Exploring the evolution of CNO chemical elements across cosmic epochs

Martina Rossi

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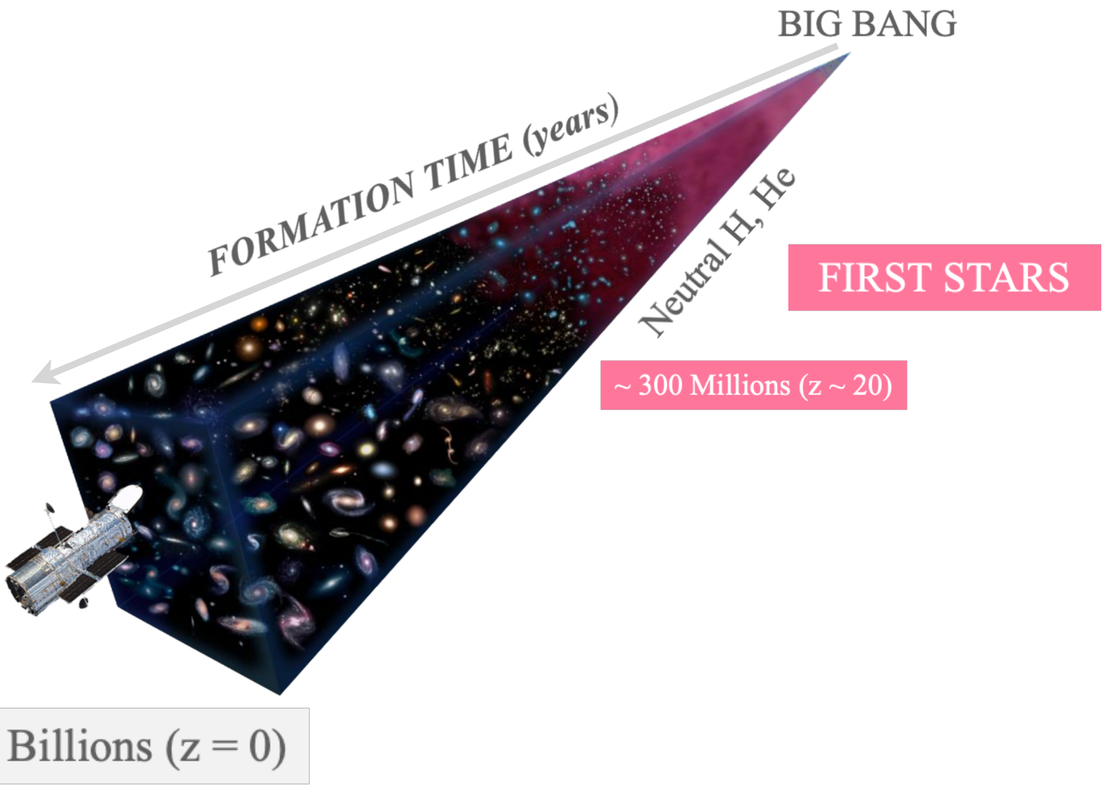
Collaborators :

Romano D. (INAF Bologna), Mucciarelli A. (UNIBO), Massari D. (OAS), Salvadori S. (UNIFI), Skúladottír Á.(UNIFI), Koutsouridou I. (UNIFI), Lucchesi R. (UNIFI), Magrini L. (INAF Arcetri)

IAU Symposium 395: Stellar populations in the Milky Way and beyond

UNKNOWN PROPERTIES OF POP III STARS

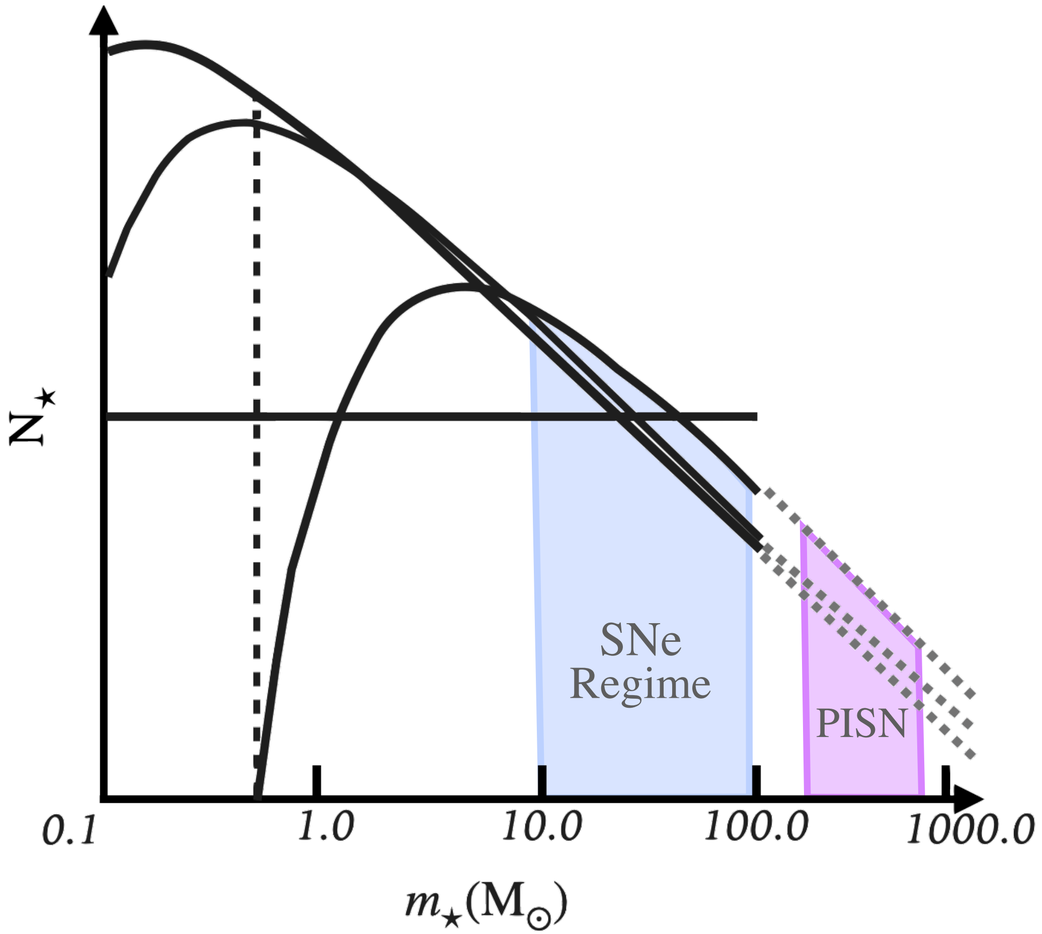


- First (PopIII) stars are metal-free
- First stars radically change the Universe
- First stars are the first source of light, heavy elements, and dust, after the Big Bang.
- PopIII started the chemical enrichment of the Universe

UNKNOWN PROPERTIES OF POP III STARS

PopIII have $m_\star > 10\ \mathrm{M}_\odot$

(Bromm et al. 1999, 2002; Abel et al. 2002; Hosokawa et al. 2011, 2016; Sugimura et al. 2020; Saad et al. 2022; Sharda & Menon 2024)



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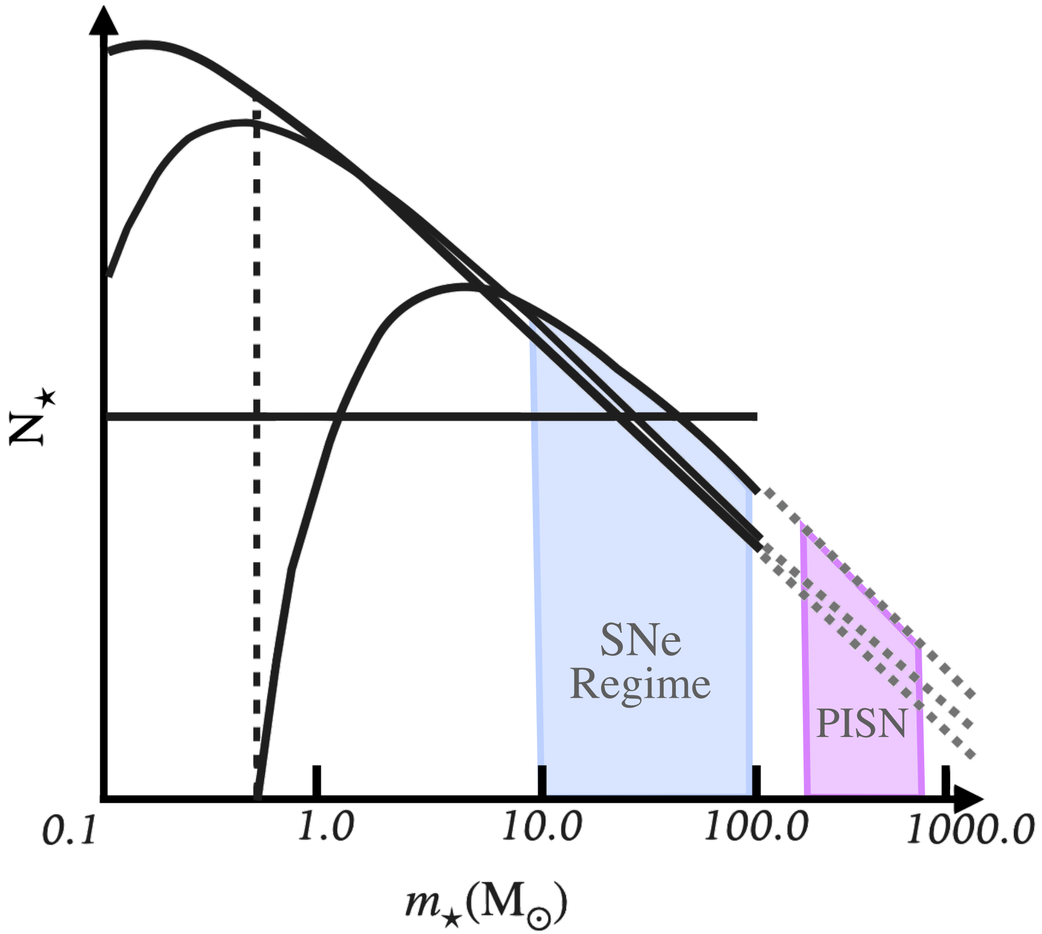

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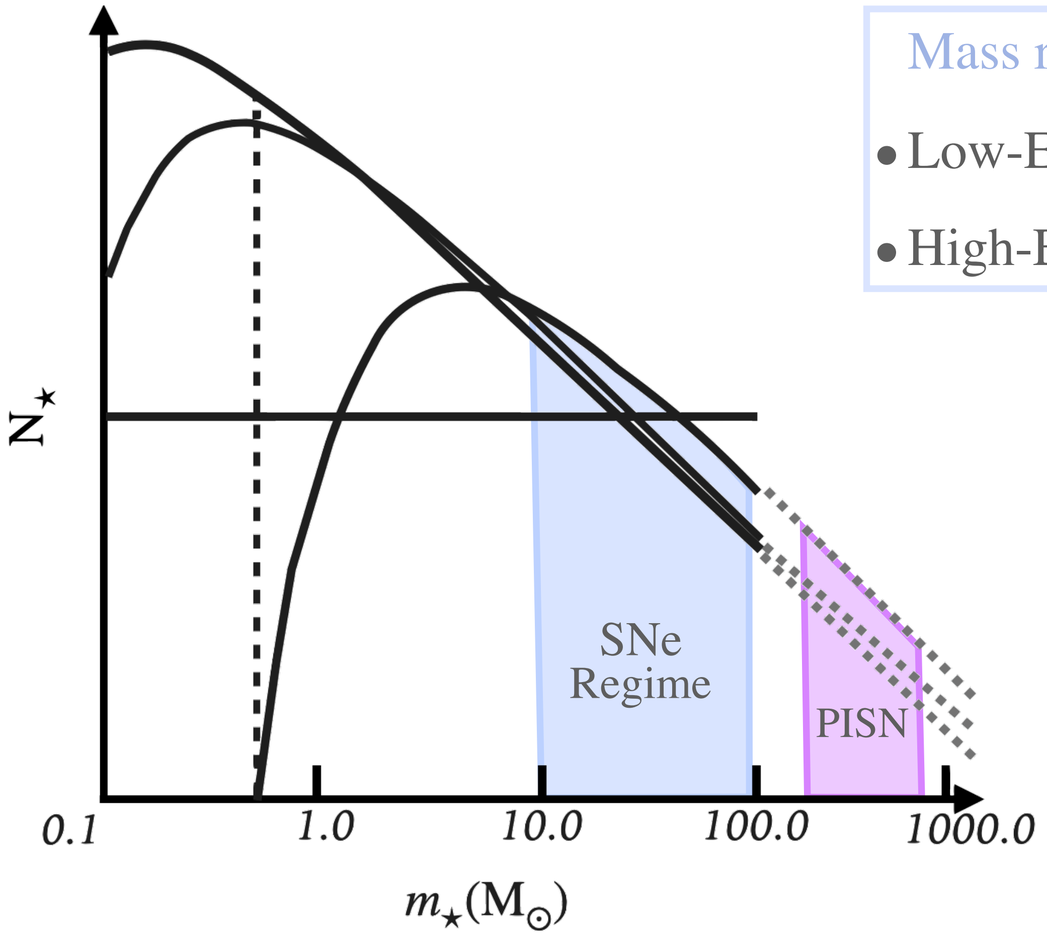

Mass range [10-100]$\mathrm{M}_\odot$:

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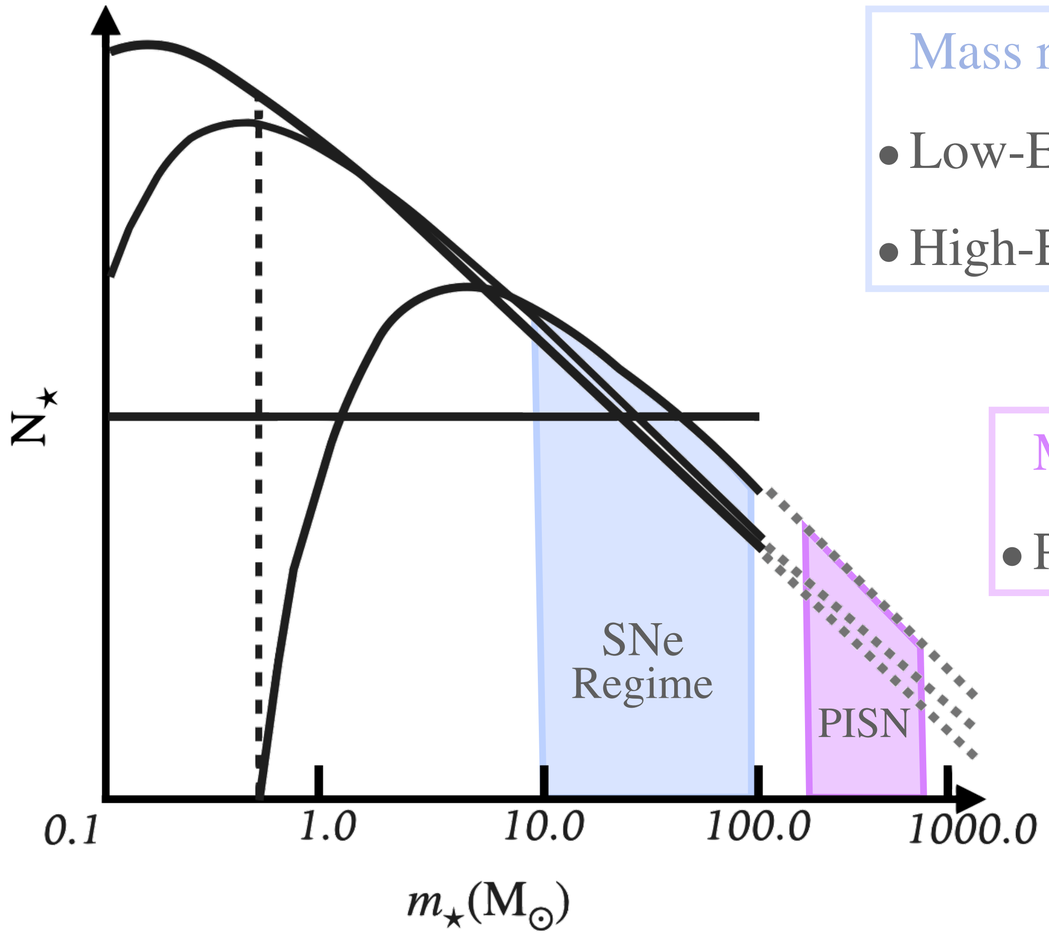

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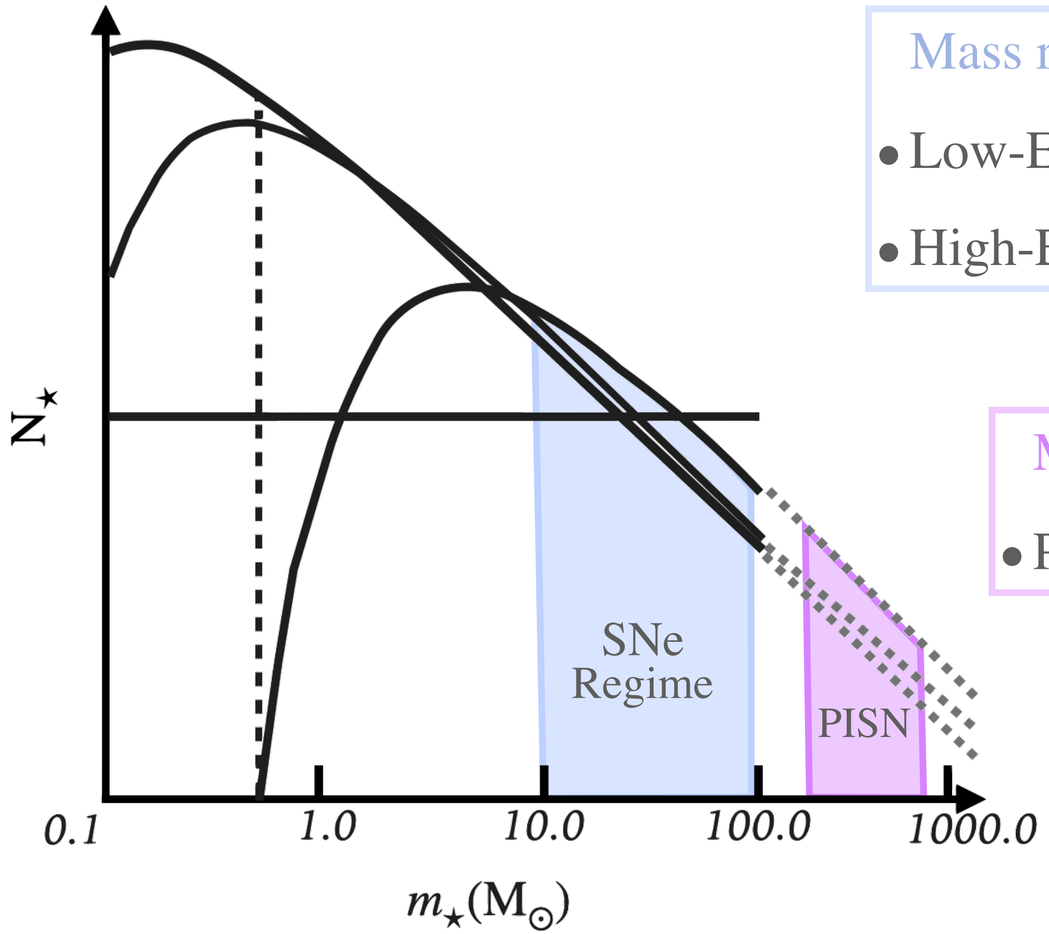

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Pop III SNe with different energies release different chemical elements in the ISM

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Chemical evolution models basic assumptions :

