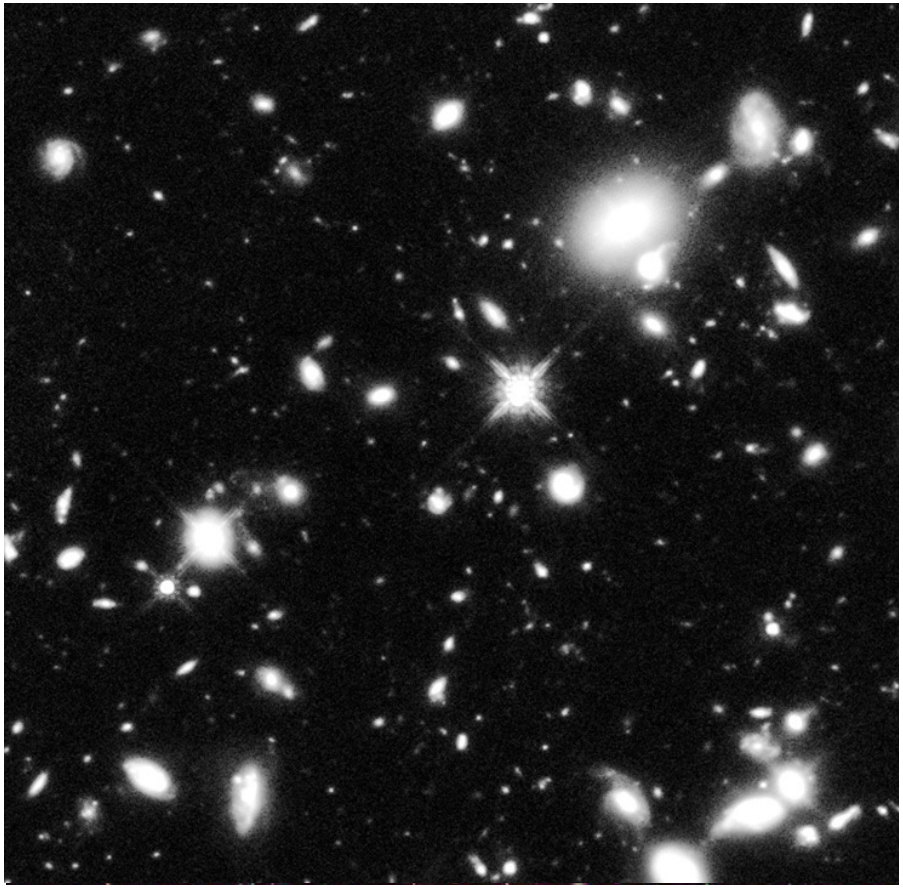
# First results from MOSFIRE: near-IR spectroscopy of high-redshift galaxies




Matthew Schenker
Caltech

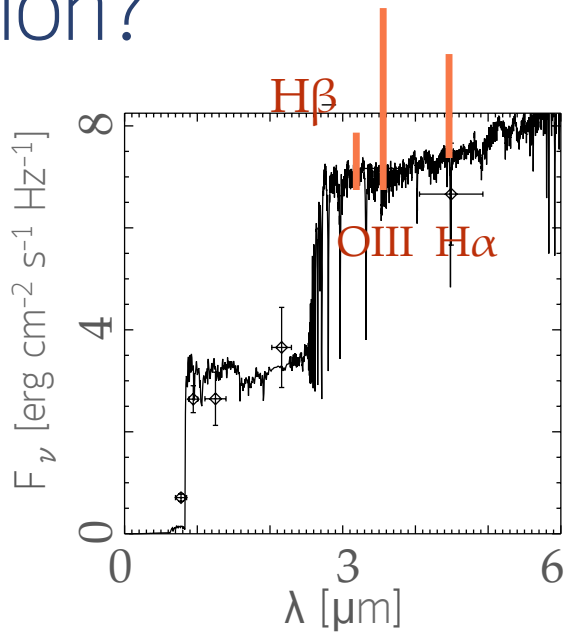
Reionization in the Red Centre
7.18.13


Richard Ellis, Dan Stark,
+ Nick Konidaris

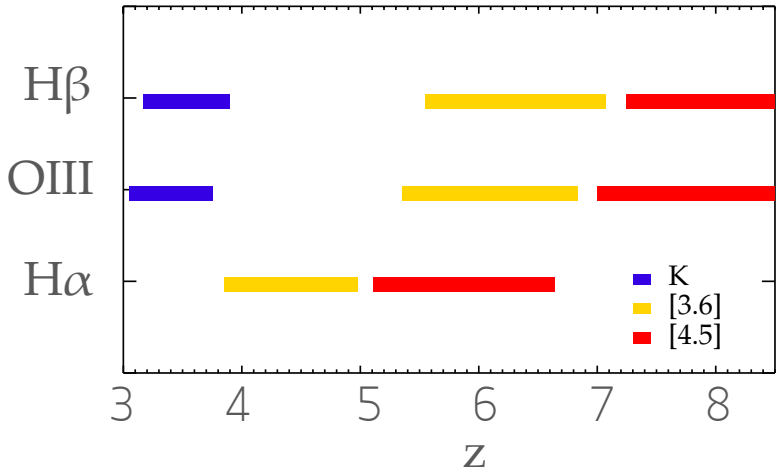
- Nebular emission – what do we know already? Evidence and consequences for strong Hα detections using broadband photometry (Stark, MAS et al. 2013)
- Keck spectroscopic survey - targeting $3.0 < z < 3.8$ LBGs with MOSFIRE
- Part I
  - Direct spectroscopic confirmation of strong nebular lines
  - Validation of deriving line strength through broadband photometry
  - Consequences for sSFR
- Part II
  - Lyman α velocity offset - connection to reionization models

# Spitzer detections - Evolved stellar mass or strong nebular emission?

- Initial detection of red rest frame UV-Optical color in z ~ 6-7 LBGs taken as evidence for large stellar masses, old populations when age of universe only ~1 Gyr (ex. Eyles et al. 2007, Gonzalez et al. 2010)
- BUT emission line equivalent width increases as (1+z) -> strong nebular lines can contaminate broadband fluxes, mimic Balmer/4000Å break (ex. Scharer & deBarros 2010)
- Stark, MAS et al. 2013 takes advantage Unique window at 3.8 < z < 5.0 to study Hα strength at high-z (Shim et al. 2011)

