Recent LOFAR results on ~~merging~~ galaxy clusters

Andrea BOTTEON

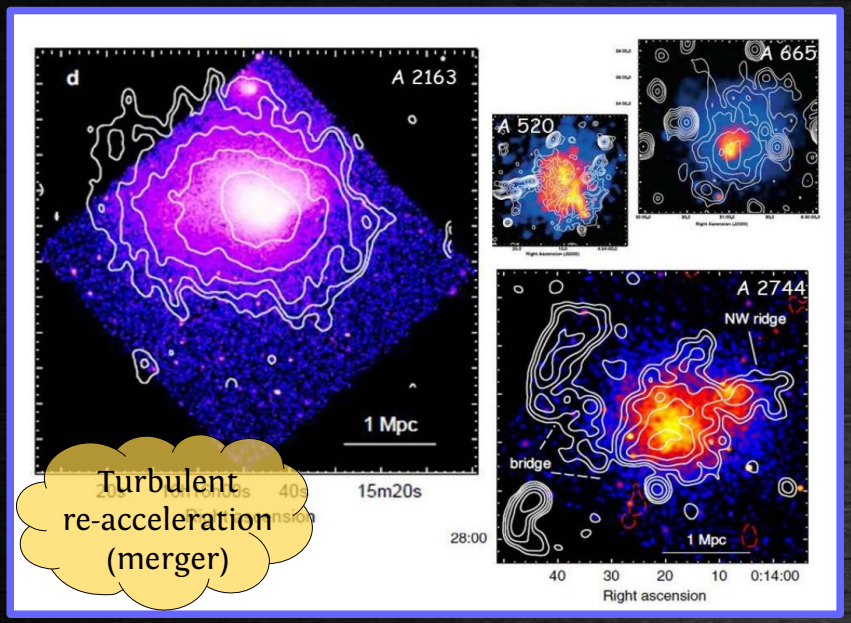
Leiden Observatory – Leiden University

In collaboration with the LOFAR Galaxy Clusters Working Group and Surveys KSP

October 14, 2020 – Radio 2020, Garching

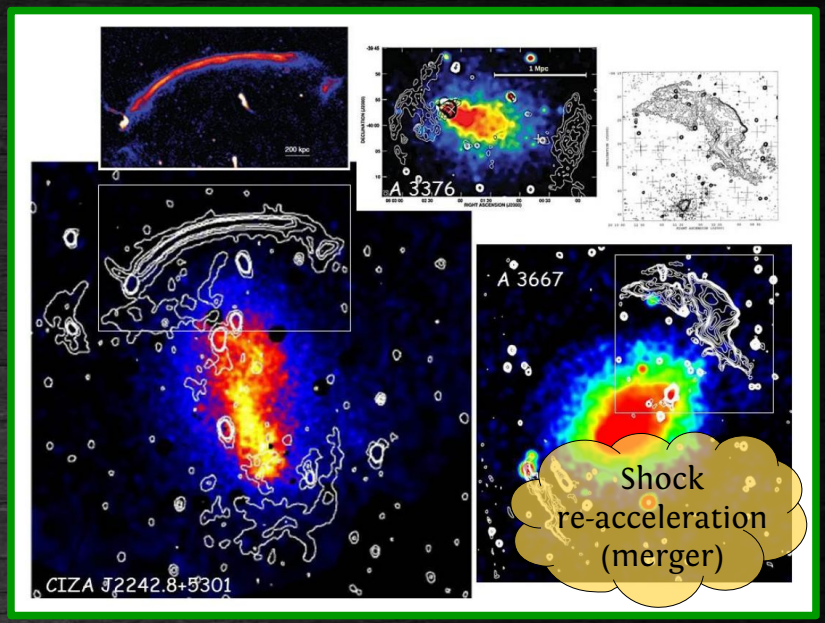
Diffuse radio sources in GCs

HALOS



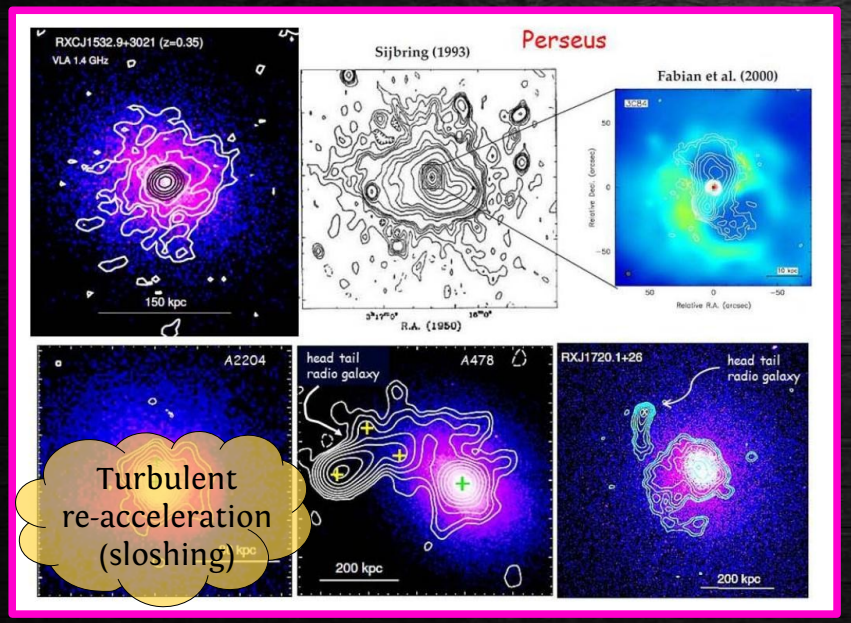
Turbulent re-acceleration (merger)

RELICS

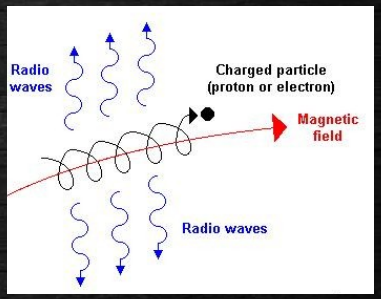


Shock re-acceleration (merger)

MINI-HALOS



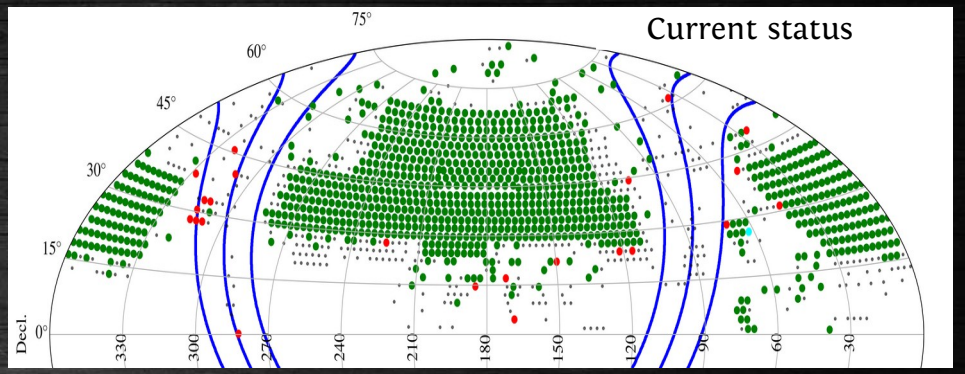
Turbulent re-acceleration (sloshing)



- *Low SB*
- *No optical counterpart*
- *Not ubiquitous*
- *α>1, with $S_\nu \propto \nu^{-\alpha}$*

Brunetti+Jones14, vanWeeren+19 for reviews

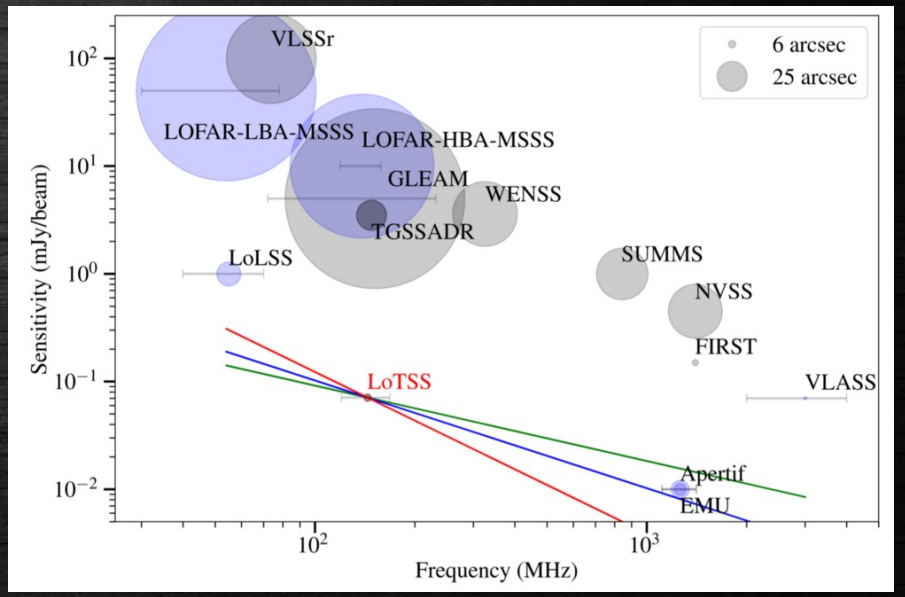
LOFAR Two-meter Sky Survey



LOFAR Two-metre Sky Survey (LoTSS):

- *frequency 120-168 MHz*
- *resolution 6”*
- *rms 100 μJy/beam*
- *FoV 6.4 deg²*
- *3170 pointings*
- *8 hr observations*

(Shimwell+17,19)



Study and detection of *new* **diffuse radio sources** in galaxy clusters

LOFAR Clusters WG results

1. *LOFAR, VLA, and Chandra Observations of the Toothbrush Galaxy Cluster,* van Weeren+
2. *A plethora of diffuse steep spectrum radio sources in Abell 2034 revealed by LOFAR,* Shimwell+

3. *Deep LOFAR observations of the merging galaxy cluster CIZA J2242.8+5301,* Hoang+
4. *Gentle reenergization of electrons in merging galaxy clusters,* de Gasperin+

5. *LOFAR discovery of an ultra-steep radio halo and giant head-tail radio galaxy in Abell 1132,* Wilber+
6. *Search for low-frequency diffuse radio emission around a shock in the massive galaxy cluster MACS J0744.9+3927,* Wilber+
7. *Discovery of large-scale diffuse radio emission in low-mass galaxy cluster Abell 1931,* Brüggen+
8. *LOFAR discovery of a double radio halo system in Abell 1758 and radio/X-ray study of the cluster pair,* Botteon+
9. *First evidence of diffuse ultra-steep-spectrum radio emission surrounding the cool core of a cluster,* Savini+
10. *LOFAR discovery of radio emission in MACS J0717.5+3745,* Bonafede+
11. *Radio observations of the double-relic galaxy cluster Abell 1240,* Hoang+

