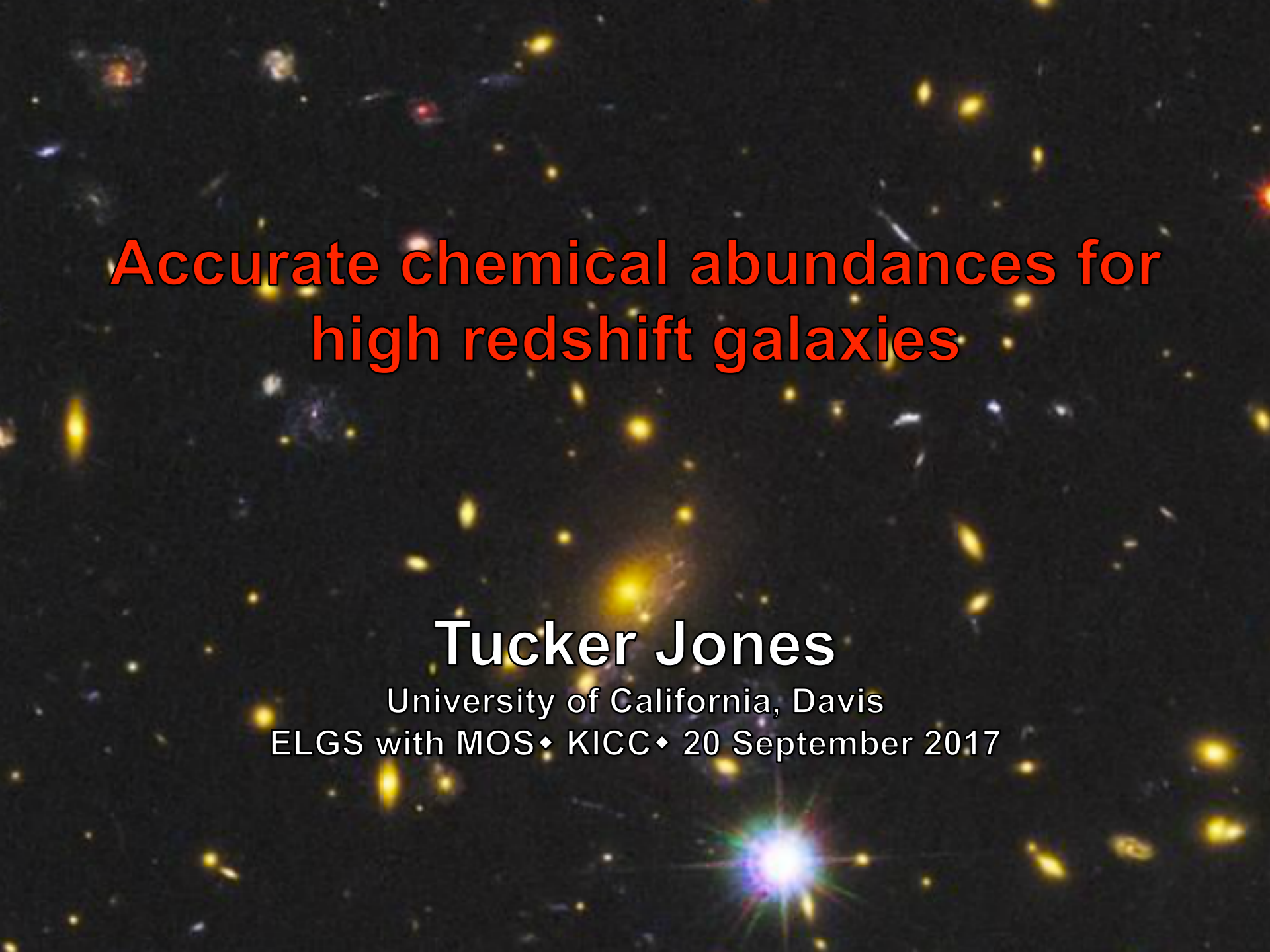
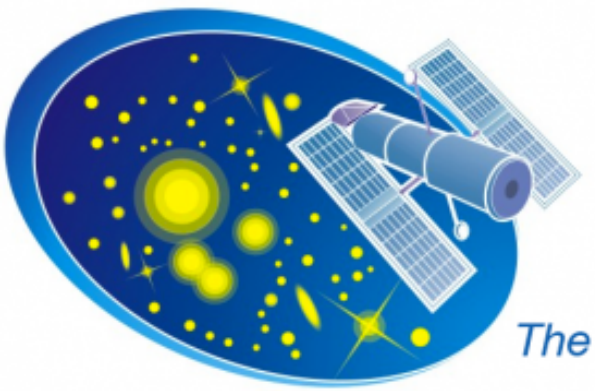


Accurate chemical abundances for high redshift galaxies

Tucker Jones

University of California, Davis

ELGS with MOS⬥ KICC⬥ 20 September 2017



GLASS

The Grism Lens-Amplified Survey from Space

Hubble WFC3-IR grism spectroscopy of 10 strong-lensing galaxy clusters

PI: Tommaso Treu

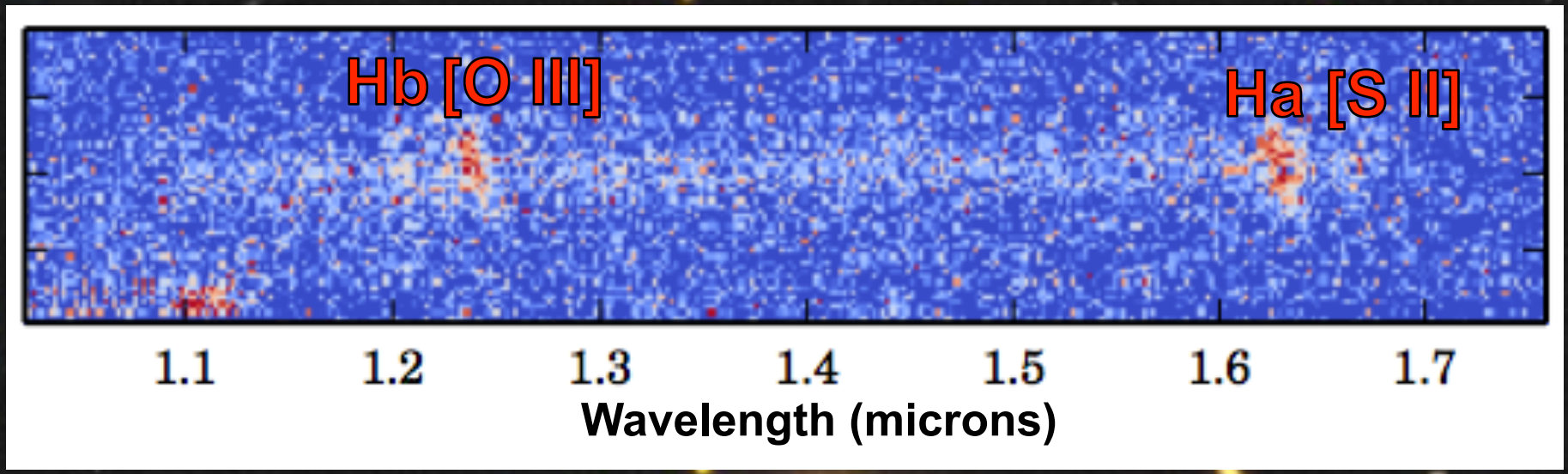
Complete wavelength coverage from 0.8–1.7 μm

Treu et al. 2015 (survey overview)
Jones et al. 2015 (first results)
Wang et al. 2017 (metallicity gradients)
Mason et al. 2017 (KMOS kinematics)

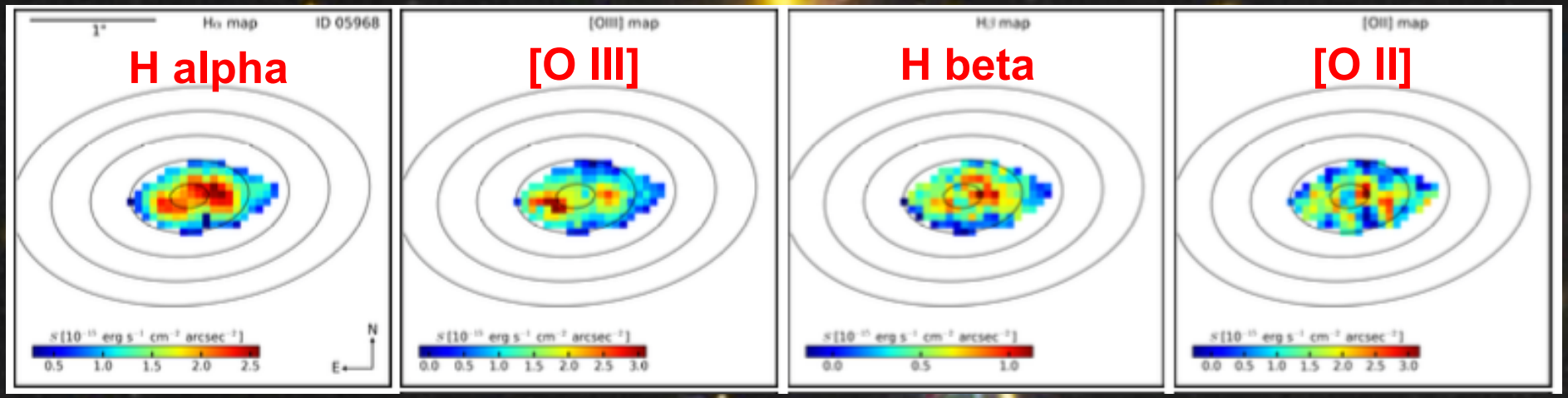
Note: consider what JWST's grisms will be capable of...

