

Fossil Groups & Clusters: past present, future

Elena D'Onghia

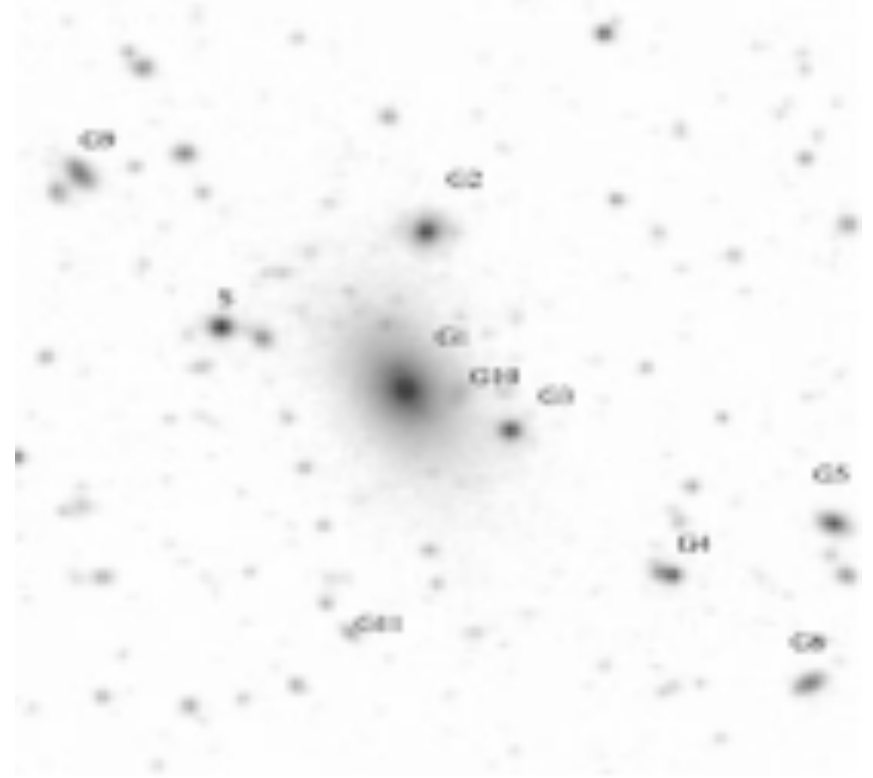
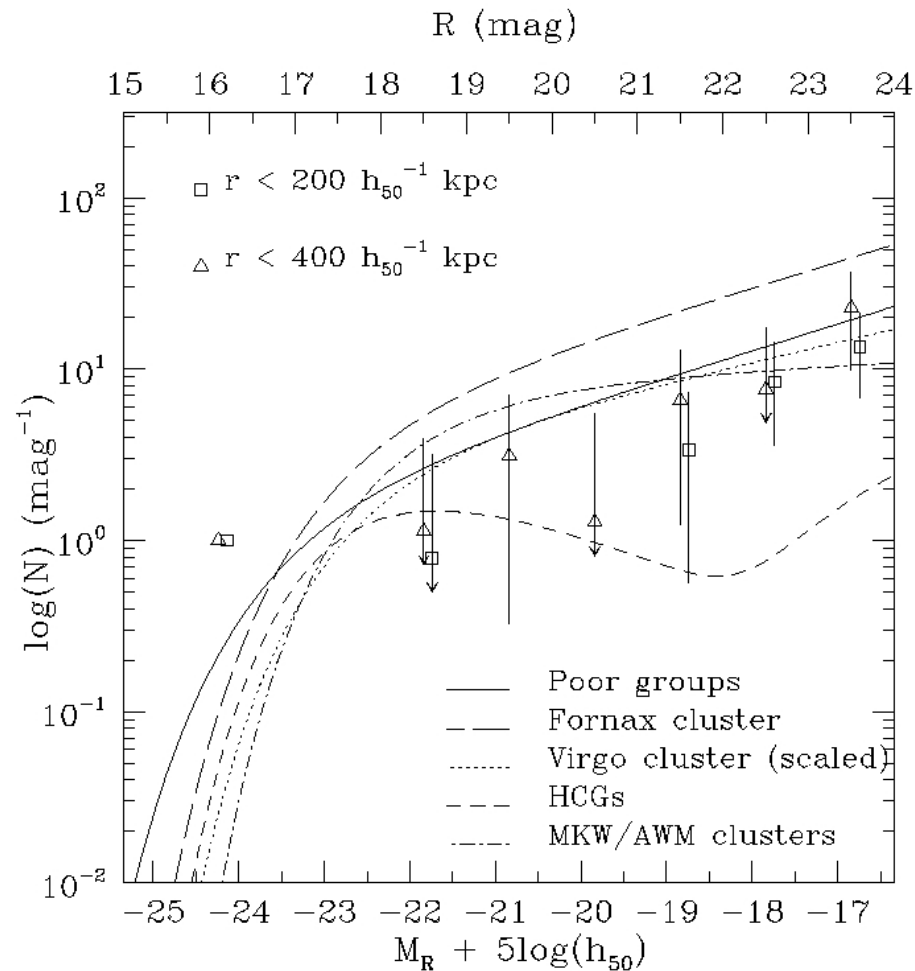
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University of Wisconsin, Madison

In collaboration with FOGOs (PI: A. Aguerri), and A. Kundert (UWisc)

✧ Early data revealed that FGs are:

- Galaxy Groups with extended X-ray halo $L_x > 10^{42} \text{ erg/s}$
(Ponman 1994; Vikhlinin et al. 1998; Mulchaey & Zabludoff 1998)
- Systems dominated from a giant elliptical
- Systems missing L^* galaxies \rightarrow magnitude gap in LF

Archetype: RXJ1340+4018



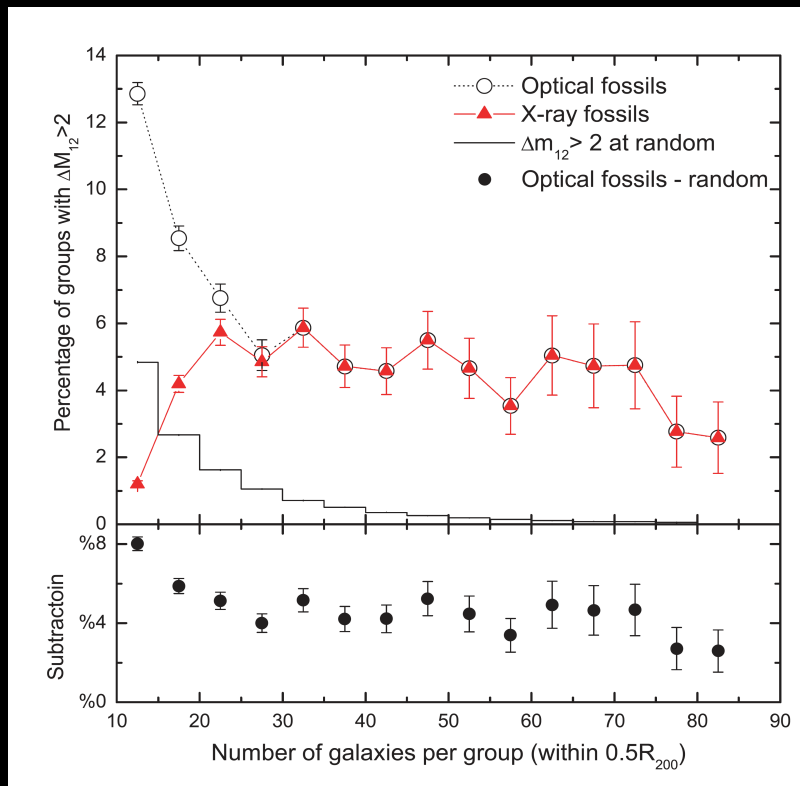
BG $M_R = -22.7$
 X-ray halo 500 kpc
 $M = 6 \times 10^{13} M_{\odot}$
 25 % of Virgo mass

Jones et al. 2000, MNRAS, 312, 139

RXJ1340+4018 is a galaxy cluster (Mendes-de Oliveira 2006)

✧ Fossil Systems are not rare:

- 8–20% of all clusters and groups with $L_x > 10^{42}$ erg/s
(Vikhlinin et al. 1999, Jones et al. 2003)
- Estimates based on PS gives 30–40% on group scales
(Milosavljević et al. 2006)
- Estimates based on 2DF: 6.5% are fossils (van den Bosch 2007)