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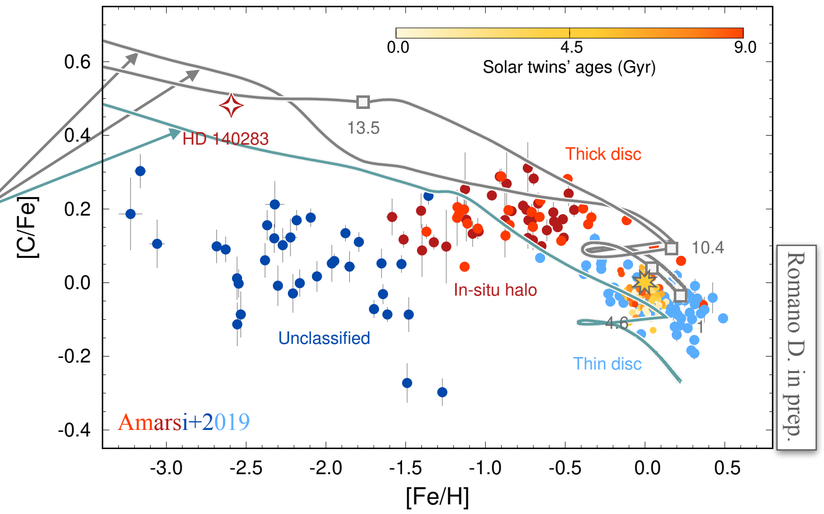
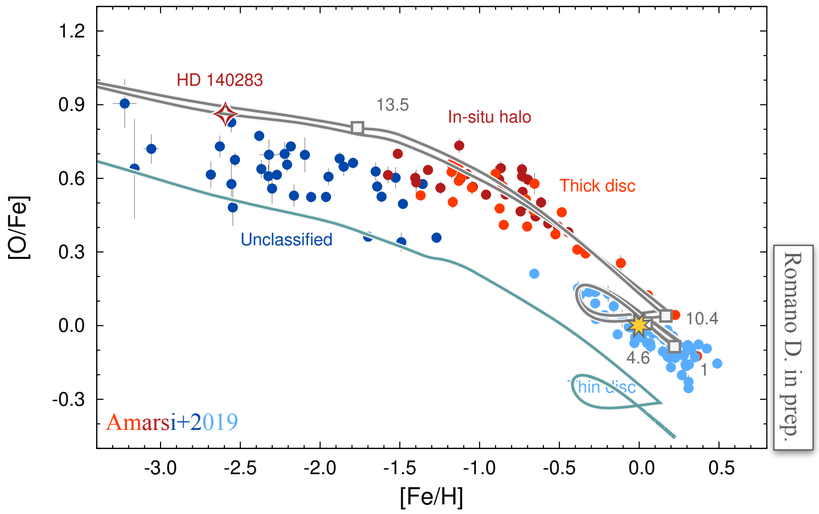
Model predictions for different set of PopII stellar yields
(Limongi&Chieffi 18)





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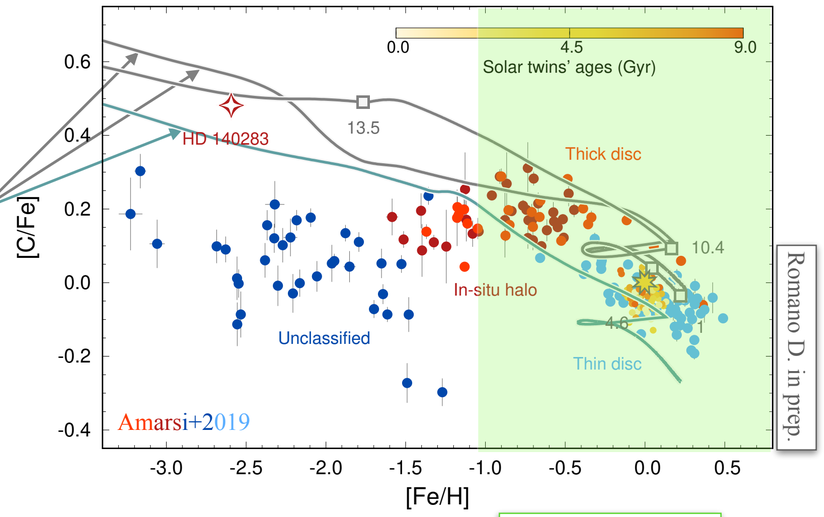

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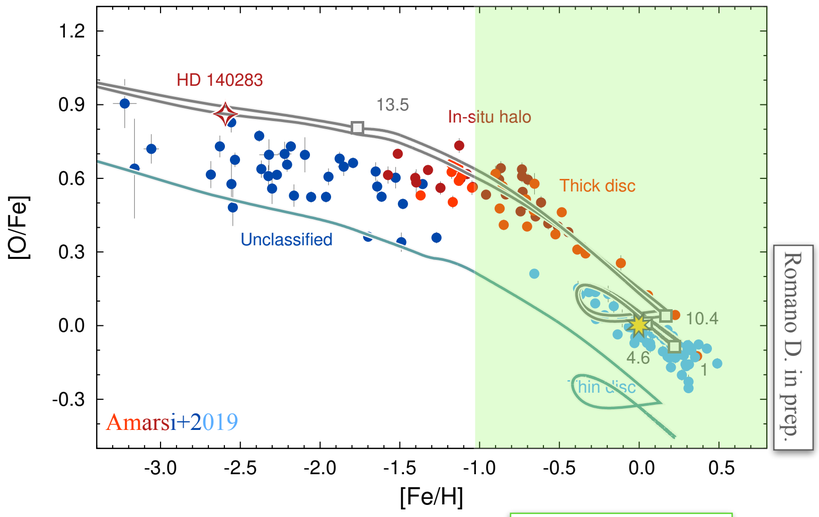

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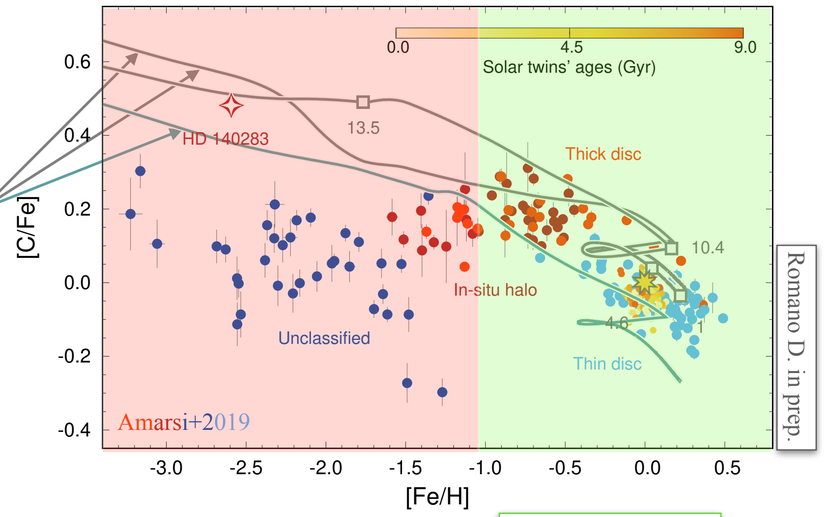

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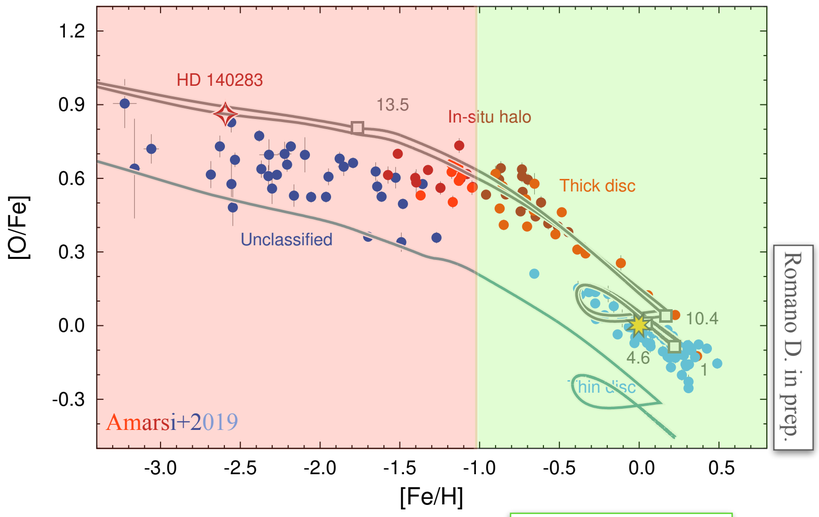

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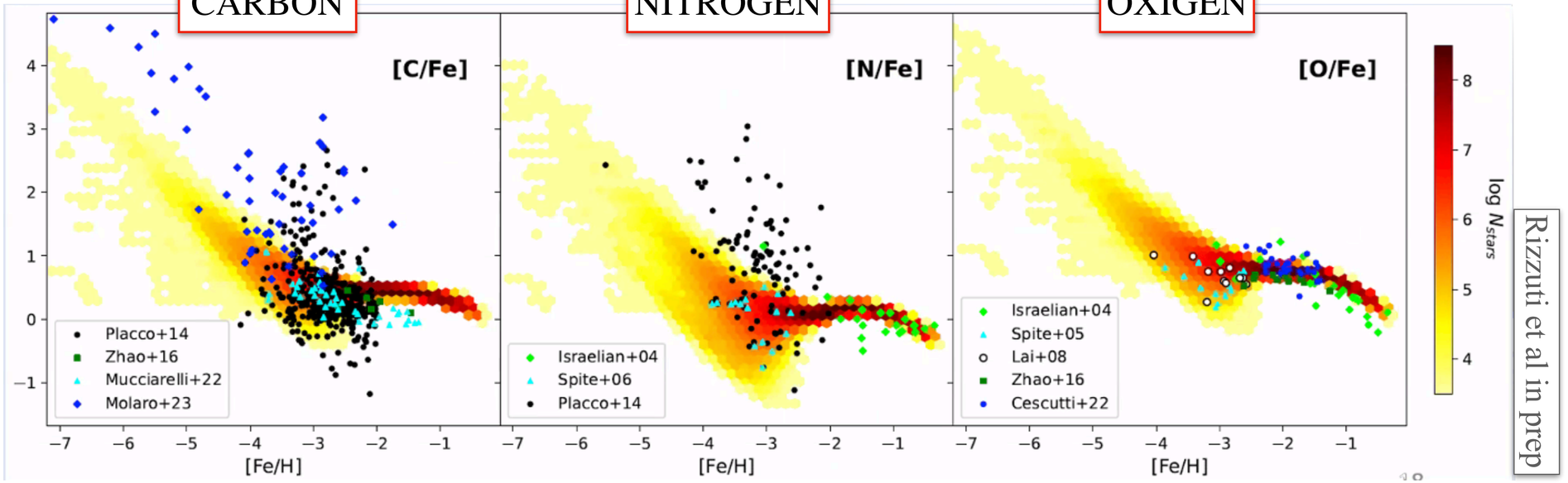

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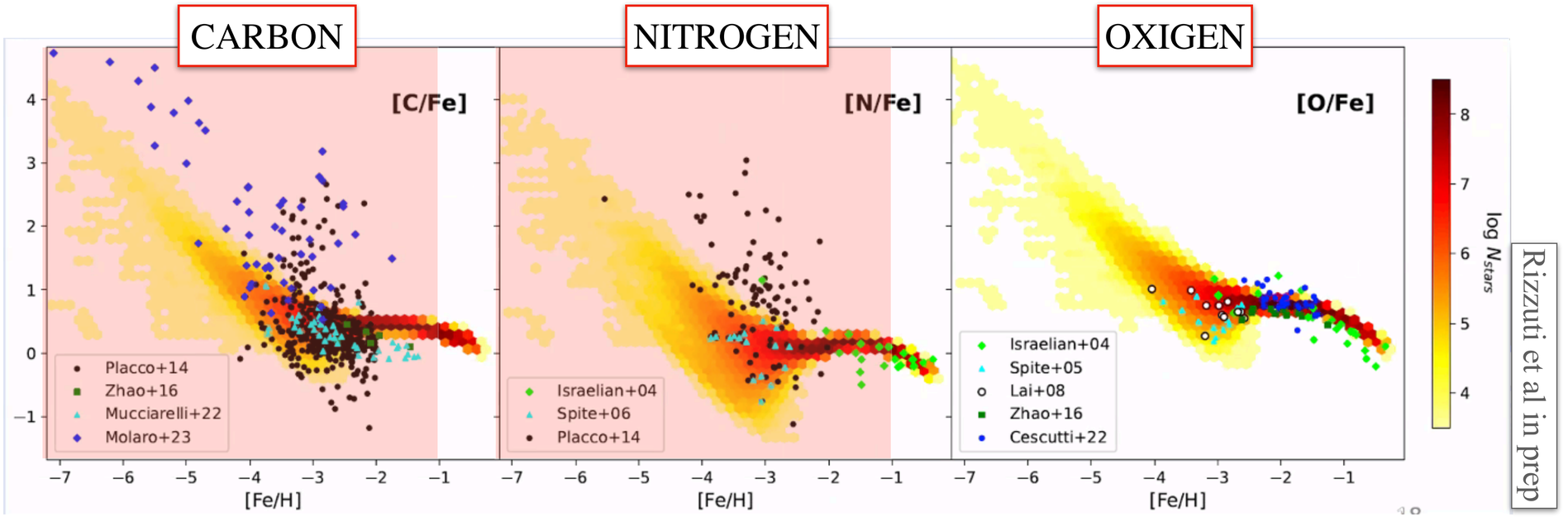

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CHEMICAL EVOLUTION MODELS – what do we need?

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What do we need to reproduce the data at low metallicities ?

CHEMICAL EVOLUTION MODELS – Milky Way halo

Galactic Chemical Evolution (GCE) models versus observations + ***stochastic processes*** + ***Pop III enrichment***

Pop III SNe with different masses and explosion energies enrich the ISM in the first phases of chemical evolution

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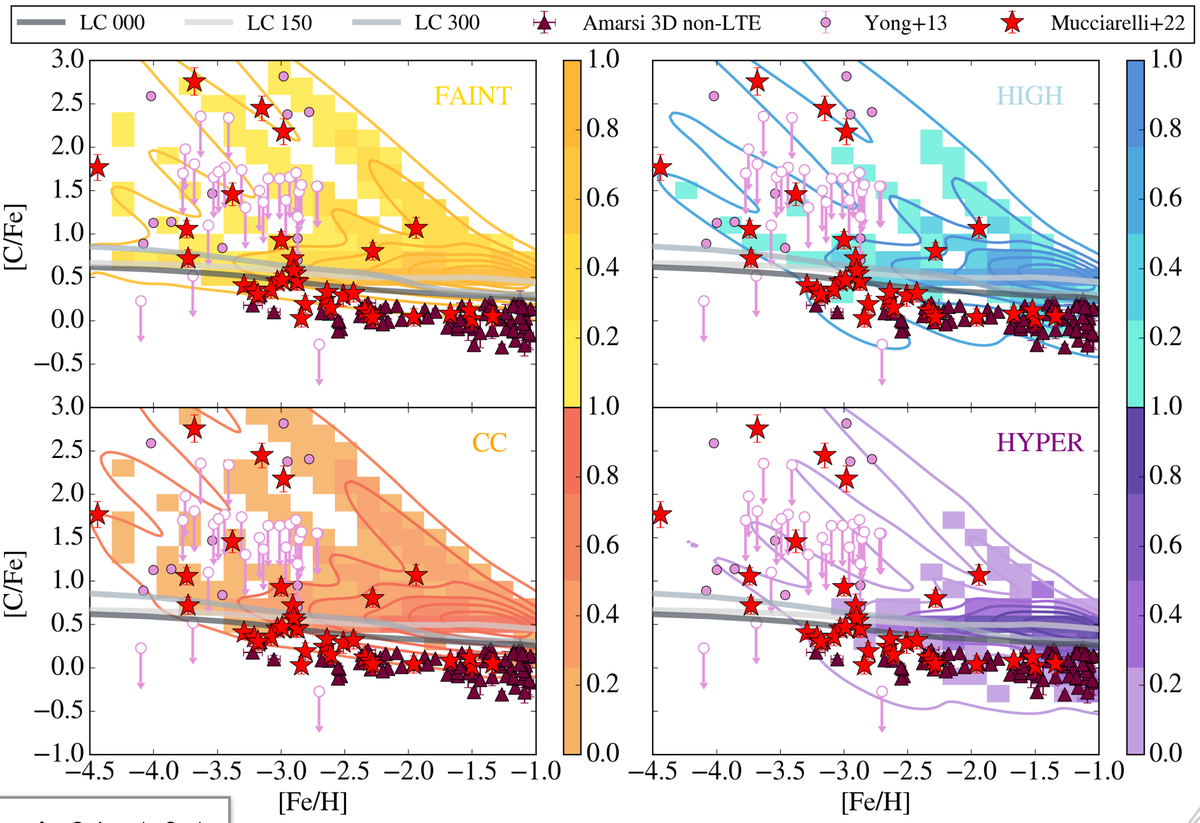

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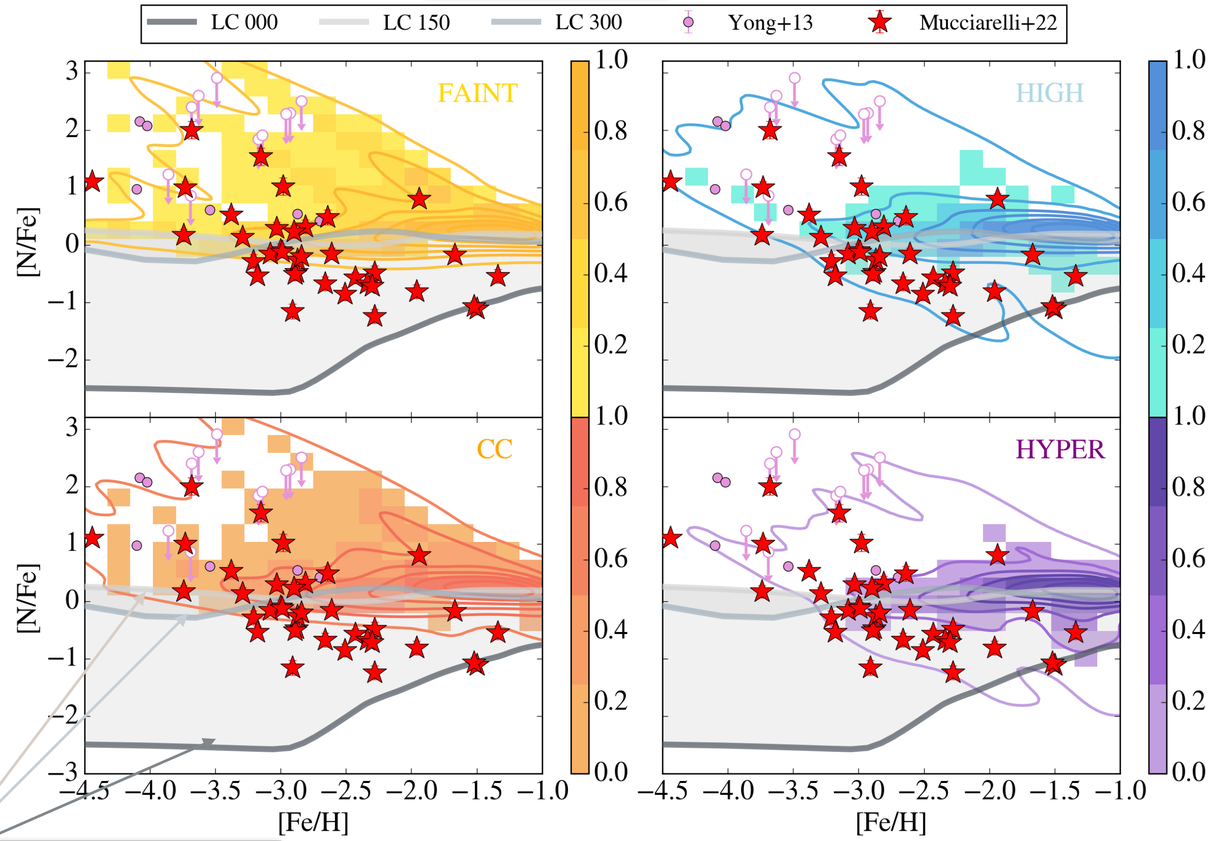

