Credit: A. L. Strom and T. A. Rector

rethinking metallicity

measuring galaxy abundances in the early universe

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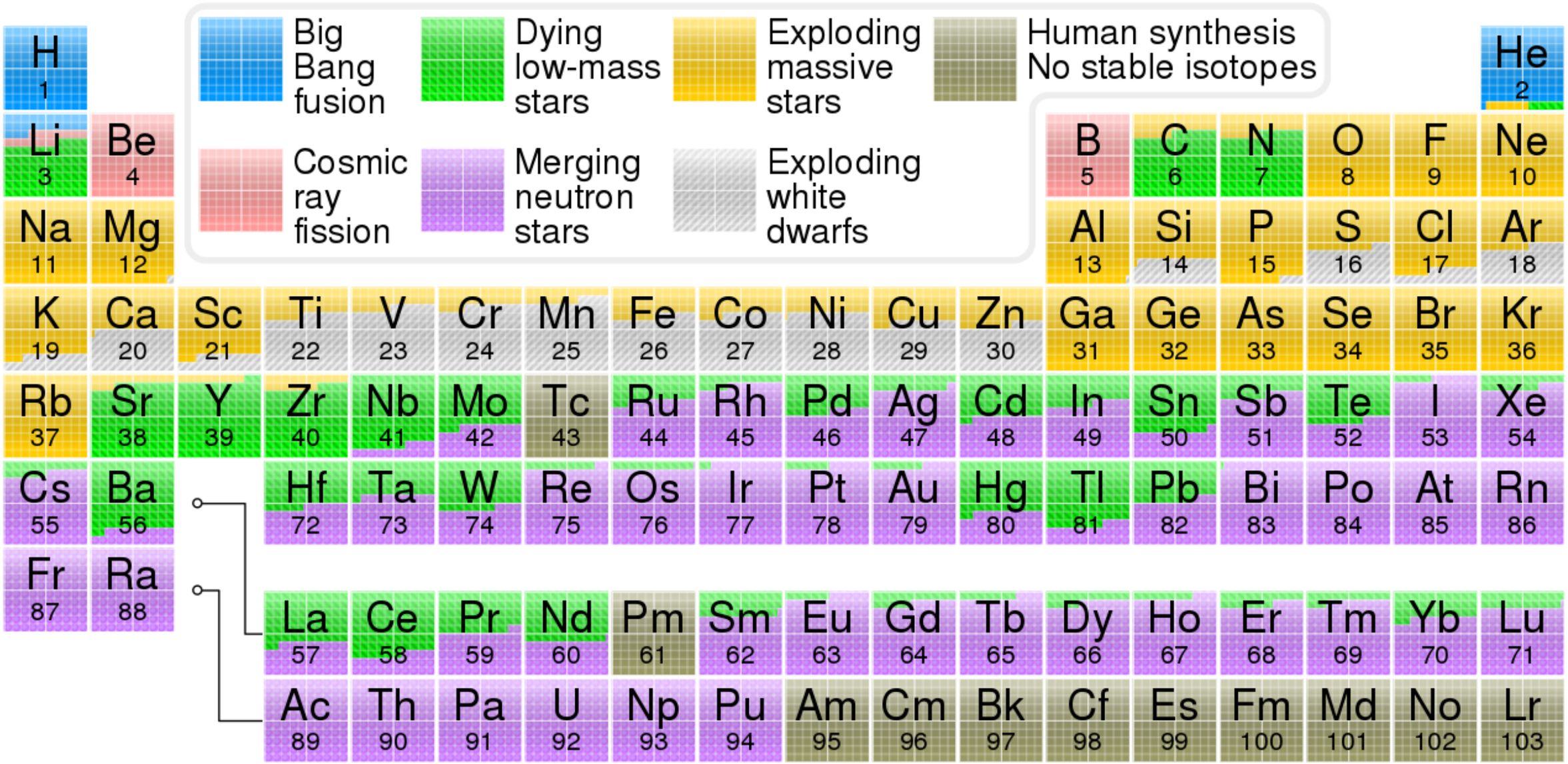
$$Z = 1 - X - Y$$

Different "metallicities" can matter—and have different origins



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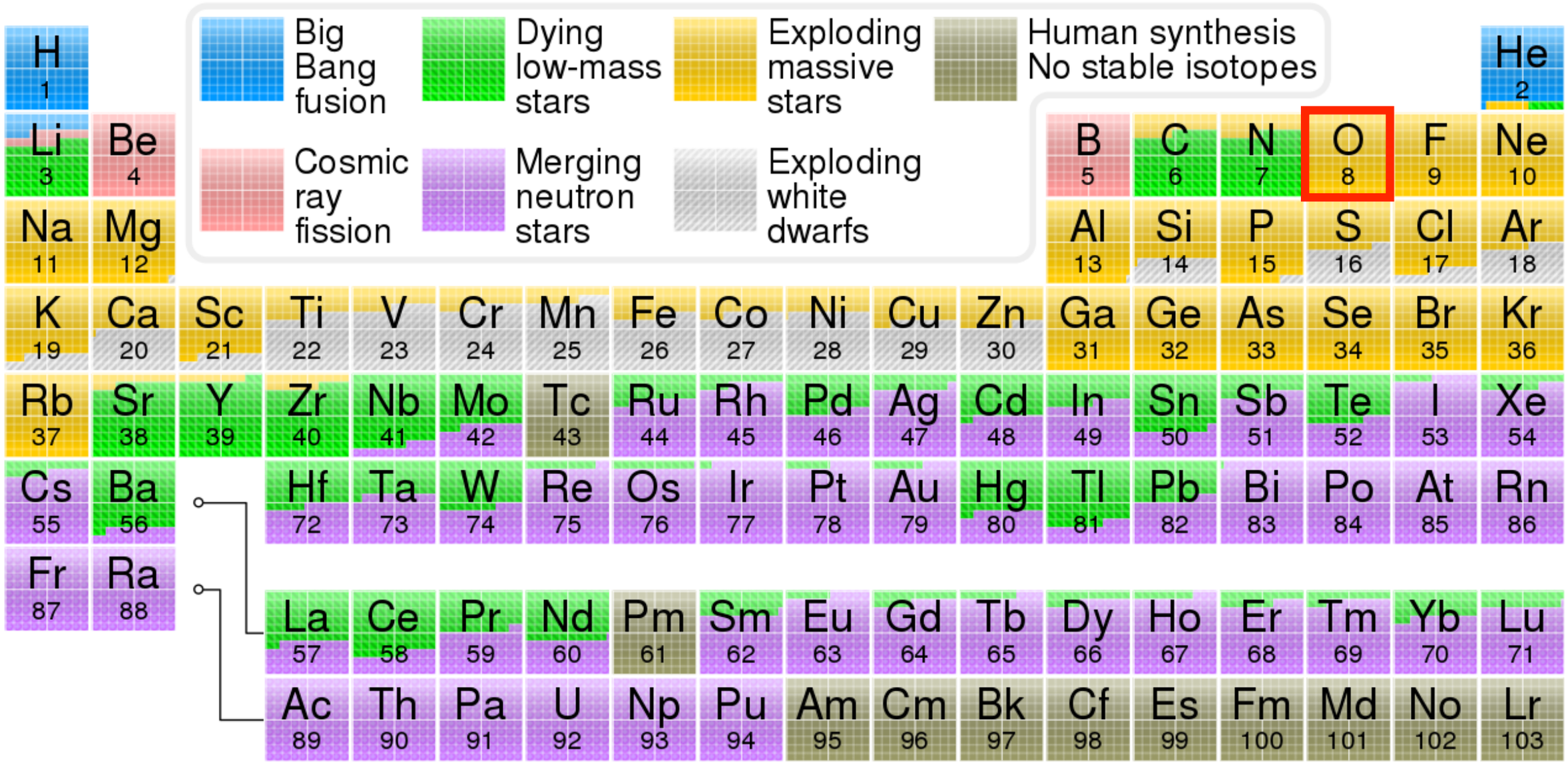

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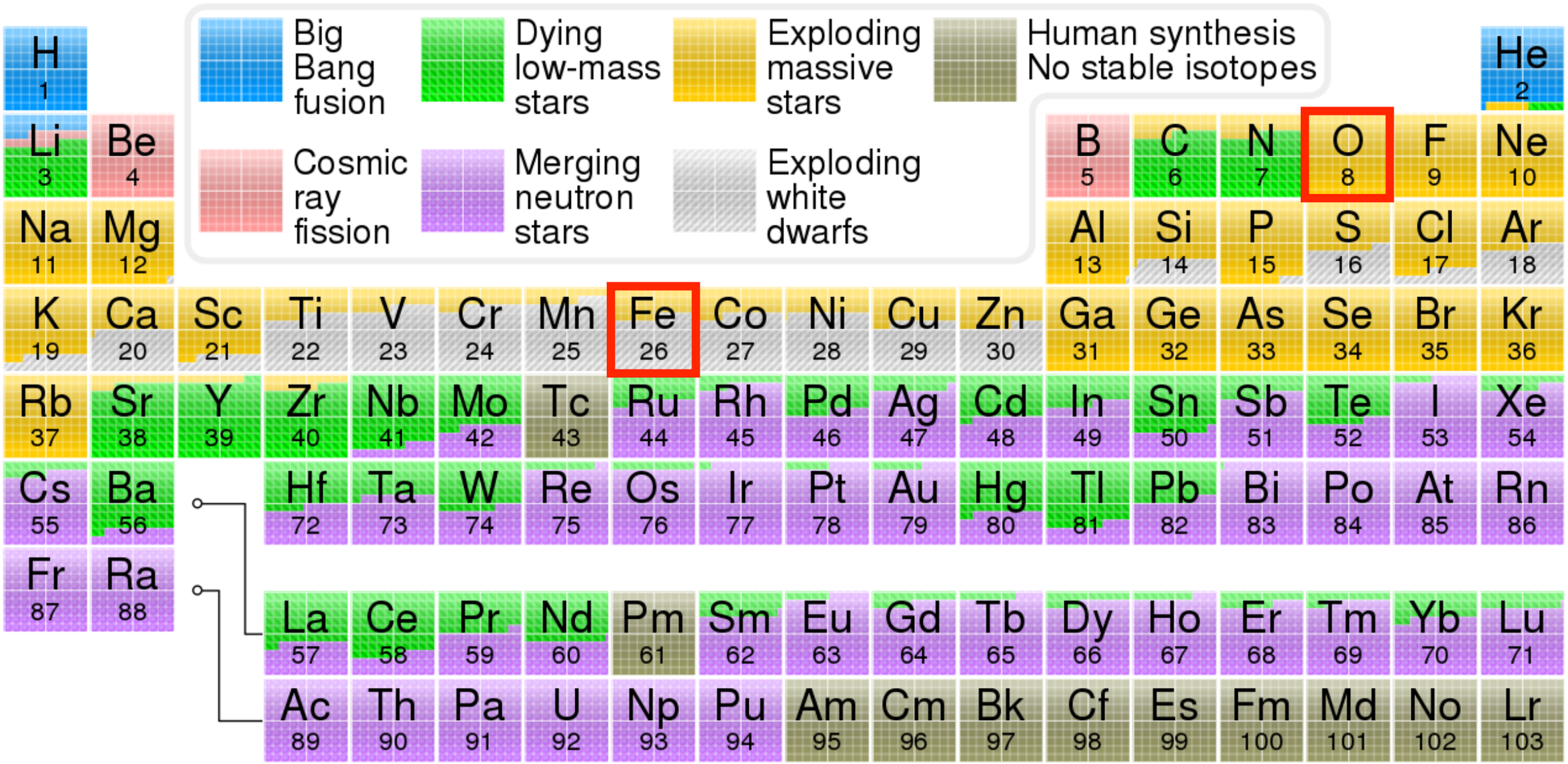
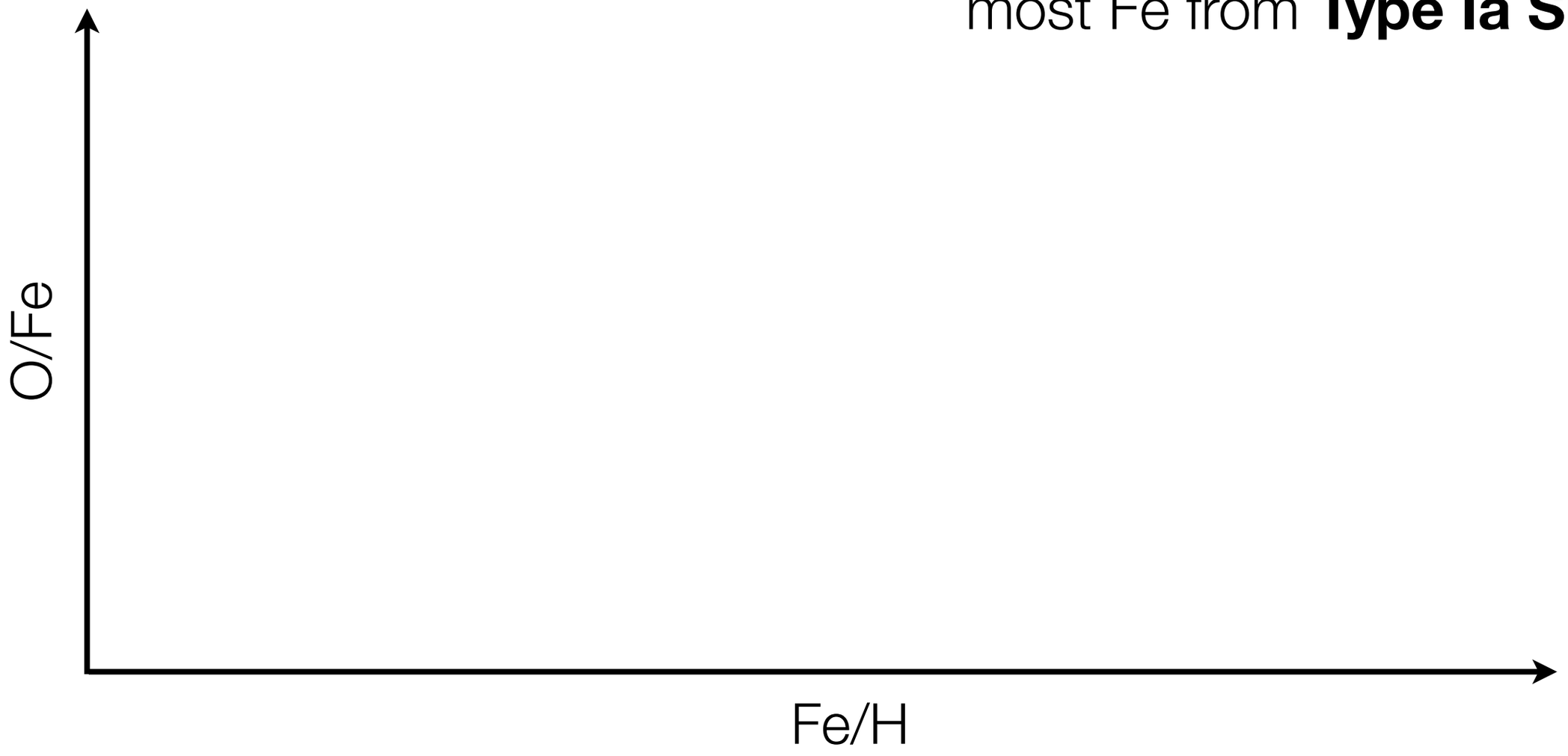
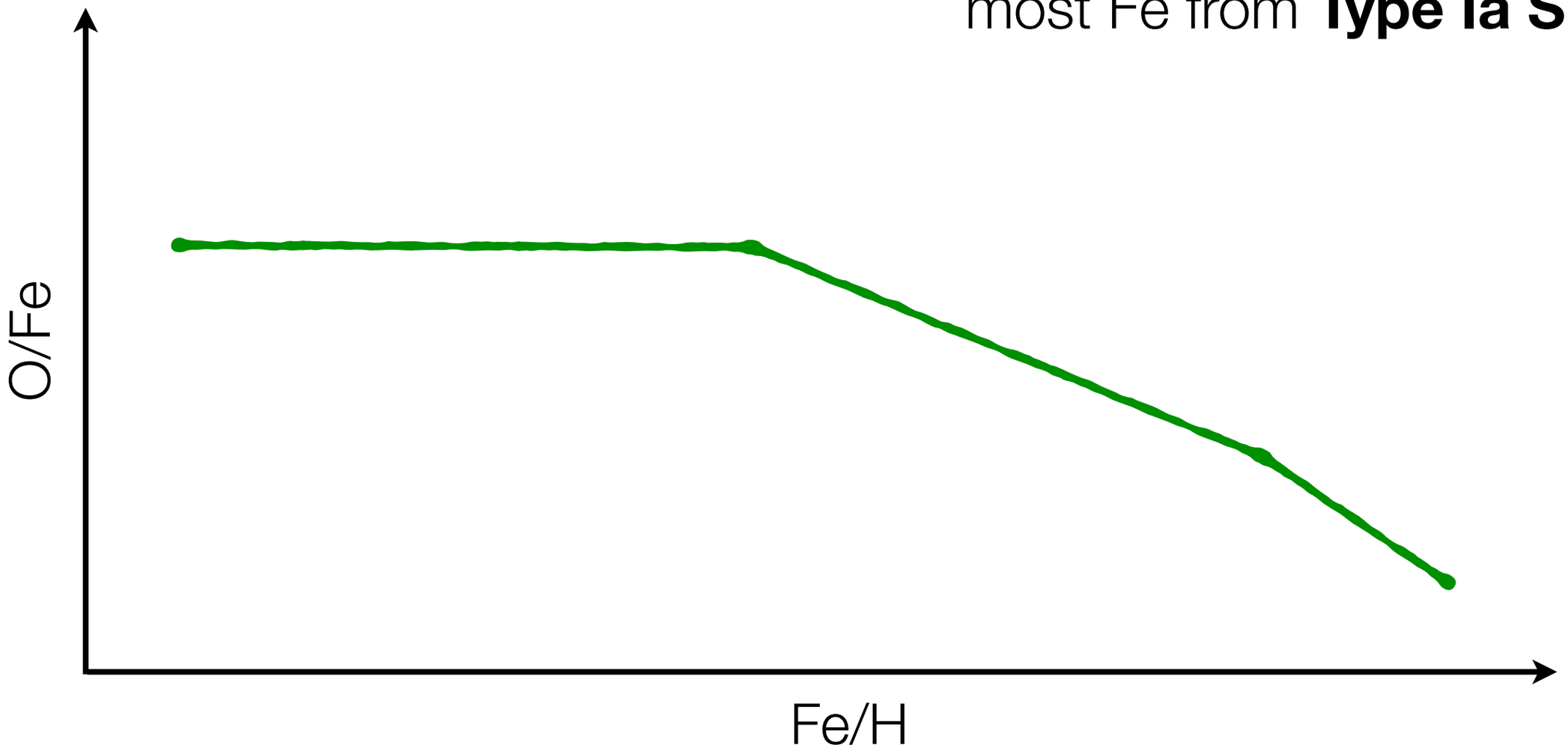


