Credits: ESO/L. Calçada

New avenues to indirectly study the nature of the first stars

A. Saccardi, S. Salvadori, V. D'Odorico et al.

2023, ApJ, 948, 35

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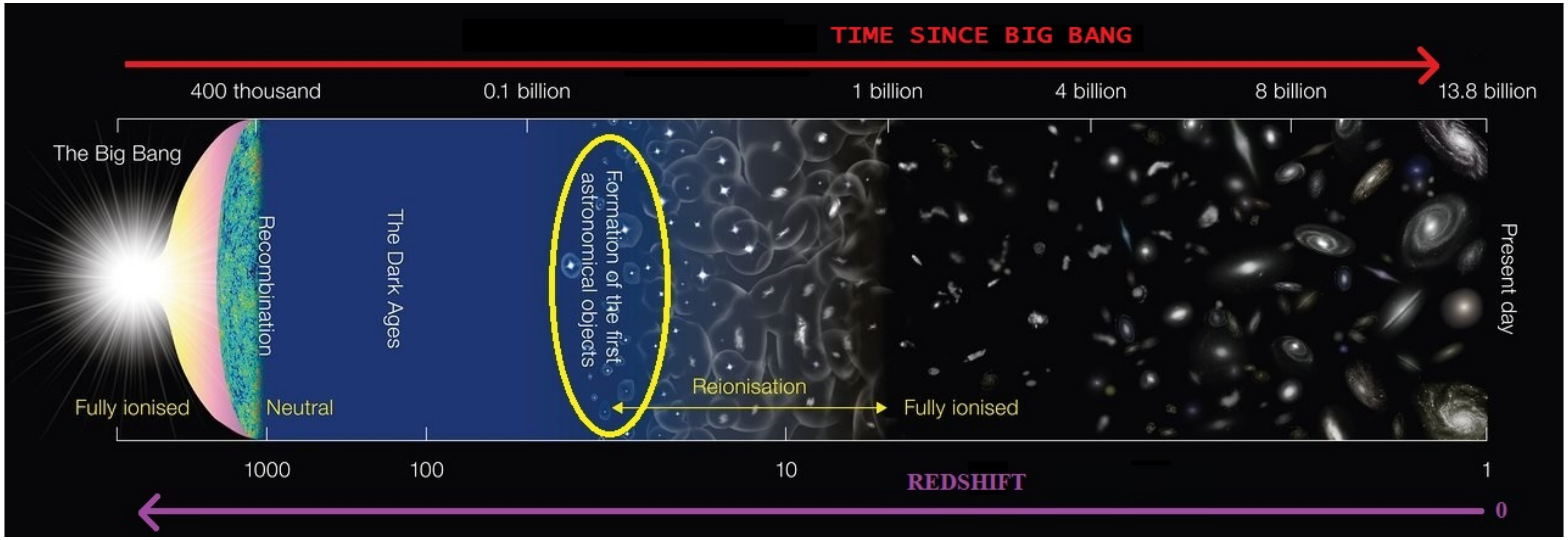
Focus Week - IFPU
Trieste 15-19 May

Why the chemical signatures of the first stars?

According to the ΛCDM cosmological model, the first stars formed ~200 million years after the Big Bang, i.e. at redshift z~20



