INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

How do galaxy clusters appear?

On the X-ray morphology of the CHEX-MATE galaxy clusters

Presented by: Maria Giulia Campitiello
Supervisors: Stefano Ettori, Lorenzo Lovisari and Annalisa Bonafede

THE MATCH

The costrain on the **cosmological parameters** are provided by:

Cosmic Microwave Background (CMB)

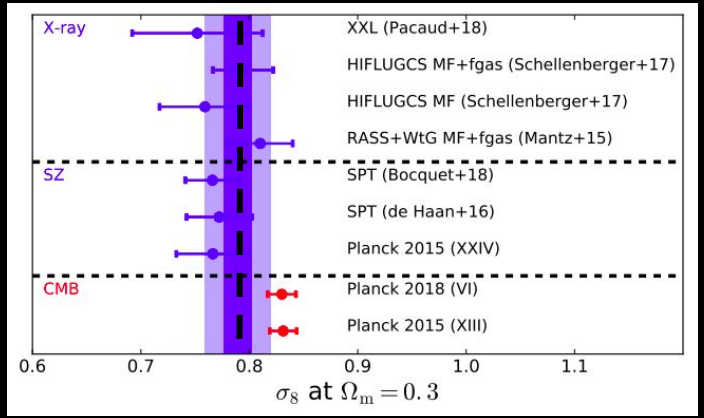
Galaxy cluster distribution in mass and redshift

THE MATCH

The telescope *Planck* revealed the presence of a tension between the two estimations

Cosmic Microwave Background

σ_8=0.830±0.013



Galaxy cluster distribution in mass and redshift

σ_8=0.789±0.012

Pratt et al. 2019

σ_8 > σ_8

(CMB) (Clusters)

THE MATCH

Let’s investigate the possible explanations:

SCENARIO A - Error from the theory

Need of a “*new physics*”? E.g.: a summed neutrino mass higher than the minimum mass (~0.06 eV), modification of gravity…

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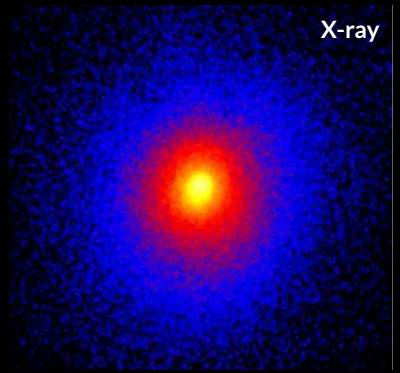
Need of a "*new physics*"? E.g.: a summed neutrino mass higher than the minimum mass (~0.06 eV), modification of gravity…

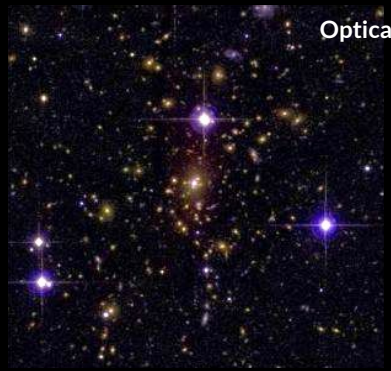
SCENARIO B - Error from the observations

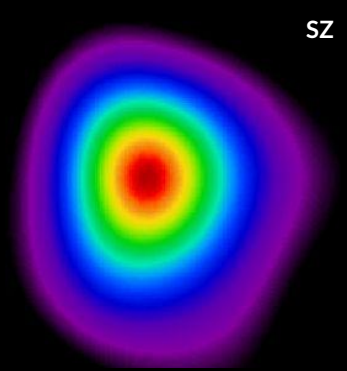
Systematic uncertainties related to: the estimation of the **mass**, **selection** effects, strumental **calibration** or **modelling** issues.

THE MATCH

Clusters of galaxies are detected through their observable barion signatures and this involves at least two issues:







ABELL 1835

THE MATCH

Clusters of galaxies are detected through their observable barion signatures and this involves at least two issues:

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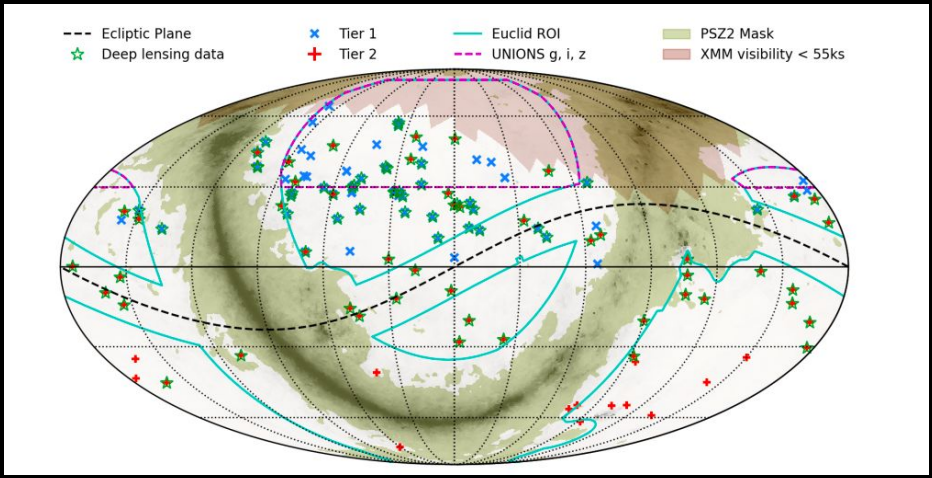
How representative are the samples that we are using for our analysis?

SZ- selected samples are needed to investigate the properties of the true underlying cluster population.

THE MATCH



CHEX-MATE: The **C**luster **HE**ritage project with ***X****MM-Newton* – **M**ass **A**ssembly and **T**hermodynamics at the **E**ndpoint of structure formation

What is the absolute cluster mass scale?

What is the ‘true’ underlying cluster population?

