Observational Properties of Fossil Systems

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The "Fossil Group Origins" (FOGO) project

MAIN GOAL:
multiwavelength observational characterization
of a large sample of FGs

Numerical simulations:
Compare theory with observations

Properties of DM halos in FGs
do the halos of FGs follow similar scaling relations than non fossil ones?
clues about earlier assembly of their DM halos?

Properties of the satellites
Do FGs have peculiar LFs?
Do FGs have similar sub-structure than non-fossil ones?
Are FGs old and dynamically relaxed systems?

Fossil Groups Origins (FOGO) project

Properties of the BGGs:
How and when did thy form?
Are BGGs in FGs similar to those of non-FGs?

The sample and observations

Santos et al. (2007) sample selected from the SDSS

wide redshift range
$0.1 < z < 0.5$

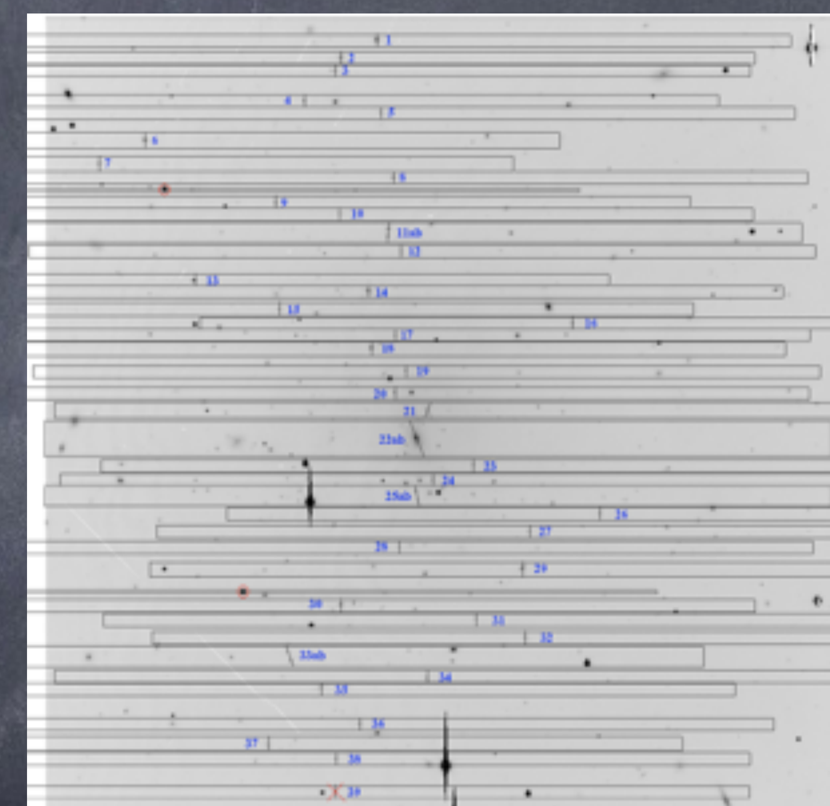
34 FG candidates

wide X-ray luminosity range
$10^{42} < Lx < 10^{44}$ erg s^{-1}

wide magnitude range for the BGGs
$-21.5 > M_r > -25.5$

SDSS data u,g,r,i,z
mag. lim. 21.5 r-band

NOT/INT data for 32 systems, mag. lim. ~ 25 r-band
LIRIS@WHT K-band data for 20 BGGs down to 21 mag.



~ 5000 spectra from SDSS DR7 (down to $m_r \sim 18$ and out to 4 R_{200}) plus ~ 1200 new spectra of possible members down to $m_r \sim 21$ mag

The sample and observations

Santos et al. (2007) sample
selected from the SDSS

wide redshift range	wide X-ray luminosity range
$0.1 < z < 0.5$	$10^{42} < L_X < 10^{44}$ erg s^{-1}
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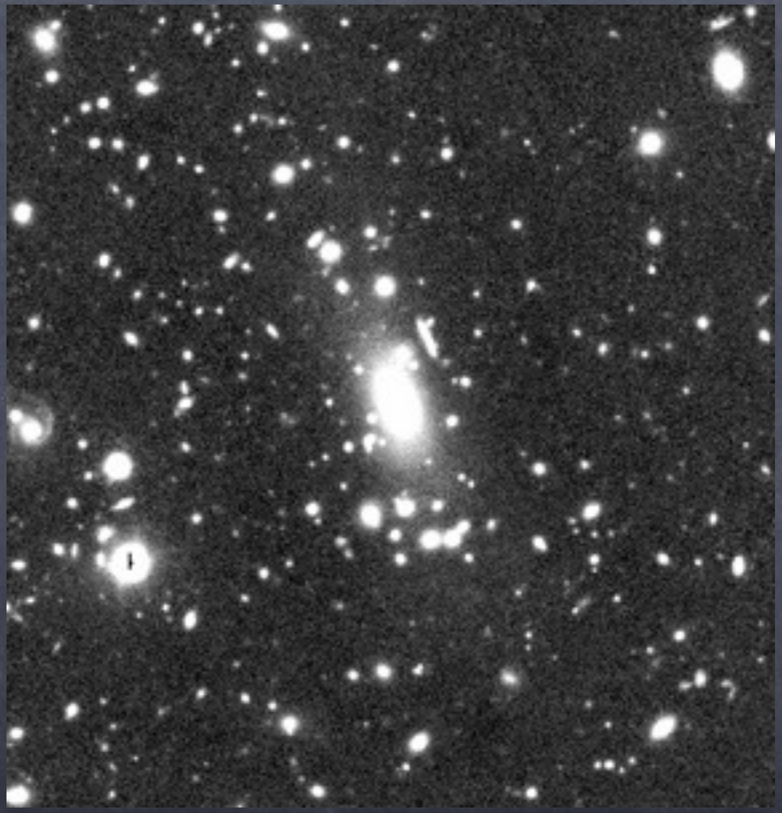

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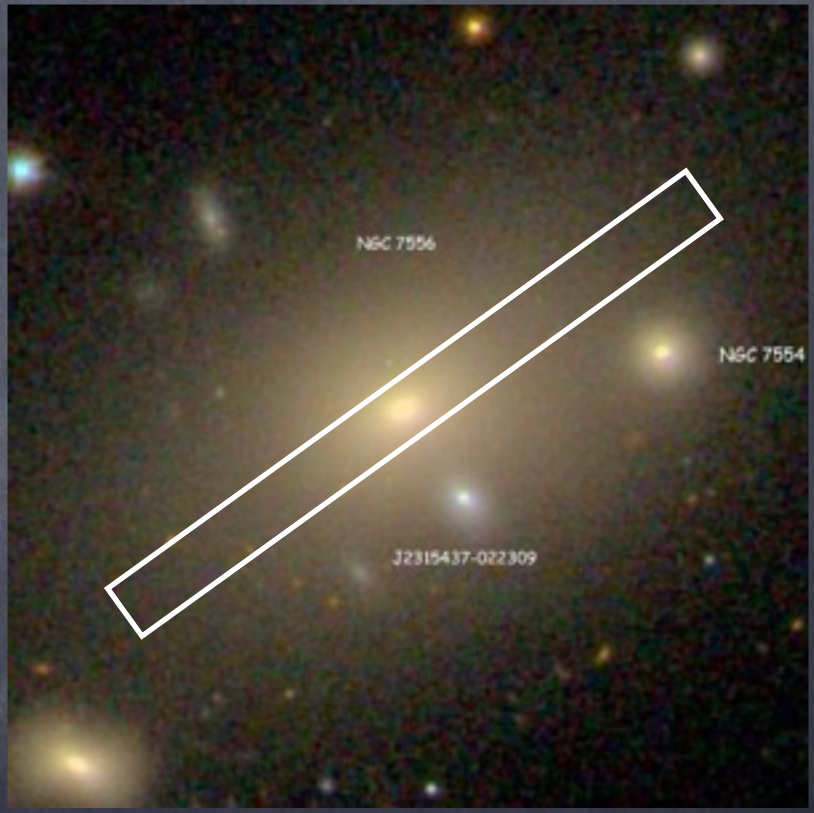


