Following the growth of early type galaxies since *z*=1

1) Early Type Galaxies (ETGs)

2) Evolution in number density

3) Estimating number of mergers from pair counts

4) New alternative to estimate number of mergers

5) Effect on the sizes of ETGs.

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From high redshift populations to Low redshift populations

Selection of high-z galaxies:

Lyman Break Galaxies: LBGs

Extremely Red Objects: EROs

Lyman alpha emitters: LAEs

DRGs, SMGs, LRGs, BzKs, …

} Different types…

Selection of low-z galaxies:

Volume and flux limited catalogs

} How to relate them to TLAs?

1) Early Type Galaxies (ETGs)

Why Early types?

Little or no star-formation activity leads to simple evolution recipes: aging alone (Stellar masses from passively evolved luminosities).

As hierarchical clustering progresses mergers may be expected. If gas free, larger ETGs (but it may be difficult to infer the number of mergers in a statistical way).

Selection: via red sequence, SED fitting, morphologies (difficult even at intermediate redshifts).

Mass selection: descendant samples at different redshifts?

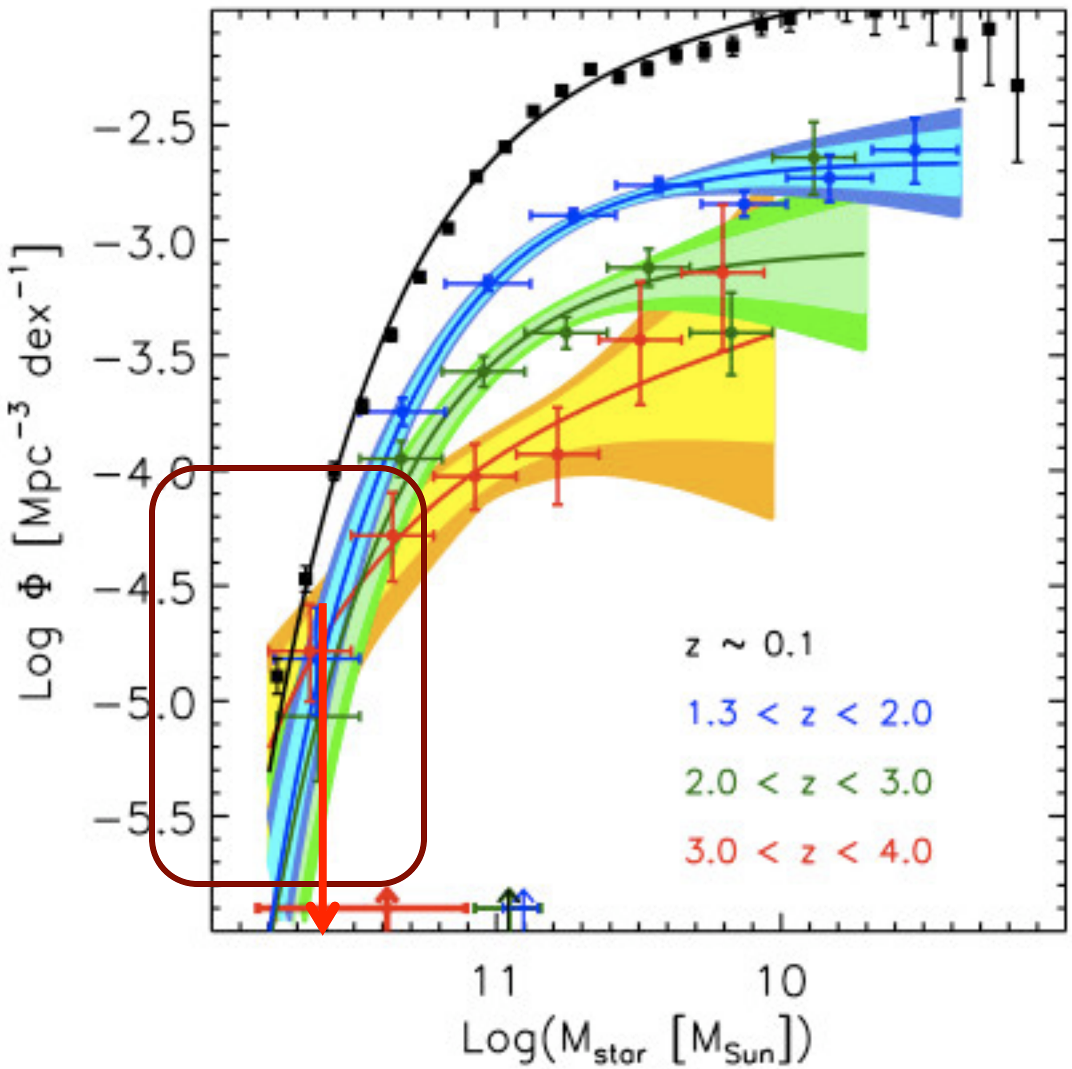
Valid if there is no mass increase.

2) Evolution in the number density of Early Type Galaxies (ETGs)

How can we follow their evolution?

St. Mass Selection: Mass Functions

the number density of massive ETGs seemed to be fixed since very high redshifts, z~2-3 (Marchesini et al., 2009)

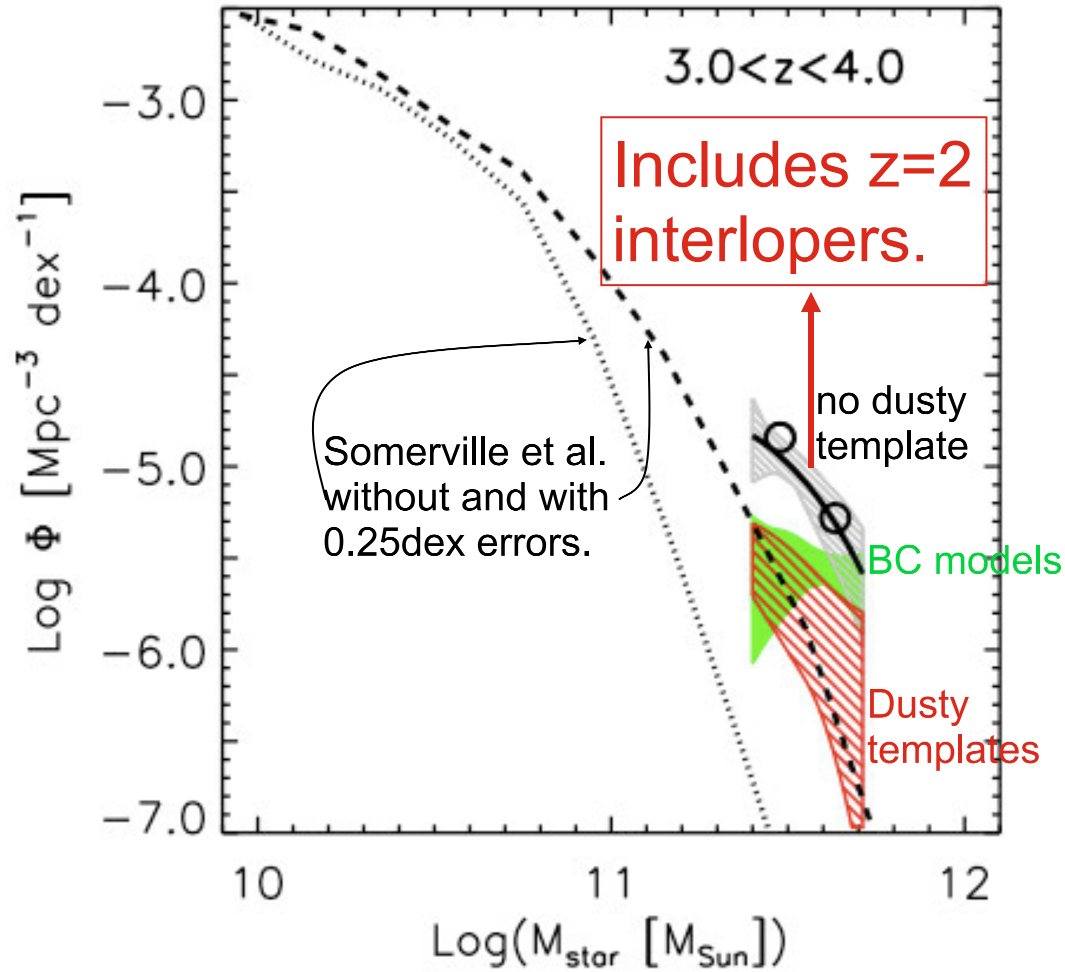


Marchesini et al. (2009)

2) Evolution in the number density of Early Type Galaxies (ETGs)

However,
when using mid-IR photometry and dusty templates for mass-selected elliptical galaxies, some evolution of the ETG number density is found.

By including a 0.25dex error in stellar masses, there is agreement with models.
(to the degree the uncertainties allow)