Star-formation history determines chemical abundance patterns



Star-formation history determines chemical abundance patterns

most O from **core-collapse SNe**
most Fe from **Type Ia SNe**



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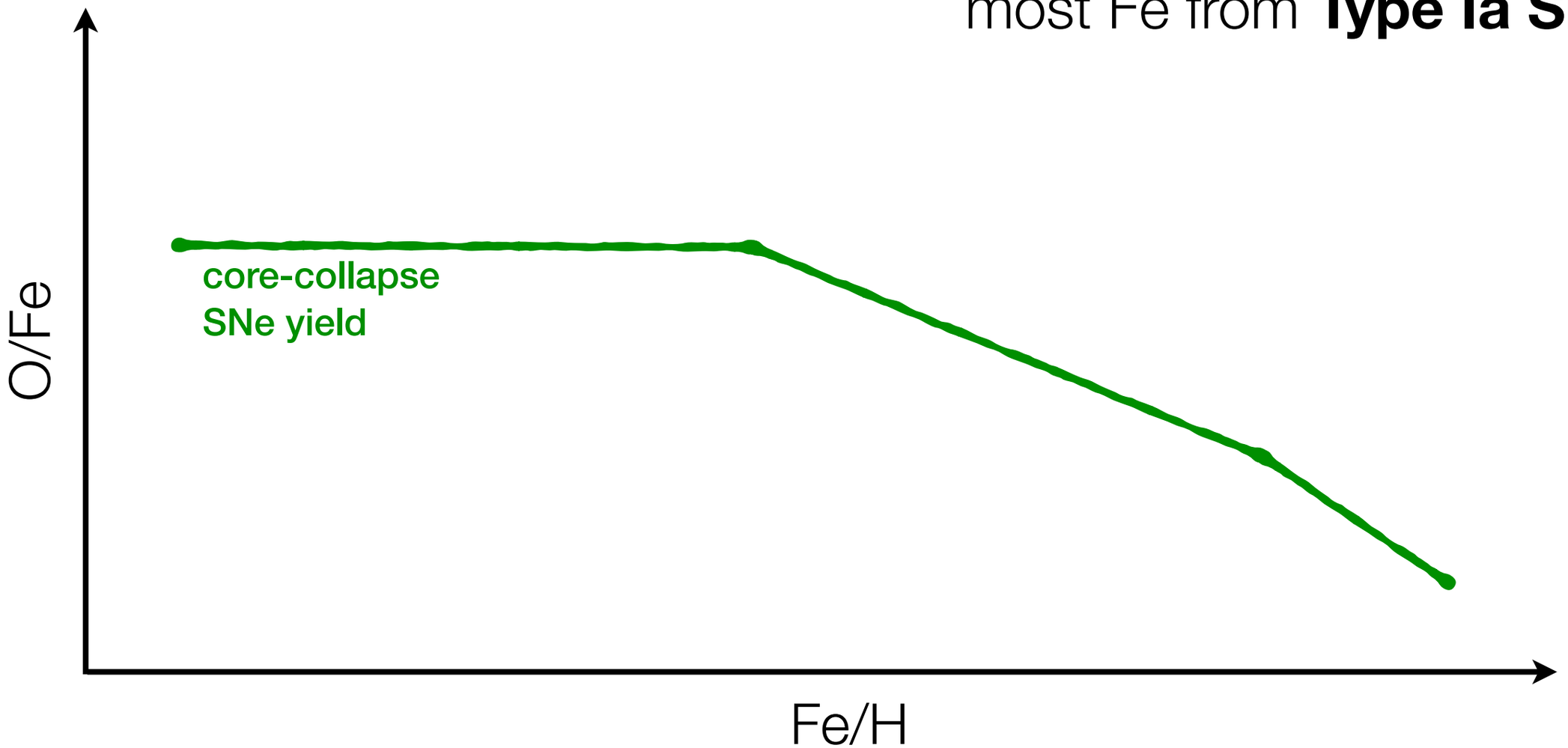

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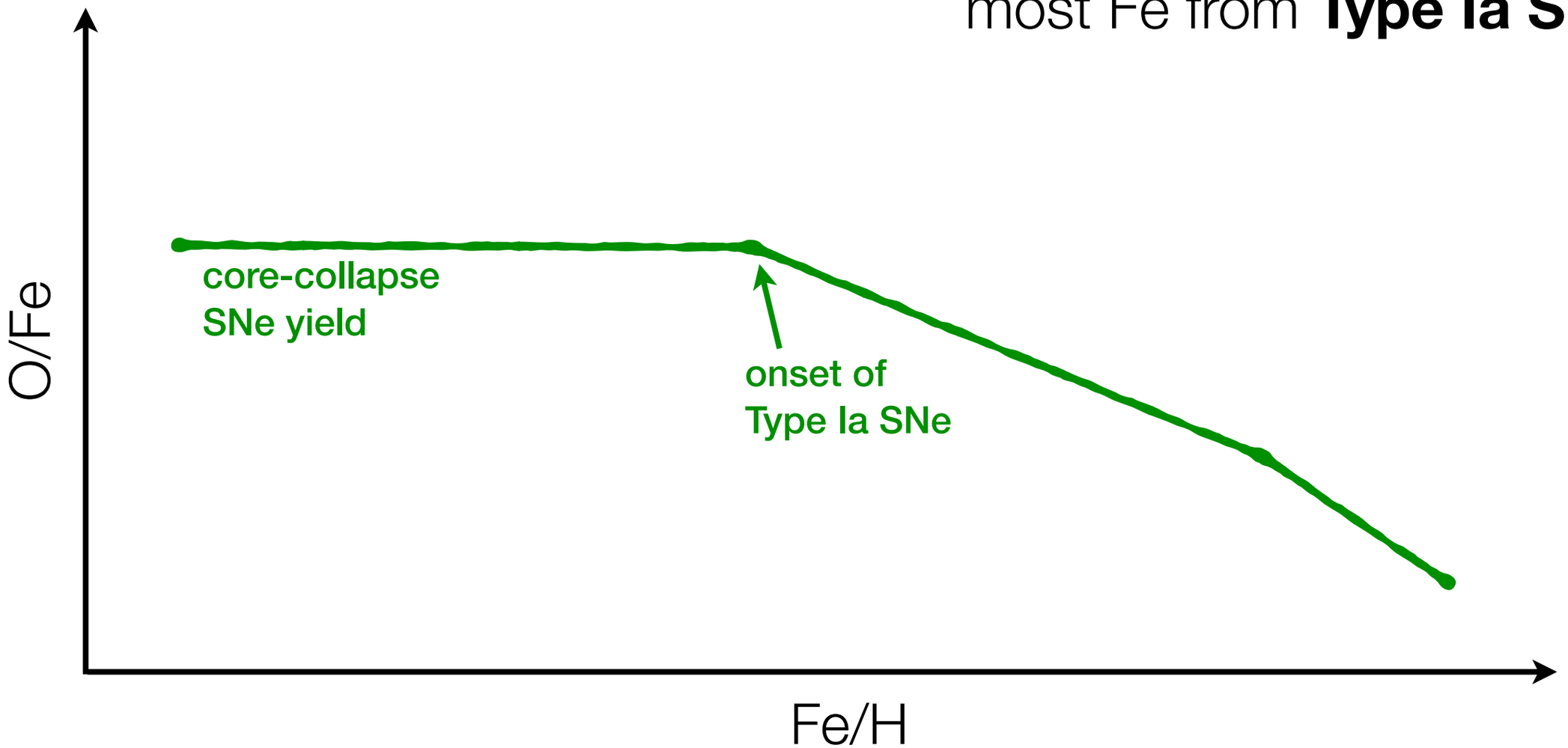

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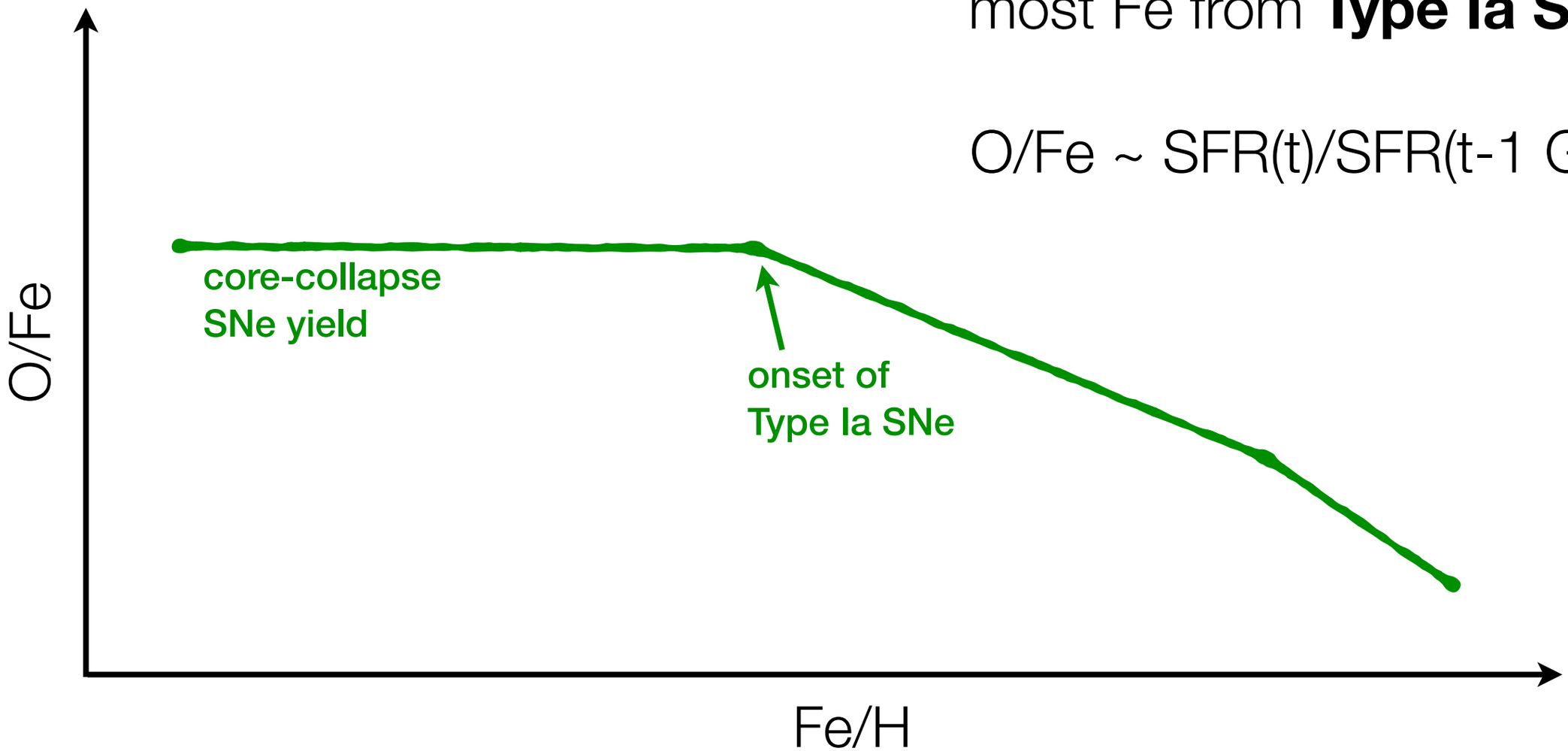
O/Fe ~ SFR(t)/SFR(t-1 Gyr)



Central Question

Can we use the same methods to study galaxies with different star formation histories across cosmic time?

Keck Baryonic Structure Survey (KBSS)

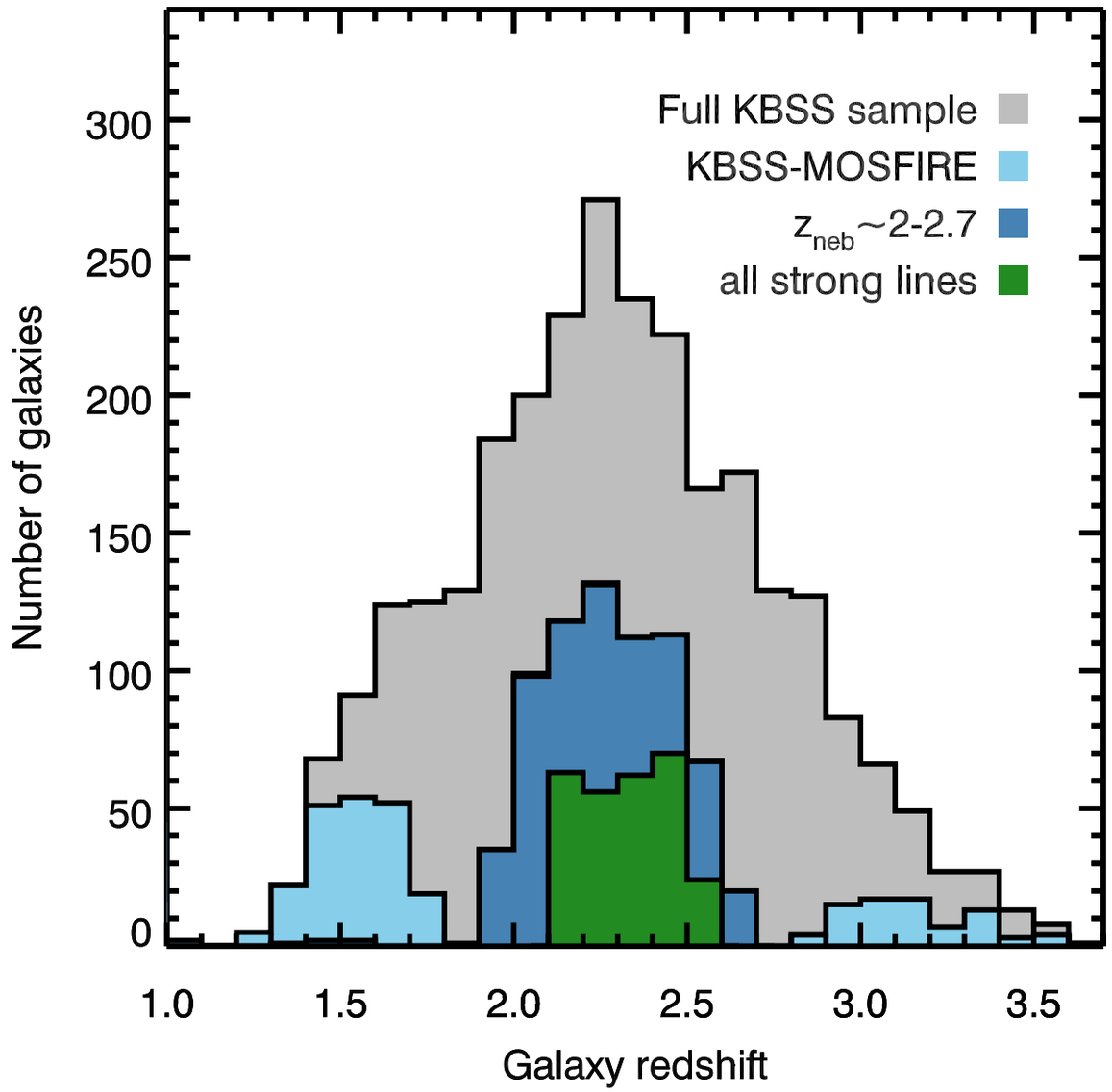
15 separate survey fields, with a total area = 0.24 deg^2

Rich spectroscopic dataset:

- **~2700 with rest-UV spectra**
- **~1300 with rest-optical spectra**

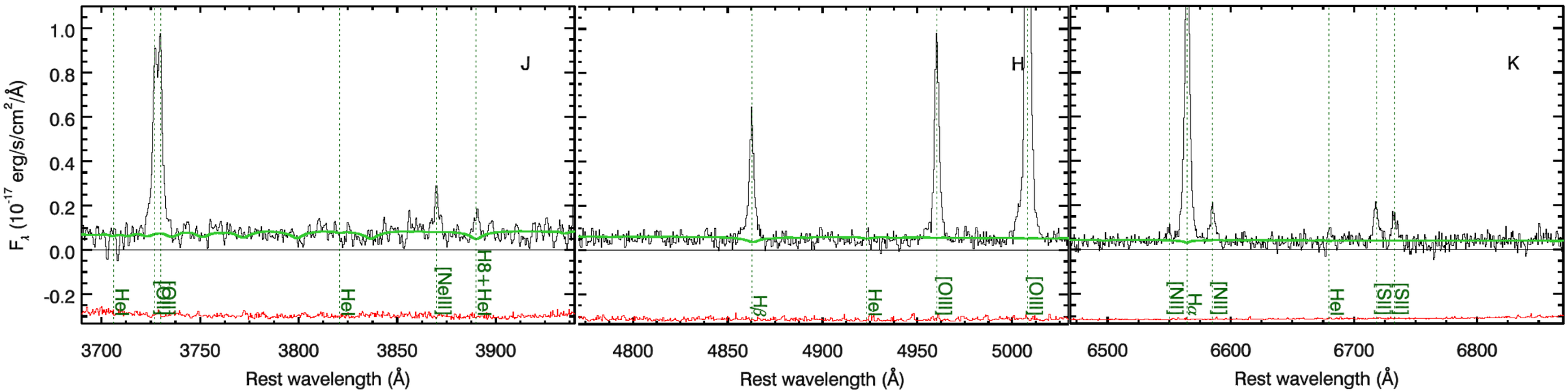
>700 galaxies with z≈2-2.7 have at least a partial rest-optical spectrum

~300 galaxies with good detections of many of the strong rest-optical diagnostic emission lines



KBSS-LM1: the same 30 galaxies at z~2.4

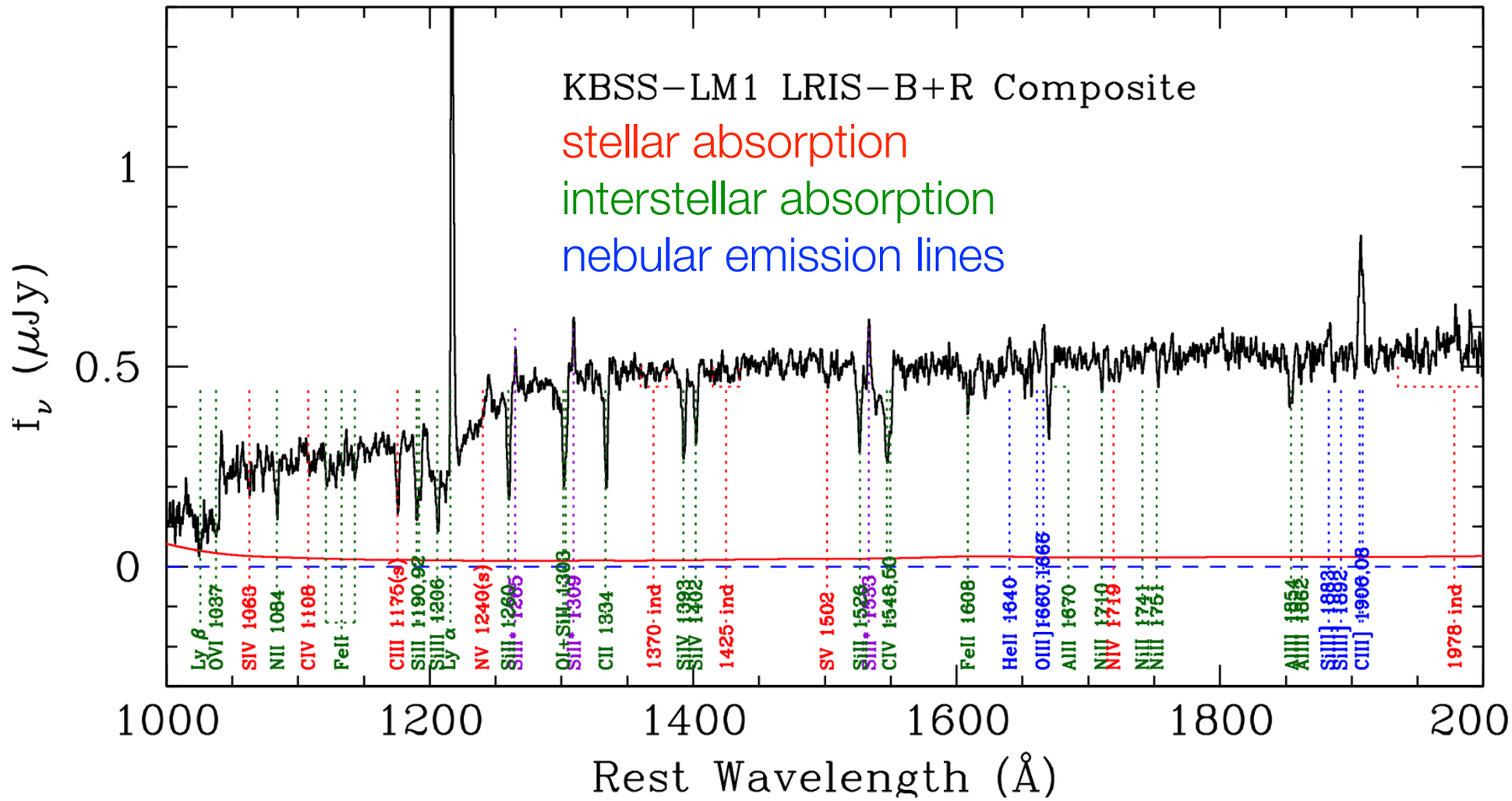
Steidel, **Strom**, et al. (2016)



