Central galaxies and satellites in fossil systems

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Outline of the talk

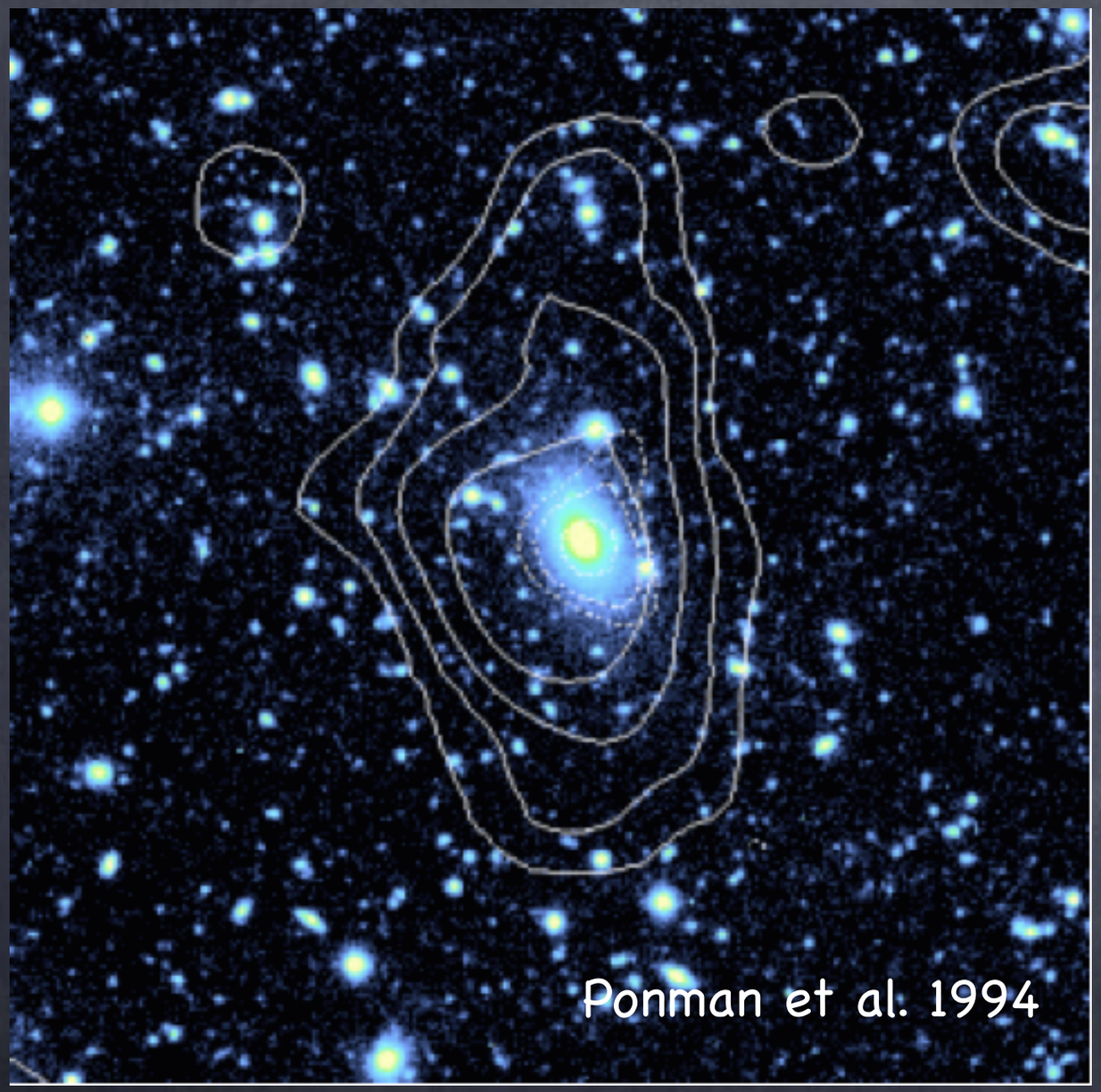
Introduction:

- The FOGO project

Results:

- Scaling relations of FGs
- Scaling relations of BGCs
- Resolved stellar populations in BCGs
- Dependence of the LF on the magnitude gap (Δm_{12})
- Spectroscopic LF of RXJ075243.6+45565
- Substructures in FGs
- Orbits in FGs
- Large-scale structure around FGs

The "Fossil Group Origins" (FOGO) project



What is a Fossil System?

Ponman et al (1994) discovered RX J1340.6+4018, a system dominated by an elliptical galaxy.

The giant elliptical is surrounded by an X-ray emitting halo of hot gas suggesting a group-sized halo (6×10^{13} $M_{\odot}$).

The "Fossil Group Origins" (FOGO) project

NASA, ESA and the Hubble Heritage (STScI/AURA)-ESA/
Hubble Collaboration. Acknowledgment: M. West (ESO, Chile)

- The observational definition of these systems was given by Jones et al. (2003).
- Magnitude gap between the two brightest galaxies: $\Delta m_{12} > 2$ mag in the r-band within half the virial radius (or $\Delta m_{14} > 2.5$, Dariush et al. 2010).

The "Fossil Group Origins" (FOGO) project

NASA, ESA, M. West (ESO, Chile), and CXC/ Penn State University/G. Garmire, et al. 2006

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- Magnitude gap between the two brightest galaxies: $\Delta m_{12} > 2$ mag in the r-band within half the virial radius (or $\Delta m_{14} > 2.5$, Dariush et al. 2010).
- X-ray emission of at least 10^{42} erg s^{-1}

The "Fossil Group Origins" (FOGO) project

First observational results:

- Higher L_X and T_X for the same L_{opt}
- Higher centrally-concentrated DM halos
- Massive BCGs
- Differences in BCGs properties
- Lack of other bright (M*) galaxies

The "Fossil Group Origins" (FOGO) project

Model for the formation of fossil systems:

- Old formation
- Fast and efficient merging of bright galaxies with the BCG
- Few interactions with the cosmic web

Consequences:

- Old and dynamically relaxed systems
- Δm_{12} correlates with the dynamical state
- Fossil relics of the ancient Universe

The "Fossil Group Origins" (FOGO) project

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

FOGO project

Numerical simulations:
Compare theory with observations

Properties of ICM
Which is the mechanism driving the metallicity enrichment of the ICM? Are there cooling cores in FGs?

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?

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

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FOGO project

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?
Are their orbits peculiar?

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

Properties of the environment
Are FGs found in peculiar large-scale environment?

The "Fossil Group Origins" (FOGO) project

E. D'Onghia (Madison)
A. Kundert (Madison)

C. del Burgo (INAOE)

R. Sánchez Janssen (Victoria)

S. Borgani (Trieste)
W. Boschin (TNG)
E.M. Corsini (Padova)
M. Girardi (Trieste)
N. Napolitano (Capodimonte)
S. De Grandi (Milano)
A. Biviano (Trieste)

FOGO

J.A.L. Aguerri (IAC)
R. Barrena (IAC)
N. Castro R. (IAC)
J. Iglesias Páramo (IAA)
J.M. Vilchez (IAA)

J. Méndez Abreu (St Andrews)

The "Fossil Group Origins" (FOGO) project

ITP programme: 52 observing nights in the period 2008-2010
at the Roque de los Muchachos observatory (La Palma, Spain)

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Multiobject spectroscopy
with DOLORES

TNG

FOGO

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WHT

FOGO

Multiobject spectroscopy with WYFFOS
K-band imaging with LIRIS
Integral field spectroscopy with INTEGRAL

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INT

r-band images with WFC

NOT

r-band images with ALFOSC

FOGO

The "Fossil Group Origins" (FOGO) project

Additional time: 10 observing nights in the period 2011-2012 at TNG under Spanish and Italian TACS

27 observing hours in semester 2013B at GTC under Spanish TAC

Long slit spectra with OSIRIS

GTC

FOGO

Scaling relations of FGs

Scientific question: are FGs over luminous in X-rays?

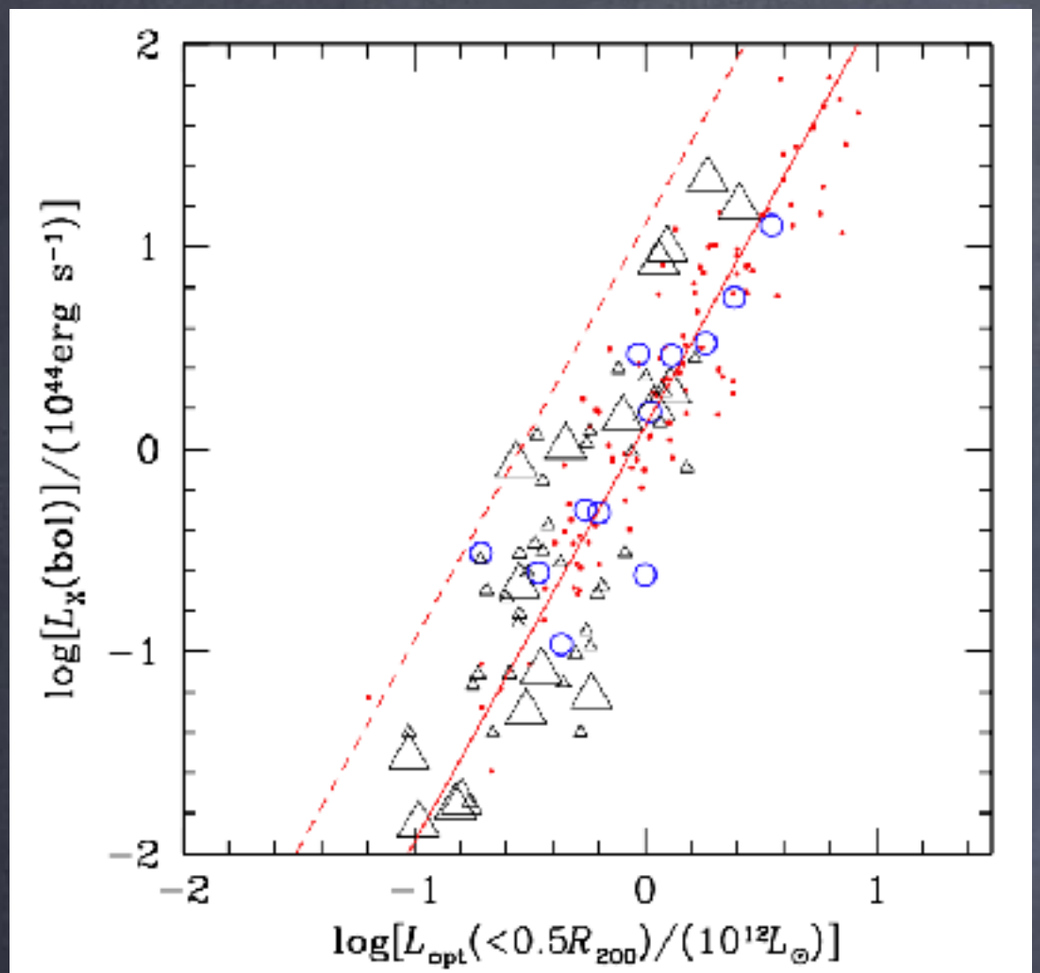

Fig. 4. Comparison with previous literature. CONF-FGSs and CLs as in Fig. 3, but for the bolometric X-ray luminosity and the optical luminosity computed within $0.5R_{200}$. The dashed line indicates overestimates by a factor of 10 in L_X(bol) or underestimates by a factor of 3 in L_{opt} with respect to our CL sample (red points fitted by the solid line). Large and small black triangles indicate the fossil and comparison systems in Harrison et al. (2012, see their Fig. 5).

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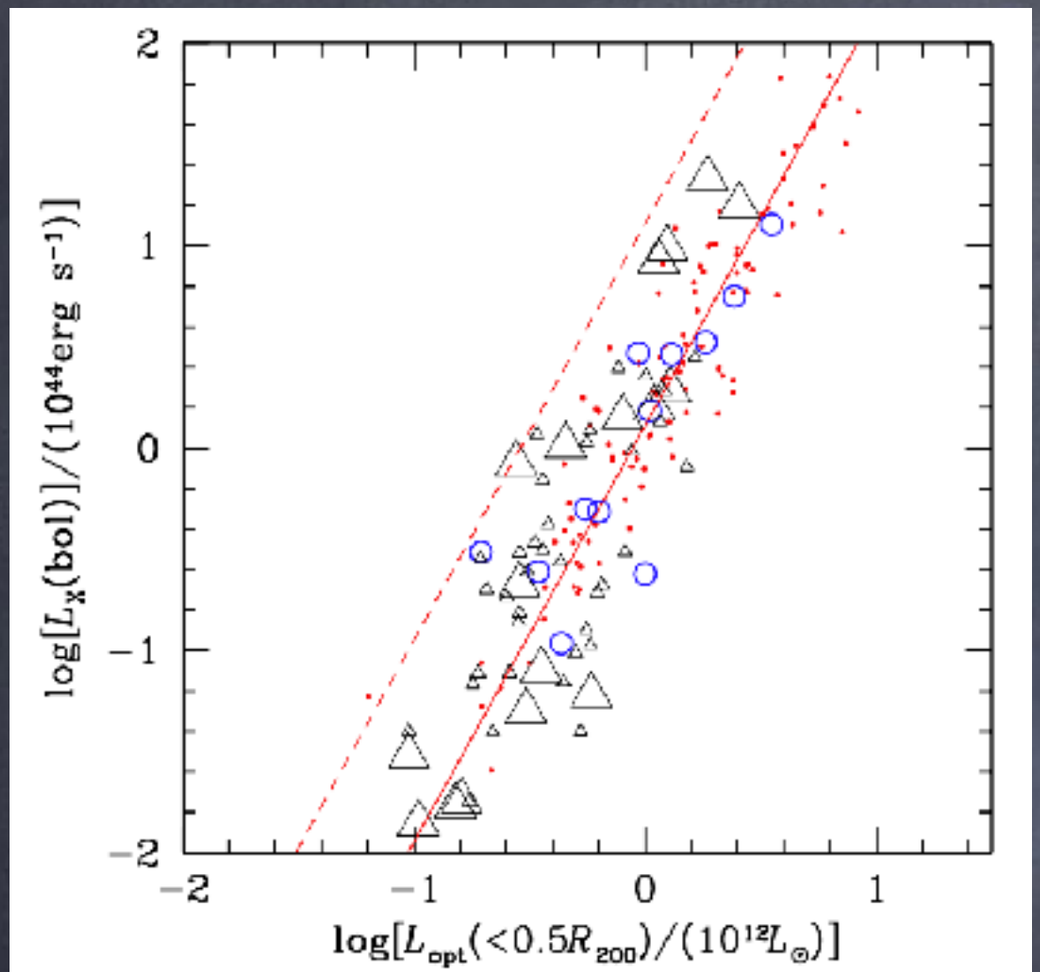

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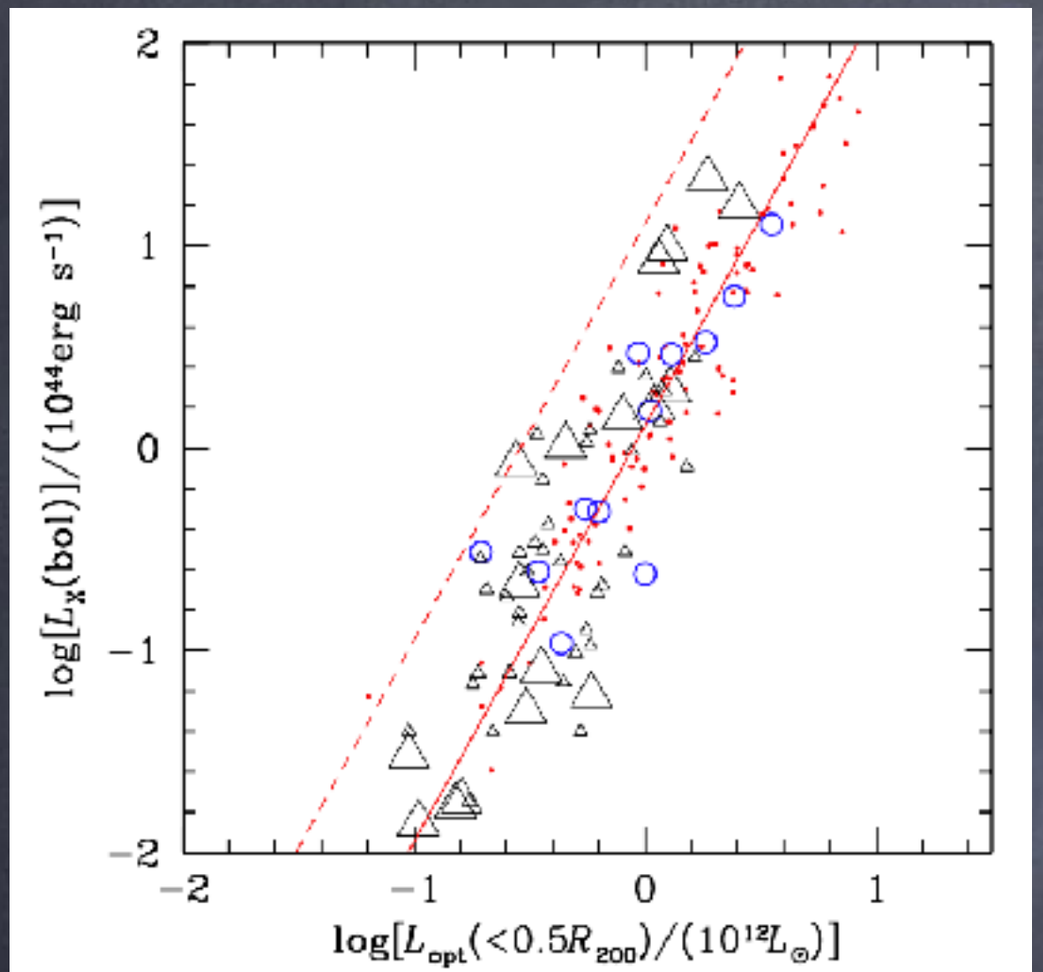

