Starburst-QSO-massive galaxy evolutionary stages: clustering, gas content, implications for feedback

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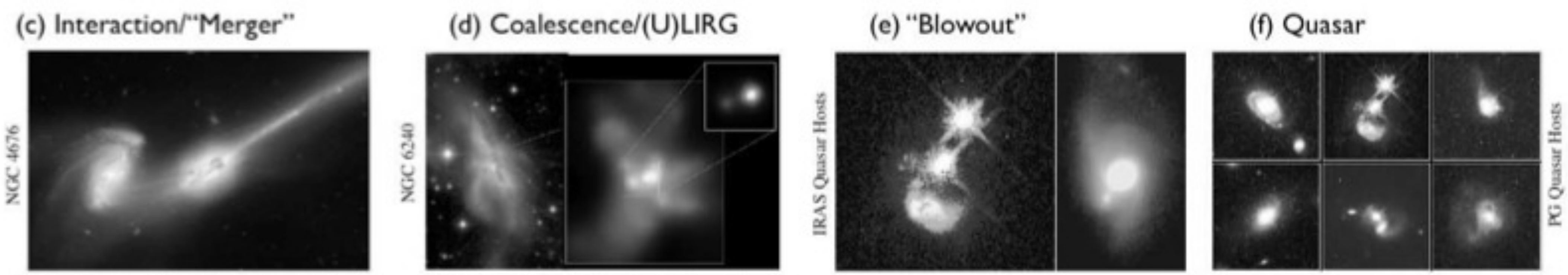
Stages of the massive galaxy life cycle

Local galaxies: above $L_{IR} \sim 10^{11} L_{sun}$ (SFR > 10), most are mergers.
However this may not be so at $z>1$, where high SFR galaxies are often disky, or at least not major mergers.

What can we tell about feedback and quenching mechanisms from properties of starburst, QSO, quiescent phases?

Ideas about feedback to make and keep red galaxies red:



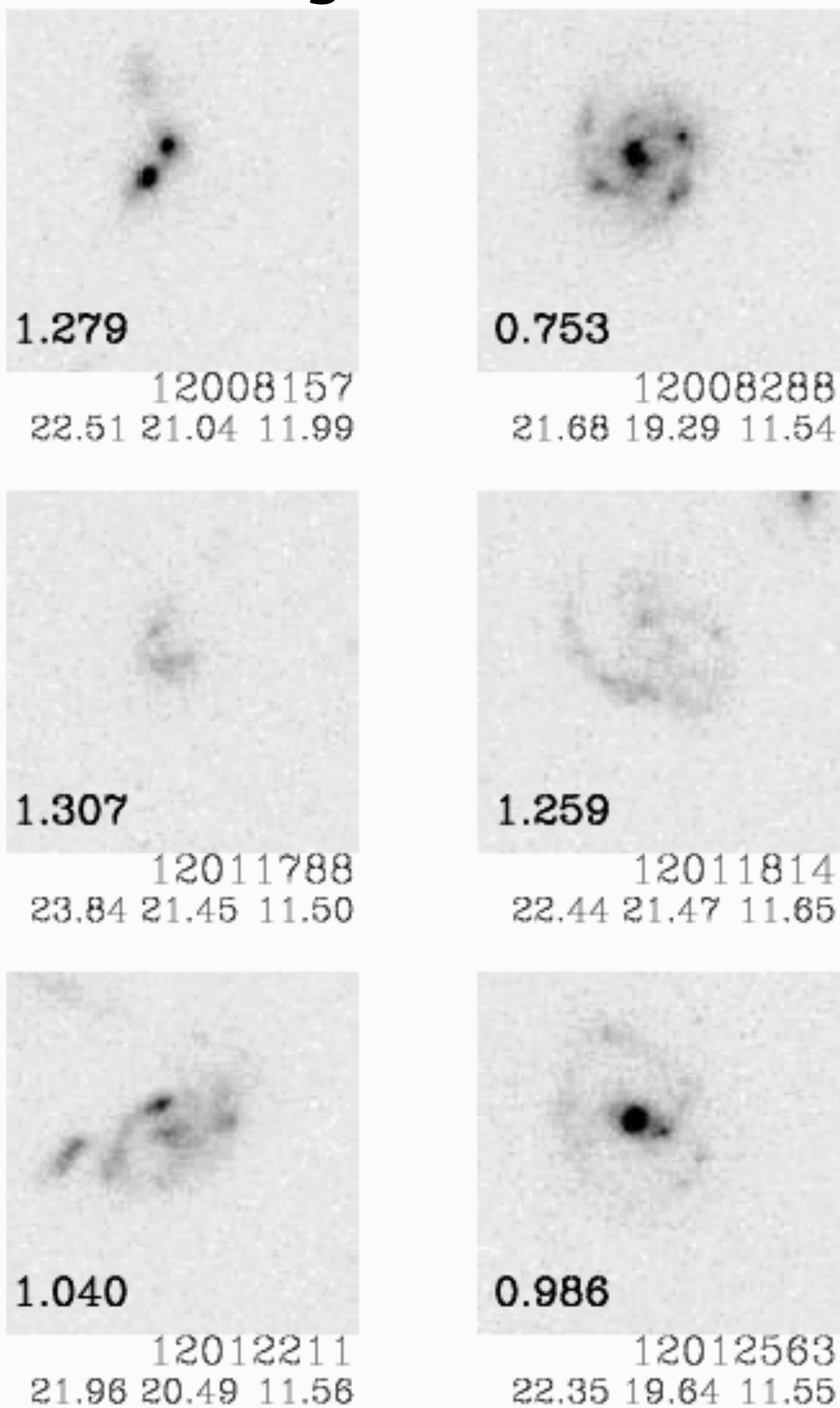
Hopkins+ 2008; also Sanders, etc

ejective or “quasar mode” - violently remove gas, quenching the galaxy.
Popular in merger -> ULIRG -> QSO -> elliptical scenario.
But not clear how to couple the QSO wind to the ISM efficiently.
 - Does this scenario actually happen? Test it with clustering.

preventive or “radio mode” - keep the hot gas in a massive galaxy heated to prevent cooling and star formation.
 - Use absorbers to probe gas content of massive galaxies.

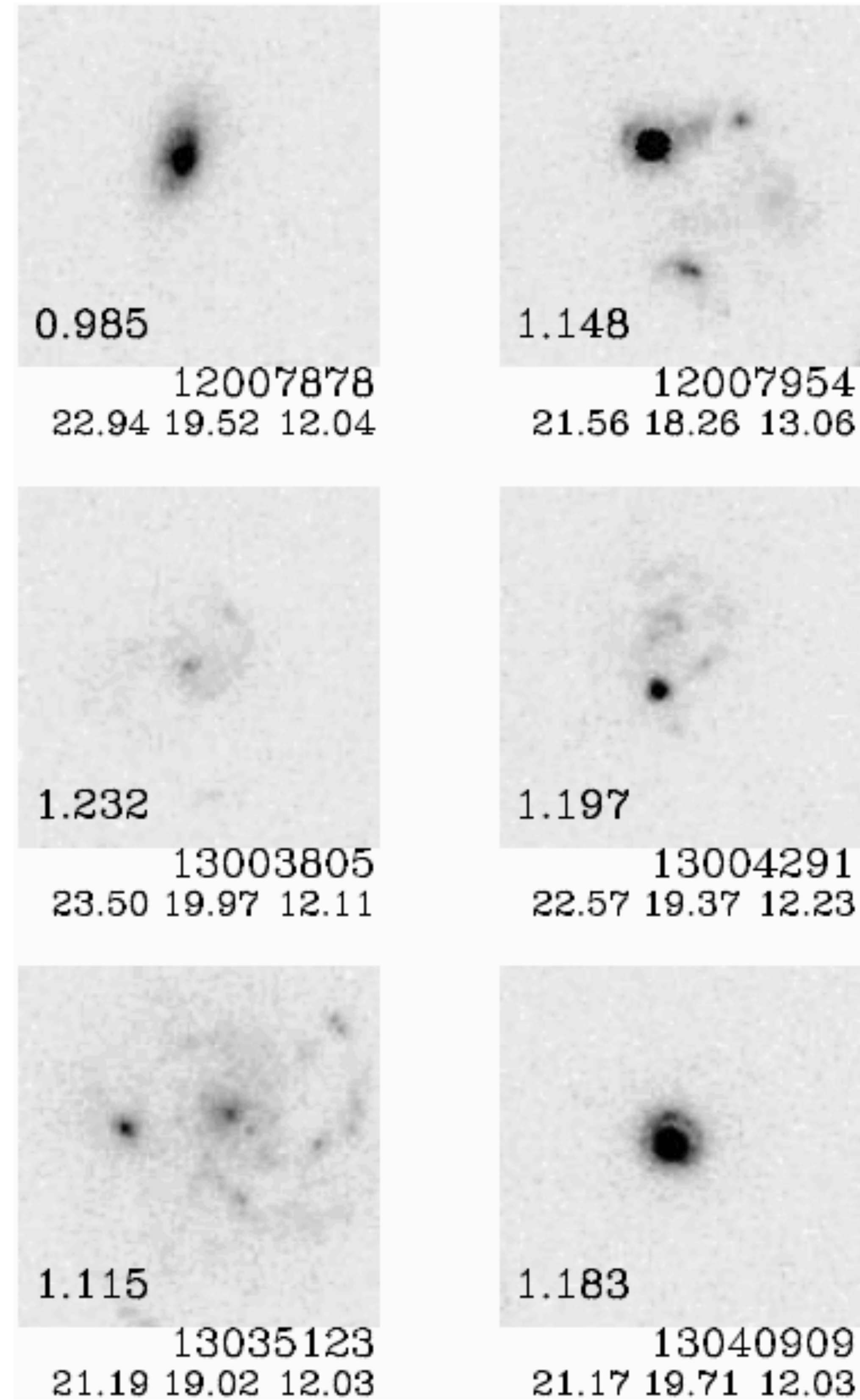
names of qso and radio mode are illustrative rather than definitive, and Darren Croton’s fault

