

Substructure and dynamics of X-ray clusters of galaxies

Gayoung Chon @ MPE

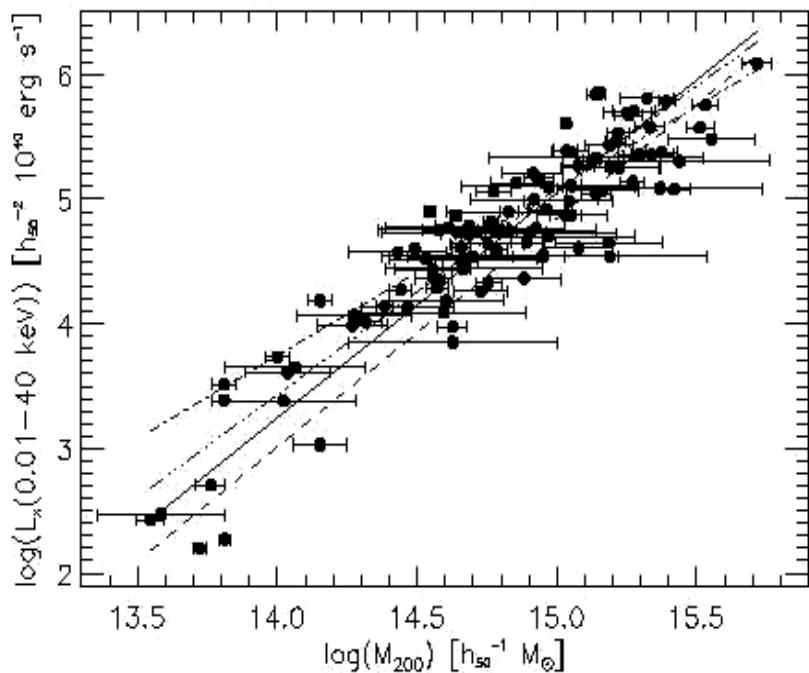
with Hans Böhringer

Based on Chon, Böhringer (2012, 2015)

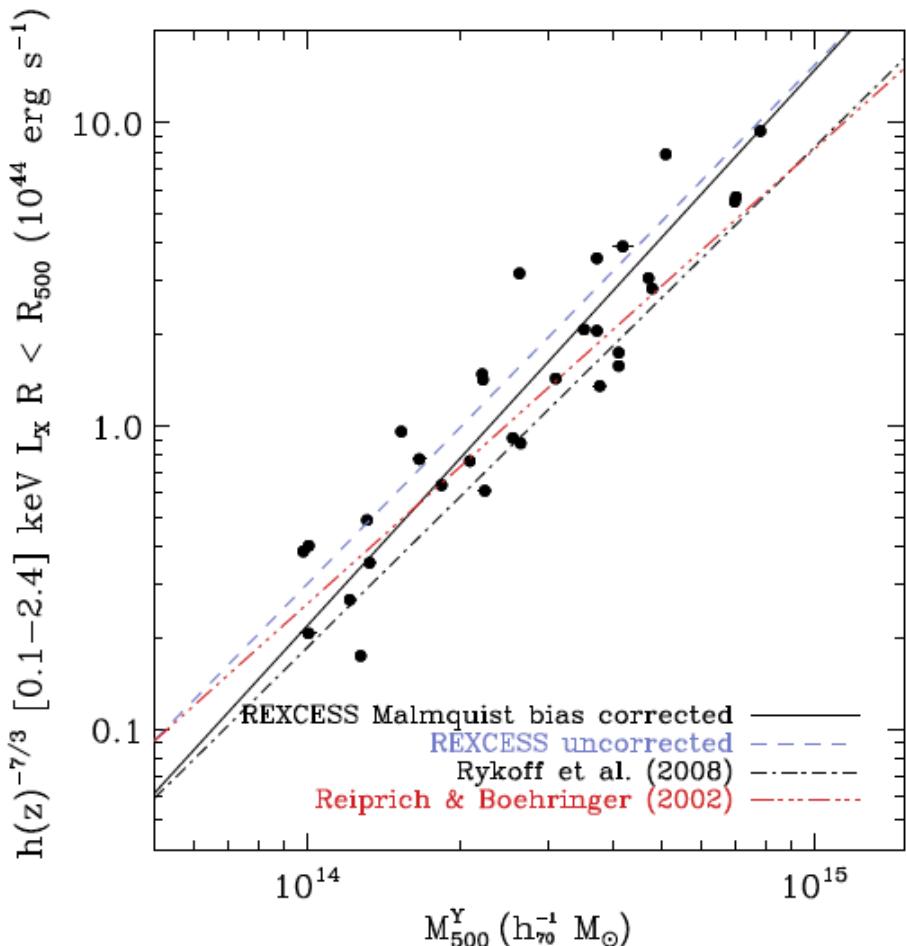
X-ray clusters to cosmology

- X-ray observations can characterise structure of clusters
- Mass of a cluster usually determined based on HSE and spherical symmetry
- Dynamically young objects → challenge to determine mass
- Accurate mass determination important for cosmology
- Currently sorting clusters by degree of substructure → diff. methods to get mass
- Extra info. to gain insight into physics

Observables to mass conversion

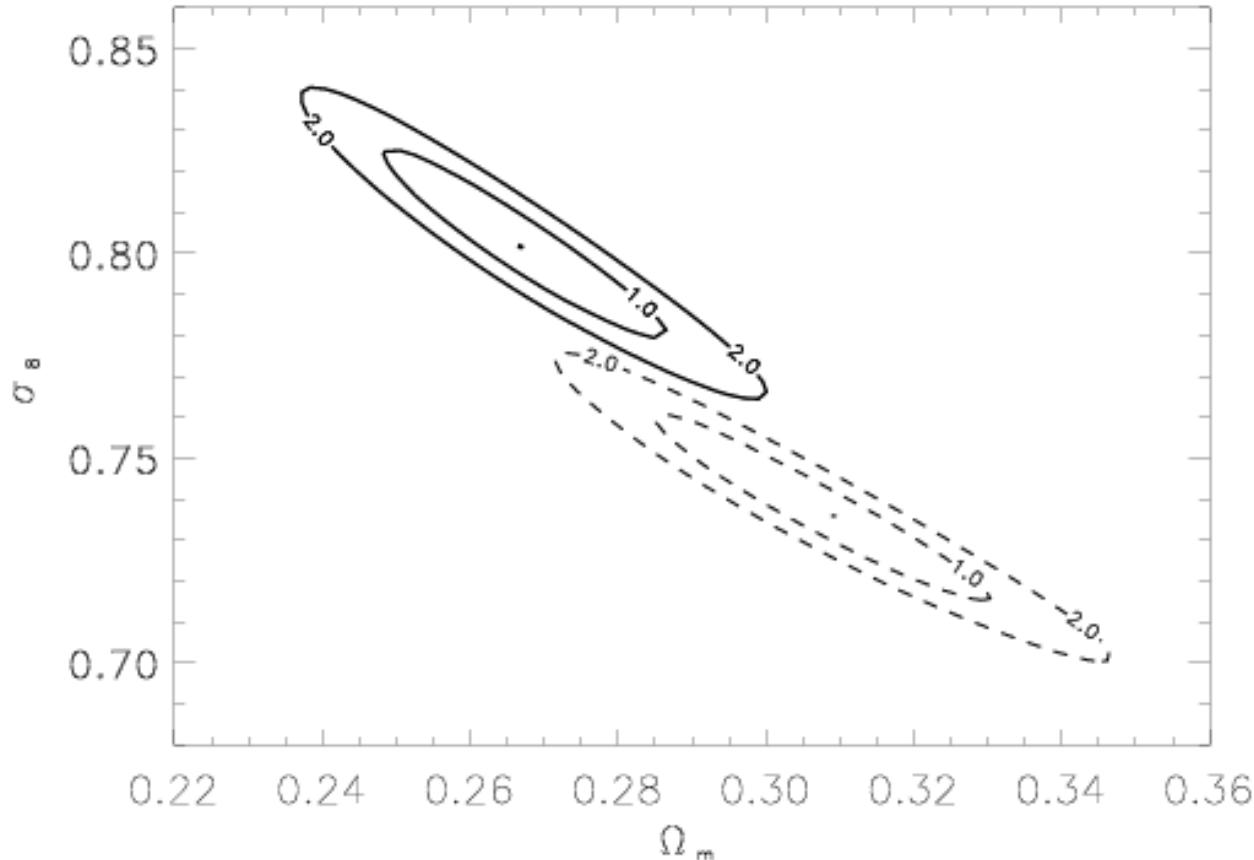


Reiprich & Böhringer (2002)



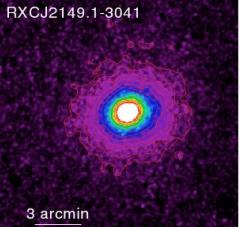
Pratt, Böhringer et al. (2009)

REFLEX II cosmology : Influence of scaling relations

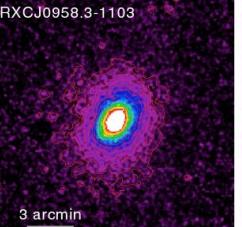


Böhringer, Chon, Collins (2013)