Totals

MOSFIRE:
30 x ~5 hr/band
@ R ~ 3660

LRIS-B+R:
30 x ~10 hr
@ R ~1500

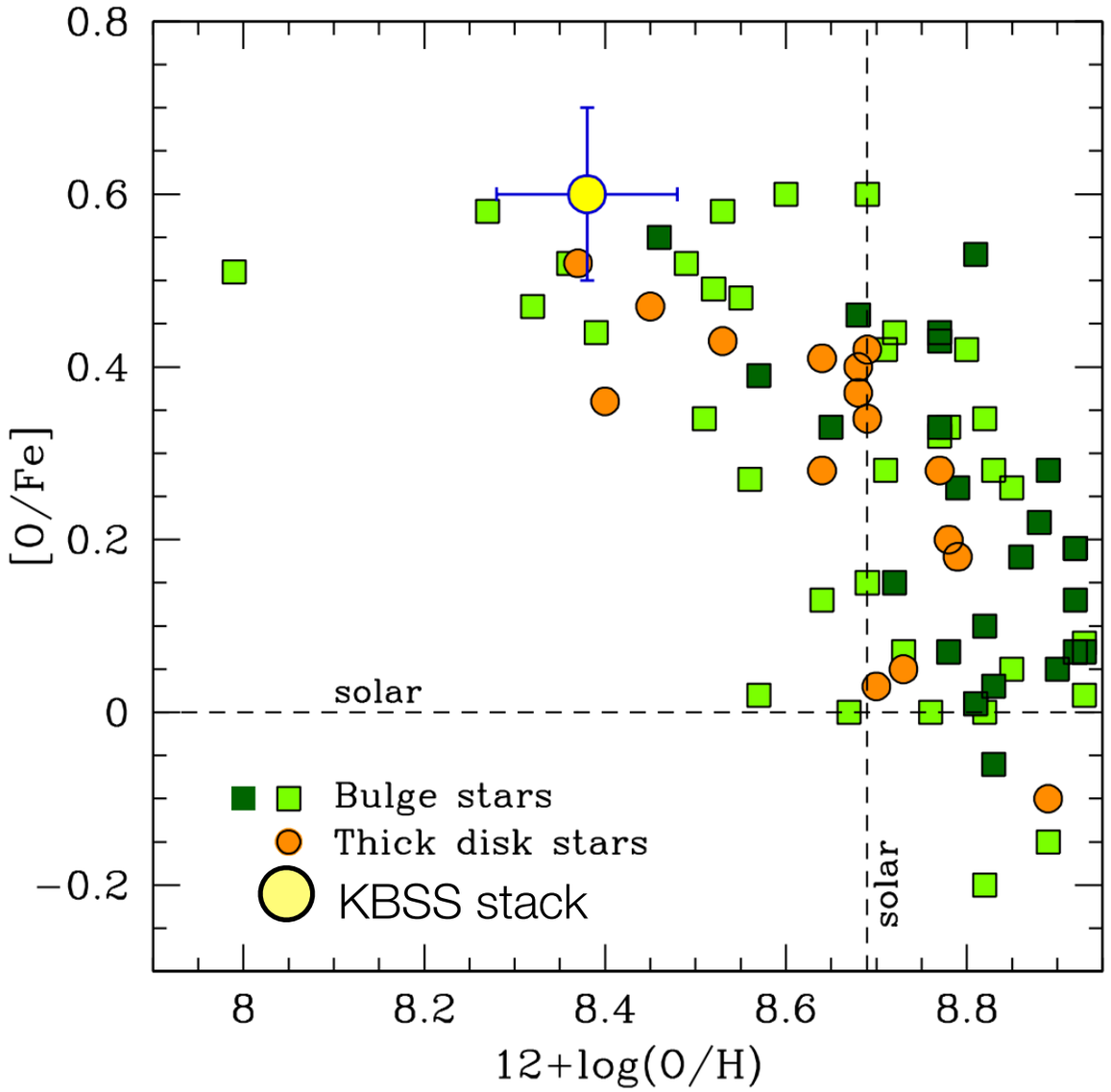


Basic Premise

Since the same stars are responsible for **both** the rest-UV and rest-optical spectra we observe, any physical model of high-z galaxies must also account for **both**.

High-z galaxies have O/Fe similar to bulge+thick disk stars

Steidel, **Strom**, et al. (2016)



KBSS stack:
O/Fe ~ 4-5(O/Fe)⊙

Consistent with predictions from Nomoto+06 for Fe-poor core-collapse SNe

Elevated O/Fe also observed in the centers of giant ellipticals (e.g., Conroy+14, Segers+16)

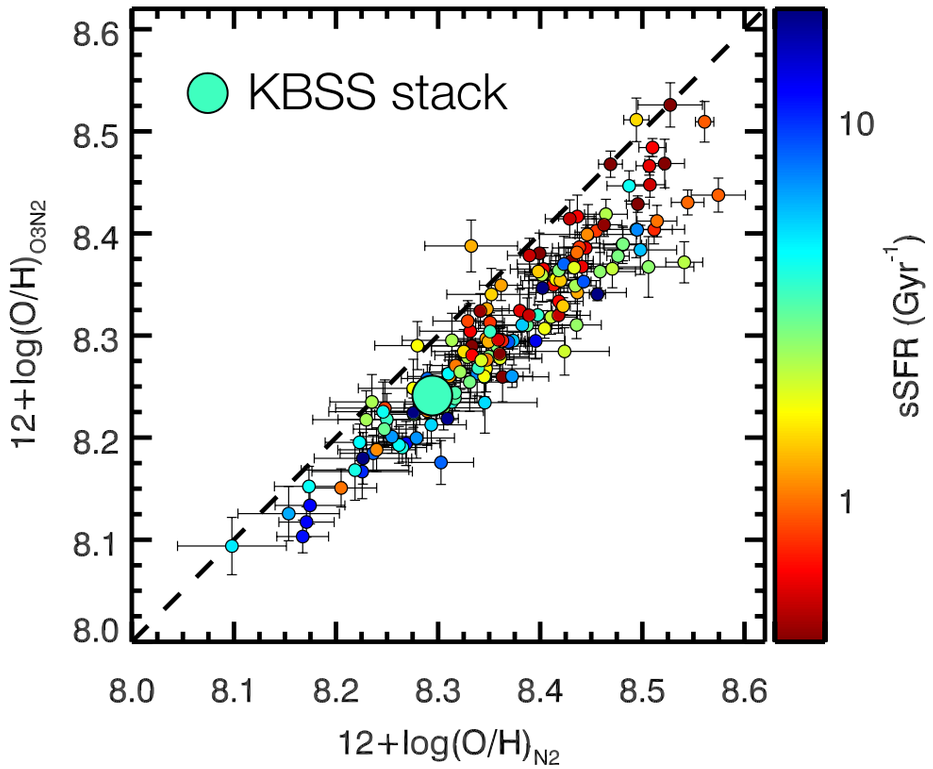
Differences in star formation history impact O/H diagnostics

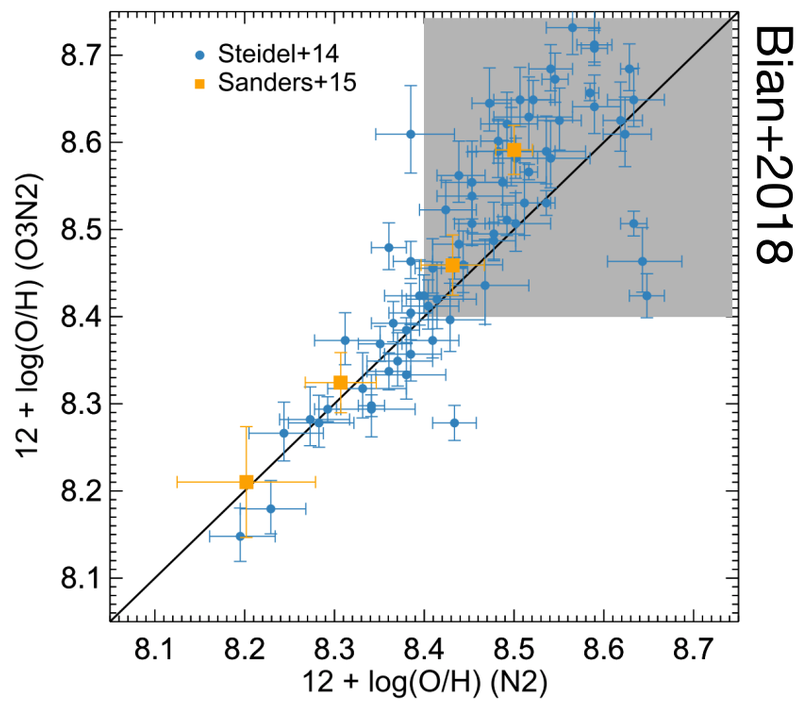
Young galaxy ages and/or rising star formation histories will result in higher excitation (i.e., O3 and R23) at fixed O/H

Strong-line calibrations rely on the underlying correlation between

1. shape of the ionizing radiation (Fe/H)
2. gas-phase C/H, N/H, and O/H

Local metallicity calibrations will be inconsistent for high-*z* galaxies, especially at high 12+log(O/H)





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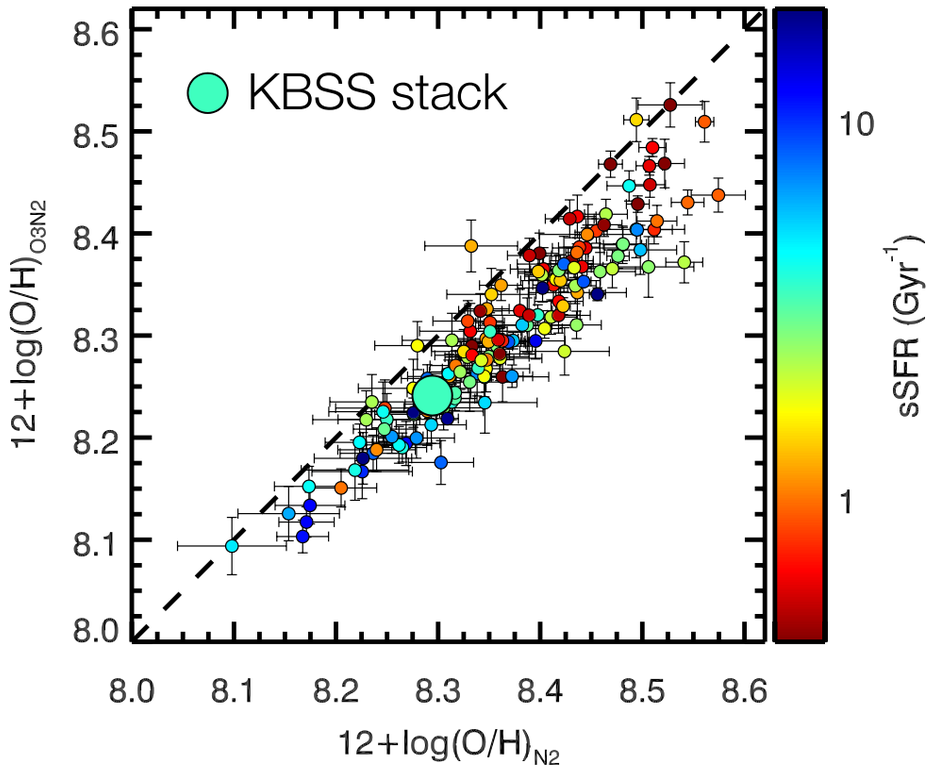
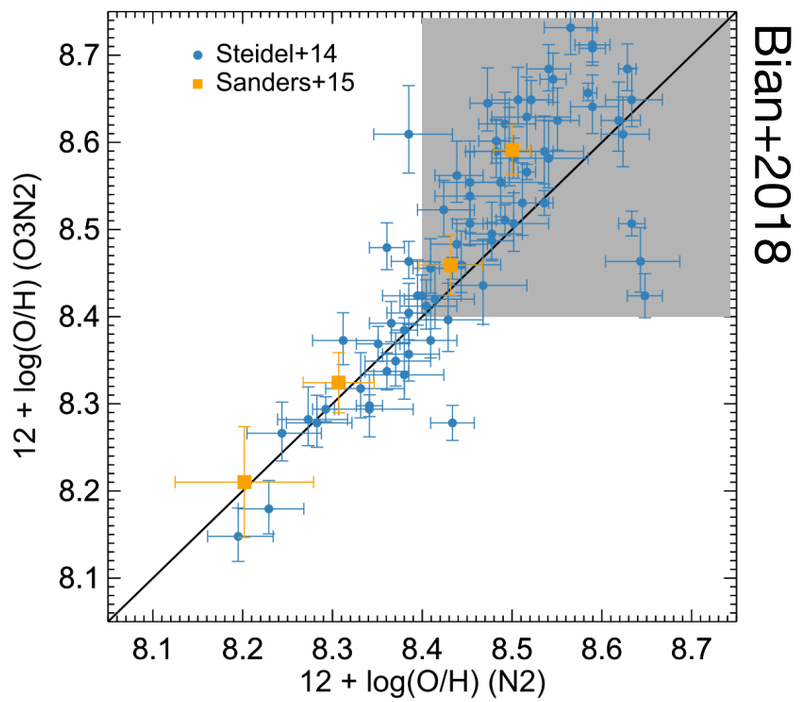
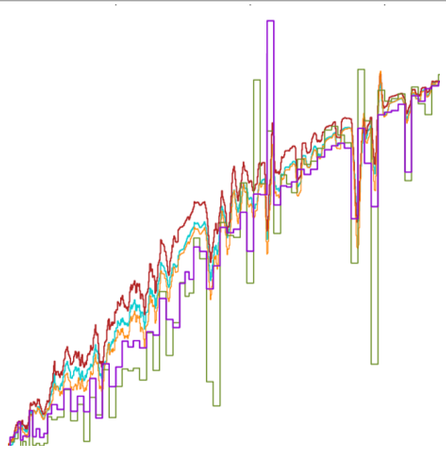
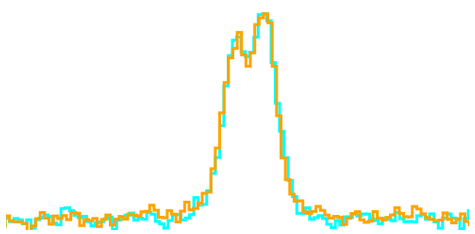
Photoionization models can help!





Measuring physical conditions using photoionization models

line ratios
f(U, Z_{neb}) =  +  + ???

shape of EUV
Fe-poor stars

electron density
n_e = 300 cm^{-3}

abundance ratios
e.g., N/O vs. O/H

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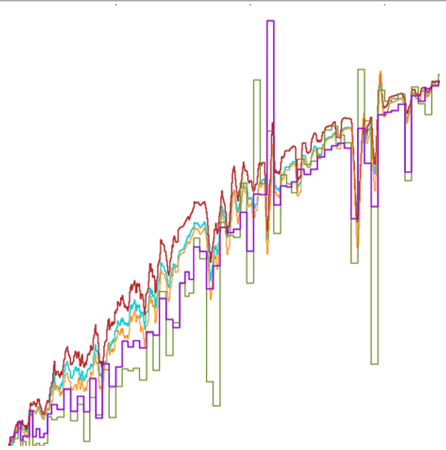
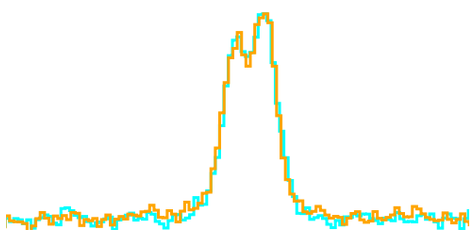
f(U, Z_{neb}) =  +  + ???

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Considerations

Stellar atmospheres care mostly about Fe, so $Z_\star$ **traces Fe/H**.
Gas cooling is largely regulated by O, so Z_{neb} **traces O/H**.

Different $Z_\star$ and Z_{neb} imply O/Fe different from solar, but **not** gas and stars with different O/H or Fe/H!

