Back at the Edge of the Universe @ Sintra
2015.03.19

# Galaxy formation activity just before its peak epoch explored with [OIII] emitters at z>3

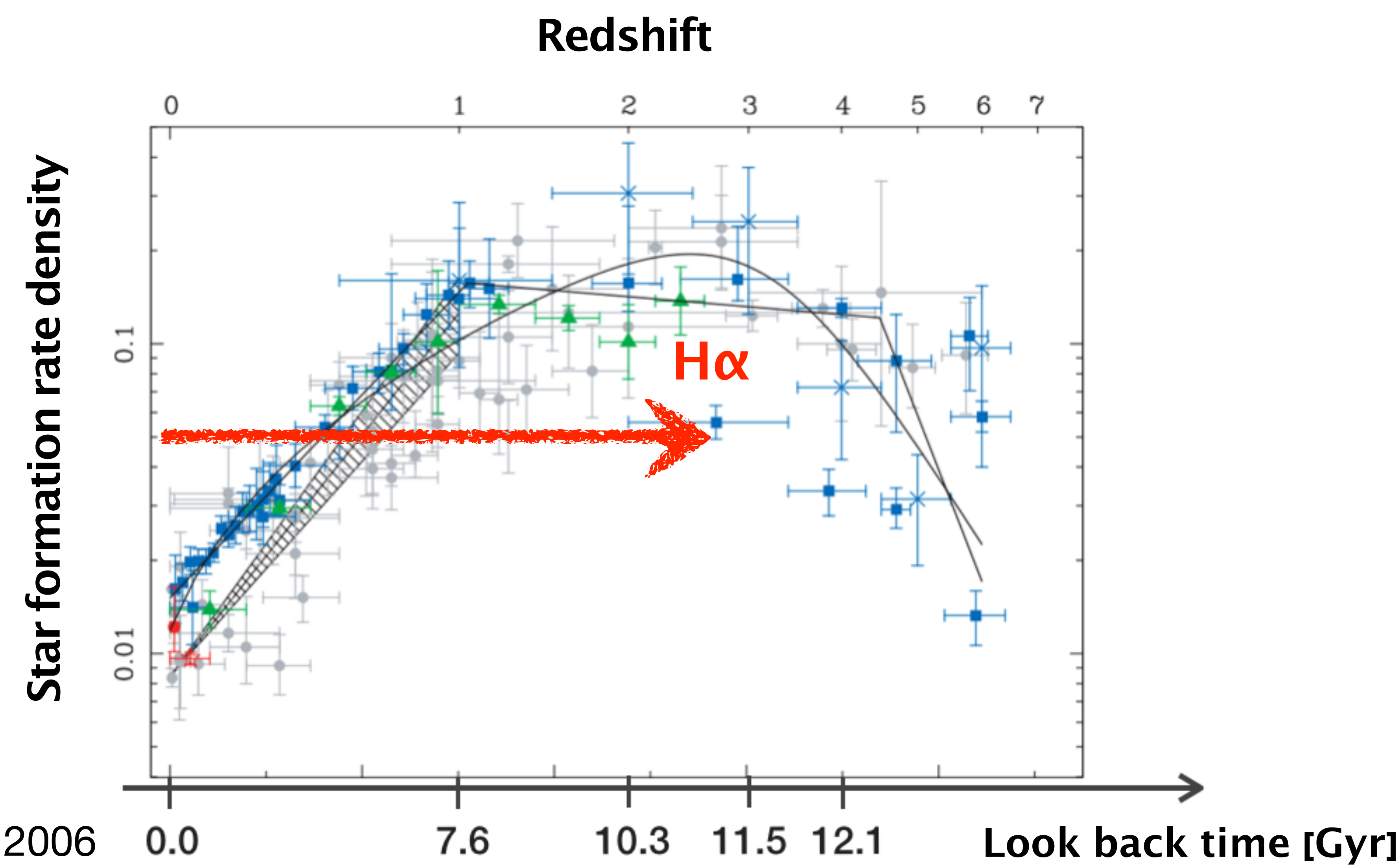
Speaker: Tomoko Suzuki (SOKENDAI/NAOJ)

T. Kodama, K.-i. Tadaki, M. Hayashi, Y. Koyama, I. Tanaka,
Y. Minowa, R. Shimakawa, and M. Yamamoto

# Introduction

◎ **Investigate galaxy formation at z > 3**

- Before the peak epoch of galaxy formation at z~2
- How galaxy formation is activated towards its peak ??
- Hα emission is not available beyond z~2.5 from the ground …




