Mining the Gap

Understanding the formation and evolution of galaxies using the luminosity gap

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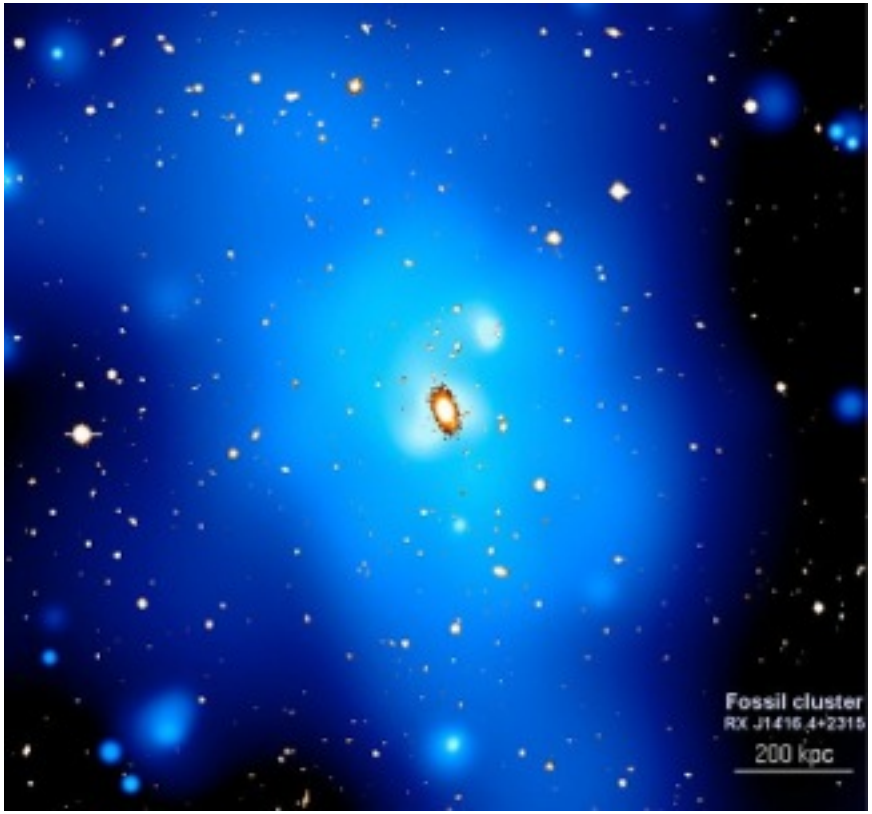
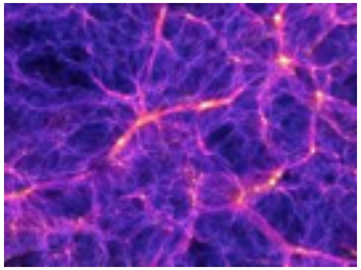
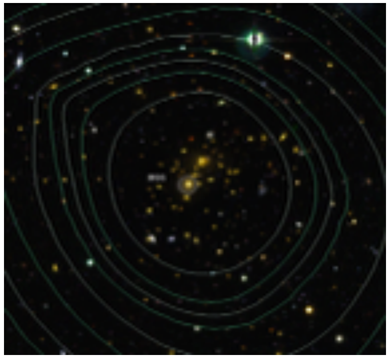
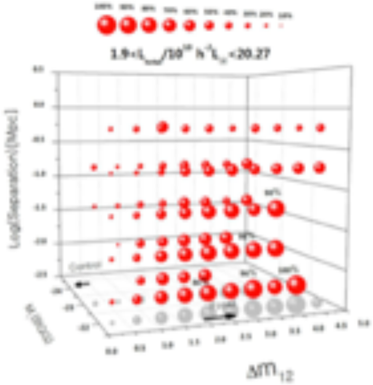


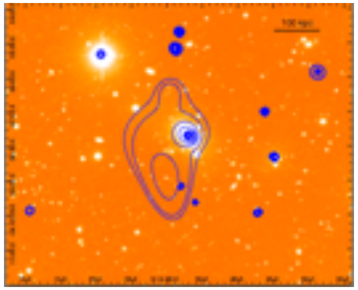
Outline

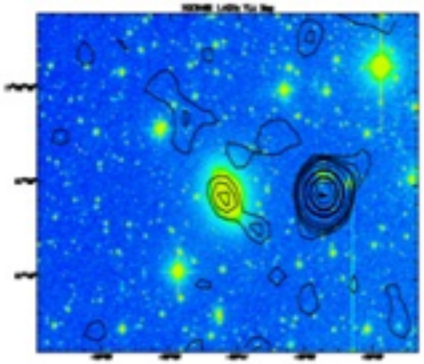
- Introducing the luminosity gap (LG) and fossil groups
- The luminosity gap and fossil groups in cosmological simulations
- Mining the gap at z~1
- Ultimate fossil groups; A routine for Age-dating galaxy groups
- What does the LG tell us about the AGN activities?
- What does a LG tell us about the BGG formation and IGM heating?





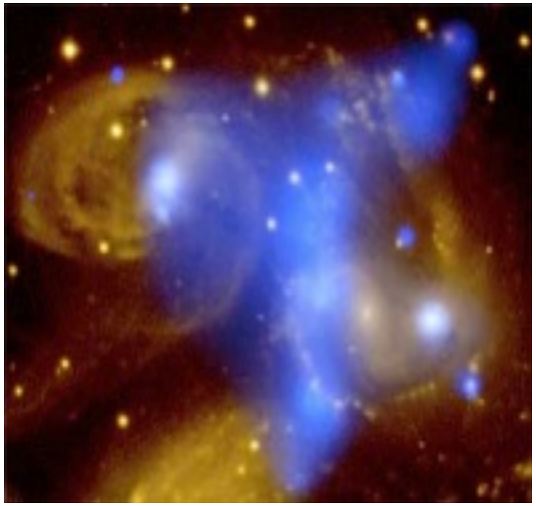






Groups and hierarchical structure formation

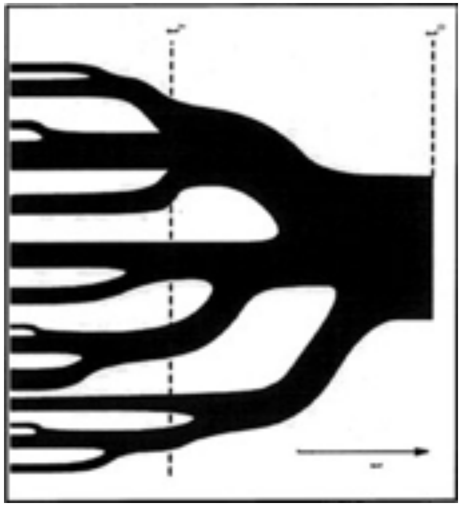
Galaxy clusters are the largest gravitationally bound objects. They form the densest part of the large scale structure of the universe. In models for the gravitational formation of structure with cold dark matter, the smallest structures collapse first and eventually build the largest structures, clusters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



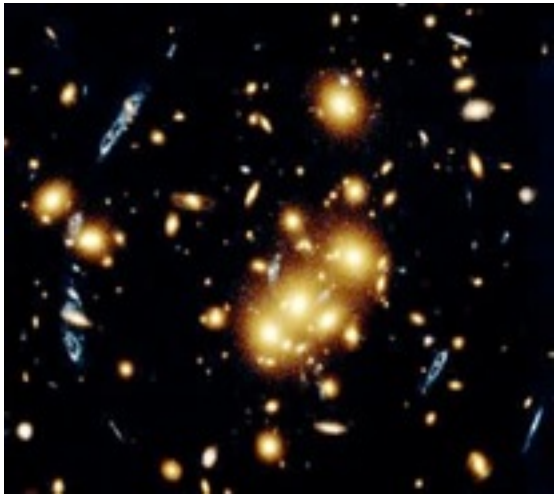
Stephan's Quintet

Low velocity dispersion

Galaxy - Galaxy merger



Merger tree



Cl 0024+16 z~0.4

High velocity dispersion

Ram Pressure Stripping

Fossil galaxy groups

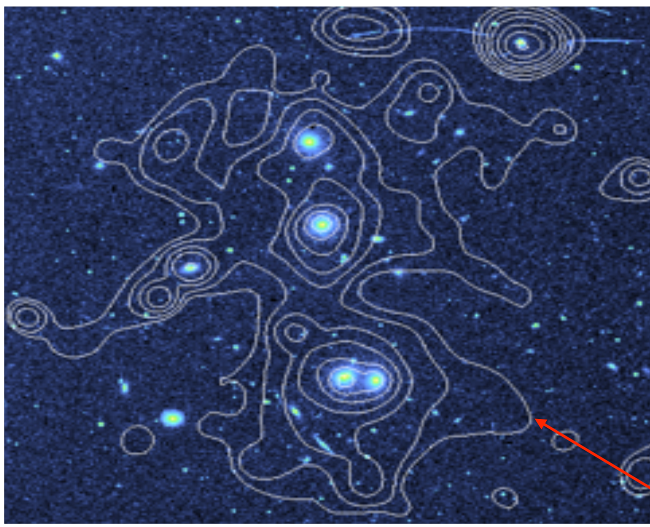
A possible fossil galaxy group

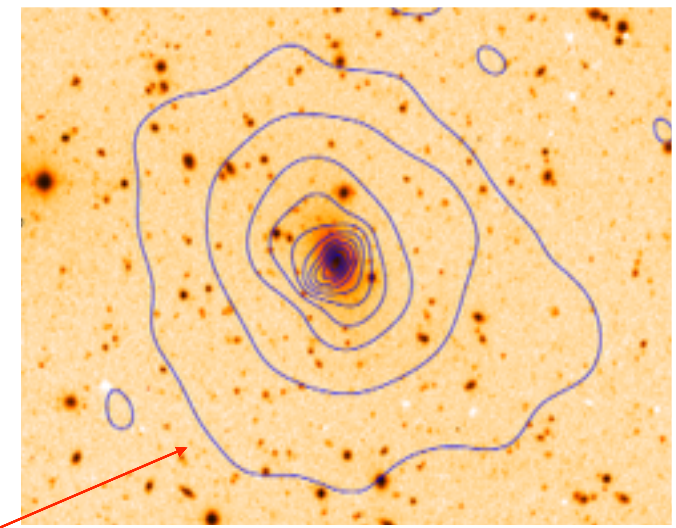
T. J. Ponman[*], D. J. Allan[*], L. R. Jones[†], M. Merrifield[*], I. M. McHardy[†], H. J. Lehto[‡] & G. A. Luppino[§]

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



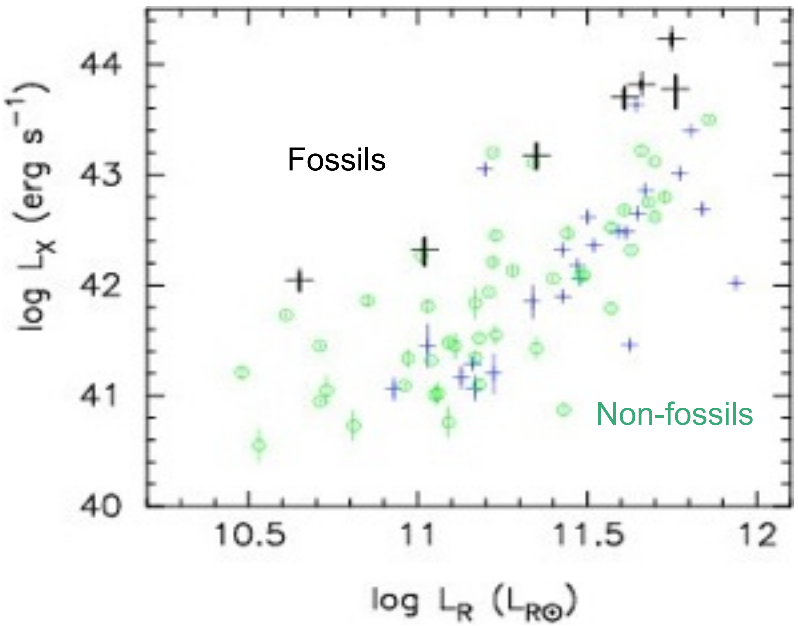


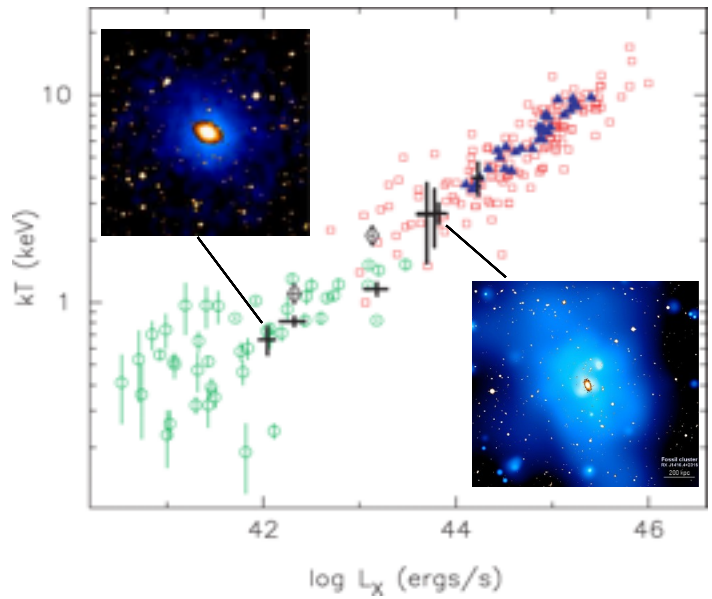
X-ray contours

- 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

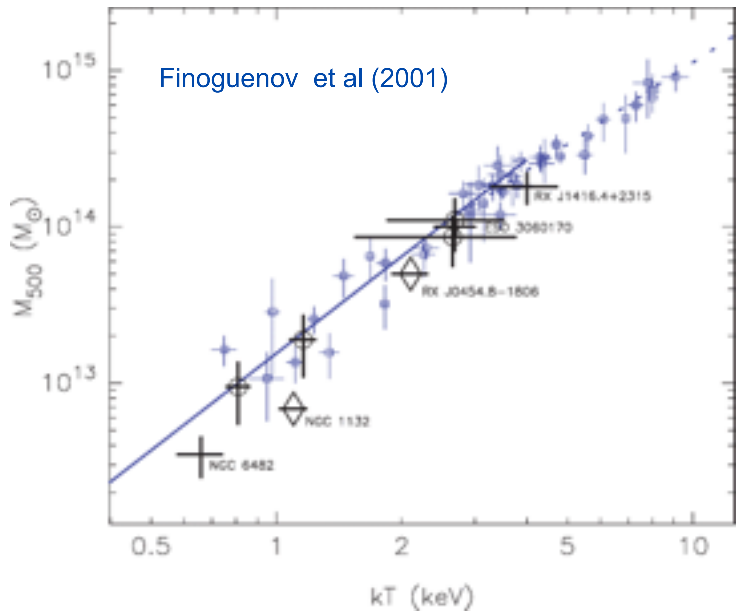
Excess X-ray luminosity for a given optical luminosity of the groups. or simply dimmer in optical?

