Fossil Groups as isolated structures rather then fossil relics of the ancient Universe

Stefano Zarattini

Fossil Group Origins (FOGO) project team: J.A.L. Aguerri (IAC, Spain), A. Biviano (OAT), Italy), E. M. Corsini (UniPD, Italy), E. D'Onghia (UW-Madison, USA), M. Girardi (OAT, Italy), S. Borgani (UT, Italy), W. Boschin (TNG, Italy), N. Castro-Rodriguez (IAC, Spain), S. De Grandi (INAF-OAB, Italy), (C. del Burgo (INAOE, Mexico), J. Iglesias-Páramo (IAA, Spain), E. Jimenez-Bailón (UNAM, Mexico), A. Kundera (UW-Madison Univ, USA), Longobardi (IAFS, Italy), J. Méndez-Abreu (IAC, Spain), L. Morelli (INCT, Chile), N. Napolitano (OAC, Italy), R. Sánchez- Janssen (Royal Observatory Edinburg), M. Santos-Lleo (XMM, Spain), J. M. Vilchez (IAA,Spain)

EXCELENCIA SEVERO OCHOA

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN

AGENCIA ESTATAL DE INVESTIGACIÓN

8 Workshop XIV

I Workshop Estallidos	Star Forming Dwarf Galaxies	Madrid, Jaunary 27-29, 2003
II Workshop Estallidos	Massive Starformation in Different Enviroments	Granada, Jaunary 26-28, 2004
III Workshop Estallidos	Star Formation and Structures in Galaxies	La Laguna, December 2-3, 2004
IV Workshop Estallidos	Una Aproximación Multifrecuencia a la Formación Estelar	Madrid, Jaunary 26-27, 2006
V Workshop Estallidos	Star Formation and Metallicity	Granada, Febrary 28 - March 2, 2007
VI Workshop Estallidos	Revisión del proyecto – Estallidos-GTC	Puerto de La Cruz, December 12-13, 2007
VII Workshop Estallidos	Formación de Investigadores e Impacto Académico	Miraflores de la Sierra, Jaunary 26-27, 2009
VIII Workshop Estallidos	Challenges for the new decade	Salobreña, March 8-10, 2009
X Workshop Estallidos	Census and fundamental properties of star-forming galaxies	Granada, May 11-13, 2015
XI Workshop Estallidos	Estallidos in motion: Bringing kinematics into the picture	Madrid, June 6-8, 2018
XIII Workshop Estallidos	XIII Estallidos Workshop	Madrid, May 18-20, 2022
XIV Workshop Estallidos	XIV Estallidos Workshop	Miraflores de la Sierra, Febrary 4-7, 2024

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IX Workshop: April 16-17 2012 in Granada

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Outline of the talk

Introduction:

- What are fossil groups (FGs)?
- The FOGO project

Results:

- Stellar age of the BGGs
- Substructure in FGs
- FGs formation in numerical simulations
- X-ray scaling relations
- Dependence of the luminosity function on Δm_{12}
- Orbits of infalling galaxies
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Workshop XIV

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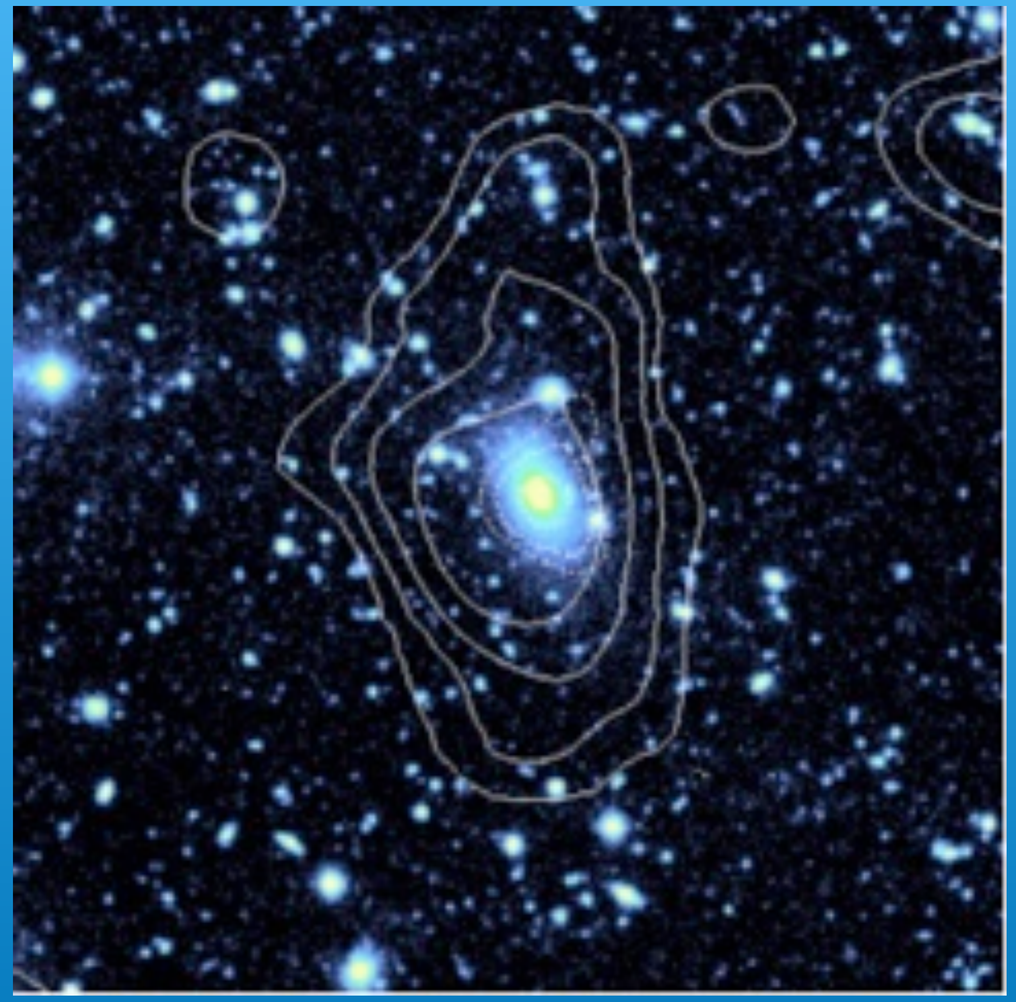
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What are fossil groups



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} $M_\odot$).

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What are fossil groups



- 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).

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What are fossil groups



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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 $L_X > 10^{42}$ erg s^{-1}

What are fossil groups



First hypothesis:

- Old & closed systems
- Dynamically relaxed
- FGs extend the missing satellite problem to larger systems
- Infalling galaxies on more radial orbits, favouring mergers

FGs are fossil relics of the ancient Universe

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The FOGO project

multiwavelength observational characterization
of a large sample of FGs

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Properties of DM halos
(scaling relations, clues of early assembly?)

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Properties of the BGGs

(formation age, stellar populations)

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Properties of the BGGs

(formation age, stellar populations)

Properties of the satellites

(LF, substructures, dynamical state)

The FOGO project

multiwavelength observational characterization
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Properties of DM halos
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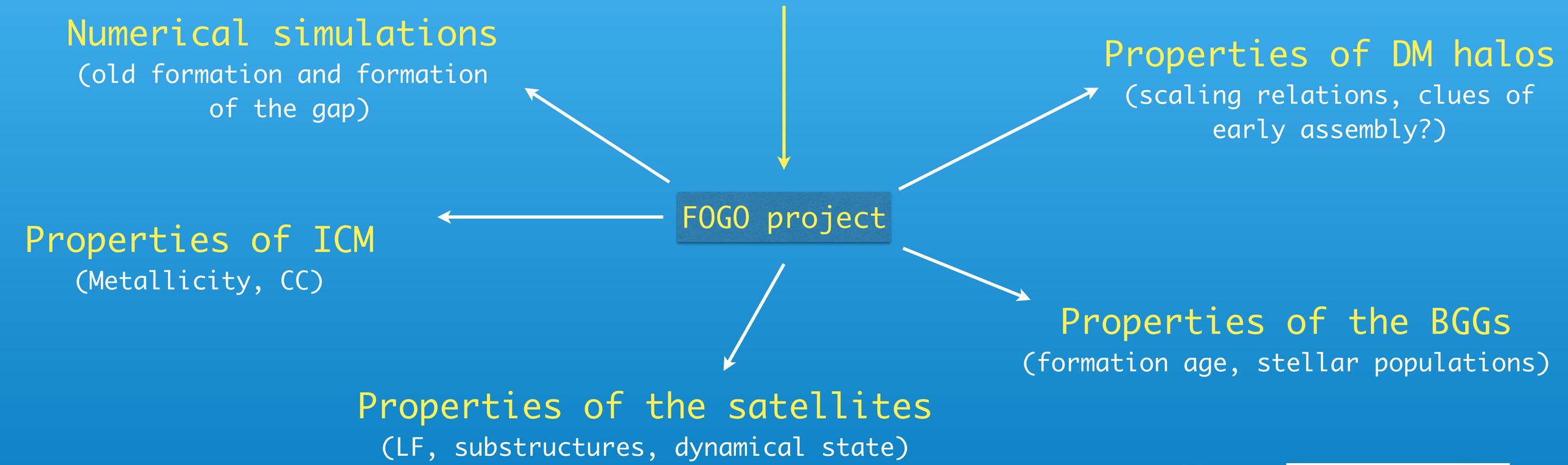
Properties of ICM
(Metallicity, CC)

Properties of the BGGs
(formation age, stellar populations)

Properties of the satellites
(LF, substructures, dynamical state)

The FOGO project

multiwavelength observational characterization
of a large sample of FGs



Numerical simulations
(old formation and formation of the gap)

Properties of DM halos
(scaling relations, clues of early assembly?)

Properties of ICM
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Properties of the BGGs
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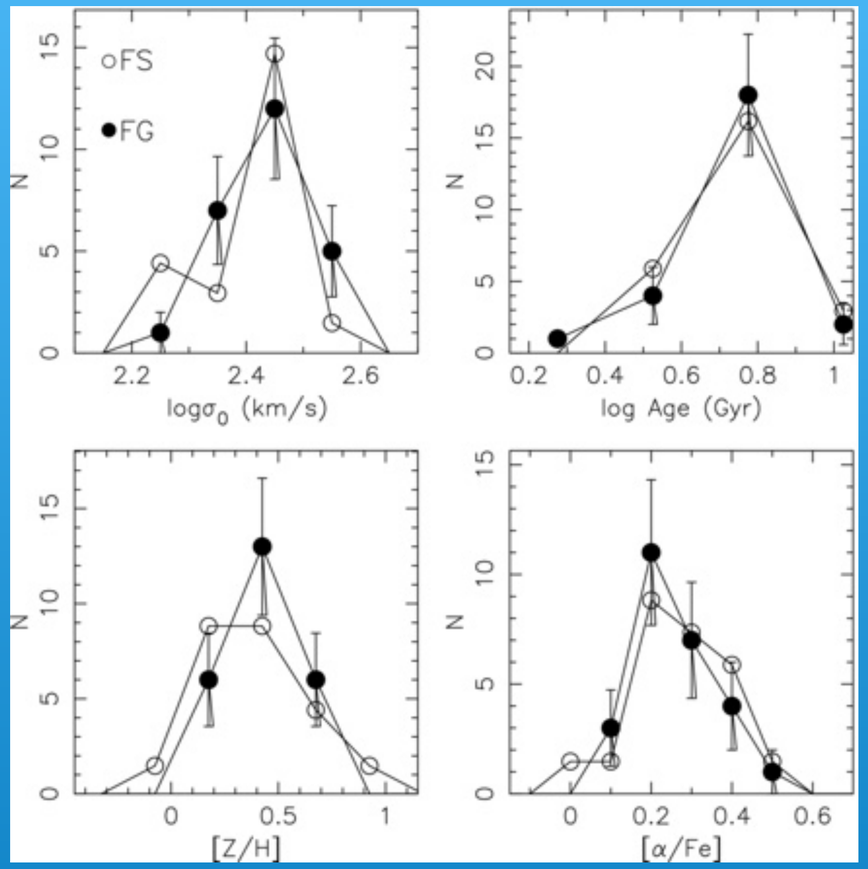
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Age of fossil groups

