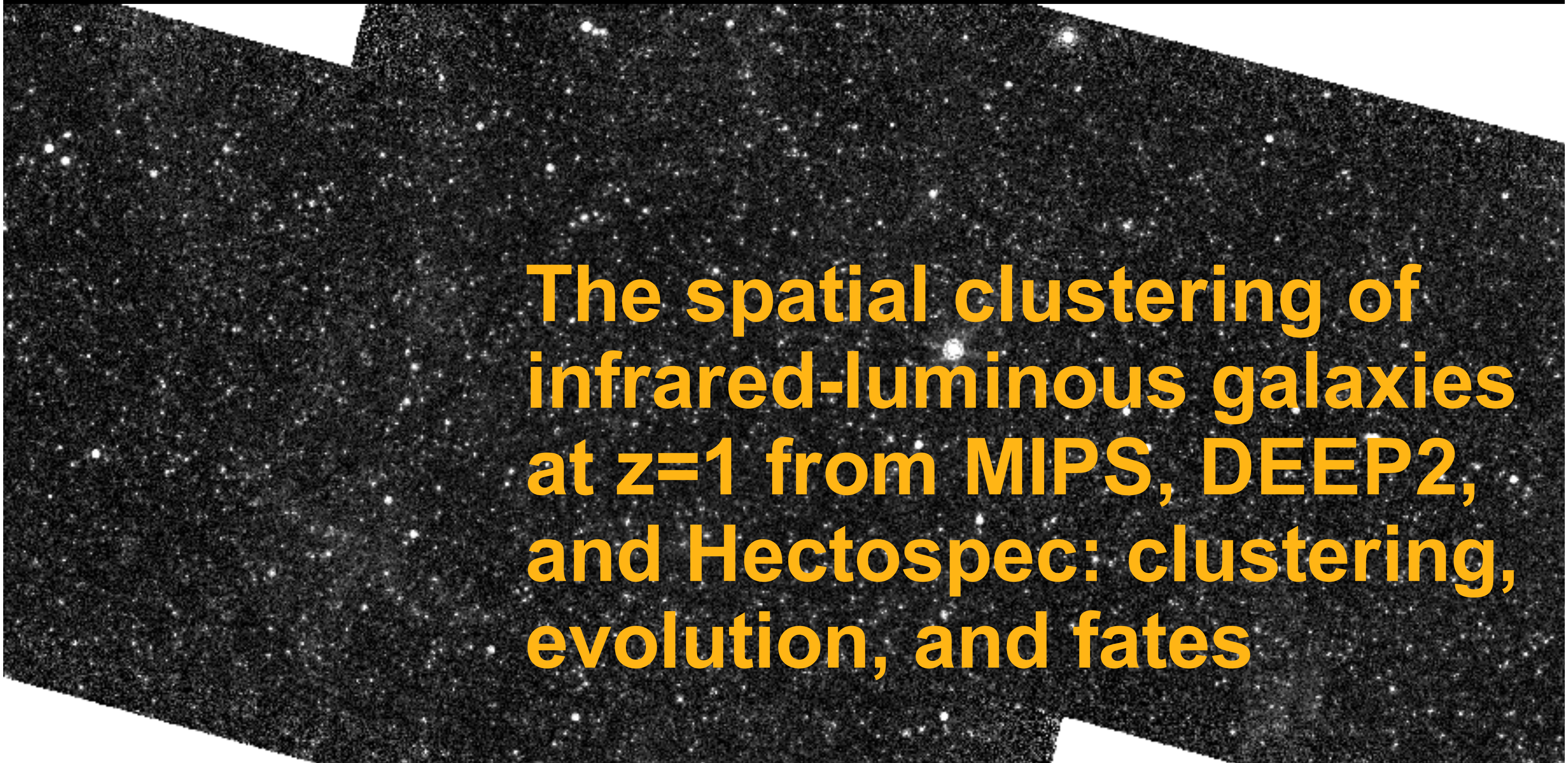
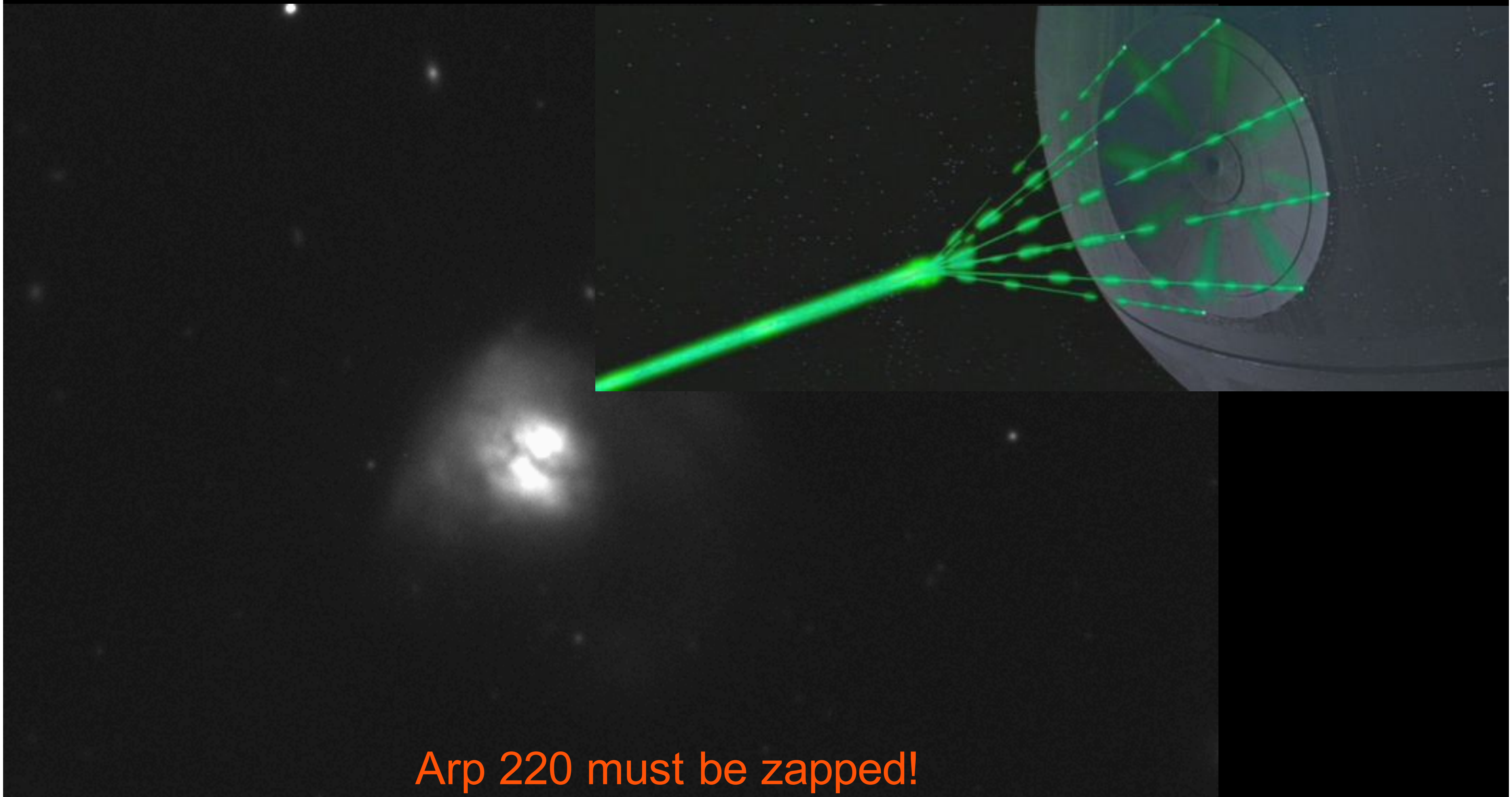


The spatial clustering of infrared-luminous galaxies at z=1 from MIPS, DEEP2, and Hectospec: clustering, evolution, and fates

Benjamin Weiner (Steward)
Alison Coil (UCSD),
with the MIPS and DEEP2 teams



Closest ULIRG, but is it archetypal?