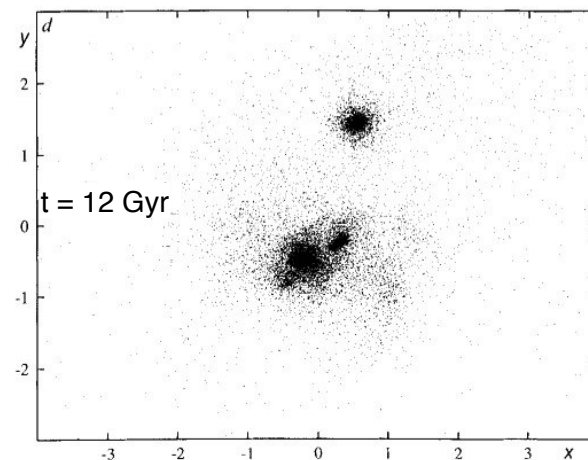
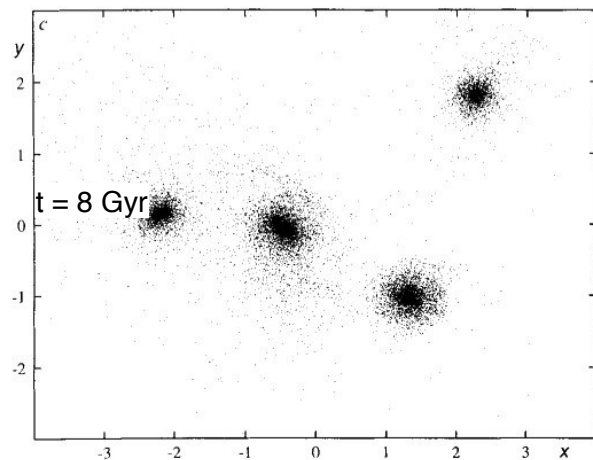
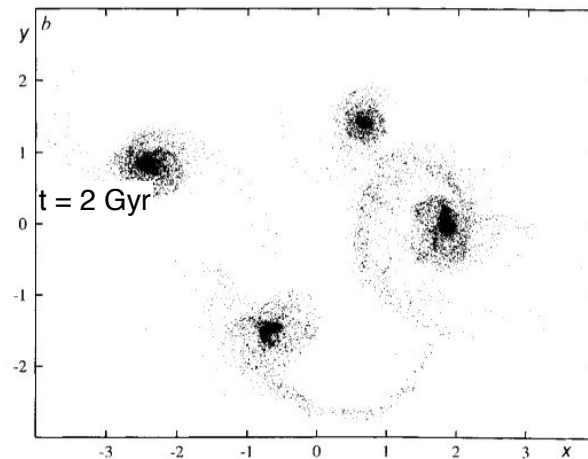
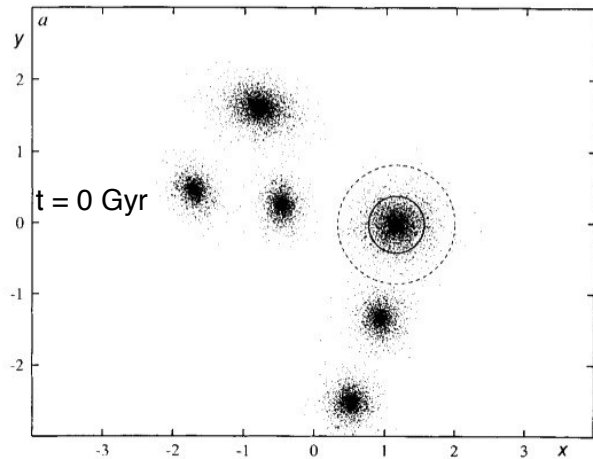


Dariush (2007)

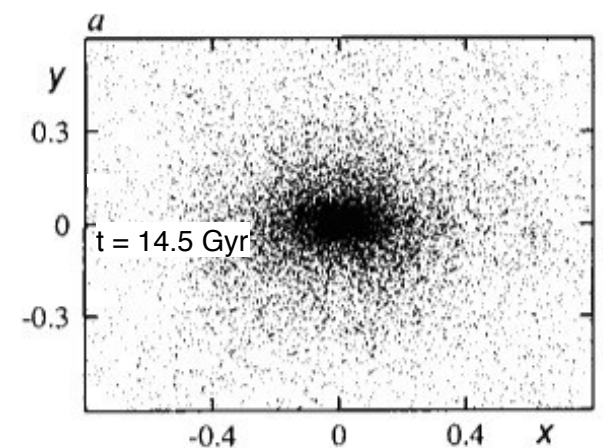
Open questions

- What is the origin of their mag gap?
- How different are fossils from non fossils besides the mag gap?
- Mag gap is arbitrary, is there a better definition?

Galaxy Merging Scenario

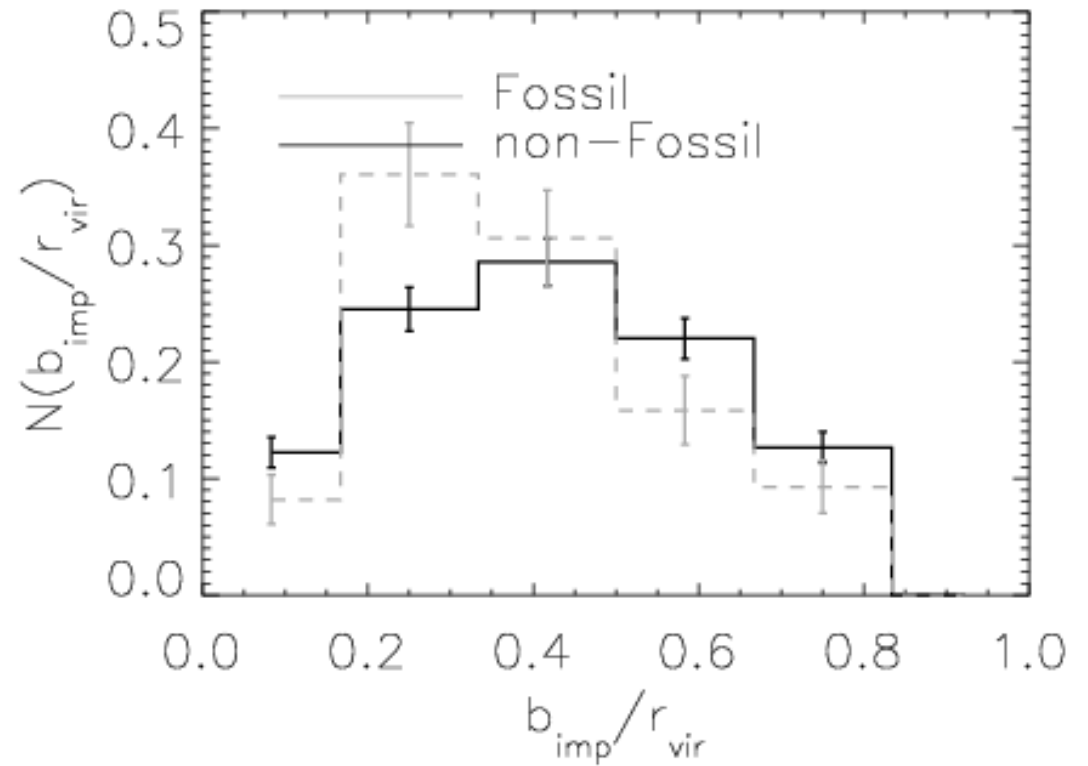
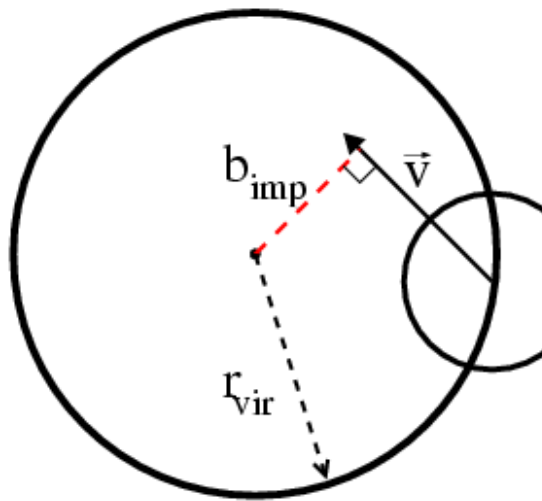