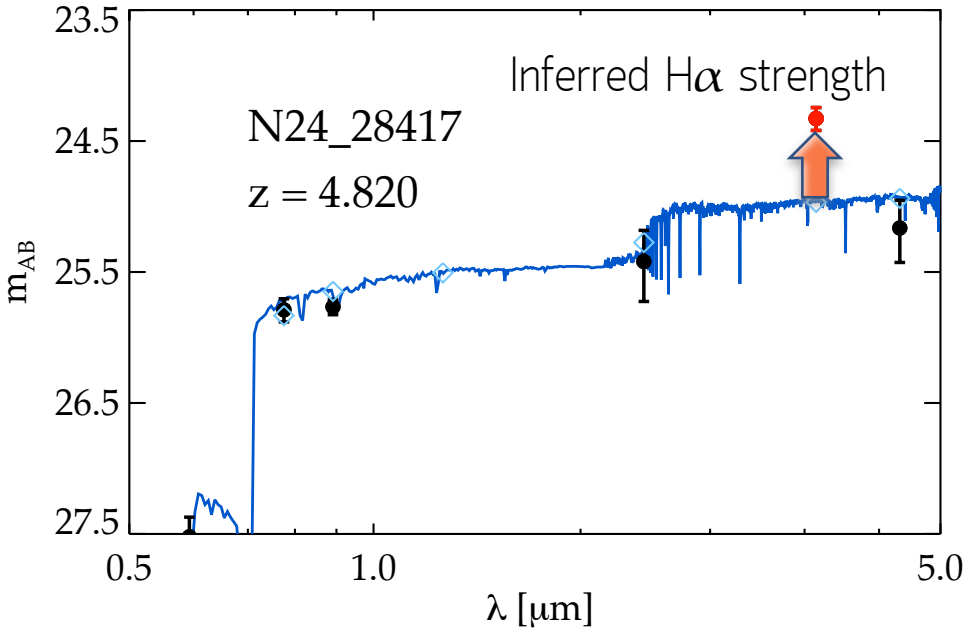


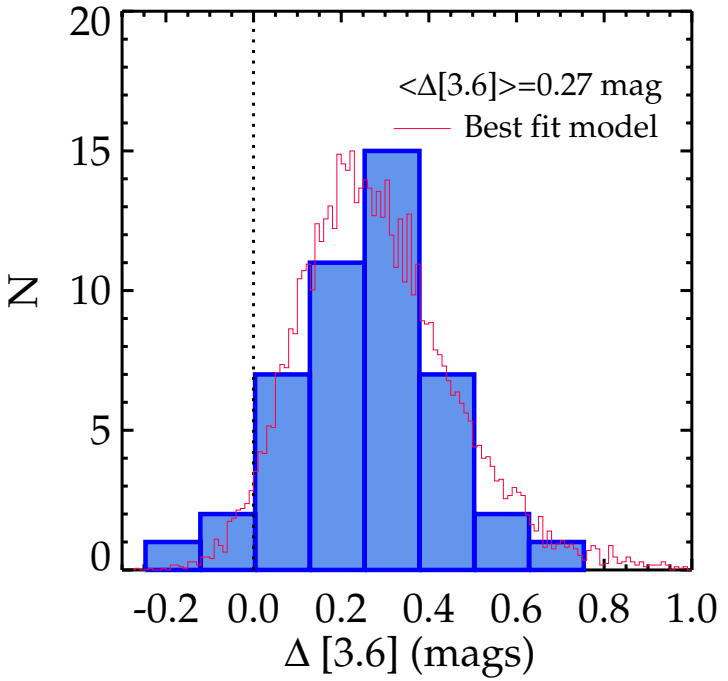

Eyles et al. 2007



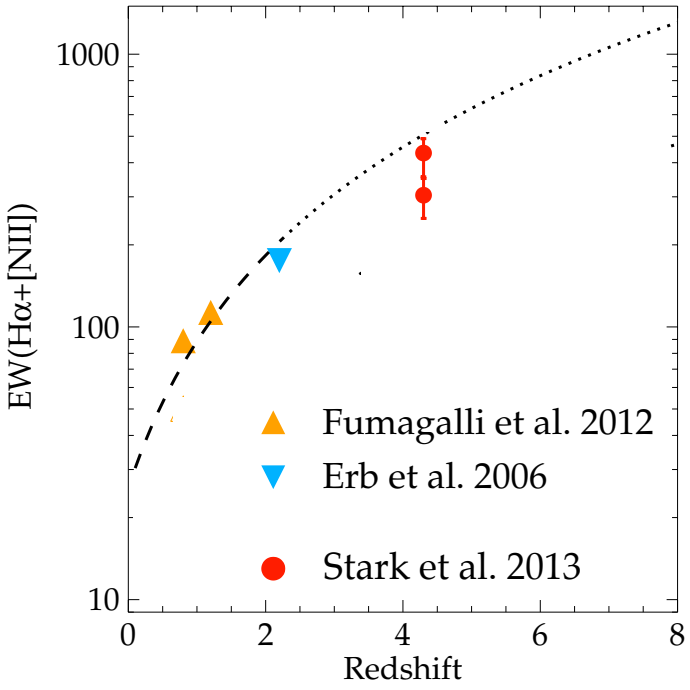
# Evidence for large nebular EWs?

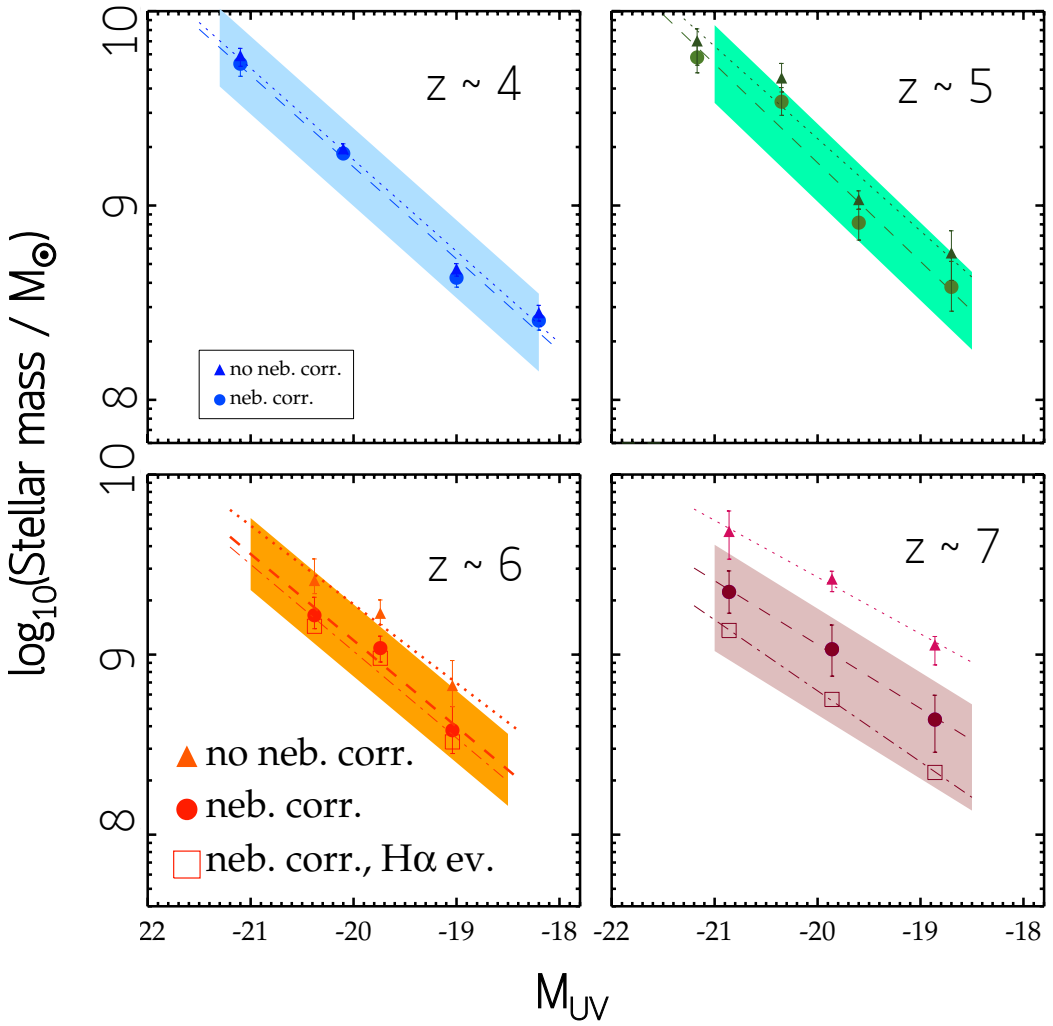
- Surveyed 45 galaxies between 3.8 < z < 5.0 with robust ( >5.0 σ) IRAC [4.5] μm detections to achieve robust measurement of rest-optical stellar continuum
- Using difference between synthetic and observed [3.6] photometry, derive mean Hα EW ~ 270 Å, rest frame



