Ultra-steep diffuse emission outside the cluster core observed with LOFAR at 144 MHz in cool-core galaxy clusters

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Collaborators: Bonafede, de Gasperin, Riseley, et al.

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DRANOEL
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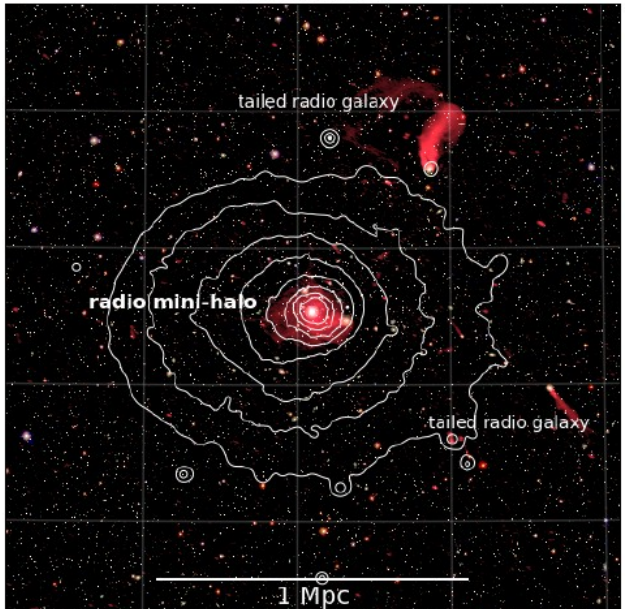
GALAXY CLUSTERS

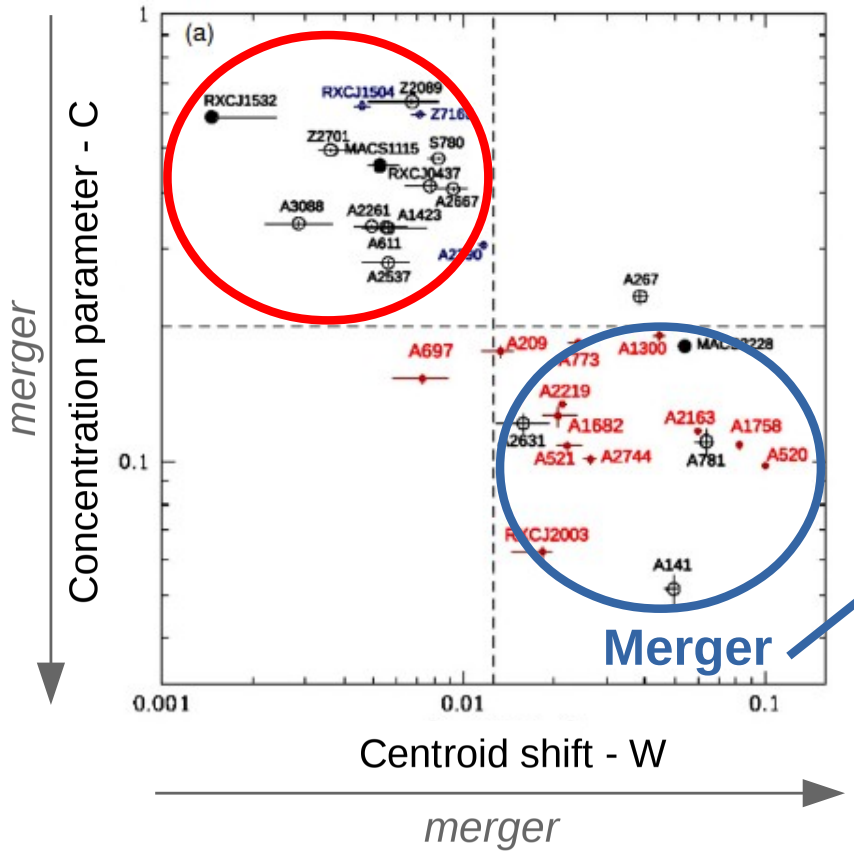
Mini halo



Radio diffuse emission:

- 100 – 500 kpc size
- at center of relaxed cool-core clusters
- due to turbulence after minor merger or collisions of protons

Relaxed

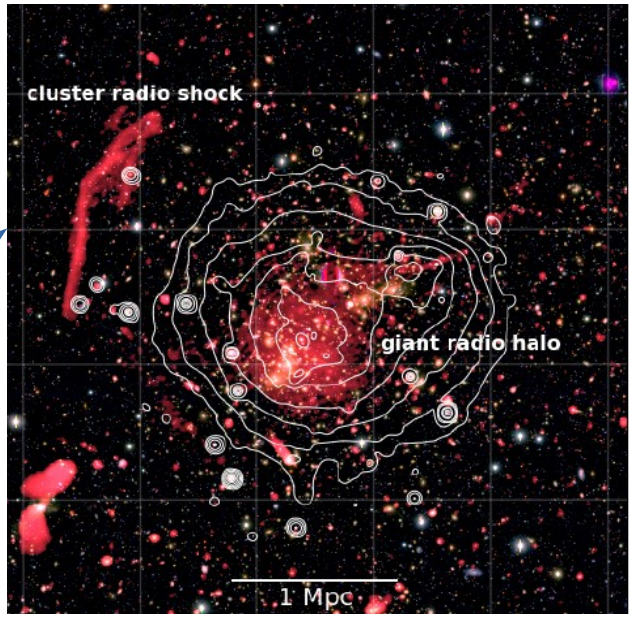


(Cassano et al. 2010)

Giant halo

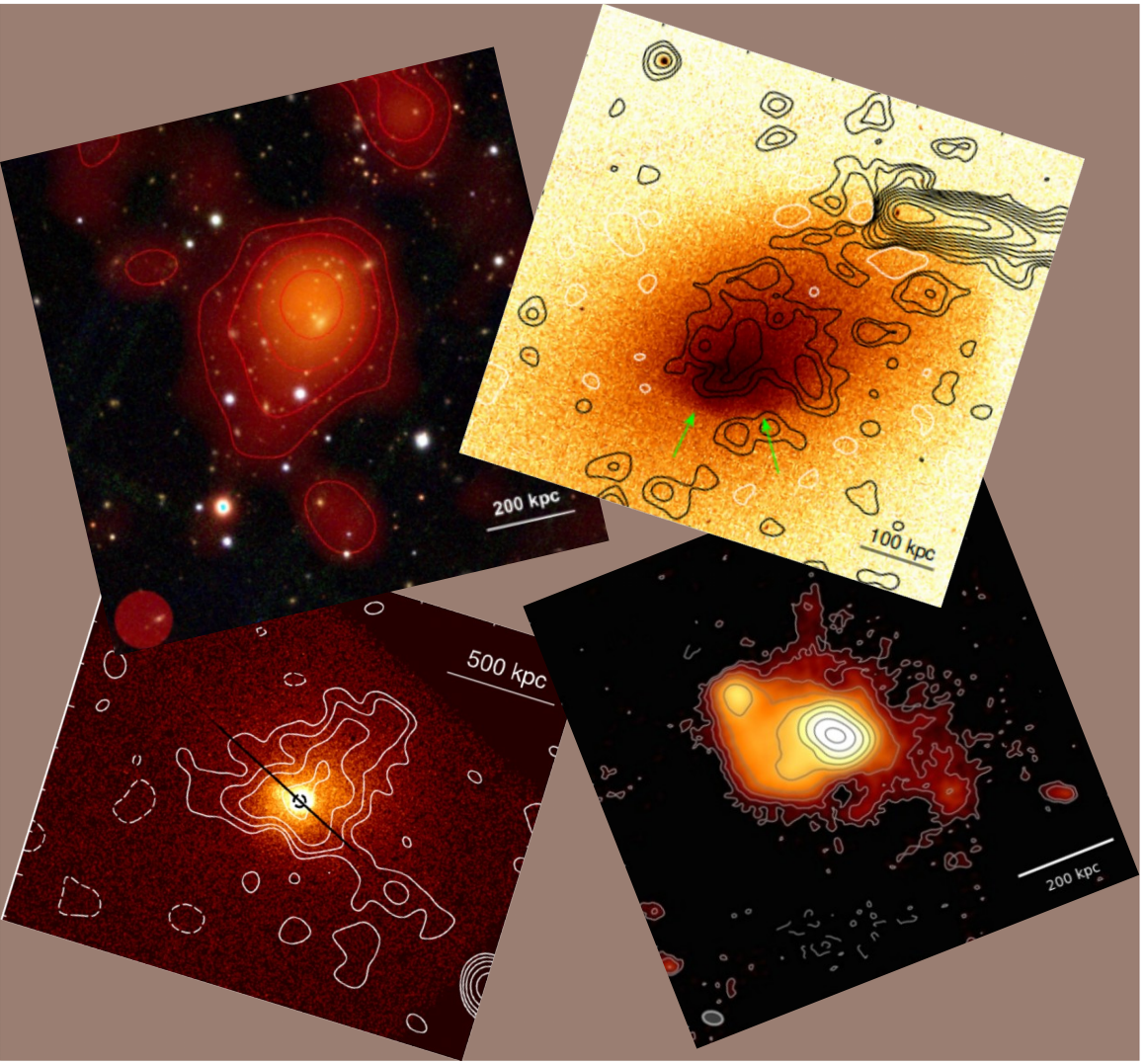
Radio diffuse emission:

- Mpc size
- Center of merging clusters
- Acceleration of particles by turbulence after major merger



(van Weeren et al. 2019)

A more complex picture ...