z=1.48

Dispersed grism spectrum



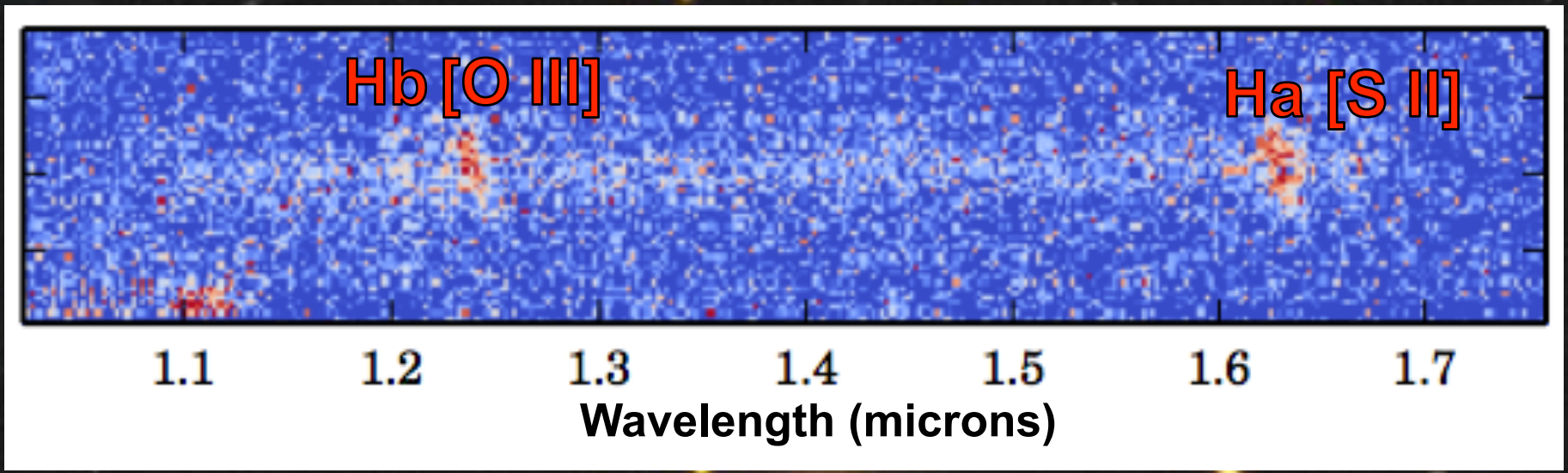
2-D emission line maps



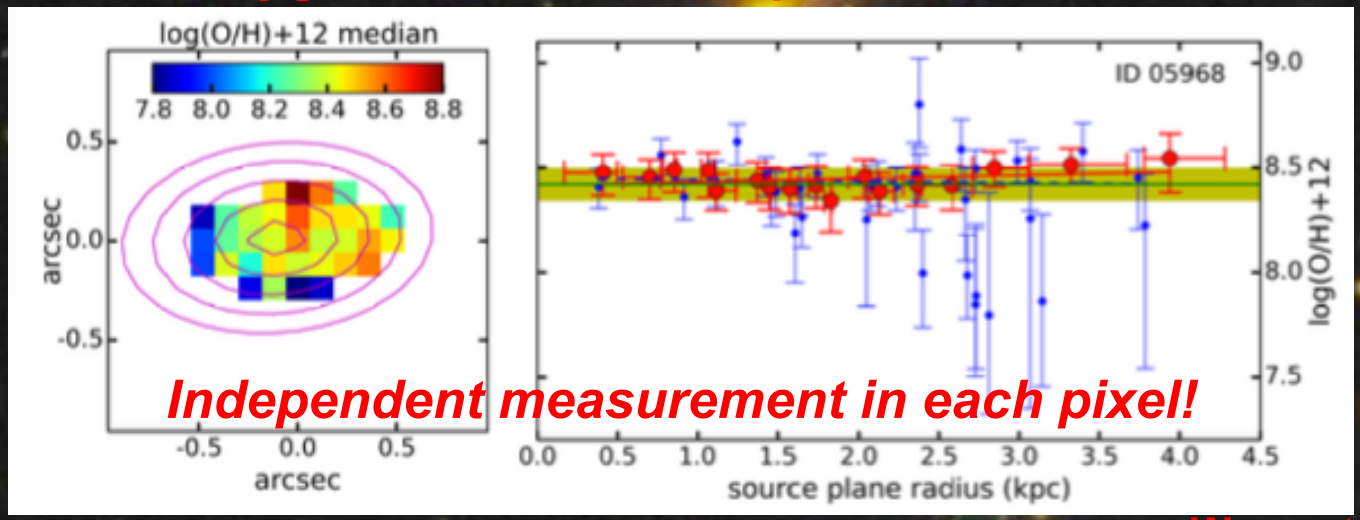
Wang et al. 2017

z=1.48

Dispersed grism spectrum

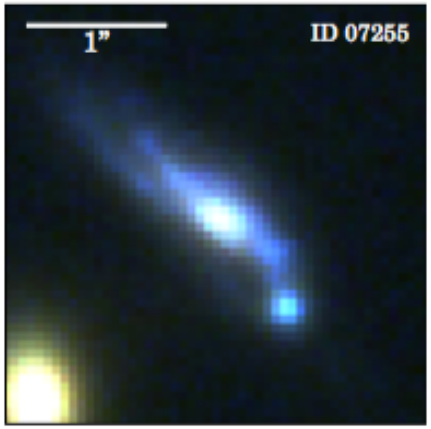


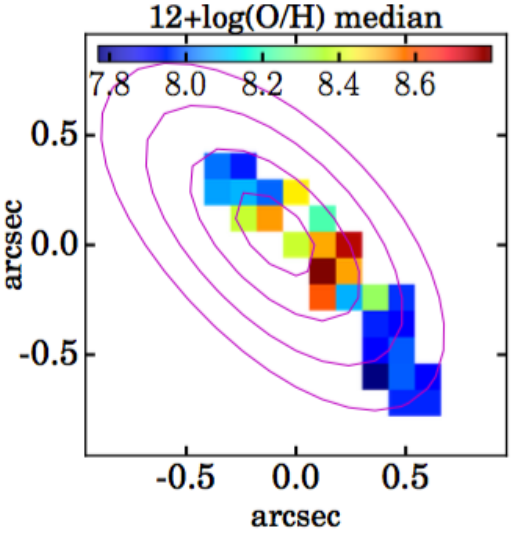
2-D oxygen abundance map

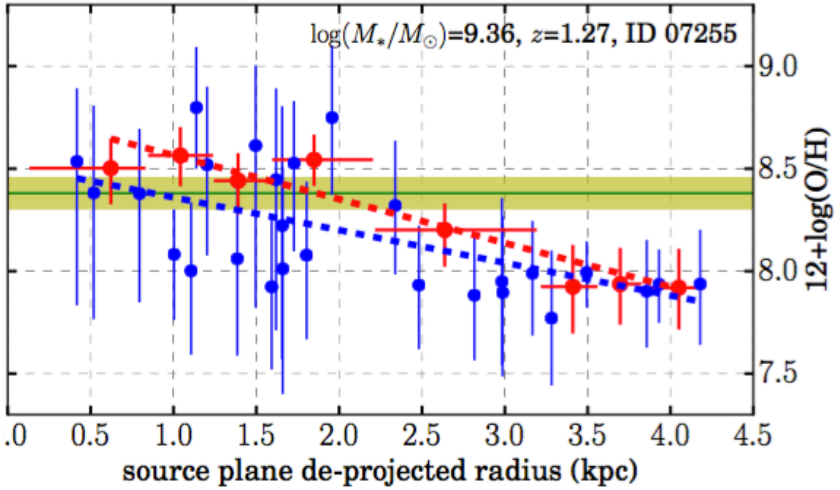


Independent measurement in each pixel!

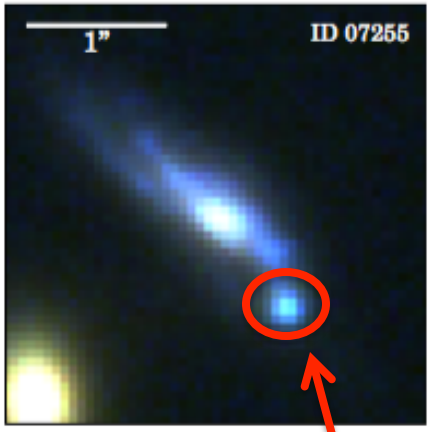
Wang et al. 2017

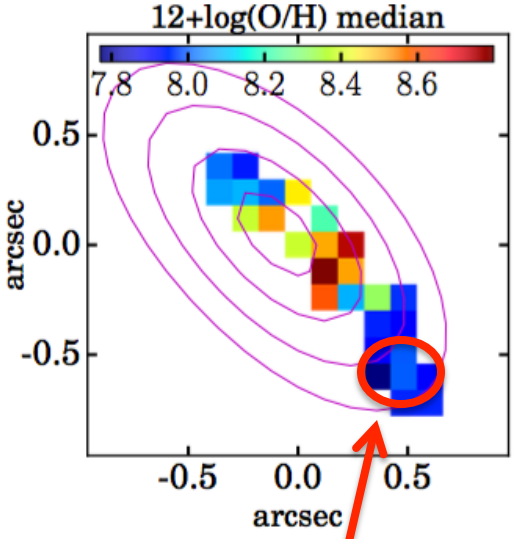


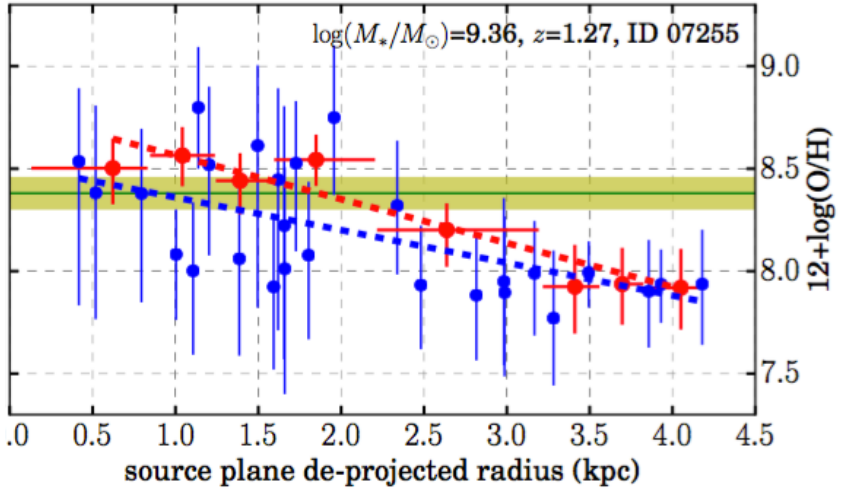




Wang et al. 2017



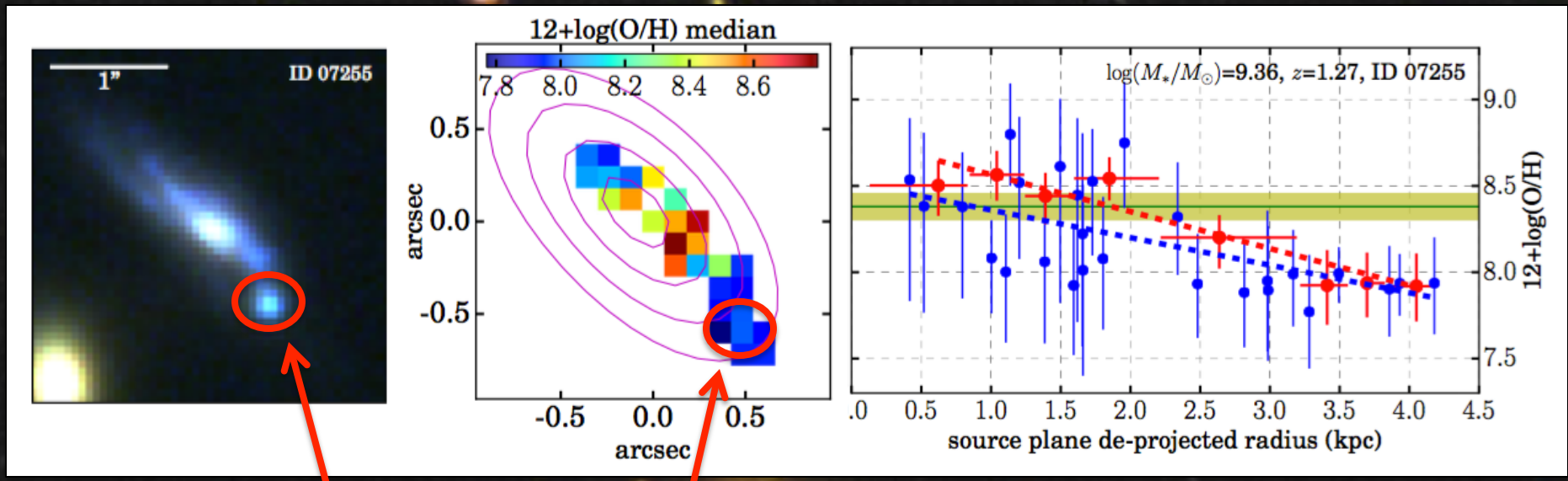




Low metallicity clump at large radius:
Signature of *ex situ* origin?

Wang et al. 2017

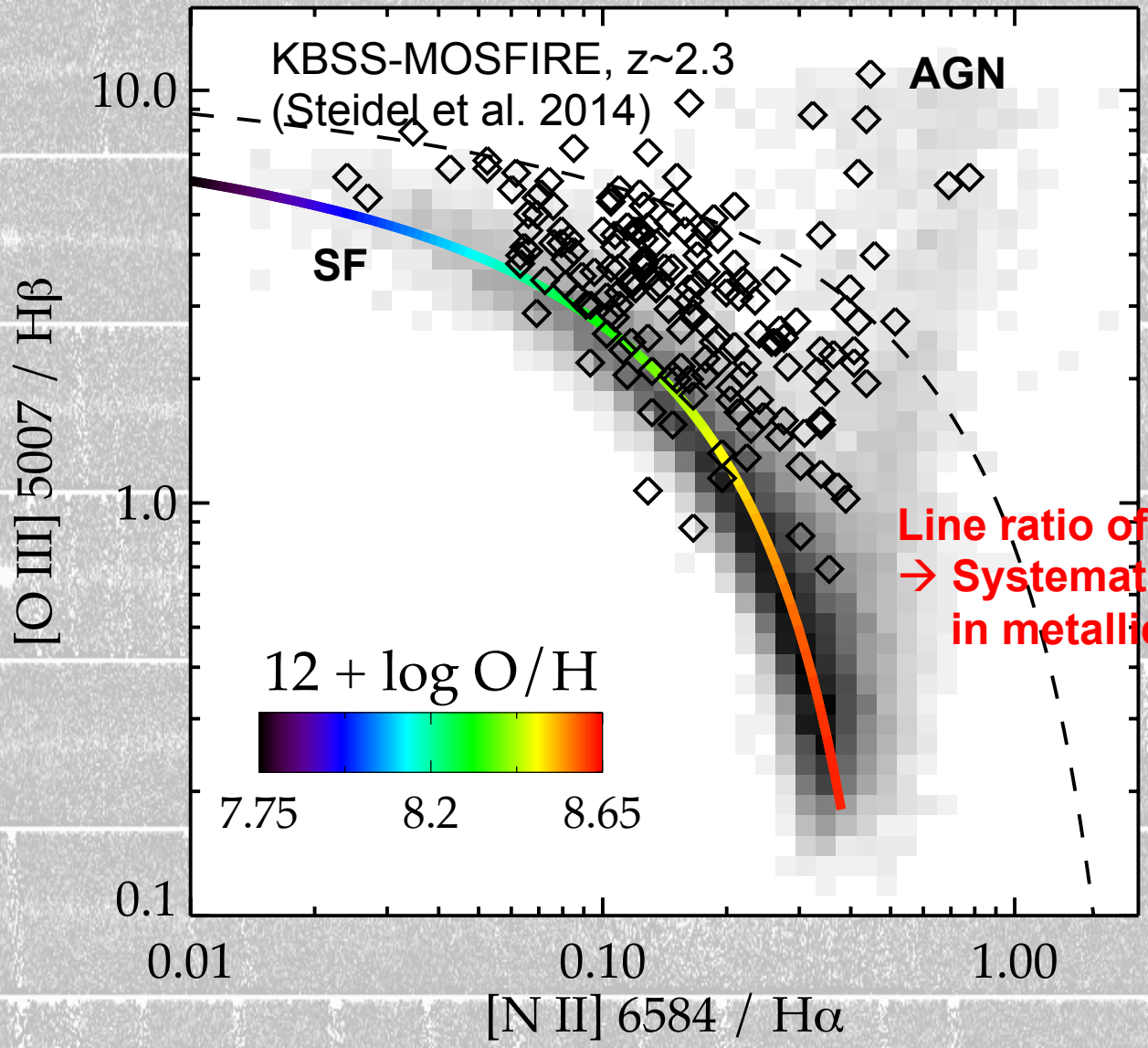
Why should we trust these "metallicities"?



