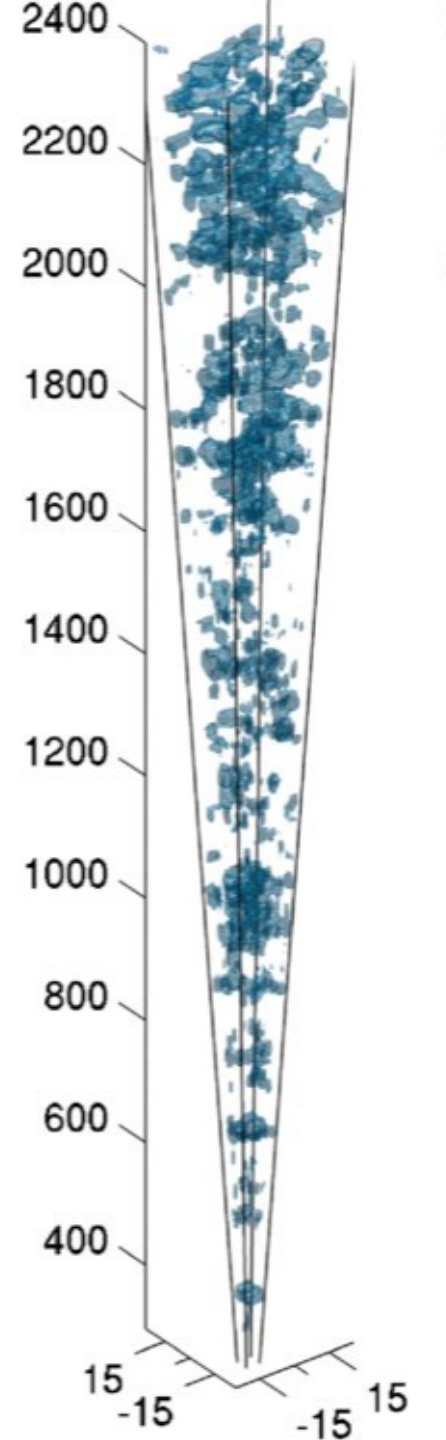
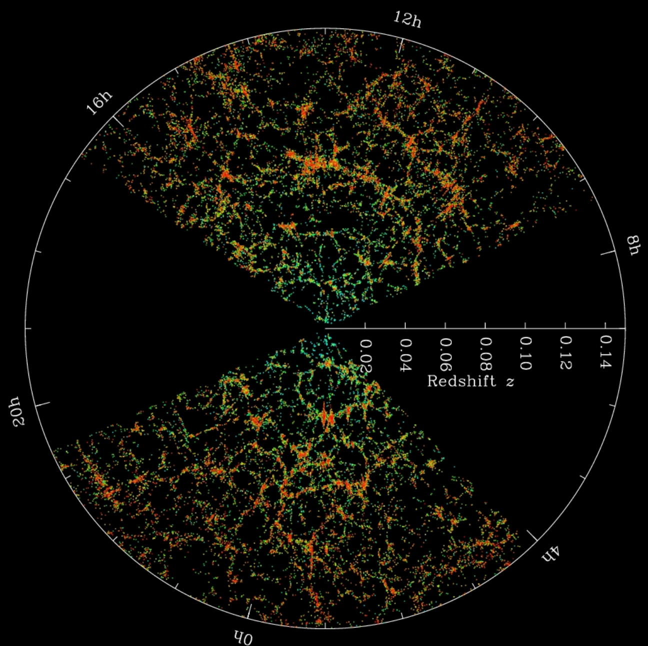


Satellite galaxies are the main drivers of the overall environmental effects at least up to z≈0.7

Katarina Kovač (ETH Zürich)