Detected diffuse radio emission
on scales larger than 500 kpc
in cool-core galaxy clusters

Hybrid morphology

Idea: minor merger energetic
enough to re-accelerate particles
on a large scale without
disrupting the cool-core?

Steep spectrum $\alpha > 1.5$

Common at low frequency?

A sample of cool-core clusters

Aims:

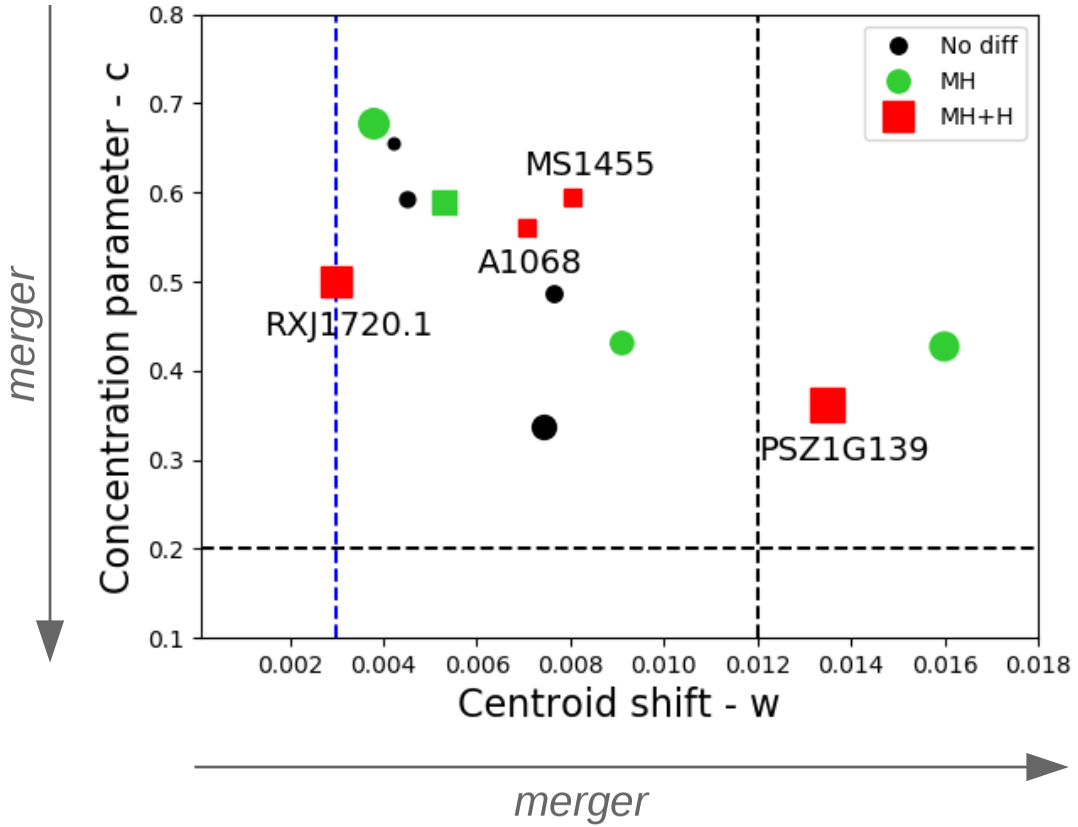
- Test occurrence of hybrid sources
- Verify minor merger scenario

Selection criteria:

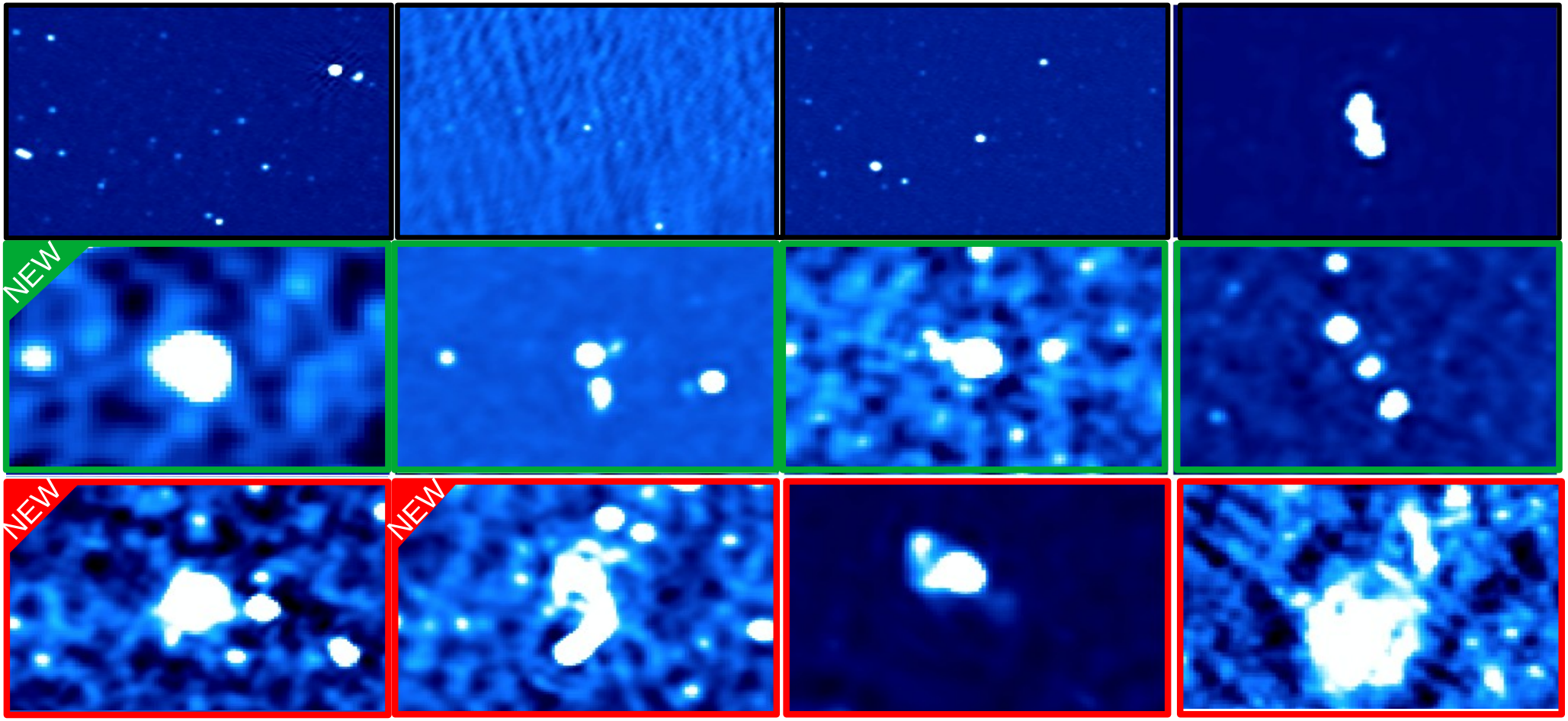
- Cool-core (c > 0.2)
- Signs of dynamical interaction
  on scales larger than the core (w > 0.003)

The sample:

- 12 cool-core clusters
- Observed with LOFAR at 144 MHz

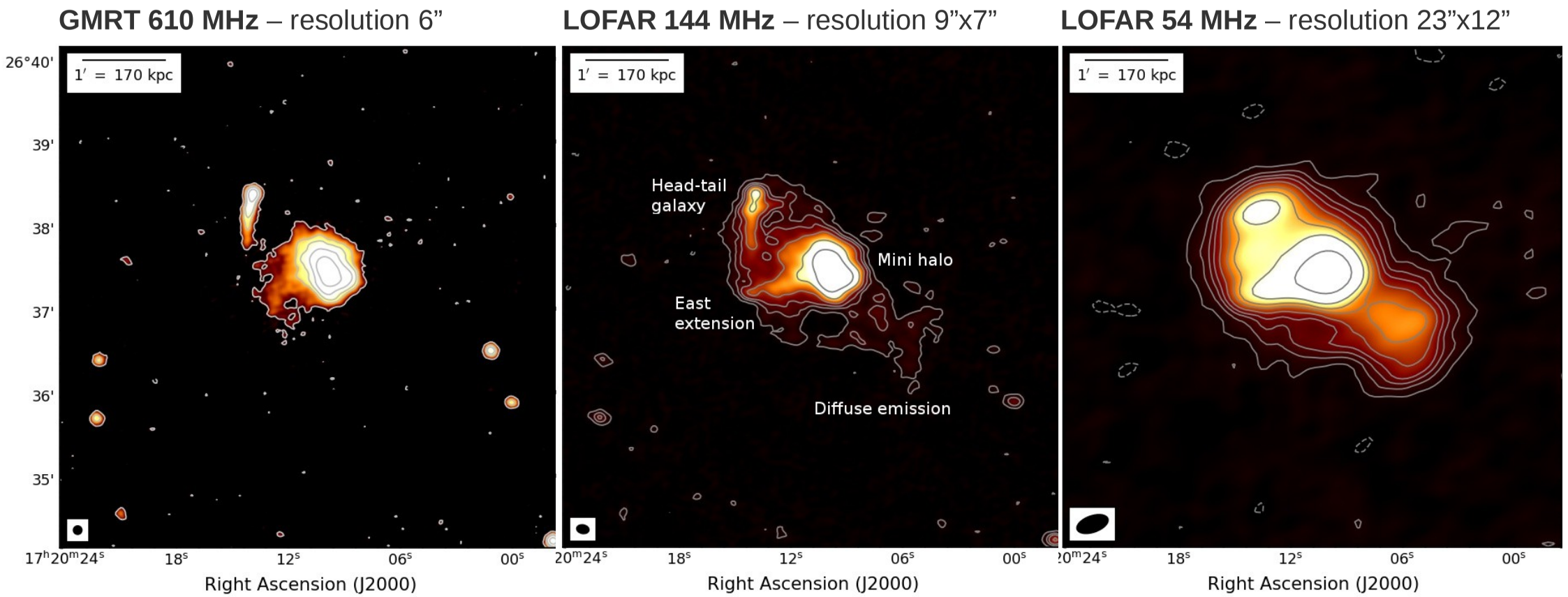


LOFAR 144 MHz – resolution 20 arcsec



4 - No diffuse emission 4 - Mini halo 4 - Hybrid sources

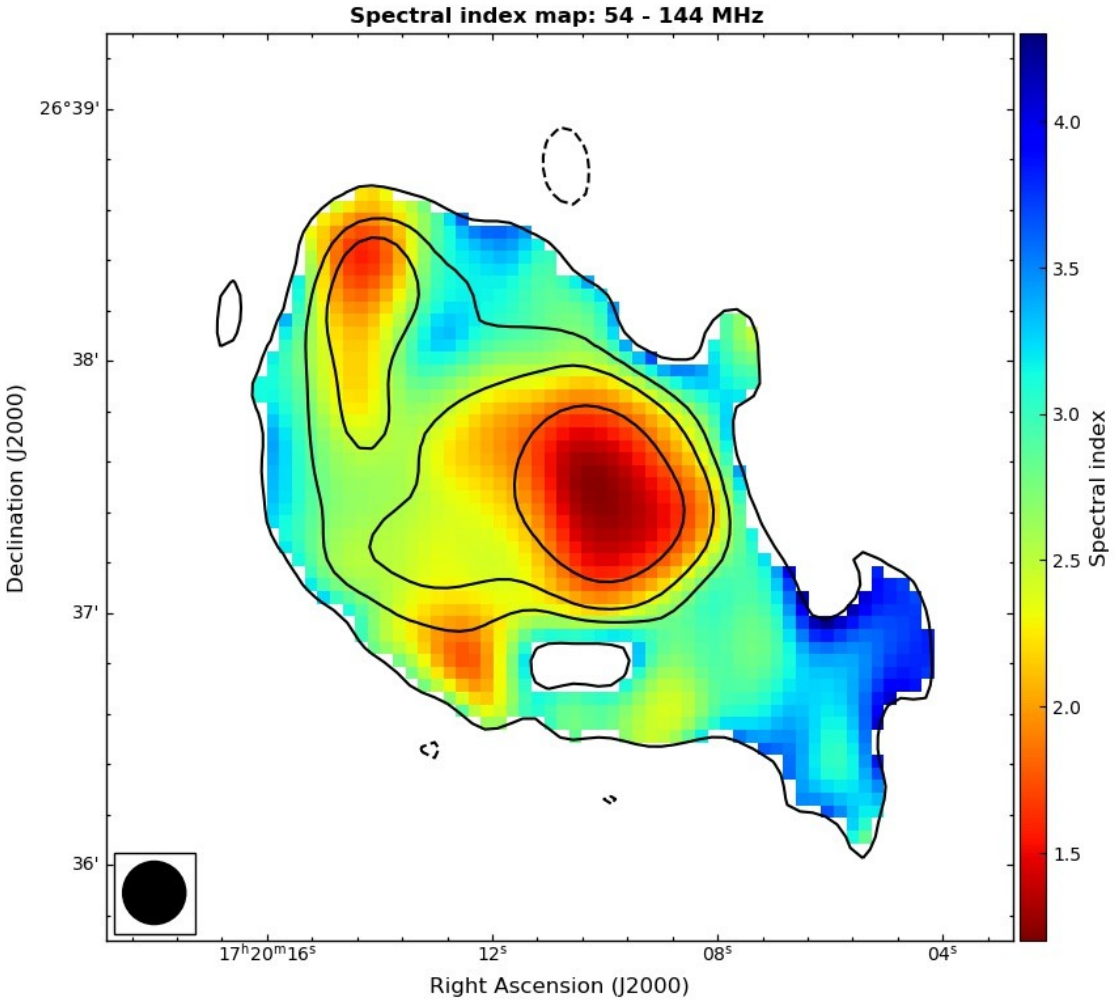
RX J1720.1+2638



- LOFAR revealed the presence of faint diffuse emission outside the cluster core (d ~600 kpc)
- Savini et al. 2018 provide a lower-limit $\alpha \geq 1.5$

→ LOFAR LBA observations to constrain the spectral index (Biava et al. 2021)

RX J1720.1+2638



Spectral index study

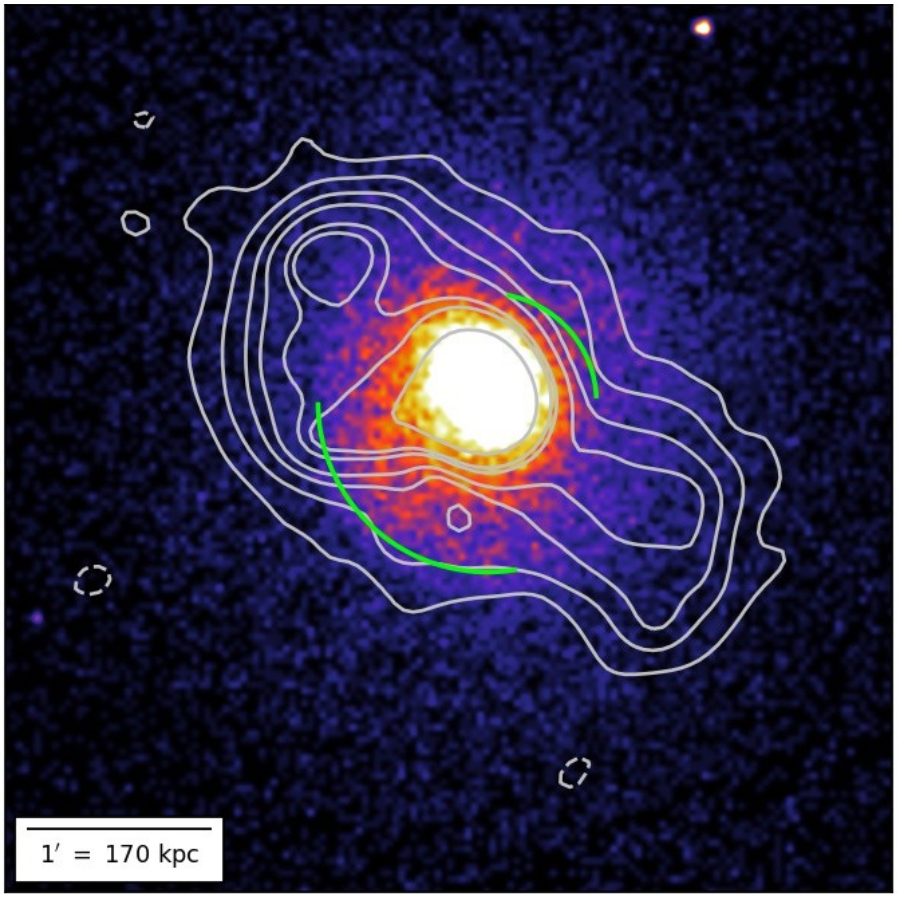
Ultra steep diffuse emission outside the cluster core