Hopkins & Beacom 2006

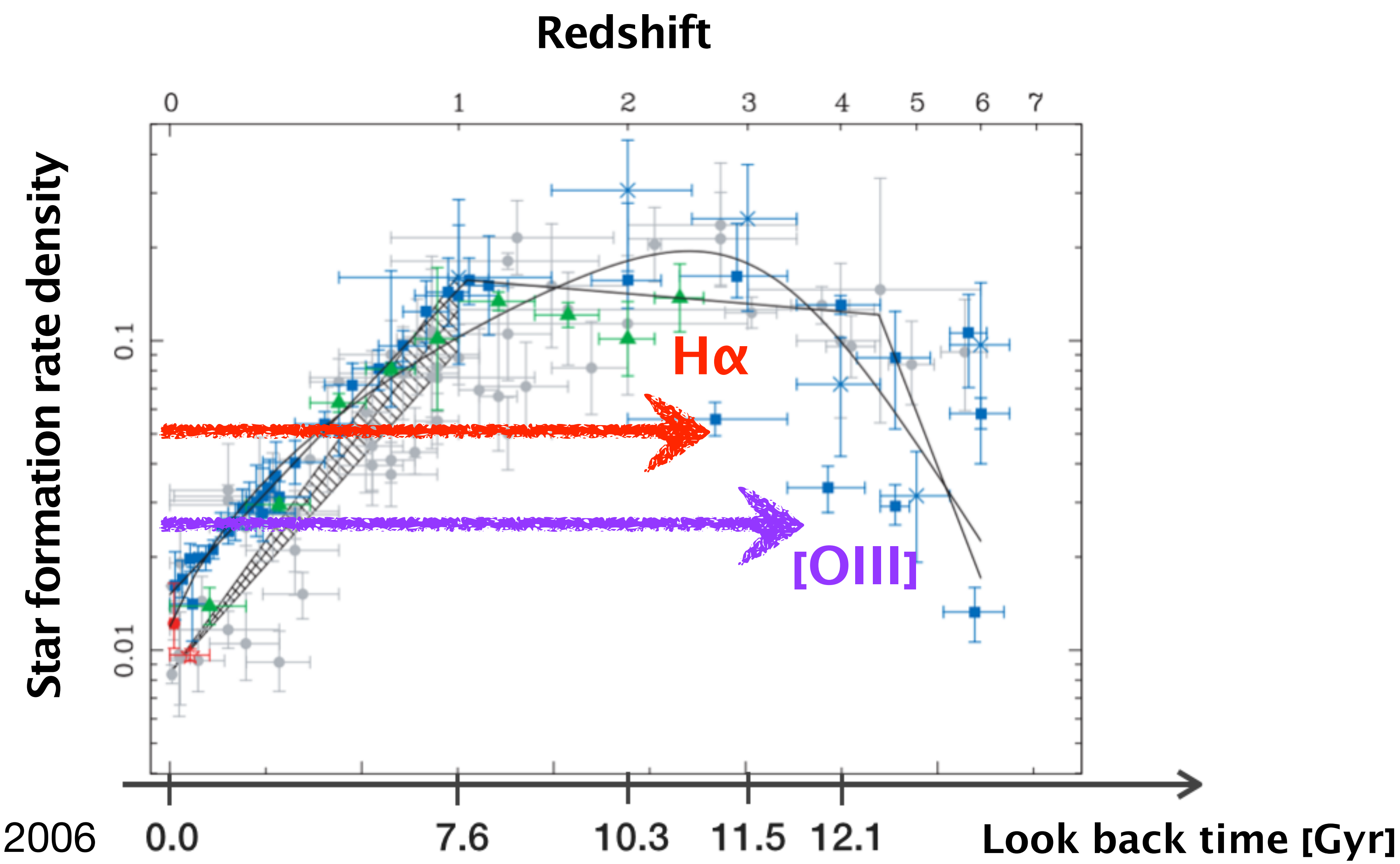
# Introduction

◎ **[OIII] emission line is an excellent tracer of star-forming galaxies at z > 3**

- Strong [OIII] emission from high-z star-forming galaxies due to higher specific SFR and/or lower metallicities (higher stellar temperature)

- less sensitive to dust extinction than the UV light

※ See Khostovan et al. 2015 for the most recent studies




Hopkins & Beacom 2006

# MAHALO-Subaru

◎ **MApping HAlpha and Lines of Oxygen with Subaru (PI: T. Kodama)**

- Narrow-band (NB) survey with Subaru / Suprime-Cam and MOIRCS
- Unique sample of emission line galaxies at various environments and cosmic times

| | environ-ment | target | $z$ | line | $\lambda$ ($\mu$m) | camera | NB-filter | conti-nuum | status (as of Oct 2014) |
|---|---|---|---|---|---|---|---|---|---|
| z < 1 clusters | Low-$z$ clusters | CL0024+1652 | 0.395 | H$\alpha$ | 0.916 | Suprime-Cam | NB912 | $z'$ | Kodama+'04 |
| | | CL0939+4713 | 0.407 | H$\alpha$ | 0.923 | Suprime-Cam | NB921 | $z'$ | Koyama+'11 |
| | | CL0016+1609 | 0.541 | H$\alpha$ | 1.011 | Suprime-Cam | NB1006 | $z'$ | not yet |
| | | RXJ1716.4+6708 | 0.813 | H$\alpha$ | 1.190 | MOIRCS | NB1190 | $J$ | Koyama+'10 |
| | | | | [OII] | 0.676 | Suprime-Cam | NA671 | $R$ | observed |
| z ~ 1.5 clusters | High-$z$ clusters | XCSJ2215–1738 | 1.457 | [OII] | 0.916 | Suprime-Cam | NB912, NB921 | $z'$ | Hayashi+'10, '12 |
| | | 4C65.22 | 1.516 | H$\alpha$ | 1.651 | MOIRCS | NB1657 | $H$ | Koyama+'14 |
| | | CL0332–2742 | 1.61 | [OII] | 0.973 | Suprime-Cam | NB973 | $y$ | observed |
| | | ClGJ0218.3–0510 | 1.62 | [OII] | 0.977 | Suprime-Cam | NB973 | $y$ | Tadaki+'12 |
| z > 2 proto-clusters | Proto-clusters | PKS1138–262 | 2.156 | H$\alpha$ | 2.071 | MOIRCS | NB2071 | $K_s$ | Koyama+'12 |
| | | HS1700+64 | 2.30 | H$\alpha$ | 2.156 | MOIRCS | BrG | $K_s$ | observed |
| | | | | [OIII] | 1.652 | MOIRCS | [Fe II] | $H$ | not yet |
| | | 4C23.56 | 2.483 | H$\alpha$ | 2.286 | MOIRCS | CO | $K_s$ | Tanaka+'11 |
| | | USS1558–003 | 2.527 | H$\alpha$ | 2.315 | MOIRCS | NB2315 | $K_s$ | Hayashi+'12 |
| | | MRC0316–257 | 3.130 | [OII] | 2.539 | MOIRCS | NB1550 | $H$ | not yet |
| | | | | [OIII] | 2.068 | MOIRCS | NB2071 | $K_s$ | observed |
| z > 2 General fields | General | GOODS-N | 2.19 | H$\alpha$ | 2.094 | MOIRCS | NB2095 | $K_s$ | Tadaki+'11 |
| | | (70 arcmin$^2$) | | [OII] | 1.189 | MOIRCS | NB1190 | $J$ | observed |
| | | SXDF-CANDELS | 2.19 | H$\alpha$ | 2.094 | MOIRCS | NB2095 | $K$ | Tadaki+'13 |
| | | (92 arcmin$^2$) | 2.53 | H$\alpha$ | 2.315 | MOIRCS | NB2315 | $K_s$ | Tadaki+'13 |
| | | | 3.17 | [OIII] | 2.093 | MOIRCS | NB2095 | $K_s$ | Suzuki+'14 |
| | | | 3.63 | [OIII] | 2.317 | MOIRCS | NB2315 | $K_s$ | Suzuki+'14 |

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$z < 1$ clusters

$z \sim 1.5$ clusters

$z > 2$ proto-clusters

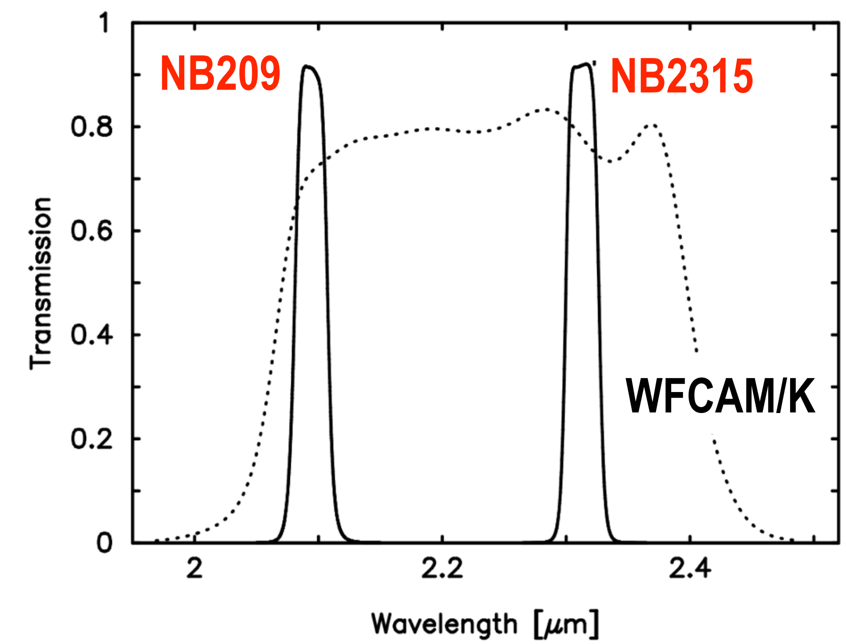
$z > 2$ General fields

**SXDF-CANDELS: Hα emitter @z=2.19, 2.53 / [OIII] emitter @z=3.17, 3.62**

# Emitter survey in SXDF-UDS-CANDELS field

◎ **Tadaki et al. 2013**
Narrow-band imaging with Subaru/MOIRCS
Survey area : ~ 90 arcmin$^2$

