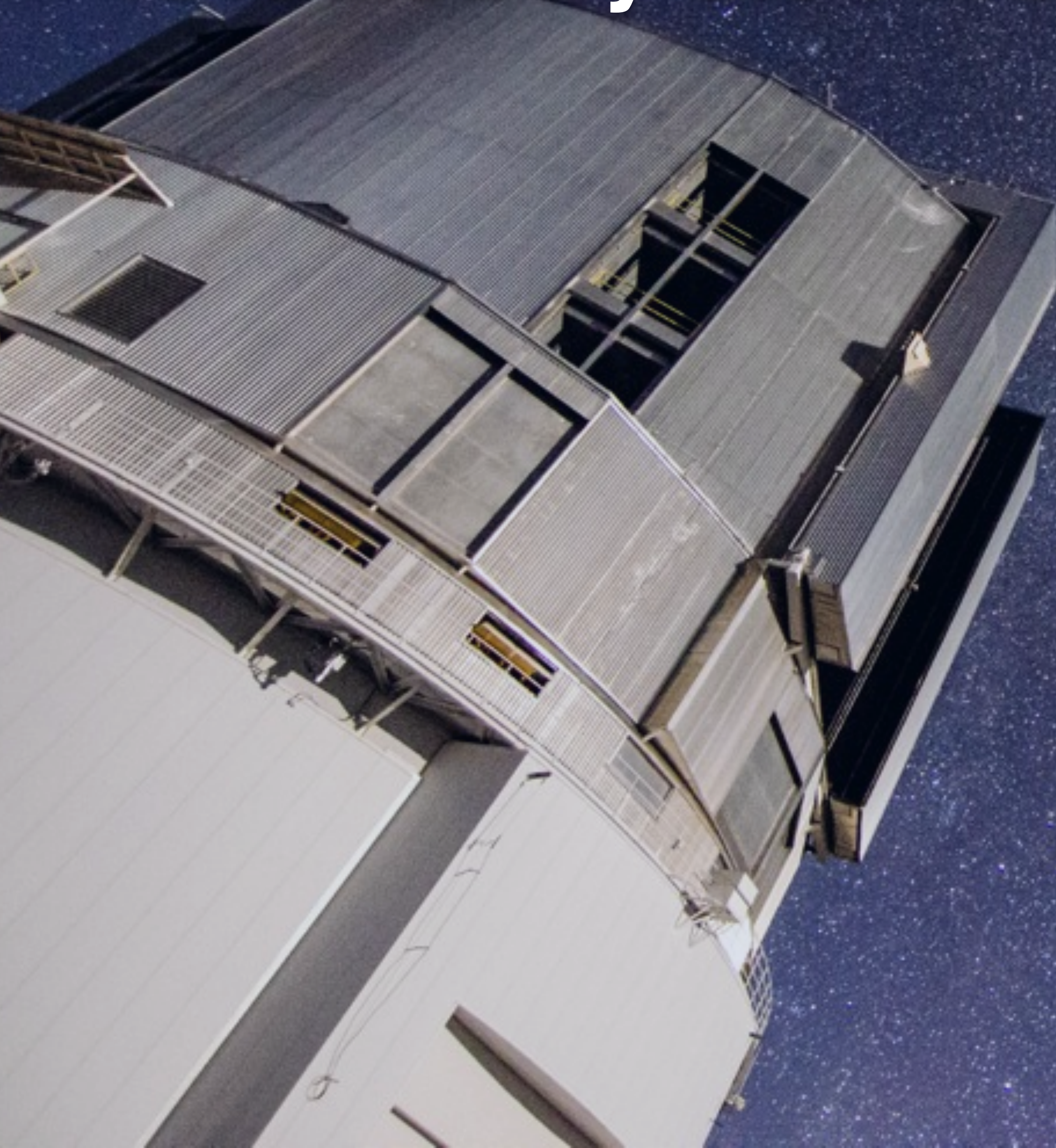
Subaru Users' Meeting FY2016

Excitation state of the ISM in star-forming galaxies at z~1.6 revealed by the FMOS-COSMOS survey



Based on FMOS-COSMOS paper IV
arXiv:1604.06802 / ApJ, in printing

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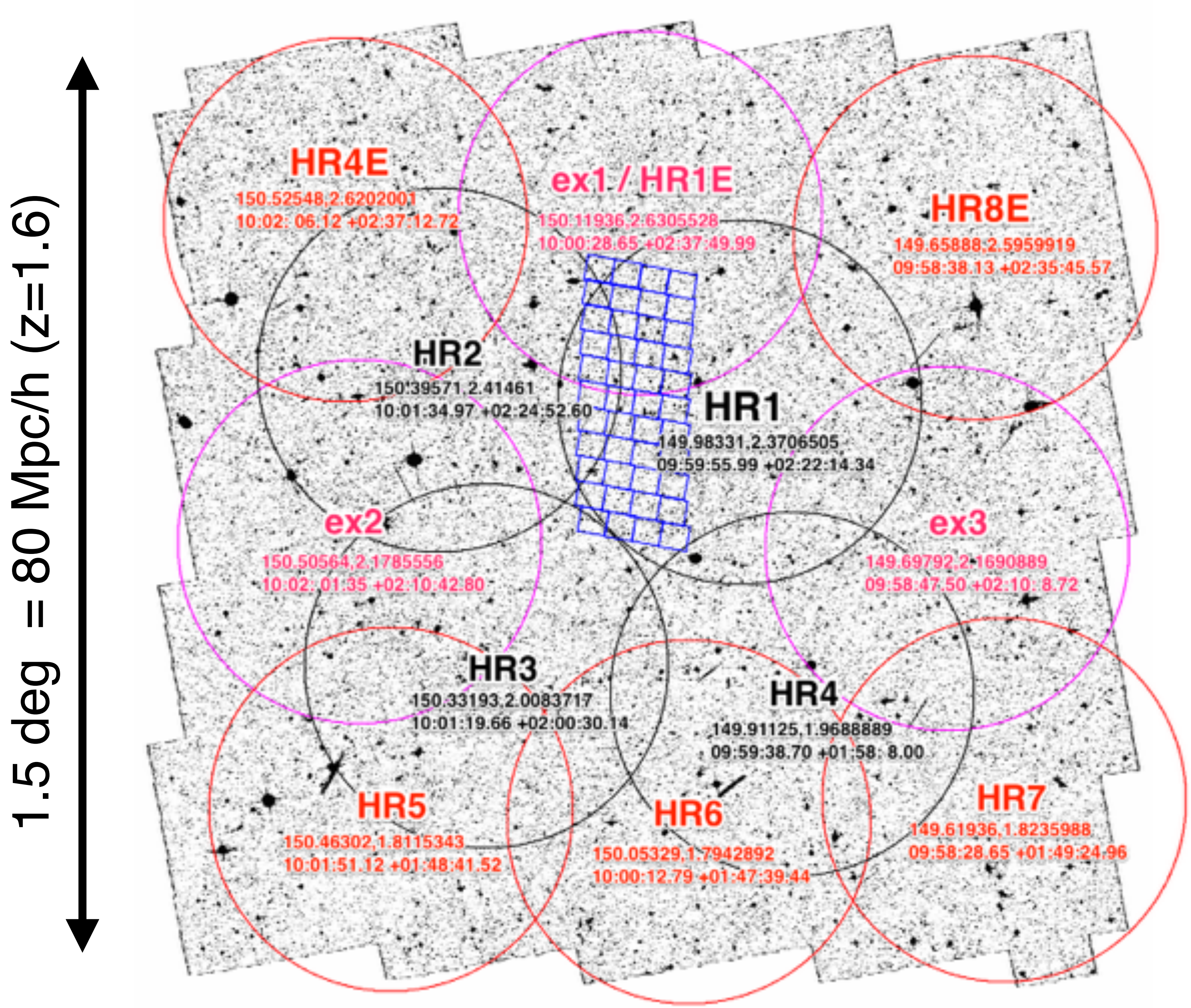
and the FMOS-COSMOS team

The FMOS-COSMOS survey

Designed to detect Hα at 1.4<z<1.7 in H-band (1.6—1.7μm)

