Fossil Galaxy Groups; Halo and all therein

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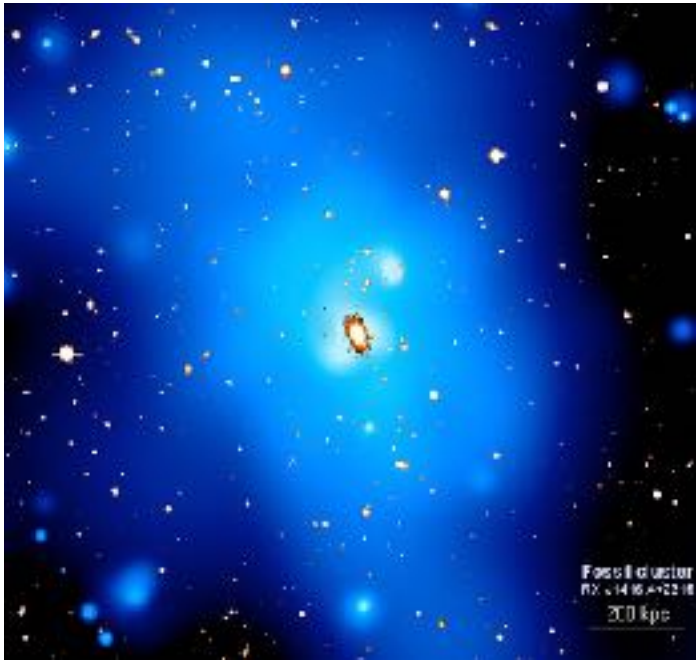

Discovery of fossil galaxy groups

A possible fossil galaxy group

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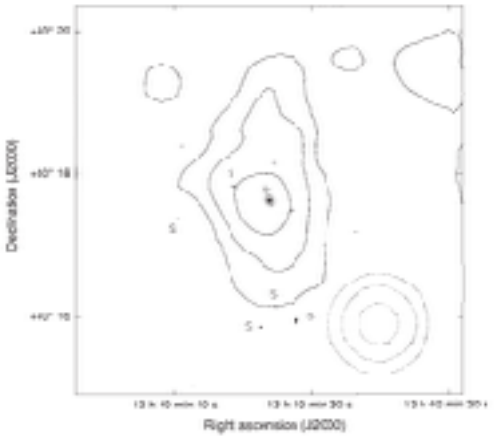
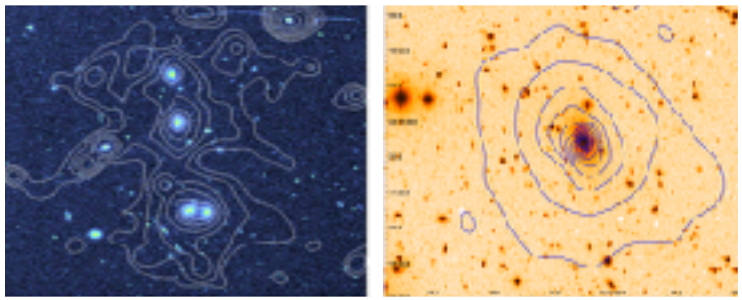
Most galaxies, including our own, are located in groups[1]. In the most compact galaxy groups, the members are separated on the sky by only a few galactic radii, and numerical simulations[2] suggest that such systems will merge to form a single elliptical galaxy (a 'fossil group') in a few billion years. Recent observations[3,4] have shown that some compact groups are surrounded by X-ray-emitting haloes of hot gas, and have suggested that they contain substantial amounts of dark matter. An elliptical galaxy formed by the merger of such a group will retain its halo[4], which is unaffected by merging. Using recent X-ray observations from Rosat we have searched for fossil groups, and we report here the discovery of a possible candidate at a redshift of 0.171. This candidate has a high X-ray luminosity, comparable to those of the brighter compact groups[5], and appears similar to the giant elliptical galaxies at the centres of clusters, yet it is apparently isolated. Its optical properties are also consistent with an origin as the merged remains of a typical compact group.





Large luminosity gap; $Dm_{12} \sim> 2$ mag

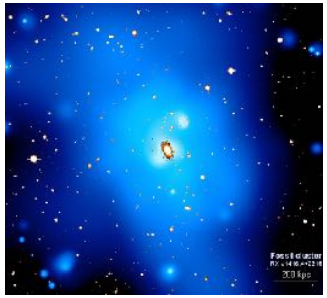
Group scale X-ray emitting halo; $L_X \sim> 10^{42}$ ergs/s

Jones+ 2003

Fossil Groups Studies

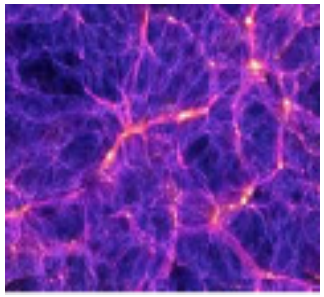
Exploring fossils

- General morphology (Halo, N density, …)
- Galaxy Properties (BGGs, GCs, AGNs, …)
- IGM (T profile, M-T, L-T, …)



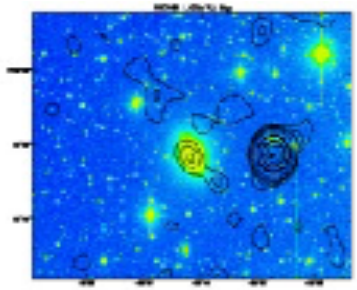
Understanding fossils

- Formation of fossil groups
- Evolutionary tracks
- IGM (scaling relations)



Employing fossils

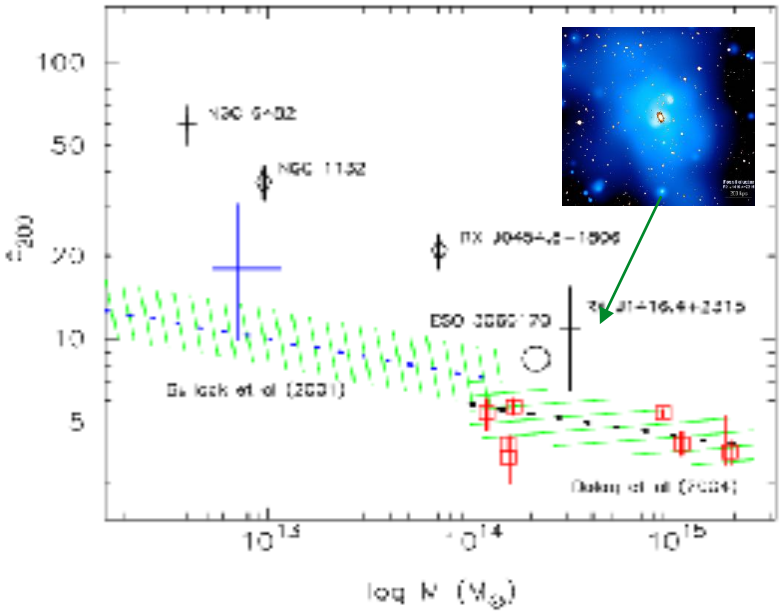
- Galaxy Formation
- Feedback
- Halo - Galaxy connection



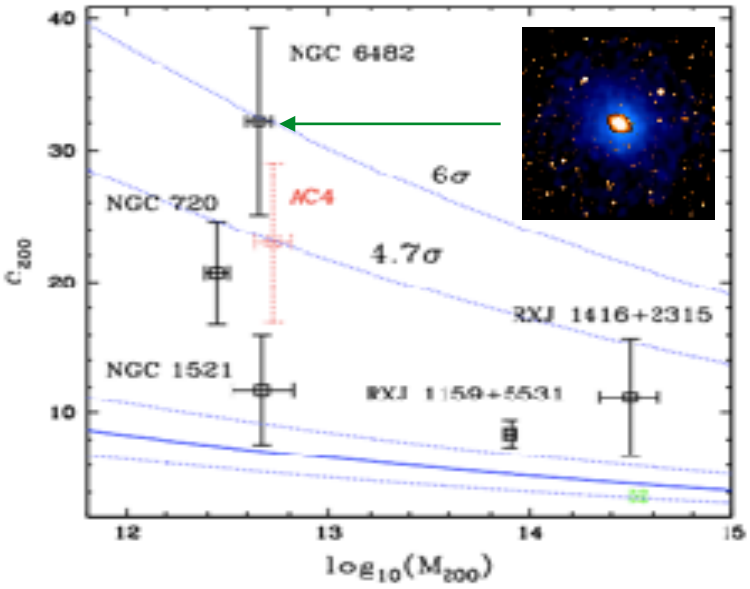
Halo concentration

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

NGC 6482 و the nearest least massive fossil و as the most extreme outlier in C-M relation.

