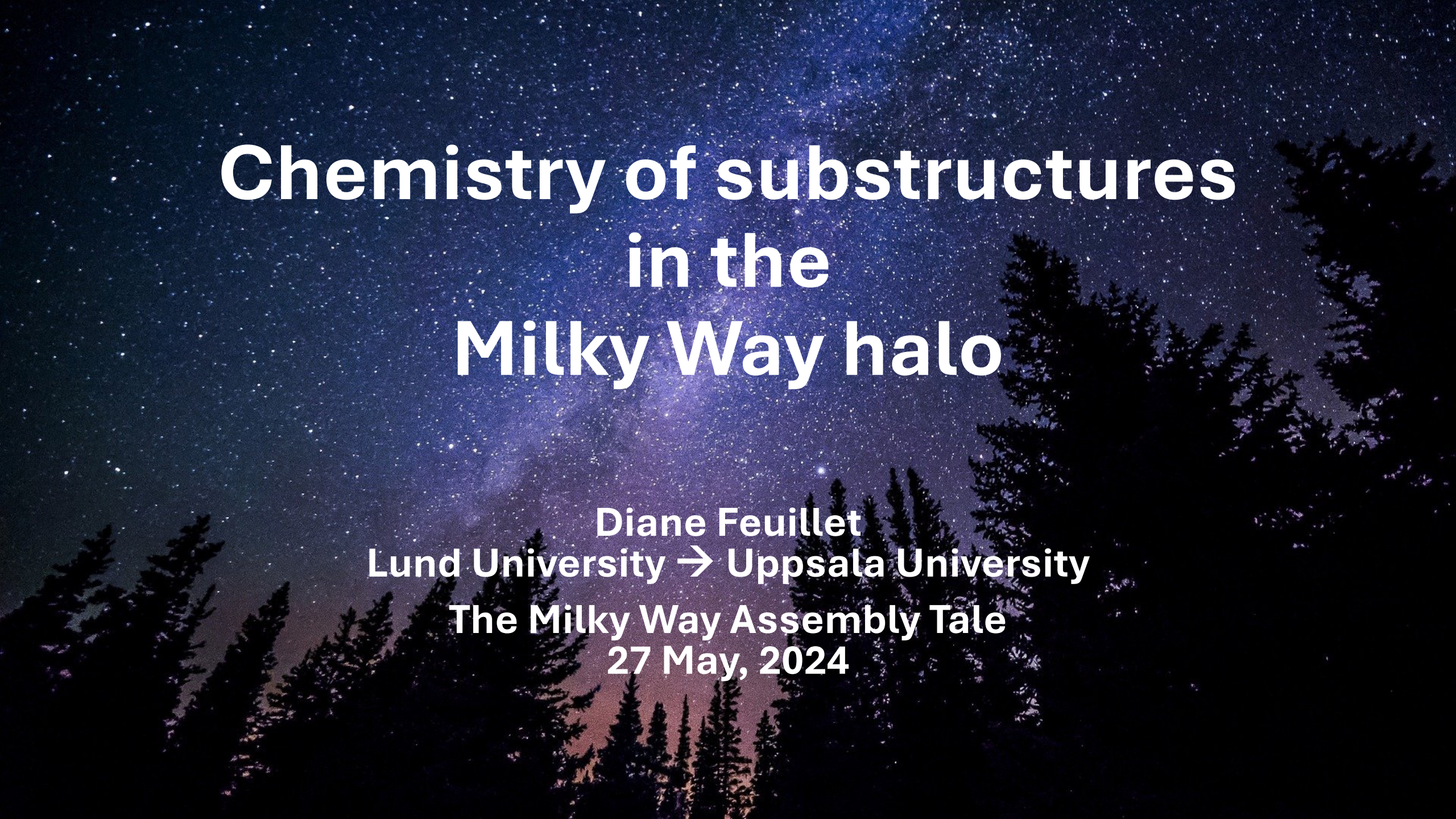


Chemistry of substructures in the Milky Way halo

Diane Feuillet
Lund University → Uppsala University

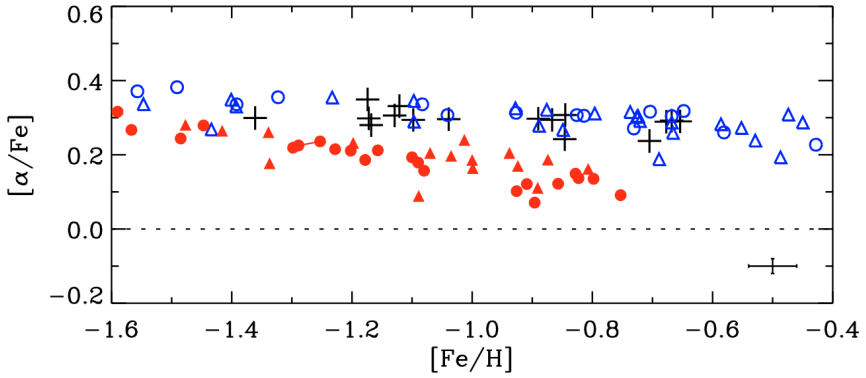
The Milky Way Assembly Tale
27 May, 2024

Chemistry of halo substructures

Gaia-Sausage-Enceladus (GSE/GES)

- Nissen & Schuster 2010

Nissen & Schuster (2010)



Chemistry of halo substructures

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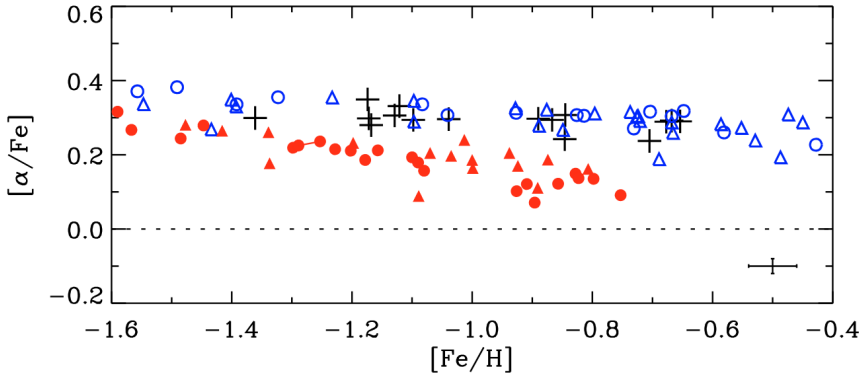
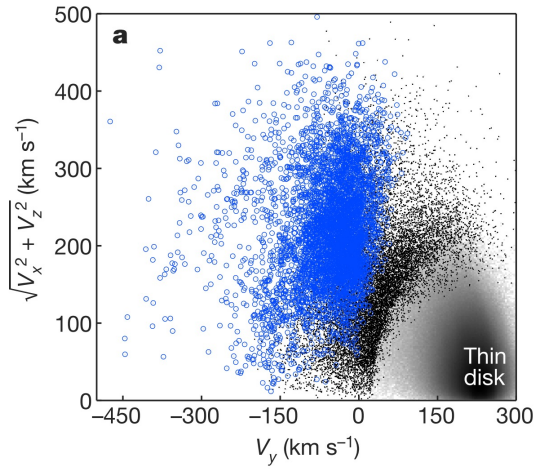
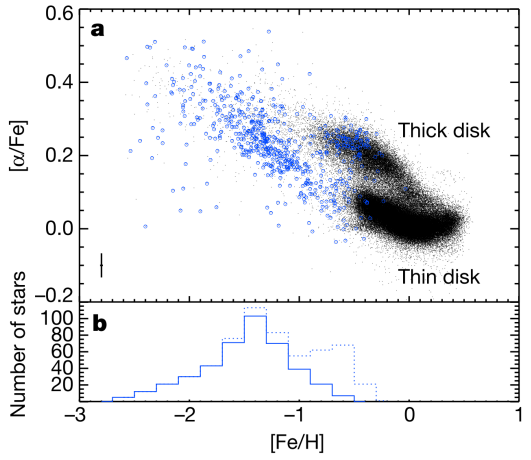
Nissen & Schuster (2010)



Helmi et al. (2018)





Chemistry of halo substructures

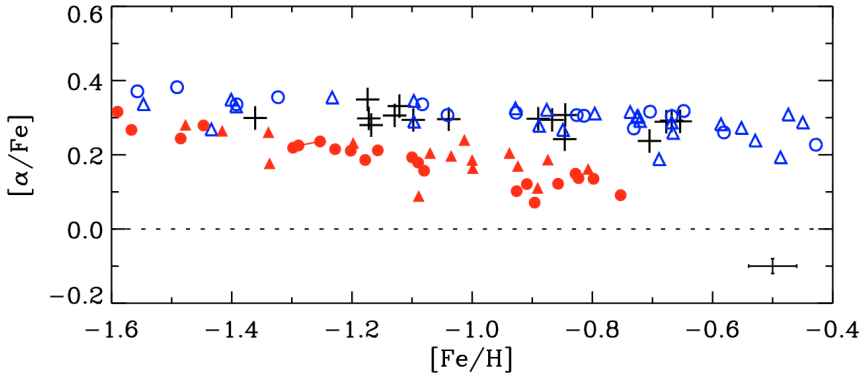
Gaia-Sausage-Enceladus (GSE/GES)

- Nissen & Schuster 2010
- Helmi et al. 2018

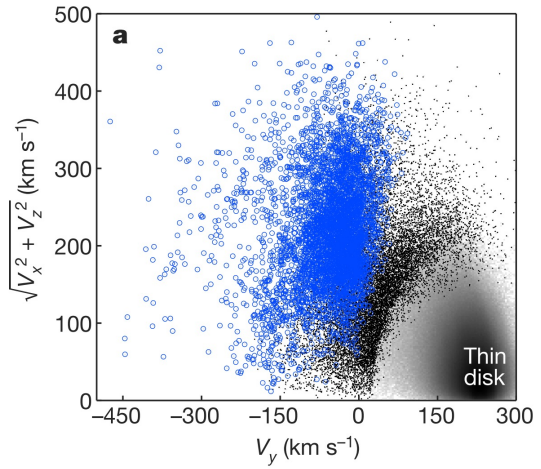
Many kinematic substructures

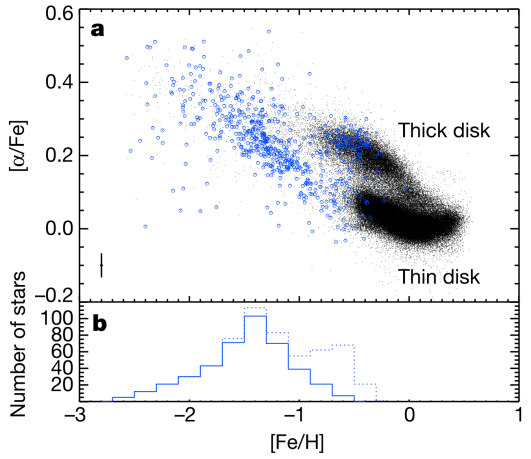
Koppelman+ 2019, Myeong+ 2019, Naidu+ 2020, Horta+ 2021
many more…

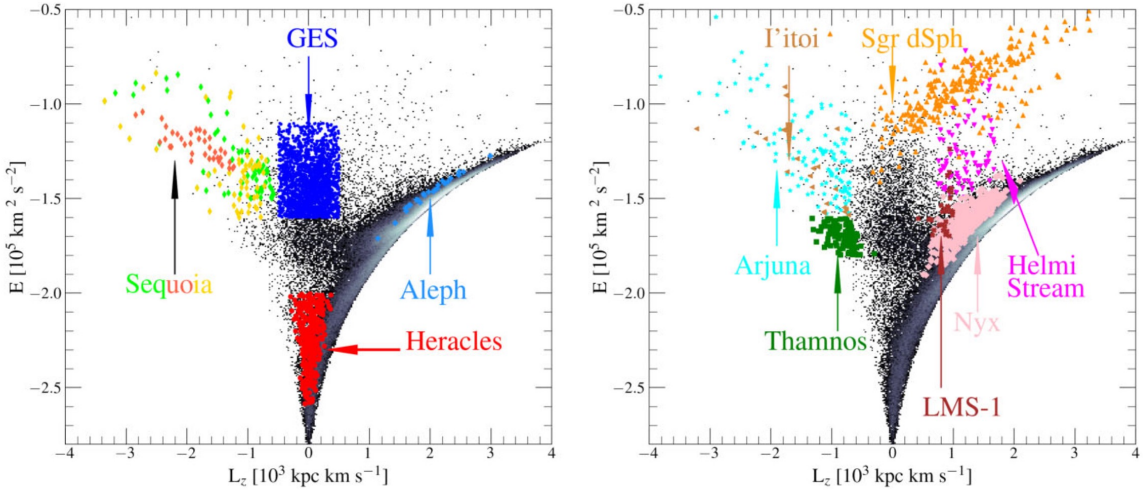
Nissen & Schuster (2010)



Helmi et al. (2018)

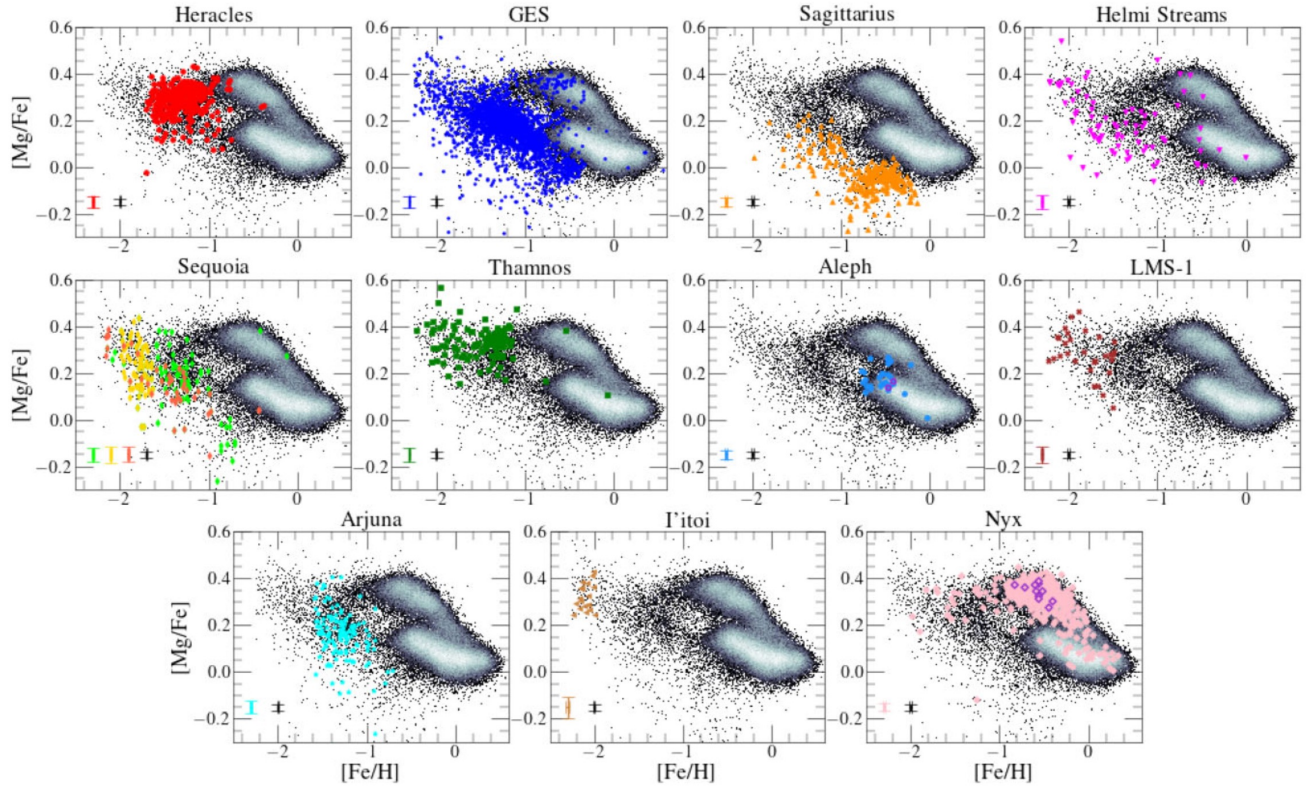






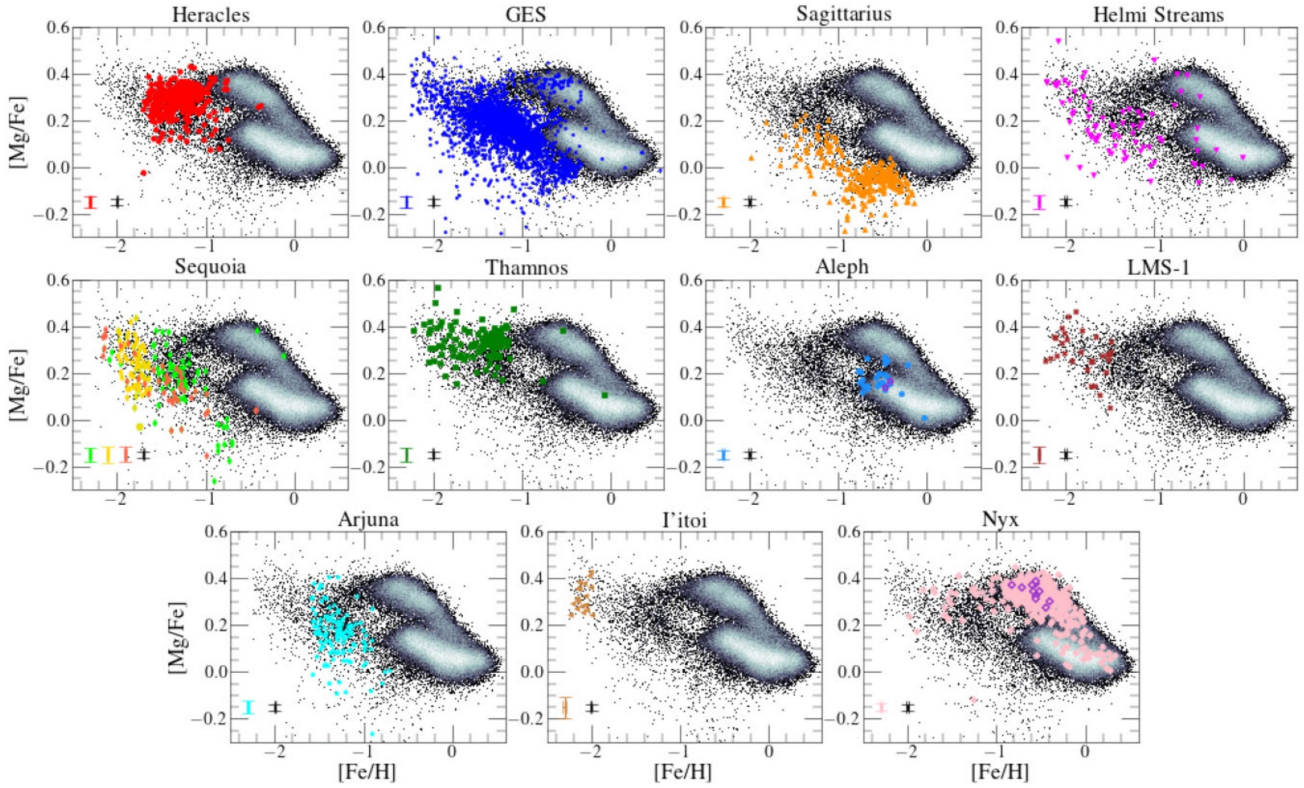
Horta et al. (2023)

Chemistry of halo substructures

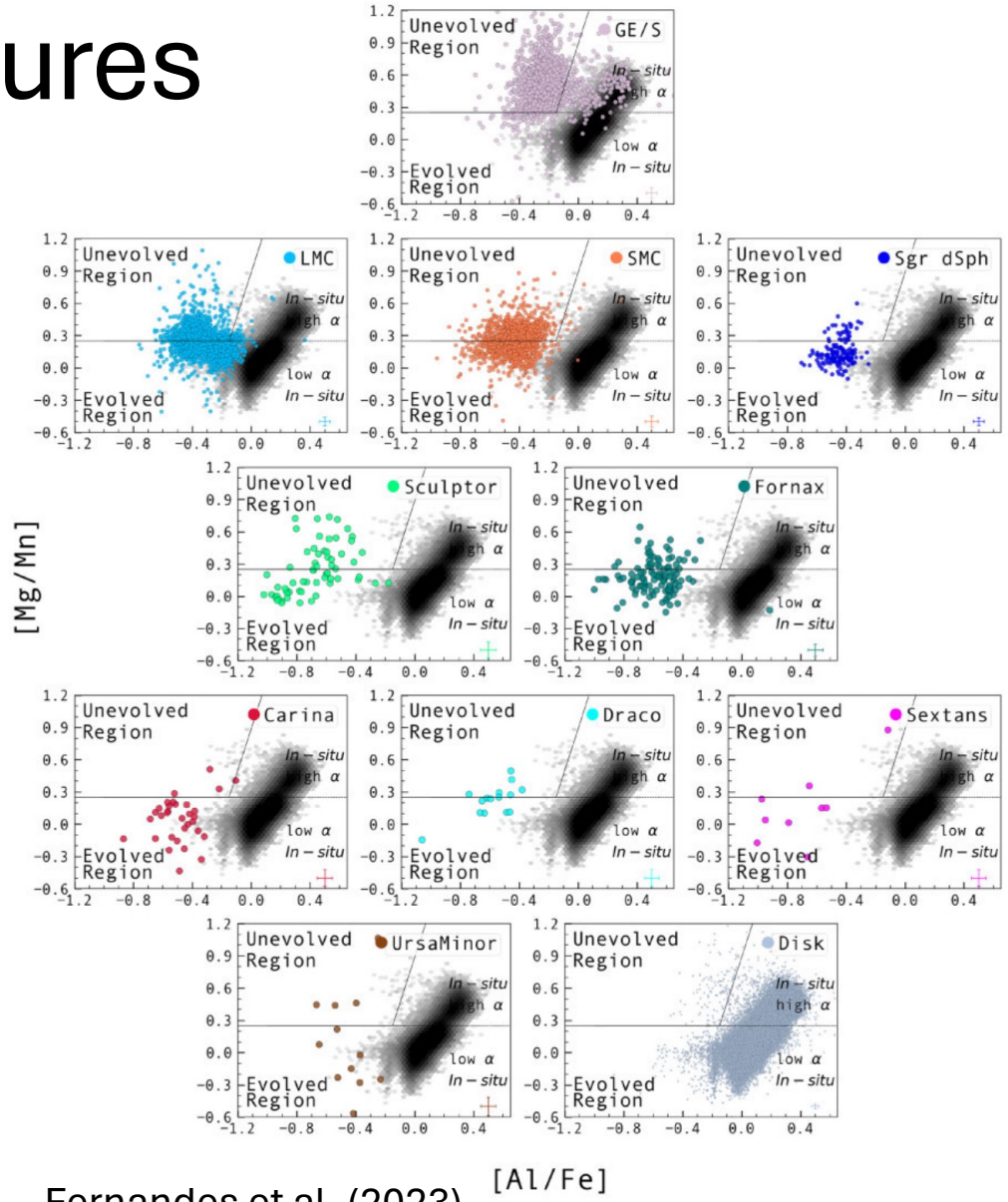


Horta et al. (2023)

Chemistry of halo substructures



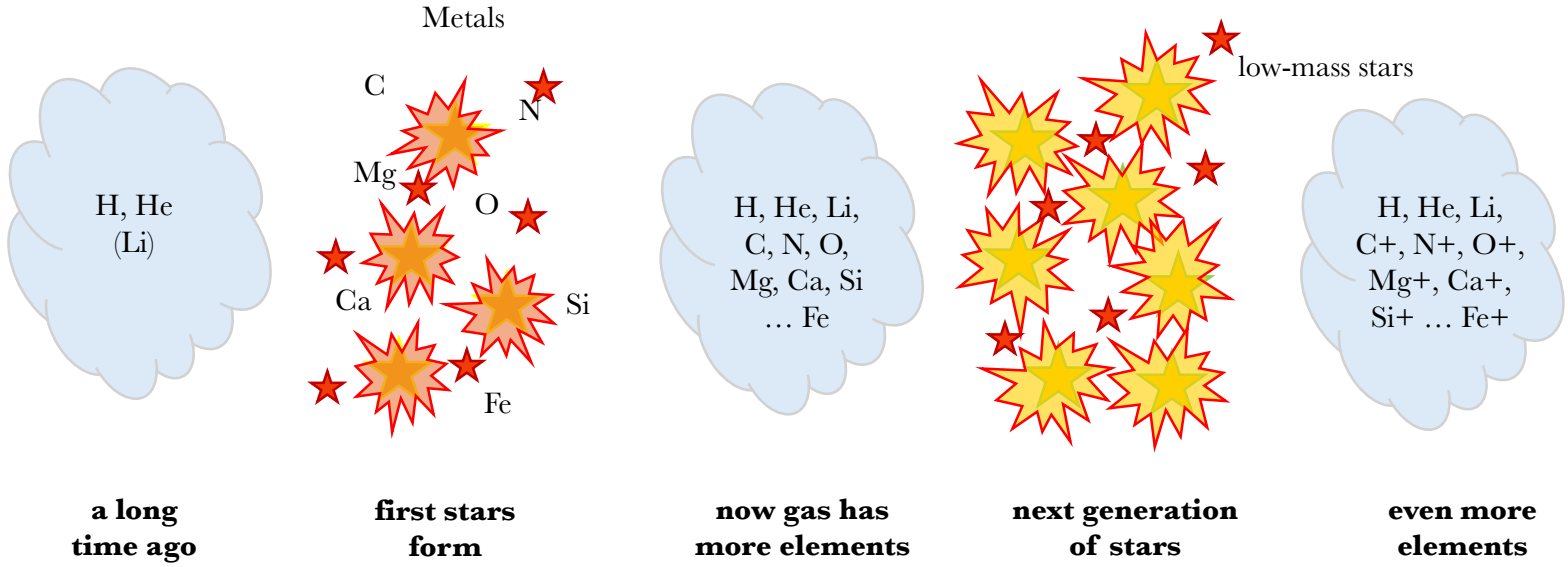
Horta et al. (2023)



Fernandes et al. (2023)

Informing progenitor properties

Elemental abundance patterns of stellar populations are dictated by the properties of the original galaxy.



