

The life cycle of massive galaxies and the effects (or not) of outflows

Benjamin Weiner (Steward)

Alison Coil (UCSD),

+ Jeff Newman, Casey Papovich, Kai Noeske,

Michael Cooper, Christy Tremonti, MIPS+DEEP2 teams, and BOSS

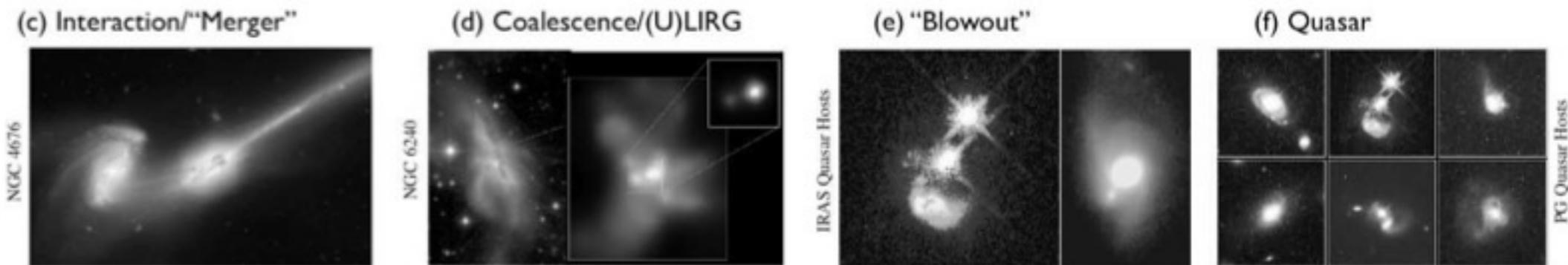


“Modes” of star formation – mergers and disks?

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 disk, or at least not major mergers.

A question: Are behavior of outflows and putative quenching mechanisms dependent on merger/starburst phases?

Ideas about feedback to make and keep red galaxies red:



Hopkins+ 2008

ejective or “quasar mode” – violently remove gas, quenching the galaxy.

Popular in merger \rightarrow ULIRG \rightarrow QSO \rightarrow elliptical scenario.

But not clear how to couple the QSO wind to the ISM efficiently.

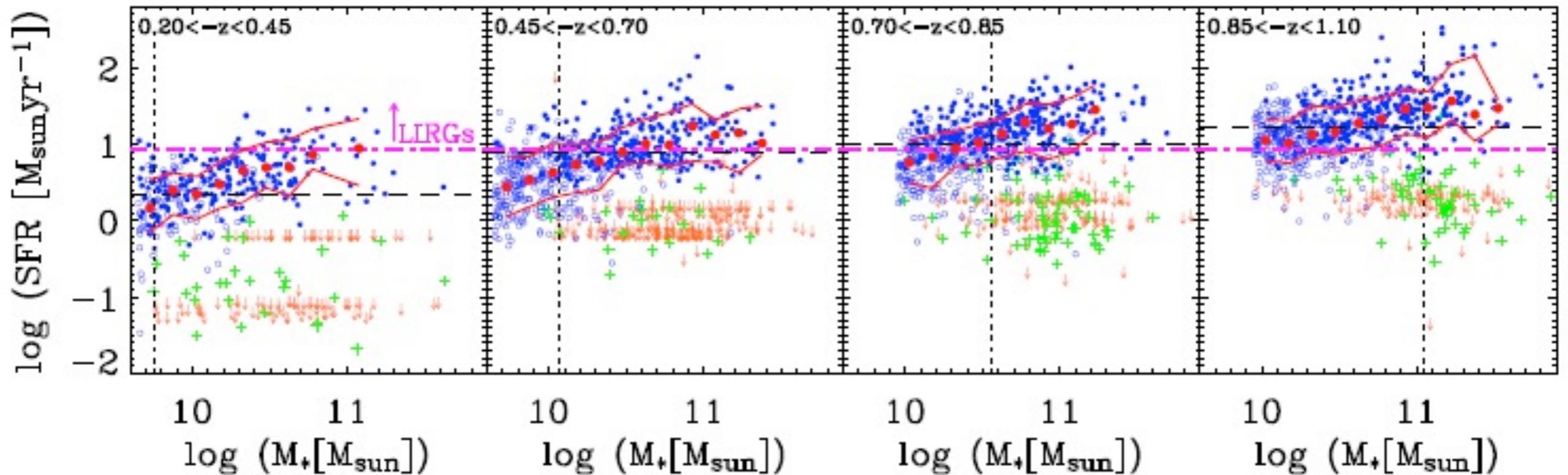
- Does this scenario actually happen? Test it with clustering.

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.

please blame Darren Croton for the names of qso and radio mode

SFR is high across the whole SF/blue galaxy population at $z \sim 1$



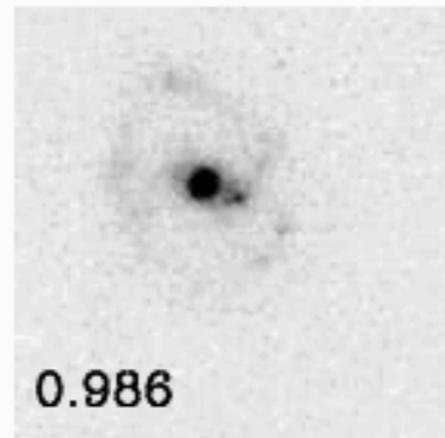
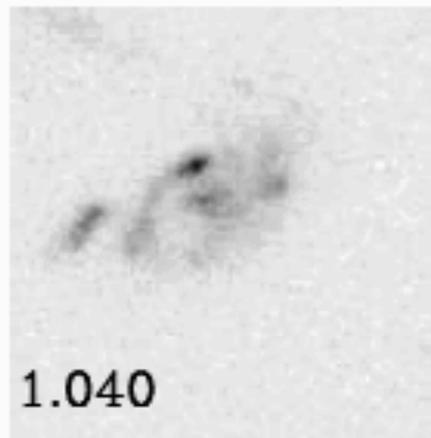
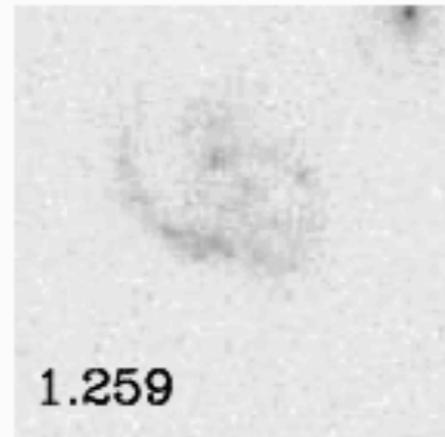
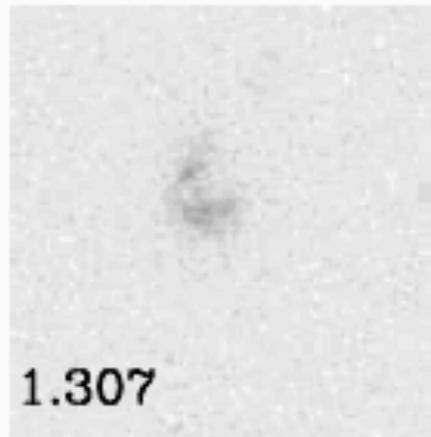
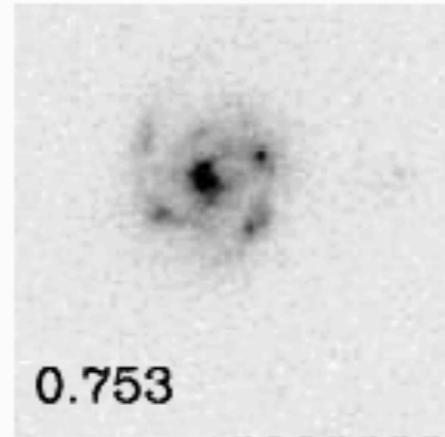
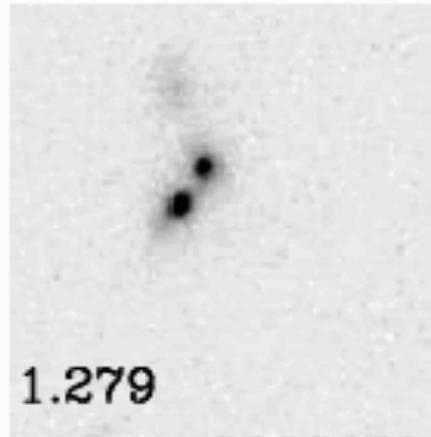
(from Kai Noeske, BJW et al 2007)

At $z=1$, the global SFR is 10x higher than today – in what galaxies does this occur?
A: Most of them.