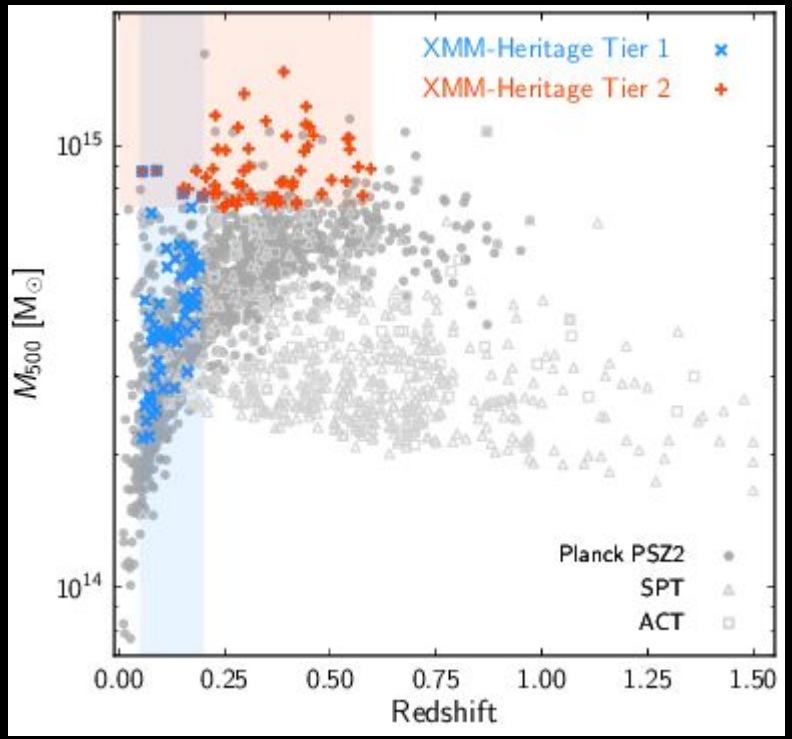
THE STRATEGY

An XMM-Newton Multi-Year Heritage program

3 Ms over the period **2018-2021** to survey homogeneously with XMM **118 clusters** detected by Planck at high S/N (>6.5):

- **Tier 1:** census of the cluster population at most recent time;
- **Tier 2:** most massive systems to have formed so far in the Universe.

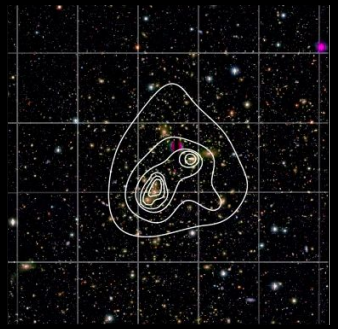
A low and intermediate redshift anchor for cluster evolution studies.



The CHEX-MATE coll. 2021

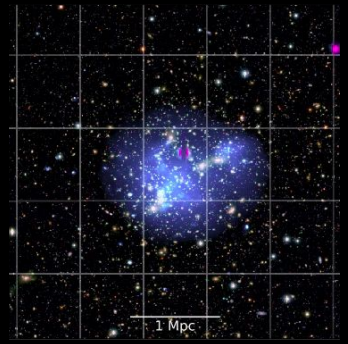
THE STRATEGY

OPTICAL AND LENSING DATA



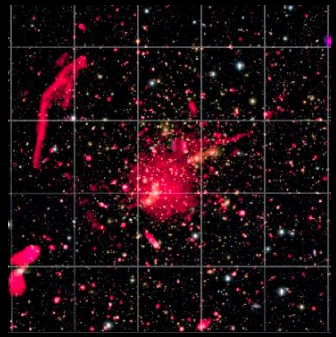
WG - Optical - Chair: Gavazzi & Umetsu
WG - Lensing - Chair: Maurogordato & sereno

X-RAY DATA



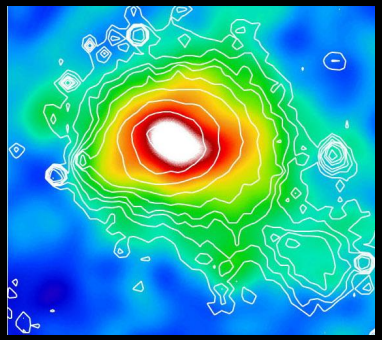
WG - X-ray - Chair: Pratt & Rossetti

RADIO DATA



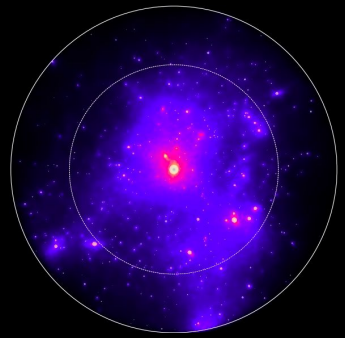
WG - Radio - Chair: Bonafede & Cassano

SZ DATA



WG - SZ- Chair: Pointecouteau & Sayers

SIMULATIONS



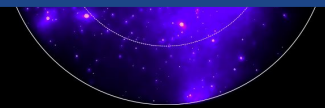
WG - Simulations - Chair: Kay & Rasia

THE STRATEGY

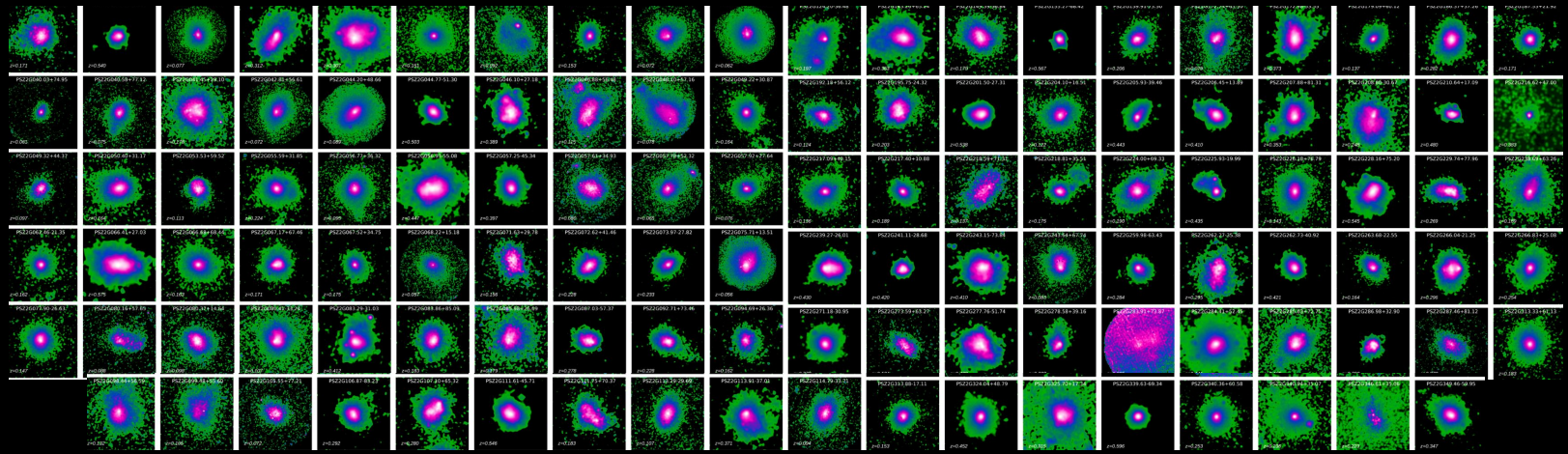


STEERING COMMITTEE: *S. Ettori* **(PI)**, *G. Pratt* **(PI)**, *D. Eckert*, *F. Gastaldello*, *R. Gavazzi*, *S. Kay*, *L. Lovisari*, *B. Maughan*, *E. Pointecouteau*, *M. Rossetti*, *M. Sereno*,*M. Arnaud* (**Retired**),

77 collaborators from **12 countries** (France, Italy, Germany, Spain, Switzerland, UK, Australia, Chile, Japan, S.Africa, Taiwan, USA)

LET'S START TO PLAY: CHARACTERIZATION OF THE X-RAY MORPHOLOGY OF THE SAMPLE



Characterise the **ICM distribution** of the CHEX-MATE clusters with the analysis of both variations of **integrated quantities** and **local edges** and **discontinuities**

THE DATASET

MORPHOLOGICAL ANALYSIS

XMM-NEWTON observations

Images produced by I. Bartalucci (INAF-IASF Milano):

- exposure corrected and background subtracted,
- filtered in the 0.7-1.2 keV band,
- point-sources masked.

