The cosmic evolution of metallicity and abundance gradients

open problems

100%
BPT-free talk

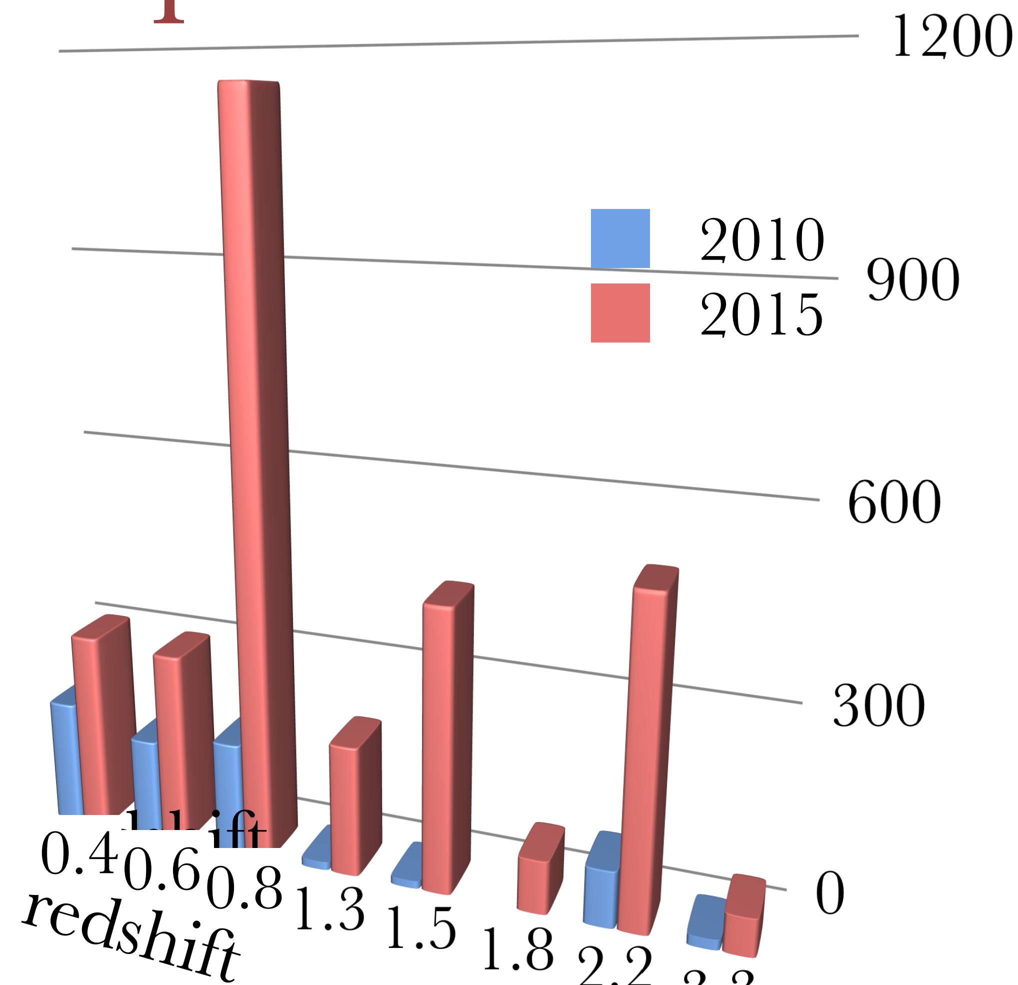
F. Mannucci

G. Cresci, R. Maiolino, A. Marconi, M. Curti, M. Perna,
G. Venturi, S. Carniani, F. Belfiore, et al.

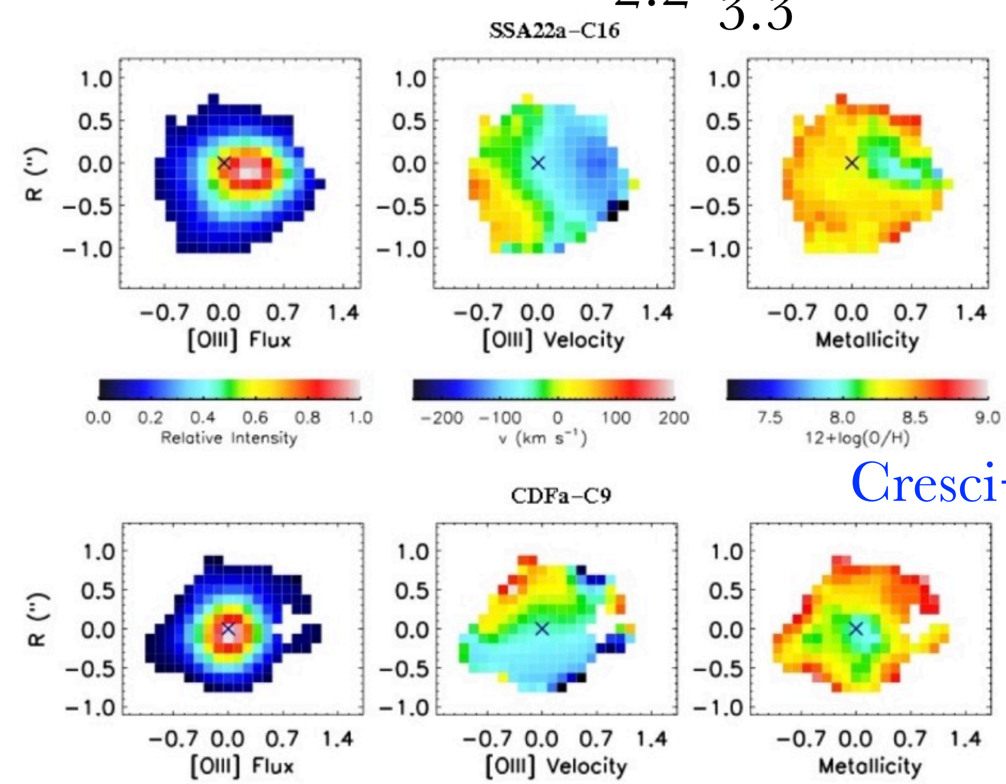
INAF - Arcetri

A new landscape

- Number of high-redshift galaxies with good rest-frame optical spectroscopic data is rapidly increasing:
  - Keck/MOSFIRE
  - Subaru/FMOS
  - LBT/LUCI



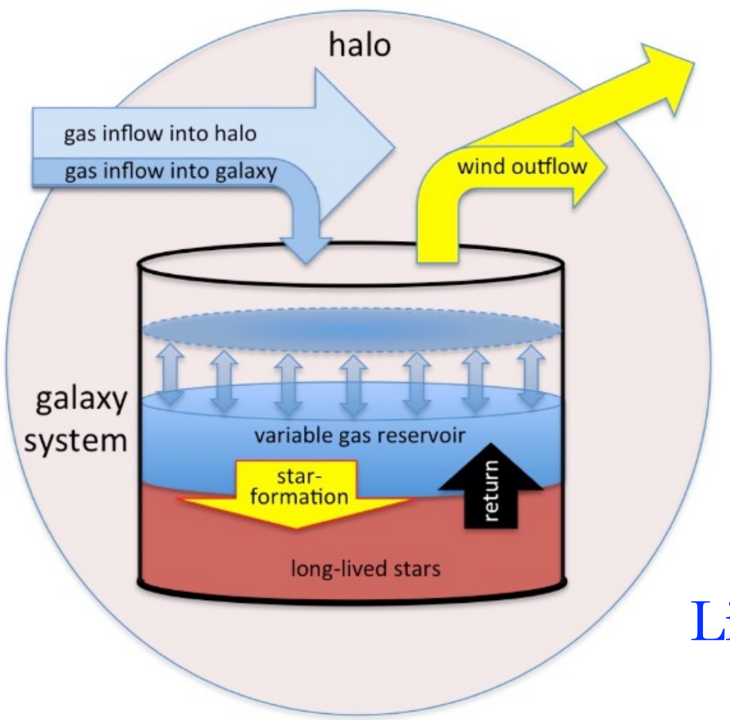
- A significant number of galaxies have spatially resolved spectroscopy:
  - VLT/KMOS
  - VLT/SINFONI
  - Keck/OSIRIS



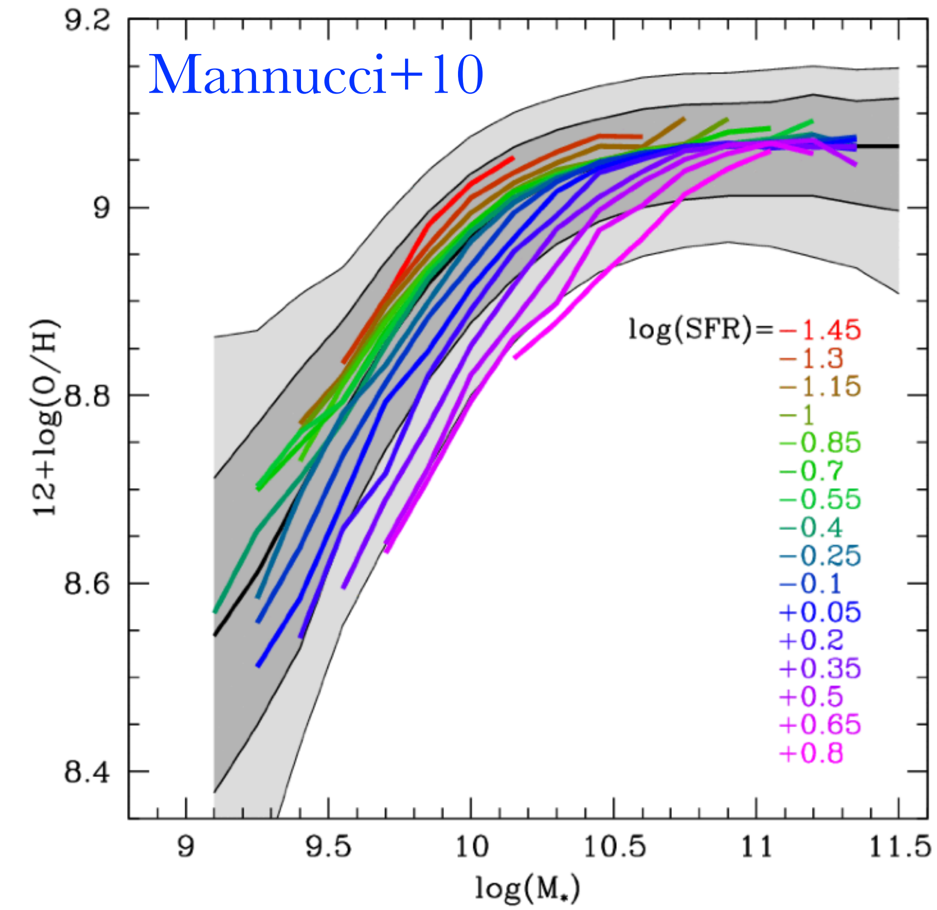
Cresci+10

New models

analytic equilibrium models



Lilly+13



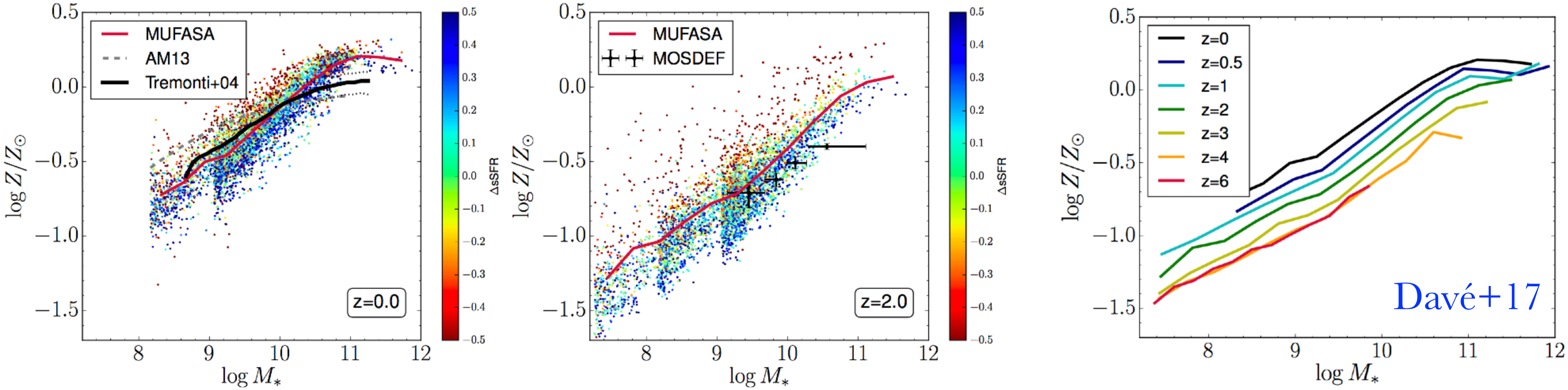
$$Z_{\rm eq}(M_\star, {\rm SFR}) = Z_0 + \frac{y}{1 + \lambda(1-R)^{-1} + \varepsilon^{-1}\left\{(1+\beta-b){\rm SFR}/M_\star - (1-R)^{-1}\frac{1.2}{t}\right\}},$$

- Z_{eq} = equilibrium metallicity
- Z_0 = metallicity of the incoming gas,
- y = chemical yield,
- λ = outflow rate/SFR = $\lambda_0 \cdot m^a$
- R = fraction of mass returned
- ε = star formation efficiency ≡ SFR/M = $\varepsilon_0 \cdot m^b$
- β = slope of the MSSF, SFR ~ M^{1+b}
- t = age of the universe

Dalcanton+04, Keres+05, Dekel+09, Brooks+07; Finlator+08, Davé+11, Campisi+11, Peeple+11, Krumholz+11, Fu+13, Dayal+13, Romeo-Velona+13,, Lilly+13, Forbes+14, Peng+14,15, Pipino+14, Obreja+14, Muñoz & Peeples 14, Lu+14, Creasy+15, Mitra+15, 17, Lu+15, Kacprzak+16, Davé+17

New models

semi-analytic models and numerical hydrodynamic simulations

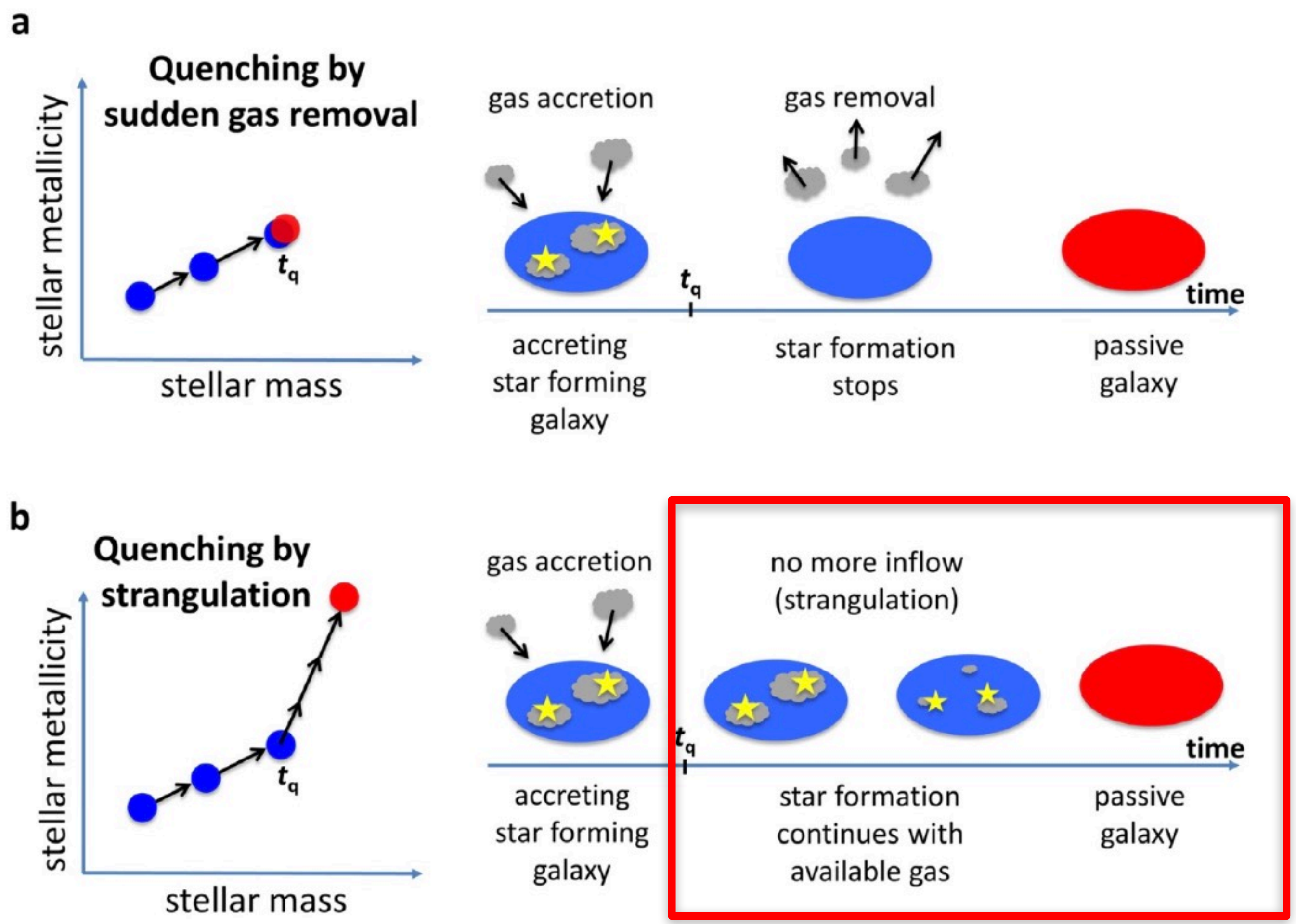


- balance between cosmological accretion, outflows, star formation, recycling and feedback
- stellar-driven winds at low masses, AGN feedback at high masses
- mass-metallicity due to outflow rate
- FMR related to stochastic variations in the inflow rate
- scatter set by the timescale to re-equilibrate
- slow evolution of the FMR with redshift

Somerville & Davé 2015

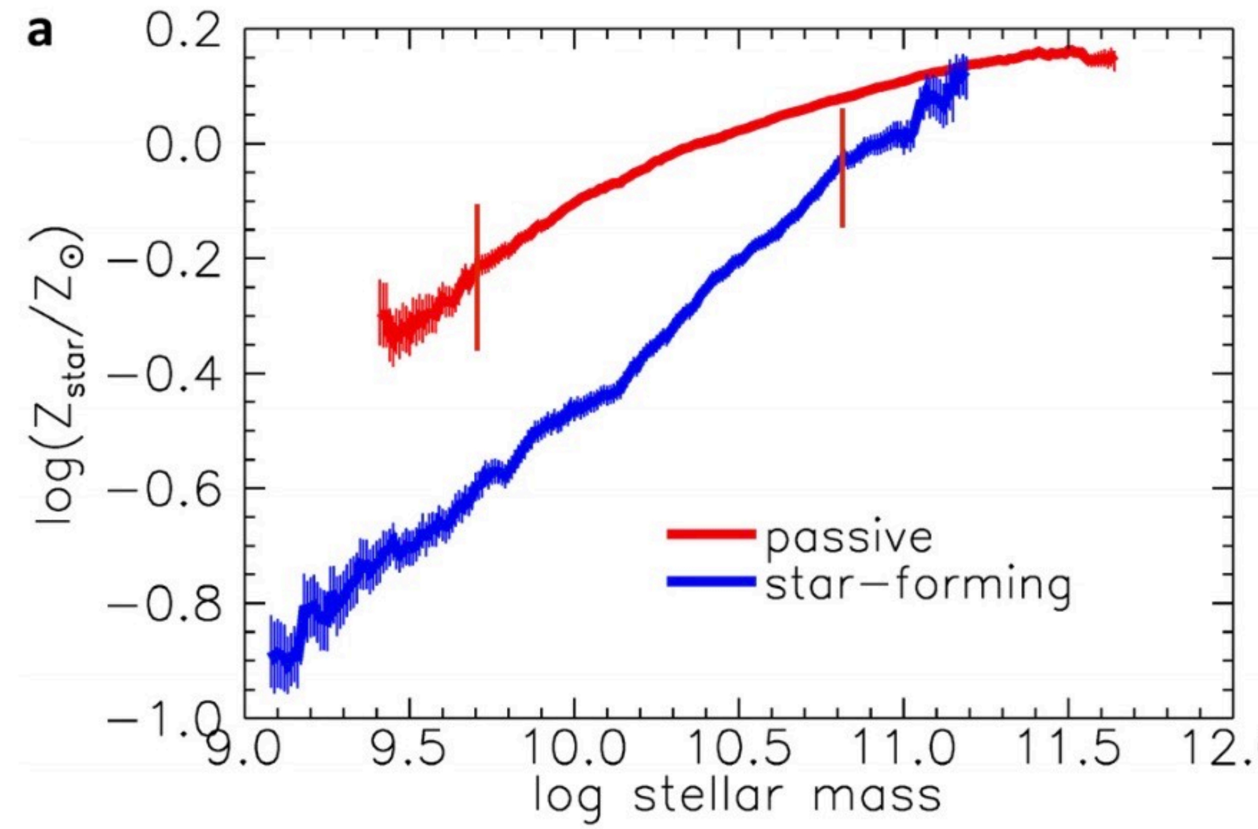
Dalcanton+04, Keres+05, Dekel+09, Brooks+07; Finlator+08, Davé+11, Campisi+11, Peeple+11, Krumholz+11, Fu+13, Dayal+13, Romeo-Velona+13,, Lilly+13, Forbes+14, Peng+14,15, Pipino+14, Obreja+14, Muñoz & Peeples 14, Lu+14, Creasy+15, Mitra+15, 17, Lu+15, Kacprzak+16, Davé+17

Strangulation model



closed-box

Peng+15



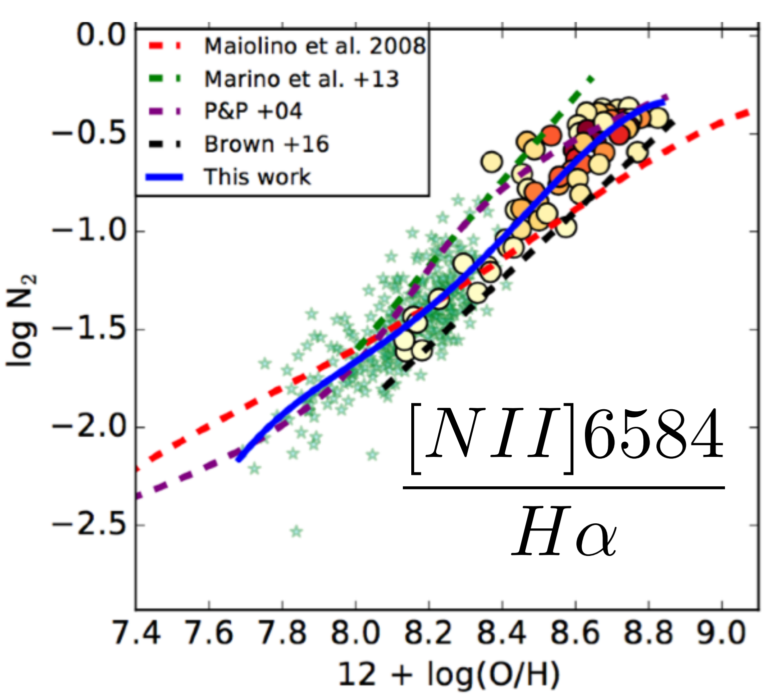
Testing the models at high z

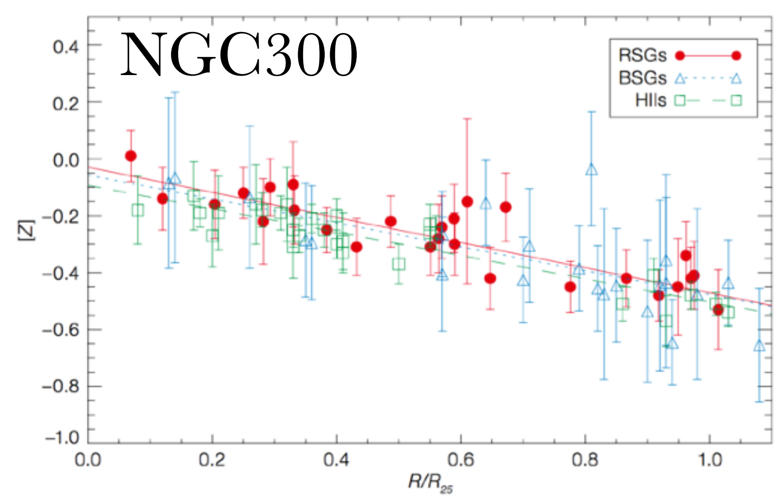
What is needed for emission-line galaxies:

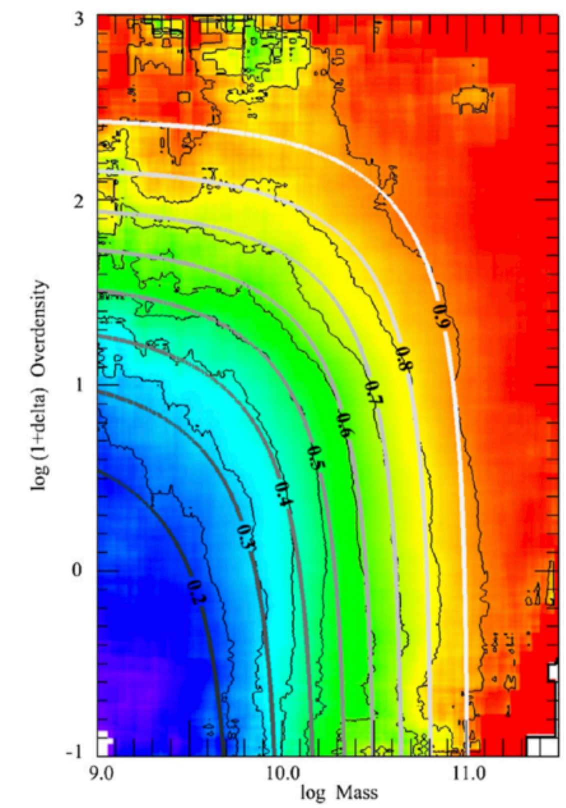
1 - More accurate ways to estimate metallicity

2- Spatial distribution of metallicity

3 - Large samples to assess the role of environments

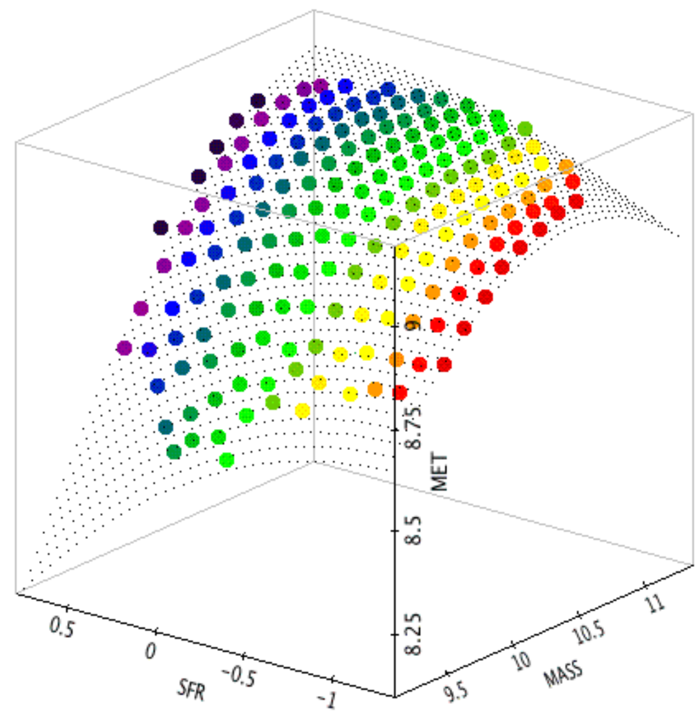


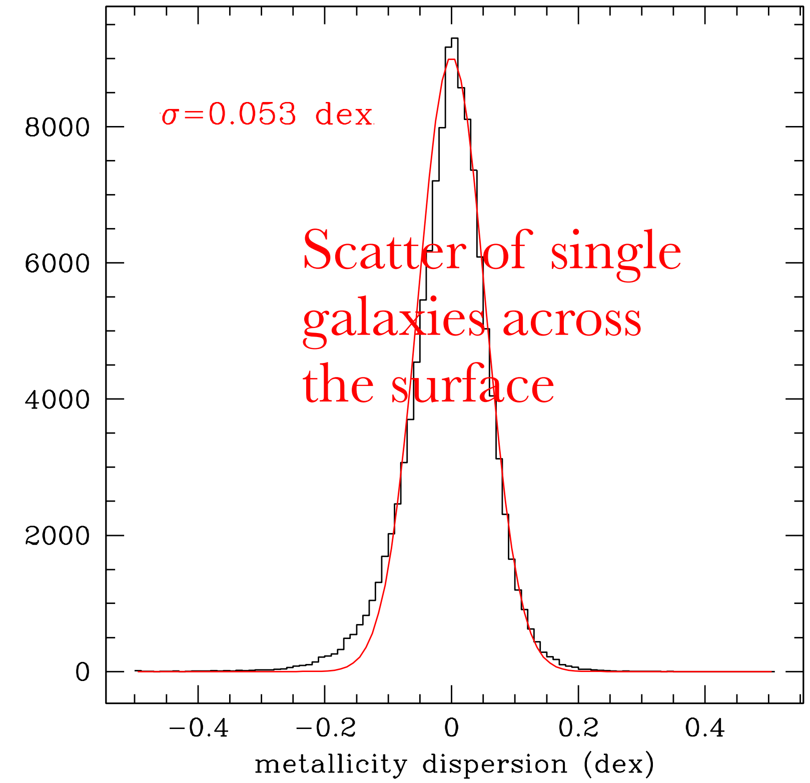




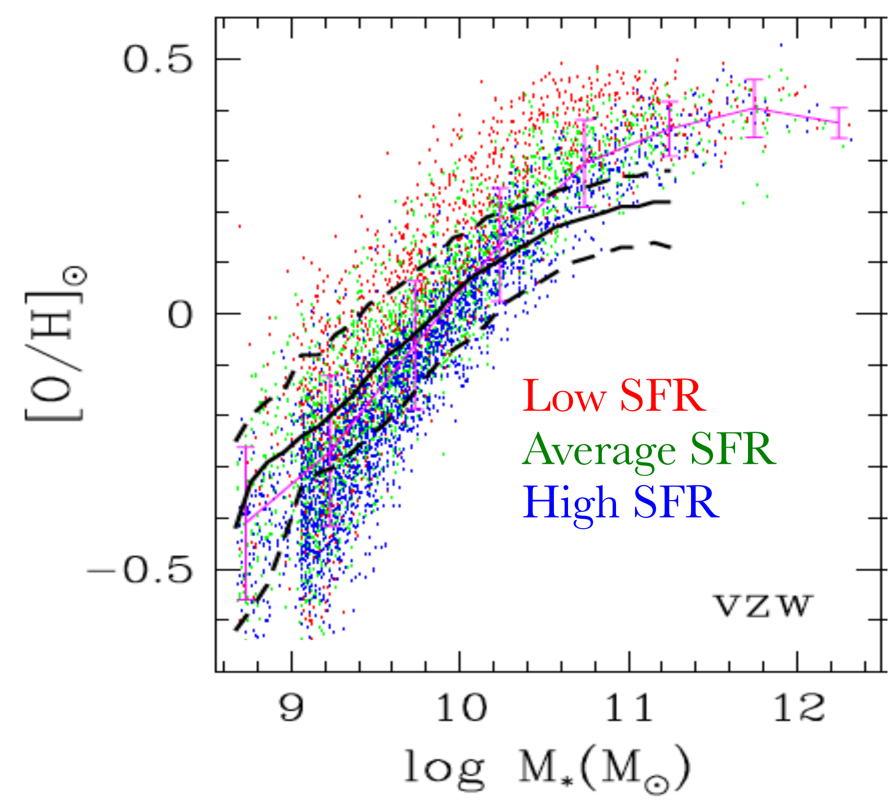
Accurate measurement of metallicity

- scatter=0.05 dex (12%)





- Comparison with models: absolute scale

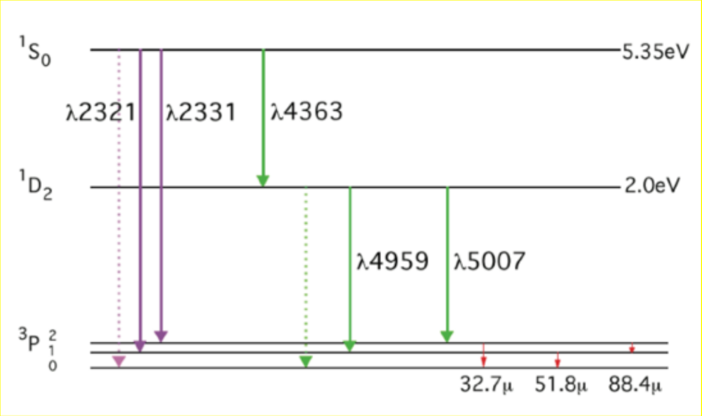


Three methods

1. CEL → Te

[OIII] 4363/5007
[NII] 5755/6548
[SII] 6312/9532

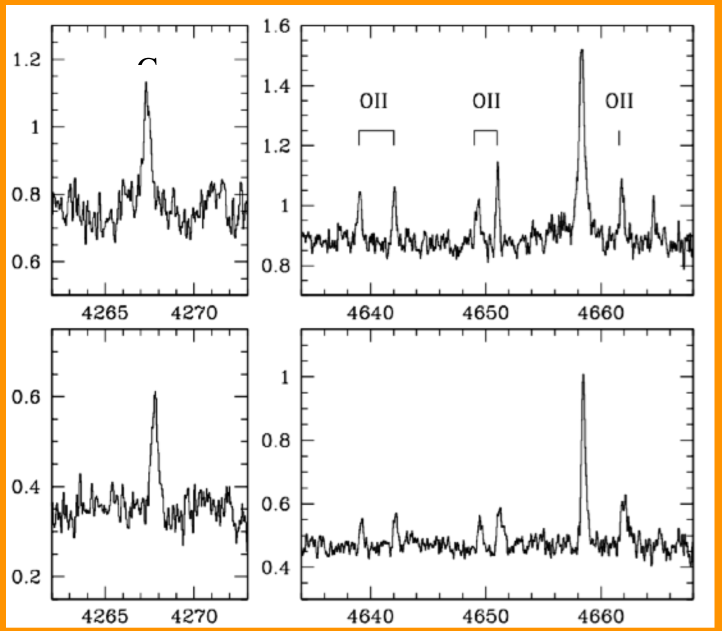
- homogeneous regions (Te, ne, X)
- *Hβ* and *CEL* from the same region
- LTE
- simple geometry



2. RL

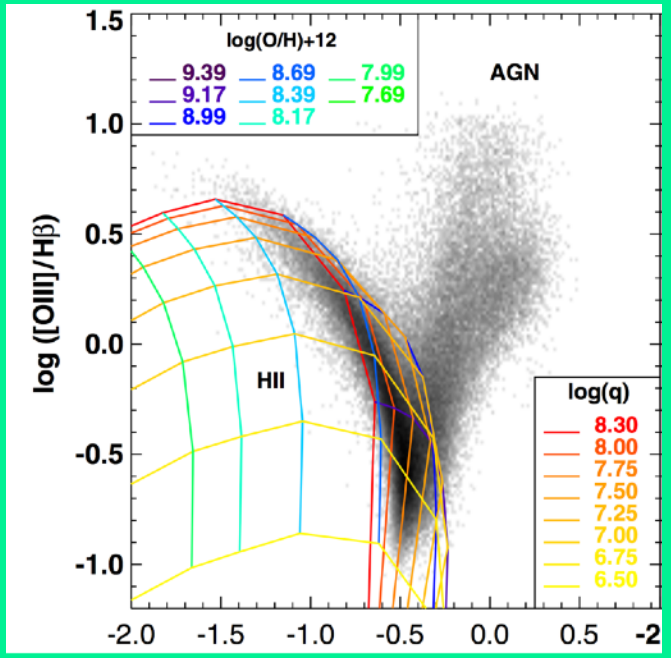
OII4650
CII4267

- most reliable?
- very faint lines
- different abundances from different lines
- inconsistencies



3. photo-models

- ionizing continuum
- ionization parameter
- gas density
- geometry
- abundance ratios
- dust distribution
- …..



strong line method

Strong line method

Based on the previous ones

- measure metallicity with one of the previous methods
- compare metallicity with line flux ratios
- calibrate the relations

1. Empirical (Te)

   Pilyugin 00,01, 03, Denicolò+02, Pilyugin & Thuan 05, Pe´rez-Montero & D´ıaz 2005, Stasinska 06; Yin+07; Peimbert+07, Pilyugin+10, 12; Marino+13;, Bianco+15, Brown+16, Curti+17

