PFS-SSP Galaxy Survey Workshop 2015

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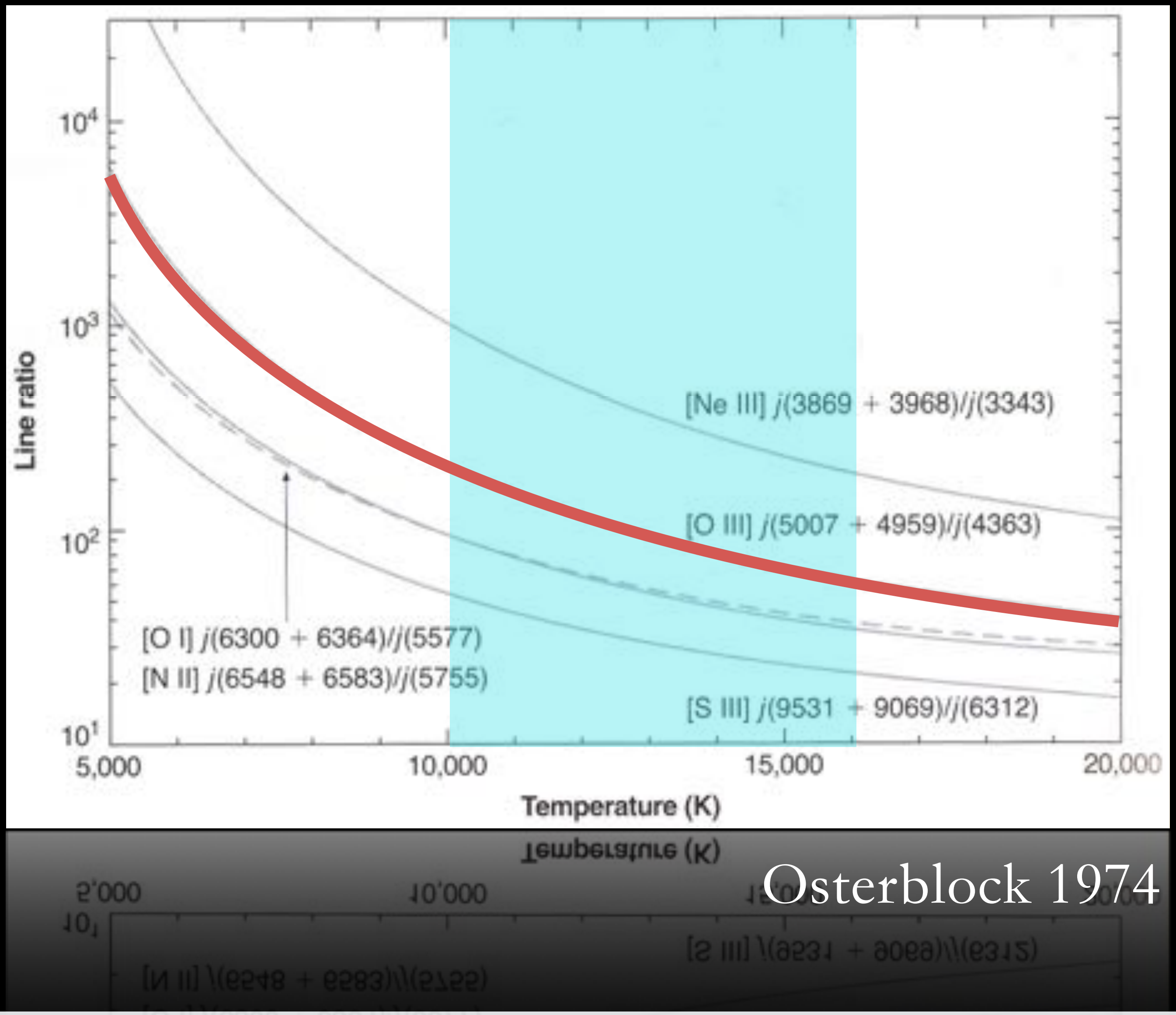
Towards the perfect consensus on redshift evolution of the ISM conditions

Importance of ISM (ionized gas) conditions

Physical parameters of ionized gas directly related to star-forming regions
We can determine gaseous metallicity (O/H, N/O) in HII regions
This informs us of gas accretion and outflow histories on the galaxy evolutions

Kewley et al. 2002
Tremonti et al. 2004
Shapley et al. 2005
Erb et al. 2006ab
Nagao et al. 2006
Maiolino et al. 2008
Kewley et al. 2008
Brinchmann et al. 2008ab
Liu et aal. 2008
Ellison et al. 2009
Mannucci et al. 2009
Mannucci et al. 2010
Erb et al. 2010
Hayashi et al. 2011
Mannucci et al. 2011
Yabe et al. 2012
Nakajima et al. 2012
Niino 2012
Hughes et al. 2013
Zahid et al. 2013
Andrew et al. 2013
Kewley et al. 2013ab
Kulas et al. 2013
Bothwell et al. 2013
Juneau et al. 2013
Nakajima et al. 2014ab
Steidel et al. 2014
Krabbe et al. 2014
Masters et al. 2014
Levesque et al. 2014
Juneau et al. 2014
Peng et al. 2014
Yabe et al. 2014
Zahid et al. 2014ab
Shirazi et al. 2014
Sanders et al. 2015ab
Shimakawa et al. 2015ab
Valentino et al. 2015
Hayashi et al. 2015
Yabe et al. 2015
Shapley et al. 2015
Coil et al. 2015
Kewley et al. 2015
…

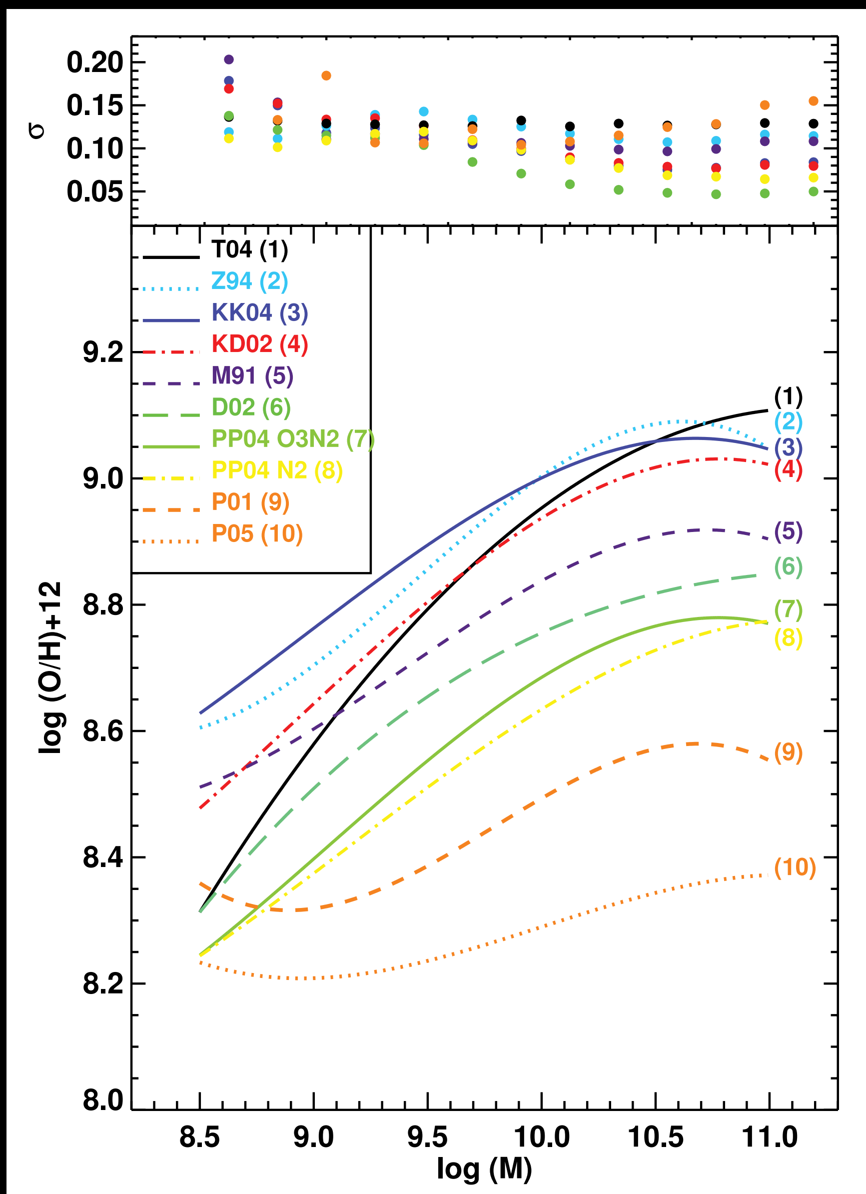
Direct estimate of Z needs $[OIII]_{\lambda 4364}$,
but $[OIII]_{\lambda 4364}$ is fainter by x30–150 than $\lambda 5007$



