ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

for Zaky

INAF OAS
BOLOGNA

The dynamical state of galaxy clusters in the CHEX-MATE sample

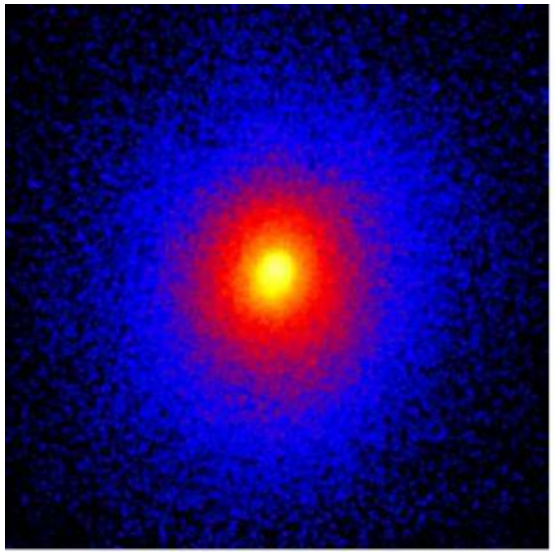
Presented by: M. Giulia Campitiello
Supervisors: Stefano Ettori and Lorenzo Lovisari

The mm Universe with @NIKA2 - 30th June 2021

Introduction

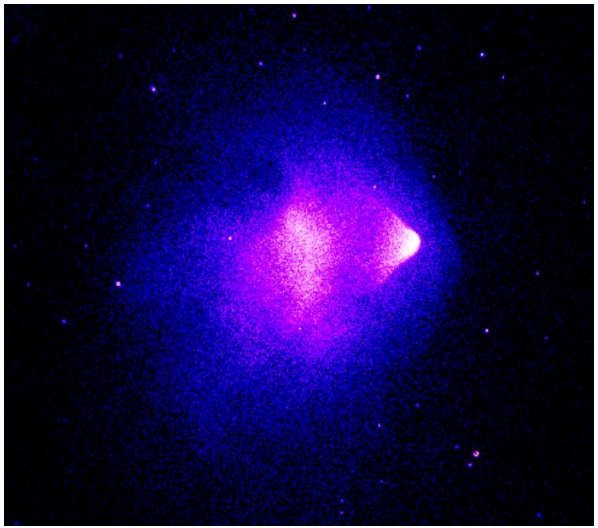
- Relaxed -

Abell1835 (z = 0.25)



- Disturbed -

The Bullet cluster (z = 0.30)



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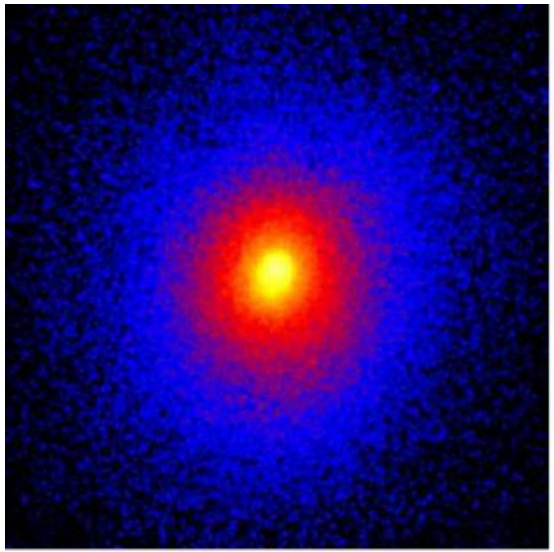

- Estimation of the cluster total mass from X-ray images.

- Disturbed -

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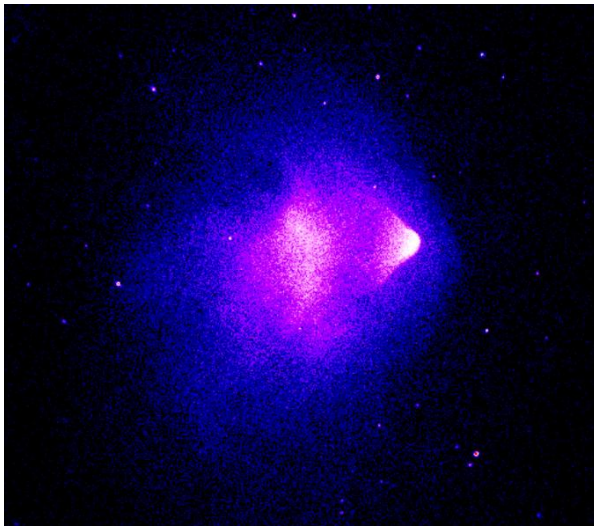
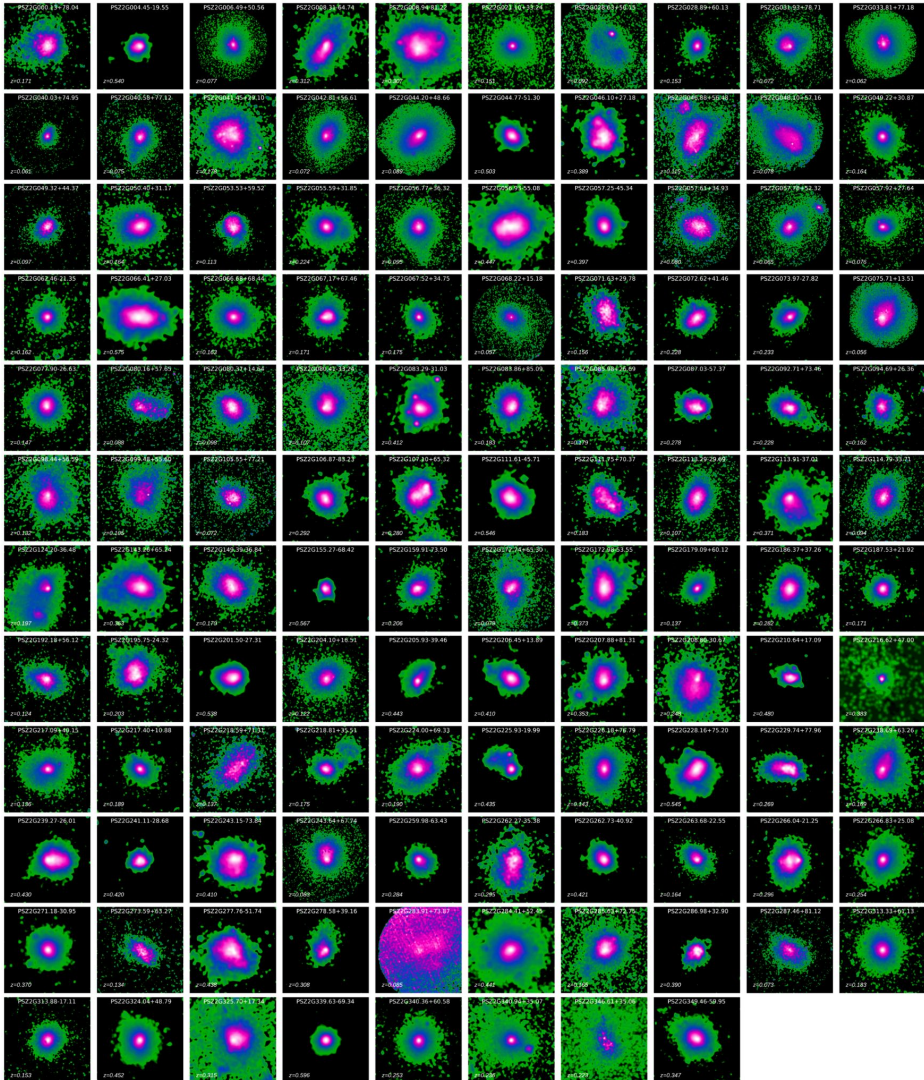


- Study of all those microphysical processes related to turbulence or sloshing of the ICM (e.g., particle acceleration mechanisms).

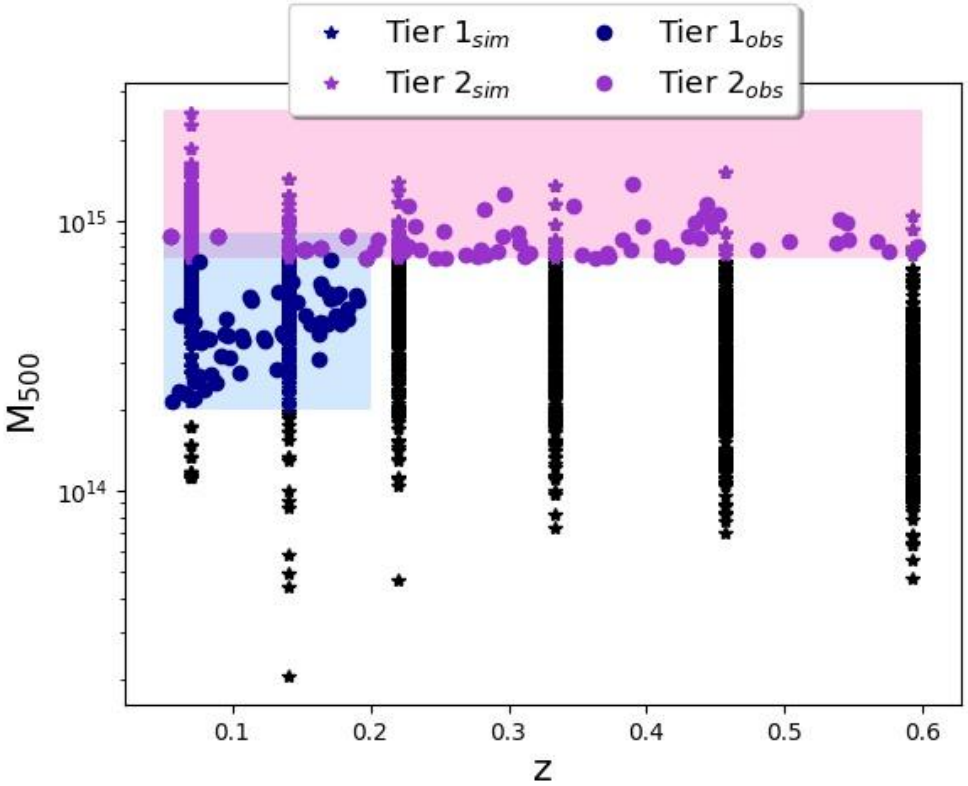
Introduction - Aim of the project

- Realise a morphological analysis of the objects of the CHEX-MATE sample to **provide** to the entire community **a dynamical classification**;

- Check the **robustness** of the techniques developed until now.



Dataset



- **118 clusters** of the CHEX - MATE sample: Background-subtracted, source-masked images filtered in the **0.7 - 1.2 keV** band.

★ Simulated sample provided by the *Three Hundred Collaboration*: same energy (**0.7 - 1.2 keV)** and redshift (**0.07 < z < 0.59**) range.