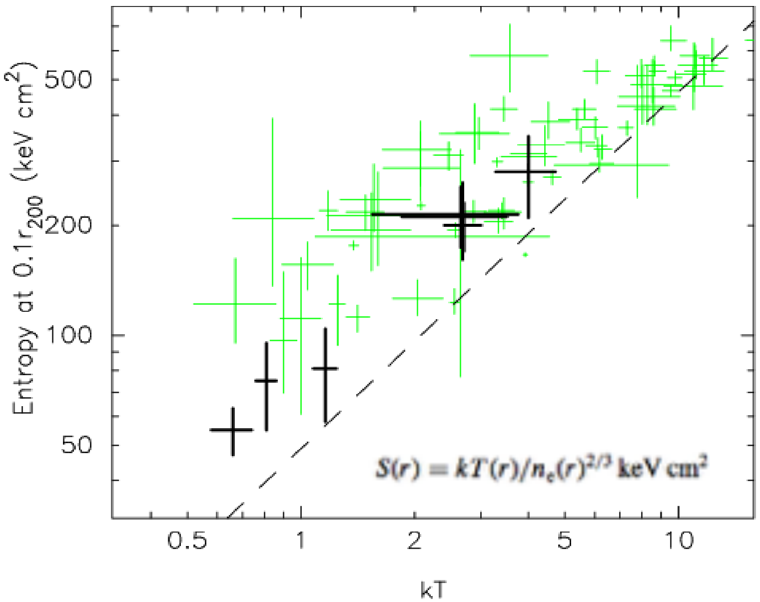
L_X - T_X relation

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

Khosroshahi et al (2007)

X-ray properties II





M - T_X relation

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

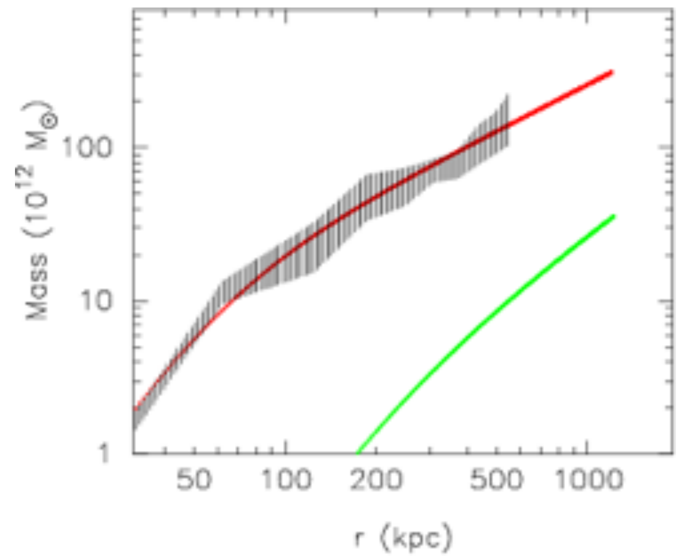
S - T_X relation

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

Khosroshahi et al (2007)

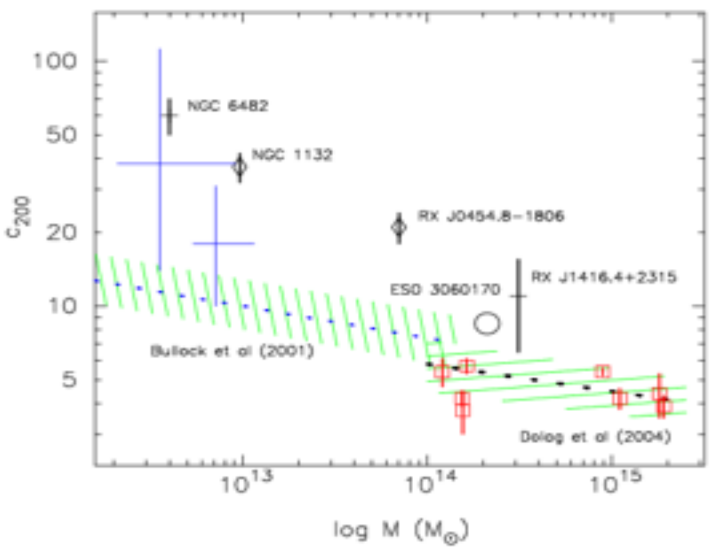
Halo concentration and luminosity gap

- 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.

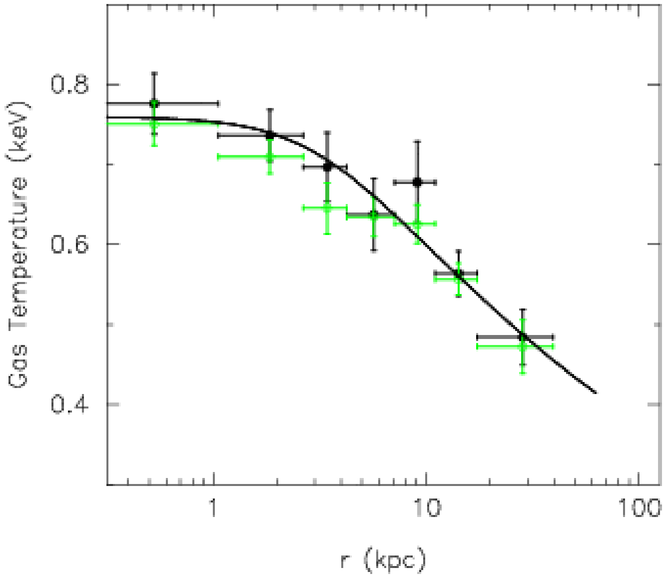


Concentration measurement requires high quality data and is subject to large uncertainties.

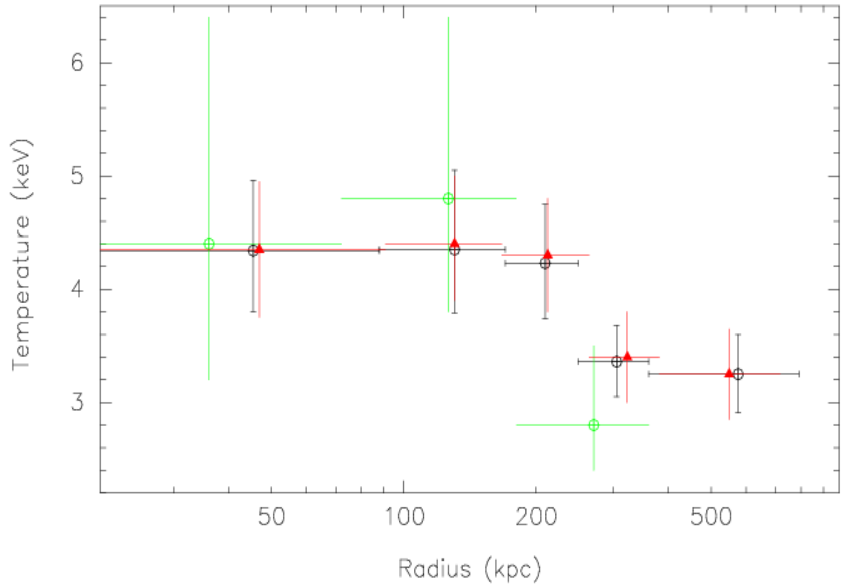
Khosroshahi et al (2007)

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)

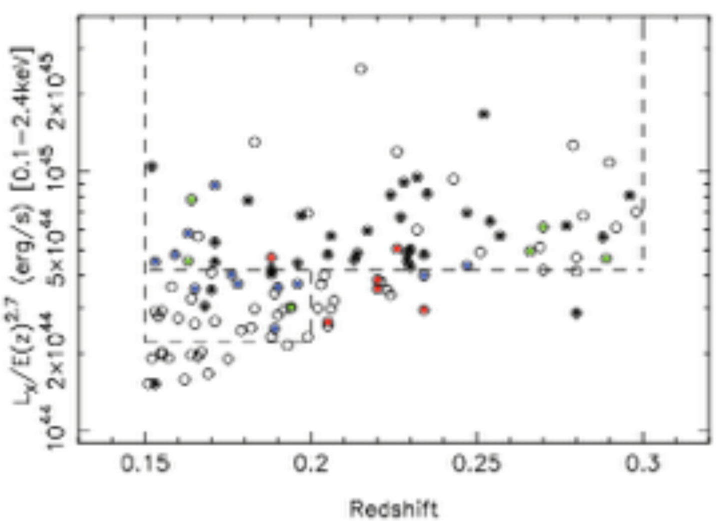
Fossil clusters in LoCuSS

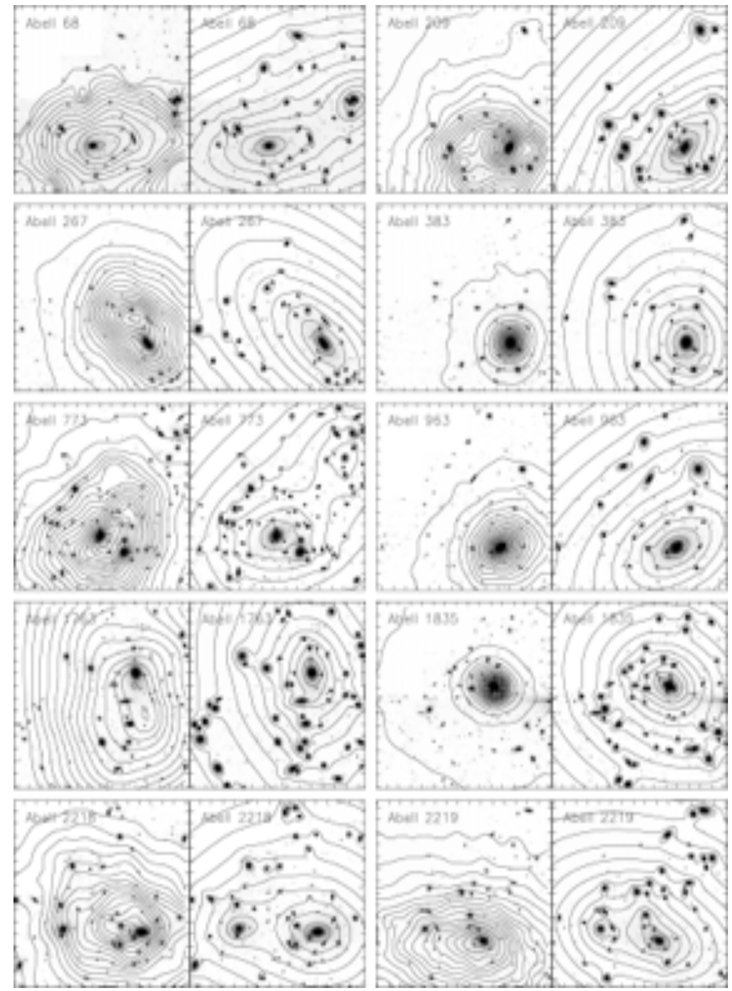
Local Cluster Substructure Survey

A survey to probe the relationship between the structure (assembly history) of galaxy clusters and the evolution of the hot gas and galaxies.

LoCuSS targets 100 low-z (0.15-0.3) clusters from X-ray through optical/IR to radio.

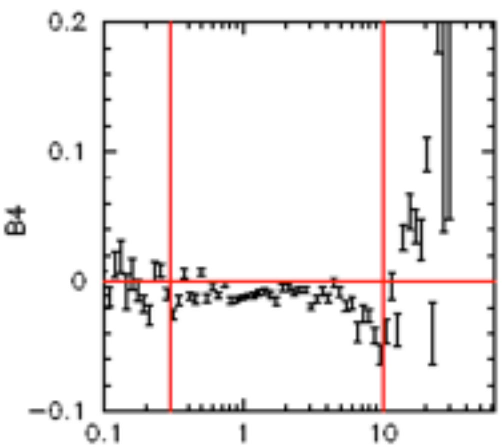
For fossil study we use Ks imaging for 60 clusters combined with HST/ACS (cycle 16) and WFPC2 observations for 35 clusters.

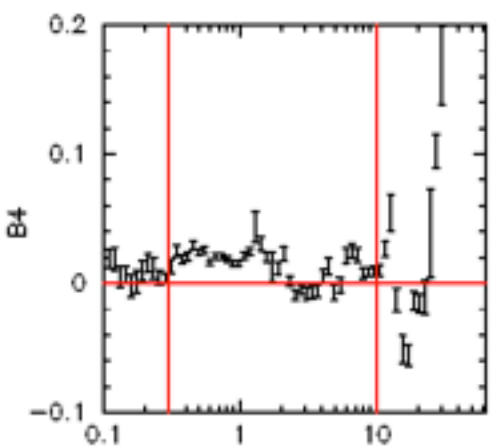




Isophotal shape of fossil BGGs

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.





