AGN-driven Outflows and Galactic Conformity at z~1-2

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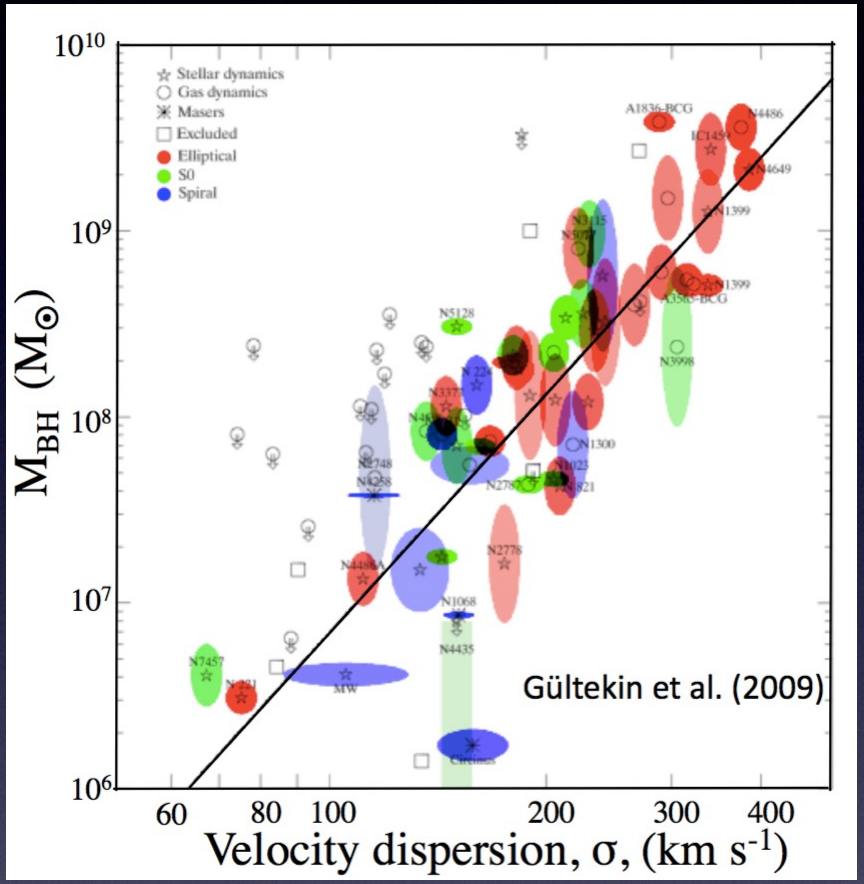
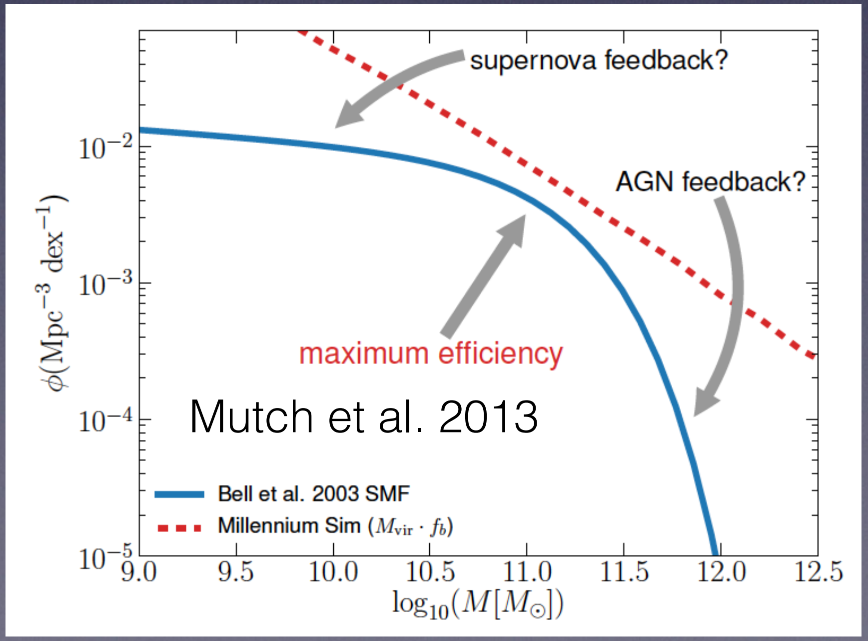
Role of AGN in Galaxy Evolution

- Regulate galaxy growth?
- Determine the shape of the high mass end of the stellar mass function?
- Quench star formation?

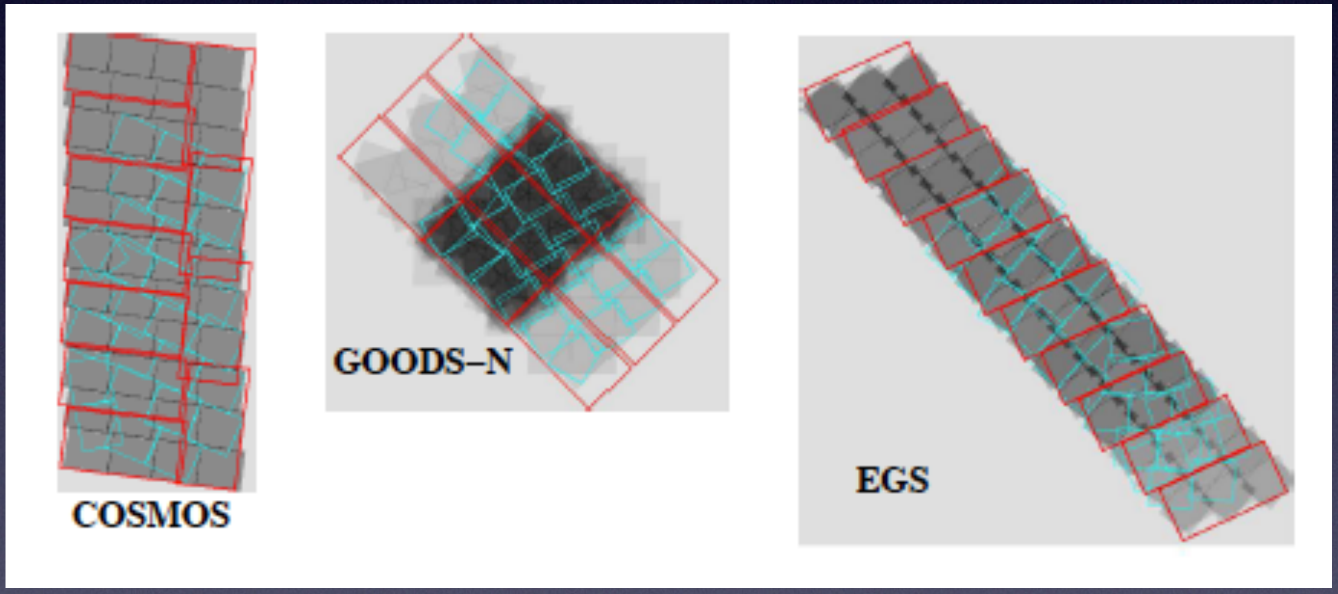
— All related to AGN feedback!





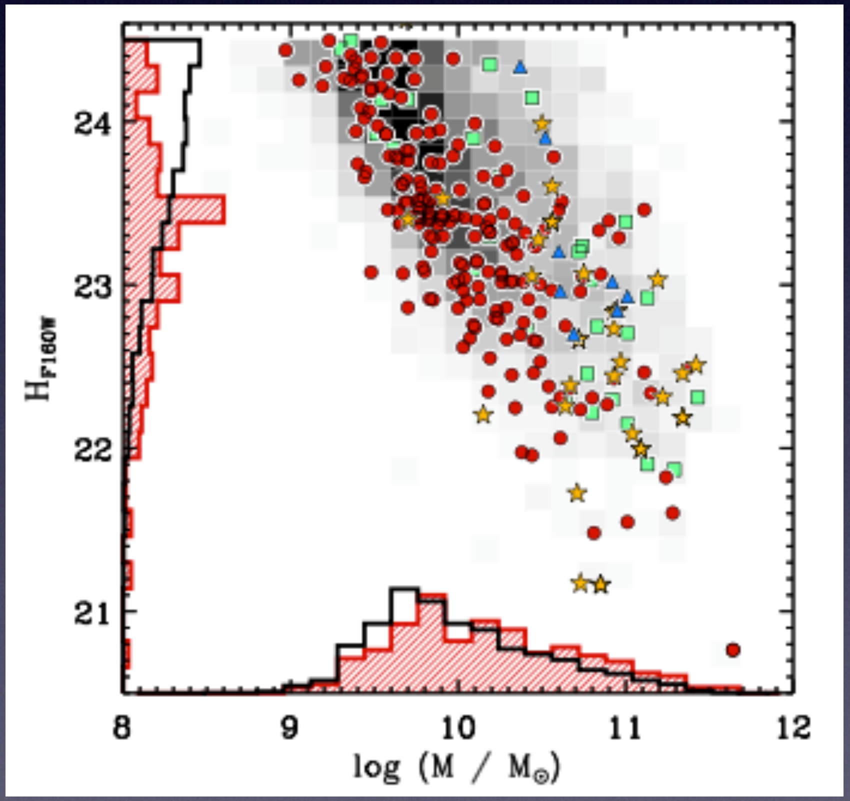
MOSDEF survey

Spectroscopic survey at 1.4 < z < 3.8 using MOSFIRE on Keck
4 year survey, 48 nights total, finished taking data this spring
Full sample has ~1500 galaxies + AGN



Kriek et al. (2015)

H mag

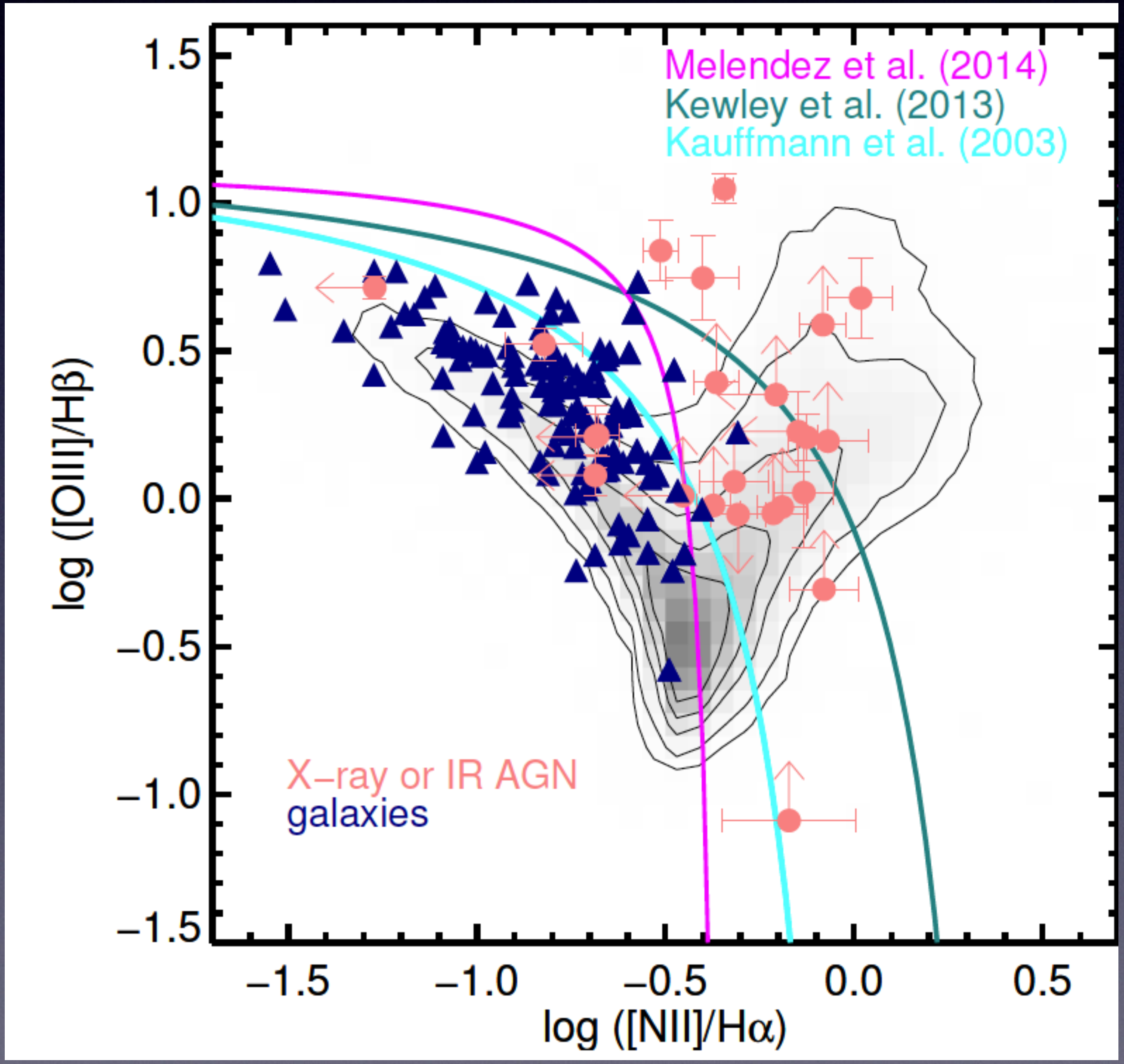


stellar mass

Targeting CANDELS fields, H-band selected (depth=24.5)
Sample spans a wide range of stellar mass and SFR

BPT Diagram at z~2

Galaxies + X-ray and IR-selected AGN (1st half of survey)