What is a LIRG/ULIRG - and is it the same at low and high z?

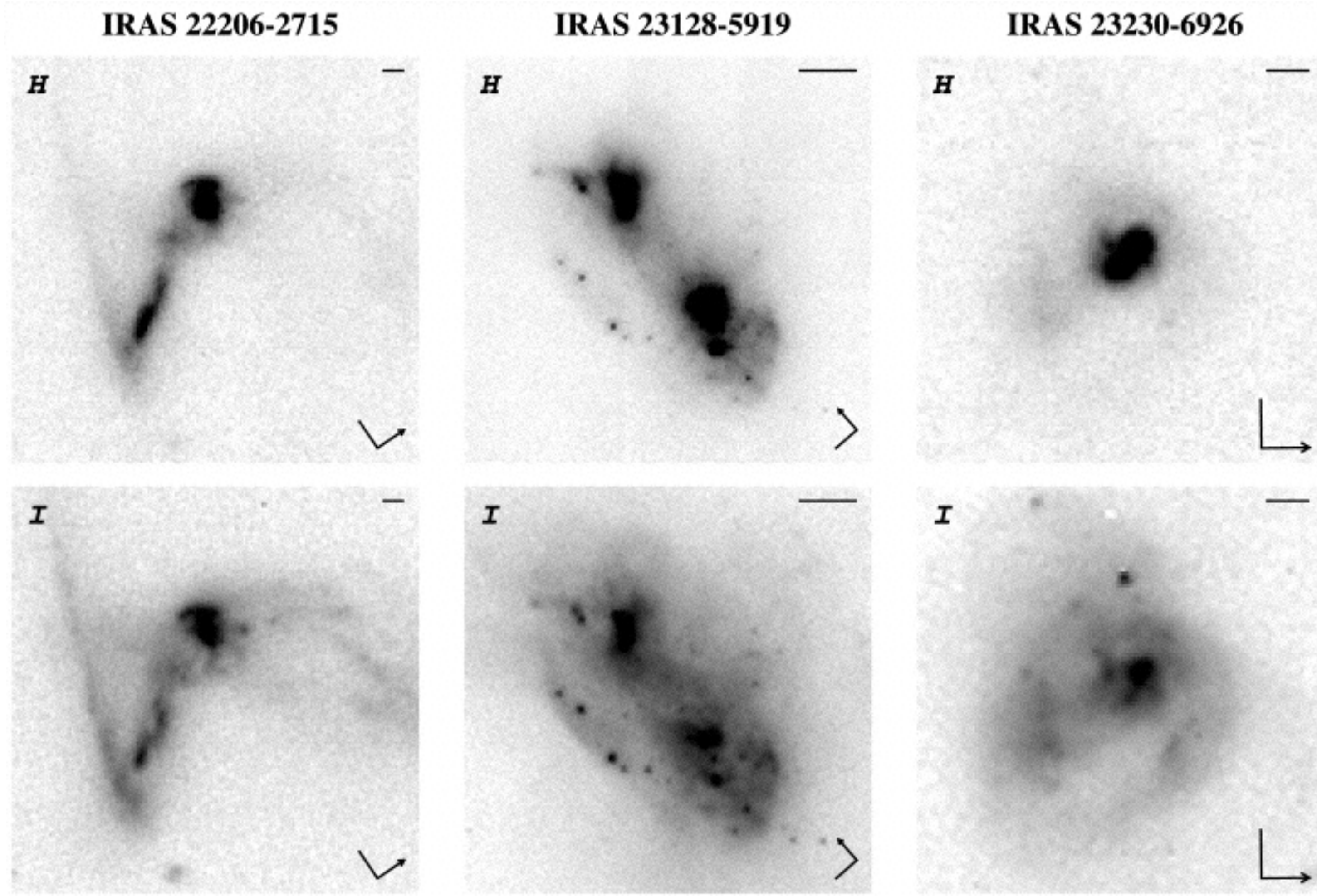
LIRG:
L(FIR)>10^11 Lsun

ULIRG:
L(FIR)>10^12

Star formation or
AGN reprocessed
by dust

Locally, mostly
interacting galaxies