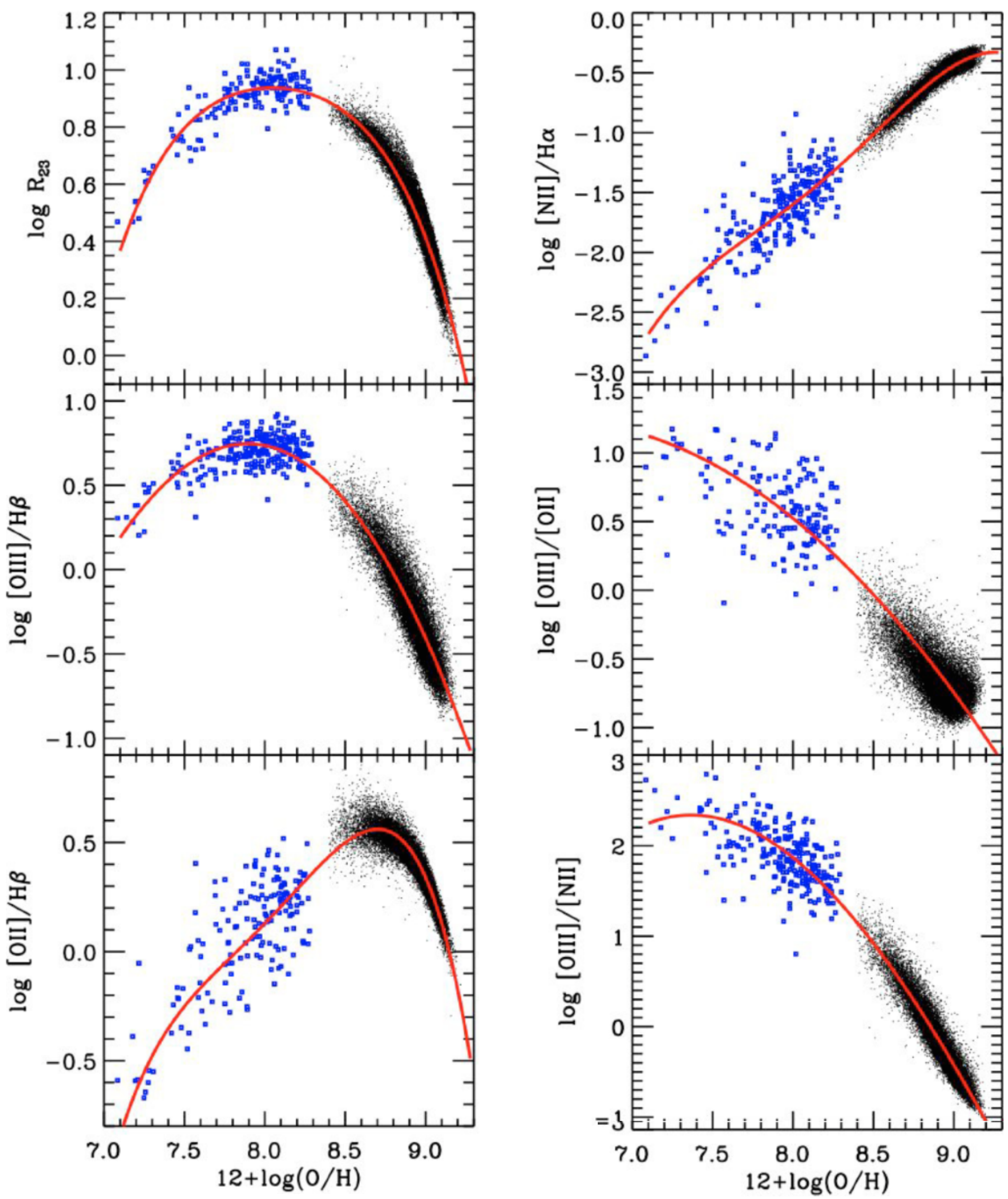
2. Theoretical (photoin. models)

   McGaugh 91; Zaritsky+94; Dopita+00; Charlot & Longhetti 01; Kewley & Dopita 02, Kobulnicky & Kweley 04, Tremonti+04, Dopita+13,16, Perez-Montero+14

3. Semi-empirical

   Alloin+79; Pagel +79; Edmunds & Pagel 84; McCall+85; Dopita & Evans 86; Skillman 89, Pettini & Pagel 04, Nagao+06, Maiolino+08,

Maiolino+08



Systematic differences

Poorly understood systematic differences

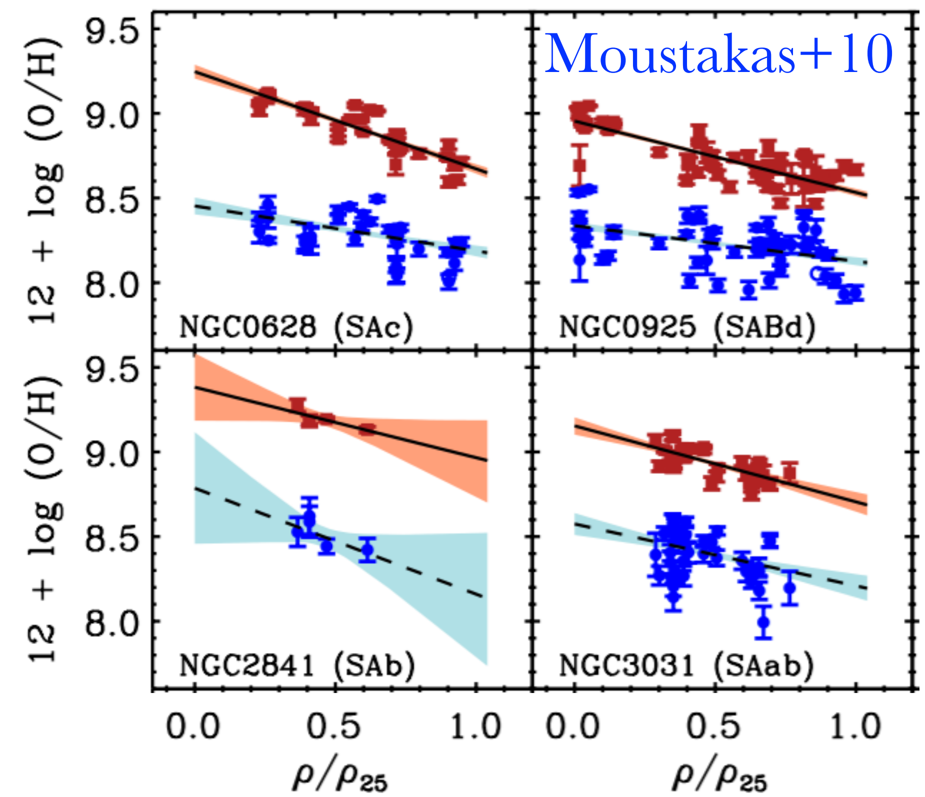
1.Theoretical: highest, 0.4-0.6 dex above Te

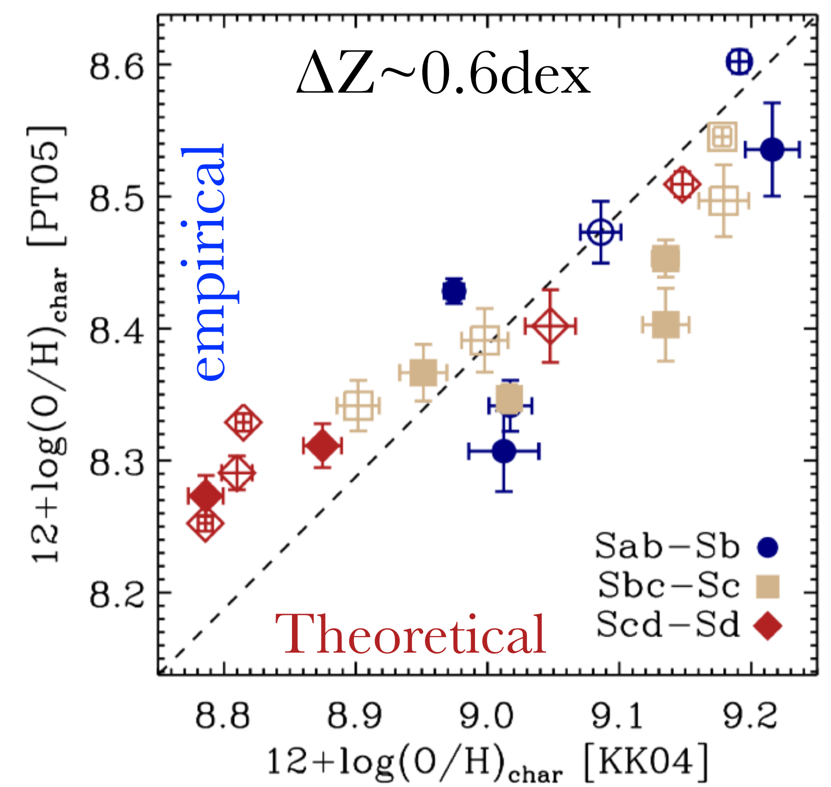
oversimplified assumptions: geometry? N/O?

2.Te lowest:

temperature gradients?

3.Recombinational lines: intermediate
(lines too faint cannot be used)

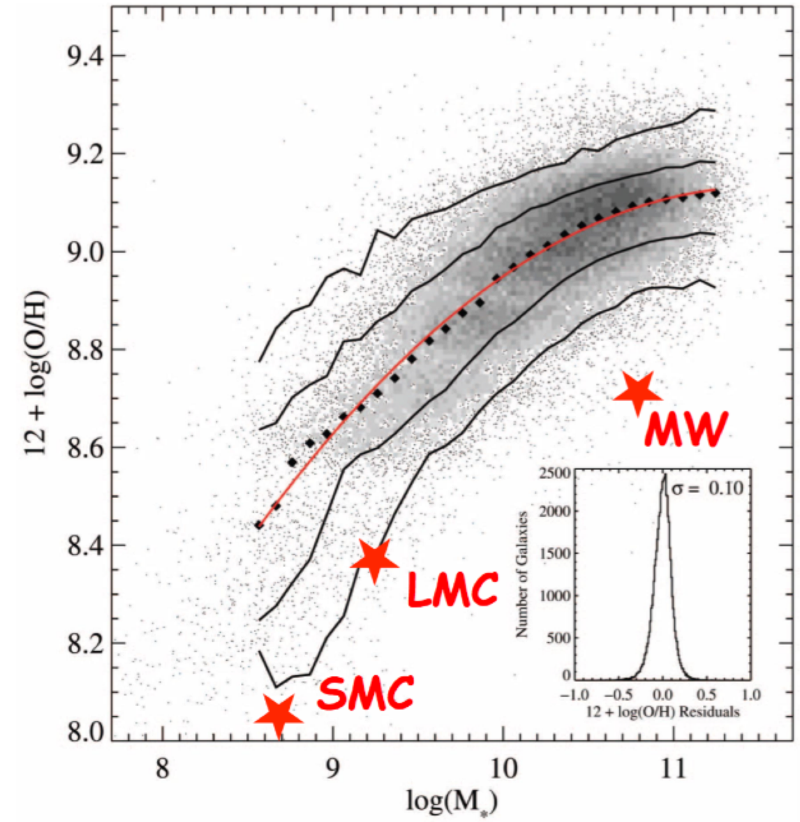




Peimbert+67, Stasinska+02,05, Kennicutt +03; Garnett+04; Bresolin+04, 05; Shi+06; Nagao+06; Liang+06; Yin+07; Kewley & Ellison 08, Moustakes+10

Empirical (CEL, Te) better than Theoretical

1. Better agreement with solar value
2. Better agreement with stellar metallicities



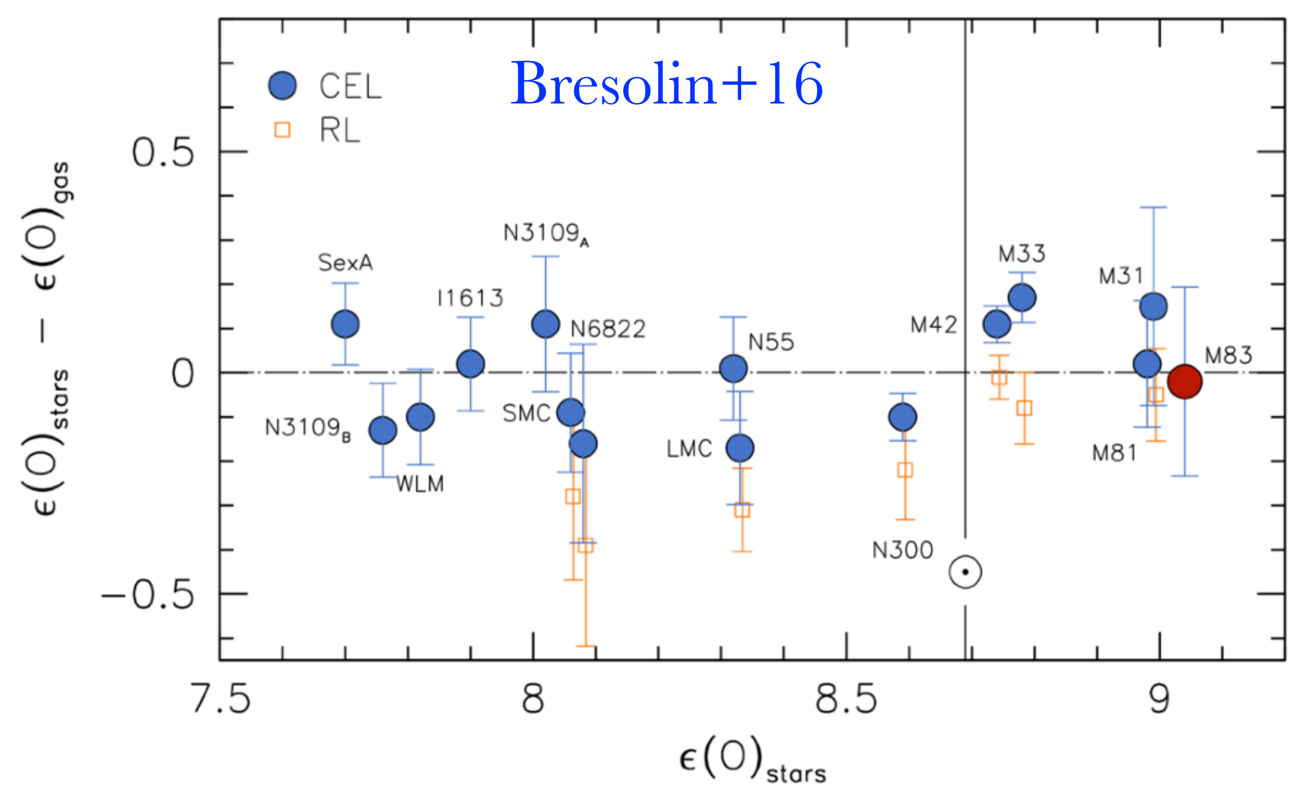
Possible biases:

- fluctuations of temperature, density, abundances

  Peimbert 1967; Kobulnicky+99, Stasinska 05; Bresolin 06

- NLTE effects

  Garcia-Rojas & Esteban 06, 07, Nicholls+12; Dopita+13, Blanc+15



Bresolin+09, Simon-Diaz+10,11, Gazak+15, Toribio San Cipriano+15, Davies+16

Strong-line calibration based on Te

- Robust calibration based on:
  - galaxies (instead of HII regions)
  - many galaxies
  - metallicities from a direct Te method
  - wide range of metallicities
  - not based on N/O

Curti+17

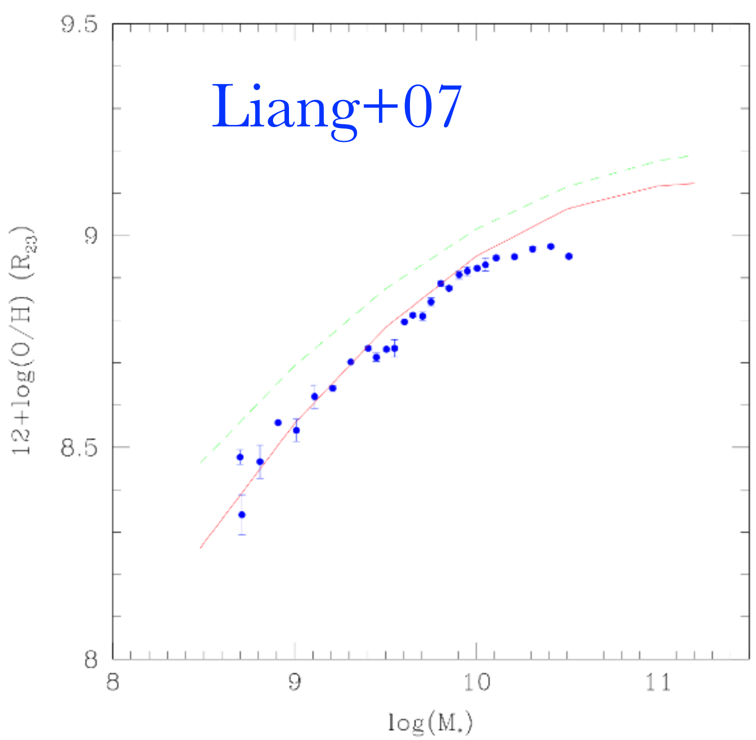
- Stacking analysis of ~120.000 SDSS spectra to detect Te-sensitive lines

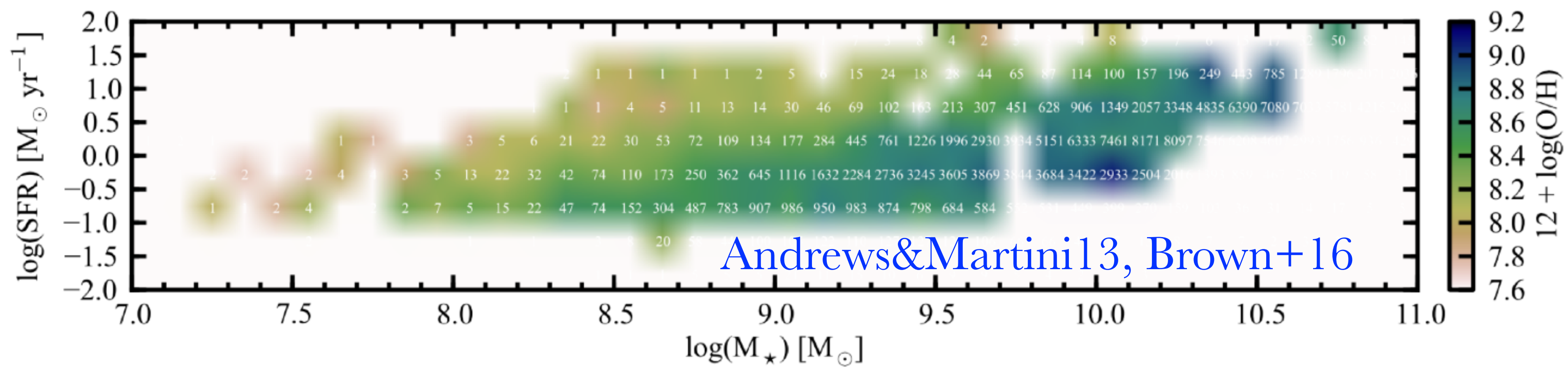
region	species	line ratio	Temp.
low ionization	**O+**	[OII] 3727, 3729/[OII] 7320, 7330	T2[OII]
	N+	[NII] 6584/[NII] 5755	T2[NII]
	S+	[SII] 6717,6731/[SII] 4069	T2[SII]
high ionization	**O++**	O[III] 5007/[OIII] 4363	T3[OIII]

Stacking procedure

Earlier attempts:

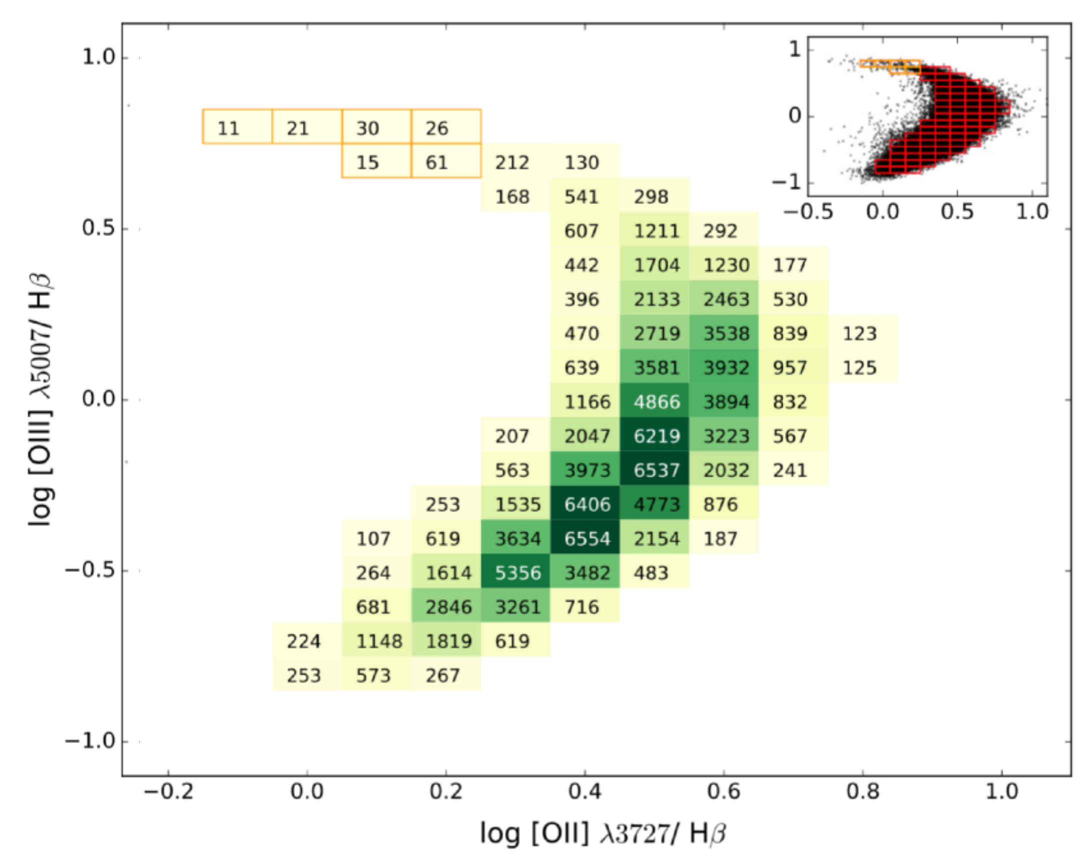
- Liang+07: MZR → stacking in mass
- Brown+16: FMR → stacking in mass and SFR



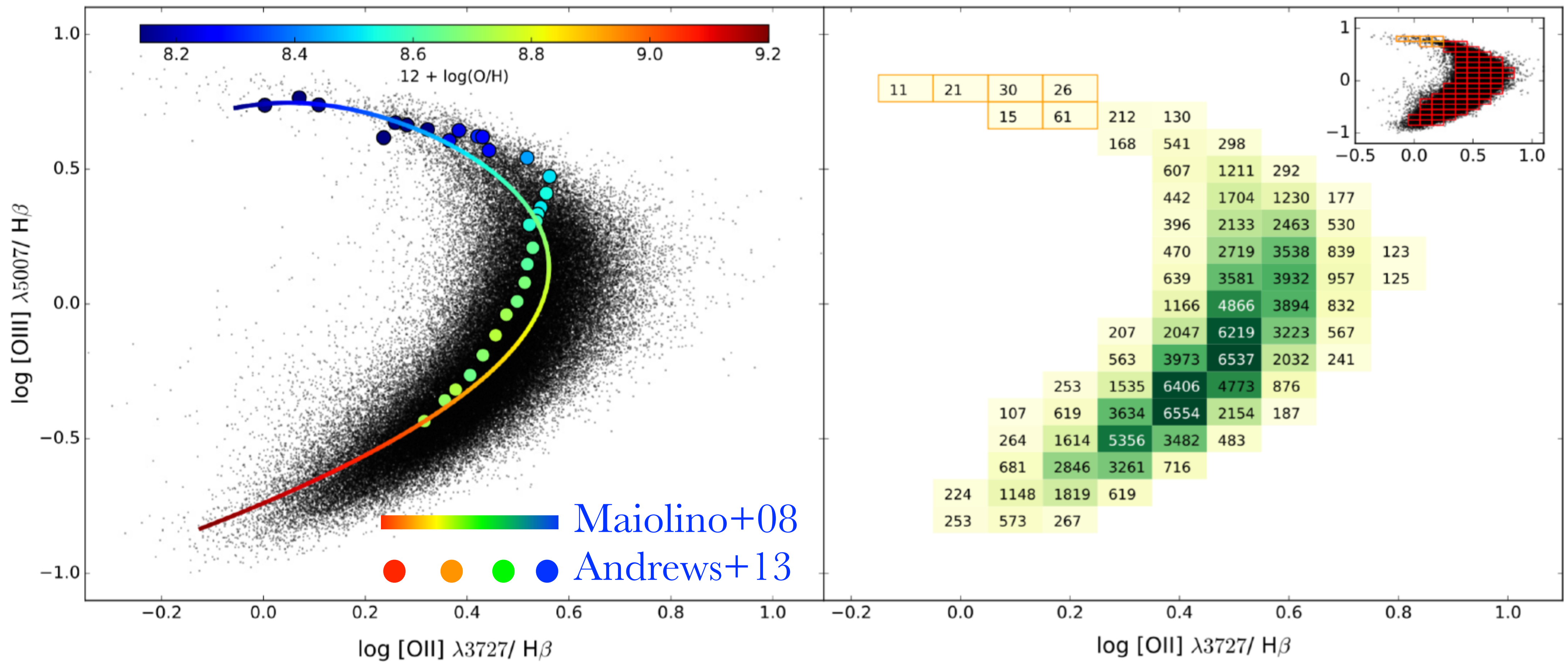


Different approach: similar properties vs similar spectra

- Bins of [OII]/Hβ and [OIII/Hβ]



Stacking procedure

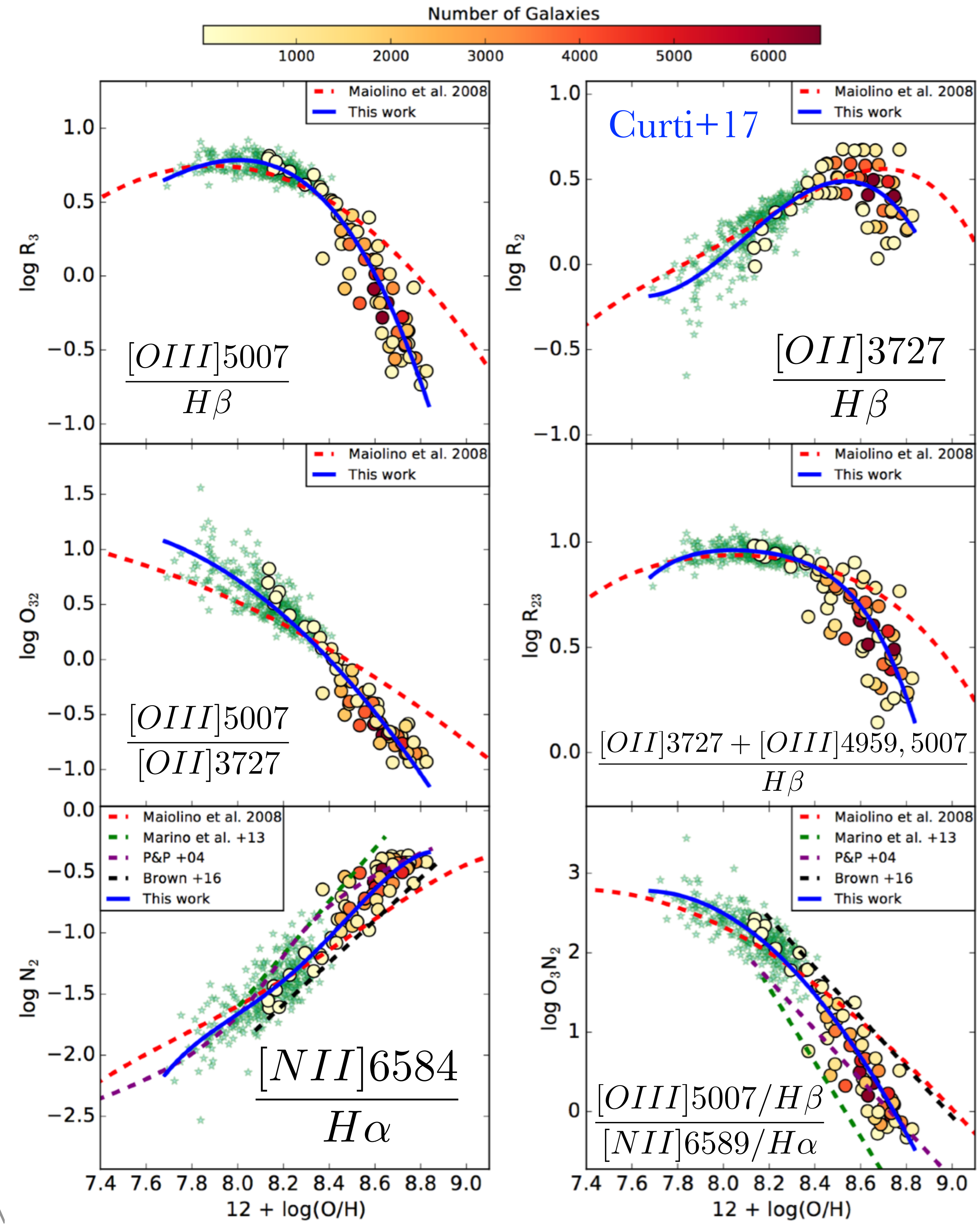


Assumption: a pair of [OII]/Hβ and [OIII]/Hβ corresponds to a value of 12+log(O/H)

- strong-line method can be used
- [OII]/Hβ and [OIII]/Hβ ∝ main ionization states of O
- [OIII]/[OII] sensitive to ionization parameter
- The flux of the auroral lines can be predicted from the strong lines → Te([OII], [OIII])
- not assuming any particular combination (e.g. R23)
- no assumptions on [N/O]

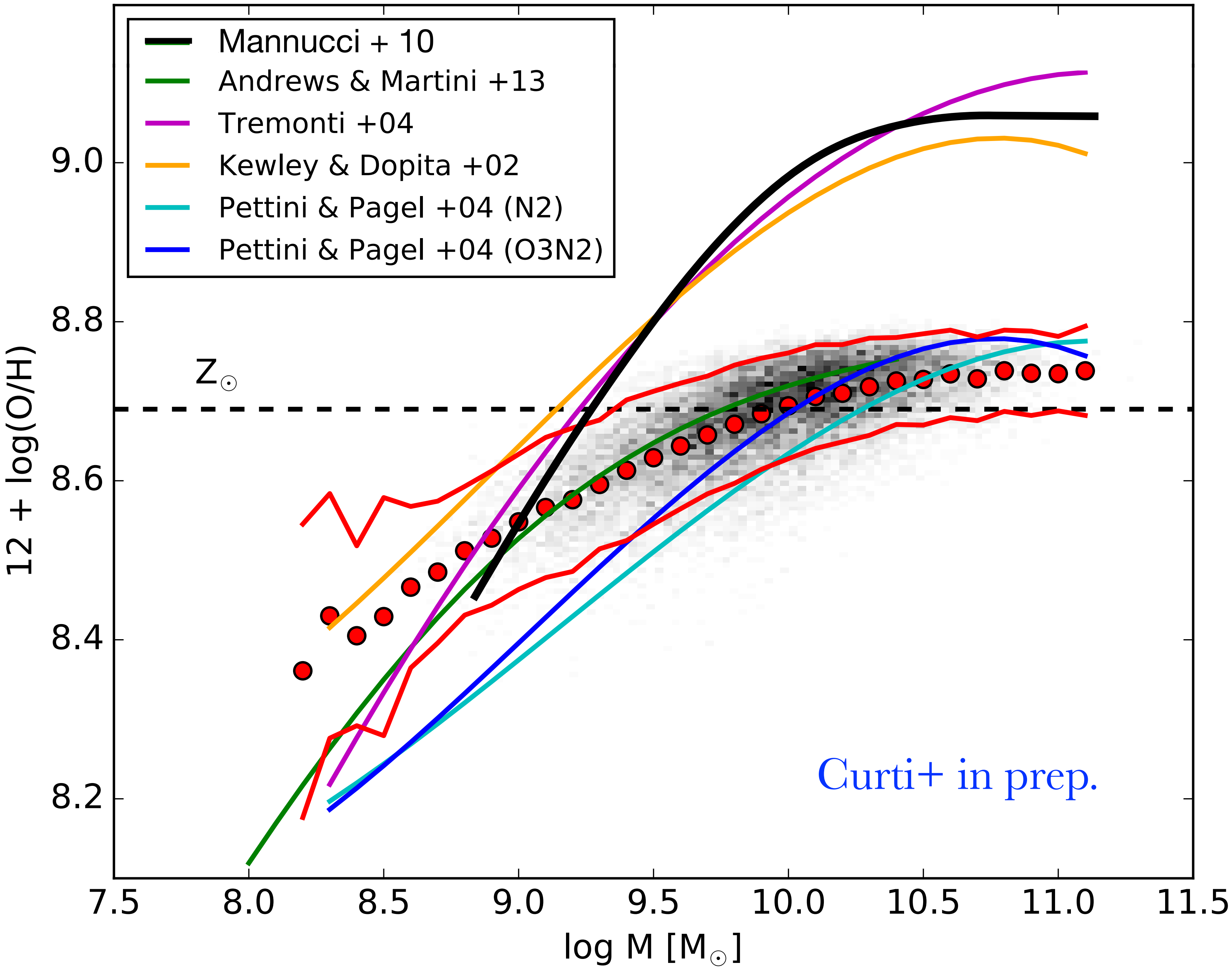
The calibrations

- main strong lines
- stacks and single galaxies (SDSS galaxies with SNR(4363)>10
- distribution on R2 and R3 due to binning



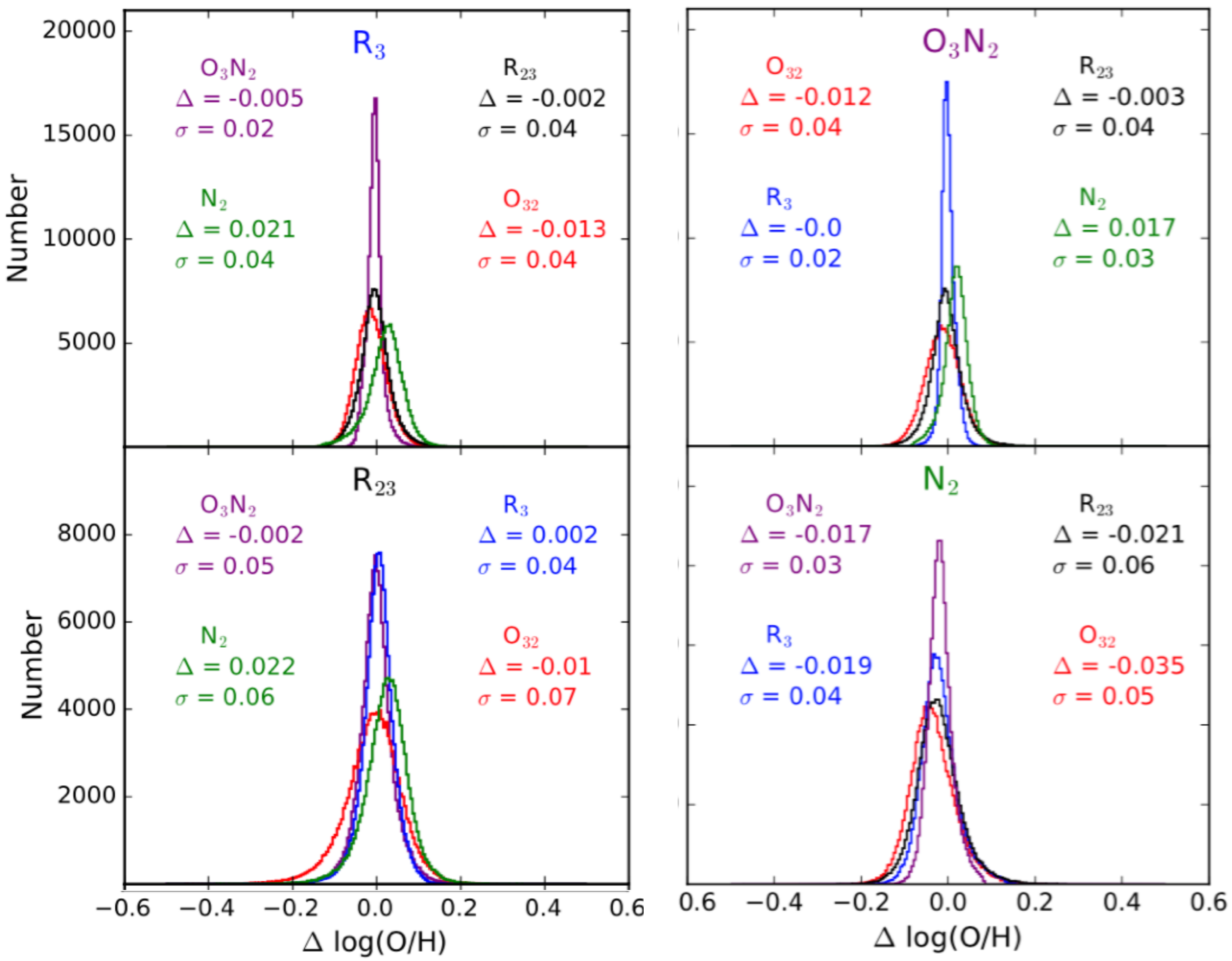
Diagnostic	σ	Range
R_2	0.26	$7.6 < 12+\log(O/H) < 8.3$
R_3	0.07	$8.3 < 12+\log(O/H) < 8.85$
O_{32}	0.14	$7.6 < 12+\log(O/H) < 8.85$
R_{23}	0.12	$8.4 < 12+\log(O/H) < 8.85$
N_2	0.10	$7.6 < 12+\log(O/H) < 8.85$
O_3N_2	0.09	$7.6 < 12+\log(O/H) < 8.85$

Mass-metallicity

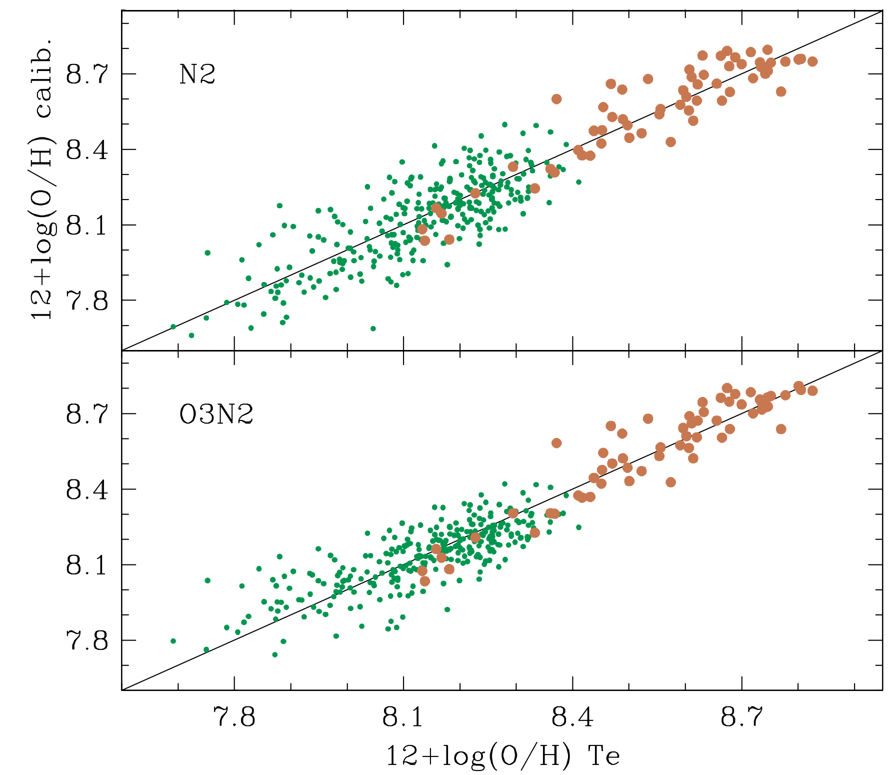


The calibrations

self-consistency



dispersion



Diagnostic	rms	σ	Range
R_2	0.11	0.26	$7.6 < 12+\log(O/H) < 8.3$
R_3	0.09	0.07	$8.3 < 12+\log(O/H) < 8.85$
O_{32}	0.15	0.14	$7.6 < 12+\log(O/H) < 8.85$
R_{23}	0.06	0.12	$8.4 < 12+\log(O/H) < 8.85$
N_2	0.16	0.10	$7.6 < 12+\log(O/H) < 8.85$
O_3N_2	0.21	0.09	$7.6 < 12+\log(O/H) < 8.85$

- metallicity does not depend on the line ratio used.
- incomplete spectra give the same metallicity

Often dominates the uncertainties: don't believe to Δmet=0.1 !!

