Smithsonian Astrophysical Observatory

X-RAY MORPHOLOGICAL ANALYSIS OF THE PLANCK ESZ SELECTED CLUSTERS

(submitted to ApJ)

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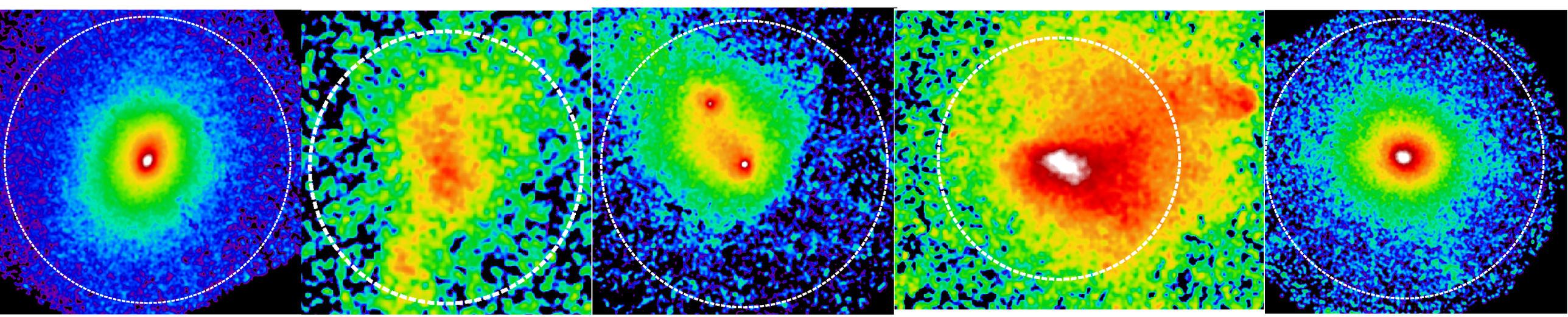
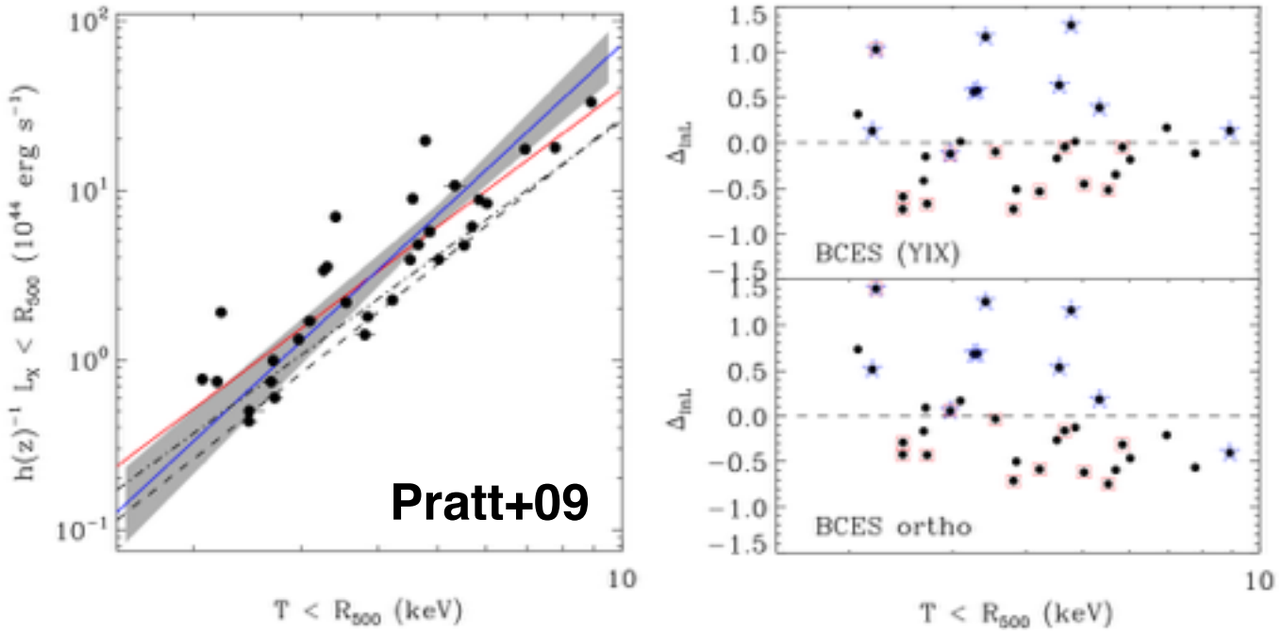
Rome, 9 June 2017 **The X-ray Universe 2017**



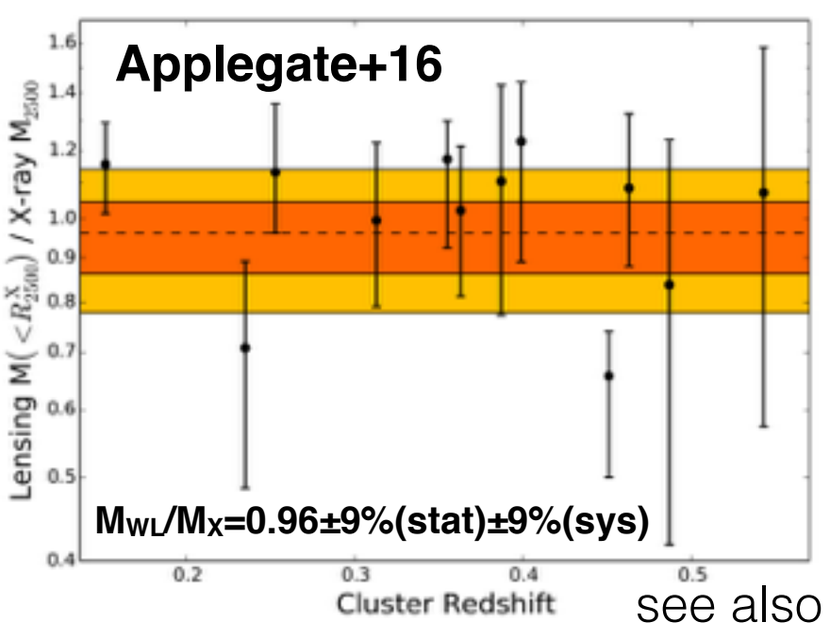
Scaling relations & Cosmology

relaxed and disturbed systems populate different regions of the residual space of scaling relations…**increased scatter**



calibration of the scaling relations better done with relaxed clusters

note that recent studies disfavor strong departure from HE for relaxed clusters



see also Israel+14 and Eckert talk

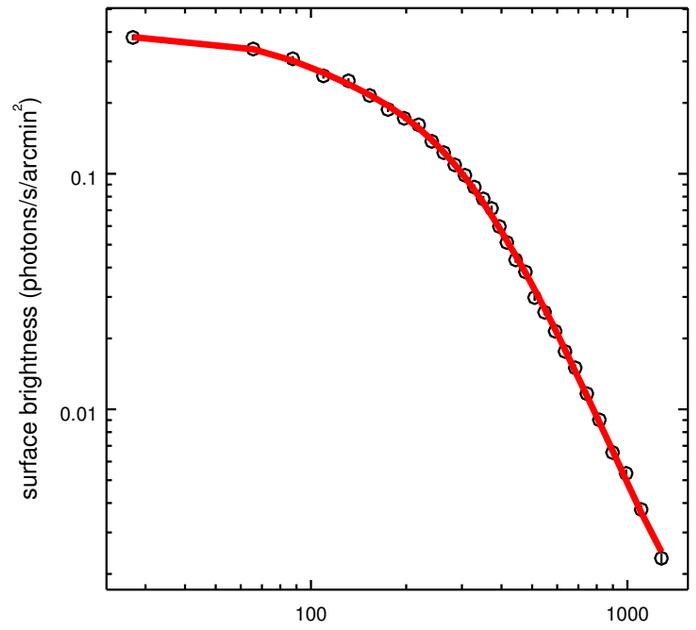
Goals

- **simple criteria to identify the most relaxed (or most disturbed) galaxy clusters from a sample**
- **study the dependence on the cluster properties**

Morphological parameters

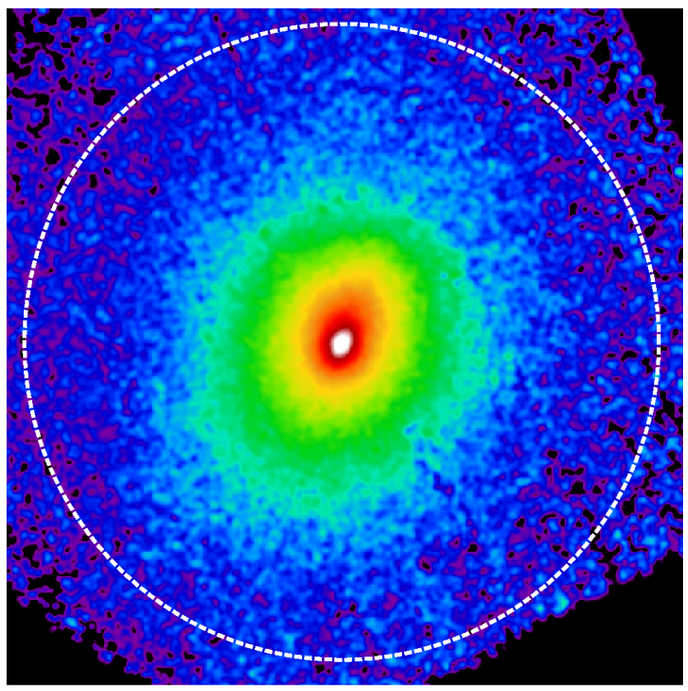
- central density n_e
- cuspiness α
- concentration c

