

*IFPU Focus Week on First Stars*



UNIVERSITÀ  
DEGLI STUDI  
FIRENZE



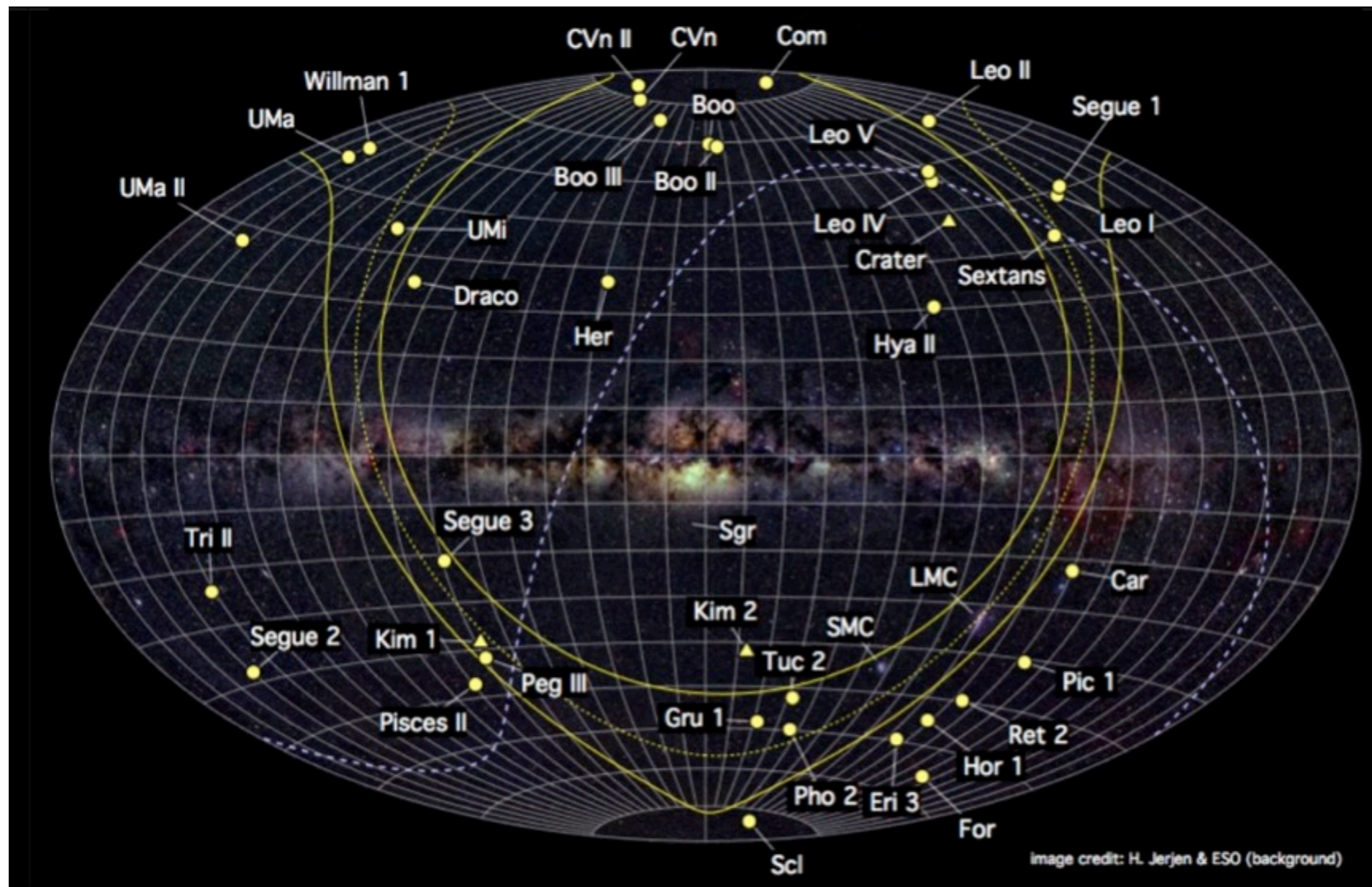
# TRACING POP III SUPERNOVAE WITH EXTREME ENERGIES

---

*Ása Skúladóttir*  
*University of Florence*

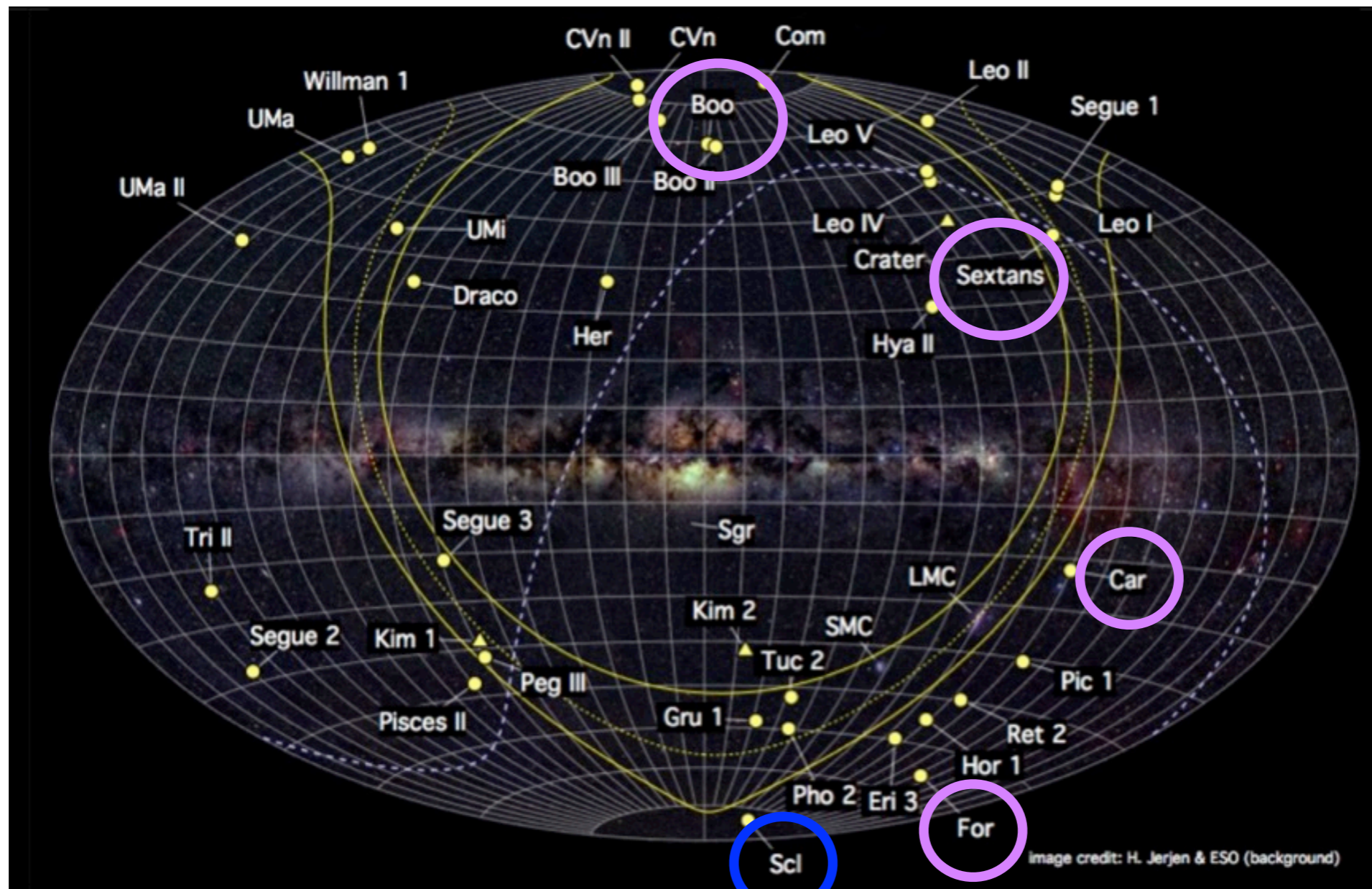
# DWARF GALAXIES AROUND THE MILKY WAY

- The Milky Way has  $>50$  known dwarf galaxy satellites
- Old and intrinsically metal-poor  $\rightarrow$  windows into early chemical enrichment and the **first stars**



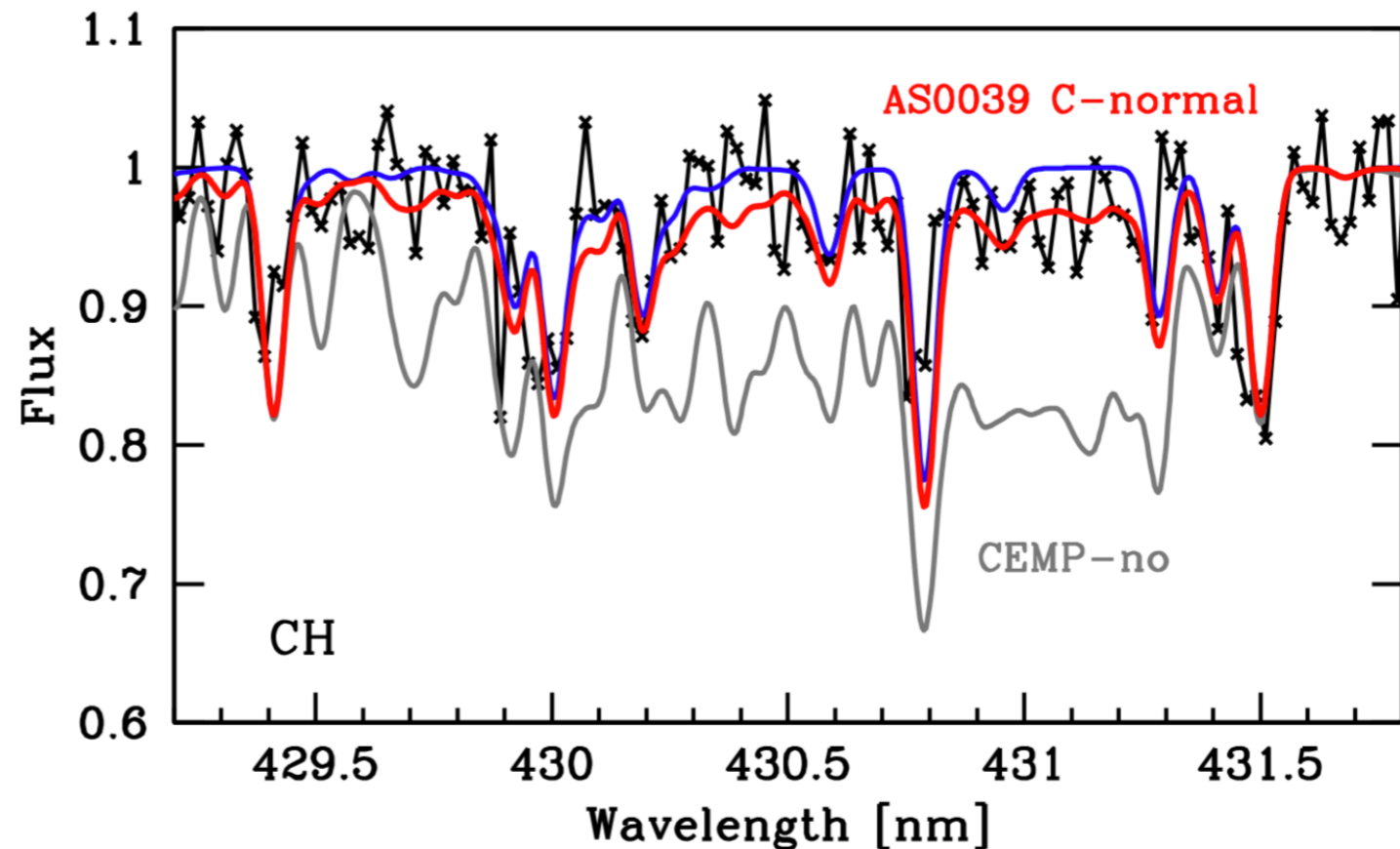
# DWARF GALAXIES AROUND THE MILKY WAY

- Survey of radial velocities and  $[Fe/H]$  - few thousand stars
- Most metal-poor star in our sample found in **Sculptor!**



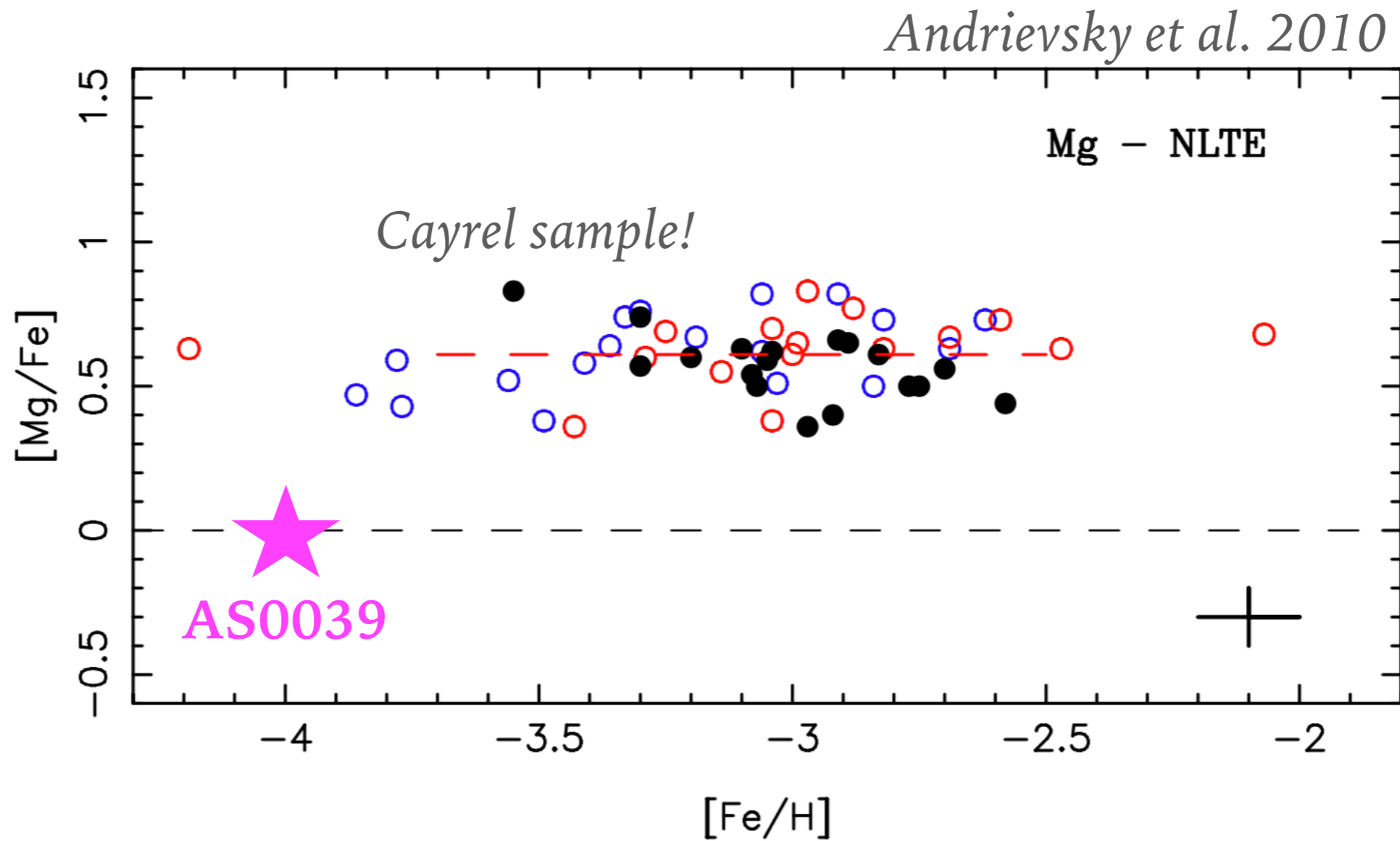
# AS0039: C-NORMAL AND EXTREMELY METAL-POOR