Period: 2012 March — 2016 April

Observed galaxies: In total, >5600 / Success rate ~35%



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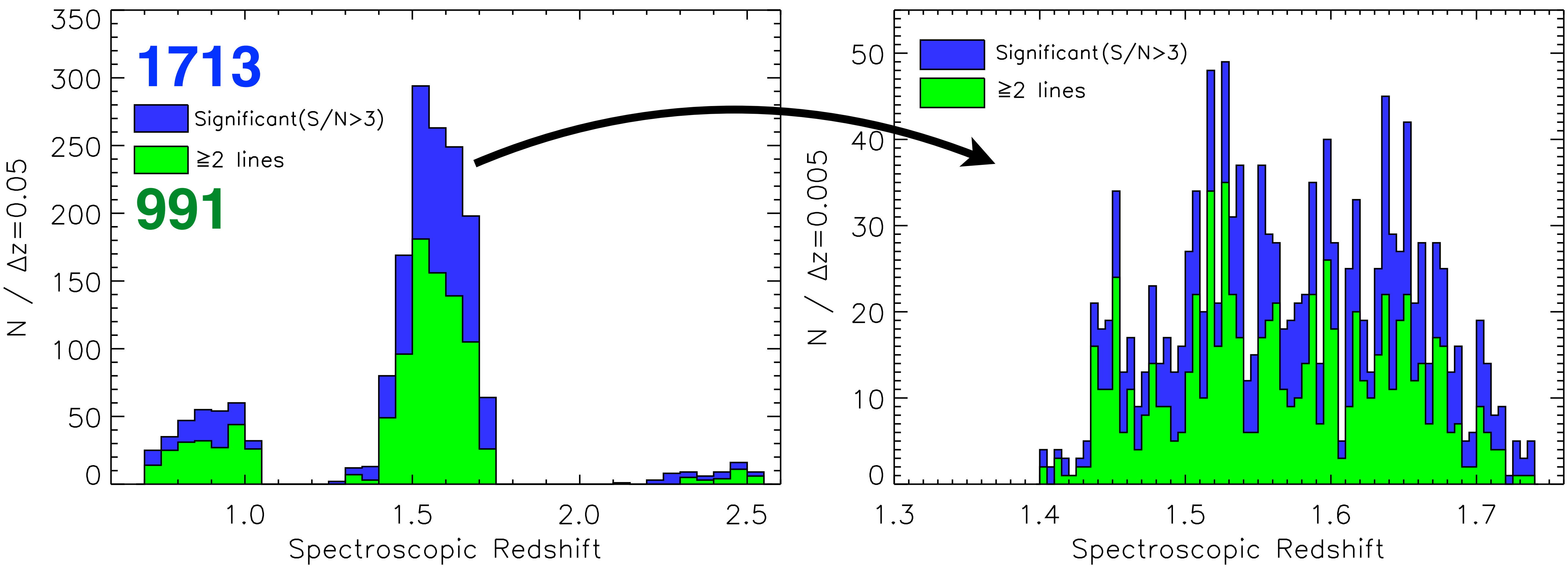
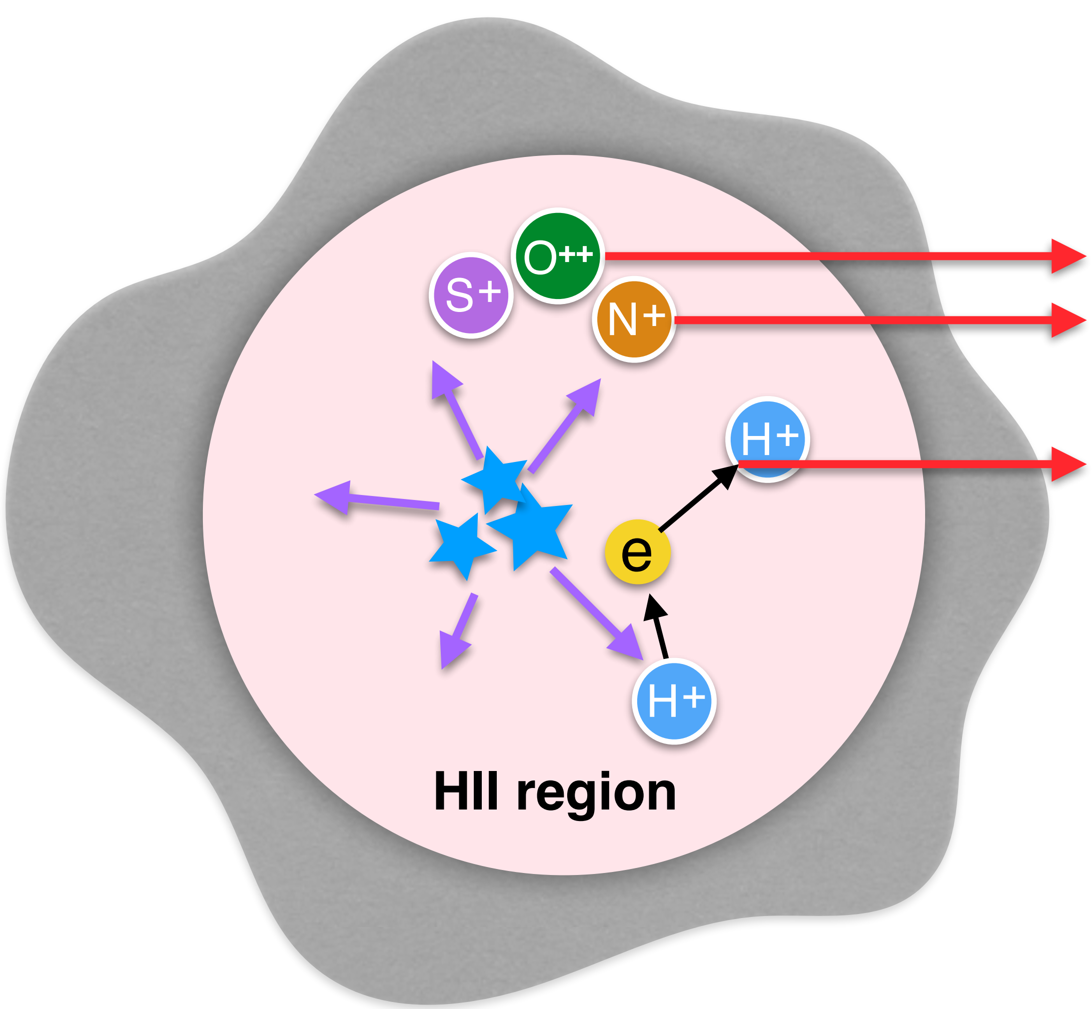


Aim

Study the physics of star formation from the ISM properties

- Metal abundance reflects the past history of star formation.
- Ionized elements emit various lines: we can observationally investigate the physical conditions of the ionized gas.