$$t_{\text{dyn}} \propto M_{\text{group}} (M_{\text{galaxy}})^{-1}$$



- Overmerged systems
- Systems with early formation time

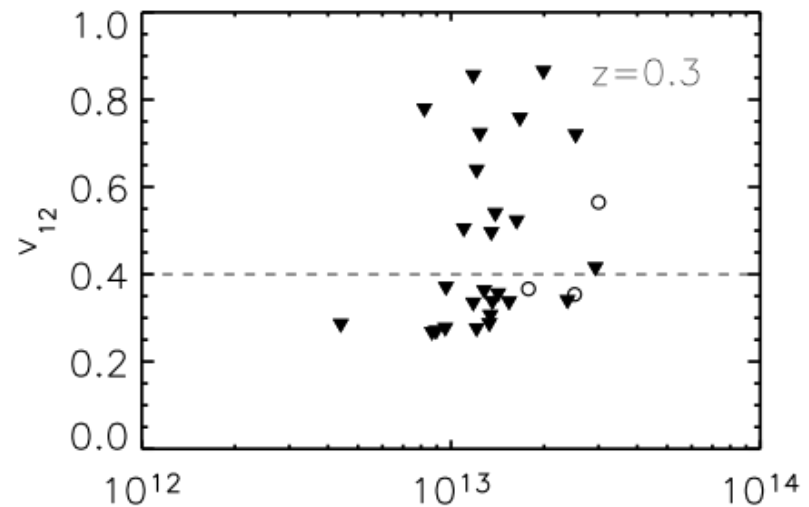
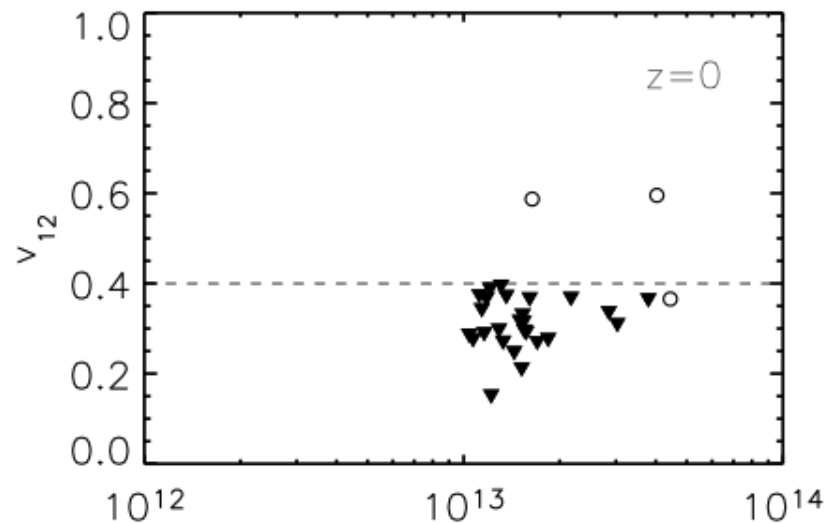
Barnes (1989)



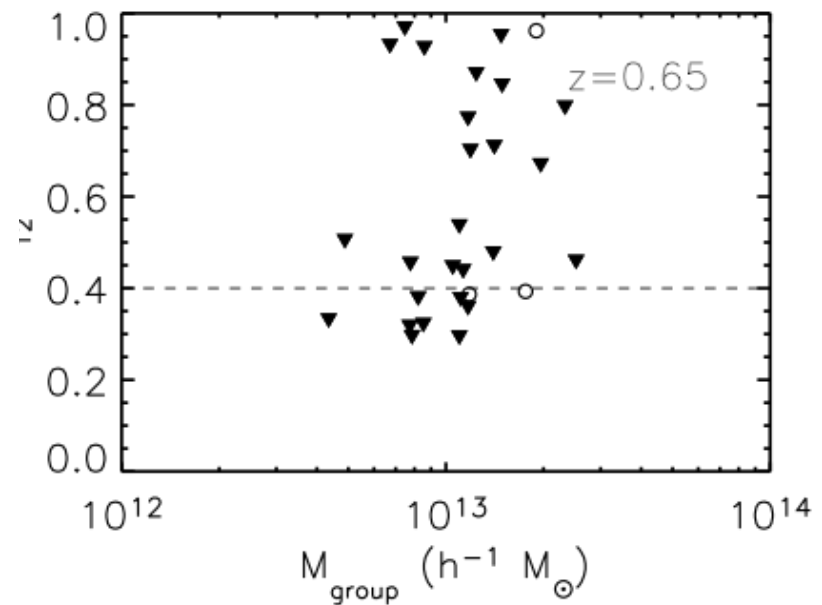
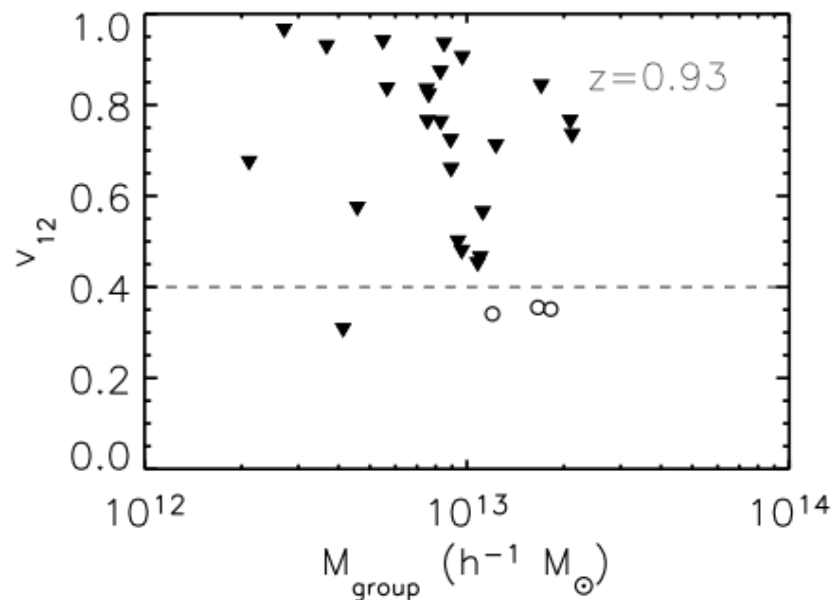
In fossil systems satellites have lower impact parameters

von Bendam-Beckmann, D'Onghia et al. 2008

The fossil phase of Fossil Systems



von Benda-Beckman, ED et al. 2008

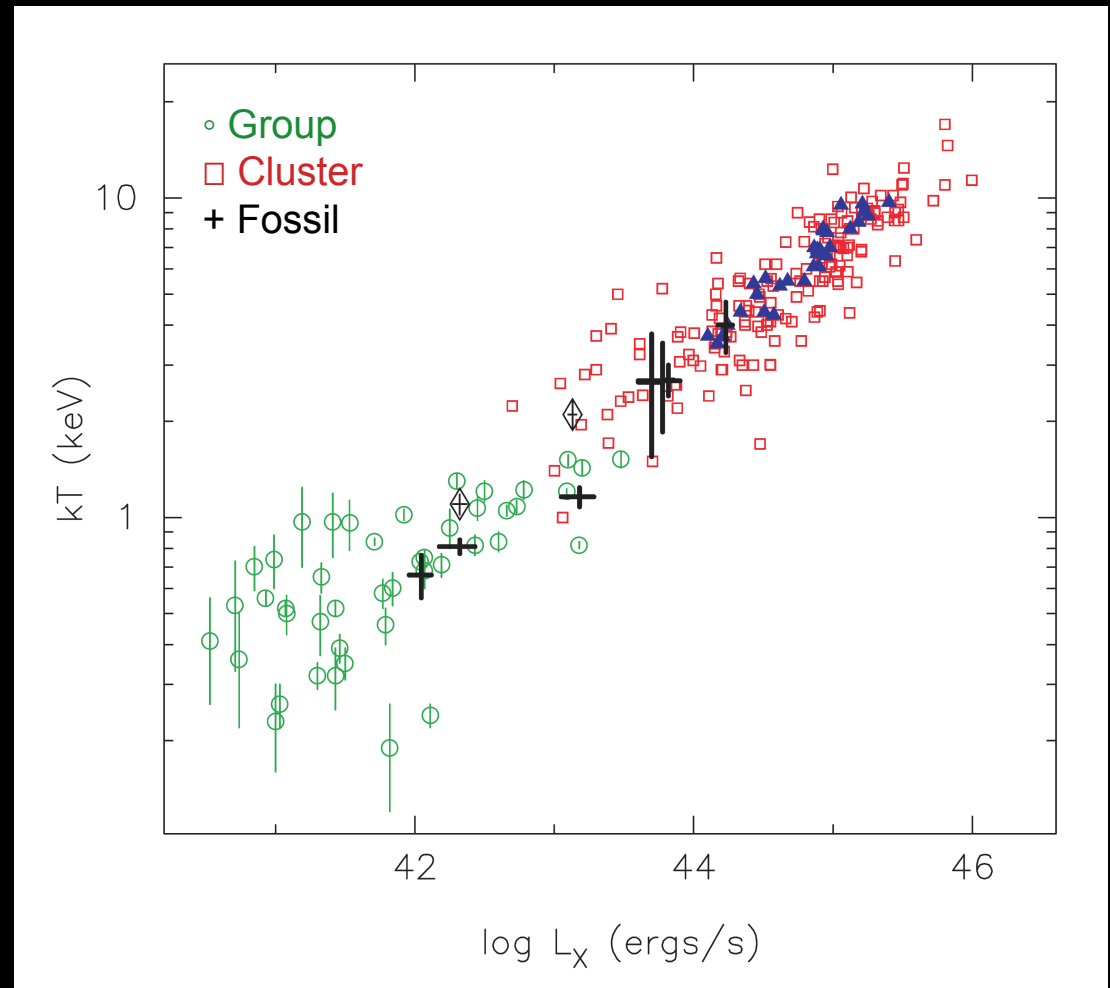


Von Benda-Bekkam, ED et al. 2008

Are Fossil systems atypical?