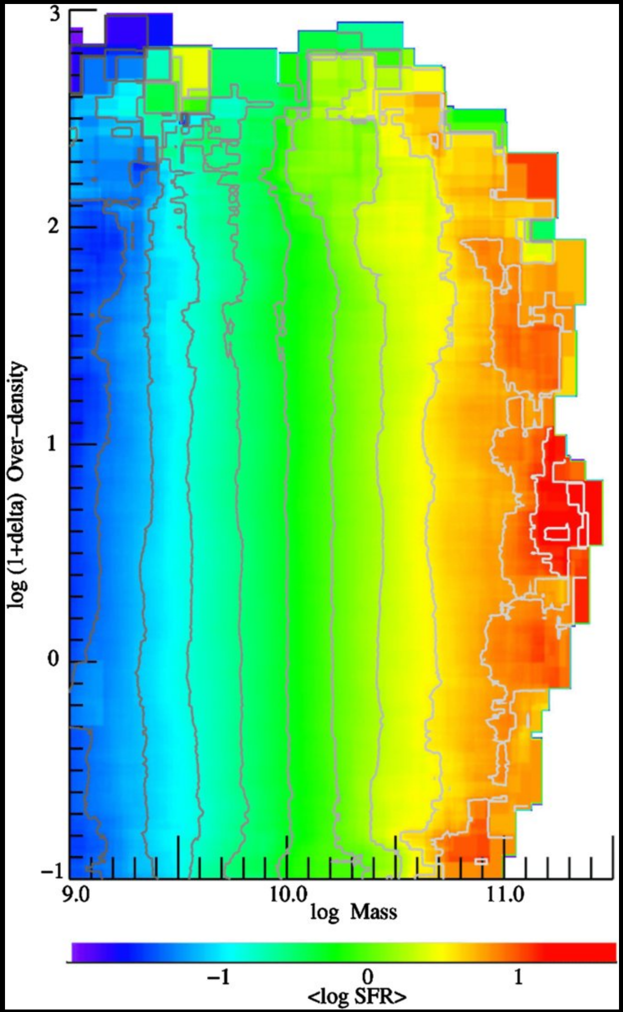
Galaxy evolution in a nutshell

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



Credit: SDSS

Galaxy evolution in a nutshell



Peng, Lilly, Kovač et al. 2010

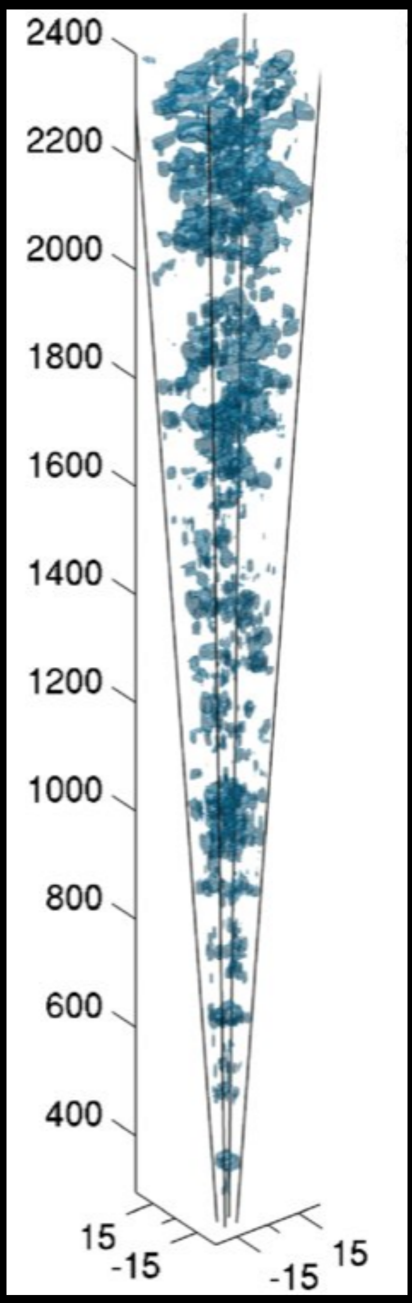
- (s)SFR of star-forming galaxies not dependent on environment (Peng et al. 2010, McGee et al. 2014)
- Galaxy property-environment relations well studied at z=0; recently extended to z<1, 1.5

Overview

- Review the colour-density relation at intermediate z, focus on the role of satellites
- Based on the final zCOSMOS-bright (i < 22.5) data set; about 17,000 galaxies with reliable redshift in 0<z<1
- Two environment indicators: local overdensity (Kovač et al. 2010, 2014) and dichotomous samples of centrals and satellites (Knobel et al. 2012)

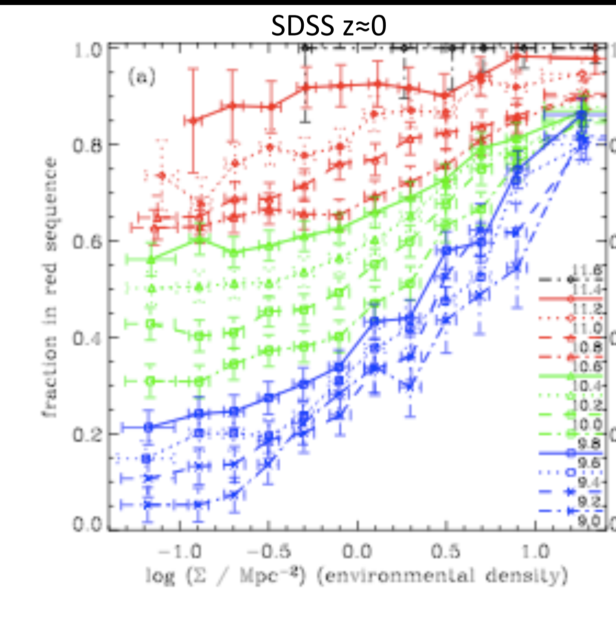
Collaborators: Simon Lilly, Christian Knobel, zCOSMOS and COSMOS teams

$1 + \delta = 3$

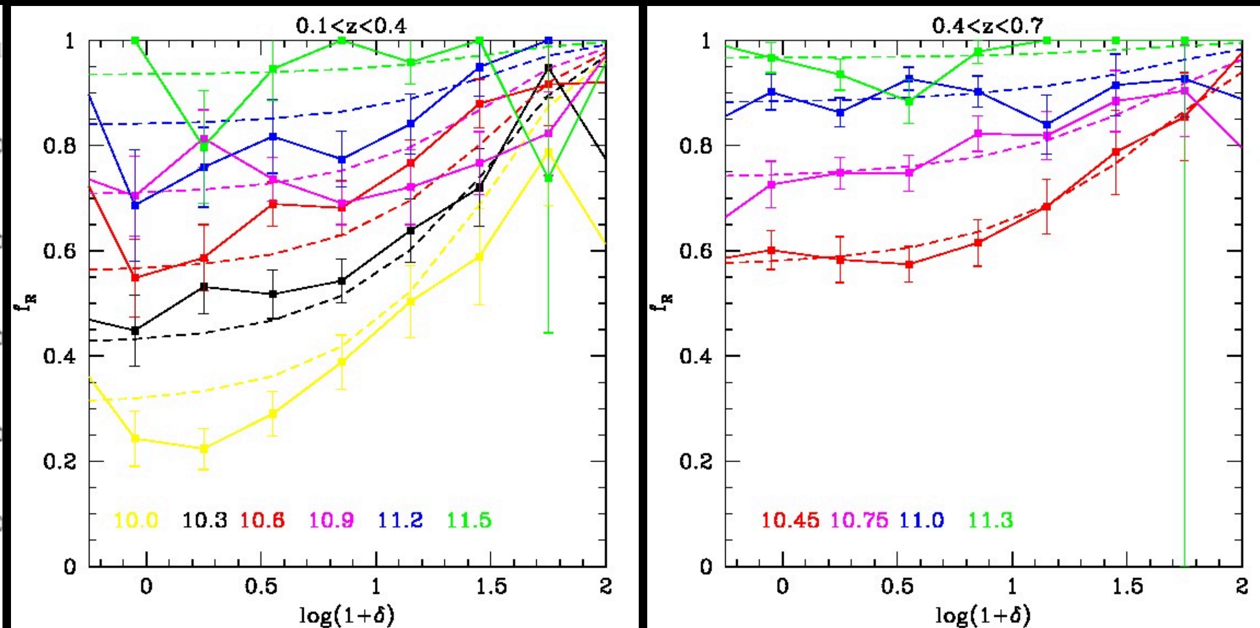


Kovač et al. (2010)

