
The emerging complexity of multi-component radio halos in galaxy clusters

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Collaborators: F. De Gasperin, V. Cuciti, R. J. van Weeren, et al.



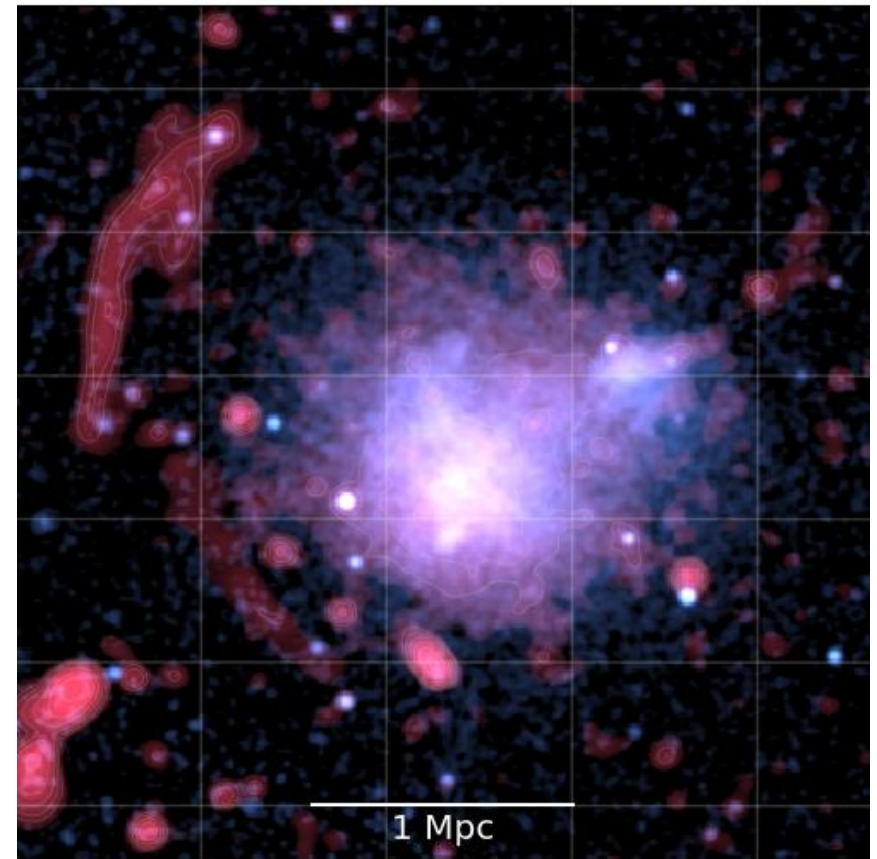
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Diffuse radio emission in galaxy clusters: radio halos (RHs)

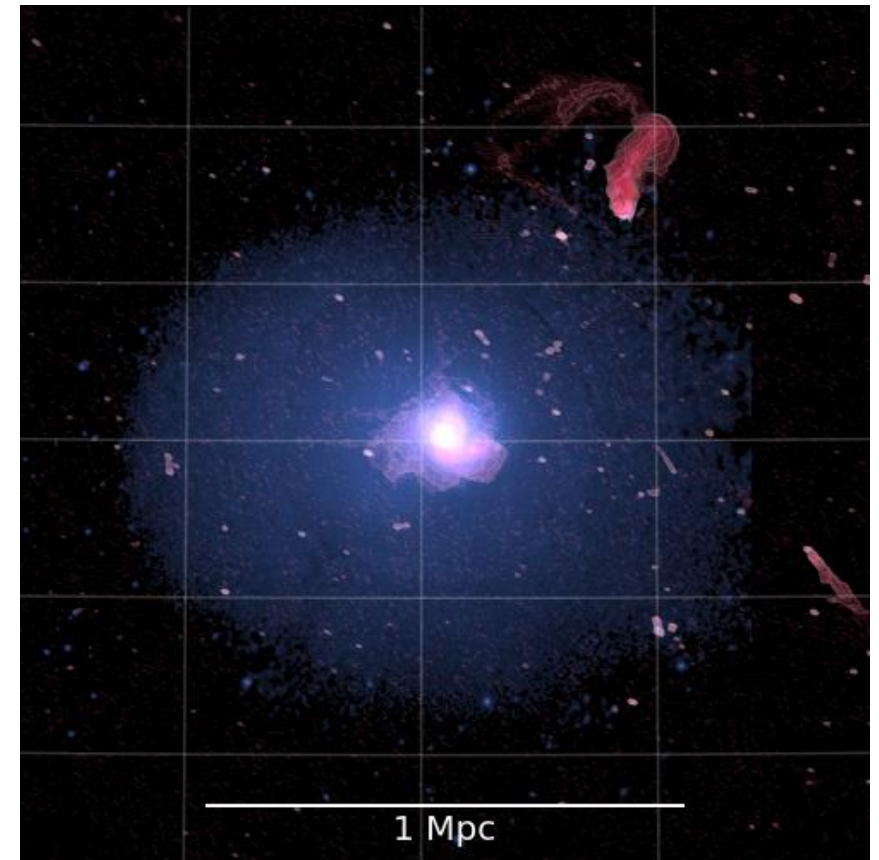
- Originated from turbulence;
- mostly found in merging clusters;
- low average surface brightness ($\sim 0.1 - 10 \mu\text{Jy}/\text{arcsec}^2$ at 144 MHz);
- **exponential surface brightness profile;**
- **$R \sim 500 - 1000 \text{ kpc}$;**
- steep spectrum ($\alpha \approx 1.3$; Feretti+12).



van Weeren et al. 2019

Diffuse radio emission in galaxy clusters: mini-halos (mHs)

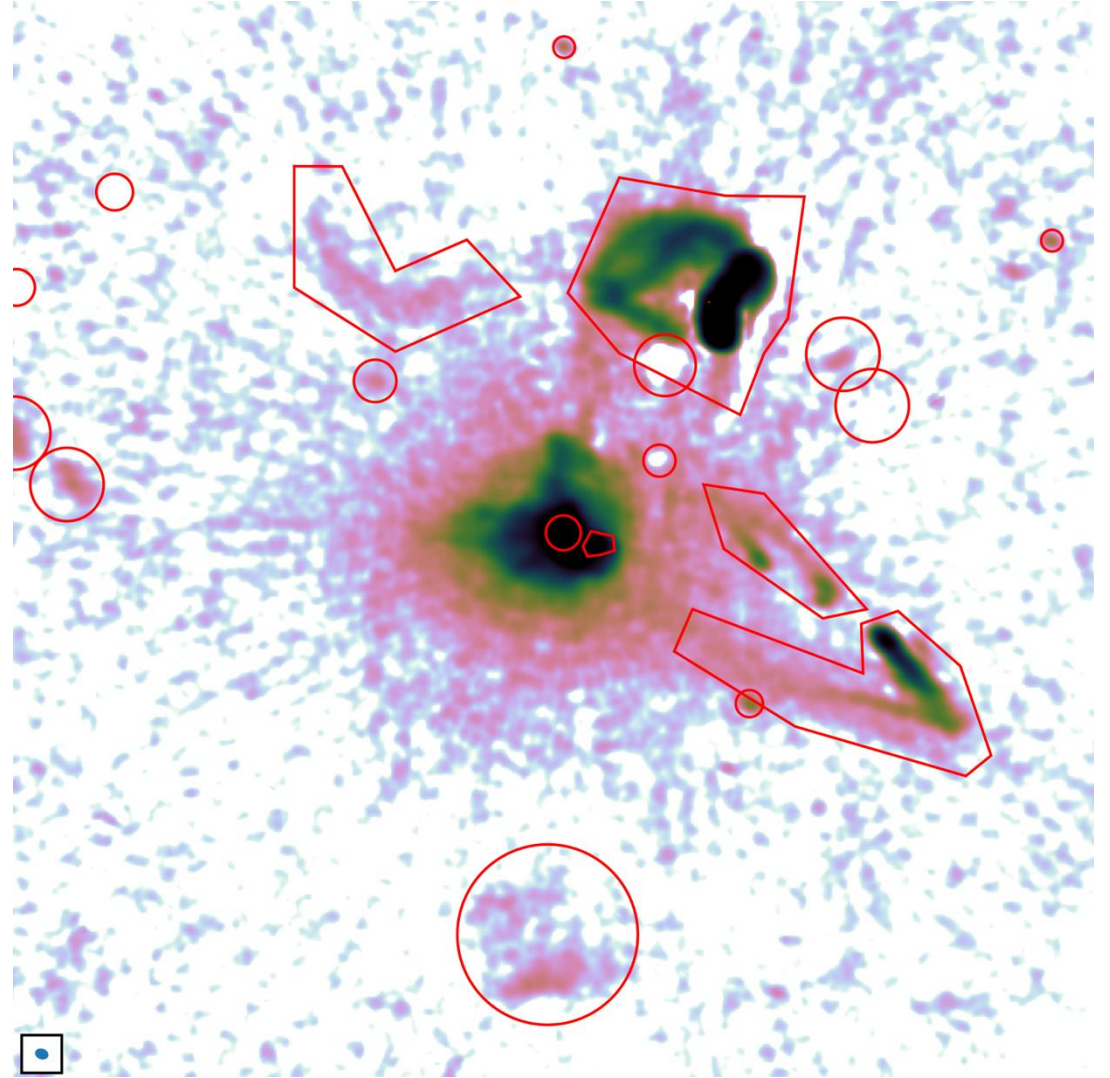
- Origin still debated - possibly gas sloshing in the cluster core;
- found in relaxed clusters;
- average surface brightness higher than the one of RHs;
- **exponential surface brightness profile;**
- **$R \sim 100 - 500 \text{ kpc}$;**
- steep spectrum.



van Weeren et al. 2019

Multi-component halos

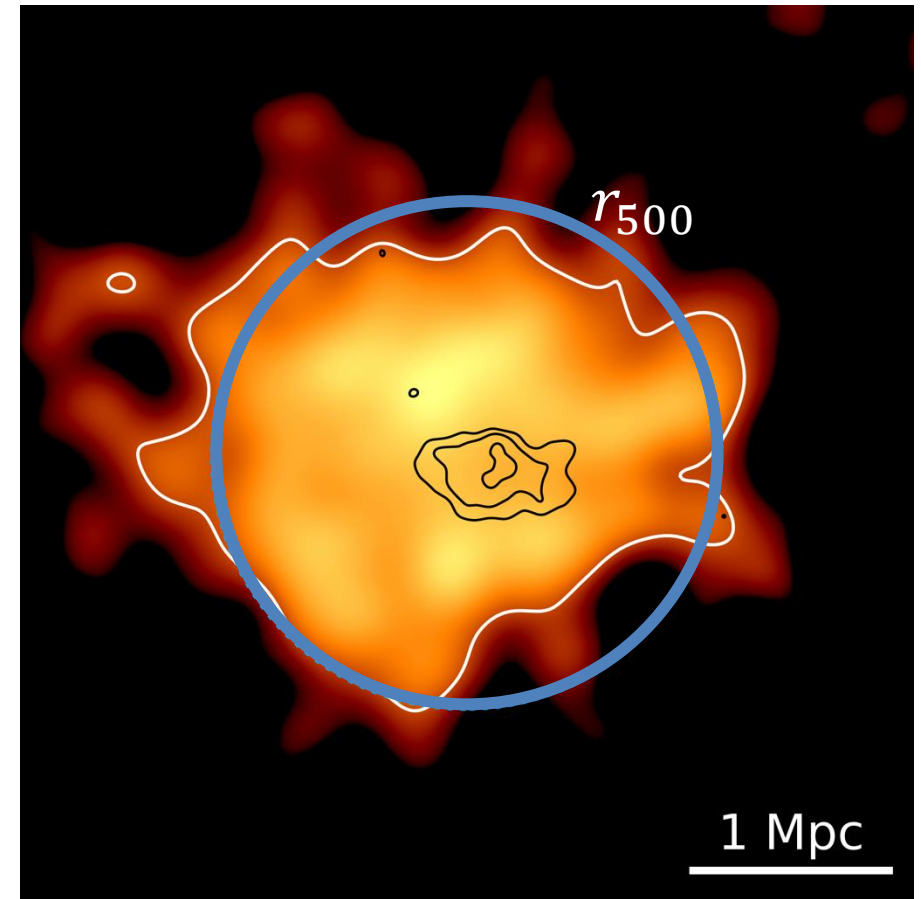
- Studies from Riseley+22, Biava+24, van Weeren+24;
- **combination of mHs + RHs;**
- **double exponential surface brightness profile;**
- no clear origin.