Metal ions' collisional-excitation lines
[OIII]5007, [NII]6584, [SII]6717,31

Recombination lines **Hα, Hβ**

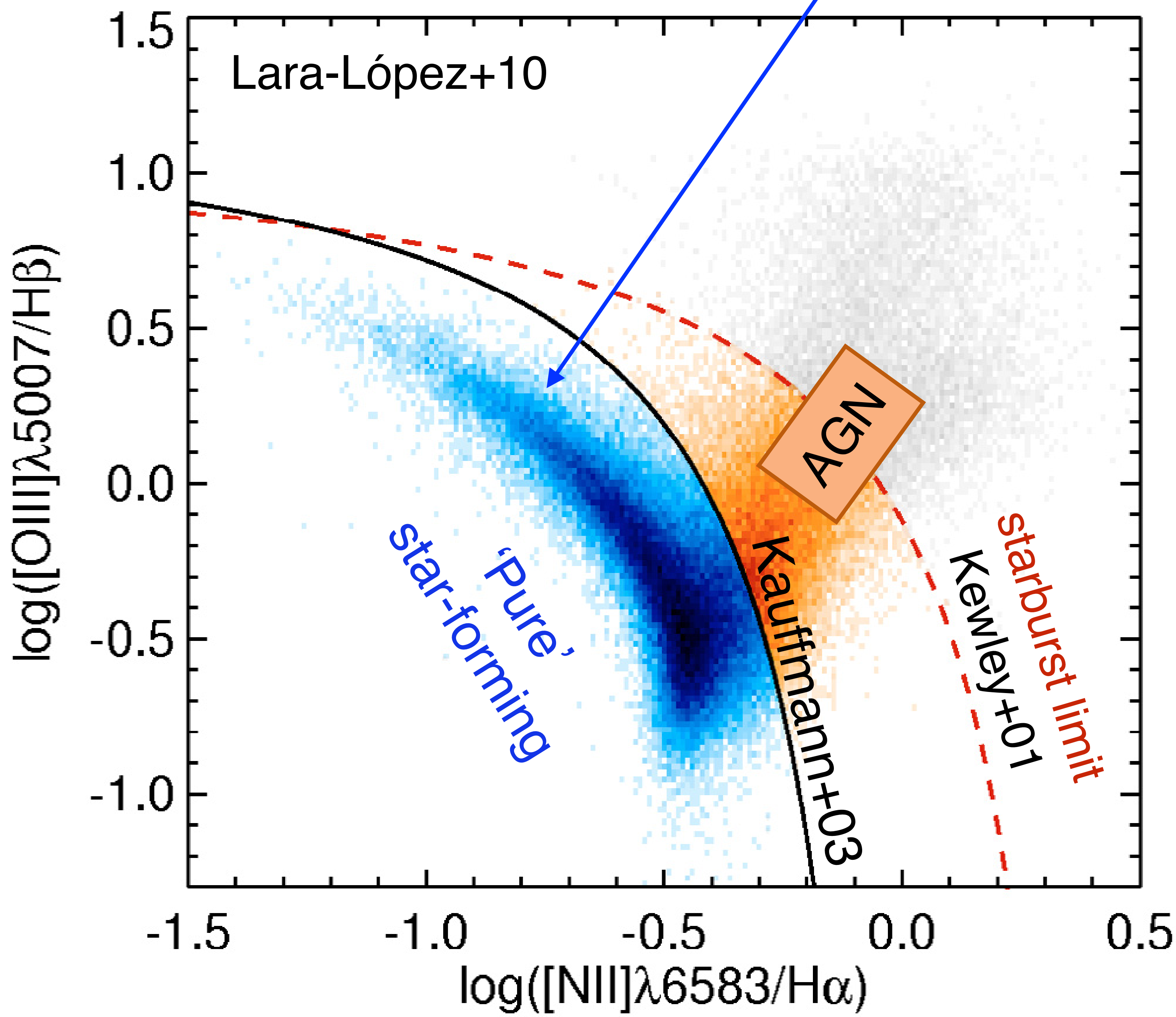
Number of ionizing photons
➡ **SFR indicator**

Metal abundance

Ionization/ Excitation state of elements

The BPT diagram

Useful tool to distinguish ionizing origins: **hot stars (pure SF)** or **AGNs.**
Purely star-forming population forms a **tight sequence.**



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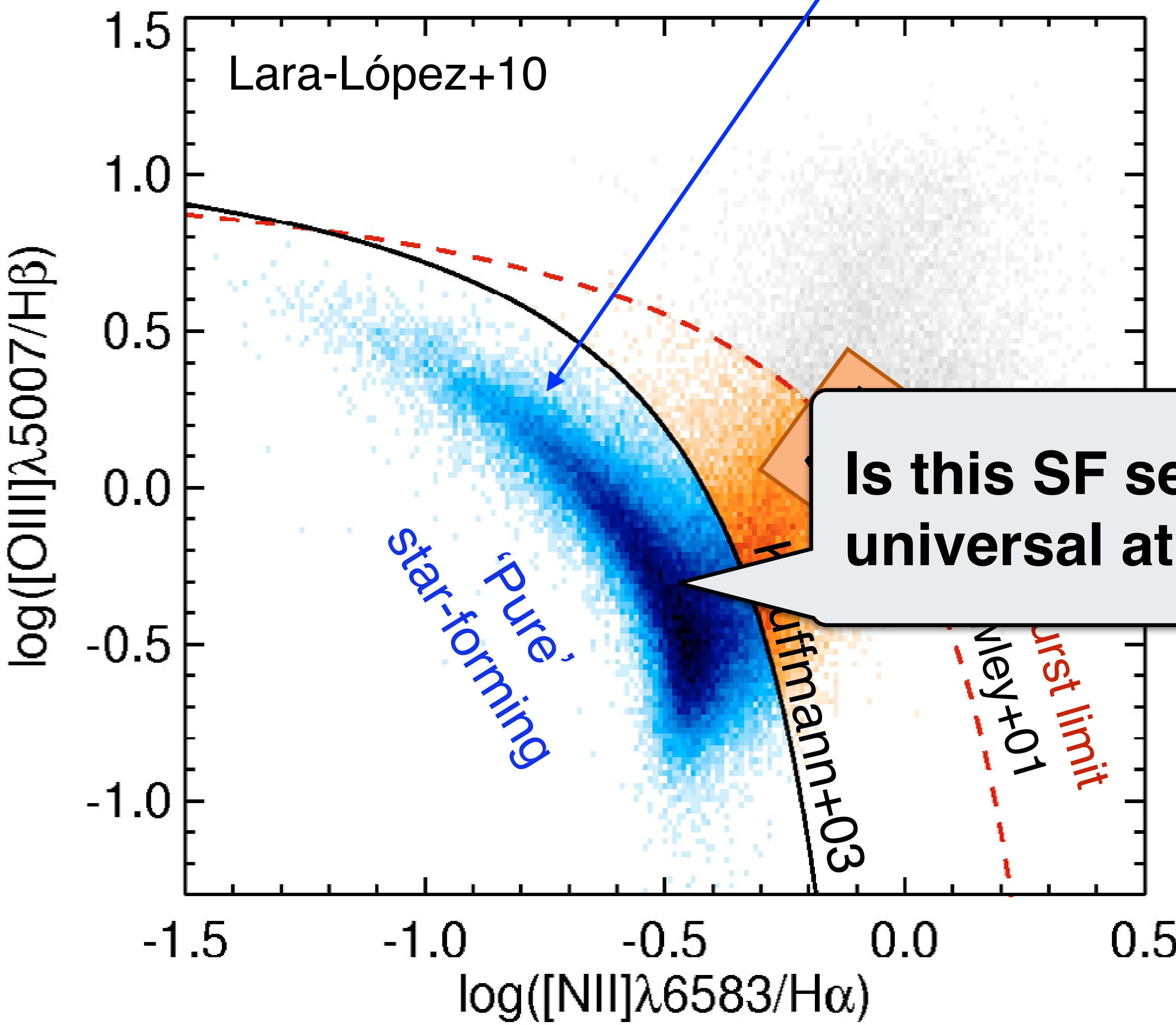
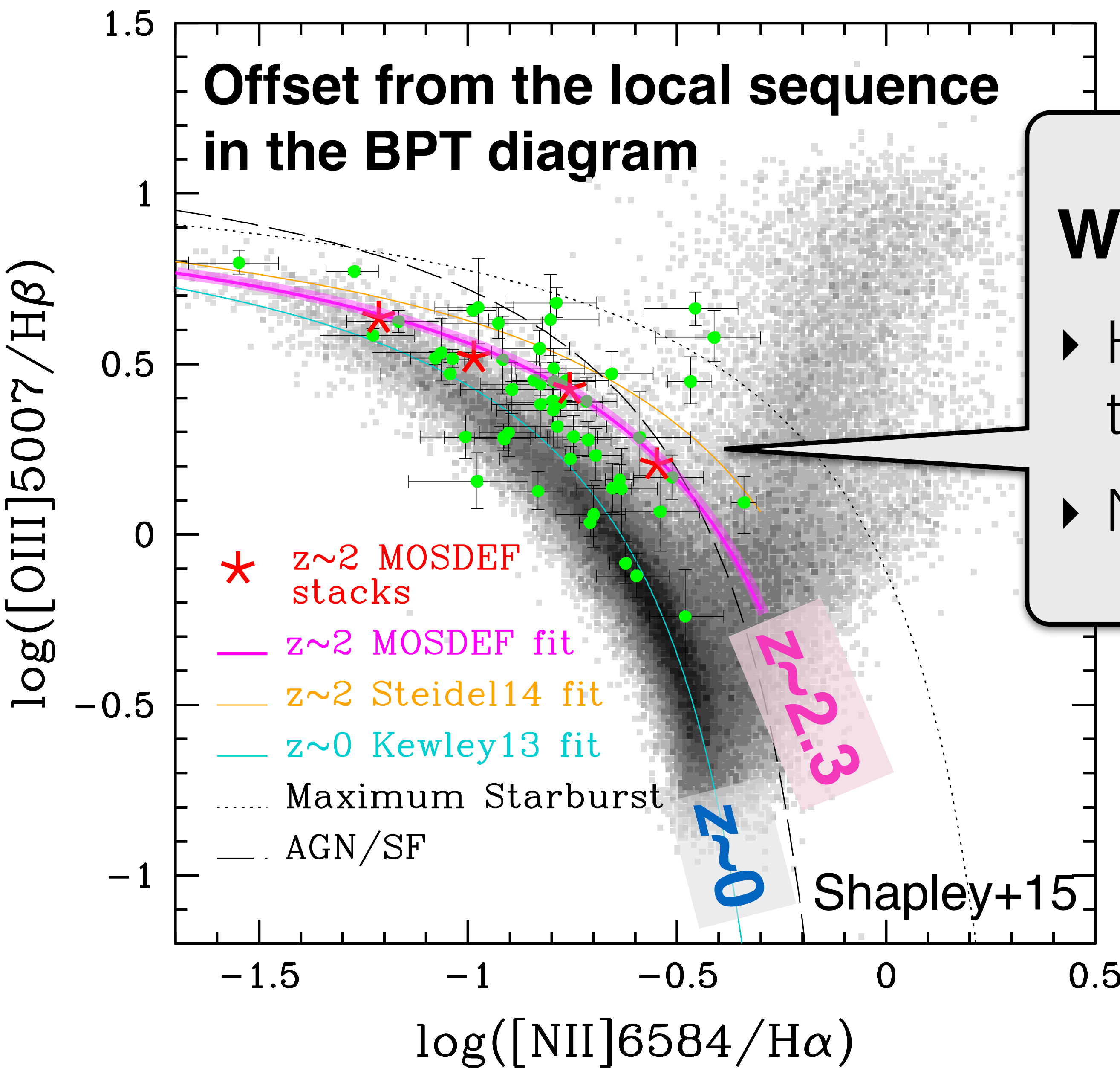