SB & n_e profiles



- Gini coefficient
- centroid-shift w
- power ratios P30-P40
- ellipticity

images



Morphological parameters

- central density n_e
- cuspiness α
- concentration c
- Gini coefficient

} **more sensitive to the core properties of the clusters**

- centroid-shift w
- power ratios P30-P40
- ellipticity

} **more sensitive to the presence of substructures**

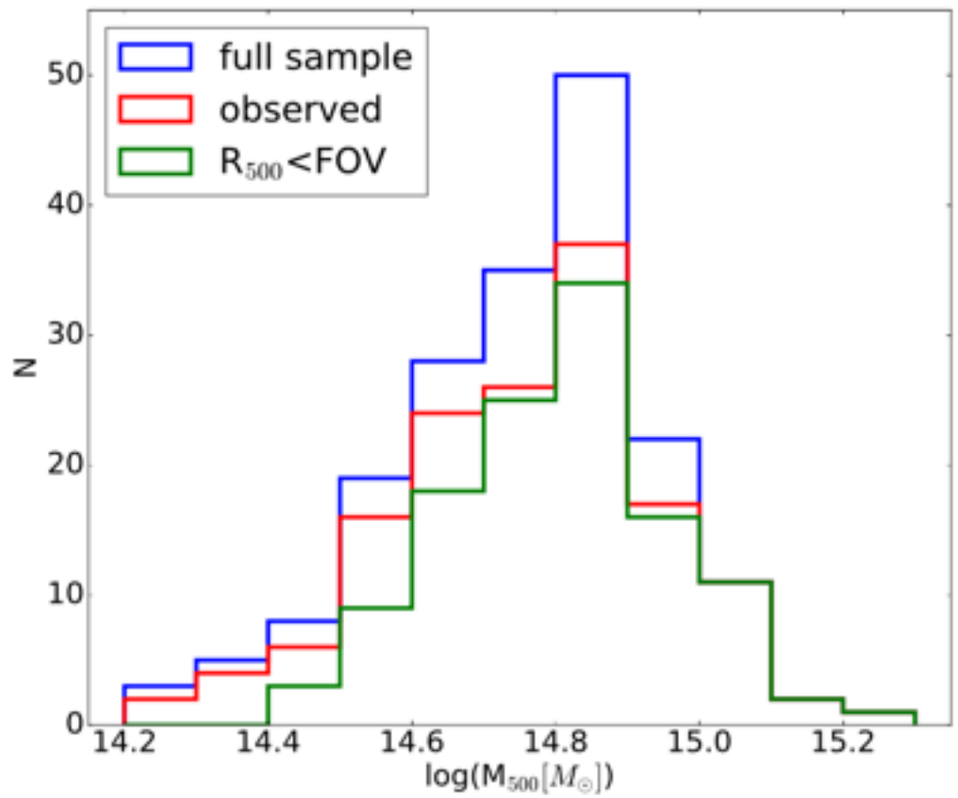
Sample

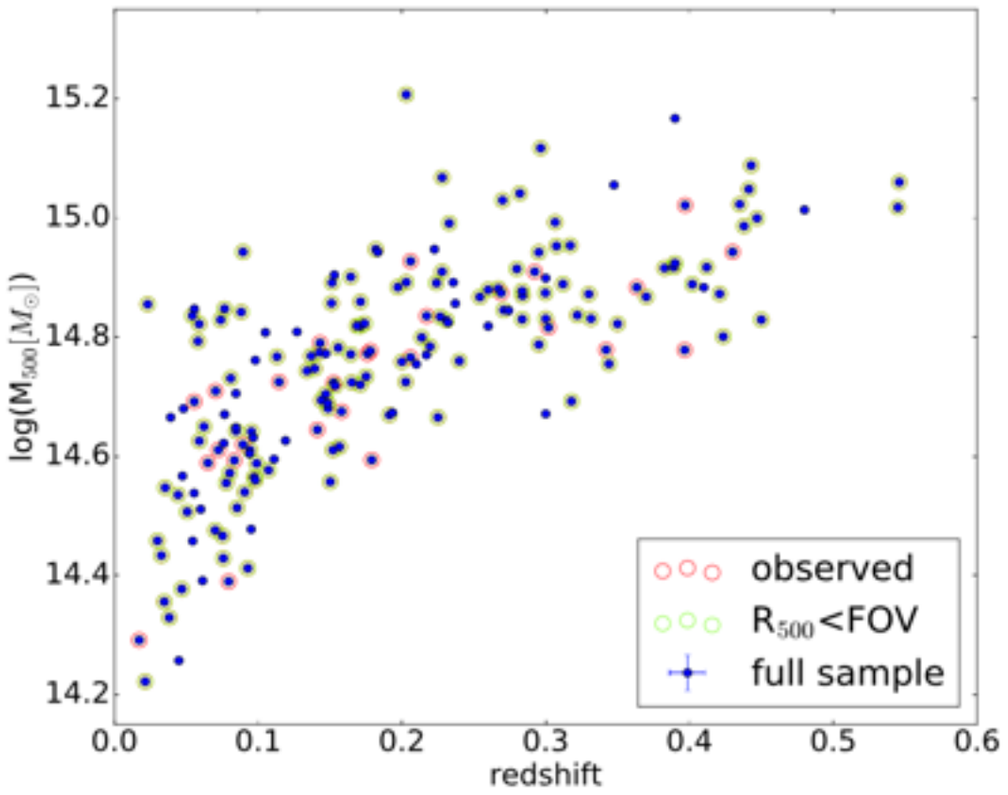
Planck All-Sky Early SZ (ESZ)
Cluster Sample: <u>188 objects</u>

redshift<0.55
mass range 1.7×10^{14}-1.6×10^{15} $M_\odot$

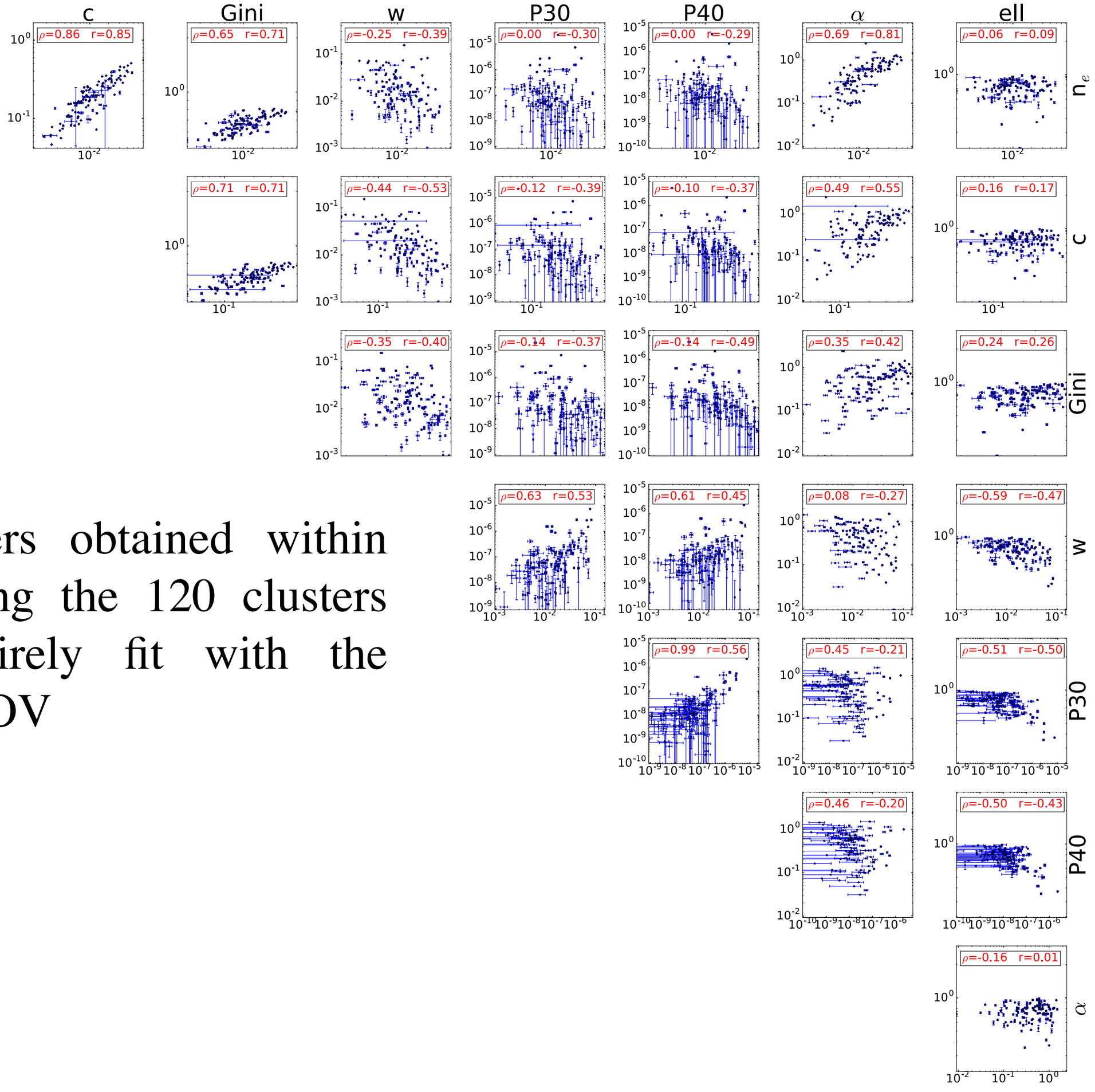
155 observed with XMM-Newton
(5 completely flared)

120 clusters R_{500}<FOV





Parameters obtained within R_{500} using the 120 clusters that entirely fit with the XMM FOV