van Weeren et al. 2024

Large scale multi-component emission: megahalos (megaHs)

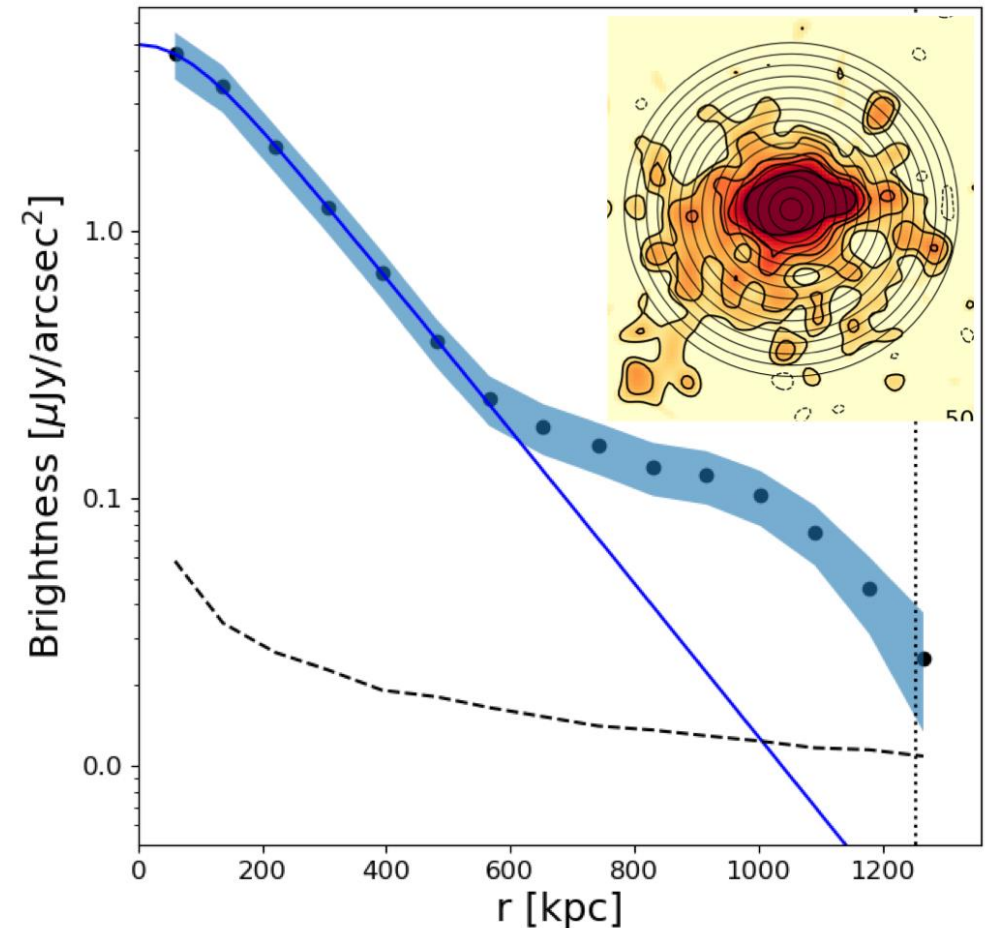
- Only four confirmed so far (Cuciti+22);
- unknown origin;
- $R \geq 1000 \text{ kpc}$;
- very low average surface brightness ($\sim 0.01 - 0.1 \mu\text{Jy}/\text{arcsec}^2$ at 144 MHz);



Cuciti et al. 2022

Large scale multi-component emission: megahalos (megaHs)

- Only four confirmed so far (Cuciti+22);
- unknown origin;
- $R \geq 1000 \text{ kpc}$;
- very low average surface brightness ($\sim 0.01 - 0.1 \mu\text{Jy}/\text{arcsec}^2$ at 144 MHz);
- almost flat surface brightness profile;
- non-exponential outer component;
- possibly ultra-steep spectrum ($\alpha \approx 1.6$).



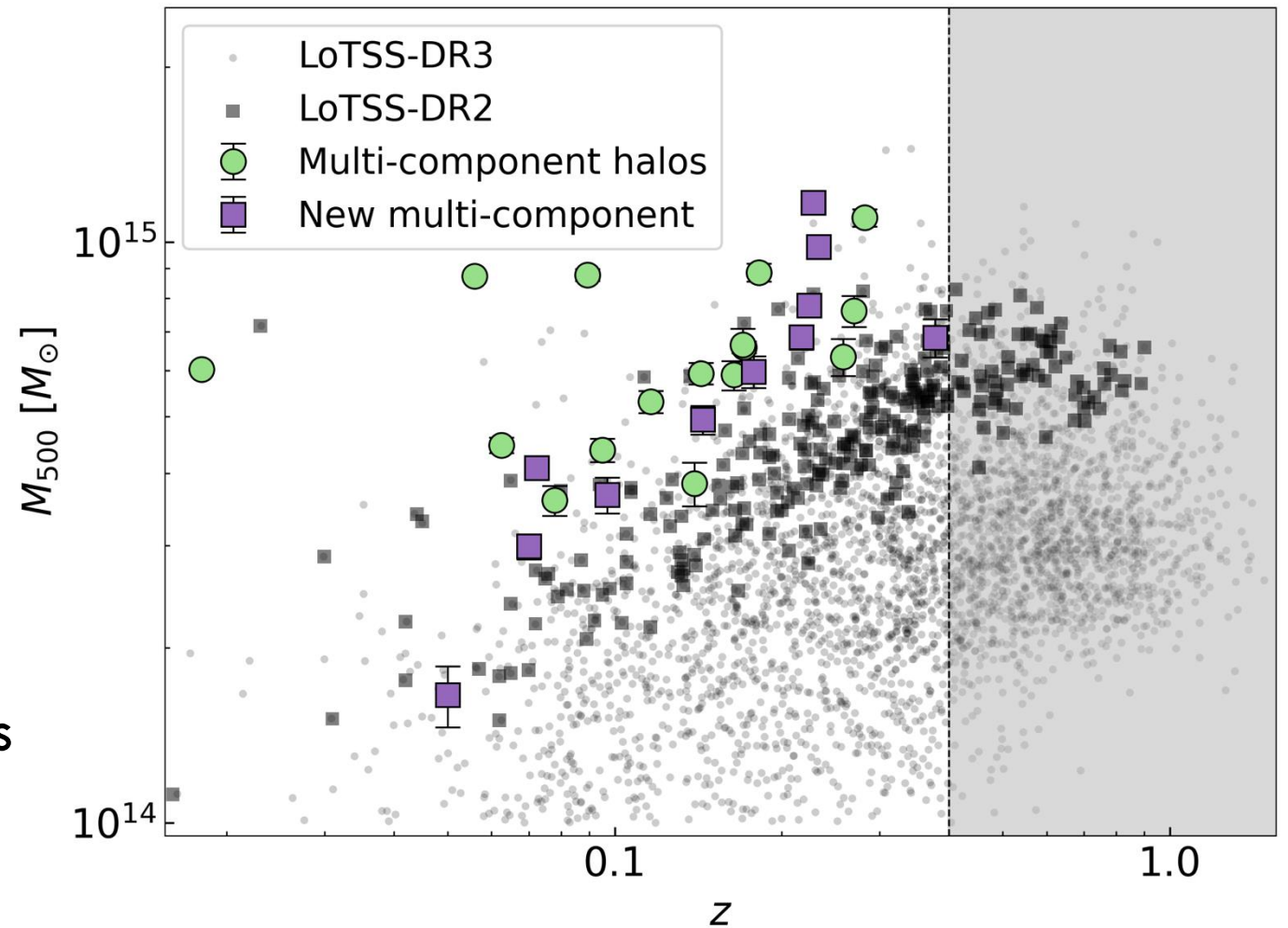
Cuciti et al. 2022

This work:

analysis of 27 multi-component halos.

Aims:

- understand the properties of multi-component halos;
- search for possible differences from classical halos.



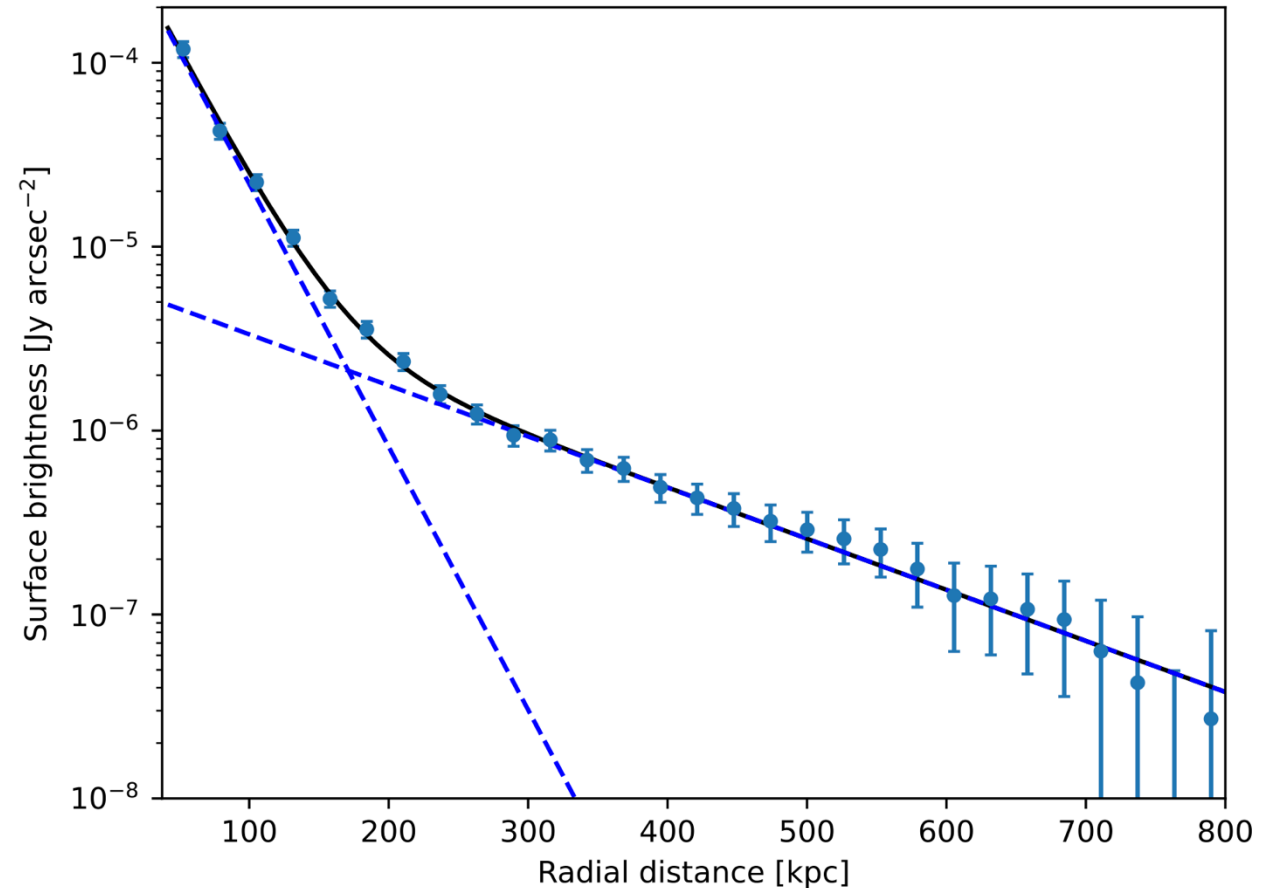
Cianfaglione et al. in prep.