Colour-density relation for all galaxies



Baldry et al. 2006



Kovač et al. (2014)

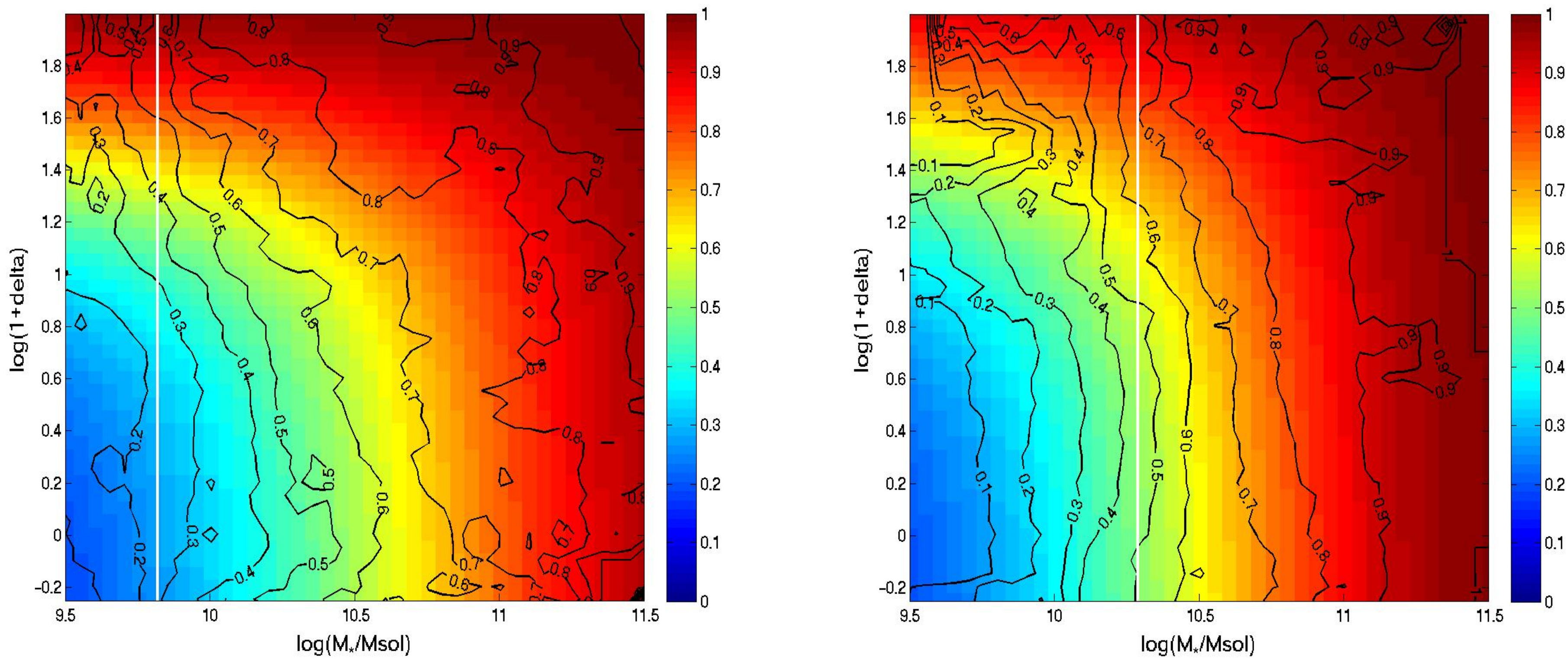
Red fraction of galaxies depends both on stellar mass and environment at least up to z=0.7.

This is consistent with the previous zCOSMOS work based on the smaller data-set (Cucciati et al. 2010) , and it is in qualitative agreement with the colour-density relations reported in the literature.

Differential effect of stellar mass and environment in 0.1<z<0.7

Functional form for the red fraction at z=0 (Baldry et al. 2006, see also Peng et al. 2010) :

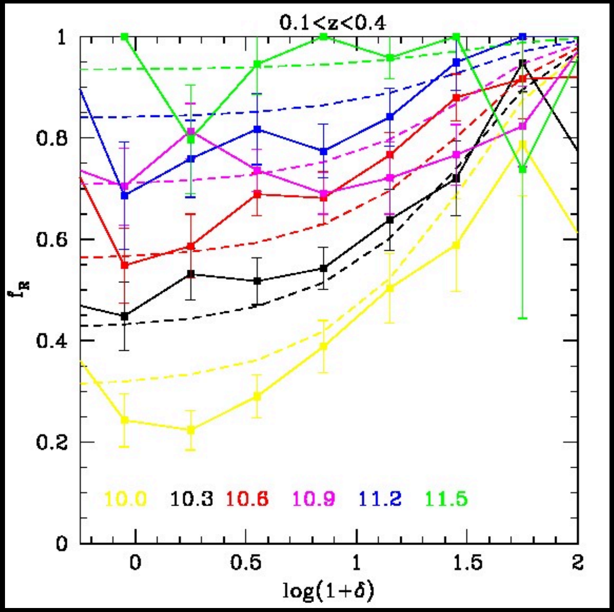
$$f\_red(\delta, M_*) = 1 - \exp[(-((\delta/p1)^{p2}) - ((M_*/p3)^{p4})] = \varepsilon_m(M_*) + \varepsilon_\rho(\delta) - \varepsilon_m(M_*)\varepsilon_\rho(\delta)$$



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

Kovač et al. 2014

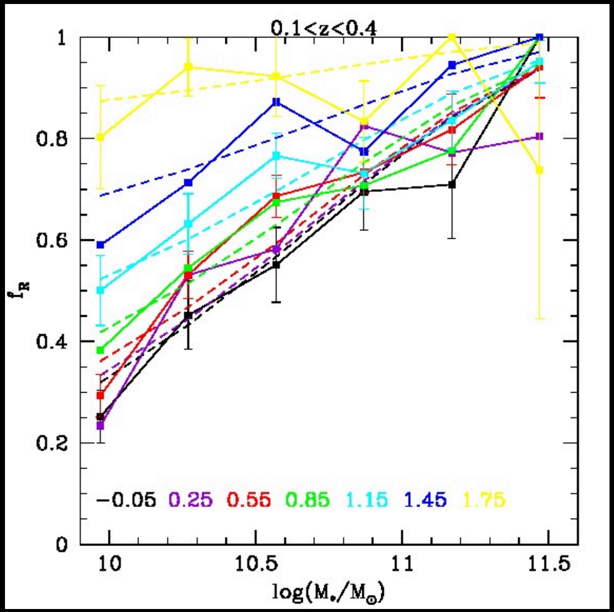
Mass and environmental quenching efficiencies