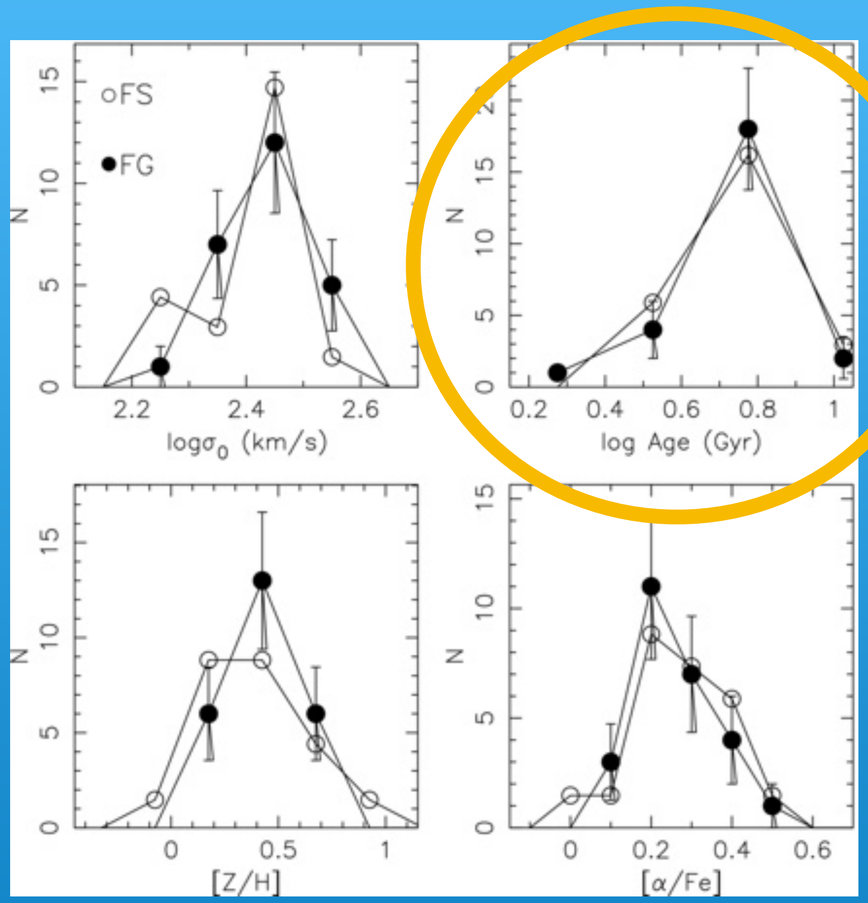


Analysis of the
stellar populations
in FGs BCGs

La Barbera+2009

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Age of fossil groups



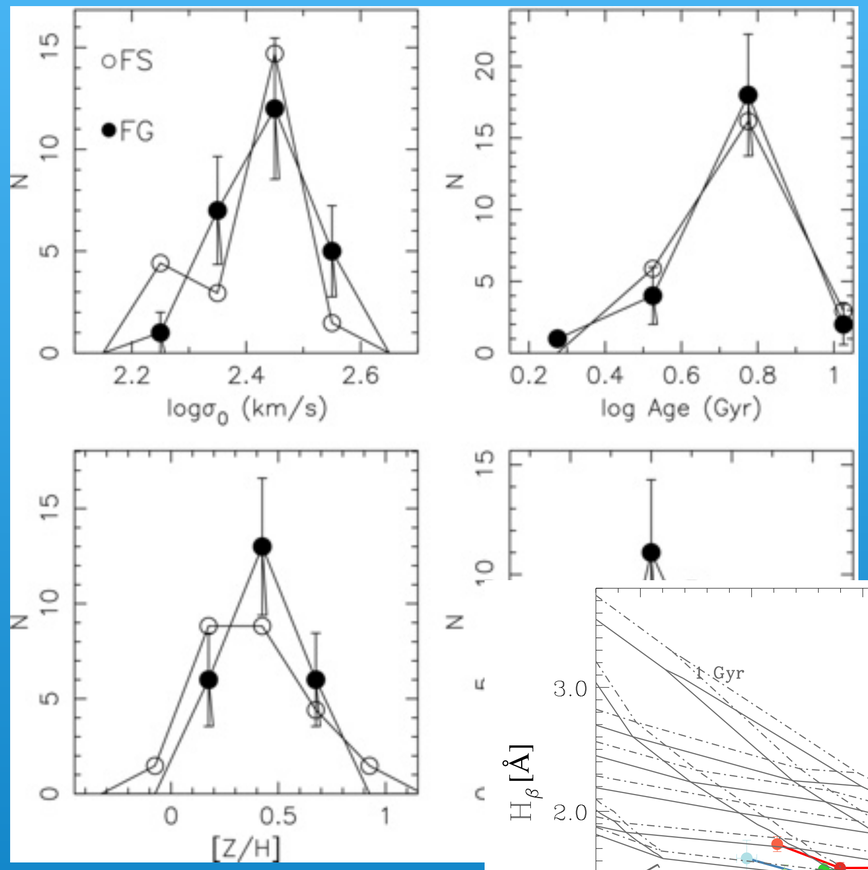
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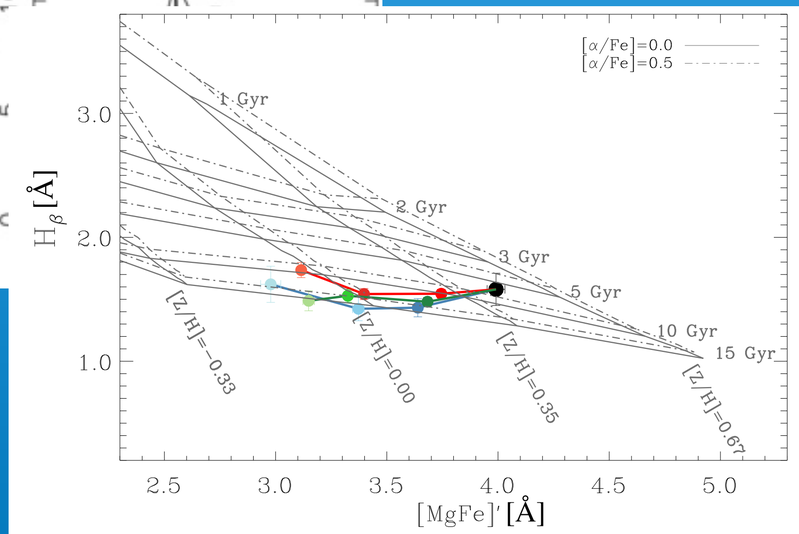
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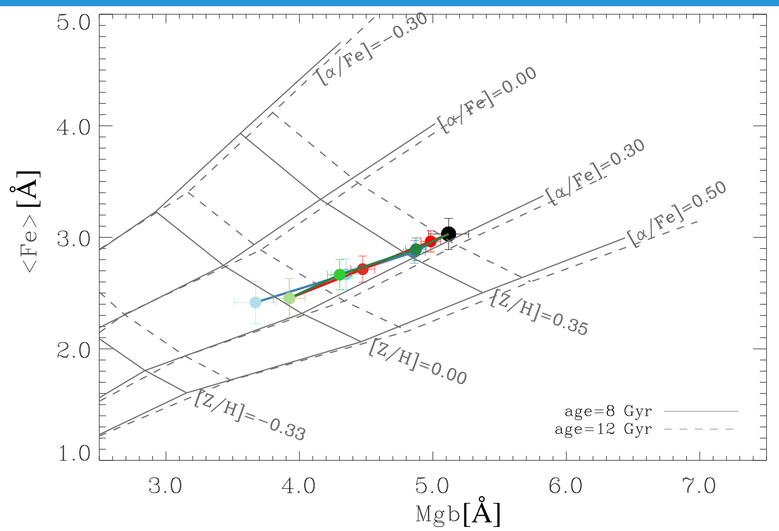
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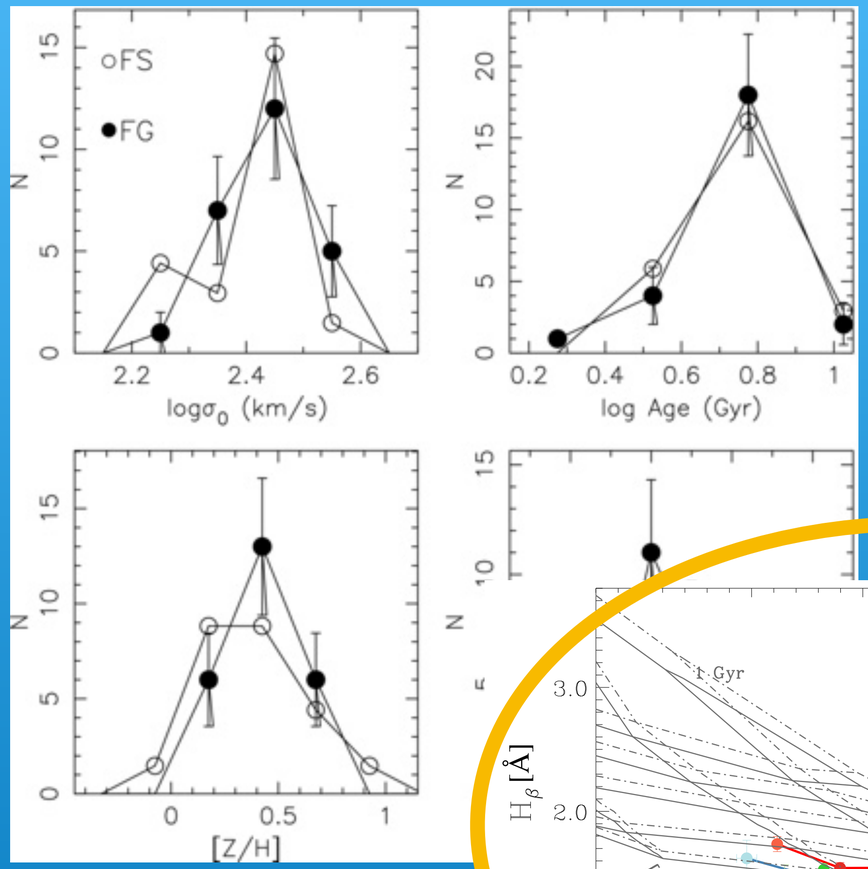




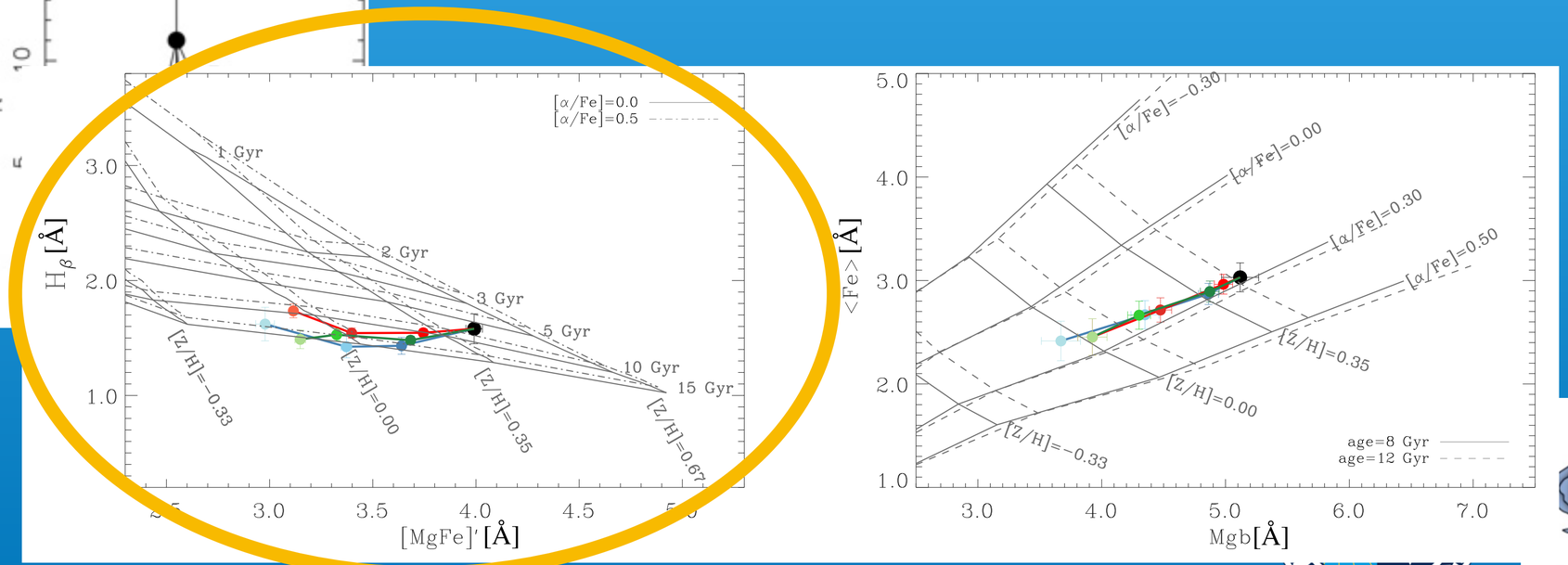
Corsini+2018

Age of fossil groups

Analysis of the stellar populations in FGs BCGs



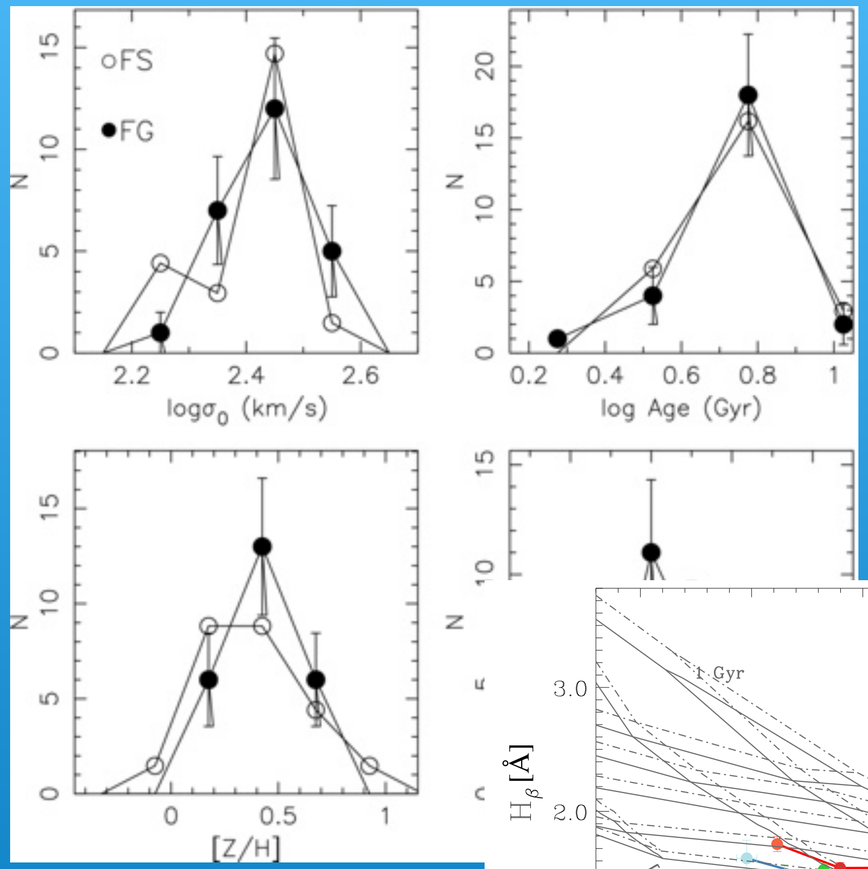
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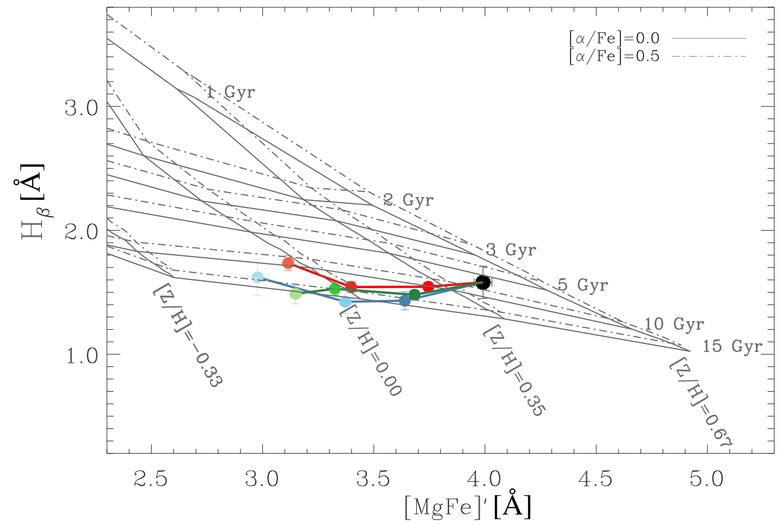
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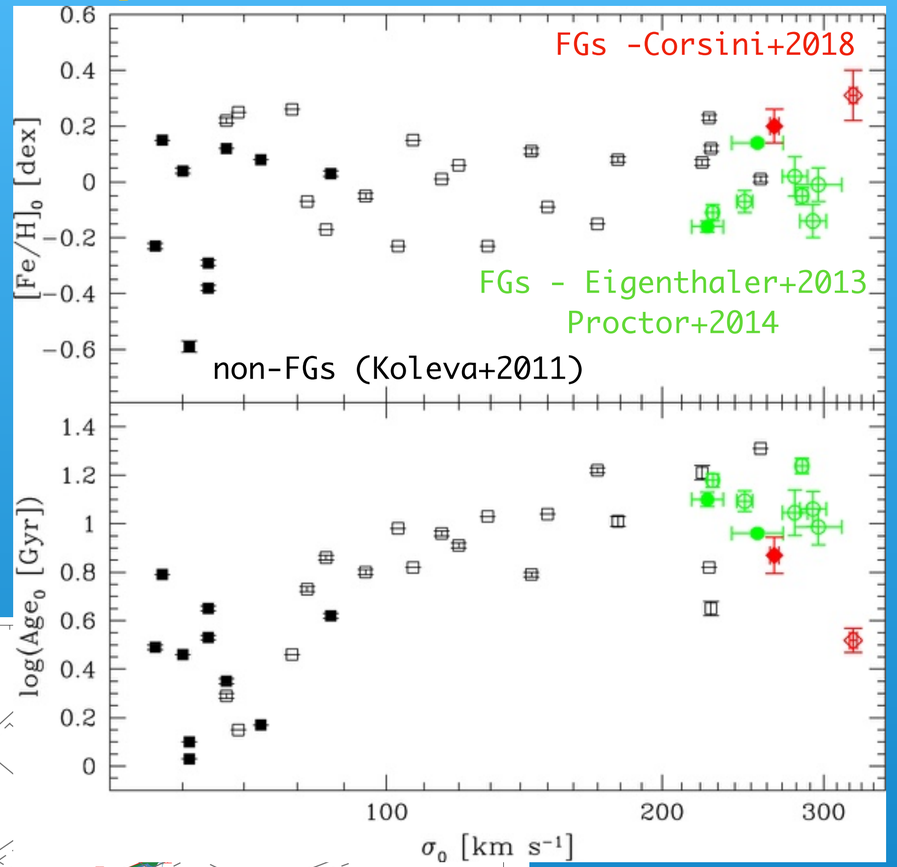
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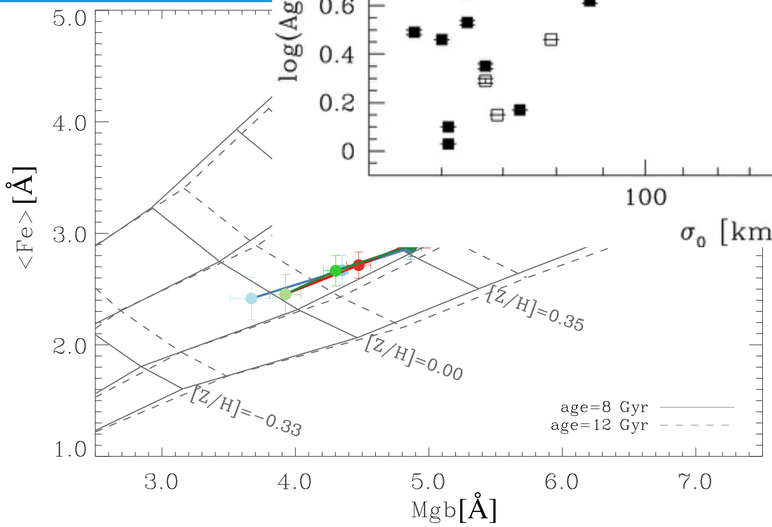
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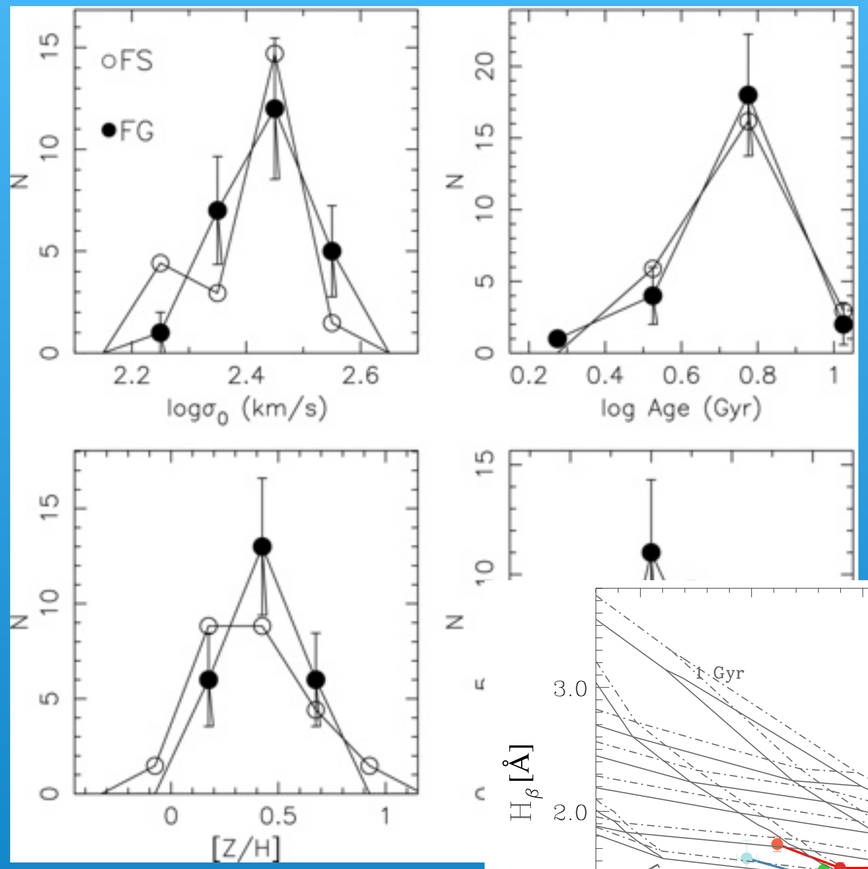