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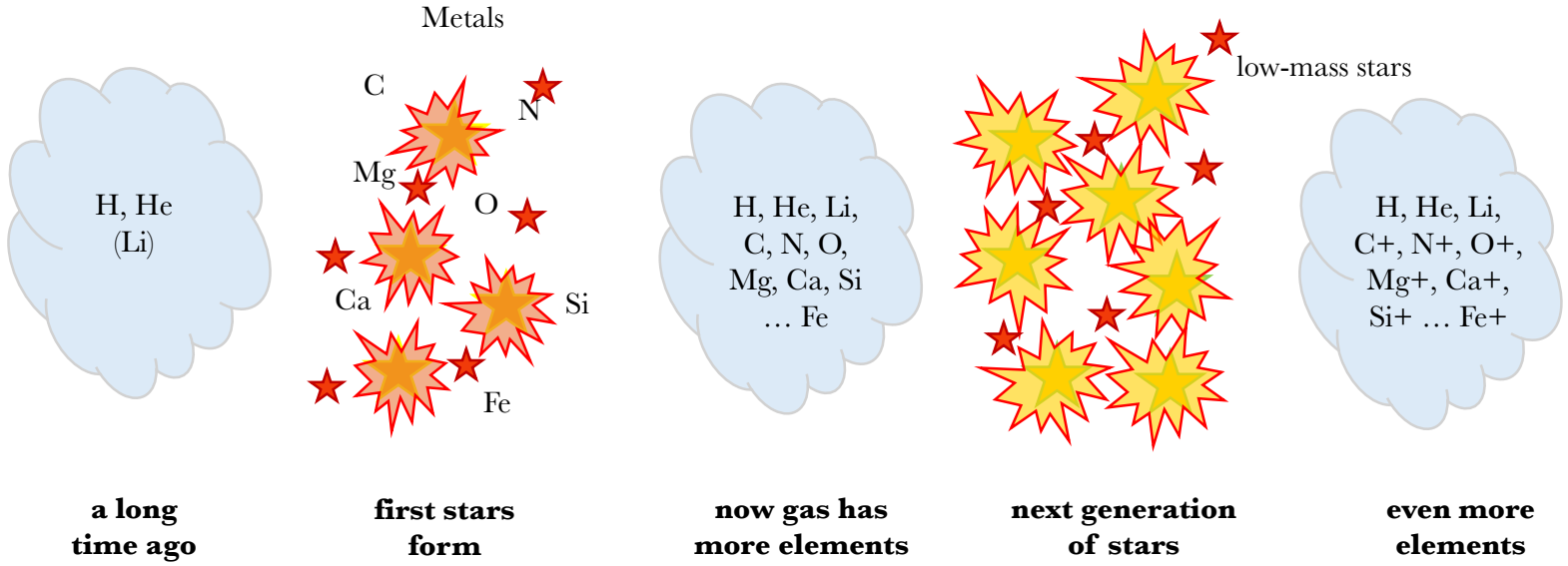
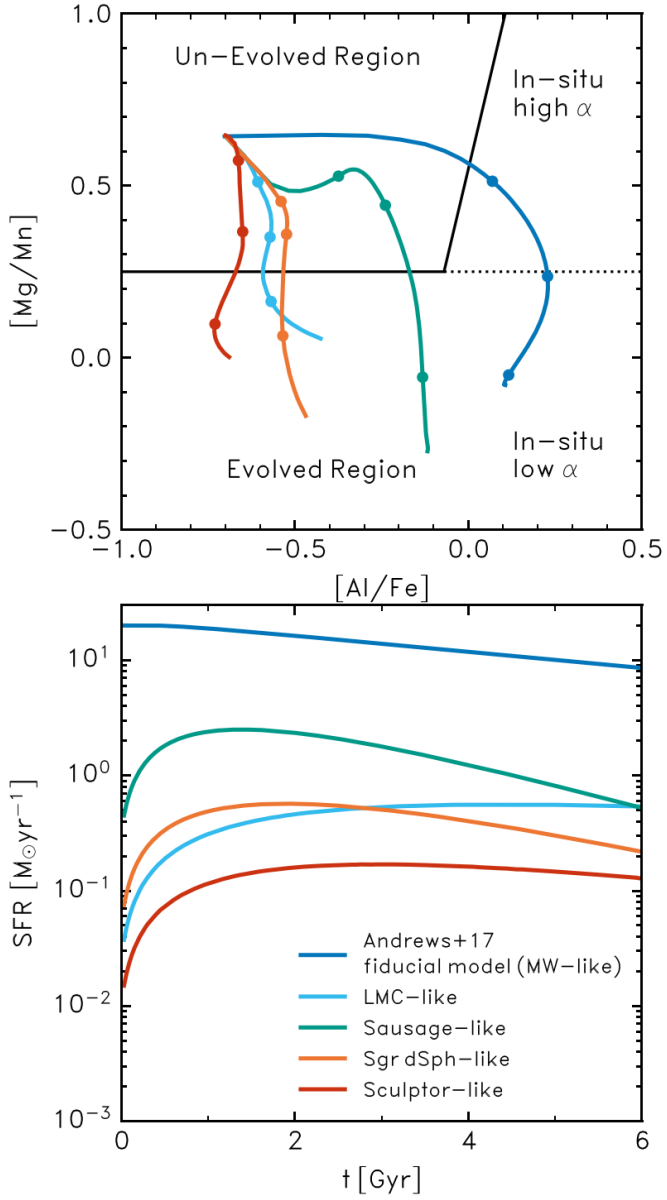
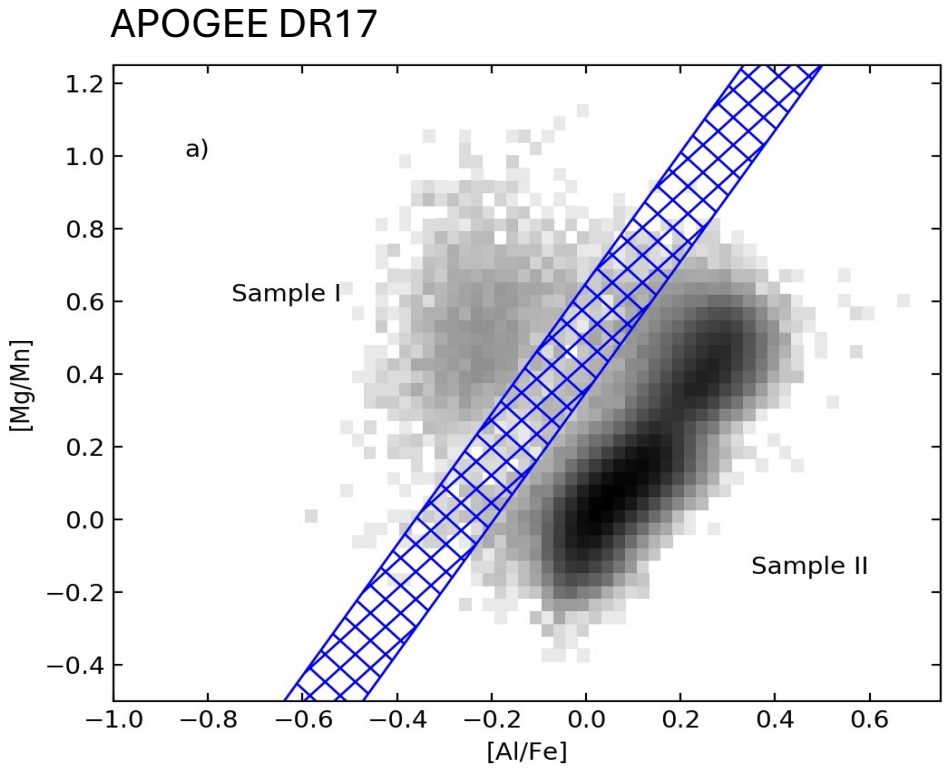


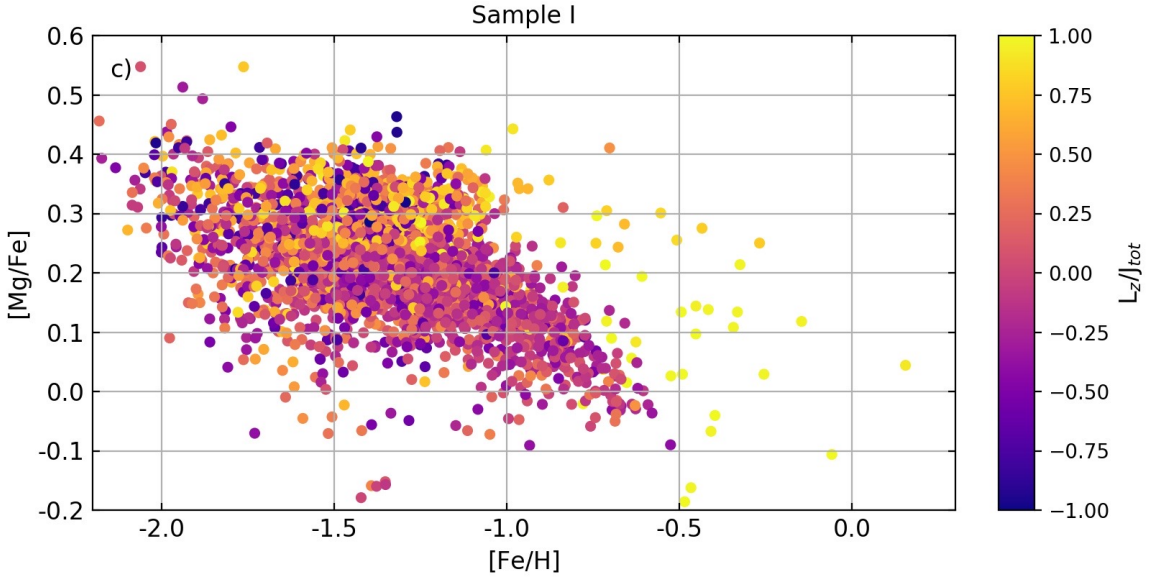


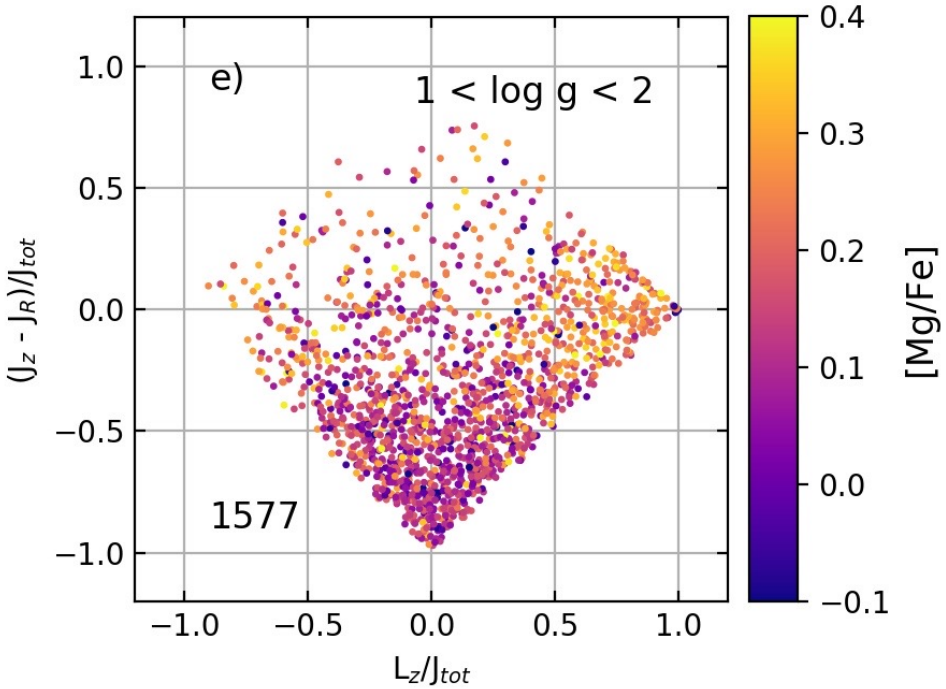
Fernandes et al. (2023)

Chemistry + kinematics recommended



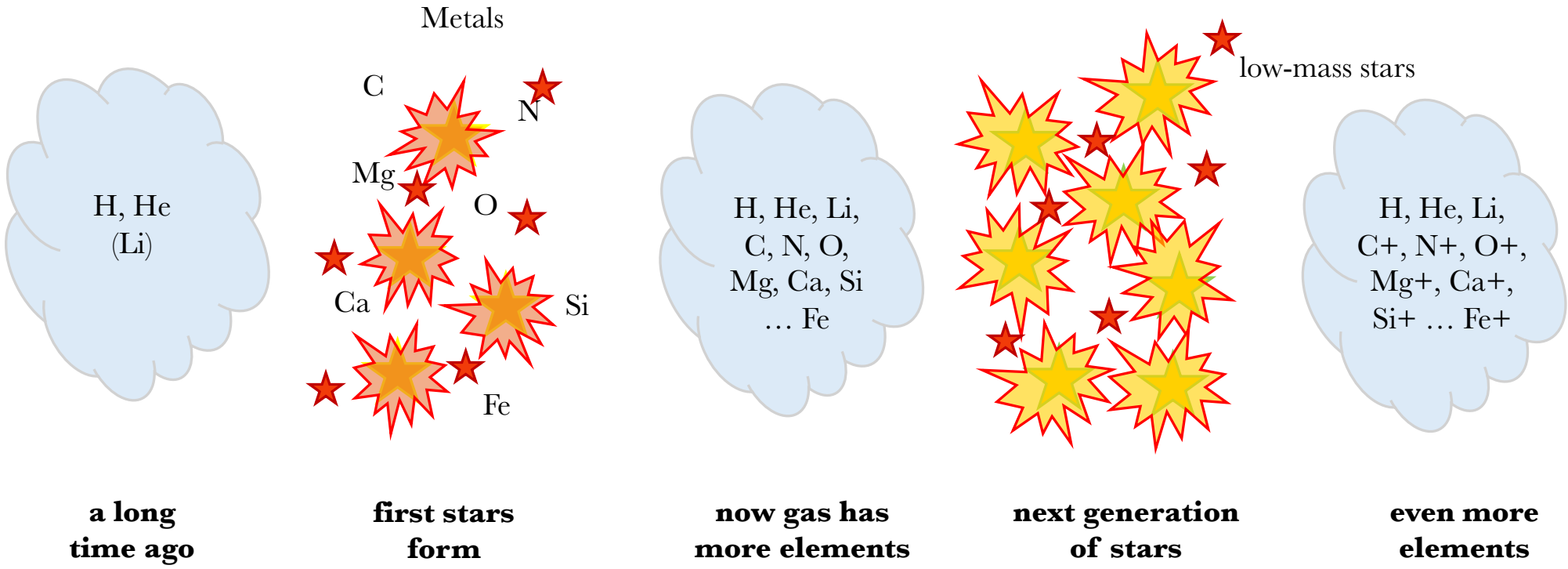
Feltzing & Feuillet 2023





Enrichment of elements

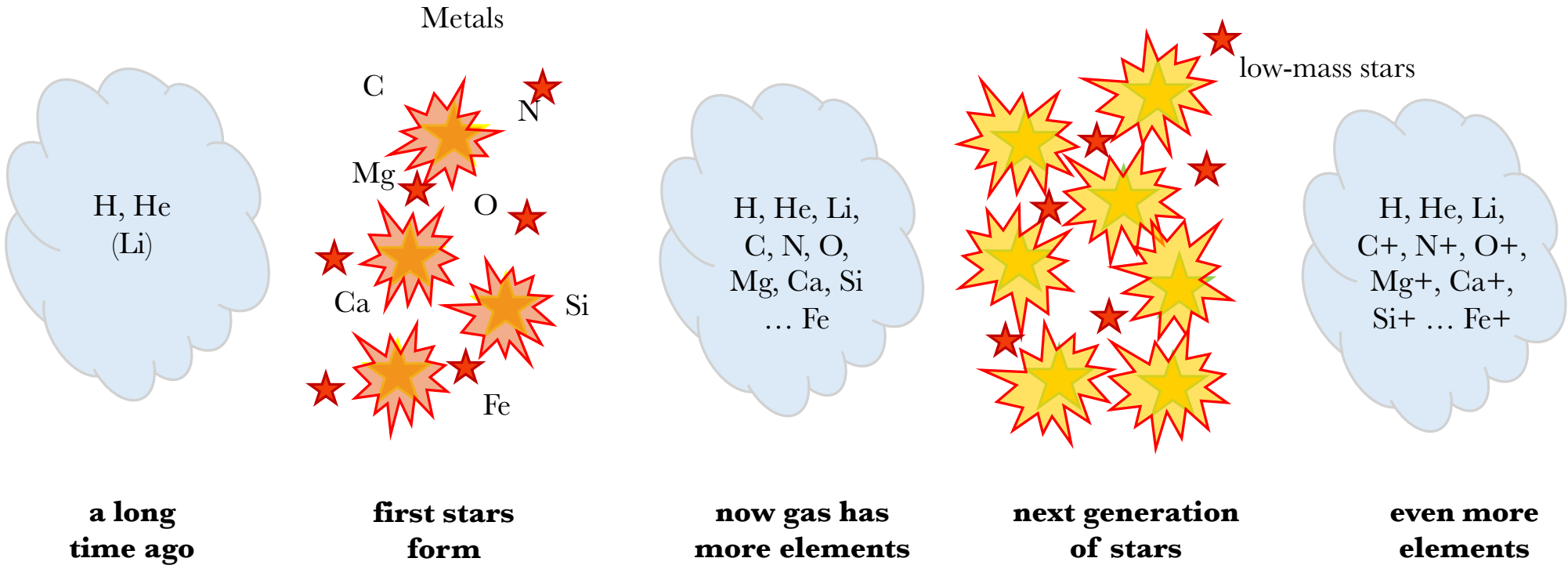
Elemental abundance patterns of stellar populations are dictated by the properties of the original galaxy.



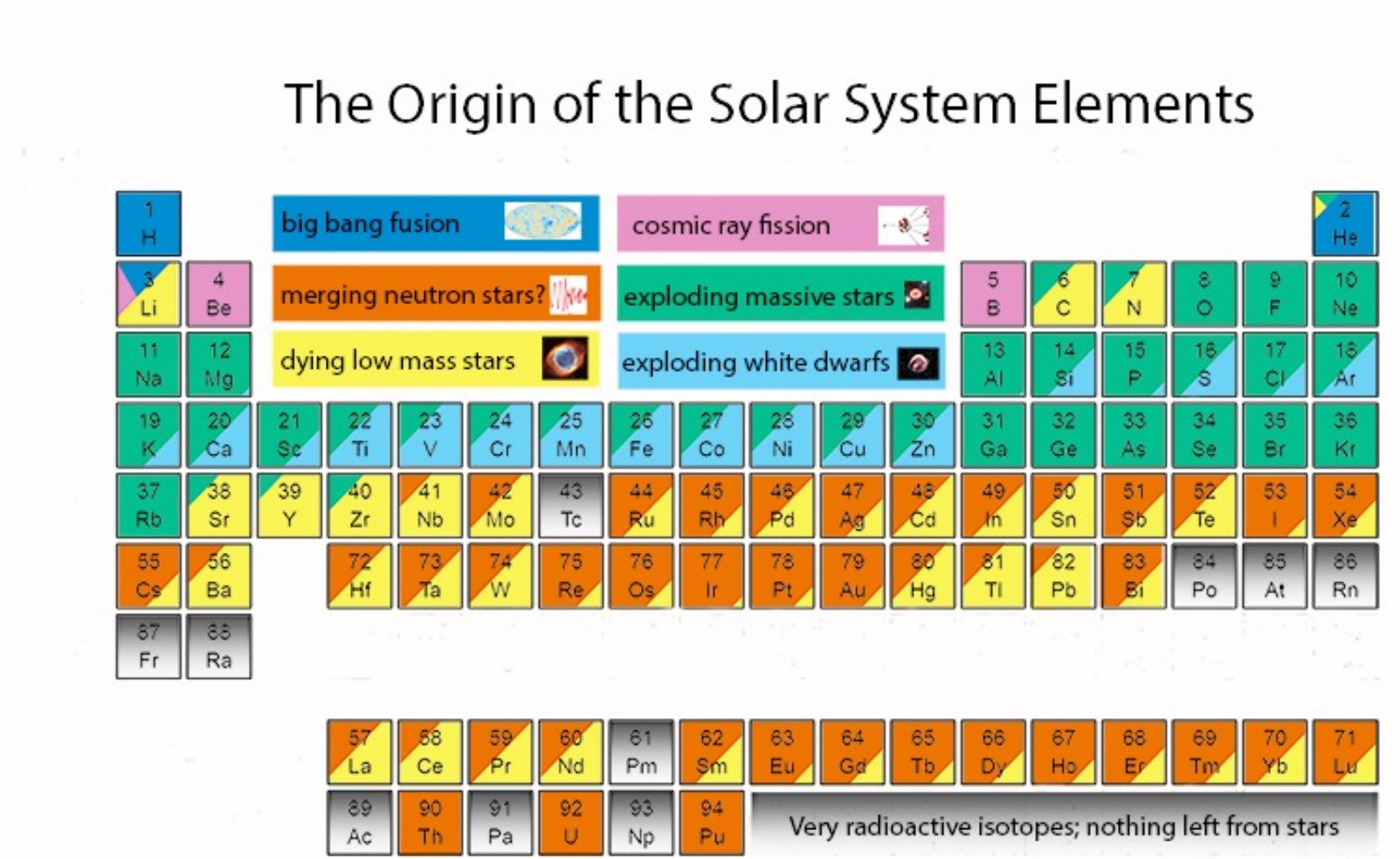
Enrichment of elements

Elemental abundance patterns of stellar populations are dictated by the properties of the original galaxy.

*Not all stars create all elements

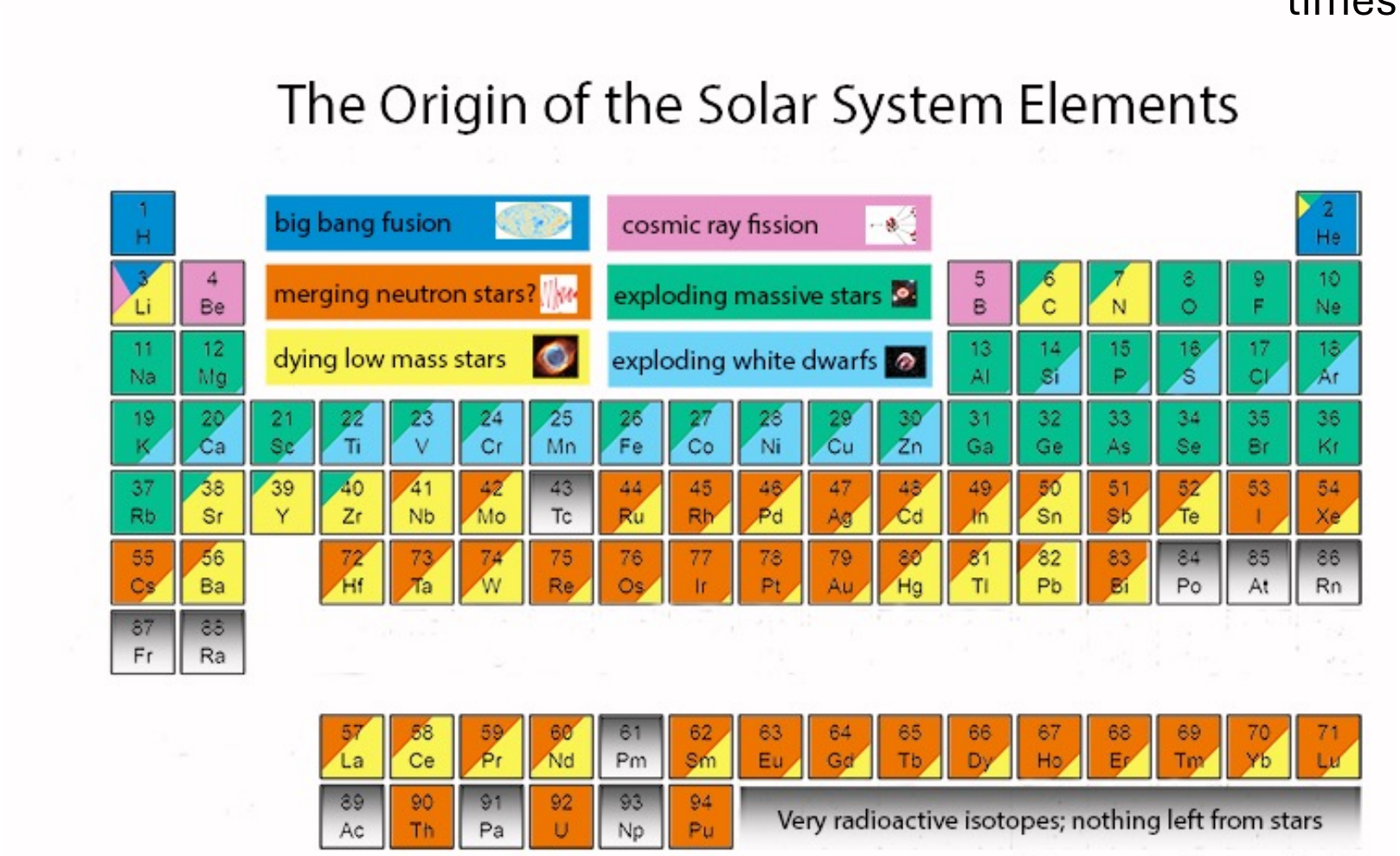


Enrichment of elements



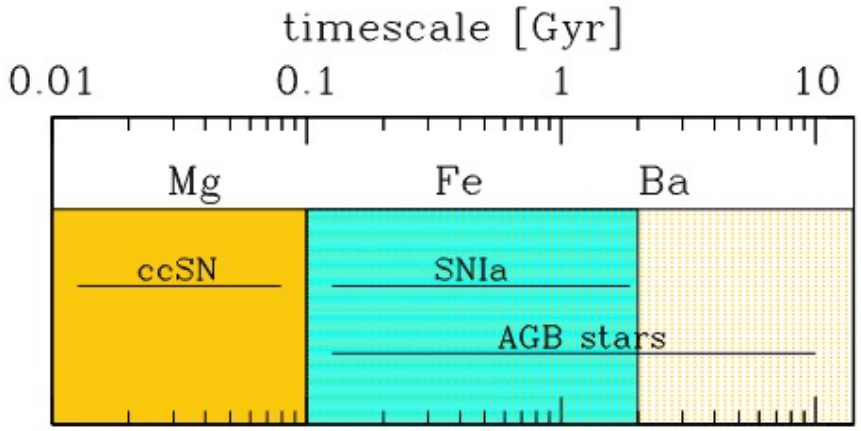
Enrichment of elements

*Not all nucleosynthesis channels enrich elements on the same timescales



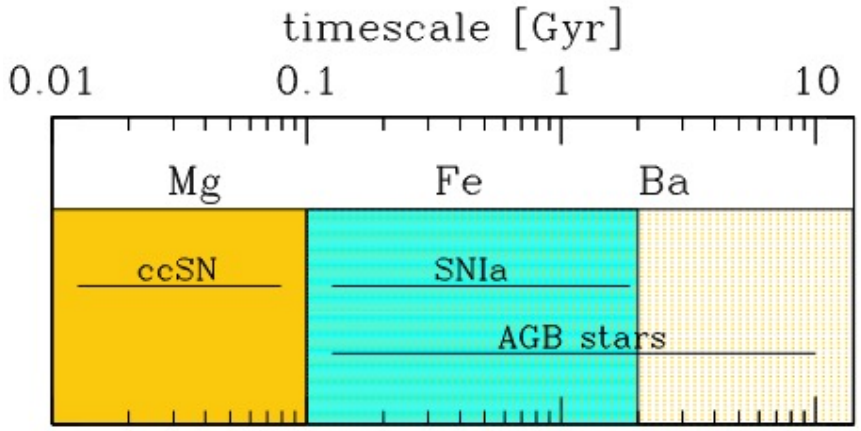
Enrichment of elements

ccSN
Massive stars, enrich quickly
Mg



Skúladóttir & Salvadori (2020)