Low metallicity clump at large radius: Signature of *ex situ* origin?

Wang et al. 2017

Strong-line metallicity estimates



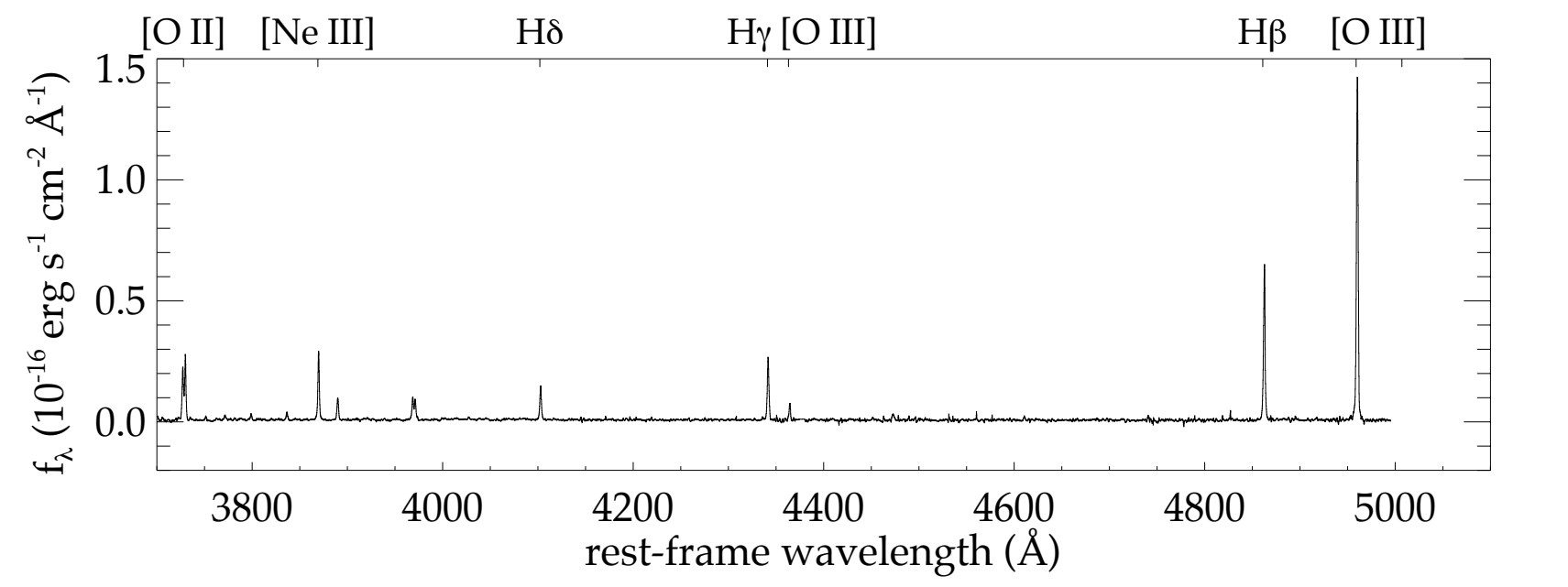
Line ratio offsets at high z!
→ Systematic error ~0.2 dex in metallicity (O/H)

Need direct measurements of O/H at high z to resolve this issue

Background image credit: the DEEP2 team

Direct metallicity measurements at z=0.8

The DEEP2 Galaxy Redshift Survey:
Keck/DEIMOS spectra of >50,000 galaxies up to z~1.5
Spectral coverage λ~6500−9100 Å, resolution R≈5000
Strong lines of [O II] and [O III] covered for z=0.72−0.87



Spectrum of a z=0.75 galaxy from the DEEP2 survey

Jones, Martin, & Cooper 2015, ApJ, 813, 126

Direct metallicity measurements at z=0.8

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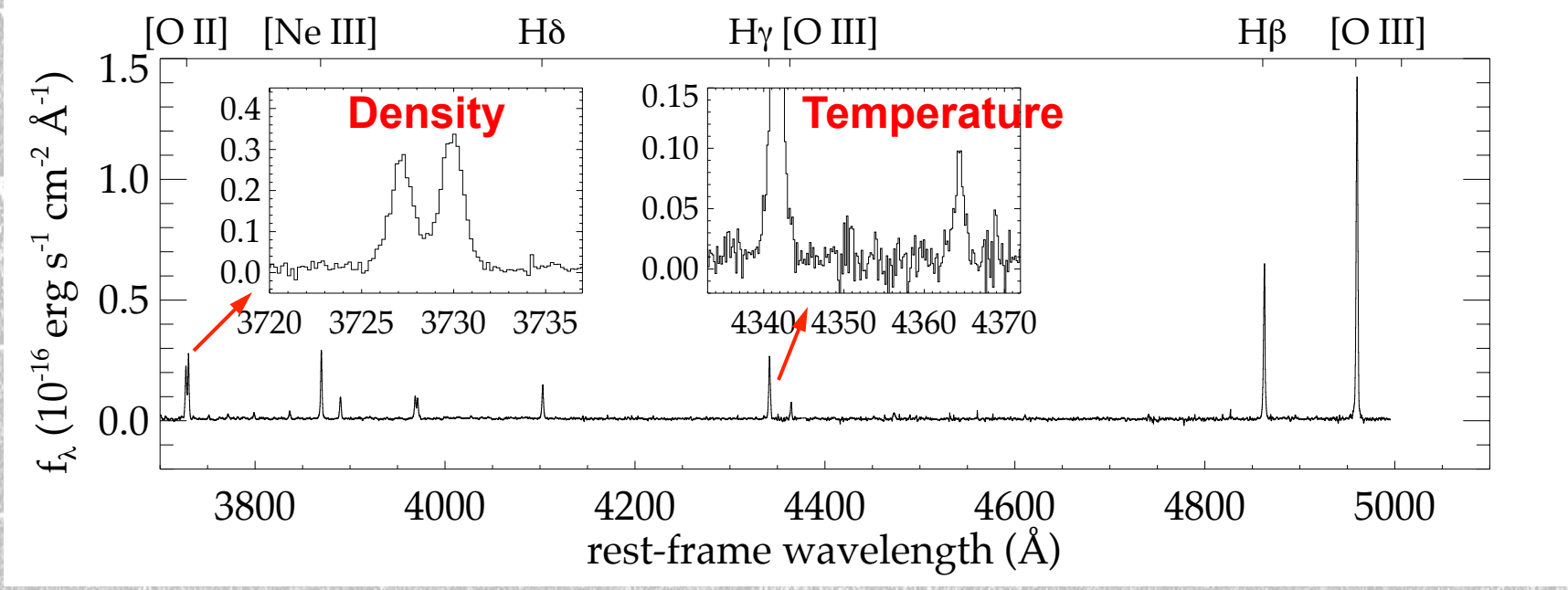
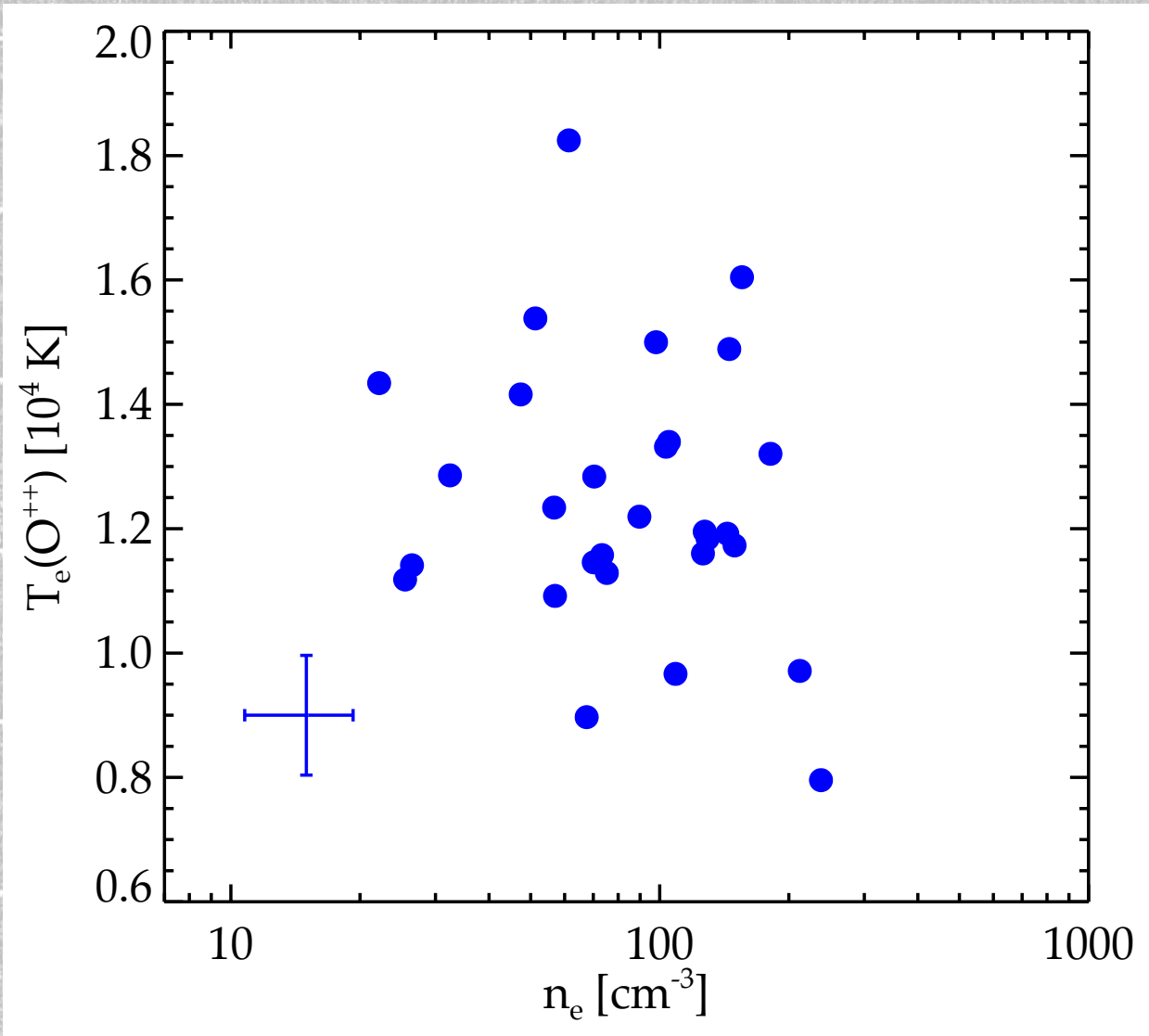