$\alpha = 3.2 \pm 0.2$

Net difference of spectral index between mini halo and more diffuse emission

Different nature of diffuse emission inside and outside the cluster core

RX J1720.1+2638



Radio & X-ray comparison

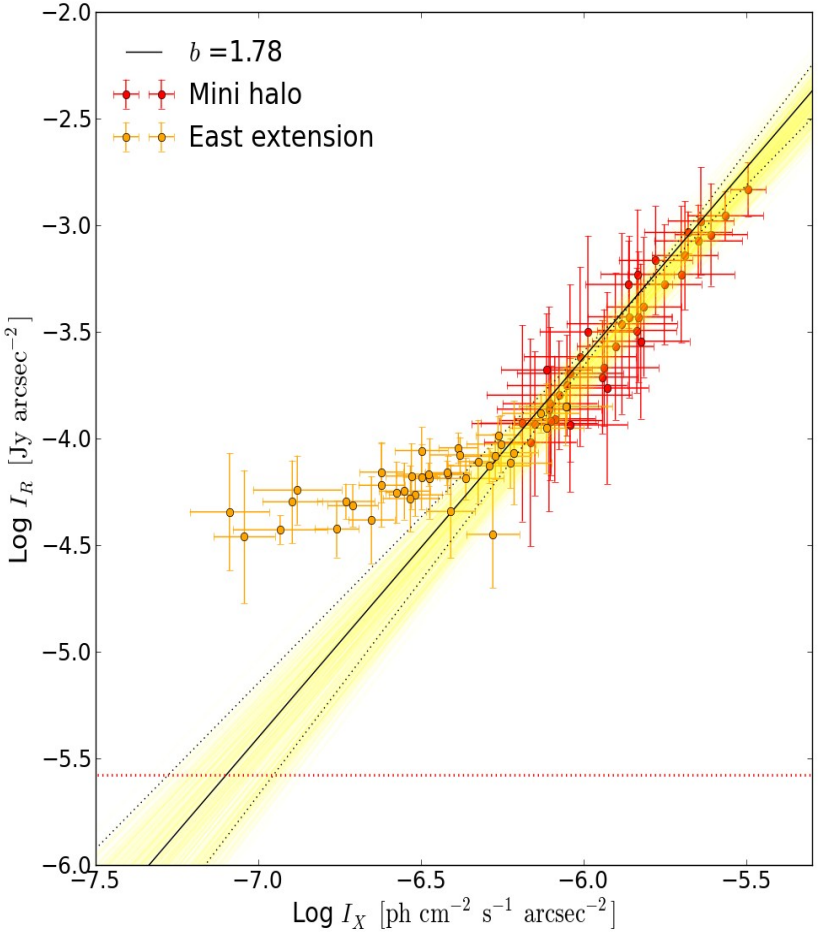
Relaxed and regular morphology on large scale with a bright central core

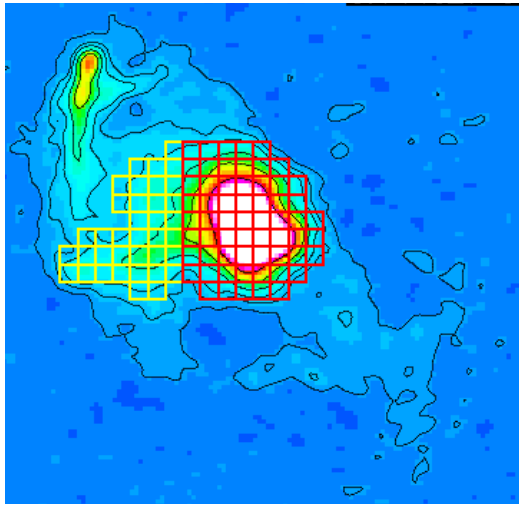
Presence of two cold-fronts (green arcs)

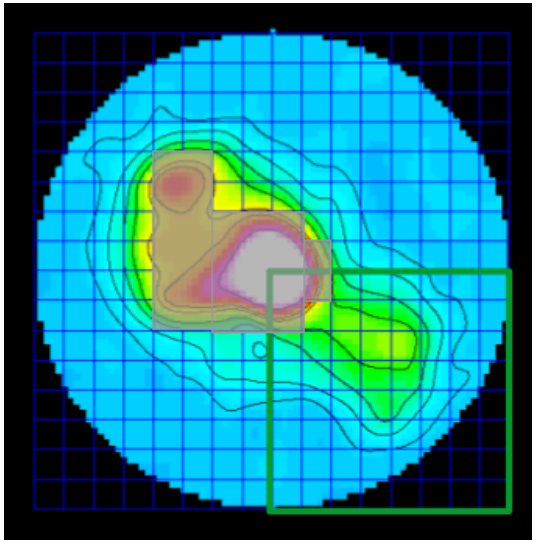
Radio emission extends beyond the cluster core, perpendicular to the cold-fronts

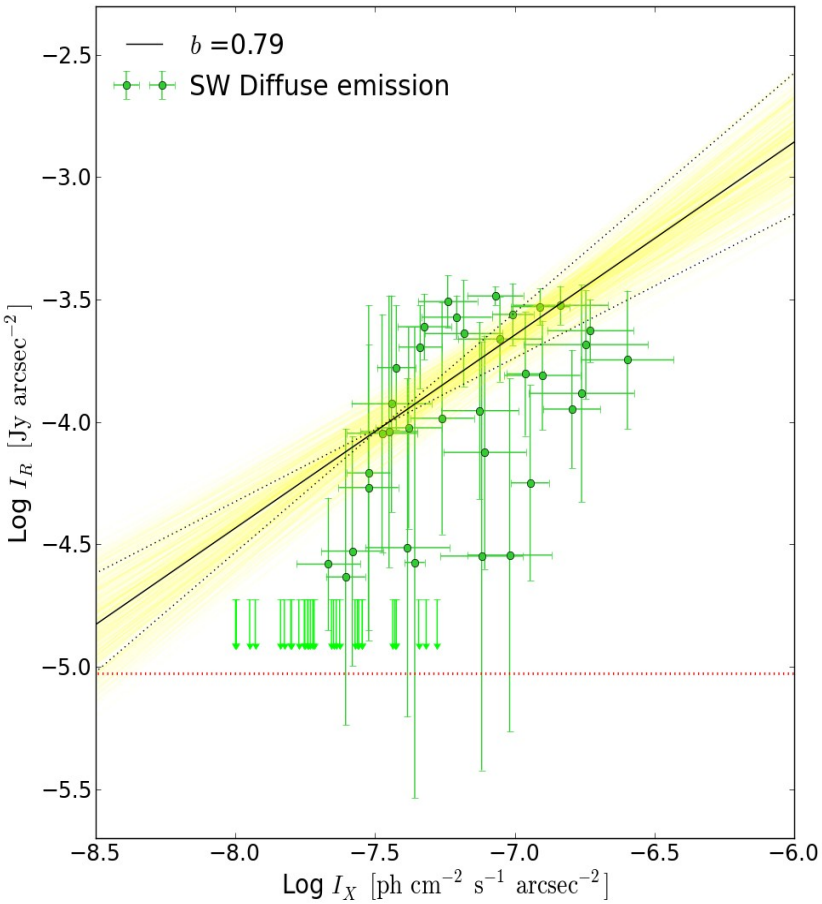
No presence of a cavity in correspondence of diffuse emission outside the cluster core