Credits: ESO

<u>Population III stars are the earliest sources of:</u>

- Photons which ionize hydrogen
- Chemical elements heavier than H, He, Li, Be

The descendants of the first stars

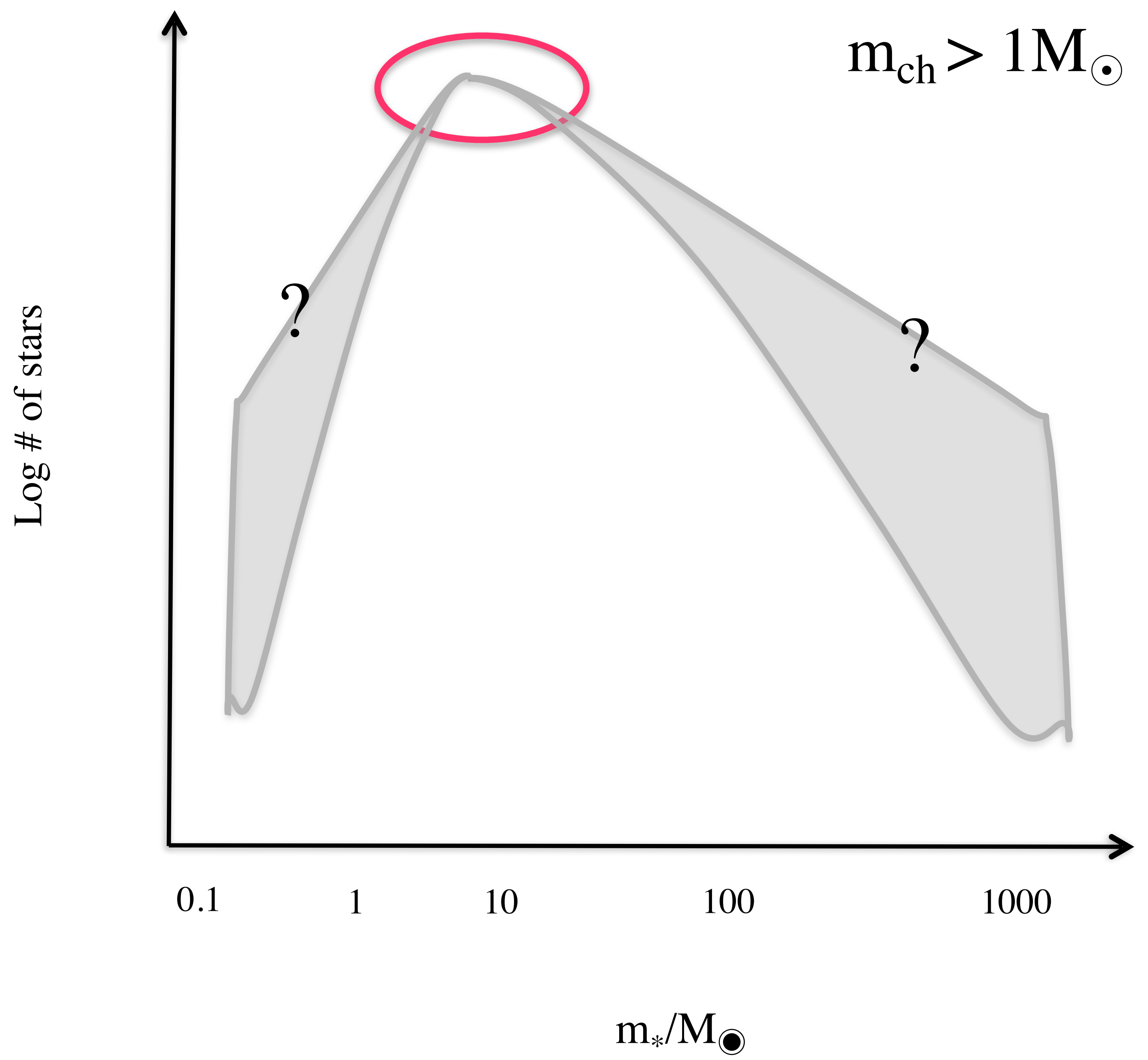
Credits: Courtesy of S.Salvadori

$Z_{ISM} = 0$

The chemical products of the first stars pollute the surrounding gas

First Stars

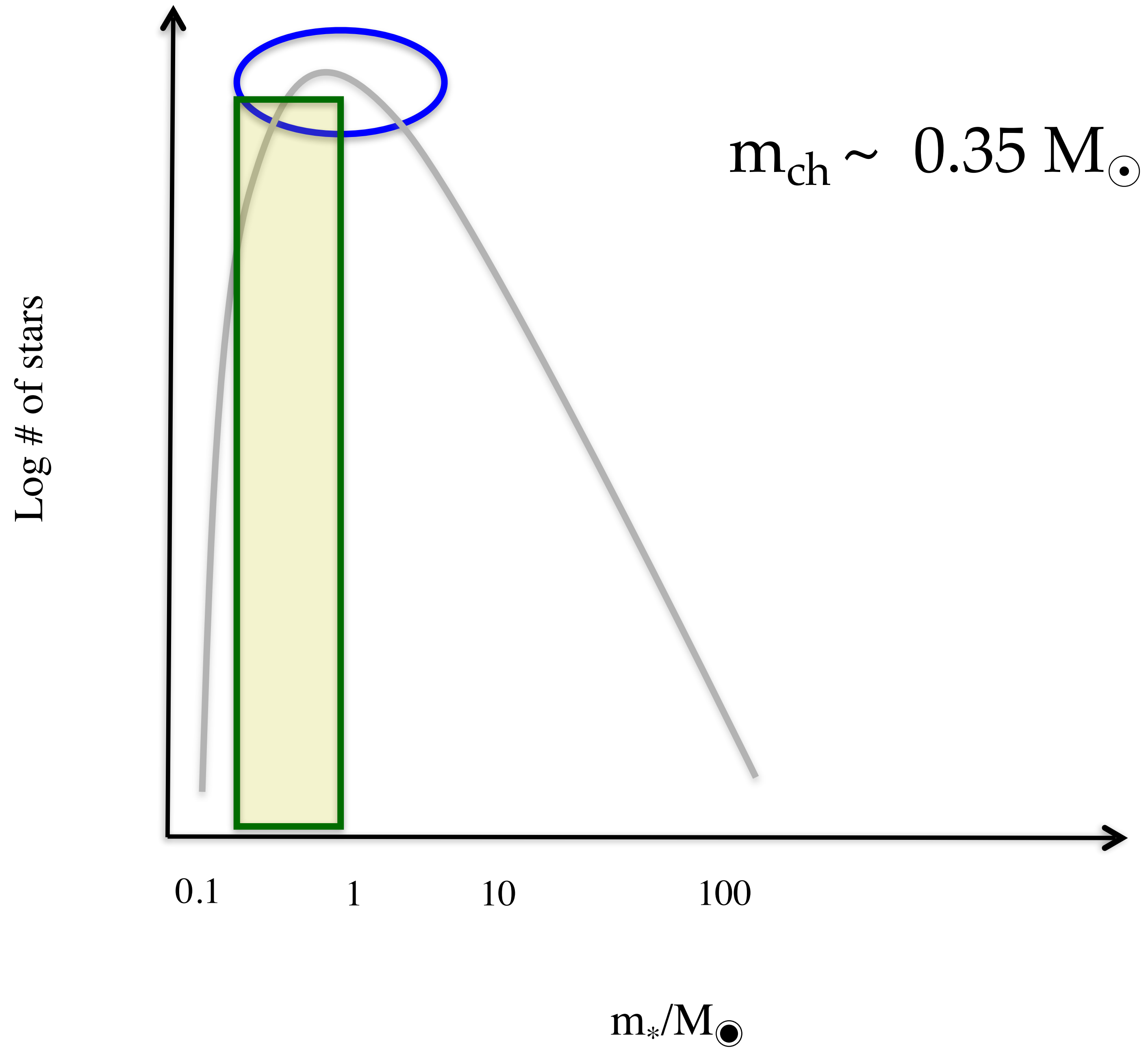
Present-Day Stars



Metals and Dust

$Z_{cr} = 10^{-5\pm1} Z_\odot$

e.g. Bromm+01; Omukai+01/05; Schneider+02/10



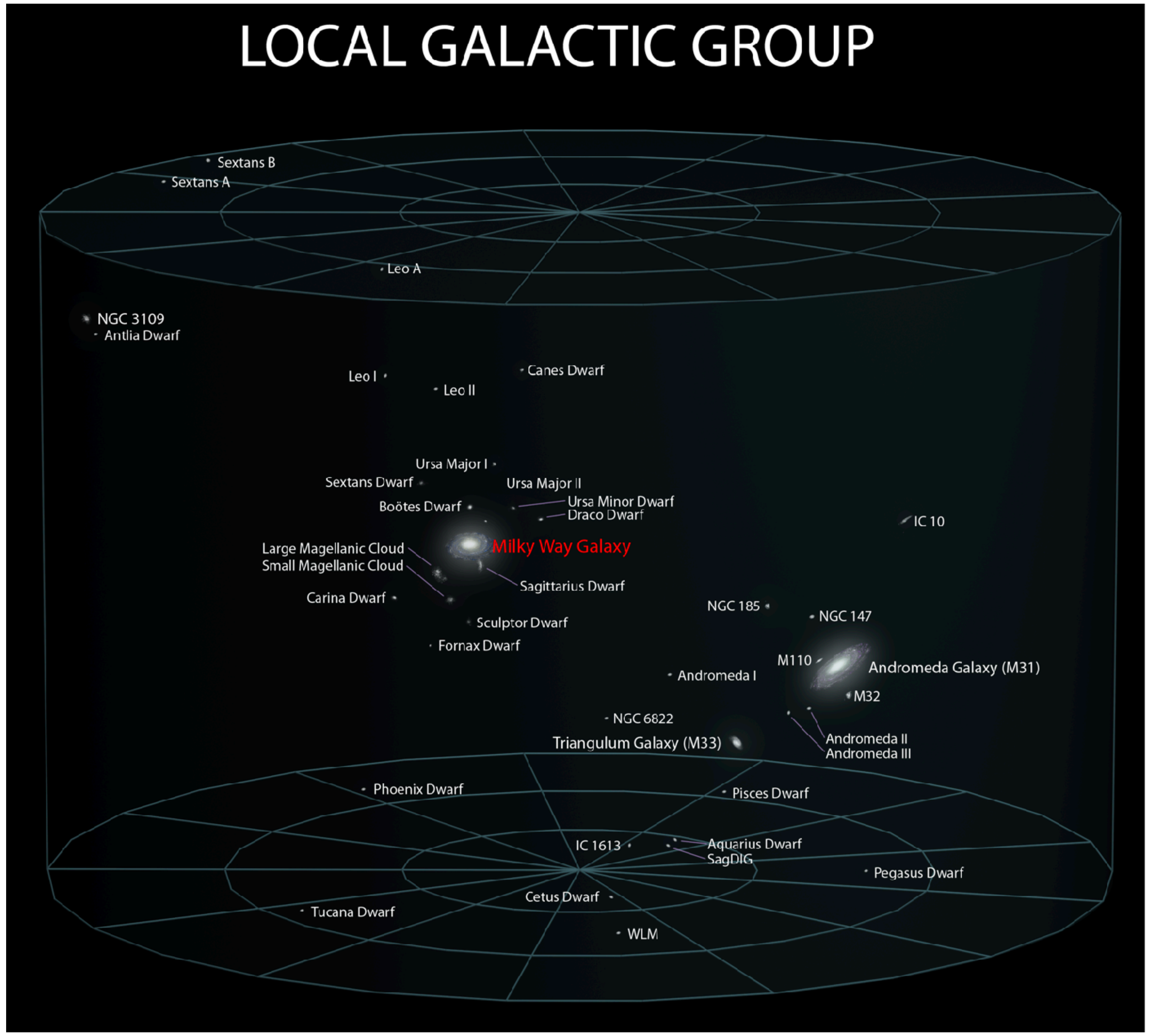
DO NOT SURVIVE UNTIL NOW!

$\tau_* > 14 \times 10^9$ **years**

OBSERVABLE!

First stars chemical signatures

Ancient stars poor of heavy elements formed from gas polluted by the first stars → **STELLAR ARCHAEOLOGY**



