Fossil systems; A multi-wavelength approach towards understanding galaxy formation

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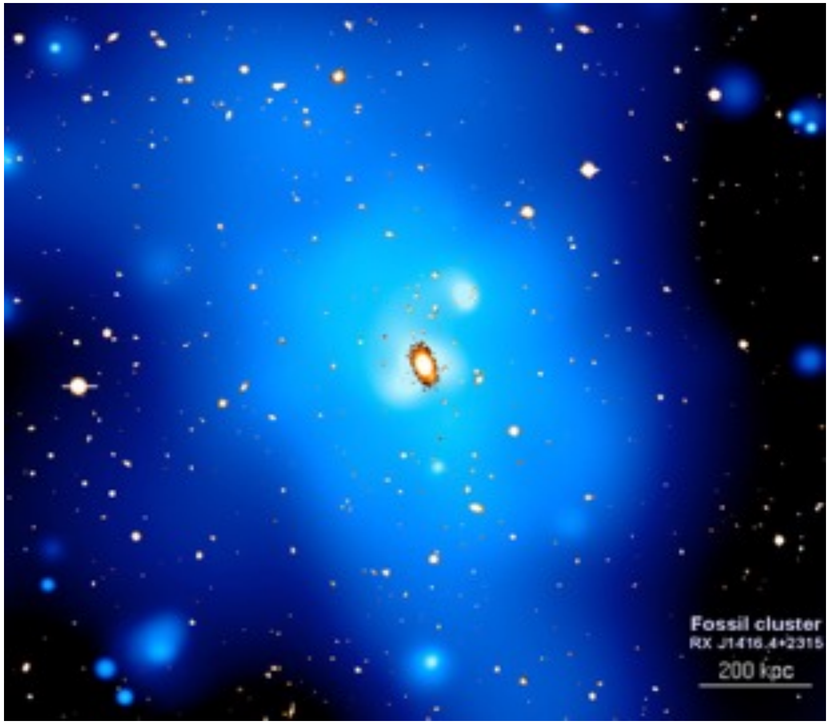

Direct contribution

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Thanks to:

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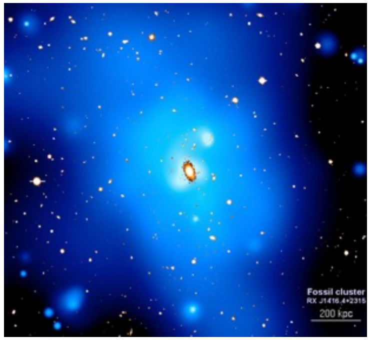
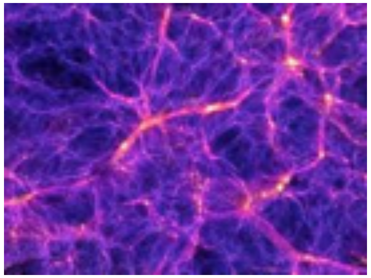
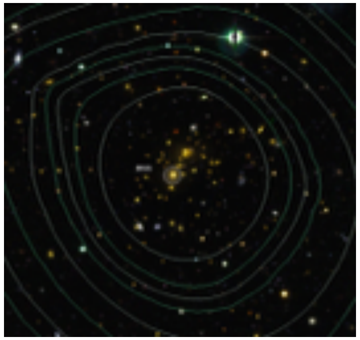
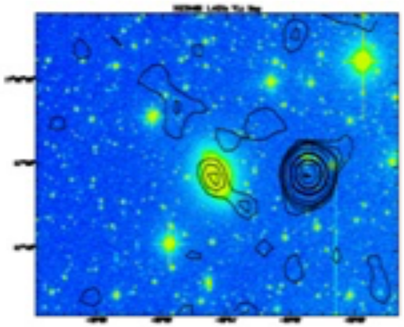
Outline

- Introducing the luminosity gap and fossil groups
- Halo, IGM and galaxies properties
- Fossils in cosmological simulations; constraints on galaxy formation models
- Mining the gap at z~1
- Ultimate fossil groups; A routine for Age-dating galaxy groups
- AGN activities in fossil BGGs









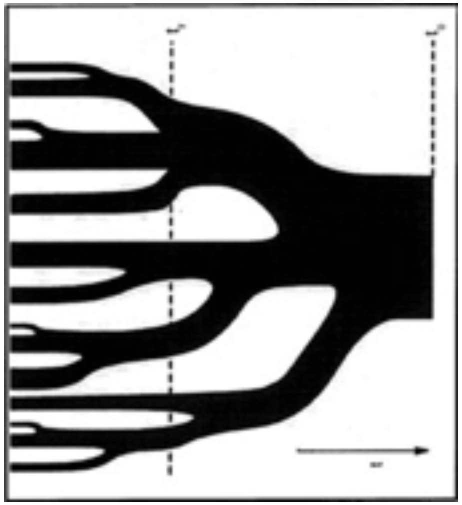
Groups and hierarchical structure formation

Galaxy clusters are the largest gravitationally bound objects. They form the densest part of the large scale structure of the universe. In models for the gravitational formation of structure with cold dark matter, the smallest structures collapse first and eventually build the largest structures, clusters of galaxies.

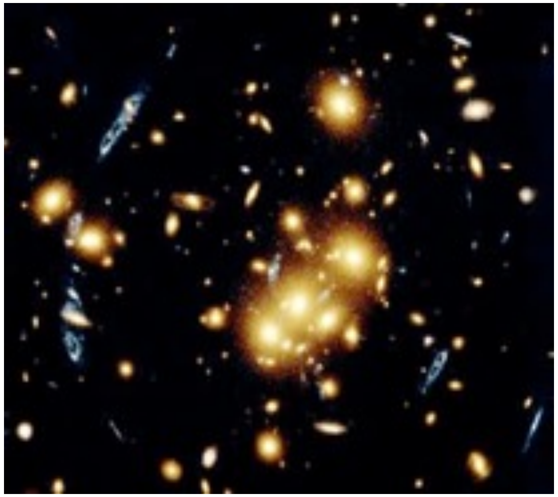
Stephan's Quintet

Low velocity dispersion

Young/Old



Merger tree



Cl 0024+16 z~0.4

High velocity dispersion

Young

A tree analogy

Fossil galaxy groups

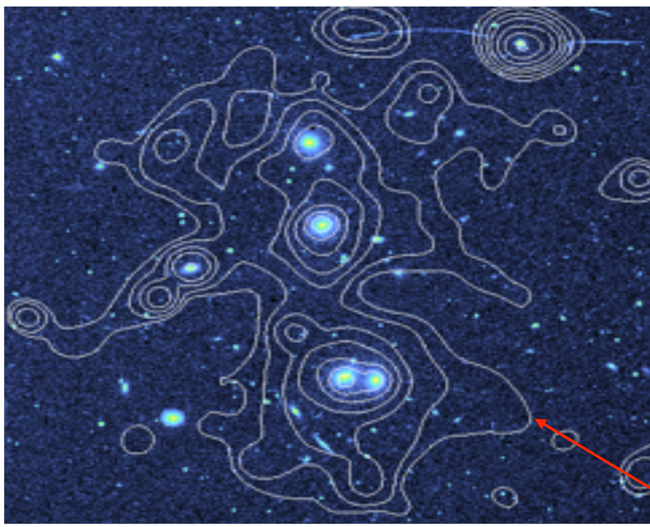
A possible fossil galaxy group

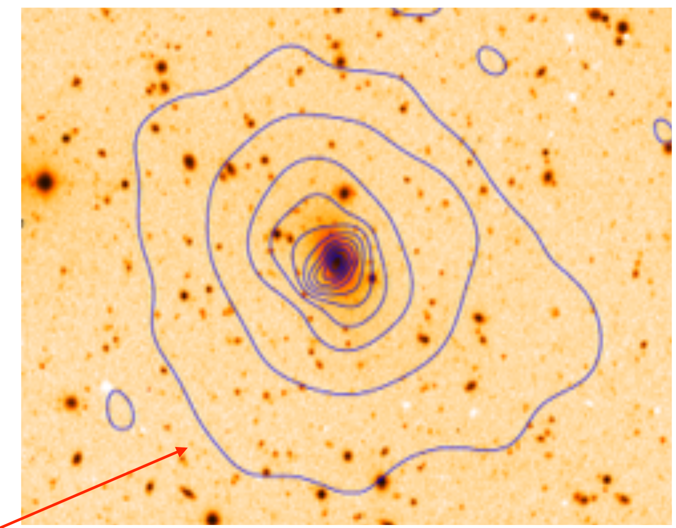
T. J. Ponman*, D. J. Allan*, L. R. Jones†, M. Merrifield*, I. M. McHardy†, H. J. Lehto‡ & G. A. Luppino§

N-body simulations show that mergers of galaxies can produce luminous elliptical galaxies that resemble observed light profile of giant elliptical galaxies at the core of groups and clusters (Barnes 1989). Thus galaxy mergers are very important processes.

