NIR Spectroscopy of Star-Forming Galaxies at z~1.4 with Subaru/FMOS

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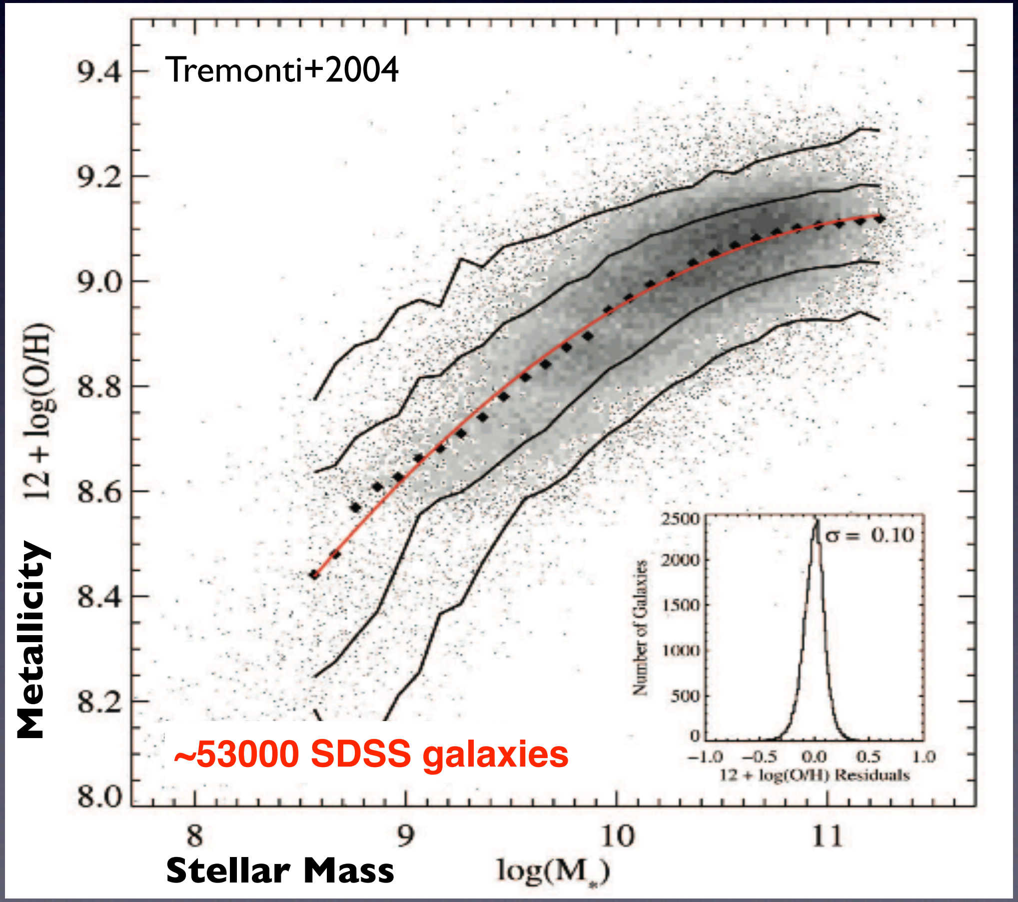
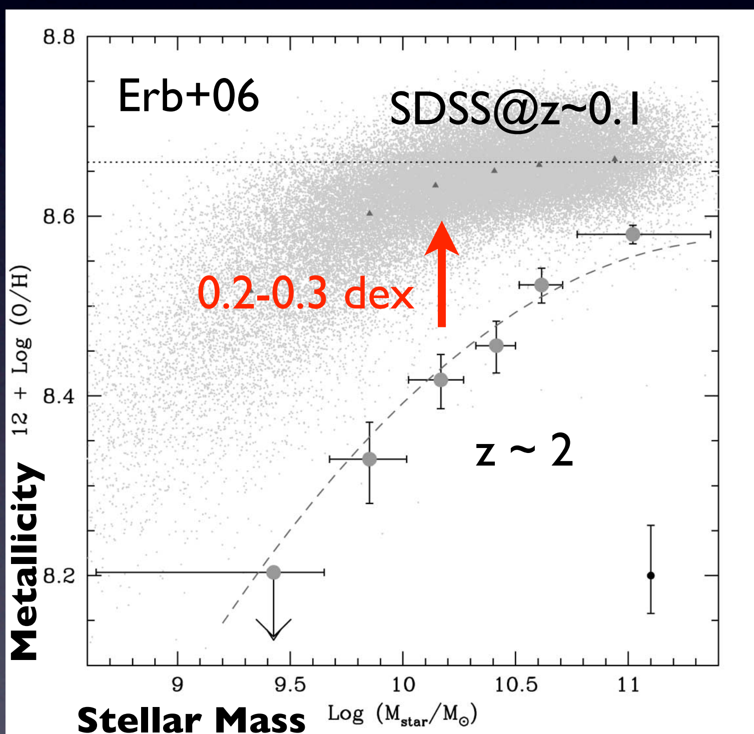
Introduction:

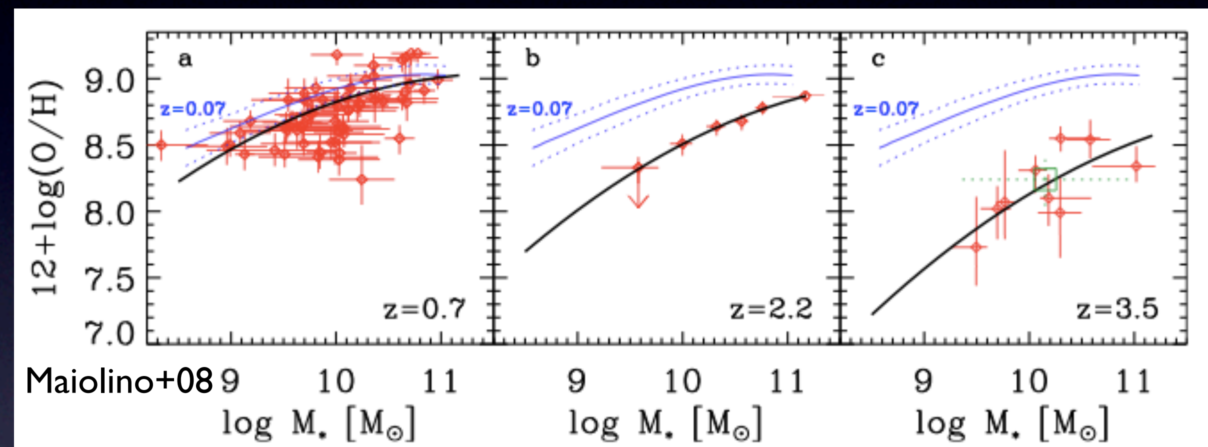
- Gas-phase Metallicity (hereafter, metallicity)
  - ✓ Metallicity traces the past star formation activity
  - ✓ It also changes via gas infall/outflow of the galaxies
  - ✓ This will be a key to understand the galaxy evolution
- It is known that galaxy mass (or luminosity) is correlated with metallicity
  - ✓ Massive (bright) galaxies tend to show larger metallicities
  - ✓ Stellar mass-metallicity (hereafter, MZ) relation at z~0 is established (Tremonti+04)

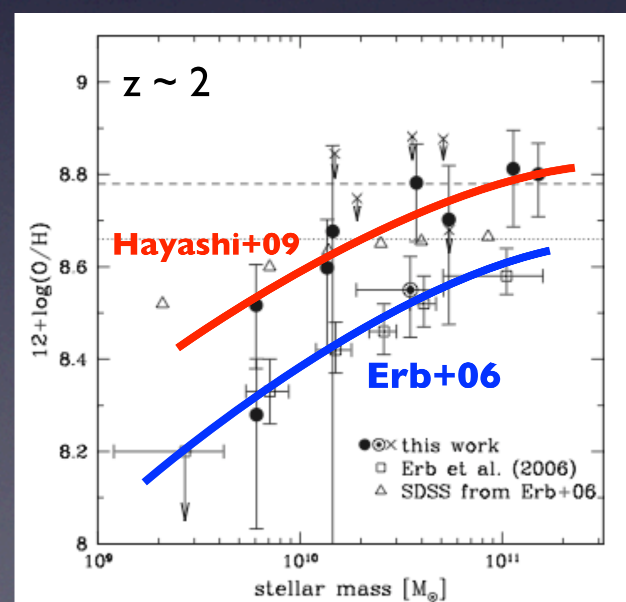


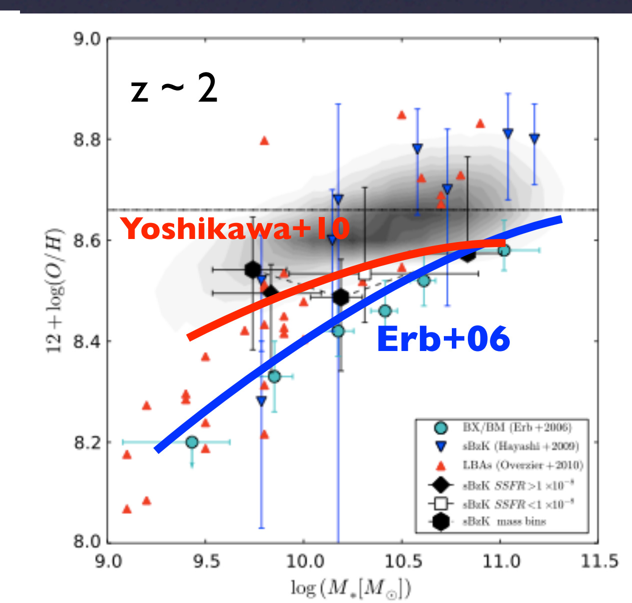
Introduction: Mass-Metallicity Relation at z>1

- MZ relation at z~2 (e.g., Erb+06) and z~3(e.g.,Maiolino+08)
  - ✓ Evolution of the MZ relation from z~3 to z~0?
  - ✓ Still controversy as to the MZR at z~2 (Hayashi+09, Yoshikawa+10, Onodera+10)
  - ✓ We need larger sample at z=1-2, when the universe in the most active/violent phase