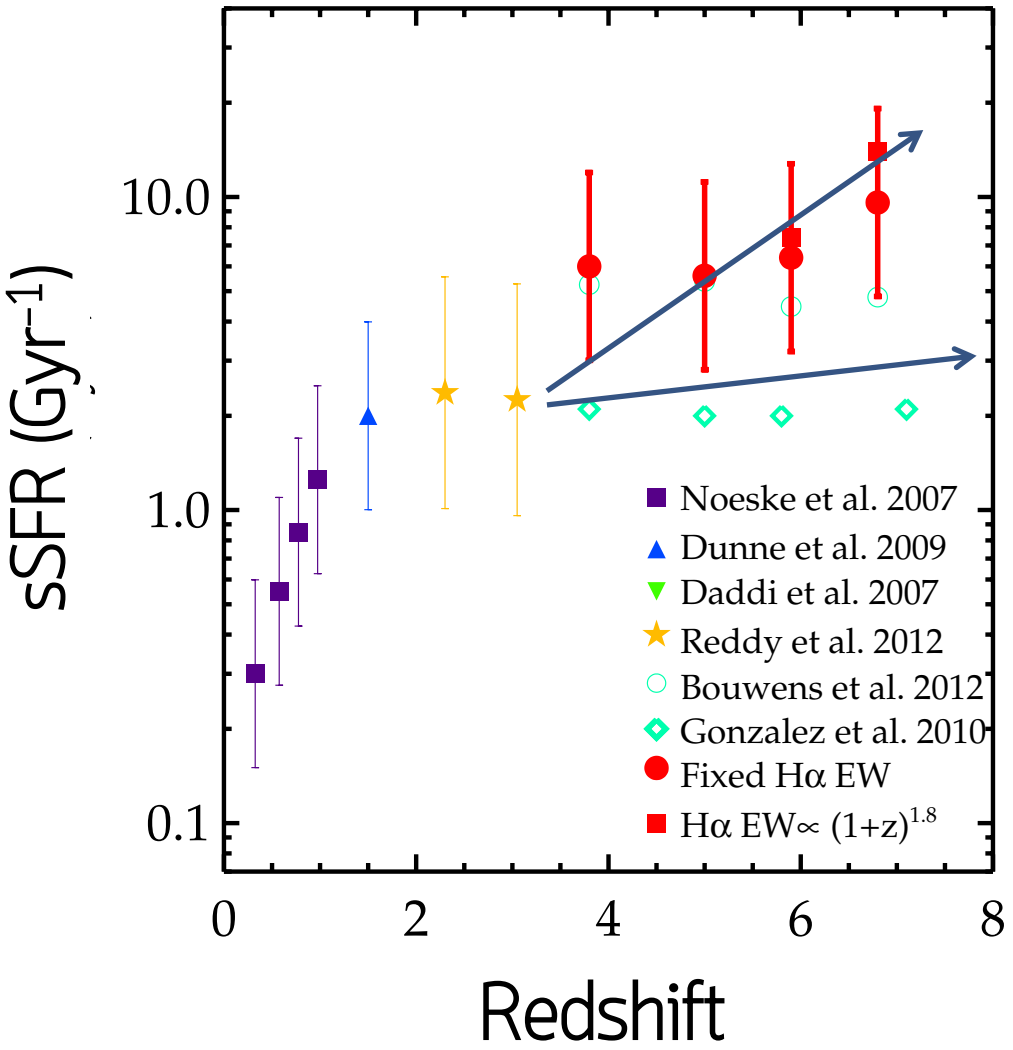



# Evolution and effect on stellar masses



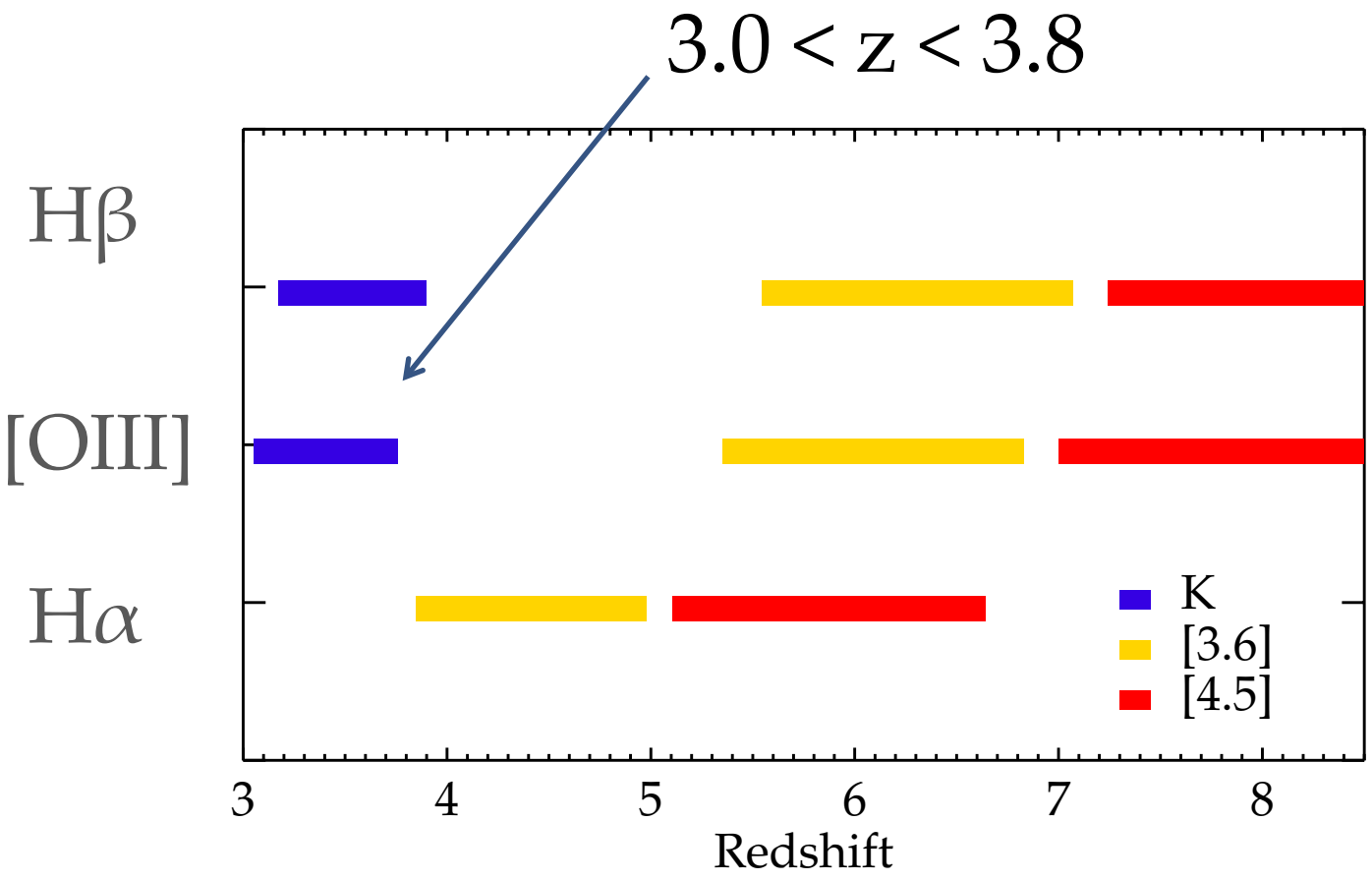
# Evolution and effect on sSFR




Stark, MAS et al. (2013)

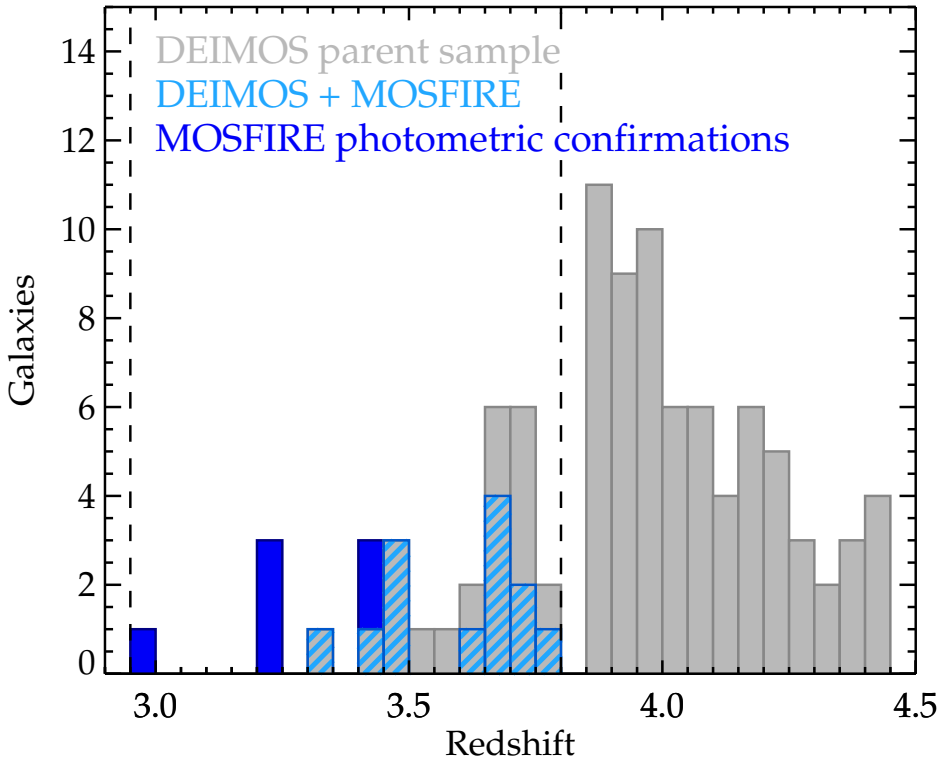
See also
Gonzalez et al. (2013)

# What's next? MOSFIRE



# MOSFIRE campaign – target selection

- 13 DEIMOS-confirmed z > 3.3 galaxies from Keck spectroscopic survey (Stark et al. in prep.)
- Additional 14 B-drops selected to have non-negligible probability to lie at 3.0 < z < 3.8 ([OIII], Hβ in MOSFIRE K-band)
- Total of 20 objects confirmed with either MOSFIRE or DEIMOS