Some bright LIRGs in EGS



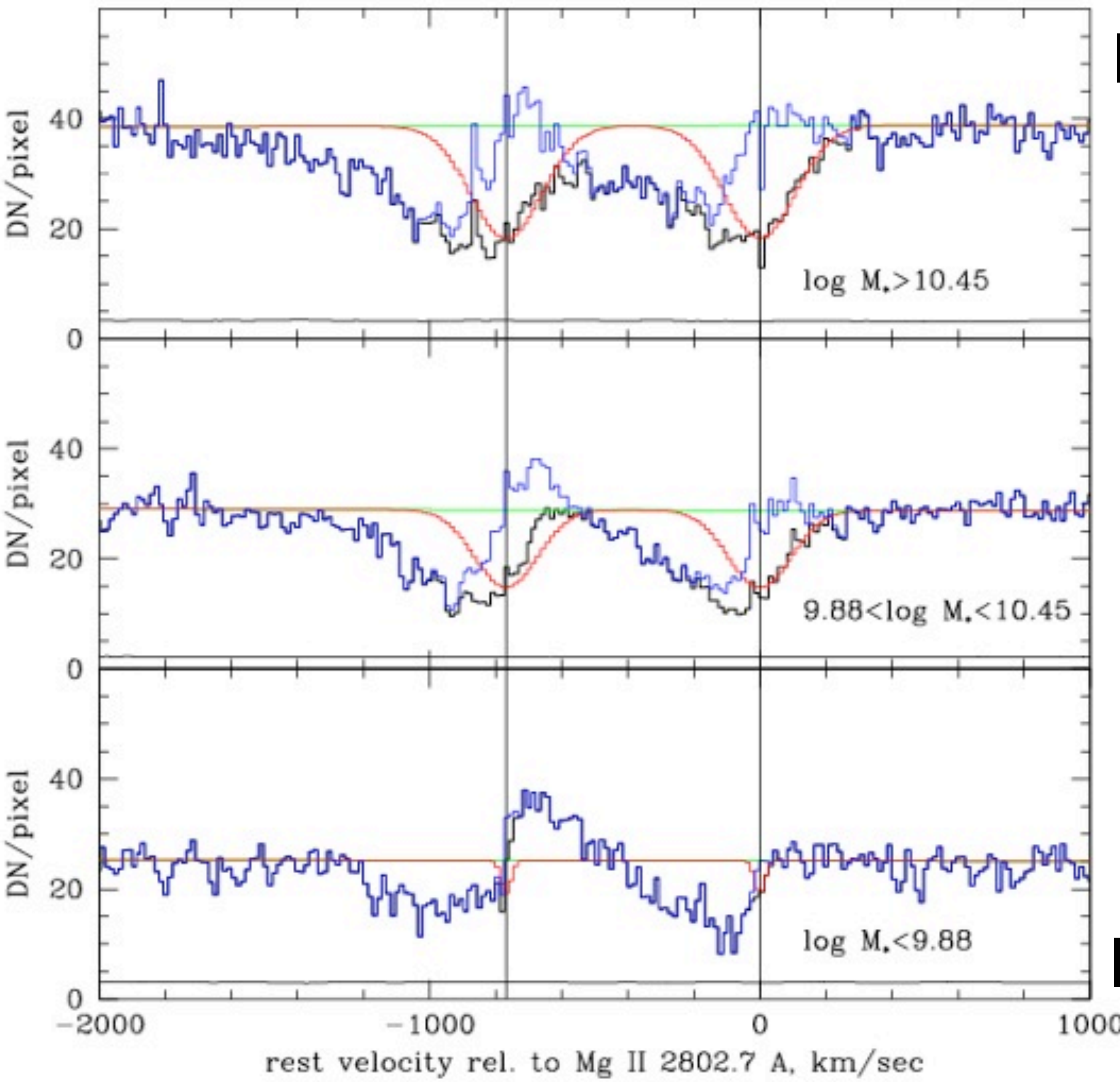
HST/
ACS I

and some ULIRGs



Some LIRGs are spirals; many ULIRGs look highly extincted.
Where do these occur, what do they evolve into?

All the z=1.4 starforming galaxies drive Mg II outflows



high M*

low M*

Vsys

DEEP2 stacked spectra:

Mg II absorption EW moderately stronger in higher M* or SFR galaxies, and always ~ saturated. dMout/dt ~ SFR, with large systematics, but suggests high mass loading.

Mg II absorption extends to greater negative velocities in higher M* or SFR galaxies. Not dependent on morphology.

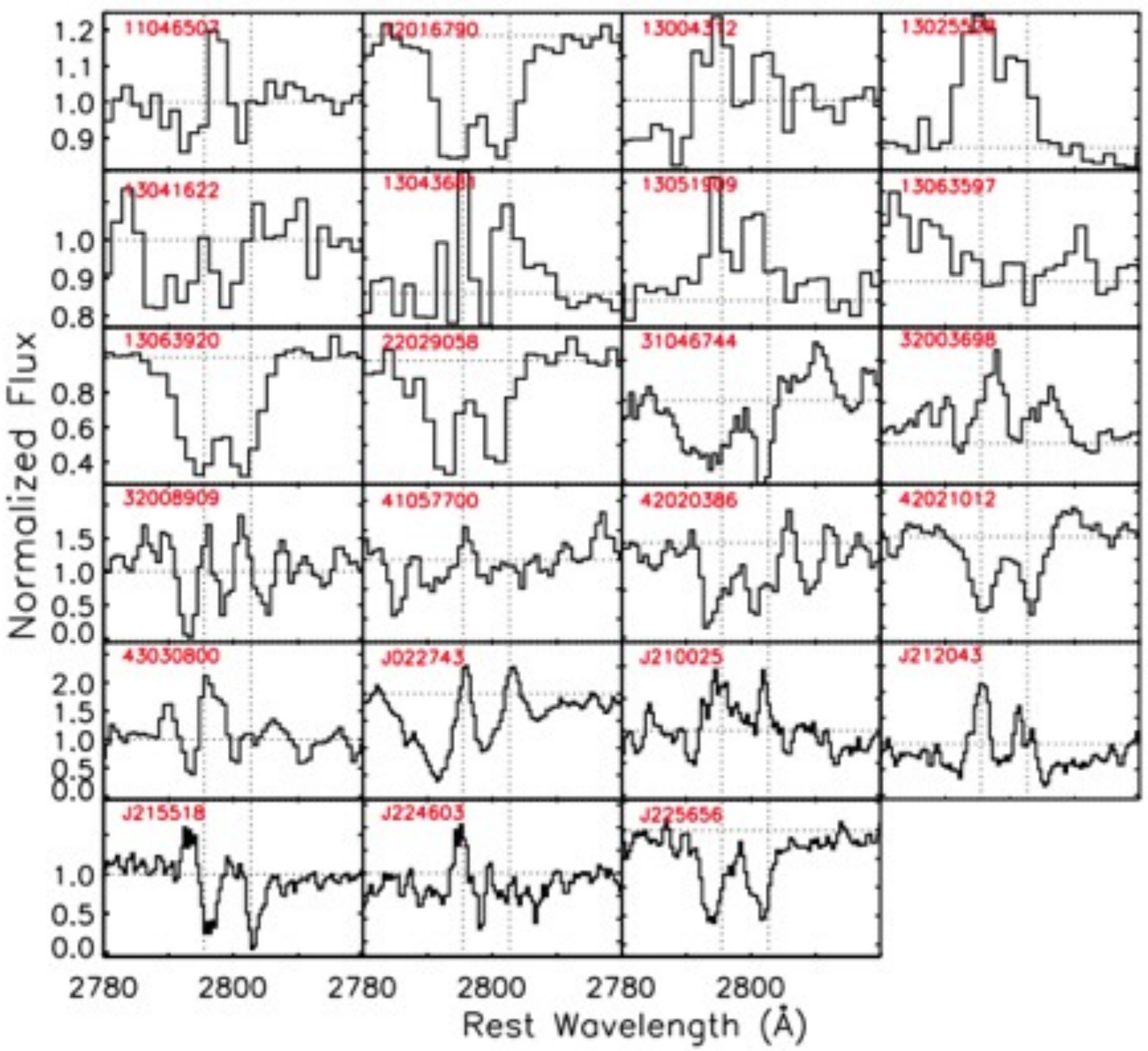
SFR and M* correlated, so can't separate wind dependence on them.