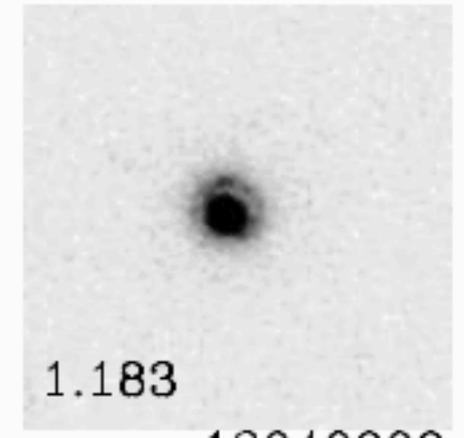
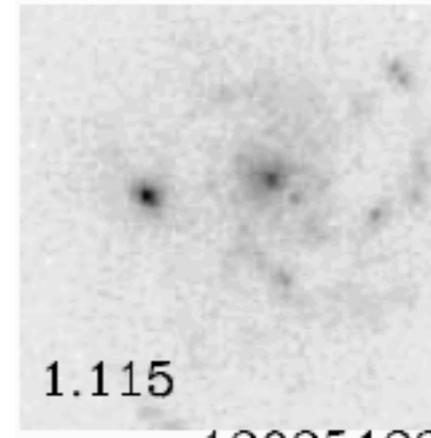
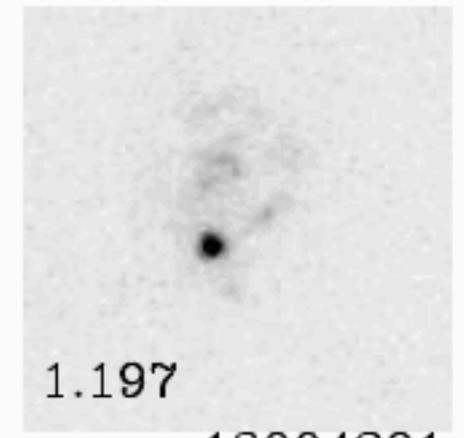
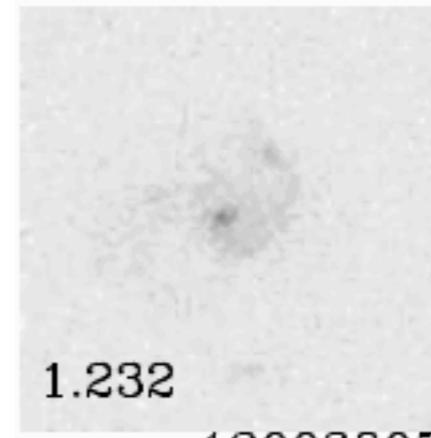
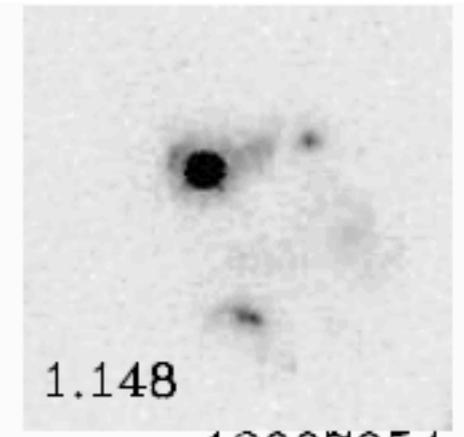
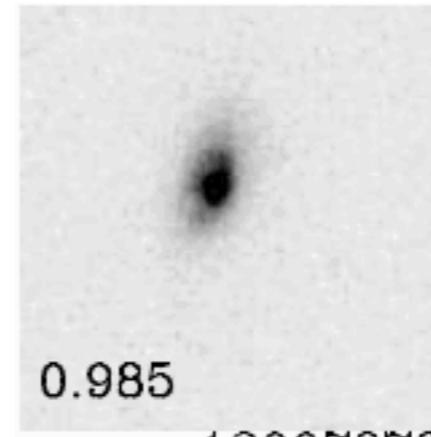
The scatter in the SFR–stellar mass relation is ~ 0.3 dex: extreme bursts/excursions are rare. The overall SFR declines gradually for the entire sample: the global decline of SFR is due to a decline in individual galaxies.

Questions: what type of galaxies turn off SF and redden, and how?
Causes of quenching: mergers, gas exhaustion, AGN outflows, halo mass threshold?
[Is SF mode actually different in mergers and disks?]

Some bright LIRGs in EGS



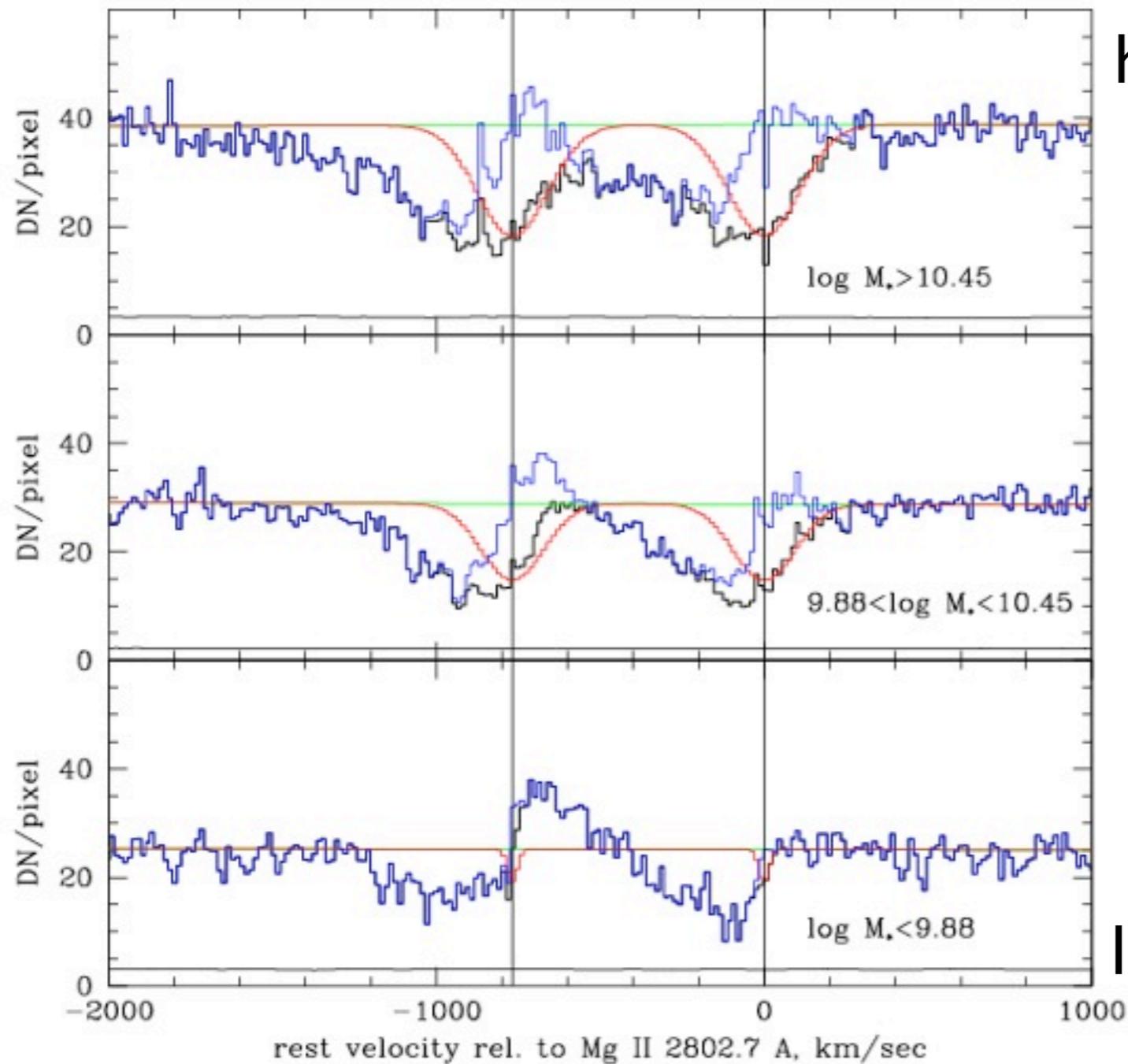
and some ULIRGs



HST/
ACS I

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

All the $z=1.4$ starforming galaxies drive Mg II outflows



high M^*

DEEP2 stacked spectra:

Mg II absorption EW moderately stronger in higher M^* or SFR galaxies, and always \sim saturated. $dM_{\text{out}}/dt \sim$ 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.

Less absorption/more emission in low mass subsample – probably geometry/dust influenced.