FMR

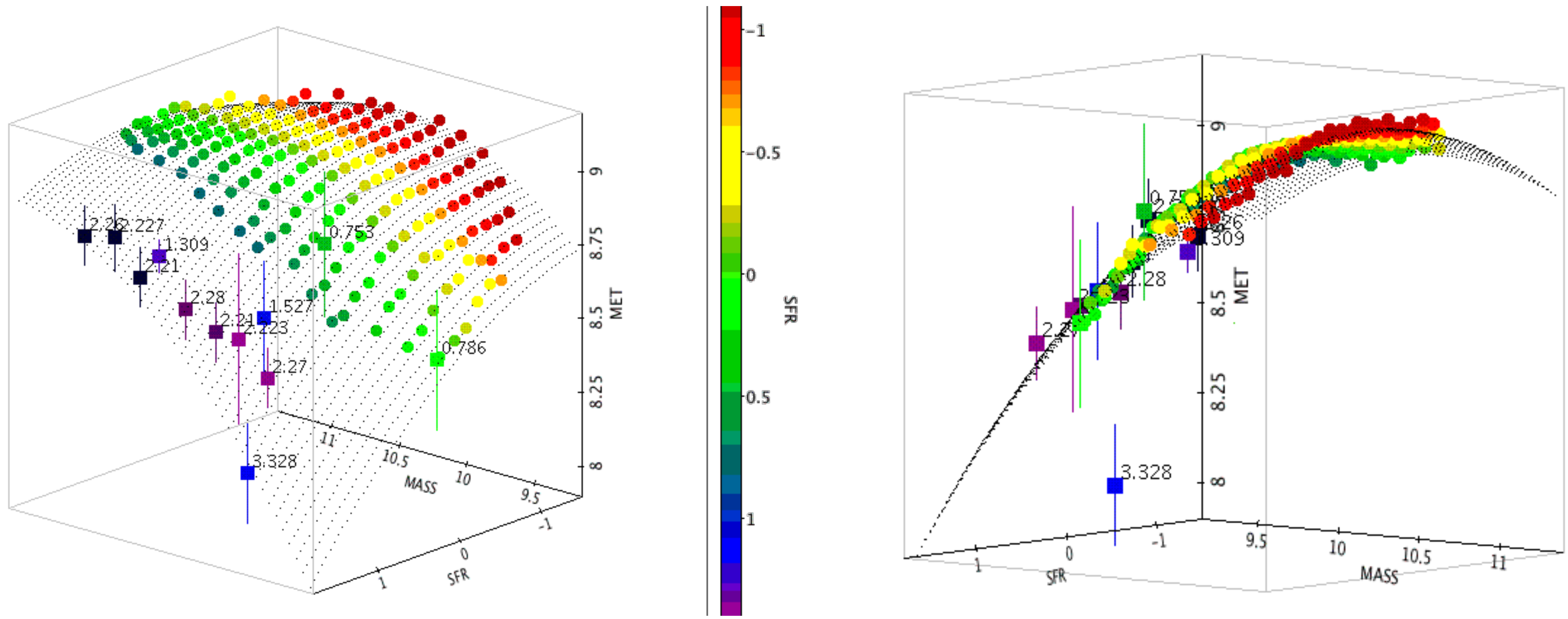
prediction of Z=Z(mass, SFR) based only on data at z=0

1- expected Z for a given mass and SFR

easier to test, average among many galaxies, does not depend on dynamic range of SFR

2- dependence of Z on SFR for galaxies of a given mass

more difficult, further subdivision of galaxies in bin, dynamic range of SFR, accuracy of determination of SFR



FMR at high redshift

Sanders+14

Table 1
Galaxy properties and emission-line luminosites from $z \sim 2.3$ composite spectra

$\log(\frac{M_*}{M_\odot})$[a]	$\langle\log(\frac{M_*}{M_\odot})\rangle$[b]	N_{gal}[c]	SFR_{med}[d] ($M_\odot\ yr^{-1}$)	$L_{[N\ II]}$[e] (10^{42} erg s^{-1})	$L_{H\alpha}$[e] (10^{42} erg s^{-1})	$L_{[O\ III]}$[e] (10^{42} erg s^{-1})	$L_{H\beta}$[e] (10^{42} erg s^{-1})
Full sample							
9.15-9.68	9.45	22	11.6	0.11 ± 0.04	2.03 ± 0.05	2.78 ± 0.14	0.60 ± 0.03
9.68-9.94	9.84	22	23.4	0.27 ± 0.05	3.03 ± 0.08	3.21 ± 0.14	0.82 ± 0.05
9.99-10.27	10.11	22	26.8	0.49 ± 0.08	3.05 ± 0.10	2.44 ± 0.20	0.76 ± 0.06
10.29-11.11	10.56	21	53.8	1.07 ± 0.10	4.82 ± 0.12	2.01 ± 0.21	...98 $\pm$ 0.08

the median mass–metallicity relation is

$$12 + \log(O/H) = 8.96 + 0.31m - 0.23m^2 - 0.017m^3 + 0.046m^4,$$

Mannucci+10

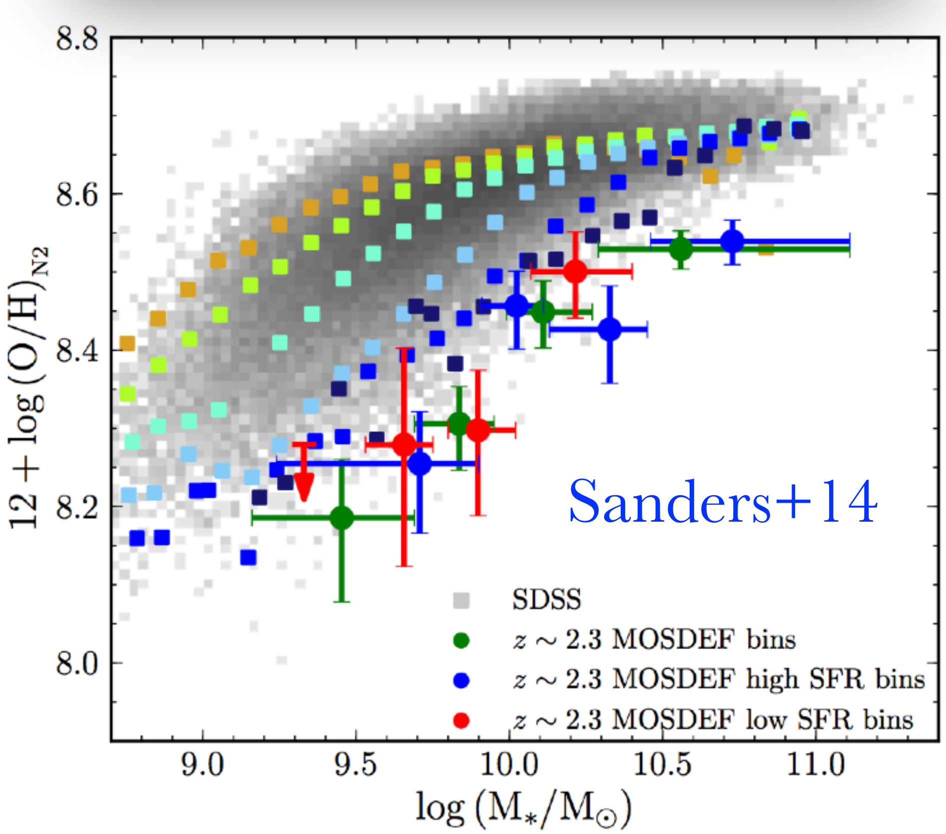
where $m = \log(M_\star) - 10$ in solar units.

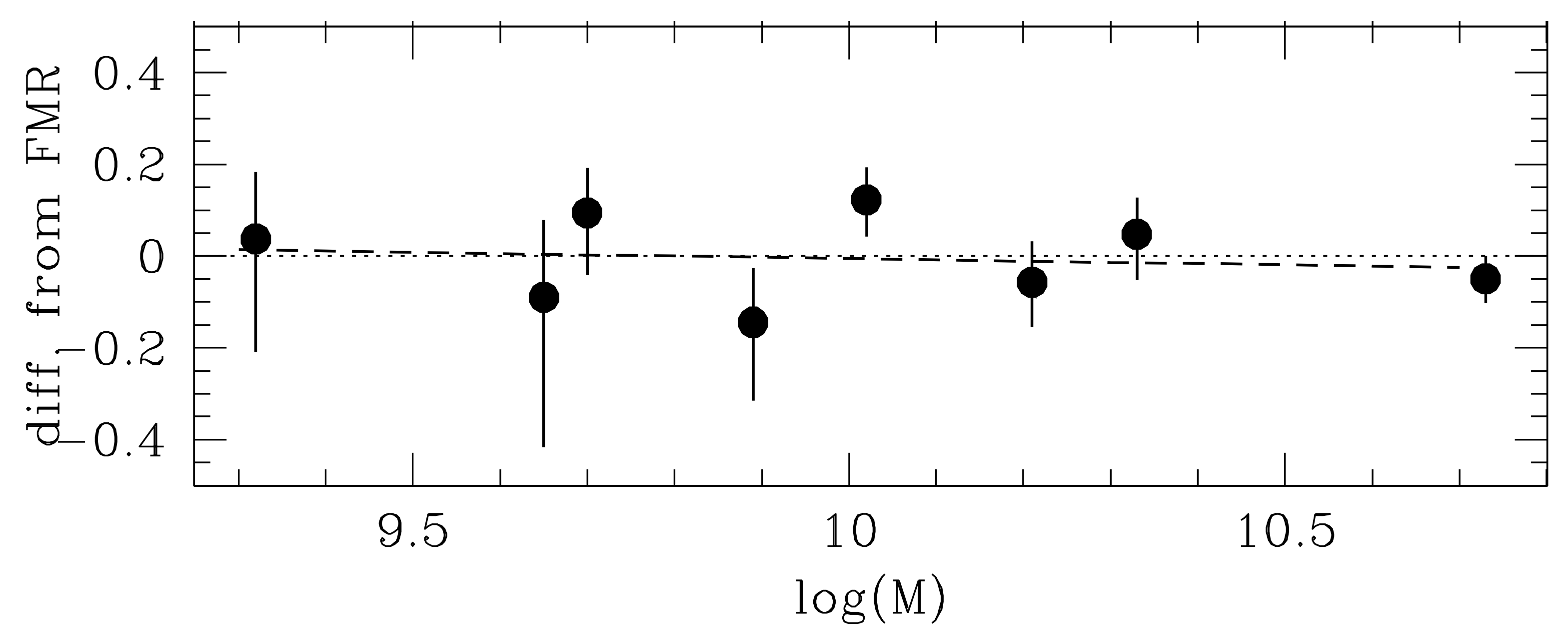
nomial is required. The general functional form for describing the strong-line metallicity calibration is therefore:

$$\log R = c_0 + c_1x + c_2x^2 + c_3x^3 + c_4x^4 \quad (1)$$

Maiolino+08

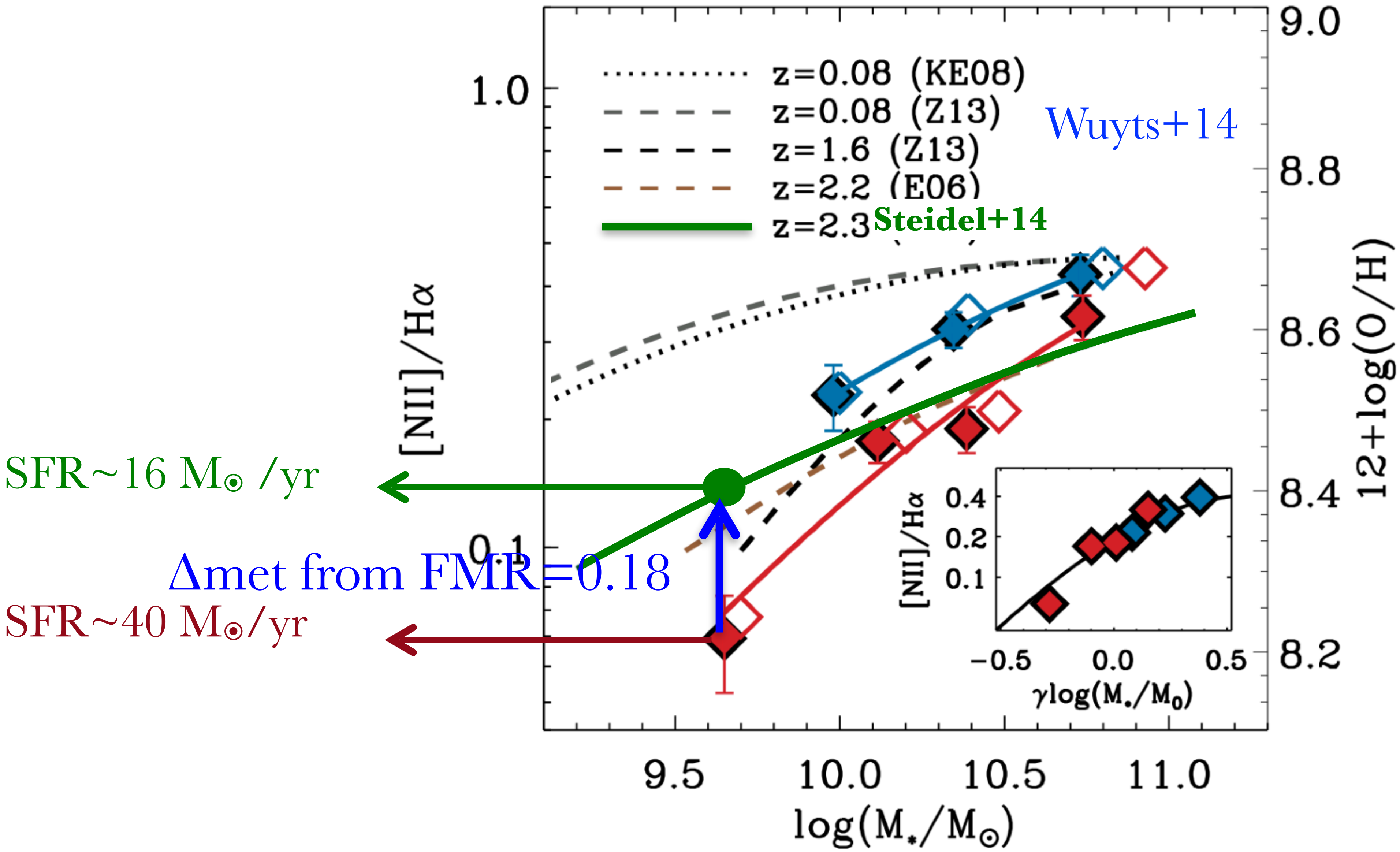
where $\log R$ is the logarithm of the strong-line ratio, and x is the metallicity relative to solar ($x = \log(Z/Z_\odot) = 12 + \log(O/H) - 8.69$, Allende Prieto et al. 2001). The coefficients $c_0 - c_4$ for





same data compared to Mannucci+10

FMR and MZR



There is no "absolute" mass-metallicity relation at any redshift depends on SFR as expected from the FMR

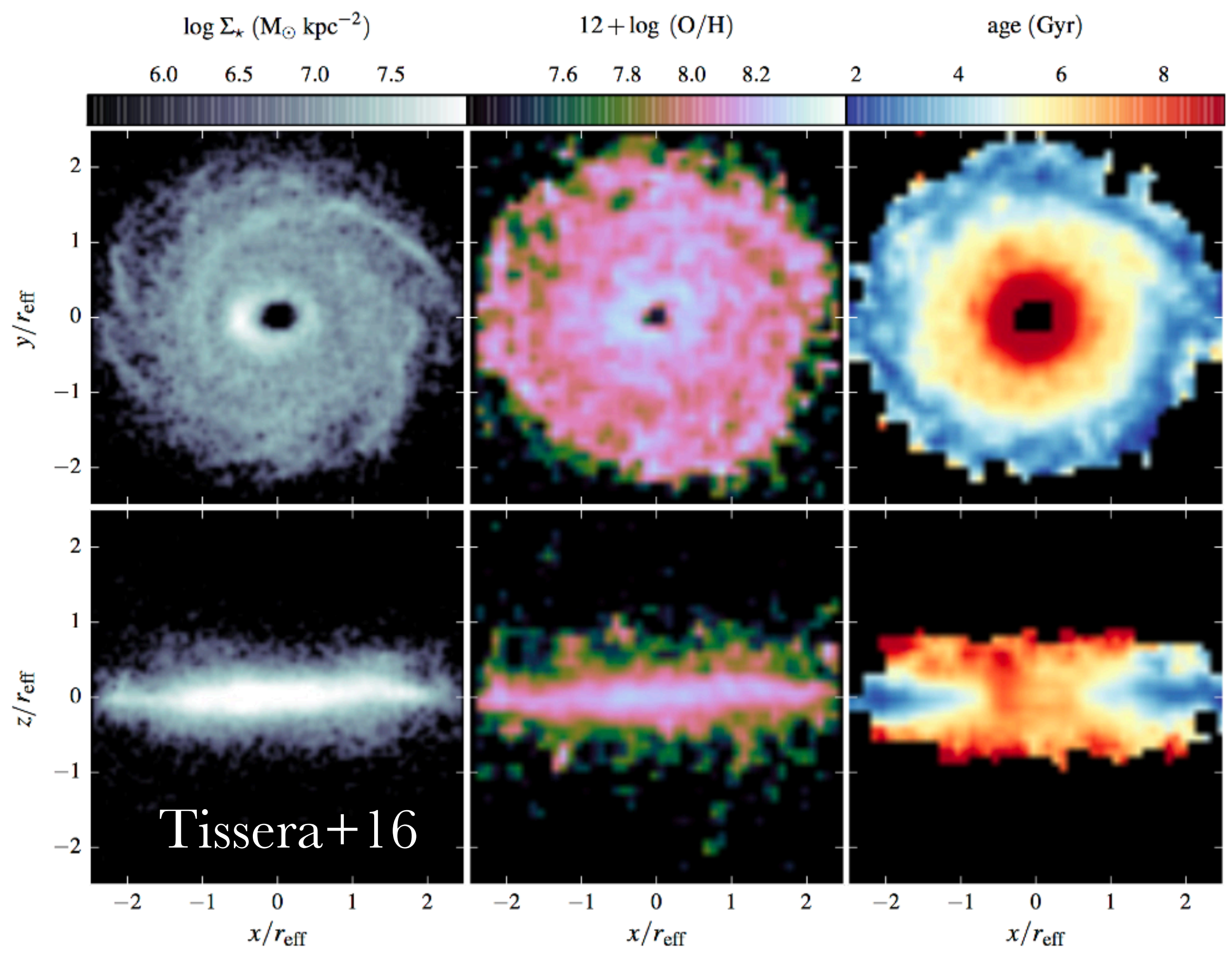
Metallicity gradients

Local galaxies:

- most show negative gradients (Zaritsky+94, van Zee+98, Manciel+03, Magrin+06, Moustakas+10, Ho+15, Davies+16)
- CALIFA & MANGA (Sánchez+14; Pérez-Montero+16; Belfiore+17)
- mergers show flat gradients, → interaction-induced inflow of metal-poor gas (Kewley+06,10; Michel-Dansac+08, Rupke+10, Perez+11, Sánchez+14).

Models: different prescription for:

- gas infall
- radial transfers
- feedback and outflows
- efficiency of star formation
- galactic fountains
- major/minor merging.

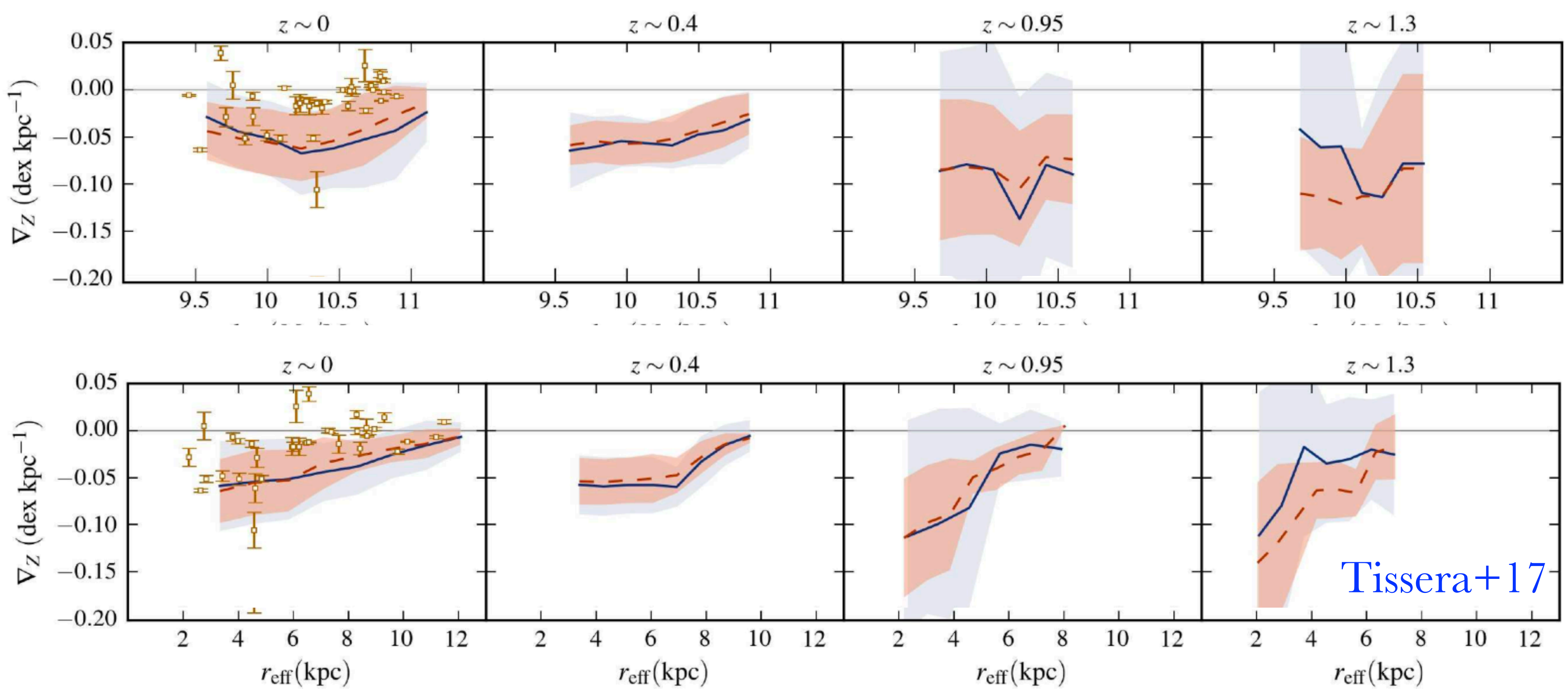


Mollà+97, Chiappini+01, Magrini+07, Fu+09, Crain+09, Di Matteo+09, Rupke+10, Spitoni+11, Kobayashi+11; Rahimi+11, Few+12; Pilkington+12; McCarthy+12, Mott+13, Gibson+13; Anglés-Alcázar+14, Tissera+16,17, Ma+17,Taylor+17, Schönrich+17

Metallicity gradients

Evolutionary scenarios and correlations.

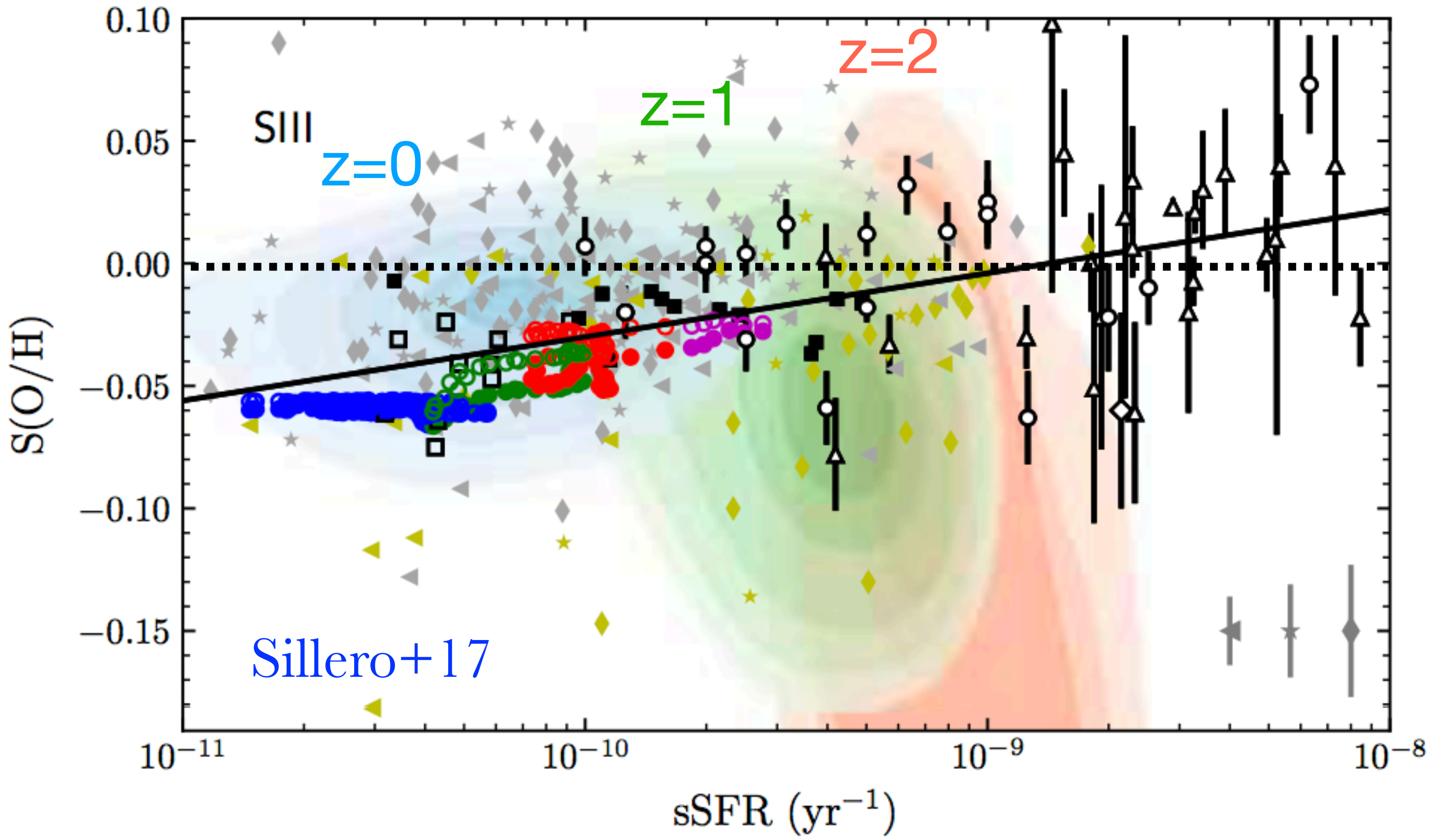
- Smooth, secular inside-out evolution → steeper gradients at high-z
- Strong feedback and outflows → flatten gradients (Pilkington+12; Gibson+13; Anglés-Alcázar+14)
- Rapid radial gas inflows → flatten or even invert gradients (Tosi+88, Chiappini+01, Mott+13)
- Merging → flattens the gradients, but merger-induced instabilities can create negative gradients (Sillero+17)
- AGN feedback prevents the building up of gradients flattened by mergers (Taylor+17)



Mollà+97, Chiappini+01, Magrini+07, Fu+09, Crain+09, Di Matteo+09, Rupke+10, Spitoni+11, Kobayashi+11; Rahimi+11, Few+12; Pilkington+12; McCarthy+12, Mott+13, Gibson+13; Anglés-Alcázar+14, Tissera+16,17, Ma+17,Taylor+17, Schönrich+17

Metallicity gradients

Large dispersions expected



Many effect and different timescales → large scatter

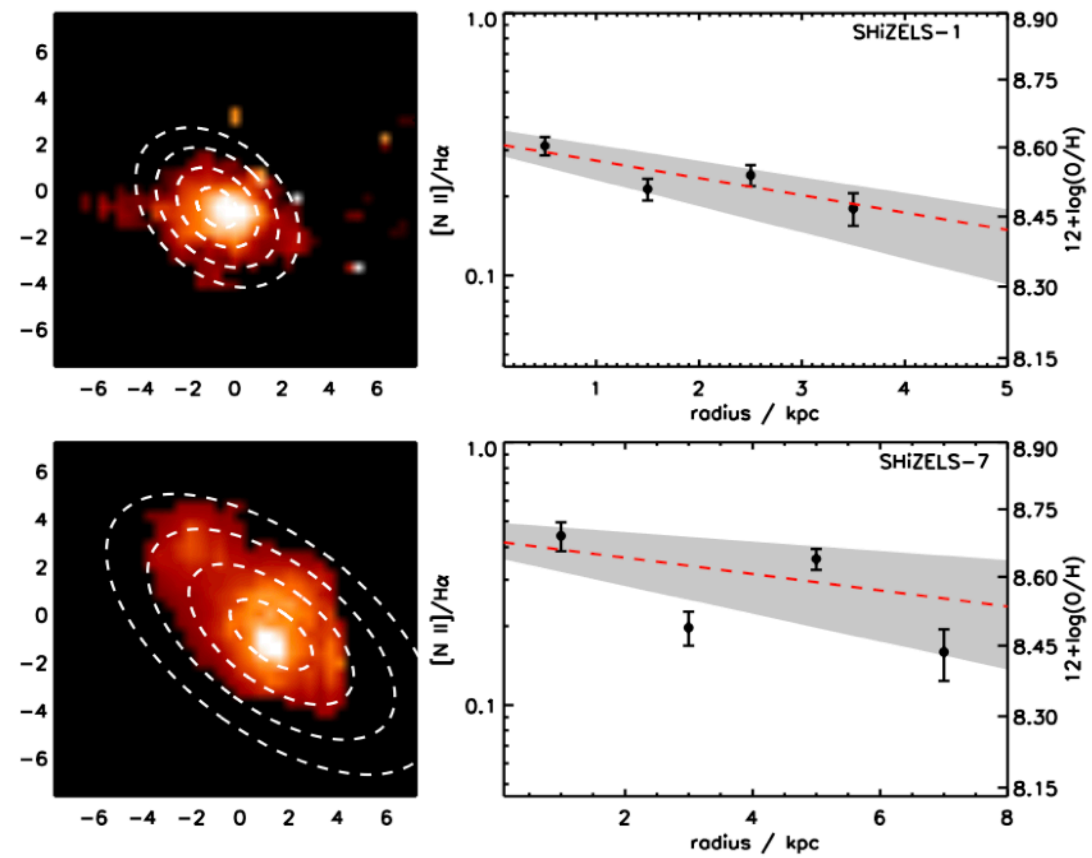
Effect of evolution, merging, feedback

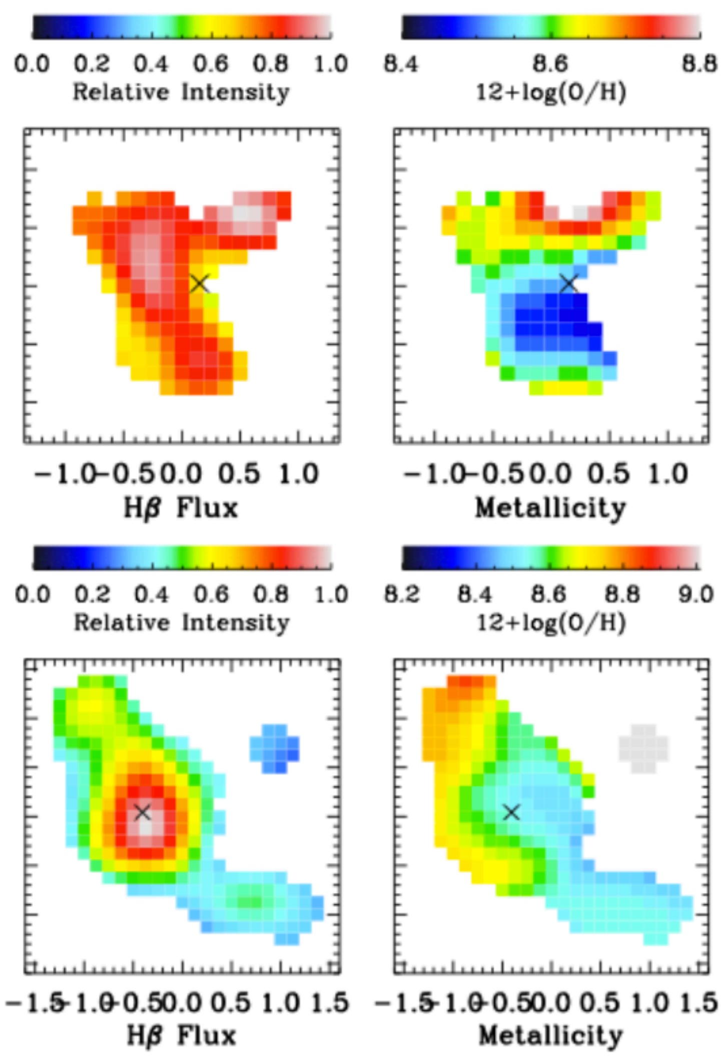
Metallicity gradients

Observations at high redshifts: large uncertainties:

- different calibrations
- few (one) line ratios
- low SNR (resolving faint lines)
- limited spatial resolution (best with AO and lensing)
- AGN
- azimuthal averages