ANALYSIS OF EDGES AND DISCONTINUITIES

Simulations

(more than 450 objects)

Images provided by E. Rasia (INAF-OA Trieste) as part of the *Three Hundred Collaboration*:

- filtered in the 0.7-1.2 keV band;
- redshift $0.0 < z < 0.59$.

Chandra archival observations

(102 objects)

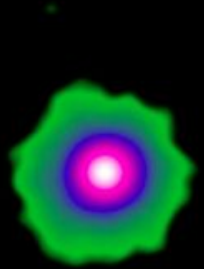
Images reprocessed by R. Duffy (Bristol University):

- exposure corrected and background subtracted;
- filtered in the 0.7-2.0 keV band,
- point-sources masked.

THE MORPHOLOGICAL ANALYSIS OF THE SAMPLE

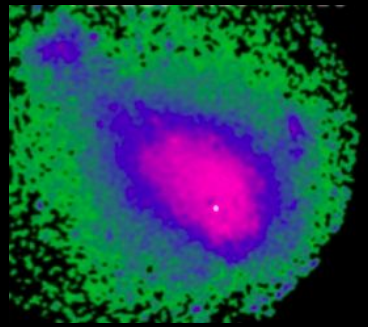
RELAXED

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



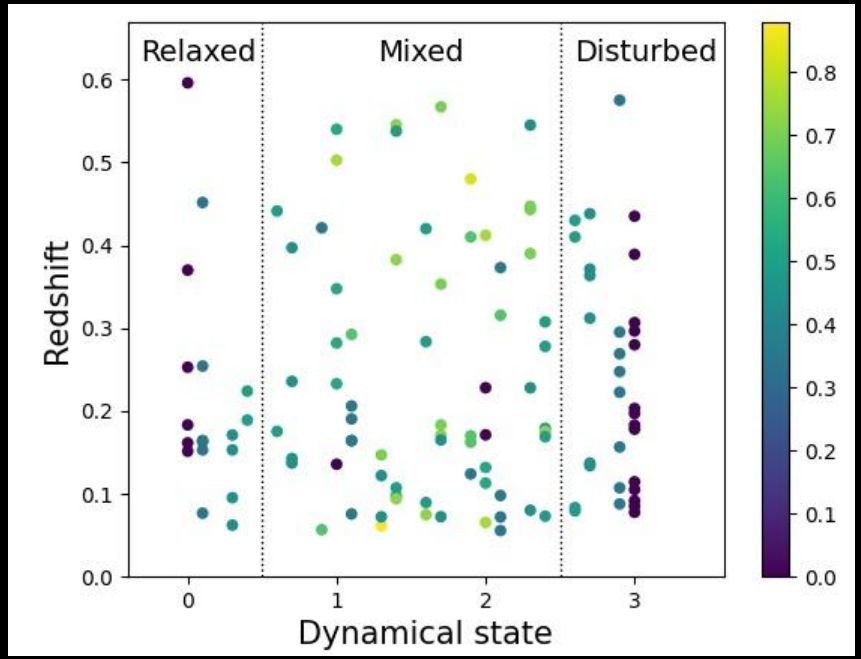
DISTURBED

Study **microphysical processes** such as turbulence or particle acceleration mechanisms.



THE RULES : visual classification

Seven astronomers involved to reduce the **subjectivity** of the method.



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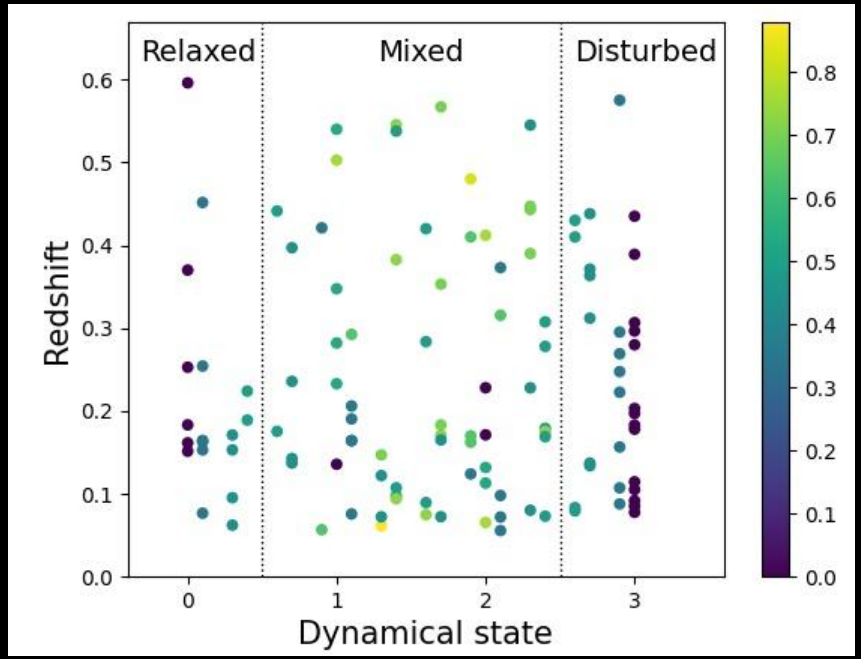
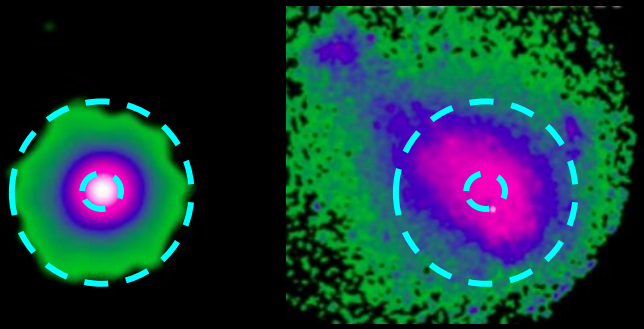