Enrichment of elements



ccSN
Massive stars,
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SNIa
Binary WD system
delayed enrichment
Fe

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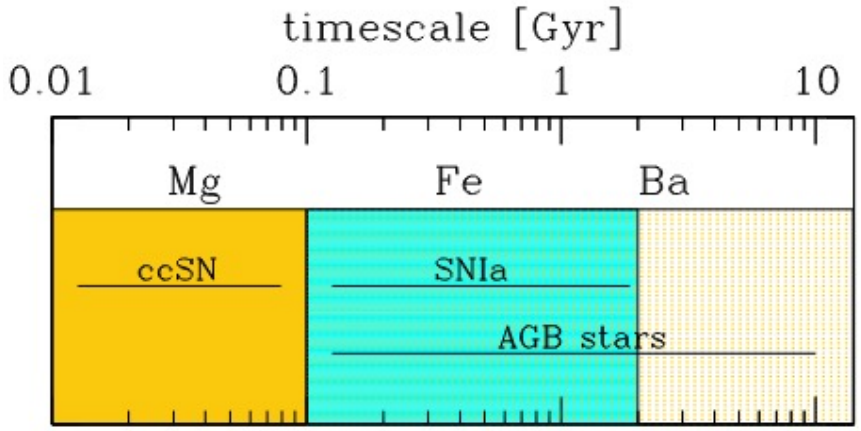
Enrichment of elements



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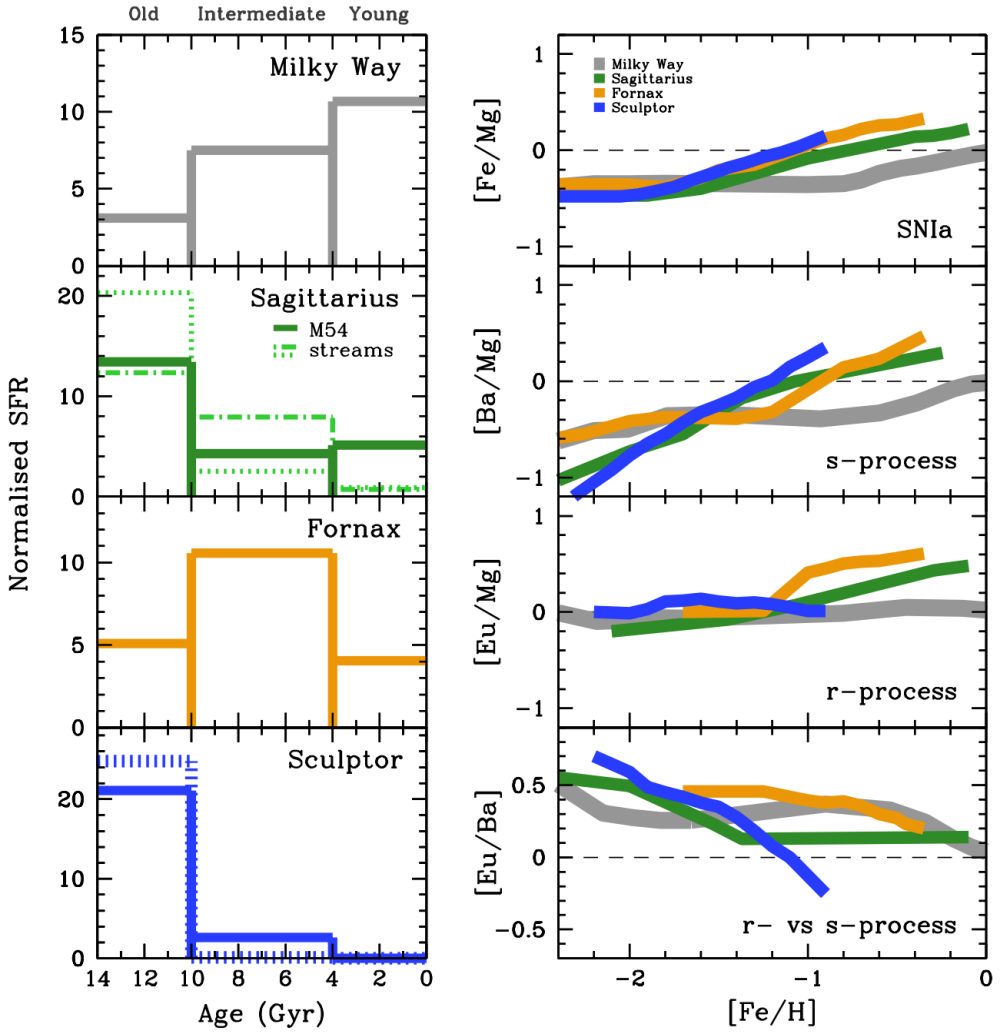
Binary WD system
delayed enrichment
Fe

AGB stars
Intermediate mass
delayed & extended
enrichment
Ba

Skúladóttir & Salvadori (2020)

Tracing star formation history

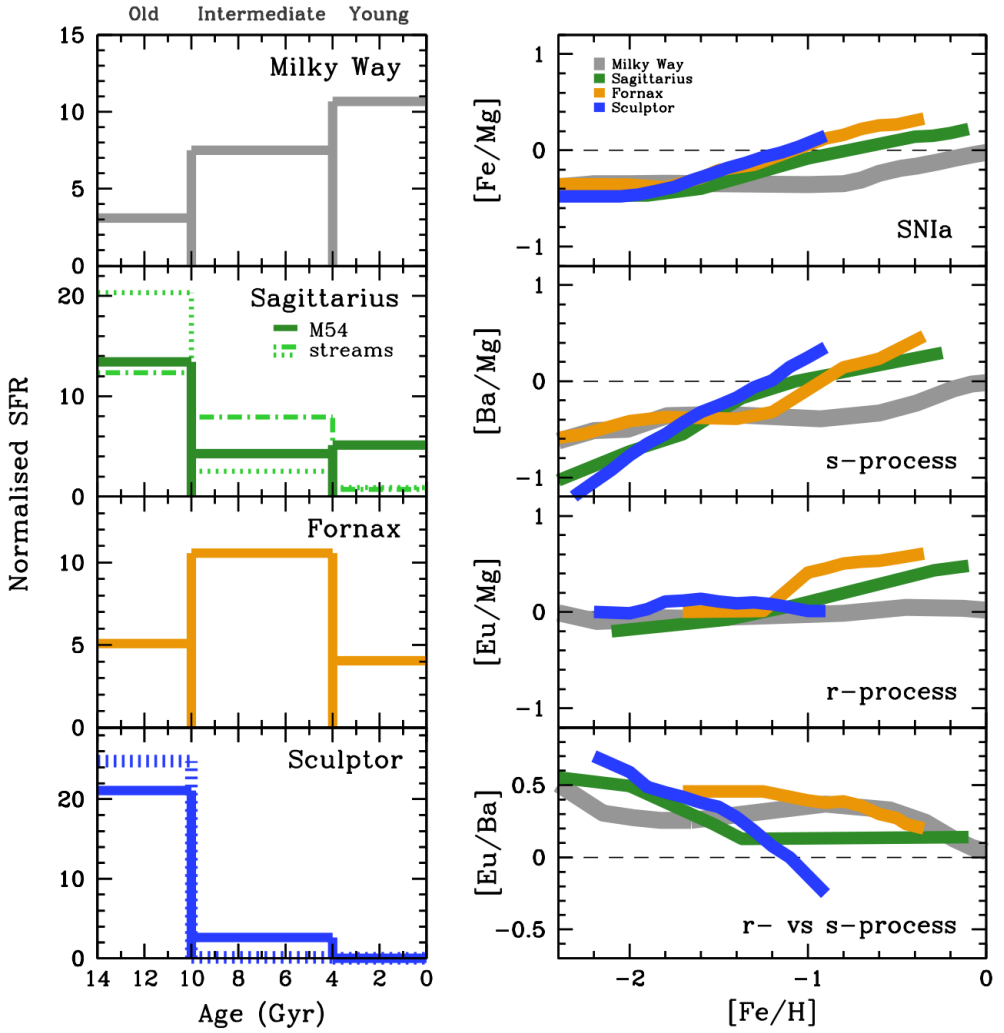
- Dwarf spheroidal galaxies with well characterized SFH



Skúladóttir & Salvadori (2020)

Tracing star formation history

- Dwarf spheroidal galaxies with well characterized SFH
- Ratios of Mg, Fe, Ba, Eu abundance reflect the SFH



Skúladóttir & Salvadori (2020)

Tracing star formation history

- Dwarf spheroidal galaxies with well characterized SFH
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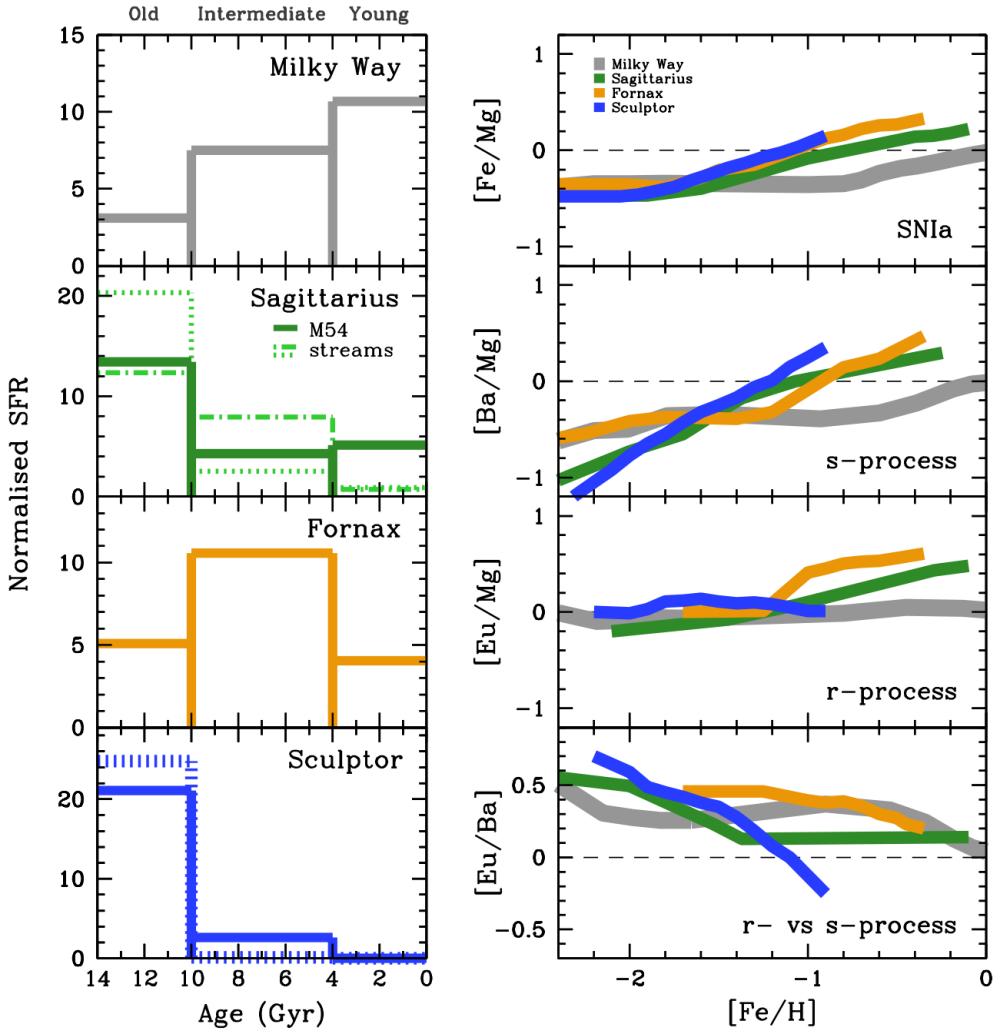
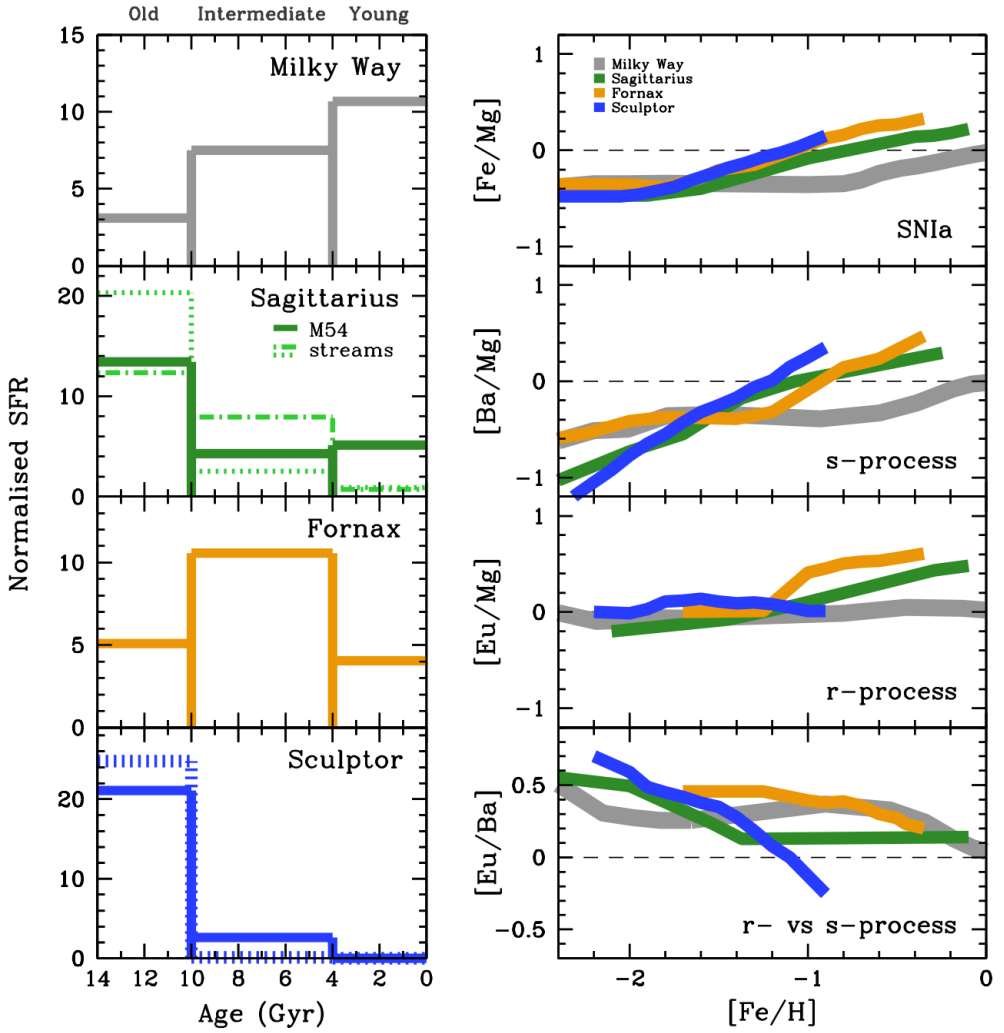
- *R*-process enriched through 2 sources, one quick, one delayed



Skúladóttir & Salvadori (2020)

Tracing star formation history

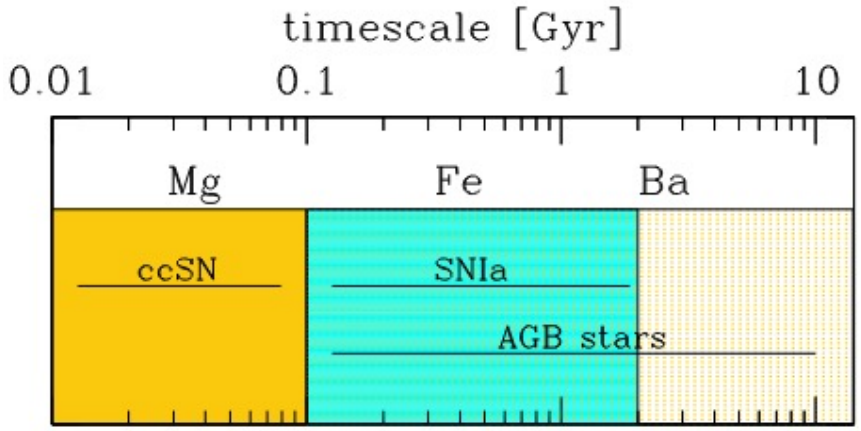
- Dwarf spheroidal galaxies with well characterized SFH
- Ratios of Mg, Fe, Ba, Eu abundance reflect the SFH
- *R*-process enriched through 2 sources, one quick, one delayed
- The delayed source contributes after ~2 Gyr
  (see updated Sculptor SFH, Bettinelli et al. 2019)



Skúladóttir & Salvadori (2020)

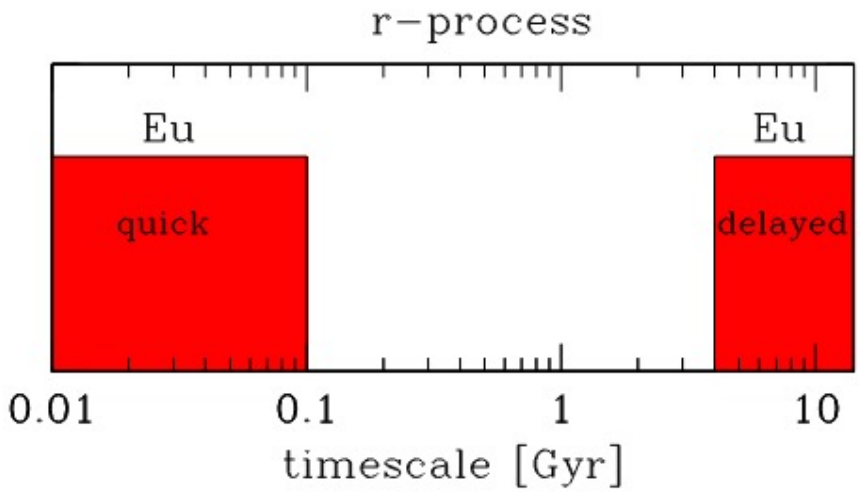
Enrichment of elements

ccSN
Massive stars,
enrich quickly
Mg



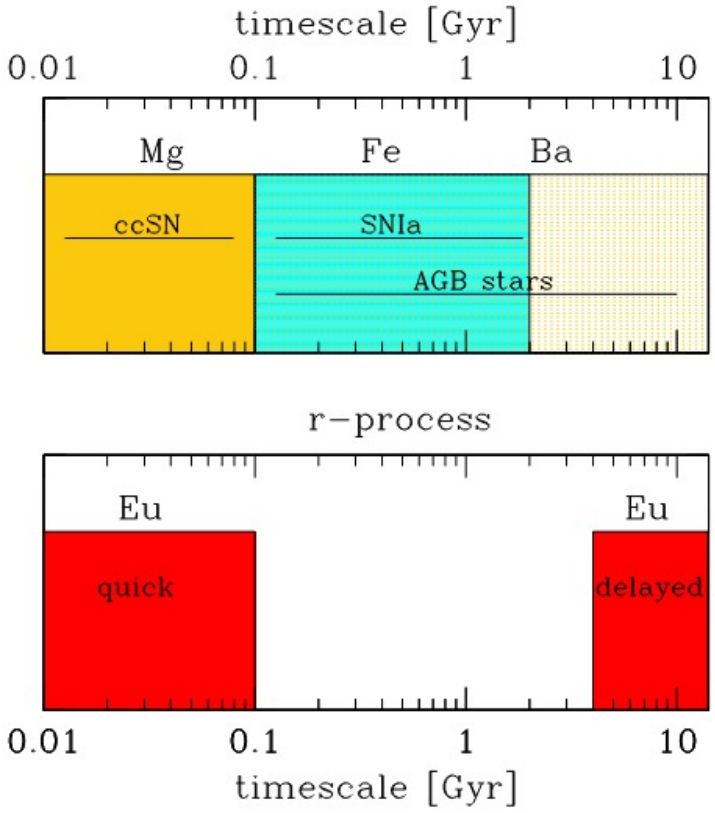
AGB stars
Intermediate mass
delayed & extended
enrichment
Ba

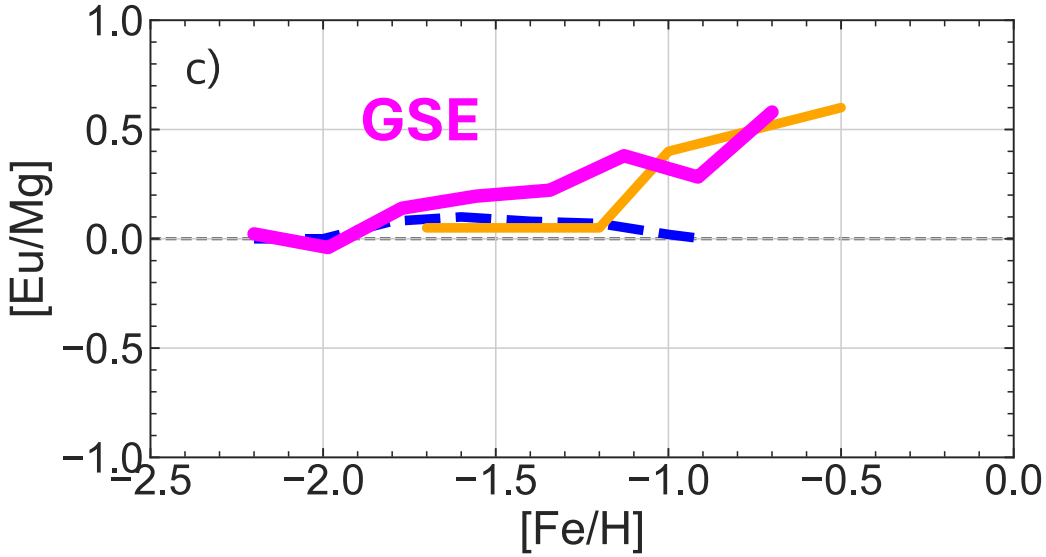
SNIa
Binary WD system
delayed enrichment
Fe

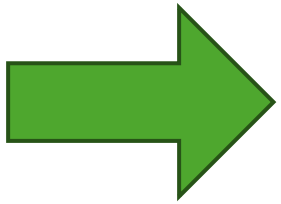


r-process
quick source
delayed source
Eu

Skúladóttir & Salvadori (2020)





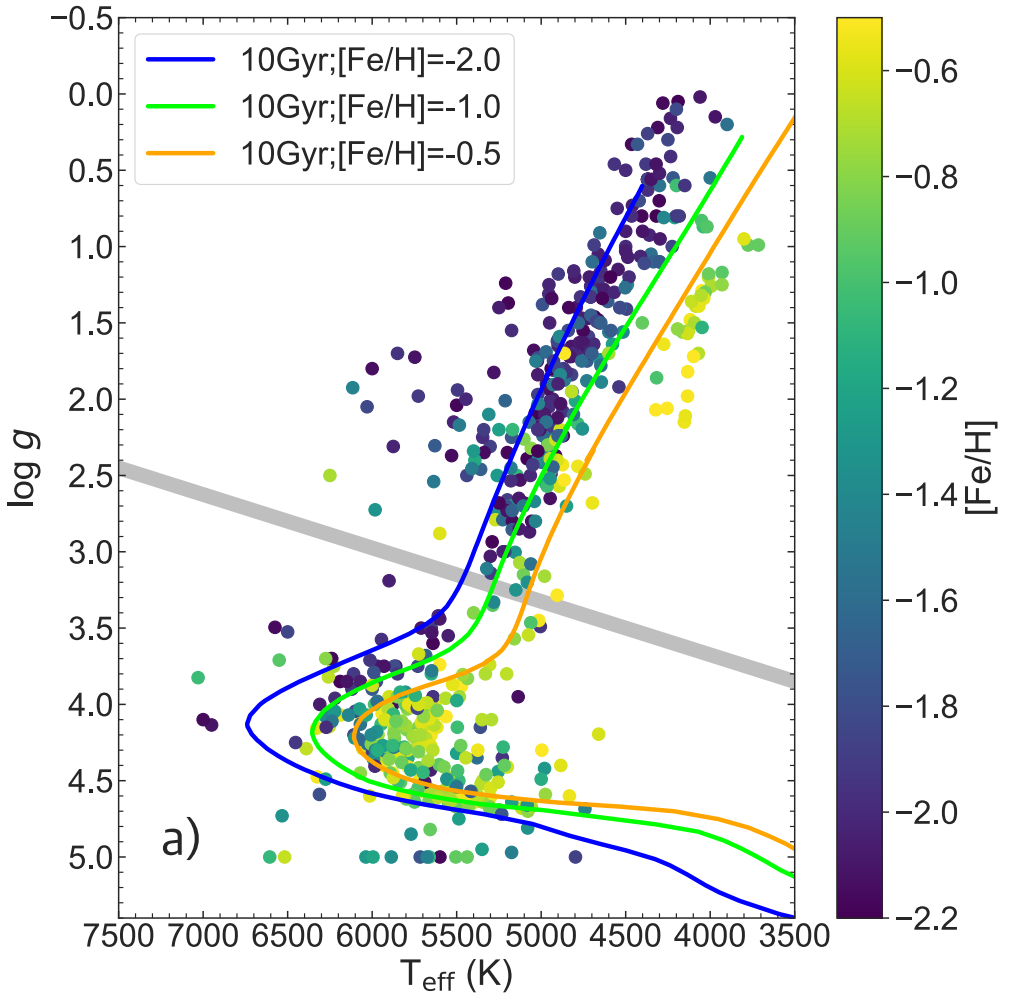


Gaia-Sausage Enceladus star formation history

Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)