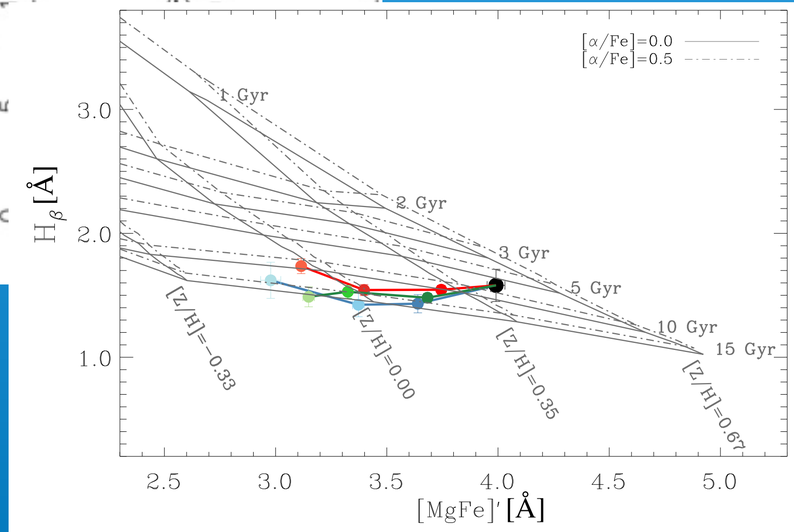
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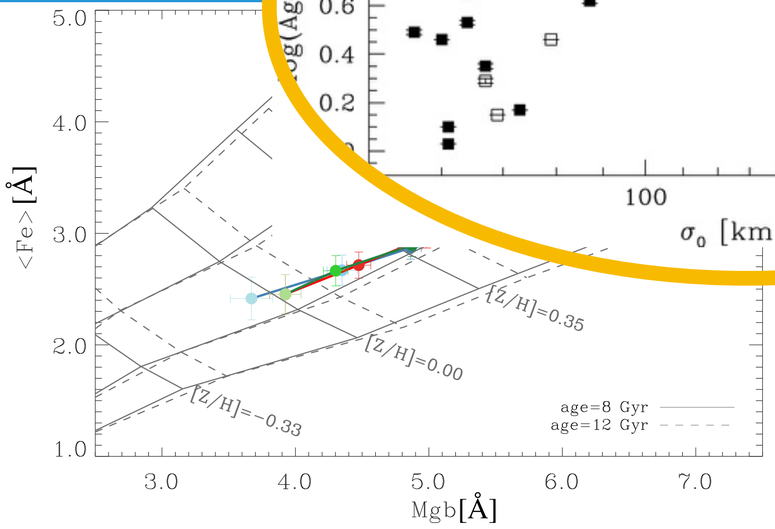
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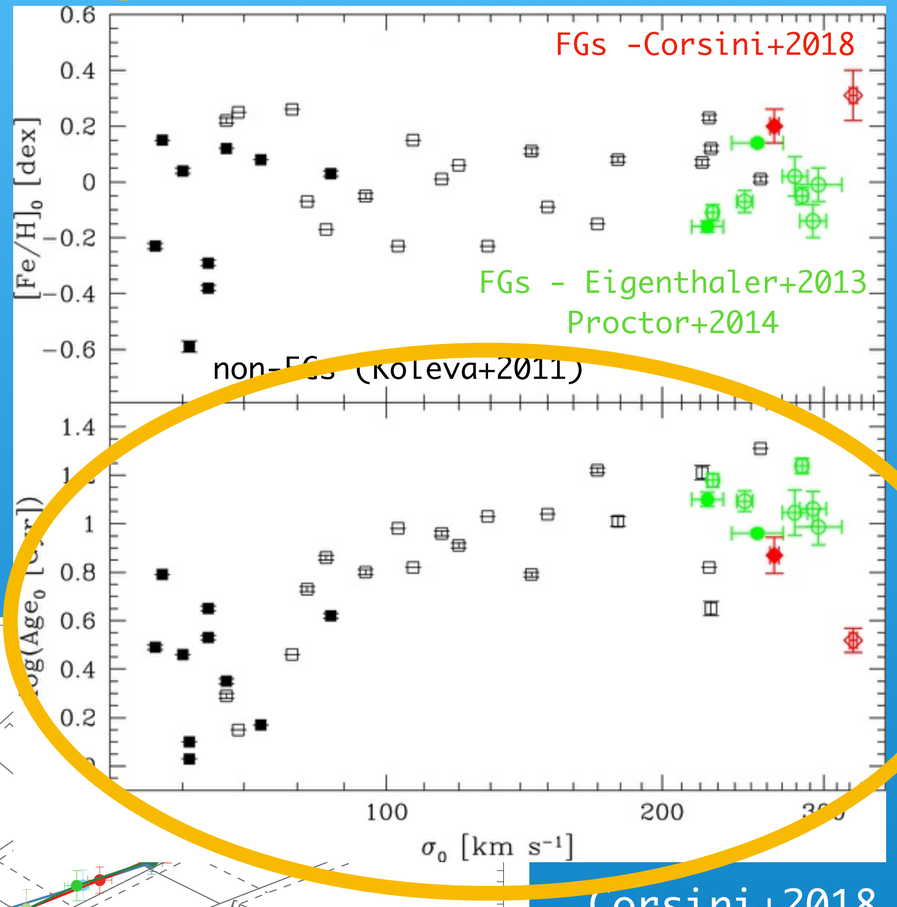
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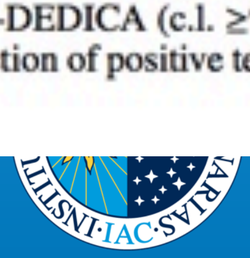
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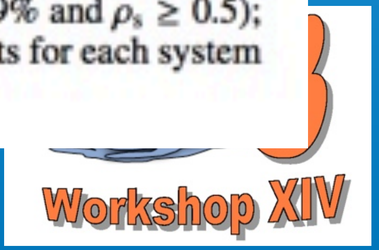
Dynamical status

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
FGS34	8.63E+13	–	–	–	–	–	–	–	Y	N	N	1/3

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 $\rho_s \geq 0.5$); 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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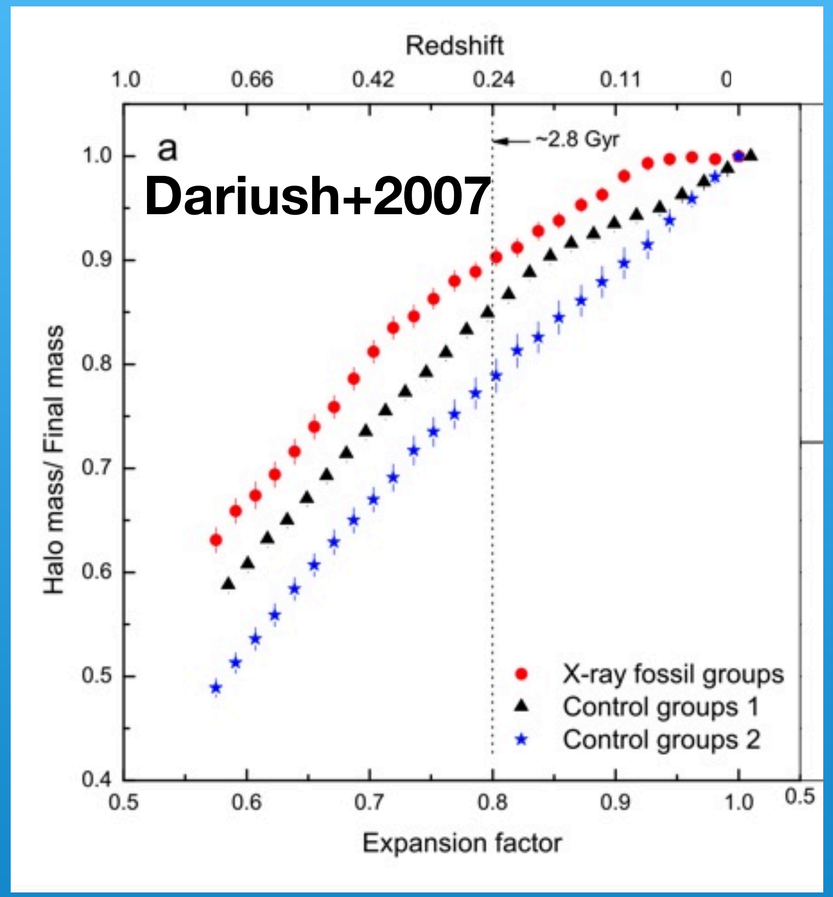
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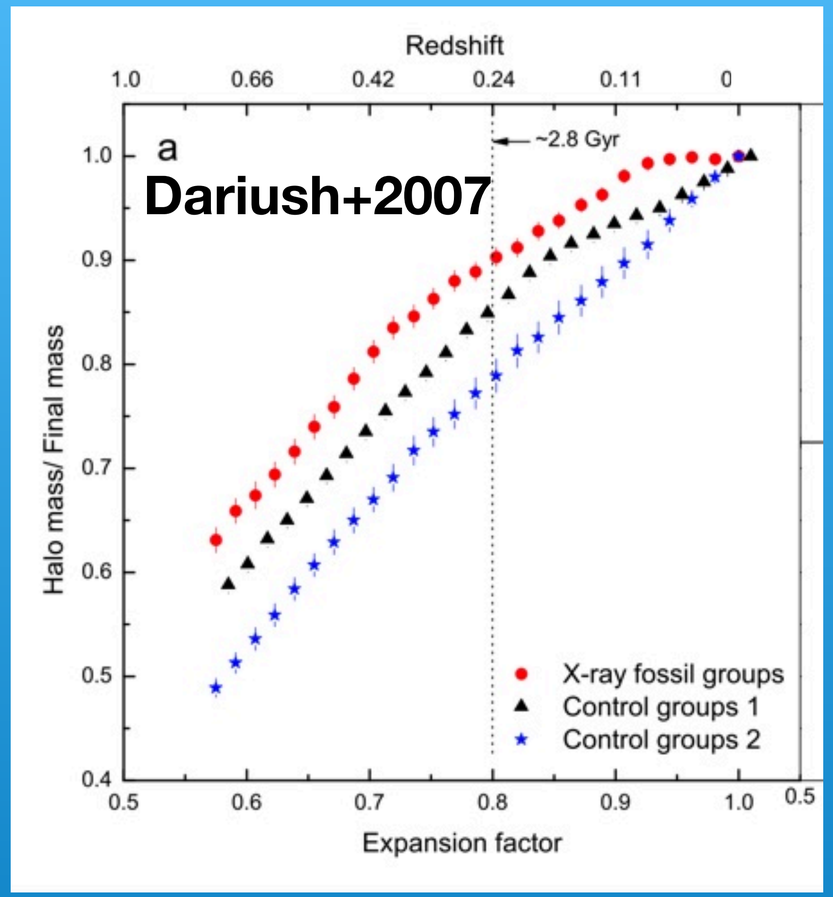