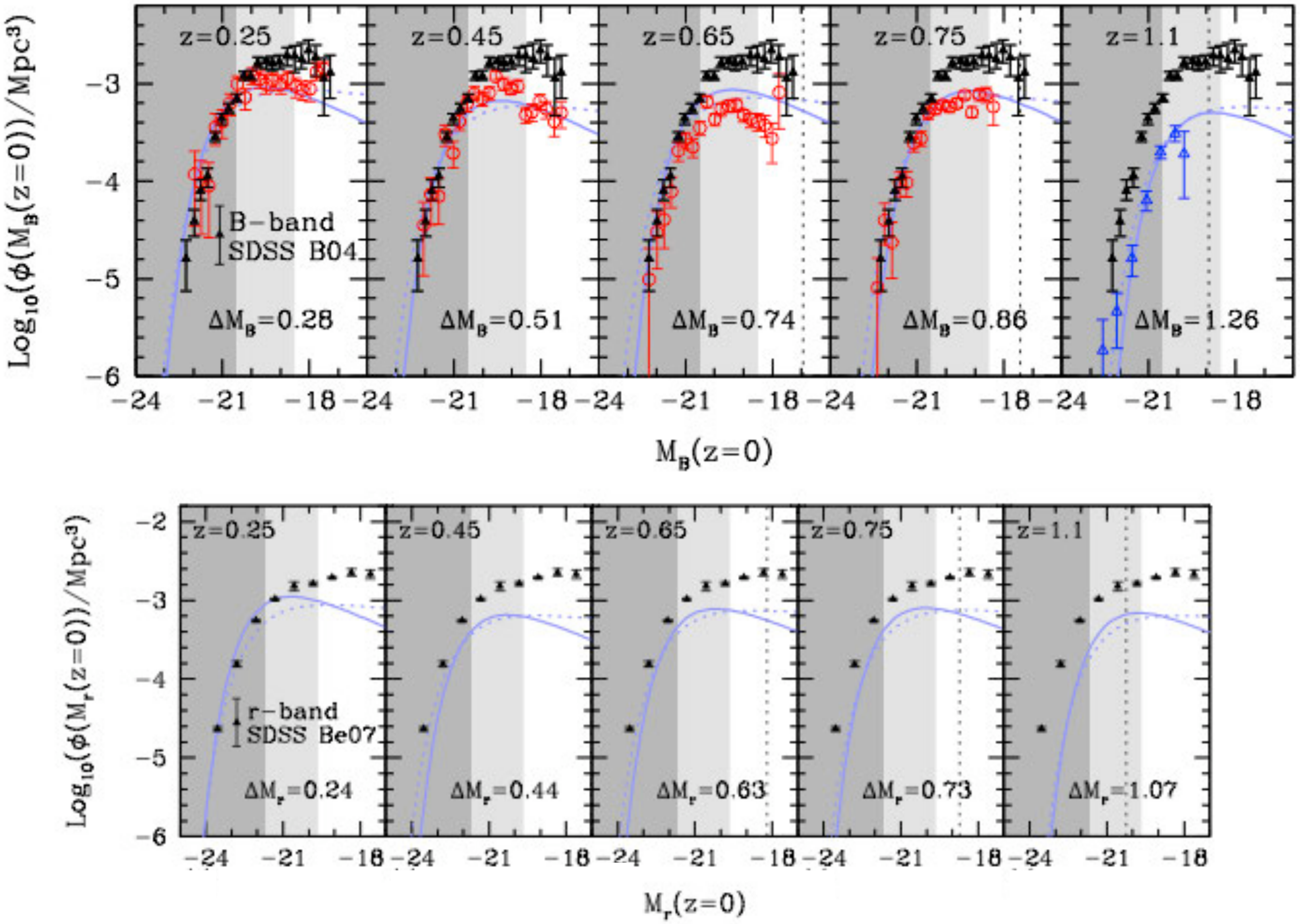


NEWFIRM Medium Band Survey
Marchesini et al. (2010)

Ok with models at high-z (Guo et al. 2011)

SDSS DEEP2 Combo17

MUSYC ECDF-S (Christlein et al., 2009, MNRAS, 400, 429)



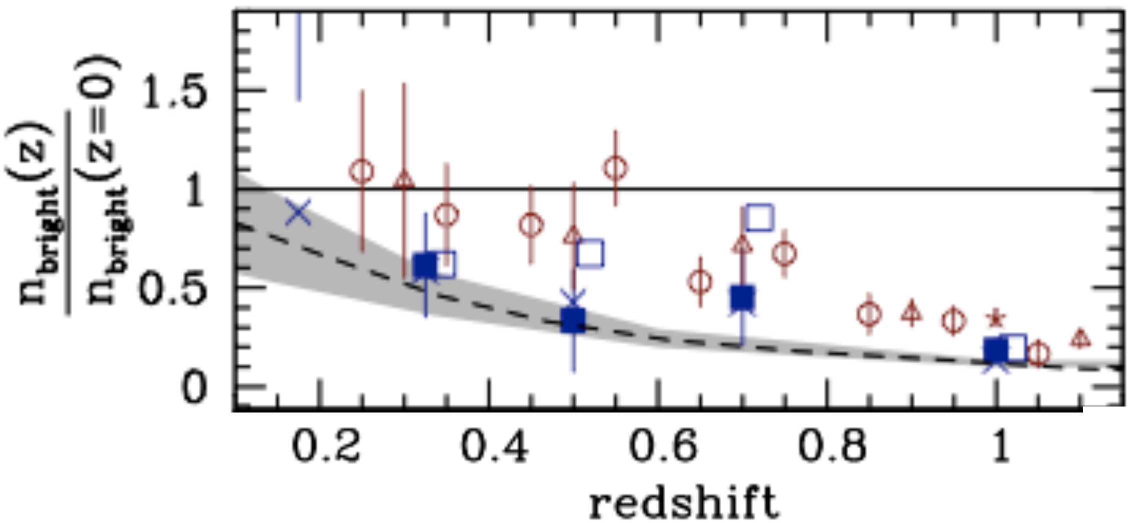
M_B and M_r are passively evolved luminosities -> stellar mass

2) Evolution in the number density of Early Type Galaxies (ETGs)

Ratios between number density of bright galaxies to the z=0 values, for >1e10Msun ETGs

Dashed lines: expected evolution in ΛCDM (De Lucia et al., 2006) shown as an example of evolution in a SAM.

COMBO17 SXDF DEEP2 MUSYC

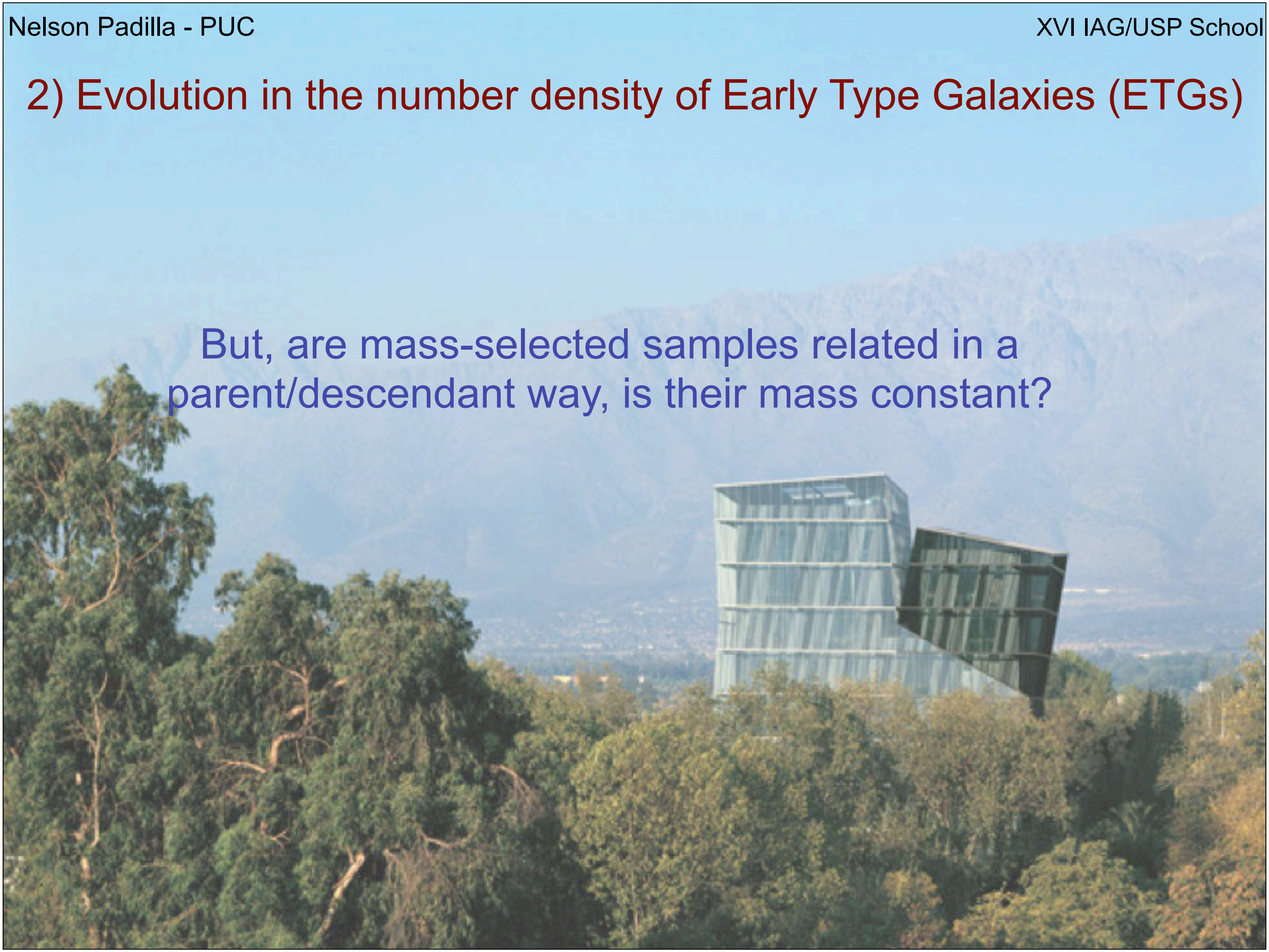


Ratio shows some evolution, also consistent with SAM models.

Padilla et al., 2011, A&A, 531, 142.

2) Evolution in the number density of Early Type Galaxies (ETGs)

But, are mass-selected samples related in a parent/descendant way, is their mass constant?



