ISM excitation and metallicity of star-forming galaxies at z~3.3 from near-IR spectroscopy

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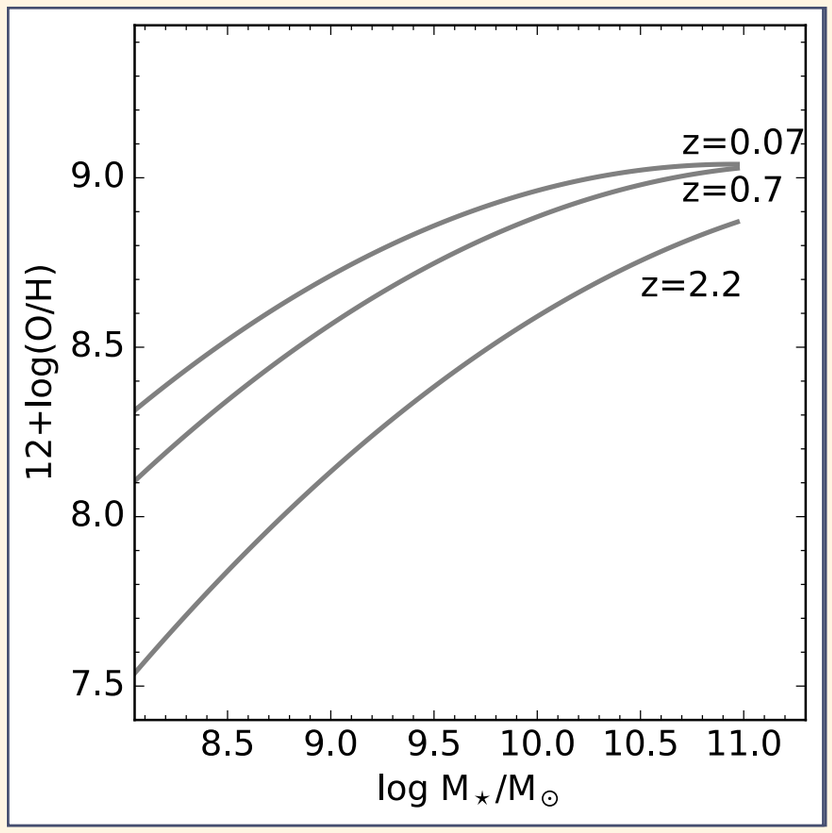
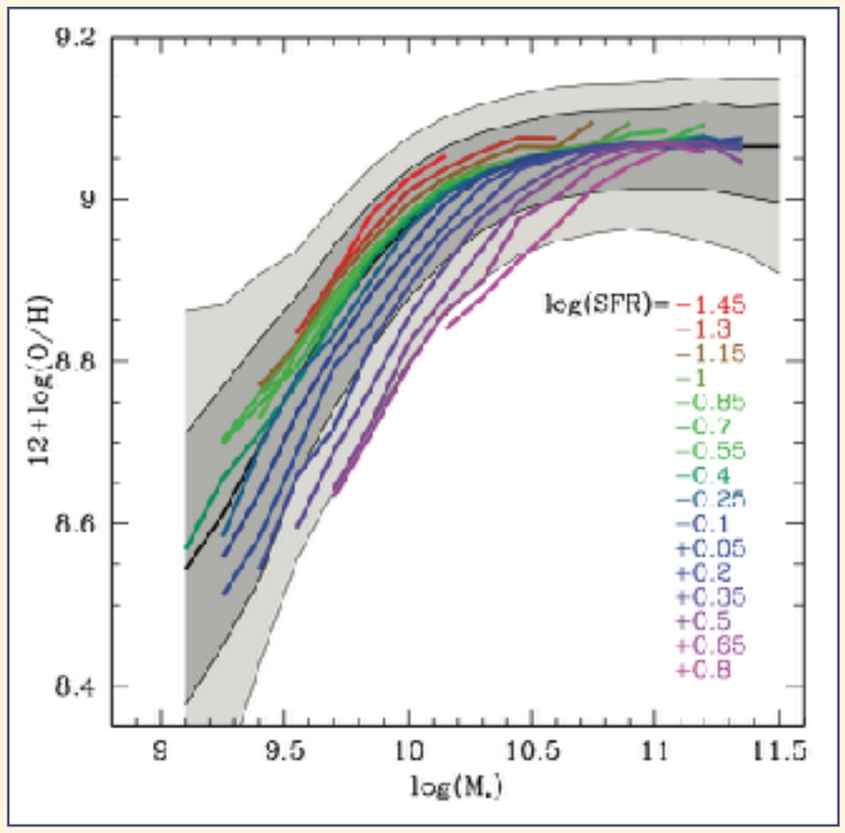
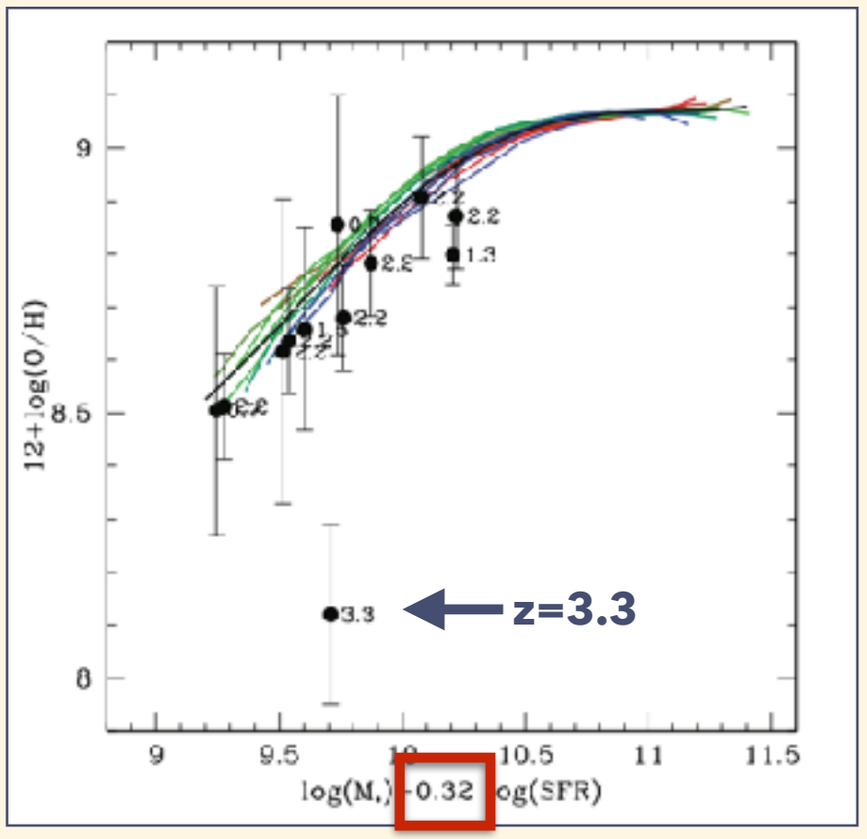
Onodera et al. (2016, ApJ, 822, 42)

