COMPACT MASSIVE GALAXIES AT LOW REDSHIFT

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A study of galaxy sizes in the local Universe as a function of environment

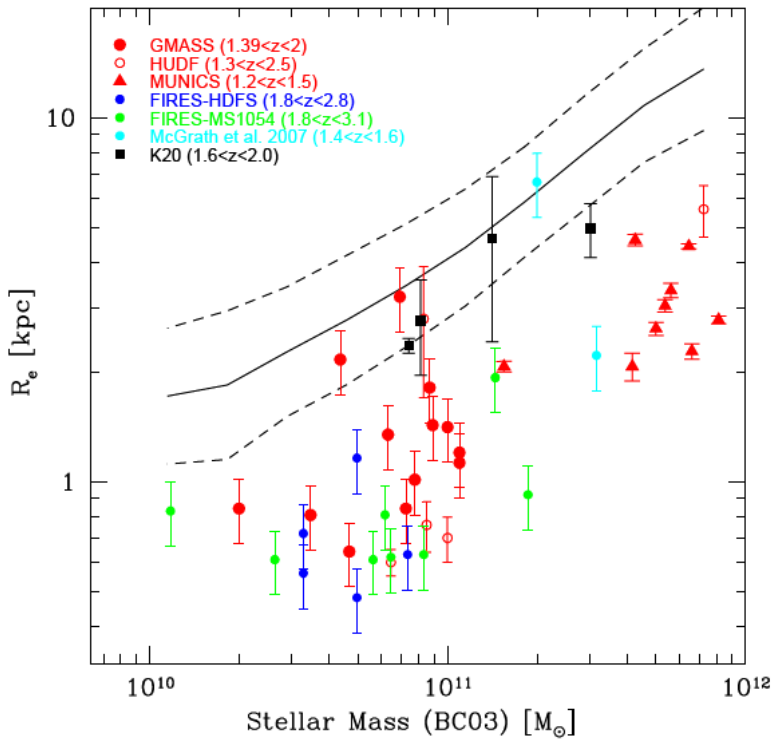
Valentinuzzi+ 2010a, 2010b, Poggianti+ 2013a, 2013b

Moretti et al. in prep.

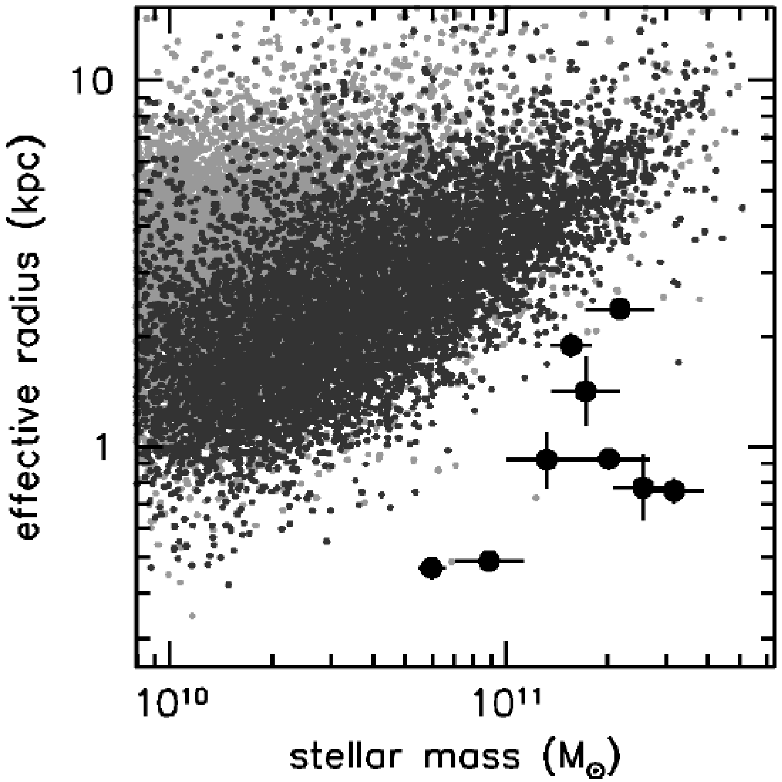
Calvi, Moretti, D’Onofrio, Bindoni, Fasano, De Lucia, Vulcani, Bettoni, Valentinuzzi, Fritz, Renzini, Gullieuszik, Omizzolo and the whole WINGS collaboration

MASSIVE COMPACT GALAXIES AT HIGH REDSHIFT

Many authors found high-z (z>1-2.5), massive ($M_* > 10^{10}$-10^{11} M_{sol}) galaxies with small sizes ("compact", R_e<1-2-3kpc)



Cimatti et al. 2008



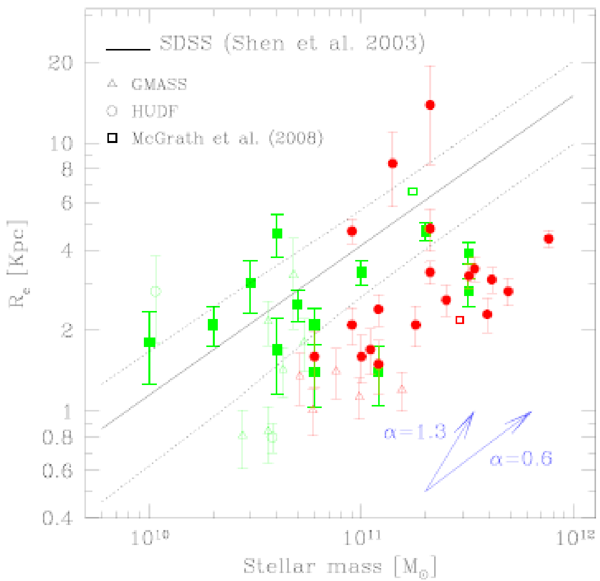
Van Dokkum et al. 2008

(Daddi+ 2005, Trujillo+ 2006, Toft+ 2007, Zirm+ 2007, Buitrago+ 2008, Cimatti+ 2008, van der Wel+ 2008, van Dokkum+ 2008, Damjanov+ 2011, Ryan+12, +..........)

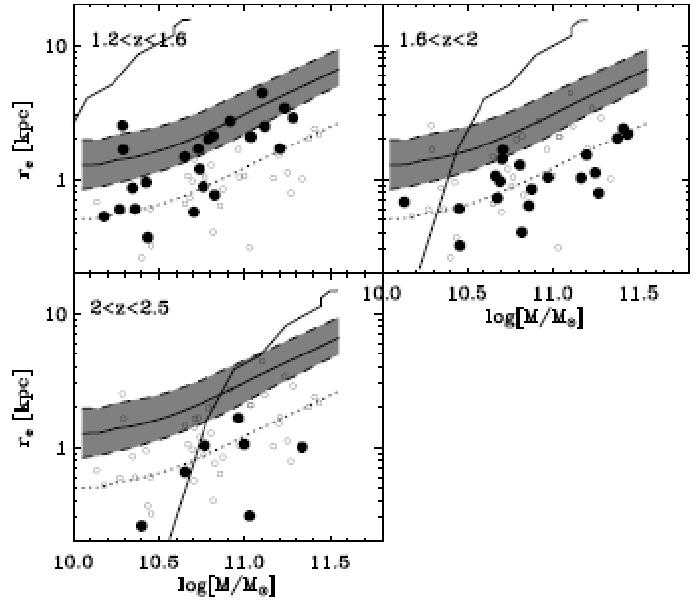
SELECTION AND LOCAL COMPARISON

In many cases, high-z galaxies **are selected to be already passive (old stars) at that z** – alternatively, morphologically selected to be early-type galaxies (van der Wel+ 2008, Saracco+ 2009, Cassata+ 2011, 2013)

Most high-z works use as local comparison the median mass-size relation for n › 2.5 galaxies (Shen+ 2003), finding high-z points to lie mostly below local relation



