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Emission Lines from Broad Band Photometry: sSFR & [OIII]/Hβ ratio at $3 < z < 6$

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with Peter Capak (Caltech/IPAC)
and the COSMOS collaboration

Based on Faisst et al. (2016b)

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The 2 Questions (out of many)

- How do galaxies at high-z grow?
  - ➡ Cold gas accretion?
  - ➡ Mergers?
  - ➡ At what redshifts?

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  - ➡ contribution of "normal" galaxies to re-ionization?
  - ➡ much less is observed at low redshifts

(Remember previous talk by Bouwens)

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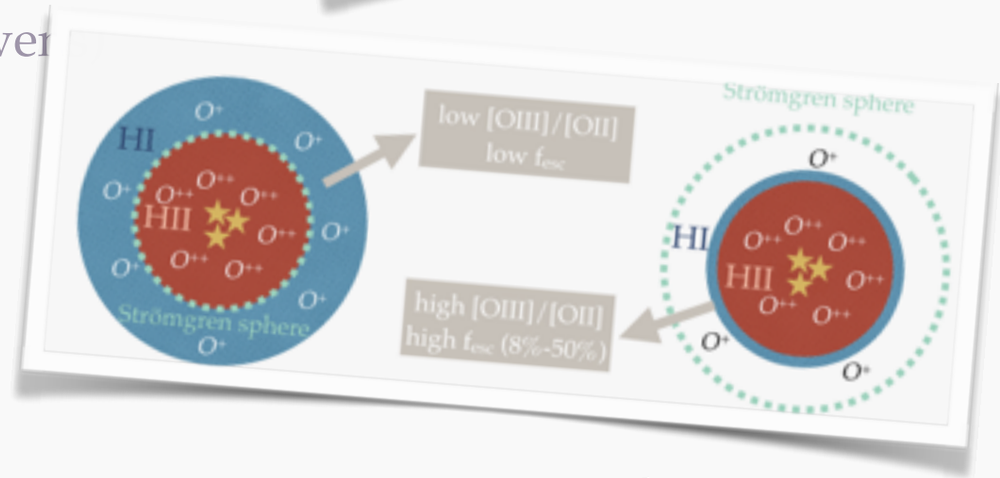

Emission line properties of high-z galaxies?

How to Probe Emission Lines at z > 3

- All important optical lines (Hα, Hβ, [OII], [OIII]) are out of reach for current near-IR spectrographs.
  - ➡ Do we have to wait for JWST??

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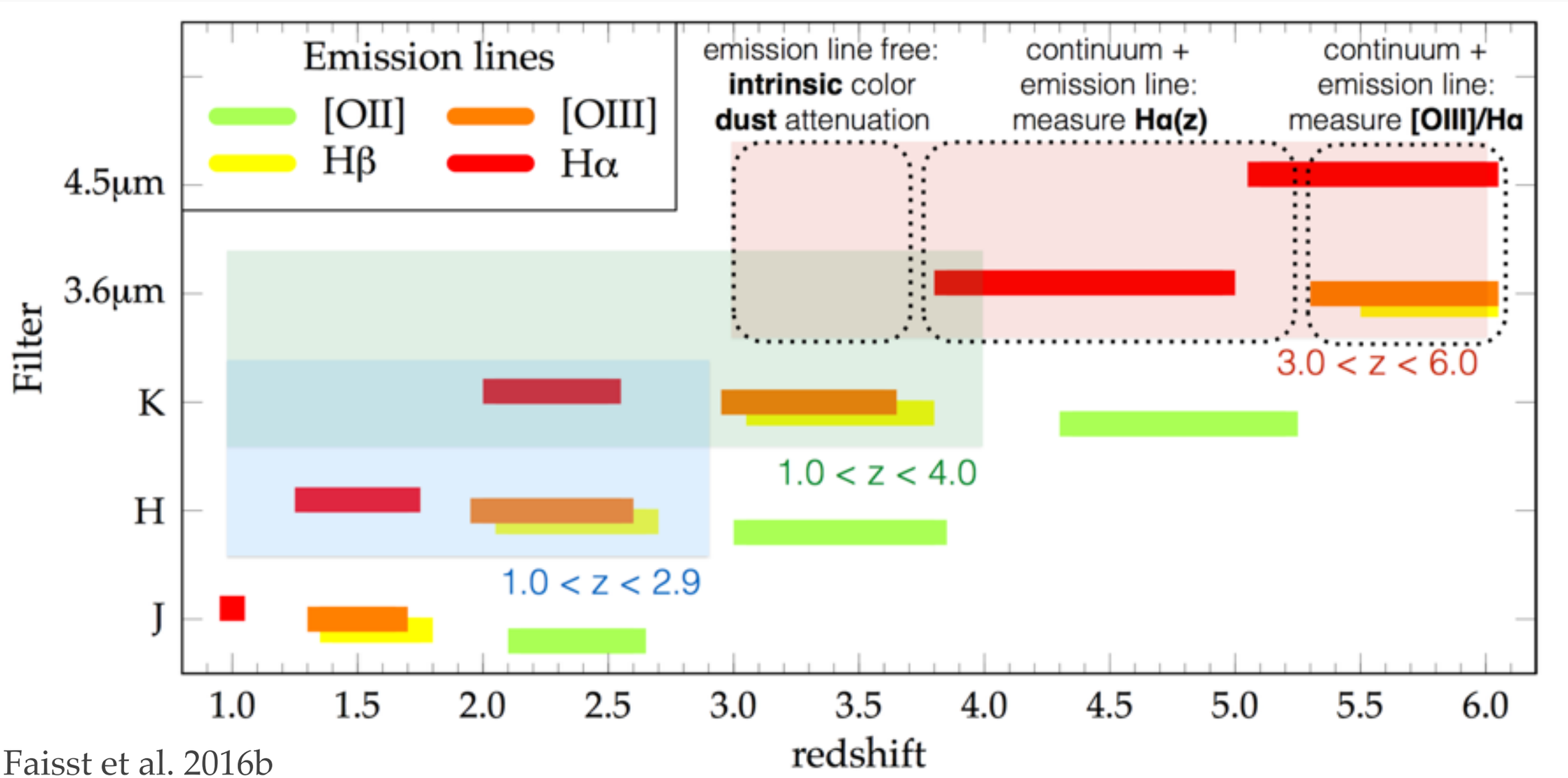
  ➡ Do we have to wait for JWST??

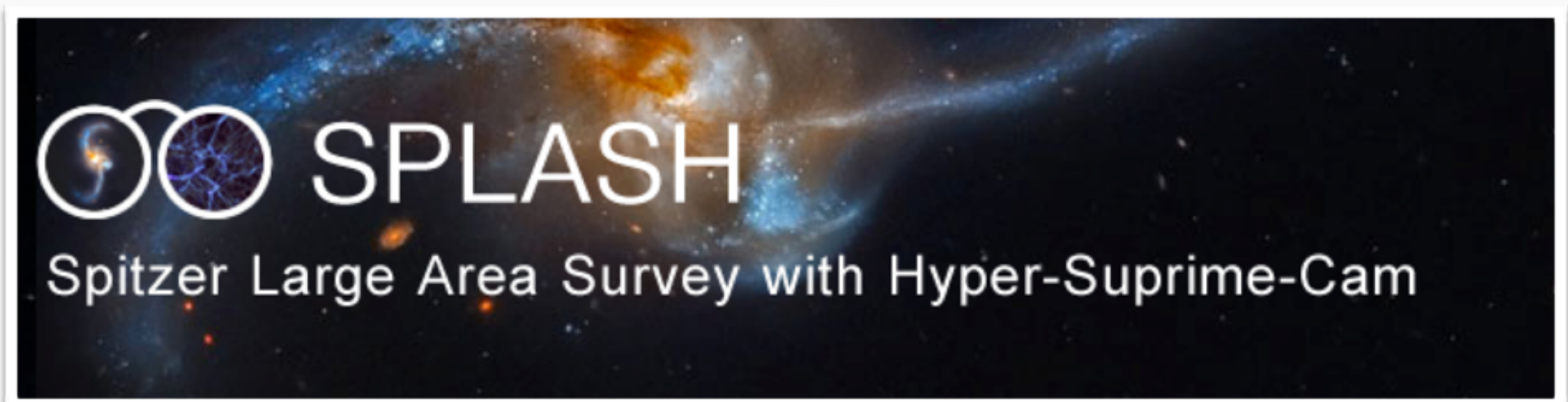
- … no… we can use broad-band photometry to measure emission line properties. (Remember previous talks by Bowler, Labbe, Stark, Bouwens)



Faisst et al. 2016b

Need: Large Area, Spectroscopy & Deep mid-IR data

- COSMOS (Scoville+07) provides
  - ➡ a **large area** (2 square degrees)
  - ➡ a **large spectroscopic sample** at z > 3: zCOSMOS, VUDS together **> 500 spectra at z > 3** (Lilly+07, LeFevre+14, Salvato+16)
  - ➡ **minimally biased** (from comparison with photo-z samples)
  - ➡ **> 30 band photometry** (Laigle+16)
  - ➡ deep (>25.5AB) **Spitzer photometry** from **SPLASH**



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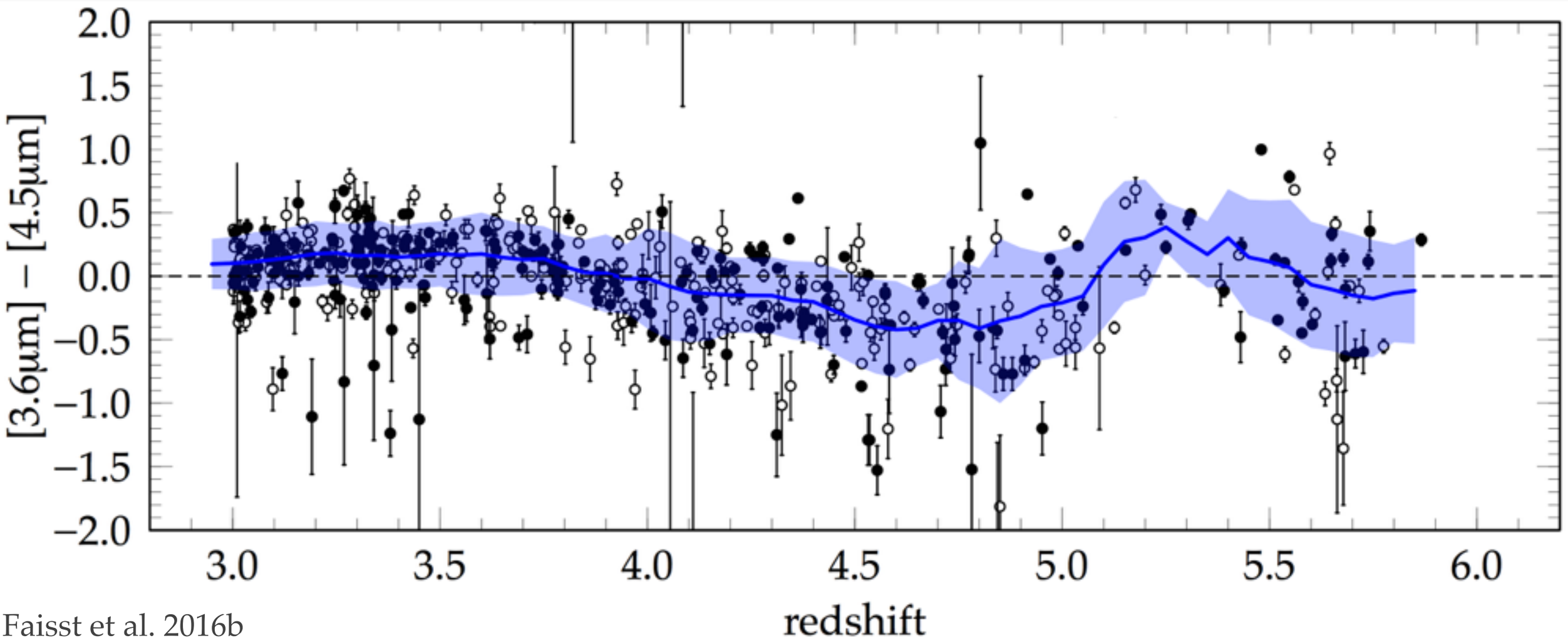
Model color vs. redshift relation

Observed color vs. redshift relation



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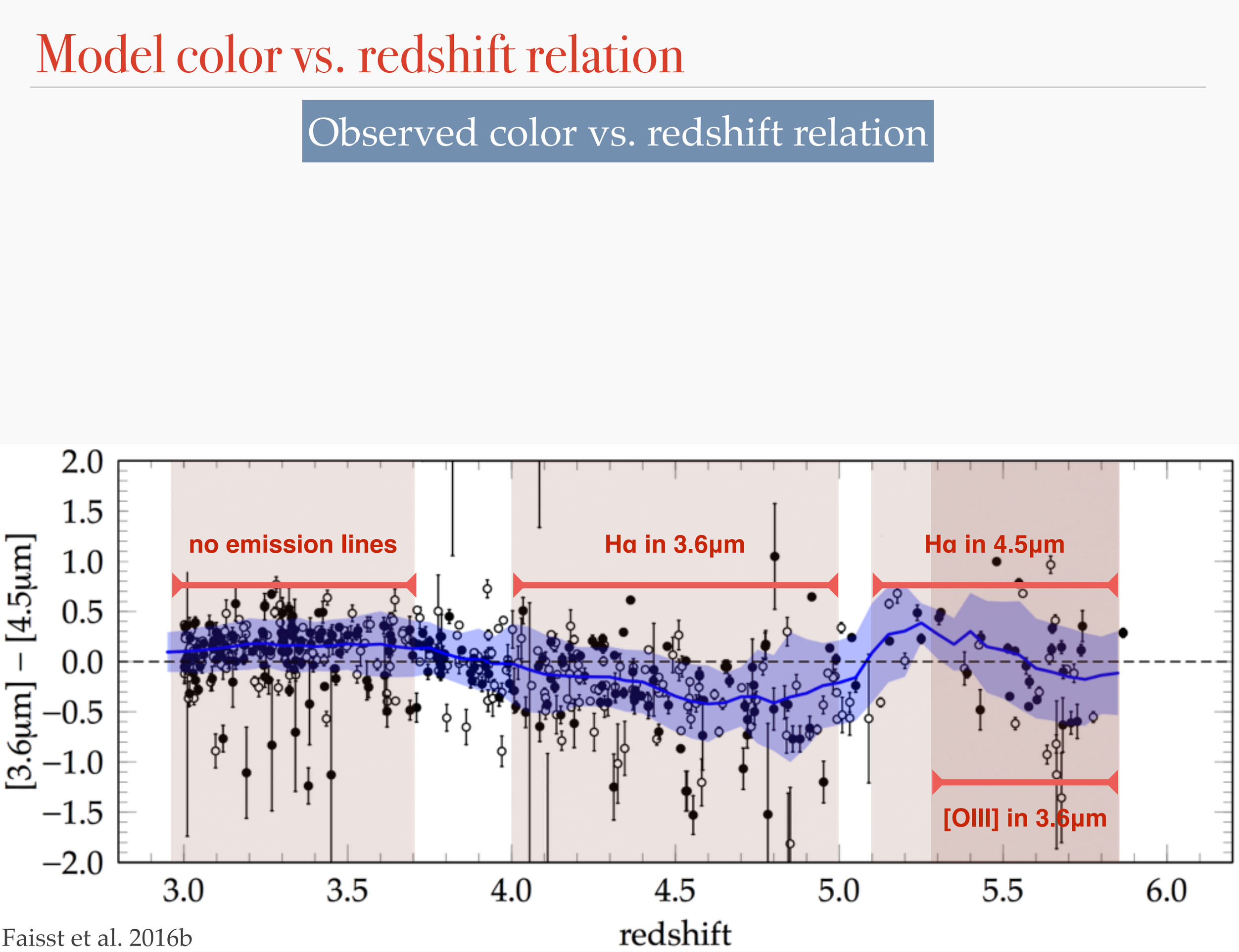