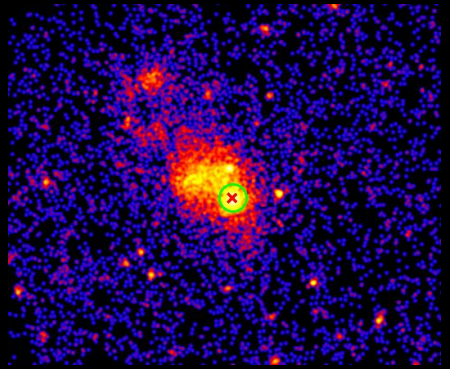
18 Relaxed (15 %)
32 Disturbed (27%)
68 Mixed (58%)

THE RULES : morphological parameters

CONCENTRATION (*c*)



CENTROID SHIFT (*w*)

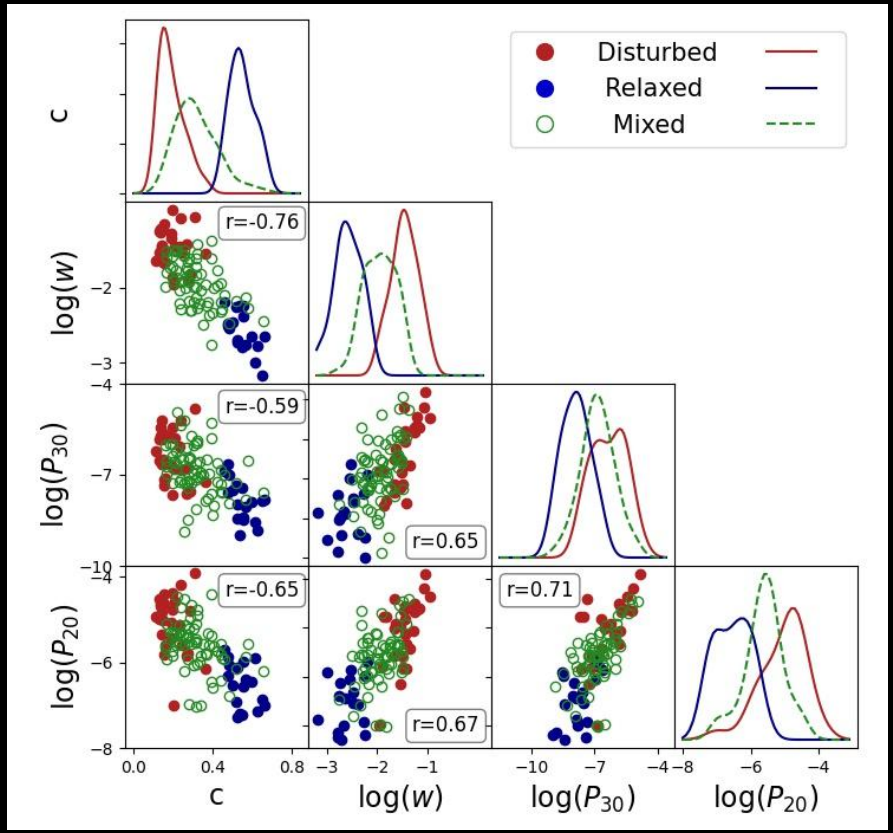


POWER RATIOS

P_{20}
ellipticity

P_{30}
asymmetries and substructures

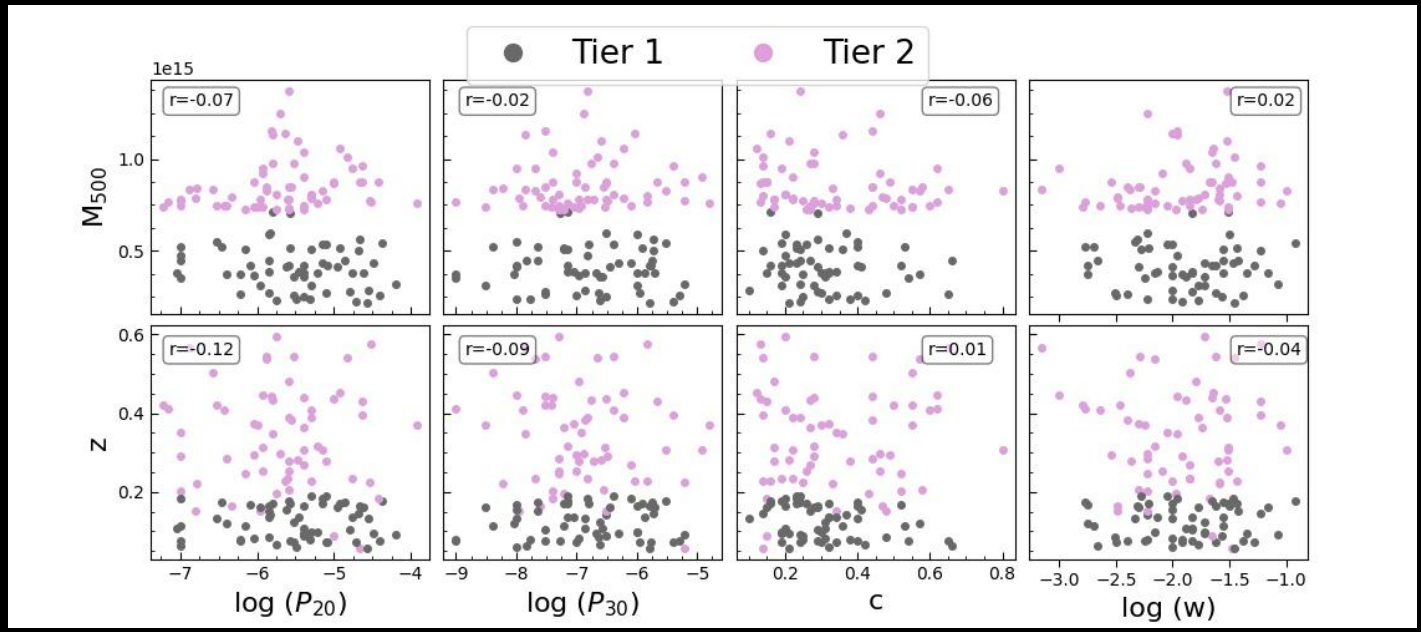
MORPHOLOGICAL ANALYSIS : correlations



- **Good correlations;**
- **c, w** are the best parameters for the detection of the **relaxed** and **disturbed** population.