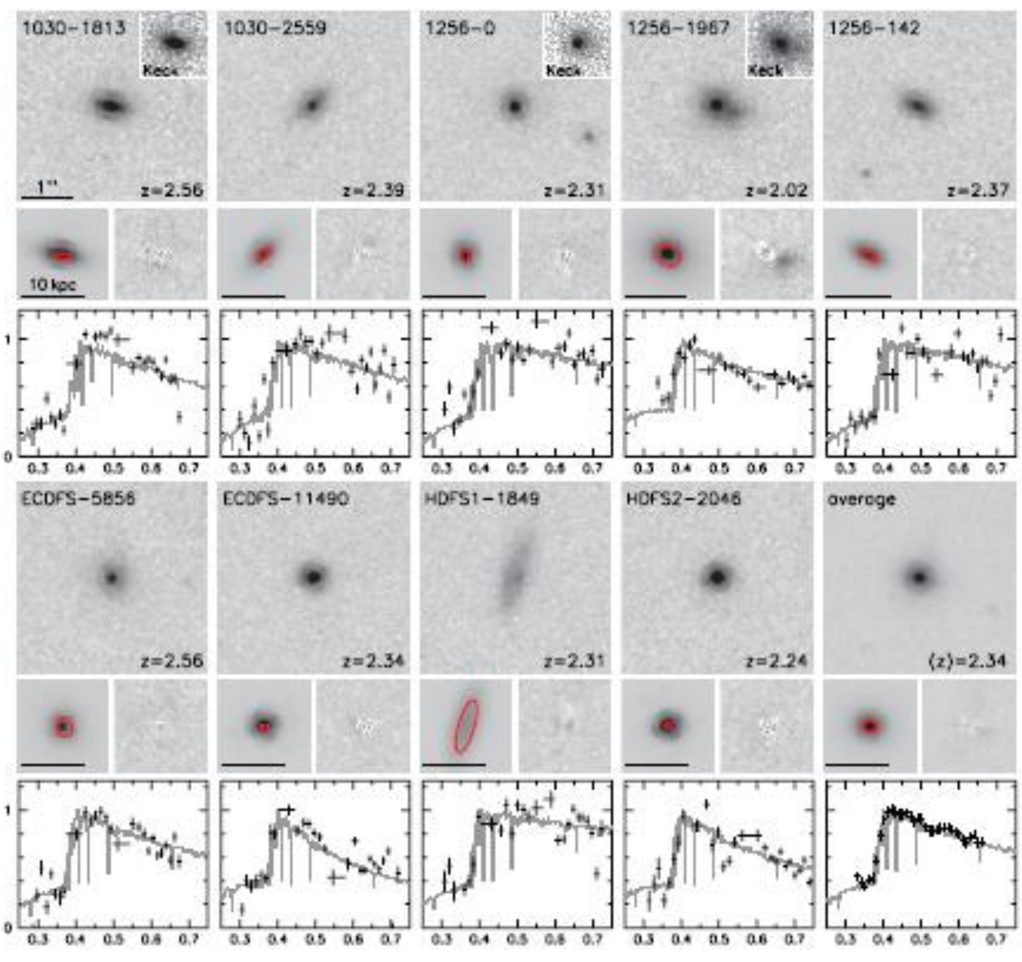
Saracco et al. 2009



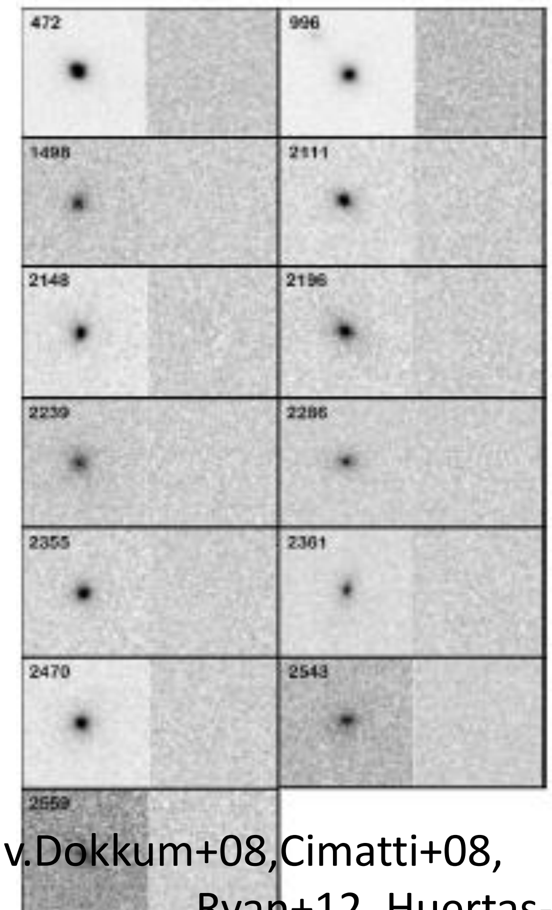
Cassata et al. 2011

ELLIPTICALS OR DISKS?

The majority of massive high-z galaxies (even passive and massive) have disks

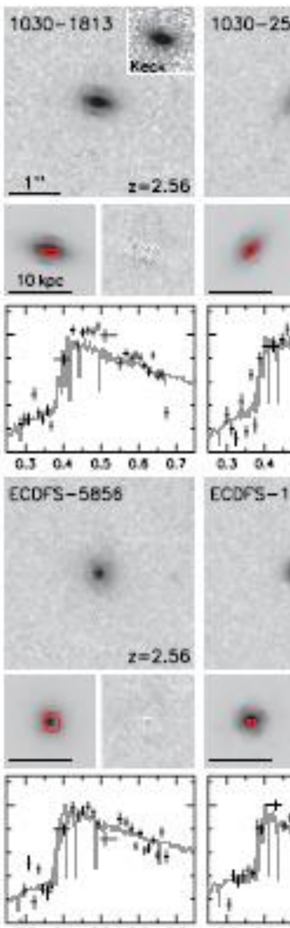


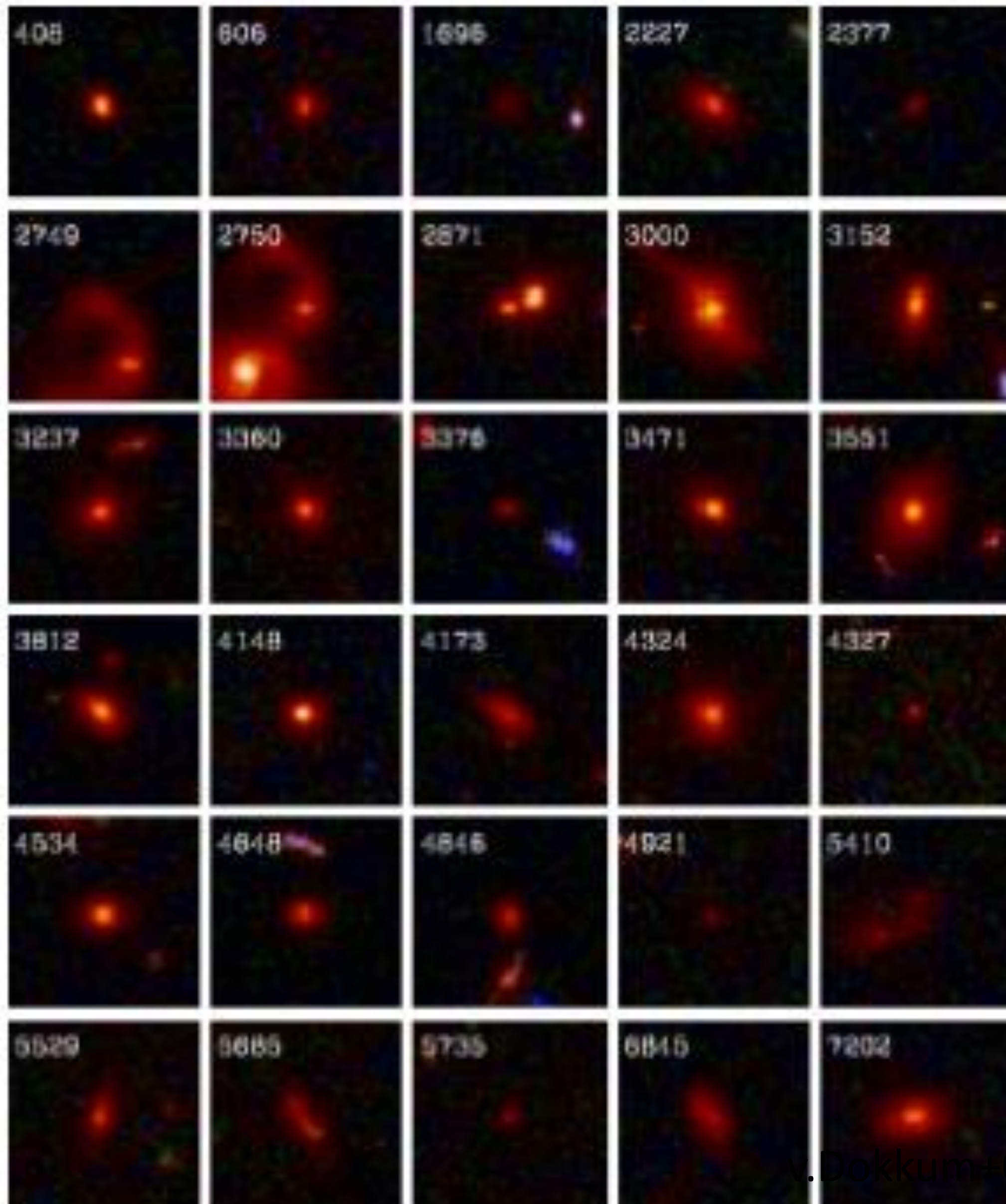
C2 images of the nine spectroscopically confirmed quiescent z > 2 galaxies from Kriek et al. (2006). Each panel spans 3.8"