Tier 1: most recent objects (0.05 < z < 0.2)

Tier 2: most massive objects ($M_{500} > 7.25 \cdot 10^{14}$ M$_\odot$)

Methods - Derive the dynamical state of clusters from X-ray morphologies

- Relaxed -

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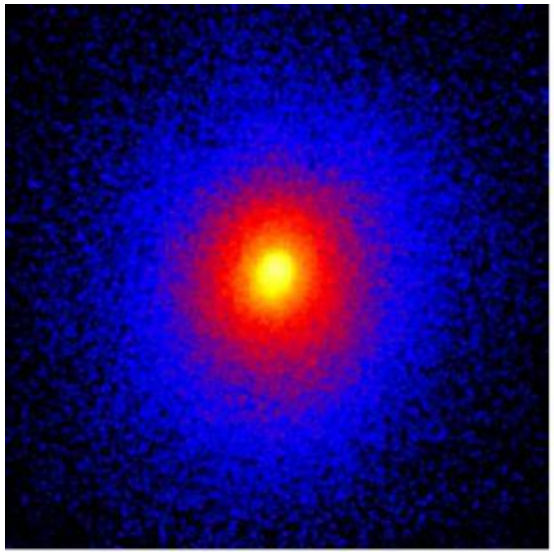

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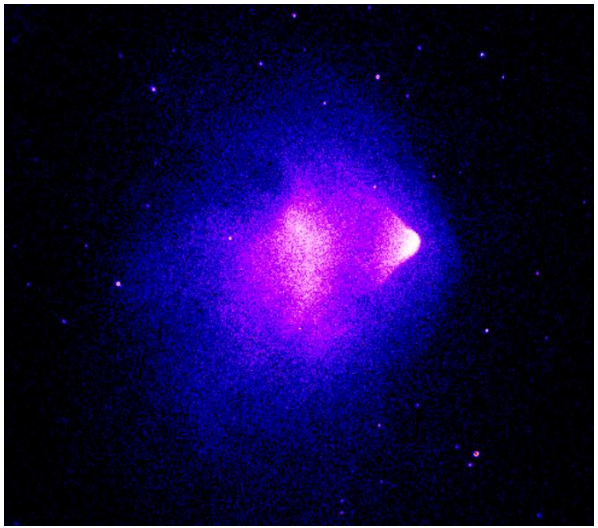


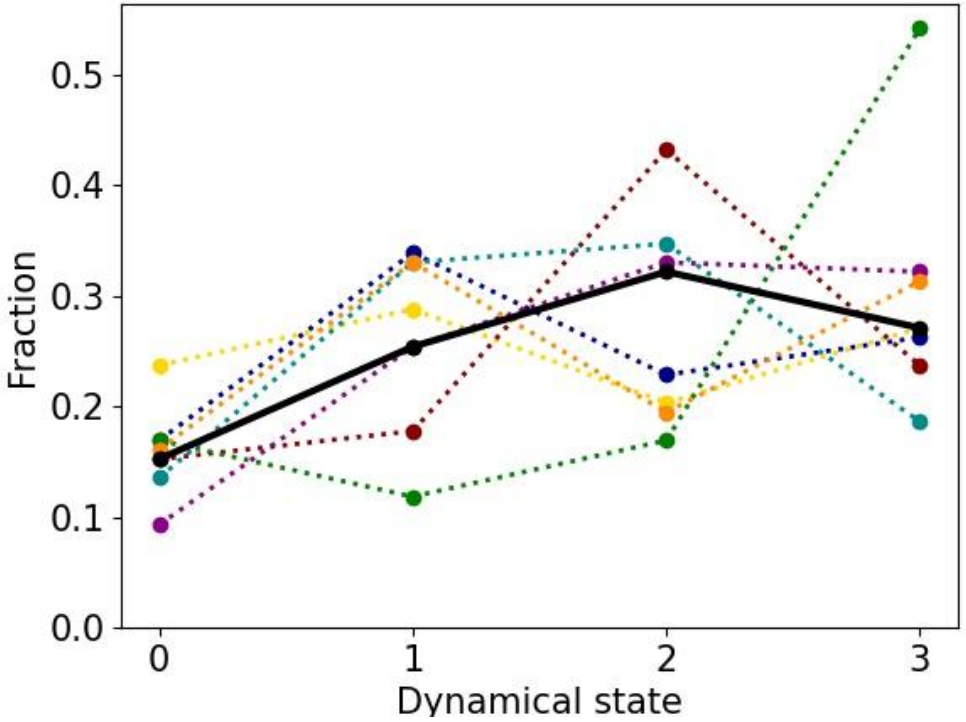
Originally -> **visual inspection**

Morphological analysis - Visual inspection

Images inspected by 7 astronomers:

- **0** relaxed
- **1** mixed-relaxed
- **2** mixed-disturbed
- **3** disturbed.

High scatters between the classifications.



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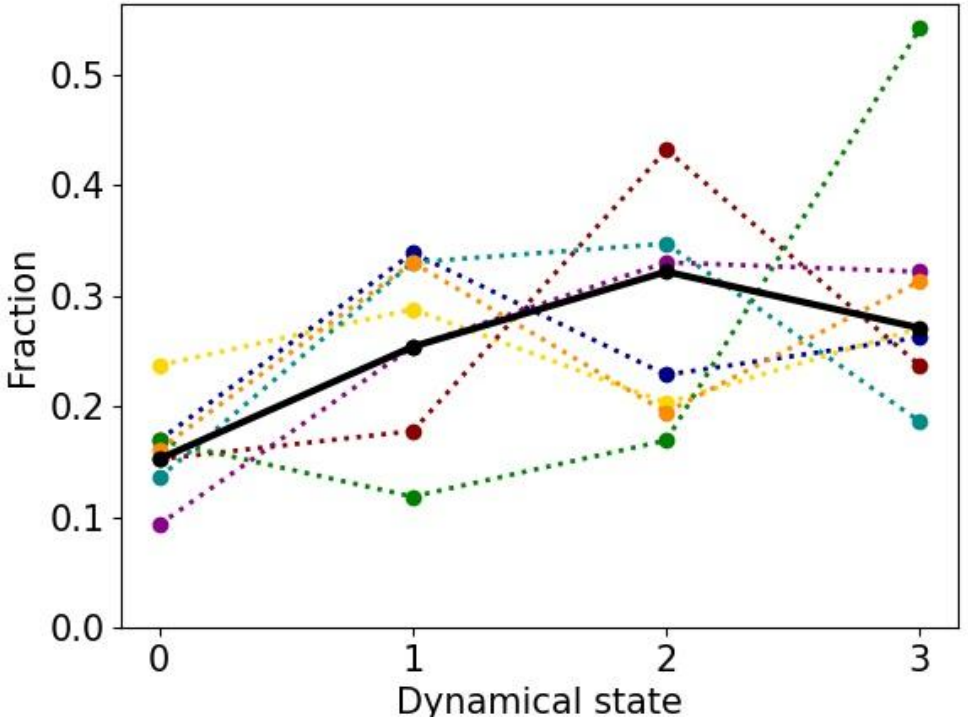


High scatters between the classifications.

very time-consuming

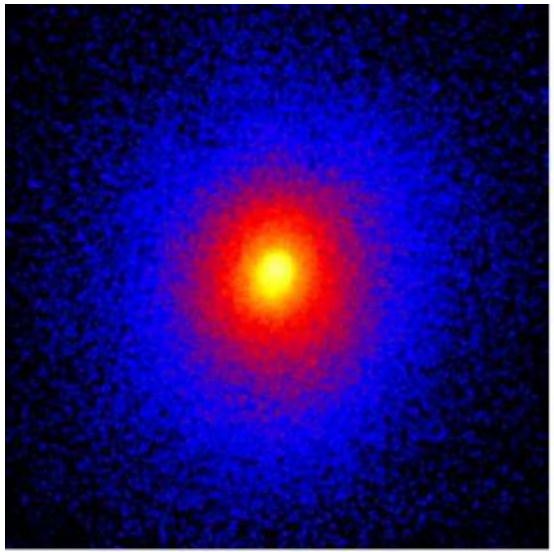
subjective

-> **not suitable** for large samples

Methods - Derive the dynamical state of clusters from X-ray morphologies

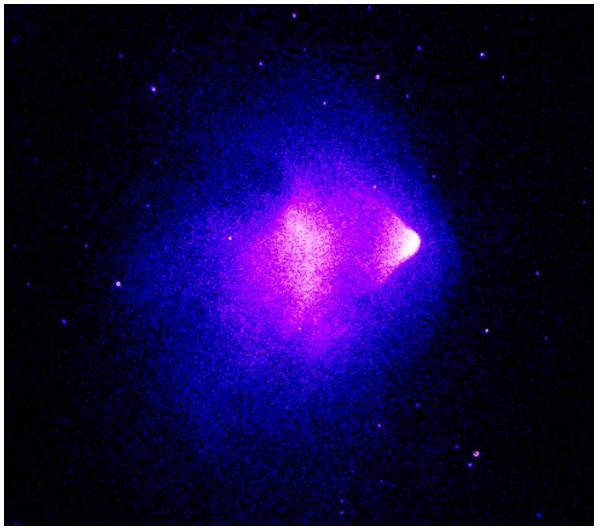
- Relaxed -

Abell1835 (z = 0.25)



- Disturbed -

The Bullet cluster (z = 0.30)

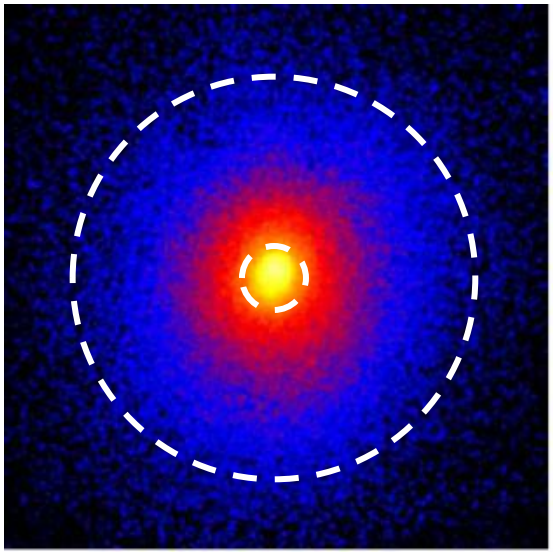


Morphological parameters -> quantify even small deviations from a perfectly regular and spherically-symmetric emission.