Swinbank+12





Williams+14

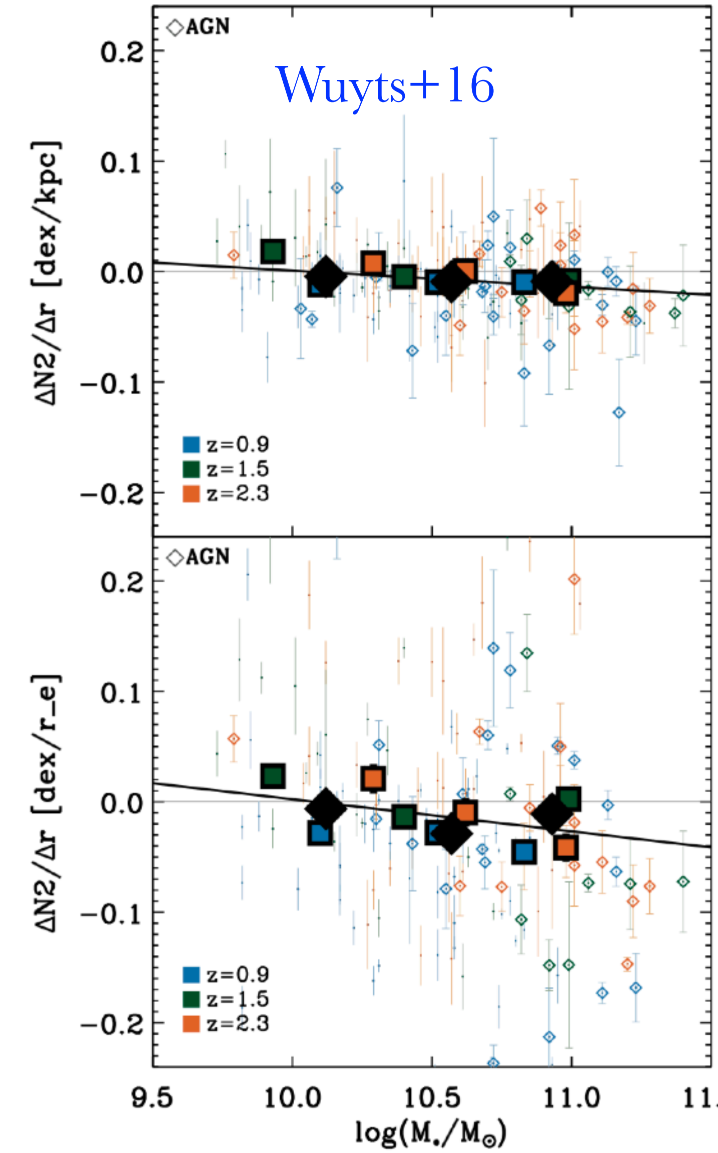
Multi-parametric approach: Gradients as a function of galaxy properties: mass, SFR, position of the MS, gas fraction, metallicity size, dynamics, dynamical mass, presence of outflows (broad wings), velocity dispersion

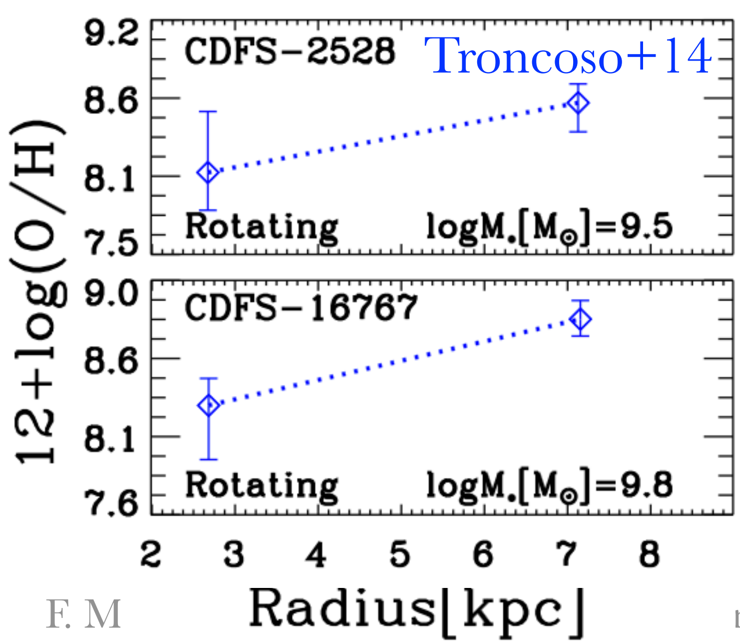
Cresci+10, Yuan+11, Queyrel+11, Swinbank+12, Jones+10,13,15,, Troncoso+14, Williams+14, Stot+14, Leethochawalit+15, Wuyts+16

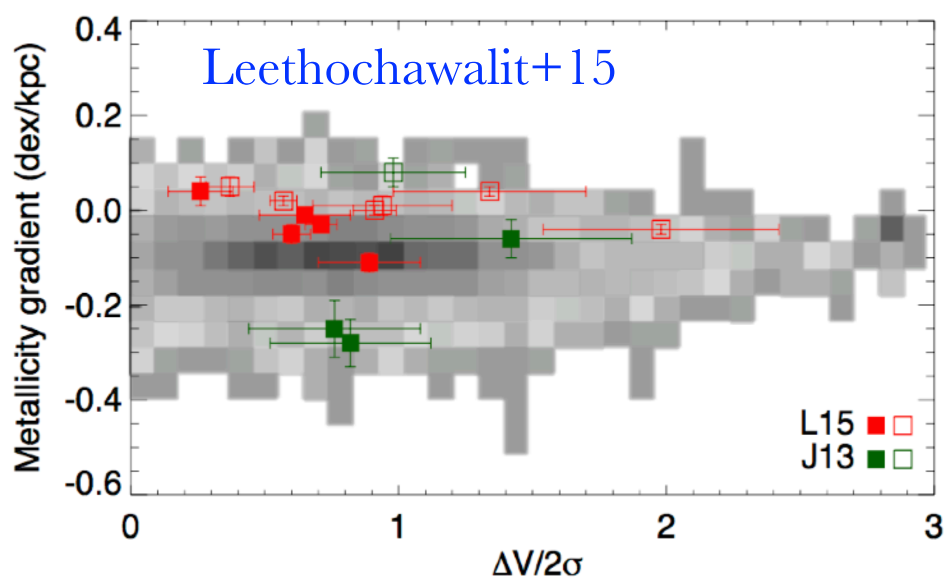
Metallicity gradients

- Large dispersions
- Only weak dependences
- differences among the different works:

Paper	Stott +14	Queyrel +12	Wuyts +16	Williams +14	Leethochawalit+15	Troncoso +14
redshift	~1	~1.2	0.9 & 2.3	~1.5	~2	~3.3
mass	NO	-	↘ 2.8σ	-	-	NO
sSFR	↗ 2.9σ	-	↗ 2.5σ	-	NO	NO
metallicity	NO	↘	NO	-	↘	-
V/σ	-	↘	NO	NO	NO	↗
size	-	-	NO	-	-	-
posit. grad.	few	many	a few	no	several	many







Cresci+10, Yuan+11, Queyrel+11, Swinbank+12, Jones+10,13,15,, Troncoso+14, Williams+14, Stot+14, Leethochawalit+15, Wuyts+16

Lensed galaxies with ARGOS

Ground Layer Adaptive Optics @ LBT

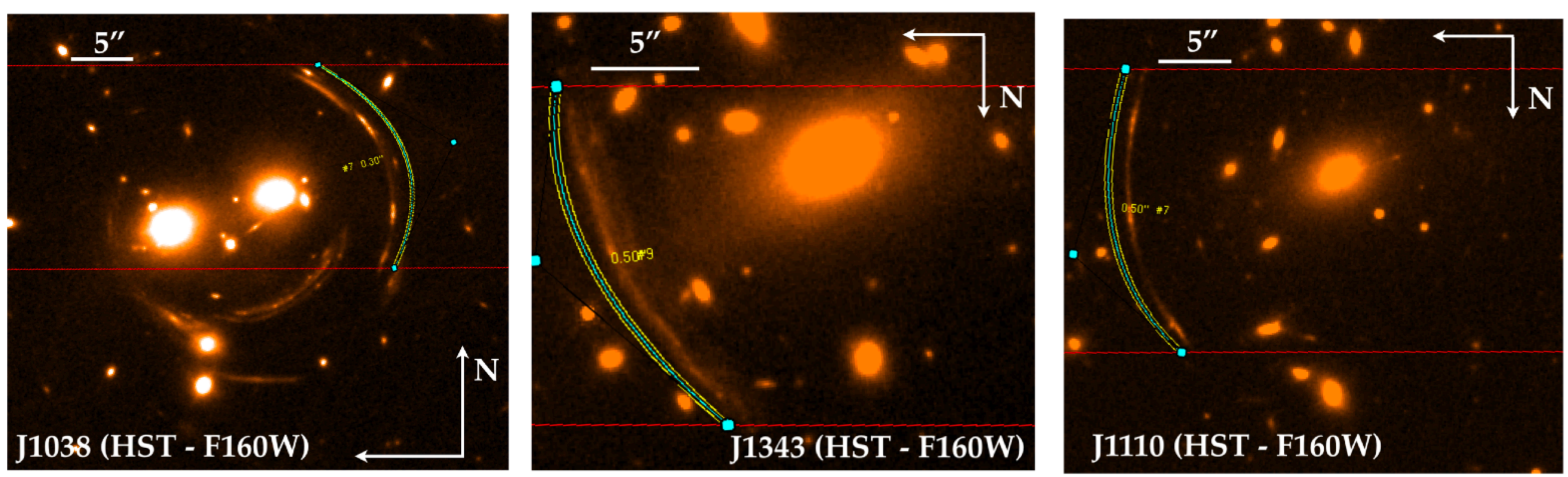
"seeing enhancer" (PSF~0.3") over a large FoV (~4'x4')

Perna+ in prep.

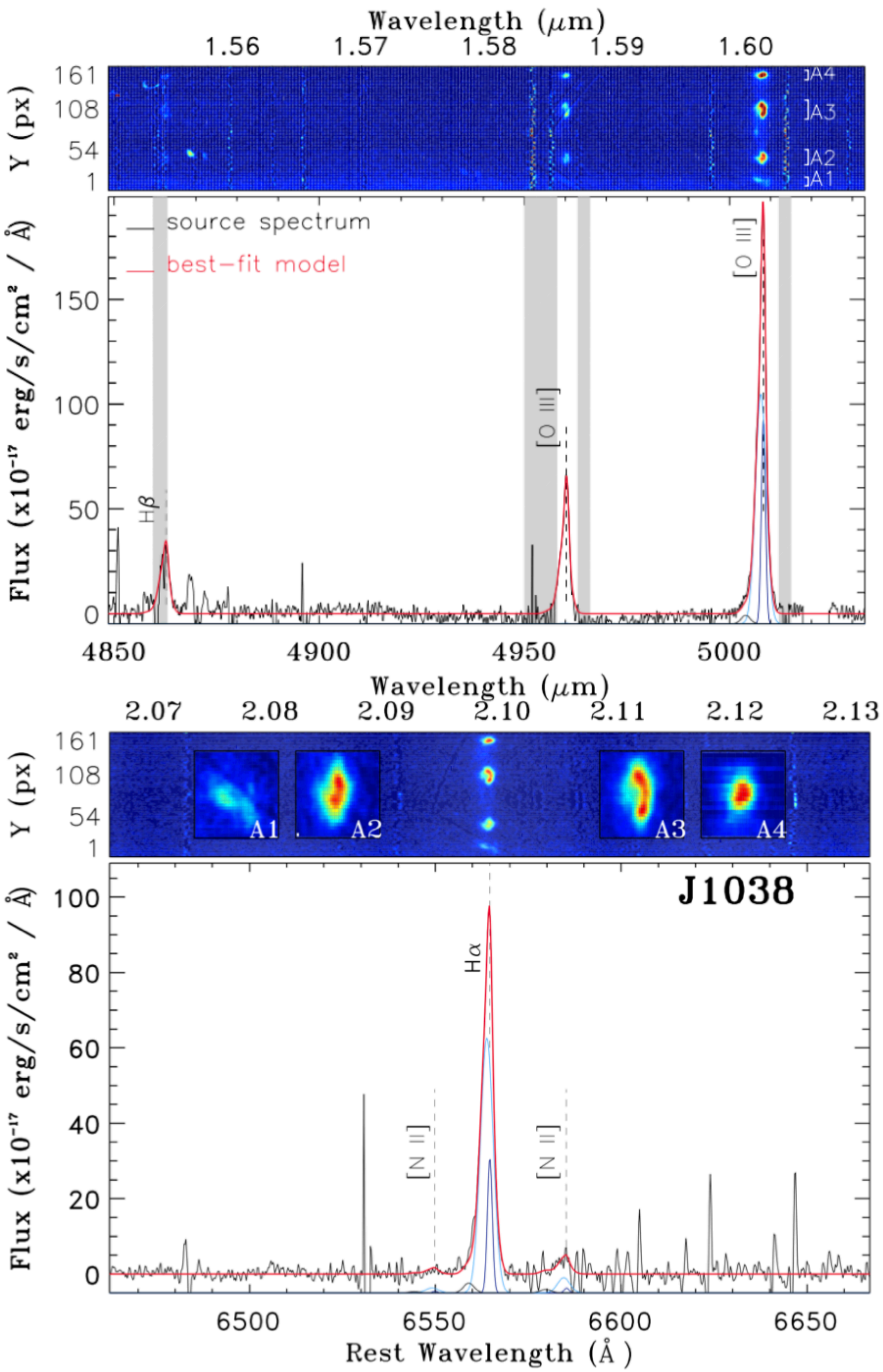
low SFR :
10 - 80 $M_{\odot}$/yr

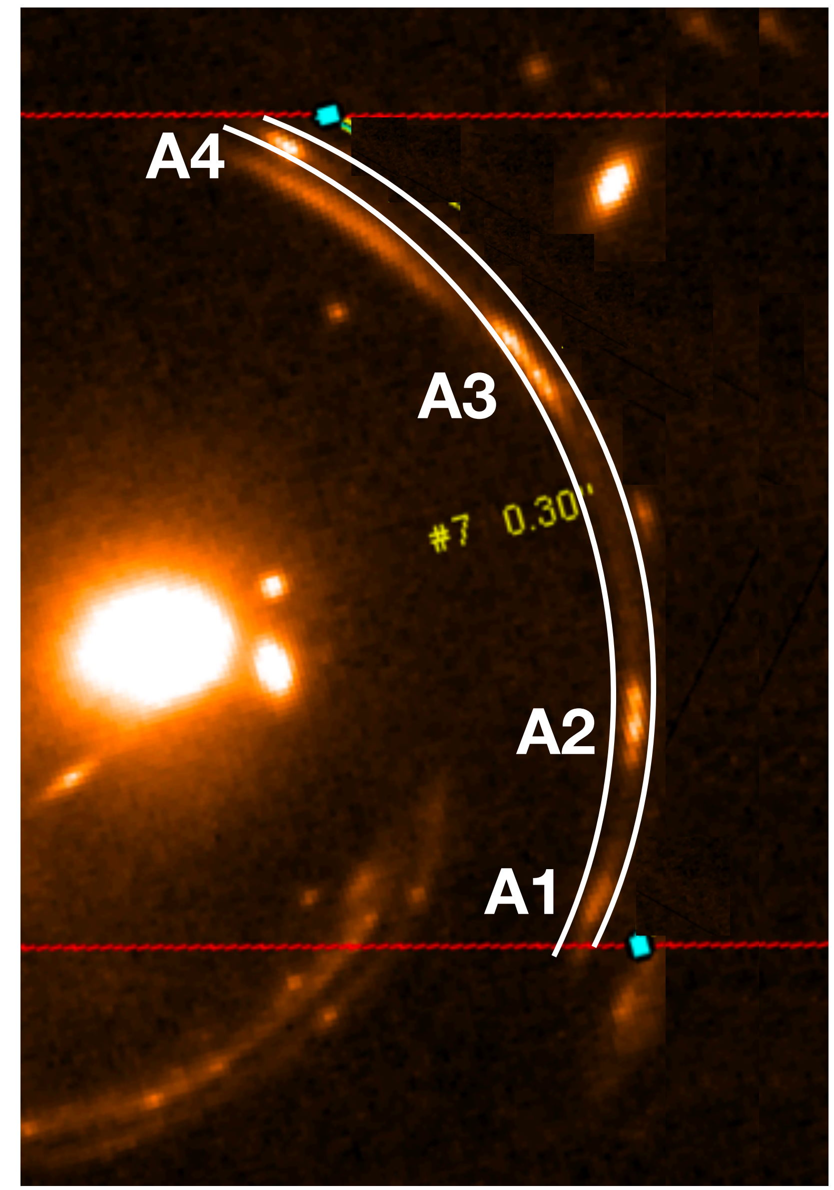
low masses,
log(M_{*}) = 9.1 - 10.3

resolution
~ 200pc



lensed galaxies with ARGOS

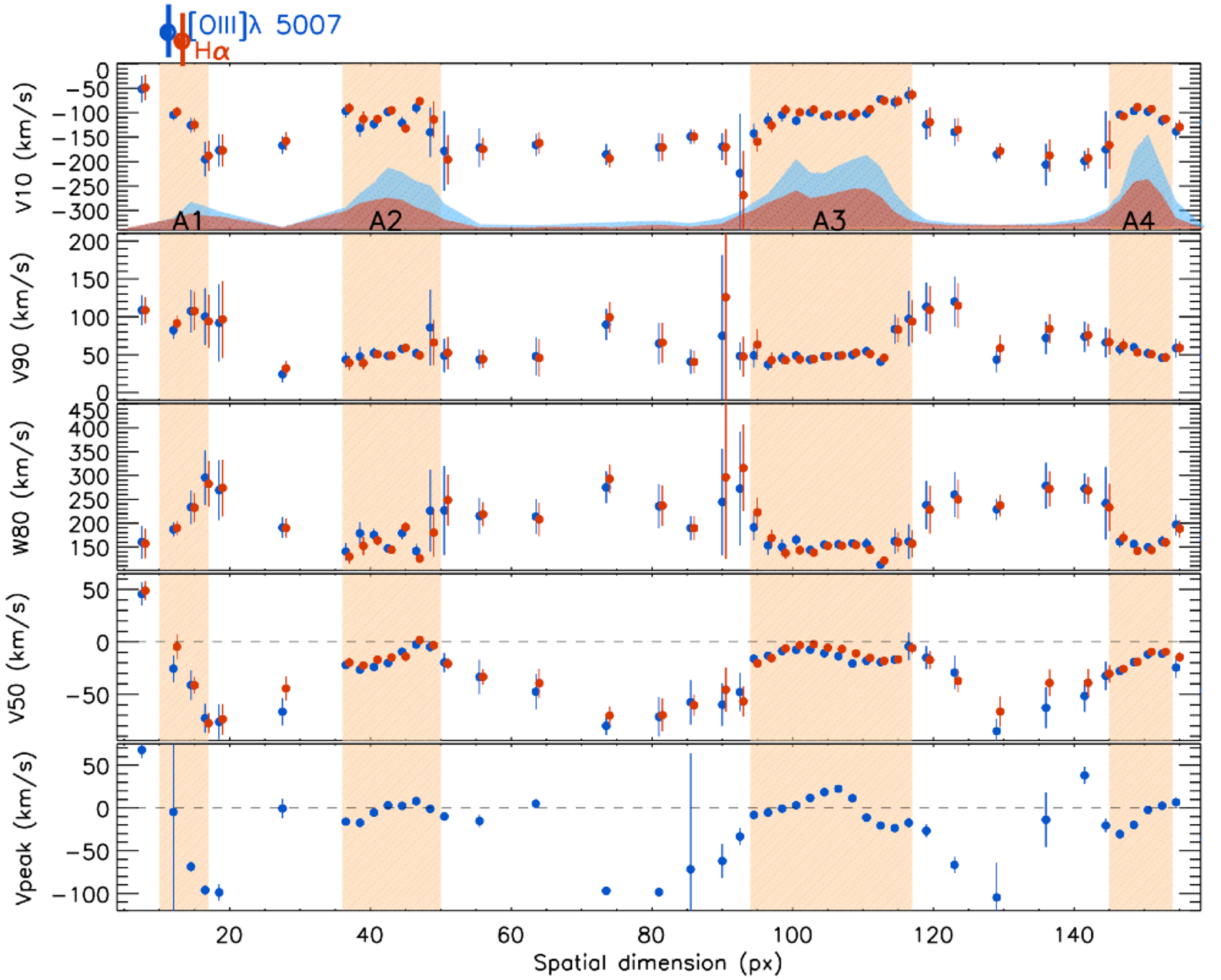


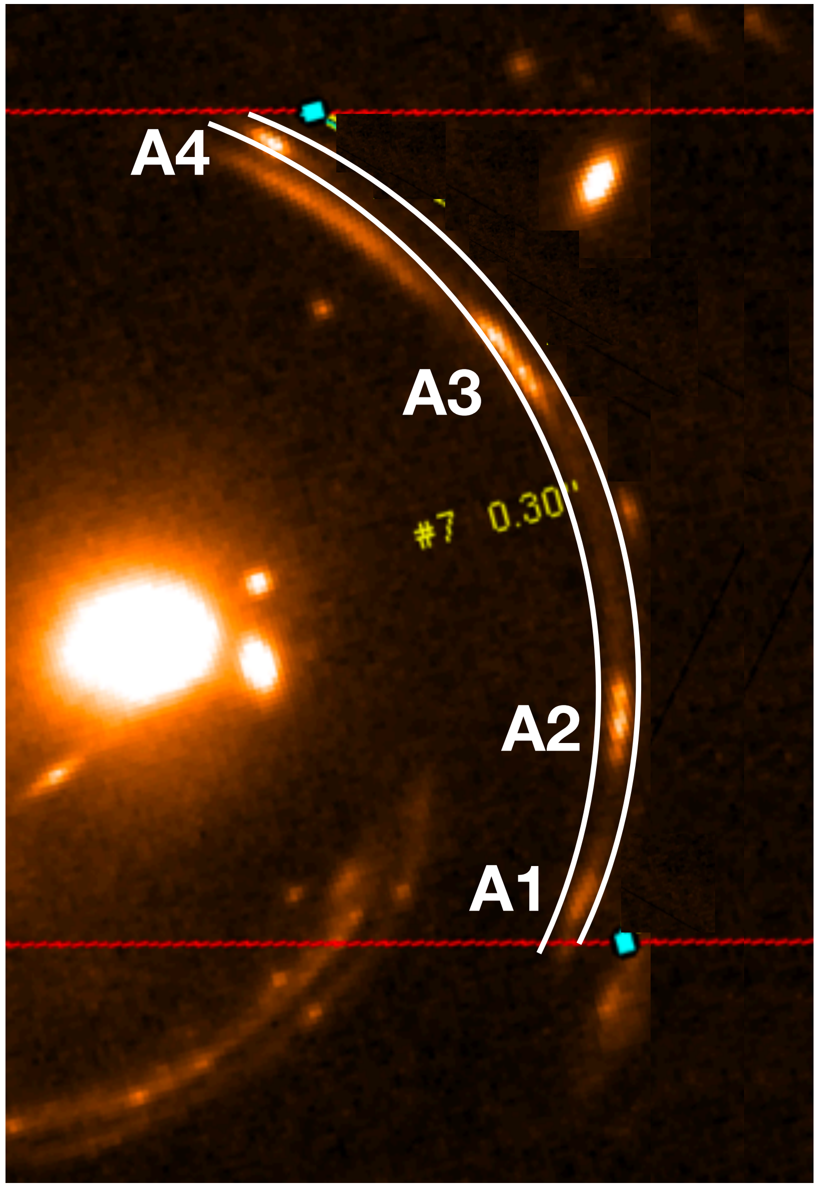


Perna+ in prep.

lensed galaxies with ARGOS

- evidence for outflows





- flat metallicity gradients both within and between the clumps

Perna+ in prep.

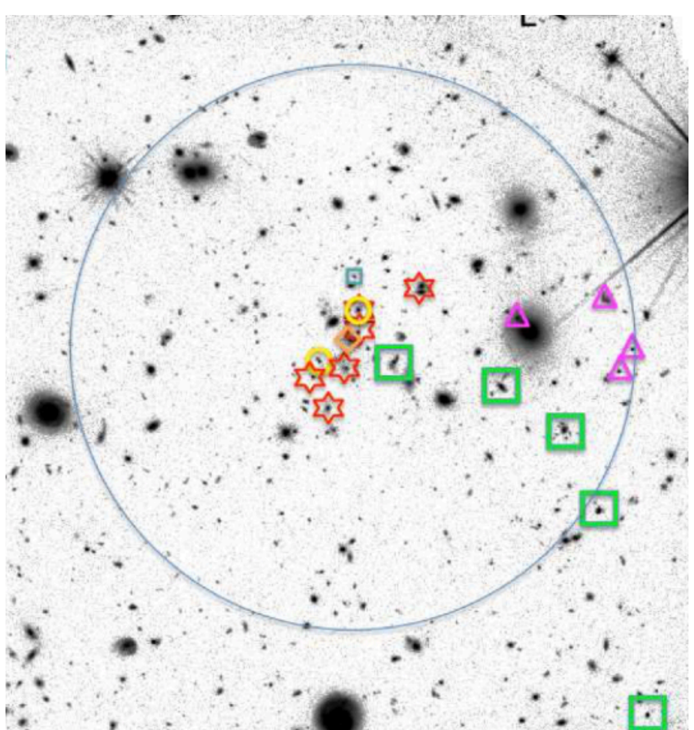
Environment

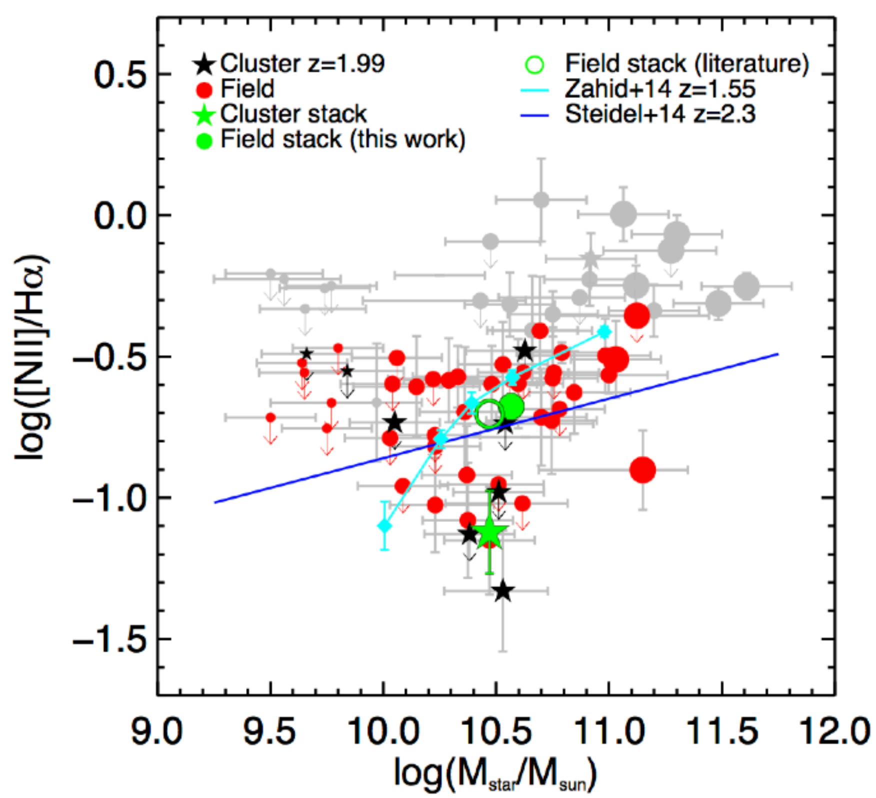
One of the fundamental parameters. Effects:

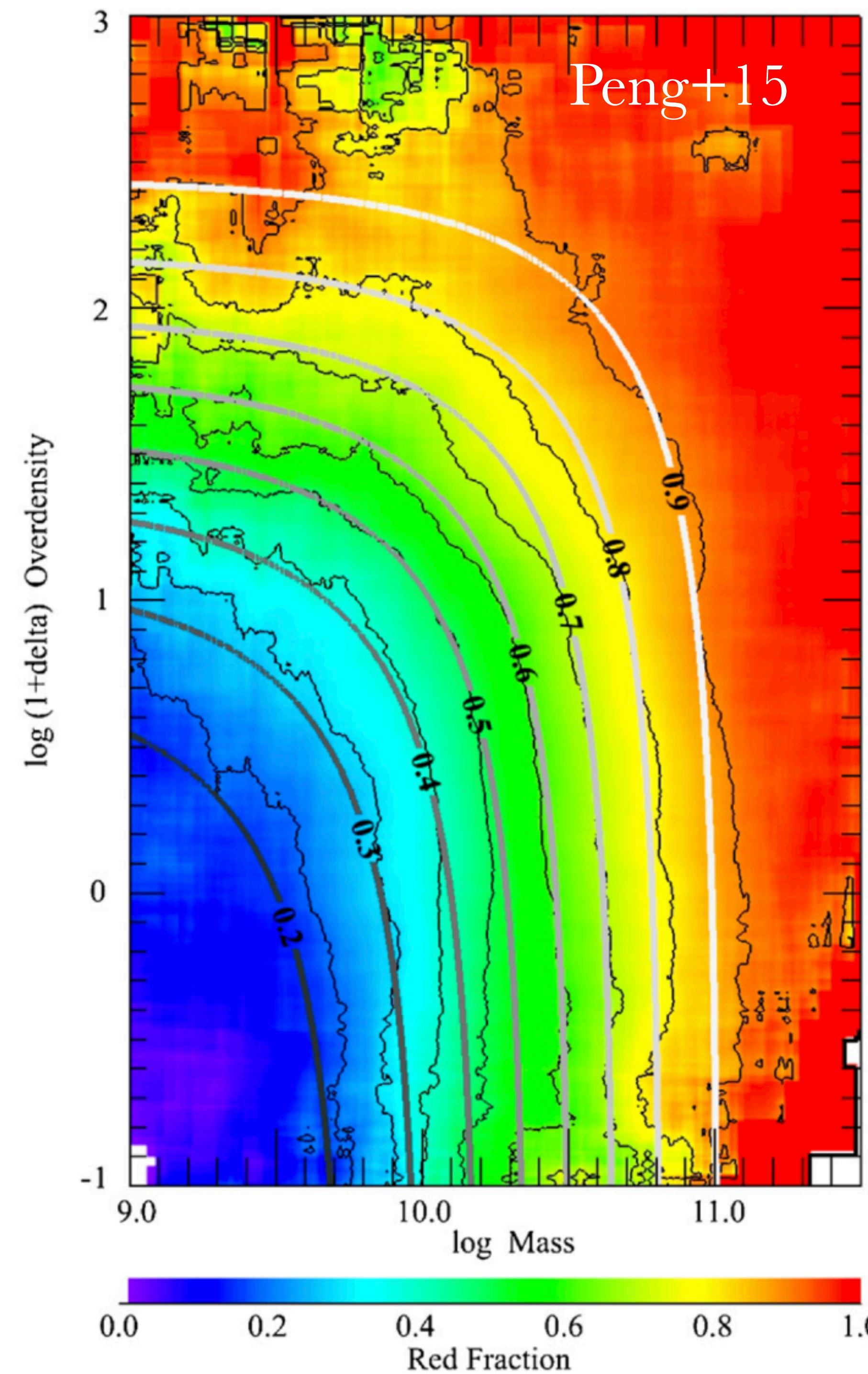
- remove metal-poor gas from the outskirts
- effect on gas recycling
- merger rates
- timescales
- interactions central galaxy - satellites

Limited effects on MZR and FMR (Mouhcine+07, Cooper+08, Ellison+09, Davé+11, Scudder+12, Pasquali+12, Magrini+12, Kulas+13, Hughes+13, Shimakawa+15, Kacprzak+15)

Valentino+15: lower metallicities (0.25 dex, 4σ) in a proto-cluster at z = 1.99.

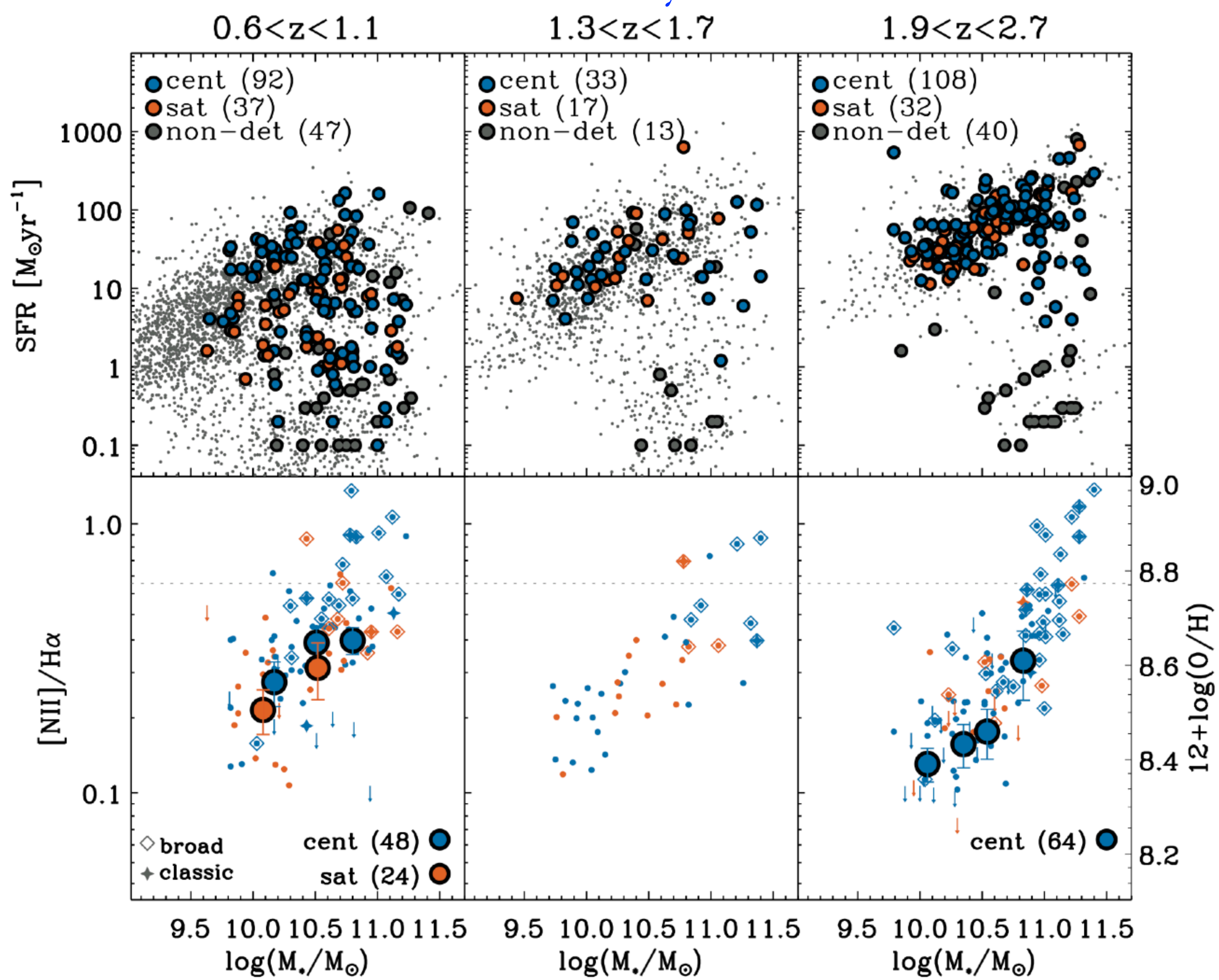






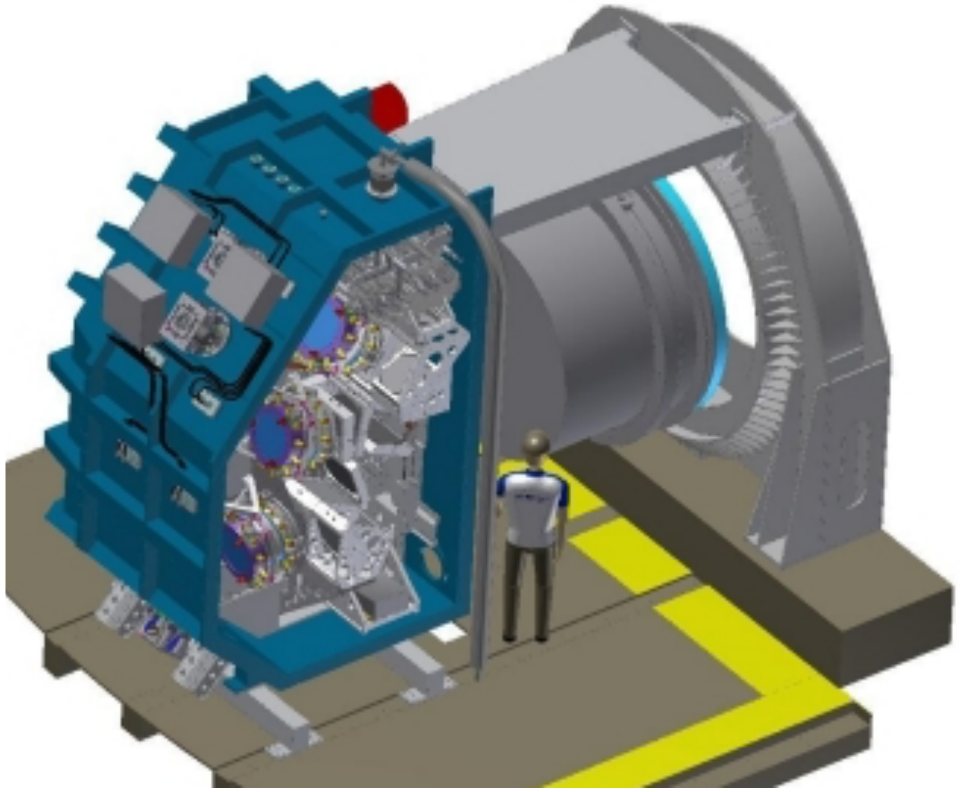
Environment

Wuyts+16



z~0.9: central galaxies have higher metallicities than satellites of 0.06 dex, low significance (<2σ)