Osterblock 1974

Risks of the past studies for metallicity measurements

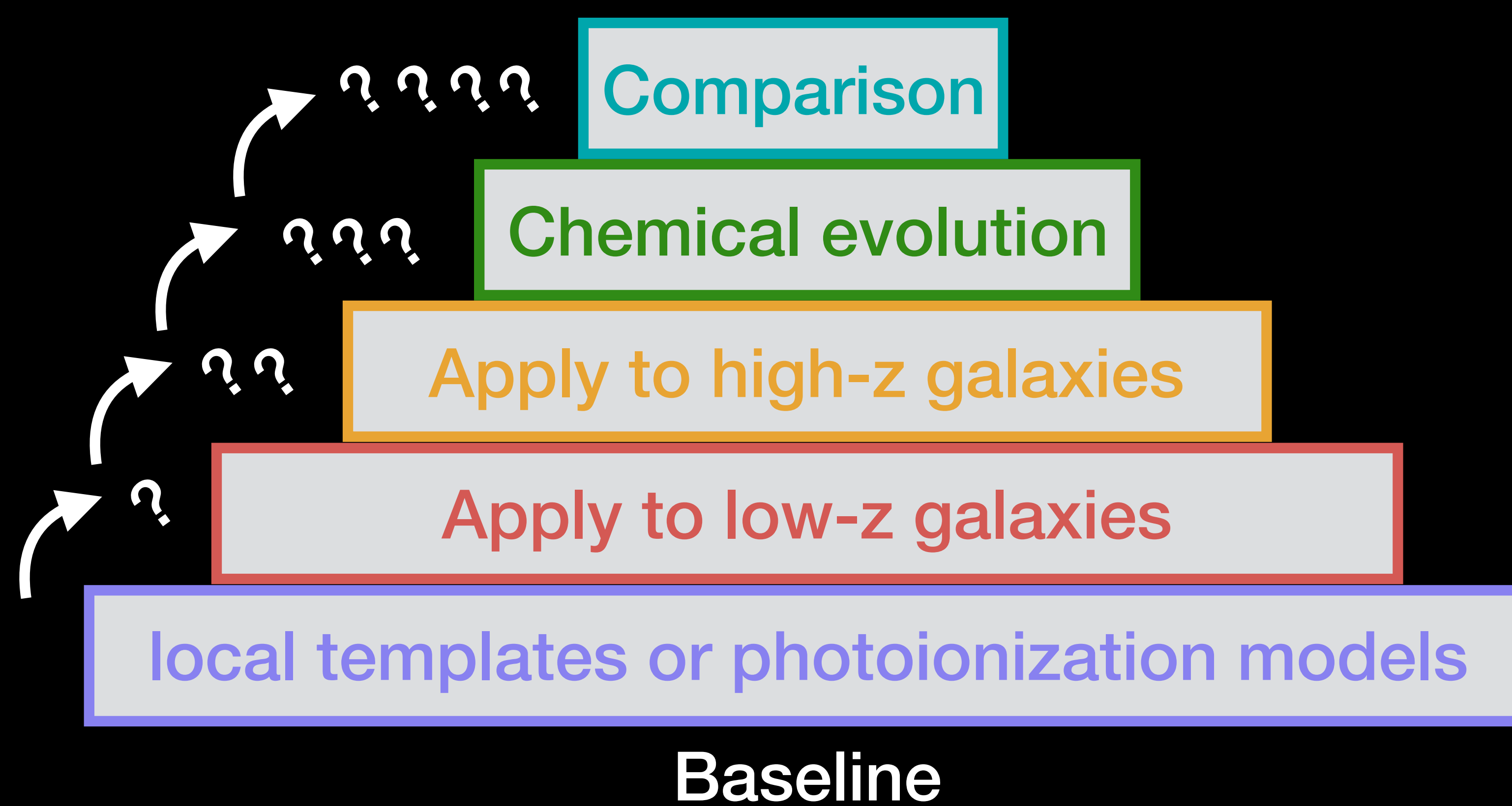
Familiar metallicity calibrations are empirically or theoretically determined
Different abundance measurements show different results
Despite this, these methods have been used also for distant galaxies so far



Kewley & Ellison 2008

Theoretical methods tend to overestimate log(O/H)
model depends on many parameters

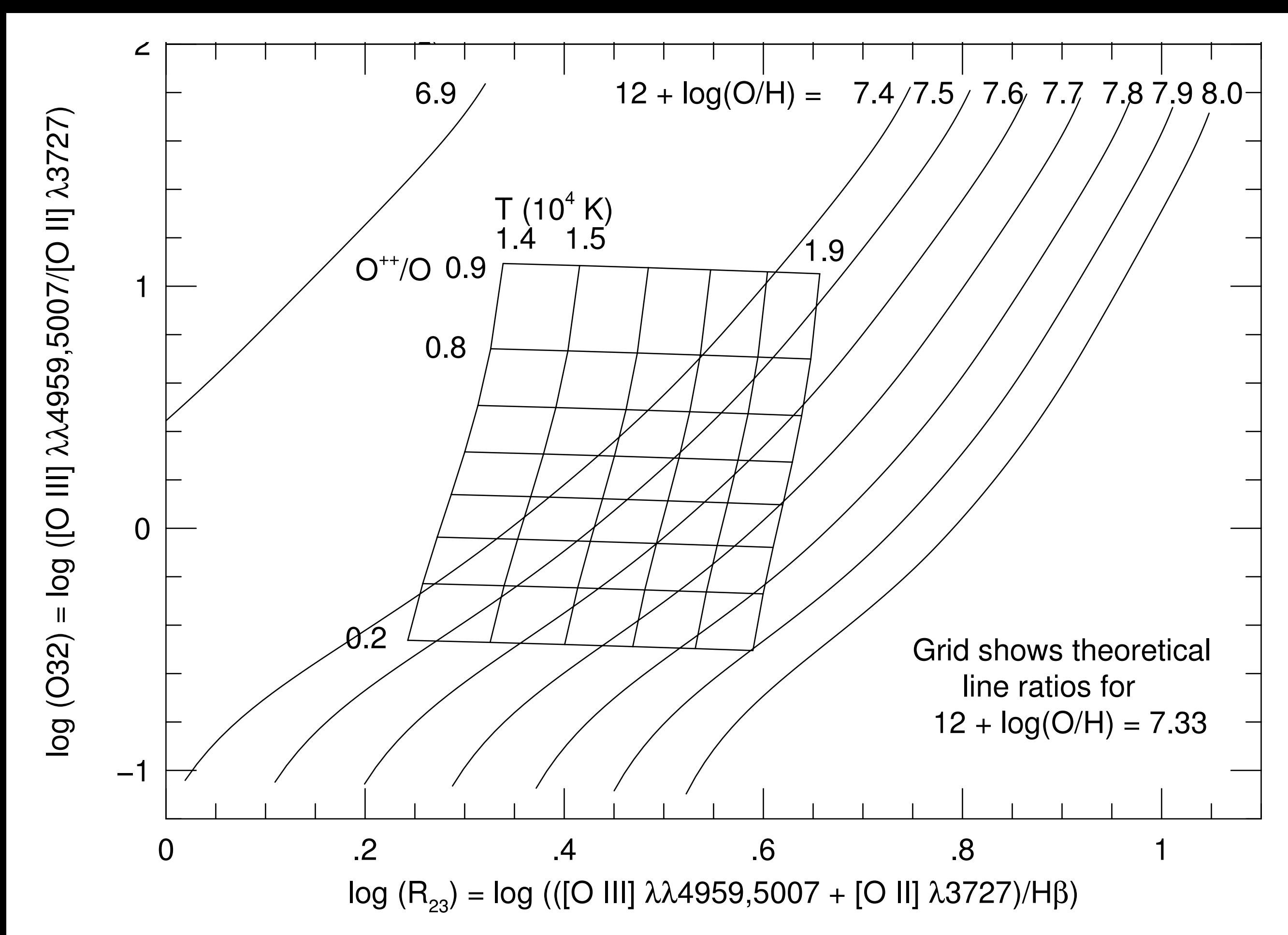
Empirical methods tend to underestimate log(O/H)
original templates have much poorer Z than gal.