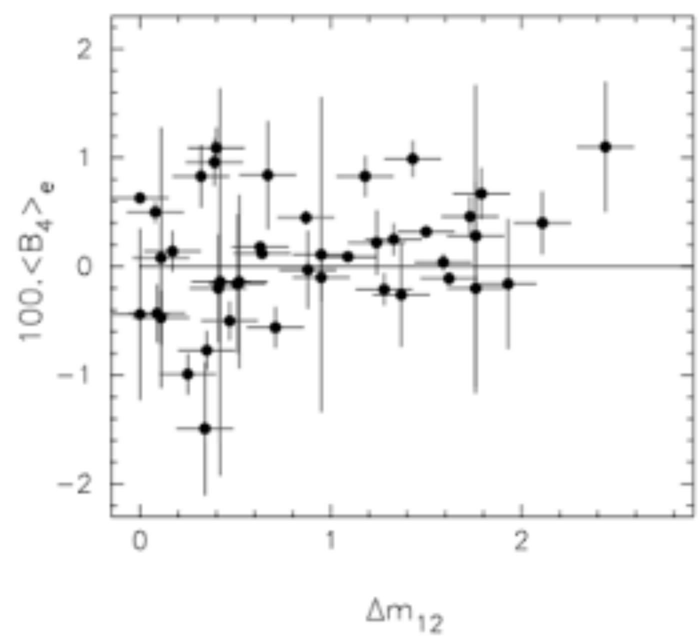


Figure 5. Luminosity gap statistic (Δm_{12}) versus error-weighted mean fourth Fourier component of the BCG light distribution ($\langle B_4 \rangle$). Positive values of $\langle B_4 \rangle$ correspond to Disky BCGs; negative values correspond to Boxy BCGs; values consistent with zero are consistent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

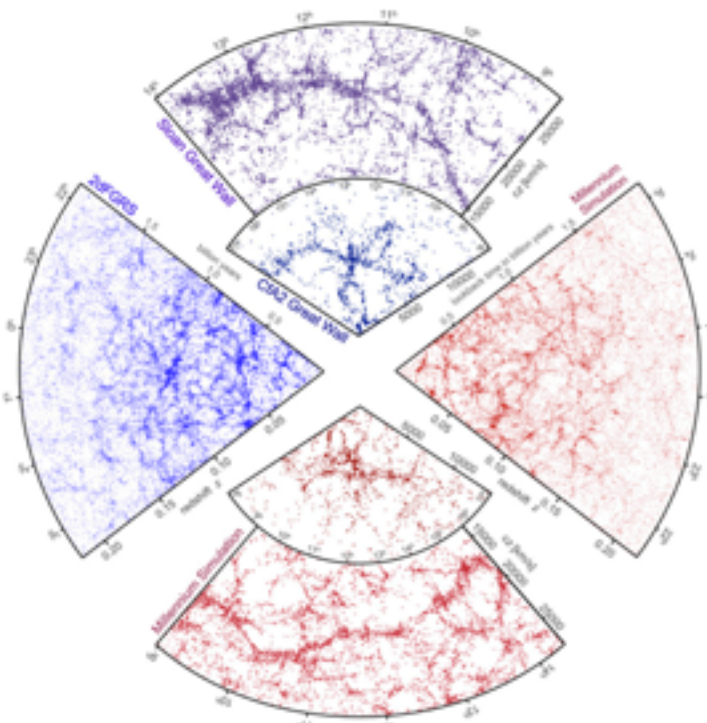
See also: Khochfar & Burkert (2005)

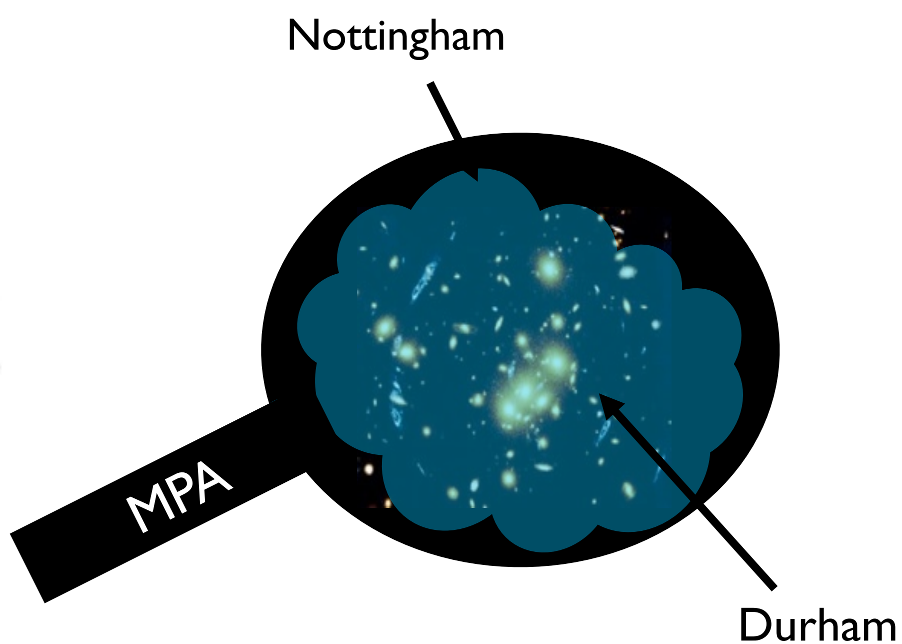
Smith, Khosroshahi et al (2010)

Semi-analytic recipe for galaxies

Dark halo + **GALAXIES** + Hot gas

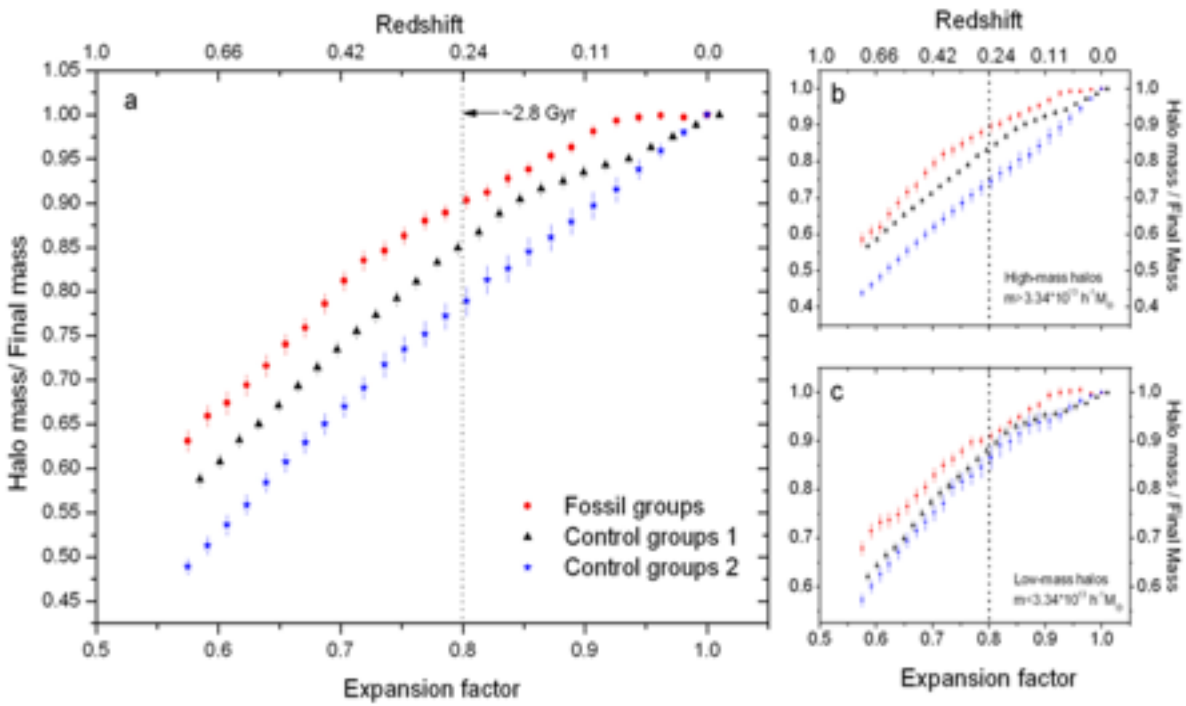
Springel et al 2005 — Croton et al 2006 — Pearce et al 2007



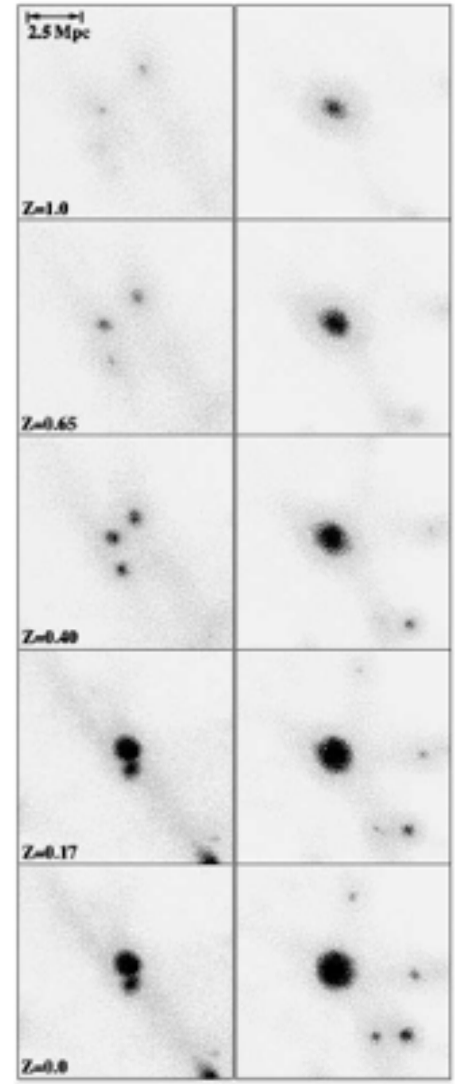


See D'Onghia et al. 2005 for a hydrodynamical appraoch

Halo mass evolution in fossil groups



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



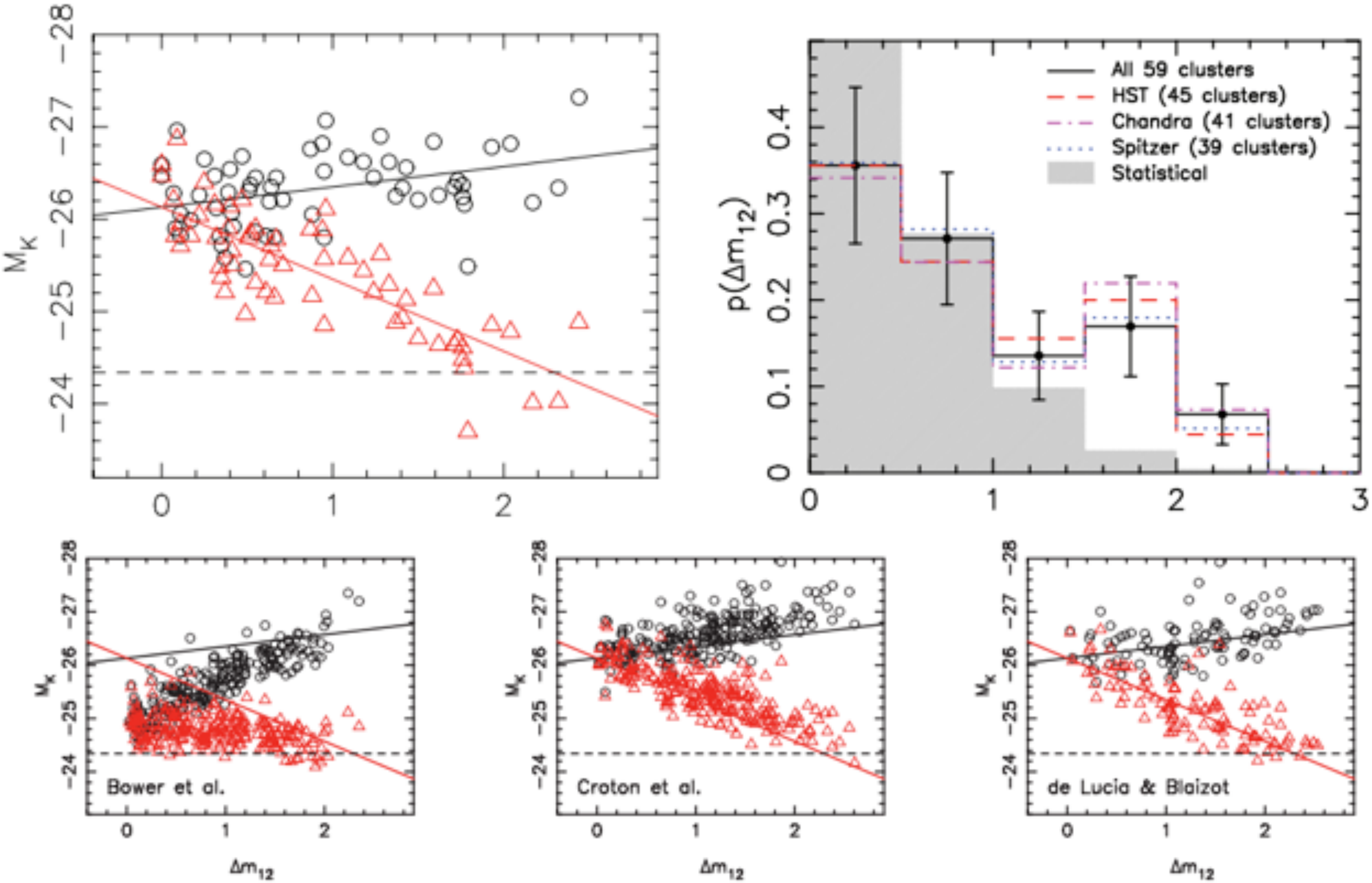
Dariush , Khosroshahi, et al (2007)

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.