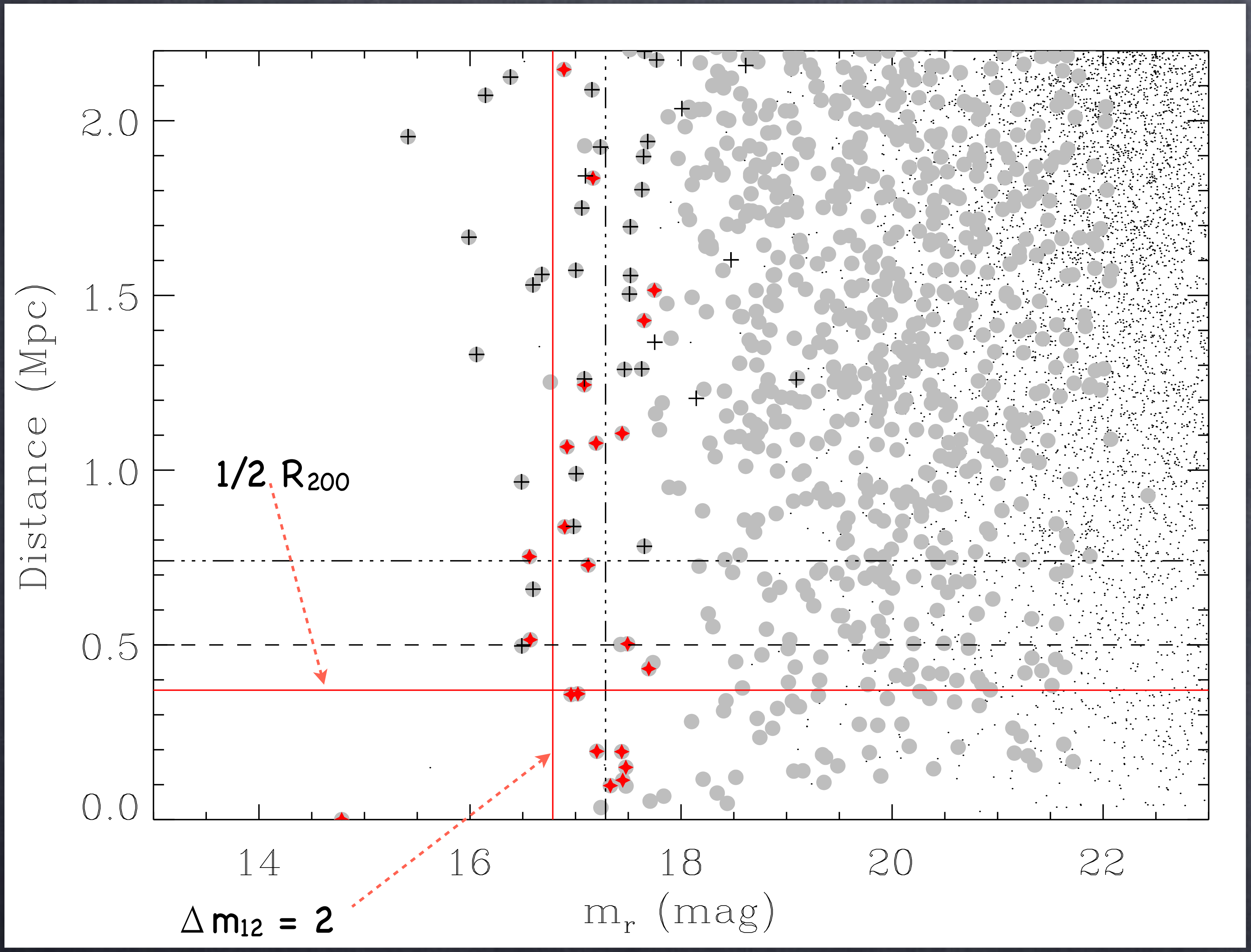
Long-slit spectroscopy for two central galaxies. R = 2500 at OSIRIS@GTC

The sample and observations

Observations of 10 FGs from FOGO sample for global scaling relations

Archival observations of 6 systems from FOGO sample
More detailed analysis

Magnitude gap determination



Black dots = all galaxies

Grey circles = possible members

Red stars = spectroscopically-confirmed members

Black crosses = spectroscopically-confirmed non-members

Fossil Criteria:

Δm_{12} > 2 mag (Jones+03)

Δm_{14} > 2.5 mag (Dariush+10)

15 confirmed FGs

Aguerri et al. 2011

Part I
Properties of the Dark matter halo

Part I: X-ray scaling relations

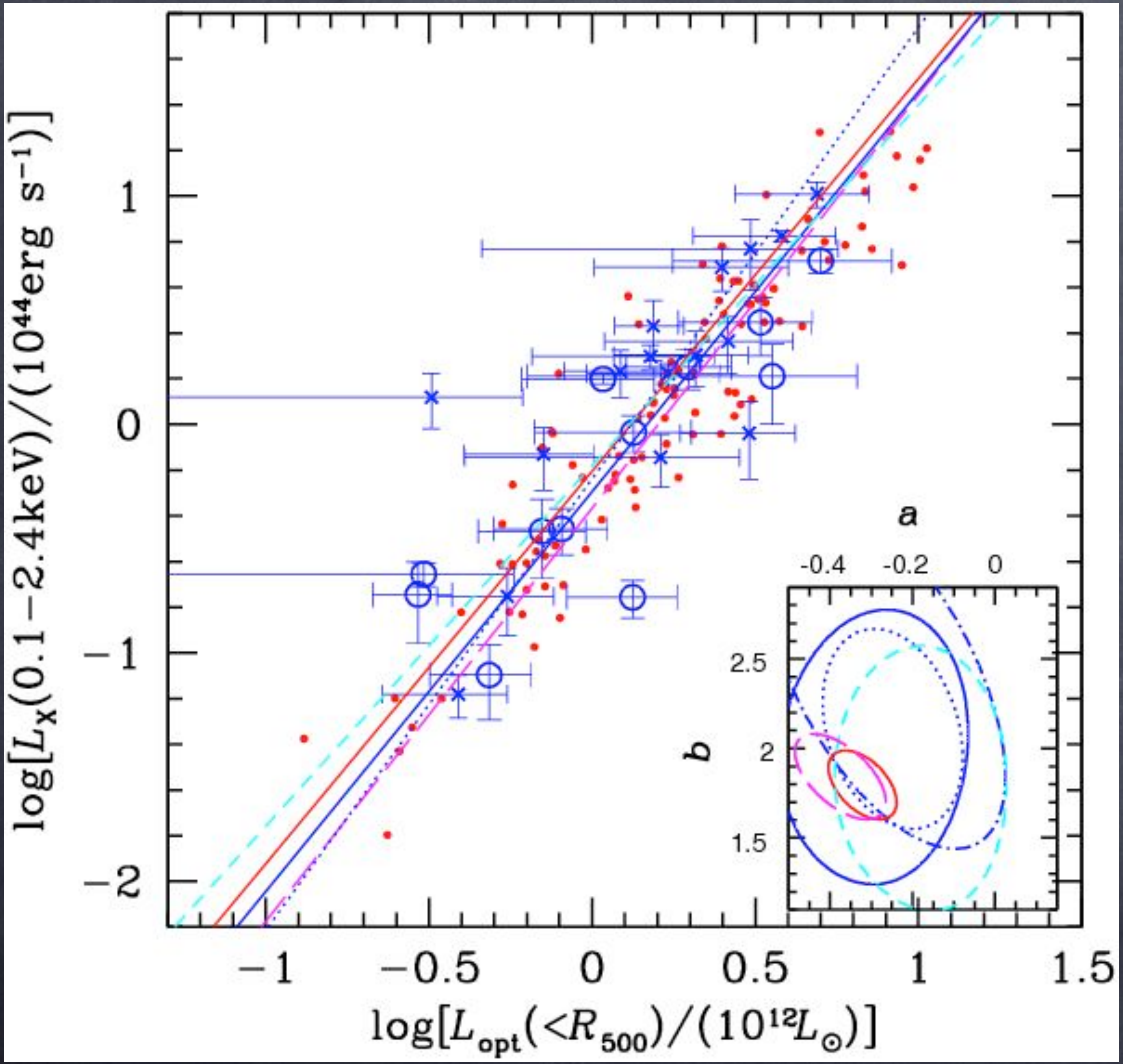
Fossil and non-fossil systems show similar scaling relations involving Lx and Tx (Khosroshahi et al. 2007; Voevodkin et al. 2009; Proctor et al. 2012; Harrison et al. 2012).

Kosroshahi et al. (2007) found that FGs shows different Lx-Lr relation than non-fossil systems. They interpreted as FGs are more luminous in X-ray than non-fossil for a given Lr. -> Different gravitational potential (more cuspy) due to early formation.

Proctor et al. (2011) also found an offset of FGs in the Lx-Lr relation. Nevertheless they interpreted as FGs are deficient in optical luminosity for a given Lx -> "failed groups or clusters"

Voevodkin et al. (2009) and Harrison et al. (2012) found no difference between fossil and non-fossil systems in the Lx-Lopt relation.