Methods - Morphological parameters

- Relaxed -

Abell1835 (z = 0.25)



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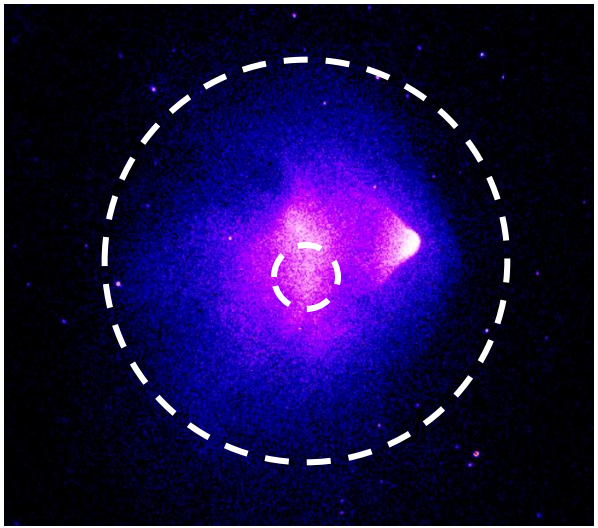
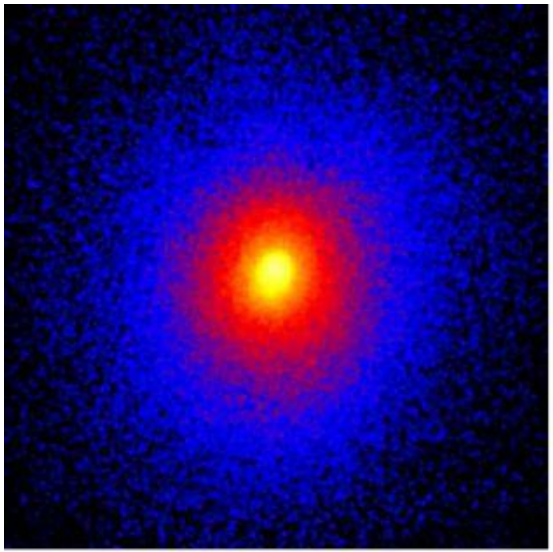


Concentration -> $$c = \frac{\mathrm{SB}\ (r < 0.15\ R_{500})}{\mathrm{SB}\ (r < R_{500})}$$

Methods - Morphological parameters

- Relaxed -

Abell1835 (z = 0.25)



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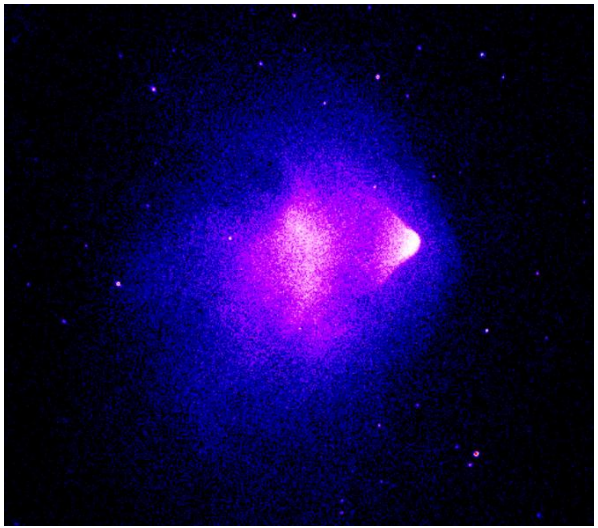
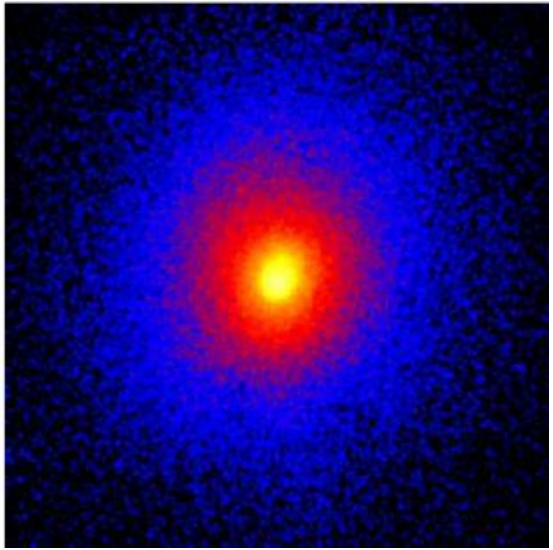


Centroid shift -> $$w = \frac{1}{R_{500}}\left[\frac{1}{N-1}\sum_i (\Delta_i - \bar{\Delta})^2\right]^{\frac{1}{2}}$$

Methods - Morphological parameters

- Relaxed -

Abell1835 (z = 0.25)



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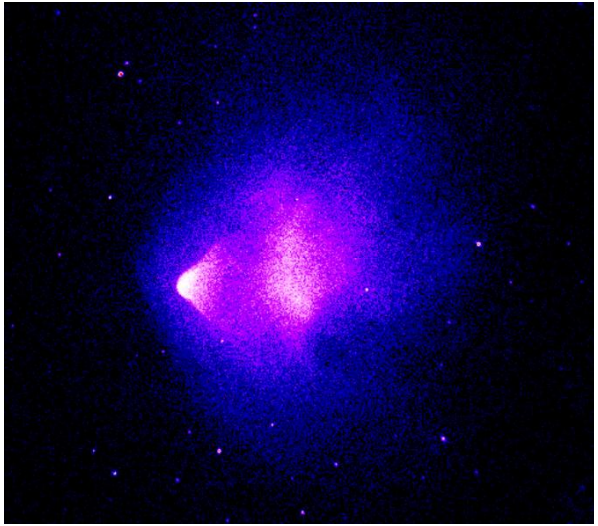


Asymmetry -> $$A = \frac{\sum_{i,j} |\mathrm{I}(i,j) - \mathrm{I}_{180}(i,j)|}{\sum_{i,j} |\mathrm{I}(i,j)|} - A_{\mathrm{bkg}}$$

Methods - Morphological parameters

Smoothness ->

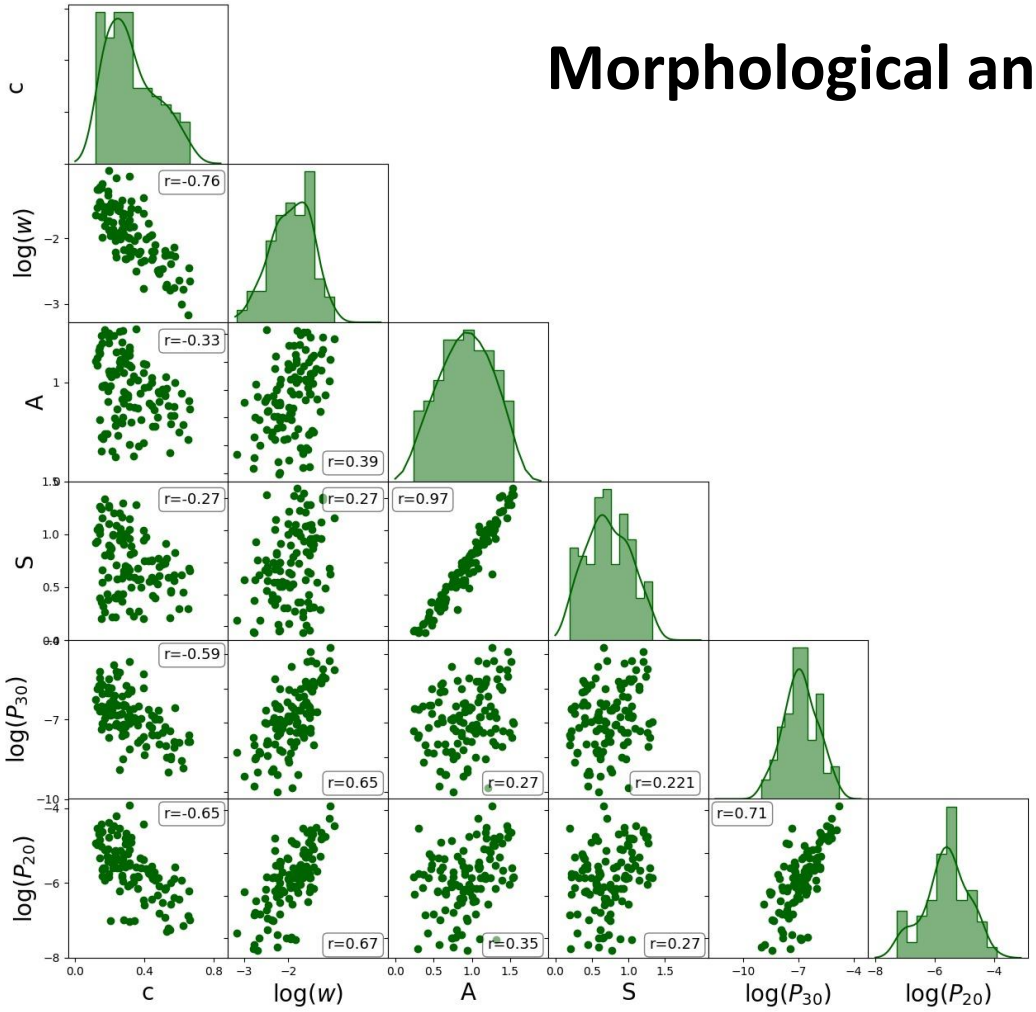
$$S = \frac{\sum_{i,j} |\mathrm{I}(i,j) - \mathrm{I_s}(i,j)|}{\sum_{i,j} |\mathrm{I}(i,j)|} - S_{\mathrm{bkg}}$$

Power Ratios ->

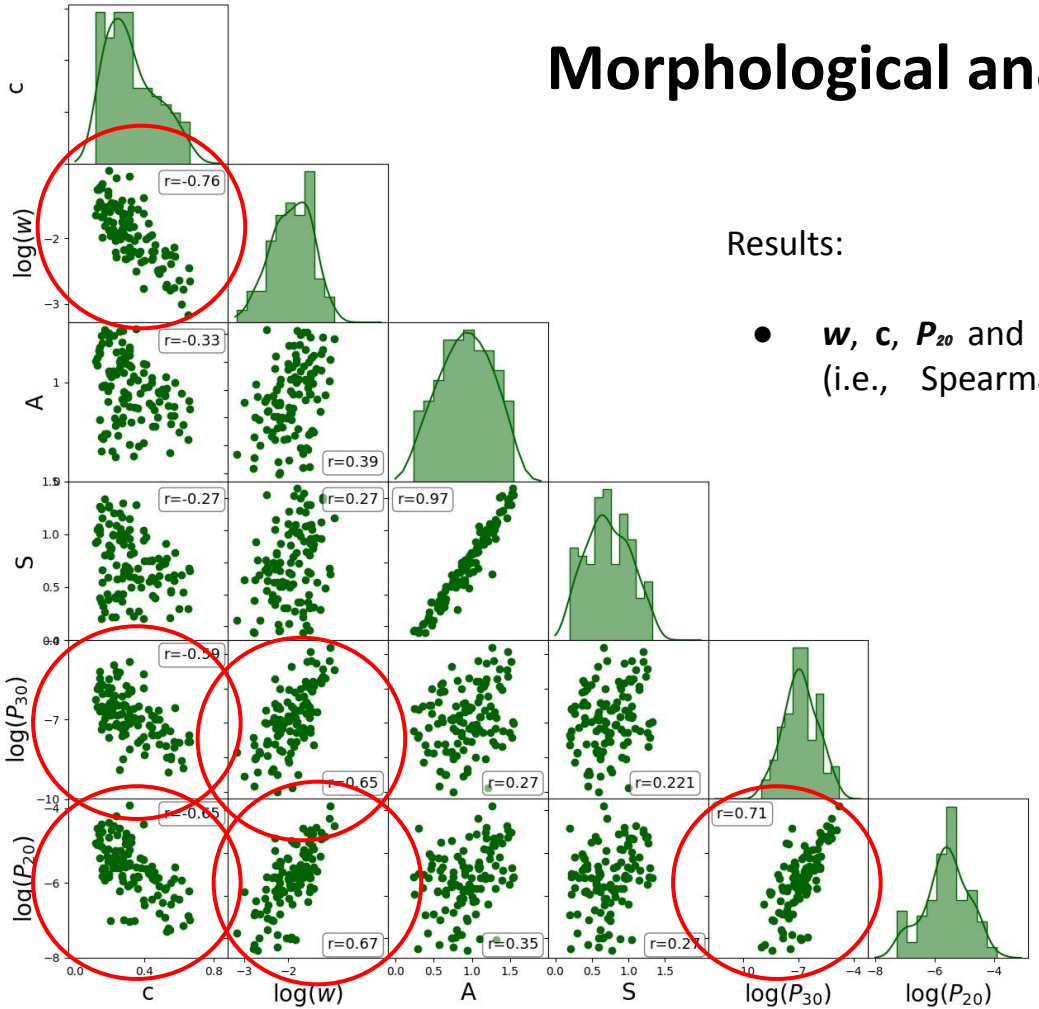
X-ray surface brightness as representation of the projected mass distribution.