Numerical simulations

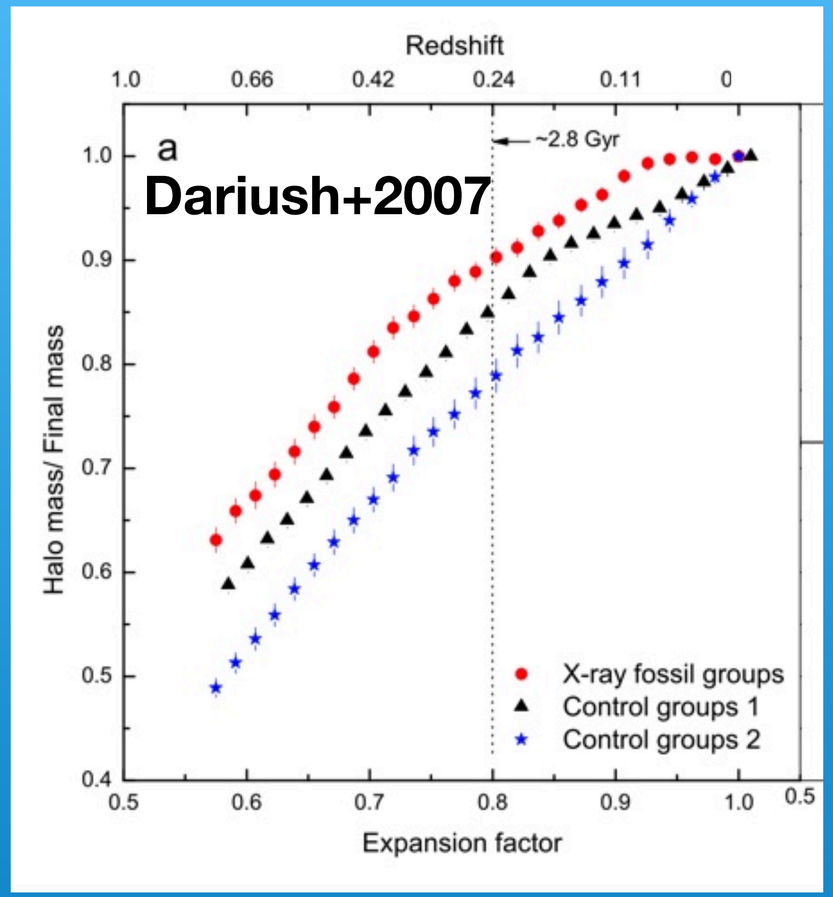


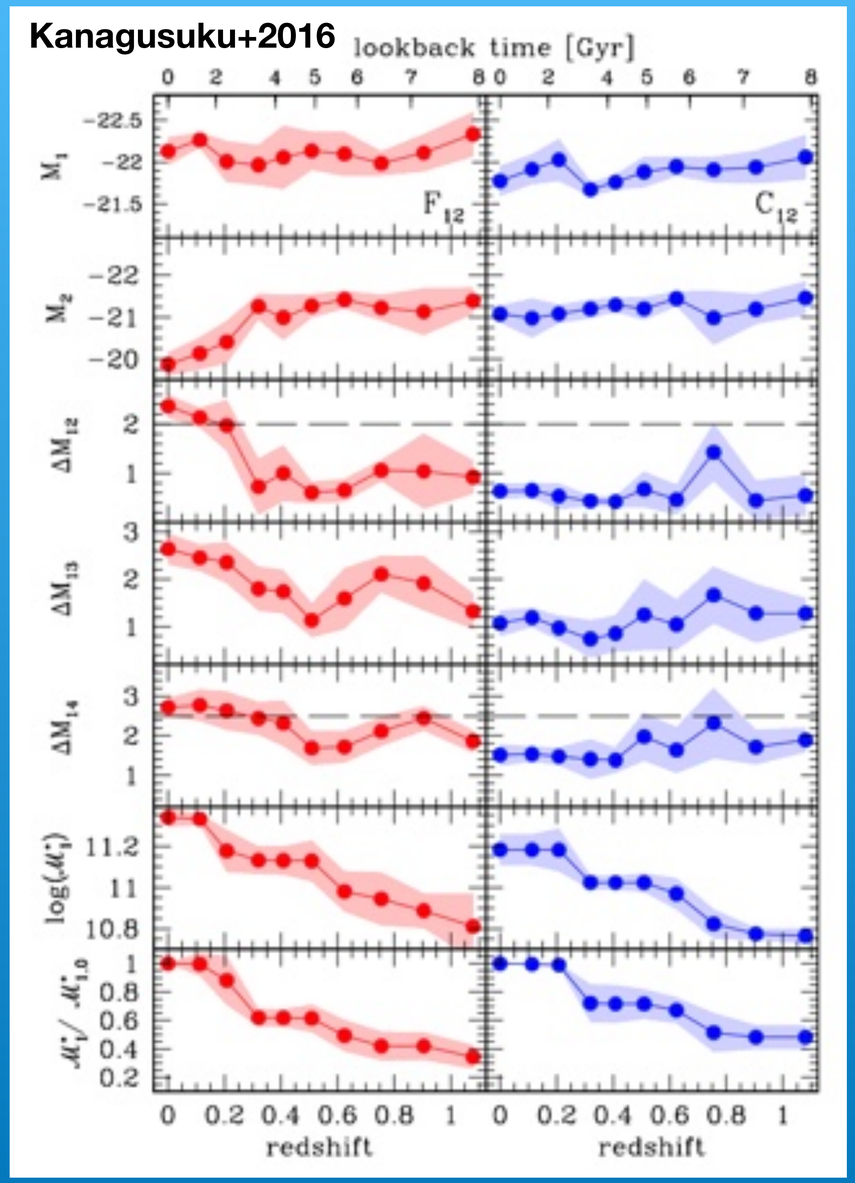
Numerical simulations



FGs assembled a higher fraction of their mass at any redshift (10-20% more mass)

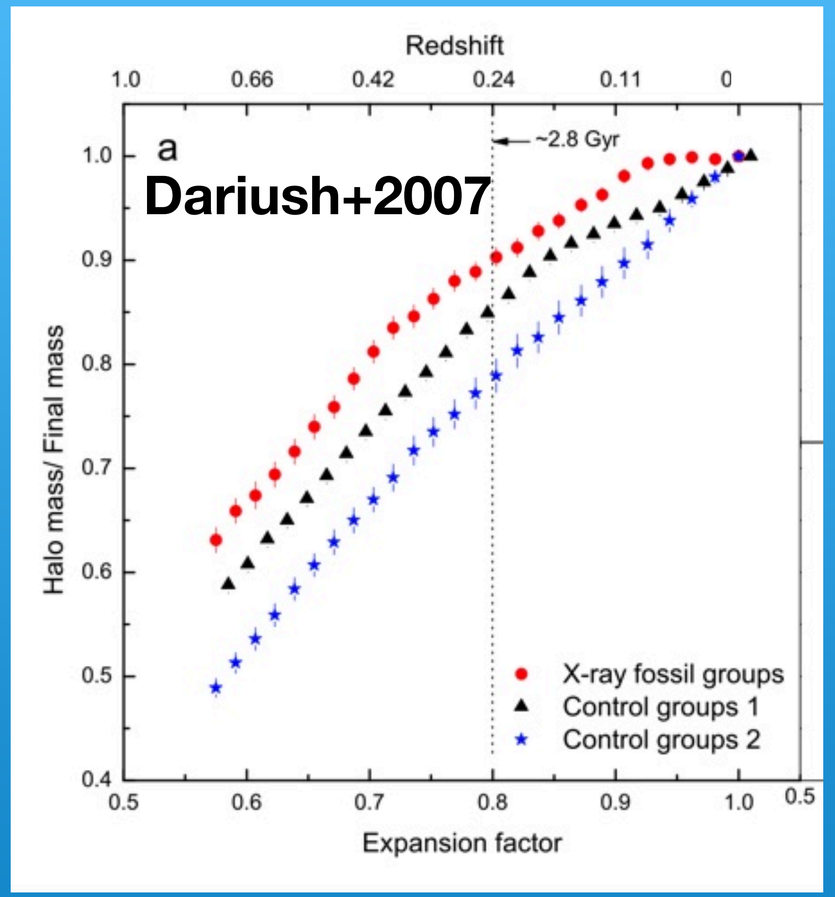
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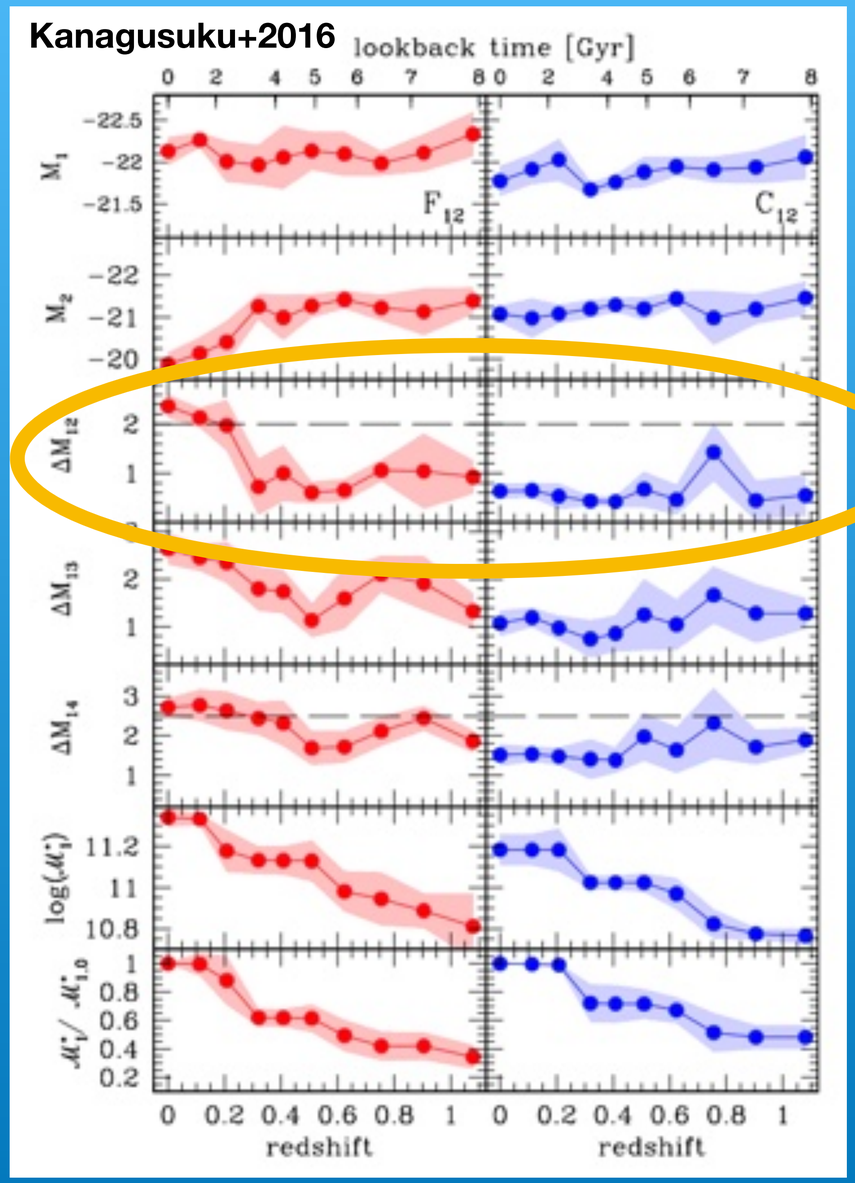




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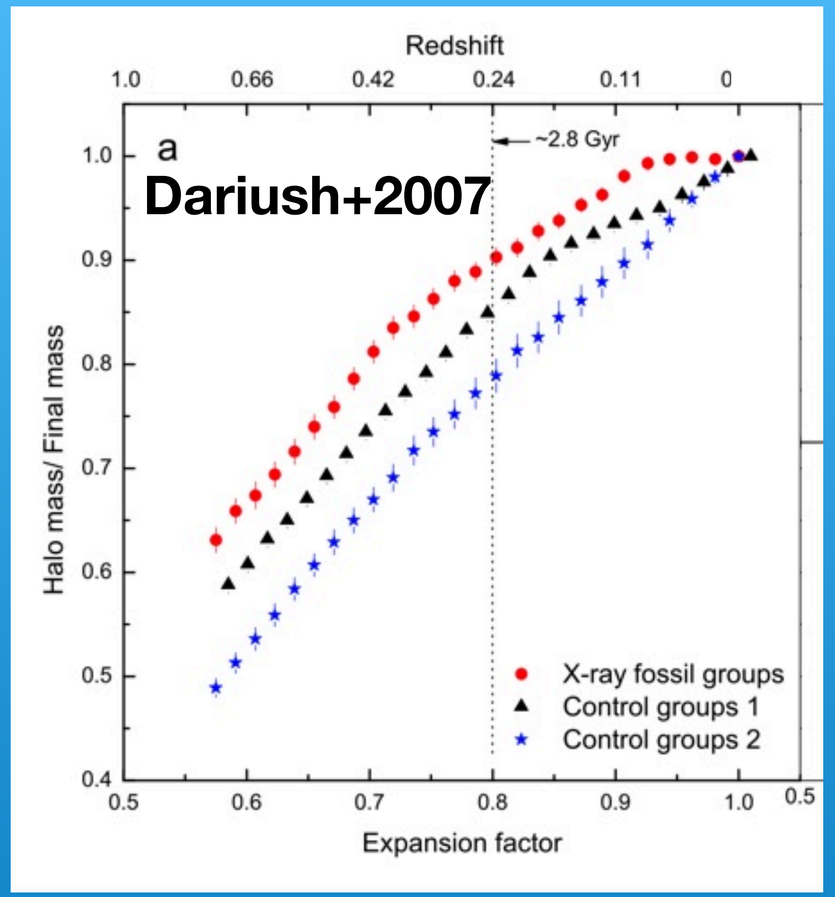
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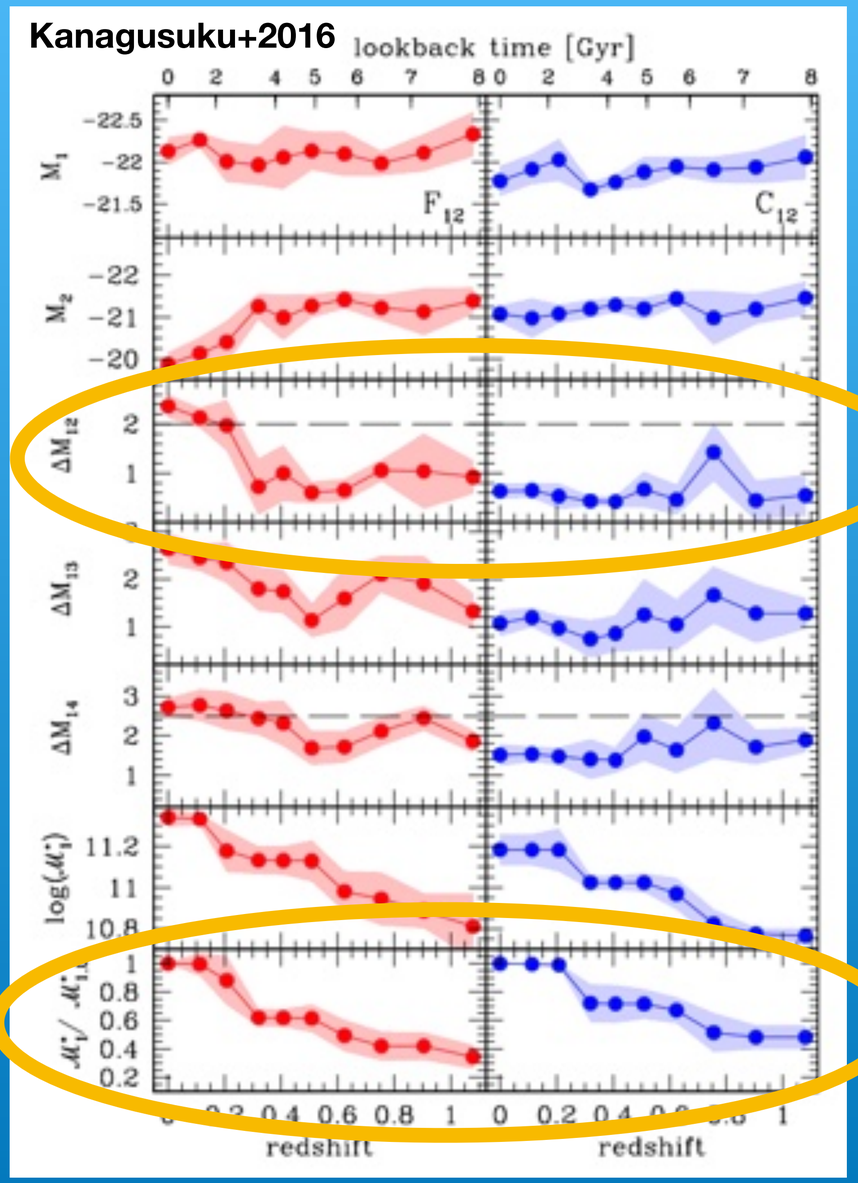