Models: double exponential

- Used to fit mHs + RHs in literature (Biava+24, van Weeren+24,26; Groeneveld+26);

$$I(r) = I_0 e^{-r/r_{e1}} + I_1 e^{-r/r_{e2}};$$

- radio powers of single components computed up to $3r_e$ (Murgia+09);
- maximum extension of the outer component assumed as $R_{max} = 3r_{e2}$.



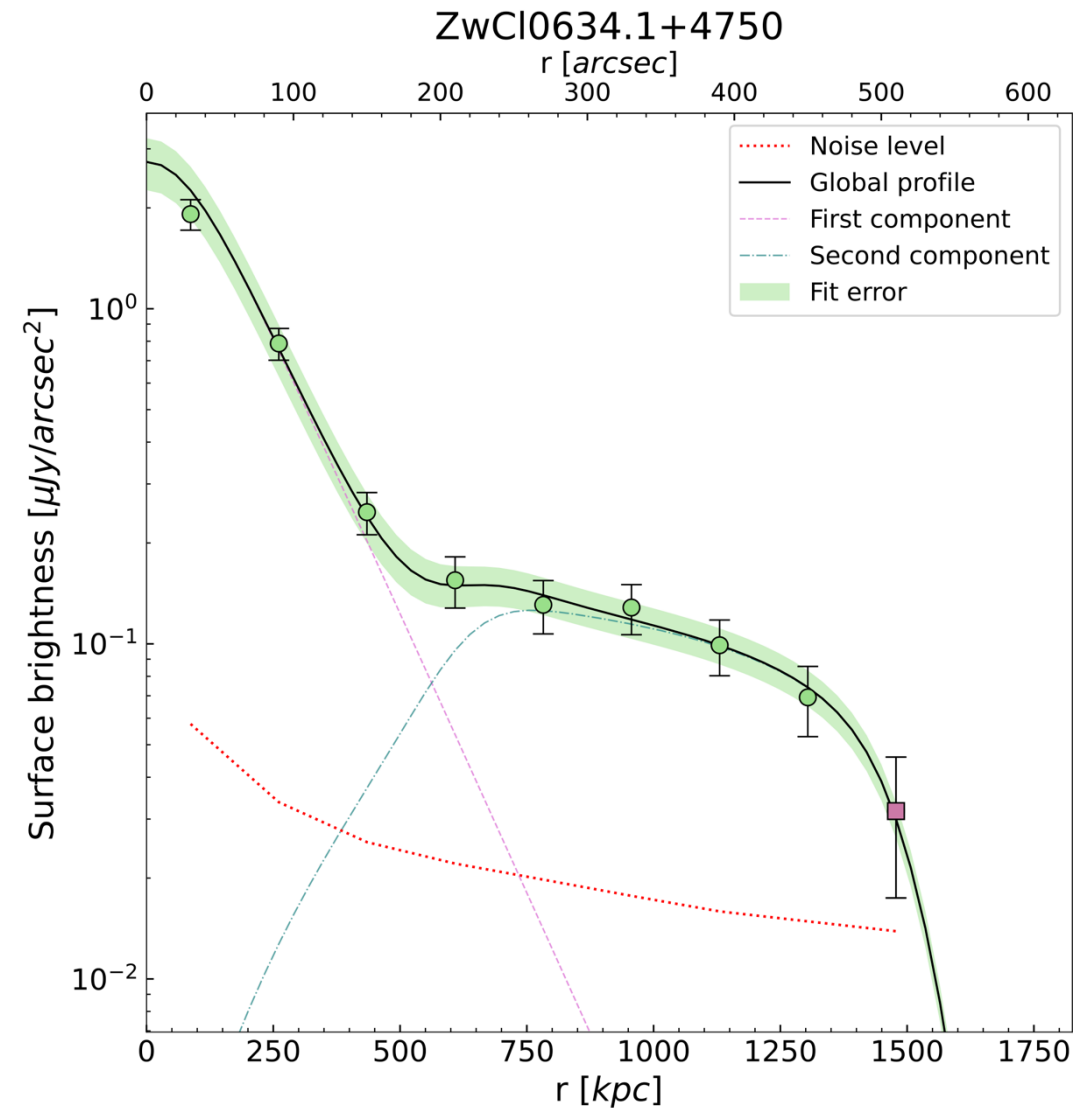
van Weeren et al. 2024

Models: shell

- Combination of exponential and projected uniform shell;
- useful to fit megaHs profiles;

$$I(r) = \begin{cases} I_0 \exp(-r/r_e) + I_1 \left(\frac{\sqrt{R_{max}^2 - r^2}}{R_{max}} - \frac{\sqrt{R_{min}^2 - r^2}}{R_{min}} \right) & r < R_{min} \\ I_0 \exp(-r/r_e) + I_1 \frac{\sqrt{R_{max}^2 - r^2}}{R_{max}} & R_{min} < r < R_{max} \end{cases}$$

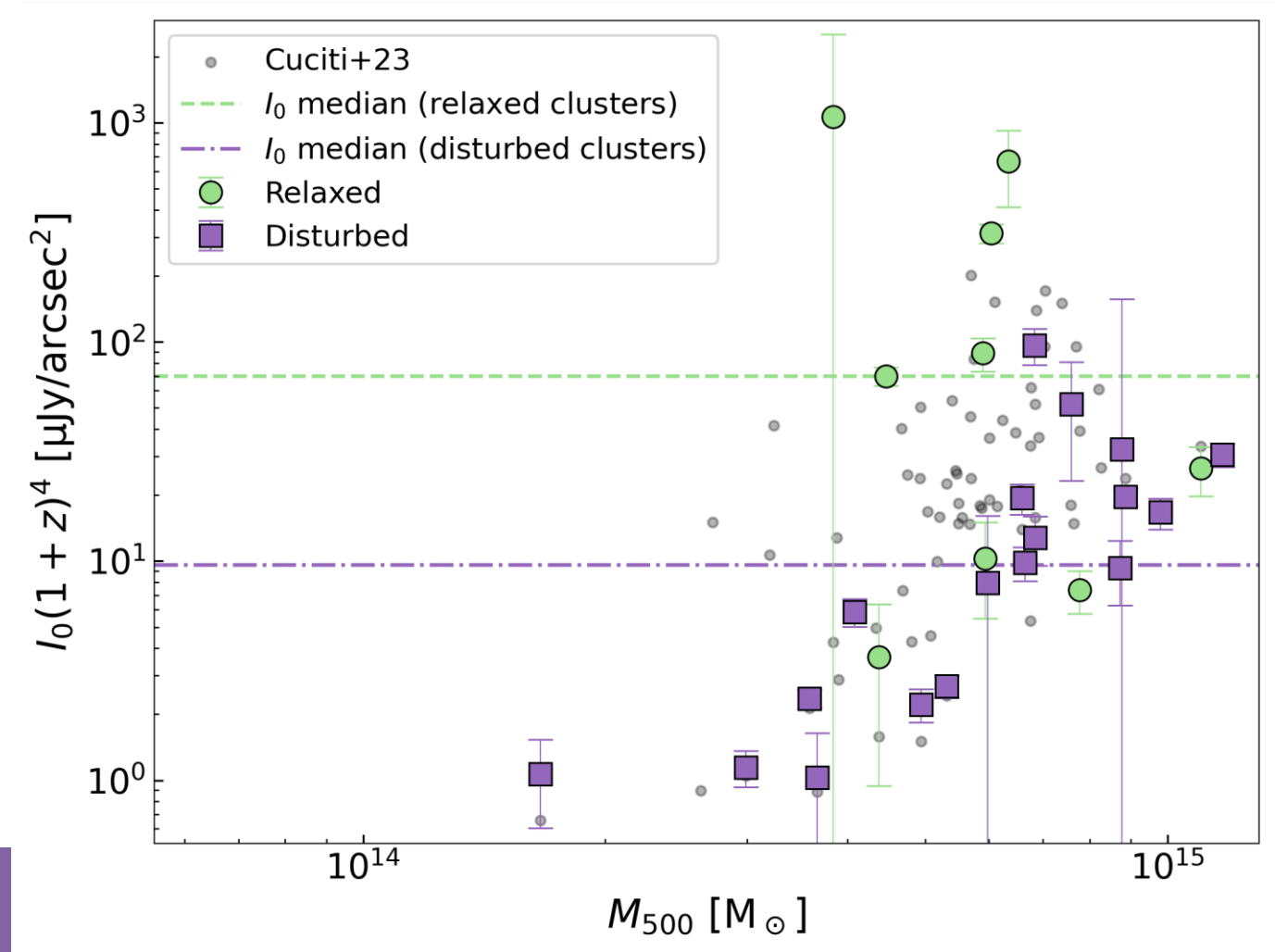
- R_{max} defines the extension of the outer component.



