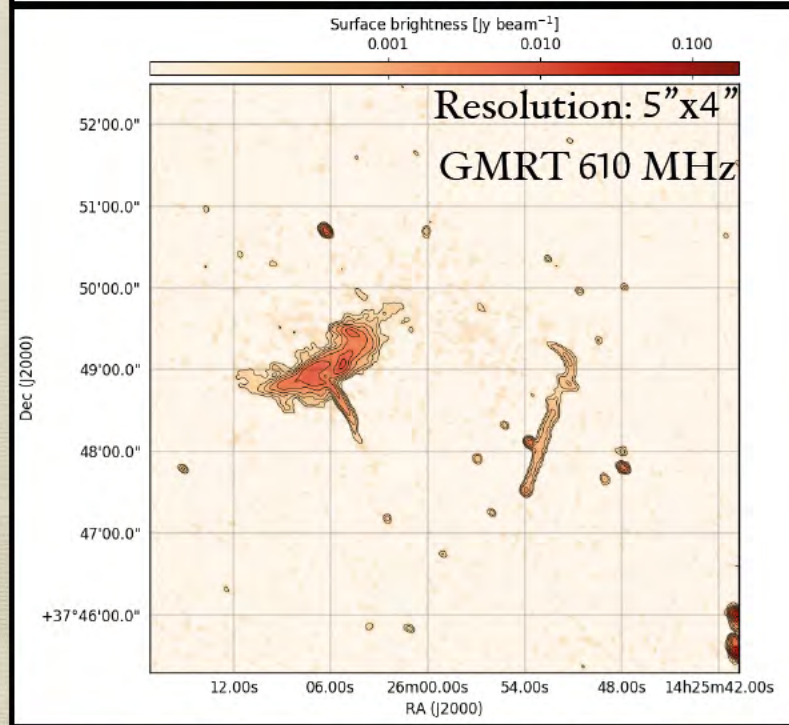
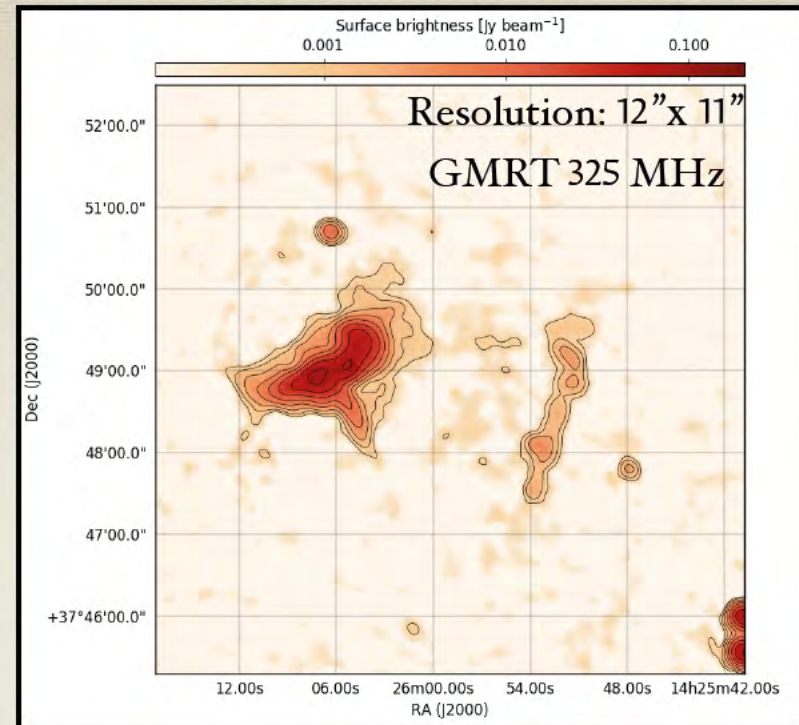
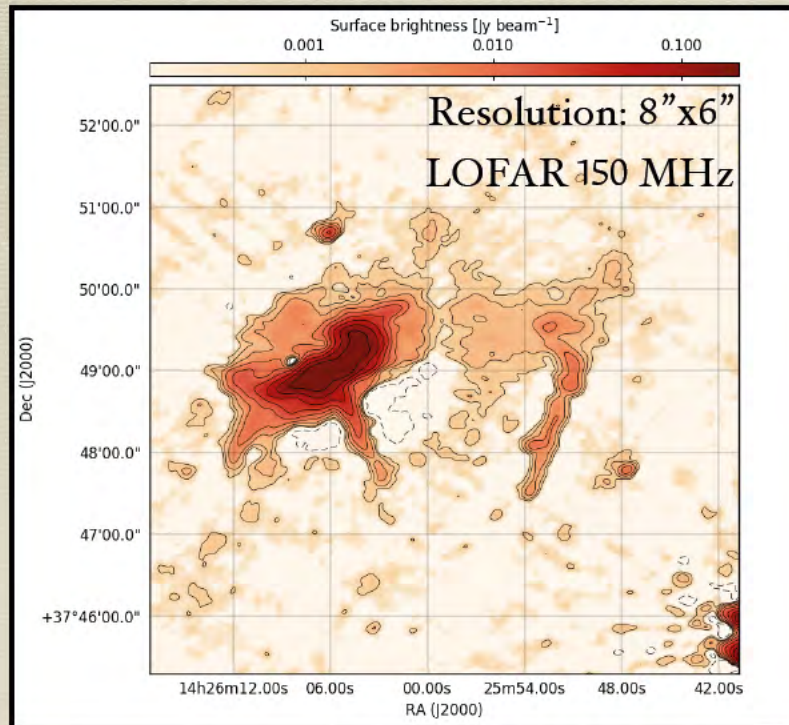
ABELL 1914