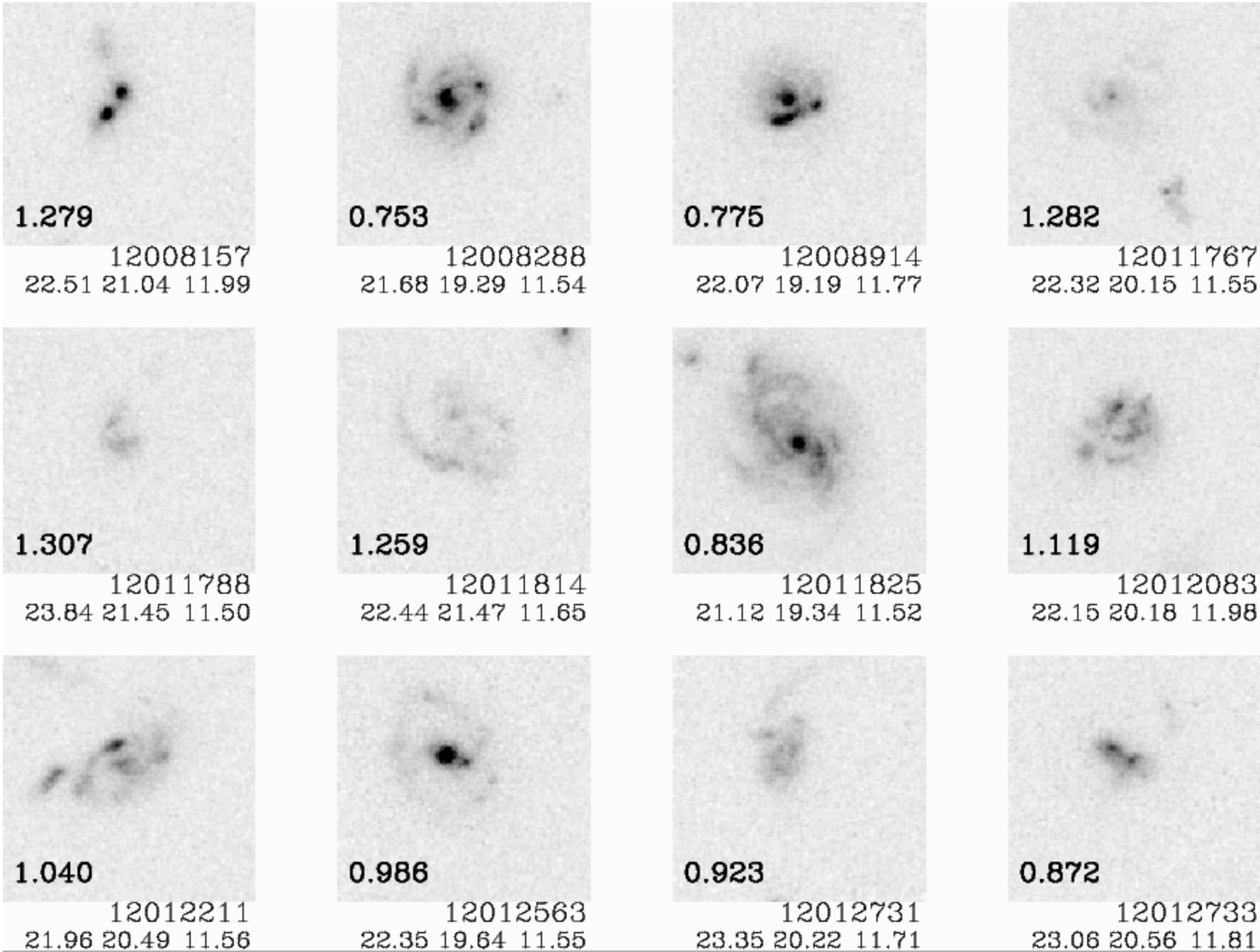
Locally, ULIRGs are rare



ULIRGs may be a stage in:
merger > ULIRG > QSO > elliptical
(e.g. Sanders 1988)

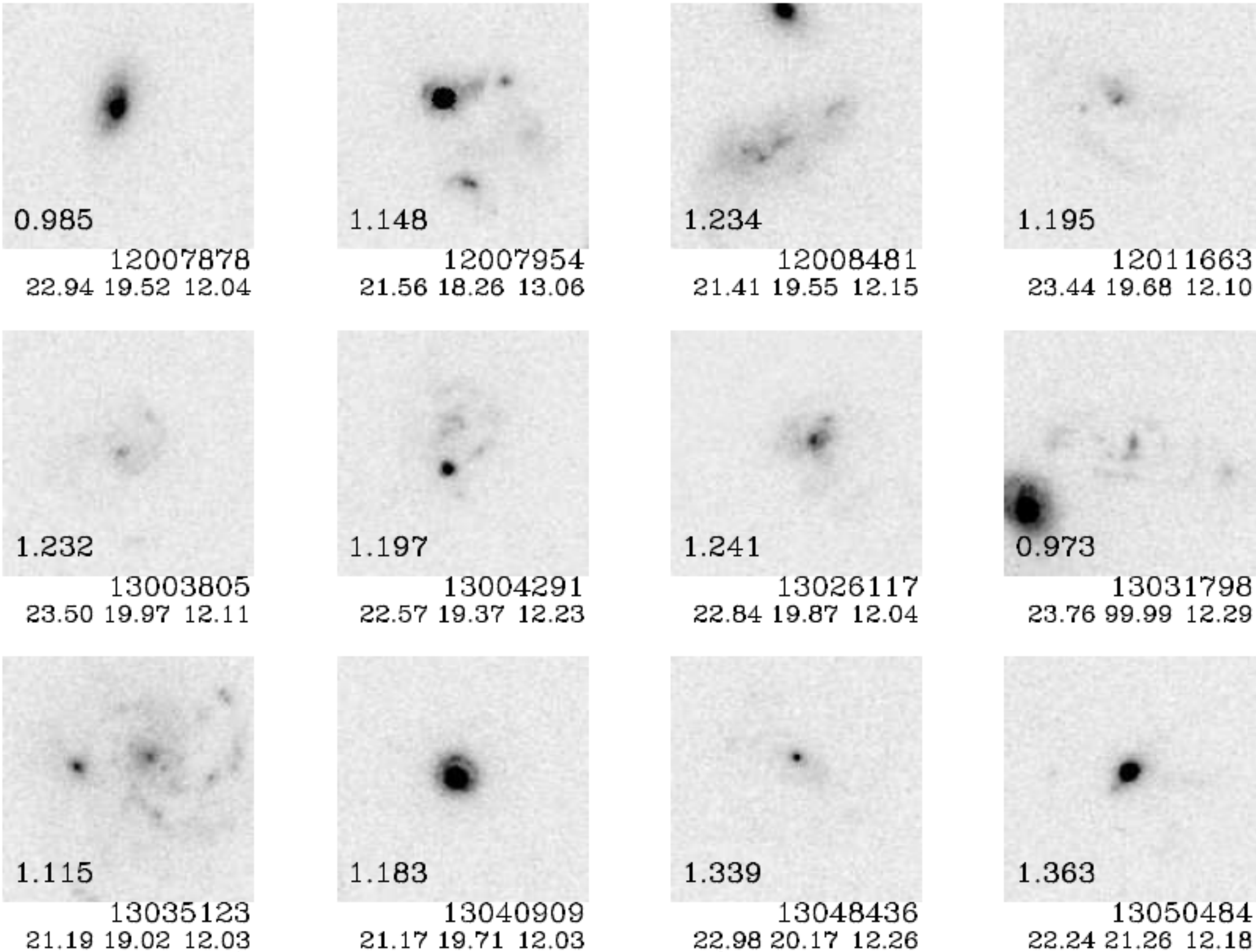
IRAS-selected ULIRGs at z~0.2
WFPC2/NICMOS, Bushouse etal 2003

