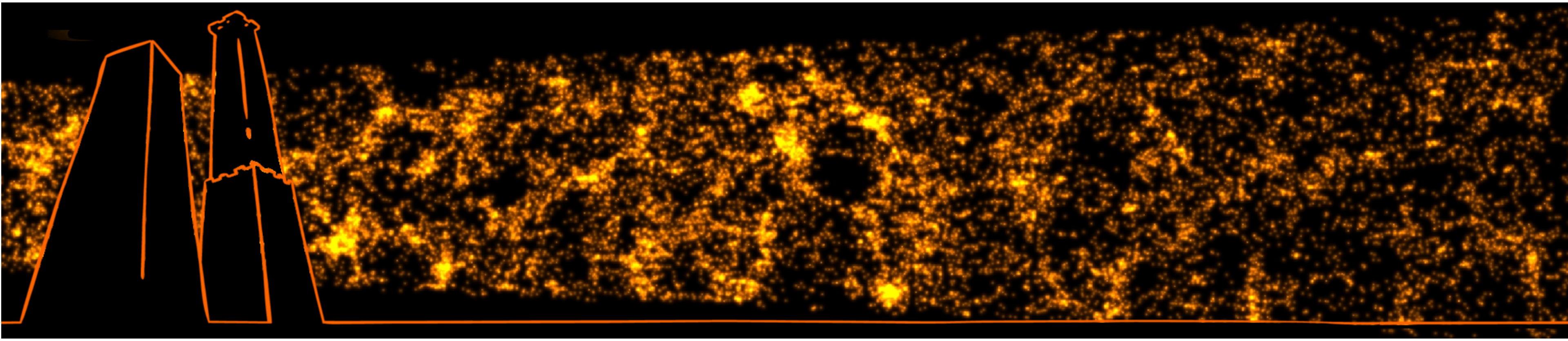
Katarina Kovač (ETH Zürich)

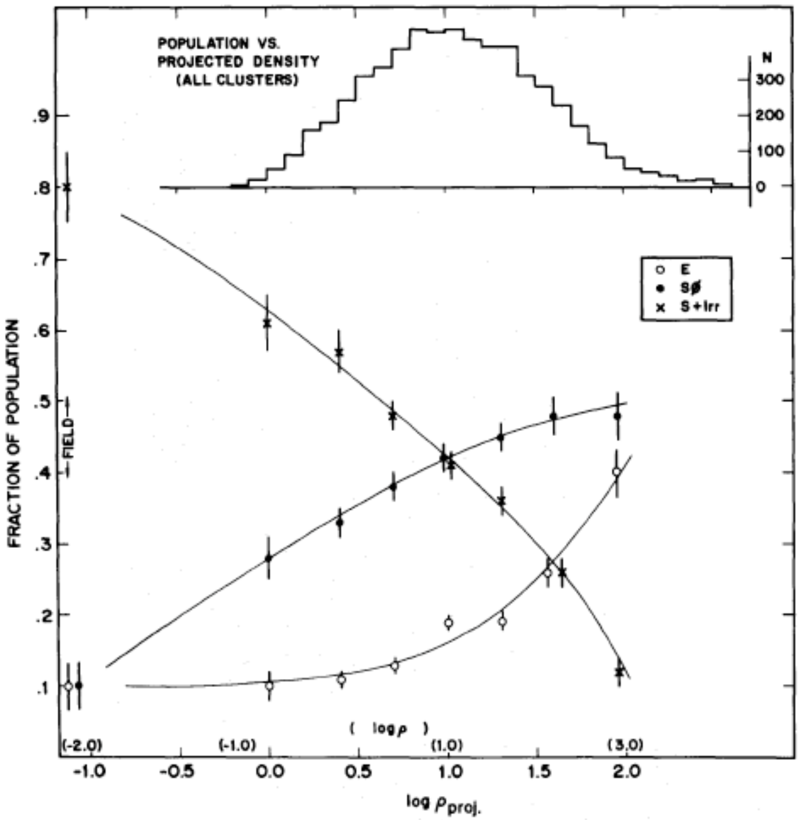
Evolving Galaxies in Evolving Environments

Concluding remarks

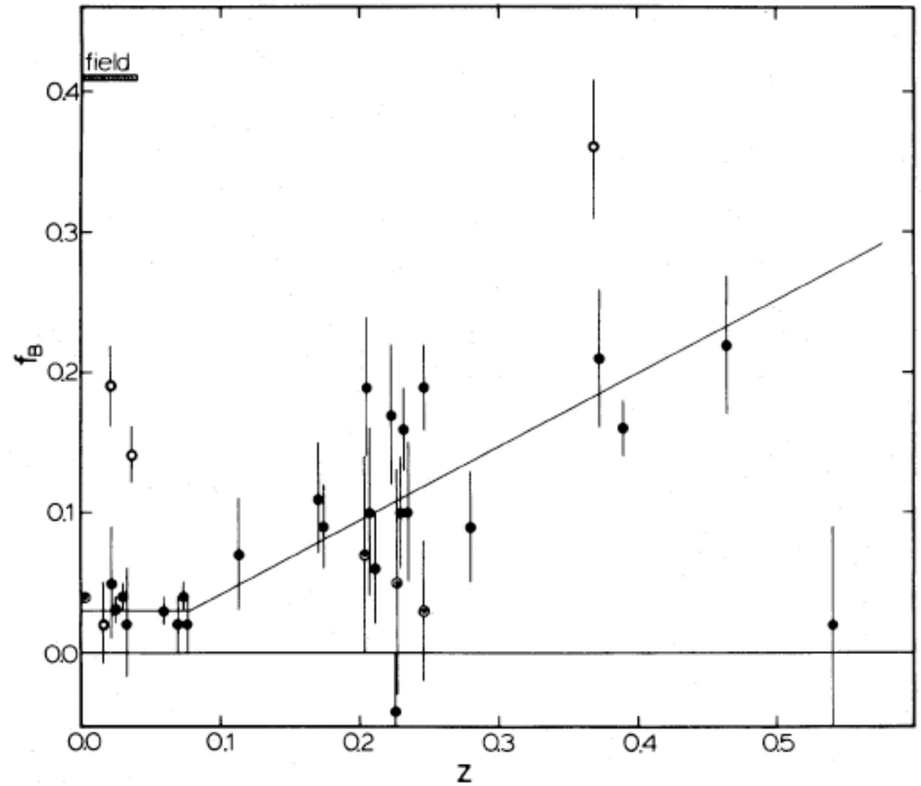


The Environmental Revolution

Dressler 1980



Butcher & Oemler 1984



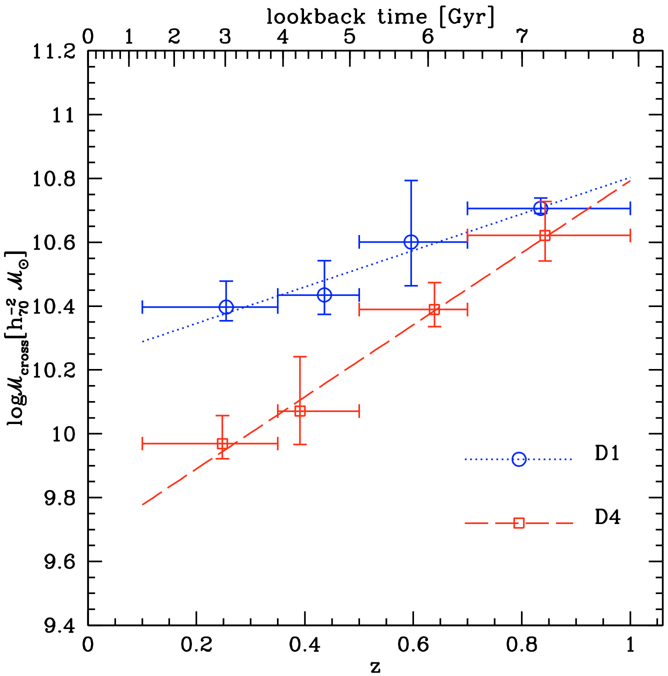
Key ingredients governing `environmental revolution'

- Morphology – density relation (T – Σ)
- Rising blue fraction $f_B(z)$

Slide from Richard Ellis' talk at "Galaxy Evolution and Environment" Malaysia 2009

The Environmental Evolution

- Galaxies in dense environments are more massive, redder, show less SF; also older and more concentrated than galaxies in less dense environments; established over 0 < z< 1,1.5 in a range of galaxy environments (e.g. Dressler 1980, Kauffmann et al. 2004, Cucciati et al. 2010, Kovač et al. 2010,2014, Quadri et al. 2012)
- Emerging picture: galaxies are getting transformed from blue, SF (and late) to red,non-SF (and early)
- Evolution mainly driven by mass

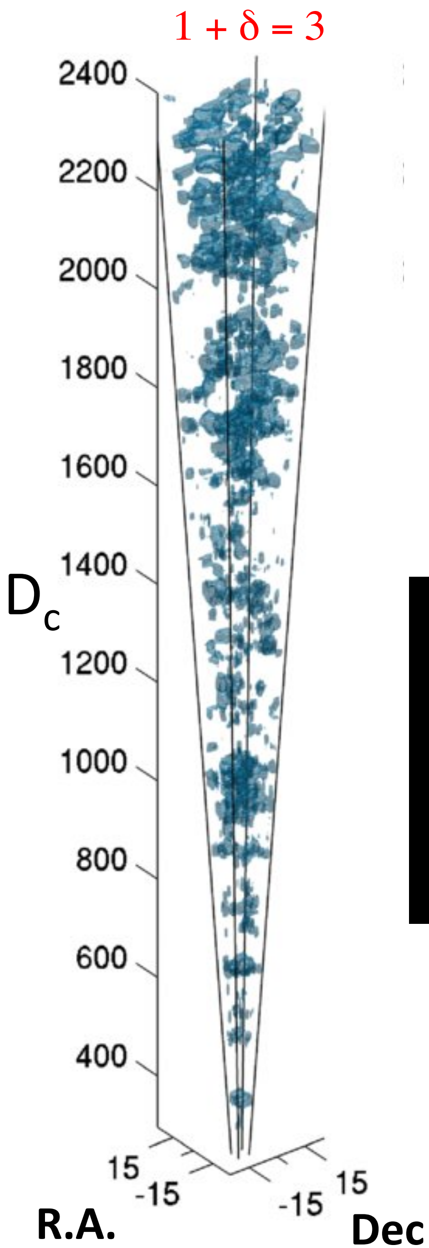


Environment is equivalent to > 2 Gyr retardation

A delay in physical processes or an indication of two different processes?

Bolzonella, Kovač + zCOSMOS 2010

What is environment? (Gray, Mamon)



Kovač et al. (2010)

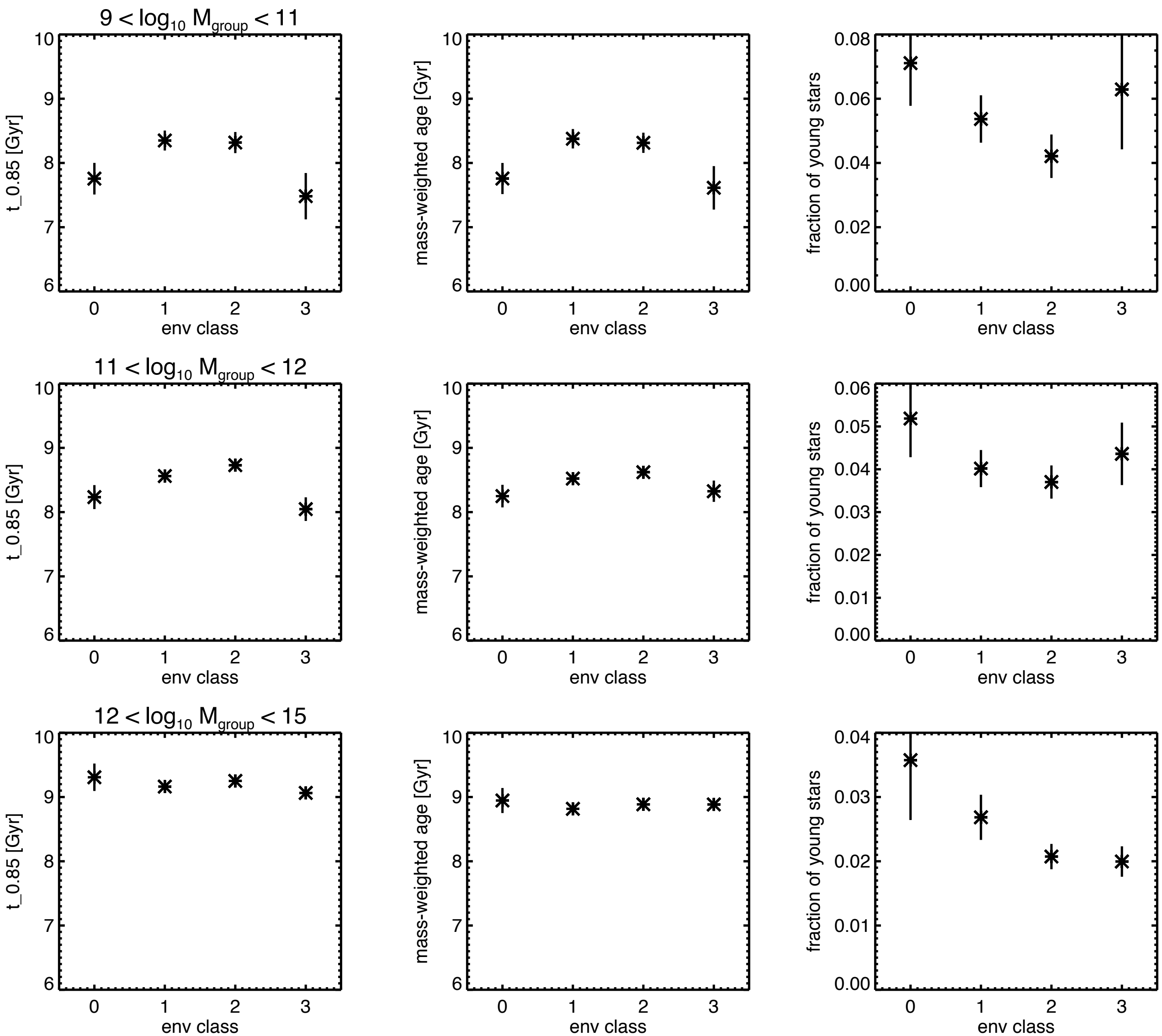
1. **Continuous environments = = galaxy counts**
2. **Groups/clusters = = virialised (bound) structures**

- not so simple in practice

Gray:

- please be specific when you talk about environment!
  - tell us how you measured it, and remember that 'high density' isn't really meaningful
  - different measures will be appropriate to probe different physical regimes

Are our environment measures too simplistic?