Red: LOFAR 150 MHz (8" x 6")

Blue: Chandra

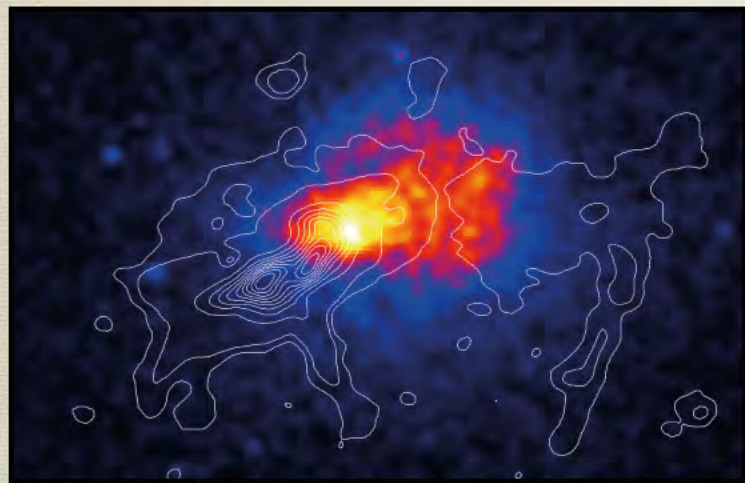
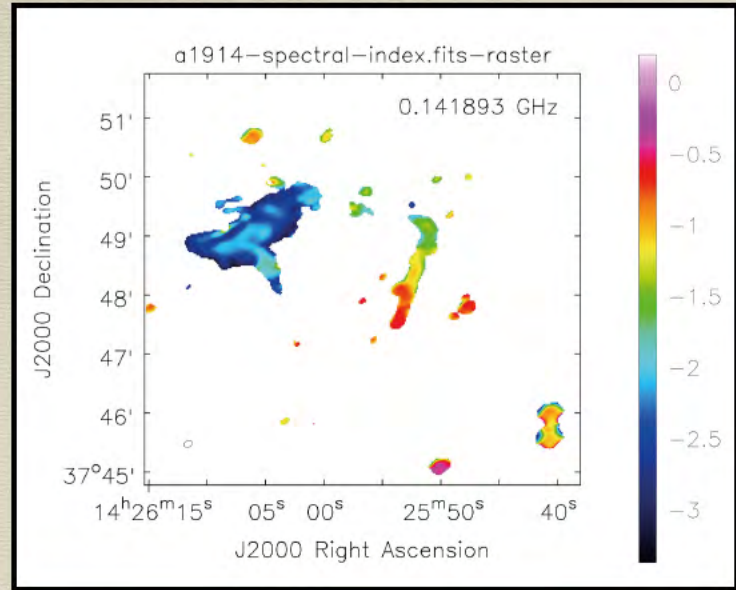