Physical properties of ionized gas in galaxies

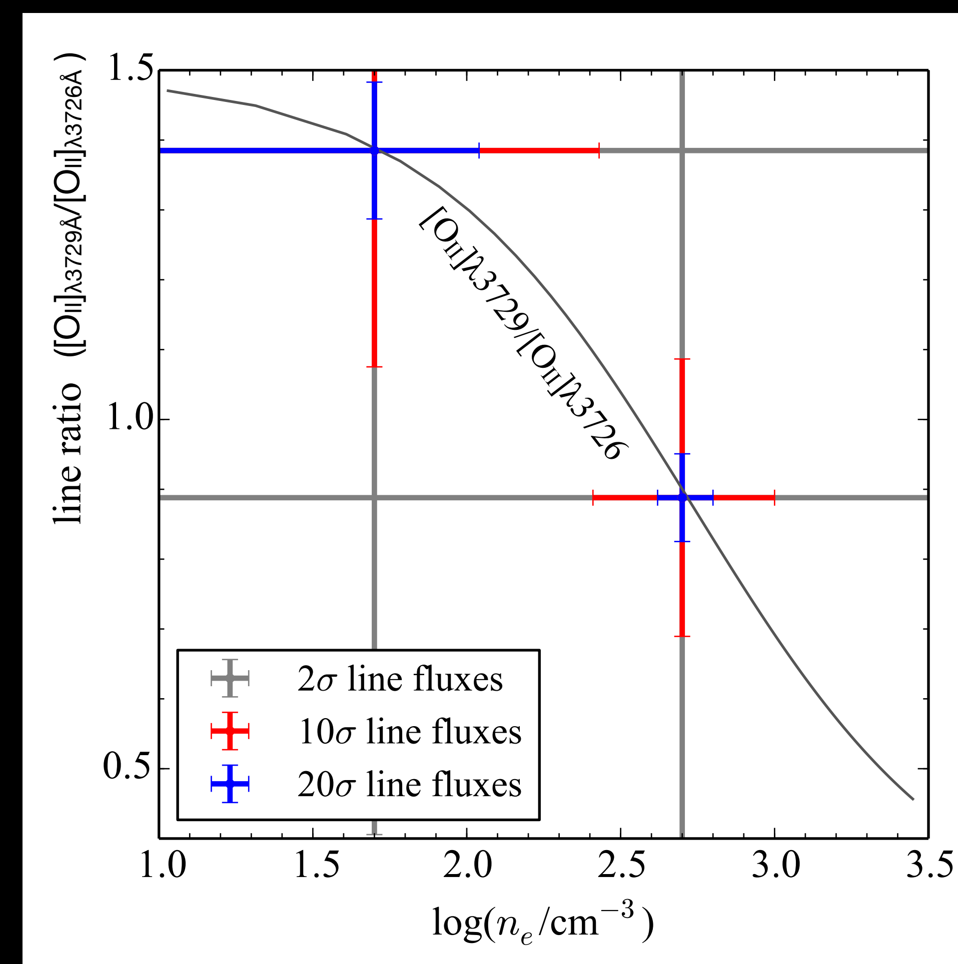
Familiar metallicity calibrations strongly depend on physical conditions of ISM
The other ISM properties are difficult to estimate from observations
<u>Observed line spectra come from various HII regions in galaxies</u>

U depends on age, metallicity, temperature, Ne



van Zee, Skillman & Haynes 2006

Ne is insensitive to line ratios

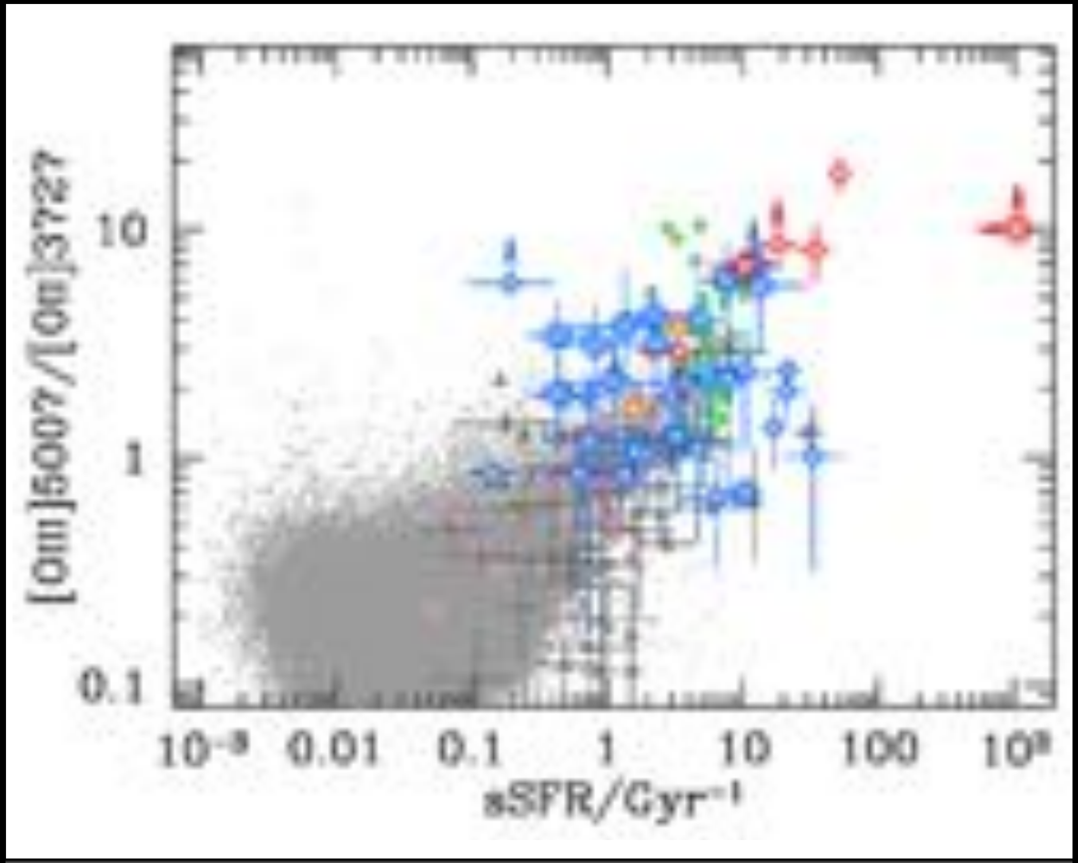


star-forming galaxies

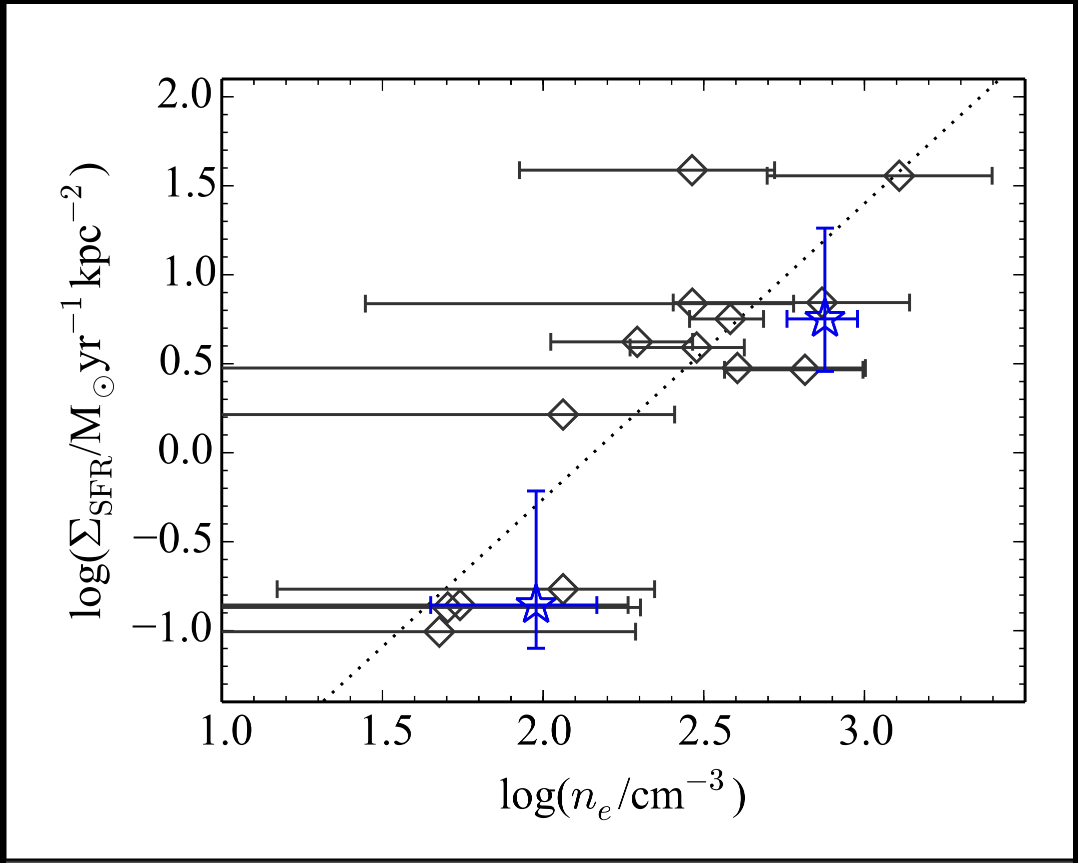
The most important problem

Theoretical analysis (photoionization model) is based on individual HII region
In practice, galaxies retain various ionized gases with different ionization states
<u>Scaling relation from radiation field to flux-weighted spectra will vary with galaxies</u>