3) Estimating mergers from pair counts

Pairs can be

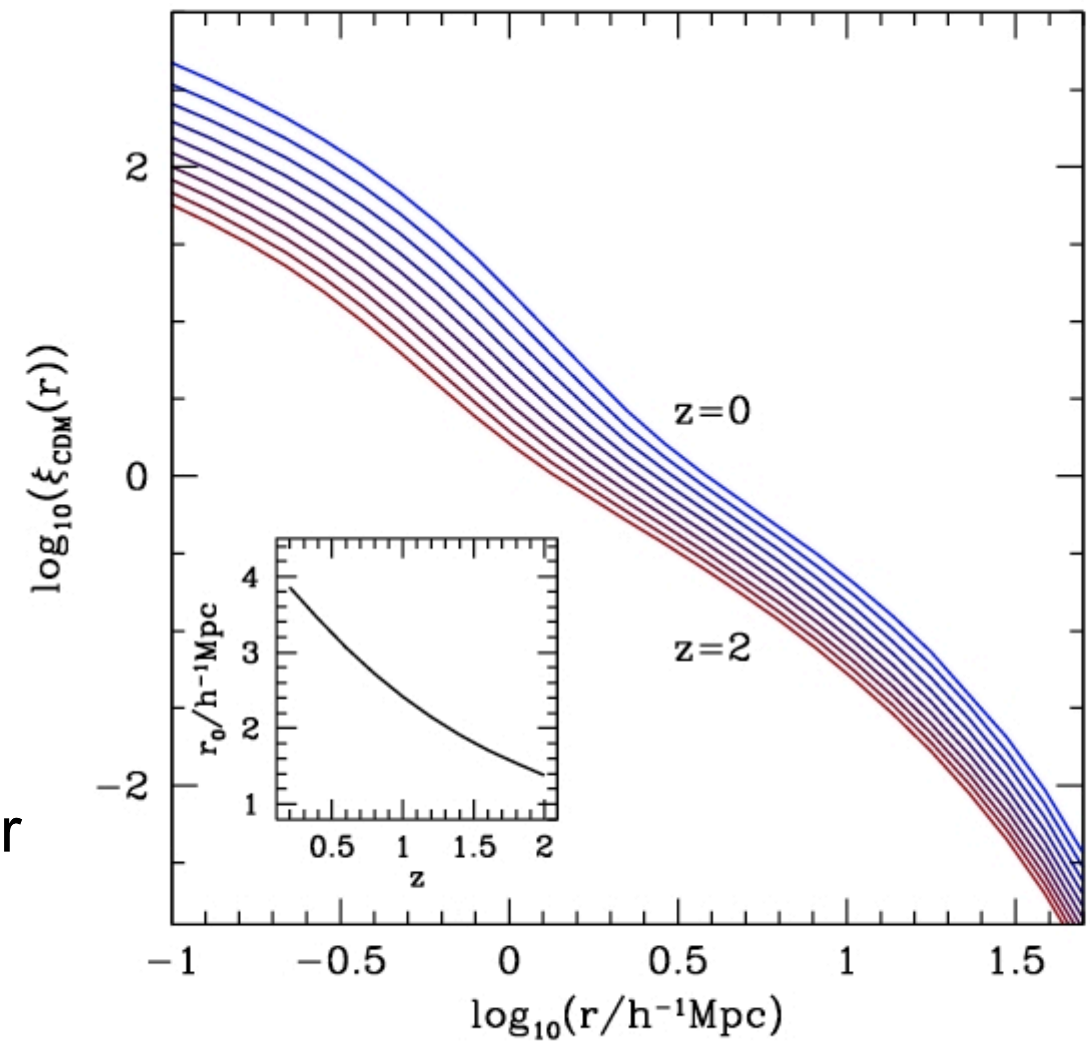
2.a) estimated from correlation functions
2.b) counted

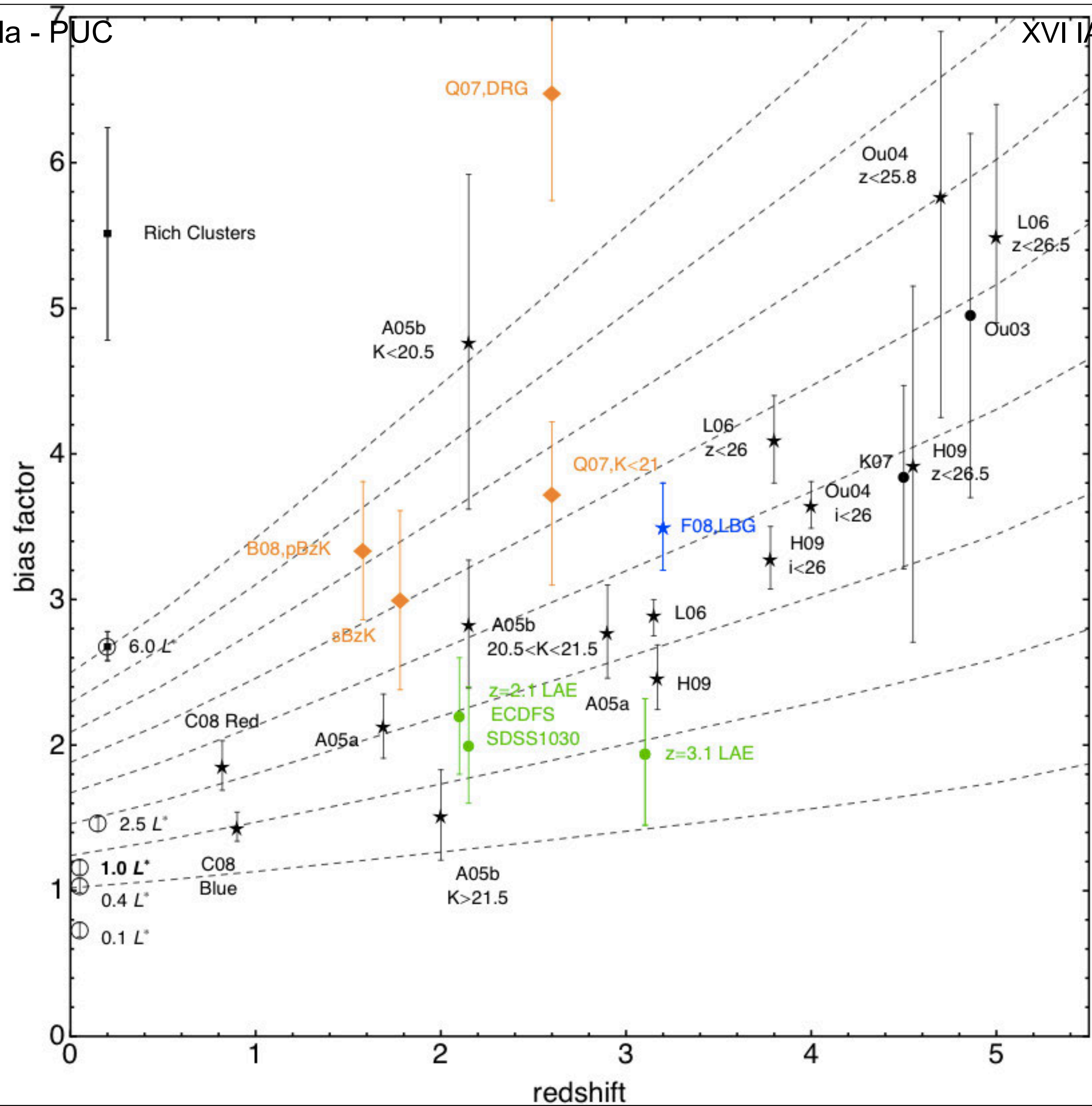
3a) Estimating mergers from pair counts

$\xi(r)=(r/r_0)^\gamma$

$\xi_M(r) = b(M)\, \xi_{\delta(x)}(r)$

Important:
amplitude of correlation function gives Dark-Matter mass of typical host.





bias factor
redshift
Rich Clusters
Q07,DRG
Ou04
z<25.8
L06
z<26.5
Ou03
A05b
K<20.5
L06
z<26
K07
H09
z<26.5
Ou04
i<26
Q07,K<21
F08,LBG
H09
i<26
B08,pBzK
sBzK
L06
A05b
20.5<K<21.5
6.0 L*
H09
z=2.1 LAE
ECDFS
SDSS1030
A05a
C08 Red
A05a
z=3.1 LAE
2.5 L*
1.0 L*
0.4 L*
0.1 L*
C08
Blue
A05b
K>21.5

3a) Estimating mergers from pair counts

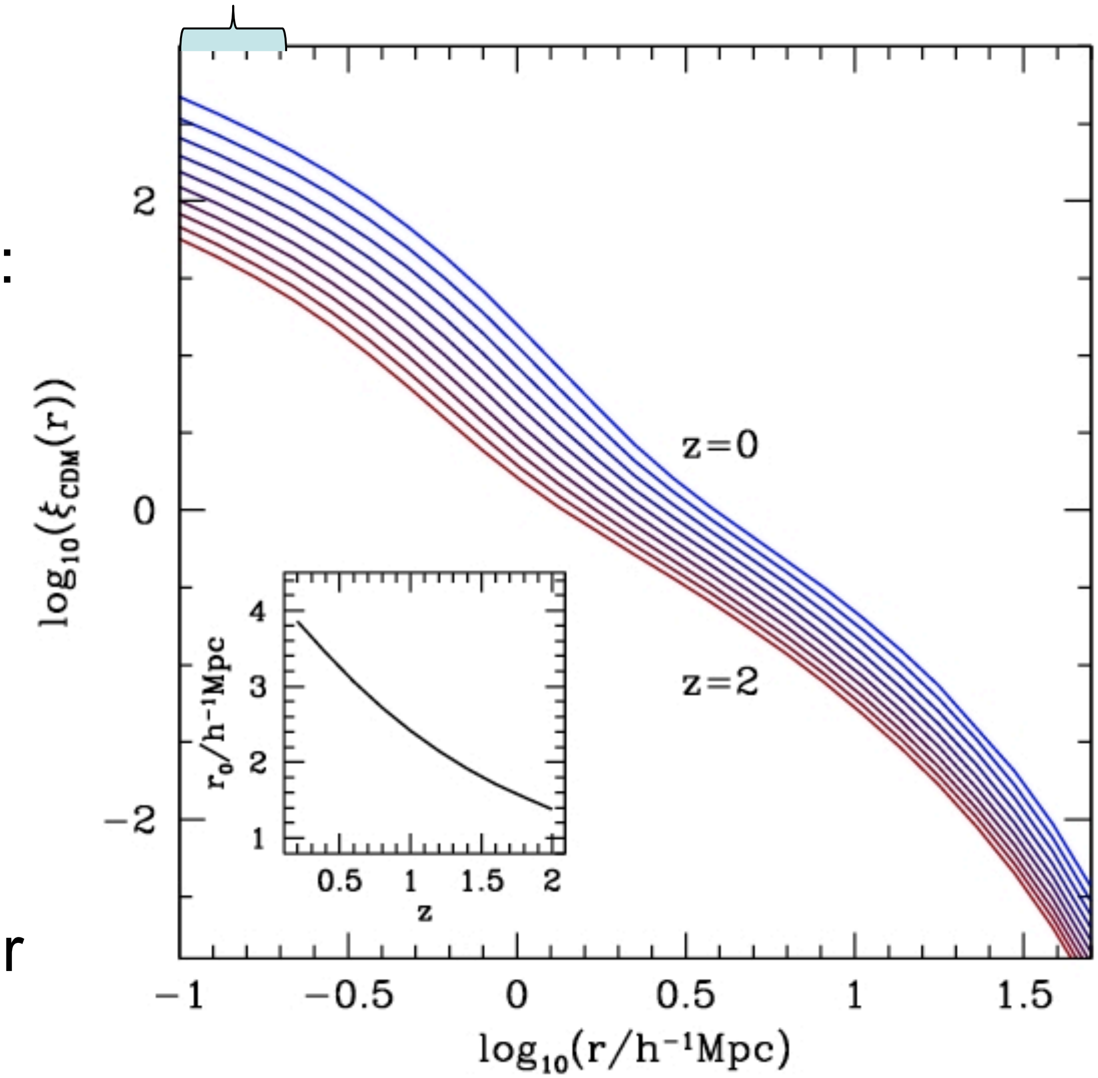
Pairs about to merge?

