Investigating the origin of cluster-scale diffuse radio emission in cool-core galaxy clusters

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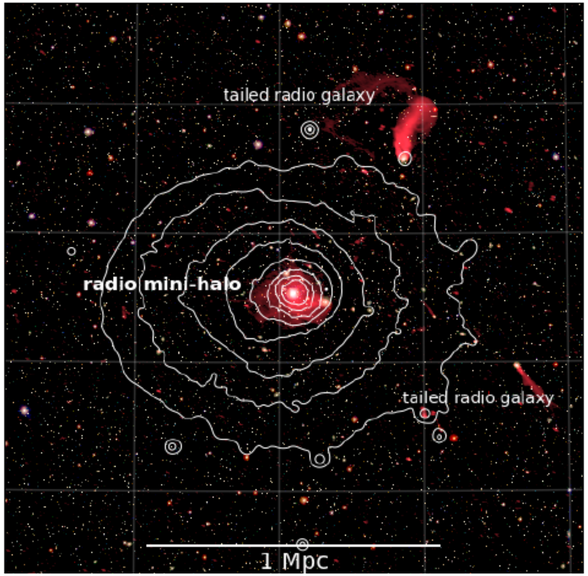
Collaborators: Bonafede, de Gasperin, Gastaldello, Riseley, Brienza et al.

LOFAR Family Meeting 2023

DRANOEL
ERC - Stg16 714245

Diffuse radio emission

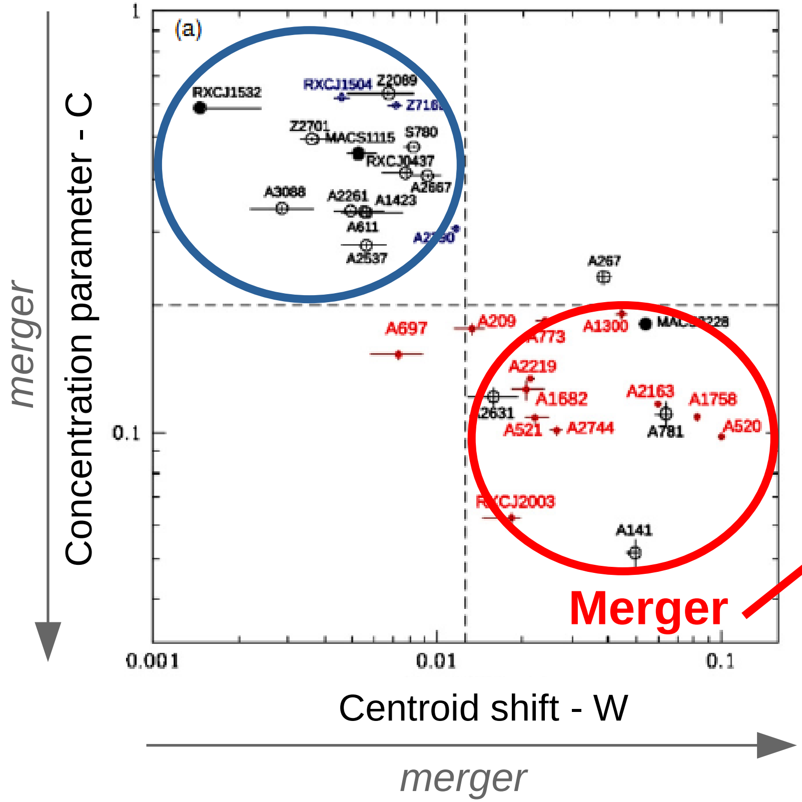
Mini halo



(van Weeren et al. 2019)

- 100 – 500 kpc size
- cool-core clusters
- due to sloshing or collisions of protons

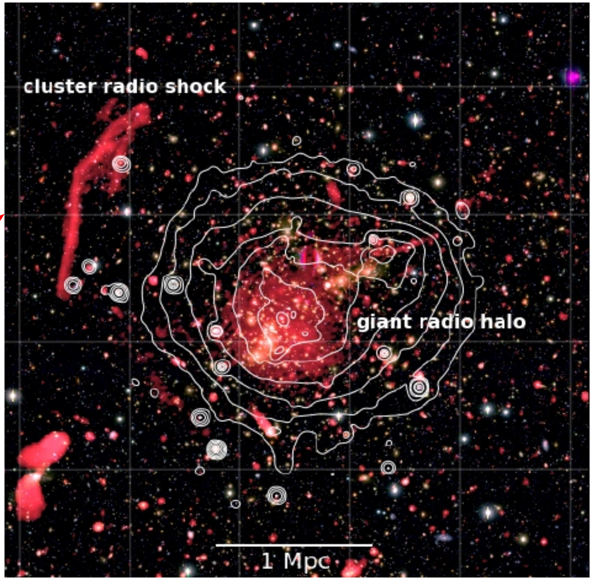
Relaxed



(Cassano et al. 2010)

Giant radio halo

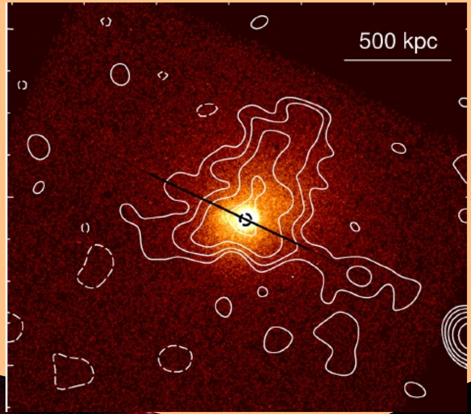
- Mpc size
- merging clusters
- Acceleration of particles by turbulence after a merger



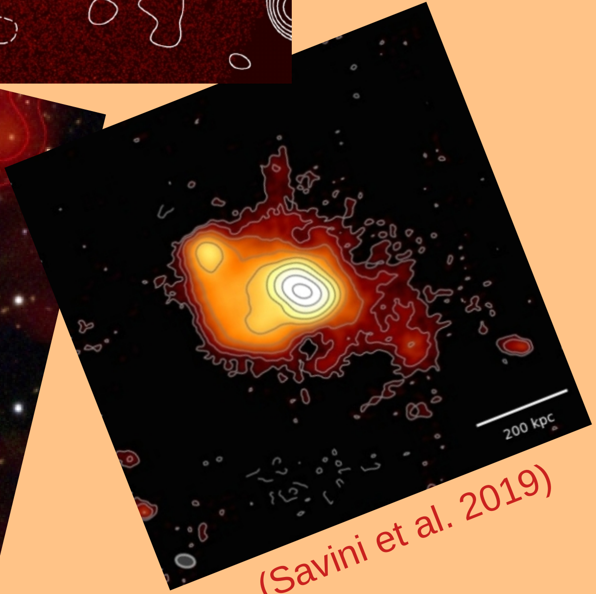
(van Weeren et al. 2019)

Diffuse radio emission

(Bonafede et al. 2014)



(Savini et al. 2018)



(Savini 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 α > 1.5

Common at low frequency?

The sample

Aims:

- Test occurrence of large-scale emission in cool-core clusters
- Verify minor merger scenario

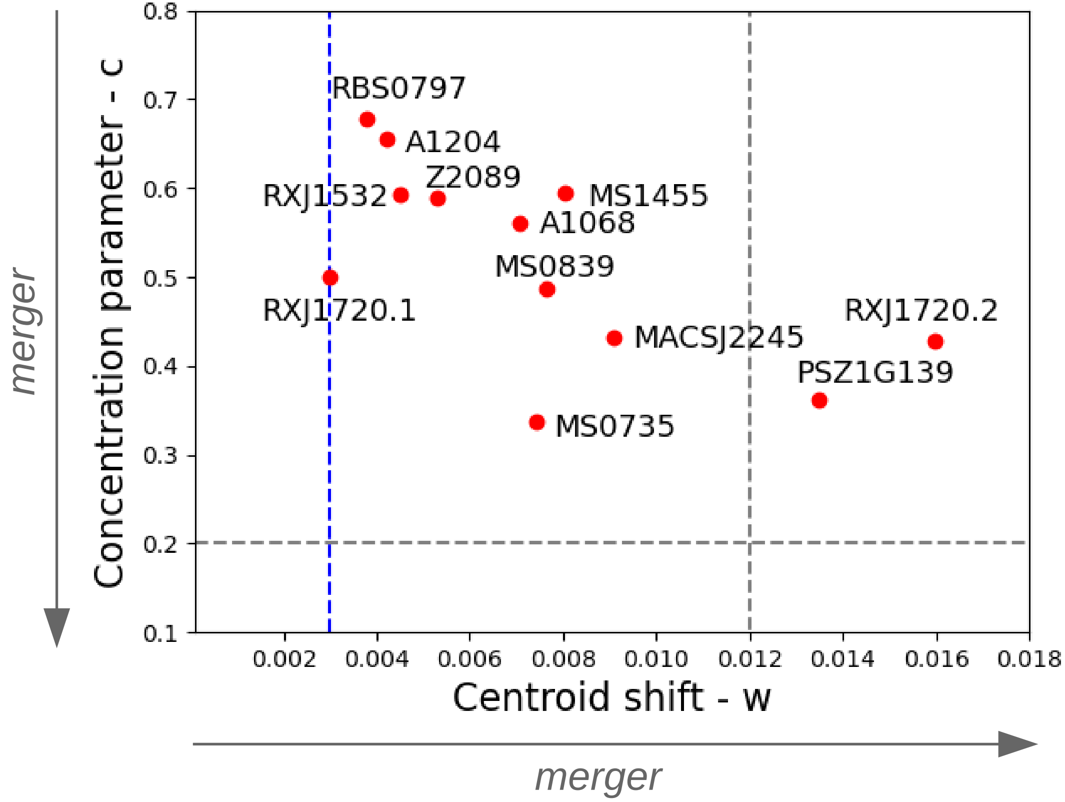
Selection criteria:

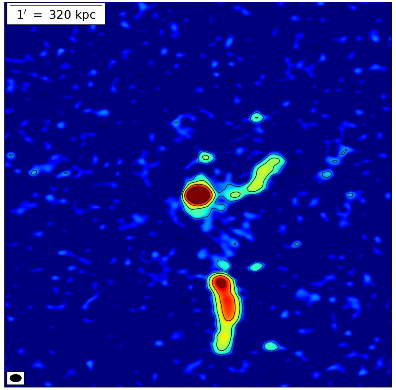
- MEMACS/ACCEPT cool-core clusters
  - Dec > 10 deg
  - Chandra obs cover central 500 kpc
  - Signs of dynamical interaction on scales larger than the core (w > 0.003)