Rossi+24a A&A

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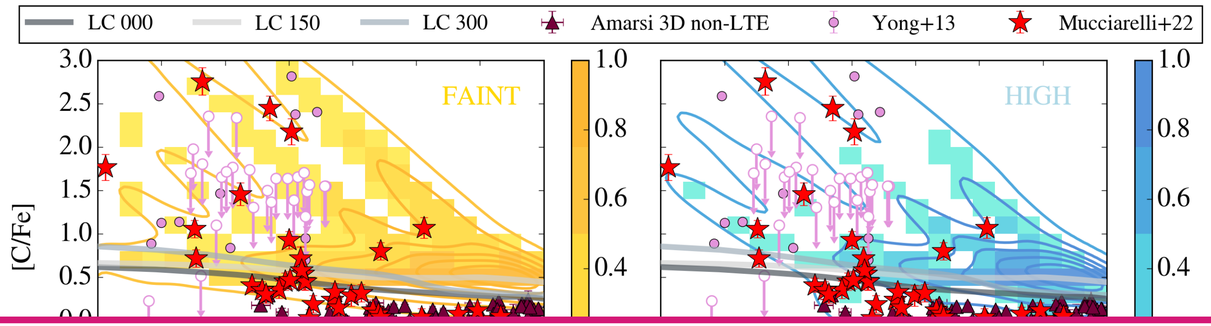
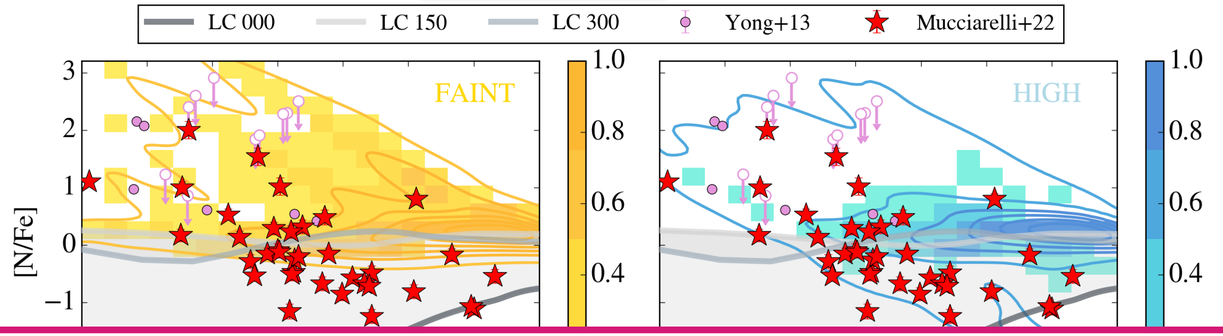
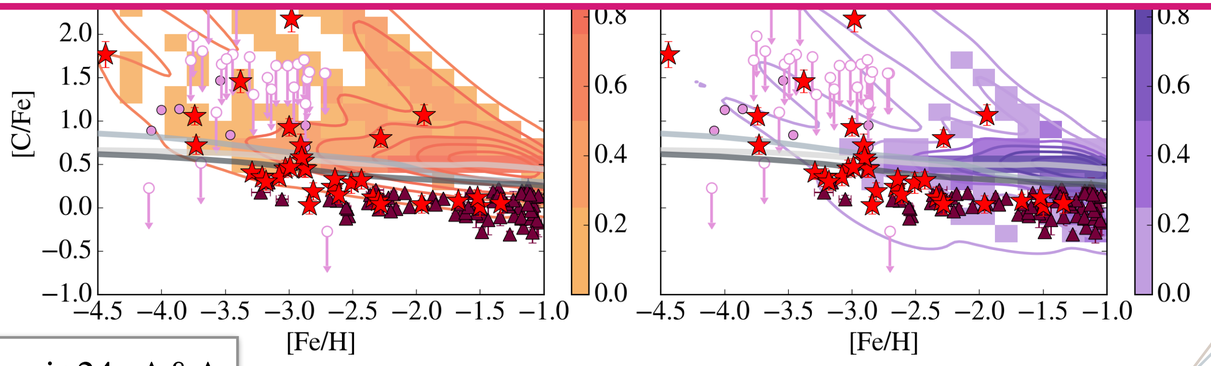
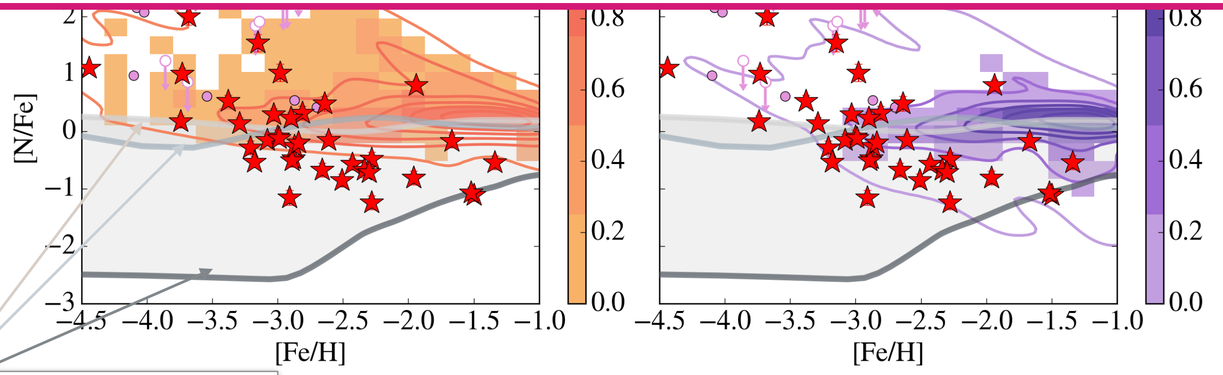




Stochastic pre-enrichment of PopIII SNe with different energies is required in GCE models to reproduce the observed scatter at low metallicity





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CHEMICAL EVOLUTION MODELS – Ultra-faint dwarf galaxies

Ultra-faint dwarf (UFD) semi-analytical model (***stochastic processes*** + ***Pop III enrichment)*** for Boötes I

Look at my CRIMSONS tool (Rossi et al 2024c in prep) https://martina-rossi.it/crimsons.php

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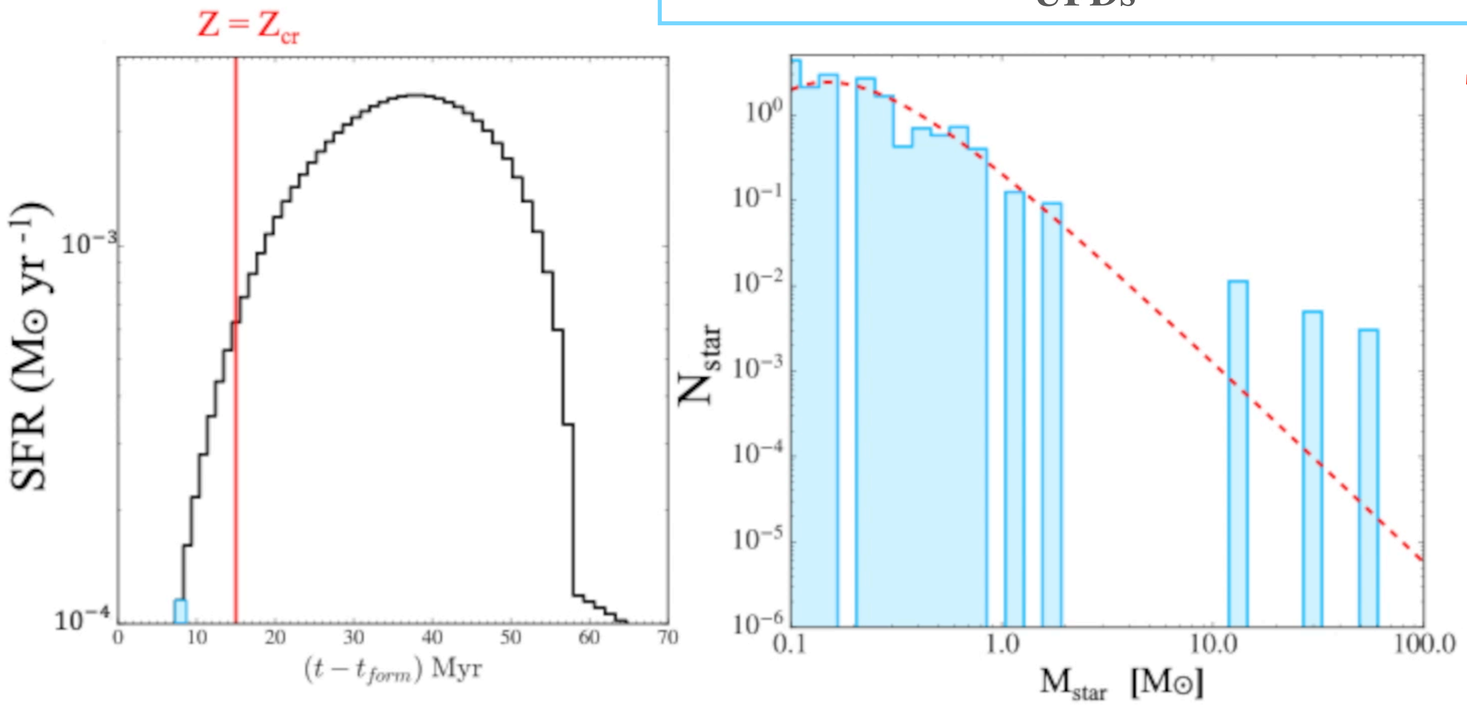
Hypothesis:

IMF fully sampled

Breaks down

for poorly star-forming (SFR $< 10^{-2} M_{\odot} yr^{-1}$) UFDs



Theoretical IMF

Effective IMF

Rossi, Salvadori+2021

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UFDs contains large fraction of Carbon Enhanced Metal Poor (CEMP) stars (Beers & Christlieb 2005; Norris et al. 2013; Yonget al. 2013; Aoki et al. 2014)

What is the connection between CEMP-no stars and the chemical elements ejected by Pop III SNe?

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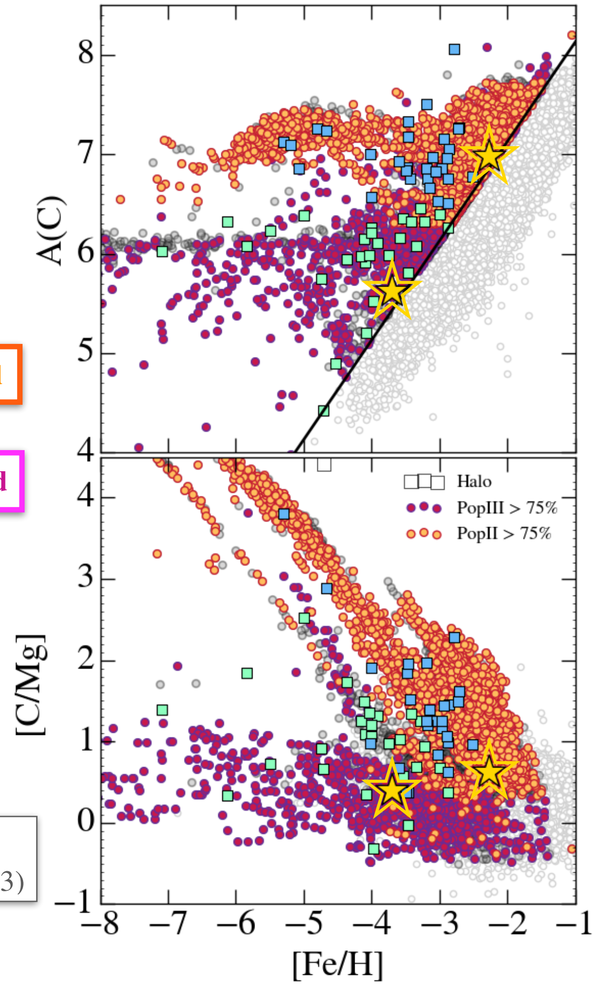

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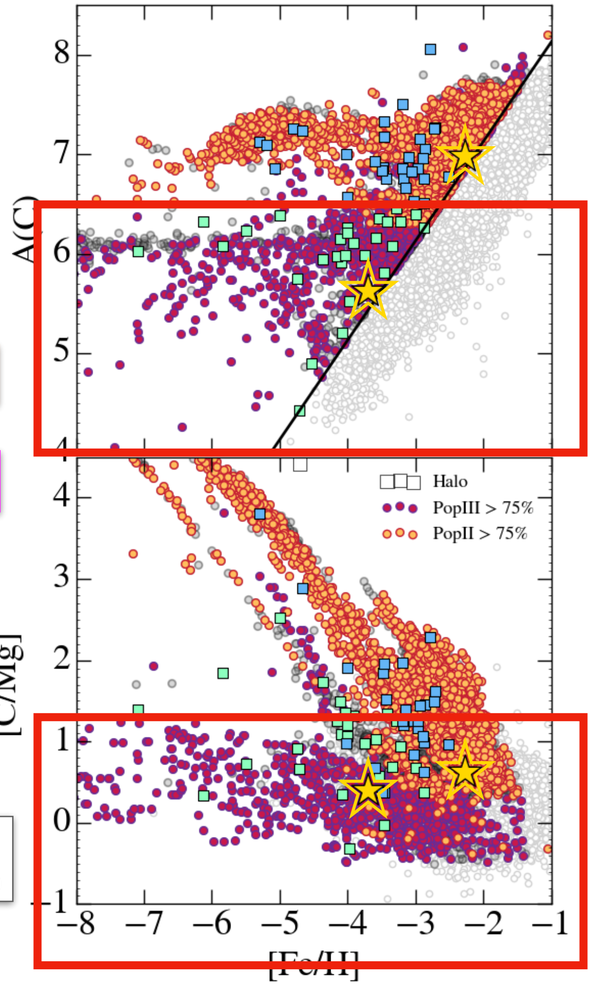

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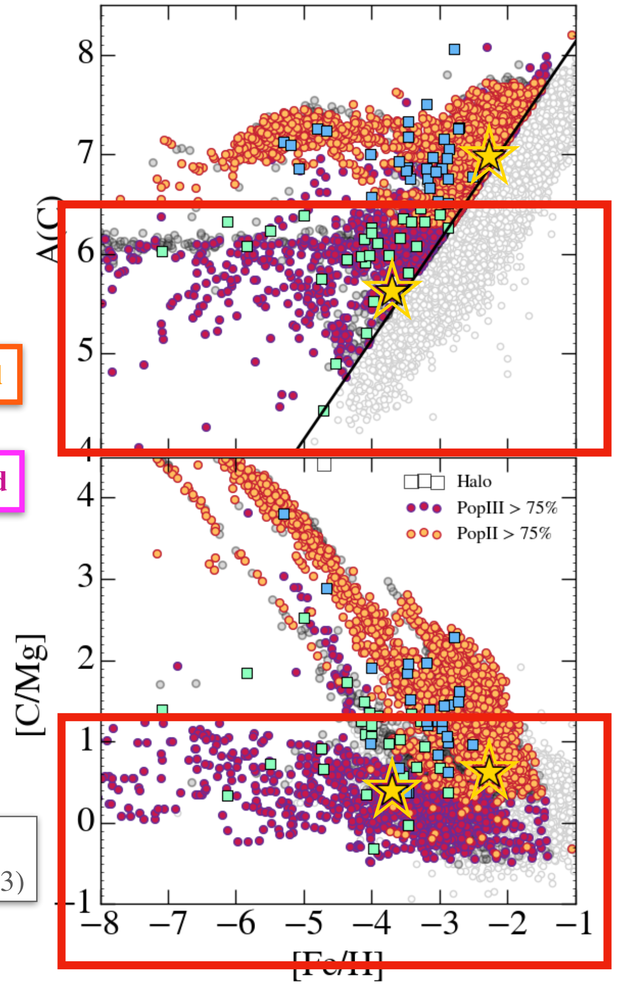

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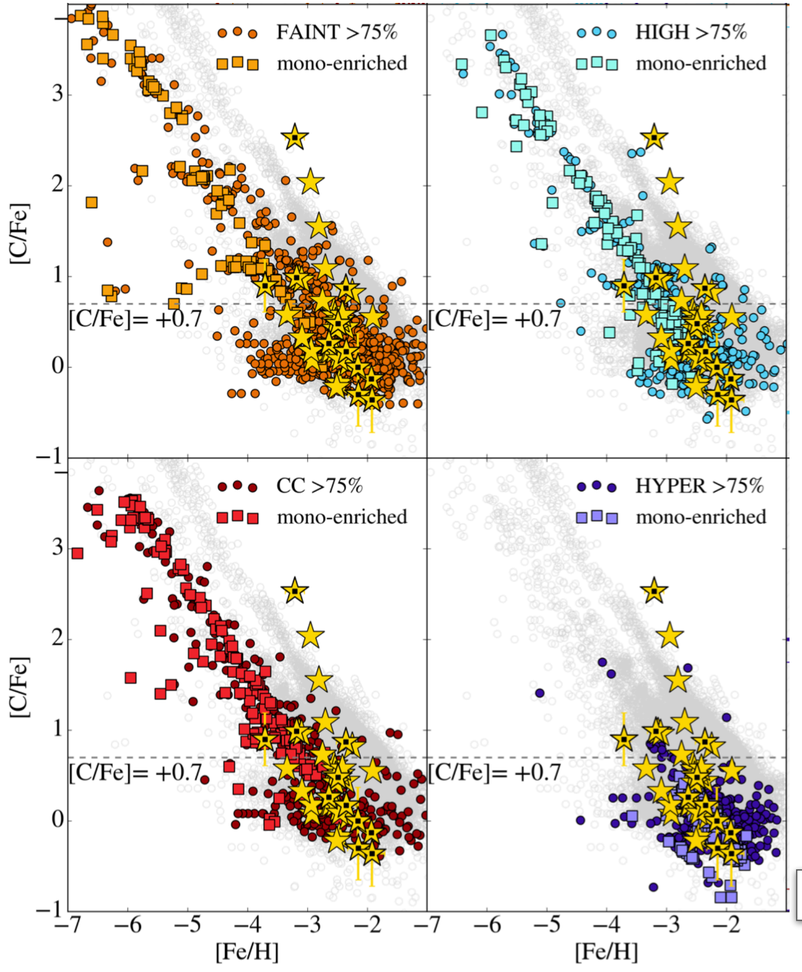

(**Rossi**+24a ApJ)

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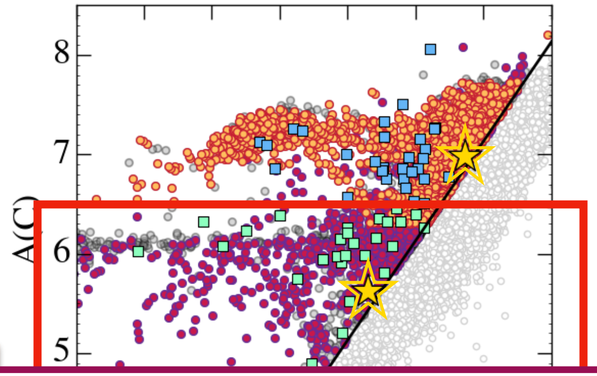

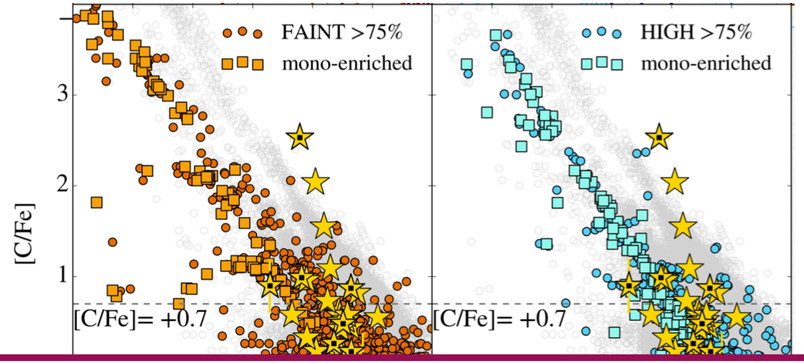

POP

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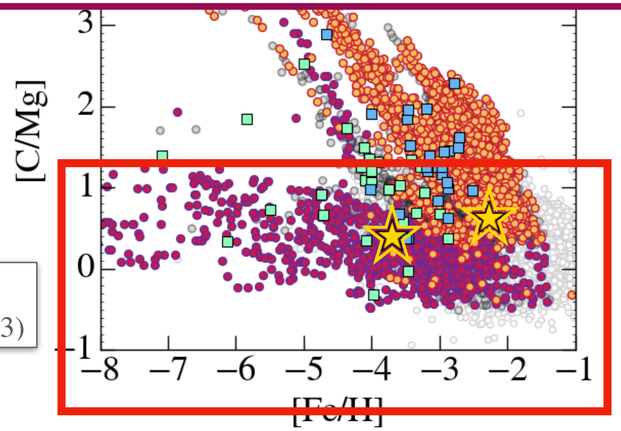
✓ The origin of CEMP star can be revealed using A(C) and [C/Mg] as diagnostic