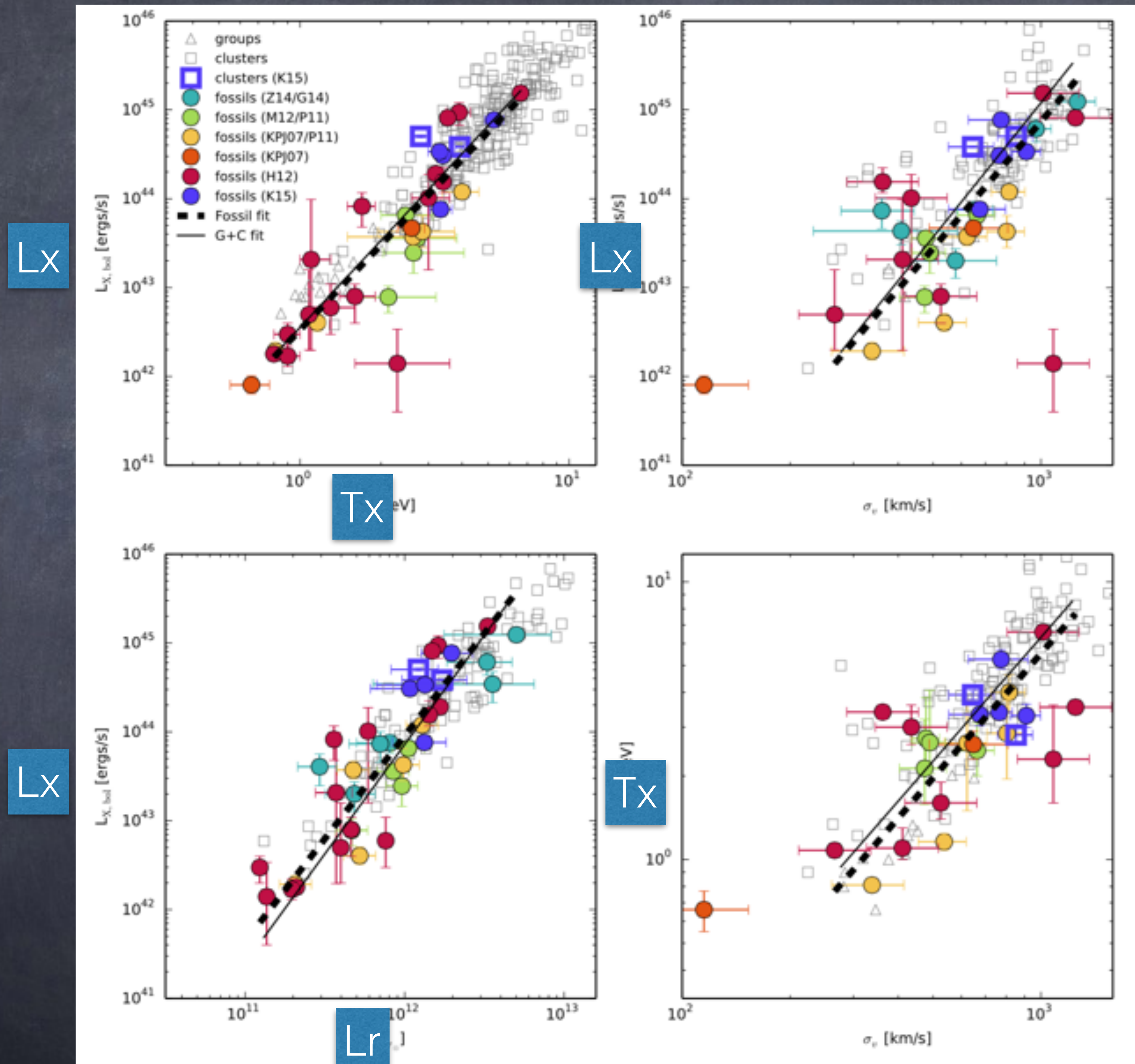
Part I: X-ray scaling relations



- Our results on the Lx-Lopt relations using the FGs from Santos et al. (2007).
- For comparison: the RASS-SDSS galaxy cluster survey. This consists on 114 nearby galaxy systems covering a large range of masses (Popesso et al. 2004).
- We take care to apply homogeneus procedures to these FGs and the Comparison cluster sample We computed Fully consistent Lx and Loptical luminositites.
- The X-ray luminosities were recomputed from ROSAT counts rates (Voges et al. 1999, 2000).