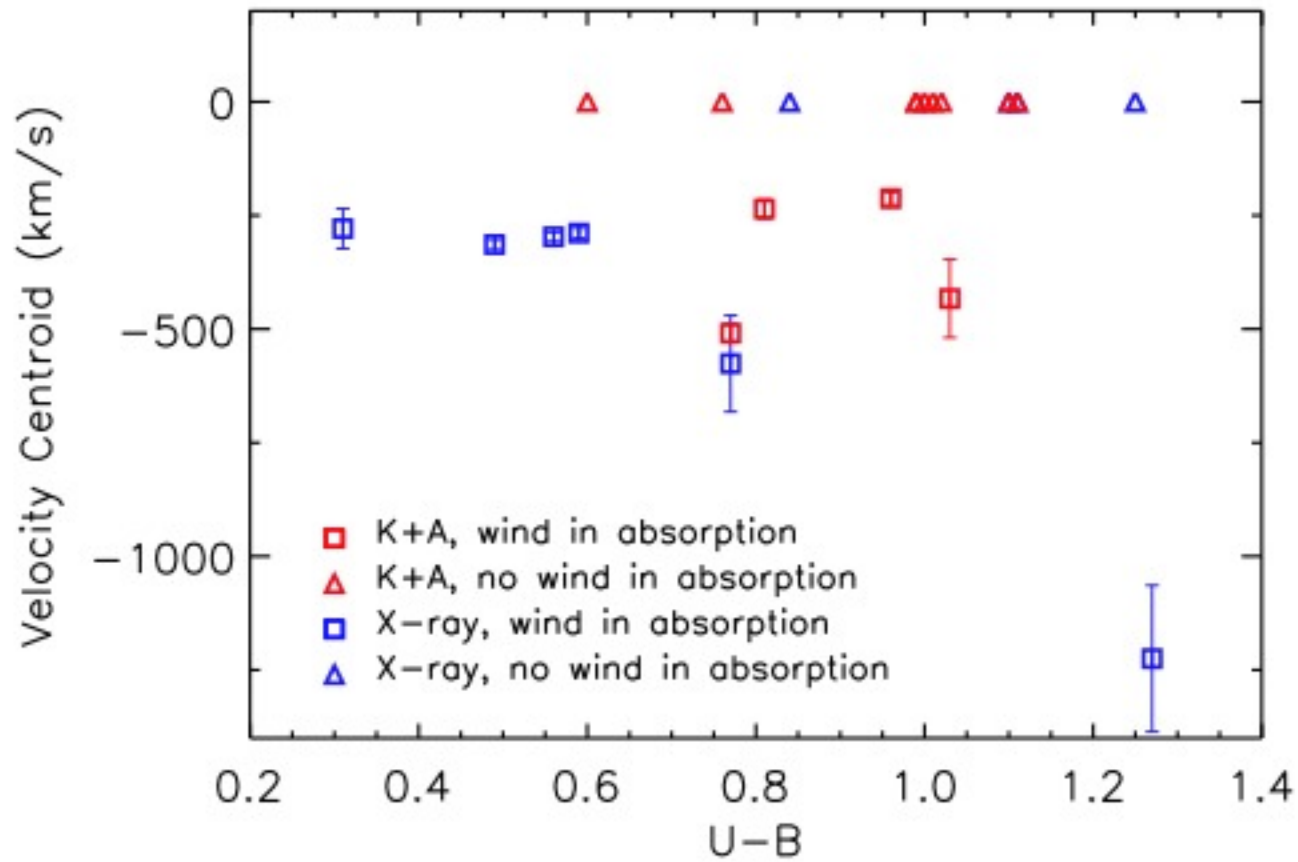
$$V_{wind} \sim SFR^{0.3}$$

Energetics: these aren't strong enough to evacuate ISM.

Weiner et al 2009
see also Koo talk, Rubin+ 2010,2012

Winds in z~0.5-0.8 post-starburst and X-ray AGN: common but not high velocity





Alison Coil, BJW et al 2011

Samples of post-starbursts and X-ray AGN from DEEP2 and SDSS:
Mg II and Fe II absorption and emission indicate outflows, but
not strikingly high velocity - not likely responsible for quenching,
not like "Eddington limit" objects found by Tremonti,
which are also now shown to be SFR-driven (Diamond-Stanic+ 2012)

Linking stages of galaxy evolution with clustering

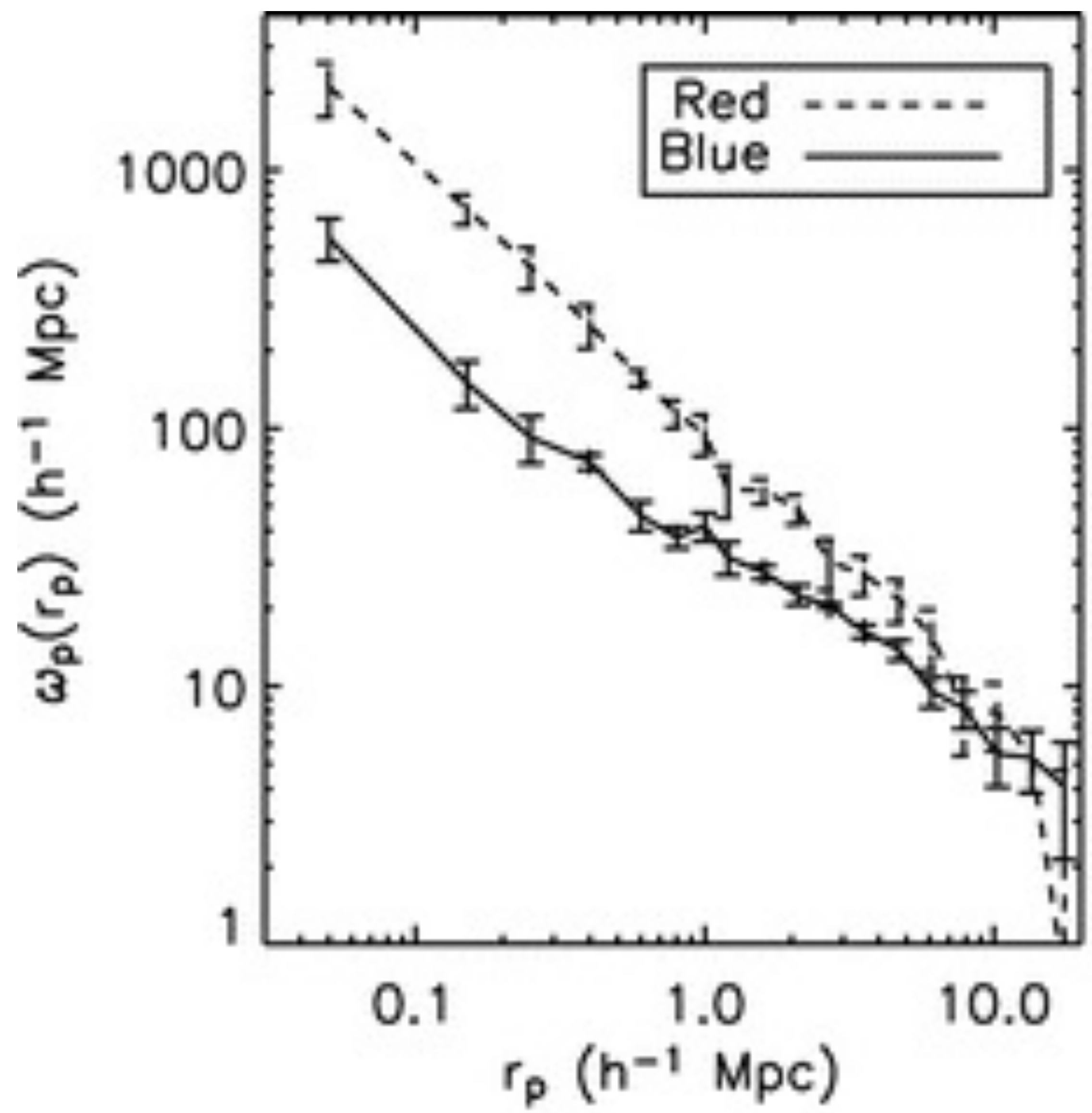
Understanding galaxy clustering is a major success of modern cosmology and is based on physics in the linear regime.

Clustering measurements allow linking populations across time – the evolution of dark matter halo clustering is well understood.

Massive objects are more strongly clustered, so clustering strength is related to host halo mass.

Measure correlation functions by counting pairs as a function of separation, to get the excess probability over random.

But galaxies are discrete, so Poisson noise means you need many galaxies.



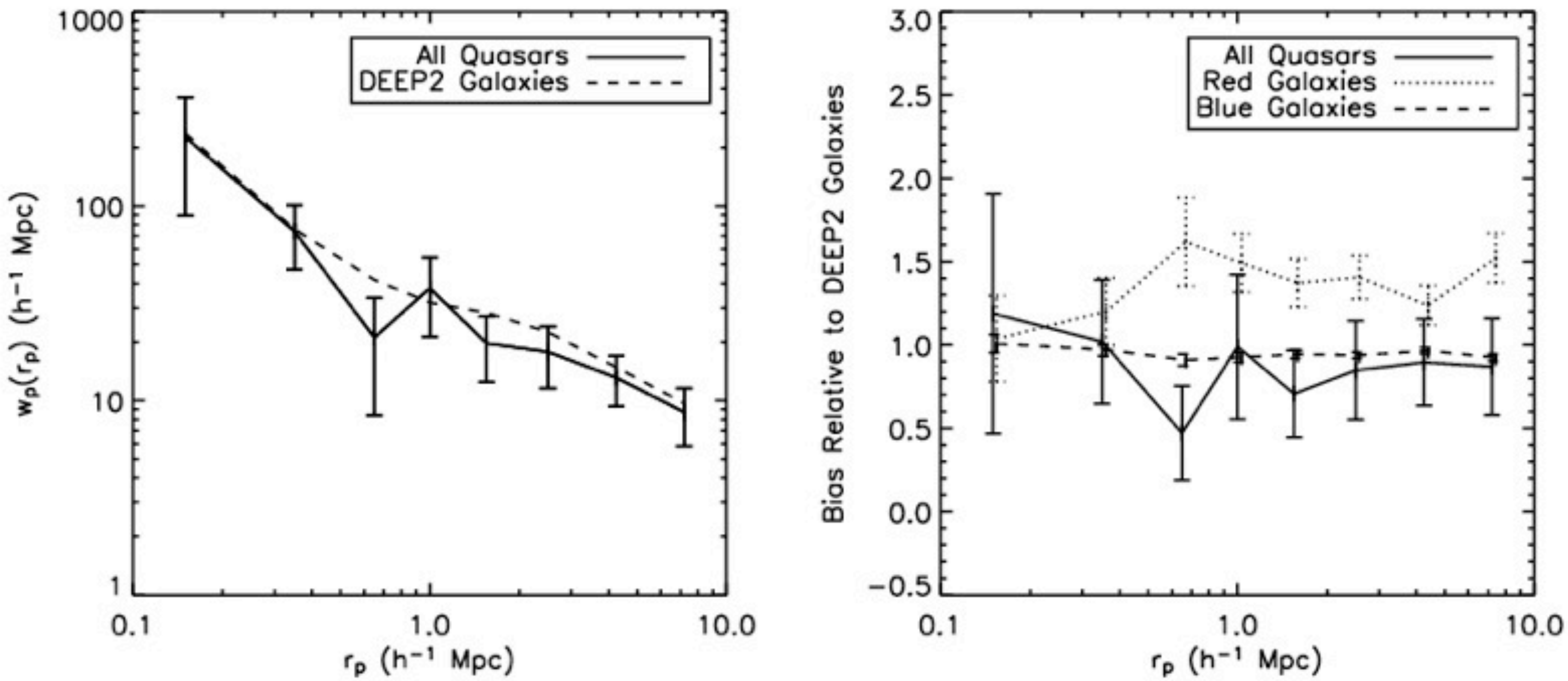
Coil et al 2008
At z=1, DEEP2 red galaxies are more clustered than blue galaxies,
as is true locally, with r0 ~ 5 h^-1 Mpc