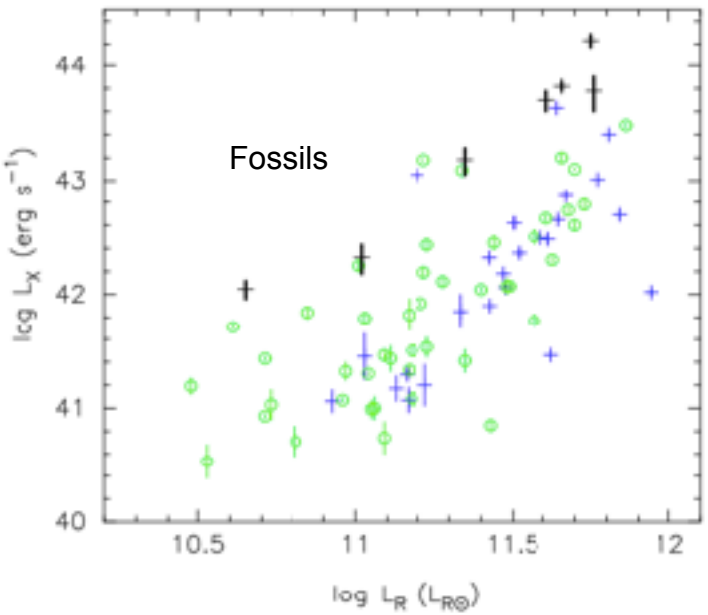


Khosroshahi+ 2007



Buote 2016

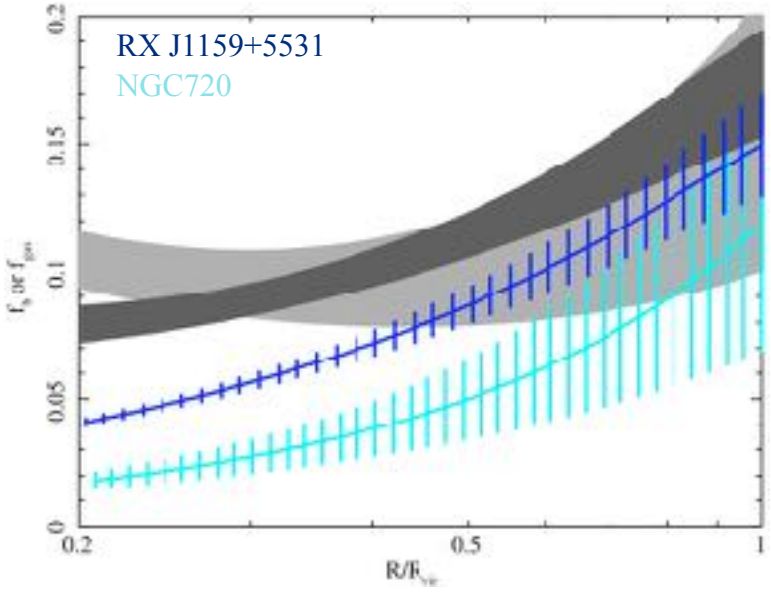
X-ray over-luminous



L_X - L_R relation

Fossils are more X-ray luminous for a given optical luminosity of the group, or they are under-luminous in optical!

Khosroshahi+ 2007

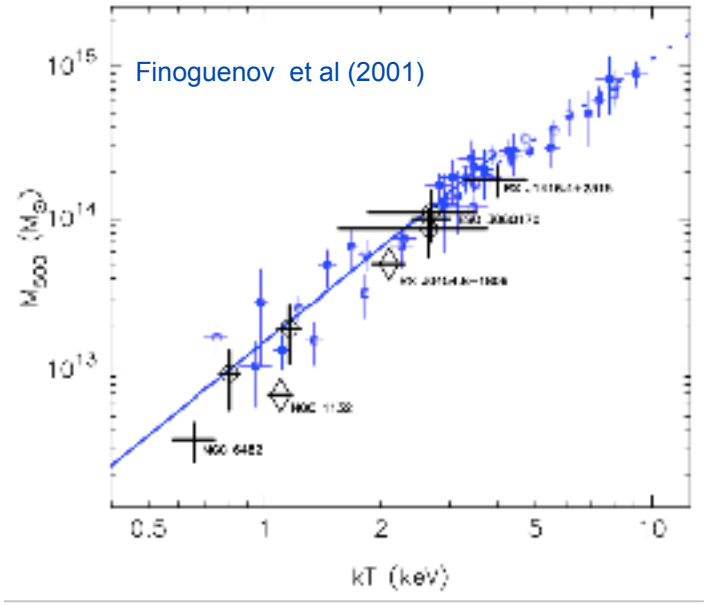


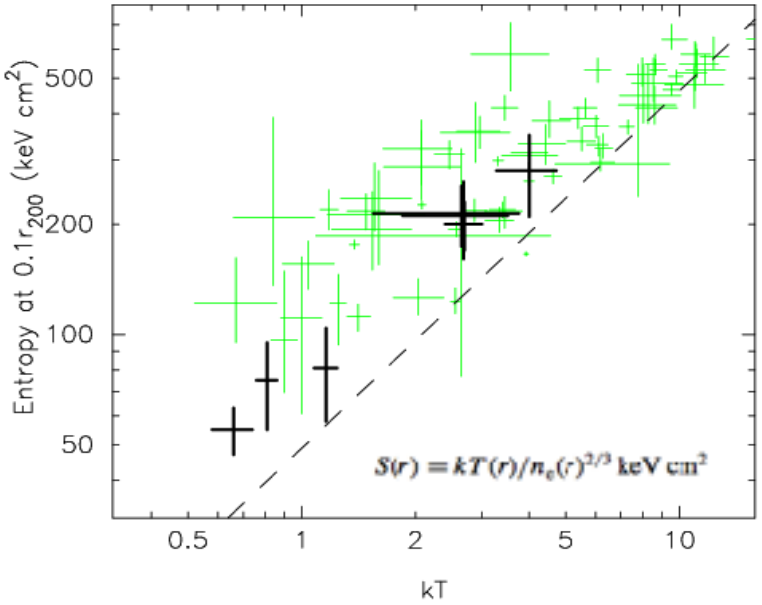
Baryonically closed

Radial profile of f_b and f_{gas} for RX J1159+5531 (dark grey and dark blue regions, respectively), Also shown is the same for NGC720.

Humphrey+ 2012

The IGM





M - T_X relation

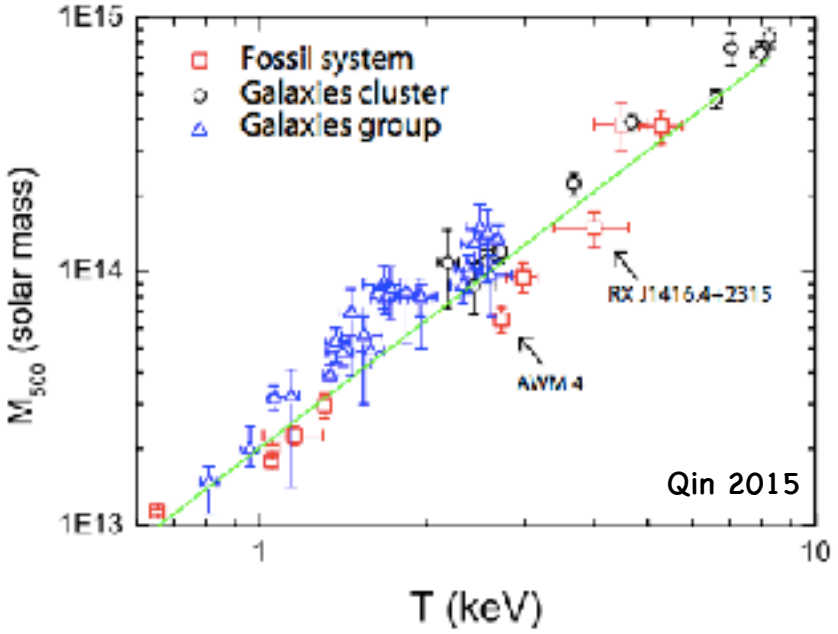
Fossils appear to be hotter than normal groups for a given mass of the system.