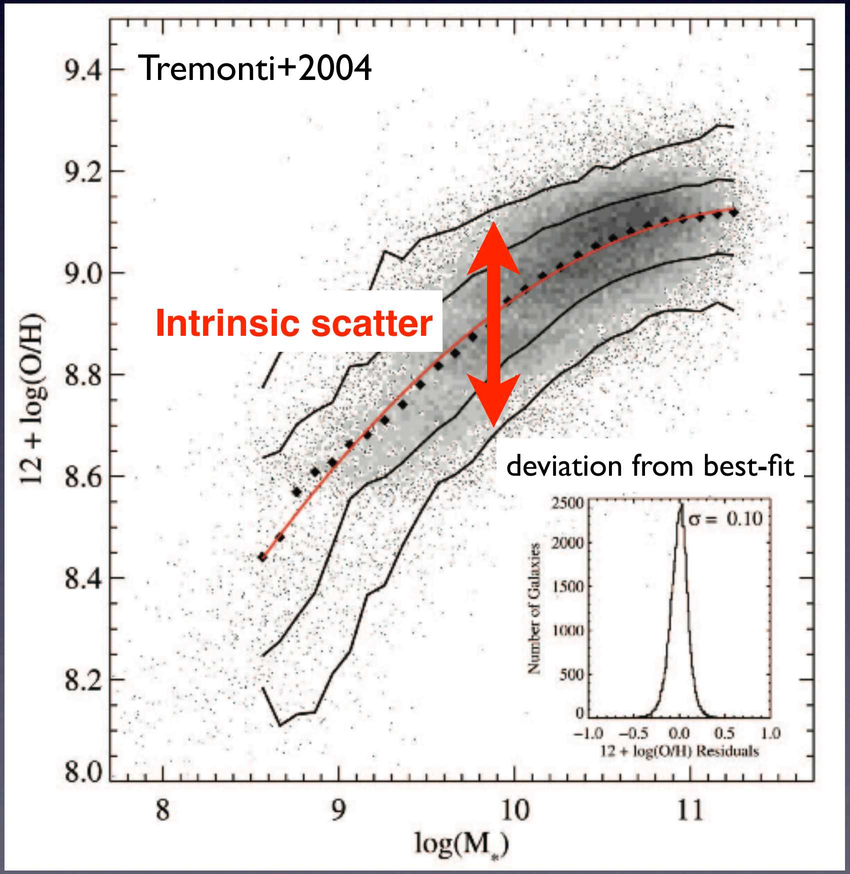


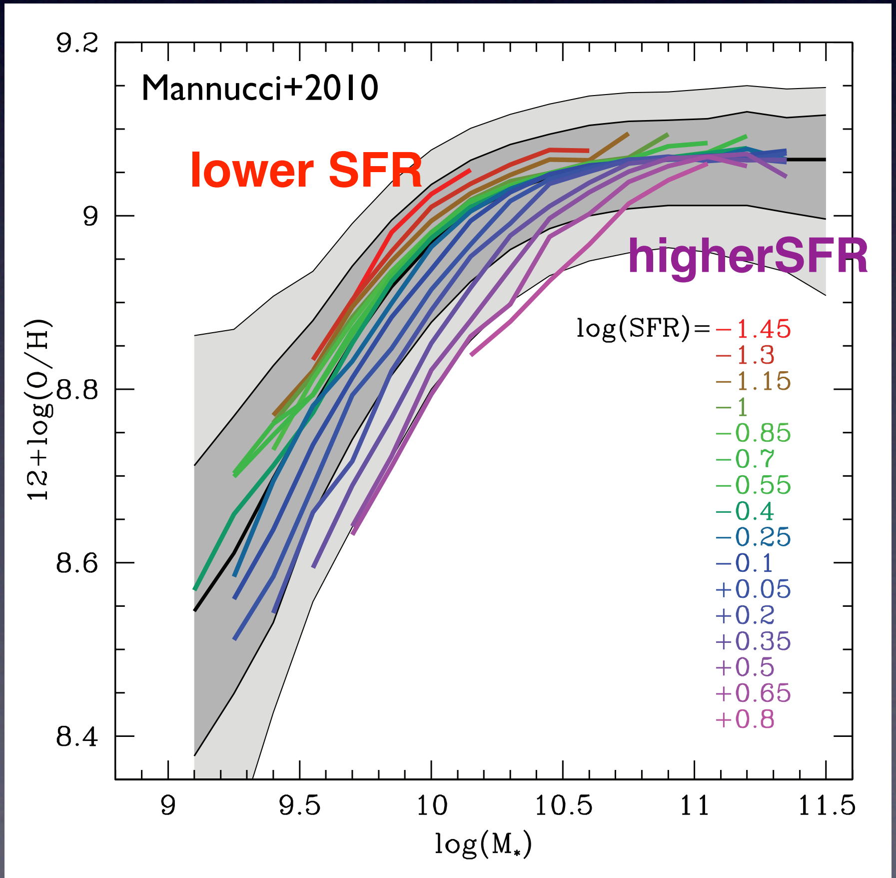




Introduction: Intrinsic Scatter of Mass-Metallicity Relation

- The MZ relation at z~0.1 has intrinsic scatters (Tremonti+04)
- What physical parameters can explain this scatter?
  - ✓ SFR (Mannucci+2010), specific SFR (Ellison+2008), half light radius (Ellison+2008), galaxy interaction (Rupke+2008)
- The intrinsic scatter of the MZ relation at high-z is still unknown
- We need large sample at high-z

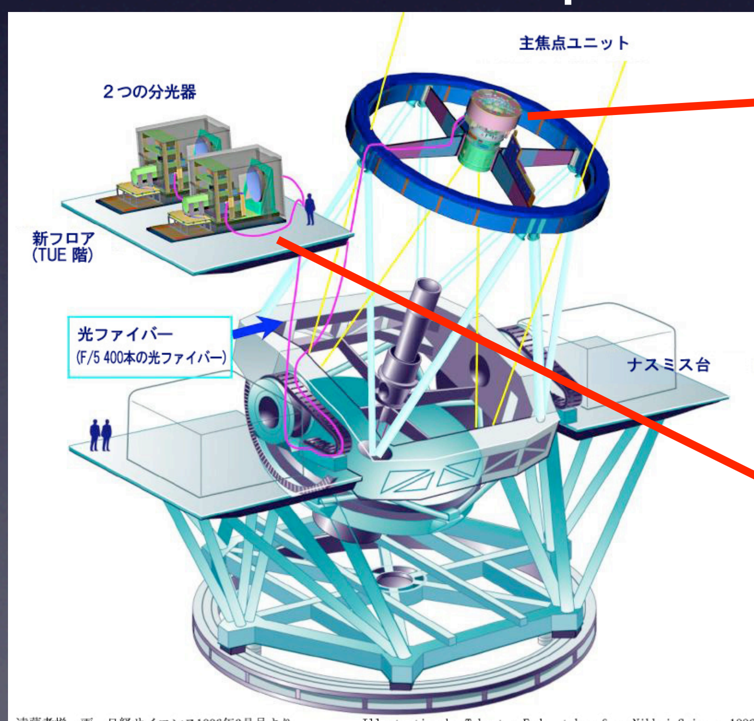




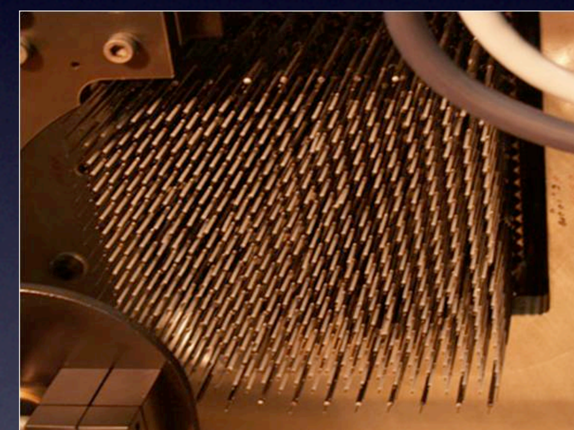
Introduction: FMOS on Subaru Telescope

- What's FMOS (Fibre Multi-Object Spectrograph)?
  - ✓ Second generation instrument for Subaru Telescope
  - ✓ Collaboration among Japan, UK, and Australia
  - ✓ Multi-object spectrograph in NIR (0.9-1.8μm) w/ 400 fibers and FoV of 30'Φ
  - ✓ Low Resolution (LR; R~650) and High Resolution (HR; R~3000) mode
  - ✓ Details are in Kimura et al. 2010, PASJ, **62**, 1135
  - ✓ We conduct large NIR spectroscopic surveys with FMOS

