Physical condition and oxygen abundance of ionized gas in star-forming galaxies at z~3.3

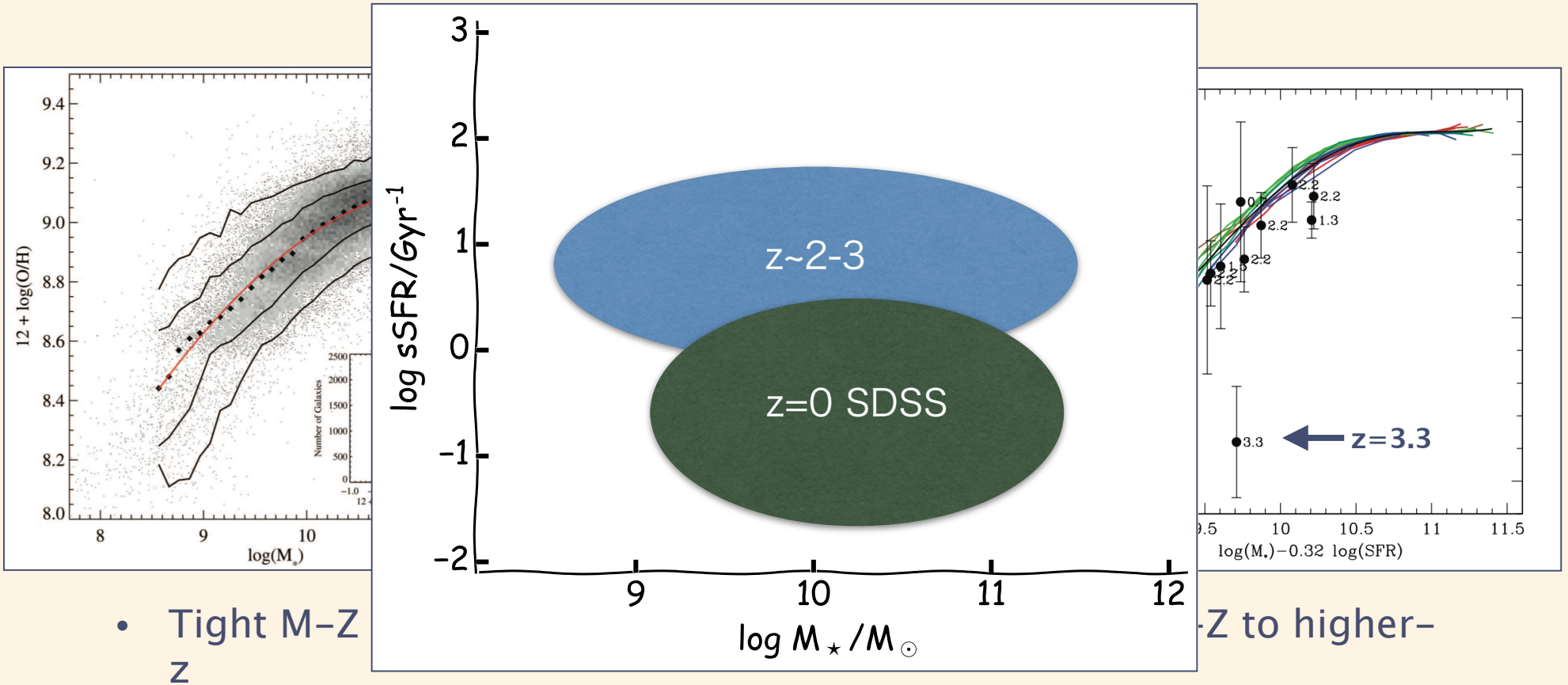
Masato Onodera

ETH zürich → Subaru Telescope from March 2016

Marcella Carollo, Simon Lilly, Sandro Tacchella (ETH Zurich),
Alvio Renzini (INAF-Padova), Nobuo Arimoto (Subaru Telescope),
Peter Capak, Nick Scoville (Caltech), Emanuele Daddi (CEA/Saclay),
Sumire Tatehora (GUAS), Gianni Zamorani (INAF-Bologna)

Onodera et al. (submitted)

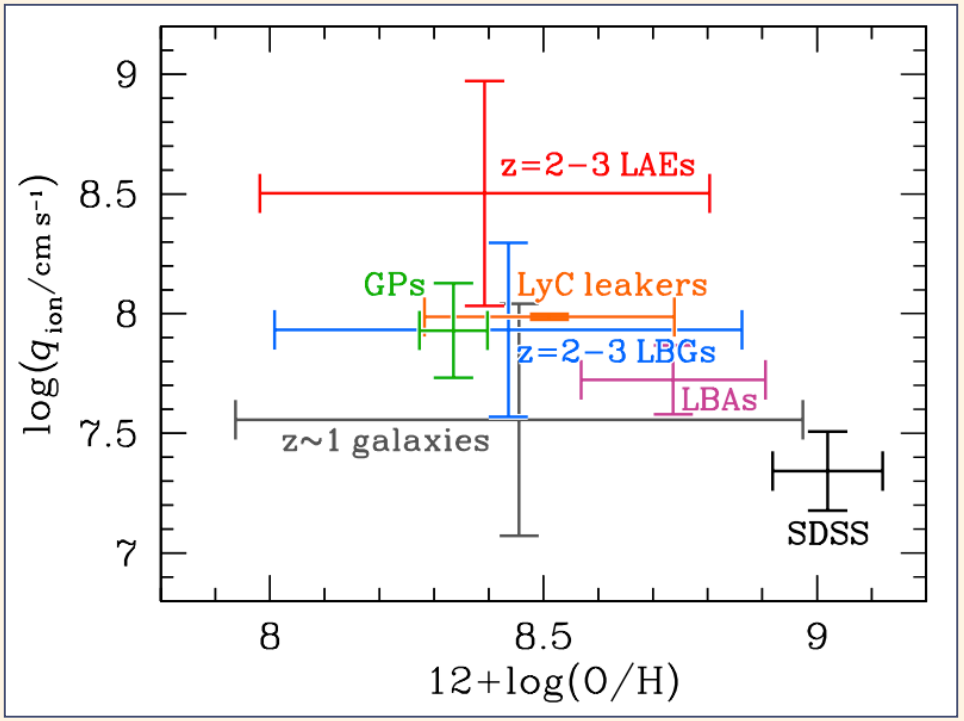
Z(M,SFR) relation from z=0 to high-z

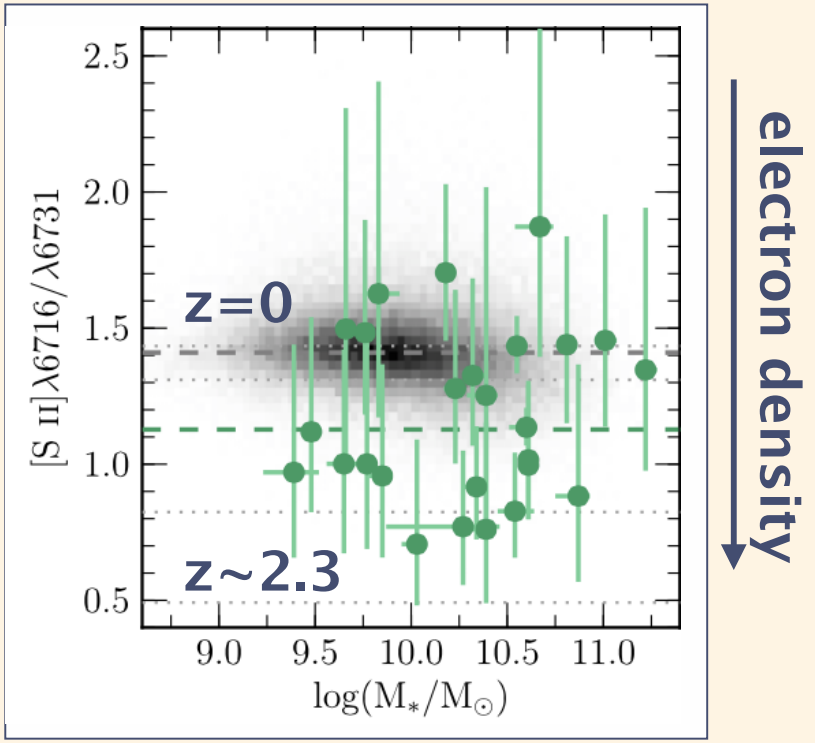


- Tight M-Z -Z to higher-z
- SFR is a second parameter of MZR at z=0
- Z(M,SFR) is claimed to be z-independent to z~2, but deviate at z>3
- However, simple extrapolation of the surface at z=0 to high-z is dangerous