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Continuum (dust, age, metallicity, SFH)

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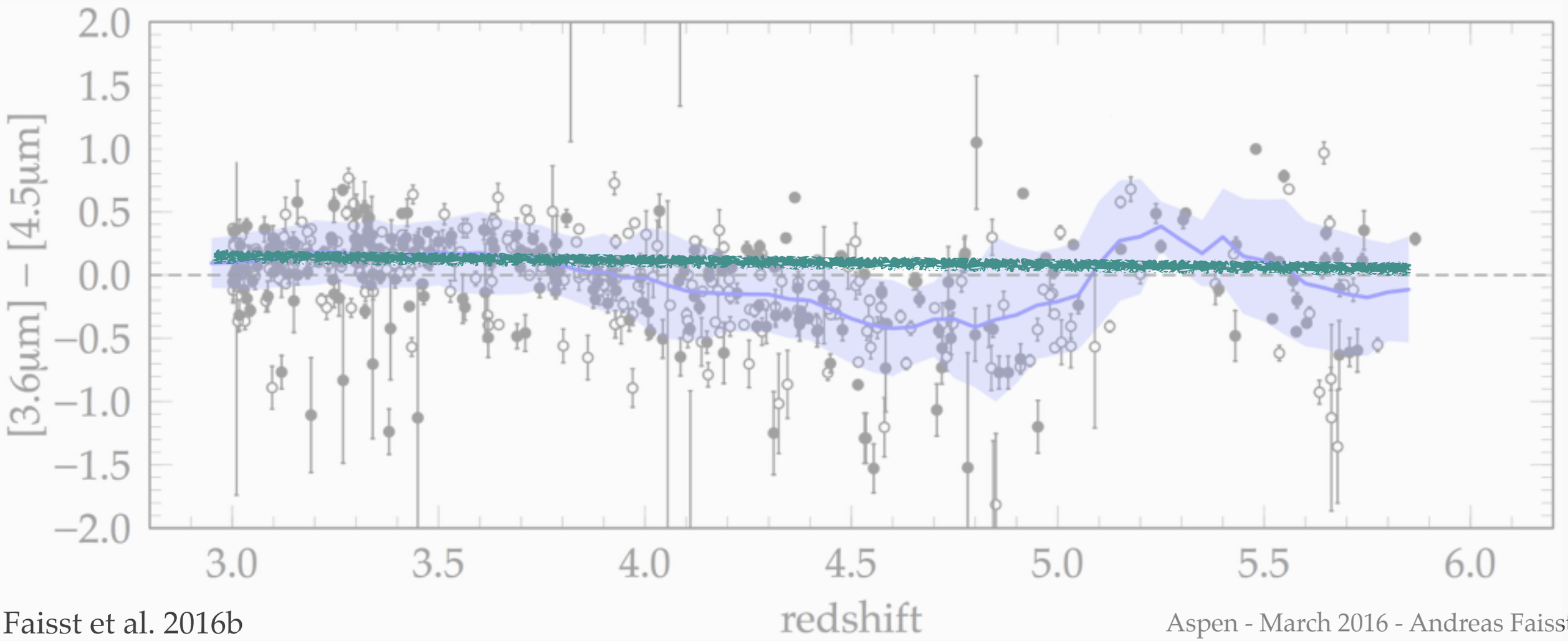

Faisst et al. 2016b

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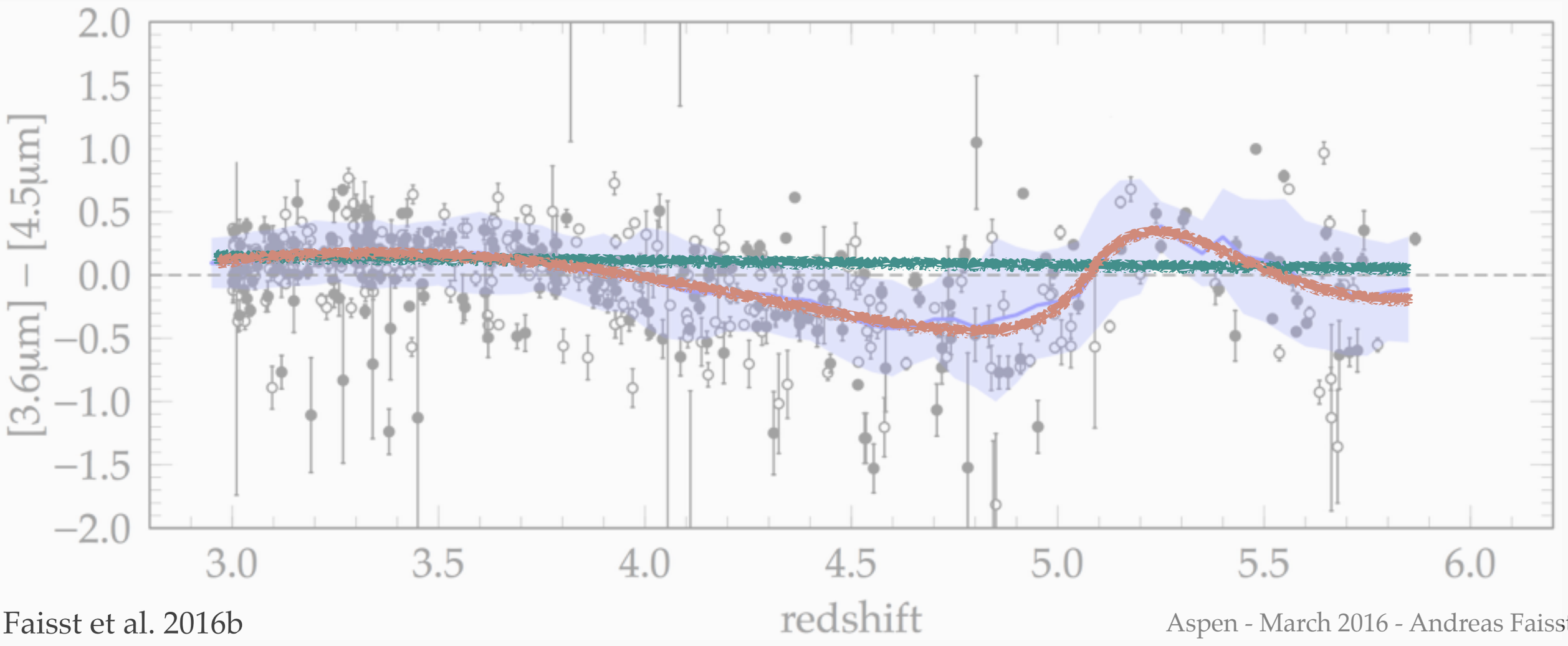

Faisst et al. 2016b

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+ color not sensitive to these at high redshifts!

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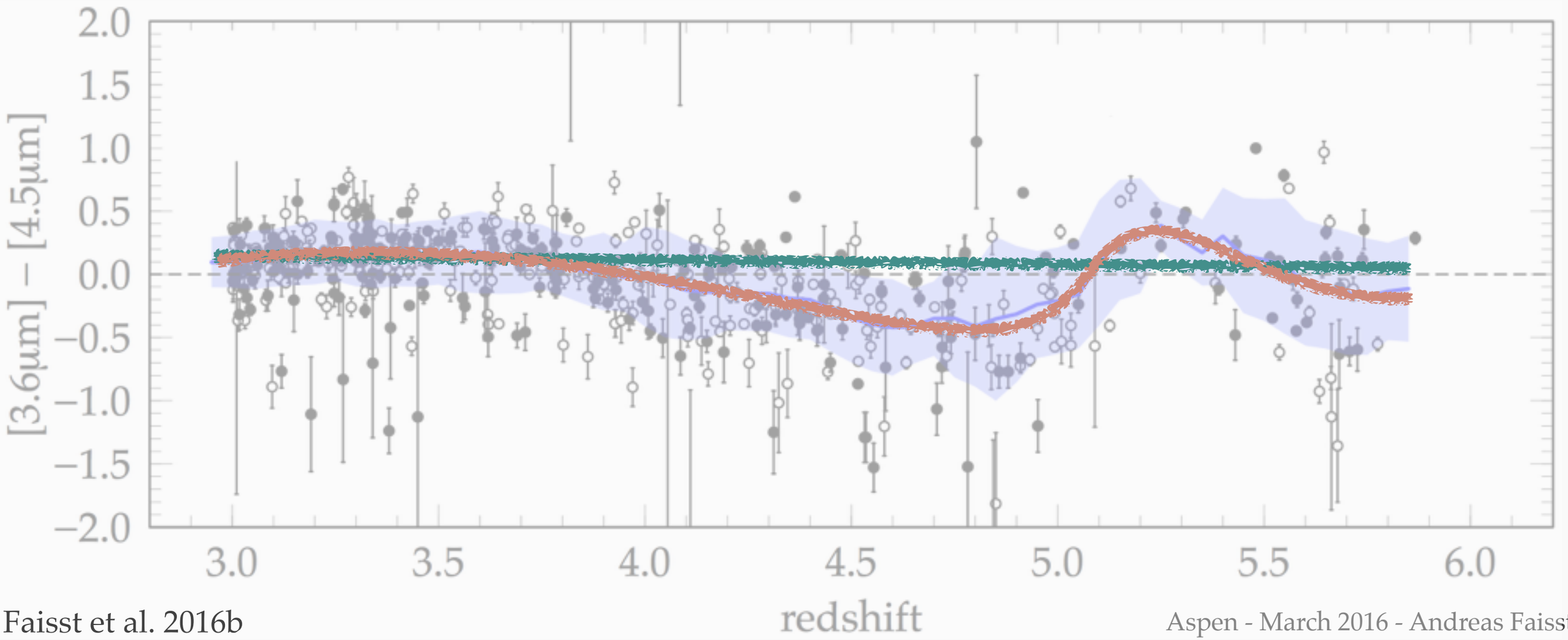


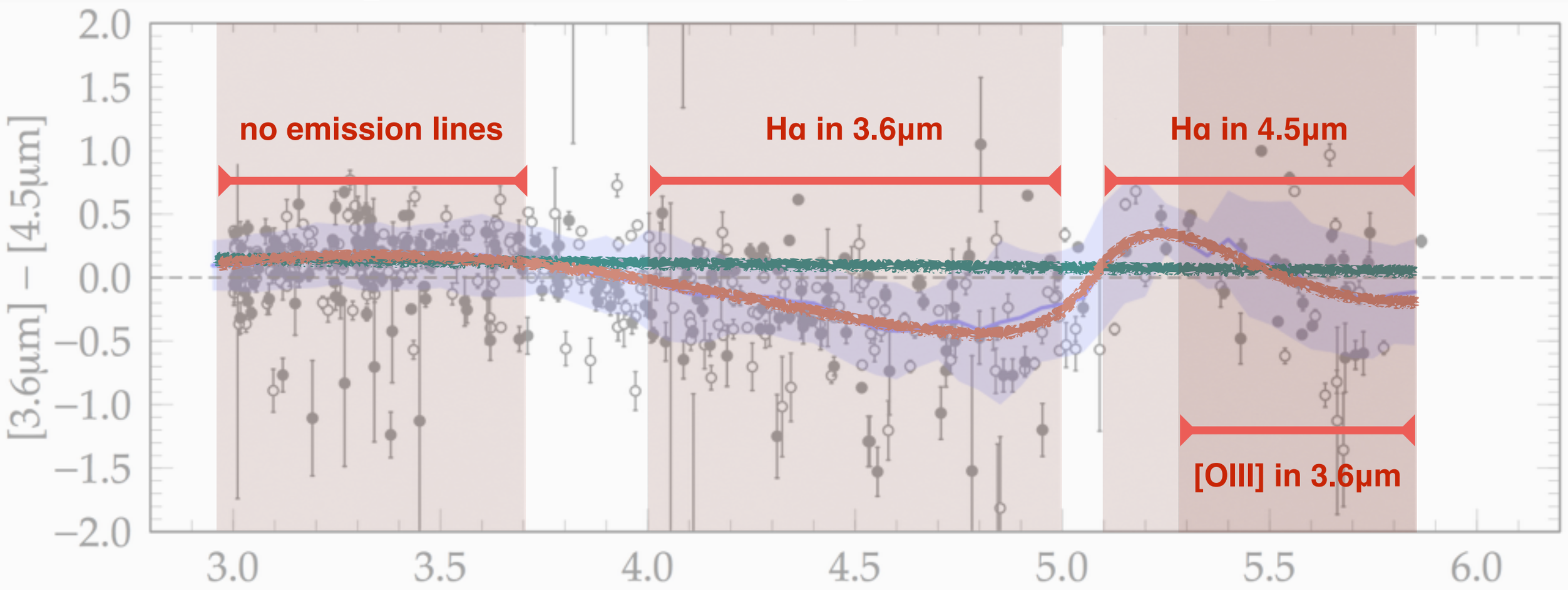
Faisst et al. 2016b

Model color vs. redshift relation

"Anchor continuum fit"

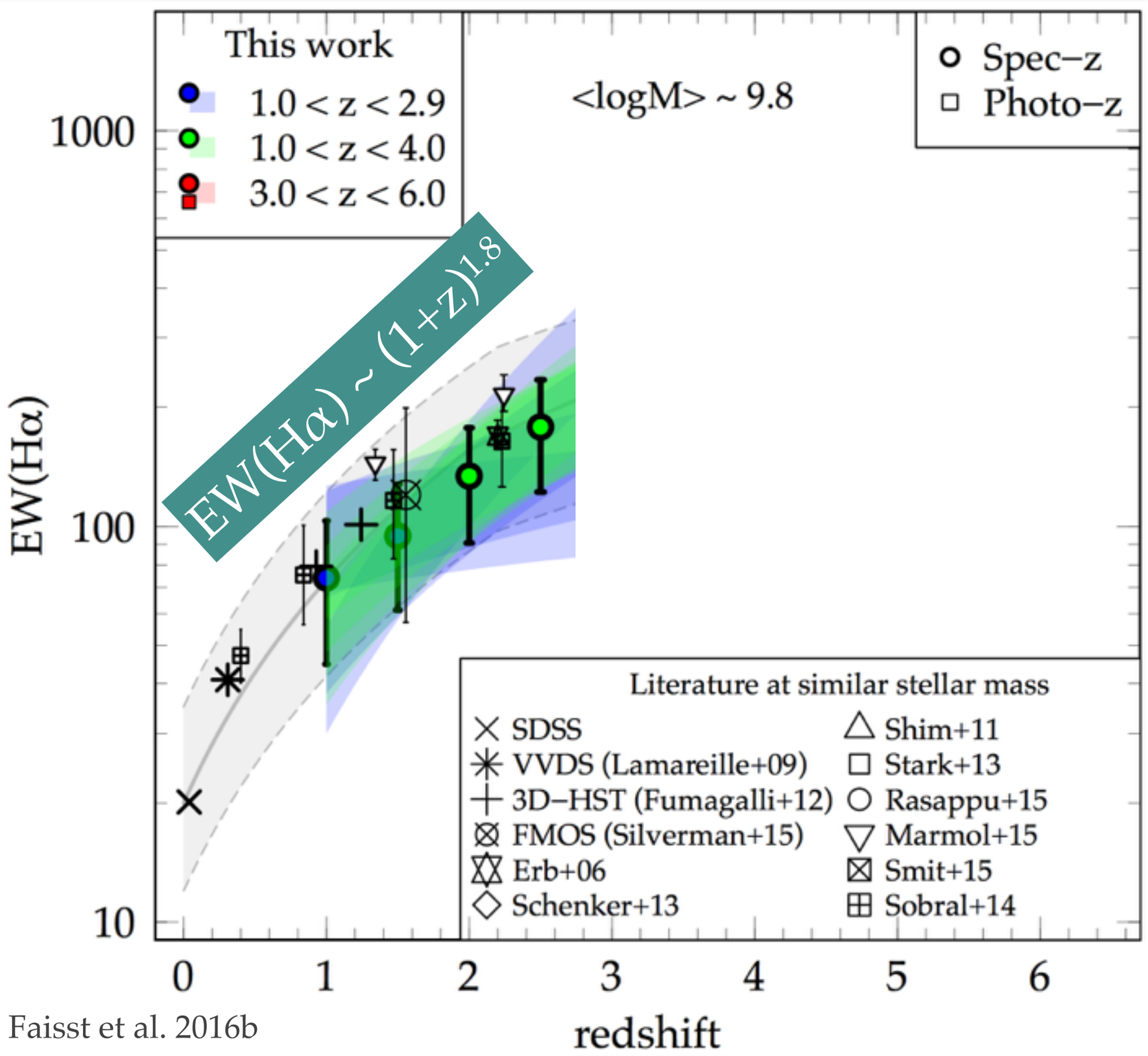
Hα equivalent-width

[OIII] / Hα line ratio



Faisst et al. 2016b

1. Steeply rising Hα equivalent-width



Faisst et al. 2016b

- **Method works** (control sample at $z < 3$)