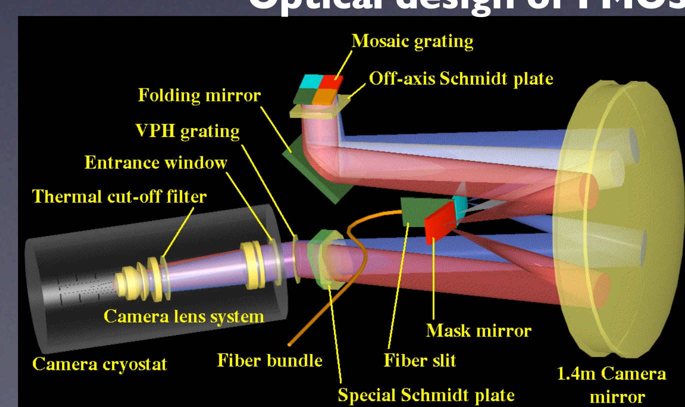
FMOS on the Subaru Telescope



Fiber positioner on prime focus

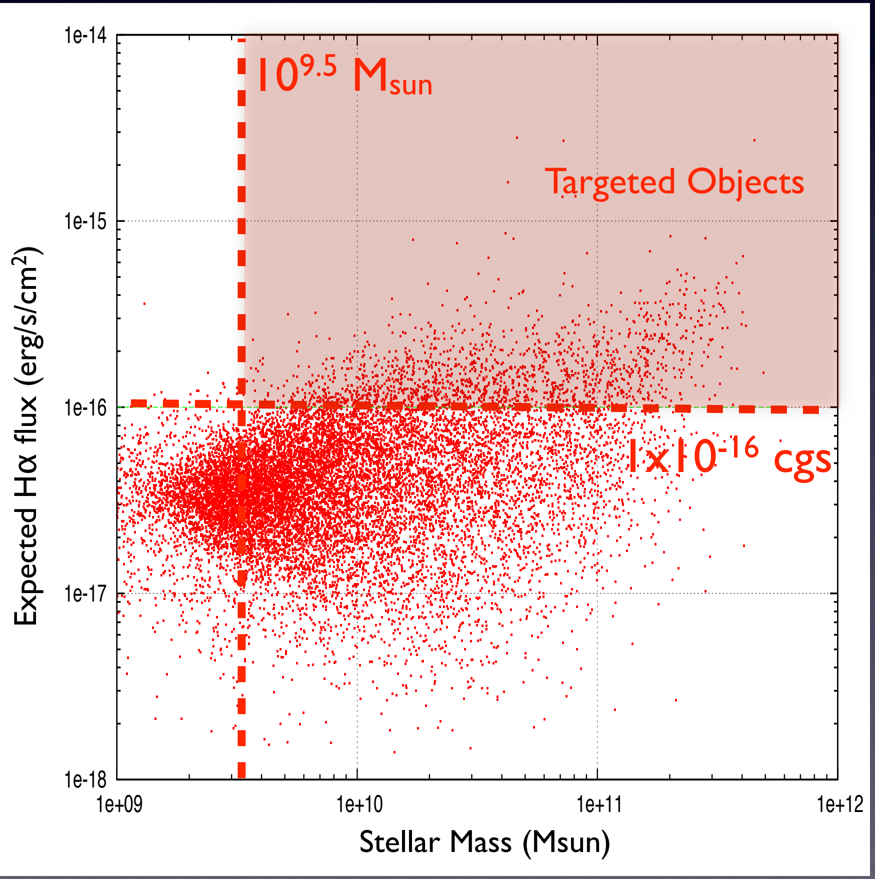


Optical design of FMOS

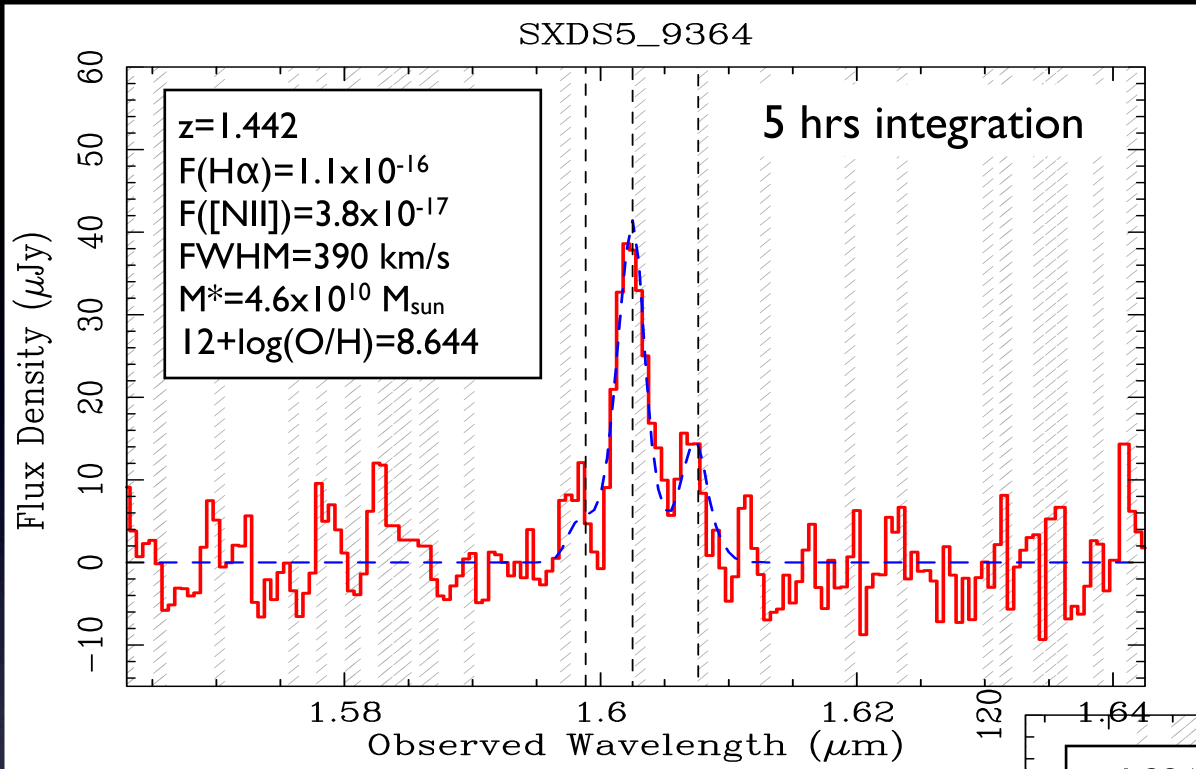


Sample Selection and Observations:

- Targeted Sample
  - ✓ Field : SXDS/UDS (effective area~0.7 deg^2)
  - ✓ $1.2<z_{phot}<1.6$, K<23.9 AB mag, $M_*>10^{9.5}$ M_{sun}, $F(H\alpha)^{exp}>1.0\times10^{-16}$ cgs
  - ✓ Excluding X-ray sources ($L_x>10^{43}$ erg/s)
  - ✓ 2500 objects in whole area of the SXDS
- Observations
  - ✓ Mainly FMOS/GTOs in 2010-2011
  - ✓ LR mode / Cross Beam Switch mode
  - ✓ Typical exposure time is 3-4 hrs per FoV
  - ✓ About 1200 objects are observed in total
- Data Reduction
  - ✓ FMOS reduction pipeline FIBRE-pac
  - ✓ Details are shown in Iwamuro+12
- Spectral Fittings
  - ✓ Fitting methods taking the OH mask effects into consideration.



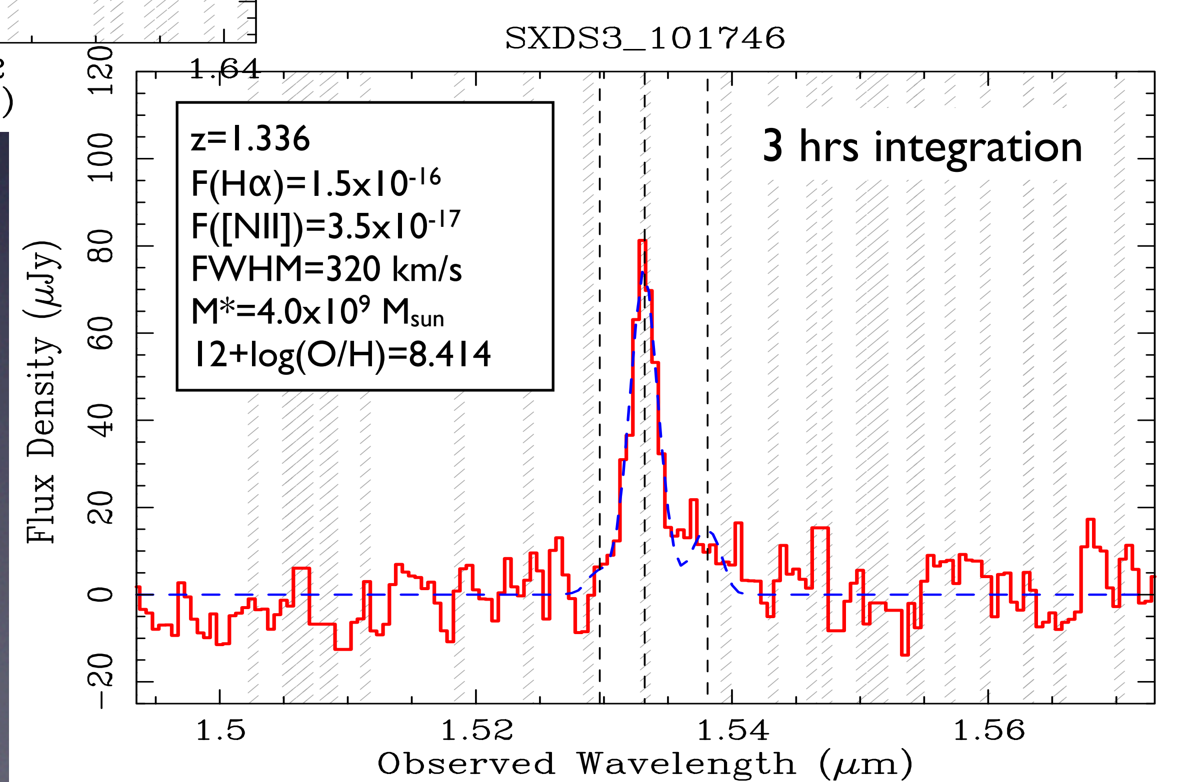
Observed Spectra:



We observed ~1200 targets in total. Among them, 343 objects show significant Hα emission (S/N>3) at z=1.2-1.6 (median=1.41). This is the largest NIR spectroscopic sample at z>1 ever.