Girardi et al. 2014

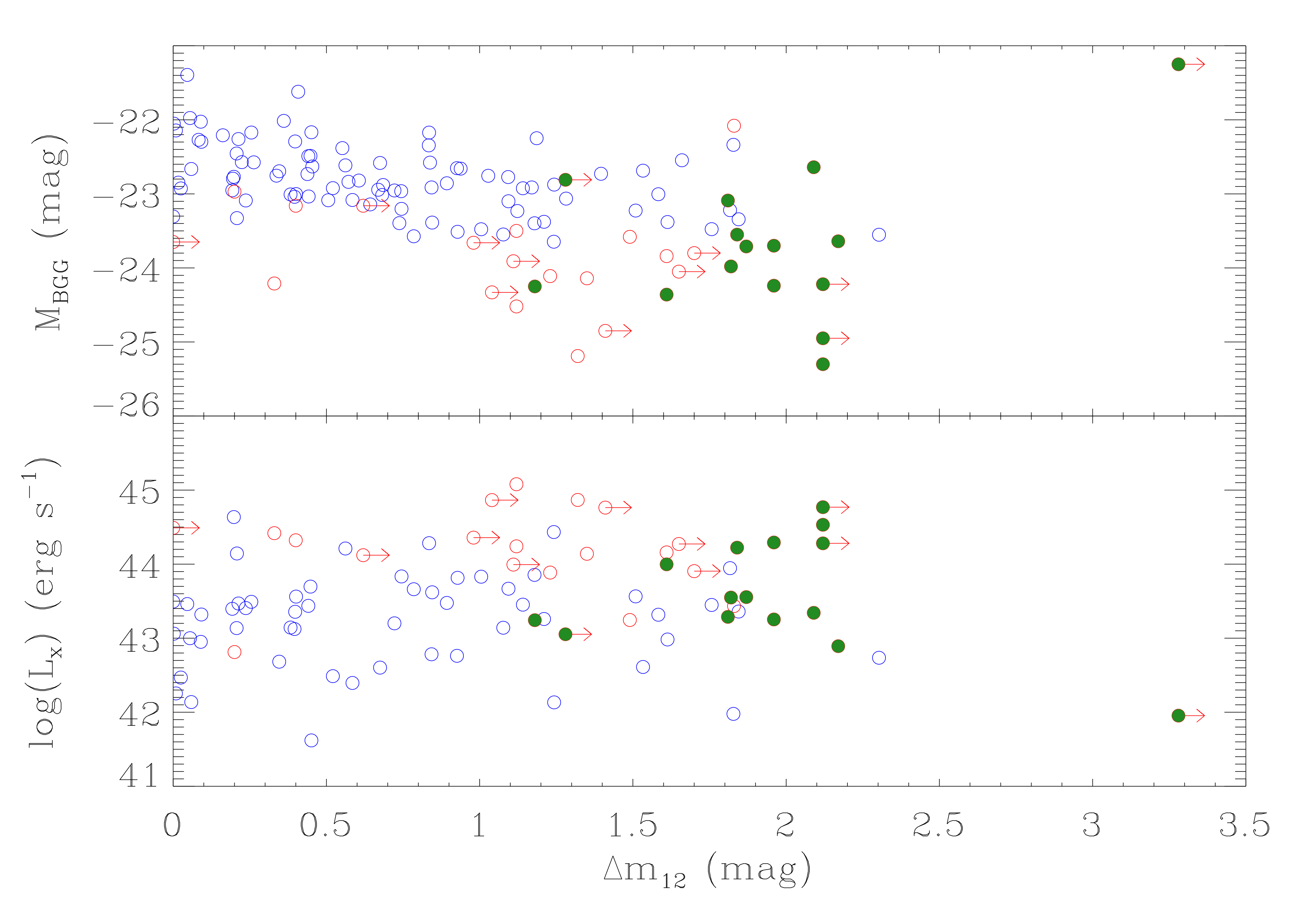
Part I: X-ray scaling relations



Kundert et al. 2015

Part II
Properties of the central galaxies

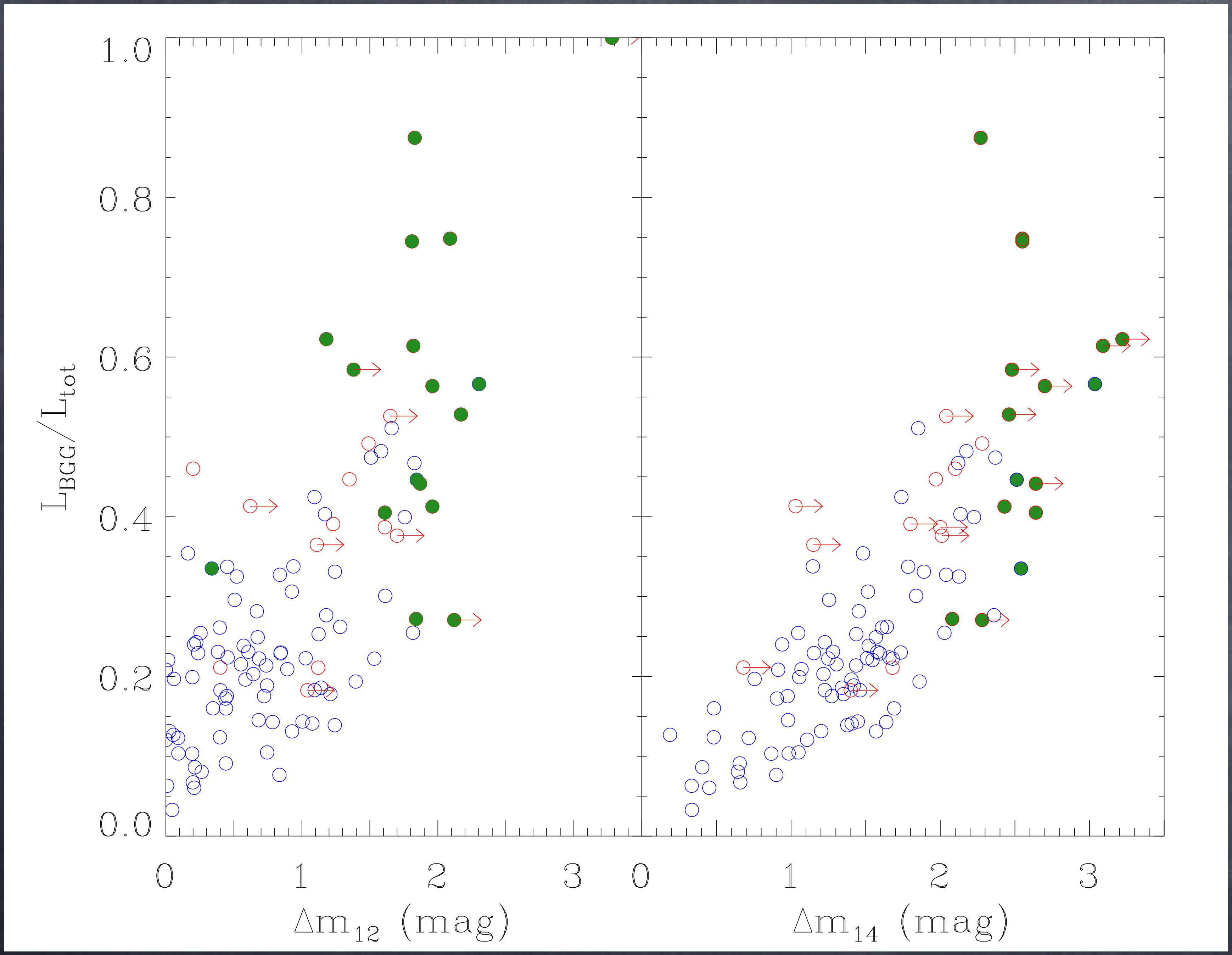
Part II: Properties of the central galaxy



- A correlation is observed between M(BGG) and the magnitude gap
- BGGs in fossil systems are in general brighter than in non-fossil ones
- No trend is observed with the X-ray luminosity of the DM halos

Zarattini et al. 2014

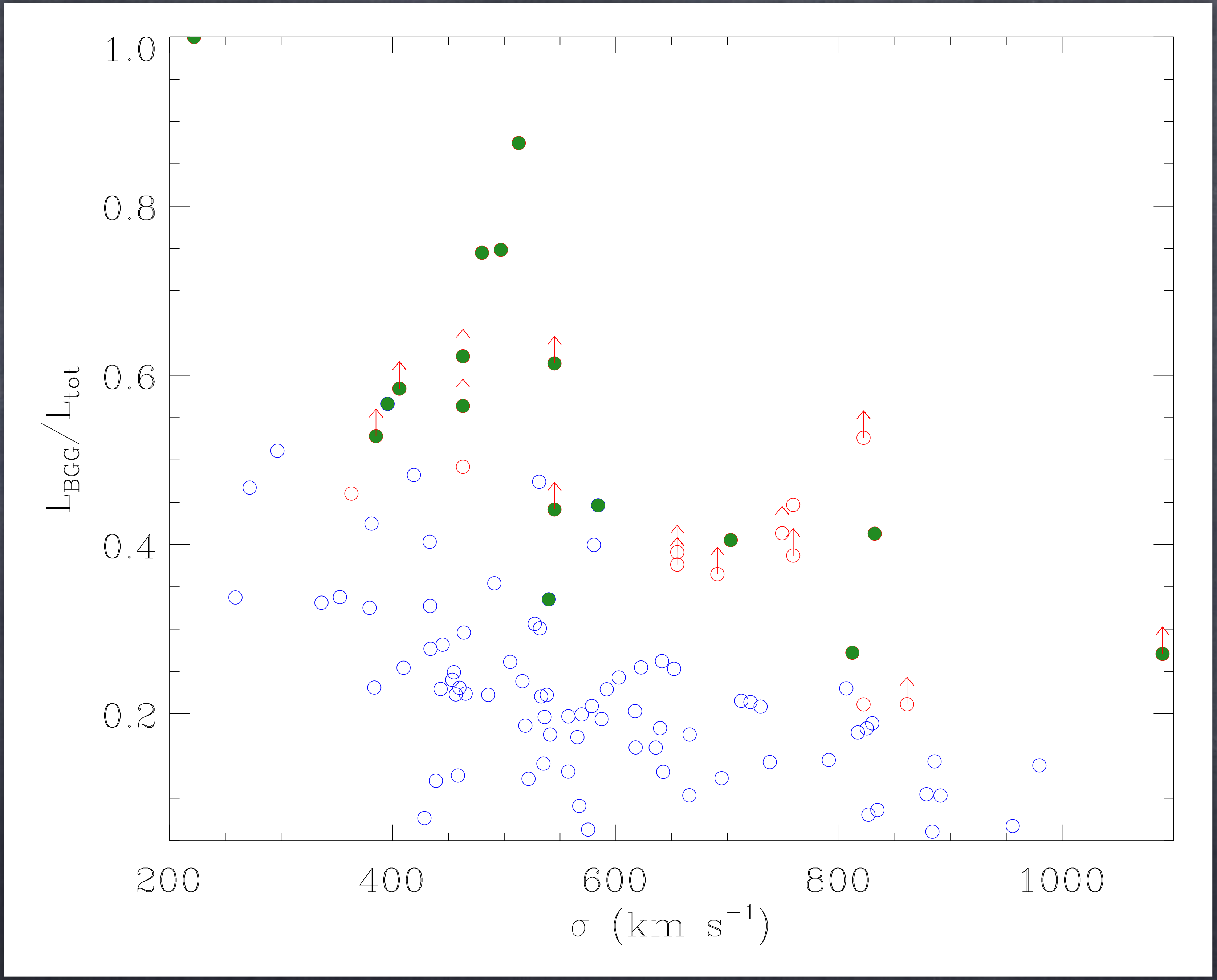
Part II: Properties of the central galaxy



Zarattini et al. 2014

- Different distribution of the optical light in fossil and non-fossil systems
- BGGs in fossil systems host a larger fraction of the optical light of the system than non-fossil ones
- Fossil systems have the optical luminosity that corresponds for its mass (Lx-Lopt relation). But it is located in a larger fraction in the central galaxy.