Example bright LIRGs (L>3e11) in the Groth Strip: MIPS 24um, ACS I



At z=1, IR-luminous galaxies more common; some LIRGs are spirals

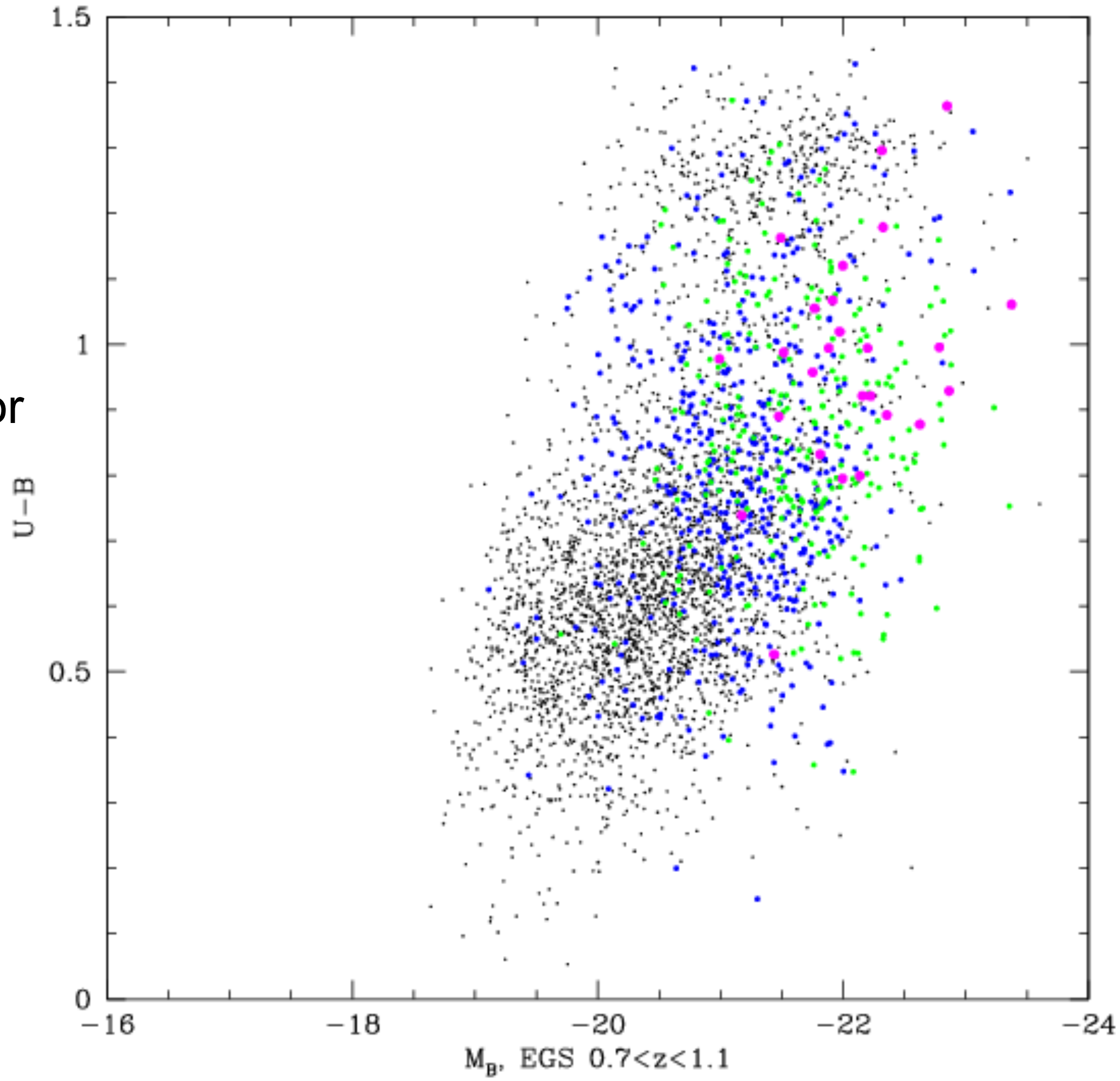
Some ULIRGs in the Groth Strip: MIPS 24um, HST/ACS I



At z=1, ULIRGs mostly look peculiar/merger, but highly extincted (see J. Kartaltepe talk). Is the LIRG/ULIRG distinction physical?

Where do z~1 ULIRGs and LIRGs sit in color-luminosity?

U-B
rest
color



red

blue

M_B rest, 0.7 < z < 1.1

LIRGs, L_IR > 10^11 Lsun
and brighter LIRGs,
L_IR > 3 x 10^11
are the brighter end of
the blue galaxy population,
edging into the "green valley"

ULIRGs, L_IR > 10^12,
are among the brightest of the
blue or green valley.
Despite being very dusty, they
do not live on the red sequence.

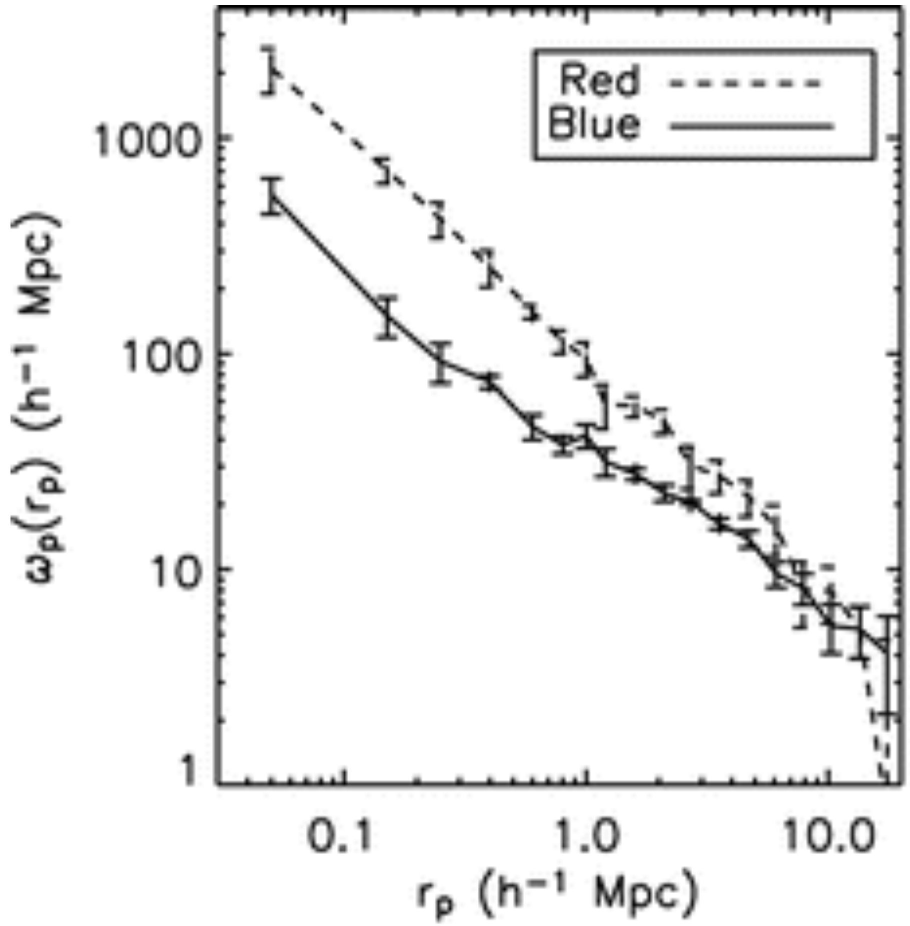
Higher SFR at higher z => Many more infrared-luminous galaxies
What will they evolve into? Ellipticals, Milky Ways, or both?

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

Massive objects are more strongly clustered.