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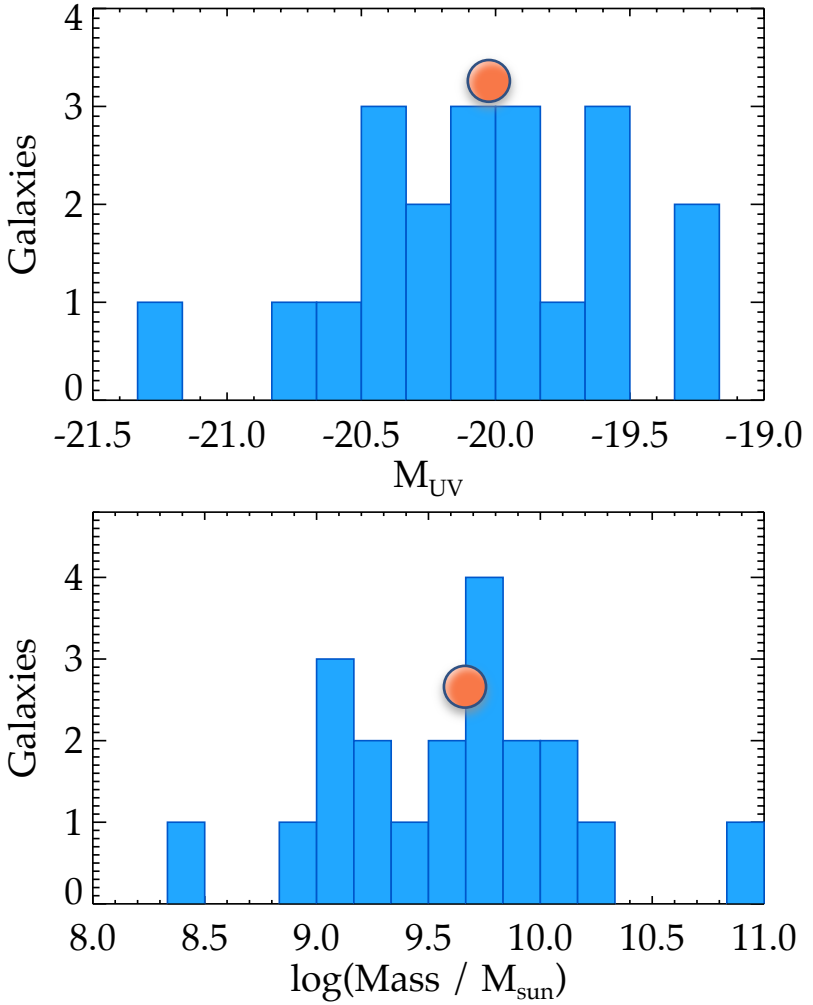
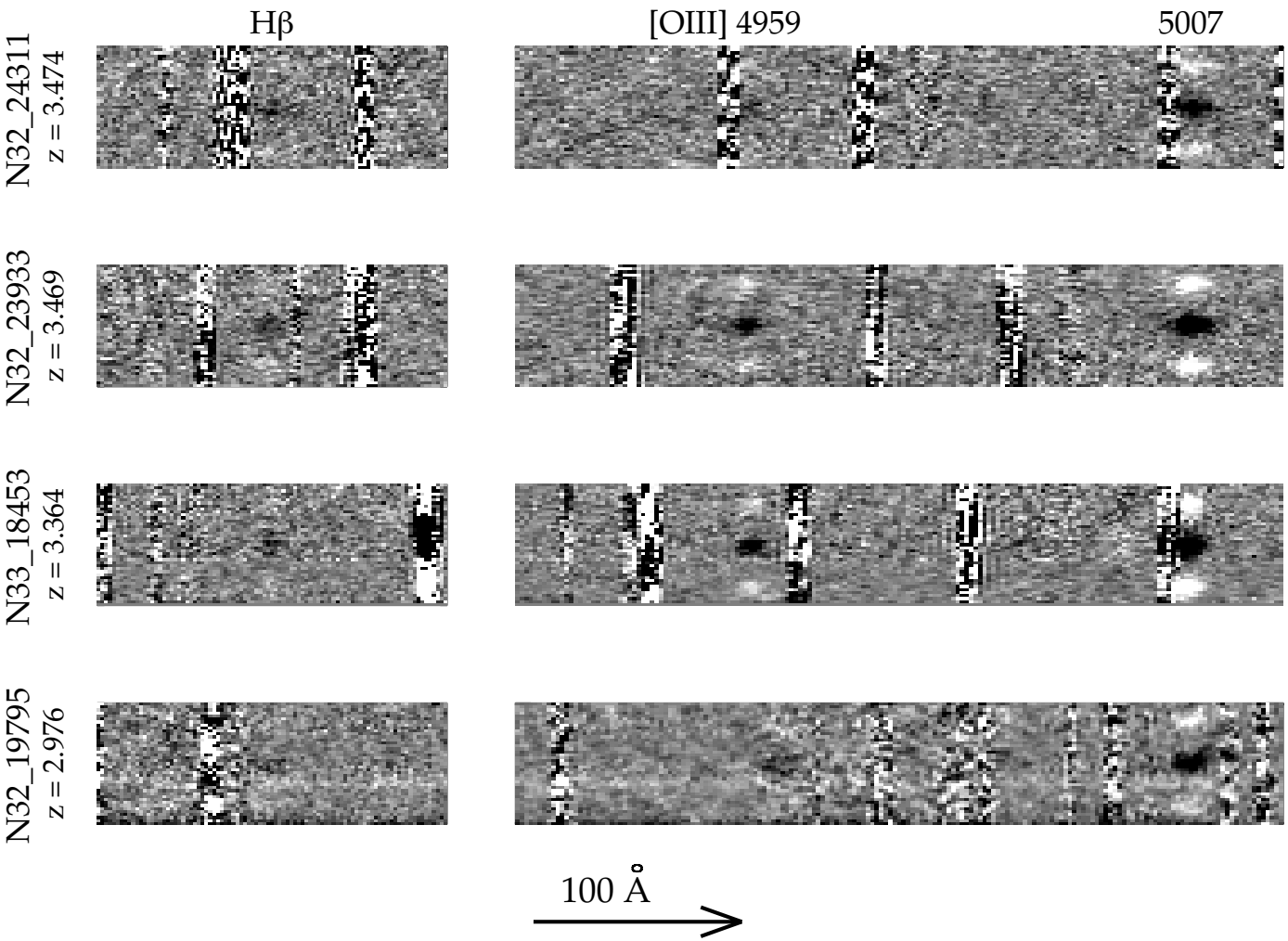
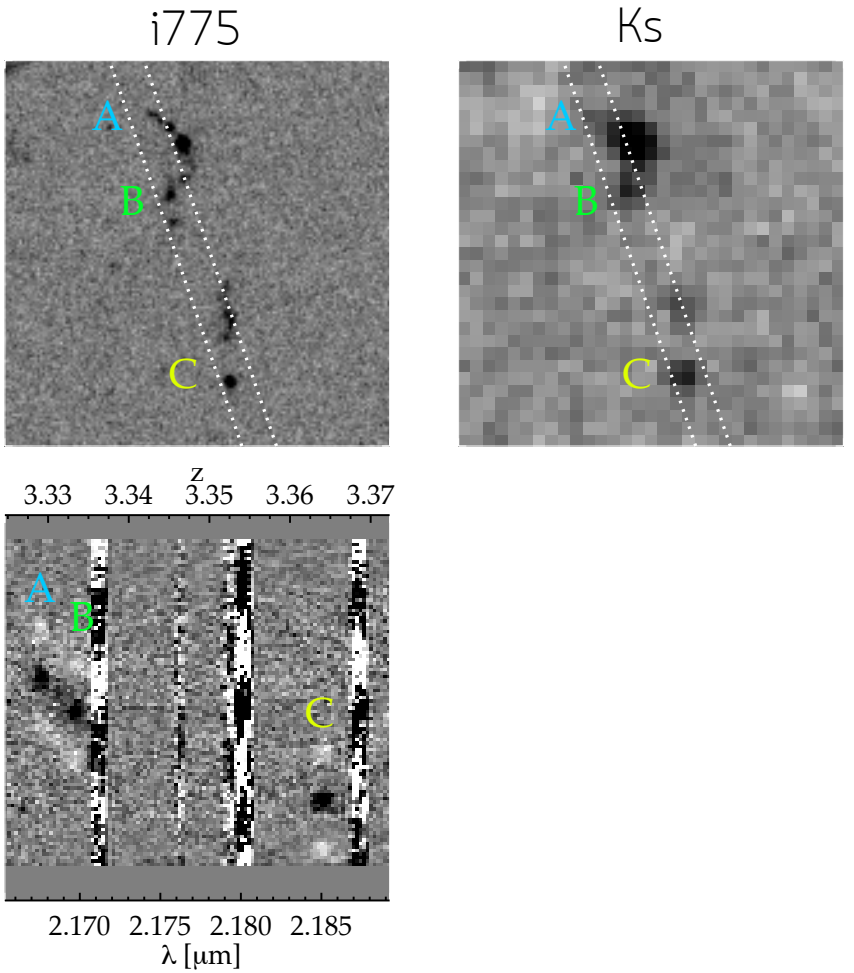