$$\xi(r) = (r/r0)^{\gamma}$$

Cross-correlation to measure rare/short-lived objects

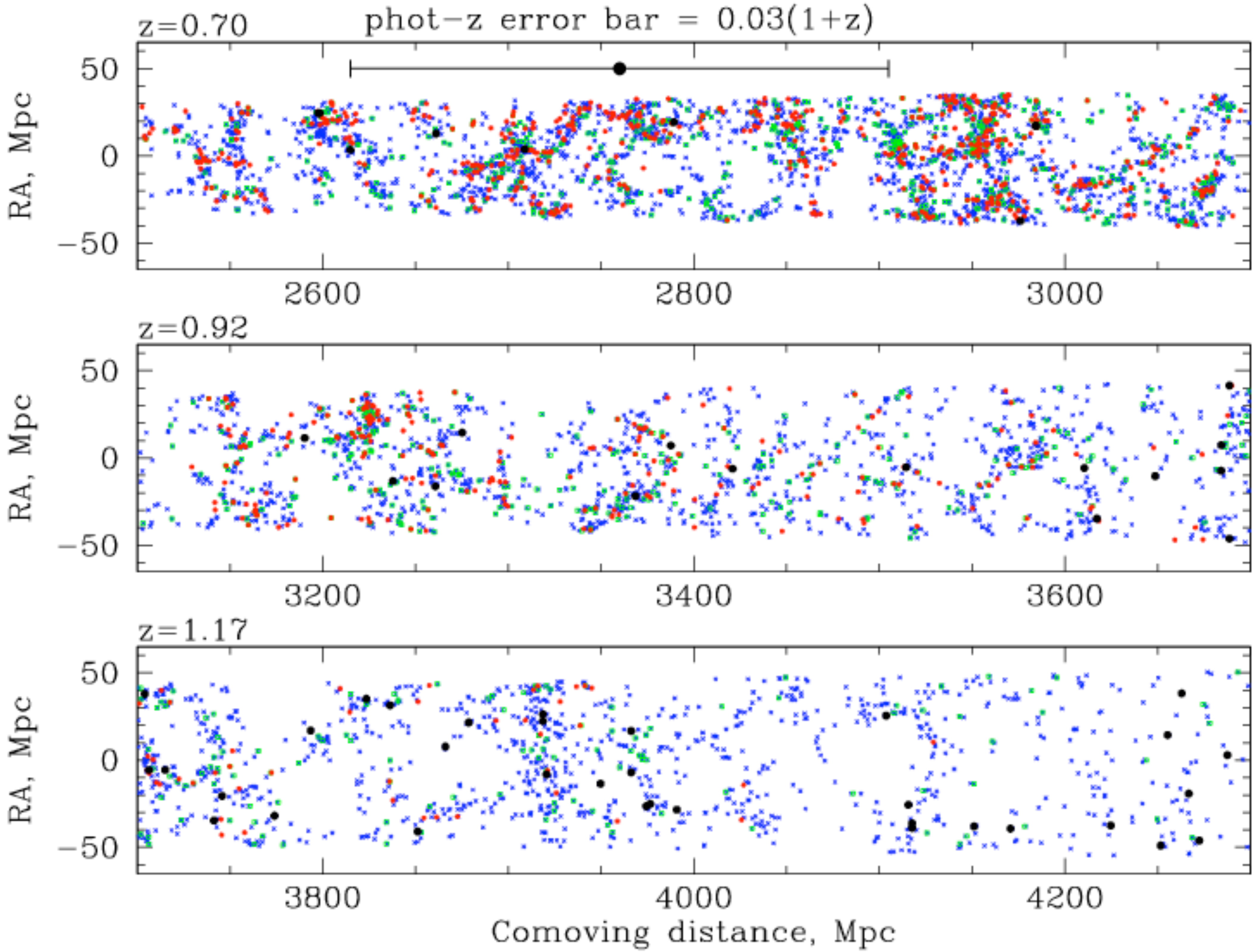
Spatial clustering is a powerful tool since it's linked to halo mass and well understood structure formation physics.

Hard to measure clustering for rare samples: can't get spatial autocorrelation of rare objects - ULIRGs, QSOs - without huge samples. But with a large sample of tracer galaxies, we can cross-correlate the ULIRGs to the galaxies. (For example, imagine cross-correlating positions of museums with people.)



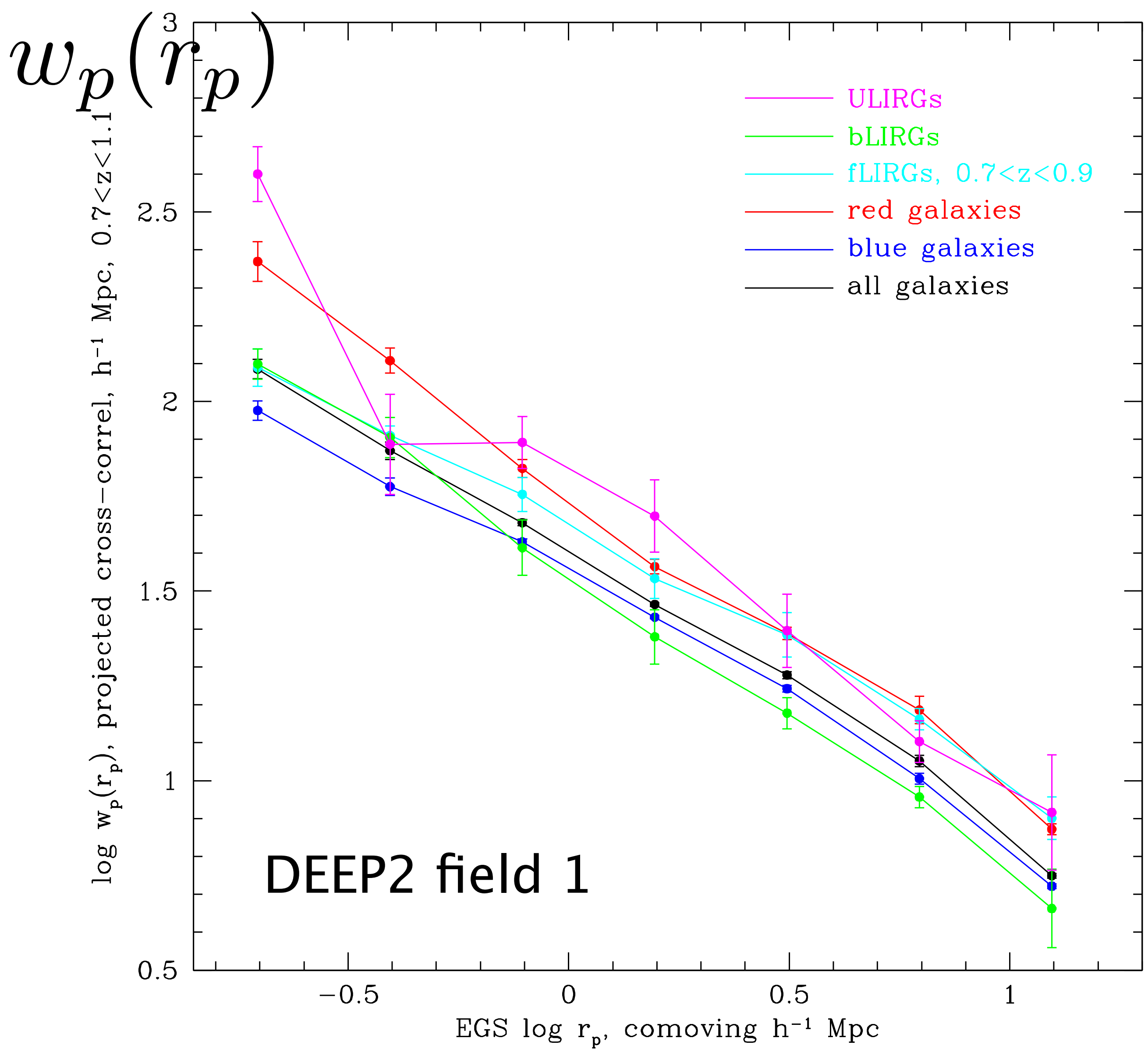
Coil et al 2007: 52 QSOs crossed with 5000 DEEP2 galaxies:
z=1 QSOs are clustered like all galaxies, not like red galaxies (at 95%).