More active star formation per unit area leads to higher U and Ne
* Specific SFR strongly correlates with SFR surface density (Shimakawa+15)



Nakajima & Ouchi 2014



Shimakawa et al. 2015

Scaling relation of radiation field depends on global star-forming activity

Recent studies imply that star-forming activities mainly control the scaling relation
High spatial resolution (<100pc) by TMT is needed to identify the scaling relation

Ionized gas is mixed with composite HII regions at various ages

Heating from older populations (diffuse ionized gas)

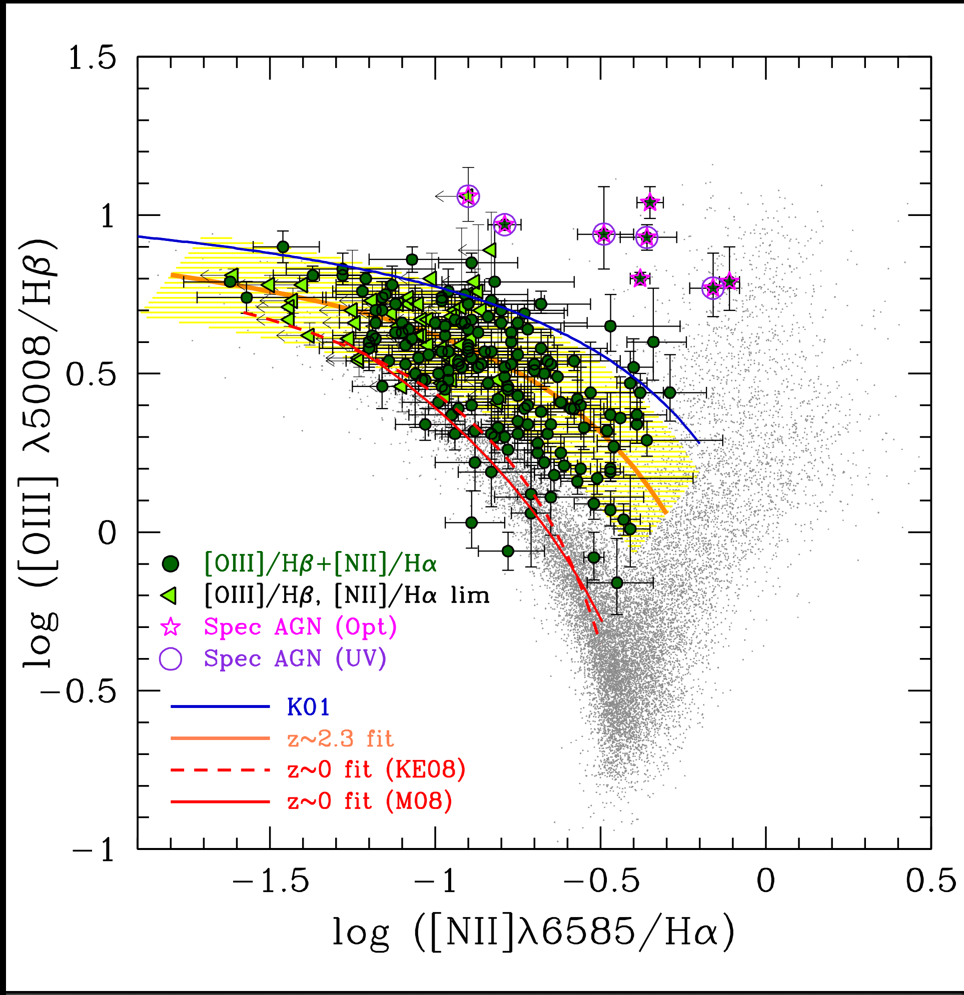
Scaling relation is needed to idenfity mean ISM condition from composite ionized regions

GPs, LAEs (t<100Myr)
may be scaled by a HII region

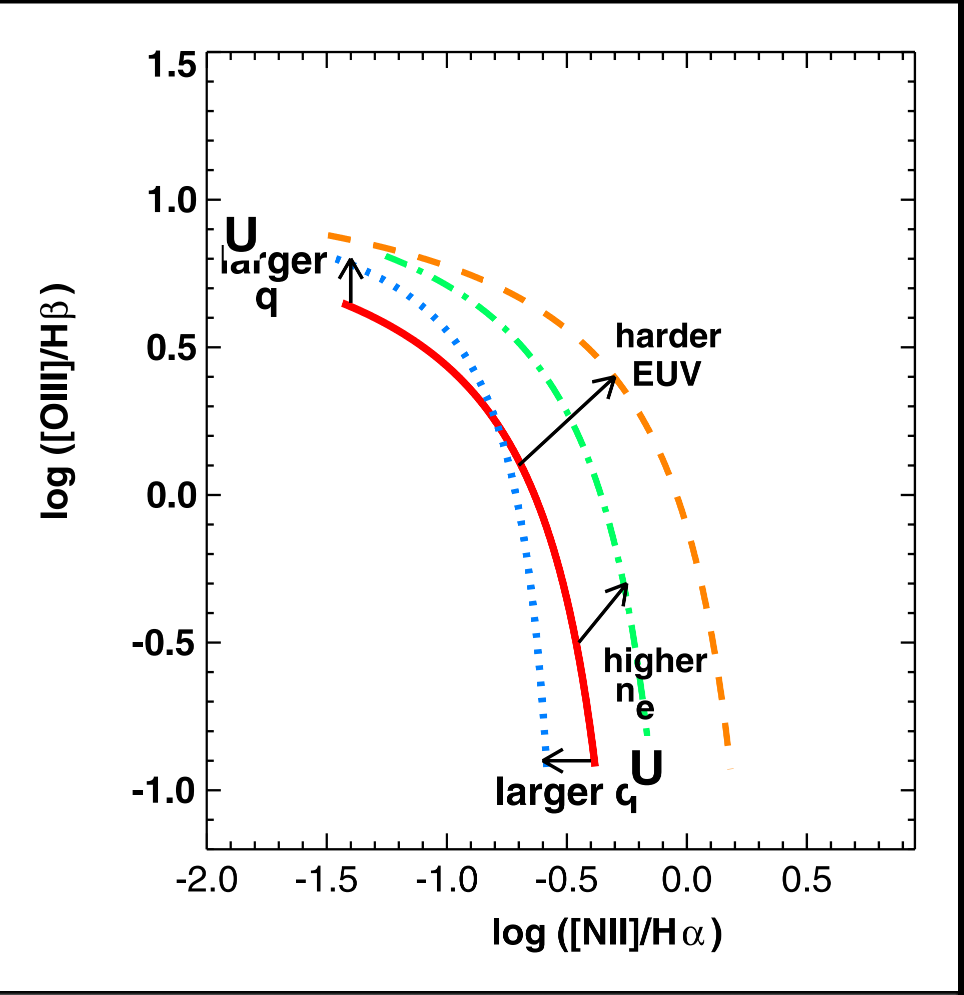
Massive galaxies
whose spectra are luminosity-weighted

ISM evolution as a function of redshift

High-z galaxies offset from the local sequence on the BPT diagram
Metallicity estimations would be also different from local calibrations
<u>The scaling relation would significantly change depending on redshift</u>
However, redshift evolutions of ISM physical parameters remain unresolved
Current surveys have insufficient sample size (~1k) to measure Te for each population