To obtain merger rates:

$\xi(r)=(r/r_0)^\gamma$

$\xi_M(r) = b(M)\ \xi_{\delta(x)}(r)$

Important:
amplitude of correlation function gives Dark-Matter mass of typical host.

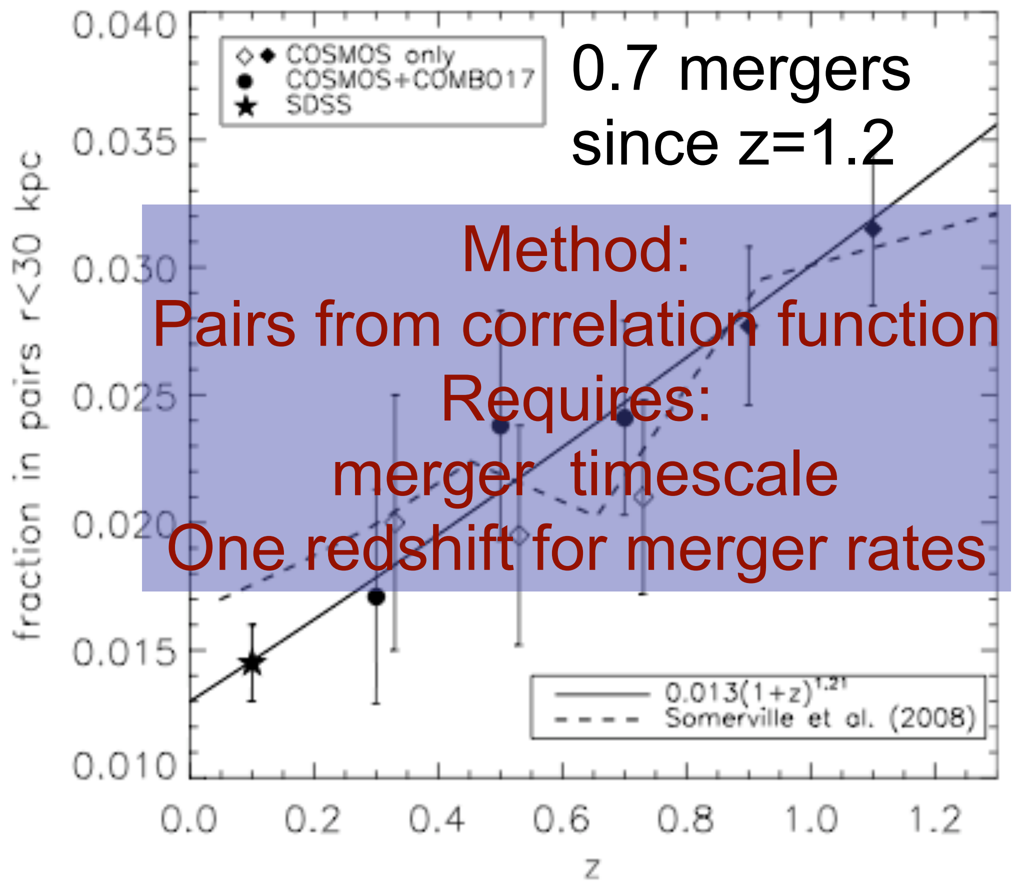


3a) Estimating mergers from pair counts

Mass selection
plus Correlation
Functions:
Count Pairs

the fraction of galaxies in close groups can be used to infer number of mergers.

Robaina et al. (2010) for mass selected samples (M>5e10Msun) use the fraction of pairs (COSMOS, COMBO-17)



0.7 mergers since z=1.2

Method:
Pairs from correlation function
Requires:
merger timescale
One redshift for merger rates

$$P(r \leqslant r_f) = \int_0^{r_f} n[1+\xi(r)]dV.$$

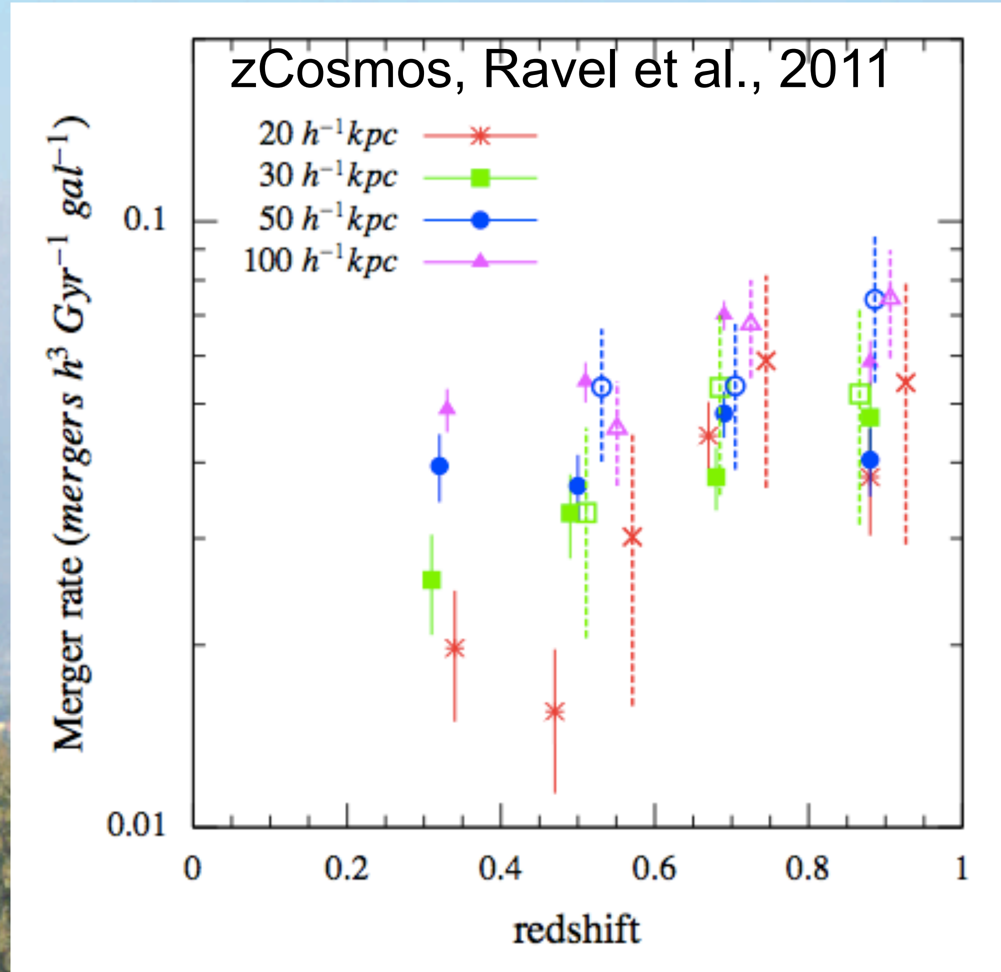
Proving mass-selected samples are not related in a parent/descendant way.

See also Patton et al. 2000; Le Fevre et al. 2000; Lin et al. 2004; Kartaltepe et al. 2007

3b) Estimating mergers from pair counts

Counting pairs in a spectroscopic survey

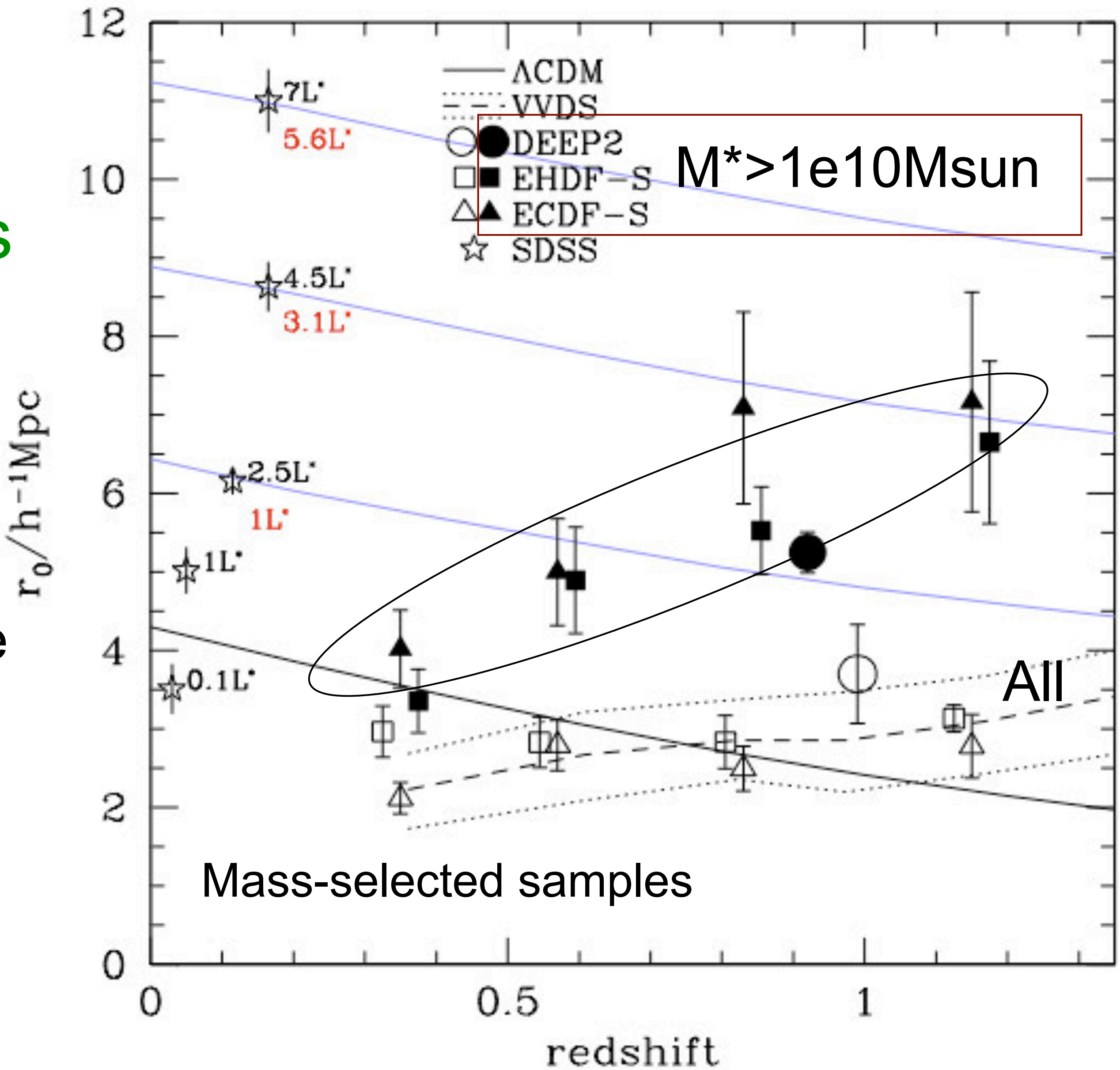
Also using Millennium simulation merger timescales