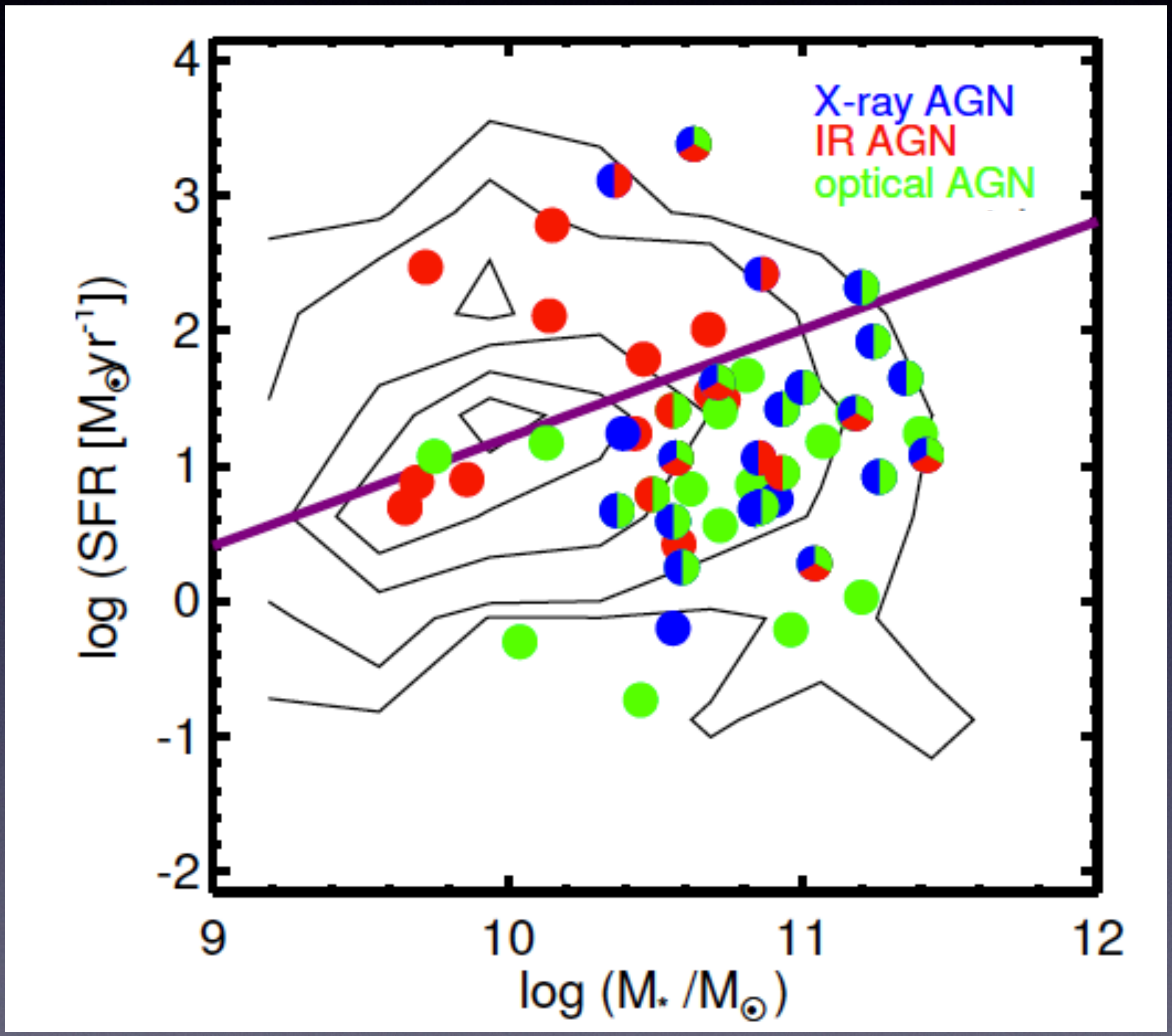


Small shift in galaxies compared to z~0, but known AGN separate well at z~2; NII/Ha is crucial.

We are using the Melendez et al. (2014) line to identify optical AGN: less contaminated than Kauffmann, much more complete than Kewley.

Azadi, Coil, et al. in prep.

AGN Host Galaxy Properties at z~2



There are well understood observational biases towards identifying AGN in massive galaxies.

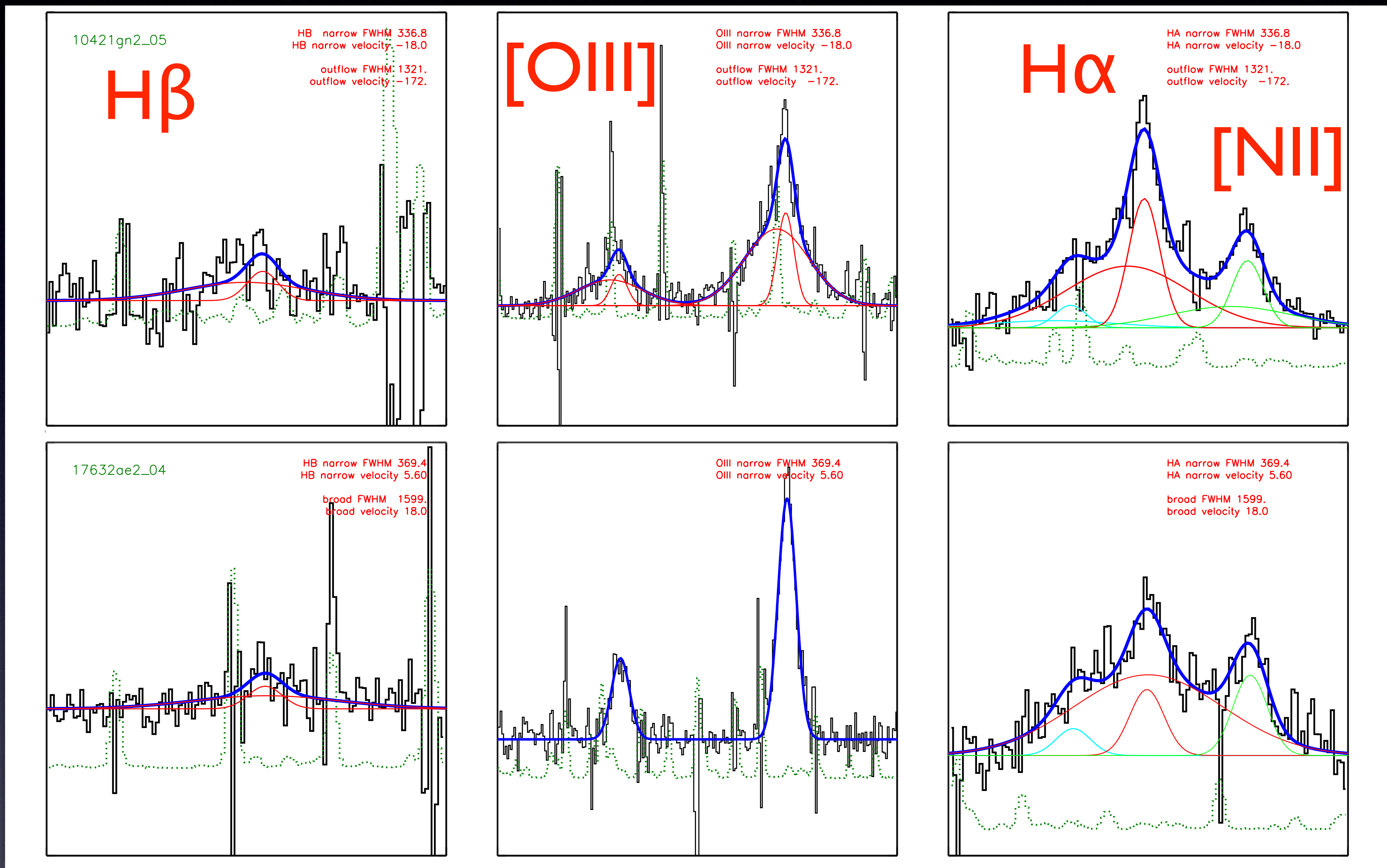
Once this is taken into account (by comparing to a mass-matched galaxy sample) the host properties of active galaxies are the <u>same</u> as inactive galaxies. Not seeing evidence for AGN quenching SF, in terms of host properties.

Azadi, Coil, et al. in prep.

Outflow Identification

object 1

object 2



outflow

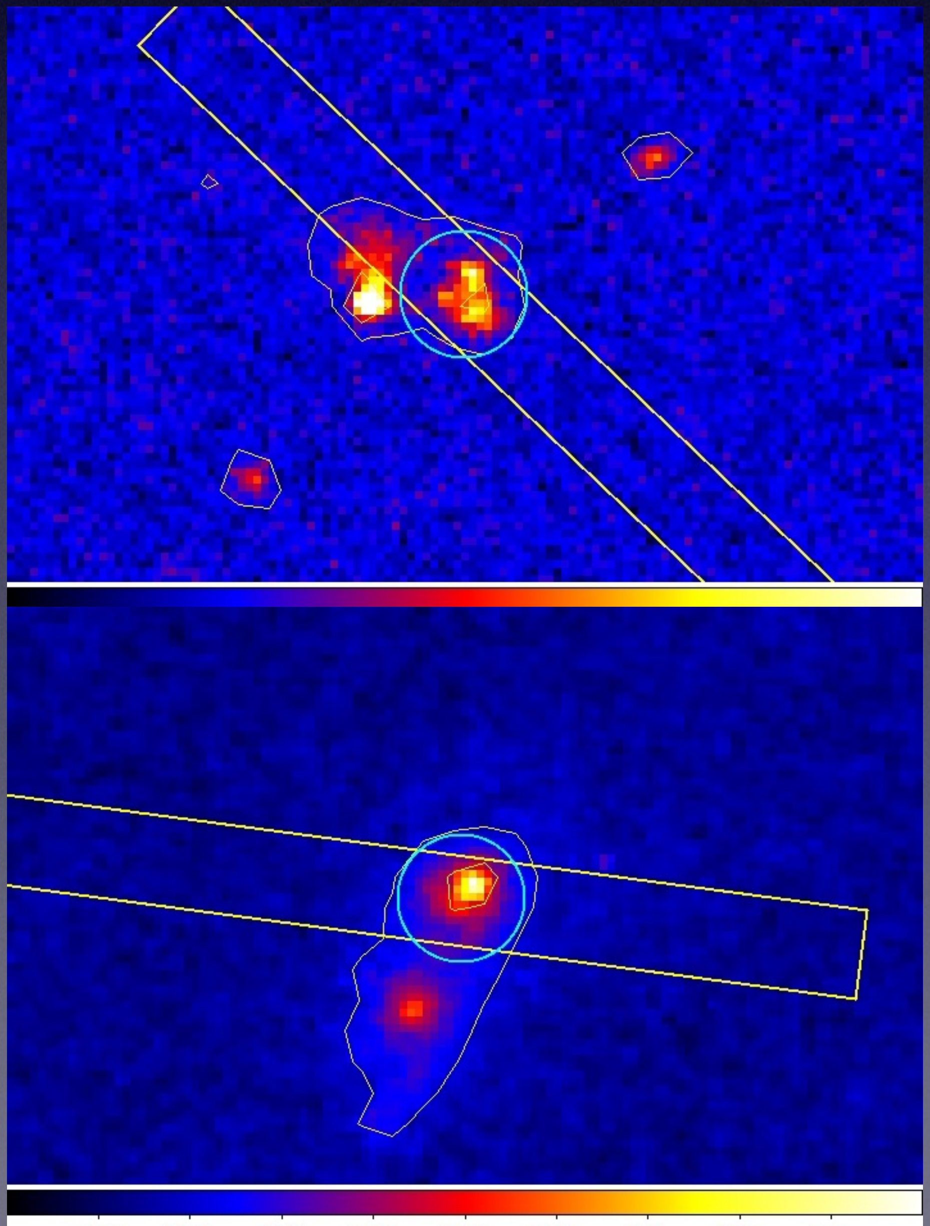
broad line,
no outflow

Perform multiple-component Gaussian fits simultaneously to Hβ, [OIII], Hα and [NII]. Allow for an outflow component in all lines and/or very broad component in Hα and Hβ.