Mass quenching:

$\varepsilon_m = 1 - \exp(-(M_*/p3)^{p4}) =$

$[f_{red}(M_*,\delta) - f_{red}(M_{*0},\delta)]/[f_{blue}(M_{*0},\delta)]$



Environmental quenching:

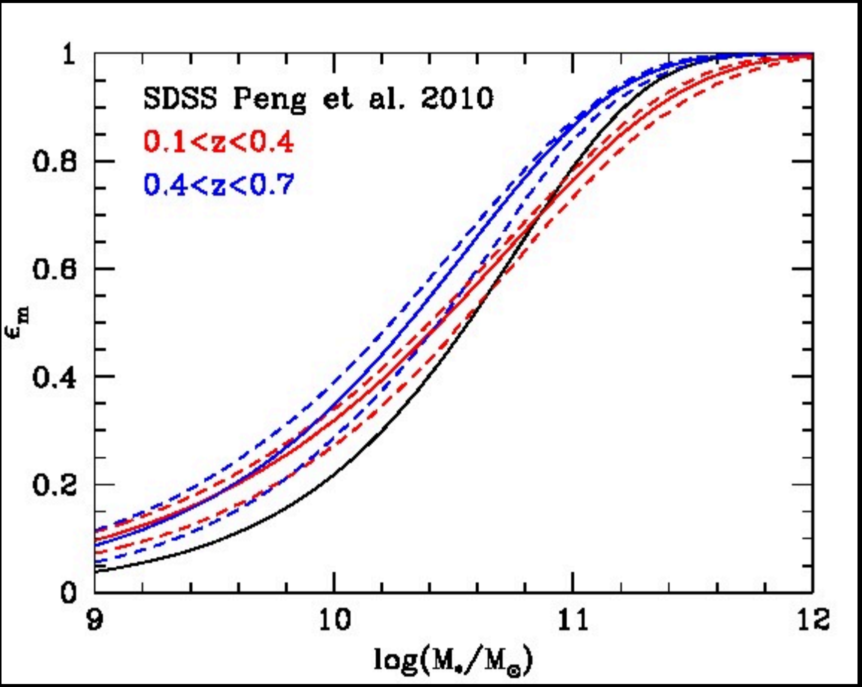
$\varepsilon_\rho = 1 - \exp(-(\delta/p1)^{p2}) =$