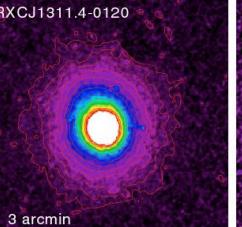
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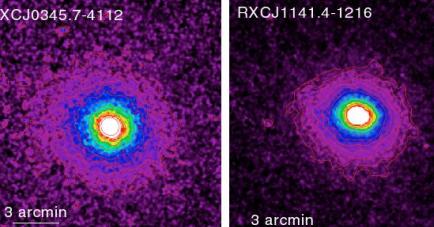
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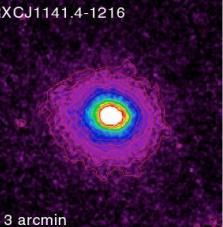
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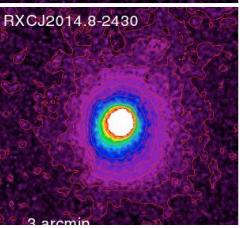


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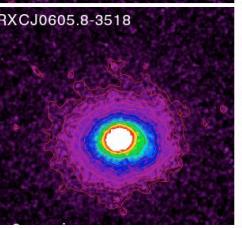


REXCESS Clusters

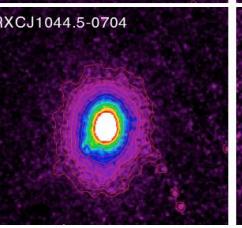
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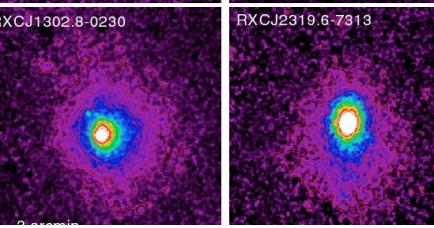
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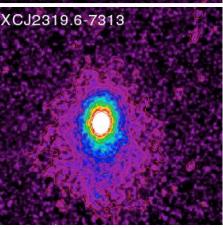
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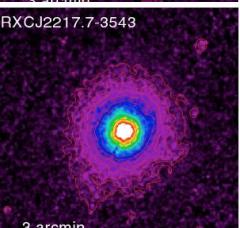
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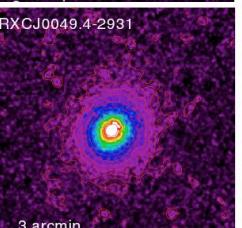
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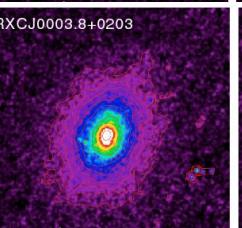
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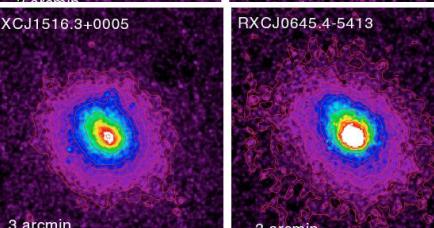
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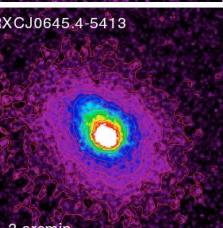
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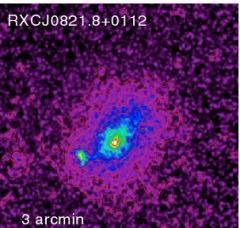
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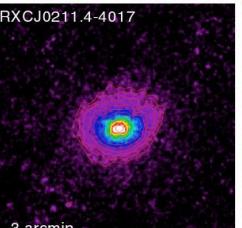
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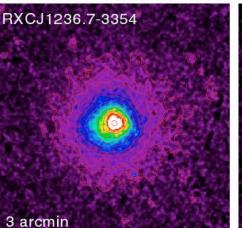
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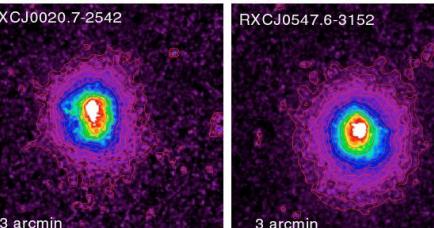
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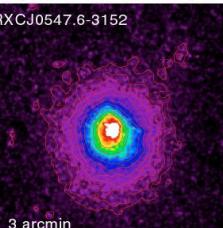
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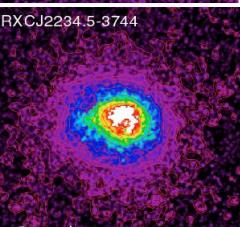
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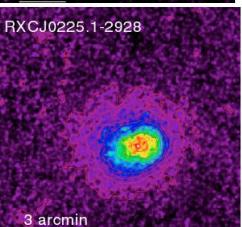
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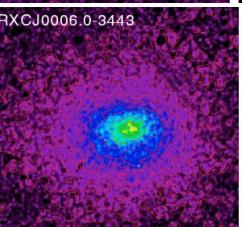
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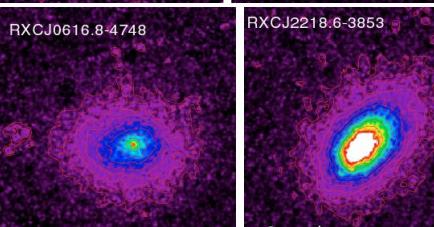
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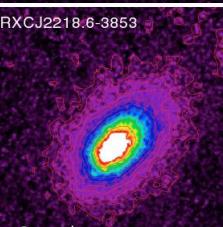
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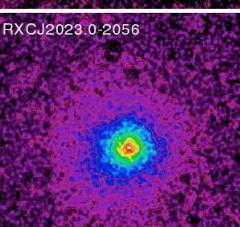
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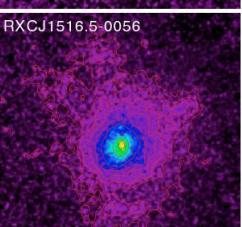
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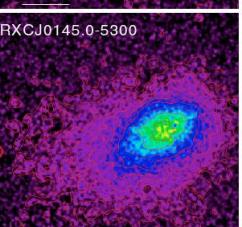
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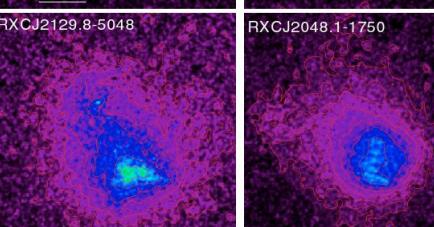
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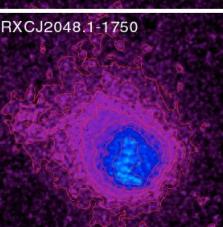
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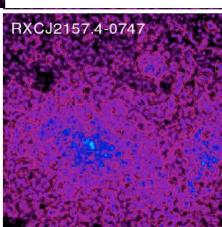
RXCJ2129.8-5048



RXCJ2048.1-1750



RXCJ2157.4-0747



Böhringer+ 2009

Diagnostic tools

$$w = \left[\frac{1}{N-1} \sum (\Delta_i - \langle \Delta \rangle)^2 \right]^{1/2} \times \frac{1}{r_{500}}$$