- **Ultra metal-poor**,  $[\text{Fe}/\text{H}] = -4$
- Not just C-“normal”, but **C-poor**:
  - $A(\text{C}) = 4.60 \rightarrow$  **Lowest C measured in any star**
  - $[\text{C}/\text{Fe}] = -0.3$  (LTE, when corrected for internal mixing)
- **Lowest metallicity measured in any star outside of the Milky Way!**



# AS0039: UNUSUAL ABUNDANCE PATTERN!

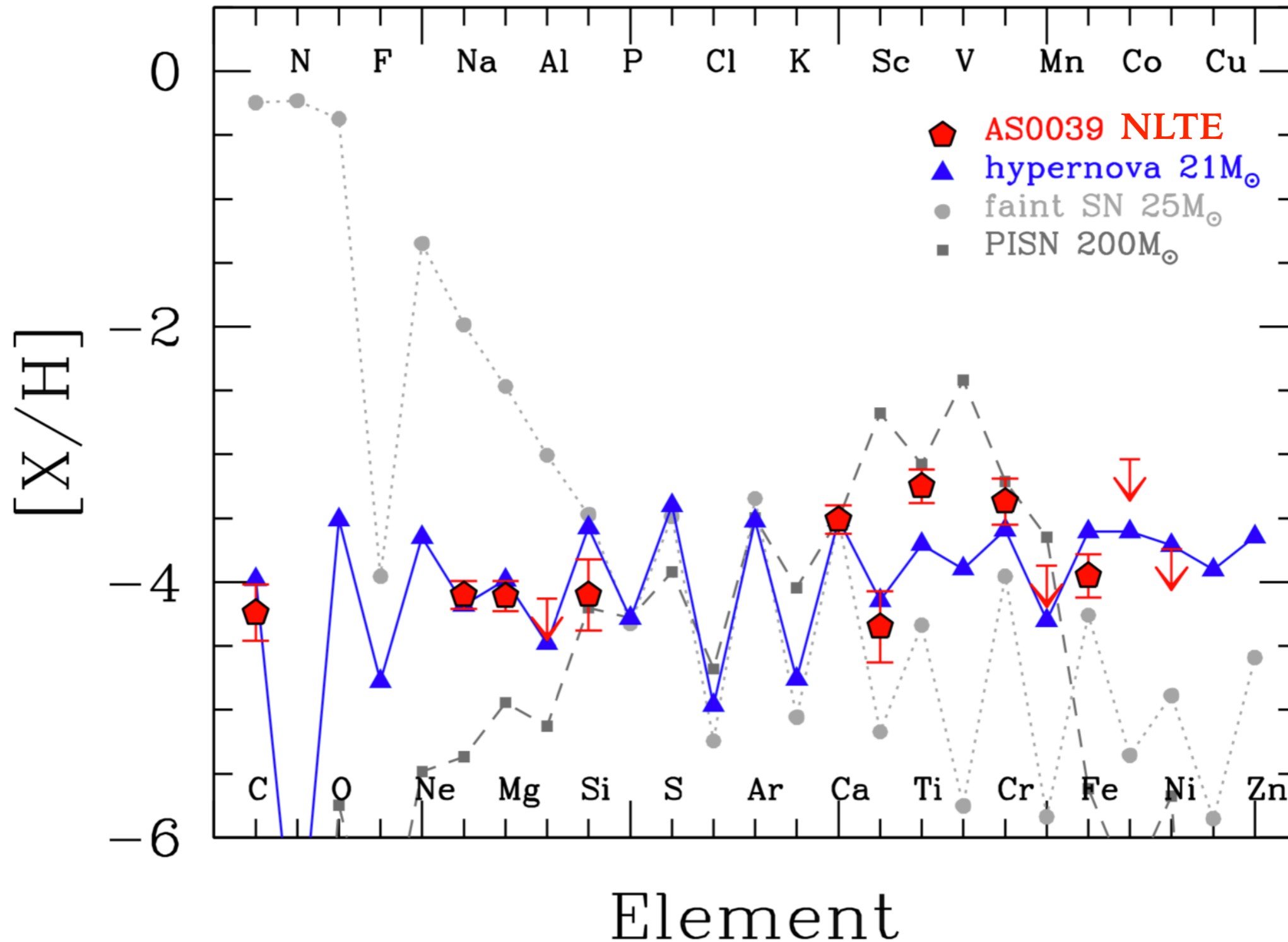
- Low  $[\text{Mg}/\text{Fe}] \approx 0$ !



# AS0039: BEST FIT – POP III HYPERNOVA!

Skúladóttir et al. 2021

Yields: Heger & Woosley 2002; 2010, Iwamoto et al. 2005



# PREDICTED POP III HYPERNOVAE DESCENDANTS

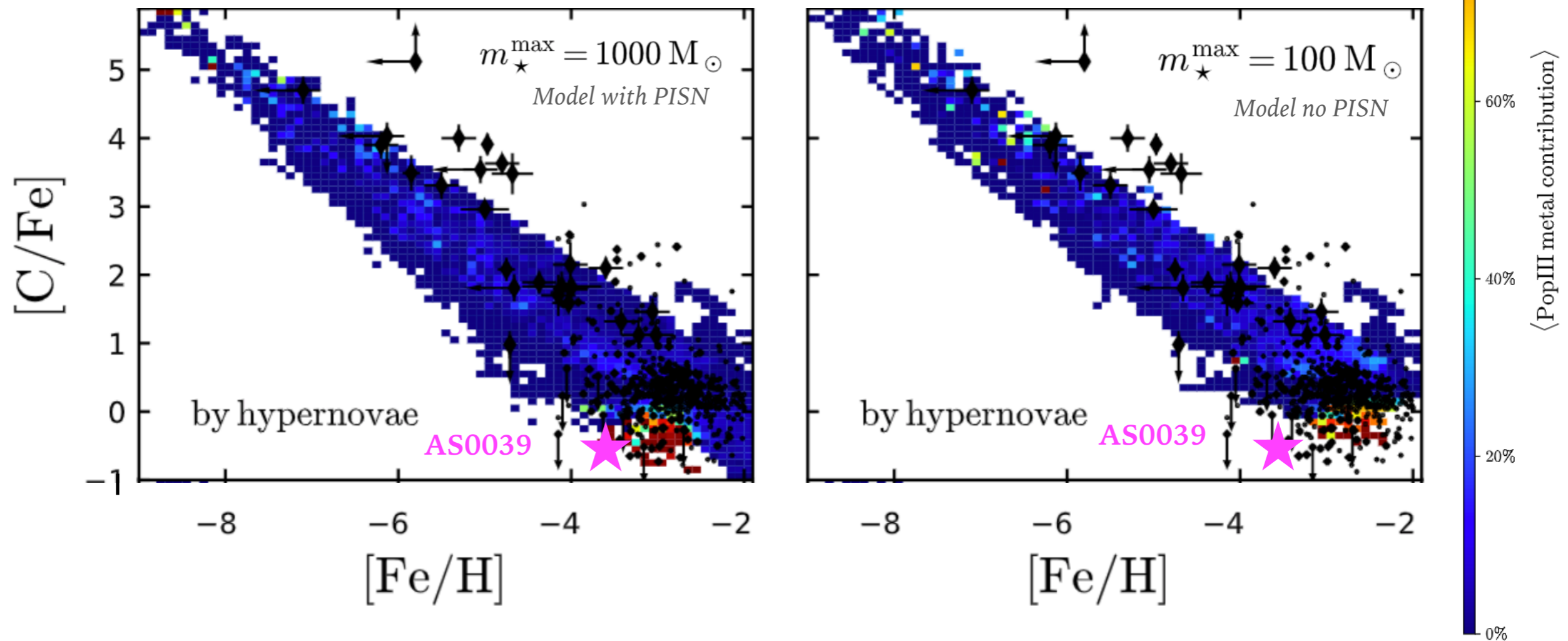
## The energy distribution of the first supernovae

I. Koutsouridou,<sup>1,2</sup>★ S. Salvadori,<sup>1,2</sup> Á. Skúladóttir,<sup>1,2</sup> M. Rossi,<sup>1,2</sup> I. Vanni<sup>1,2</sup> and G. Pagnini<sup>3</sup>

<sup>1</sup>Dipartimento di Fisica e Astronomia, Università degli Studi di Firenze, Via G. Sansone 1, 50019 Sesto Fiorentino, Italy

<sup>2</sup>INAF/Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, 50125 Firenze, Italy

<sup>3</sup>GEPI, Observatoire de Paris, PSL Research University, CNRS, Place Jules Janssen, 92195 Meudon, France



- Model of Boötes I predicts PopIII HN descendants at  $[Fe/H] \approx -4$  (Rossi et al. in prep).

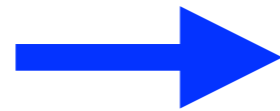
# BETTER DATA - NEW RESULT?

---

Data

Progenitor

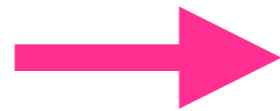
X-Shooter spectra



Pop III Hypernovae  
21 M<sub>⊙</sub>

UVES spectra

*More elemental abundances!*



?



# BETTER DATA - NEW RESULT?

*Skúladóttir et al. 2023, in press*

Data

Progenitor

X-Shooter spectra



Pop III Hypernovae  
21 M<sub>⊙</sub>

UVES spectra

*More elemental abundances!*



Pop III Hypernovae  
20 M<sub>⊙</sub>

**Tracing Pop III supernovae with extreme energies  
through the Sculptor dwarf spheroidal galaxy<sup>★</sup>**

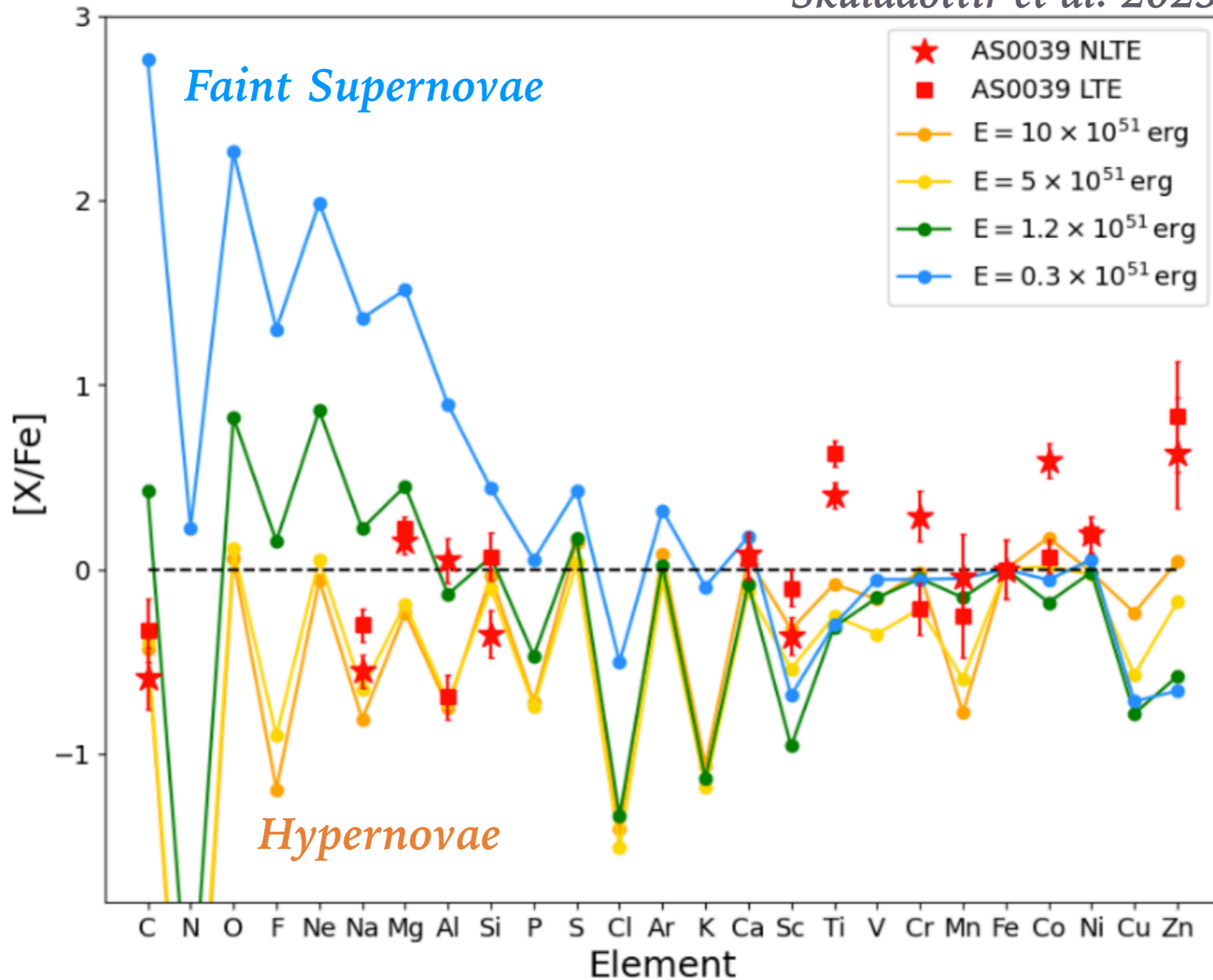
Á. Skúladóttir<sup>1,2</sup>, I. Vanni<sup>1,2</sup>, S. Salvadori<sup>1,2</sup>, and R. Lucchesi<sup>1</sup>

<sup>1</sup> Dipartimento di Fisica e Astronomia, Università degli Studi di Firenze, Via G. Sansone 1, I-50019 Sesto Fiorentino, Italy.  
e-mail: asa.skuladottir@unifi.it

<sup>2</sup> INAF/Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy.