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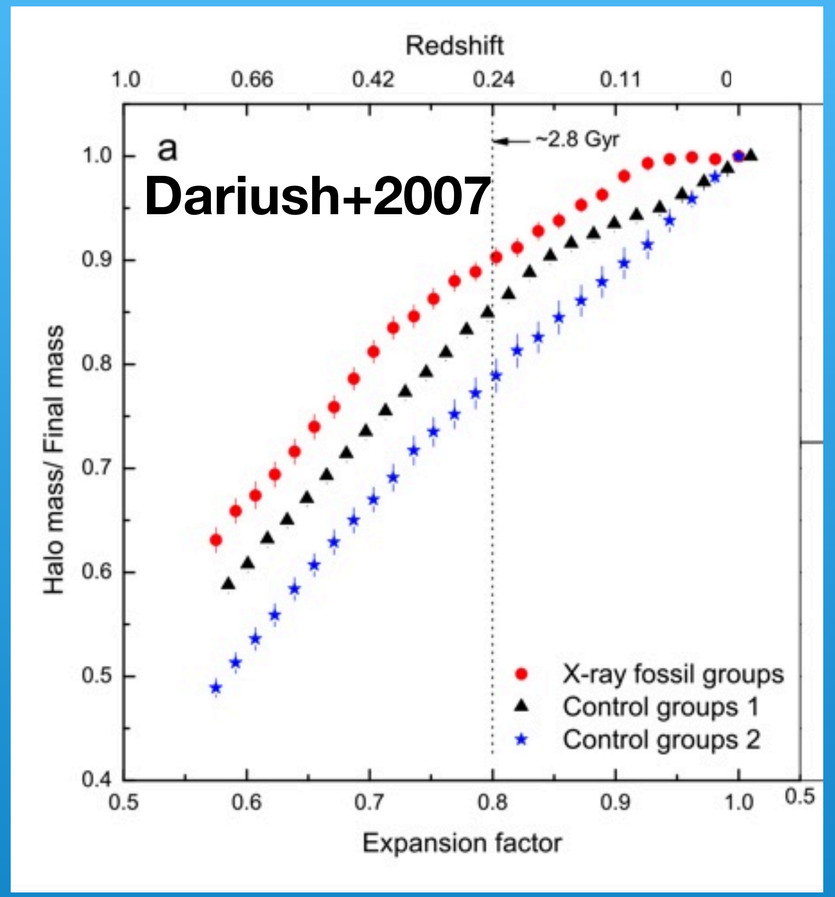
Numerical simulations





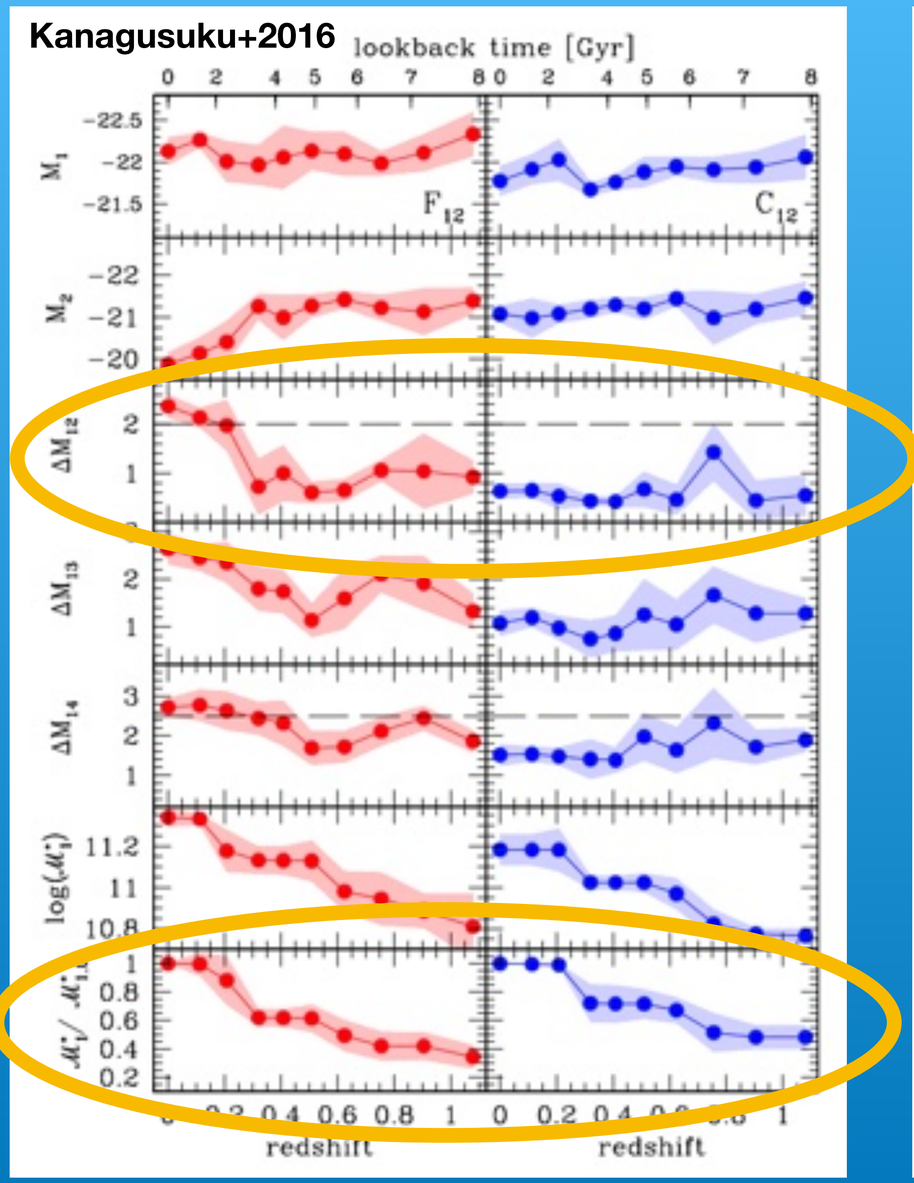
FGs assembled a higher fraction of their mass at any redshift (10-20% more mass)

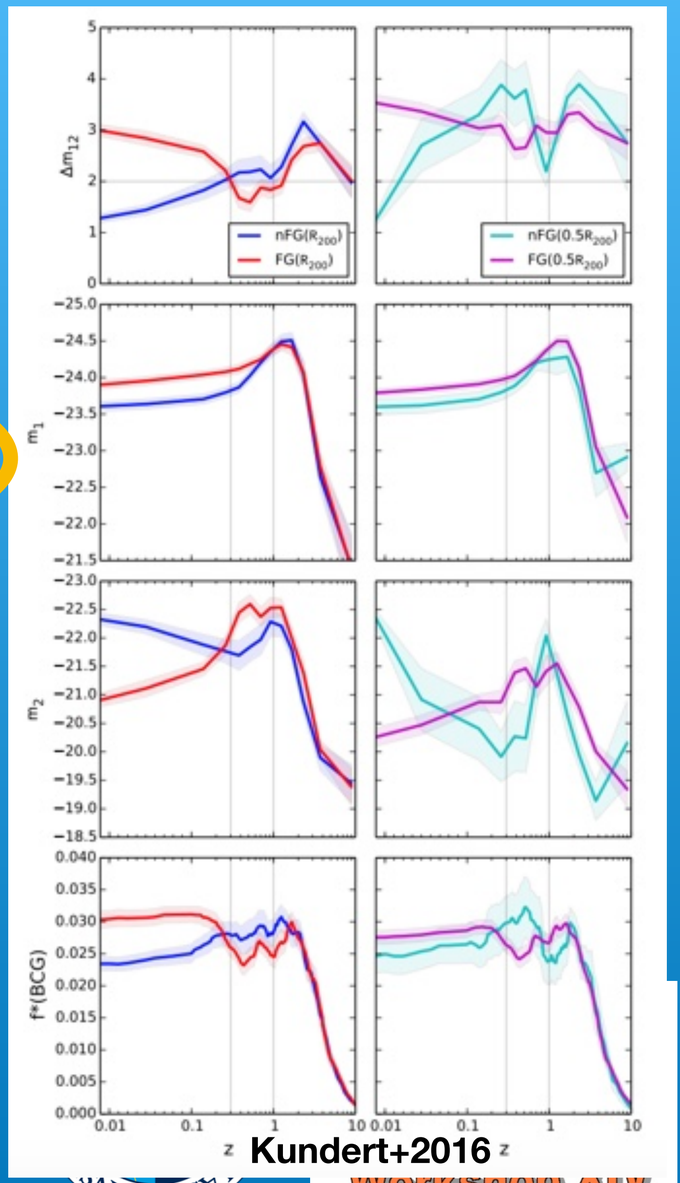
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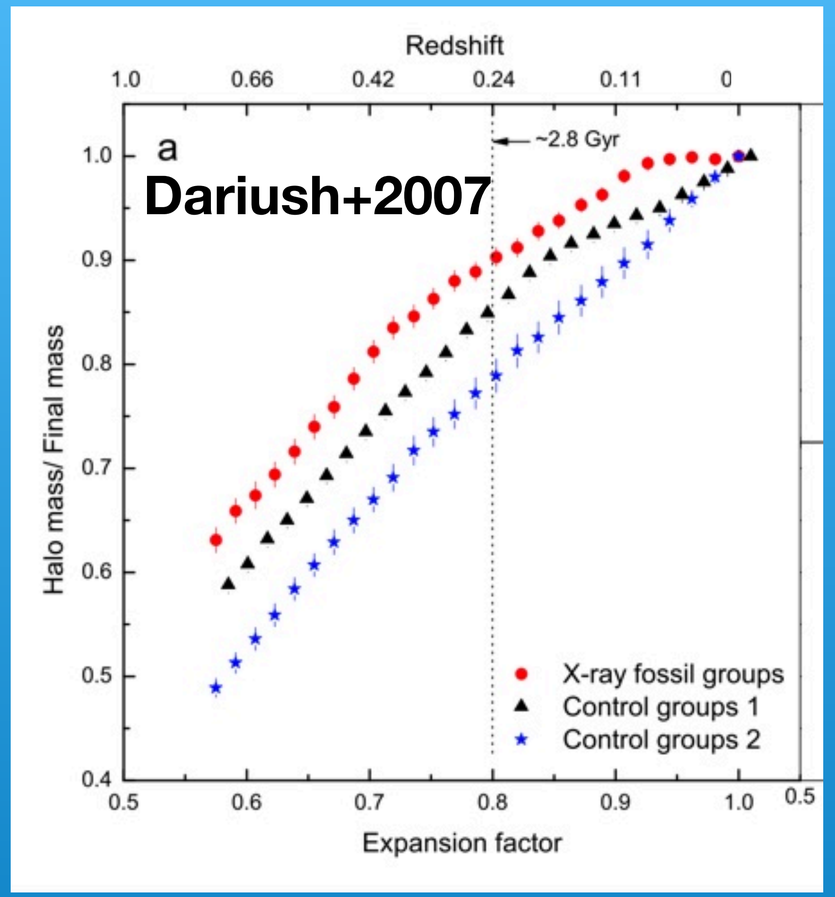
Kanagusuku+2016