Shaded area: OH airglow mask

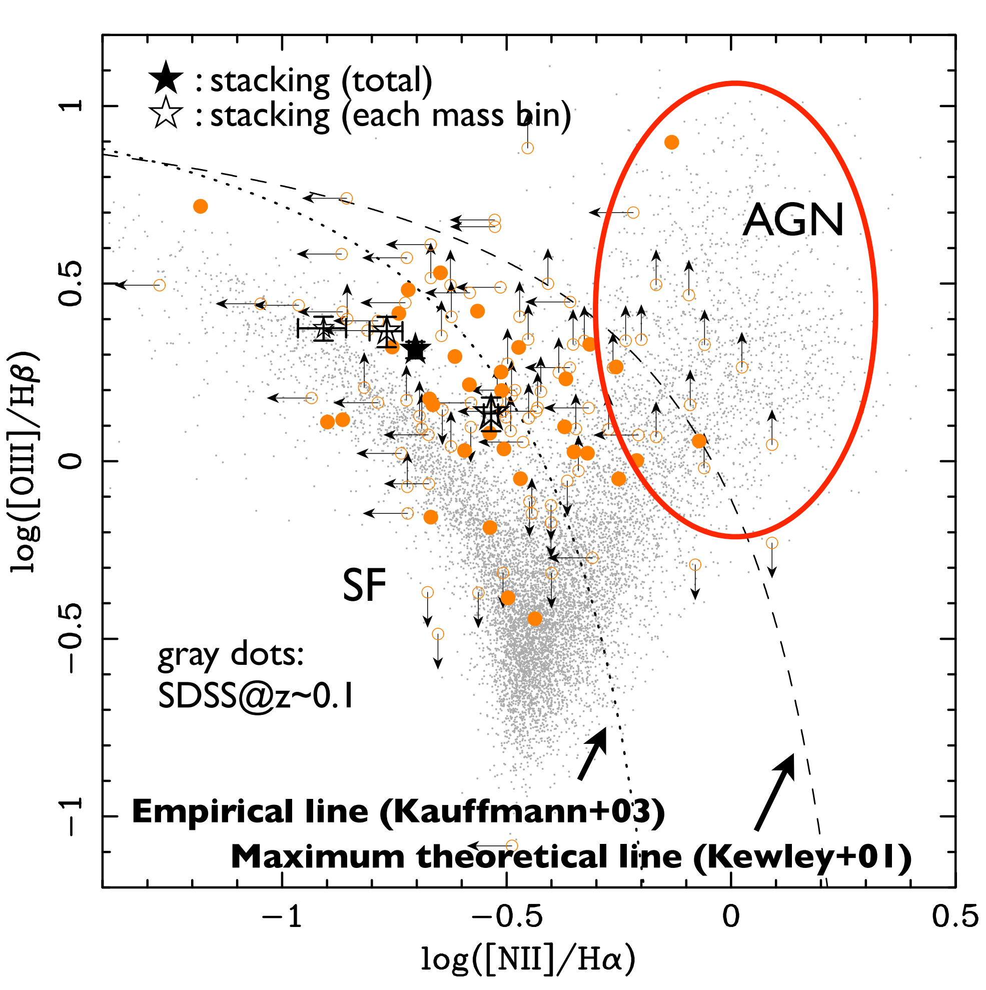
Solid : Observed Spectra
Dashed : Best-fit Model Spectra

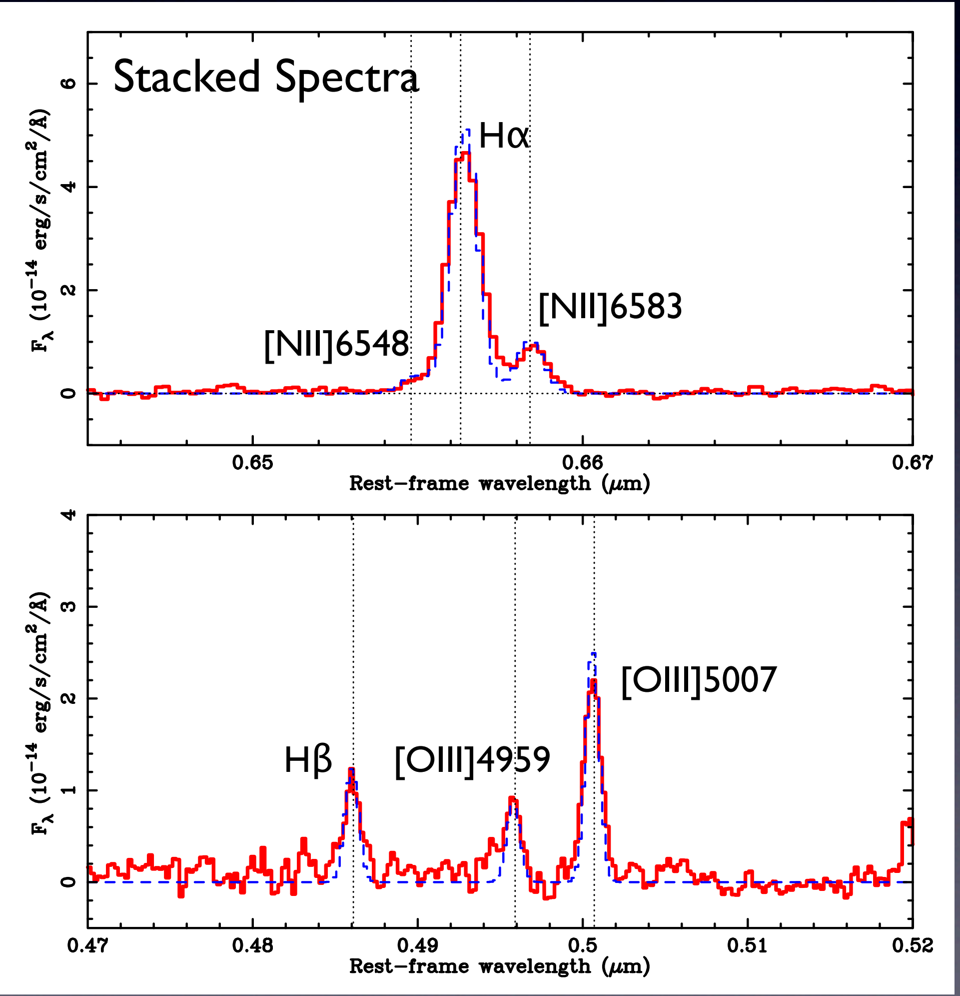


Initial results (GTO in 2010; 71 Hα detections) are already presented by Yabe+12 (arXiv:1112.3704). In this talk, we also present preliminary results of all GTO runs.

AGN Contributions:

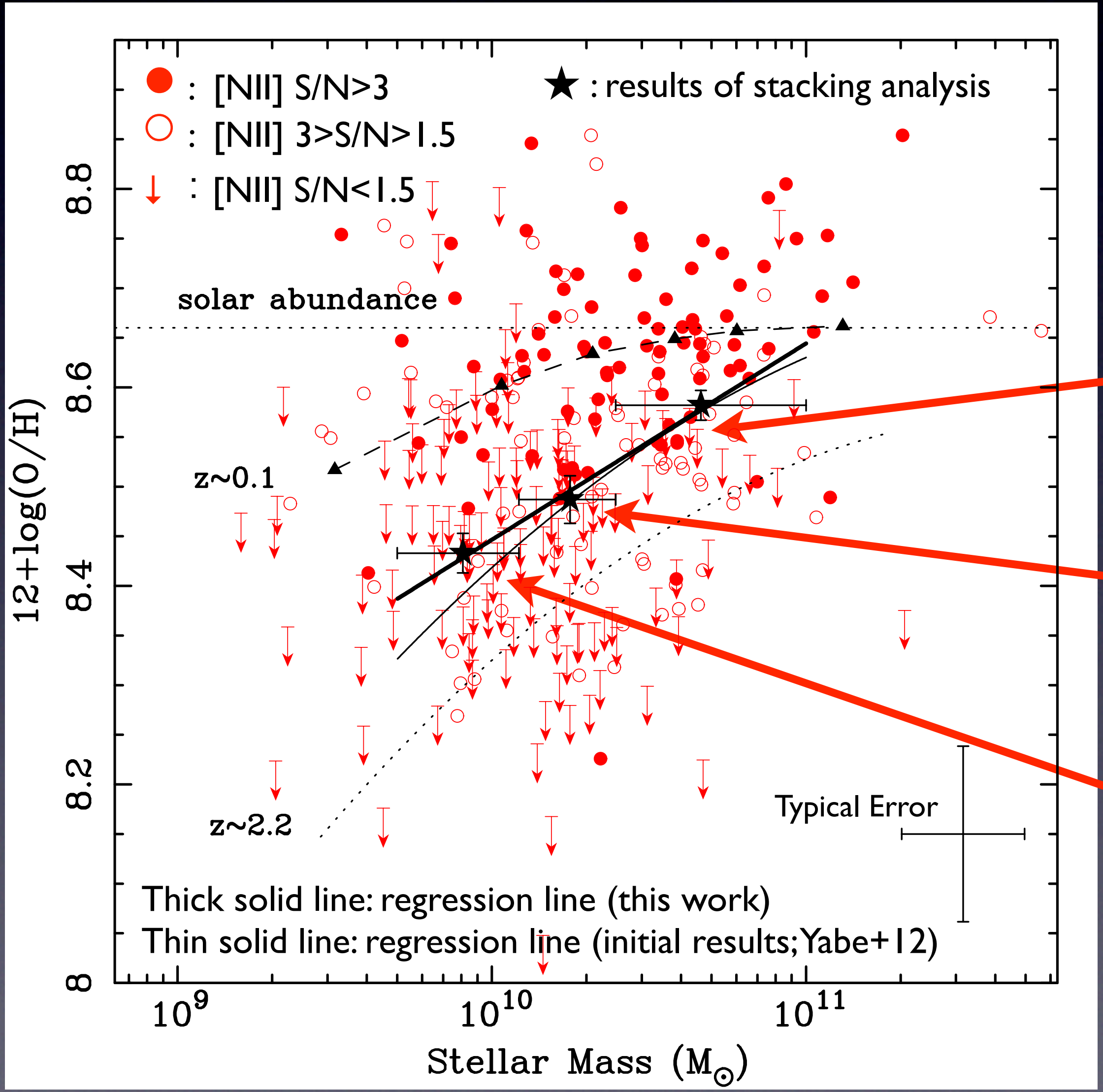
- AGN diagnostics from the BPT diagram ([NII]/Hα vs. [OIII]/Hβ)
- Most objects are placed in the SF region in the BPT diagram
- 21 objects are AGN candidates (BPT, extremely large [NII]/Hα ratio and line width)
- Stacking analysis shows that our sample is on the SF region on average