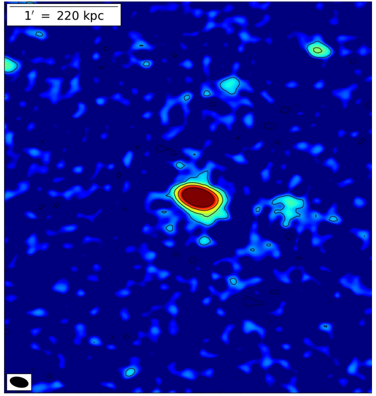
The sample:

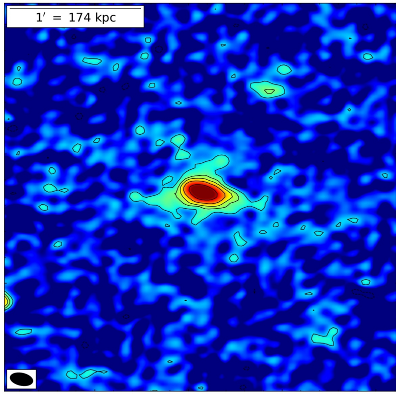
- 12 cool-core clusters
  - M_{500} = 3.2 – 7.6 x 10^{14} $M_\odot$
  - z = 0.14 – 0.39

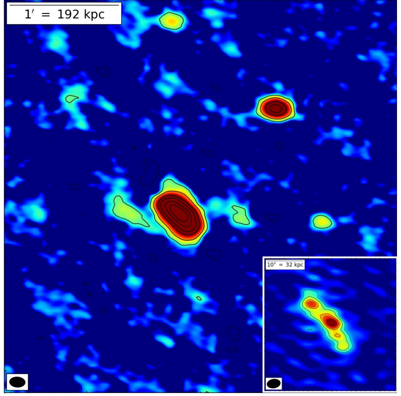
→ Observed with LOFAR at 144 MHz

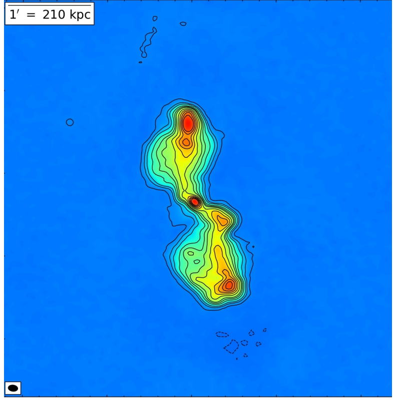


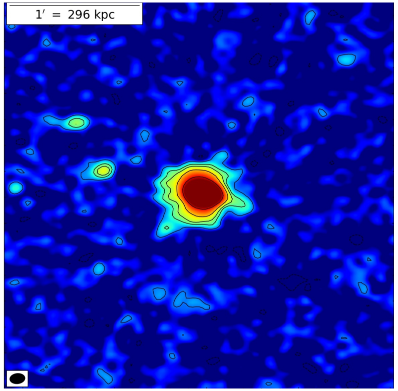




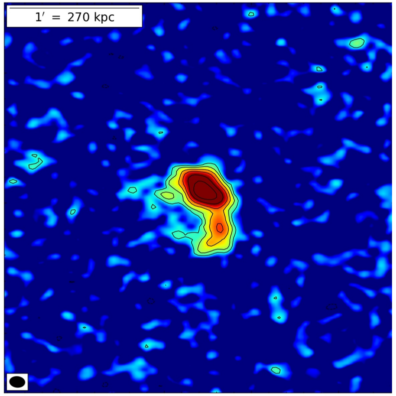


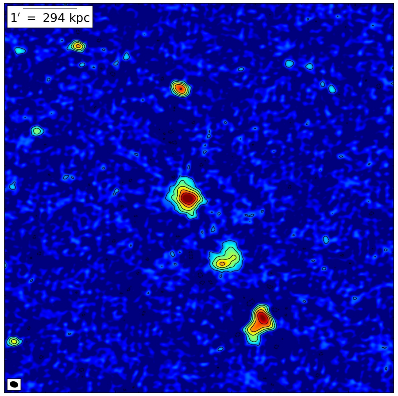


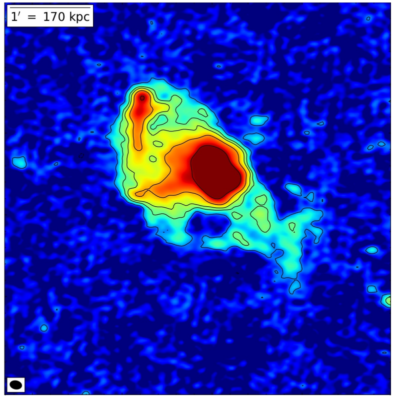


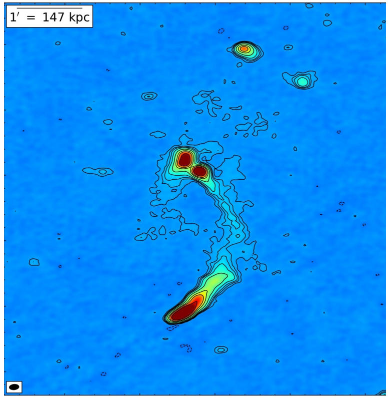


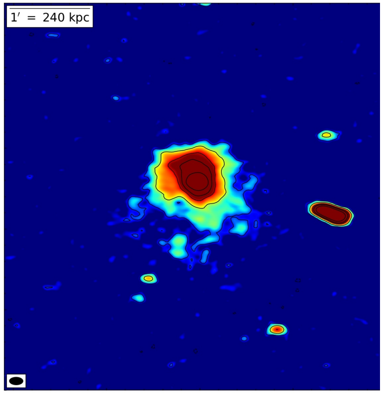
A sample of cool-core clusters

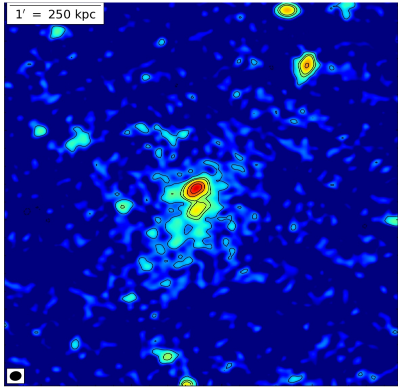


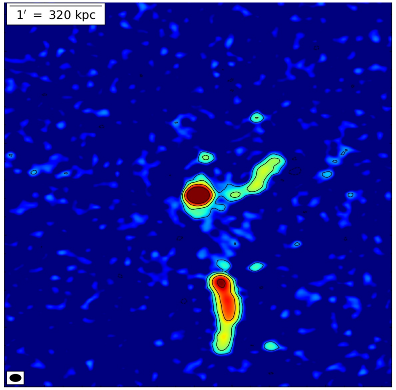


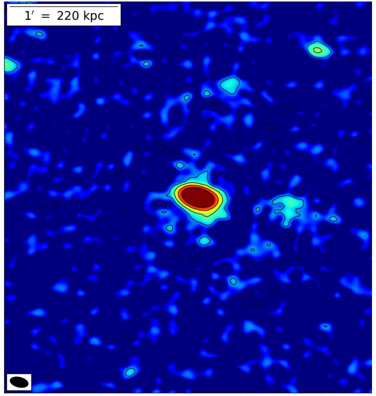


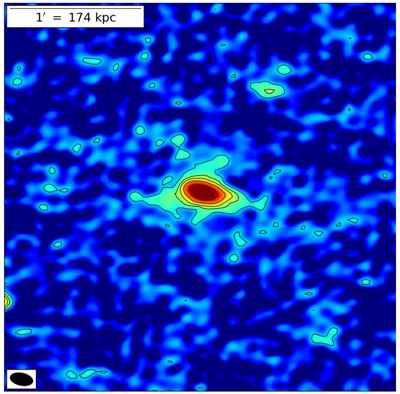


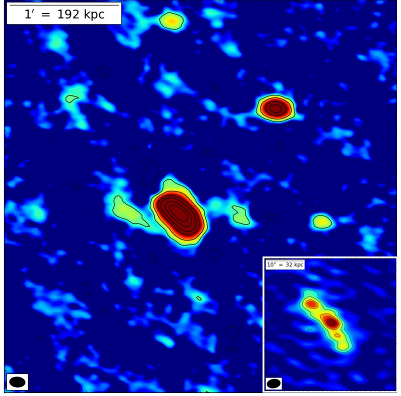


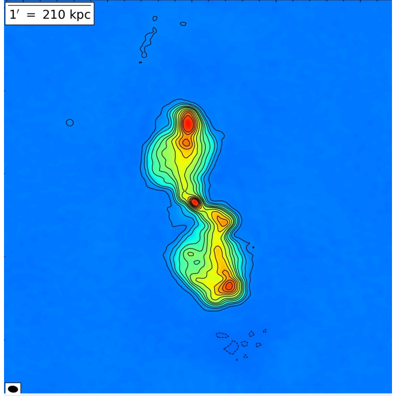


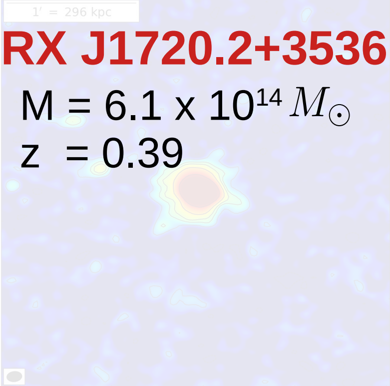


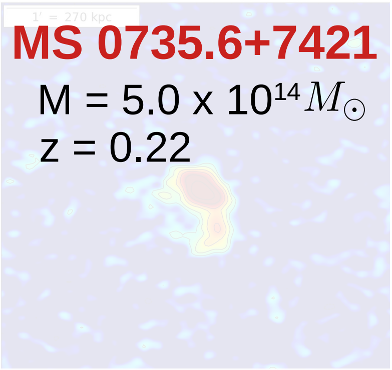












RX J1720.2+3536

M = 6.1 x $10^{14} M_\odot$
z = 0.39

Z2089

M = 3.2 x $10^{14} M_\odot$
z = 0.24

A1204

M = 3.3 x $10^{14} M_\odot$
z = 0.17

MS 0839.8+2938

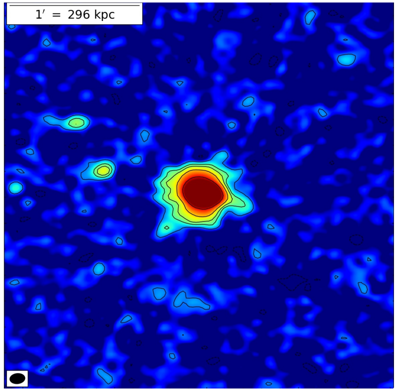
M = 3.4 x $10^{14} M_\odot$
z = 0.19

MS 0735.6+7421

M = 5.0 x $10^{14} M_\odot$