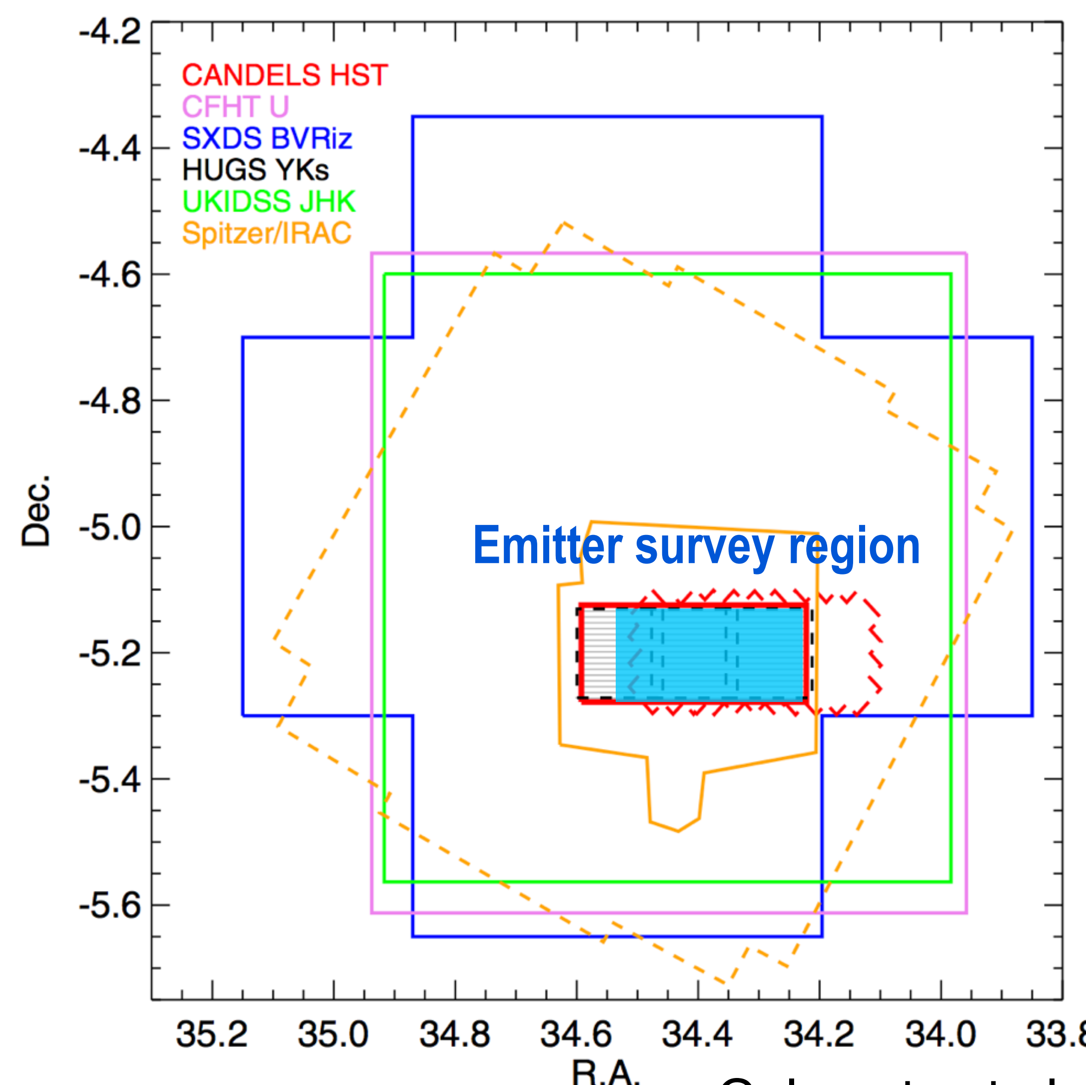
- NB209
  Hα @ z=2.2 / [OIII] @ z=3.2
- NB2315
  Hα @ z=2.5 / [OIII] @ z=3.6




**Multi-wavelength Data**

| | |
|---|---|
| CFHT/MegaCam | U |
| Subaru/Suprime-Cam | BVRiz |
| VLT/HAWK-I | YKs |
| UKIRT/WFCAM | JHK |
| Spitzer/IRAC | 3.6, 4.5, 5.8, 8.0 μm |
| Spitzer/MIPS | 24 μm |