Probing Semi-analytic models

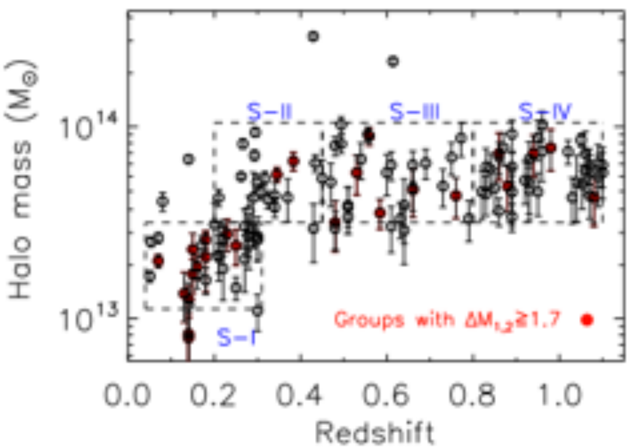


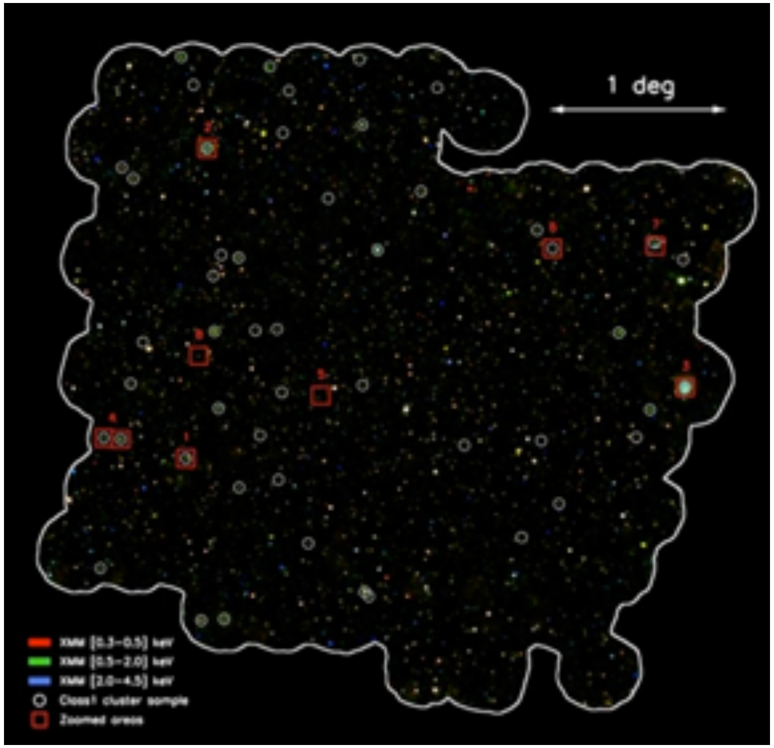
Smith, Khosroshahi et al (2010)

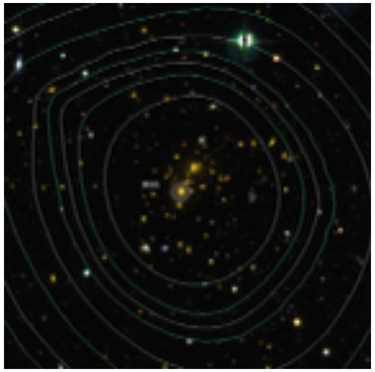
Mining the gap at z~1

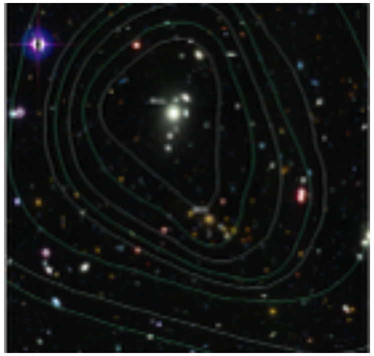
We identify and study 129 X-ray galaxy groups, covering a redshift range 0.04 <z< 1.10, selected in the 3 degree² of the CFHTLS W1 field overlapping XMM observations performed under the XMM-LSS project.

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.





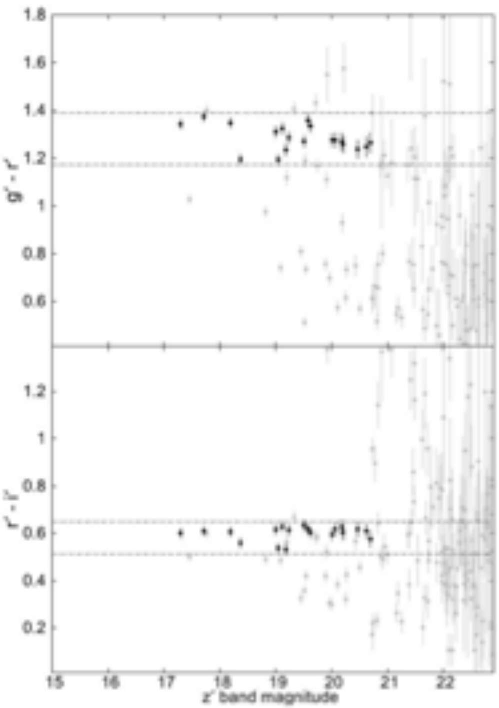


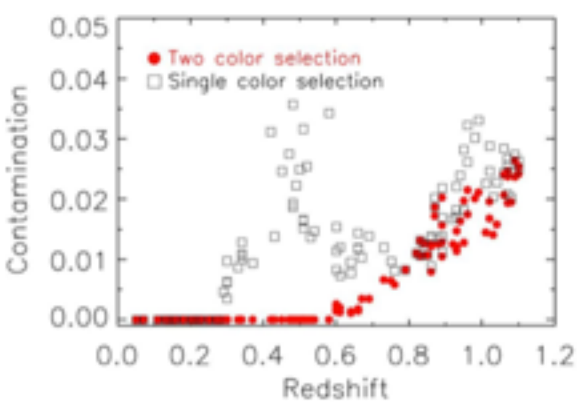


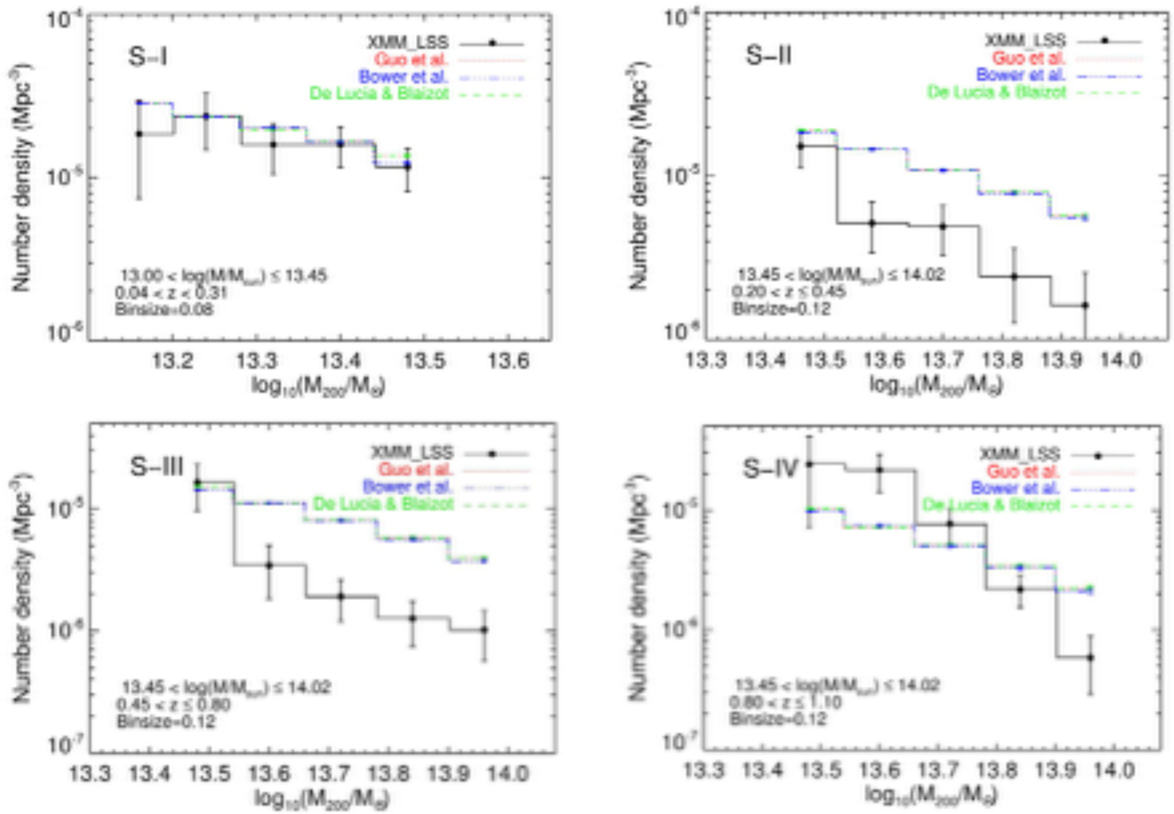
We carry out a statistical study of the redshift evolution out to redshift one of the magnitude gap between the first and the second brightest cluster galaxies of a well defined mass-selected group sample.

Gozaliasl, Finoguenov, Khosroshahi et al (2014)

Group identification; two colours selection

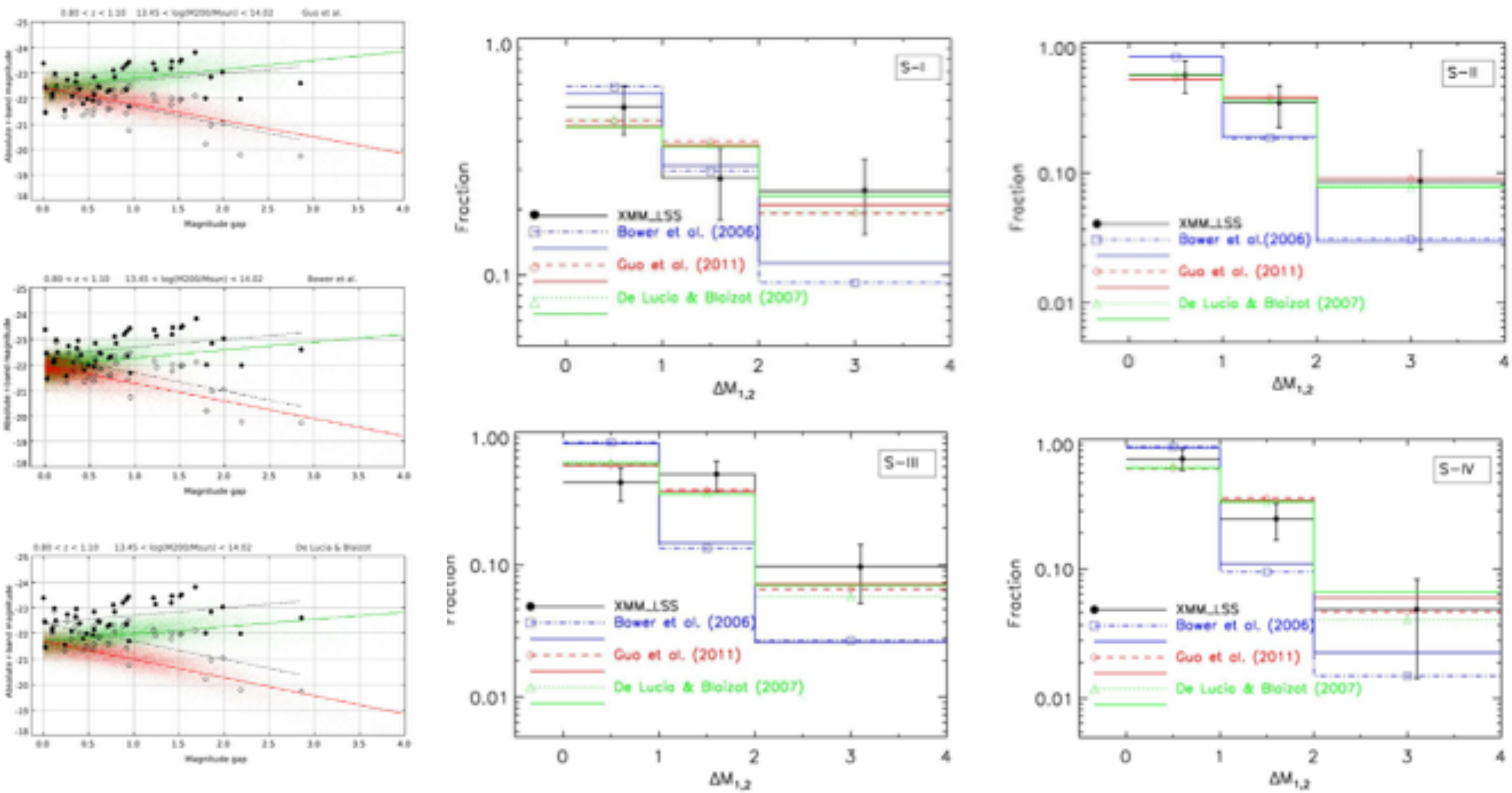






The observed number density of galaxy groups as a function of halo mass (black histogram with error bars) compared to the halo catalogs of B06, DLB07 and G11 for S–I (top left panel), S–II (top right panel), S–III (bottom left panel) and S–IV (bottom right panel).

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; beyond the LG

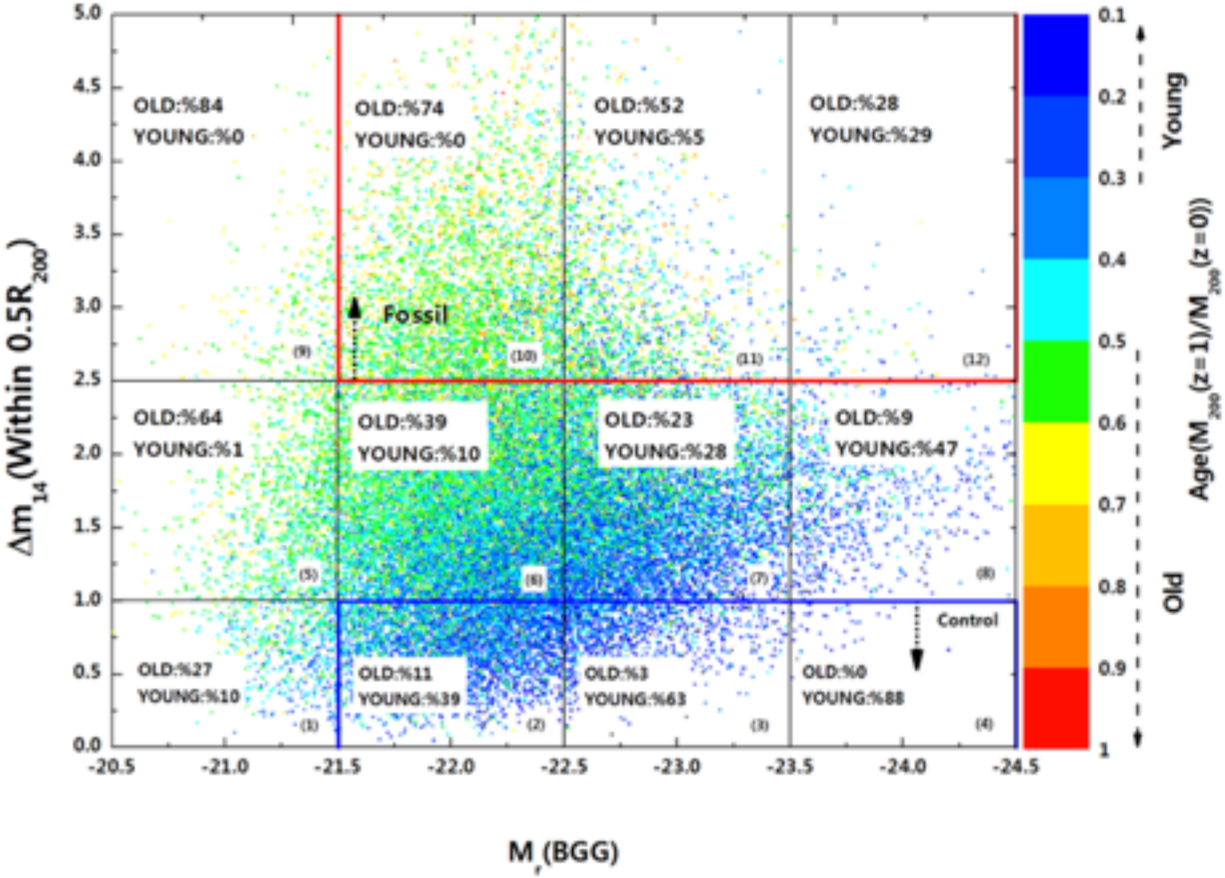
Galaxy groups possessing a large luminosity gap between the two brightest galaxies within a half a Virial radius are relatively older.