Centroid shift

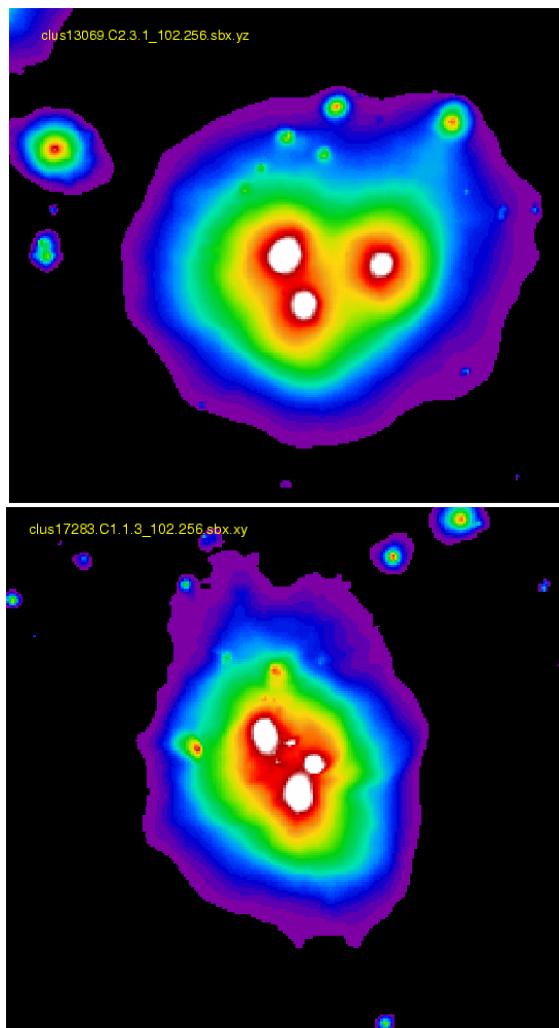
$$P_0 = [a_0 \ln(R_{\text{ap}})]^2$$

$$P_m = \frac{1}{2m^2 R_{\text{ap}}^{2m}} (a_m^2 + b_m^2)$$

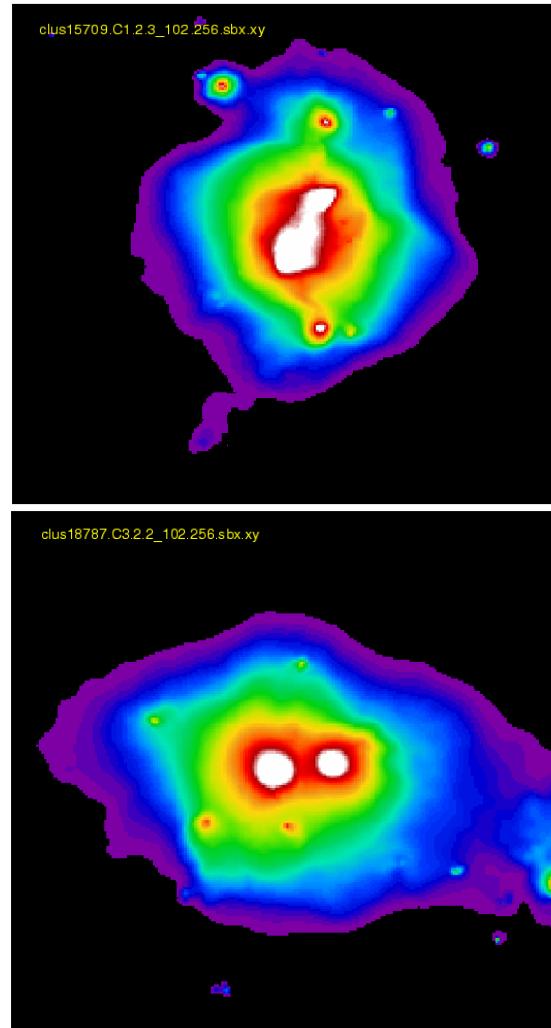
Power ratios
Buote & Tsai 95, 96

$$a_m(r) = \int_{r \leq R_{\text{ap}}} dx S(x) r^m \cos(m\phi) \quad b_m(r) = \int_{r \leq R_{\text{ap}}} dx S(x) r^m \sin(m\phi).$$