Tremonti+2004; Mannucci +2010

ISM conditions





Higher ionization parameters at higher redshift star-forming galaxies

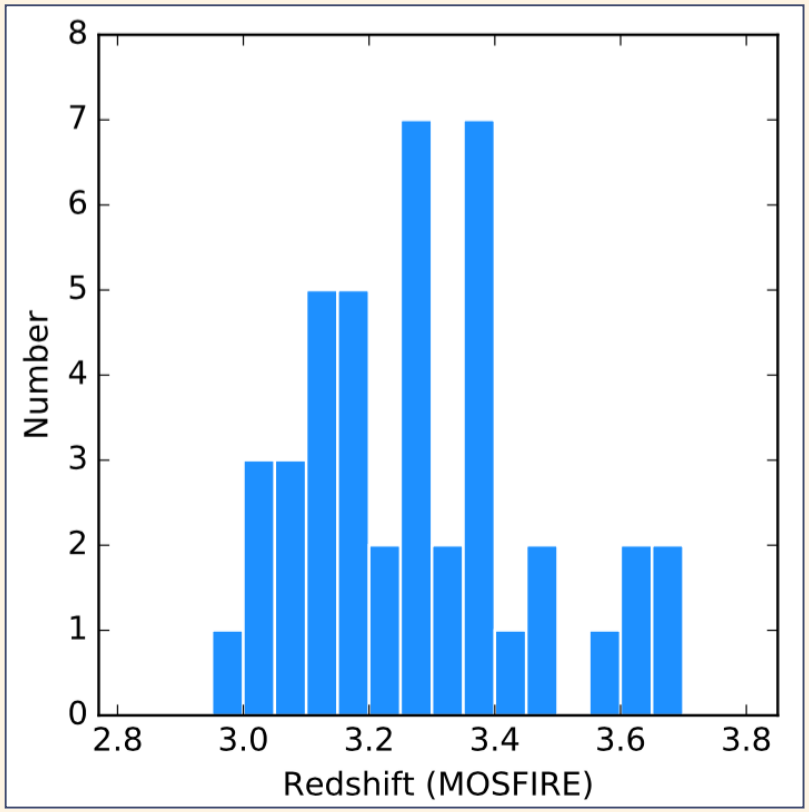
Higher electron density (~10x) at z~2.3 than z~0

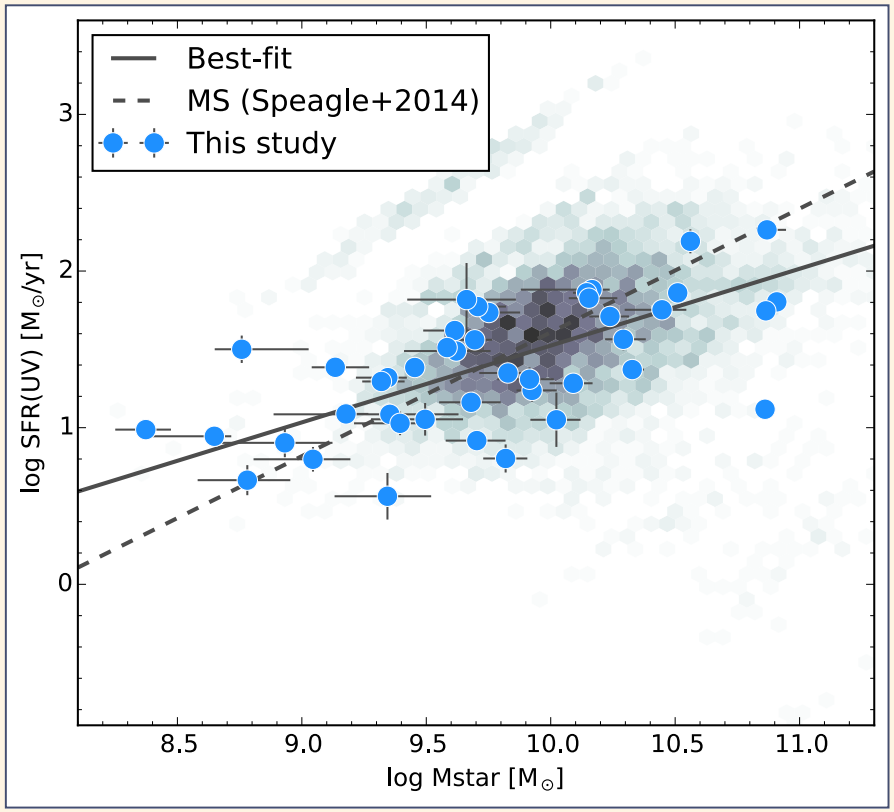
Nakajima & Ouchi (2013); Sanders+2016

Questions to be addressed

- What are the properties of ionized gas in 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**

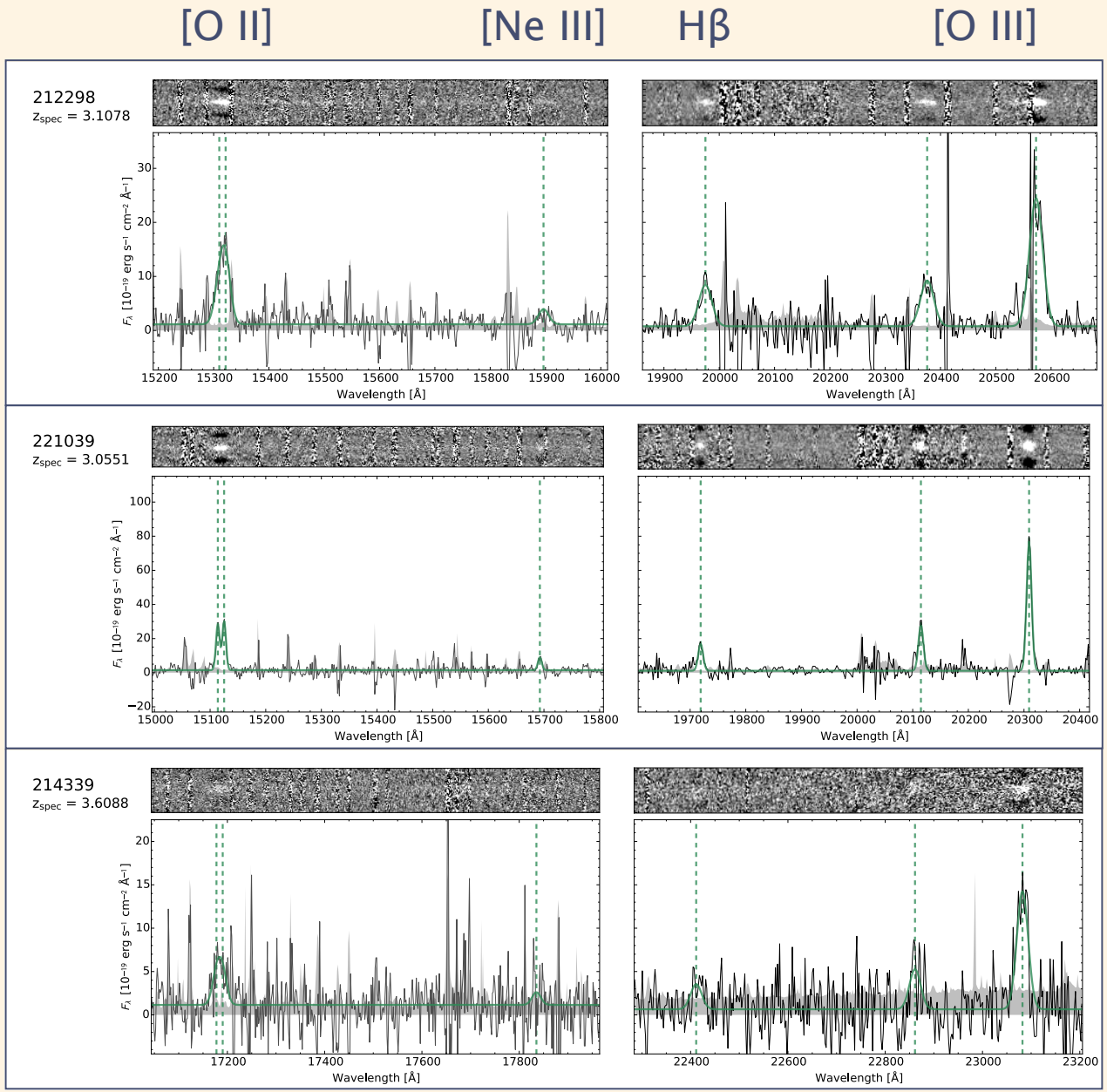
Primary sample: **zCOSMOS-Deep** with robust spectroscopic redshifts