- FSs follow same X-ray scaling relations as groups and clusters

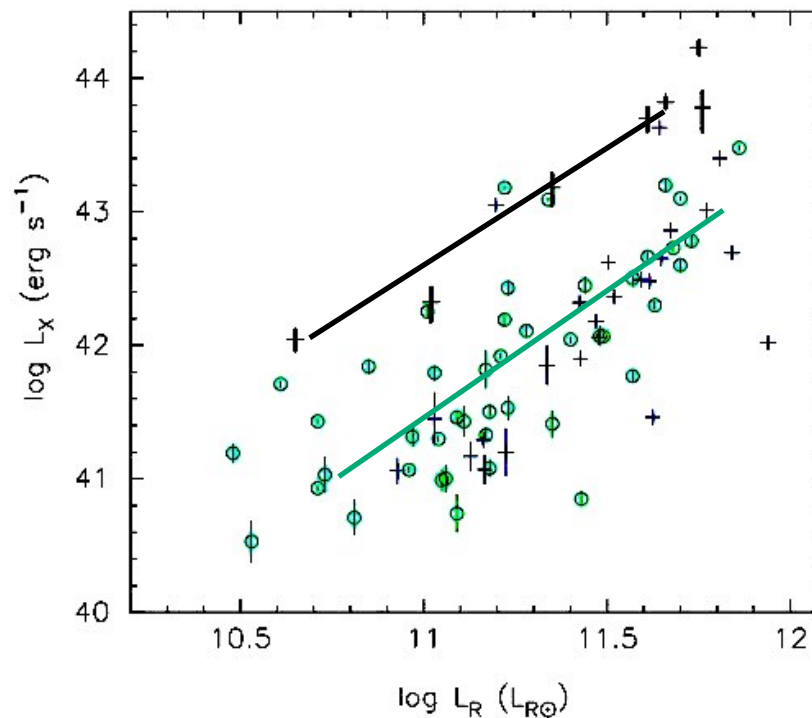
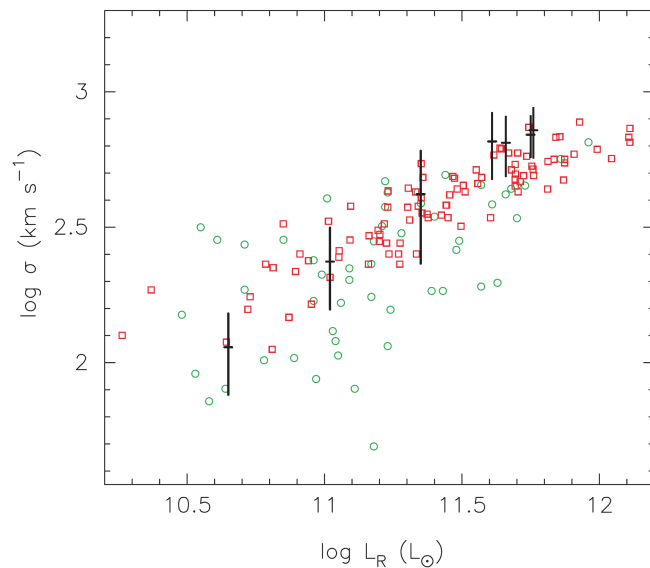
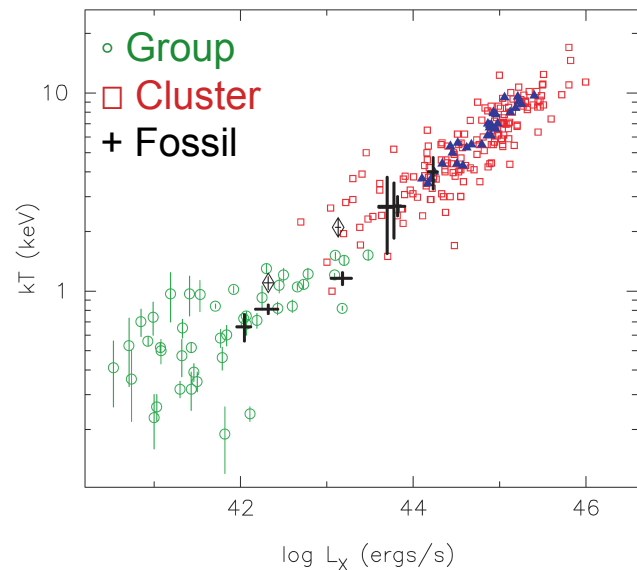
Early observations
of Scaling X-ray
Relations



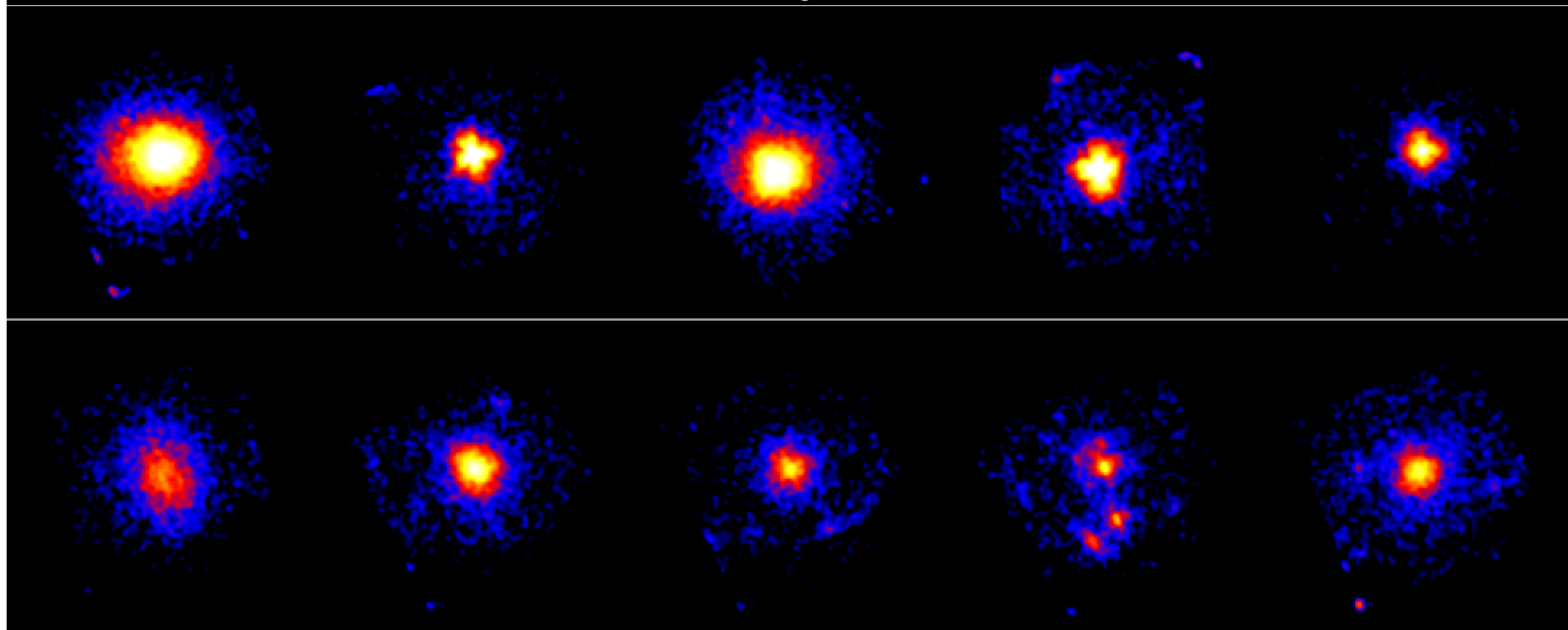
Early Work on Global Scaling Relations

Results: fossils display boosted X-ray properties compared to non-fossils systems.