✓ CEMP progenitors can be Pop III SNe with different energies



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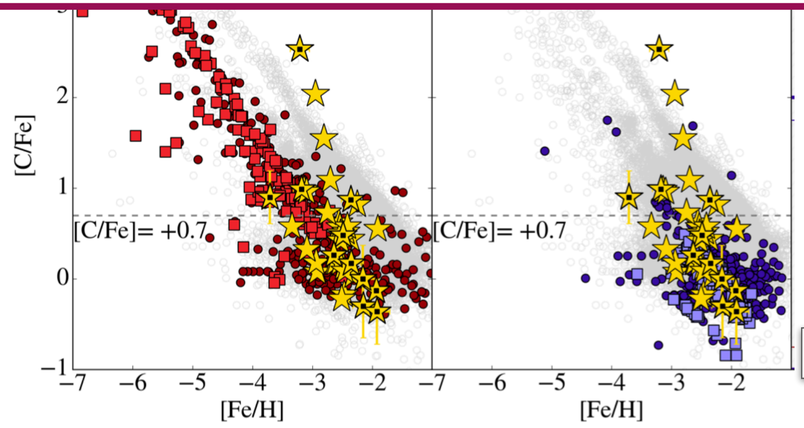


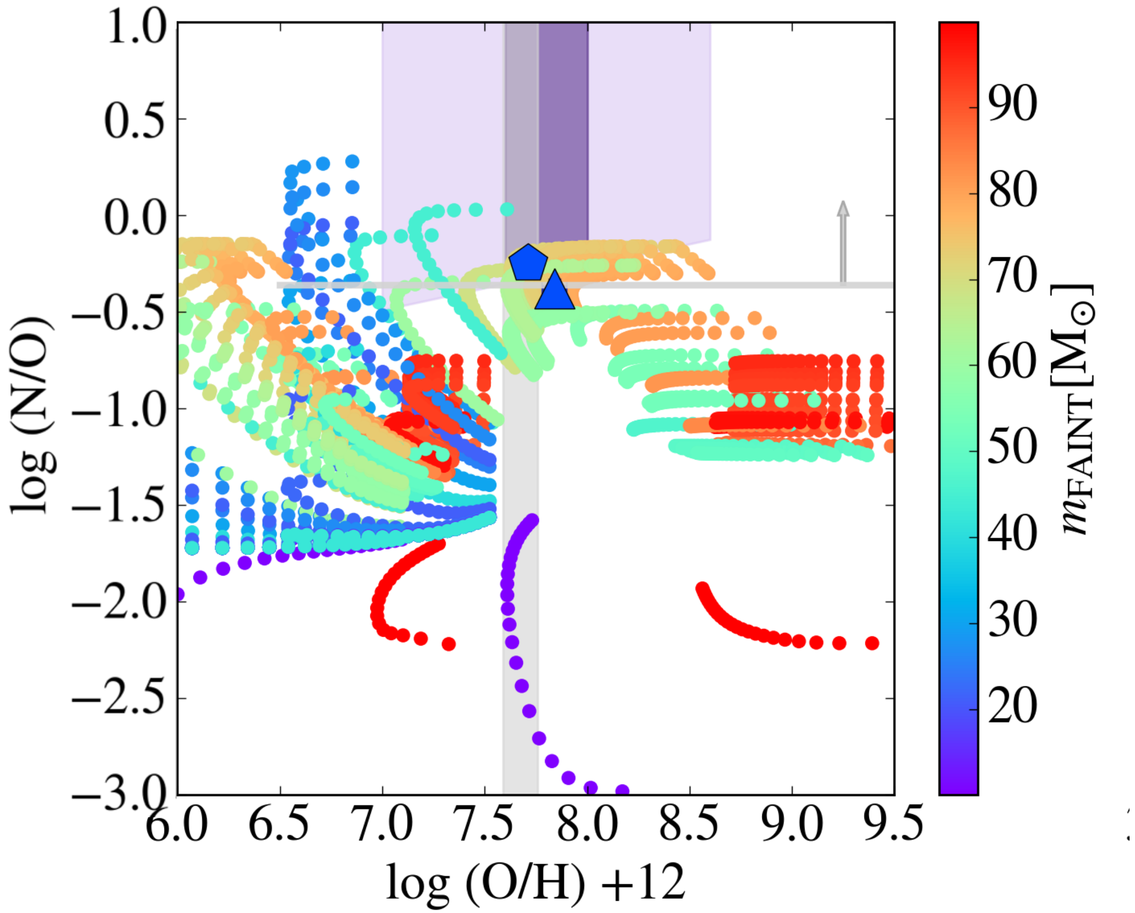
(**Rossi**+24a ApJ)

From Local to high-z

(**Rossi** M., Romano D., Mucciarelli A. et al 2024b)

Chemical evolutions models for high redshift galaxies : GN-z11

The models are tailored in order to reproduce SFR and the total stellar mass at the observation epoch



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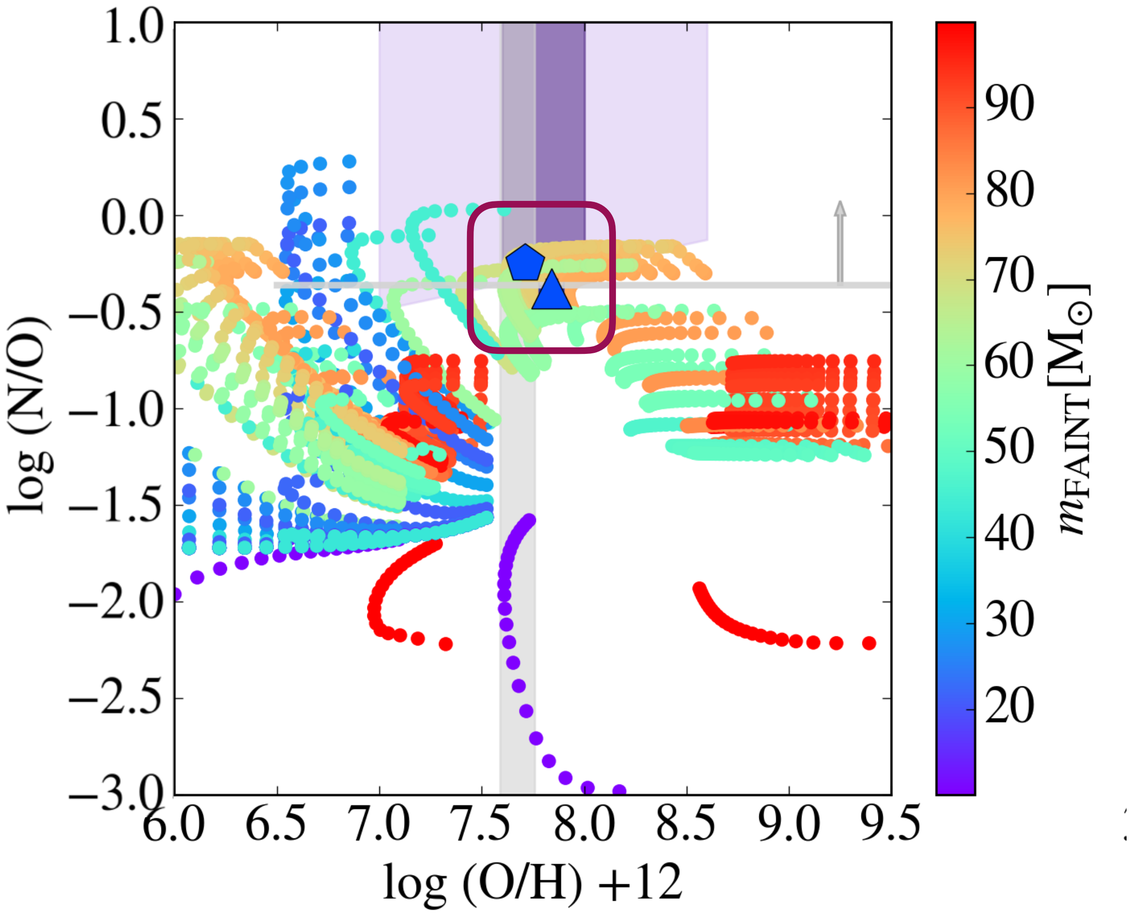

✓ Low energy Pop III SNe with mass [50-85]$M_\odot$ can explain the high value of N/O observed

Conclusions

Galactic Halo

- ✤ Stochastic enrichment of PopIII with different energies is required to reproduce the observed scatter in metal-poor stars (**Rossi** et al 2024b)
- ✤ Pop III SNe with different energy populate different regions in [CNO/Fe] versus [Fe/H] space

Ultra-Faint Dwarf galaxies

- ★ In low star forming systems it is crucial account the incomplete sampling of the IMF (**Rossi** et al 2021)
- ★ The origin of CEMP-no stars can be revealed through their A(C) value (**Rossi** et al 2023)
- ★ Nearly all CEMP-no stars with $A(C) \lesssim 6$ and $[C/Mg] \lesssim 1$ are predicted to be pure PopIII descendants

High redshift galaxies: GN-z11

- Massive, faint Pop III stars likely contribute to high observed N/O and C/O ratios in early Universe galaxies, highlighting their role in the initial phases of chemical evolution at high redshift

CHEMICAL EVOLUTION MODELS – data sample is important

Galactic Chemical Evolution (GCE) models versus observations + ***stochastic processes*** + ***Pop III enrichment***

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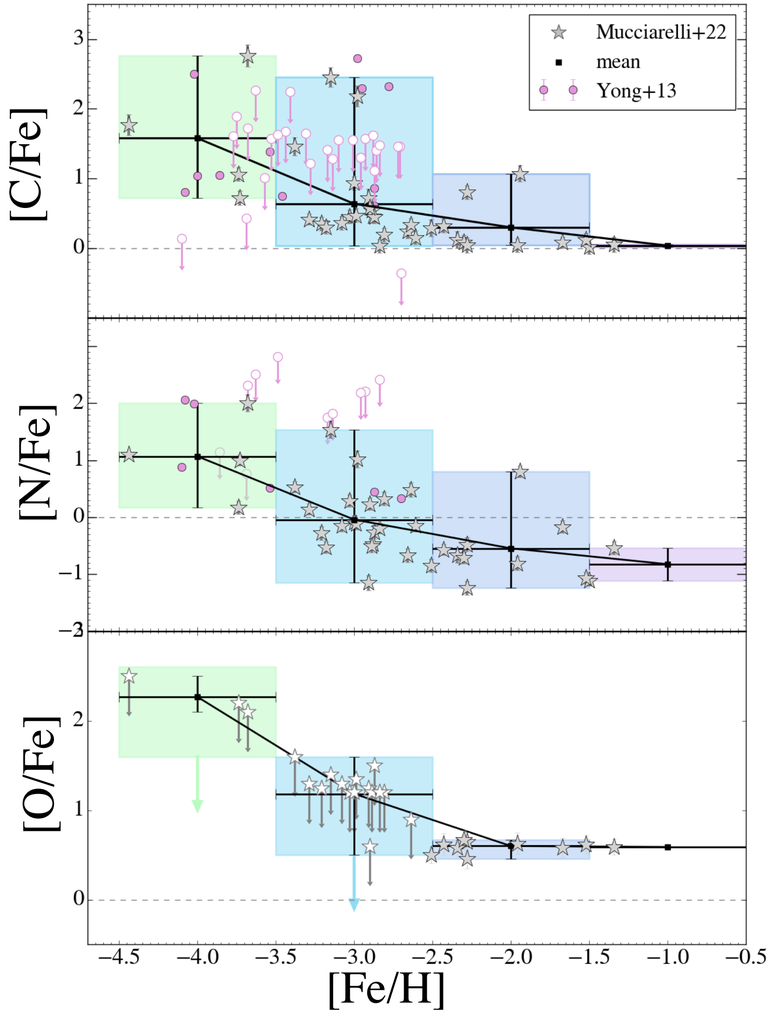

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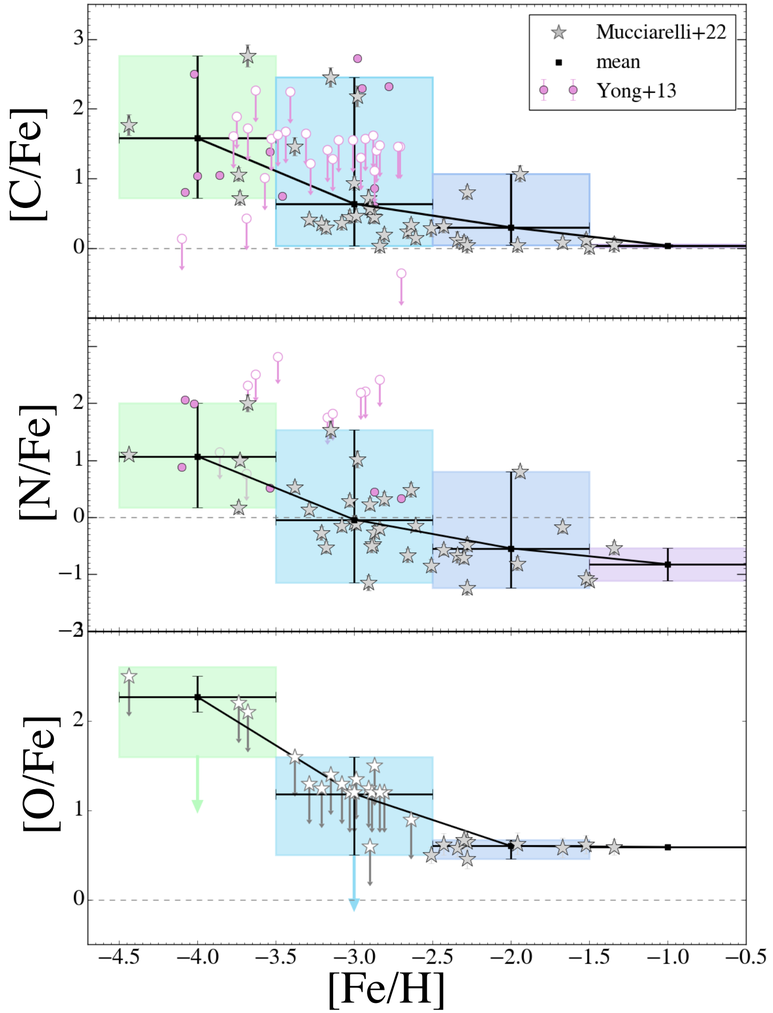

Could the scatter reflect stars belonging to distinct halo substructures with different star-formation and chemical enrichment histories?

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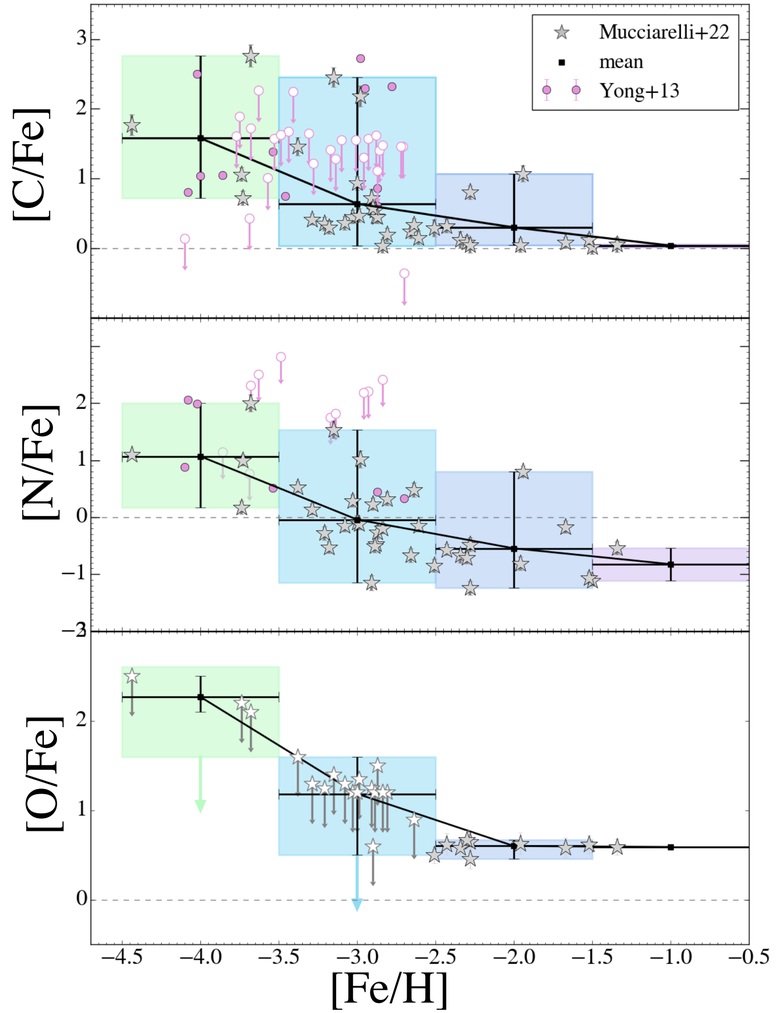
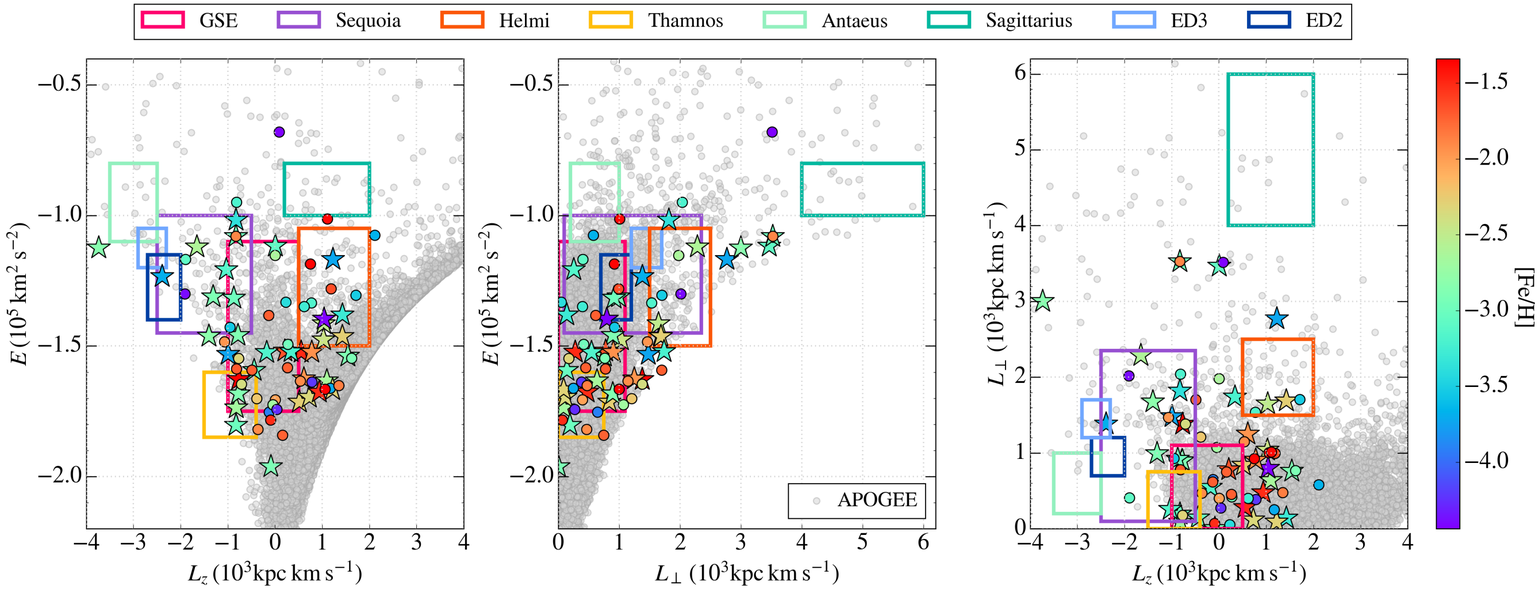
MW Halo **DATA SAMPLE**: Homogeneous sample on unmixed **dwarf** stars