Z(M,SFR) relation from z=0 to high-z



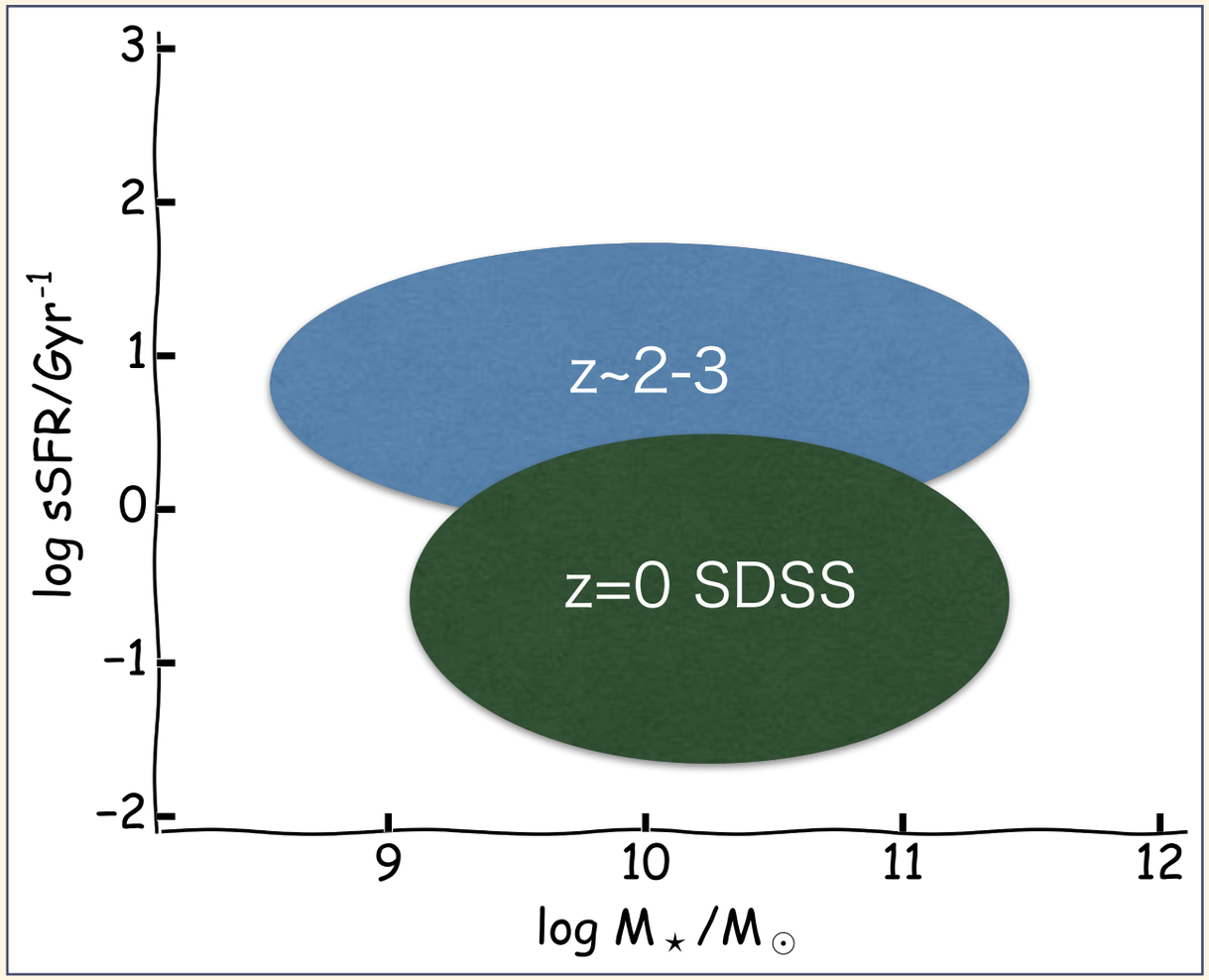


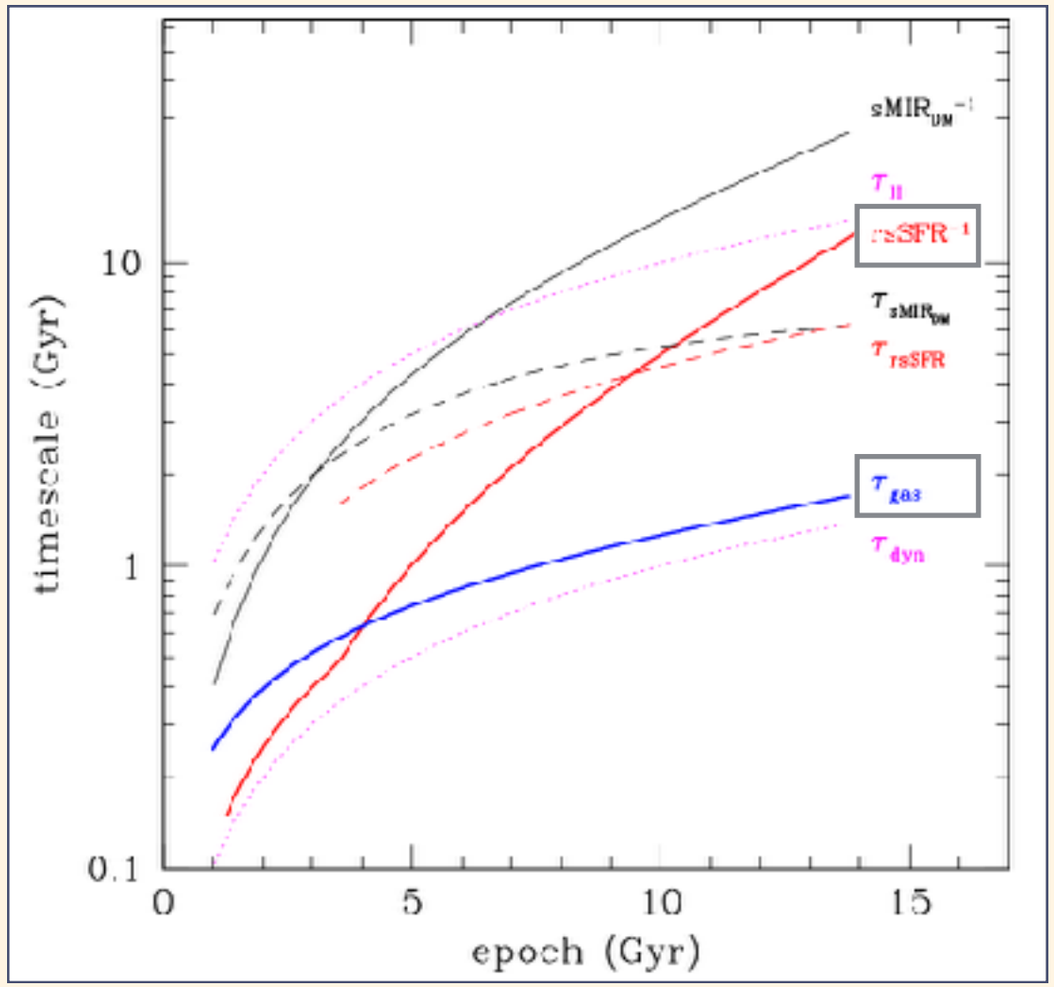


- Tight M-Z relation (MZR) at z=0, and evolution toward lower-Z to higher-z
- SFR appears to be a second parameter of MZR at z=0
- Z(M,SFR) is claimed to be z-independent to z~2 (FMR), but deviate at z>3 (?)