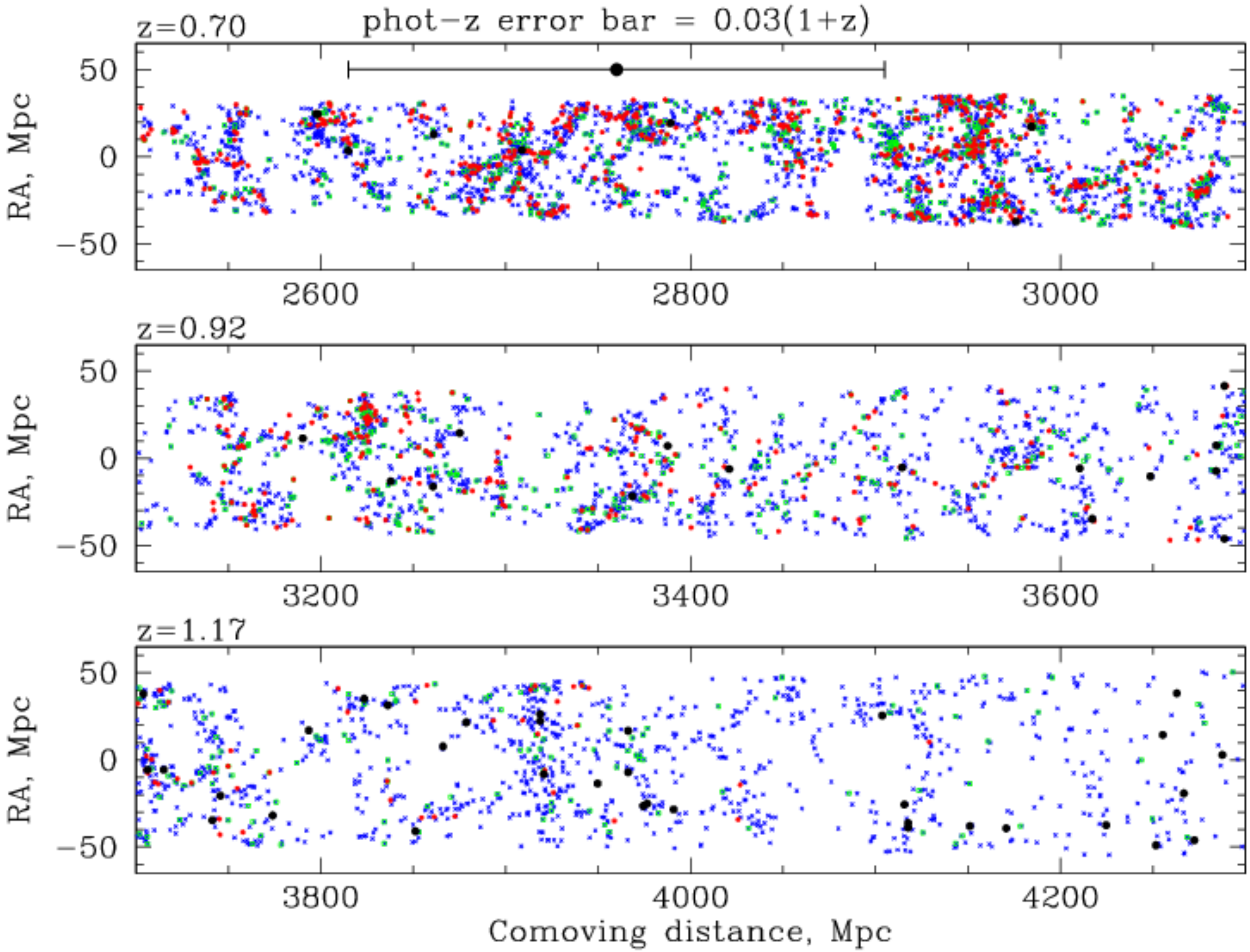
Measure correlation functions by counting pairs as a function of separation, to get the excess probability over random.

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 locally.
r0 ~ 5 h^-1 Mpc

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



Cone diagram of DEEP2 field 2: rich clustering structure

Angular clustering measurements, in principle, can measure clustering without needing lots of redshifts - but with major caveats

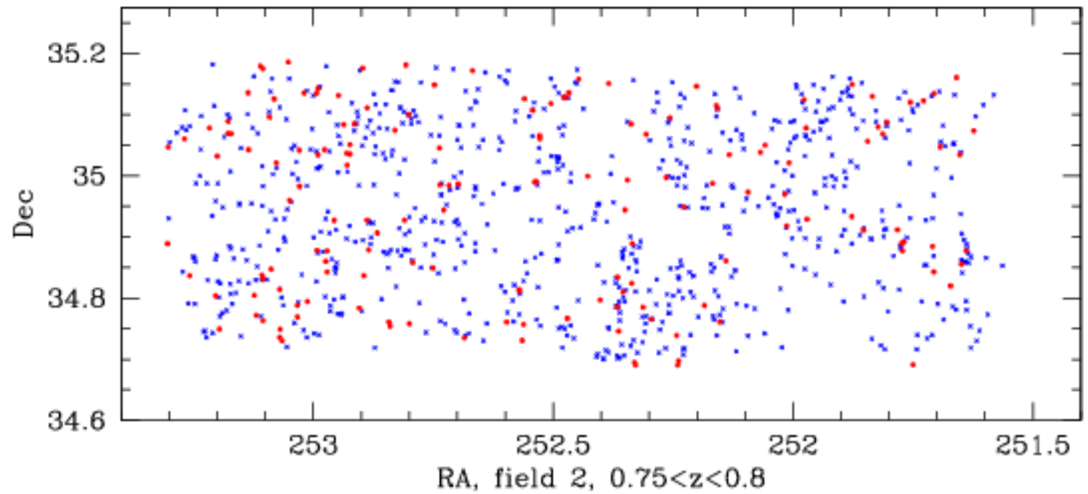
If the angular and spatial correlation functions are power laws, the angular correlation can be inverted to get the spatial:

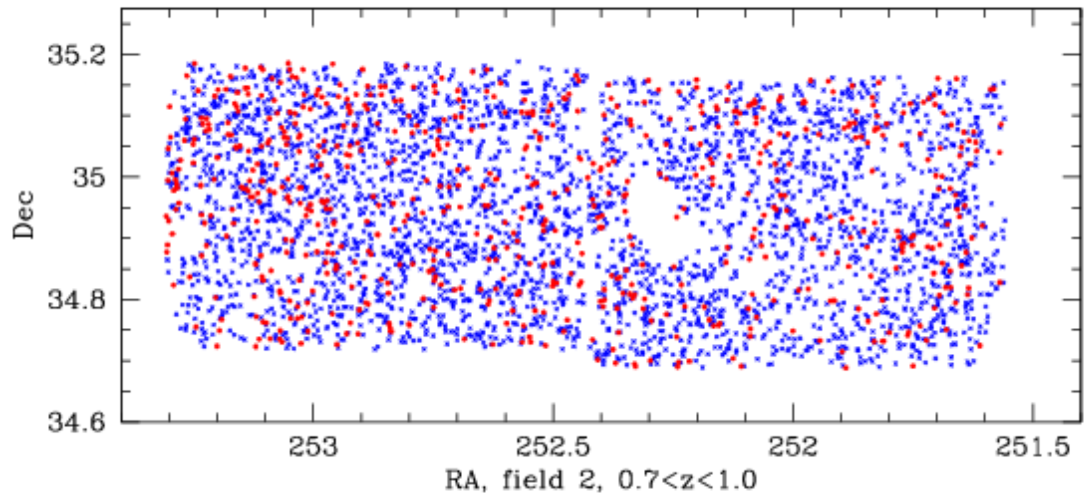
$$w(\theta) = A\,\theta^{1-\gamma}$$
$$\xi(r) = (r/r0)^{\gamma}$$
$$r0 \sim (stuff \times A\,\Delta z)^{1/\gamma}$$

(Limber's equation, Limber 1954)