RX J1720.1+2638









b = 1.78 ± 0.22 r_p = 0.96

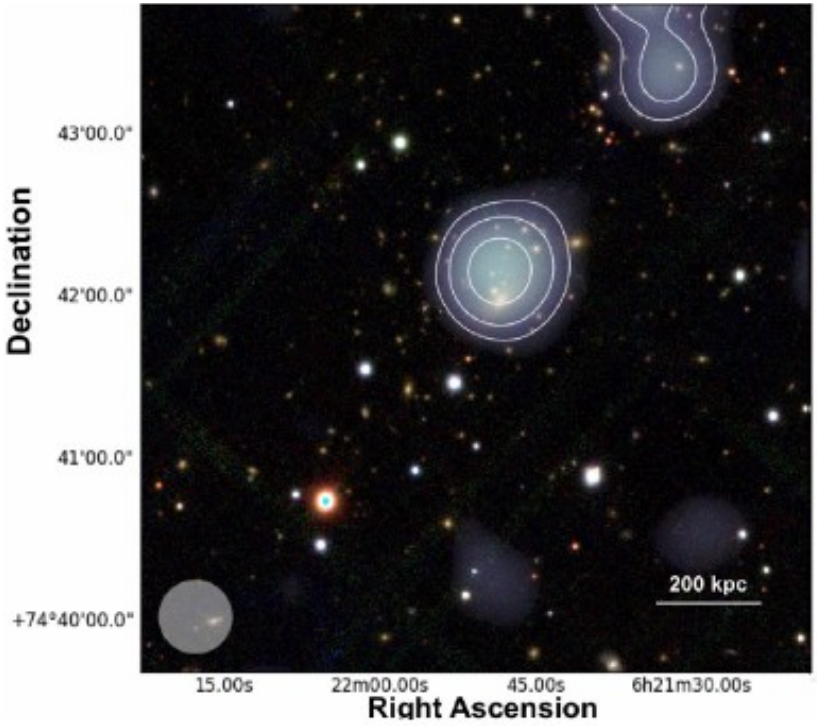
b = 0.61 ± 0.08 r_p = 0.79

b = 0.79 ± 0.20 r_p = 0.71

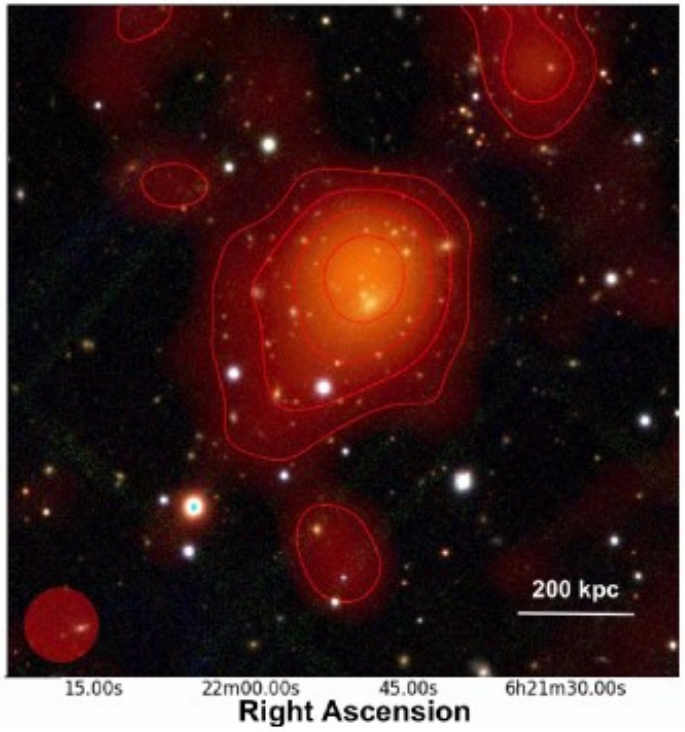
(Biava et al. 2021)

PSZ1G139.61+24

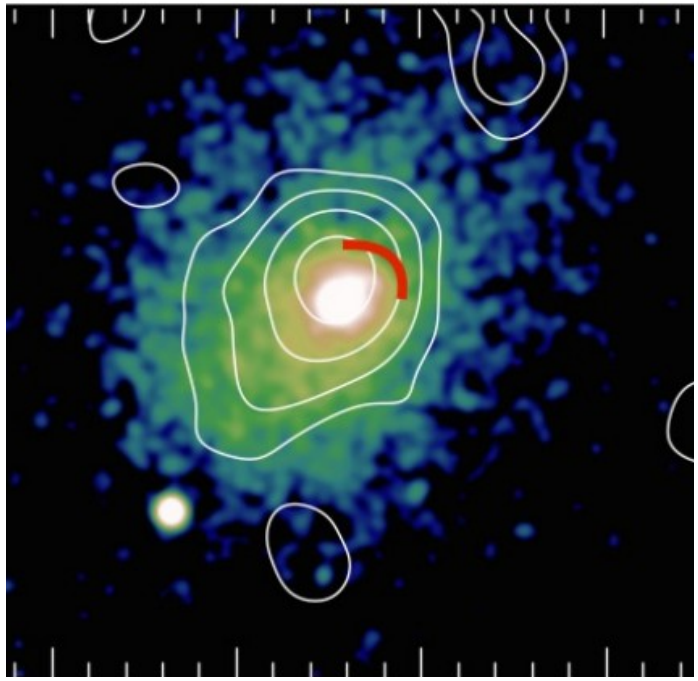
GMRT 610 MHz – resolution 35”



LOFAR 144 MHz - resolution 35”

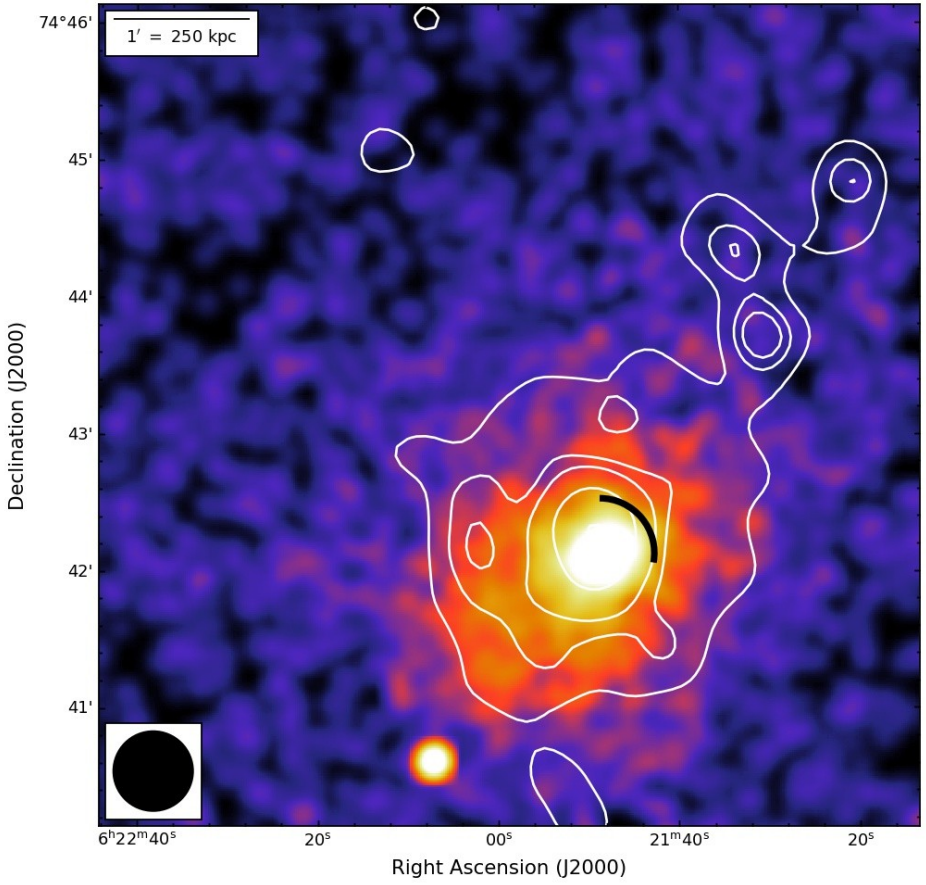


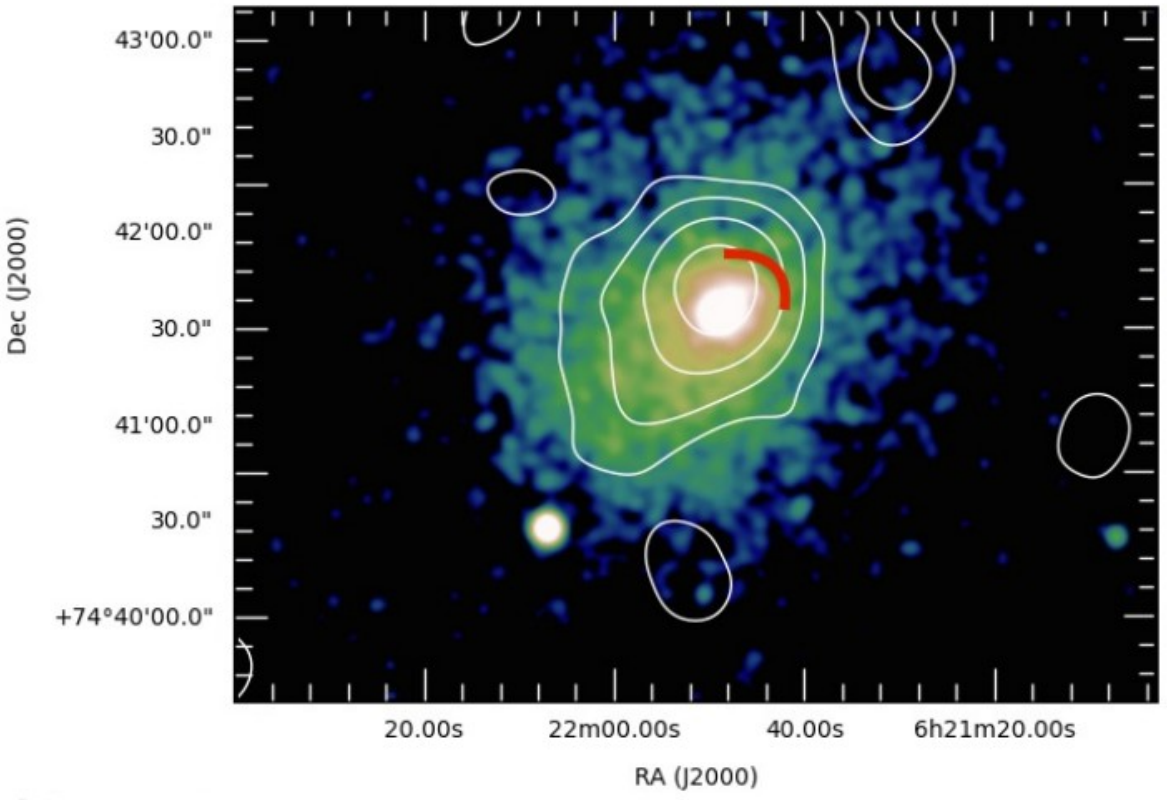
Chandra map + LOFAR contours (35”)



- LOFAR revealed the presence of faint diffuse emission outside the cluster core (d ~600 kpc)
- Savini et al. 2018 provide a lower-limit $\alpha \geq 1.7$
- Presence of X-ray cold-front