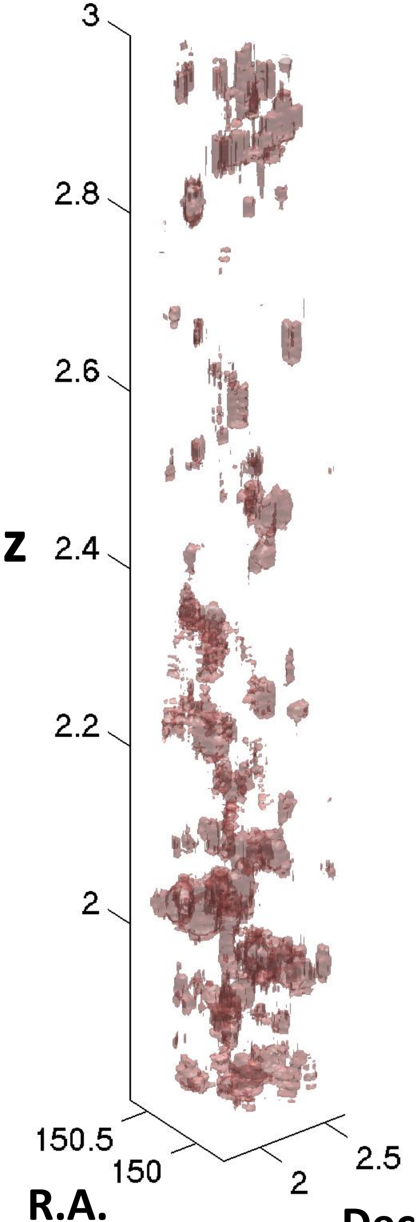


env class: void, filament, sheet, cluster

“Tentative statement: at fixed group/halo mass ... no dependence of the stellar assembly time on geometric/global environment”

Tojeiro (also Cibinel)

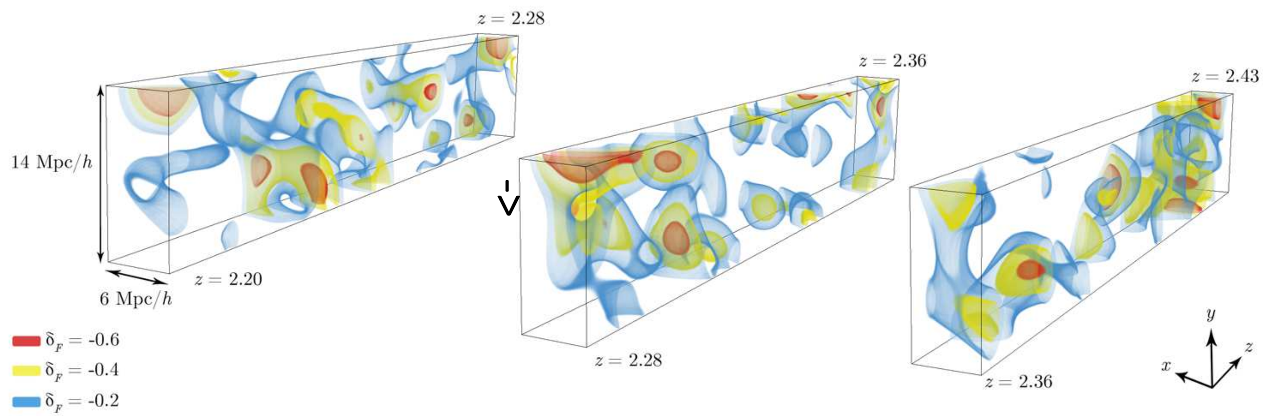
Moving to z>1.5,2



Kovač et al. (in prep)

<- Number counts (zCOSMOS)

K.-G. Lee: Lyα Forest as a Probe of the Cosmic Web

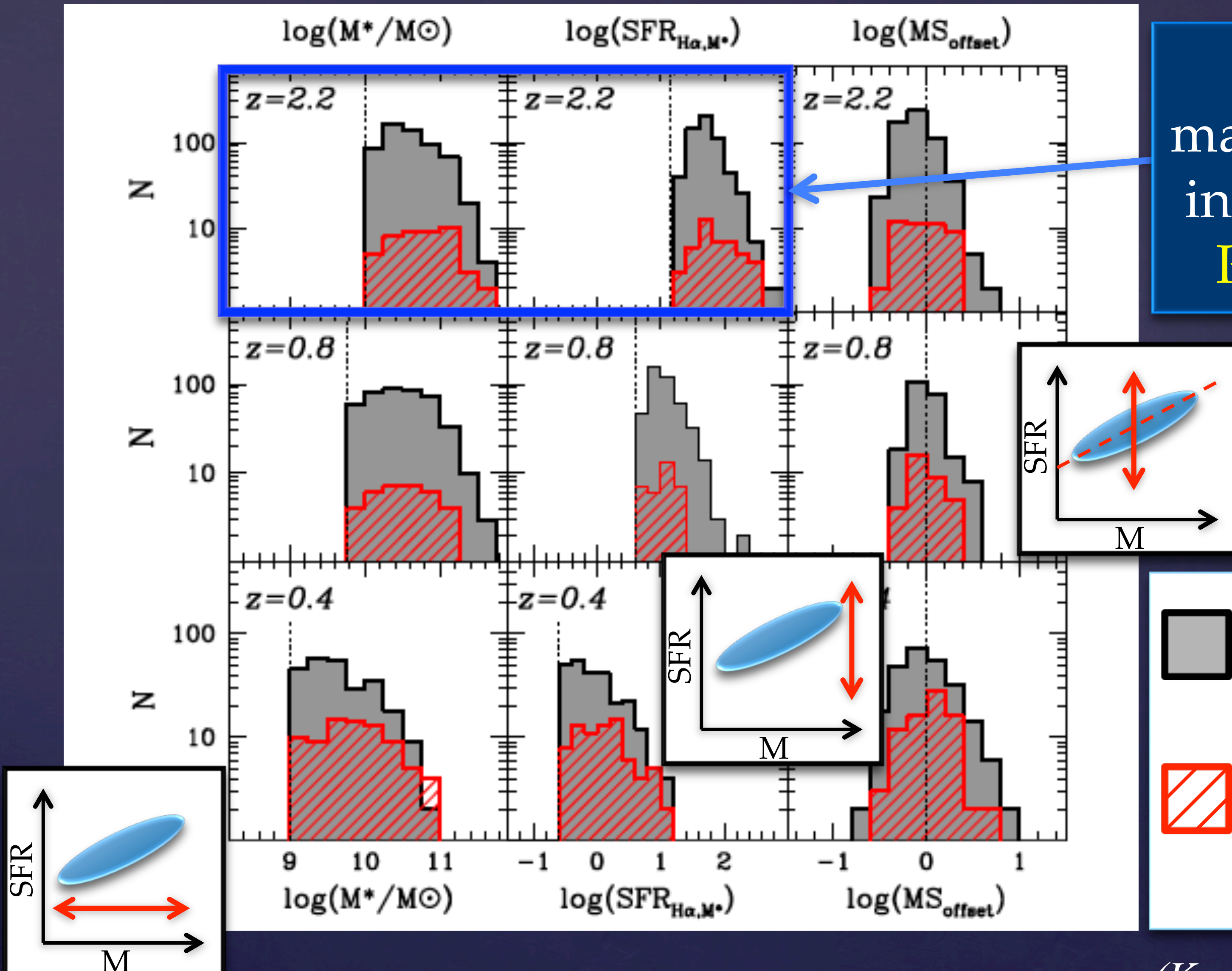


Note: Negative δ_F corresponds to higher densities

Orsi, Lemaux, Koyama, Gray: Tracing protoclosters

- Lyα blobs
- Radio galaxies
- Quasars

M★, SFR, ΔMS distribution



Excess of massive galaxies in proto-cluster PKS1138-262

consistent with Lemaux, also zCOSMOS-deep

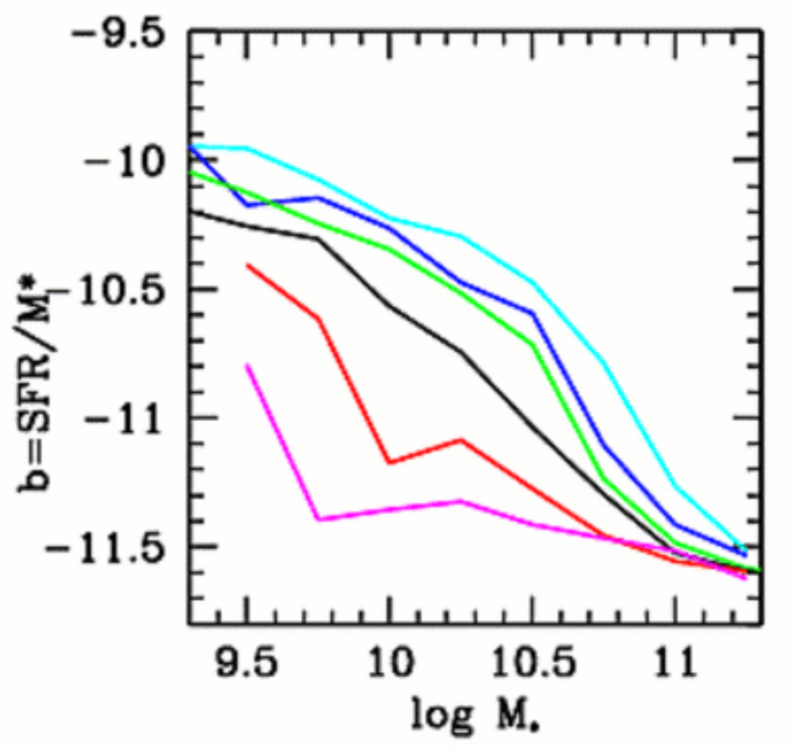
: Field (HiZELS)

: Cluster (MAHALO)

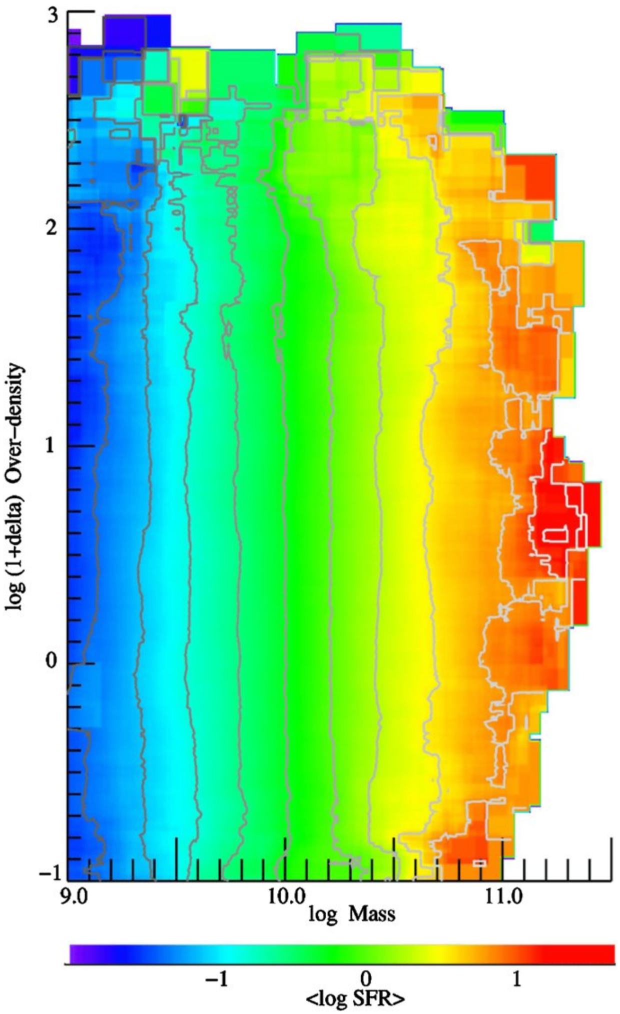
(Koyama et al. 2013b)

SFR vs environment

- (s)SFR of star-forming galaxies do not dependent on environment (Peng et al. 2010, McGee et al. 2014)



Kauffmann et al. 2004

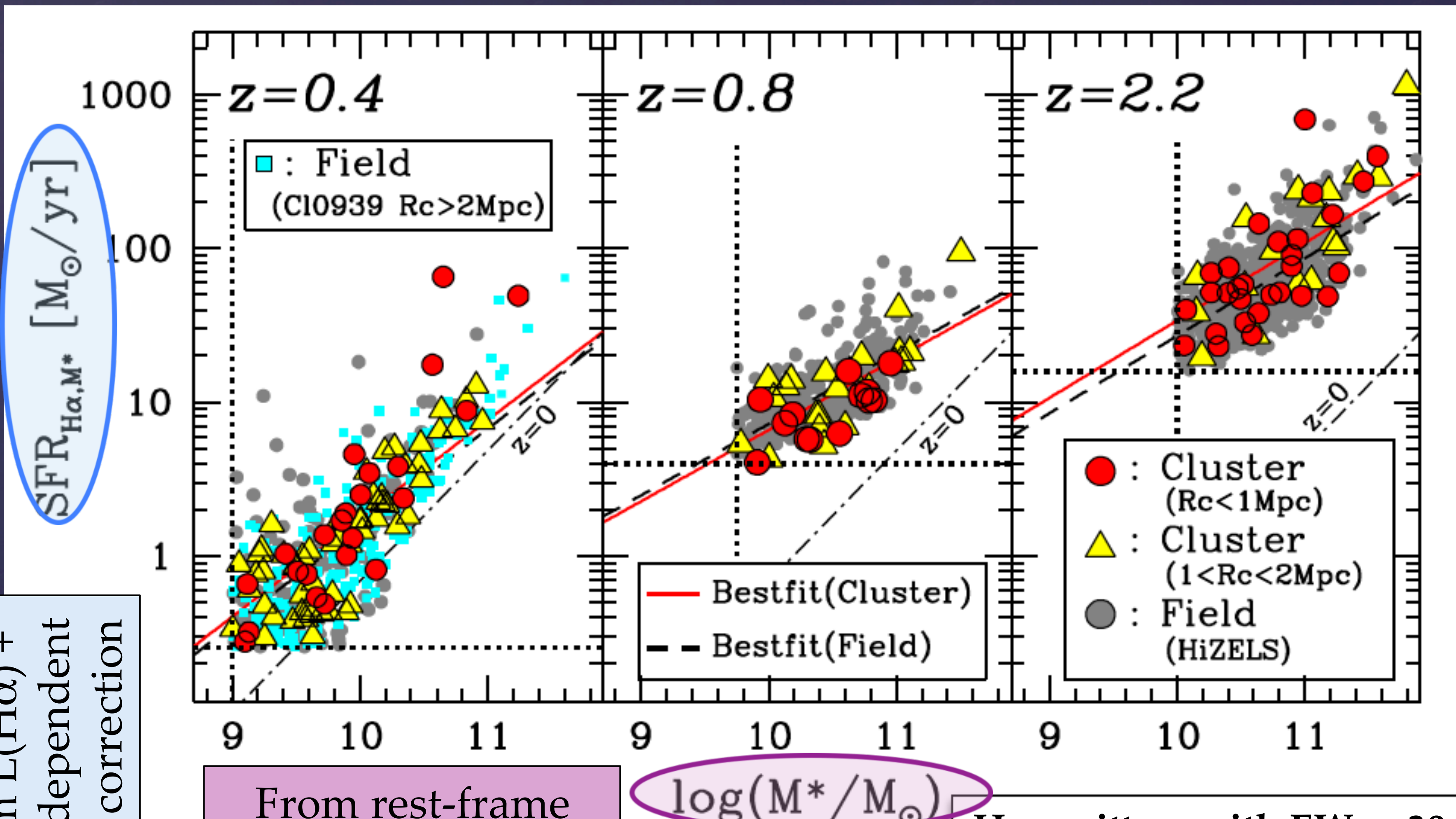


Peng, Lilly, Kovač et al. 2010

Steele:
Holds also for all “emission class” objects in GAMA

Cluster vs. Field comparison out to z~2

The MS location is always independent of environment since z~2 !