**+ High resolution images of HST**

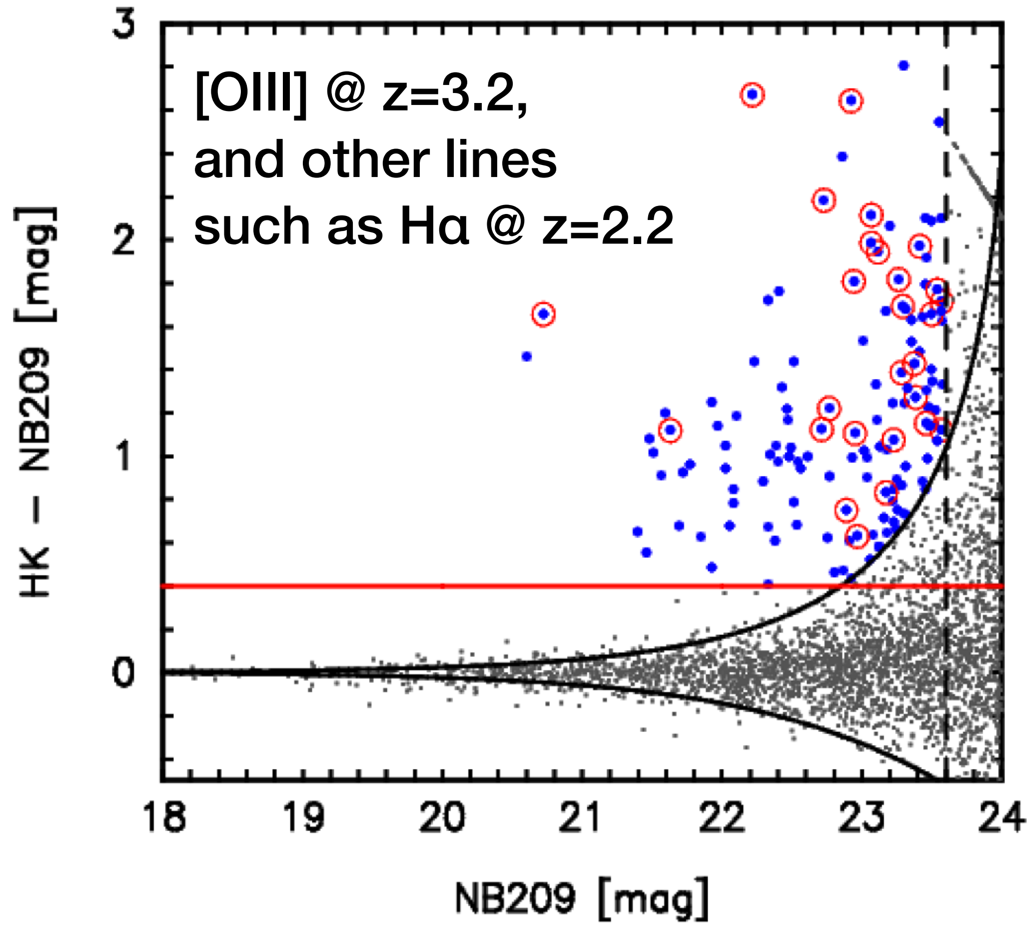



Galametz et al. 2013

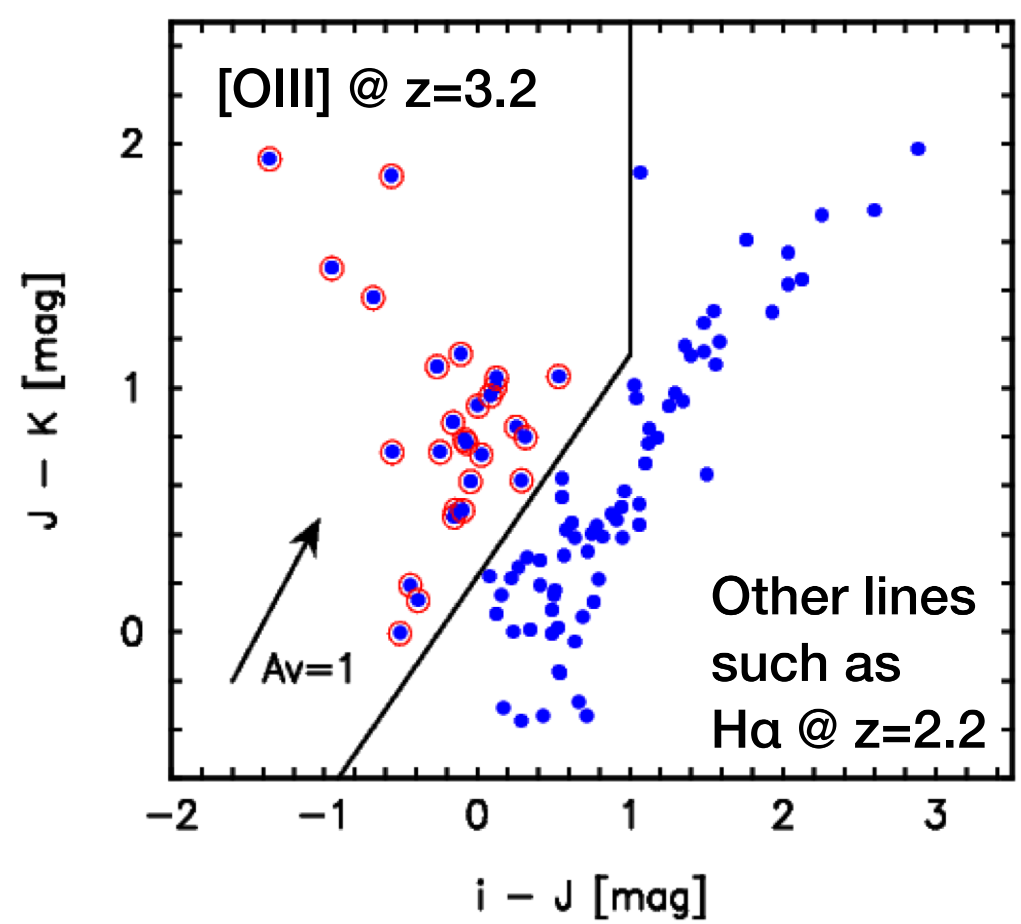
# Selection of [OIII] emitters at z=3.2, 3.6

◎ **Emitter Selection （NB209）**

NB excess object selection




[OIII] emitter selection by colors




● NB emitters
○ [OIII] emitter candidates

・NB209 (z=3.17) + NB2315 (z=3.62)

→ 34 [OIII] emitter candidates

・AGN contribution??

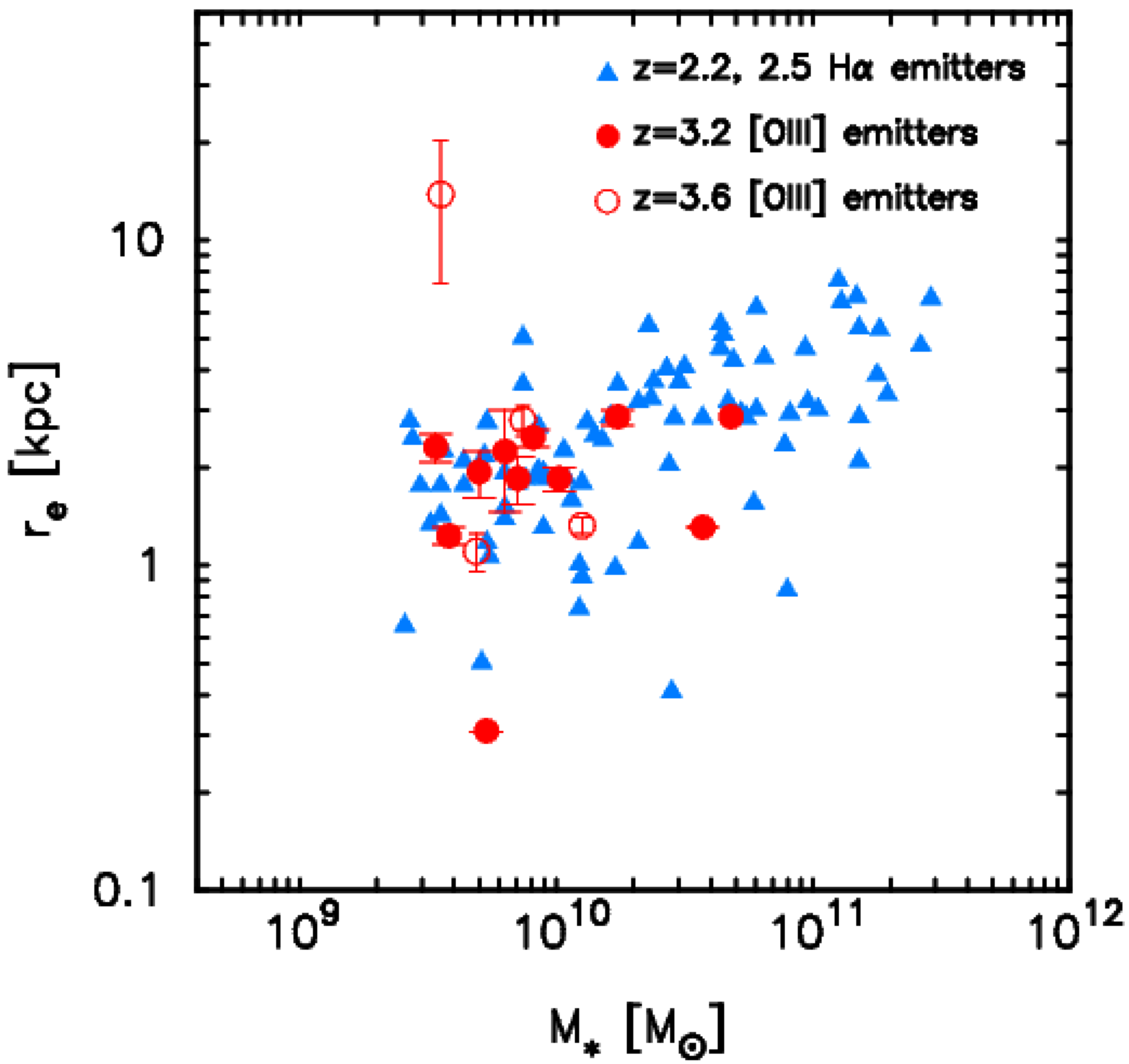
- No X-ray detected source (XMM-Newton) → No unobscured AGN
- MIPS (24μm) detected : 3 objects → AGN or dusty starburst