MORPHOLOGICAL ANALYSIS : correlations

No correlation with **mass** and **redshift**



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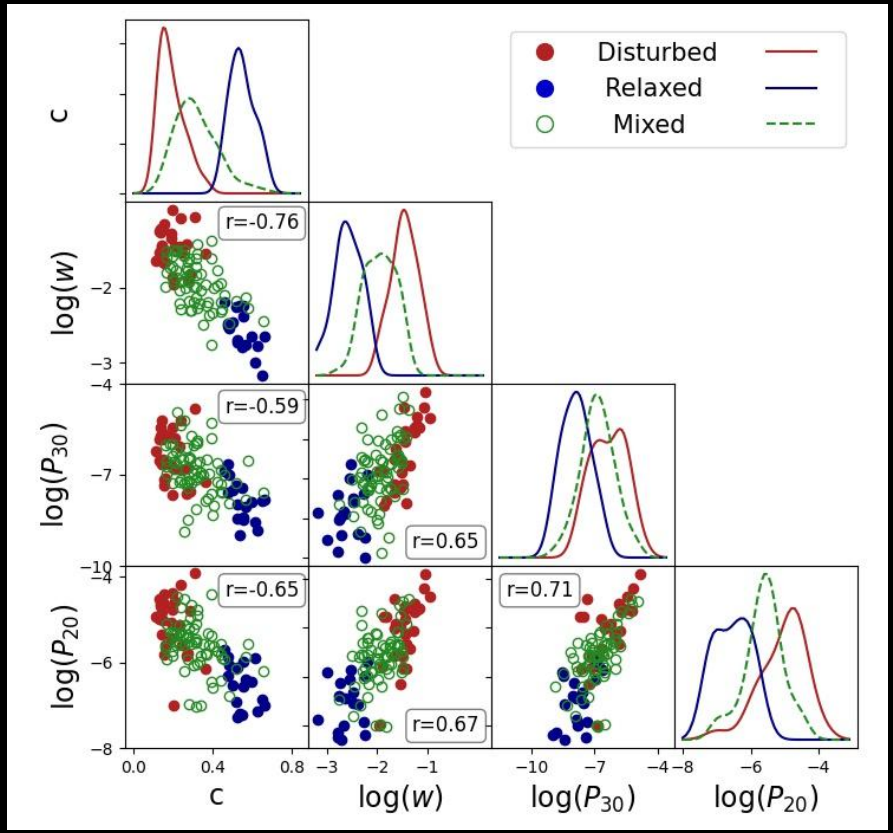

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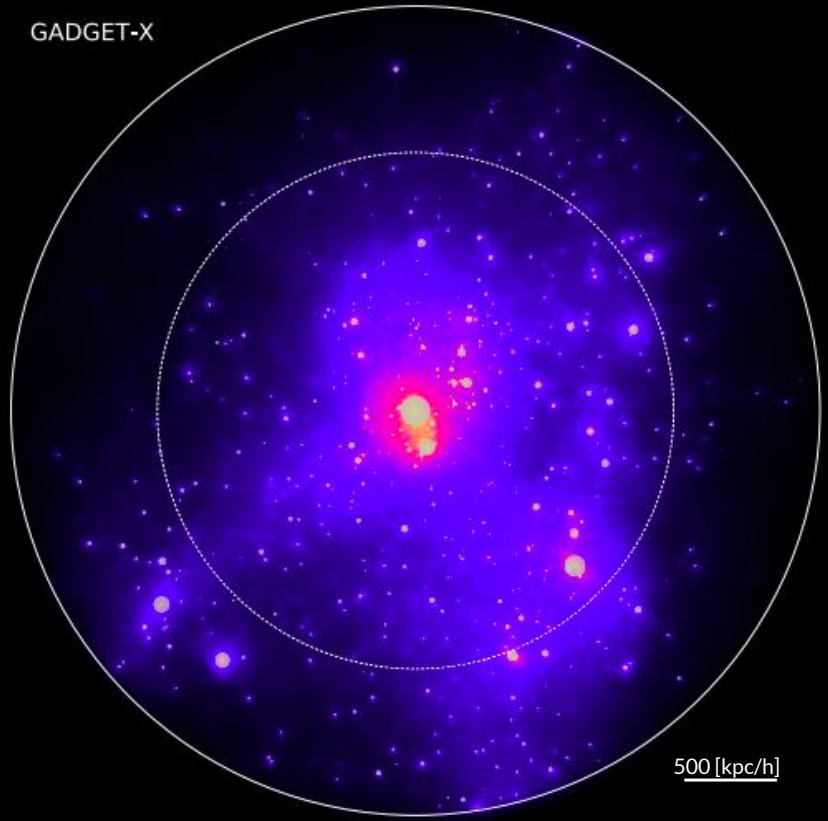
MORPHOLOGICAL ANALYSIS : simulations

THE THREE HUNDRED: a set of 324 cluster-centric regions of 15 *Mpc/h*. **GADGET X** hydrodynamical simulations which include the description of:

- Artificial thermal diffusion ;
- Time-dependent viscosity;
- Gas cooling with metal contributions;
- Star formation with chemical enrichment and feedback from stars in the asymptotic giant branch;
- Supernovae;
- Active Galactic Nuclei.



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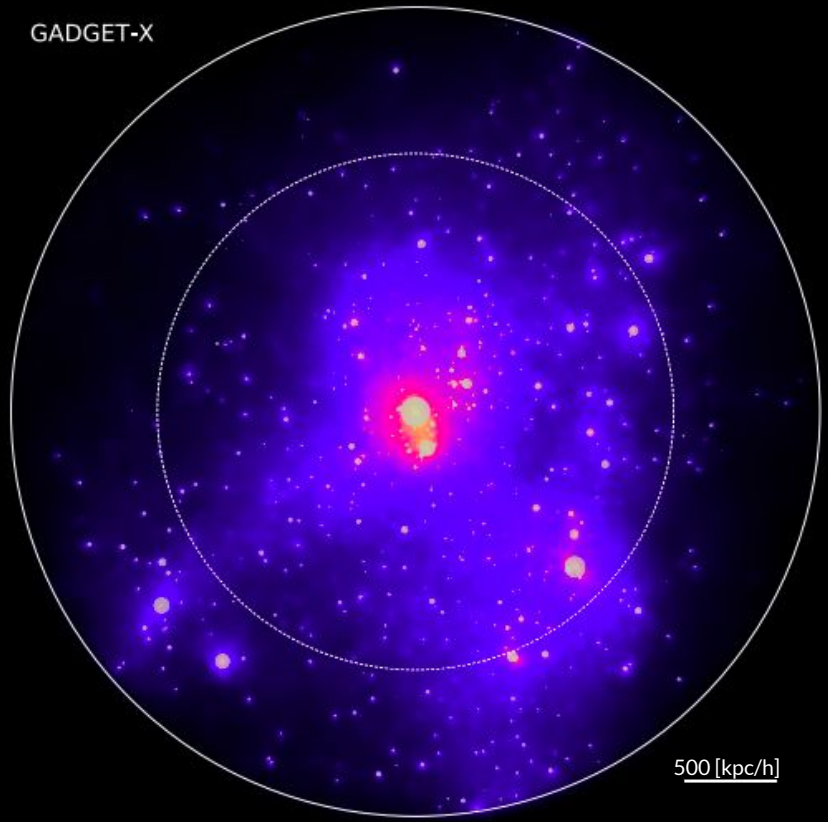