From L(Hα) + M★-dependent dust correction

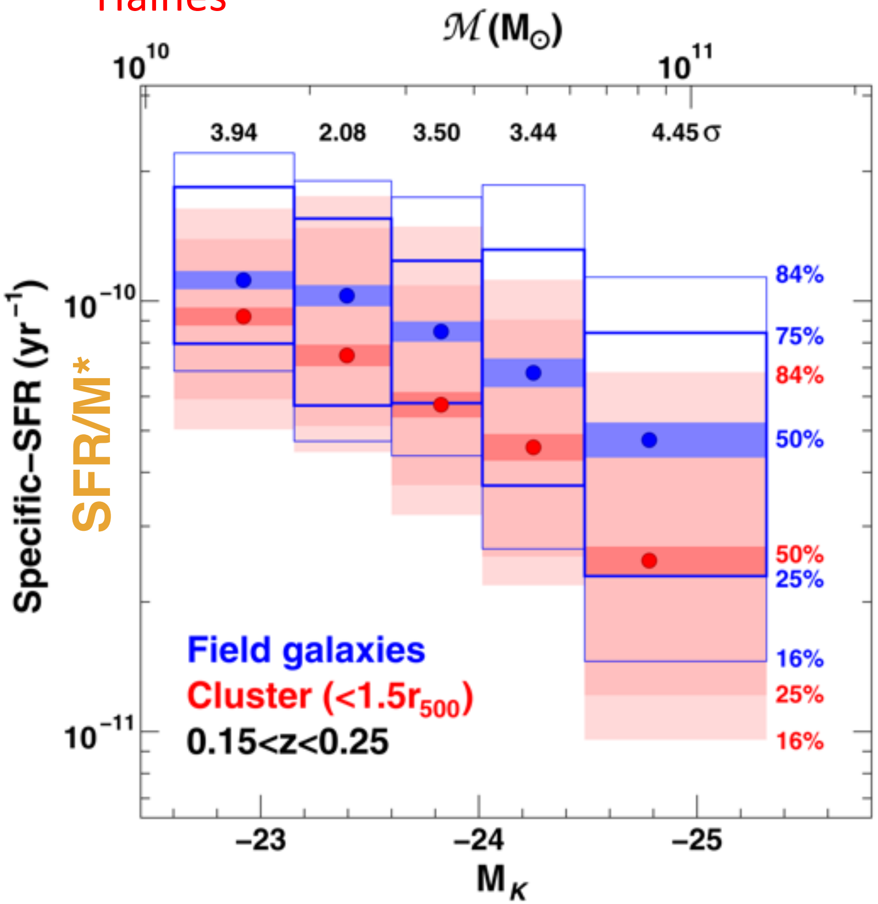
From rest-frame R-band photometry + M/L correction

Hα emitters with EWr > 30A

(Koyama et al. 2013b, MNRAS, 434, 423)

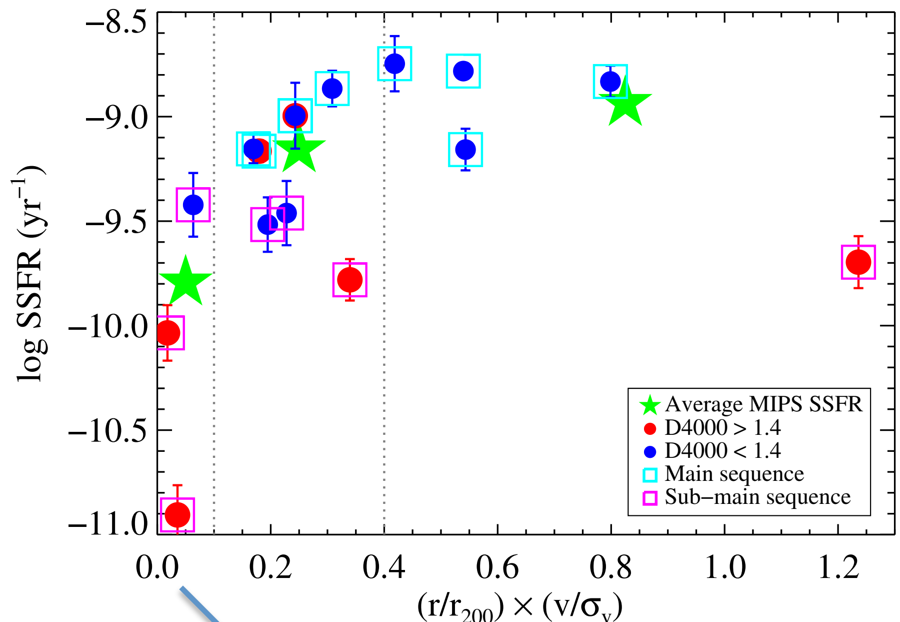
Clusters: SSFR depends on environment

Haines



z ≈0.9

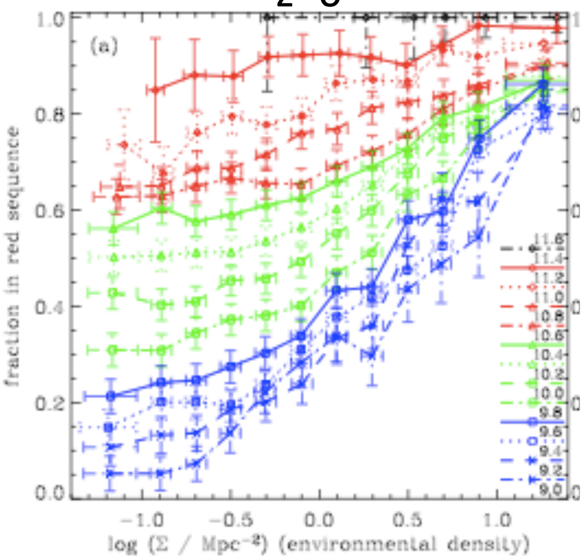
Noble



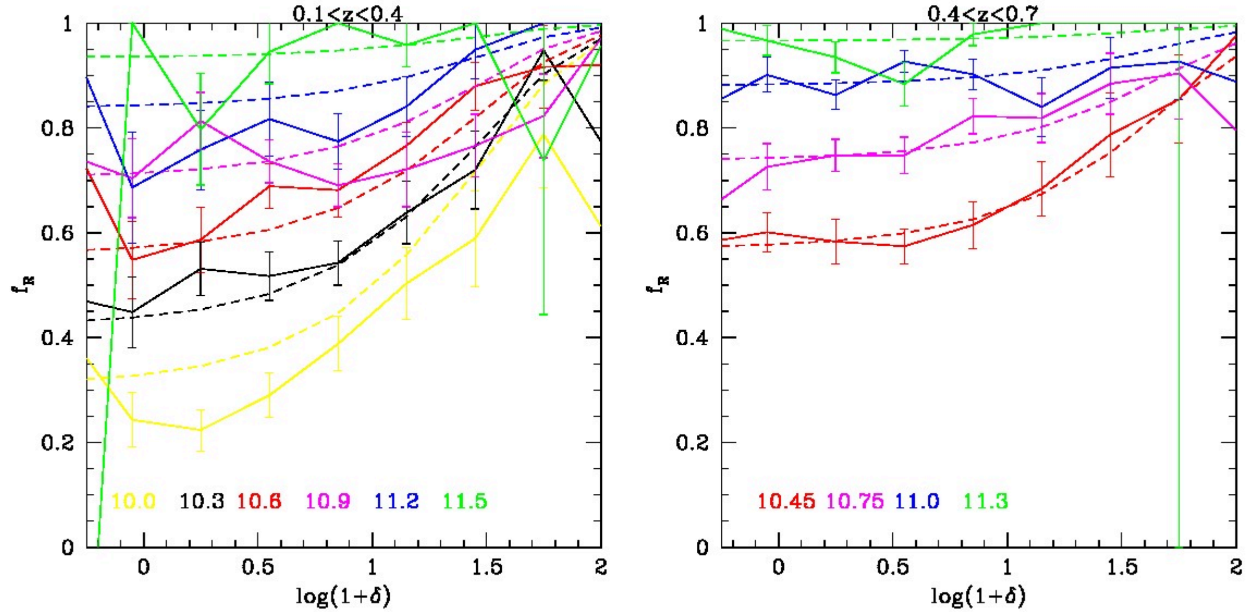
Galaxies accreted at earlier time

Mass and environment in the galaxy evolution

z=0



Baldry et al. 2006



Kovač et al. 2014

Red fraction of galaxies depends both on stellar mass and environment (also ChangHoon Hahn PRIMUS results):

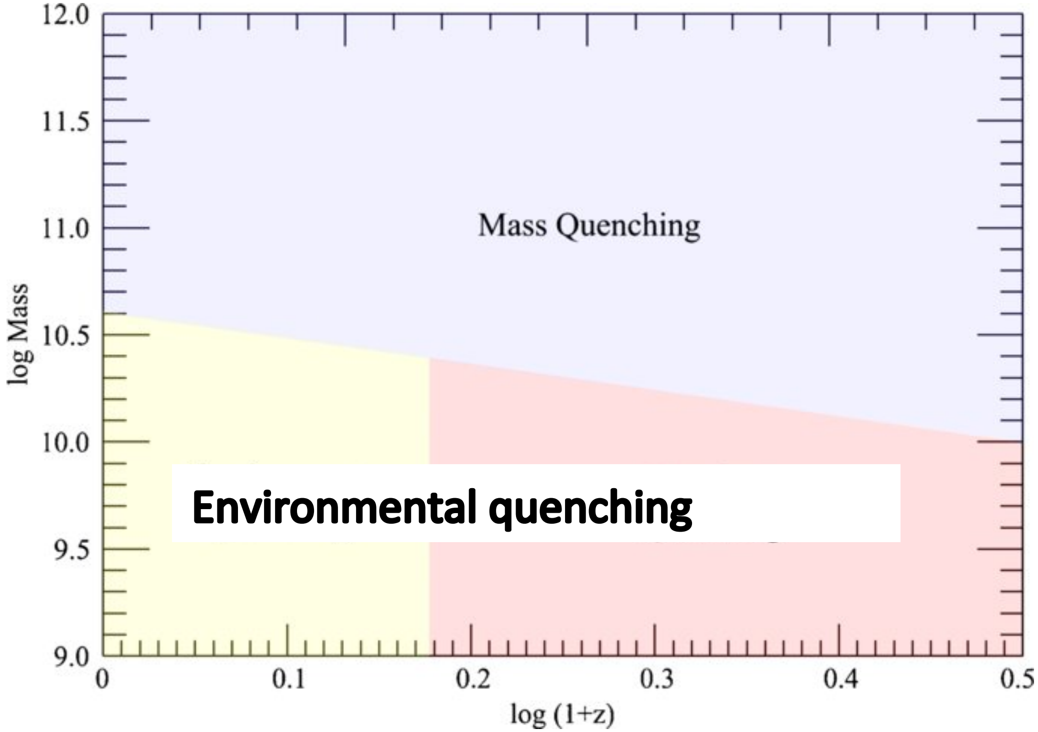
$$f\_red\ (\rho,m)=1 - \exp[(-((\rho/p1)^{p2}) - ((m/p3)^{p4})]$$ (Baldry et al. 2006, Peng et al. 2010)

$$= \varepsilon_m(M_*) + \varepsilon_\rho(\delta) - \varepsilon_m(M_*)\varepsilon_\rho(\delta)$$

Separability holds to a good degree at least up to z<0.7; possible cross-term within the errors

Mass and environmental quenching over time

Dominant mechanism for the quenching of galaxies changes with time



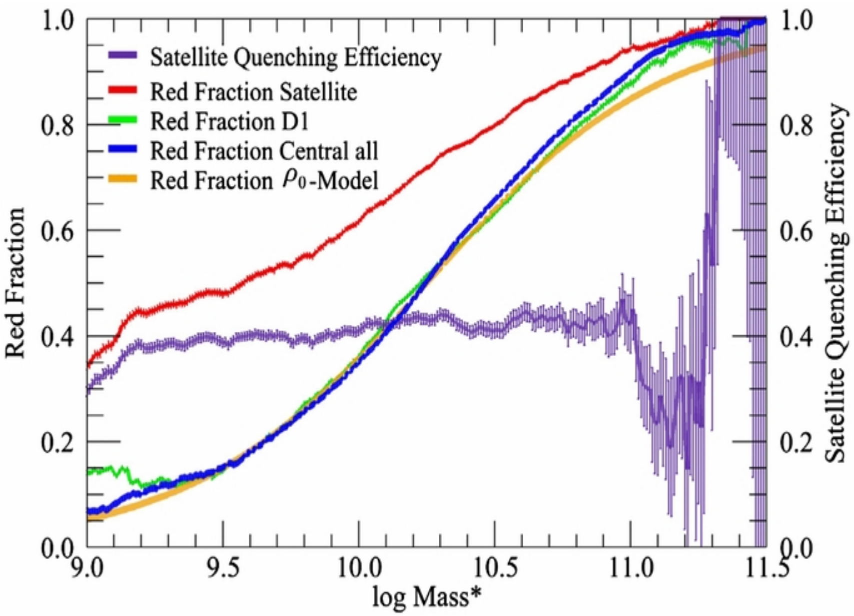
Model from Peng et al. (2010) based on the assumption of separability of the mass and environmental quenching up to high redshift

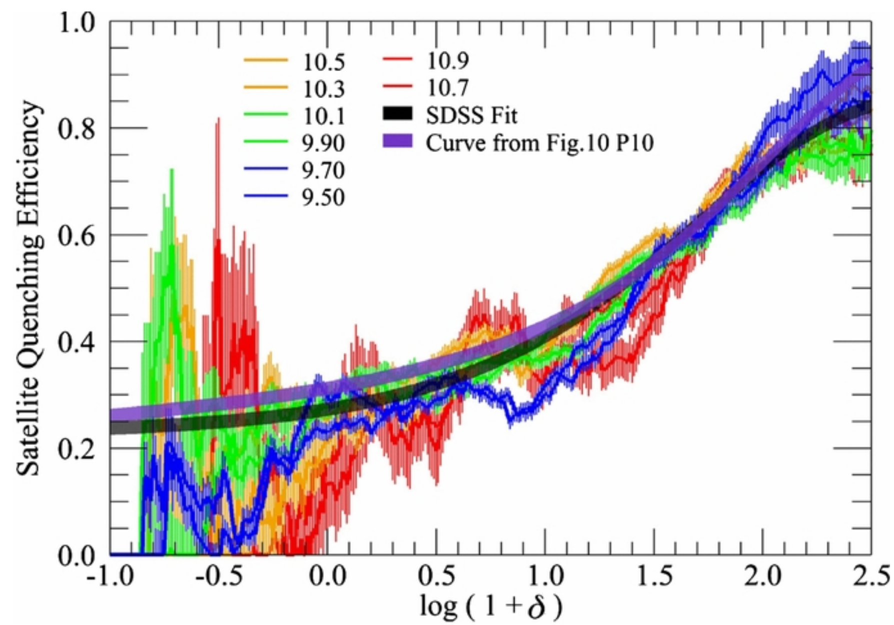
Importance of the environmental quenching increases with cosmic time and with decreasing stellar mass – qualitatively consistent with the growth in the LSS and infall of (lower mass) satellites to the larger structures producing the observed environmental effects

Lucrative idea from the theory: many physical processes suggested

Satellite quenching efficiency (z=0)

$\varepsilon_{sat}(m) = [f_{r,sat}(m) - f_{r,cen}(m)]/[f_{b,cen}(m)]$ $\varepsilon_{sat}(m,\rho) = [f_{r,sat}(m,\rho) - f_{r,cen}(m,\rho)]/[f_{b,cen}(m,\rho)]$