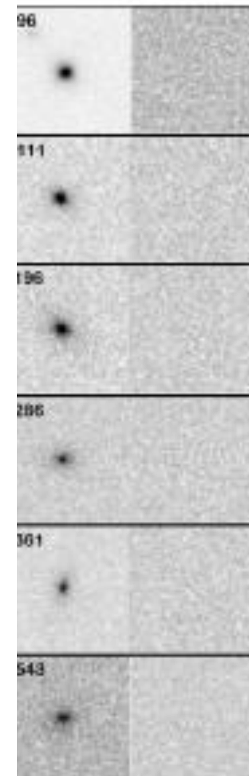


v.Dokkum+08,Cimatti+08, Ryan+12, Huertas-Company+12

The majorit ve and
massive) h







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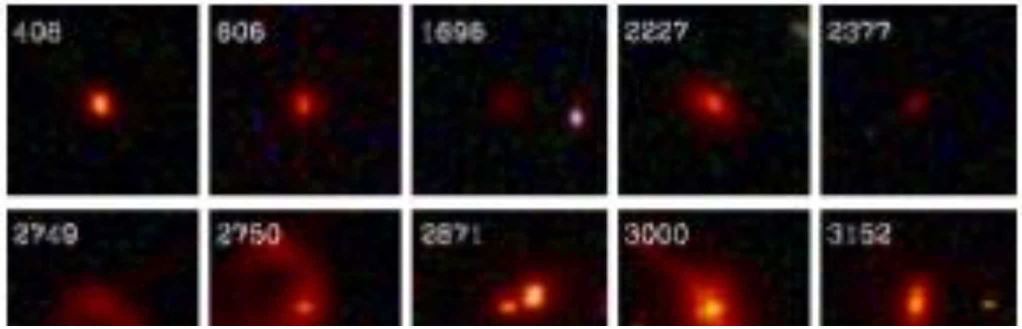
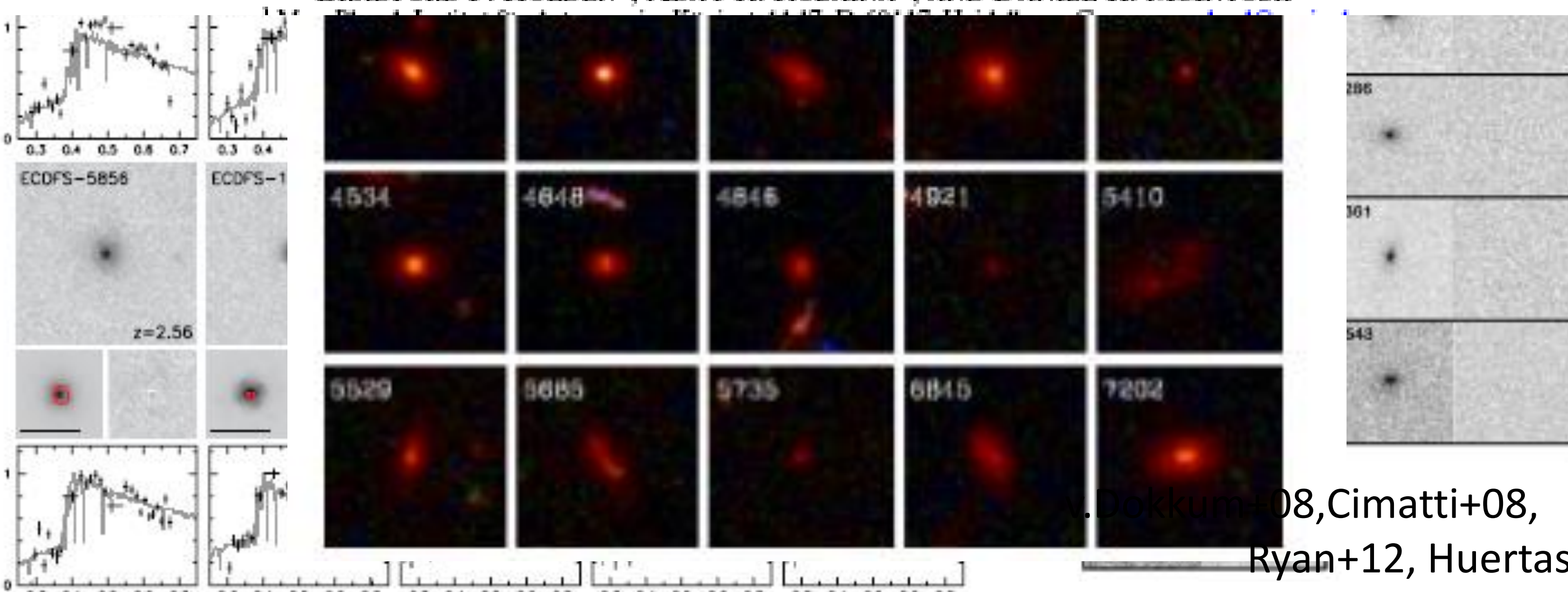
The majorit… …ve and massive) ha…



THE ASTROPHYSICAL JOURNAL, 730:38 (5pp), 2011 March 20 doi:10.1088/0004-637X/730/1/38

THE MAJORITY OF COMPACT MASSIVE GALAXIES AT $z \sim 2$ ARE DISK DOMINATED

ARJEN VAN DER WEL[1], HANS-WALTER RIX[1], STIJN WUYTS[2], ELIZABETH J. MCGRATH[3], ANTON M. KOEKEMOER[4], ERIC F. BELL[5], BRADFORD P. HOLDEN[6], ADAY R. ROBAINA[7], AND DANIEL H. MCINTOSH[8]



…C2 images of the nine spectroscopically confirmed quiescent $z > 2$ galaxies from Kriek et al. (2006). Each panel spans 3.8"…

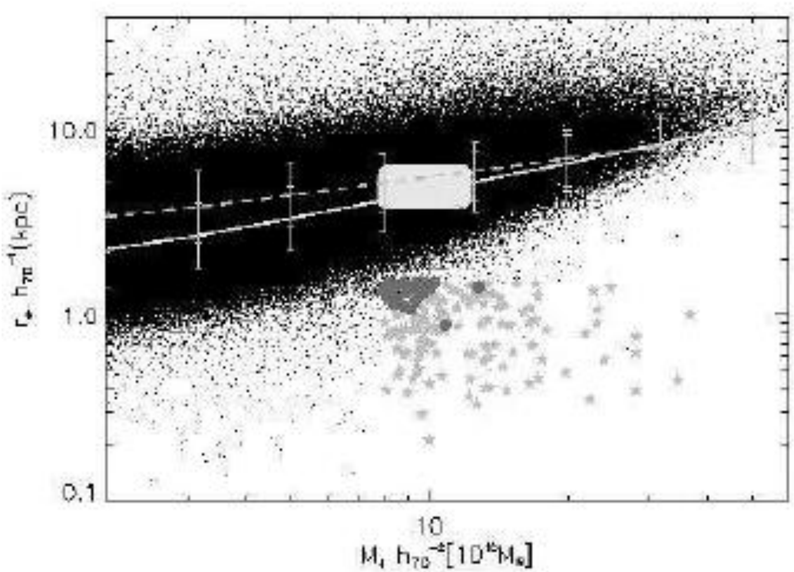
…Dokkum+08,Cimatti+08, Ryan+12, Huertas-Company+12

GENERAL FIELD AT LOW-Z

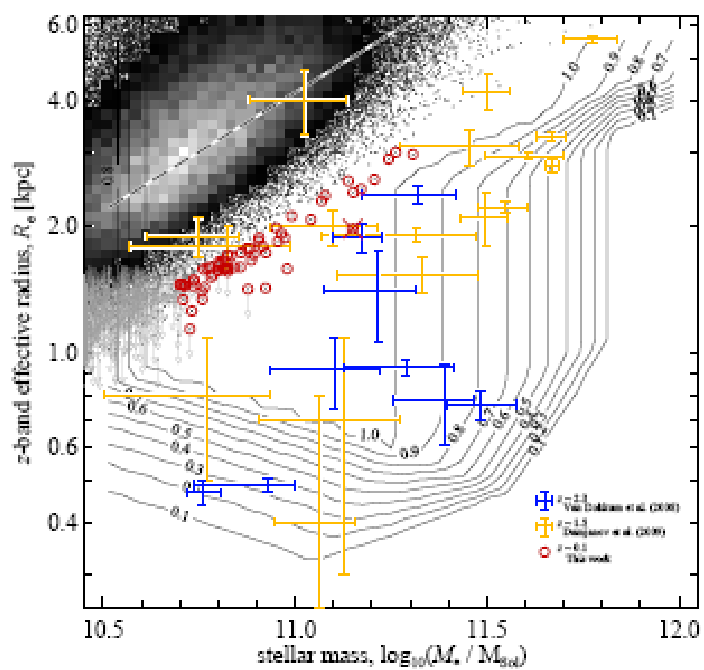
Trujillo et al. (2009) and Taylor et al. (2010) searched for massive compact galaxies at low-z – both found very few such galaxies in the general field at low-z

Almost none of the massive compact high-z galaxies have "survived"?

See also Trujillo+2014 NGC1277



Trujillo et al. 2009



Taylor et al. 2010

WIde-field Nearby Galaxy-cluster Survey

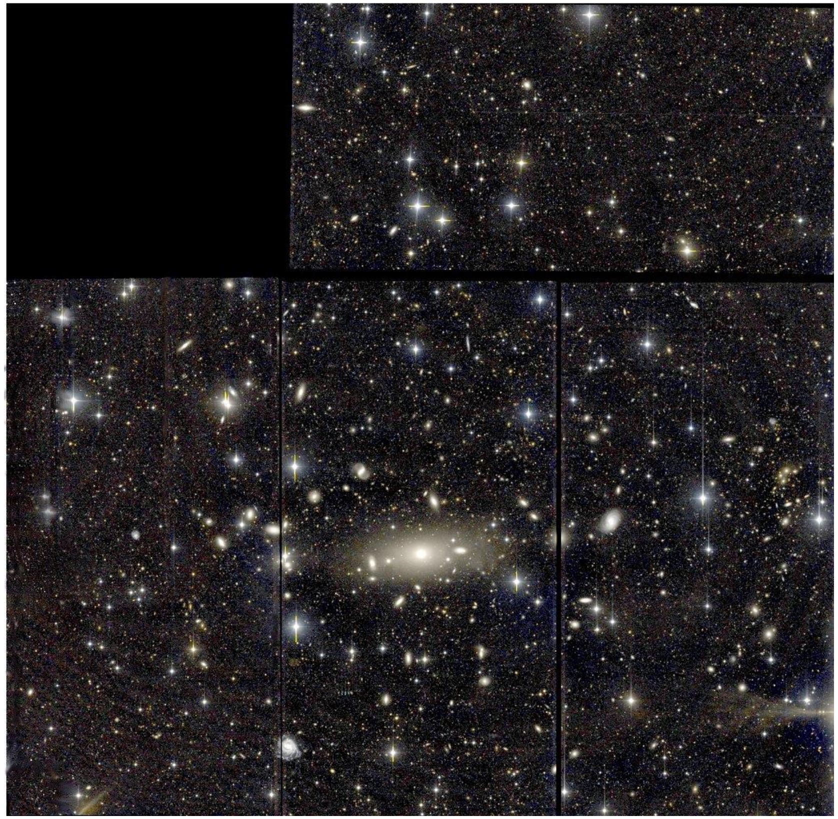
(WINGS) and its extension (OMEGAWINGS)