This is critically dependent on knowing the redshift distribution of your sources and its width Dz.

z~2 very bright ULIRGs in large area surveys (SWIRE, Bootes) have high angular clustering and inferred r0 ~ 6-10 h^-1 Mpc, though unknown dN/dz can be a problem (Farrah+; Magliochetti+; Brodwin+)

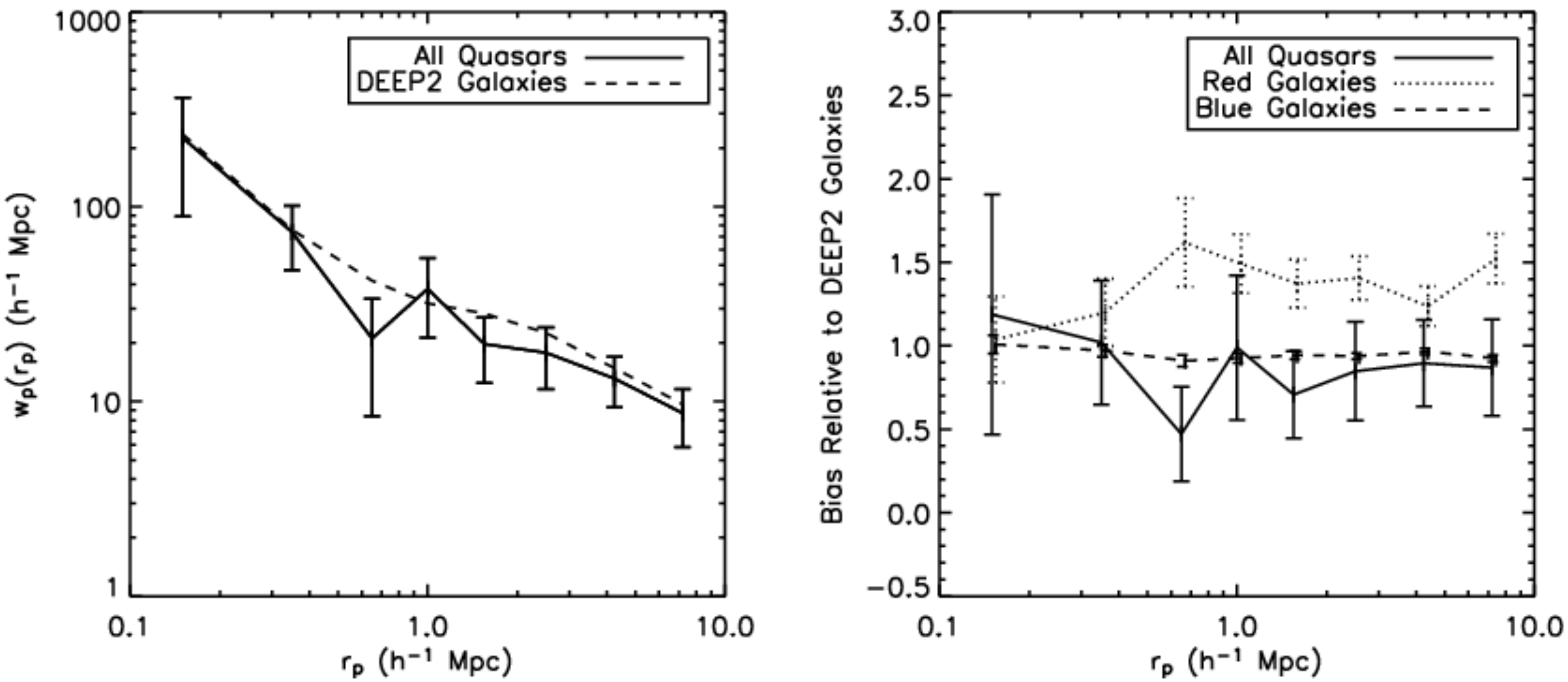




Larger redshift depth => less angular correlation

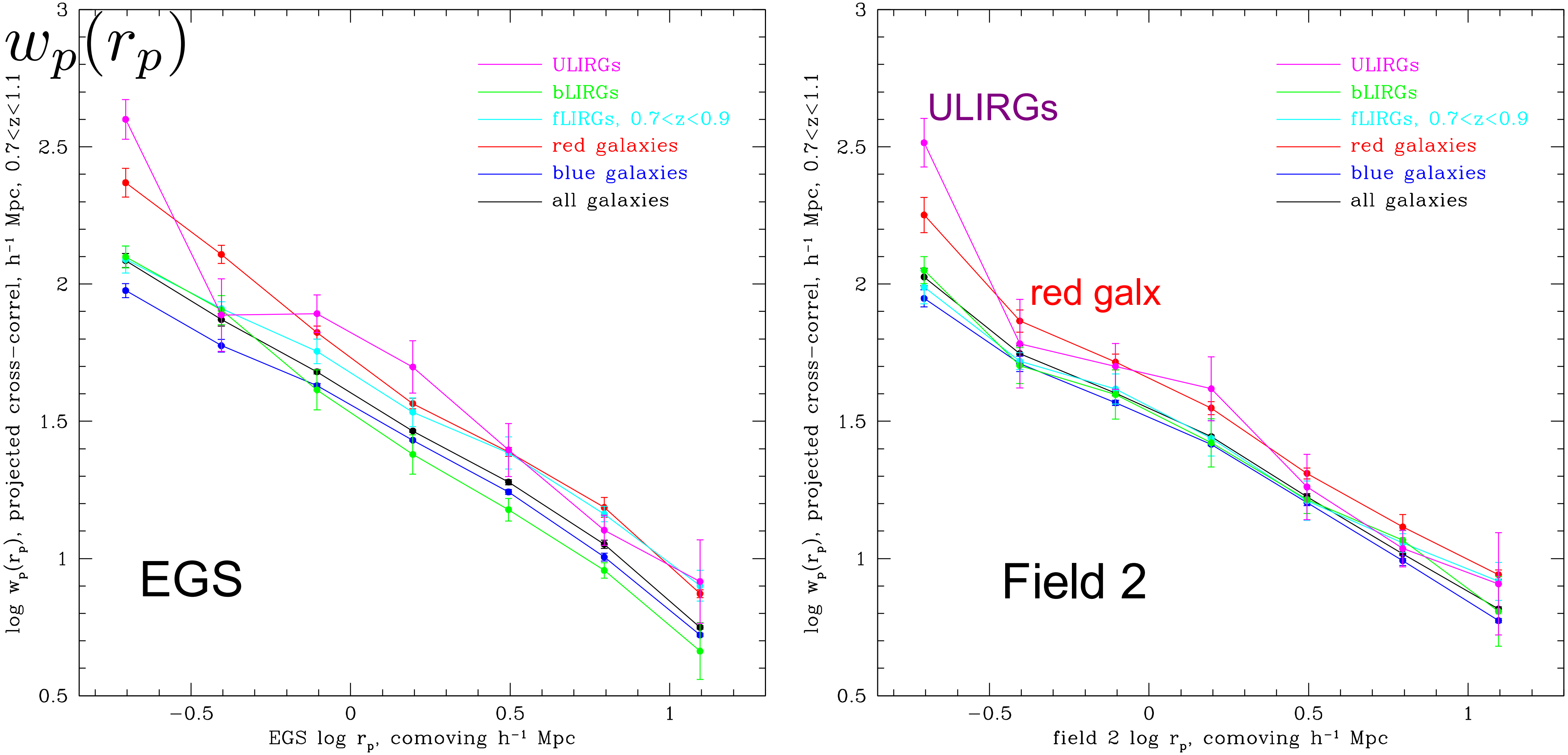
Spatial clustering: beating the Poisson noise by cross correlation

Spatial clustering is more accurate than angular, but can't measure spatial autocorrelation of rare objects - ULIRGs, QSOs - without huge samples. However, given 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.
We took MIPS data to 200 mJy in DEEP2 field 2, to do this for ULIRGs.