# PARAMETER SPACE – HYPERNOVA A ROBUST RESULT

Skúladóttir et al. 2023



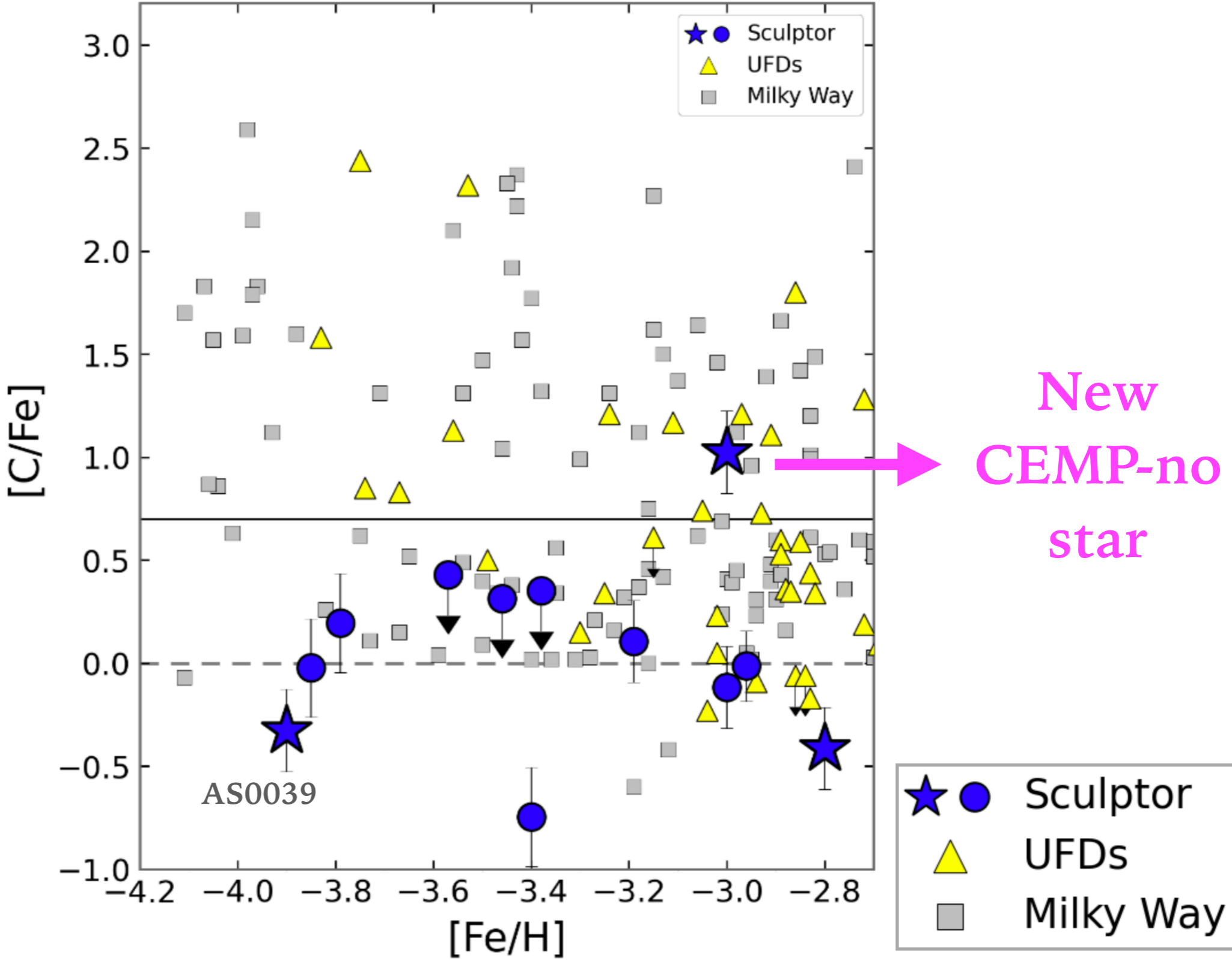
# REST OF SCULPTOR AT $[Fe/H] < -3$

*Skúladóttir et al. 2023*

---

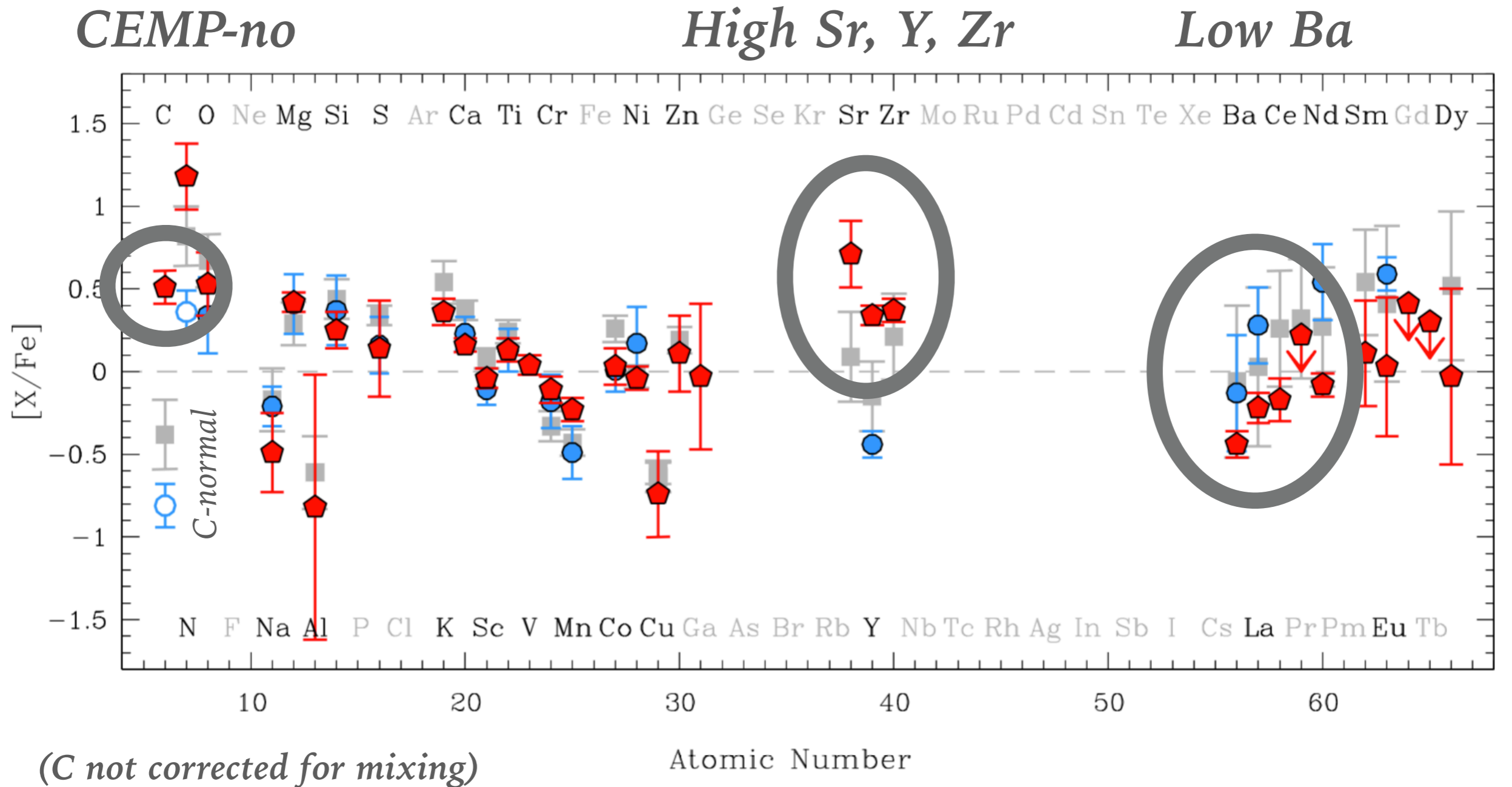
- Reanalysed all the available Spectra in Sculptor at  $[Fe/H] < -2.8$
- (Plus two new stars)

# A NEW CEMP-NO STAR IN SCULPTOR!



# CEMP-NO IN SCULPTOR

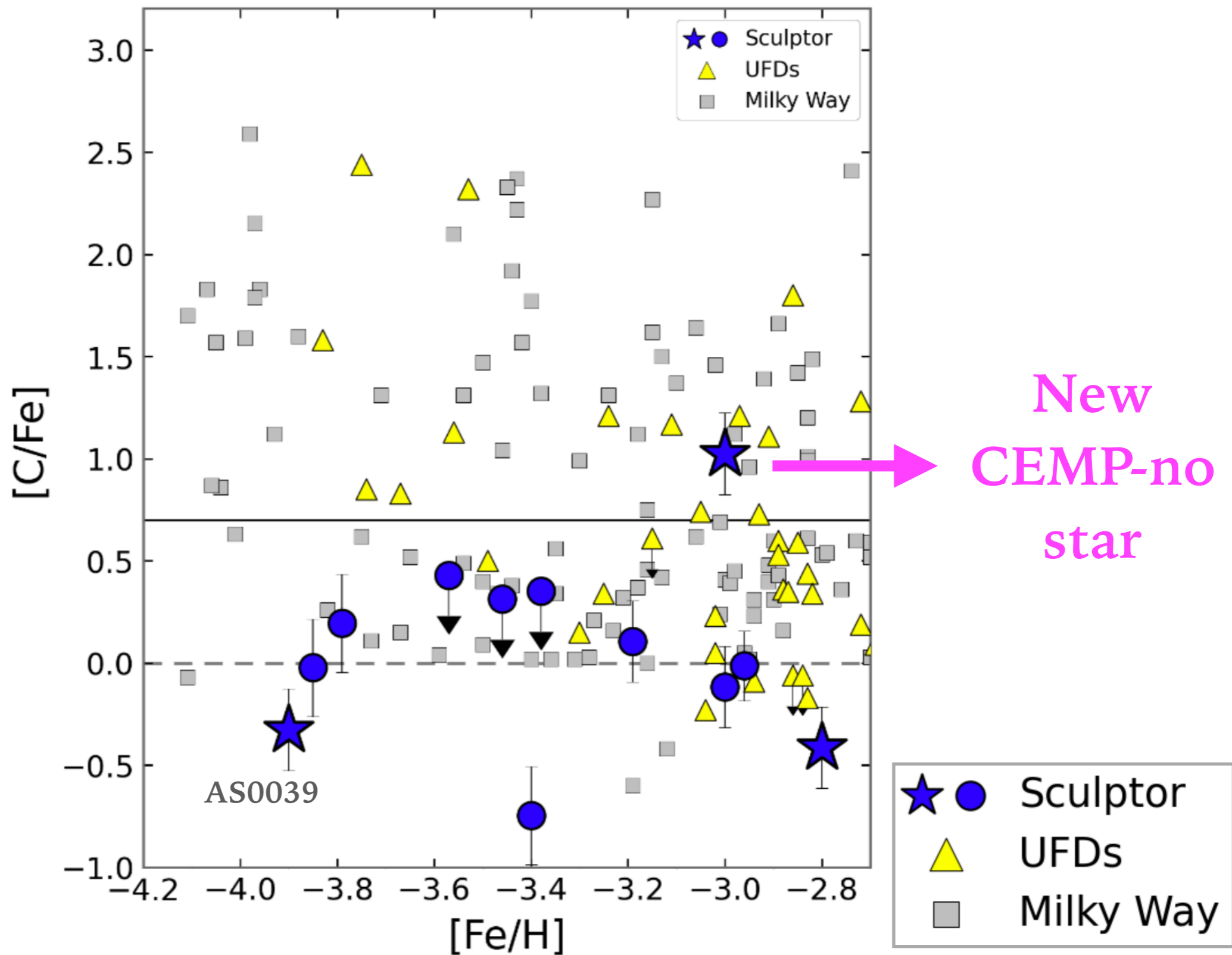
Skúladóttir et al. 2015



**[Fe/H] = -2**

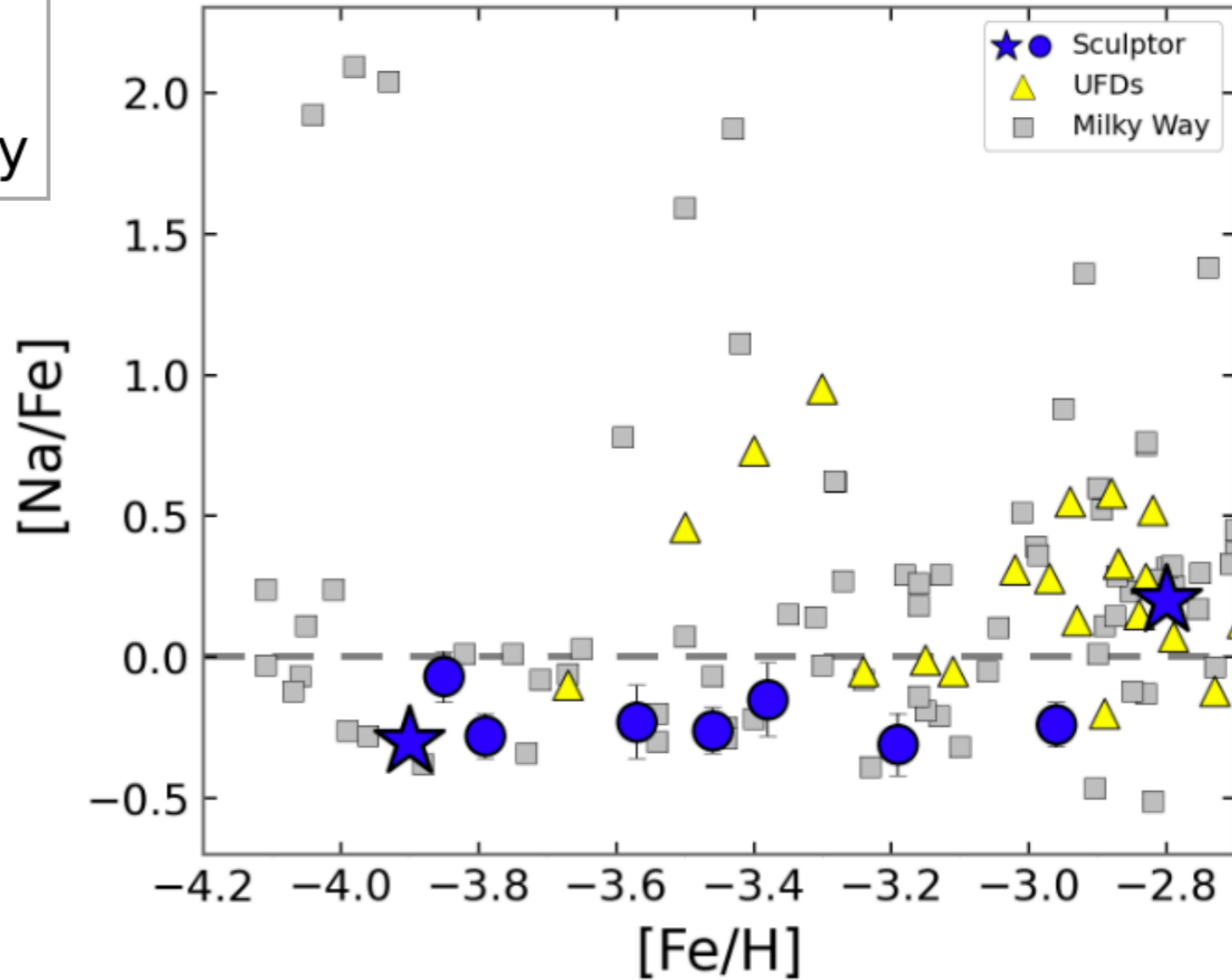
# A NEW CEMP-NO STAR IN SCULPTOR

Why not more?