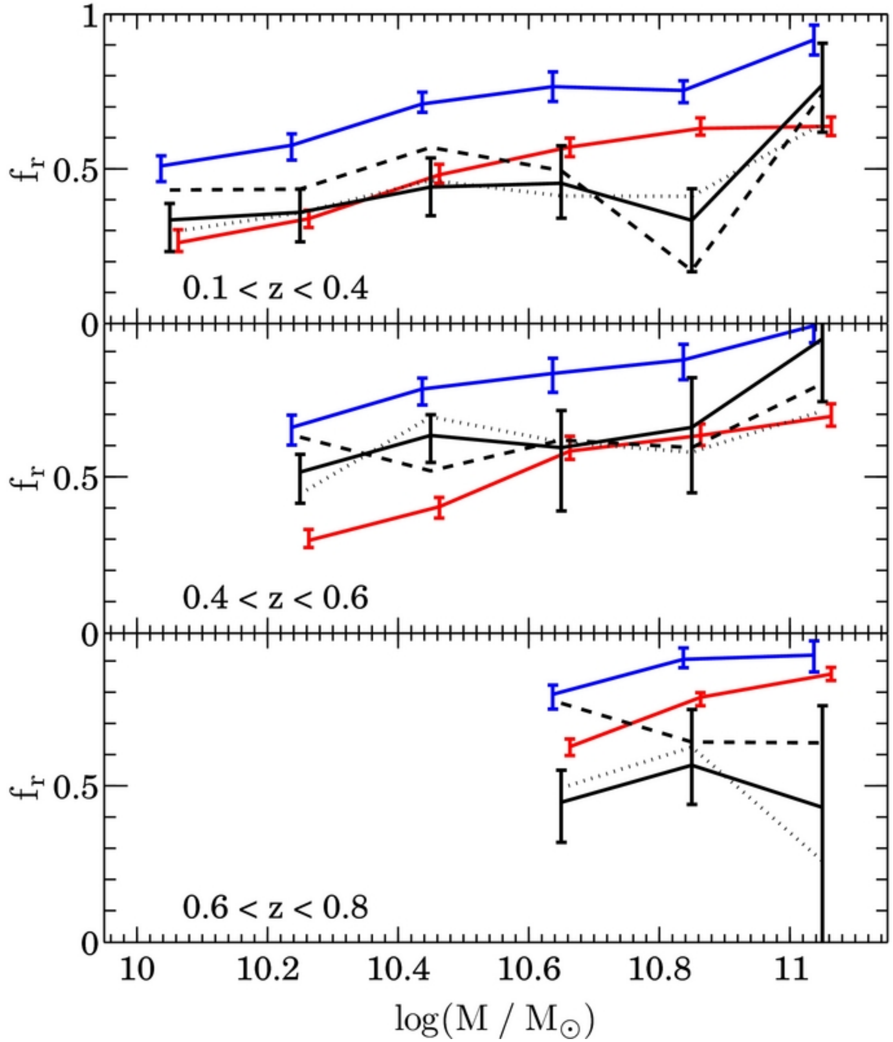
also van den Bosch et al. (2008)

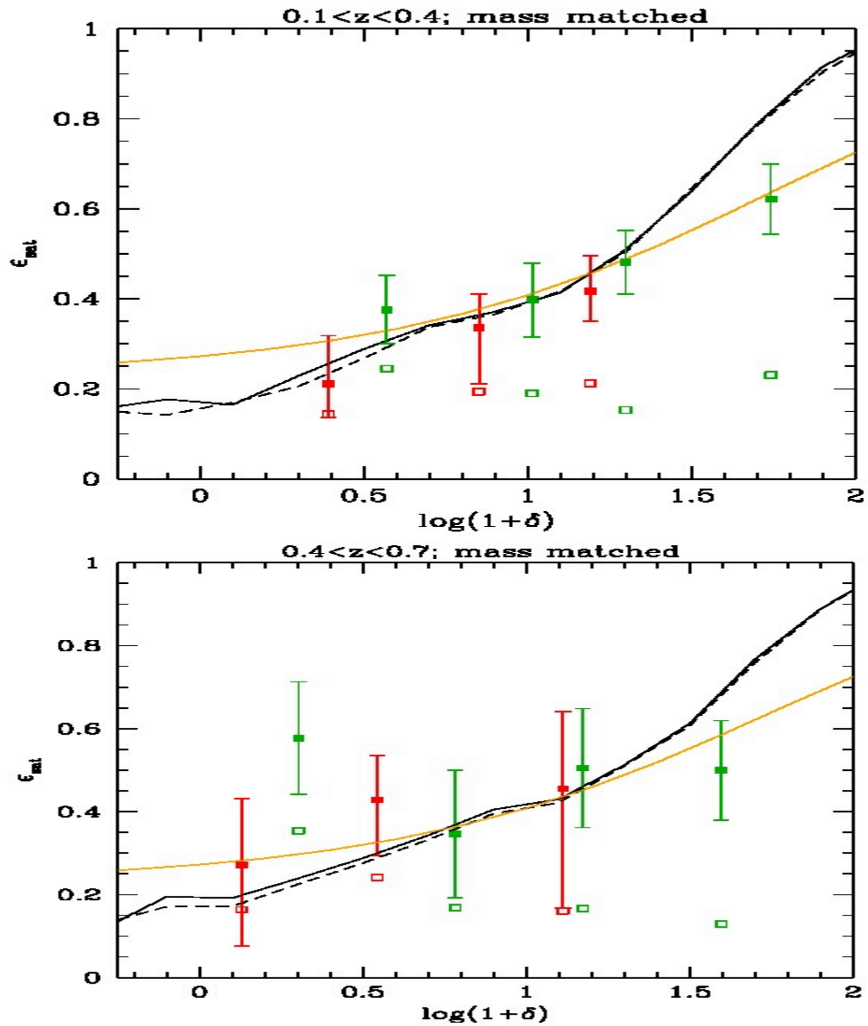
(Peng et al. 2012)

At z~0 and log(M*/Msol)<11: 1) red fraction of centrals does not show strong dependence on environment

2) satellite quenching constant with mass and responsible for most of the observed environmental quenching

Satellites are the major drivers of the overall observed environmental effects up to (at least) 0.7





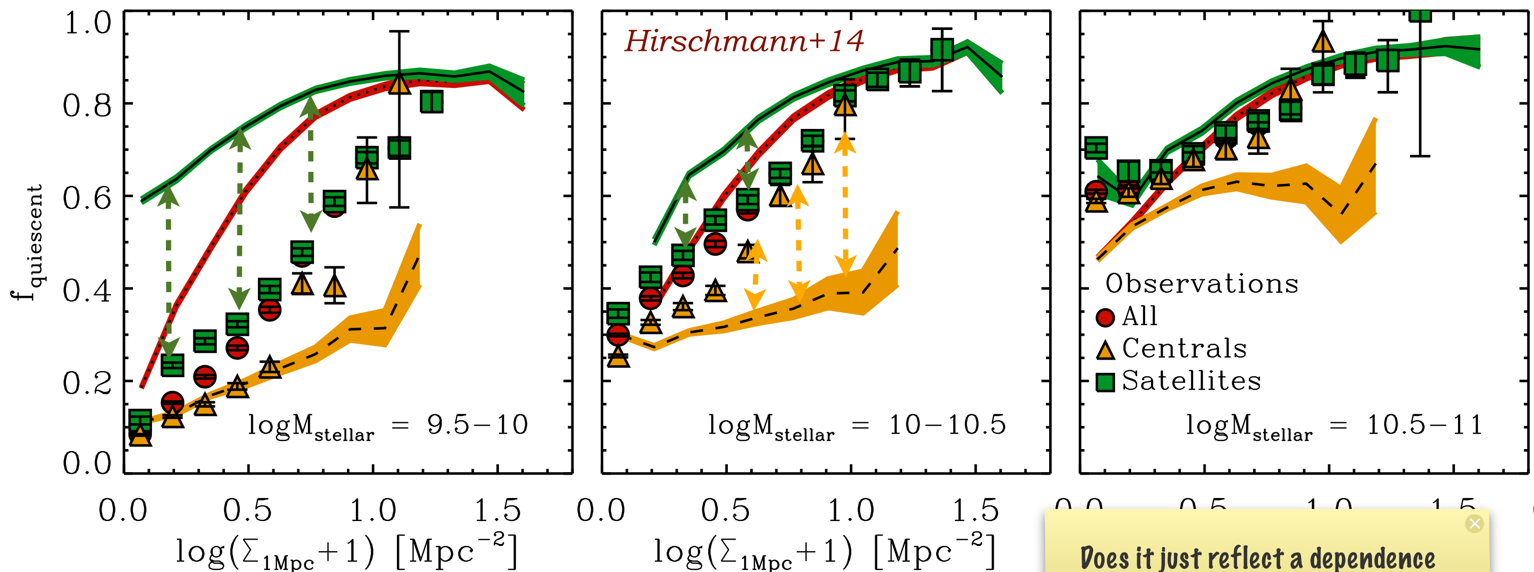
Knobel, Lilly, KK+ et al. 2013

Kovač et al. 2014

Quiescent galaxy fractions

Hirschmann

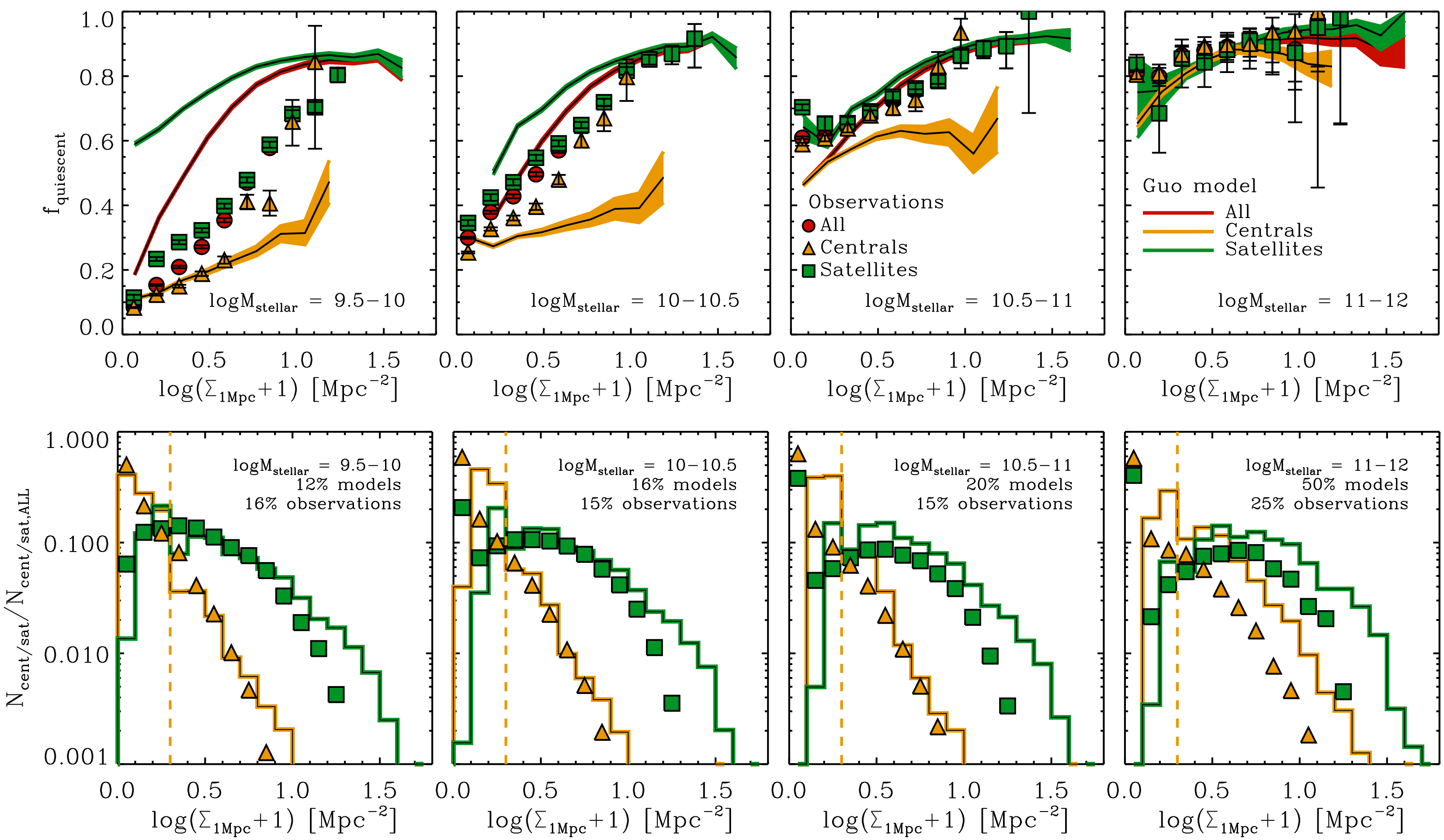
Stellar mass



Does it just reflect a dependence on halo mass, a theoretical measure for environment?

- *Observations*:
  overall density dependence mainly driven by satellites *(Kovac et al.,2013)*
  similar behavior of centrals & satellites & strong density dependence
- *Models*: *centrals & satellites behave differently & weaker density dependence*
  ⇨ Over-estimating *quiescent satellites* *(e.g. Kimm+09)*
  ⇨ Under-estimating *quiescent centrals*

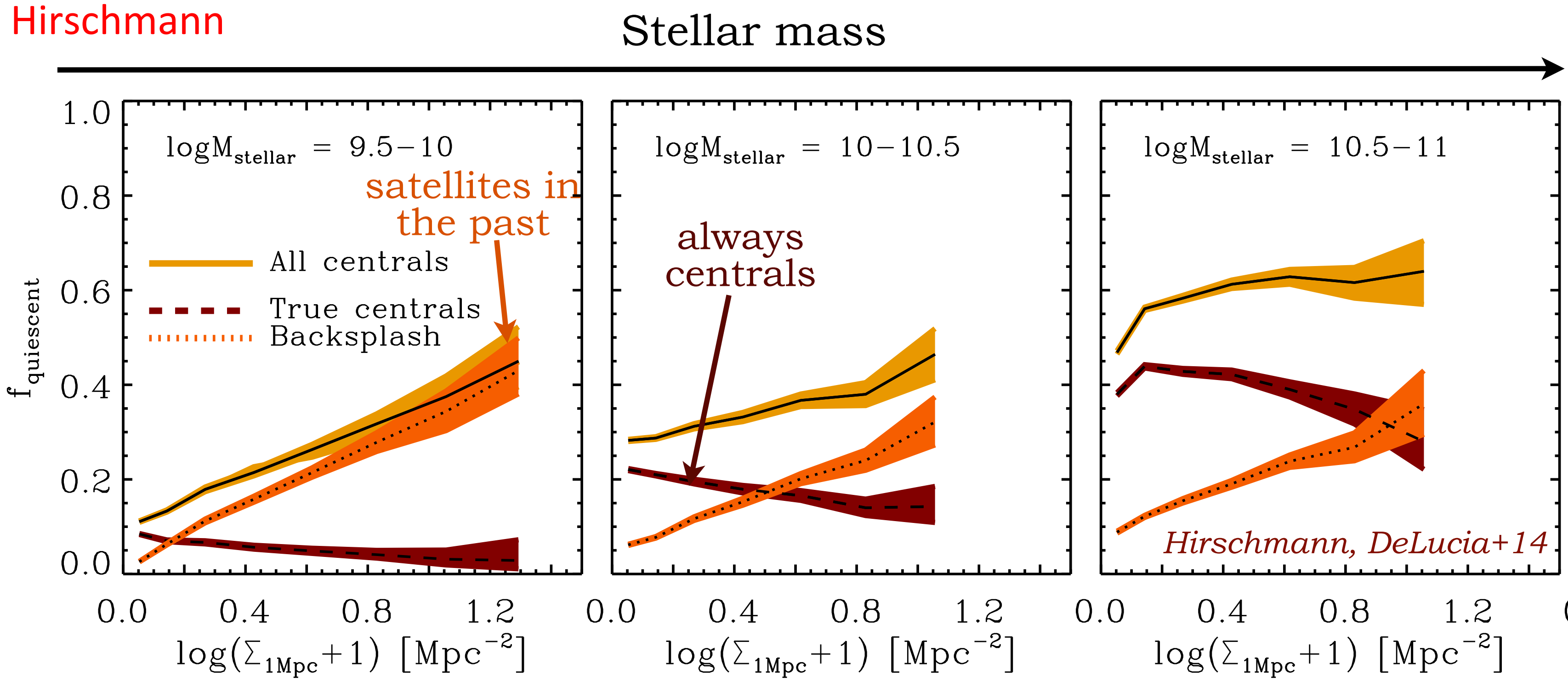
Satellites are the major drivers of the overall observed environmental effects
… but … some centrals are the same as satellites