Multipole decomposition of the X-ray surface brightness inside a certain aperture.

Morphological analysis - Parameters



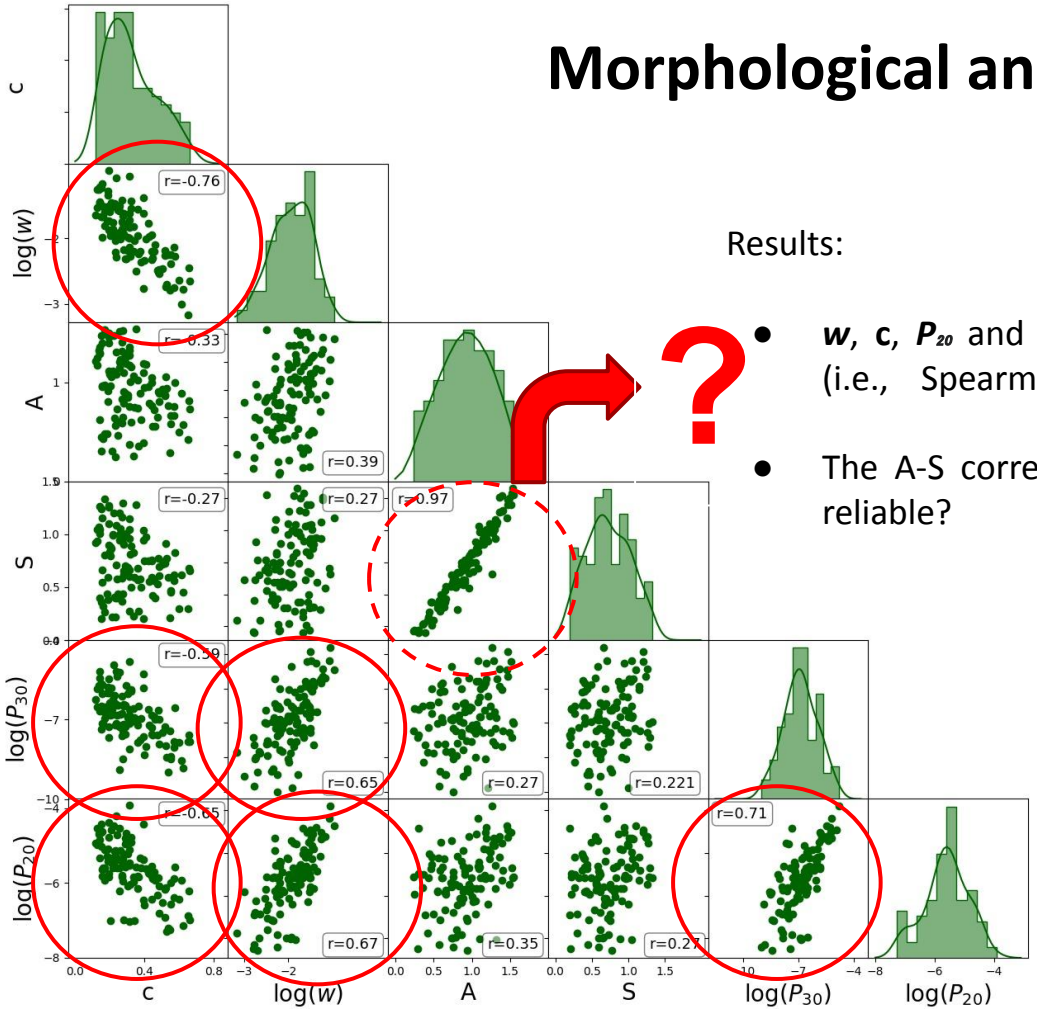
Morphological analysis - Parameters



Results:

- ***w***, **c**, P_{20} and P_{30} show good correlations (i.e., Spearman coefficient ***r*** > 0.5);

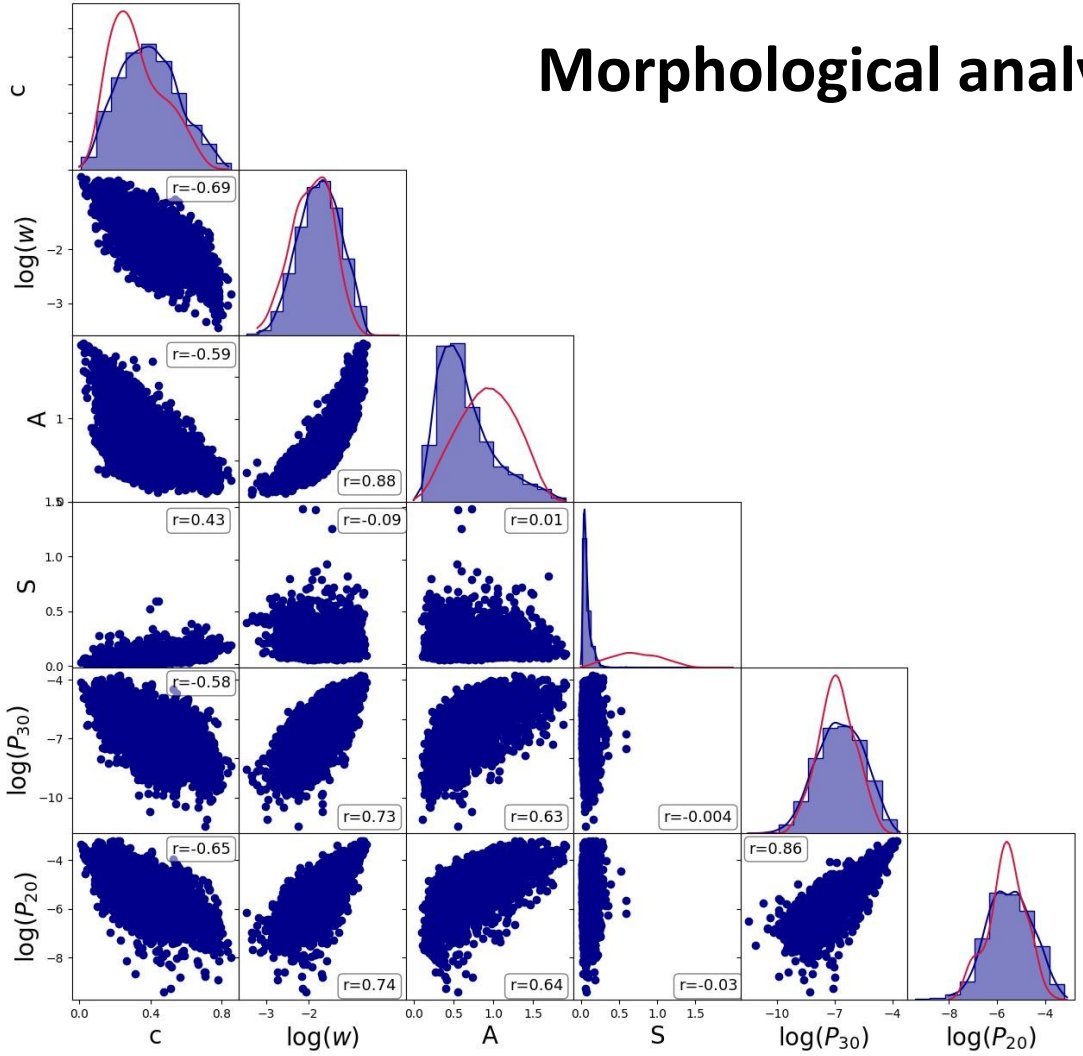
Morphological analysis - Parameters



Results:

- ***w***, **c**, ***P₂₀*** and ***P₃₀*** show good correlations (i.e., Spearman coefficient ***r*** > 0.5);
- The A-S correlation is “too” strong. Is it reliable?