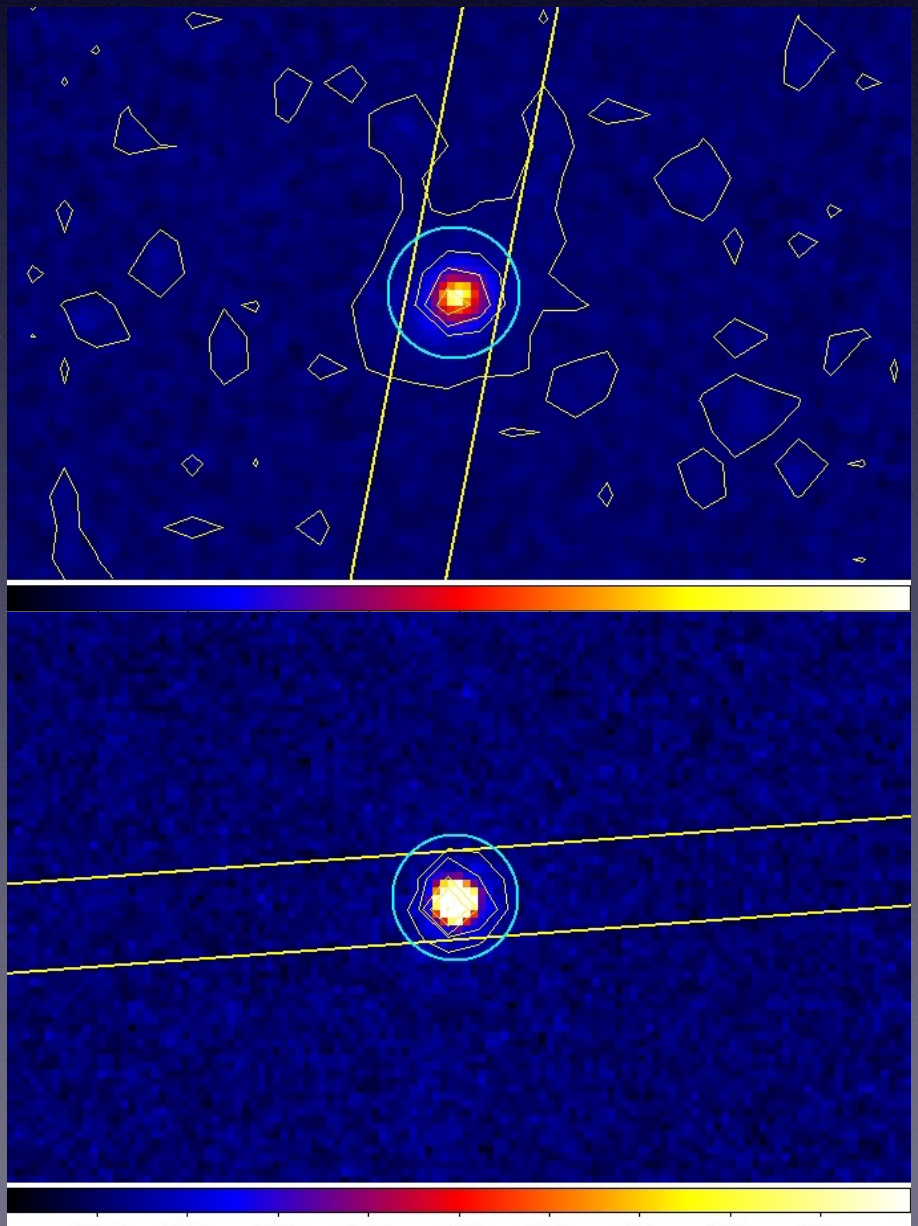
Outflow vs Merger

Use HST imaging to remove potential mergers

potential mergers



no indication of merger

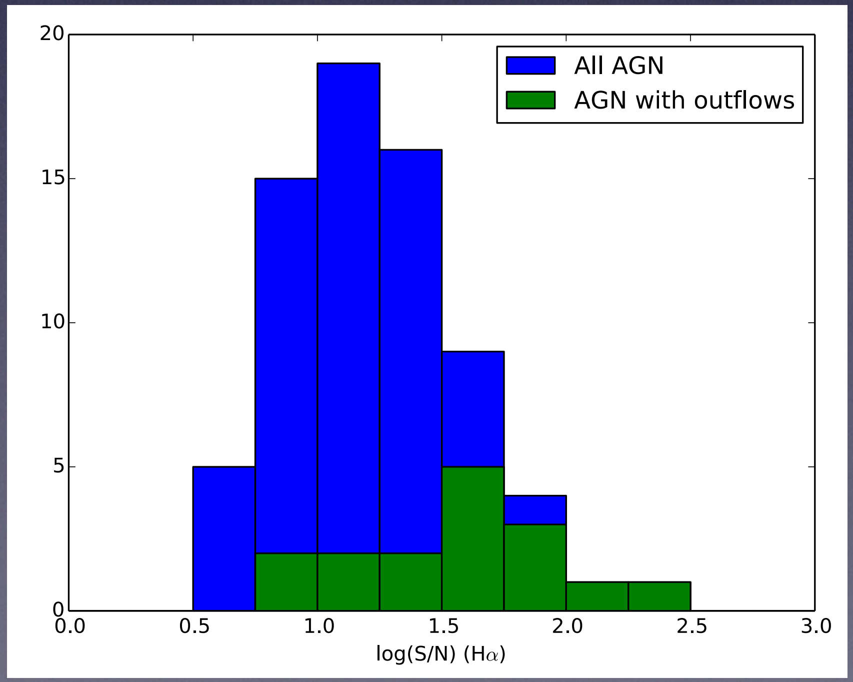


Incidence of Detected Outflows

Out of initial sample of 67 AGN (X-ray/IR/optical):

- 19 sources have a potential outflow component (ie, a 2nd kinematic component) with S/N>3 in [OIII] and/or Hα
- 13 of those do *not* appear to be potential mergers in HST
- The detected outflow rate is 19% - this is a lower limit on the actual AGN outflow rate, as need high S/N spectra and/or fast outflow to detect (and some mergers could have outflows).

number



Hα S/N

Incidence of Detected Outflows

AGN vs galaxies:

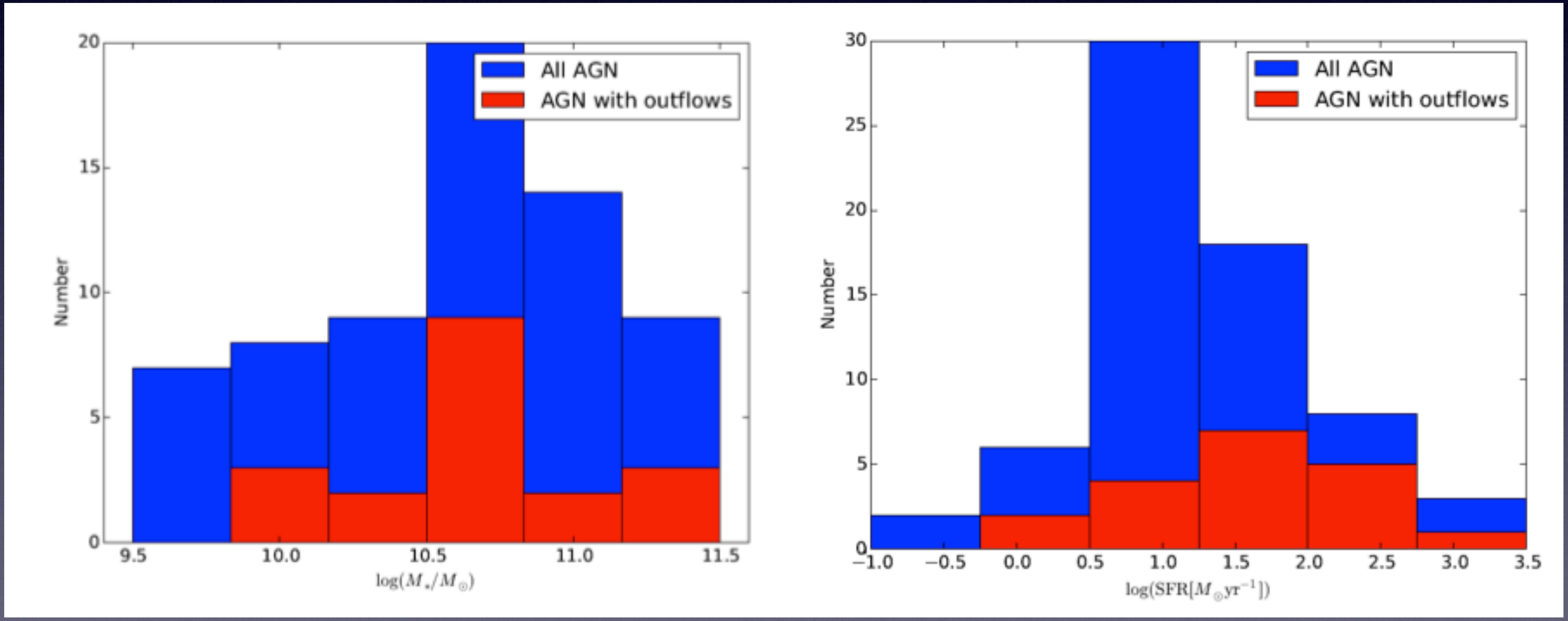
- The detected AGN outflow rate is 19% (excluding mergers)
- For galaxies without detected AGN it is only 1.8%
  (8 galaxies with outflows out of sample of 457 galaxies)

— 10 times more likely to detect an outflow in a galaxy *with* an AGN!

AGN Outflow Host Galaxy Properties

All star-forming hosts, span the main sequence:

N



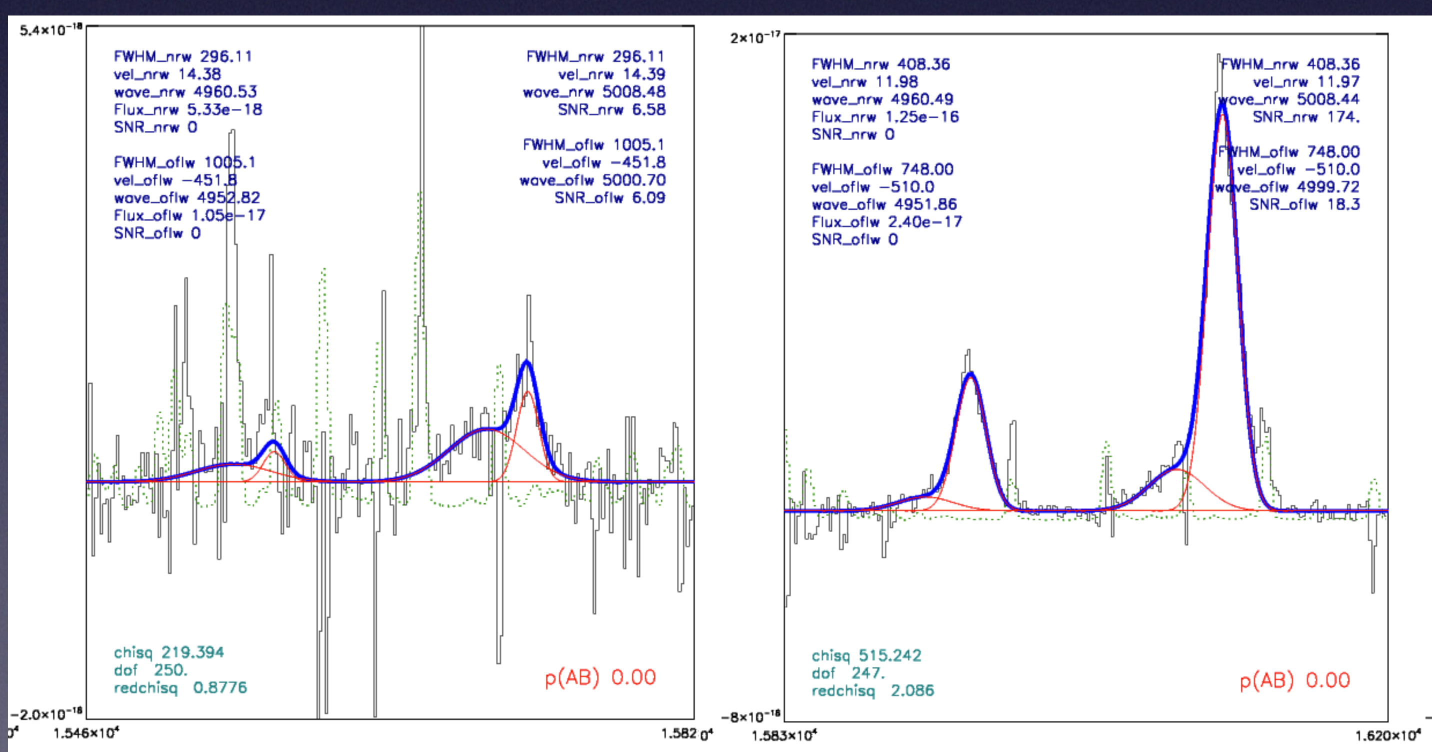
M*

SFR

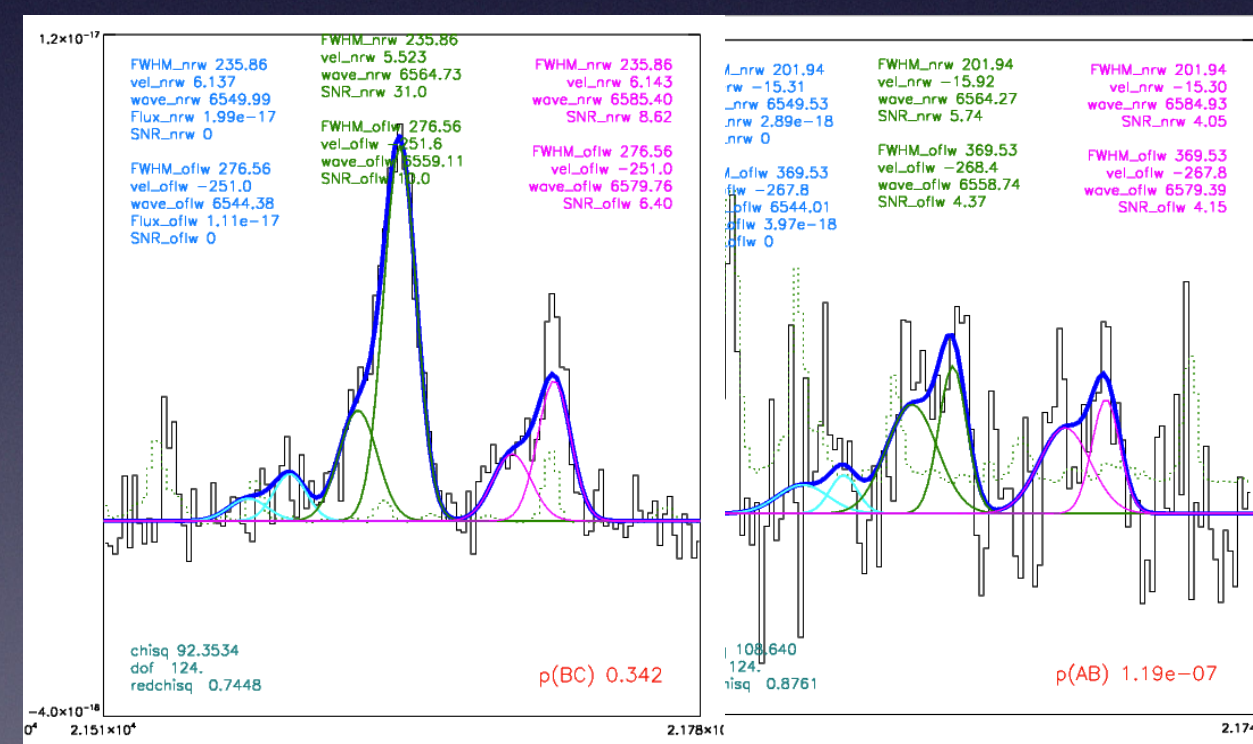
Leung, Coil, et al. in prep.