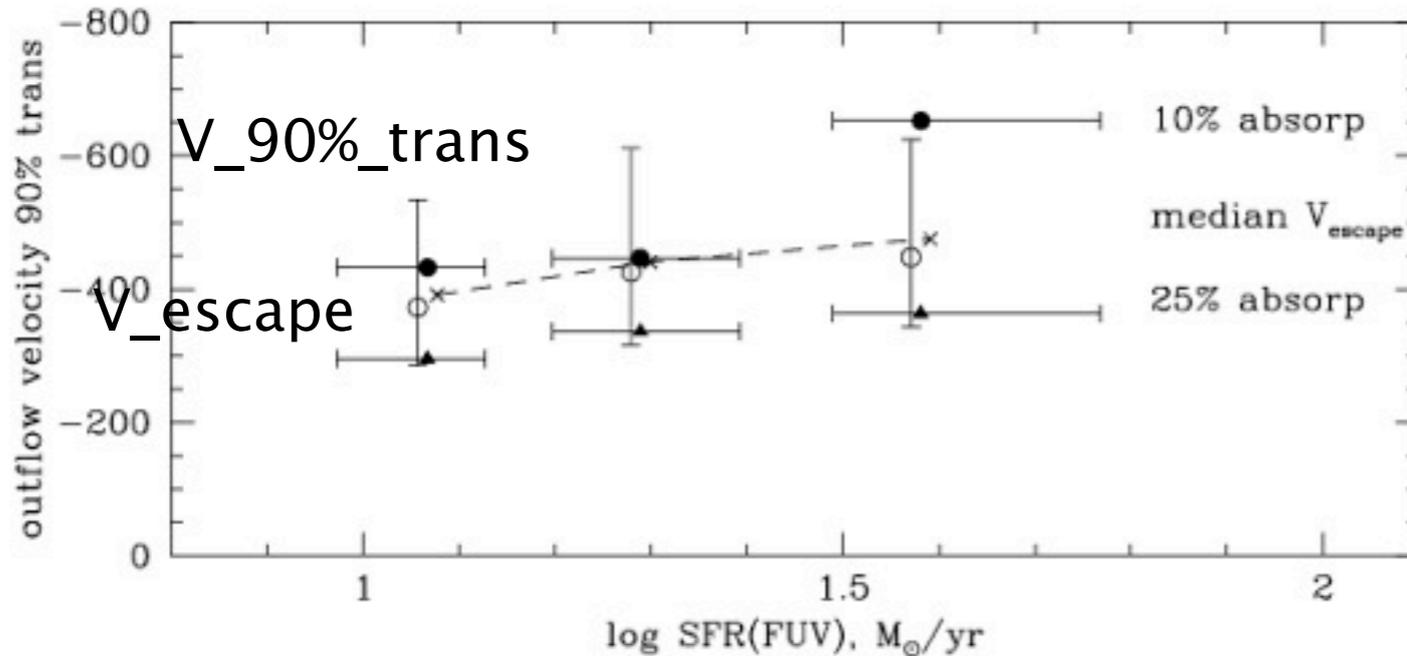
low M^*

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

V_{sys}

Weiner et al 2009

Tail of outflow velocity distribution may reach escape

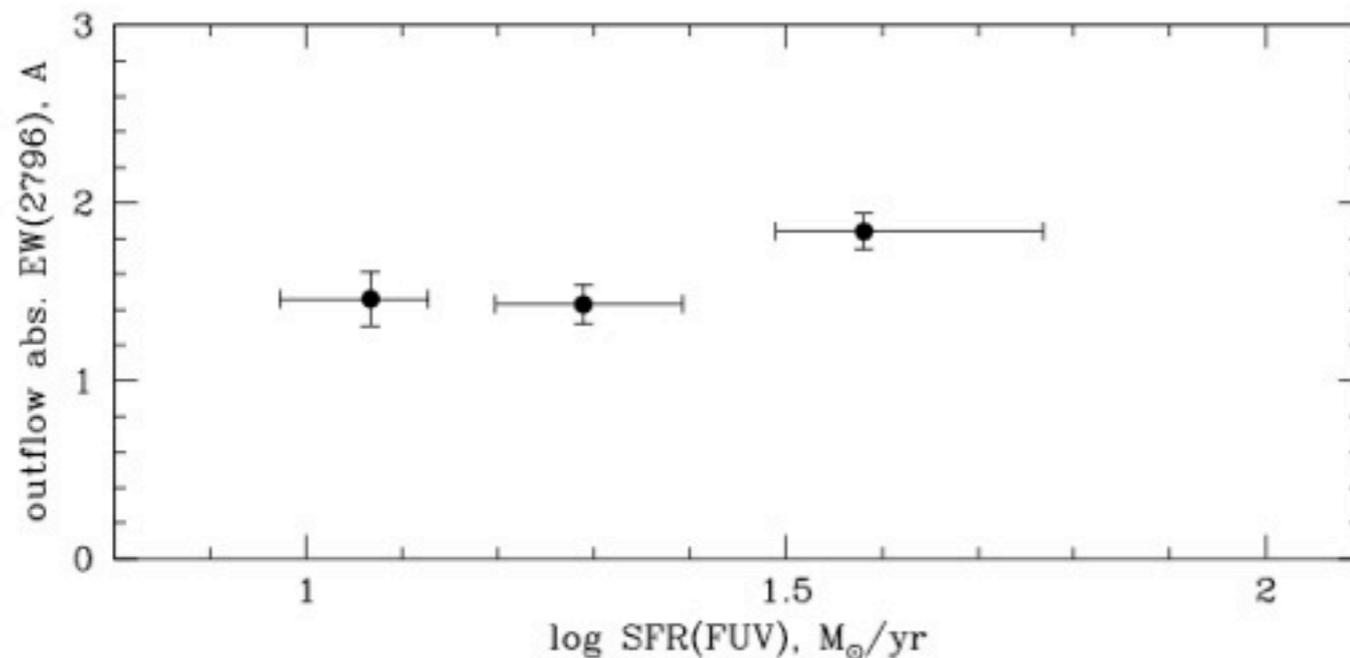


Velocity

In the high-SFR (40 M_{sun}/yr) bin, the 10% absorption depth is beyond the mean escape velocity from [O II] linewidth.

$$V_{\text{esc}} \sim 3 V_{\text{rot}}$$

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



EW(out)

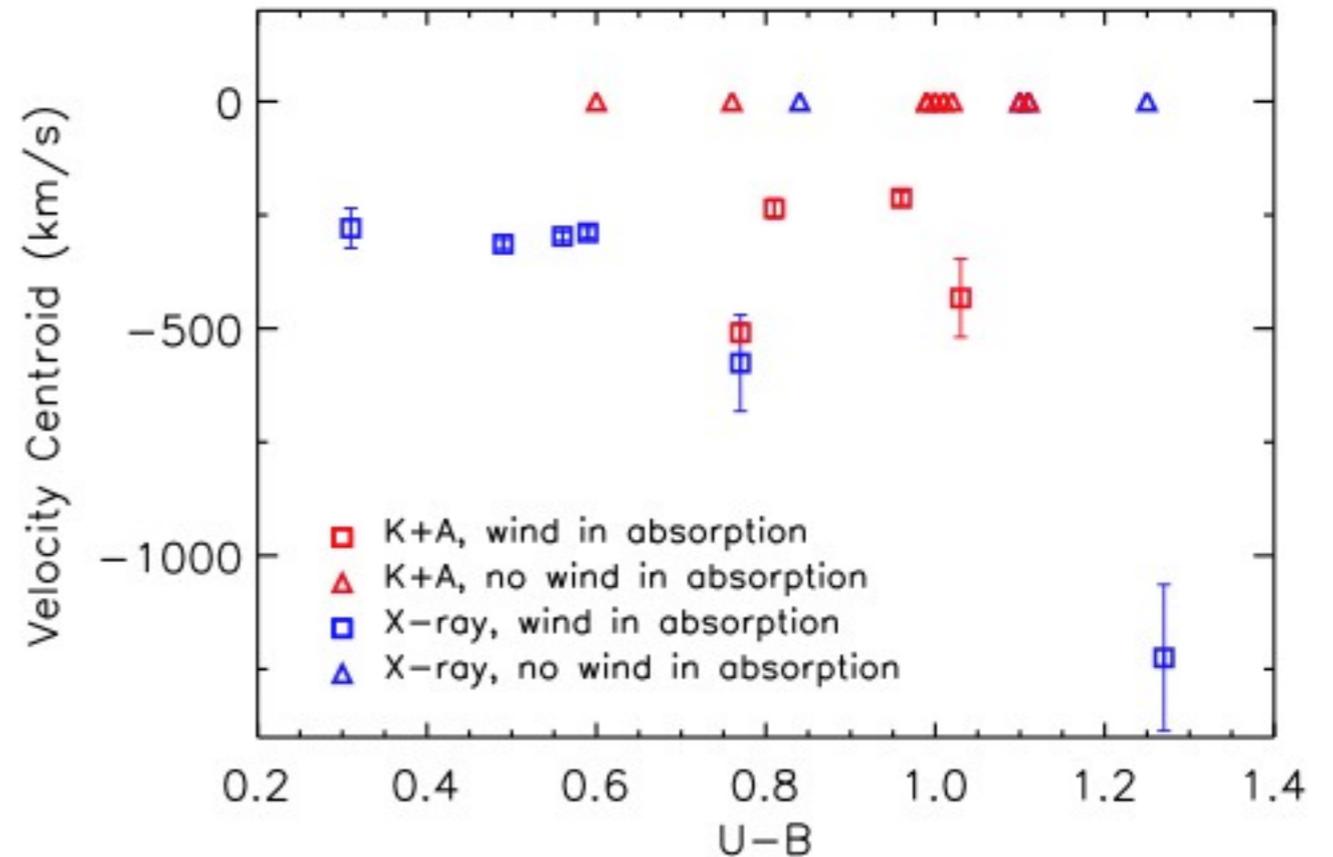
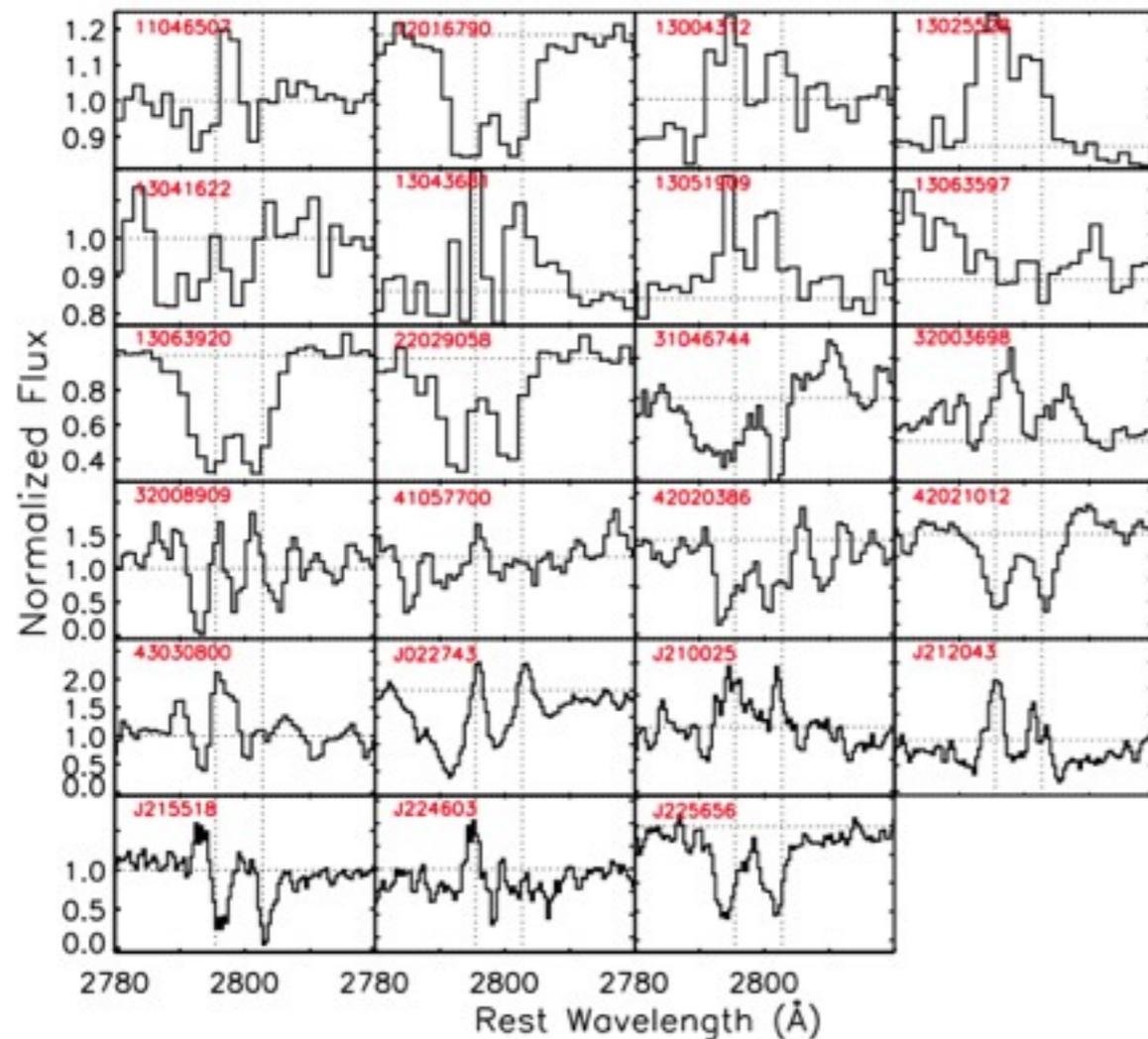
If anything, could be more escape from high-SFR, high-mass galaxies. This is just the tail of the velocity distribution and fate of gas is unclear.