GSE literature compilation

- SAGA database
  - Require Eu abundances, add Fe, Mg, Ba
  - Multiple entries per star, take median of all available values



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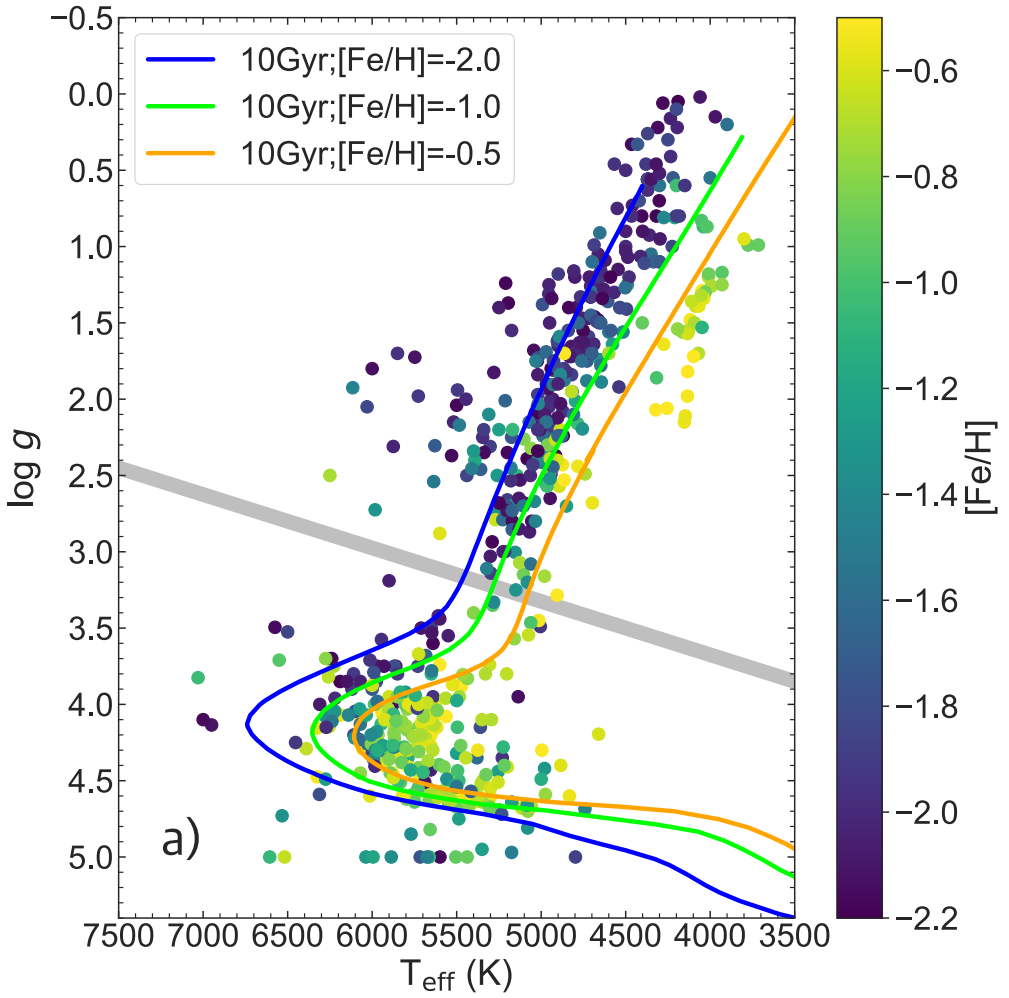

Ernandes, Feuillet, Feltzing & Skúladóttir
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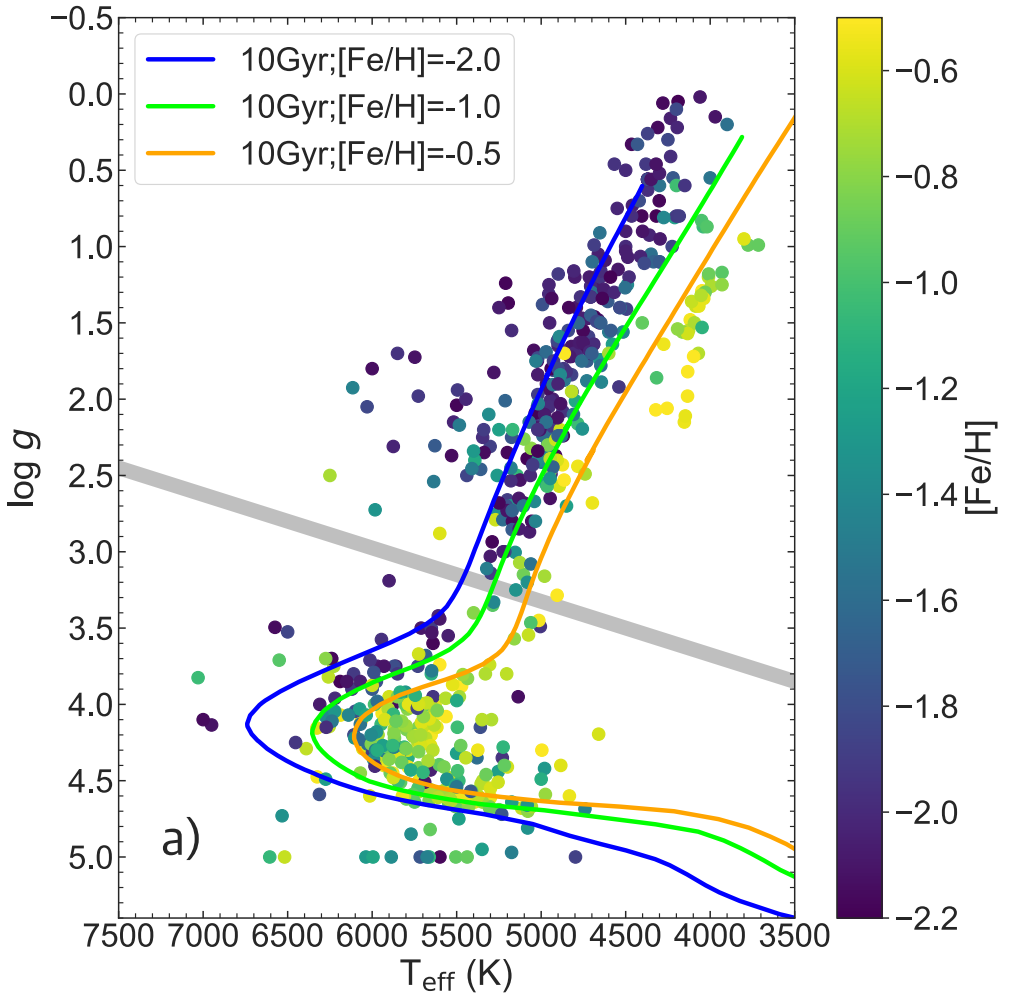
GSE literature compilation

- SAGA database
  - Require Eu abundances, add Fe, Mg, Ba
  - Multiple entries per star, take median of all available values
- Gaia + RVS parameters
  - galpy kinematics using MWPotential14 & McMillan17
- 654 unique stars
- 73 GSE stars selected in $L_Z - J_R$
  Feuillet+ (2021)



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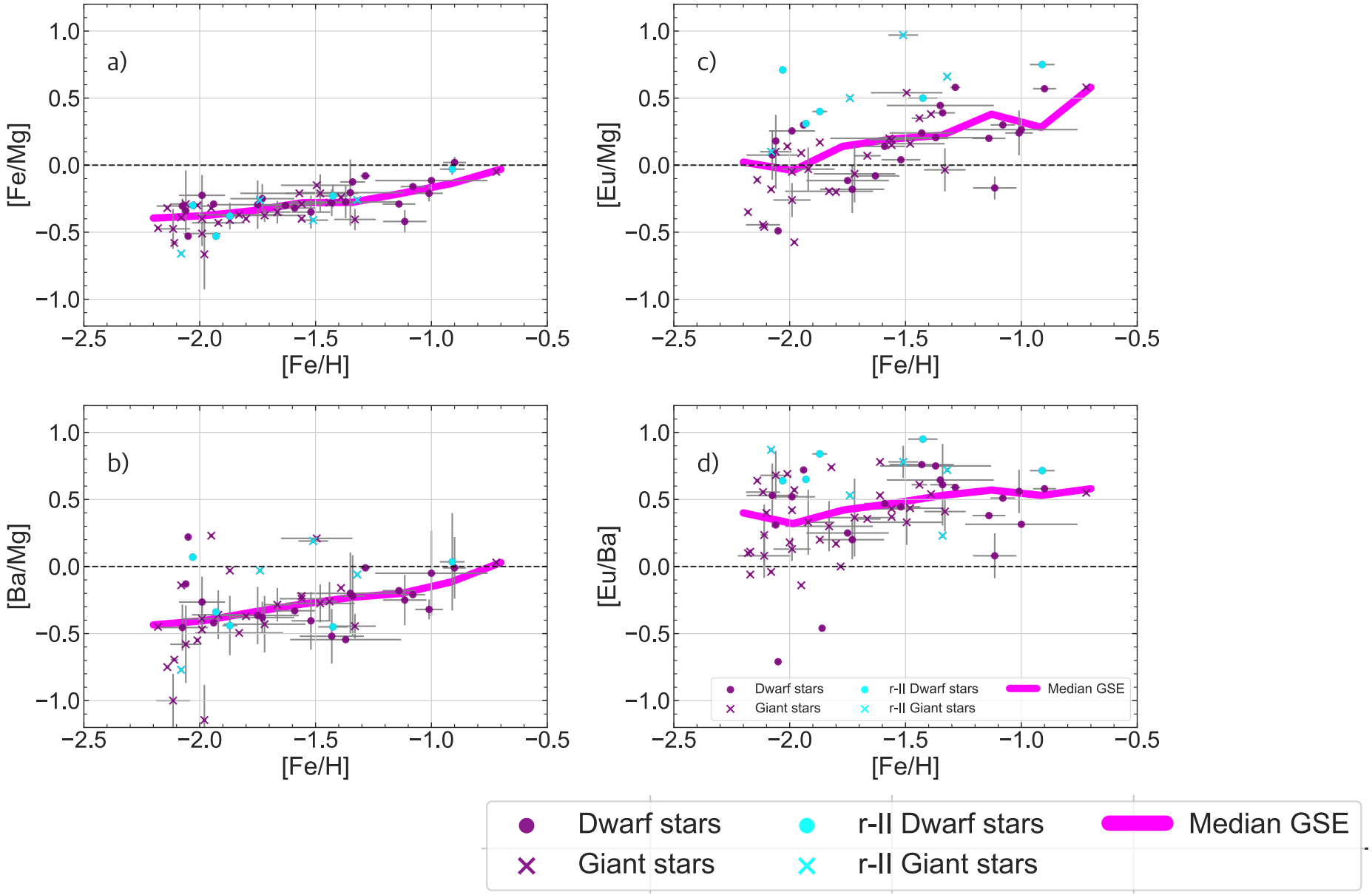
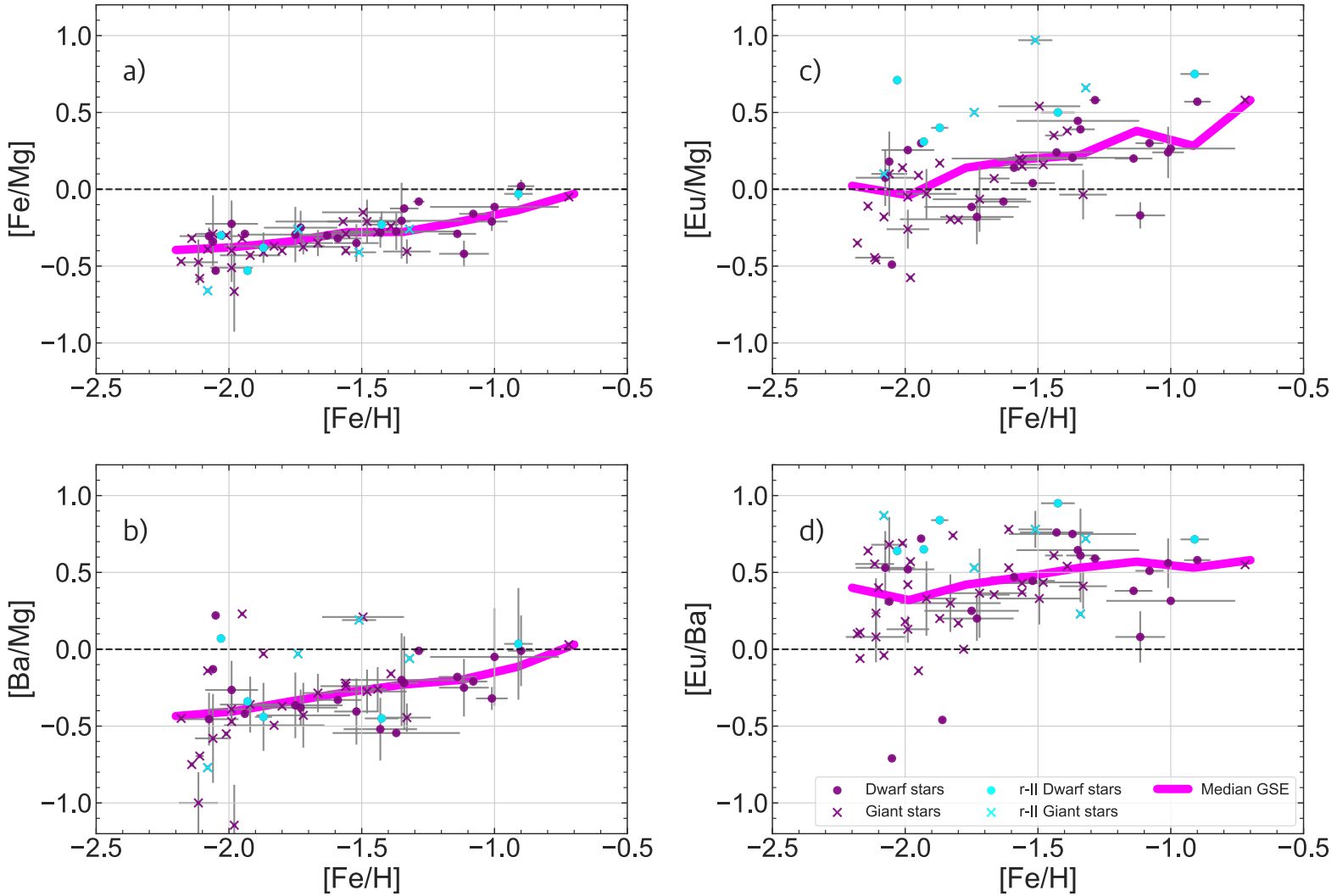


Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)

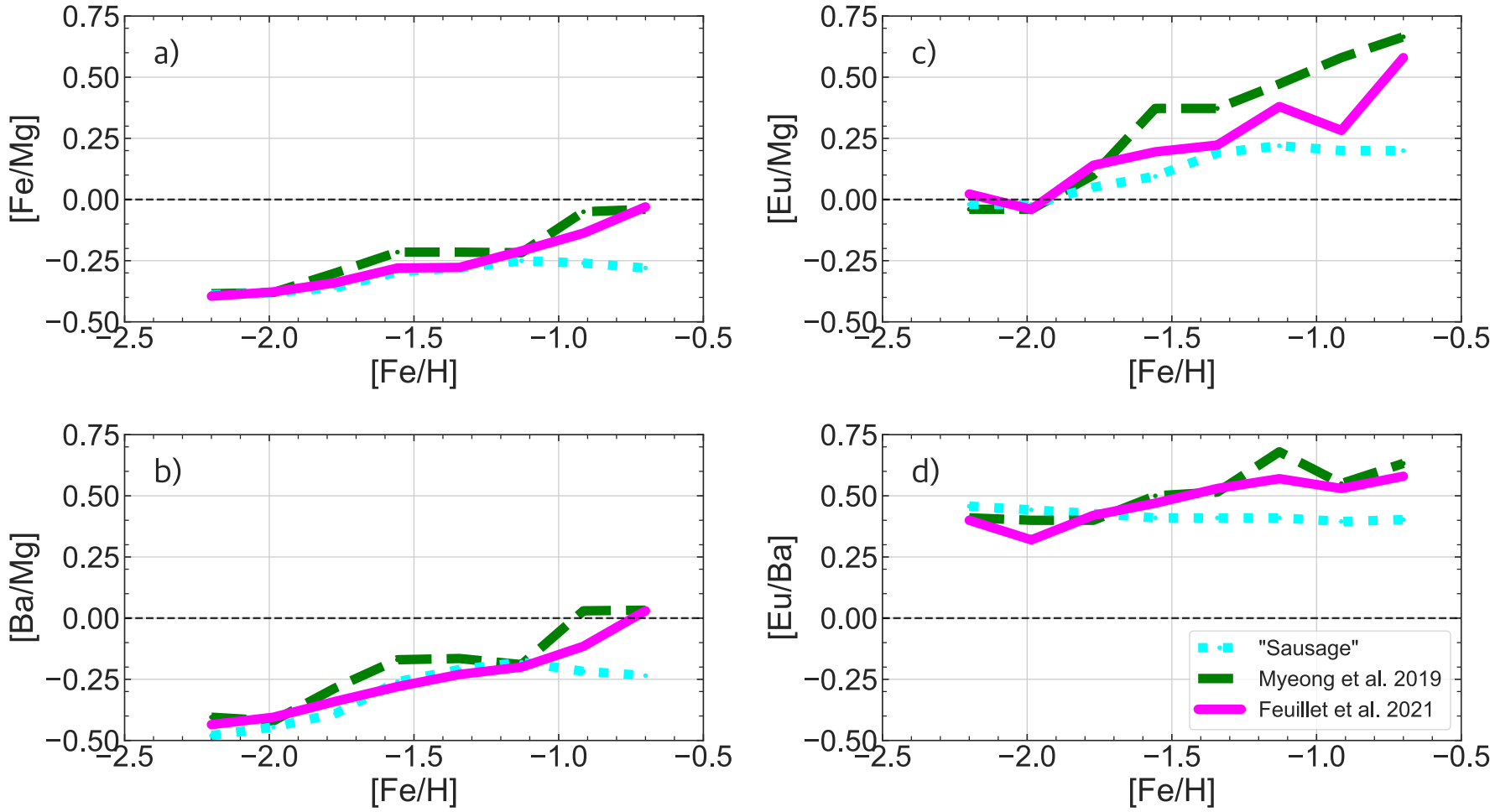
Included datasets:
Nissen & Schuster (2010/2011)
Matsuno+ 2021
Aguado+ 2021



Median trends consistent with results from Naidu+ (2022), others

error bars indicate median deviation in reported literature values

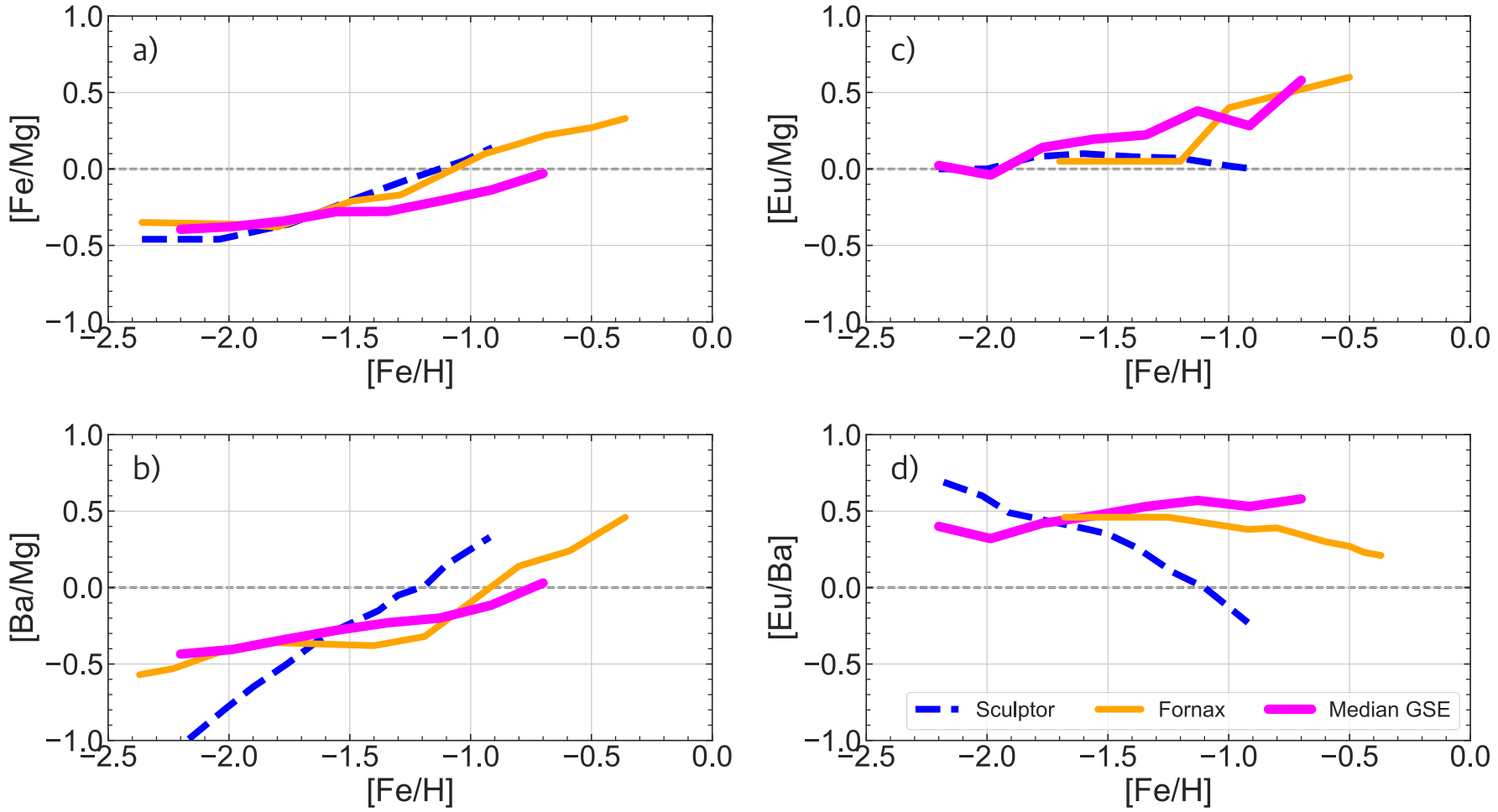
Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)



Different GSE selection schemes produce similar abundance trends

"Sausage"
Myeong et al. 2019
Feuillet et al. 2021

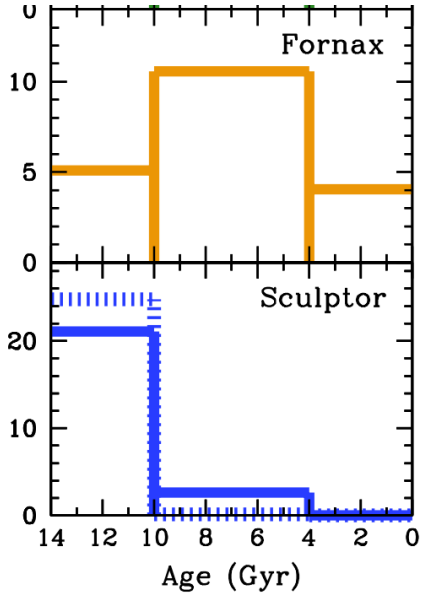
Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)