PSZ1G139.61+24

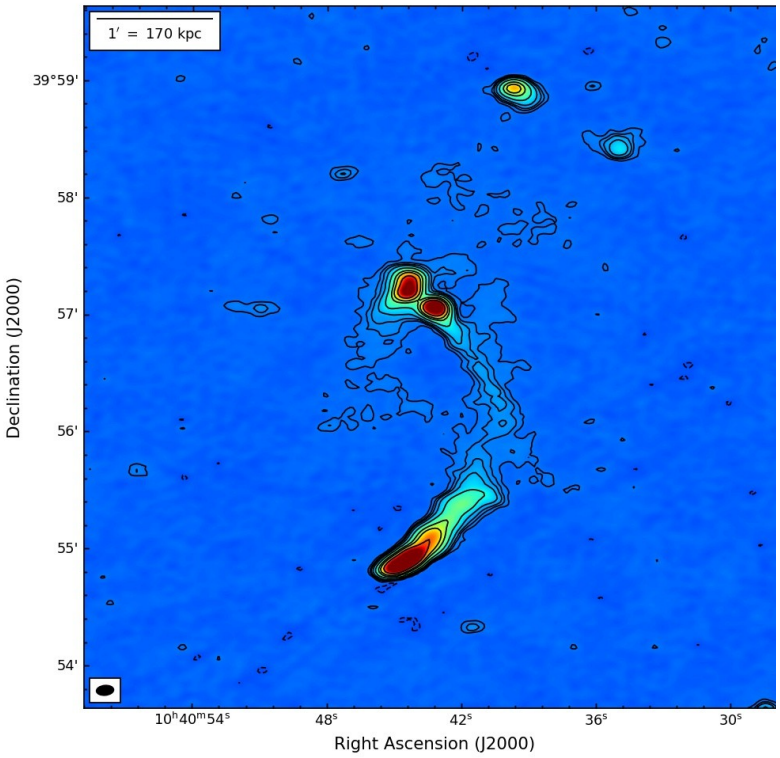




Recalibration of LOFAR data: Diffuse emission is more extended than previously observed

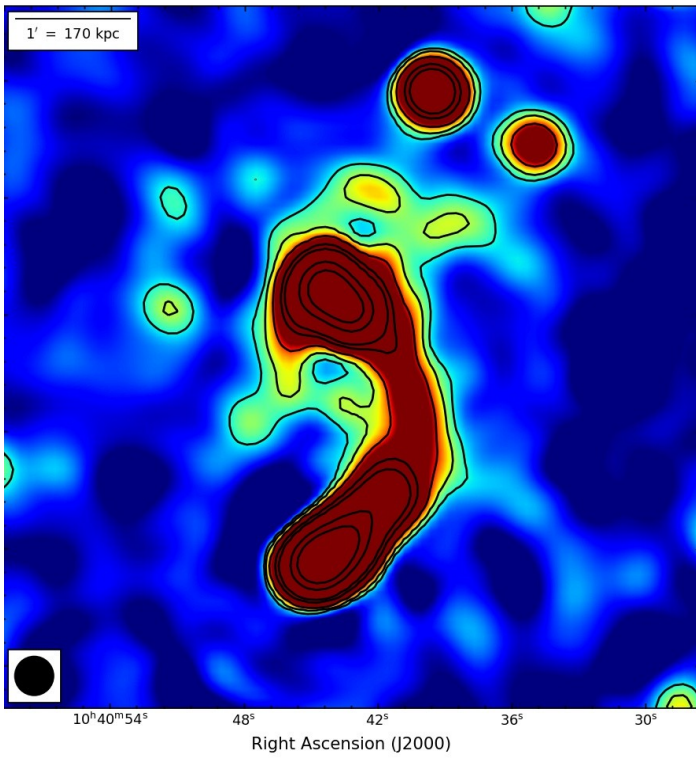
Abell 1068

LOFAR 144 MHz – resolution 7”x5”



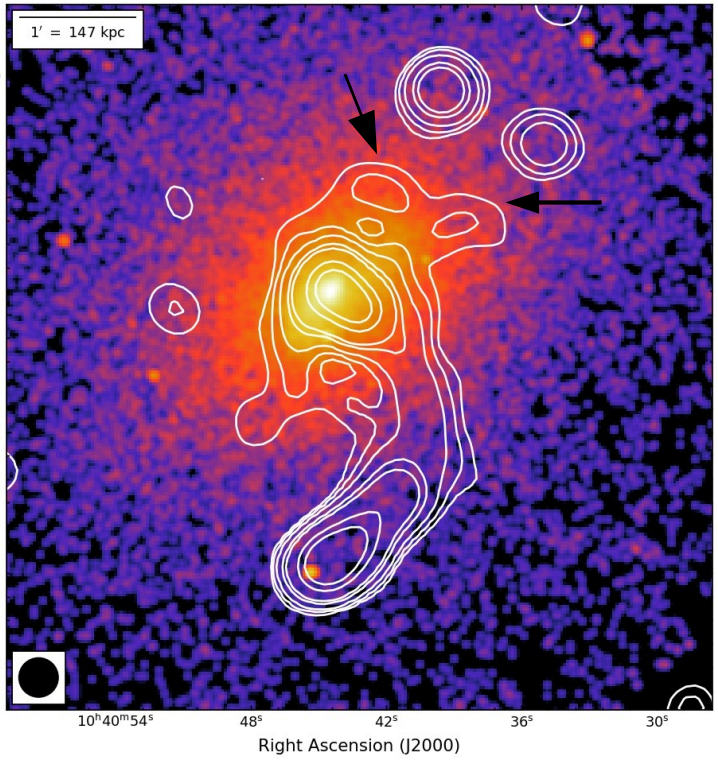
- Center: BCG + HT galaxy
  Mini halo?
- Sud: HT galaxy

LOFAR 144 MHz - resolution 20”



- Faint diffuse emission
- ~ 220 kpc size
- elongated NW-SE direction

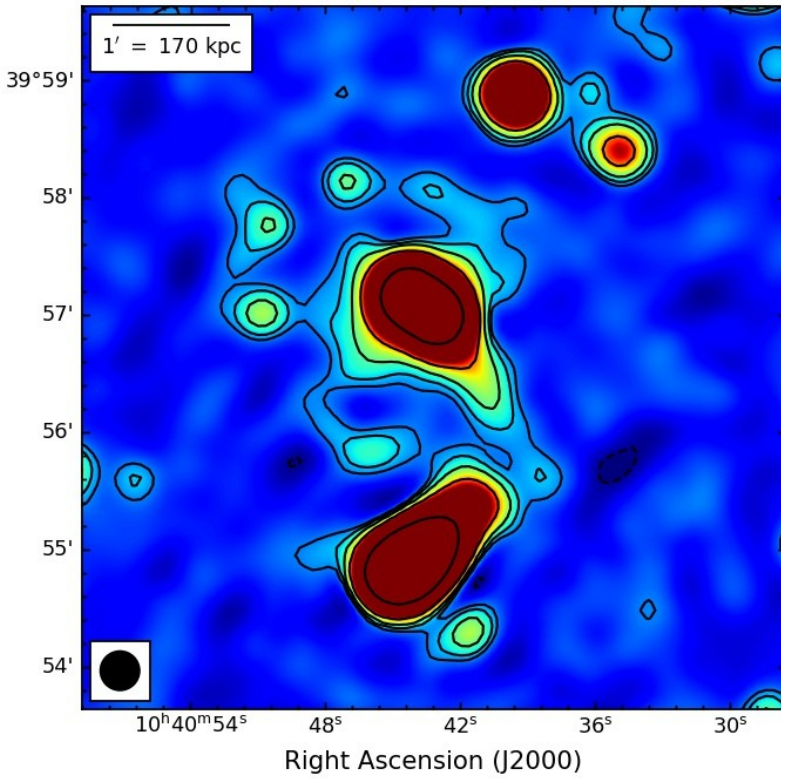
Chandra map + LOFAR contours (20”)



- Radio emission extends in the same direction of the X-ray emission

Abell 1068

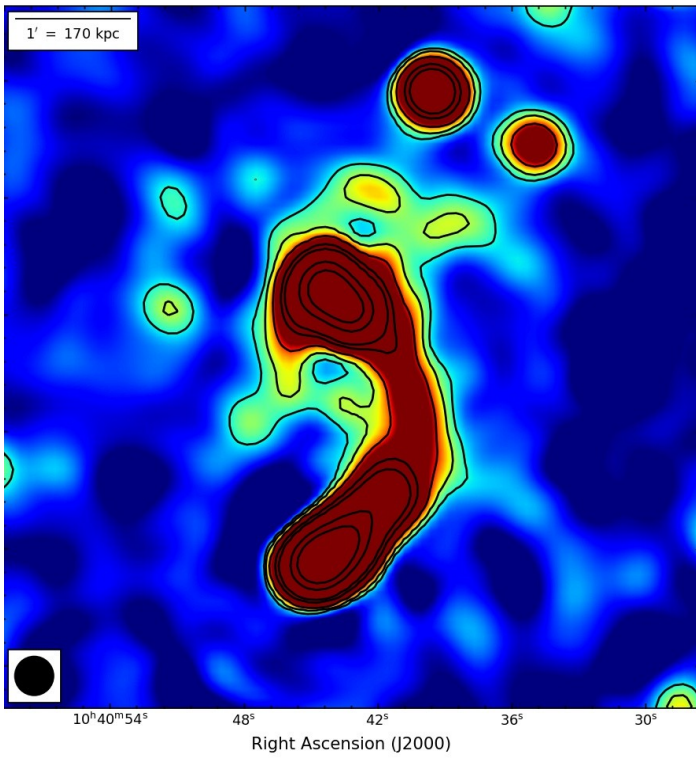
uGMRT 650 MHz – resolution 20”