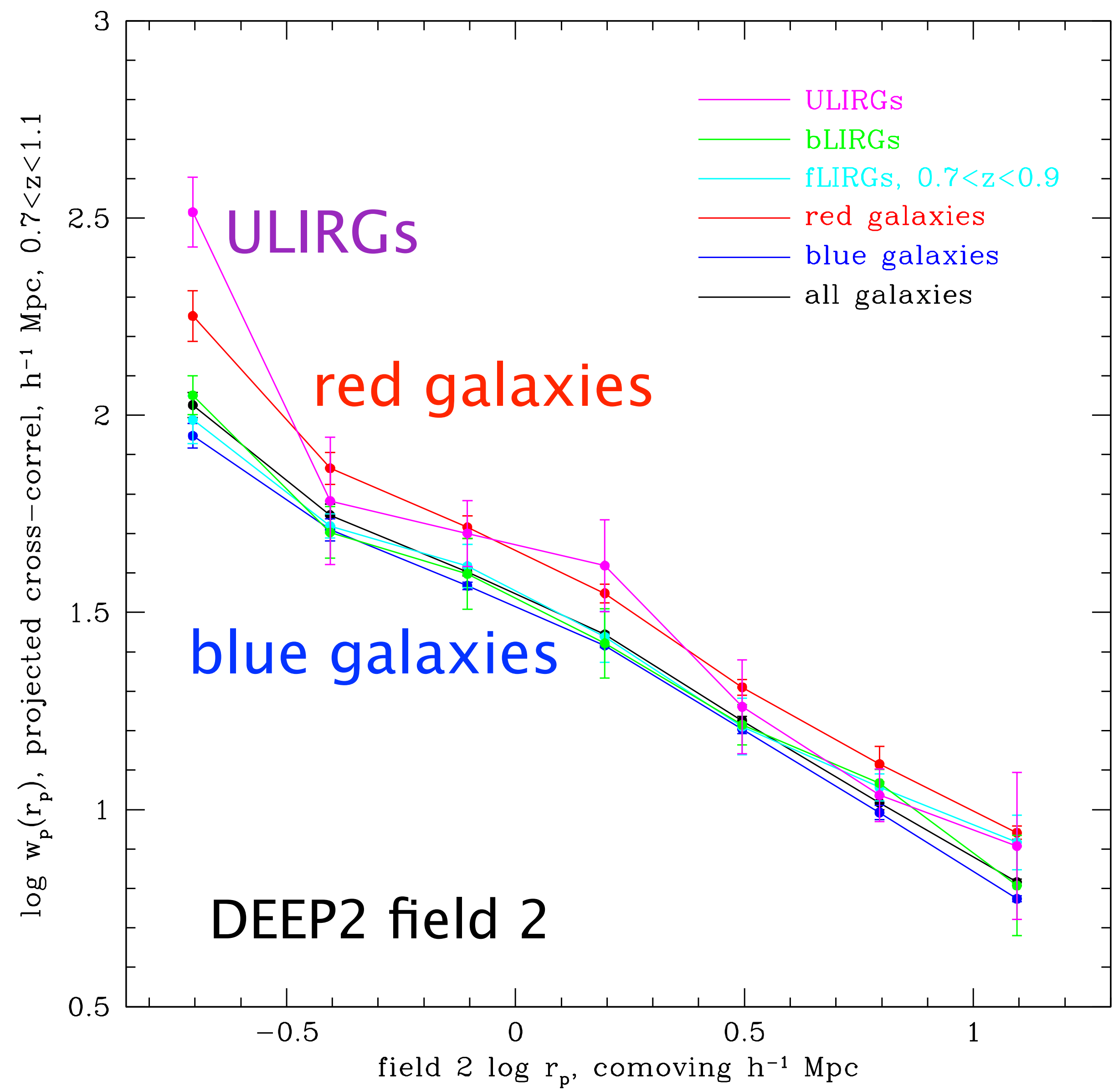
Coil et al 2009: X-ray AGN are clustered like red galaxies.
We have MIPS data in two DEEP2 fields, to do this for ULIRGs.



Cone diagram of DEEP2 field 2: rich clustering structure

Cross-correlation measurements at 0.7<z<1.1 (two fields)