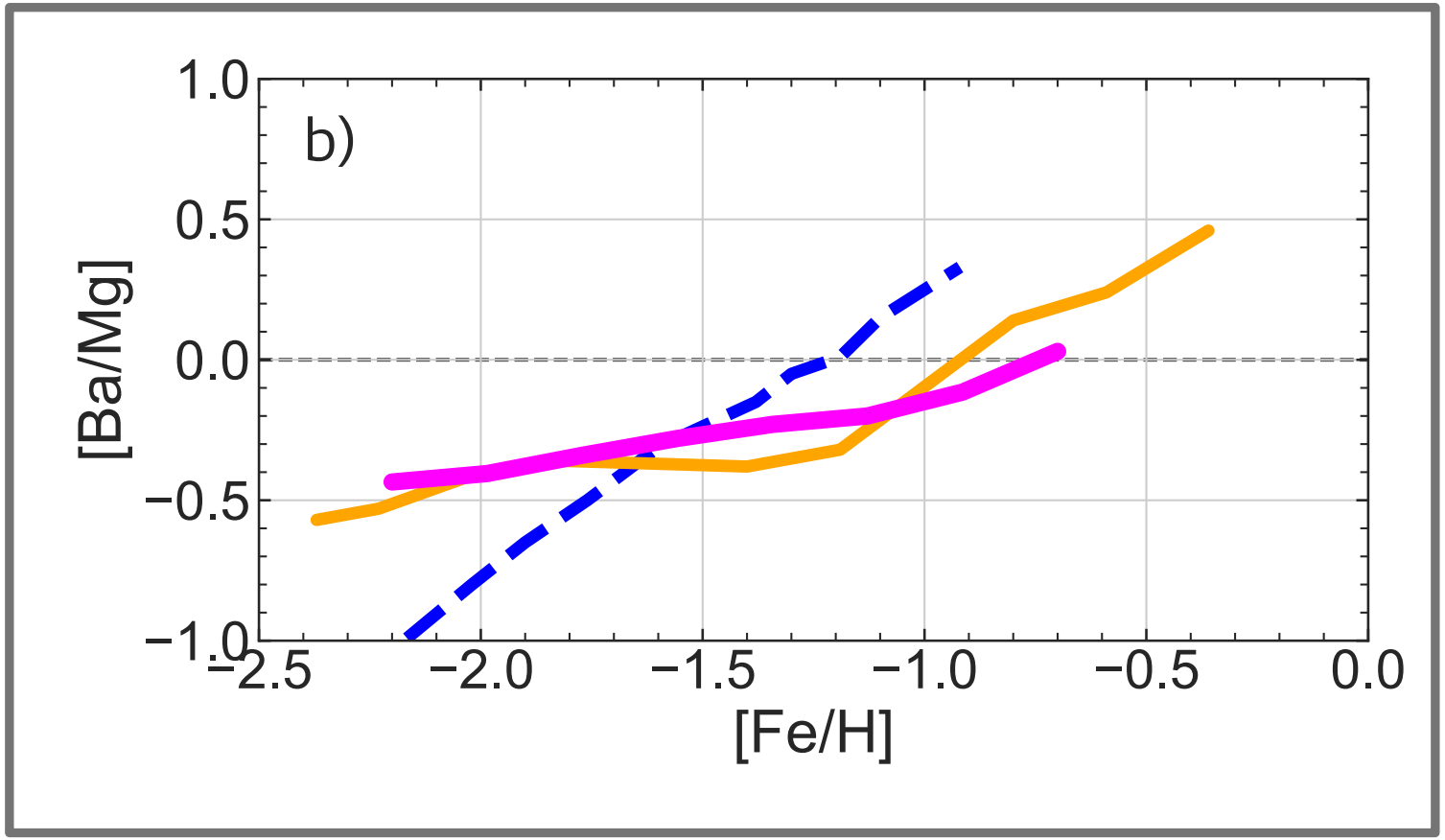
Sculptor Fornax Median GSE

Skúladóttir & Salvadori (2020)

Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)



AGB vs ccSN
delayed & extended
vs
quick



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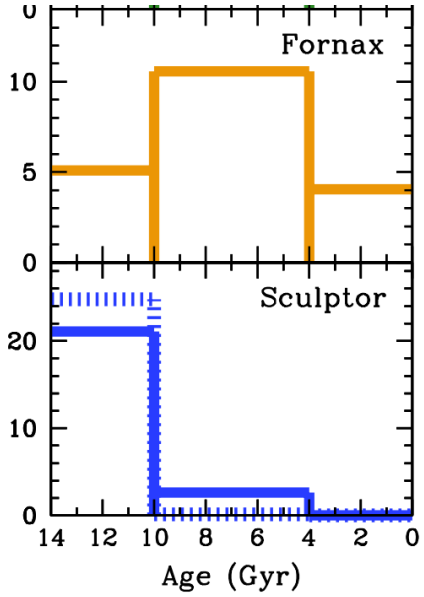

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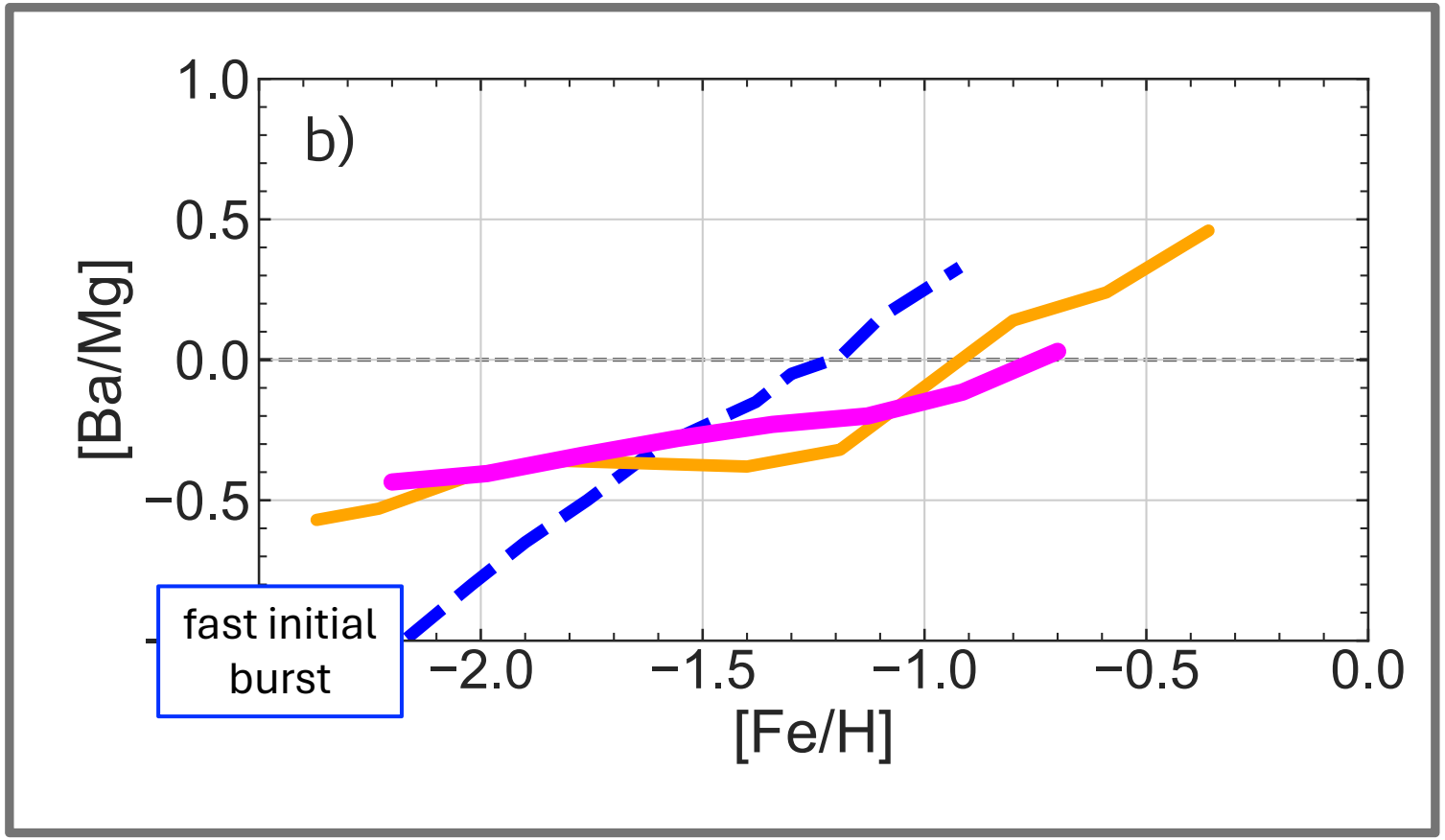

Sculptor Fornax Median GSE

Ernandes, Feuillet, Feltzing & Skúladóttir
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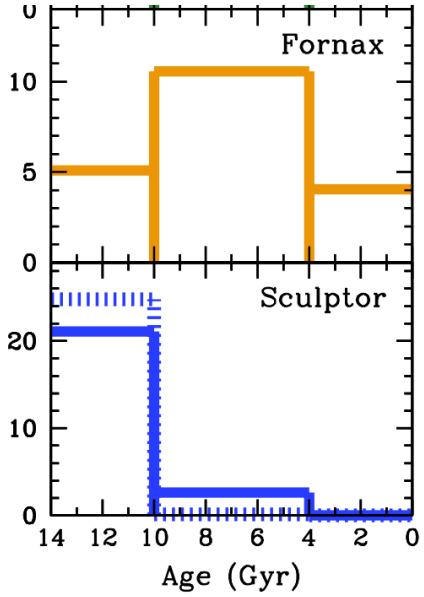

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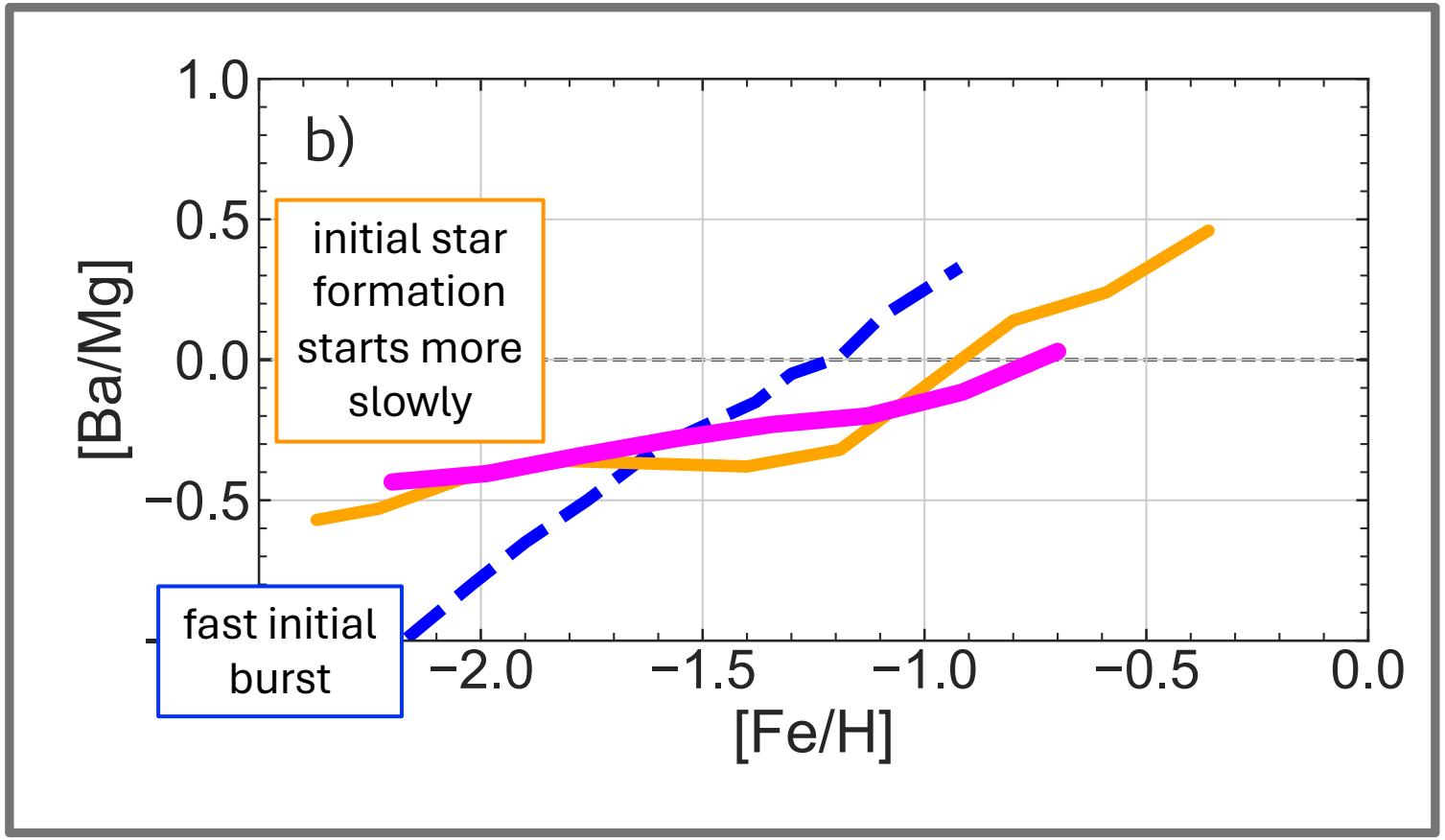

Sculptor Fornax Median GSE

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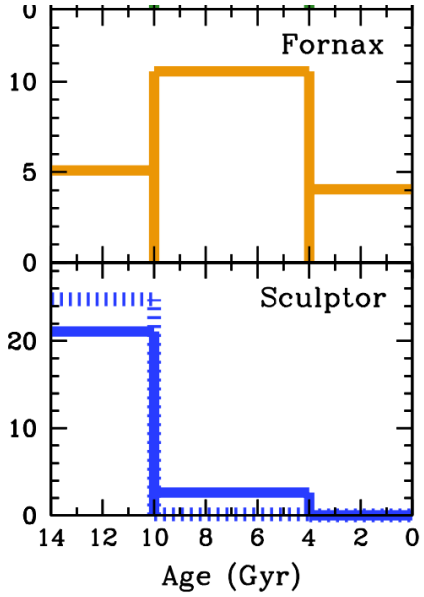

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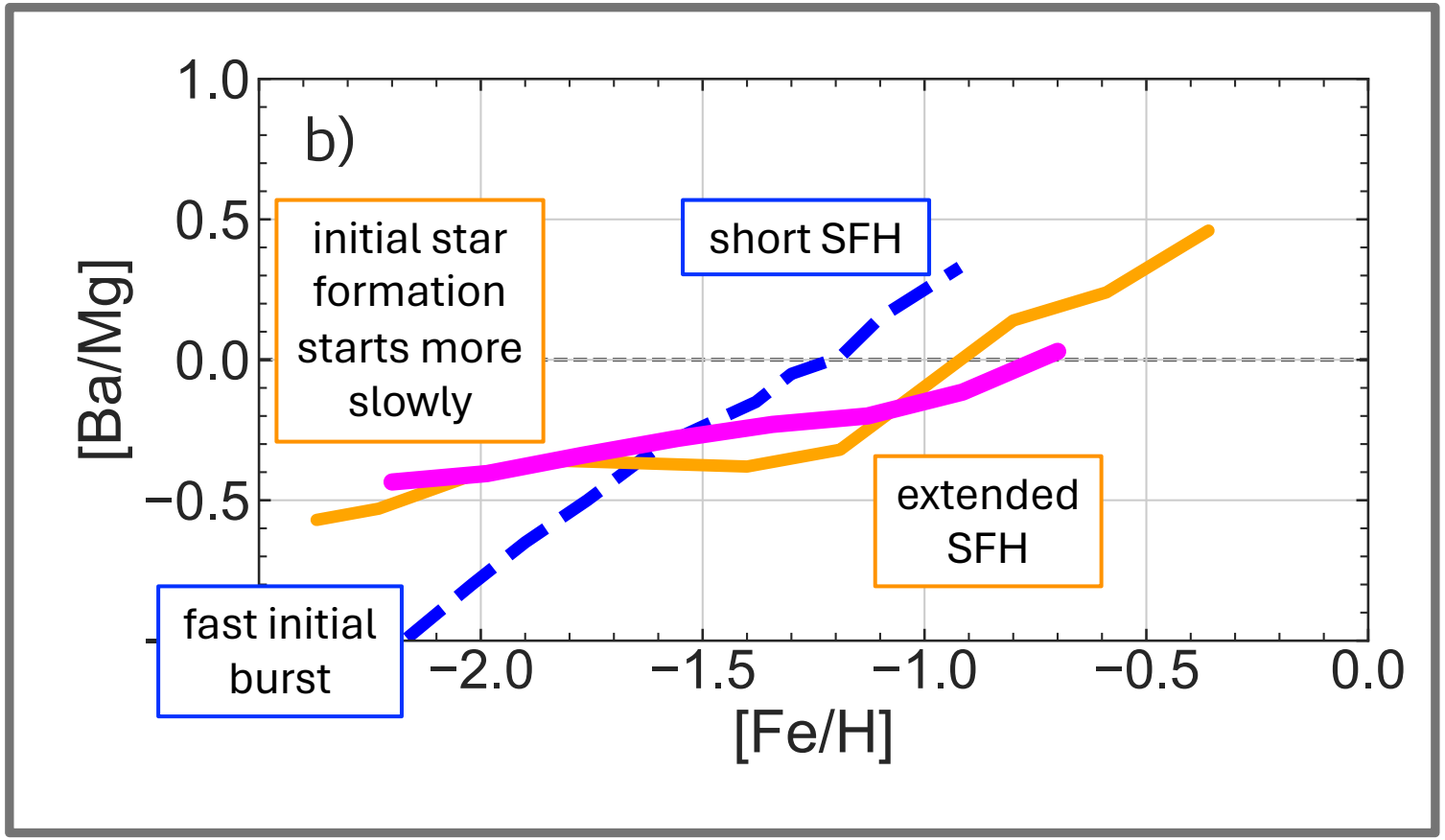
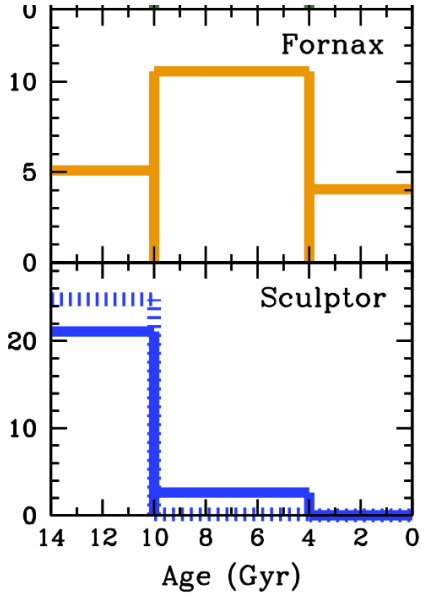
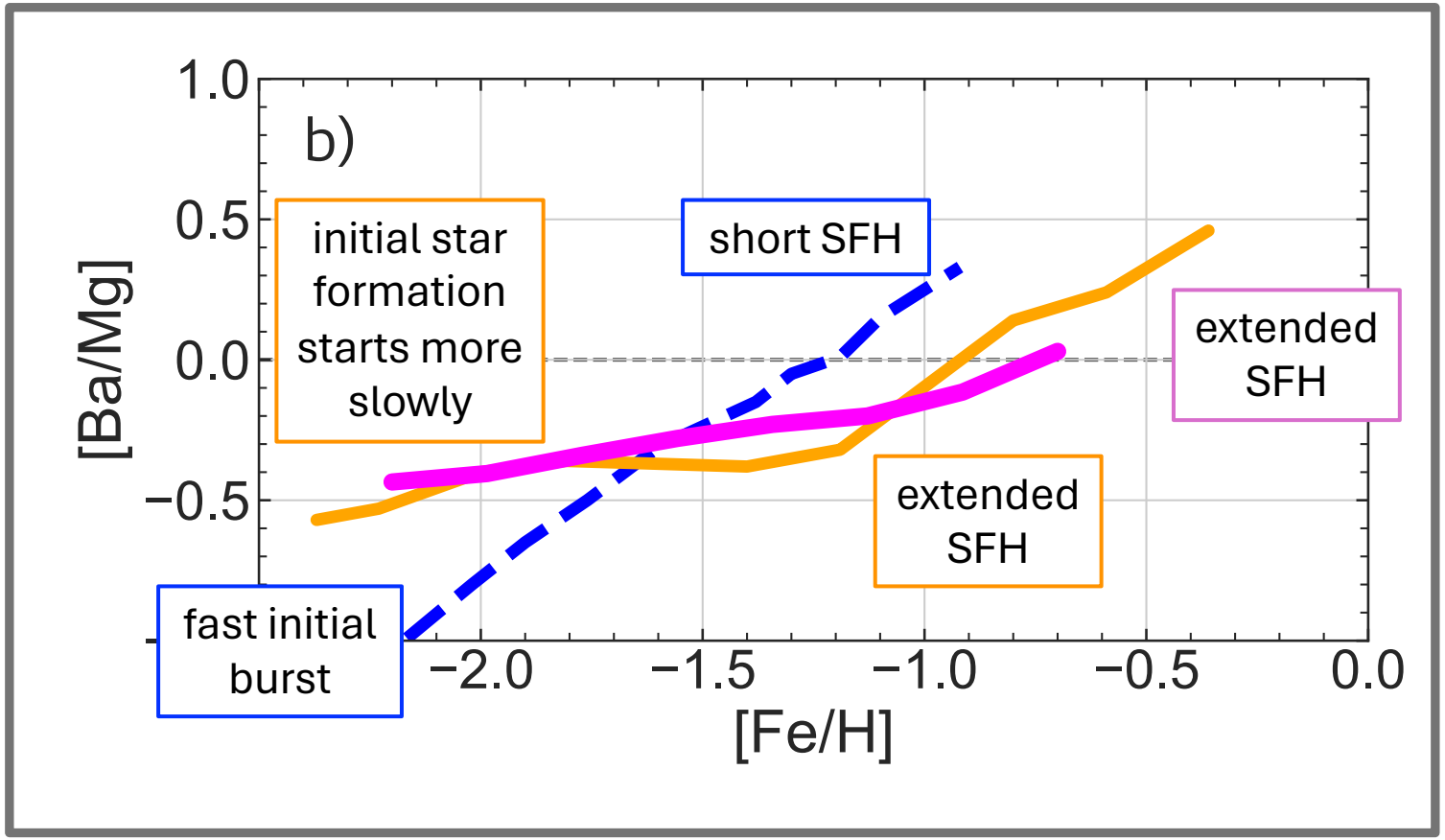


Sculptor Fornax Median GSE

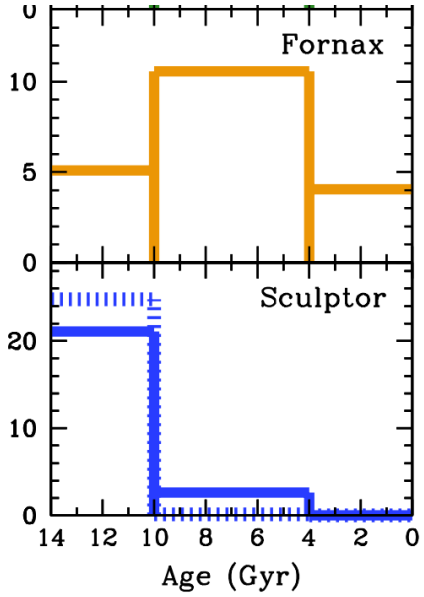
Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)



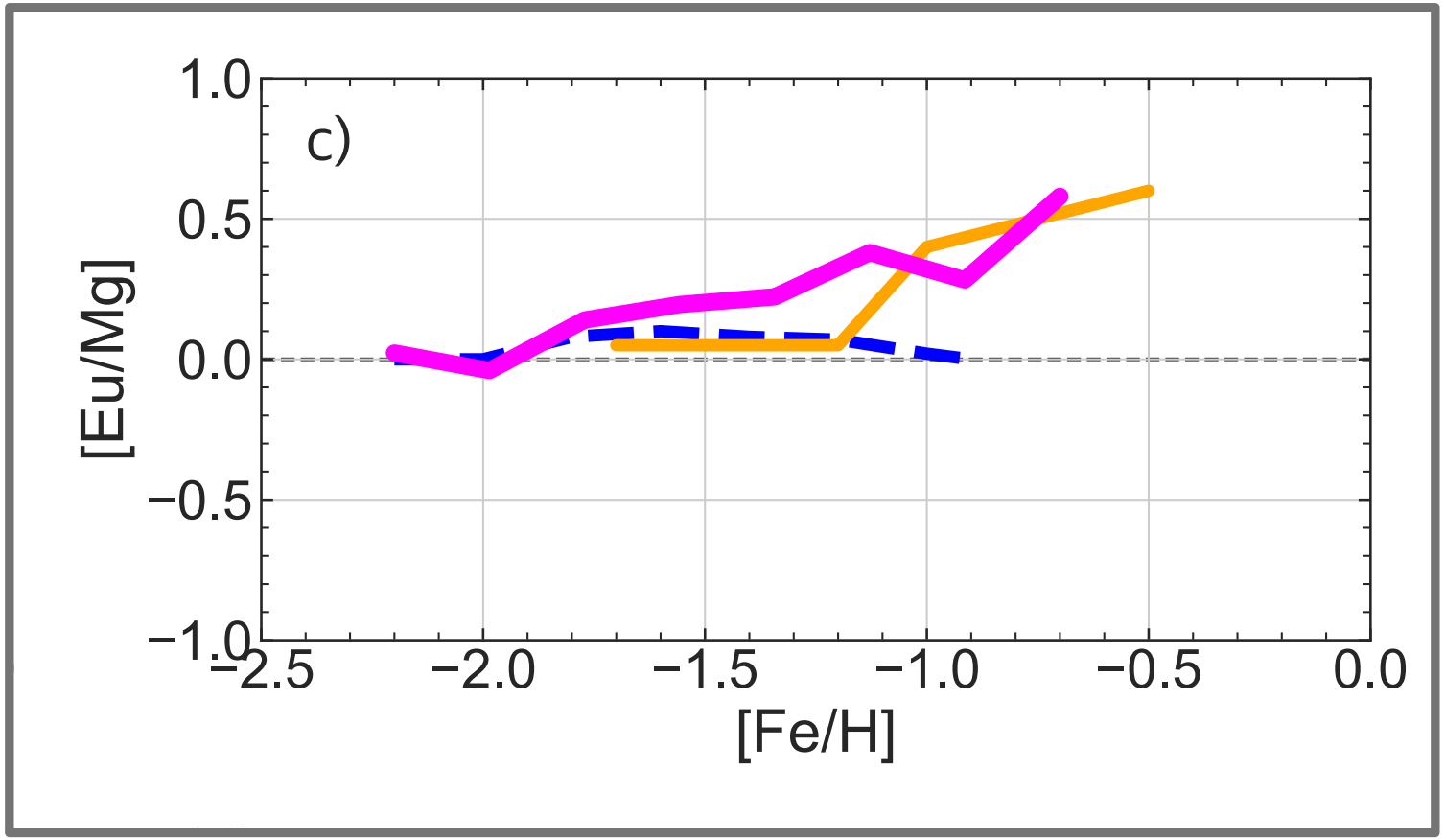
AGB vs ccSN
delayed & extended
vs
quick



Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)