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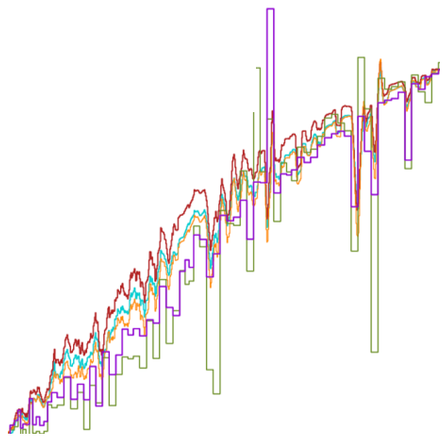
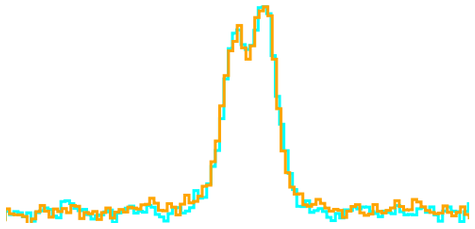
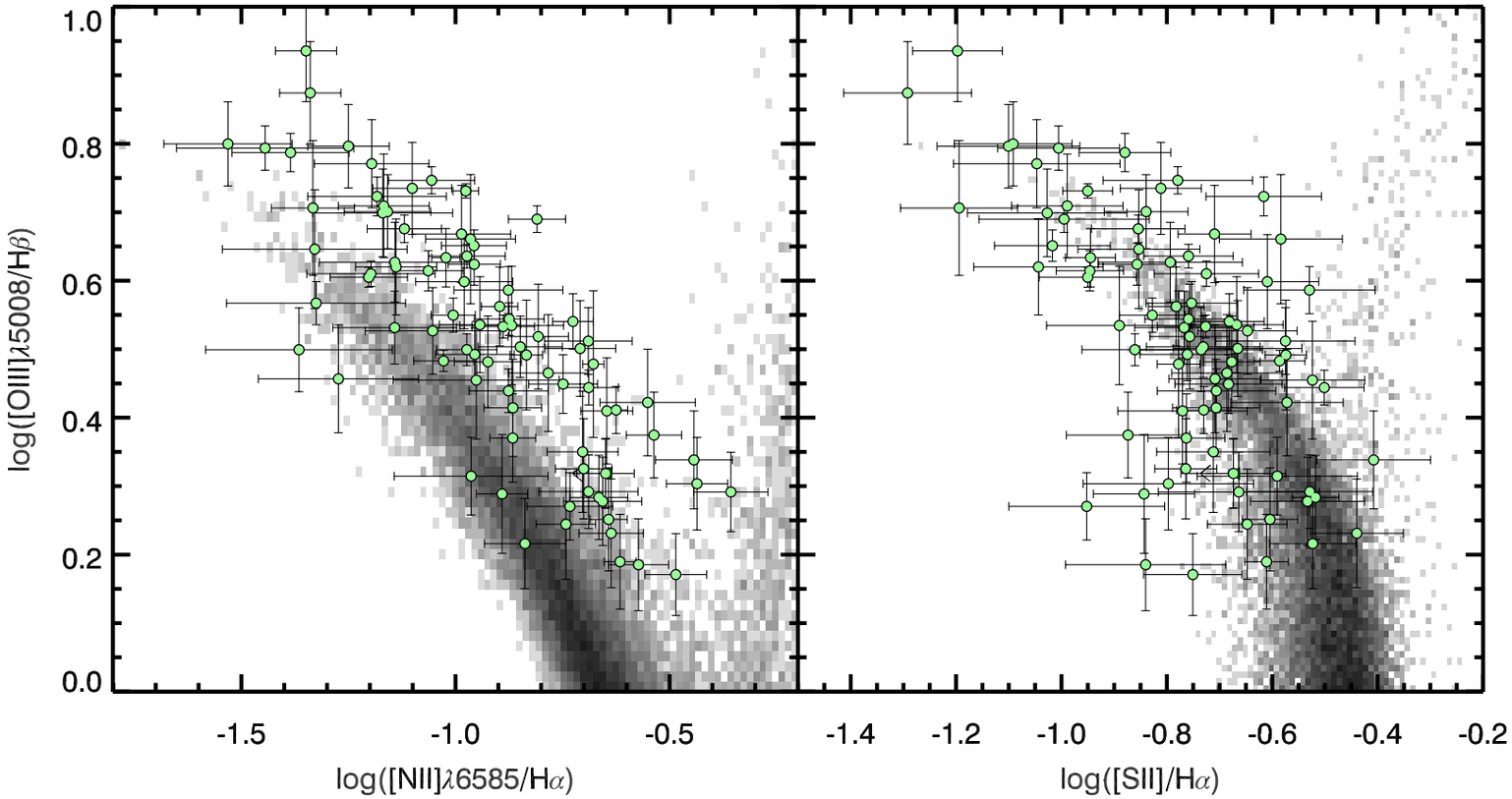
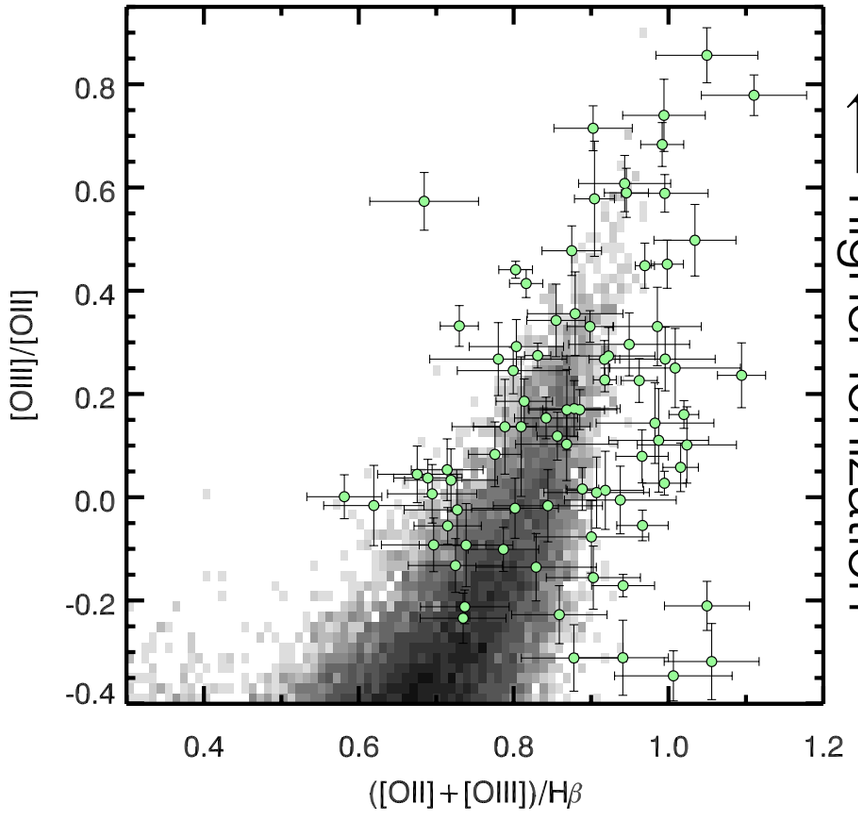
f(U, Z_{neb}) =  +  + ???

higher excitation ⟹





⟸ higher ionization

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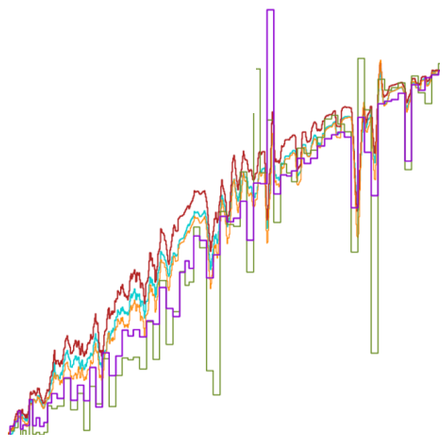
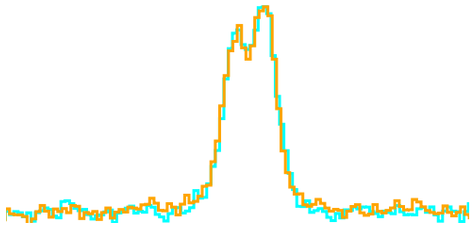
f(U, Z_{neb}) =  +  + ???

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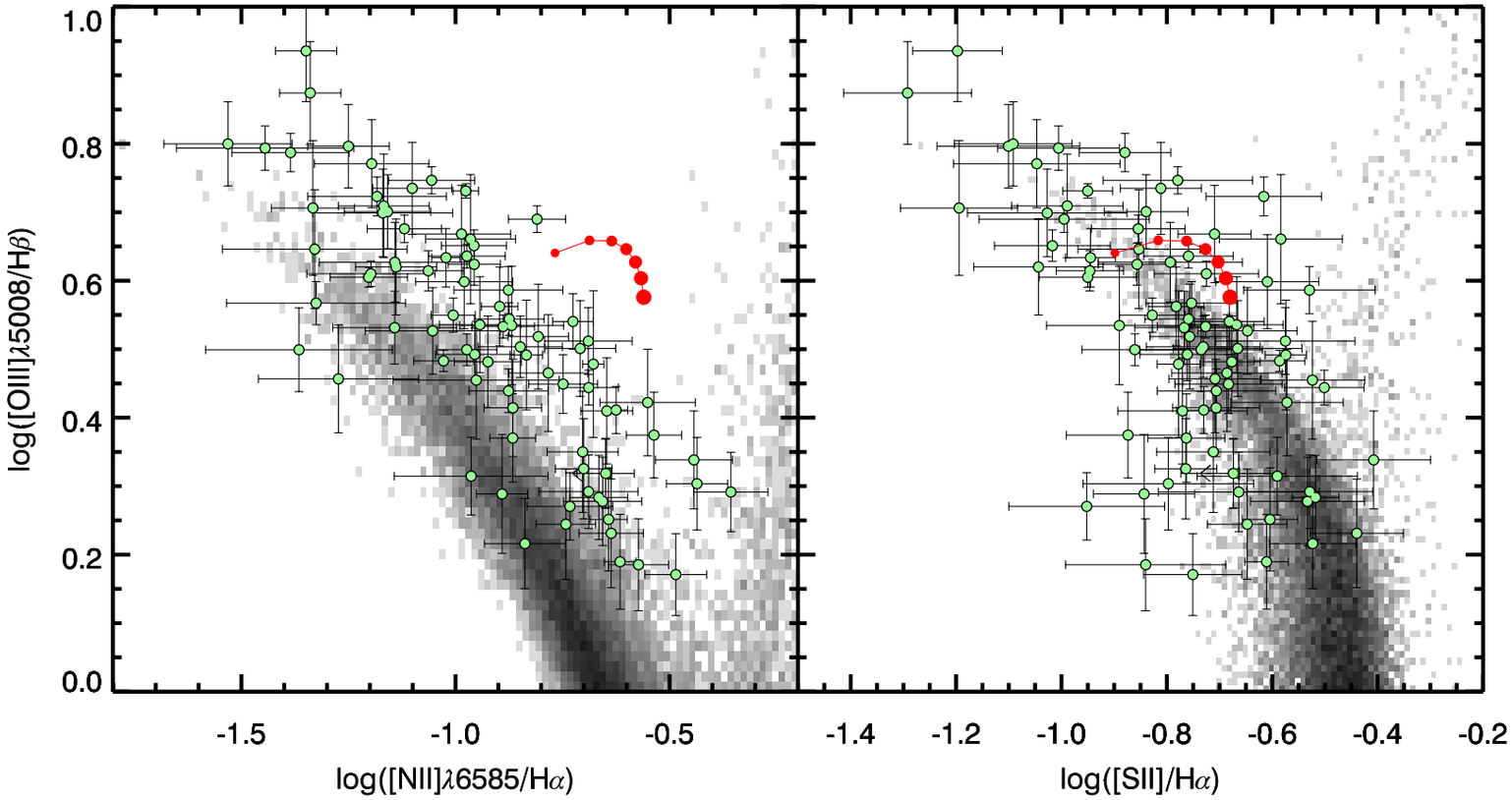

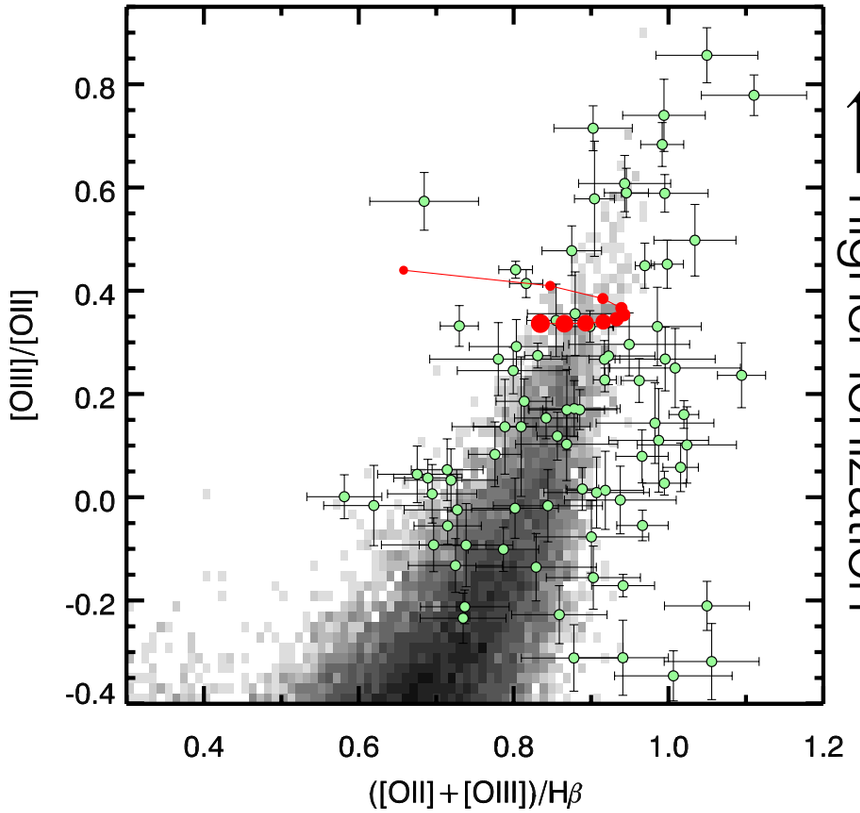

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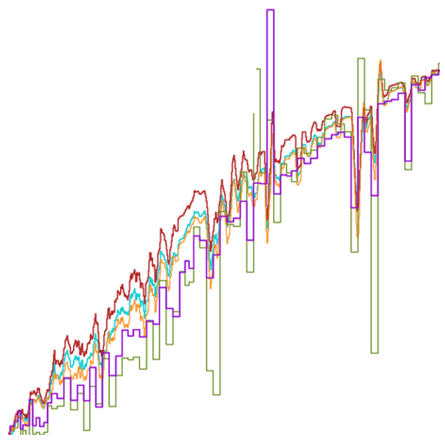

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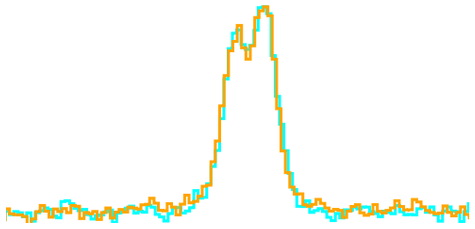

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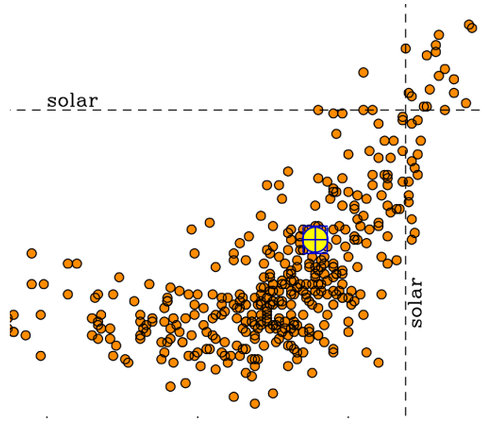

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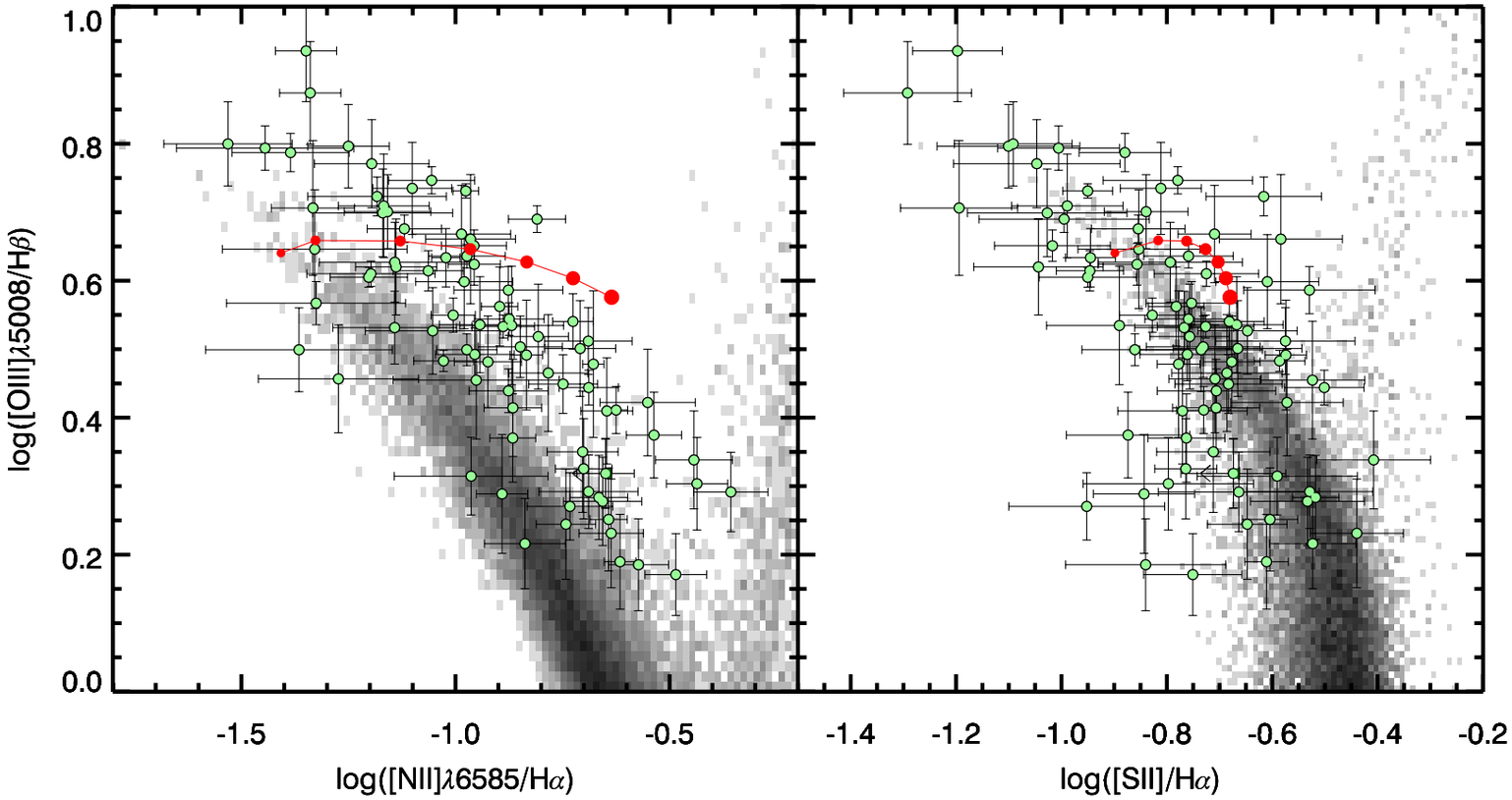

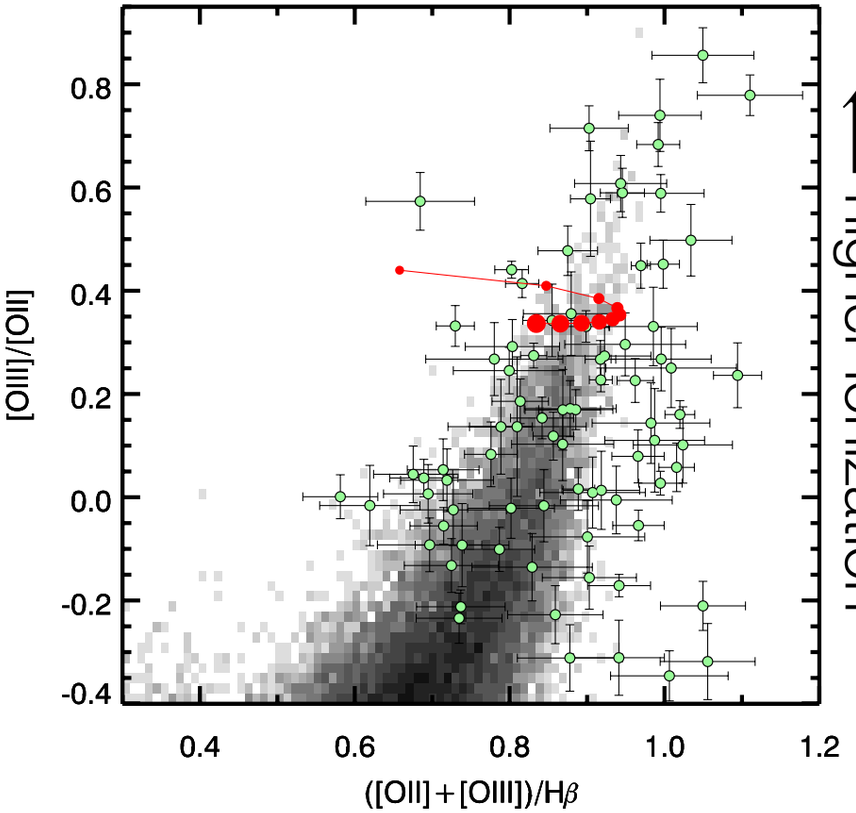

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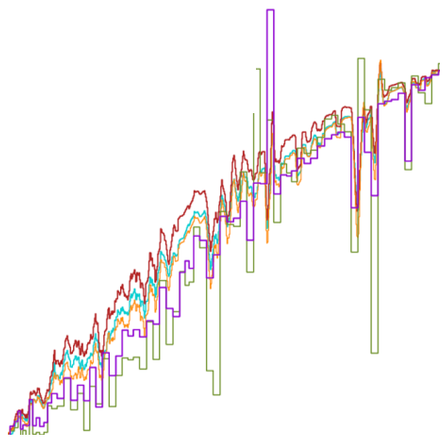

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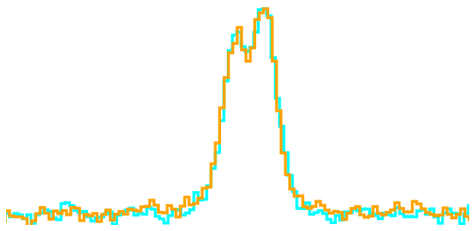