The success is limited!

Other age indicators include:

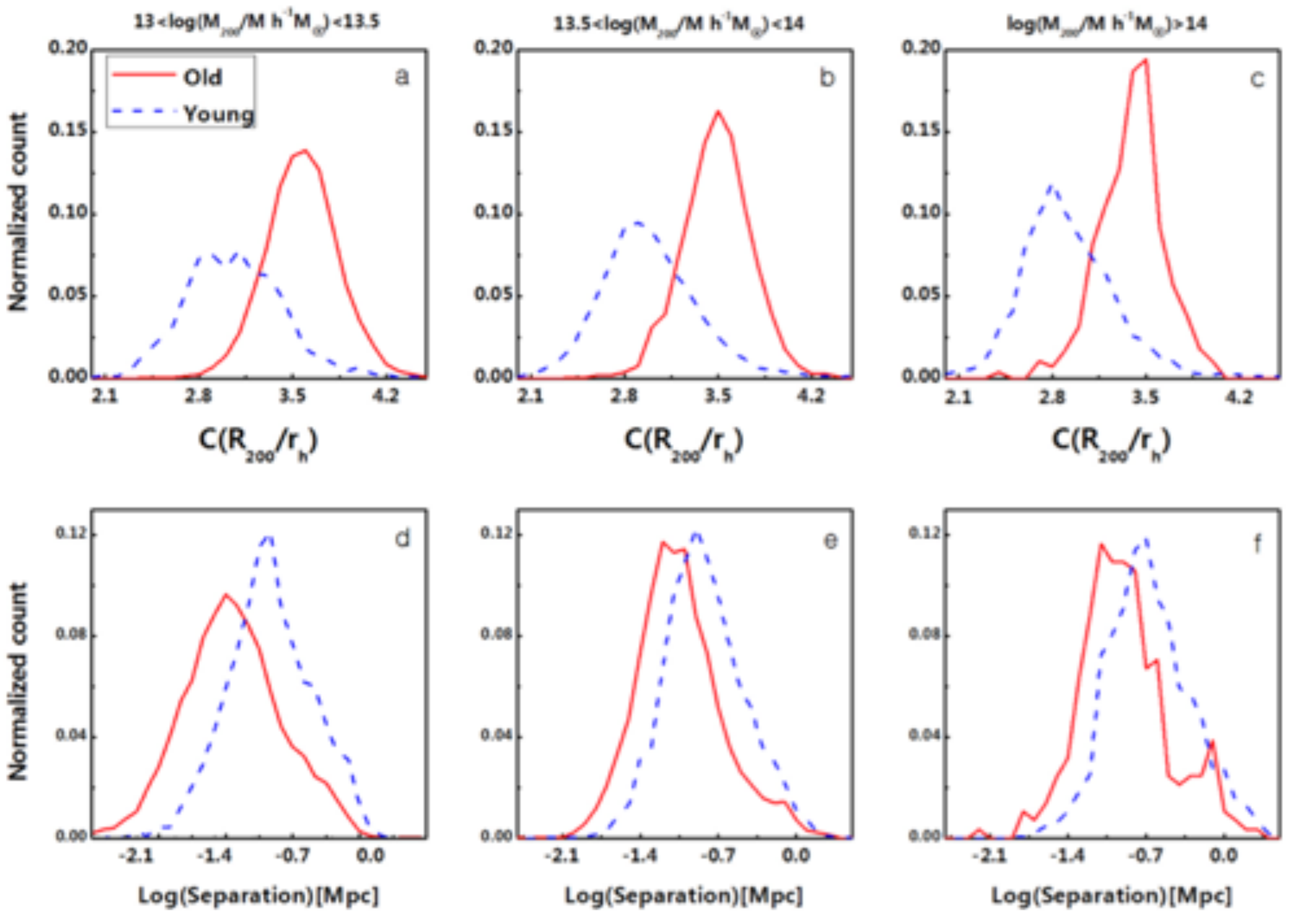
Halo concentration

de-centring



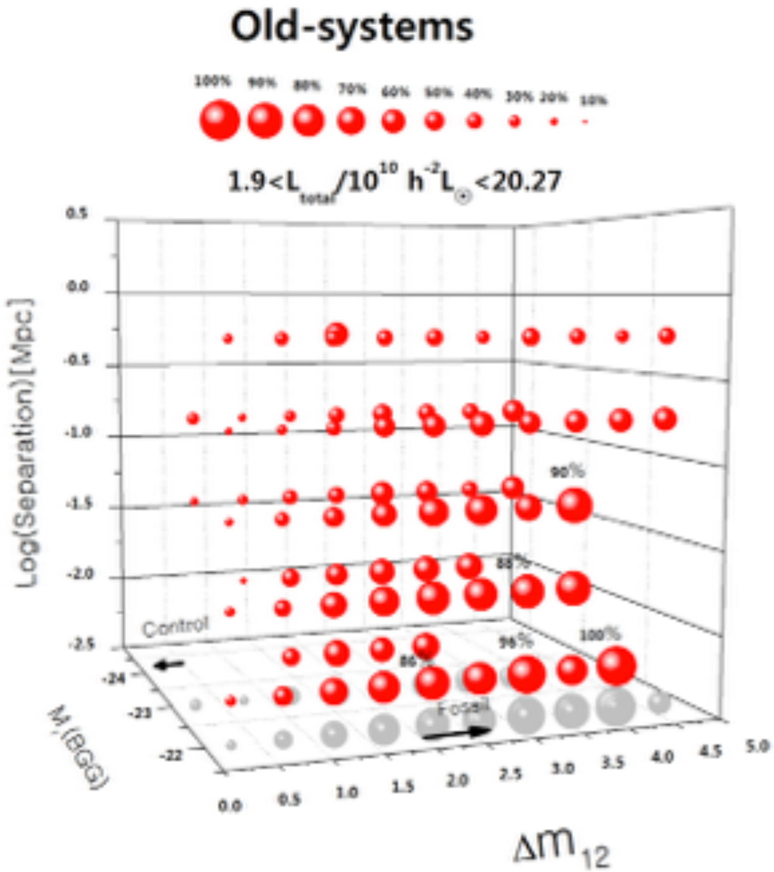
Raouf and Khosroshahi et al (2014)

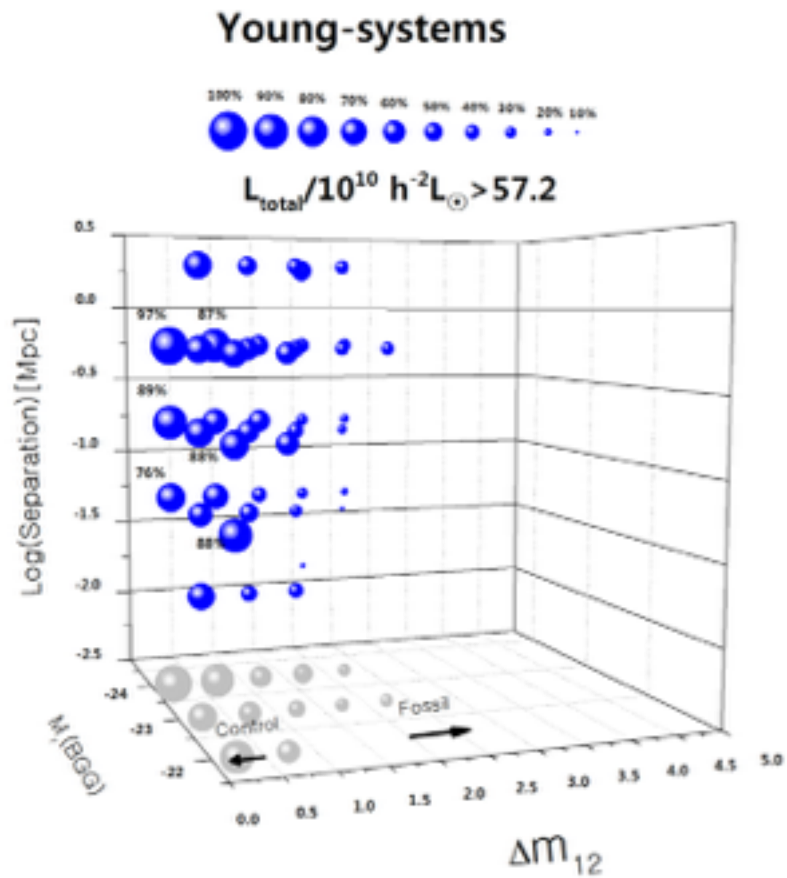
Age dating galaxy groups; beyond the LG



Raouf and Khosroshahi et al (2014)

Age-dating in multi parameter space



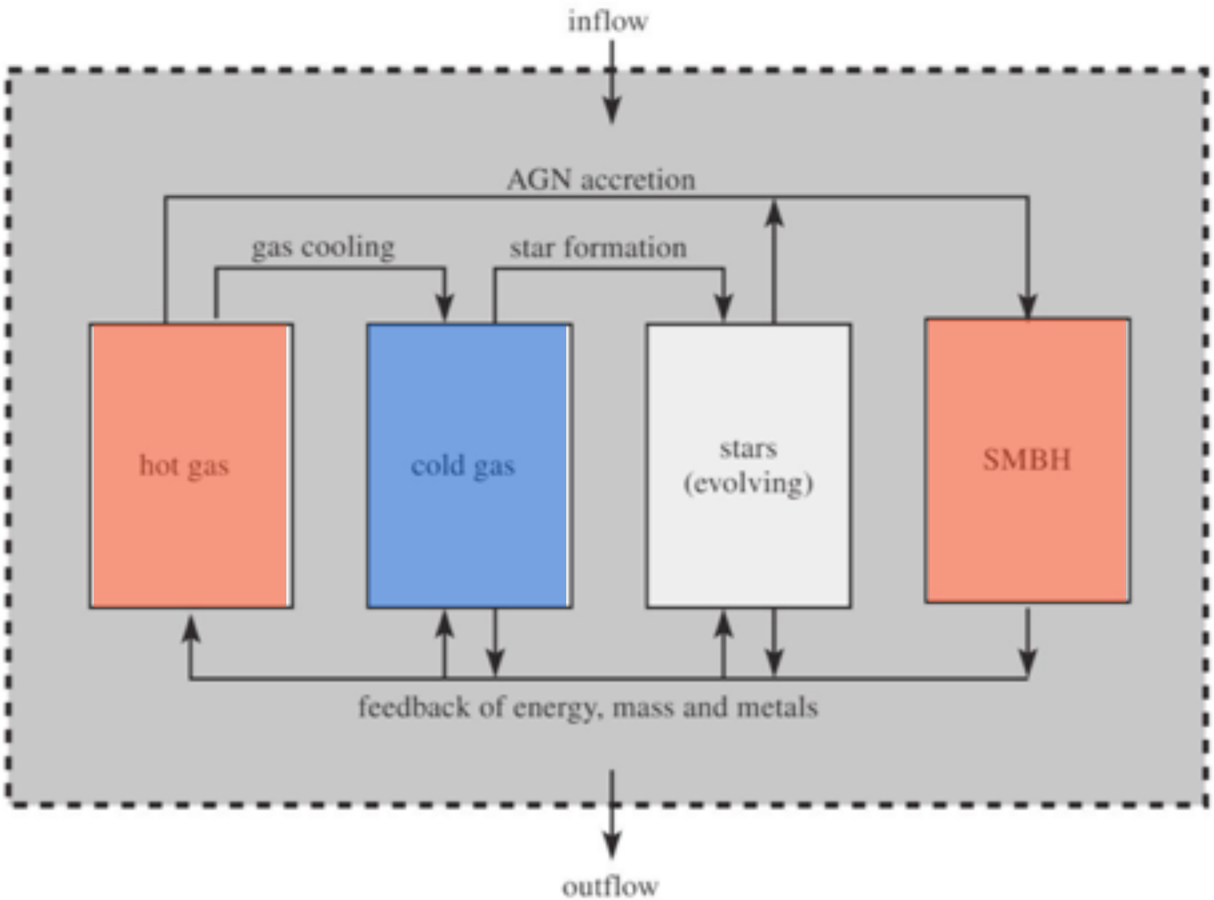


Statistical age-dating routine based on a photometric measurements of galaxies only.

Raouf and Khosroshahi et al (2014)

Fossils; simple lab for galaxy evolution

Group mergers can remove cool cores



Galaxy mergers can trigger AGN

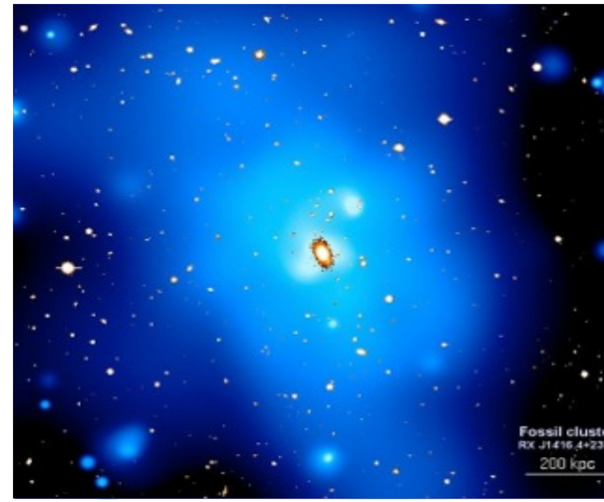
A frank assessment of the state-of-the-art in SAMs (Benson 2010) found that there were some 70 free parameters that need to be adjusted in the newest SAM, quote from Joe Silk.