$[f_{red}(\delta, M_*) - f_{red}(\delta_0, M_*)]/[f_{blue}(\delta_0, M_*)]$

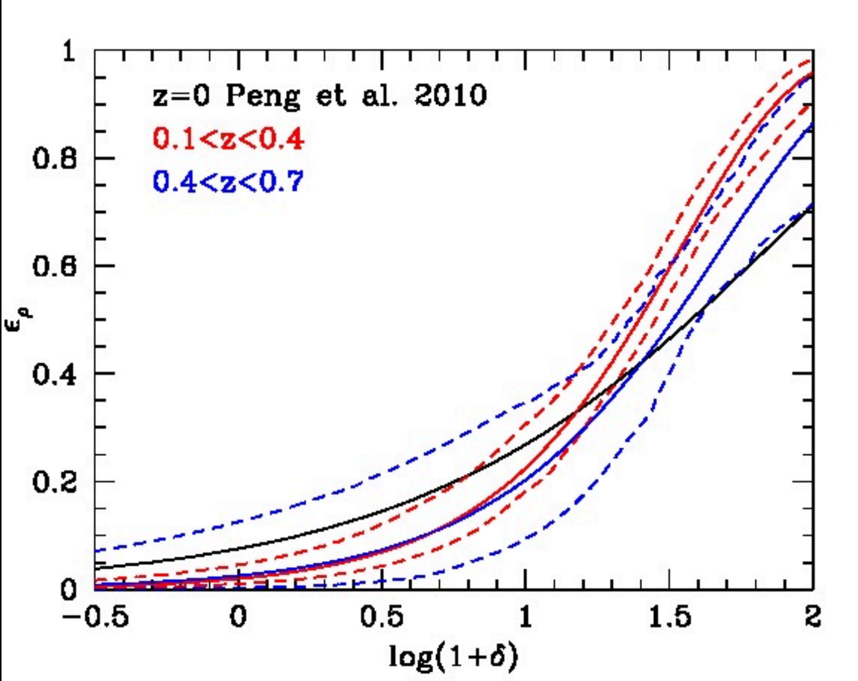
Kovač et al. 2014

Mass and environmental quenching over time

Mass quenching



Environmental quenching

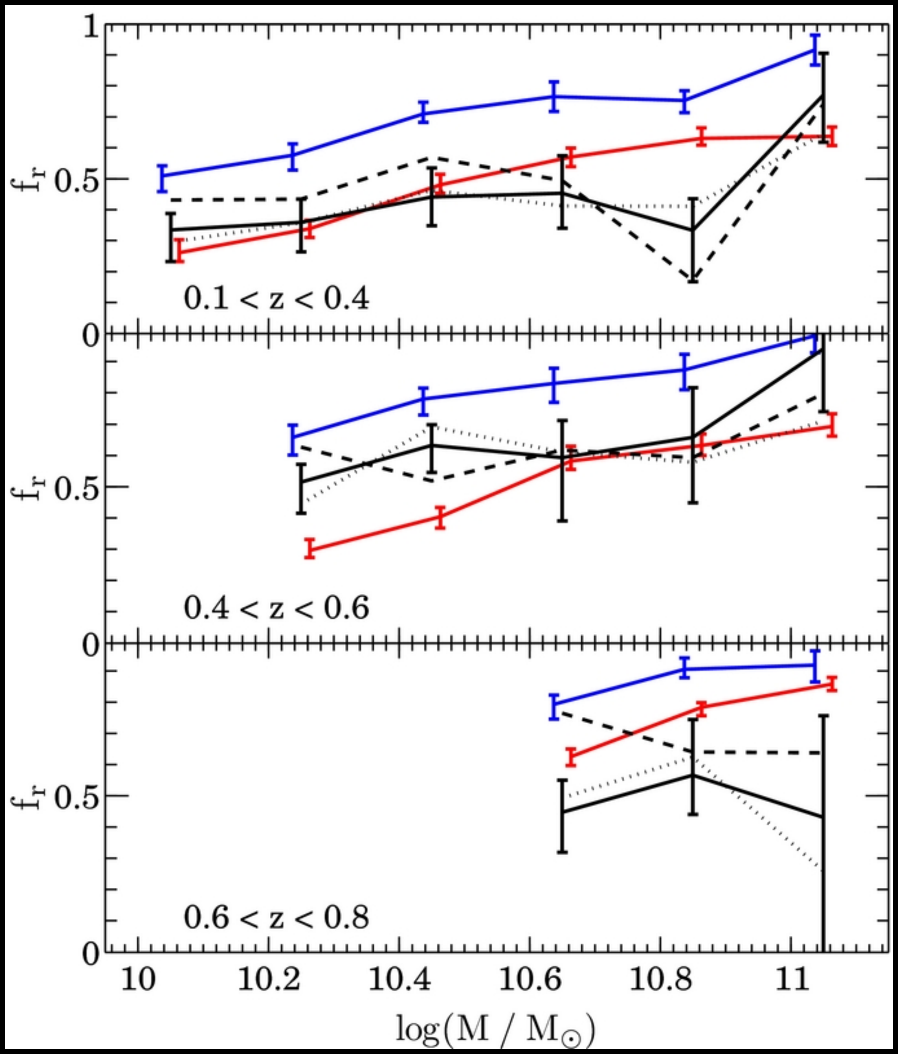


Constancy over time: physical processes responsible for quenching act in the same way over time

Dominant mechanism for quenching of galaxies changes with time

Kovač et al. 2014

Central/satellite dichotomy: satellite quenching f(mass) at 0.1<z<0.8



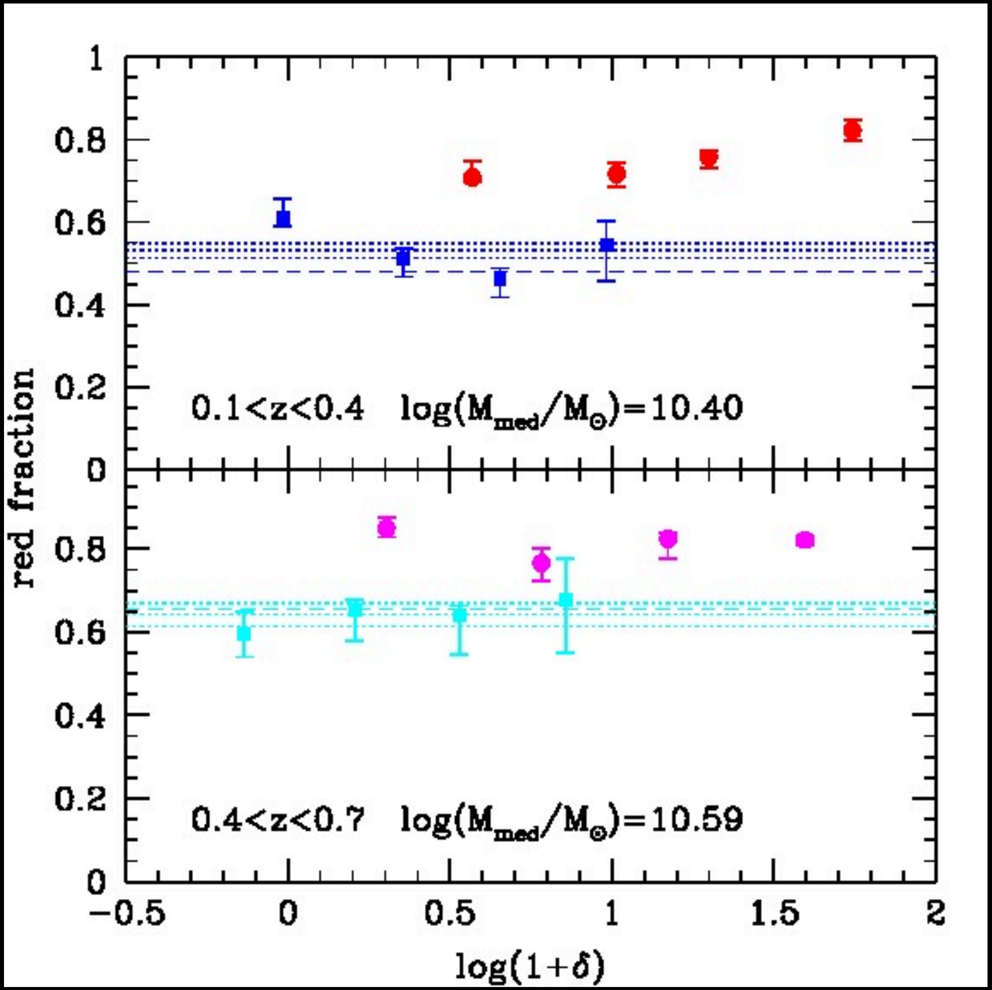
High-fidelity 20k zCOSMOS catalogue (Knobel et al. 2012)

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

Satellite quenching: constant at all masses, mirroring z~0 SDSS results; no evolution with redshift

Knobel, Lilly, KK+ et al. 2013

Fraction of red centrals and satellites as a function of local environment in 0.1<z<0.7