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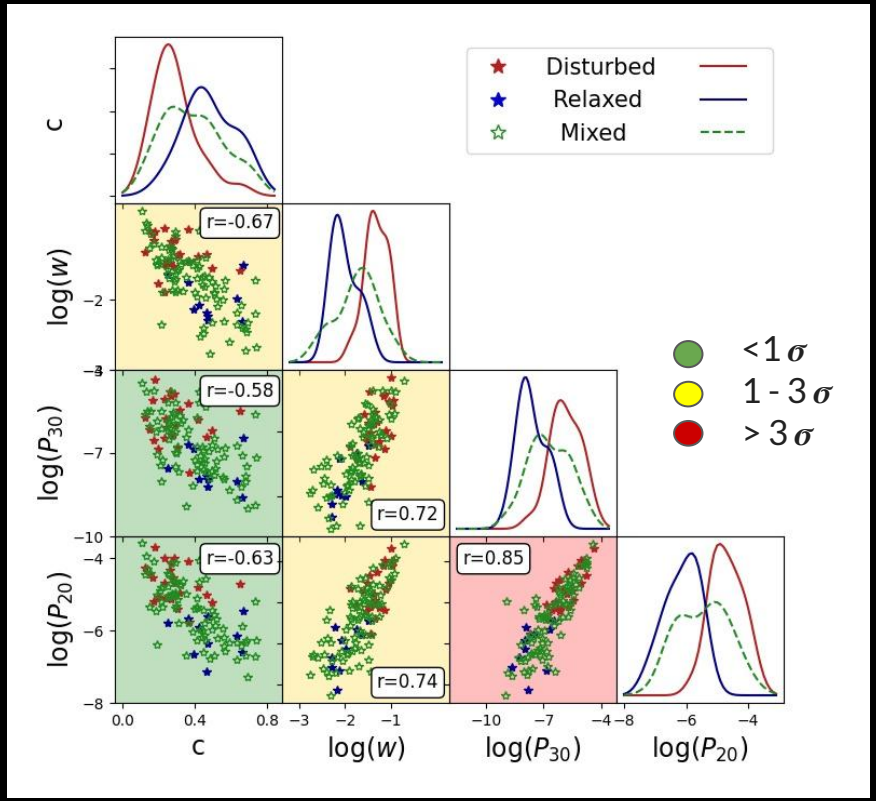
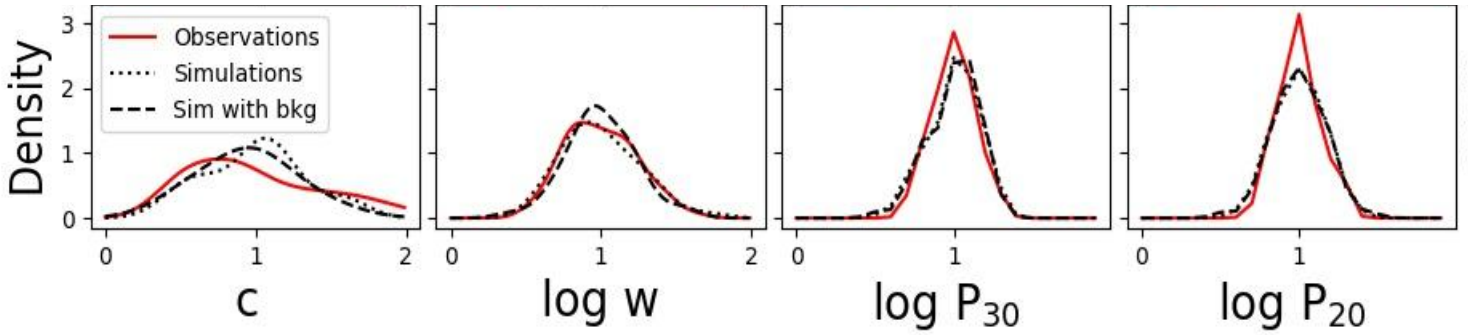
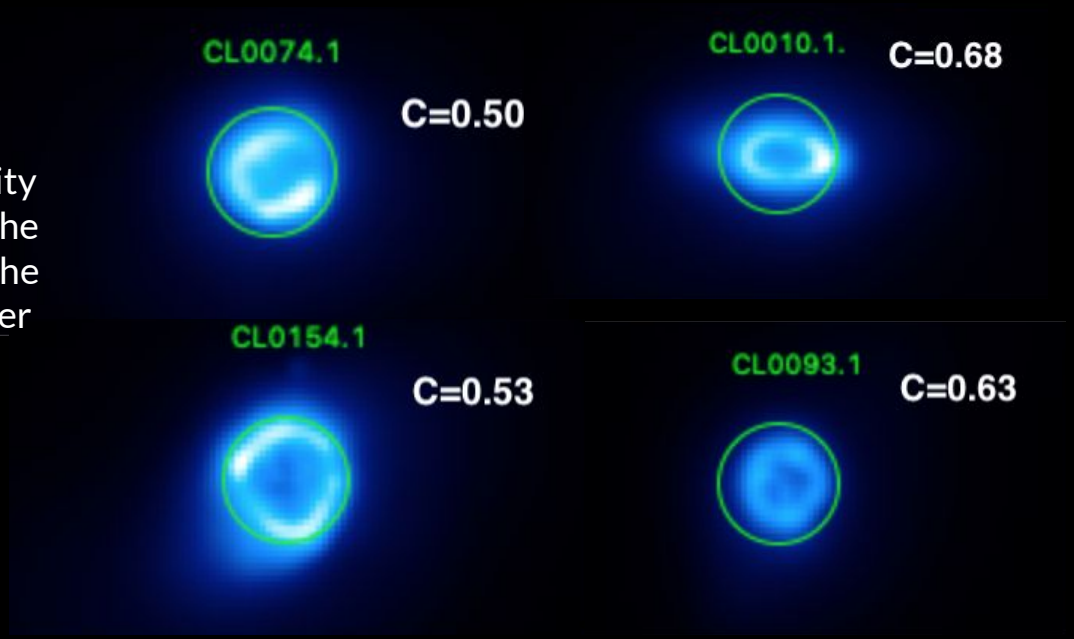


COMPARISON WITH SIMULATIONS



COMPARISON WITH SIMULATIONS

Presence of particles with high **SPH** density in the central regions (<40 kpc) of the simulated clusters, due to the action of the **isotropic feedback from AGNs** → Higher concentration observed.