ABELL 1914 Radio Observations

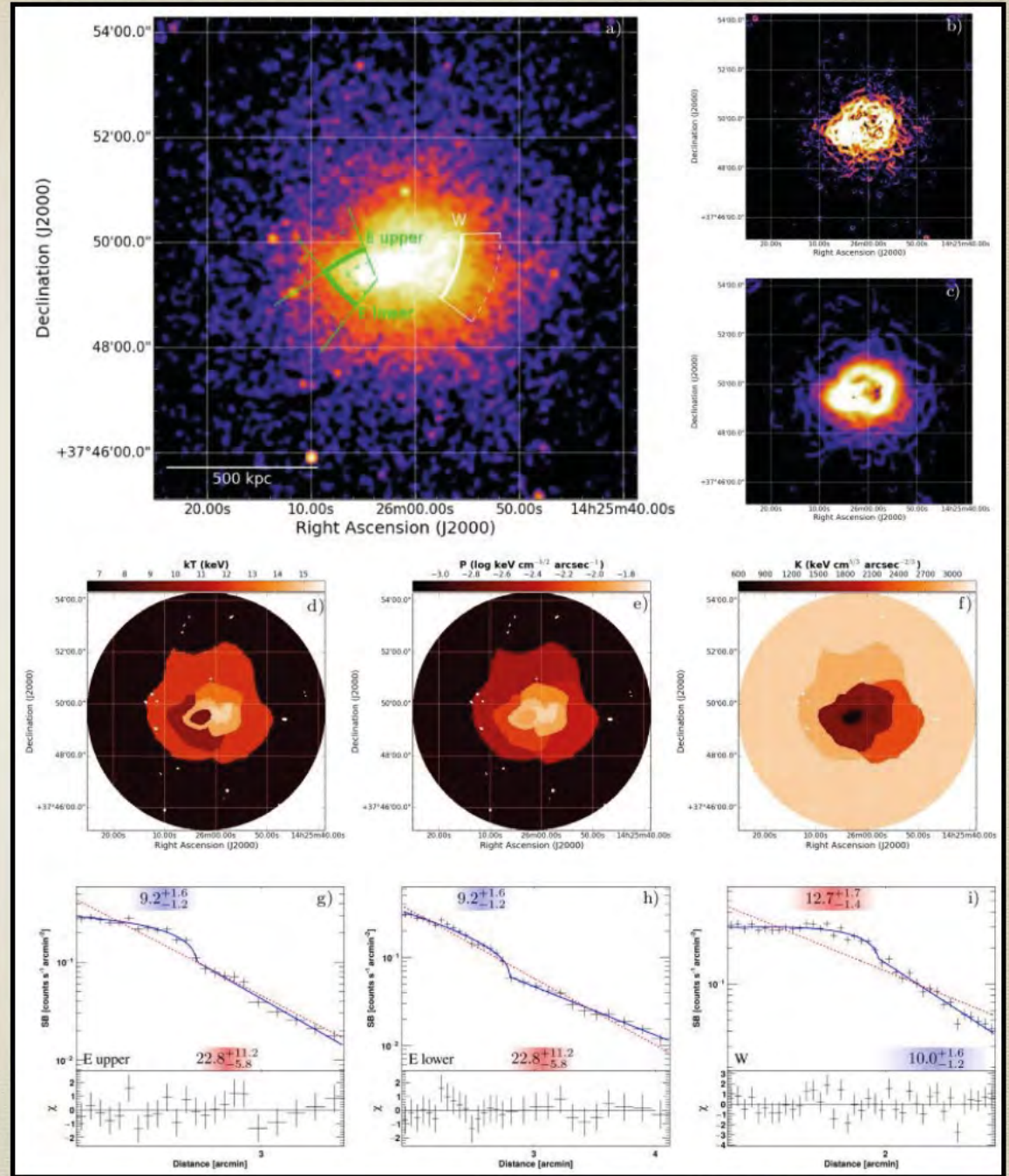


ABELL 1914

Spectral Index Map LOFAR 150 MHz and GMRT 610 MHz