Credits: Andrew Z. Colvin

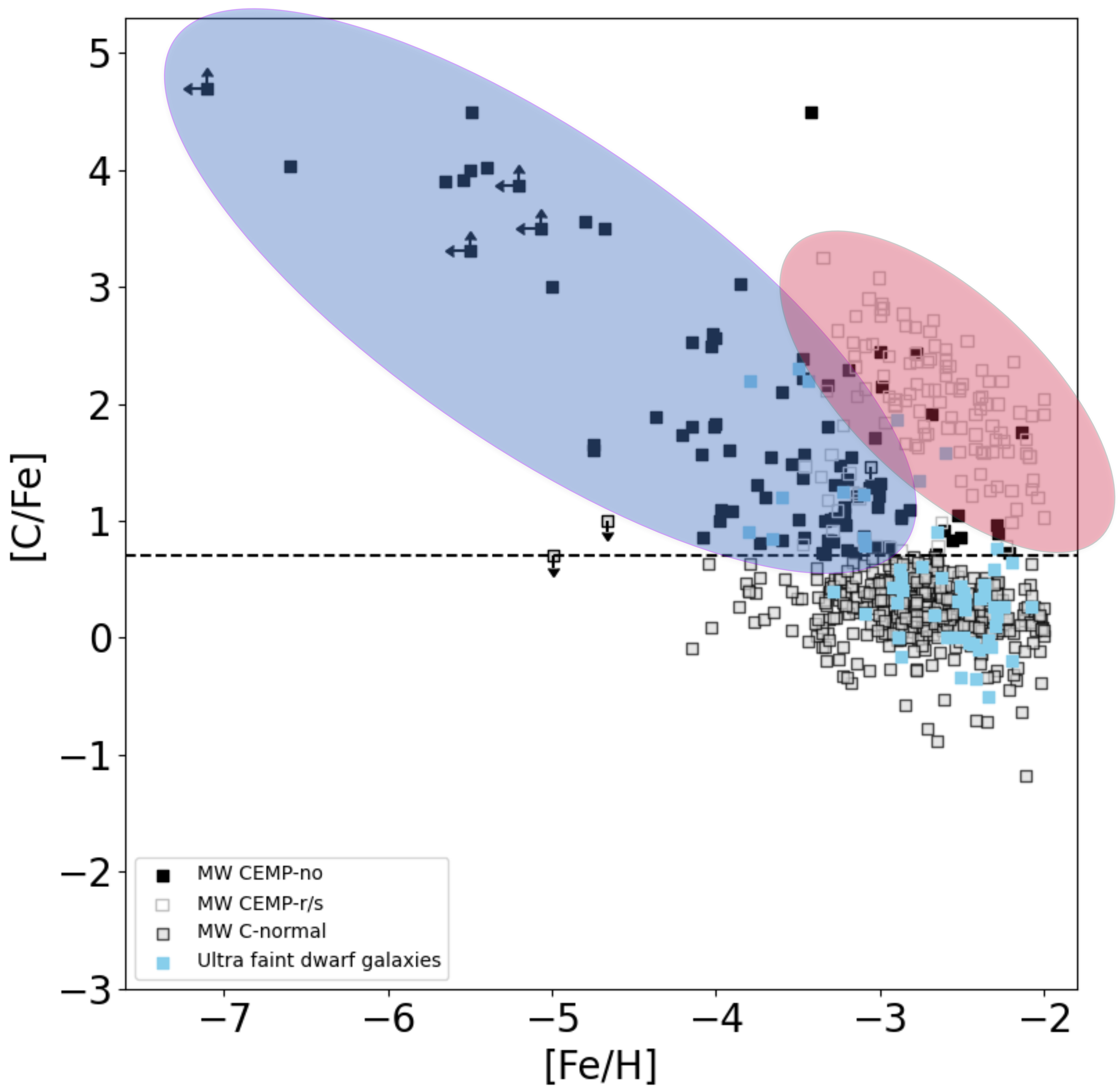
Local Group:

-Galactic Halo stars

-Dwarf satellite galaxies

Have the signatures of PopIII stars ever been observed?

$$[X/Y] = \log(N_X/N_Y) - \log(N_X/N_Y)_\odot$$



Salvadori et al. 2015 - re-adapted and updated

Very metal-poor stars, [Fe/H] < −2, and carbon-enhanced [C/Fe] > 0.7 (CEMP)

CEMP-no stars:

[C/Fe] > 0.7
[Ba/Fe] < 0

First stars signature!

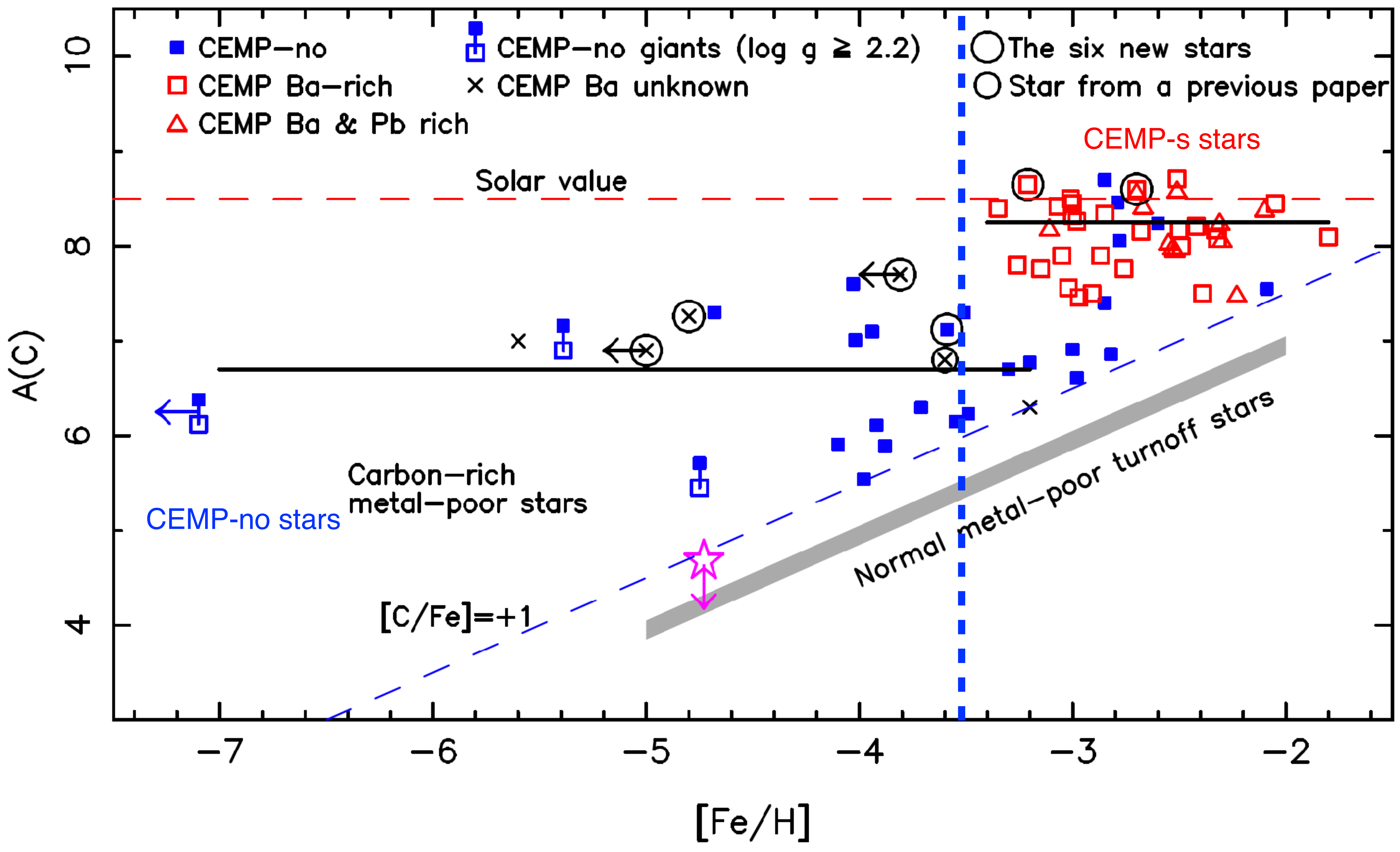
CEMP-s/r stars:

[C/Fe] > 0.7
[Ba/Fe] > 0

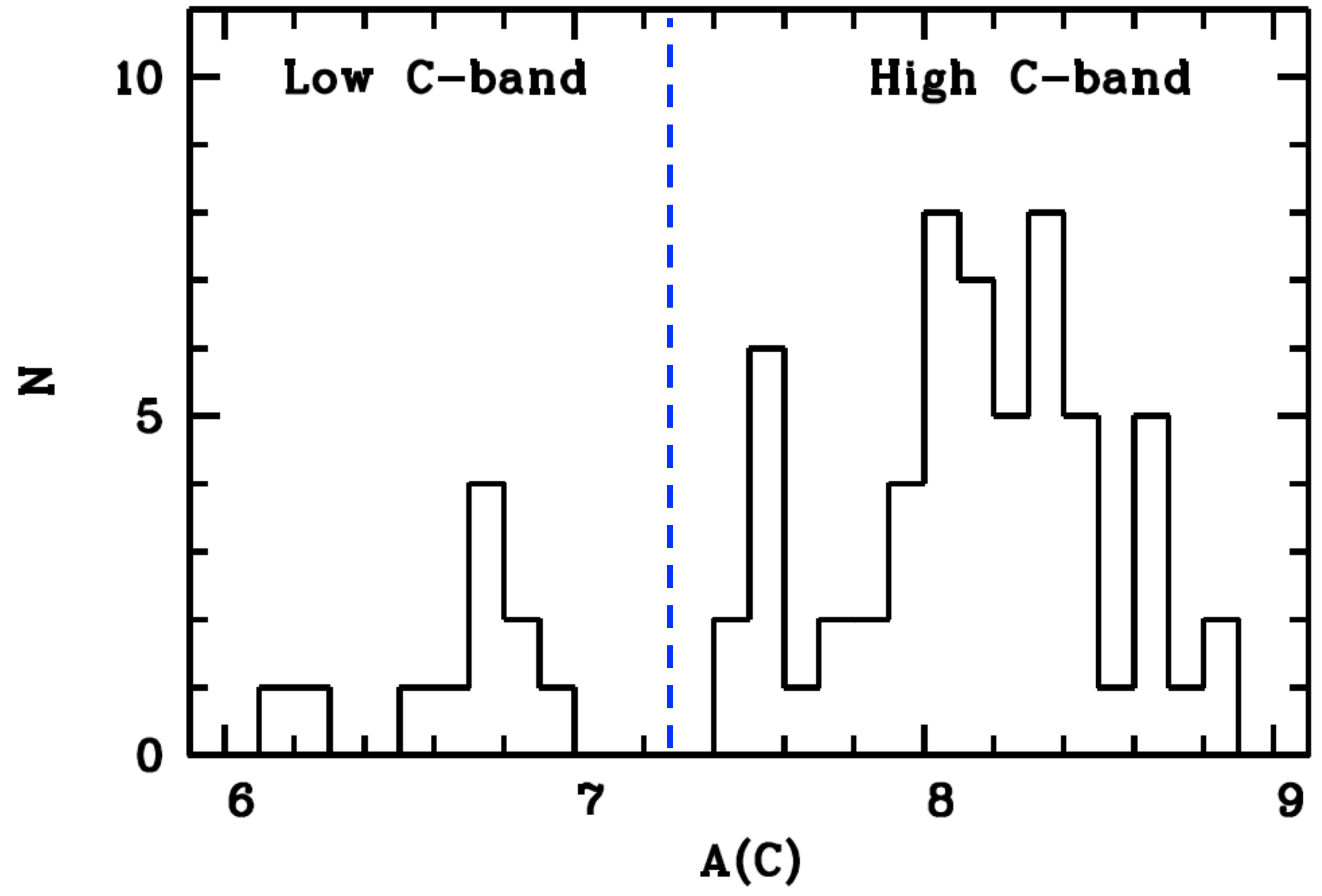
AGB stars signature!

CEMP-no stars are *not* preferentially in binary systems. Chemical composition representative of the gaseous environment (ISM) of formation

Low and High Carbon Bands



Bonifacio et al. 2015



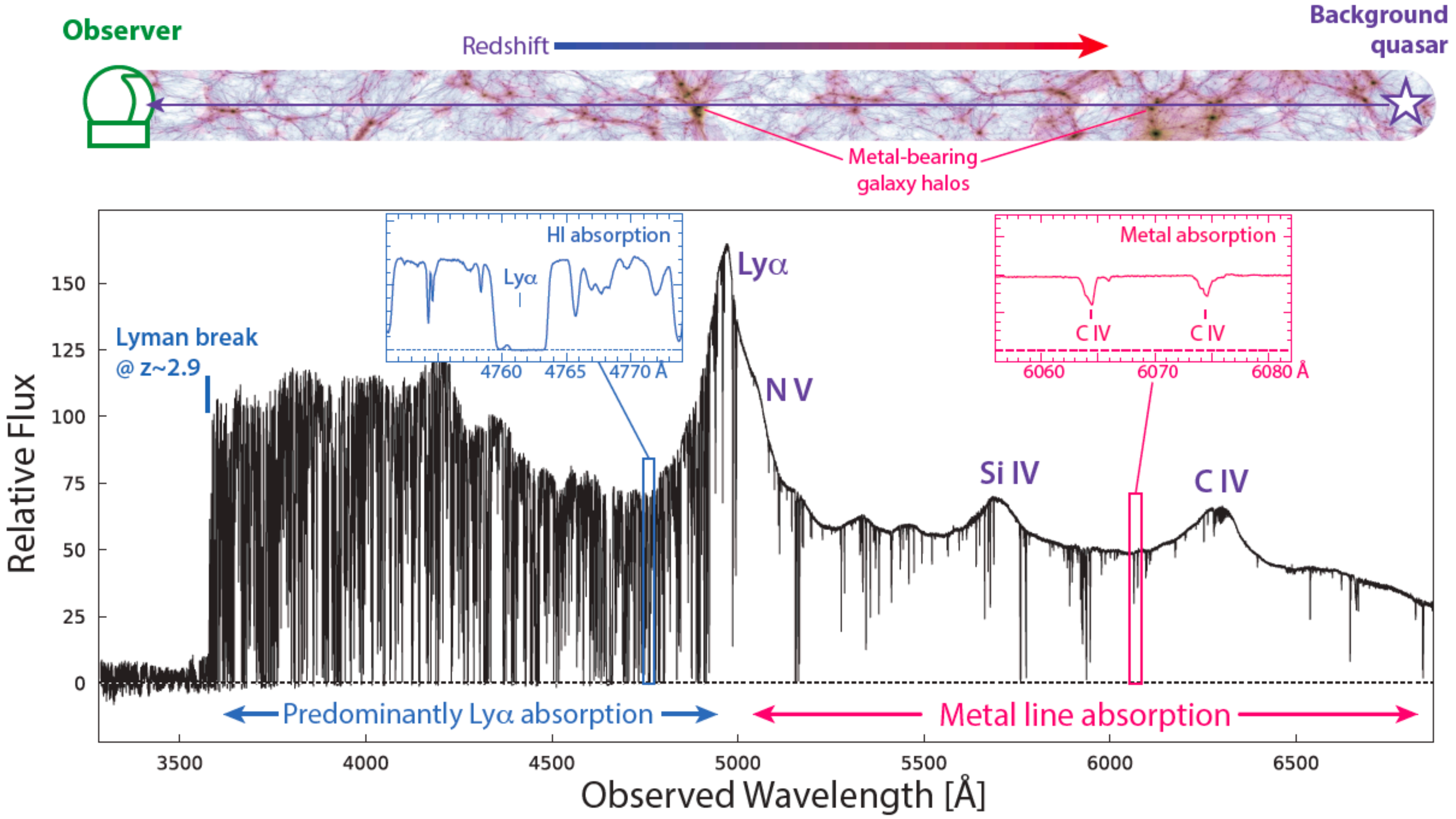
Bonifacio et al. 2015

Chasing first stars signatures : Quasar absorption lines

MAIN QUESTION

Can we observe the first stars signature at high-redshift?
Do CEMP-no absorption systems exist?

Peroux et al. 2020



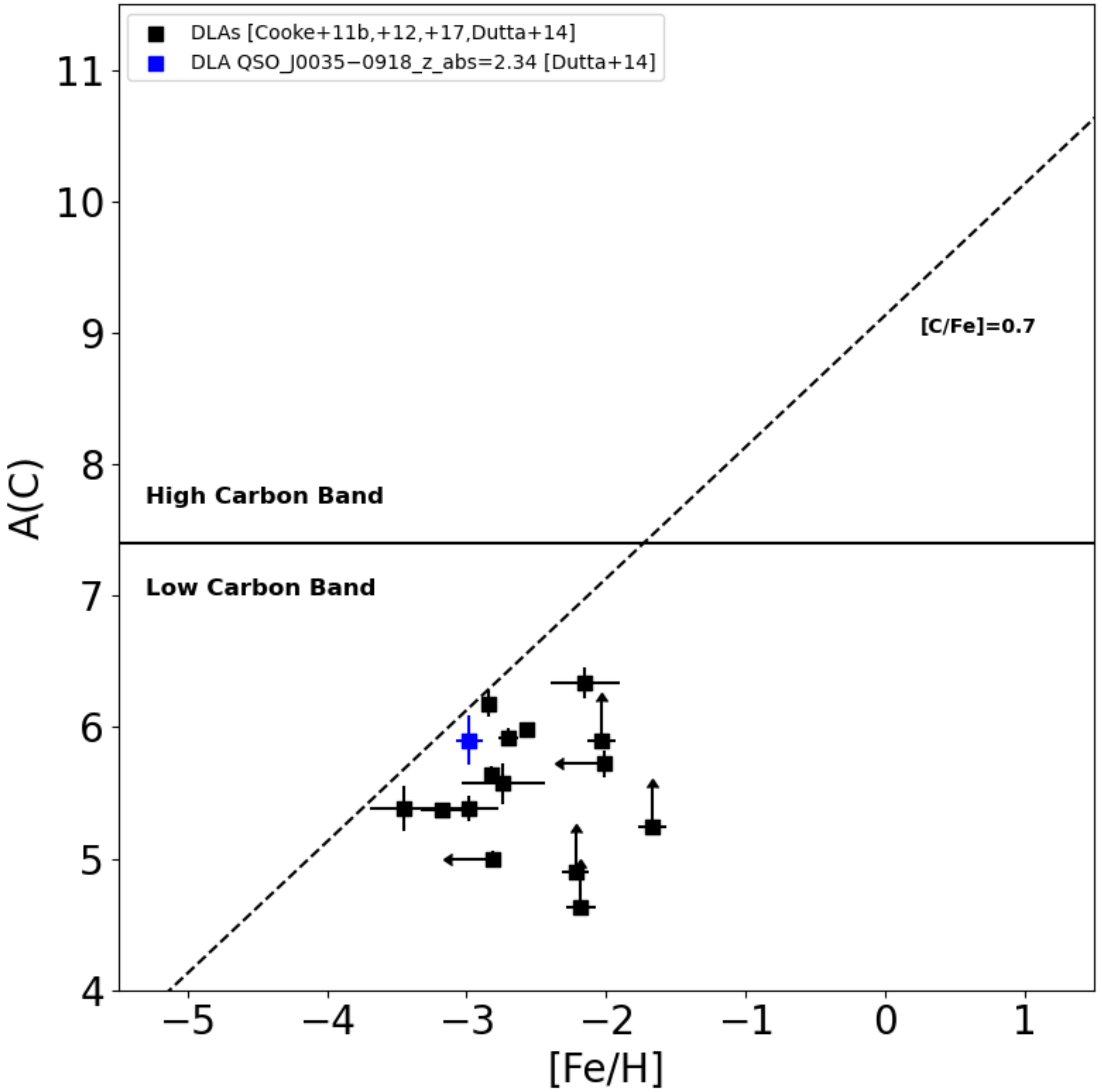
Damped Lyman α Systems (DLA)
$\log(N_{HI}/cm^{-2}) > 20.3$