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

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



Measurements

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

SFR: extinction corrected rest-frame UV luminosity

12+log(O/H): R_{23}, [OIII]/Hβ, [OIII]/[OII], [OII]/Hβ, and [NeIII]/[OIII] (Maiolino+13)

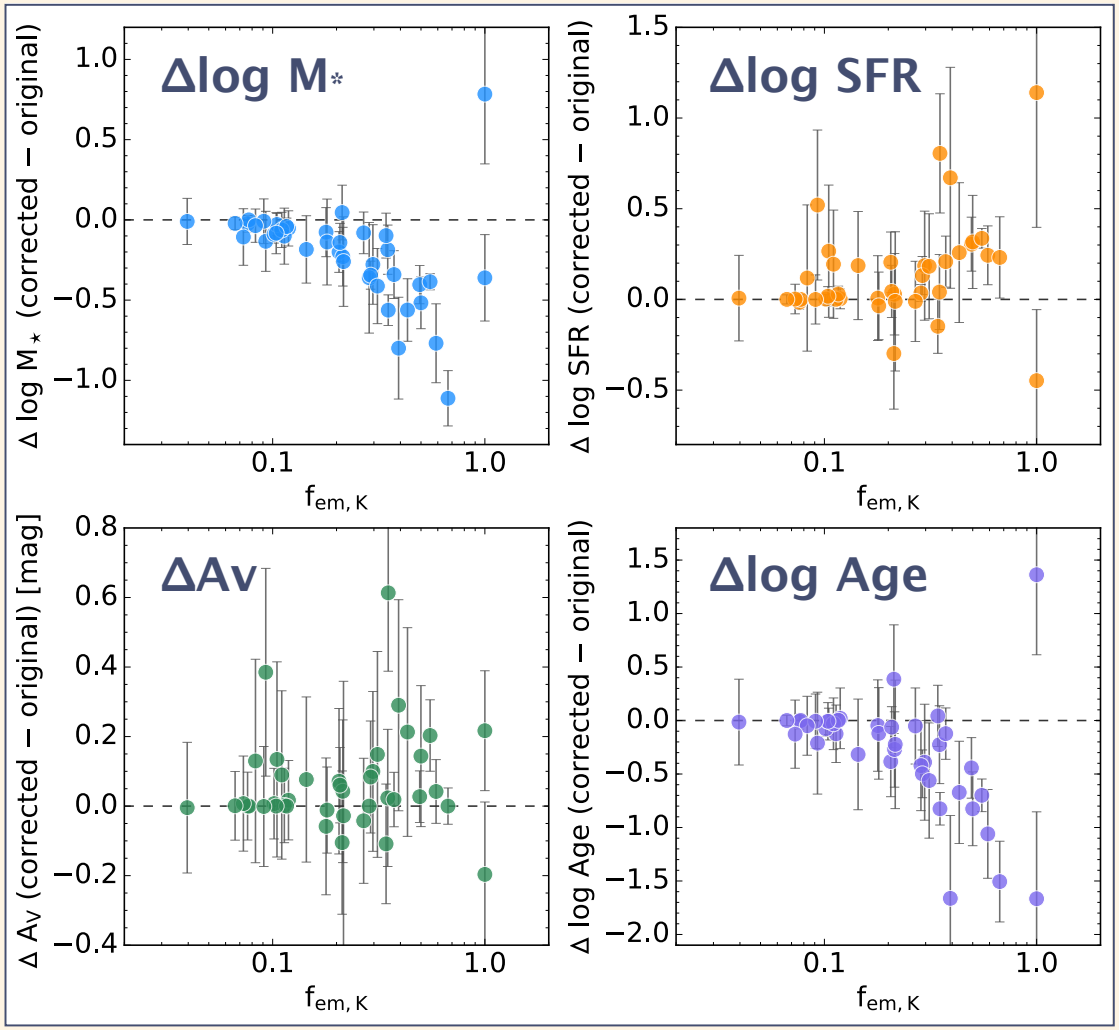
Ionization parameter, q: [OIII]/[OII] (Kobulnicky & Kewley 2004)

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

Impact of emission lines on SED fitting

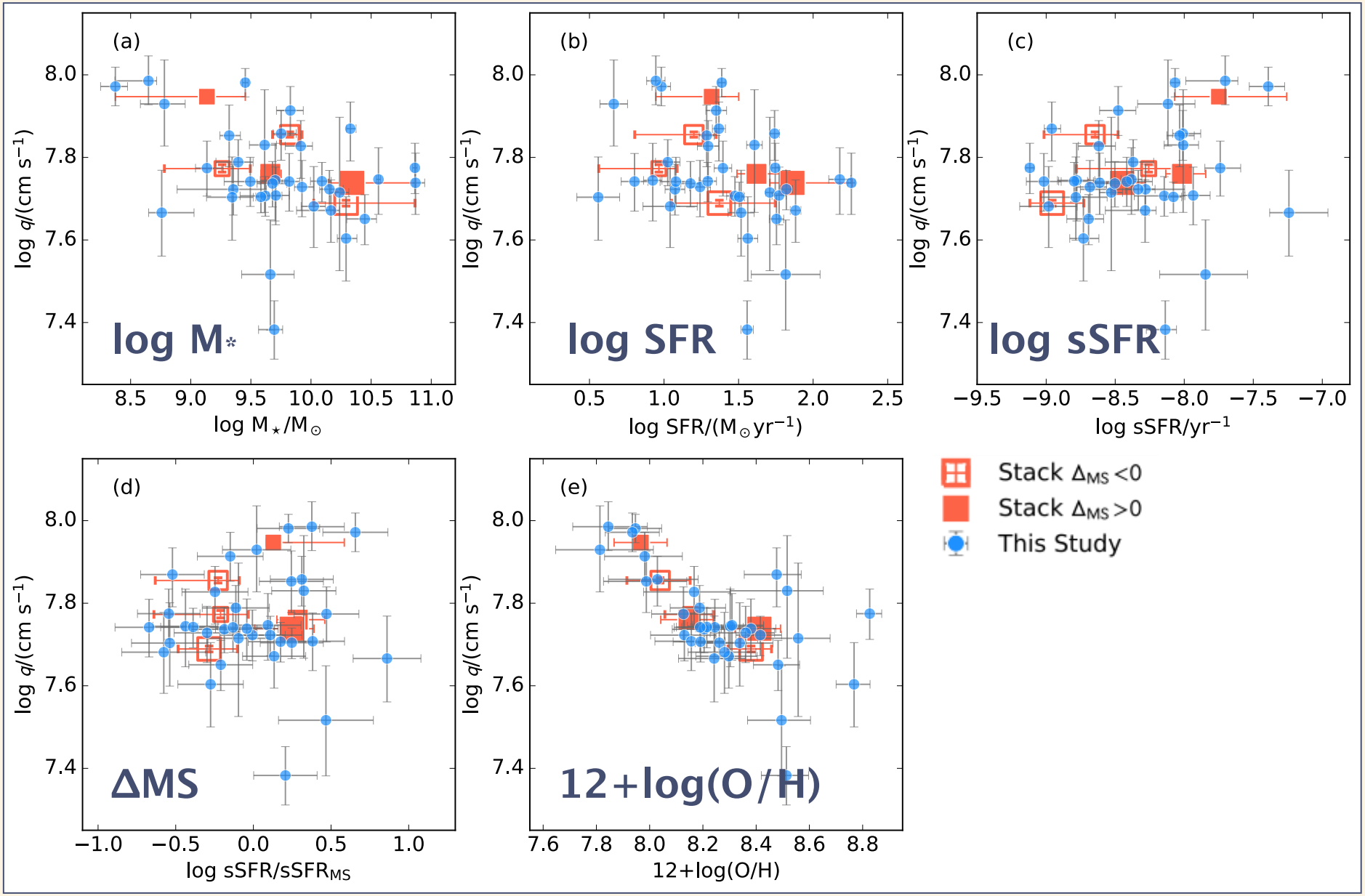
Larger change in M* and age with increasing emission line contribution