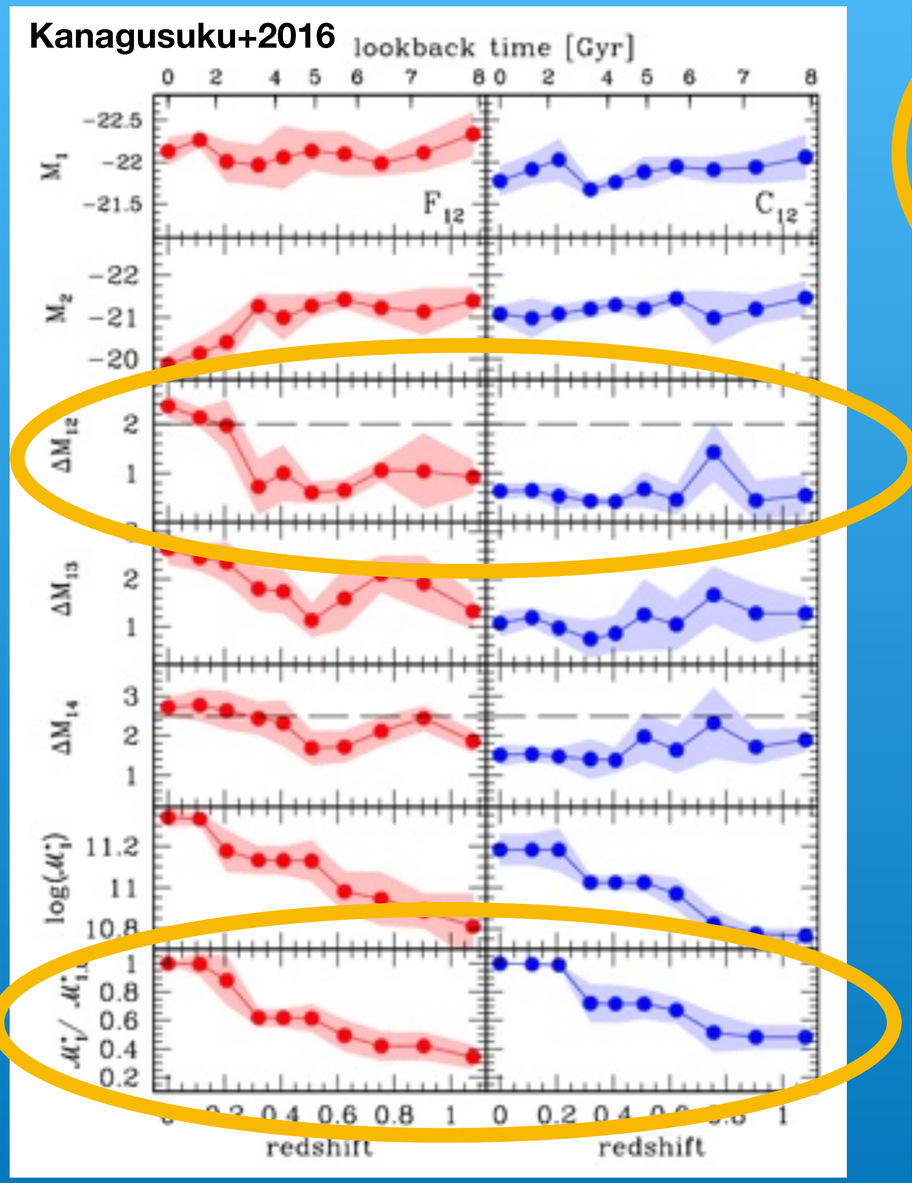
Kundert+2016

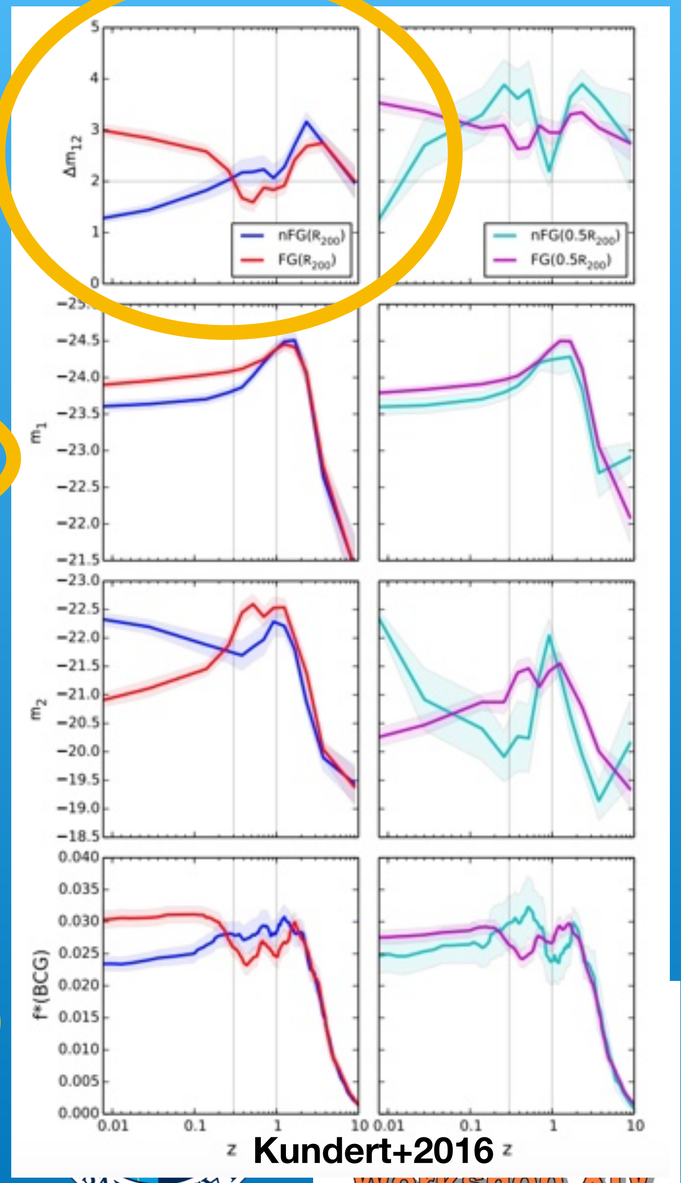
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Kundert+2016

Outline of the talk

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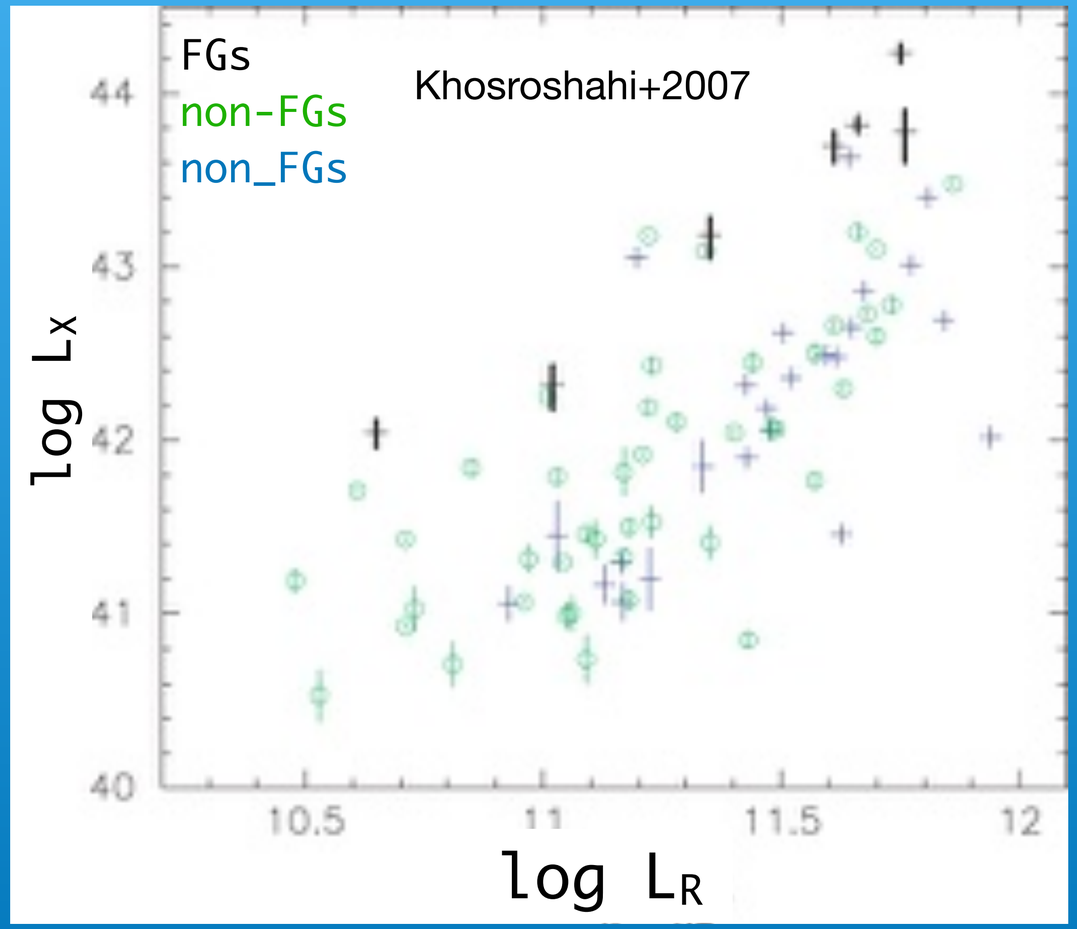
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X-ray scaling relations

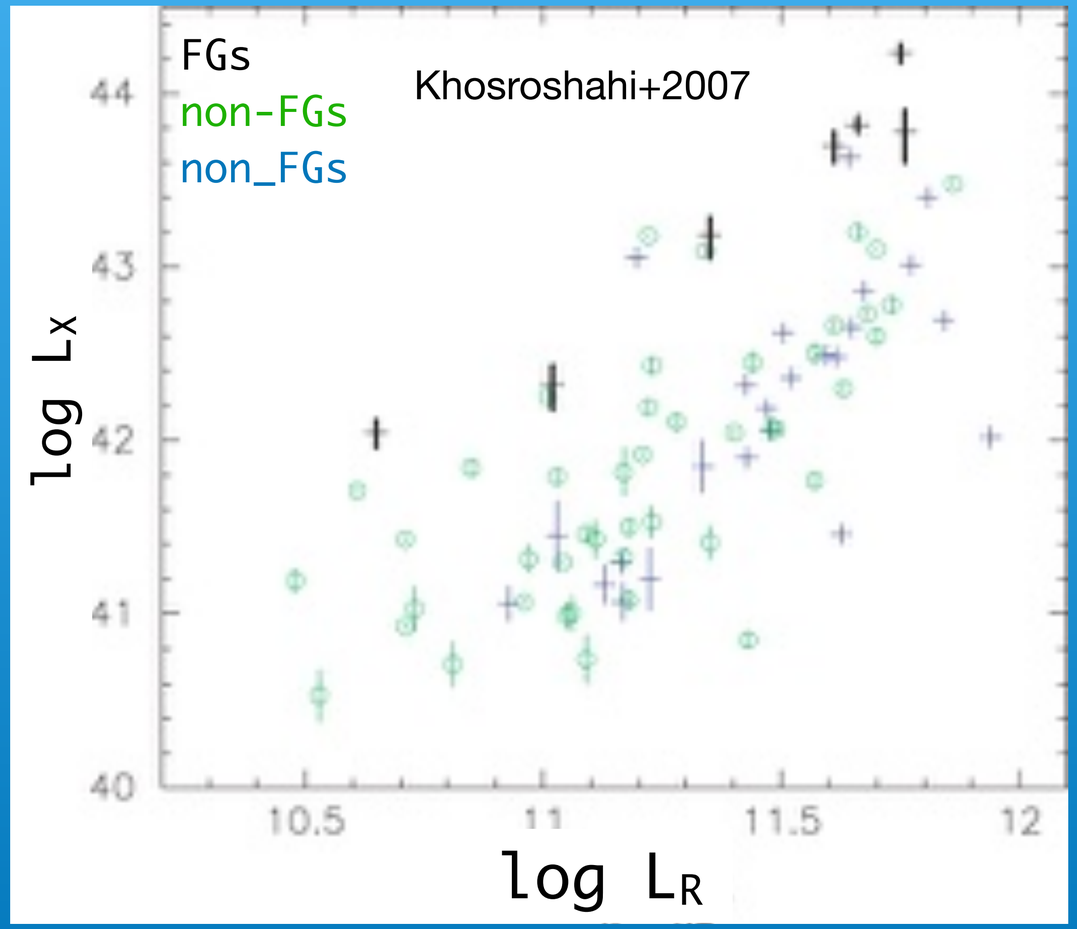
Higher L_x for the same L_{opt}?

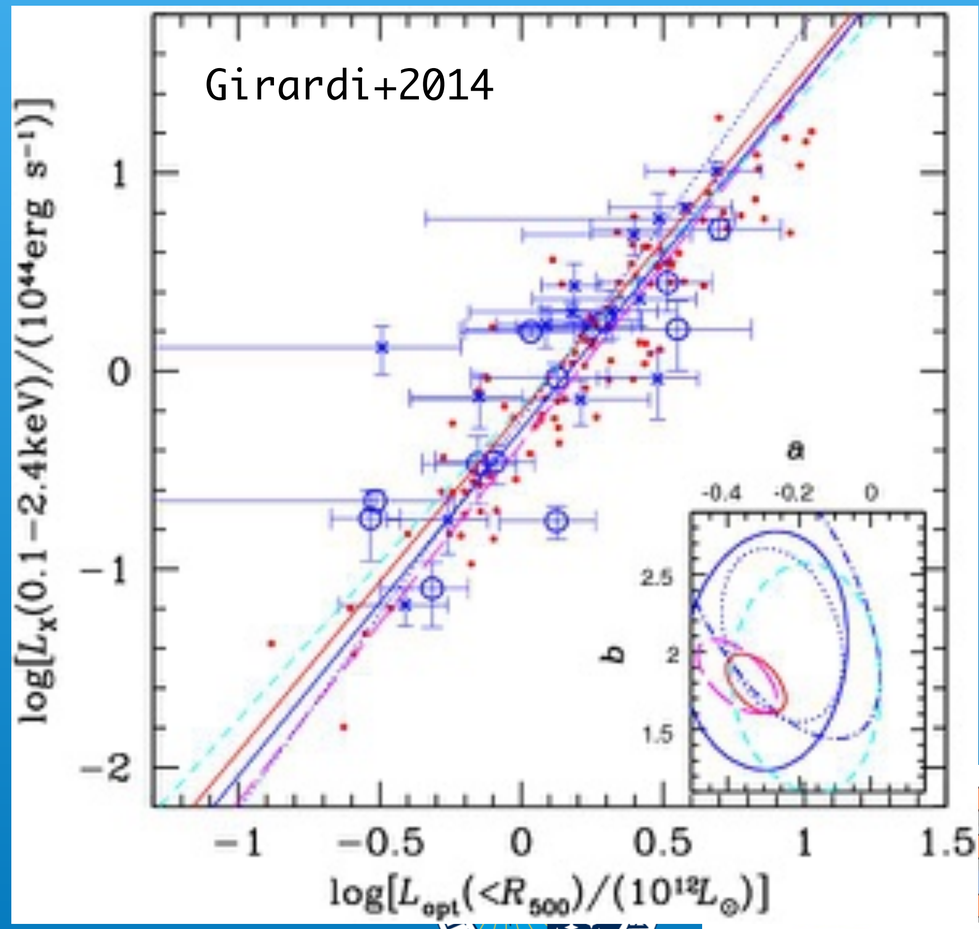


X-ray scaling relations

Higher L_X for the same L_{opt}?

No! Differences due to inhomogeneities in the datasets!





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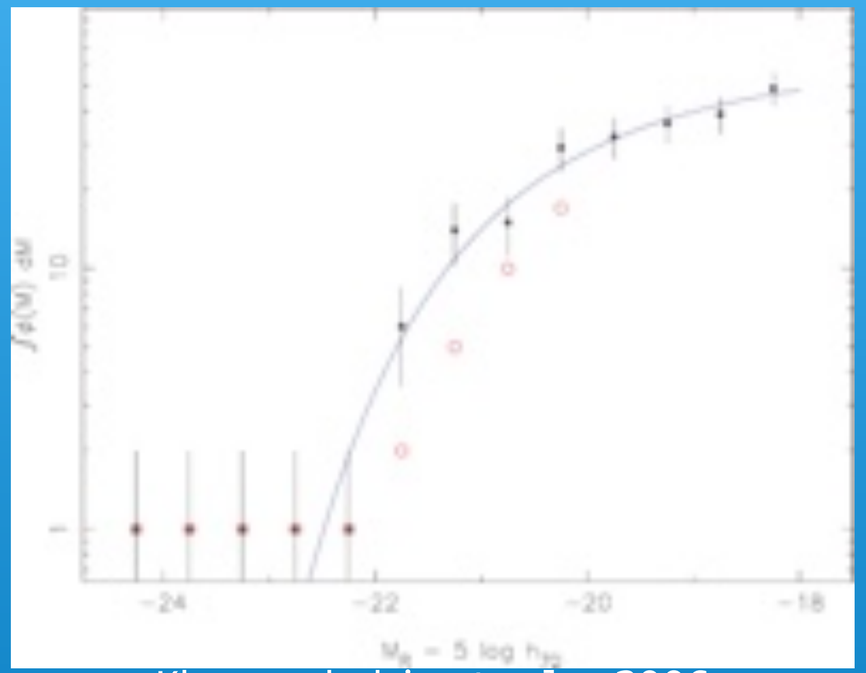
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Luminosity Functions

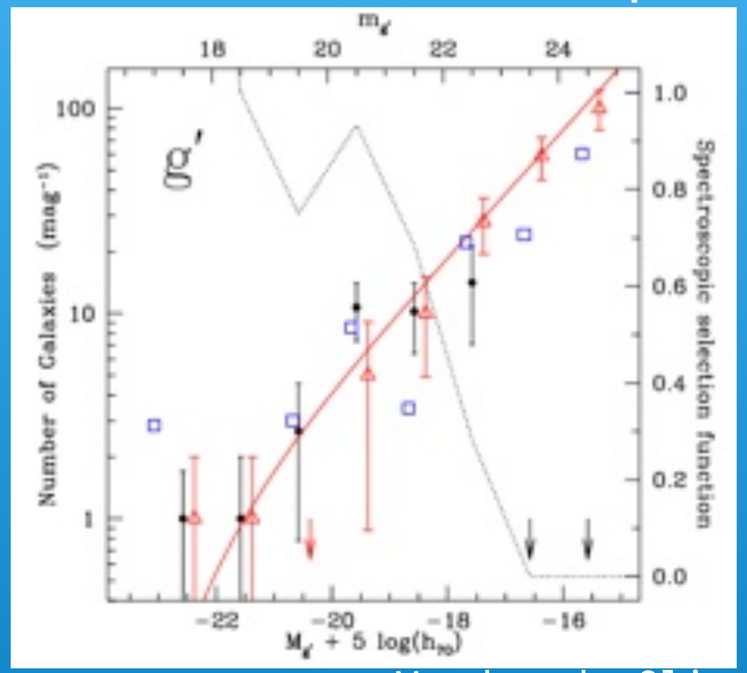
Are FGs really missing satellites? And which satellites?