Analysis in the mass-matched samples to obtain reliable results

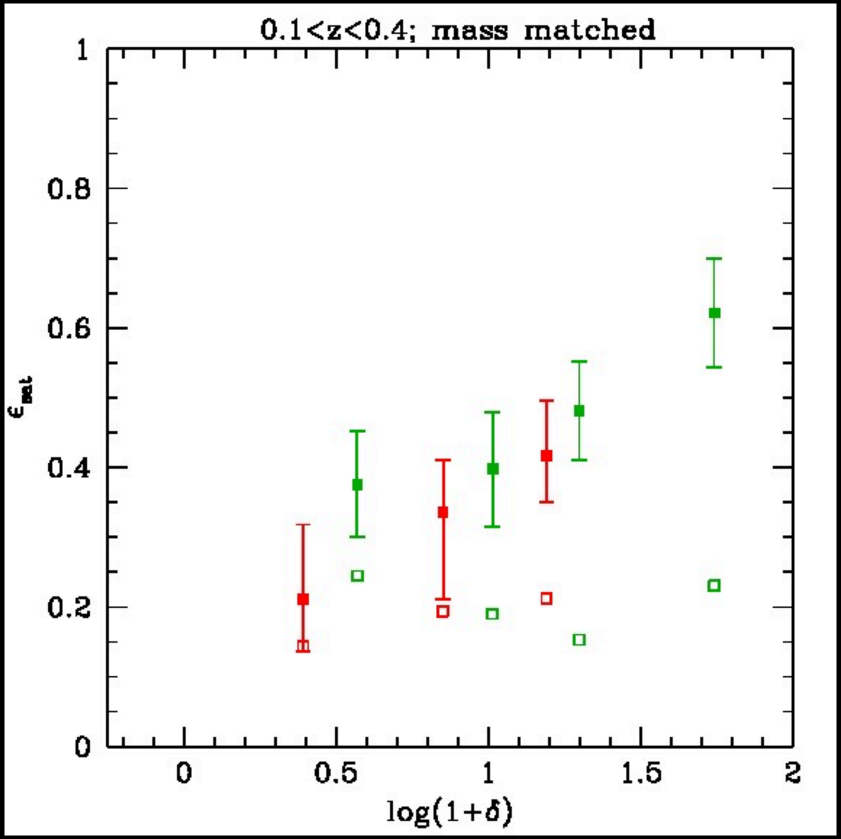
Centrals consistent with being independent of δ, i.e. fr,cen is consistent with ε_m (>95%) where f_red = $\varepsilon_m + \varepsilon_\rho - \varepsilon_m \varepsilon_\rho$

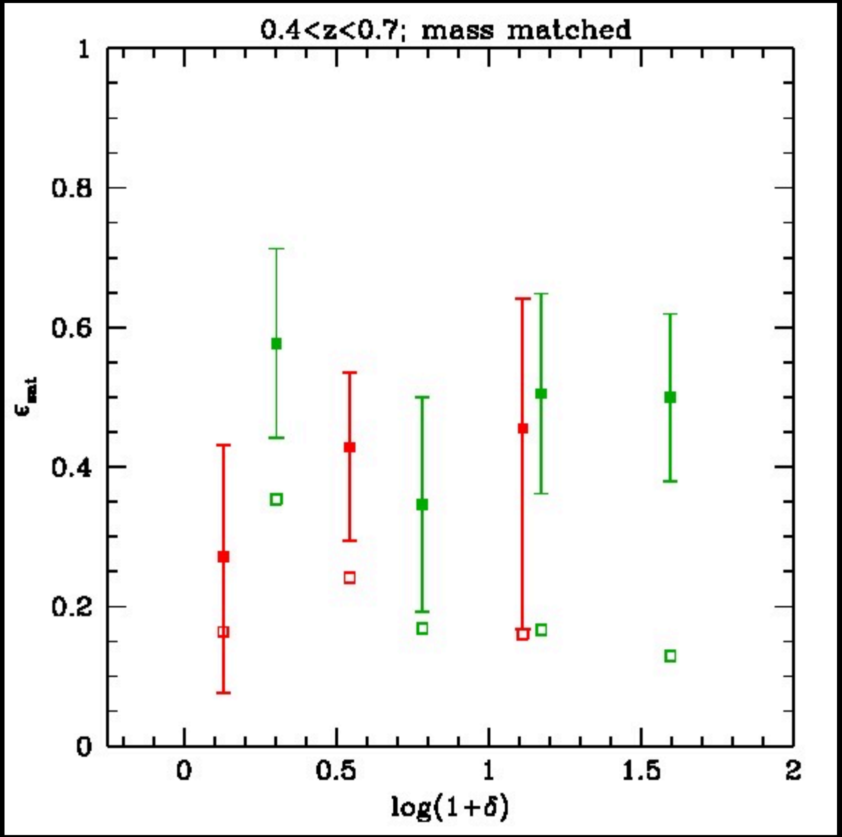
Red fraction of satellites require some additional form of quenching in addition to ε_m

Kovač et al. 2014

Central/satellite dichotomy: satellite quenching f(δ)

$$\varepsilon_{sat}(M_*,\delta) = [f_{r,sat}(M_*,\delta) - f_{r,cen}(M_*,\delta)]/[f_{b,cen}(M_*,\delta)]$$