Spectrum of a z=0.75 galaxy from the DEEP2 survey

Jones, Martin, & Cooper 2015, ApJ, 813, 126

Sample properties

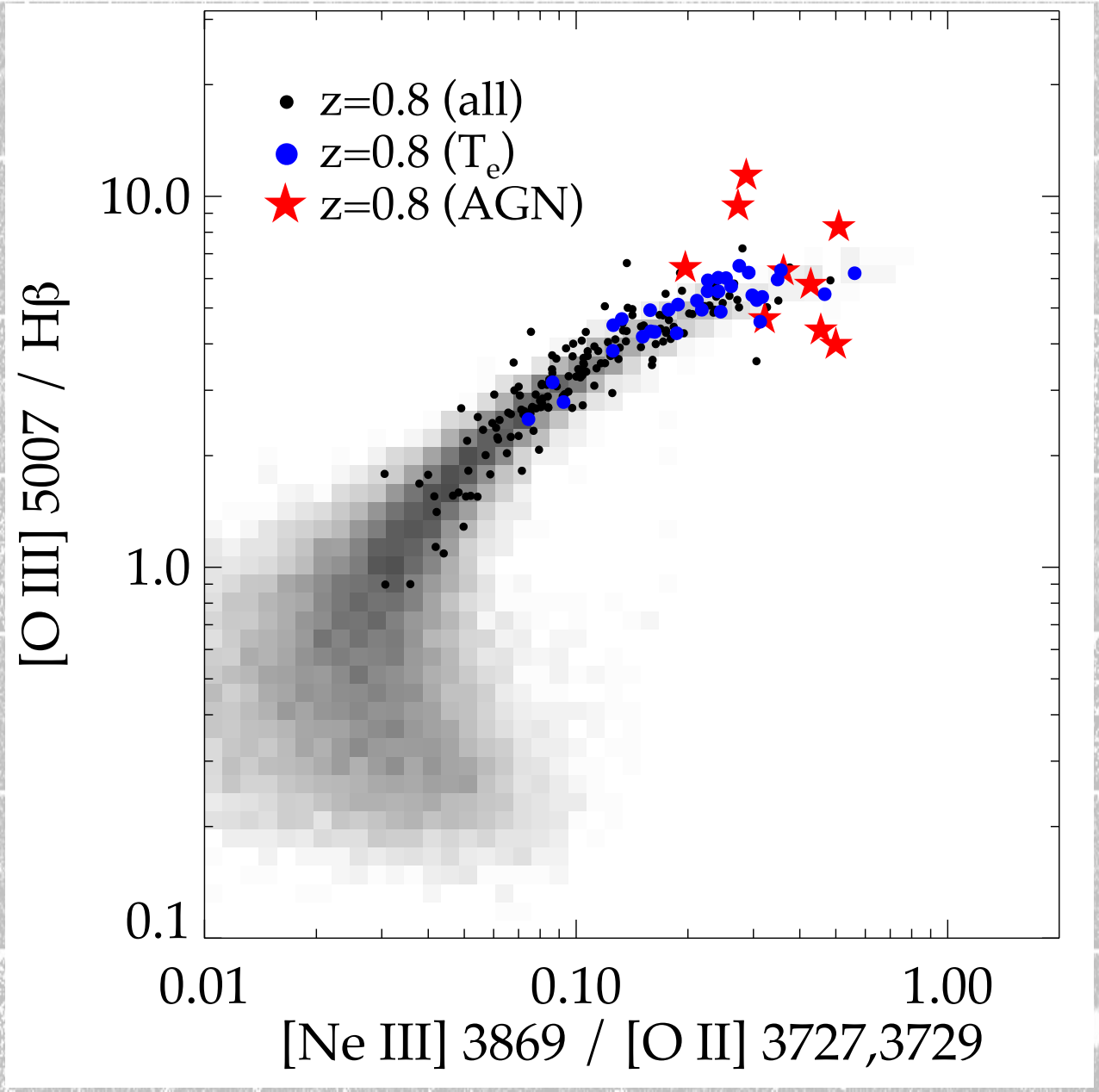


Sensitivity completeness threshold:

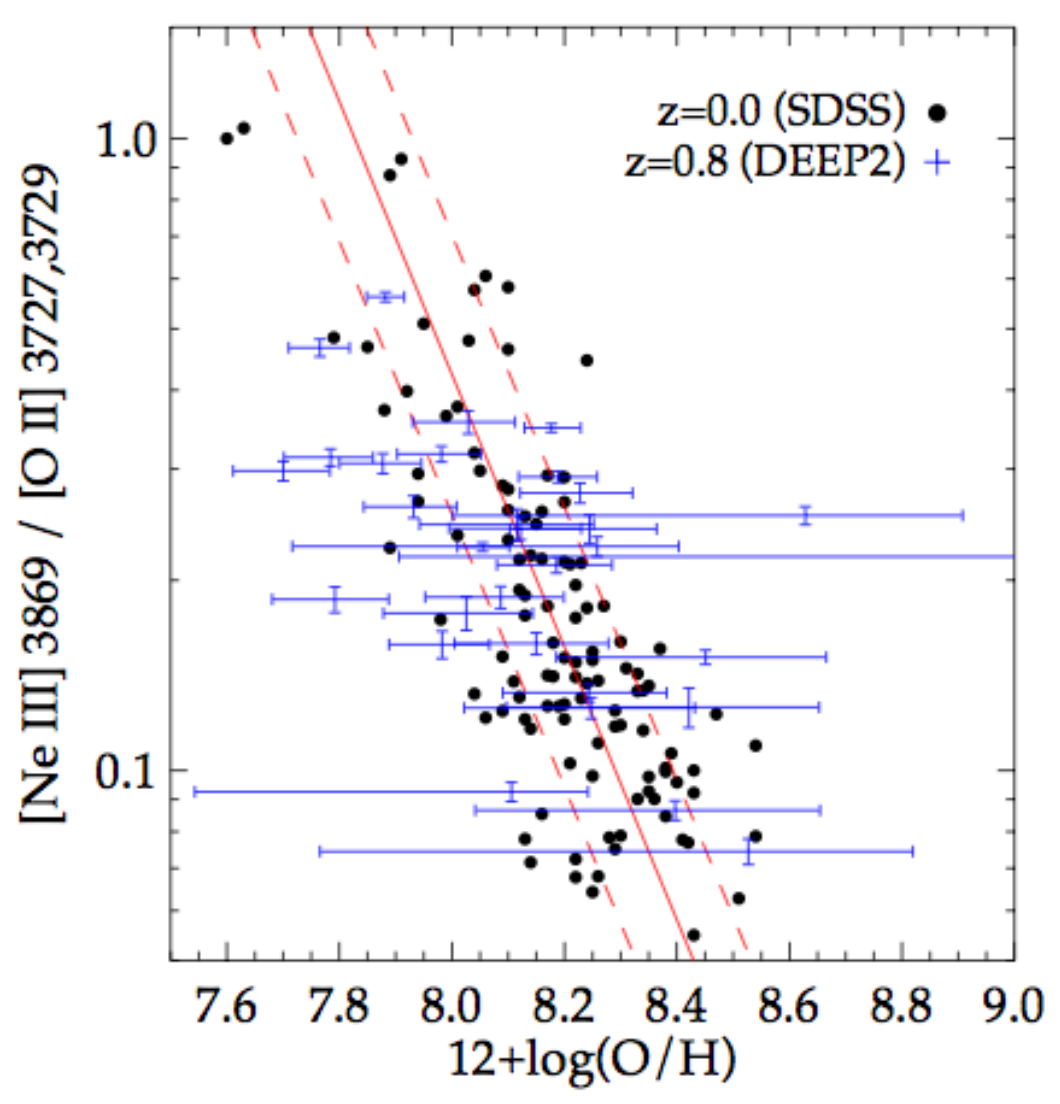
[O III] λ4363 detected at >2σ for $T_e \geq 10^4$ K

Not selected based on λ4363 SNR (this introduces a bias)

Line ratios are representative of z=0.8 population

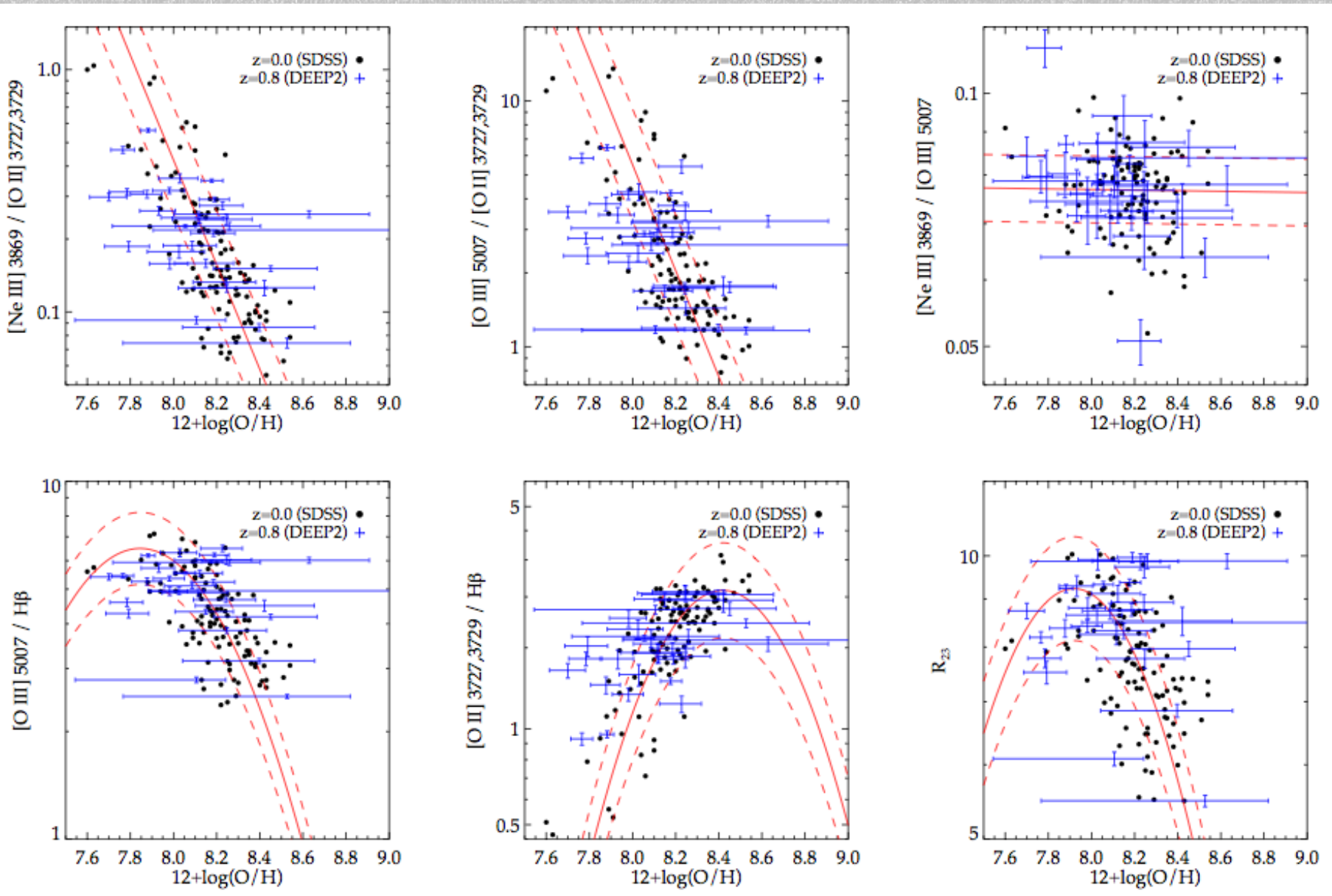


Strong-line metallicity diagnostics at z=0.8



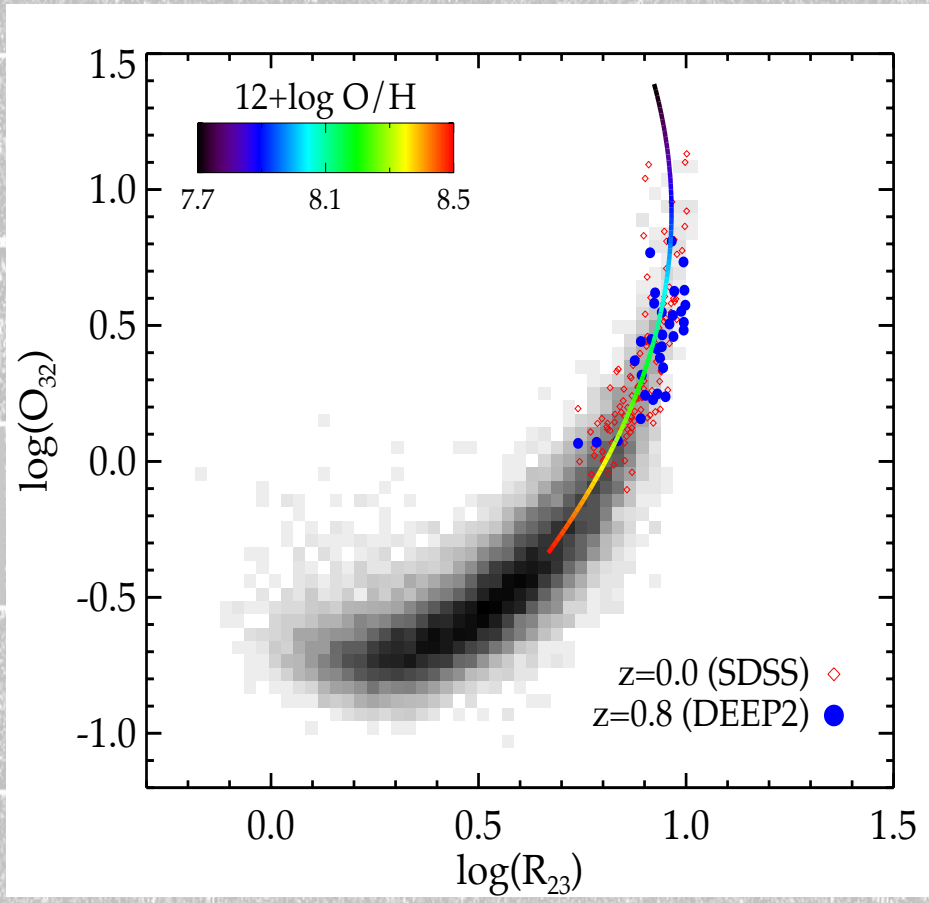
No evolution in α-element diagnostics: Δlog(O/H) = 0.01±0.03