Part II: Properties of the central galaxy



Zarattini et al. 2014

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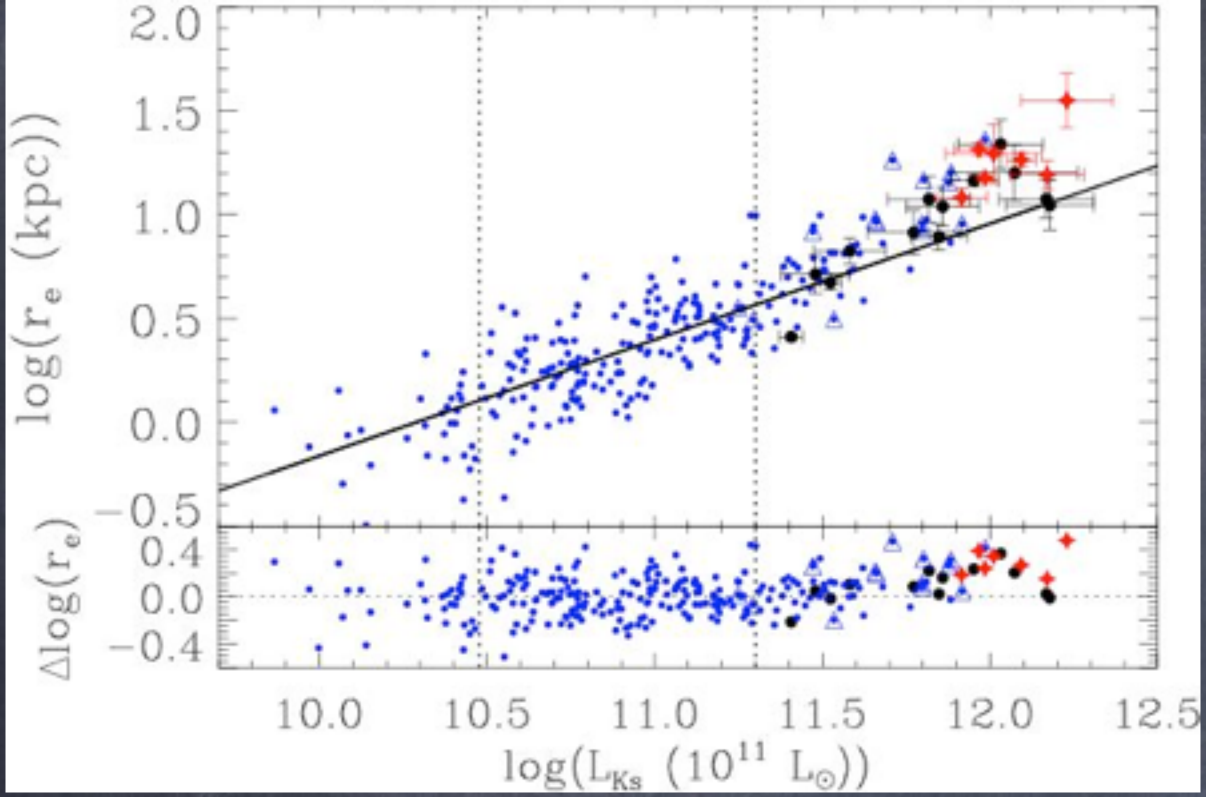
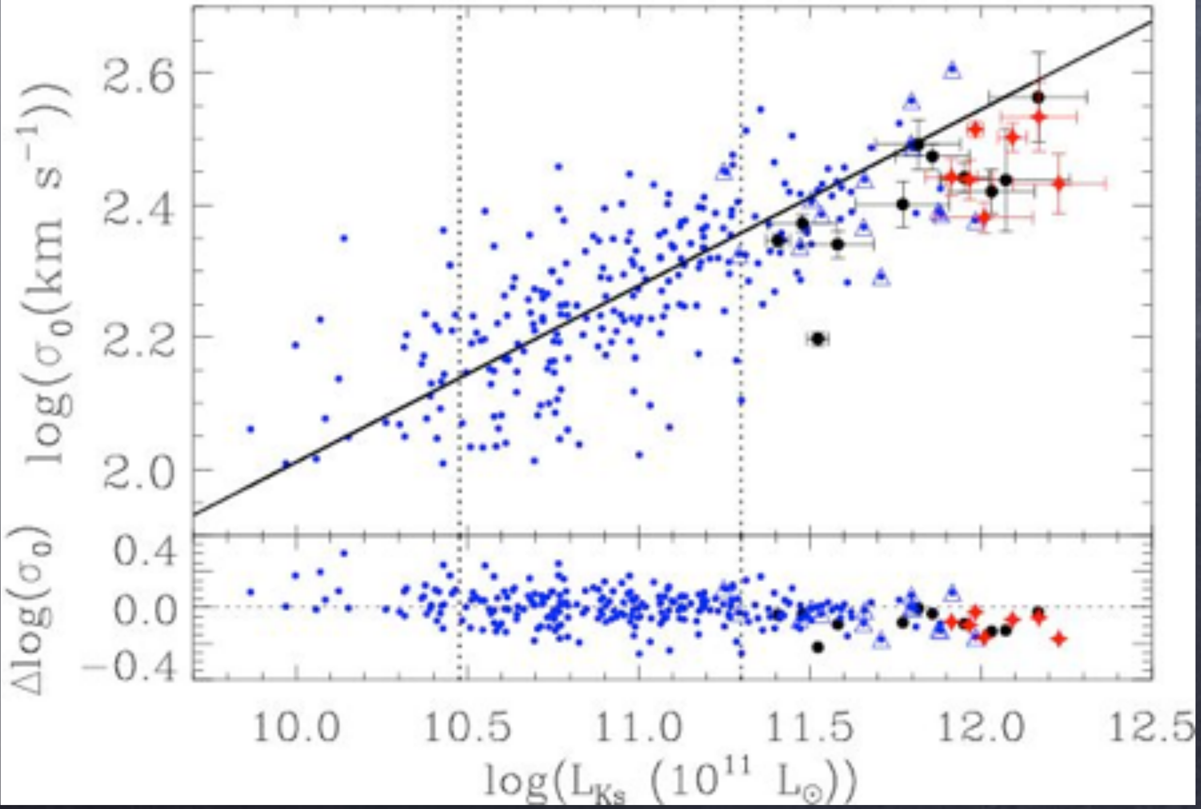
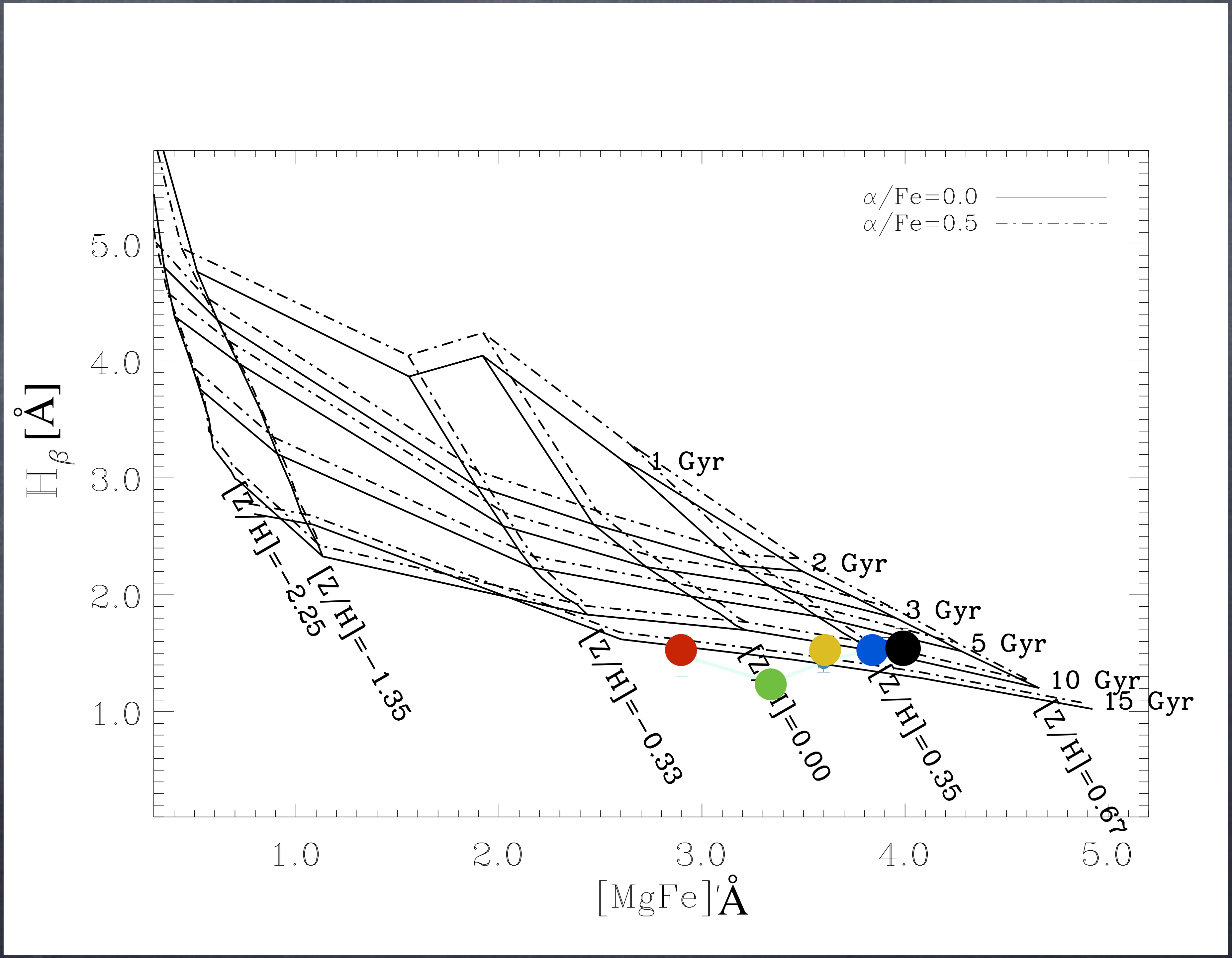




- BGGs in Fossil systems show different scaling relations than elliptical galaxies with intermediate luminosities.
- Similar relations as those found in other non-fossil brightest cluster galaxies (see Bernardi et al. 2011)
- Several dry mergers along the history of the galaxies.
- But...