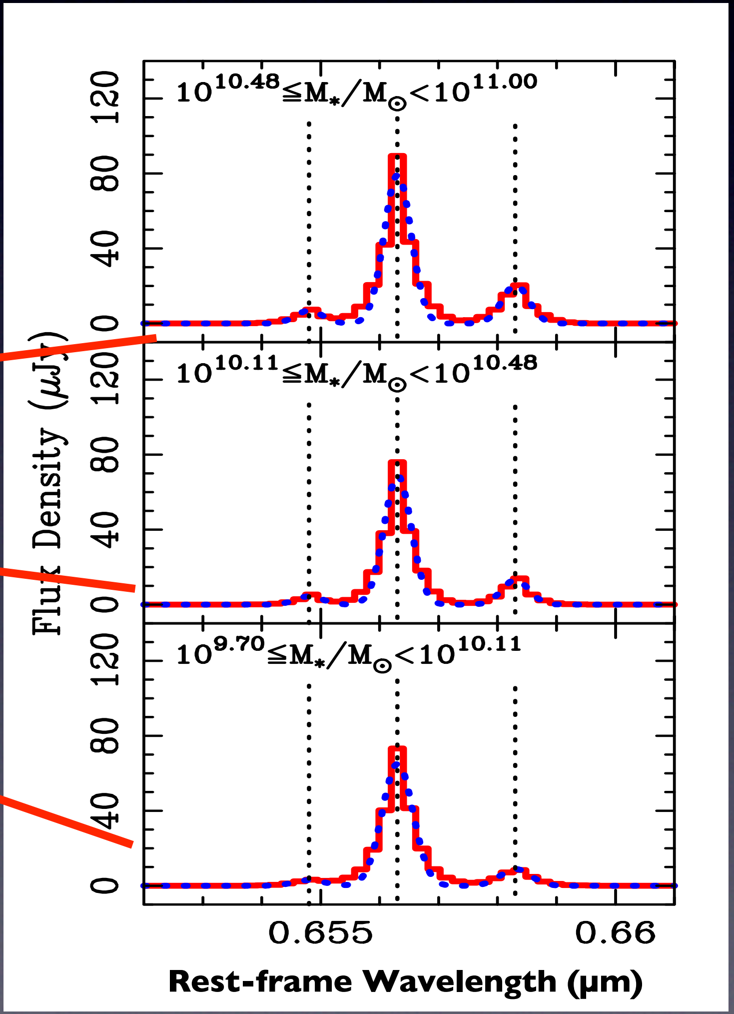




Mass-Metallicity Relation at z~1.4:

- 12+log(O/H) from [NII]/Hα line ratio (N2 method; Pettini & Pagel 2004)
- No significant [NII] emission (S/N<3.0) from ~70% of the objects
- Stacking analysis dividing our sample into 3 stellar mass bins (5×10^9-1×10^{11} M_{sun})
- The largest sample ever at z>1

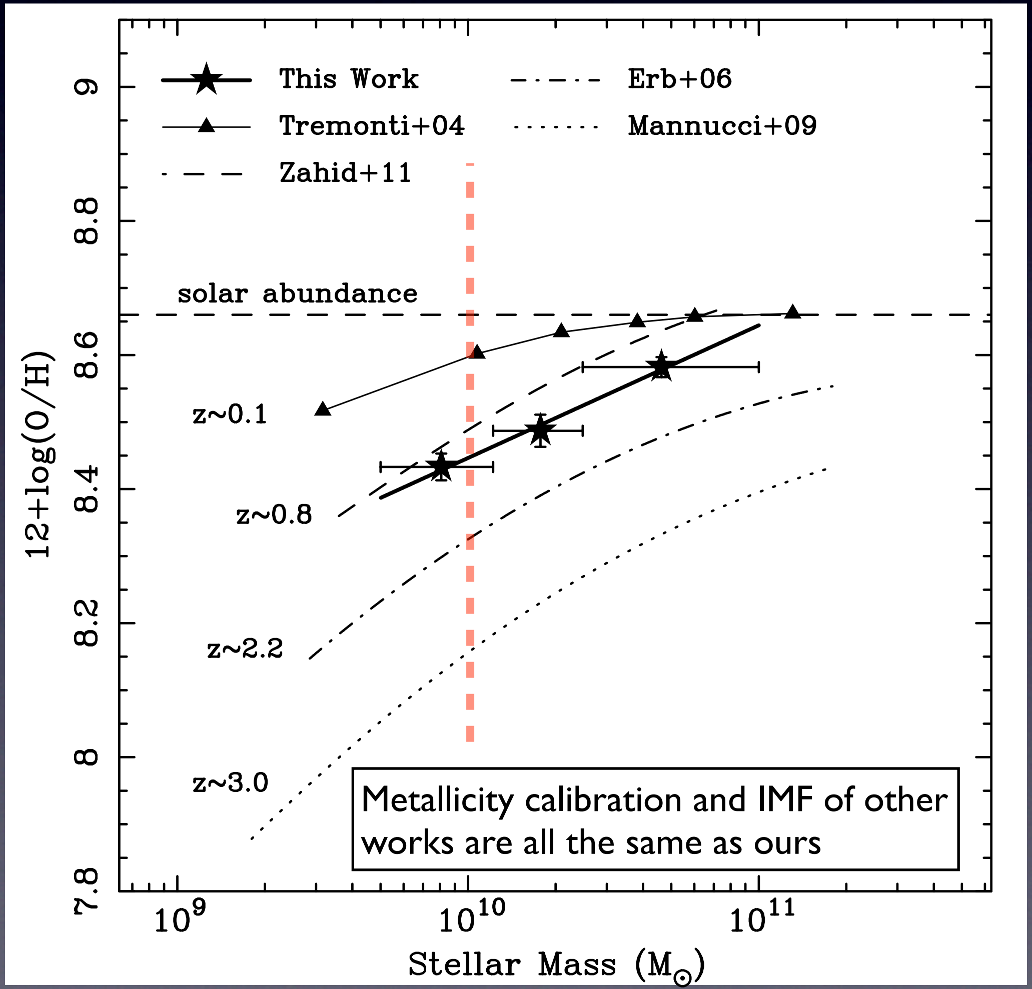


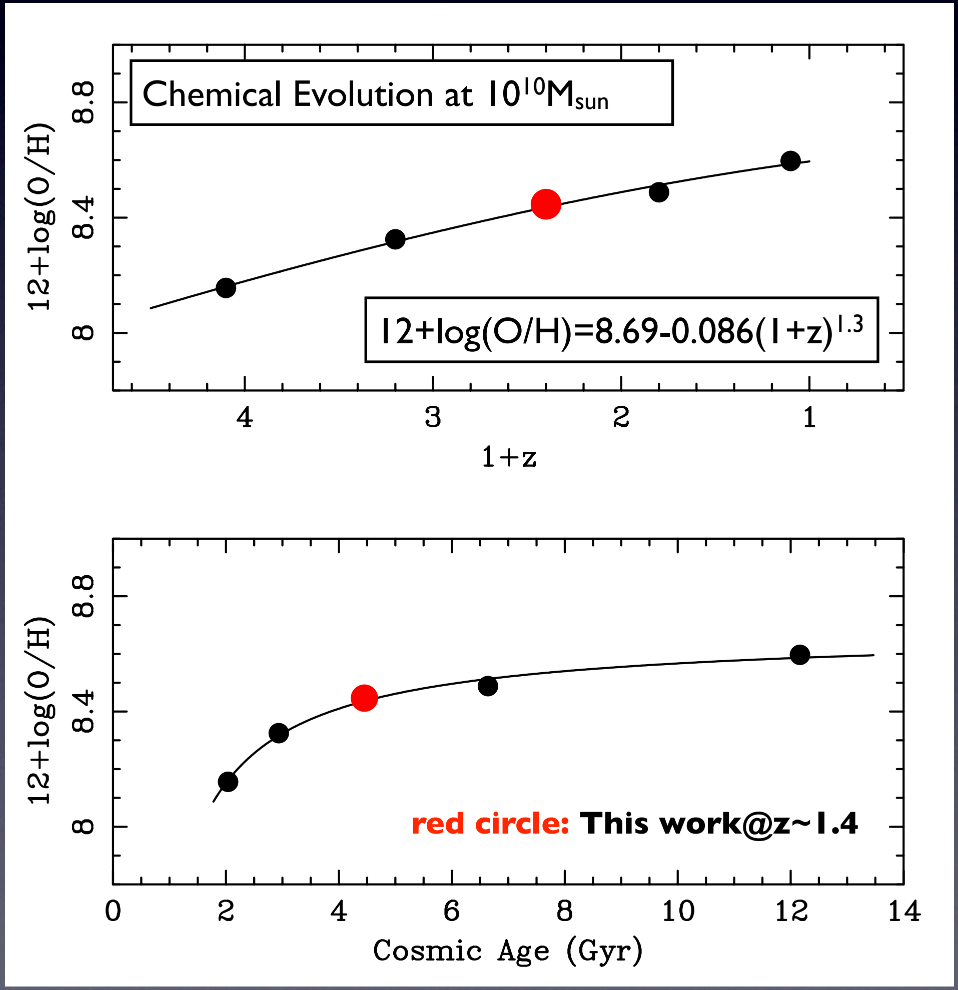


Typical number in each mass bin is ~90

Cosmic Evolution of Mass-Metallicity Relation:

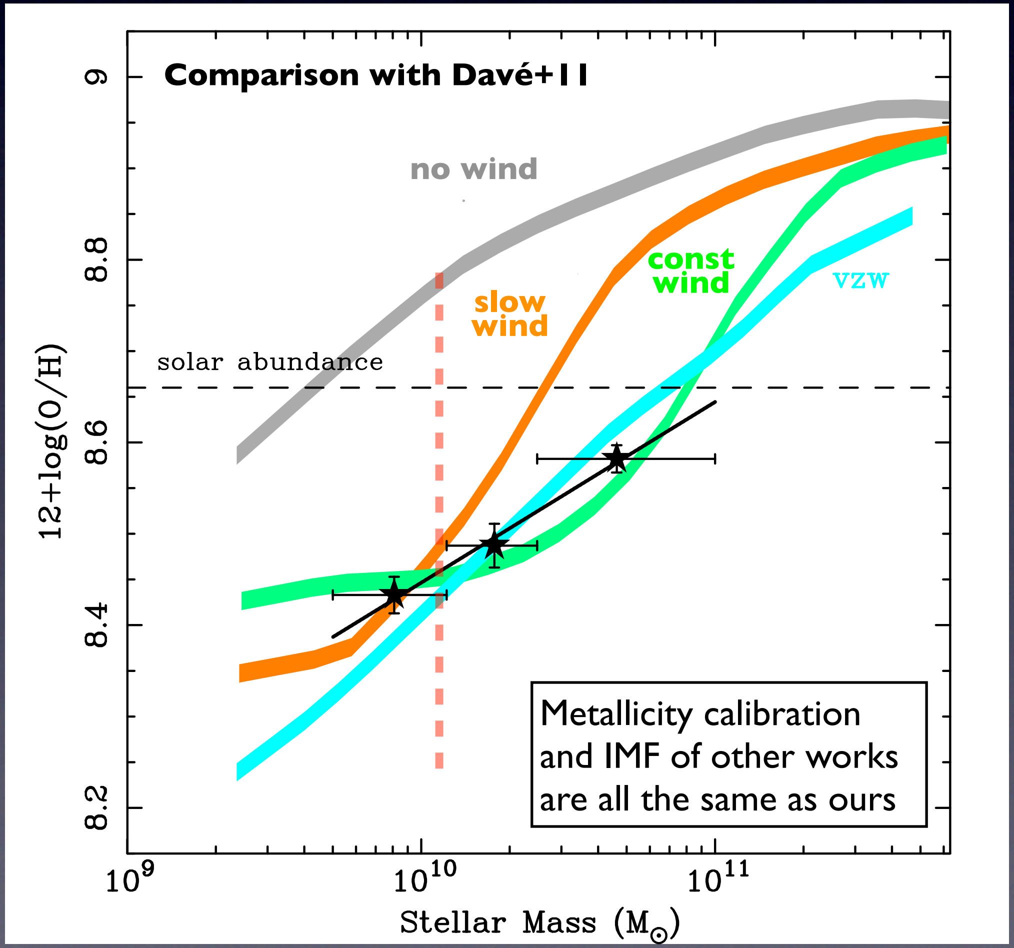
- Comparison to the previous works up to z~3
  - ✓ Our results at z~1.4 are between those at z~0.8 and z~2.2
  - ✓ Anti-downsizing-like evolution from z~1.4 to z~0.8?
- Evolution of the MZ relation from z~3 to z~0
  - ✓ Smoothly evolves from z~3 to z~0
  - ✓ MZ relation evolution at $M^*=10^{10}M_{sun}$z : $12+\log(O/H)=8.69-0.086(1+z)^{1.3}$