Sub-Damped Lyman α Systems (sub-DLA)
$18.5 < \log(N_{HI}/cm^{-2}) < 20.3$

Lyman Limit Systems (LLS)
$17.3 < \log(N_{HI}/cm^{-2}) < 18.5$

Lyman α Forest (IGM)
$\log(N_{HI}/cm^{-2}) < 17.3$

First stars signatures at high redshift: STILL MISSING!



Chemical properties of z ~ 2-4 DLAs

No CEMP DLA systems in the low-Carbon band!

Can we identify the first stars signatures at high-redshift in more diffuse LLSs and sub-DLAs?

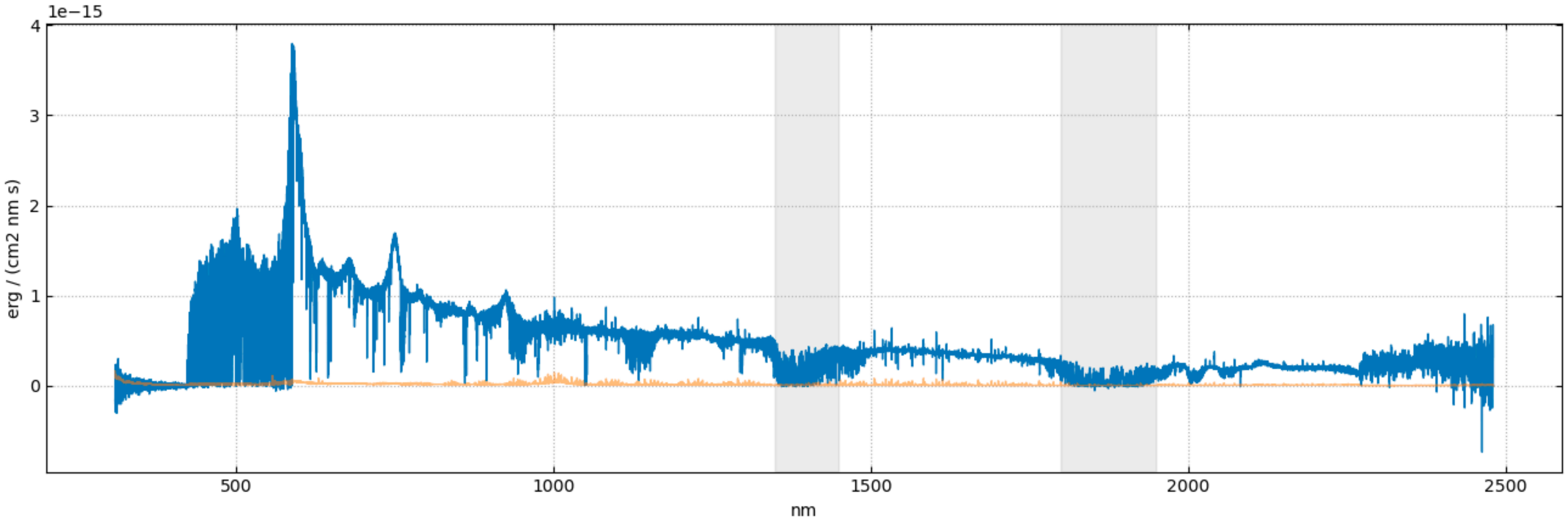
Theoretically promising candidates:

less dense than DLAs and therefore expected to be (I) more metal-poor and (II) likely not contaminated by subsequent generations of normal stars.

e.g. Pallottini+14;
Salvadori & Ferrara+12

Data Analysis of LLSs and Sub-DLAs

Homogeneous and high-quality sample of spectra from the XQ-100 survey (VLT/X-Shooter), which targets one hundred quasars at z ~ 3.5 – 4.5 with spectral coverage from 315 to 2500 nm.



Lopez et al. 2016

Analysis Steps

Identify the absorption systems starting from MgII doublet

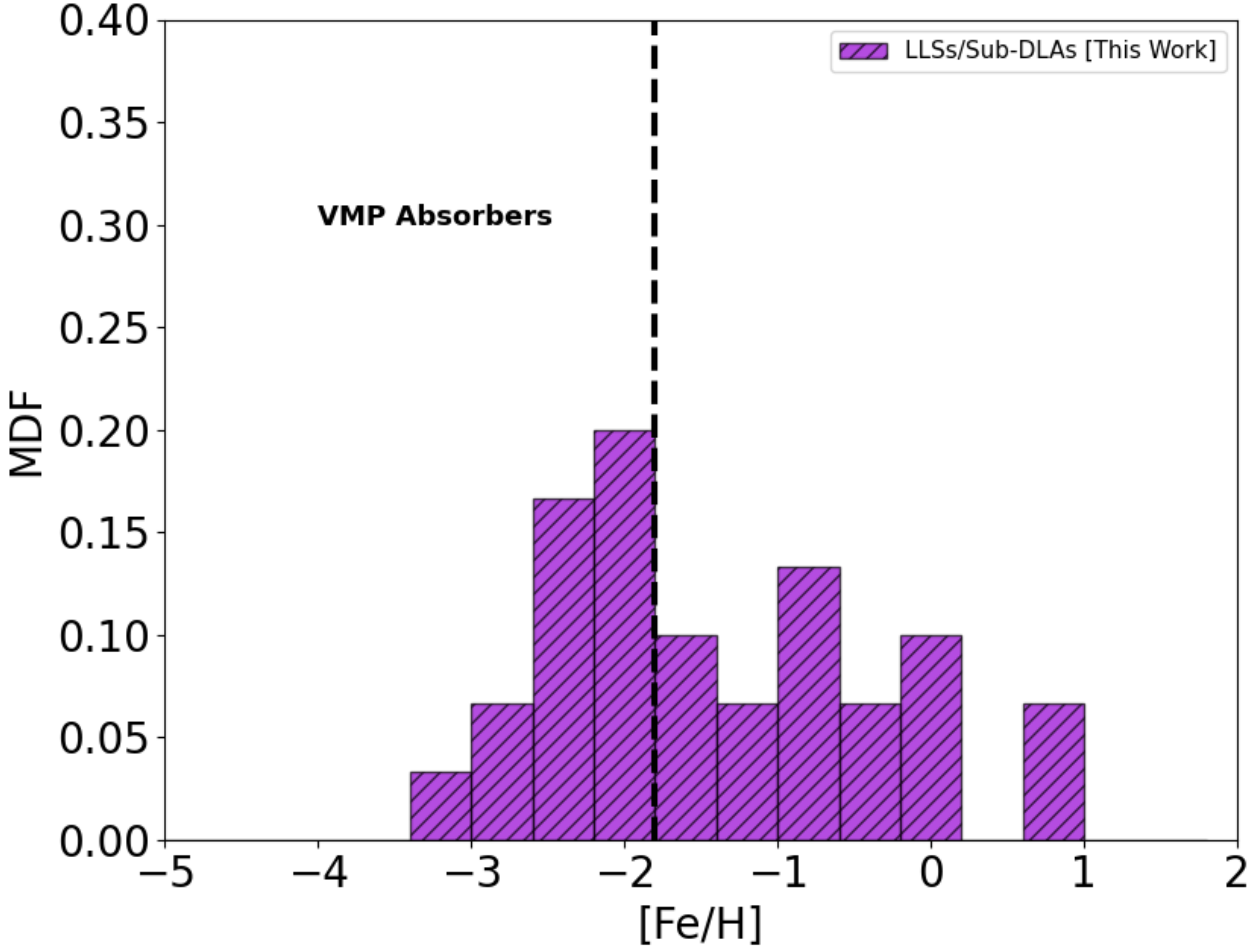
Fit metal lines/neutral hydrogen to determine the column densities *Astrocook* (Cupani+20)