Tremonti+2004; Savaglio+2005; Erb+2006; Mannucci+2010

Issues in studying Z(M,SFR) at high-z



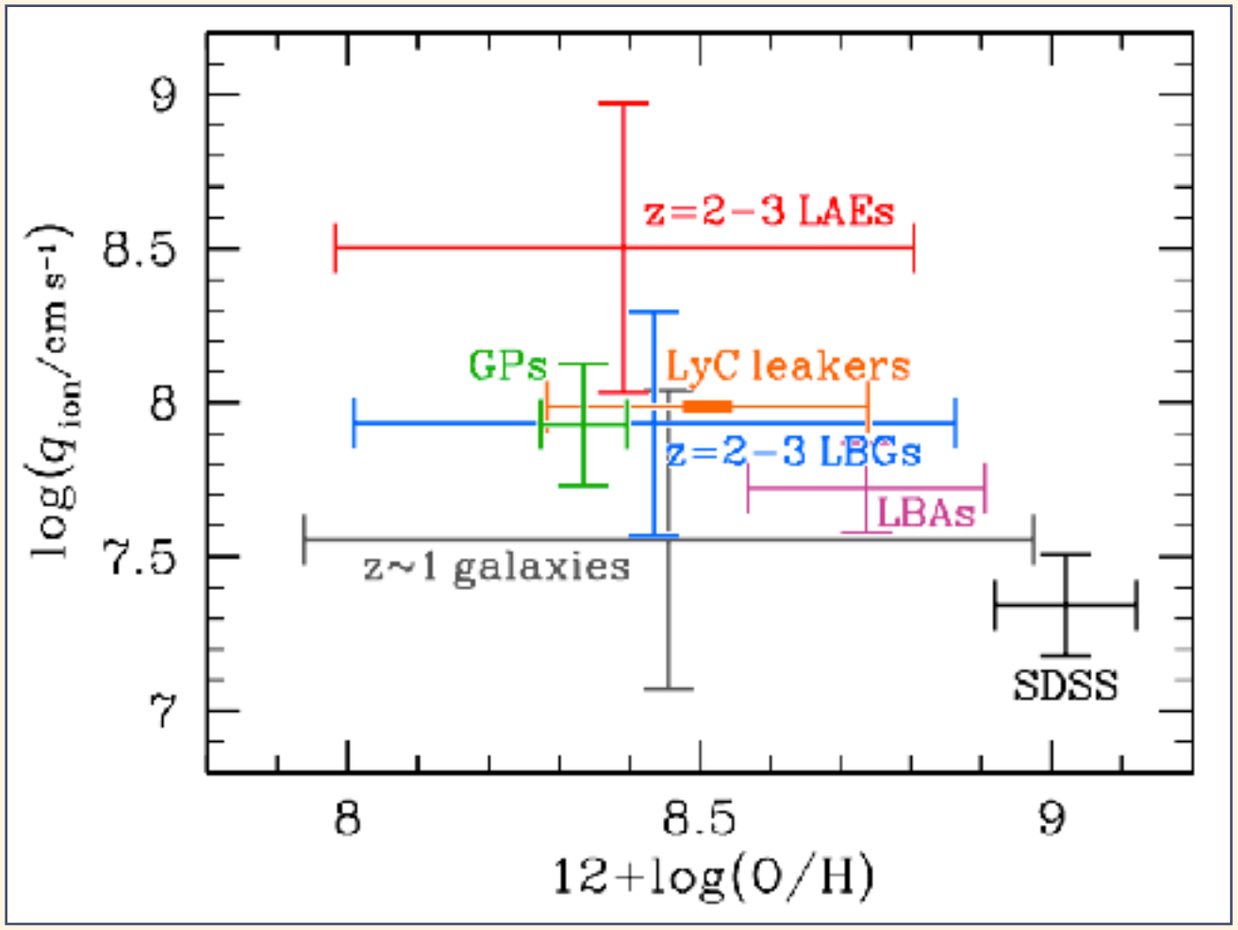


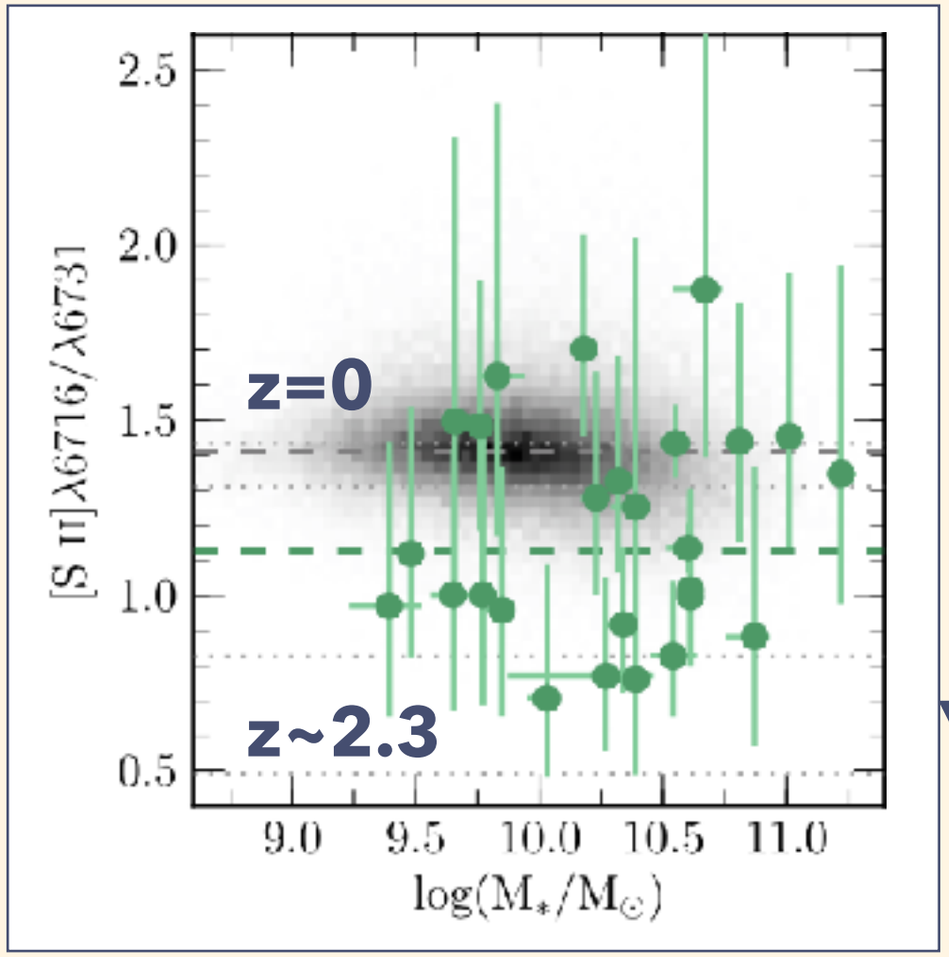
Simple extrapolation of Z(M,SFR) at z=0 to z=2-3 is dangerous

Gas consumption timescale (τ_{gas}) and mass increase timescale ($rsSFR^{-1}$) become closer at higher redshift

Maier+2014; Lilly+13

Evolving ISM conditions





Higher ionization parameters in higher redshift star-forming galaxies

Higher electron density (~10x) at z~2.3 than at z~0

Up to z~2.5, a large number of sample has started being obtained

Nakajima & Ouchi (2013); Sanders+2016

Questions to be addressed

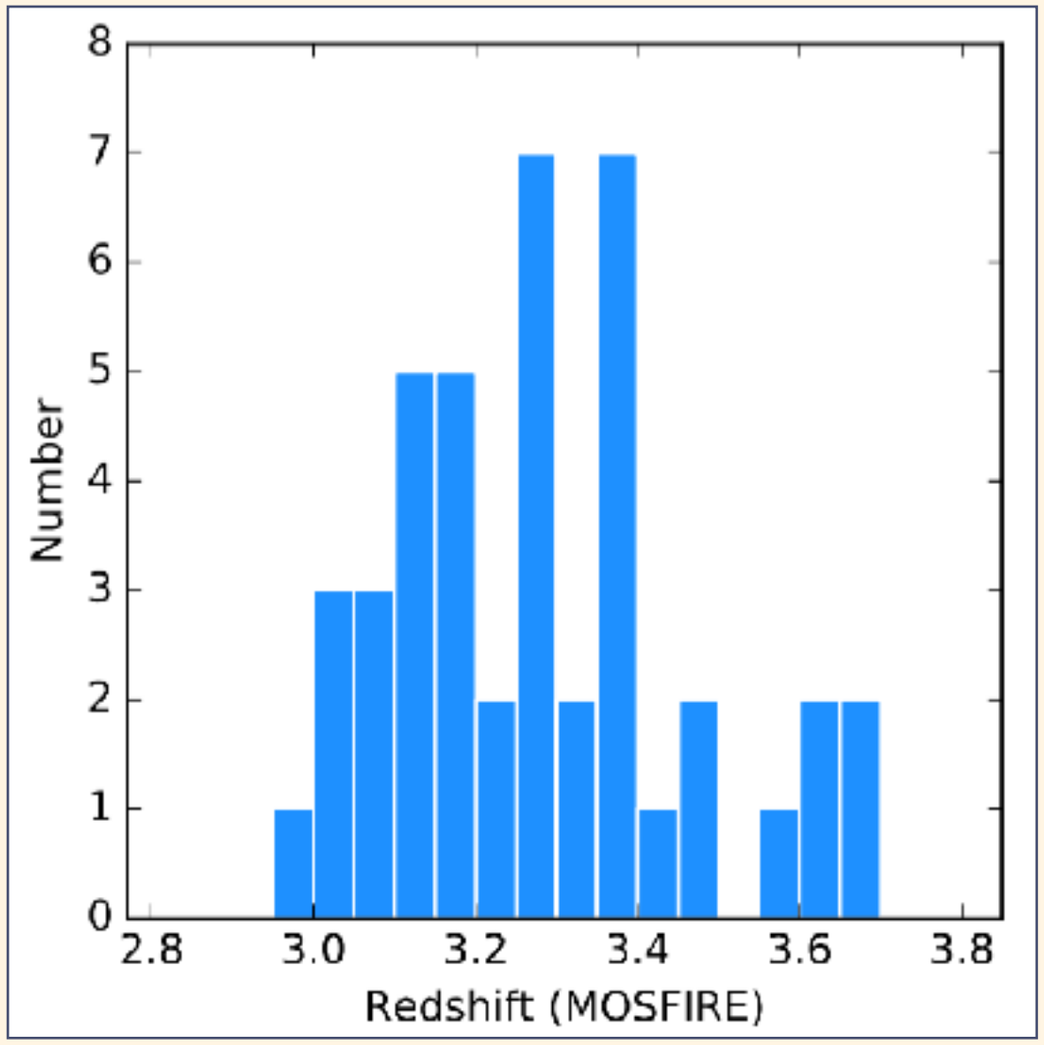
What are the properties of ionized gas in normal star-forming galaxies at z>3 and their relations with galaxies' global properties?

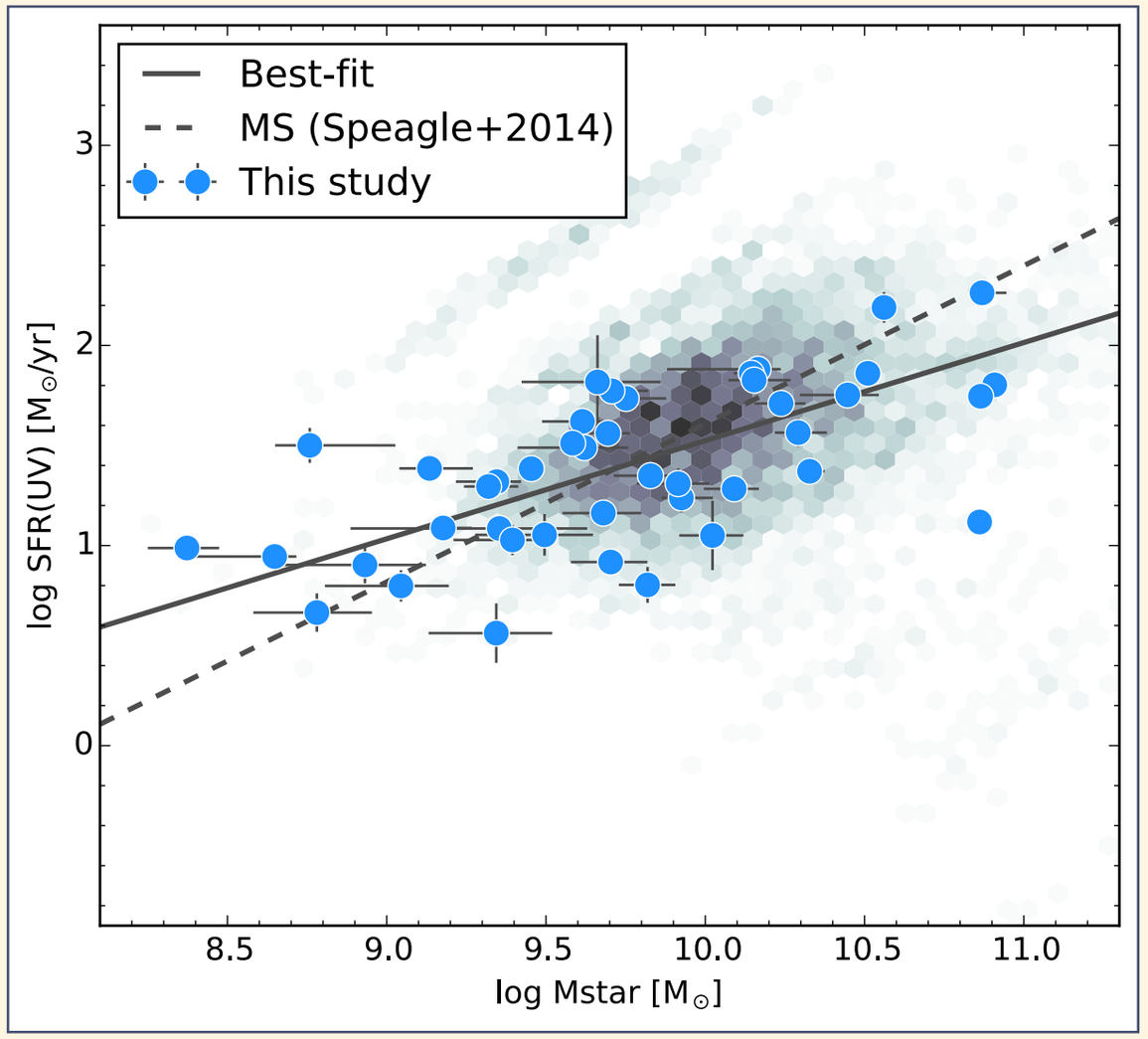
Does SFR play as a second parameter of MZR at z>3?