12. *The spectacular cluster chain Abell 781 as observed with LOFAR, GMRT and XMM-Newton,* Botteon+
13. *Ultra-steep spectrum emission in the merging galaxy cluster Abell 1914,* Mandal+
14. *A LOFAR study of non-merging massive galaxy clusters,* Savini+
15. *The evolutionary phases of merging clusters as seen by LOFAR,* Wilber+
16. *Radio observations of the merging galaxy cluster Abell 520,* Hoang+
17. *Characterizing the radio emission from the binary galaxy cluster merger Abell 2146,* Hoang+
18. *A massive cluster at z = 0.288 caught in the process of formation: The case of Abell 959,* Birzan+
19. *Signatures from a merging galaxy cluster and its AGN population: LOFAR observations of Abell 1682,* Clarke+
20. *LOFAR discovery of a radio halo in the high-redshift galaxy cluster PSZ2 G099.86+58.45,* Cassano+
21. *Particle acceleration in a nearby galaxy cluster pair: the role of cluster dynamics,* Botteon+

22. *Revived fossil plasma sources in galaxy clusters,* Mandal+
23. *LOFAR observations of X-ray cavity systems,* Birzan+
24. *The beautiful mess in Abell 2255,* Botteon+
25. *Reaching thermal noise at ultra-low radio frequencies. The Toothbrush radio relic downstream of the shock front,* de Gasperin+
26. *A giant radio bridge connecting two galaxy clusters in Abell 1758,* Botteon+
27. *The great Kite in the sky: a LOFAR observation of the radio source in Abell 2626,* Ignesti+
28. *Fast magnetic field amplification in distant galaxy clusters,* Di Gennaro+

2016 2017 2018 2019 2020

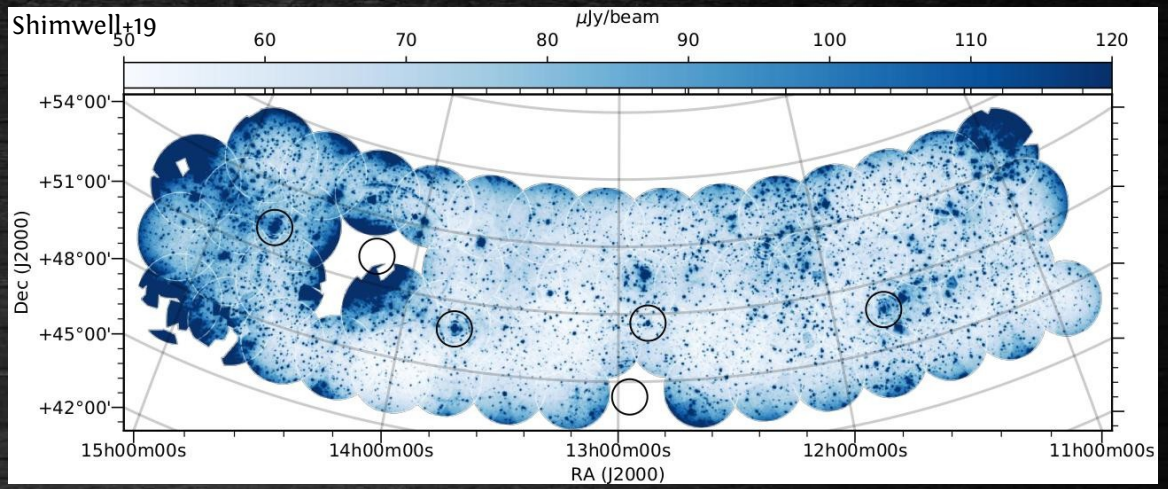
HETDEX sample

The **first** LoTSS DR occurred in *February 2019*

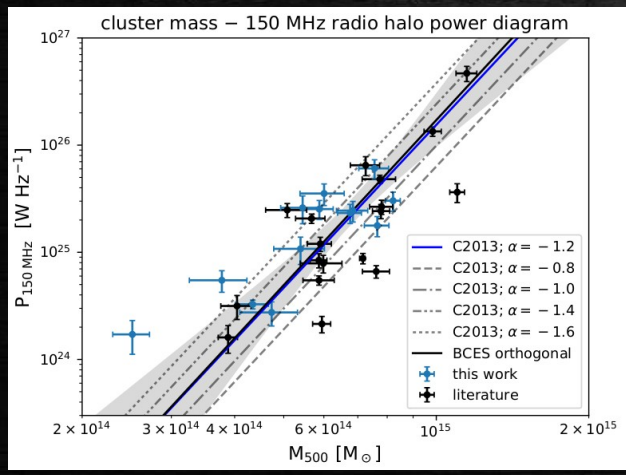
HETDEX region:

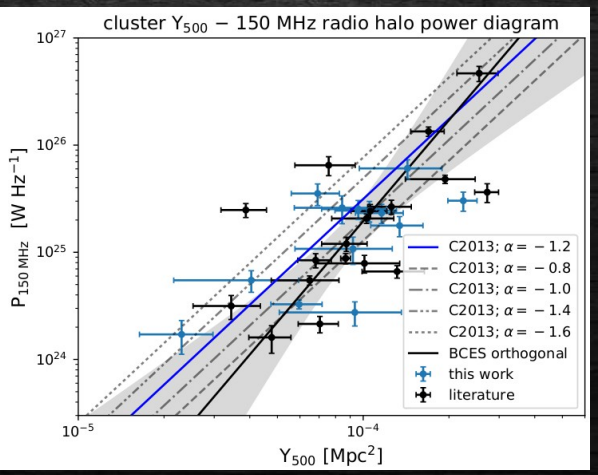
- *424 deg²*
- *41 clusters (26 PSZ2)*
- *New halos and relics*

vanWeeren+ in prep.



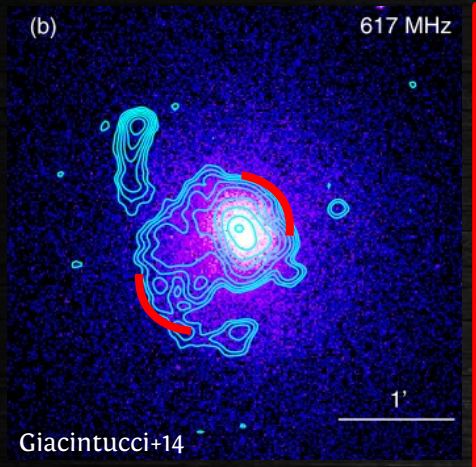
First large **LOFAR** sample to study galaxy clusters at **144 MHz**



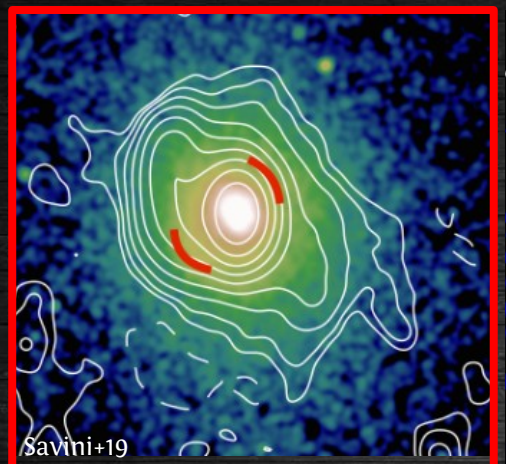


- M_{500}, Y_{500}, **P_{150MHz}** correlations
- **>500** clusters with diffuse emission are expected in LoTSS