A wide-field survey of 77 X-ray selected clusters at z=0.04-0.07

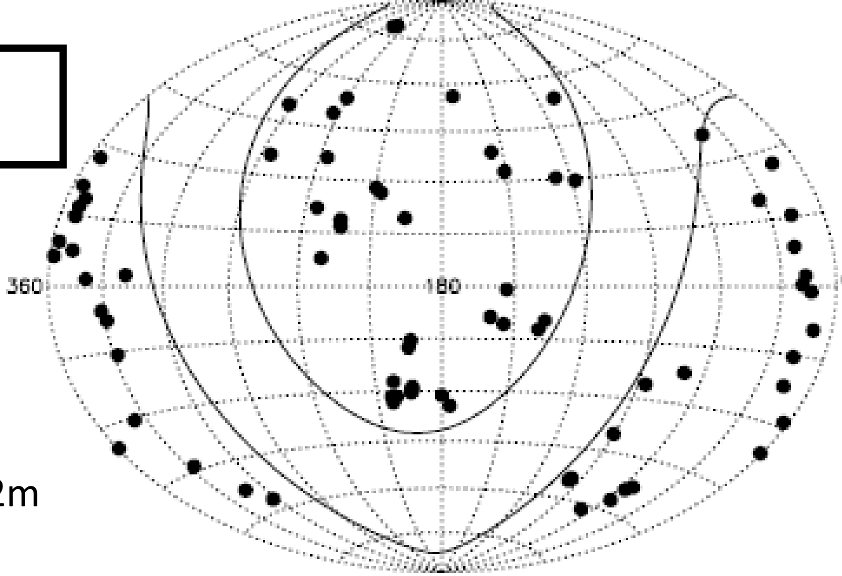
Daniela Bettoni
Mauro D'Onofrio
Giovanni Fasano (co-PI)
Alessandro Omizzolo
Bianca M. Poggianti (PI)

Antonio Cava
Jacopo Fritz
Tiziano Valentinuzzi
Jesus Varela
Alessia Moretti
Benedetta Vulcani
Marco Guilleuszik
Angela Paccagnella
Valentina Guglielmo

Alan Dressler
Warrick Couch Per
Kjaergaard
Mariano Moles



THE WINGS DATASET



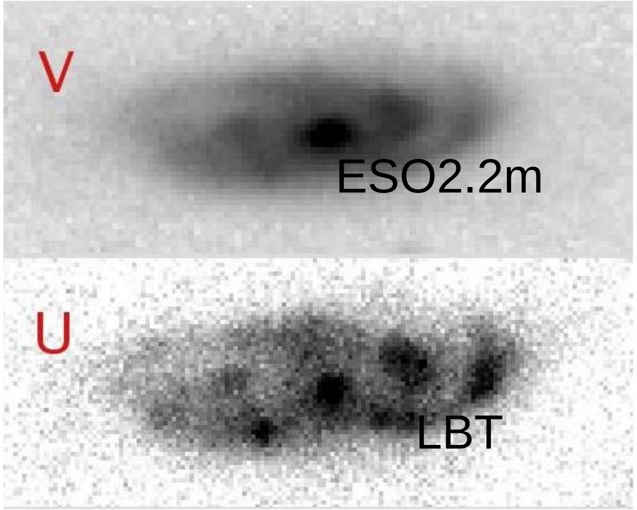
Sigma=500-1200+km/s, Log L_X=43.3-44.7 erg/s

B and V deep photometry with WFC/INT and WFC/2.2m on 34'X34'

FOV 1.2-2.7Mpc, res. 0.7-1.6kpc, M_V~-13
400.000 gal phot., 40.000 surf.phot + morph

Optical fibre spectroscopy with 2dF/AAT and WYFFOS/WHT

48 clusters, 6500 spectra, 100-200 galaxies/cluster, down to M_V~-17



Near-IR deep photometry, J and K with WFC/UKIRT

36 clusters – galaxy masses, SED + struct.props

Some U-band with INT, LBT & Bok

Reaching out to 0.6 virial radii for most clusters

Padova-Millennium Galaxy and Group Catalogue (PM2GC)

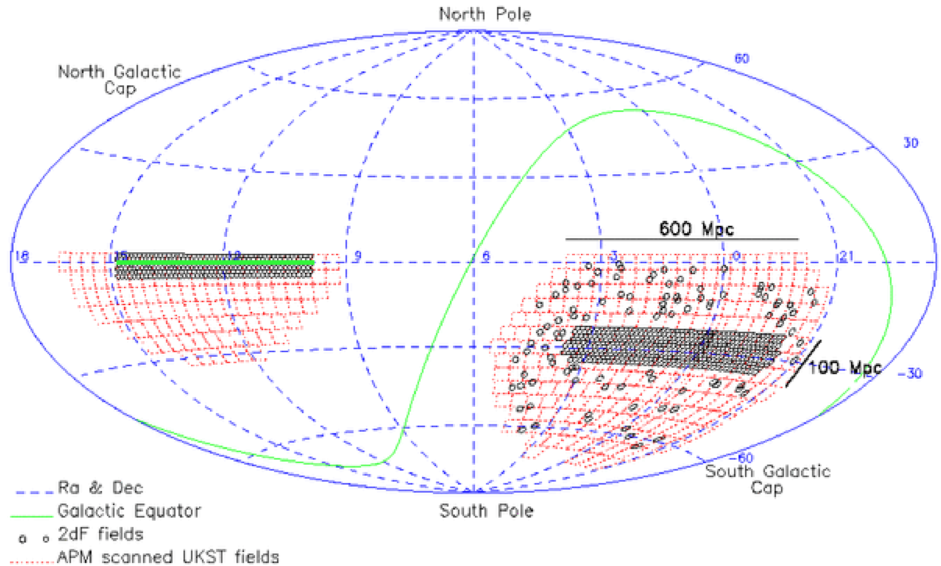
Rosa Calvi + WINGS collaborators

A general field galaxy sample at z=0.04-0.1

Based on the Millennium Galaxy Catalogue (PI Simon Driver, Liske et al. 2003), a 38 deg^2 equatorial survey

B-band imaging with WFC/INT

AAT/2dF redshift survey combined with 2dFGRS and SDSS: spectroscopic completeness in the area 96% to B=20



MGC
Millennium Galaxy Catalogue

Padova-Millennium Galaxy and Group Catalogue (PM2GC)

ADVANTAGES compared to SDSS:

Better imaging quality

Spectroscopic completeness (14% of all, 27% of our compacts missing in SDSS)

Group catalogue (groups, binaries and singles) and environment characterization (FOF algorithm)

- Galaxy morphologies
- Galaxy stellar masses
- SFHs and stellar populations from spectral analysis

Calvi et al. 2011, 2012, 2013

1. MASSIVE AND COMPACT GALAXIES ALSO AT LOW REDSHIFT

WINGS -- Valentinuzzi et al. 2010a,b

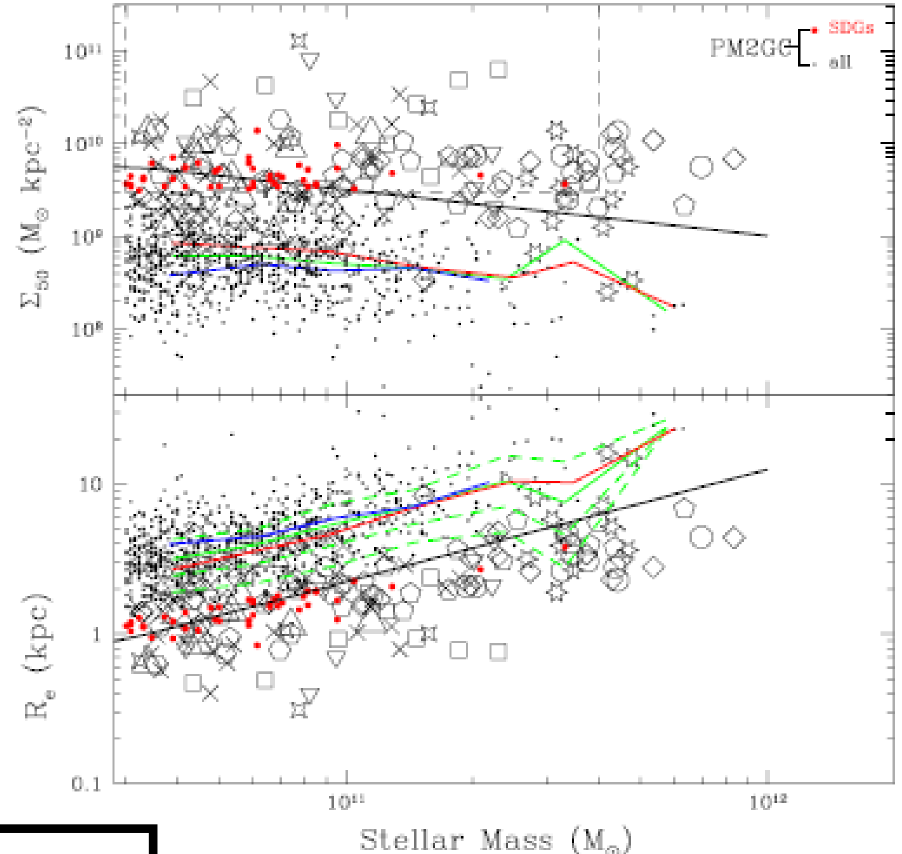
In nearby clusters, a significant population of compact galaxies with masses and sizes similar to high-z galaxies

~12% (B-band) of all galaxies with $3 \times 10^{10} < M < 4 \times 10^{11}$ (all types and colors) – BCGs excluded!