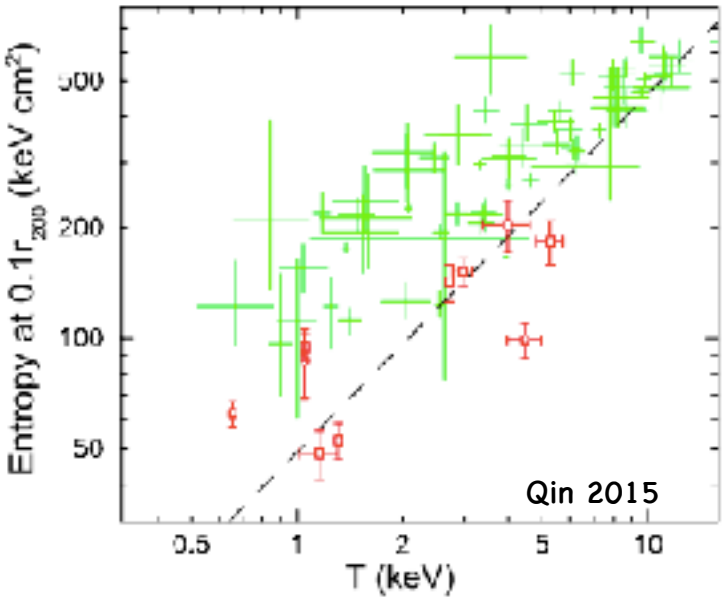
S - T_X relation

Fossils appear to be closest halos to the prediction of self-similar scaling relation than any other system.

Khosroshahi et al (2007)

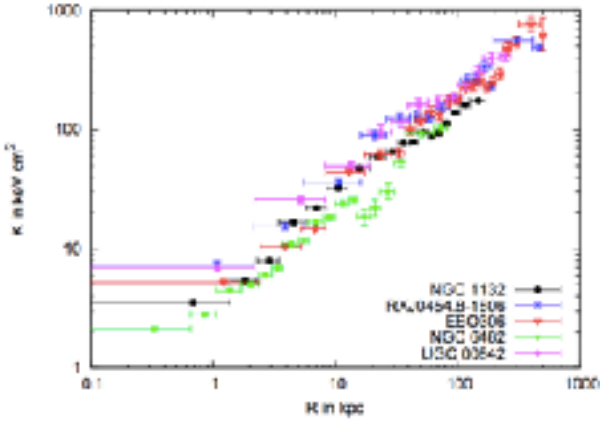
The IGM





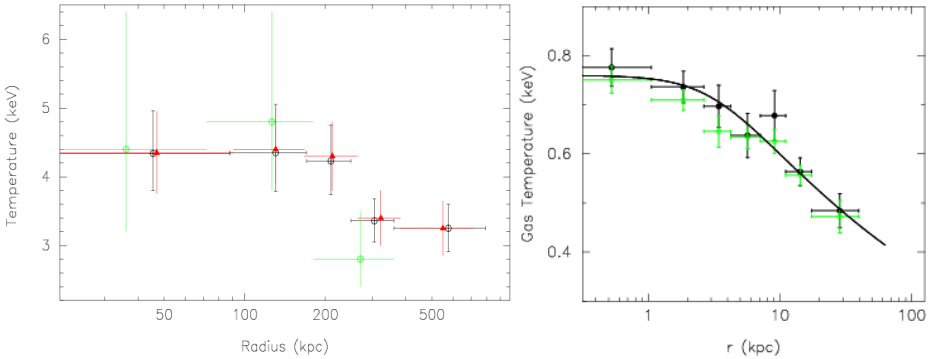
The entropy profiles of the $z < 0.05$ fossil systems can be described well by a power law with shallower indices than what is expected for pure gravitational processes.

Bharadwaj+ 2015



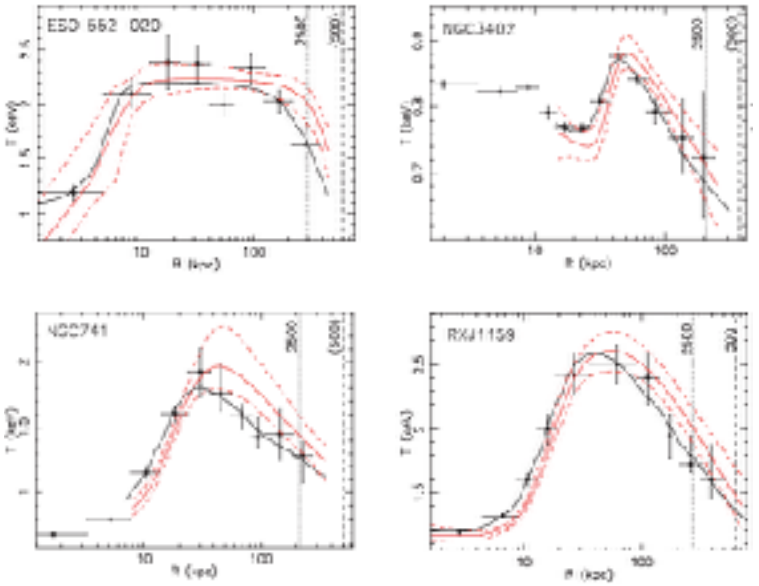
Temperature profile

With no evidence for recent mergers, fossils are ideal environments for the formation of cool cores.

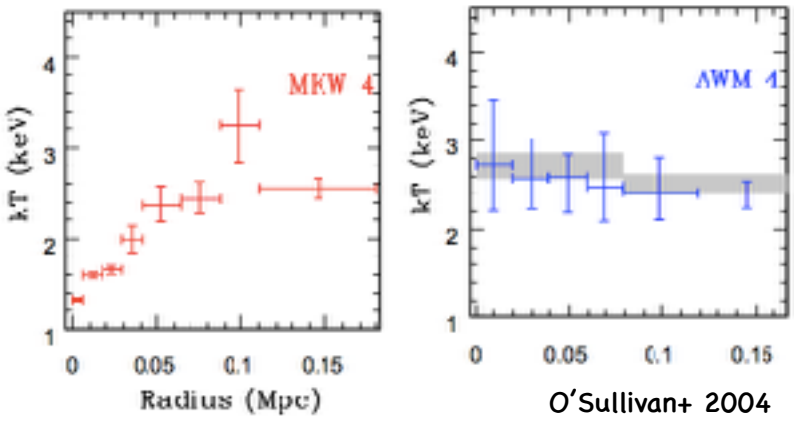


J1416.4+2315 (khosroshahi+ 2006) NGC 6482 (khosroshahi+ 2004)

But the feedback (AGNs, SNe, SF) are in operation!