NIRSPEC/JWST and MOONS/VLT



1000 fibers, 500 sq.arcmin FoV

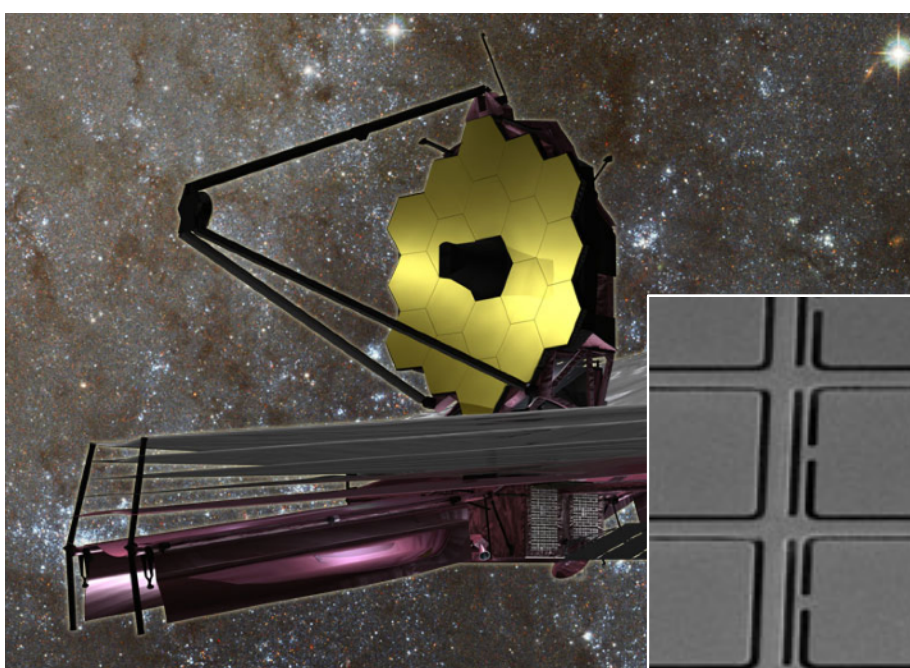
λ: 0.64 -1.8 μm simultaneous wavelength range

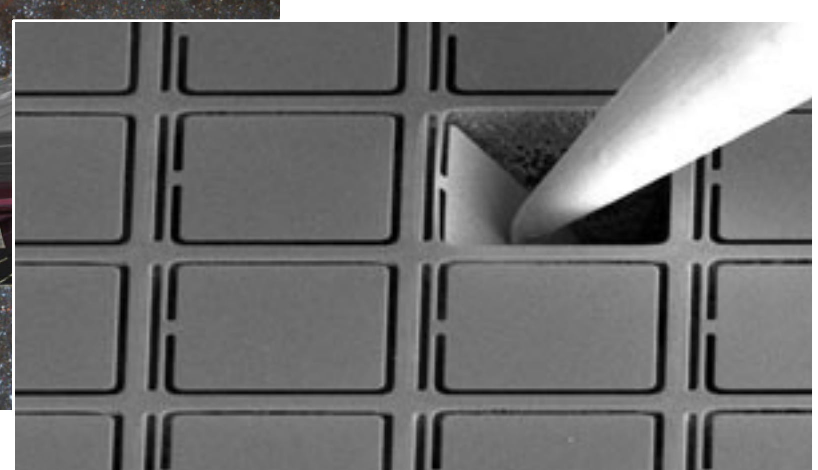
R=4000-6000

100.000 galaxies at 0.5<z<2.5

→ [OII] Hβ [OIII] Hα [NII] [SII]

→ [NeIII]3870 [SII]4069 [OIII]4363 [NII]5755 [OII]7320





R=100, 1000, 2700
λ: 0.6 - 5.3 μm

Conclusions

metallicity: entering the era of precise measurements and model testing

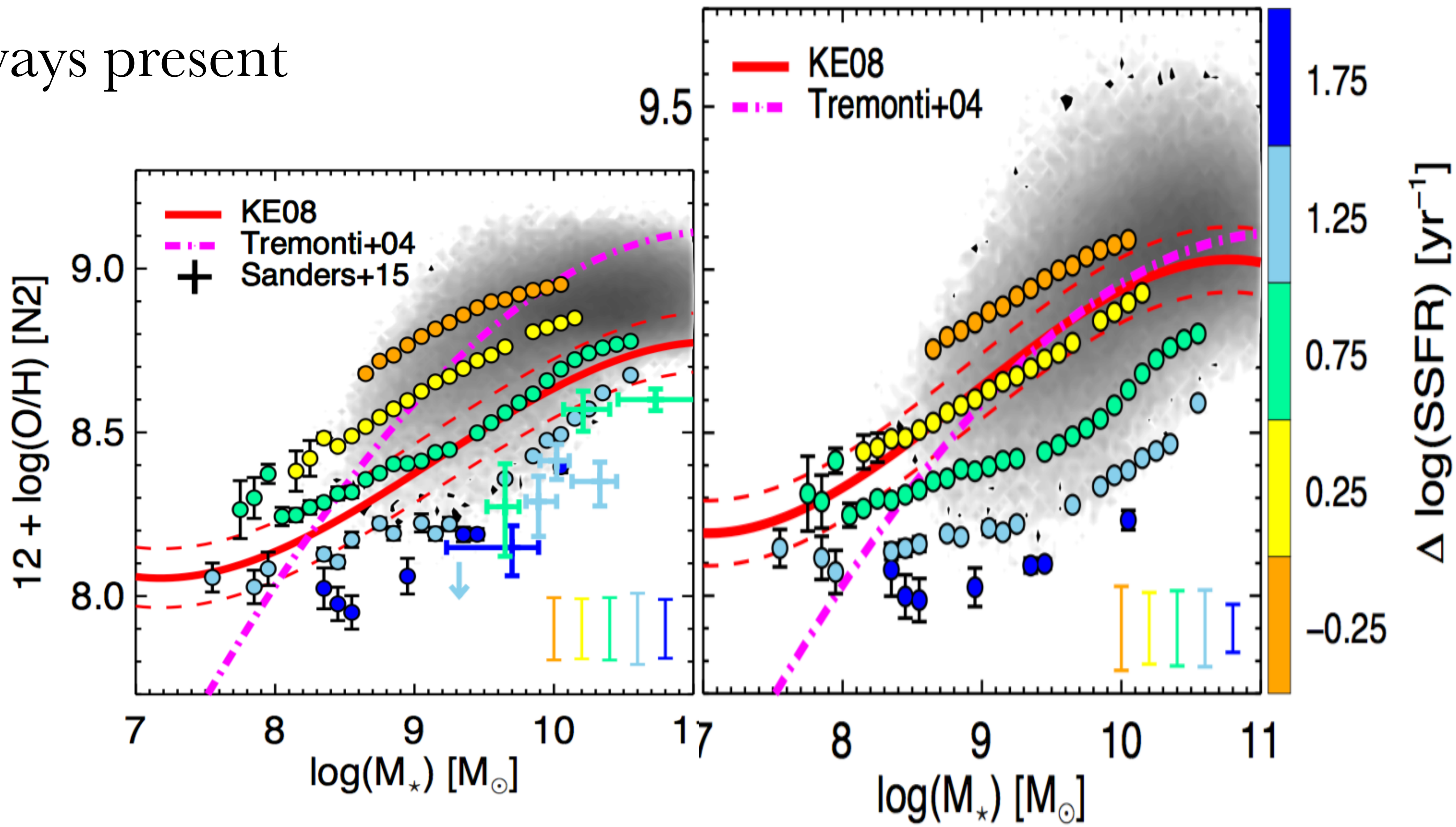
1. more accurate and predictive models
2. more accurate calibrations
3. more powerful multi-object instruments
4. more powerful multi-object IFUs (with and without AO)

- multi-parametric scaling relations
- distribution inside galaxies

- JWST & MOONS will change the landscape

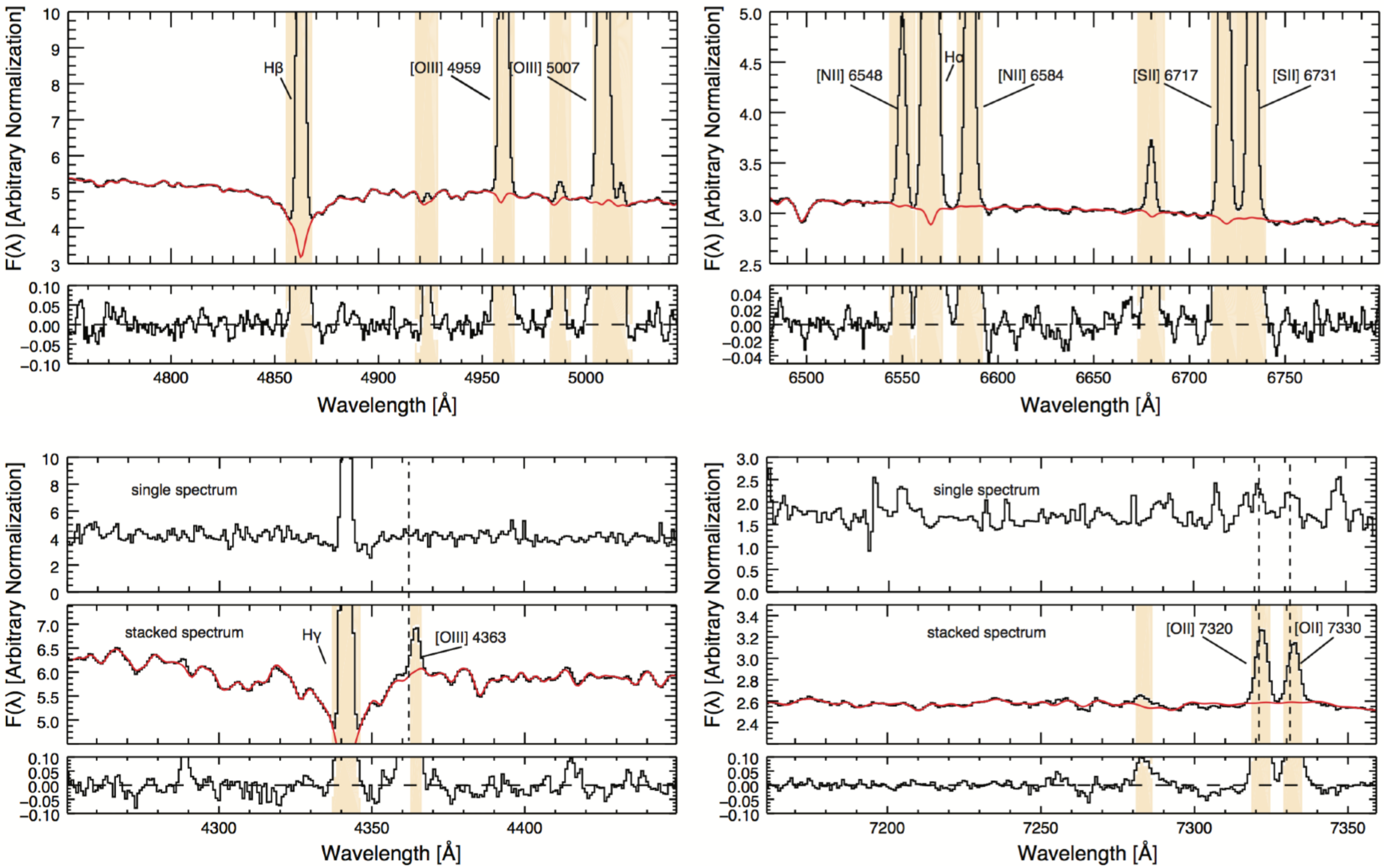
Internal consistency

- differences of the metallicity derived for single galaxies using various calibrations
- not always present



Brown+16

Resulting spectra



Line
(1)
[OII] λ3727
[NeIII]λ3870
[SII]λ4069
Hδ λ4102
Hγ λ4340
[OIII] λ4363
Hβ λ4861
[OIII] λ4960
[OIII] λ5007
[NII] λ5756
[NII] λ6549
Hα λ6563
[NII] λ6584
[SII] λ6717
[SII] λ6731
[OII] λ7320
[OII] λ7330

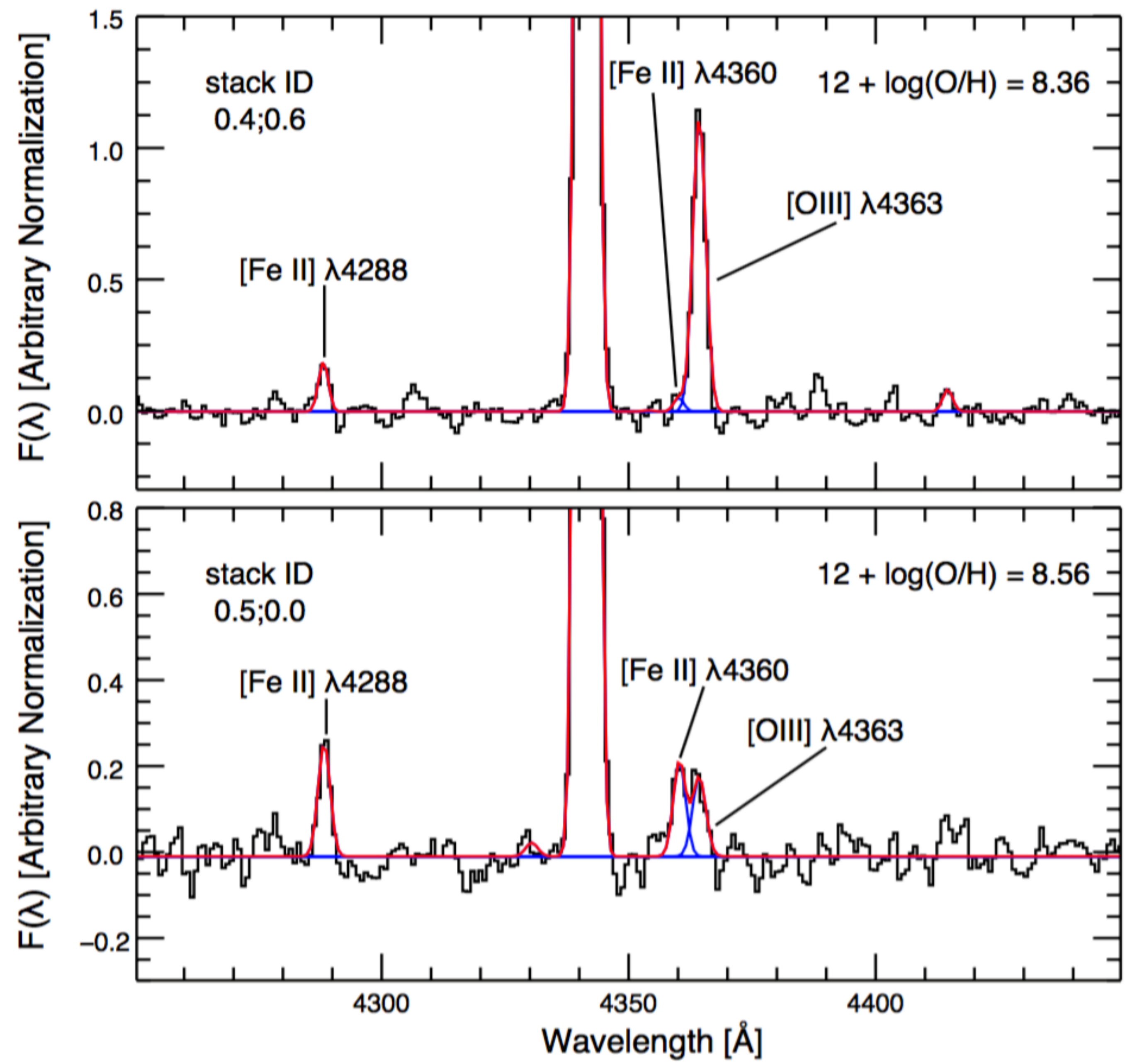
Continuum subtraction: MIUSCAT

Vazdekis+12, Ricciardelli+12, Falcón-Barroso+11, Cenarro+01, Vazdekis+10; Sánchez-Blázquez+06

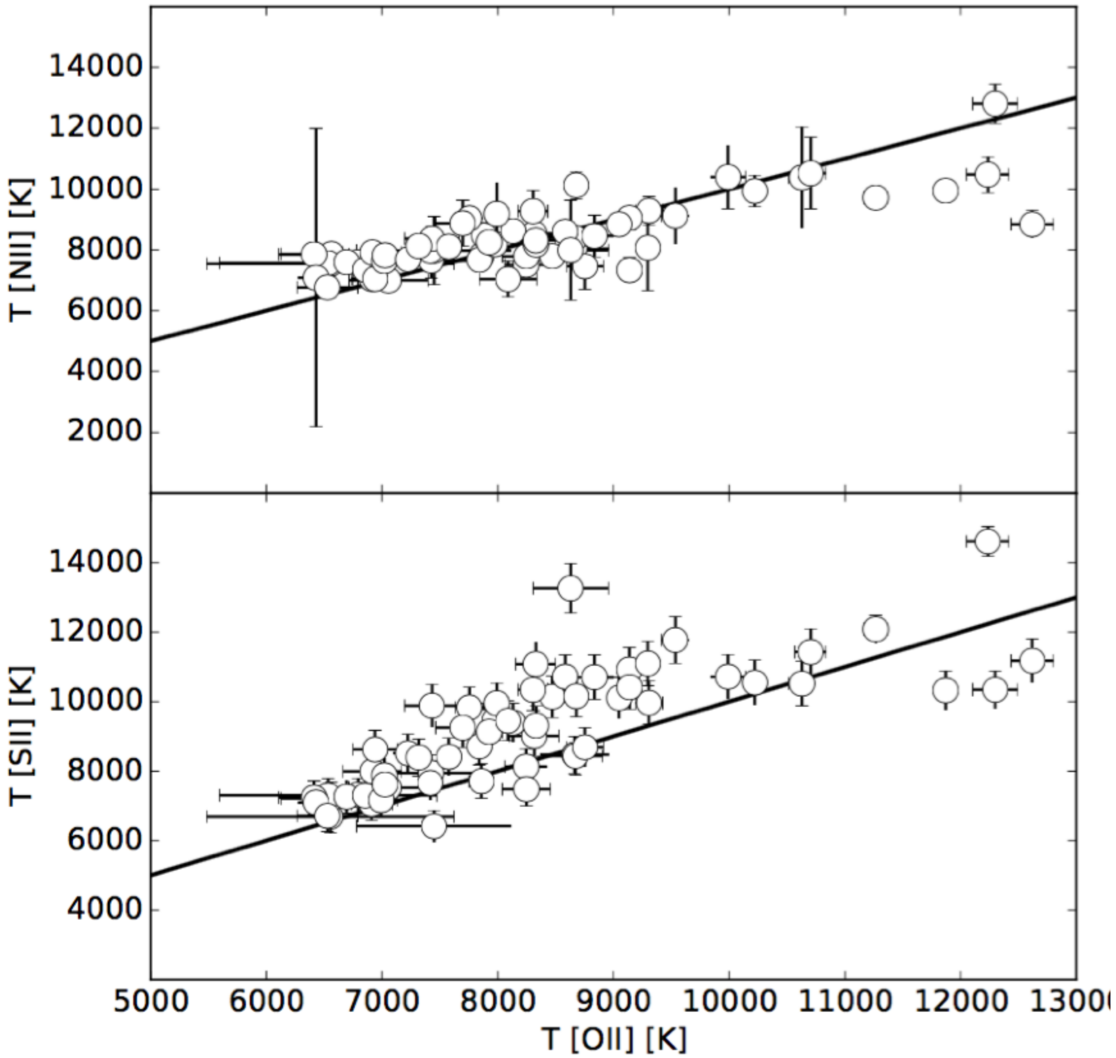
Iron below Oxygen ?

- [OIII]4363 is contaminated in high-metallicity galaxies (12+log(O/H)≳8.3)
- [OIII]4363 flagged "unreliable" when f(FeII)>0.5 · f(OIII)

Problem in old measurements of Te?



Measuring temperature

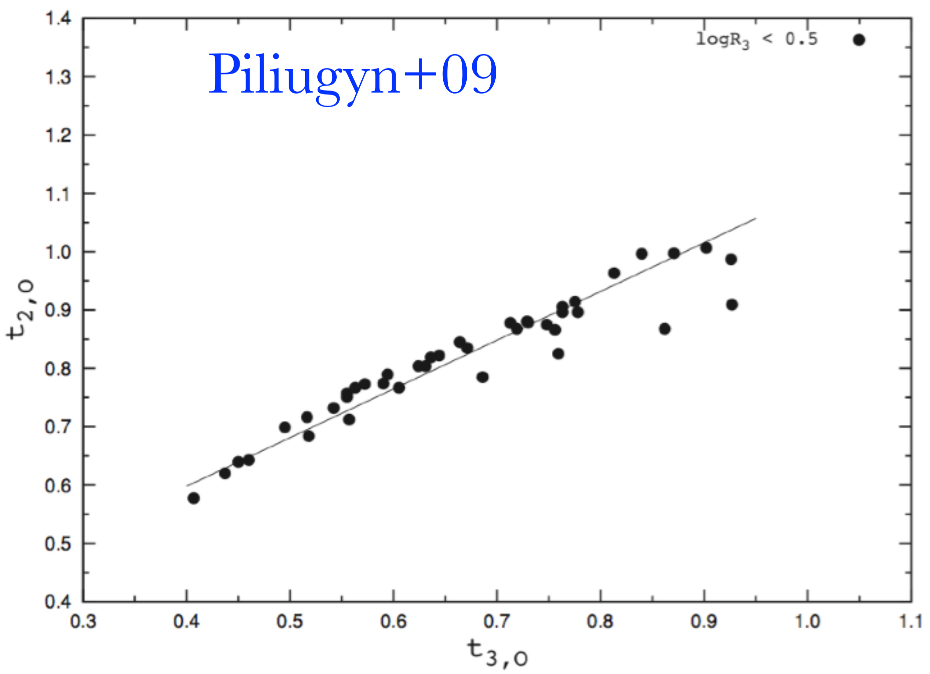


$T_2[NII] \sim T_2[OII]$

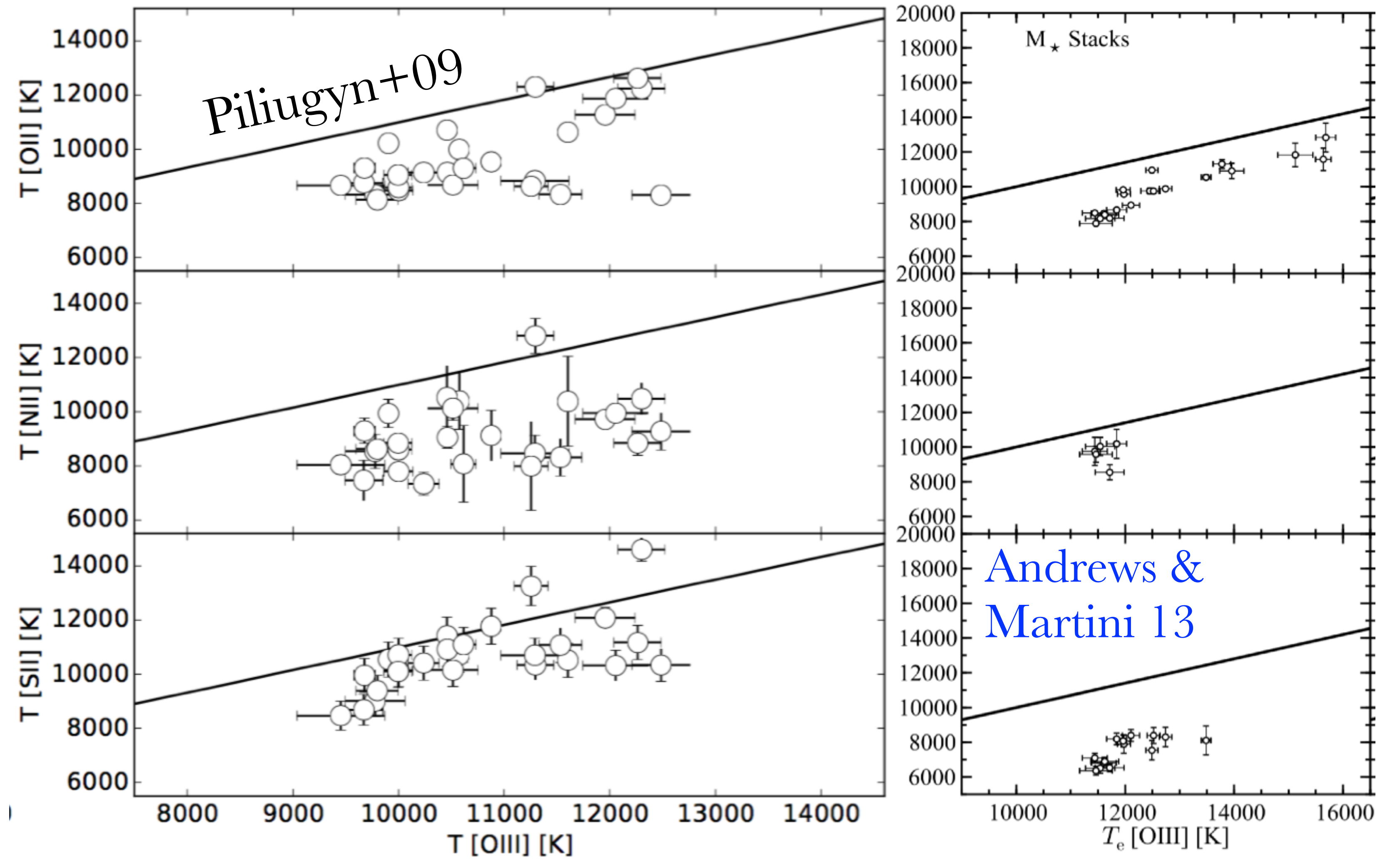
$T_2[SII] > T_2[OII]$

t2 - t3

HII regions



SDSS galaxies

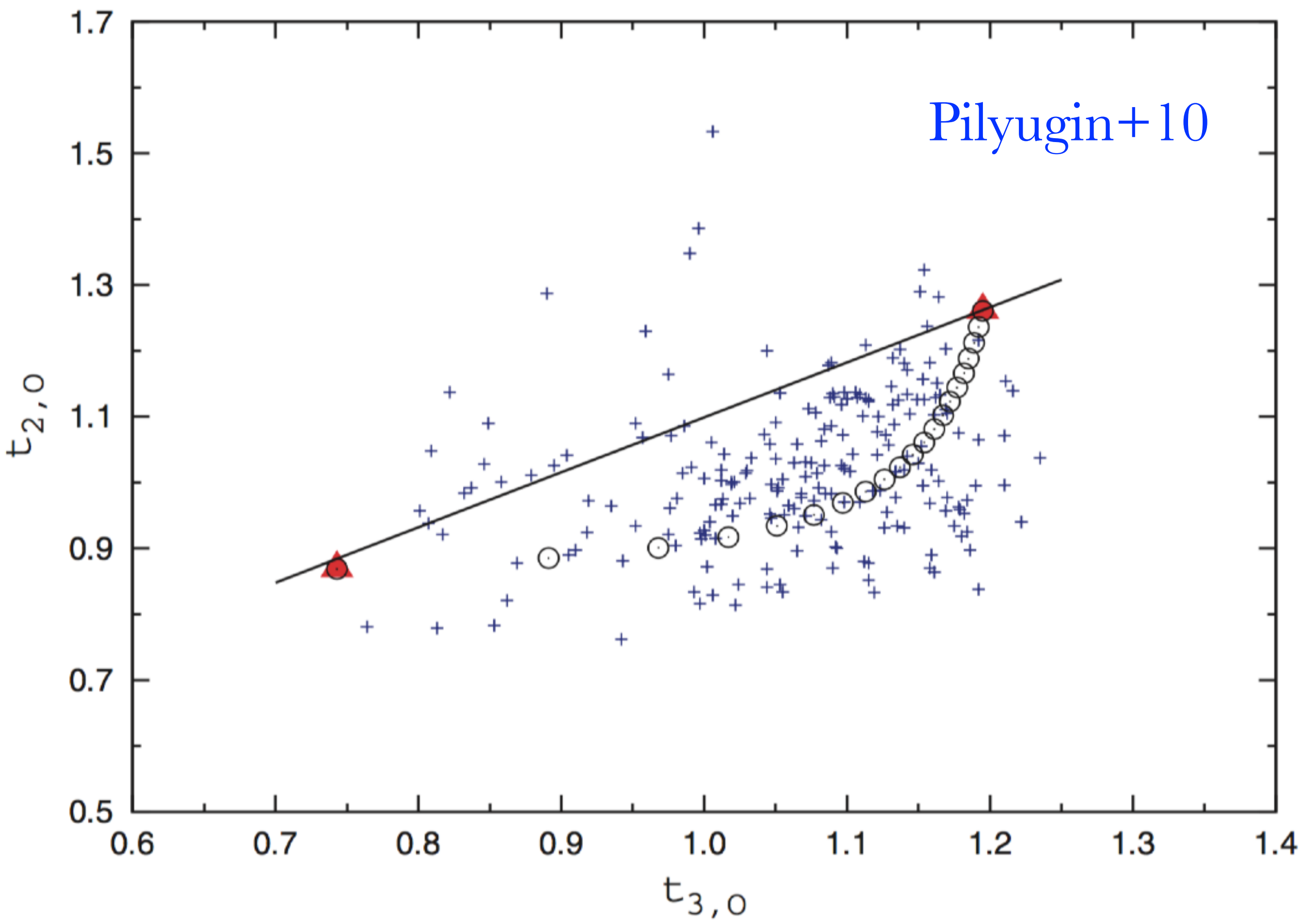


- different relations between galaxies and HII region

Campbell+86, Garnett 92; Izotov+06; Pilyugin+06, 09, 10, Andrews&Martini13

t2 - t3

- Mixing between HII regions with different temperatures?
- Diffused gas?



Moustakas & Kennicutt 2006, Pilyugin+10

galaxies without lines: f-f relation

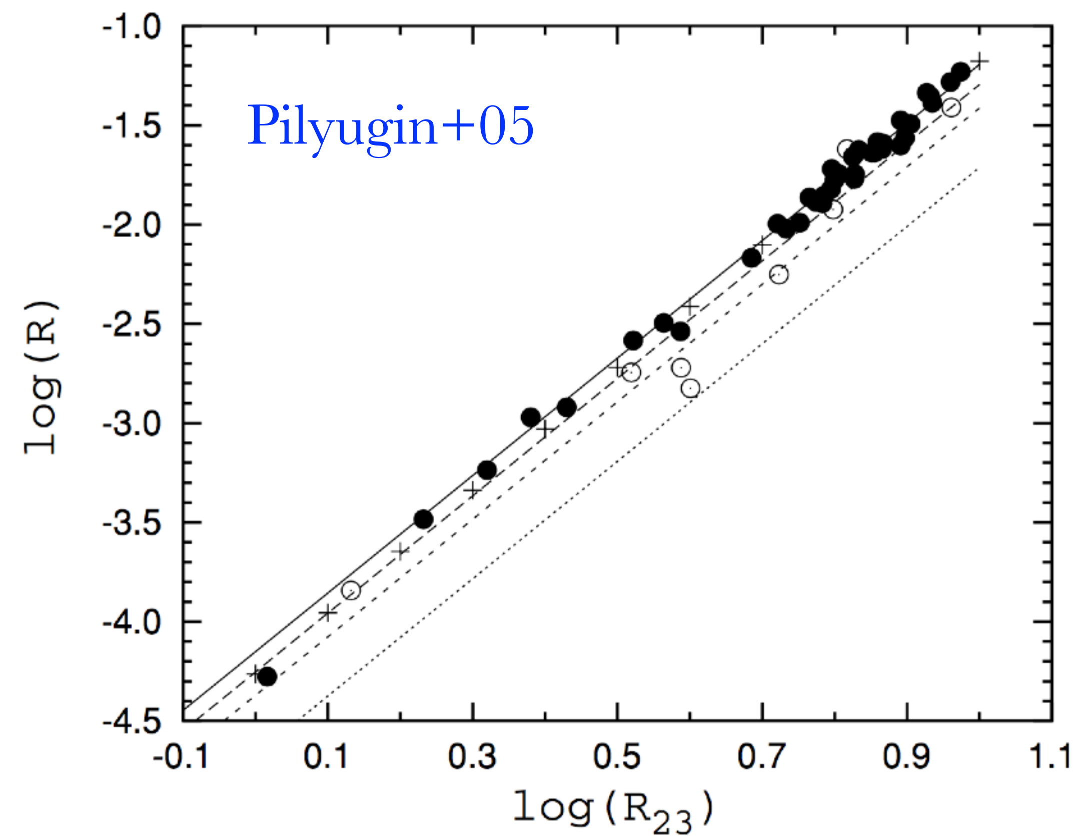
observed relation between auroral and strong lines

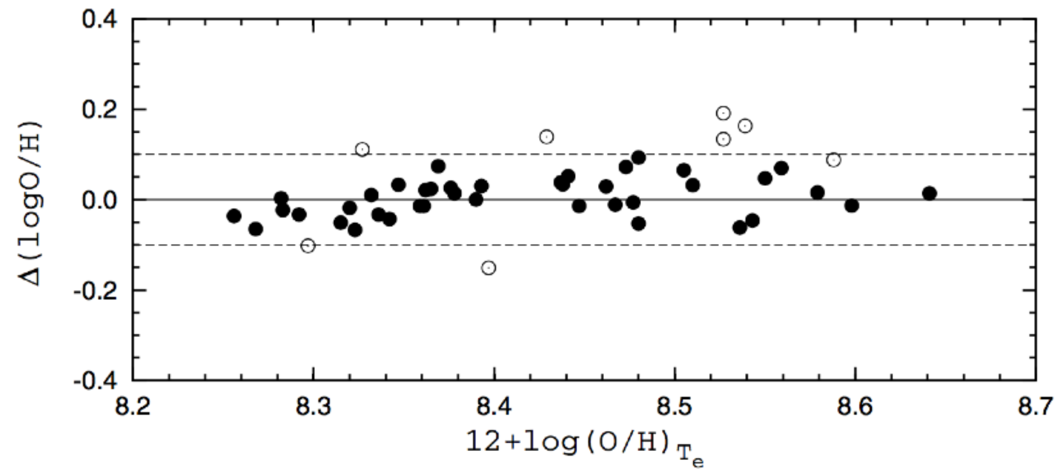
1 - [OIII]

$$R = \frac{[OIII]4363}{H\beta}$$

$$P = \frac{[OIII]4959,5007}{[OIII]4959,5007\ +\ [OII]3727}$$

$$R3 = \frac{[OIII]4959,5007}{H\beta}$$





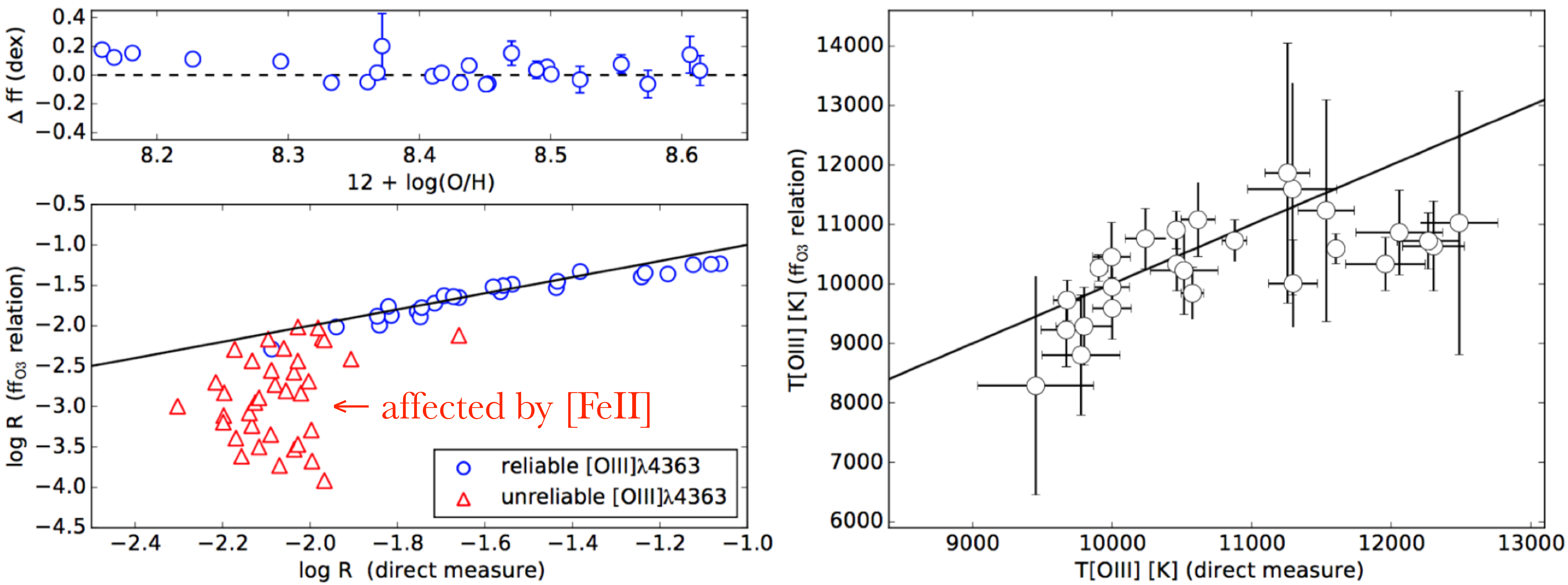
$$\log R = -4.151 - 3.118 \log P + 2.958 \log R_3 - 0.680 (\log P)^2$$