# Data – robust emission line detections

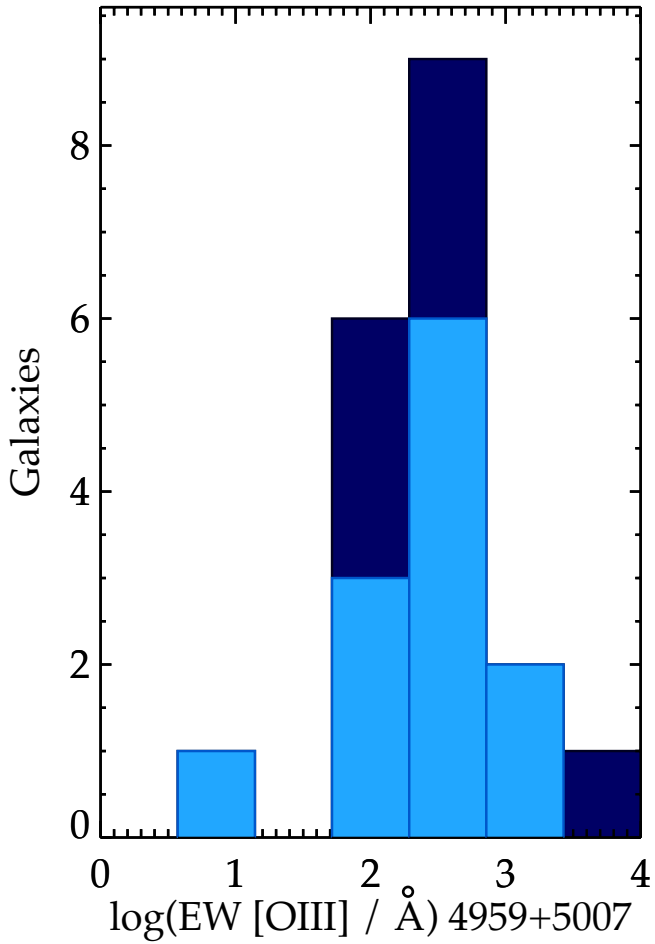


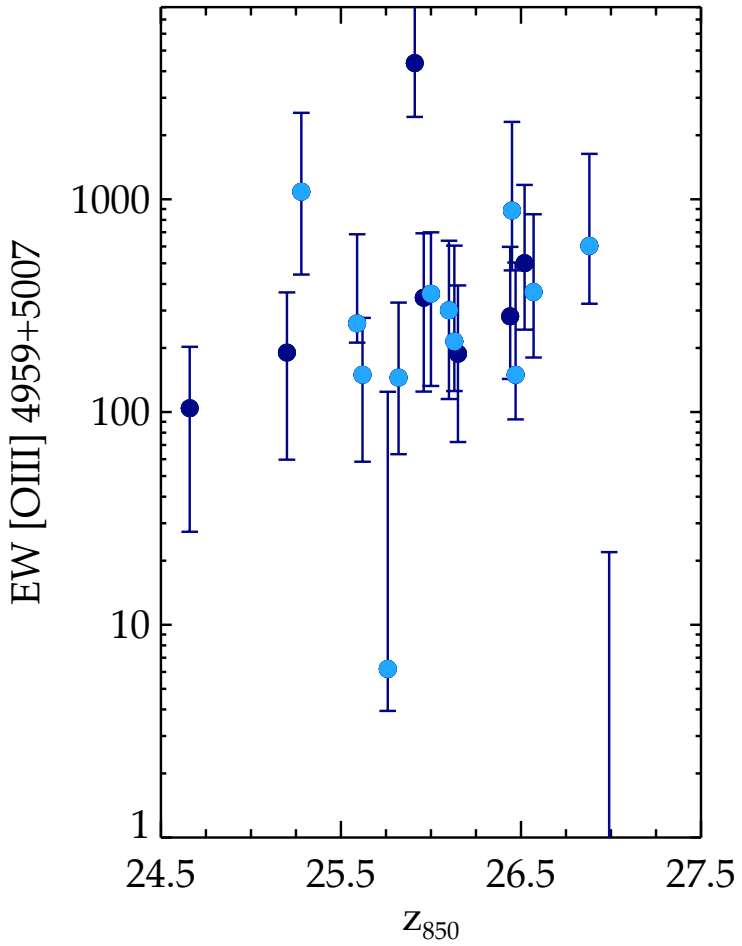
# Serendipitous detections

- Some of strongest emission lines observed part of star-forming complex
- 'B' originally targeted LBG, 'A', and 'C' identified in MOSFIRE spectra and confirmed to be B-drops in HST imaging
- 'C' component has $EW_{[OIII]}$ ~ 4000Å



# Spectroscopic EW distribution



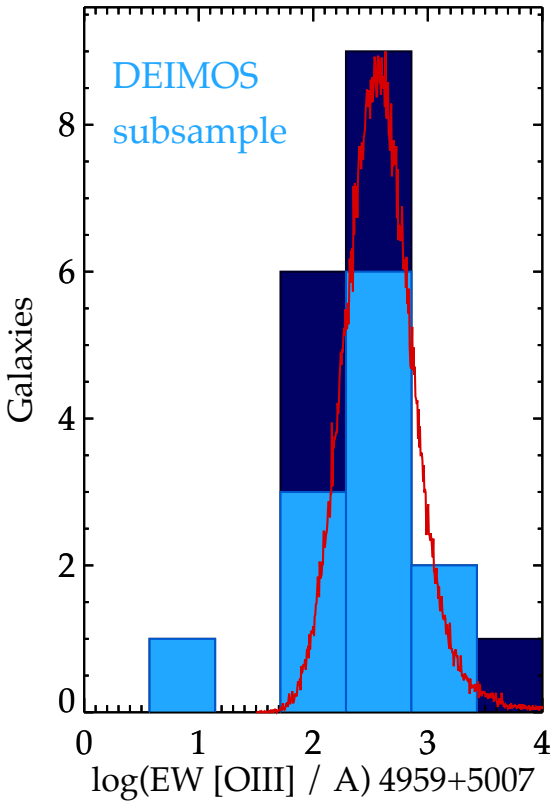




DEIMOS + MOSFIRE

MOSFIRE only (photometric)

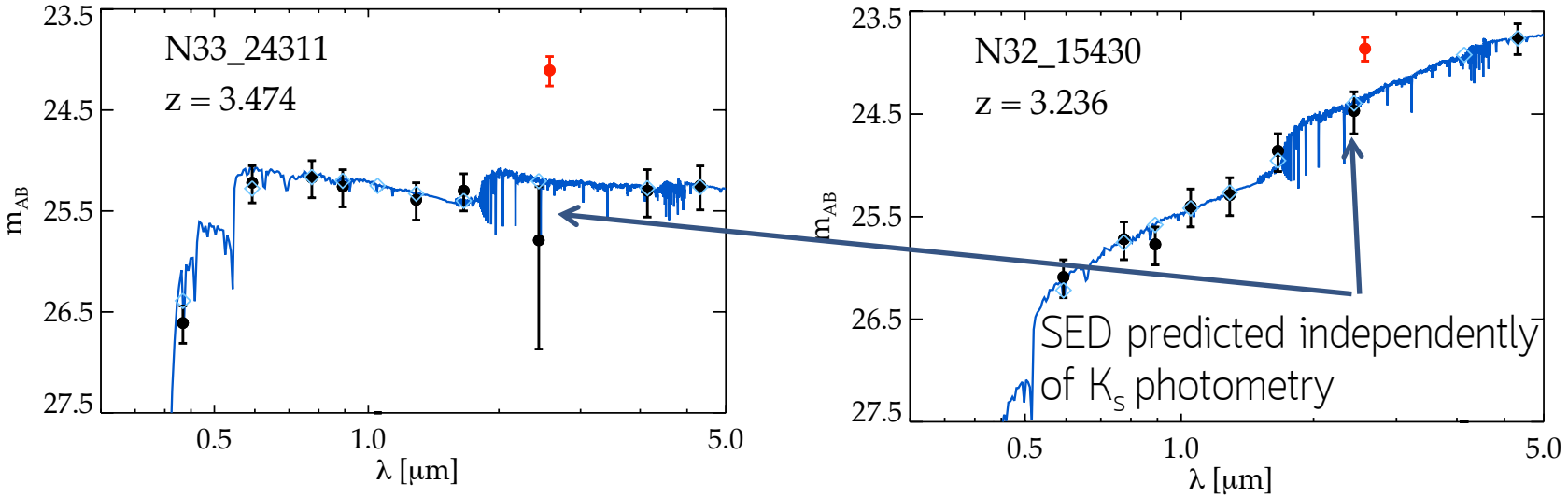
# Comparison with Stark, MAS et al. 2013

- Want to investigate whether photometrically-infererred Hα distribution at 3.8 < z < 5.0 is reasonable given our robust [OIII] EW distribution at 3.0 < z < 3.8
- Assume:
  - Flux ratio of H alpha : OIII = 1 : 2.2, motivated by empirical line fluxes from Anders and Alvensleben 2003, with Z = 0.2 $Z_{sun}$
  - Flat stellar continuum between H alpha and [OIII]
  - Intrinsic distribution is lognormal, as derived in Stark et al. (2013), gives for [OIII] $EW_c$ = 350 Å, σ = 0.25
- Perform MC simulation, add noise consistent with our observations



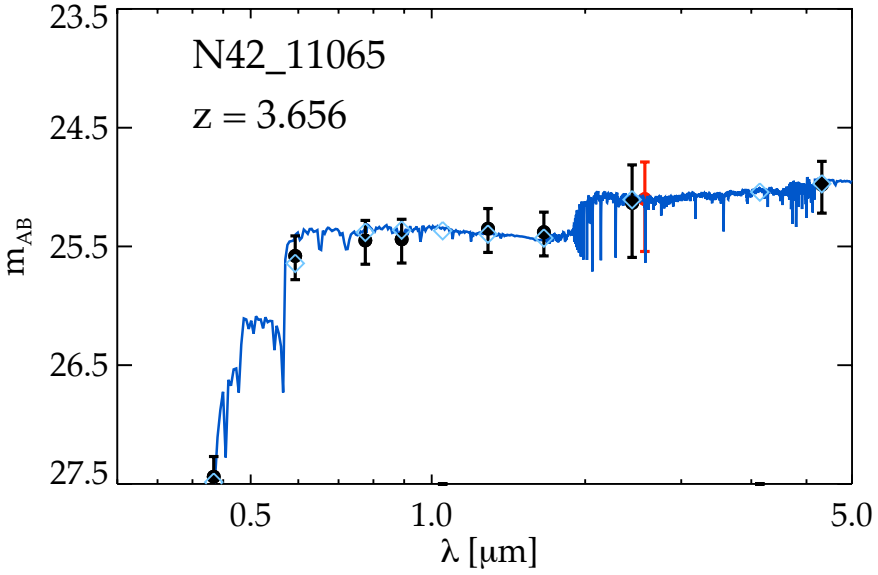
# Validating the Stark, MAS et al. (2013) method