Outflow Kinematics

- velocity centroid of outflow component ~100-500 km/s
- maximum velocity of outflow component ~300-1300 km/s
- FWHM ~100-1300 km/s



[OIII]

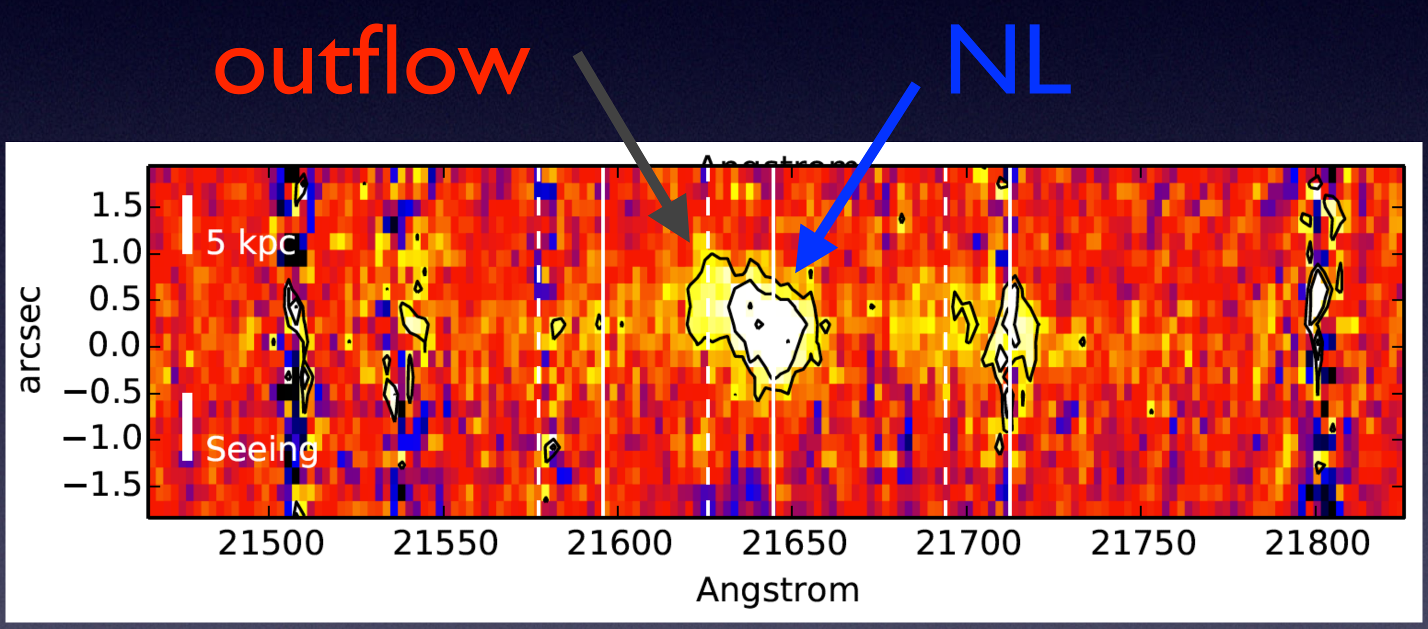


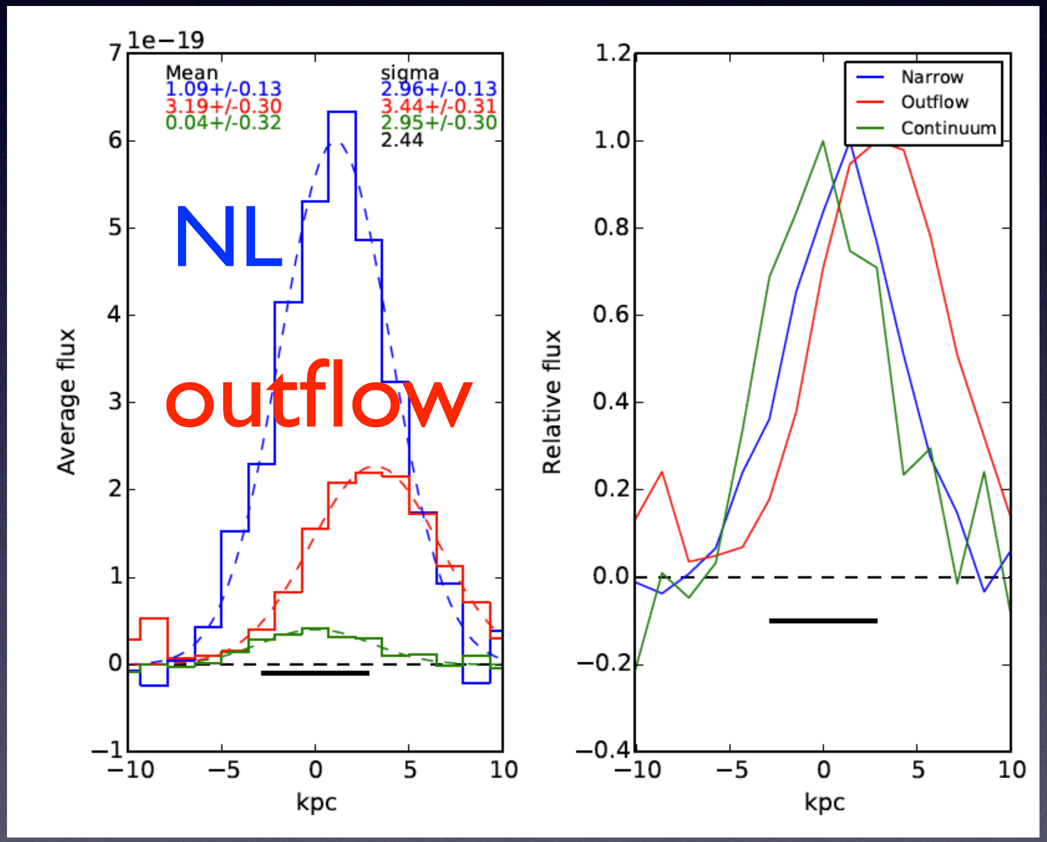
[NII] + Hα

Leung, Coil, et al. in prep.

Outflow Sizes

Spatial extent from 2d spectra:





kpc kpc

7/13 are resolved, FWHM of physical extent is ~3-10 kpc

6/13 are spatially offset from narrow line, with a max. physical offset of ~7 kpc

Mass and Energy Outflow Rates

Can get a lower limit from counting photons from recombining hydrogen atoms and an upper limit assuming an energy conserving bubble expanding into a uniform medium:

$dE/dt \sim (0.3 - 9.6) \times 10^{43}$ erg/s
AGN $L_{Bol} \sim 10^{44-46}$ erg/s

$dM/dt \sim (0.5 - 3.8) \times 10^{2}\ M_{\odot}/yr$
SFR $\sim (0.02 - 24) \times 10^{2}\ M_{\odot}/yr$

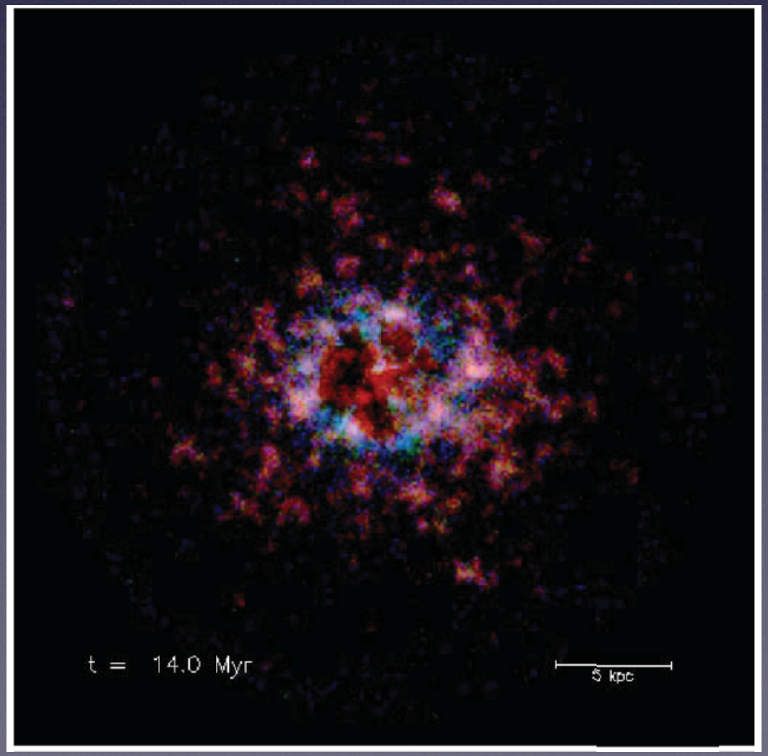
Rates are ~order of magnitude lower than ULIRGs at z~2 (Harrison et al. 2012) - sizes and velocities are a bit lower for our sample than in ULIRGs

Positive AGN Feedback

Usually AGN feedback is thought to be "negative" - shuts off star formation, clears away and/or heats gas in a galaxy.

"Positive" AGN feedback is when an AGN drives a jet that shocks the ISM in a galaxy and induces star formation (at least temporarily).