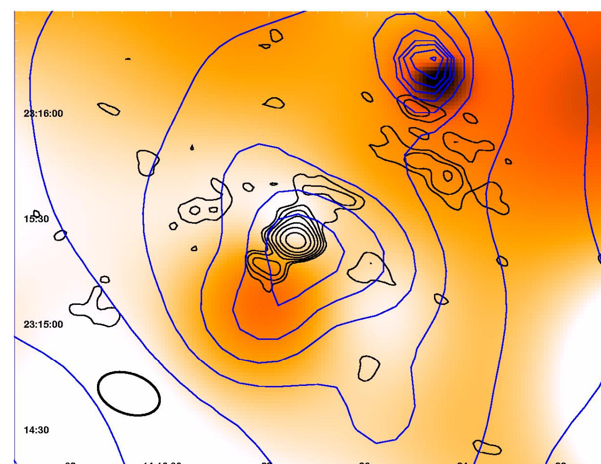
Credit: Galaxy Formation and Evolution; Mo, van den Bosch, White

Radio studies of fossil dominant galaxy

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





GMRT 610 MHz and 1.4 GHz maps

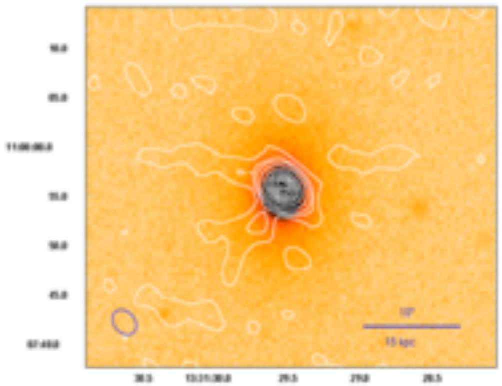


Figure 1. The 1.4 GHz radio map of J1331, overlaid on SDSS r-band image of the central galaxy. Contour levels of $\sigma = 0.18$ mJy × 2 , 3 , 4 , 5 , 10 , 20 , 30 , 40 , 50 , 60 , 70 are shown.

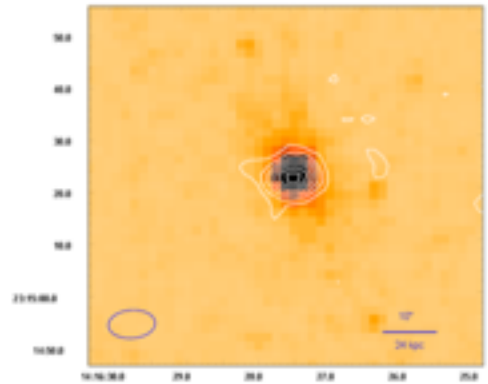


Figure 3. The 1.4 GHz radio map of J1416, overlaid on DSS image of the central galaxy. Contour levels of $\sigma = 0.12$ mJy × 3 , 5 , 7 , 9 , 11 , 13 , 17 , 21 , 25 , 29 , 33 are shown.

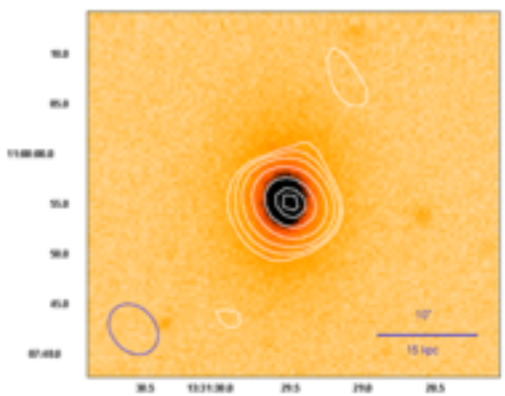


Figure 2. The 610 MHz radio map of J1331, overlaid on SDSS r-band image of the central galaxy. Contour levels of Contour levels of $\sigma = 0.2$ mJy × 2 , 3 , 5 , 10 , 30 , 40 , 45 are shown.

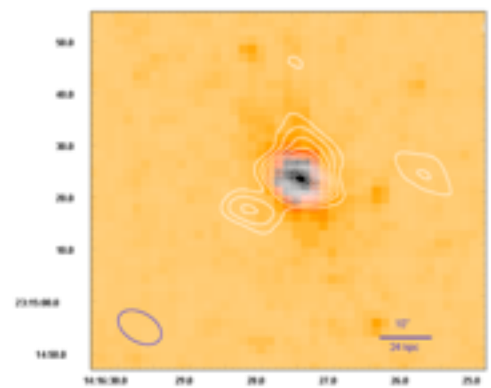


Figure 4. The 610 MHz radio map of J1416, overlaid on DSS image of the central galaxy. Contour levels of $\sigma = 0.12$ mJy × 3 , 5 , 7 , 9 , 11 , 13 , 17 , 21 , 25 , 29 , 33 are shown.

Fossil dominant galaxies smoke light!

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.

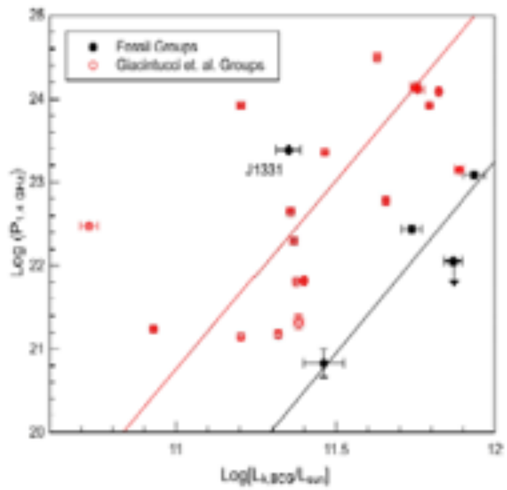


Figure 13. 1.4 GHz luminosity vs k-band BGGs luminosity of fossil galaxy groups (black), and Giacintucci et al. (2011) groups (red). The red and black lines correspond to fits to the red and black samples.

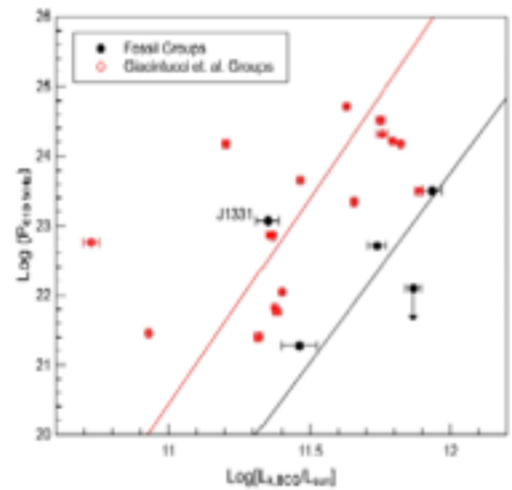
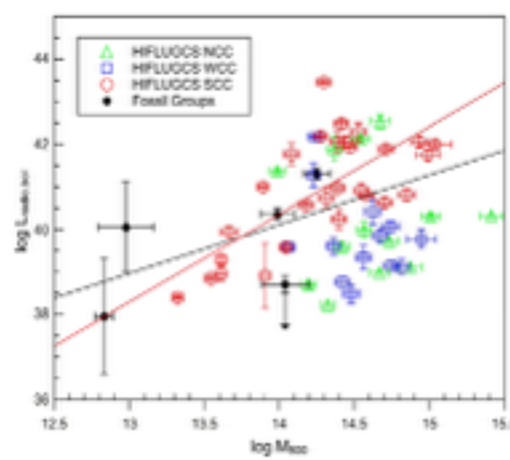


Figure 14. 610 MHz luminosity vs k-band BGGs luminosity of fossil galaxy groups (black) and Giacintucci et al. (2011) groups (red). The red and black lines correspond to fits to the red and black samples.



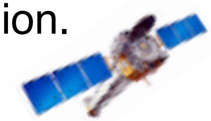
Hess et al (2012) reported fresh AGN activities in fossil groups!

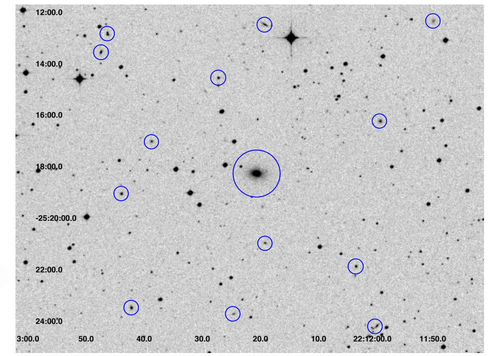
What drives the "apparently" conflicting observations?
Proper age-dating
Or else!

Mir Aghaee, Khosroshahi 2014

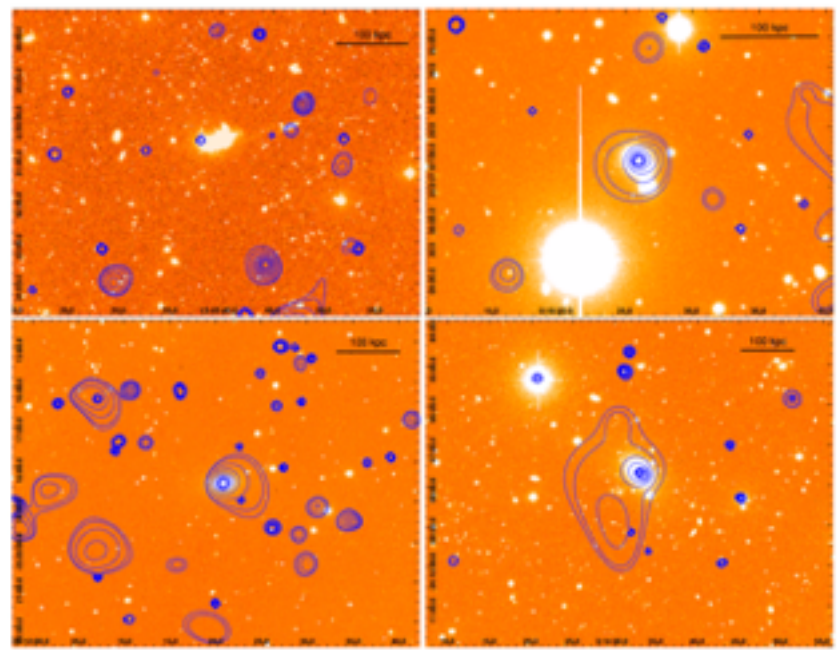
Optically selected fossils; searching for hot IGM

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.





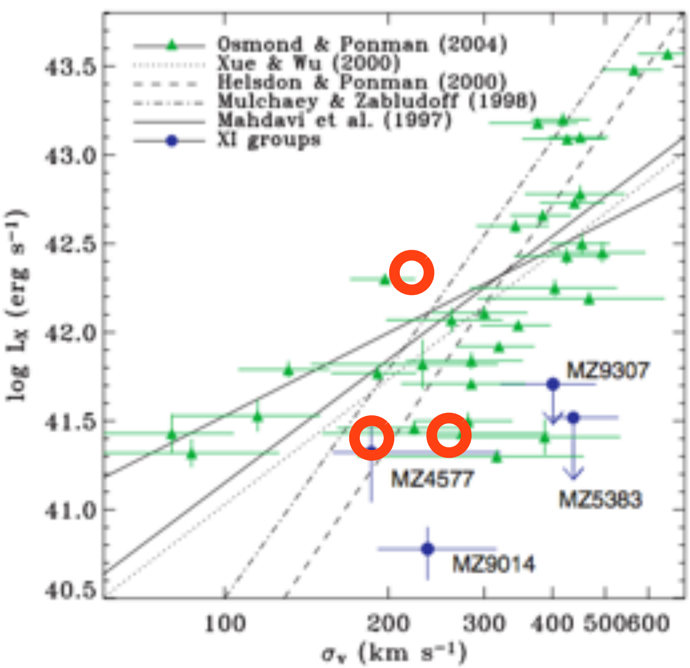
- Groups with at least five confirmed members ($N_{gal} > 4$)
- Groups with magnitude difference between first and second ranked galaxies $\Delta M_{12} > 2.0$
- Groups with a bright early-type dominant galaxy $M_B < -21.5$ and choose only elliptical galaxies.

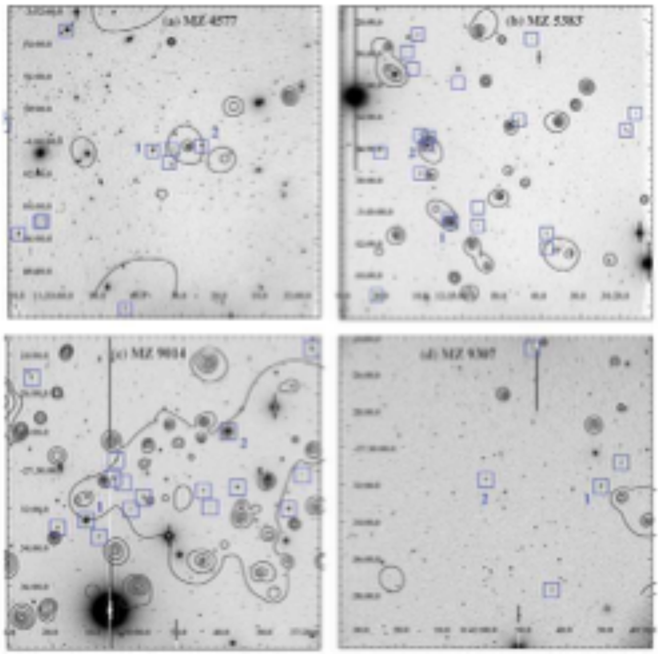


Khosroshahi et al (2014)

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.



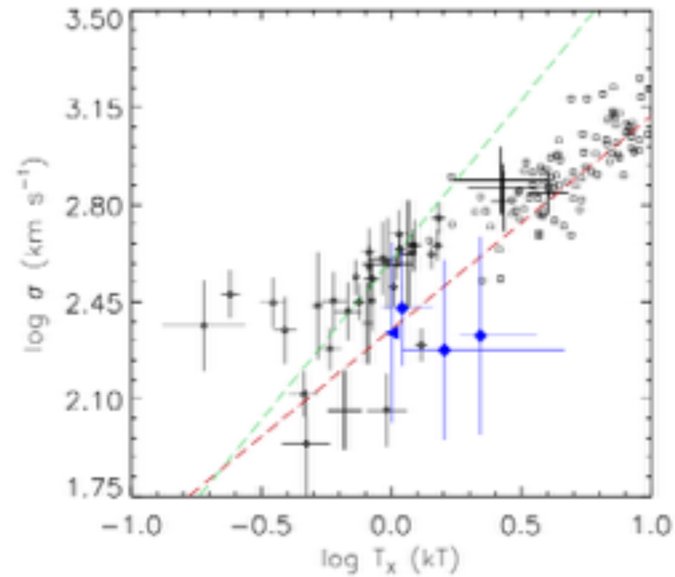


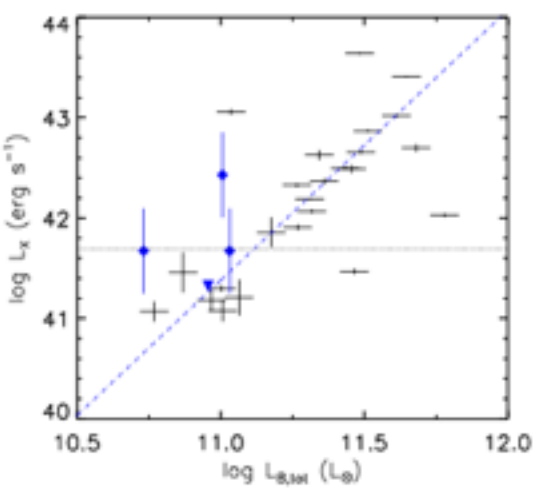
Rasmussen et al (2006)

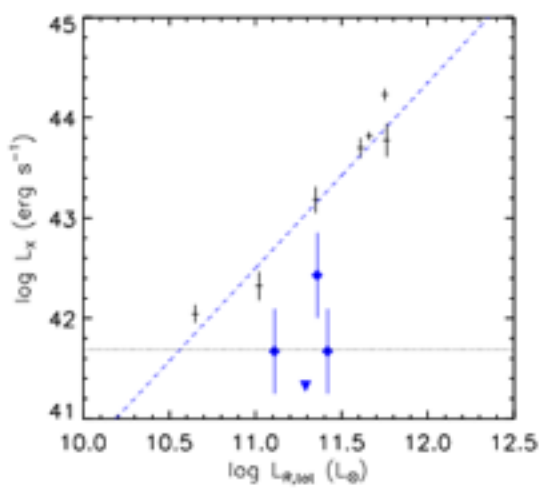
A large luminosity gap makes a difference!