COMPACT DEFINITION

Compact definition chosen to match high-z points in Density-Mass diagram

$\Sigma_{50} = 0.5\ M_* / \pi\ Re^2$



Σ_{50}

R_e (kpc)

Stellar mass

$M_* = 3 \times 10^{10} - 4 \times 10^{11}$ Msun

$\Sigma_{50} \geq 3 \times 10^9$ Msun/kpc^2

LOW-Z FIELD COMPACT MASSIVE GALAXIES

After inspecting each candidate, 44 galaxies / 995 in PM2GC

Compact fraction M>3X10^10: 4.4±0.7% in PM2GC, 11.8±1.7% in WINGS B-band (in >500km/sec PM2GC “groups” 14±7)

using literature values (masses and sizes) in PM2GC 3.7±0.7%

Mass-size relations PM2GC-WINGS instead are quite similar.

	PM2GC		WINGS B-band	
Quantity	Value	RMS error	Value	RMS error
SDGs	44	7	51	11
$\langle R_e \rangle$	1.45	0.26	1.57	0.34
$\langle n \rangle$	2.8	0.6	3.1	0.8
$\langle b/a \rangle$	0.48	0.13	0.65	0.16
$\langle M_* \rangle$	$6.0\times10^{10} M_\odot$	$1.9\times10^{10} M_\odot$	$9.1\times10^{10} M_\odot$	$3.6\times10^{10} M_\odot$
$\langle V_{abs} \rangle$	-20.87	0.42	-20.68	0.38
$\langle Lw - age \rangle$	5.45	1.87	9.64	2.10
$\langle Mw - age \rangle$	9.25	1.08	11.95	1.39
Ellipticals frac.	22.7%	7.2%	29.1%	7.8%
S0s frac.	70.5%	12.7%	62.0%	10.7%
Late-type frac.	6.8%	3.9%	8.8%	4.4%

See also Delaye+13 at high-z

Poggianti et al. 2013a

HOW MANY OF THE DISTANT COMPACTS HAVE REMAINED COMPACT UNTIL TODAY?

number density of compact galaxies

Taylor+10: strong evolution in ND (>5000) for extremely compact galaxies – local comparison disk-free red sequence SDSS

Cassata+10, 13: evolution in ND driven both by size growth of compact galaxies and – mostly -appearance of new early-type galaxies with larger size

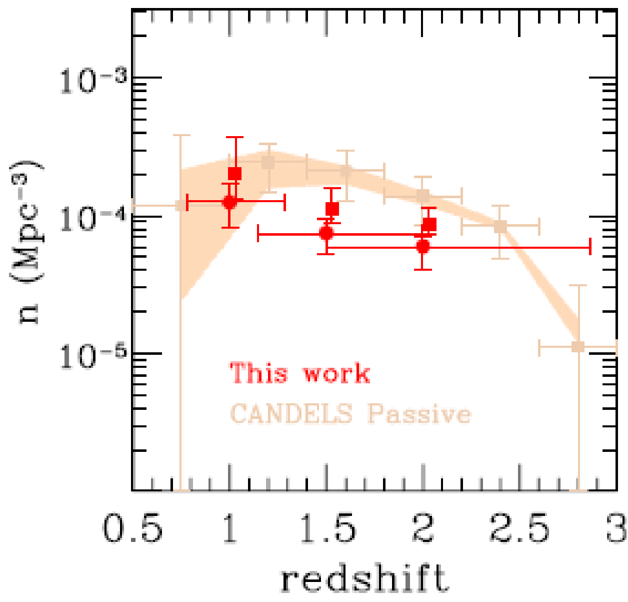
Saracco+10: negligible evolution in ND for early-type galaxies

Carollo+13: no change in ND over $0.2 < z < 1$ for passive early-types for $M < 10^{11}$, 30% decrease at higher masses

HOW MANY OF THE DISTANT COMPACTS HAVE REMAINED COMPACT UNTIL TODAY?

number density of compact galaxies

PM2GC vs CANDELS at z=1-3: upper limit factor ~2 to evolution of the number density -- at most half of the high-z compact galaxies have evolved in size. Evolution may be stronger (upper limits 2 to 5) for ultracompact galaxies (≥0.4 dex below local mass-size relation, 20% of high-z population)



Poggianti et al. 2013b

2. IMPORTANCE OF SELECTION EFFECTS

WINGS -- Valentinuzzi et al. 2010a,b

As time goes by, **more and more galaxies are added to the passive population** – Those that are added later have on average **larger sizes** than those that were already old/early

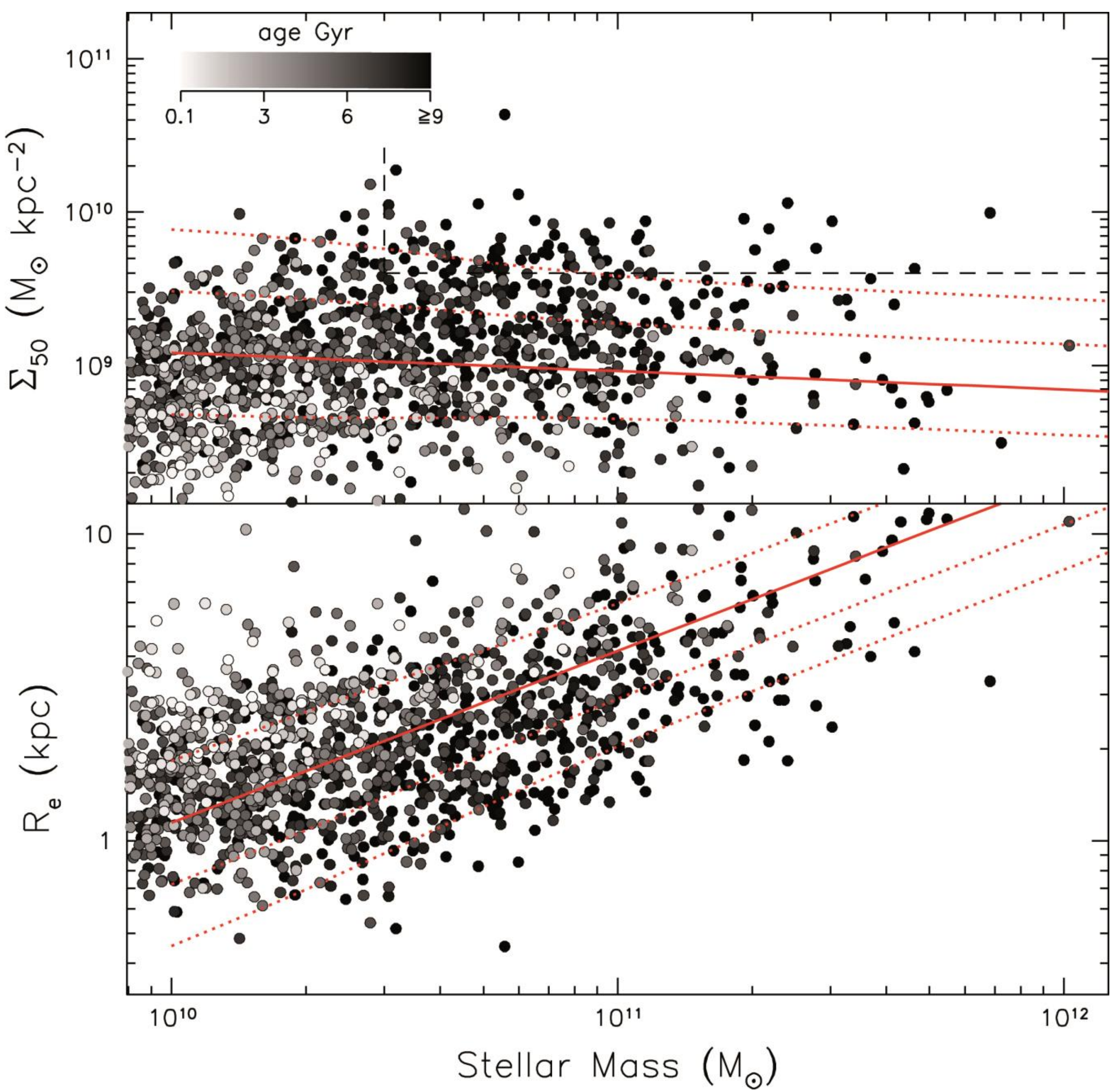
At a given mass, galaxy sizes depend on stellar population ages: **galaxies that stopped forming stars sooner are smaller** (also Saracco+ 2009, van der Wel 2009, Cappellari+2012 + others)

Selecting galaxies to be old results in selecting the most compact ones.