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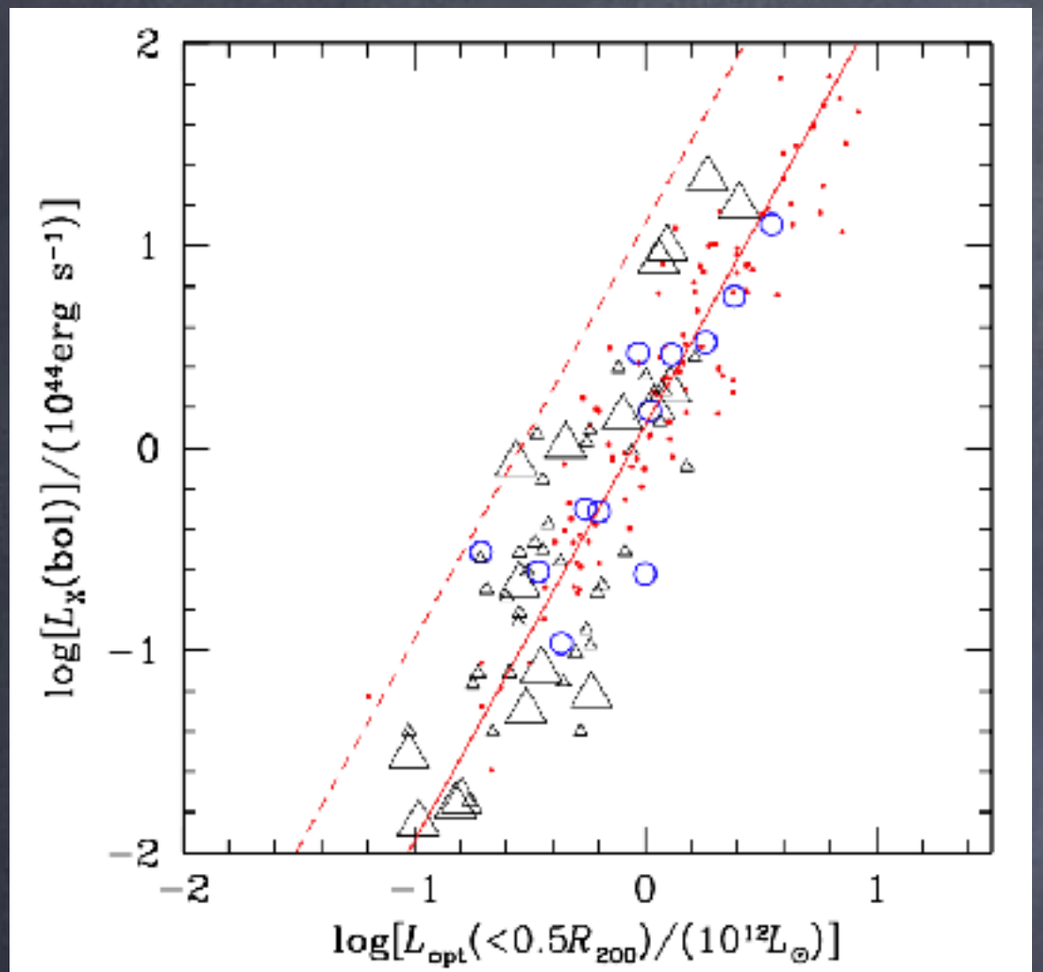

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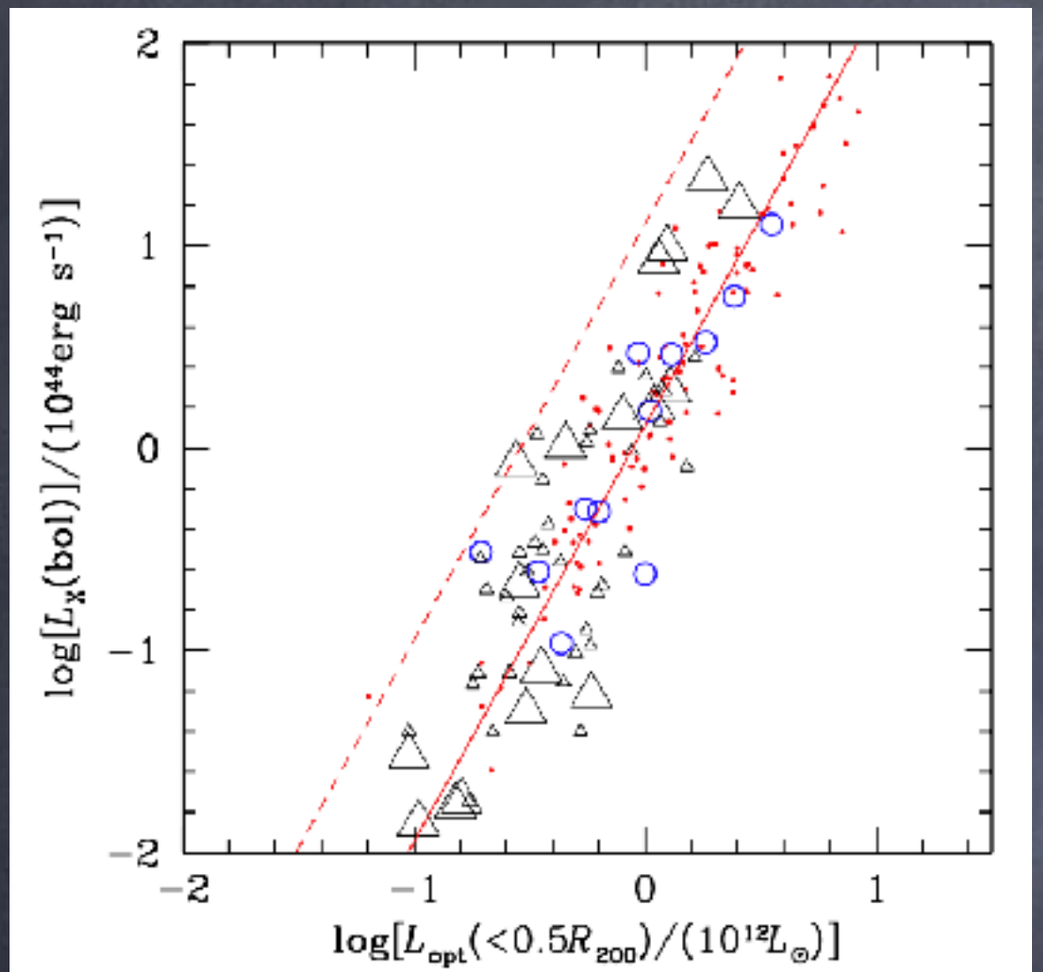

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Girardi+2014

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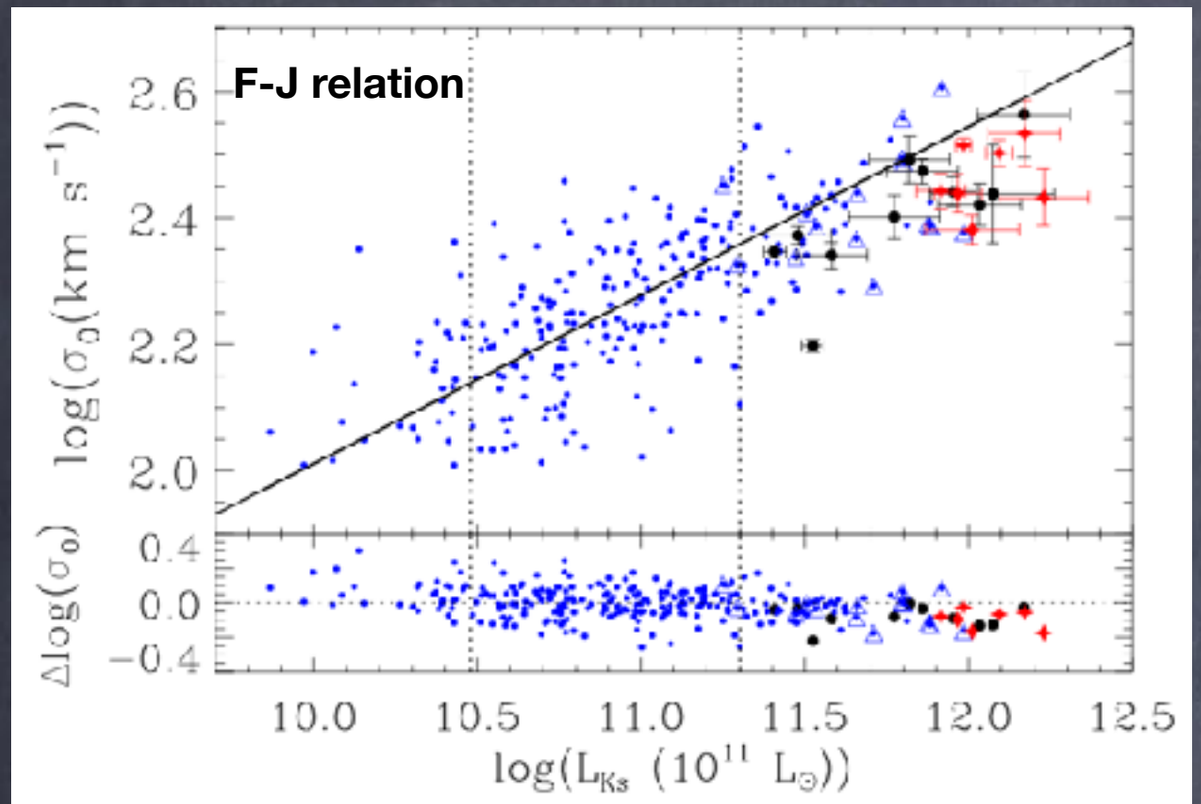
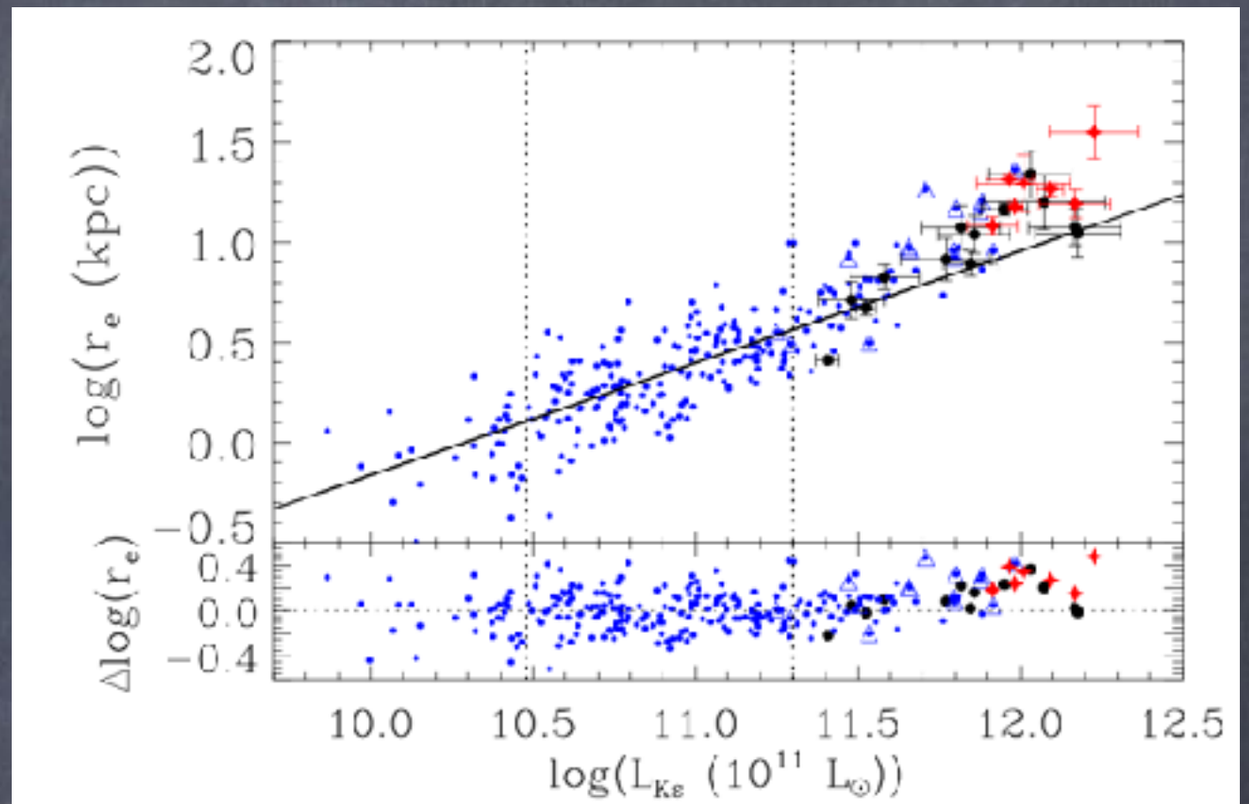
Scaling relations of the BCGs

Scientific question: how BCGs in FGs were formed?

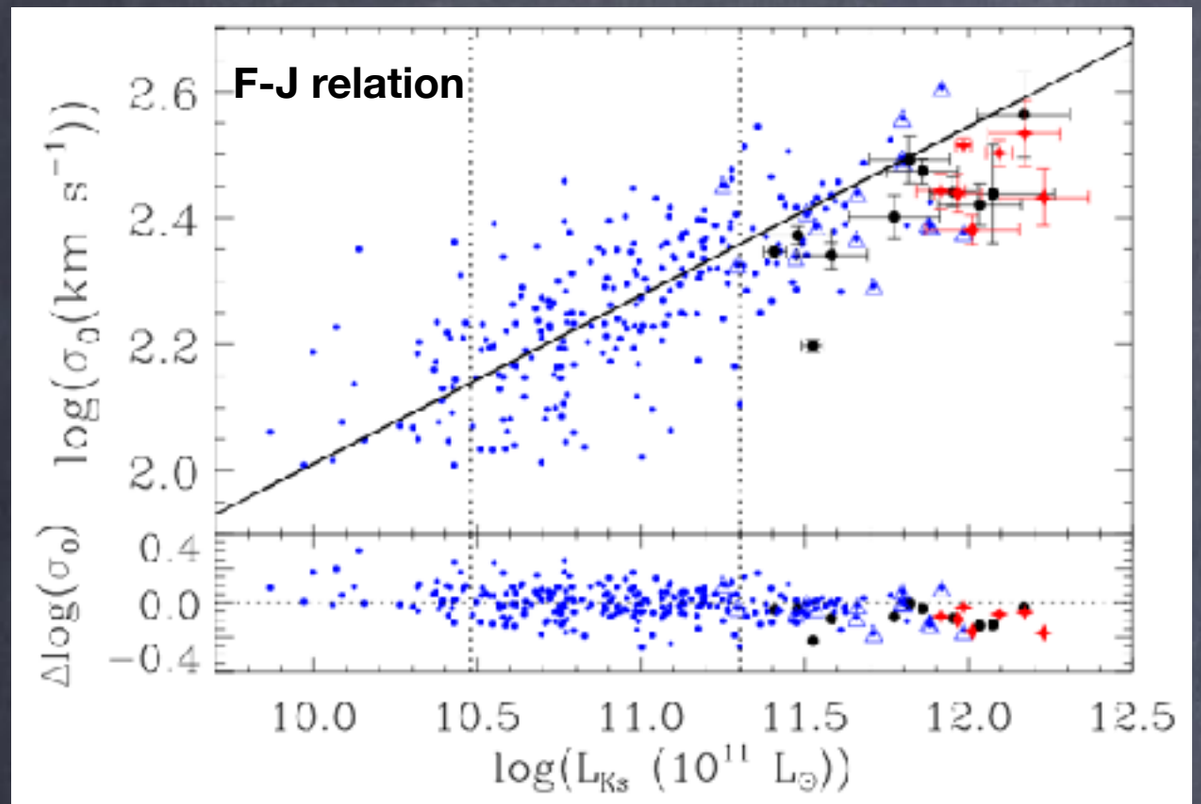


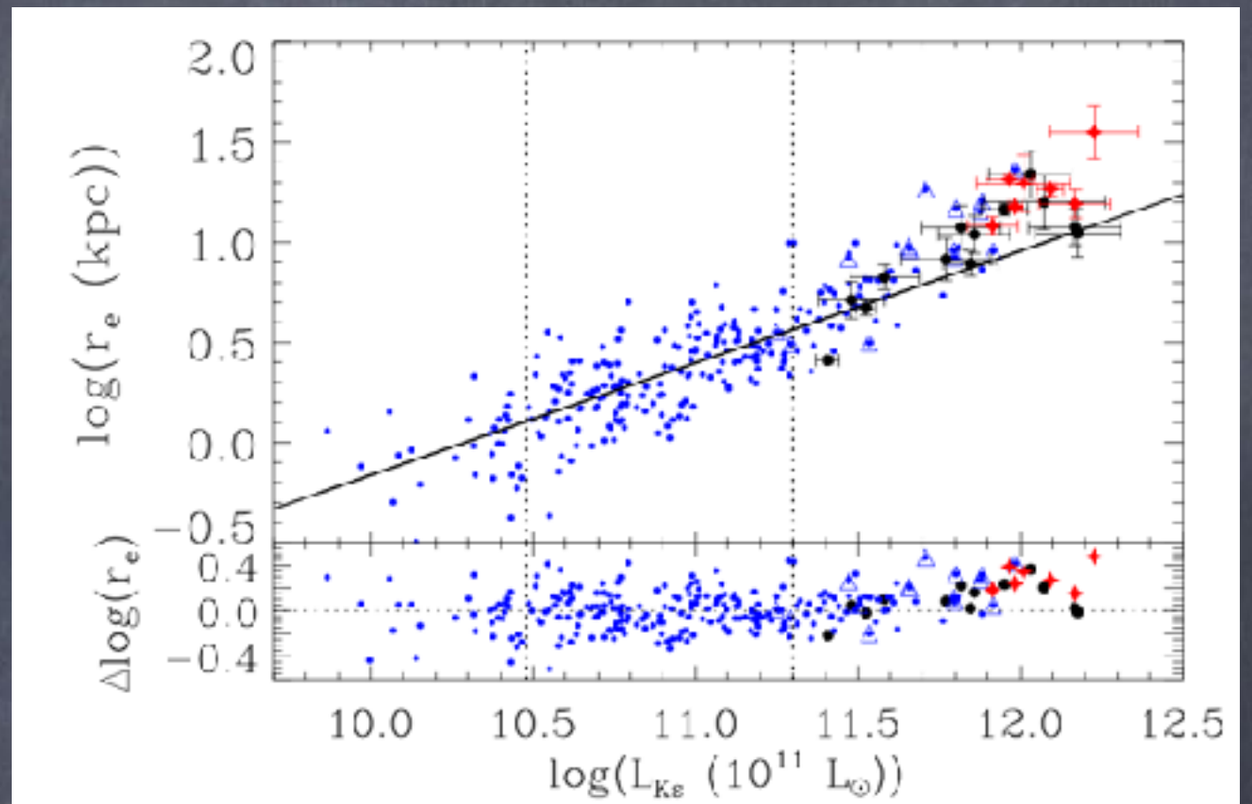


- Early-type galaxies from Pahre+1998
- BCGs from Pahre+1998
- BCGs from FOGO with ell > 0.3
- BCGs from FOGO with ell < 0.3

Scaling relations of the BCGs

Scientific question: how BCGs in FGs were formed?