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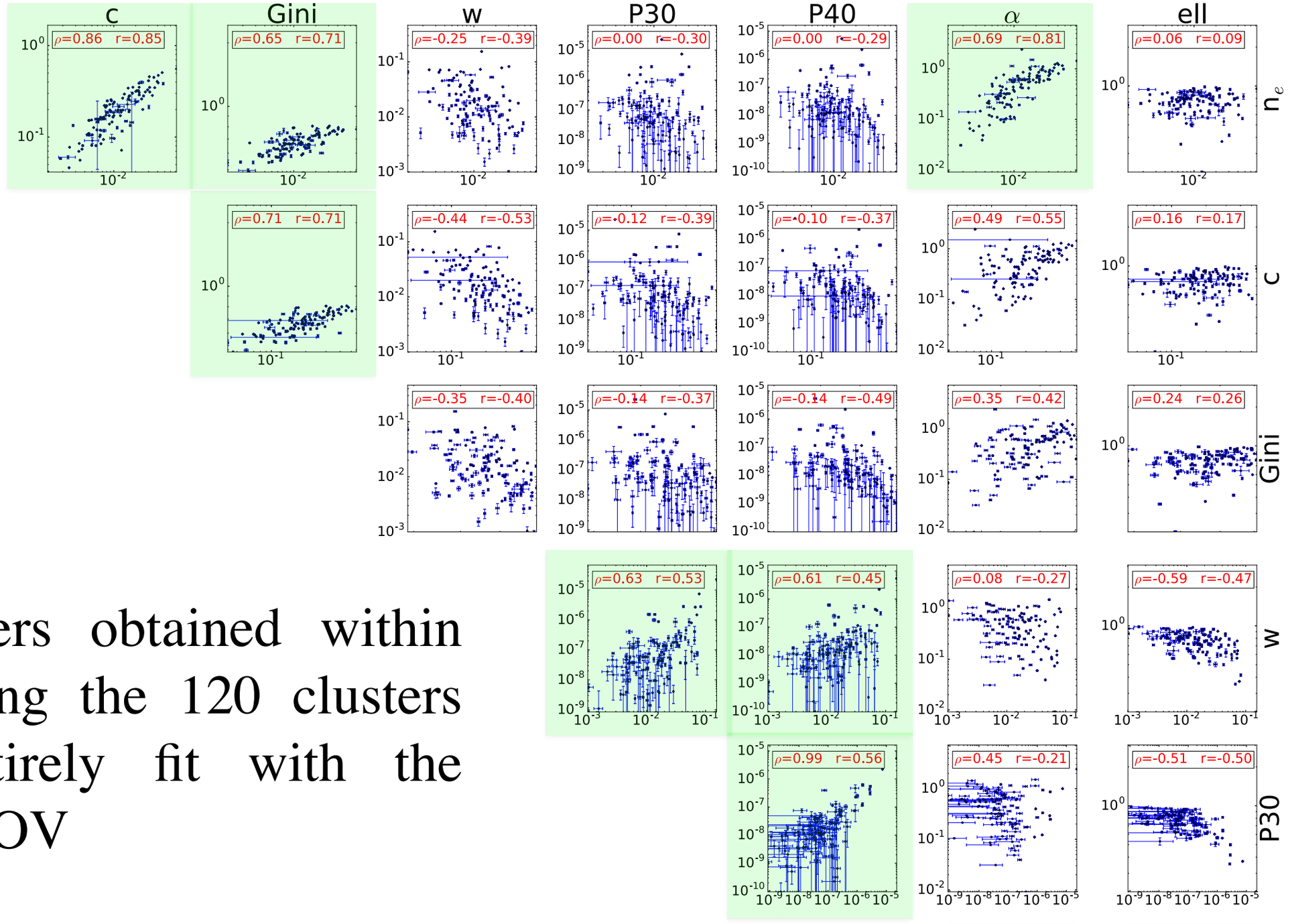


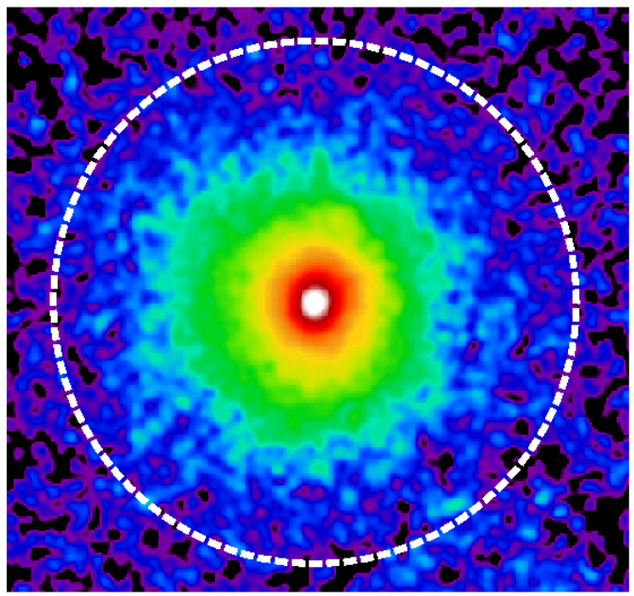
Although the different plots show a significant intrinsic scatter, the expected correlation between several parameters can still be observed

Finding the most relaxed clusters

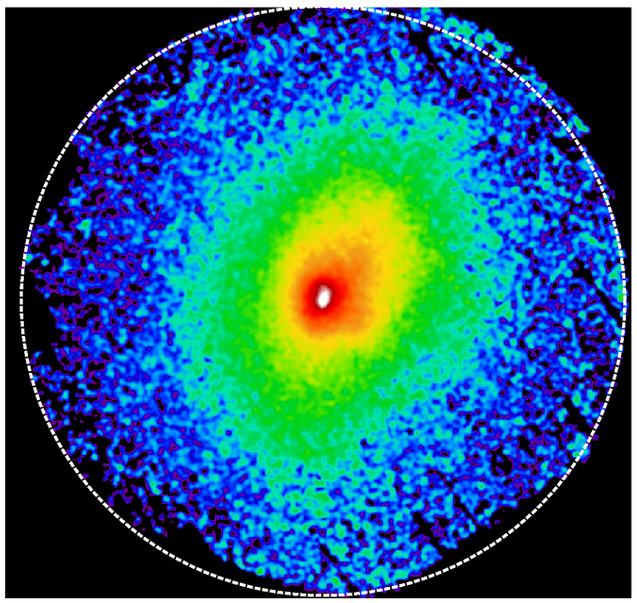
visual classification
by 6 astronomers with
grade 1-4