Hirschmann

Backsplash population

Hirschmann

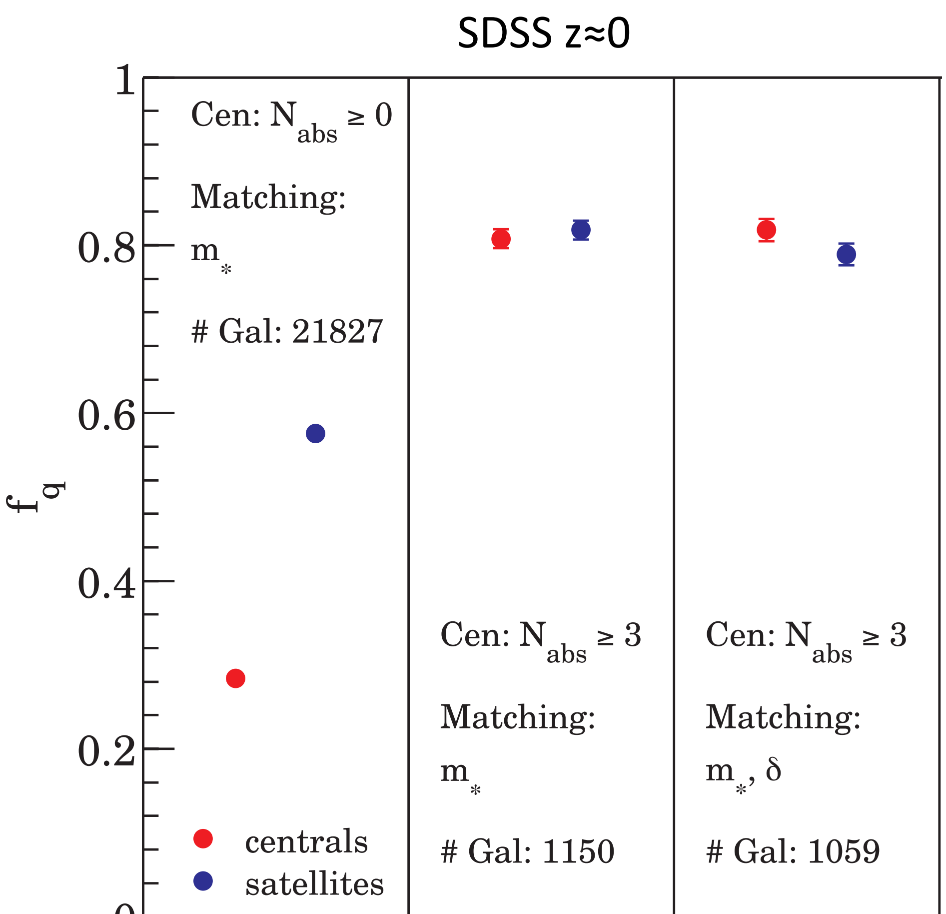


✦ ***True centrals:*** *No dependence on density*

✦ ***Backsplash centrals:*** Responsible for *over-all density dependence* ⇨ *environment mainly relevant for low mass centrals at high densities*

Spend on average *1.5-3 Gyrs* at *z=0.5-2* as a satellite (depending on density & mass)

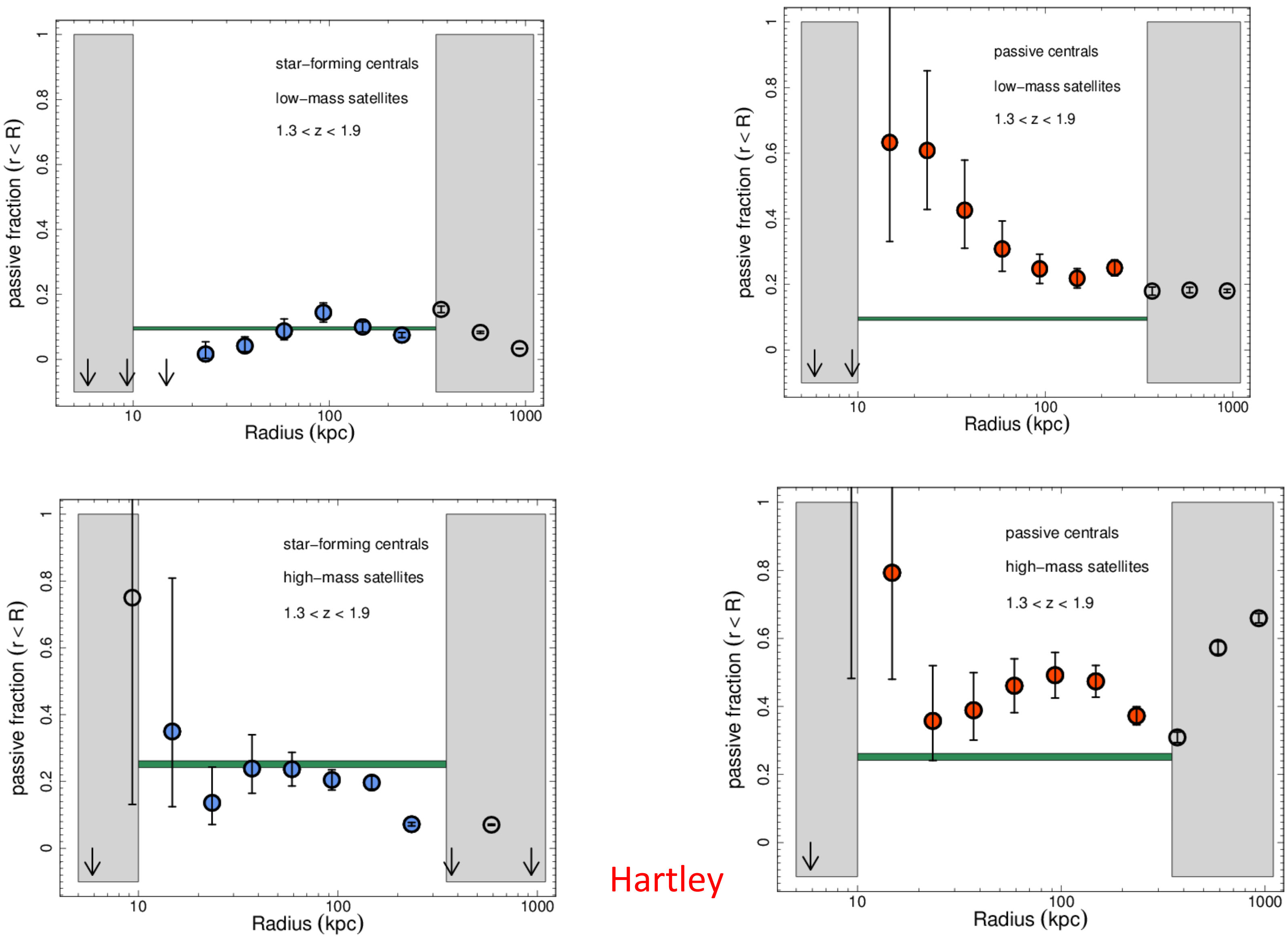
Satellites are the major drivers of the overall observed environmental effects
... but ... some centrals are the same as satellites



Knobel, Lilly, Woo, Kovač 2014

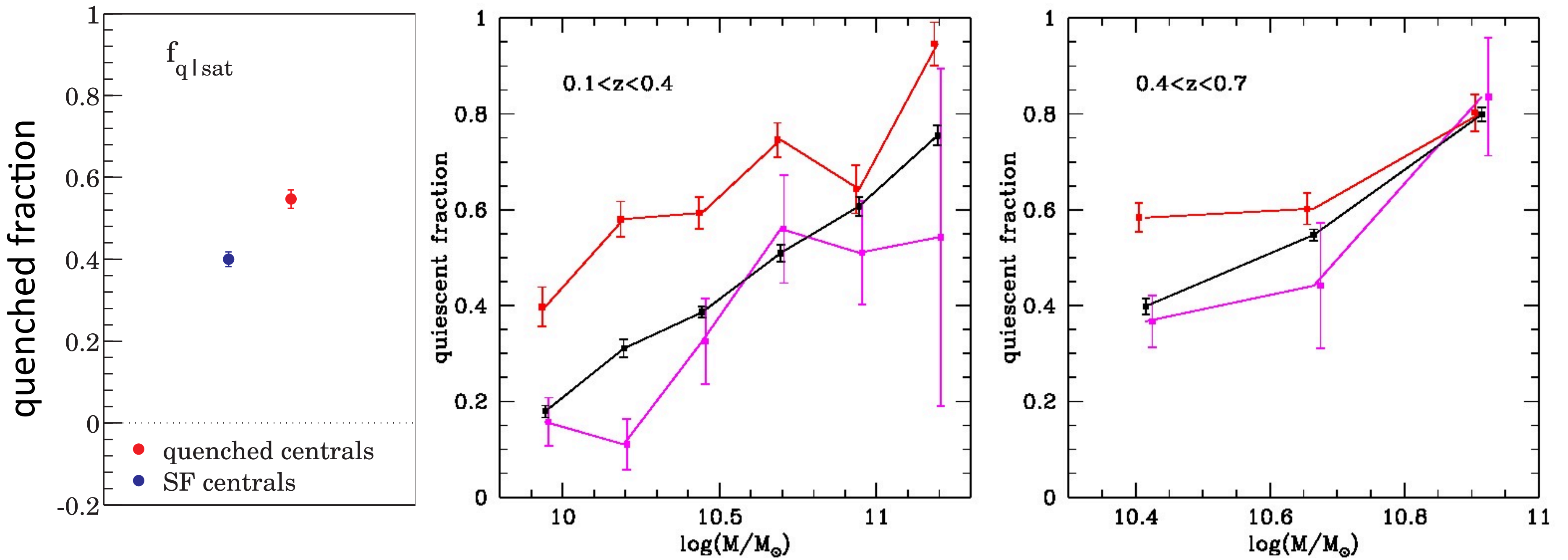
Quenched fraction of centrals in the "large" groups same as the quenched fraction of satellites when matched in the stellar mass and environment

Satellites are the major drivers of the overall observed environmental effects … but … properties of satellites depend on properties of their central



Hartley

Satellites are the major drivers of the overall observed environmental effects … but … properties of satellites depend on properties of their central

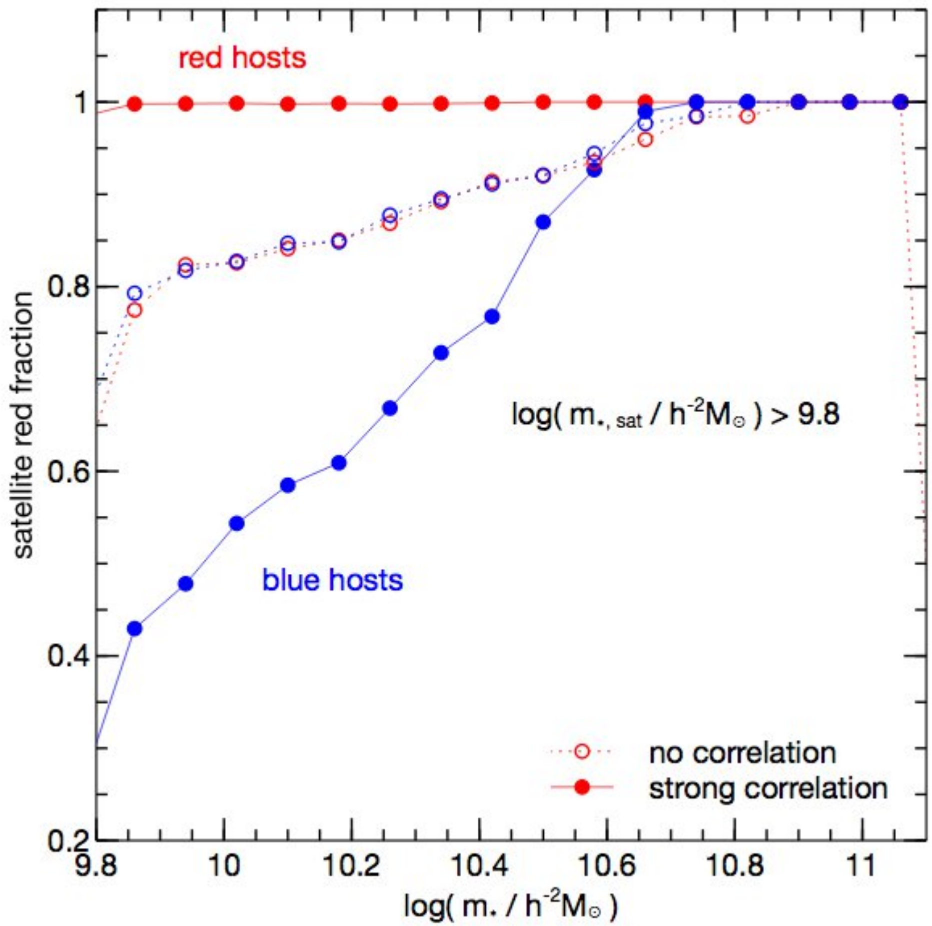


Knobel, Lilly, Woo, Kovač 2014

Kovač K.+, in prep.

Satellites of the quenched centrals have a larger probability to be quenched than the satellites of the star-forming centrals (conformity)

Assembly bias and conformity

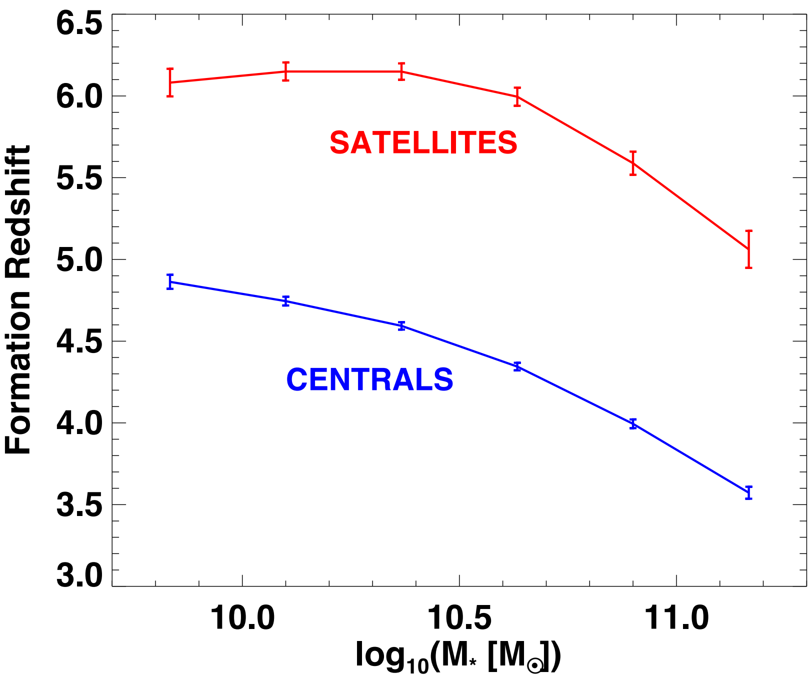


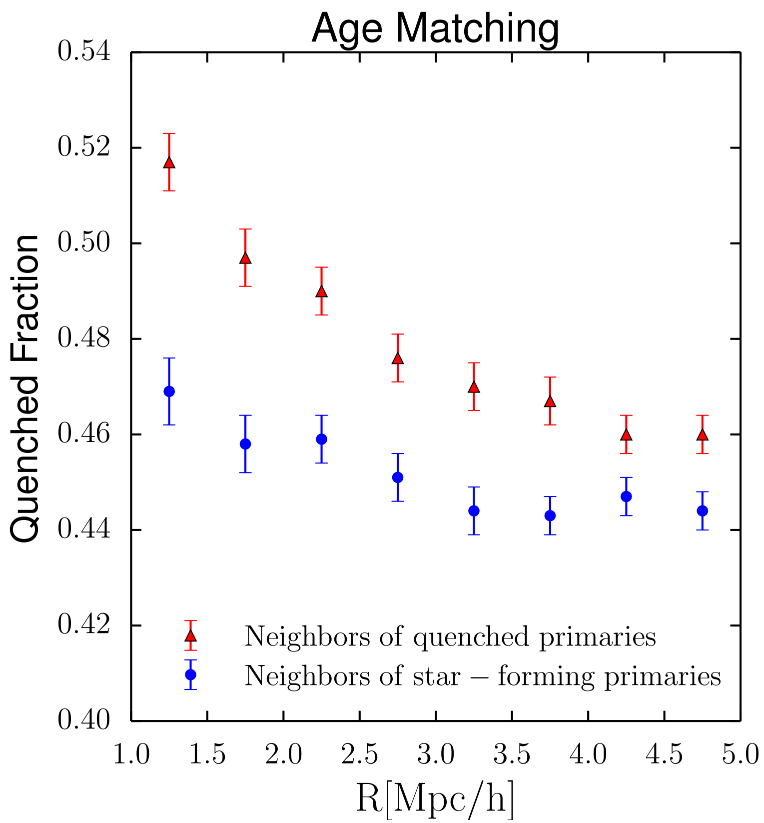
Correlation with the formation time (in this case C) can explain the observed conformity signal

Paranjape+ Hartley, Kovač in prep)

Do we need satellite-specific quenching at all?