Sun+ 2009

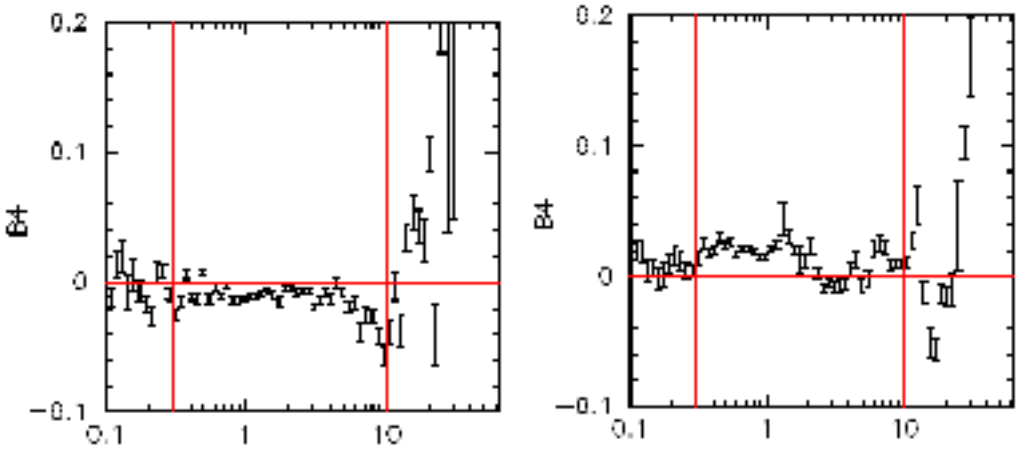


O'Sullivan+ 2004

IPM

The Brightest Group Galaxy

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.



See Khochfar & Burkert (2005)

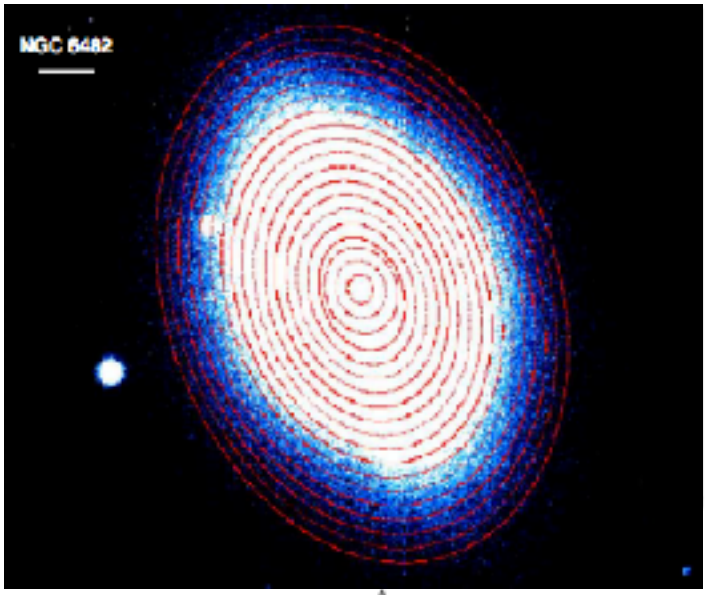


Figure 5. Luminosity gap statistic (Δm_{12}) versus error-weighted mean fourth Fourier component of the BCG light distribution ($\langle B_4 \rangle$). Positive values of $\langle B_4 \rangle$ correspond to Disky BCGs; negative values correspond to Boxy BCGs; values consistent with zero are consistent 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).

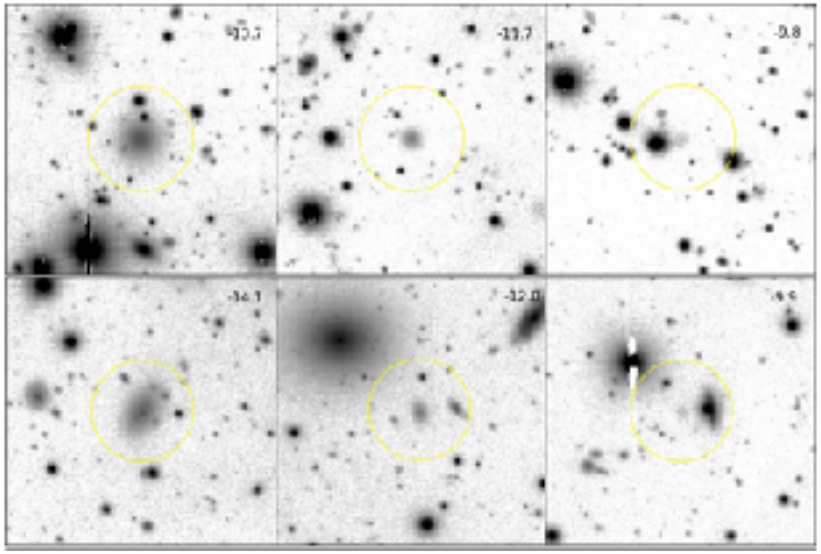
Khosroshahi+ 2006

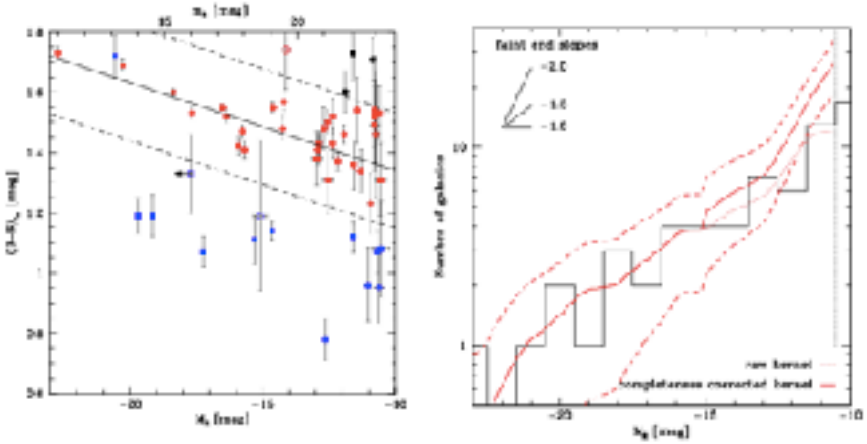
Dwarf galaxies in fossil groups

Subaru/Suprime-Cam wide-field, deep imaging study in the B– and R–bands of the nearest fossil group NGC 6482 covering the virial radius out to 310 kpc.

The completeness-corrected luminosity function is dominated by early-type dwarfs and is characterised by a faint end slope $\alpha = -1.32 \pm 0.05$ (similar to average slope of nearby galaxy clusters).

Photometric properties consistent with those of regular galaxy clusters and groups, including a normal abundance of faint satellites.