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- BCGs follow the tilt of the FJ
- BCGs have larger re than normal ellipticals

Scaling relations of the BCGs

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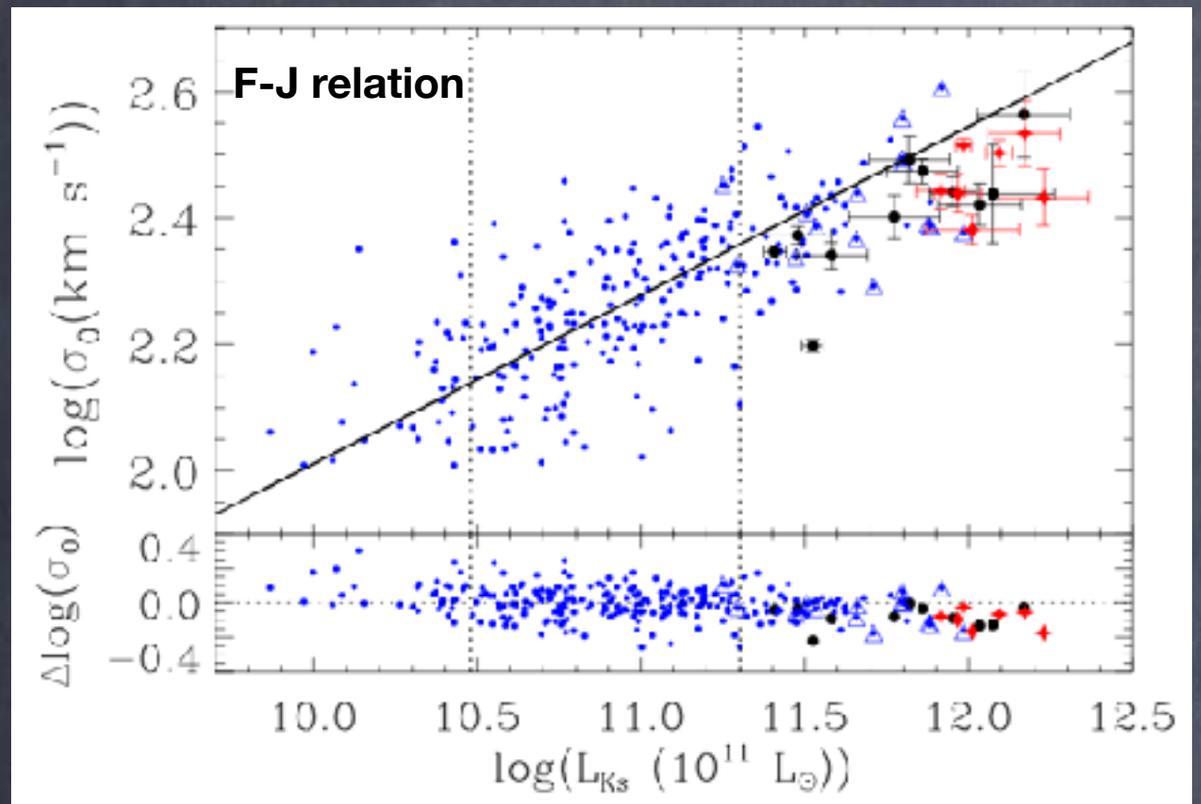

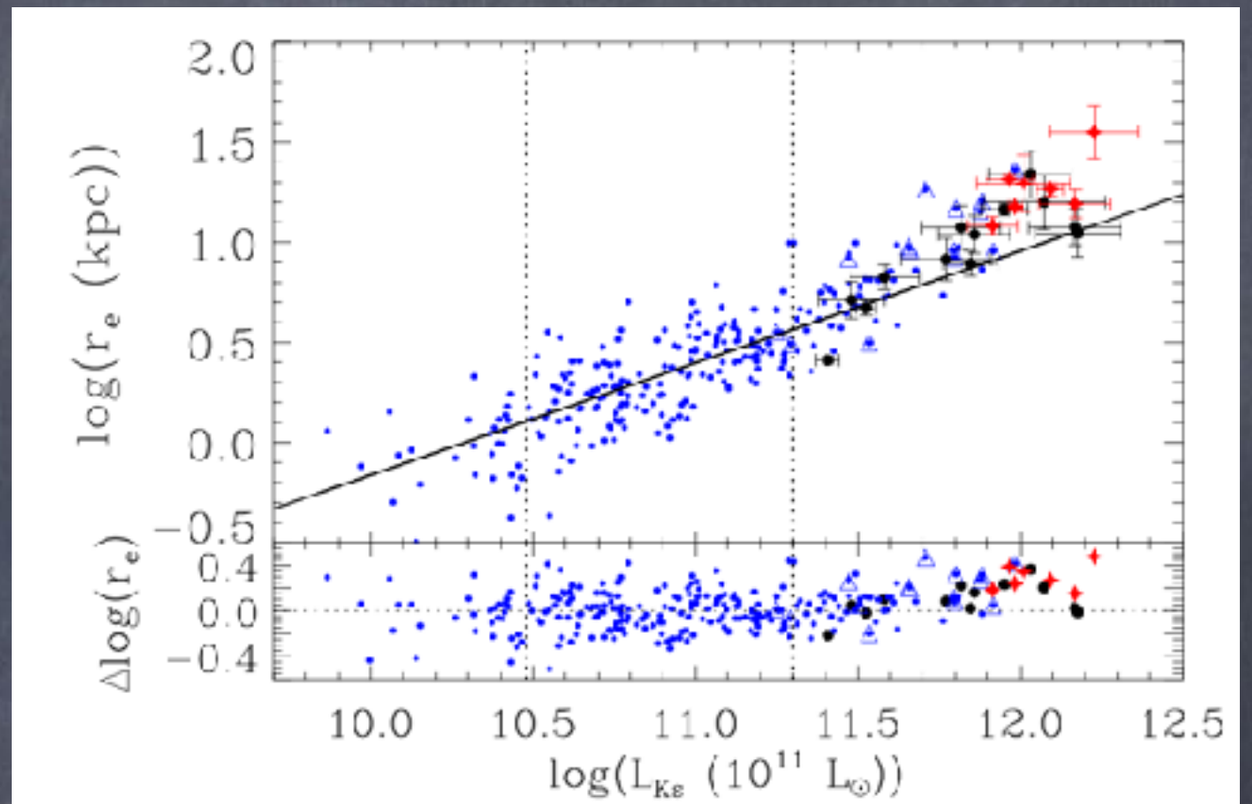

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Mergers with gas only at early time, then mergers without gas

Scaling relations of the BCGs

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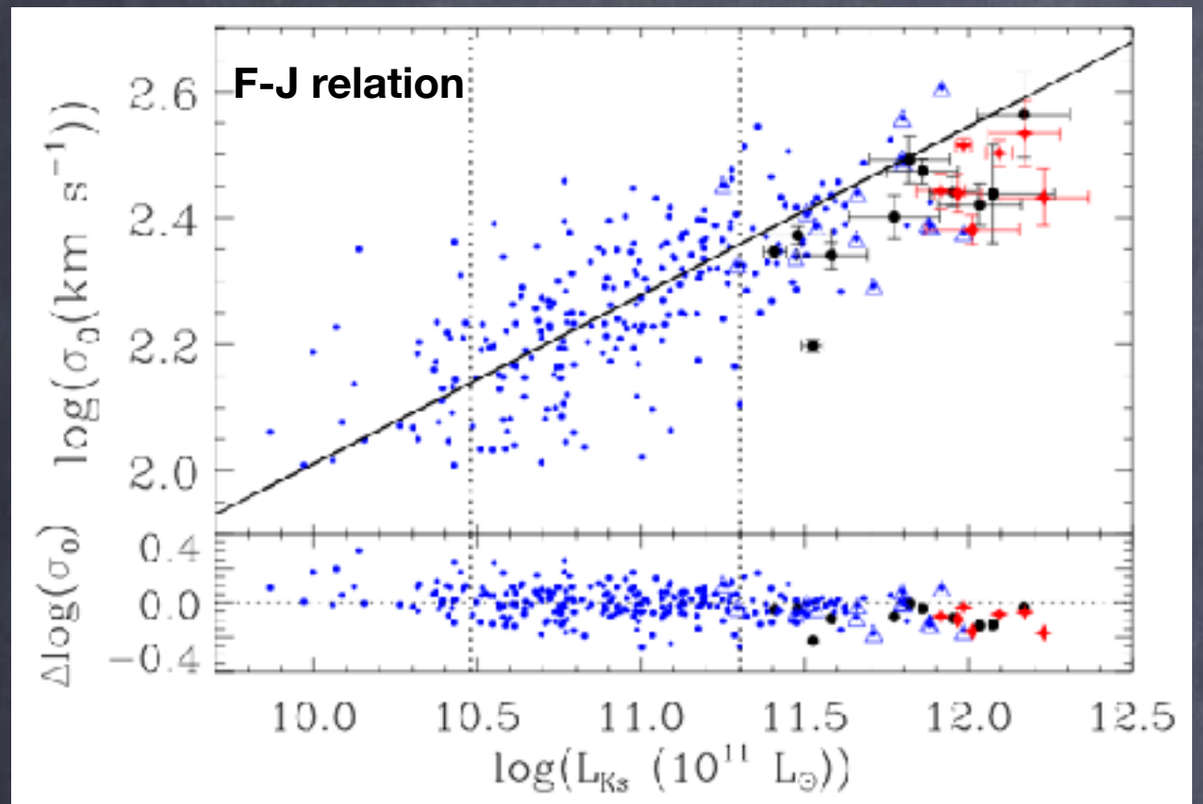

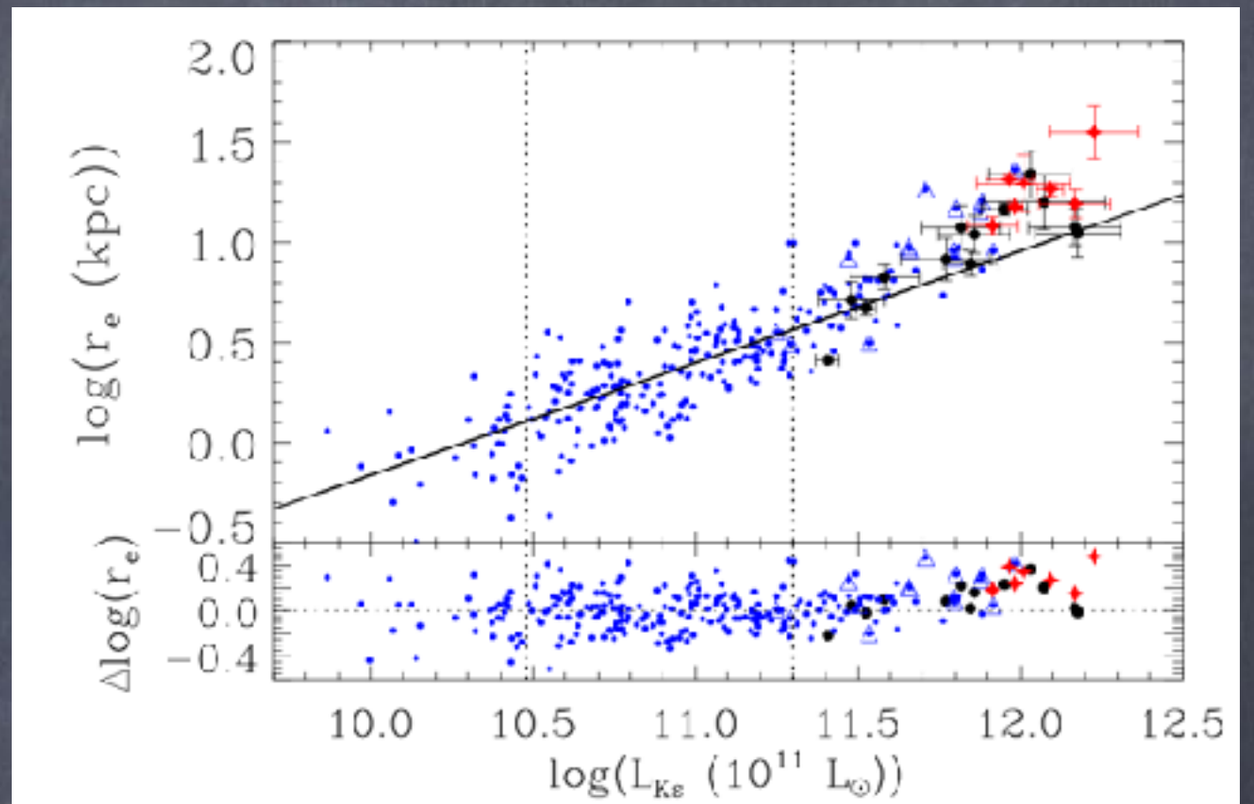

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Méndez-Abreu et al. 2012

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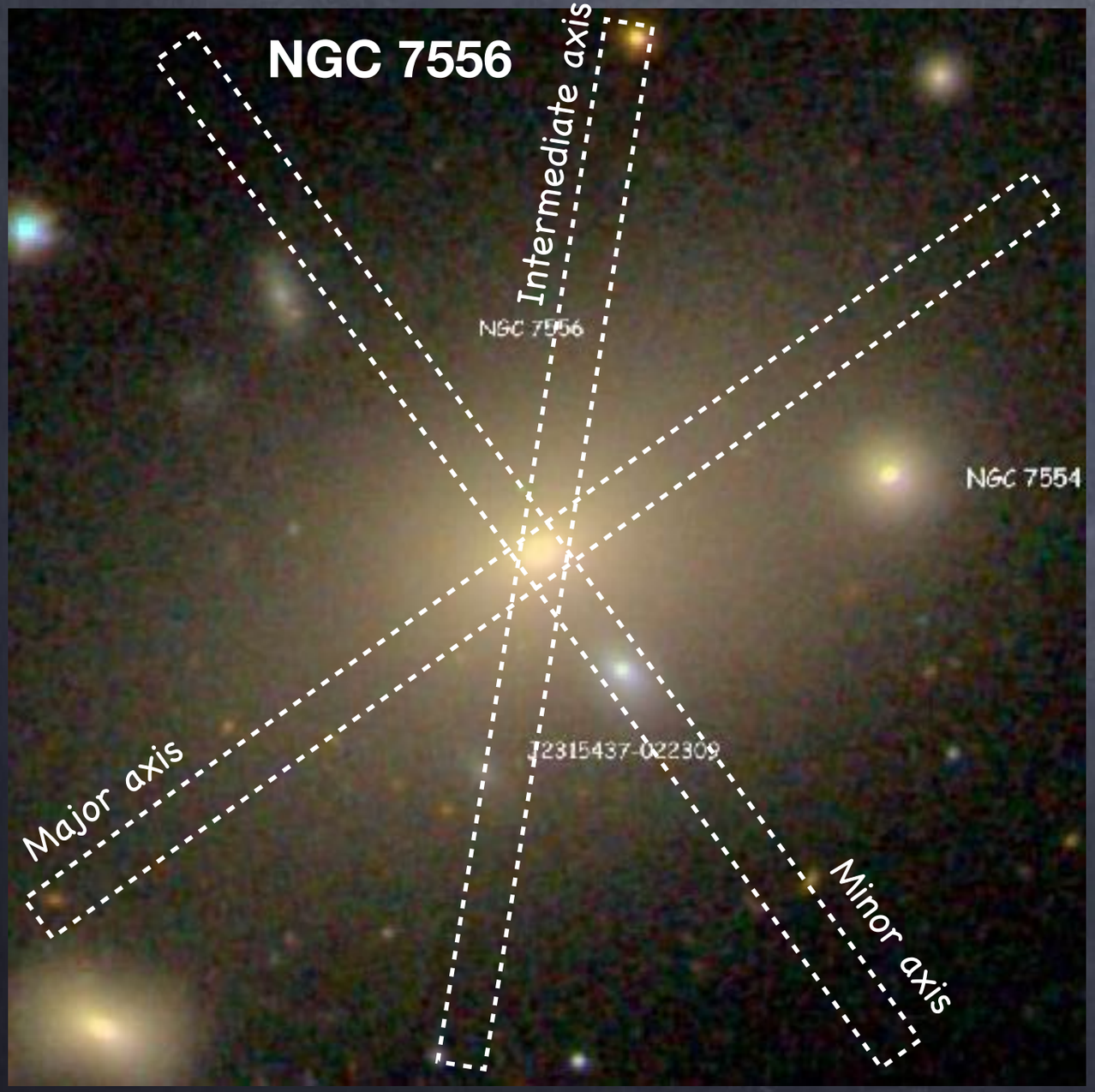
Stellar populations of NGC 7556 and NGC 6482

Scientific question: when BCGs in FGs were formed?