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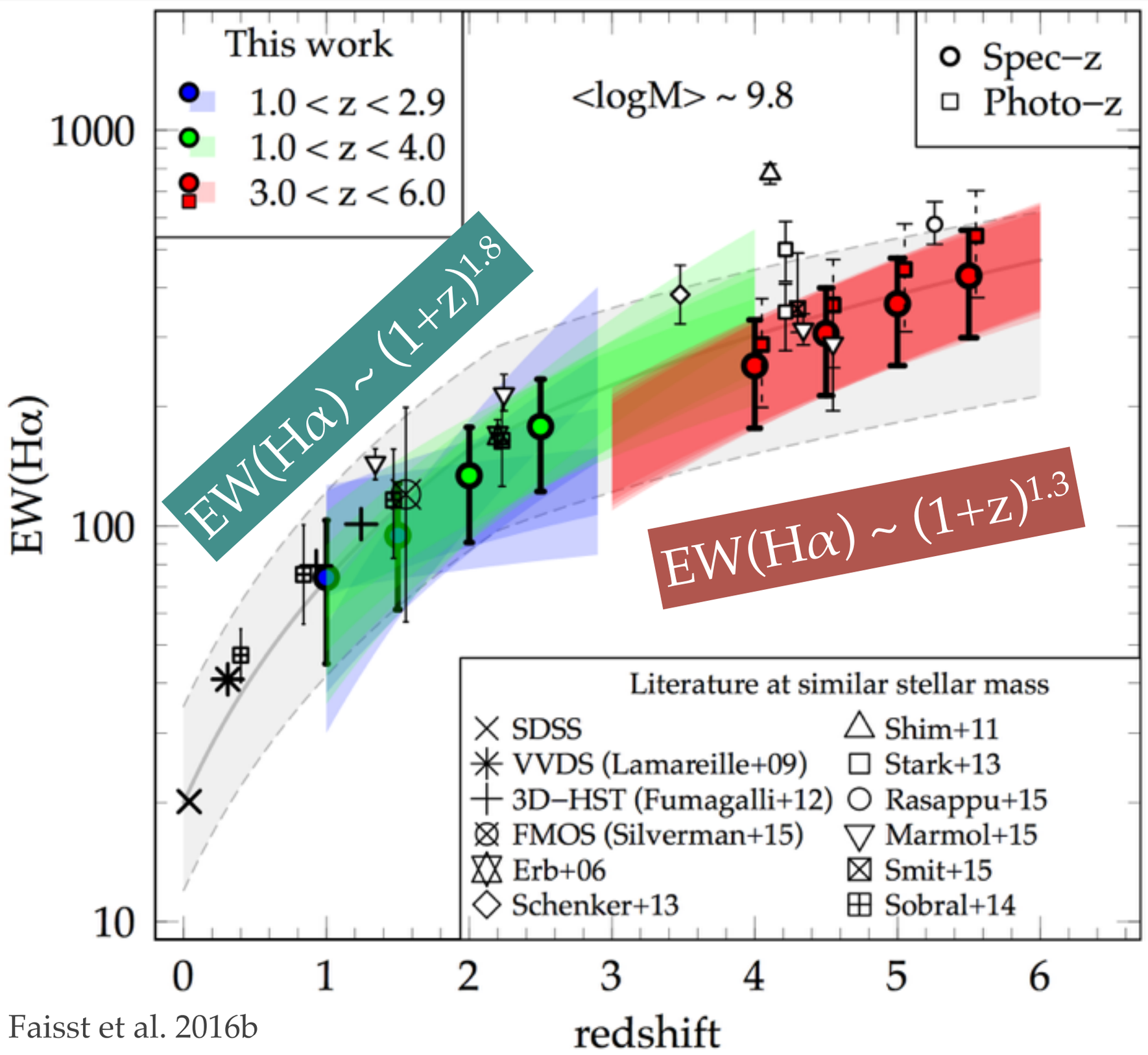

Faisst et al. 2016b

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- EW(Hα) ~ 600A on average at z>5

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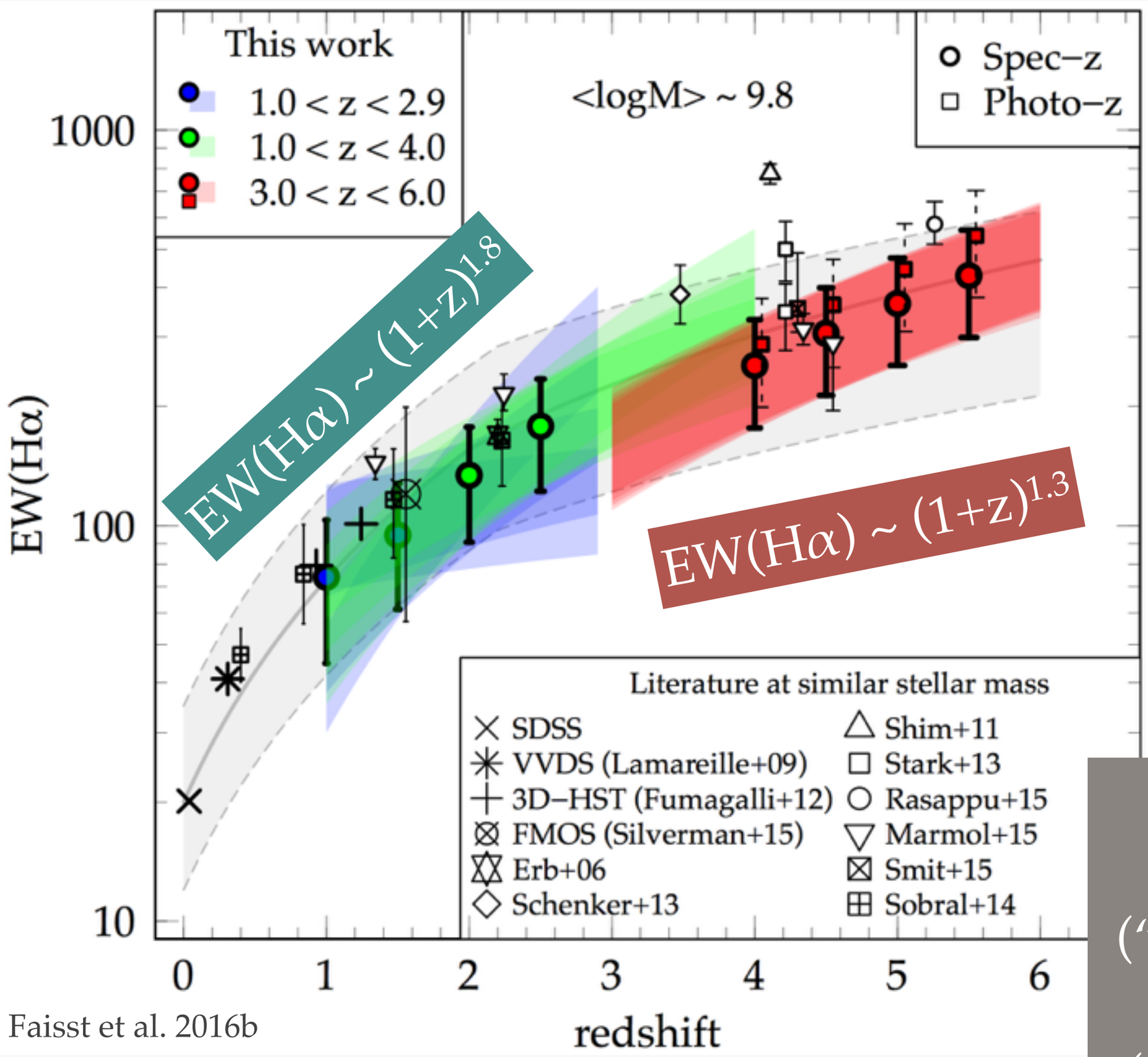

Faisst et al. 2016b

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Convert Hα EW directly into sSFR ("forward modeling")

(**without** SED fitting)

2. Rising sSFR - inconsistent with cold accretion only

Self-consistently modeled **directly from observed color** (i.e., Hα), **negligible dependence** on {age, SFH, metallicity, dust} at $z > 4$

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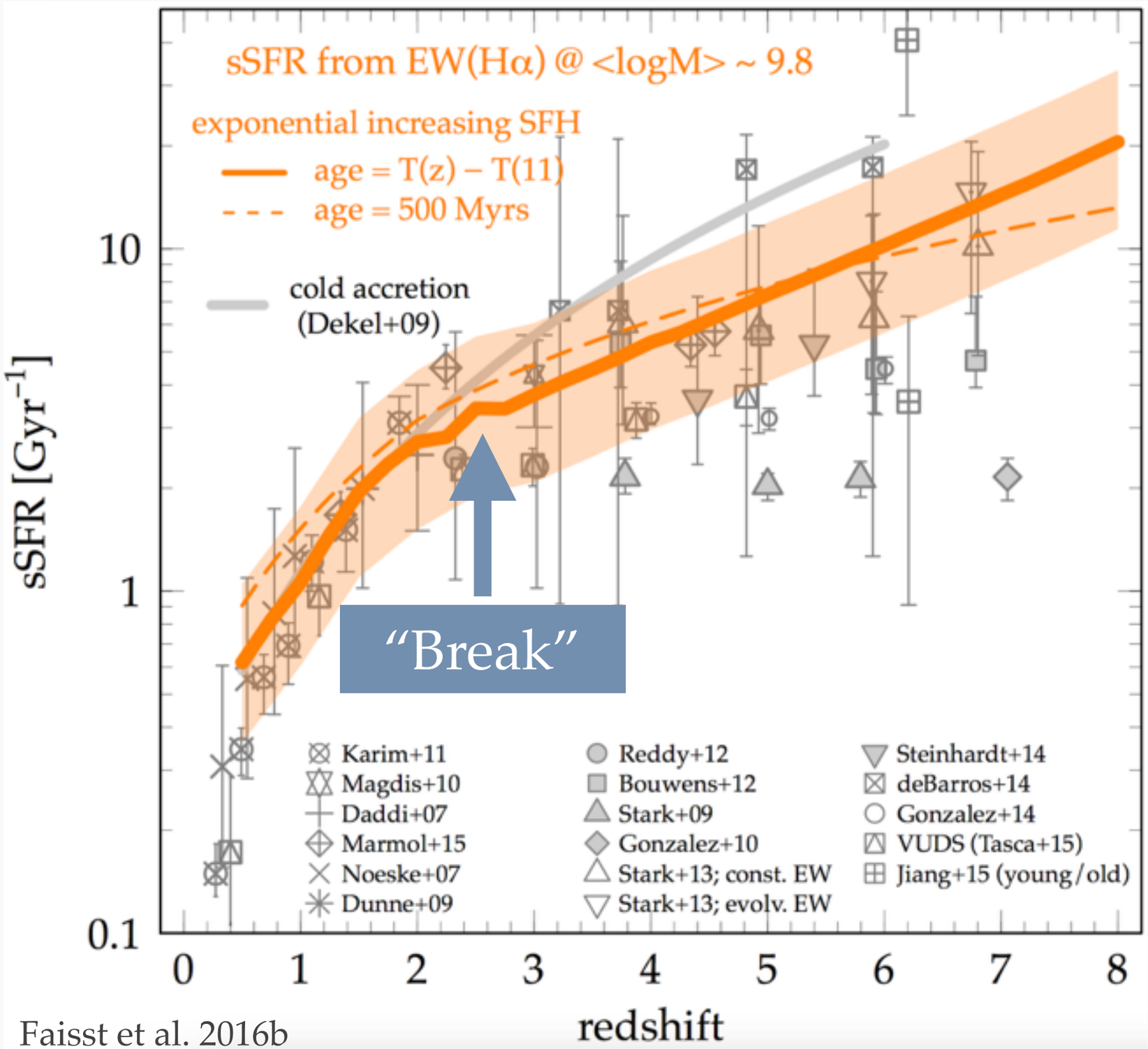

- Mass doubling **time-scales of ~200 Myrs** at z~6
- **Mergers** likely to **contribute significantly** to growth of galaxies at high-z