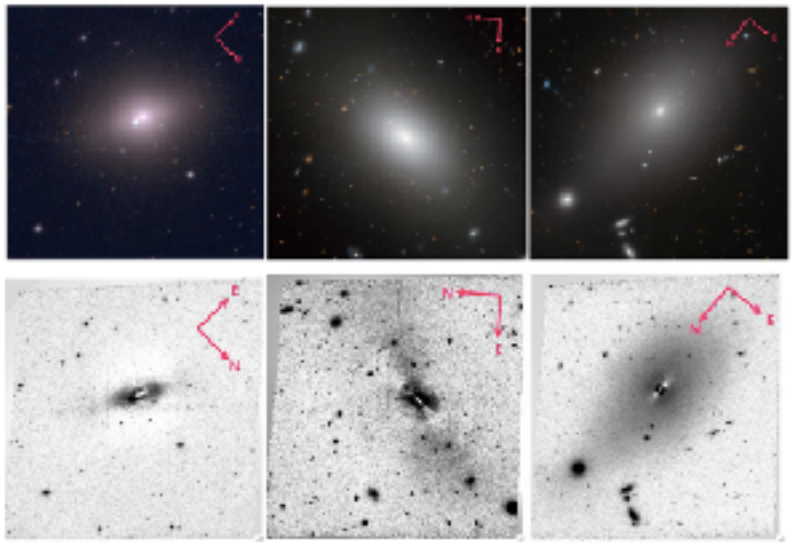




Lieder+ 2013

The BGG - Globular Clusters

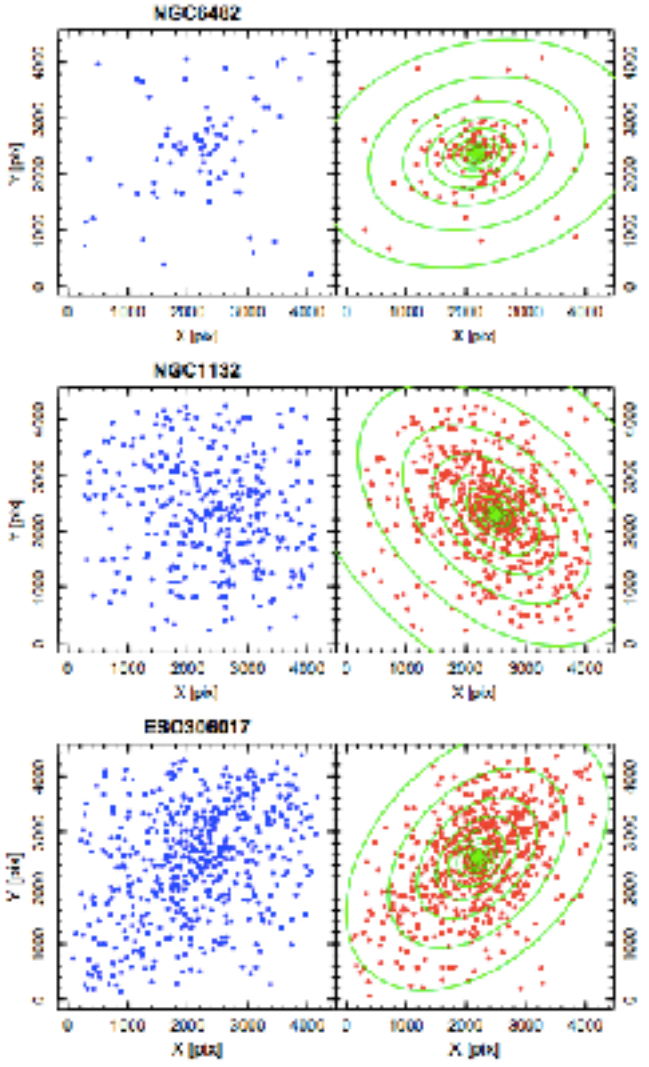
GCs are among the oldest objects in the universe and are powerful tracers of galaxy evolution. The colour bi-modality could, for instance, indicate major episodes in galaxy evolution.



… the paradigm of FGs as relaxed, undisturbed systems needs to be reconsidered.