- BCG of RXC J2315.7-0222 system
- z = 0.025
- L_X = 2.1 x 10^{43} erg s^{-1}
- R_{200} = 862 kpc
- M_{200} = 7.4 x 10^{13} $M_\odot$
- Δm_{12} = 1.88 (bona fide FG)
- Cool core system

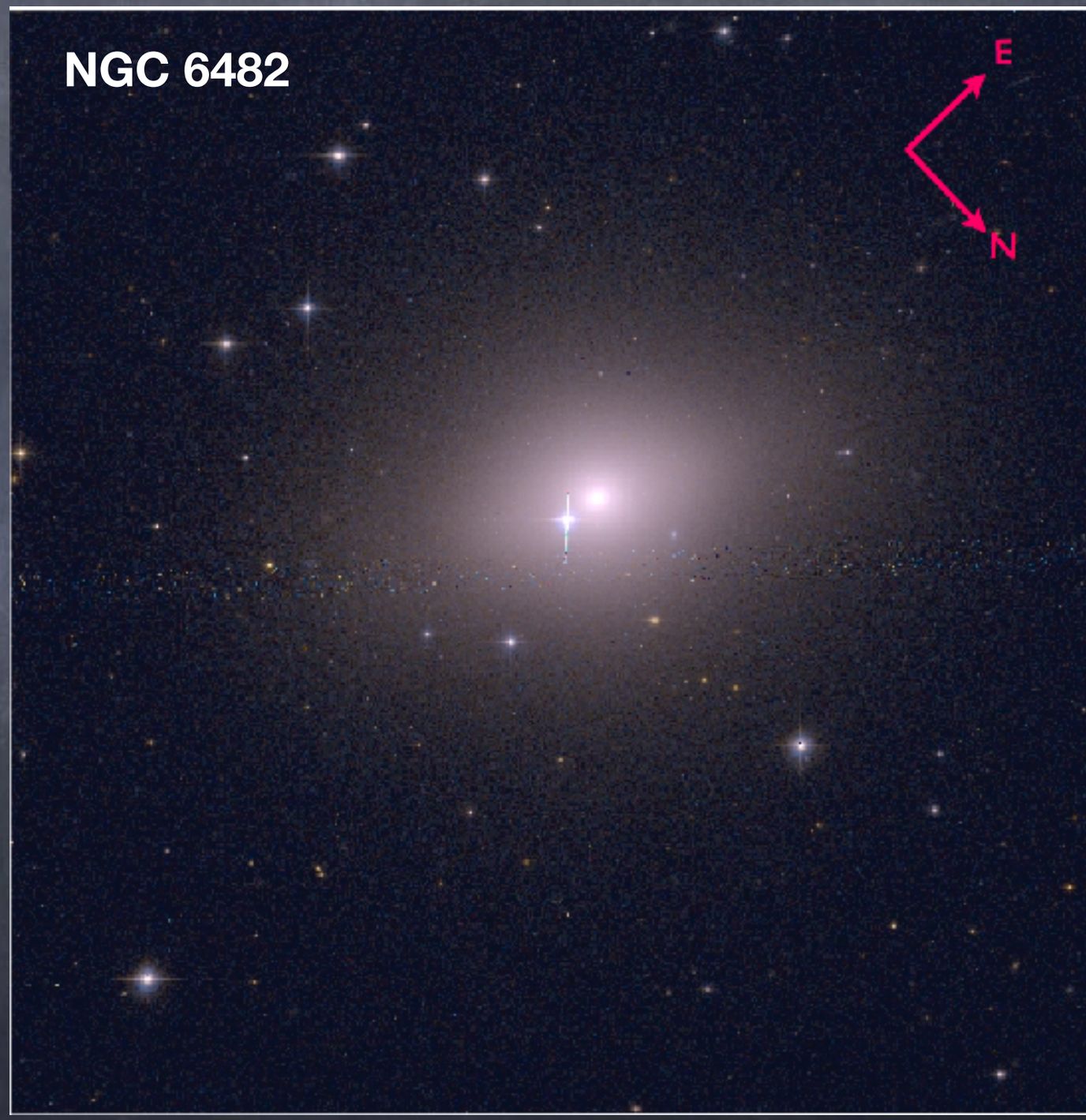
- Observations with OSIRIS@GTC:
  - 1" x 7.4' slits
  - Resolution: 2500
  - 3 axes: major, minor, and intermediate
  - 3.2 - 3.2 - 2.4 hours

Stellar populations of NGC 7556 and NGC 6482

Scientific question: when BCGs in FGs were formed?

- BCG of MCXC J1751.7+2304 system
- z = 0.013
- $L_X = 1 \times 10^{42}$ erg s^{-1}
- $R_{200} = 310$ kpc
- $M_{200} = 4 \times 10^{12}\ M_\odot$
- $\Delta m_{12} = 2.19$
- Non cool core system

- Observations with OSIRIS@GTC:
  - 1″ x 7.4′ slits
  - Resolution: 2500
  - 3 axes: major, minor, and intermediate
  - 2.5 - 2.5 - 1.8 hours



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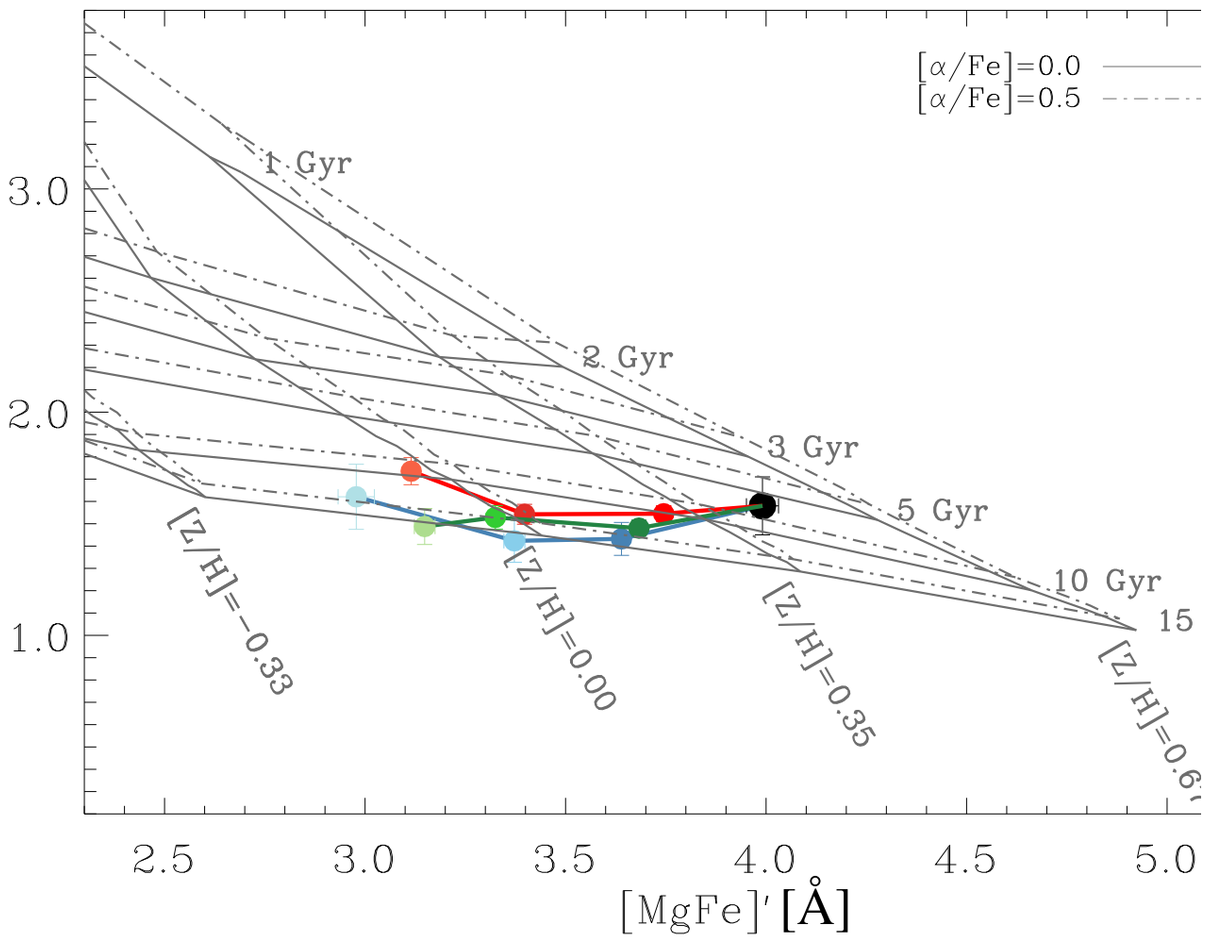
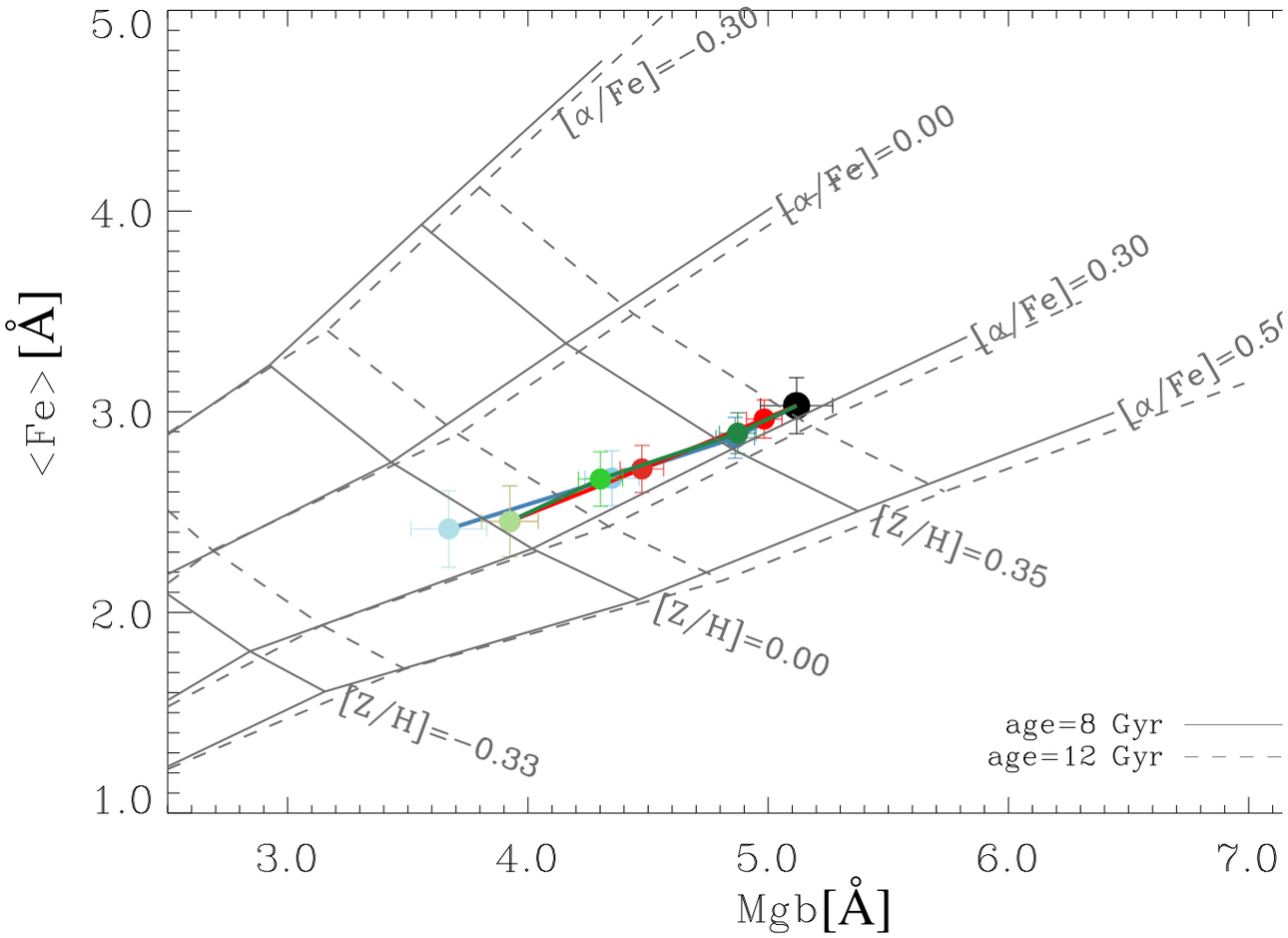
NGC 7556





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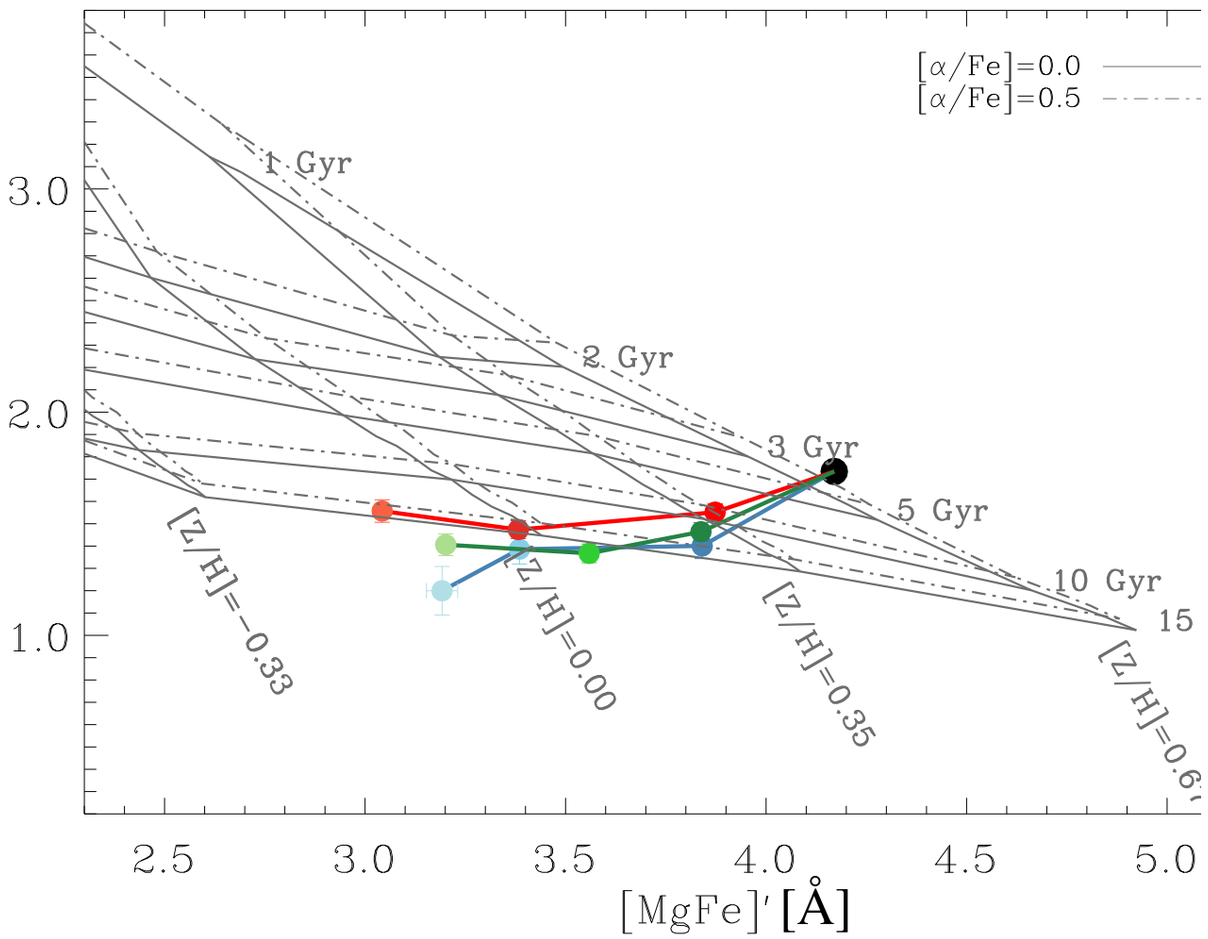
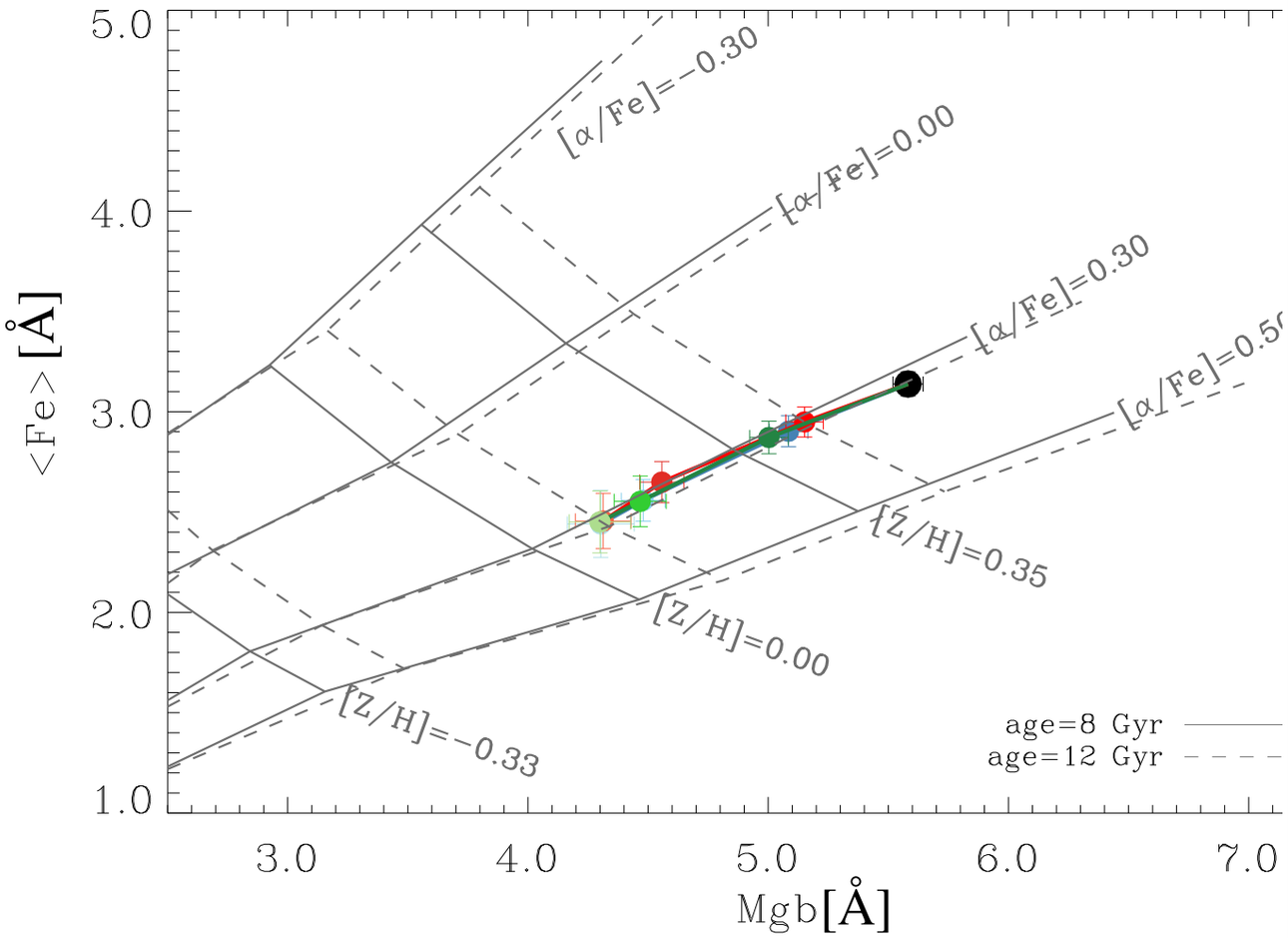
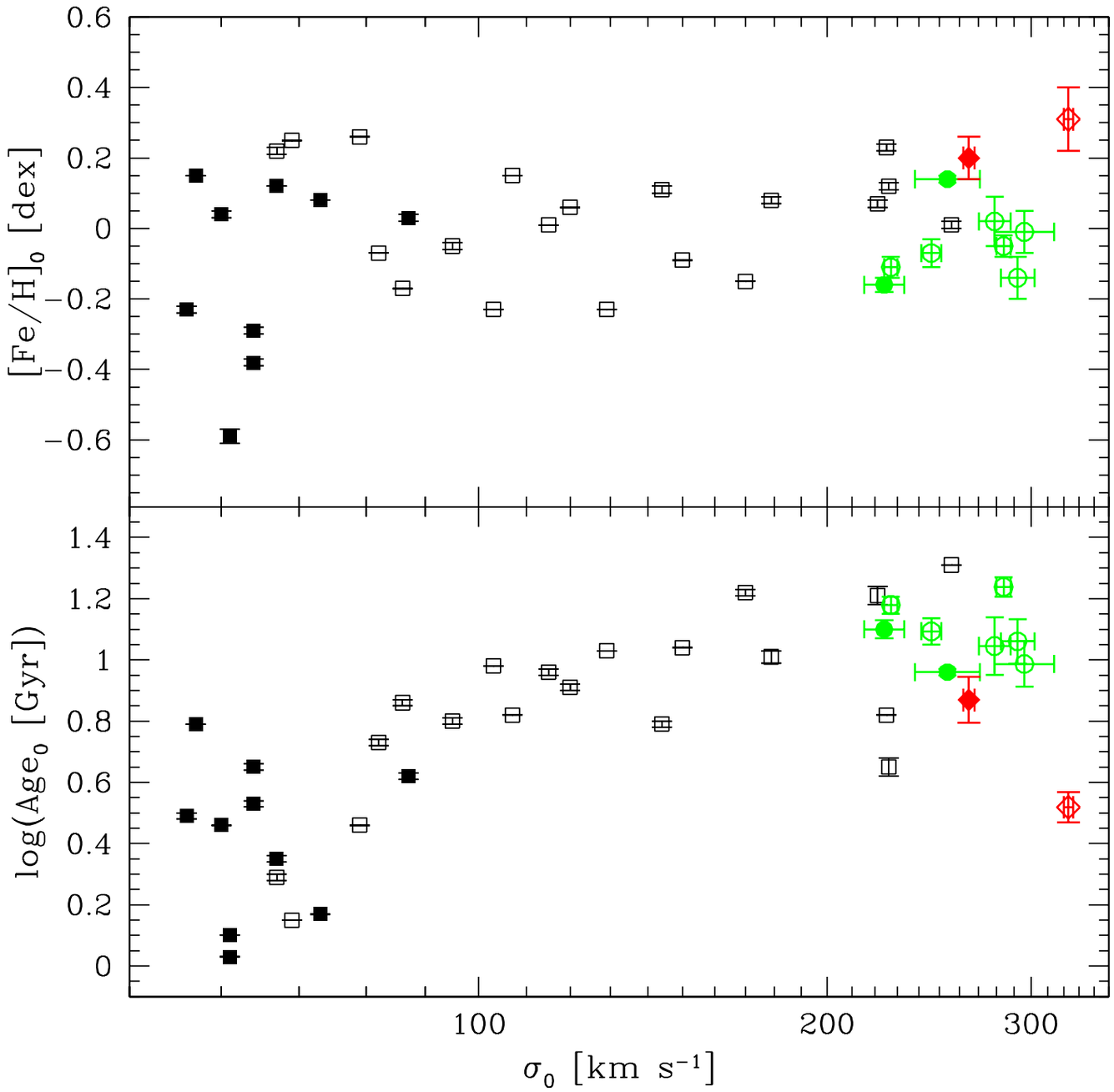