Khosroshahi+2007



Fossil clusters observed with the Suzaku X-ray Telescope



Sample Selection

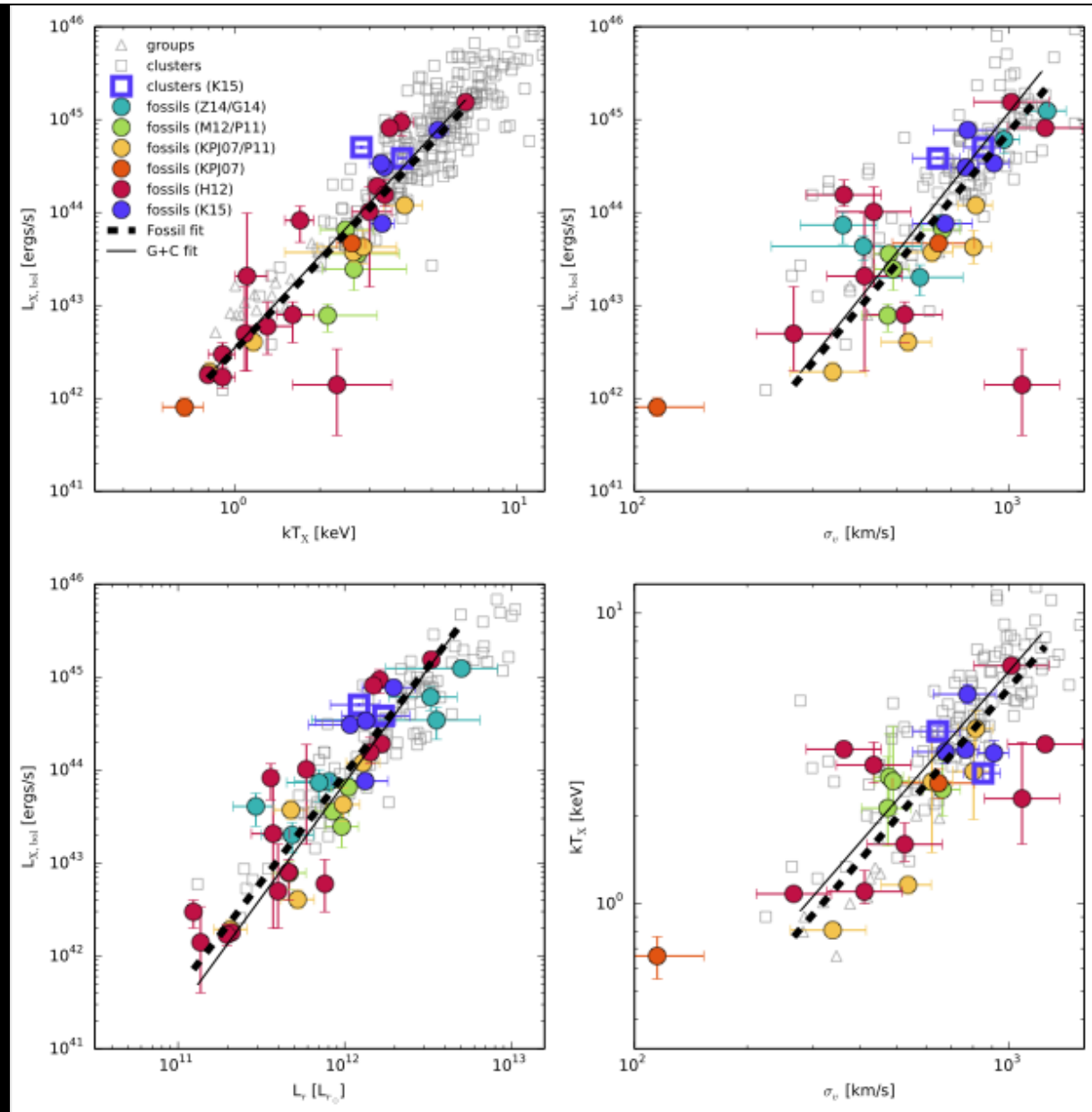
- Santos+07 catalogue
- optical: SDSS
- X-ray: RASS
- revised fossil characterization from Zarattini+14

The first pointed X-ray observations of these galaxy systems!

Complementary L_r , σ_v measurements

Kundert et al. 2015

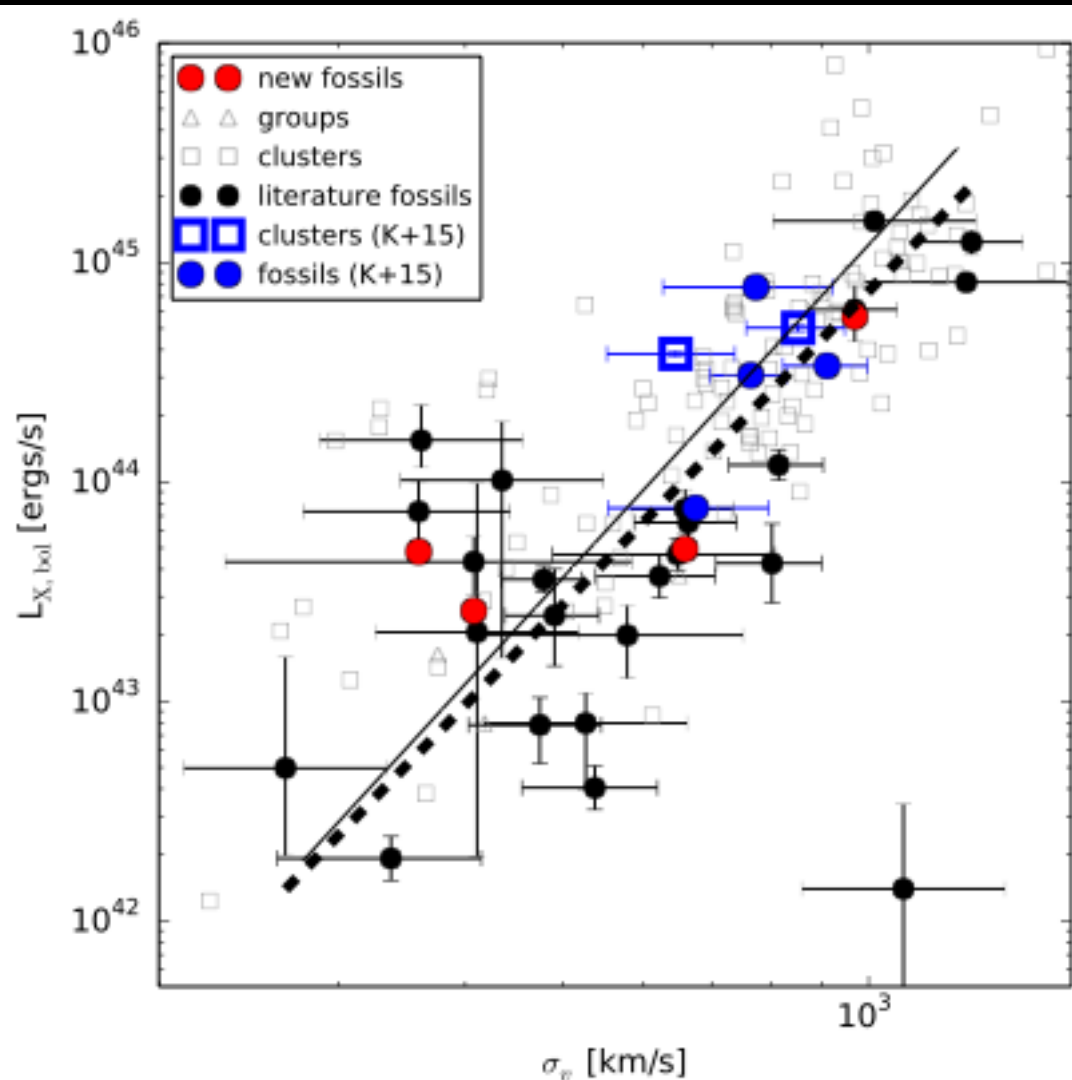
Scaling Relations: Fossils and non-fossils do follow similar scaling relations