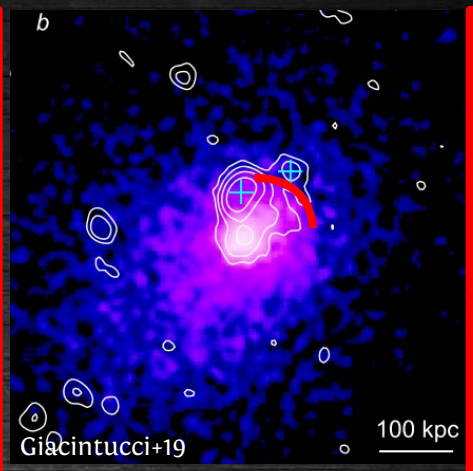
Mini(?)-halos



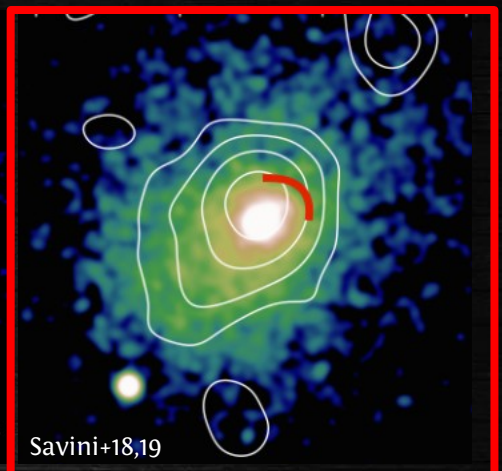
GMRT 617 MHz



LOFAR 144 MHz

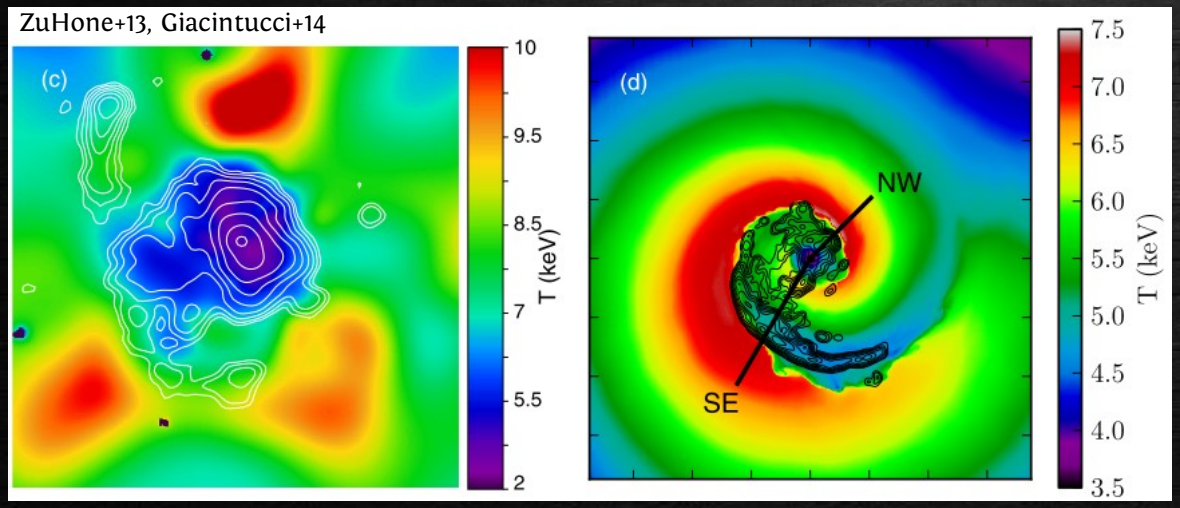


GMRT 610 MHz



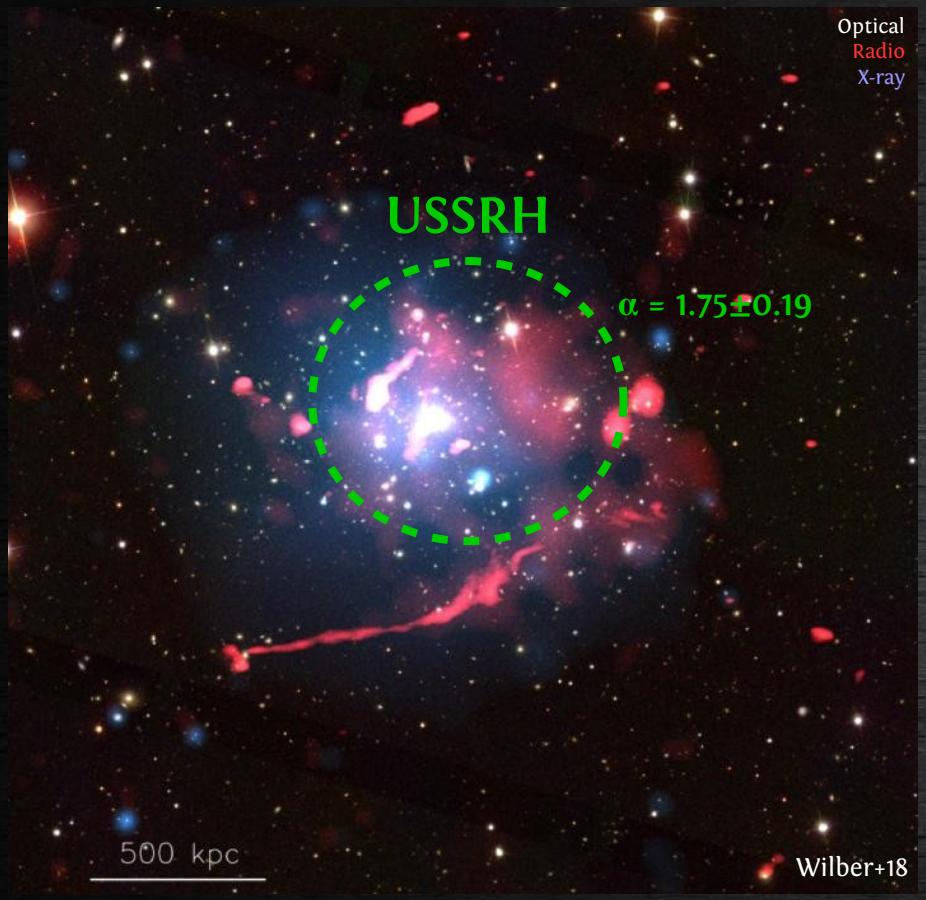
LOFAR 144 MHz

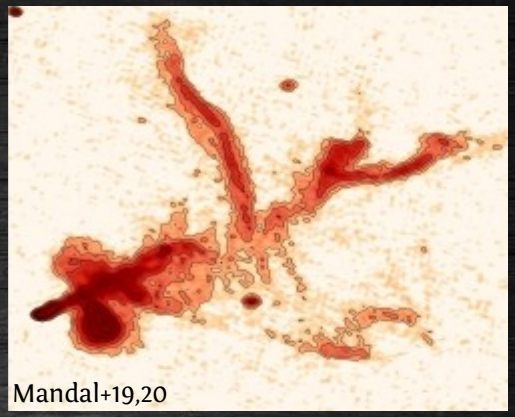
Confinement of **mini-halos** in sloshing *cold fronts*

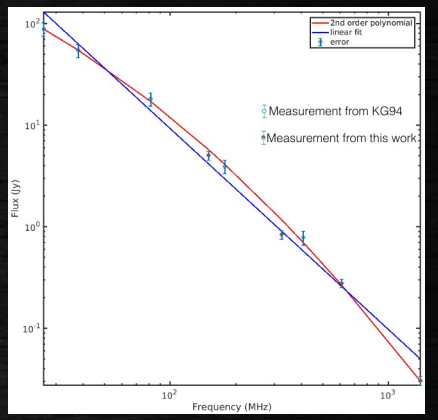


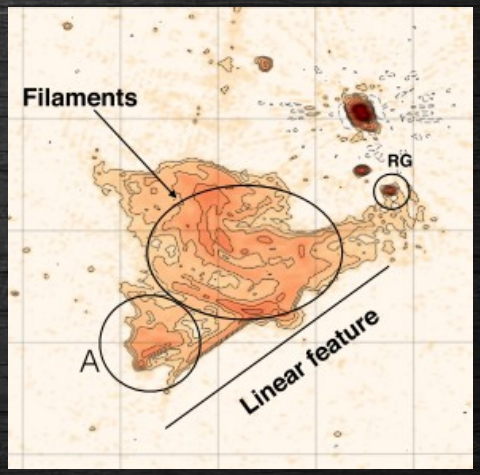
Some **mini-halos** are surrounded by *steep spectrum* emission

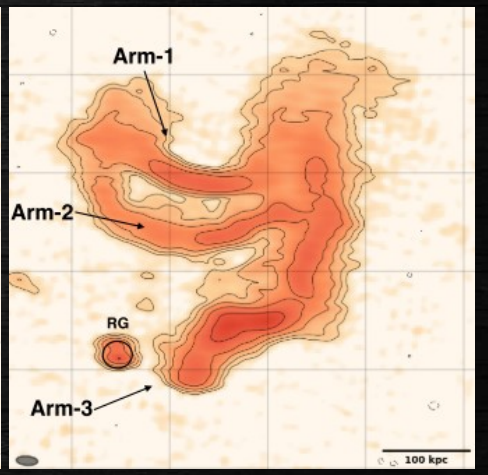
USS radio sources







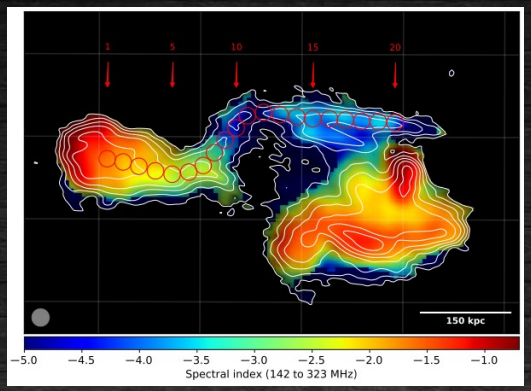




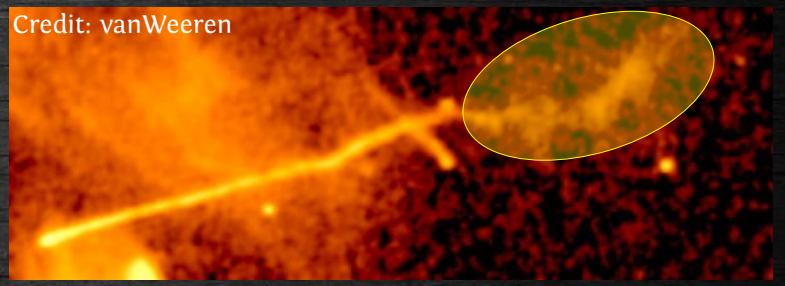
USSRHs are an expectation of the *turbulent re-acceleration* model

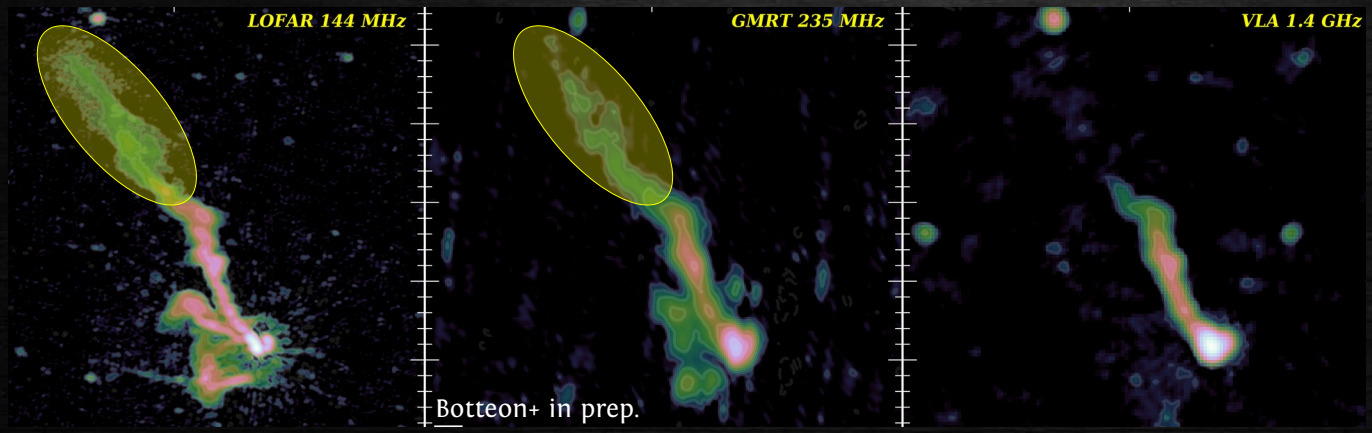
Revived fossil plasma sources with *steep* and *curved* spectra, their origin is still *unclear*

GReET and long tails



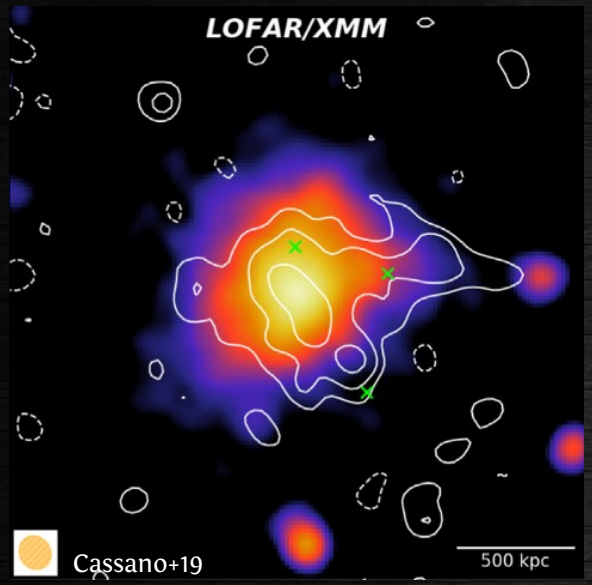
Gentle re-energetizion mechanims *barely balance* radiative losses