Adapted from Cuciti et al. 2022

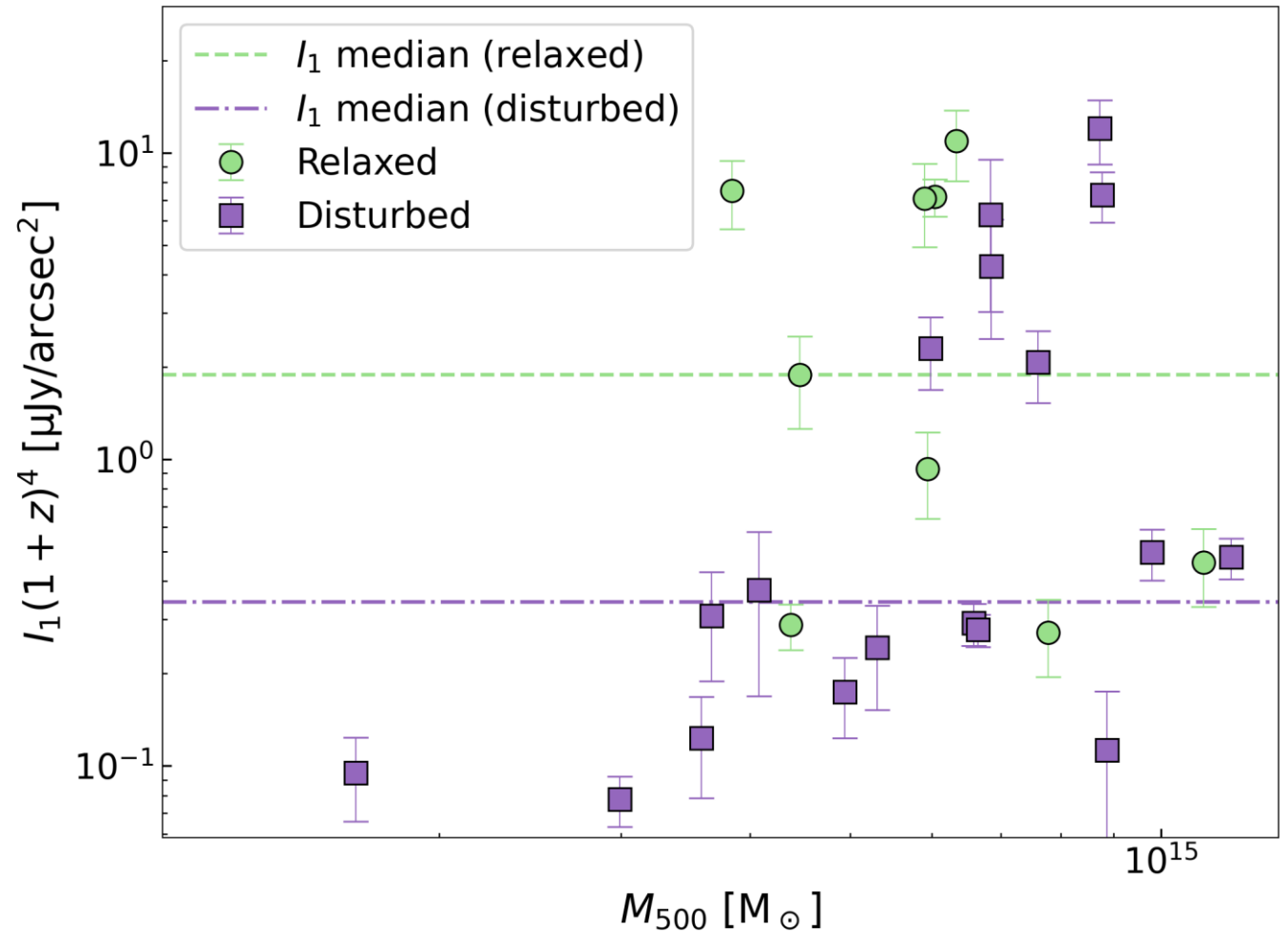
Preliminary results: $I_0 - M_{500}$

- I_0 correlates with M_{500} in disturbed clusters ($r_{Spear} = 0.82$, $p = 2.6 \cdot 10^{-5}$);
- relaxed clusters have larger I_0 than disturbed clusters.



Preliminary results: $I_1 - M_{500}$

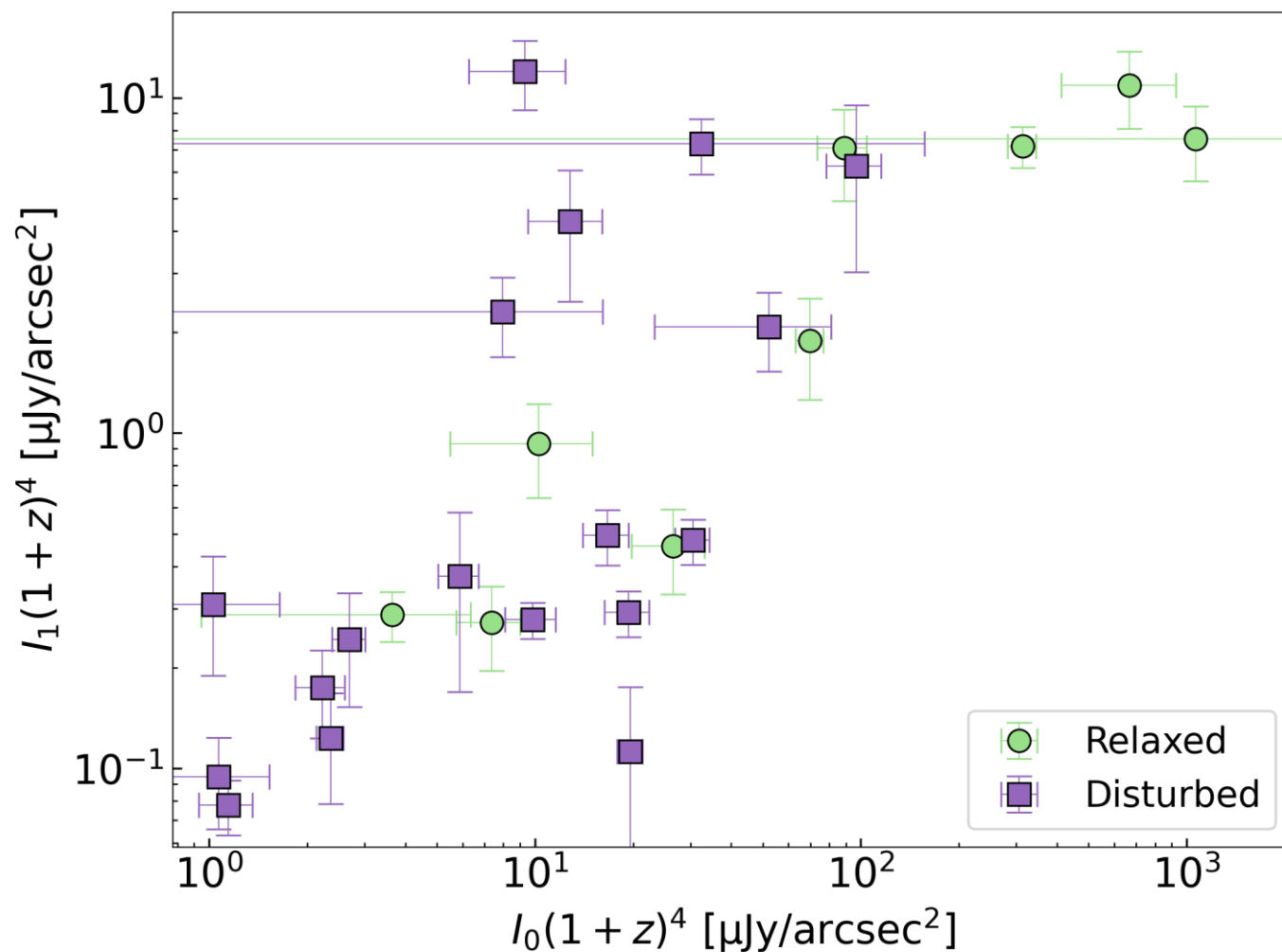
- No correlation observed between I_1 and M_{500} ;
- outer component in disturbed clusters has lower central surface brightness.



Preliminary results: $I_0 - I_1$

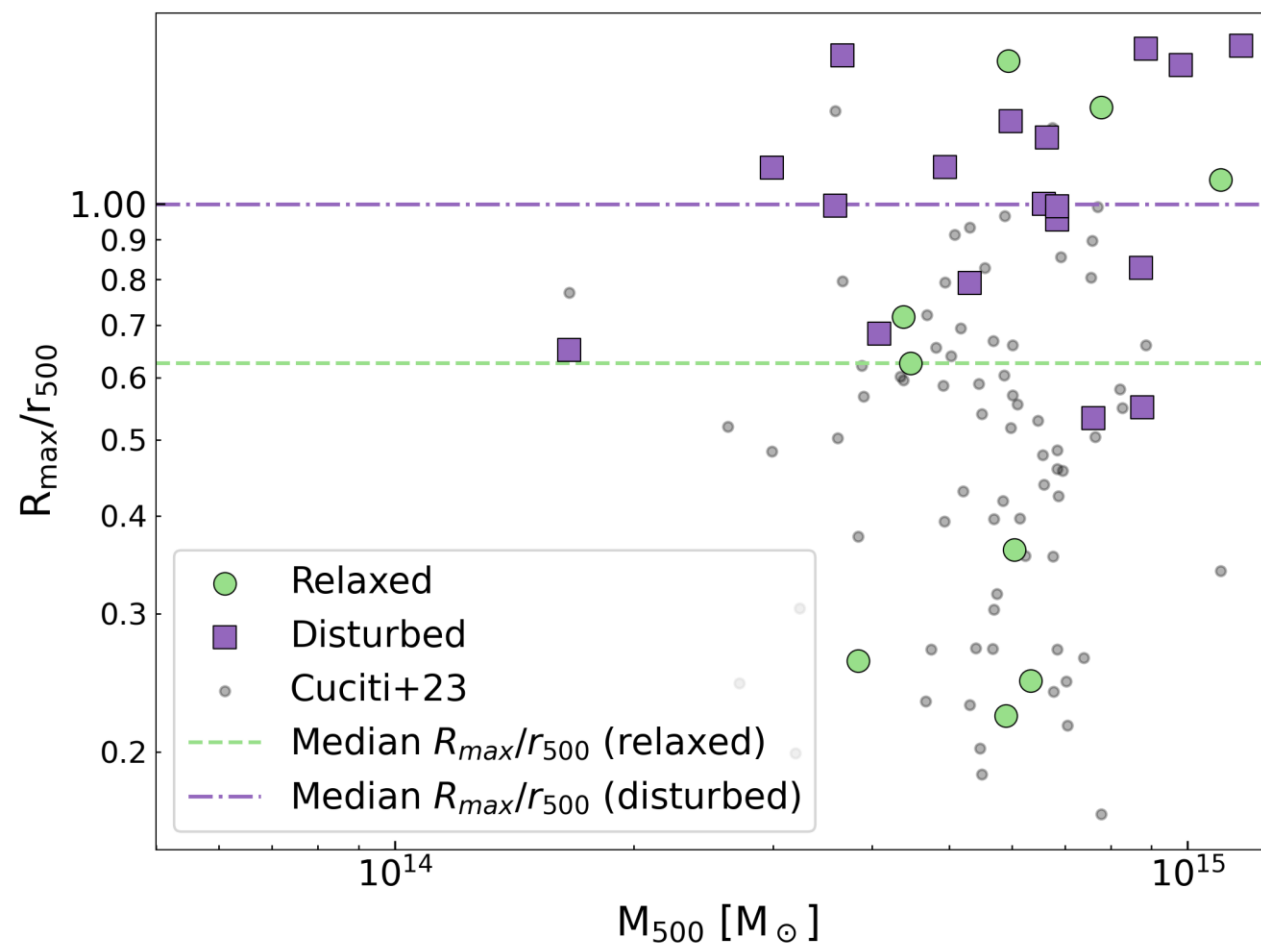
Strong $I_0 - I_1$ correlation for the entire sample:

$$r_{Spear} = 0.73, p = 1.4 \cdot 10^{-5}$$



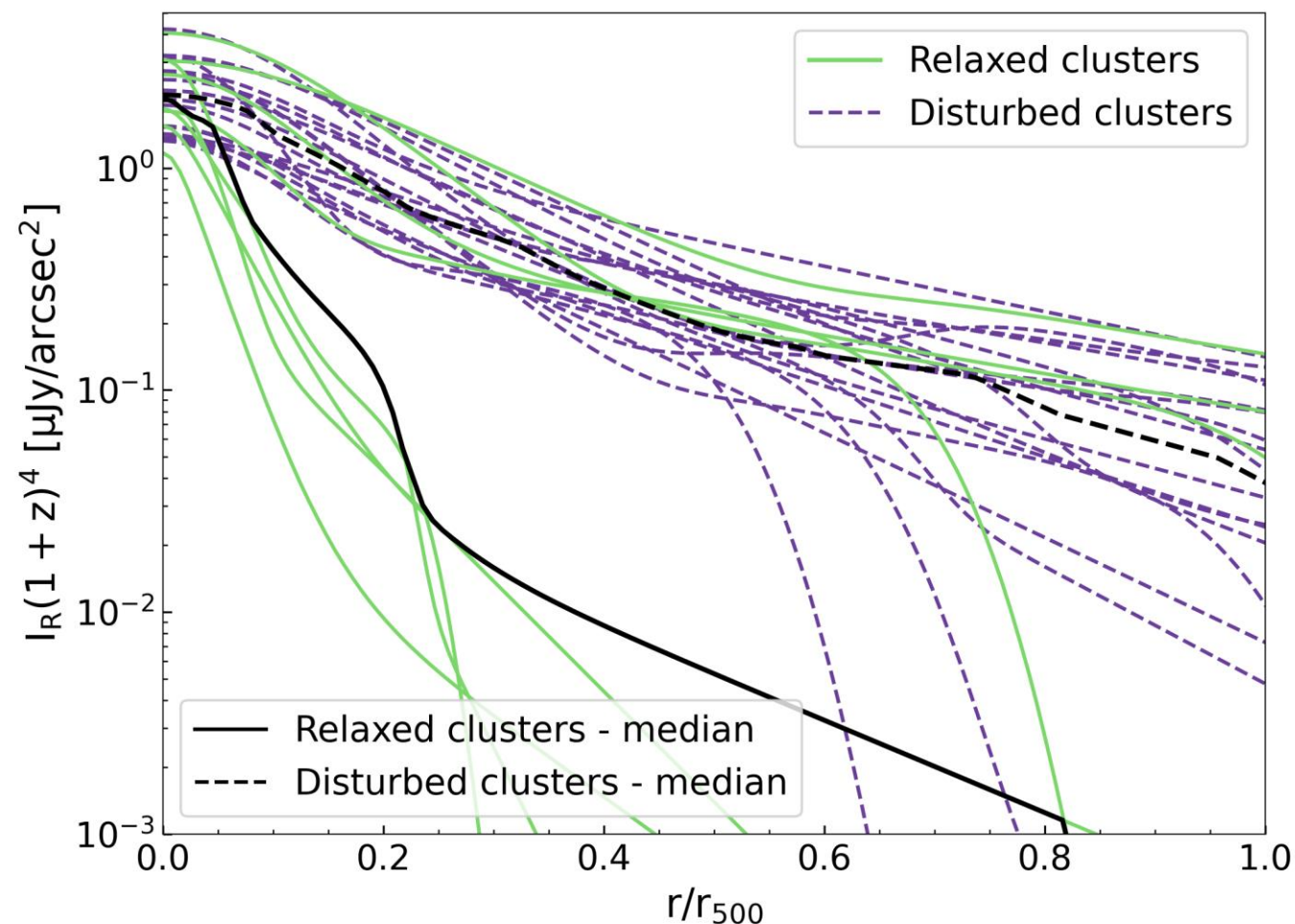
Preliminary results: $R_{\max} - M_{500}$

- Diffuse emission in disturbed clusters reaching $\sim r_{500}$;
- diffuse emission in disturbed clusters is more extended than the one in relaxed clusters.



Preliminary results: radial profiles

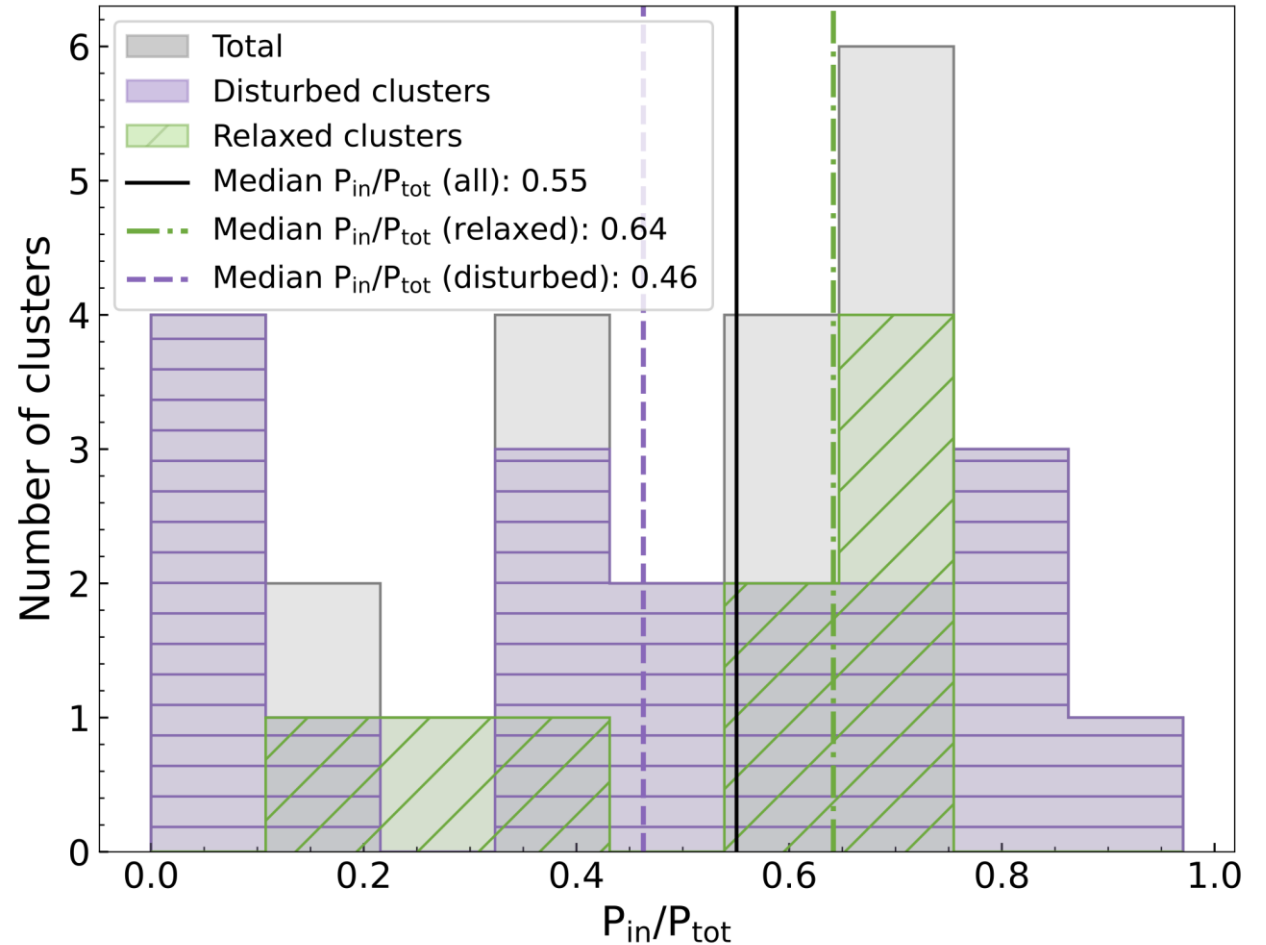
Some relaxed clusters show profiles that are clearly different from disturbed clusters.



Preliminary results: power distribution of the two components

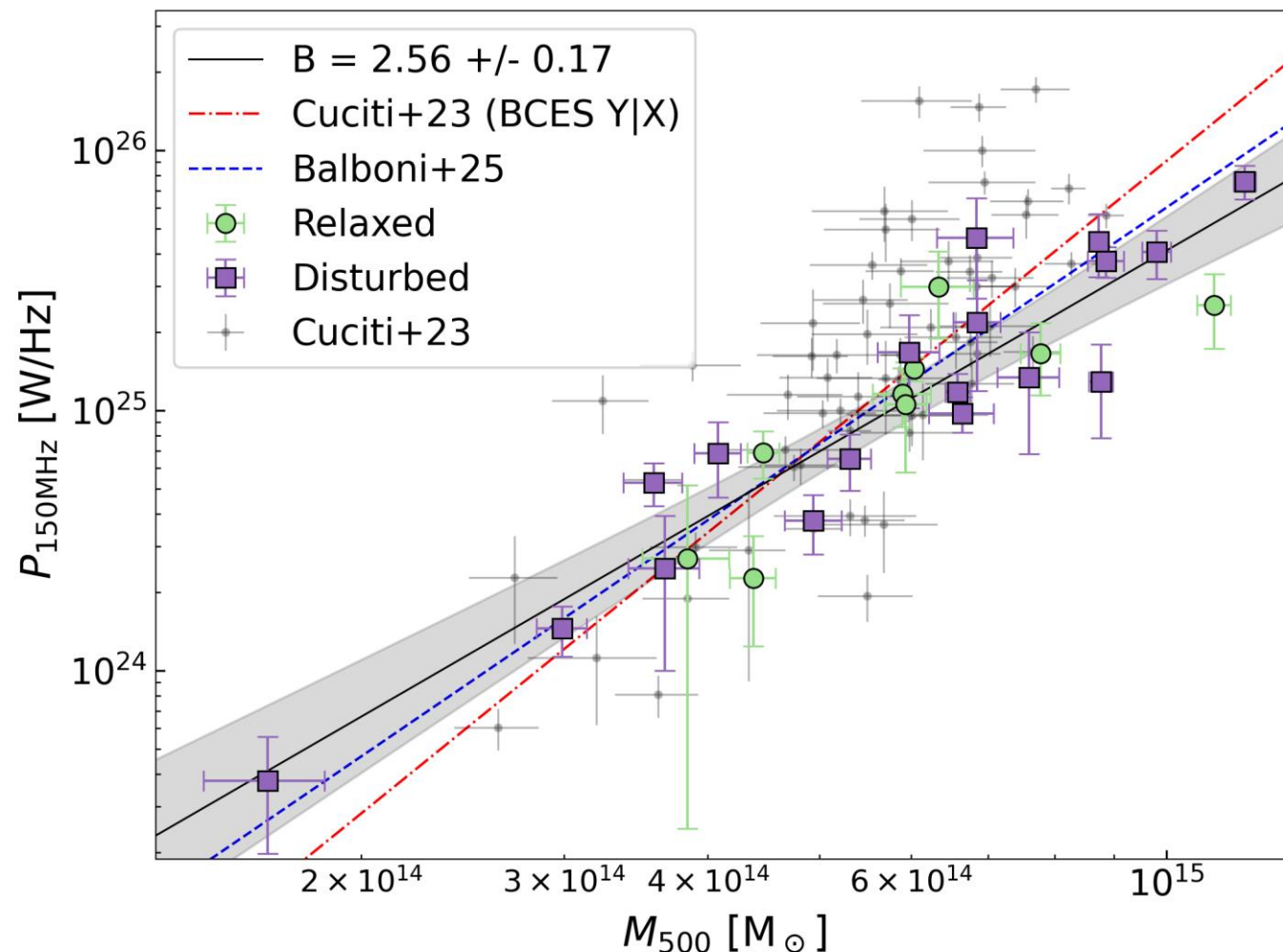
Radio power is almost equally distributed between the two components.