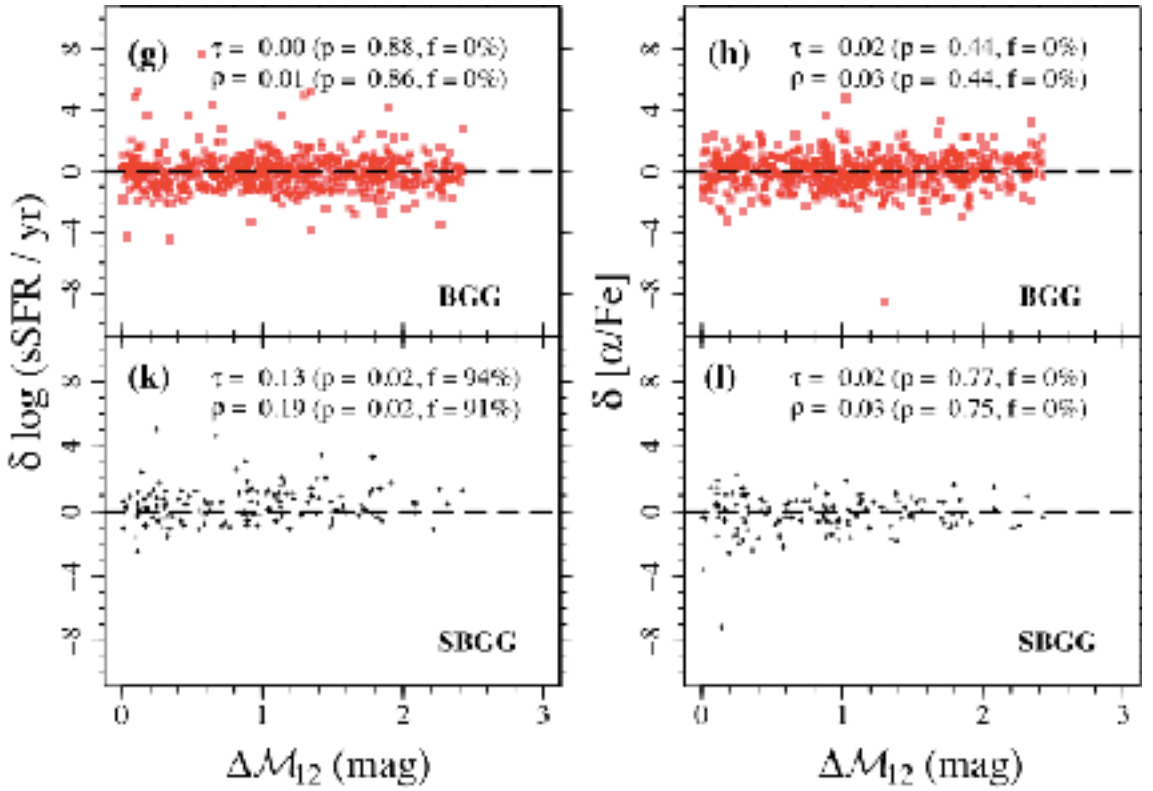
Alamo-Martinez+ 2012

May be not! **Fossil BGGs are merger products …**

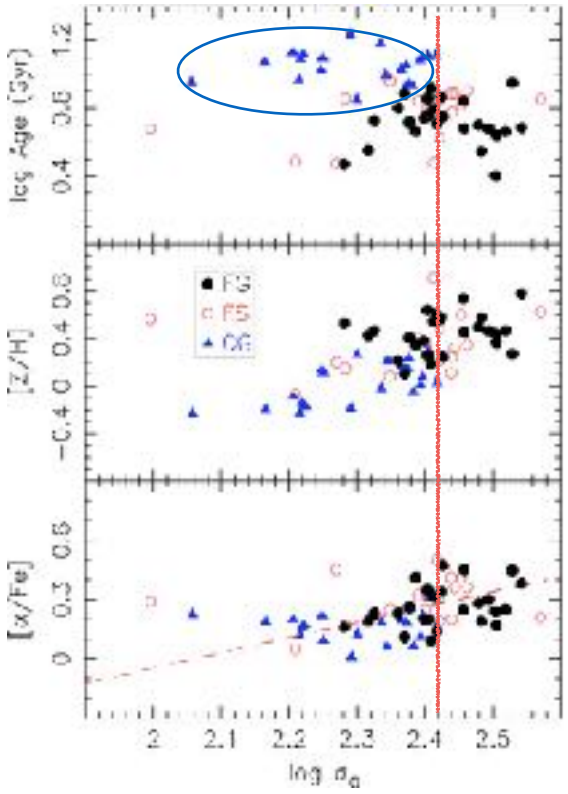


Alamo-Martinez+ 2012

The BGG; Stellar Population



Trevisan+ 2016

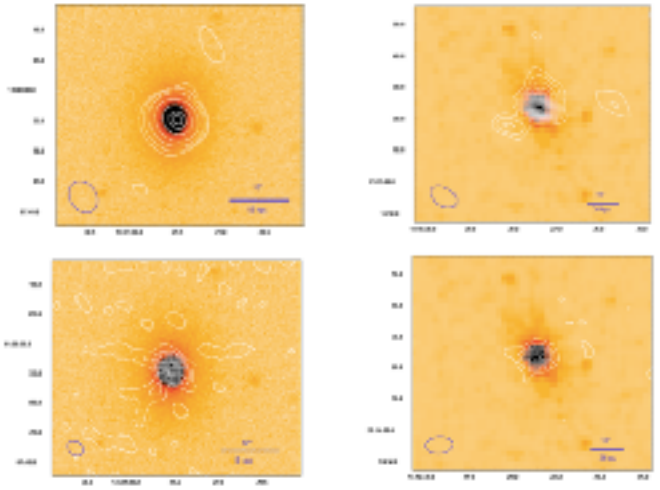


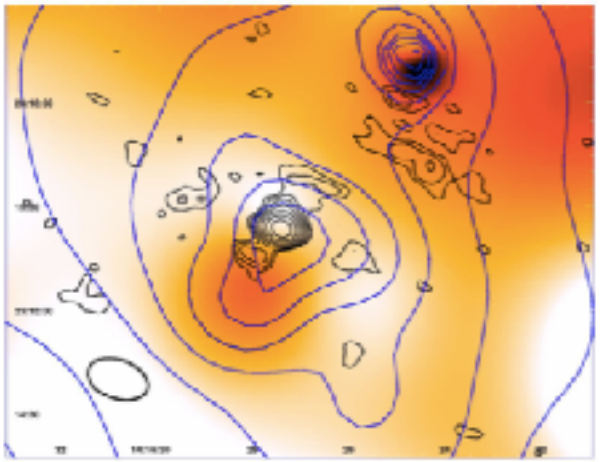
La Barbera+ 2012

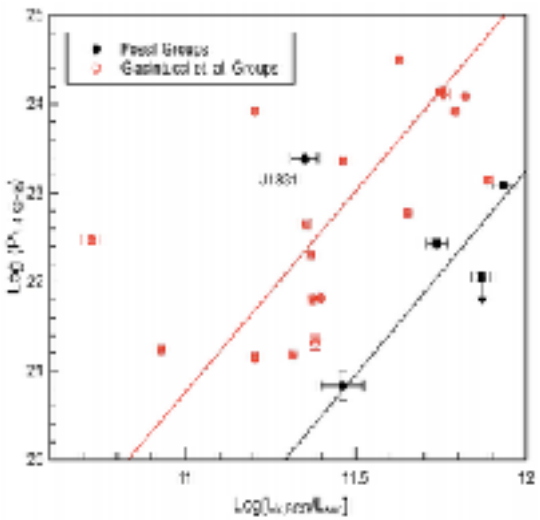
Lack of any meaningful trend with luminosity gap was also suggested by Eigenthaler and Zeilinger (2013)

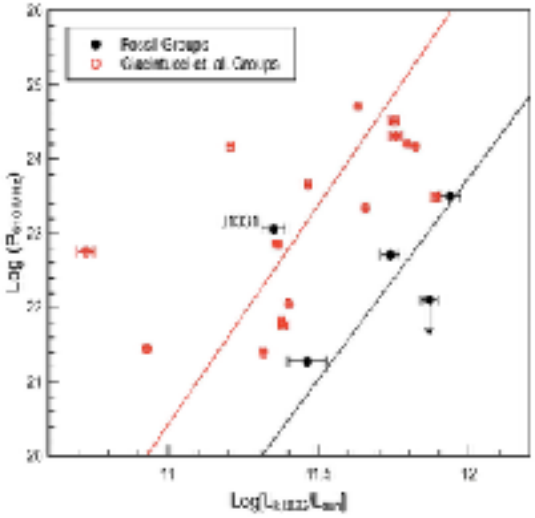
Radio studies of fossil dominant galaxy

GMRT radio observations in 1.4 GHz and 610 MHz observations suggest that for a given stellar mass the BGGs in fossil groups are under-luminous in radio emission.





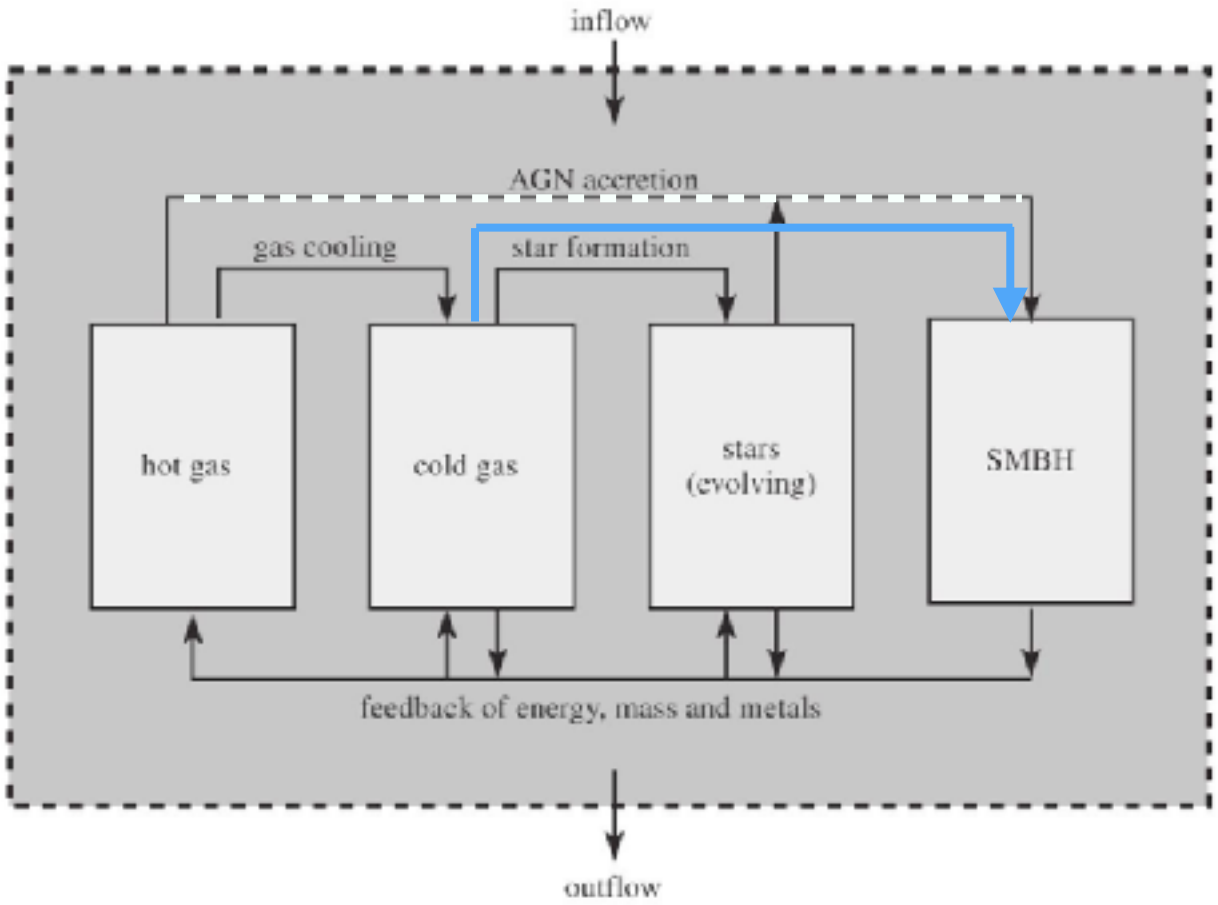




Miraghaee+ 2014, 2015

Dynamically relaxed groups; A simple lab

Group mergers can remove cool cores



Galaxy mergers can trigger AGN activity

Galaxy Formation and Evolution; Mo, van den Bosch, White

Luminosity gap vs. Dynamical relaxation

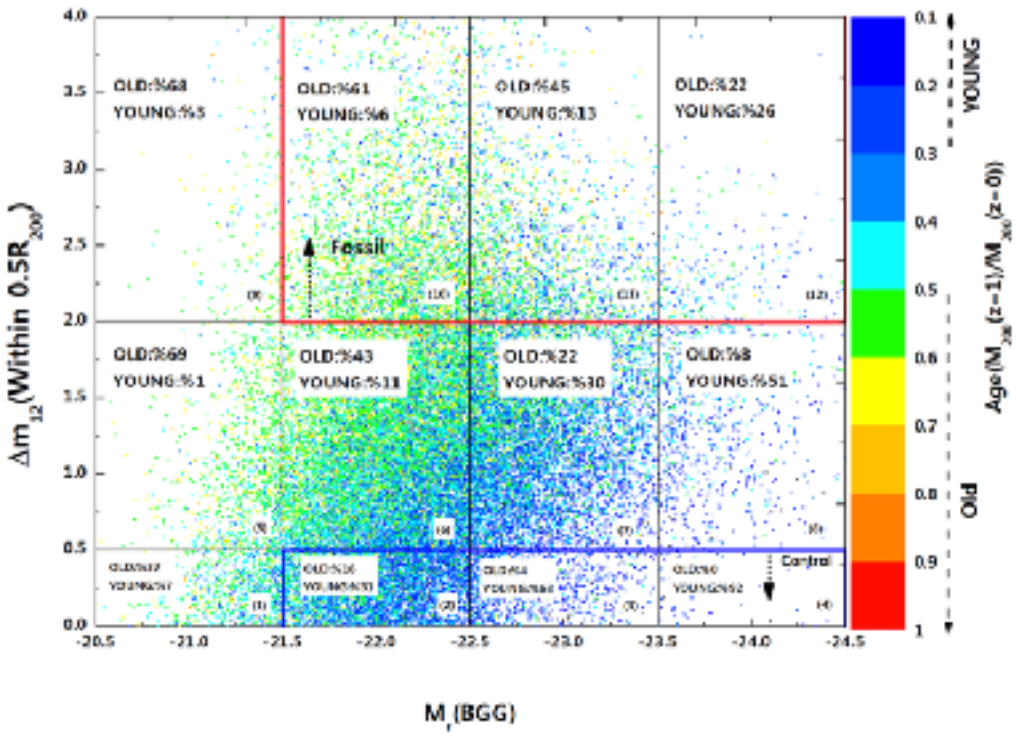
Galaxy groups possessing a large luminosity gap between the two brightest galaxies within a half a Virial radius are relatively older.