Broken and **long** (› 1 Mpc) tails suggest ongoing particle *re-acceleration*

High-z radio halos

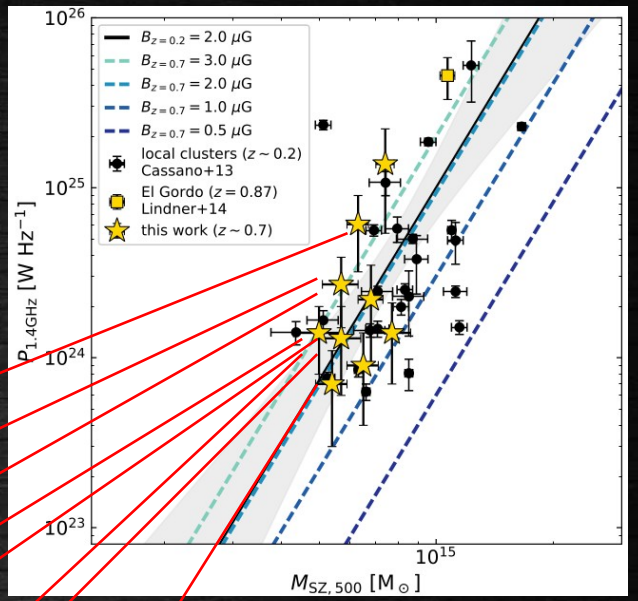


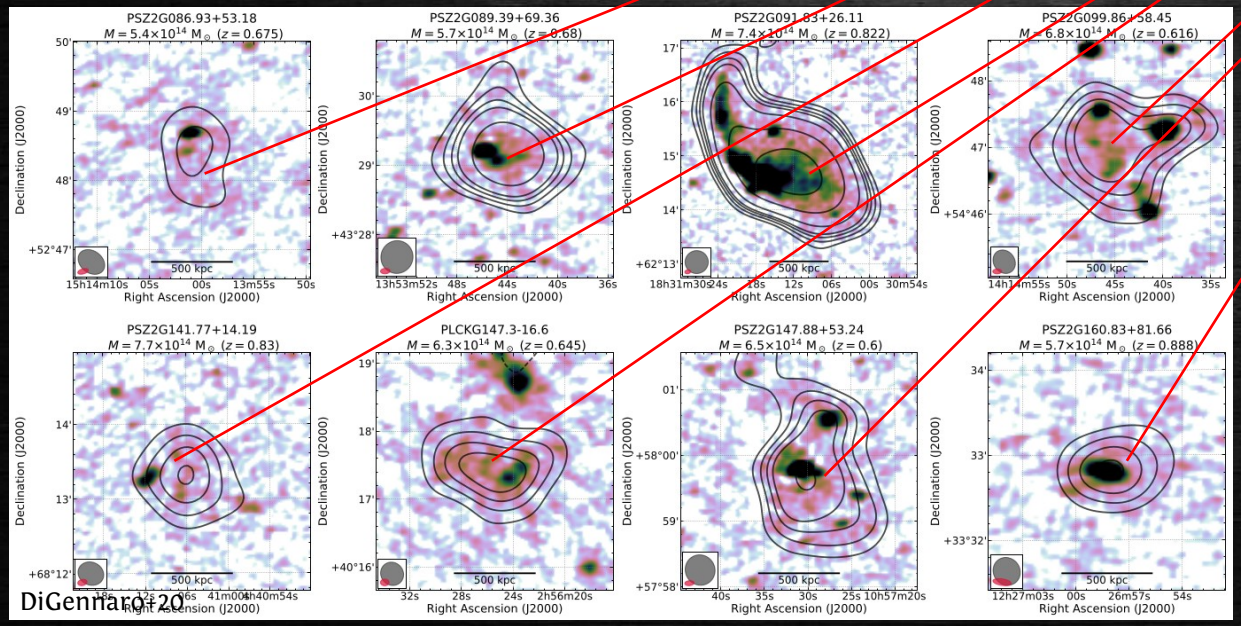
Relativistic electrons lose energy via:

$$\frac{d\gamma}{dt} \propto -\left(B_{CMB}^2 + B^2\right)\gamma^2$$

where

$$B_{CMB} = 3.25(1+z)^2 \mu\mathrm{G}$$





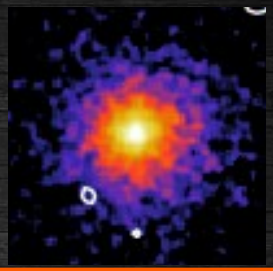
DiGennaro+20

Fast magnetic field amplification in *distant* galaxy clusters

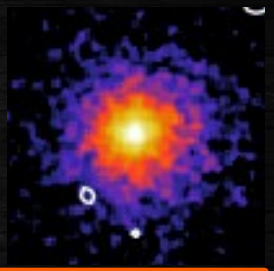
nature astronomy

Pre-merging pairs

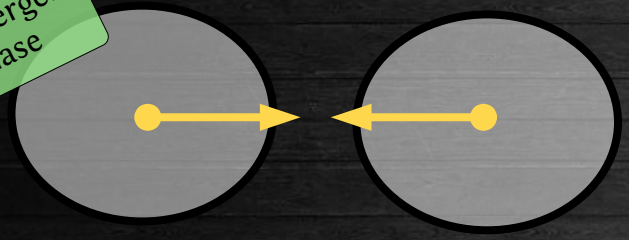
Relaxed, not interacting clusters



No radio emission!

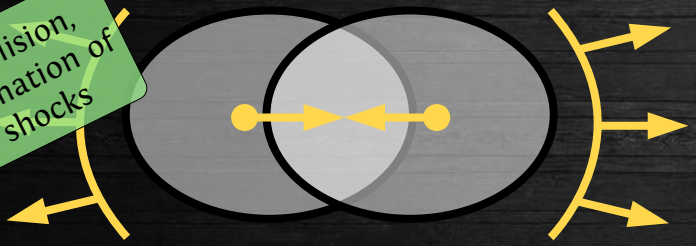


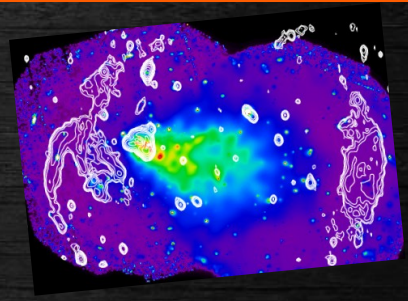
Pre-merger phase



?

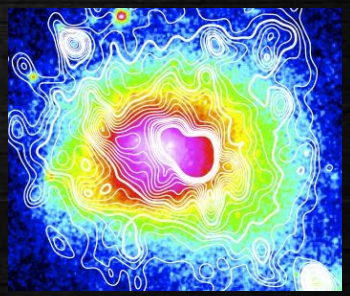
Collision, formation of shocks





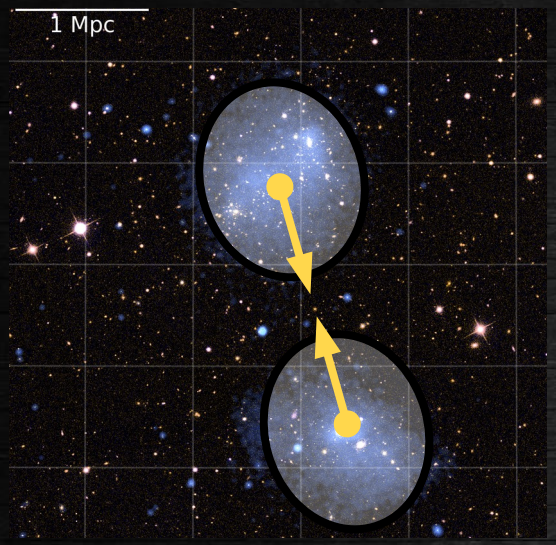
Radio relics!

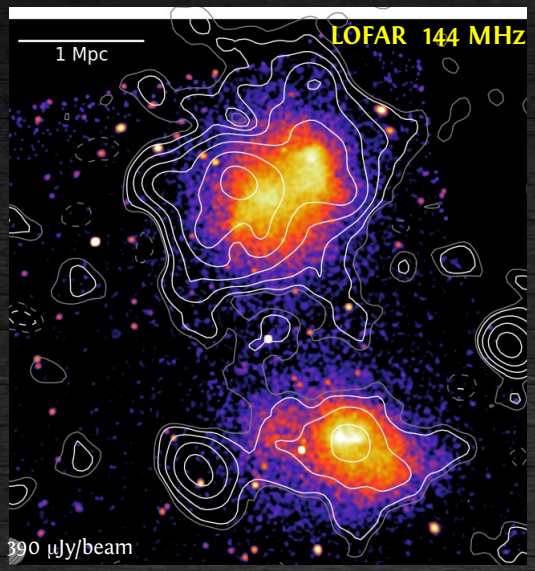
Turbulence injected in the ICM



Radio halos!