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

log SFR

Note EW(outflow) only weak dependence on SFR! EW is complex: correlations don't prove mechanisms directly.

Winds in $z \sim 0.8$ post-starburst and X-ray AGN: common but not high velocity



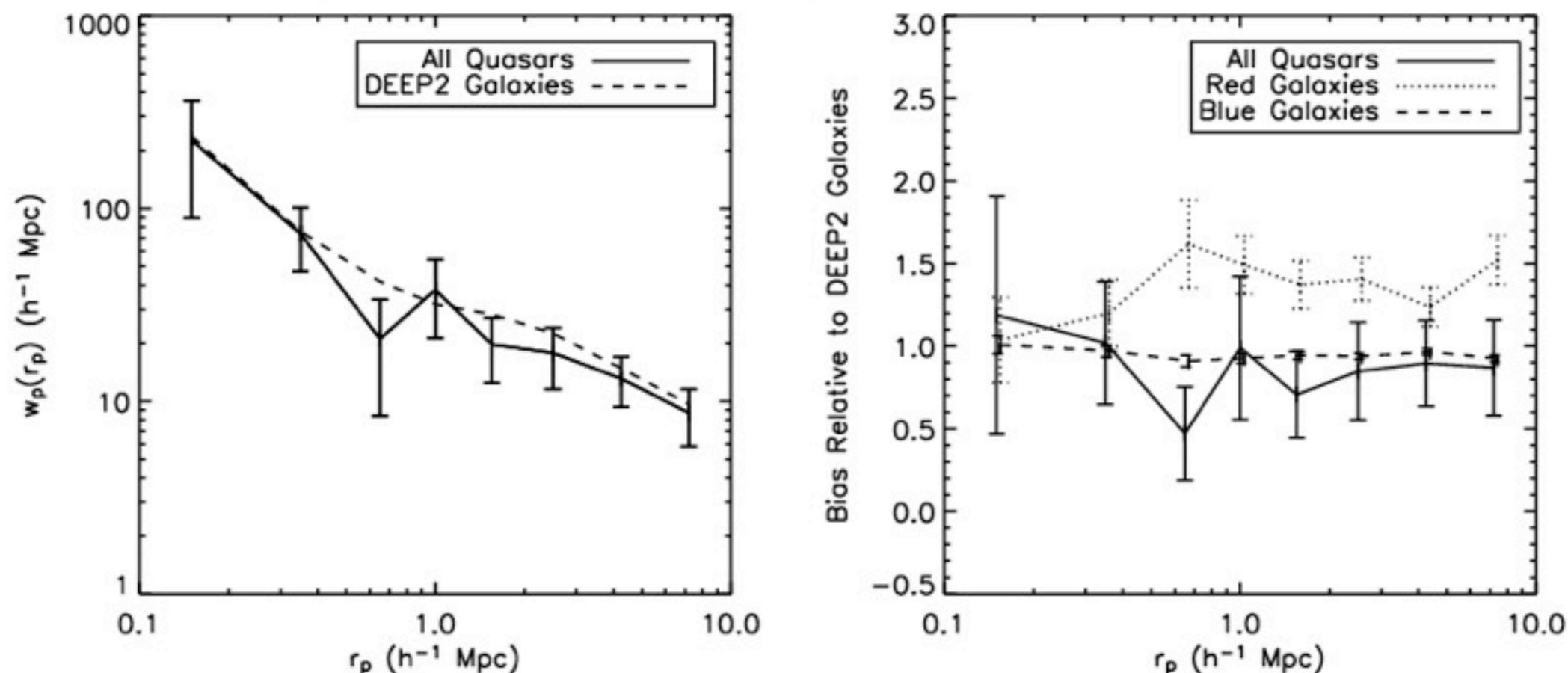
Alison Coil, BJW et al 2011

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, nor like “Eddington limit” objects shown by Tremonti, Diamond–Stanic