Stellar populations of NGC 7556 and NGC 6482

Scientific question: when BCGs in FGs were formed?

Central metallicity



→ **metal richer**

Central age

→ **younger**

Stellar populations of NGC 7556 and NGC 6482

Scientific question: when BCGs in FGs were formed?

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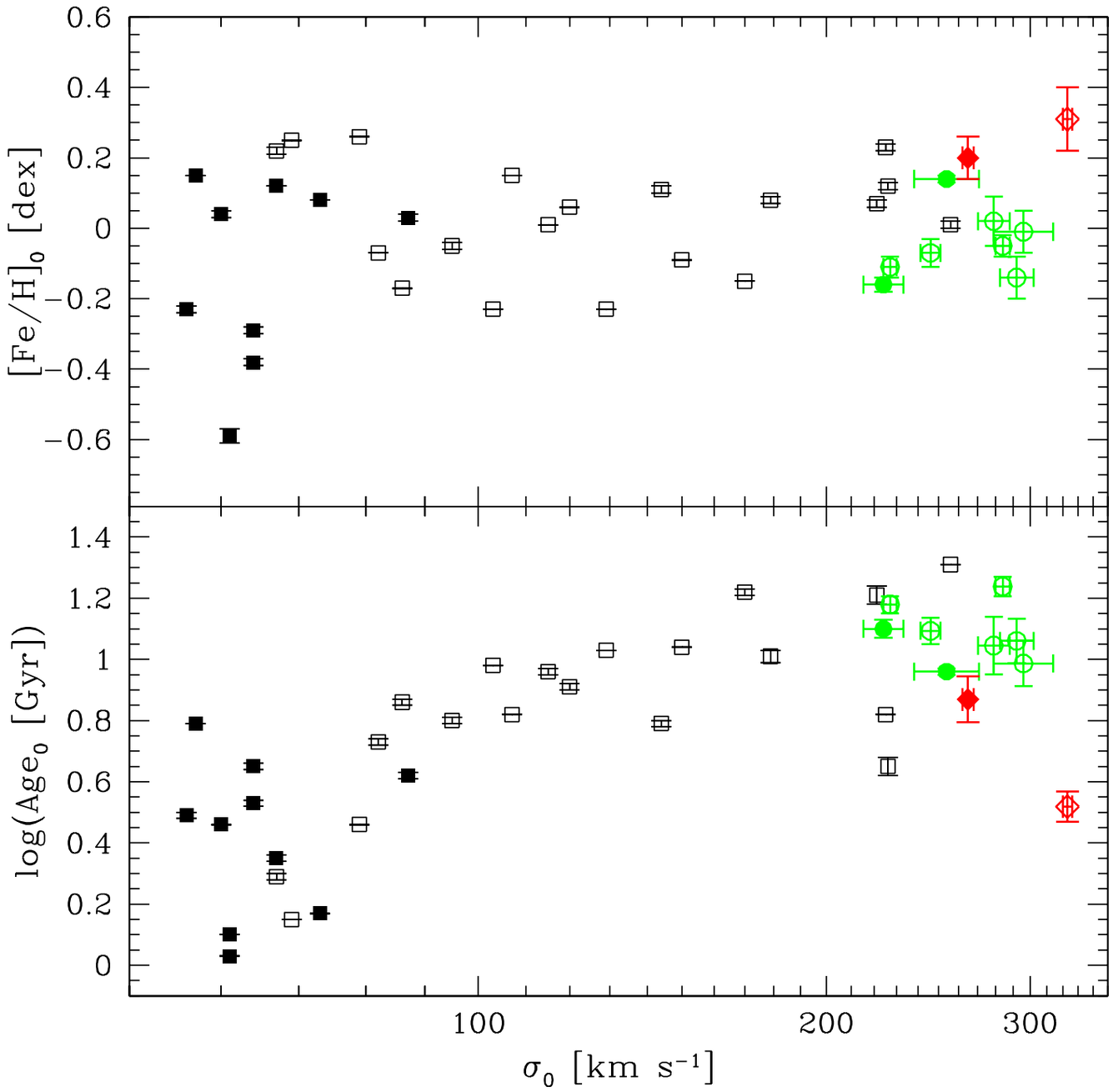

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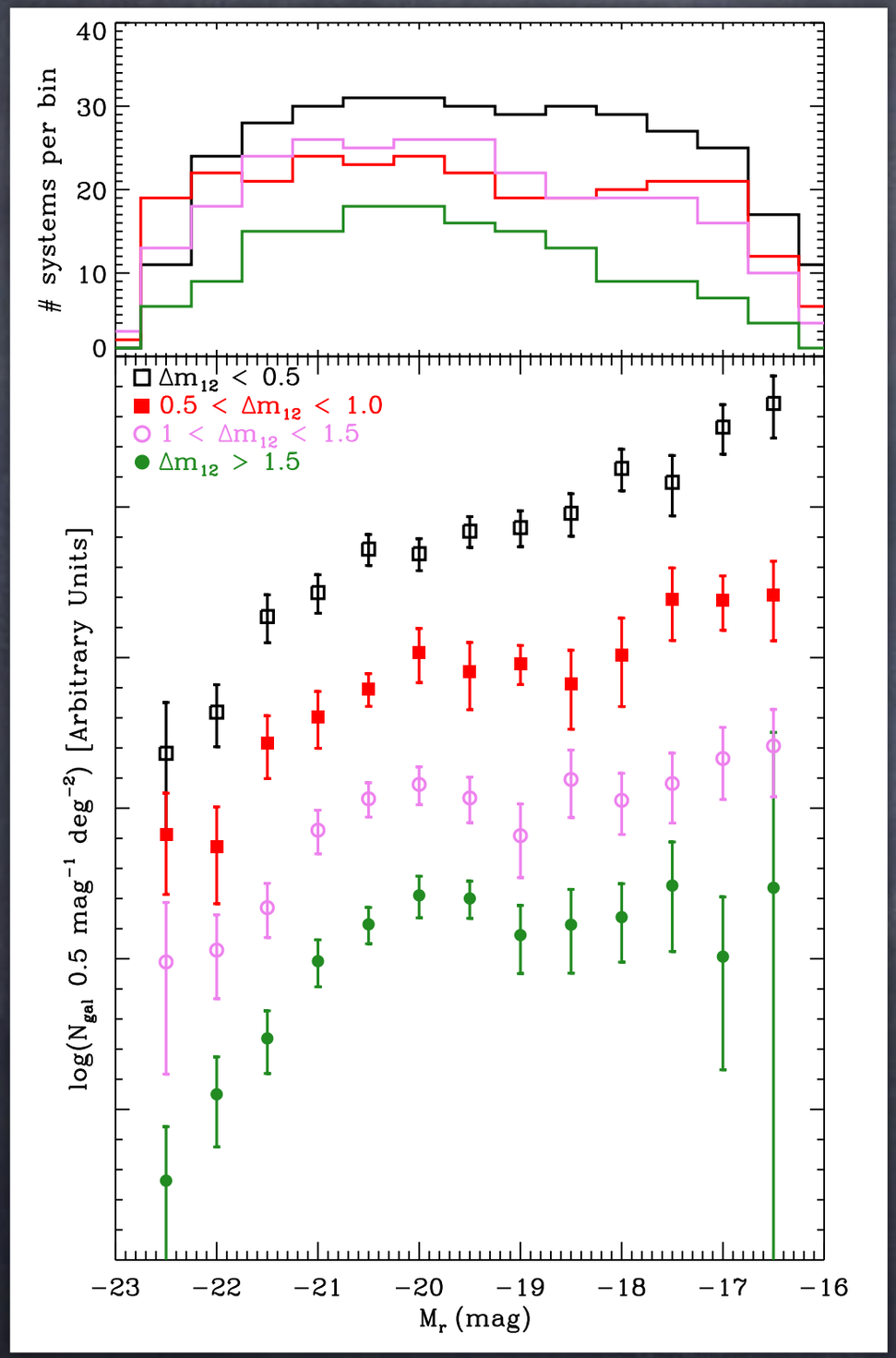
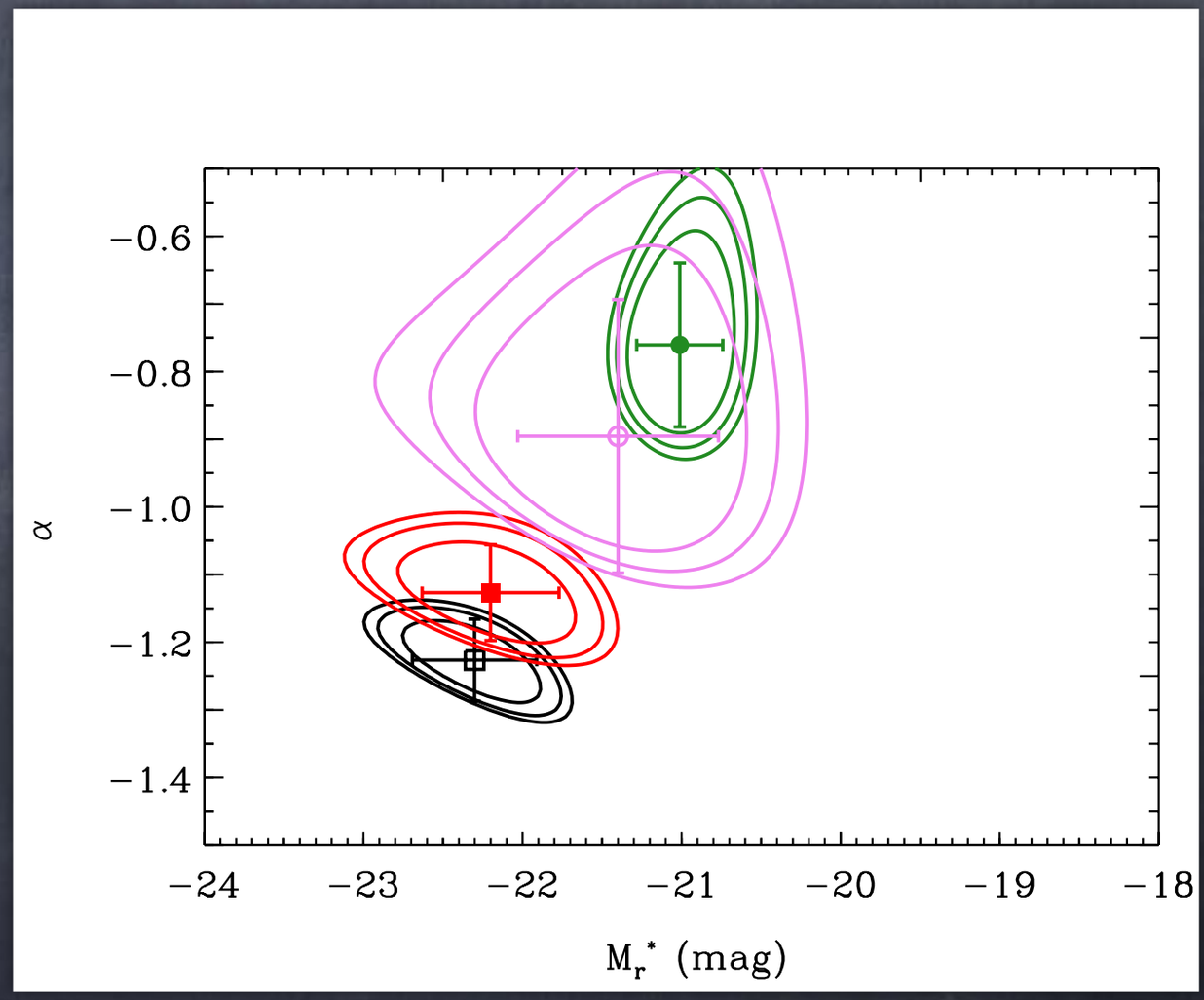
Corsini+2018

Luminosity functions in FGs: Dependence of the LF on the magnitude gap



Fit of the LFs using the Schechter formula:

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



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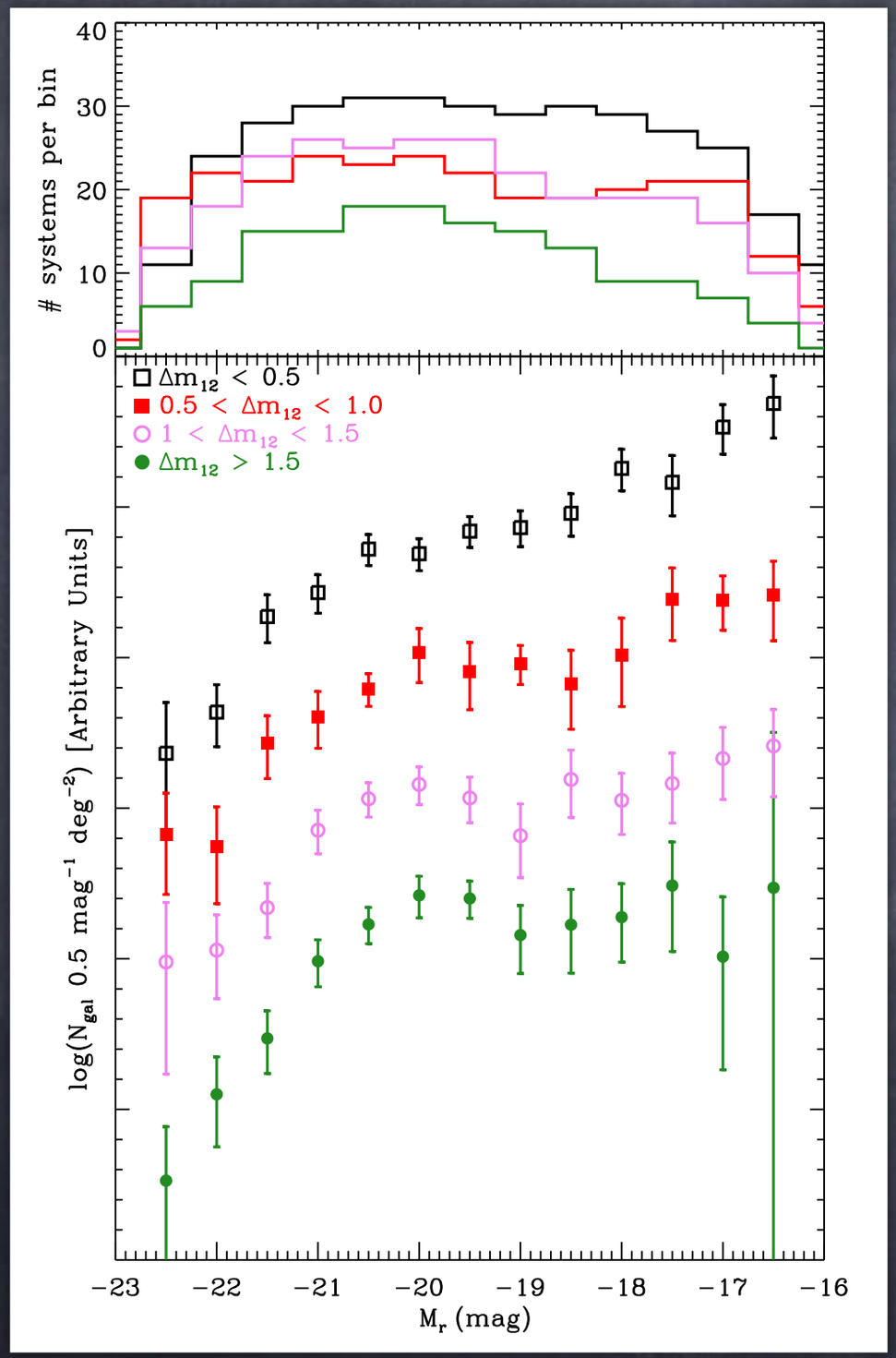

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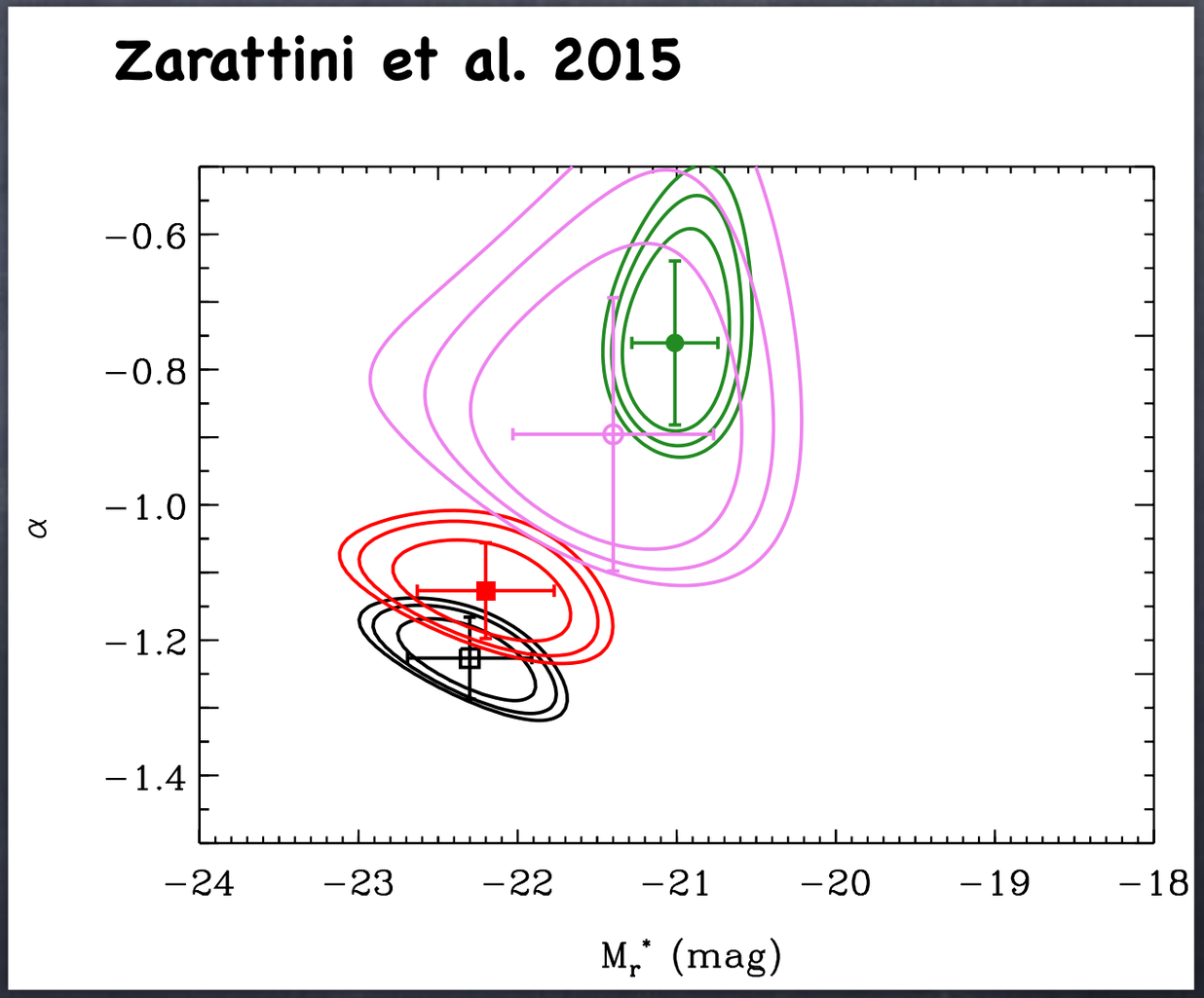
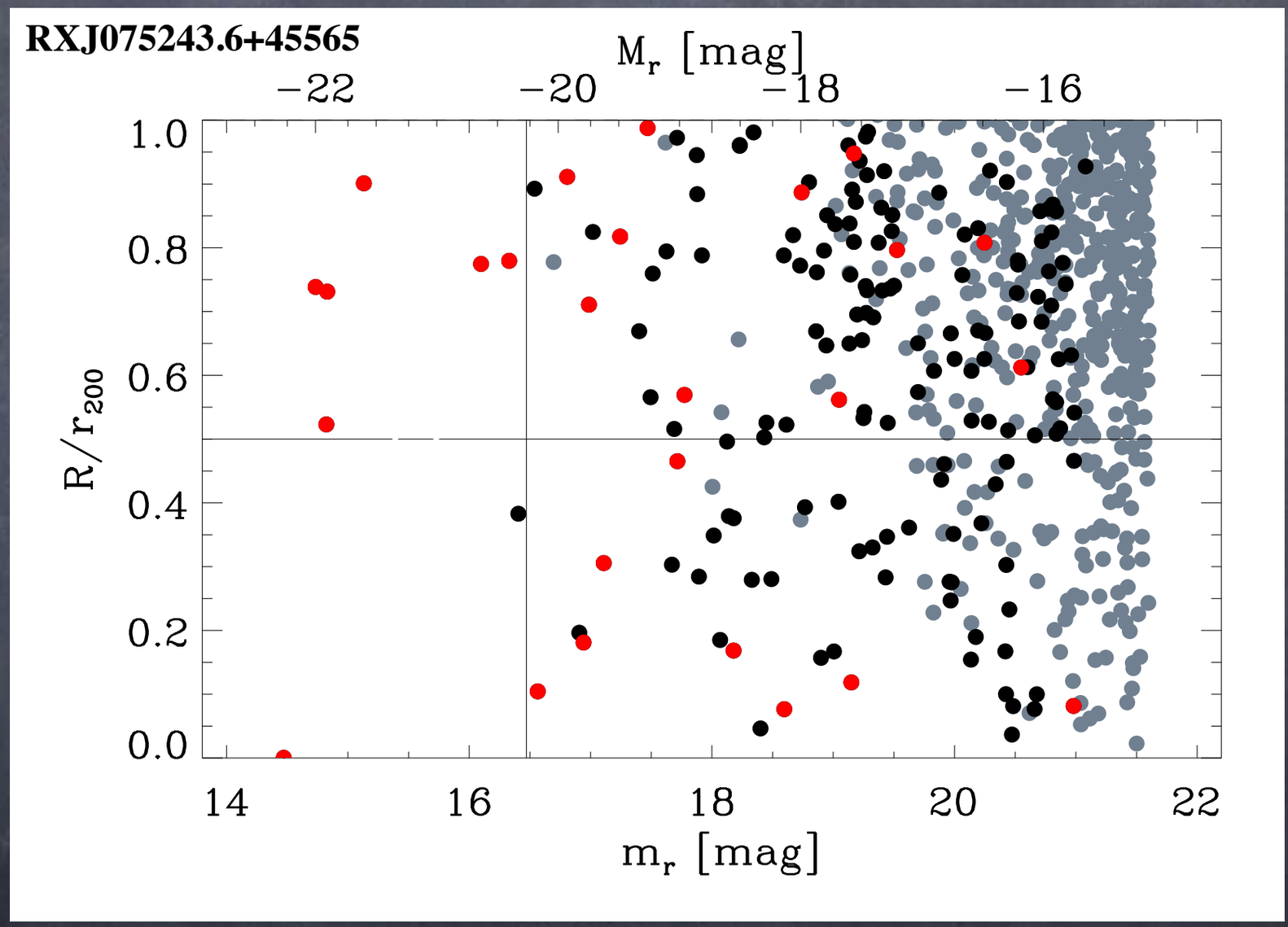
Zarattini et al. 2015



Luminosity functions in FGs: Spectroscopy

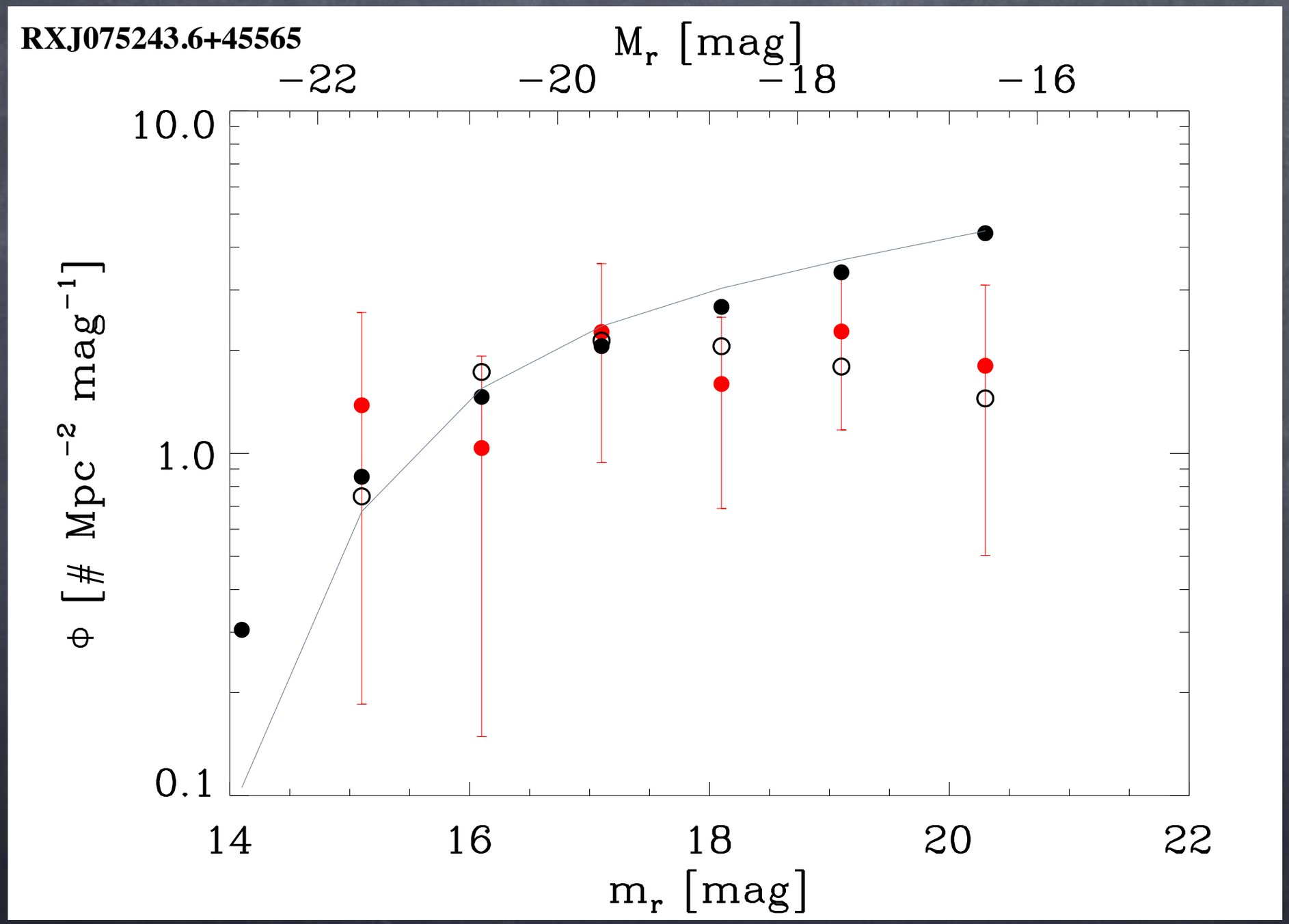
Fossil Group FGS03 (RXJ075243.6+45565):

- z_c = 0.05
- σ_v = 333 km/s
- R_{200} = 0.96 Mpc
- L_X = 2.2 x 10^{43} erg/s
- M_{tot} = 4.2 x 10^{13} $M_\odot$
- M_r BGG = -22.67
- Δm12 = 2.1



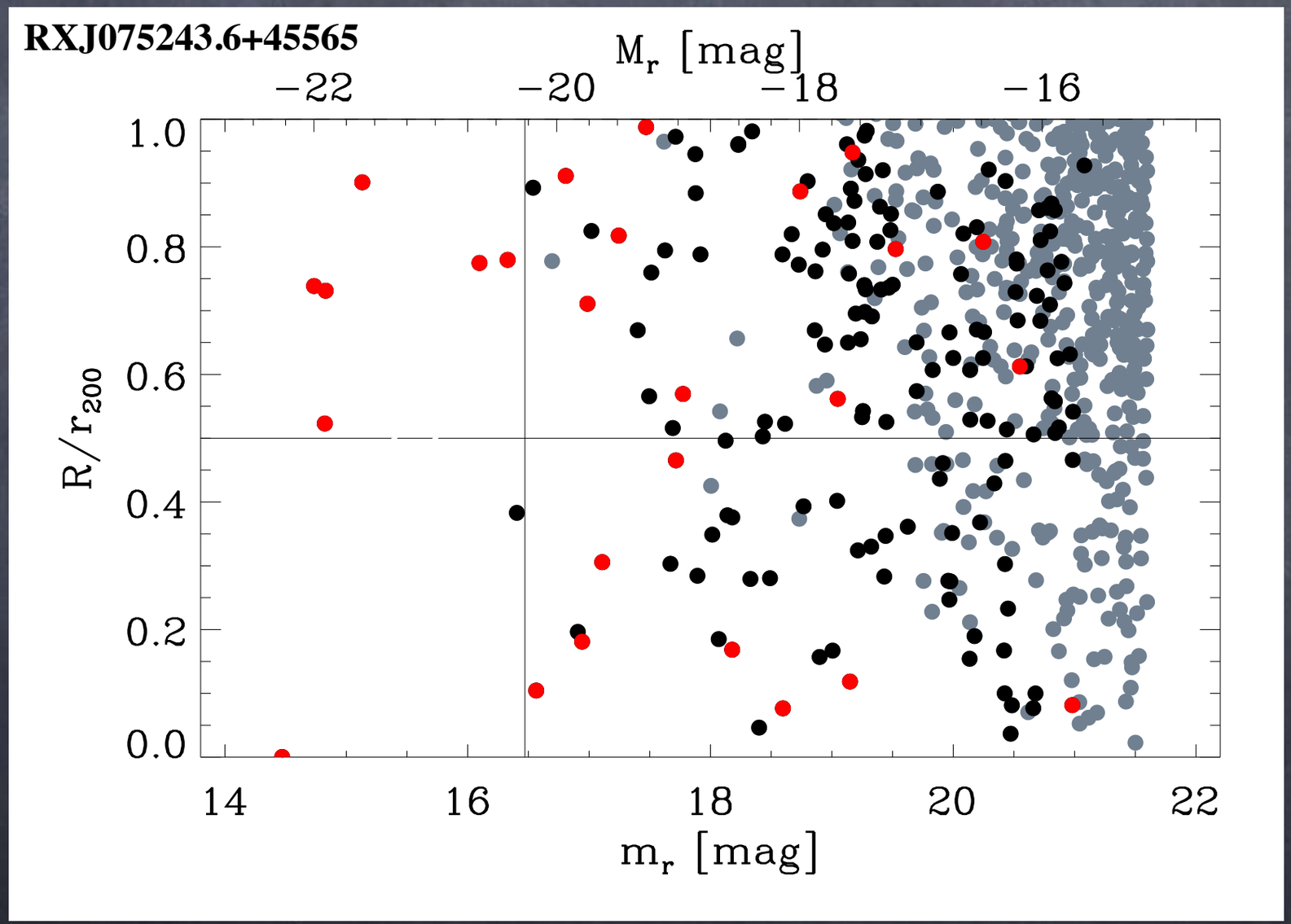
250 new spectra with WHT and GTC within R_{200} → **26 members**