A1758N & A1758S

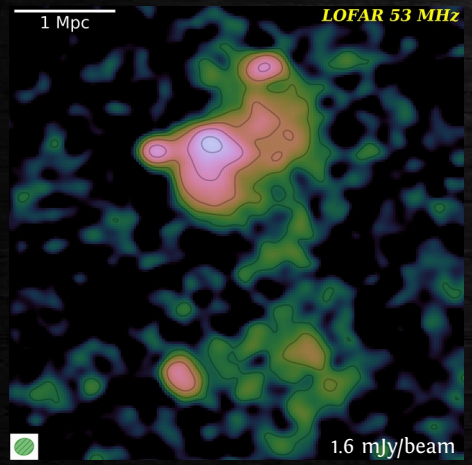


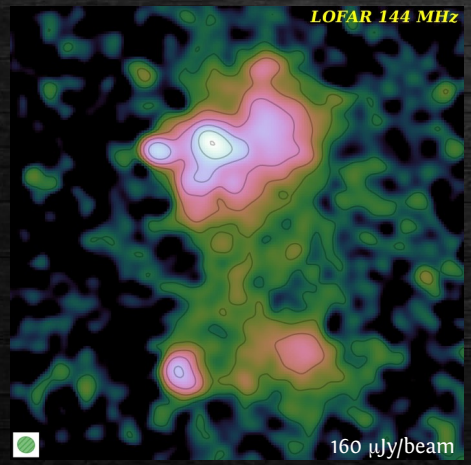


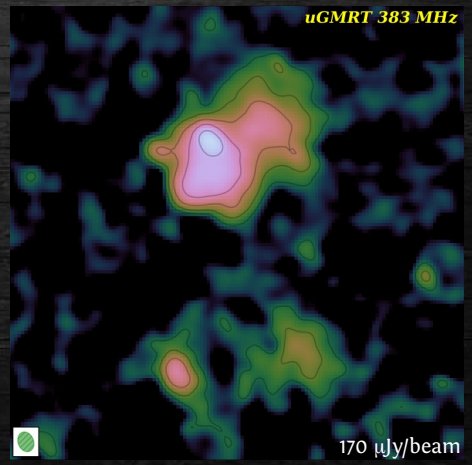
Separated by **2 Mpc**, A1758N & A1758S form a *pre-merging* system

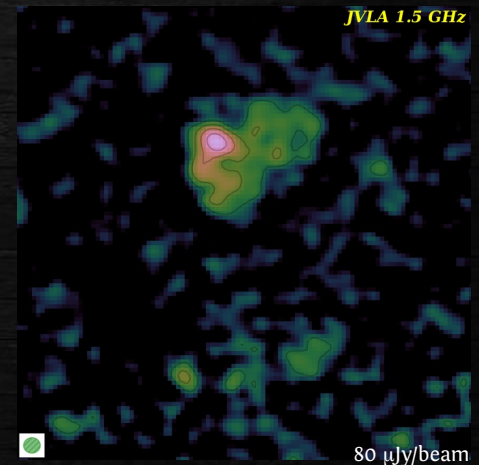
Discovery of a double radio halo + candidate relic + *tentative bridge*
(Botteon+18)

Deep LBA, HBA, uGMRT, JVLA follow-ups → **bridge confirmed** (Botteon+20)