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SIMULATIONS → OBSERVATIONS

more investigations needed

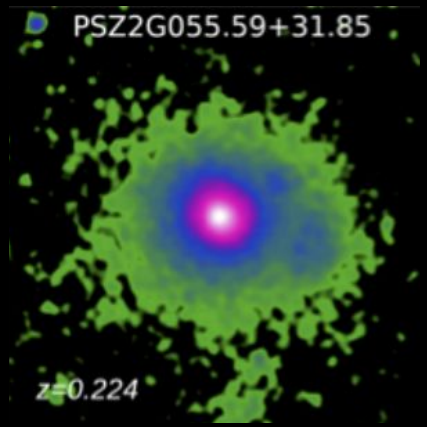
COMPARISON WITH SIMULATIONS

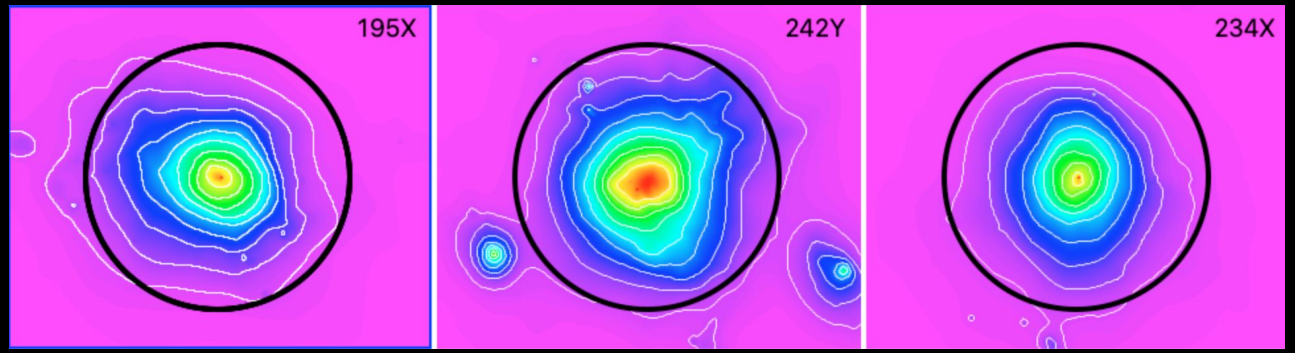
Match between 28 CHEX-MATE objects and simulations selected with the following criteria:

- Closest z;
- M_{500} ± 10%;
- Closest 3 clusters in the c - w plane.

COMPARISON WITH SIMULATIONS

SIMULATIONS ← ? → OBSERVATIONS

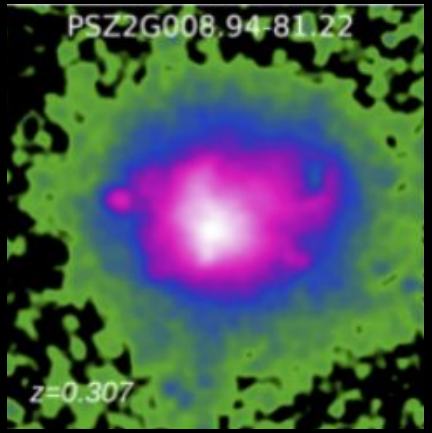


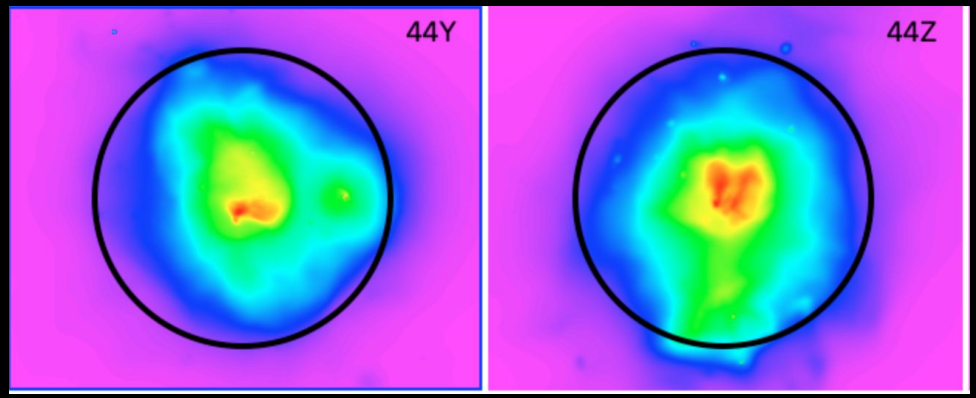


c	0.457	0.461	0.448	0.444
w	0.006	0.008	0.0045	0.005

COMPARISON WITH SIMULATIONS

SIMULATIONS ← ? OBSERVATIONS

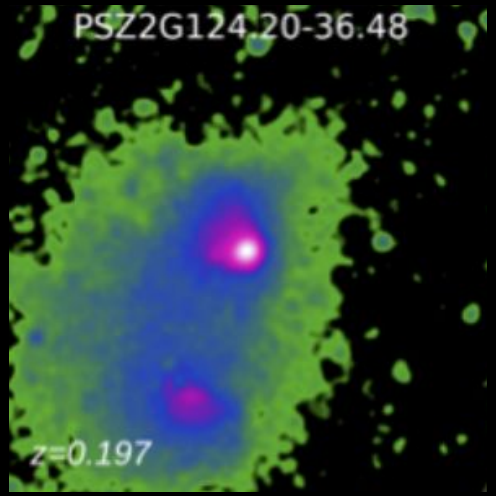


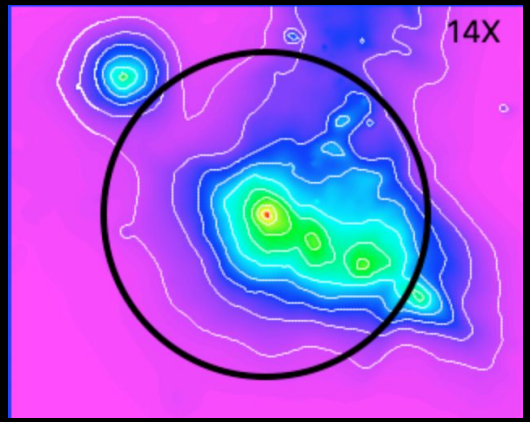


c	0.189	0.216	0.236
w	0.053	0.049	0.05

COMPARISON WITH SIMULATIONS

SIMULATIONS ← ? OBSERVATIONS



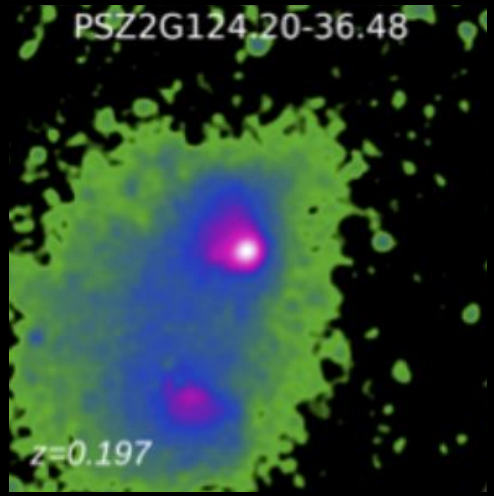


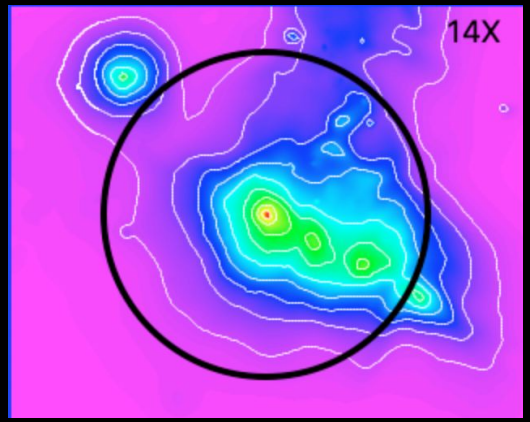
c	0.312	0.287
w	0.088	0.085

COMPARISON WITH SIMULATIONS

?