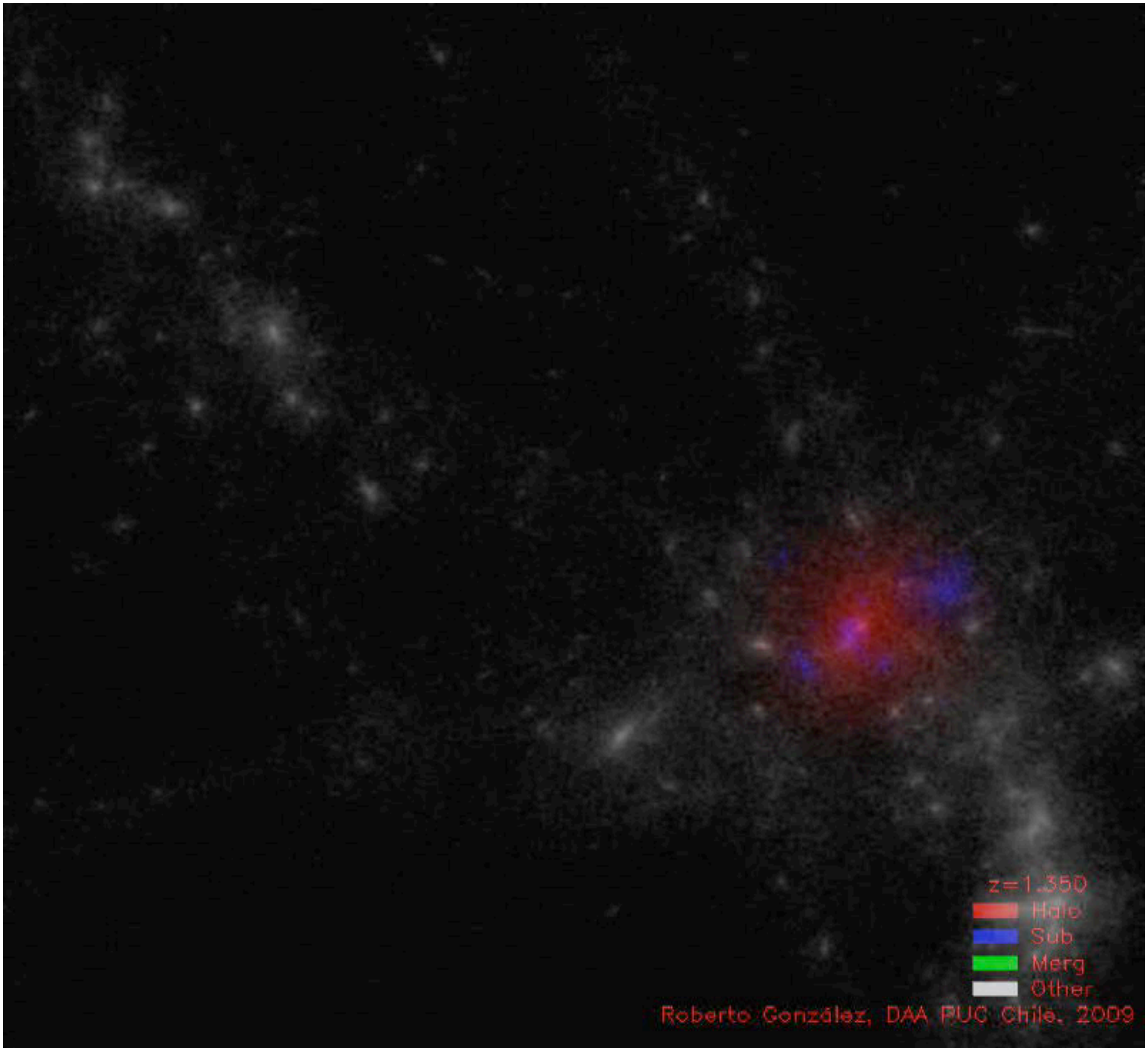


4) New approach to obtain merger rates

combine clustering measurements and space densities

■ and ▲ :
Early-types, same stellar mass
□ and △:
All galaxies brighter than M_r=-21



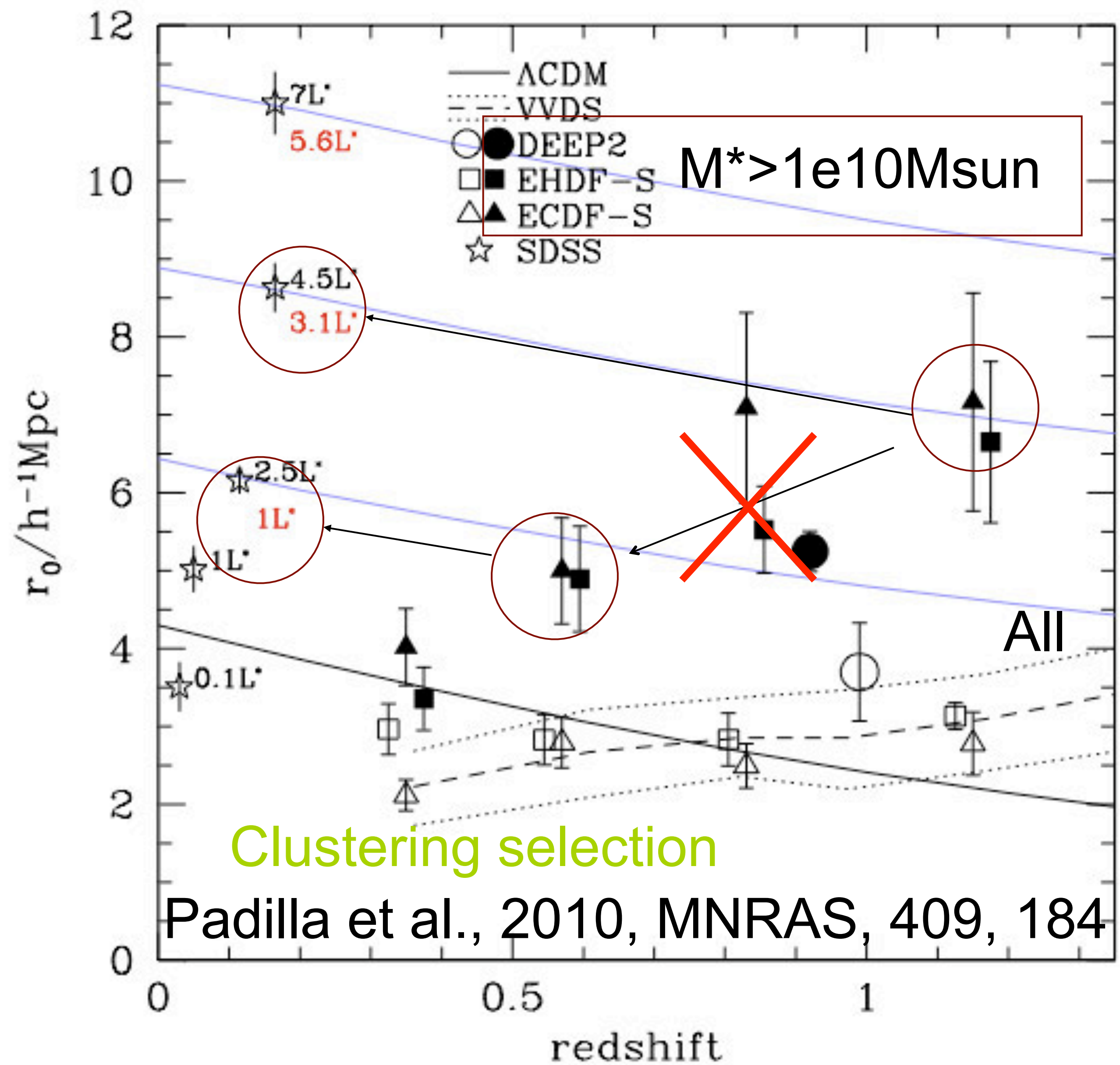

z=1.350
Halo
Sub
Merg
Other
Roberto González, DAA PUC Chile. 2009

4) New approach to obtain merger rates

■ and ▲:
Early-types, same stellar mass

□ and △:
All galaxies brighter than M_r=-21

Blue lines: Haloes followed in a numerical simulation (to help understand evolution). Similar to assu-ming EPS-SMT