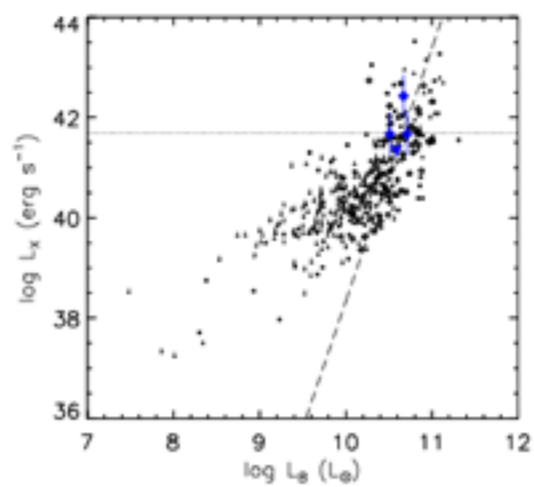
2PIGG ID	RA (J2000)	Dec (J2000)	z	M_B	σ_v km/s	R_{vir} kpc	$M_{halo,dyn}$ $10^{12}h^{-1}M_\odot$	t_{obs} ks
1404	13 45 39.8	-05 30 33	0.052	-21.9	218	532	22.5	10
1635	00 16 25.8	-27 07 05	0.056	-21.8	189	461	11.6	20
2515	22 12 20.7	-25 18 29	0.062	-21.6	268	653	37.4	20
2868	03 14 33.1	-34 07 42	0.067	-22.2	213	520	25.2	10

2PIGG ID	t_{exp} (ks)	R (kpc)	counts	S/N	N_H (10^{20} cm^{-2})	T (keV)	Z ($Z_\odot$)	$L_{X,0.3-2\,keV}$ (10^{41} erg s^{-1})	$L_{X,bol}$ (10^{41} erg s^{-1})
1404	10.7	100	−6	0.0	1.84	1.0*	0.4*	< 1.3	< 2.1
1635	19.4	100	69	3.5	3.04	$1.6^{+1.7}_{-0.6}$	0.4*	1.4 ± 0.2	2.5 ± 0.3
2515	19.9	100	73	3.7	1.99	$1.1^{+0.3}_{-0.2}$	0.4*	1.7 ± 0.2	2.7 ± 0.3
2868	9.9	200	197	7.6	1.95	$2.2^{+1.1}_{-0.4}$	0.4*	10.1 ± 1.5	19.1 ± 2.9









Khosroshahi et al (2014)

IPM

Summary

- The LG is shown to be a strong probe of evolutionary state of galaxy groups.
- The space density of fossils in the observations and simulations agree well.
- Mining the luminosity gap up to z~1 helps to probe semi-analytic galaxy models.
- Luminosity gap is a key but not a sufficient age indicator for a galaxy system.
- No sign of a strong AGN activities in giant elliptical galaxies dominating fossil groups, at least not as much as expected for the stellar masses.
- There are indications that a large luminosity gap at the presence of a giant elliptical galaxy signals a collapsed group as a host.


IranDeserts.com

Iranian National Observatory Project

Habib Khosroshahi
on behalf of
INO management: Reza Mansouri
Sepehr Arbabi
Ahmad Reza Haghighat
and other INO project members

IRANIAN NATIONAL OBSERVATORY

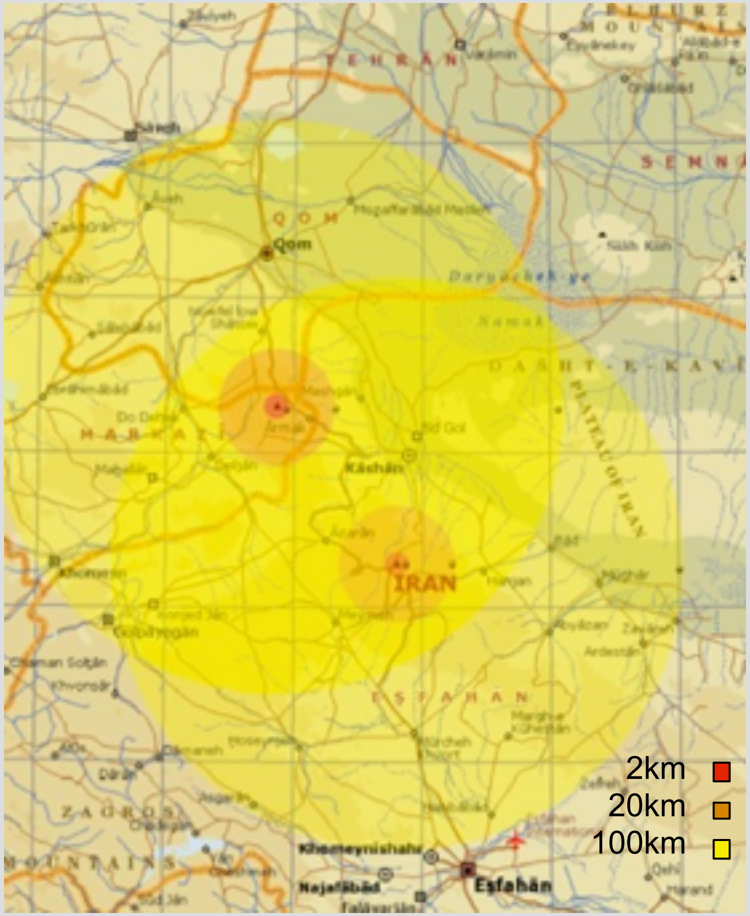
A modern observatory in the land of ancient observatories

Iranian National Observatory
IPM

Time domain/critical observations

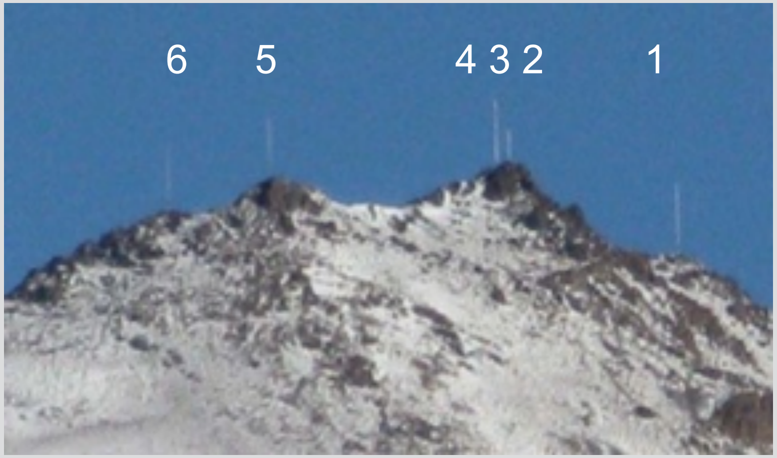
benefiting from geographic location

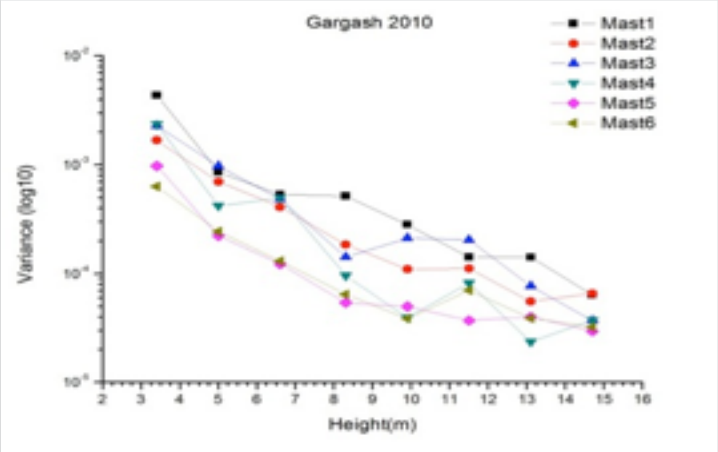
Site selection

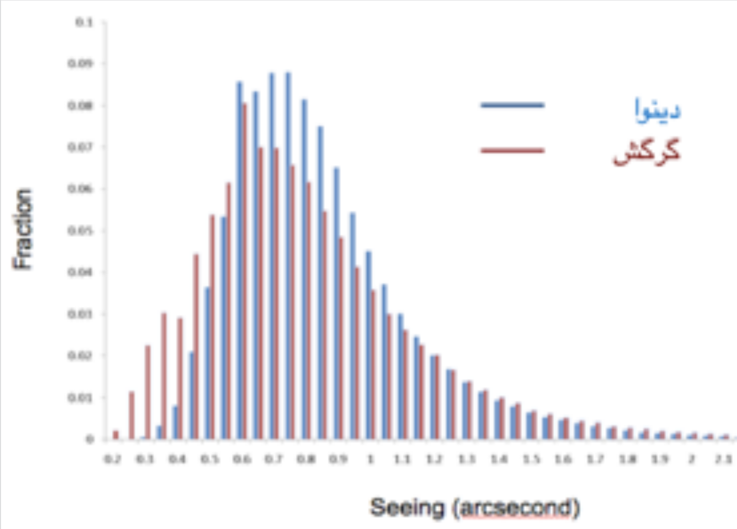


led by S. Nasiri (2001-2008)

Seeing and Microthermal measurements







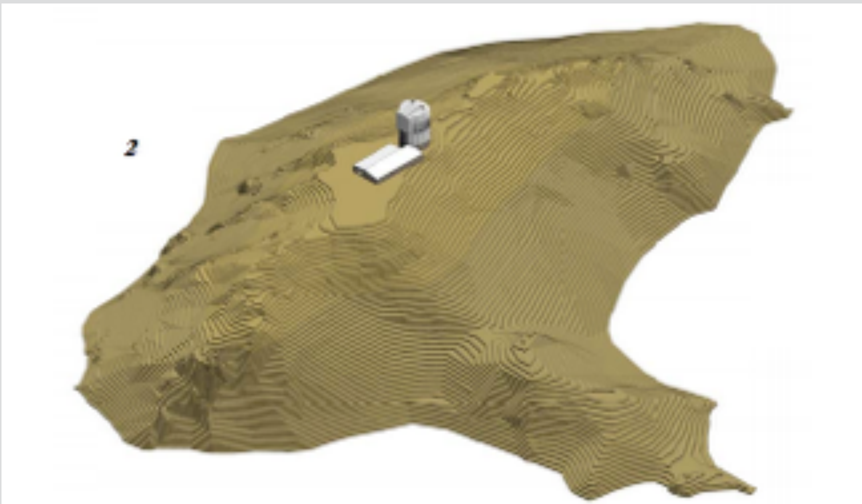

Joshaghan
S1
S2
Gargash
INO road
12 km
S3

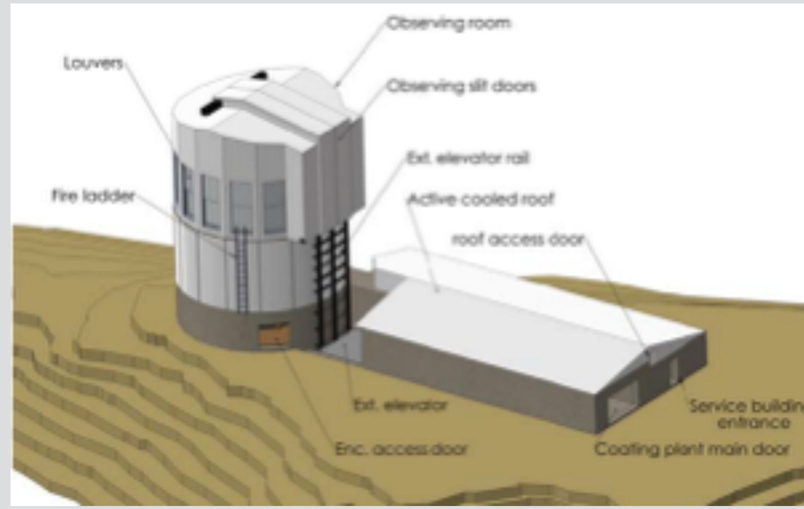
Thanks to our hardworking technical staff