z = 0.22

No halo-like emission

Mini halos



RBS 797

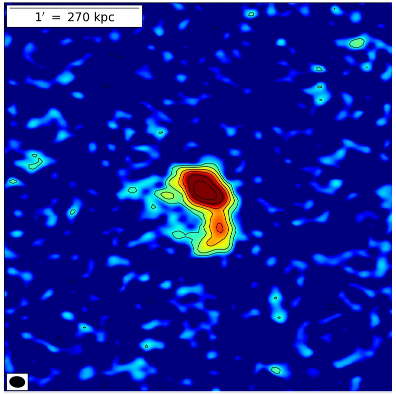
M = 5.6 x $10^{14} M_{\odot}$

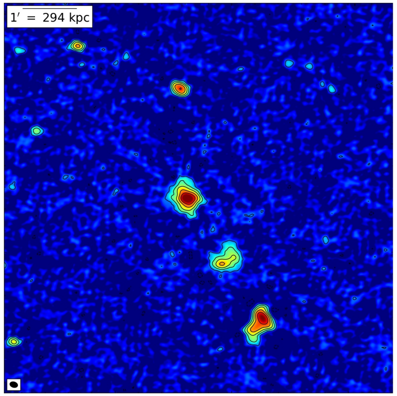
z = 0.35

MACS J2245.0+2637

M = 4.8 x $10^{14} M_{\odot}$

z = 0.30

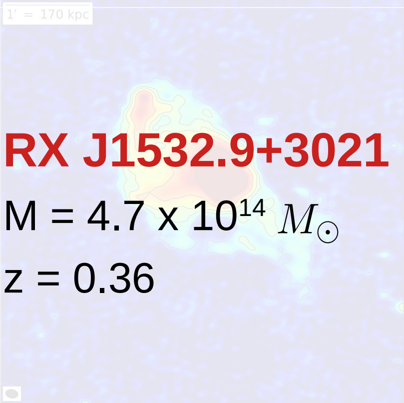




RX J1532.9+3021

M = 4.7 x $10^{14} M_{\odot}$

z = 0.36

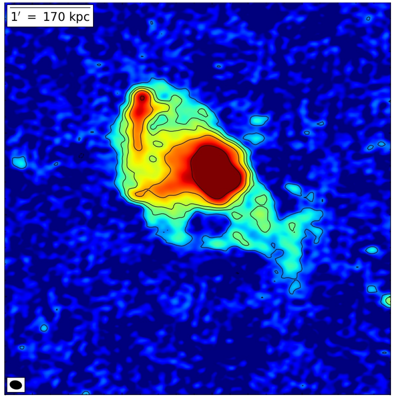


Large - scale diffuse emission

RX J1720.1+2638

M = 5.9 x $10^{14} M_{\odot}$

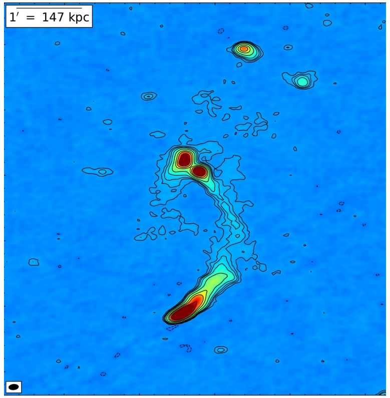
z = 0.16



A1068

M = 3.8 x $10^{14} M_{\odot}$

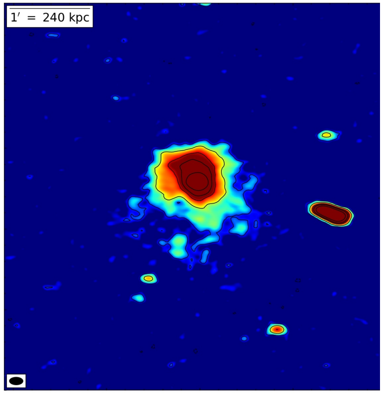
z = 0.14



MS 1455.0+2232

M = 3.5 x $10^{14} M_{\odot}$

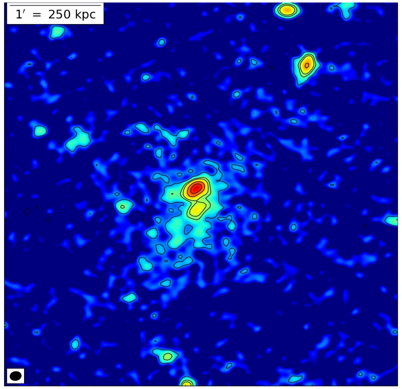
z = 0.26

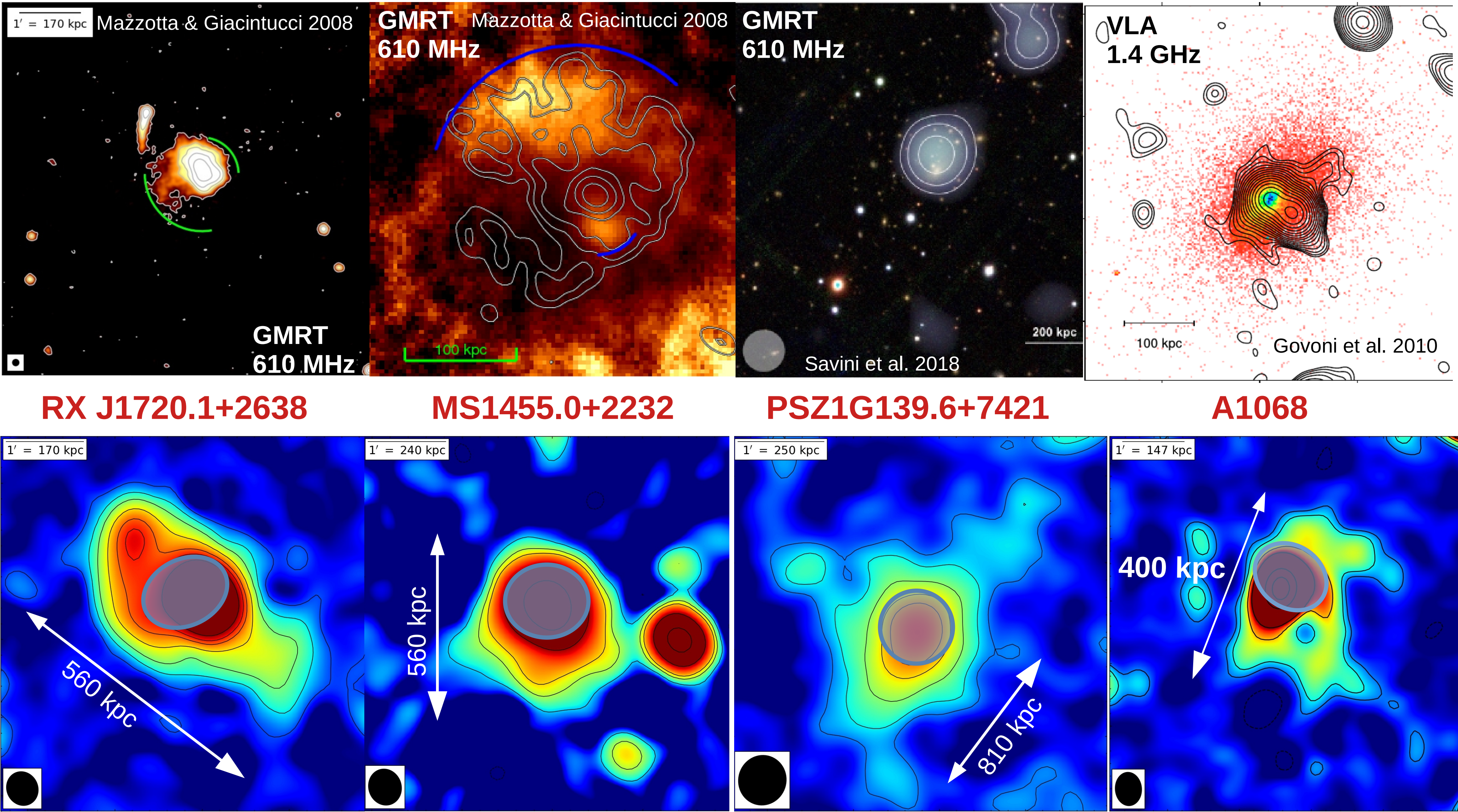


PSZ1G139.6+7421

M = 7.6 x $10^{14} M_{\odot}$

z = 0.27

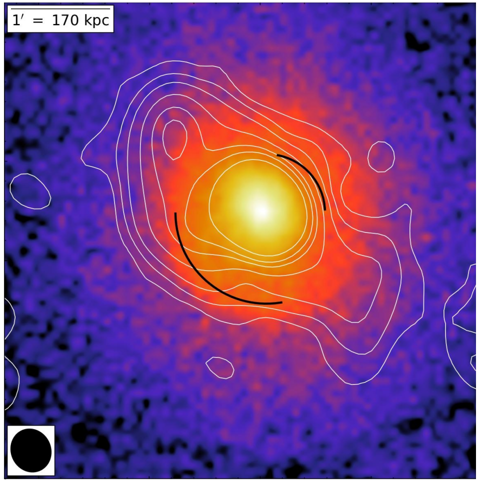




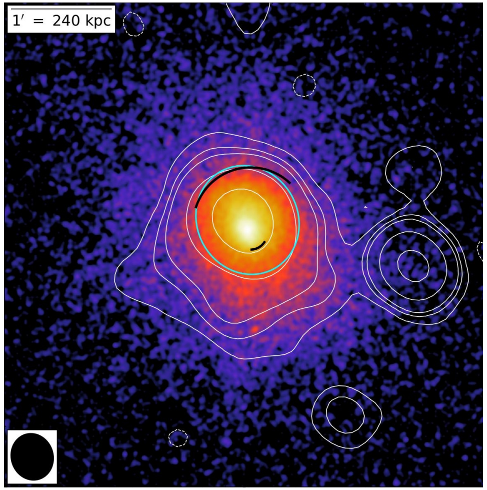
1′ = 170 kpc
Mazzotta & Giacintucci 2008
GMRT
610 MHz
GMRT
610 MHz
Mazzotta & Giacintucci 2008
100 kpc
GMRT
610 MHz
200 kpc
Savini et al. 2018
VLA
1.4 GHz
100 kpc
Govoni et al. 2010
RX J1720.1+2638
MS1455.0+2232
PSZ1G139.6+7421
A1068
1′ = 170 kpc
560 kpc
1′ = 240 kpc
560 kpc
1′ = 250 kpc
810 kpc
1′ = 147 kpc
400 kpc