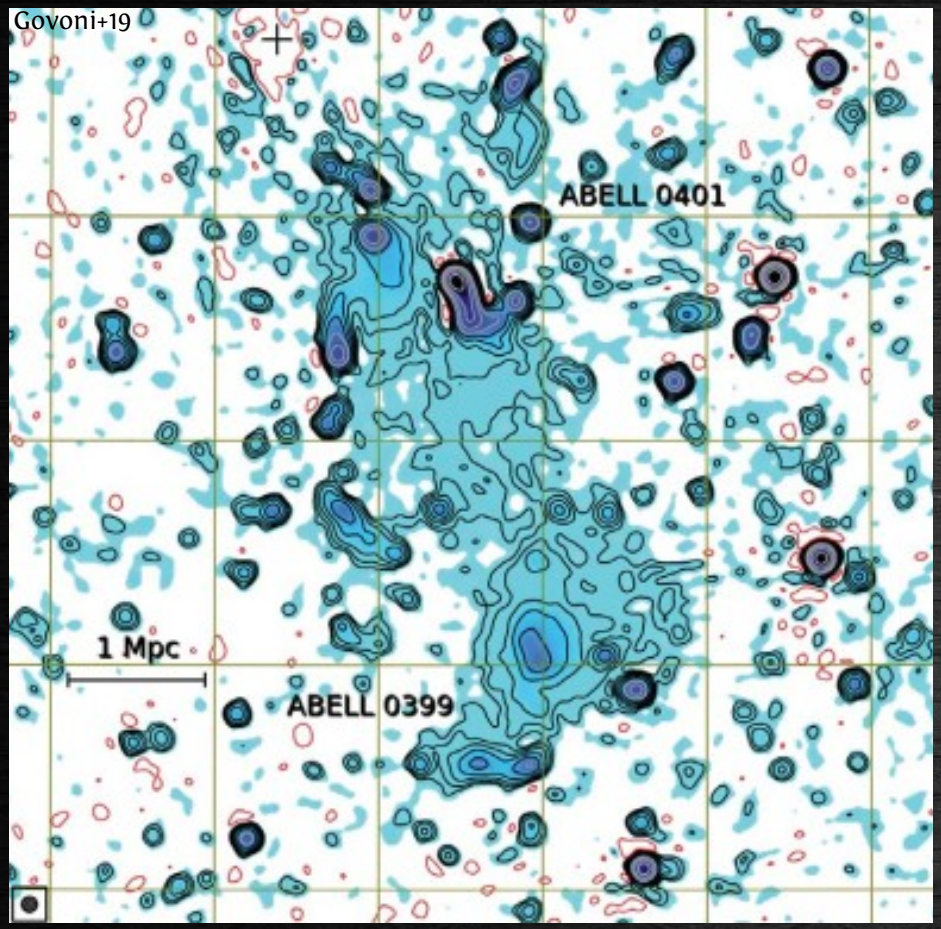


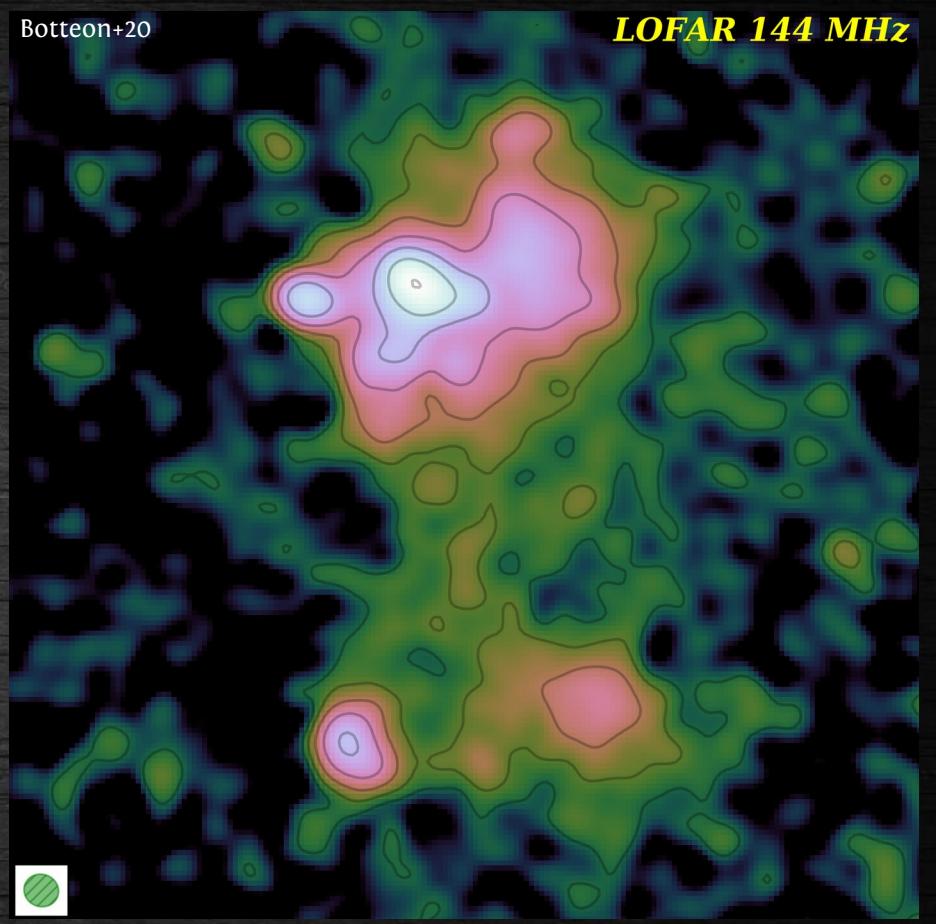






A399+A401 & A1758

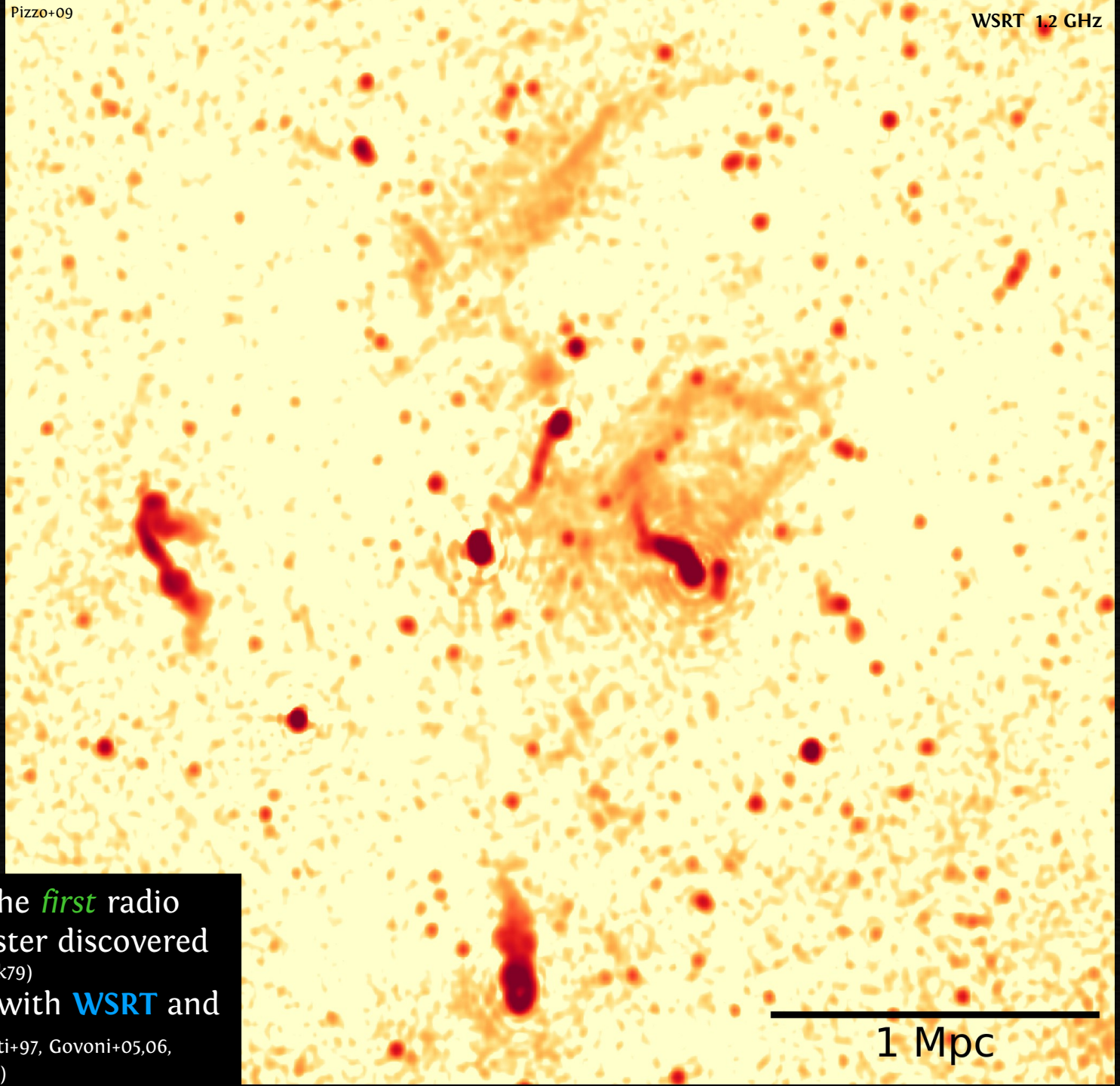




LOFAR has discovered *radio bridges*
connecting *pre-merging* galaxy clusters

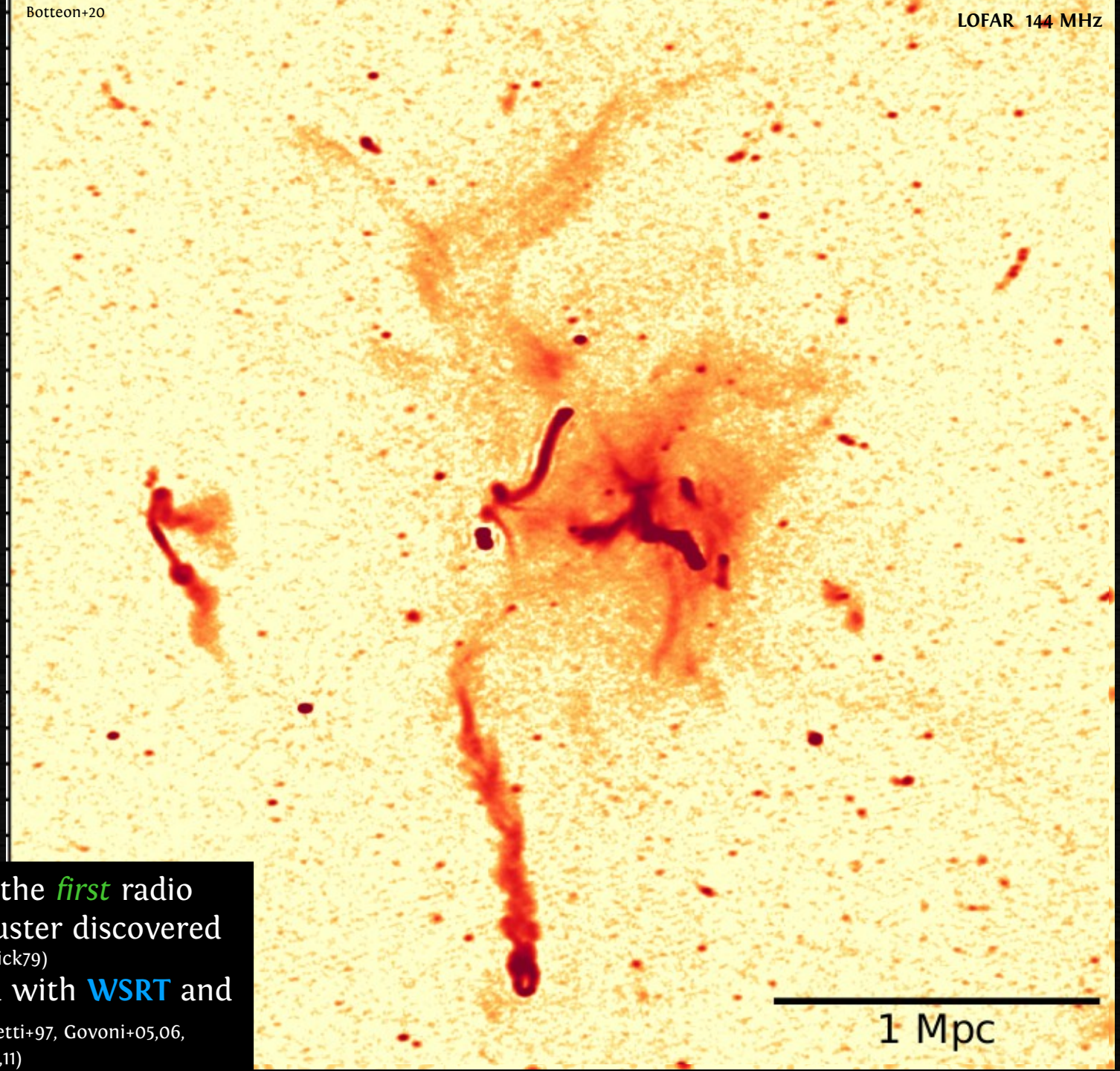
Shock re-acceleration (Govoni+19)? *Turbulent* re-acceleration (Brunetti+Vazza20)?

Abell 2255



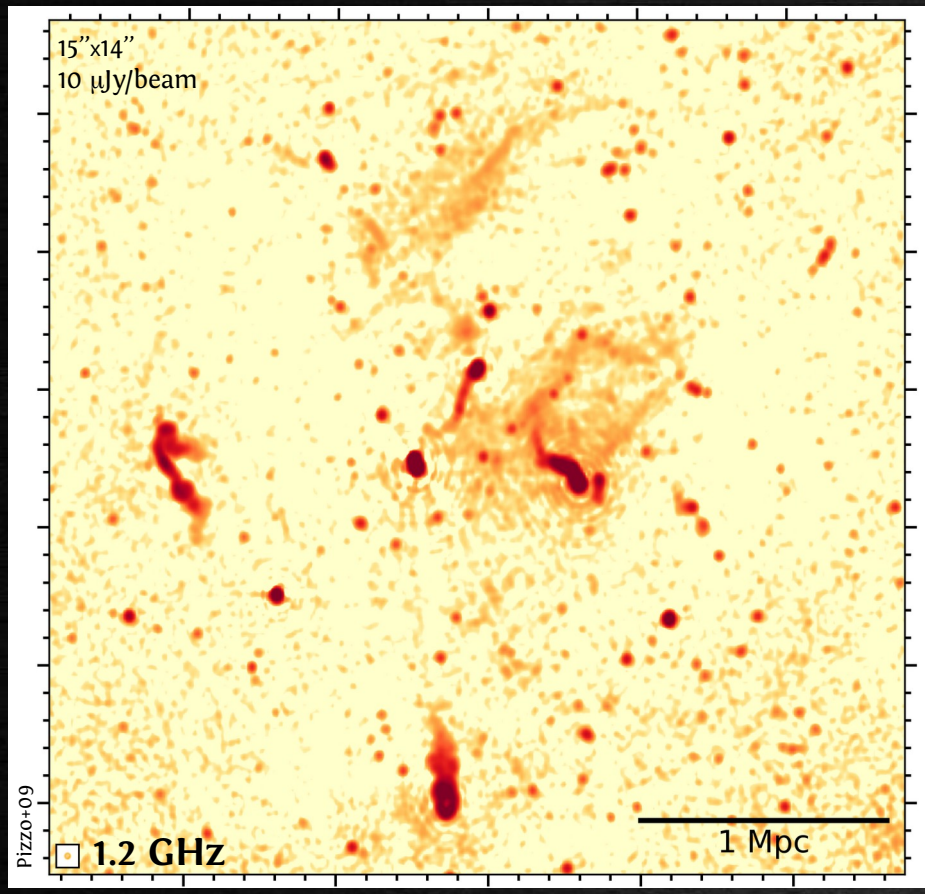
- One of the *first* radio halo cluster discovered (Jaffe+Rudnick79)
- Studied with **WSRT** and **VLA** (Feretti+97, Govoni+05,06, Pizzo+08,09,11)

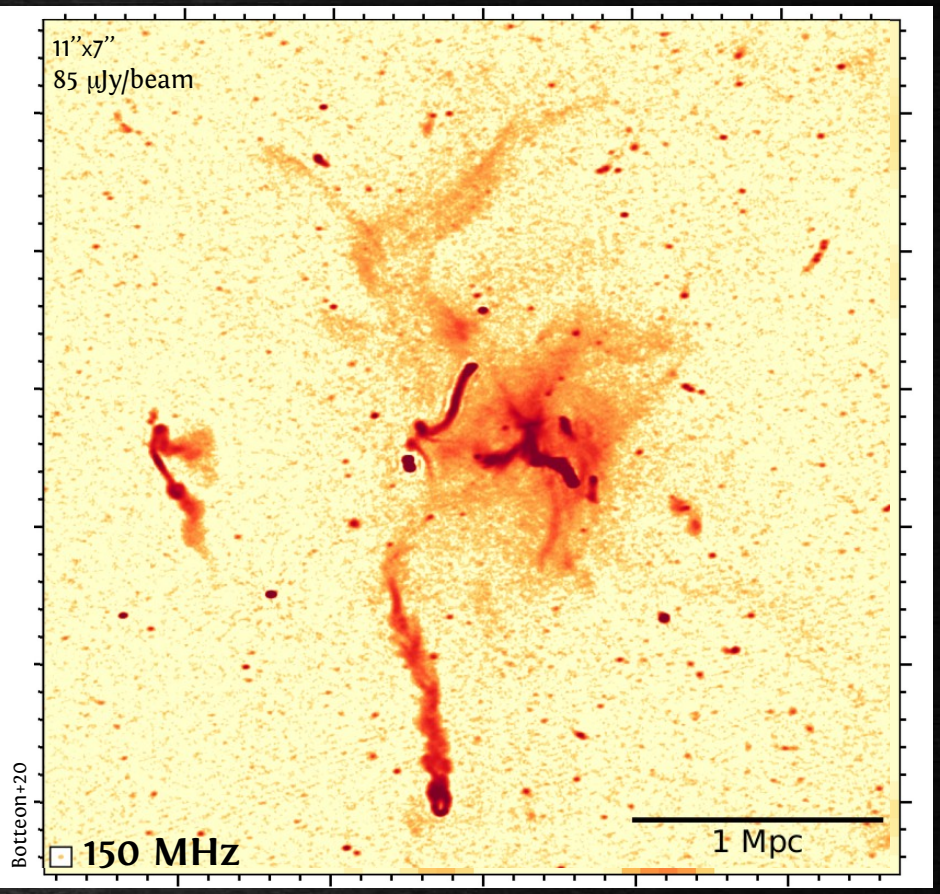
Abell 2255



- One of the *first* radio halo cluster discovered (Jaffe+Rudnick79)
- Studied with **WSRT** and **VLA** (Feretti+97, Govoni+05,06, Pizzo+08,09,11)