Minkowski's object, Croft et al. 2006

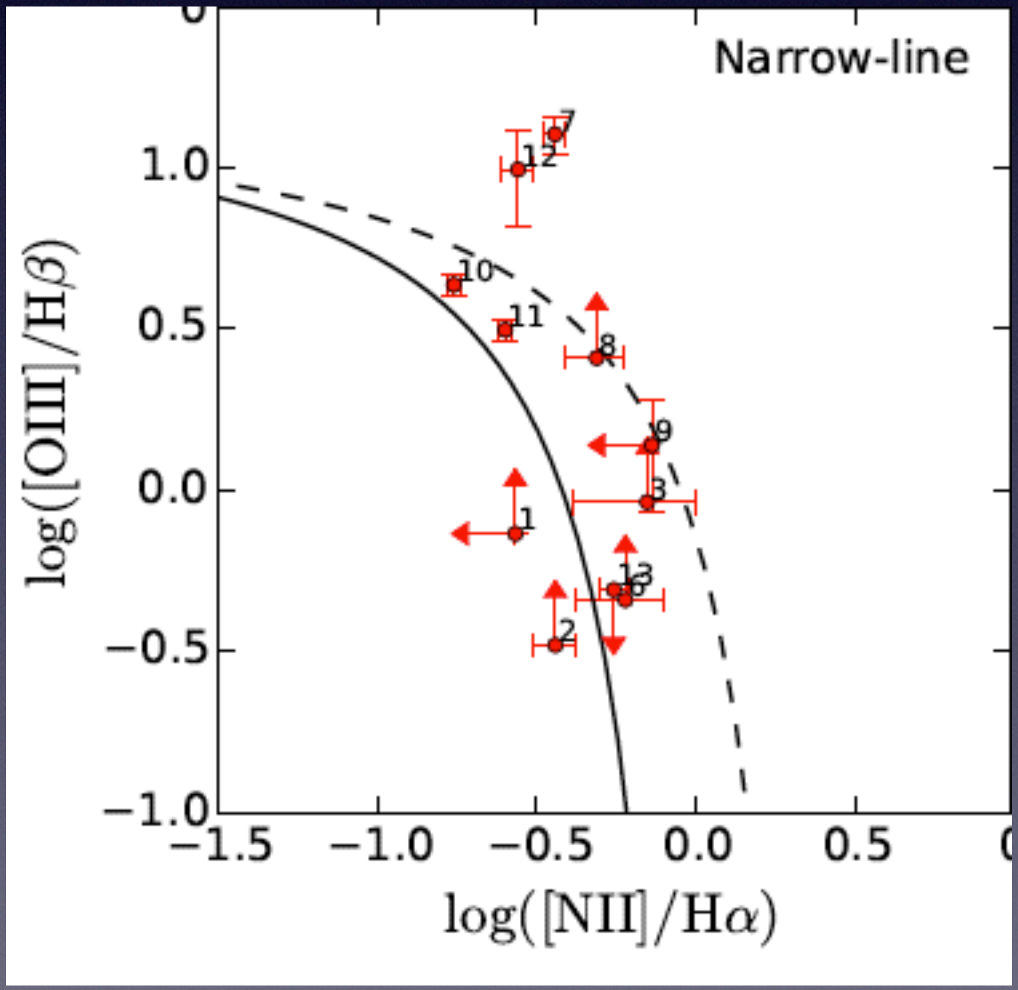


simulation, Gaibler et al. 2012

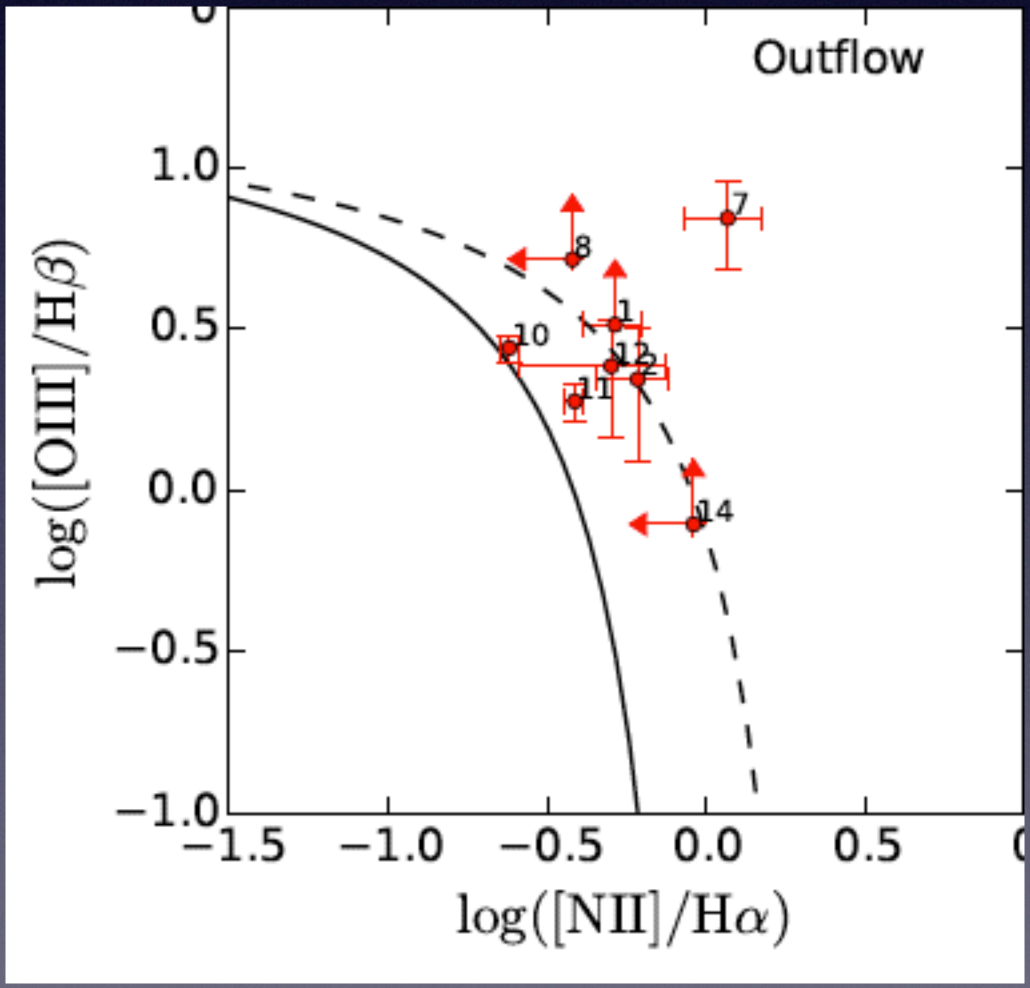
Positive AGN Feedback

Not seen in MOSDEF

narrow line component:



outflow component:



log ([OIII]/Hβ)

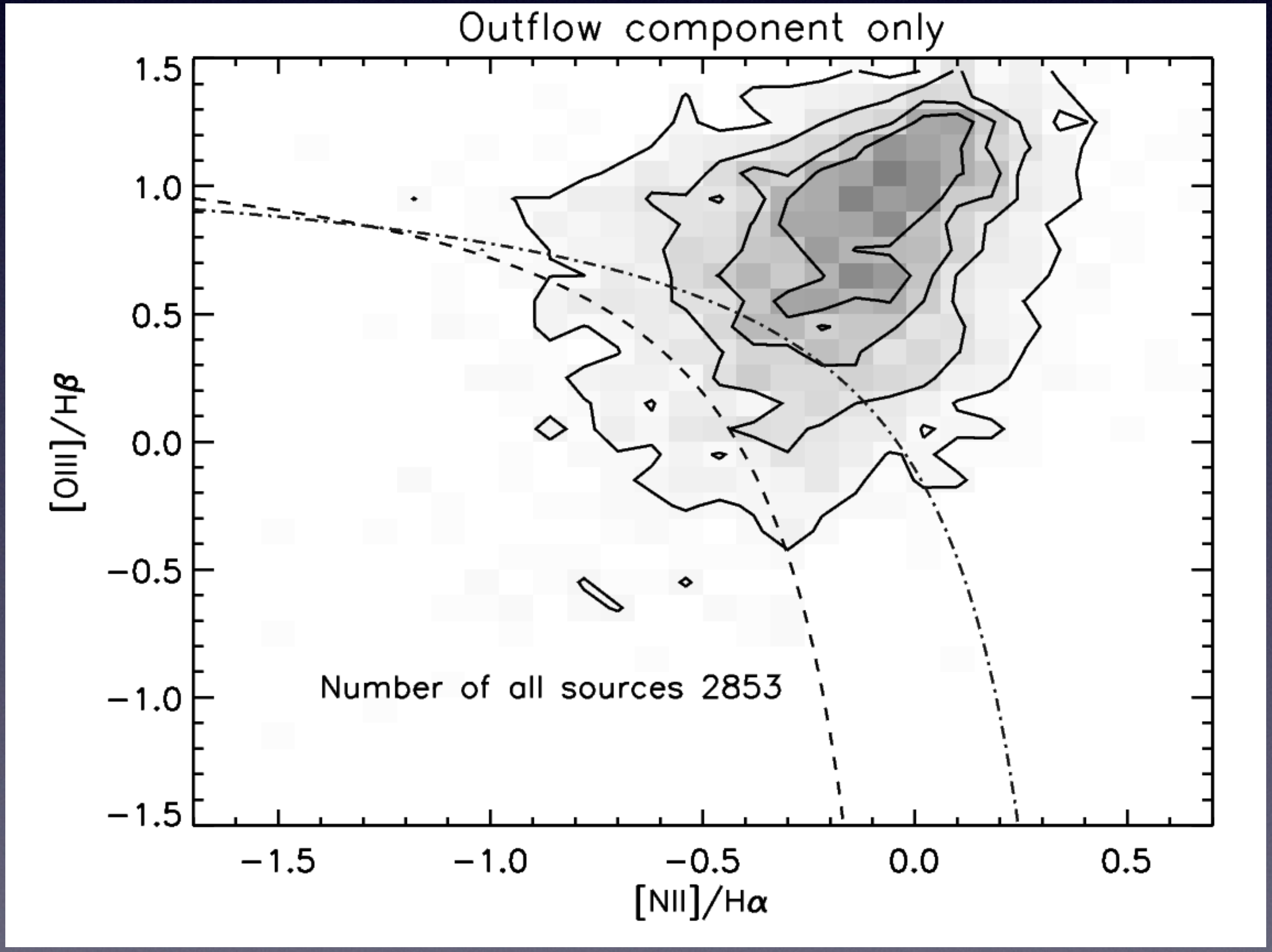
log ([NII]/Hα)

Leung, Coil, et al. in prep.

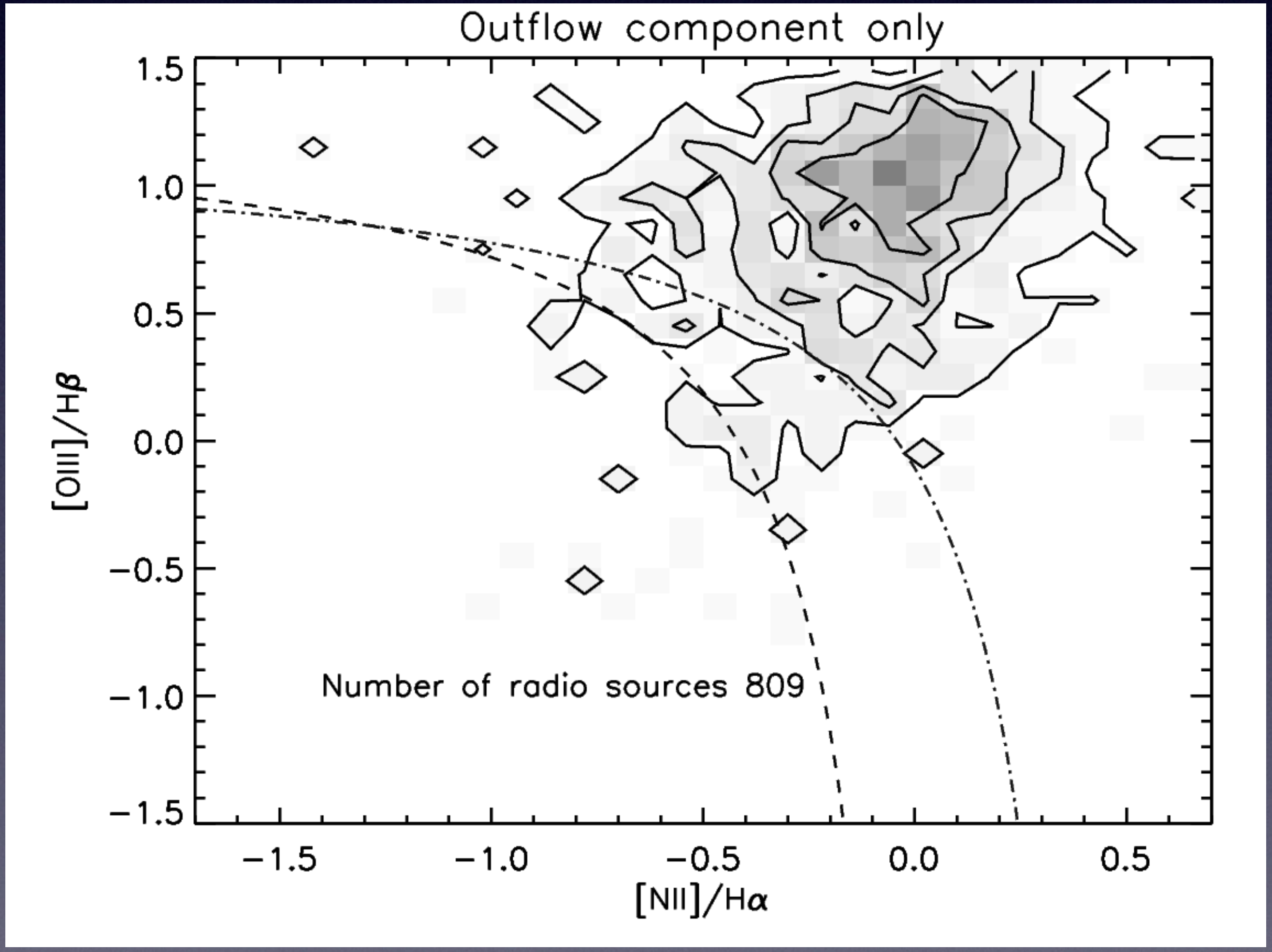
Positive AGN Feedback

Not seen in SDSS

NL optical AGN:



NL optical + radio AGN:



using catalogs from Mullaney et al. 2013

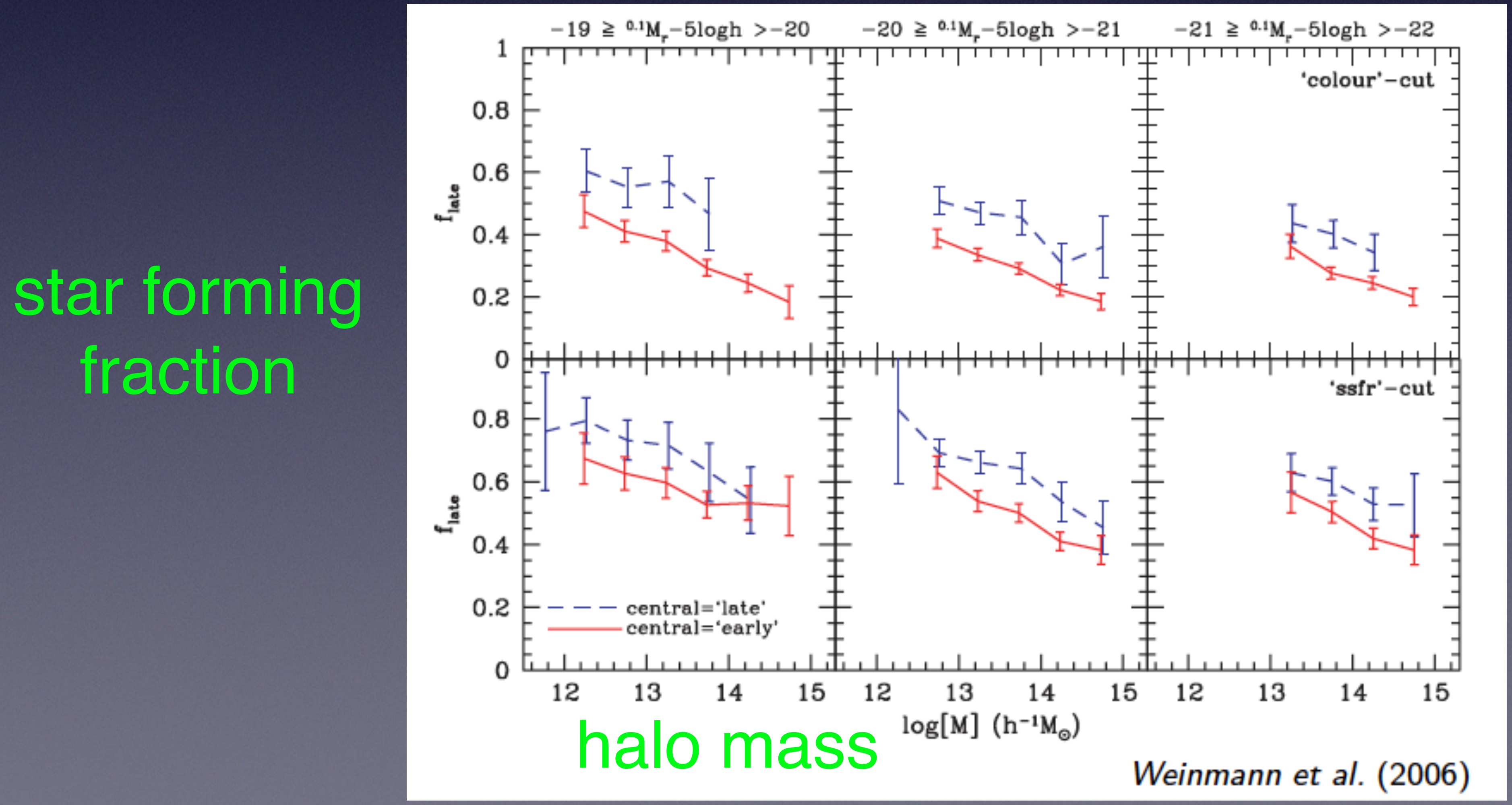
Galactic Conformity

- Observed correlation between whether a "central" galaxy is quenched and its neighbor galaxies are also quenched.