Ages

Combined effect of mass and size in determining the luminosity-weighted age.

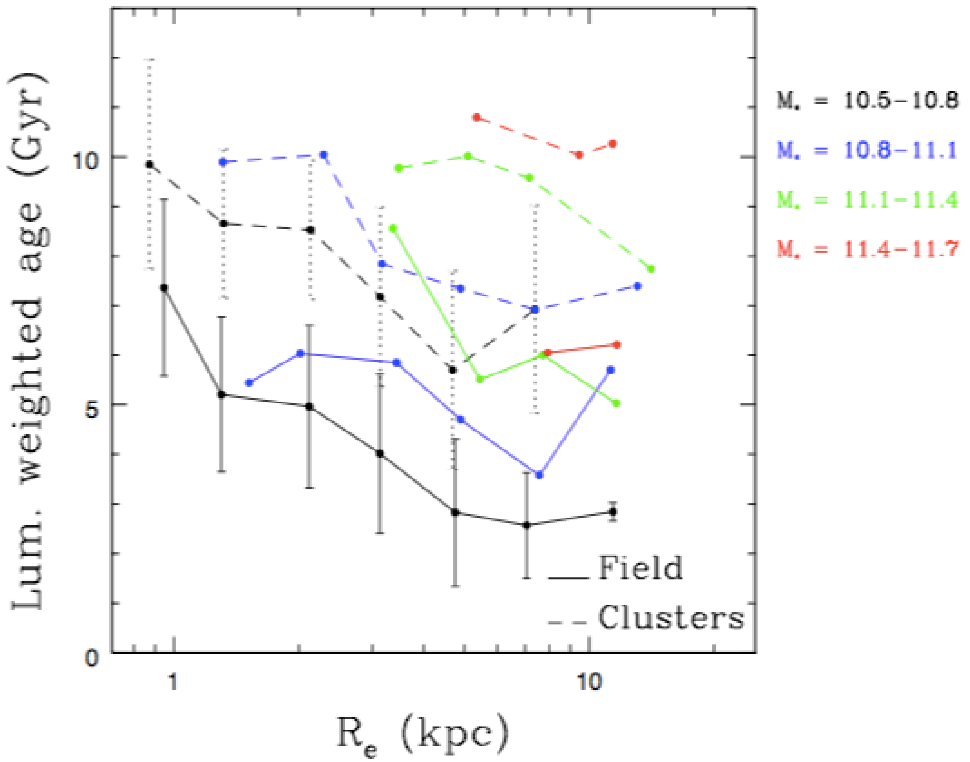
Selecting galaxies to be old at a certain redshift results in selecting the most compact ones.



Valentinuzzi et al. 2010

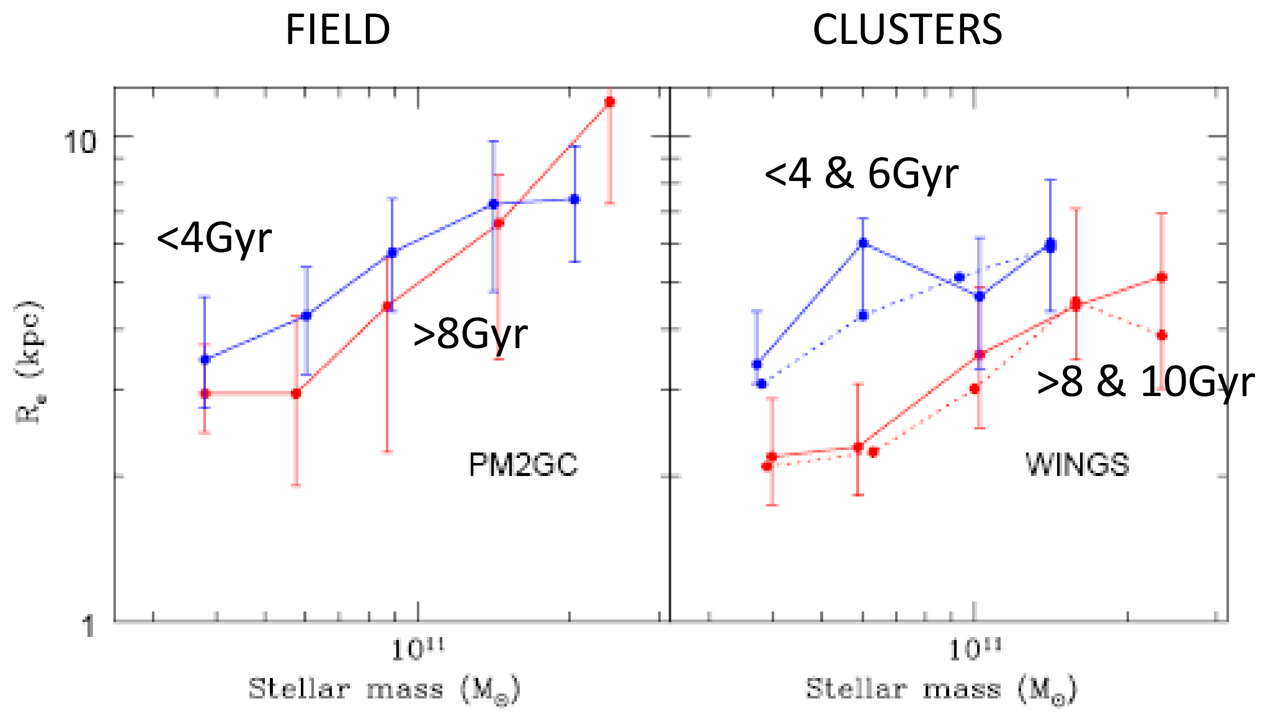
STELLAR AGES AS A FUNCTION OF GALAXY SIZE, GALAXY MASS AND ENVIRONMENT

1. At given size, more massive galaxies are older
2. At given mass, smaller galaxies are older
3. At given mass and size, cluster galaxies are older than field



Poggianti+ 2013a

MASS-SIZE RELATION AS A FUNCTION OF LUMINOSITY-WEIGHTED AGE



Older LW age galaxies are smaller

Effect stronger in clusters than in the field

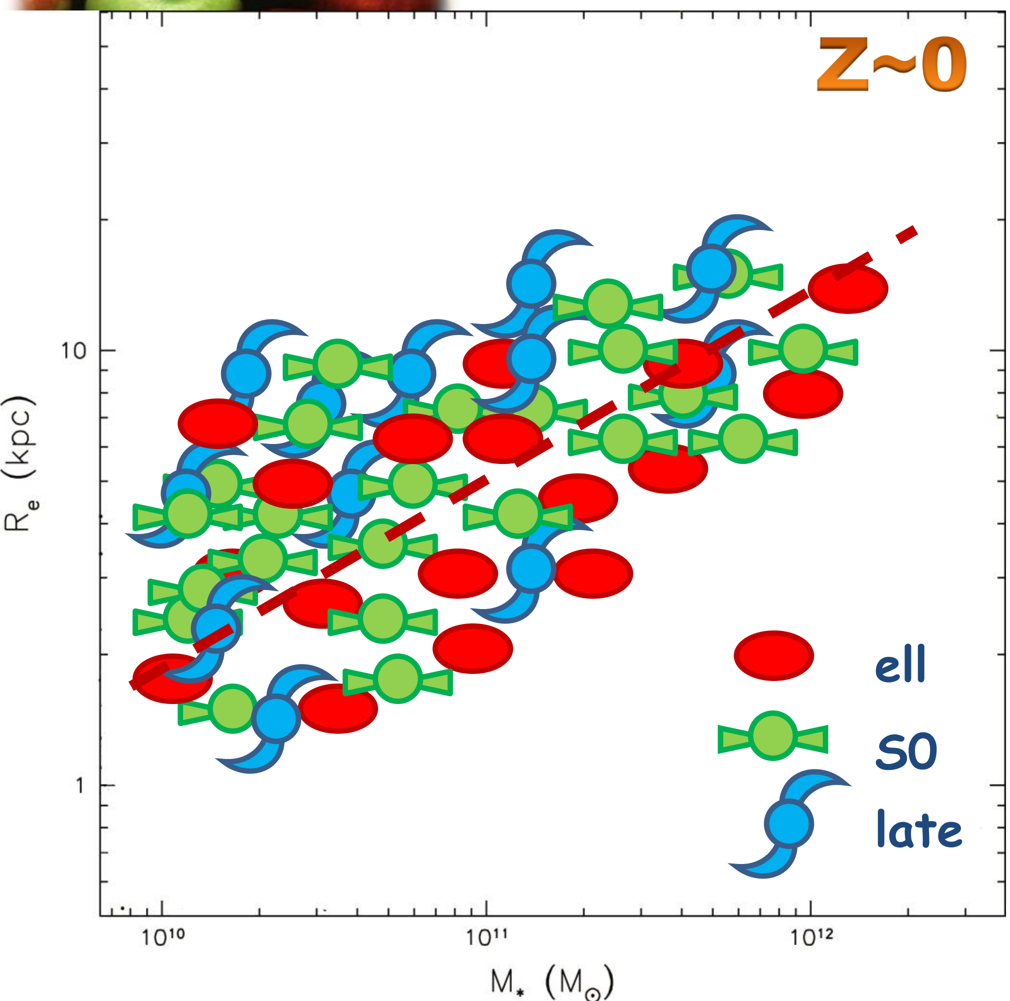
Most works find same effect (van der Wel et al. 2009, Saracco et al. 2009, Williams et al. 2010, Cappellari et al. 2012, now also McDermid+ 2015 – but see Trujillo et al. 2011)

Galaxy LW ages depend on galaxy stellar mass, galaxy size and environment.