Méndez-Abreu et al. 2012

Part II: Properties of the central galaxy



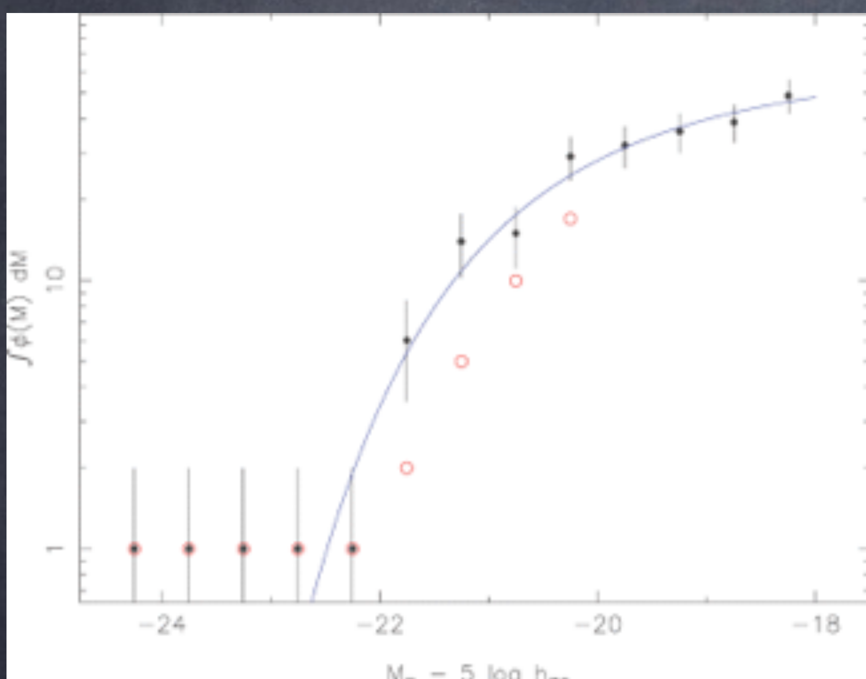
- Stellar population analysis of NGC7556

Zarattini et al. 2017 in prep

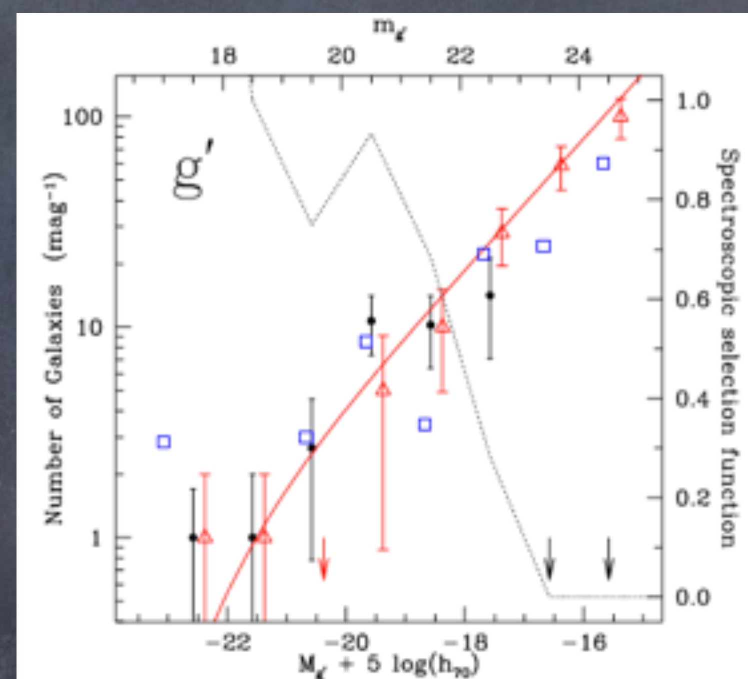
Part III
Properties of the satellites

Part III: Properties of the galaxy satellite population

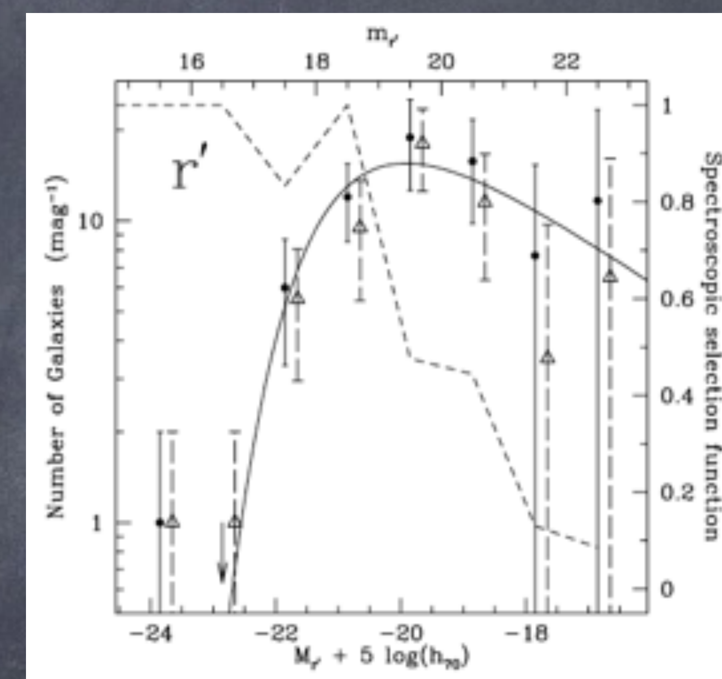
- Few LFs of FGs studied in the literature
  - values of the faint-end slope in the range $-0.5 < \alpha < -1.6$



Khosroshahi et al. 2006
$\alpha = -1.23 \pm 0.28$



Mendes de Oliveira et al. 2006
$\alpha = -1.6 \pm 0.2$



Mendes de Oliveira et al. 2006
$\alpha = -0.6 \pm 0.2$

LFs from very flat to steep!

Part III: Properties of the galaxy satellite population

SAMPLE: 102 systems from: Santos et al. 2007 and Aguerri et al. 2007

(all systems with $z < 0.25$, SDSS r-band model magnitudes)