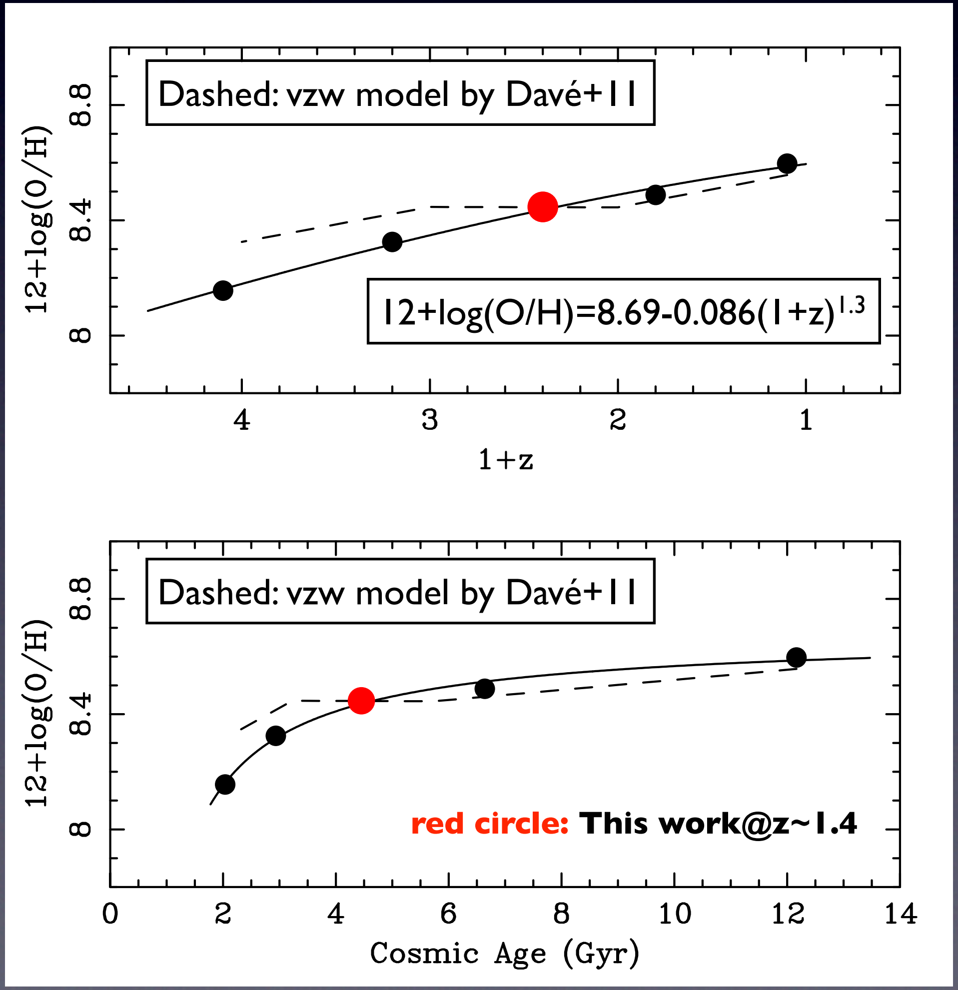




Comparison with the theoretical models:

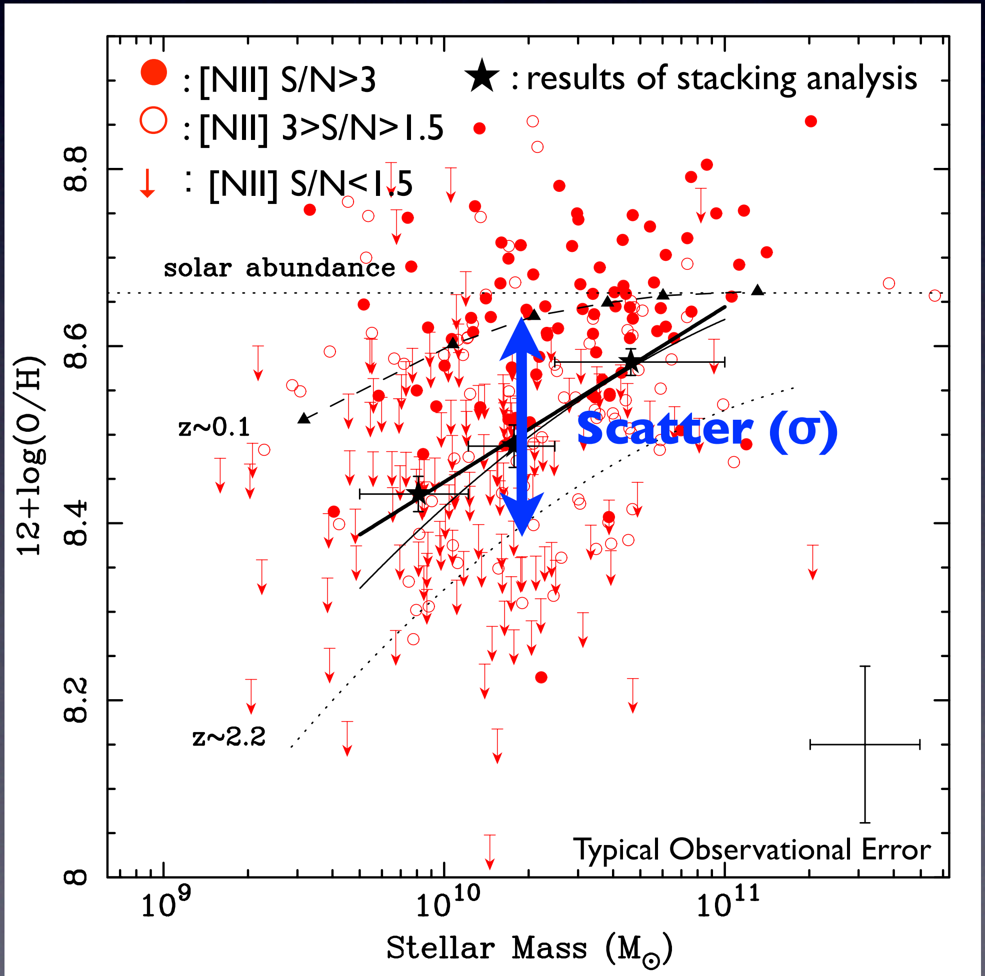
- Comparison with theoretical predictions (Davé et al. 2011)
  - ✓ N-body + SPH cosmological simulations
  - ✓ 4 wind models (no wind; constant wind; slow wind; mass dependent wind) implemented
    - ✳ Constant wind (cw) : $dM_{wind}/dt=2\times SFR$, $v_{wind}=680$ km/s
    - ✳ Mass dependent wind (vzw) : velocity dispersion (=mass) dependent wind
- Our result agrees with **cw** or **vzw** model

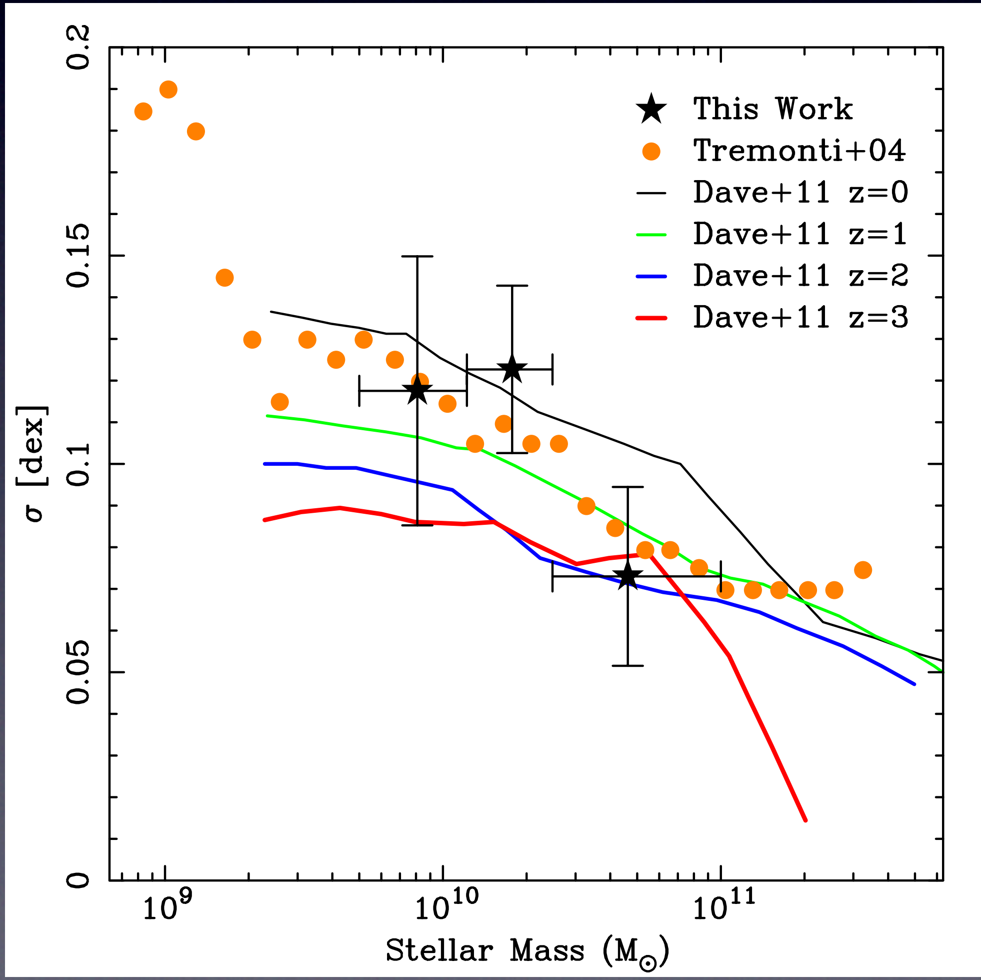




Intrinsic Scatter of Mass-Metallicity Relation:

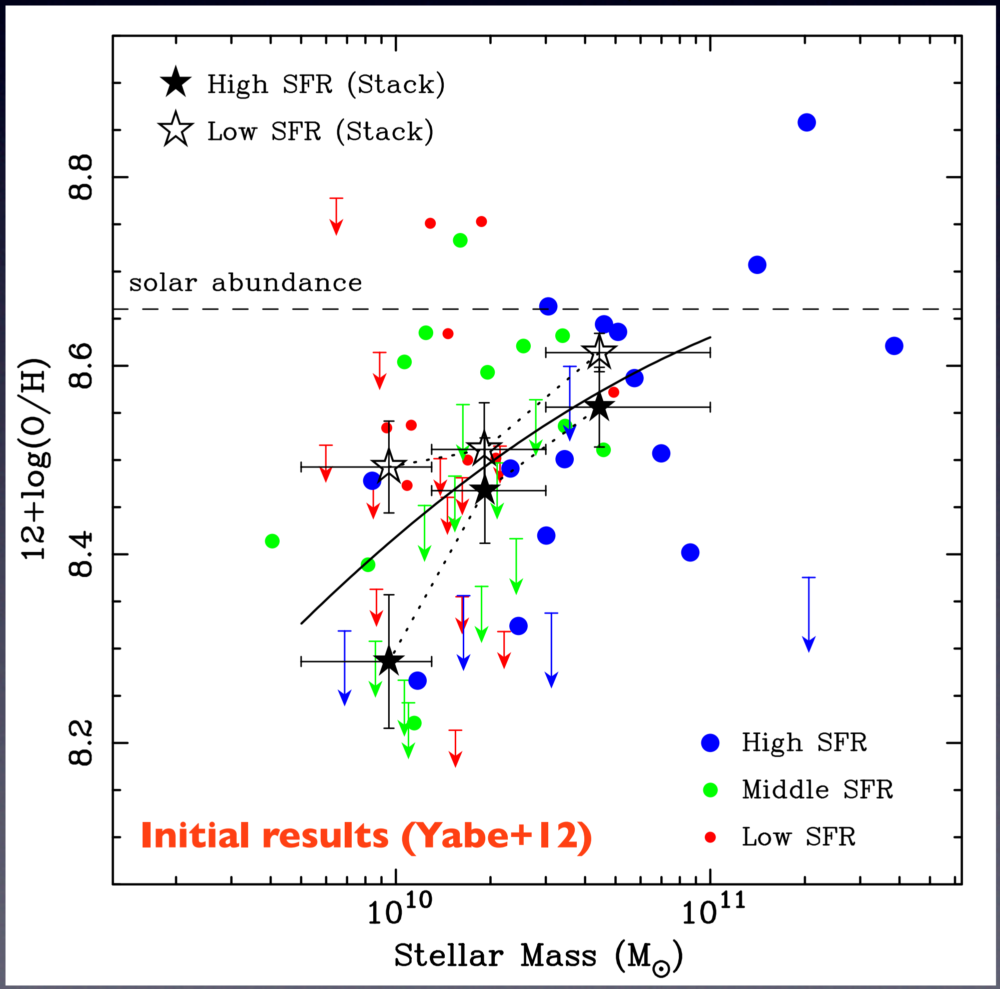
- We found that the MZ relation at z~1.4 has intrinsic scatters of ~0.1 dex
  - √ Observational errors are subtracted from the observed scatters
  - √ Well agrees with SDSS results at z~0.1 within the error bars
  - √ However, note that the values should be lower limit because some metallicities are upper limit
- What makes the intrinsic scatter?

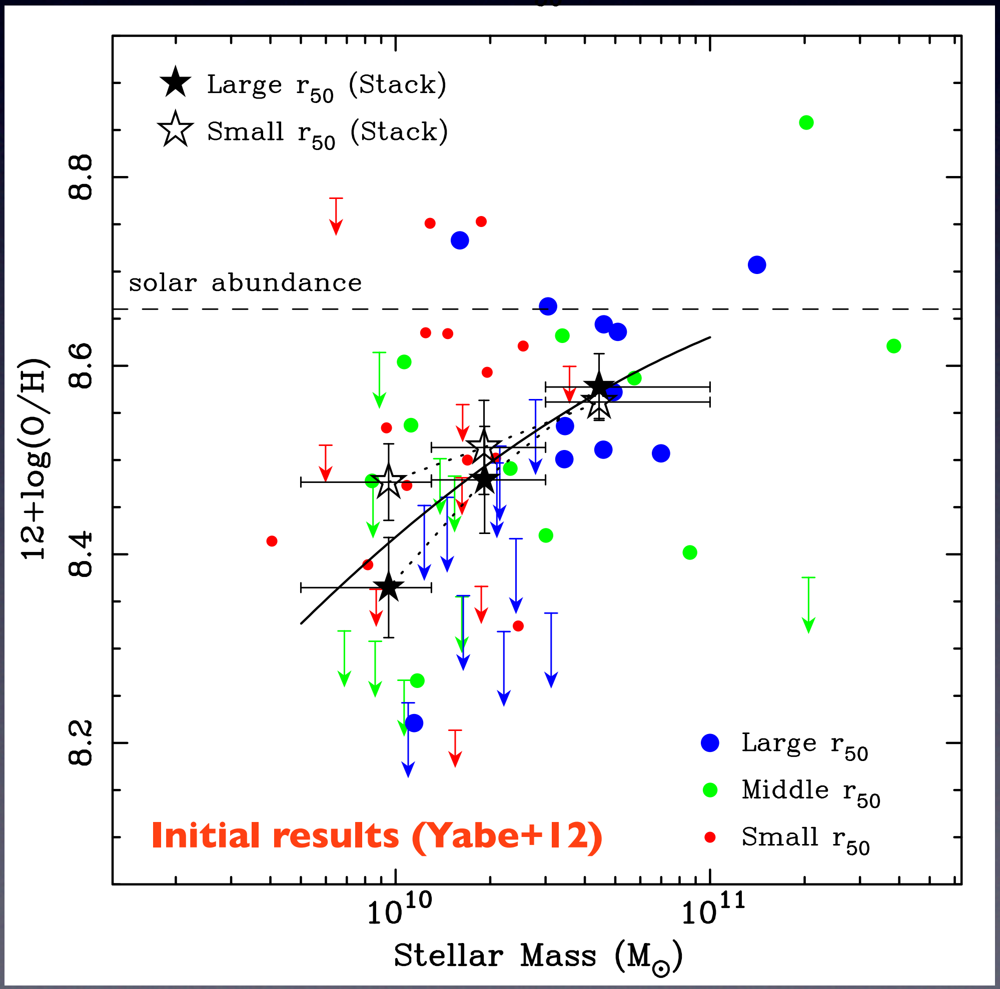




Second Parameter Dependency (Yabe+12):

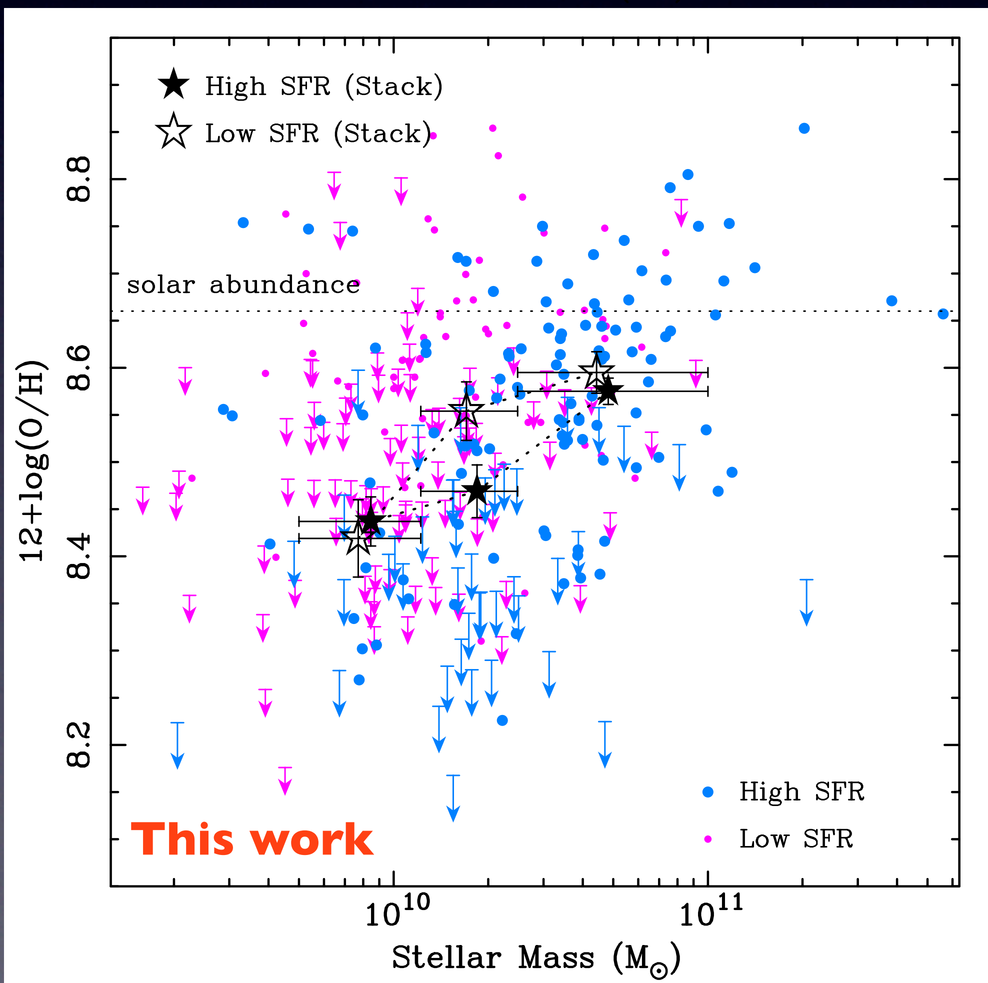
- Dependency of SFR and size on the MZ relation
  - ✓ SFR : derived from Hα luminosity corrected for the dust extinction
  - ✓ We take half light radius (R_{50}) as galaxy size (from K-band image)
  - ✓ Dividing the sample into three groups by the parameter
  - ✓ Stacking analysis in each group
  - ✓ Galaxies with larger SFRs and size tend to show lower metallicities