# Same location of the mass-size relation between the two epochs

◎ Size vs $M_\star$

Size : half-light radius of the same rest-frame image by HST
( H-band for [OIII] emitters and J-band for Hα emitters )

[OIII] emitters @ z=3.2, 3.6
and Hα @ z=2.2, 2.5 in SXDF



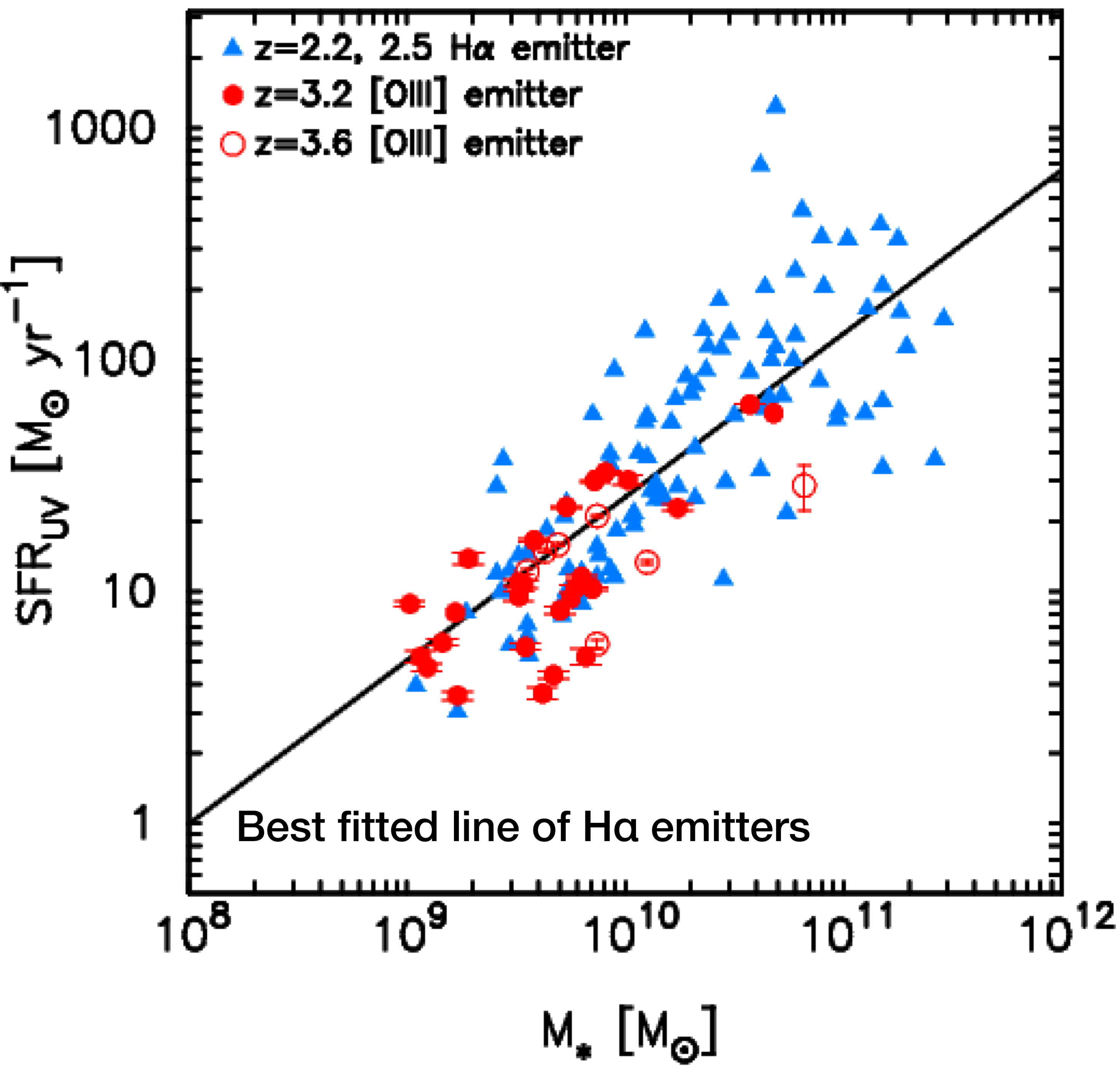

※ Limited to brighter objects

[OIII] emitters : H < 25

Hα emitters : J < 25

# Same location of the SFR-$M_\star$ relation between the two epochs

[OIII] emitters @ z=3.2, 3.6
and Hα @ z=2.2, 2.5 in SXDF




◎ the "Star-forming main sequence"