Chandra data – Cold fronts

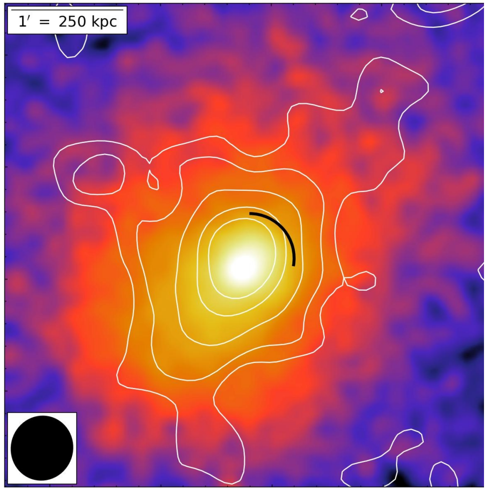
RX J1720.1+2638



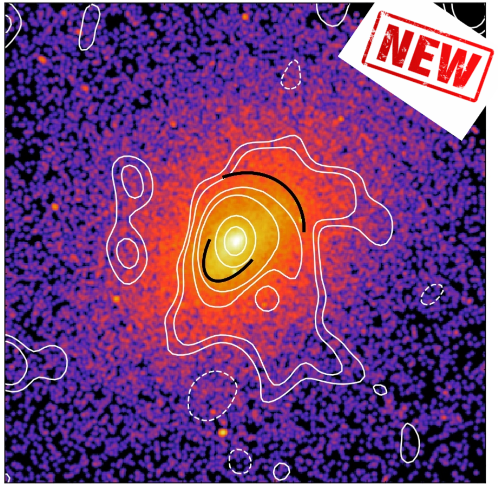
MS1455.0+2232



PSZ1G139.6+7421



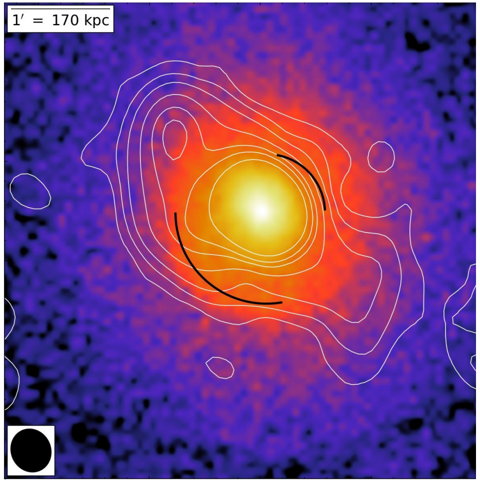
A1068



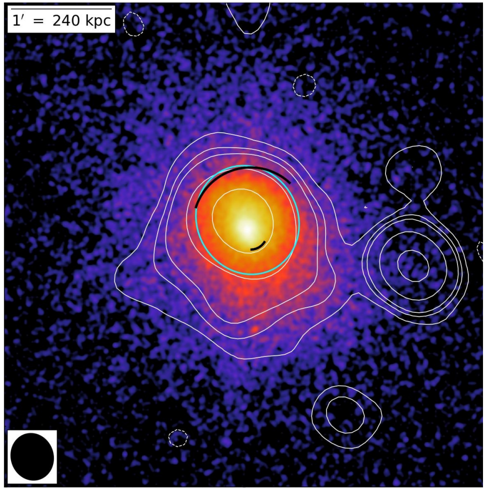
Diffuse radio emission extends beyond the cold fronts → Due to low efficiency perturbation generated outside the sloshing region

Chandra data – Cold fronts

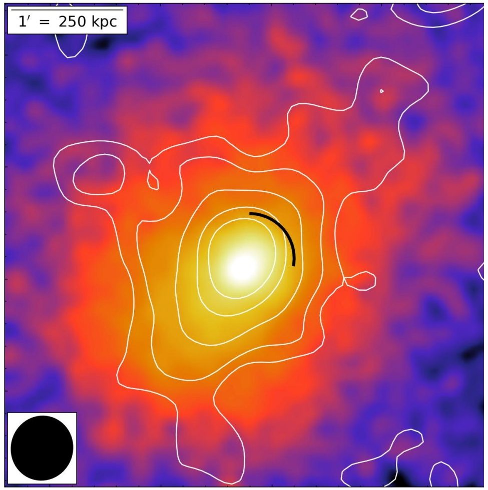
RX J1720.1+2638



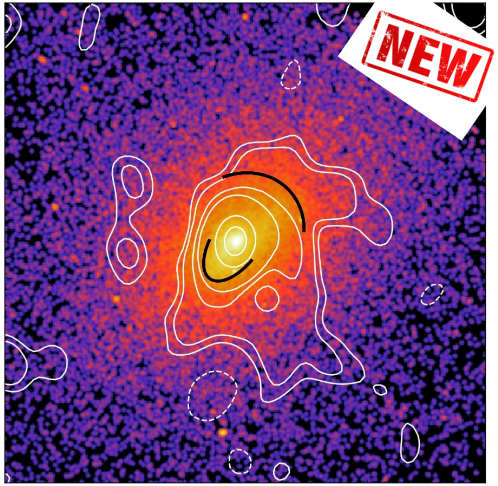
MS1455.0+2232



PSZ1G139.6+7421



A1068

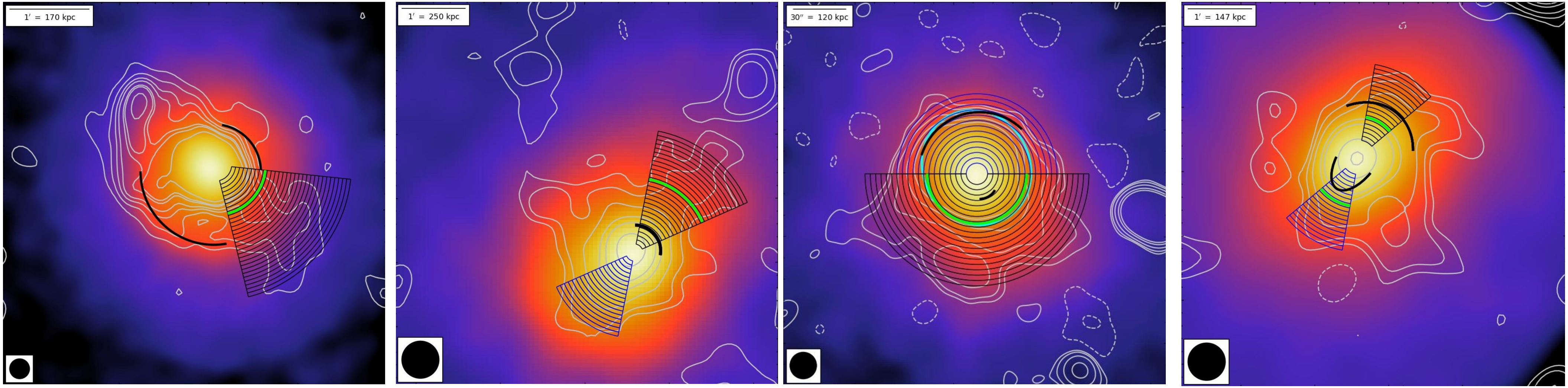


Diffuse radio emission extends beyond the cold fronts → Due to low efficiency perturbation generated outside the sloshing region

No sloshing features detected in the other clusters in the sample → **Coincidence of cluster-scale radio emission and cold fronts**