Large P_3



Simulation by Borgani+ 2004

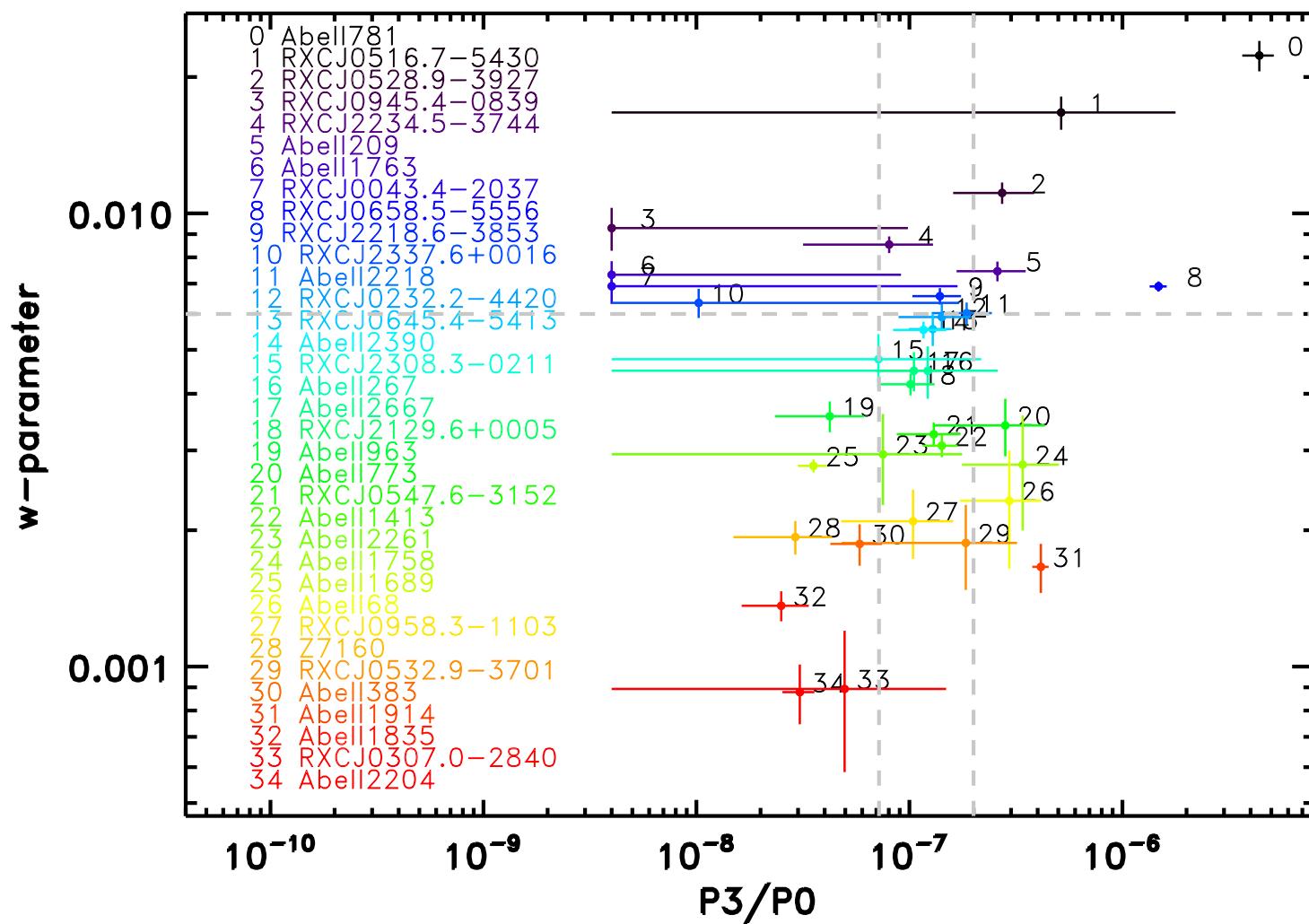


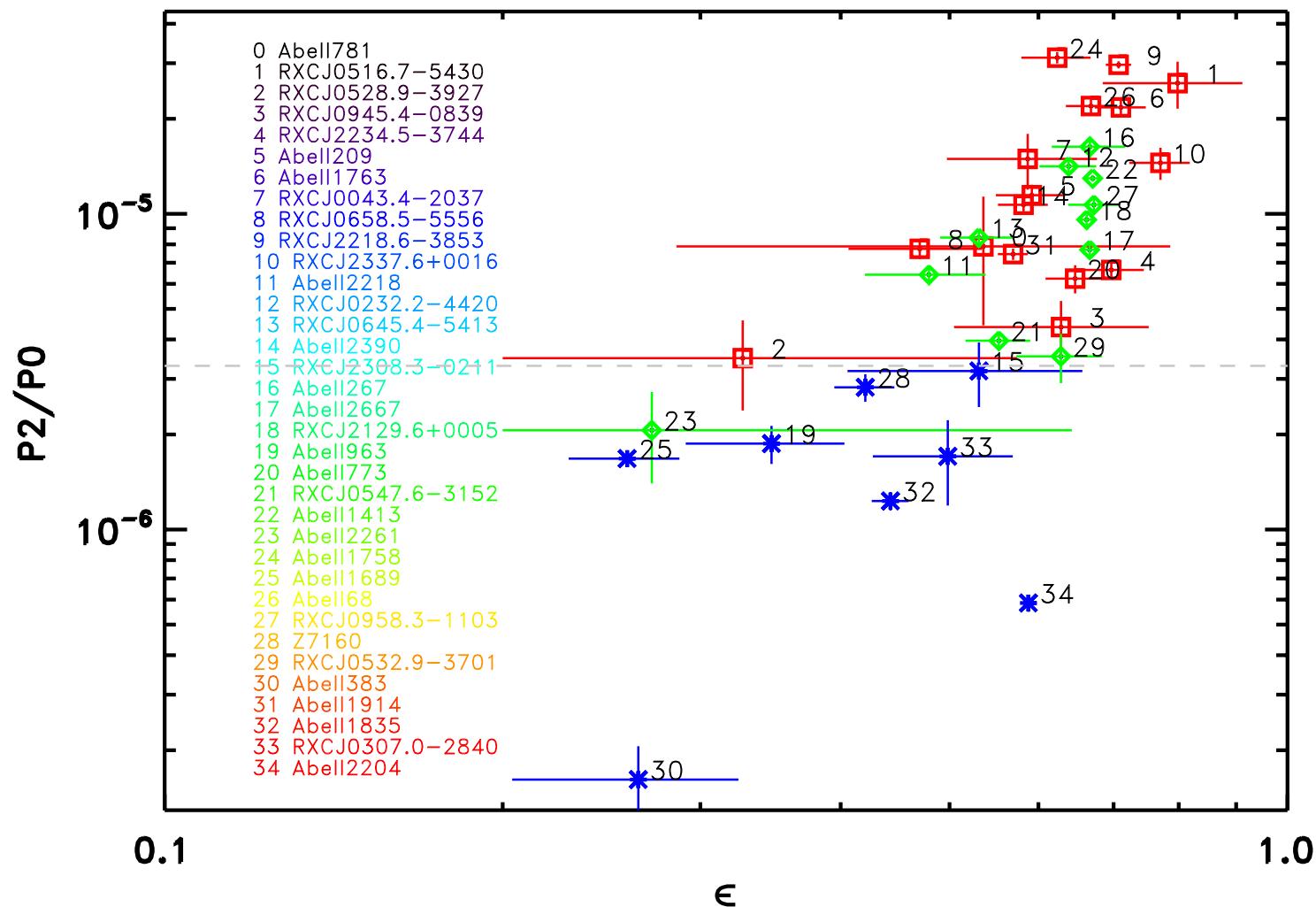
Böhringer+ 2010

To study morphology

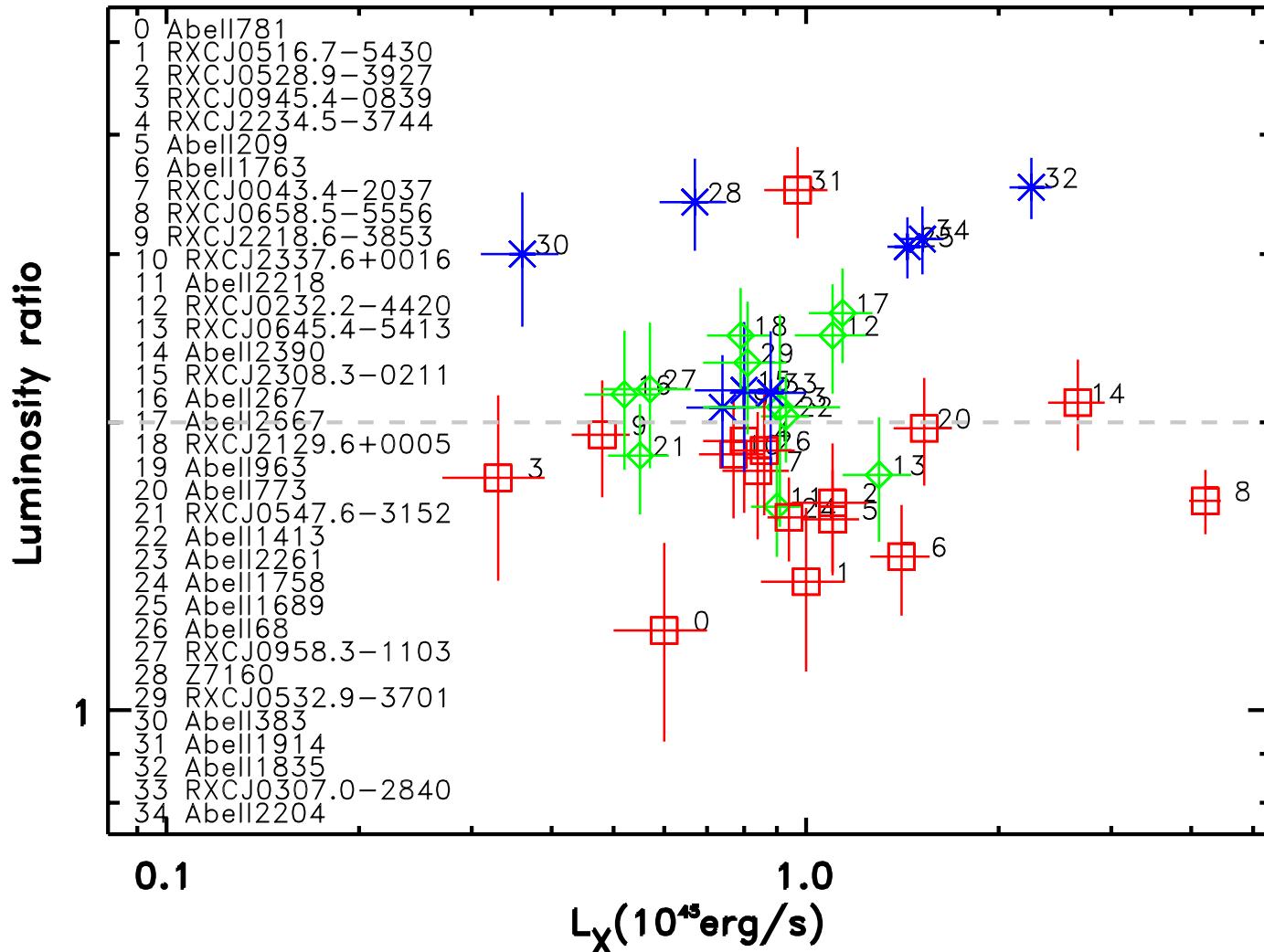
- Diagnostics
 - Centroid shift
 - Power ratios – higher moments, $P_m/P_0 = P_m$
- Application
 - REFLEX sub-sample
 - $L_x/E(z)^{2.7} > 4.1 \times 10^{44}$ erg/s, $z=0.15-0.3$, $n_H < 7 \times 10^{20}$ cm $^{-2}$
 - 35 clusters in total with deep XMM observations

$W - P_3$

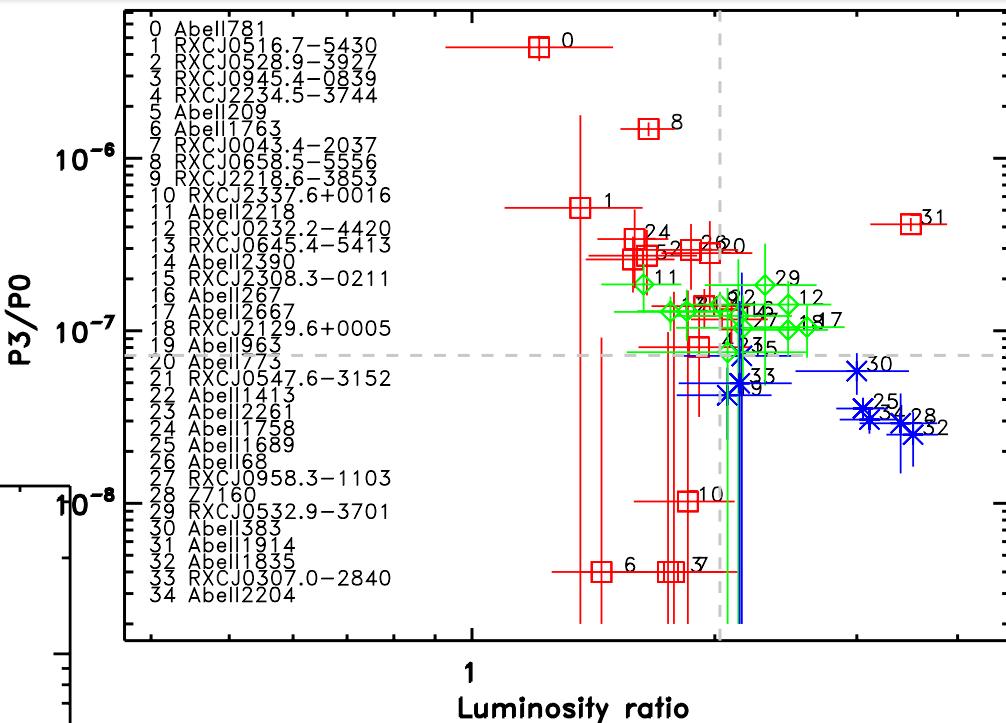
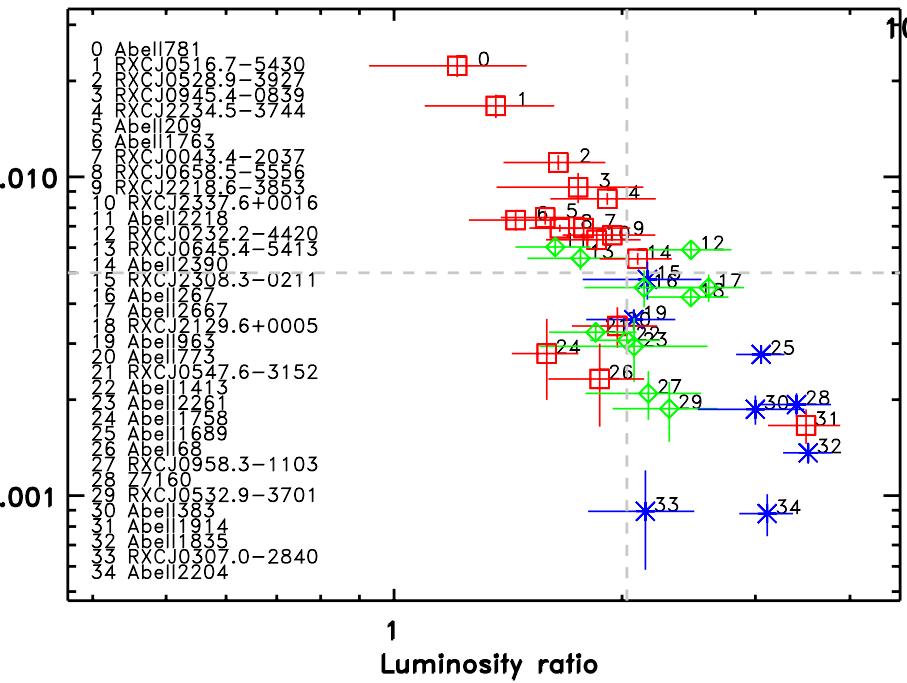