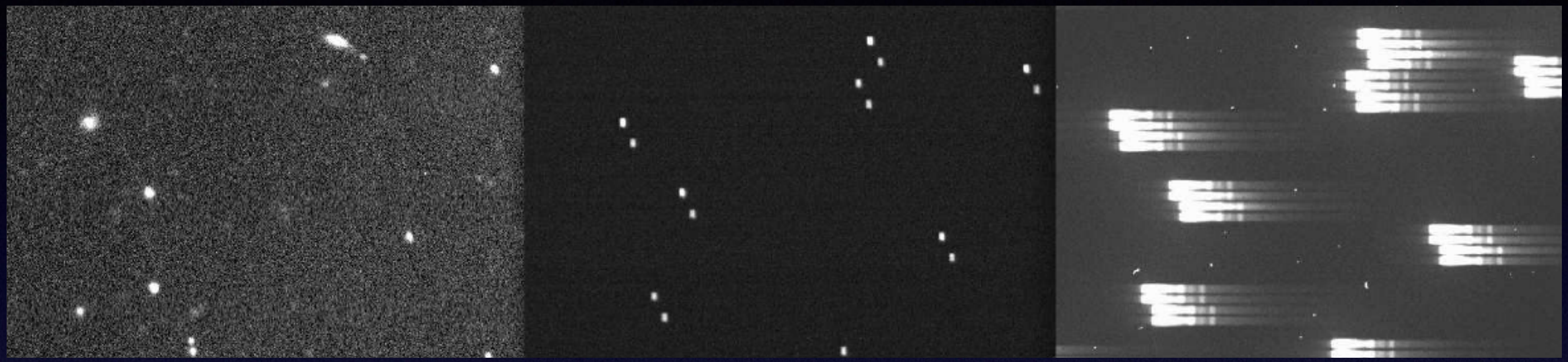
- 1-halo vs 2-halo conformity:
  - 1-halo (*intra-halo*): correlation between central and satellite galaxies being quenched
  - 2-halo (*inter-halo*): correlation between central galaxy and galaxies in *adjacent* halos being quenched

Galactic Conformity

- 1-halo conformity first observed in SDSS (Weinmann et al. 2006)
- 2-halo conformity recently observed in SDSS (Kauffmann et al. 2013)
- z > 0.2 measurements have all been 1-halo only and used photometric redshifts (Kawinwanichakij et al. 2015, Hartley et al. 2015)

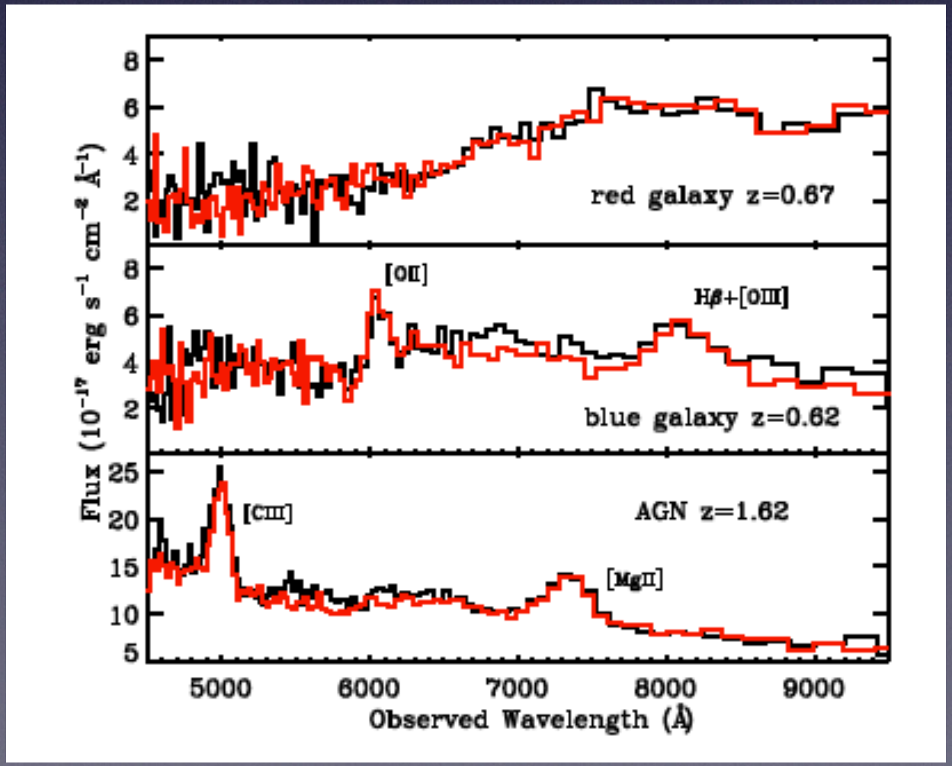


PRIMUS Redshift Survey



Spectroscopic faint galaxy redshift survey using IMACS on Magellan

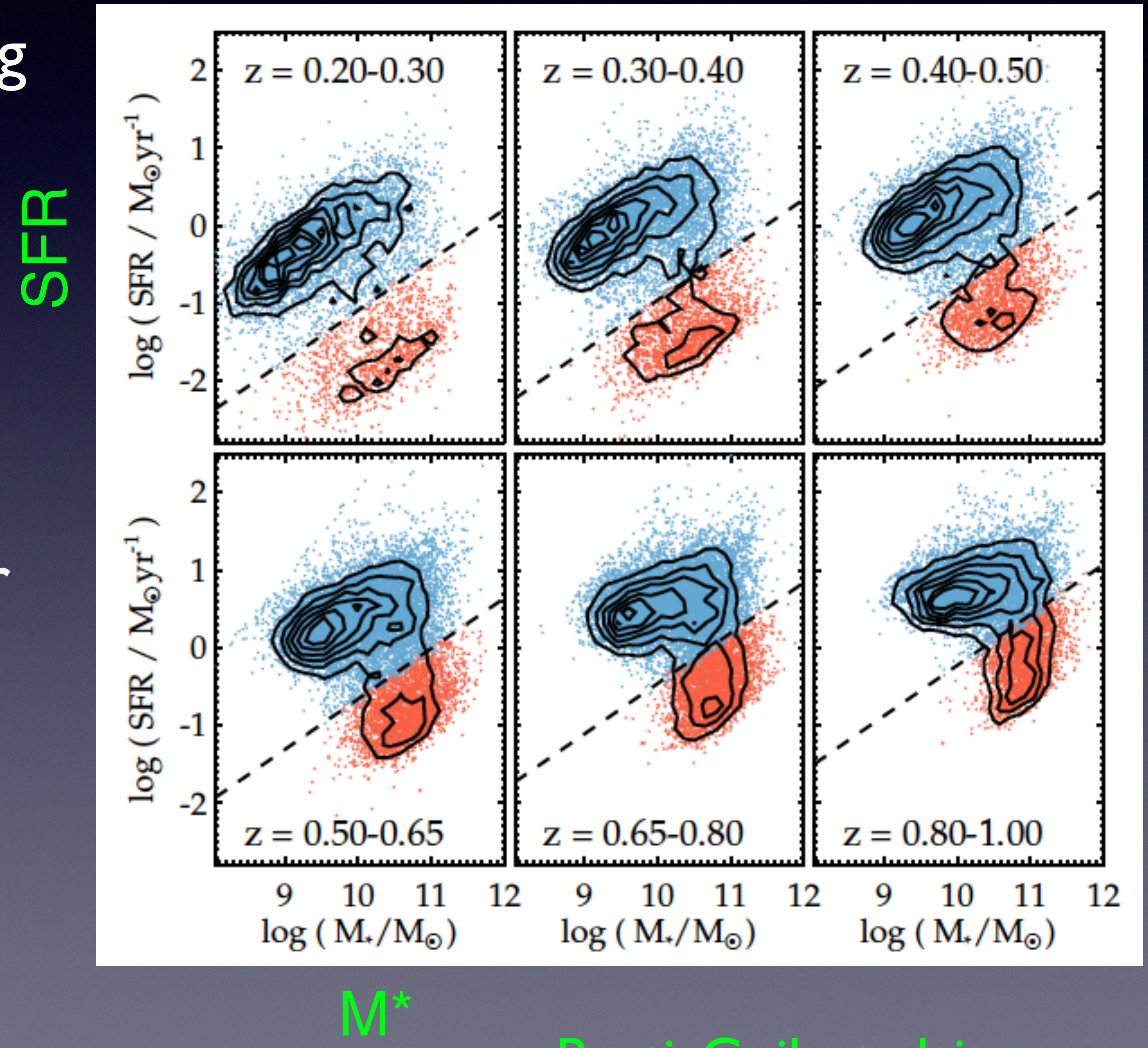
- Used a low-dispersion prism to measure redshifts to $dz/(1+z)=0.5\%$
- $0.2 < z < 1.2$ to a depth of $i=23$
- ~120,000 spec z's
- 9 sq. deg. over 7 independent fields with multi-wavelength coverage



Coil et al. (2012)

PRIMUS Conformity Sample

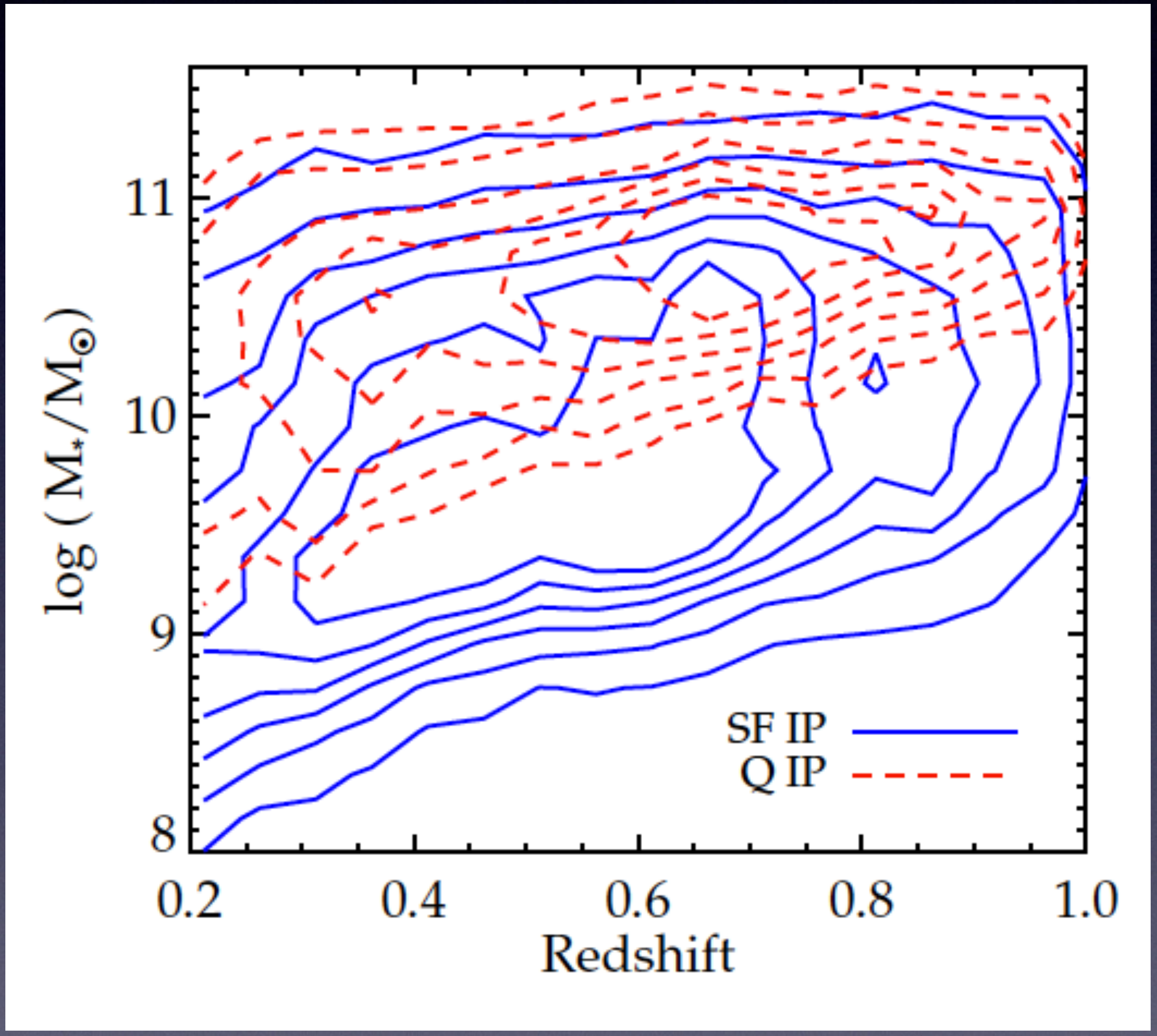
- 4 separate fields covering 5.5 deg^2
- $0.2 < z < 1.0$
- 60,000 galaxies with spectroscopic redshifts
- Split into star forming or quiescent using evolving SFR-M* cut:



Berti, Coil, et al. in prep.