Hp: off-axis minor merger

A double component radio emission

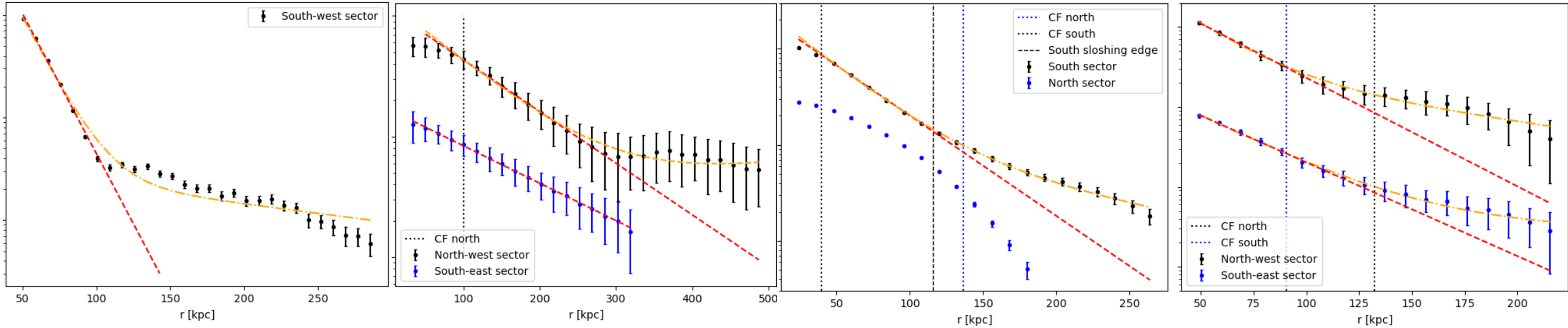


RX J1720.1+2638

PSZ1G139.6+7421

MS1455.0+2232

A1068



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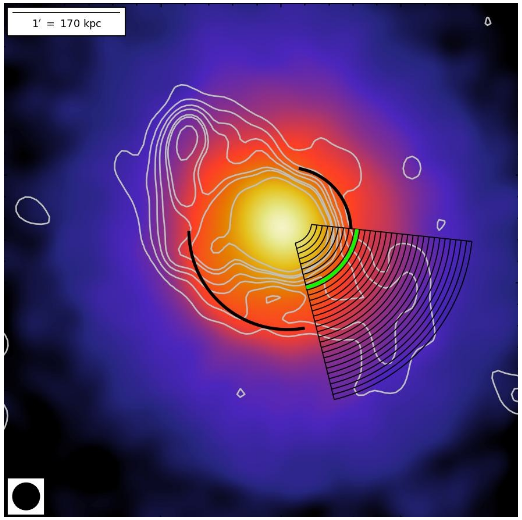
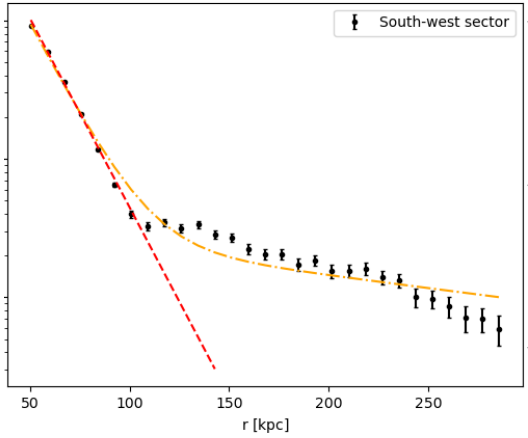
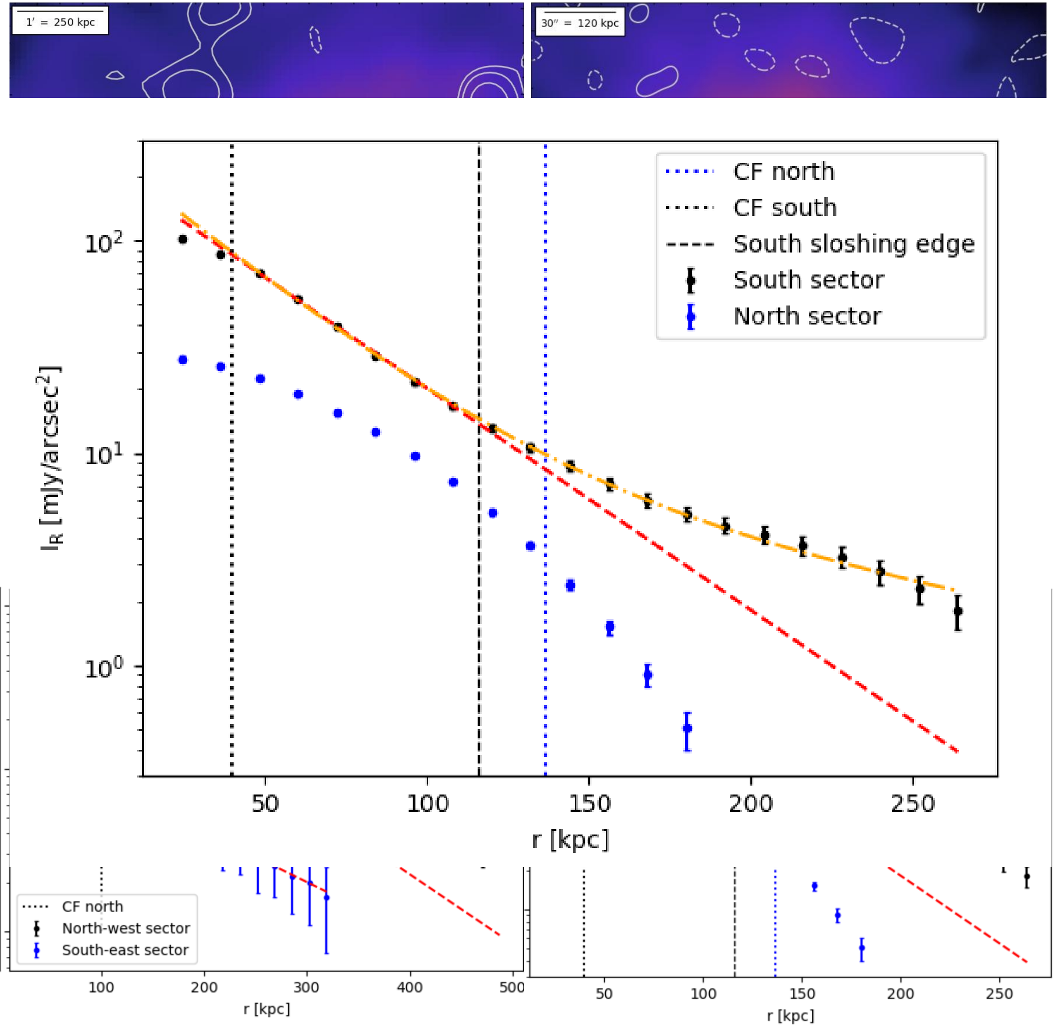
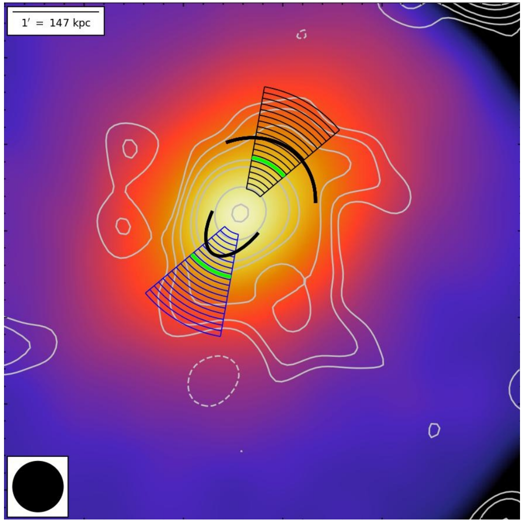


RX J1720.1+2638







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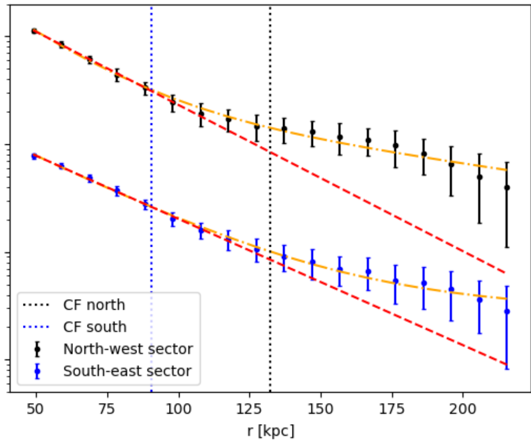
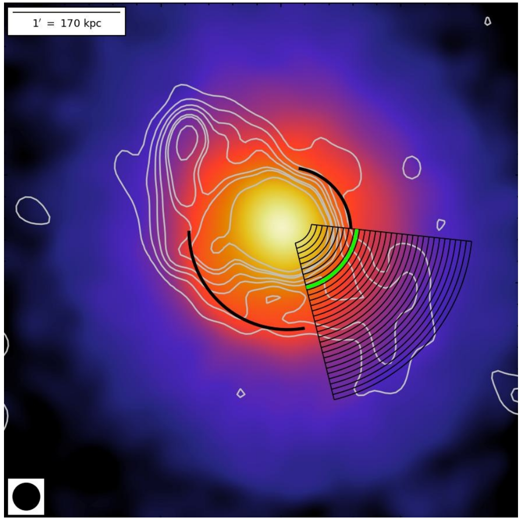
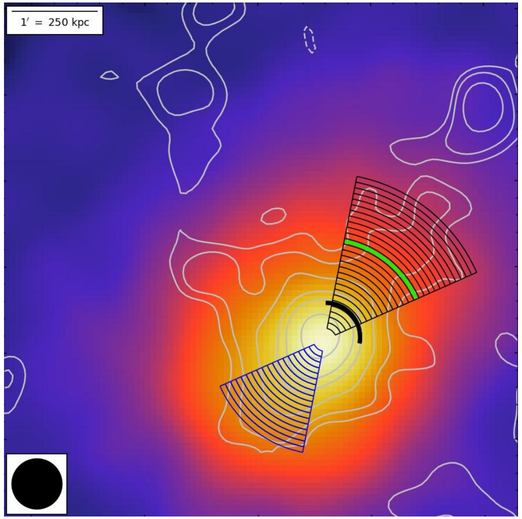
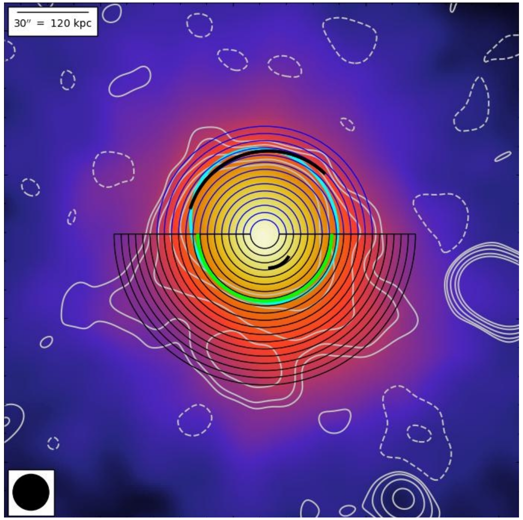
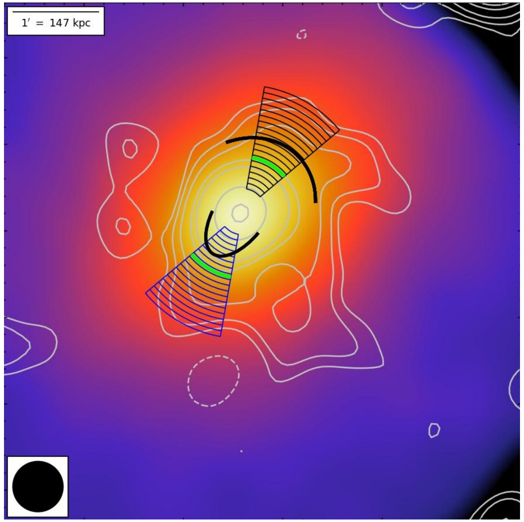