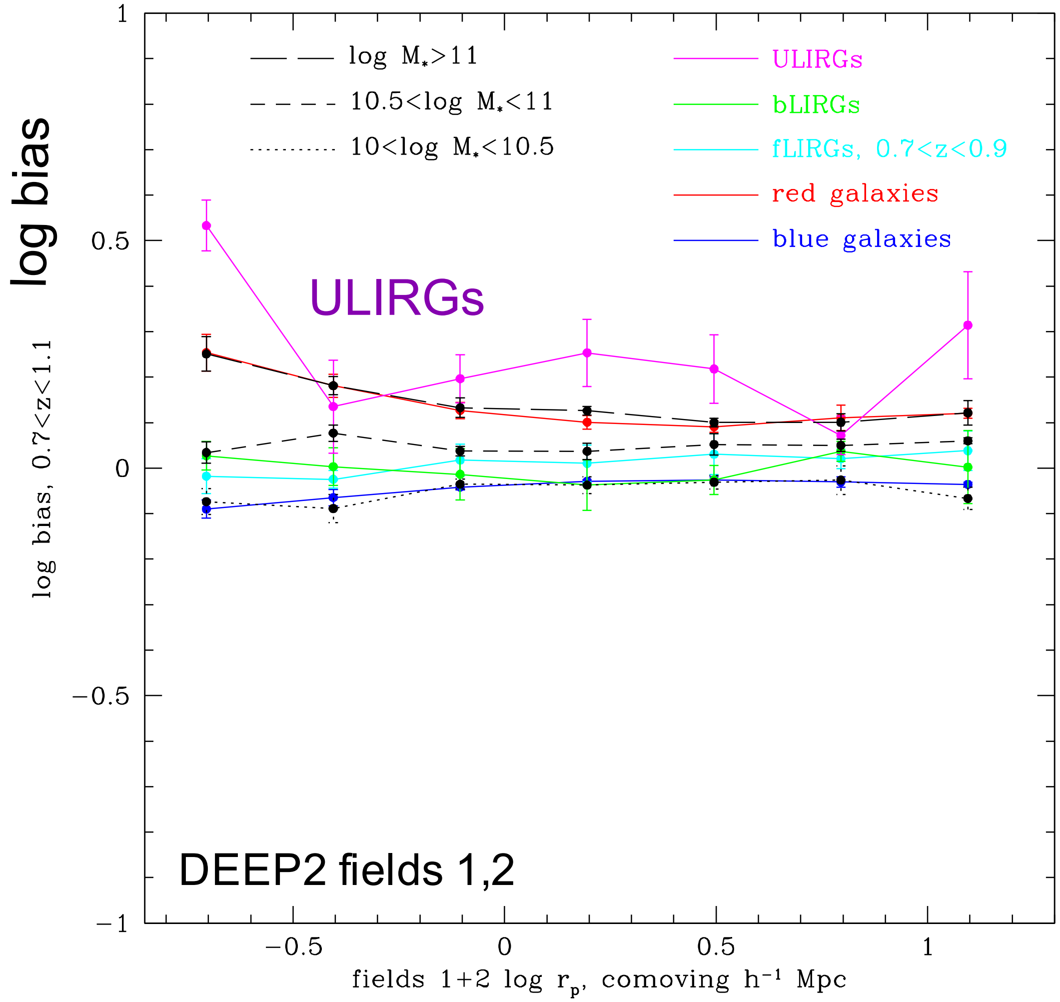
Results: U/LIRG cross-correlations at 0.7<z<1.1 in two DEEP2 fields

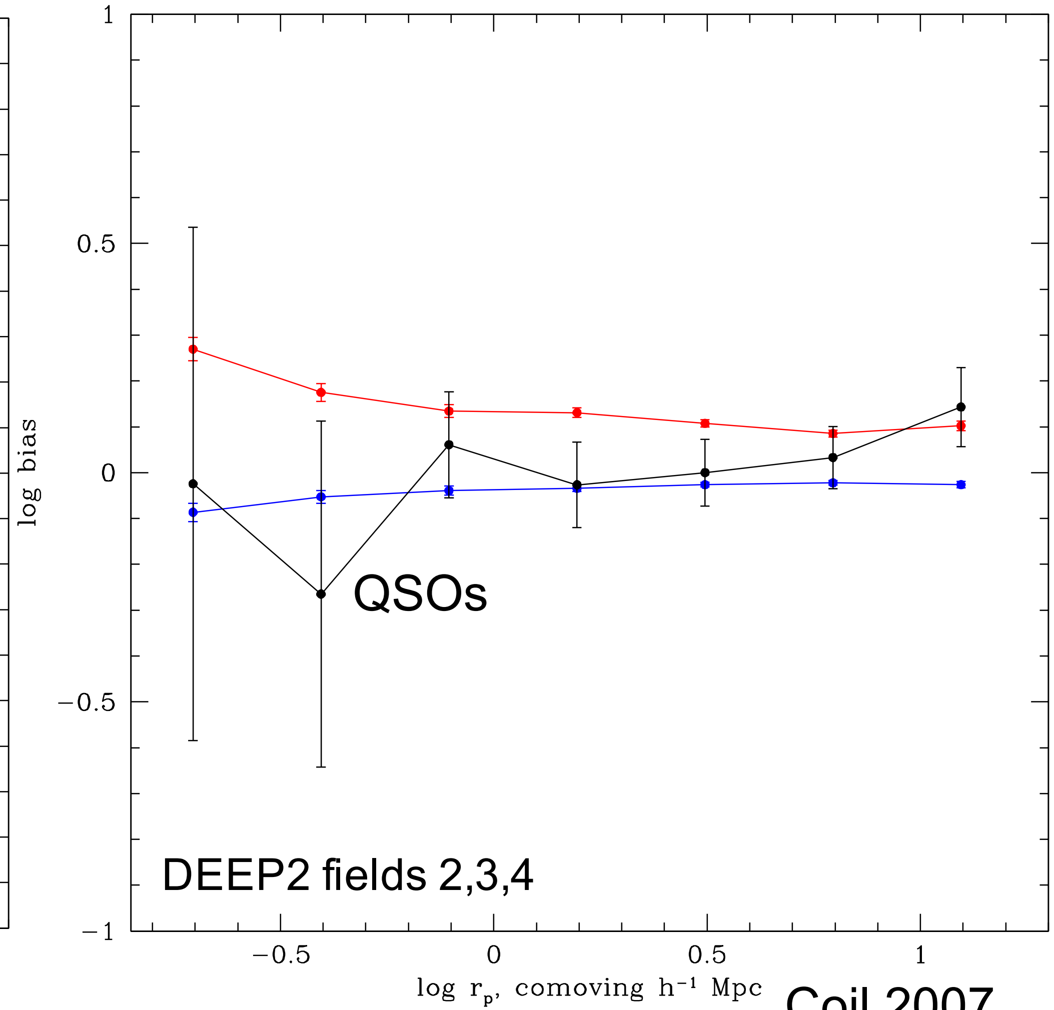


LIRGs are very similar to blue/intermediate galaxies
ULIRGs are as clustered as red galaxies at r ~ few Mpc

ULIRGs => probably occurring in groups (no rich clusters in DEEP2)
Strong clustering, but r_0 is not large (~5, not ~10 Mpc!)
Nominally, typical halo mass ~ 1-3e13 Msun.