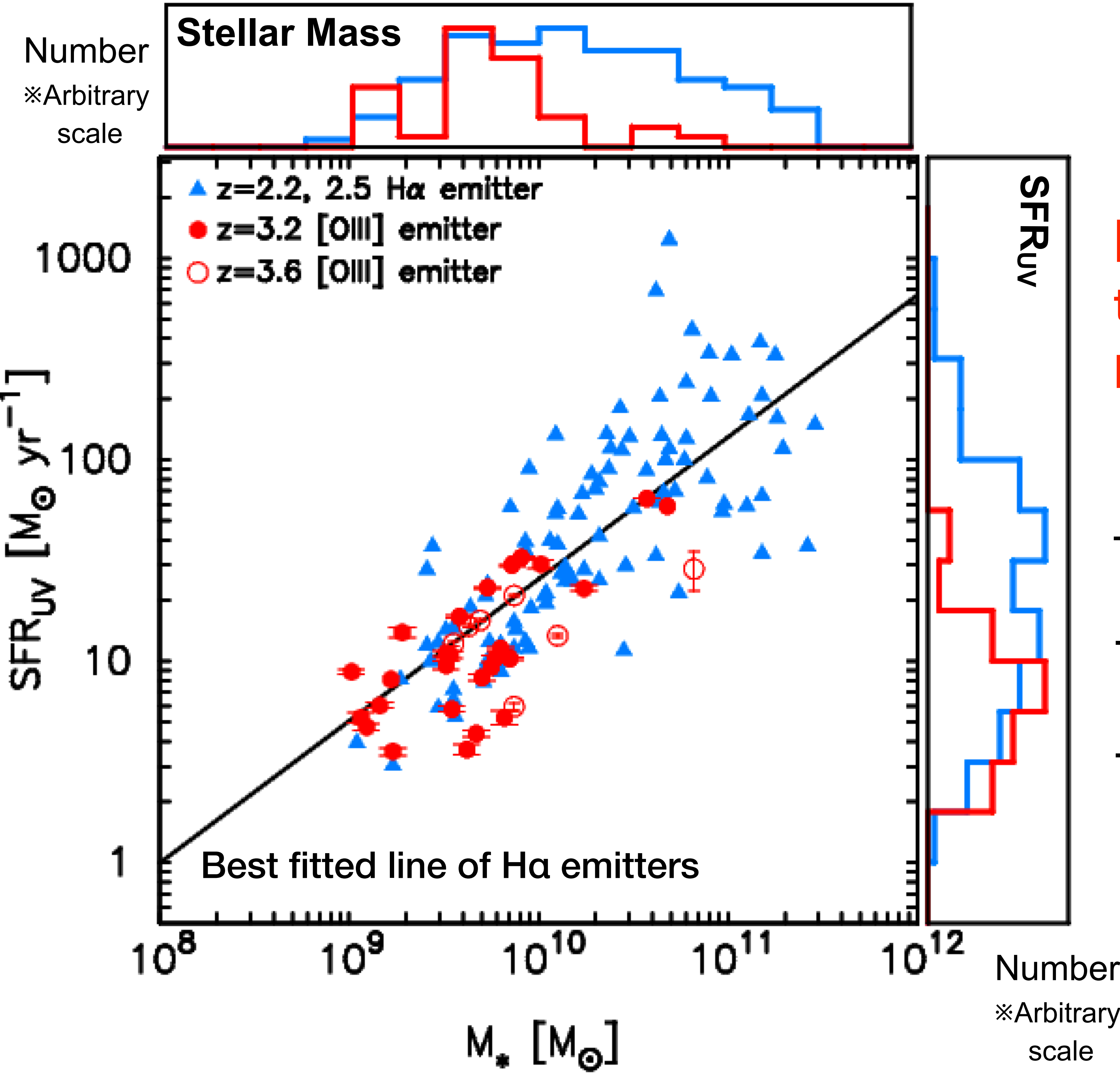
Stellar Mass : from SED fitting

SFR :

- From UV luminosity
- Correct for dust extinction based on $A_V$ from SED fitting

$$\mathrm{SFR}\ (\mathrm{M_\odot yr^{-1}}) = \frac{L(1600\text{Å})}{8 \times 10^{27}\ (\mathrm{erg\ s^{-1} Hz^{-1}})}$$

# But different Mass / SFR distribution between two samples




[OIII] emitters occupy the lower stellar mass and lower SFR range

Two interpretations :

- Evolution from z=3.2 to z=2.2
- Selection biases between [OIII] and Hα emitters

# Evolution or Selection effect ??

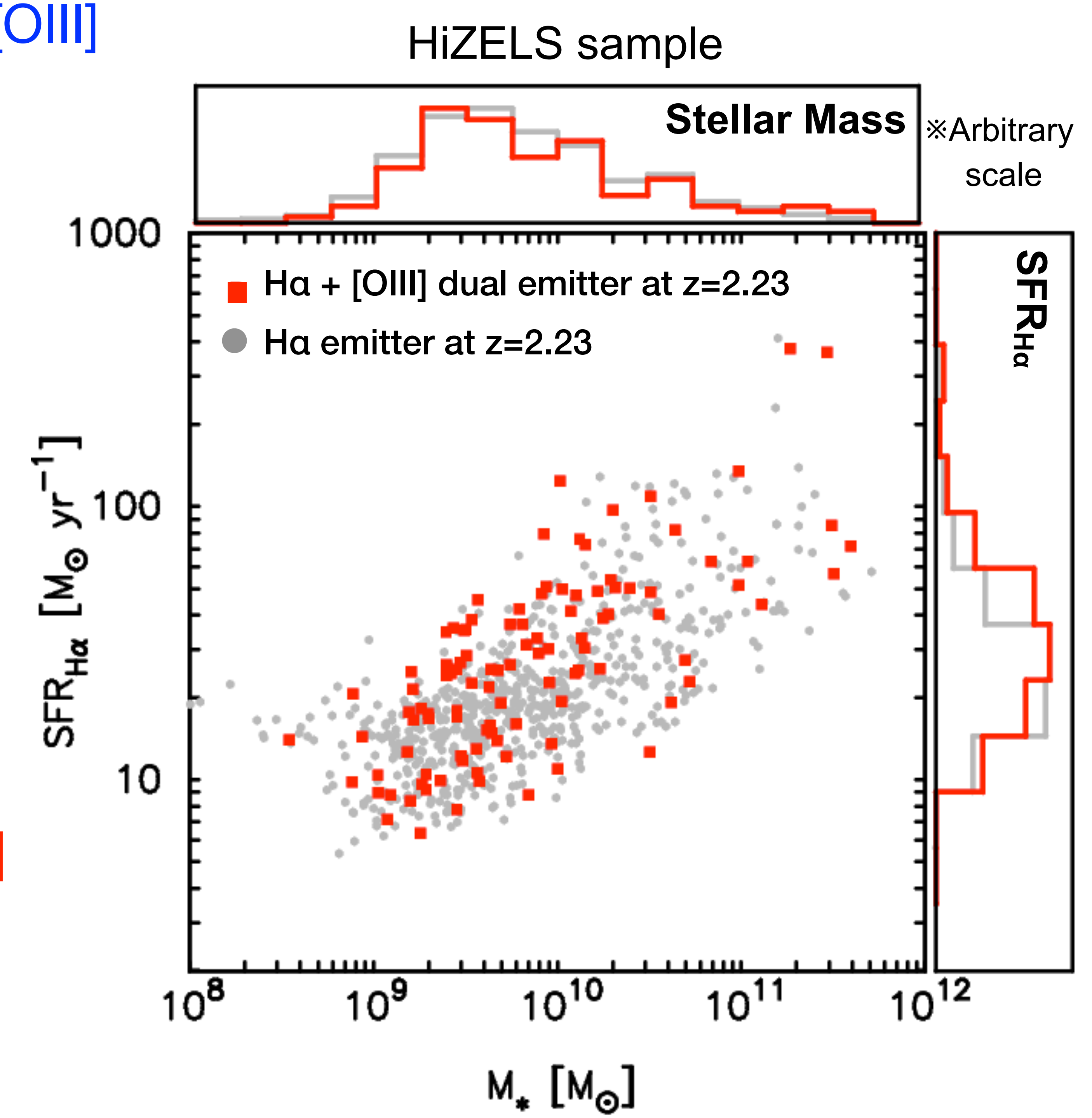
◎ Two interpretations for different stellar mass (SFR) distribution between [OIII] emitters at z=3.2, 3.6 and Hα emitters at z~2.2, 2.5.