Data at z=0 and z=0.8 analyzed with identical methods

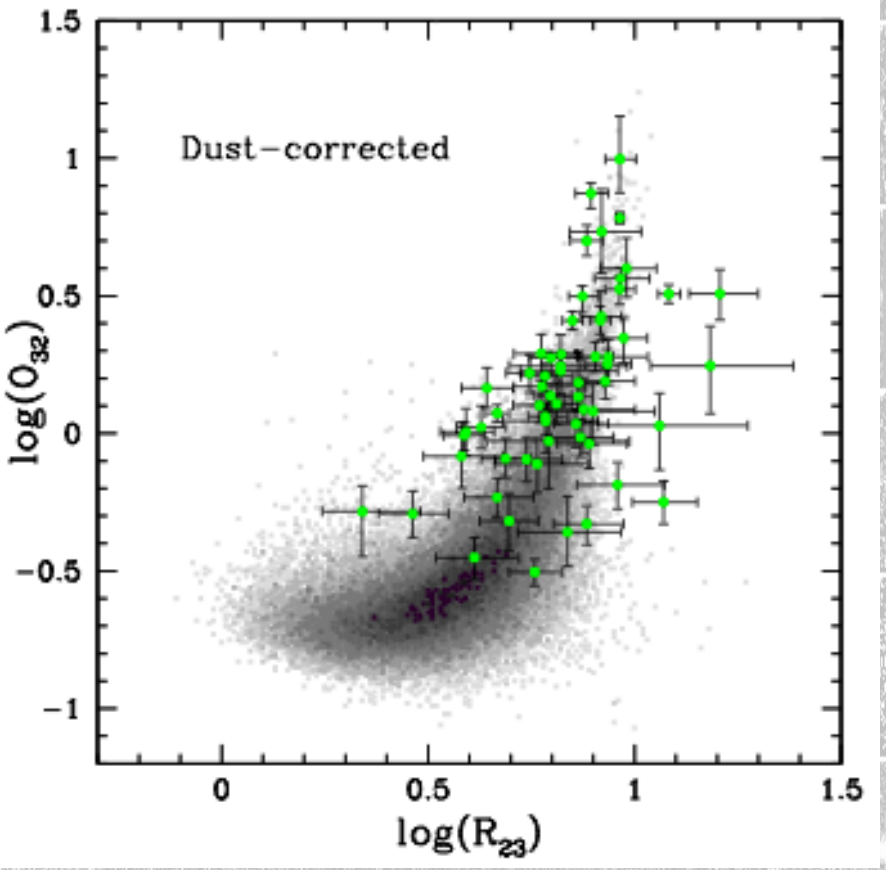


No evolution in α-element diagnostics: Δlog(O/H) = 0.01±0.03

α-element lines are reliable diagnostics!
(at least at z<1, and likely at z>2)



z=0.8 (Jones et al. 2015)

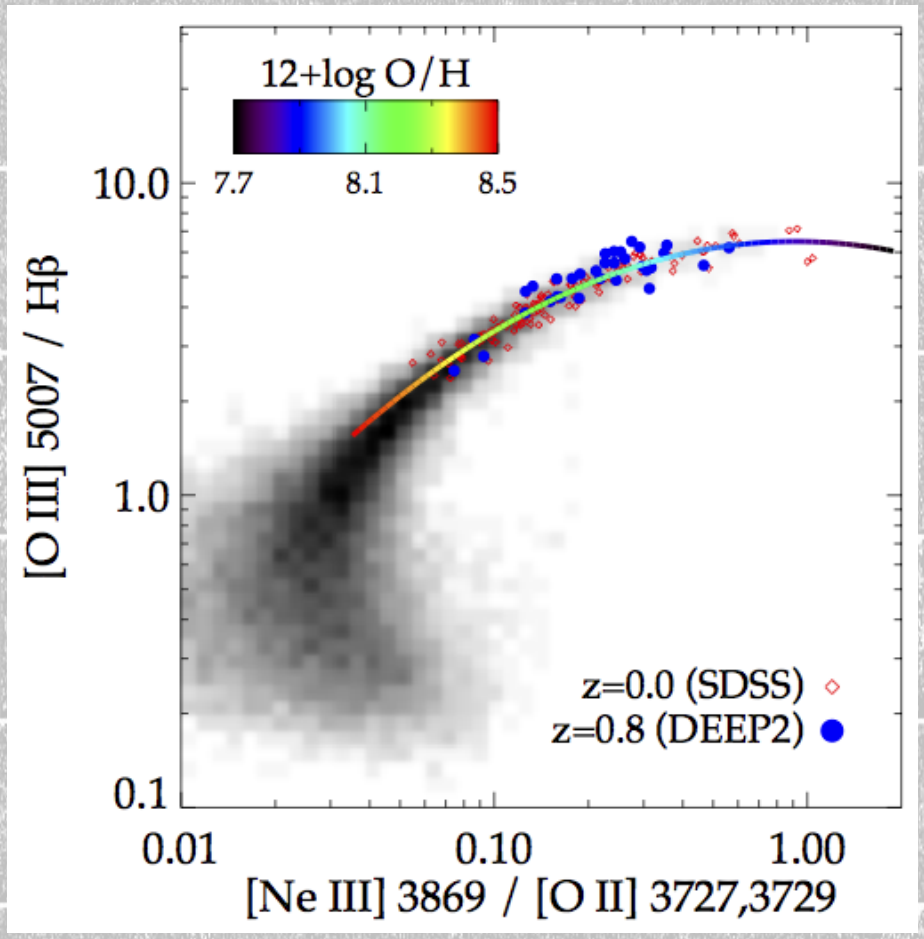


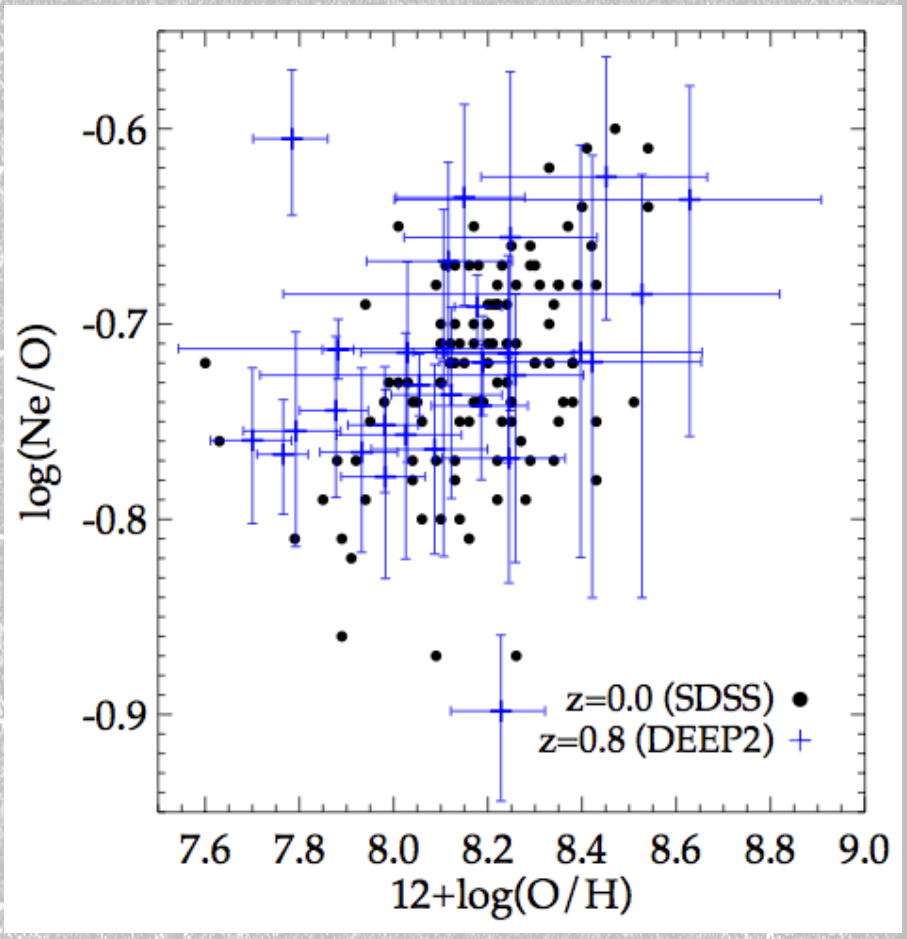
z=2.3 (Shapley et al. 2015)

Alice Shapley's talk

O, Ne line ratios show no offset from z = 0→2.3

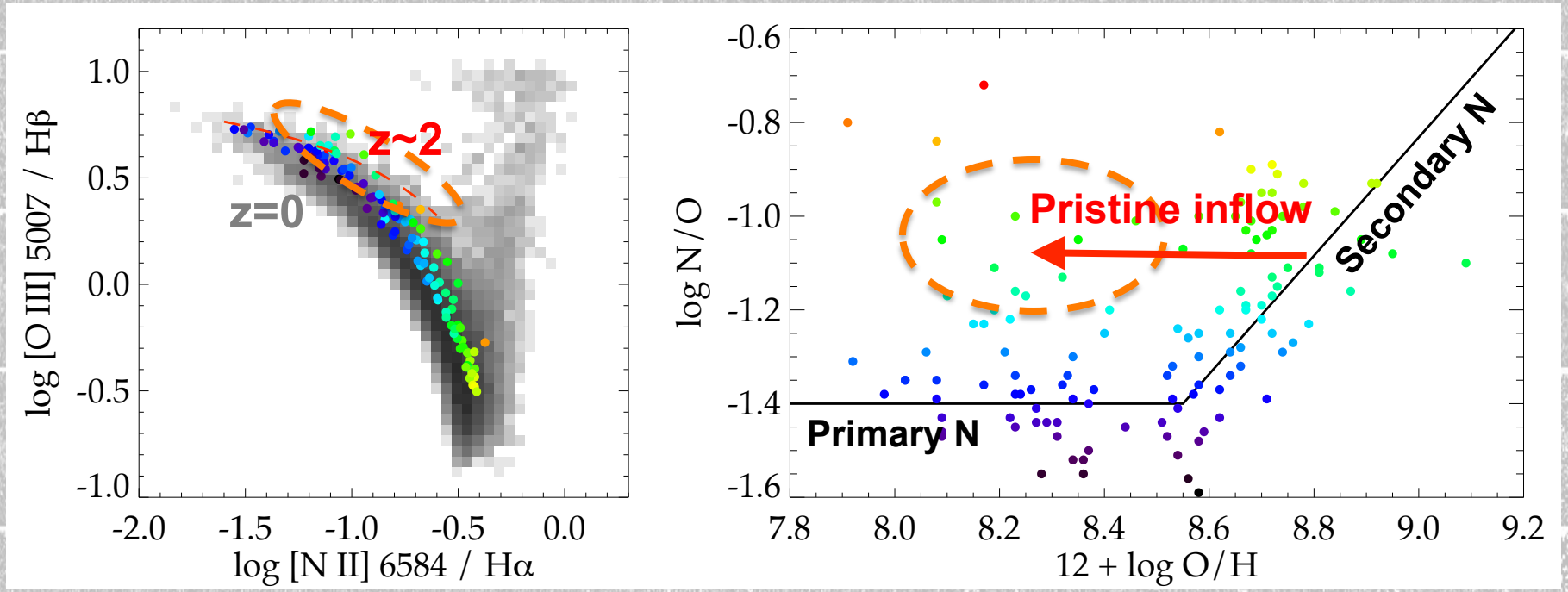
Multi-element abundance ratios: Ne/O





- ✓ [Ne III] / [O II] correlates with O/H, is independent of reddening, and is observable to z~5 from the ground
- ✓ Ne/O has very little scatter, weak dependence on O/H, and shows no systematic evolution with redshift (0.01 ± 0.01 dex)