SFR and Av are less affected

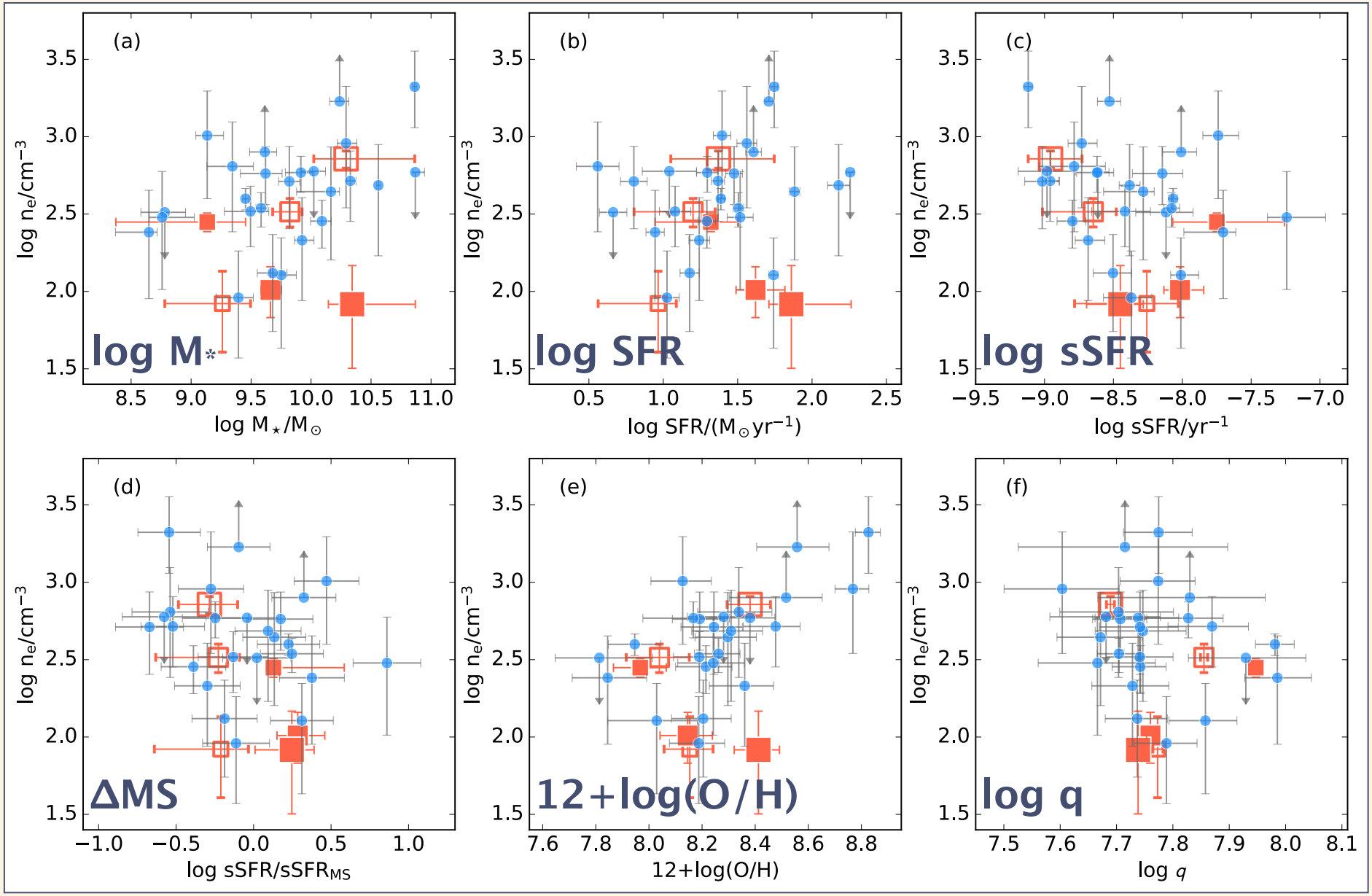


Fraction of Hβ and [OIII] flux in K-band flux

Ionization parameter

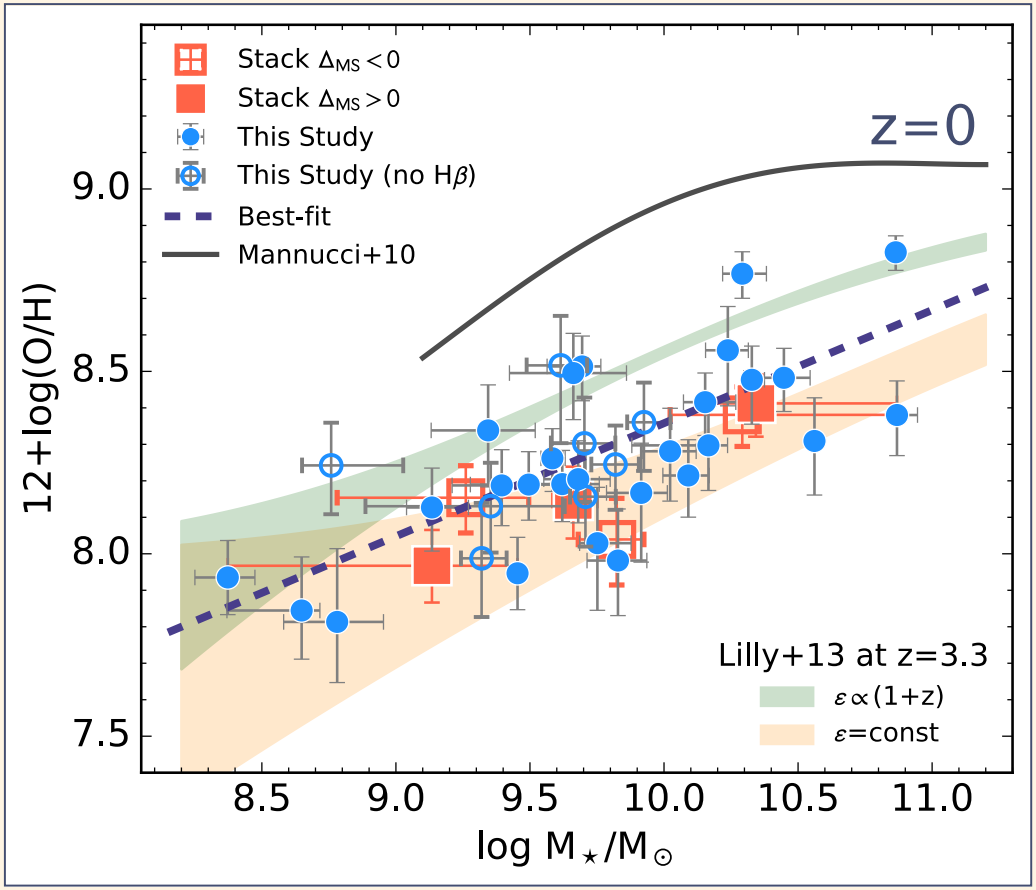


Electron density



Mass-metallicity relation

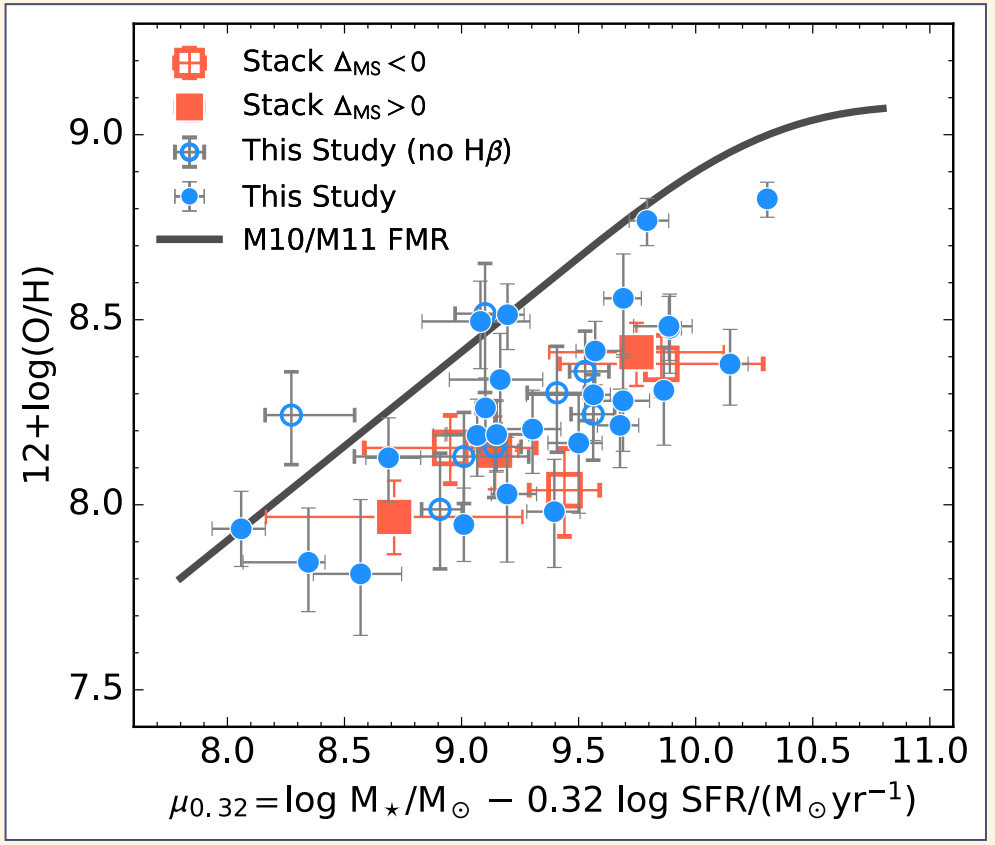
- ~0.7 dex lower metallicity than the z=0 relation, ~0.3 dex compare to the z=2 relation
- No apparent dependence on SFR at a given stellar mass
- Lilly+13 model w/ and w/o evolution in gas consumption timescale $\tau_{gas}=1/\varepsilon=M_{gas}/SFR$ can enclose the z~3.3 MZR



Mass–metallicity–SFR relation