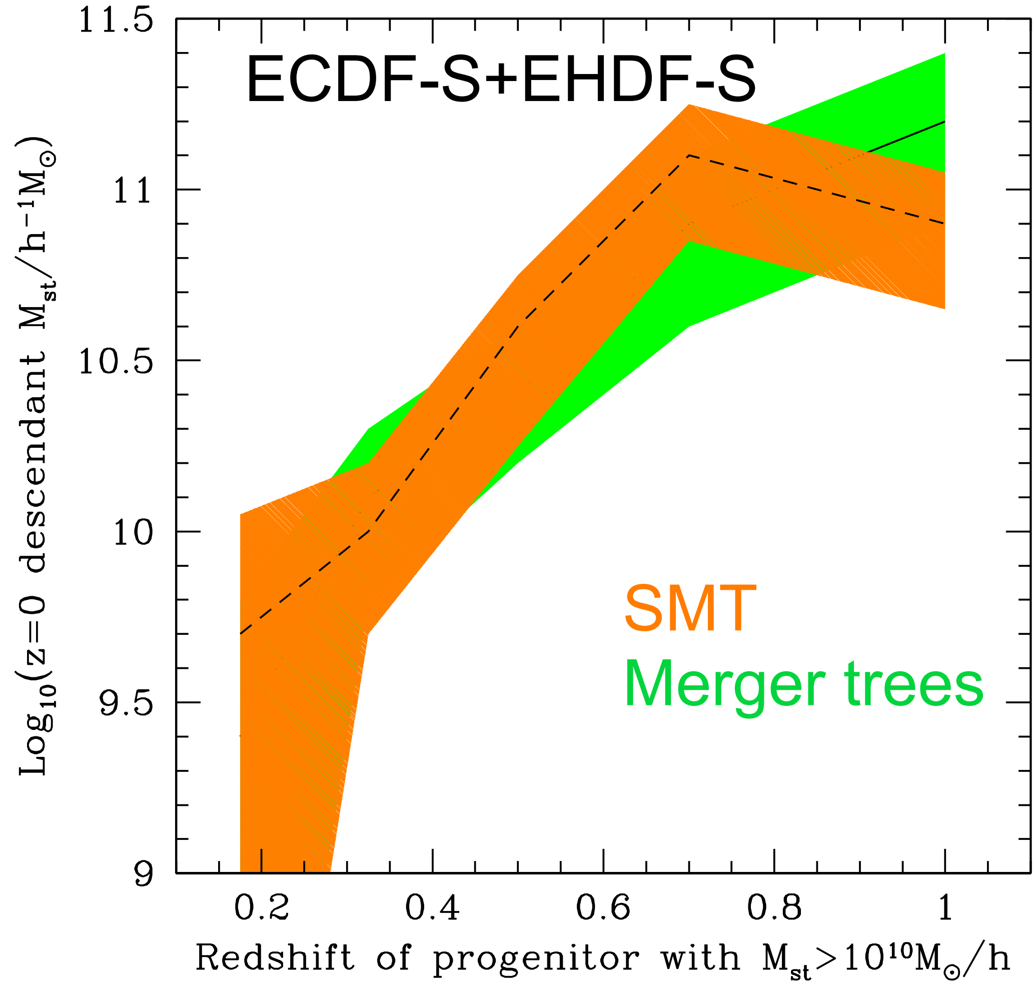


Padilla et al., 2010, MNRAS, 409, 184

4) New approach to obtain merger rates

MUSYC results on clustering-selected Descendant luminosities:

According to clustering measurements,
ETGs of similar stellar mass would evolve
to different final typical stellar masses from diffe-rent redshifts.



Factor x10 increase in mass for sample of >1e10Msun ETGs

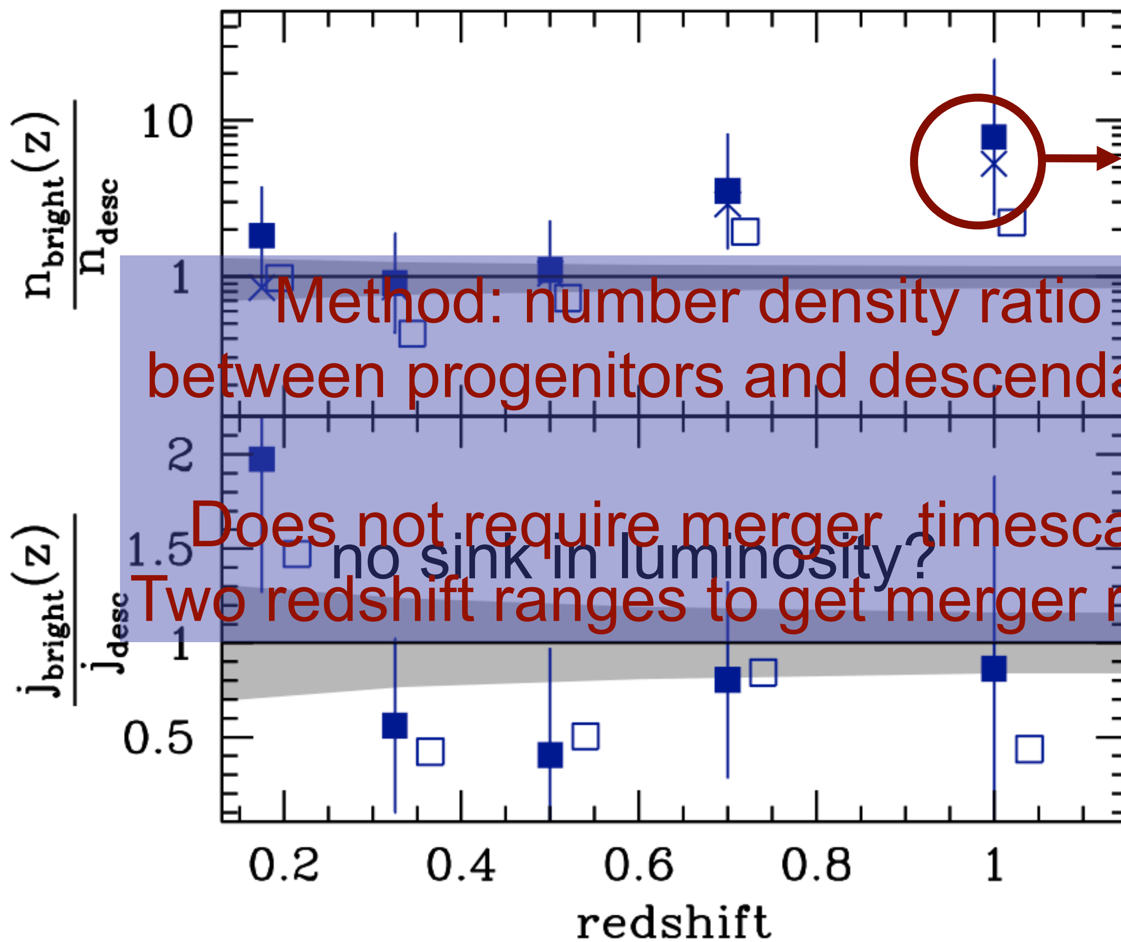
Compare space densities of progenitors and descendants

4) New approach to obtain merger rates: uses 2) but with M*(z)

Combining with MUSYC LF measurements:
ETG merger rates!

Top: Ratio of number density of clustering-selected ETGs at redshift z, to that of their z=0 descendants

Bottom: Ratio of Luminosity density of descendants to redshift z ETGs



Method: number density ratio between progenitors and descendants

Does not require merger timescale

no sink in luminosity?

Two redshift ranges to get merger rates

5.5 +- 4.0 mergers since z=1 seem to be needed. Major or minor?

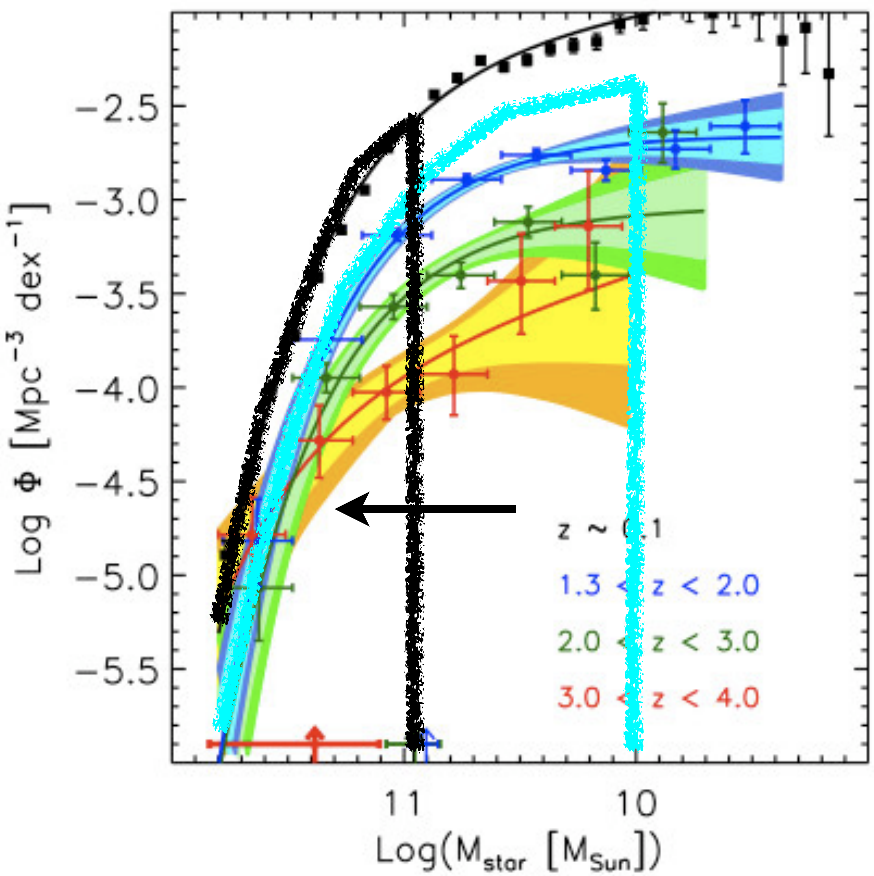
Padilla et al., 2011, A&A, 531, 142

Factor x10 increase in mass for sample of >1e10Msun ETGs

5.5 +- 4.0 mergers since z=1 seem to be needed

Major or minor?

This is an important question, since this can help understand the increase in average mass of the sample (e.g. minor mergers deplete low mass end), and the type of merger influences the size evolution of the ETGs.