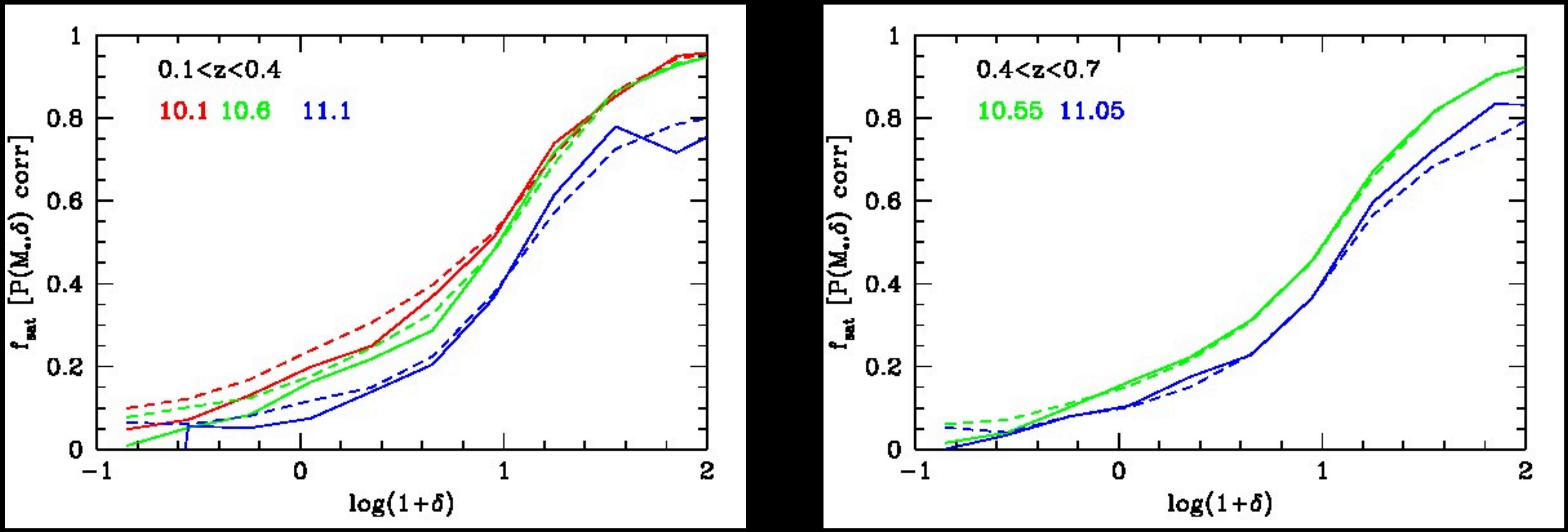


Satellite quenching: 0.1<z<0.4 increases with the overdensity; 0.4<z<0.7 large errors – but consistent with the lower redshift measurement

Kovač et al. 2014

Fraction of satellites as a function of local environment and mass in 0.1<z<0.7

$\varepsilon_\rho(\delta)$ increases with δ; if satellites are responsible for the environmental quenching then $\varepsilon_{sat}(M_*,\delta) = \varepsilon_\rho(\delta) / fsat(M_*,\delta)$

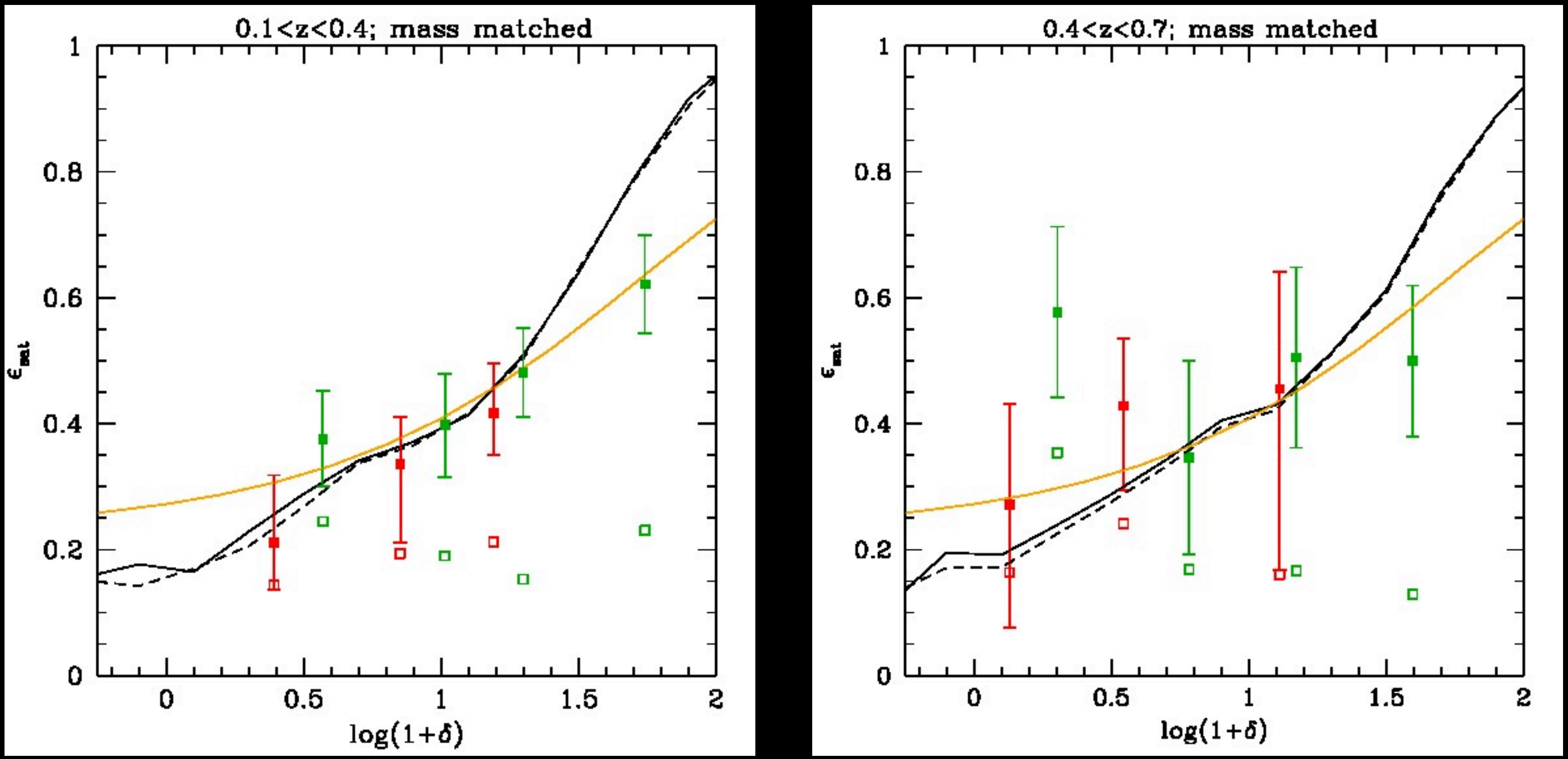


Fraction of satellites increases with the local overdensity;
slowly decreases with the stellar mass