SFR of a galaxy is determined by its dark matter halo formation history





Satellites (at a given mass) are redder because their subhaloes form earlier than host haloes

Watson et al. 2014

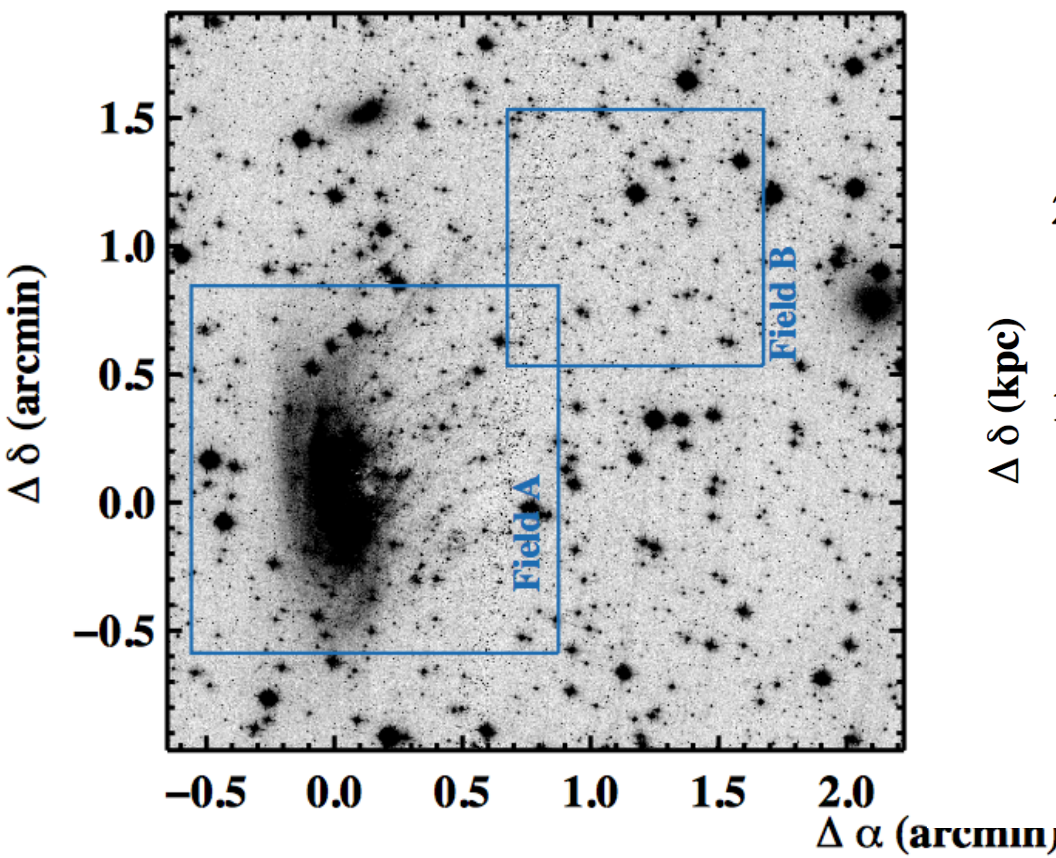
Hearin et al. 2014

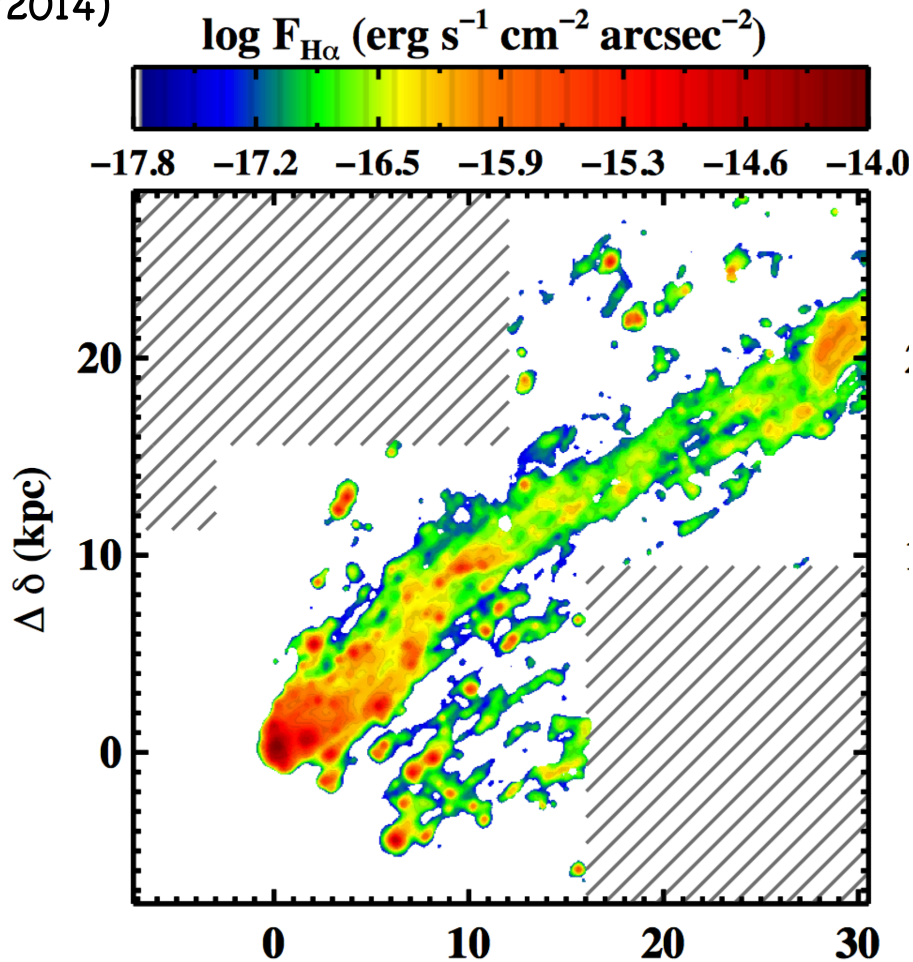
Smoking guns (of ongoing environmental transformation)

Gavazzi

ESO137–001 in Norma cluster

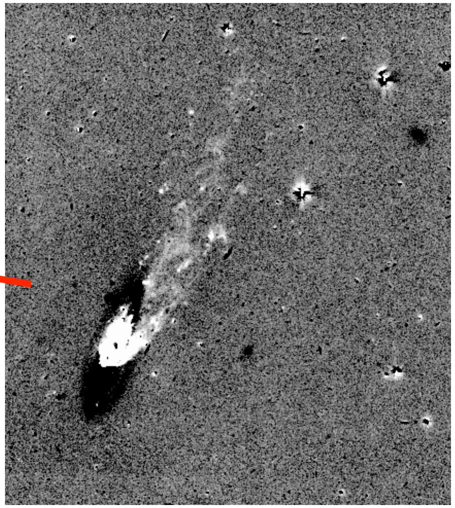
Fumagalli+14 First MUSE s.v. paper (28/7/2014)

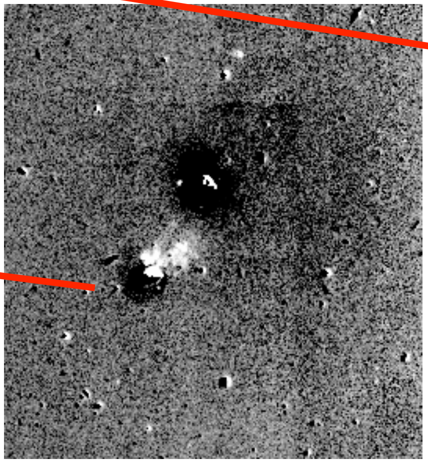


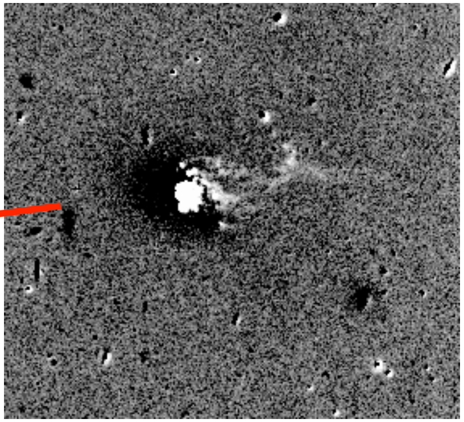


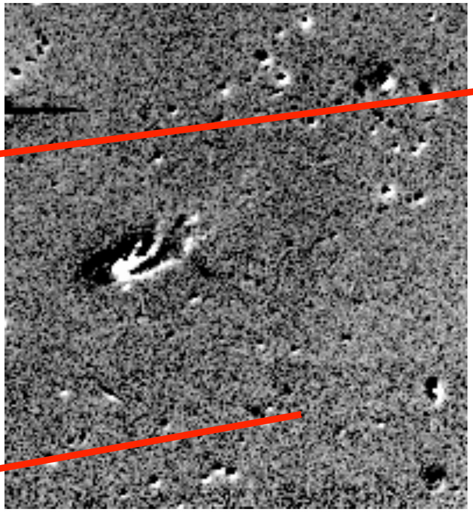
Coma Subaru 2014

Gavazzi





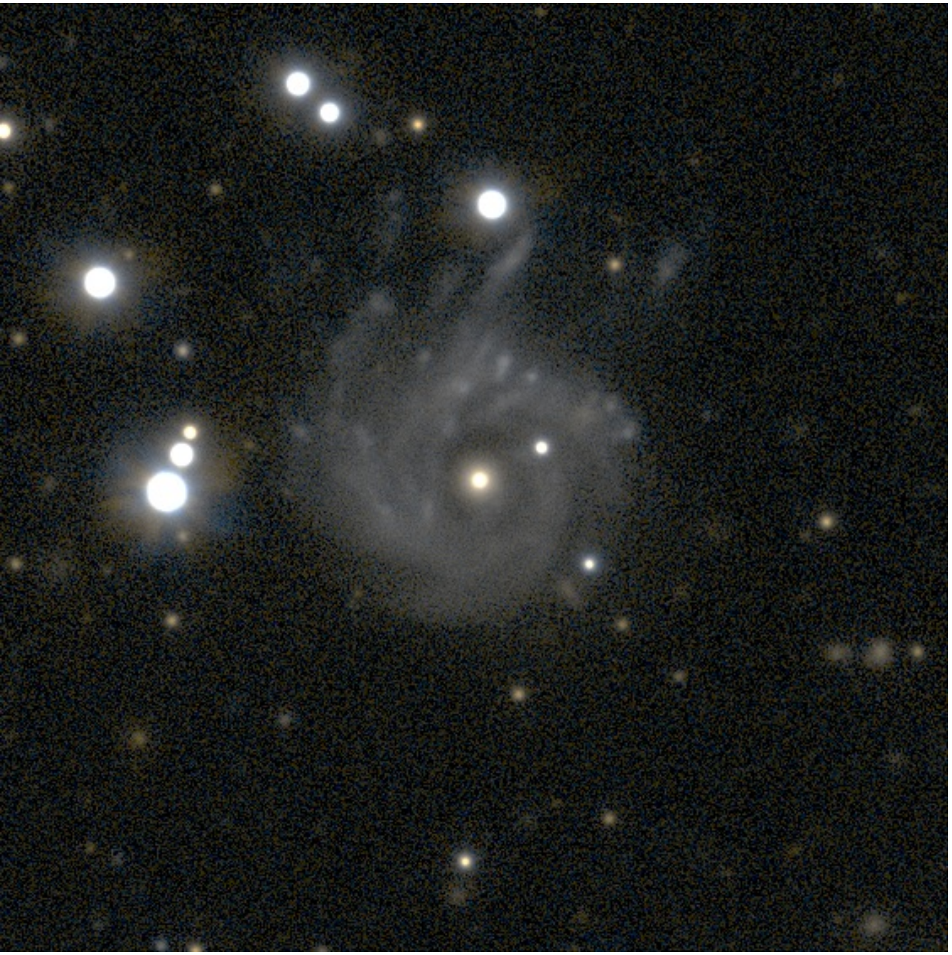


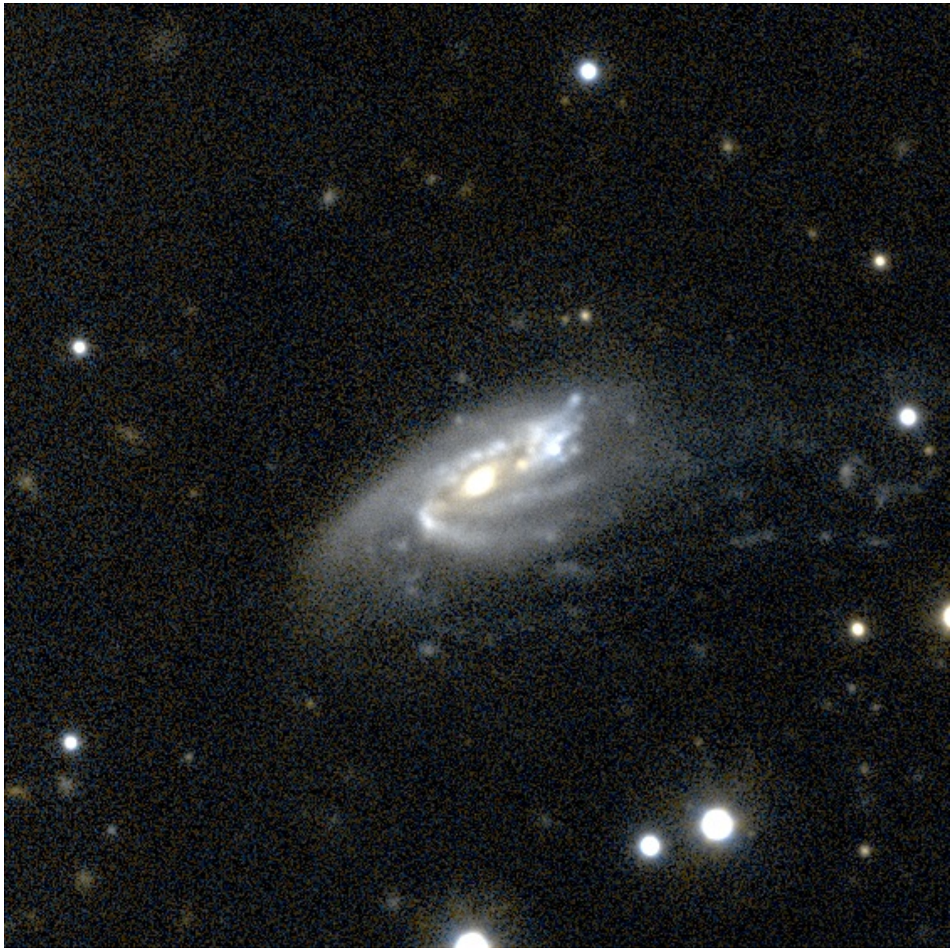


27/64 (42%) LTGs display extended asymmetric ionized gas!