- Faint diffuse emission partially detected

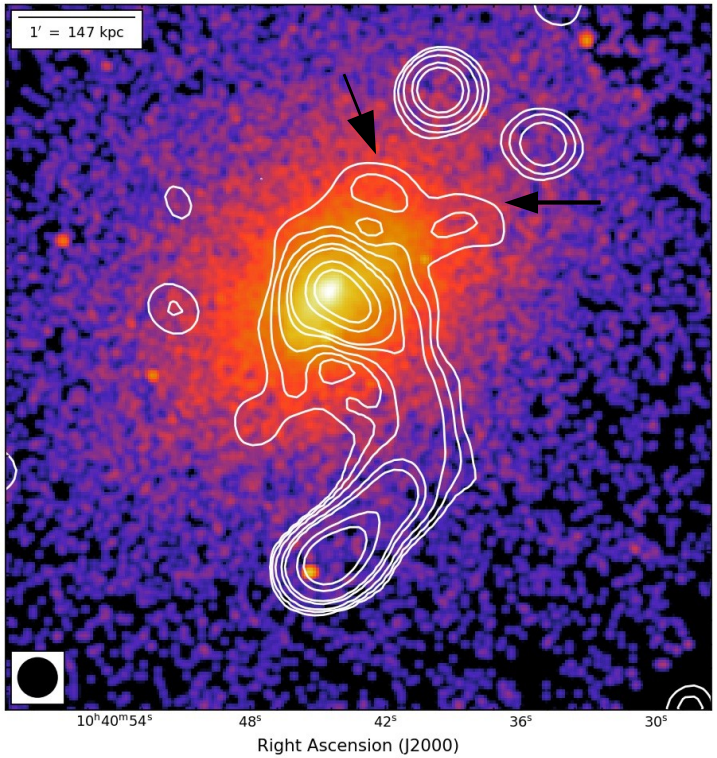
  → α ≥ 1.6

LOFAR 144 MHz - resolution 20”



- Faint diffuse emission
- ~ 200 kpc size
- elongated NW-SE direction

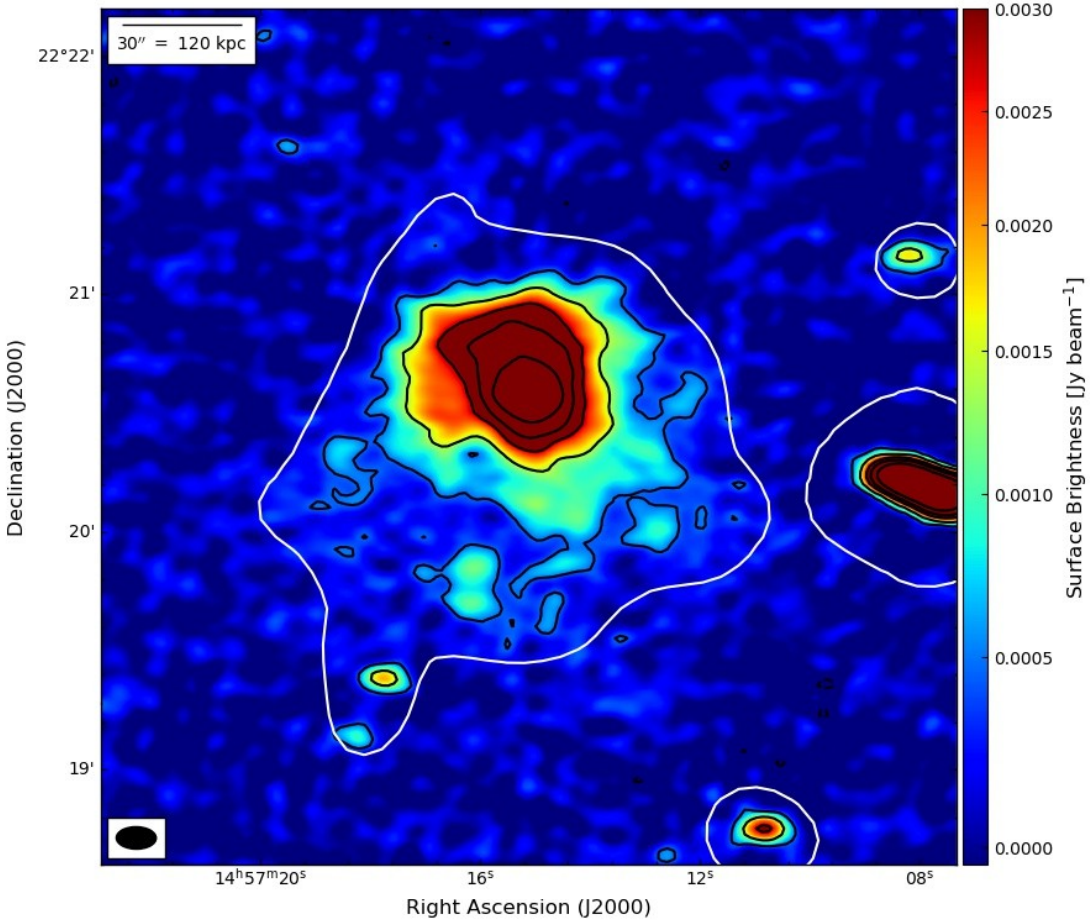
Chandra map + LOFAR contours (20”)



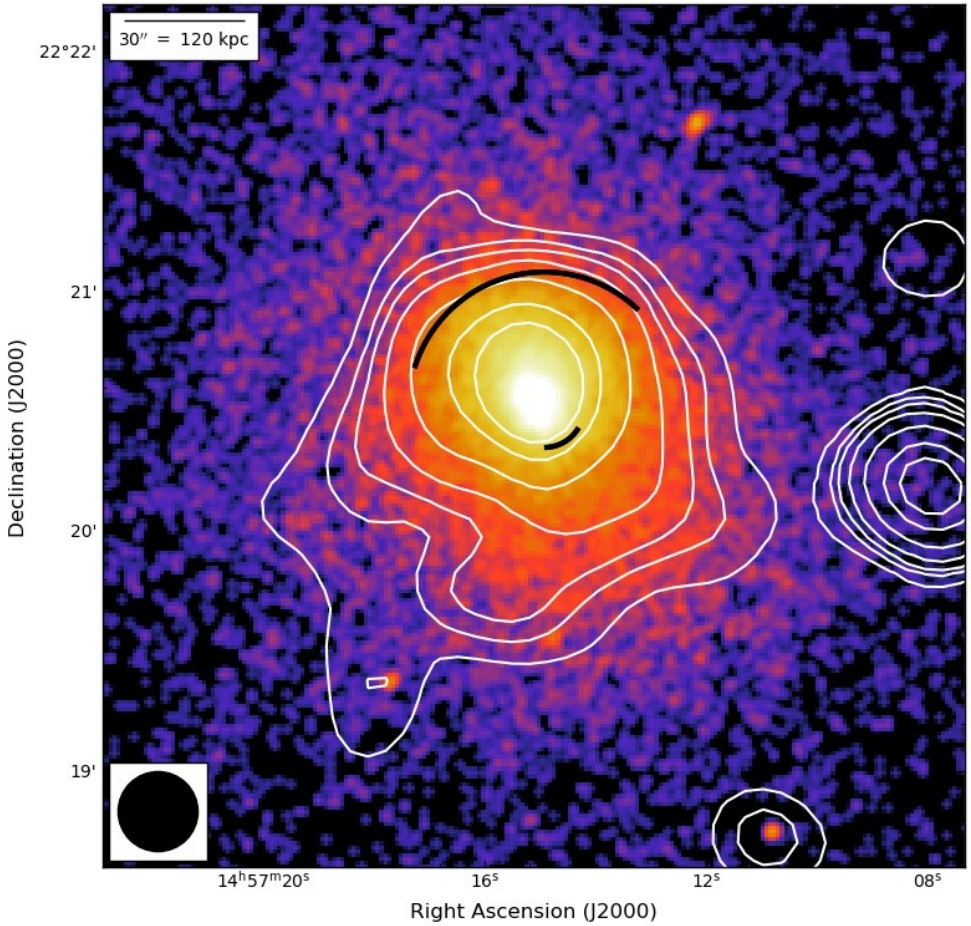
- Radio emission extends in the same direction of the X-ray emission