Is the dependence of MZR on SFR, if any, consistent w/ the locally defined z-independent FMR?

Does the simple gas regulator model for star formation and chemical evolution work at z>3?

Sample





Main-sequence star-forming galaxies at 3<z<3.7 with a **median z=3.3**

Primary sample: **zCOSMOS-Deep** with robust spectroscopic redshifts

Secondary sample: **photo-z** objects from the COSMOS photo-z catalog

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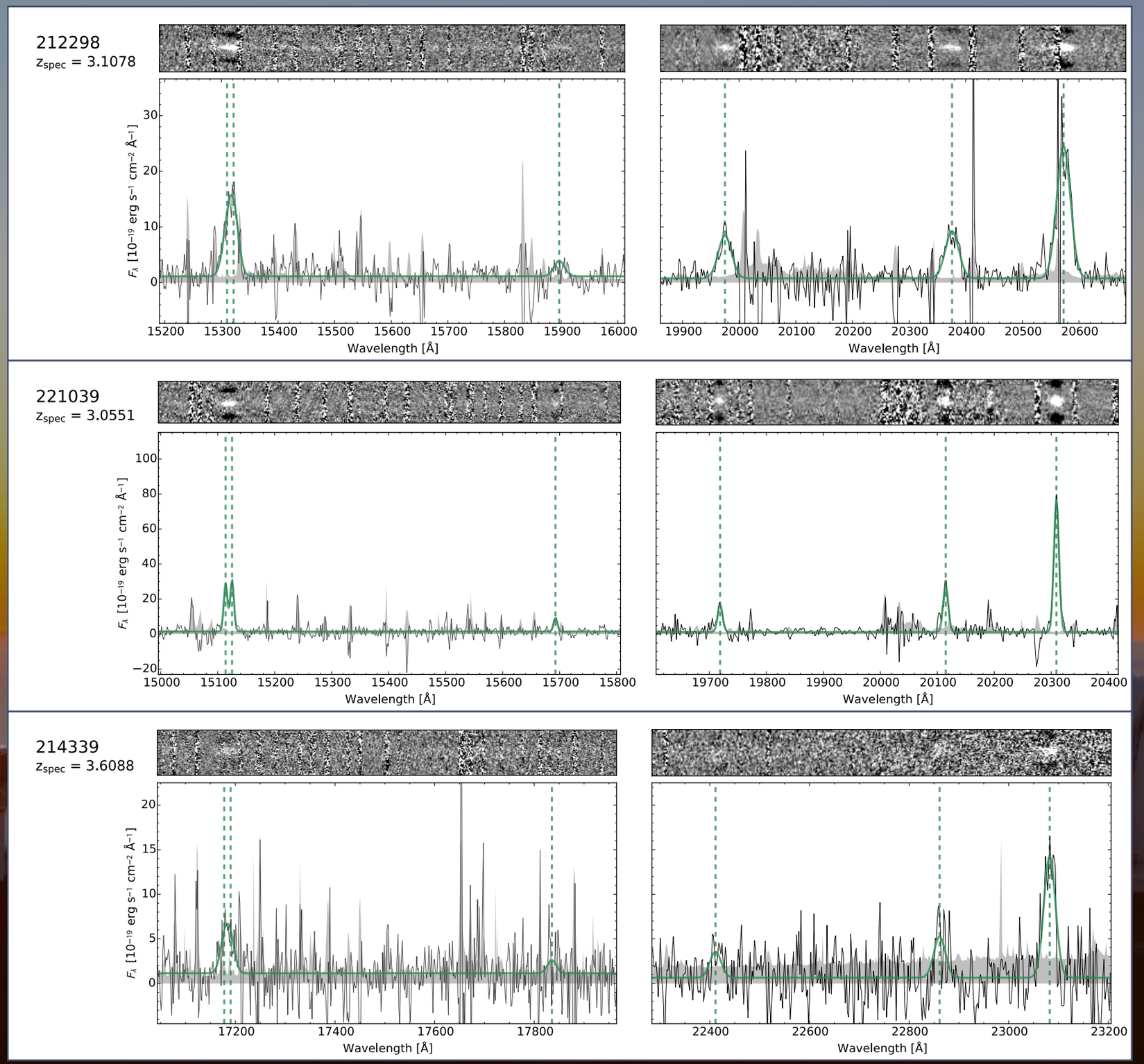
Data

H and K bands with Keck/MOSFIRE for **30-80 min** per band in total 3 out of 8.1 nights in January 2014 and 2015

43 out of 54 objects with detected emission line(s): resolved [OII]3727, [NeIII]3869, Hβ, [OIII]4959,5007



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Stack

Stacking w/ binning by M* and SFR (above/below MS)

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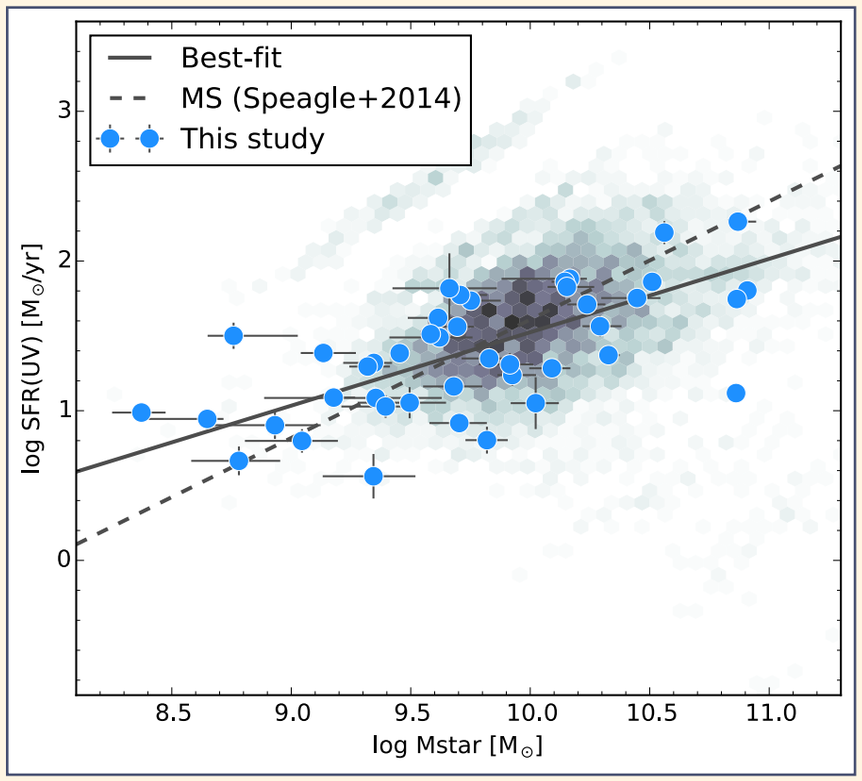
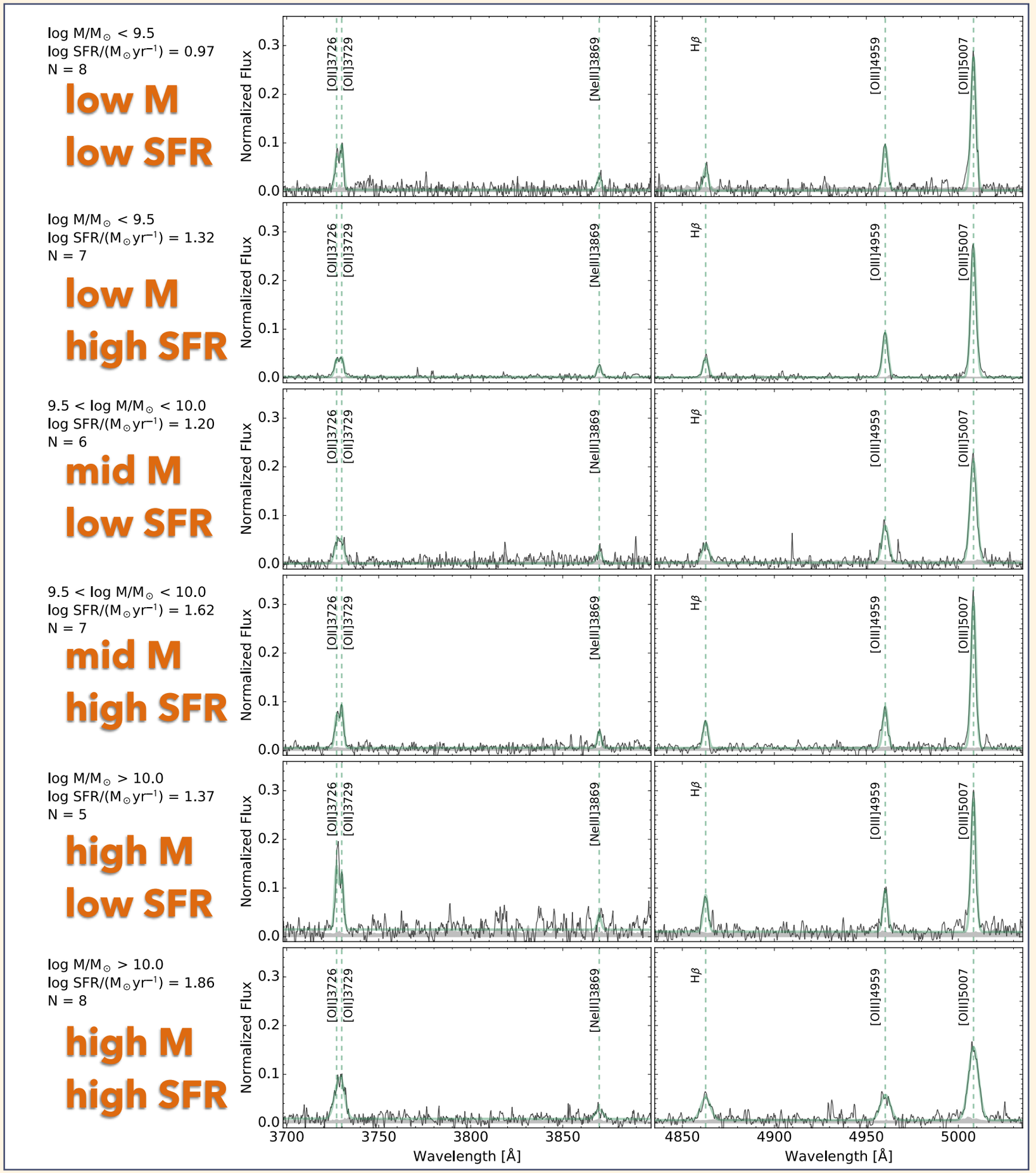