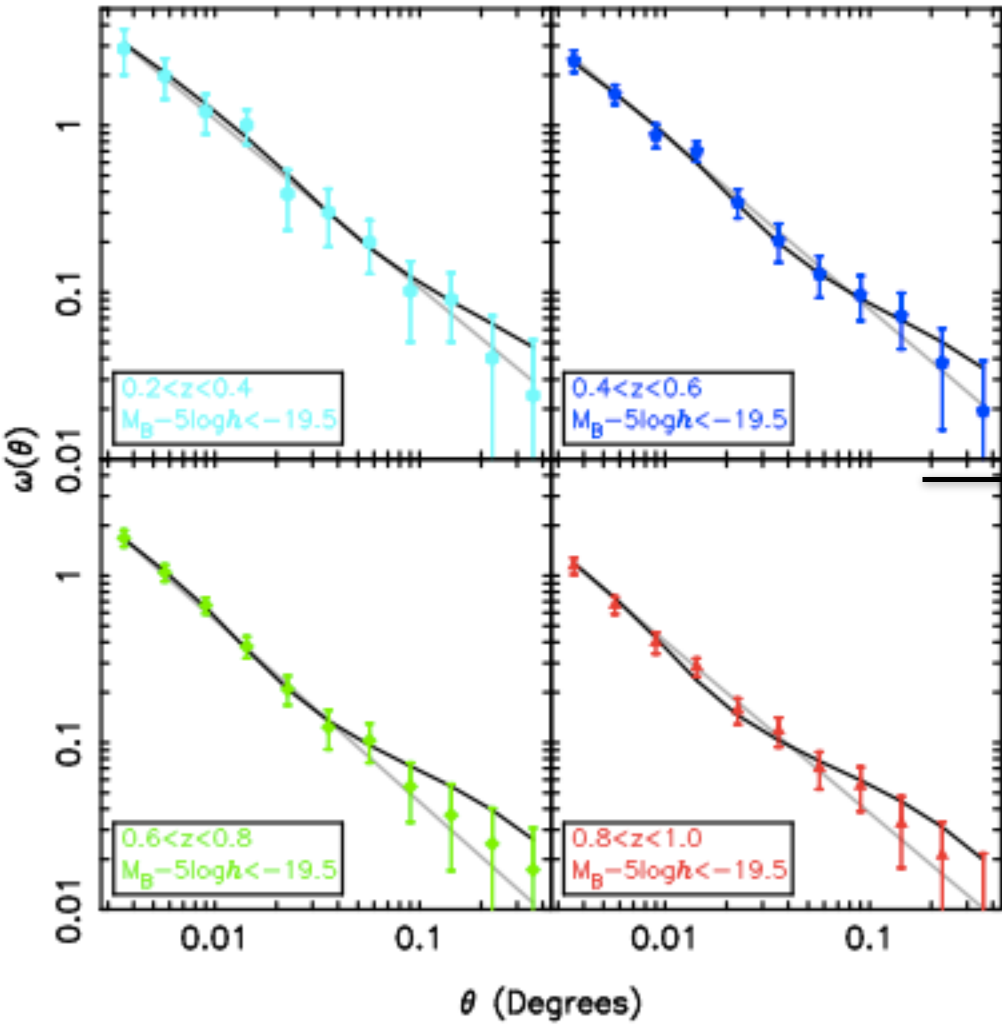


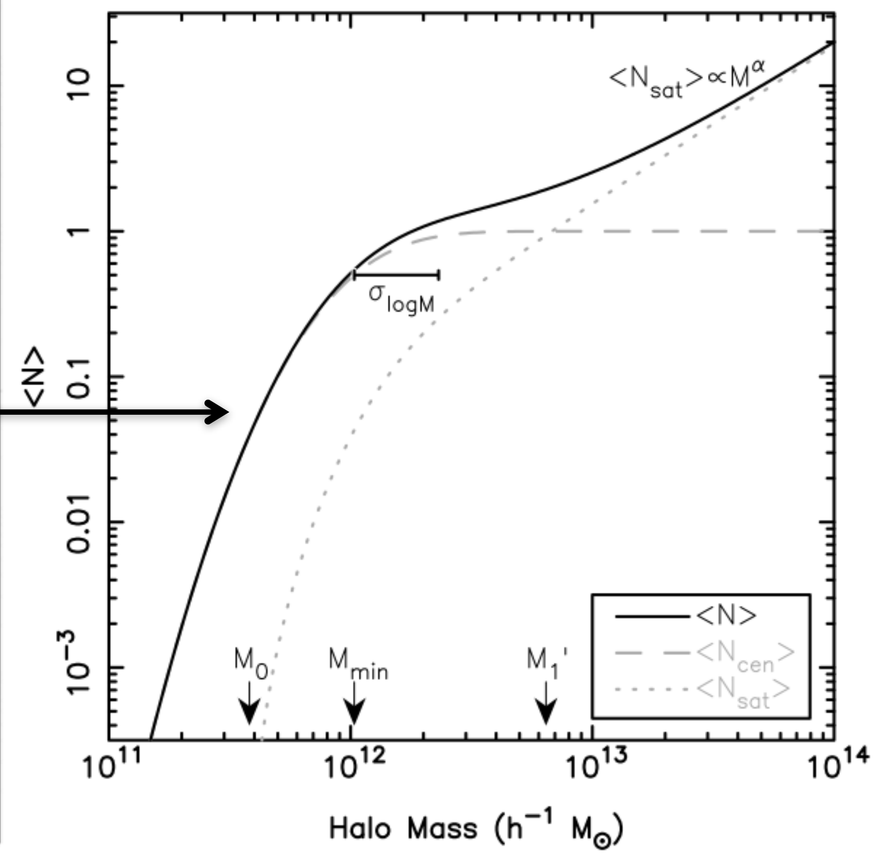
Marchesini et al. (2009)

4) New approach to obtain merger rates

Combining with MUSYC LF measurements with universal HOD from the Boötes Field (from Brown et al, 2008, 2010)

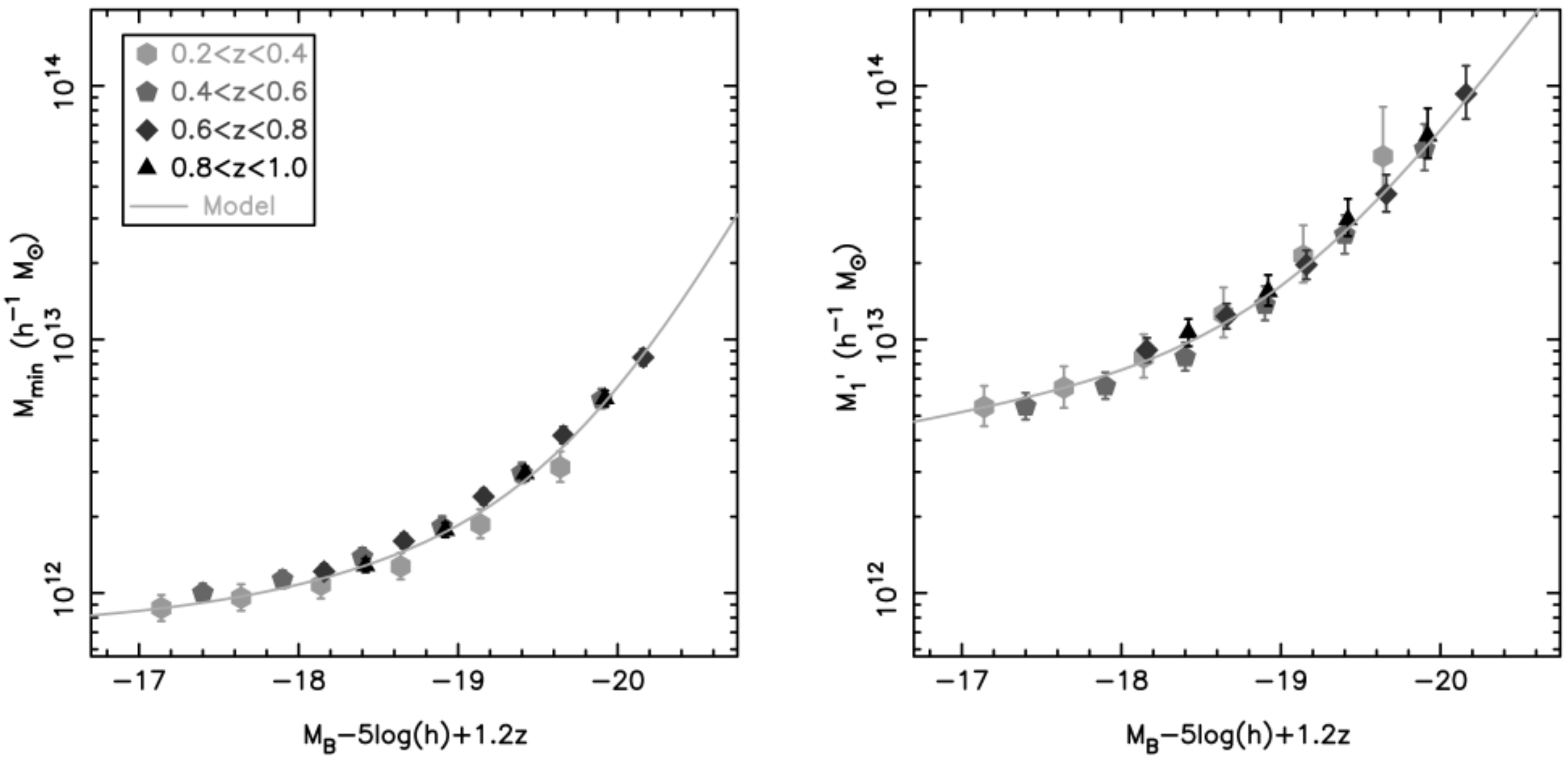
Fits to correlation function assuming occupation distribution:





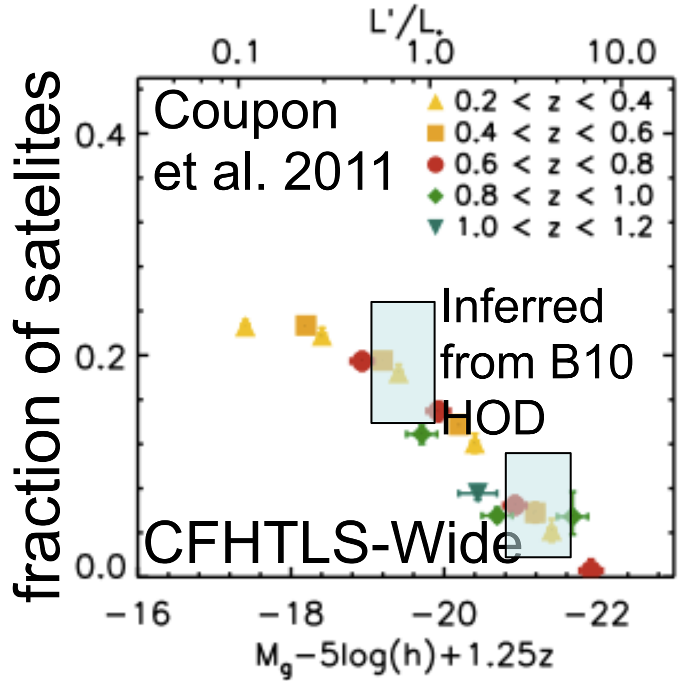
4) New approach to obtain merger rates

Combining with MUSYC LF measurements with universal HOD from the Boötes Field (from Brown et al, 2008, 2010)