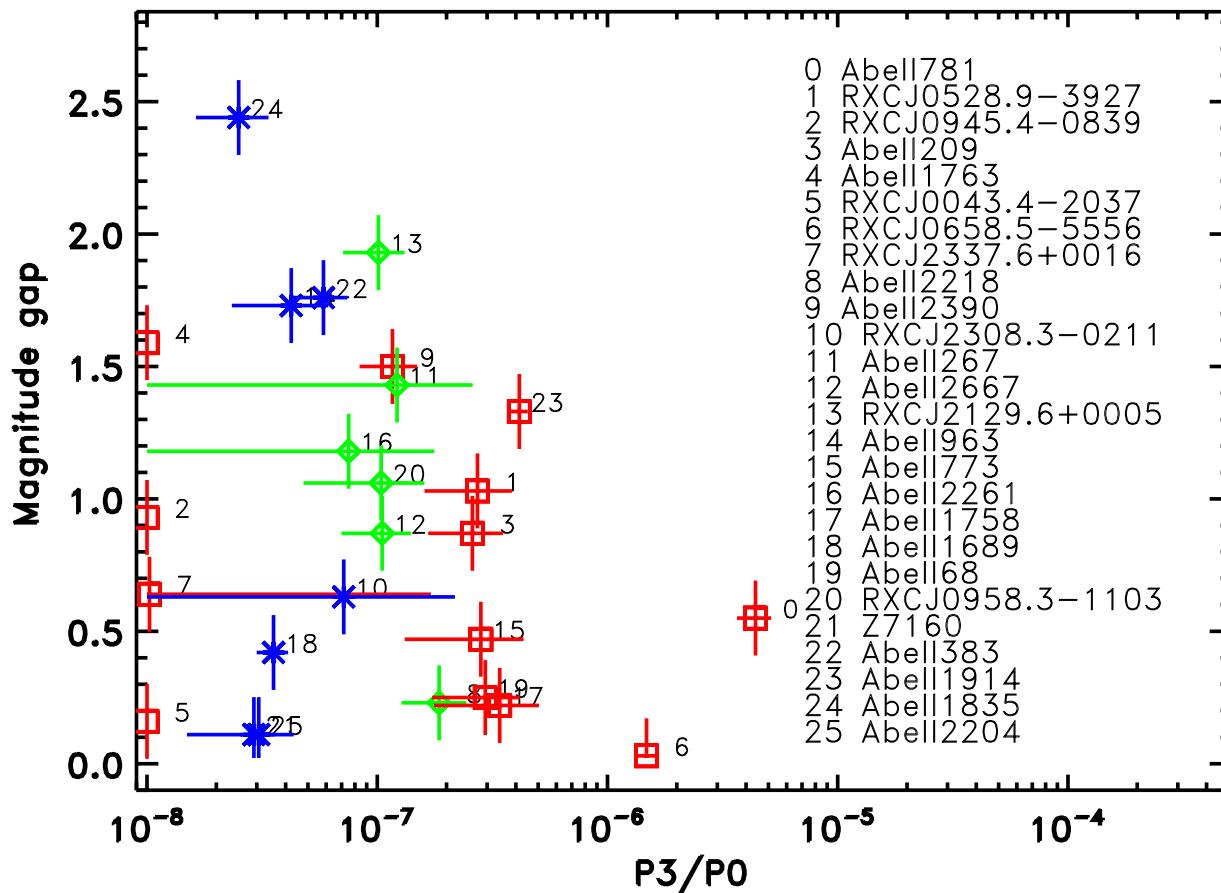
Luminosity ratio vs. luminosity

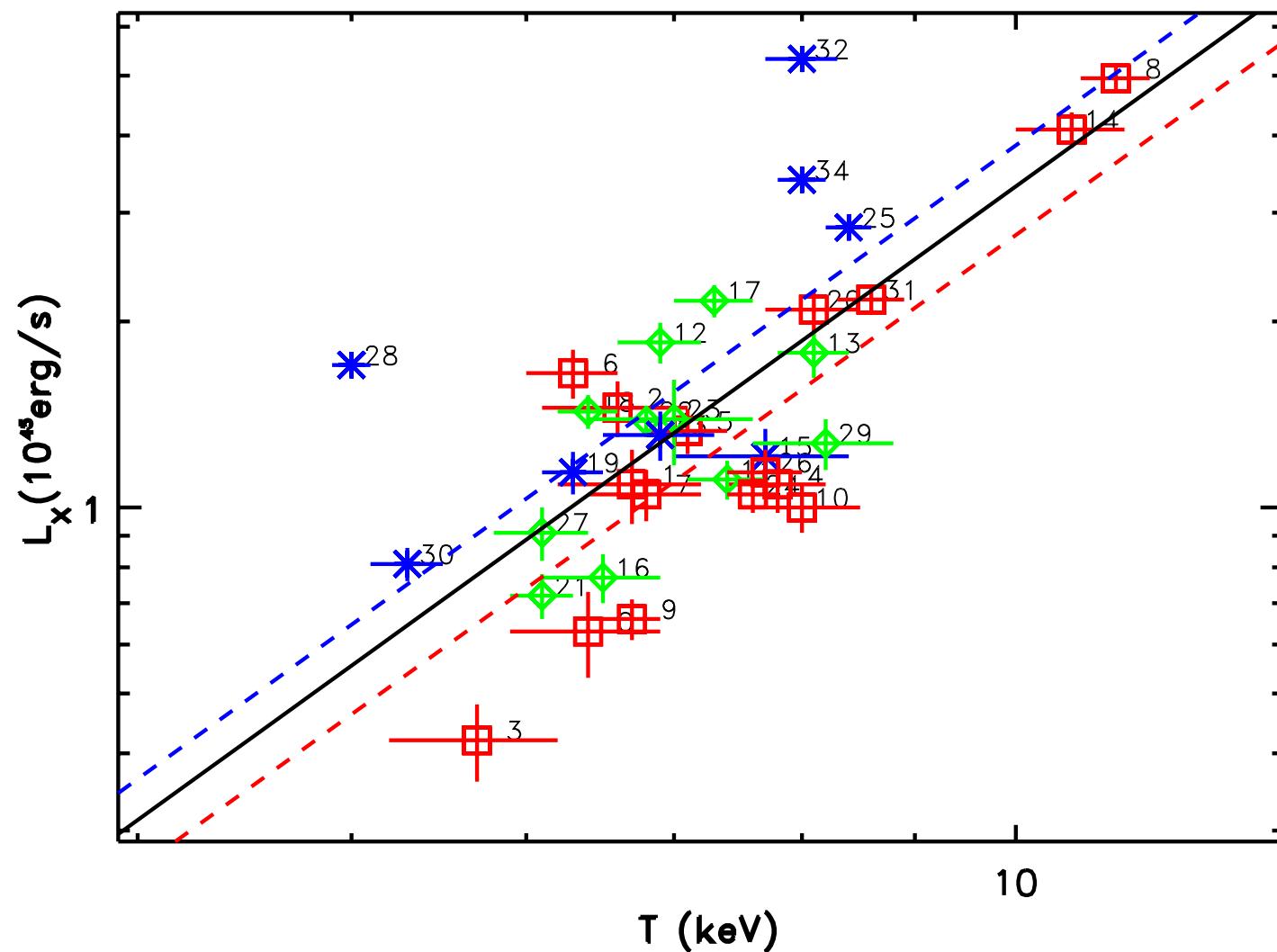


w/P₃ – luminosity ratio

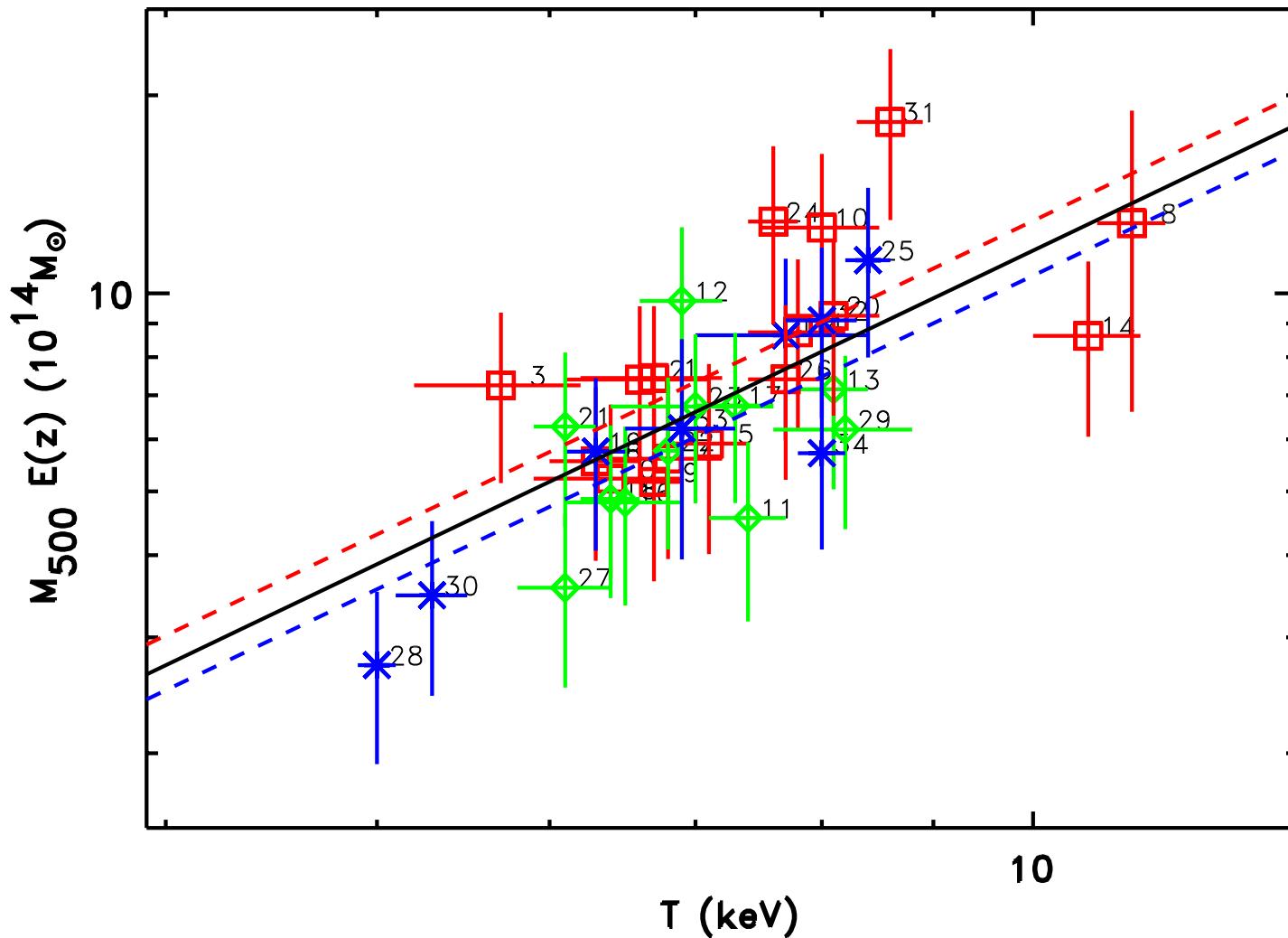