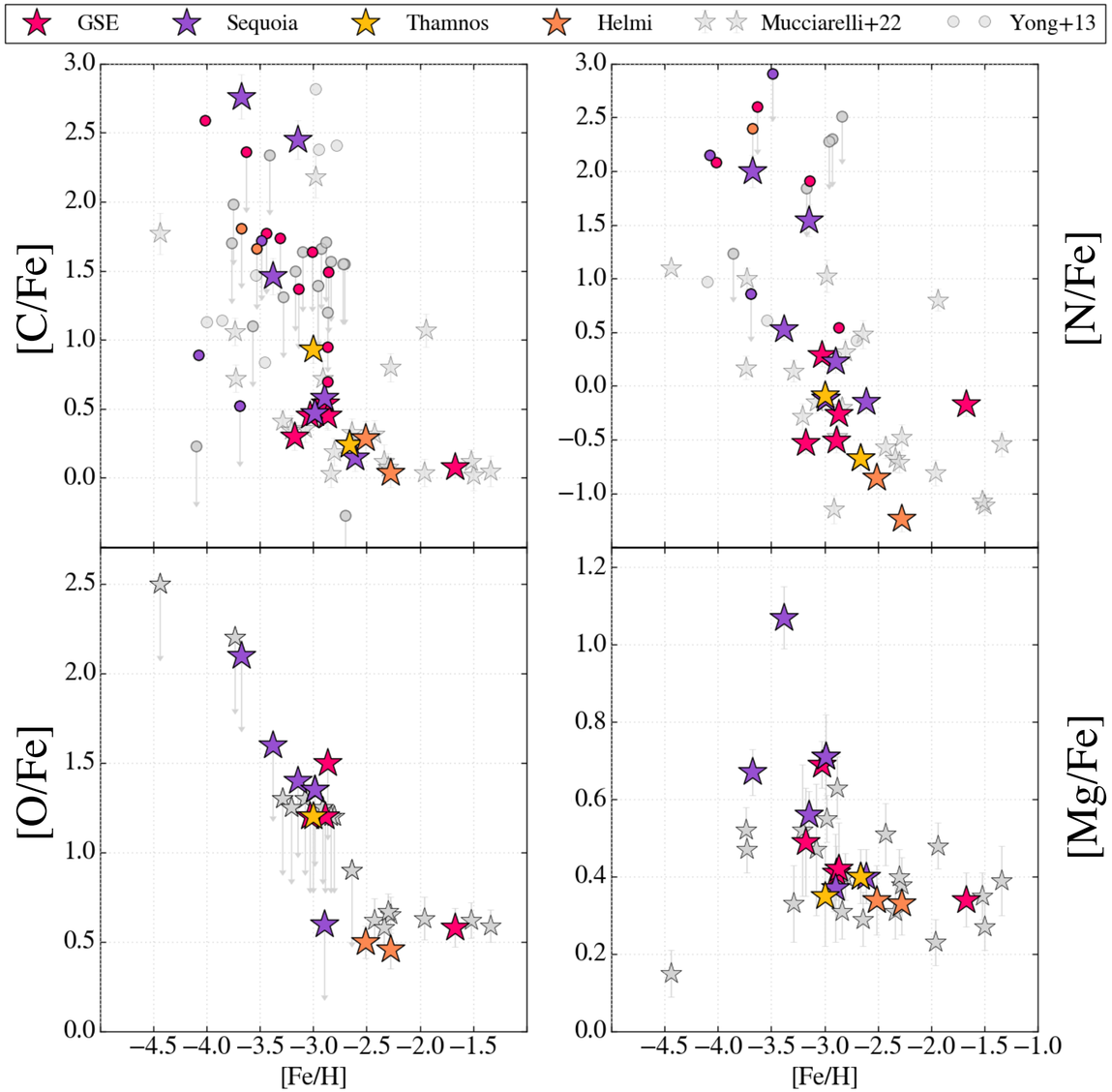
Could the scatter reflect stars belonging to distinct halo substructures with different star-formation and chemical enrichment histories?



Rossi+24a A&A

CHEMICAL EVOLUTION MODELS – Milky Way halo

Galactic Chemical Evolution (GCE) models versus observations + ***stochastic processes*** + ***Pop III enrichment***



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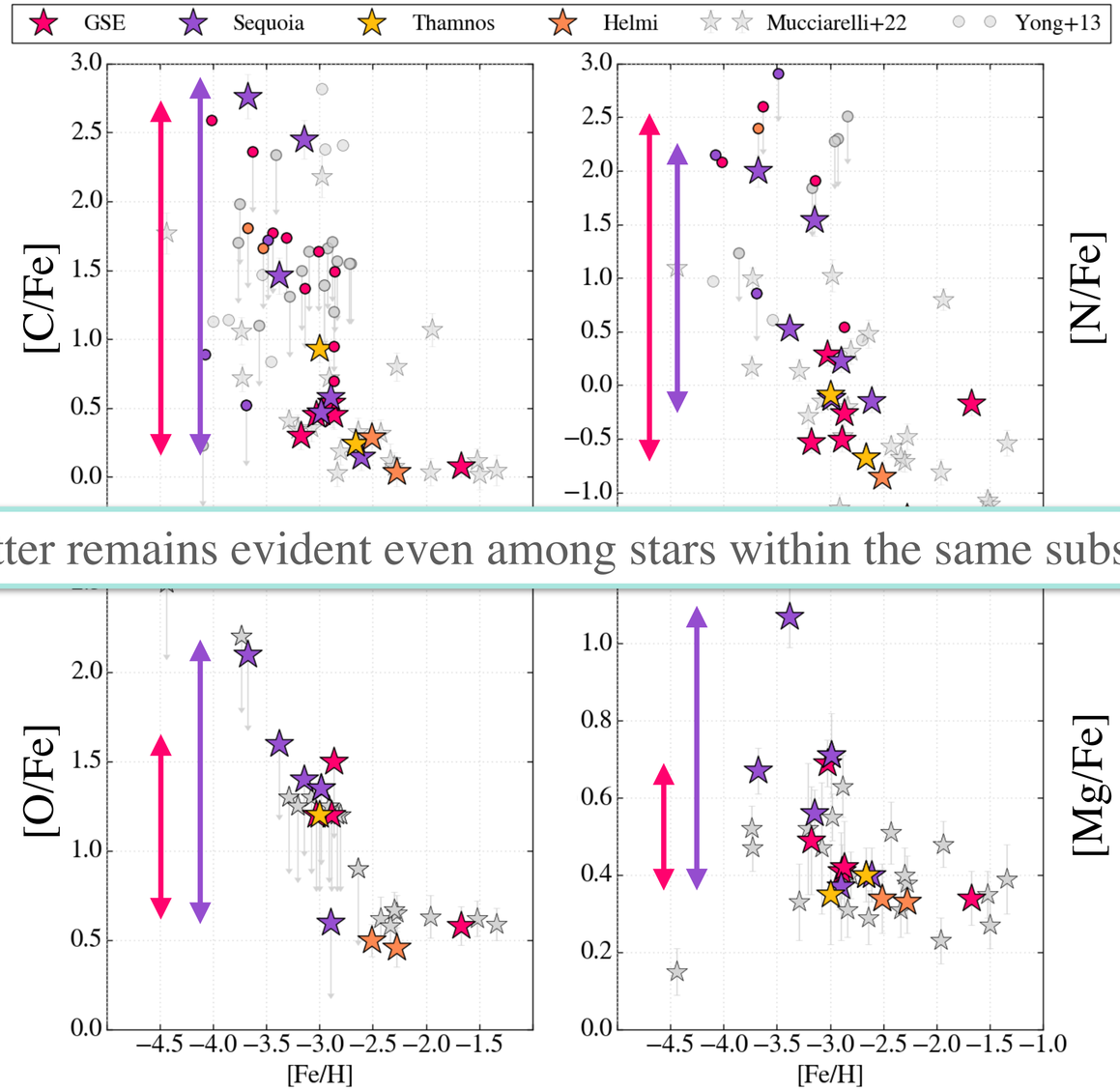


The scatter remains evident even among stars within the same substructure

CHEMICAL EVOLUTION MODELS – Milky Way halo

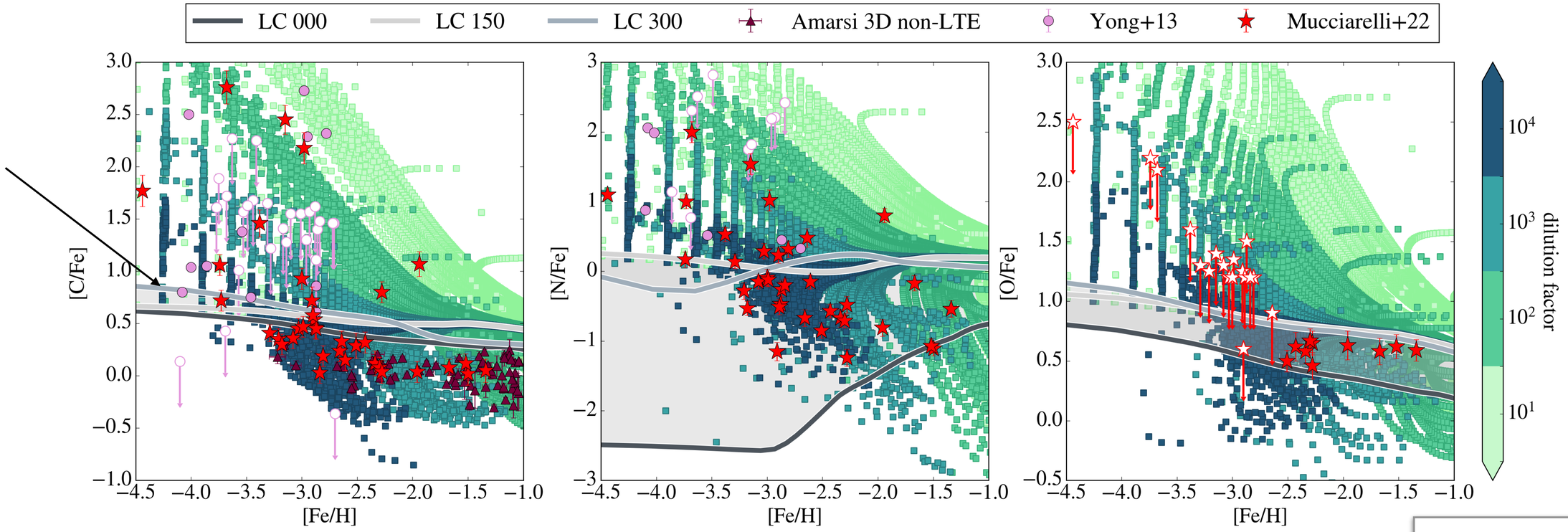
Galactic Chemical Evolution (GCE) models versus observations + ***stochastic processes*** + ***Pop III enrichment***

Pop III SNe with different masses and explosion energies enrich the ISM in the first phases of chemical evolution

CARBON

NITROGEN

OXIGEN



Rossi+24a A&A

Dilution factor: ratio between H mass and the mass ejected by PopIII SNe

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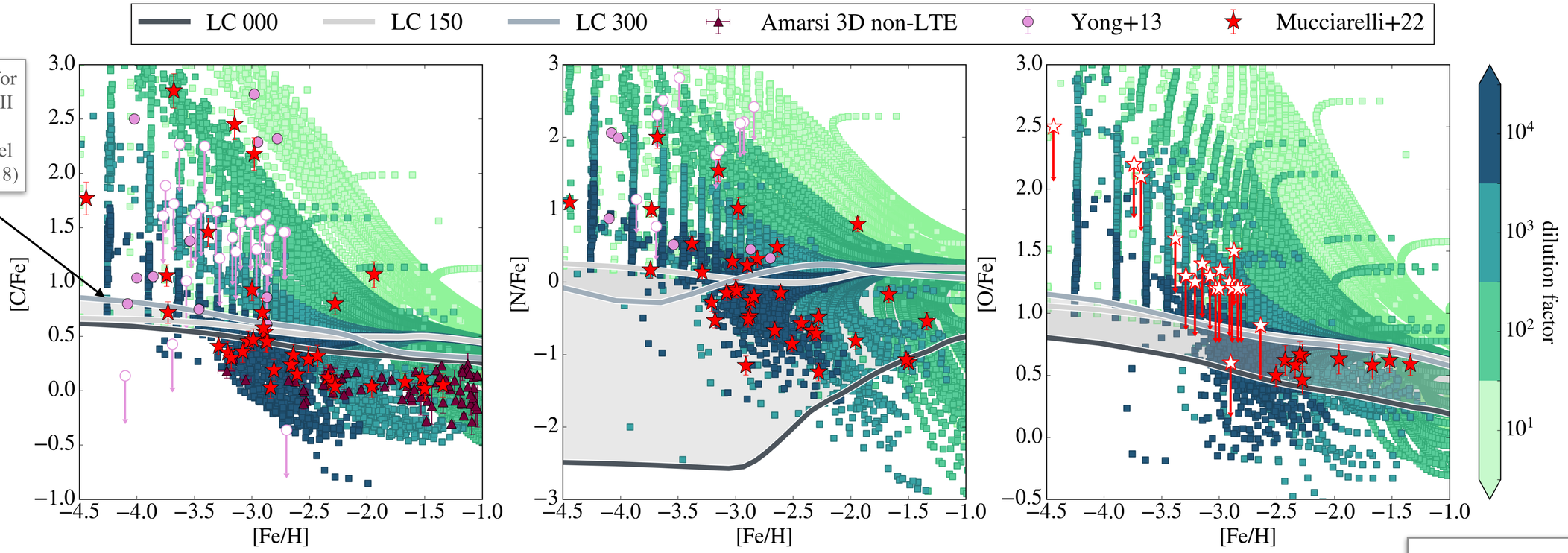


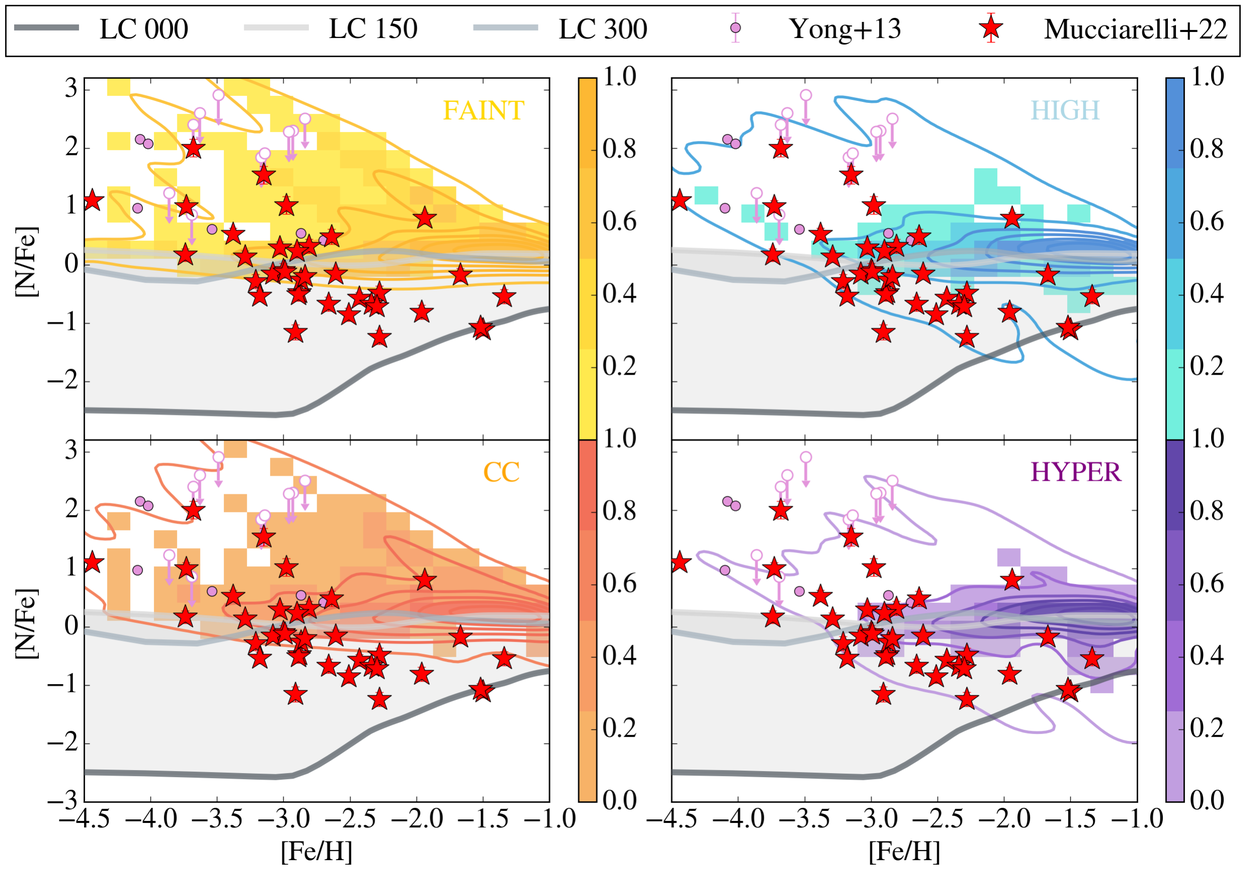
Model predictions for different set of PopII stellar yields and homogeneous model (Limongi&Chieffi 18)

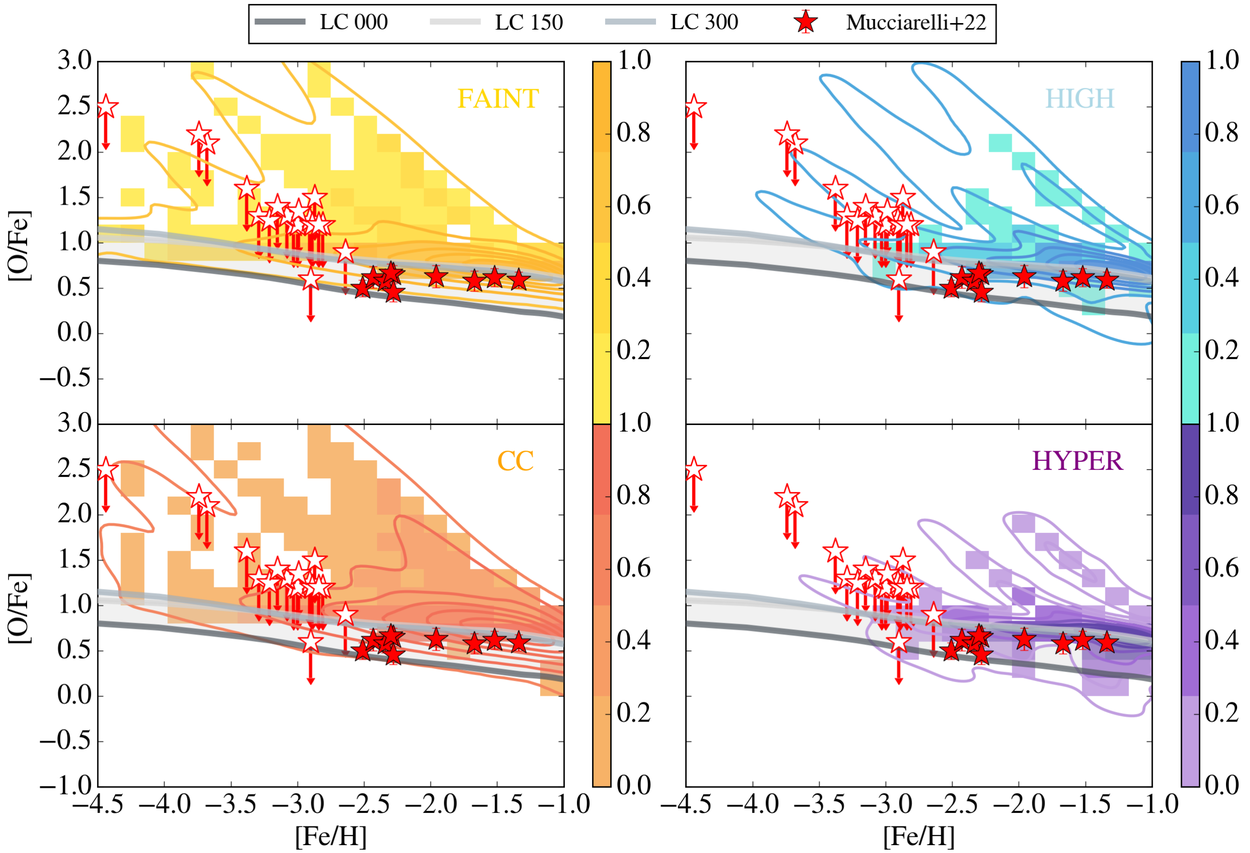
Rossi+24a A&A

Dilution factor: ratio between H mass and the mass ejected by PopIII SNe

Moving to Galactic Halo

(**Rossi** M., Romano D., Mucciarelli A. et al 2024 **arXiv:2406.14615**)