Pilyugin+05, 06

galaxies without lines: f-f relation

observed relation between auroral and strong lines

1 - [OIII]

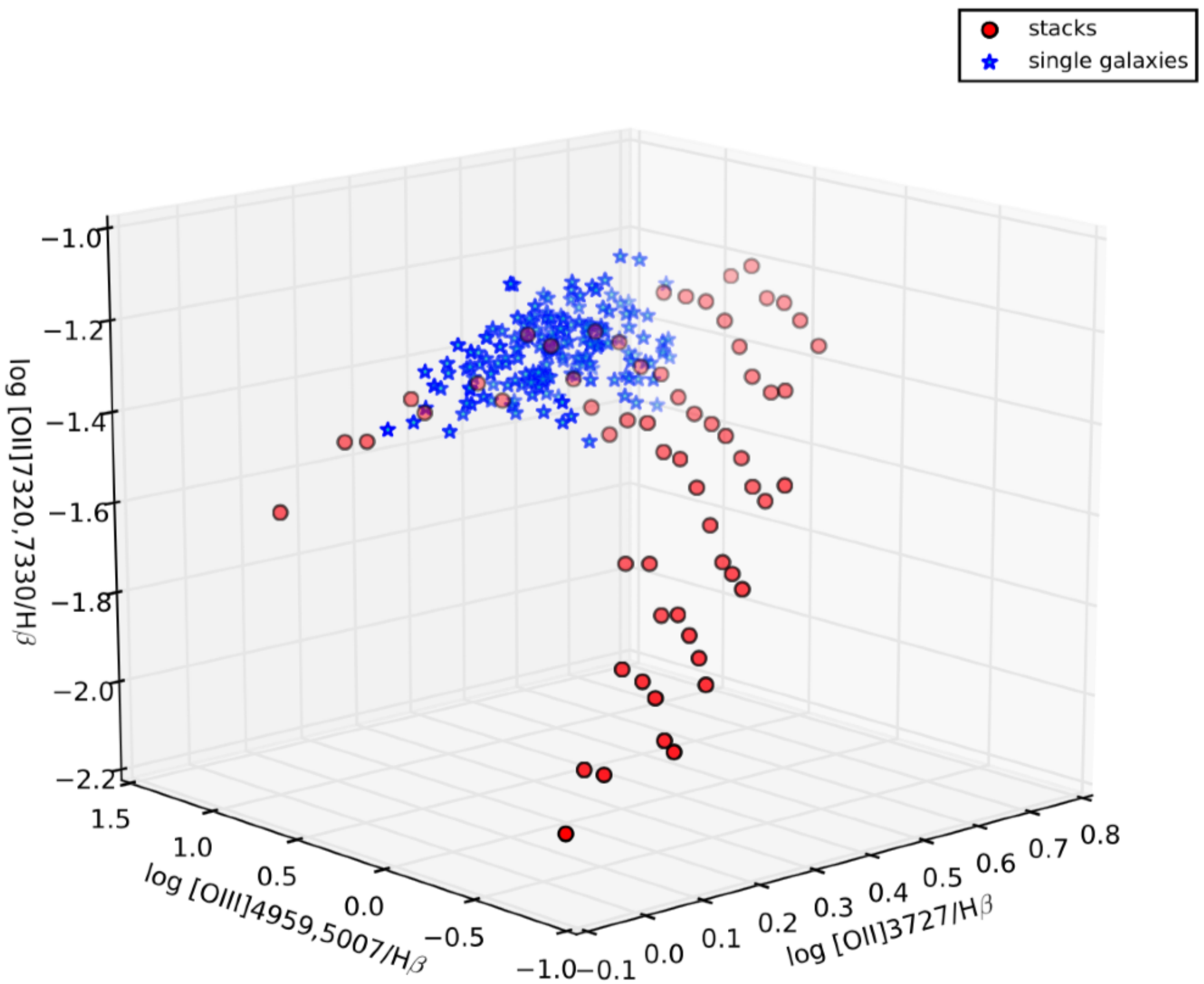


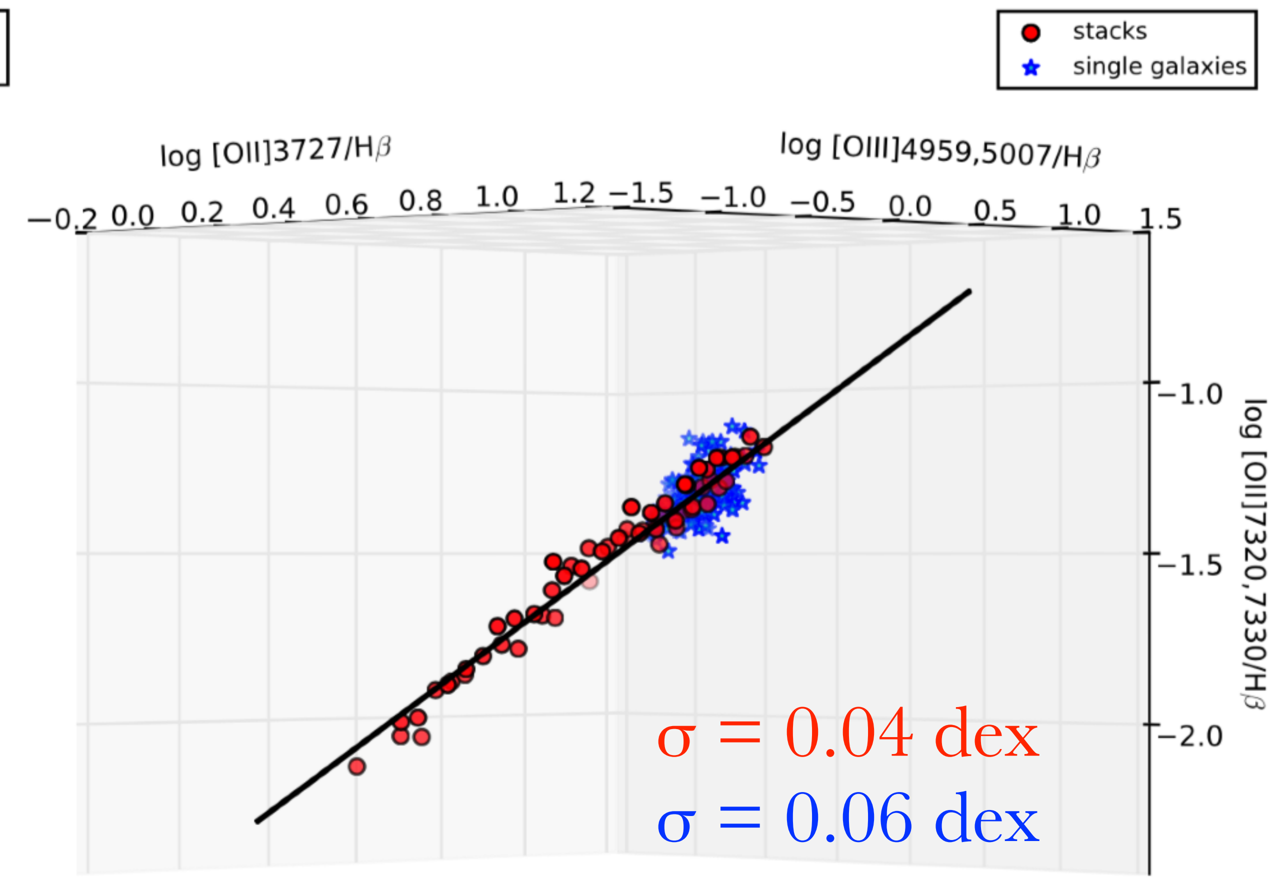
$$\log R = -4.151 - 3.118 \log P + 2.958 \log R_3 - 0.680 (\log P)^2$$

galaxies without lines: f-f relation

observed relation between auroral and strong lines

2 - [OII]7320,7330 combination of [OII]/Hβ and [OIII/Hβ





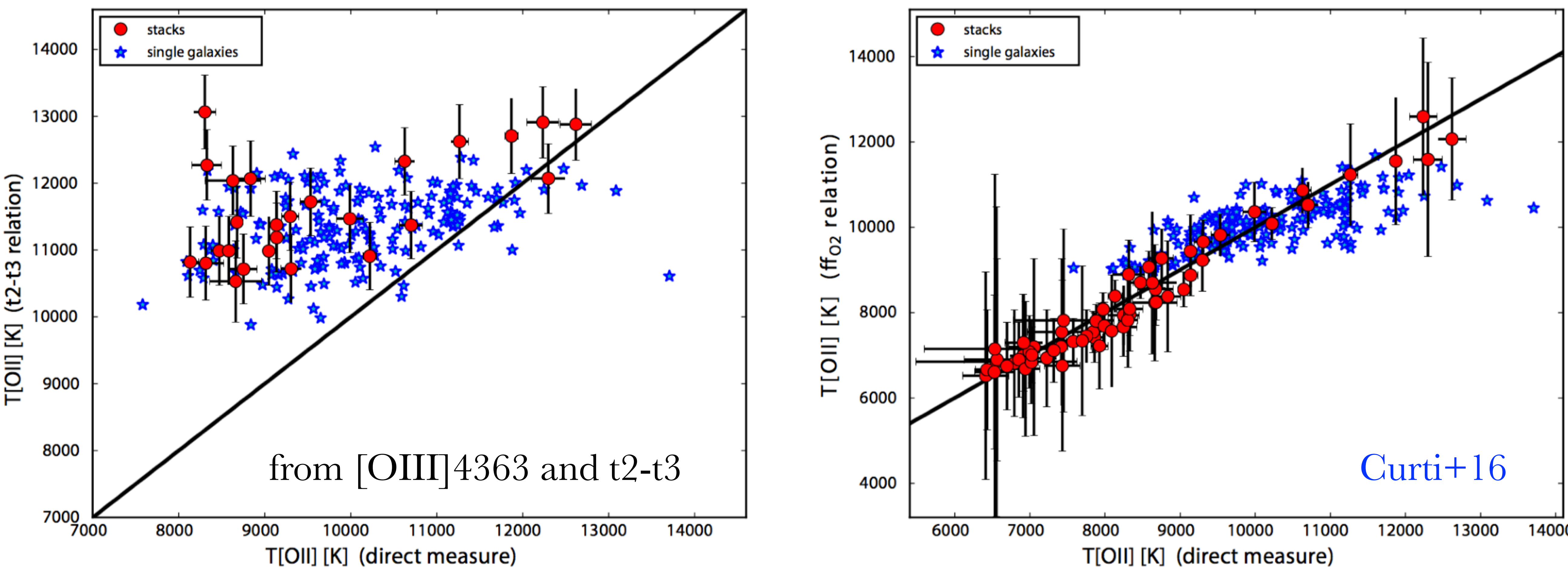
$$R_{[\mathrm{O\,II}]} = I_{[\mathrm{O\,II}]\ \lambda7320,7330}/I_{\mathrm{H}\beta}$$

$$\log R_{[\mathrm{O\,II}]} = -1.913 + 0.806 \log R_2 + 0.374 \log R_3$$

galaxies without lines: f-f relation

observed relation between auroral and strong lines

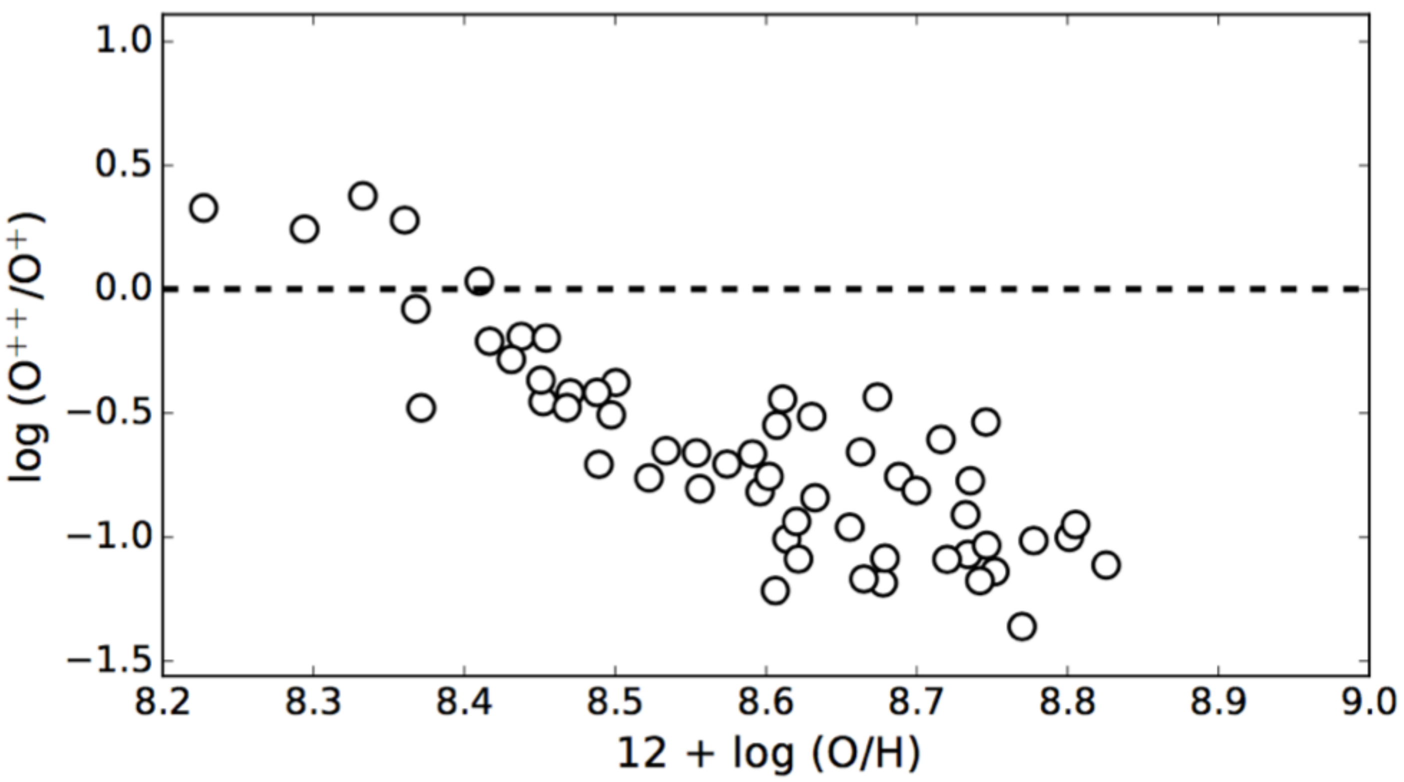
2 - [OII]7320,7330



$$\log R_{[\mathrm{OII}]} = -1.913 + 0.806 \log R_2 + 0.374 \log R_3$$

Deriving O/H

- pyneb from: temperature, density, line flux ratios
  - O^+ and O^{++}



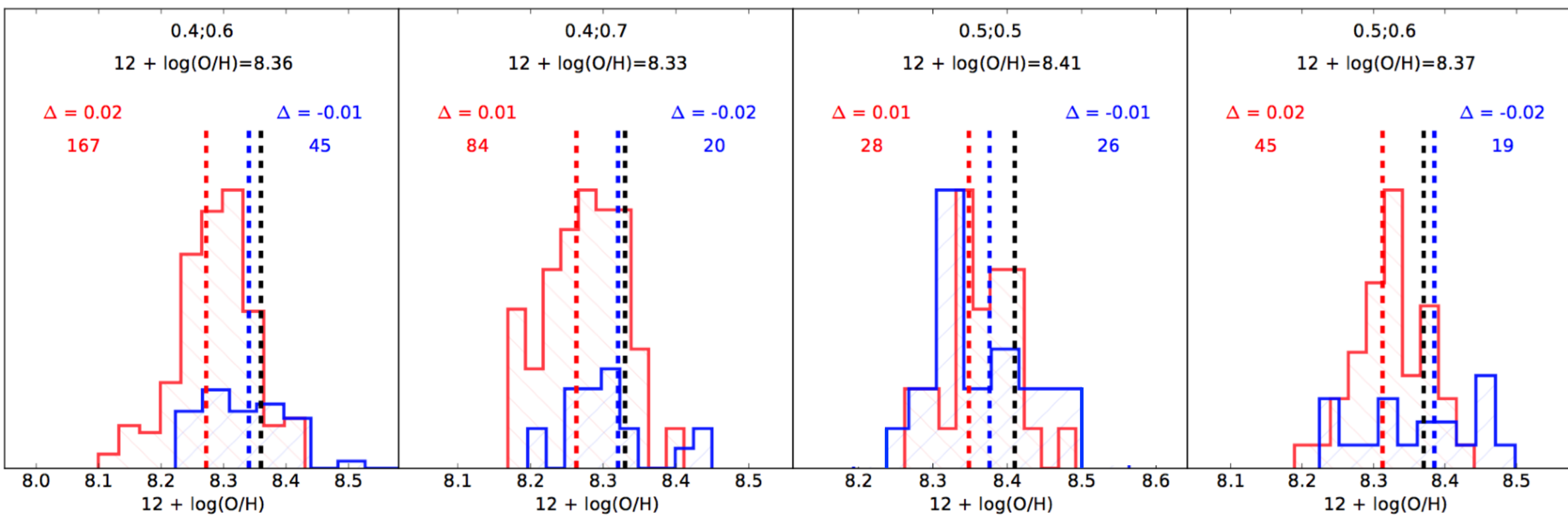
Tests of the method

1. similar values of both R2 and R3 correspond to similar metallicities
2. stacking does not introduce undesirable effects

Single galaxies:

- from Pilyugin+10 with detected [OIII]4363 and [OII]7320,7330
- from SDSS7 with detected [OIII]4363 ([OII] from ff relation)

Same procedure



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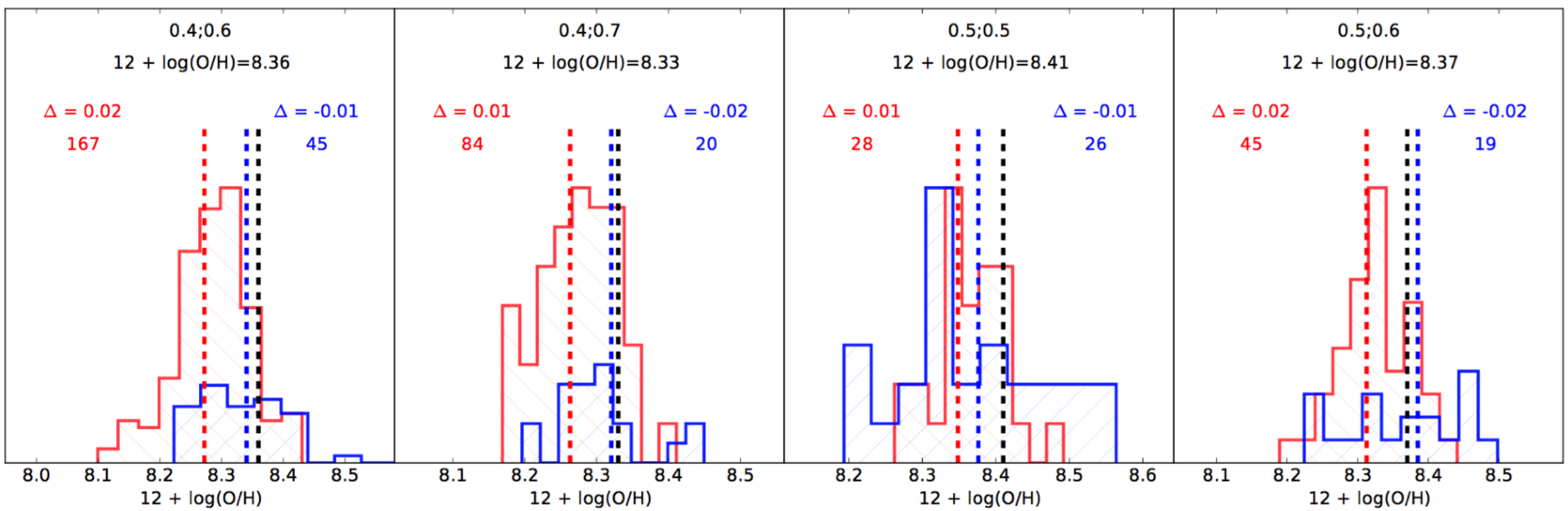
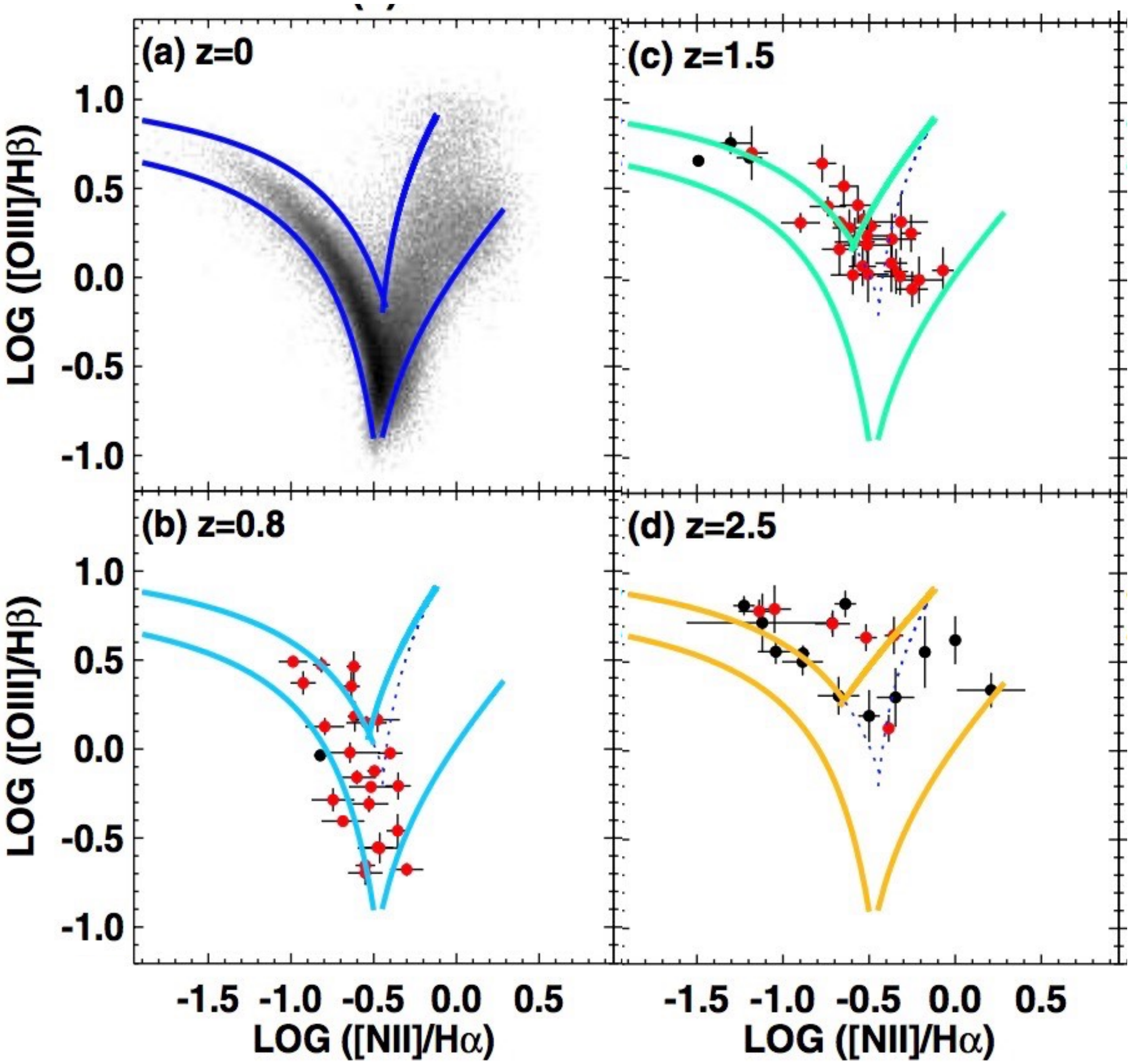
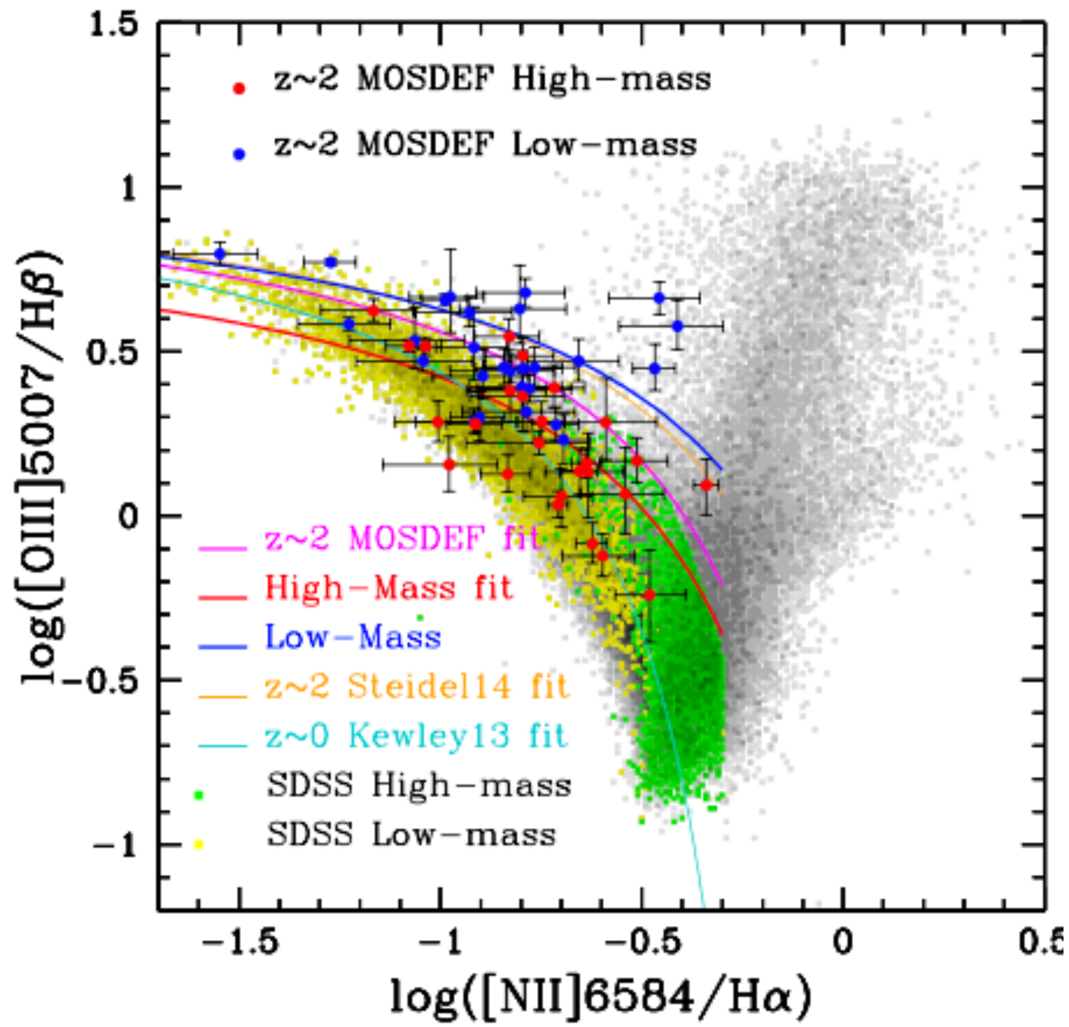


Evolution of line ratios and BPT



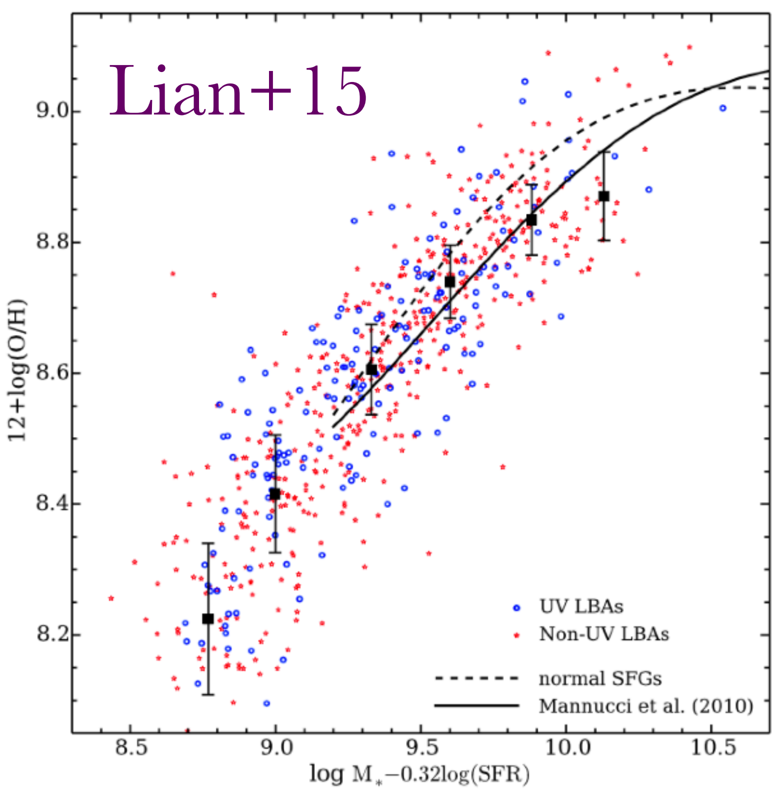


evolution of BPT diagram at z>0.8 as a function of mass and SFR

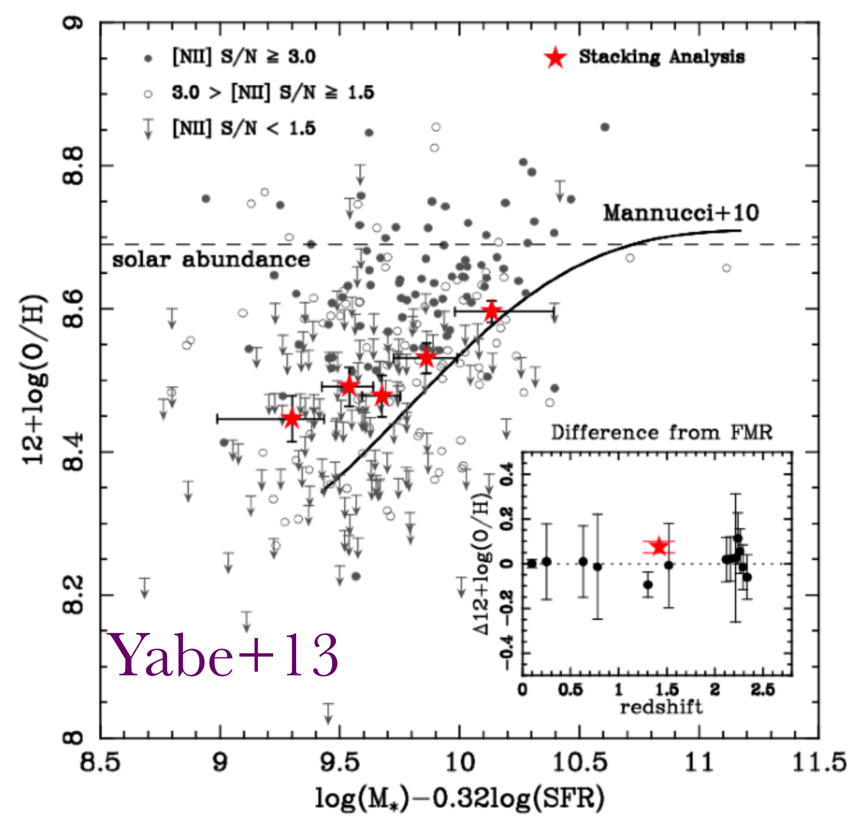
Observational status of FMR

- Numerous confirmations (predictions!) at all redshifts

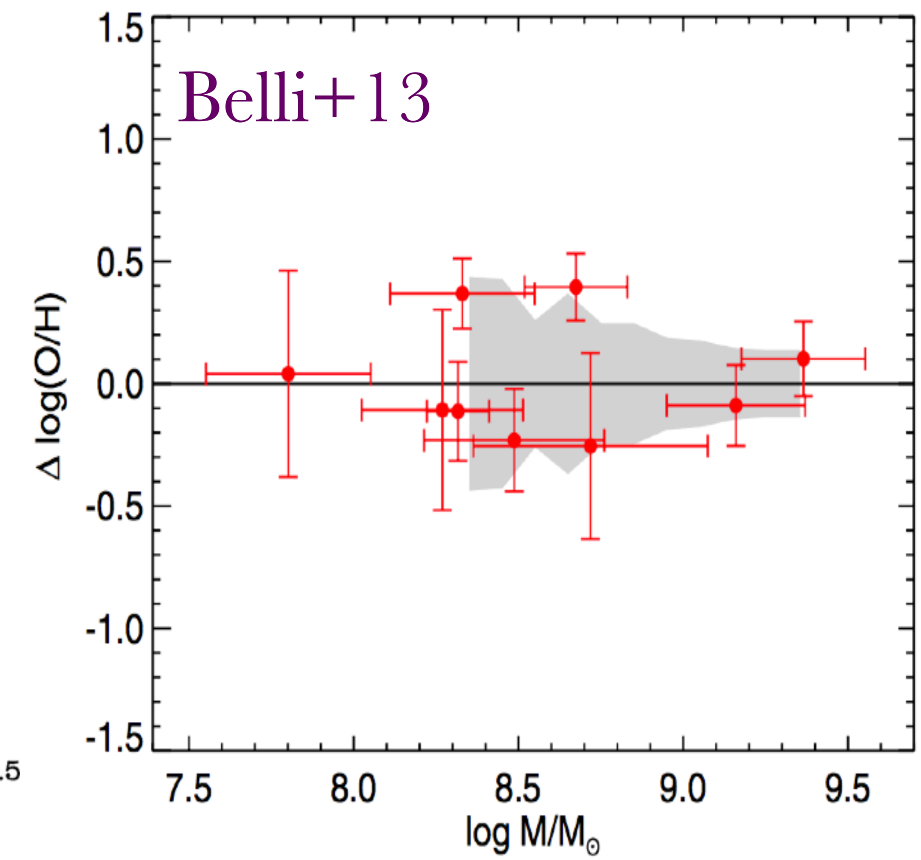
LBG-analogs, z~0.1, high SFRs



K-selected, z~1.4



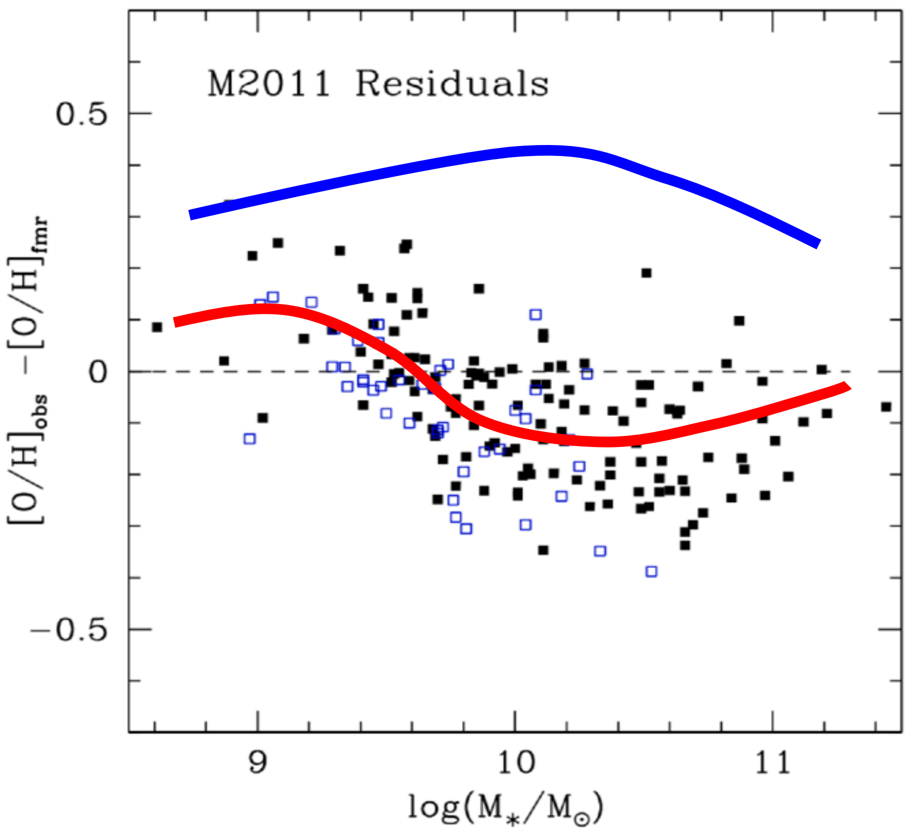
grav. lensed galaxies, 1.5<z<3, low-mass



- wide range of selections, properties, and redshifts
- cautions when selecting in metallicity (OIII4363, OIII5007)

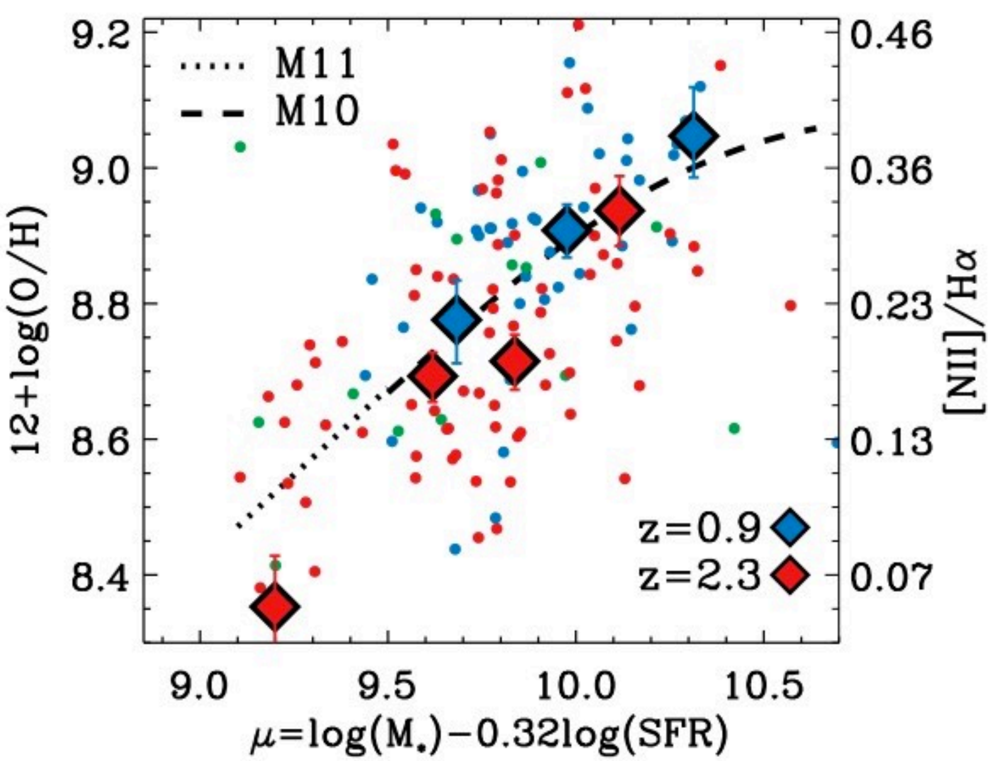
Richard+10, Nakajina+11, Erb+10, Contini+11, Sanders+11, Dessauges+11, Cresci+12, Wuyts+12, Roseboom+12, Cullen+13, Pilyugin+13, Ly+13, Belli+13, Henry+13a,13b, Yabe+13, Maier+14, Stott+14, Lian+15

Redshift evolution of the FMR



Steidel et al. 2014: 179 galaxies at z~2.3 with MOSFIRE:

We find that the dependence of inferred gas-phase metallicity on SFR at a given M∗ is much weaker at high redshift than at z ∼ 0, indicating that z ∼ 2.3 galaxies do not adhere to the same "fundamental metallicity relation" as star-forming galaxies at low redshift.