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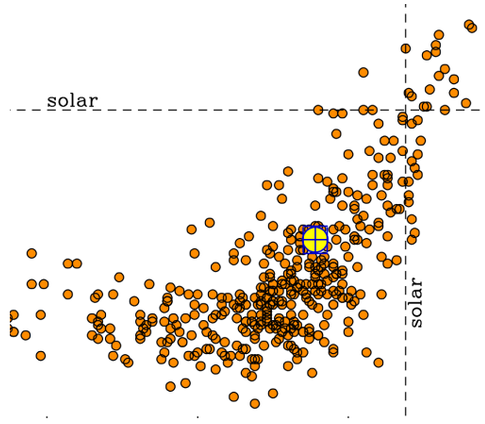

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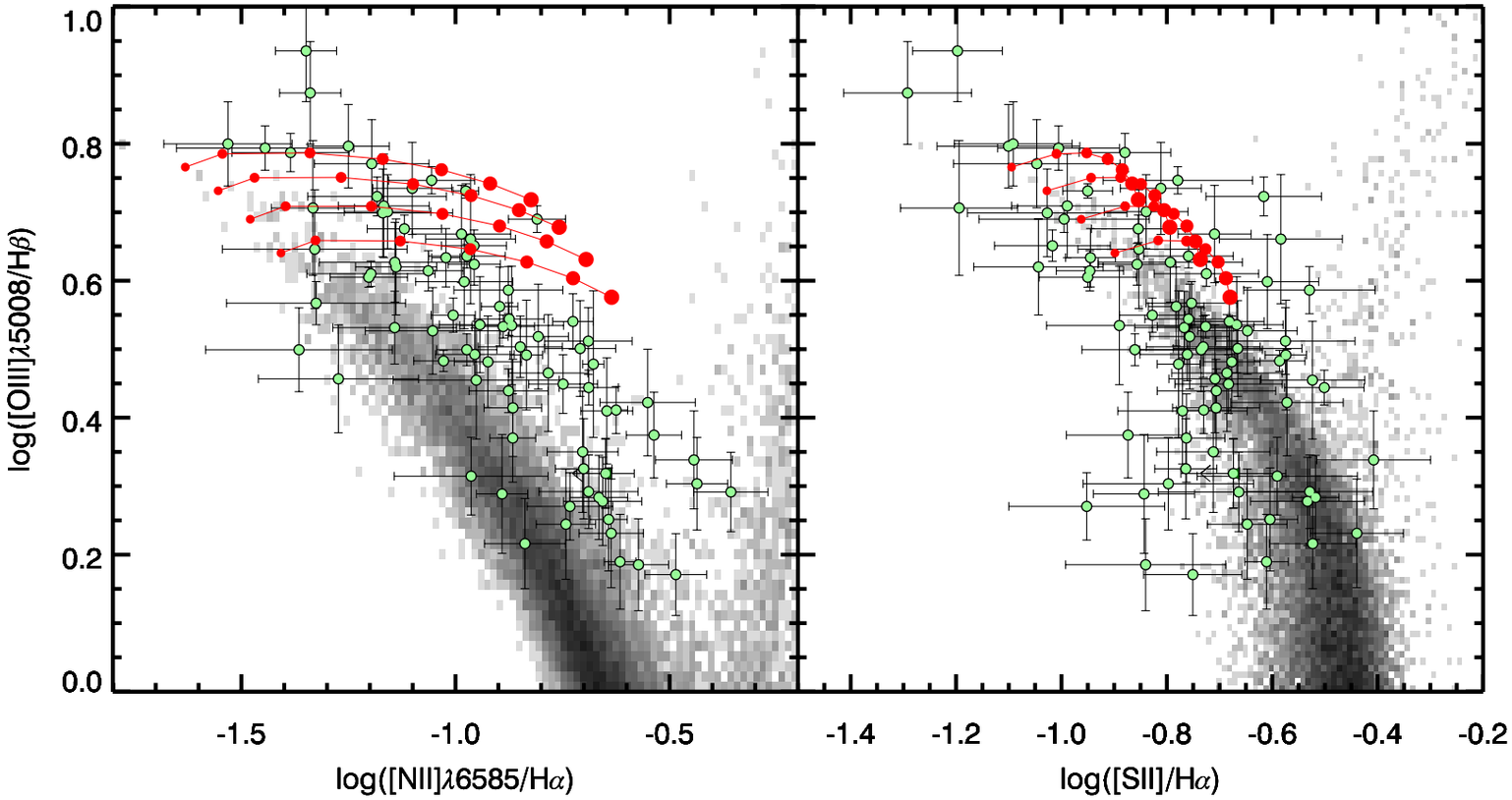

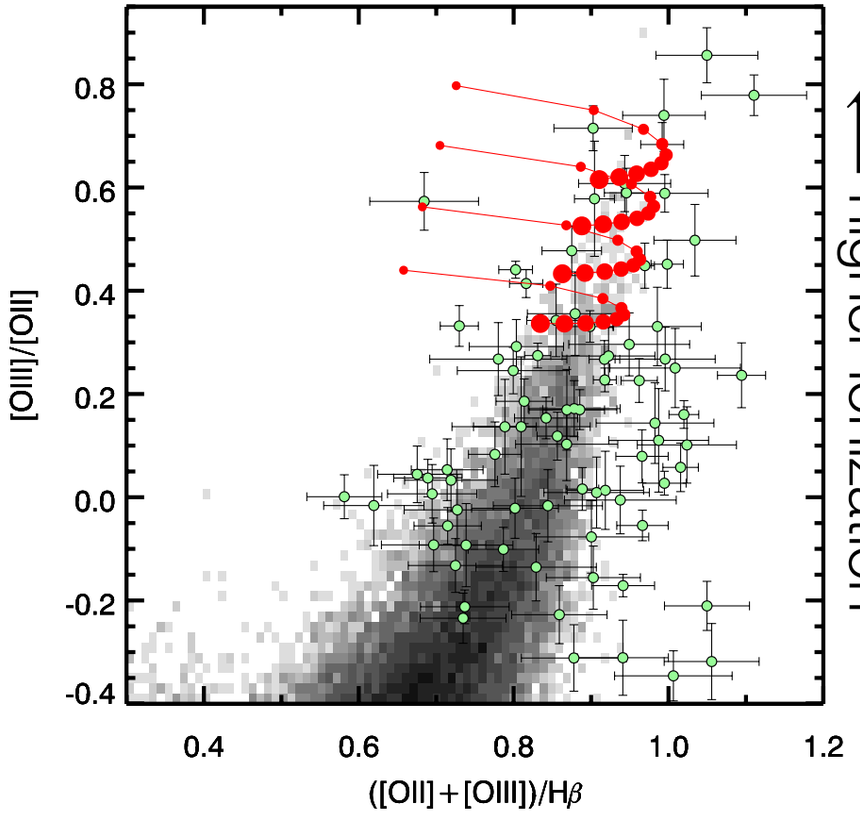

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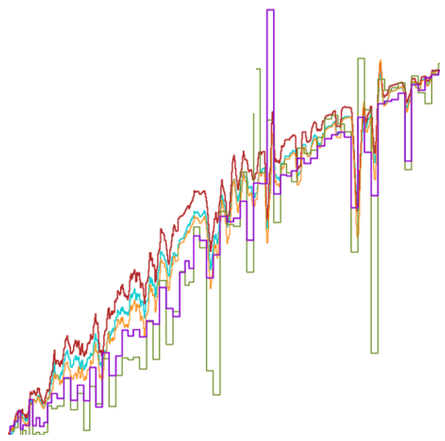

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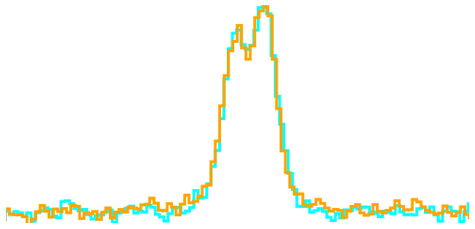

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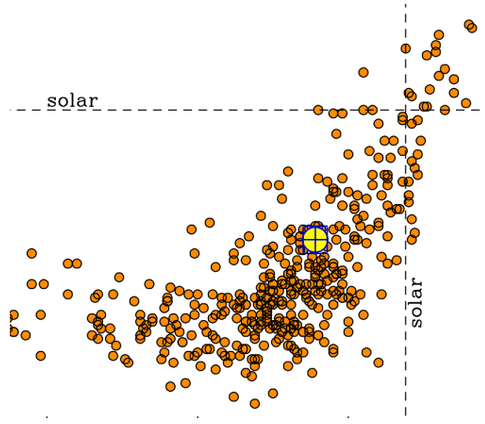

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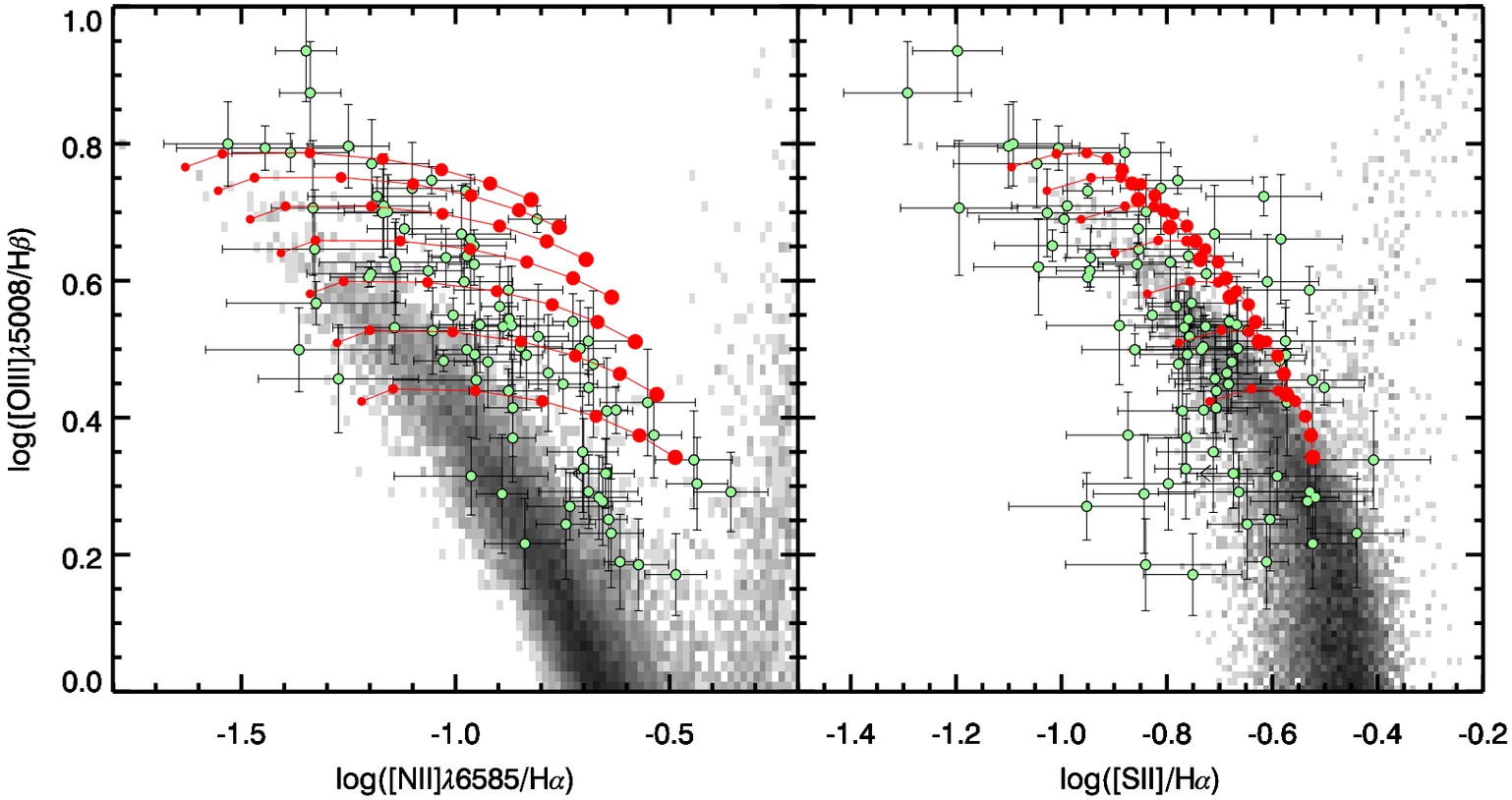

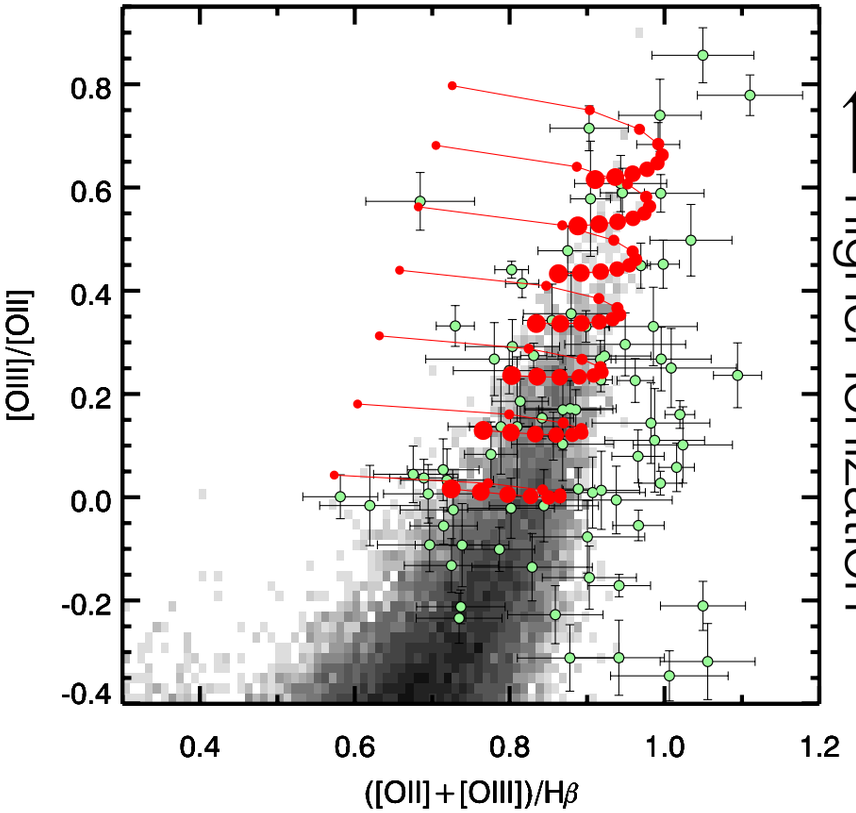

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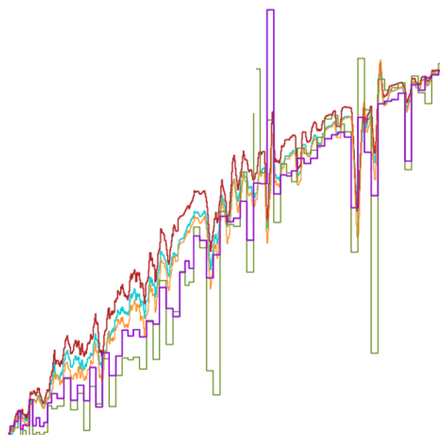

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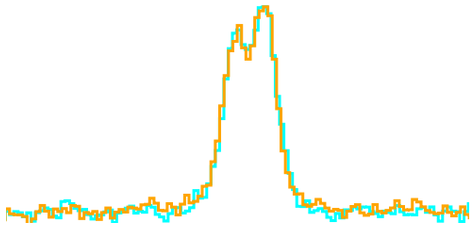

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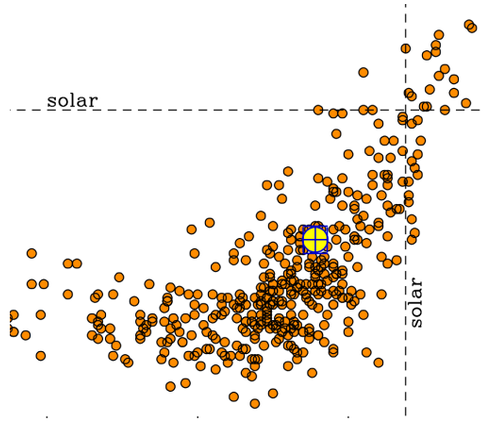

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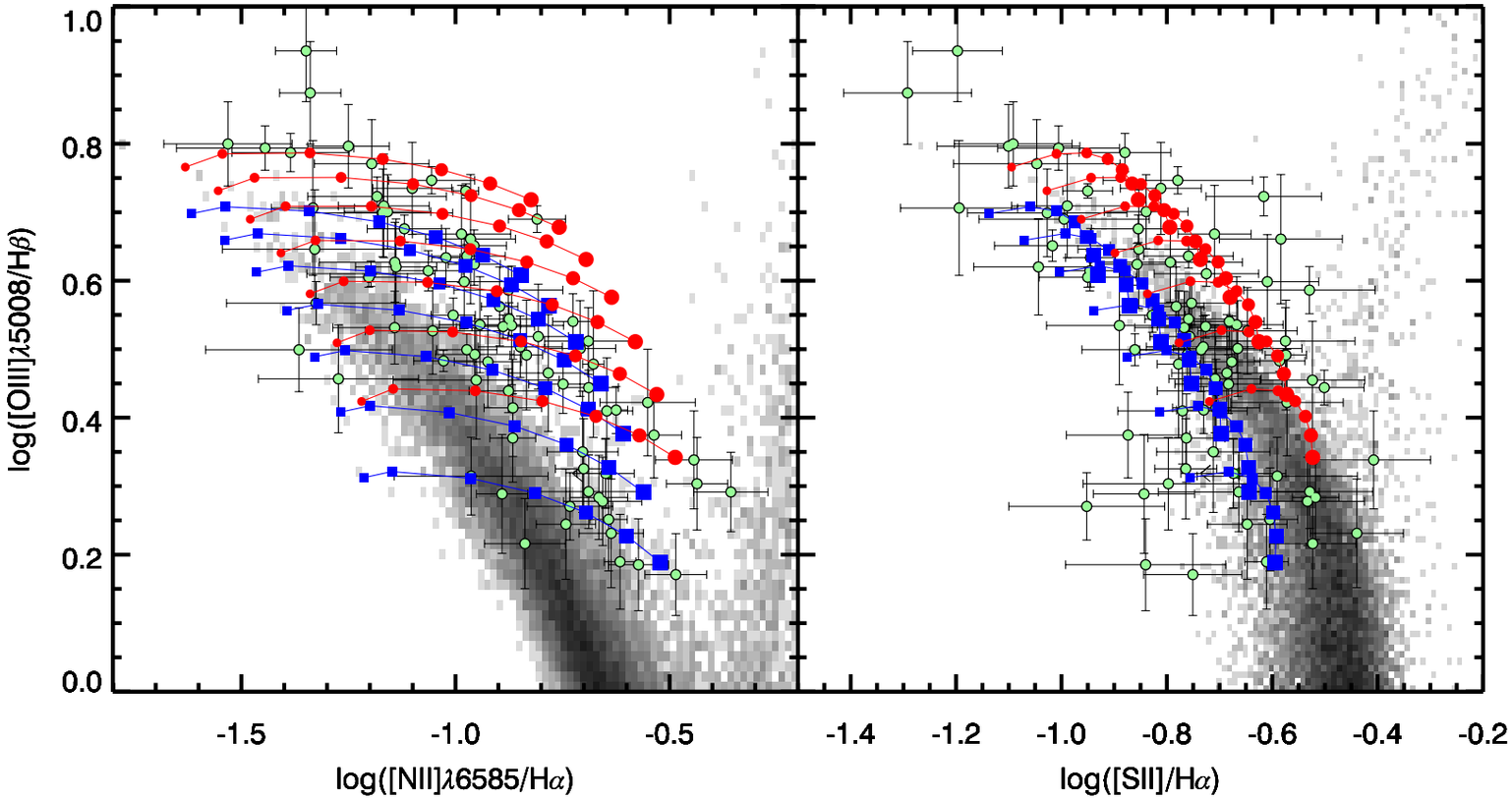