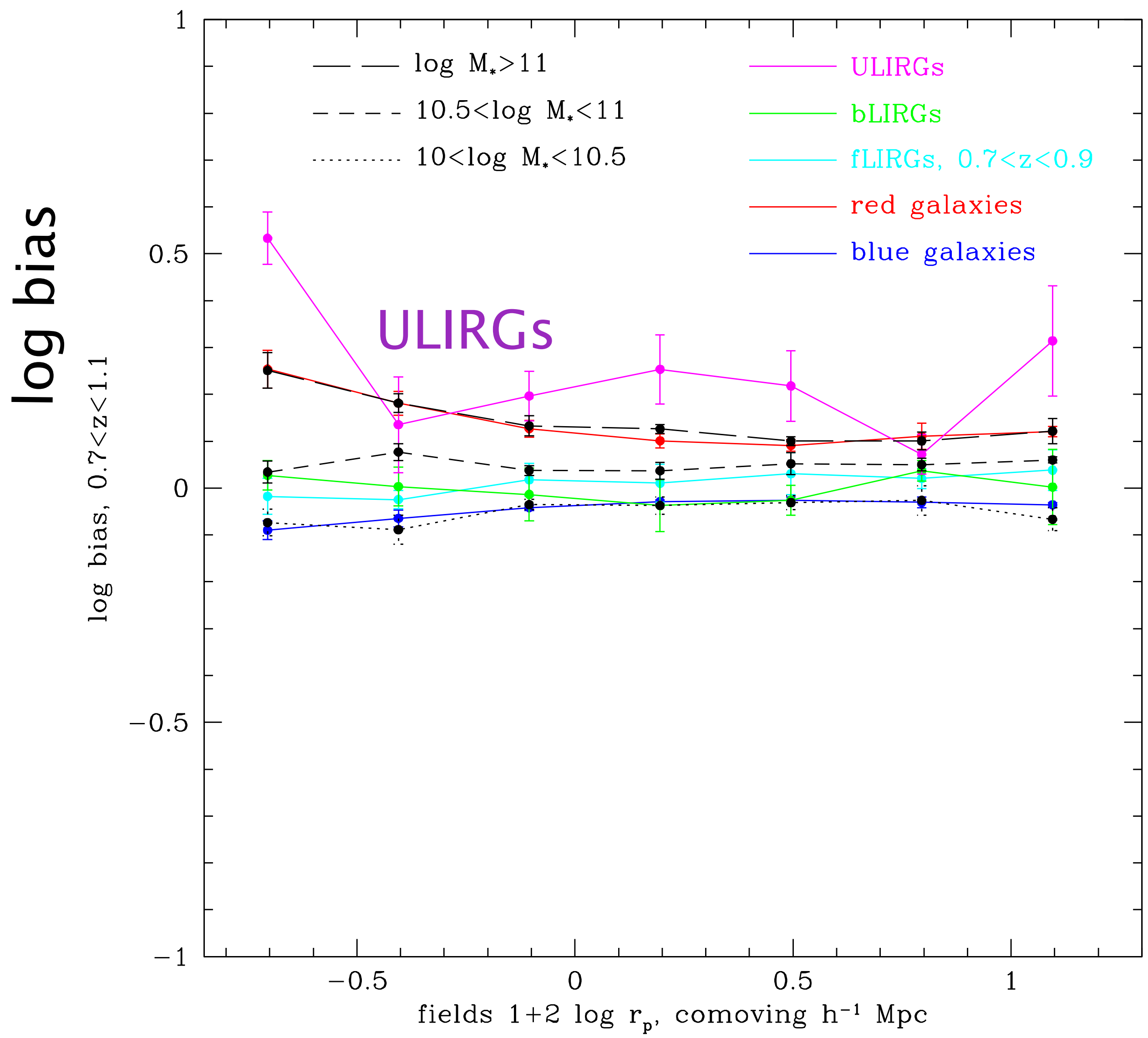


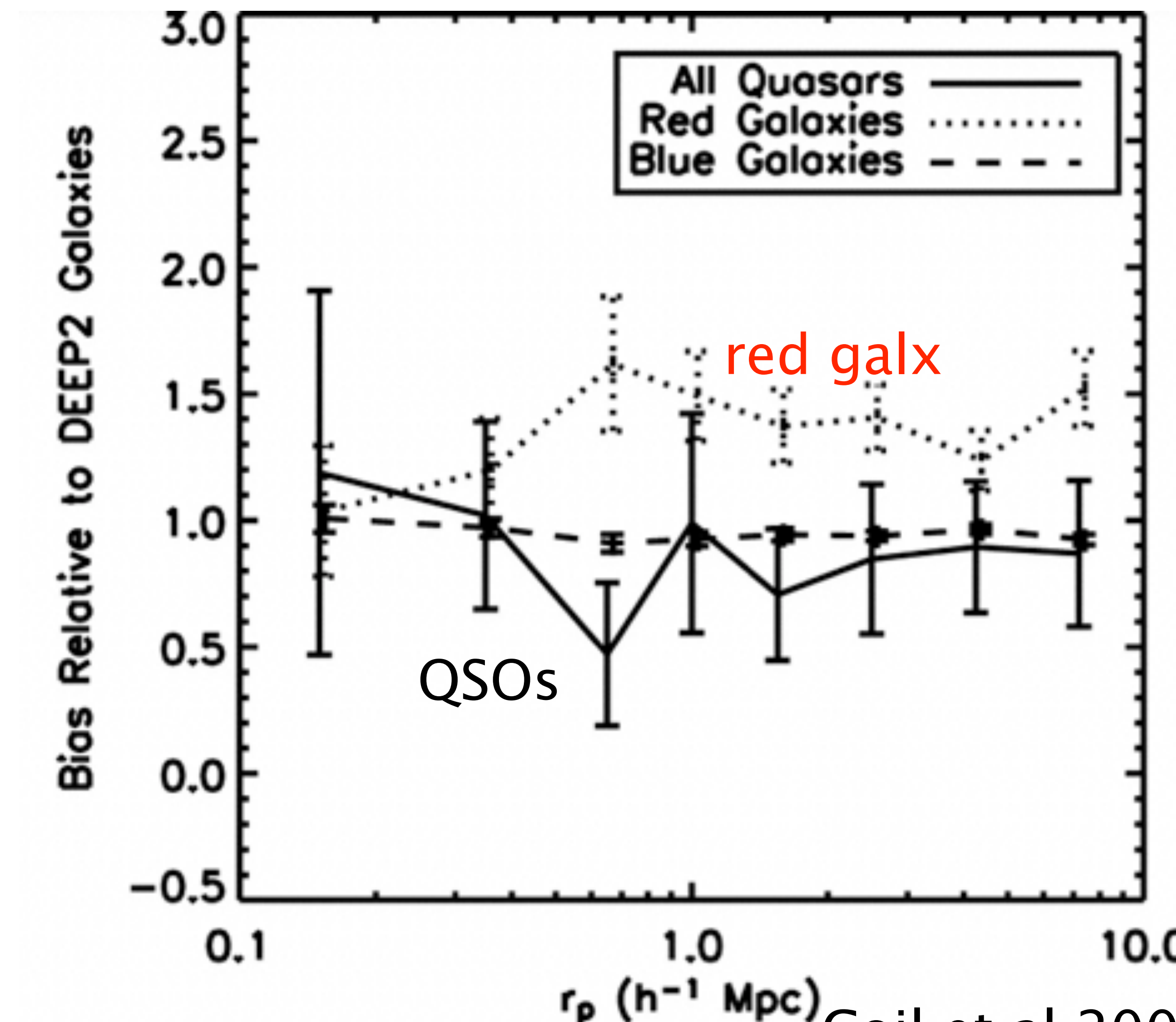


LIRGs are very similar to blue/intermediate galaxies
ULIRGs are as clustered as red galaxies at r ~ few Mpc

at z=1, the ULIRG threshold happens to also be a real physical distinction.
ULIRGs => probably occurring in groups (no rich clusters in DEEP2),
peak at small r => one-halo term?
Strong clustering, but r_0 is not huge (not ~10 Mpc)
LIRGs => not going to evolve into red galaxies on short timescales.

Relative bias: ULIRGs are like red galaxies, but moderate-luminosity optical QSOs are like blue galaxies





Coil et al 2007

Same cross-correlation technique, crossed with same field galaxy samples at similar redshifts. Short timescales and different clustering => can't evolve quickly from one to the other.

z=1 ULIRGs could only go to subset of QSOs.

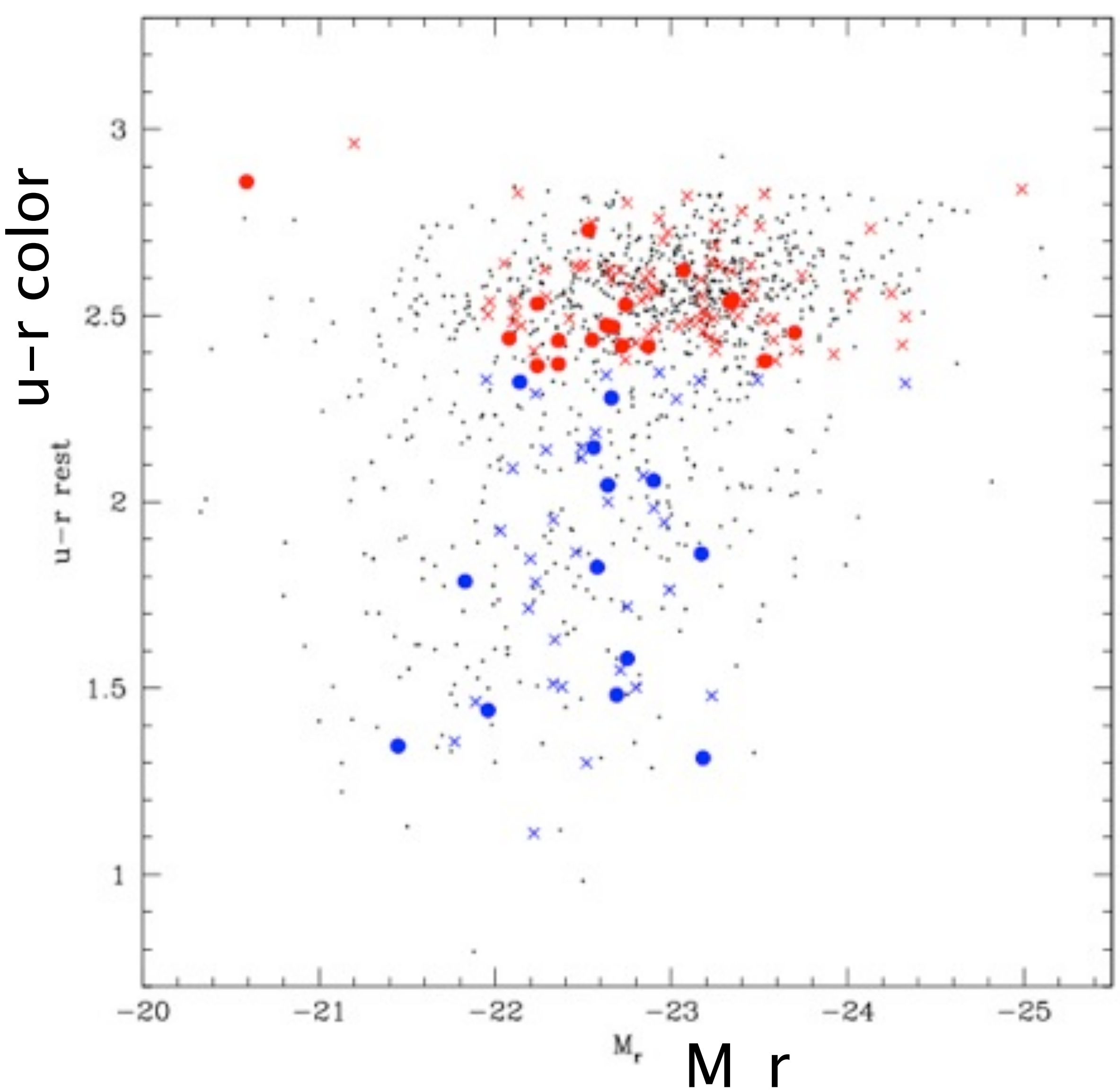
z=1 QSOs cannot go to z=1 red galaxies =>

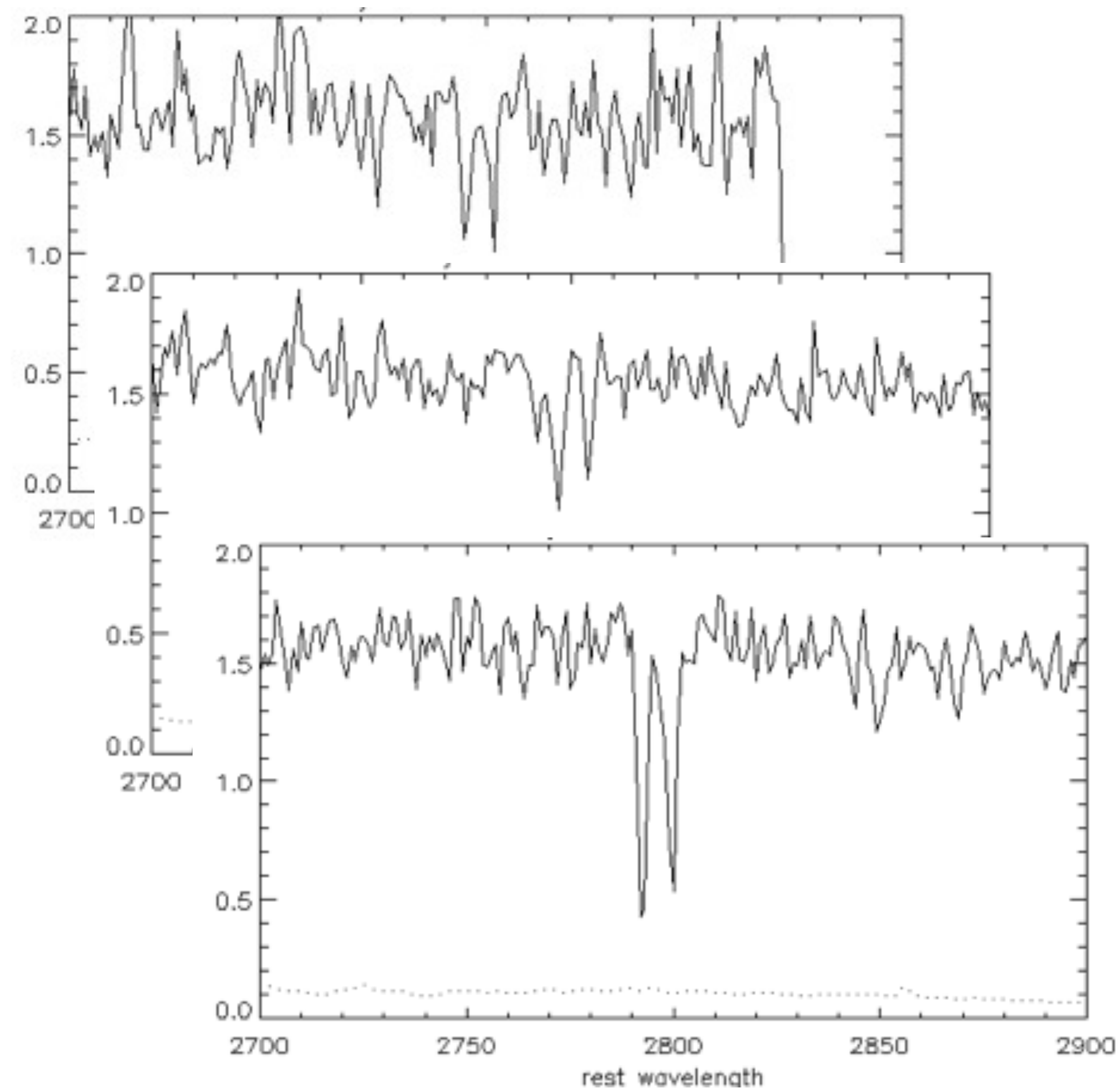
EJECTIVE FEEDBACK CANNOT ALWAYS QUENCH.