SIMULATIONS ← OBSERVATIONS





The **combination** of the morphological parameters is a **powerful tool** for the description of the X-ray morphology of clusters

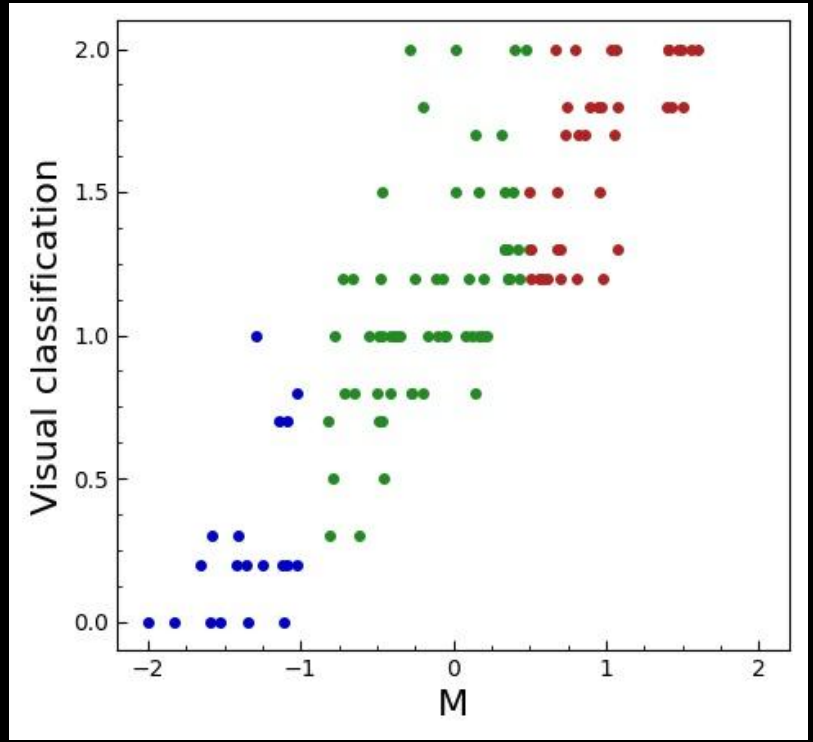
MORPHOLOGICAL ANALYSIS : combining the parameters

Construction of the **parameter M** (e.g. De Luca 2021):

$$M = \sum \frac{\log_{10}(\mathcal{P}^{\alpha_{\mathcal{P}}}) - < \log_{10}(\mathcal{P}^{\alpha_{\mathcal{P}}}) >}{\sigma_{\log_{10}(\mathcal{P}^{\alpha_{\mathcal{P}}})}}$$

<u>Classification based on M:</u>

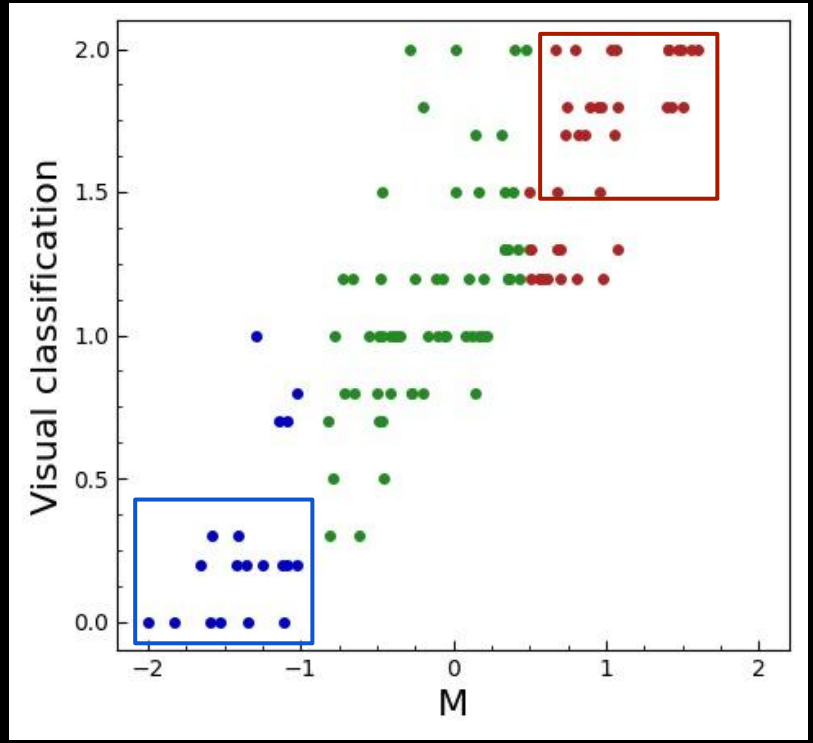
- **Relaxed** = 18* objects with the lowest values of M
- **Disturbed** = 32* objects with the highest values of M



[*18 and 32 = fraction of relaxed and disturbed objects found with the visual classification]

MORPHOLOGICAL ANALYSIS : combining the parameters

Comparison between the classification based on M and the visual classification.



FINAL RESULTS

15 Relaxed (12.7 %)
25 Disturbed (21.1%)
78 Mixed (66.2 %)

MORPHOLOGICAL ANALYSIS - CONCLUSION

- We performed a morphological analysis of the sample using four morphological parameters: c, w, P_{20} and P_{30};
- Correlation between the morphological parameters, but **NO evolution** with mass and redshift;
- **15** objects are classified as most relaxed (12.7 %) and **25** as most disturbed (21.1 %);
- Good agreement between observations and simulations, for the exception of the concentration→ **Limits** in the description of the **core?**

CHEX-MATE: Morphological analysis of the sample

M. G. Campitiello[1,2,⋆], S. Ettori[1,3], L. Lovisari[1,4], I. Bartalucci[5], D. Eckert[6], E. Rasia[7,8], M. Rossetti[5], F. Gastaldello[5], G.W. Pratt[9], B. Maughan[10], E. Pointecouteau[11], M. Sereno[1,3], V. Biffi[12,13], S. Borgani[7,12,14,15], F. De Luca[16], M. De Petris[17], M. Gaspari[1,18], S. Ghizzardi[5], P. Mazzotta[16], and S. Molendi[5]