- Evolution from z=3.2(3.6) to z=2.2(2.5)
- Selection effects between Hα and [OIII]

▶ From HiZELS emitter sample
( Sobral et al. 2013, 2014, in prep )

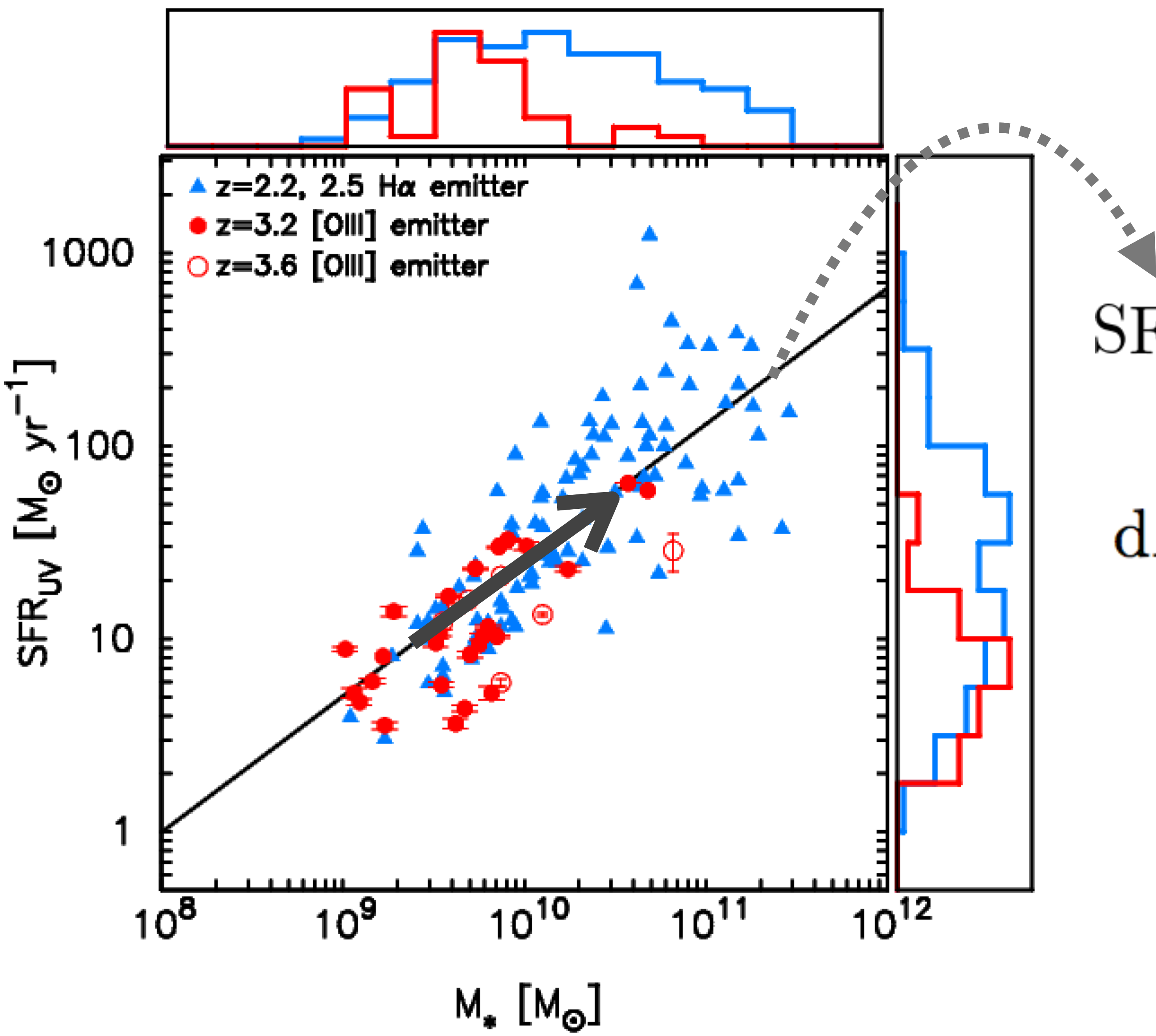
NB at K-band : Hα @ z=2.23
NB at H-band : [OIII] @ z=2.23

No selection bias between Hα and [OIII] emitters



# “Climb-up” on the main sequence

The same sequence between the two epochs
→ Assuming a simple model
: Evolution along the constant sequence from z=3.2(3.6) to z=2.2(2.5)