Clustering difference shows ULIRG -> QSO -> elliptical evolution scenario is oversimplified, although ULIRG -> elliptical link is plausible.

BOSS galaxies: study associations with Mg II in SDSS QSOs

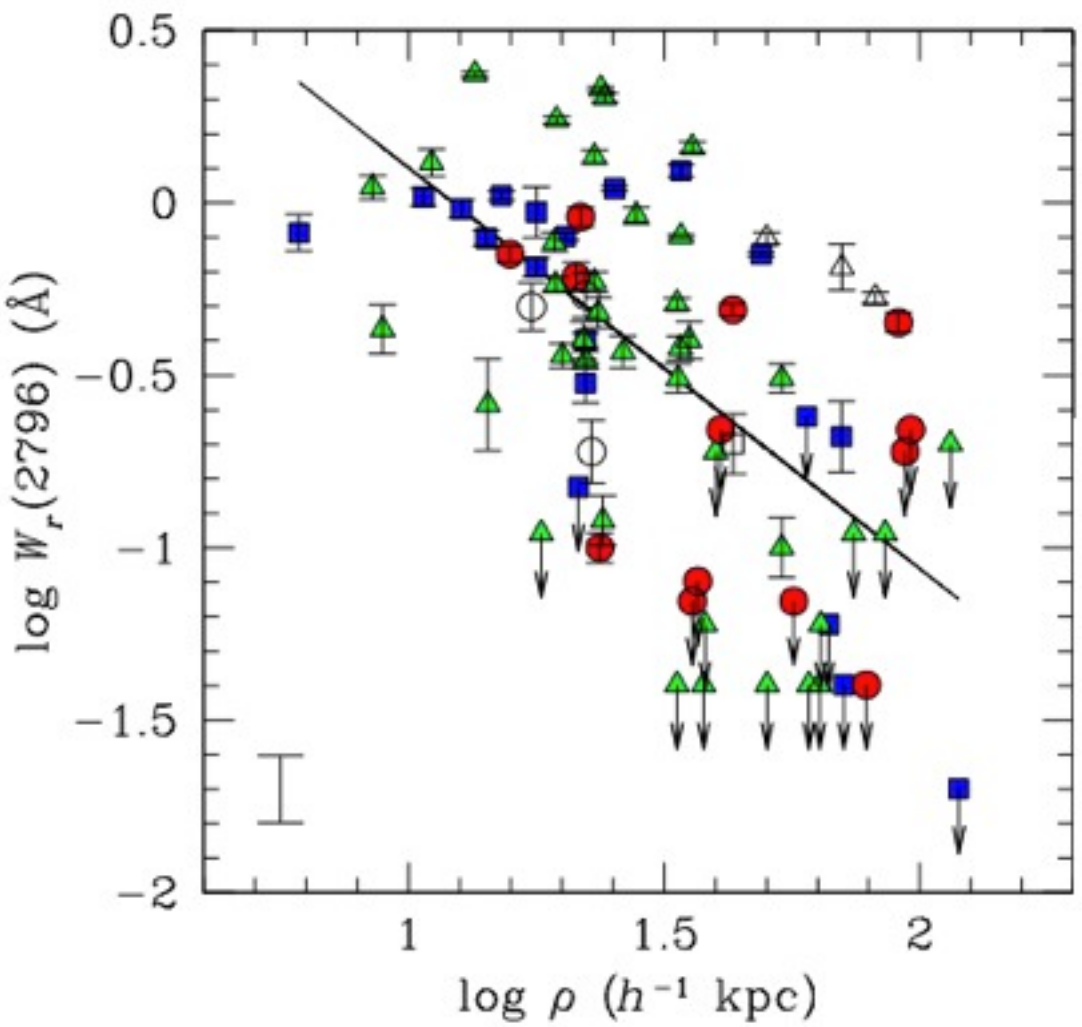
with C Tremonti, J Tinker, B Menard, T Heckman, P Petitjean, B Lundgren, G Zhu, SDSS-3 Collaboration



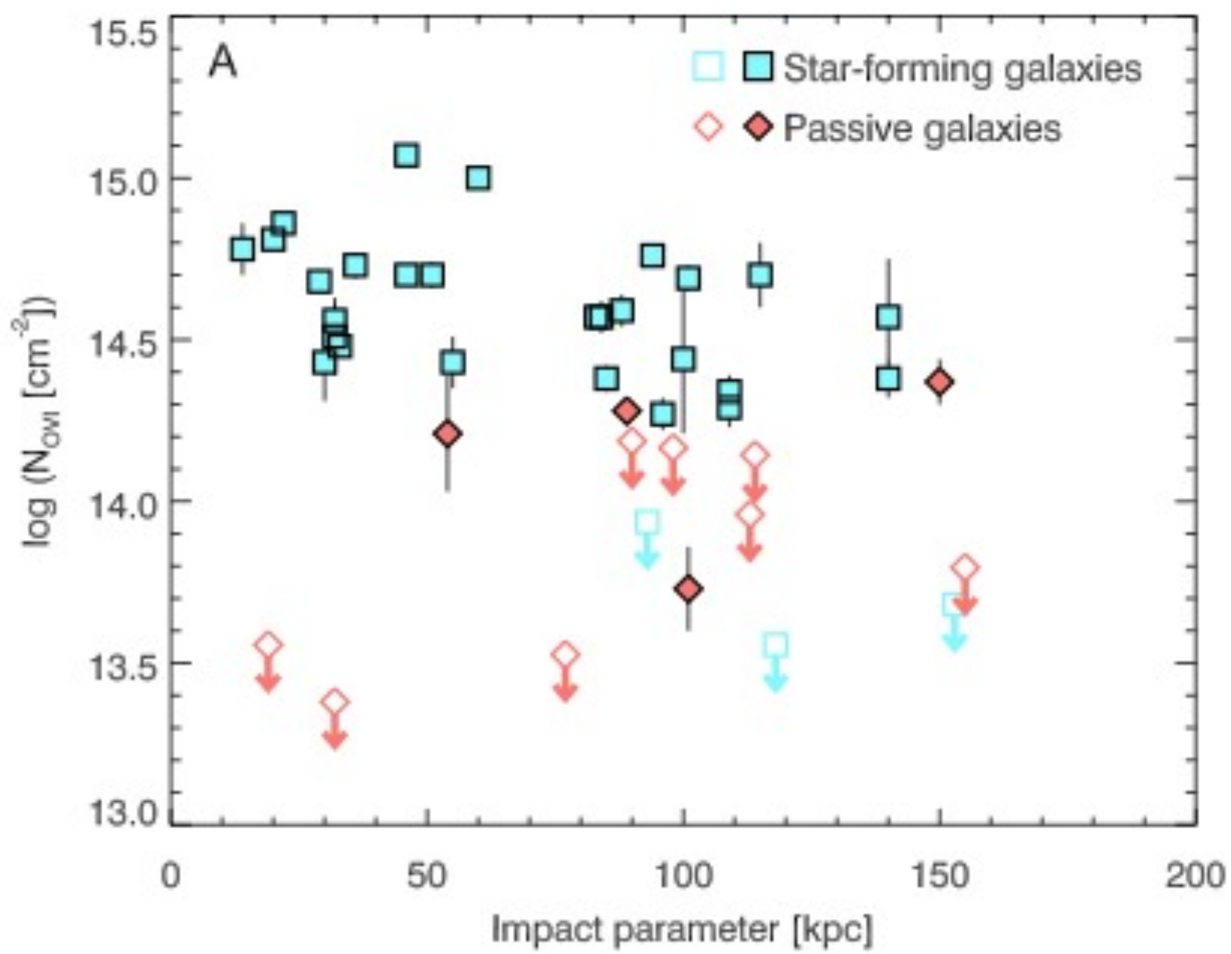


Inspect SDSS-2 QSO spectra for strong Mg II absorbers at BOSS galaxy redshift. Probes cool gas around massive galaxies at z~0.4-0.5. Can accumulate large sample of QSO-galaxy pairs over course of survey, since BOSS re-covers the SDSS area.