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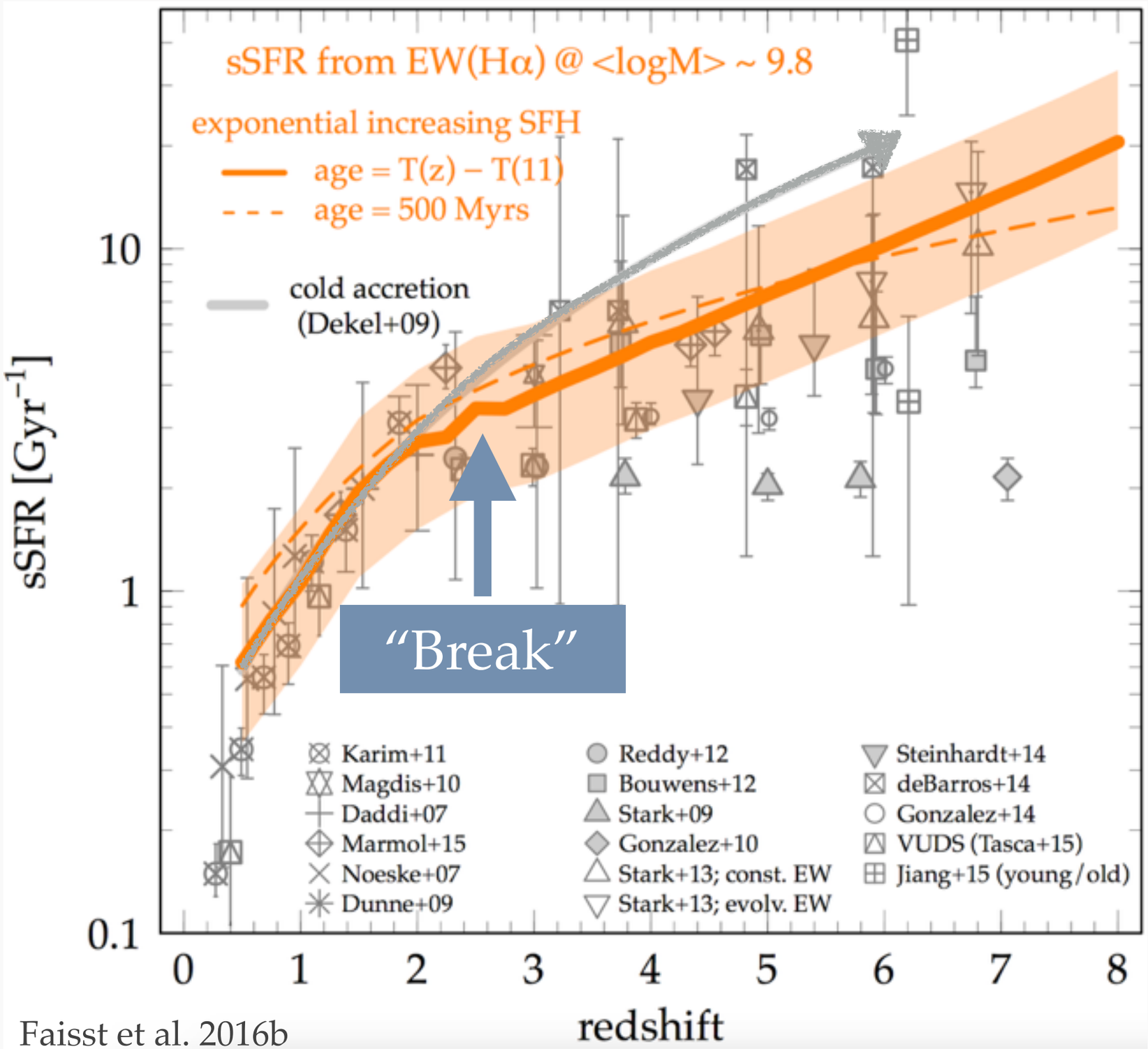

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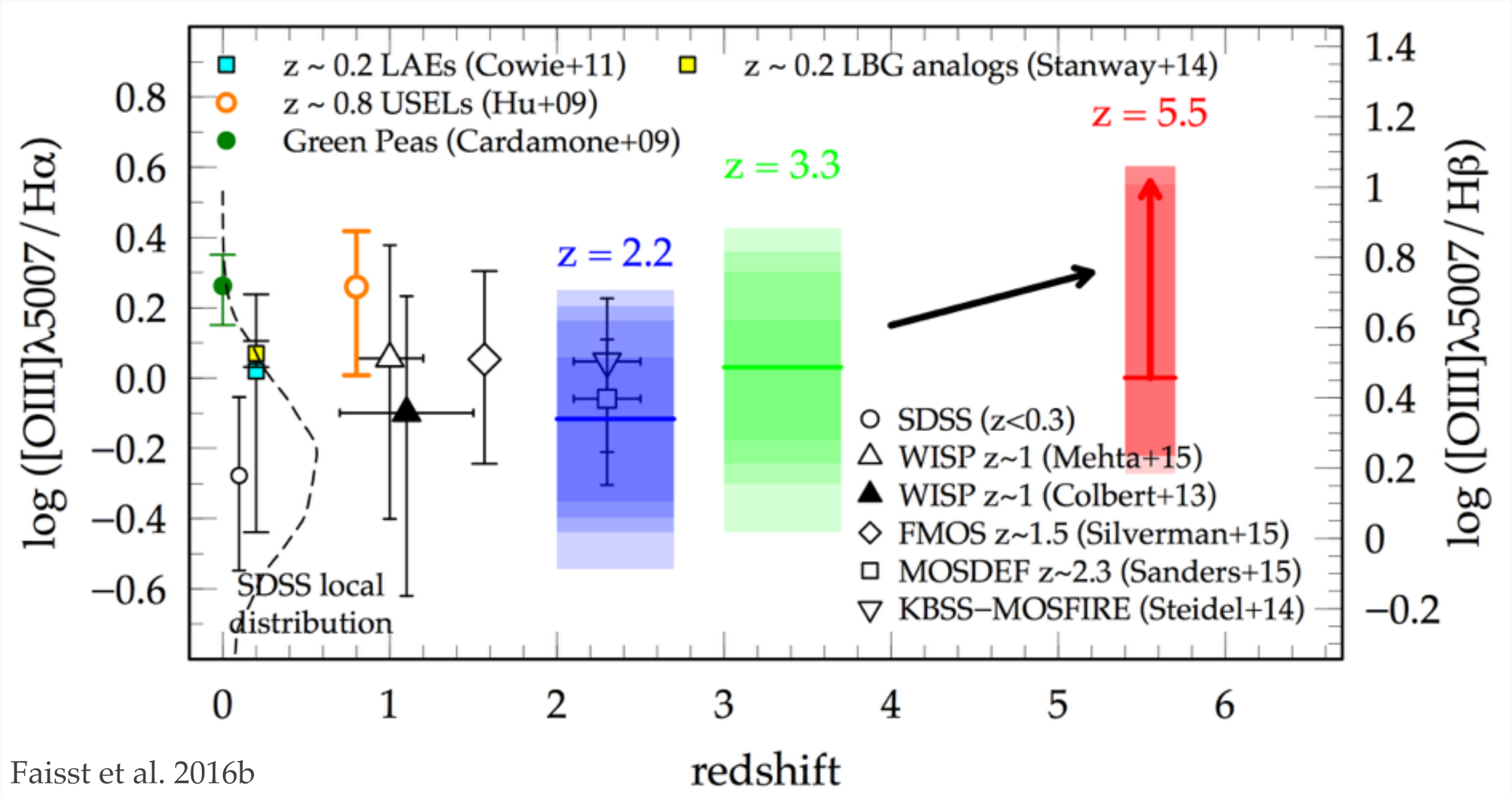
Faisst et al. 2016b

3. Significantly higher [OIII]/Hβ ratios

[OIII]/Hβ > 5 are common at z > 5



Faisst et al. 2016b

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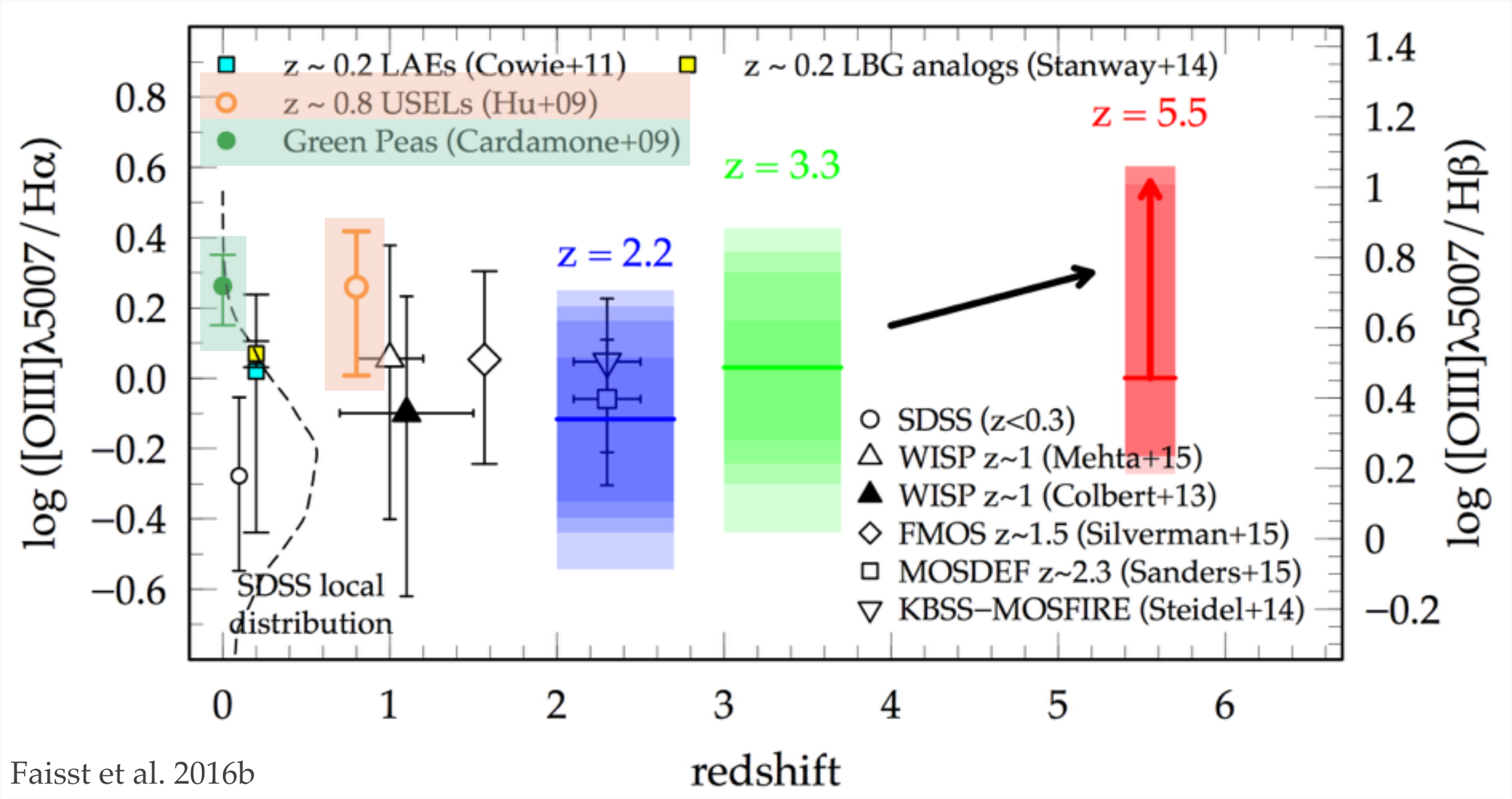
➡ Similar to **Green Peas** or **USELs** (Hu+09, Cardamone+09, also Stanway+14)



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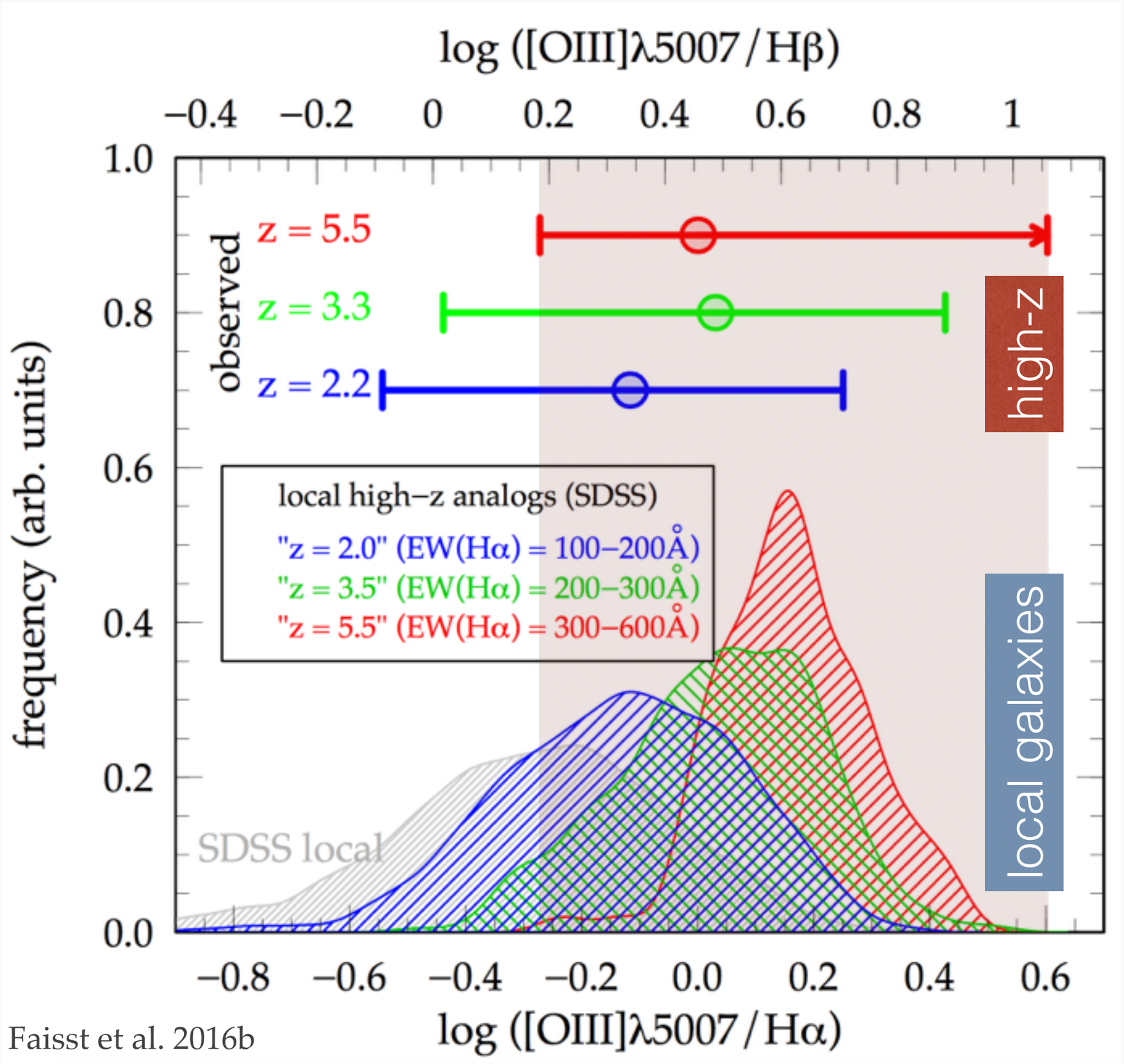
Tying high-z and local/low-z galaxies



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Similar emission line properties as at high-z

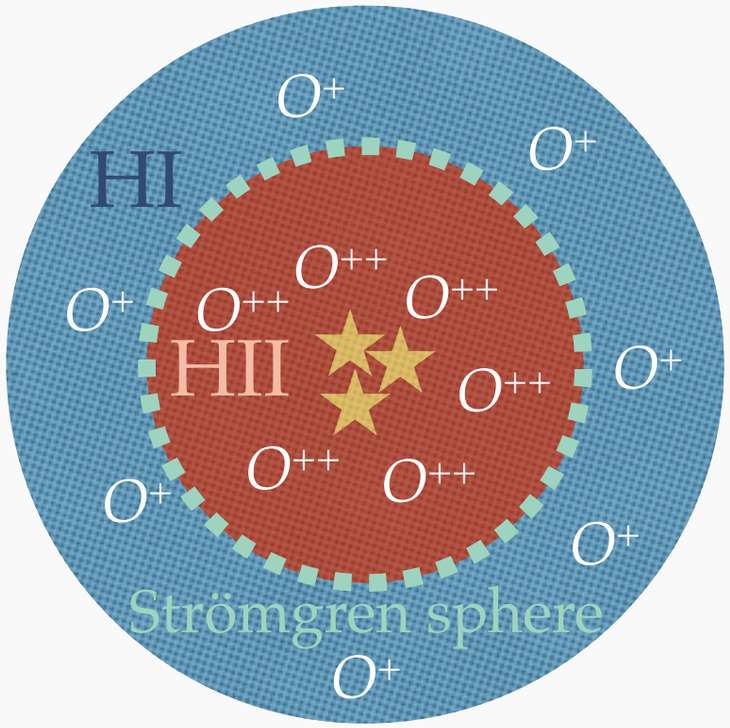
Local galaxies just selected by Hα EW

[OIII]/[OII] and LyC escape fraction at high-z

- Use local galaxies to see what's going on at high-z
- Large [OIII]/[OII] ratios correlate with a large escape fraction of ionizing radiation (Nakajima+14, deBarros+15, Izotov+16, Vanzella+16)