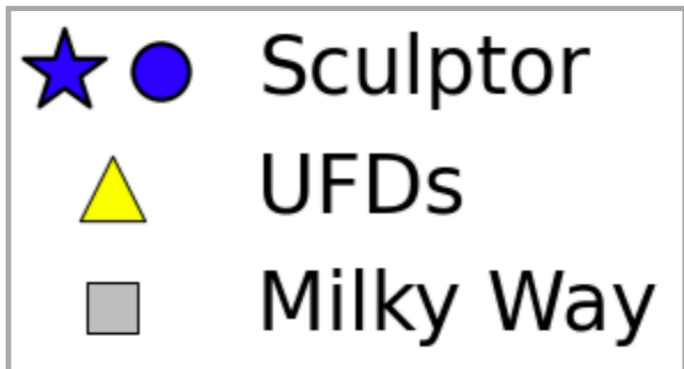
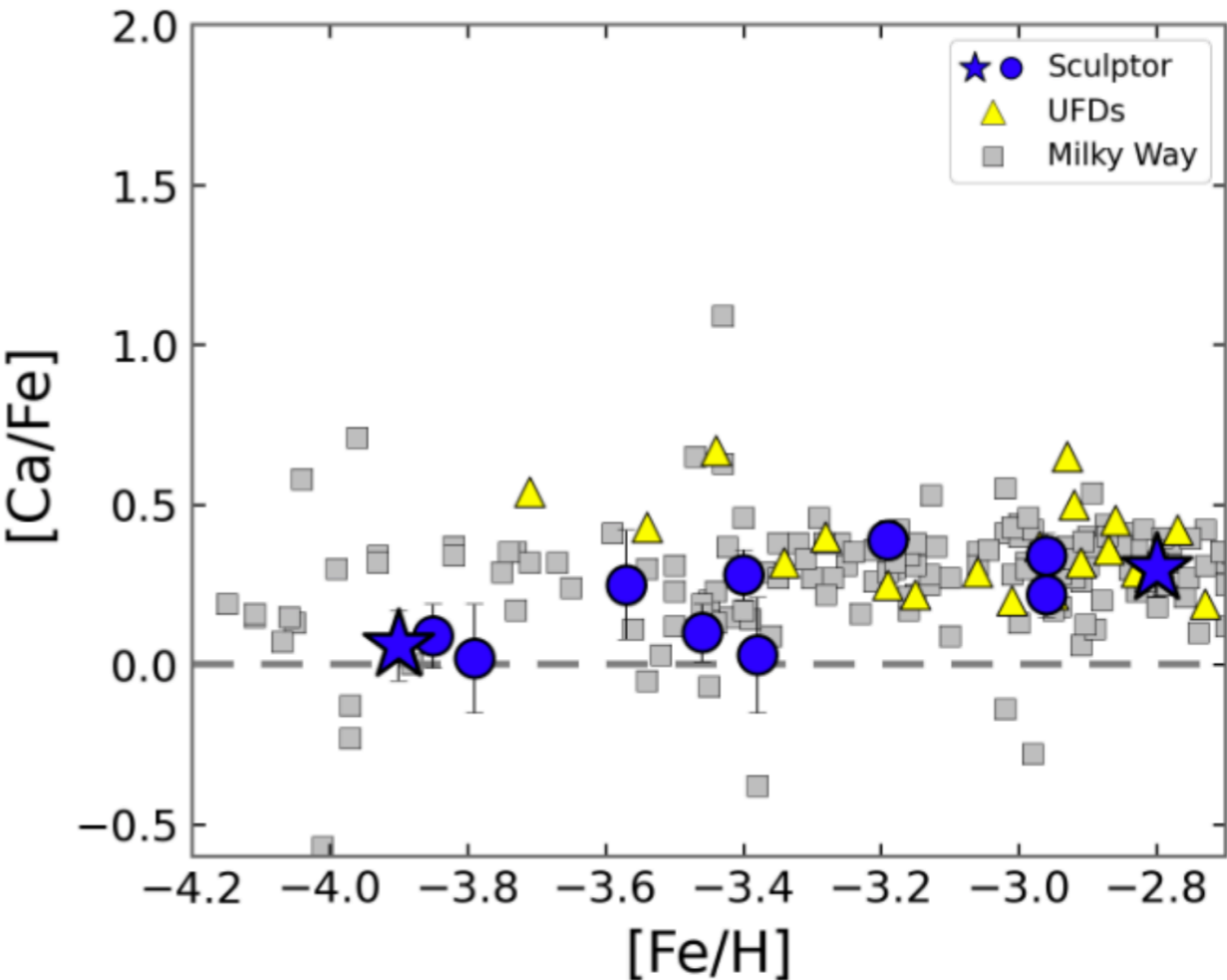
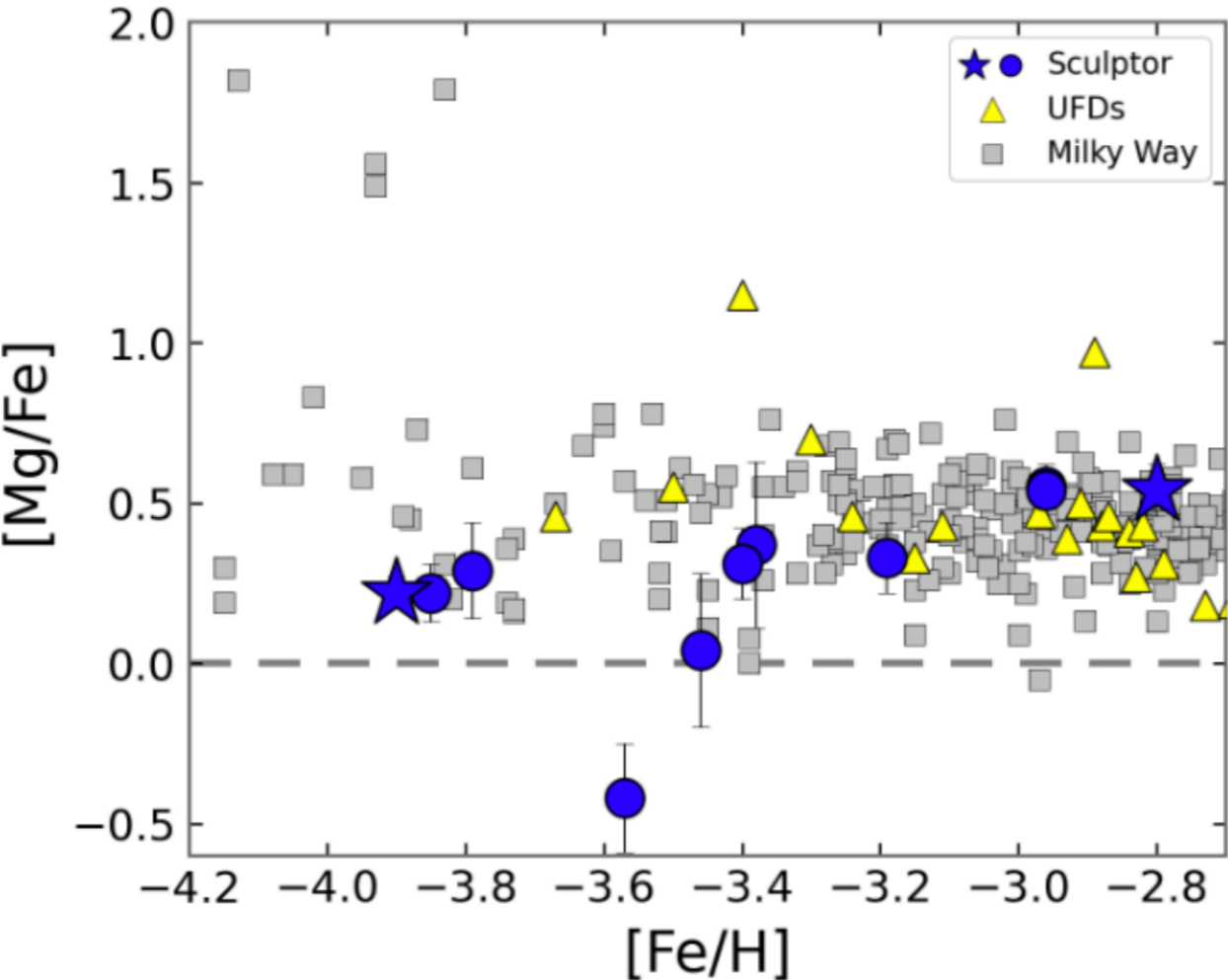


New CEMP-no star

# LIGHT ELEMENTS!

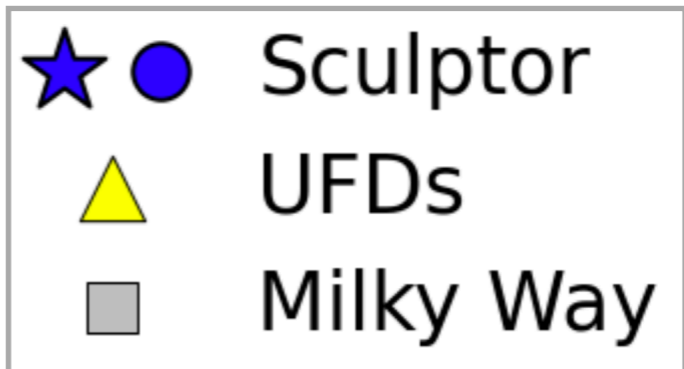
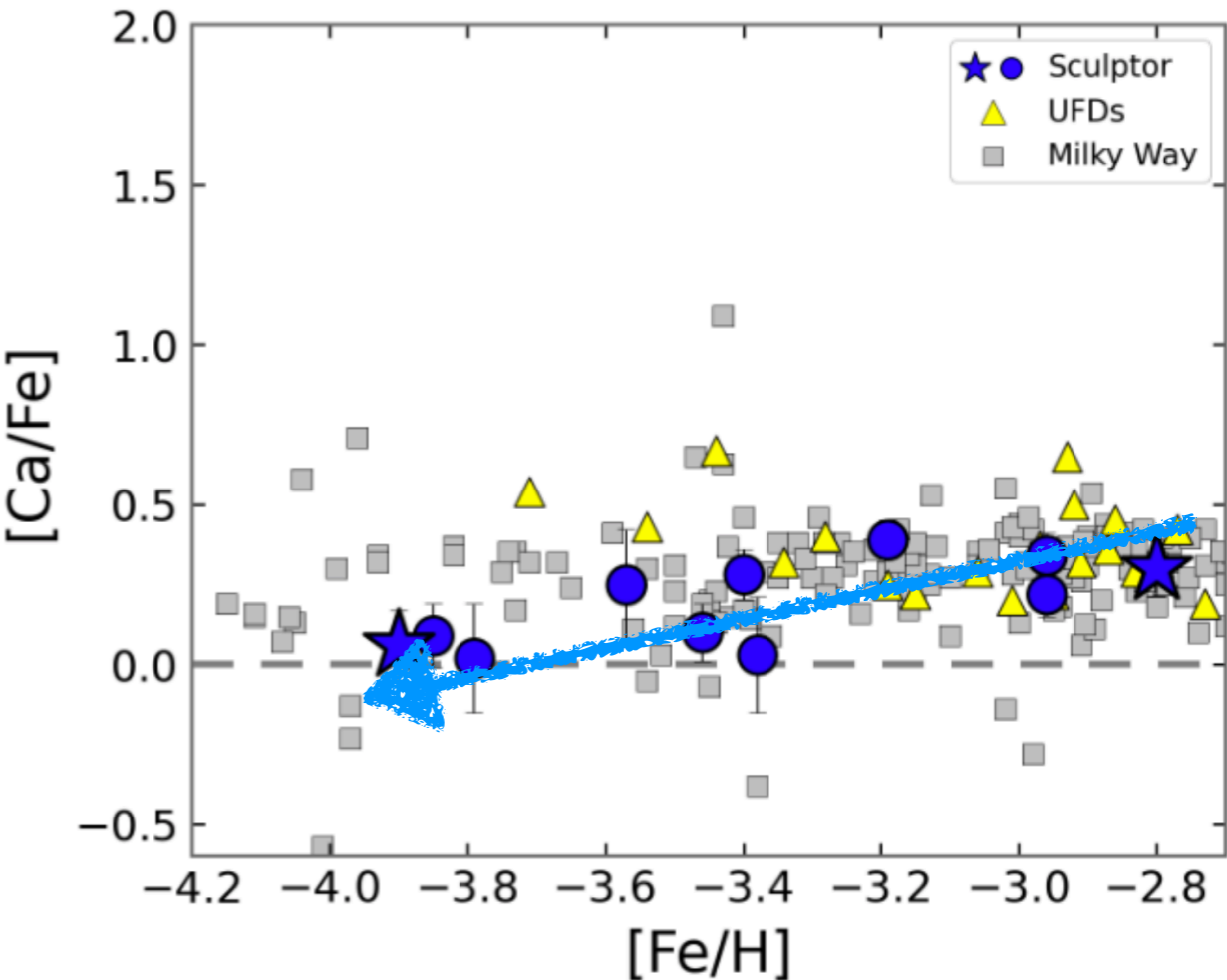
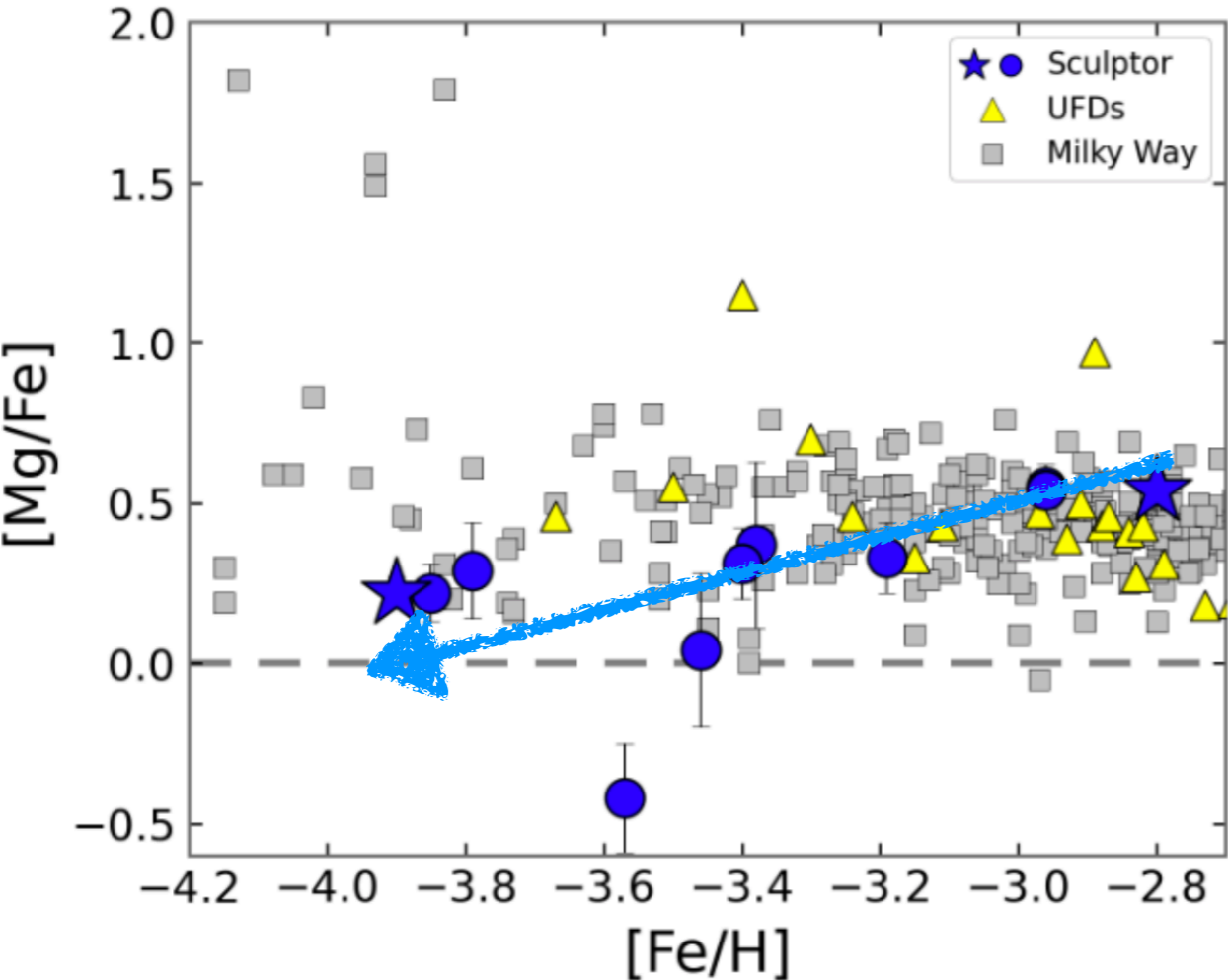