Pre-FOGO situation: from flat to steep faint-end slopes



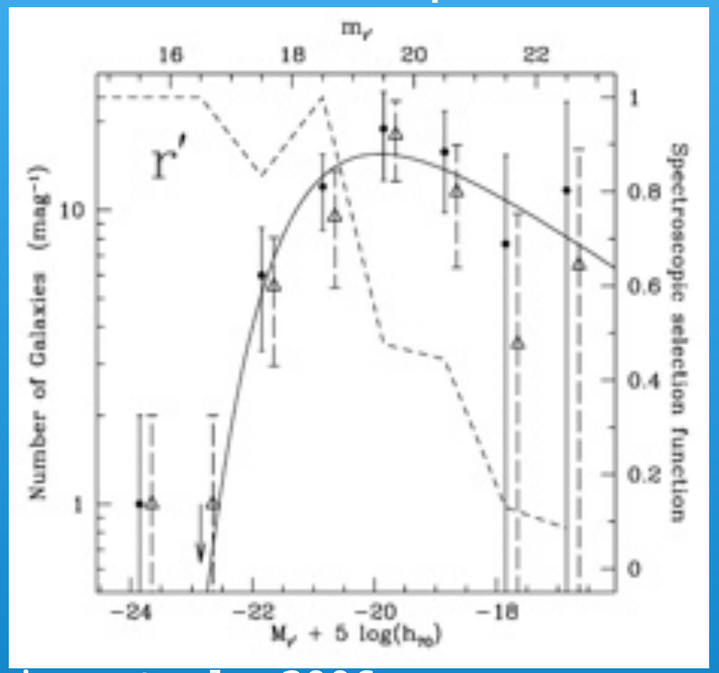
Khosroshahi et al. 2006

α = -1.23 ± 0.28



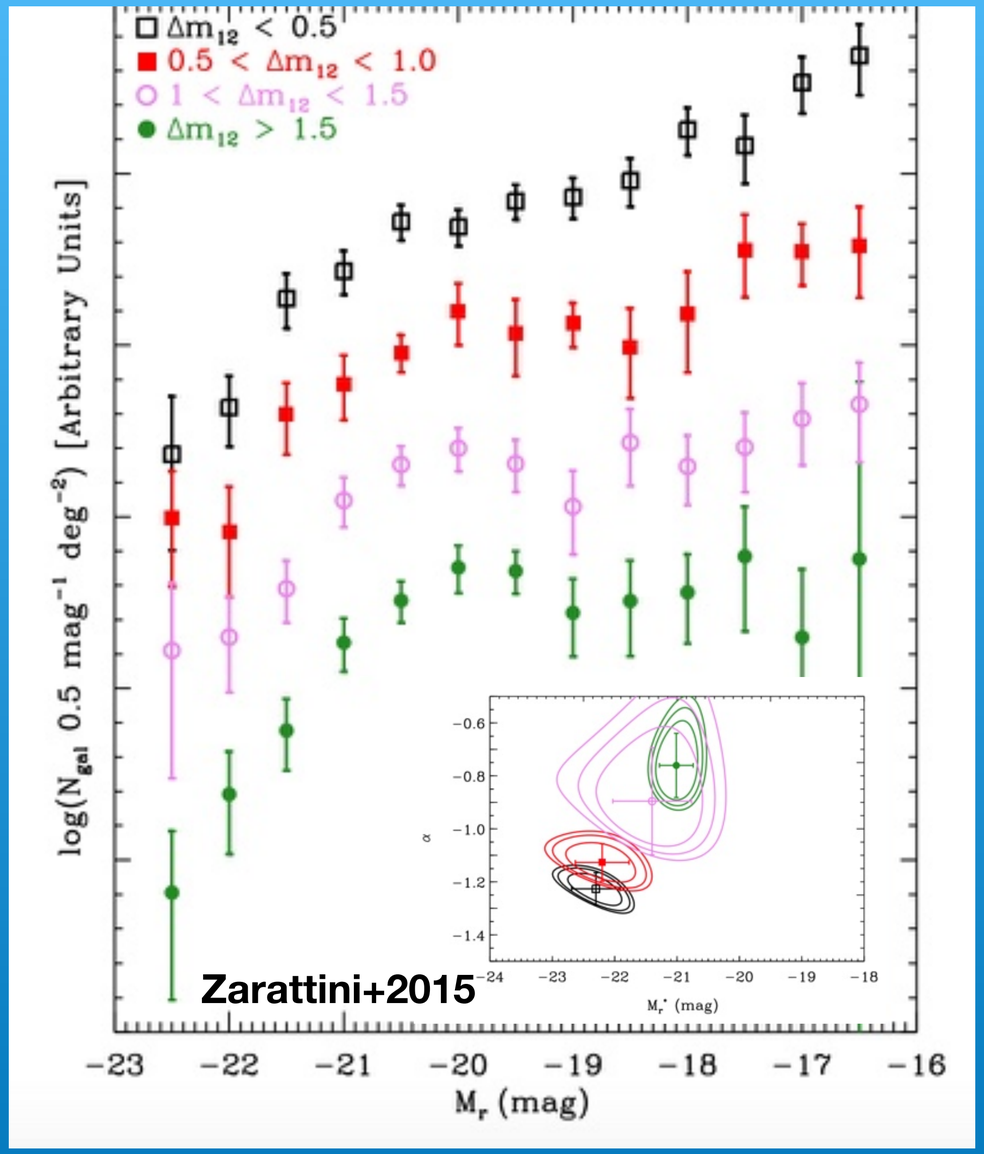
Mendes de Oliveira et al. 2006

α = -1.6 ± 0.2



α = -0.6 ± 0.2

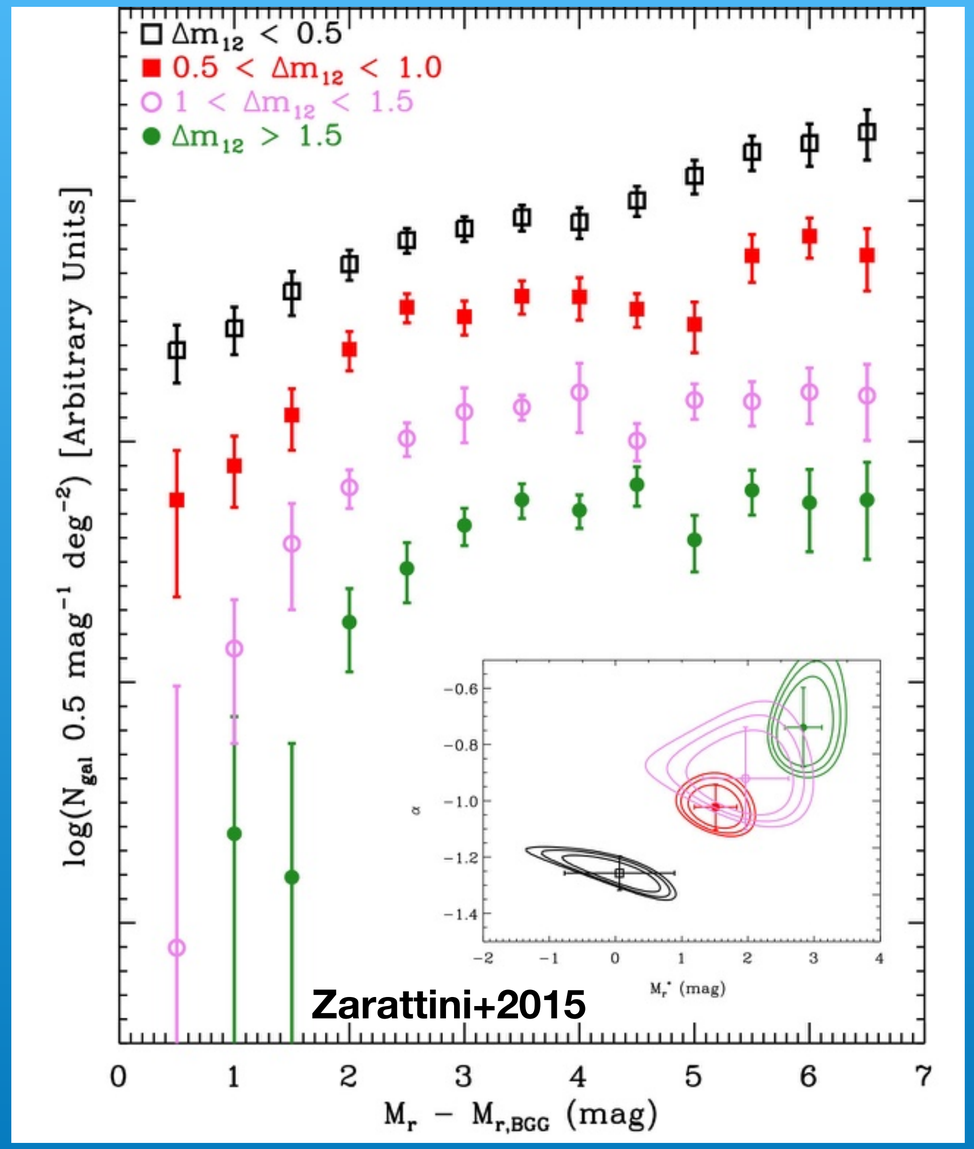
Luminosity Functions



FOGO: dependence of the LF on the magnitude gap

- Sample: ~ 100 clusters and groups from FOGO + Aguerri et al. (2007)

Luminosity Functions

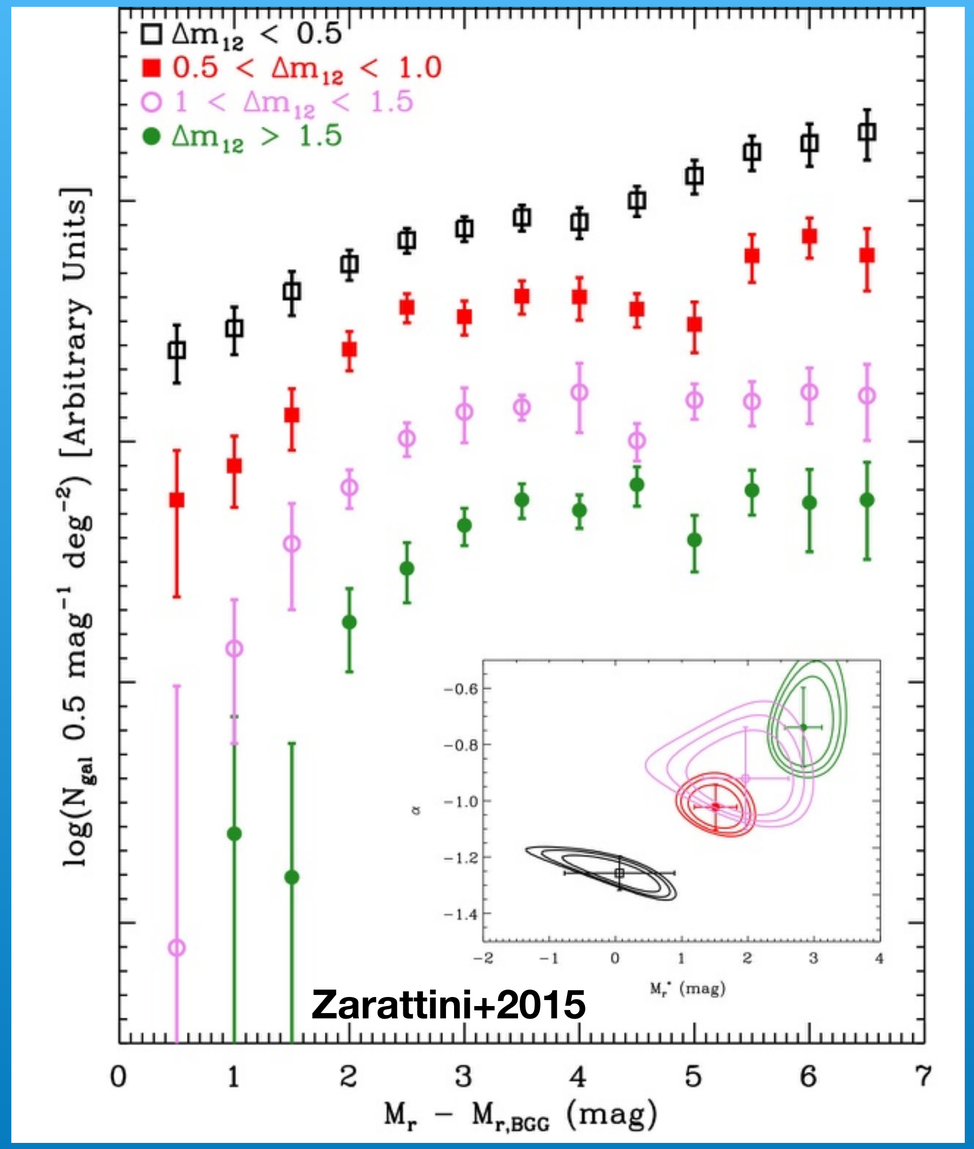


FOGO: dependence of the LF on the magnitude gap

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Workshop XIV

Luminosity Functions



FOGO: dependence of the LF on the magnitude gap

- Sample: ~ 100 clusters and groups from FOGO + Aguerri et al. (2007)

Systems with the largest Δm_{12} have:

- Fainter M* magnitudes
- Flatter faint-end slopes

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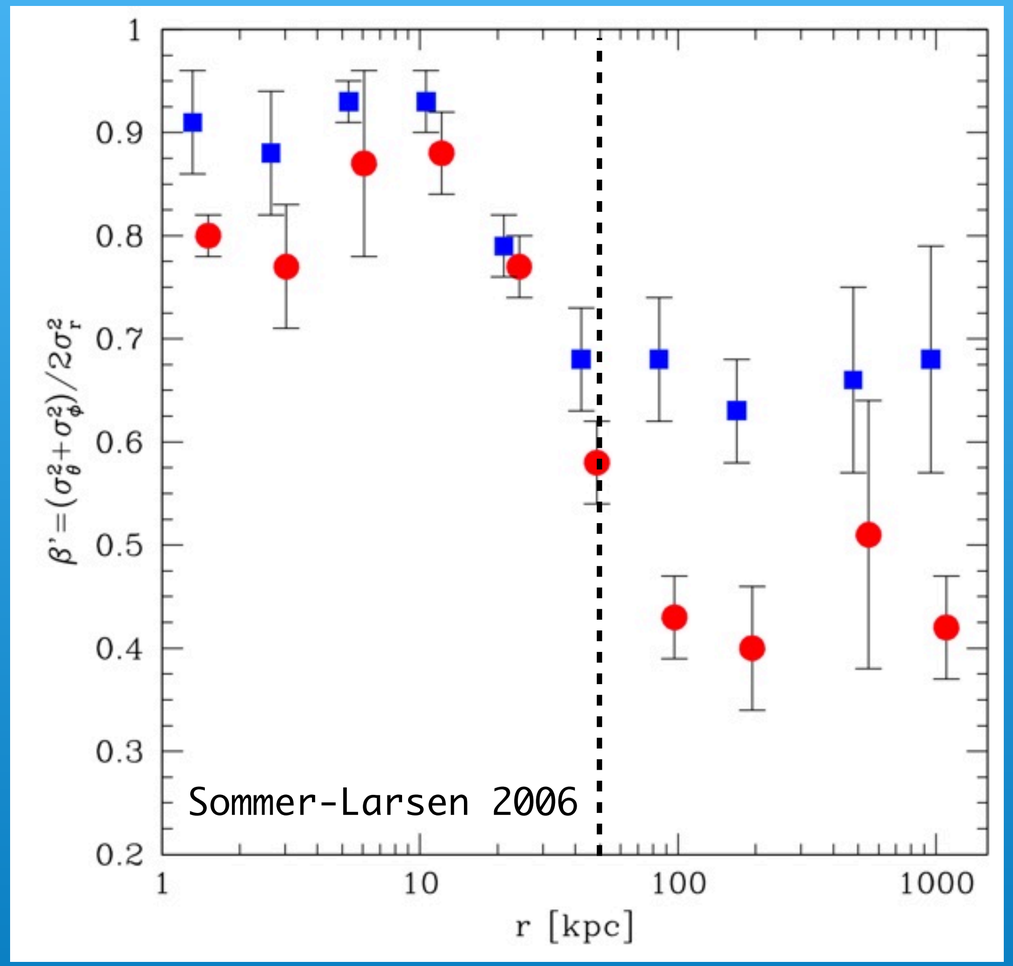
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Orbital shape - theory