MS 1455.0+2232

LOFAR emission extends beyond the cold fronts

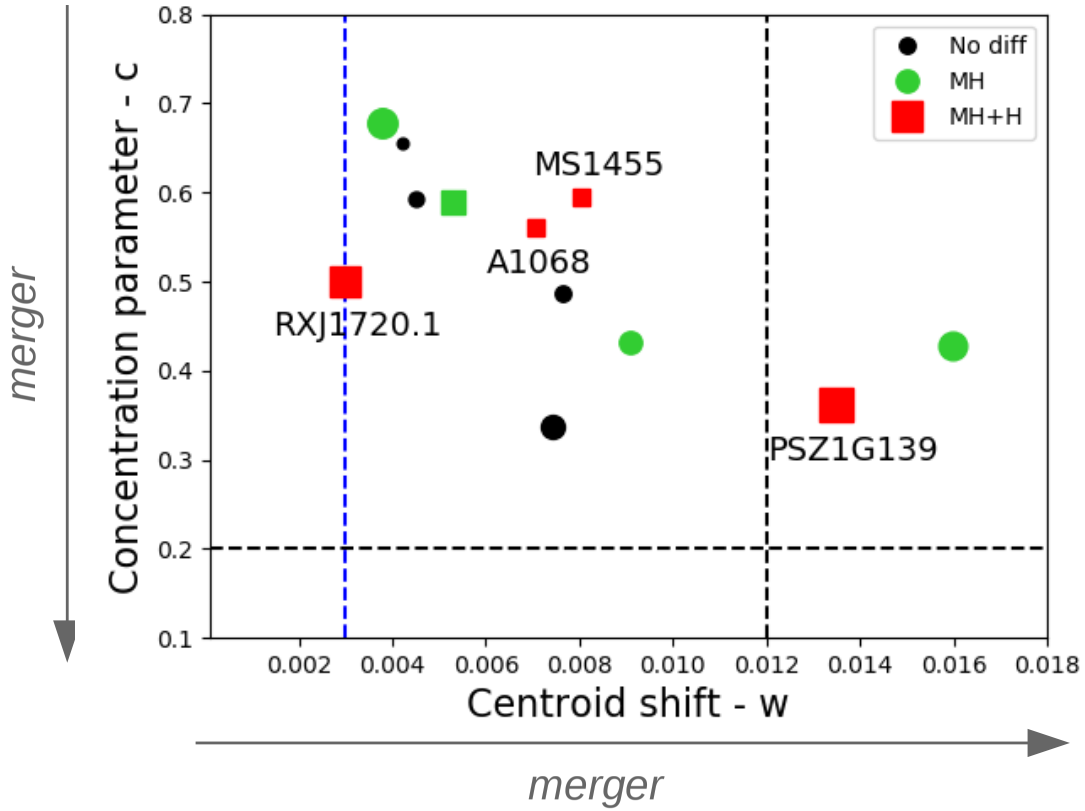


LOFAR 144 MHz image – resolution 6”

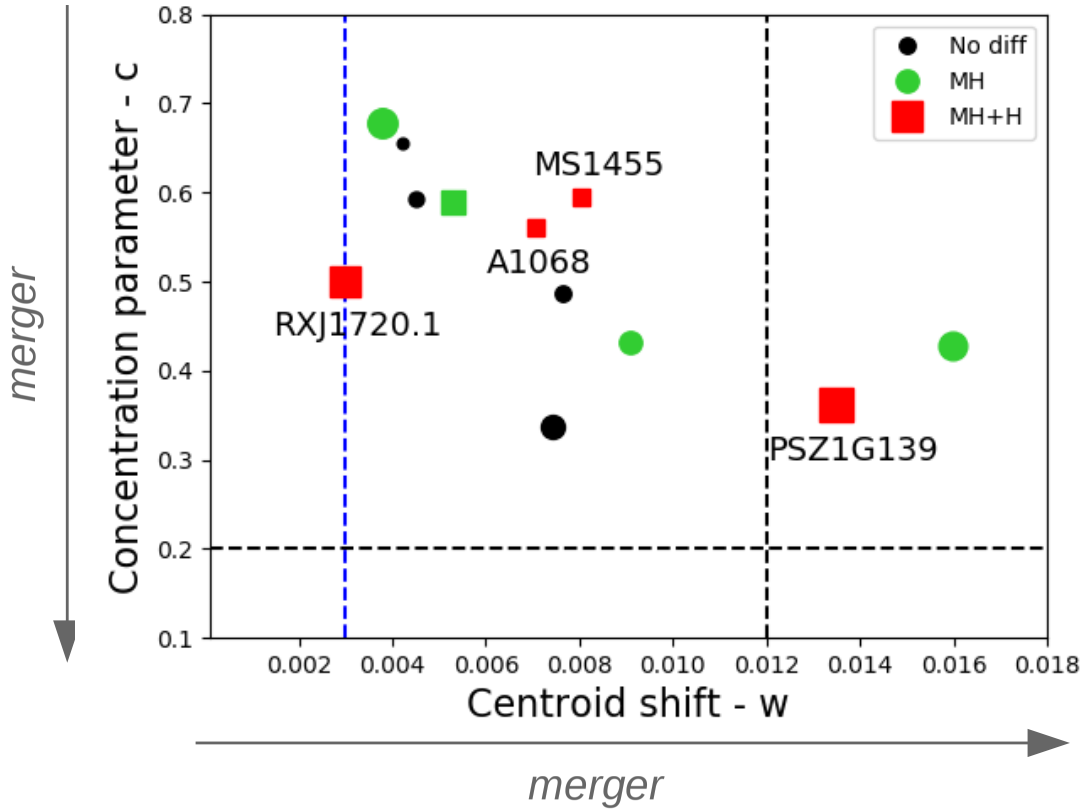


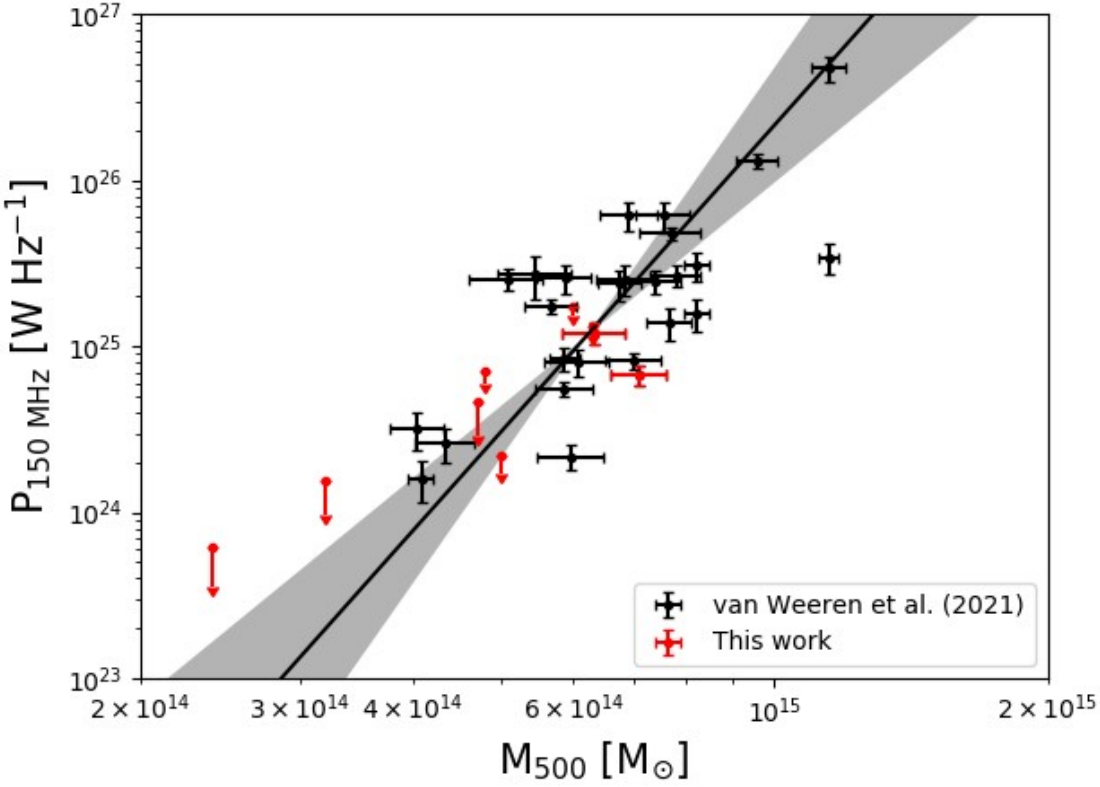
Chandra map + LOFAR 144 MHz contours (20”)

A sample of cool-core clusters



A sample of cool-core clusters





Conclusions

Observed a sample of 12 cool-core clusters with LOFAR at 144 MHz

- Detected difuse emission outside the cluster core in four clusters
- This emission presents an ultra-steep spectrum
- The clusters show evidence of perturbation in the X-rays such as cold-fronts or not regular morphology

→ Low efficiency perturbation may be sufficent to reacelerate particles on large scales

Thank you for the attention