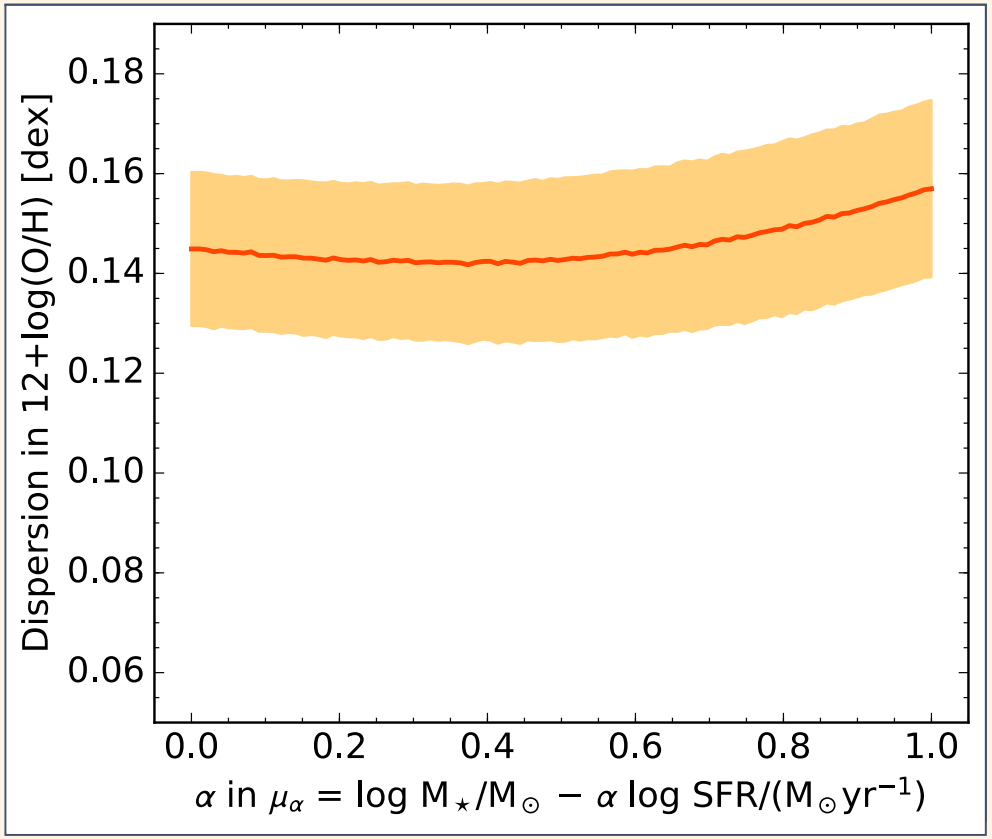
A majority of z~3.3 galaxies does **not follow the FMR**, but shows **~0.3–0.5 dex offset** toward lower metallicity

No reduction of the scatter by the projection?



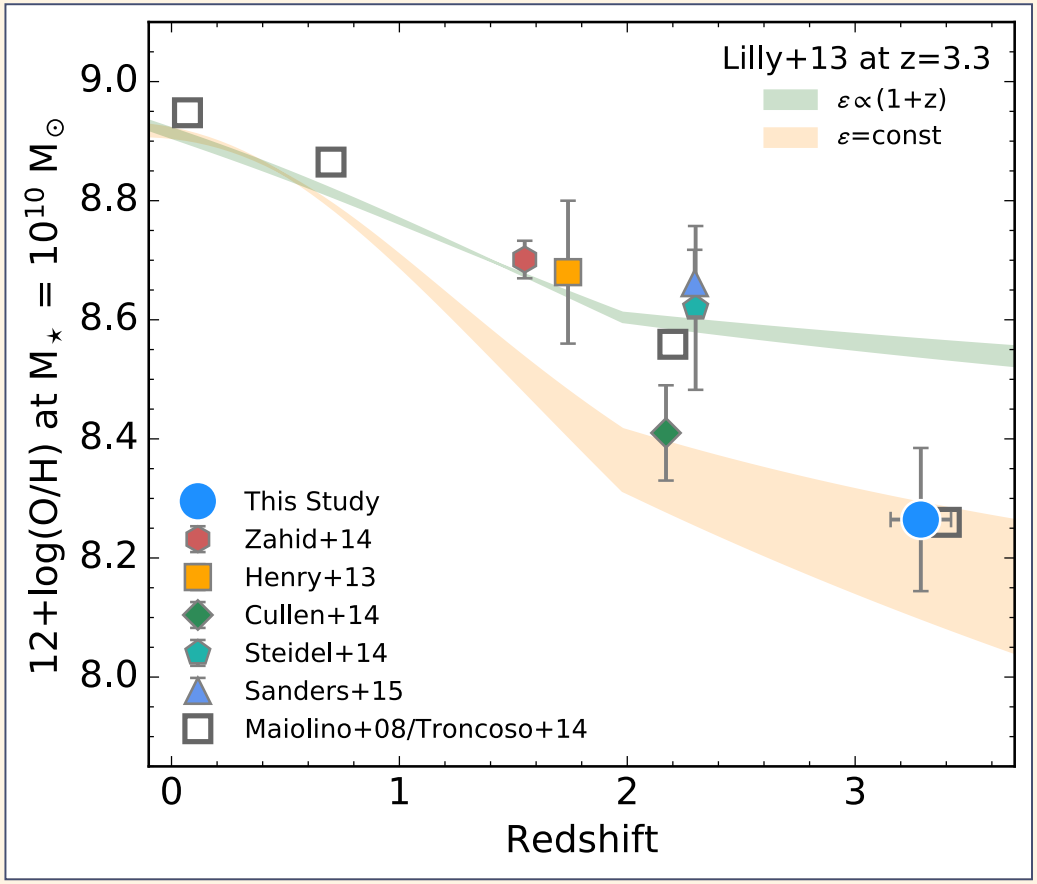
Less important role of SFR on MZR

- 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



Redshift evolution of MZR

- Strong evolution of gas consumption timescale ε 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)
- N/O enhancement issue for N2 metallicities at 1<z<2 studies? (e.g., Yabe+15)