$$\mathrm{SFR} = 129(M_*/10^{11}M_\odot)^{0.705}$$

$$\mathrm{d}M_*/\mathrm{d}t = (1-R)\times\mathrm{SFR}$$

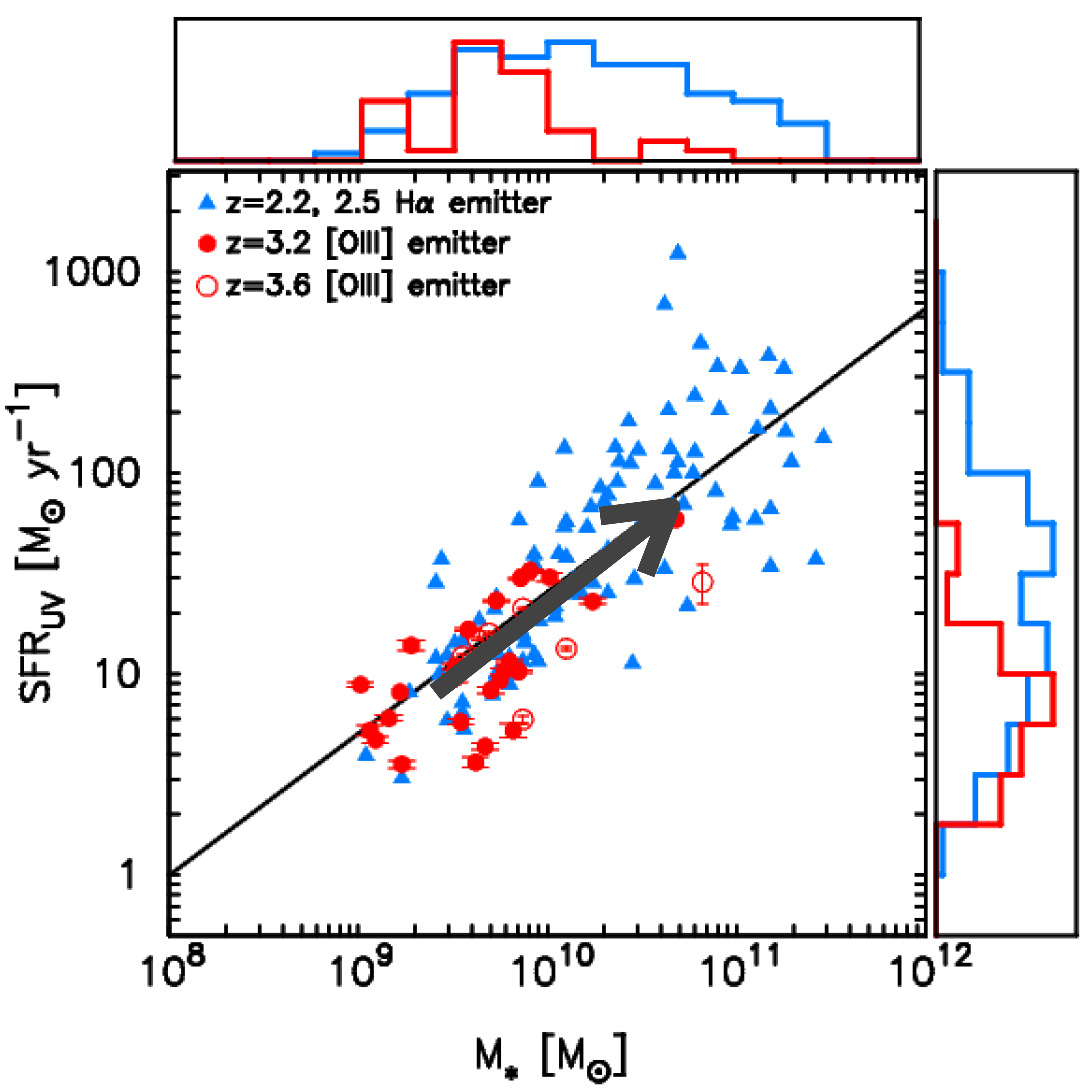
※ R: return mass fraction

# Accelerated galaxy growth on the main sequence

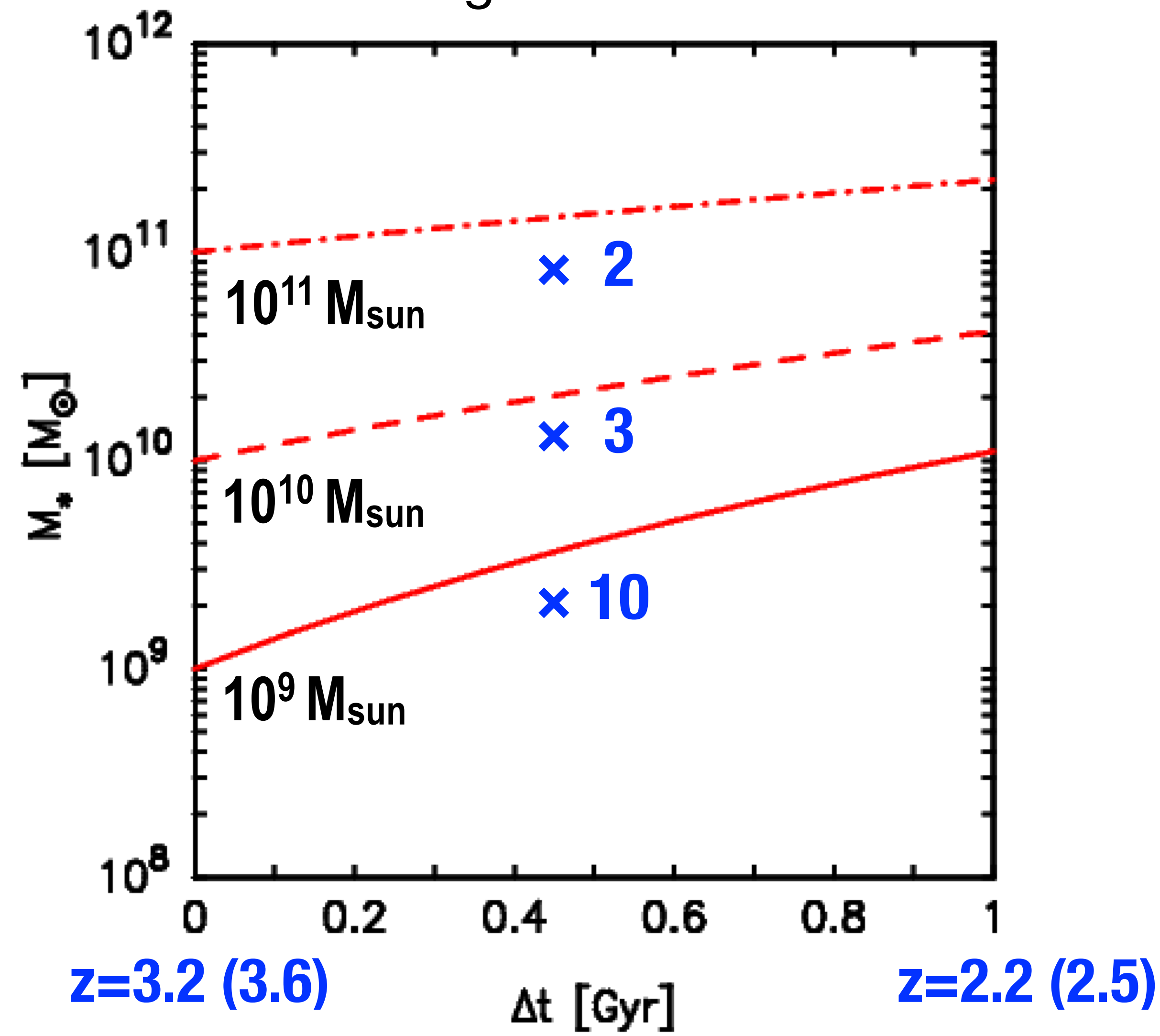
- 50-90% of the stellar mass can be formed during 1Gyr.
  **: Significant mass growth from z=3.2(3.6) to z=2.2(2.5)**

- SFR increases as the stellar mass grows.

→ Star formation activities increase from z=3.2(3.6) to z=2.2(2.5)




Mass growth with time



# Summary

In order to investigate galaxy formation at z > 3, we construct the [OIII] emitter sample in the SXDF-UDS-CANDLES field.
We obtain 34 [OIII] emitters at z=3.2 and 3.6.

◎ For a given stellar mass, sizes of the [OIII] emitters at z=3.2 and 3.6 are almost same with the Hα emitters at z=2.2, 2.5.

◎ The location of the SFR-$M_\star$ relation of the [OIII] emitters is identical to that of the Hα emitters, but they have different mass (SFR) distribution with each other.

◎ Assuming that the evolution along the constant sequence, galaxies are expected to be increased their stellar masses significantly during just a Gyr.

◎ In that case, SFRs of galaxies also increase with time.

→ **Star-forming activities are accelerated towards the peak epoch at z~2**

END