Kundert+2015

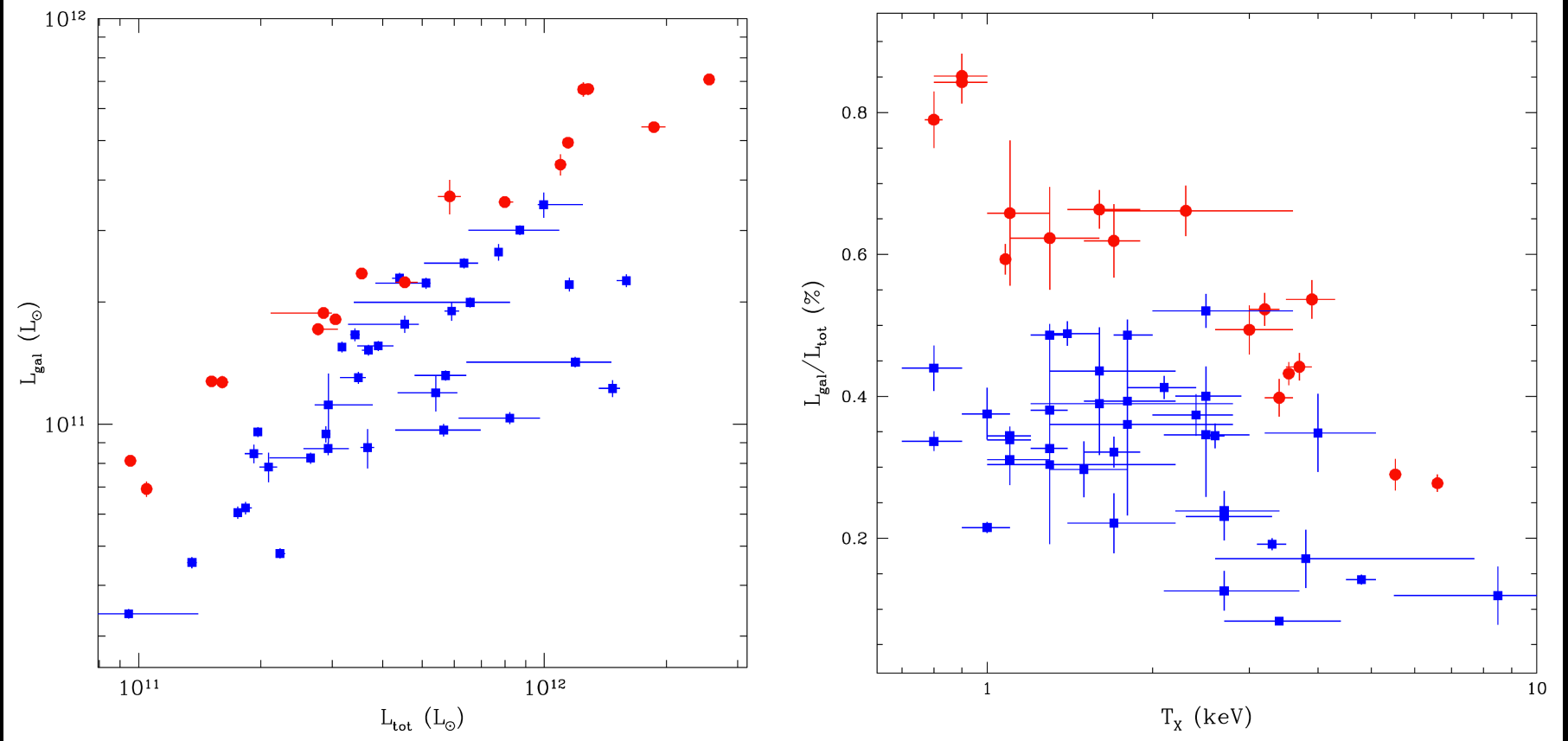
See poster in this conference by Kundert!

New upcoming Suzaku observations



Kundert et al. in prep

BCG of fossil systems contribute up to 80% of the total luminosity

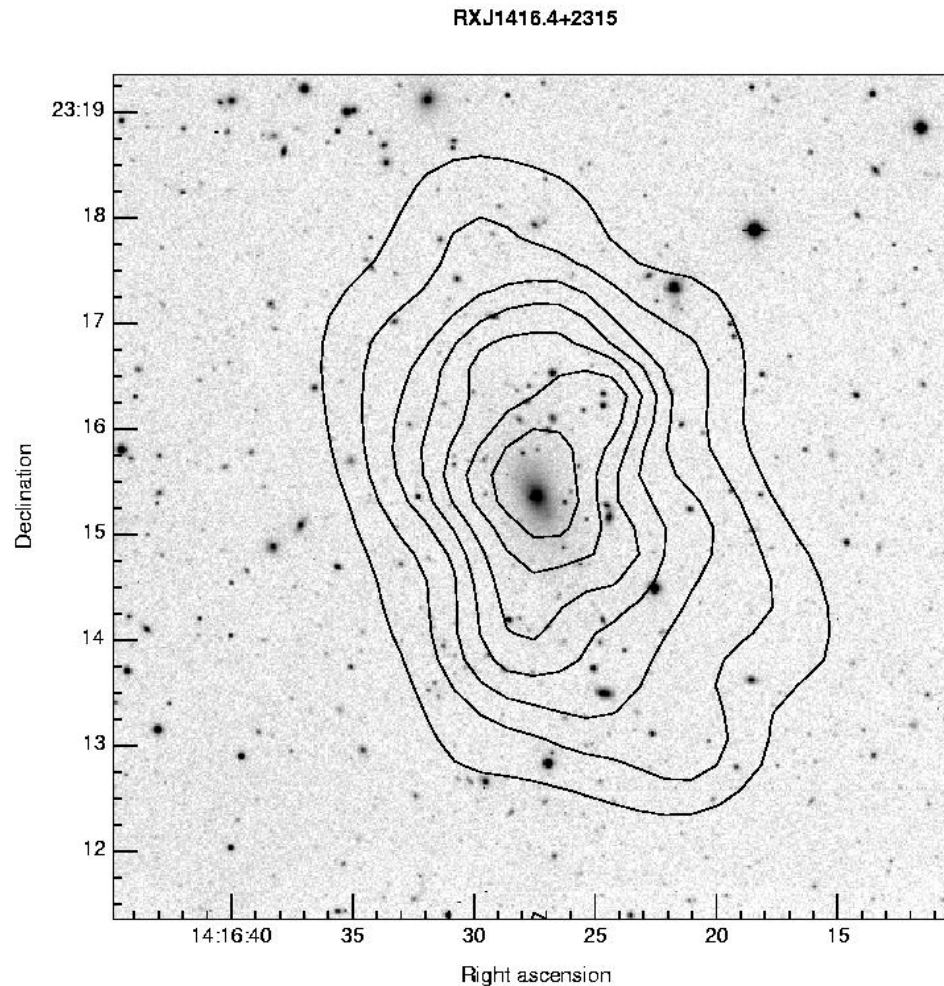


Harrison+12

✧ However there are several similarities with normal ellipticals:

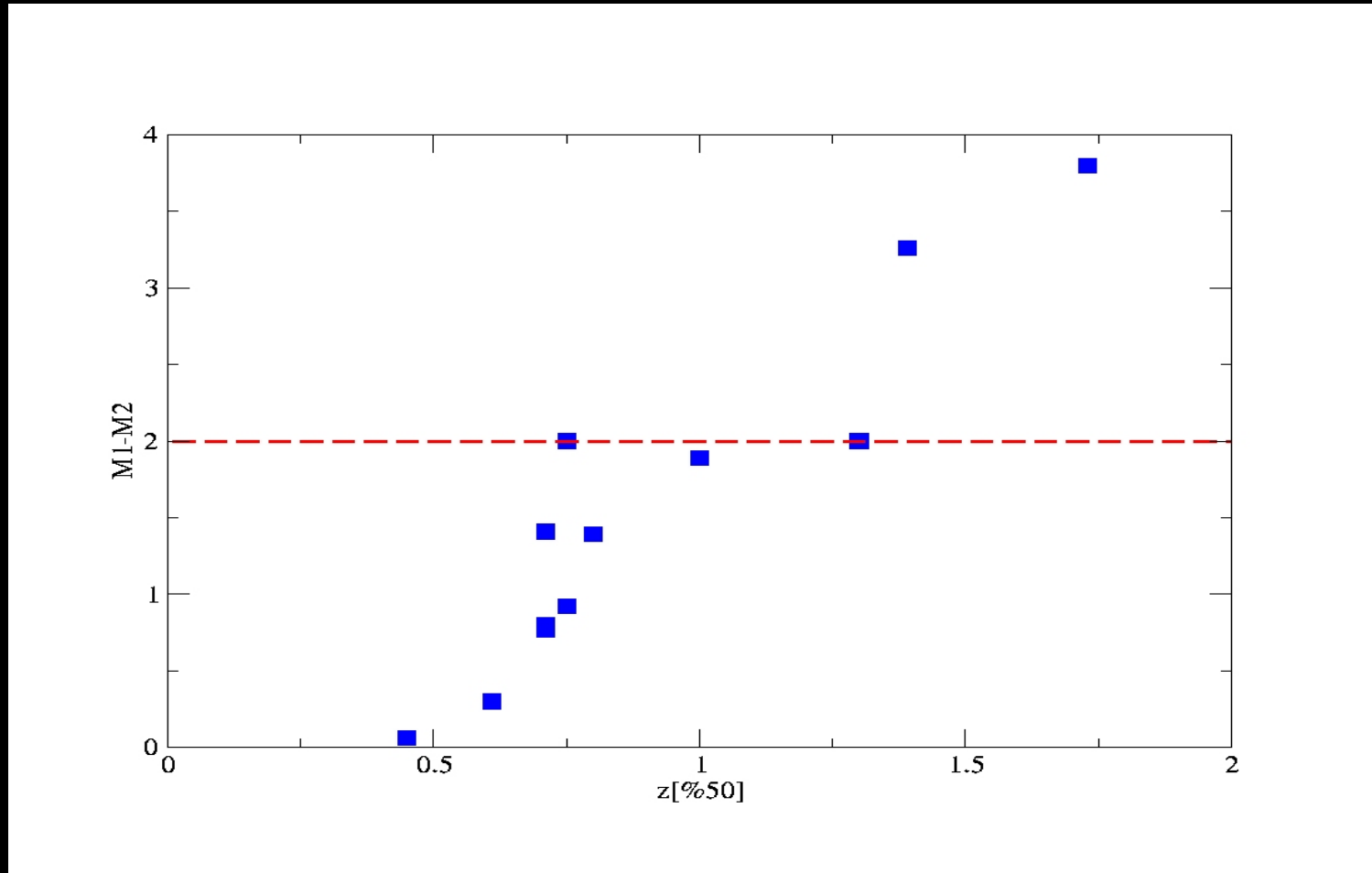
- Fossil BCGs similar in age, metallicities, SFH (La Barbera et al. 2009,2012; Cui et al. 2011; Proctor 2014).
- Similar globular clusters (Alamo-Martinez et al. 2012).
- Do follow the Fundamental plane (Mendez-Abreu et al. 2012)