End product of the mergers of galaxies in a group

No recent major merger ⇒ simple laboratories



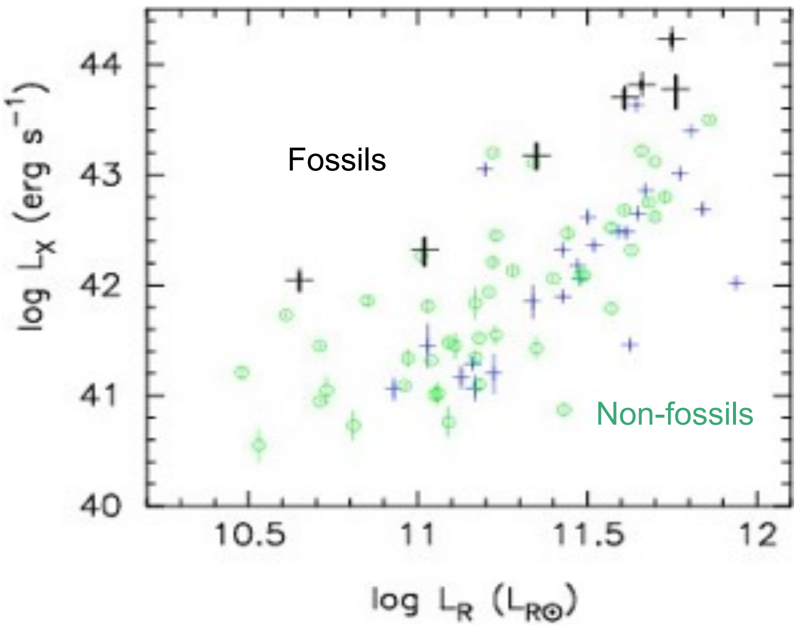


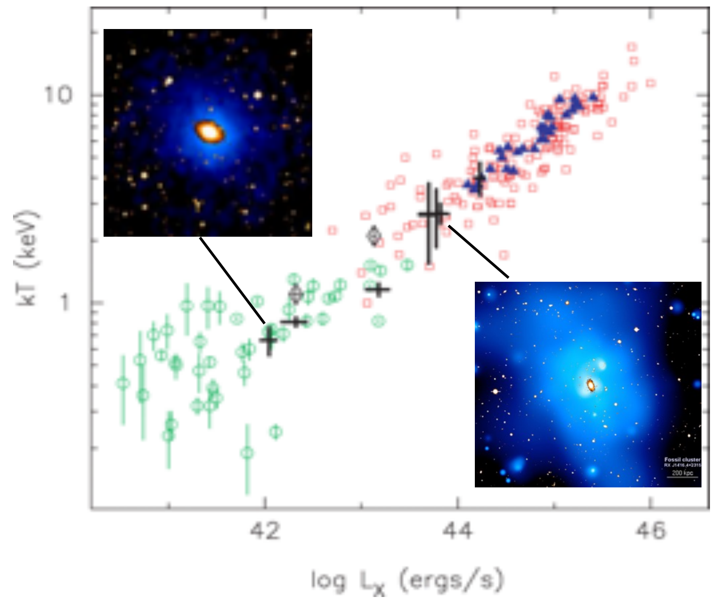
X-ray contours

- Should present a large luminosity gap, > 2 mag
- Groups scale X-ray emission

See Jones et al (2003) for conventions and justifications and space density.

X-ray properties I





L_X - L_{opt} relation

Excess X-ray luminosity for a given optical luminosity of the groups. or simply dimmer in optical?

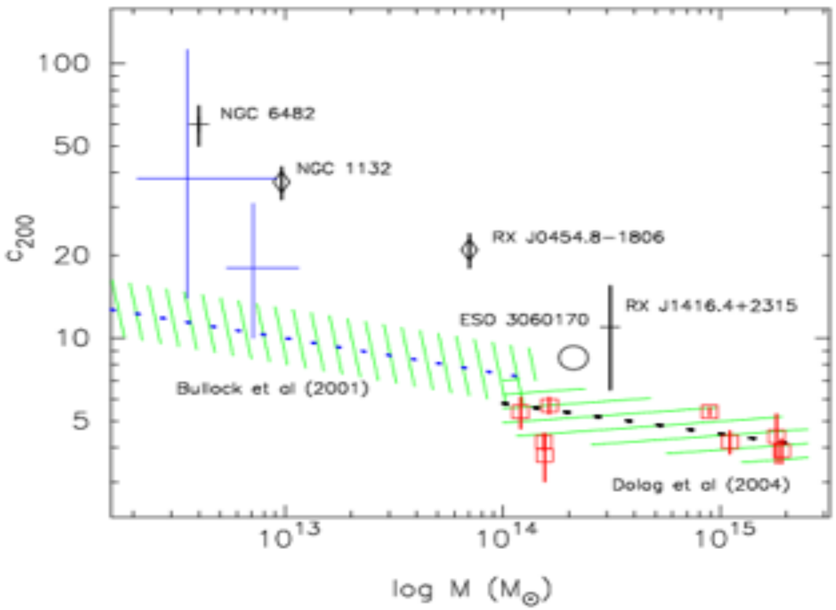
L_X - T_X relation

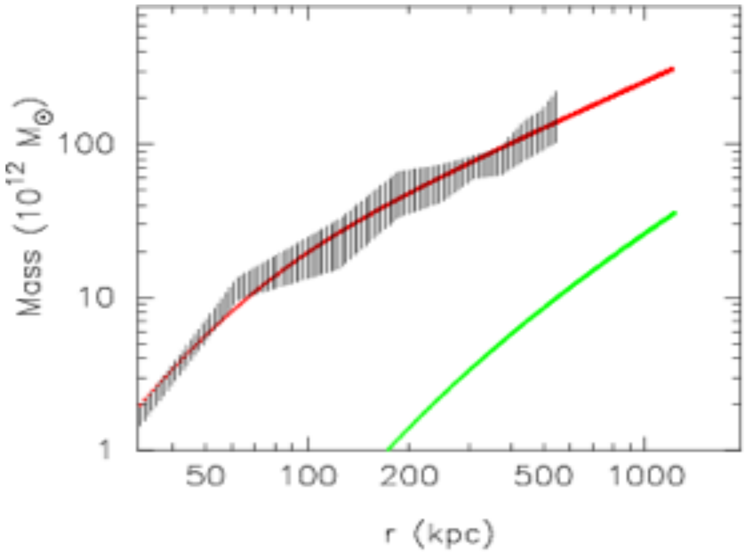
Fossils all comfortably on the conventional L-T relation in contrast to an earlier study by Jones et al (2003).