Isolated Primary Sample

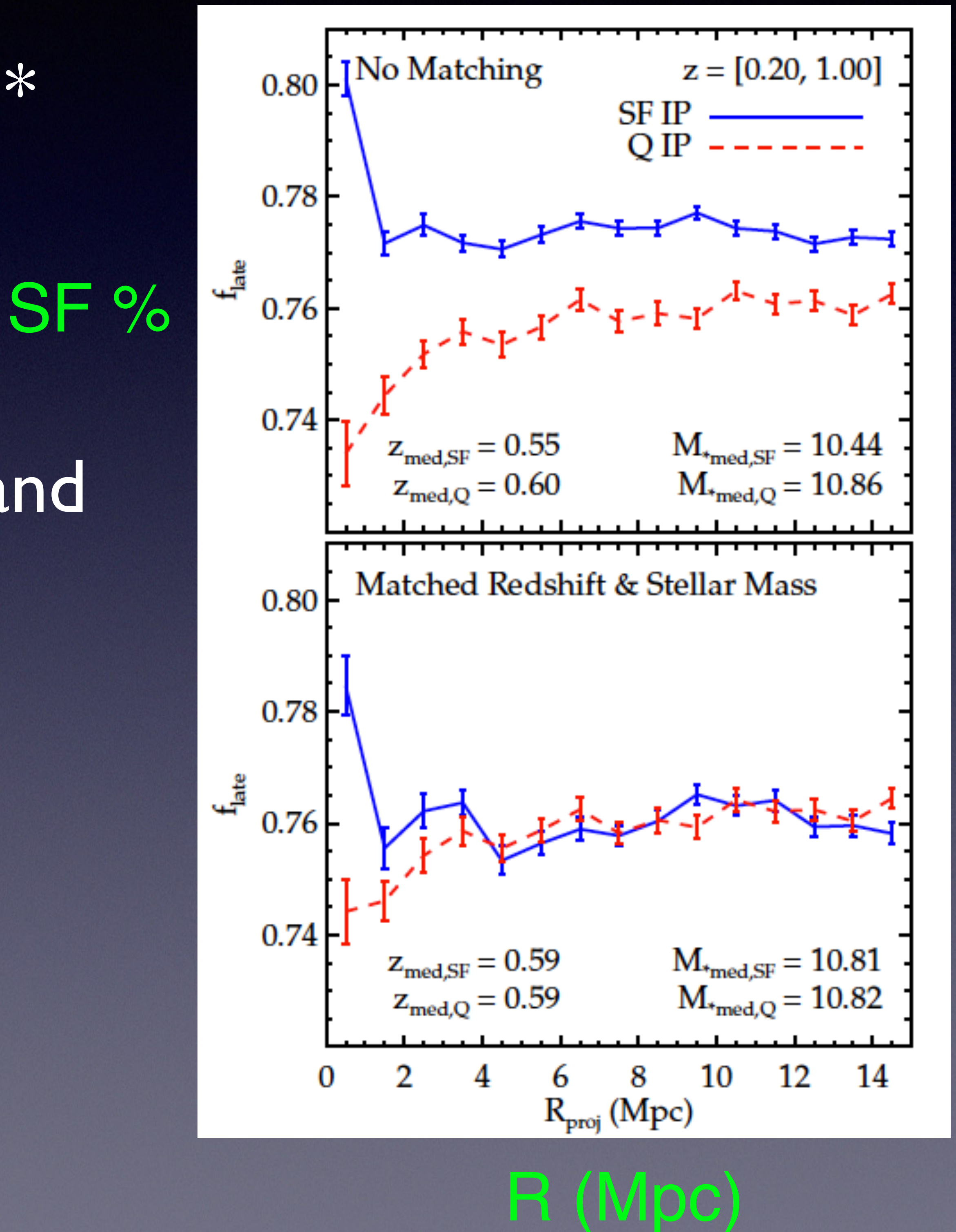
- Stellar mass completeness cut
- Similar isolation (i.e., central) criteria as Kauffmann et al. 2013:
  - Isolated primary (IP) galaxies have no other galaxies within R=500 kpc and $M^* > M^*_{IP}/2$
- ~20,000 IP/central candidates



Berti, Coil, et al. in prep.

Isolated Primary: Matching M* and z

- Small differences in median M* and z of the SF vs Q isolated primary samples mimics conformity signal!
- We therefore match the M* and z *distributions* of the SF and Q isolated primary galaxies
- Results in ~6,000 Q IPs and ~4,000 SF IPs



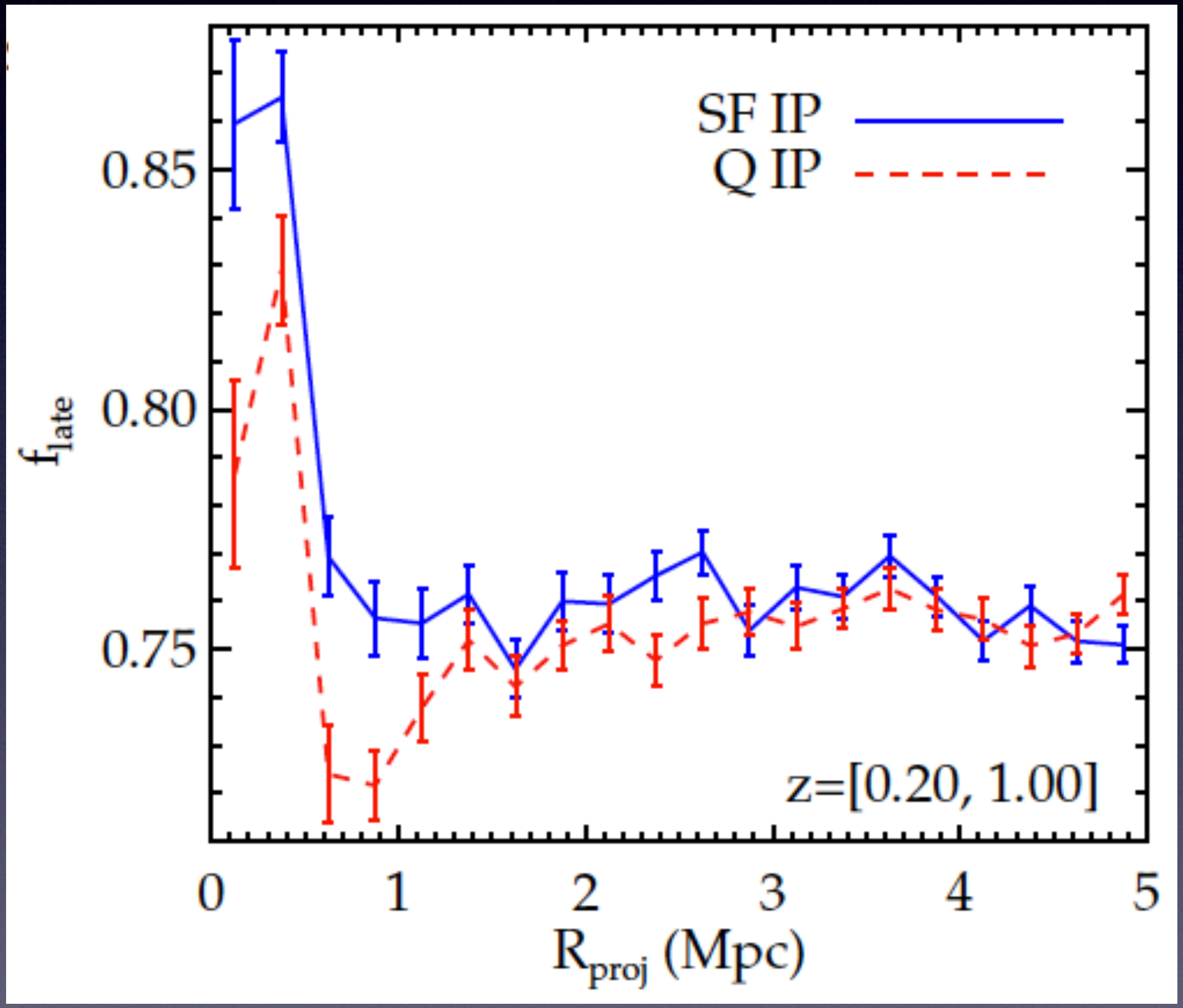
Berti, Coil, et al. in prep.

Conformity Signal at z~0.7

- f_{late} = late-type (SF) fraction of satellites / neighbors around SF and Q IPs
- Shown as a function of projected distance (R_{proj})
- Normalized signal:

$$\xi_{norm} = \frac{f_{late}^{SF\text{-}IP} - f_{late}^{Q\text{-}IP}}{\left(f_{late}^{SF\text{-}IP} + f_{late}^{Q\text{-}IP}\right)/2}$$

SF %



R (Mpc)

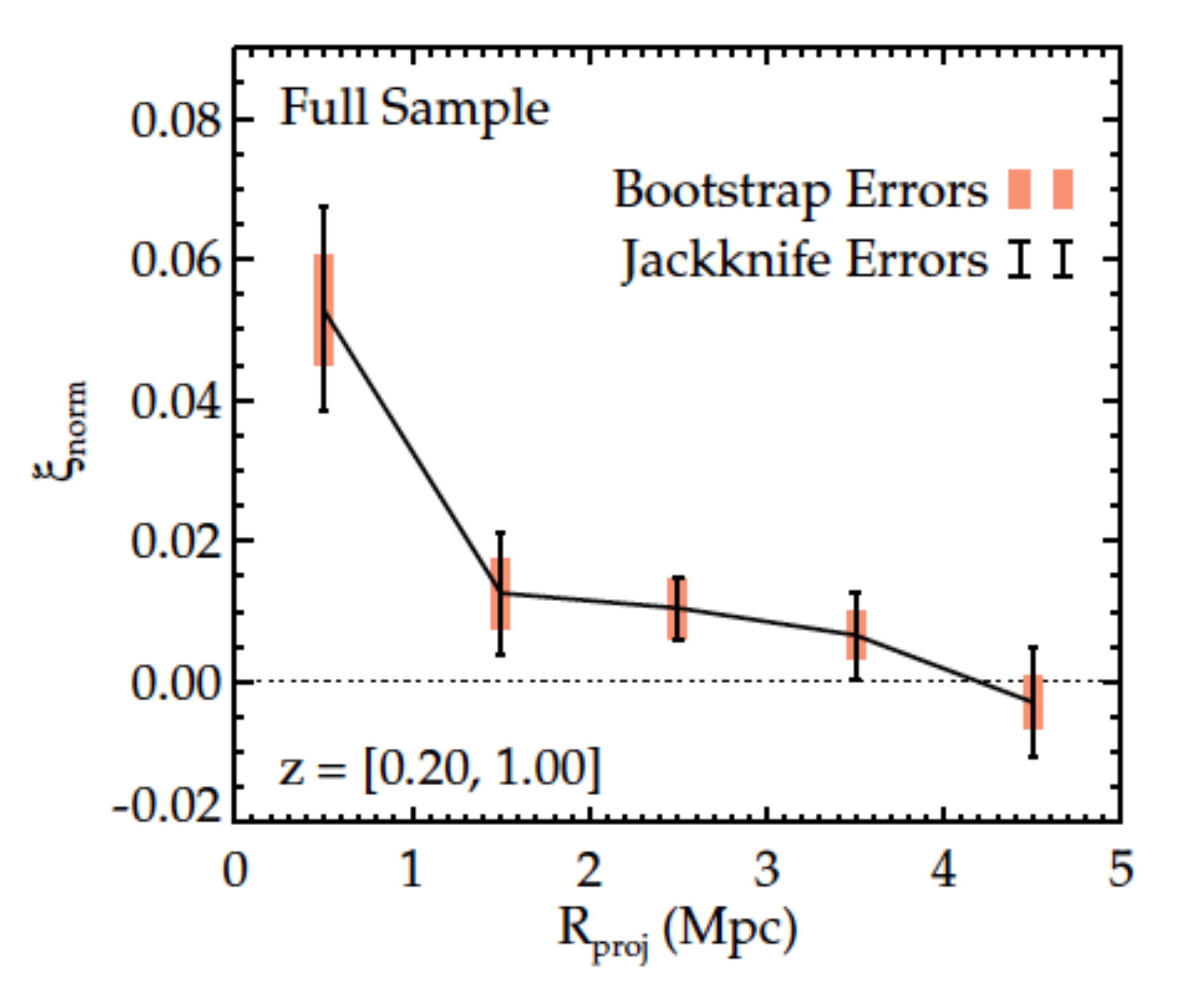
Berti, Coil, et al. in prep.