Multi-element abundance ratios: N/O



Colored points: z=0 stacked SDSS spectra from Andrews & Martini (2013)

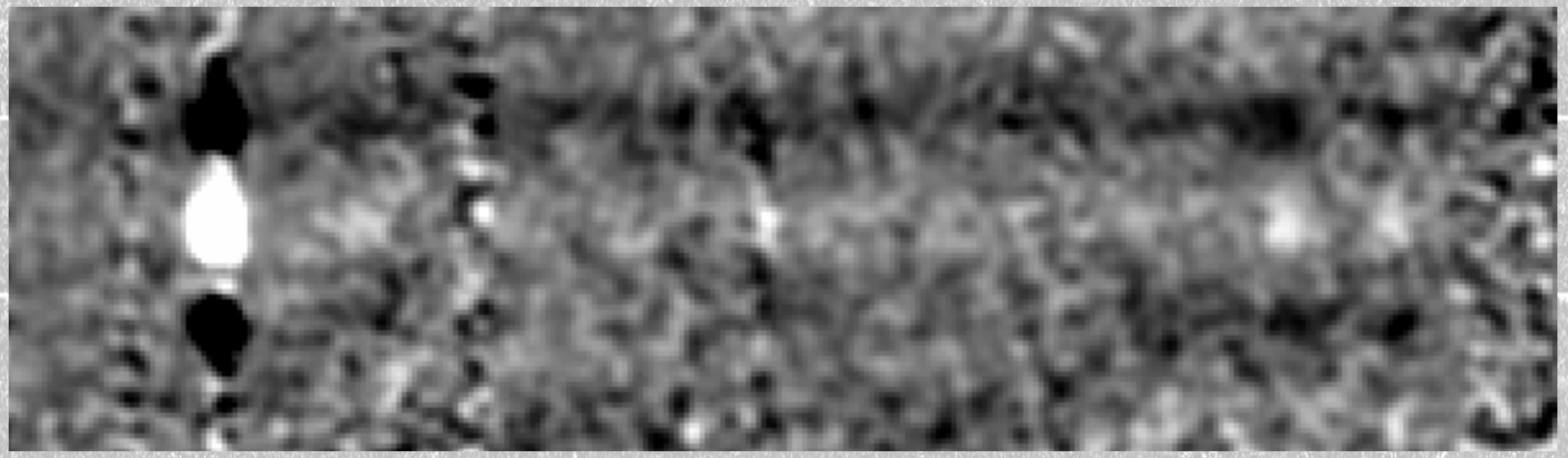
Dan Masters' talk

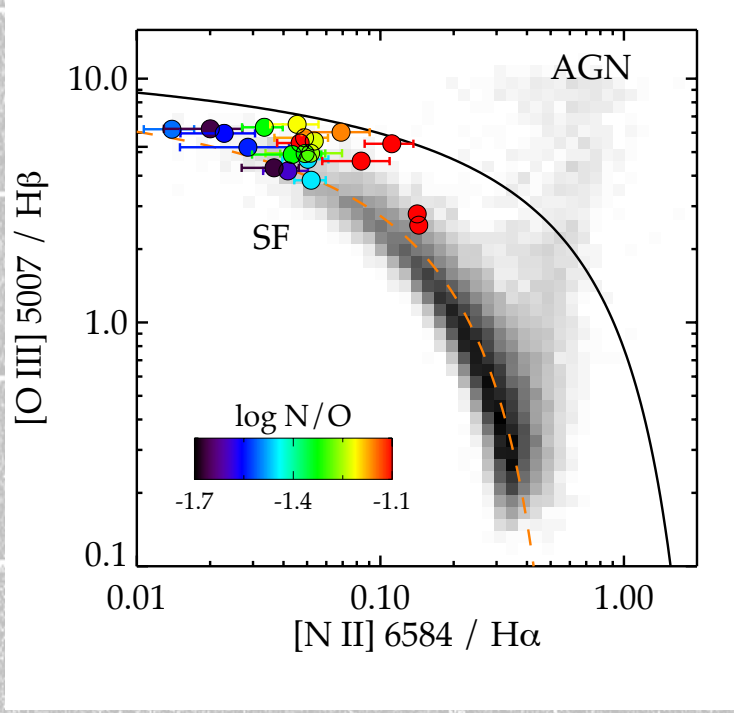
Gas flows at high redshift can lead to high N/O relative to local galaxies at fixed O/H → offset toward higher [N II]/Hα

Other effects: temperature and density evolution, DIG vs HII regions, etc.

Multi-element abundance ratios: N/O

Hα [N II] **[S II]**





Near-IR spectroscopic followup to measure N/O in z=0.8 DEEP2 sample

Results: emission line ratios offsets are correlated with N/O abundance ratio

Ongoing spatially resolved followup: effect of AGN, shocks, DIG

Summary

Substantial progress enabling accurate, systematic-free chemical evolution studies

Jones, Martin, & Cooper 2015, ApJ, 813, 126

- Direct metallicities measured for a carefully defined sample at z=0.8, drawn from the DEEP2 survey
- Oxygen and Neon abundances follow the same relations with strong line ratios as at z=0
  - ✓ Locally-calibrated *α-element* diagnostics work at z~1!
  - ✓ [NII] diagnostics appear to be unreliable
- Ongoing work: check for AGN contamination, shocks, DIG, etc. with spatially resolved data

Image credit: the DEEP2 team

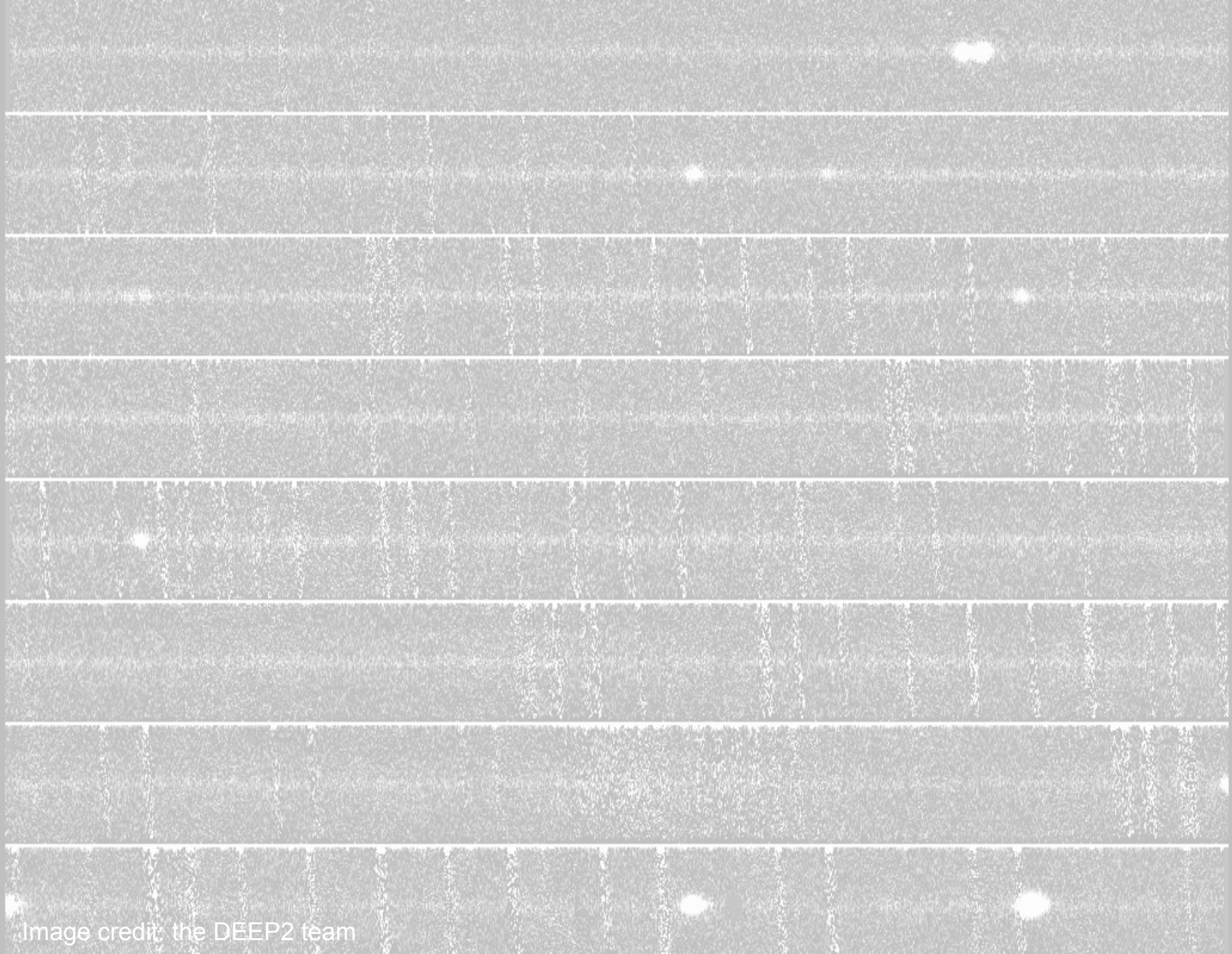
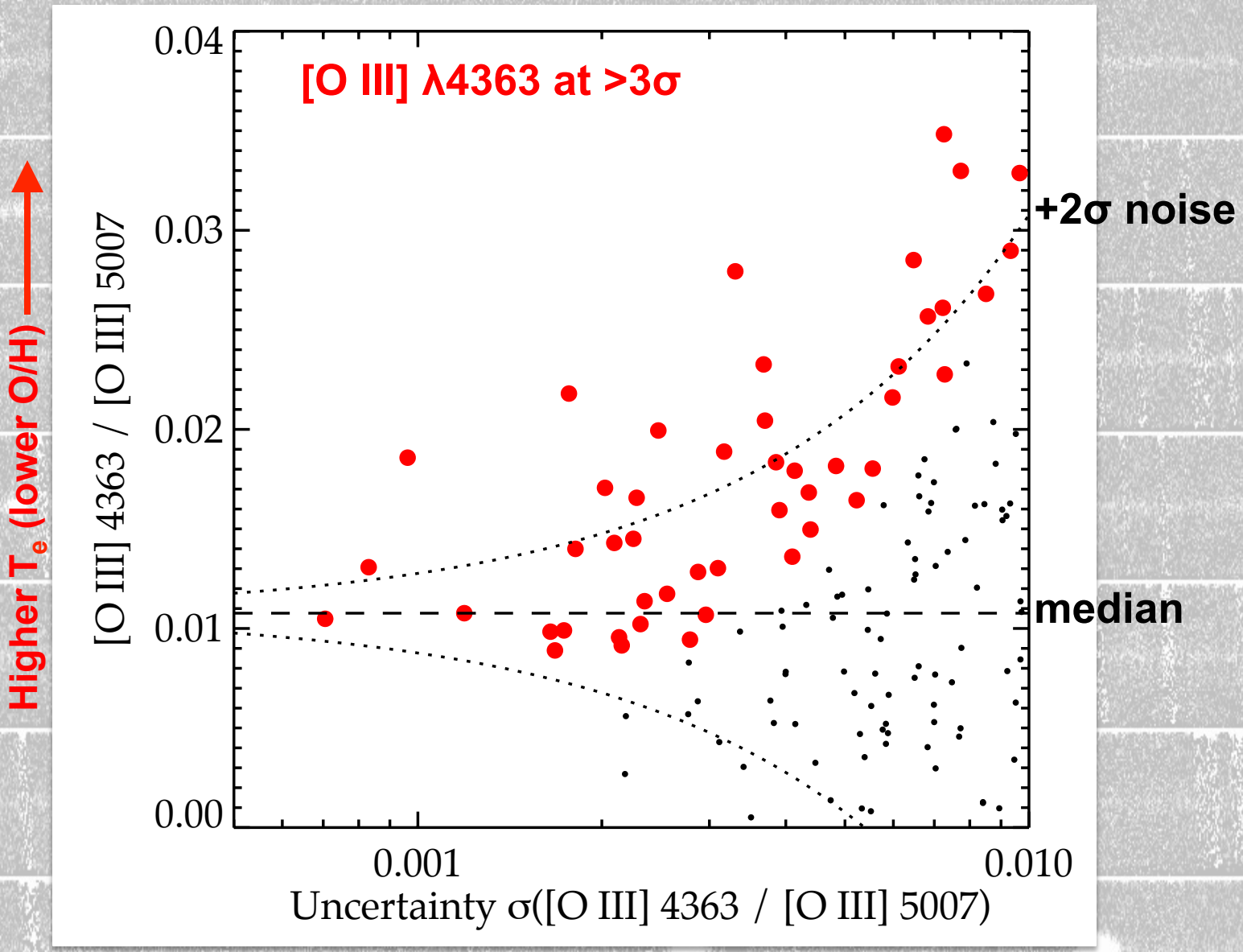