Is this SF sequence universal at high-z?

High-z galaxies on the BPT diagram

High-z galaxies DO NOT follow the local (low-z) rules.
Changes in emission-line ratios for high-z SF galaxies are directly related to the physical conditions of the ISM (ionized gas).



What changes? What causes?

- How do the physical parameters of the ionized gas evolve?
- No clear picture and consensus.

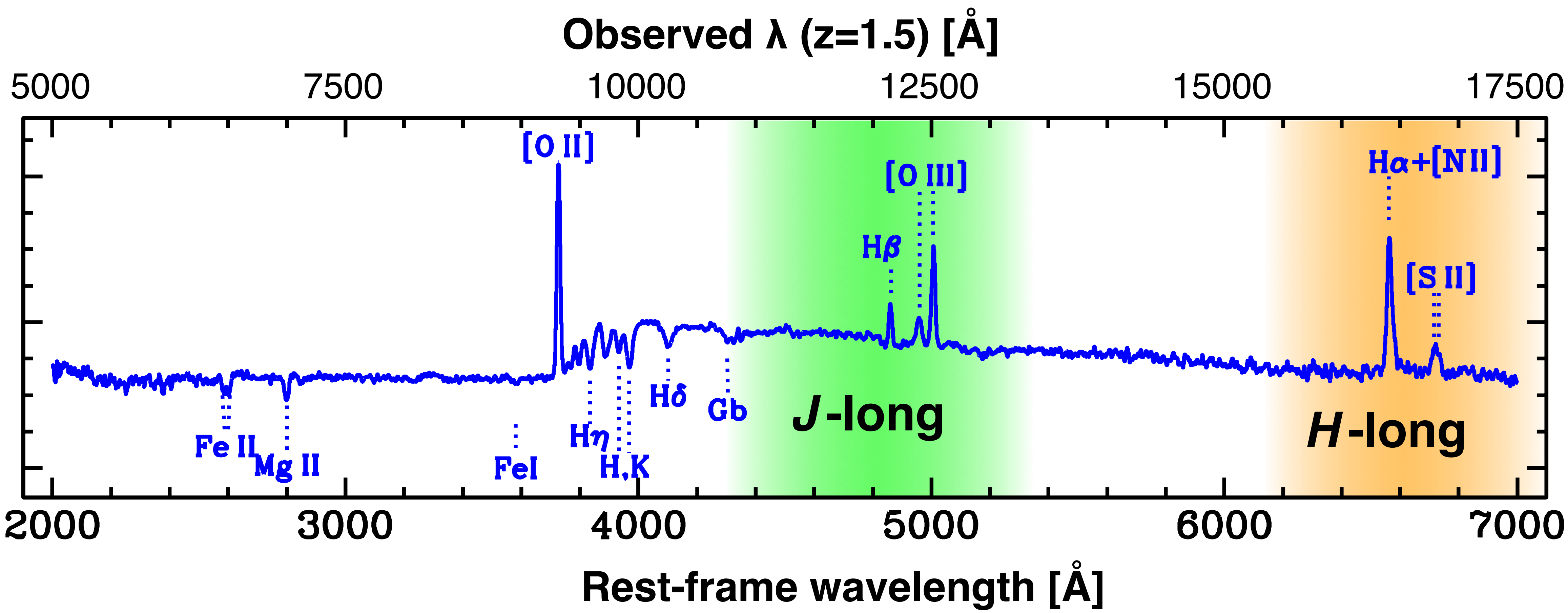
e.g., Shapley+05, Erb+06, Liu+08, Newman+14, Masters+14, Yabe+12,14, Steidel+14, Shapley+15, Hayashi+15, Zahid+14, Kartaltepe+15, Masters+16

Galaxy sample - FMOS-COSMOS

COSMOS photometric catalog (McCracken+12, Ilbert+13)

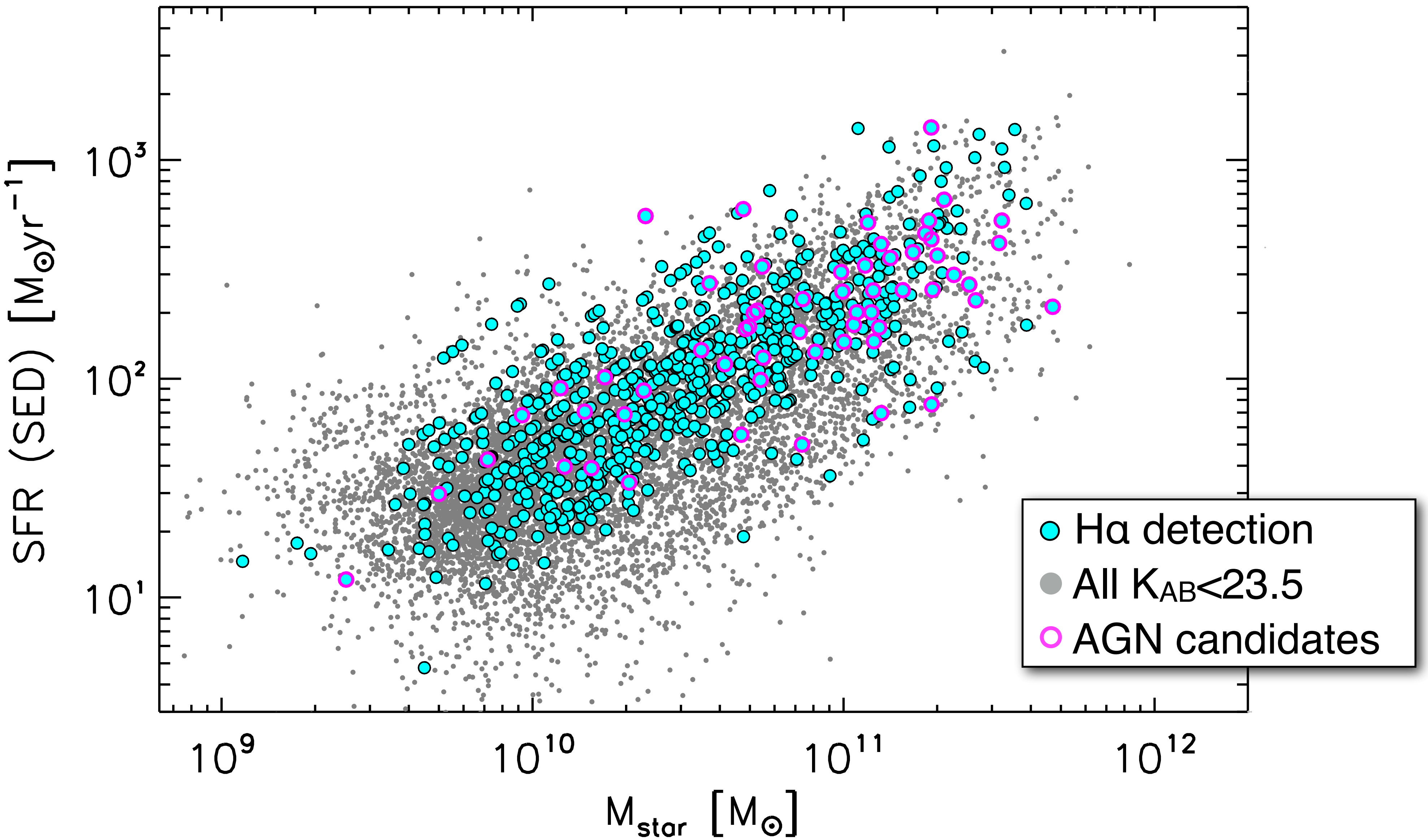
$1.43 \leq z \leq 1.67$, $K_{AB} < 23.5$, $M_{*} \gtrsim 10^{9.6} M_{\odot}$, Predicted $f(H\alpha) \gtrsim 10^{-16}$ erg/s/cm^2