Khosroshahi et al (2007)

Halo concentration and luminosity gap

- Hydrostatic equilibrium
- Spherical symmetry
- NFW profile ($c_{200}=r_{200}/r_s$)





J1416.4+2315,
Khosroshahi et al. 2006

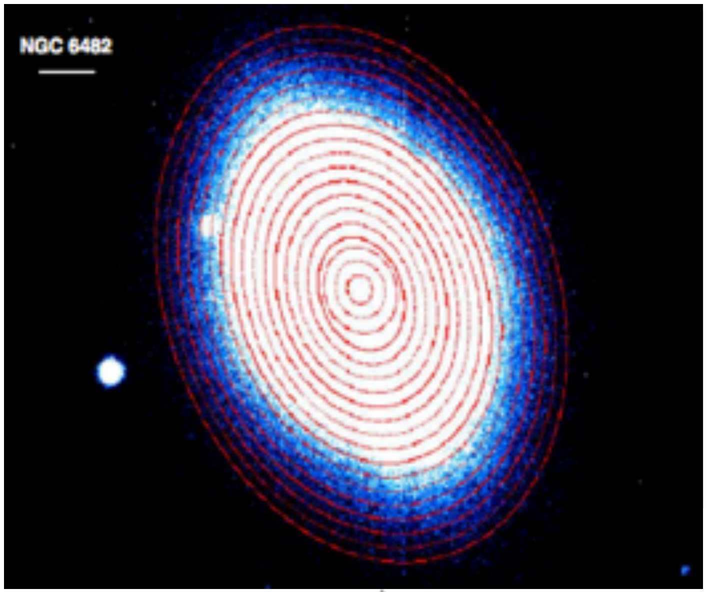
Fossils show higher concentration in their mass profiles compared to non-fossils systems with similar masses. This is an indication of early formation epoch.

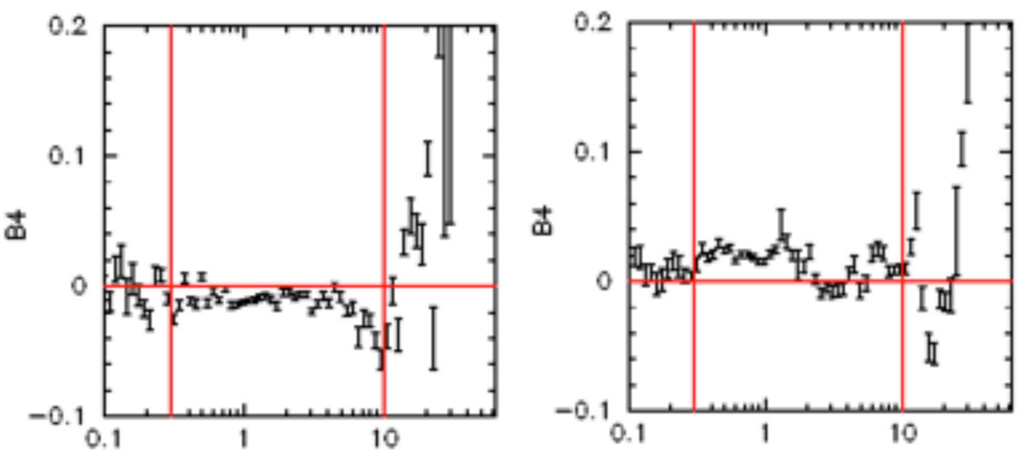
Concentration measurement requires high quality data and is subject to large uncertainties.

Khosroshahi et al (2007)

Isophotal shape of fossil BGGs

Non-boxy isophotes for the fossil BGGs was reported in 2006 (Khosroshahi, Jones and Ponman 2006). A similar trend was found in LoCuSS sample. Clusters with largest luminosity gap are dominated by non-boxy isophote giant elliptical galaxies.





Δm_{12}

Figure 5. Luminosity gap statistic (Δm_{12}) versus error-weighted mean fourth Fourier component of the BCG light distribution ($\langle B_4 \rangle$). Positive values of $\langle B_4 \rangle$ correspond to Disky BCGs; negative values correspond to Boxy BCGs; values consistent with zero are consistent with elliptical isophotes. Clusters with $\Delta m_{12} \lesssim 1$ host BCGs with both Boxy and Disky isophotes. In contrast clusters with $\Delta m_{12} \gtrsim 1$ host only non-Boxy (i.e. Elliptical or Disky BCGs).

See also: Khochfar & Burkert (2005)

Khosroshahi et al (2006)

Smith, Khosroshahi et al (2010)

Summary (I)

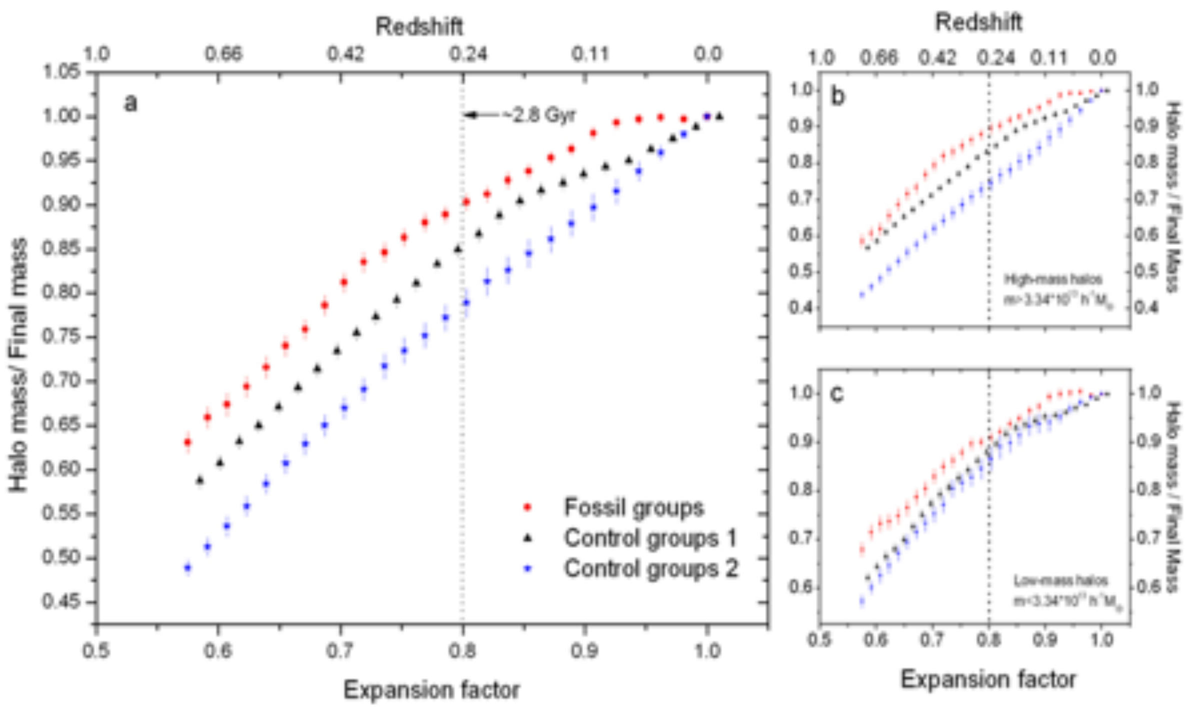
Fossil Groups identified on the basis of a large luminosity gap in groups, as a representative of old/dynamically relaxed galaxy systems show interesting properties:

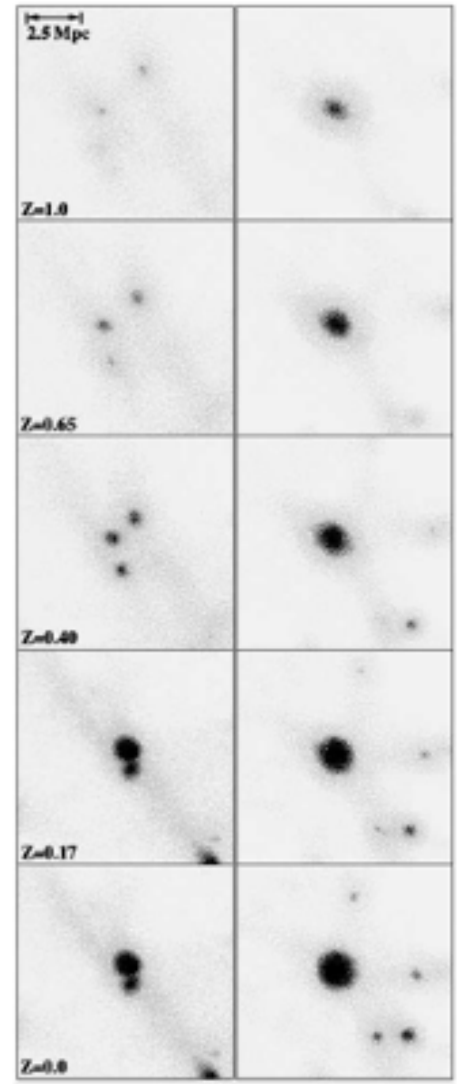
- High halo concentration
- Non-boxy dominant giant elliptical galaxies pointing at wet nature of the past mergers
- IGM observations consistent with the argued formation scenario

Issues:

- Limited statistics
- Disagreements (possibly due to galaxy cluster contamination)

Halo mass evolution in fossil groups





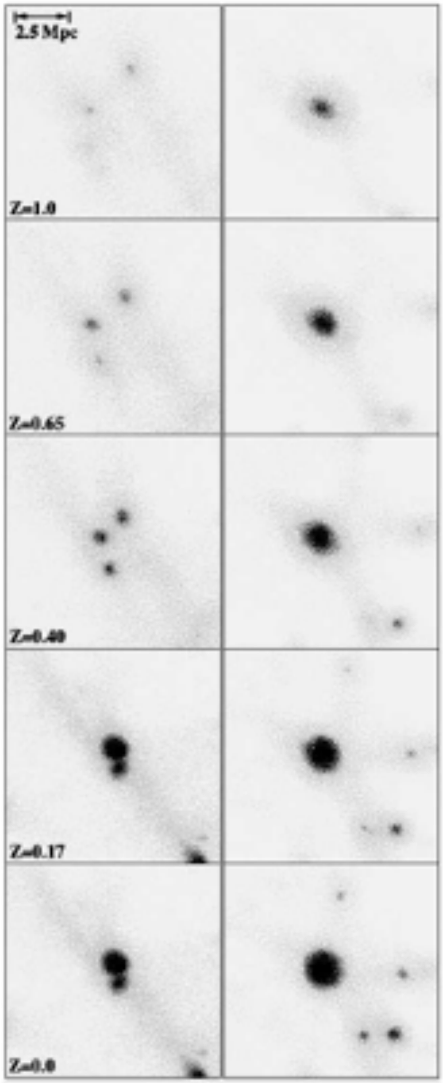
Dariush , Khosroshahi, et al (2007)

Fossils accumulate most of their mass at high redshifts, they are therefore old.

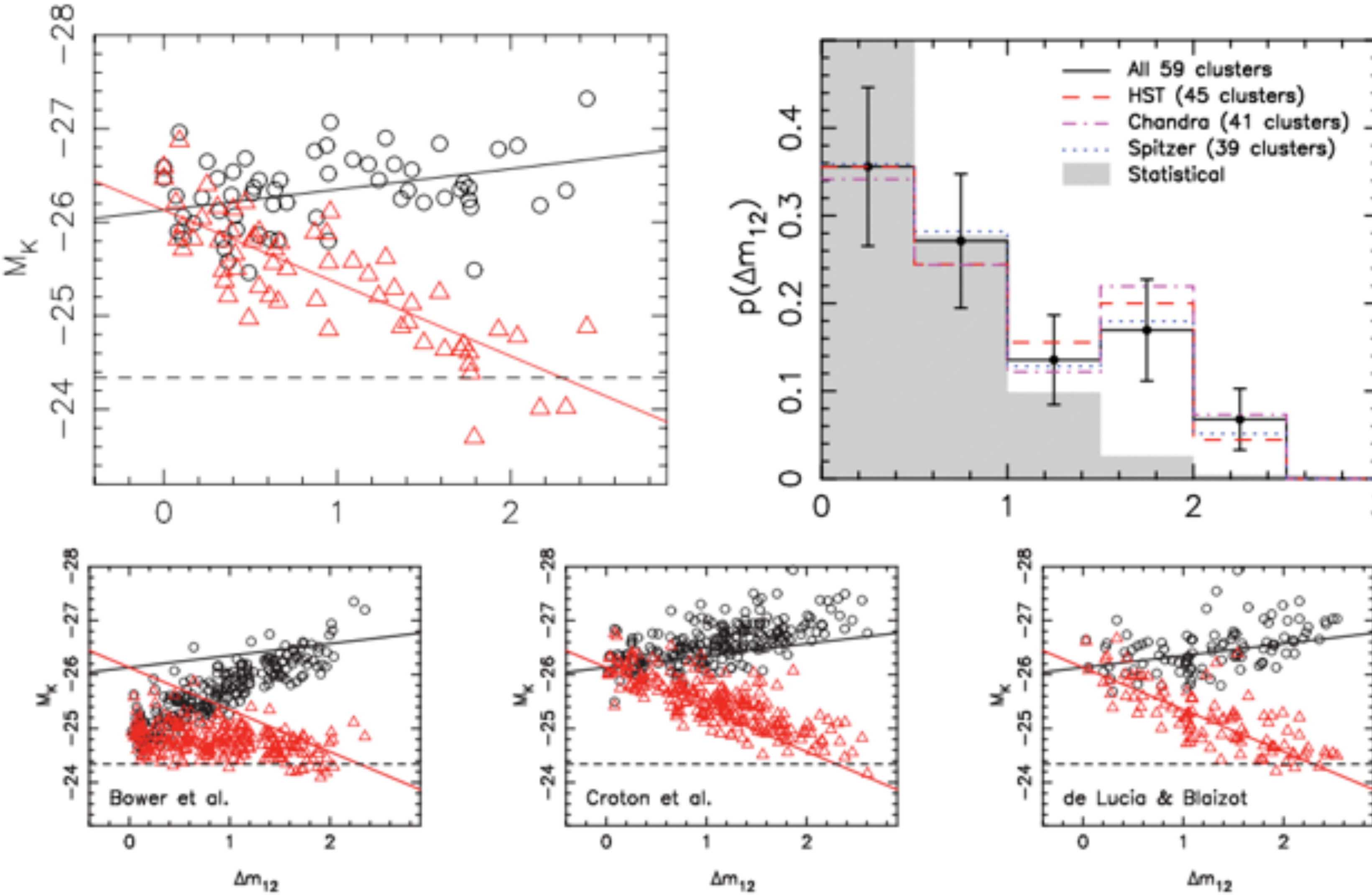
Space density of fossils

L_X[a]	N_f[b]	Density[c]	Reference[d]	This study[c]
>0.25	5	320^{+216}_{-144}	J03	104 ± 3
>2.5	3	$16^{+15.2}_{-8.8}$	J03	22.4 ± 1.3
>2.5	4	$36.8^{+47.2}_{-18.4}$	V99	22.4 ± 1.3
>2.5	3	~160	R00	22.4 ± 1.3
>5.0	4	$19.2^{+24.8}_{-9.6}$	V99	12.8 ± 1.0

[a] In units of $10^{42}\,h^{-2}$ erg s^{-1}. [b] Number of fossils. [c] In units of $10^{-7}\,h^3$ Mpc^{-3}. [d] V99: Vikhlinin et al. (1999), R00: Romer (2000), J03: Jones et al.