relaxed mean grade <2
disturbed mean grade >3
"mix" all the others

relaxed



semi-relaxed



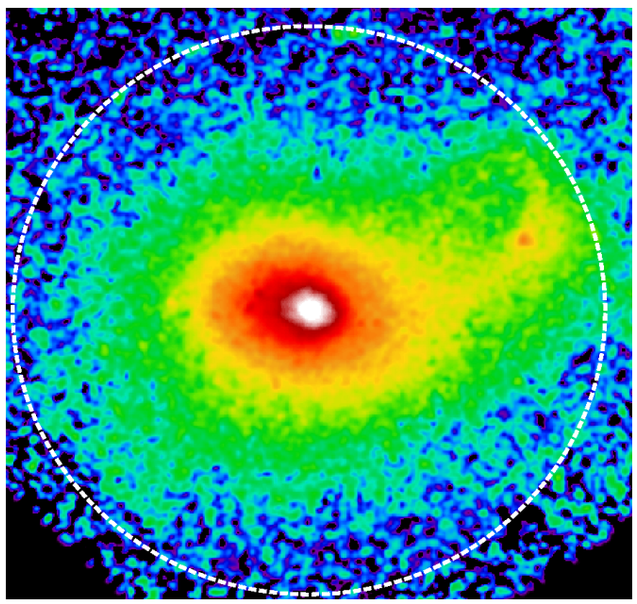
Robustness tests

- *repeated classification*

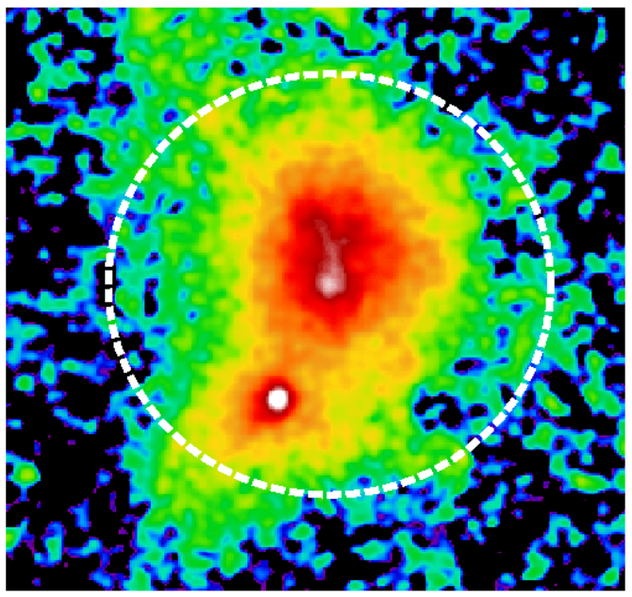
$\sigma_{rel,dist}$=0.12 σ_{mix}=0.37

- *reduce image quality*

σ=0.14

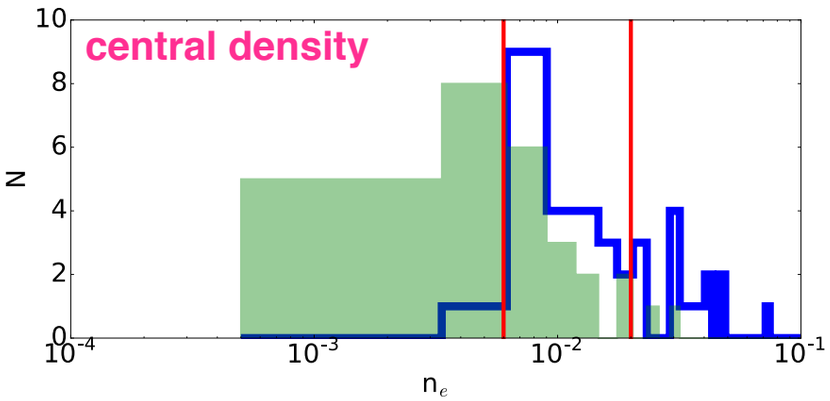


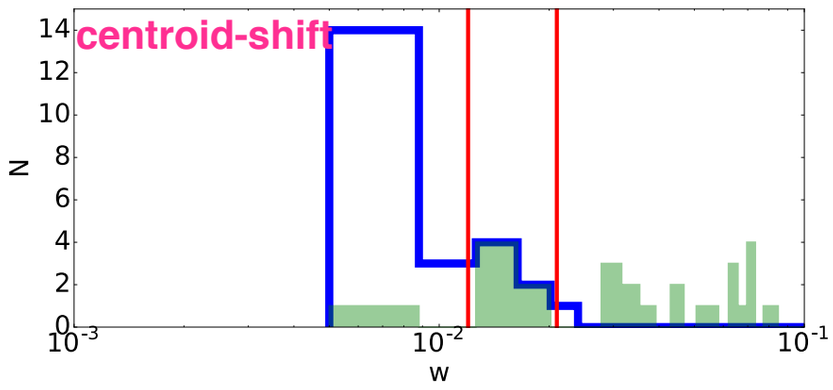
semi-disturbed

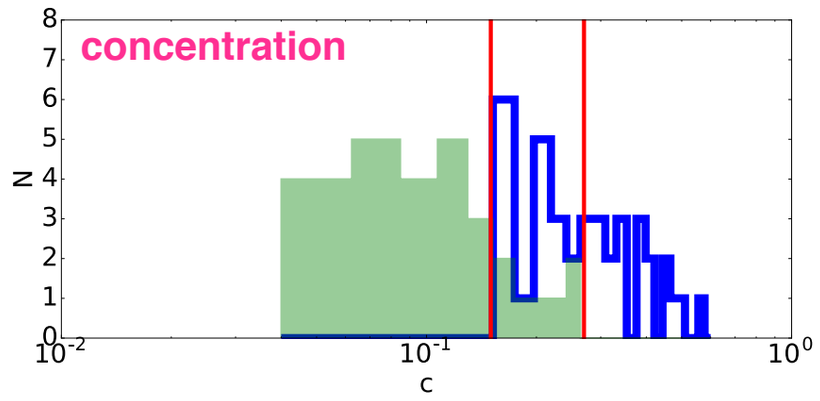


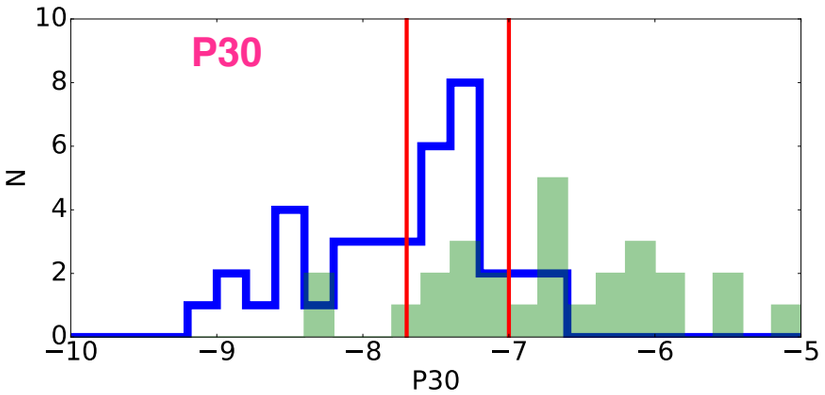
disturbed

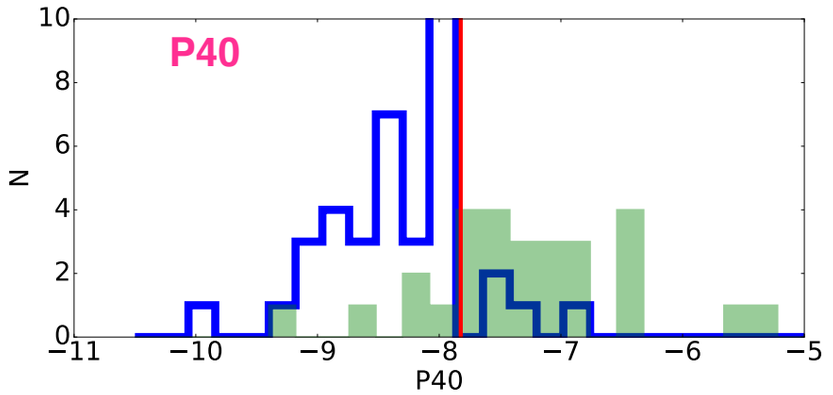
Finding the most relaxed clusters

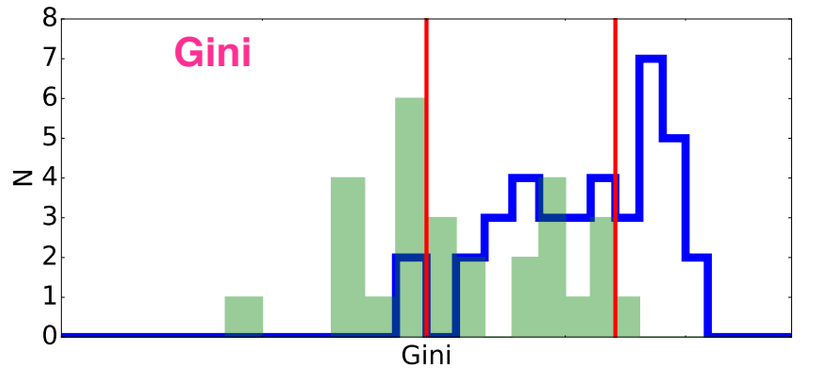


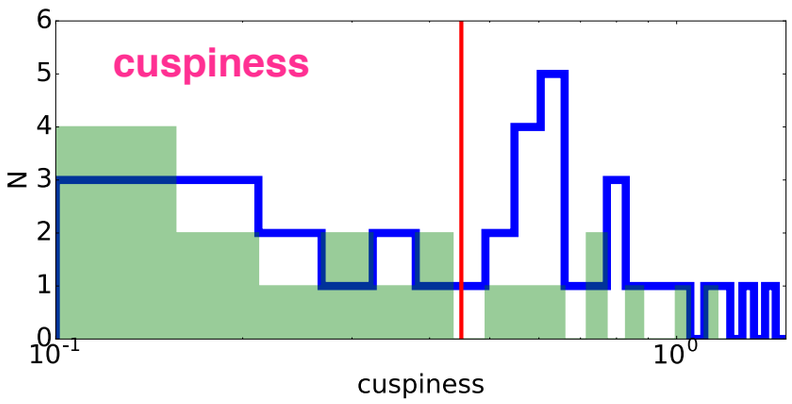


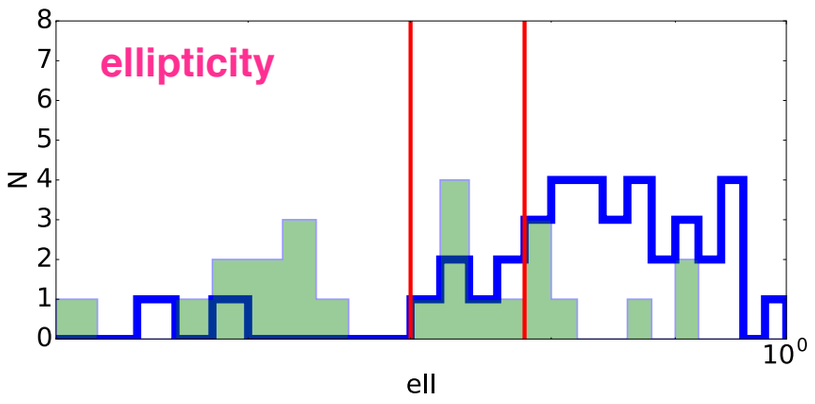












- **relaxed**
- **disturbed**

completeness

$$C_r = \frac{QN(relaxed)}{TN(relaxed)}$$

purity

$$P_r = \frac{QN(relaxed)}{QN(relaxed + disturbed)}$$

Finding the most relaxed clusters

Par	relaxed				disturbed			
	L_r	C_r	P_r	P_{ext}	L_d	C_d	P_d	P_{ext}
n_e	>6.0e-3	0.97	0.71	0.41	<3.1e-2	1.00	0.49	0.27
n_e	>2.0e-2	0.39	0.88	0.56	<7e-3	0.54	0.94	0.58
w	<2.1e-2	1.00	0.84	0.49	>1.0e-2	0.96	0.73	0.36
w	<1.2e-2	0.82	0.97	0.61	>1.8e-2	0.82	0.92	0.50
c	>0.15	1.00	0.84	0.48	<0.22	0.89	0.64	0.35
c	>0.27	0.53	1.00	0.67	<0.15	0.75	1.00	0.57
Gini	>0.6	0.95	0.69	0.40	<0.75	1.00	0.54	0.28
Gini	>0.74	0.45	0.94	0.68	<0.60	0.43	0.86	0.48
P30	<1.0e-7	0.89	0.77	0.45	>2.0e-8	0.93	0.57	0.31
P30	<2.0e-8	0.47	0.90	0.58	>2.0e-7	0.54	1.00	0.78
P40	<1.5e-8	0.89	0.87	0.57	>5.0e-9	0.93	0.58	0.30
cusp	>0.10	0.97	0.64	0.35	<1.00	0.93	0.44	0.24
ell	>0.70	0.95	0.72	0.43	<0.80	0.86	0.69	0.37

Finding the most relaxed clusters

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	L_r	C_r	P_r	P_{ext}	L_d	C_d	P_d	P_{ext}
n_e	>6.0e-3	0.97	0.71	0.41	<3.1e-2	1.00	0.49	0.27
n_e	>2.0e-2	0.39	0.88	0.56	<7e-3	0.54	0.94	0.58
w	<2.1e-2	1.00	0.84	0.49	>1.0e-2	0.96	0.73	0.36
w	<1.2e-2	0.82	0.97	0.61	>1.8e-2	0.82	0.92	0.50
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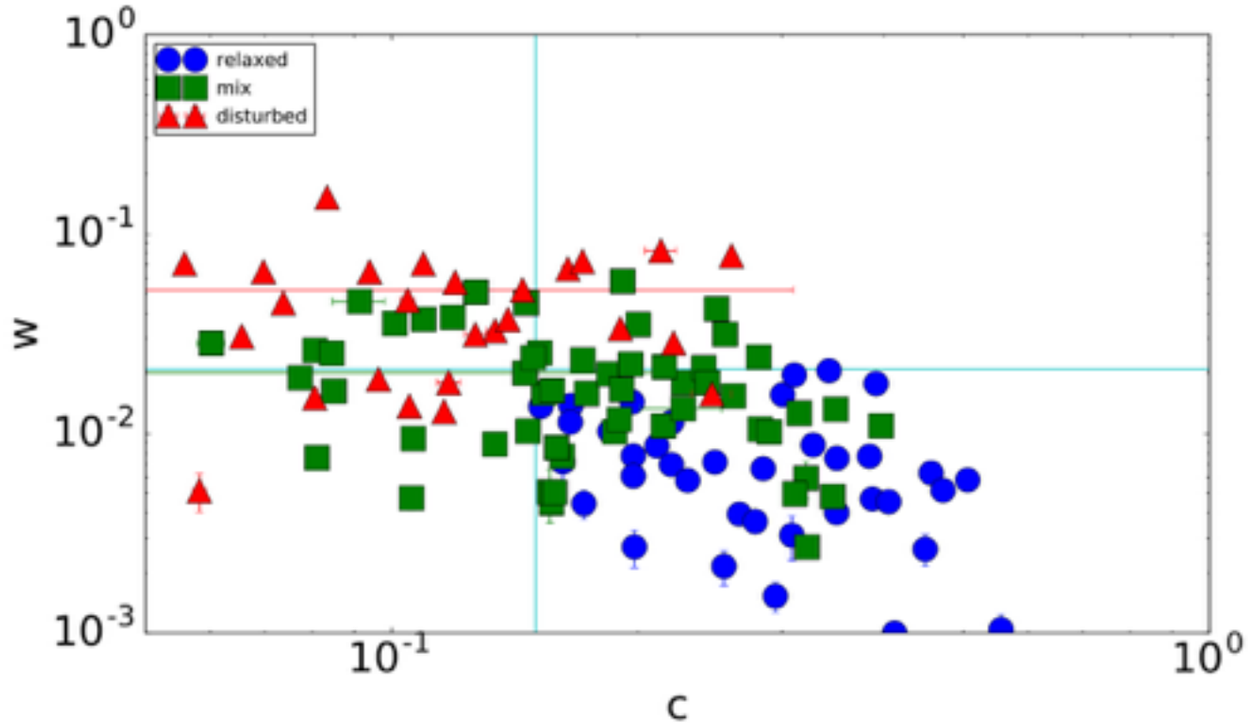
Finding the most relaxed clusters