Image credit: the DEEP2 team

The z=0.8 direct metallicity sample



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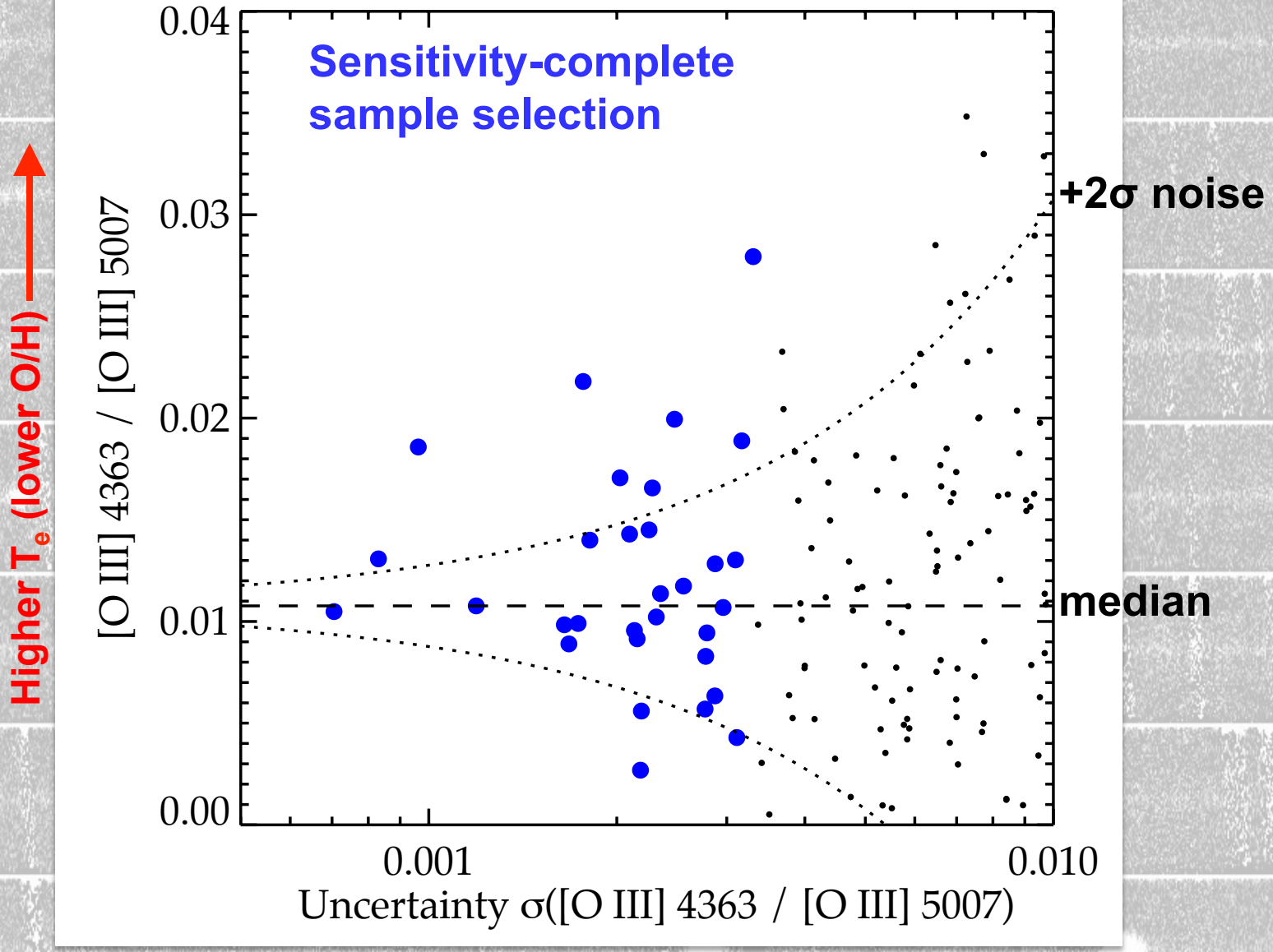
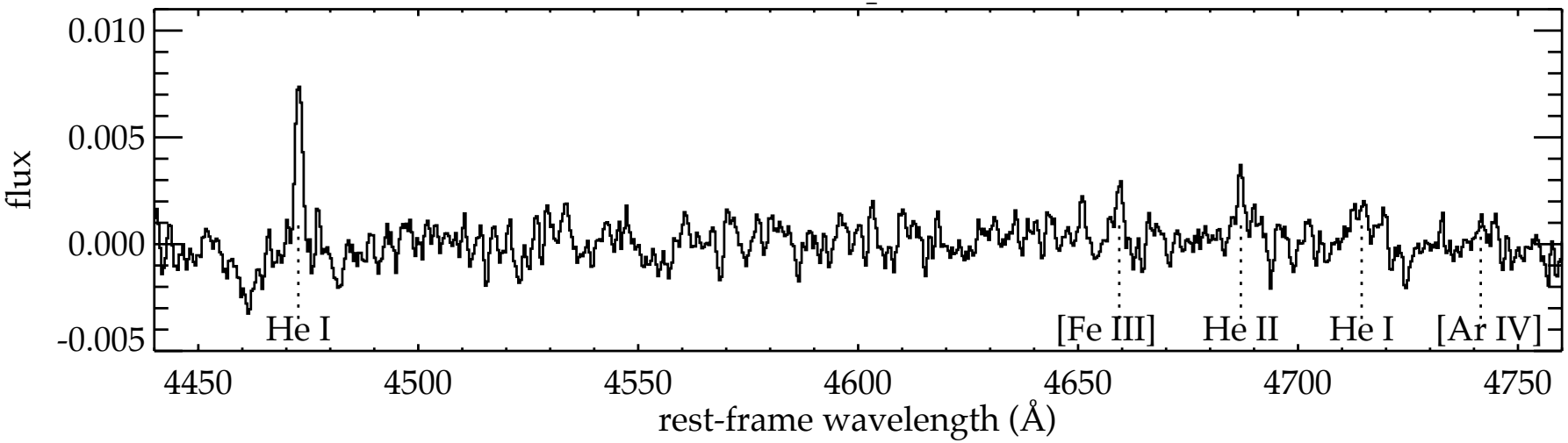
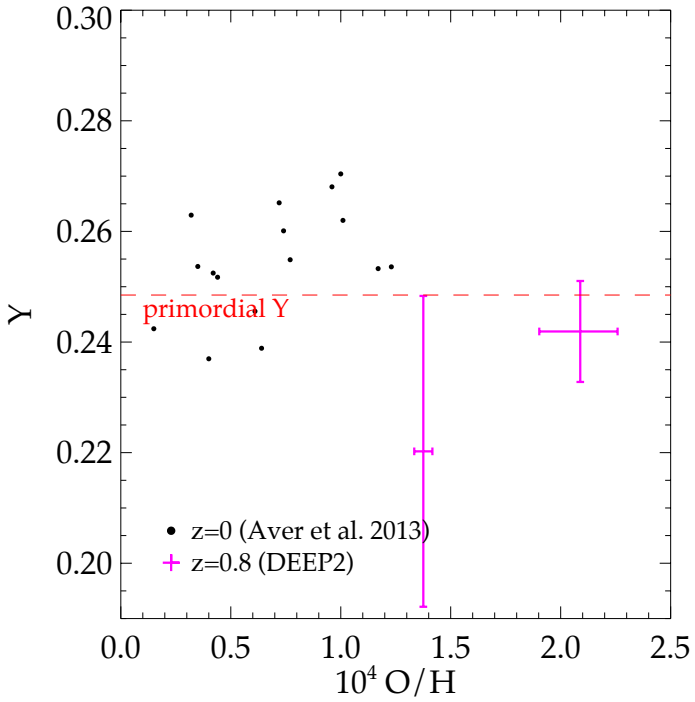


Multi-element abundance ratios: Helium





Helium abundance is reasonable

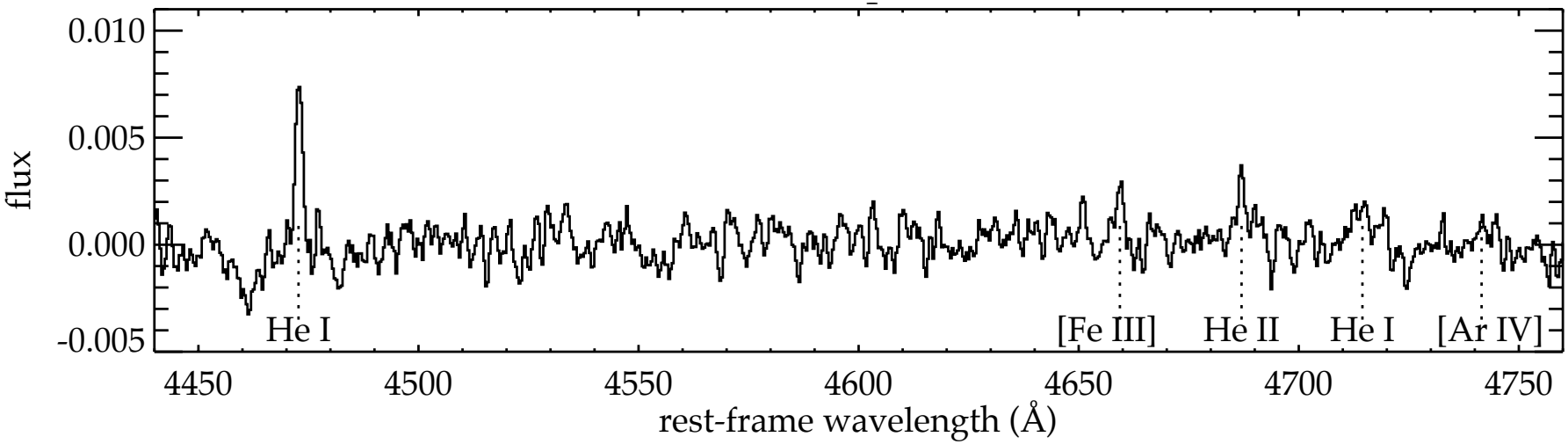
→ Consistent with primordial Y (barely), with different results from different lines

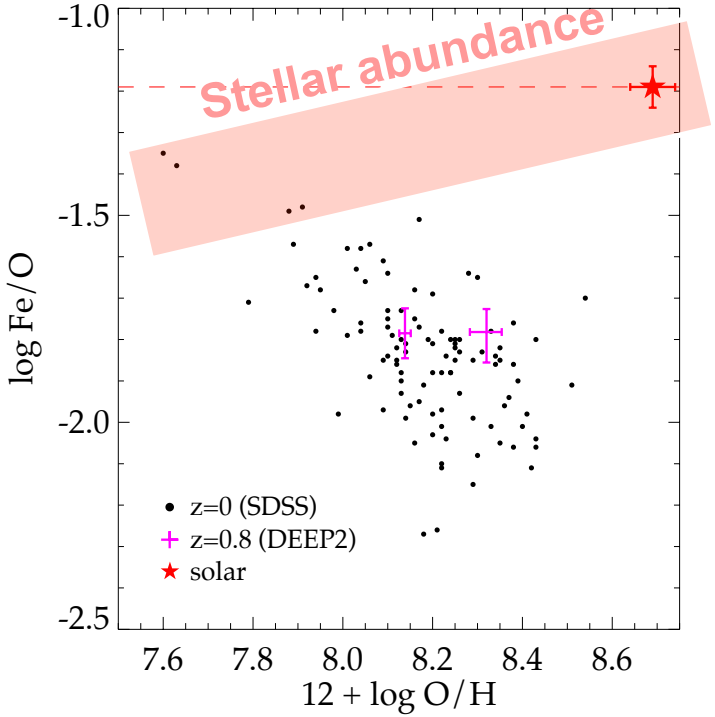
→ Discrepancy is probably from underestimated stellar absorption