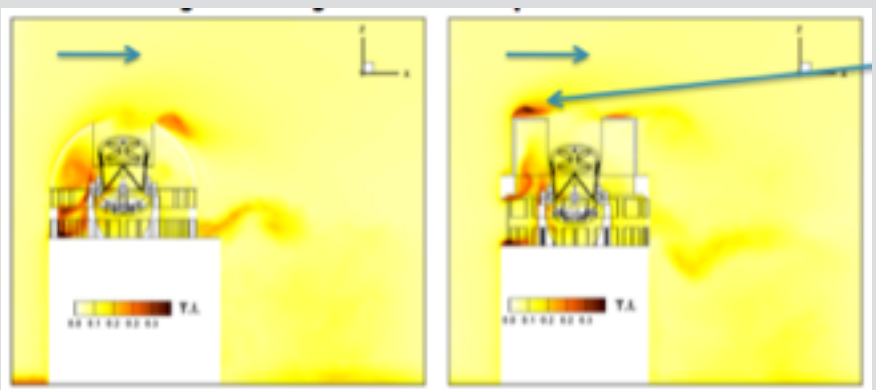
A. Behnam

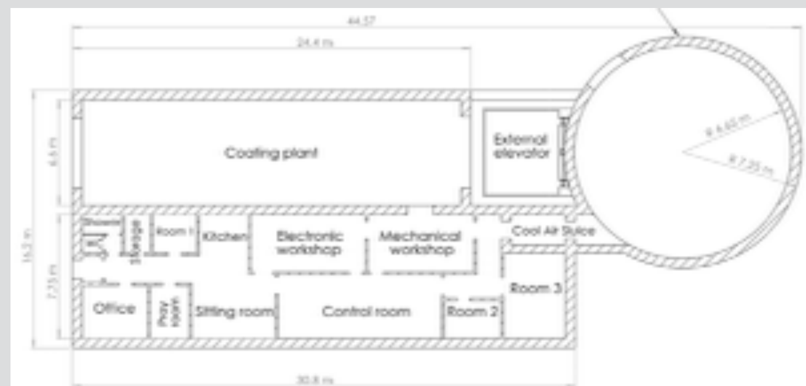
Light pollution control

Enclosure design

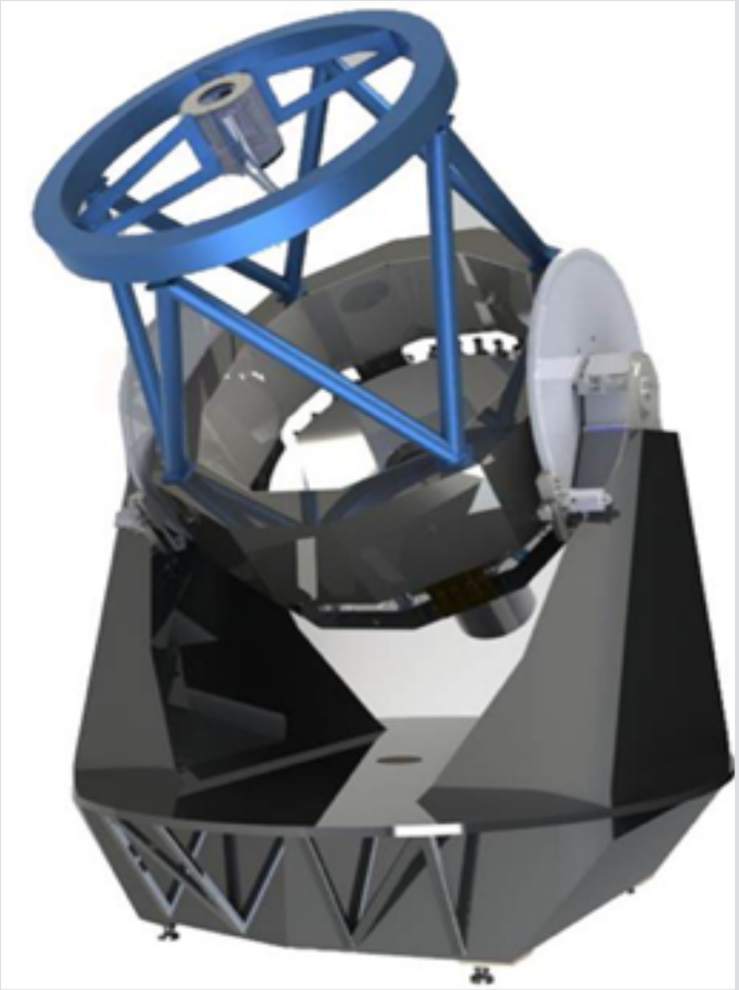






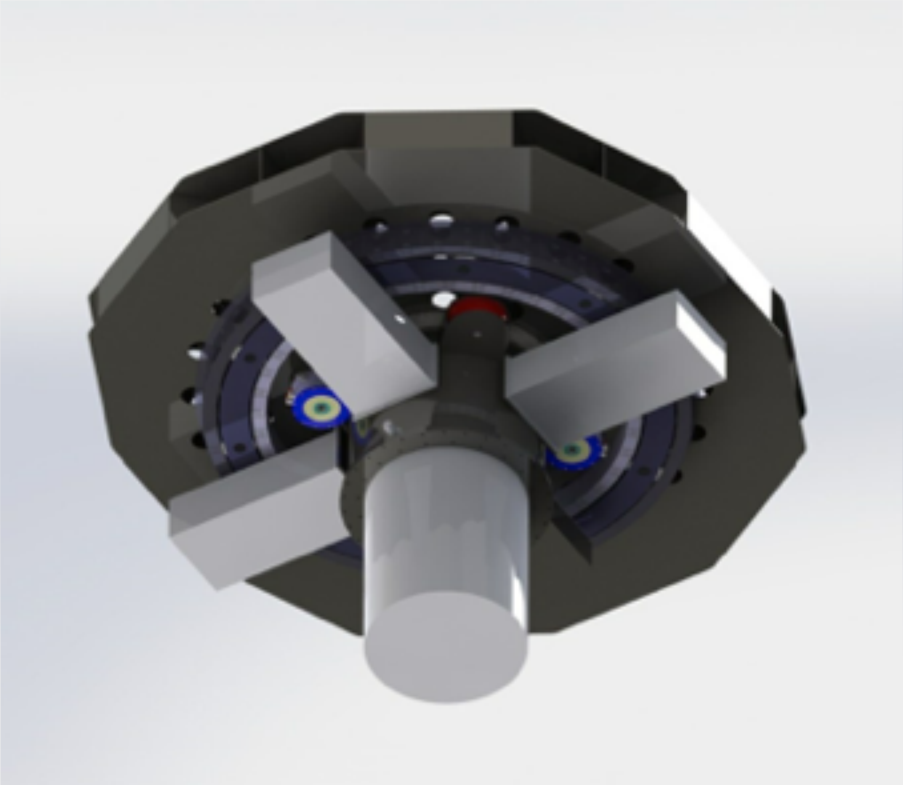


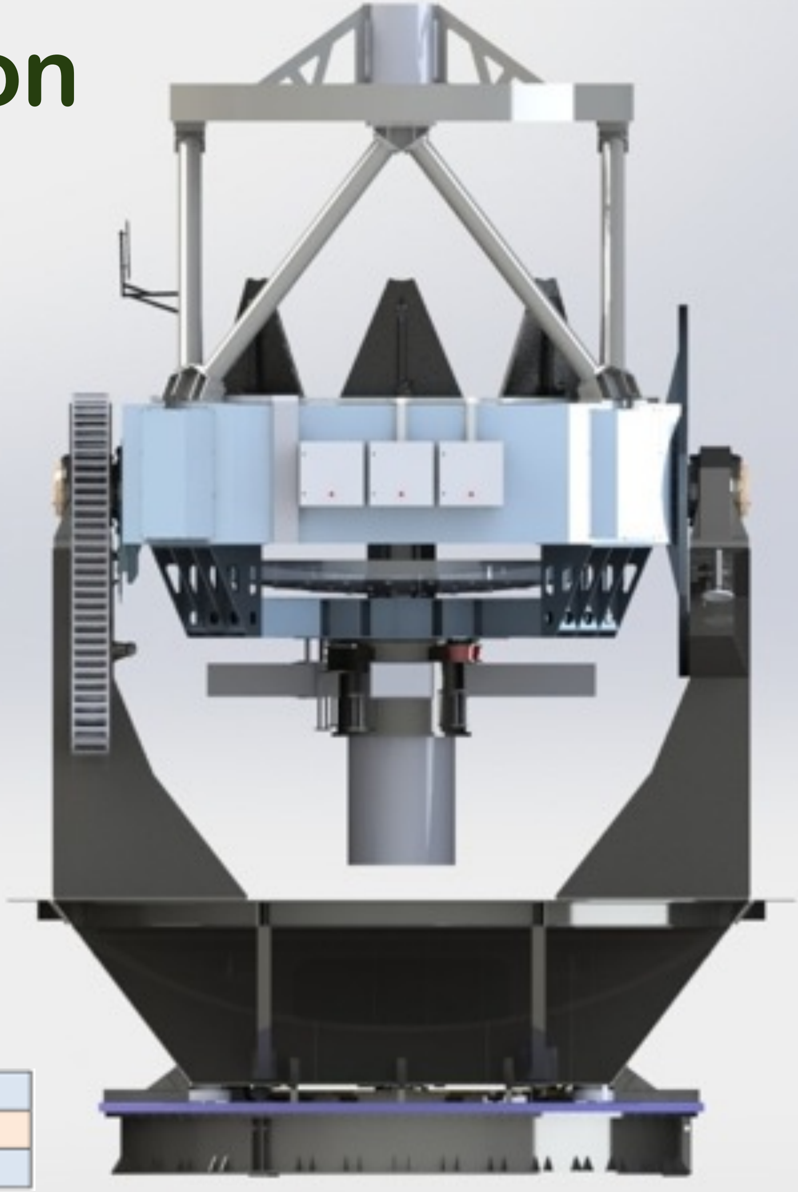
Telescope design specifications



Optical configuration	Ritchey-Chrétien Cass
Wavelength range	325-2500 nm
Primary mirror diameter, ID/OD (Nominal)	3400/700 mm
Primary mirror focal ratio	f/1.5
Exit focal ratio	f/11.363
Entrance pupil location	On primary
Back focal distance	1750 mm
Unvignetted field of view diameter	30 arcmin

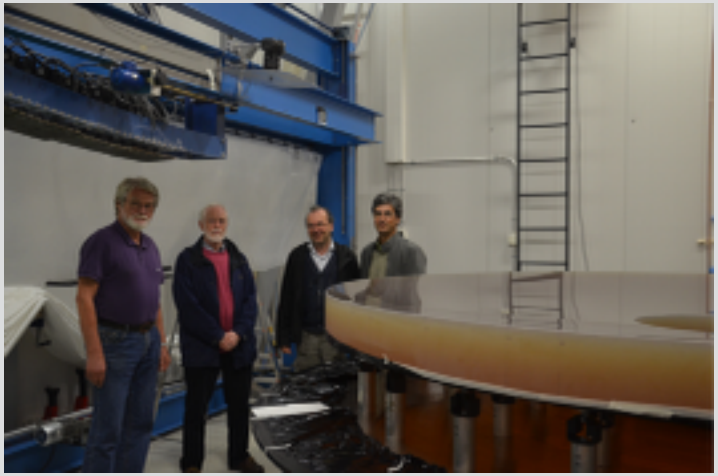
Backend configuration

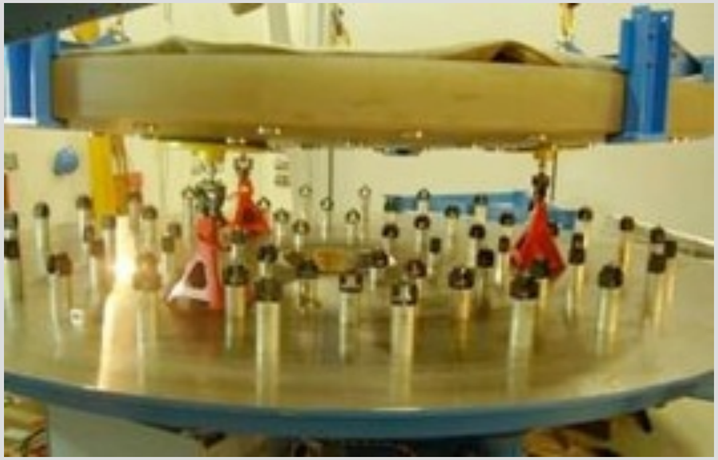


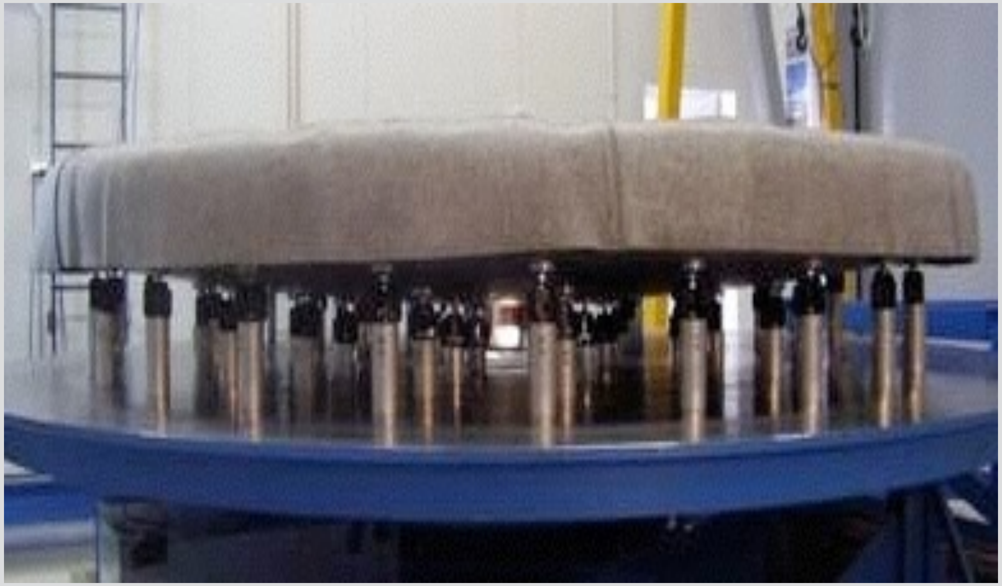


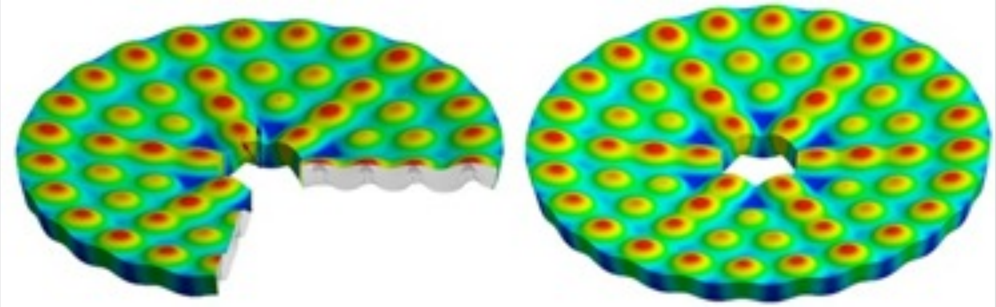
Property	On-axis	Side Cass
Maximum weight	1200 kg	3 x 100 kg
Maximum length	1200mm	1200mm

Mirror blank and polishing









RMS deflection = 5.5 nm

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Iranian National Observatory

More than a telescope …