Are Fossil Systems relaxed and early forming?



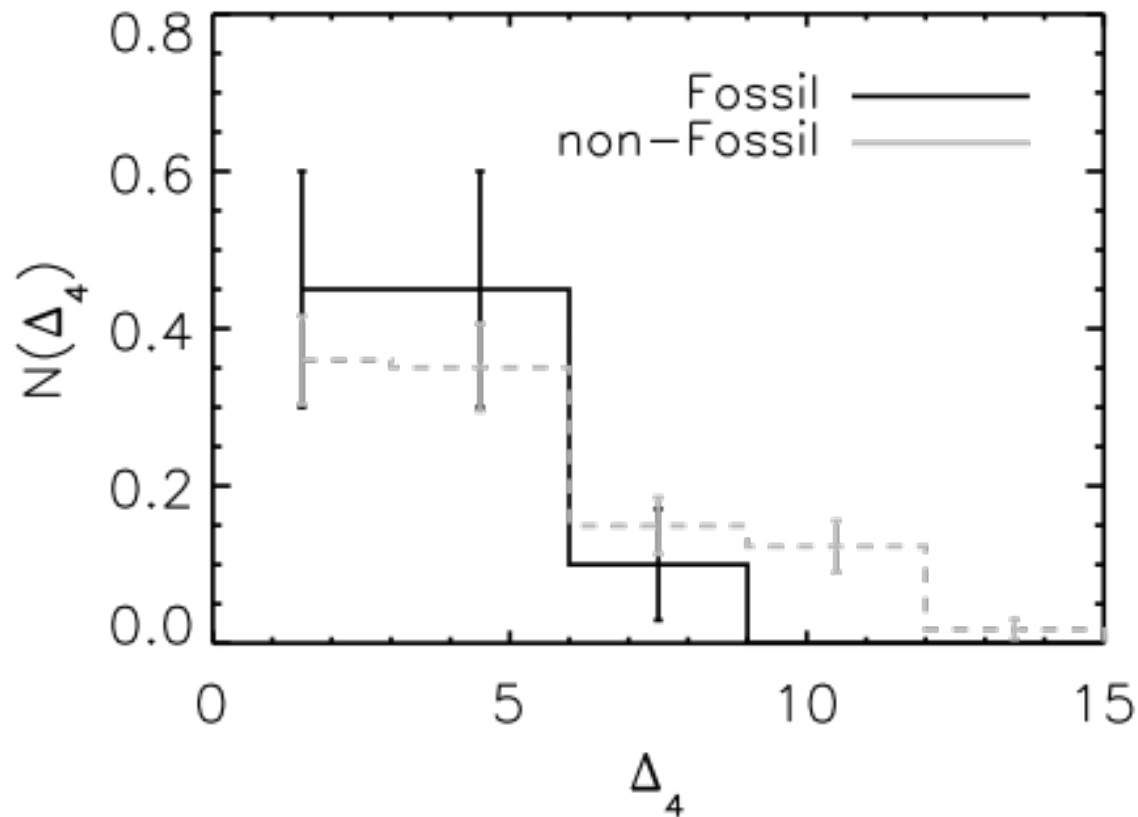
Magnitude gap FORMATION

- There is a time dependence for the mag gap formation



D'Onghia, Sommer-Larsen et al. 2005 ApJL

In simulations of DARK MATTER ONLY:

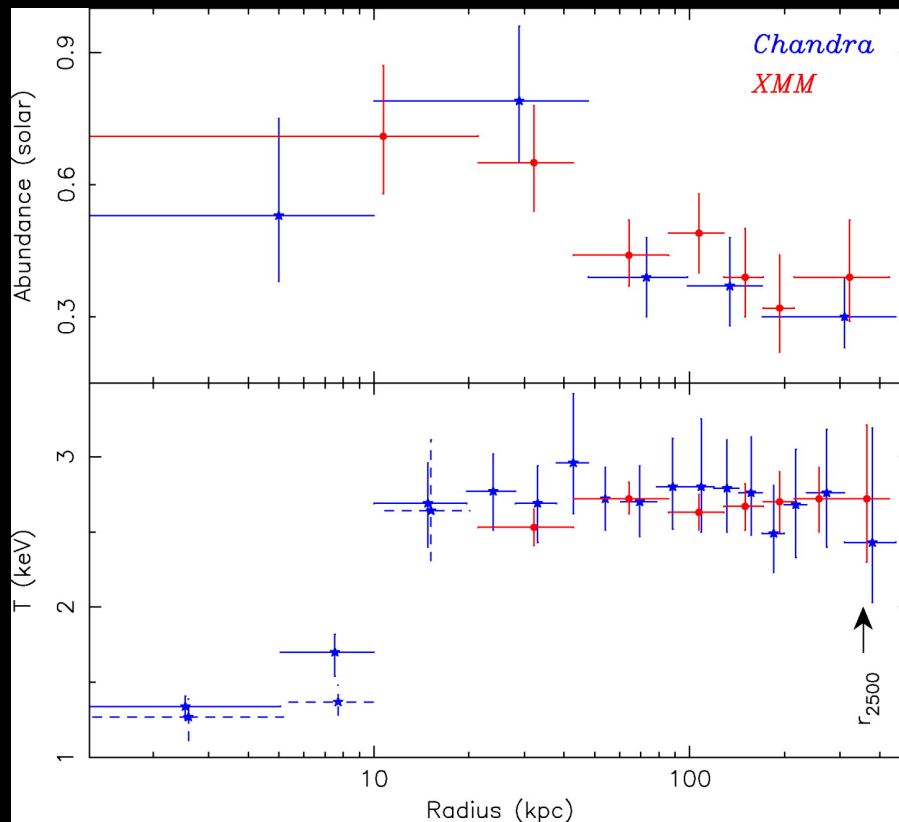


They seem to avoid high density regions

von Bendam-Beckmann, D'Onghia et al. 2008

- If Fossil Systems formed early and relaxed they should develop a cooling flow.

Cool flows are not there or smaller than expected
(Sun et al. 2004, Democles et al. 2010)



ESO 3060170

Sun et al. 2004

More data are needed from Chandra and XMM !