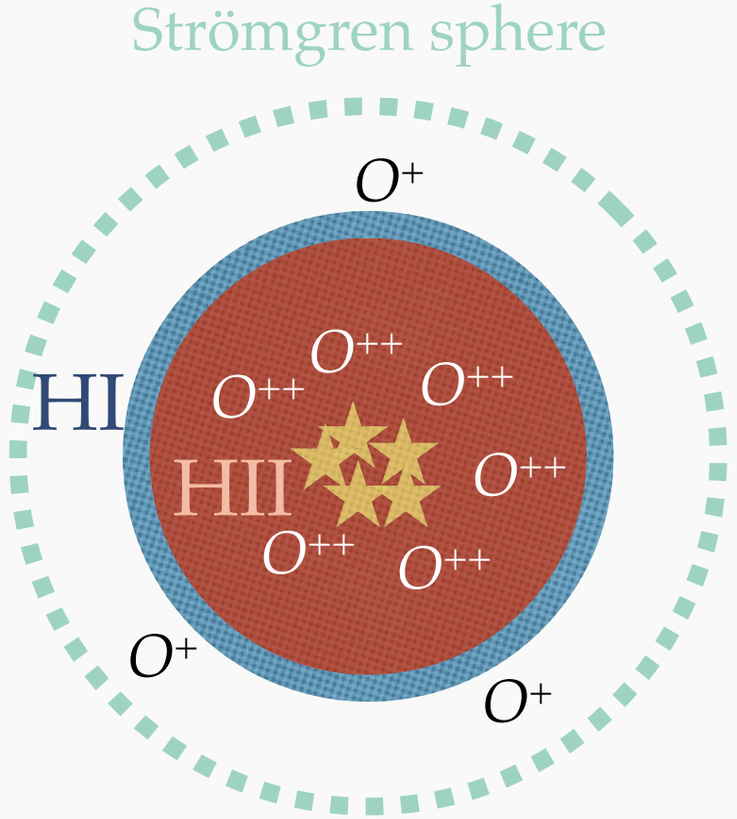
ZW 18 (blue, compact local dwarf galaxy)

[OIII]/[OII] and LyC escape fraction at high-z



Ionzation-bound nebula

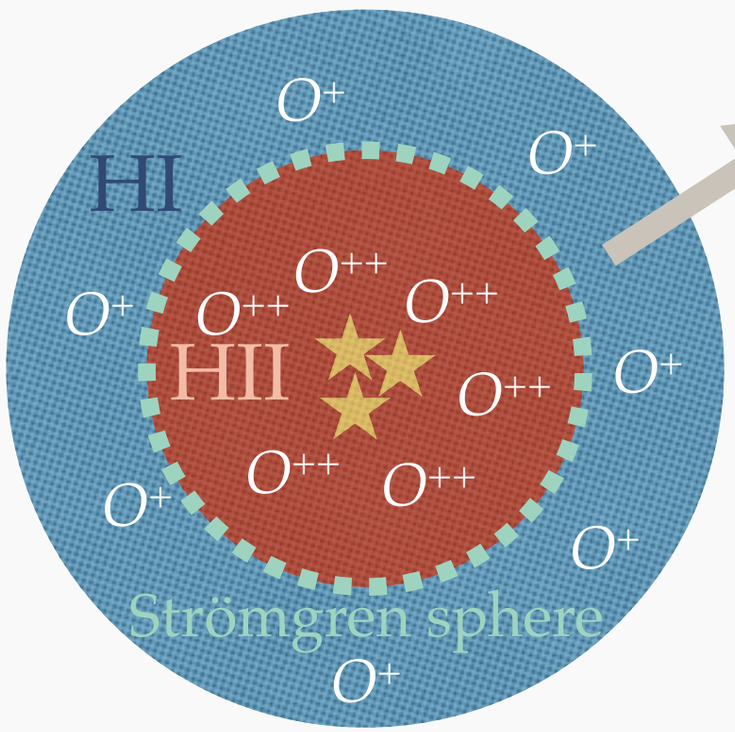
increasing redshift?



Density-bound nebula

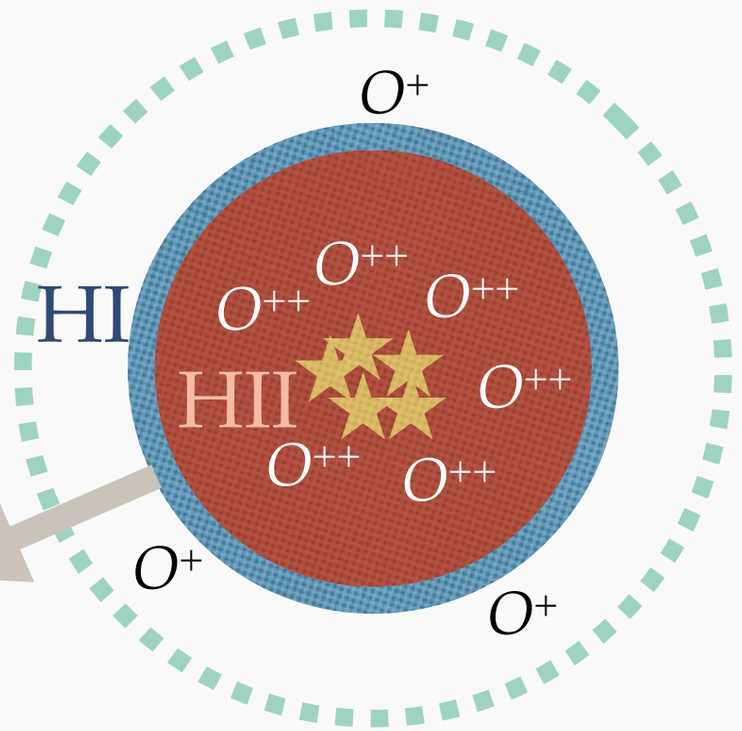
(Nakajima+14, deBarros+15, Izotov+16, Vanzella+16)

[OIII]/[OII] and LyC escape fraction at high-z



low [OIII]/[OII]
low f_{esc}

high [OIII]/[OII]
high f_{esc} (8%-50%)



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Ionzation-bound nebula → increasing redshift? → **Density-bound nebula**

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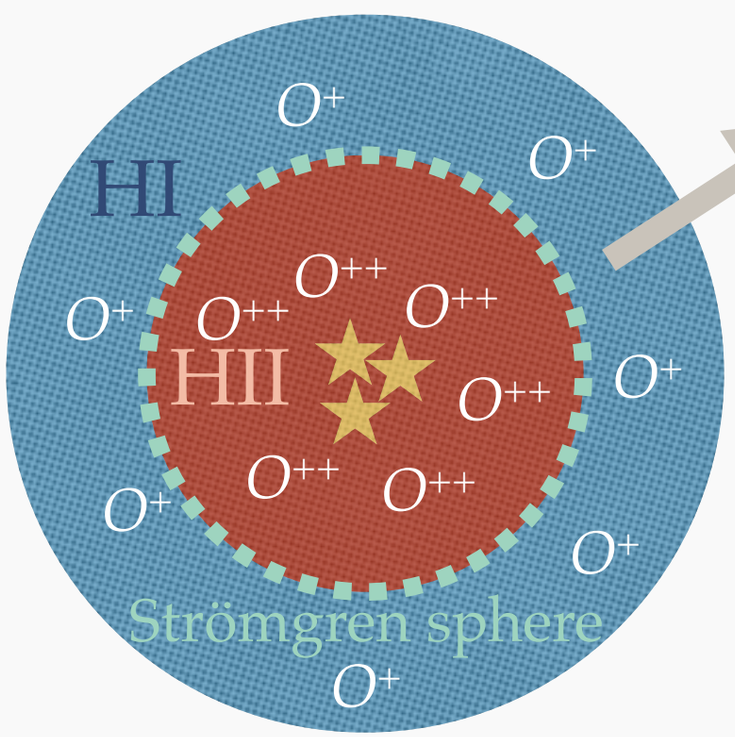

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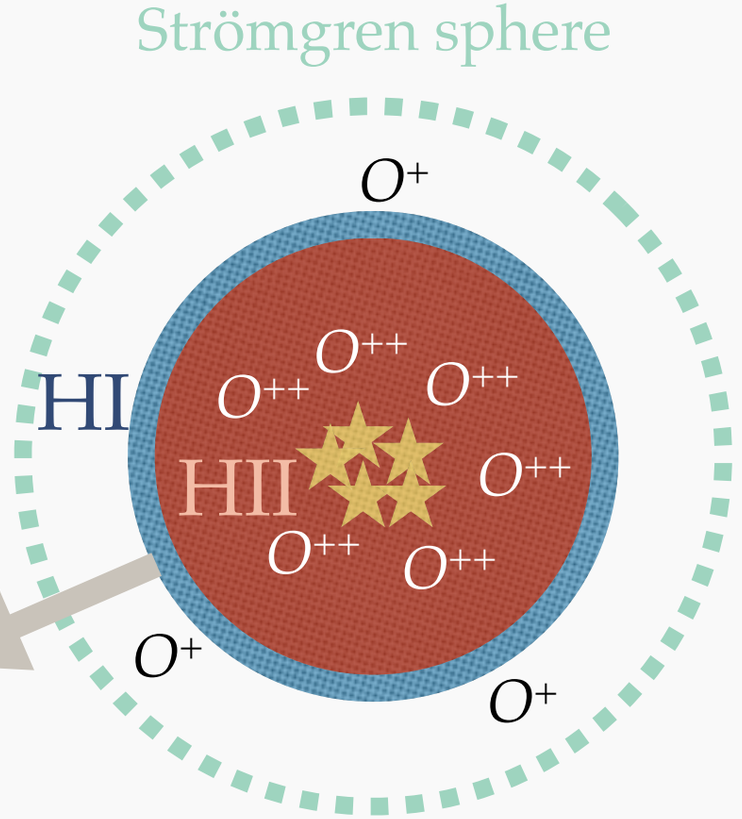

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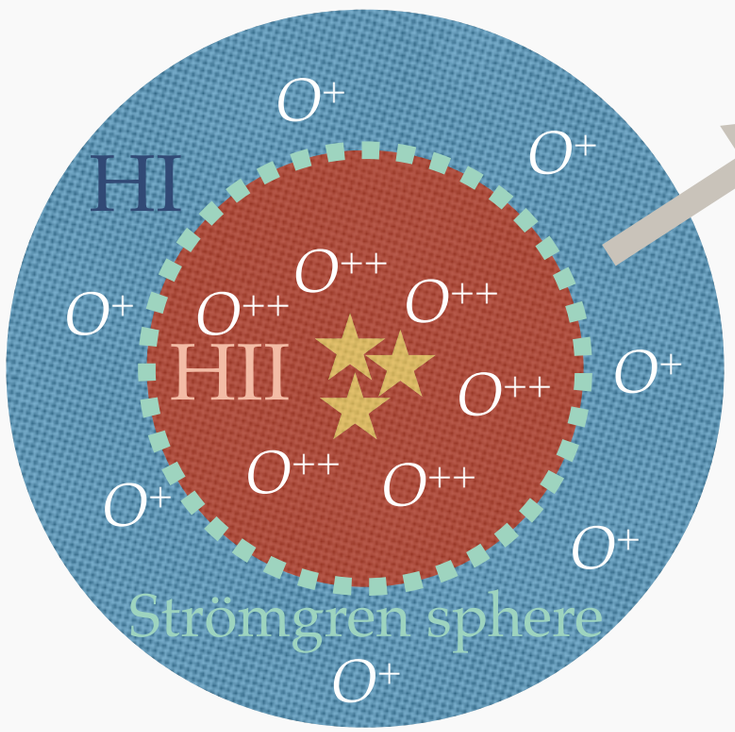
Ionzation-bound nebula

Density-bound nebula

Increasing [OIII]/Hβ ratio and [OIII] emission at high-z

[OIII]/[OII] and LyC escape fraction at high-z



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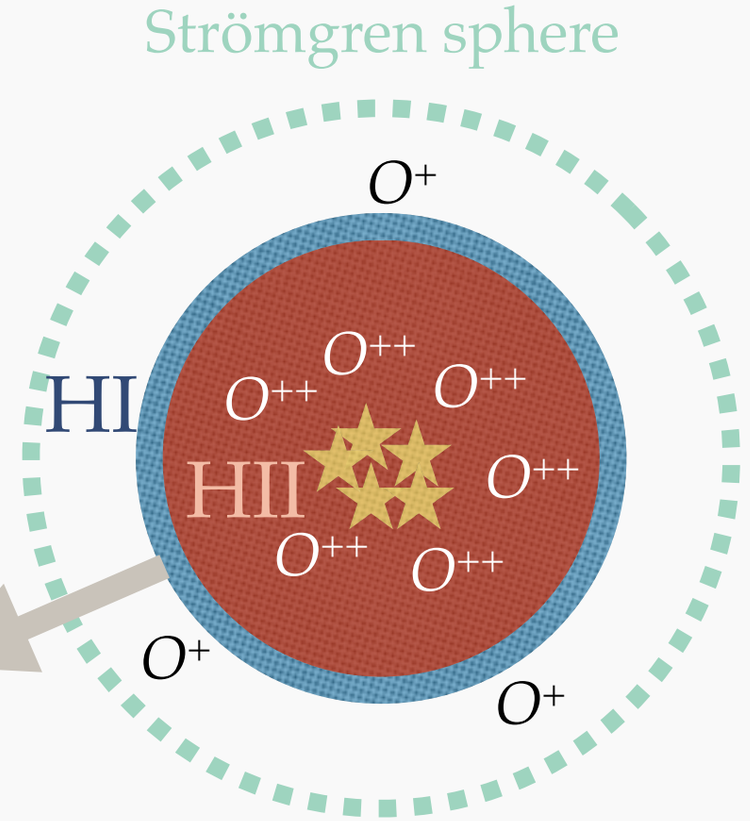