Testing the life cycle of galaxy phases with clustering

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

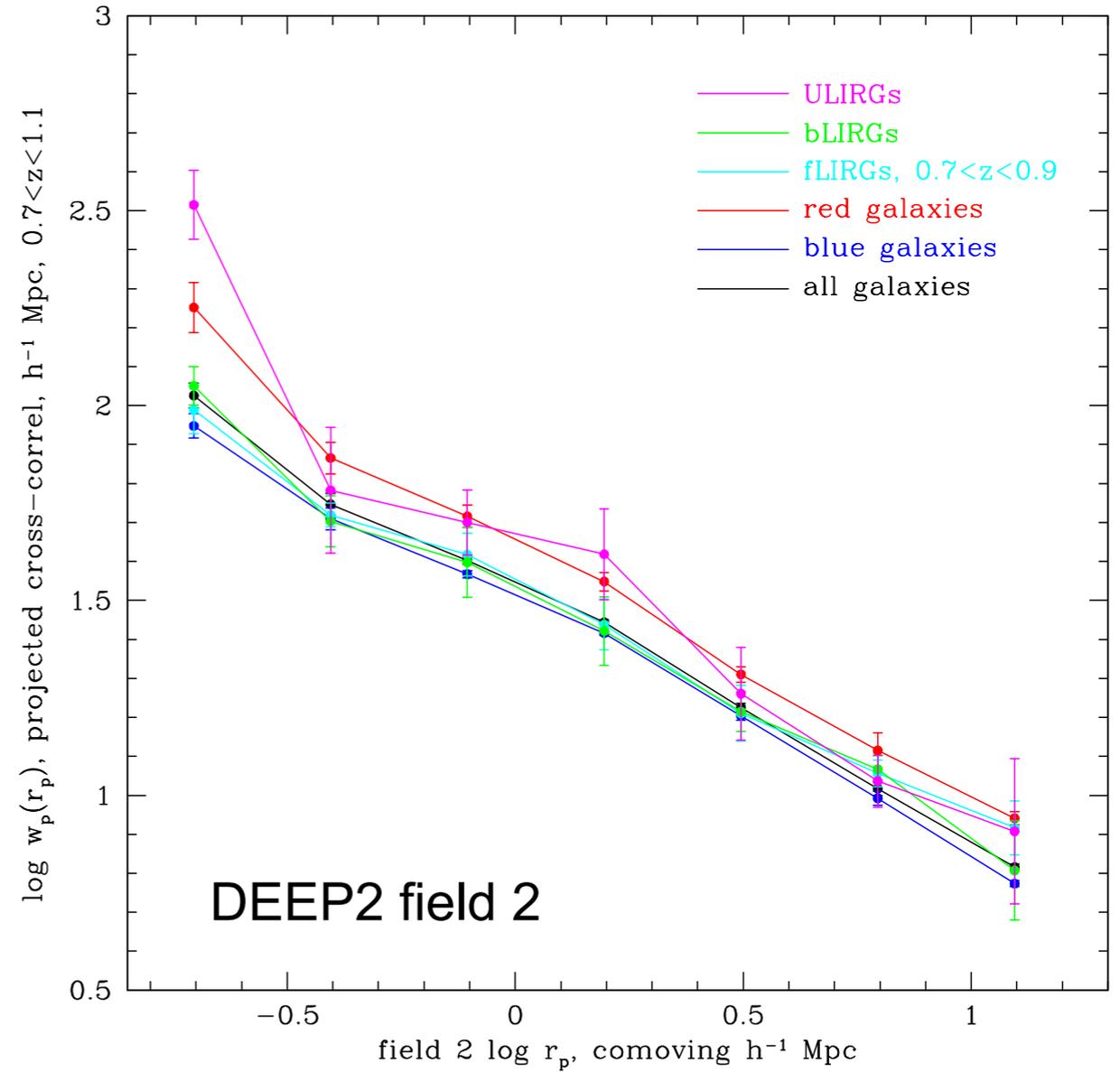
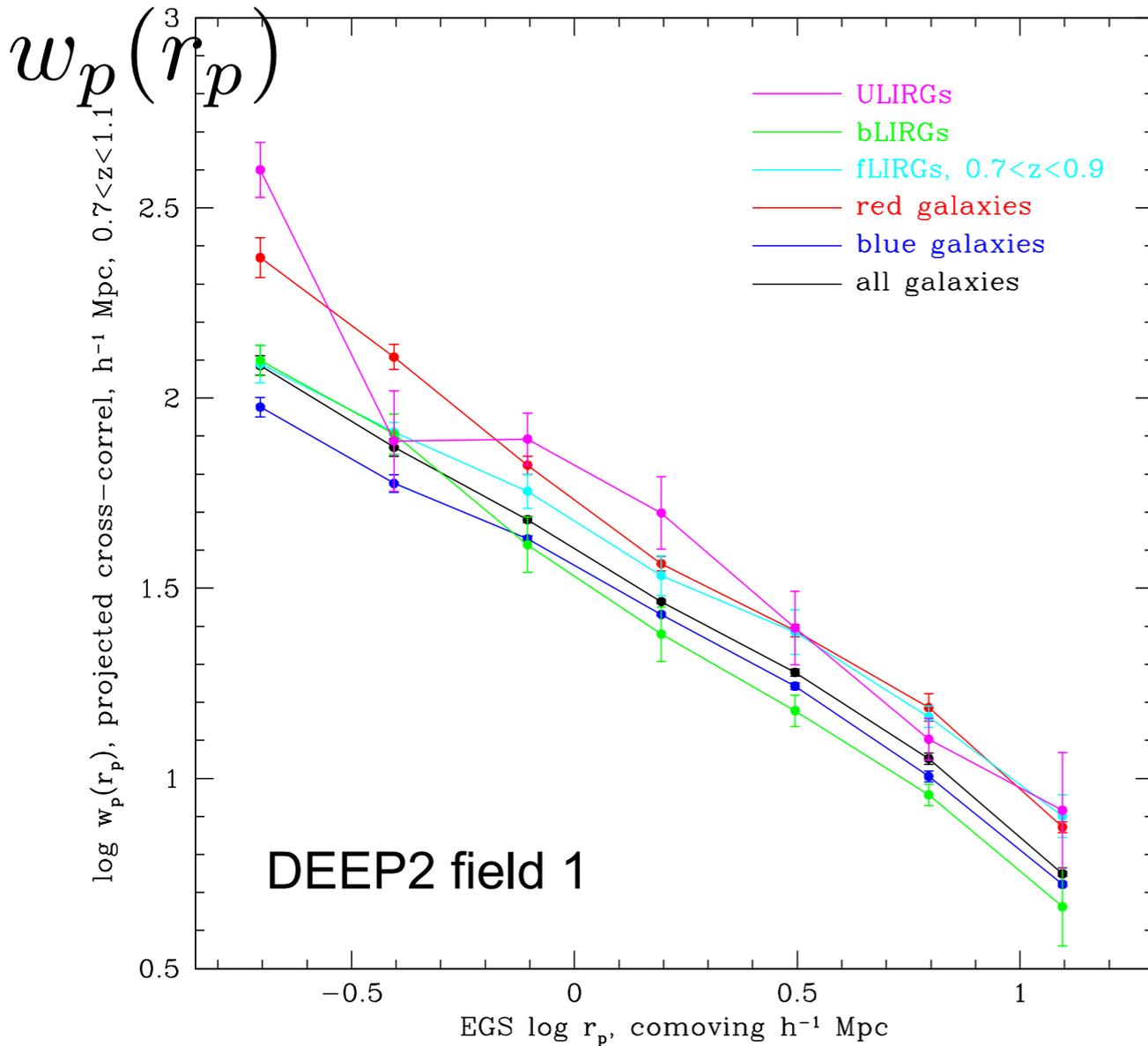
Hard to measure clustering for rare samples: can't get spatial autocorrelation of rare objects – ULIRGs, QSOs – without huge samples. But with a large sample of tracer galaxies, we can cross-correlate the ULIRGs to the galaxies. (For example, imagine cross-correlating positions of museums with people.)



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%).

We have MIPS data in two DEEP2 fields, to do this for ULIRGs.

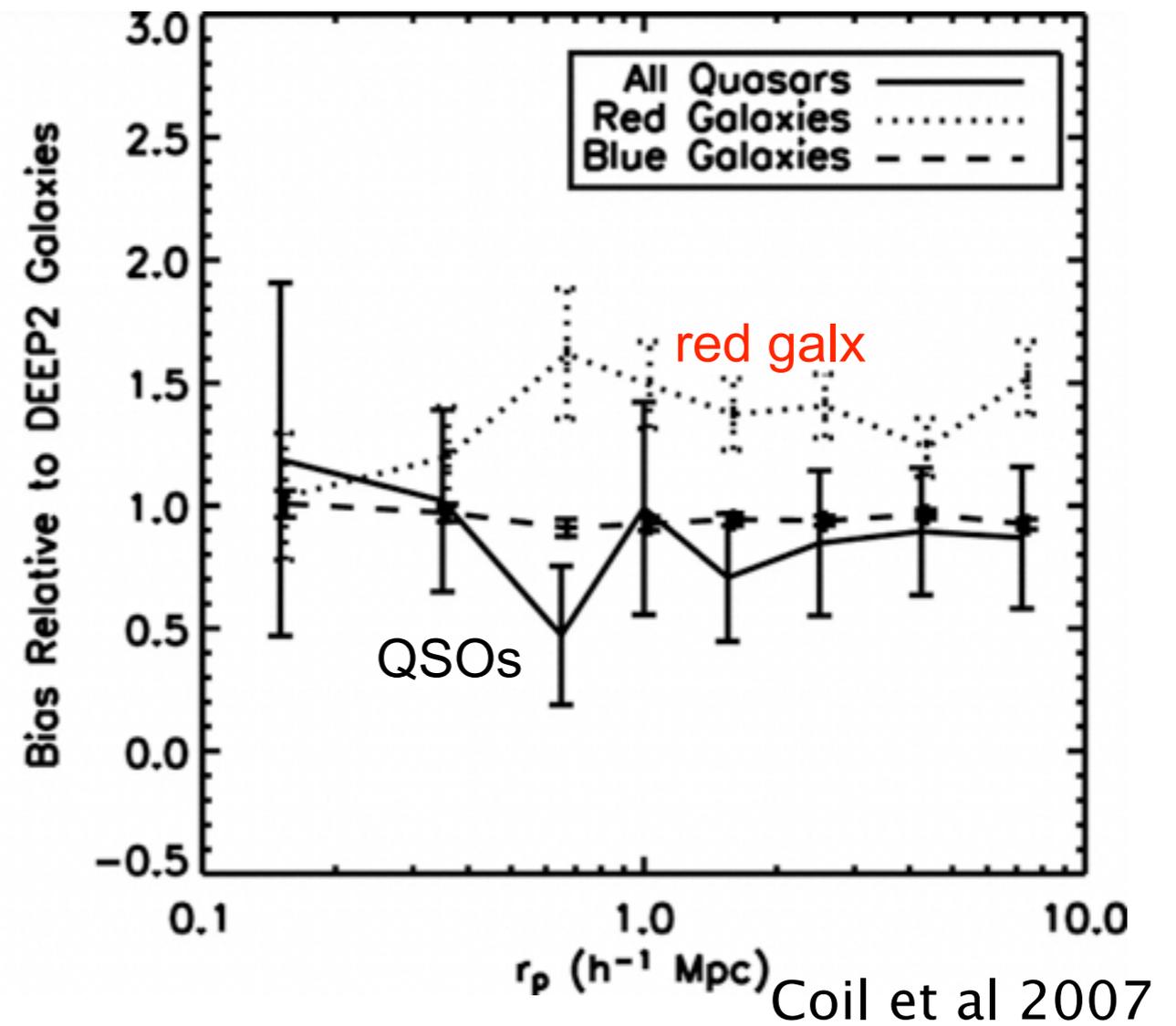
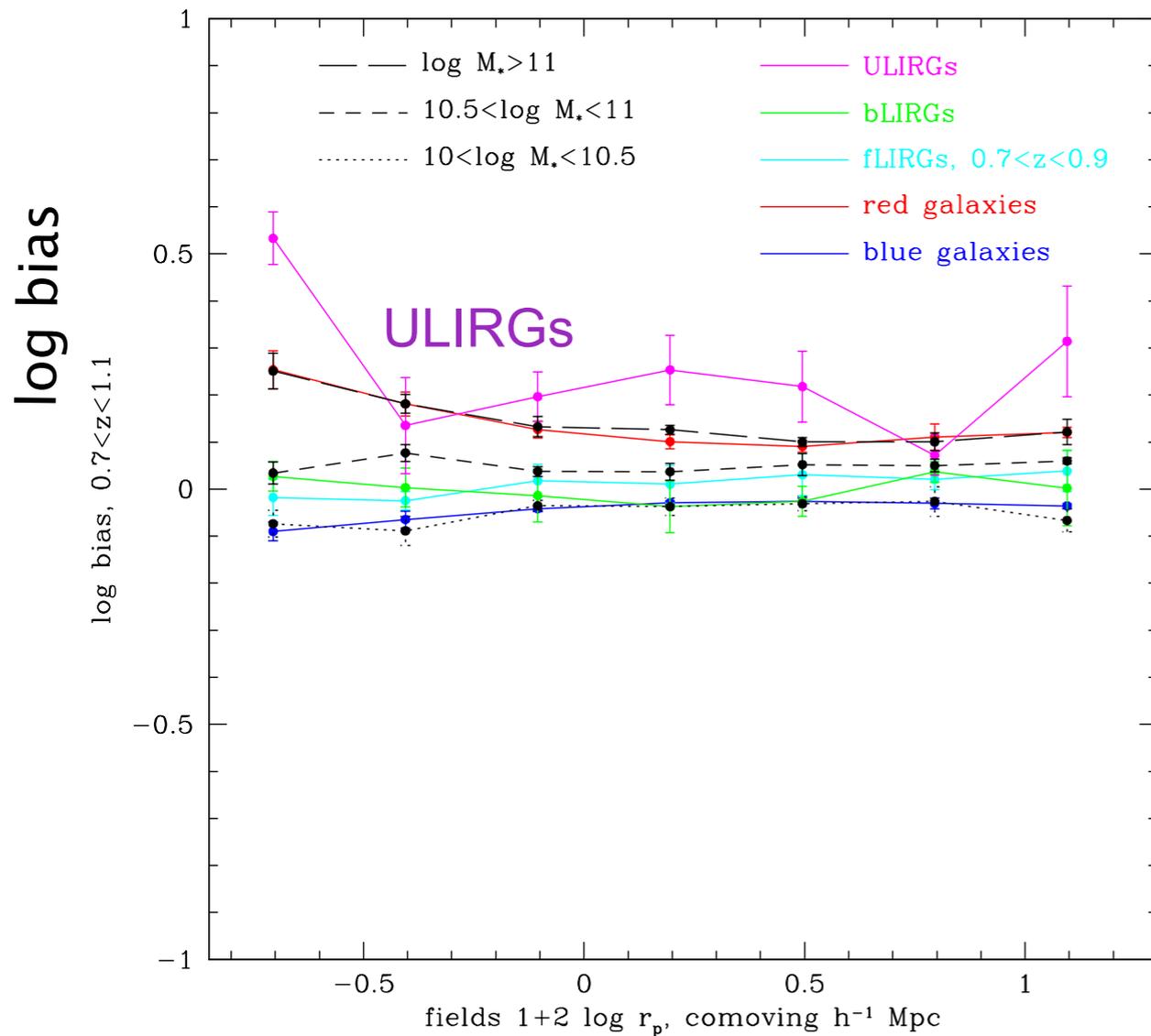
Cross-correlation measurements at $0.7 < z < 1.1$ (two fields)