Measurements

Stellar mass: SED fitting on **emission line removed photometry** (BC03 library; exp. declining SFH; Chabrier IMF; Calzetti extinction law)

Star formation rate (SFR): extinction corrected rest-frame UV luminosity

12+log(O/H): R_{23}, [OIII]/Hβ, [OIII]/[OII], [OII]/Hβ, and [NeIII]/[OIII] (Maiolino+08)

Ionization parameter, q: [OIII]/[OII] (Kobulnicky & Kewley 2004)

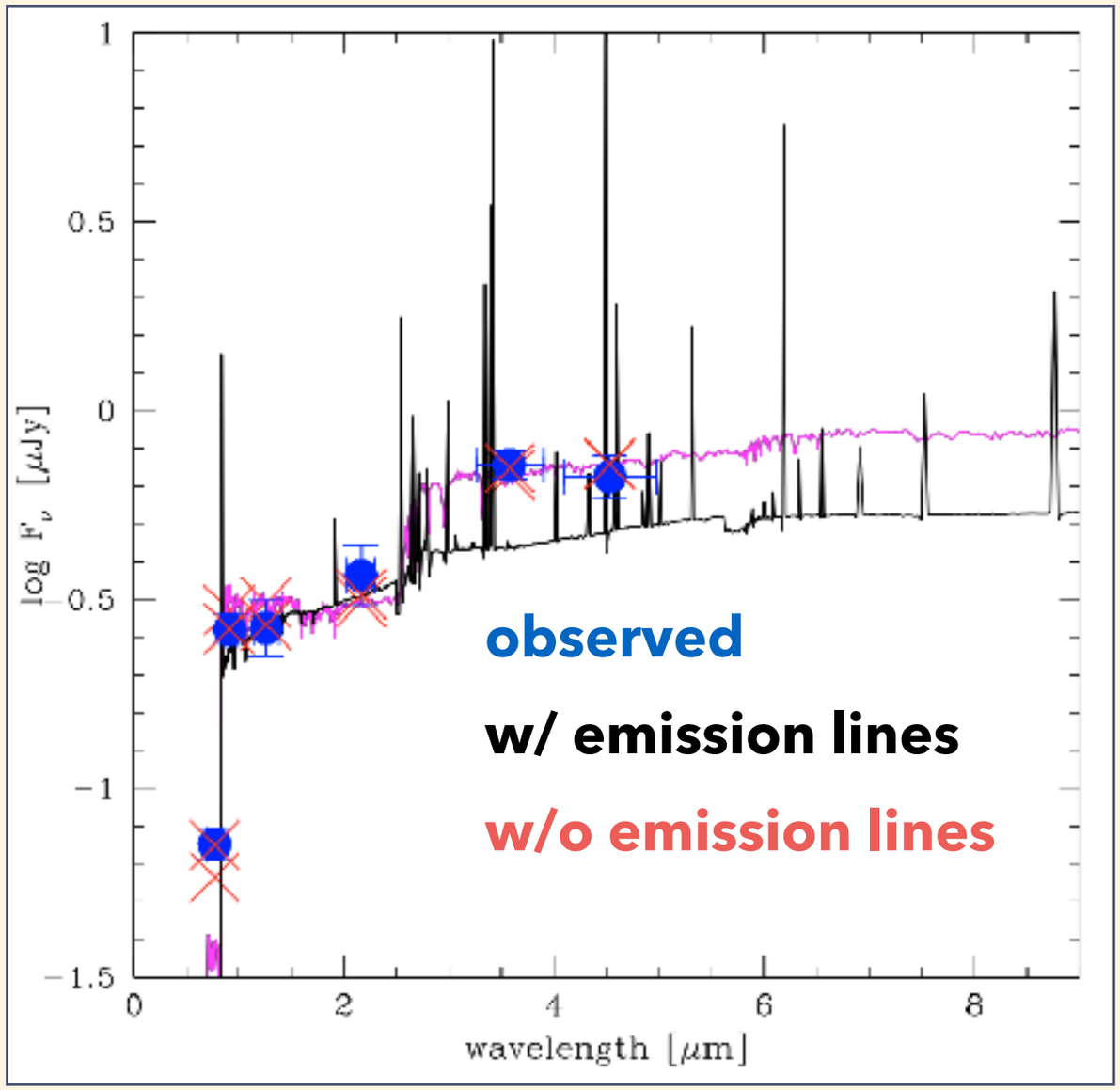
Electron density, n_e: [OII]3726/[OII]3729

Impact of emission lines on SED fitting

Strong emission lines affect the estimate of stellar populations

Older and more massive, if not included in the broad-band SED fitting

We know exact amount of emission line fluxes



Schaerer & de Barros (2009)

Impact of emission lines on SED fitting

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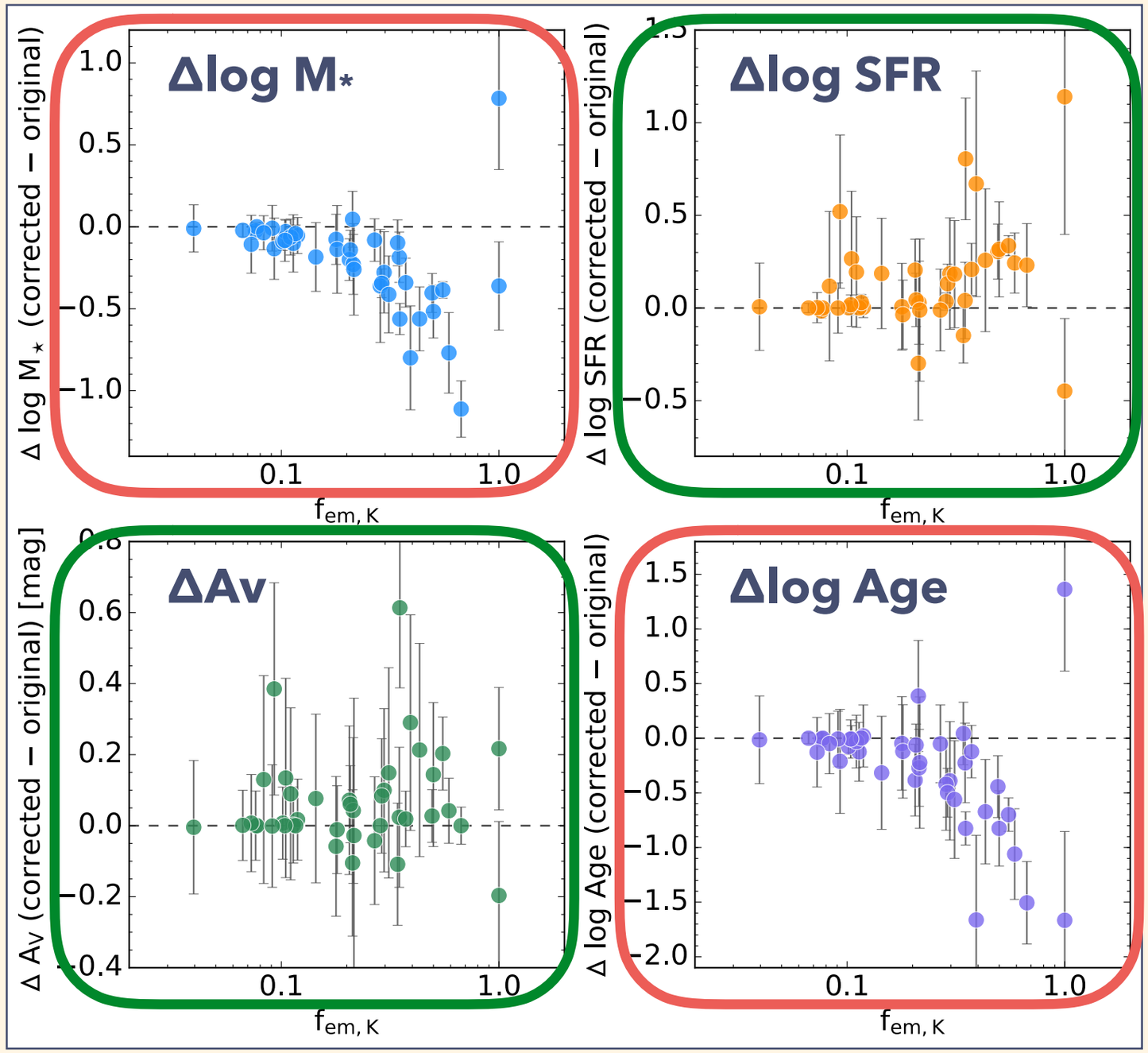
Larger changes in M* and age with increasing emission line contribution