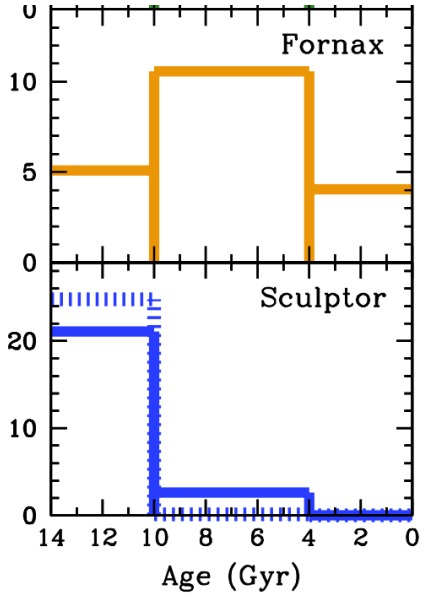


r-process vs ccSN
quick + delayed
vs
quick

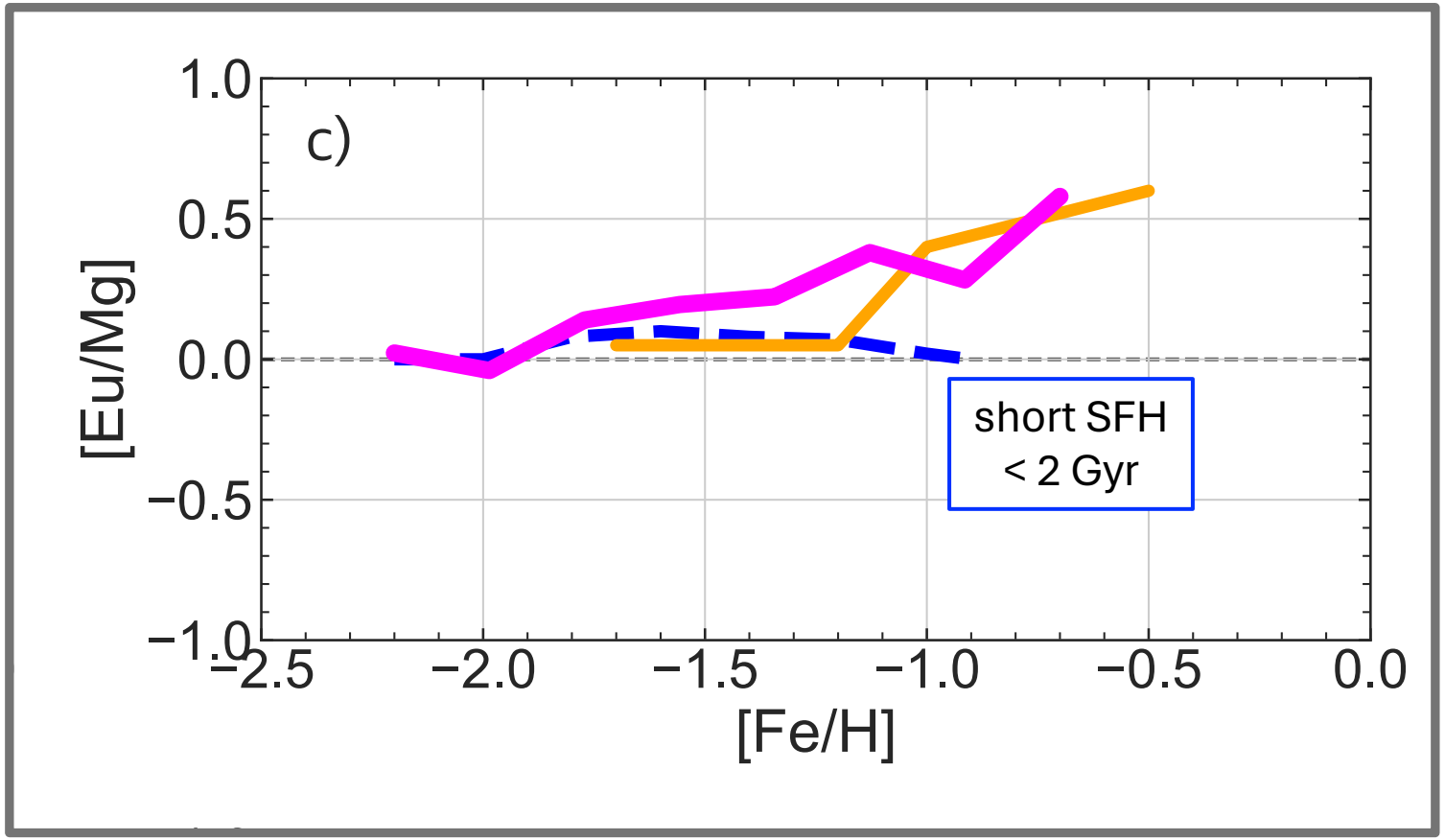


Sculptor Fornax Median GSE

Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)

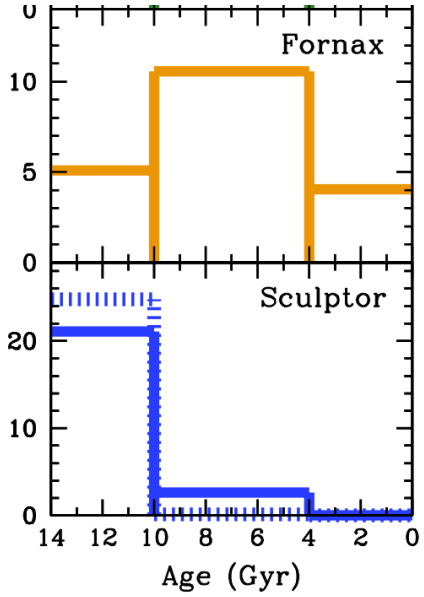


r-process vs ccSN
quick + delayed
vs
quick

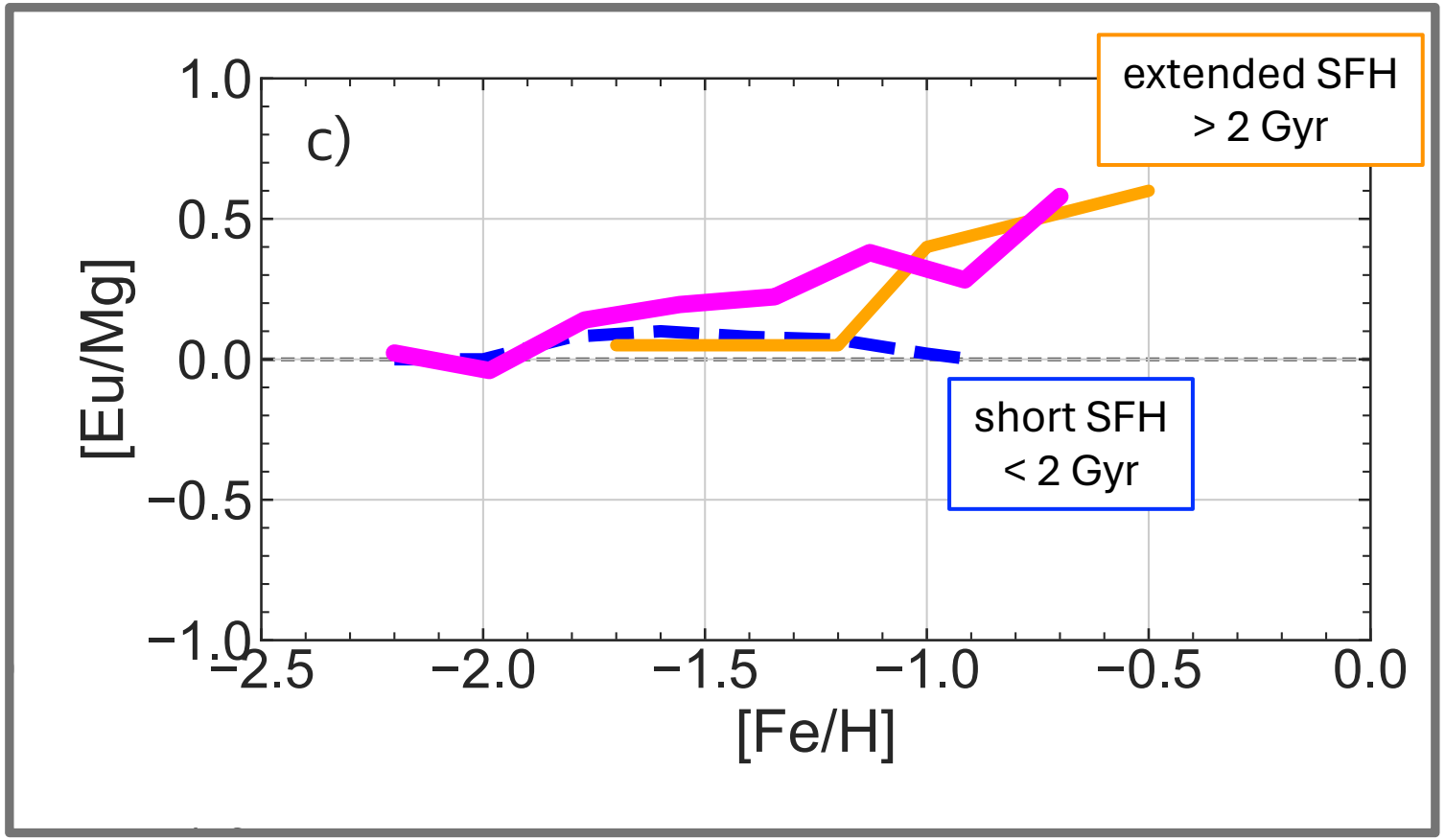


Sculptor Fornax Median GSE

Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)

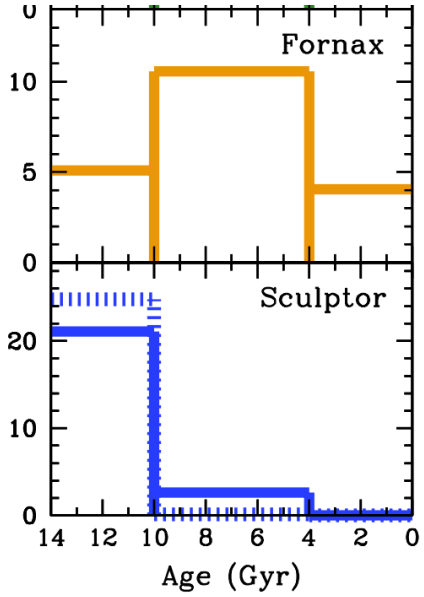


r-process vs ccSN
quick + delayed
vs
quick

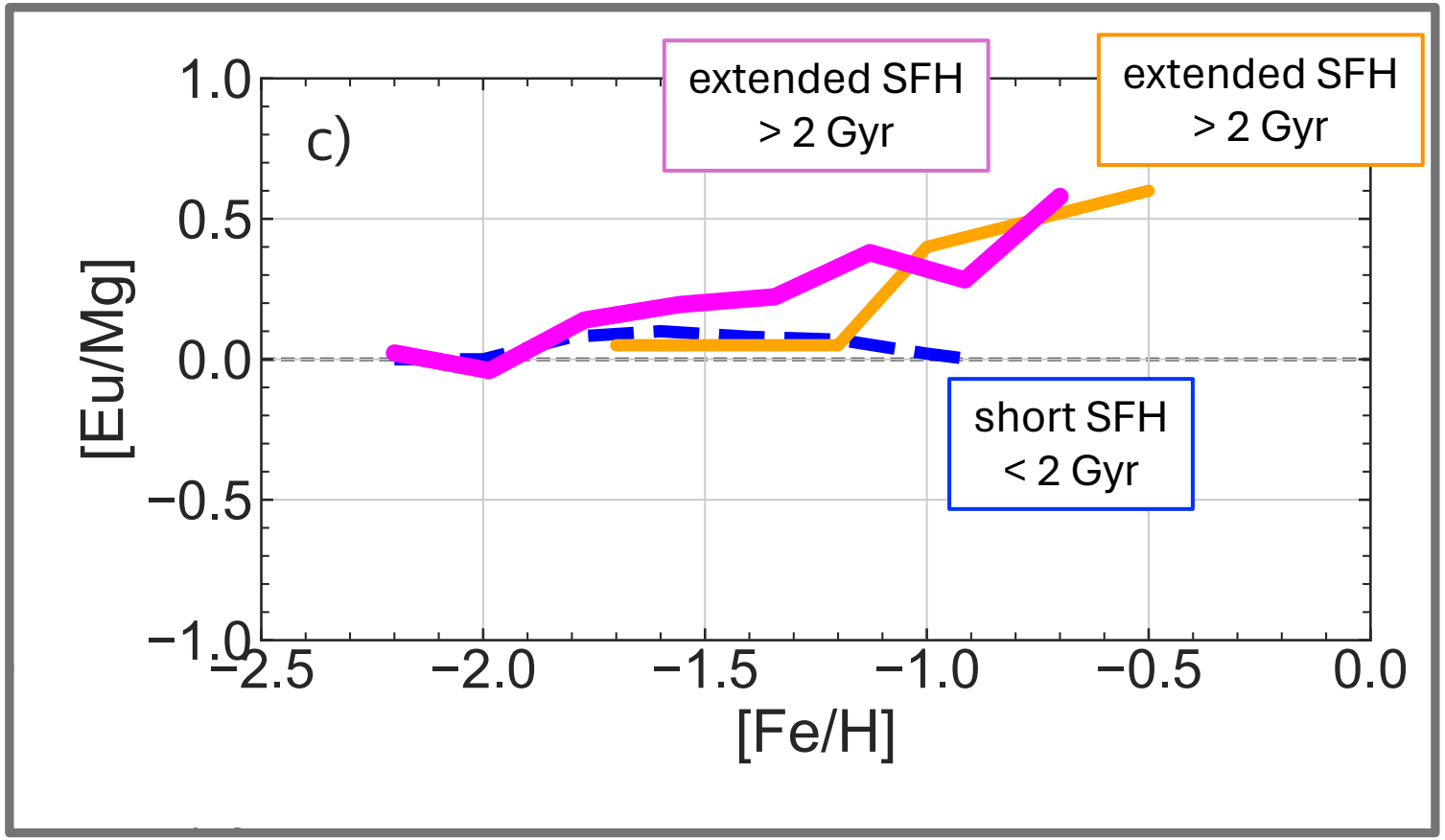


Sculptor Fornax Median GSE

Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)



r-process vs ccSN
quick + delayed
vs
quick



Ernandes, Feuillet, Feltzing & Skúladóttir
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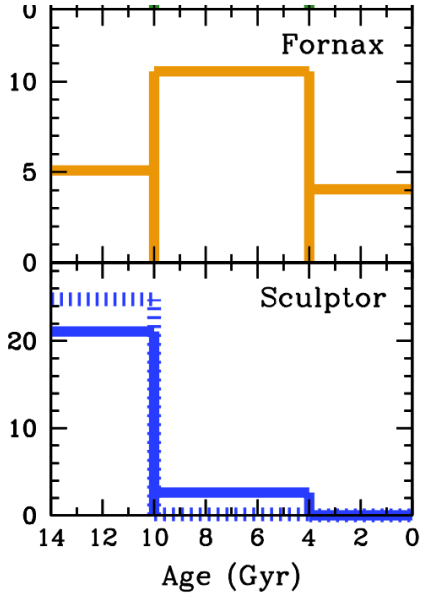
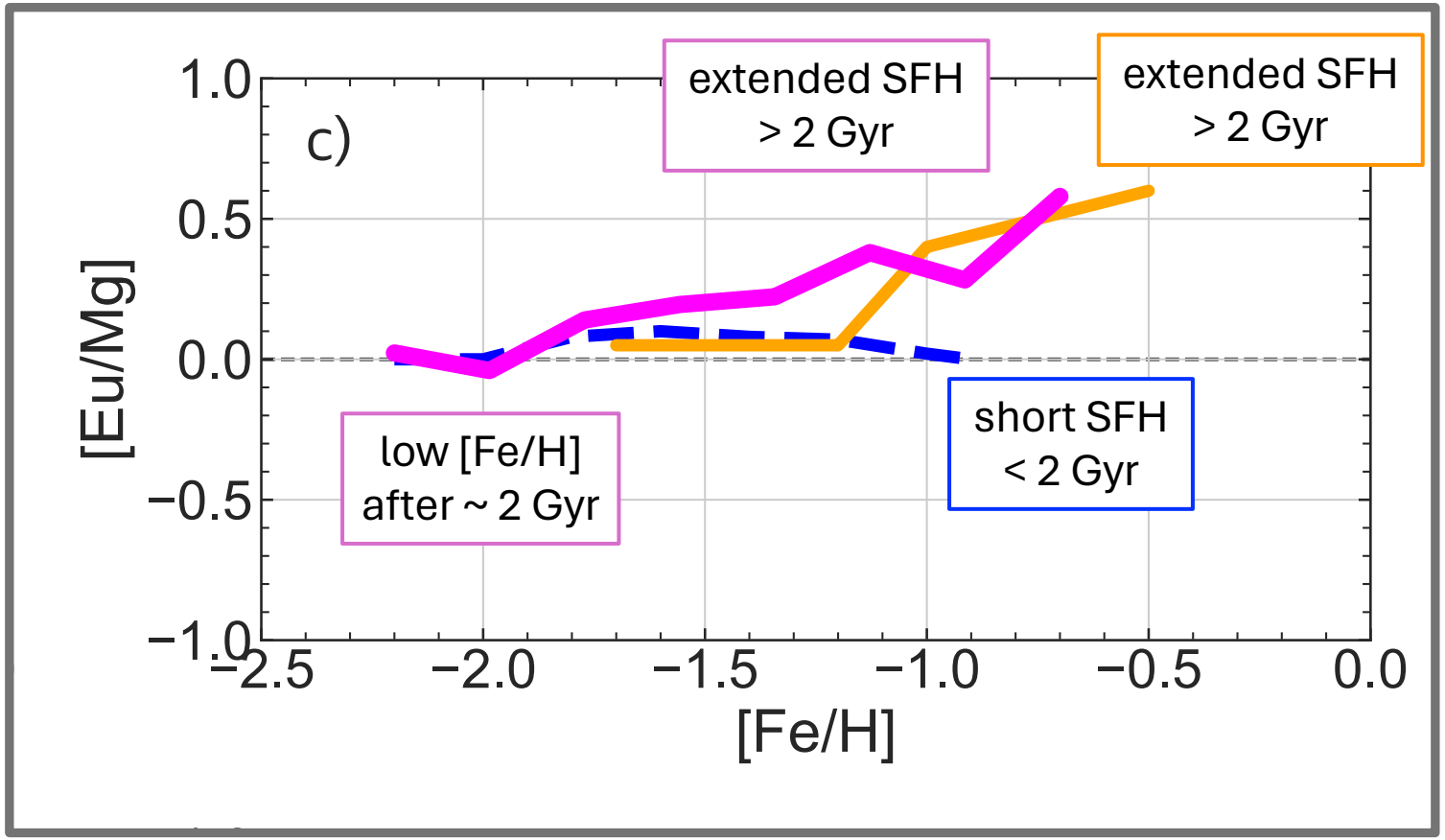
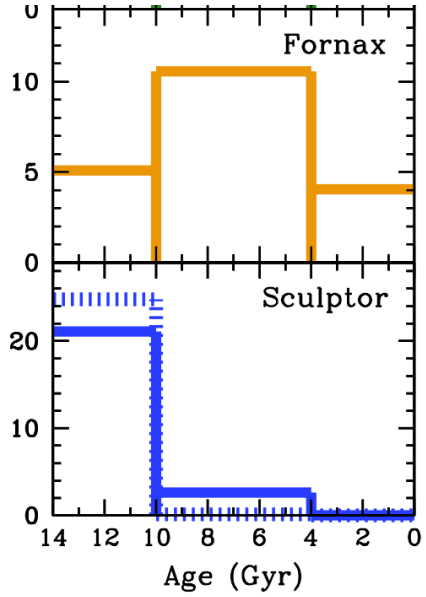


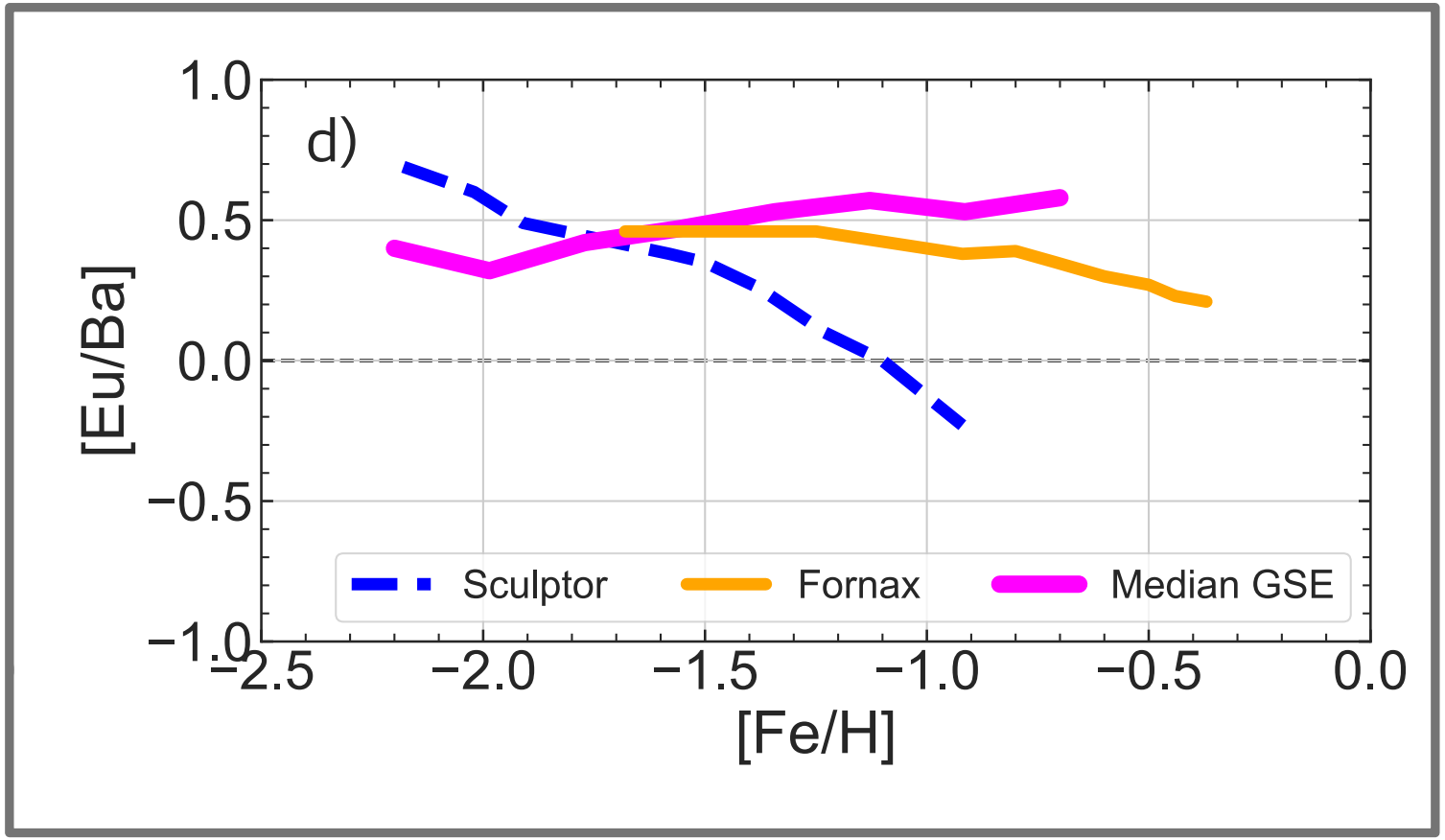
r-process vs ccSN
quick + delayed
vs
quick



Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)



r-process vs AGB
quick + delayed
vs
delayed & extended



Ernandes, Feuillet, Feltzing & Skúladóttir
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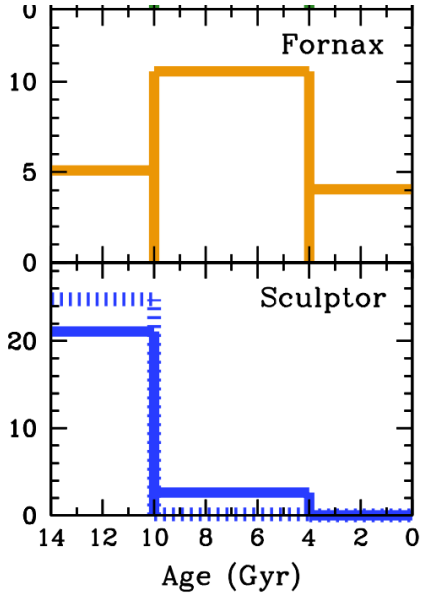
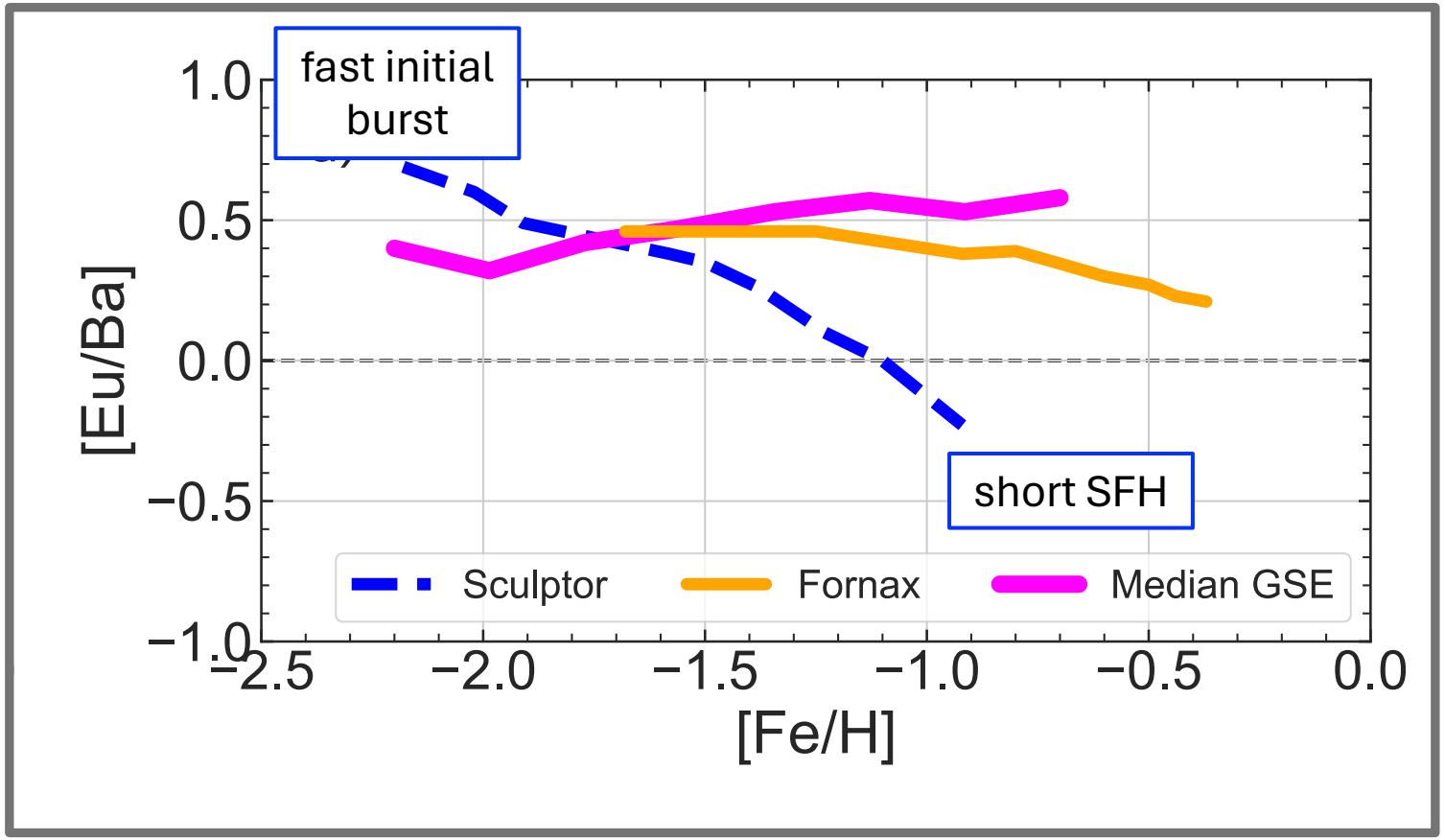
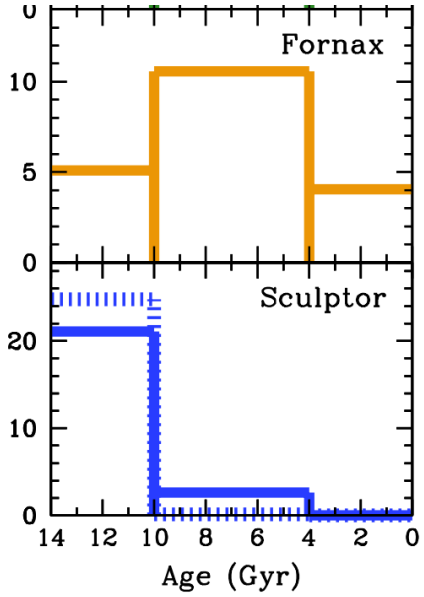


r-process vs AGB
quick + delayed
vs
delayed & extended

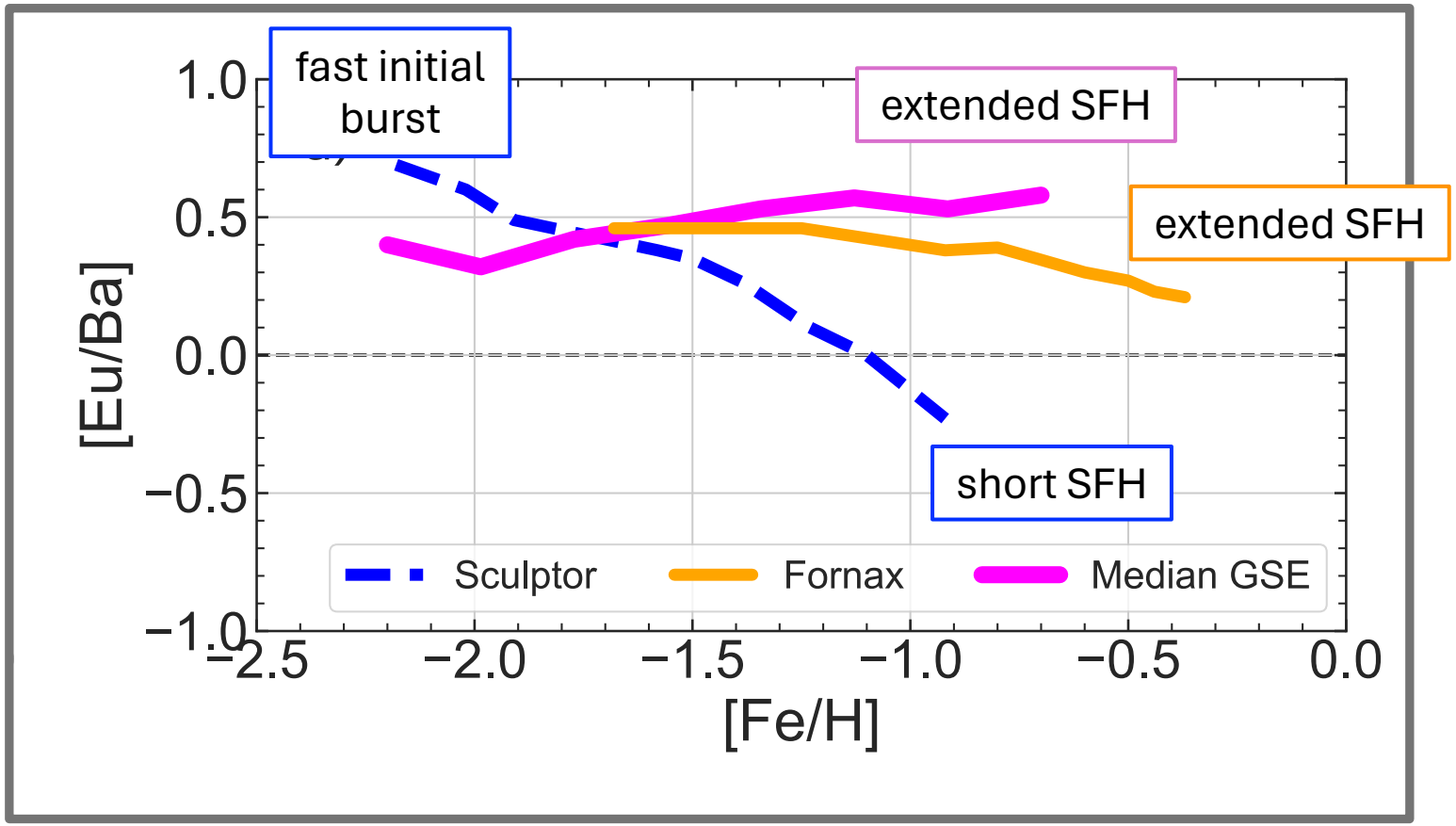


Sculptor
Fornax
Median GSE

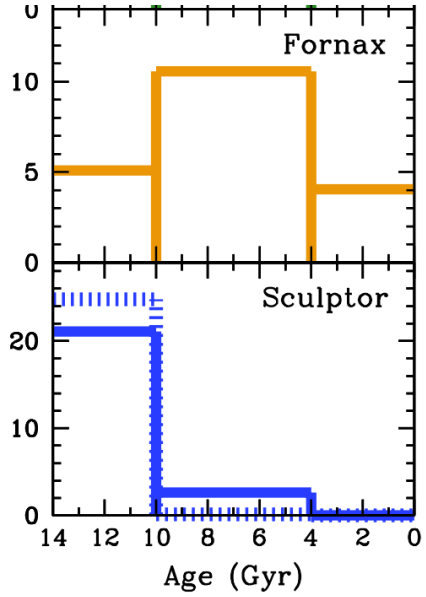
Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)



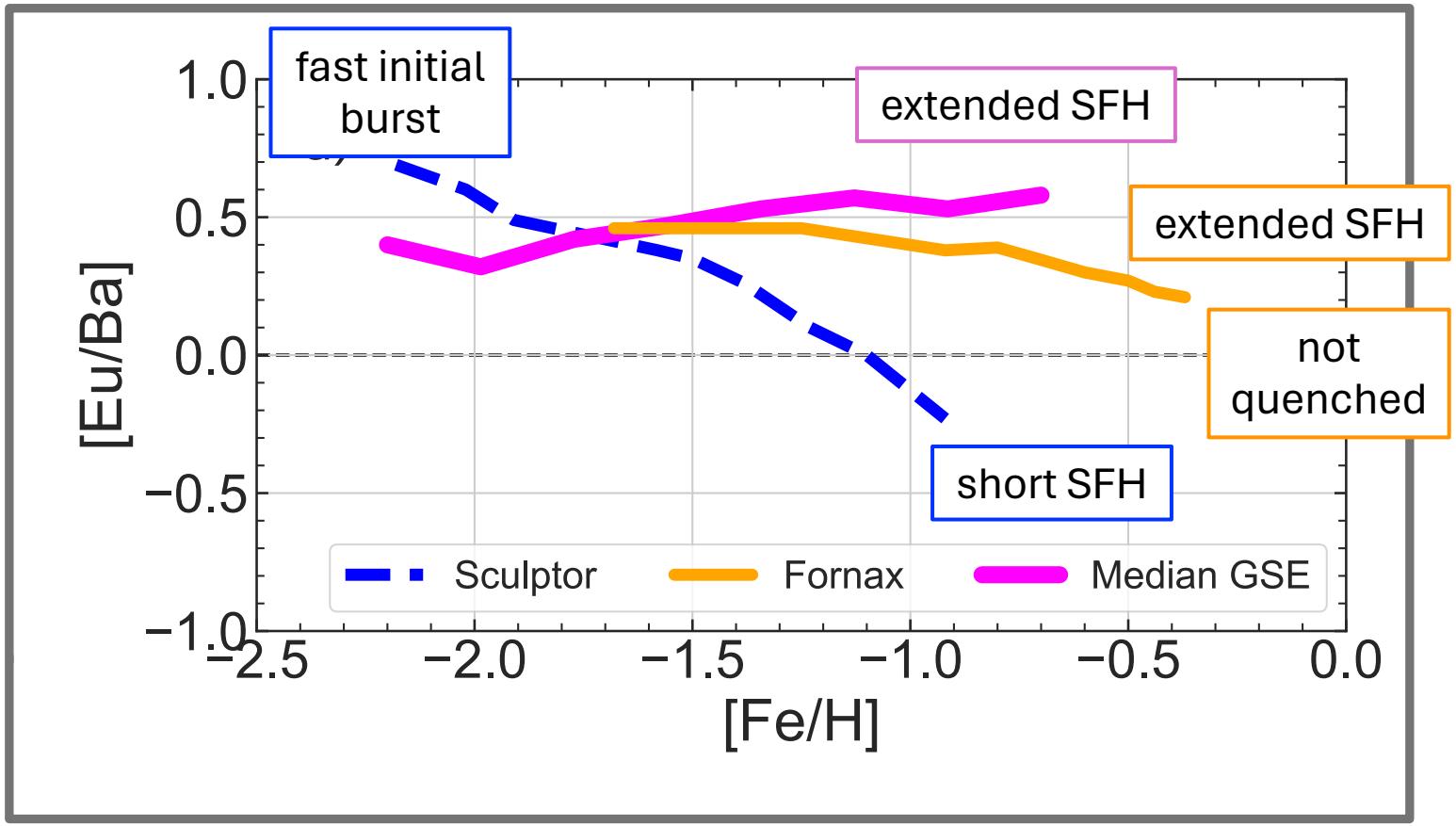
r-process vs AGB
quick + delayed
vs
delayed & extended



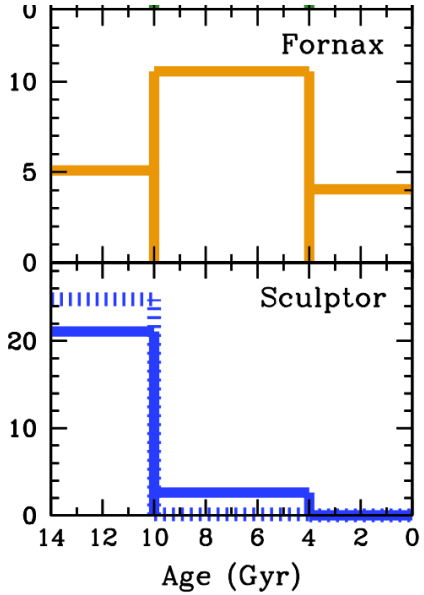
Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)



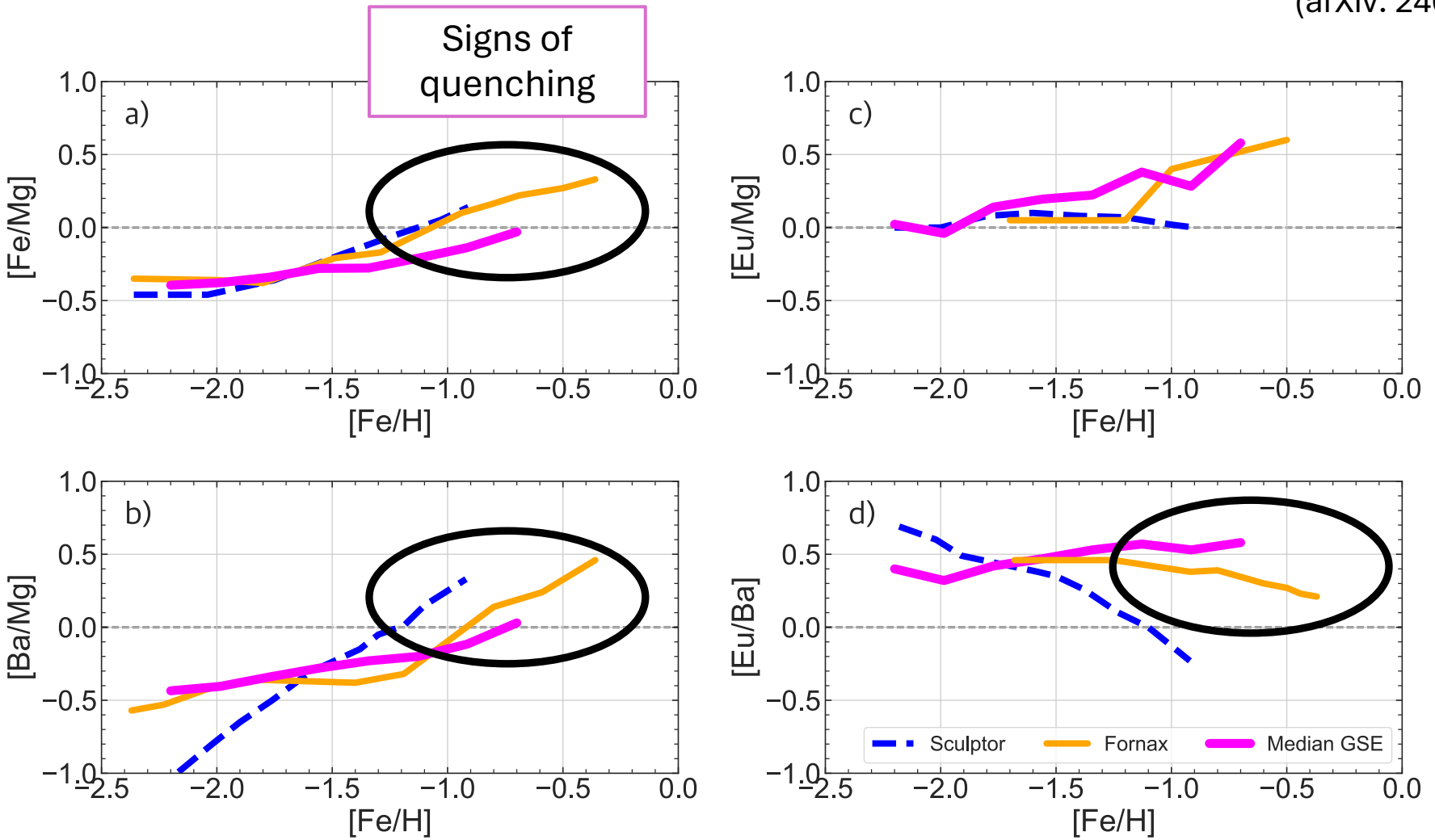
r-process vs AGB
quick + delayed
vs
delayed & extended



Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)



late SF tail
vs
quenched SF



Sculptor Fornax Median GSE

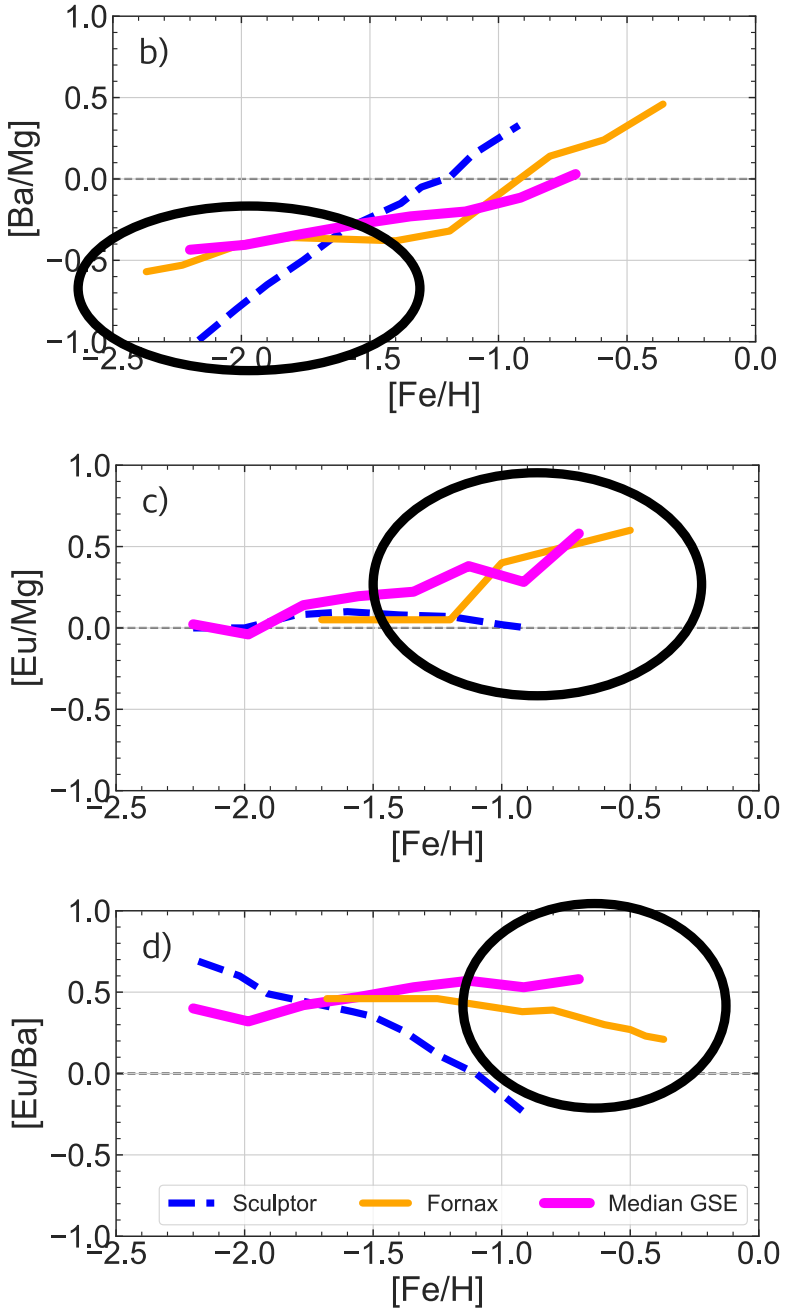
GSE star formation history

GSE more similar to Fornax than to Sculptor

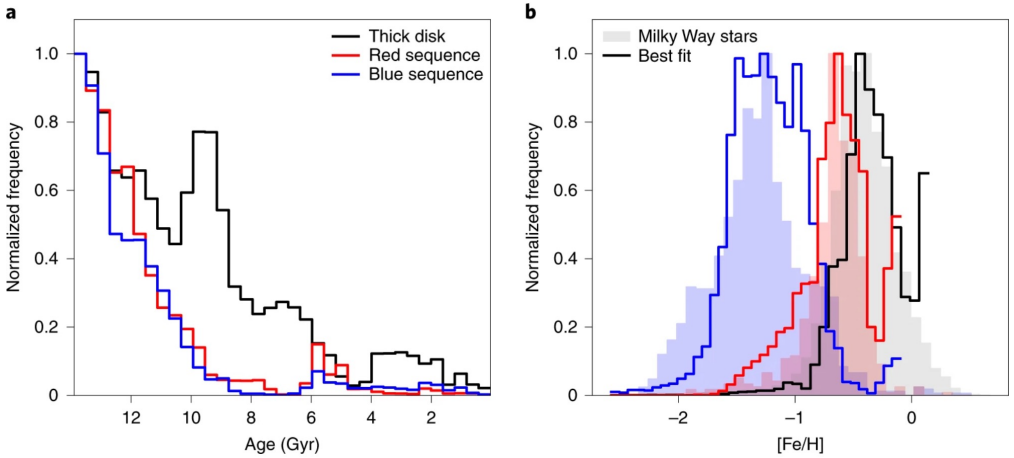
1. Initially slow star formation
2. Extended, lasting longer than 2 Gyr
3. Quenched around [Fe/H] = -0.5

13 dwarf stars with age > 10 Gyr

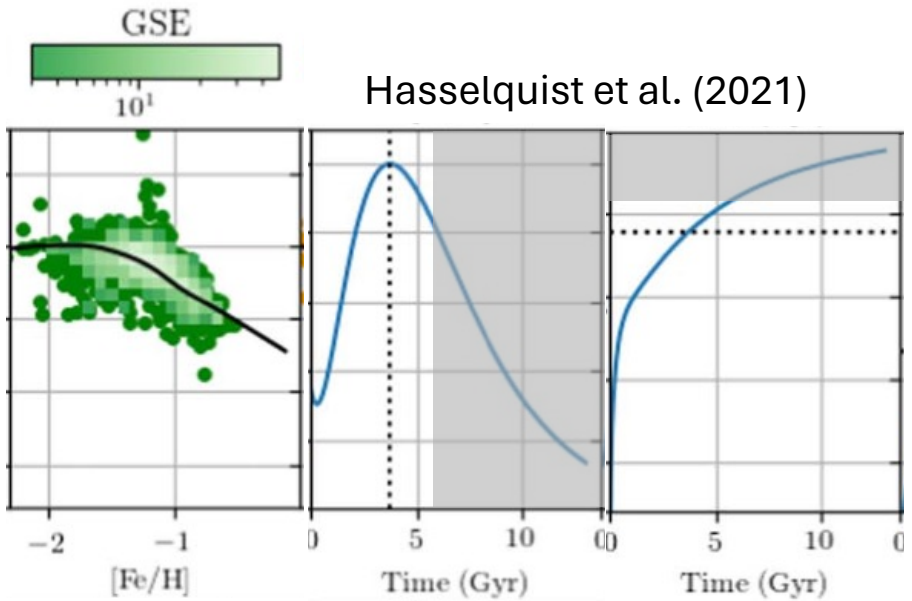
Ernandes, Feuillet, Feltzing & Skúladóttir
(A&A submitted)
arXiv: 2405.13641



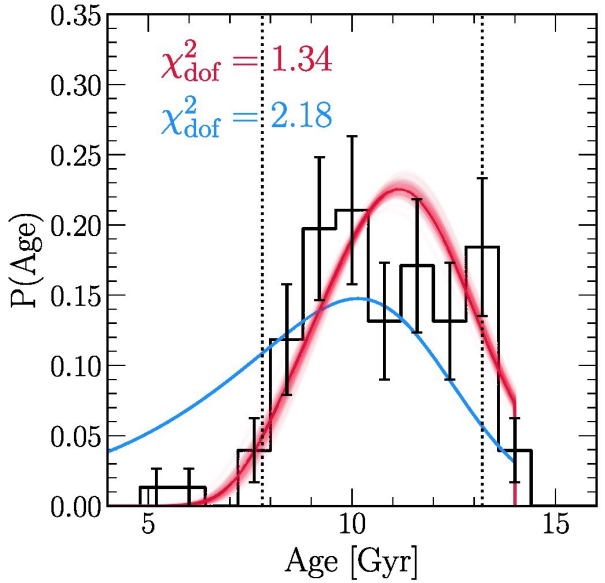
GSE star formation history



Gallart et al. (2019)