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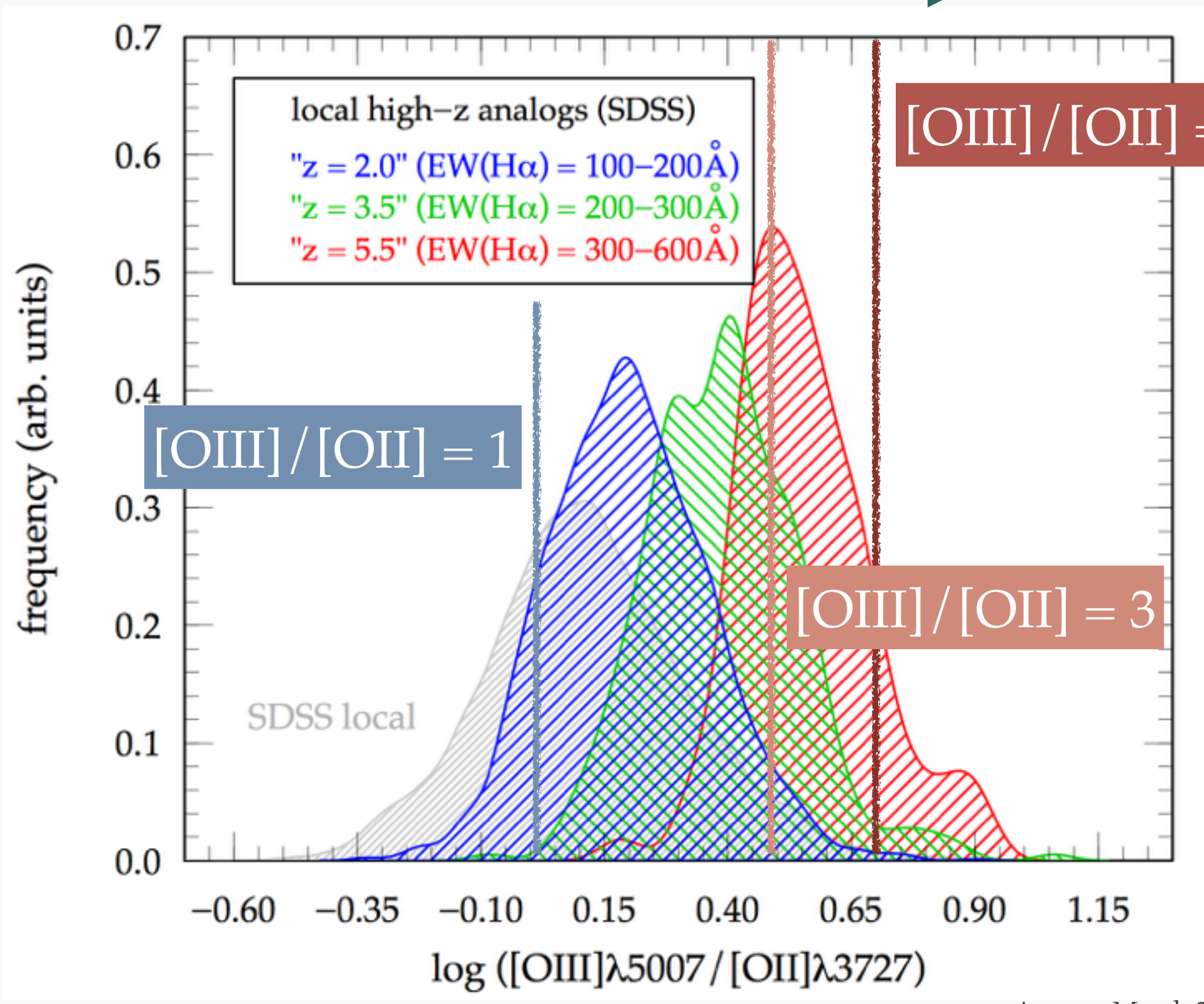
(Nakajima+14, deBarros+15, Izotov+16, Vanzella+16)

[OIII]/[OII] and LyC escape fraction at high-z

- From local galaxies!



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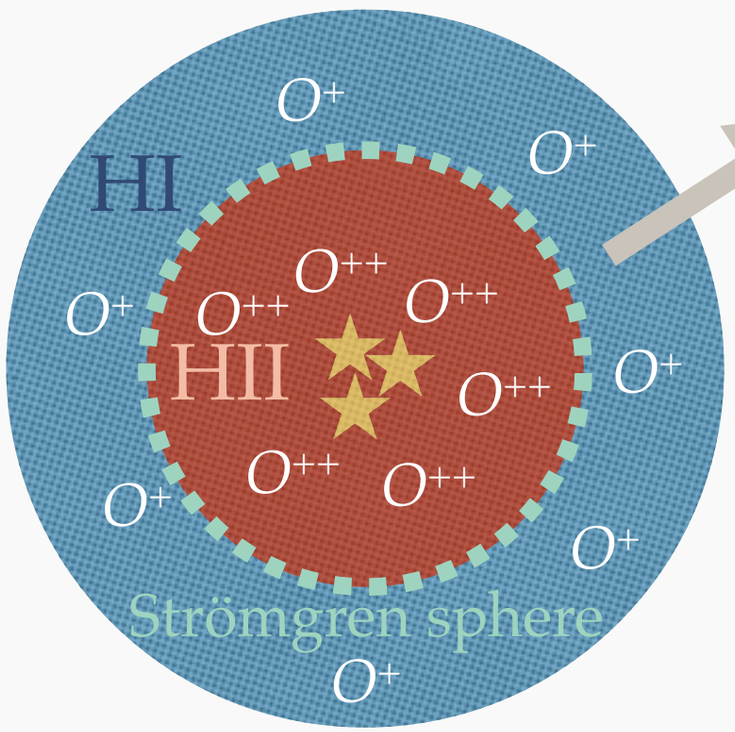

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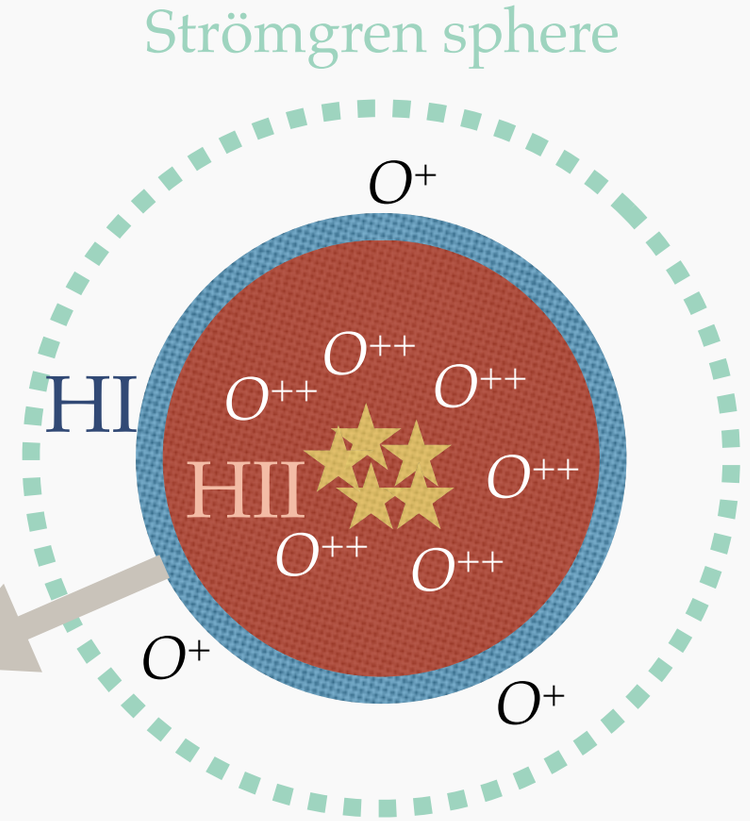

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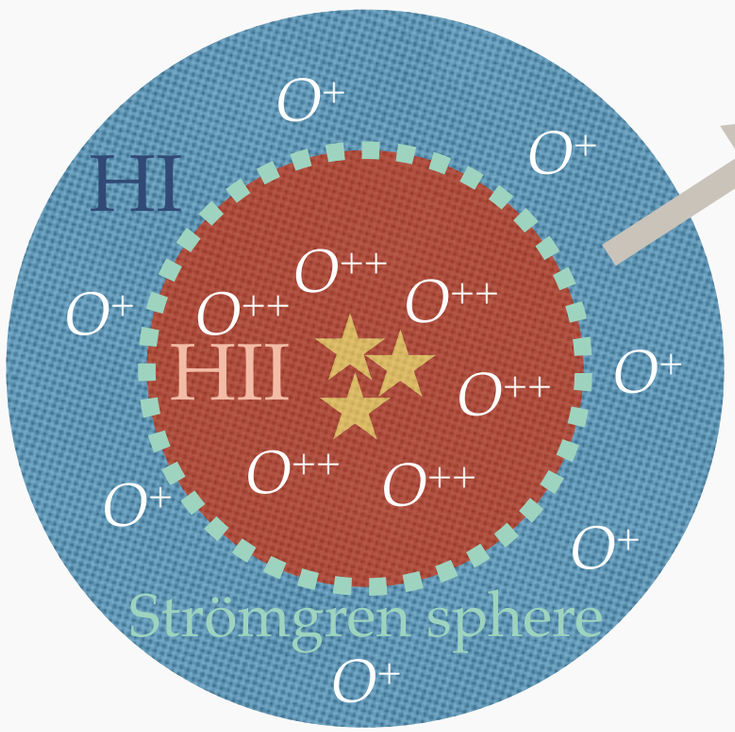

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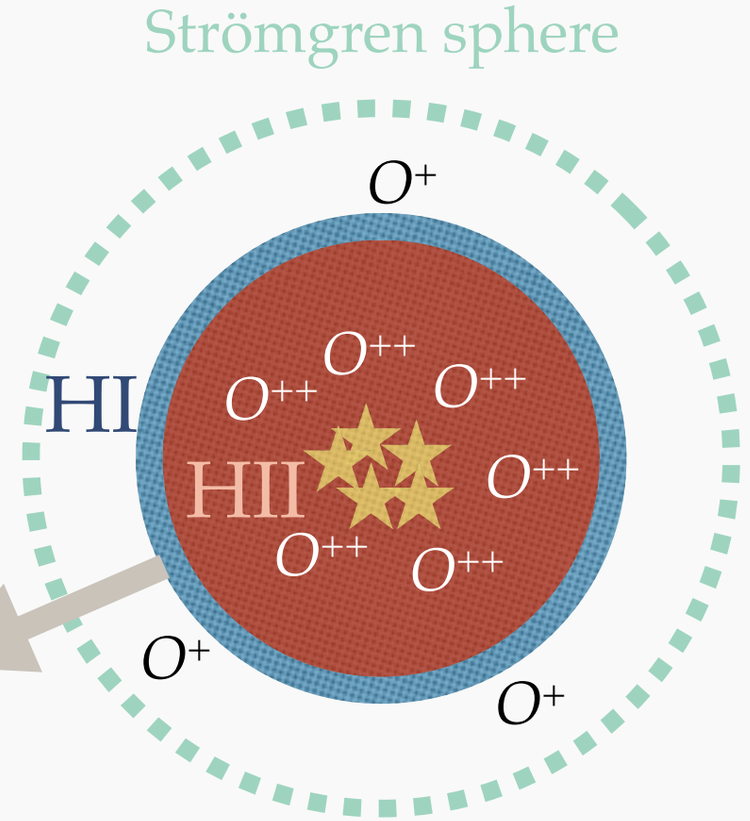

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Ionzation-bound nebula

Density-bound nebula

Increasing [OIII]/Hβ ratio and [OIII] emission at high-z

Increasing [OIII]/[OII] ratios

eventually **hit f_{esc}=20% for bulk of galaxies!**

Summary

- With our approach:
  sSFR by default corrected for dust and emission lines.
  Based solely on observed colors and therefore largely model independent at $z > 3$.

- **Significant contribution of mergers** to galaxy growth at high-z.

- **Large [OIII]/Hβ ratios (>5) in high-z galaxies**. Suggest increasing escape fraction (**eventually hitting 20%?**) in connection with **increasing [OIII]/[OII] ratios**
  Such ratios are also present in local galaxies.

- Study local galaxies! :)

Back-up slides

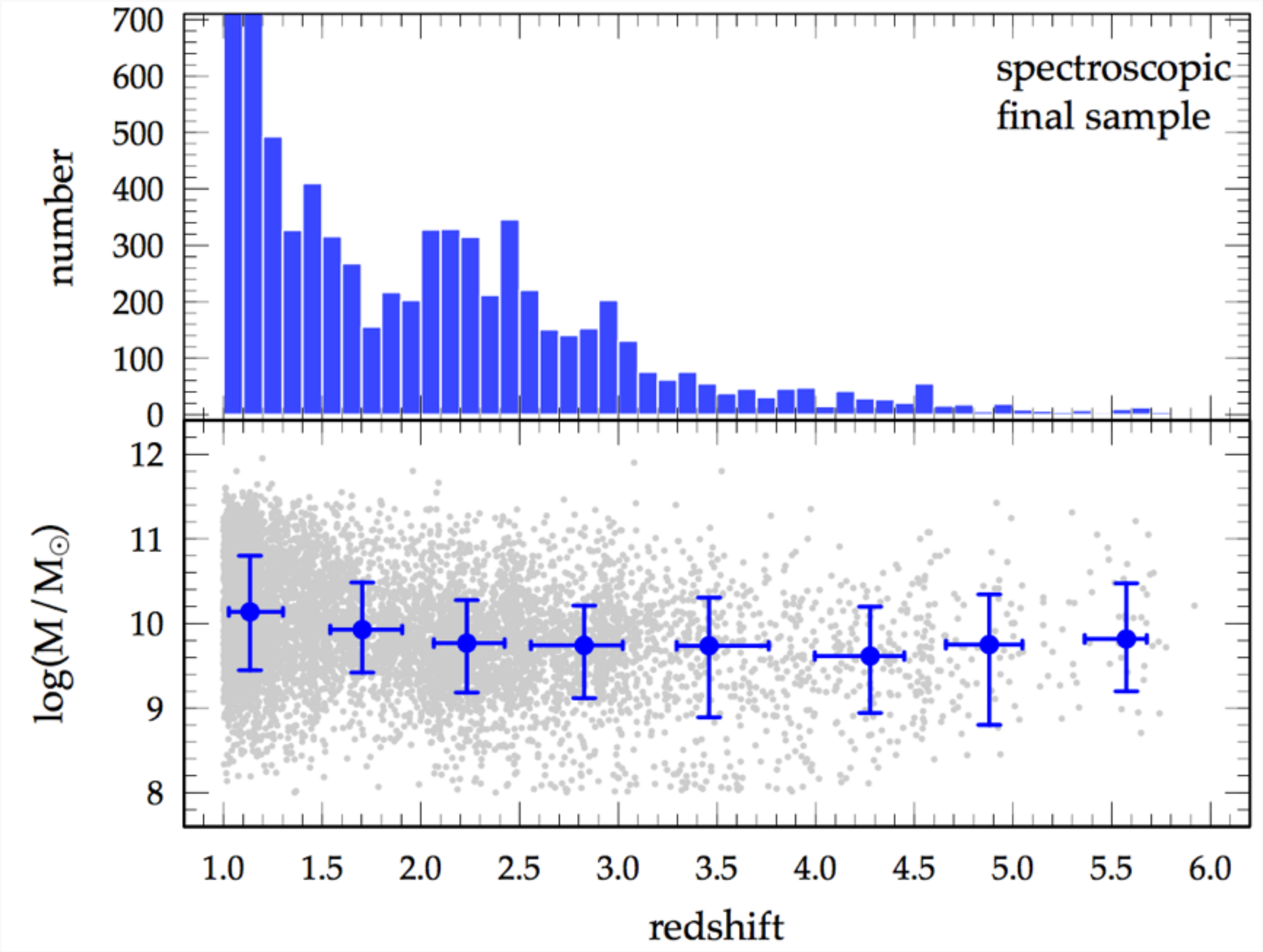
- Based on Faisst et al. 2016a,b and others

Emission lines are important...