Poggianti et al. 2013a

MATCHING HIGH-Z and LOW-Z POPULATIONS

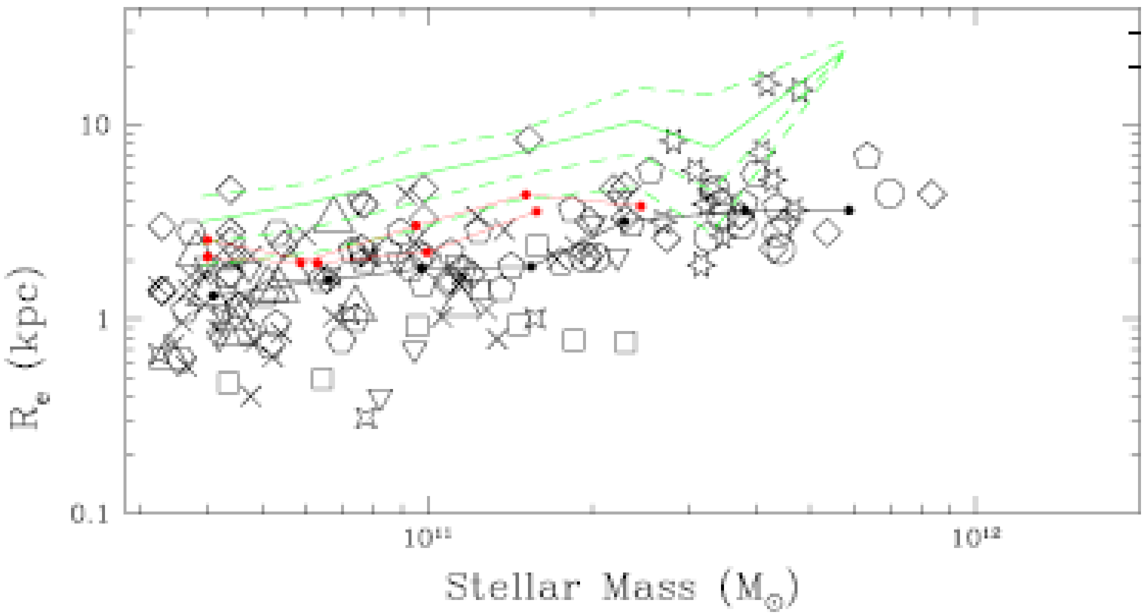
How to identify local descendants? – every method is imperfect (passivity,morphology, number density…)



use as local comparison ONLY those galaxies whose <u>lum.wei. age</u> is so old that they already looked passive at high-z

See also Cassata+2013, Carollo+ 2013, Belli+ 2014

THE AMOUNT OF SIZE EVOLUTION



Half of the observed evolution of the median mass-size relation is due to progenitor bias:

Considering only galaxies with OLD LW ages at low-z average evolution is a factor 1.6 (instead of 3.1)

MILD EVOLUTION IN SIZE OF INDIVIDUAL GALAXIES

Poggianti et al. 2013a

3. WHERE ARE THE DESCENDANTS OF HIGH-Z COMPACT MASSIVE GALAXIES TODAY (IN WHAT ENVIRONMENT)?

Millennium Simulation + semianalytic model (De Lucia & Blaizot 2007):

60% of all galaxies that at z=2 are massive (>10^{11}) *and* passive end up in clusters above 10^{14} Msun by z=0 [40% if only massive]

Studying massive galaxies at high-z means to a large extent studying the progenitors of today's cluster galaxies

40% of all galaxies that at z=2 are massive (>10^11) *and* passive are **BCGs** of clusters above 10^14 Msun by z=0

For cluster BCGs, large evolution in both size and mass required comparing WINGS with EDisCS at z=0.4-0.8: a factor of 2 in mass and 4 in size (Valentinuzzi+ 2010b)

Poggianti et al. 2013a

4. PASSIVE MASS EVOLUTION

Evolution of the stellar mass of a generation of stars born at age=0 evolving passively

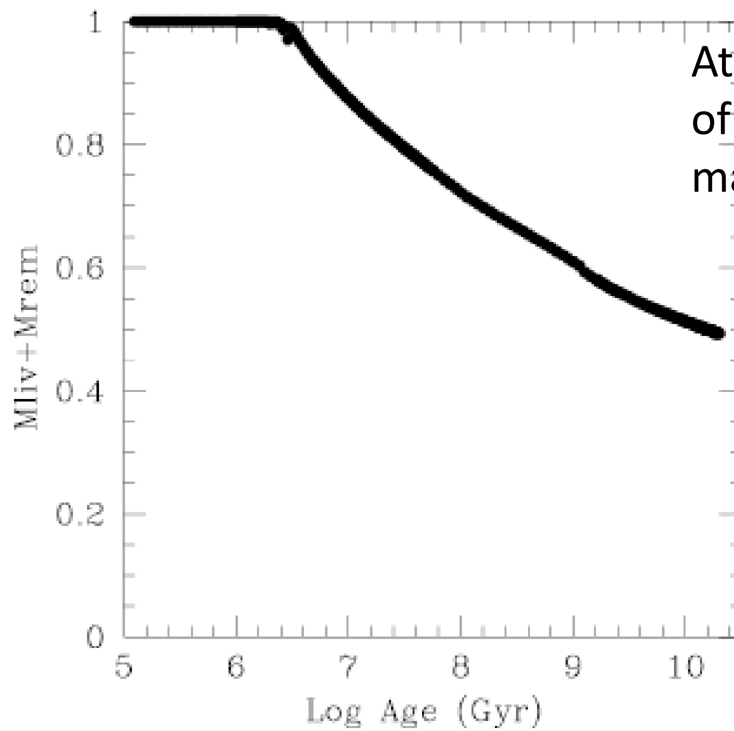
Fraction of age=0 stellar mass (Mstars_alive+remnants) as a function of age.

A galaxy forming most stars at z=2.5, between z=2-2.2 and low-z will have lost 19-23% of its z=2-2.2 mass.

Already at z=1, 13-17% of its 2-2.2 mass.

This effect could be much larger for galaxies that stopped forming stars just before being observed as passive at high-z. Could this be the reason for the apparent strong evolution occurring between z=2 and z=1?

Poggianti+ 2013b



At z=0 50% of initial mass

Mass today 80% of high-z observed mass (assuming SF stopped 0.6Gyr before high-z observations)

Passive evolution in mass should be taken into account when comparing high-z and low-z sample

THERE ARE COMPACT MASSIVE GALAXIES AT LOW REDSHIFT (but not the most extreme ones….)

OUR RESULTS SUGGEST EVOLUTION OF SIZES OF INDIVIDUAL GALAXIES IS MILD (in the mass range 3X10^10-4X10^11)

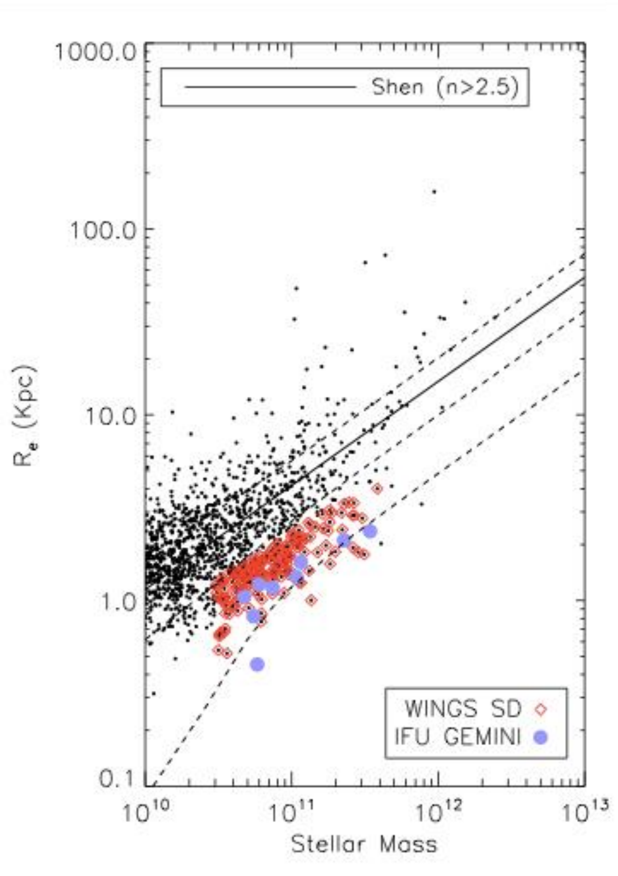
EXCEPT FOR TODAY' S BCGs, which do evolve strongly