2.5 Mpc
Z=1.0
Z=0.65
Z=0.40
Z=0.17
Z=0.0

Probing Semi-analytic models

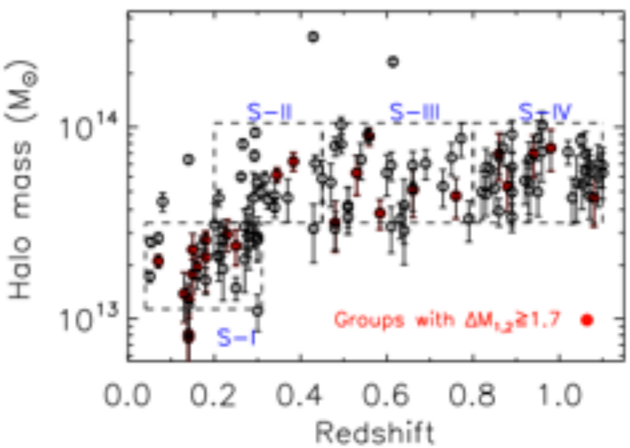


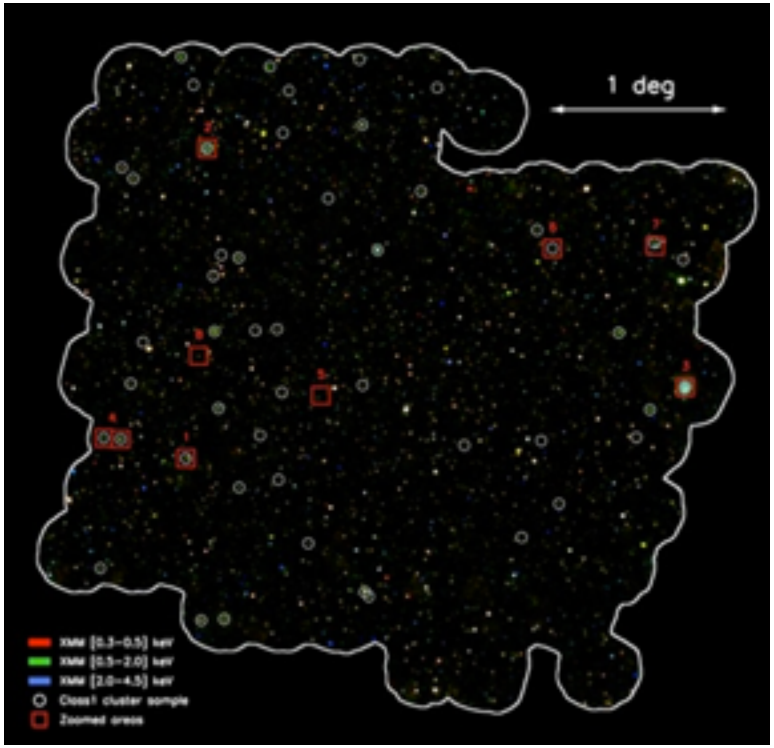
Smith, Khosroshahi et al (2010)

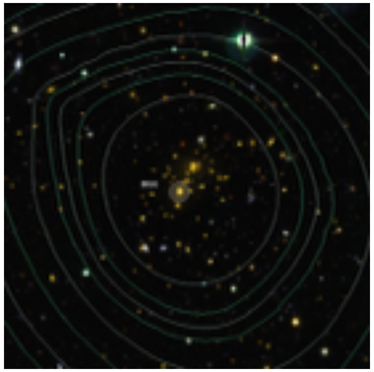
Mining the gap at z~1

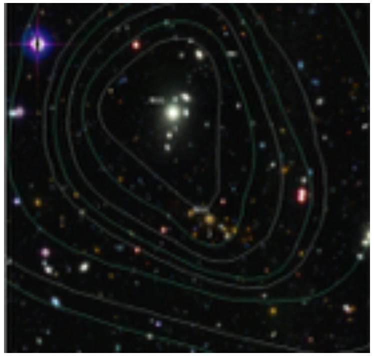
We identify and study 129 X-ray galaxy groups, covering a redshift range 0.04 <z< 1.10, selected in the 3 degree^2 of the CFHTLS W1 field overlapping XMM observations performed under the XMM-LSS project.

We find that the slope of the relation between the fraction of groups and the magnitude gap steepens with redshift, indicating a larger fraction of fossil groups at lower redshifts. We find that 25±7% of our groups at z<0.6 are fossil groups.





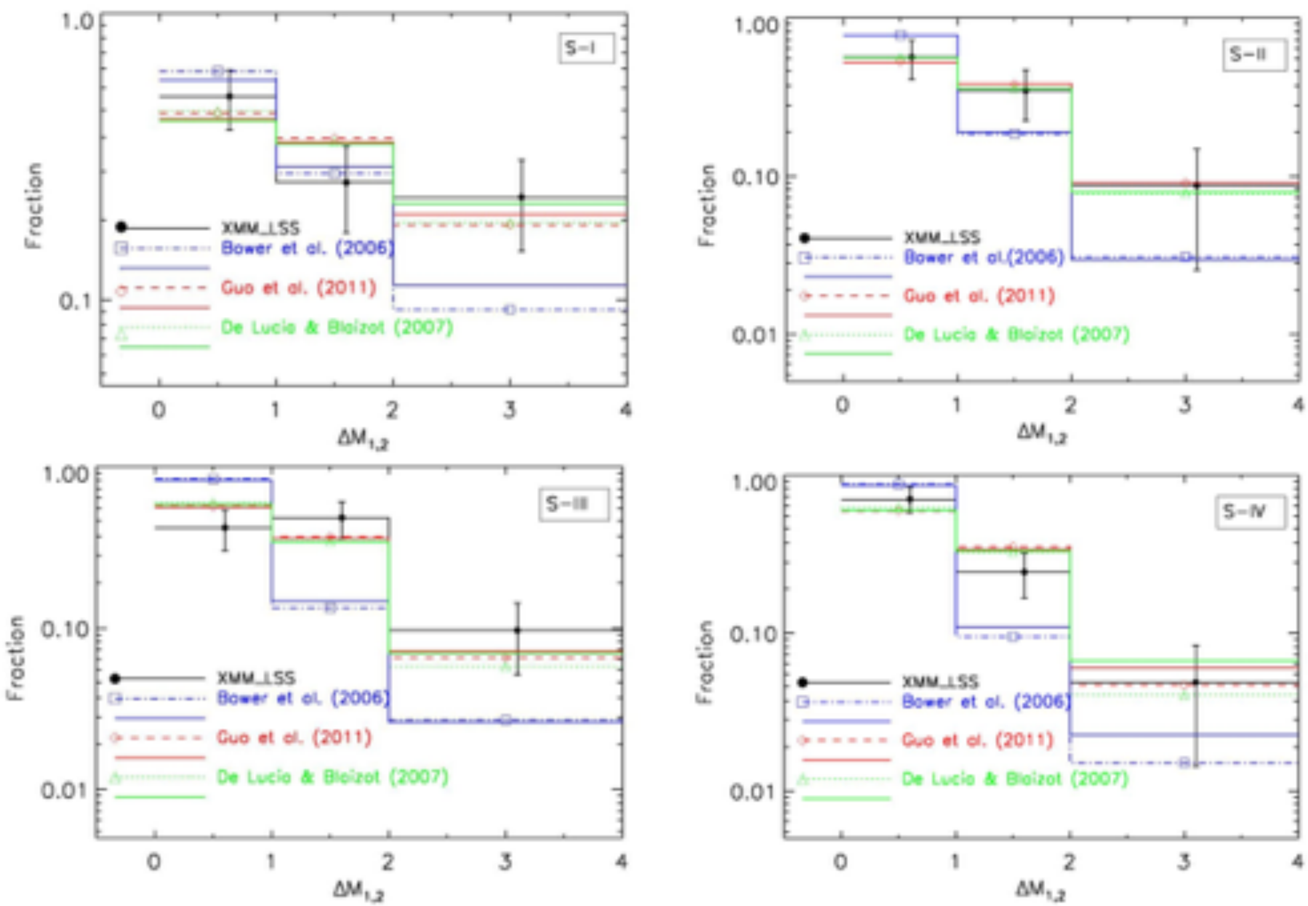




We carry out a statistical study of the redshift evolution out to redshift one of the magnitude gap between the first and the second brightest cluster galaxies of a well defined mass-selected group sample.