Luminosity functions in FGs: Spectroscopy



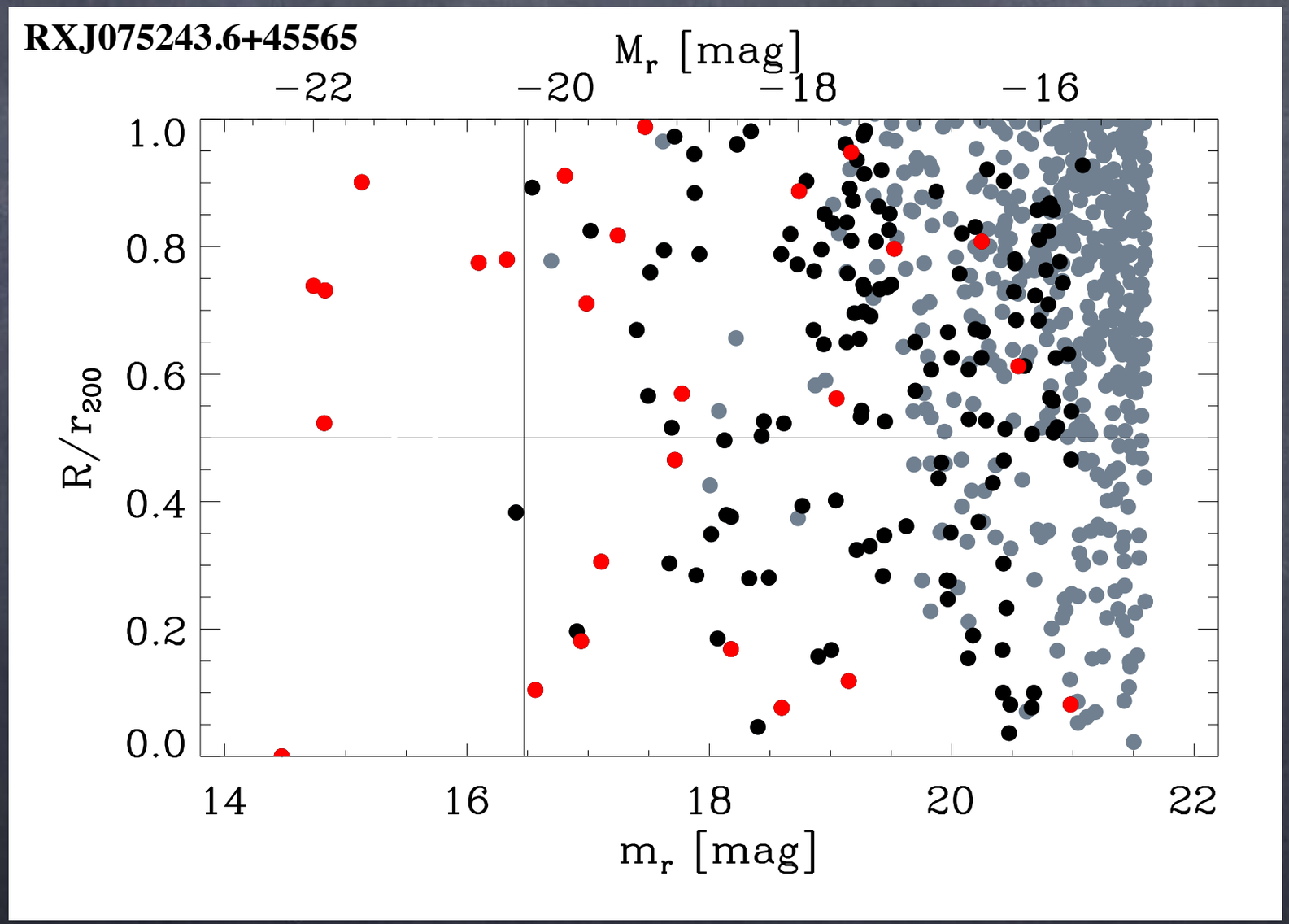
Luminosity functions in FGs: Spectroscopy

A transitional fossil group?



Luminosity functions in FGs: Spectroscopy

A transitional fossil group?



Aguerri+2018

Substructures in FGs

Scientific question: are FGs dynamically relaxed?

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Table 1. Substructure in the FGs of our sample.

Name	Mass [$M_\odot$]	AI	STI	Weighted gap	1D-DEDICA	V_{BGG}	DS	V_{grad}	2D-DEDICA	VTP	ϵ	TOT+/TOT
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
FGS02	1.87E+15	N	Y	N	N	N	Y	N	Y	Y	N	4/10
FGS03	4.20E+13	–	–	–	–	–	–	–	N	N	N	0/3
FGS14	5.55E+14	N	Y	N	N	Y	N	N	Y	N	N	3/10
FGS17	–	–	–	–	–	–	–	–	N	N	N	0/3
FGS20	1.63E+14	–	–	–	–	–	–	–	N	N	N	0/3
FGS23	2.86E+14	N	N	N	Y	N	N	N	N	N	N	1/10
FGS26	2.67E+14	–	–	–	–	–	–	–	N	Y	N	1/3
FGS27	6.69E+14	N	N	N	N	N	Y	N	Y	Y	Y	4/10
FGS29	9.66E+13	–	–	–	–	–	–	–	N	N	N	0/3
FGS30	5.57E+14	N	Y	N	N	N	N	N	N	Y	Y	3/10
FGS32	–	–	–	–	–	–	–	–	N	N	N	0/3
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Notes. Column (1): system number as in Santos et al. (2007); Col. (2): system mass as in Zarattini et al. (2014); Col. (3): asymmetry index (c.l. ≥99%); Col. (4): scale tail index (c.l. ≥99%); Col. (5): weighted gap (c.l. ≥99%); Col. (6): 1D-DEDICA (c.l. >99%); Col. (7): peculiar velocity of the BGG (c.l. ≥90%); Col. (8): DS test (c.l. ≥95%); Col. (9): velocity gradient (c.l. ≥99%); Col. (10): 2D-DEDICA (c.l. ≥99% and $\rho_c \geq 0.5$); Col. (11): Voronoi Tessellation and Percolation (c.l. ≥99%); Col. (12): ellipticity (c.l. ≥99.7%); Col. (13): fraction of positive tests for each system Y = presence of substructure; N = no substructure; – = not applicable.

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Zarattini+2016

Orbits in FGs

Scientific question: if FGs are not old, why are they so effective in merging galaxies?

Sommer-Larsen2005 suggested that massive galaxies on radial orbits can merge faster than those in tangential orbits…but how can we measure orbits?

We need to estimate the anisotropy parameter!

$$\beta(r) = \sigma_r / \sigma_\theta$$

PROBLEM! we need to compute in two steps:

1) The mass profile M(r) using the kinematics of galaxies
2) The anisotropy profile using the Jeans' equation

BUT M(r) and β(r) are degenerate!

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MAMPOSSt (Mamon+2012) breaks the degeneracy
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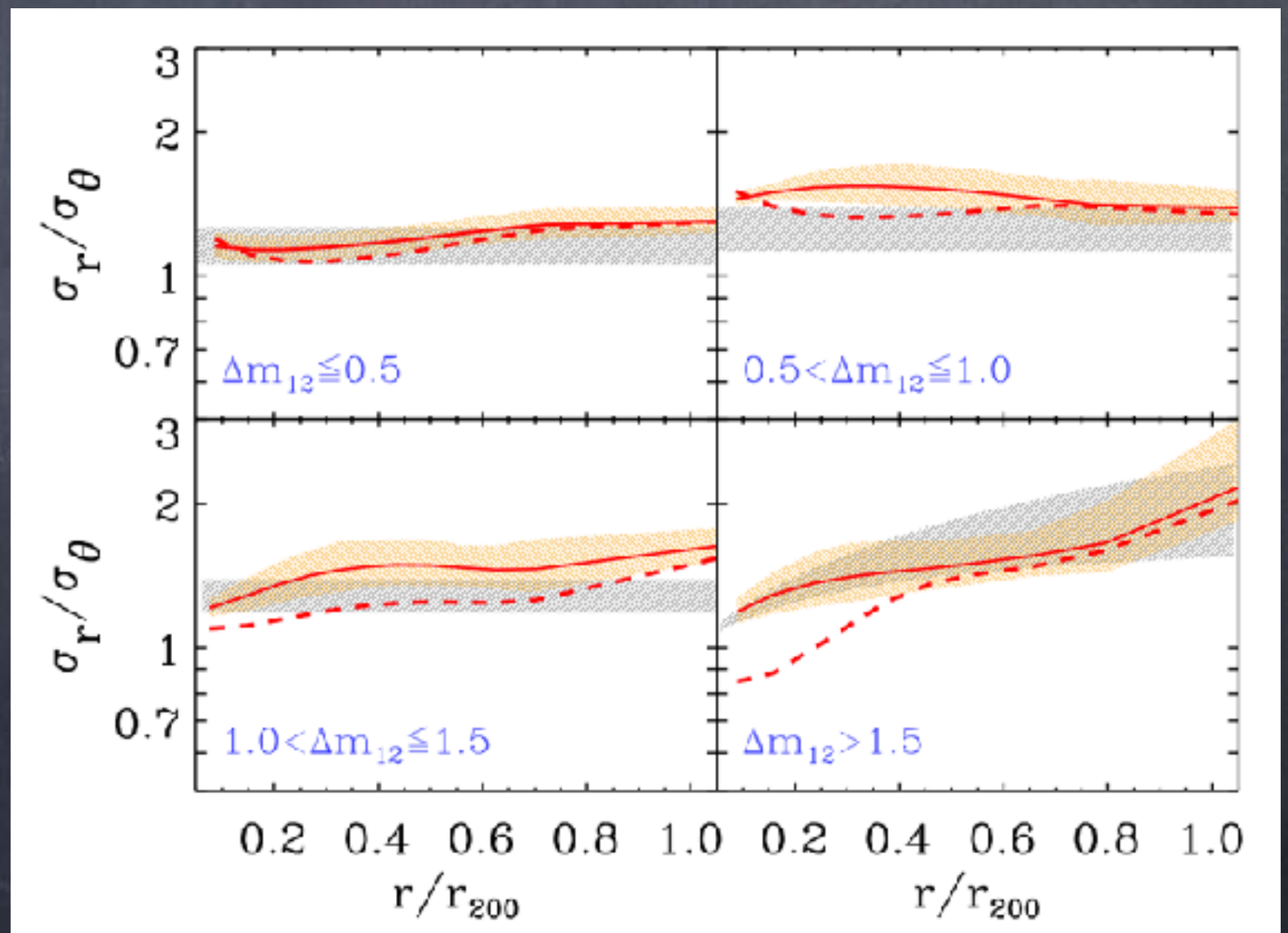

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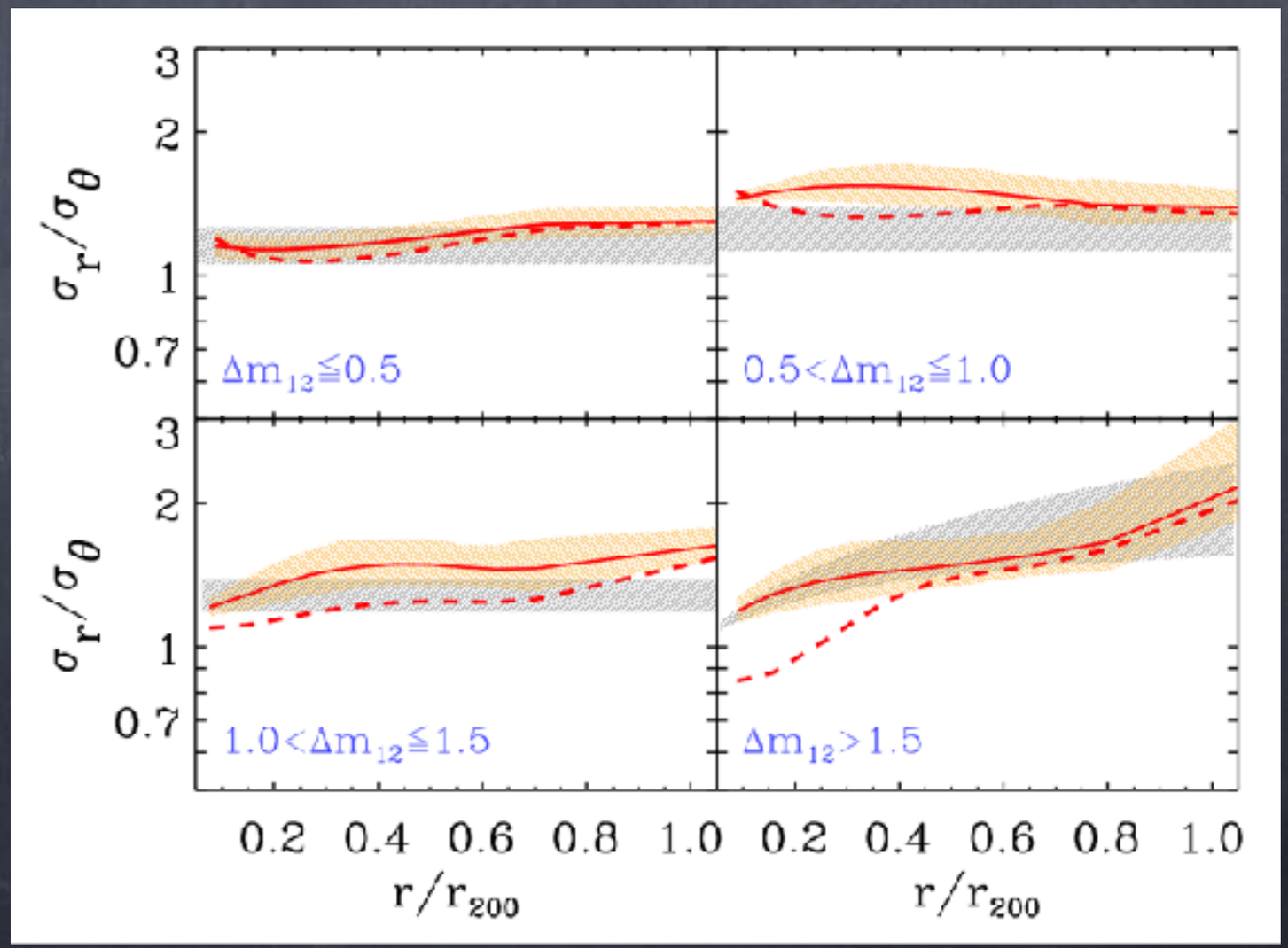
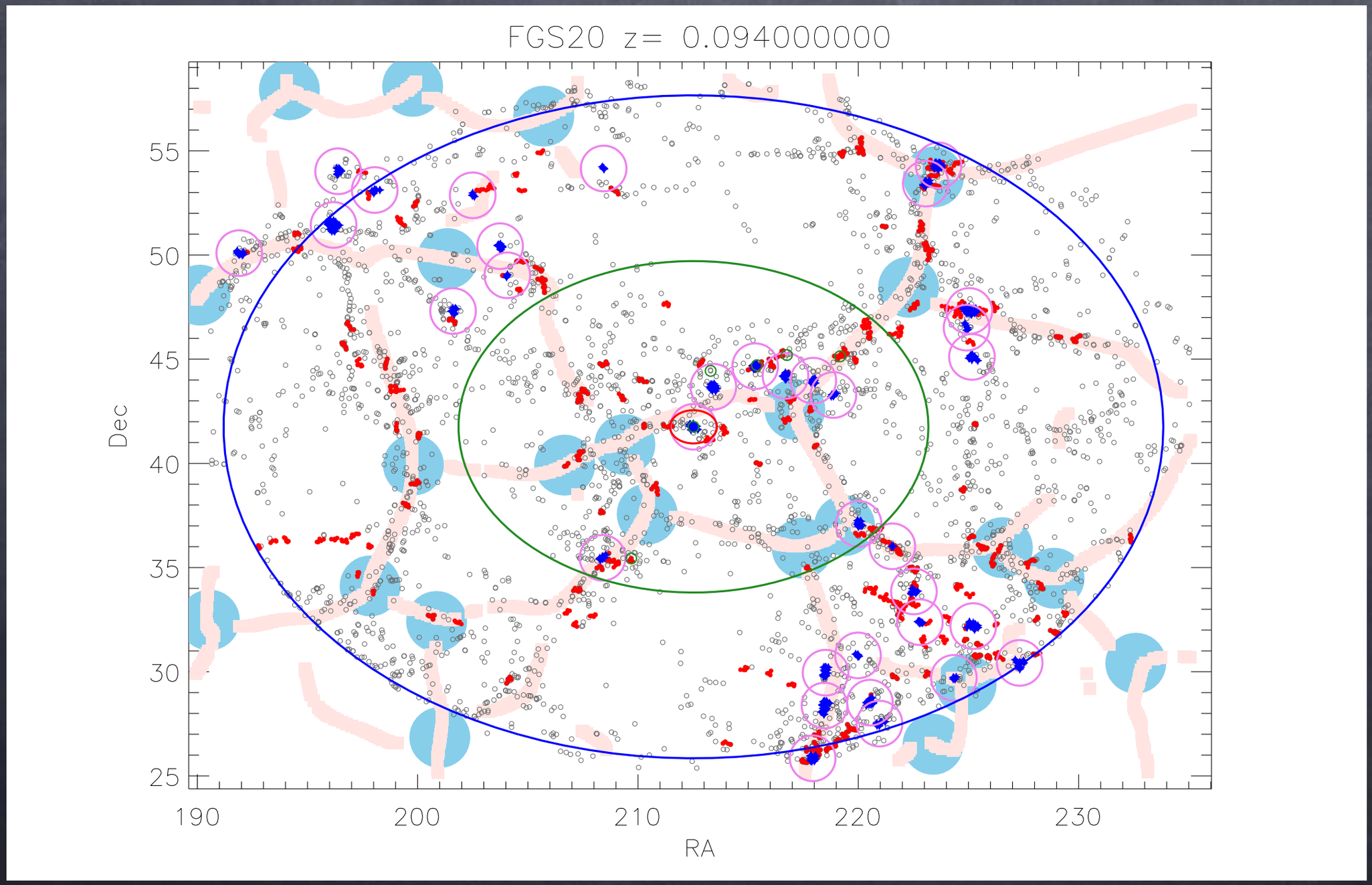
Zarattini+2021



Large-scale environment

Scientific question: FGs were predicted to be isolated from the cosmic web.
Is it true?