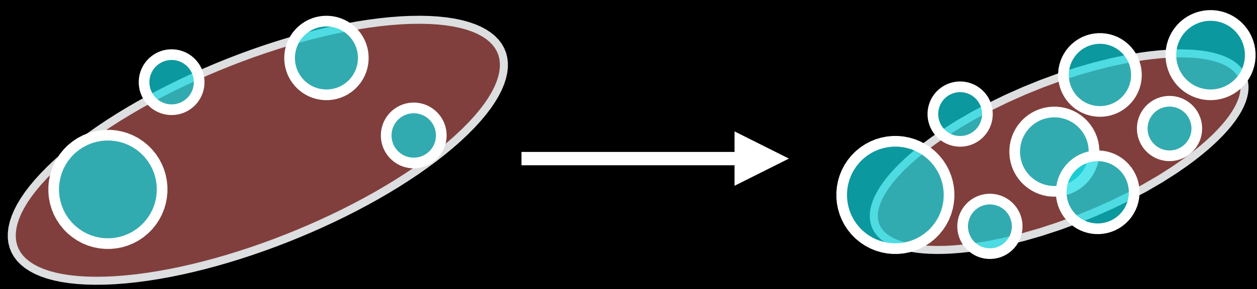
Steidel et al. 2014



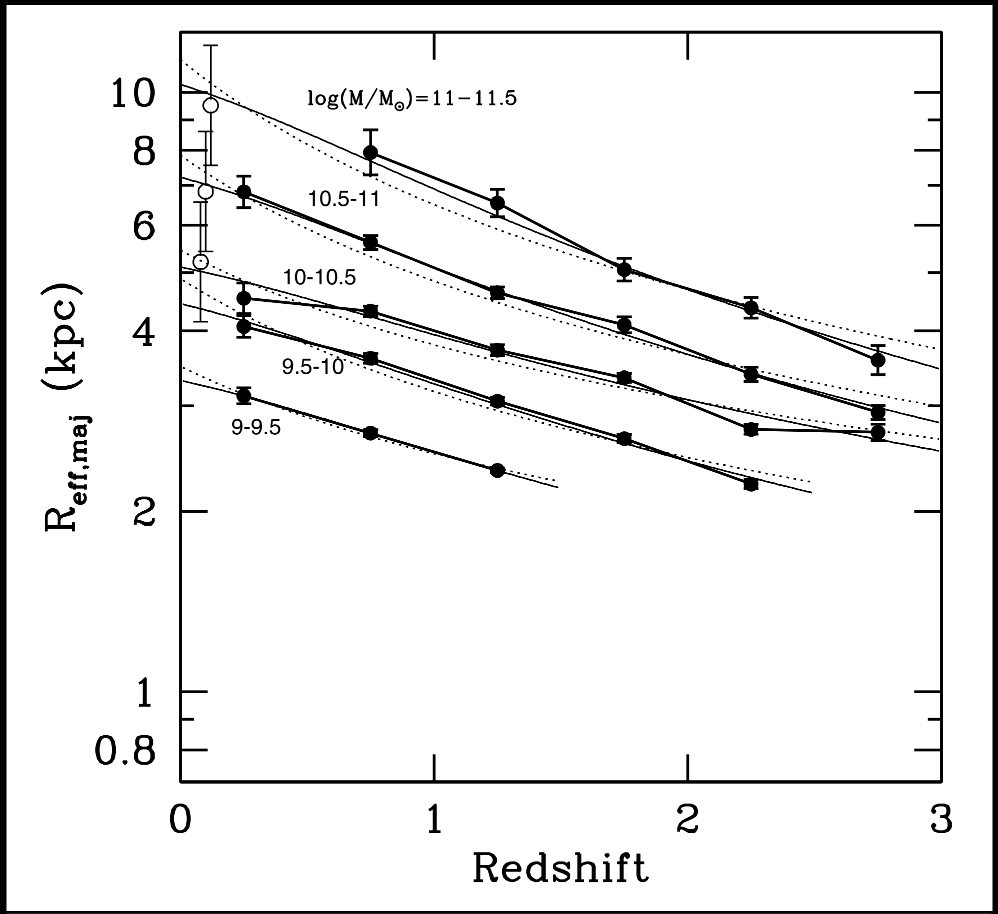
Kewley et al. 2014

Towards the perfect consensus on the ISM evolution

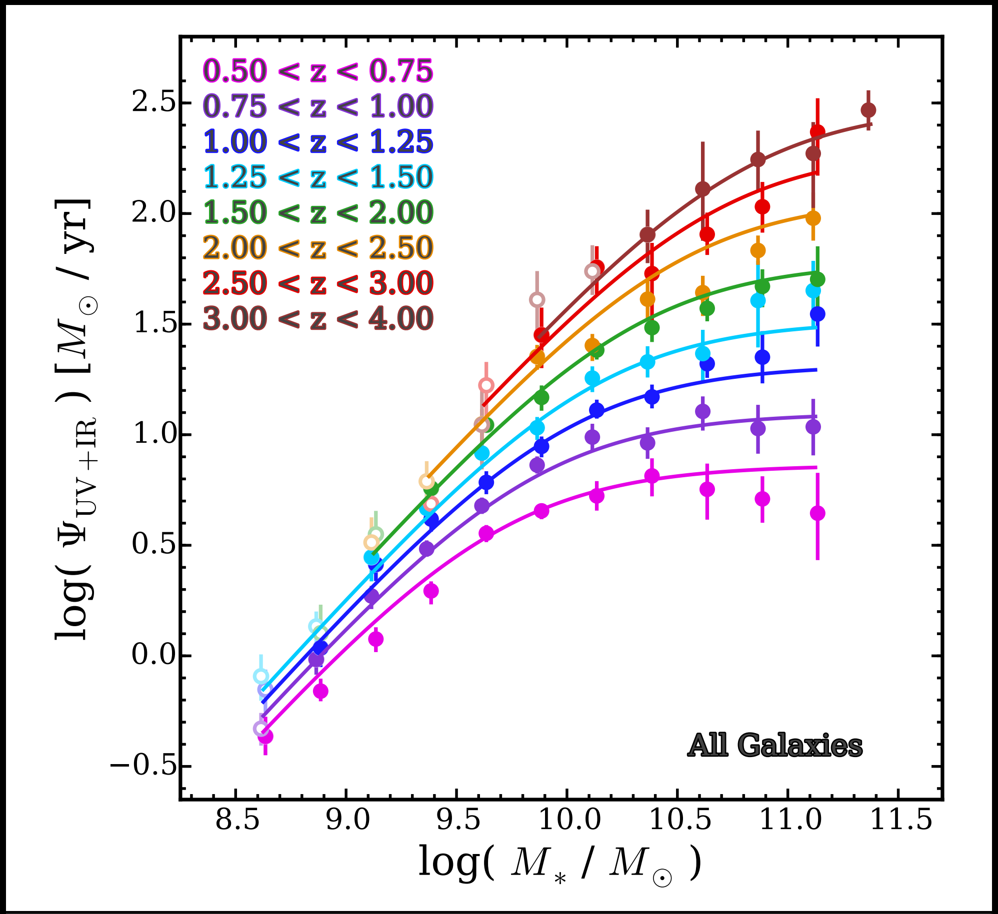
At higher redshifts, more active star formations occur per unit area
<u>Empirical metal measurements should be established at each redshift & population</u>
This allows to measure more robust mean metal abundances of individual galaxies



High-z (high ΣSFR)
Young HII regions are more dominant
= higher [OIII] & lower [SII] rate