Covering factor depends on impact, luminosity, and maybe color

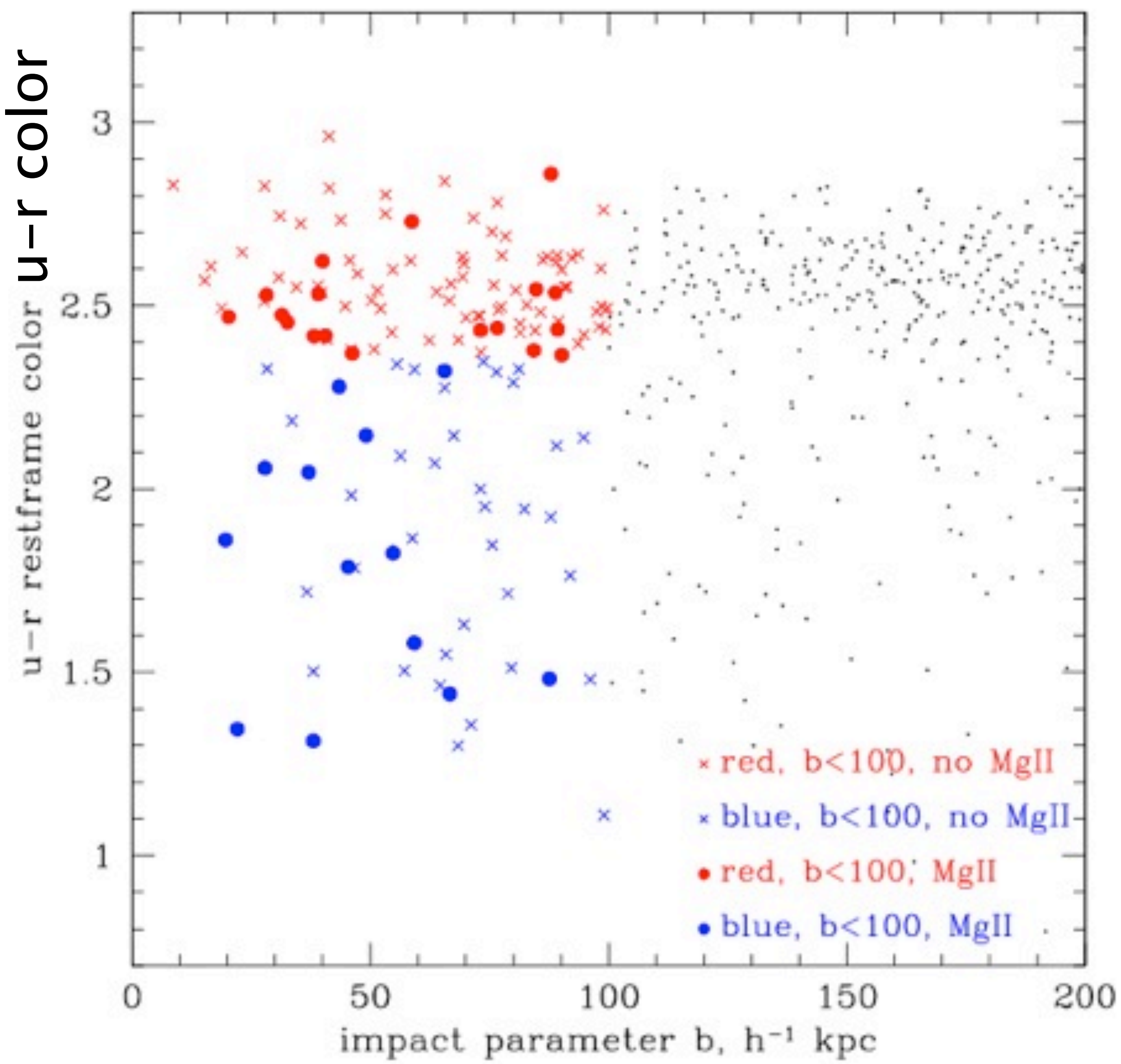


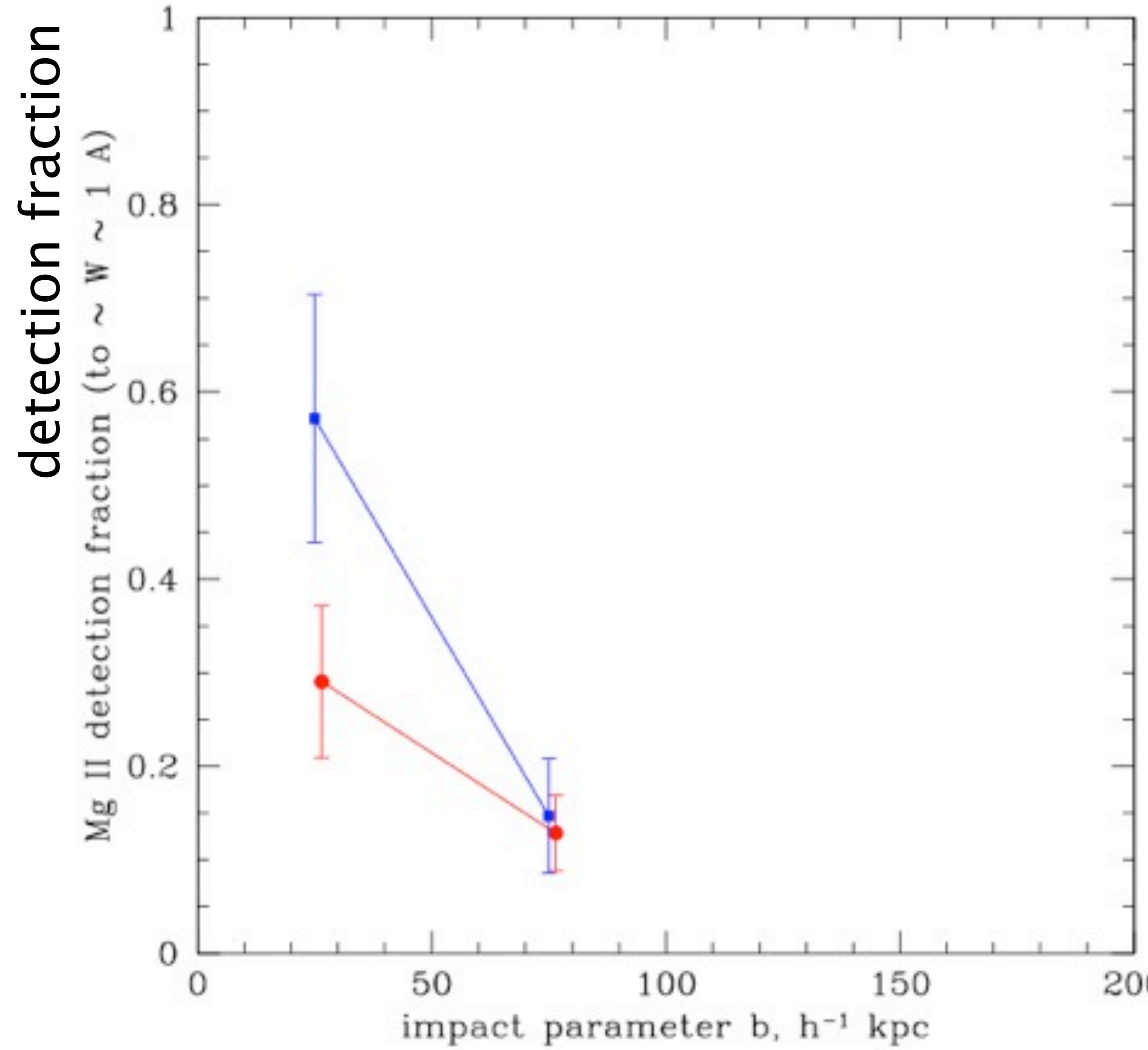
H.-W. Chen+ 2010; Gauthier+ 2011
Mg II survey: cool gas, to lower EW than SDSS-2 spectra.
Not a significant difference between covering factor around red/blue galaxies.
Covering factor/column density depends on impact parameter and galaxy luminosity.



Tumlinson et al 2011 (see J. Werk talk)
HST/COS O VI survey: warm gas, sensitive, strong dependence on red/blue galaxy.
high O VI covering factor around blue galaxies to 150 kpc, low around red.

BOSS galaxy sample + strong Mg II absorbers: covering fraction fairly independent of color





With a large sample of sightlines near red galaxies, we confirm that Mg II is present near (massive) red galaxies, unlike O VI. There is cool gas around z~0.4 red galaxies – within R_vir. (Similar to COS-Halos, Jessica Werk's talk) Is this late time accretion that needs to be deterred by a "radio mode" TBD?

In progress: larger sample, Mg II EW correlations, galaxy properties; sample for followup of QSOs with higher-res spectra, for lower Mg II EW

Summary:

Spatial clustering with cross-correlation:
z=1 ULIRGs are strongly clustered like contemporaneous red galaxies,
but z=1 QSOs are more weakly clustered, like blue galaxies.

This calls into question the ULIRG-QSO-quenching link: both the idea that the QSO is what turns off the starburst, and that the QSO wind quenches star formation permanently to make an elliptical.

Ejective "quasar mode" feedback is hard to couple efficiently to the entire ISM, and it doesn't fit with the QSO clustering. Mergers may quench - but not by QSO blowout. Sudden quenching by AGN is a crutch that props up models; time to explore doing without it?

Maybe it's boring old gas exhaustion. Once gas is driven to the center, it should get used up by star formation quickly anyway; the real problem could be keeping gas from recycling or accreting at later times.

BOSS galaxy - absorber associations show that there are strong Mg II systems with massive red galaxies, inside R_vir. Need a way to keep cool gas from causing further star formation and turning galaxies blue? Late time accretion rate is supposed to be small, but something's happening here.