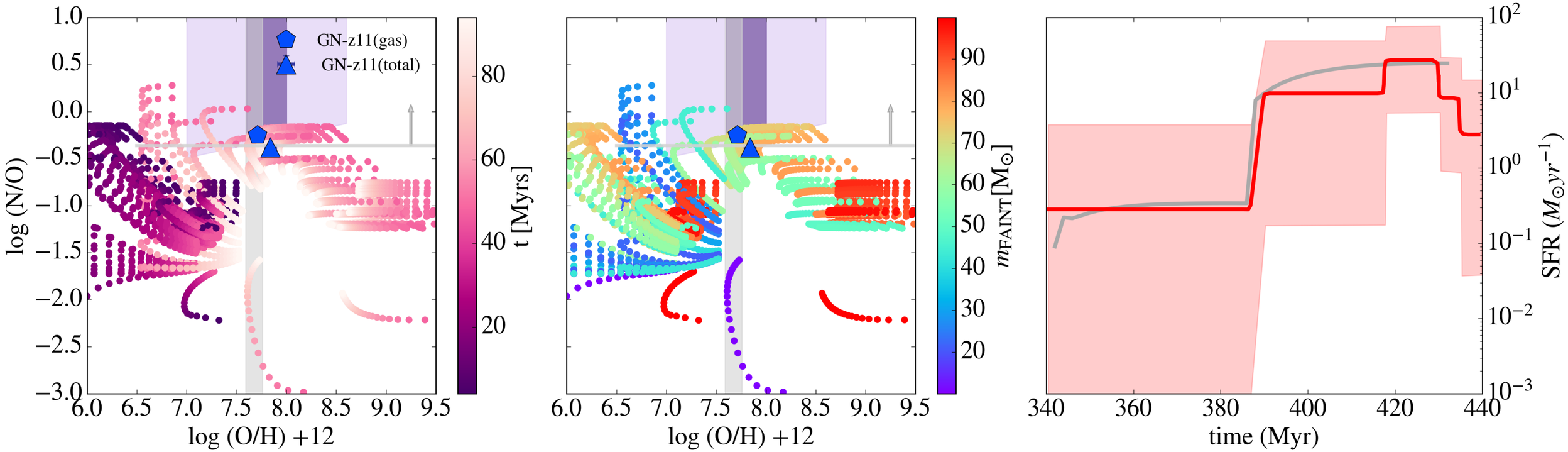




From Local to high-z

(**Rossi** M., Romano D., Mucciarelli A. et al 2024 **arXiv:2406.14615**)

Chemical evolutions models for high redshift galaxies : GN-z11



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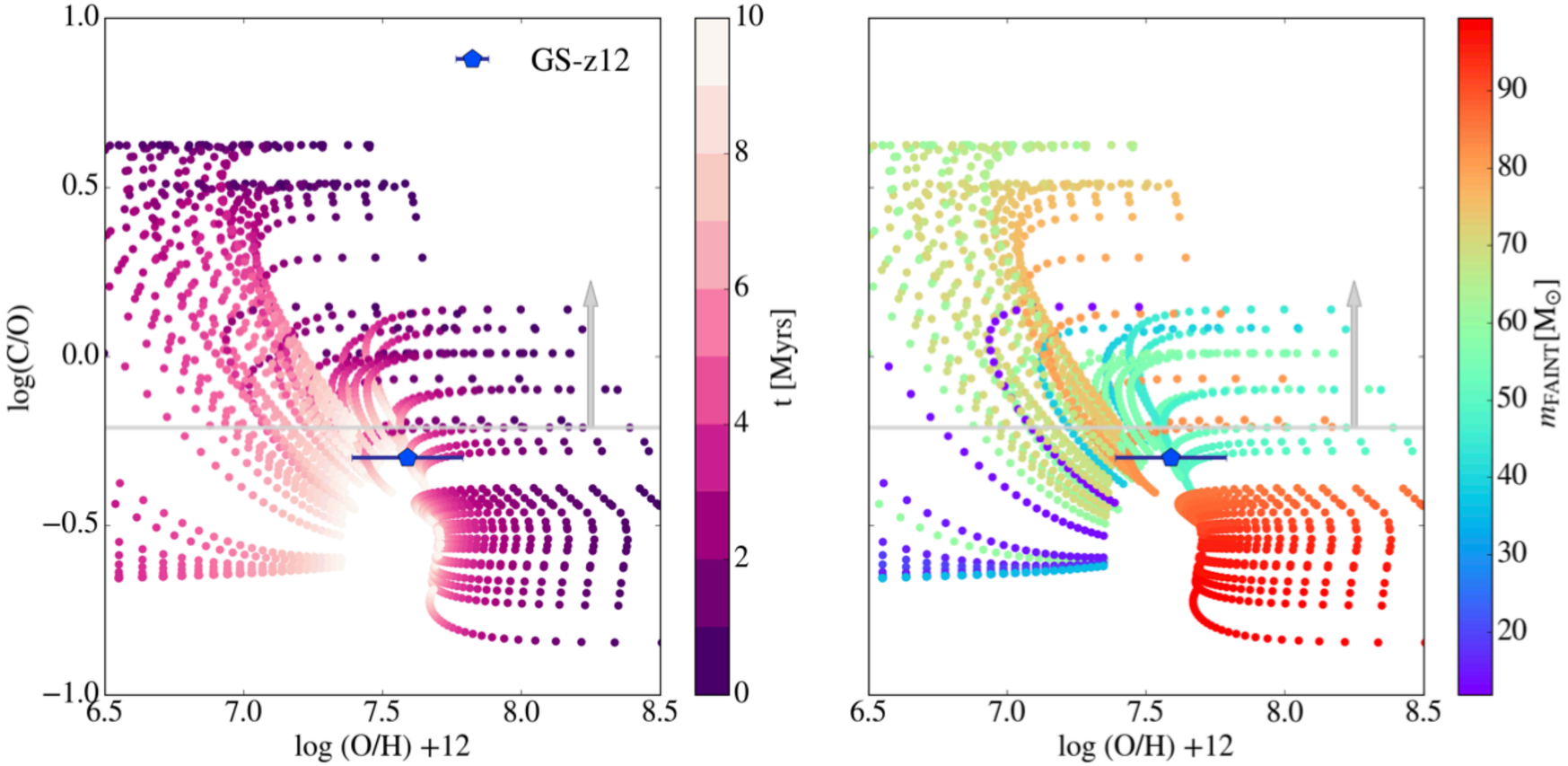
(**Rossi** M., Romano D., Mucciarelli A. et al 2024 **arXiv:2406.14615**)

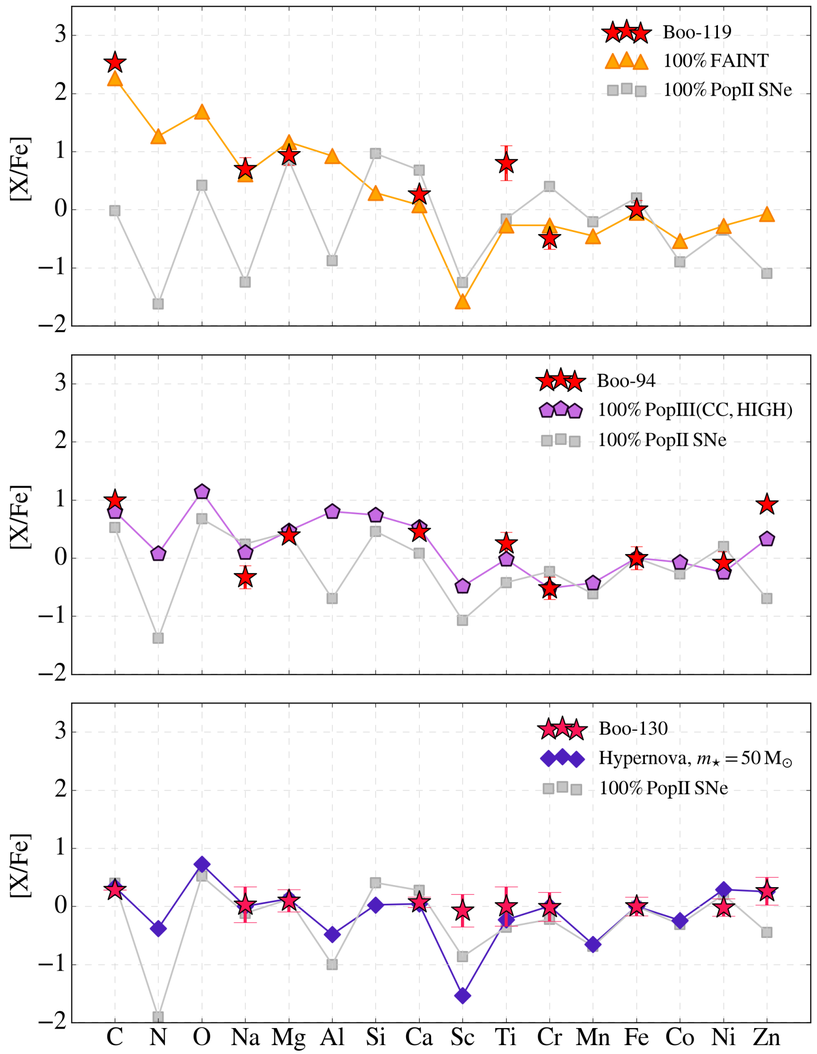
Chemical evolutions models for high redshift galaxies : GS-z12



POPIII stars descendants: CEMP stars

Rossi M., 2024 (submitted to ApJ)

Hidden Pop III descendants



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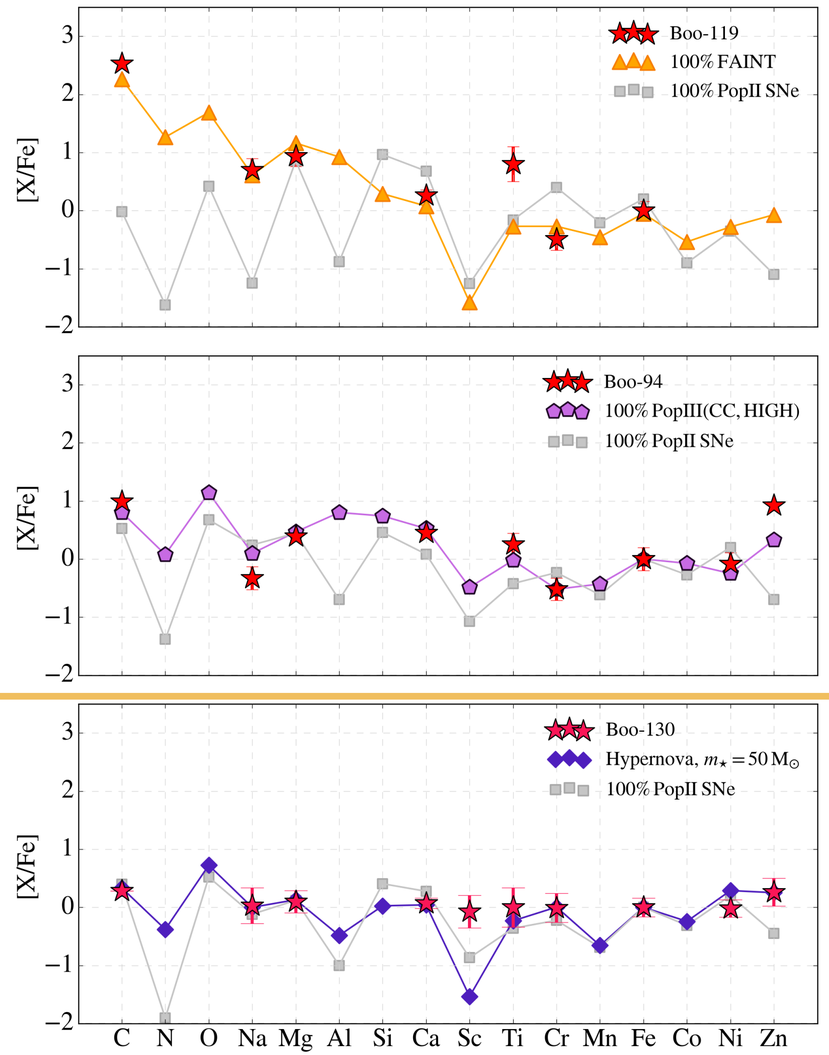

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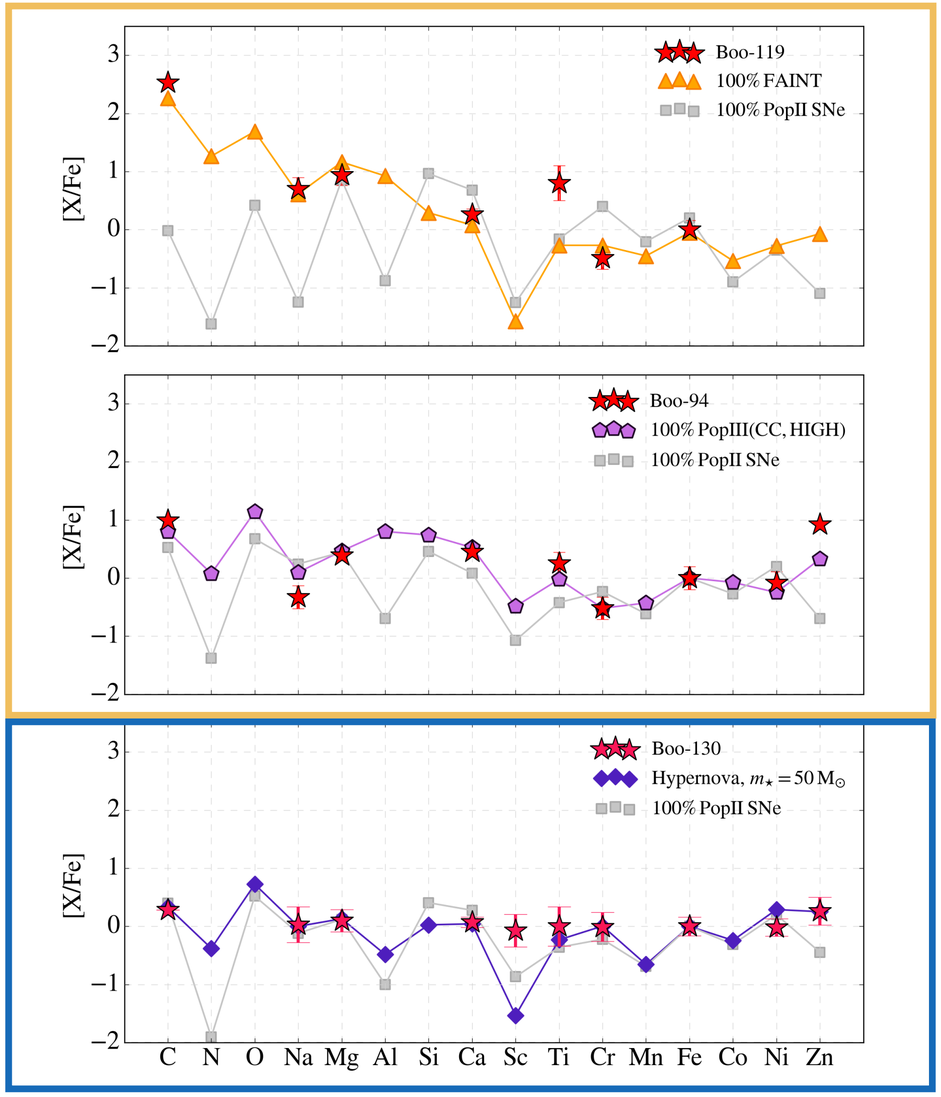

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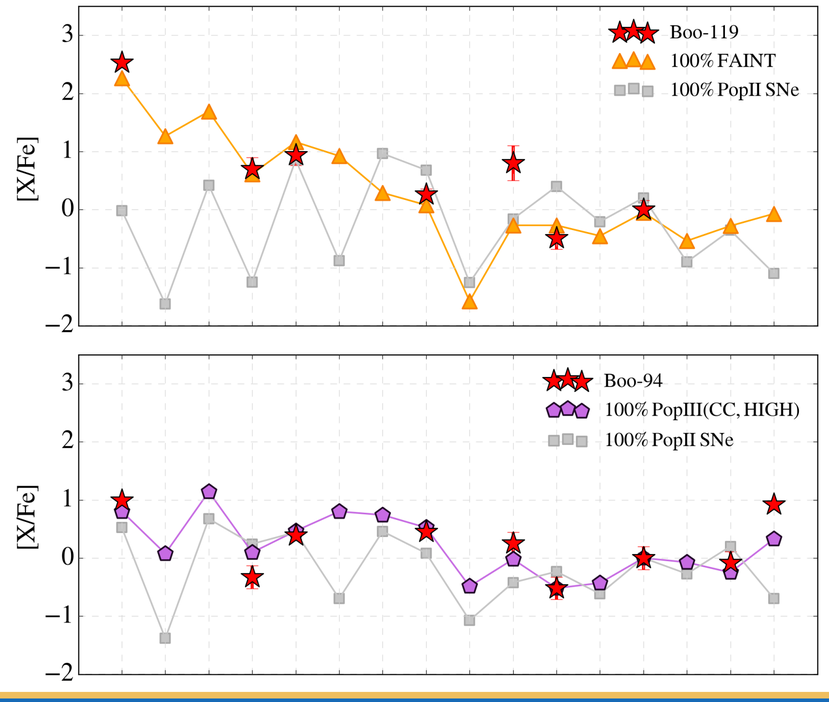

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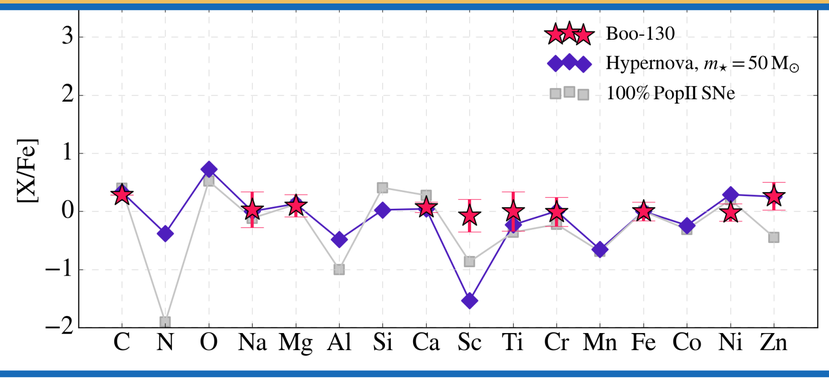

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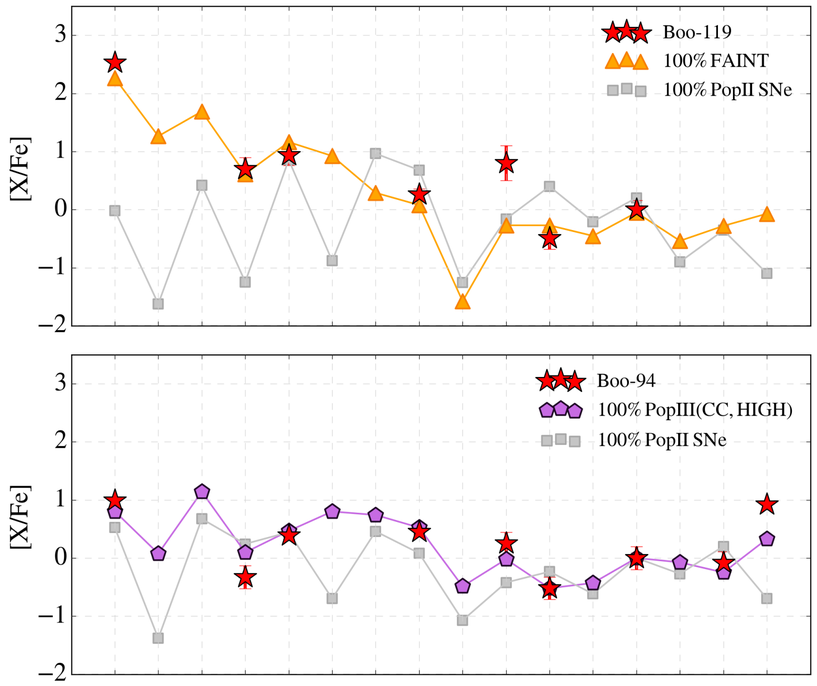