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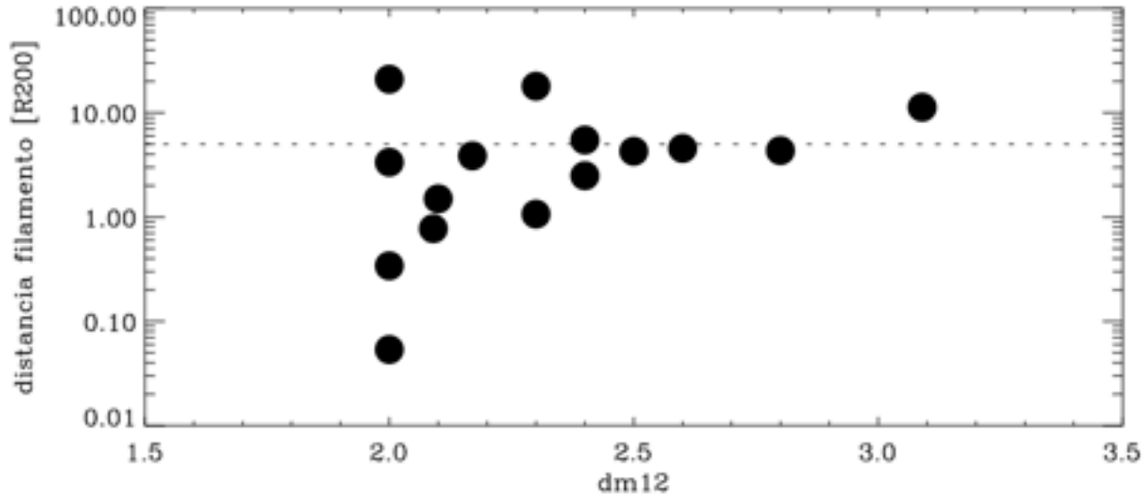

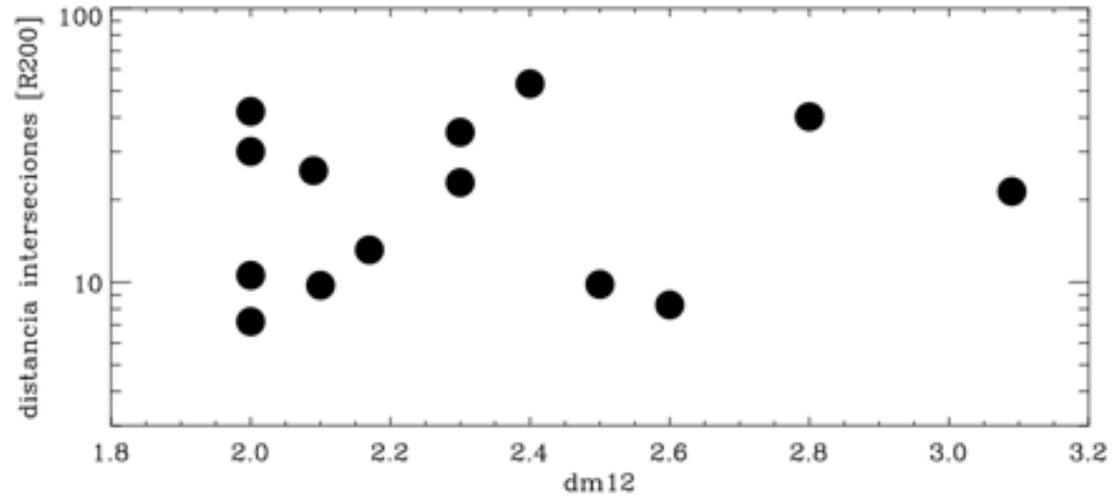

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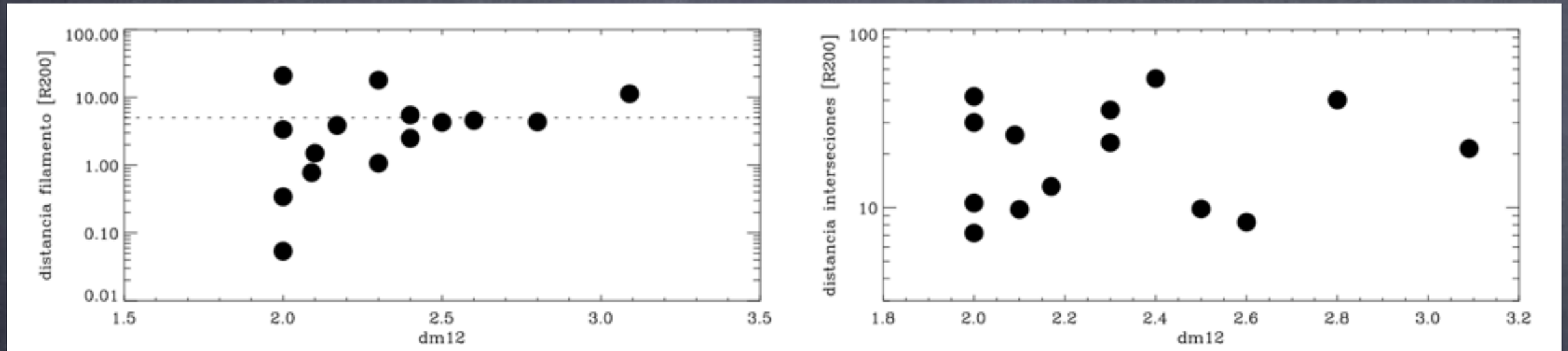

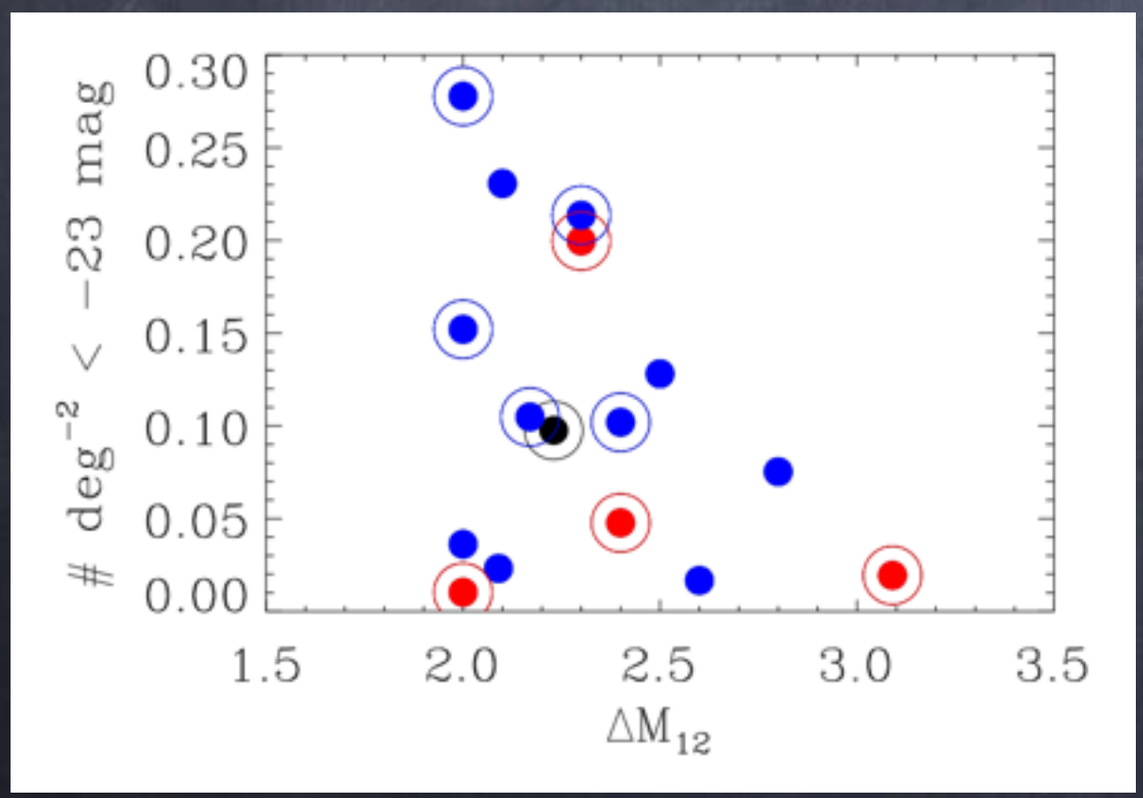

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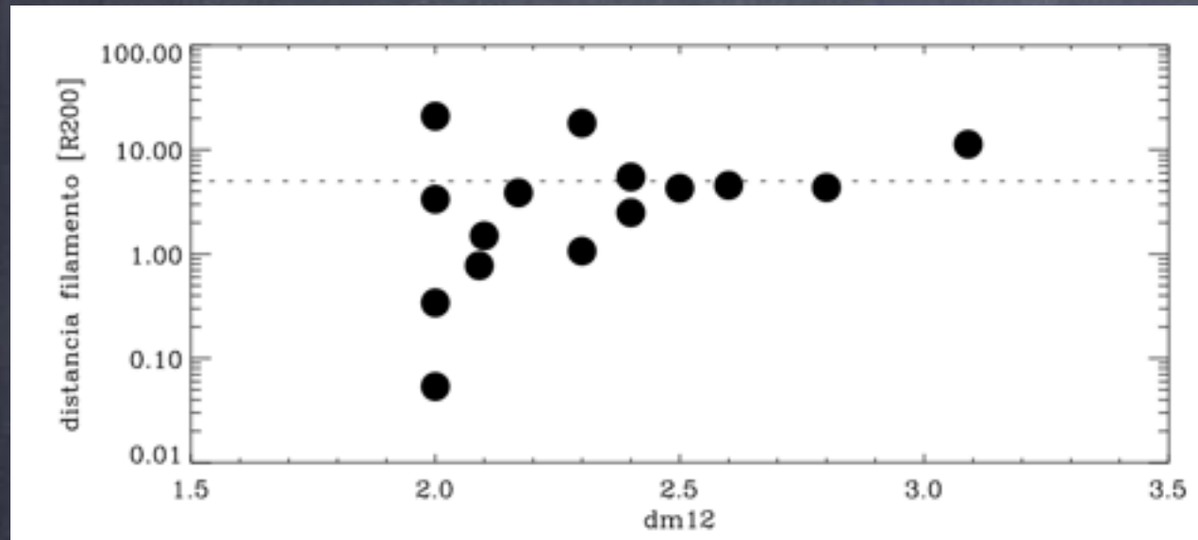

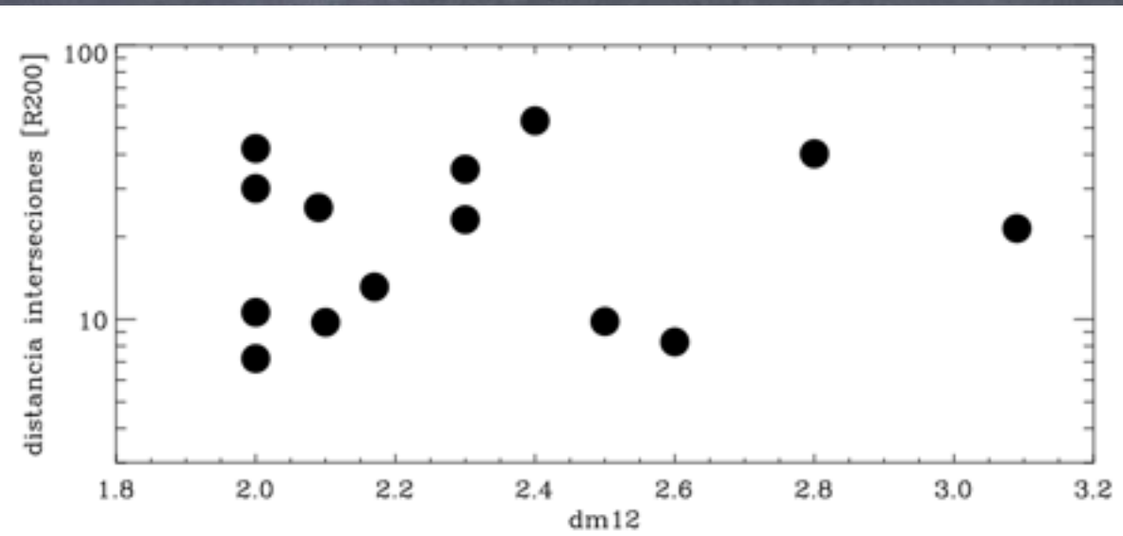

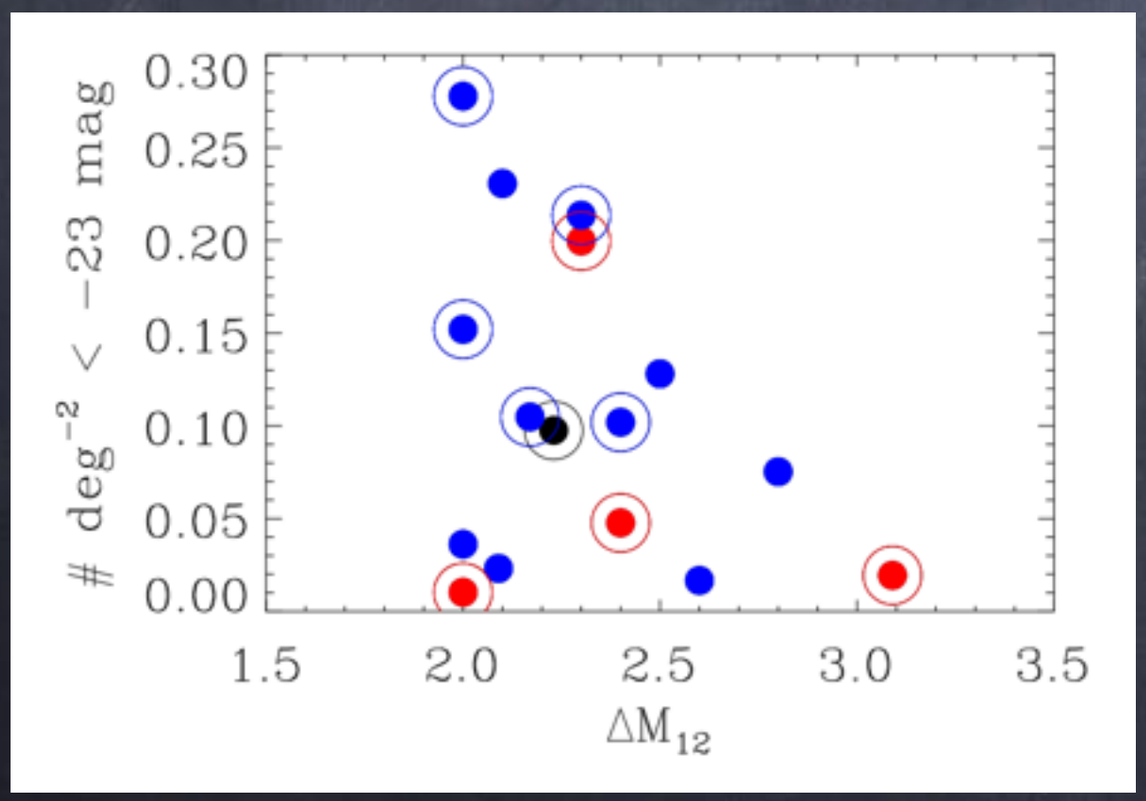

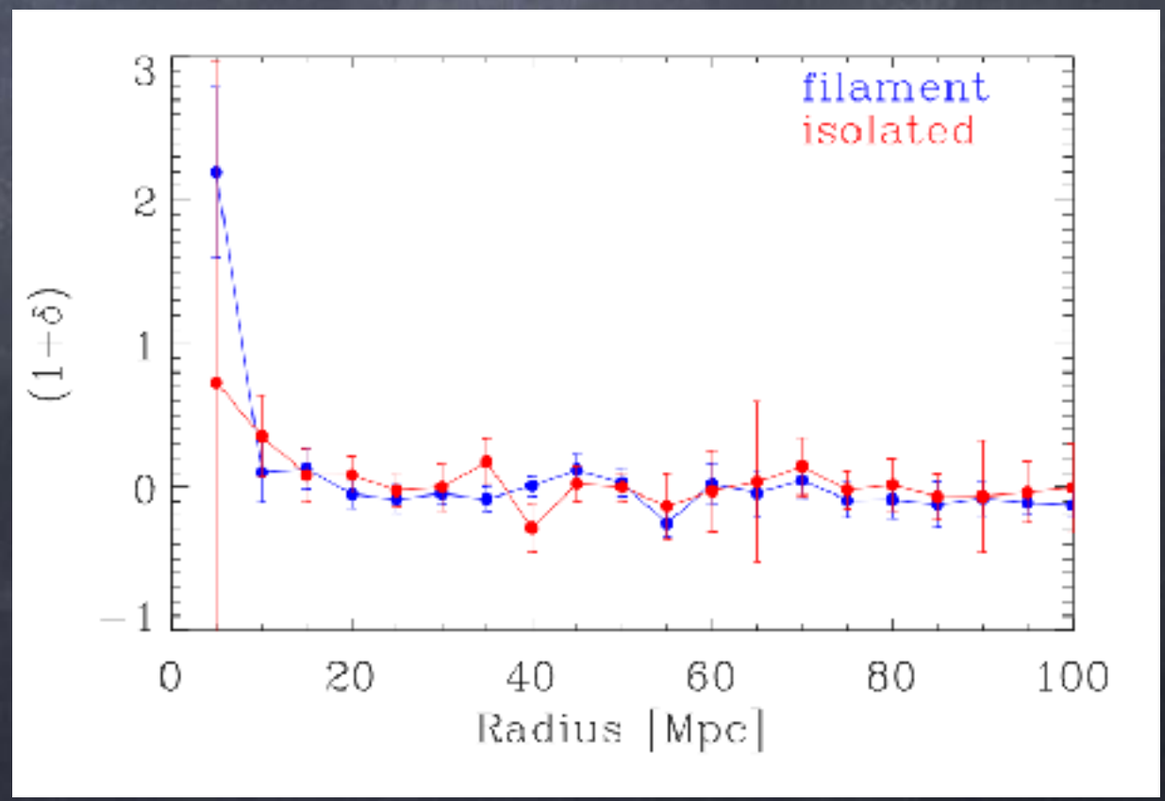

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