# ALPHA ELEMENTS





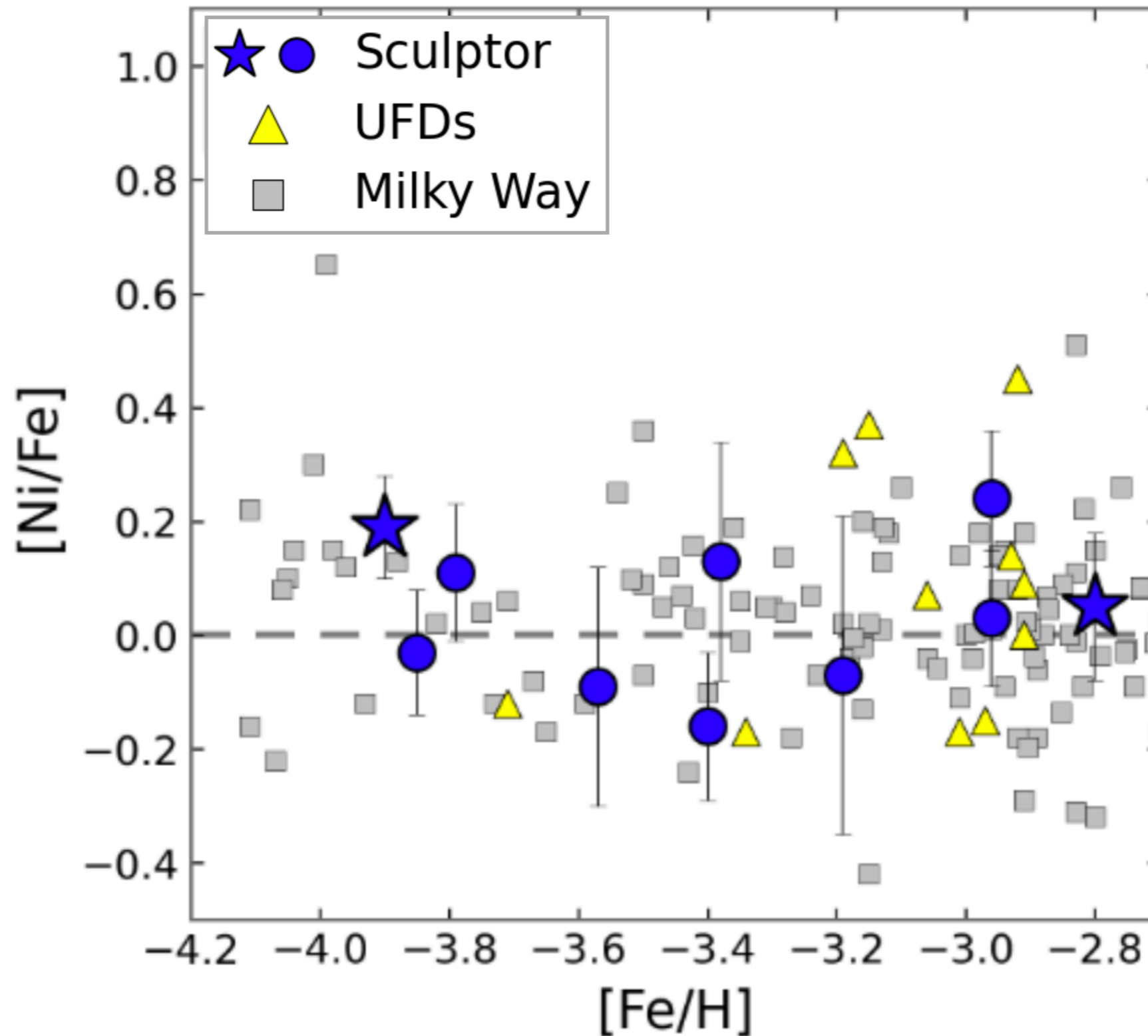
# ALPHA ELEMENTS



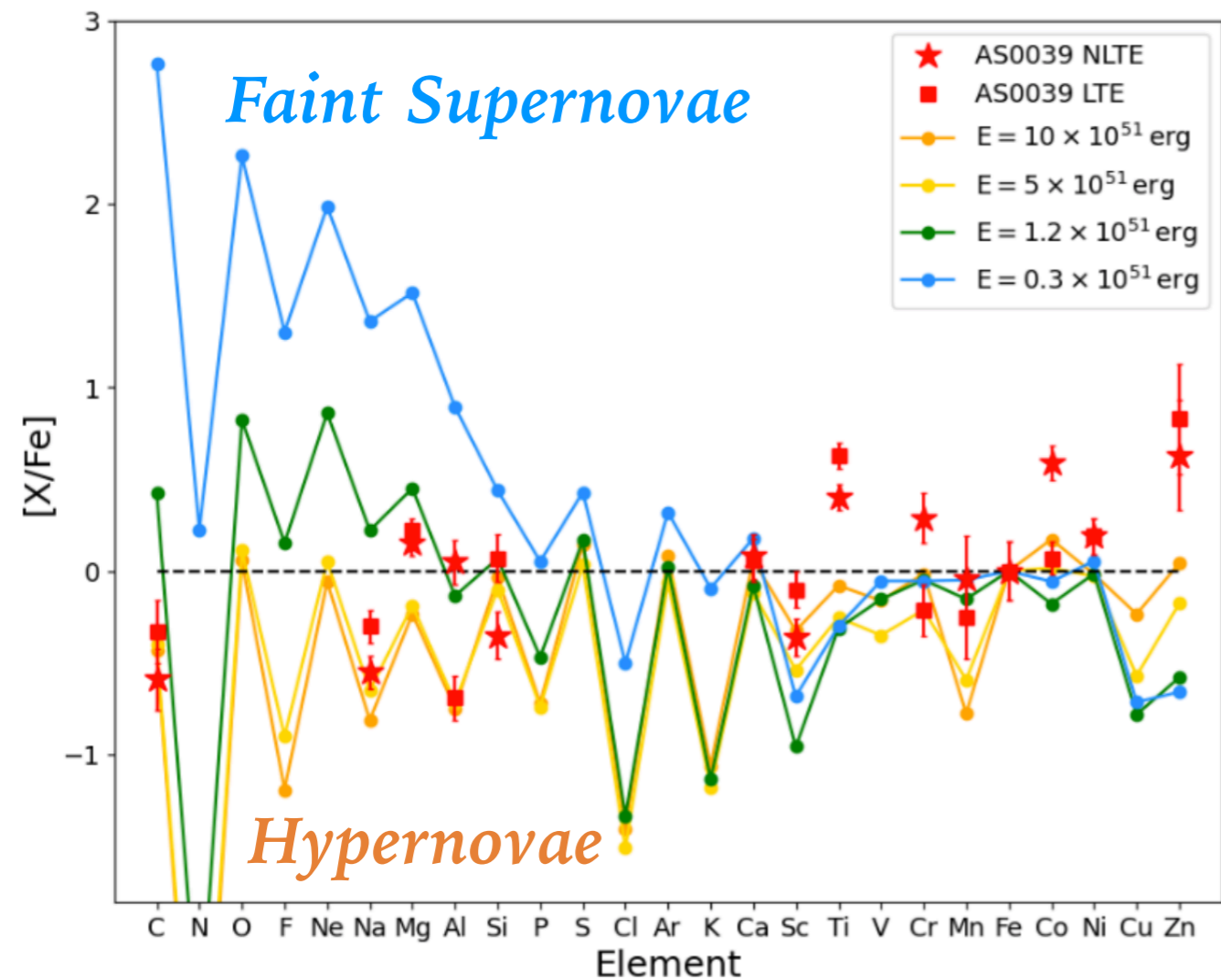
*Unique Trends in the Sculptor data?*

# IRON-PEAK ELEMENTS

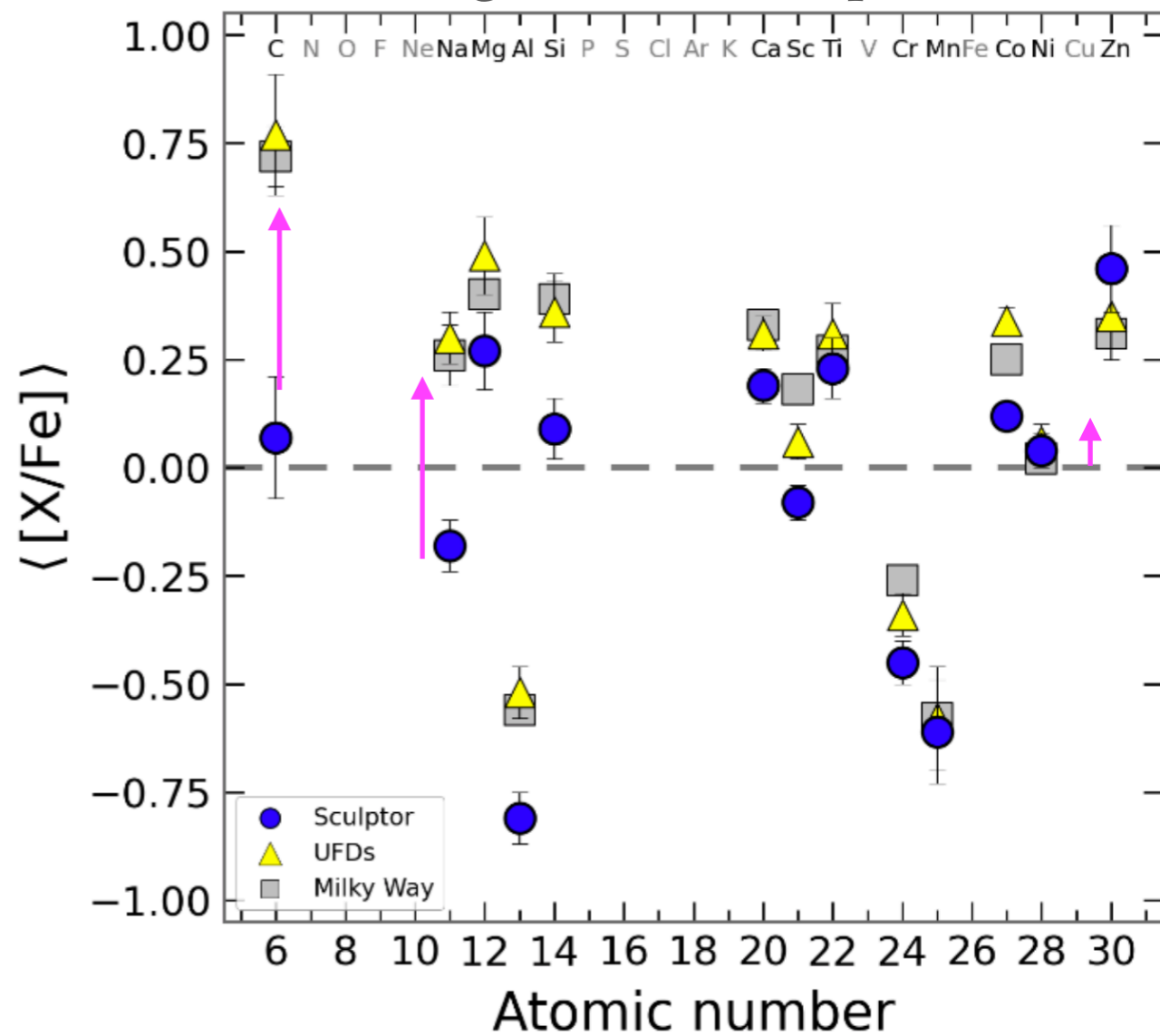
*See more abundances in  
Skúladóttir et al. 2023*