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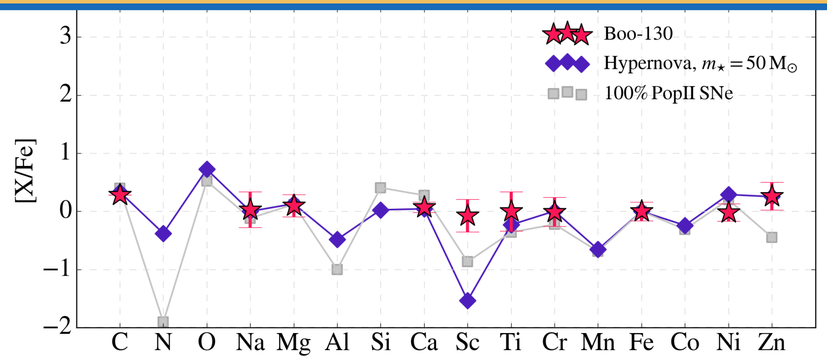

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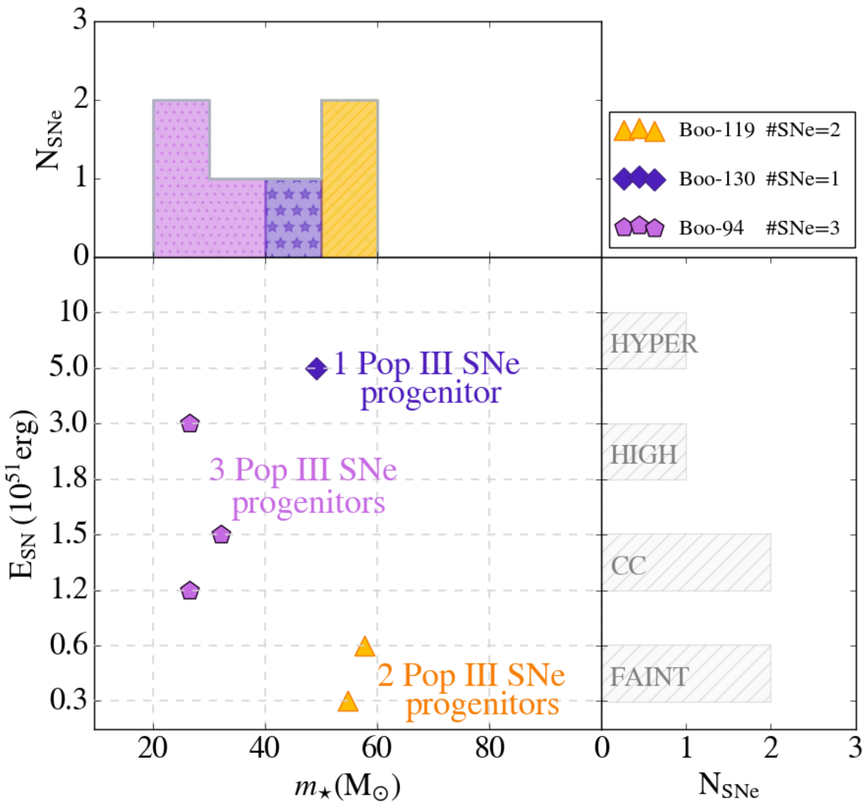

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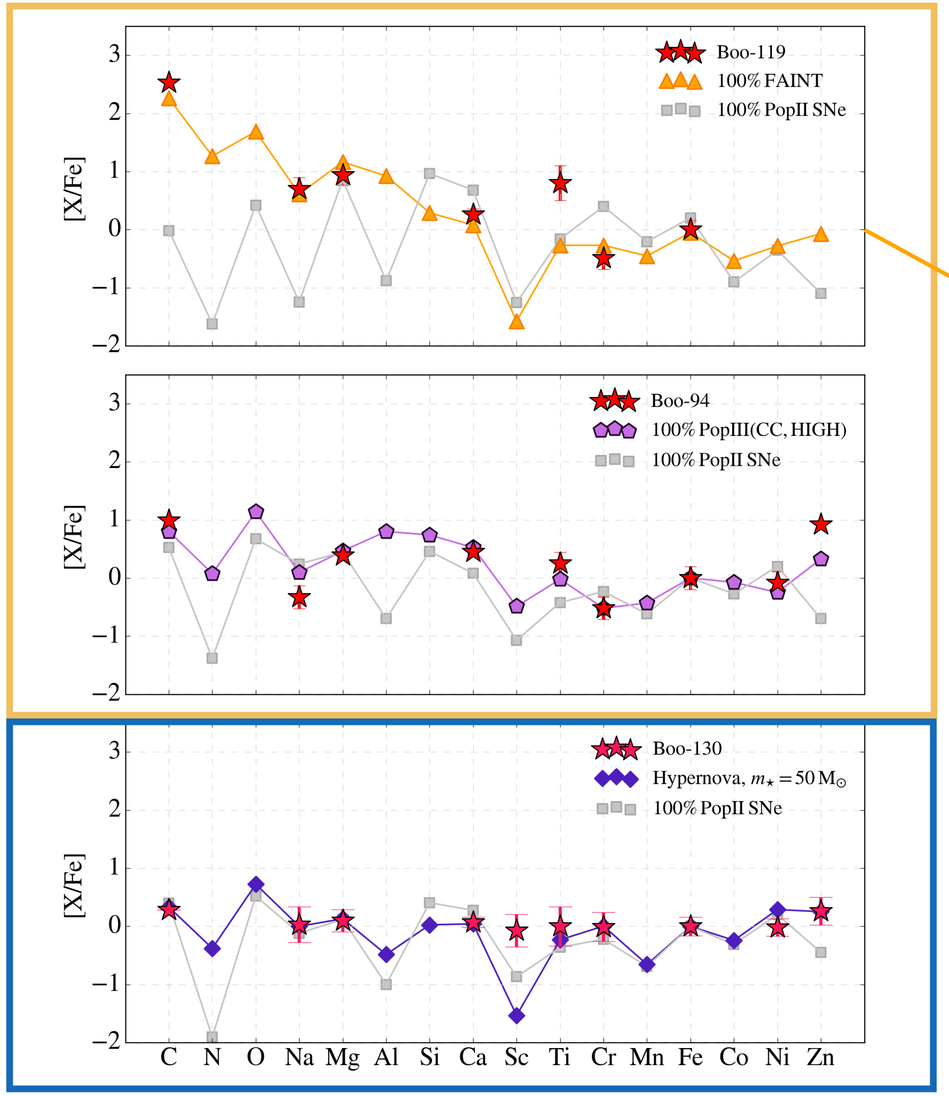

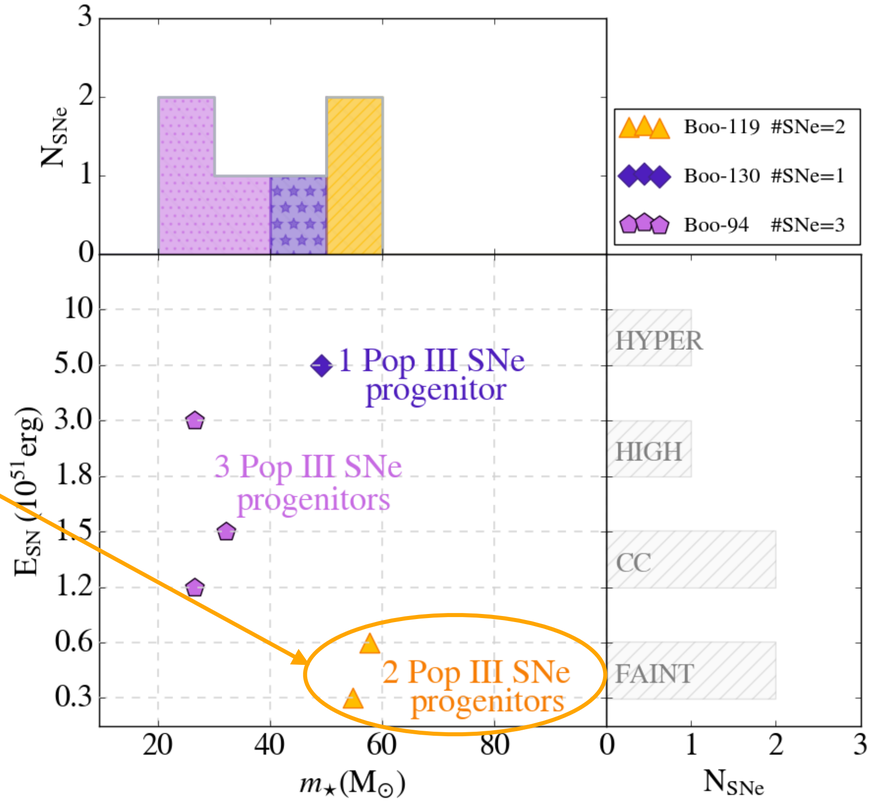

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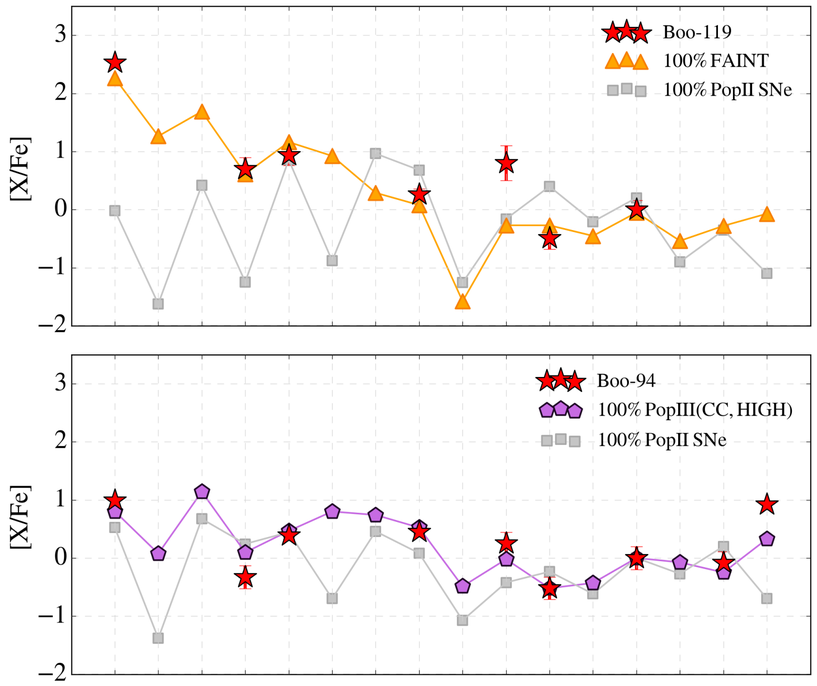

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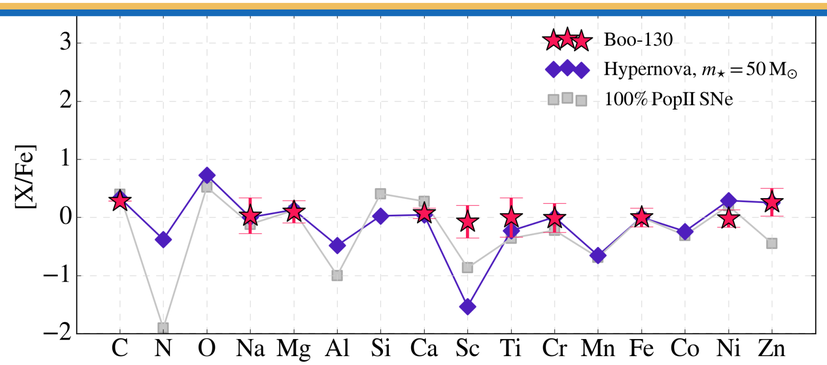

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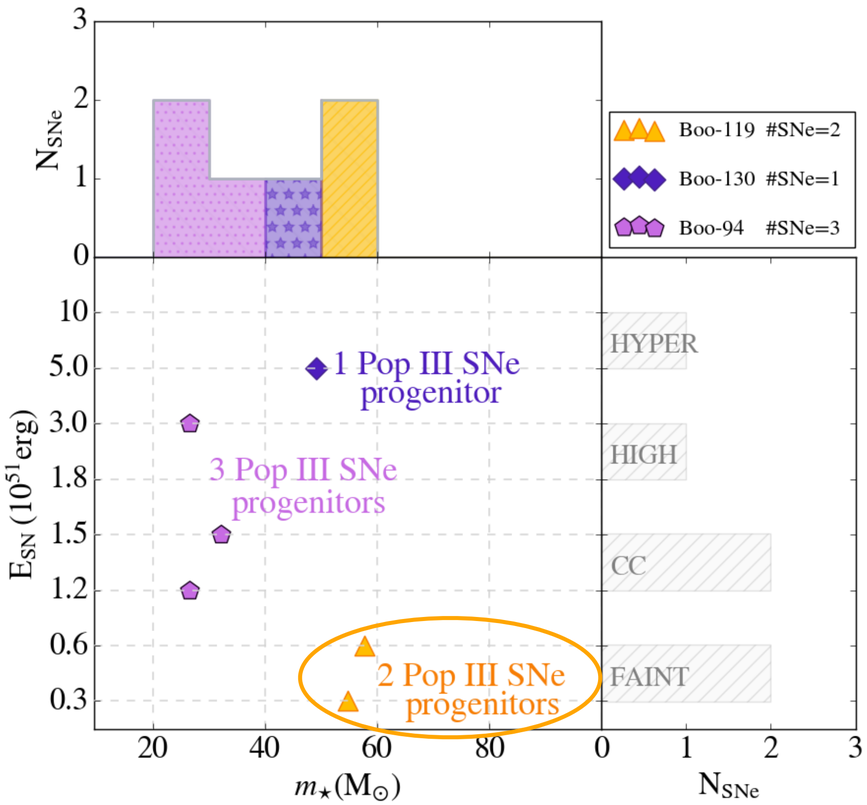

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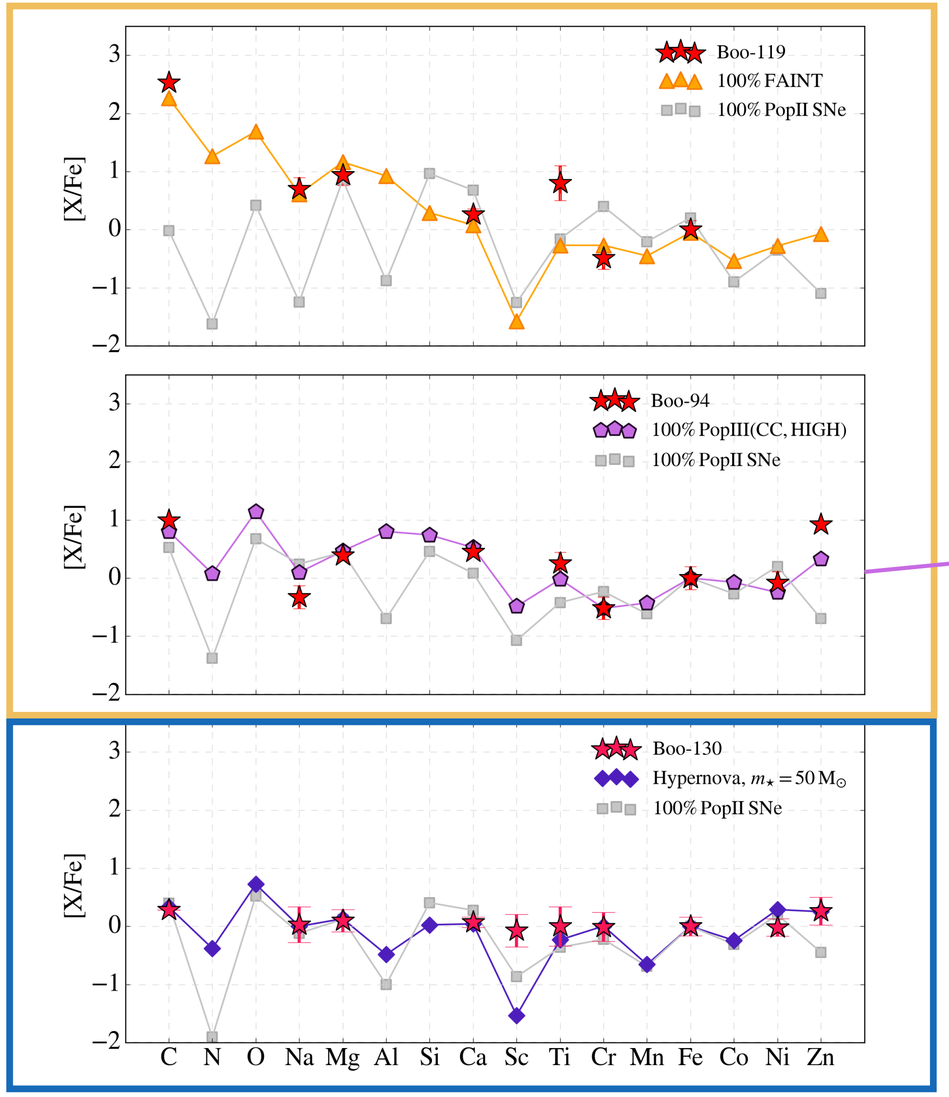

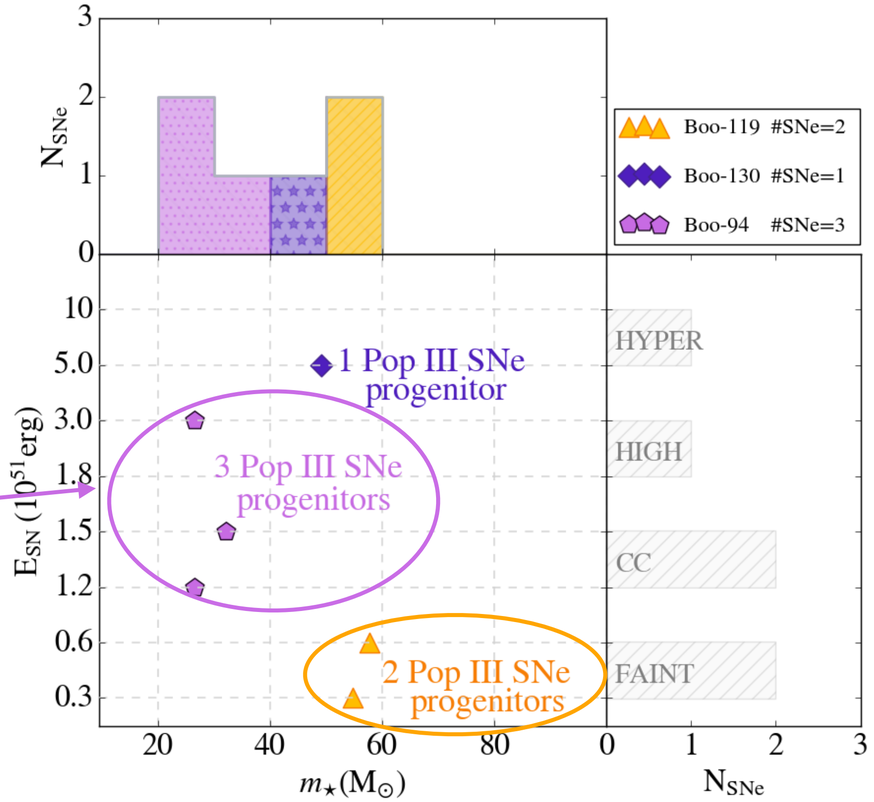

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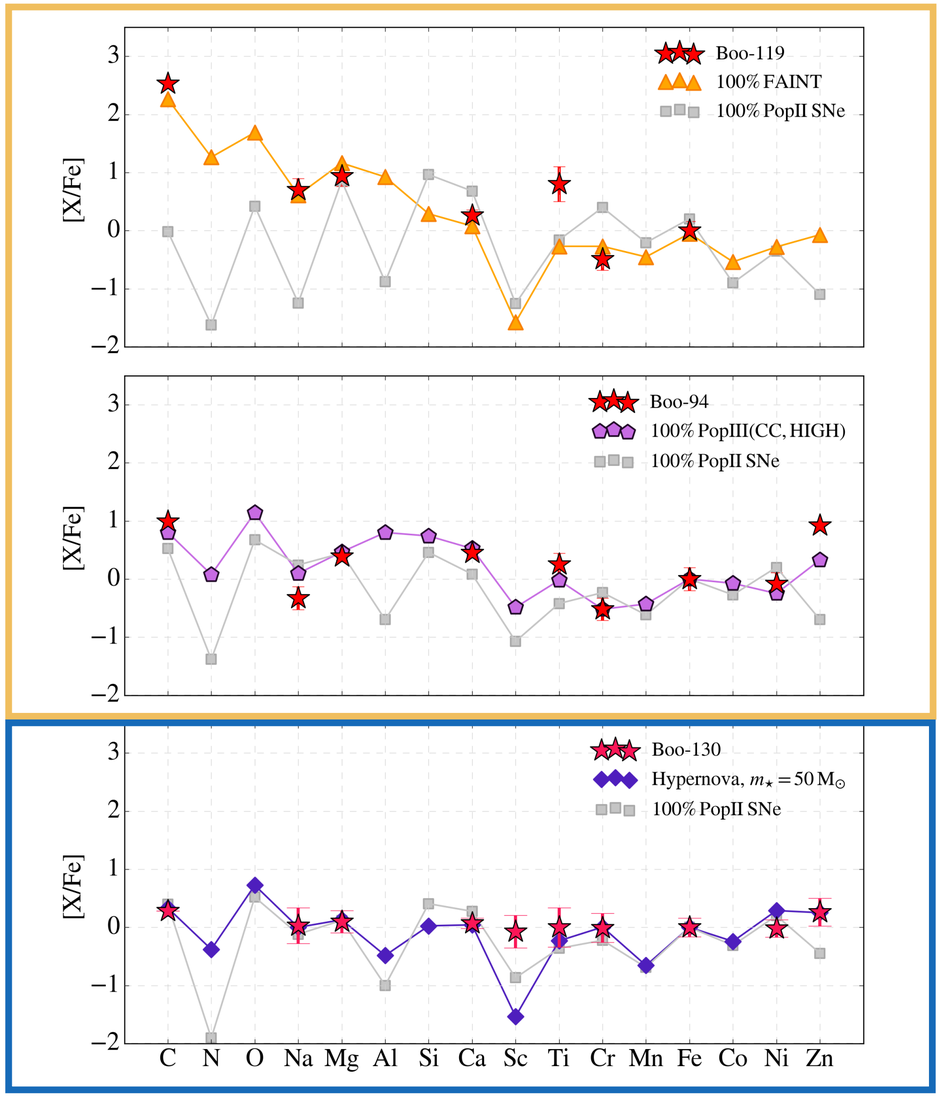