Wuyts et al. 2014: 222 z~2.2 with SINFONI/KMOS:

"our data do not show a correlation between the [N II]/Ha ratio and SFR, which disagrees with the 0.2-0.3 dex offset in [N II]/Ha predicted by the "fundamental relation" between stellar mass, SFR and metallicity discussed in recent literature"

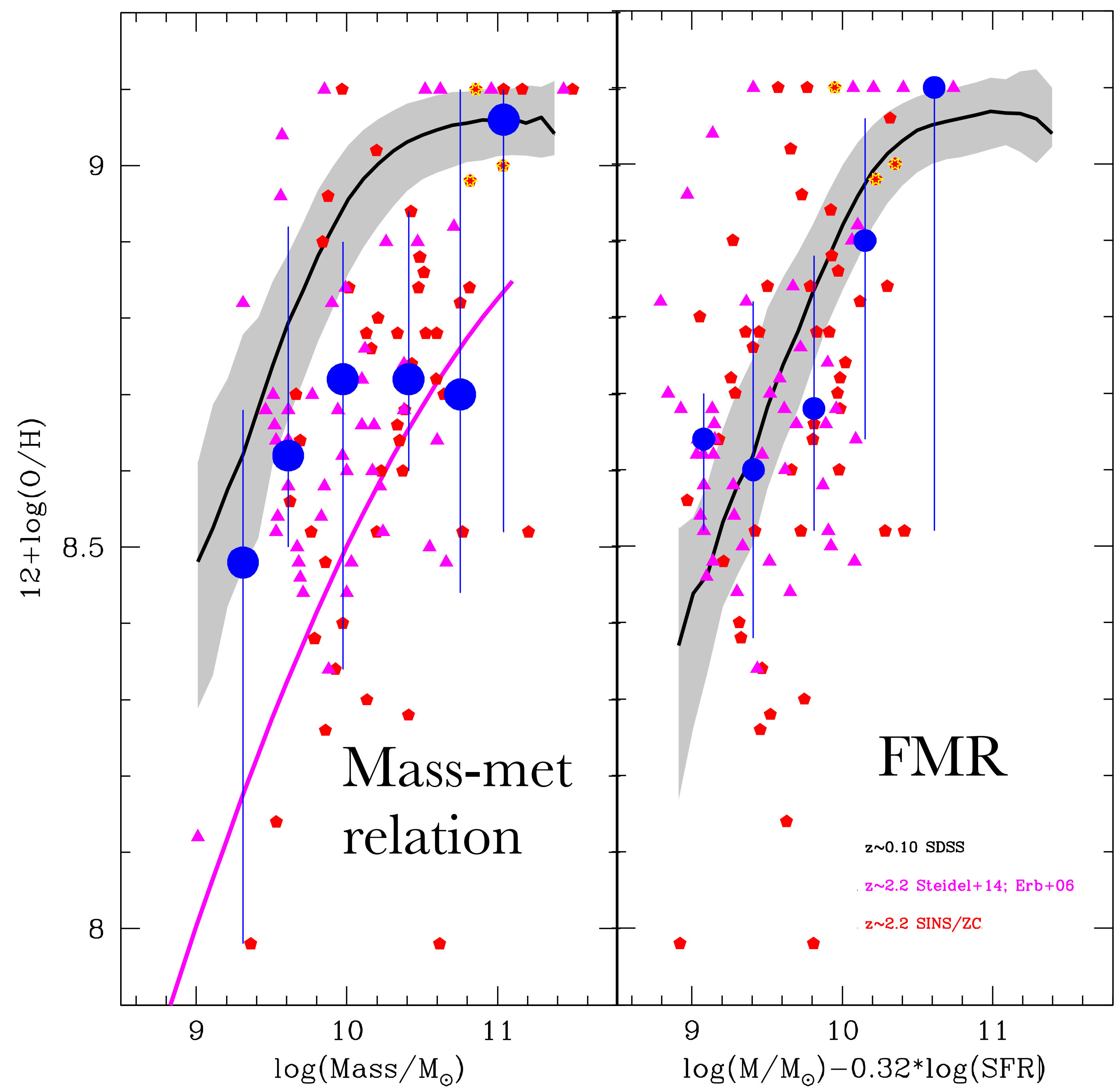
Redshift evolution of the FMR

scatter can be reduced by considering SFR only if the intrinsic scatter is smaller than the dependence on SFR

1. quality of data:
   - metallicity
   - SFR
   - mass
2. range in SFR (usually narrow)
3. mass range
4. larger intrinsic scatter at high redshifts

FMR: prediction of the median value of metallicity from local galaxies

mass-metallicity relations: different parts of the same FMR



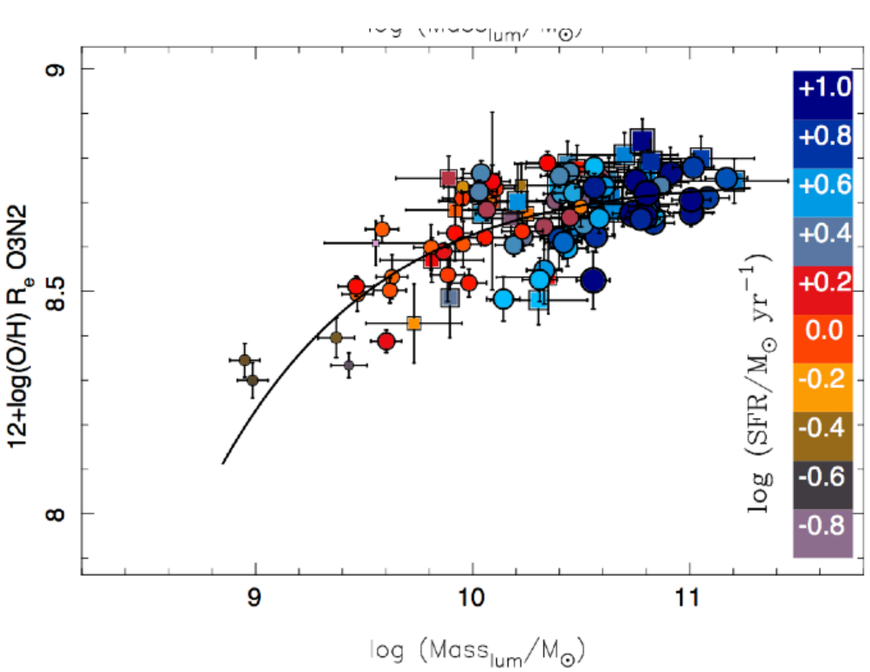
FMR and apertures

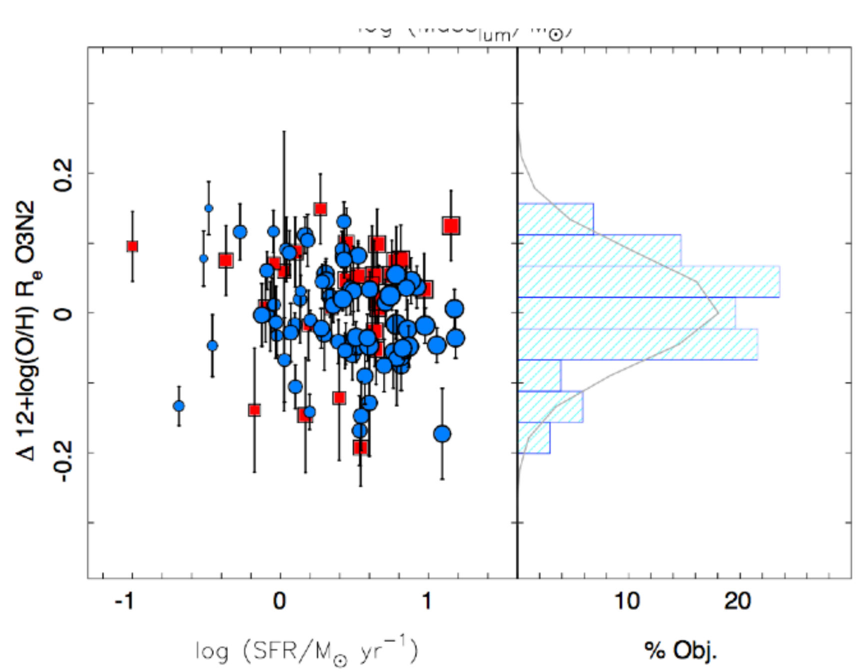
FMR: due to aperture because of gradients?

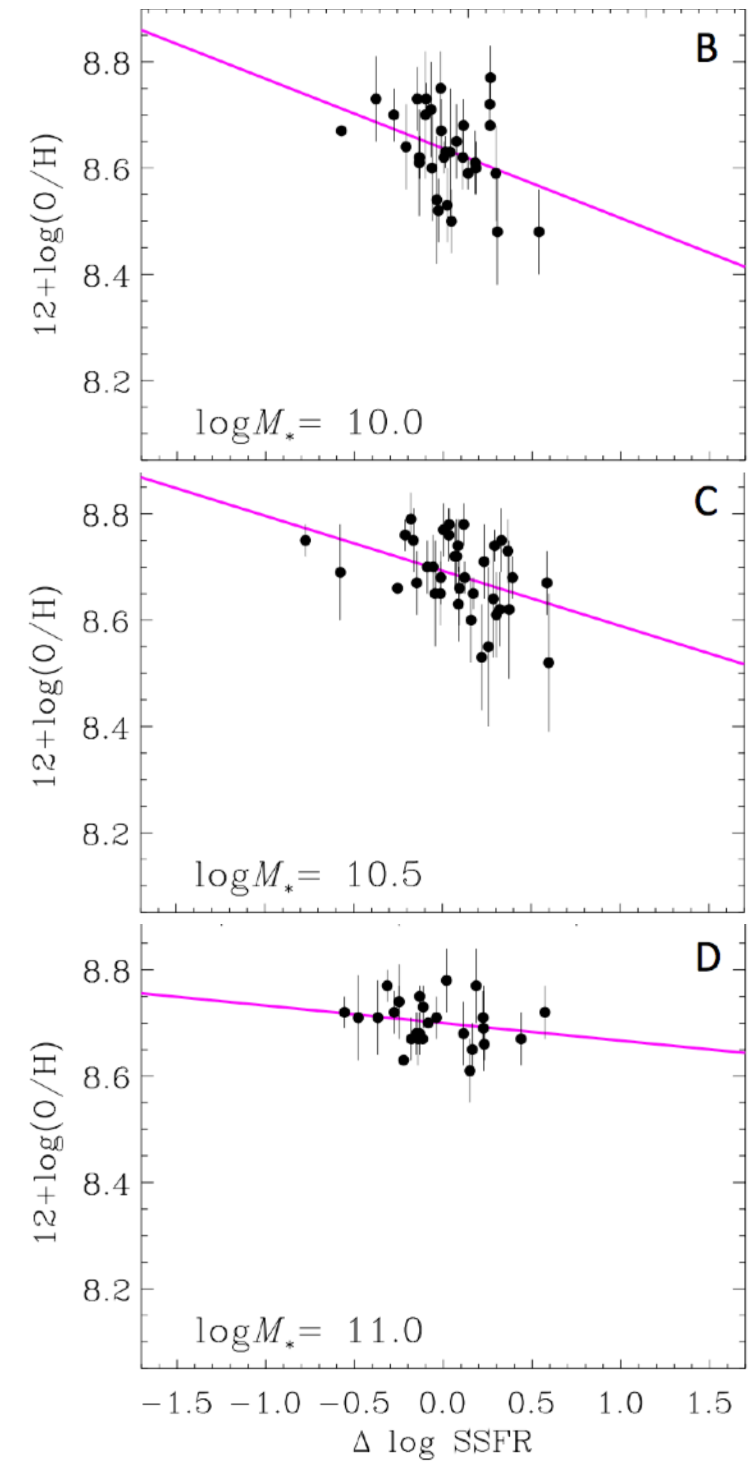
SDSS spectra: 3" fiber
metallicity gradients and dimensions correlated to SFR?

1. min dist = 300Mpc, aperture=4kpc (median 6kpc)
2. no dependence on distance
3. no dependence on light fraction

Sanchez et al 2012"*The Mass-Metallicity relation explored with CALIFA: Is there a dependence on the star formation rate?*"
"..we do not find any secondary relation with the star-formation rate.."



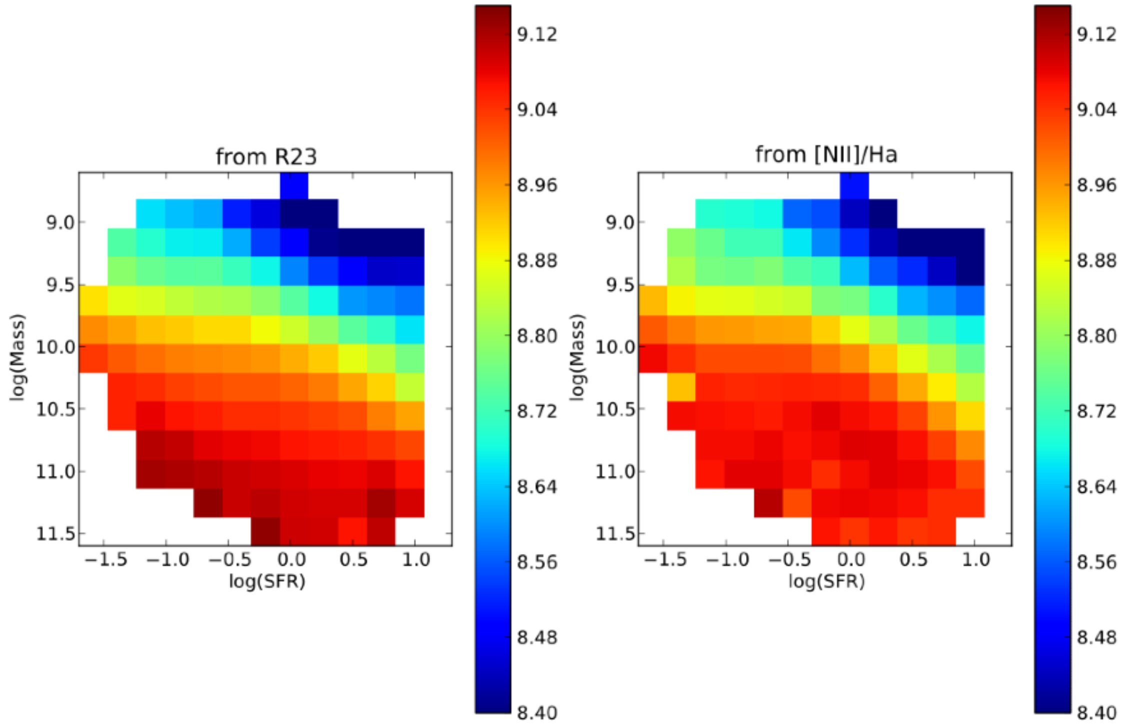


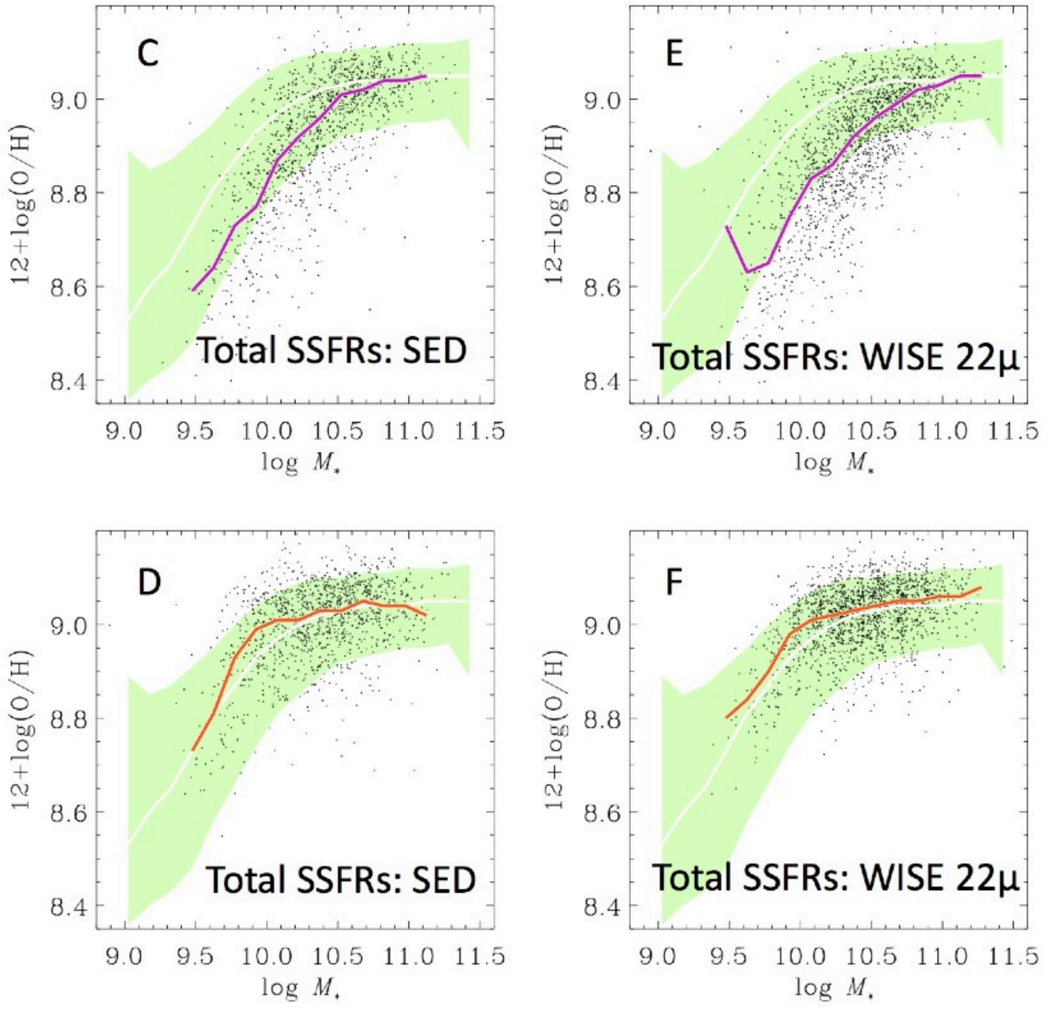


Salim+14

Observational status of FMR

1. dependence on Hα
2. Lilly et al 2013
3. "The use of the Hα line in both metallicity and SFR measurements may introduce coupling of errors"

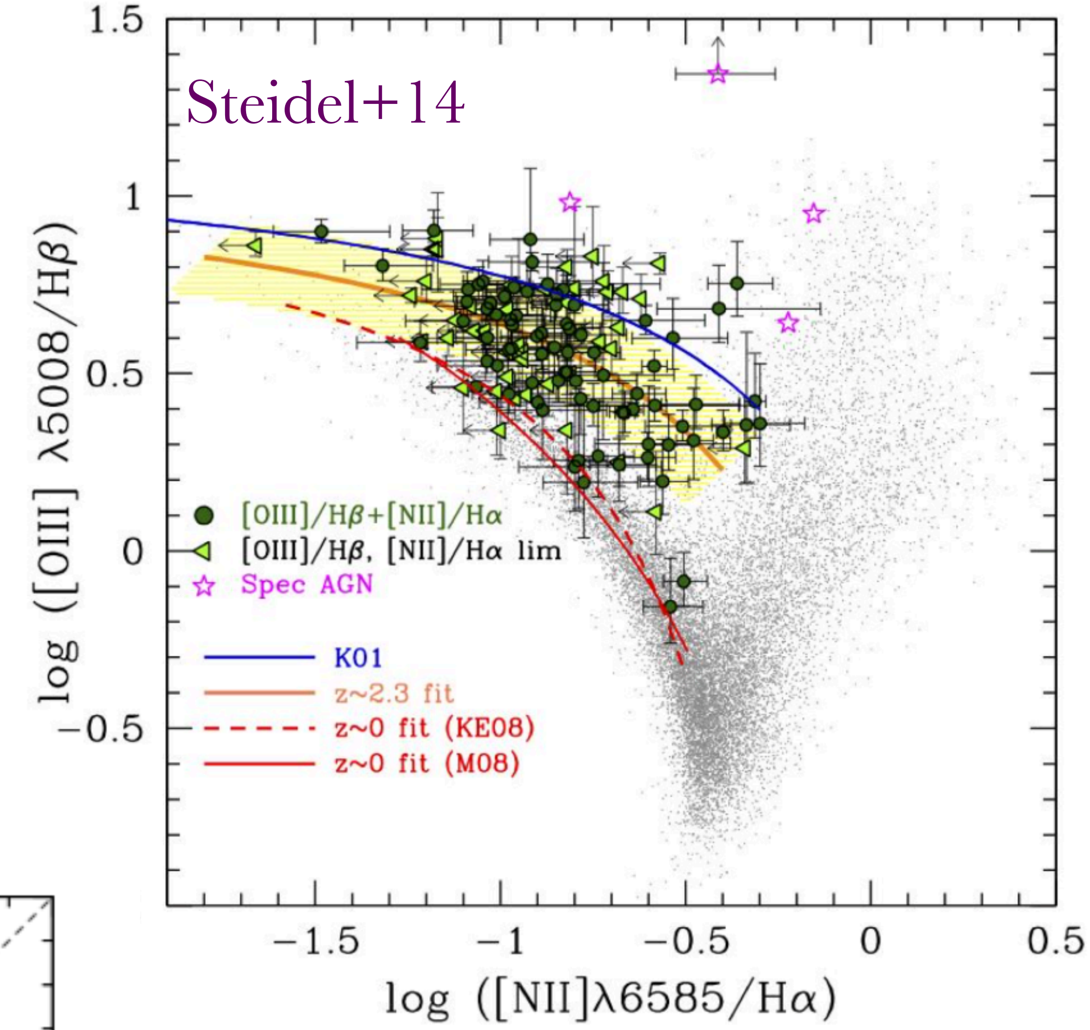


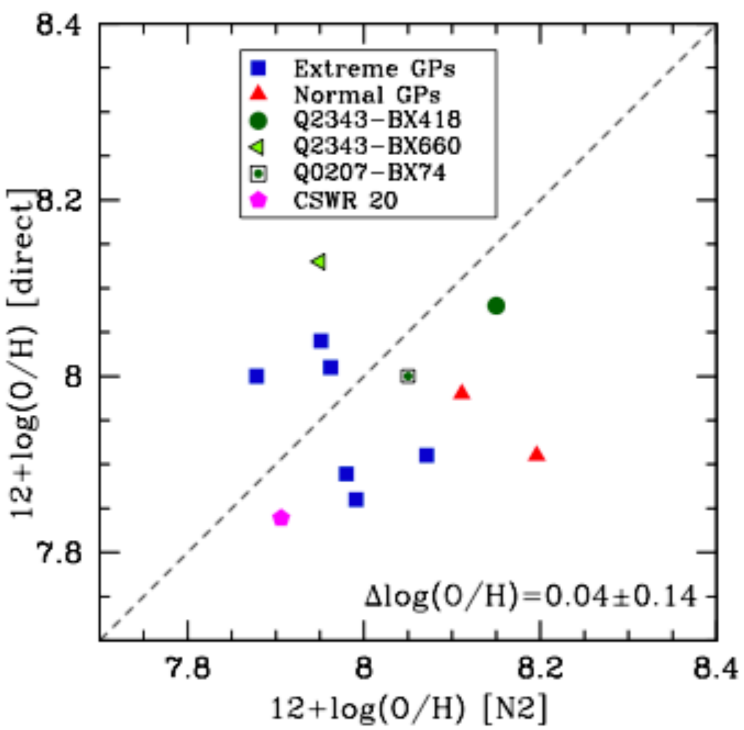


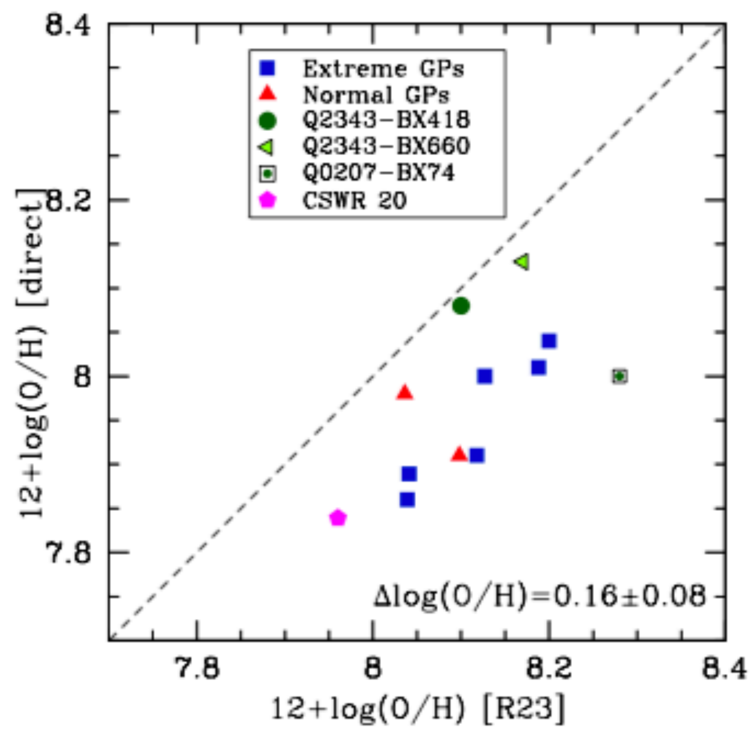
Salim , Lee, Ly, Brinchmann ,Davé , Dickinson , Salzer , & Charlot, 2014

Calibrations and evolutions

- shape depends on metallicity calibrat
- different conditions at high redshift
- evolution in the BTP diagram
- significant spread when using Te



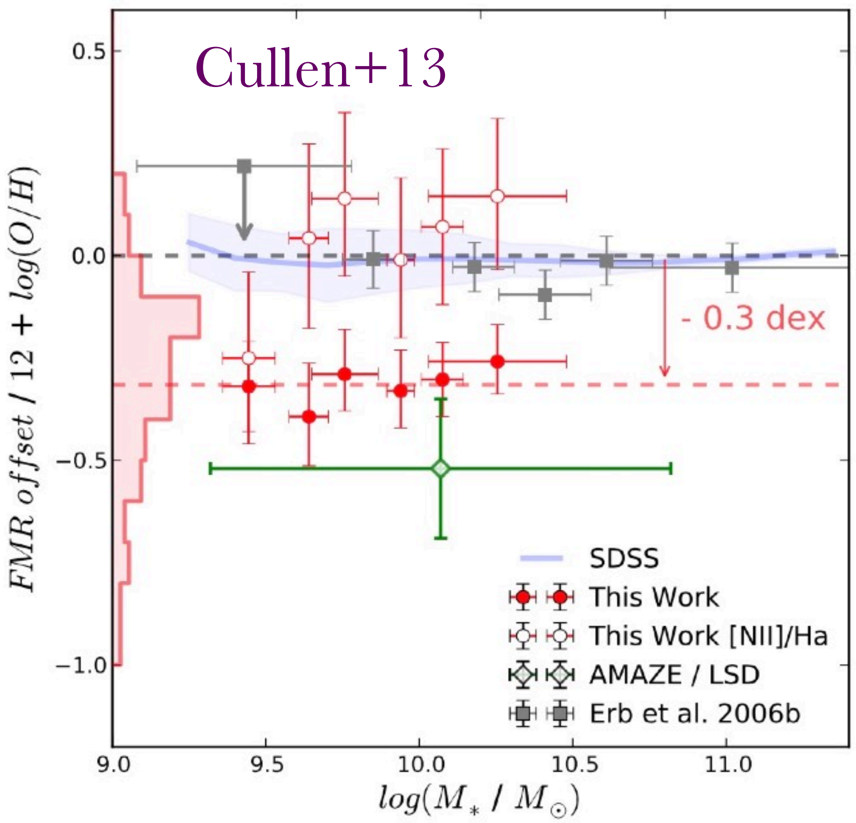


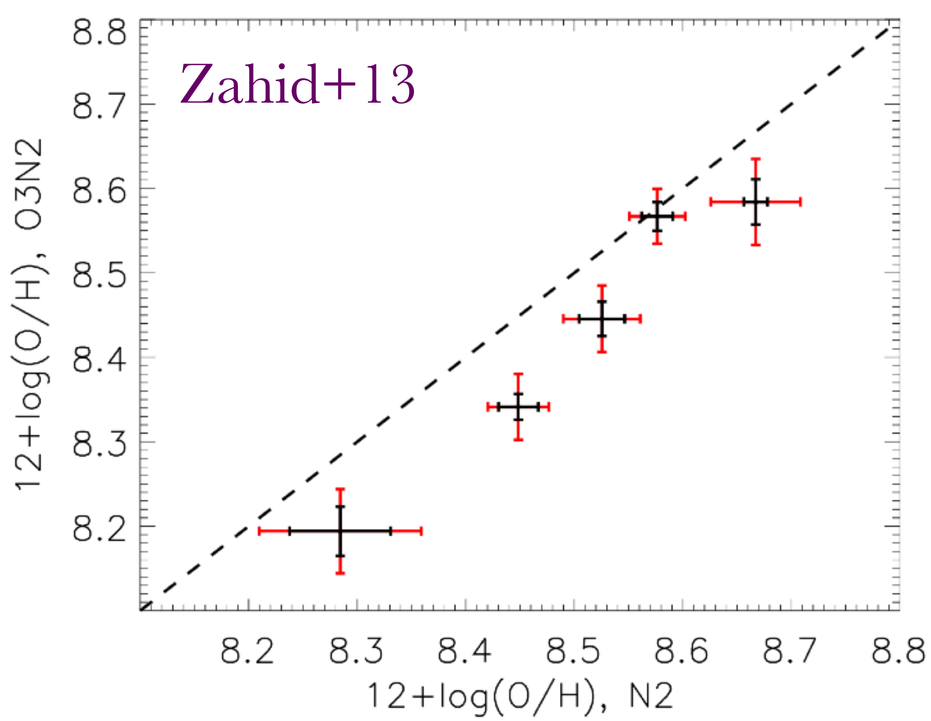


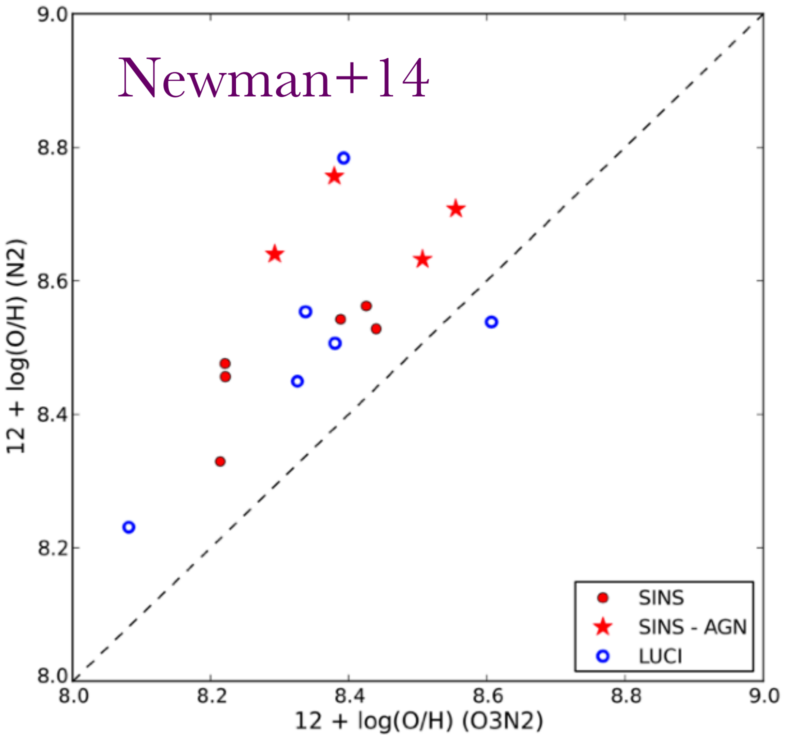
Shapley+05, Brinchman+08, Cullen+13, Wuyts+14, Steidel+14, Shapley+14, Kweley+13, Cullen+13

Calibrations and evolutions

- systematic offset between NII/Ha and O3+O2

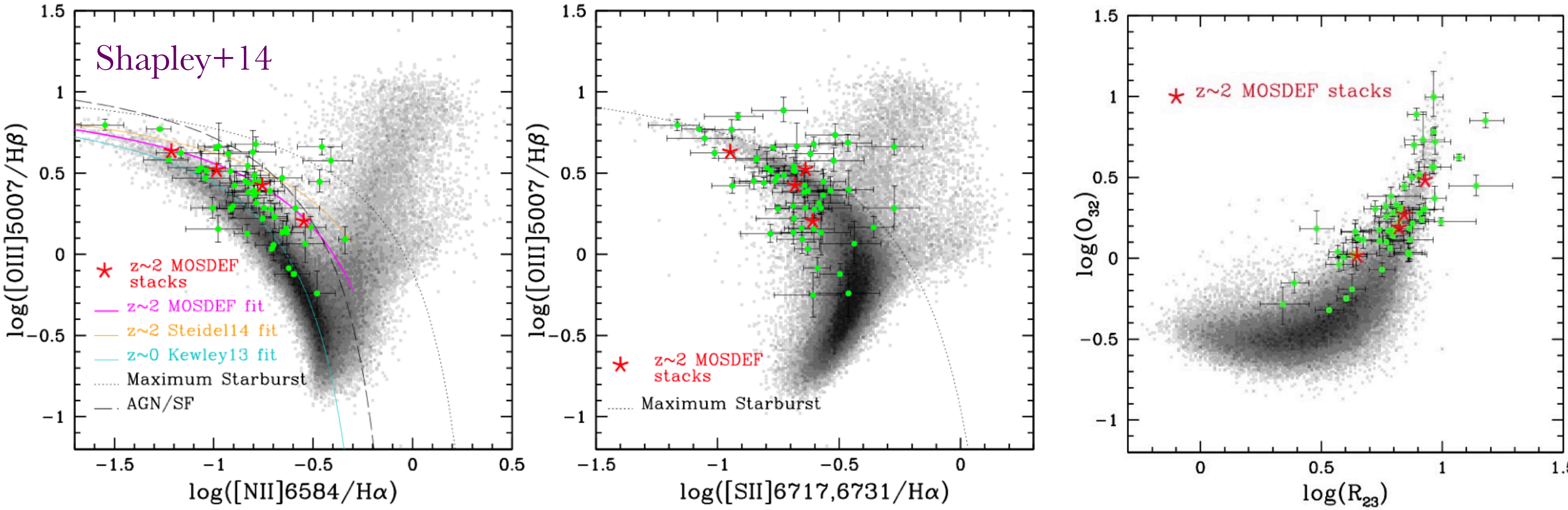


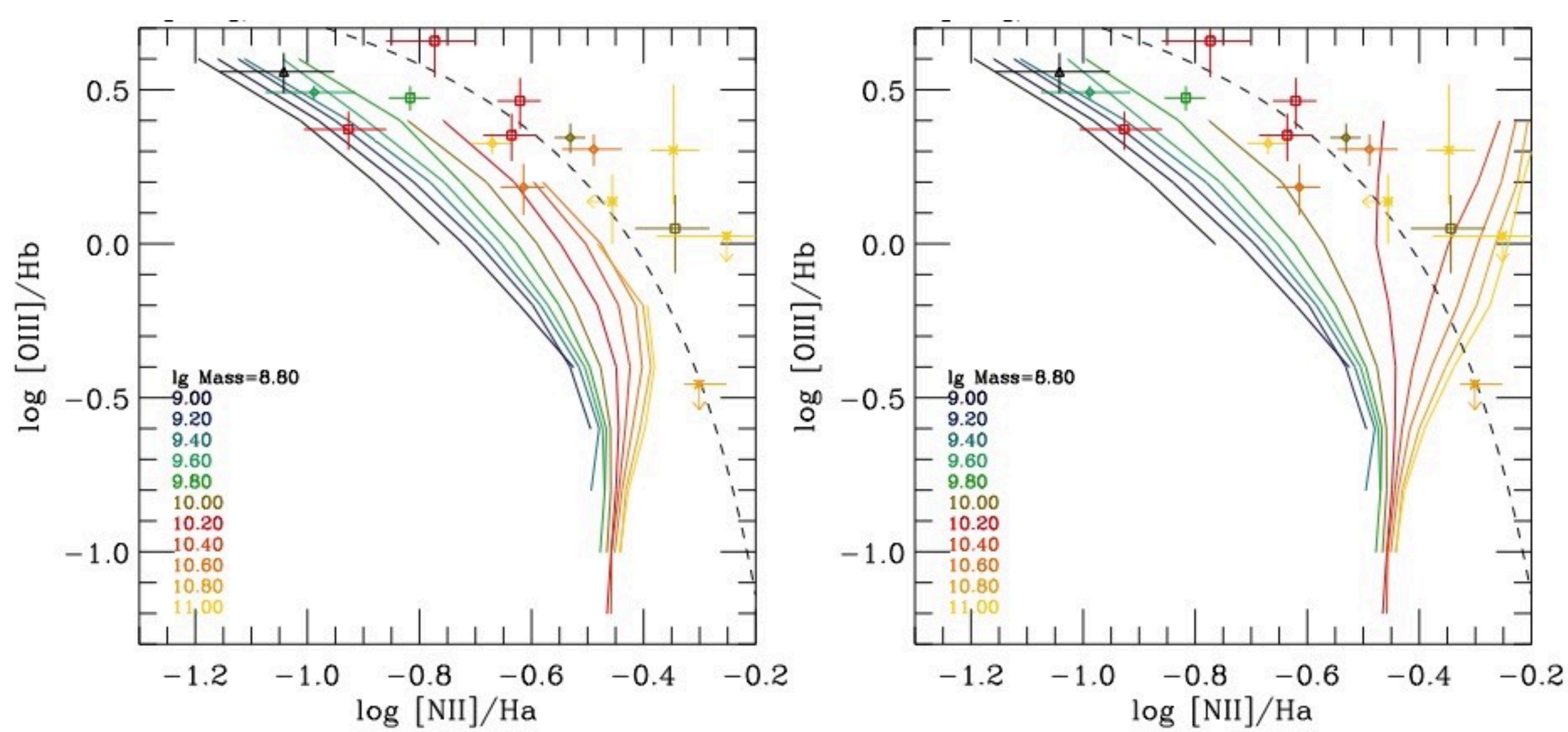




Calibrations and evolutions

Oxygen better than Nitrogen?