“JELLYFISH” GALAXIES IN OMEGAWINGS

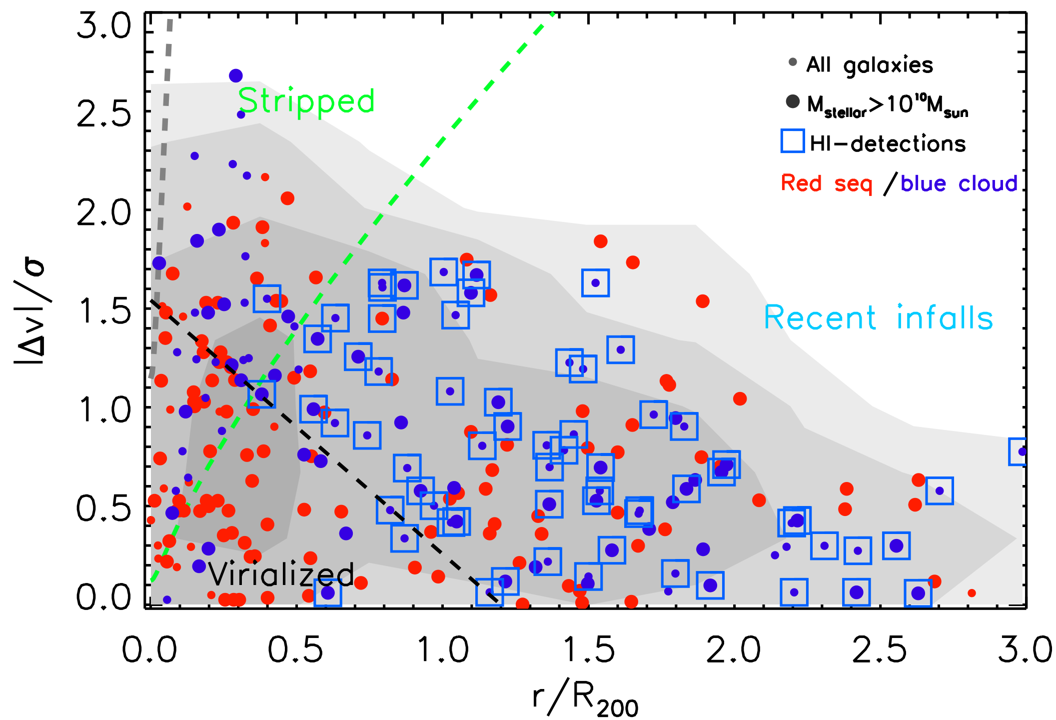
Poggianti





In prep.

COMPARING WITH A SIMPLE RAM PRESSURE MODEL



Poggianti (also Cybulski)

a simple model following Gunn & Gott prescription, a beta cluster model and galaxy parameters for the Milky Way

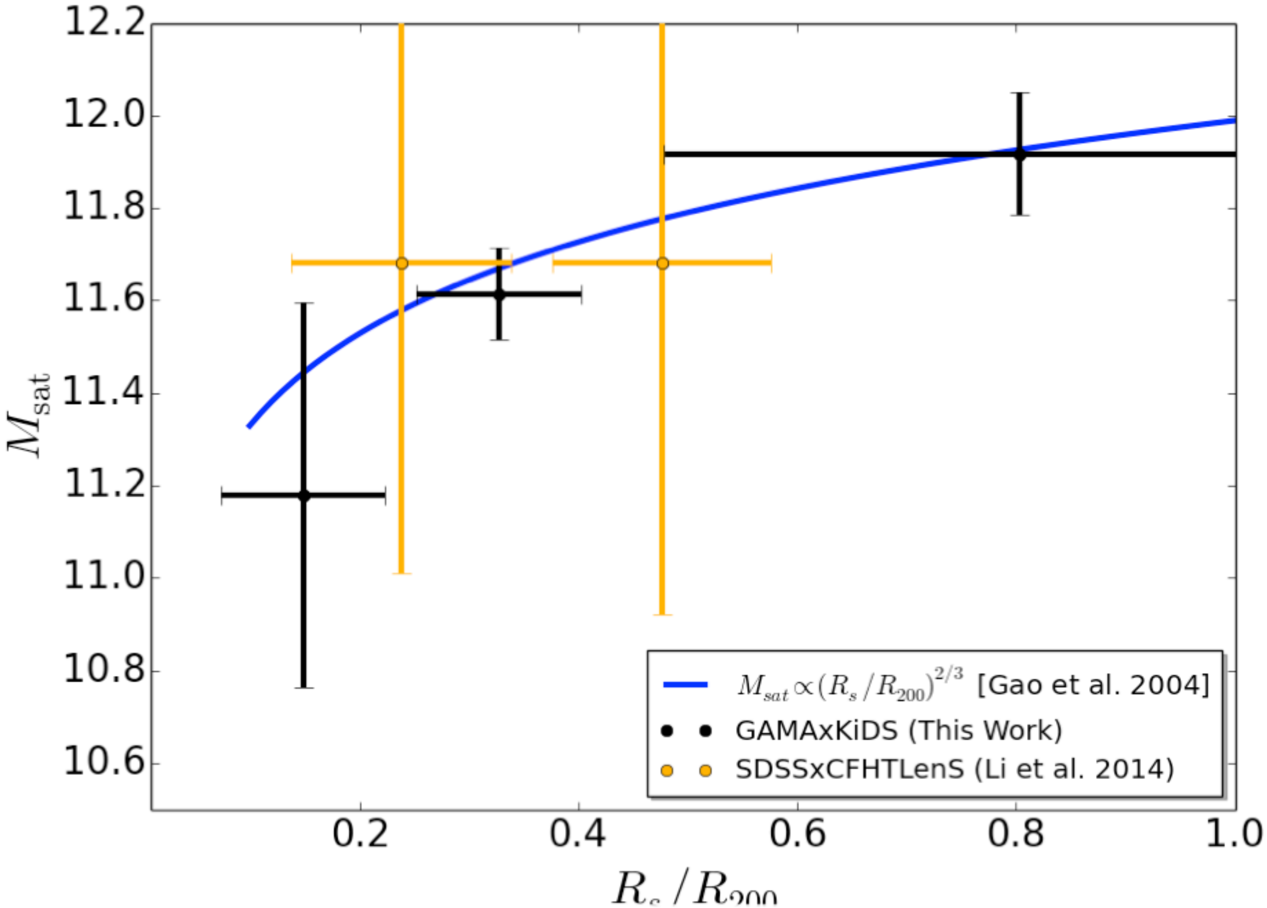
Dashed grey line: to the left of which MW-like galaxies are expected to be completely stripped of HI gas

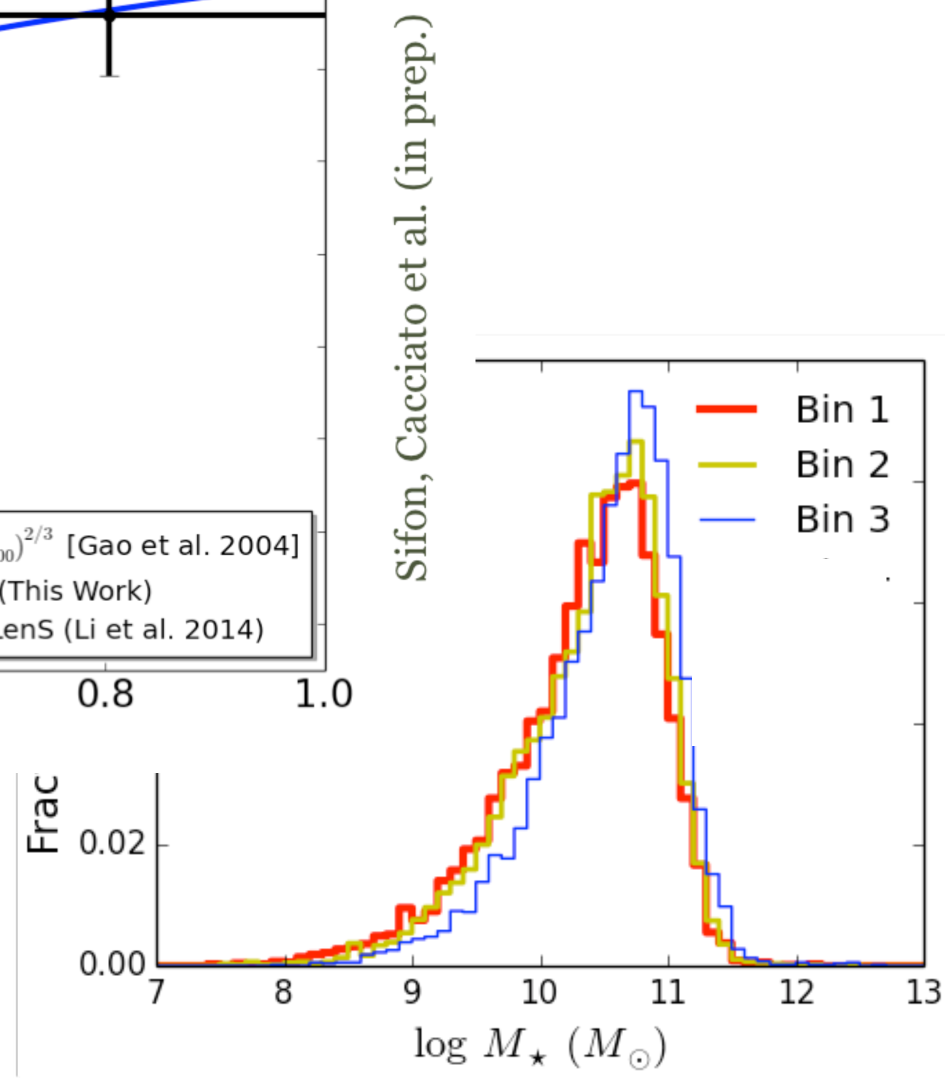
Solid green where galaxies are stripped enough to fall below our HI detection limit

These are effects on first infall galaxies

"Virialized region roughly at r<R200 and Av<1.5sigma, where many of the galaxies have passed pericenter more than once, thus have been in the cluster for > 2 Gyr

Stripping in action?





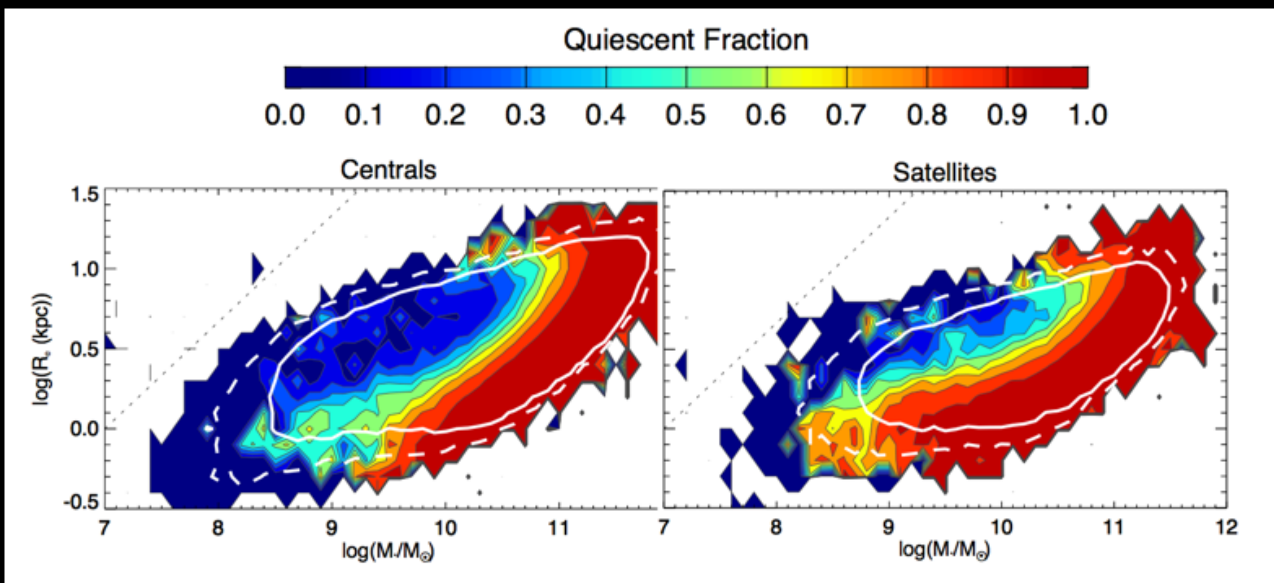
Cacciato

Central galaxies

Quenching: a stronger function of central stellar mass **density** (bulge) rather than stellar mass

Omand+ 2014

Effective Radius



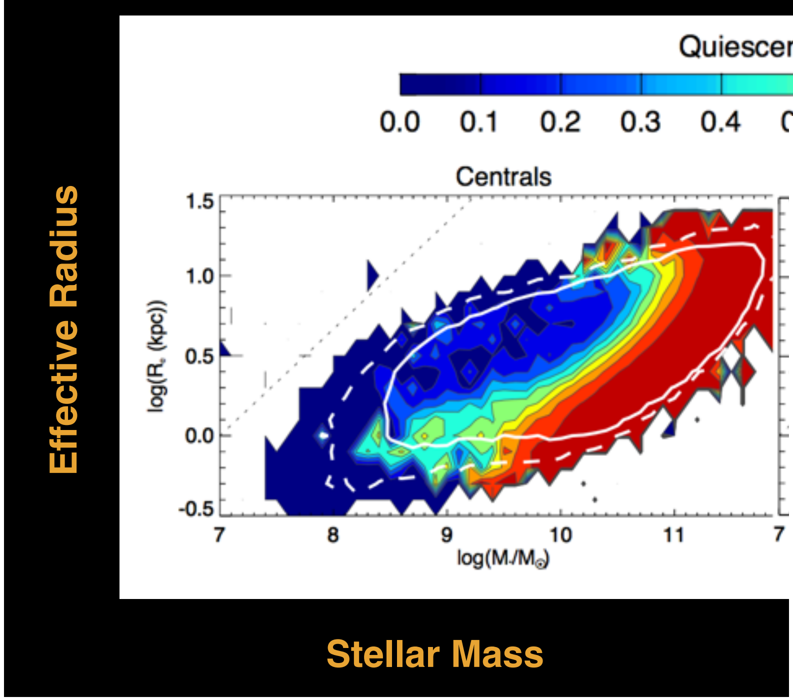
Stellar Mass   Stellar Mass

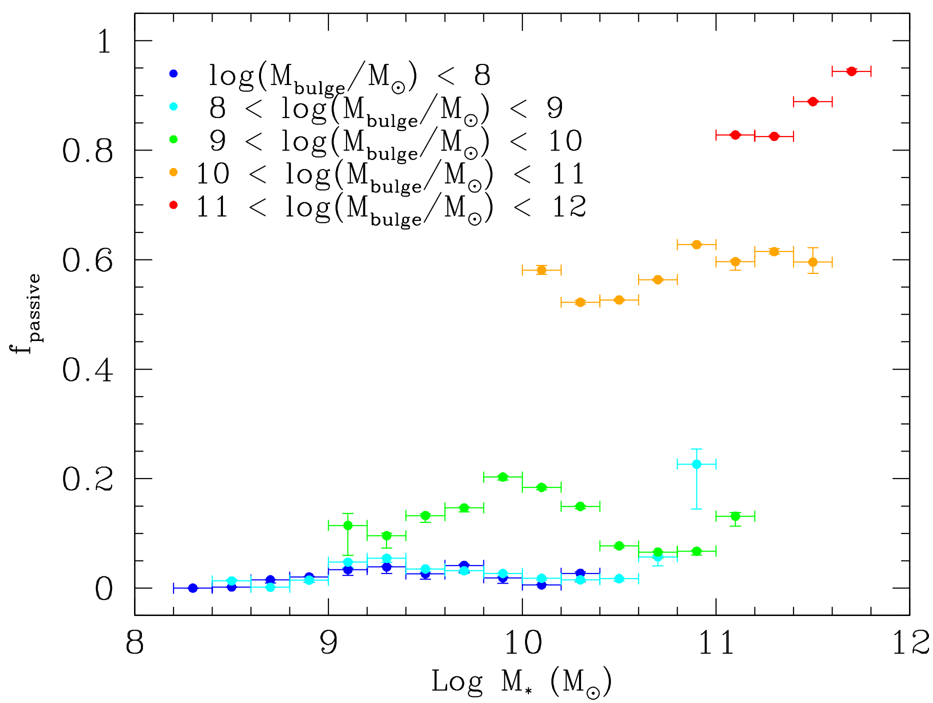
Tremonti

Central galaxies

Quenching: a stronger function of central stellar mass **density** (bulge) rather than stellar mass