- Unique data set allows us to test the method of deriving emission line strengths from contaminated broadband photometry
- Out of 20 objects, 9 include a robust IRAC detection in either [3.6] or [4.5] band. Fit SED ignoring K-band photometry, then derive estimated line strength from difference between synthetic and observed fluxes



# Validating the Stark, MAS et al. (2013) method

- Out of 9 objects, predict (and observe) significant line fluxes in 8
  - 7 these 8 objects have $1/1.7 < f_{pred} / f_{obs} < 1.7$
- Remaining object with observed [OIII] < 7.0e-18 predicted by our method to have no significant line flux (below left)



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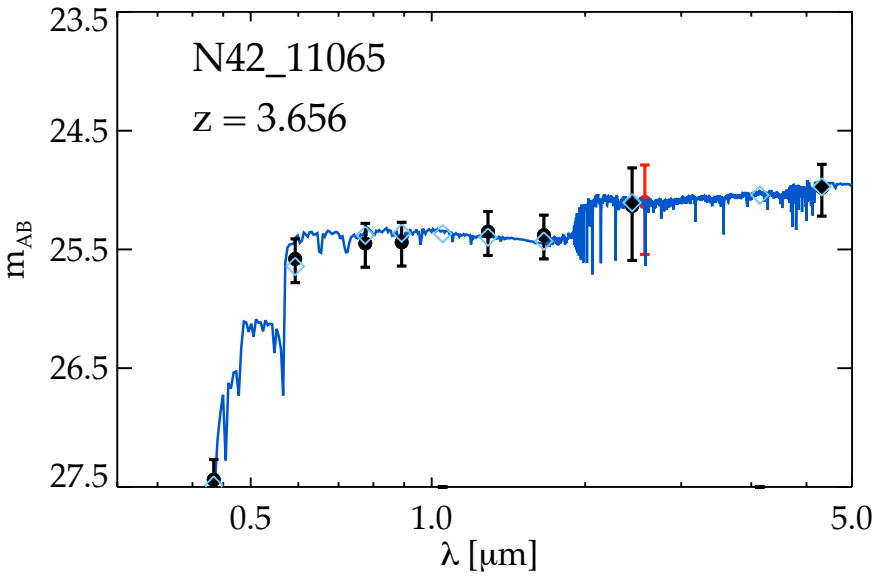
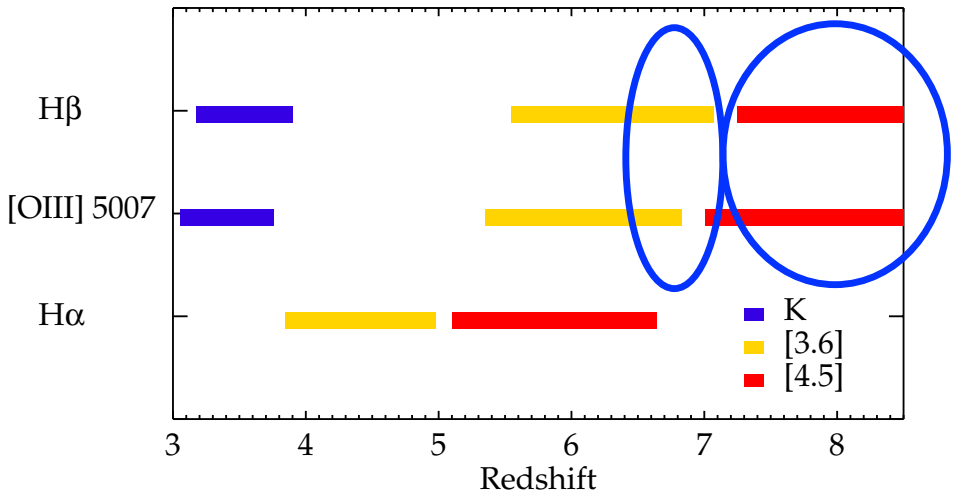
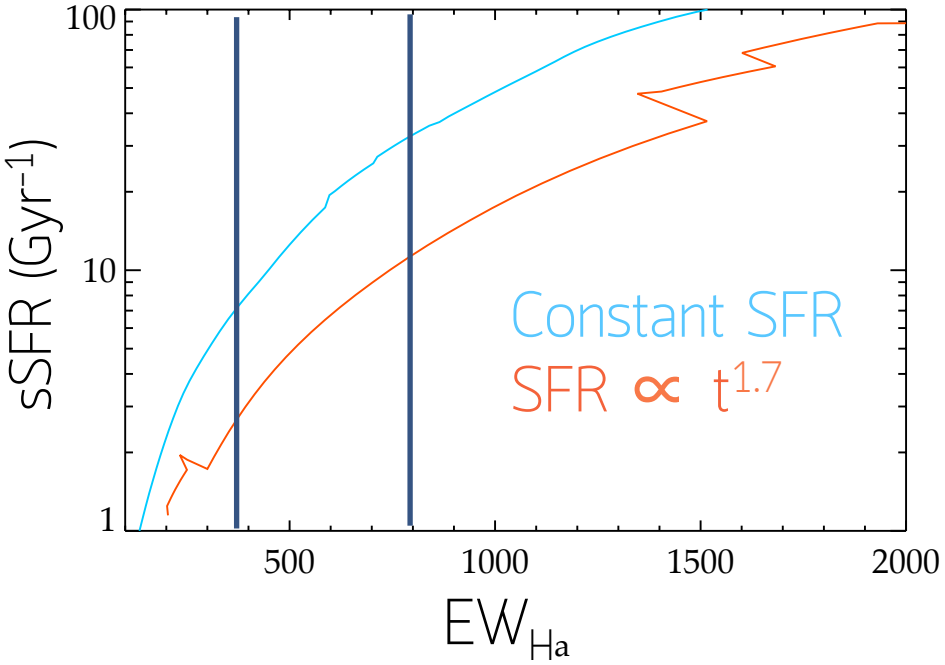