Par	L_r		relaxed C_r	P_r	P_{ext}
$c-w$	>0.15	<2.1e-2	1.00	0.98	0.59
$c-P30$	>0.15	<2.0e-7	1.00	0.90	0.54
$c-P40$	>0.15	<5.0e-8	0.97	0.93	0.54
$c-ell$	>0.15	>0.70	0.95	0.92	0.60
n_e-w	>6.0e-3	<2.1e-2	0.97	0.88	0.55
n_e-c	>6.0e-3	>0.15	0.97	0.84	0.49
$P30-w$	<1.0e-7	<2.1e-2	0.90	0.90	0.56
$P30-P40$	<1.0e-7	<5.0e-8	0.90	0.79	0.47

Par	L_d		disturbed C_d	P_d	P_{ext}
$c-w$	<0.28	>1.2-2	0.96	0.90	0.47
n_e-w	<3.1e-2	>1.2-2	0.96	0.84	0.44
n_e-c	<2.0e-2	<0.25	0.93	0.62	0.33
$c-ell$	<0.25	>0.35	0.93	0.62	0.33



combining centroid-shift and concentration provides complete and clean sample or relaxed clusters

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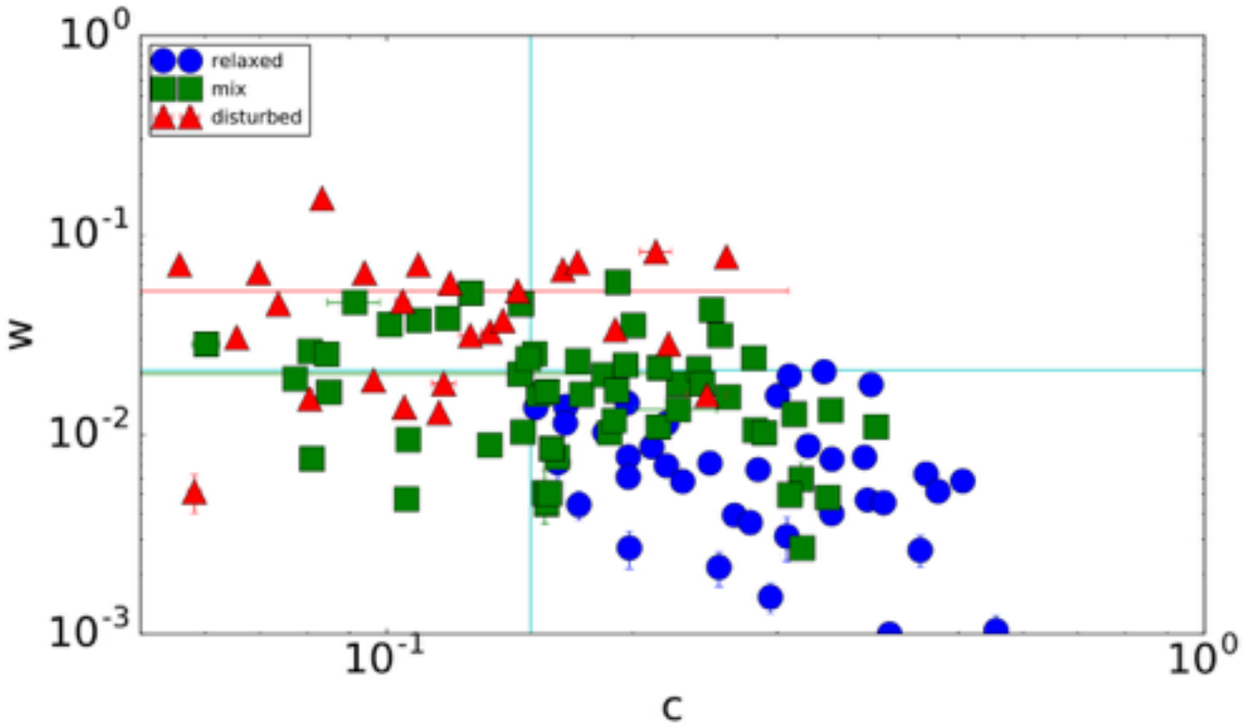
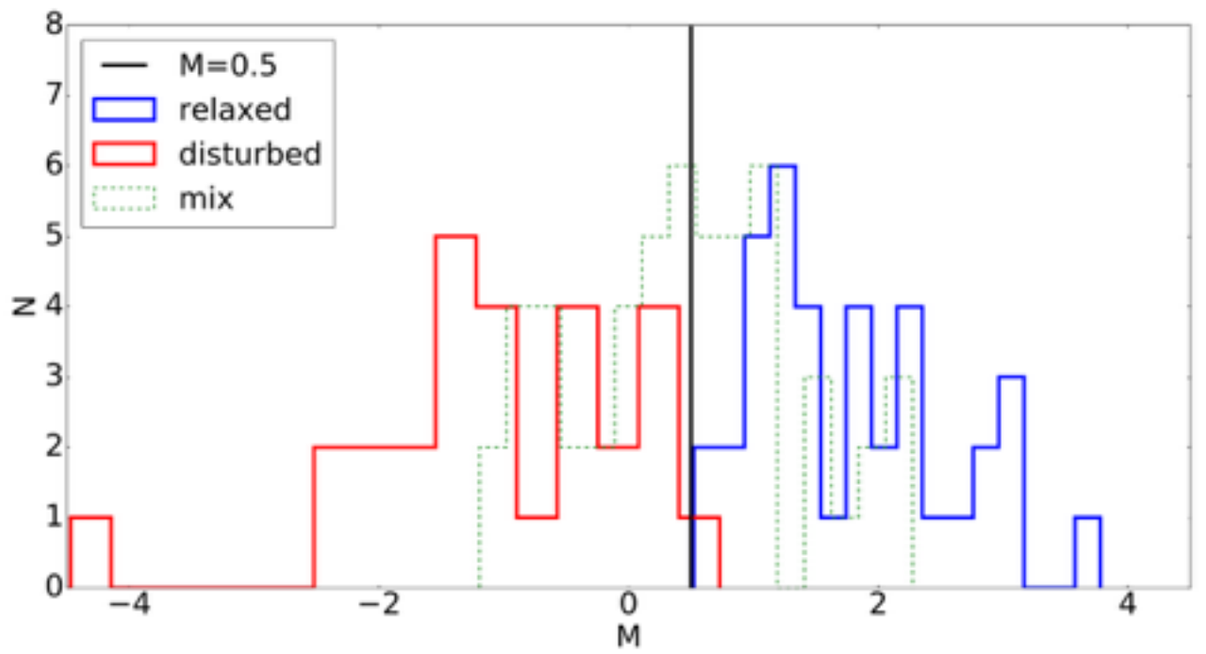


$$M = \frac{1}{2}\left(\frac{c-0.15}{c_{quar}-c_m} - \frac{w-0.021}{w_{quar}-w_m}\right)$$



Cluster properties and morphology

Total mass

The hierarchical structure formation model predicts massive clusters to form through episodic mergers → statistically one might expect to find the most massive objects in a more disturbed dynamical state