- Physical properties of galaxies
  - ➡ Trace SFR and galaxy growth (sSFR)
  - ➡ Metal content, ionization parameter
  - ➡ Indirect: escape fraction of UV photons

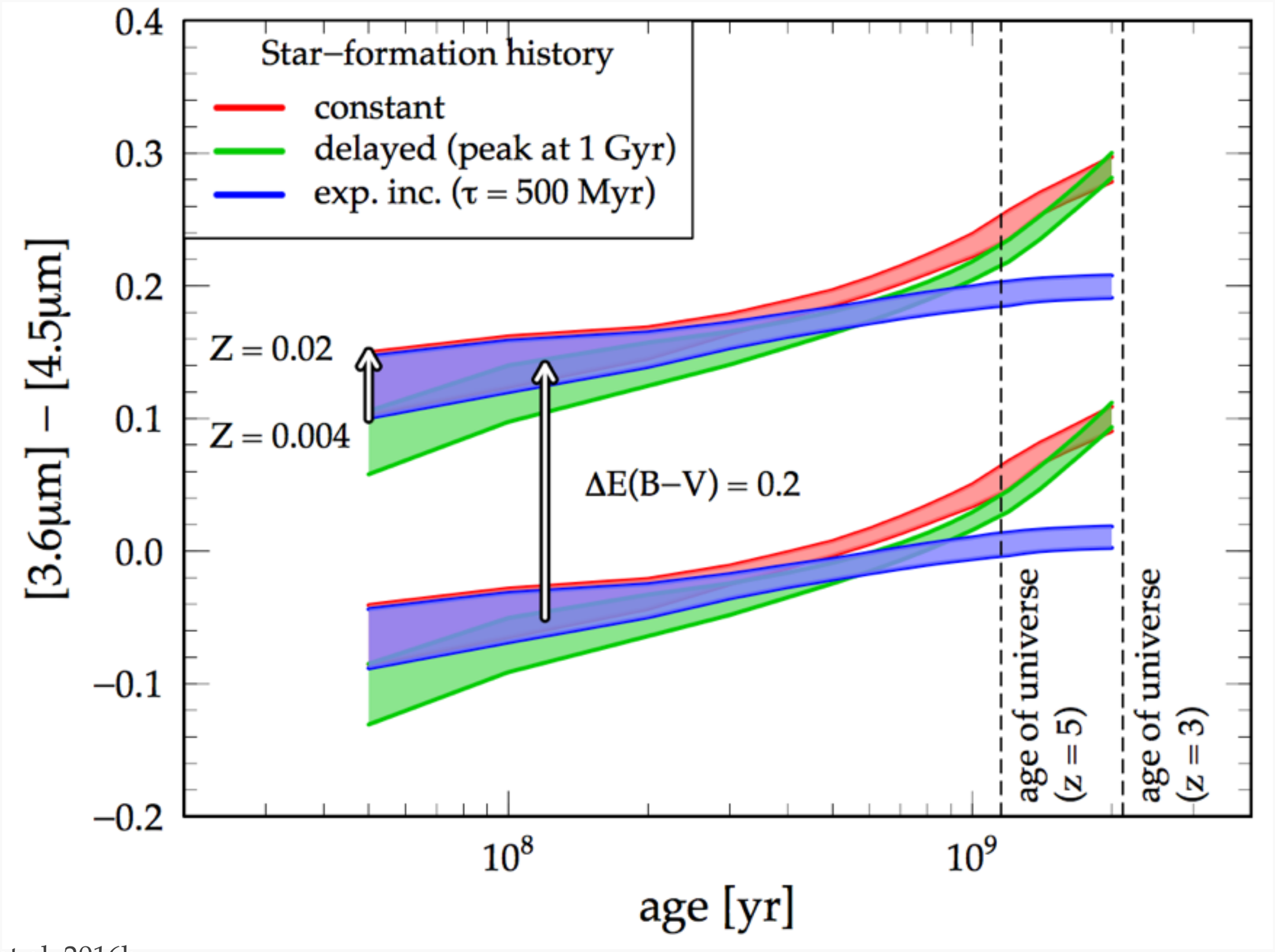
- Technical importance
  - ➡ Realistic templates at high-z used by SED fitting codes
  - ➡ Improved stellar masses and ages from SED fitting

Sample properties



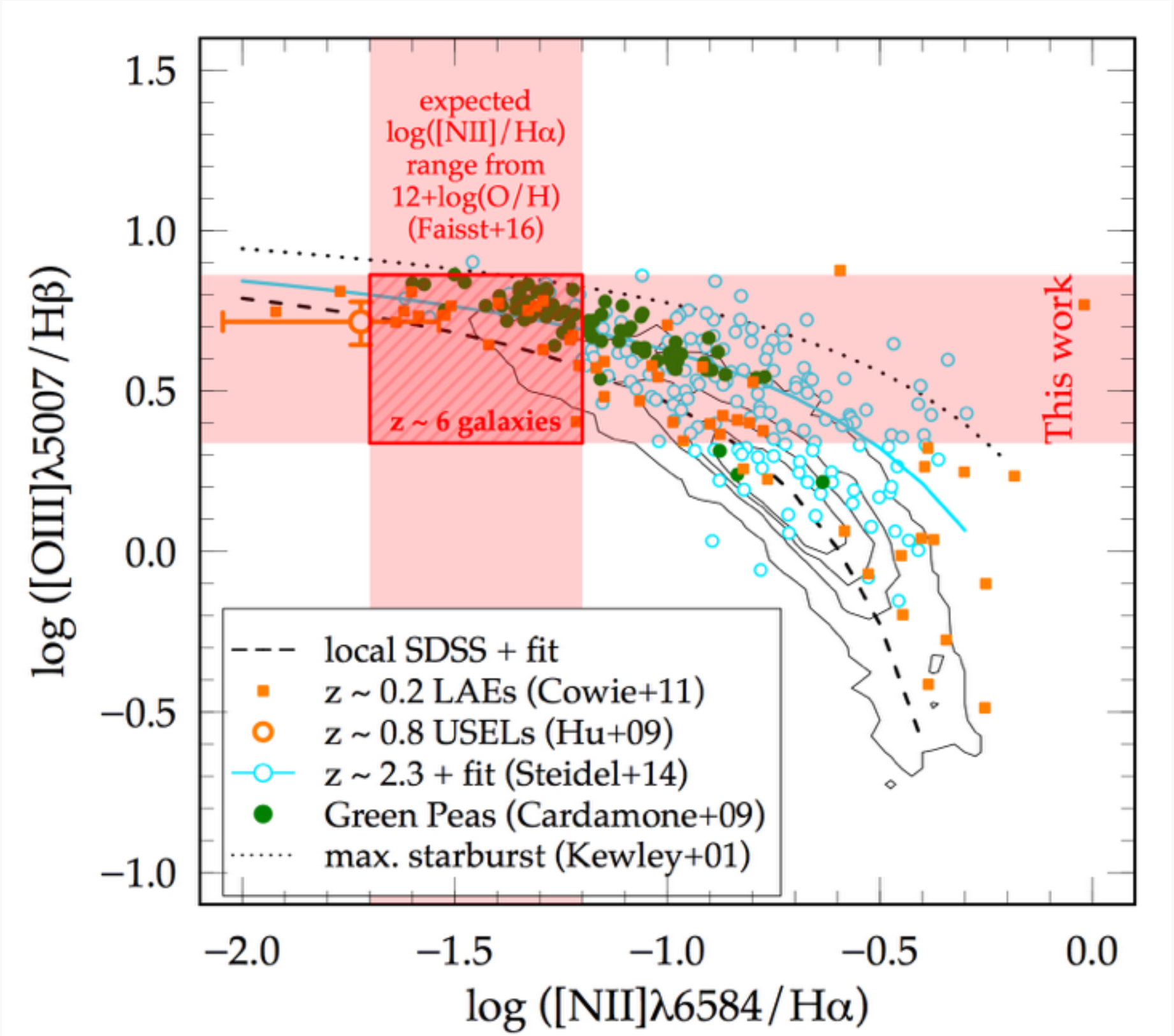
Faisst et al. 2016b

Model independent



Faisst et al. 2016b

Going optimistic: The BPT diagram at z = 6



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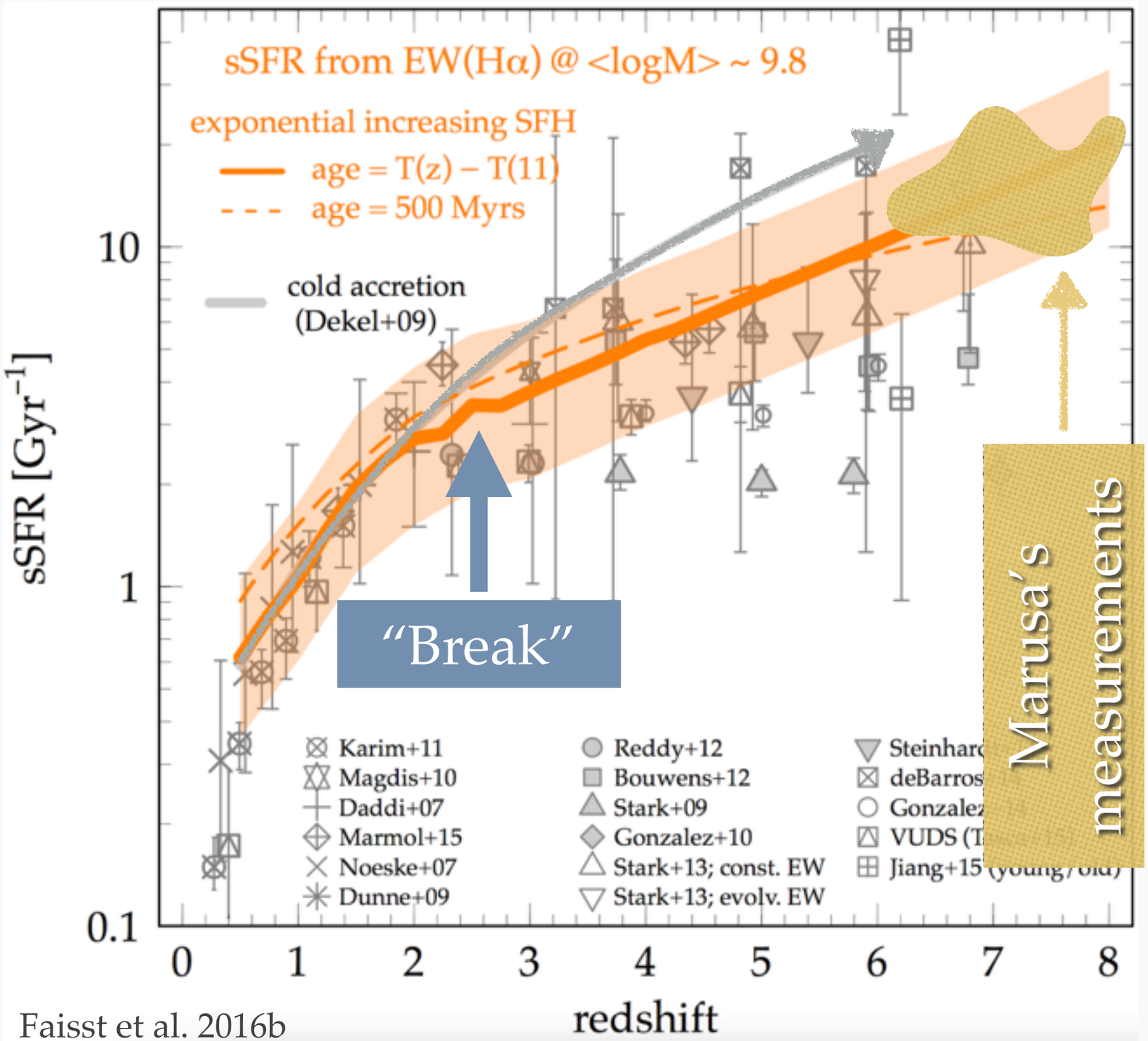

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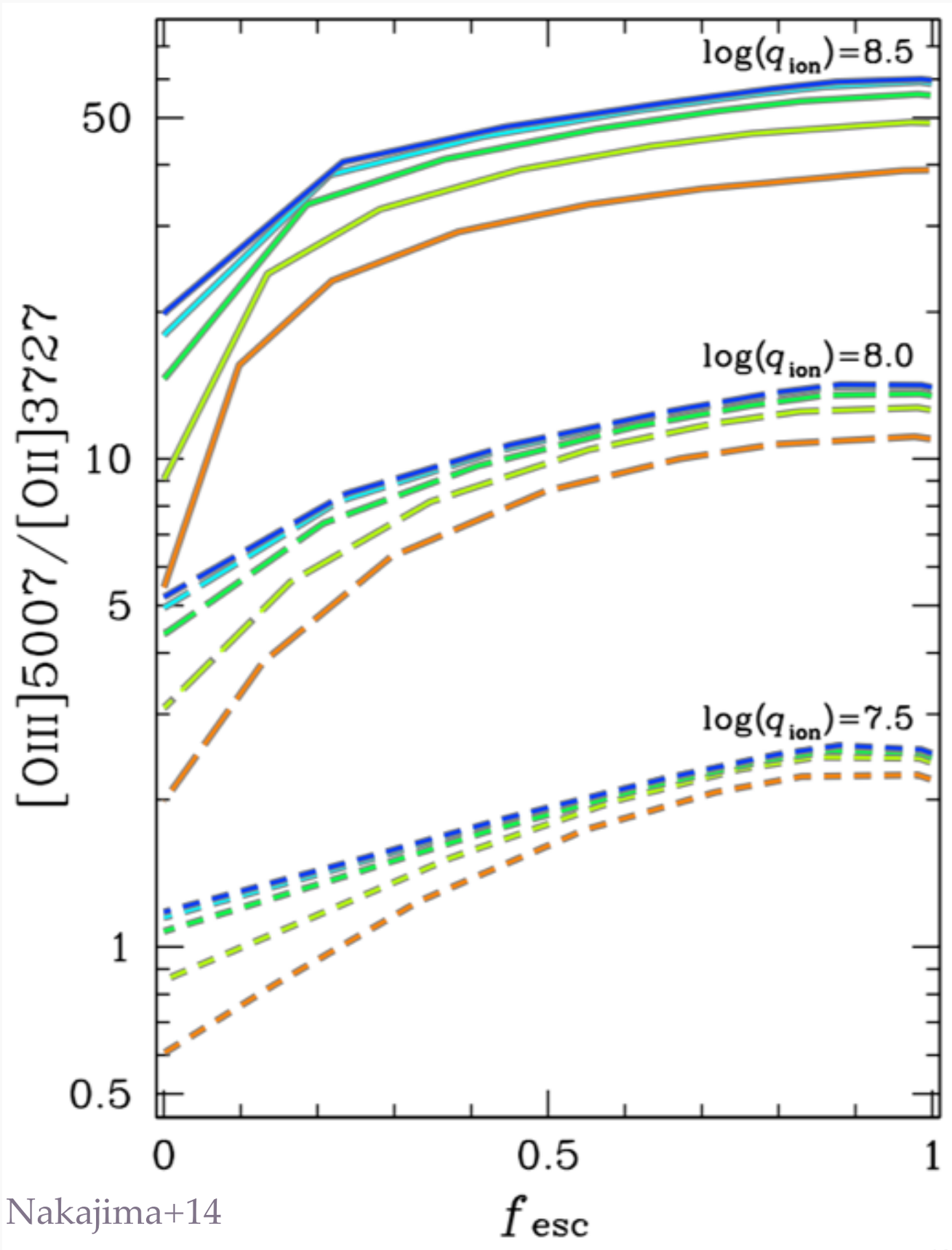
Faisst et al. 2016b