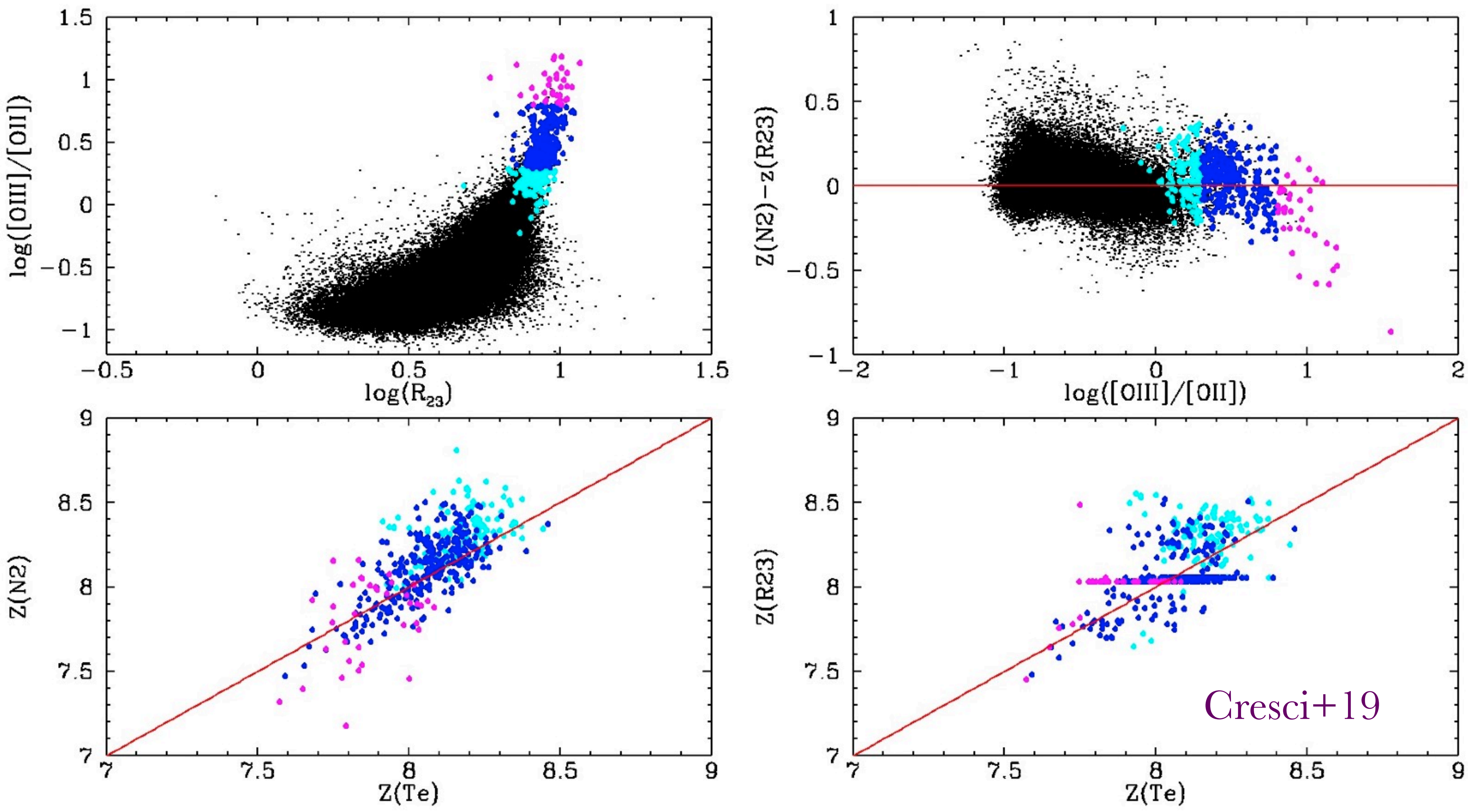




Maiolino+18

Calibrations and evolutions

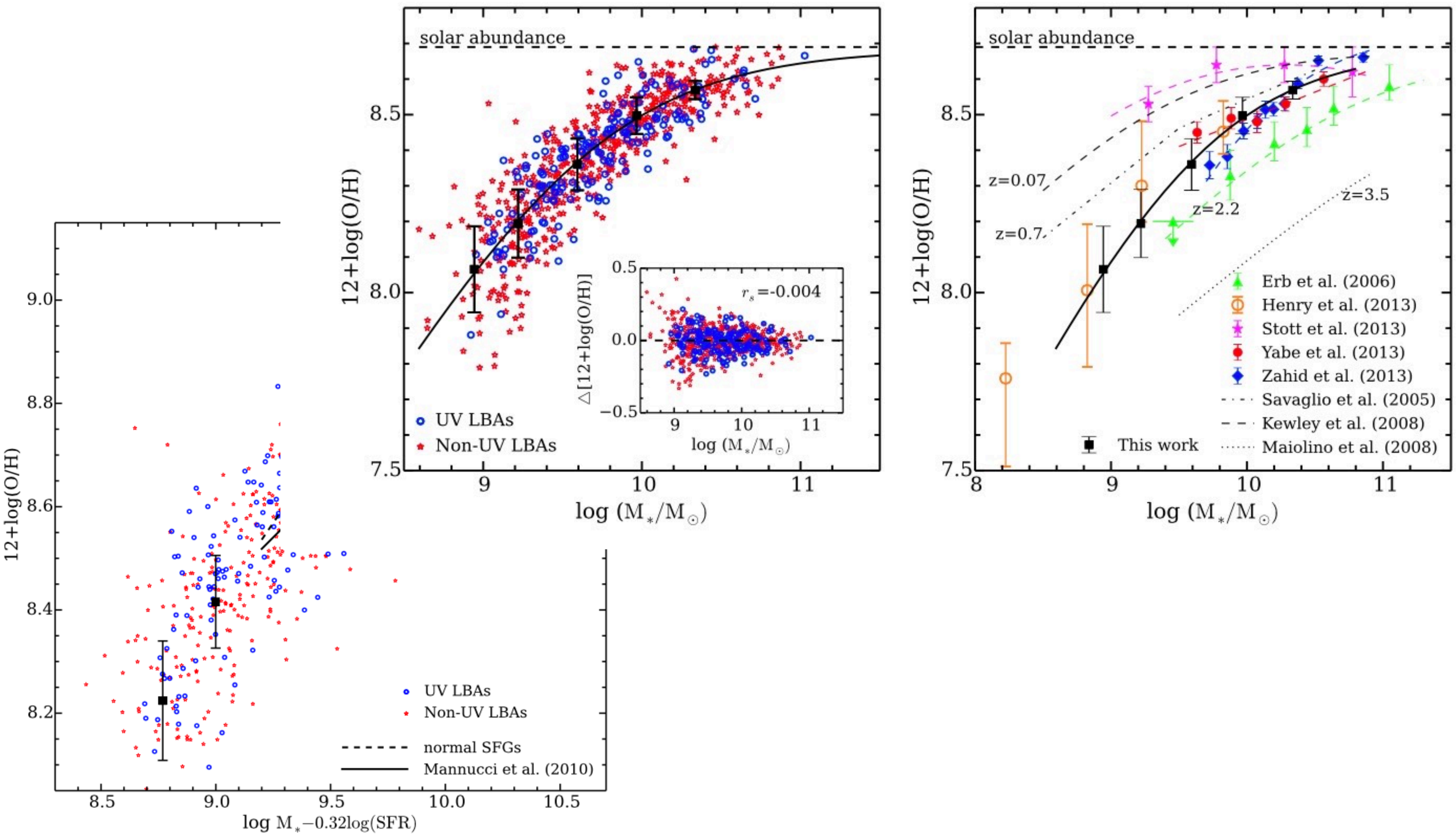
Oxygen better than Nitrogen?



SDSS galaxies with [OIII]4363 detection, binned in OIII/OII (i.e. ionization parameter): no clear trend with ionization parameter, and no differences with Te and N2 metallicity

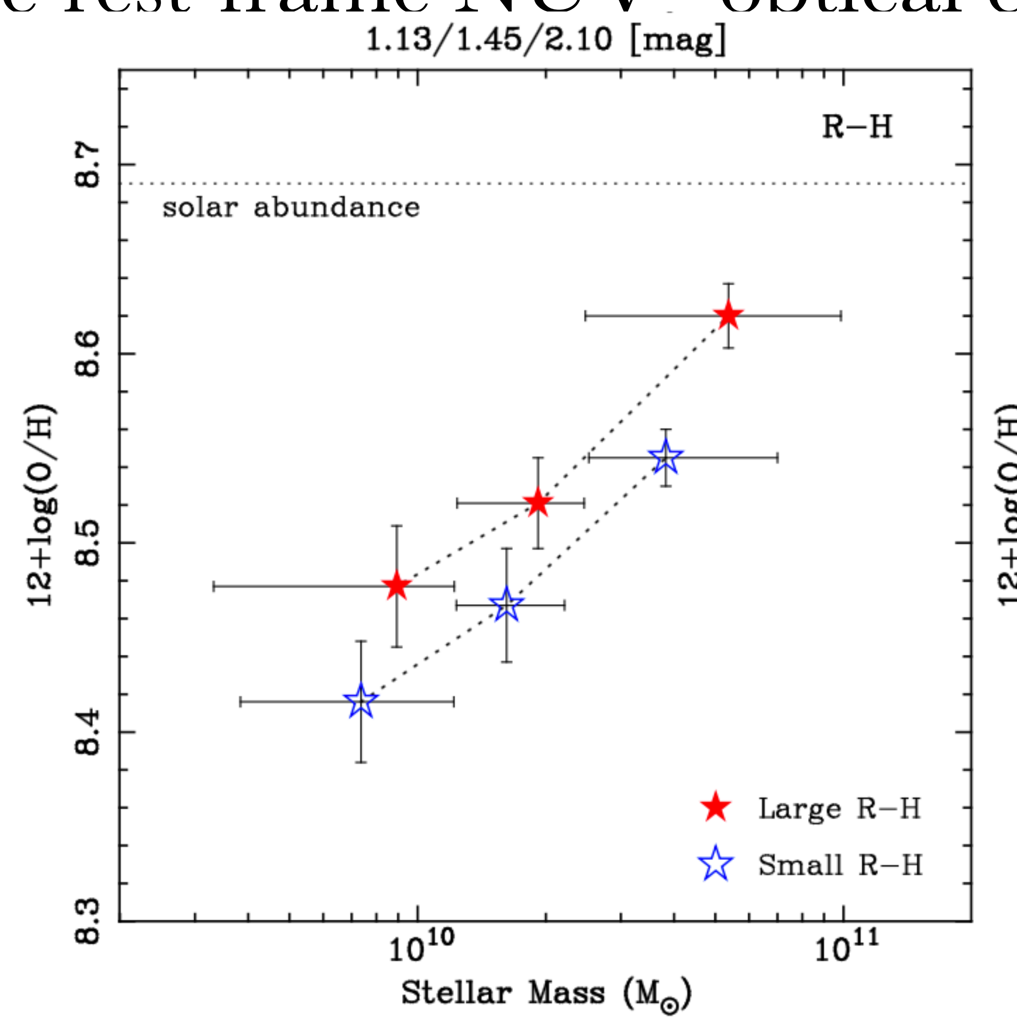
conferme FMR

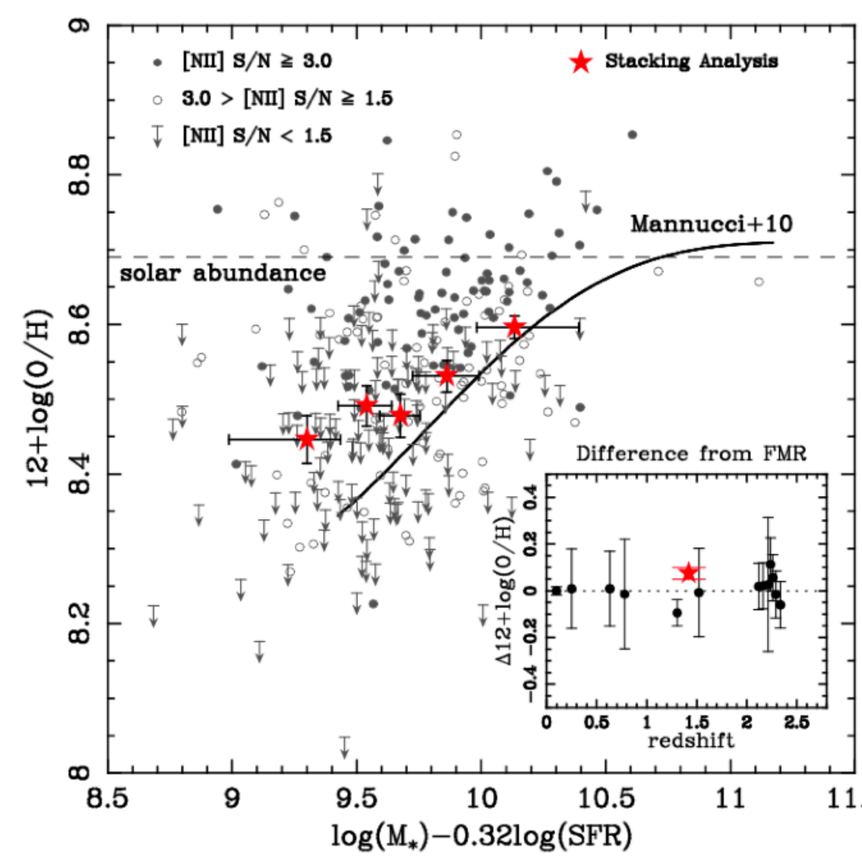
- Lian et al 2015: 703 LBG-analogs, selected in Ha luminosity and surface brightness, 8.5<log(M)<11, 0.05<z<0.30, D(4000)<1.1



Yabe+13

- Yabe et al. (2013) 340 K-band selected star forming galaxyes, FMOS/Subaru, 1.2<z<1.6, N2, stacking analysis
- low depndence on SFR, but only ~0.1dex expected!
- FMR works to reproduce average metallicity
- "found that the metallicity of galaxies at high redshift correlates with the rest-frame NUV−optical colour at a fixed mass. Galaxi … have higher metallicities."





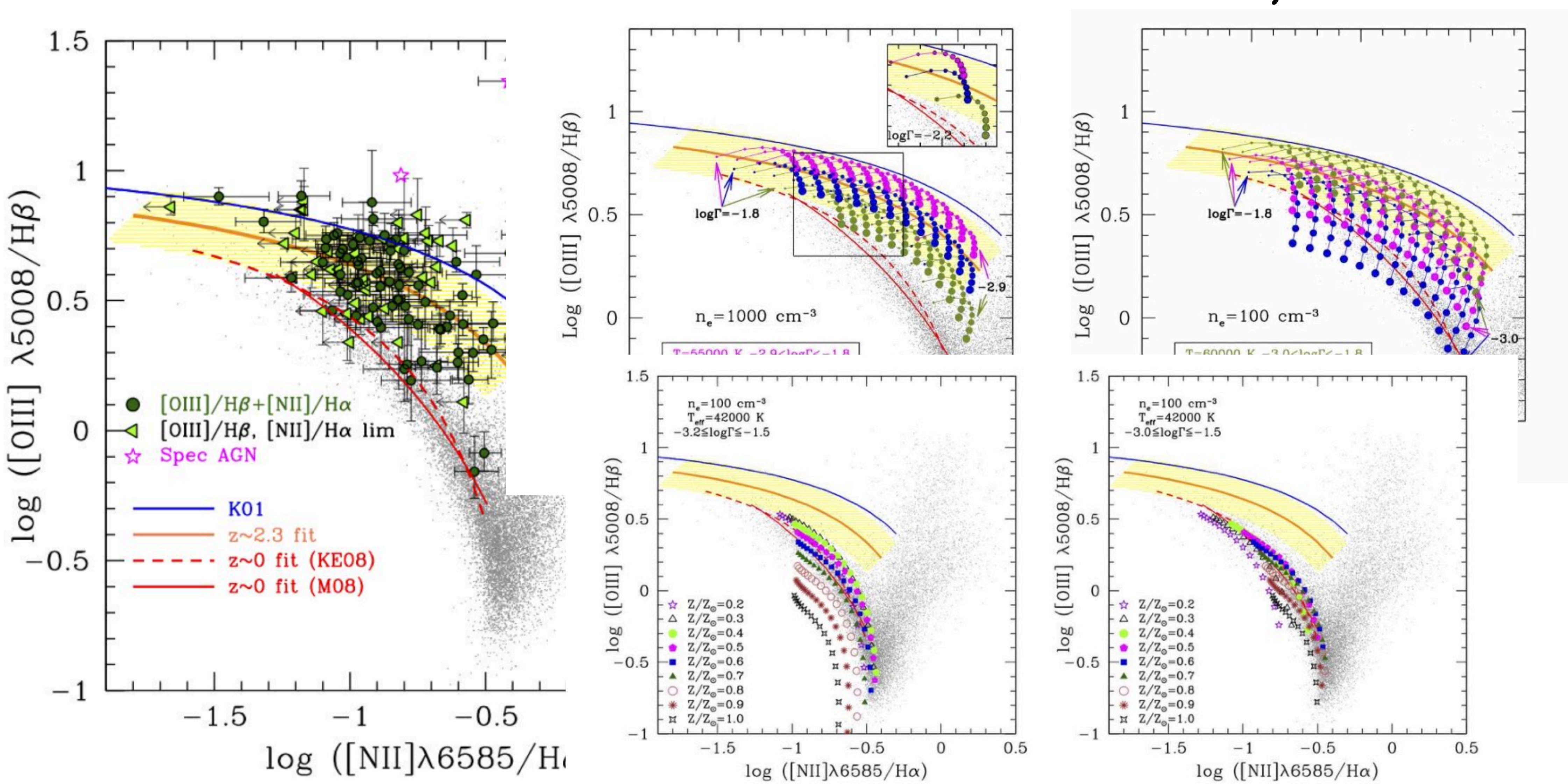
Wuyts genzel +14

- 222 galaxies, 0.8<z<2.6, 9<M<11.5, LUCI+SINFONI+KMOS
- KMOS: K<23, mass-selected parent sample from the 3D-HST survey, cover the star formation−stellar mass (M∗) and rest-frame (U − V) − M∗ planes uniformly.
- SFR from UV+IR

- steep slope of the MZR

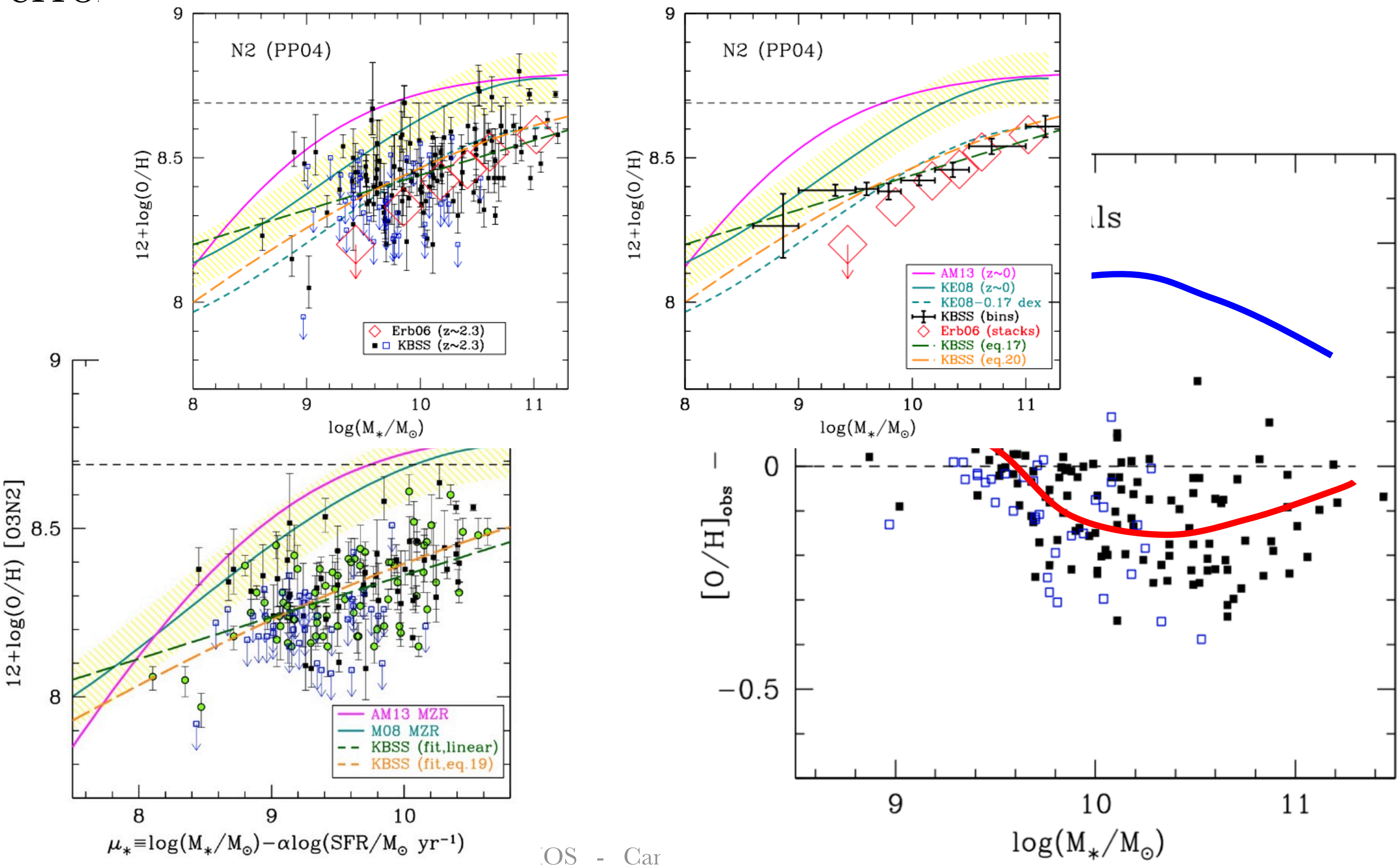
Steidel 14

- 179 galaxies at 2.0<z<2.6, 5 < SFR < 150 M/yr8.8 < log(M)< 11.5.
- extinction from continuum fit
- models: correlation between Gamma and metallicity



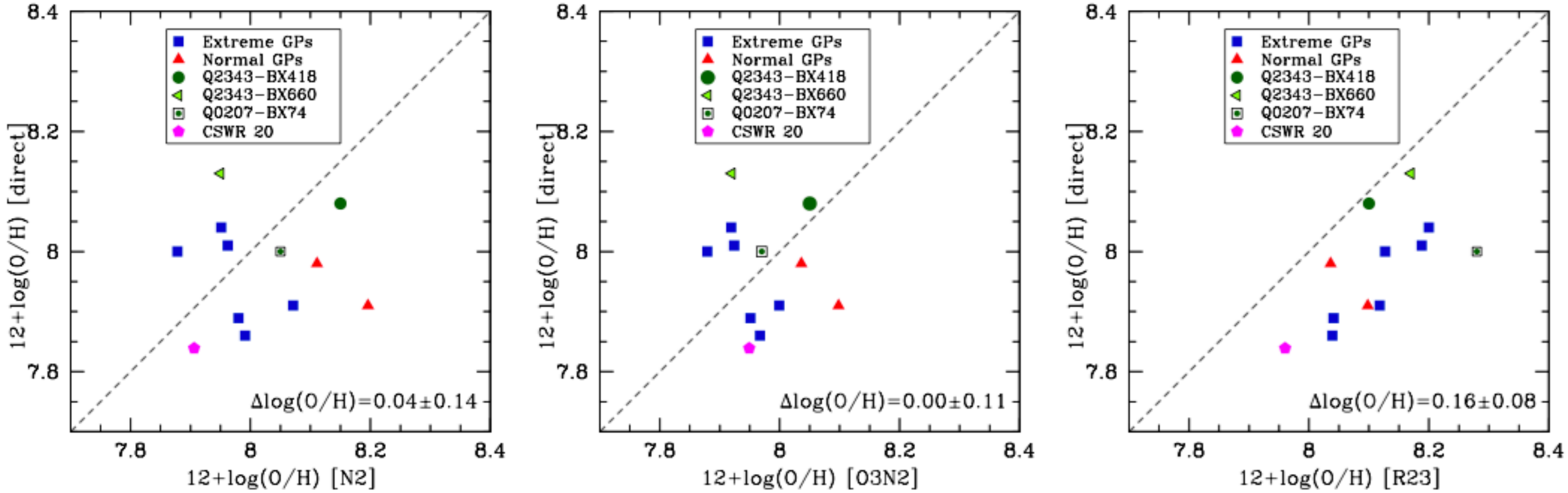
Steidel 14

- shallow MZR,
- erro



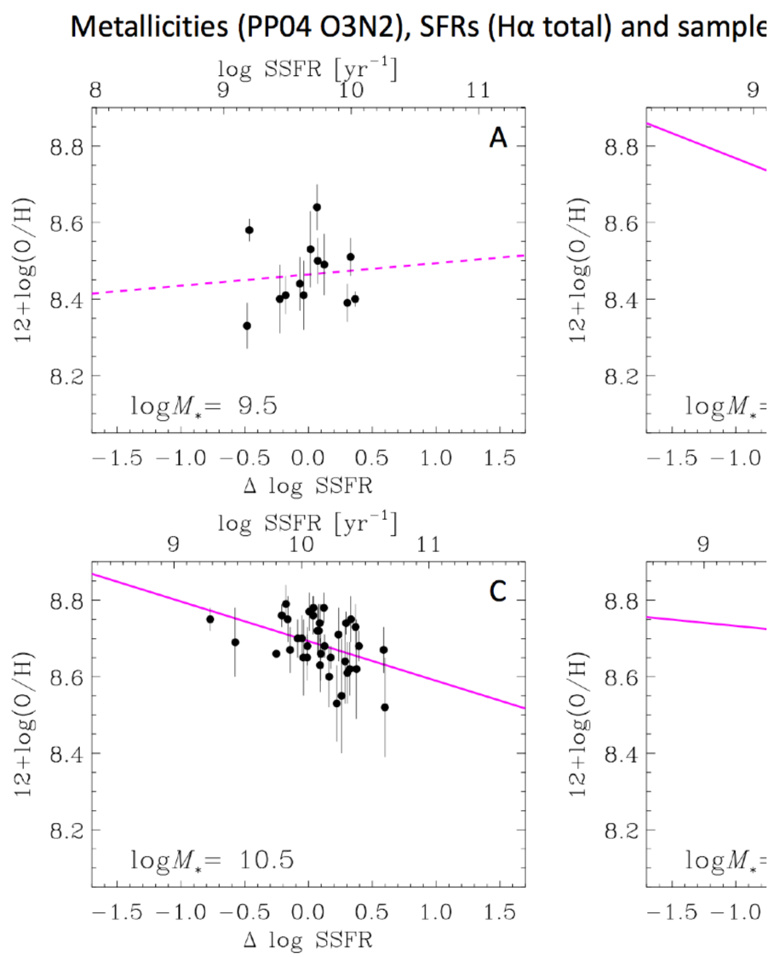
Steidel 14

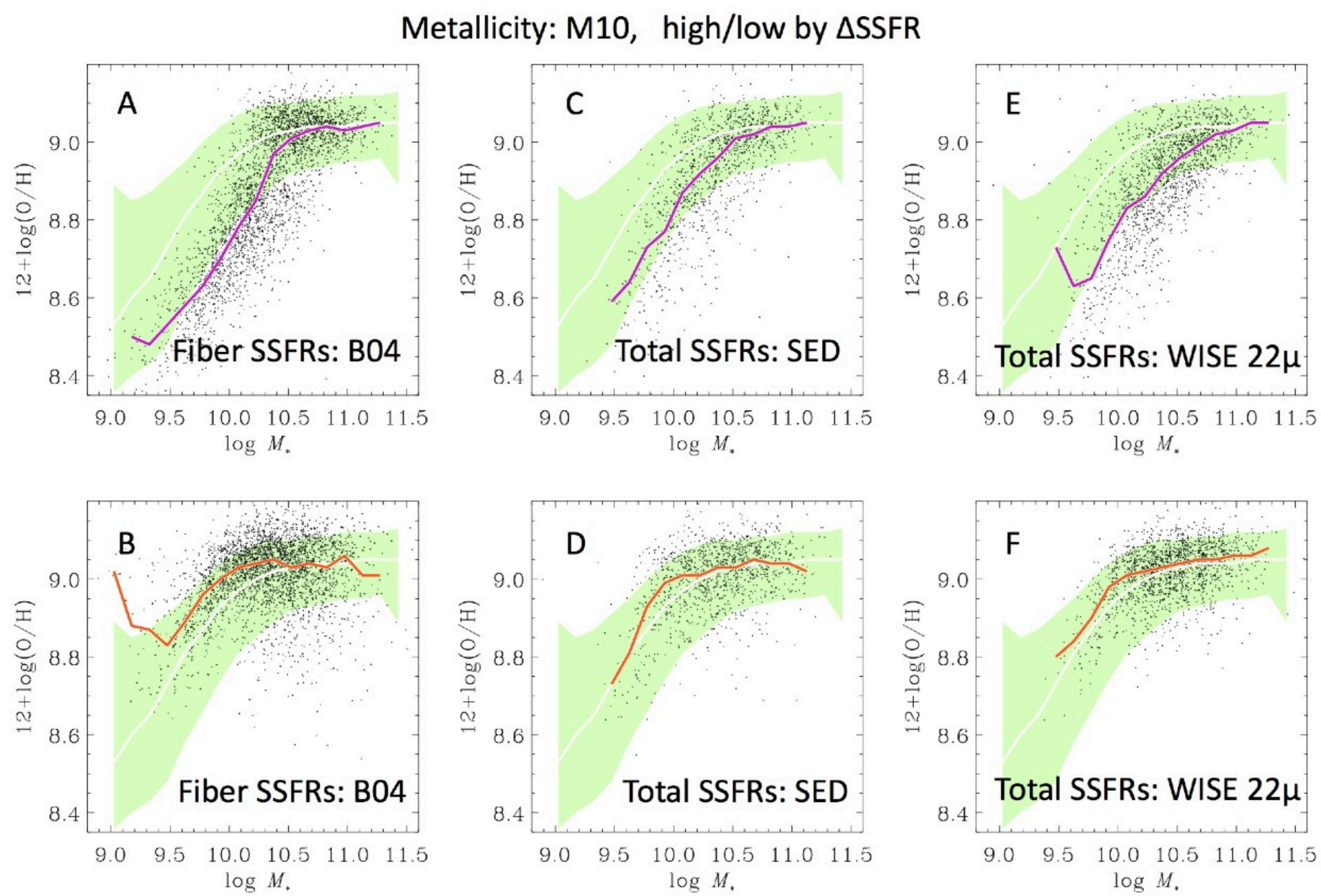
- shallow MZR,
- error in computing the FMR



salim 14

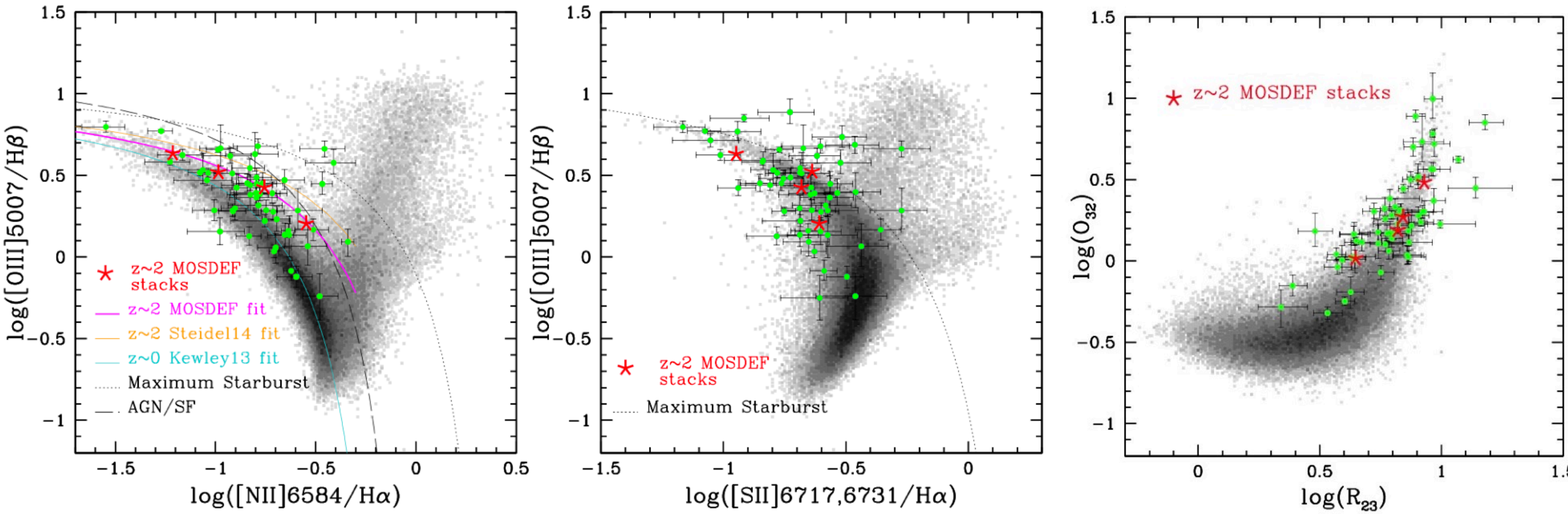
- dependence of SFR with all the SFRs, no spurious dependence on Ha
- M10 results more robust that T04
- dependence on aperture even in Sanchez





Shapley 14

- 53 MOSDEF galaxies, MOSFIRE
- galaxies outdside the BPT only when N2 is used:



newman 14

- 22 galaxies at z~1.5, spatially resolved
- importance of shocks and faint AGNs
- O3N2 works better than N2, offset