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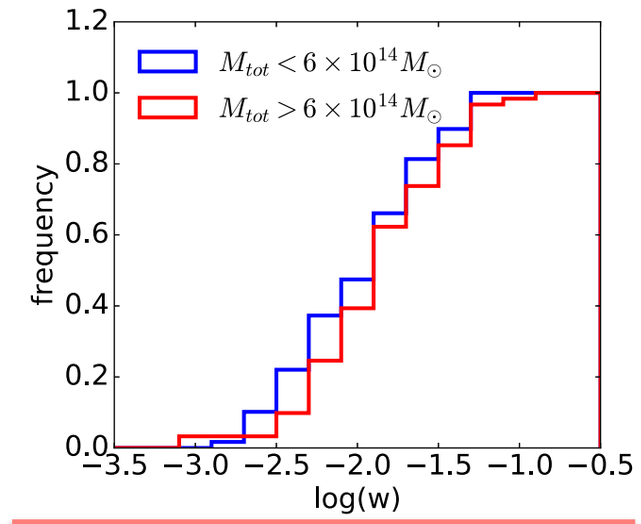
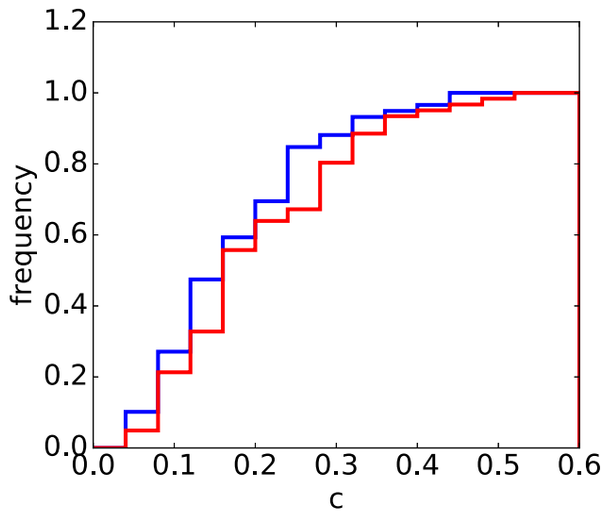
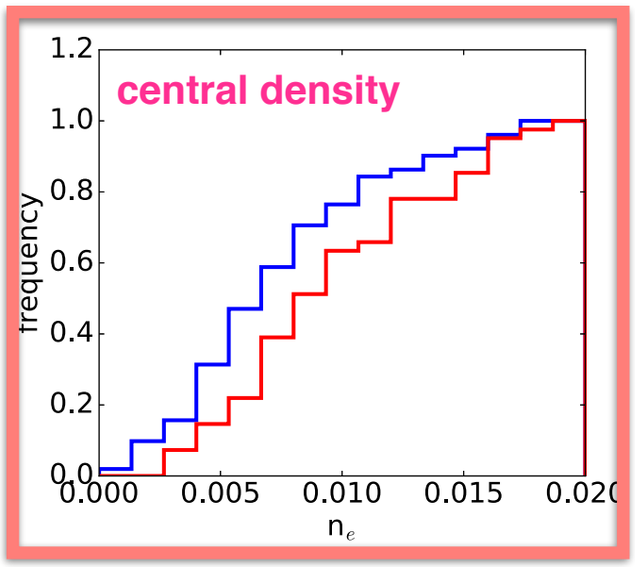
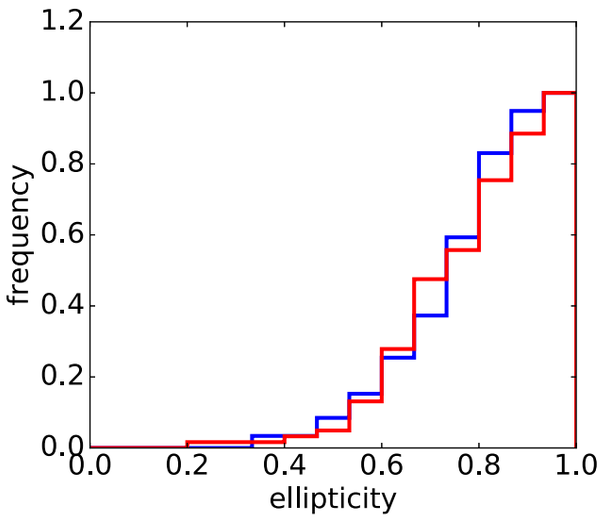
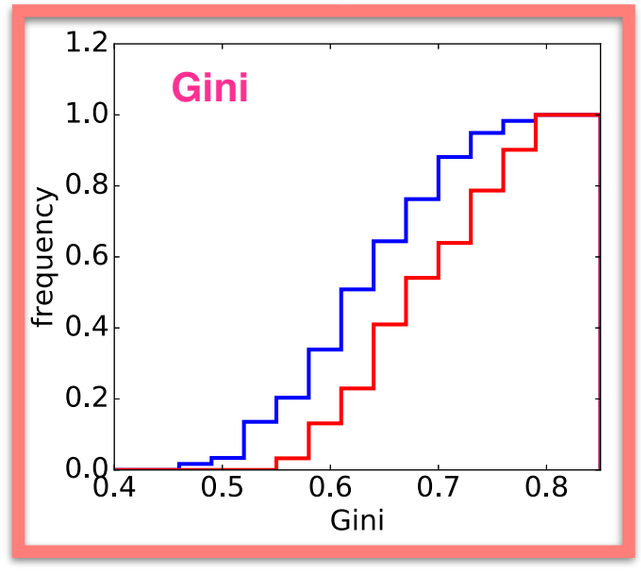
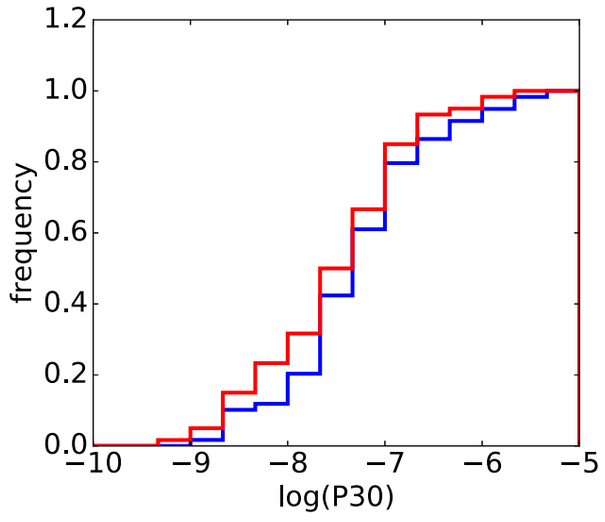