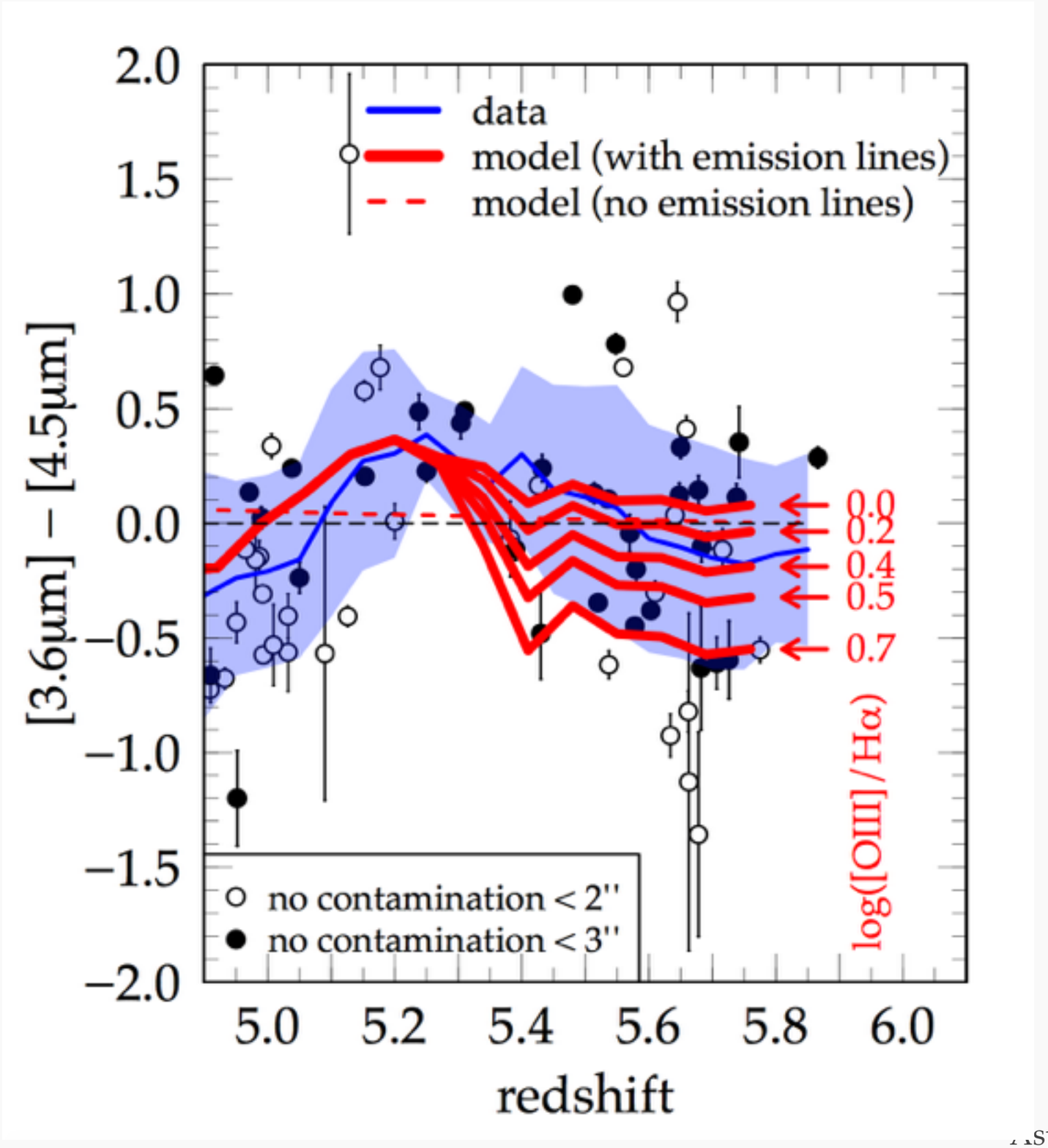
Escape fraction as function of [OIII]/[OII]



Nakajima+14

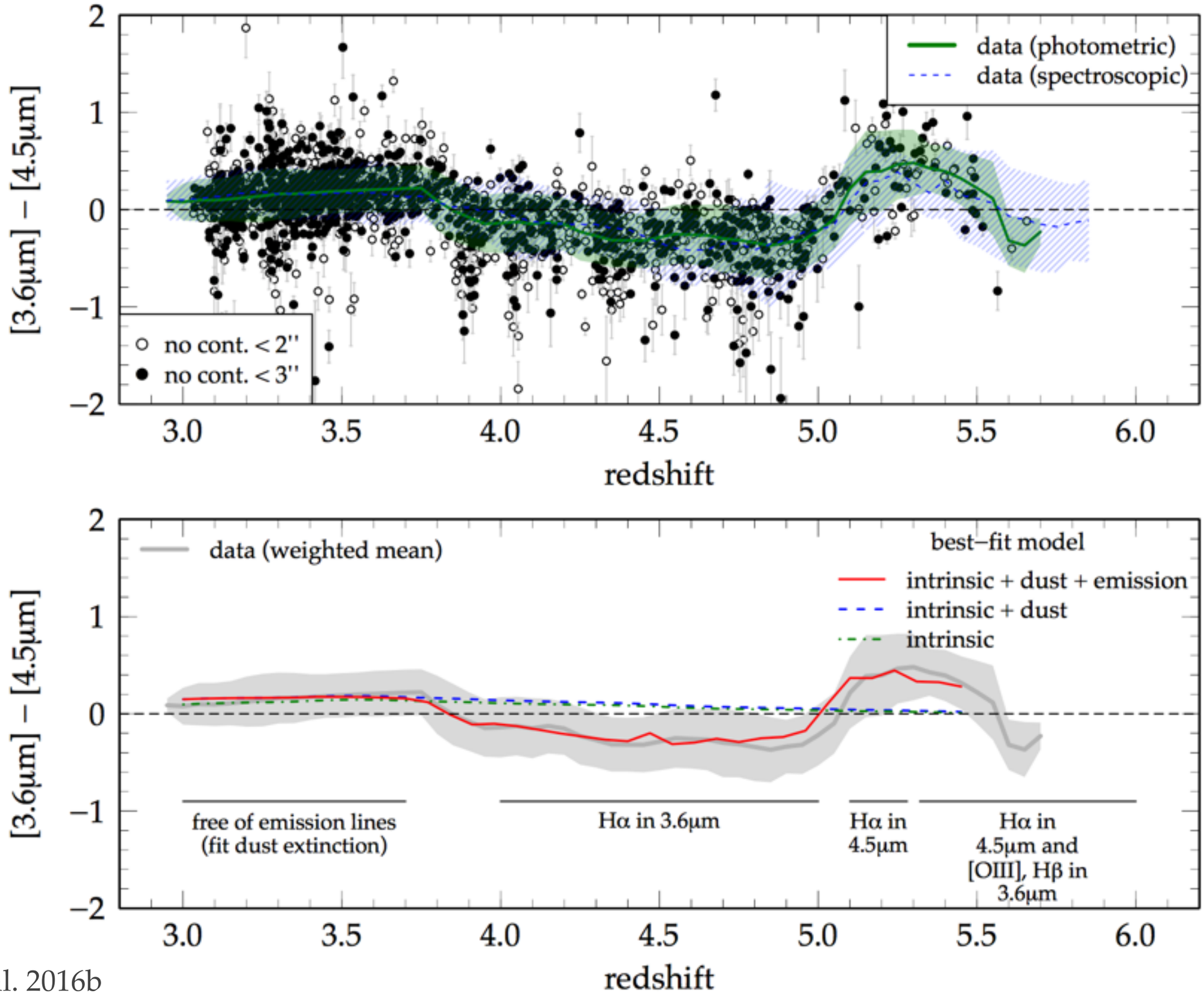
Fitting [OIII]/Hβ at high-z

- It is uncertain and there is a large scatter, mostly towards high ratios.



Faisst et al. 2016b

Photometric redshifts are awesome!



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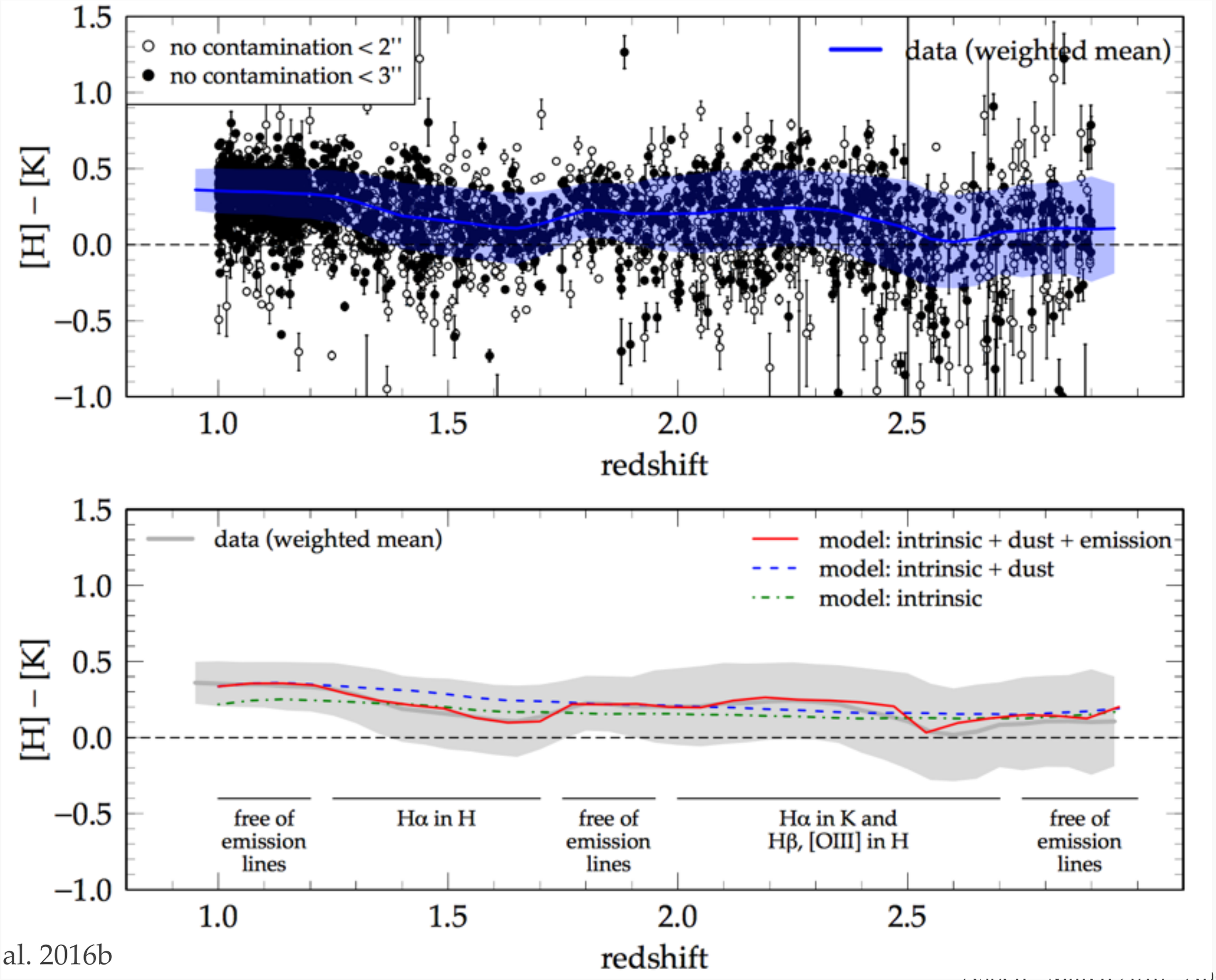
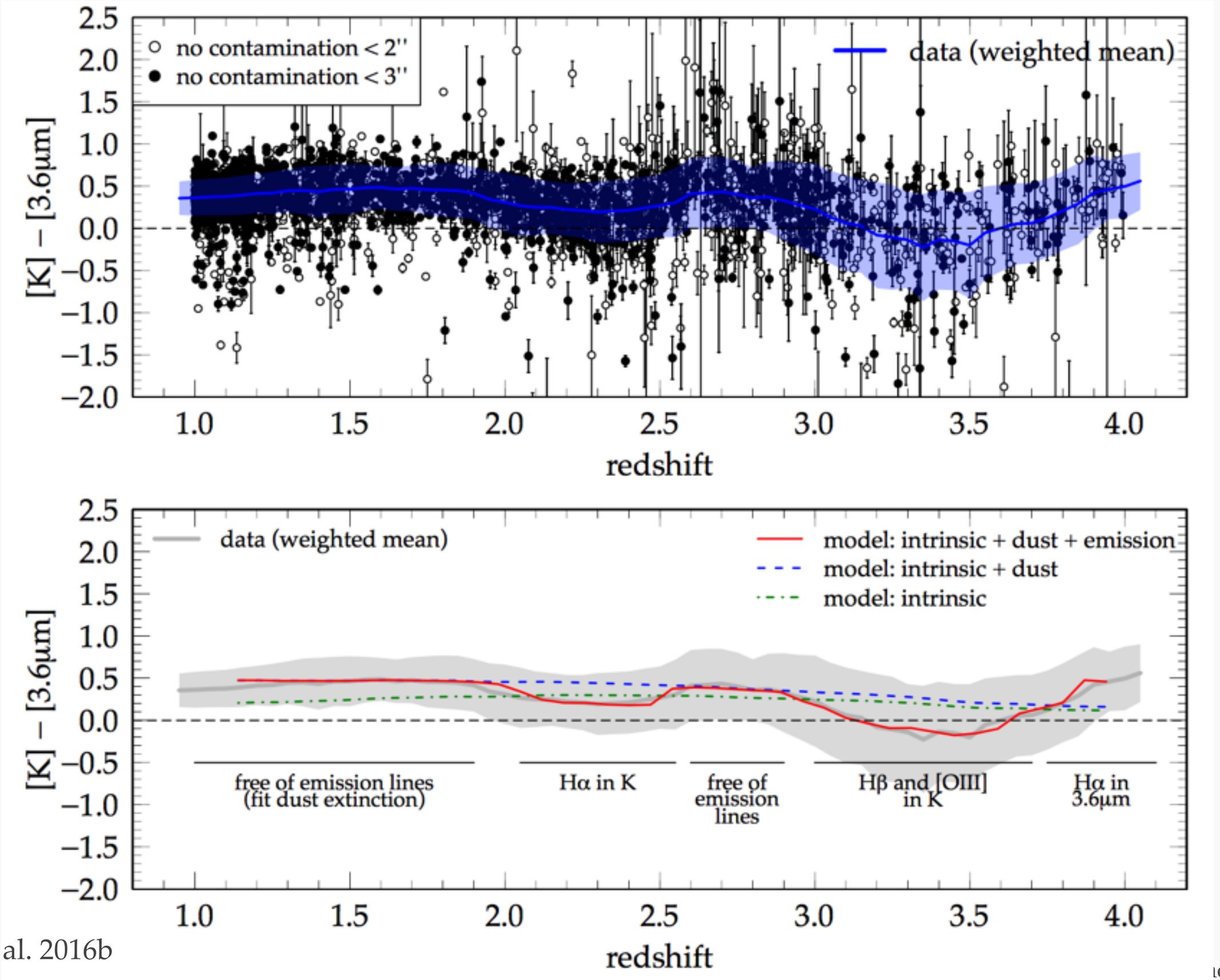
The story at low redshift I



Faisst et al. 2016b

The story at low redshift II



Faisst et al. 2016b