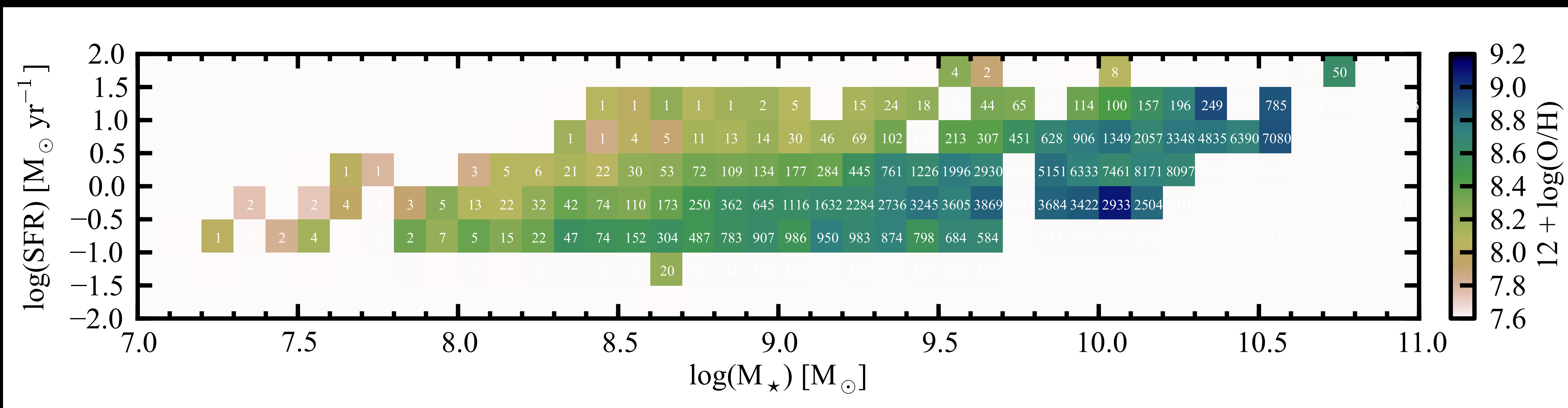
van der Wel et al. 2014

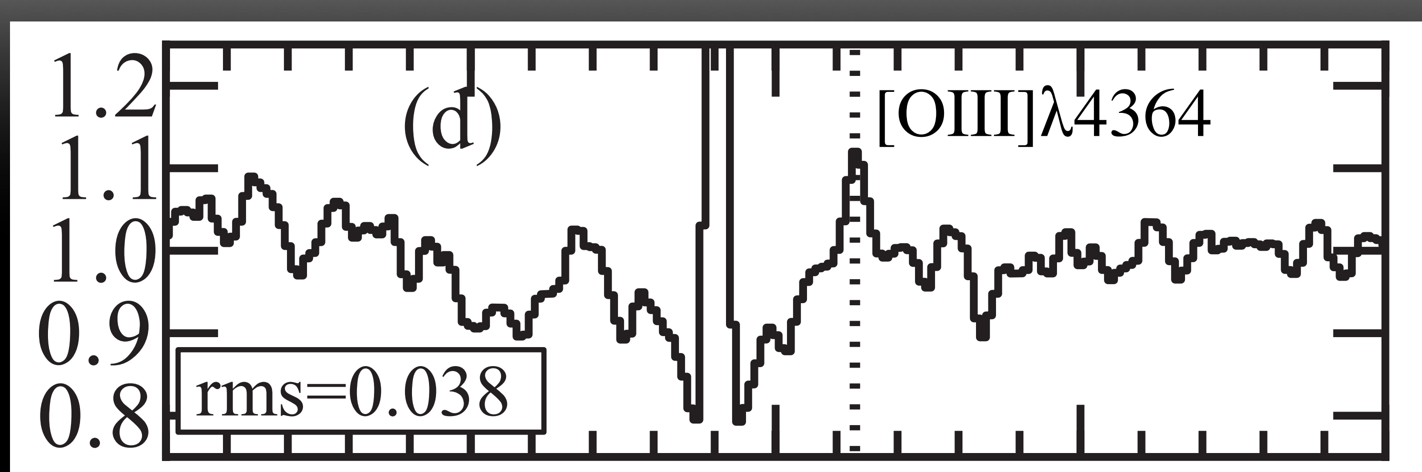


Tomczak et al. 2014

SDSS built the baseline of spectroscopic studies for the galaxies at z~0

SDSS project for the first time estimate M-Z relation of local galaxies
SDSS can define metallicity measurements for local galaxies & different populations
Revised metal abundances can be used for the comparison studies with simulations



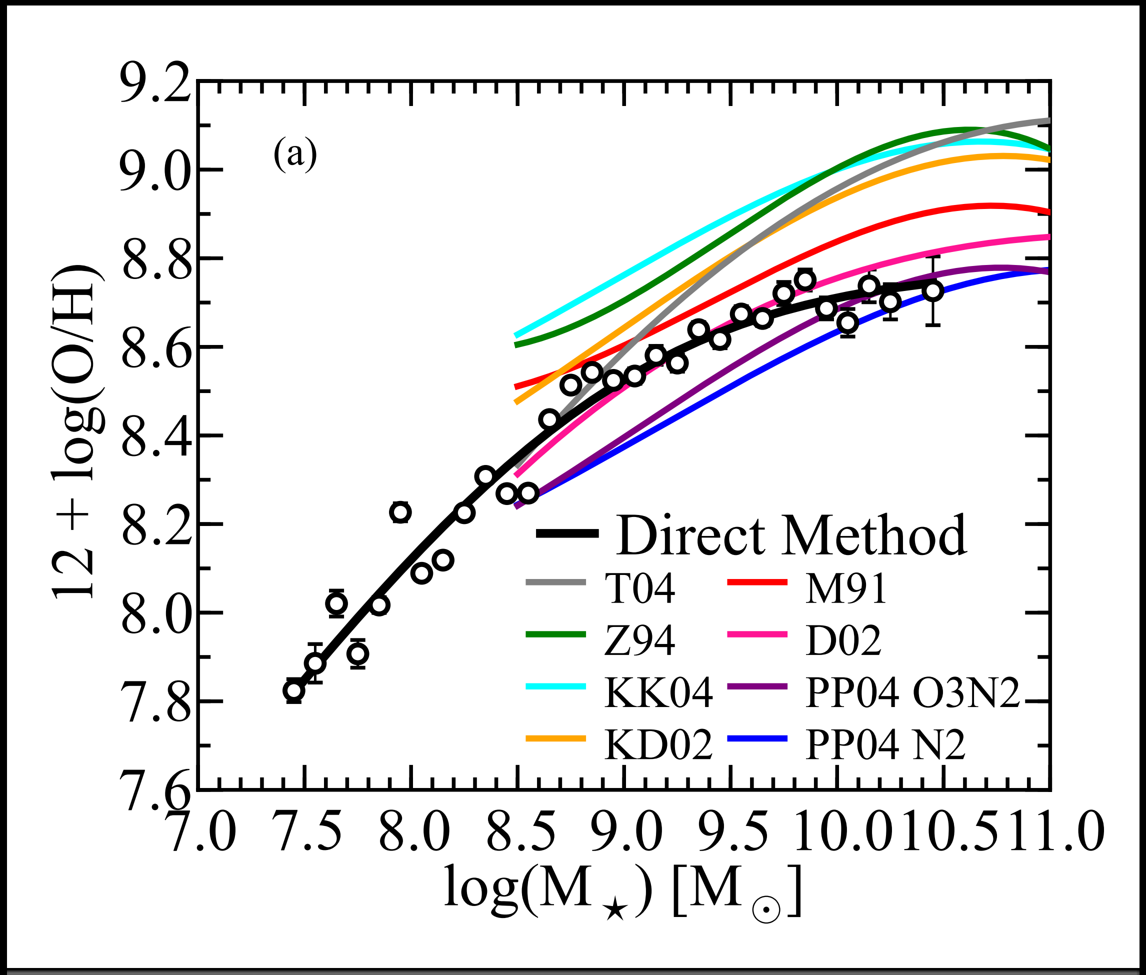


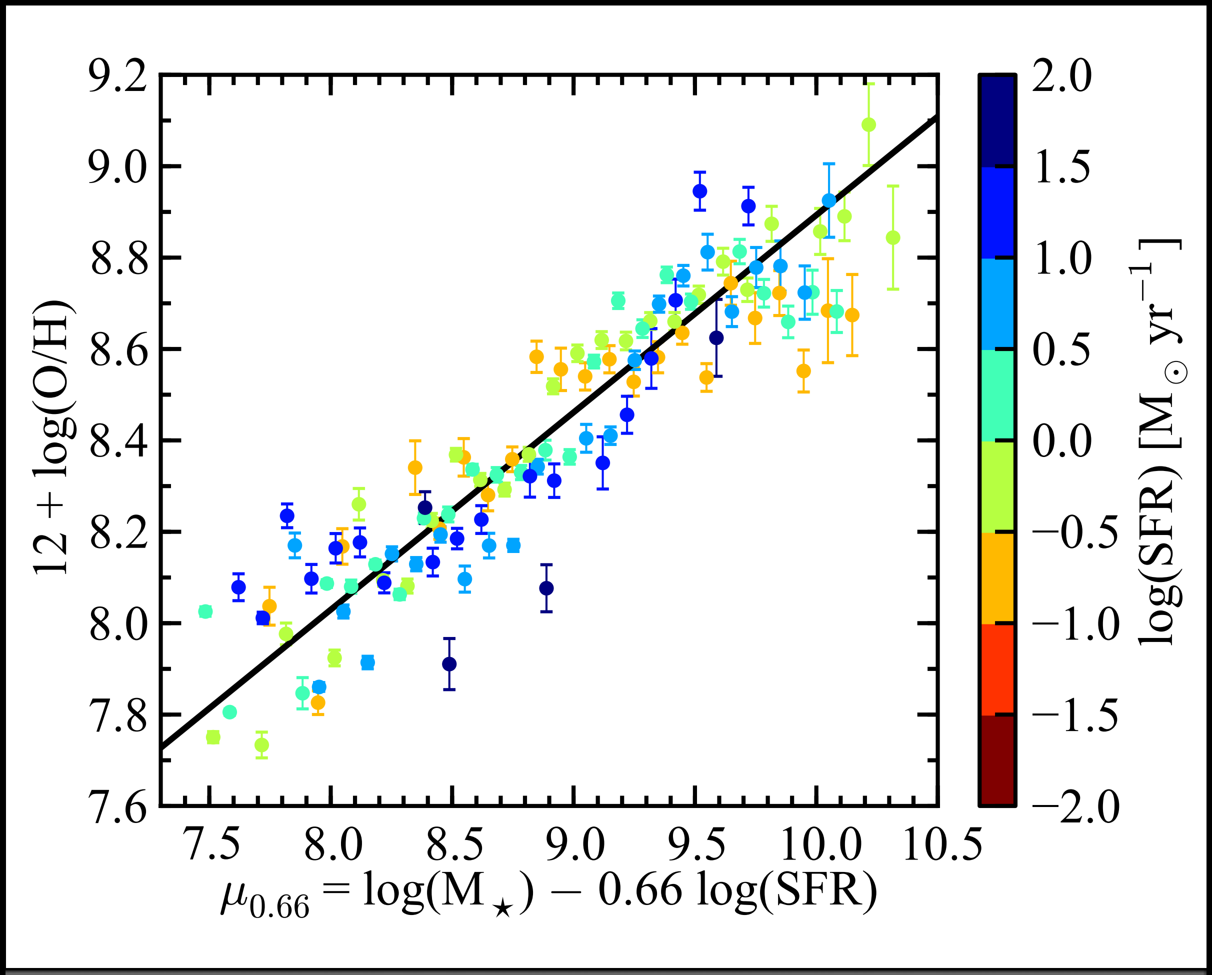
Andrews & Martini 2013

The strong baseline leads to more robust results

<u>Example; Andrews & Martini 2013</u>
Revised M-Z relation and fundamental metallicity relation
Previous works combined several empirical measurements