A double component radio emission

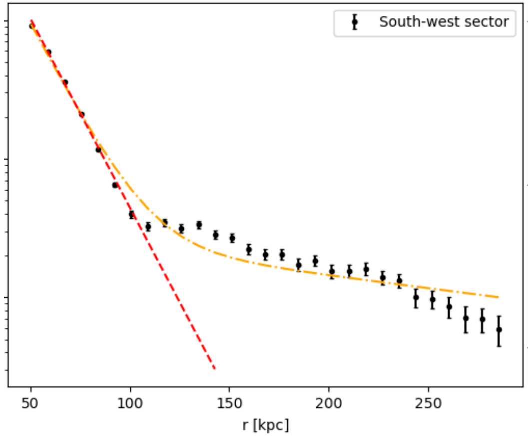


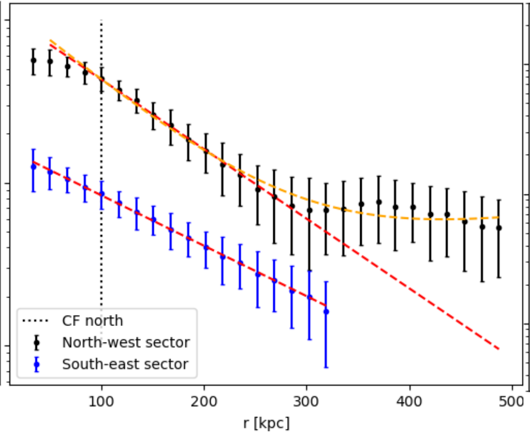


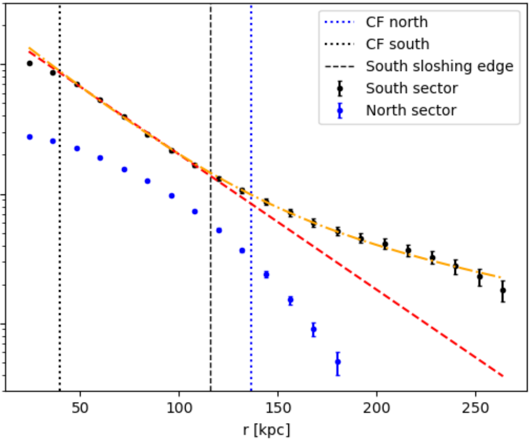


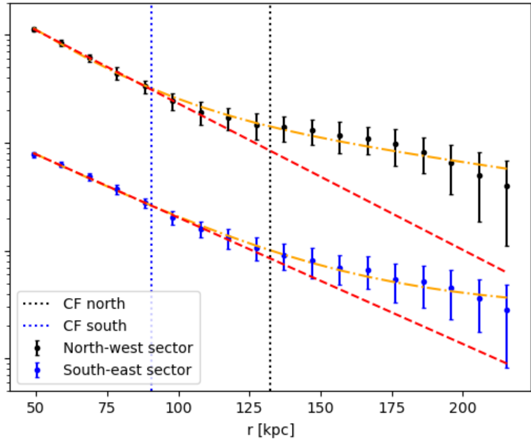


RX J1720.1+2638 **PSZ1G139.6+7421** **MS1455.0+2232** **A1068**



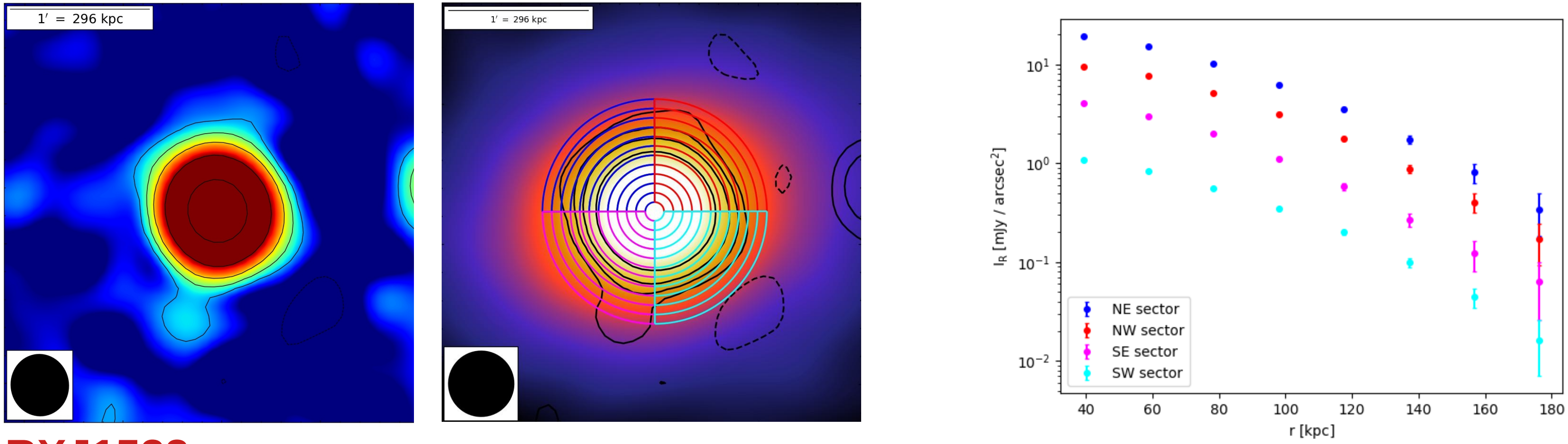




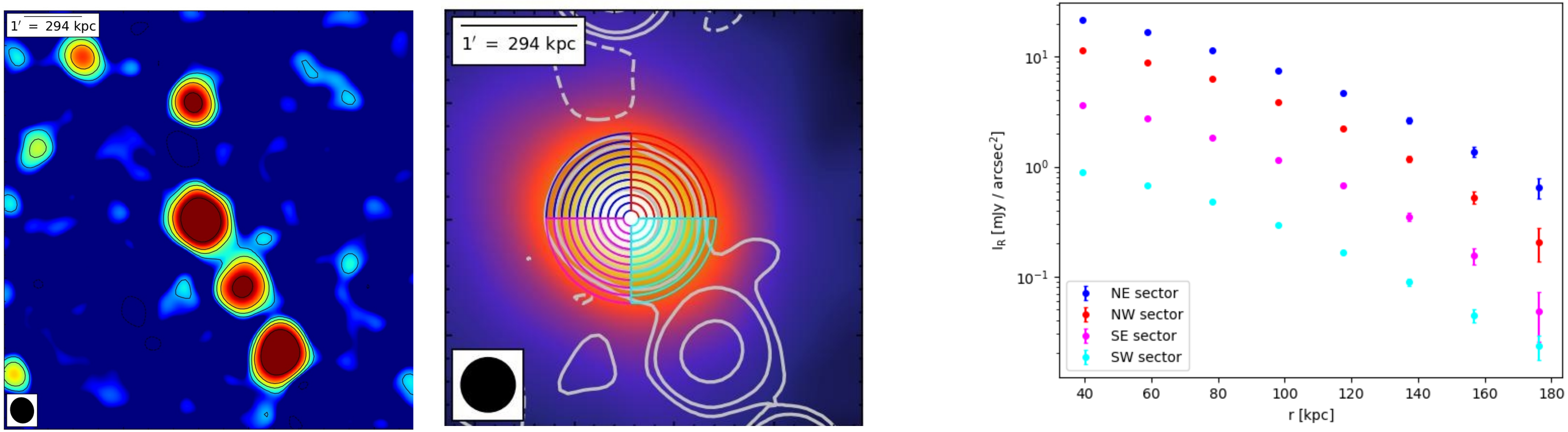


Classical mini halos

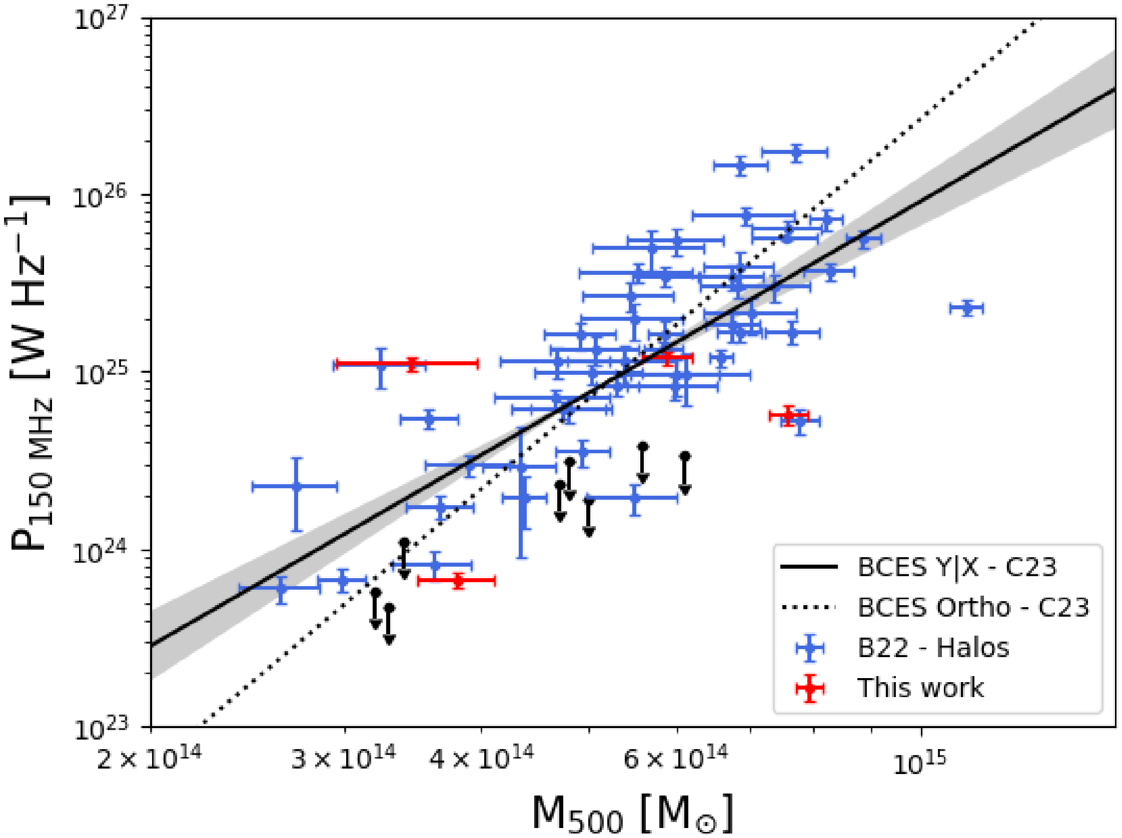
RBS 797



RXJ1532



Halo power & upper-limits



Clusters with MH+H:

Halo power
comparable to that of RH
detected in merging clusters

Other clusters in the sample:

Upper-limits
Mock halo injection
Below the correlation

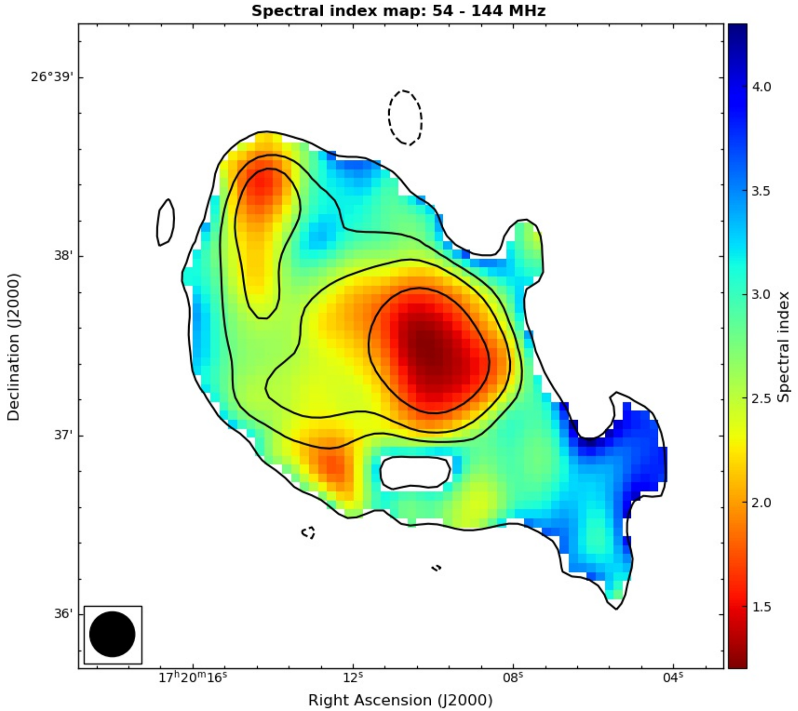
RX J1720.1+2638

(Biava et al. 2021 - MNRAS)

Different nature of radio emission inside and outside the cluster core

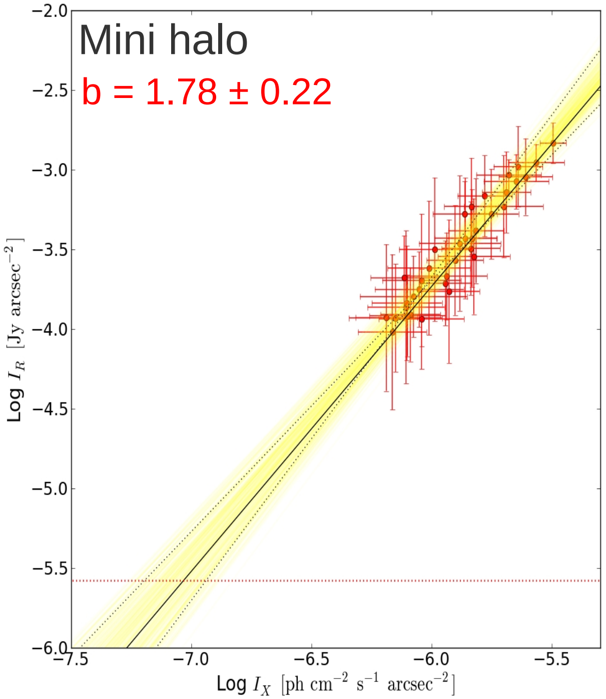
Spectral index: 54 – 144 MHz

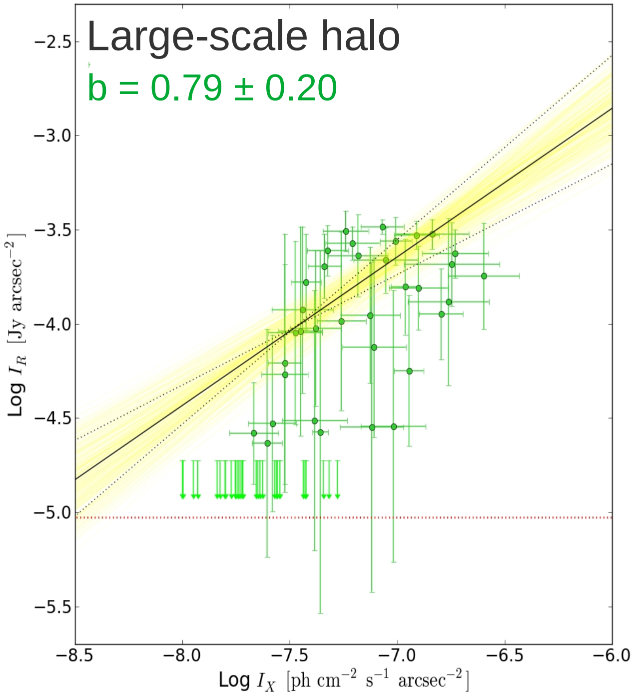
- Mini halo: $\alpha \sim 1$
- Large-scale halo: $\alpha \sim 3$



Radio & X-ray comparison

Different correlations in the two components

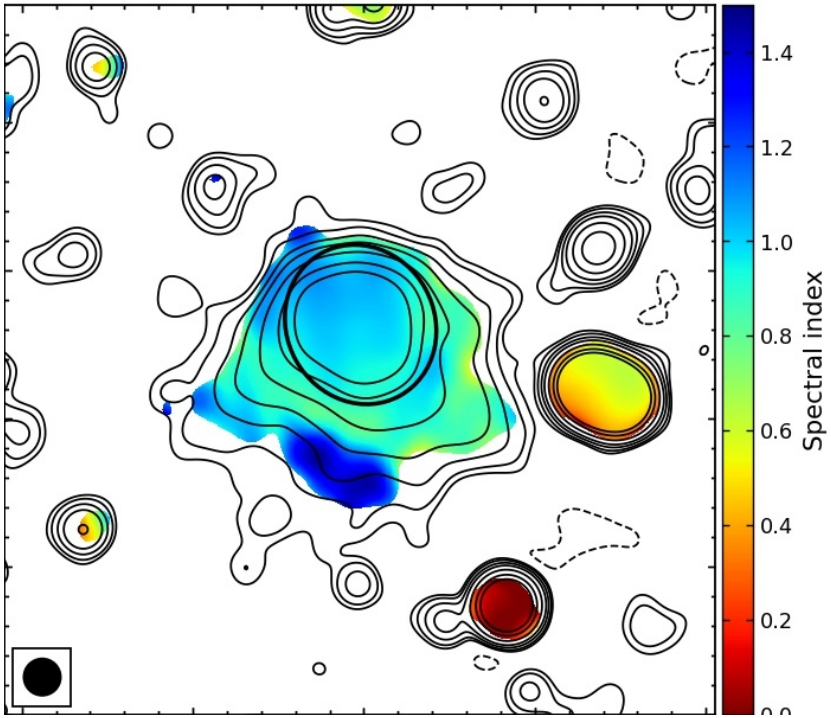




MS 1455.0+2232

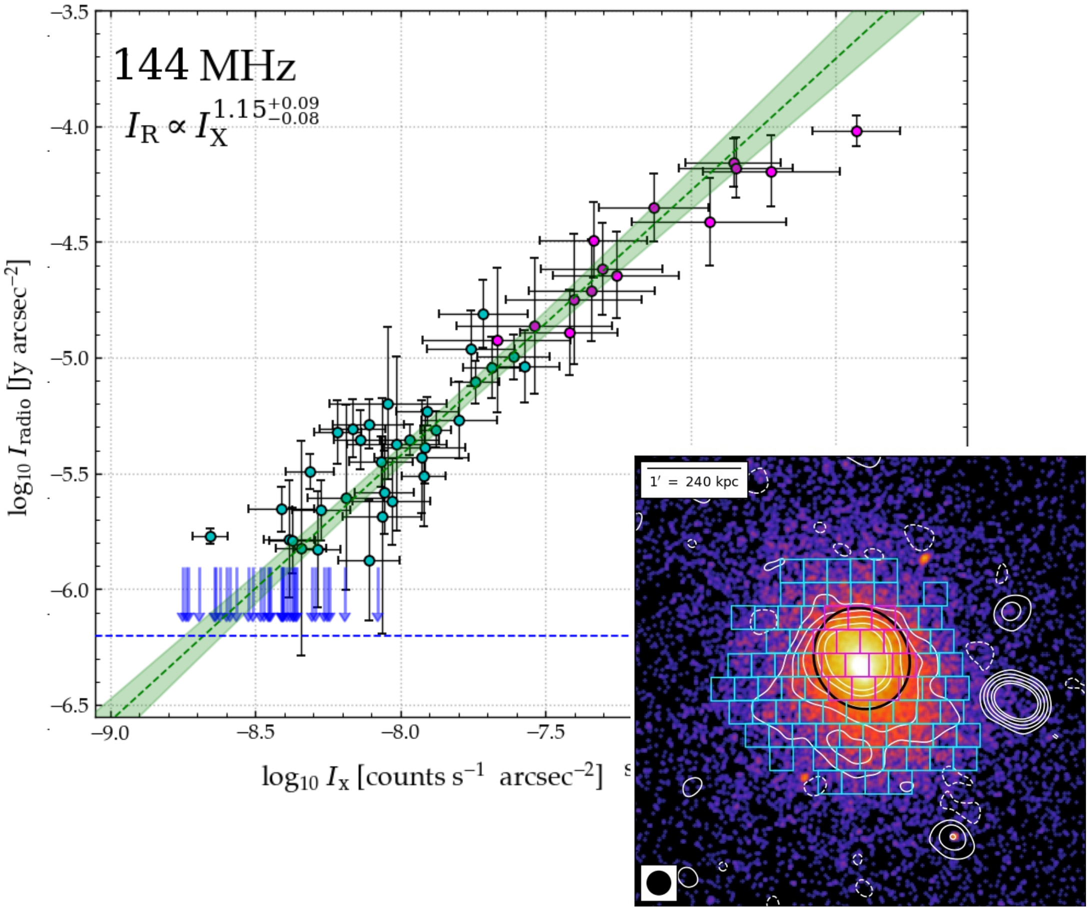
(Riseley,…, Biava et al. 2022)