Gozaliasl, Finoguenov, Khosroshahi et al (2014)

Mining the gap deep into z~1



Fraction of galaxy groups as a function of the magnitude gap (black points with error bars) compared to predictions of the semi-analytic galaxy formation models, Bower et al 2006 (solid and dashed-dotted blue histograms), De Lucia and Blaizot (solid and dotted green histograms) and Guo et al 2011 (solid and dashed red histograms) for S–I (top left panel), S–II (top right panel), S–III (bottom left panel) and S–IV (bottom right panel).

Age dating galaxy groups

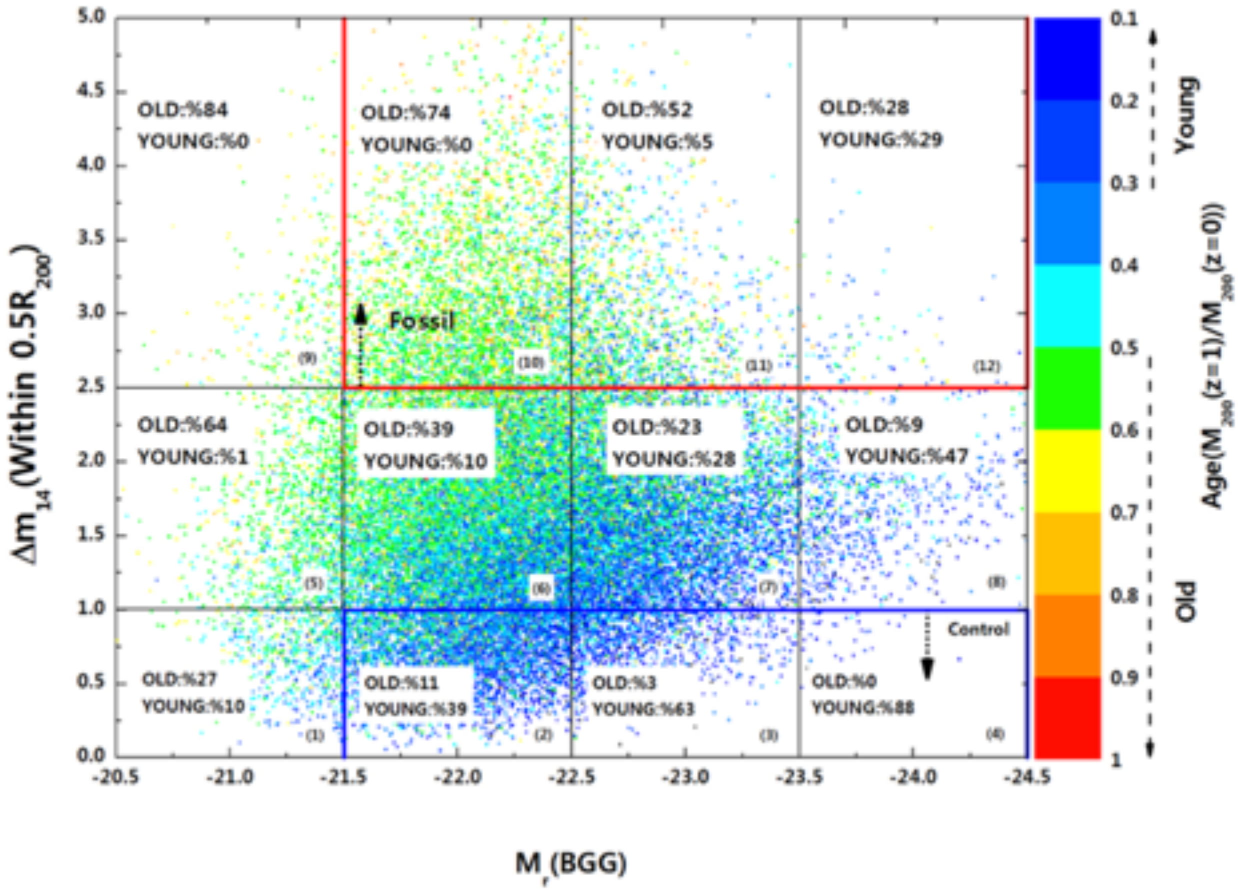
Galaxy groups possessing a large luminosity gap between the two brightest galaxies within a half a Virial radius are relatively older.

The success is limited!

Other age indicators include:

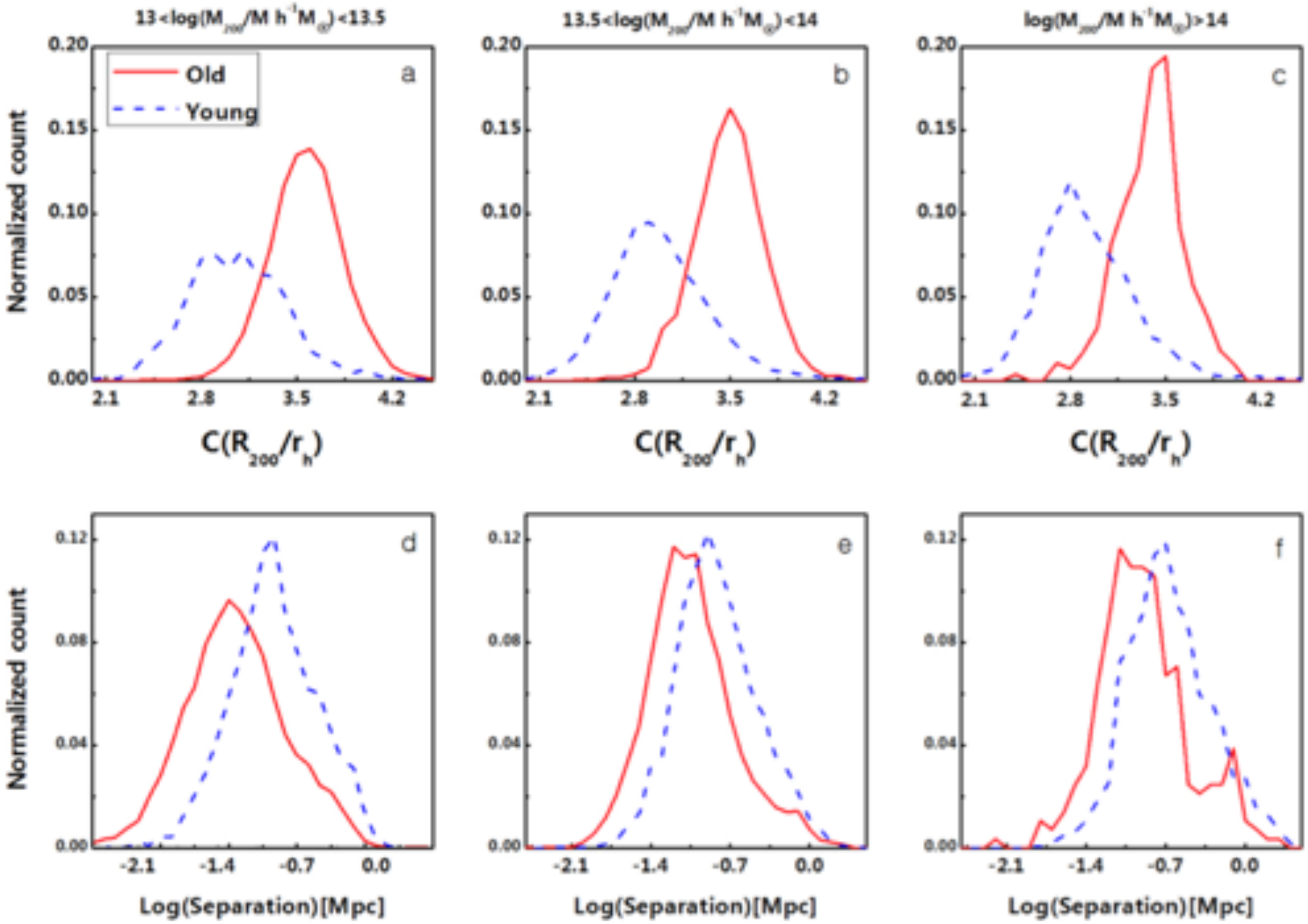
Halo concentration

de-centring



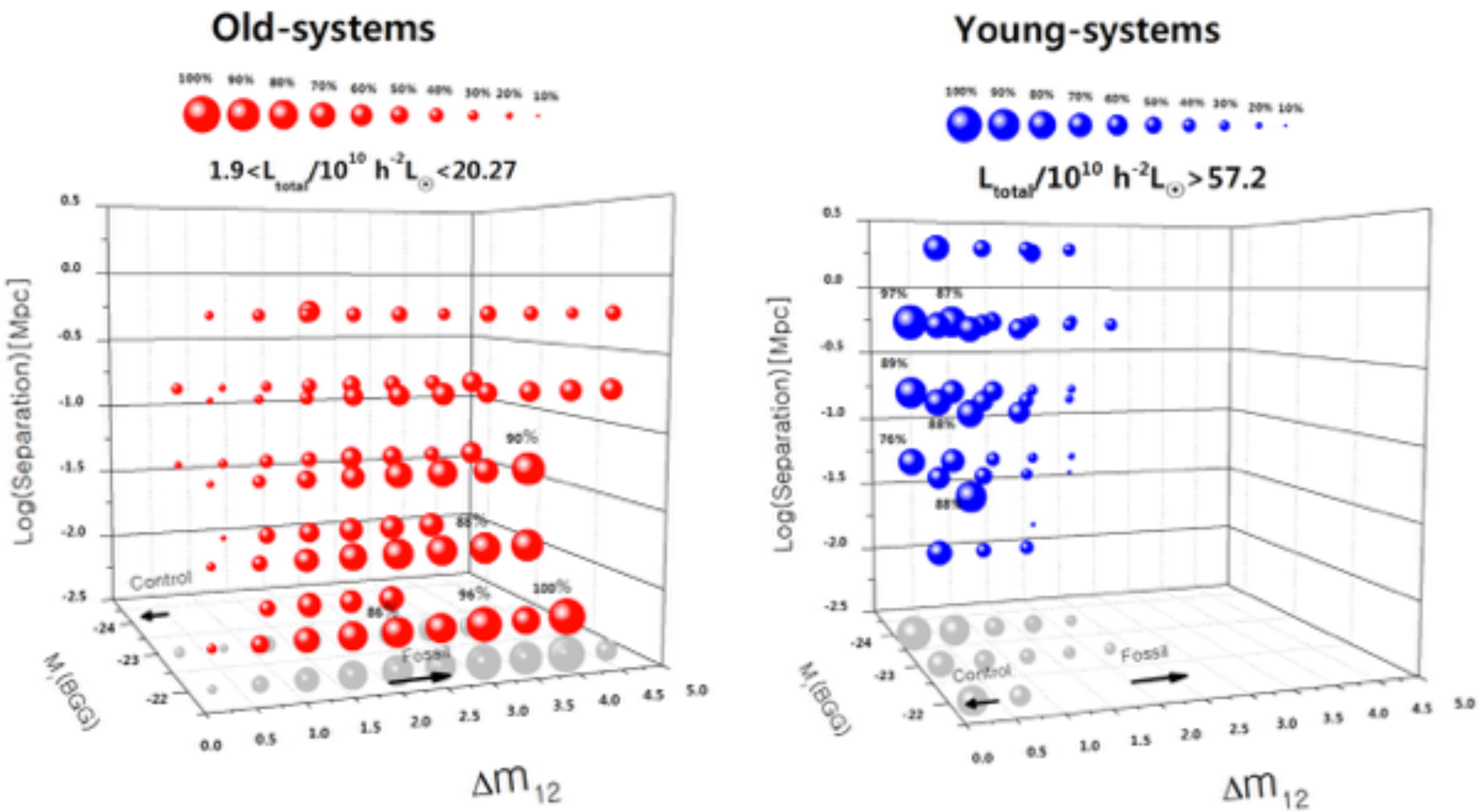
Raouf and Khosroshahi et al (2014)

Age dating galaxy groups; beyond the LG



Raouf and Khosroshahi et al (2014)

Age-dating in multi parameter space



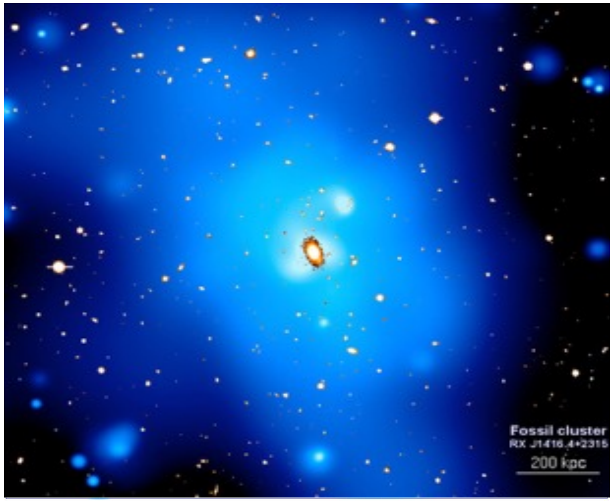
Statistical age-dating routine based on a photometric measurements of galaxies only.

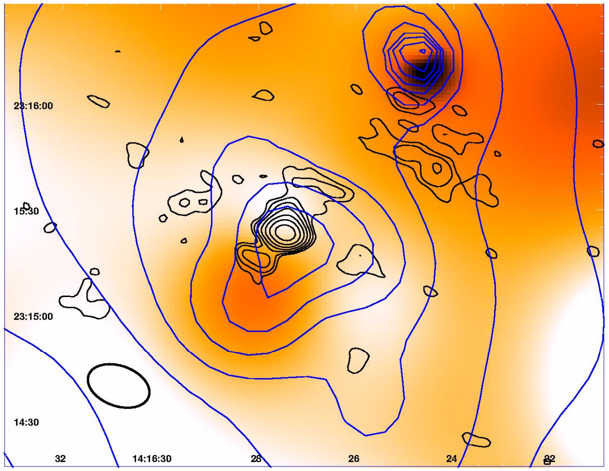
Raouf and Khosroshahi et al (2014)