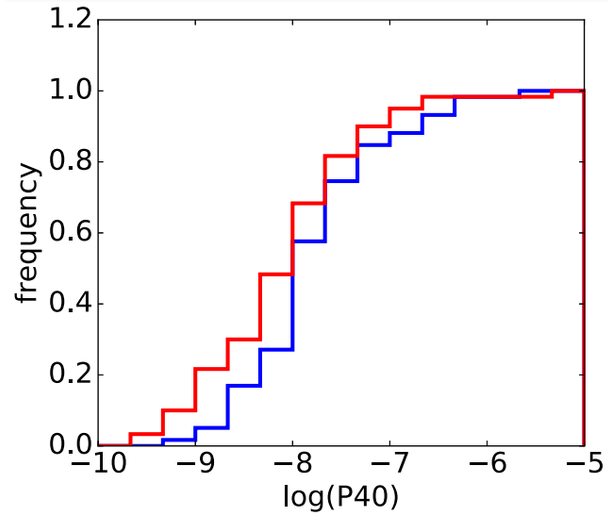


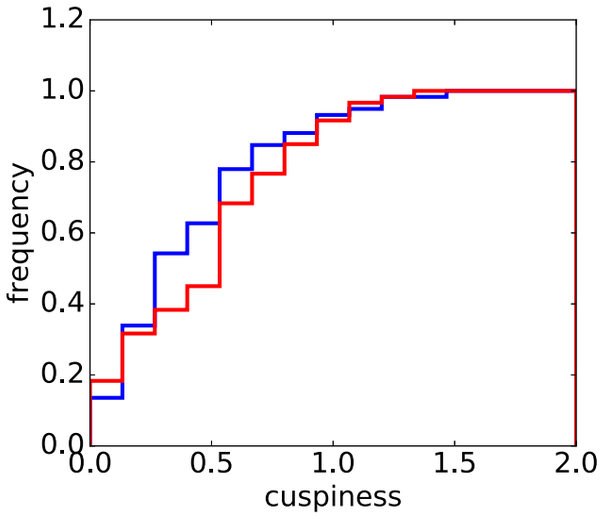






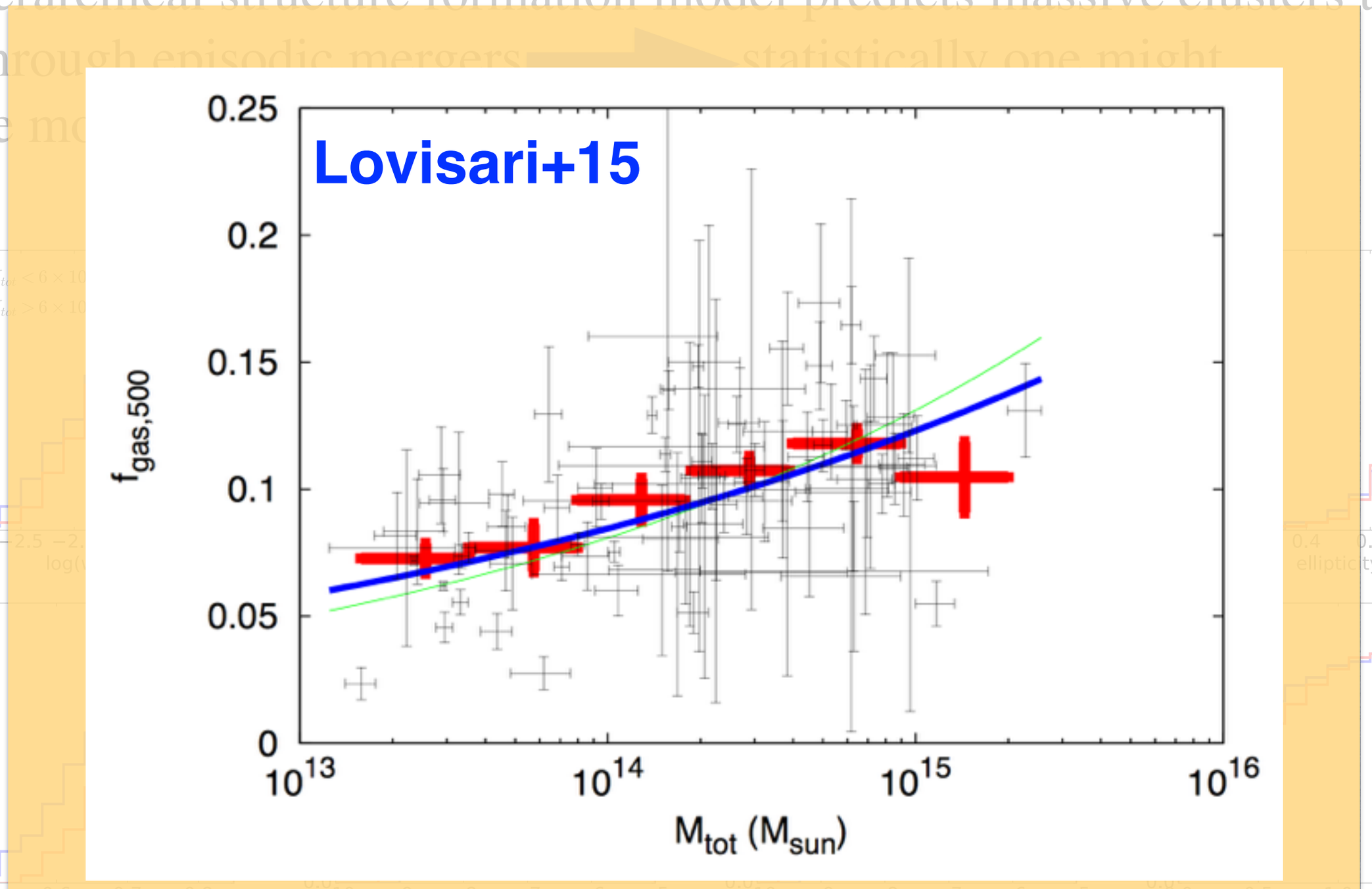






Cluster properties and morphology

Total mass



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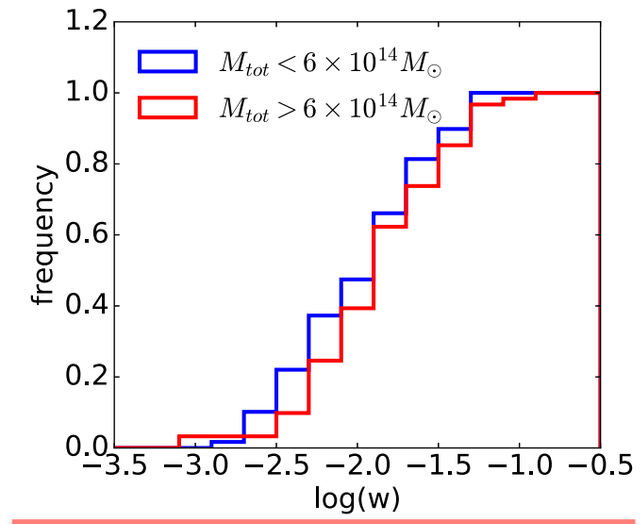
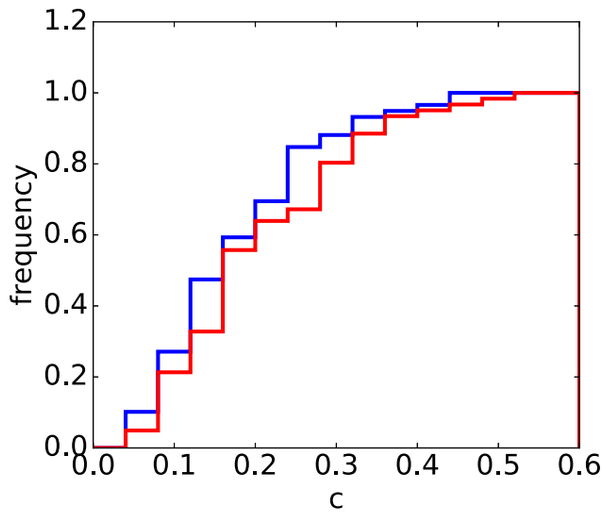
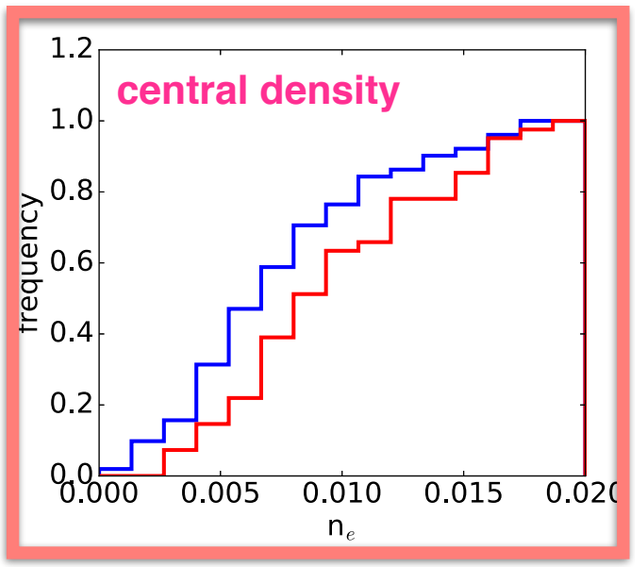
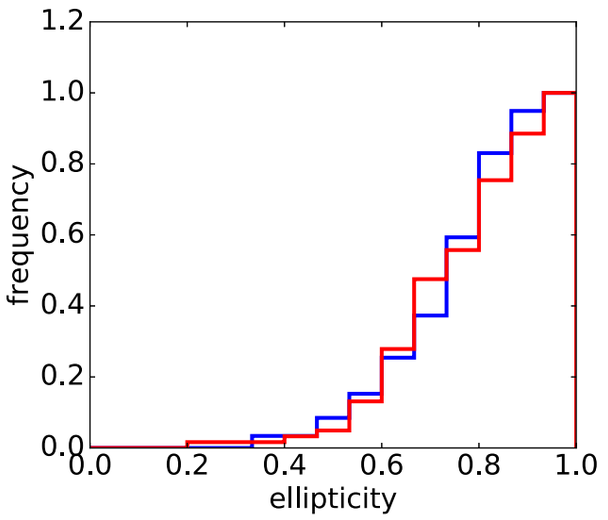
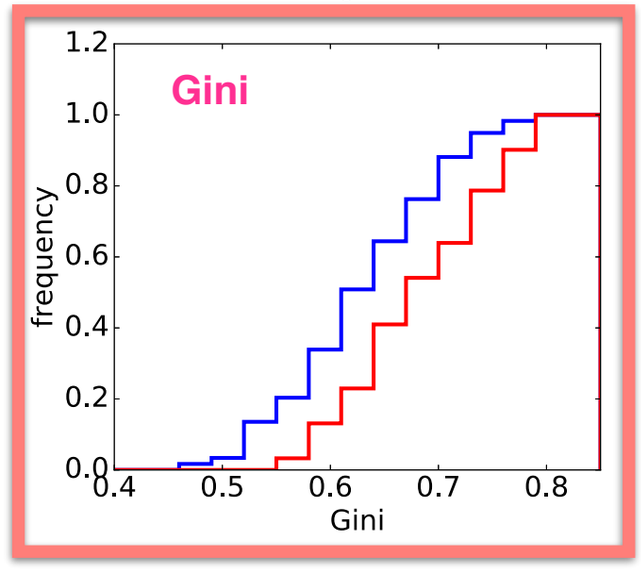
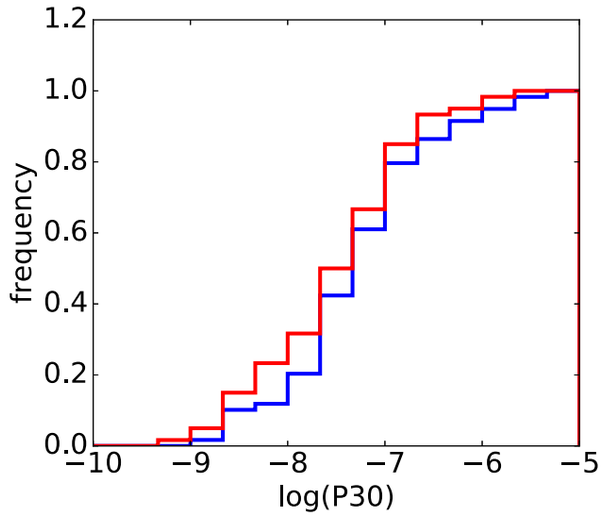


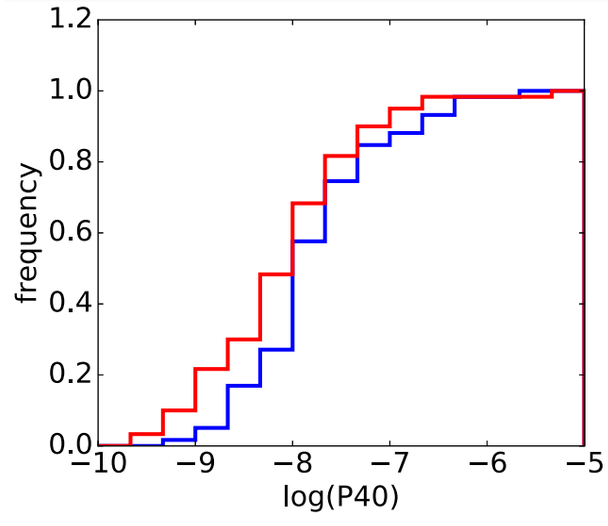


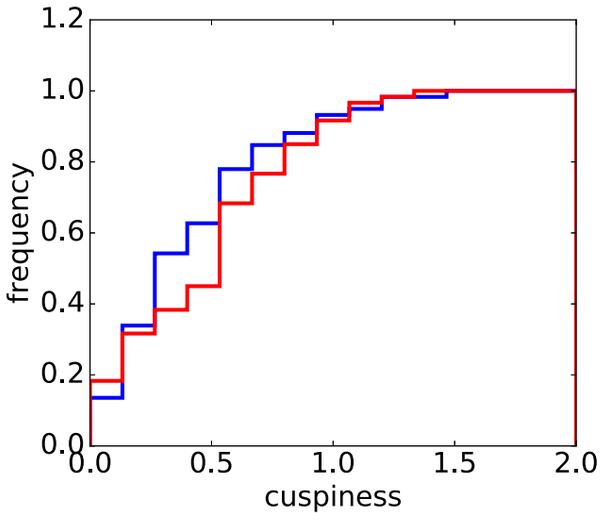












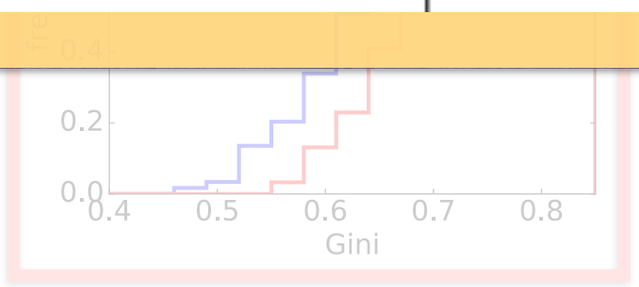
Cluster properties and morphology

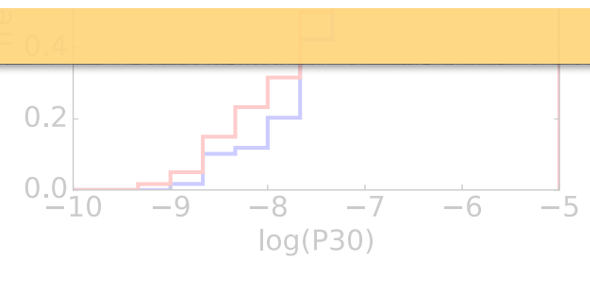
Total mass

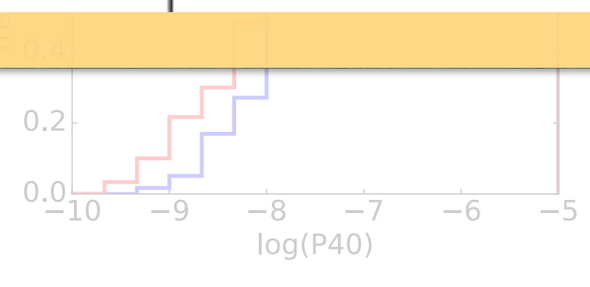
The hierarchical structure formation model predicts massive clusters to form through episodic mergers ⟹ statistically one might find the most massive ... more dynamical state

r=Spearman ρ=Pearson

Relation	R_{500} r	p-value	ρ	p-value	$0.5R_{500}$ r	p-value	ρ	p-value
M_{500}-c	0.14	0.09	0.06	0.44	0.09	0.27	0.03	0.70
M_{500}-w	0.04	0.62	0.07	0.42	0.07	0.38	0.14	0.09
M_{500}-n_e	0.28	<0.01	0.15	0.06	0.28	<0.01	0.15	0.06
M_{500}-Gini	0.41	<0.01	0.35	<0.01	0.10	0.24	0.05	0.58
M_{500}-cusp	0.00	0.97	-0.05	0.59	0.00	0.97	-0.05	0.59
M_{500}-P30	-0.15	0.11	-0.06	0.48	0.10	0.25	-0.07	0.41







ESZ vs REXCESS

Why comparing SZ and X-ray selected samples?