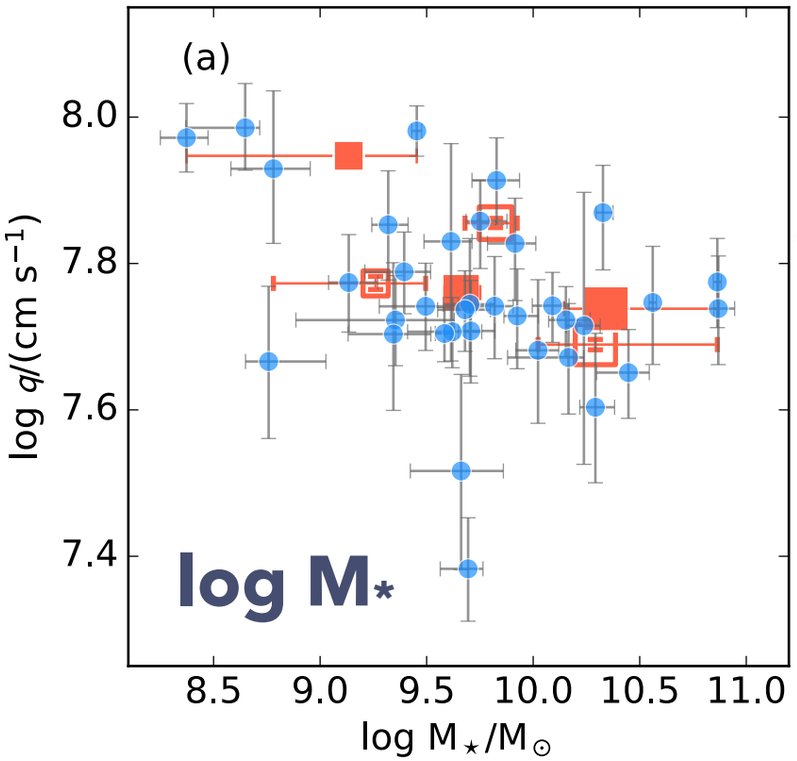
SFR and Av are less affected as they are mostly constrained by UV

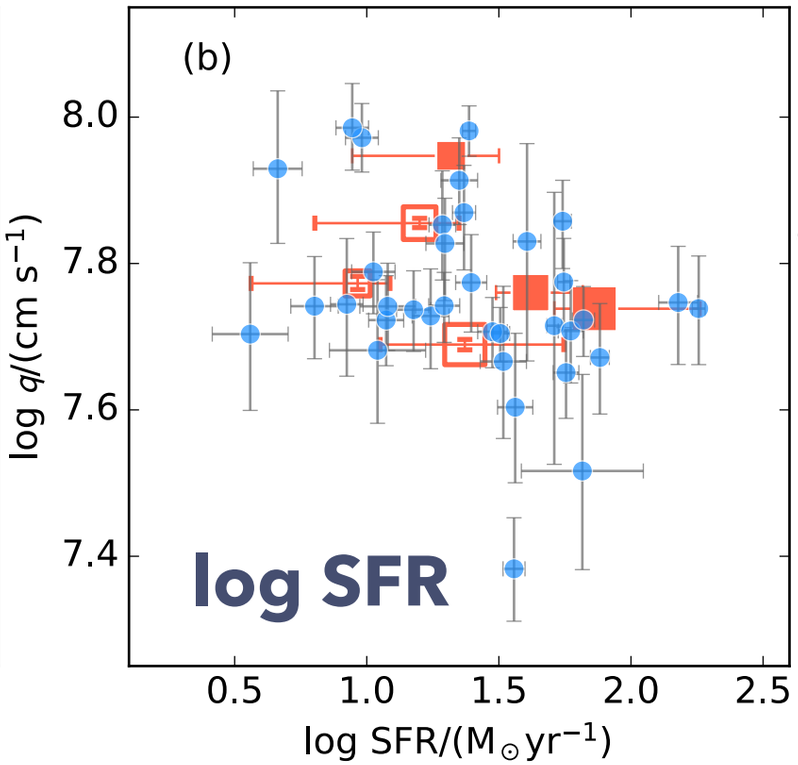


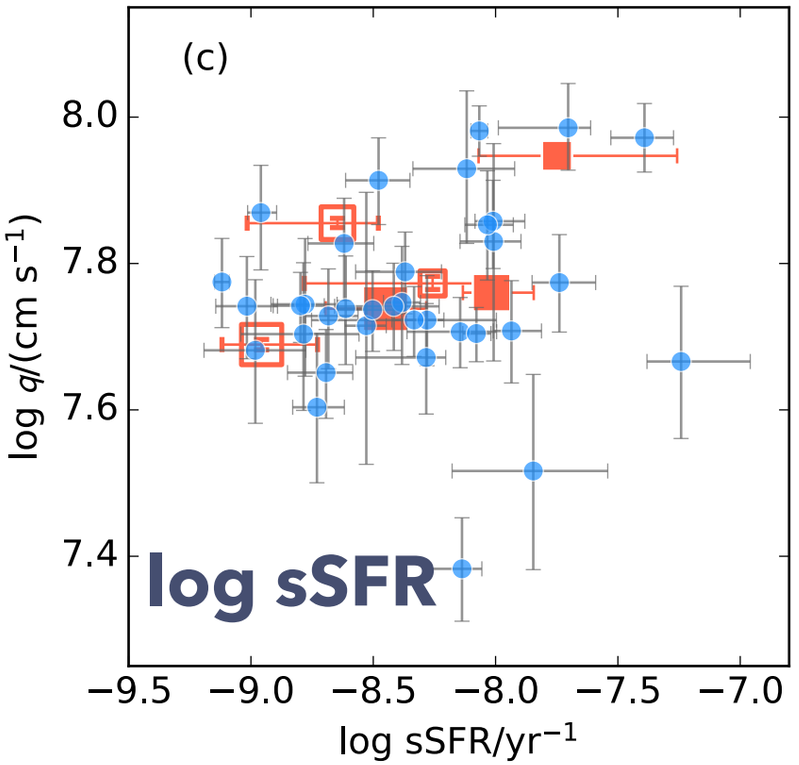
Fraction of Hβ and [OIII] flux in K-band flux