AGN in fossils

GMRT Low frequency observations

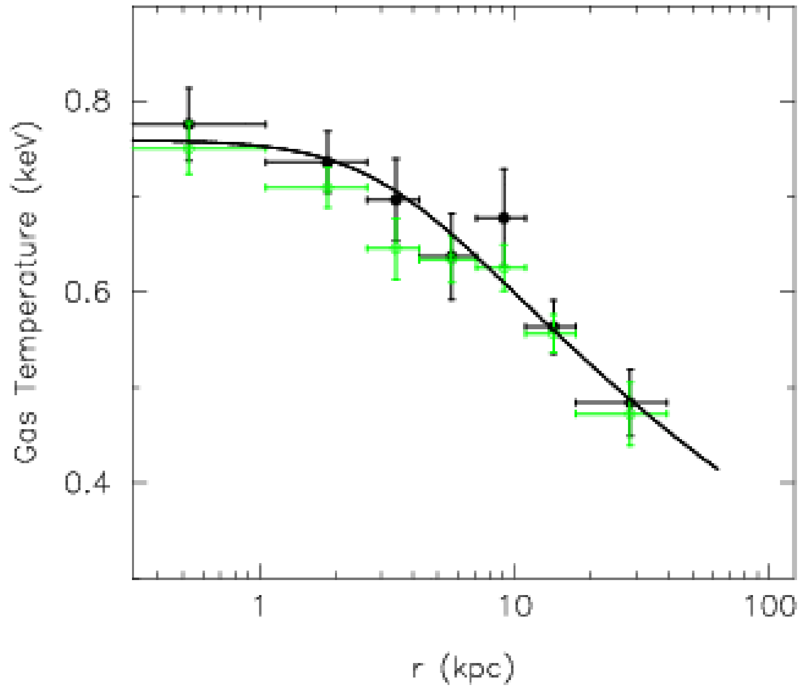
Frequency (MHz)	Position J2000	Peak Flux mJy	Integrated Flux mJy	Map rms mJy	Resolution (arcsec)
610	14 16 27.357 +23 15 22.00	4.29 ± 0.13	7.10 ± 0.33	0.18	8.03 × 5.36
610	14 16 27.647 +23 15 18.00	2.00 ± 0.20	2.08 ± 0.20	0.18	8.03 × 5.36
610	14 16 27.502 +23 15 24.00	7.60 ± 0.65	12.41 ± 1.60	0.98	40.39 × 34.28
1420	14 16 27.473 +23 15 22.40	2.60 ± 0.13	3.55 ± 0.27	0.13	8.30×6.96
1420	14 16 27.502 +23 15 22.00	3.40 ± 0.43	3.48 ± 0.76	0.36	32.98×29.78



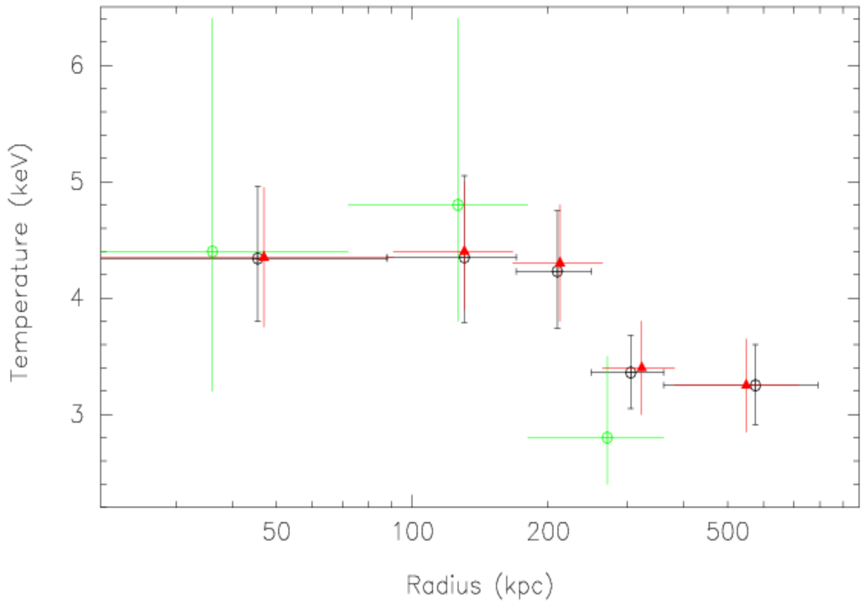


Fossils and cool core

With no evidence for recent mergers, fossils are ideal environments for the formation of cool cores. Observations suggest that the reverse may be true!



NGC 6482 (khosroshahi et al 2004)



J1416.4+2315 (khosroshahi et al 2006)

Radio properties of fossil BGGs

Some fossil groups show no sign of strong cool cores and their IGM is hotter for a given halo mass.

- SNe and stellar feedback
- AGN feedback

If there has been no major mergers in the past ~ few Gyr, how this affects the AGN activities? AGNs are powered by super massive black holes, which require fuelling.

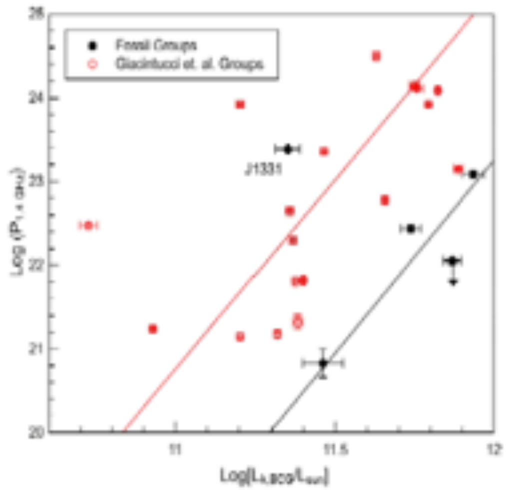


Figure 13. 1.4 GHz luminosity vs k-band BGGs luminosity of fossil galaxy groups (black), and Giacintucci et al. (2011) groups (red). The red and black lines correspond to fits to the red and black samples.

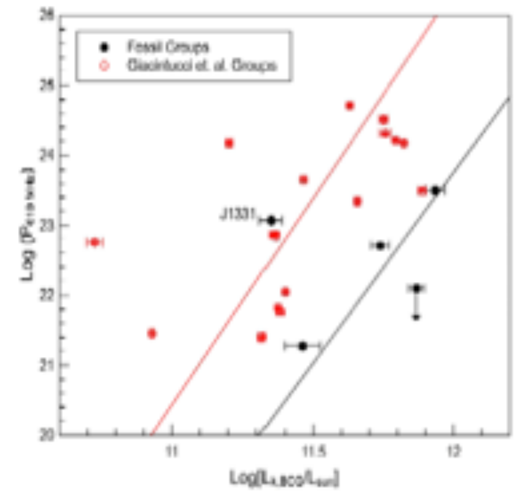
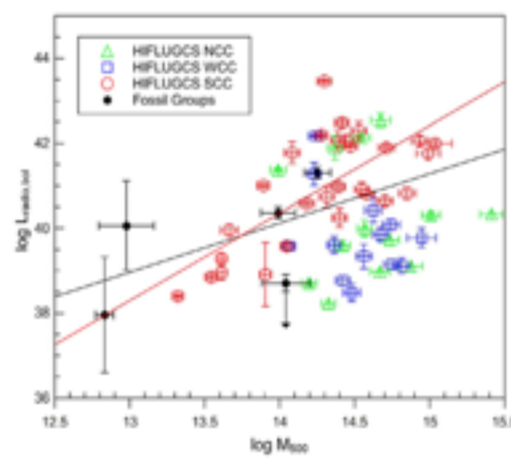


Figure 14. 610 MHz luminosity vs k-band BGGs luminosity of fossil galaxy groups (black) and Giacintucci et al. (2011) groups (red). The red and black lines correspond to fits to the red and black samples.



Mir Aghaee, Khosroshahi 2014

Hess et al (2012) reported fresh AGN activities in fossil groups!

What drives the “apparently” conflicting observations?

Proper age-dating

Or else!

Summary (II)

- The luminosity gap is a strong probe of evolutionary state of galaxy groups.

- The space density of fossils in the observations and simulations agree well.

- Luminosity gap is a key but not the only indicator to identify dynamically relaxed galaxy systems.

- Fossil/dynamically relaxed groups are a “NO SMOKING” zone for giant elliptical galaxies.

- There are indications that where a giant elliptical galaxy dominates a galaxy group a hot extended diffuse X-ray emission is found suggestive of a collapsed core as a host.