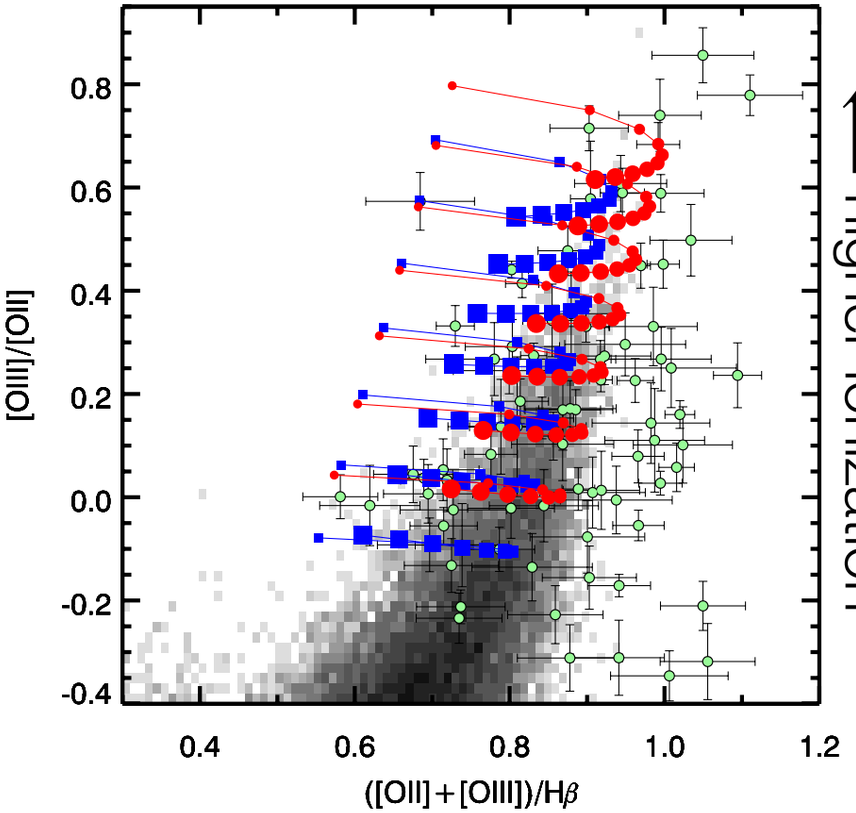

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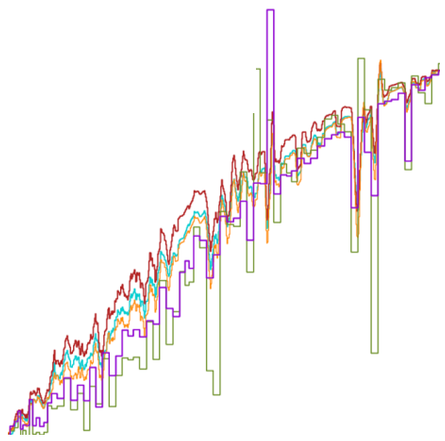

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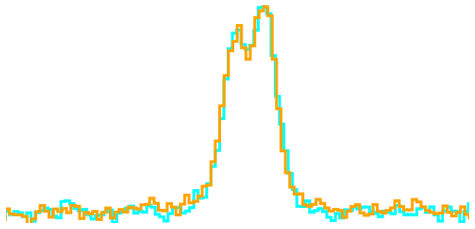

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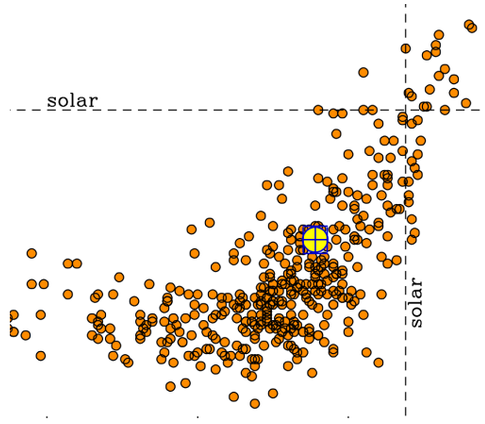
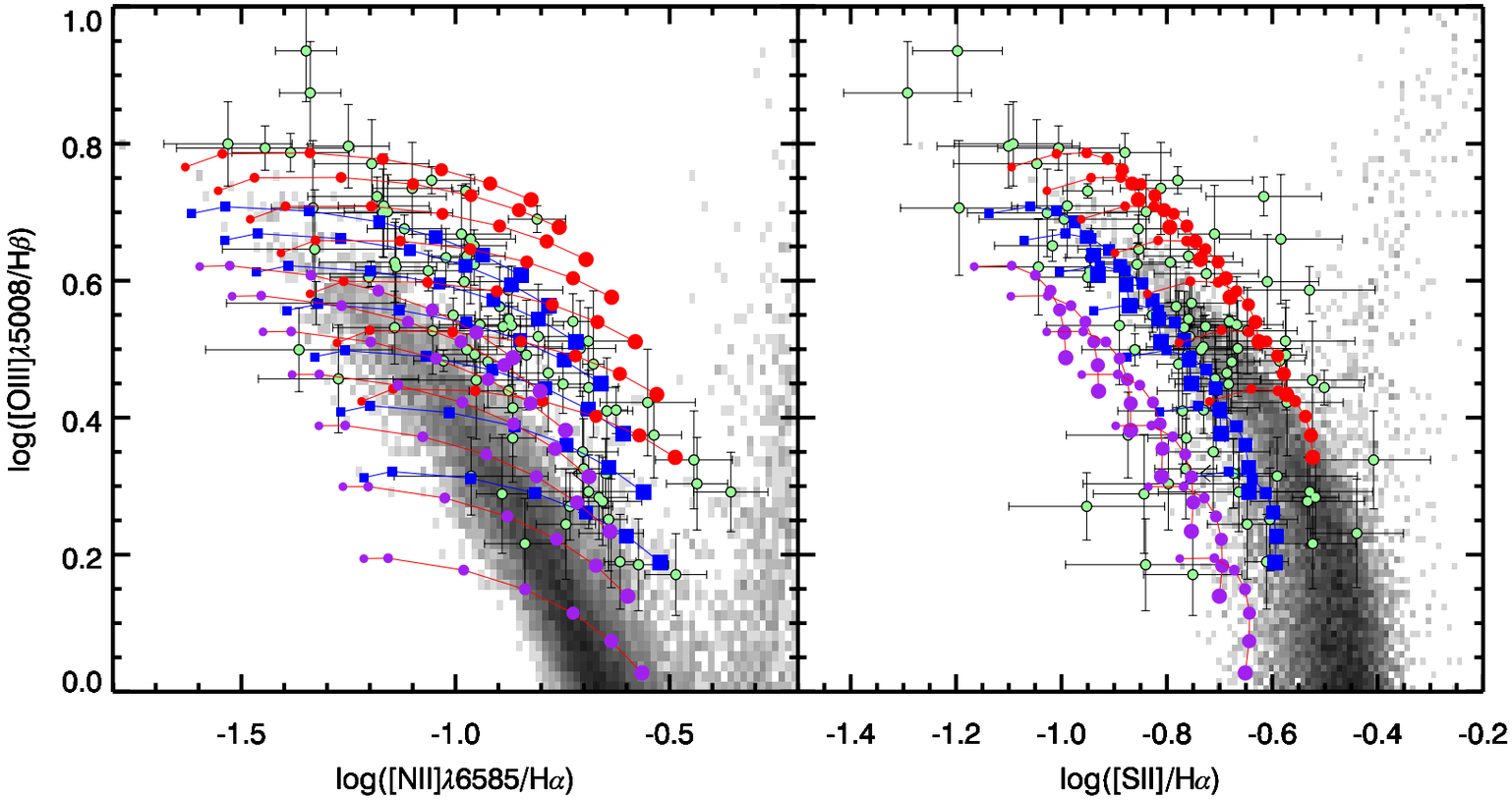
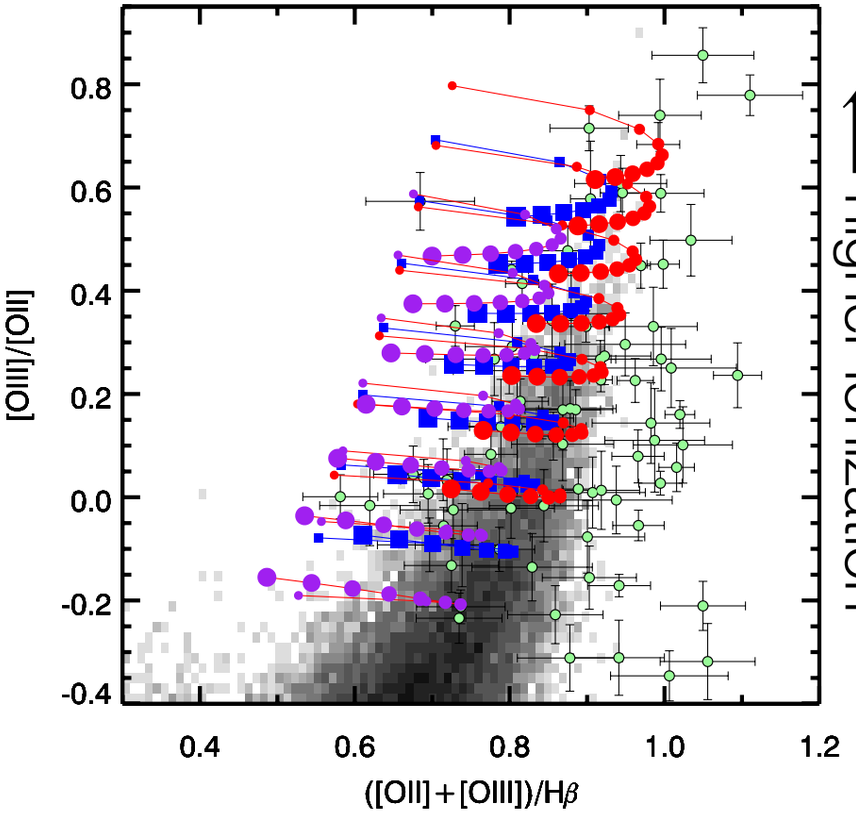


higher excitation ⟹

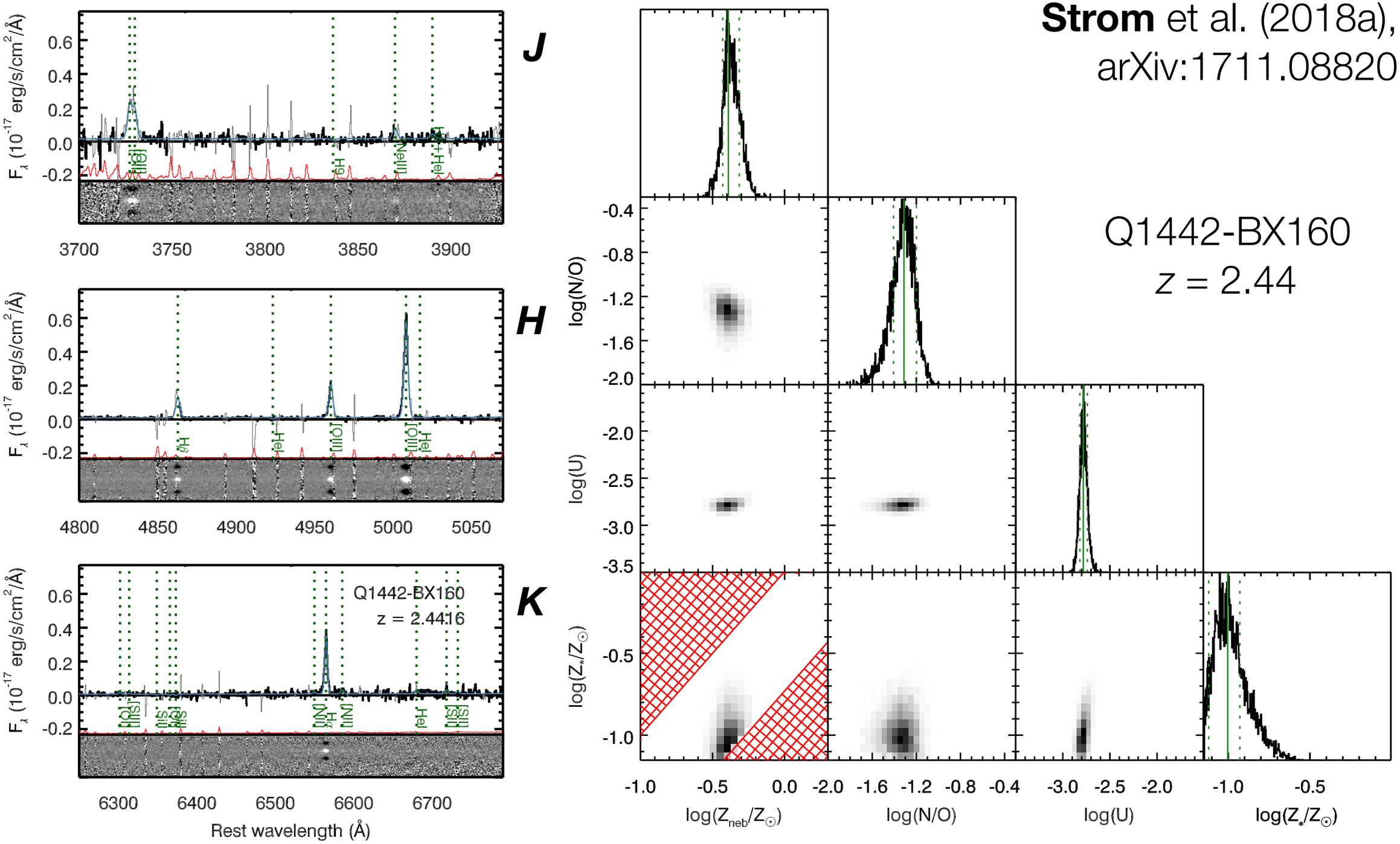




⟸ higher ionization

Allison Strom, GalFRESCA, 16 August 2018

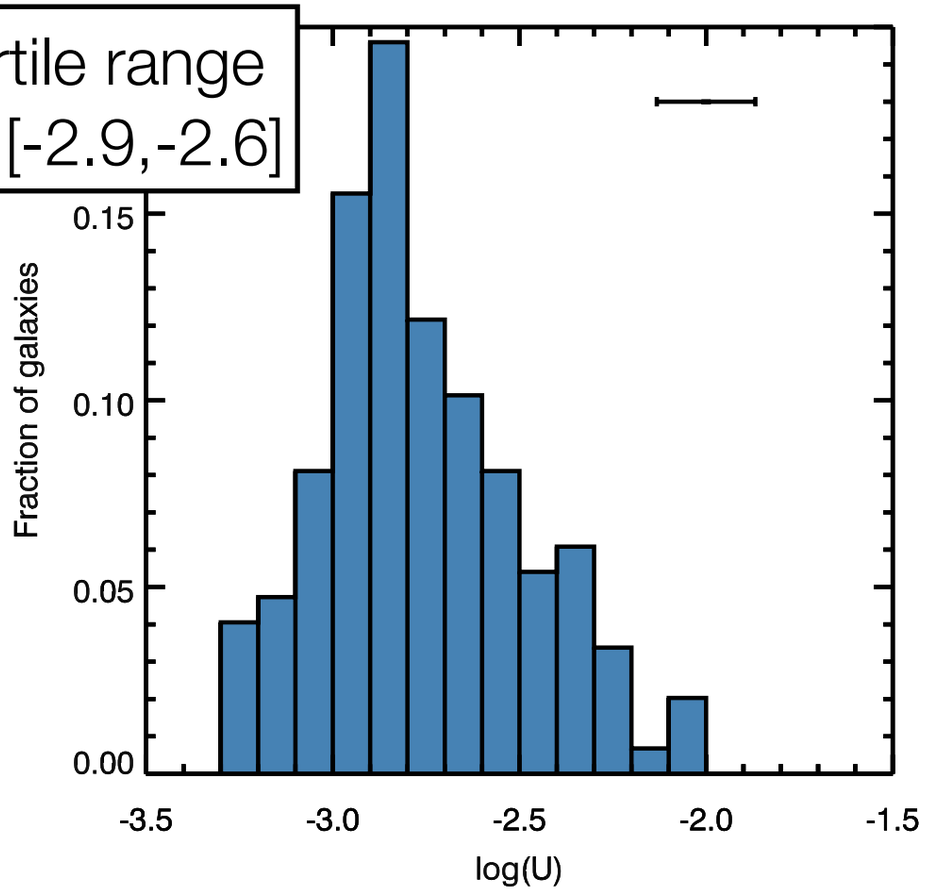
Measuring Z_{neb}, N/O, U and $Z_\star$ for individual galaxies

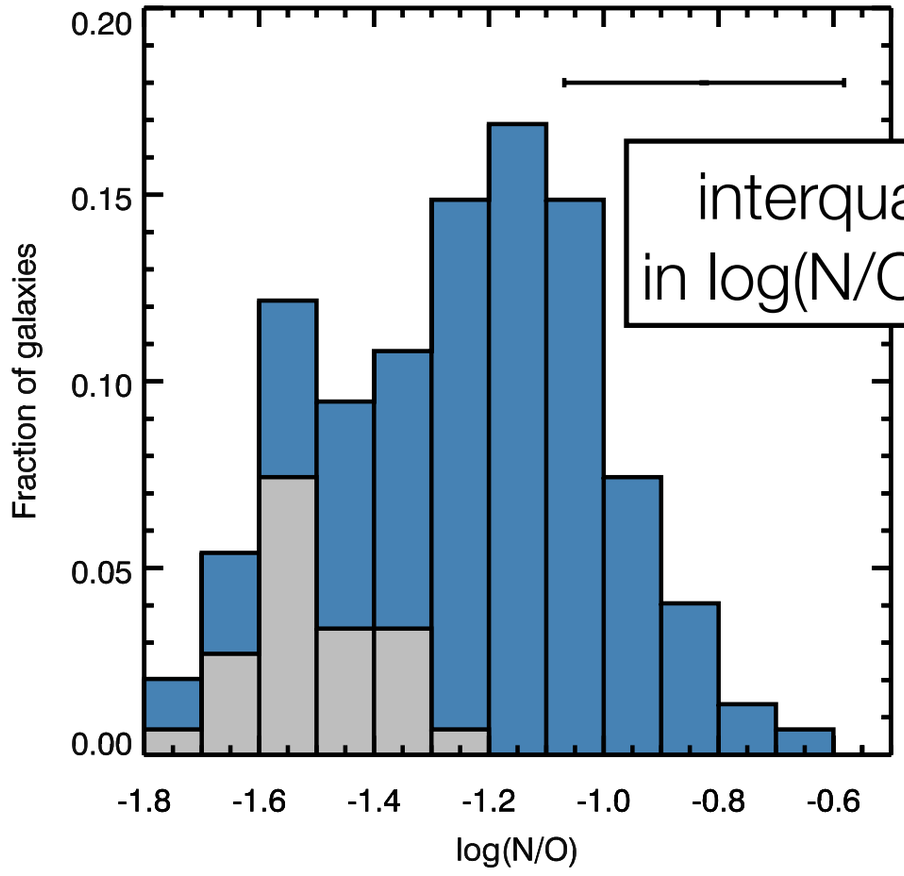


Strom et al. (2018a),
arXiv:1711.08820

Q1442-BX160
$z = 2.44$

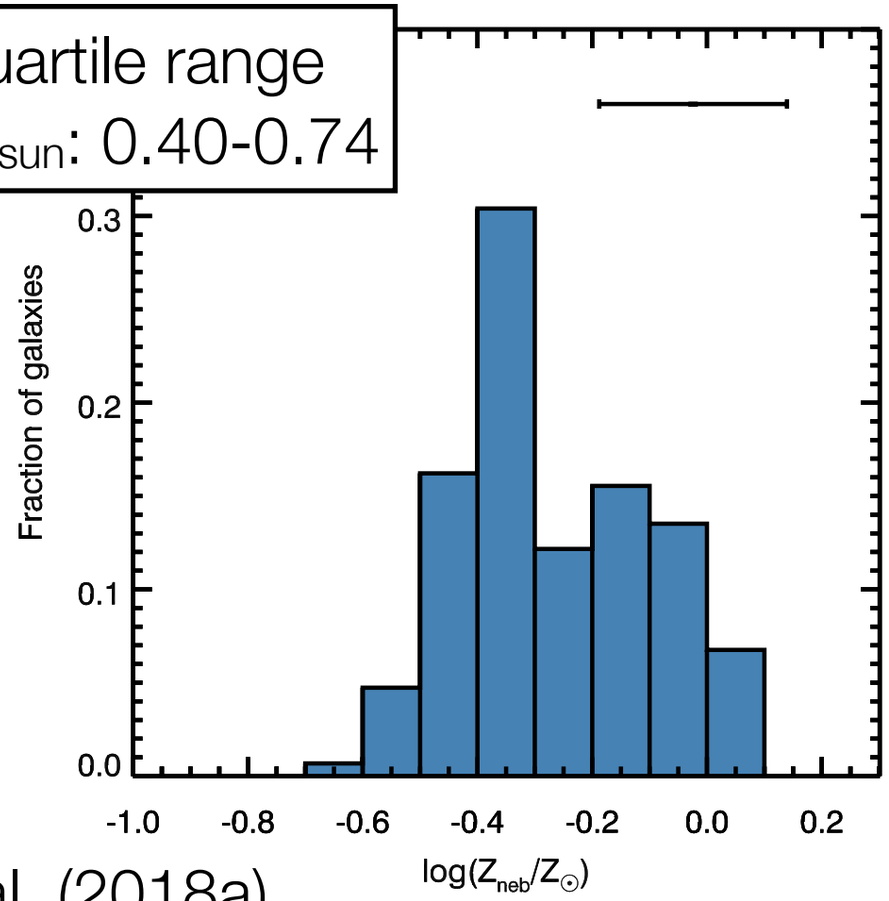
interquartile range
in log(U): [-2.9,-2.6]