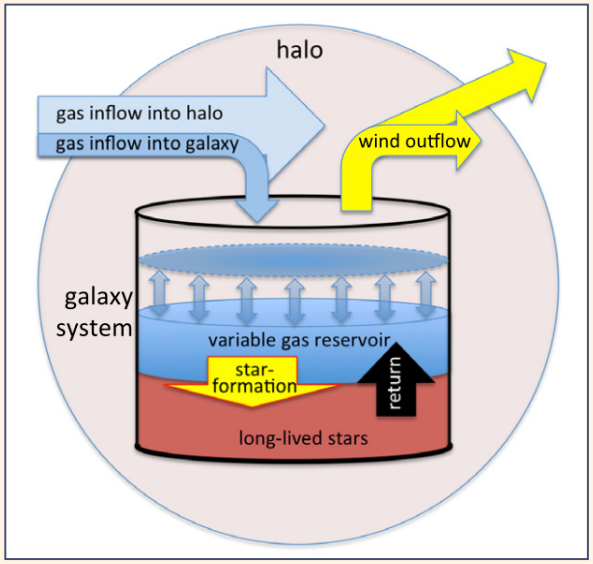


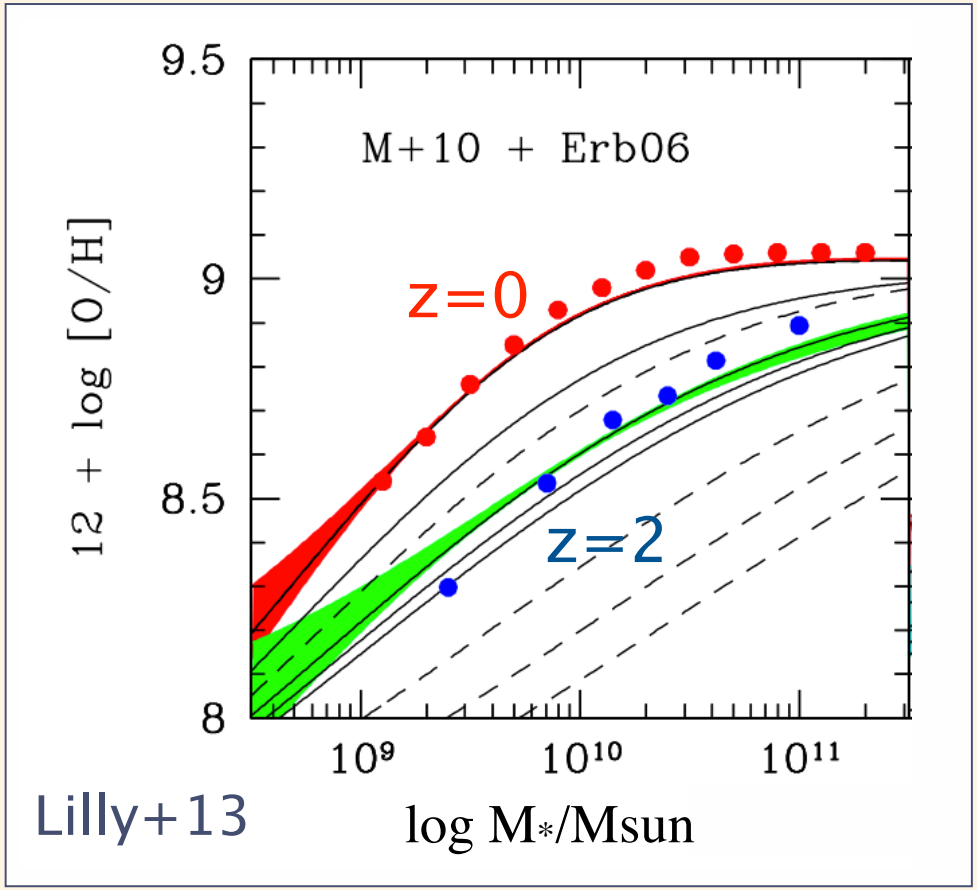
Summary

- We studied metallicity and ionization conditions 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

Gas regulation model

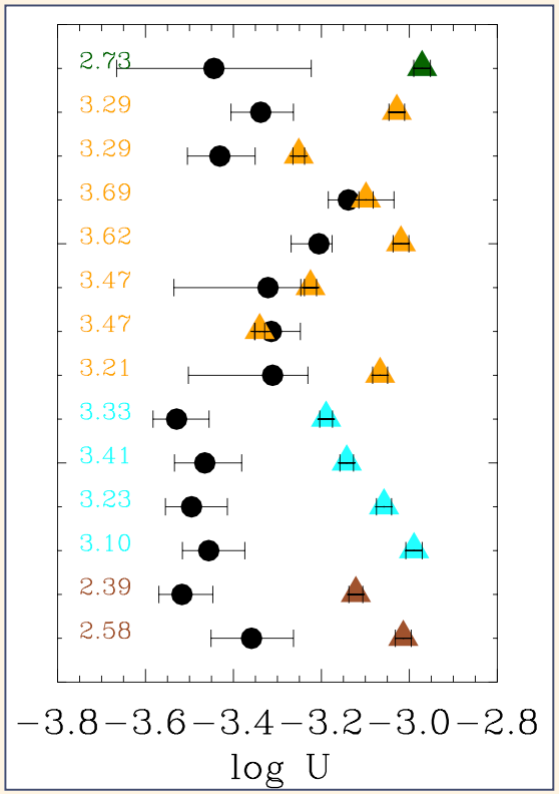
- Parameters (SFE, mass-loading factor, yield, etc.) of resulting Z(M,SFR) calibrated at z=0 appear reasonable
- Successful at least to z~2

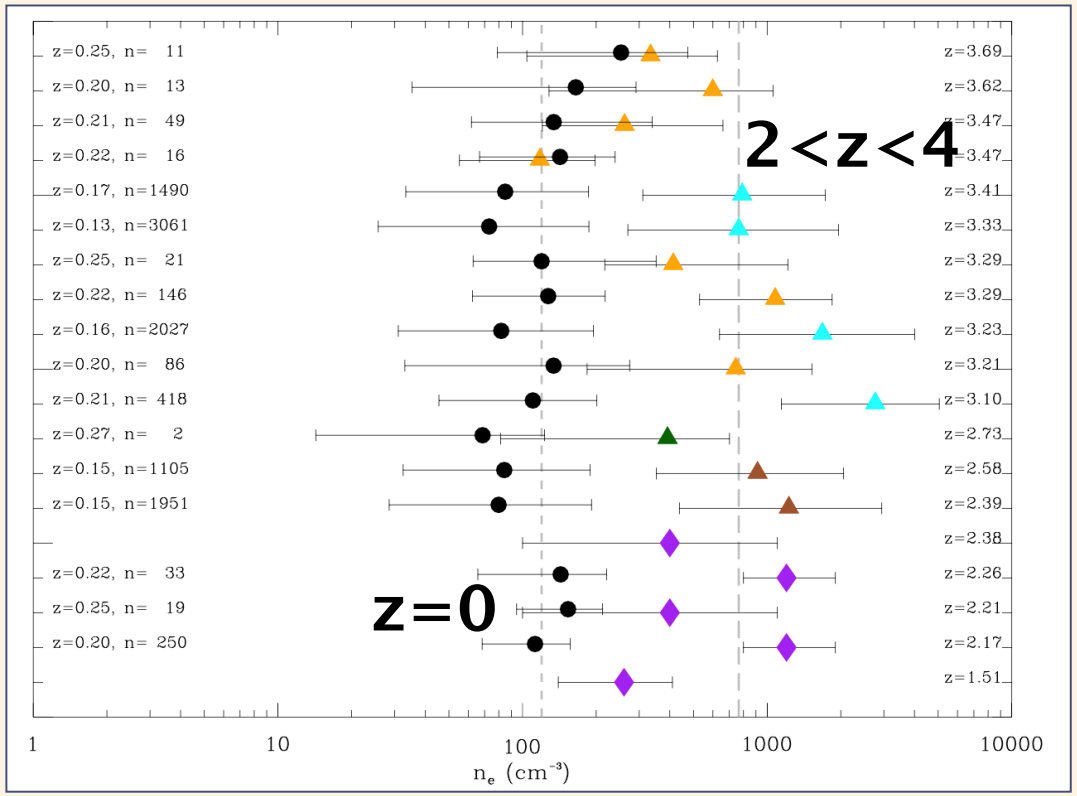




ISM condition

- Higher ionizing parameters at higher redshift
- Denser environment of star formation