# OVERALL TREND

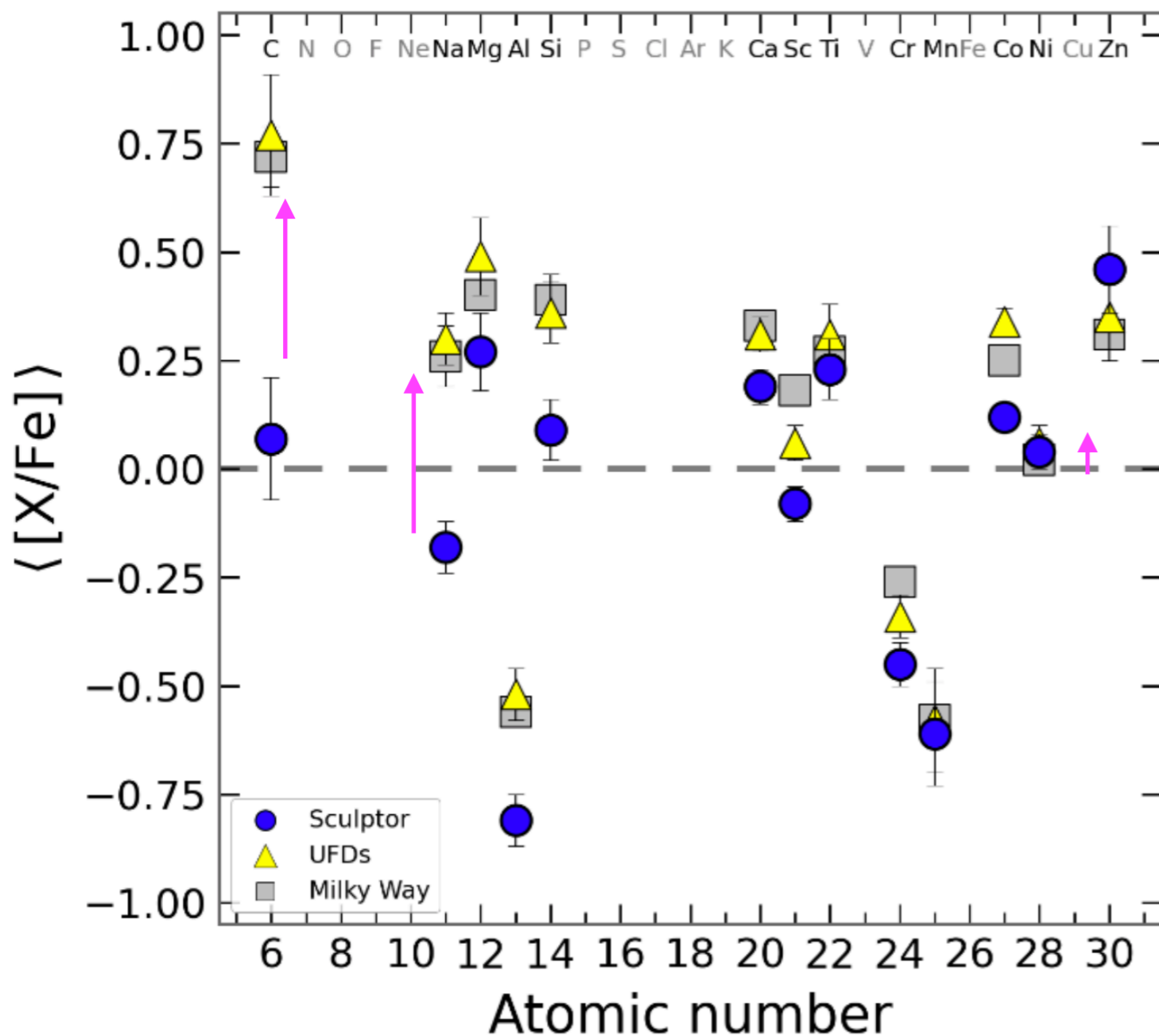


## Average abundance pattern



# OVERALL TREND

*Average abundance pattern*



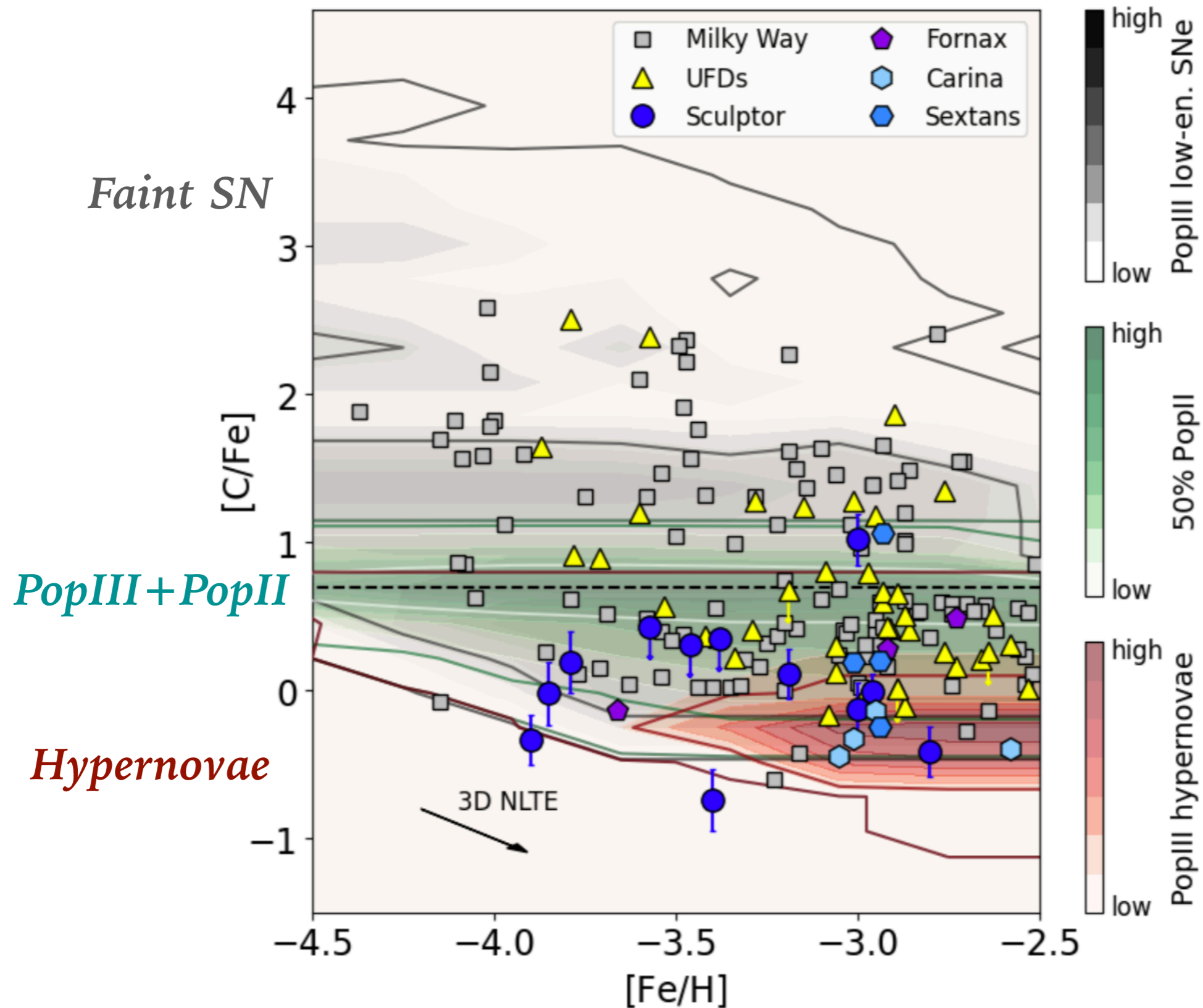
Sculptor experienced a significant pollution by high-energy Pop III supernovae!



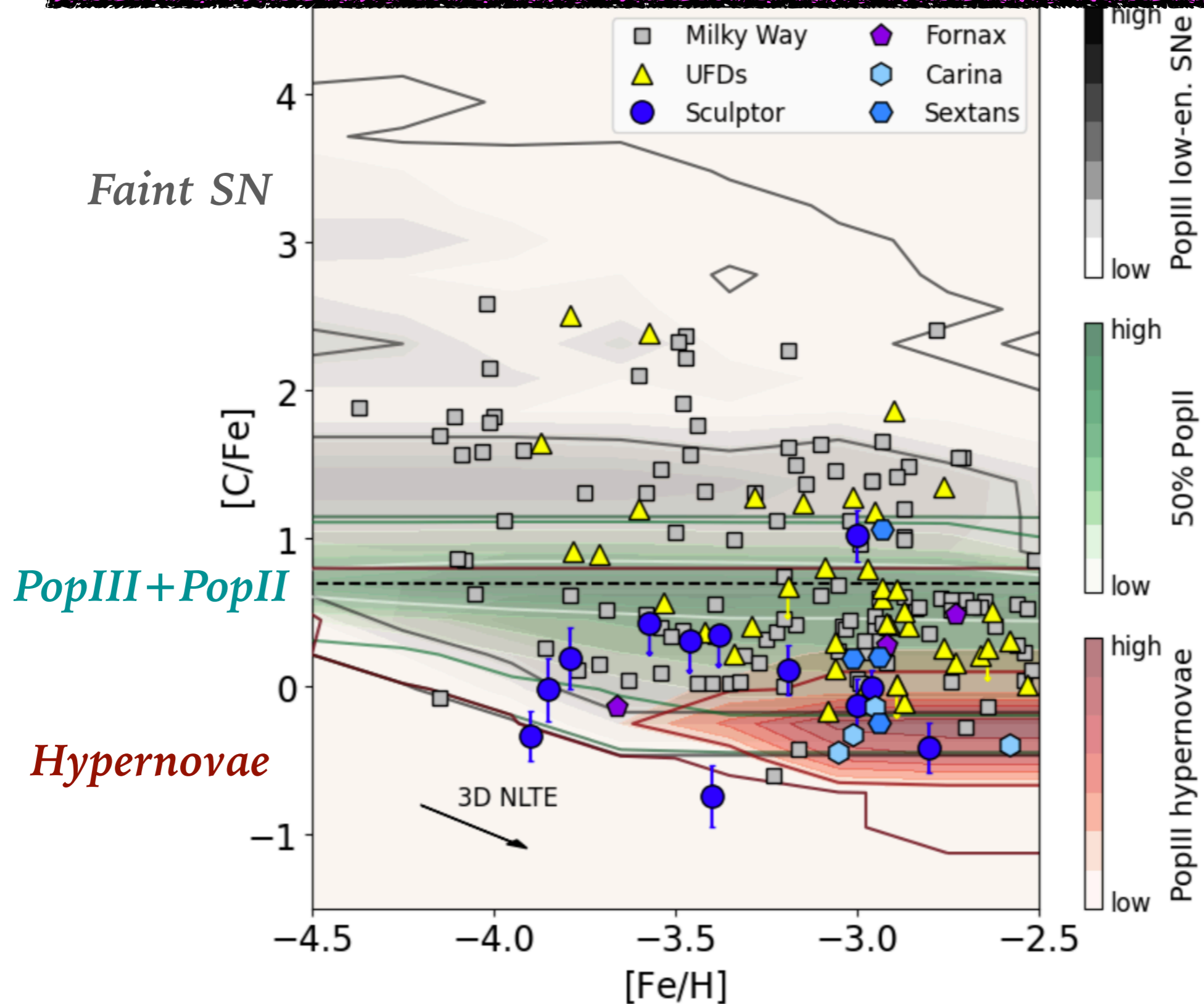
# CARBON IN DIFFERENT SYSTEMS

Skúladóttir et al. 2023

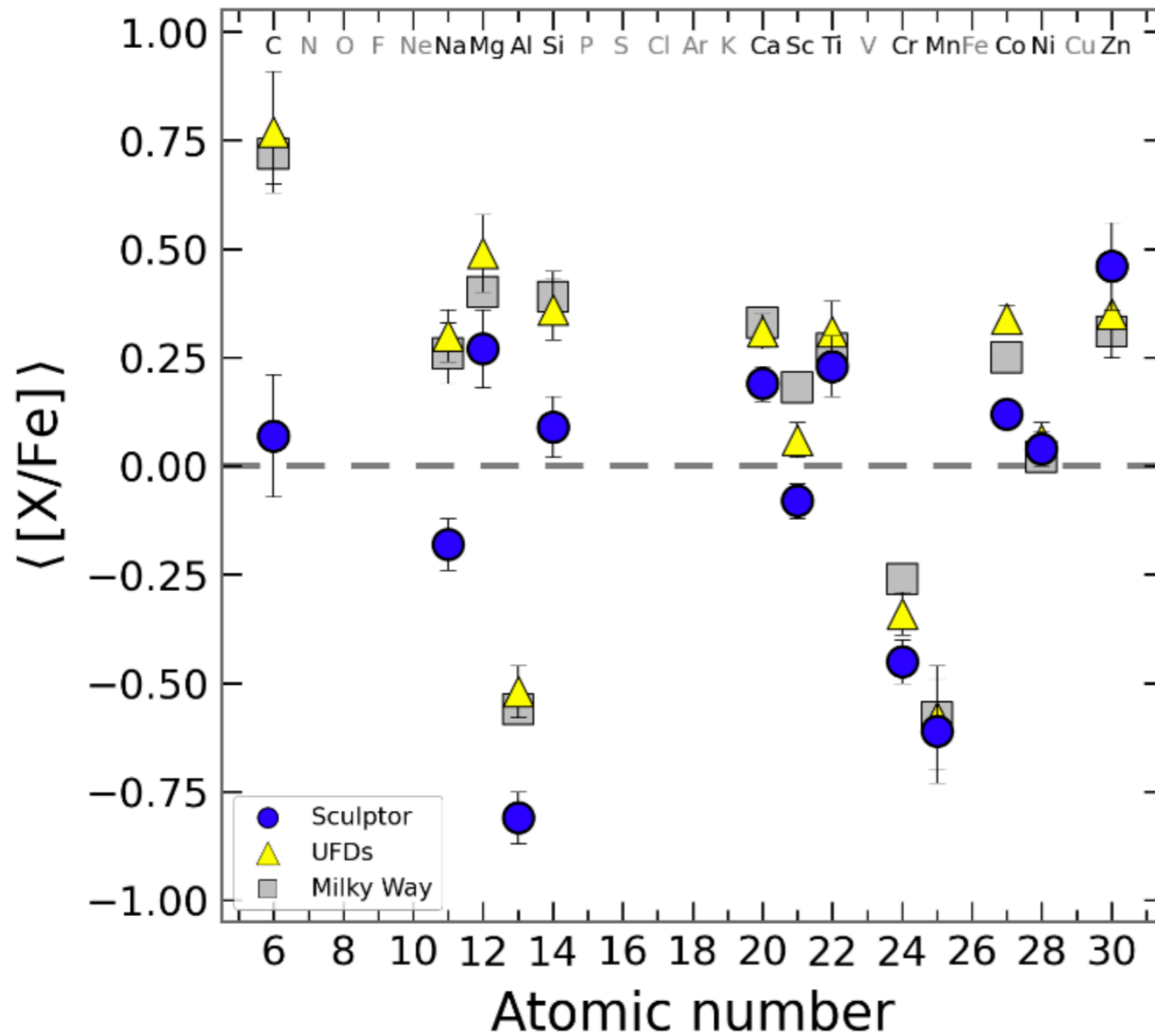
Based on Vanni et al. 2023



# Dwarf spheroidal galaxies lack CEMP-no stars!



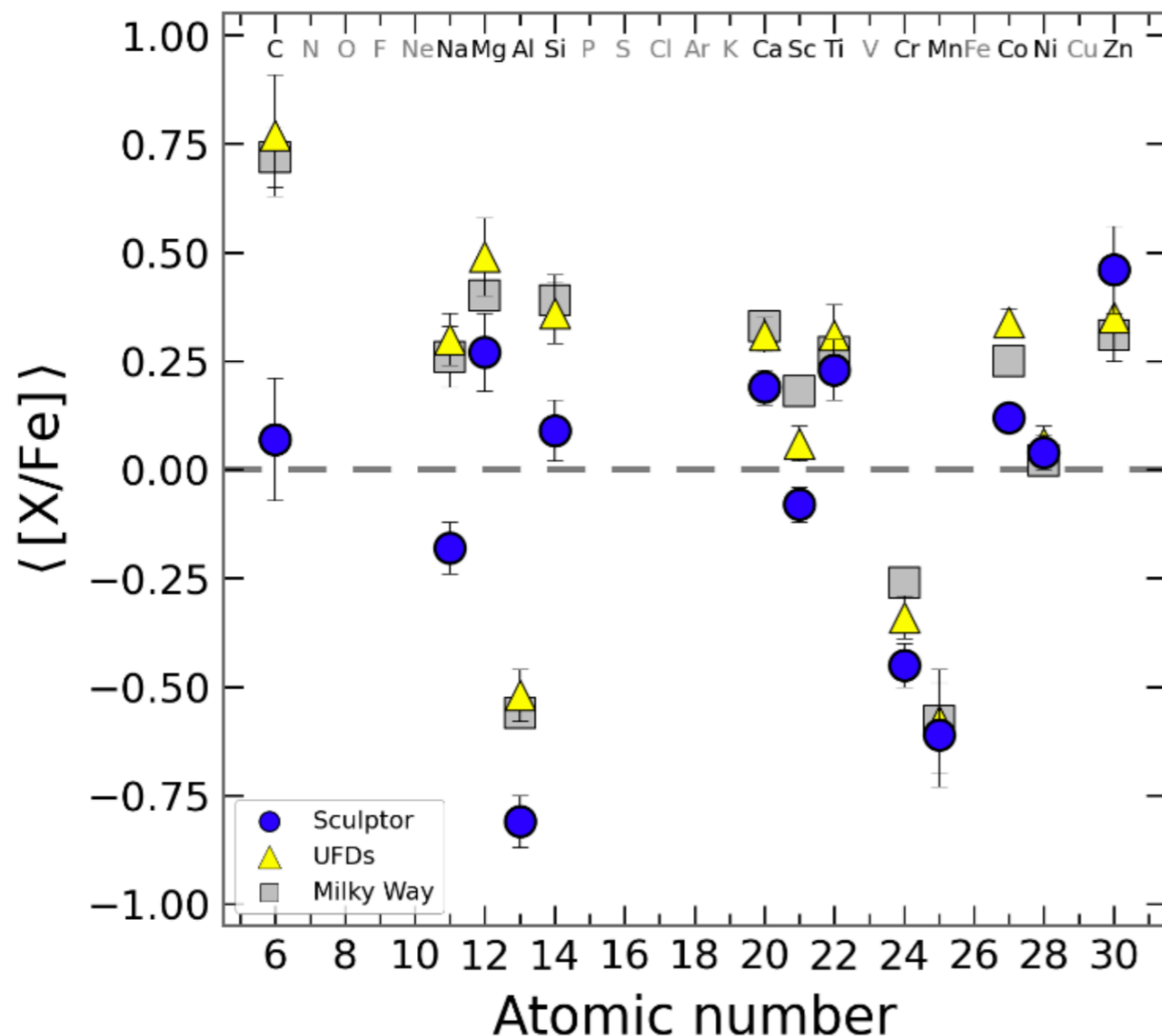
# QUESTIONS!



Why are the MW halo and UFDs the same?

# THE BUILD UP OF THE MILKY WAY HALO

*Skúladóttir et al. 2023*



- Simulations (Deason et al. 2016) predict that UFDs contribute only 2-5% of MW halo stars at  $[Fe/H] < -2$
- Rest is done by more massive dwarfs.
- Discrepancy between models and data?



➤ **Conclusion:**

- The MW halo at  $[\text{Fe}/\text{H}] < -3$  is **NOT** made up of Sculptor-like galaxies.