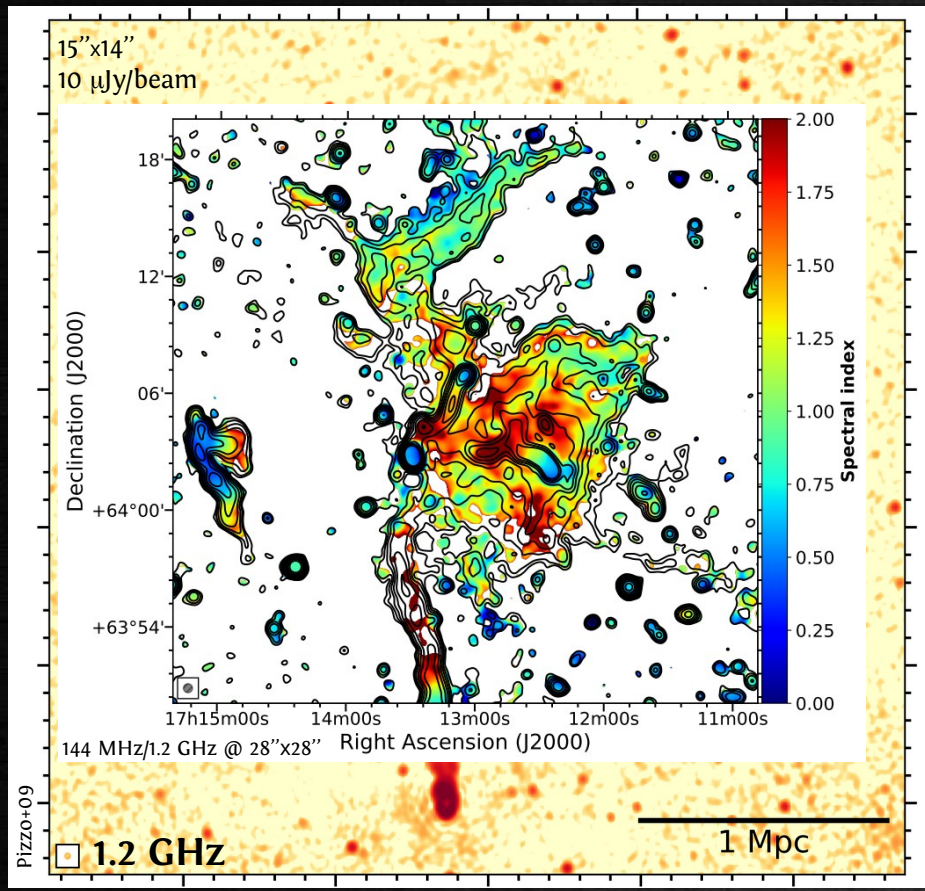
WSRT vs LOFAR

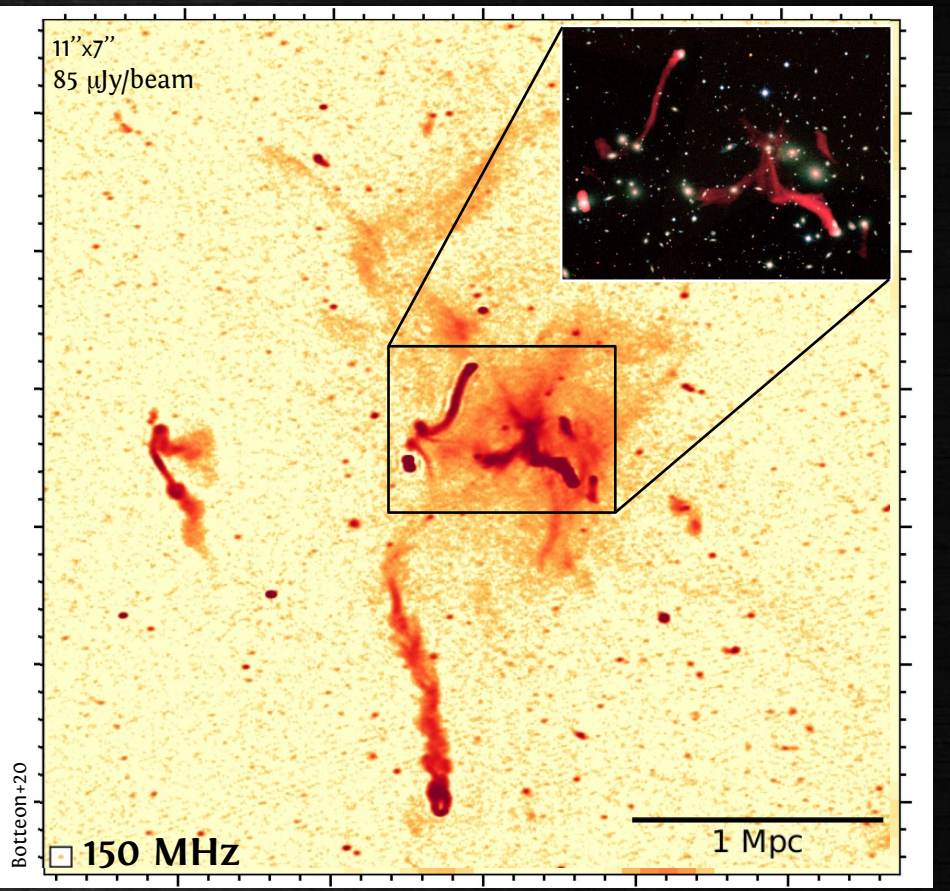




LOFAR demonstrates the power of *highly* sensitive *low frequency* observations

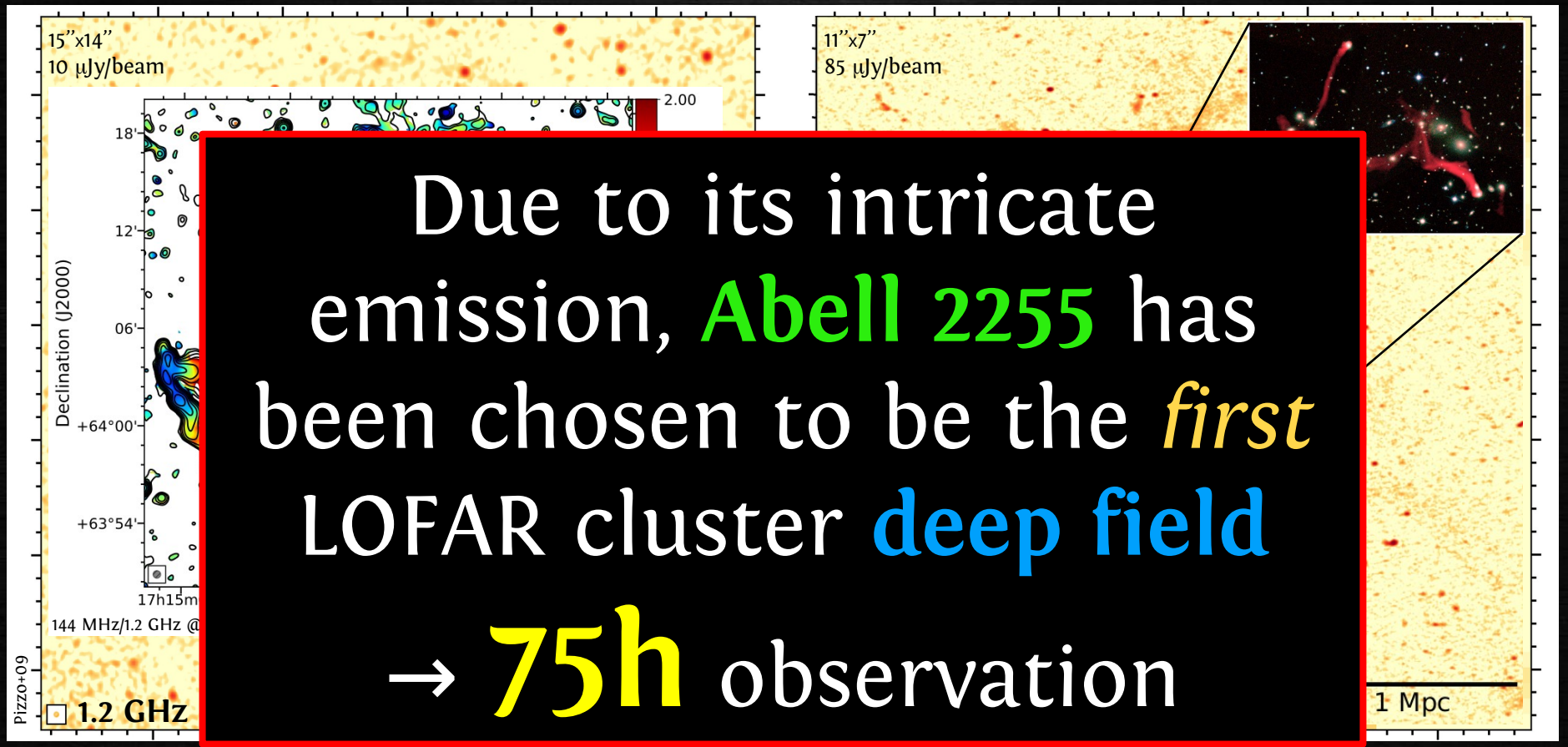
WSRT vs LOFAR





LOFAR demonstrates the power of *highly* sensitive *low frequency* observations

WSRT vs LOFAR



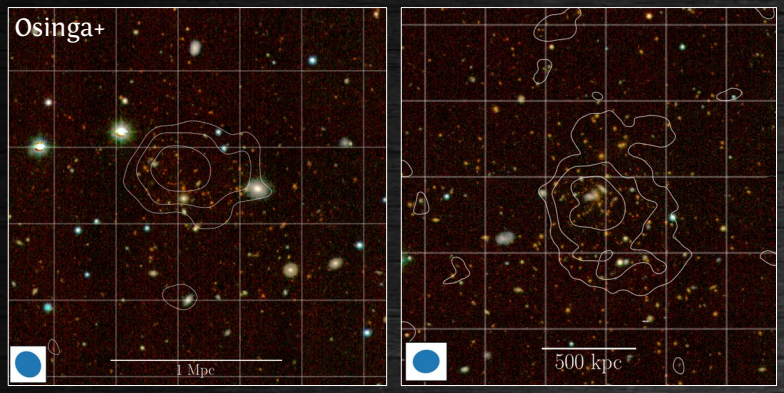
Due to its intricate emission, **Abell 2255** has been chosen to be the *first* LOFAR cluster **deep field**

→ **75h** observation

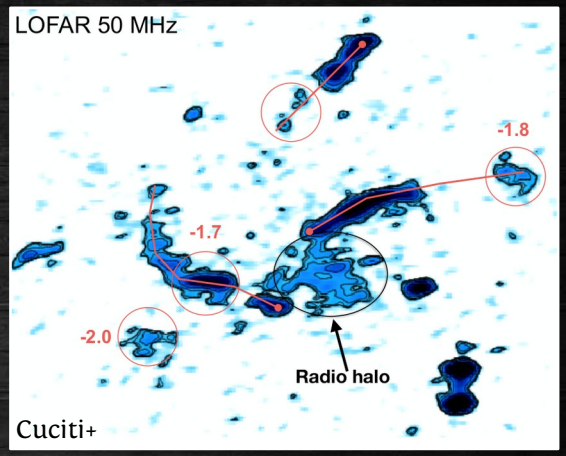
LOFAR demonstrates the power of *highly* sensitive *low frequency* observations

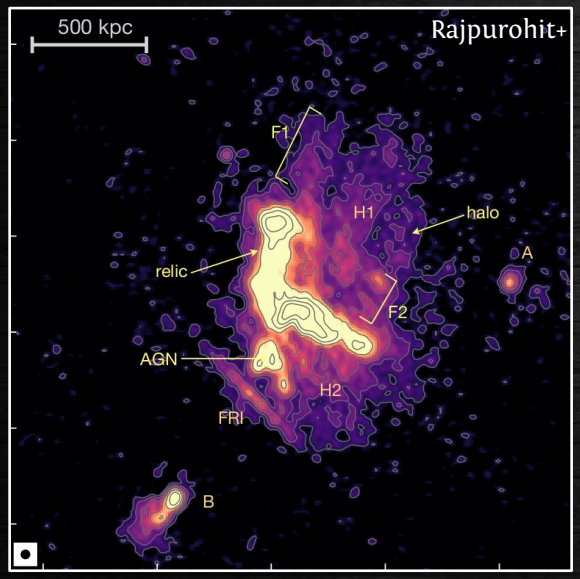
Coming soon...