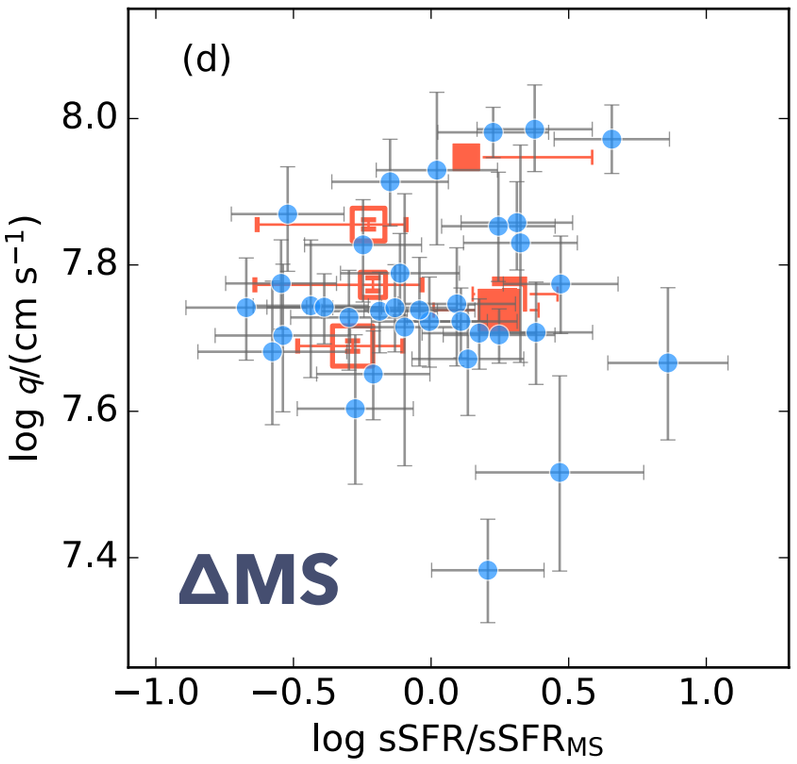
Ionization parameter

log Ionization parameter









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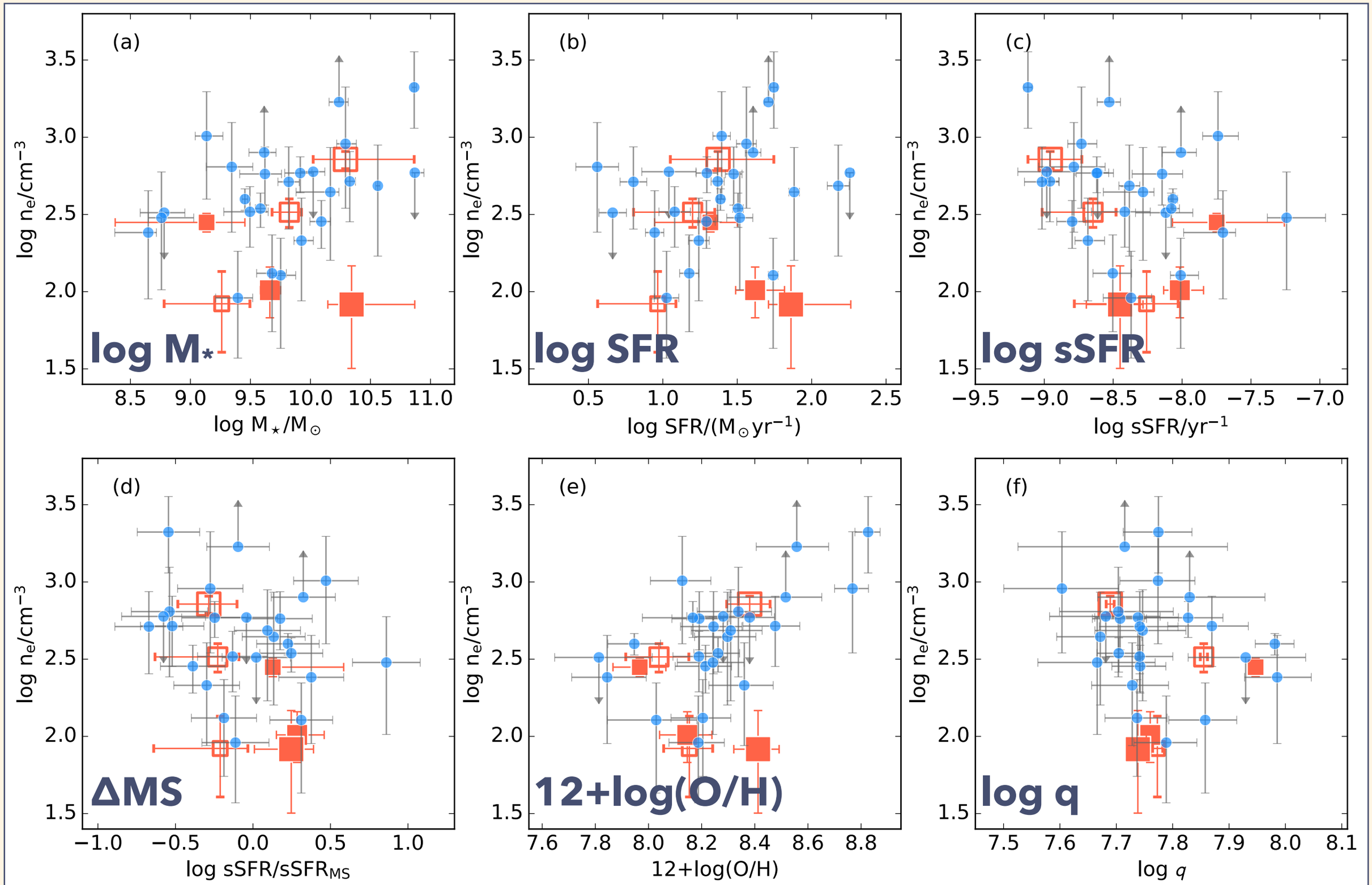
Electron density



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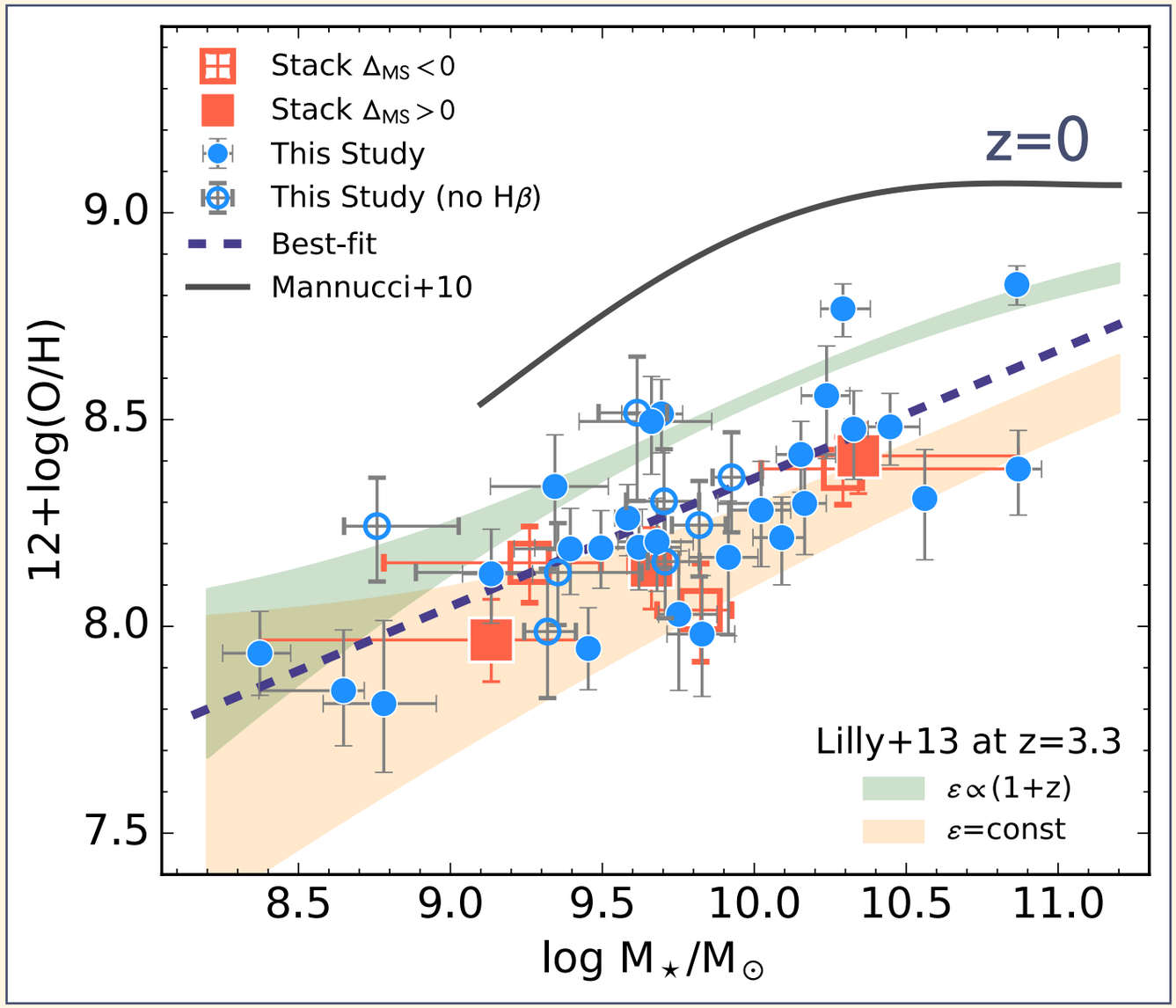
Mass-metallicity relation

~0.7 dex lower metallicity than the z=0 relation, ~0.3 dex compare to the z=2 relation

Lilly+13 model w/ and w/o evolution in gas consumption timescale $\tau_{gas}=1/\varepsilon=M_{gas}/SFR$ can enclose the z~3.3 MZR

No apparent dependence on SFR at a given stellar mass



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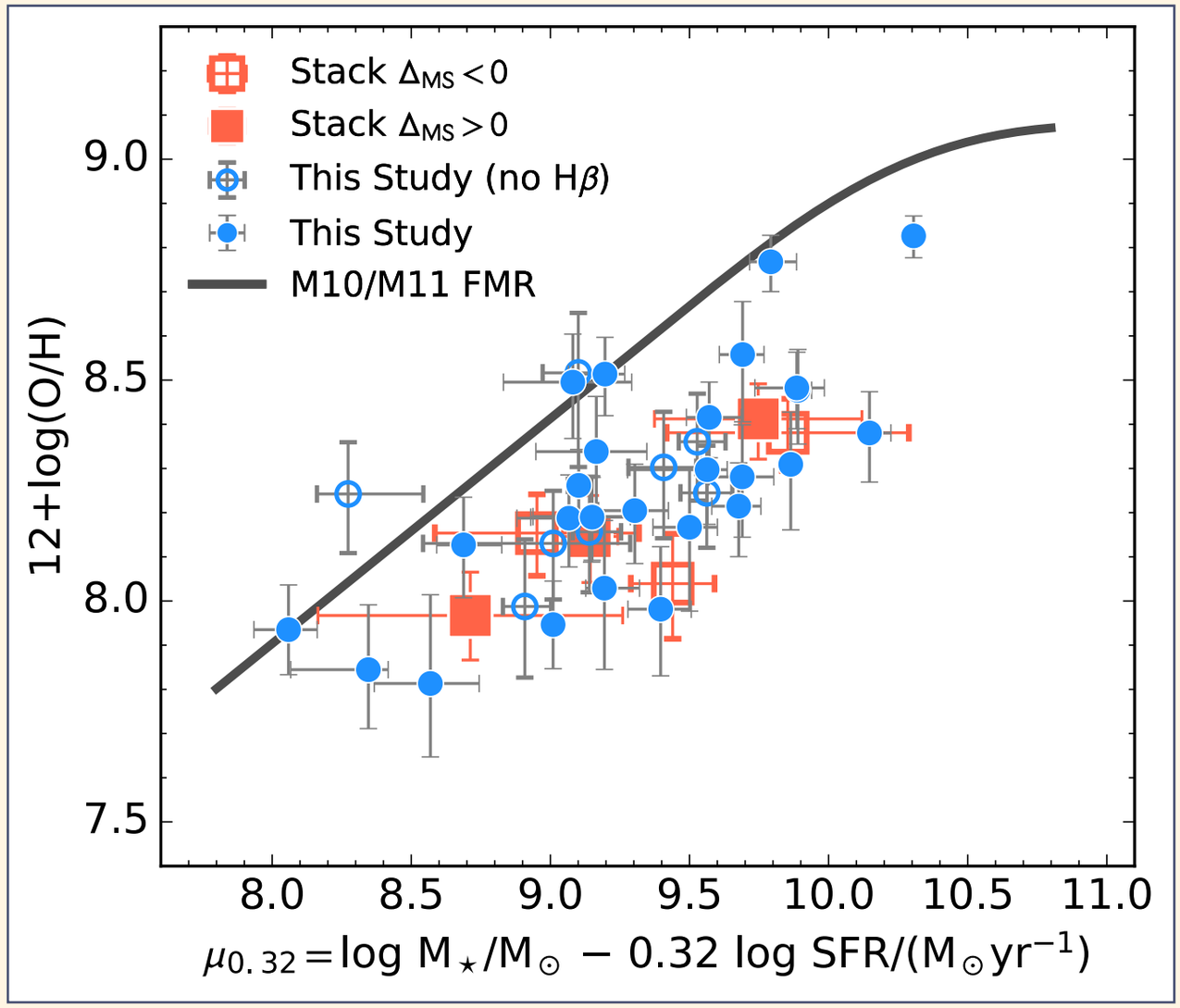
Mass-metallicity-SFR relation

A majority of z~3.3 galaxies does **not follow the FMR**, but shows **~0.3-0.5 dex offset** toward lower metallicity

But, no reduction of the scatter by the projection?