Conformity Signal at z~0.7

- 1-halo signal: 5% (3.6σ)
- 2-halo signal: 1% (2.5σ)

- Using jackknife errors
- Errors are 2x smaller using bootstrap resampling, which does not capture cosmic variance.

% signal



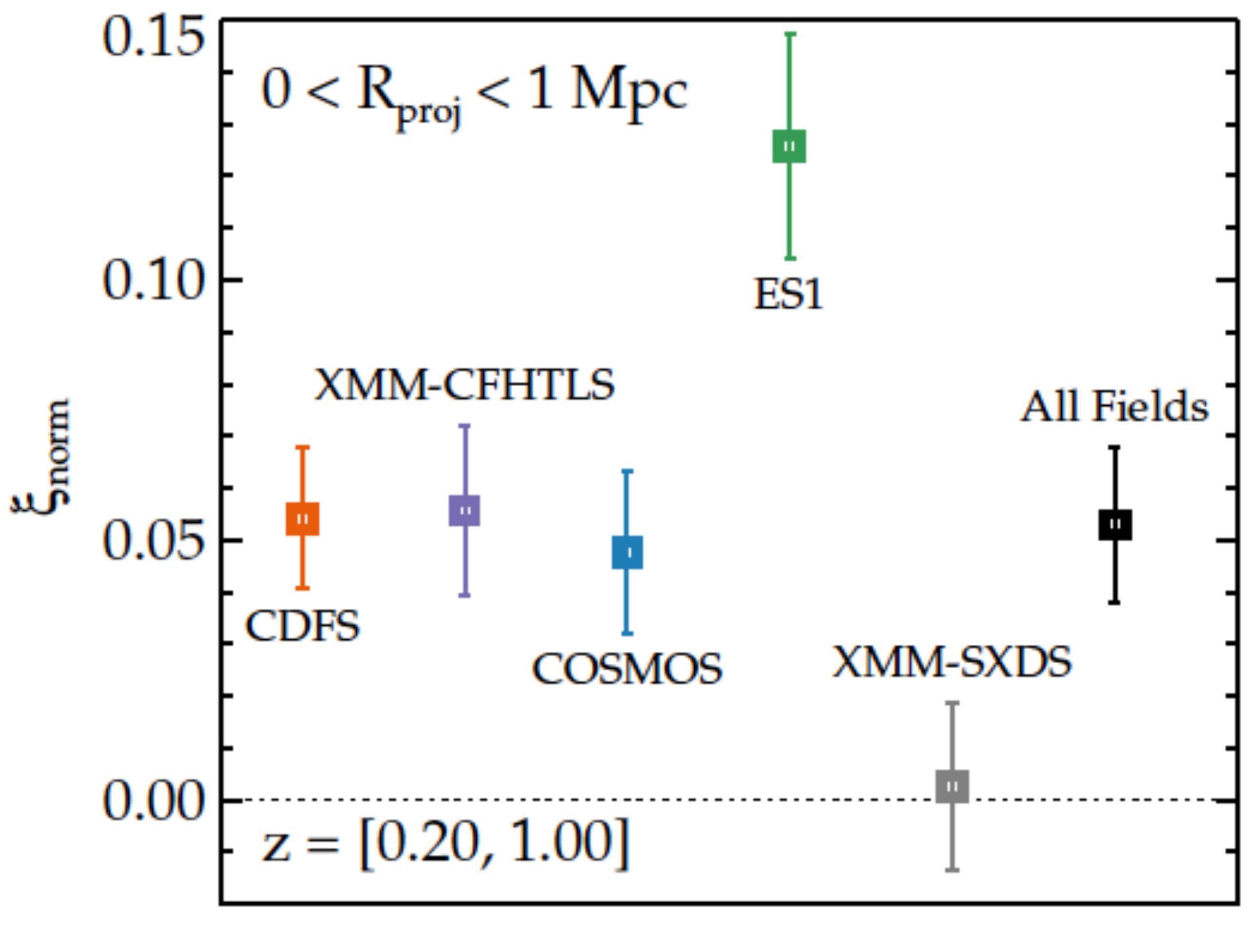
R (Mpc)

Berti, Coil, et al. in prep.

Cosmic Variance

- Substantial variation in 1-halo signal among different fields
- A meaningful measure of conformity at z > 0.2 should include several spatially separate fields

% signal

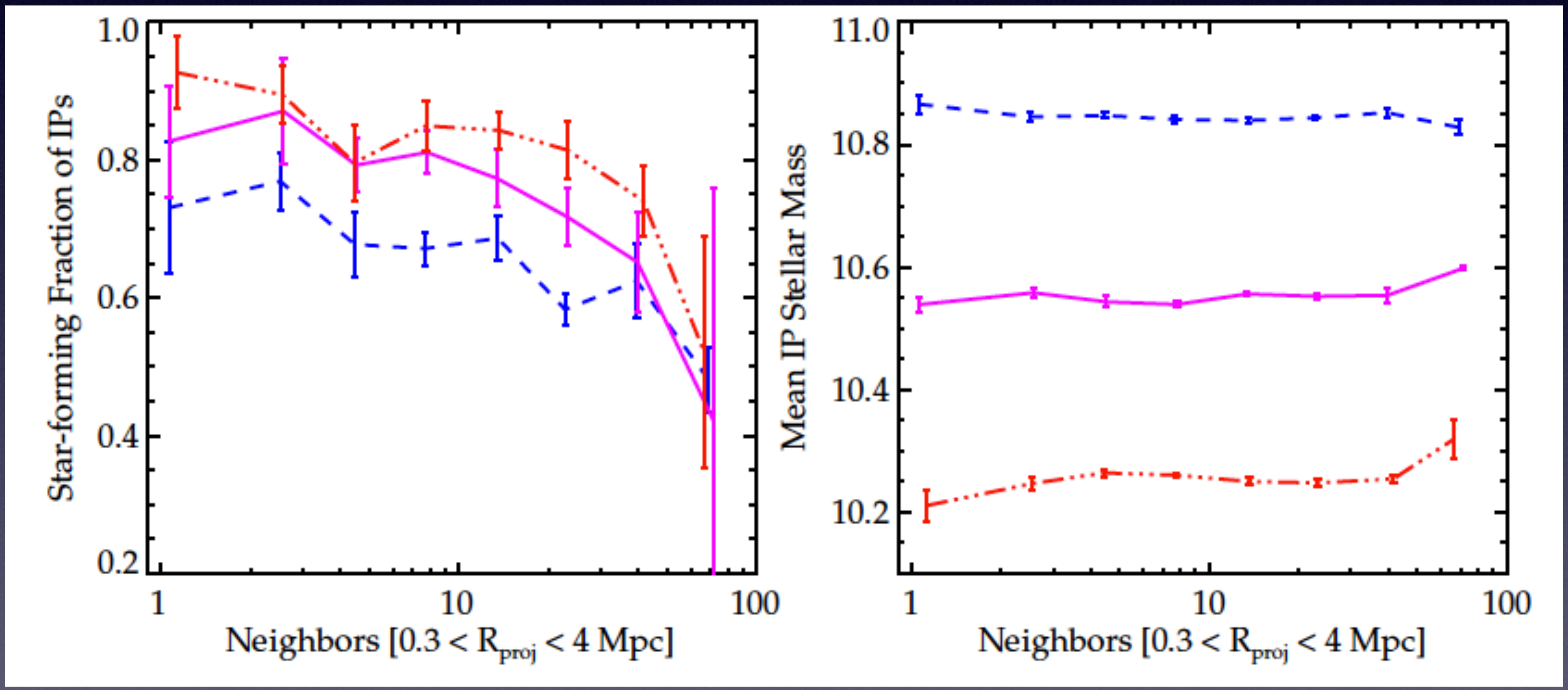


Berti, Coil, et al. in prep.

A Related Quenching Signal

Another 2-halo conformity signal is star-forming fraction of central galaxies and large-scale environment:

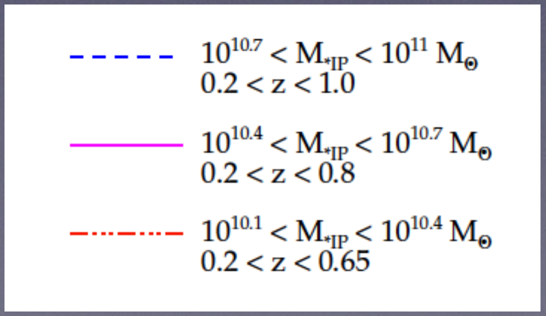
SF % central galaxies



M*

# of neighbors

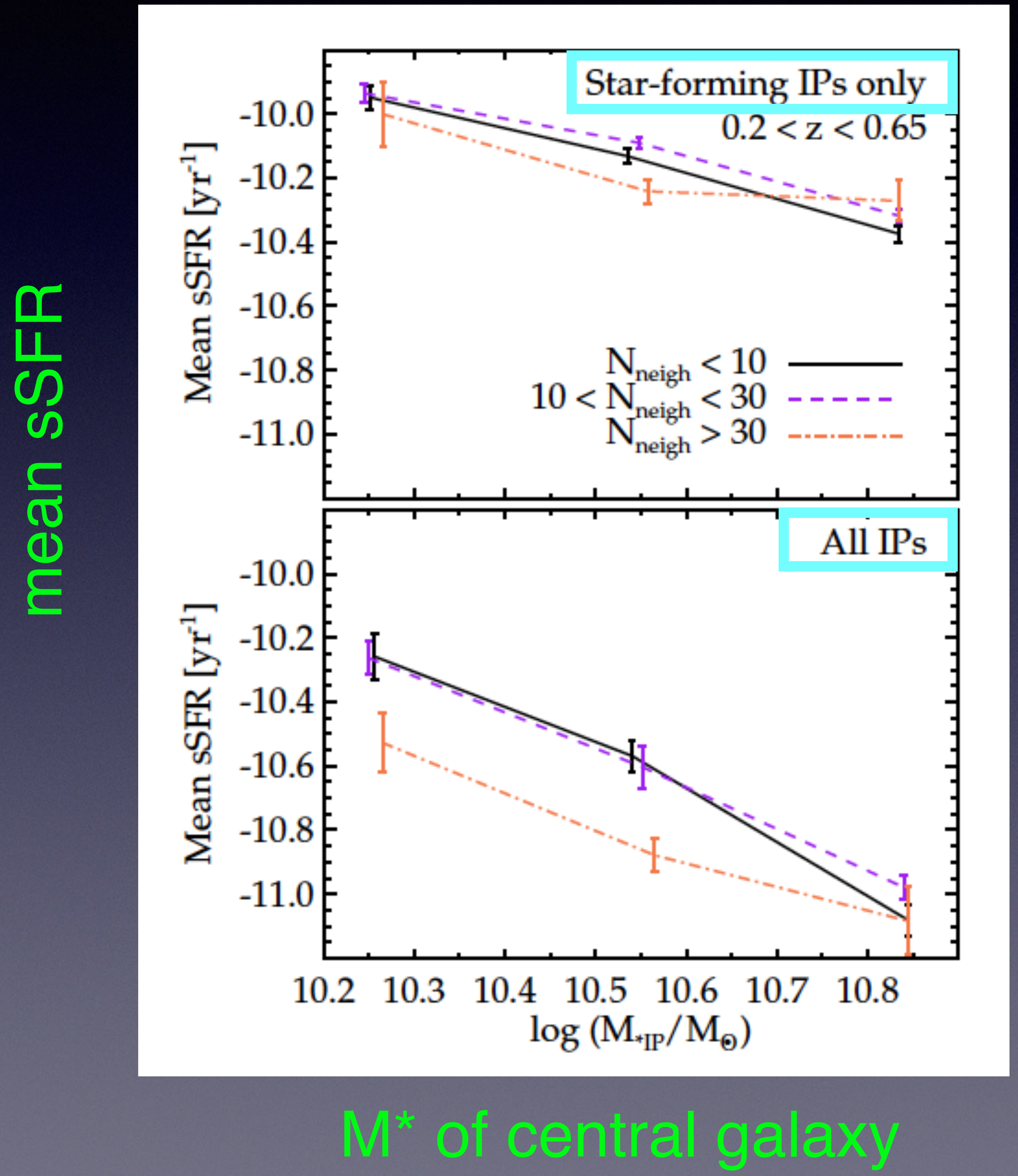
# of neighbors



2-halo signal now detected at 5σ !

Berti, Coil, et al. in prep.

Environment Quenches SF



Central galaxies only:

Mean sSFR of star-forming central galaxies is <u>not</u> impacted by environment.

But quenched fraction is!

Environment doesn't impact SF of centrals, until it halts it.

Conclusions

AGN-driven outflows occur in at least 19% of X-ray/IR/optical AGN at z~2 in "normal" star-forming galaxies.

Outflows are often resolved and/or spatially offset. We detect physical sizes (FWHM) of ~3-10 kpc. These are galaxy-wide outflows.

Maximum velocities ~300-1200 km/s. Energy injection rates ~10^{43} erg/s and mass outflow rates ~10^{2} Mo/yr.

Galactic conformity on 1 and 2-halo scales has now been robustly detected at z > 0.2. Have to be very careful about systematic errors and cosmic variance at z > 0.2. Likely observational evidence for assembly bias!

Environment doesn't impact the sSFR of central galaxies while they are still forming stars, but it can impact quenching of centrals.