Fossils in the ILLUSTRIS Simulation



- * Early forming? - merger trees
- * Relating formation epoch to observational properties:
 - M/L
 - Central ICM entropy
 - Mass, luminosity of BCG
- * Definition of fossil systems

Illustris

Volume: $\sim(100 \text{ Mpc})^3$

Total particle count: $\sim 18 \text{ B}$

$z \sim 127-0$

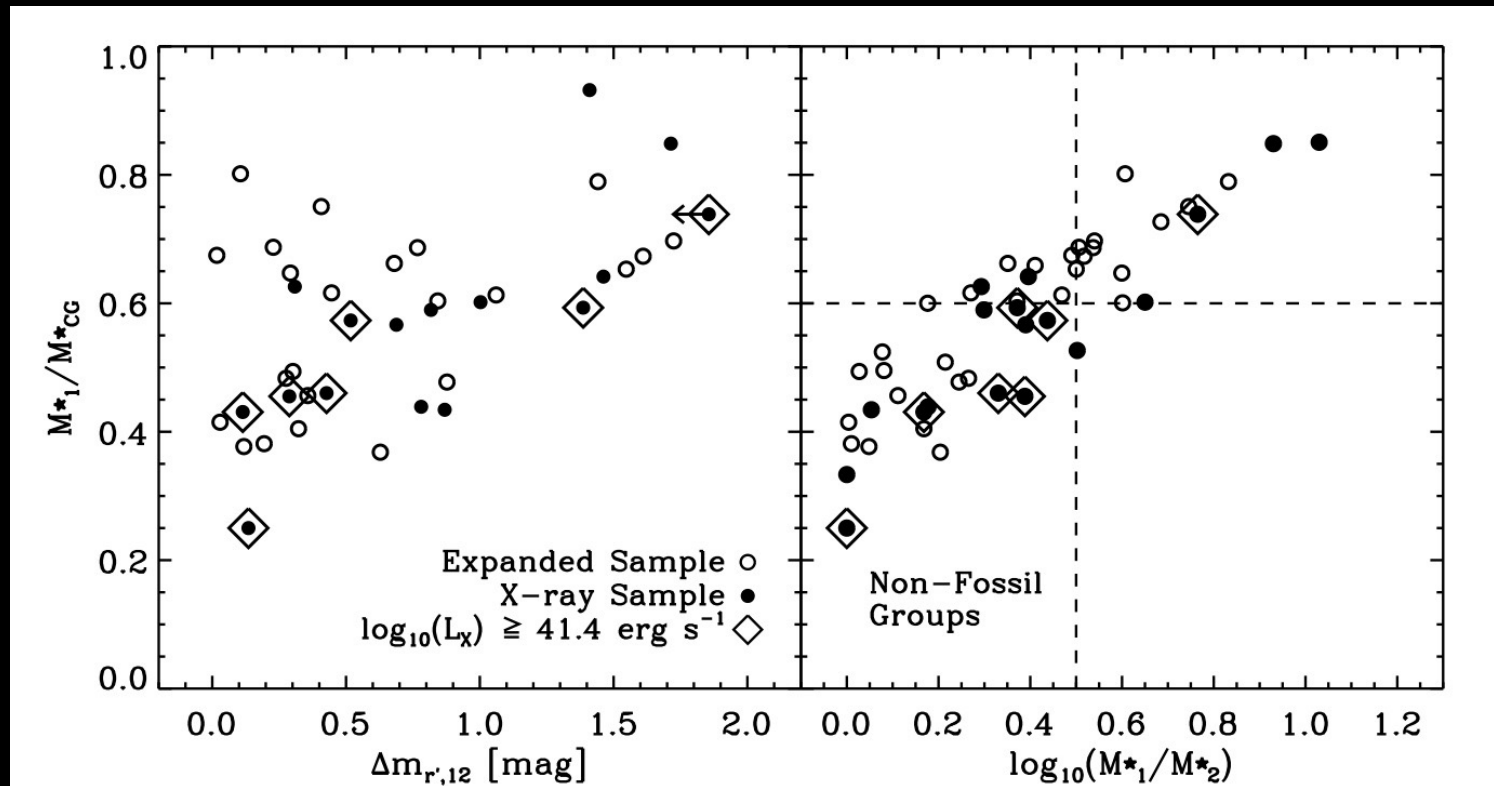
DM resolution: $6.26 \text{E}6 \text{ M}_\odot$

$r_{\text{gas}} = 48 \text{ pc}$

Galaxy formation model:

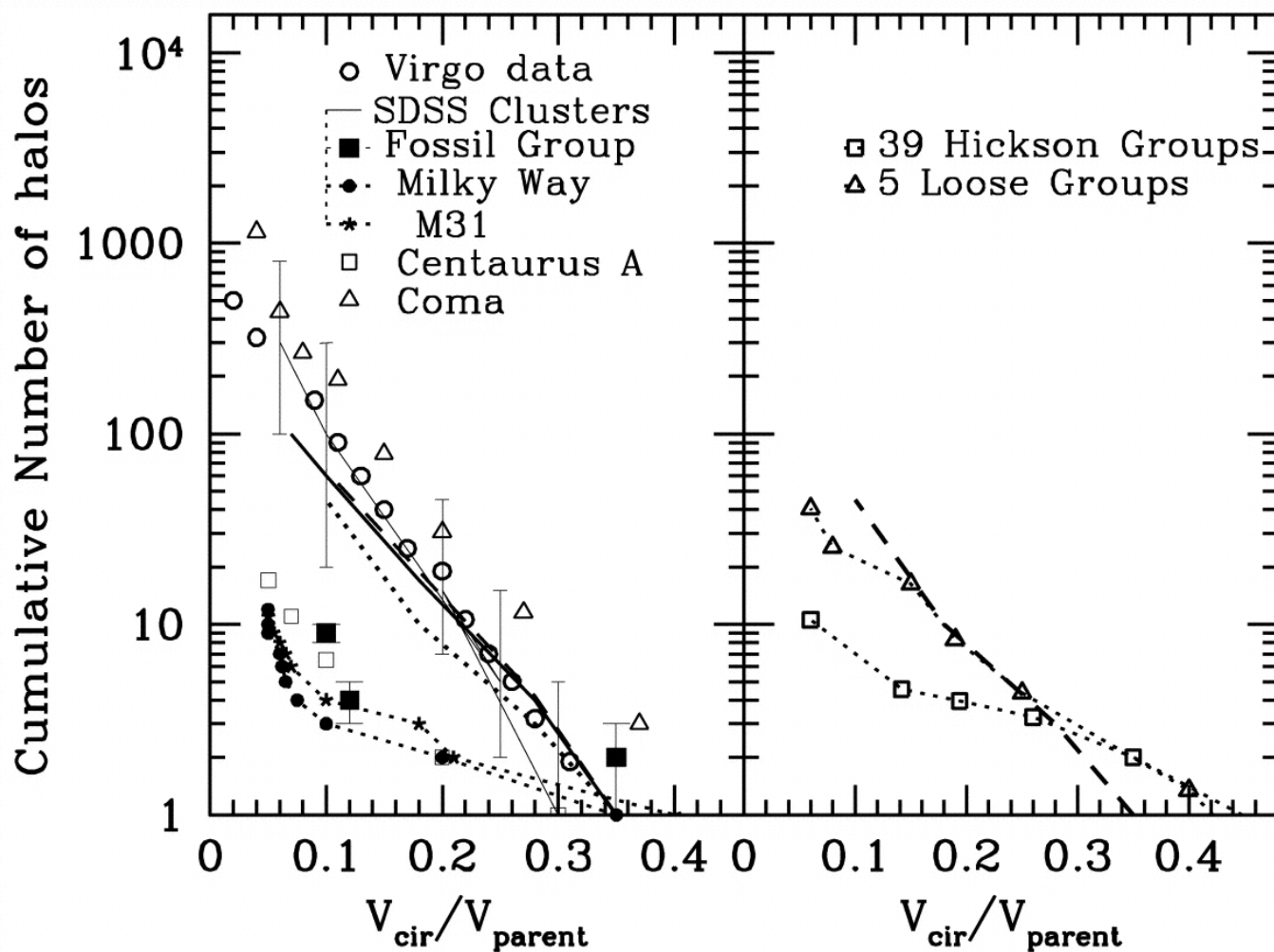
- gas cooling, recycling, enrichment
- stellar evolution and SMBH growth
- feedback from: SN, AGN

Alternate fossil definitions



Desjardins+2014

Fossil systems as transition objects



D'Onghia & Lake 2004

Investigating 'fossilness' in lower mass regimes

- Fossil systems are transition objects
- Possible that a gap in brightness/mass between the brightest structure and the next brightest may be a typical characteristic of systems in transition
- Studying fossils at all scales tells us how objects accrete material and how the mass function is formed

Summary

- 1) Fossil Systems are clusters and groups of galaxies!
- 2) Similar scaling relations as non fossil systems
- 3) BCGs are overluminous
- 4) Do they have cooling flows? Do they form early?
It is still unclear!
- 5) If we define them more generally, the majority of systems are fossils, and important to understand how to form the mass function