Sommer-Larsen (2006) proposed that galaxies falling into FGs could have been on more radial orbits than non fossil systems

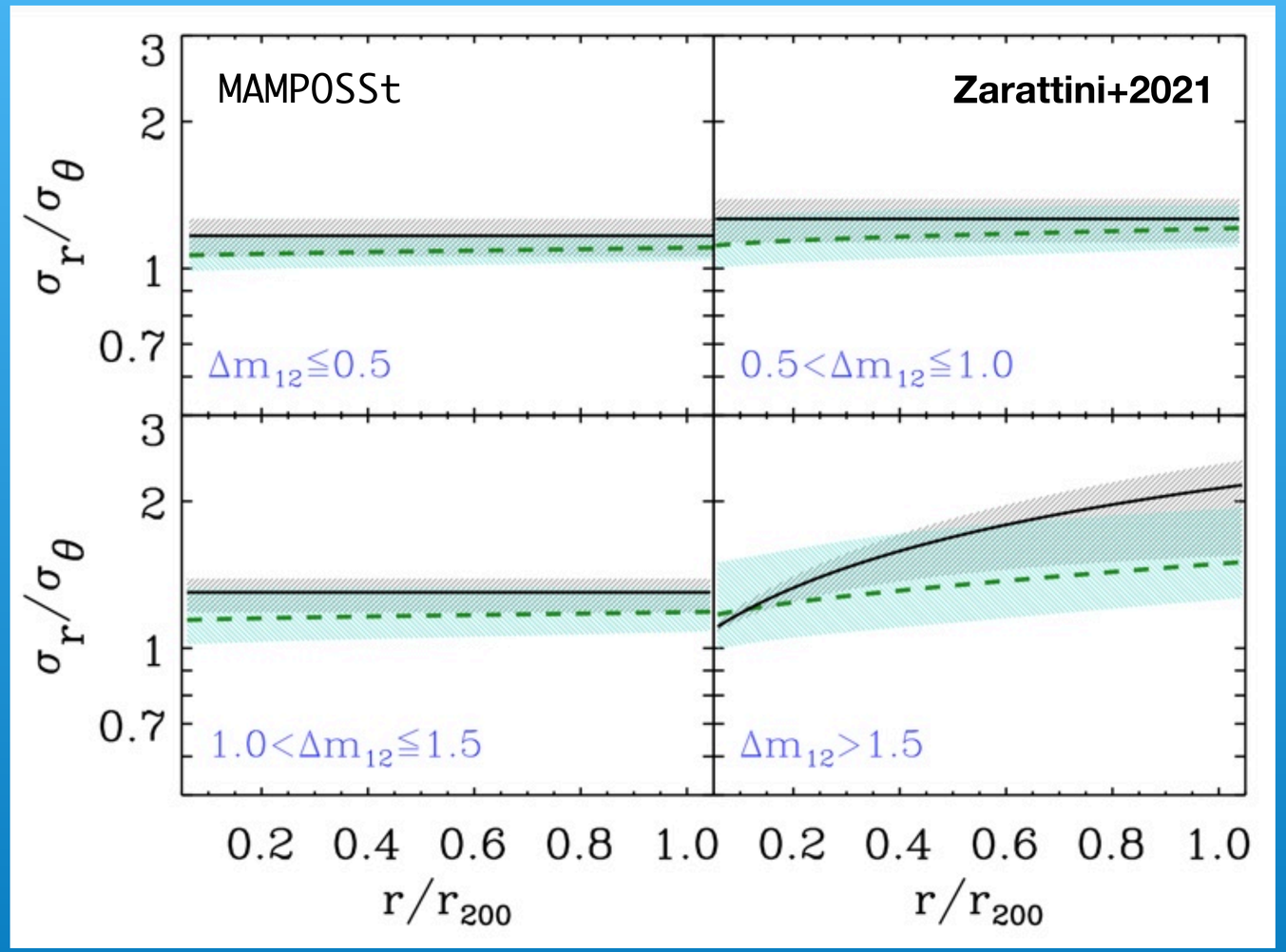
↓

Faster merging rate for massive satellites

Orbital shape - observations

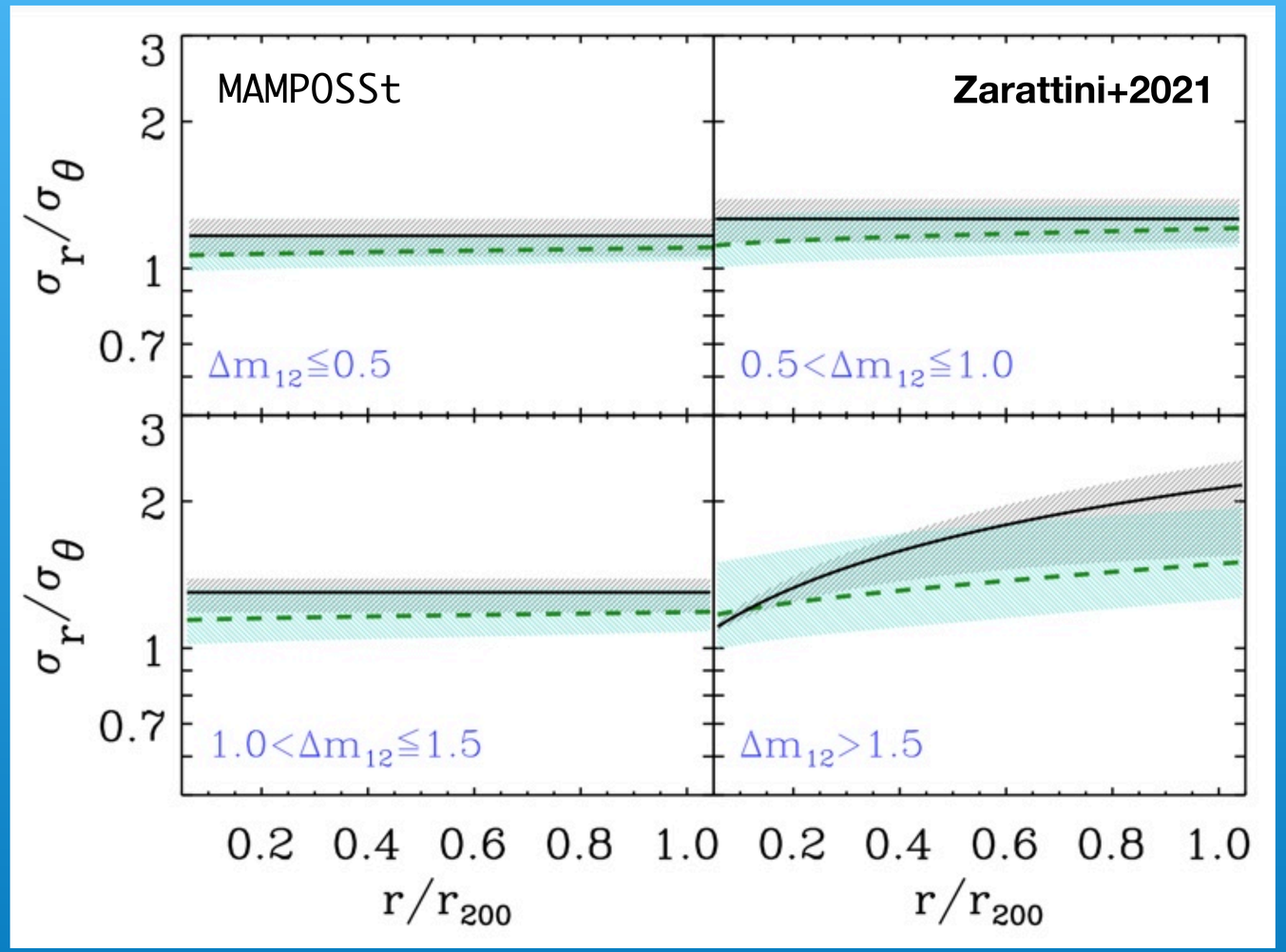
- Sample: ~ 100 clusters and groups from FOGO + Aguerri et al. (2007)
- Method: MAMPOSSt (Mamon+2013), a code that estimates the mass and anisotropy profiles

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↓

We found hints of more radial orbits in the external regions of FGs

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Large-scale structure around FGs

First hypothesis: FGs must be *closed systems*

Large-scale structure around FGs

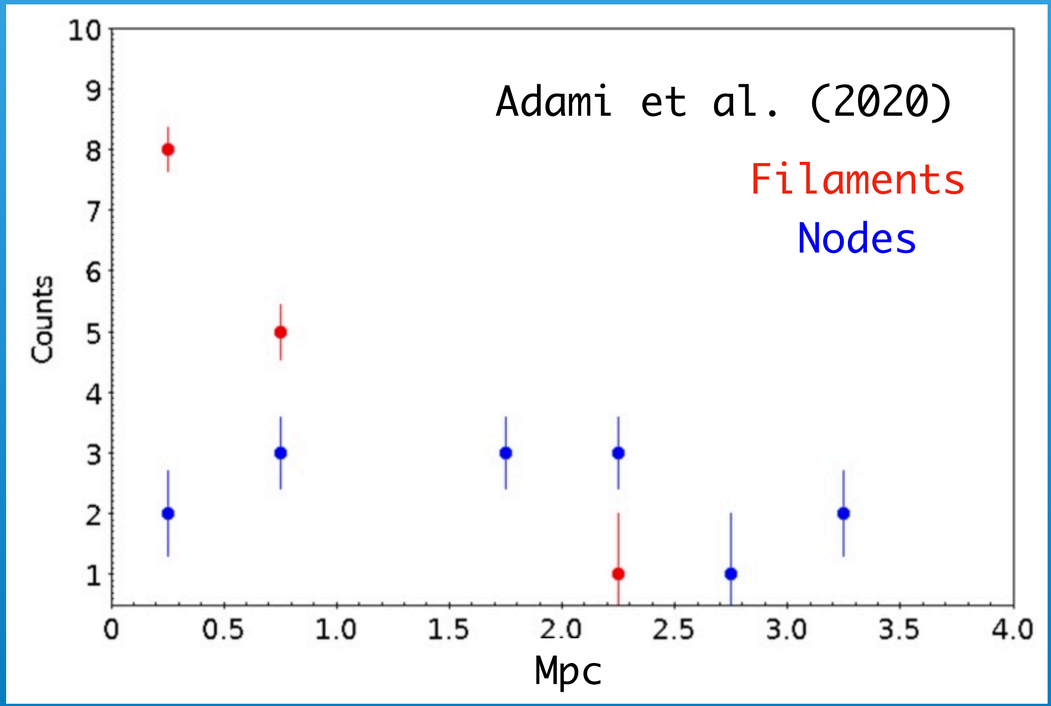
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***ad hoc* hypothesis?**

Large-scale structure around FGs

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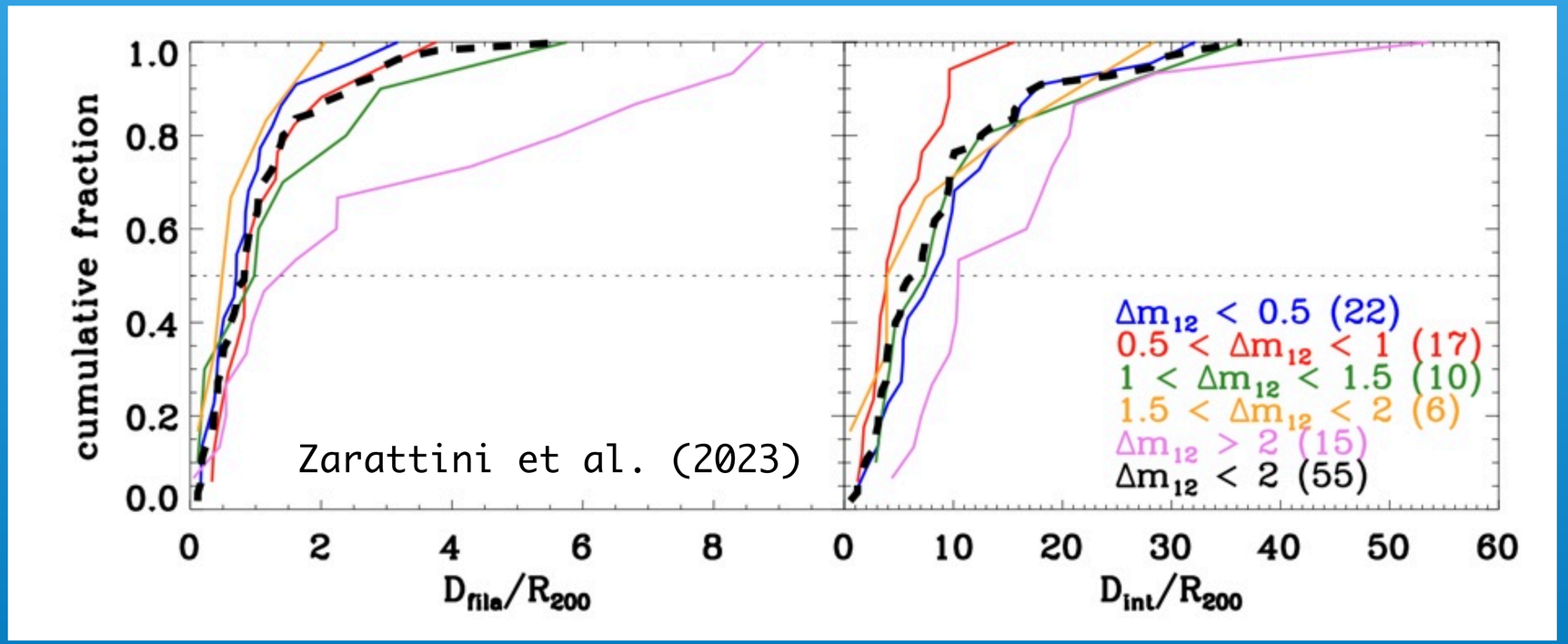


Large-scale structure around FGs

First hypothesis: FGs must be *closed systems*

***ad hoc* hypothesis?**

- Statistical distribution of all NON-FGs are coming from the same parent distribution



- FGs are statistically different (systematically farther from filaments and nodes!)

D_int/R200

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- PARADIGM SHIFT: FGs are peculiar not for their formation time but (probably) due to their position within the large-scale structure
- The infalling of galaxies on radial orbits favour the formation of the magnitude gap at recent times



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