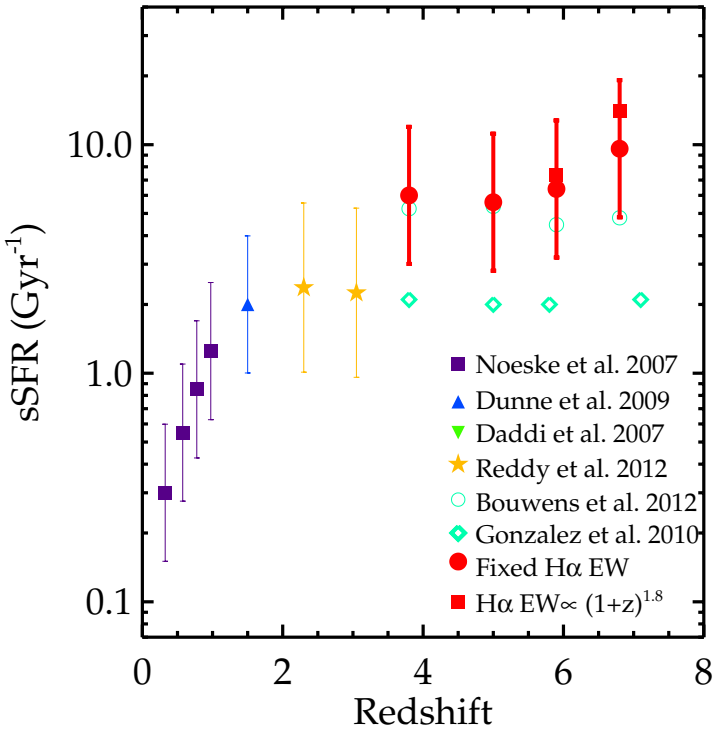

Similar windows at
z > 6.6
e.g. Ono+ 2012, Bouwens' talk

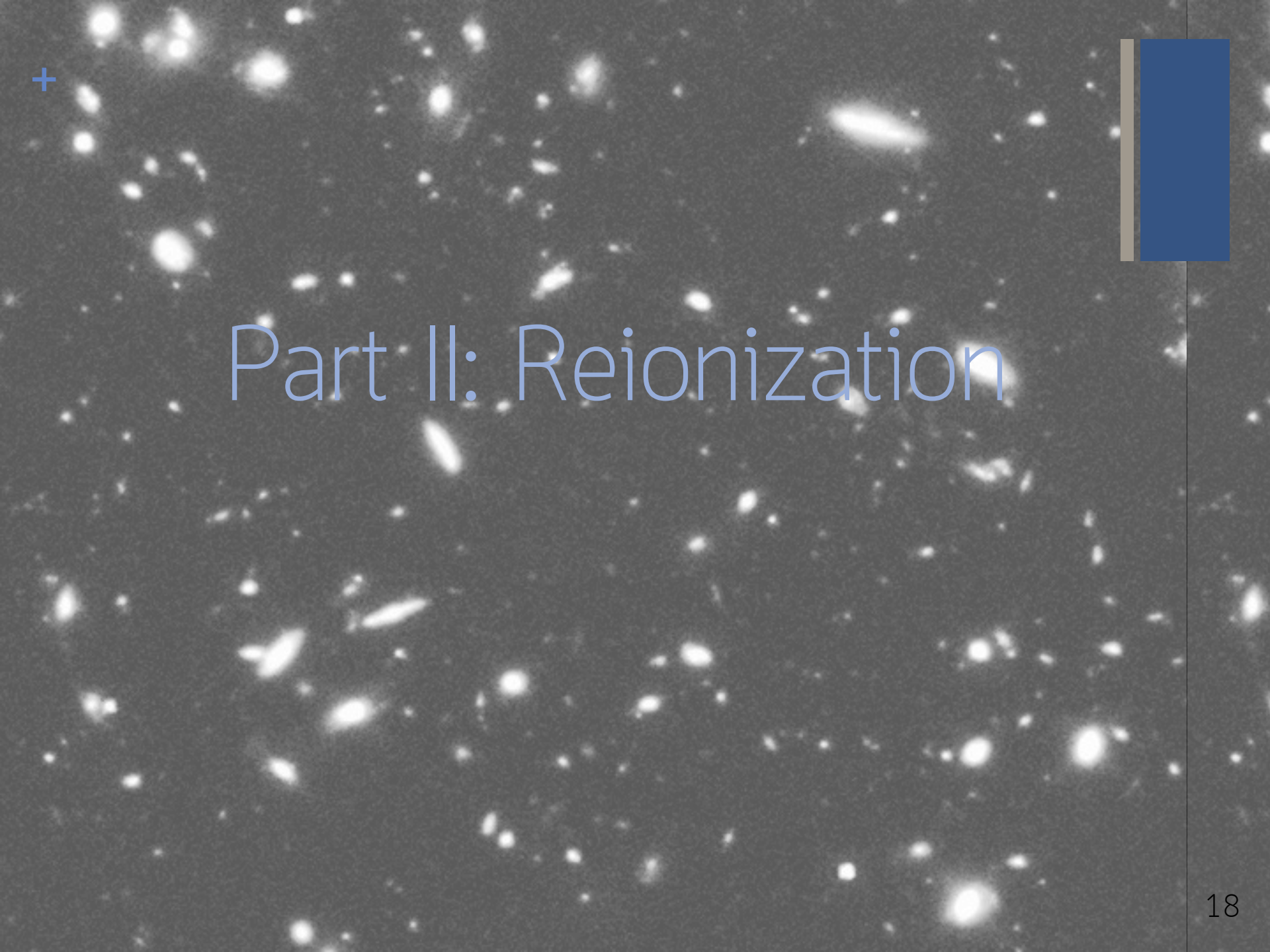


# sSFR implications

- Using Hβ measurements and SEDs, predict average $EW_{H\alpha}$ = 380 Å
  - Factor of ~4 higher than Erb et al. (2006) at z ~ 2 (though our sample at lower masses)
- For 8 galaxies with Hβ detected at > 3σ, median $EW_{H\alpha}$ = 680 Å!



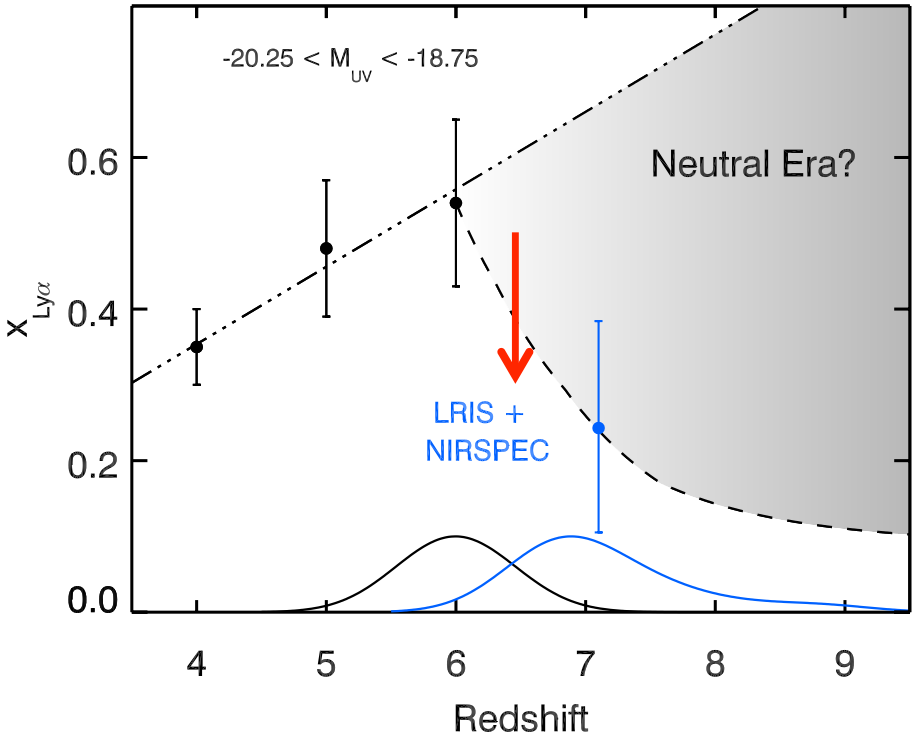





# Part II: Reionization

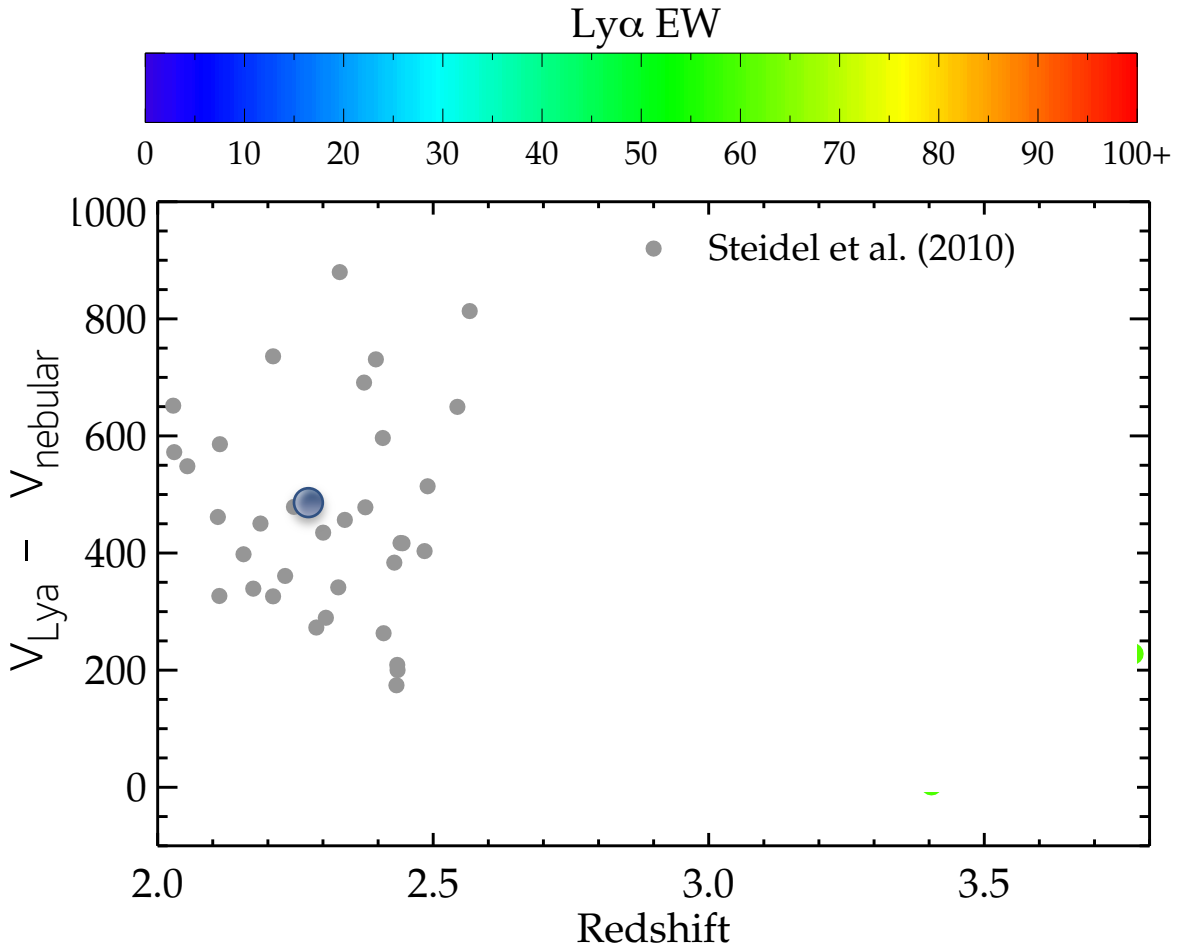
# Reionization tests – $x_{Ly\alpha}$

- $x_{Ly\alpha}$ = Fraction of LBGs which display strong Lyα in emission
- Relevant: forthcoming sample of 200 $6 < z < 7.3$ LBGs from VLT large program (Fontana)
- Incredibly important to inferring a neutral Hydrogen fraction, $X_{HI}$, from any decrease in $x_{Ly\alpha}$ is the velocity offset of Lyα from systemic velocity of galaxy