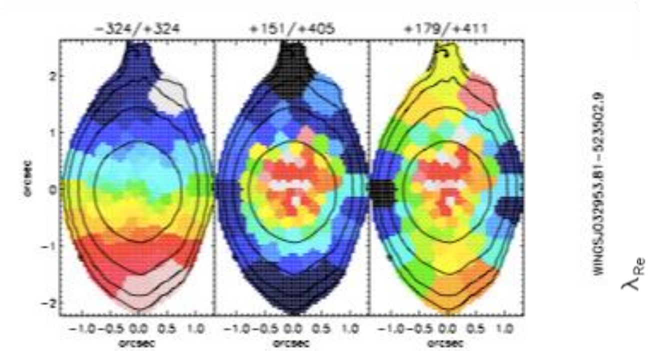
COMPARING WITH CANDELS, ALSO NUMBER DENSITY EVOLUTION IS MILD: ≥ 50% of high-z compact galaxies have remained compact until today

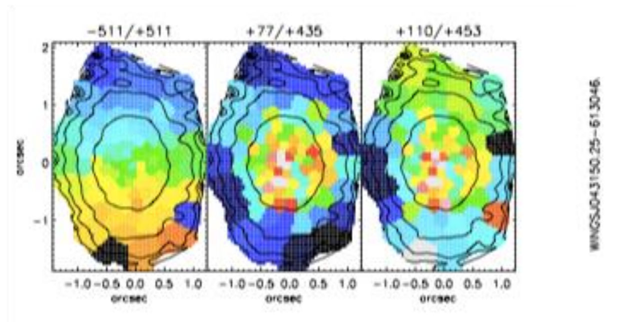
ENVIRONMENTAL DEPENDENCE: COMPACT GALAXIES MORE FREQUENT IN CLUSTERS THAN IN FIELD AT LOW-Z

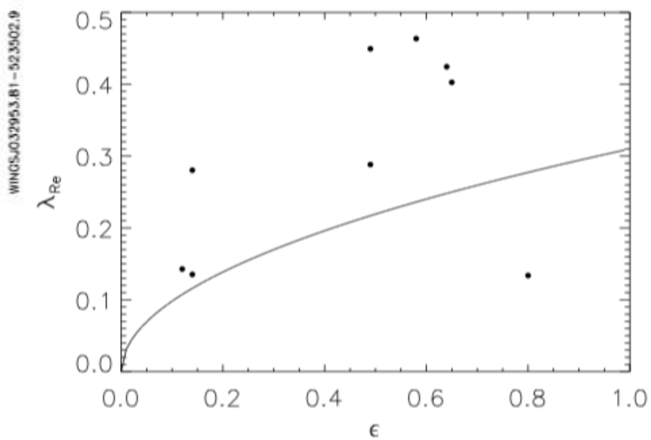
MASSIVE COMPACT "RELICS" ARE NOW BEGINNING TO BE STUDIED IN DETAIL…..

LOW REDSHIFT RELICS:
IFU OF 18 WINGS SUPERDENSE GALAXIES WITH GMOS/GEMINI AND VIMOS/VLT







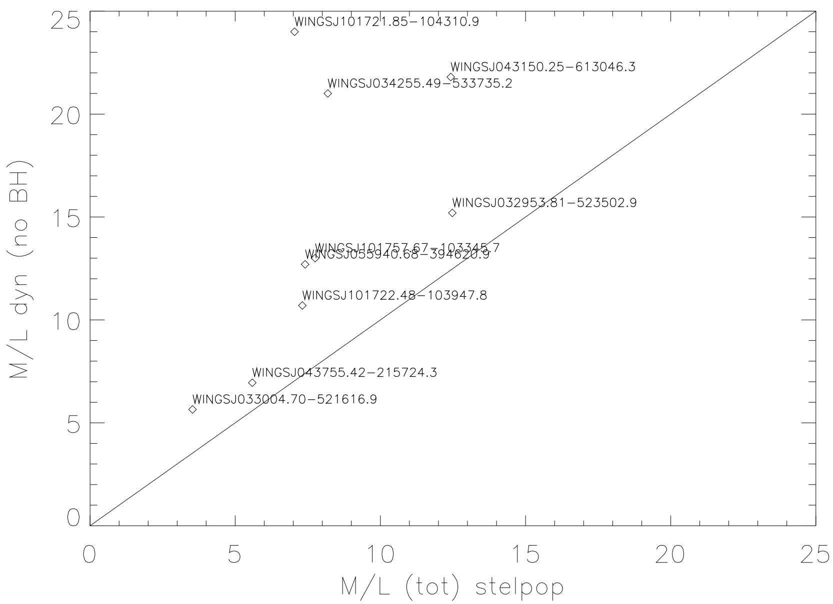


8 fast rotators, 1 slow rotator

Moretti+ in prep.

LOW REDSHIFT RELICS:
IFU OF 18 WINGS SUPERDENSE GALAXIES WITH GMOS/GEMINI AND VIMOS/VLT

M/L dyn



M/L stell pop

Dynamical mass confirms previous stellar mass estimate, and finds very high M/L ratios for the three oldest galaxies (BH, IMF or DM?)

Old stellar ages confirmed – now spatial analysis

Moretti+ in prep.

Stellar kinematics with PPXF algorithm (Cappellari&Emsellem 2004)
Dynamical masses with JAM modeling (Cappellari+ 2008)

OPEN QUESTIONS FOR DISCUSSION

1. SELECTION EFFECTS

What is the best way to take selection effects into account? What amount of size evolution is left after removing such effects?

2. BCGs vs THE REST

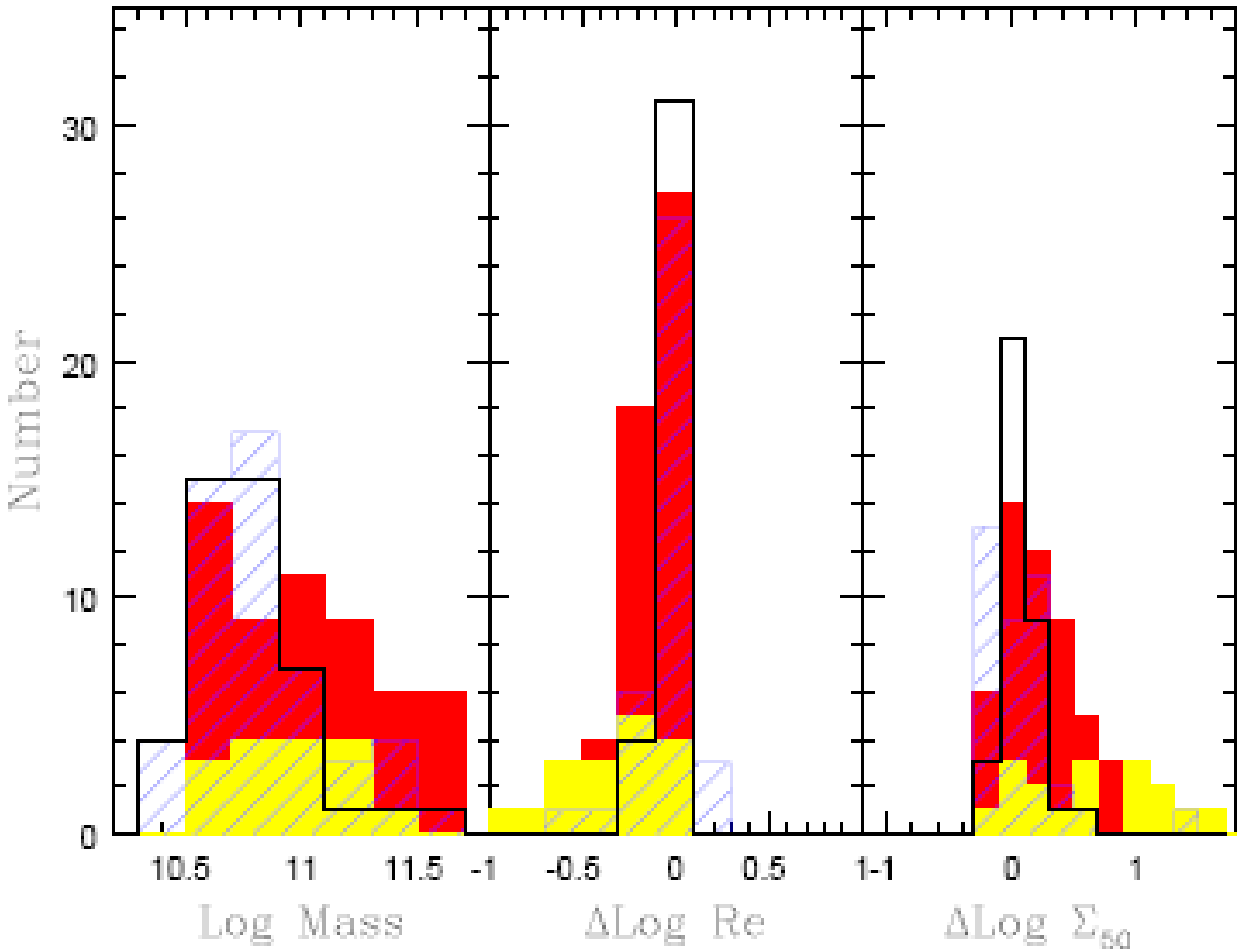
Do BCGs follow a markedly different evolution in size from other galaxies, therefore do they need to be considered separately?

3. ENVIRONMENTAL DESTINY

If it is true that most high-z massive compact galaxies end up in clusters today, how does that change our picture of galaxy size evolution in general?

4. PASSIVE MASS EVOLUTION

Do we need to take passive mass evolution into account? What effects does it have on our interpretation of high-z observations?



Number
30
20
10
0
10.5
11
11.5
-1
-0.5
0
0.5
1-1
0
1
Log Mass
ΔLog Re
ΔLog Σ50