The success is limited!

Other age indicators include:

Halo concentration

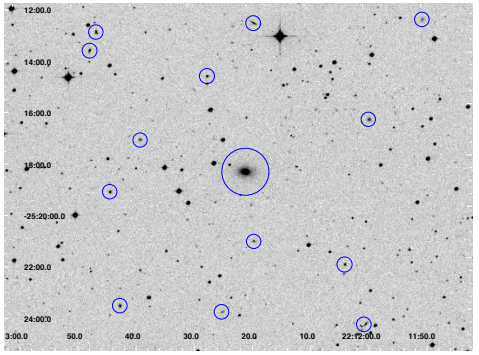
de-centring



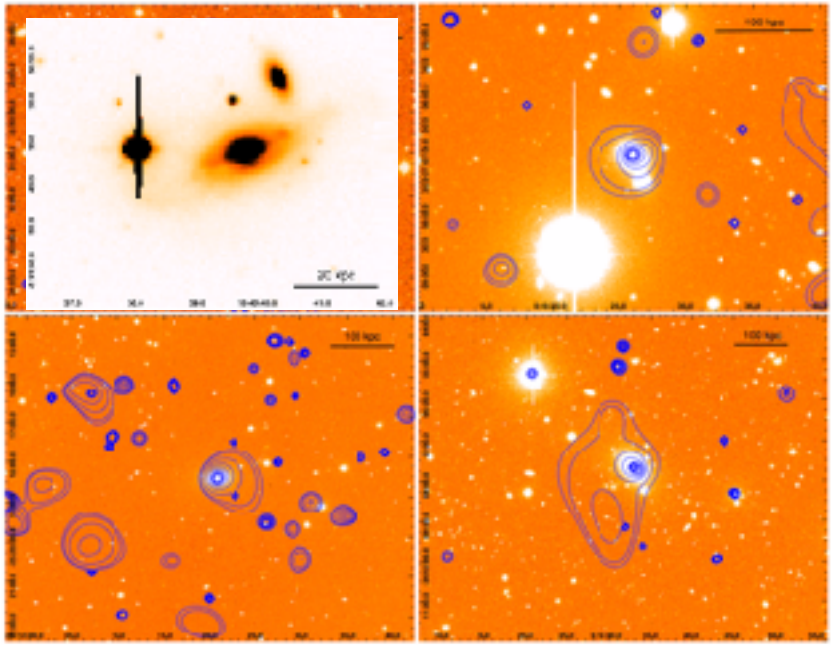
Raouf+ 2014

Optically selected fossils; searching for hot IGM

The primary aim of this work was to test the hypothesis that most of the galaxy merging which builds up giant ellipticals actually takes place in collapsed groups. If this hypothesis is true, then we would expect the great majority of purely optically elected fossil groups to show group-scale X-ray emission.



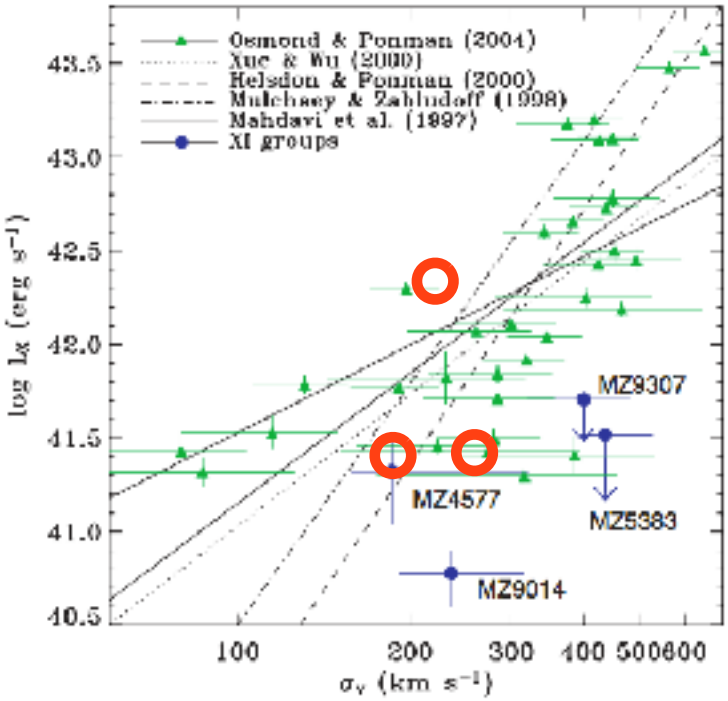
- Groups with at least five confirmed members ($N_{gal} > 4$)
- Groups with magnitude difference between first and second ranked galaxies $\Delta M_{12} > 2.0$
- Groups with a bright early-type dominant galaxy $M_B < -21.5$ and choose only elliptical galaxies.

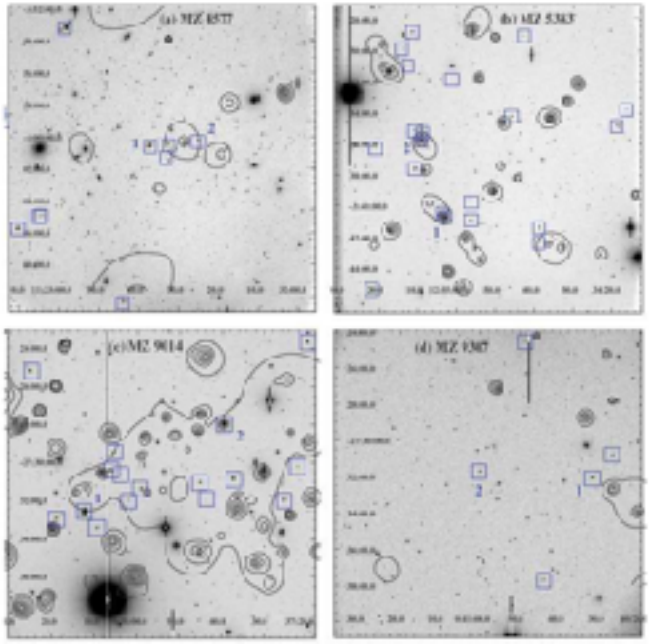


Khosroshahi+ 2014

IGM in optical fossils and in XI groups

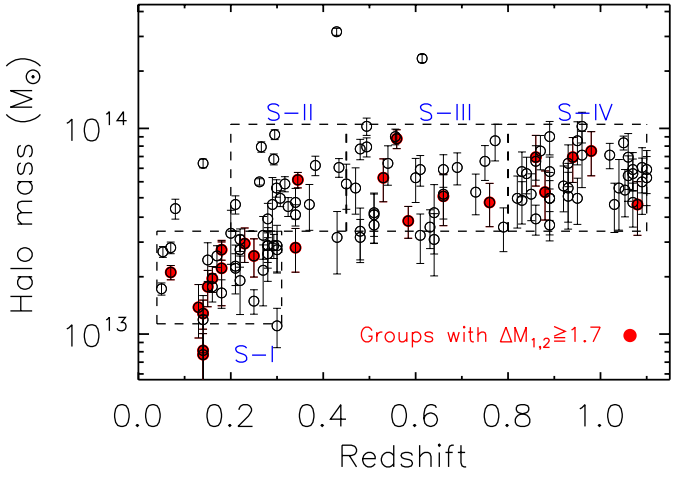
The first results of the XI (XMM/IMACS) Groups Project, a study targeting a redshift-selected, statistically unbiased sample of galaxy groups using deep X-ray data reveals surprisingly faint X-ray emission. They conclude that the X-ray selected sample of groups may not be quite representative of IGM properties of galaxy groups. Possible explanations for the lack of significant X-ray emission in these groups is that they are most likely collapsing for the first time.