Magnitude gap – P_3

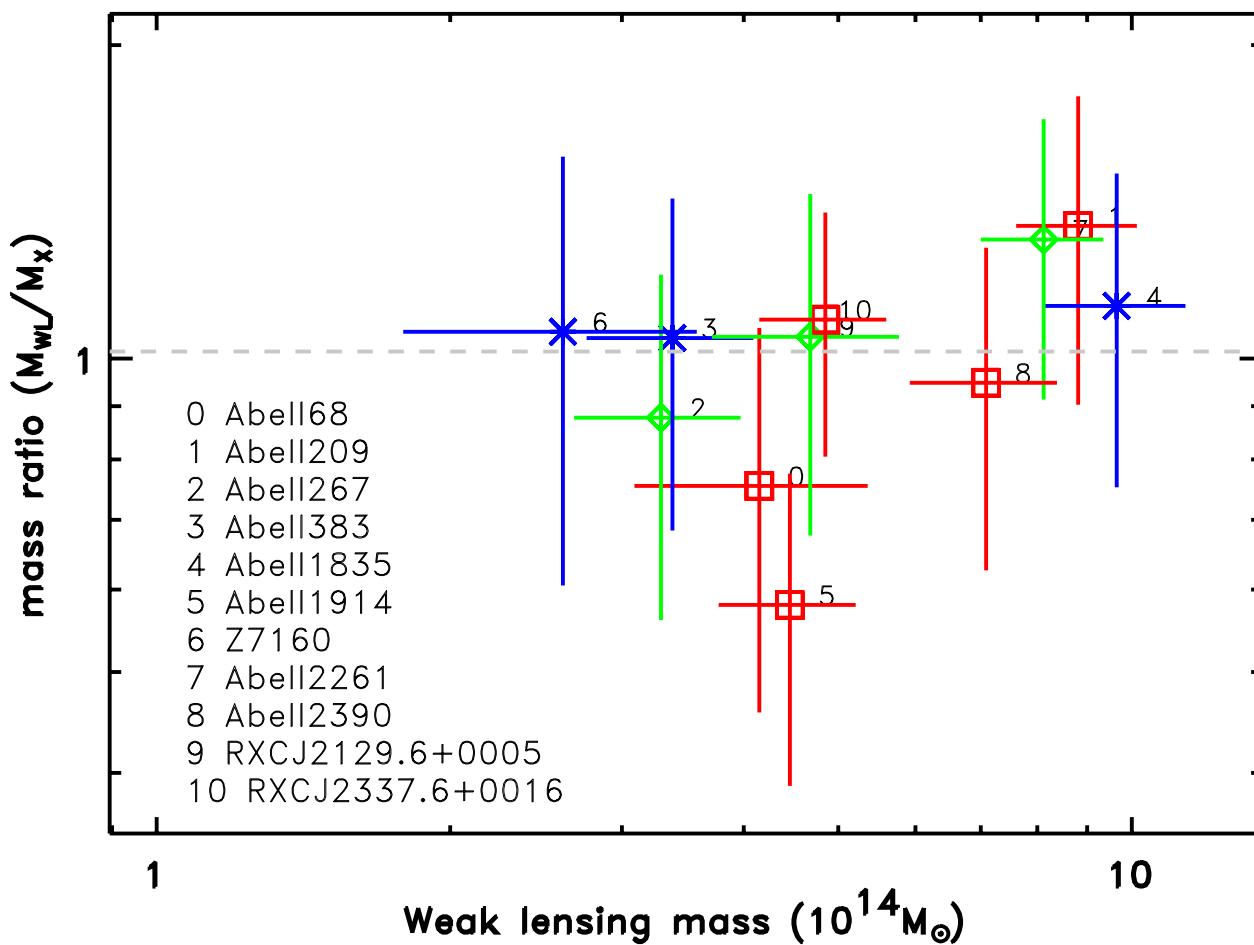




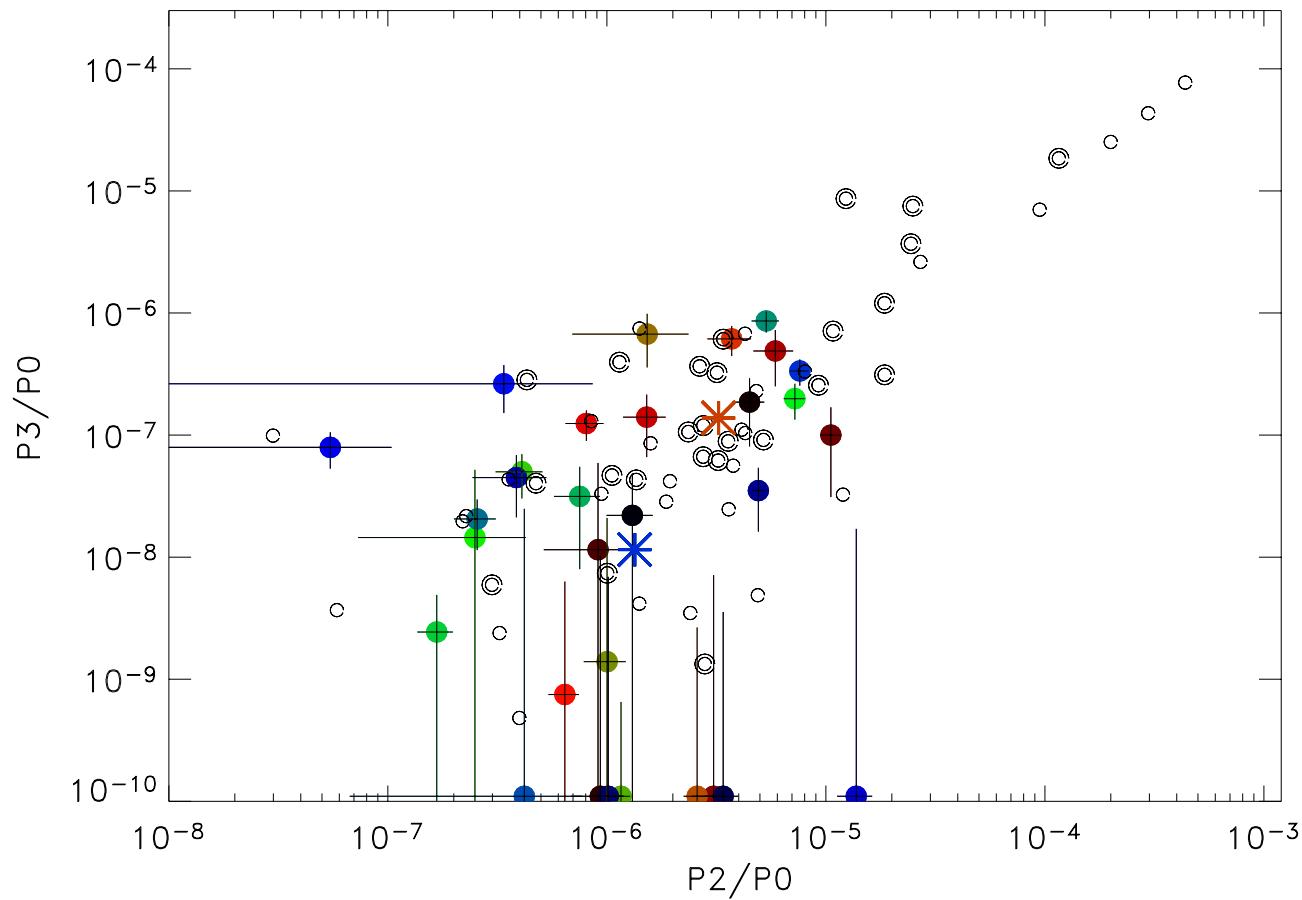
$M_{500} - T$



Mass ratio – weak lensing mass

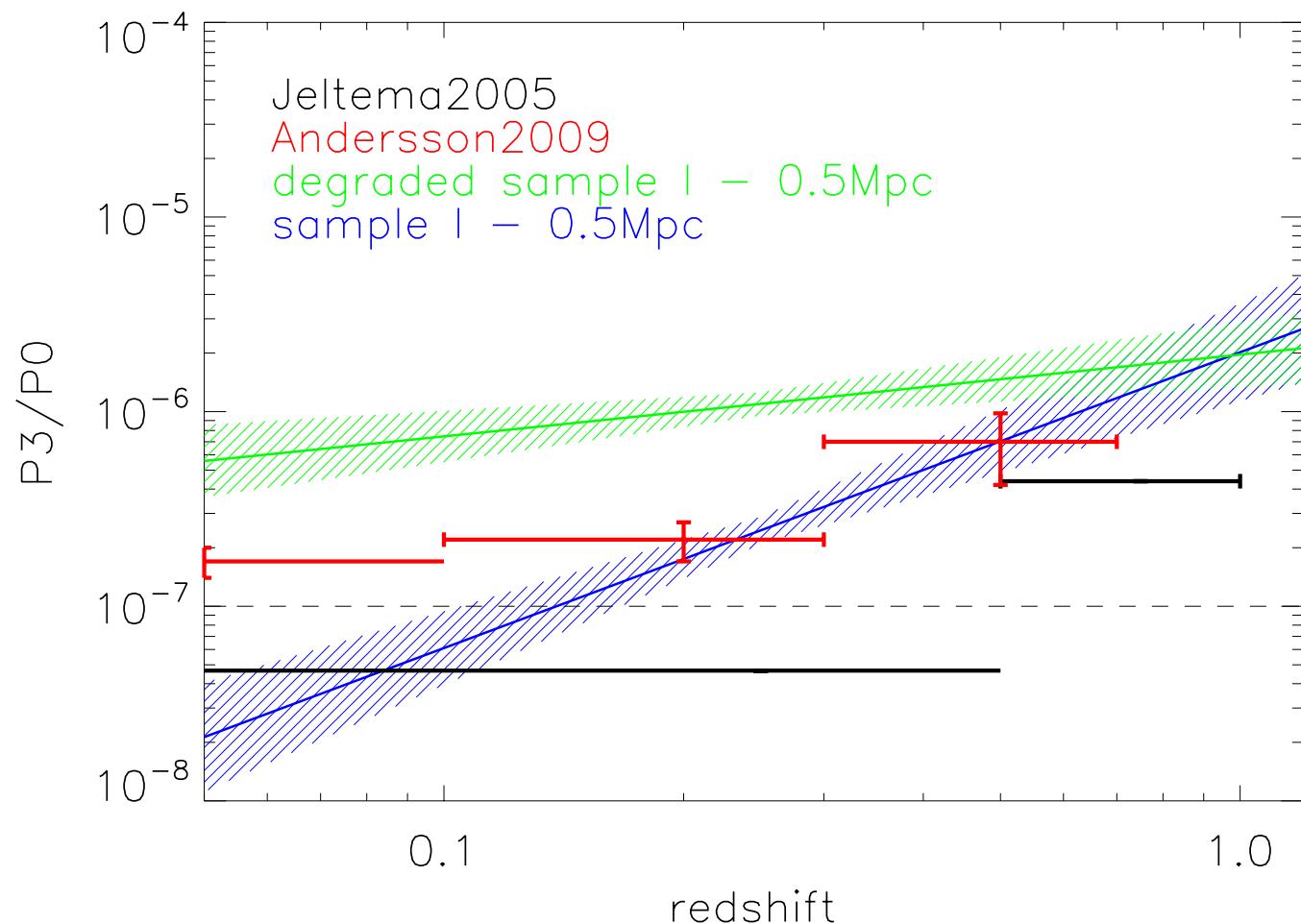