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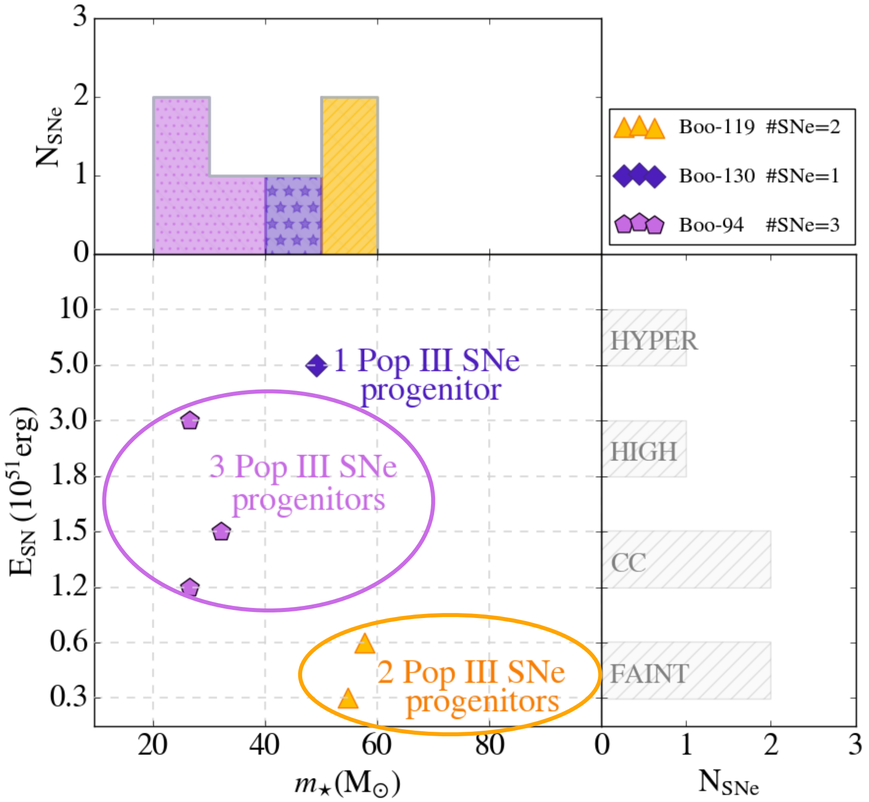

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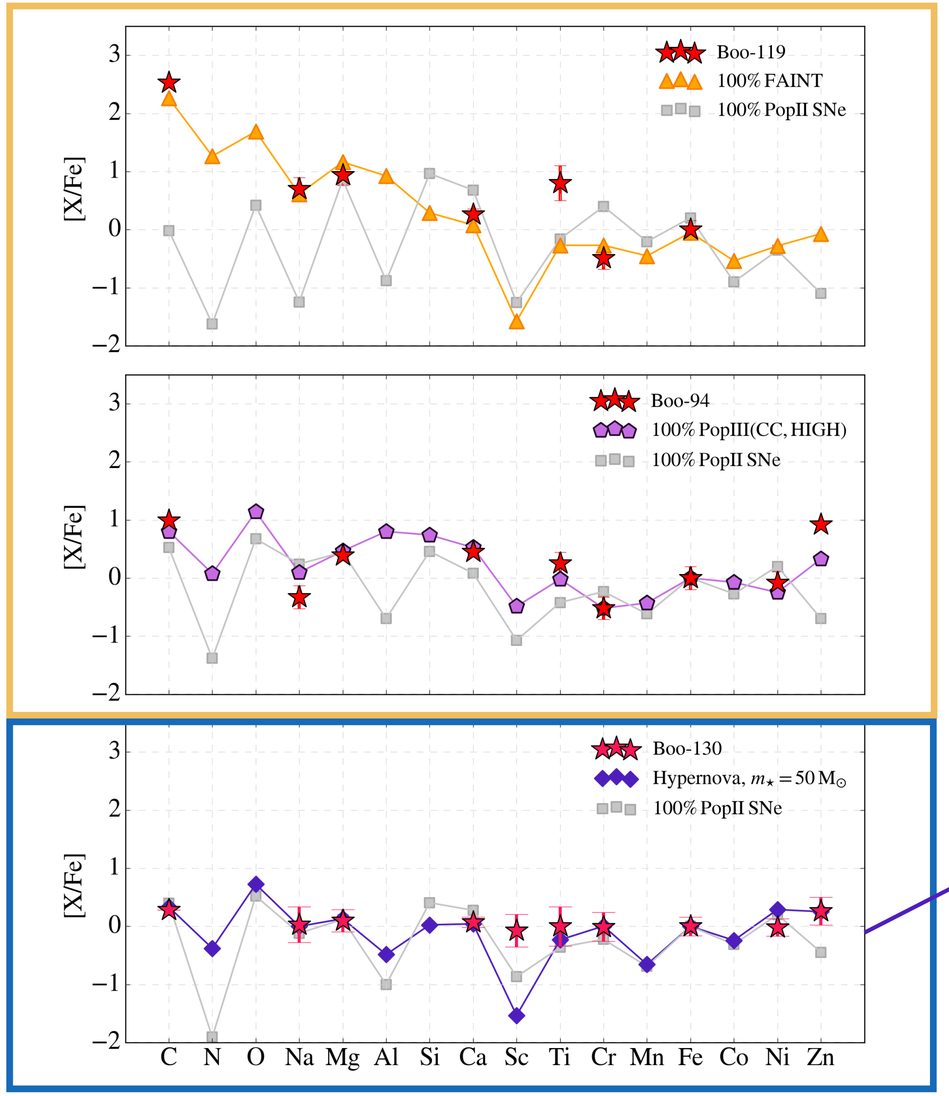

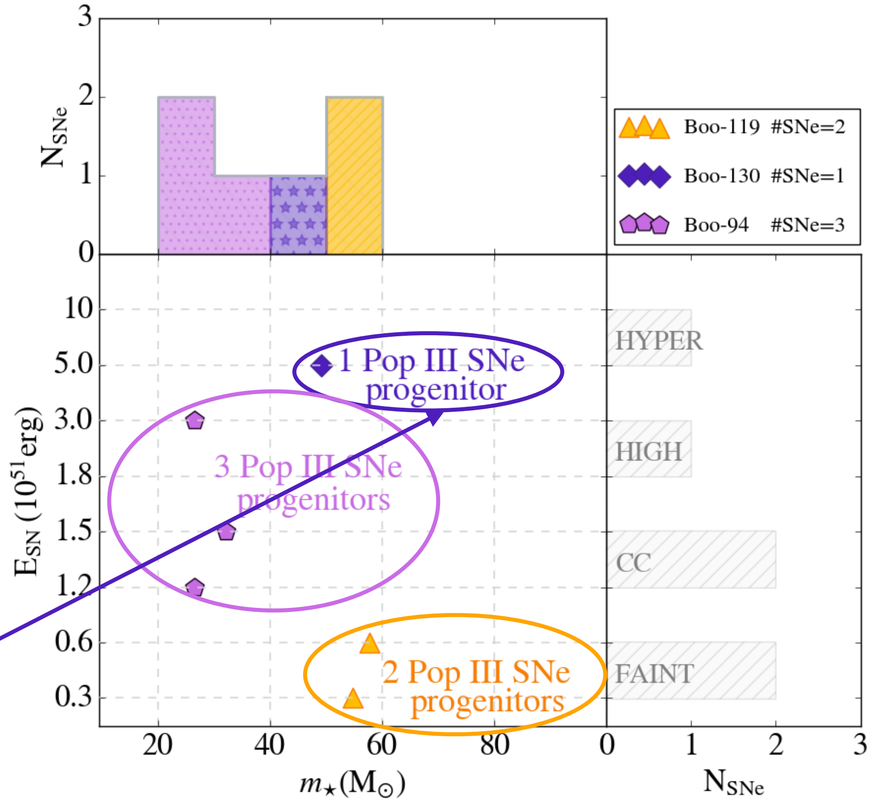

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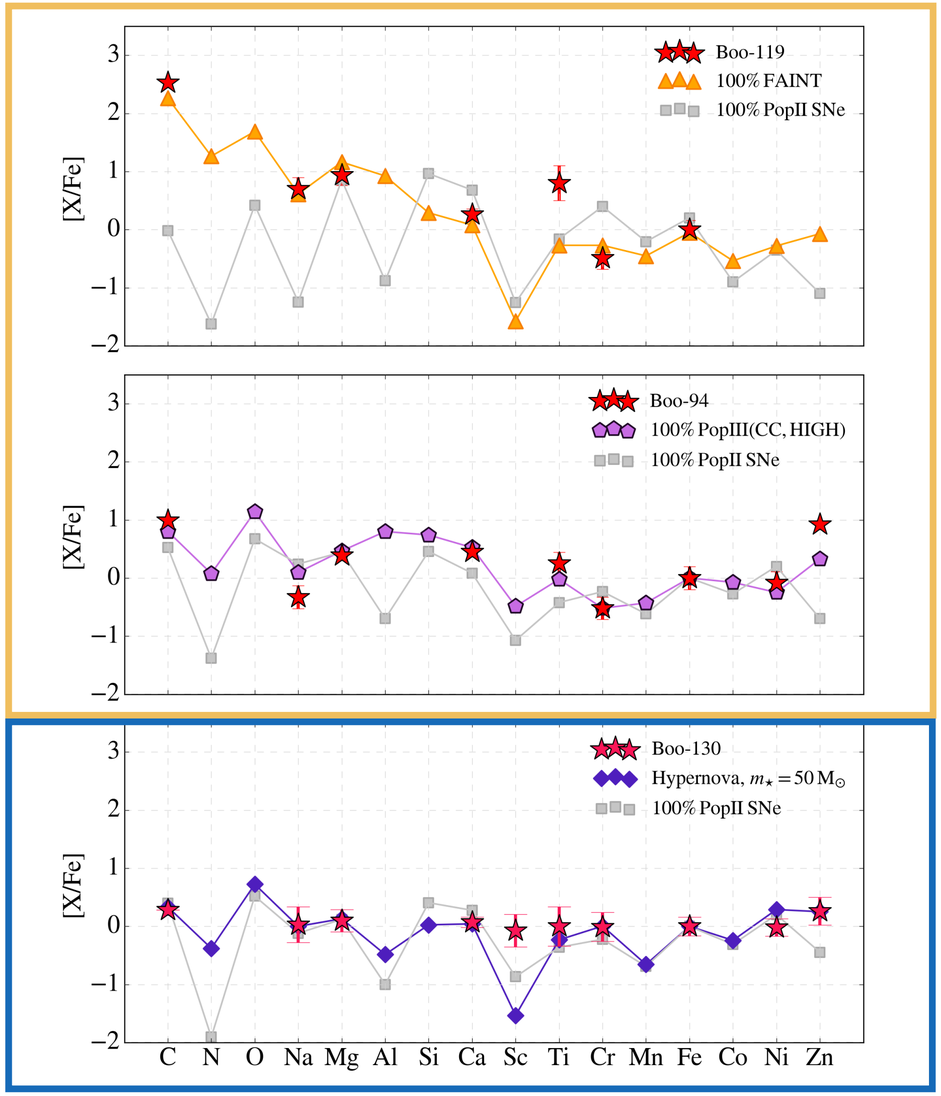

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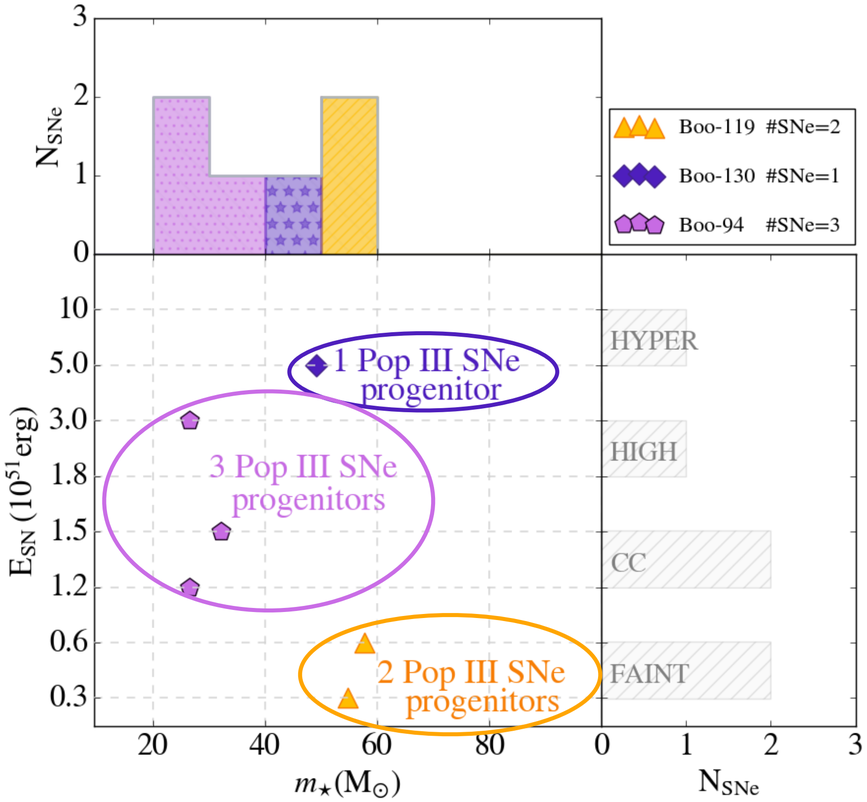

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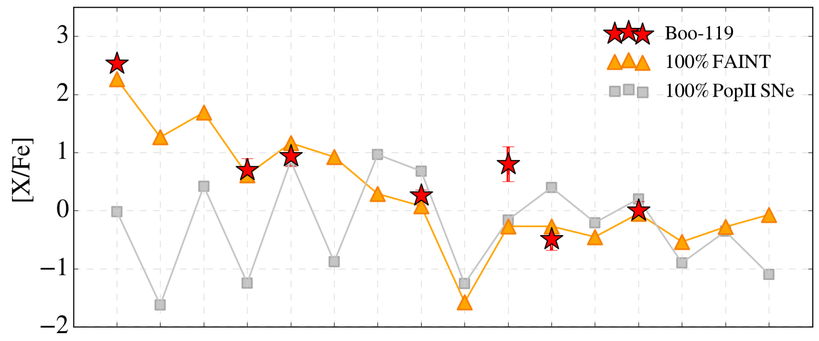

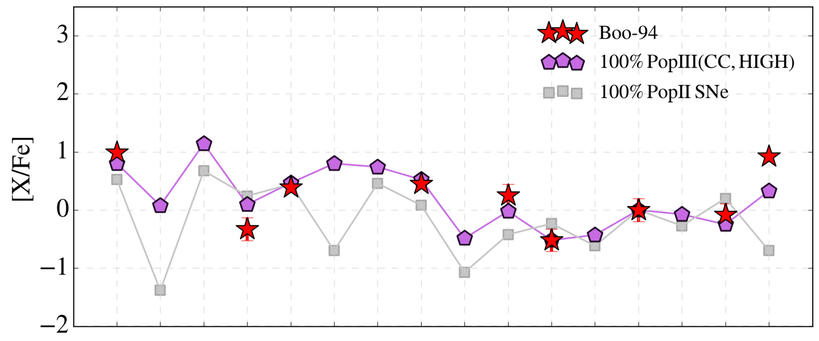

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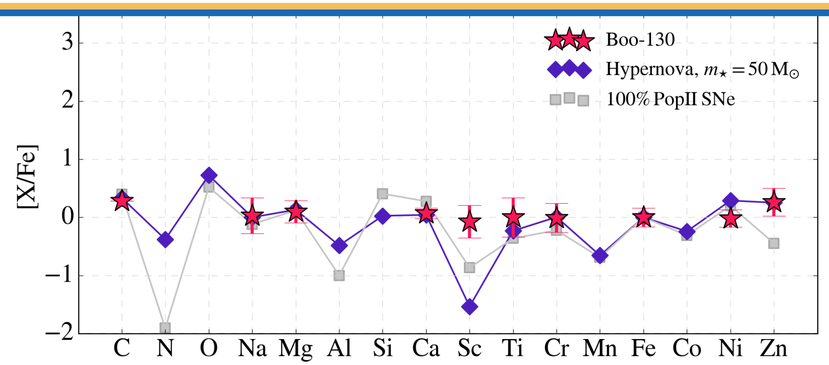

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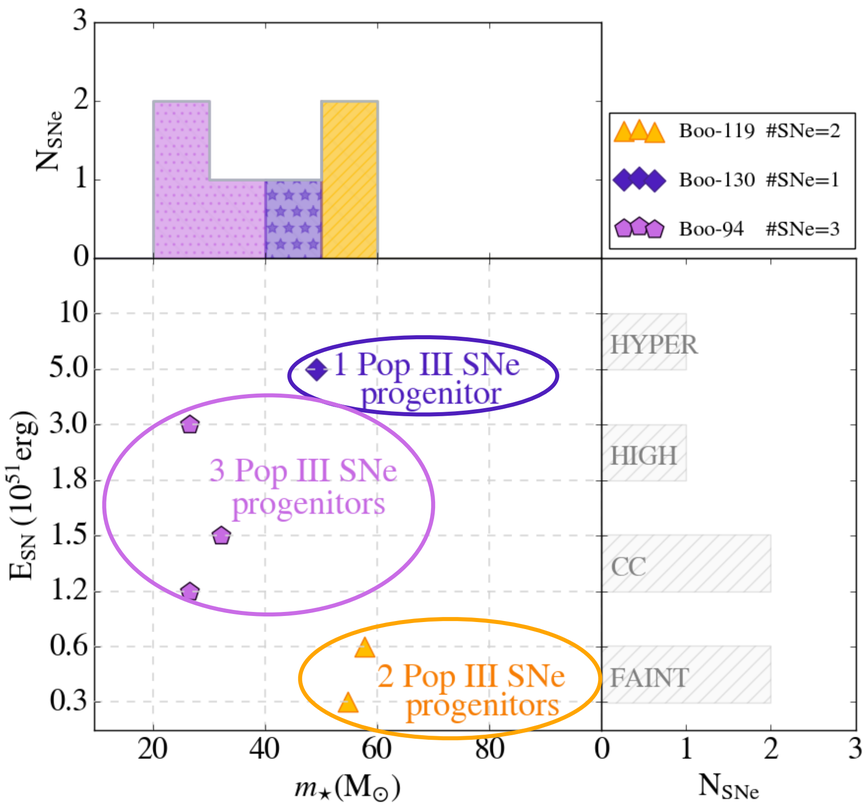

Our results attest the existence of **Pop III stars** in mass range $[20 - 60]M_\odot$ and explosion energies $E_{SN} = [0.3 - 5]10^{51}$ erg (from faint to hypernovae)