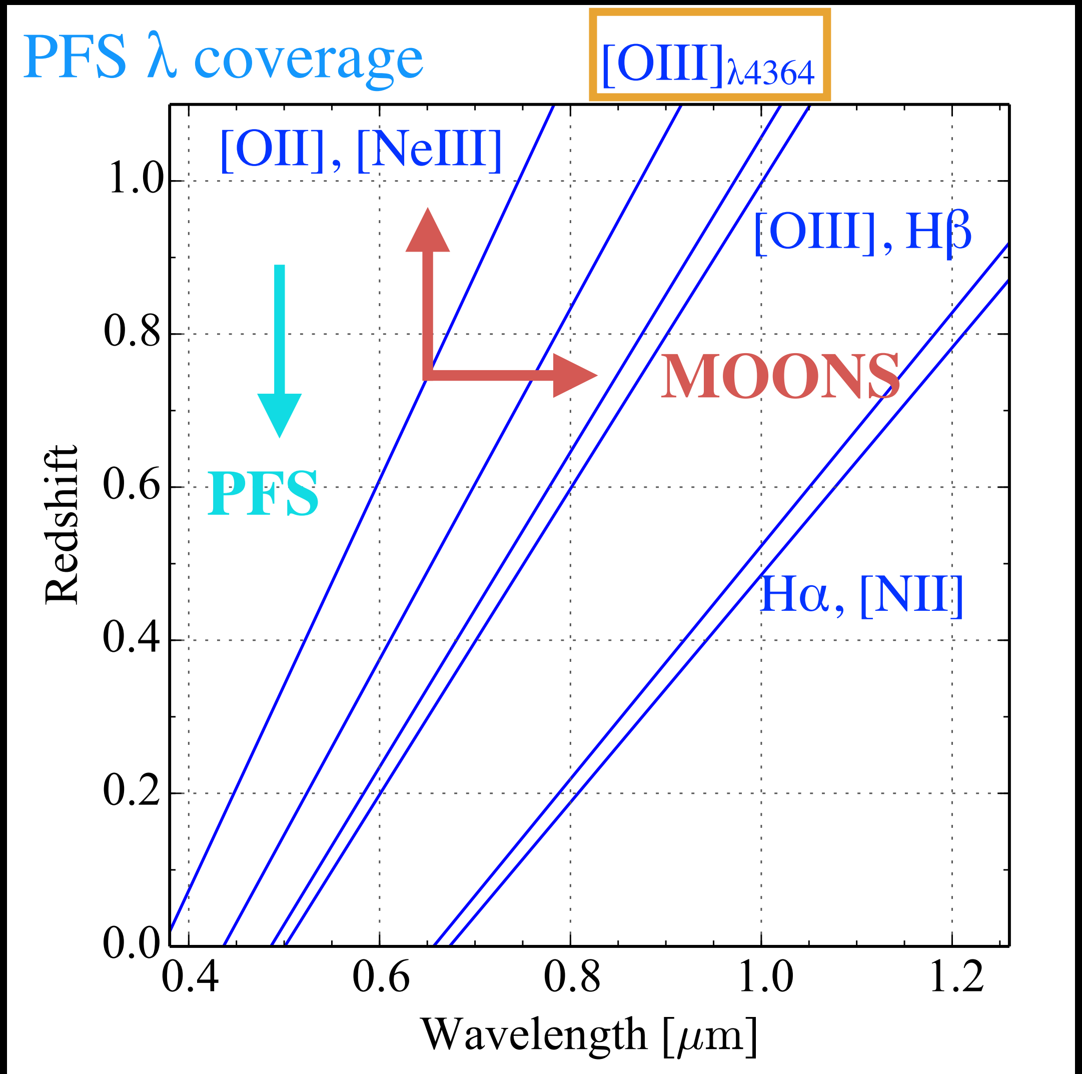
Original FMR has μ=0.32 (Mannucci et al. 2010), but revised value is μ=0.66 from direct method
PFS has a potential to resolve FMR plane at higher redshift (Nino-san's talk)

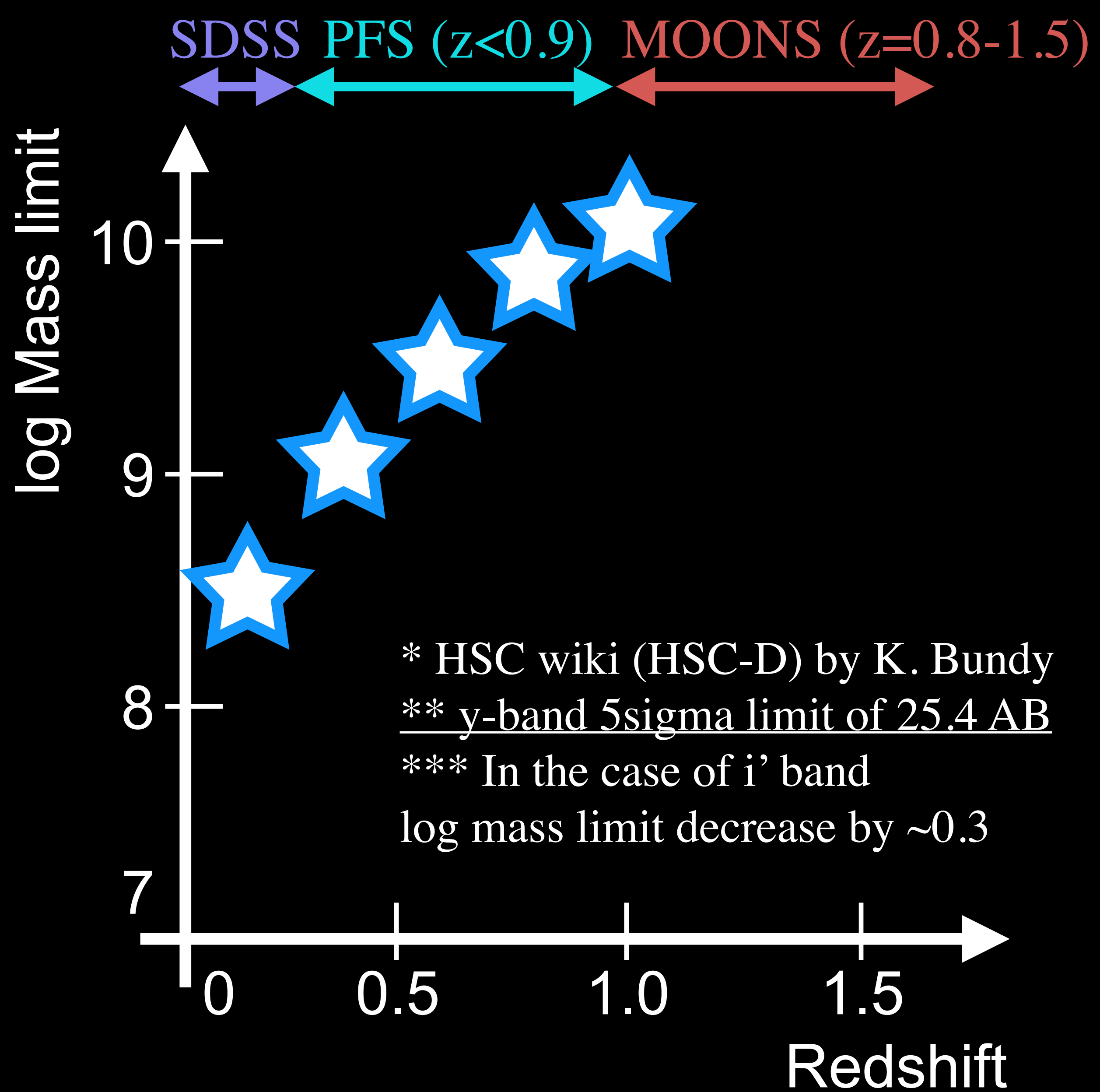




PFS should establish the baseline for the galaxies at redshift <1.6

PFS for the first time identify realistic M-Z relation and its evolution at z<1.6
PFS data can revise metallicity measurements for galaxies at given redshift
PFS can provide self-consistent empirical calibrations until z~0.9
Composite spectra of ~1k galaxies for each bin will be needed to detect $[OIII]_{\lambda 4364}$