Take into account ionization corrections *MCMC* (Fumagalli+16); *Cloudy* (Ferland+17)

Metallicity Distribution Function

RESULTS

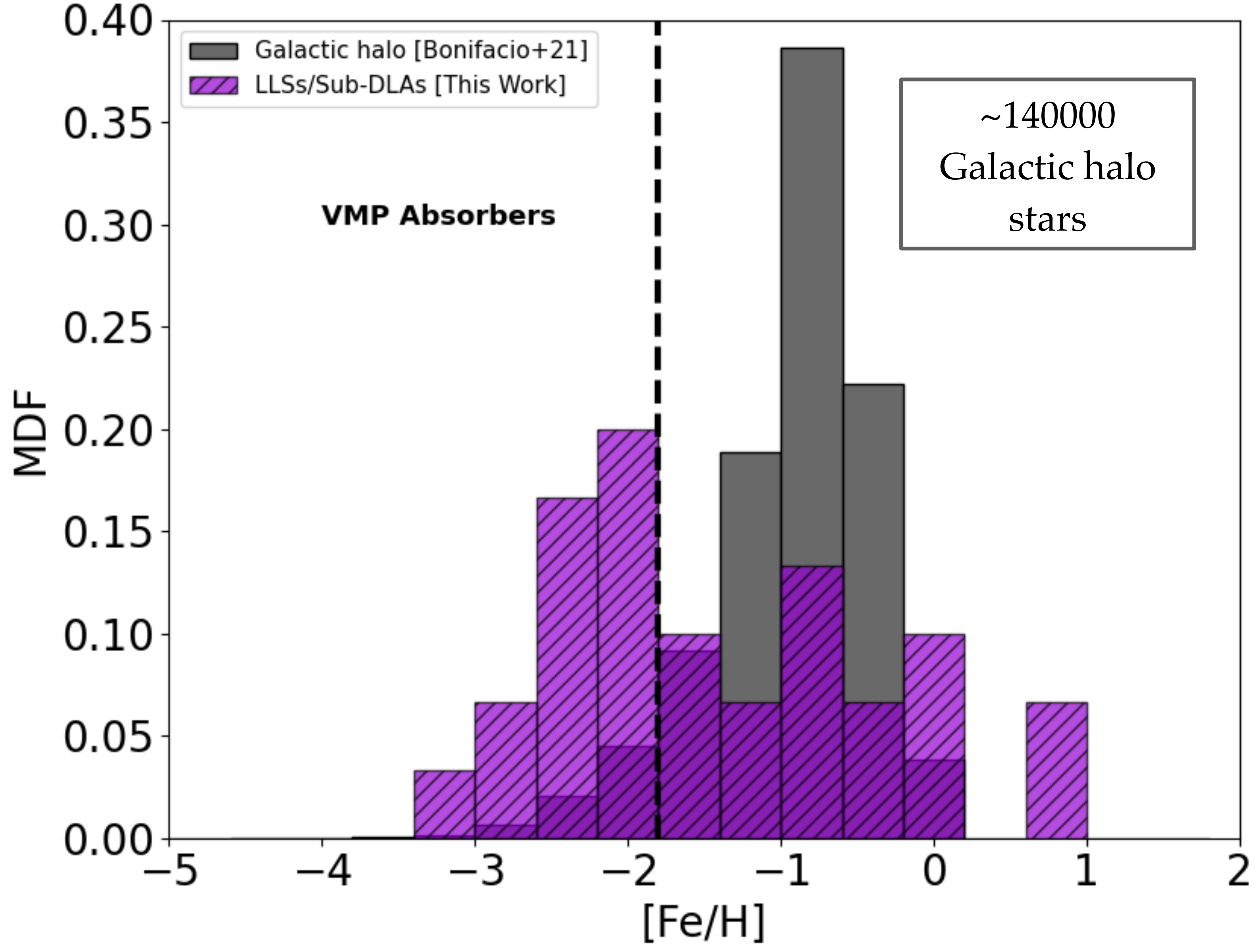
We identify 14 very metal-poor absorbers!
[Fe/H] < -2