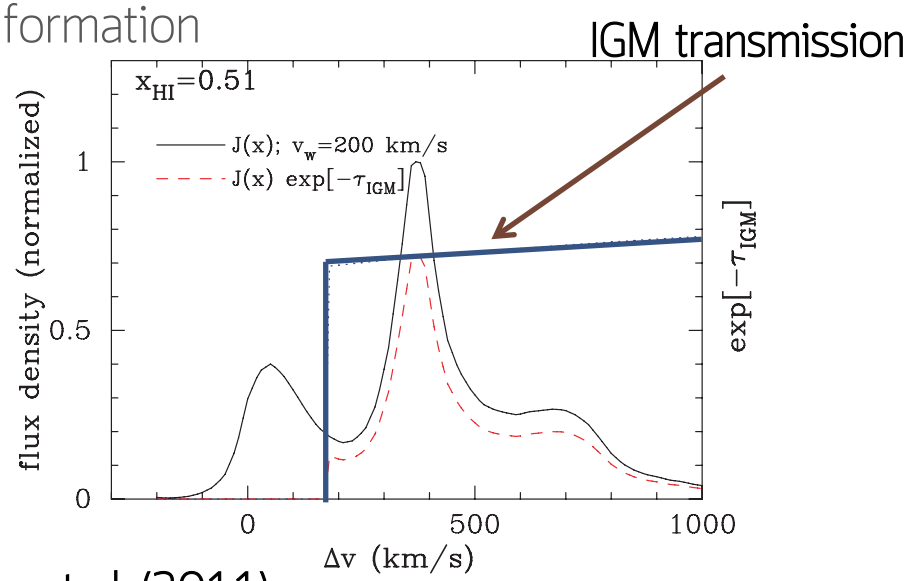

Schenker et al. (2012)

# Lyman alpha velocity offset

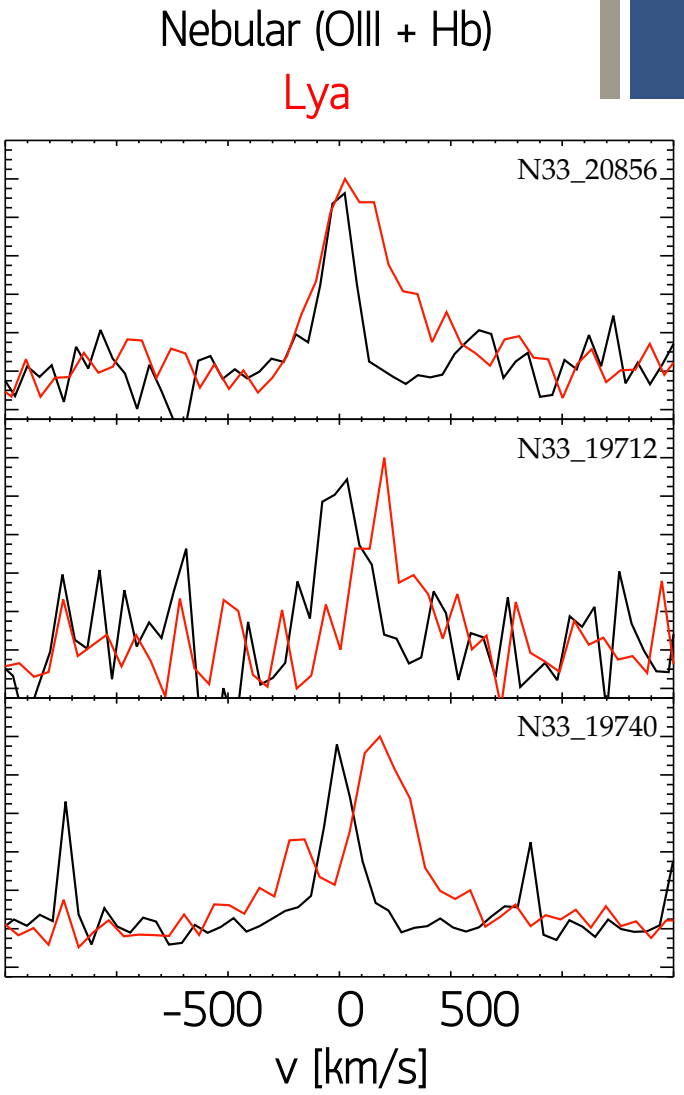


# Lyman alpha velocity offset

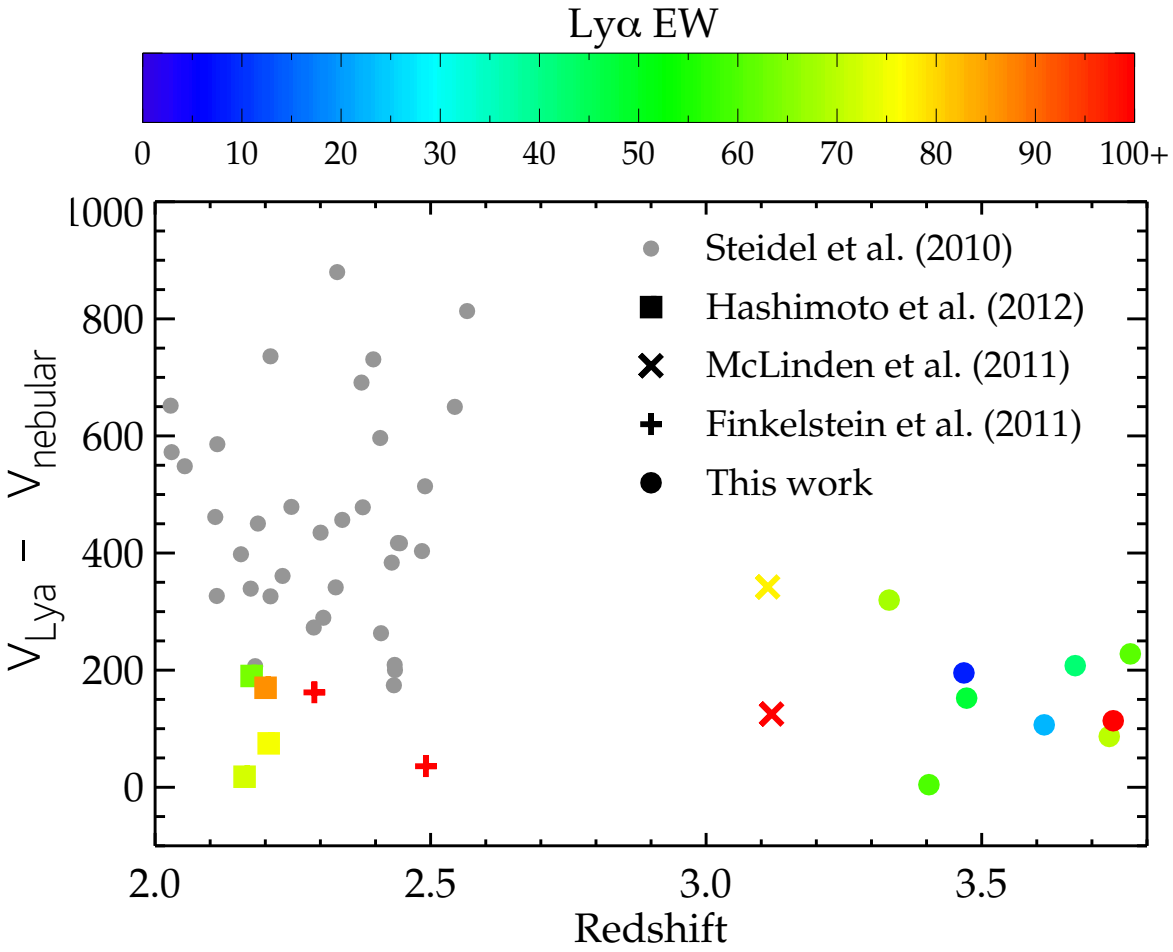
- Velocity offset with which **Lyα** emerges from galaxy critical to determine appropriate IGM transmission (Dijkstra et al. 2011, previous talk!)
- For our sample with both DEIMOS and MOSFIRE coverage, can compare velocity of **Lyα** w.r.t. sites of star formation




Dijkstra et al. (2011)



# Lyman alpha velocity offset




This work (9 galaxies):
$< v_{Lya} > = + 157$ km/s

+ Strong Lya emitters (17 galaxies):
$< v_{Lya} > = + 149$ km/s

Implies a reduction in initially high $X_{HI}$ values derived from $\mathbf{x_{Ly\alpha}}$ test!

# Conclusions

- Confirm earlier findings of strong nebular emission lines at $z > 3$ with direct near-IR spectroscopy
- Validate technique of deriving high-z line strengths through broadband photometry
- Evidence for increase in sSFR beyond $z = 2$, more in line with theoretical expectations
- Lyman alpha velocity offsets provide valuable input for reionization modeling with $x_{Lya}$ – perhaps no longer need to resort to extreme reionization scenarios