CC and disturbed systems occupy distinct regions in the L-M plane (e.g. Pratt+09).

X-ray flux-limited surveys are thought to preferentially select relaxed, centrally peaked, galaxy clusters. Planck-selected clusters are thought to be in general more morphologically unrelaxed.

Recent studies:

Rossetti+16,+17 ; Andrade-Santos+17 found that X-ray selected samples tend to be more relaxed than Planck SZ selected clusters.

Nurgaliev+16 did not find significant differences in the observed morphology of X-ray and SPT SZ samples.

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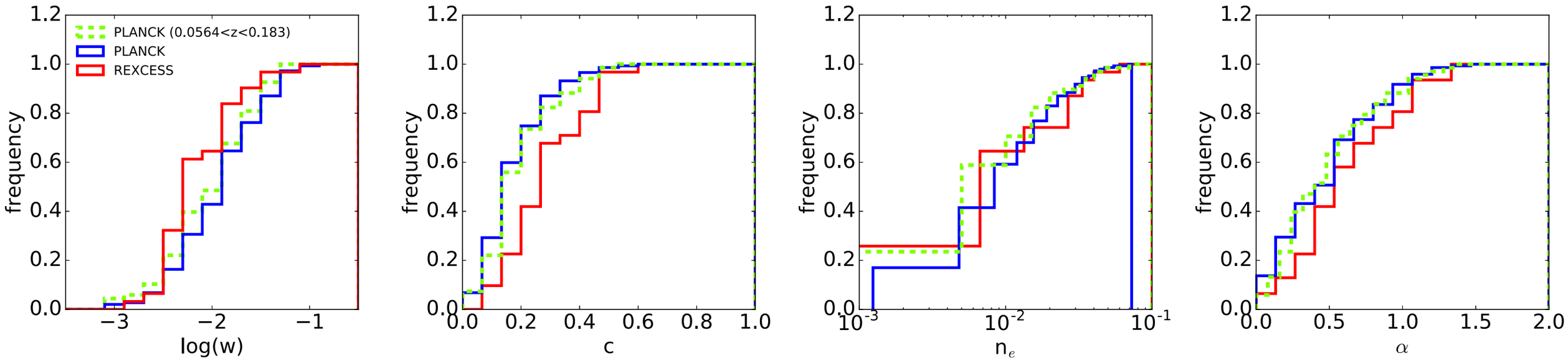
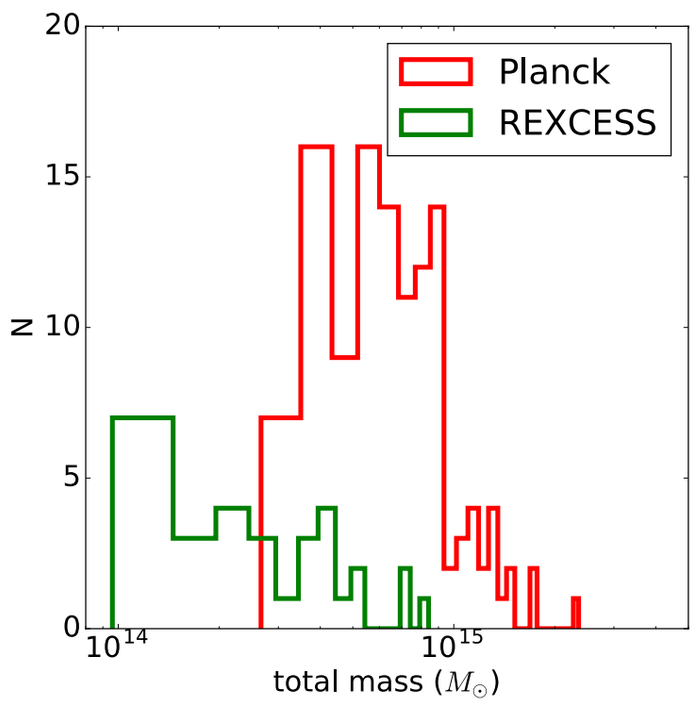


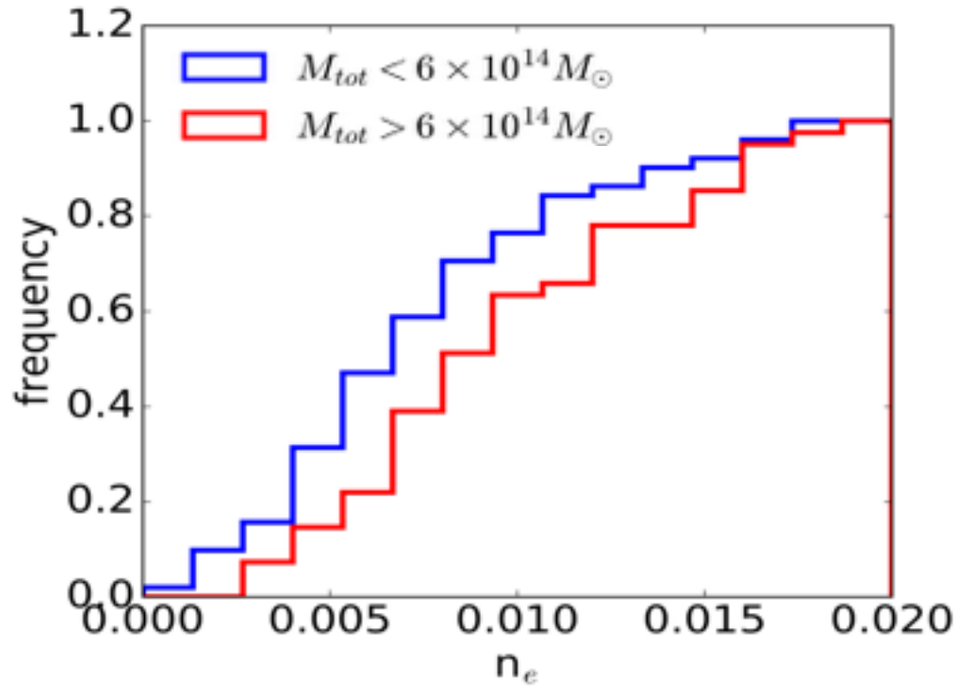
w, c, and α confirm that SZ clusters are more disturbed than X-ray clusters

ESZ vs REXCESS

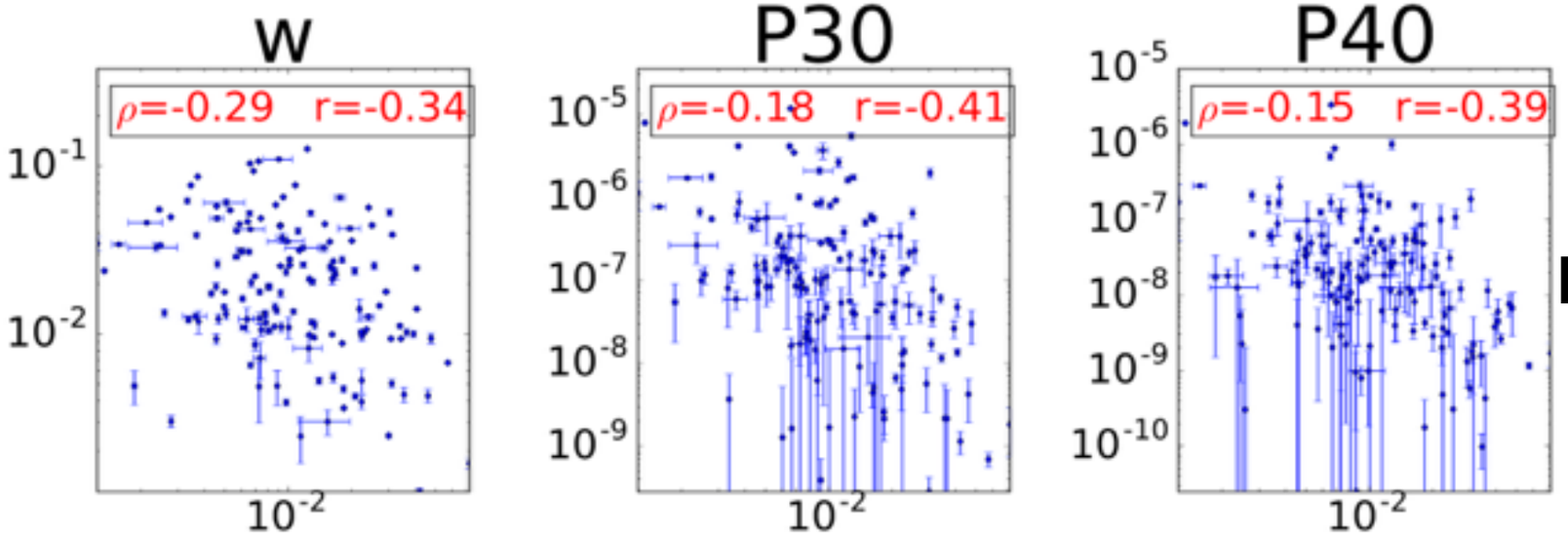
n_e probably affected by selection bias

ESZ more massive than REXCESS so higher n_e





ESZ more disturbed than REXCESS so lower n_e



to use n_e to compare SZ and X-ray sample one must assure they span a similar range of masses (and redshift)

Summary

- Concentration and centroid-shift are the parameters that perform better in identifying relaxed systems.
- Combining a parameter more sensitive to substructures (e.g. w, P30, and P40) with a parameters more sensitive to the core properties (e.g. n_e and c) is a powerful way to get complete and clean samples. Best combination *c-w*.
- Identifying the most disturbed systems by using the morphological parameters is in general more difficult than identifying the most relaxed ones.
- Apart from the central gas density and Gini coefficient, there is no dependence on the morphological parameters with M_{tot}.
- Samples of SZ selected clusters tend to be more dynamically disturbed than the X- ray selected samples in agreement with what has been found by other recent studies.