Morphological analysis - Simulations



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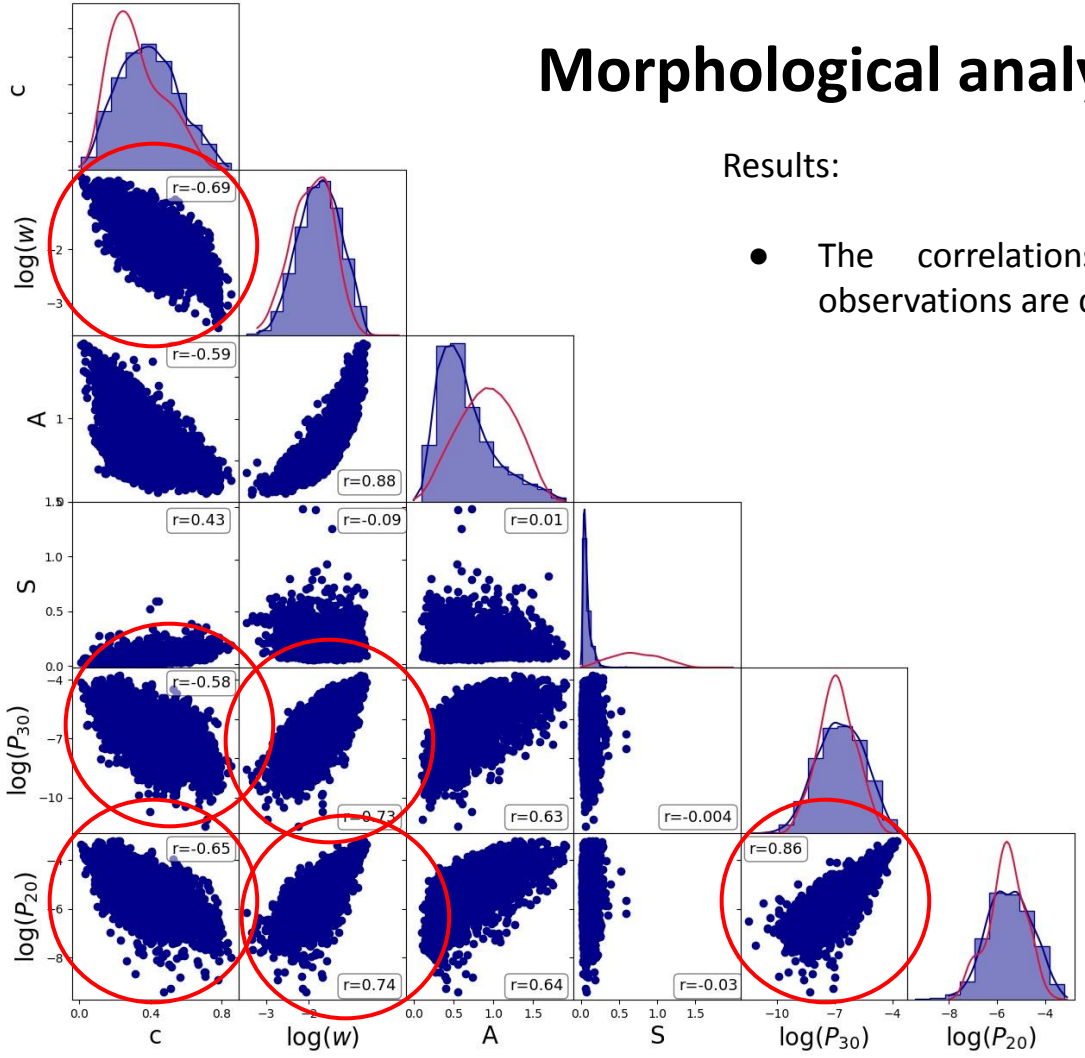
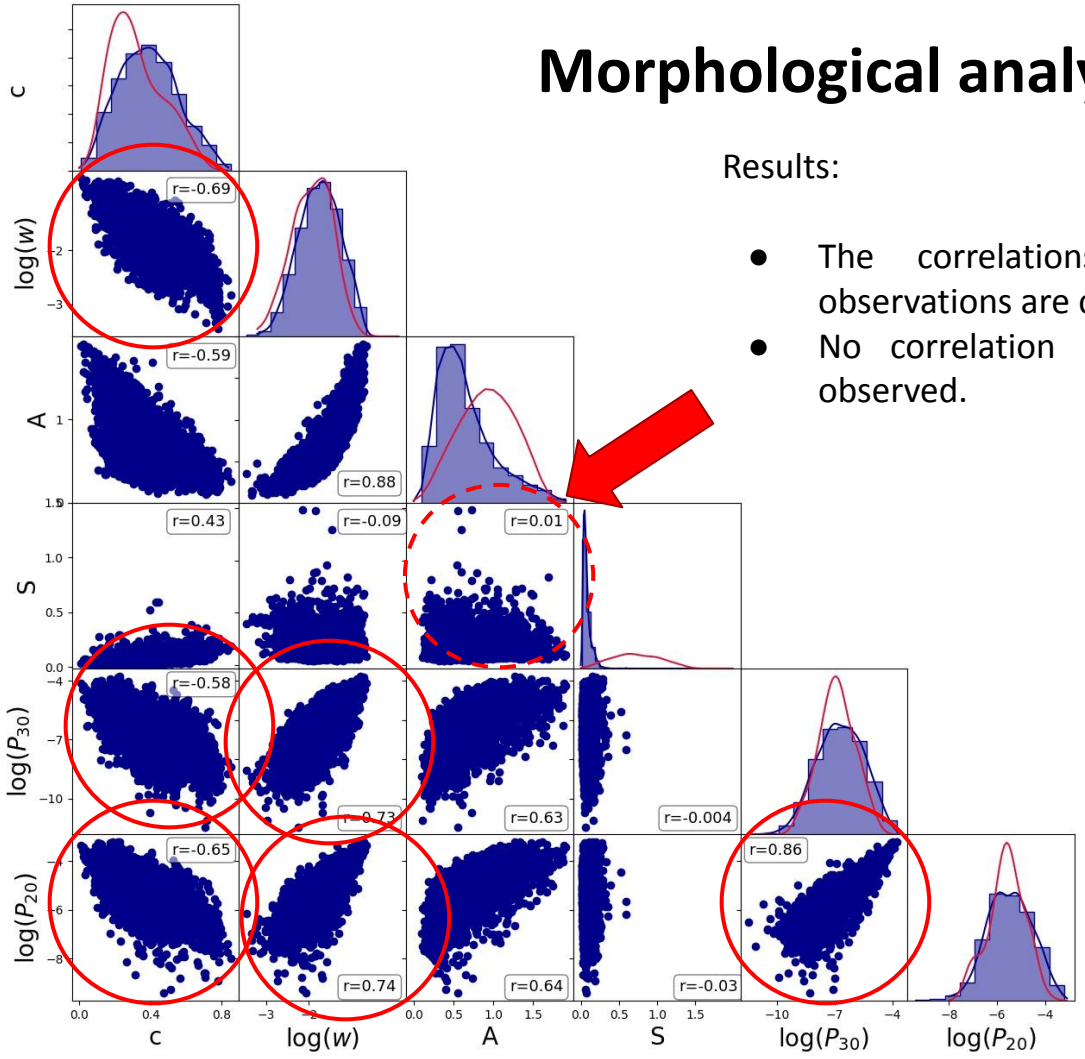


Results:

- The correlations observed for the observations are confirmed.

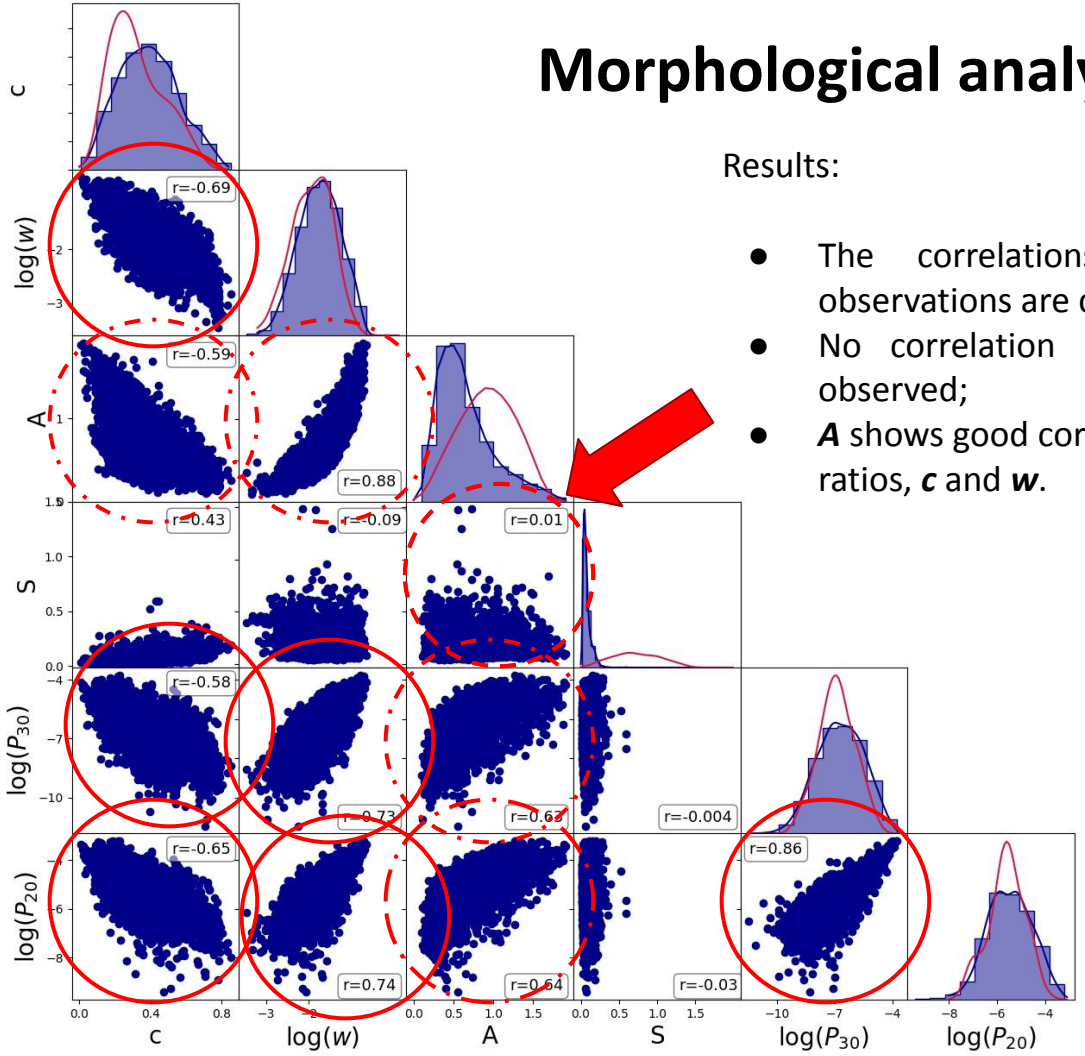
Morphological analysis - Simulations



Results:

- The correlations observed for the observations are confirmed;
- No correlation between ***A*** and ***S*** is observed.

Morphological analysis - Simulations



Results:

- The correlations observed for the observations are confirmed;
- No correlation between ***A*** and ***S*** is observed;
- ***A*** shows good correlations with the power ratios, ***c*** and ***w***.

Quality check - 1) ROC Curves

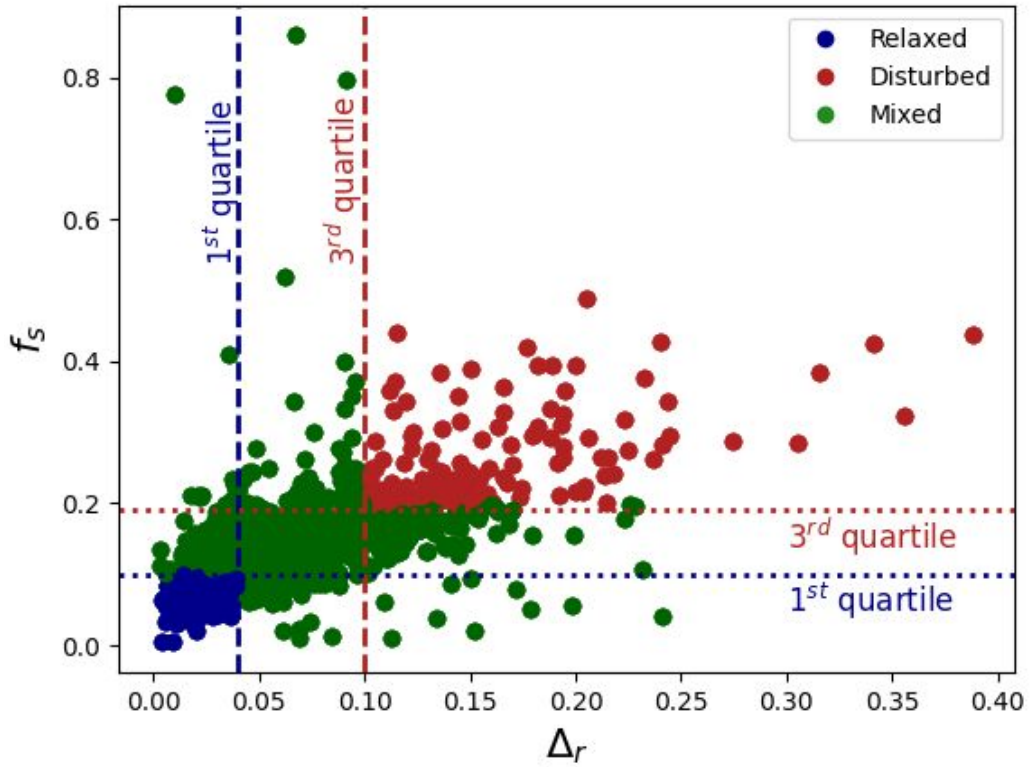
The most relaxed and disturbed systems of the sample were identified by means of:

1) The **offset** of the center of mass:

$$\Delta_r = \frac{|r_{cm} - r_c|}{R_{200}}$$

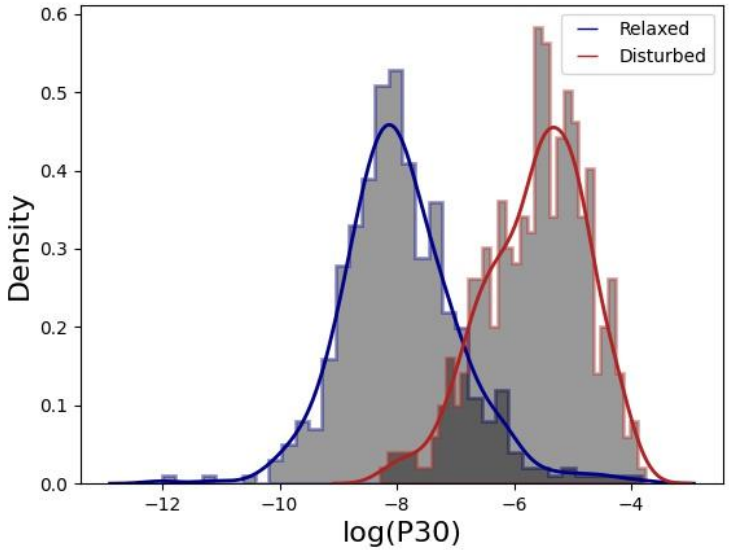
2) The **mass fraction** of all sub-halo in the cluster:

$$f_s = \frac{\Sigma_i M_i}{M_{200}}$$



Quality check - 1) ROC Curves

We investigated the ability of the parameters in distinguish the two populations, by means of the so-called ROC curves.

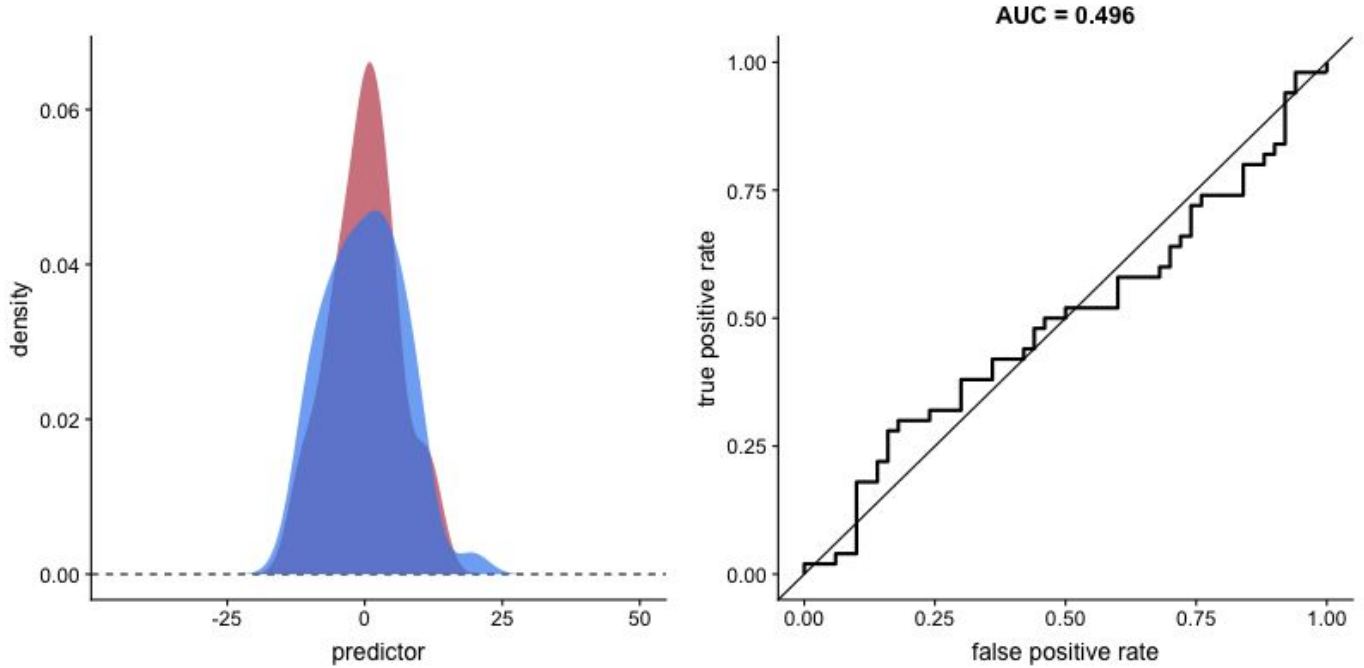


	Relaxed (reality)	Disturbed (reality)
Relaxed (morpho)	TP	FP
Disturbed (morpho)	FN	TN