➤ **Solutions?:**

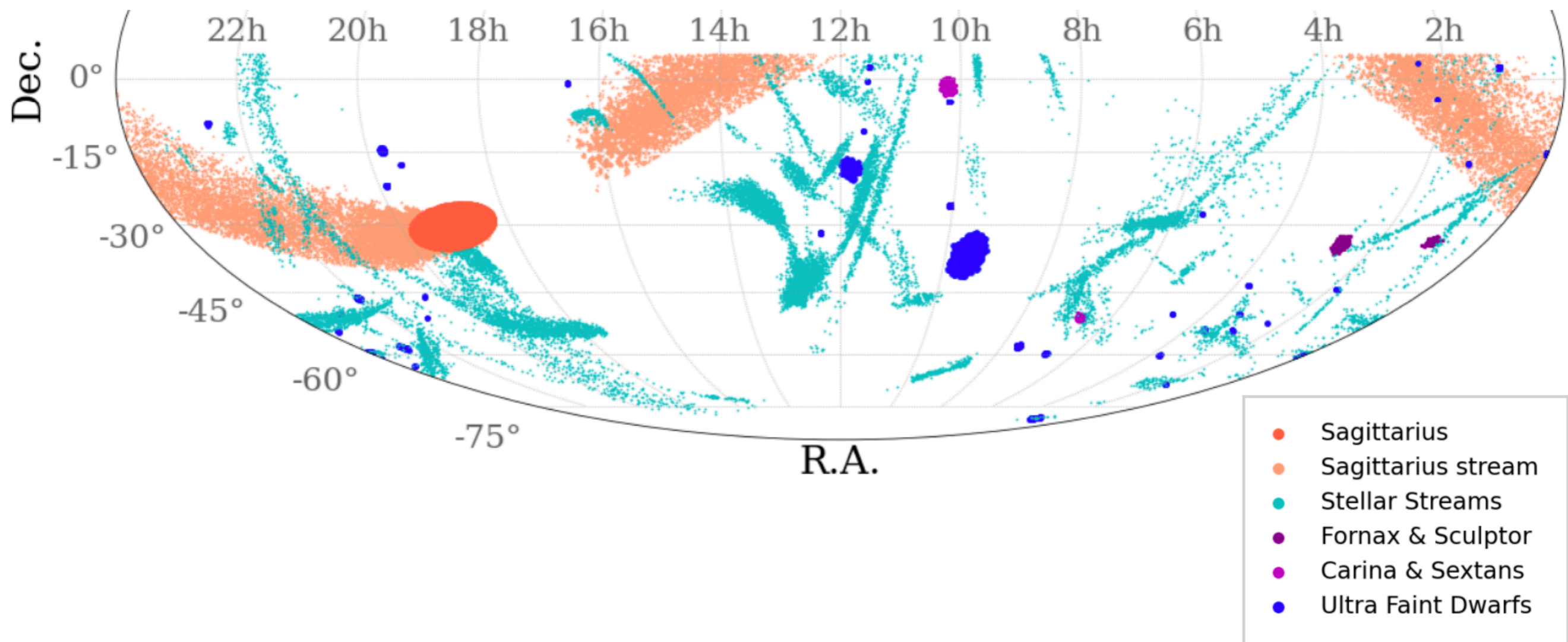
- The dSph galaxies building up the Galactic halo, had different early chemical enrichment → Sophisticated chemical evolution **model needed**.
- Sculptor is a unique outlier, other dSph lack data → Better **observations needed**

# BIG SURVEY OF DWARF GALAXIES

Skúladóttir et al. 2023 (4DWARFS)

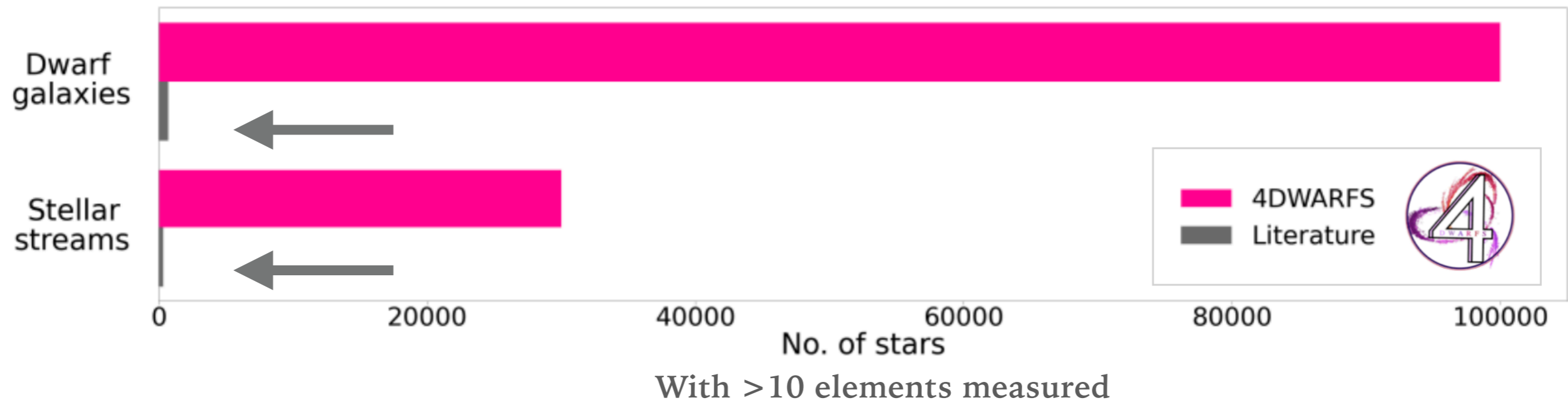
The 4MOST Survey of Dwarf Galaxies and their Stellar Streams (4DWARFS)

520 000 fibre hours



# 4DWARFS

Skúladóttir et al. 2023 (4DWARFS)



# KEY SCIENTIFIC QUESTIONS

---

*Skúladóttir et al. 2023 (4DWARFS)*

What are the properties of the first stars?

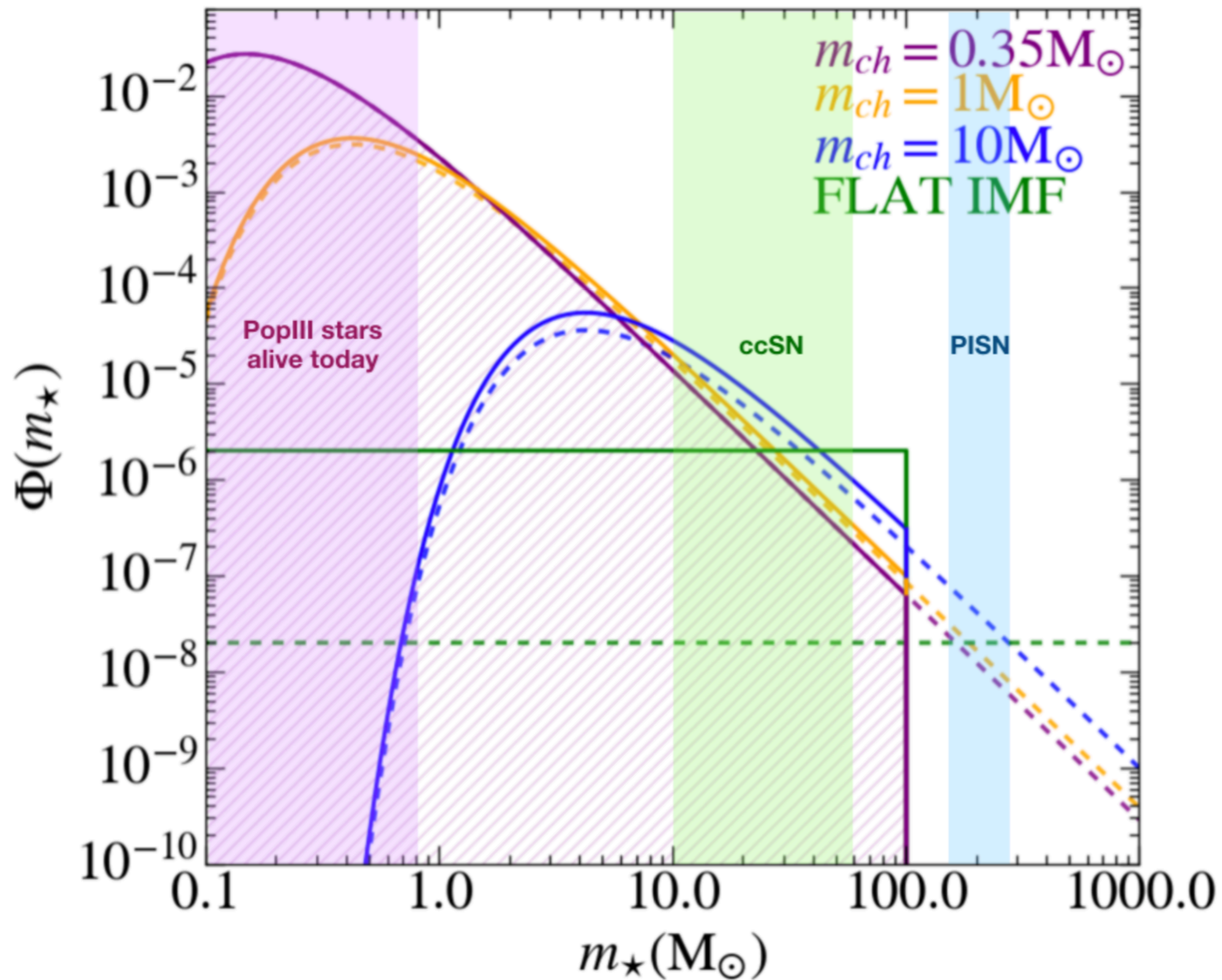
How are the chemical elements created and distributed?

What are the dynamical properties of dwarf galaxies?

What are the small-scale limits of hierarchical galaxy formation?

# FIRST STARS: IMF AND SN ENERGY

Skúladóttir et al. 2023 (4DWARFS)



# FIRST STARS: IMF AND SN ENERGY

Skúladóttir et al. 2023 (4DWARFS)

(Non)-detection of zero-metallicity stars

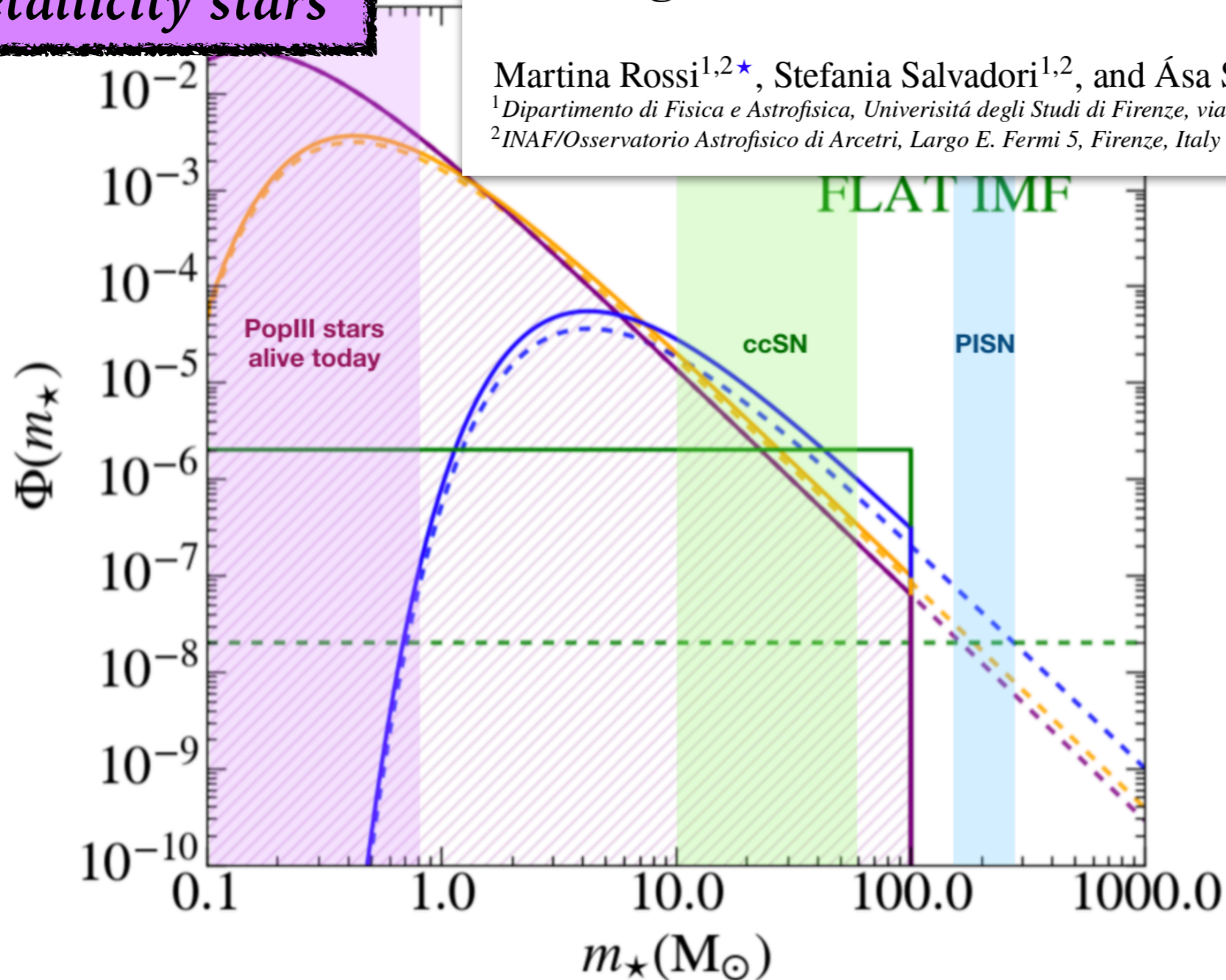
Ultra-faint dwarf galaxies:  
unveiling the minimum mass of the first stars

2021

Martina Rossi<sup>1,2</sup>★, Stefania Salvadori<sup>1,2</sup>, and Ása Skúladóttir<sup>1,2</sup>

<sup>1</sup>Dipartimento di Fisica e Astrofisica, Univerisatá degli Studi di Firenze, via G. Sansone 1, Sesto Fiorentino, Italy

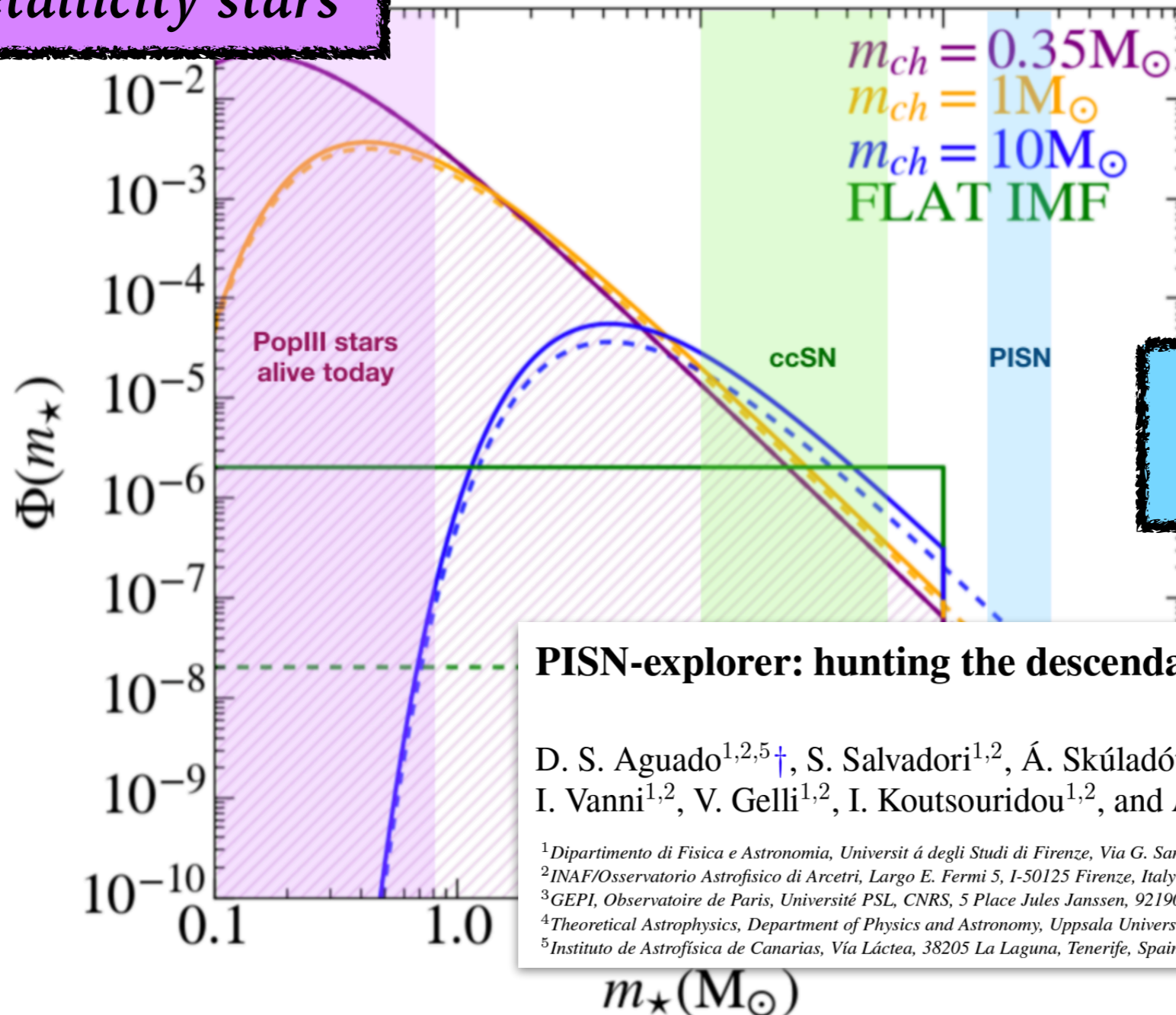
<sup>2</sup>INAF/Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, Firenze, Italy