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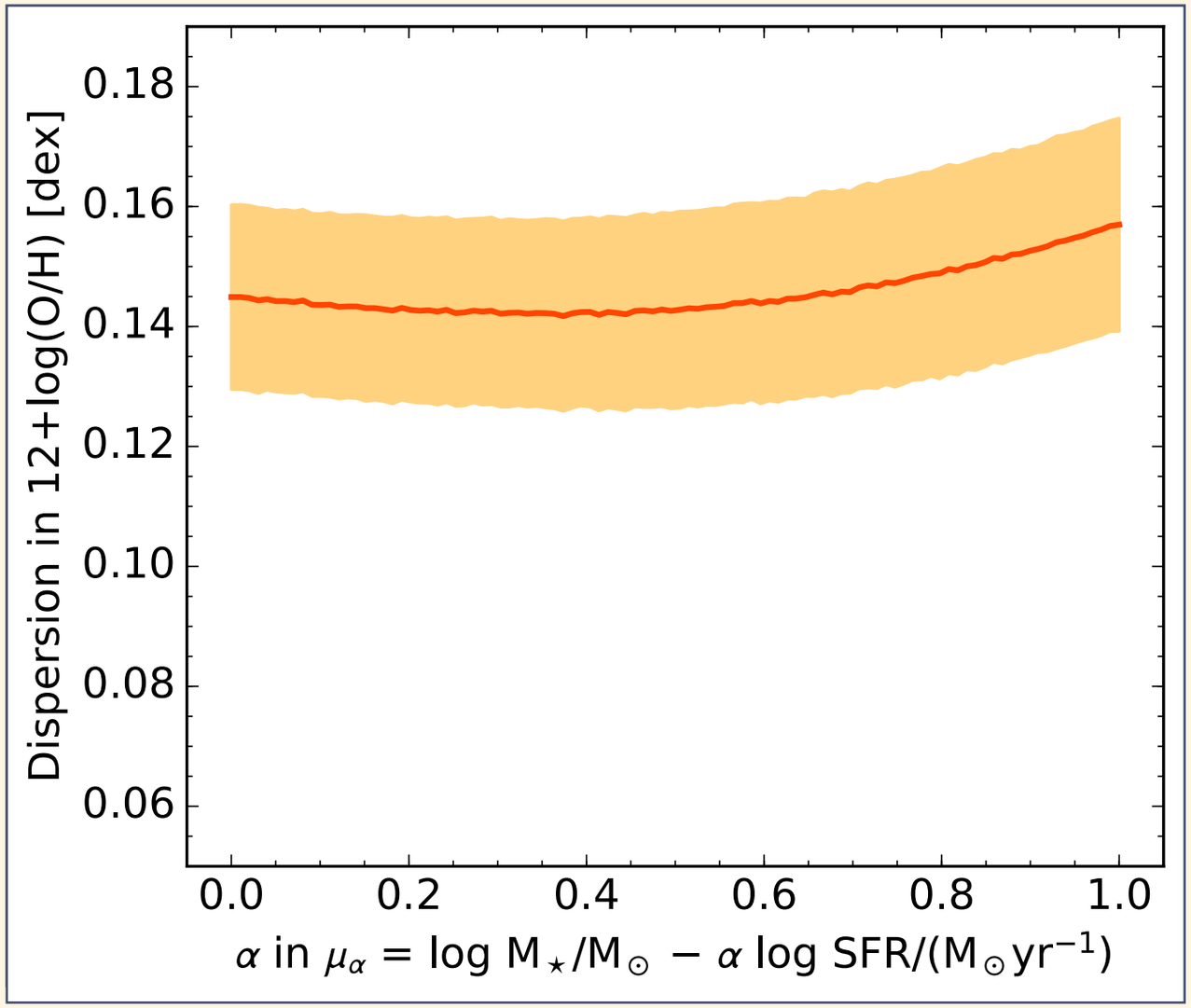
Less important role of SFR on MZR

No dependence on SFR in contrast to the local FMR or model predictions

No reduction of the scatter in any projections of Z(M, SFR)

This may be due to the small sample size and large errors in metallicity



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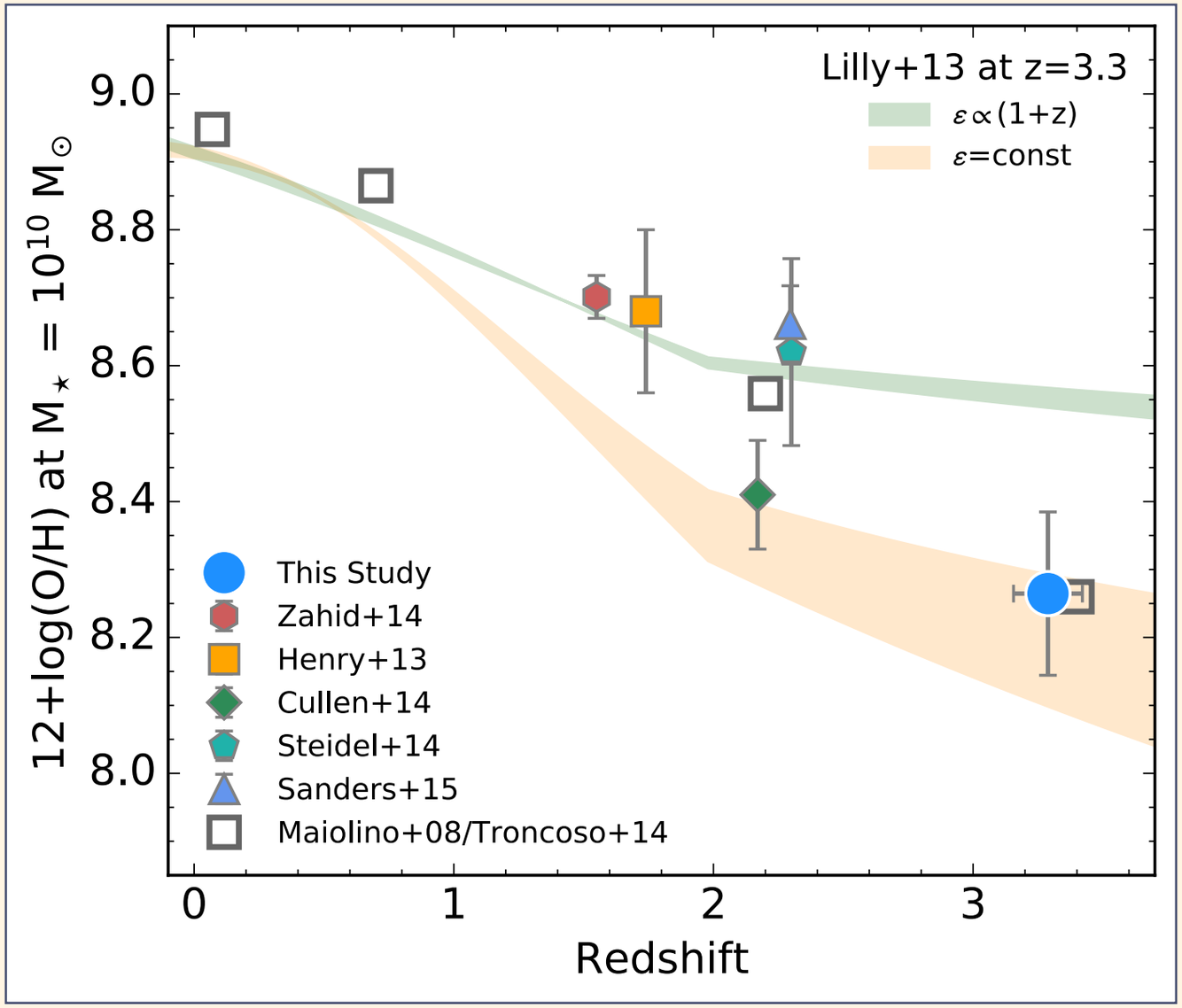
Redshift evolution of MZR

Strong evolution of SFE ε (inverse of τ_{gas}) fit well up to z~2

At z~3, a milder evolution of ε is preferred (cf. $\varepsilon \propto (1+z)^{0.34}$ by Genzel+15; talk by Groves; Schinnerer+16)

Nitrogen-related issues for N2 metallicities at 1<z<2 studies? (e.g., Yabe+15; Kashino+2016ab; Masters+2016)



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Summary

- We studied metallicity and ionization properties of normal star-forming galaxies and their relationship with stellar mass and SFR at z~3.3
- Emission line contribution has an important impact on SED fitting
- No correlation is found in either electron densities or ionization parameters with galaxies' global properties
- The M-Z relation shows ~0.7 dex offset from the z=0 one, and ~0.3 dex even since z~2
- SFR does not appear to play a significant role in MZR at z~3.3
- The MZR at z~3.3 and redshift evolution of MZR can be explained by the Lilly+13 model with a mild evolution of gas consumption timescale toward high redshift