$$FPR = \frac{FP}{TN + FP}$$

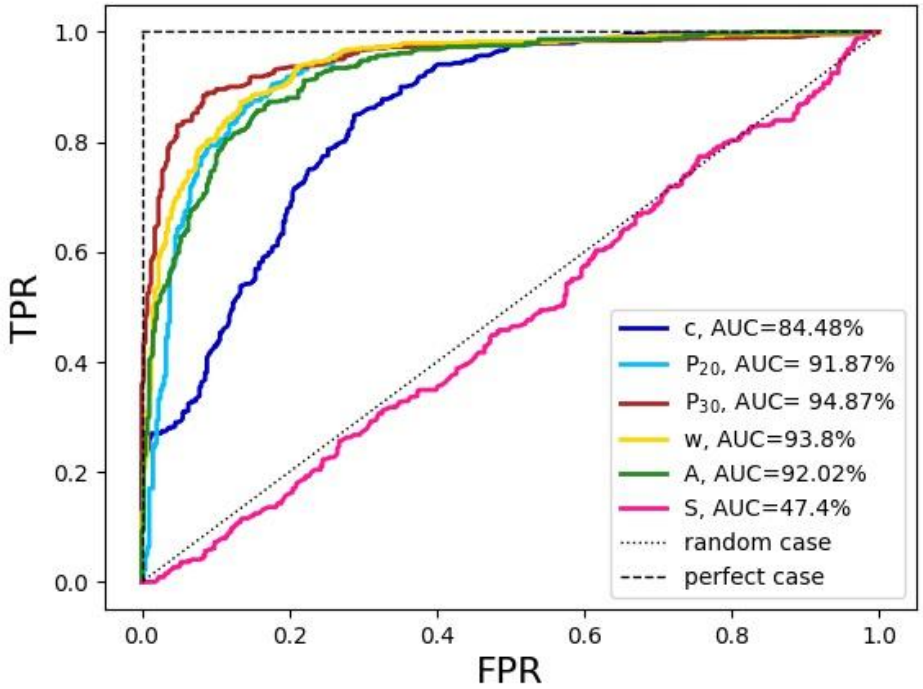
$$TPR = \frac{TP}{TP + FN}$$

Quality check - 1) ROC Curves

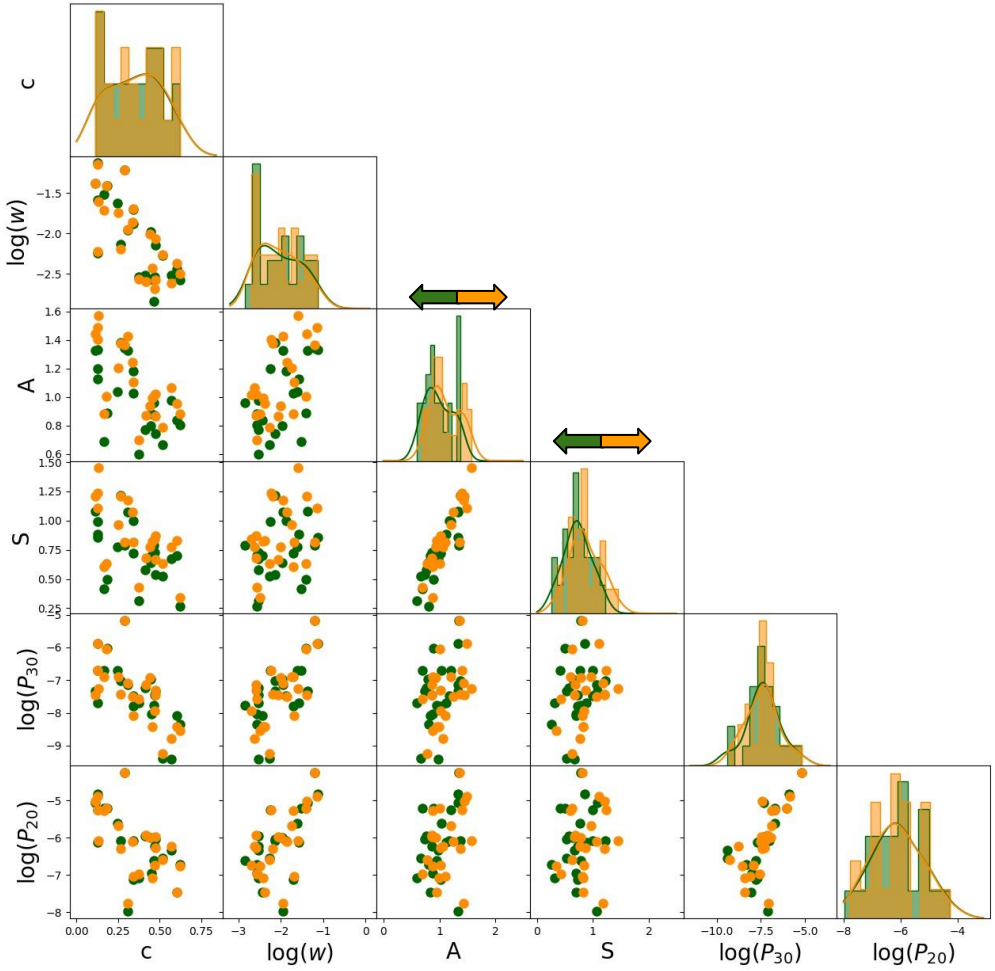


Quality check - 1) ROC Curves

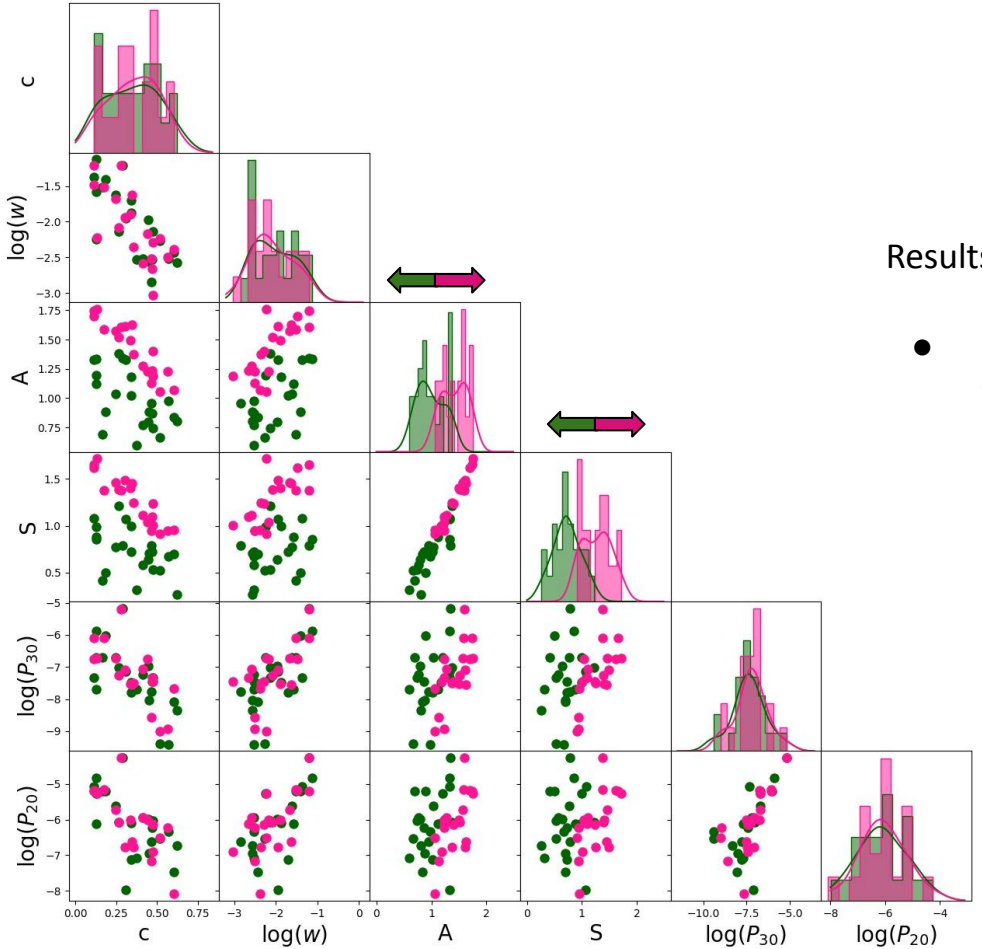
P_{20}, P_{30}, w, A and c are able to distinguish the two populations.



Quality check - 2) Exposure time = **50 % original time**



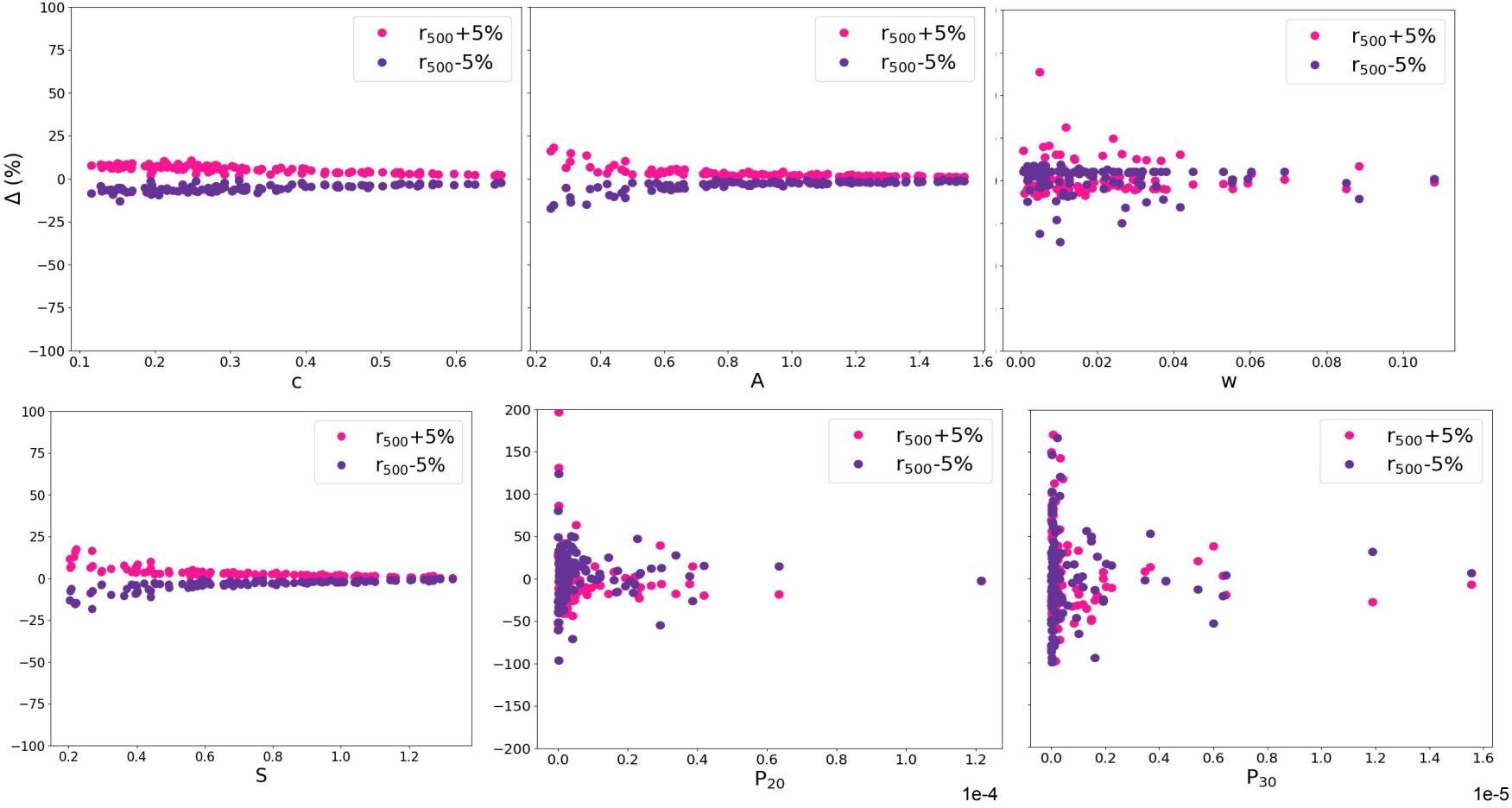
Quality check - 2) Exposure time = **5 ks**



Results:

- A and S are **strongly** affected by the **noise** -> not reliable.

Quality check - 3) Different radii



Morphological analysis - First conclusions

- The best parameters for the identification of the relaxed and disturbed populations are **P_{20}**, **P_{30}**, **w**, **A** and **c.**

However:

- **A** is strongly influenced by the noise of the images.
- **P_{20}** and **P_{30}** are influenced by the considered radius.

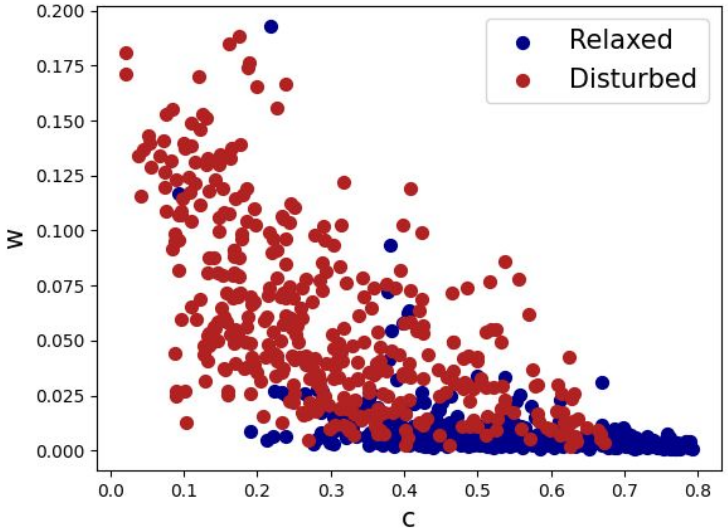
Only **c** and **w** remain.

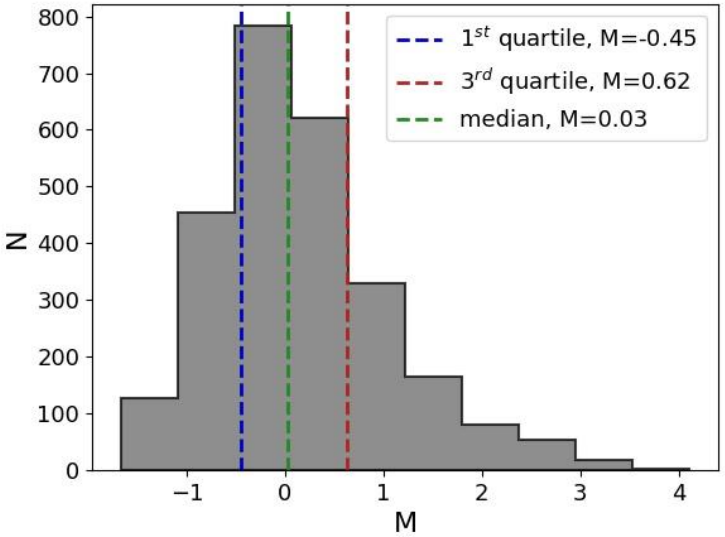
HOW TO COMBINE THE INFORMATION INCLUDED IN THESE TWO PARAMETERS?

Combine the information in a single parameter

Construction of the **parameter M** (Rasia et al. 2013)

$$M = \frac{1}{2}\left(\frac{w - w_m}{\sigma_w} - \frac{c - c_m}{\sigma_c}\right)$$





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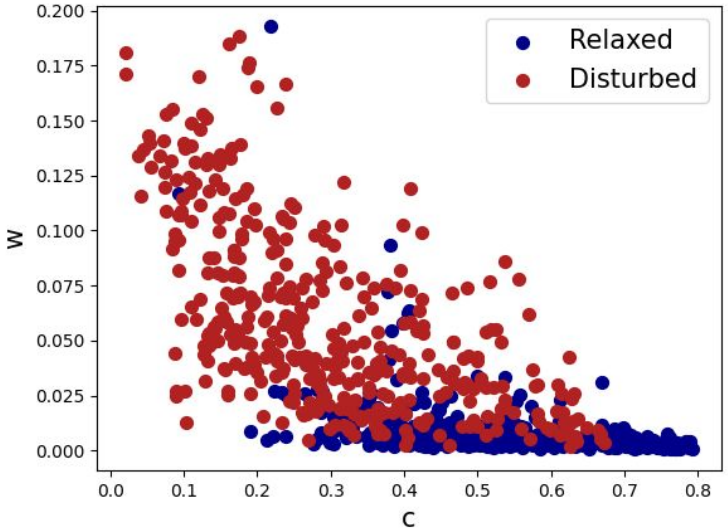
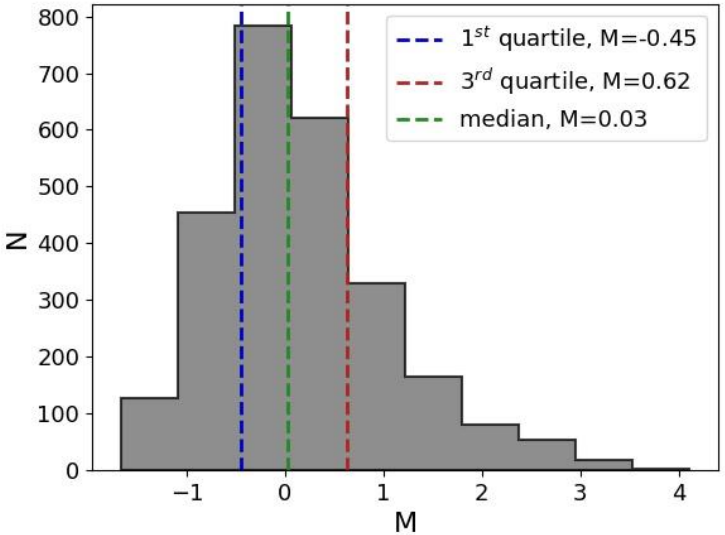




Application of these Methods on the
CHEX - MATE clusters (**preliminary results**)

Most Relaxed
26 %

Most Disturbed
15 %

First conclusions

- Identification of the strongest relations between the morphological parameters.
- Check of the robustness of the morphological parameters -> we found that **c** and **w** are particularly suitable for the identification of **relaxed** and **disturbed** systems.
- Combine the information included in **c** and **w** in a unique parameter;
- Derive the dynamical classification of the CHEX-MATE sample using the calibrated classification obtained from simulations;




and future steps ...