Spectral index: 144 – 1280 MHz



Quite uniform spectral index
over the whole emission

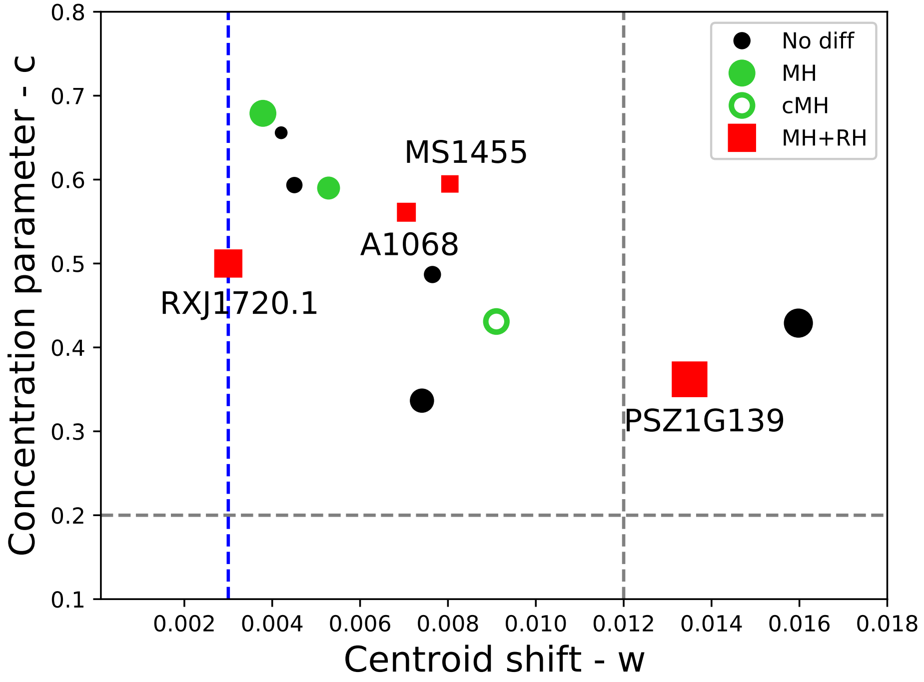
Radio & X-ray comparison



Summary

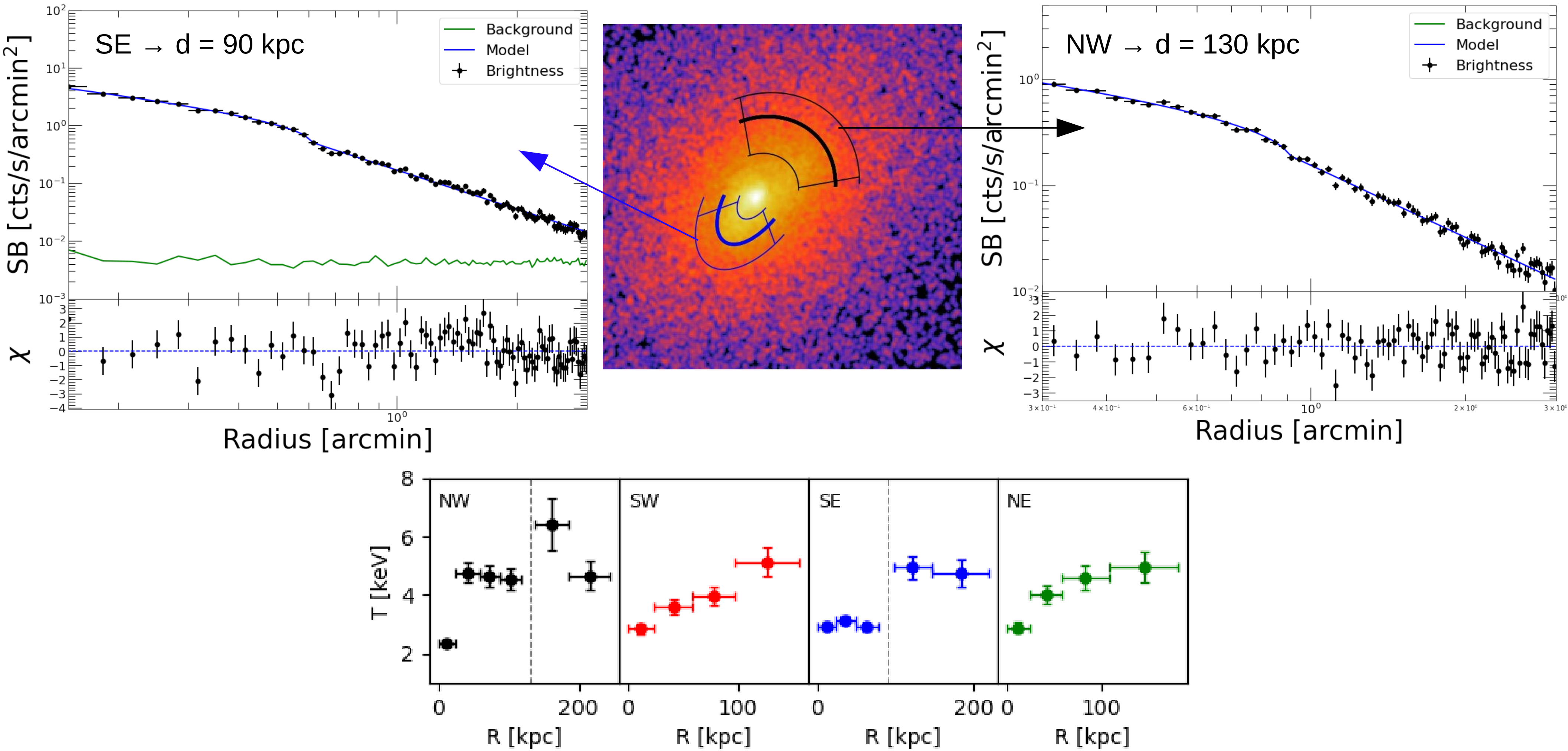
Investigate the presence of cluster-scale diffuse radio emission in cool-core galaxy clusters

- Not always present in cool-core clusters (1/3 of the clusters in the sample)
- **Connected to sloshing mechanism**
  Hp: off-axis minor merger
- **Always present in case of minor merger?**
  (ampliate the sample – CC+CF)
- Made of two different components (MH+H)
- Ultra-steep spectrum?
  (complete spectral analysis)

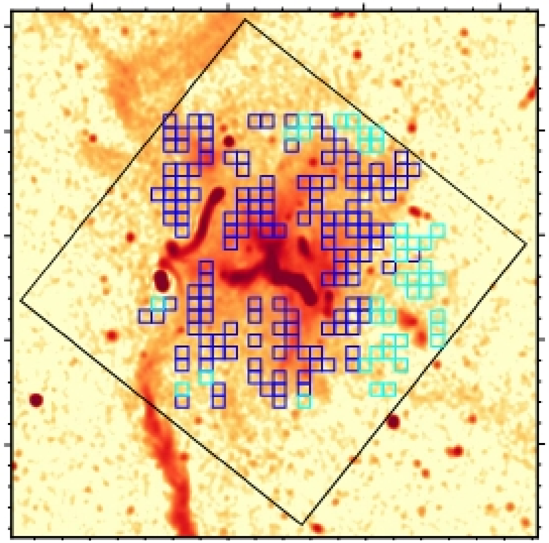


Thank you for the attention

A1068 – Cold fronts

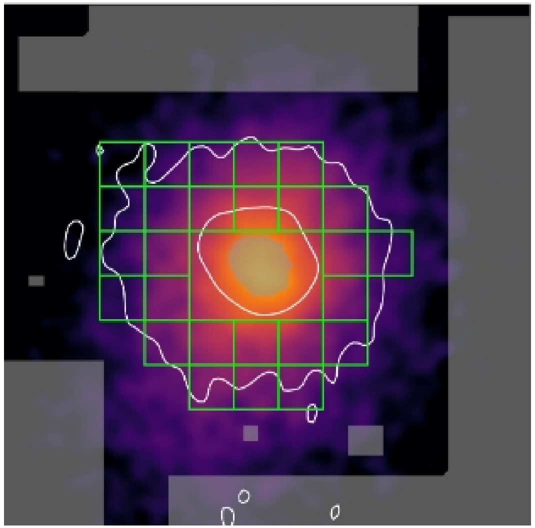


Abell 2255

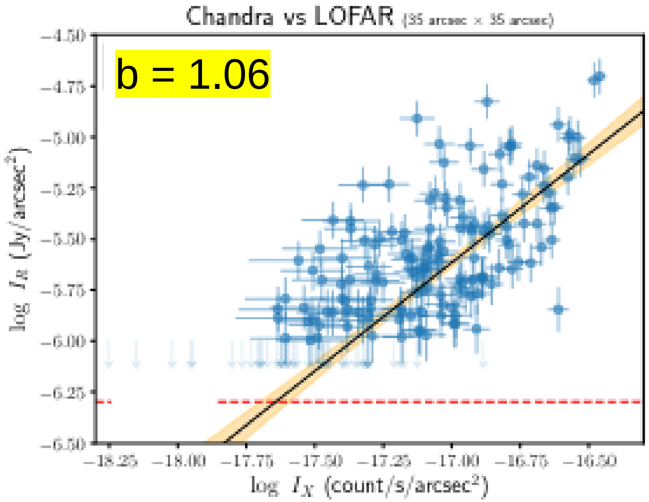


Point-to-point comparison Radio - X-ray surface brightness

Abell 3444



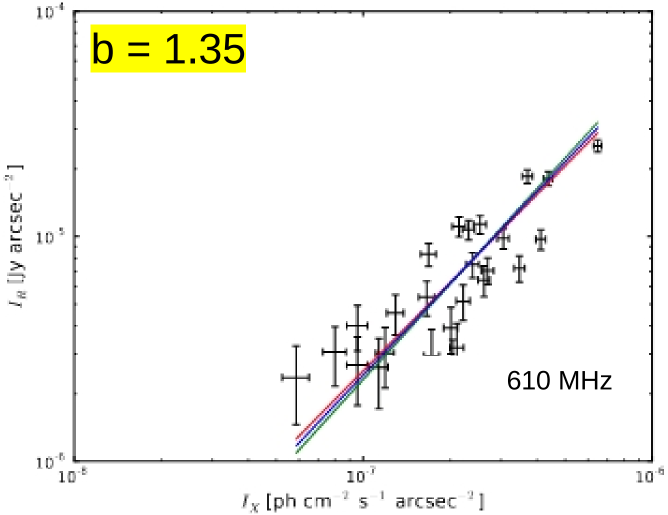
$$\log I_R = b \log I_X + c$$



From the literature:

- Giant radio halo $b \leq 1$
- Mini halo $b > 1$

→ Different sources



(Botteon et al. 2020)

(Ignesti et al. 2020)