FMOS Band	Range	Lines	*N* Hα det. (S/N>3)
H	1.6-1.8μm	Hα [NII] [SII]	**554**
J	1.11-1.35μm	Hβ [OIII]	**246 → BPT diagram**



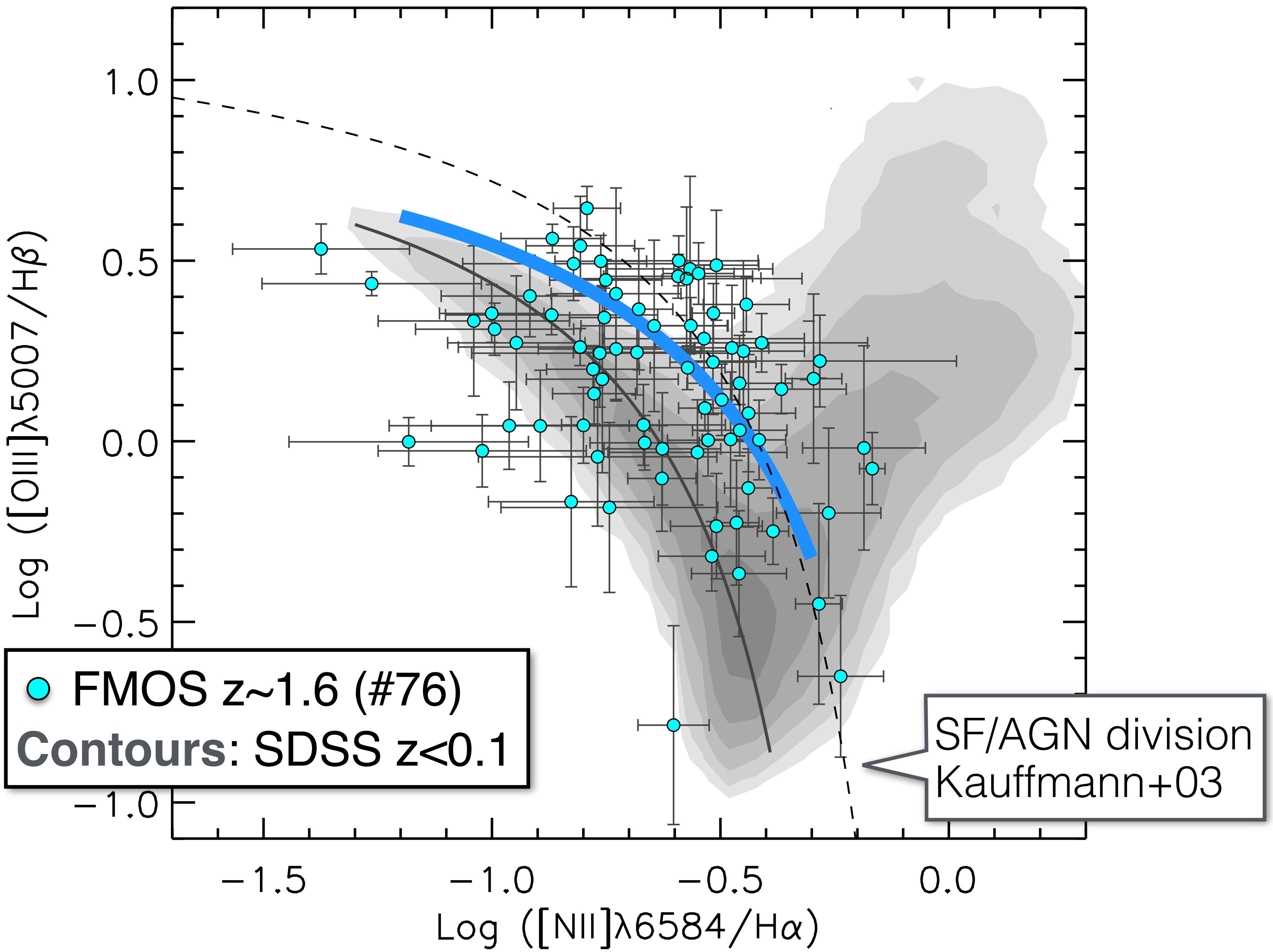
Galaxy sample

- Tracing well trace the epoch's main sequence
  = 'normal' SF population
- High sampling rate of massive ($M_* \gtrsim 10^{11} M_\odot$) population
- AGNs are removed based on Chandra X-ray data (Civano+16).



Results: the BPT diagram

FMOS galaxies deviate from the local sequence towards the upper-right.