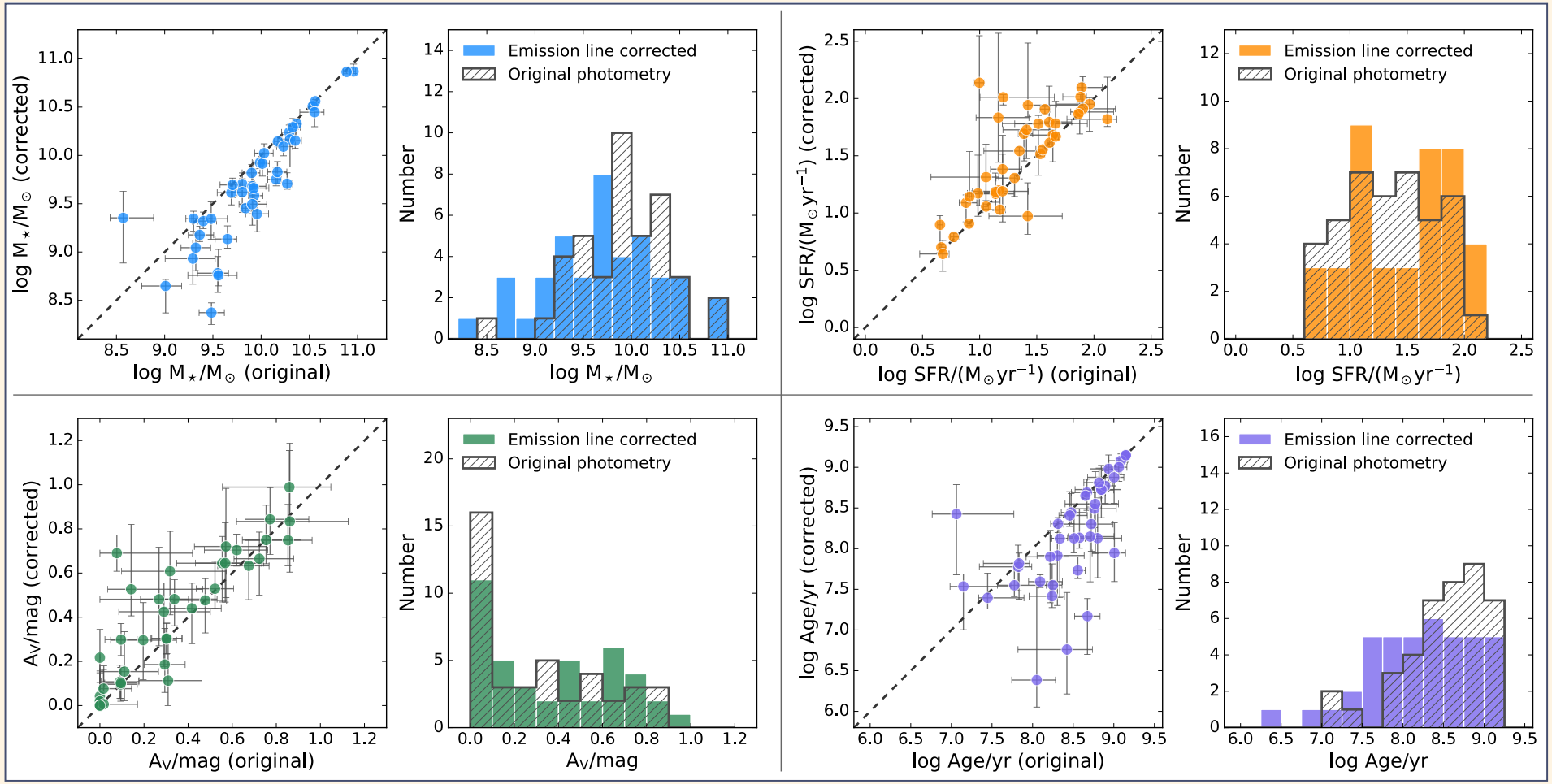


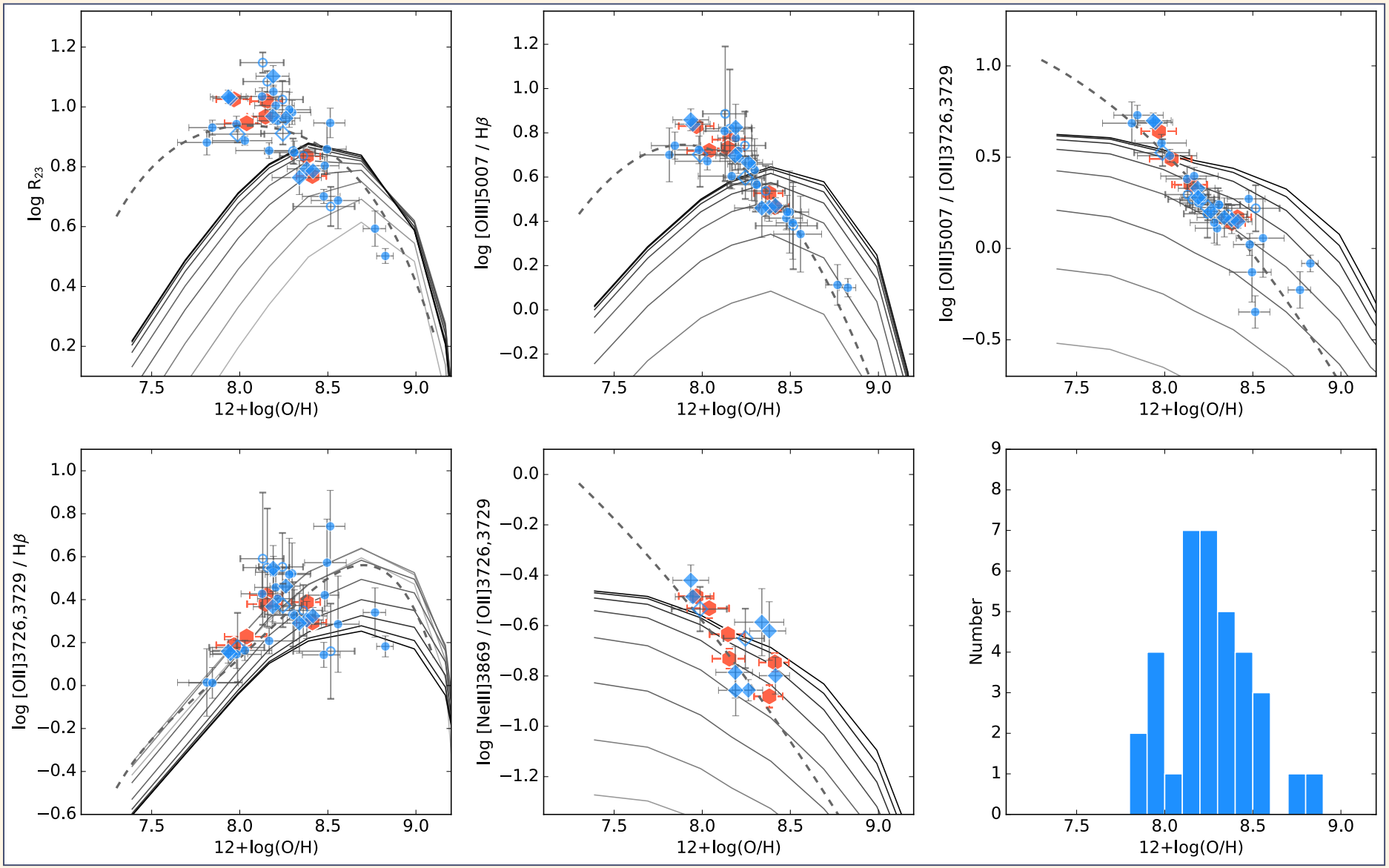


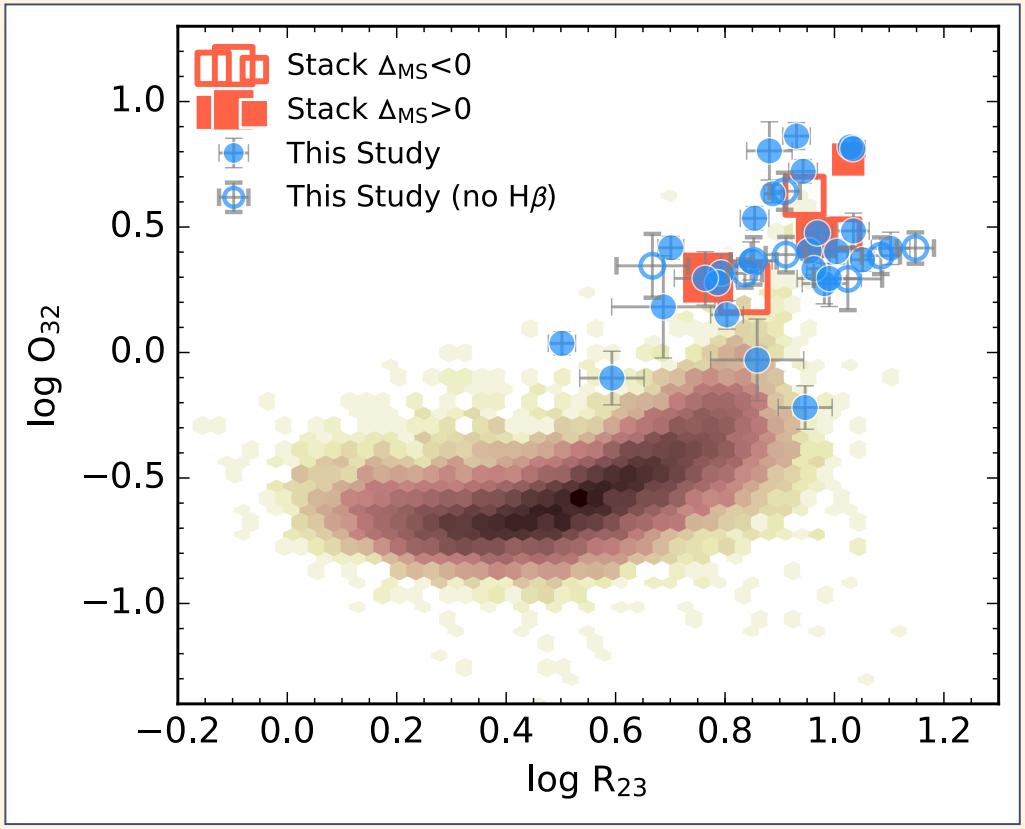
Matched in SFR and stellar mass

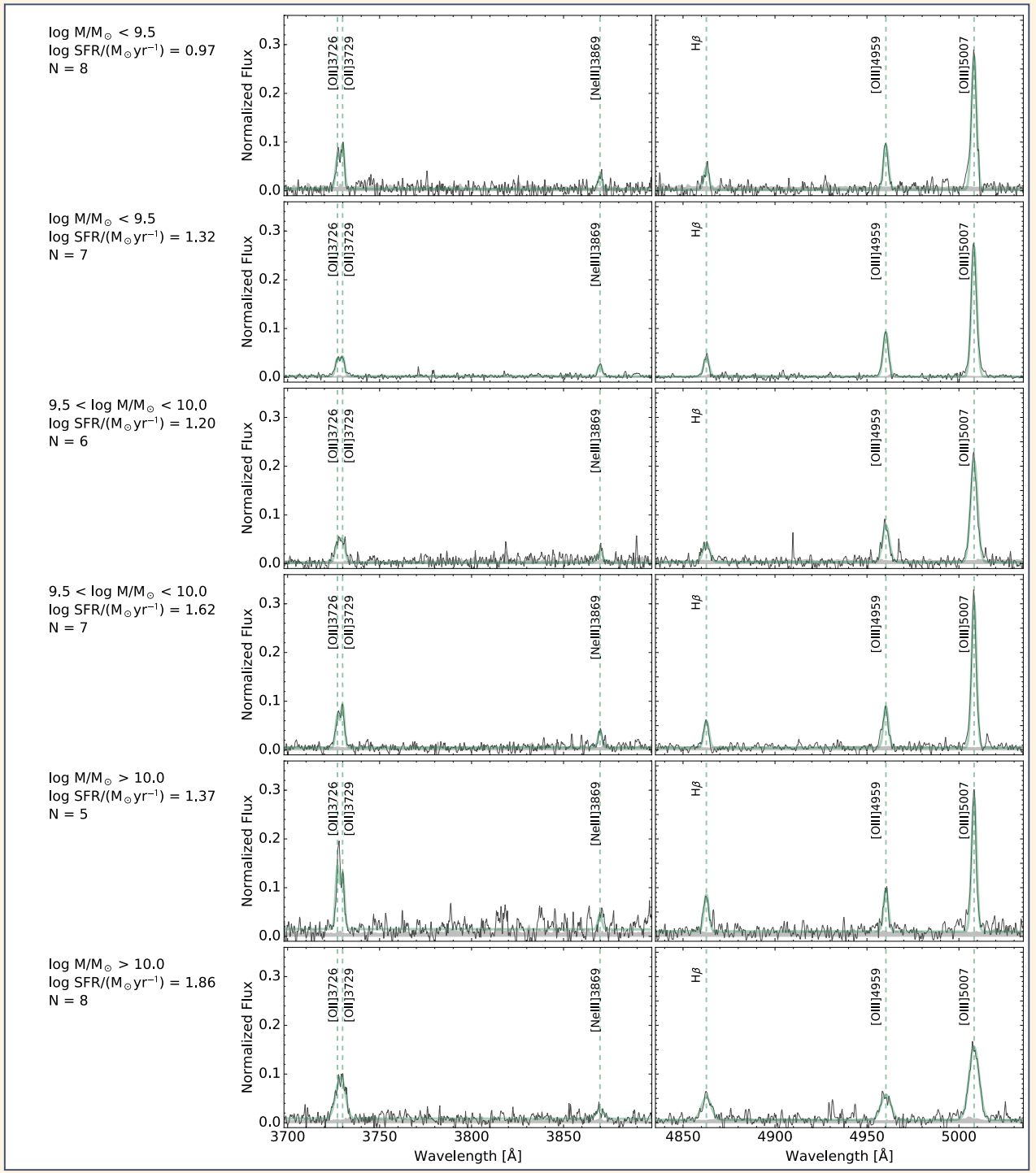
Shirazi+14

Impact of emission lines on SED fitting




log R23
12+log(O/H)
log [OIII]5007 / Hβ
log [OII]3726,3729 / Hβ
log [NeIII]3869 / [OII]3726,3729
Number


Stack Δ_{MS}<0
Stack Δ_{MS}>0
This Study
This Study (no Hβ)
log O_{32}
log R_{23}
1.0
0.5
0.0
−0.5
−1.0
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2


log M/M⊙ < 9.5
log SFR/(M⊙yr⁻¹) = 0.97
N = 8
log M/M⊙ < 9.5
log SFR/(M⊙yr⁻¹) = 1.32
N = 7
9.5 < log M/M⊙ < 10.0
log SFR/(M⊙yr⁻¹) = 1.20
N = 6
9.5 < log M/M⊙ < 10.0
log SFR/(M⊙yr⁻¹) = 1.62
N = 7
log M/M⊙ > 10.0
log SFR/(M⊙yr⁻¹) = 1.37
N = 5
log M/M⊙ > 10.0
log SFR/(M⊙yr⁻¹) = 1.86
N = 8
Normalized Flux
[OII]3726
[OII]3729
[NeIII]3869
Hβ
[OIII]4959
[OIII]5007
Wavelength [Å]