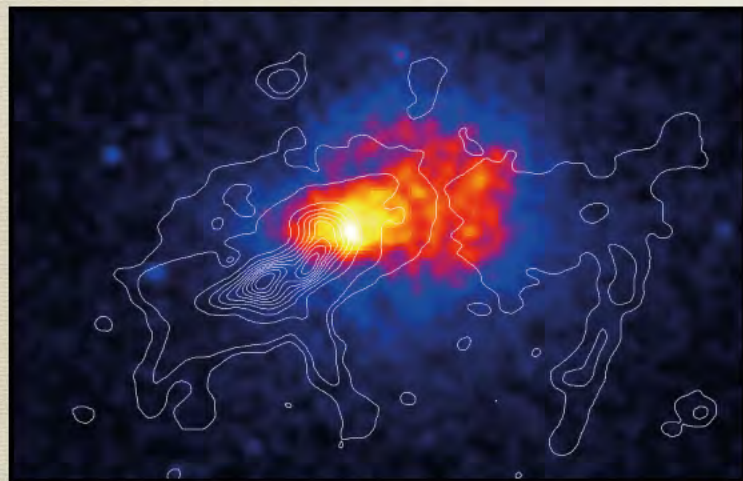
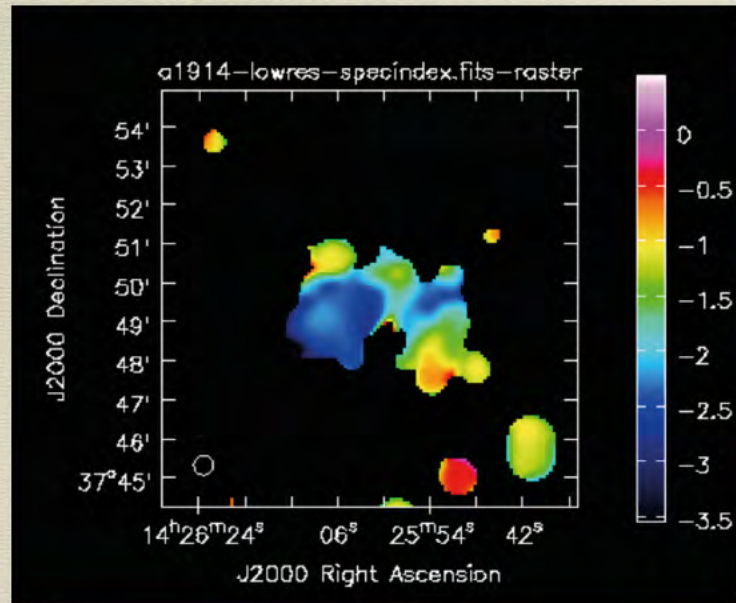
Chandra Map with LOFAR 150 MHz contours