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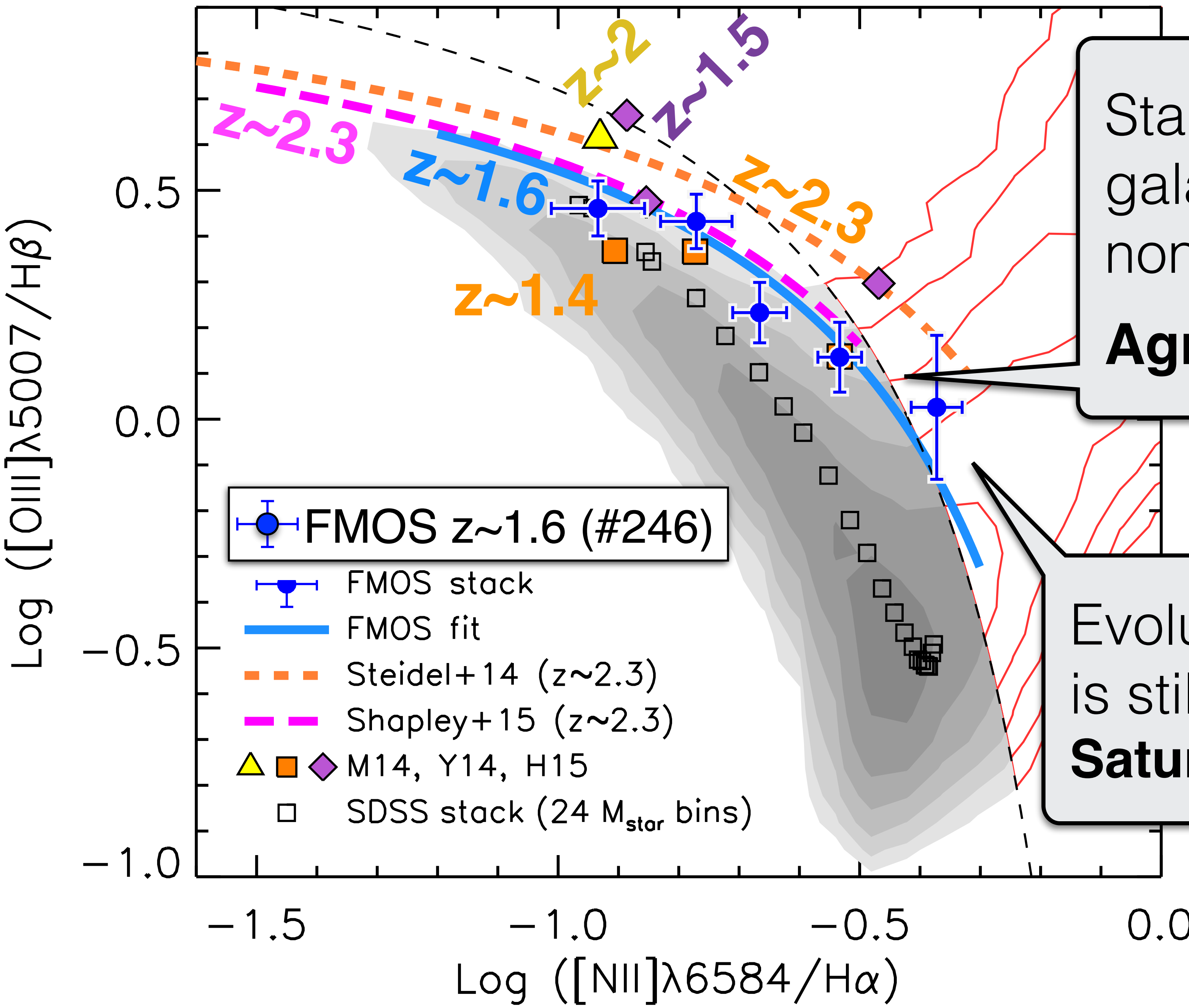
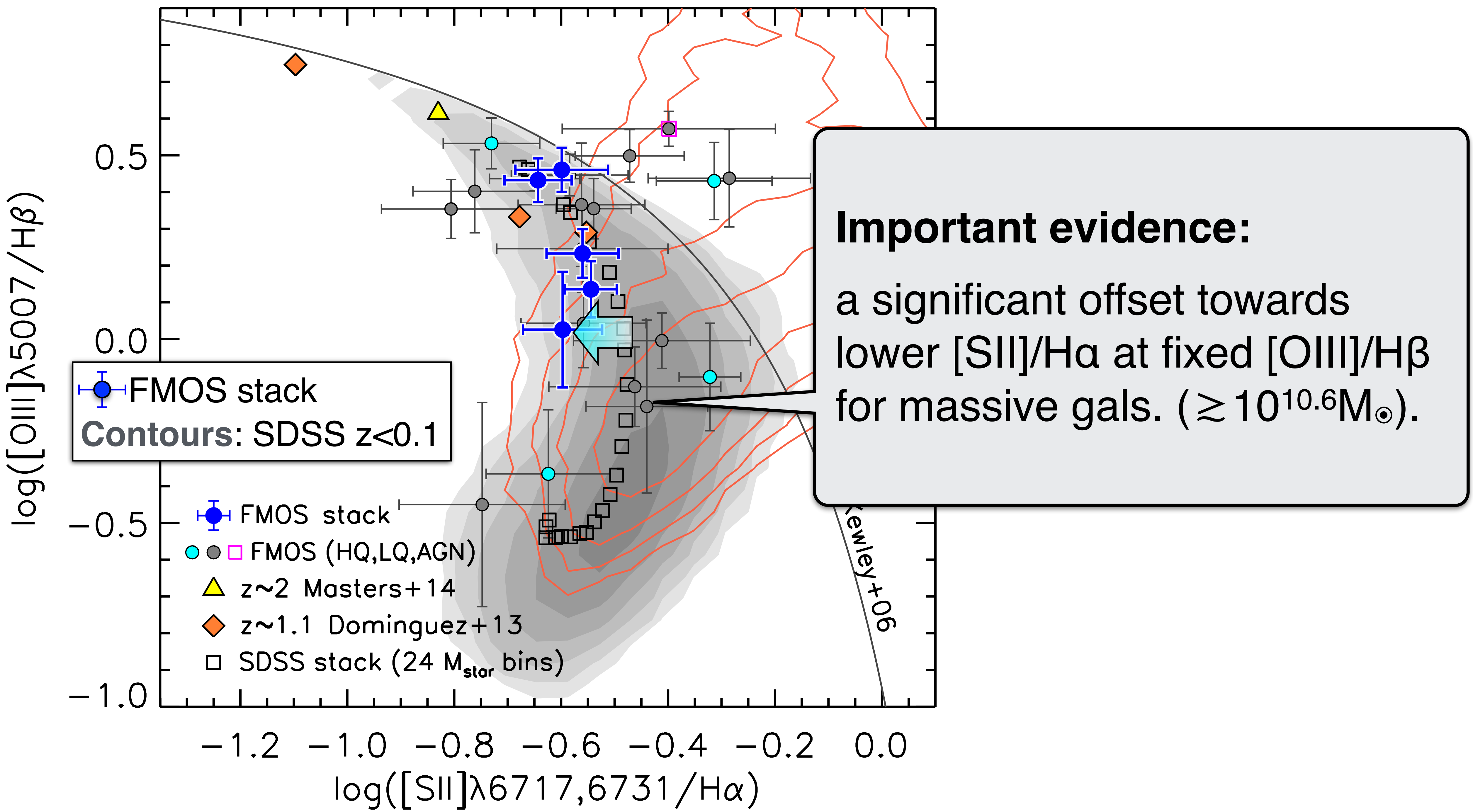


Stacks include all Hα-det. galaxies: no bias due to non-det. of weak lines.

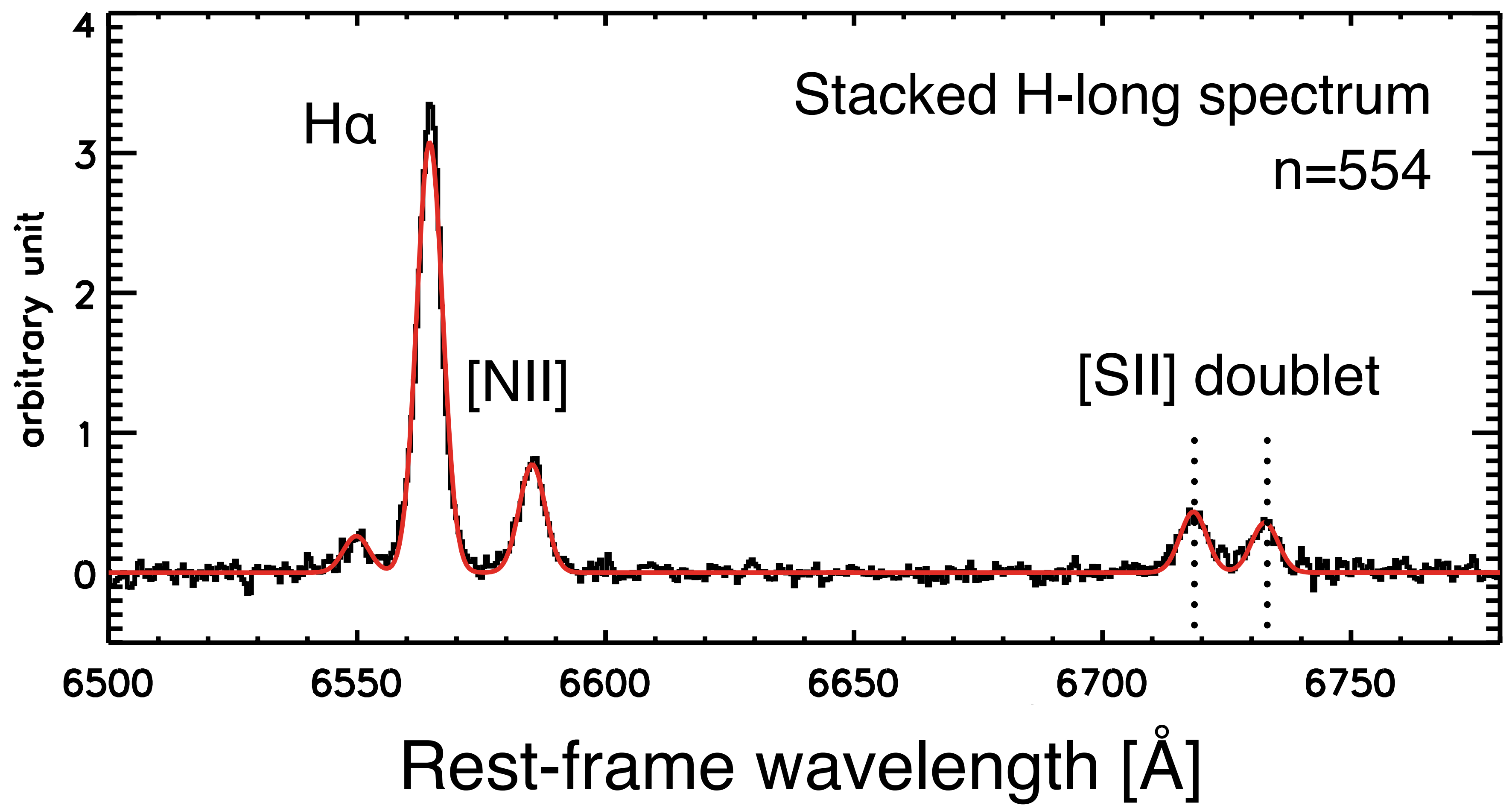
Agree well with the fit

Evolution beyond z~1.6 is still unclear:
Saturates or keeps increasing?