LIRGs are very similar to blue/intermediate galaxies
 ULIRGs are as clustered as red galaxies at $r \sim$ 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



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.**

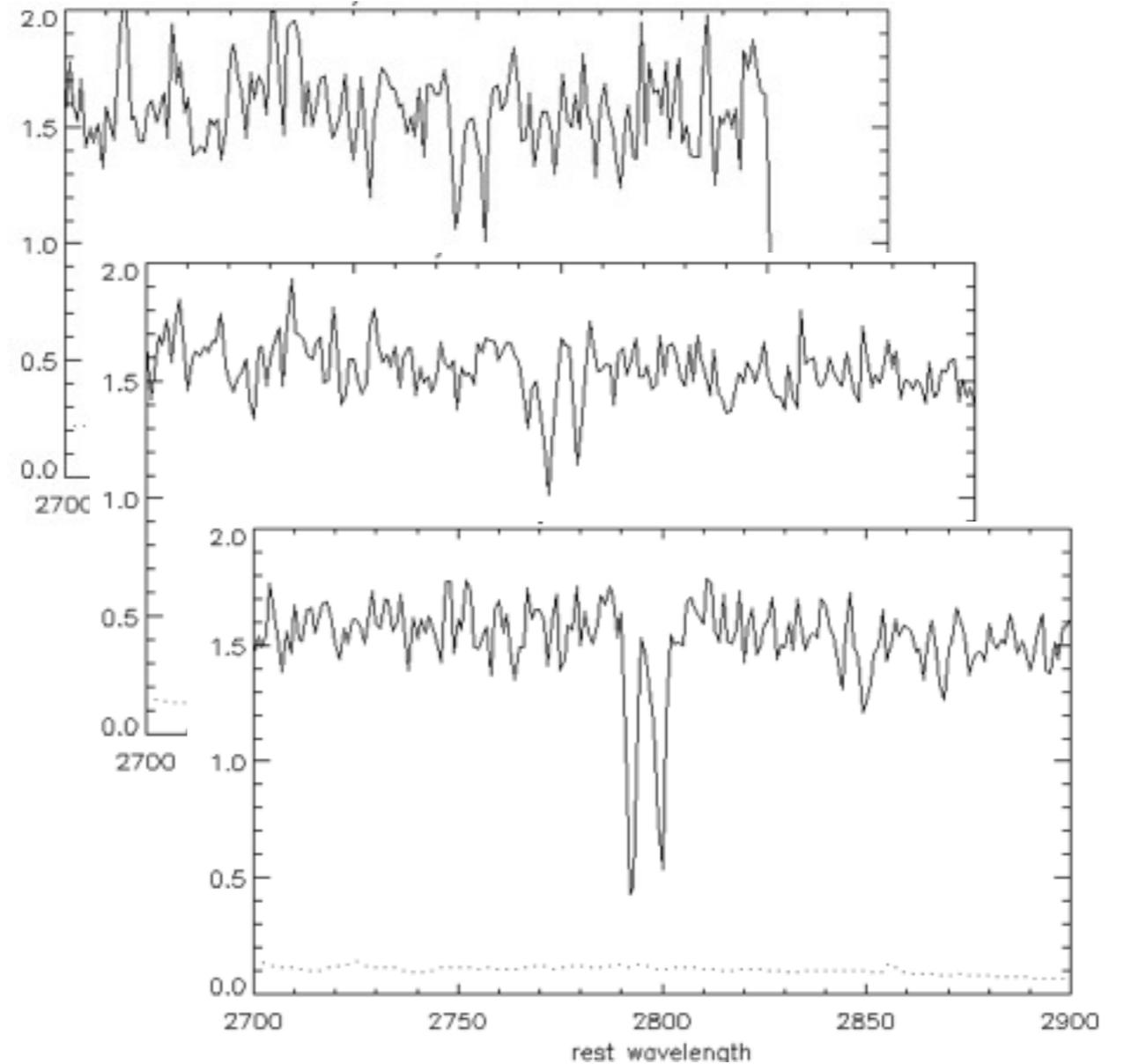
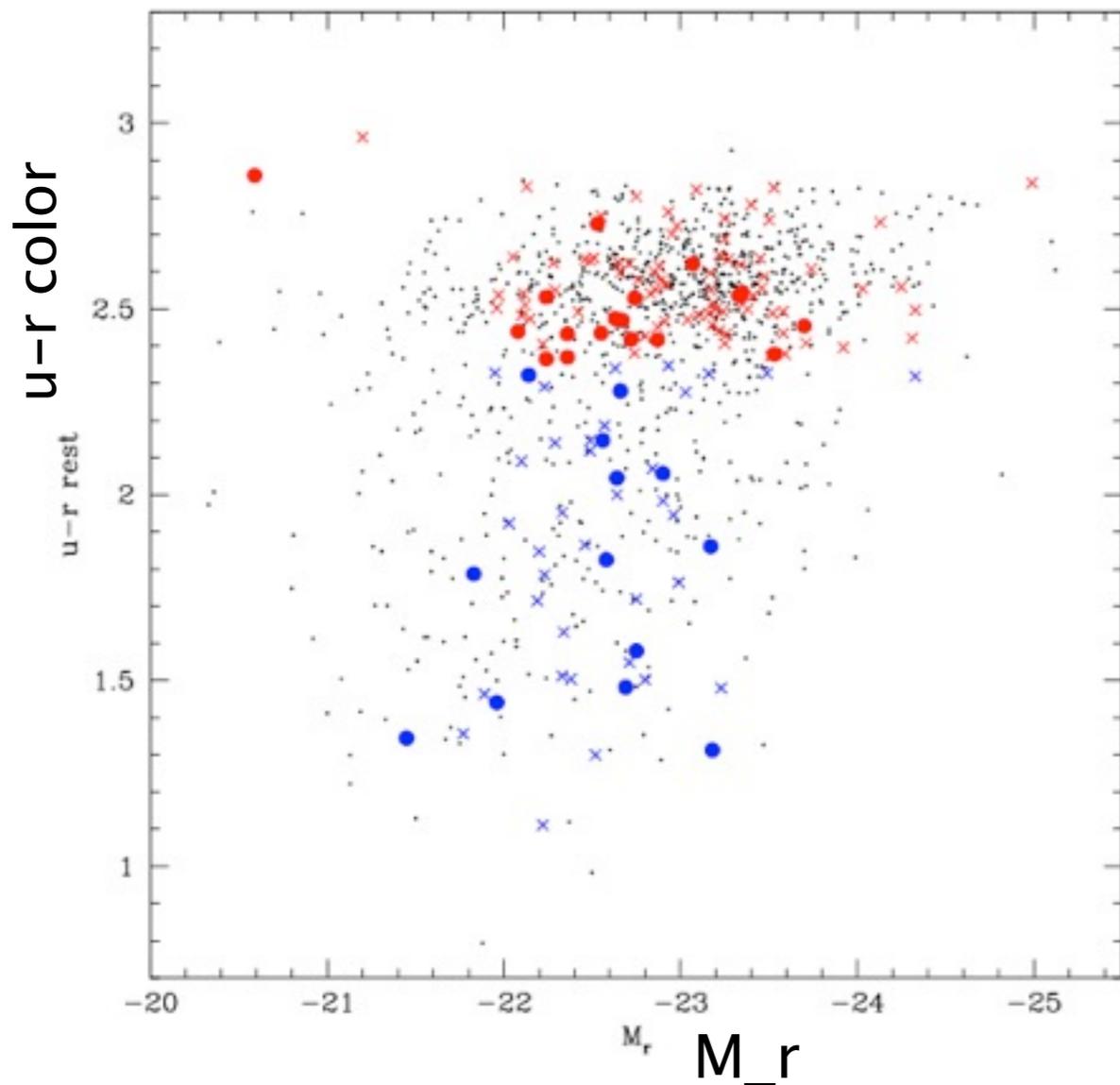
$z=1$ ULIRGs could only go to subset of QSOs.