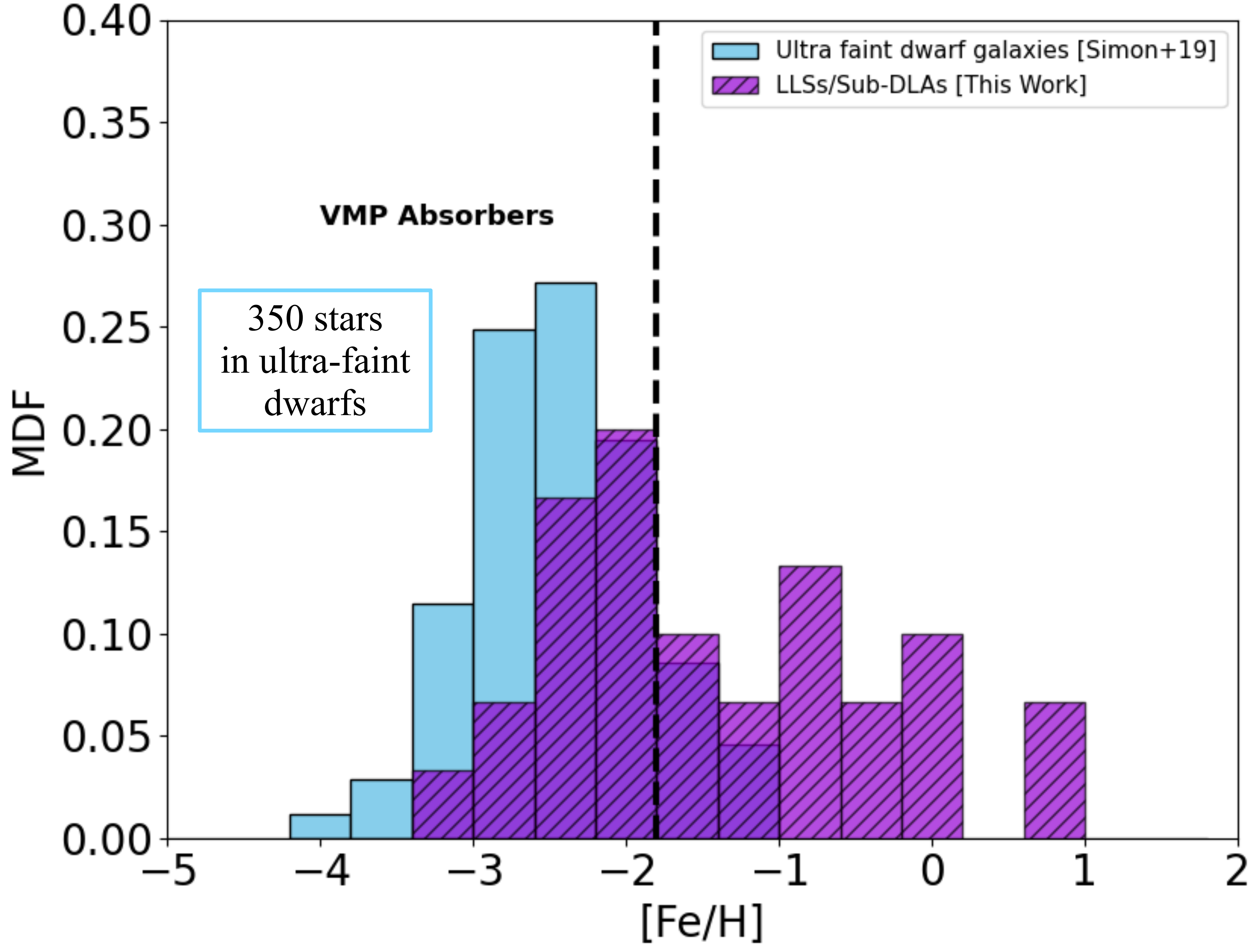


Metallicity Distribution Function

RESULTS

A. Saccardi, S. Salvadori, V. D'Odorico et al. 2023



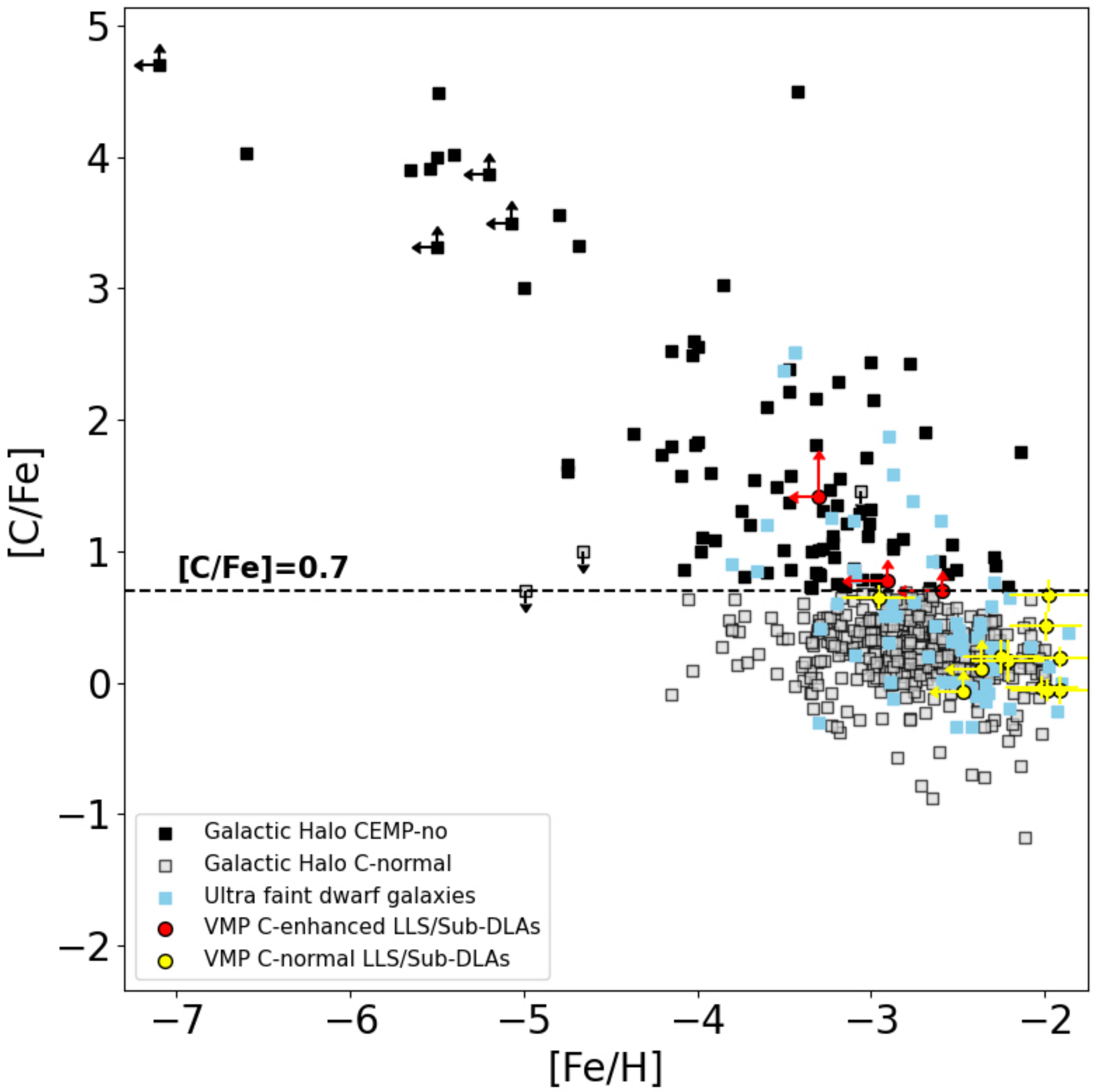


Let's now focus on the VMP absorbers, [Fe/H] < -2, so that the dust contribution can reasonably be neglected (e.g. Vladilo +98/+18)

Carbon over Iron Abundances

RESULTS

A. Saccardi, S. Salvadori, V. D'Odorico et al. 2023



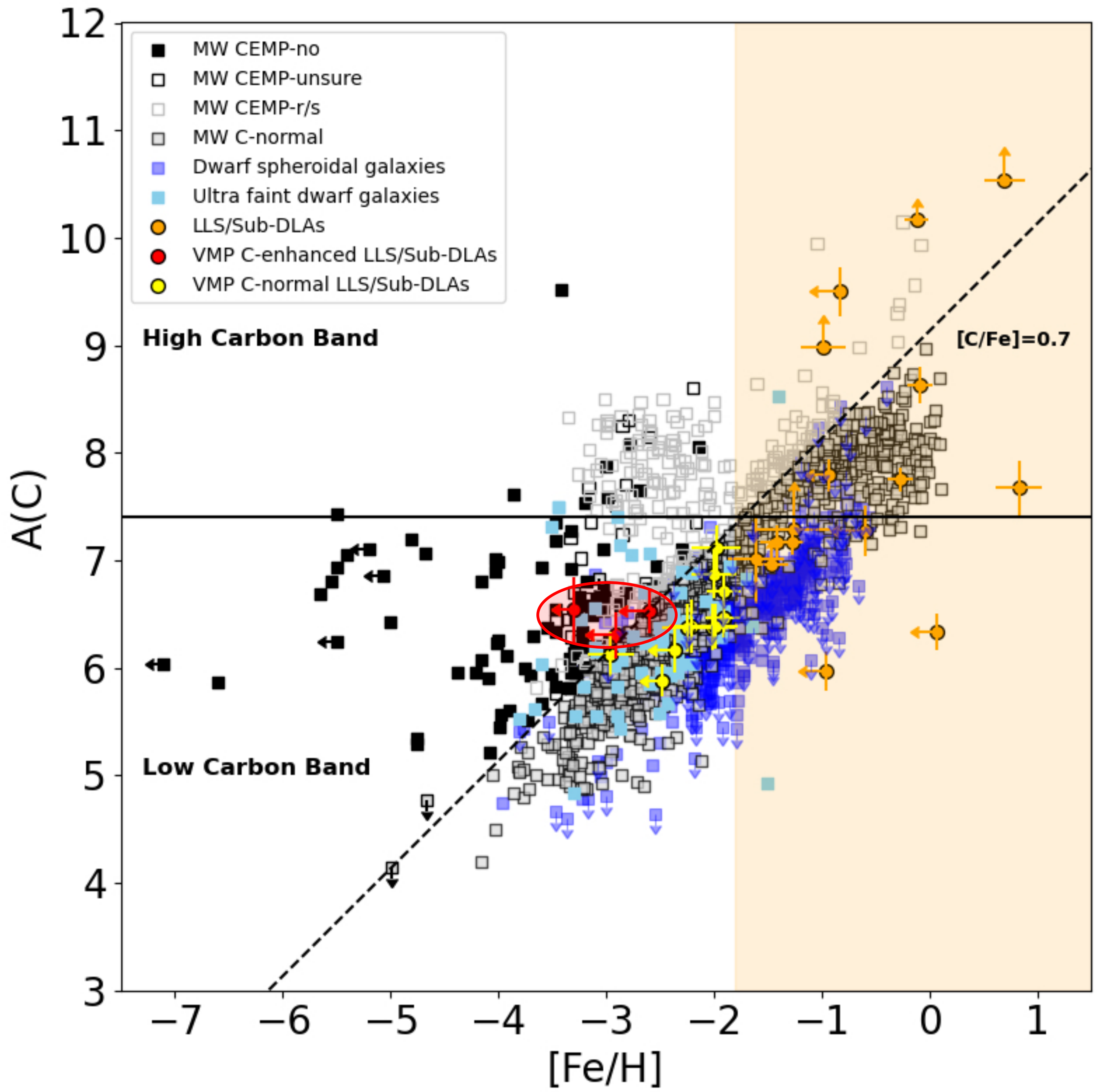
Same [C/Fe] vs [Fe/H] trend observed in today ancient stars