# FIRST STARS: IMF AND SN ENERGY

Skúladóttir et al. 2023 (4DWARFS)

(Non)-detection of zero-metallicity stars



Quantify PISN descendants

**PISN-explorer: hunting the descendants of very massive first stars<sup>\*</sup>**

D. S. Aguado<sup>1,2,5†</sup>, S. Salvadori<sup>1,2</sup>, Á. Skúladóttir<sup>1,2</sup>, E. Caffau<sup>3</sup>, P. Bonifacio<sup>3</sup>,  
I. Vanni<sup>1,2</sup>, V. Gelli<sup>1,2</sup>, I. Koutsouridou<sup>1,2</sup>, and A. M. Amarsi<sup>4</sup>

<sup>1</sup>Dipartimento di Fisica e Astronomia, Università degli Studi di Firenze, Via G. Sansone 1, I-50019 Sesto Fiorentino, Italy

<sup>2</sup>INAF/Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy

<sup>3</sup>GEPI, Observatoire de Paris, Université PSL, CNRS, 5 Place Jules Janssen, 92190 Meudon, France.

<sup>4</sup>Theoretical Astrophysics, Department of Physics and Astronomy, Uppsala University, SE-751 20 Uppsala, Sweden

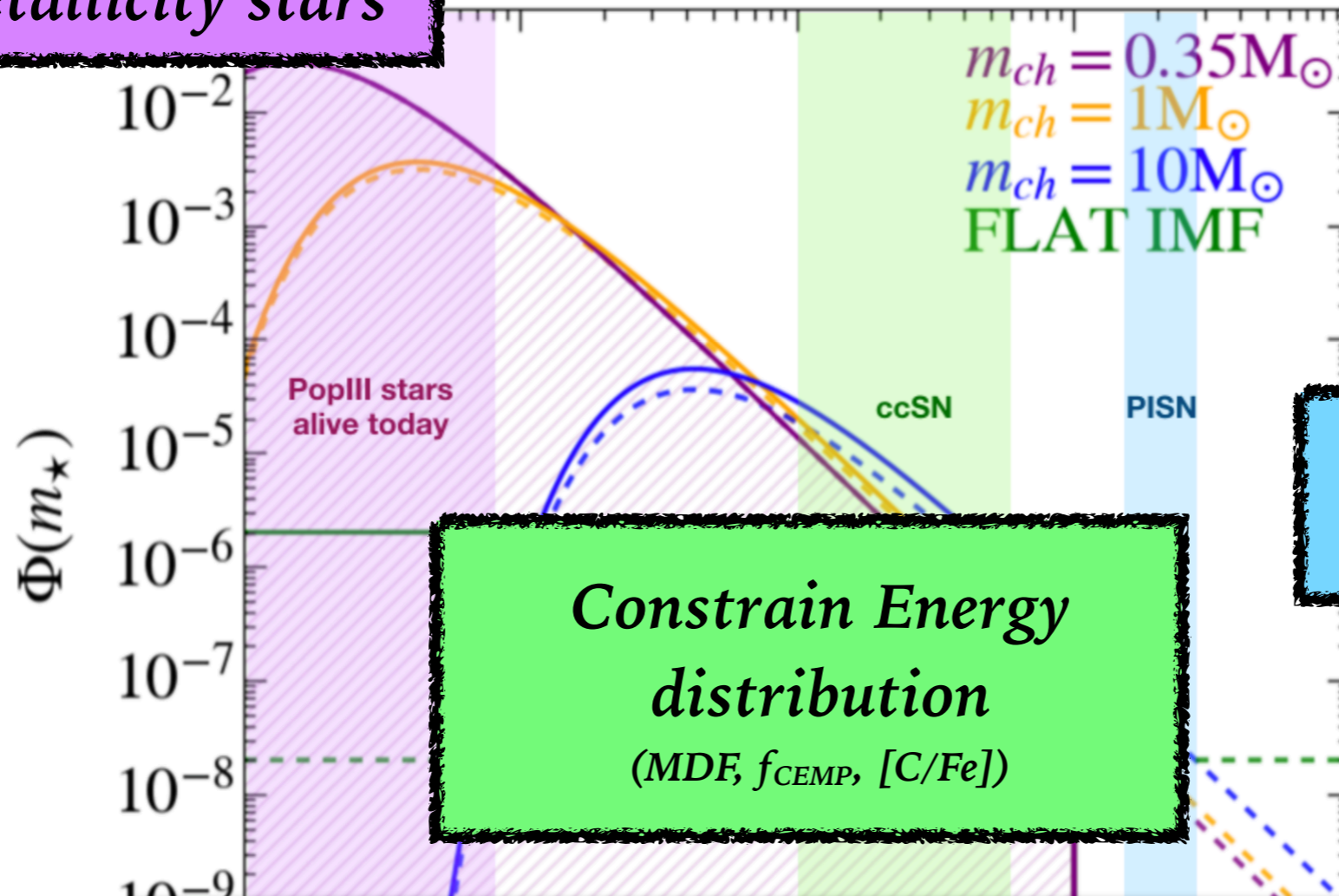
<sup>5</sup>Instituto de Astrofísica de Canarias, Vía Láctea, 38205 La Laguna, Tenerife, Spain

2023

# FIRST STARS: IMF AND SN ENERGY

Skúladóttir et al. 2023 (4DWARFS)

(Non)-detection of zero-metallicity stars



Quantify PISN descendants

The energy distribution of the first supernovae

MNRAS submitted

I. Koutsouridou,<sup>1,2\*</sup> S. Salvadori,<sup>1,2</sup> Á. Skúladóttir,<sup>1,2</sup> M. Rossi,<sup>1,2</sup> I. Vanni<sup>1,2</sup> and G. Pagnini<sup>3</sup>

<sup>1</sup>Dipartimento di Fisica e Astronomia, Università degli Studi di Firenze, Via G. Sansone 1, 50019 Sesto Fiorentino, Italy

<sup>2</sup>INAF/Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, 50125 Firenze, Italy

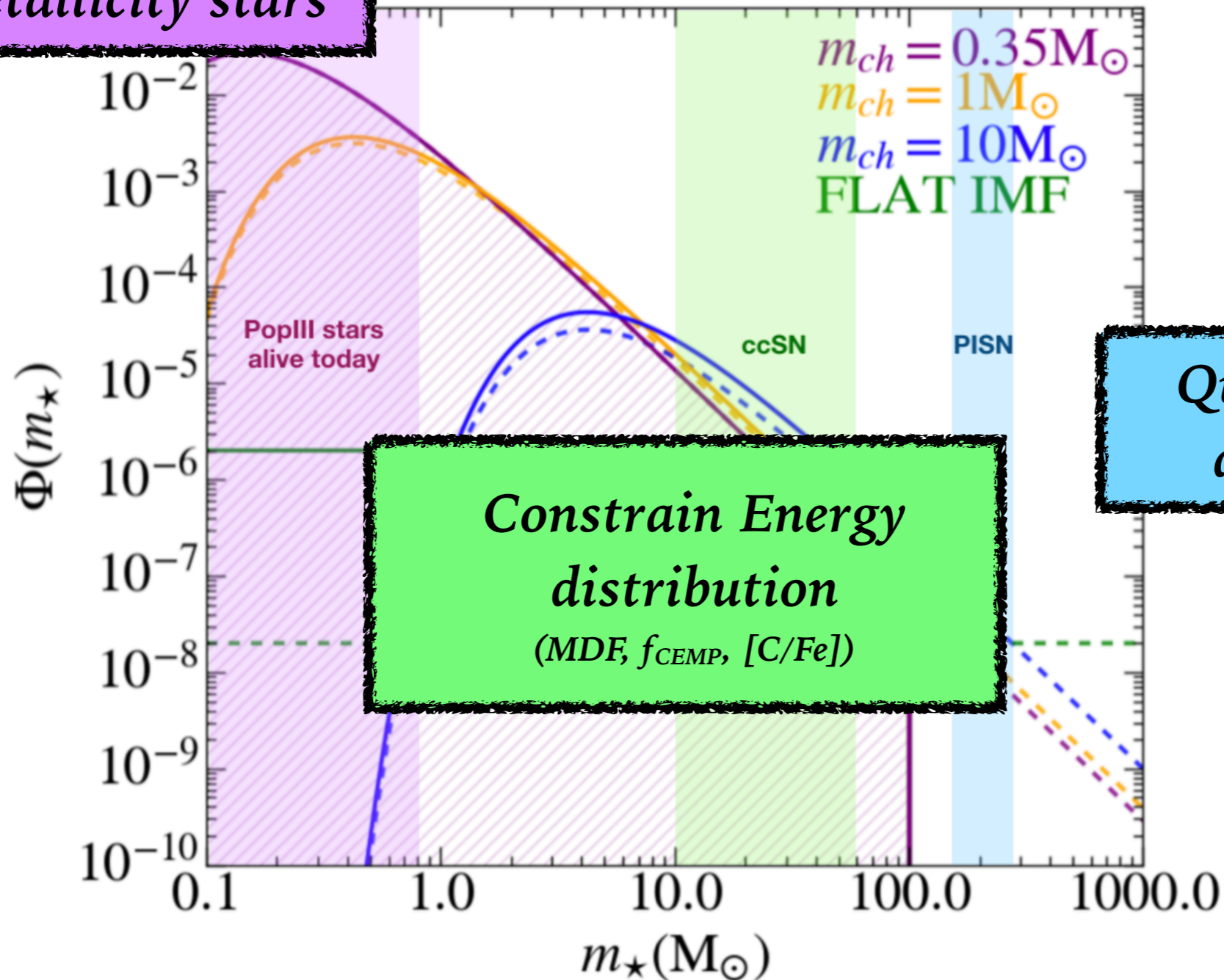
<sup>3</sup>GEPI, Observatoire de Paris, PSL Research University, CNRS, Place Jules Janssen, 92195 Meudon, France



# FIRST STARS: IMF AND SN ENERGY

Skúladóttir et al. 2023 (4DWARFS)

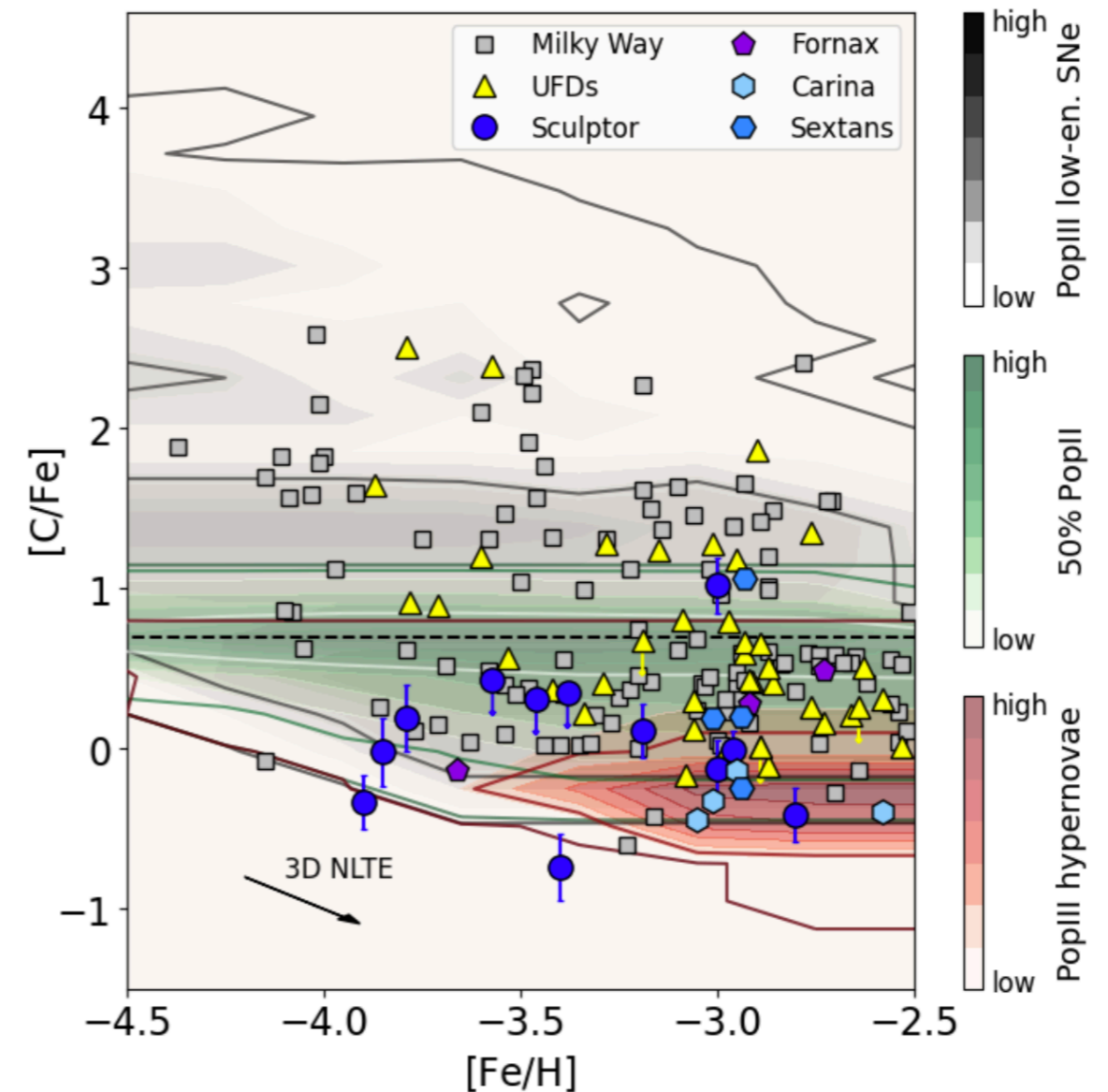
(Non)-detection of zero-metallicity stars



# CONCLUSIONS

Skúladóttir et al. 2021; 2023; 2023 (4DWARFS)

- AS0039: Pop III hypernovae descendant in Sculptor!
- **Sculptor traces the extremes of Pop III SN energies.**
- The Milky Way halo at  $[\text{Fe}/\text{H}] < -3$  **cannot** be made from Sculptor-like galaxies.



# CONCLUSIONS

Skúladóttir et al. 2021; 2023; 2023 (4DWARFS)

➤ AS0039: Pop III hypernovae

➤  
B  
➤  
C  
galaxies.

*DATA are coming!!!*