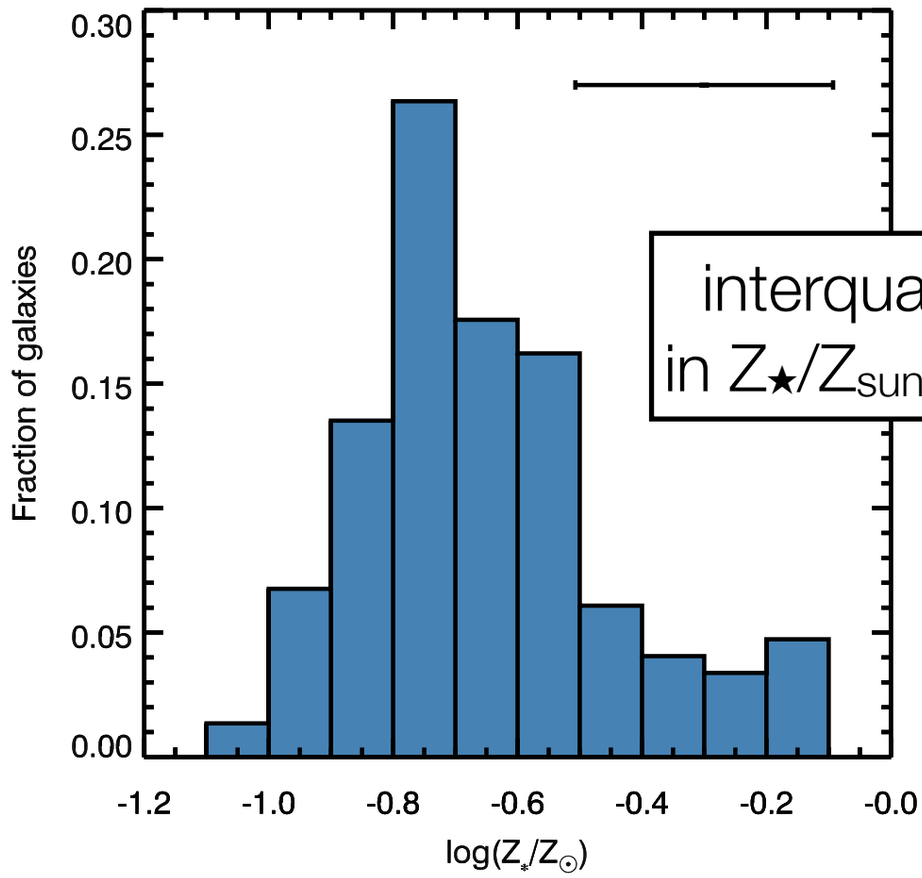




interquartile range
in log(N/O): [-1.4,-1.1]

interquartile range
in Z_{neb}/Z_{sun}: 0.40-0.74



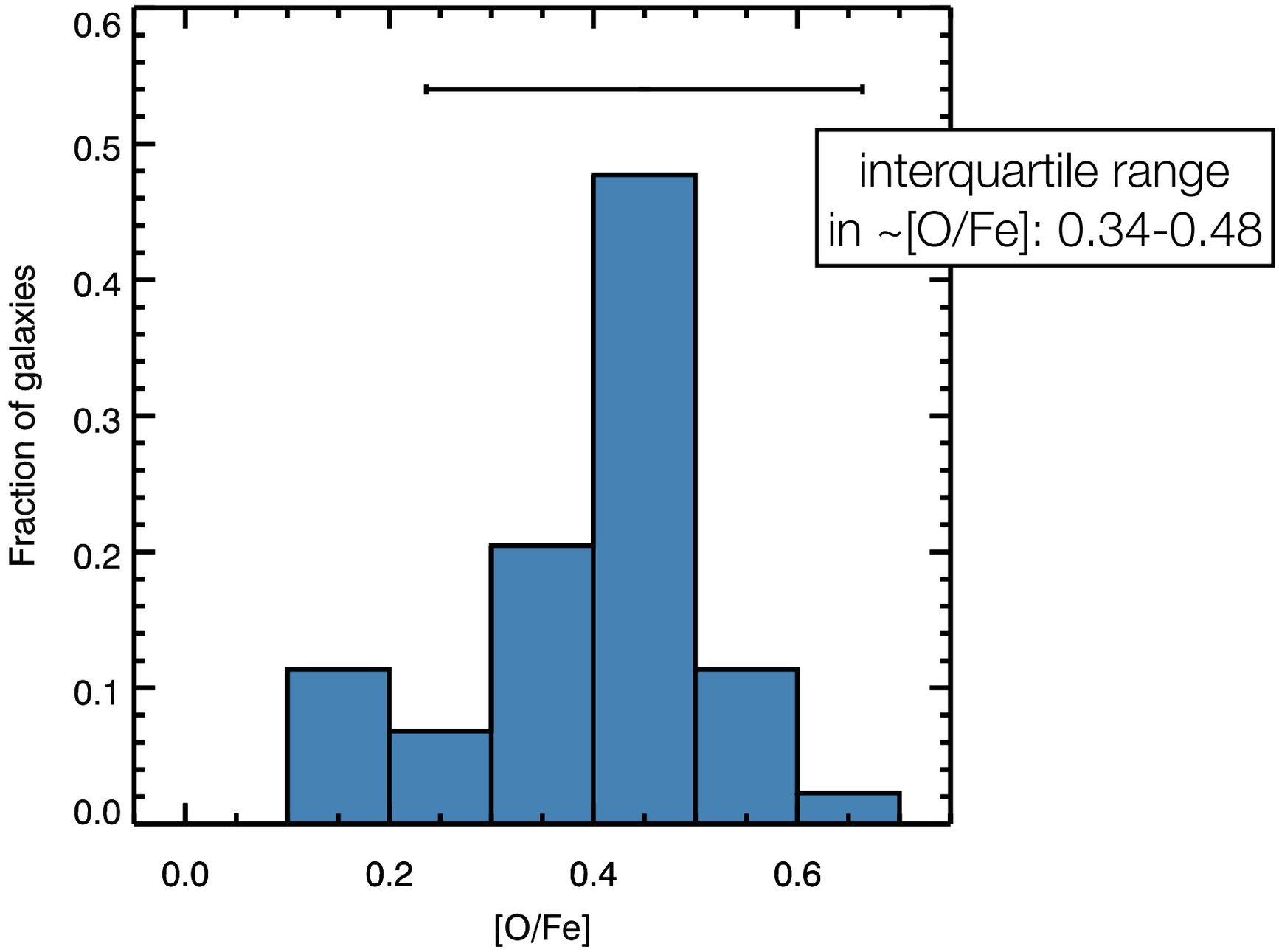


interquartile range
in $Z_{\star}/Z_{sun}$: 0.16-0.30

Strom et al. (2018a),
arXiv:1711.08820

Evidence for super-solar O/Fe in the ISM of high-z galaxies

Strom et al. (2018a), arXiv:1711.08820

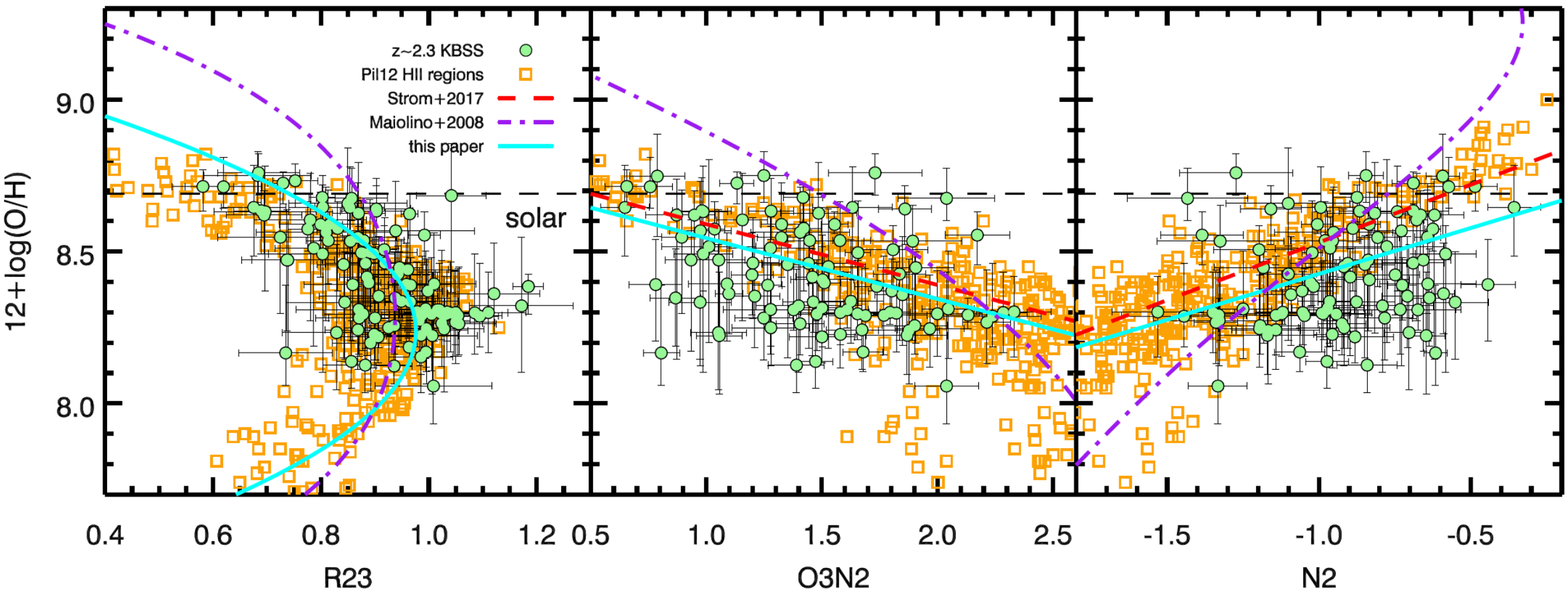


Allison Strom, GalFRESCA, 16 August 2018

Common strong-line indices are less sensitive to O/H

Strom et al. (2018a), arXiv:1711.08820

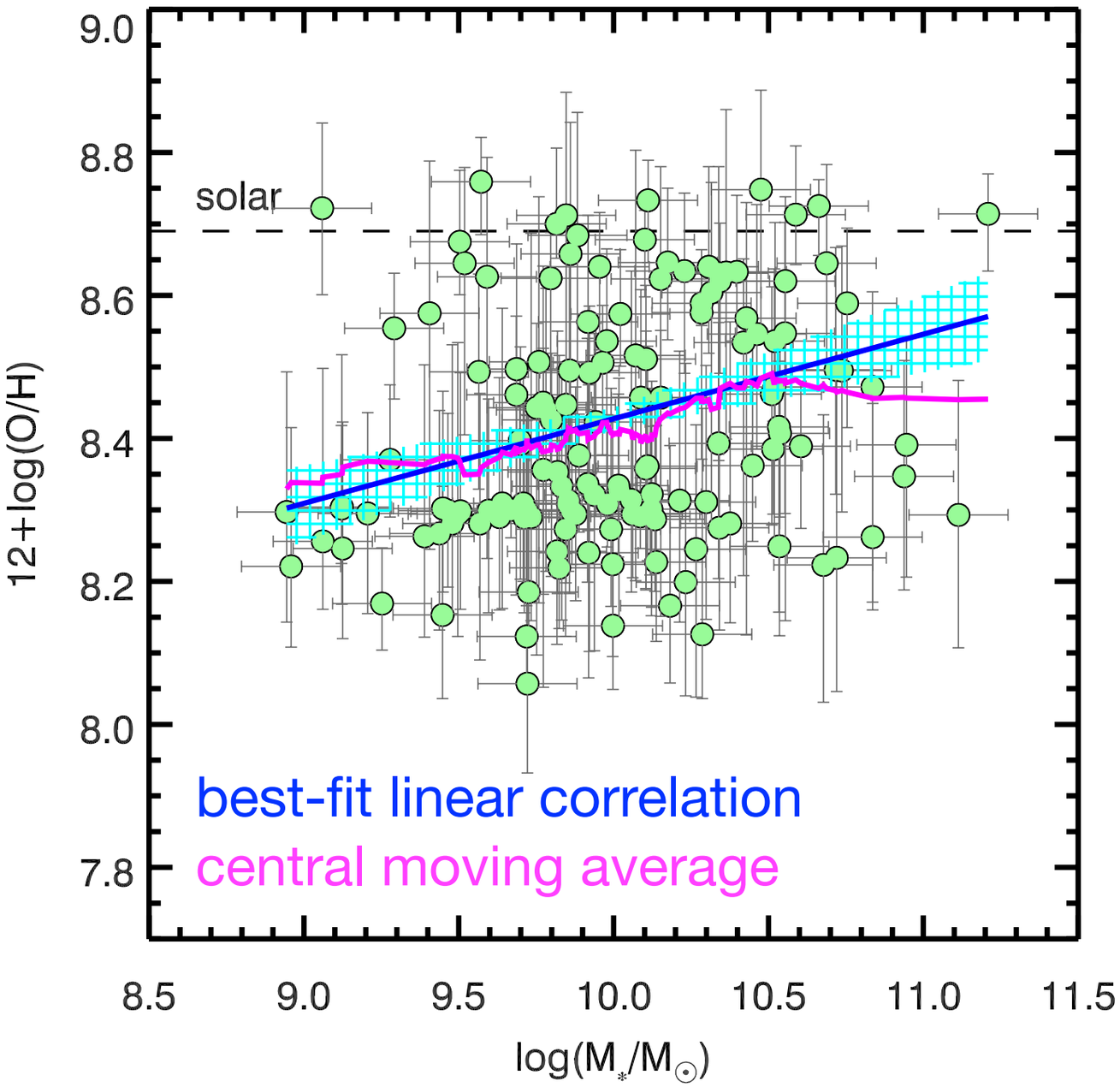
Maiolino+2008
Strom+2017 (based on *z*~0 HII regions)
calibrations from this work



There are still important differences in the way the **nebular spectra of high-*z*** galaxies respond to physical conditions compared to **local HII regions**

The z~2 mass-"metallicity" relation is shallow with moderate scatter

Strom et al. (2018b, in prep.)



Spearman ρ = 0.25, 2.9σ

Accounting for measurement uncertainties:

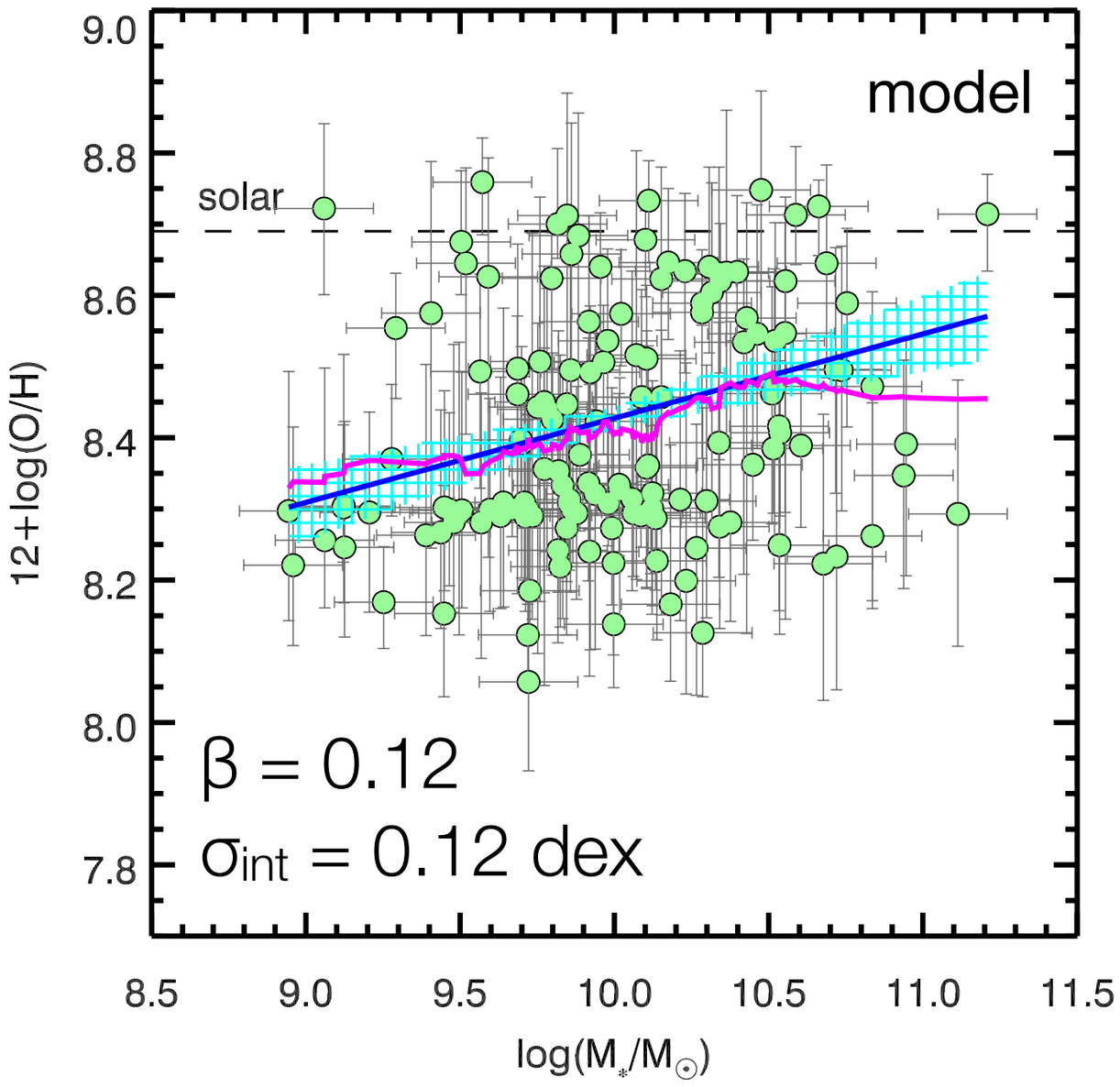
ρ = 0.41 (99.8% confidence)