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

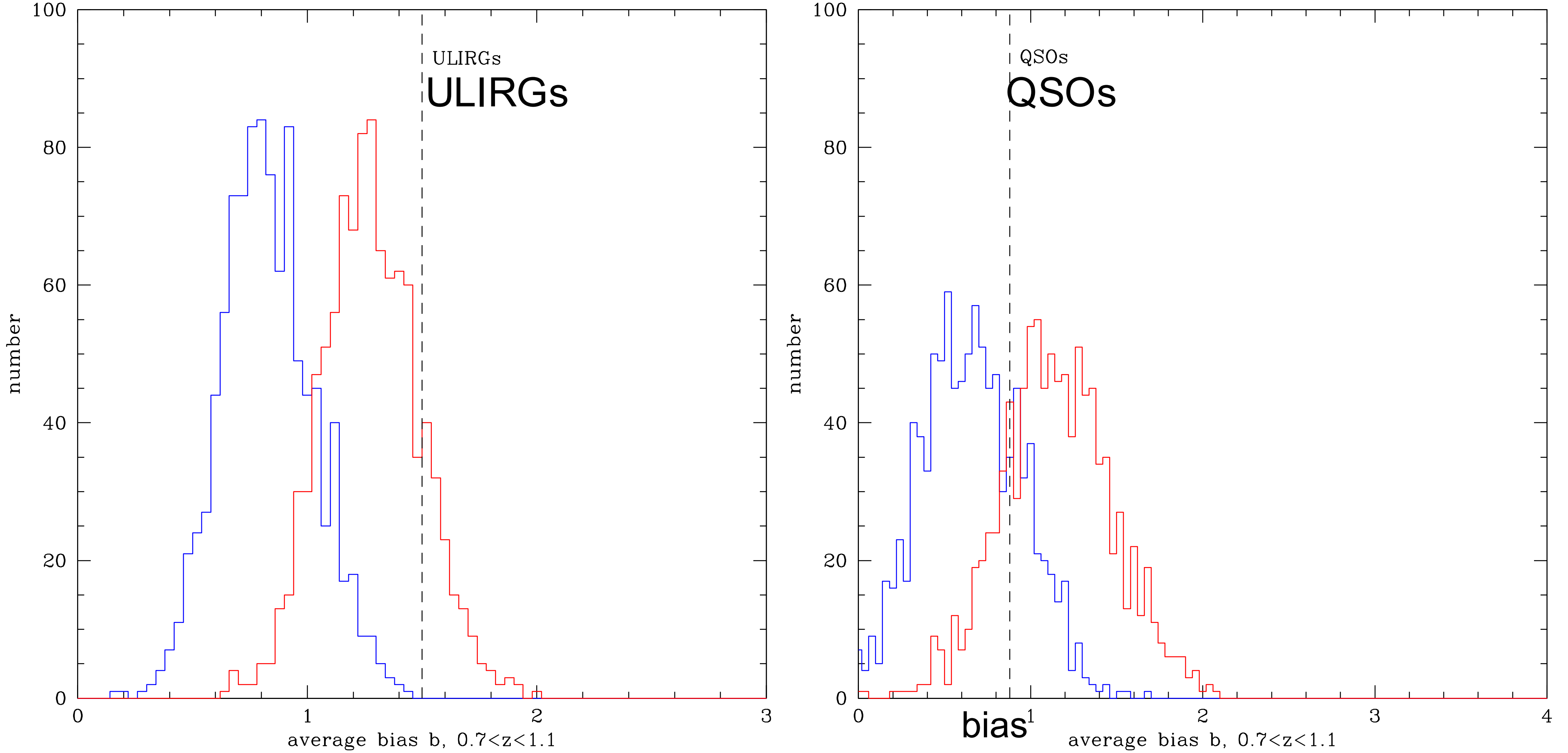




Coil 2007
QSO sample

Measurements are made with the same cross-correlation technique and crossed with similar field galaxy samples at same redshifts.
Suggests the ULIRG -> QSO evolution scenario is oversimplified, although ULIRG -> elliptical link is plausible.

Testing significance of clustering:



Compare bias of ULIRGs or QSOs (bias = ratio of CF to that of all galaxies)
to Monte Carlo samples drawn from blue or red galaxies.
ULIRGs are higher than average red galaxy, completely inconsistent with blue galaxies. QSOs are a bit above blue galaxies, below red galaxies.
Similar in both z = 0.7-1.1 and z = 1.1-1.4.
Over 0.7<z<1.4, QSOs are less clustered than red galaxies at 95% conf.

The Problem:

Coil et al 2007 showed that QSOs at z=1 are clustered like DEEP2 blue galaxies in the same volume and are inconsistent with coeval DEEP2 red galaxies at z=1 (at 95% level).

One could rescue a QSO -> massive elliptical scenario by proposing a time delay (a form of progenitor bias): suppose QSOs at z=1 evolve into non-coeval galaxies that are red later, are lower mass, and less clustered.

However, we find that ULIRGs at z=1 are clustered a bit more strongly than coeval red galaxies, and a lot more strongly than the QSOs in the same volume, measured the same way.

This frustrates the rescue attempt since the QSOs and ULIRGs are both short-lived phases: no significant time delay. The ULIRG -> QSO evolutionary scenario will not work as a 1:1 correspondence.

The ULIRGs are both more frequent (~5x) and more clustered - implies the QSOs have a much shorter timescale.

Conclusions:

Cross-correlation with galaxy redshift surveys is an efficient method for measuring clustering. Large area surveys for rare objects take advantage (eg WISE x BOSS or BigBOSS?)

LIRGs at z=1 are intermediate color galaxies and are clustered like them; less clustered than if they were to all evolve into massive ellipticals.

ULIRGs at z=1 are clustered about like massive red galaxies, which gives them r0 ~ 5 h^-1 Mpc.

ULIRGs at z=1 are more abundant and more strongly clustered than QSOs in the same volume. This implies ULIRGs are higher mass, QSOs are much shorter timescale, and casts doubt on the merger-> ULIRG->QSO scenario as a 1:1 correspondence.

ULIRGs at z=1 are not as extreme as the ULIRG at z=2 samples. dN/dz worries me for high-z angular clustering samples.