Comparison between results of 3) and 4)

Padilla et al., 2011, A&A, 531, 142



Case of z=1 ETGs and their z=0 descendants with Brown+ HODs:

z=1: (80±5)% are centrals
z=0: (93±4)% are centrals

Use sharp cutoffs in luminosity to separate centrals and sats:

Centrals increase their luminosity by x1.7(+2.2-0.5)
Satellites increase theirs by a factor x2.5(+1.0-1.2)

Total luminosity in progs. to that of desc. x4(+4-2) SINK? (Conroy+ 07)

Centrals decrease their num. density x4.0(±2)
Satellites decrease their num. density x10 (±7)

Comparison between results of 3) and 4)

Padilla et al., 2011, A&A, 531, 142

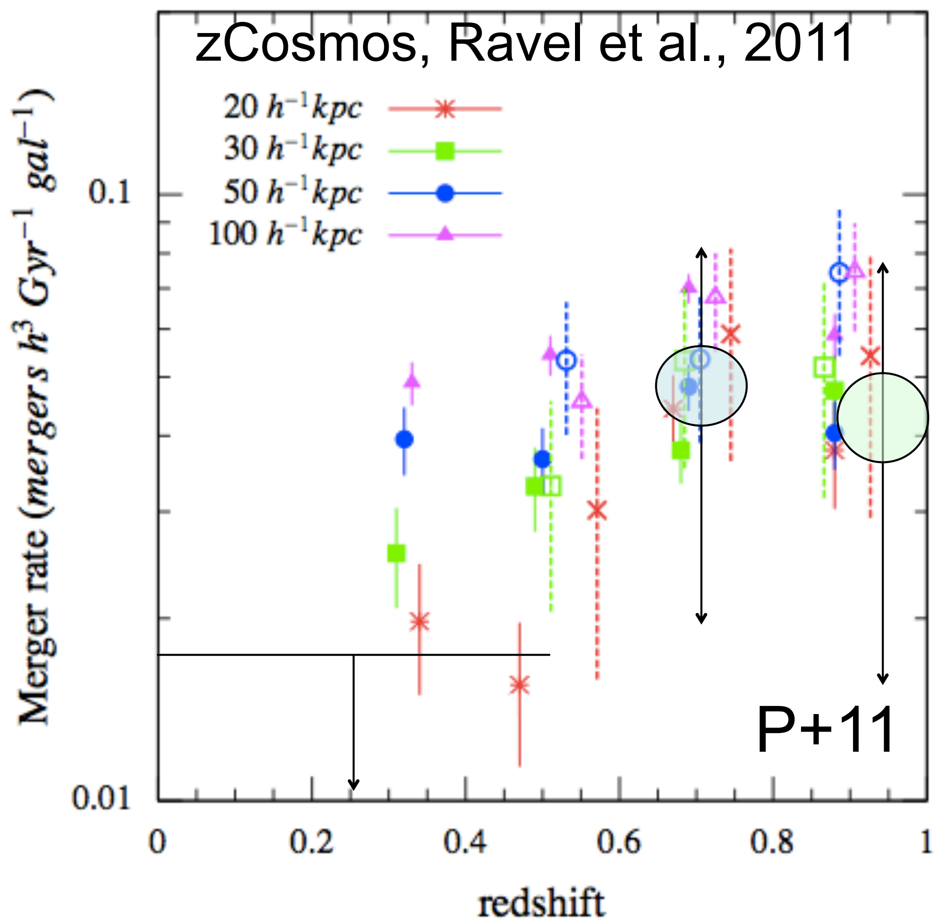
Case of z=1 ETGs and their z=0 descendants.

From an average of 4 mergers needed, only one occurs with another central galaxy (dashed).

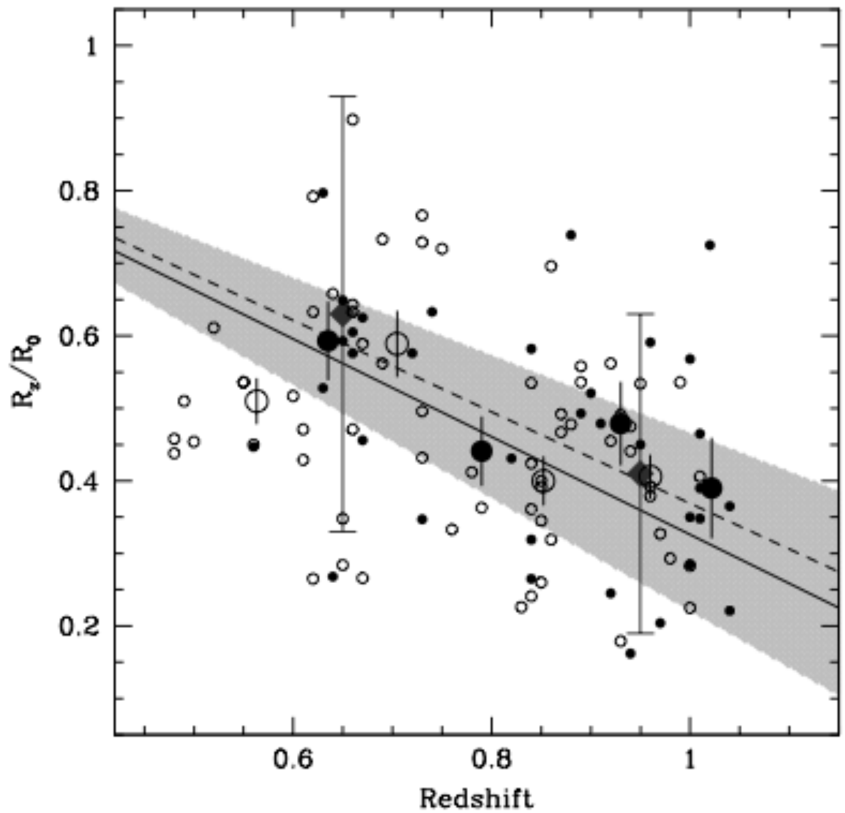
~31% of galaxies undergo a major merger since z=1

~4% probability of Major merger/gx/Gyr.

~70% of major mergers are with another central.



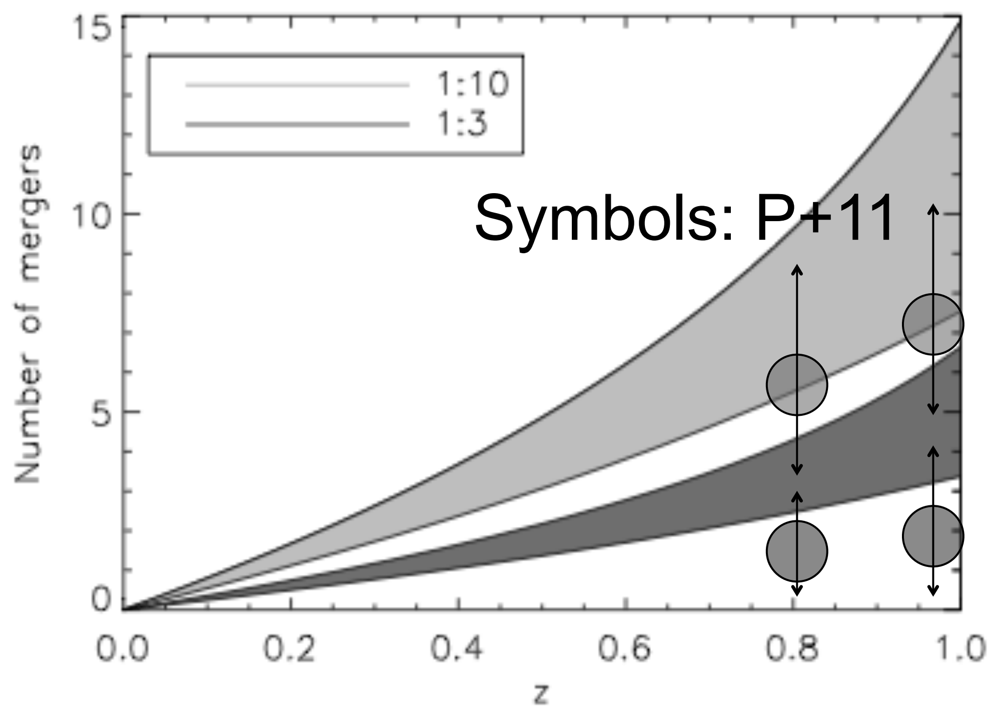
5) Consequences for ETG sizes



Consequences for size evolution of galaxies

Trujillo et al. 2011
(See also Damjanov+11, Fan+10, in simulations Naab+09)

Number of mergers that provide the observed size evolution.



Christlein et al. 2009, MNRAS, 400, 429
Padilla et al., 2010, MNRAS, 409, 184
Padilla et al., 2011, A&A, 531, 142

Conclusions

- ETGs are an attractive population of galaxies to study evolution due to their simple properties.
- Number density evolution useful for comparison between models, but involves samples that are not direct descendants when connecting these TLAs with SDSS.
- Pair counts provide evidence of mergers, which reinforces previous point.
- Combining clustering and number density evolution provides consistent estimates of merger rates.
- Merger rates in some tension with size evolution.

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Come to Católica

- Simulations group now consisting of 2 staff, 4 postdocs, 3 PhD students.
- Semi-analytics, DM and Hydro simulations
- Recently updated computer of 20Tflop and 4TB memory
- Excellent synergy with observational galactic and extragalactic astronomy groups, and
- Sometimes a nice view of the Andes

Obrigado!