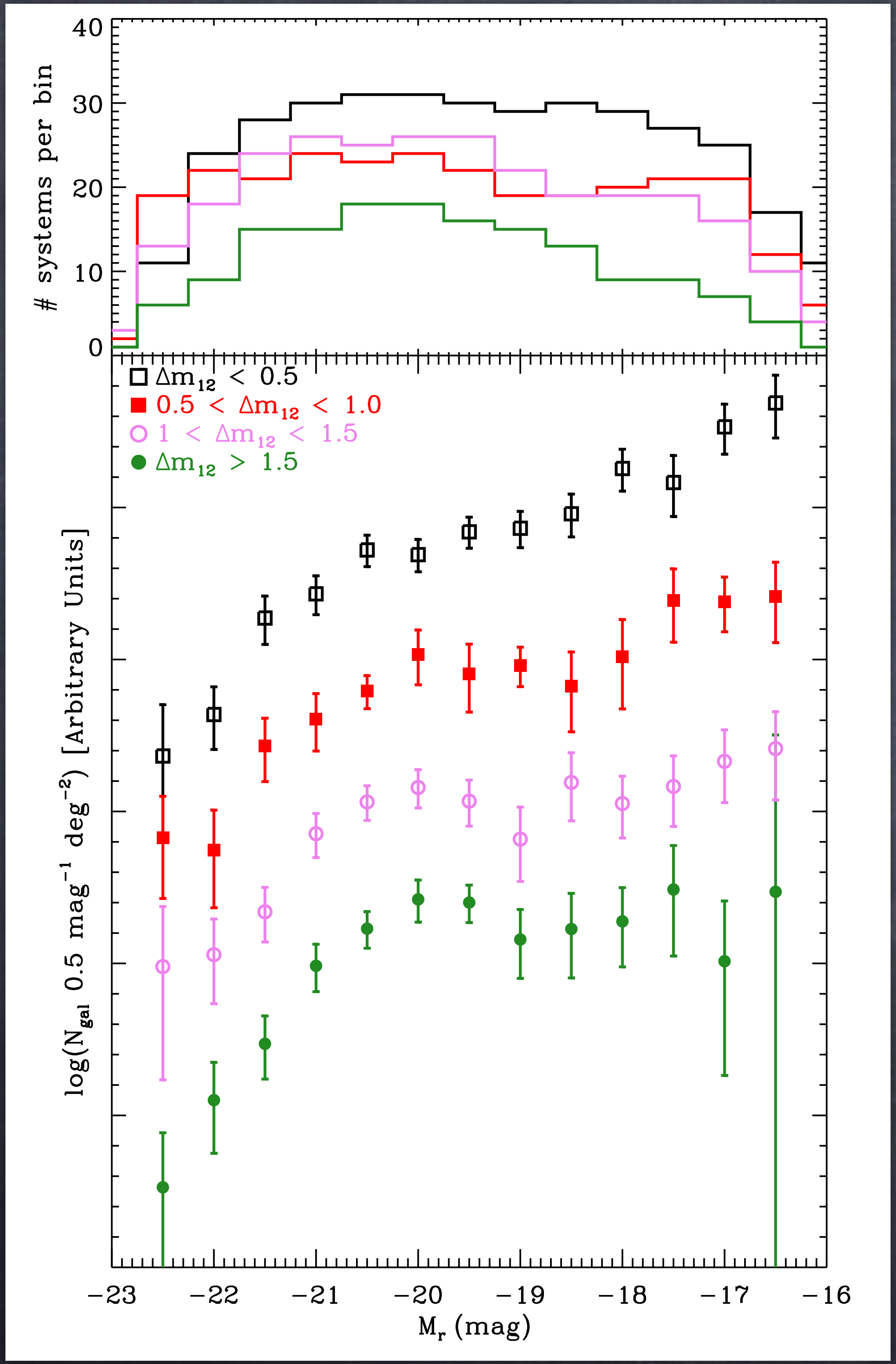
31 with $\Delta m_{12} < 0.5$

24 with $0.5 \leq \Delta m_{12} < 1$

26 with $1 \leq \Delta m_{12} < 1.5$

21 with $\Delta m_{12} \geq 1.5$

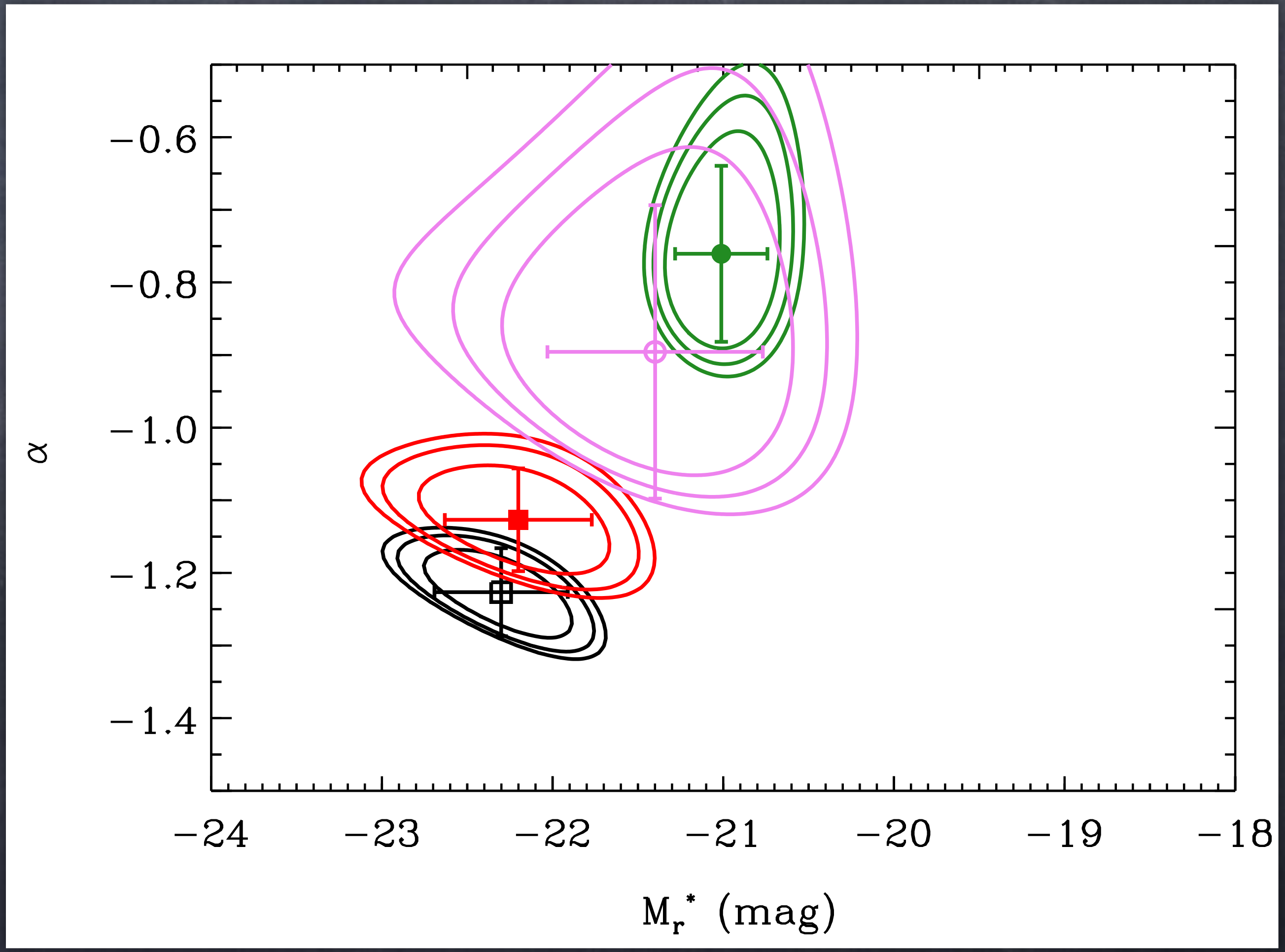
Part III: Properties of the galaxy satellite population



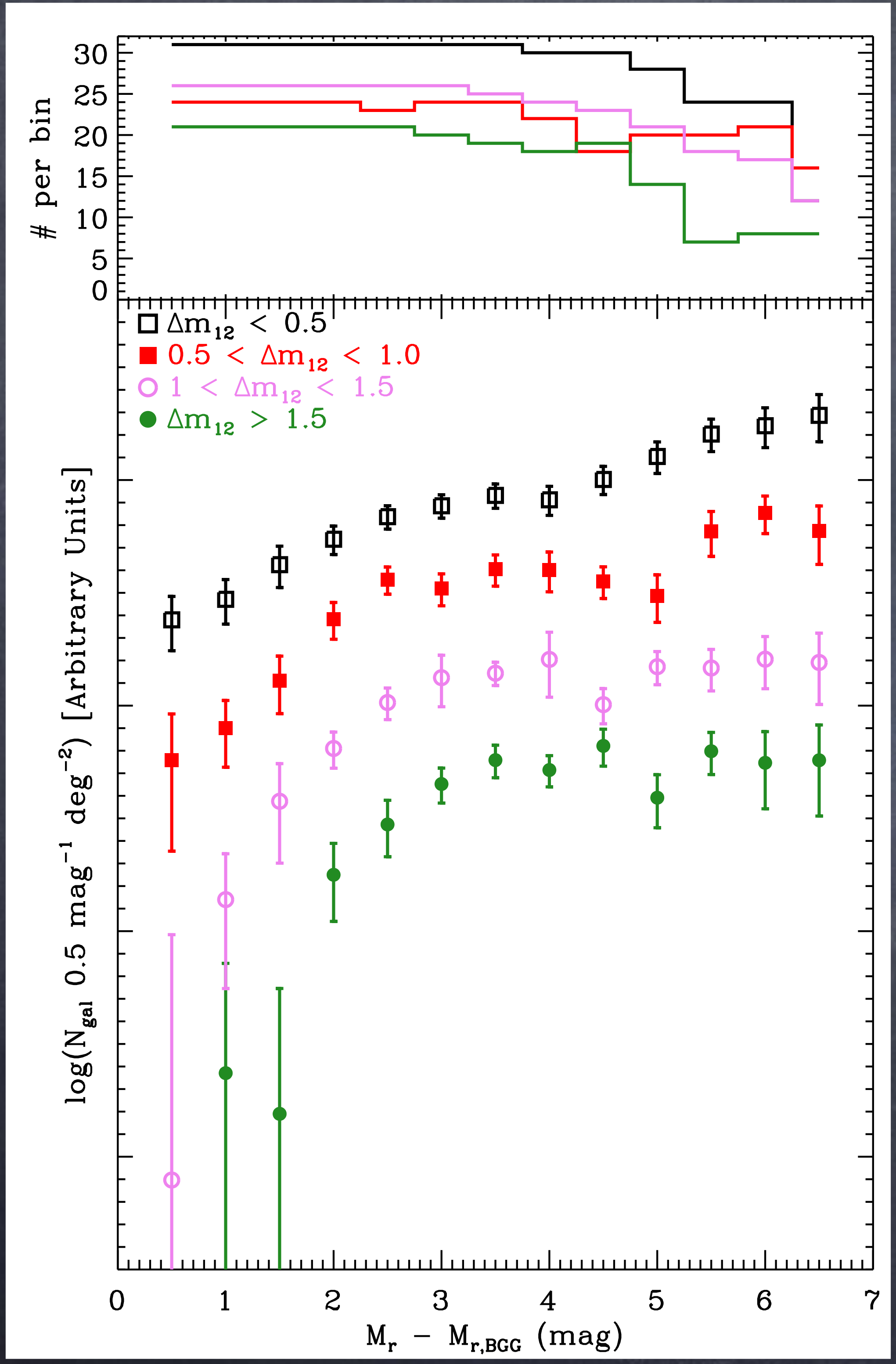
Fit of the LFs using the Schechter formula:

$$\varphi(M)dM = \varphi^* 10^{0.4(M^*-M)(\alpha+1)} \exp(-10^{0.4(M^*-M)})dM$$

Zarattini et al. 2015



Part III: Properties of the galaxy satellite population



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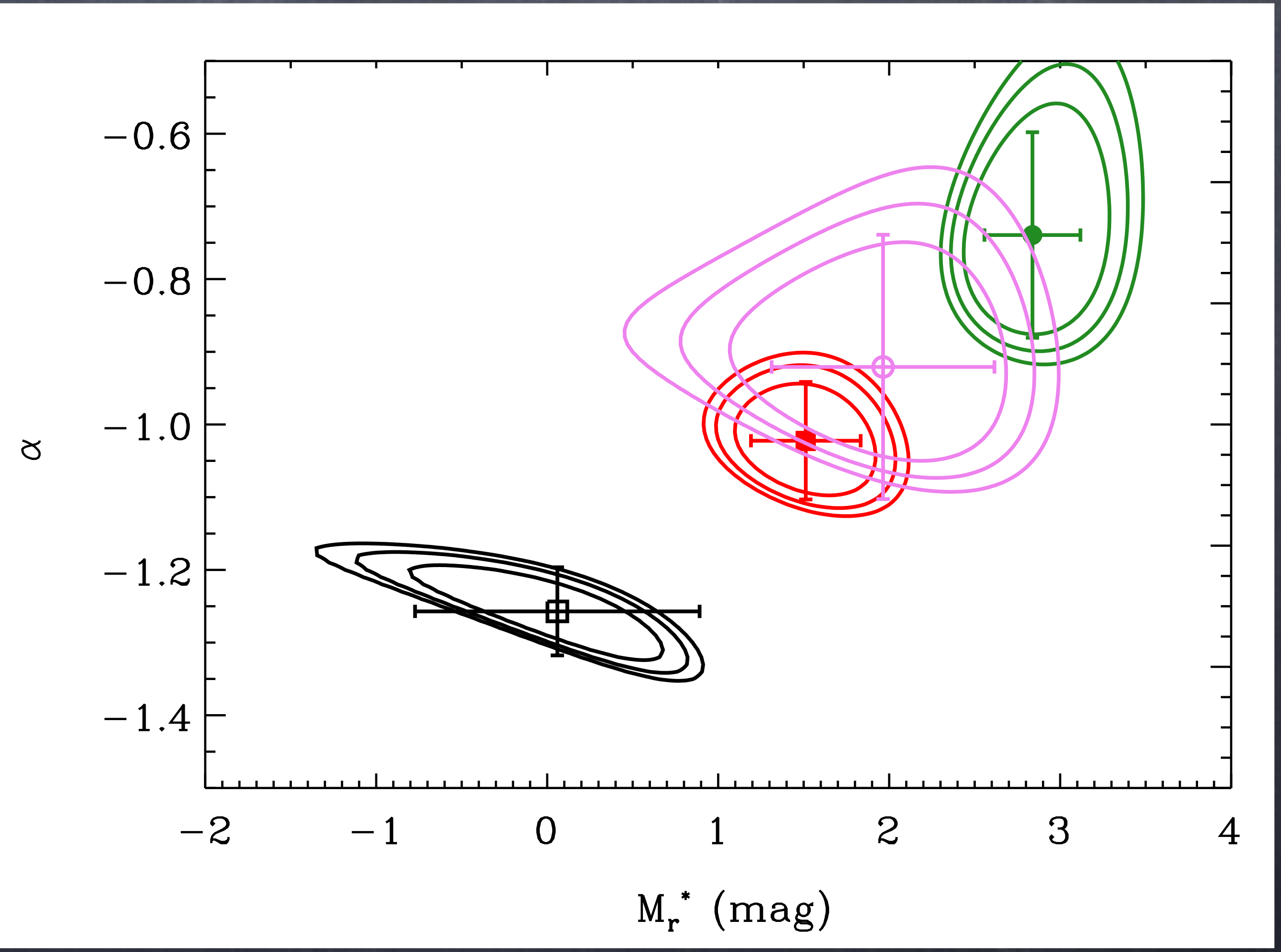

Part III: Properties of the galaxy satellite population

13 spectroscopically-confirmed FGs with z < 0.25

Are they OLD and dynamically RELAXED systems as predicted by simulations?
Is the magnitude gap a good indicator of the dynamical age of the system?

Applied to 5 FGs with more than 30 members

1D tests:
Asymmetry Index (AI)
Scale Tale Index (STI)
Weighted gap
1D-DEDICA
V_{BGG}

2D tests:
2D-DEDICA
Ellipticity
Voronoi Tessellation and Percolation (VTP)

3D tests:
Dressler-Schectman
Velocity gradient

Applied to 5 FGs with more than 30 members

Part III: Properties of the galaxy satellite population

name	AI	STI	weighted gap	1D-DEDICA	V_{BGG}	DS	V_{grad}	2D-DEDICA	VTP	ϵ	BGG
FGS02	N	Y	N	N	N	Y	N	Y	Y	N	N
FGS03	-	-	-	-	-	-	-	N	N	N	N
FGS14	N	Y	N	N	Y	N	N	Y	N	N	N
FGS17	-	-	-	-	-	-	-	N	N	N	N
FGS20	-	-	-	-	-	-	-	N	N	N	N
FGS23	N	N	N	Y	N	N	N	N	N	N	N
FGS26	-	-	-	N	-	-	-	N	Y	N	N
FGS27	N	N	N	N	N	Y	N	Y	Y	Y	N
FGS28	-	-	-	-	-	-	-	-	-	-	Y
FGS29	-	-	-	-	-	-	-	N	N	N	N
FGS30	N	Y	N	N	N	N	N	N	Y	Y	N
FGS32	-	-	-	-	-	-	-	N	N	N	N
FGS34	-	-	-	-	-	-	-	Y	N	N	N

Zarattini et al. 2016

Part III: Properties of the galaxy satellite population

name	AI	STI	weighted gap	1D-DEDICA	V_{BGG}	DS	V_{grad}	2D-DEDICA	VTP	ϵ	BGG
FGS02	N	Y	N	N	N	Y	N	Y	Y	N	N
FGS03	-	-	-	-	-	-	-	N	N	N	N
FGS14	N	Y	N	N	Y	N	N	Y	N	N	N
FGS17	-	-	-	-	-	-	-	N	N	N	N
FGS20	-	-	-	-	-	-	-	N	N	N	N
FGS23	N	N	N	Y	N	N	N	N	N	N	N
FGS26	-	-	-	N	-	-	-	N	Y	N	N
FGS27	N	N	N	N	N	Y	N	Y	Y	Y	N
FGS28	-	-	-	-	-	-	-	-	-	-	Y
FGS29	-	-	-	-	-	-	-	N	N	N	N
FGS30	N	Y	N	N	N	N	N	N	Y	Y	N
FGS32	-	-	-	-	-	-	-	N	N	N	N
FGS34	-	-	-	-	-	-	-	Y	N	N	N

Zarattini et al. 2016

Each FG gives at least one positive result for the presence of substructures when velocities are considered

Part III: Properties of the galaxy satellite population

name	AI	STI	weighted gap	1D-DEDICA	V_{BGG}	DS	V_{grad}	2D-DEDICA	VTP	ϵ	BGG
FGS02	N	Y	N	N	N	Y	N	Y	Y	N	N
FGS03	-	-	-	-	-	-	-	N	N	N	N
FGS14	N	Y	N	N	Y	N	N	Y	N	N	N
FGS17	-	-	-	-	-	-	-	N	N	N	N
FGS20	-	-	-	-	-	-	-	N	N	N	N
FGS23	N	N	N	Y	N	N	N	N	N	N	N
FGS26	-	-	-	N	-	-	-	N	Y	N	N
FGS27	N	N	N	N	N	Y	N	Y	Y	Y	N
FGS28	-	-	-	-	-	-	-	-	-	-	Y
FGS29	-	-	-	-	-	-	-	N	N	N	N
FGS30	N	Y	N	N	N	N	N	N	Y	Y	N
FGS32	-	-	-	-	-	-	-	N	N	N	N
FGS34	-	-	-	-	-	-	-	Y	N	N	N

Zarattini et al. 2016

Each FG gives at least one positive result for the presence of substructures when velocities are considered

When only positions are considered, several FGs give positive results

Main observational properties

Fossil systems have one of the most luminous/massive central galaxies in the Universe

The Central galaxies has grown by merging M* galaxies. But similarly to other BCGs for non-fossil systems

No differences in the properties of the DM halos are found

They are not relaxed and dynamically old systems

Only the magnitude gap is not a good indicator of the dynamical age of the system (see Raouf et al. 2014)