He^{++} accounts for <3% of total He

No strong W-R features

Multi-element abundance ratios: Iron





Iron abundance is reasonable

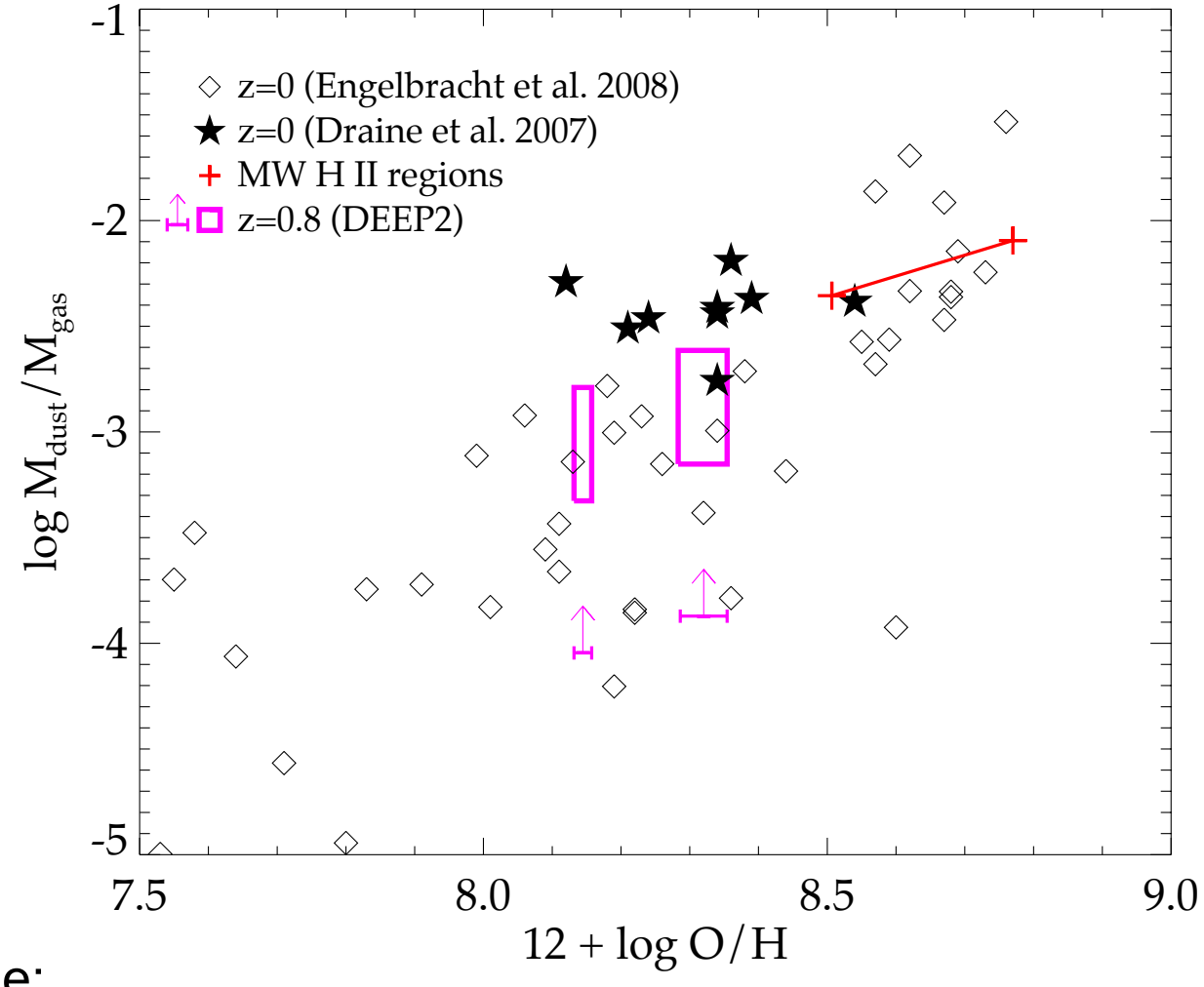
→ Consistent gas-phase abundance in local galaxies of similar O/H

→ Lower than found in stars of similar O/H

Low *gas-phase* Fe/O compared to *stellar*

→ depletion of iron onto dust grains!

Dust-to-gas ratios at z=0.8

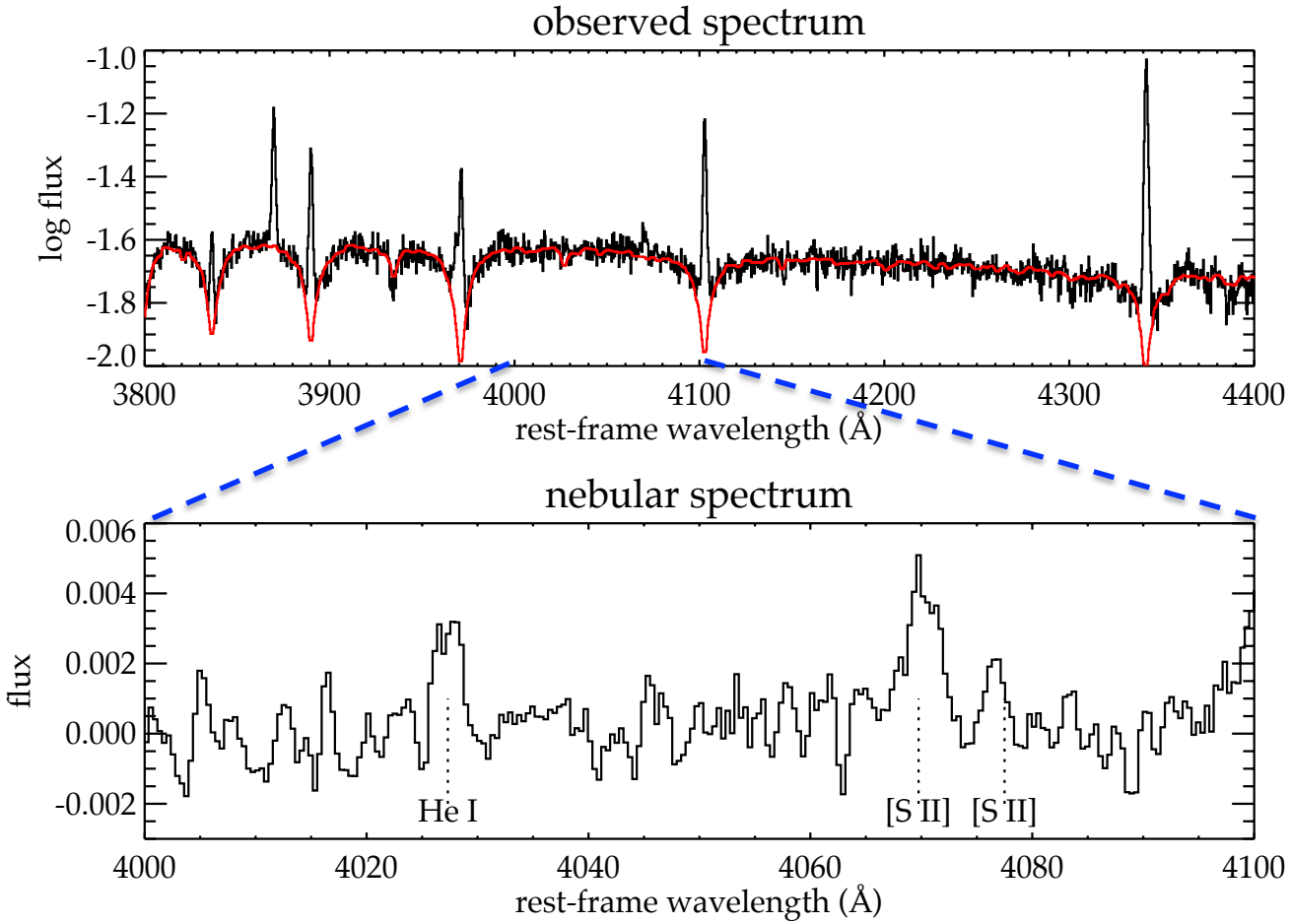


Assume:

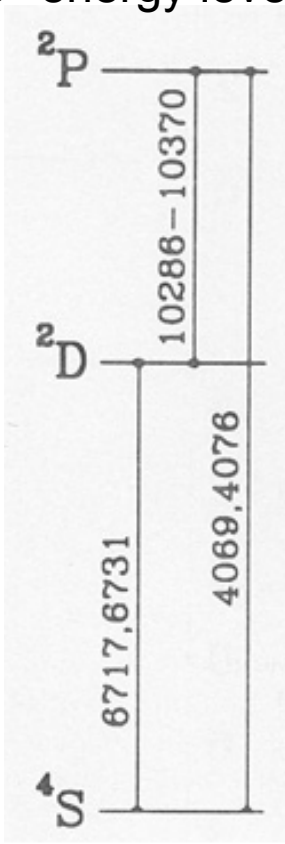
- Intrinsic total [Fe/α] between -0.3 (typical MW bulge) and 0 (solar)
- Same dust composition as MW HII regions (~20% iron by mass)

→ Dust mass is ~0.1 % of gas mass, as expected for the O/H

Ongoing work: T_e method at higher O/H



S⁺ energy levels



- ✓ 12+log O/H = 8.32 ± 0.04 based on [O III] 4363. 54% of oxygen is in O^+
- ✓ [O III] 4363 detected at 6σ, while **[S II] 4069,4076 detected at 16σ**
  - → *Typically ~3σ detection of T_e-sensitive [S II] for individual spectra!*
    … just need [S II] 6717,6731 and [S III] 6312,9069,9532 in the near-IR

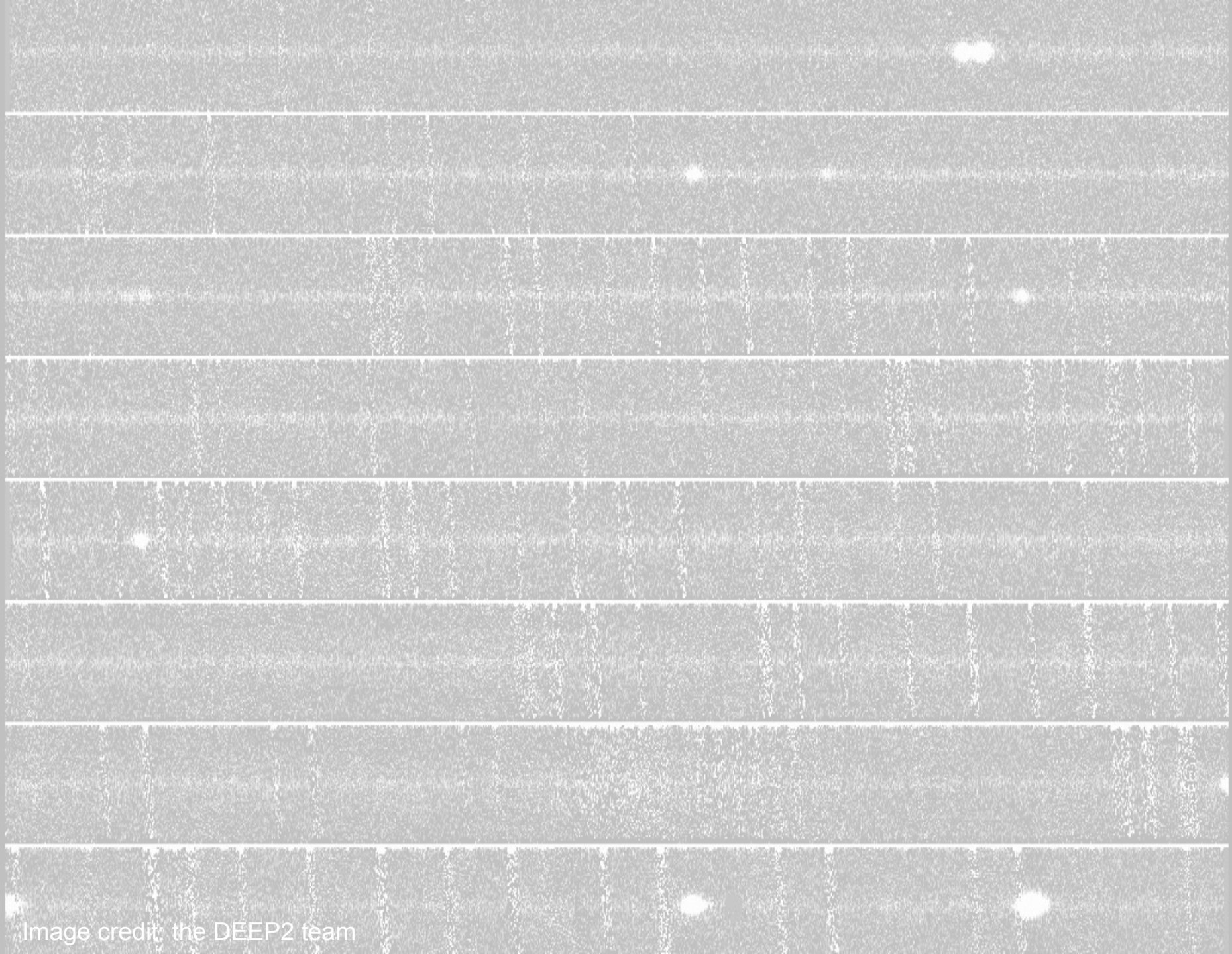


Image credit: the DEEP2 team