Towards the perfect consensus on the ISM evolution

PFS can observe optical-emission lines within the wide redshift range ($0<z<1.6$)
This allows to trace galaxy evolution continuously from z=1.6 to z=0
PFS can also unveil ISM redshift evolutions of other physical parameters (U, Ne, Te)

R=4000 is enough to resolve [OII] doublet to estimate Ne
Te & Ne are insensitive to each other

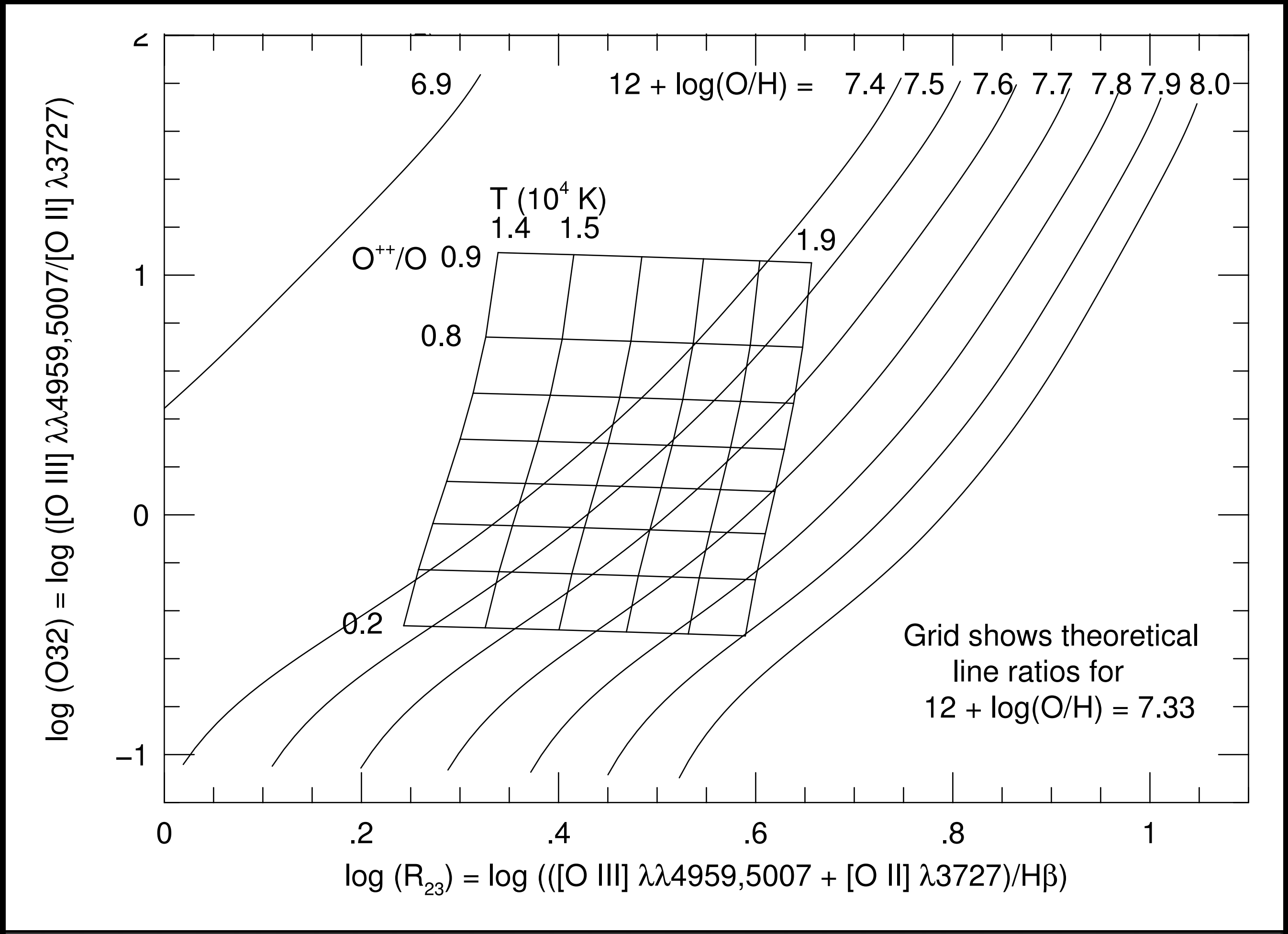
Given Ne, Te and Z,
we can measure U accurately

$$t = \frac{1.432}{\log[(\lambda 4960 + \lambda 5008)/\lambda 4364] - \log C_T}$$

$$C_T = (8.44 - 1.09t + 0.5t^2 - 0.08t^3)\frac{1 + 0.0004x}{1 + 0.044x}$$

$$t = -10^{-4} T_e$$

$$x = -10^{-4} N_e t^{-0.5}$$



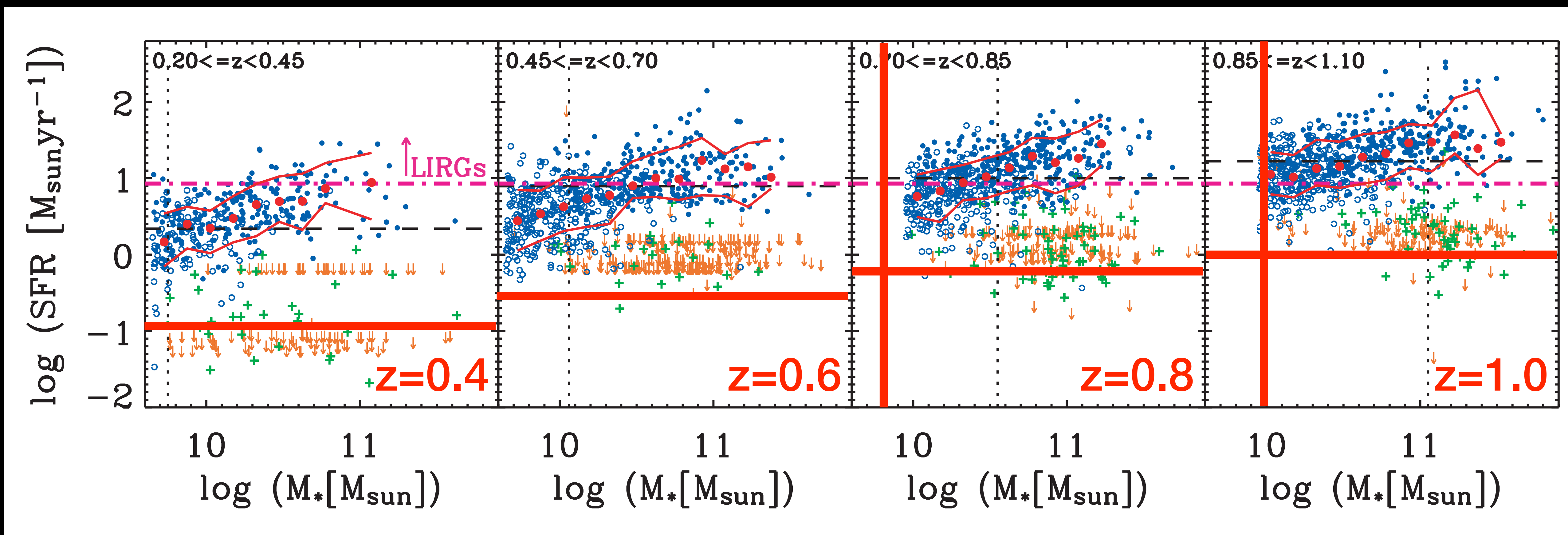
van Zee, Skillman & Haynes 2006

Request on the target selection

Needs mass-complete sample for star-forming galaxies
HSC-D covers z<1 galaxies at the stellar mass <1E10 M_{solar} with SFR>1 M_{solar}/yr
MOONS complement PFS-SSP for the galaxies at z=0.8-1.5 (0.6-1.8μm)

PFS 1-2hr integration has enough depth to trace SFGs
also will allow multi-emission line detection

Flux limit of 1hr integration time by PFS
Mass limits assuming y-mag limit =25.4 mag
SFR limits assuming A(Hα) =1 mag



Noeske et al. 2007
Keck: DEEP2 (AEGIS), 2095 field galaxies

A survey plan I like

I believe SDSS-type observation is the most unbiased plan for any science community
Practically, 100 nights is insufficient to accumulate a complete sample

- I prefer to focus on flux-limited observation for z~0.3-0.8 galaxies (>100k sample)
- Less biased selection criteria are more favored (photo-z or color?)
- We should collaborate with MOONS team to collect galaxies at z<1.5
- PFS-SSP is powerful for follow-up spec. of HSC-NBEs etc, but it already started

+ Mg_{II} and Fe_{II} absorption lines at z=0.5-3.5 can be observed by PFS
I will propose deeper Intensive program (~10hrs/config.) to get UV absorptions at z~2

SDSS (z<0.2) → PFS (z<0.8) → MOONS (z<1.5) → Ultimate-Subaru? (z<2.6)