- Study edges/ fluctuations/ discontinuities in an homogeneous way in the XMM X-ray images of the entire Chex-mate sample, assessing for the first time their frequency and radial distribution (with the support of **Chandra** and **LOFAR** data).

Morphological parameters

- The concentration parameter, c, is defined as the ratio of the surface brightness inside two concentric apertures:

$$c = \frac{\mathrm{SB}\ (\mathrm{r} < 0.15\ \mathrm{R}_{500})}{\mathrm{SB}\ (\mathrm{r} < \mathrm{R}_{500})}$$

- The centroid shift parameter, w, is defined as the standard deviation in unit of Rmax of the projected separation between the X-Ray peak and the centroid of the X-ray surface brightness computed within ten apertures of increasing radius:

$$w = \frac{1}{\mathrm{R}_{max}}\left[\frac{1}{\mathrm{N}-1}\sum_{i}(\Delta_i - \bar{\Delta})^2\right]^{\frac{1}{2}}$$

- The asymmetry parameter, A, is a measure of how the light distribution differs from a symmetric distribution:

$$A = \frac{\sum_{i,j} |\mathrm{I}(i,j) - \mathrm{I}_{180}(i,j)|}{\sum_{i,j} |\mathrm{I}(i,j)|}$$

Morphological parameters

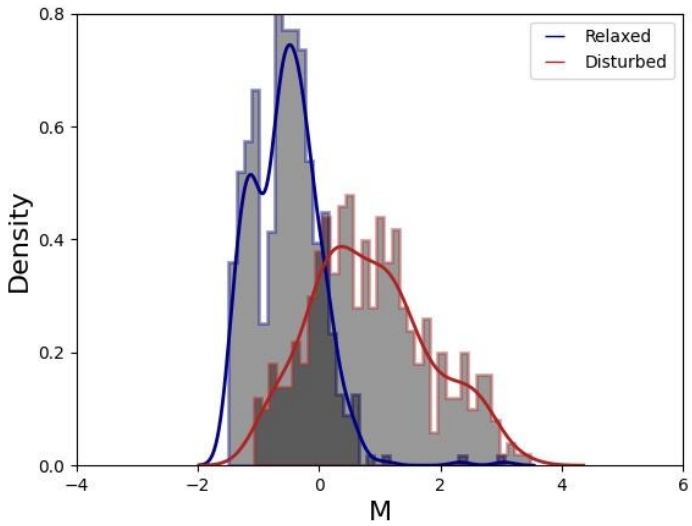
- The smoothness parameter, S, is able to detect the presence of peaks of high X-ray flux presumably linked to small-scale structures and is obtained by subtracting a smoothed image from the original one:

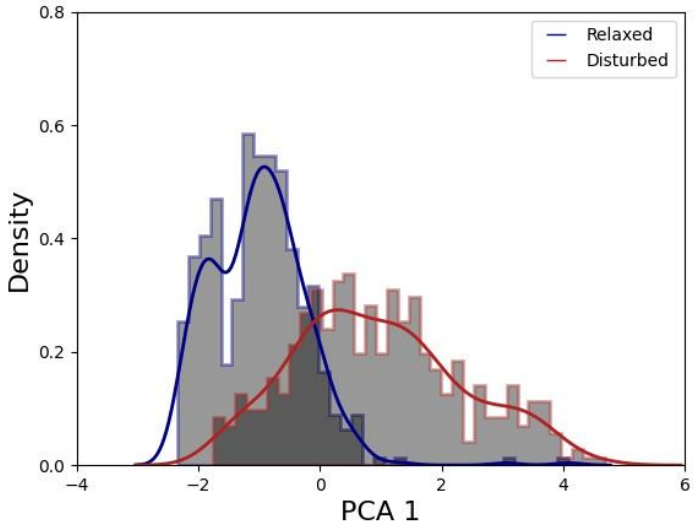
$$S = \frac{\sum_{i,j} |\mathrm{I}(i,j) - \mathrm{I}_s(i,j)|}{\sum_{i,j} |\mathrm{I}(i,j)|}$$

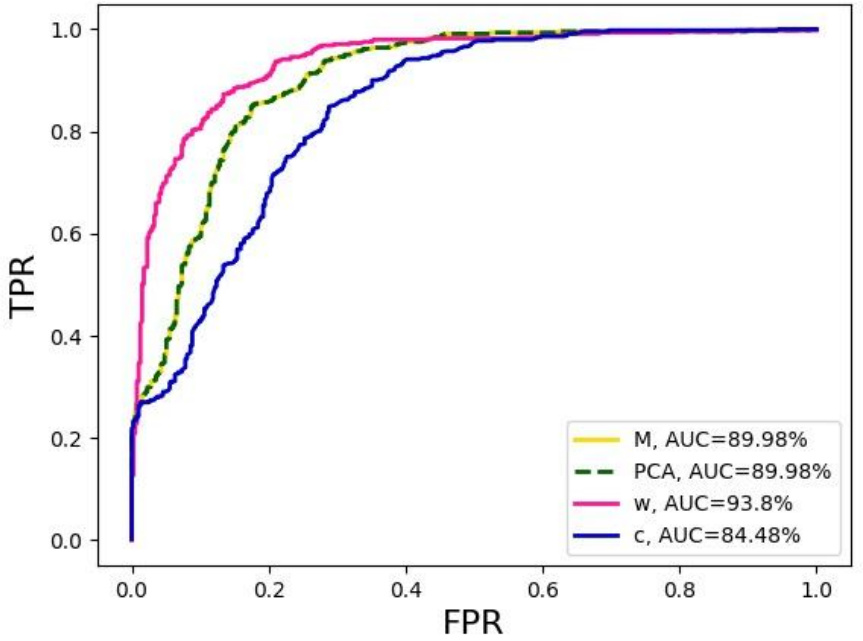
- The power ratios parameters are supported by the idea that the X-ray surface brightness of a cluster could be the representation of its projected mass distribution. They are computed as a multipole decomposition of the X-ray surface brightness inside a certain aperture. The m-order power ratio is defined as Pm/P0, where:

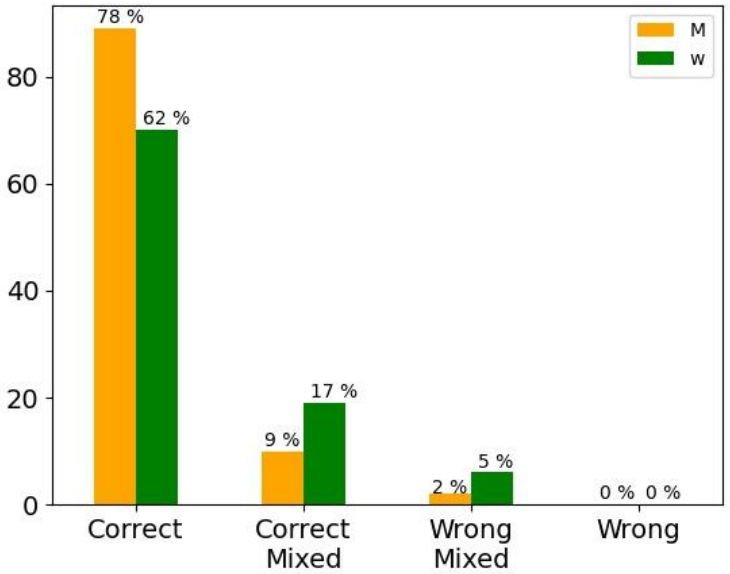
$$P_0 = [a_0 \ln(R_{ap})]^2, \qquad P_m = \frac{1}{2m^2 R_{ap}^{2m}}(a_m^2 + b_m^2)$$

$$a_m(R) = \int_{R<R_{ap}} S(x) R^m \cos(m\phi) d^2x \qquad b_m(R) = \int_{R<R_{ap}} S(x) R^m \sin(m\phi) d^2x$$


Relaxed
Disturbed
Density
M


Relaxed
Disturbed
Density
PCA 1


TPR
FPR
M, AUC=89.98%
PCA, AUC=89.98%
w, AUC=93.8%
c, AUC=84.48%



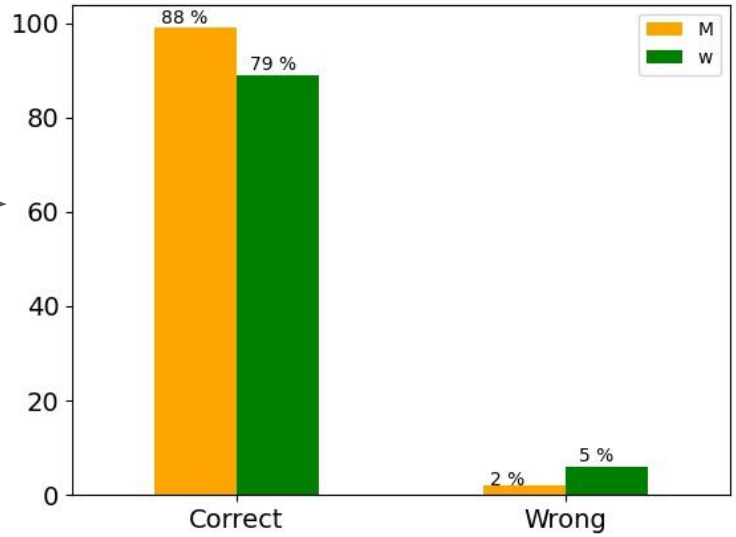
Comparison between M(or w) and the visual classification

Correct: R-R, D-D and M-M

Correct Mixed: R-MR and D-MD

Wrong Mixed: R-MD and D-MR

Wrong: R-D and D-R



Comparison between M(or w) and the visual classification

Correct: Correct + Correct Mixed

Wrong: Wrong + Wrong Mixed