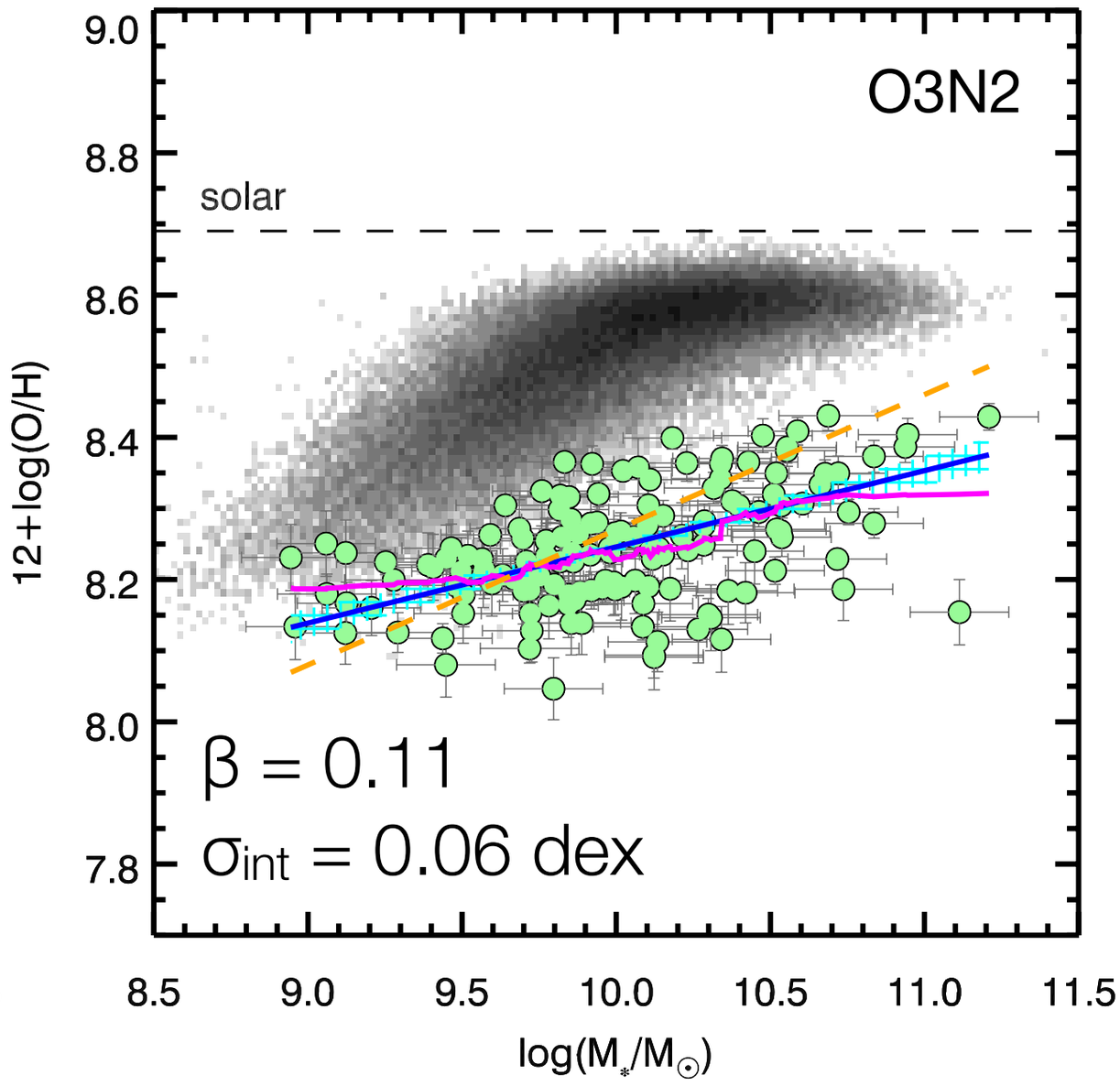
β = 0.12

σ_{int} = 0.12 dex

Strong-line indices result in relation with much lower scatter

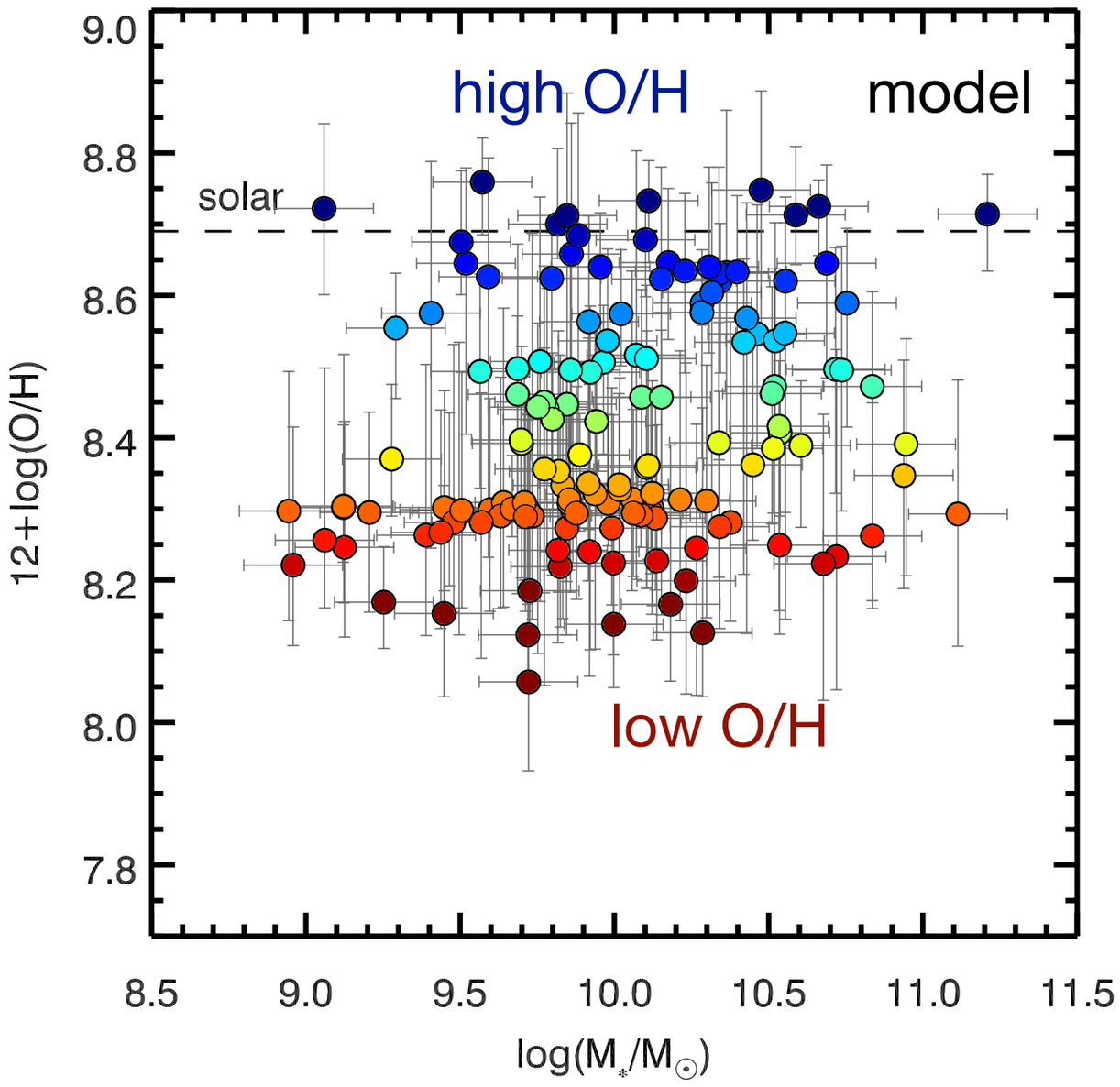
Strom et al. (2018b, in prep.)

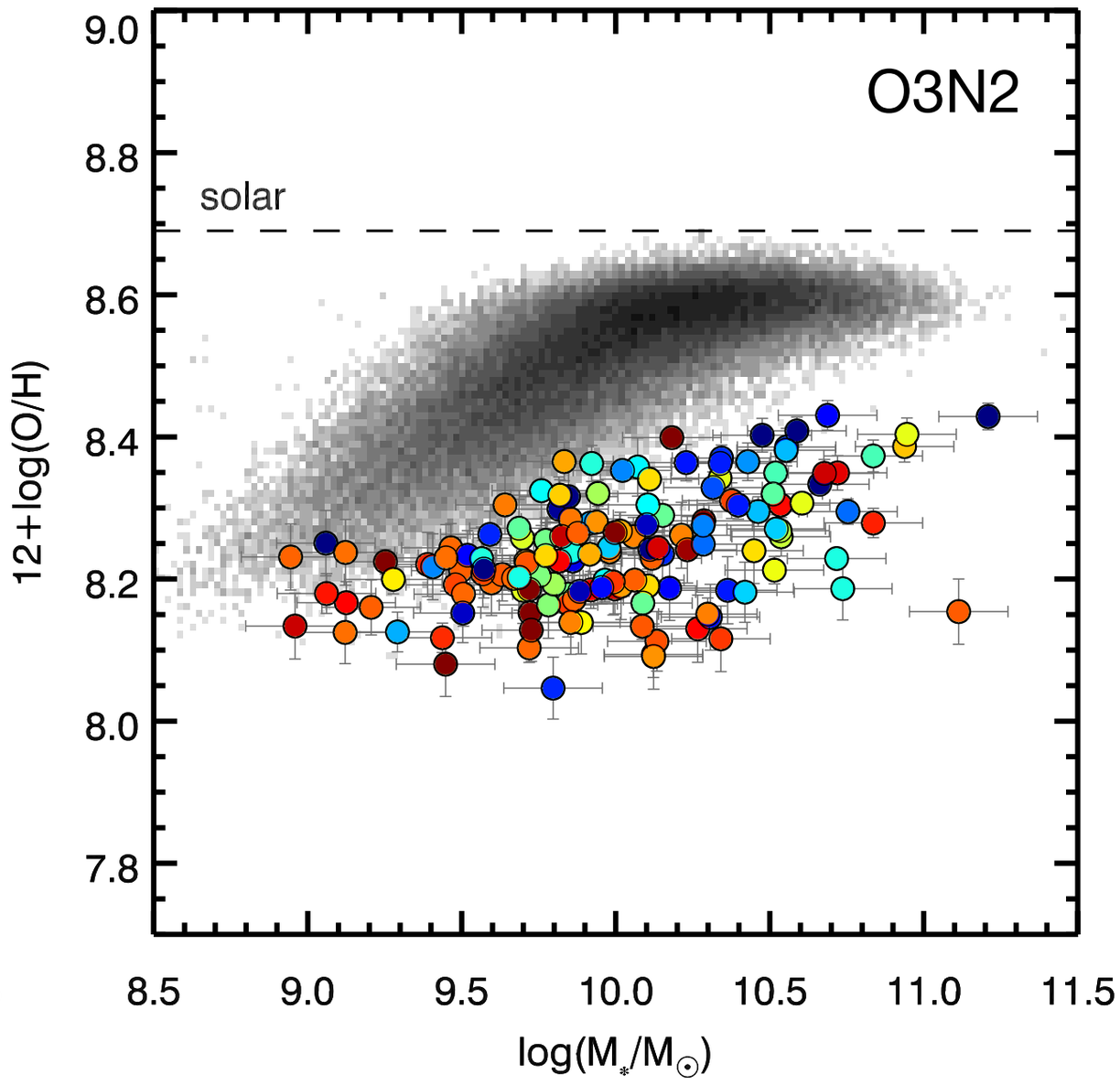




Common strong-line indices are tracing more than just O/H

Strom et al. (2018b, in prep.)





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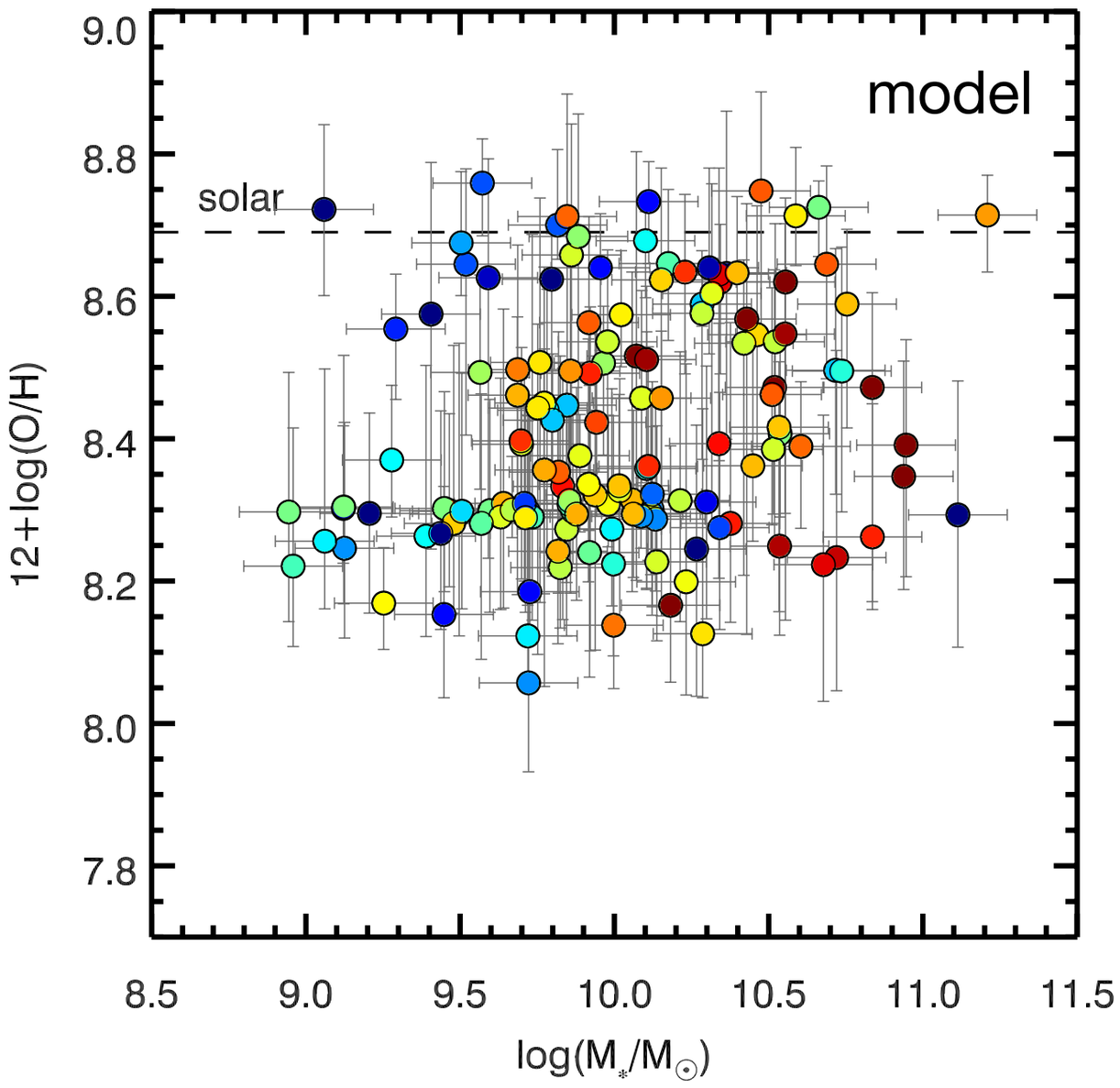

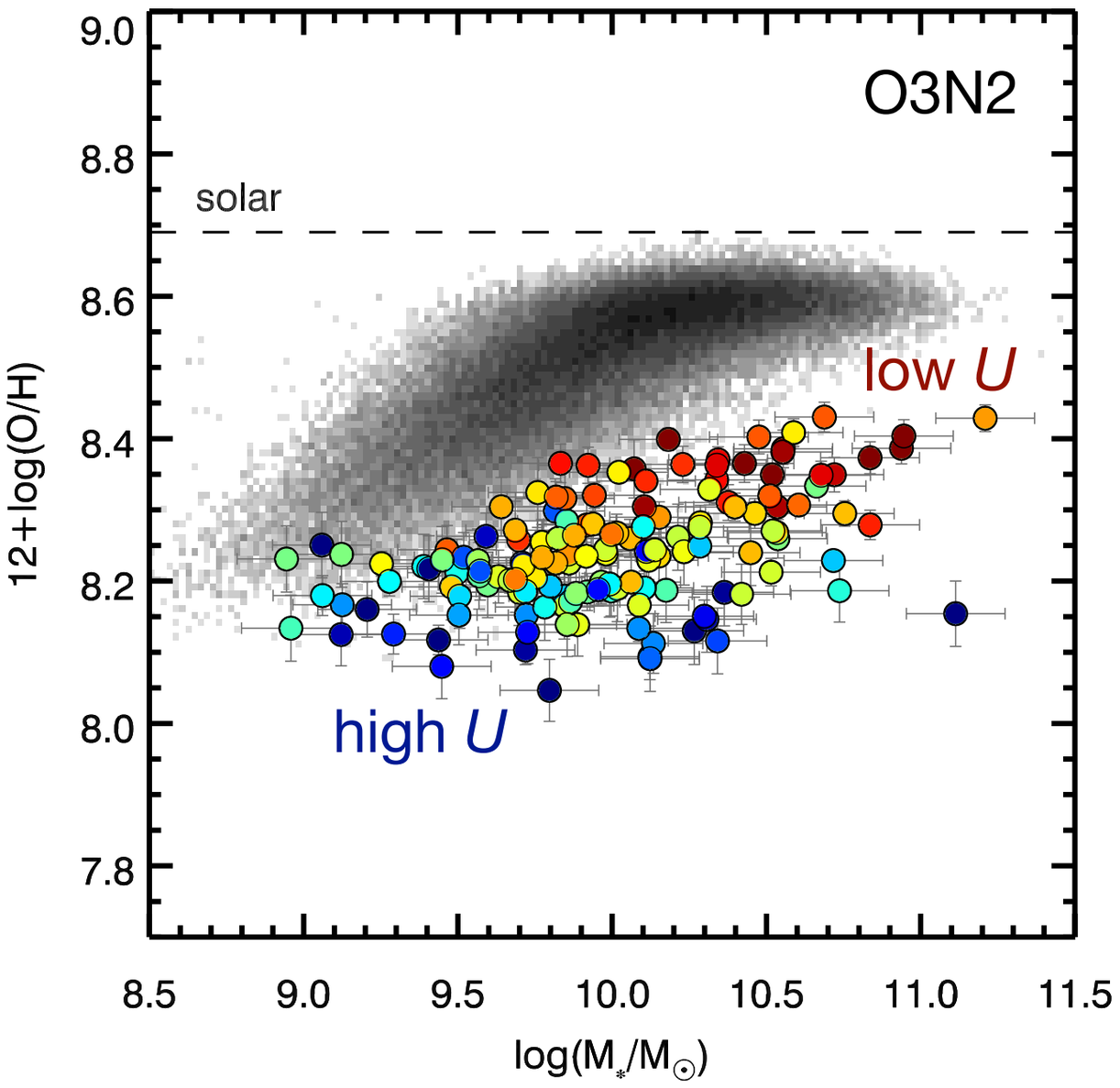

Credit: A. L. Strom and T. A. Rector

What to keep in mind

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Know what you mean when you say “metallicity”!