Omand+ 2014





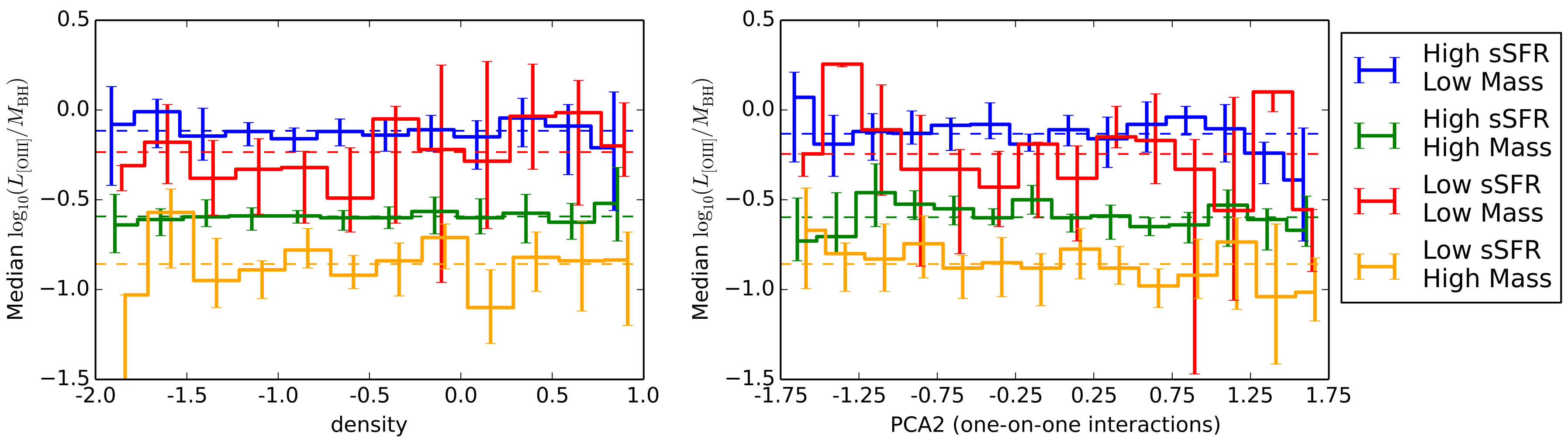
Tremonti

Bluck et al. 2014

AGN and environment

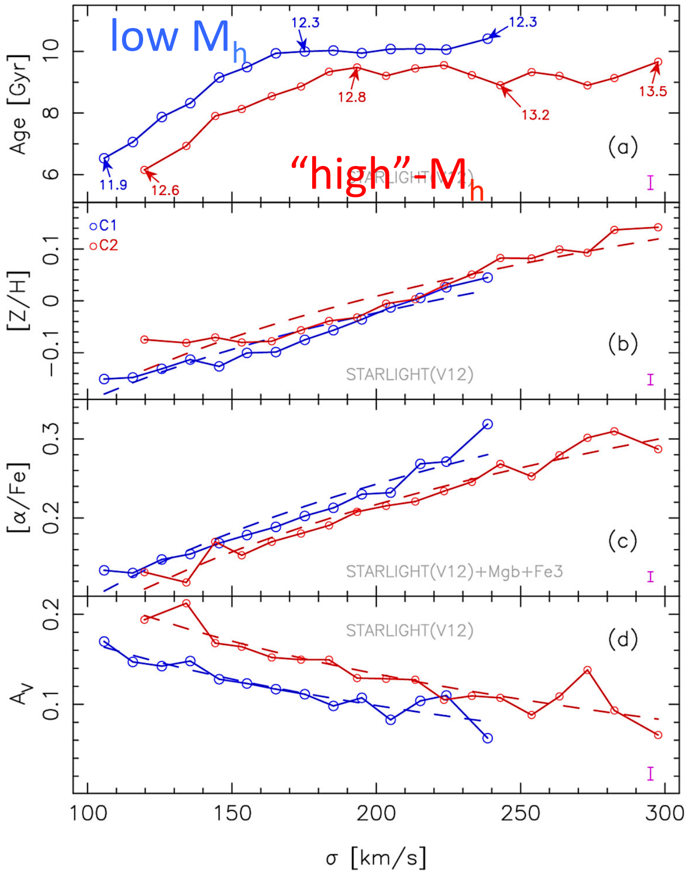
- Best: Radiative mode can keep the quenched galaxies quenched
- Sabater: (at fixed mass) decrease of optical AGN fraction and increase of the fraction of radio AGN in denser environments
- both enhanced by (one-on-one) galaxy interactions (Patton)
- with central star formation matched: only indirect effect of environment

Activity level



Central galaxies

Central ETGs



La Barbera

Centrals in "groups", i.e. with "high"-M_h (sample C2), have younger ages, higher [Z/H], lower [α/Fe], and higher A_V than those with low M_h (sample C1).

"ETGs in C2 underwent gas-rich interactions more than those in C1"

BCGs as special centrals

Yen-Ting Lin

central location controls how they feed

HST

BCGs as special centrals

Yen-Ting Lin

Ling: little stellar mass growth in real BCGs since z<0.5

Fraser-McKelvie: (WISE) SF in BCGs is rare

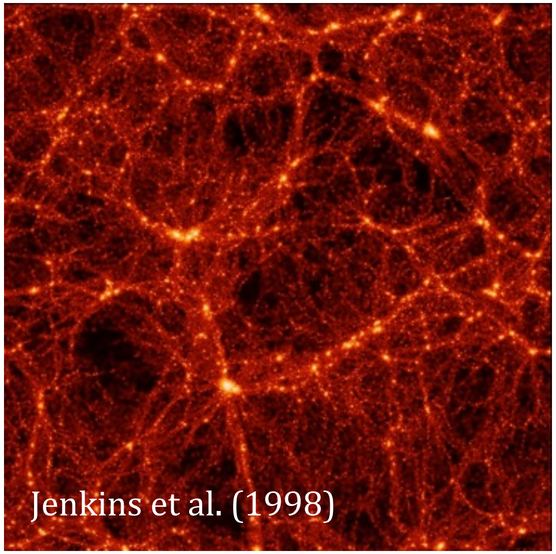
Zhao: cDs tend to be more massive and reside in higher densities than elliptical BCGs: cDs build-up through minor mergers?

central location controls how they feed

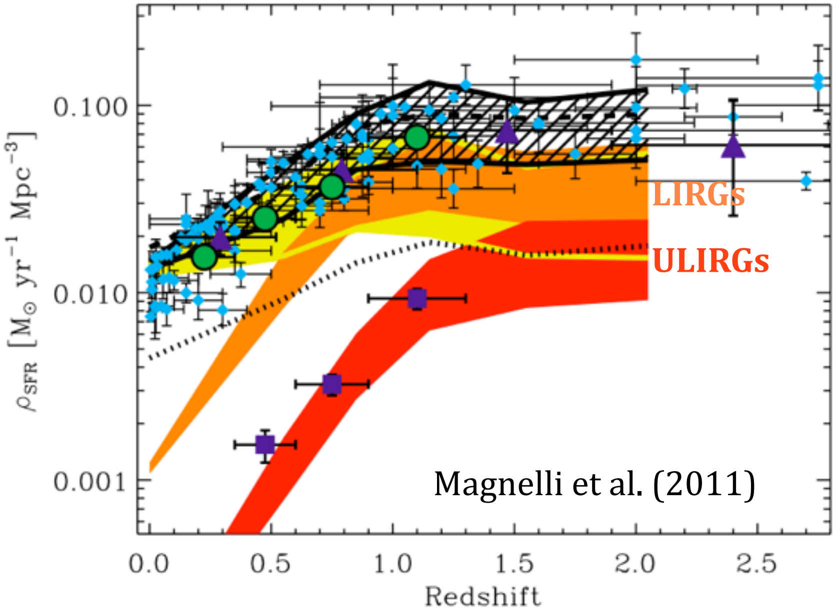
HST

What about mergers?

Saintonge: The old picture: merger-driven galaxy evolution



Jenkins et al. (1998)

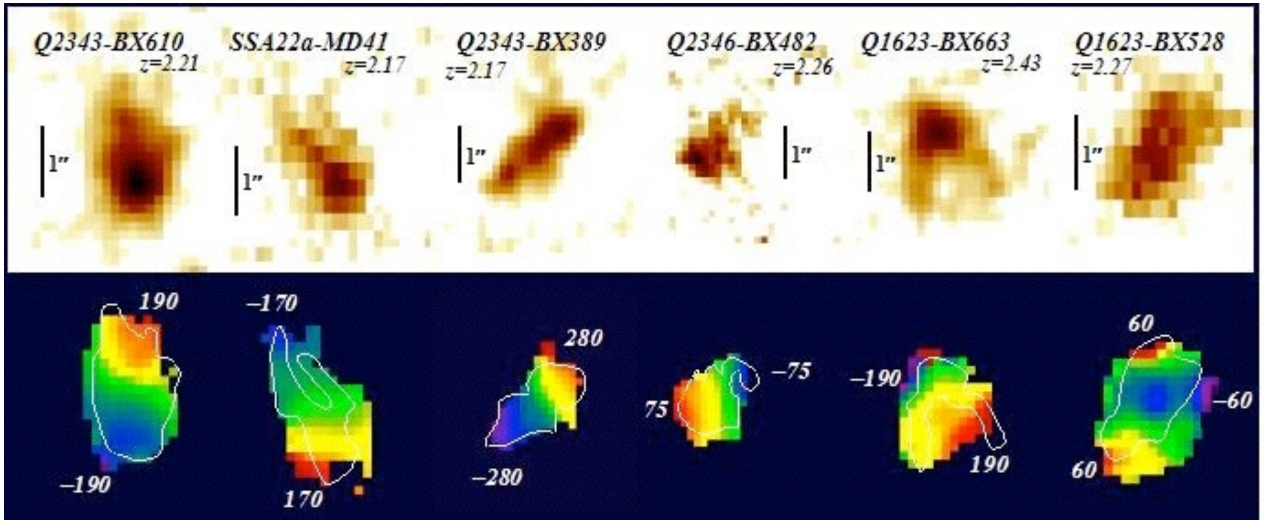


Magnelli et al. (2011)

from mid-80s to 5-10 years ago: merging of galaxies seen as the main driver of galaxy evolution

What about mergers?

Saintonge: The global picture: accretion-driven galaxy evolution



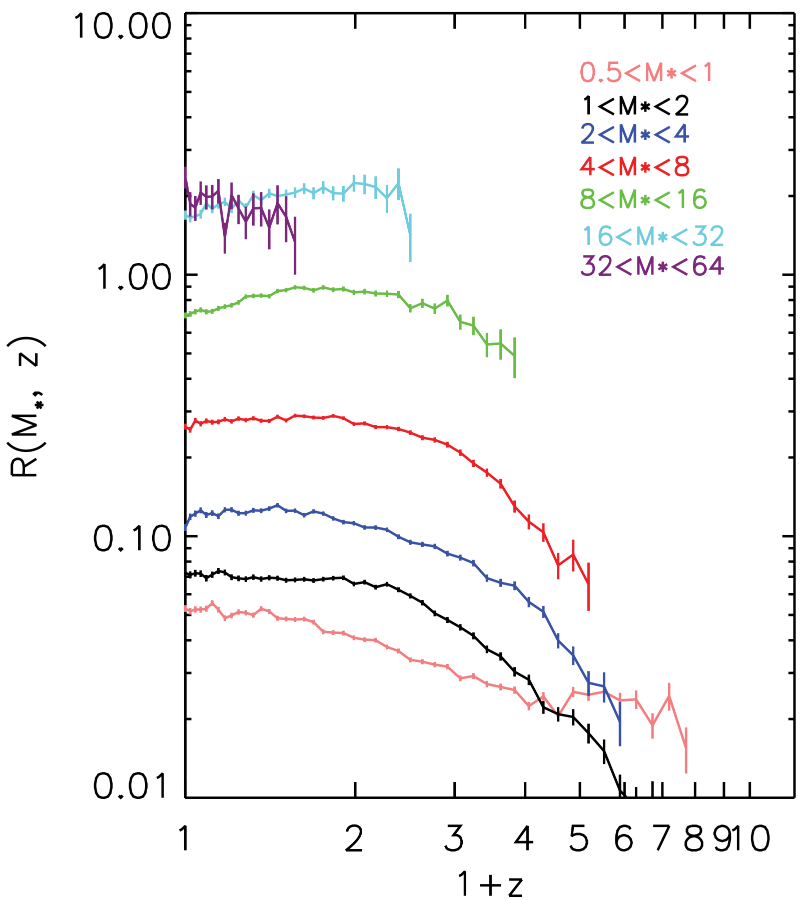
Forster Schreiber et al. (2006)

near-IR IFU work: z~2 galaxies with high SFRs are in large part well ordered discs, and not major mergers.

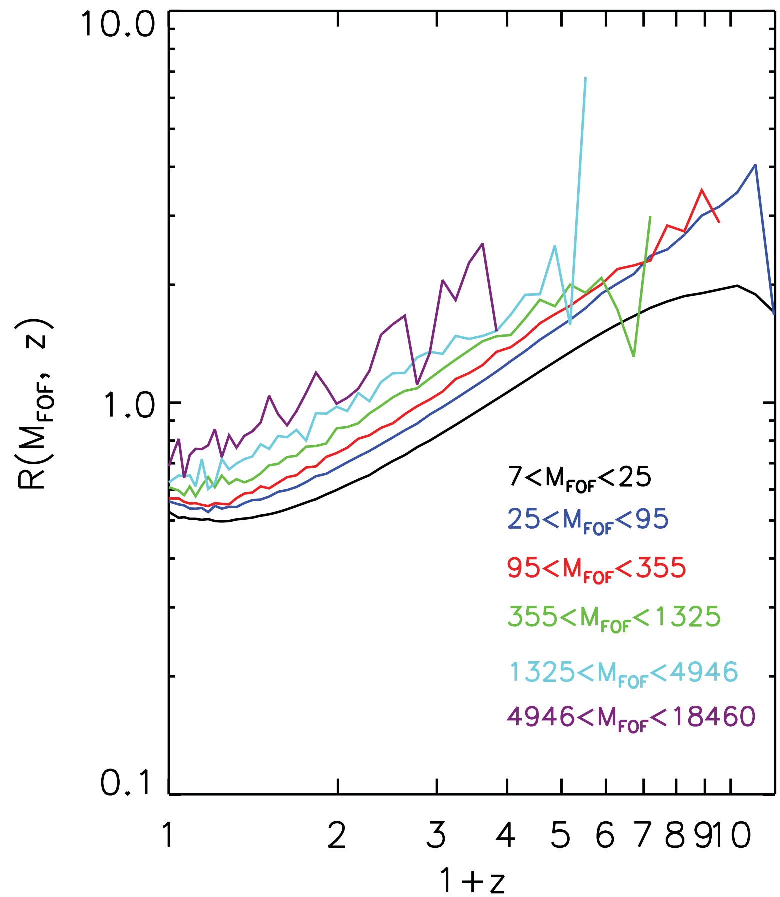
What about mergers?

Specific rate of formation through major mergers

galaxies



DM haloes



Guo&White 2008

Discussion

- Importance of mergers/interactions
- Structure/morphological transformation w.r. to mass and environmental quenching
- Quenching timescales
- Growth of structure
- Overall quenching?

THANKS to the Organizers...

...and have a safe journey home!