WARNING: possible presence of selection bias that excludes clusters with fainter outer components!



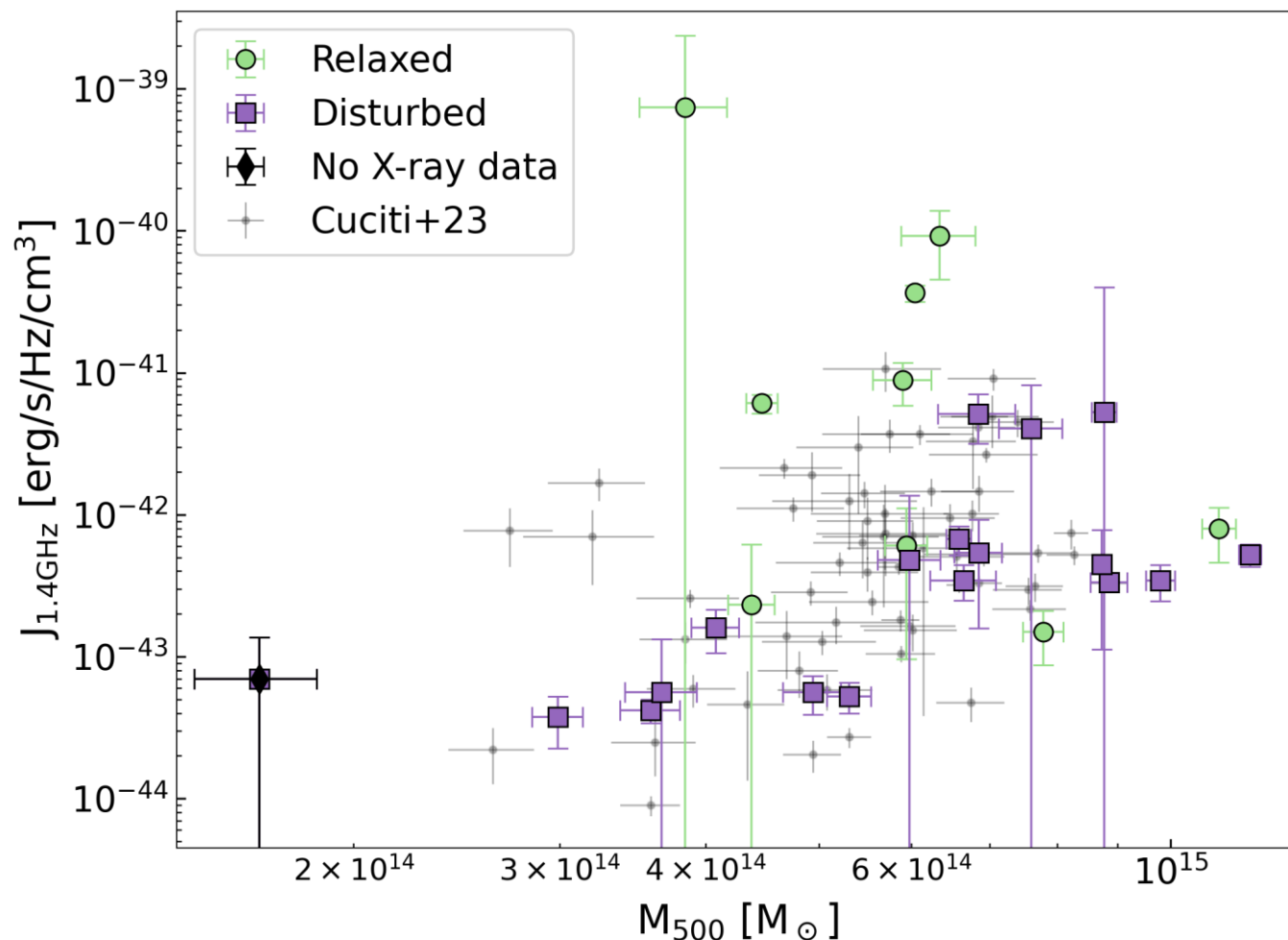
Preliminary results: power-mass relation

- RHs follow a power-mass (P-M) relation (Cassano+13, Cuciti+21,+23, Balboni+25);
- multi-component halos show no significant differences from previous known correlations.

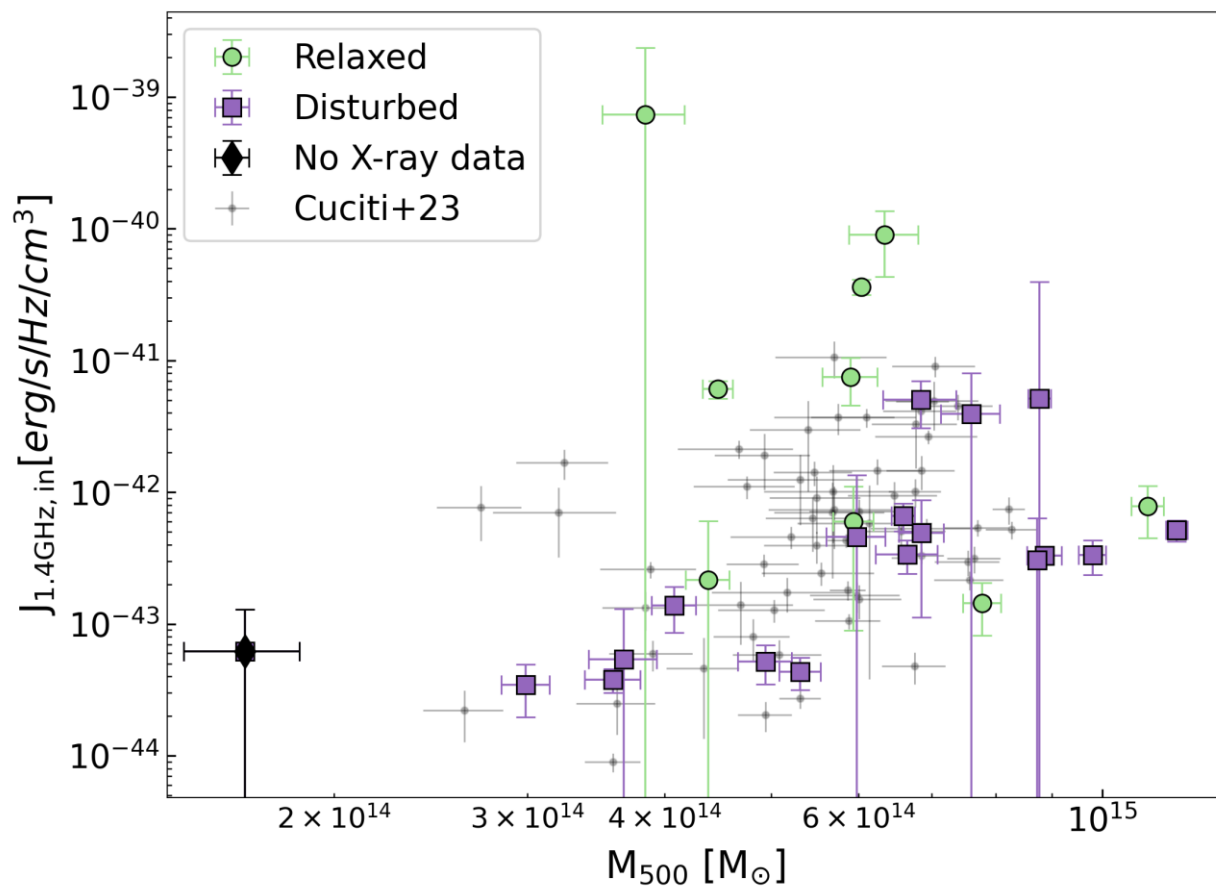


Preliminary results: emissivity-mass diagram

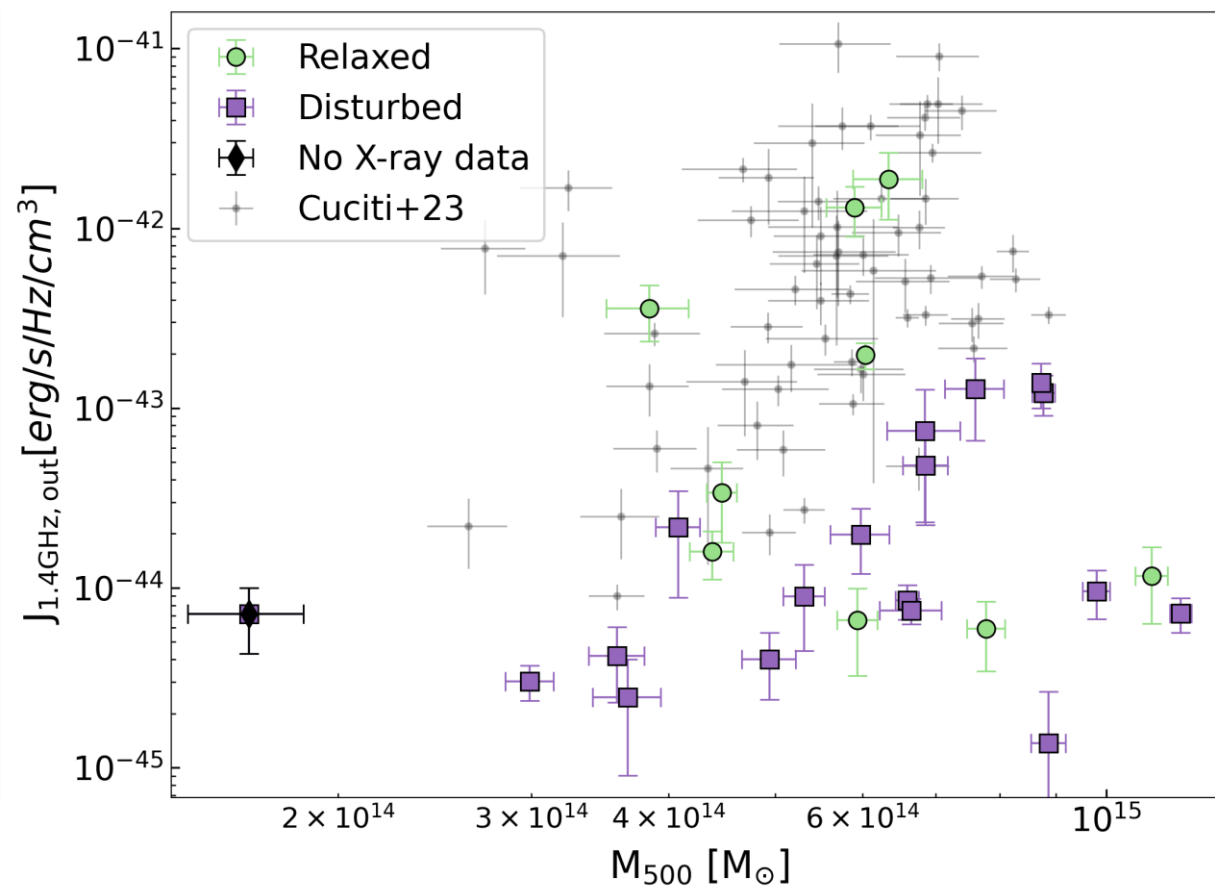
- Some relaxed clusters clearly host mHs;
- disturbed clusters have emissivity comparable to single component RHs.