$z=1$ QSOs cannot go to $z=1$ red galaxies => **EJECTIVE FEEDBACK CANNOT ALWAYS QUENCH.**

Clustering difference shows ULIRG \rightarrow QSO \rightarrow elliptical evolution scenario is oversimplified, although ULIRG \rightarrow elliptical link is plausible.

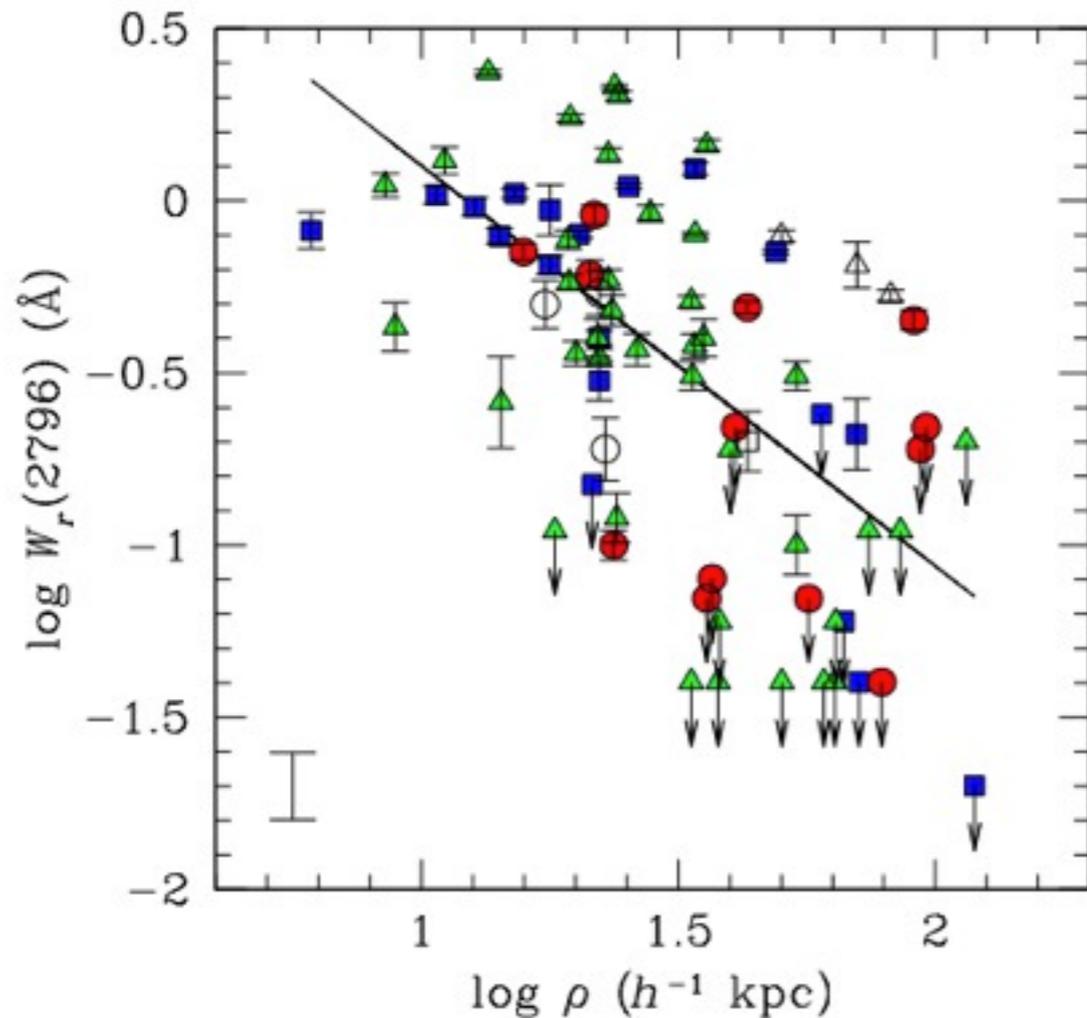
BOSS galaxies: study associations with Mg II in SDSS QSOs

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

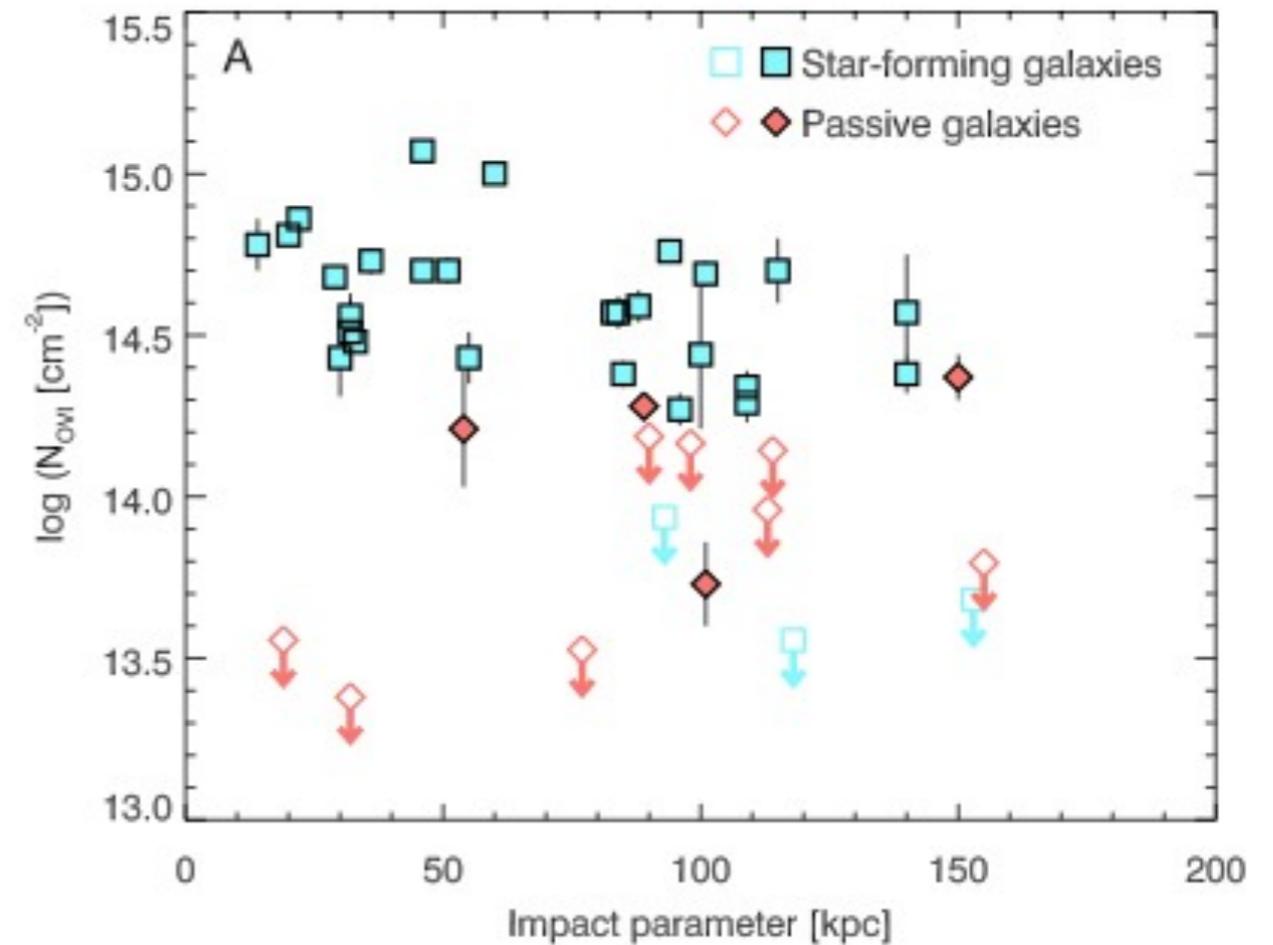


Inspect QSO spectra for Mg II at galaxy redshift. Probes cool gas around massive galaxies at $z \sim 0.4-0.5$. Can accumulate large sample over course of survey since BOSS re-covers the SDSS area.