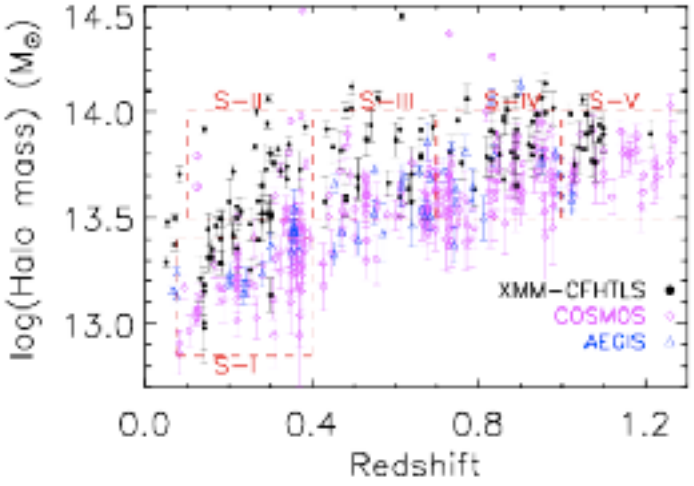




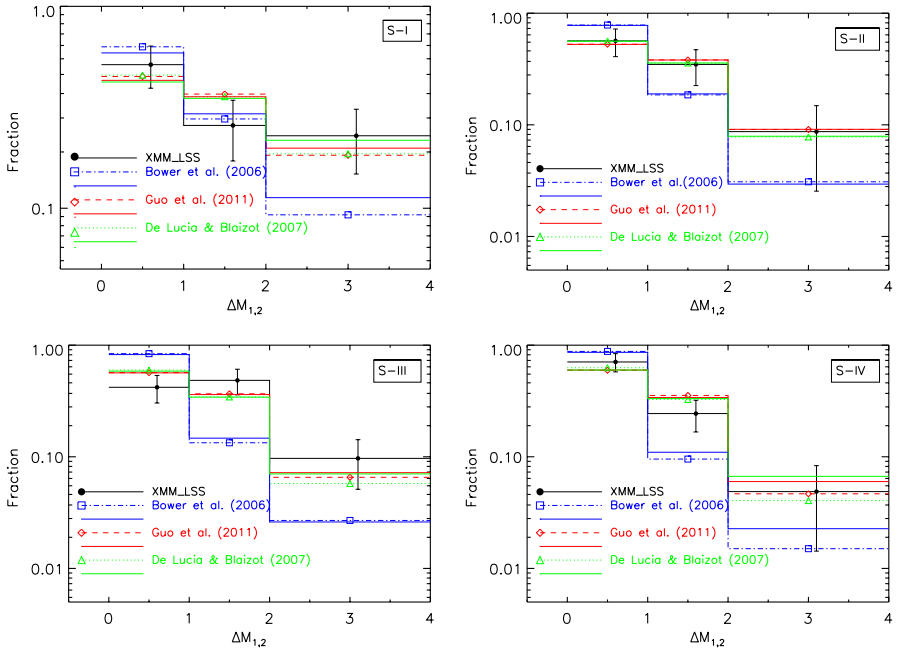
Rasmussen+ 2006

A new sample of fossil groups

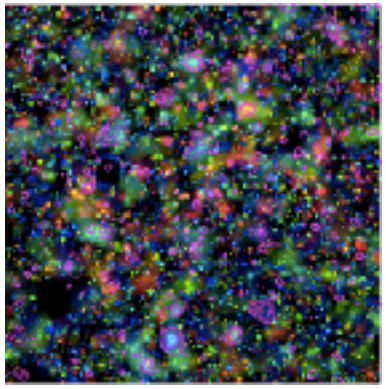


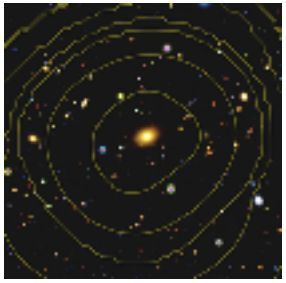


Gozaliasl+ 2016

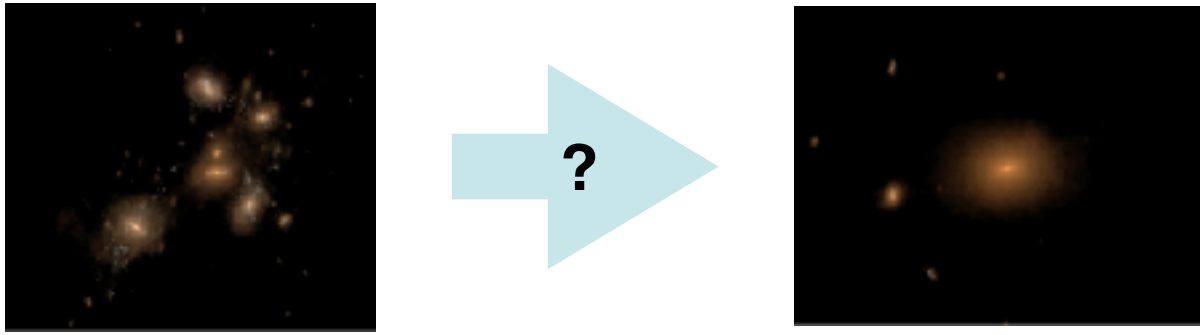


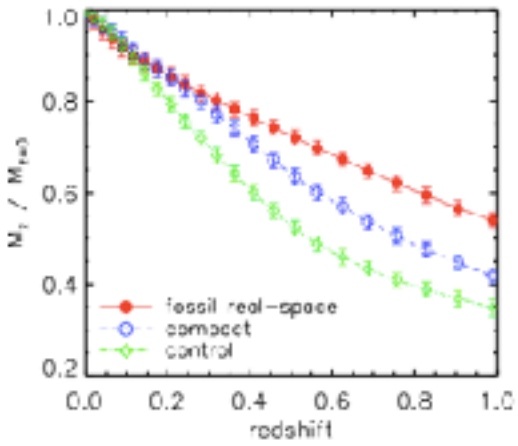
Gozaliasl+ 2014

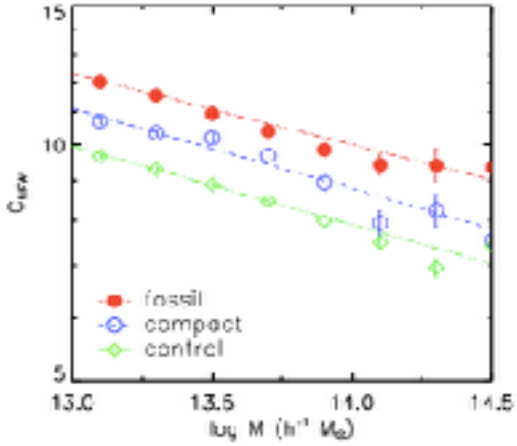




Connection with compact groups







About 30% of fossil groups go through a compact group phase in their life time. Only 2% of compact groups are fossils at any epoch.

Farhang+ in prep.

Fossils Galaxy Groups; verdict … so far!

- Clearly very interesting objects
- Luminosity gap matters but …
- … dynamical relaxation is the key phenomena
- High halo concentration still debated
- Hotter IGM still debated but no contradiction
- No distinction in dominant galaxy properties
- Possible distinct AGN activity
- Only 30% have been compact in the past
- Large statistics and improved sample selection