Preliminary results: emissivity-mass diagram



Inner components emissivities



Outer components emissivities

Conclusions

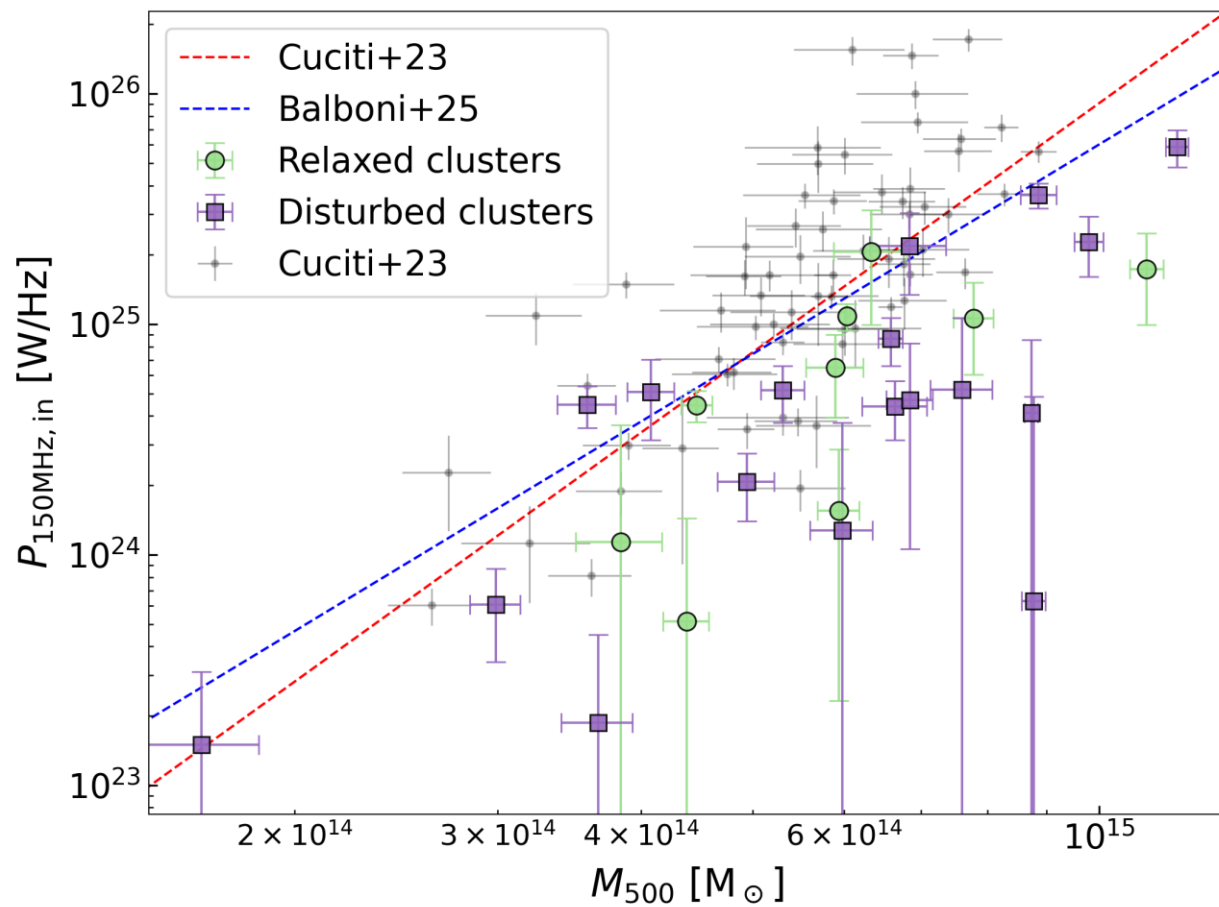
- relaxed and disturbed clusters both can host multi-component halos;
 - multi-component halos follow the same P-M relation of RHs;
 - radio power between the two components is almost equally distributed;
 - diffuse emission in relaxed clusters covers smaller scales compared to disturbed clusters;
 - I_0 shows a correlation with the cluster mass;
 - clusters with a brighter inner component host also a brighter outer component.
-