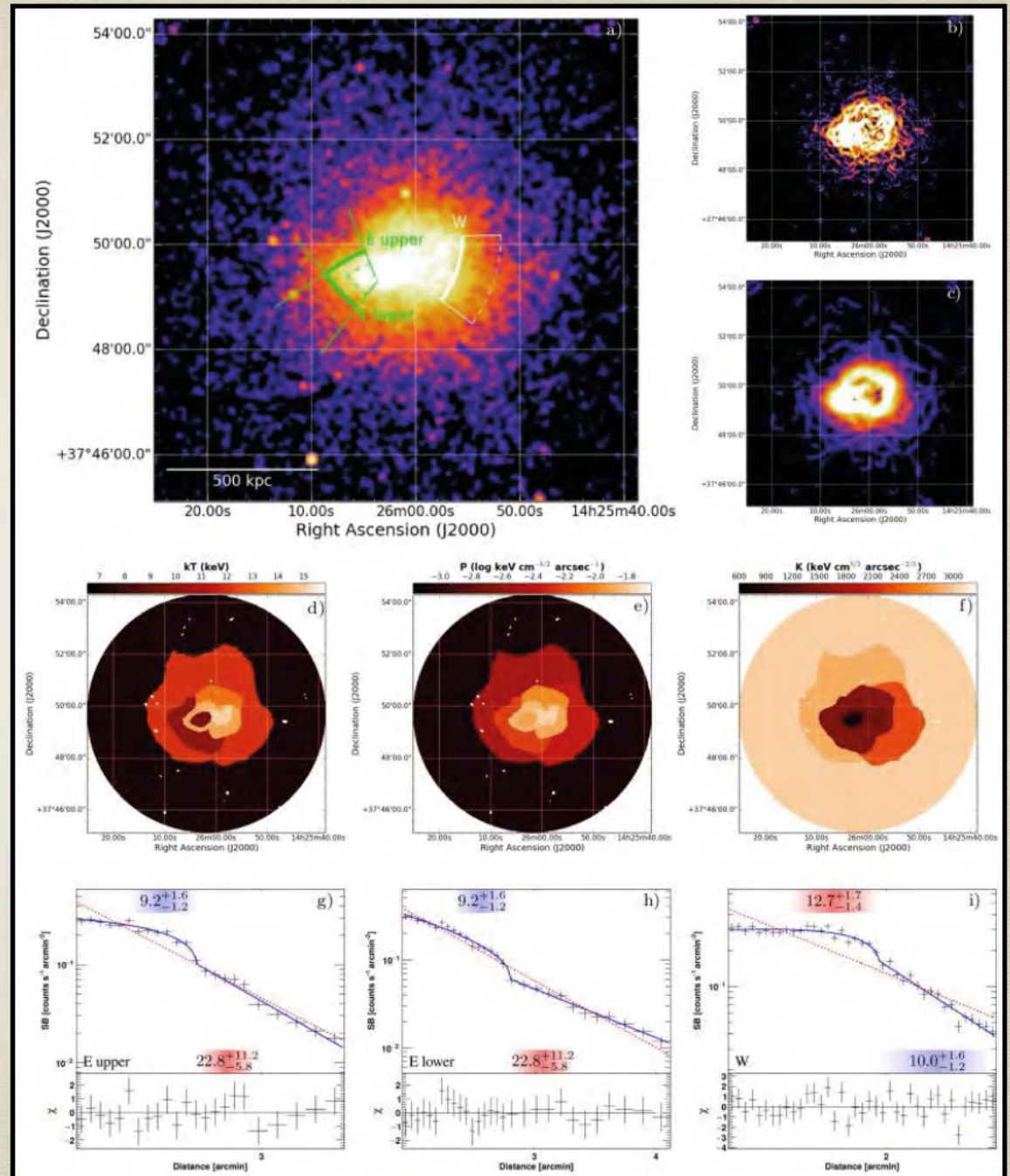
Chandra 25 ks analysis

ABELL 1914

Spectral Index Map LOFAR 150
MHz and GMRT 610 MHz



Chandra Map with LOFAR 150
MHz contours



Chandra 25 ks analysis

Follow Up Work

- Determine the dynamical state
- Map the overall temperature distribution
- Determine the mass of the cluster



- * *Chandra*: GTO for 2 sources
- * *XMM-Newton*: proposal submitted: 4 sources
- * Archival X-ray data for the rest: Analysis in Progress

- Old fossil plasma volume inside the cluster
- Delineate the source morphology
- Possible sites of Fermi-I type (re)-acceleration



- * *GMRT 610 MHz*: proposal accepted (observation starts this week!!)
- * *LOFAR 150 MHz*: proposal submitted for 8 sources
- * *LOFAR 150 MHz*: 2 sources already observed as survey product

SUMMARY & CONCLUSION

- First time a flux limited complete sample of USSS in galaxy clusters
- At this moment, scratching the tip of the iceberg (the brightest sample)
- Radio- and X-ray follow-ups underway
- Low Frequency surveys like TGSS and upcoming LoTSS (LOFAR Two Meter Sky Survey) (Shimwell + 2017) are necessary to obtain complete samples -> precursor to the SKA-Low
- MHD simulations (future work)

N

Thank you for your attention!