Observations vs. simulations



Böhringer+ 2010

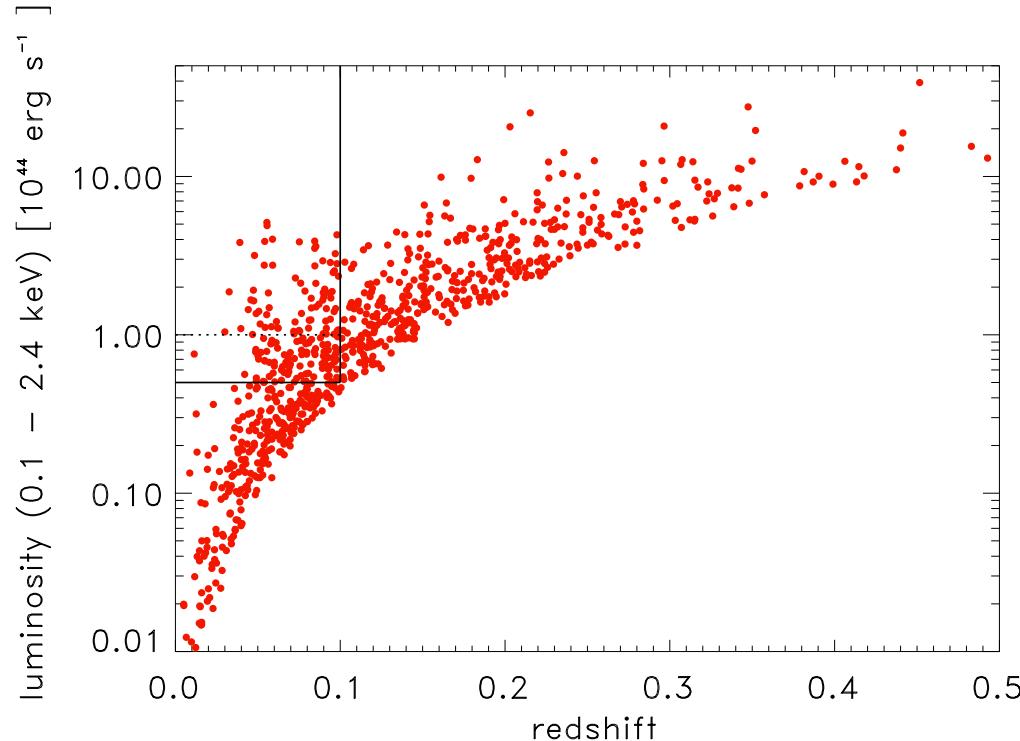
Evolution of substructure ?



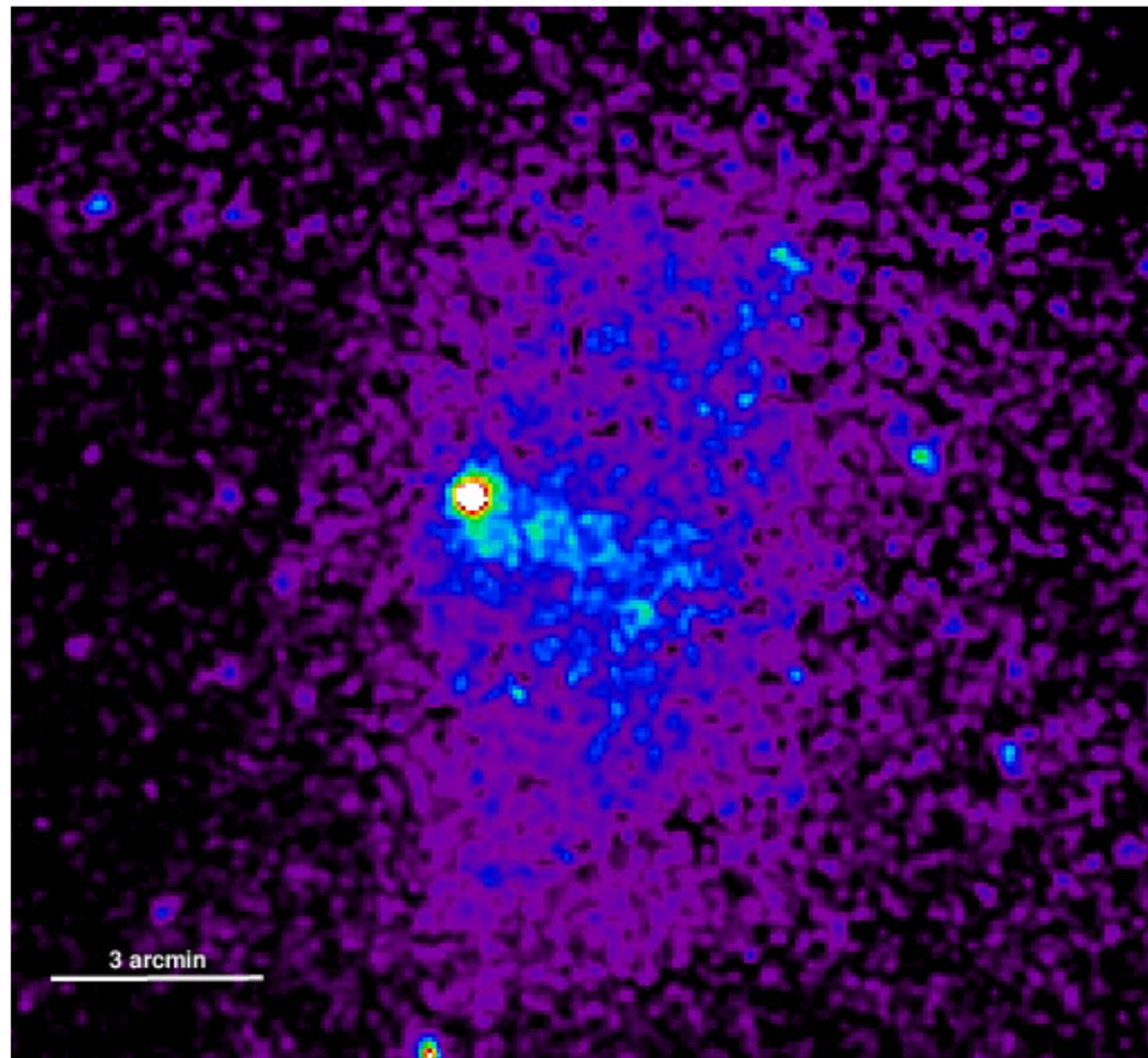
Weimann, Böhringer, Chon (2013)