Thank you for the attention

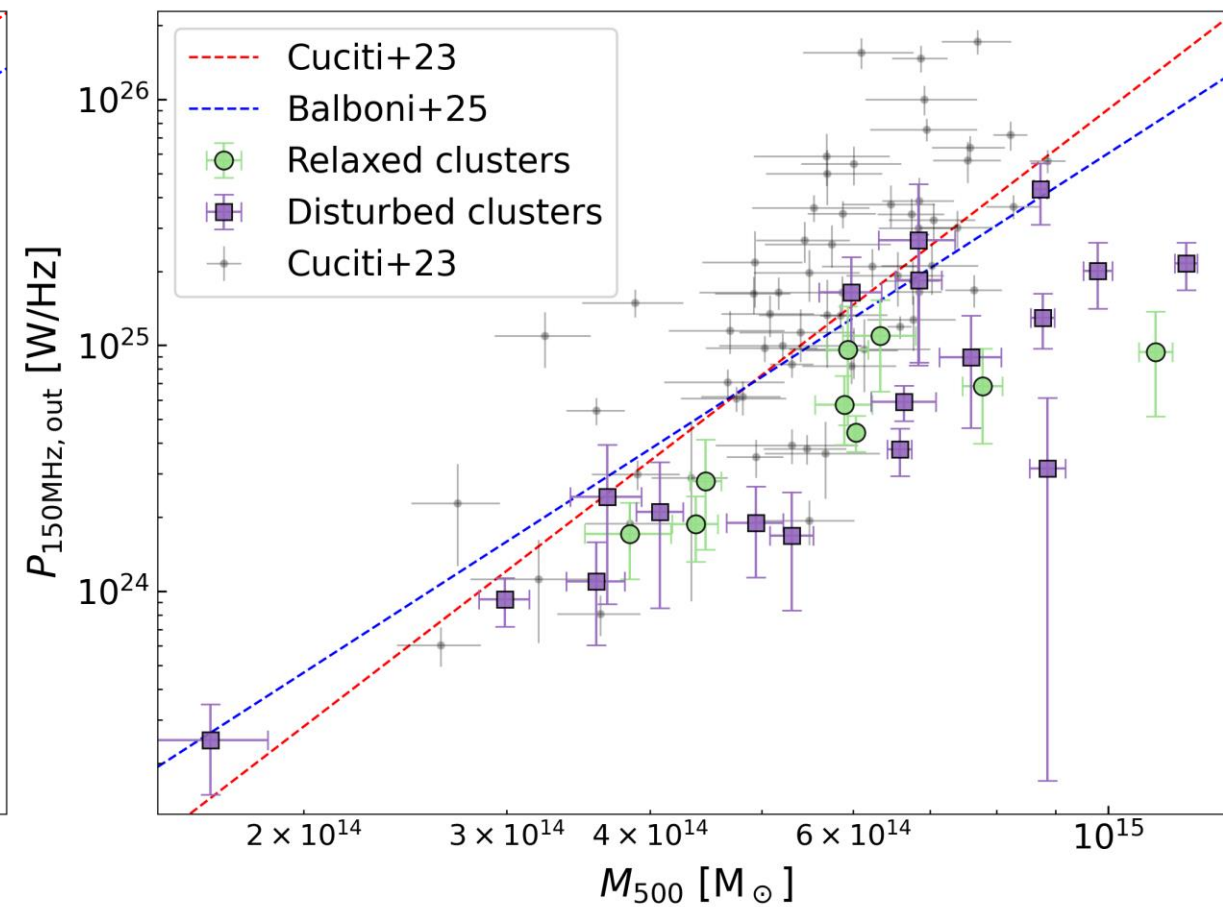


EXTRA SLIDES

Preliminary results: power-mass relation



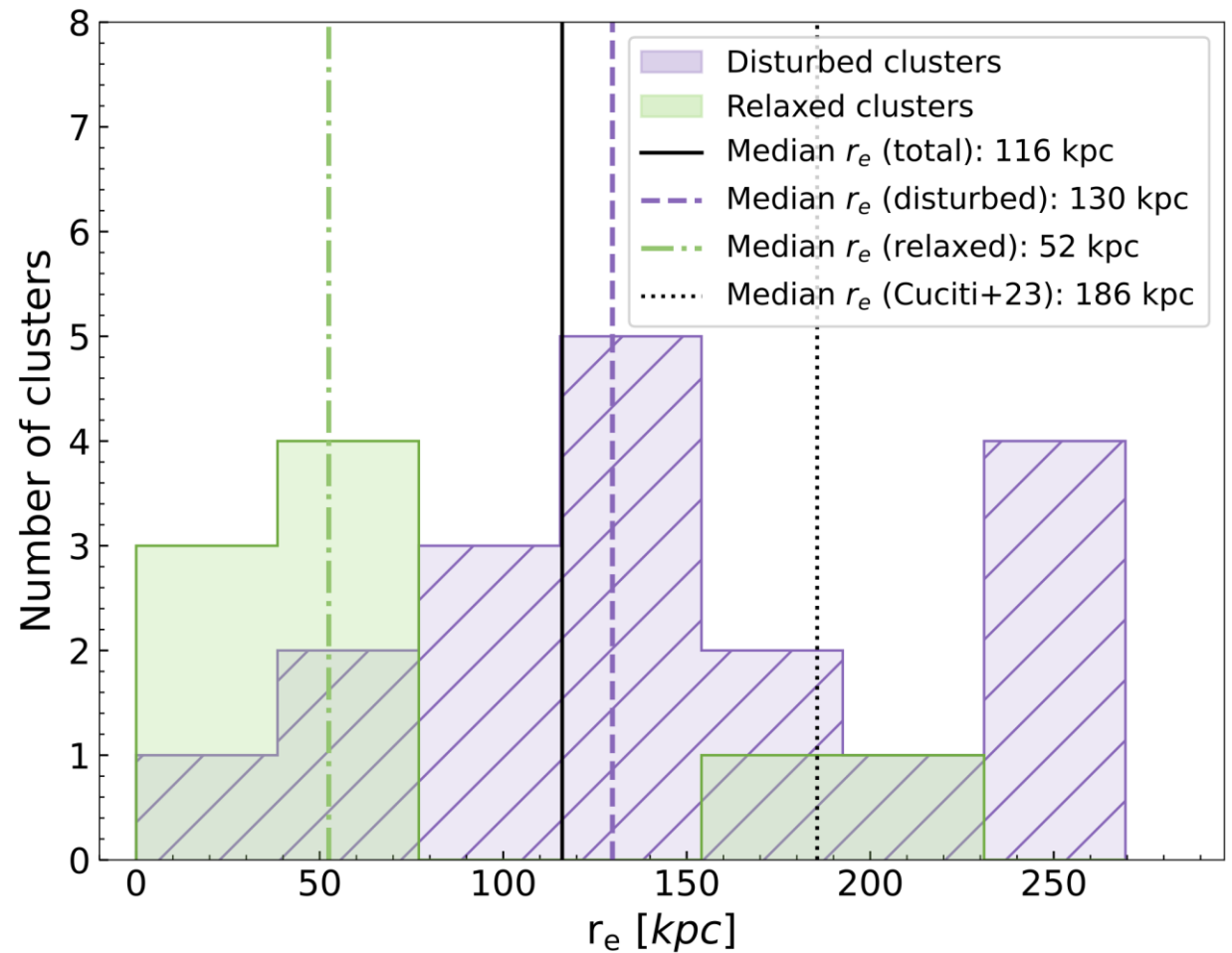
Inner components powers



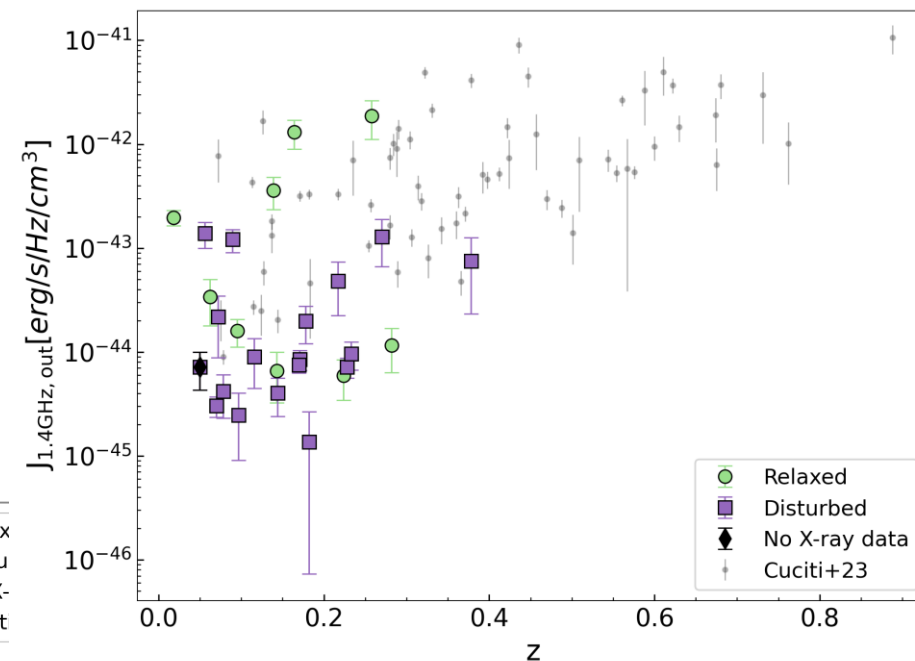
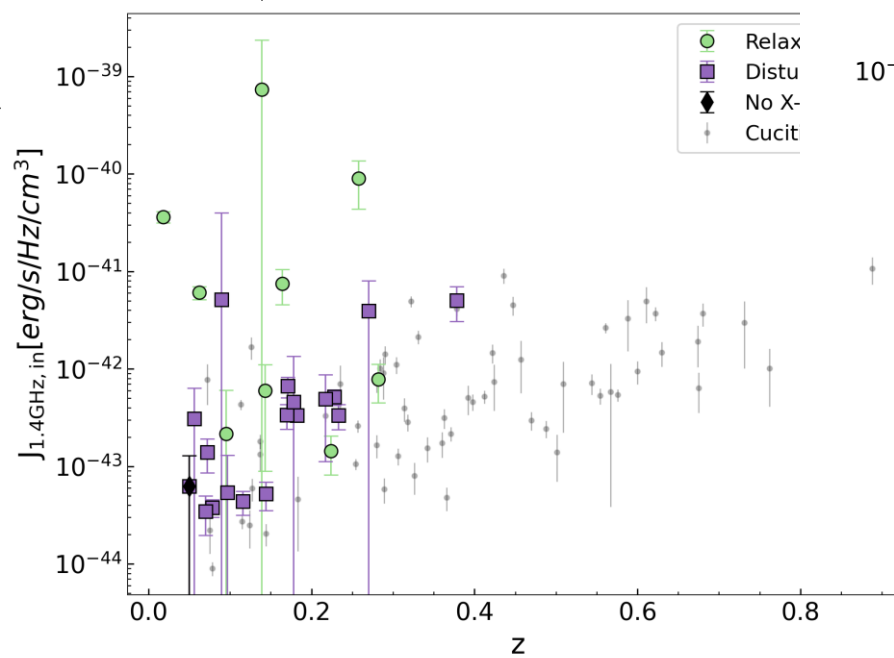
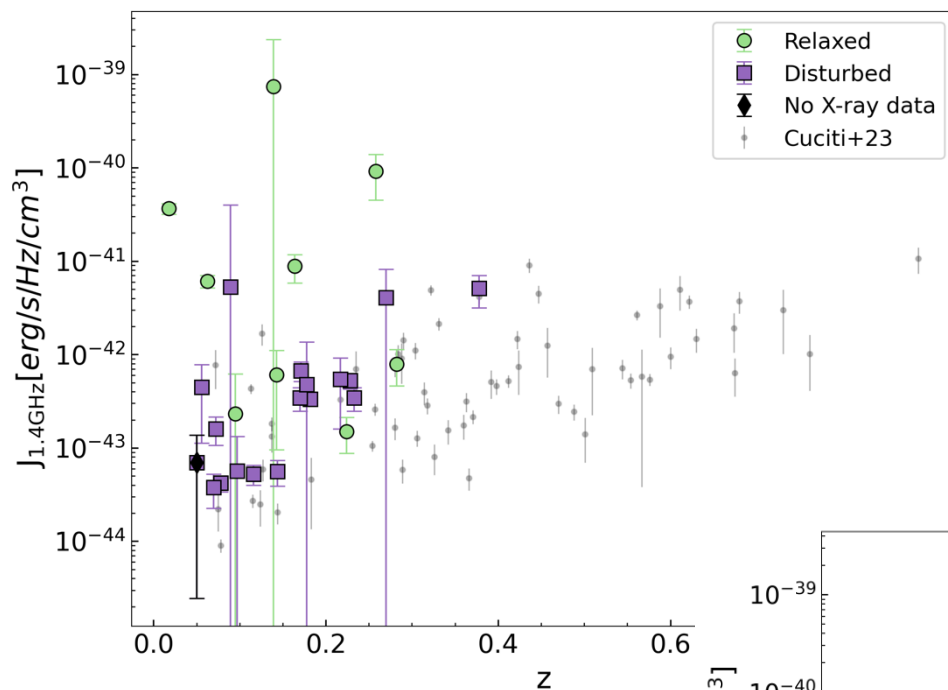
Outer components powers

Preliminary results: r_{e1} distribution

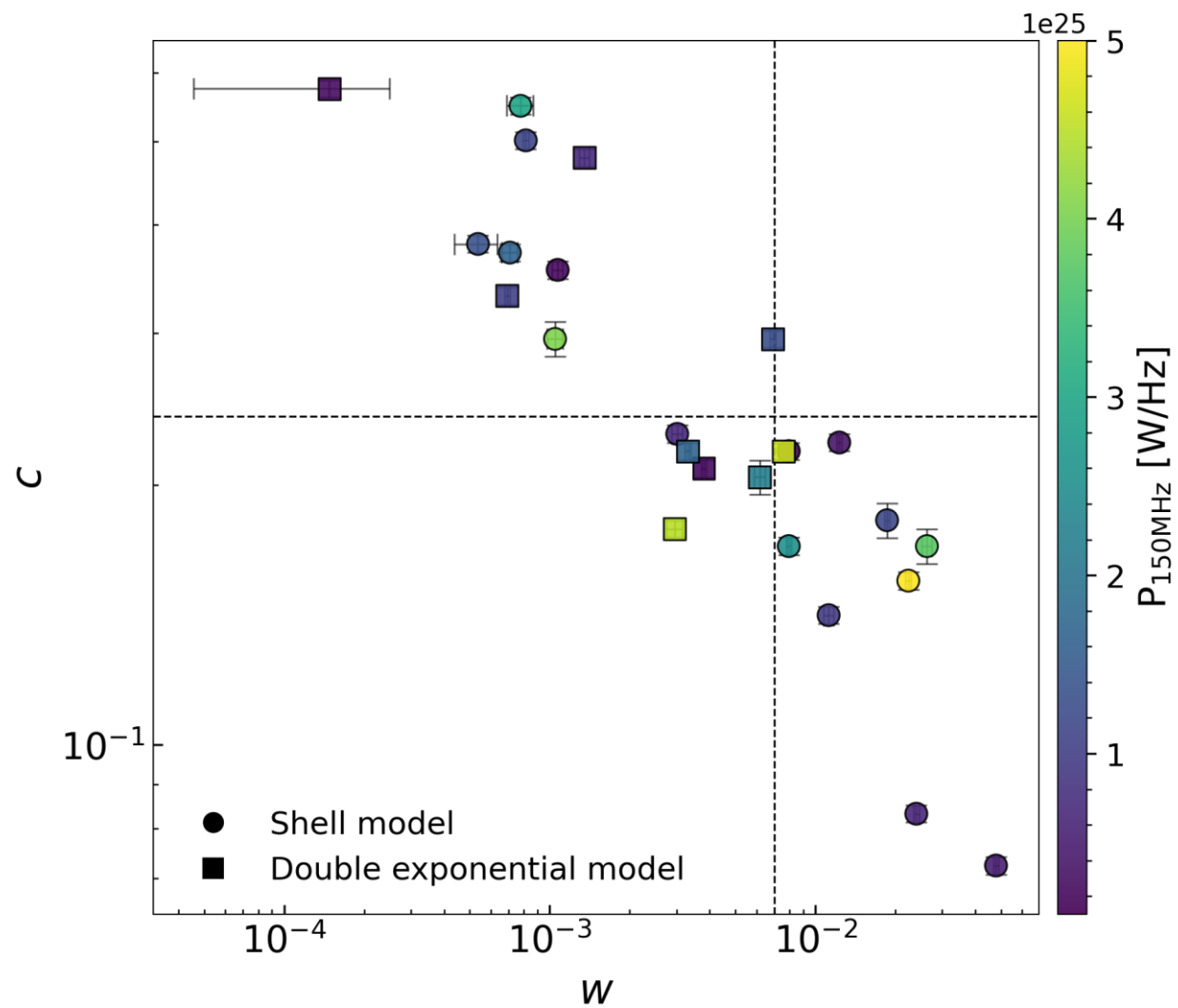
Relaxed clusters show a smaller effective radius compared to disturbed clusters.



Emissivity



c-w diagram



I vs z