Results: offset in the [SII]-BPT diagram



Results: electron density



Local SF galaxies

10–100 cm^{-3}

(e.g., Brinchmann+08)

2–10倍 →

FMOS sample at z~1.6

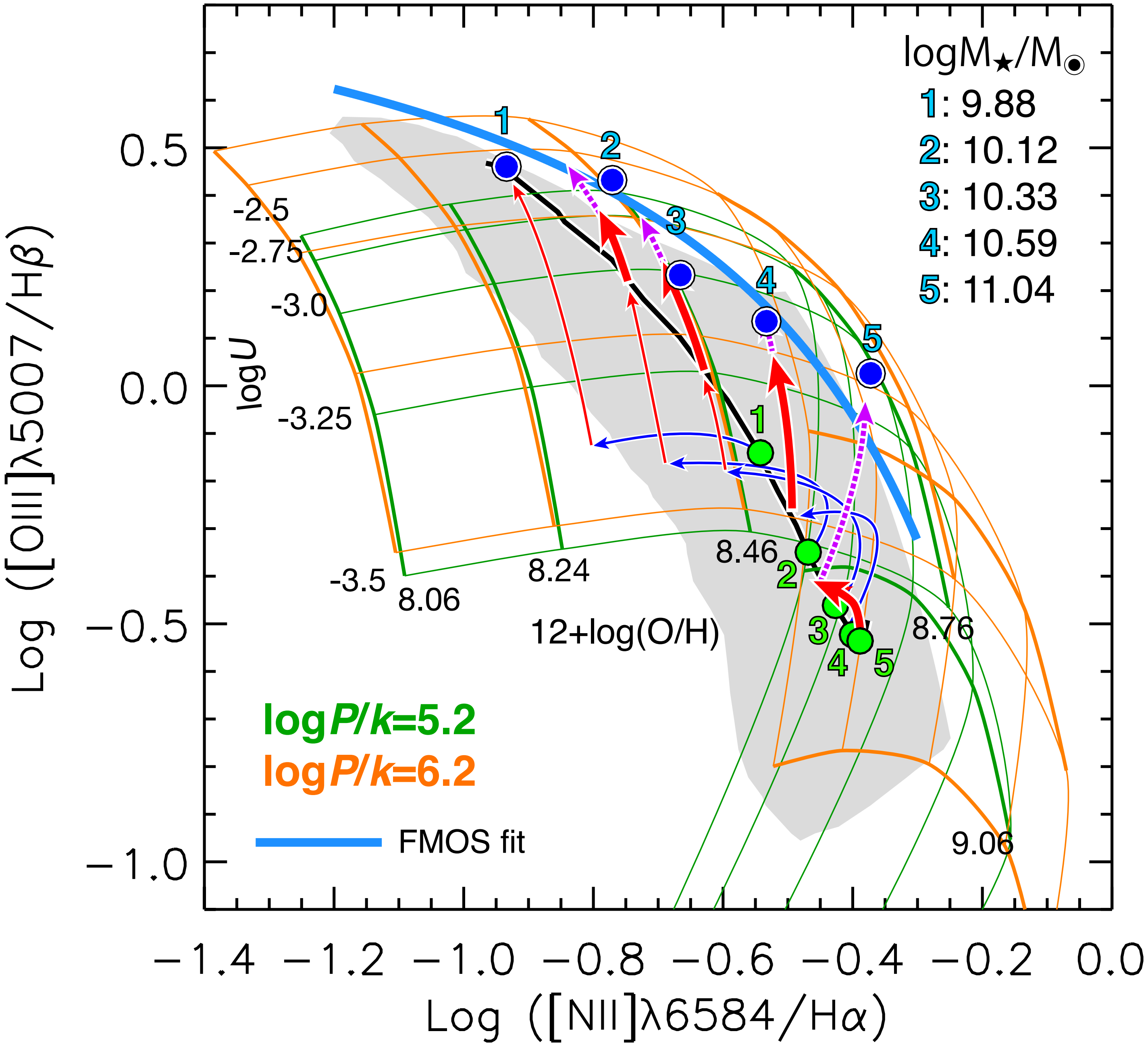
$$n_e = 222^{+172}_{-128}\ \mathrm{cm}^{-3}$$

$$(P/k = 2n_e T \approx 3 \times 10^6 \mathrm{cm}^{-3}\ \mathrm{K})$$

Consistent with recent studies at z~2:
(e.g., Shirazi+14, Shimakawa+15, Sanders+15)

Discussions: comparison with model

What is the origin(s) of the changes of emission-line ratios?



Photoionization model: Mappings V (Nicholls et al., Dopita et al. 2016)

Metallicity *Z*

decreases from *z*=0 to 1.6, except for the most massive bin.

➡ the MZ relation

Ionization parameter *U*

✓ Increase from the local *U*-*Z* anti-correlation

✓ Additional excess

Essential

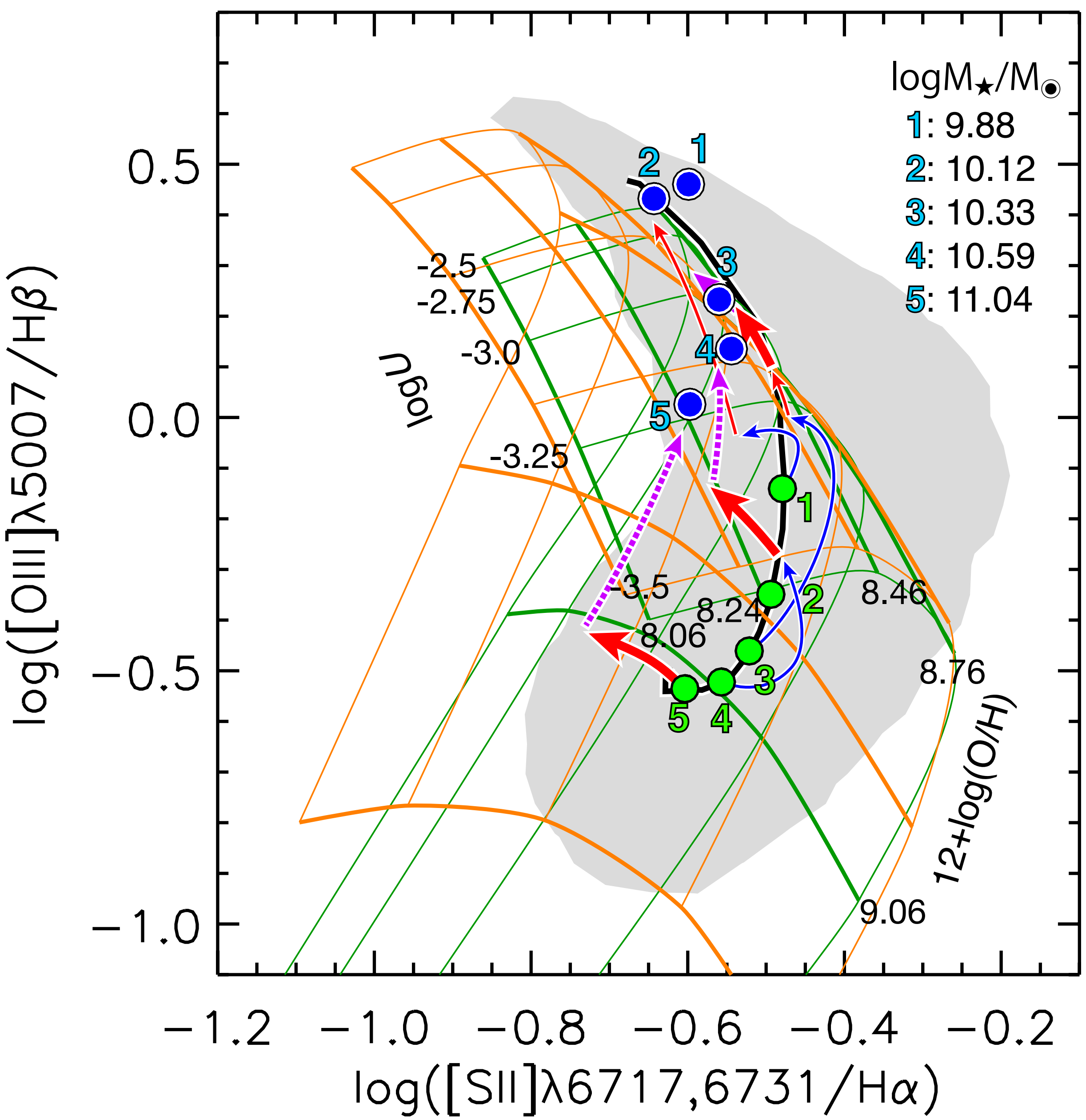
Additional effects

high n_e (*P/k*)