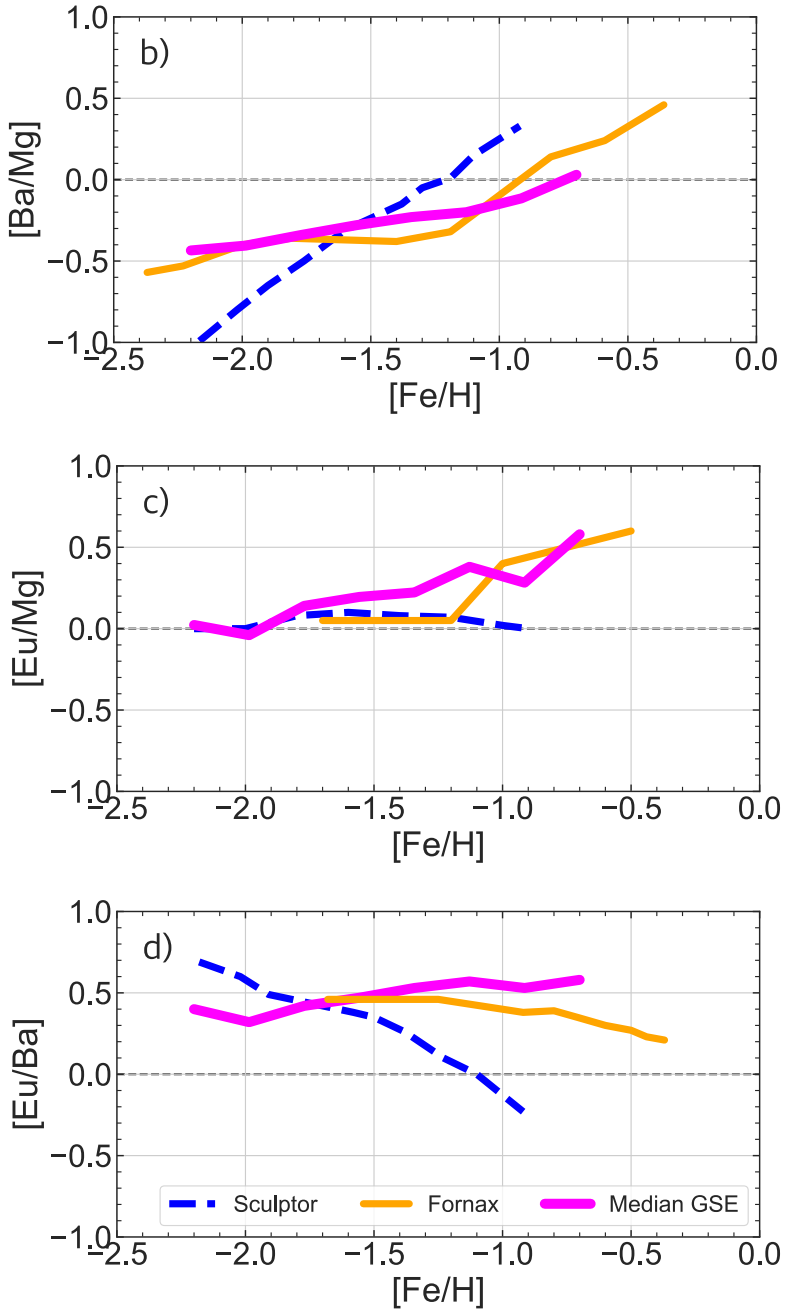
Hasselquist et al. (2021)



Johnson et al. (2023)

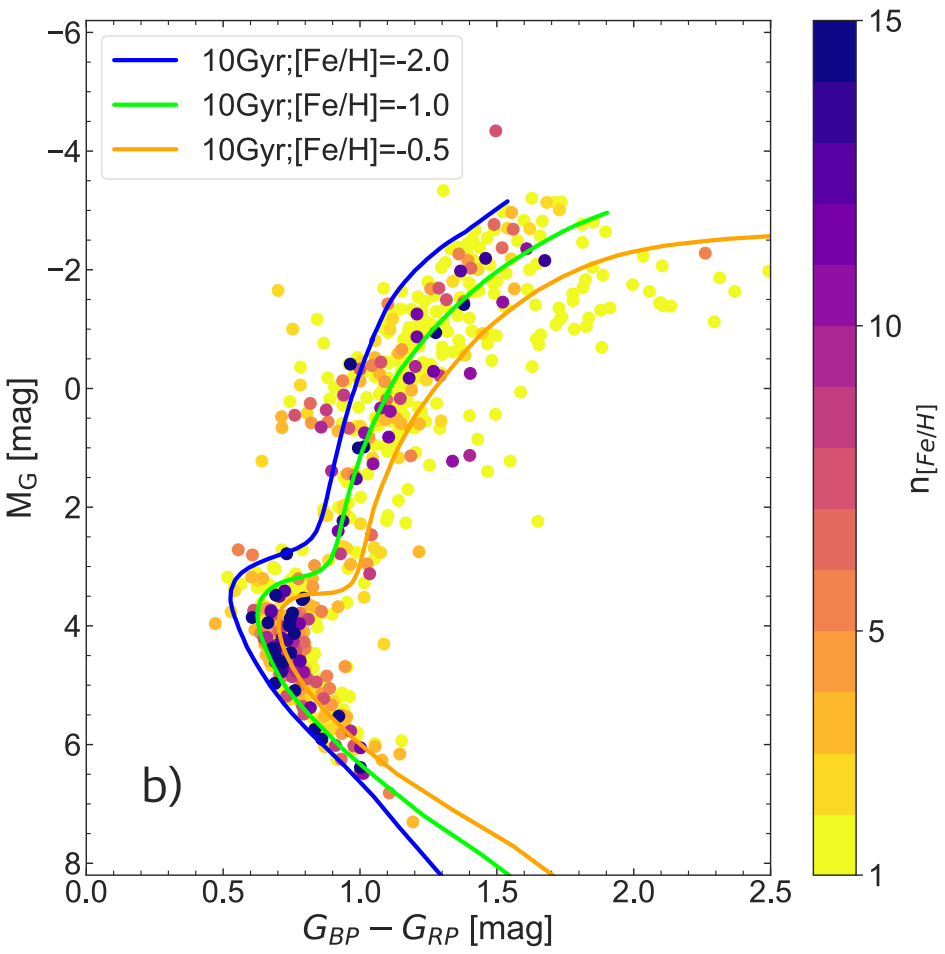
Conclusions

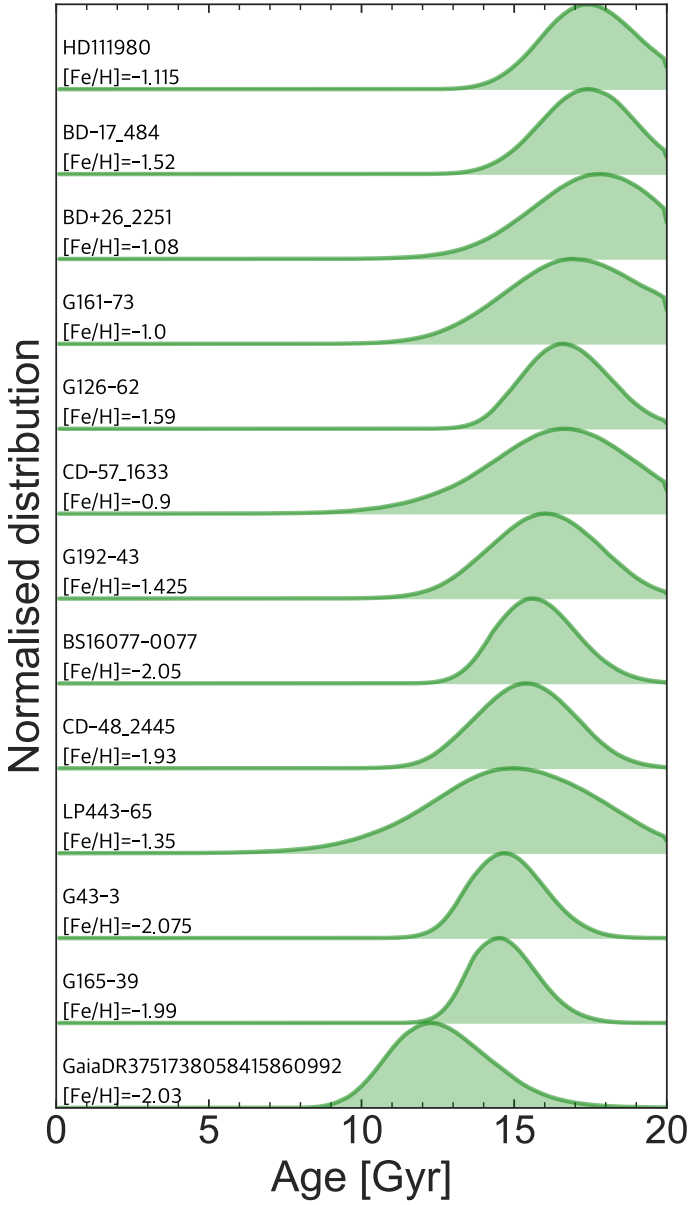
- Chemistry + kinematics is key
- GSE star formation history
  1. Initially slow star formation
  2. Extended, lasting longer than 2 Gyr
  3. Quenched around [Fe/H] = -0.5
- s- & r-process abundances measured across the full range of [Fe/H] can be used to constrain star formation history.

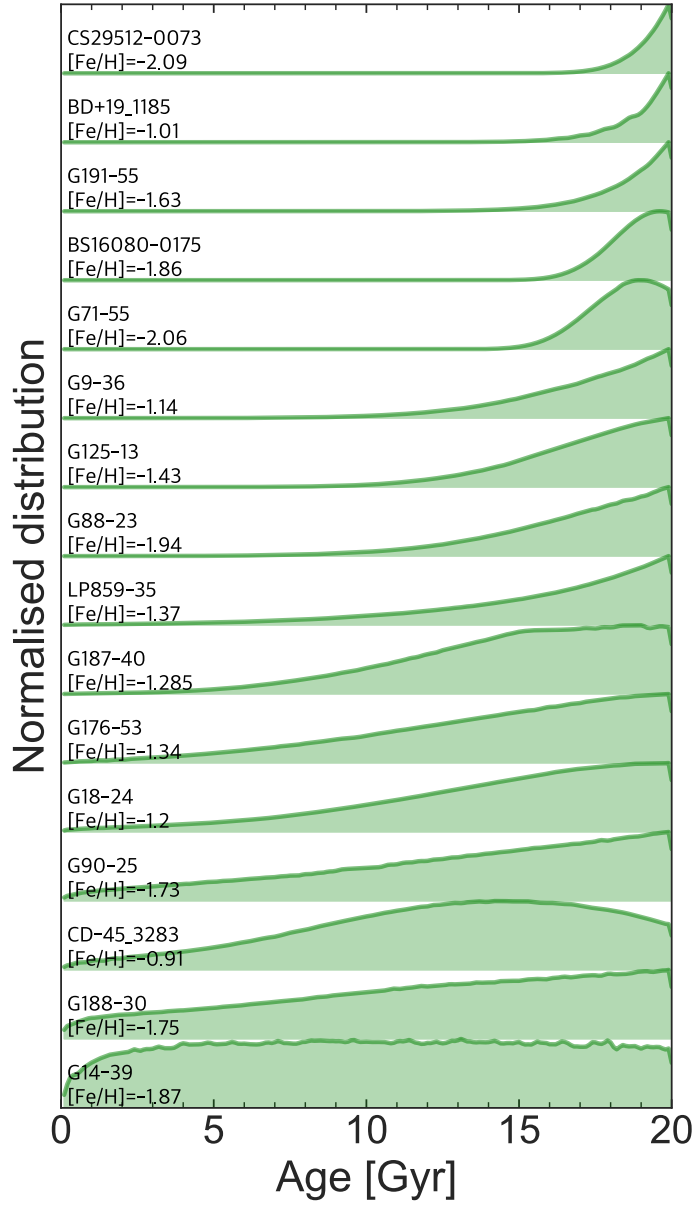


Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)


Questions?







Ernandes, Feuillet, Feltzing & Skúladóttir
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Ernandes, Feuillet, Feltzing & Skúladóttir
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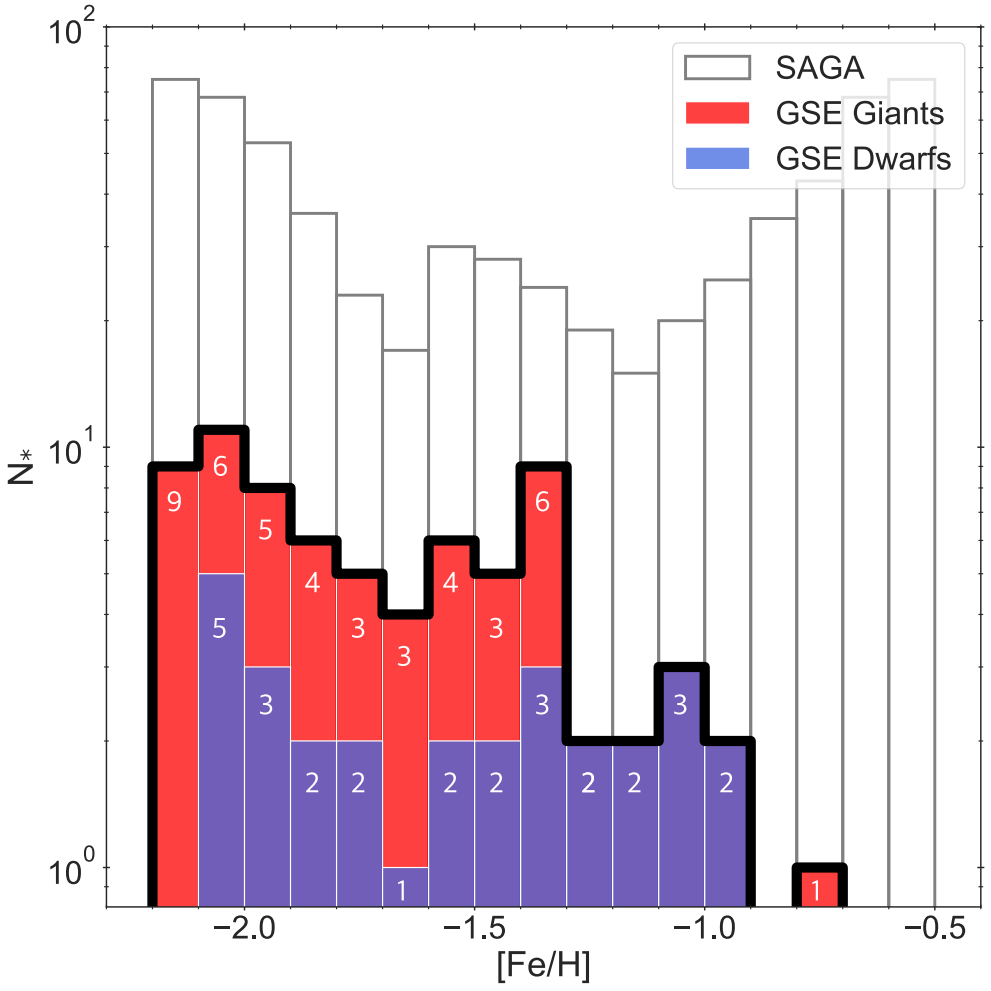
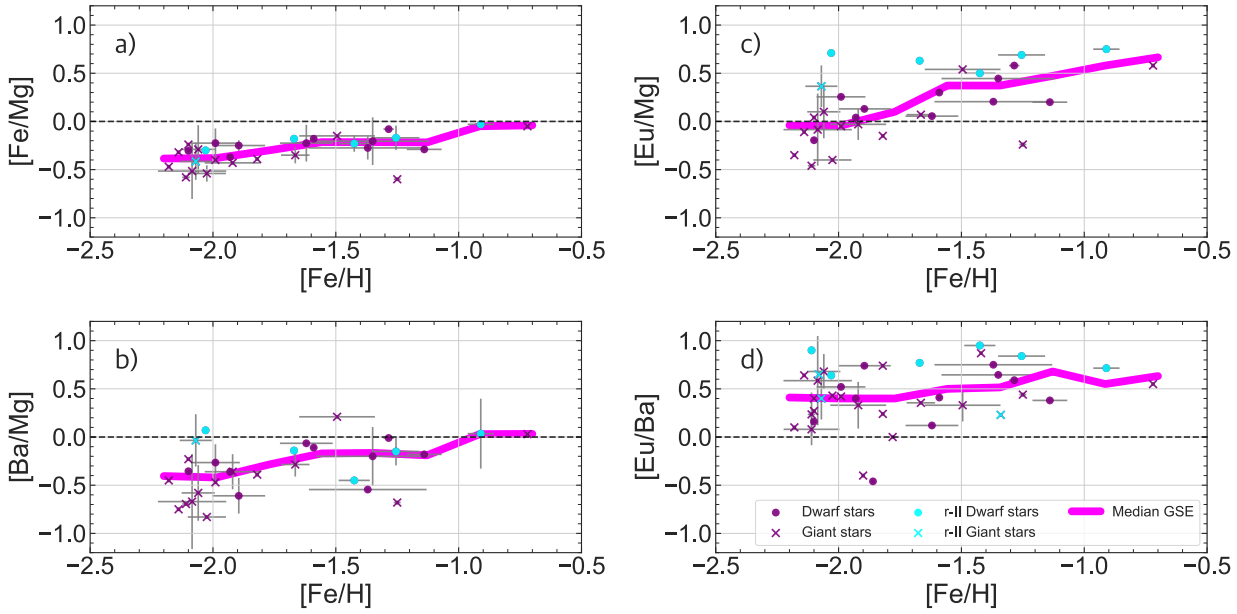
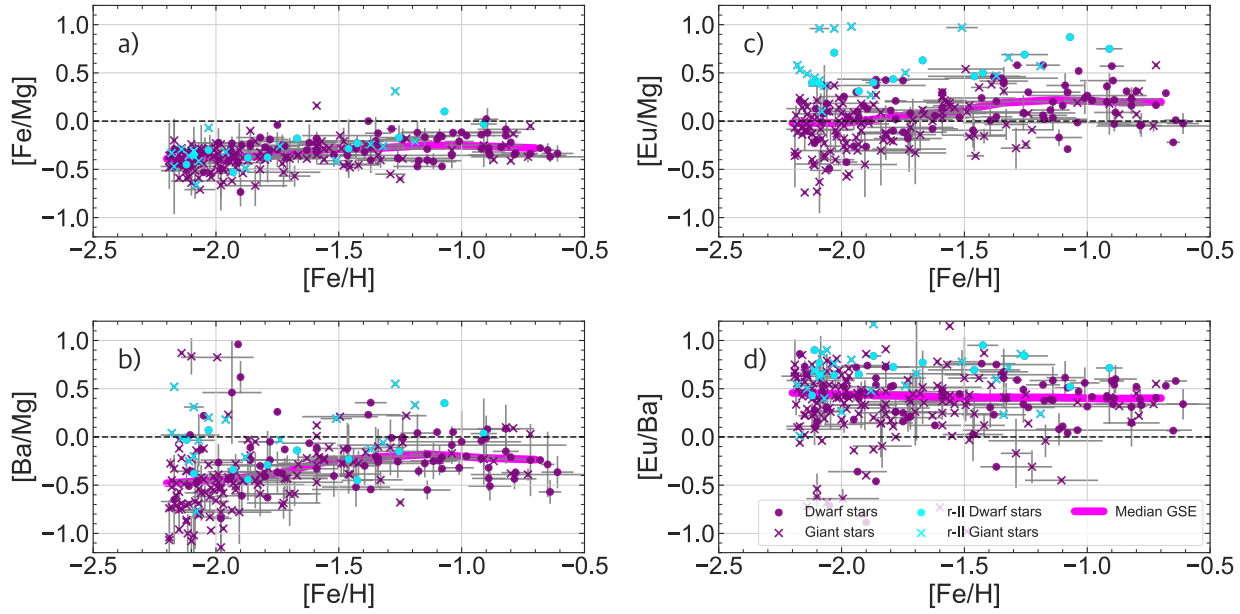


Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)

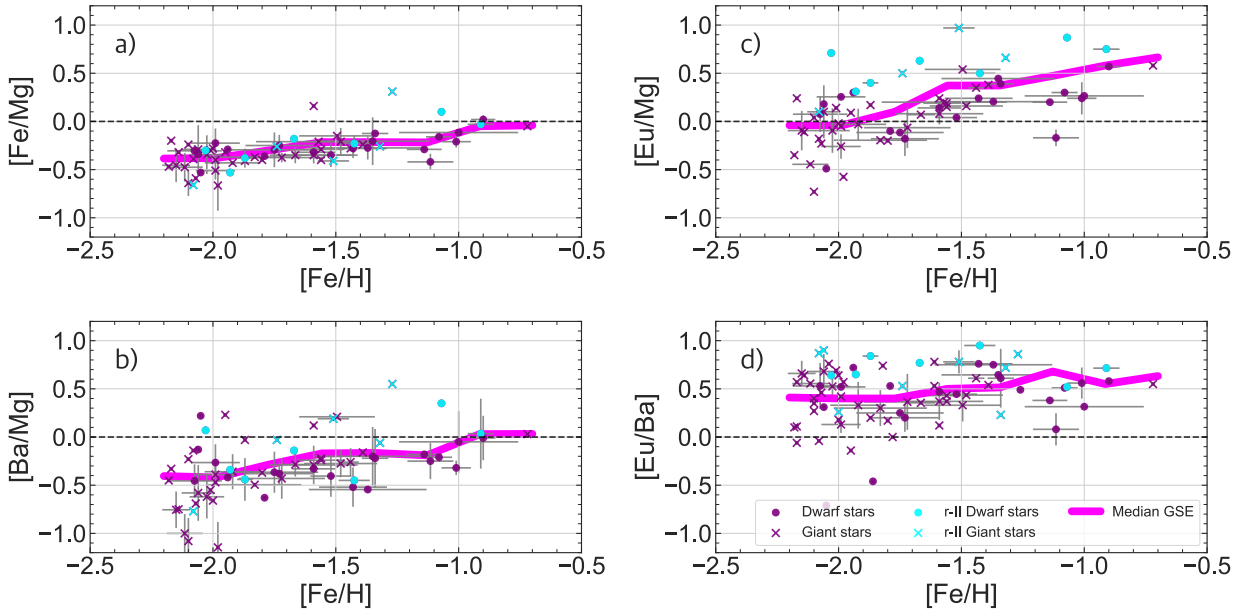
Myeong et al. (2019)



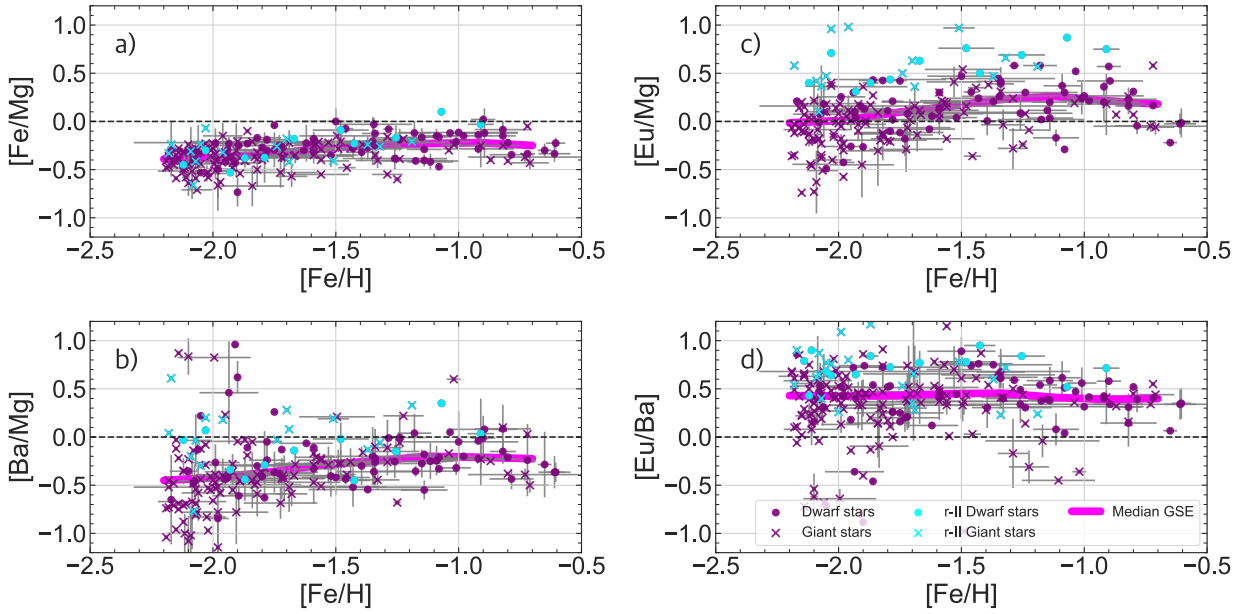
"Sausage"



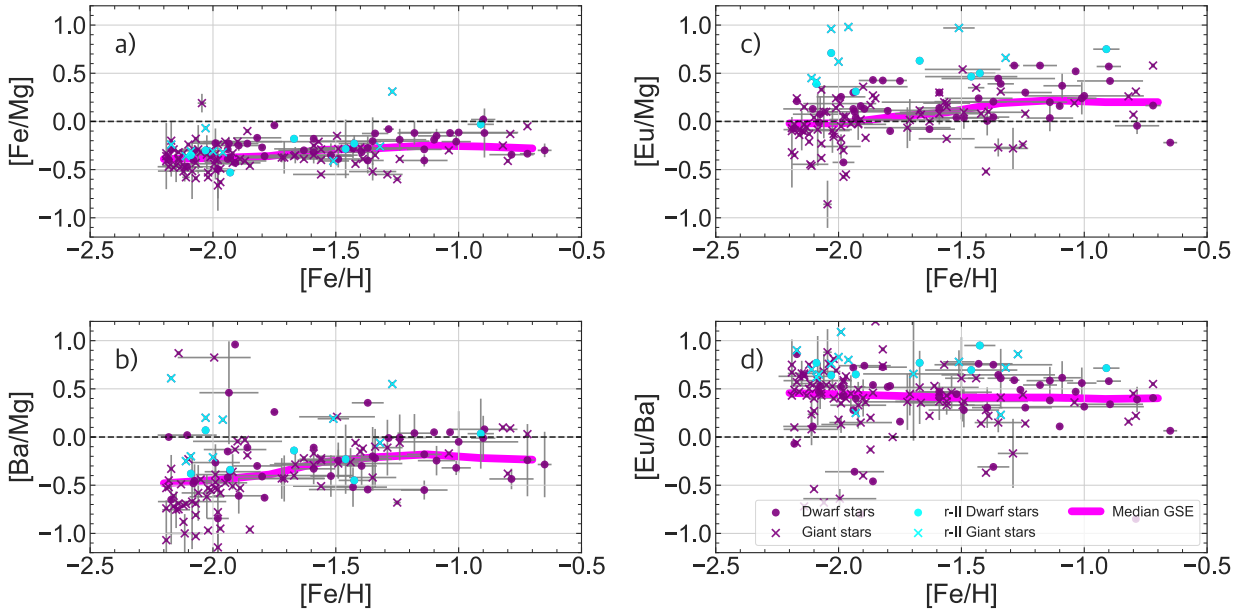
Horta et al. (2023)



Naidu et al. (2020)



Helmi et al. (2018)



Ernandes, Feuillet, Feltzing & Skúladóttir
(arXiv: 2405.13641)