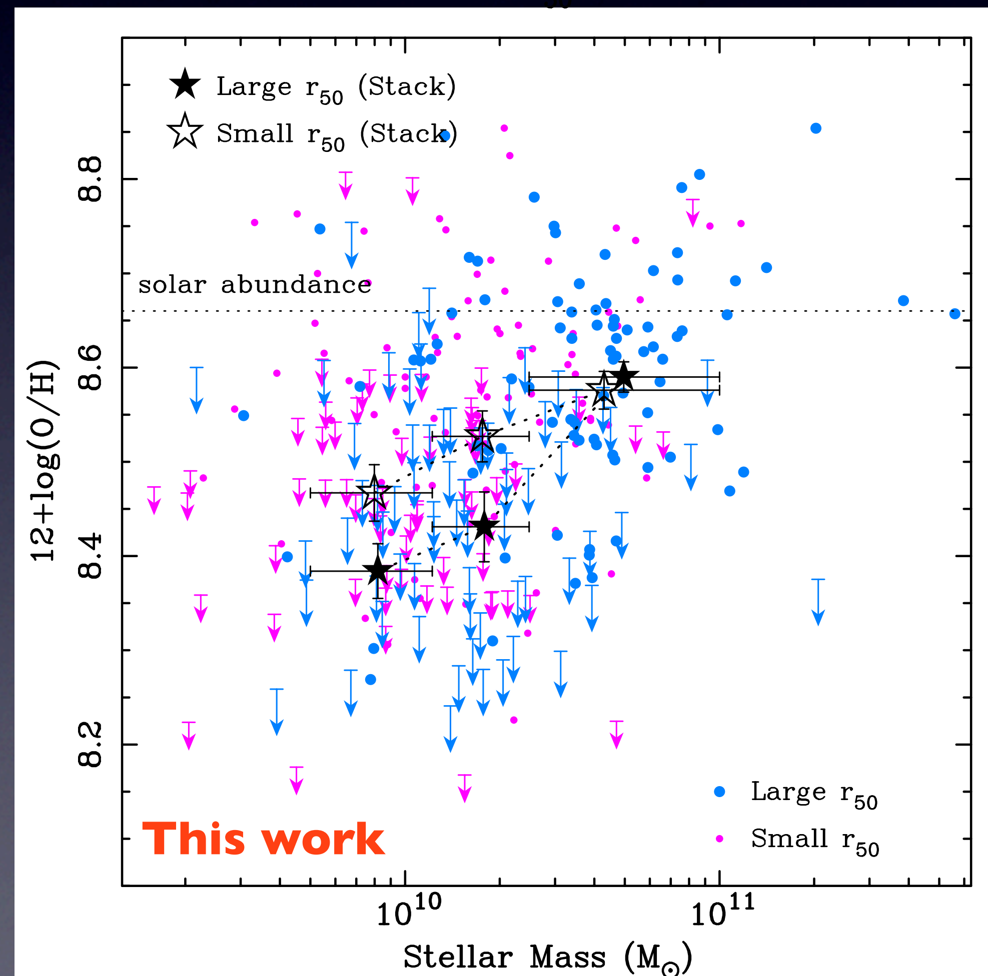




Second Parameter Dependency (this work):

- Dependency of SFR and size on the MZ relation
  - ✓ Methods are all the same as before
  - ✓ The dependency of SFR on the MZ relation disappears in the least massive bin
  - ✓ The dependency of R_{50} still survives





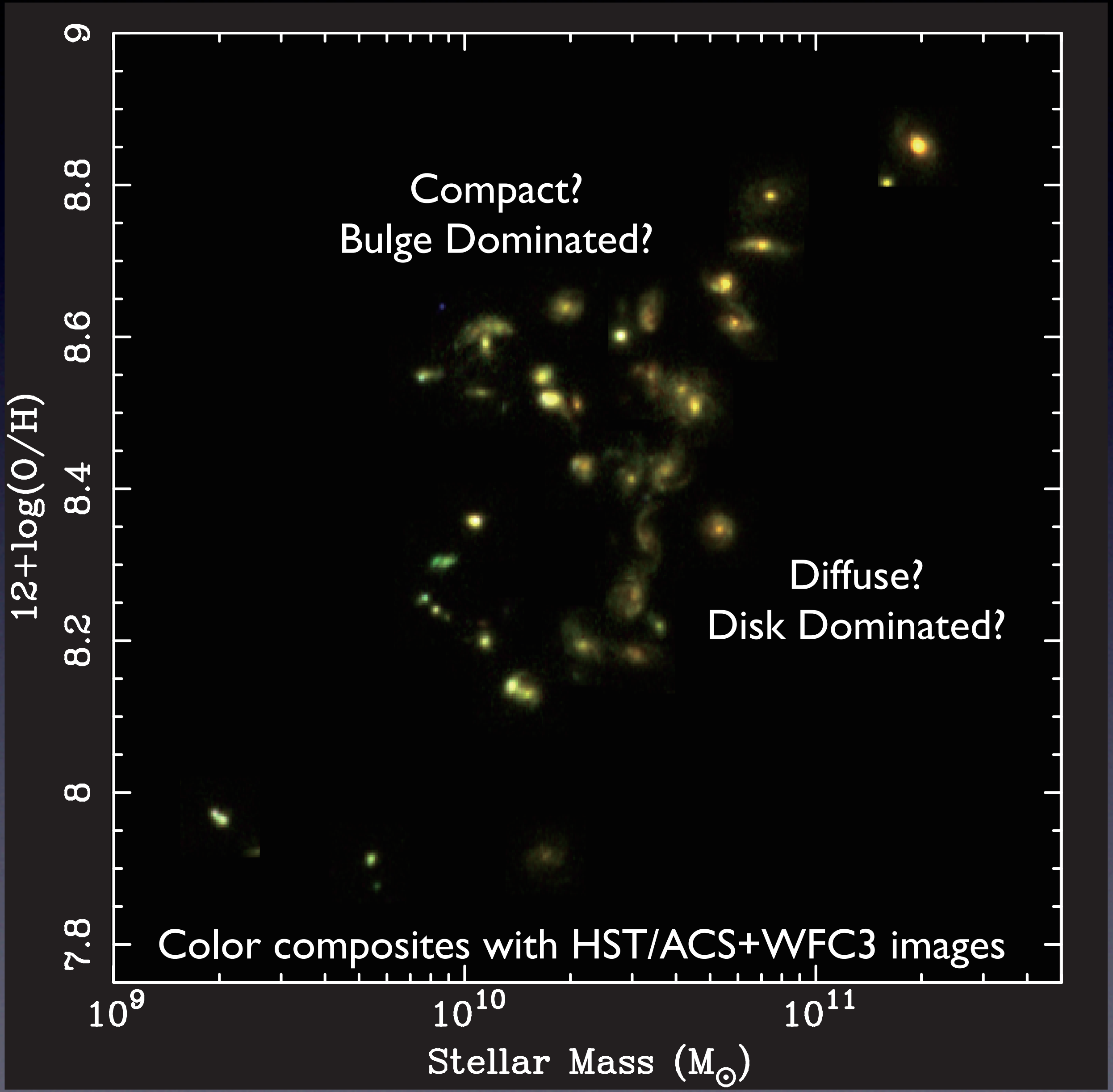
Morphological trends (**very preliminary**):

- About 50 objects in the CANDELS/UDS field are observed with FMOS
- For these objects, morphological properties can be examined as well as metallicities

- Diffuse and disk dominated galaxies tend to show lower metallicity than compact and bulge dominated galaxies?

- This result and the size dependency may support the "Different Evolutionary Stage" scenario:
  - ✓ Galaxies with smaller size have higher gas surface density
  - ✓ These are rapidly grown in the past and chemically evolved
  - ✓ These are also morphologically evolved?

The trend is still vague, so we need larger sample in the CANDELS fields



Summary:

- We observed star-forming galaxies at z~1.4 are measured with Subaru/FMOS
- We detected Hα line from ~300 objects with significance of S/N>3
- Gas-phase metallicity is derived from [NII]/Hα line ratio
- We construct the mass-metallicity (MZ) relation at z~1.4 with the largest sample ever
- By comparing previous results:
    - ✓ The MZ relation evolves smoothly from z~3 to z~0
    - ✓ They agree with theoretical models with wind
- The MZ relation at z~1.4 has an intrinsic scatter of ~0.1 dex
- We examined the dependency of physical parameters on the MZ relation for the scatter
    - ✓ Clear trend for size: Galaxies with larger R_{50} tend to show lower metallicity
    - ✓ No clear trend for SFR: Disagree with that at z~0.1 by Mannucci+10
- Preliminary results show the morphological dependence?:
    - ✓ Bulge-dominated galaxies are located in the upper region on the MZ relation
    - ✓ Disk-dominated galaxies are located in the lower region on the MZ relation
    - ✓ "Different evolutionary stage" scenario may be plausible?
    - ✓ Further observations in the CANDELS field are required