+ hard radiation (e.g., Steidel+16)

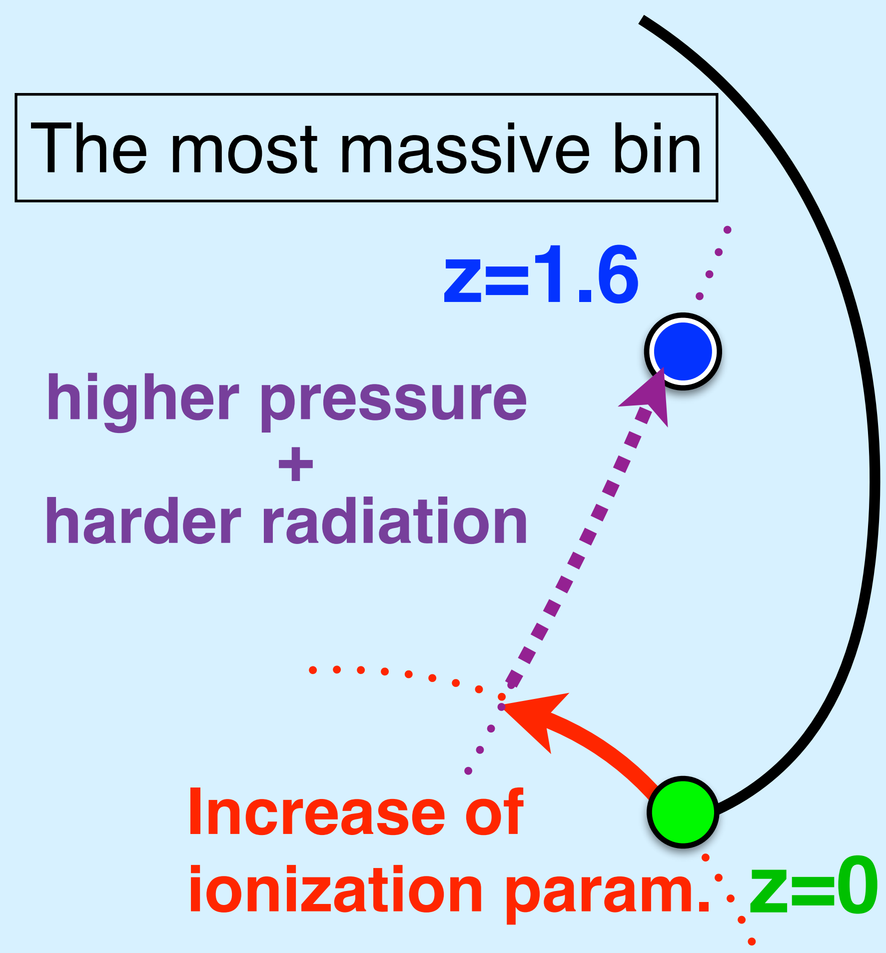
Discussions: [SII]-BPT diagram

Evidence of both **the *U* enhancement** and **additional effects** required for massive galaxies

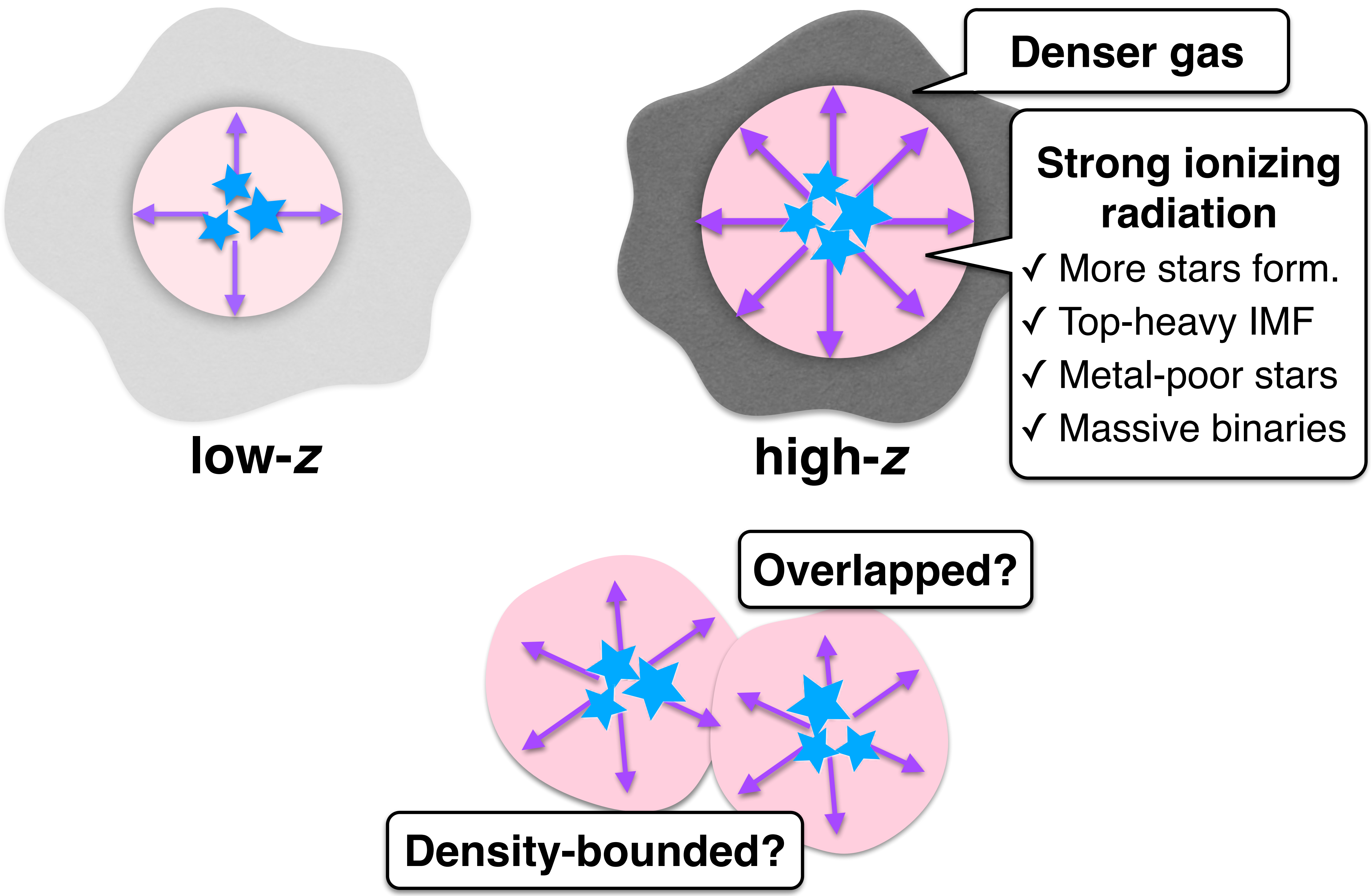


High-z offset can be explained by both **an increase in ionization parameter** and **additional effects:**

– high *P*/k & harder ionizing radiation



Expected situations in high-z star-forming regions



Summary

- ✓ a significant BPT offset at z~1.6.
- ✓ higher gas density (2—10 times higher than local)
- ✓ "excessive" enhancement of ionization parameter is the primary origin for the changes in high-z emission-line ratios.
- ✓ plus, high gas density and harder ionizing radiation are likely important.

➡ *A lot of "circumstantial evidence", but still far from understanding the physical of star formation.*

- ★ *Chemical composition — N/O enhancement?*
- ★ *Geometrical properties?*
- ★ *Evolution of IMF, stellar population, stellar spectra*