Clusters in deep fields

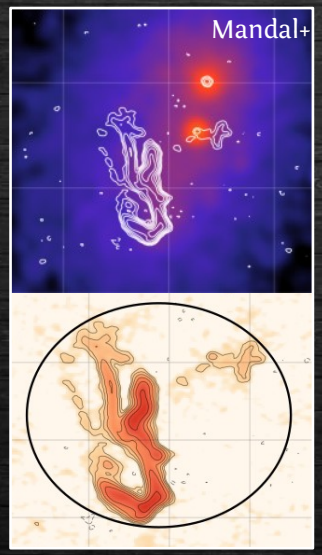


Extended+steep tails

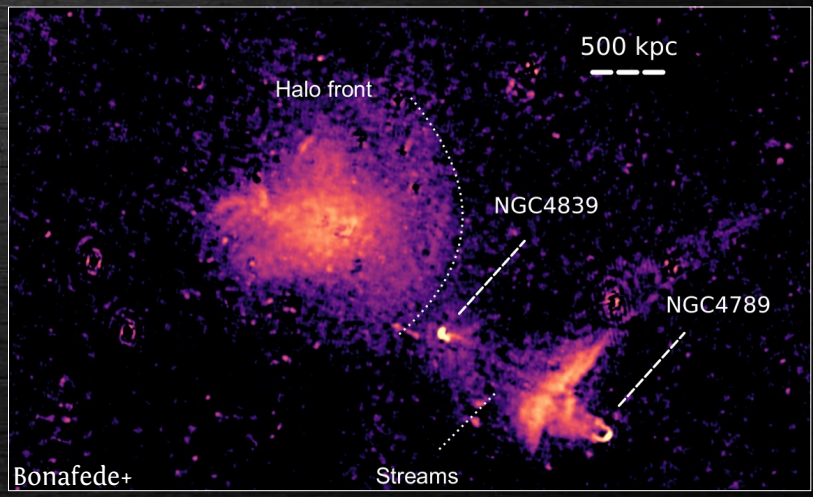




MACS J0717.5+3745



New phoenixes

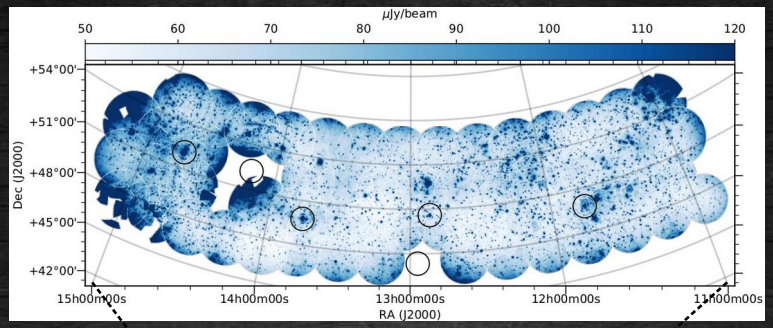


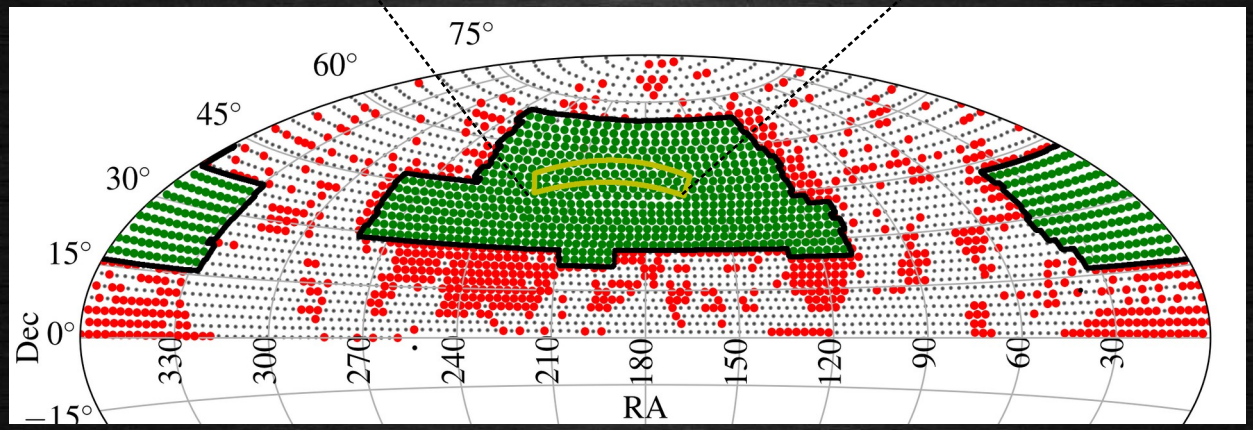
Coma cluster

LoTSS-DR2

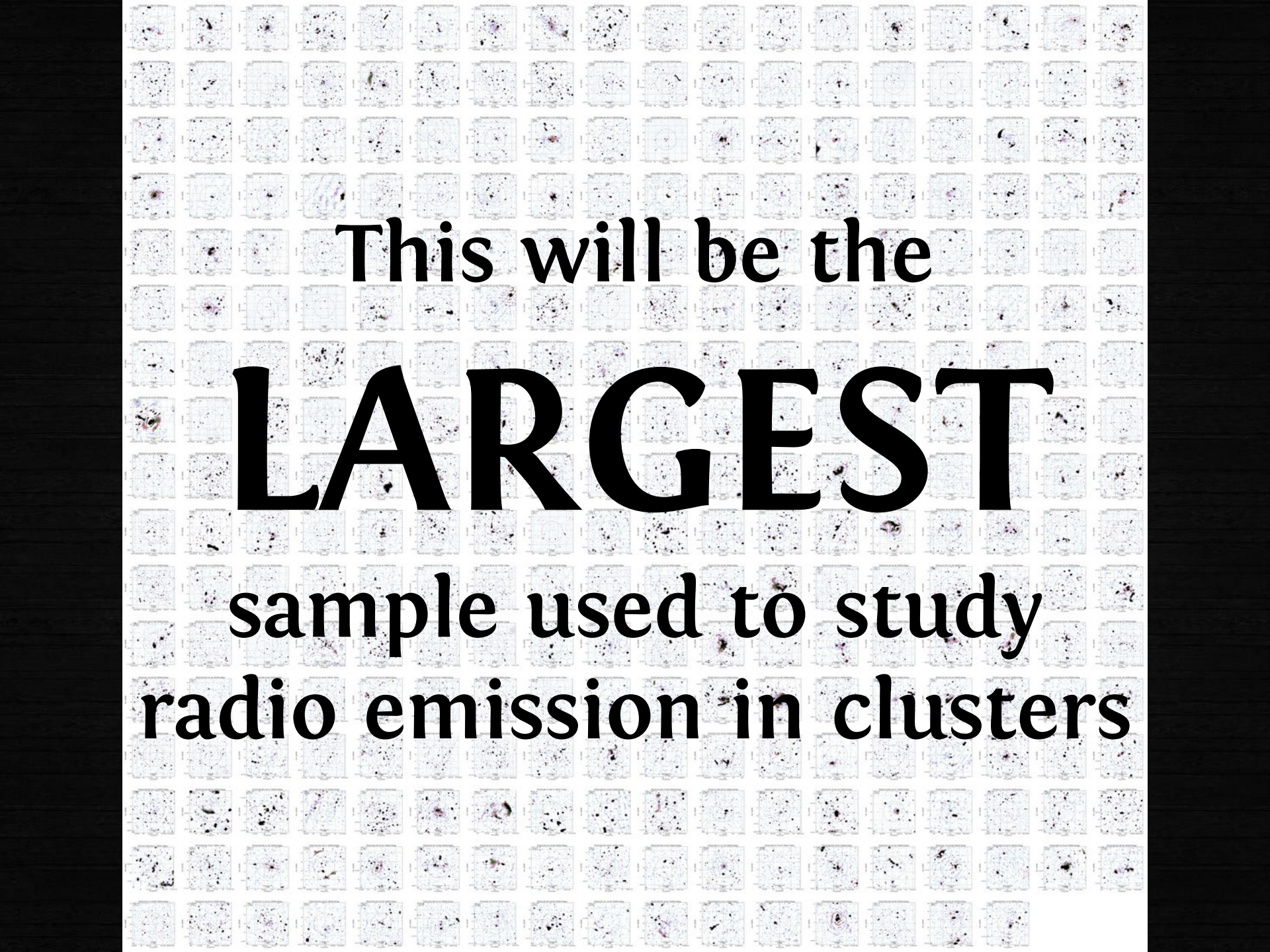
The **second** LoTSS DR will occur in *2021*

DR2 ≃ **13x** DR1





Statistical analysis of **309** PSZ2 galaxy clusters exploring new ranges of *redshift* and *mass*


This will be the
LARGEST
sample used to study
radio emission in clusters

Conclusions

- Diffuse radio sources in the **ICM** probe CRs and B on *large* scales
- Connection with **ICM motions**: *turbulence* and *shocks*
- **LOFAR** & **LoTSS** are ideal tools to study galaxy clusters
- Discovery of *new* kind of sources in the ICM
- Implications on *acceleration mechanisms*+*B formation/evolution*
- Detection of radio emission on *unprecedented large scales*
- Many forthcoming results, including **LoTSS-DR2**

Thank you