REFLEX II-XMM-Newton

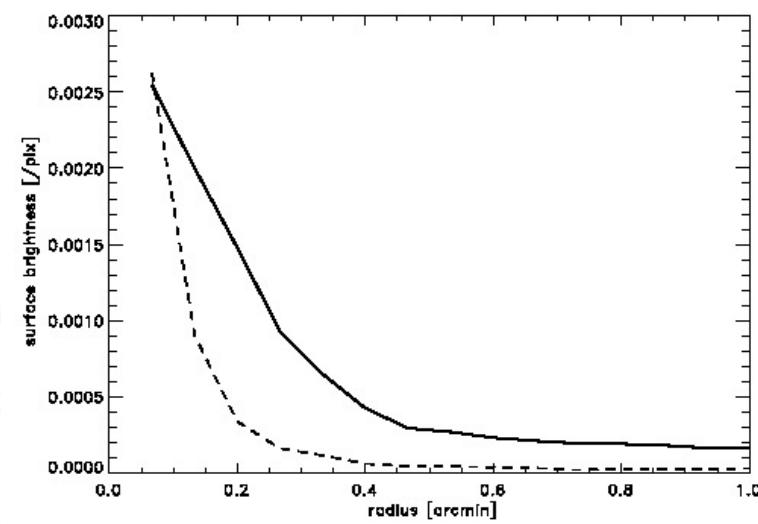
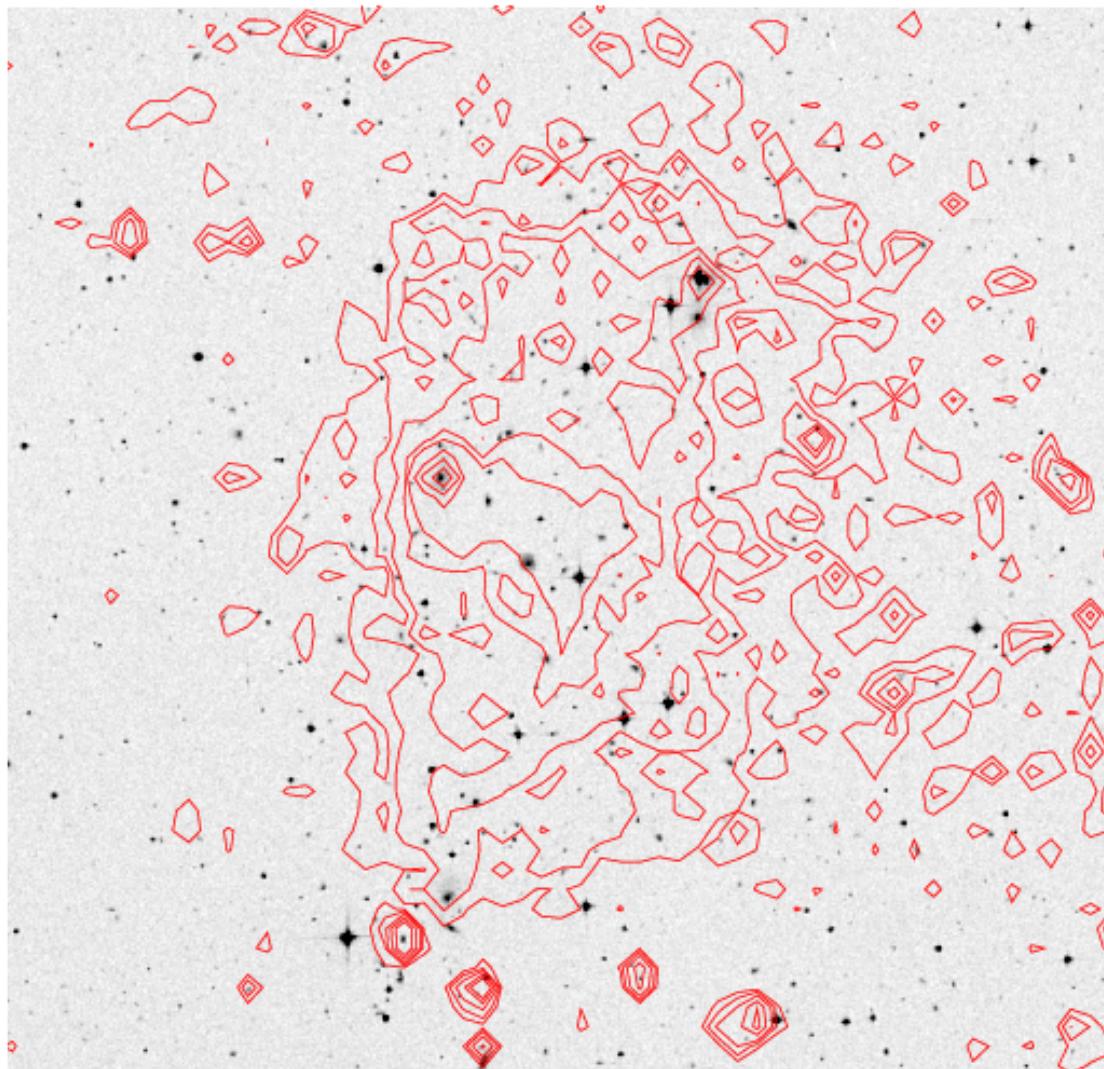
- Large *XMM-Newton* project (P.I. H. Böhringer)
- Volume-limited Sample of REFLEX II
 - constraints : $z < 0.1$ and $L_x > 5e43 \text{ erg/s}$



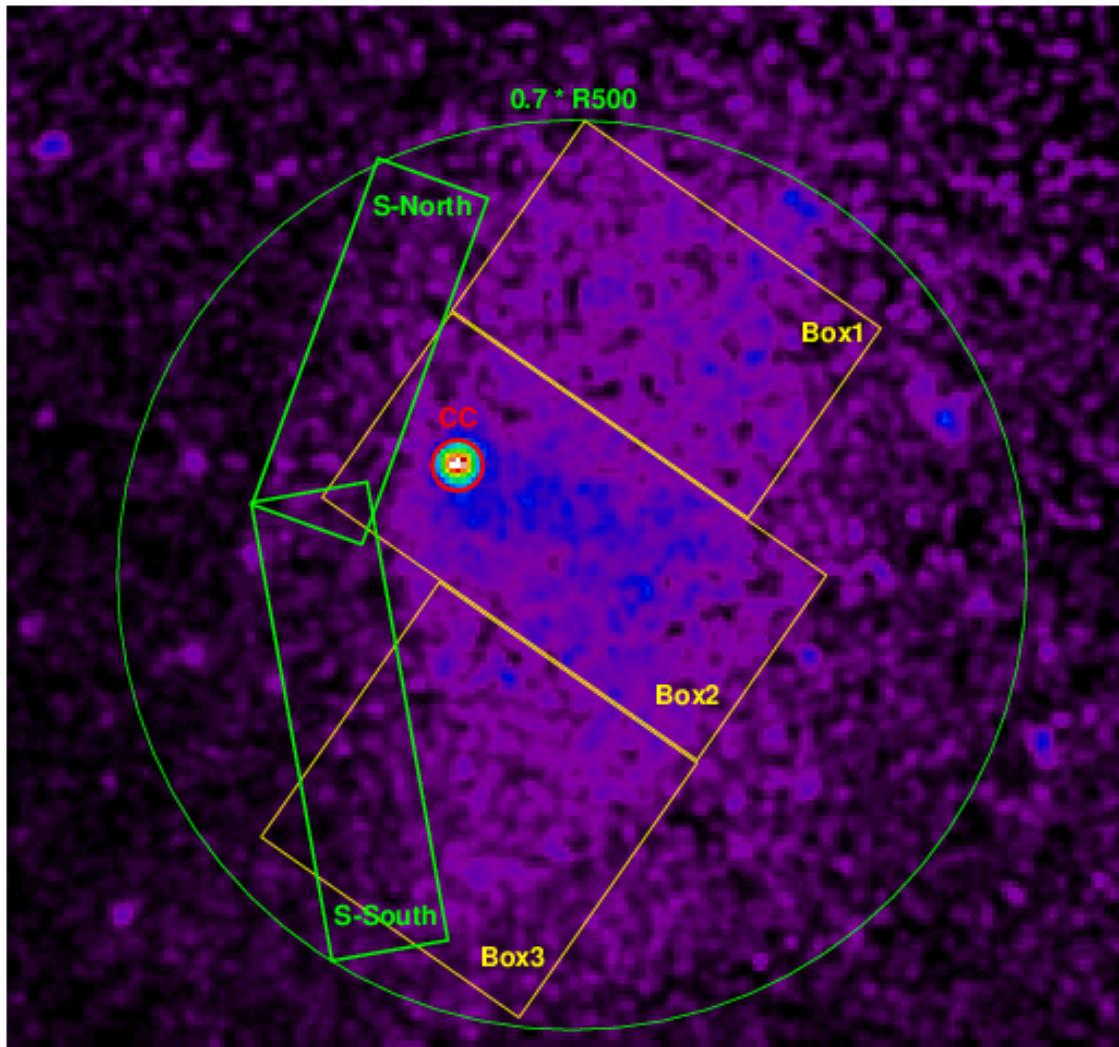
RXCJ2359-6042 – “cool bullet cluster”



Bullet component



Tracing history



region	T (keV)	Z_{\odot}
CC	1.55 ± 0.10	0.75 ± 0.19
cluster -cc	3.12 ± 0.13	$0.17 \pm 4e-2$
b1	3.54 ± 0.26	$0.18 \pm 9e-2$
b2-cc	3.08 ± 0.12	$0.27 \pm 8e-2$
b3	3.54 ± 0.22	$0.18 \pm 7e-2$
shock (n+s)	4.5 ± 0.59	0.35 ± 0.22

Summary

- X-ray substructure analysis
 - morphological classification reflecting dynamical states
 - degree of substructure influences scaling relations
 - for physical interpretation, can separate relaxed vs. un-relaxed
 - observation vs. simulations: substructure frequency
 - evolution
- Still need ...
 - better data @ high-z
 - larger statistical sample → REFLEX-XMM