Kovač et al. 2014

Central/satellite dichotomy: satellite quenching f(δ)

$$\varepsilon_{sat}(M_*,\delta) = [f_{r,sat}(M_*,\delta) - f_{r,cen}(M_*,\delta)]/[f_{b,cen}(M_*,\delta)]$$



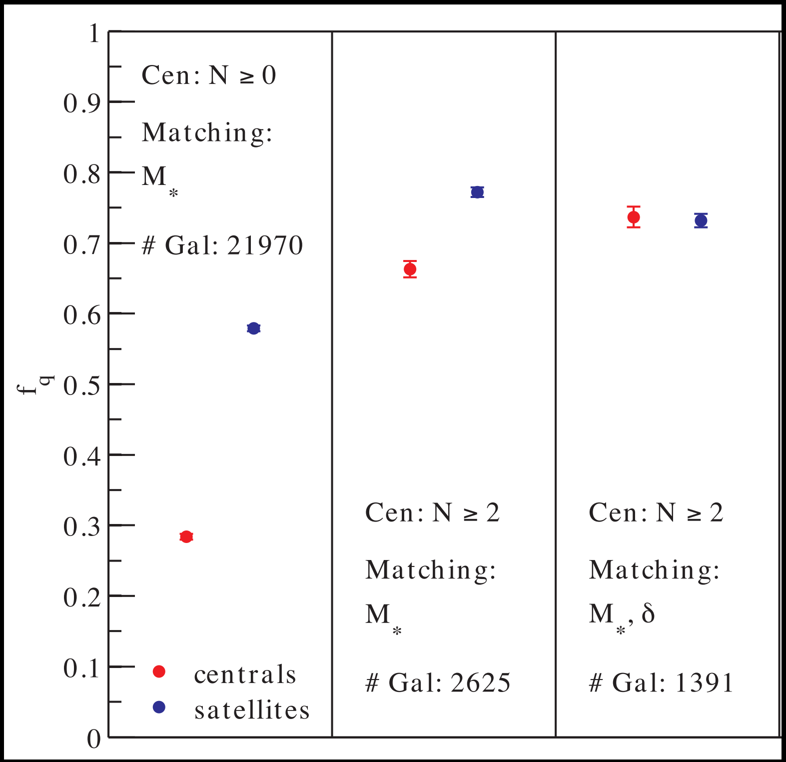
Satellite quenching: consistent with ε_ρ/fsat, when centrals are not dependent on environment; mirroring the z~0 SDSS (Peng et al. 2012) results

Satellites are the major drivers of the overall observed environmental differences up to z~0.7

Kovač et al. 2014

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

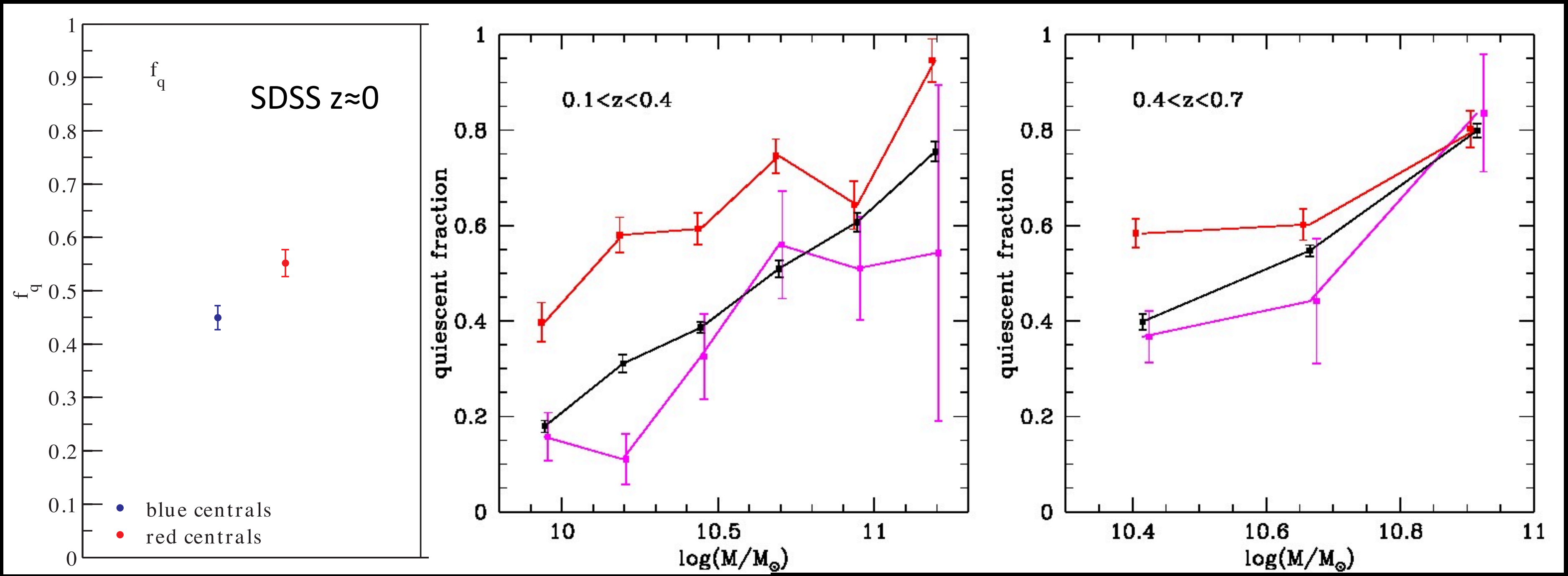
SDSS z≈0



Knobel C., in prep.

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



Knobel C.+, in prep.

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)

Conclusions

- red fraction in 0.1<z<0.7 appears to be separable in mass and environment, suggesting the existence of the two independent quenching mechanisms: mass quenching and environmental quenching
- the differential effect of these two mechanisms does not change with cosmic time and they appear to be essentially the same at z=0.7 as locally
- red fraction of centrals is consistent with being independent of overdensity
- red fraction of satellites requires additional quenching mechanism in addition to the mass quenching
- at the same mass and overdensity, satellites are redder; satellite quenching efficiency can explain majority of the overall environmental effects at least up to z=0.7
- given the associated uncertainties, our statements should be understood as approximations to physical reality, rather than physically exact formulae