Covering factor depends on impact, luminosity, and maybe color

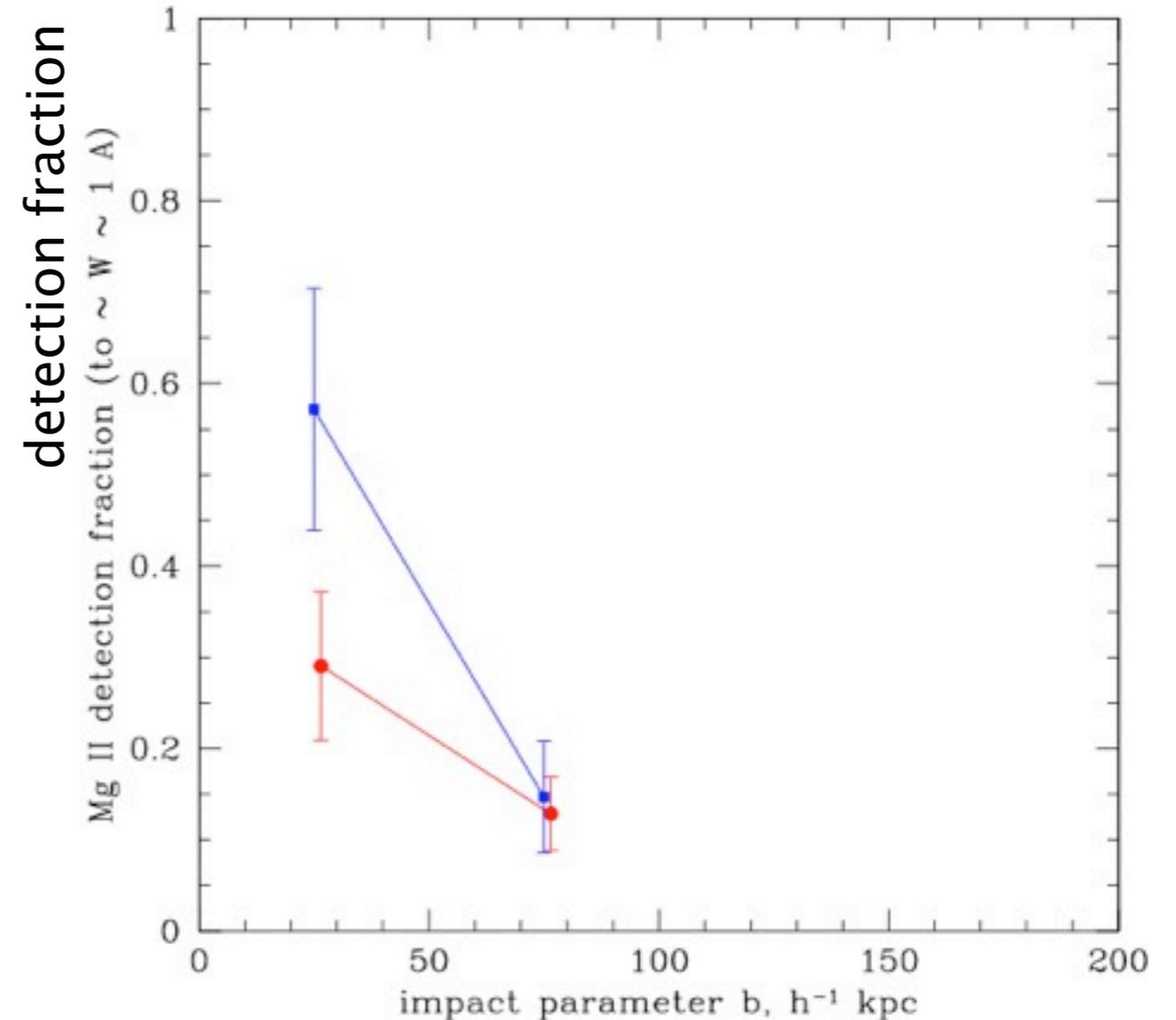
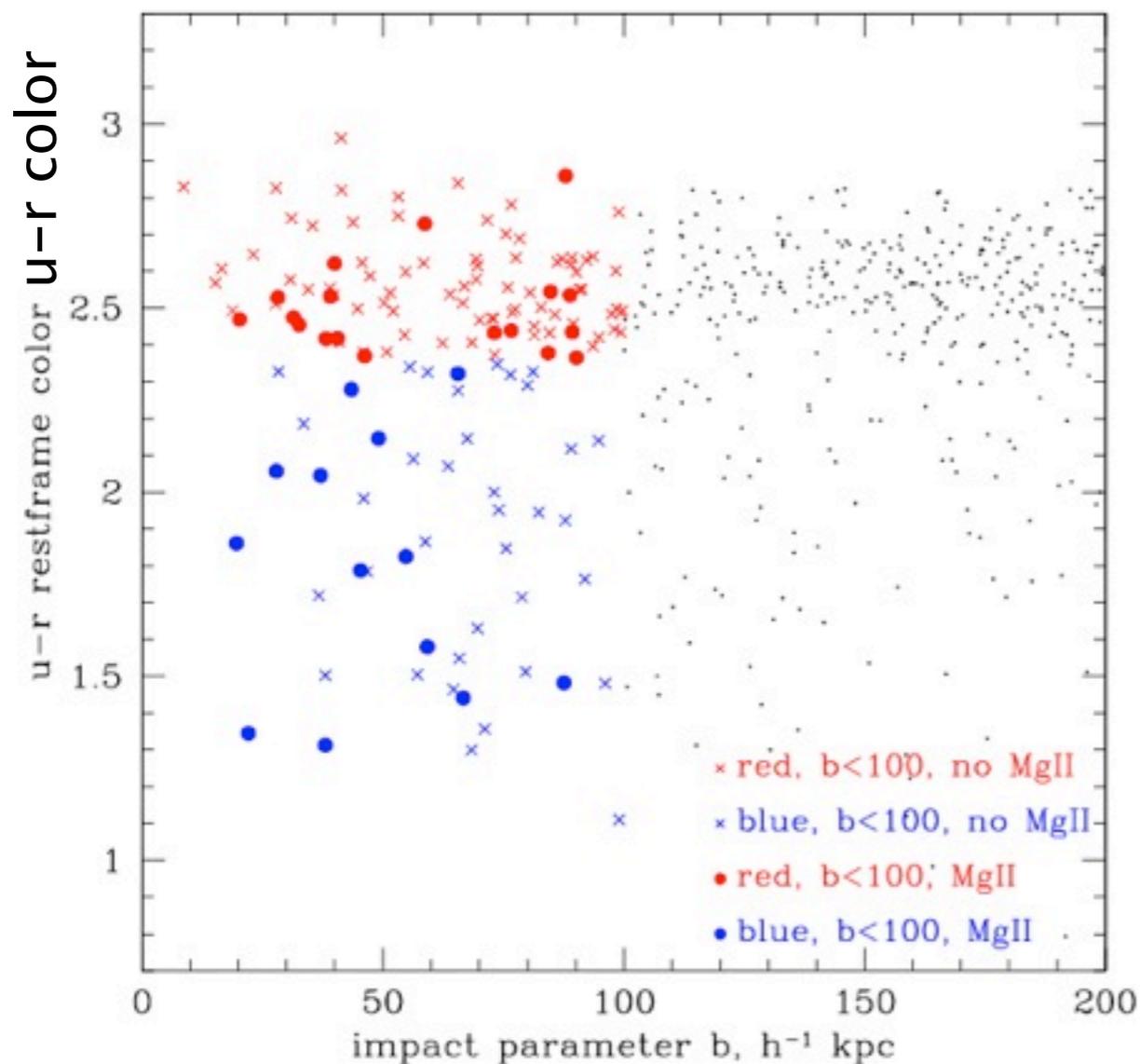


H.-W. Chen et al 2010
Mg II survey: cool gas, to lower EW than SDSS-2 spectra.
Not a significant difference between covering factor around red/blue galaxies.
Covering factor/column density depends on impact parameter and galaxy luminosity.



Tumlinson et al 2011
HST/COS O VI survey: warm gas, sensitive, **very 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 $z \sim 0.4$ red galaxies – within R_{vir} – 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:

At $z \sim 1$, many star-forming galaxies are above the LIRG threshold. These are unlike local U/LIRGs – not generally major mergers.

The $z > 1$ SF galaxies drive winds, with significant, but not well constrained, mass loading. Dependence on mass/SFR, but no strong dependence on morphological type (though only a small sample have HST imaging).

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 ISM and it doesn’t fit with the QSO clustering. Mergers may quench – but not by QSO blowout. Maybe it’s boring old gas exhaustion.

BOSS galaxy – absorber associations show that there are strong Mg II systems with massive red galaxies, inside R_{vir} . Need a way to keep gas from causing further star formation/turning galaxies blue? Late time accretion rate is supposed to be small, but something’s happening here.