3 CEMP absorption systems identified for the first time

Low vs High Carbon Bands

RESULTS

A. Saccardi, S. Salvadori, V. D'Odorico et al. 2023

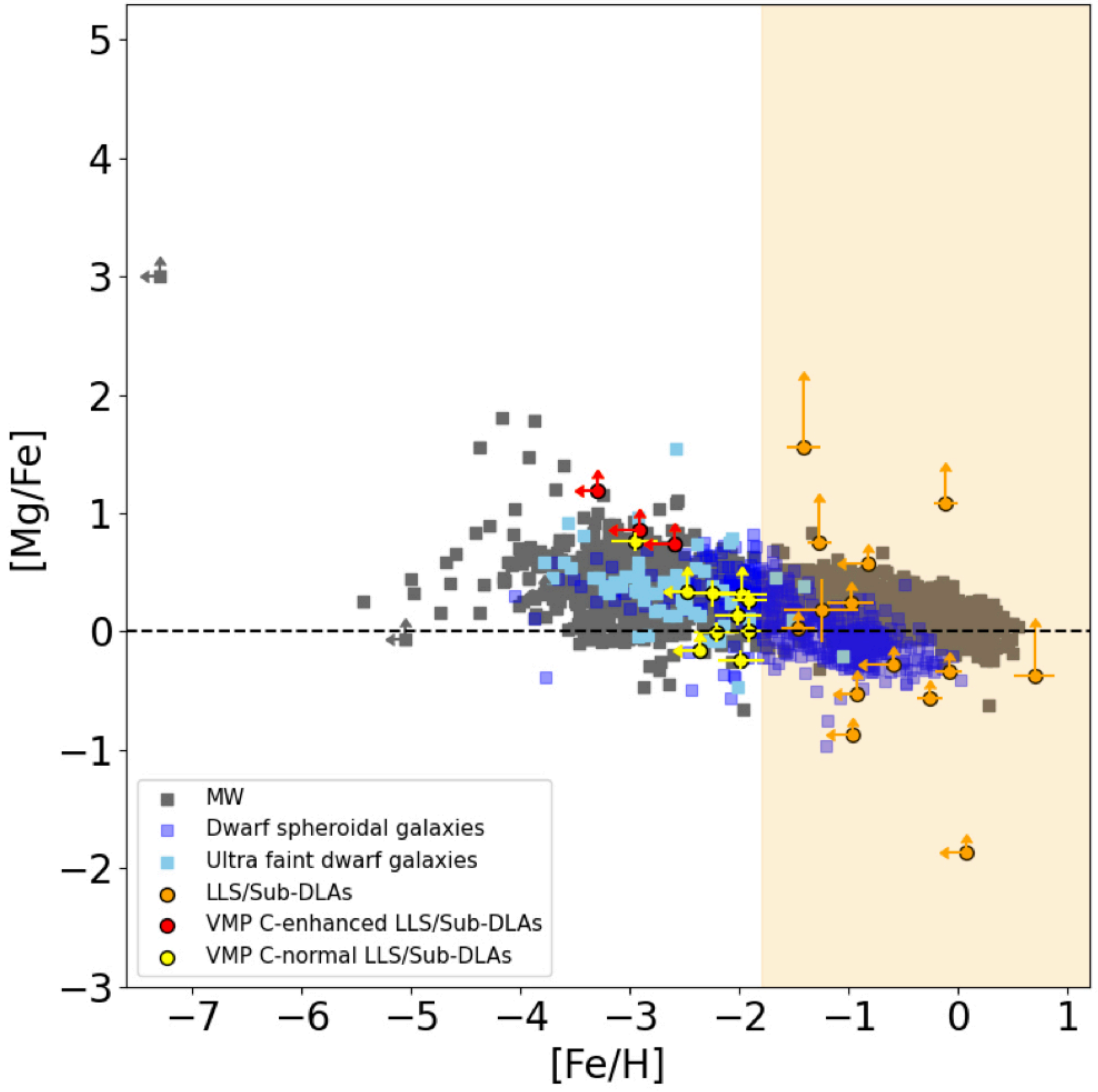


We have identified three CEMP-no high-z absorption systems!

Magnesium over Iron Abundances

RESULTS

A. Saccardi, S. Salvadori, V. D'Odorico et al. 2023



The 3 CEMP-no absorbers are also Magnesium-rich

↓

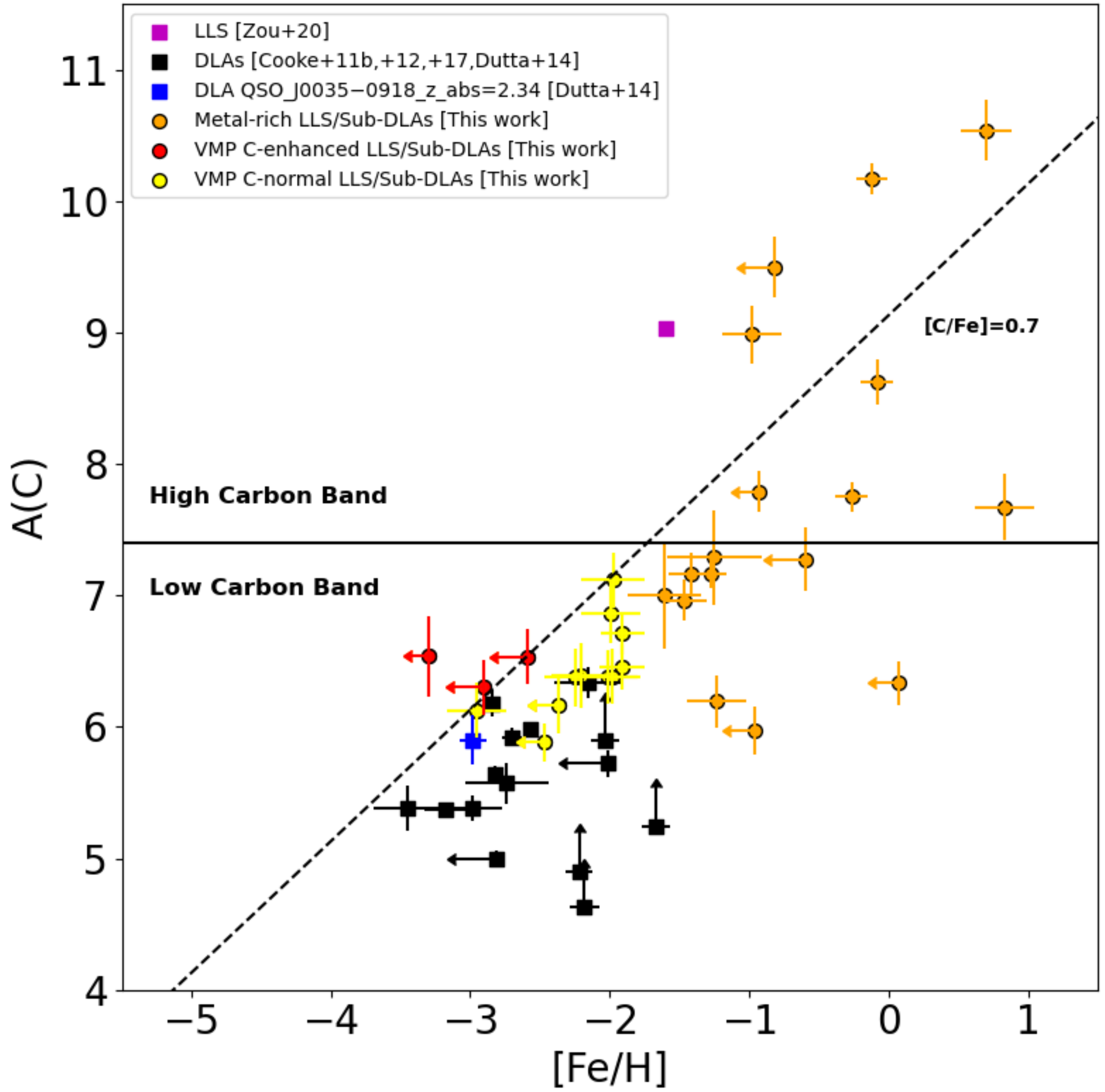
AGB do not produce Magnesium!

↓

Confirmation of gas enriched by first stars!

Conclusions

A. Saccardi, S. Salvadori, V. D'Odorico et al. 2023 re-adapted



We identified 14 VMP diffuse (LLSs/sub-DLAs) absorption systems out of 30 found at z ~ 3

We provide the first evidence of first stars-enriched gas at high redshift: 3 CEMP-no absorbers

***ANDES* @ELT will find more of these objects —> Complementing stellar archaeology to constrain the properties of the first stars**

Credits: ESO/L. Calçada

THANKS FOR YOUR ATTENTION

Evidence of first stars-enriched gas in high redshift absorbers
A. Saccardi, S. Salvadori, V. D'Odorico et al. 2023

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