Galactic Archaeology with Globular Clusters:

Europium is a Chemical Tag Between Globular and their Hosts Across All Metallicities

Stephanie Monty (Institute of Astronomy, Cambridge)

Primarily In Collaboration with:

Vasily Belokurov, Jason Sanders, Terese Hansen, Charli Sakari, Madeleine Mckenzie, GyuChul Myeong, Elliot Davies, Anke Ardern-Arentsen & Davide Massari

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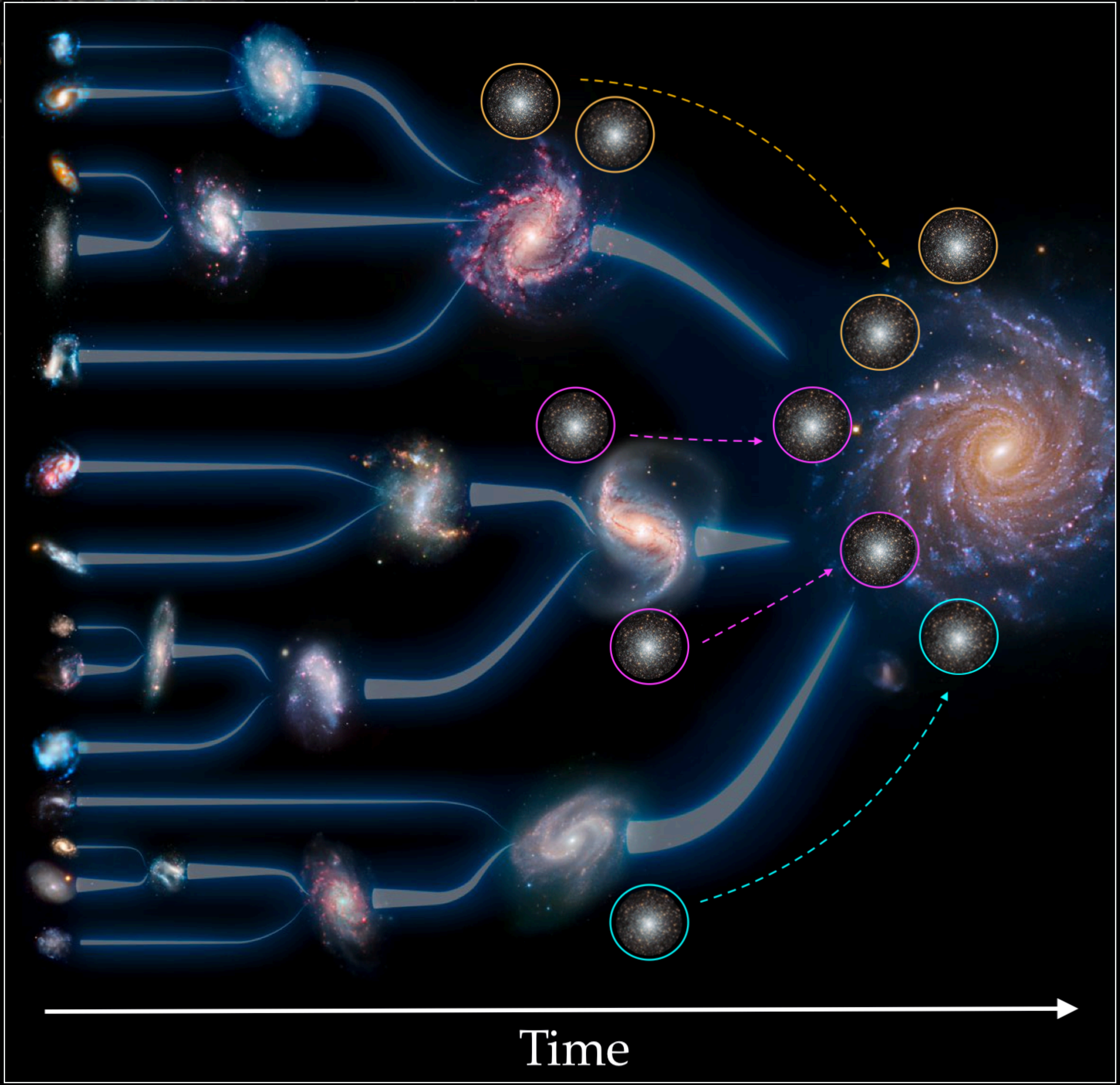

ESO/L. Calçada

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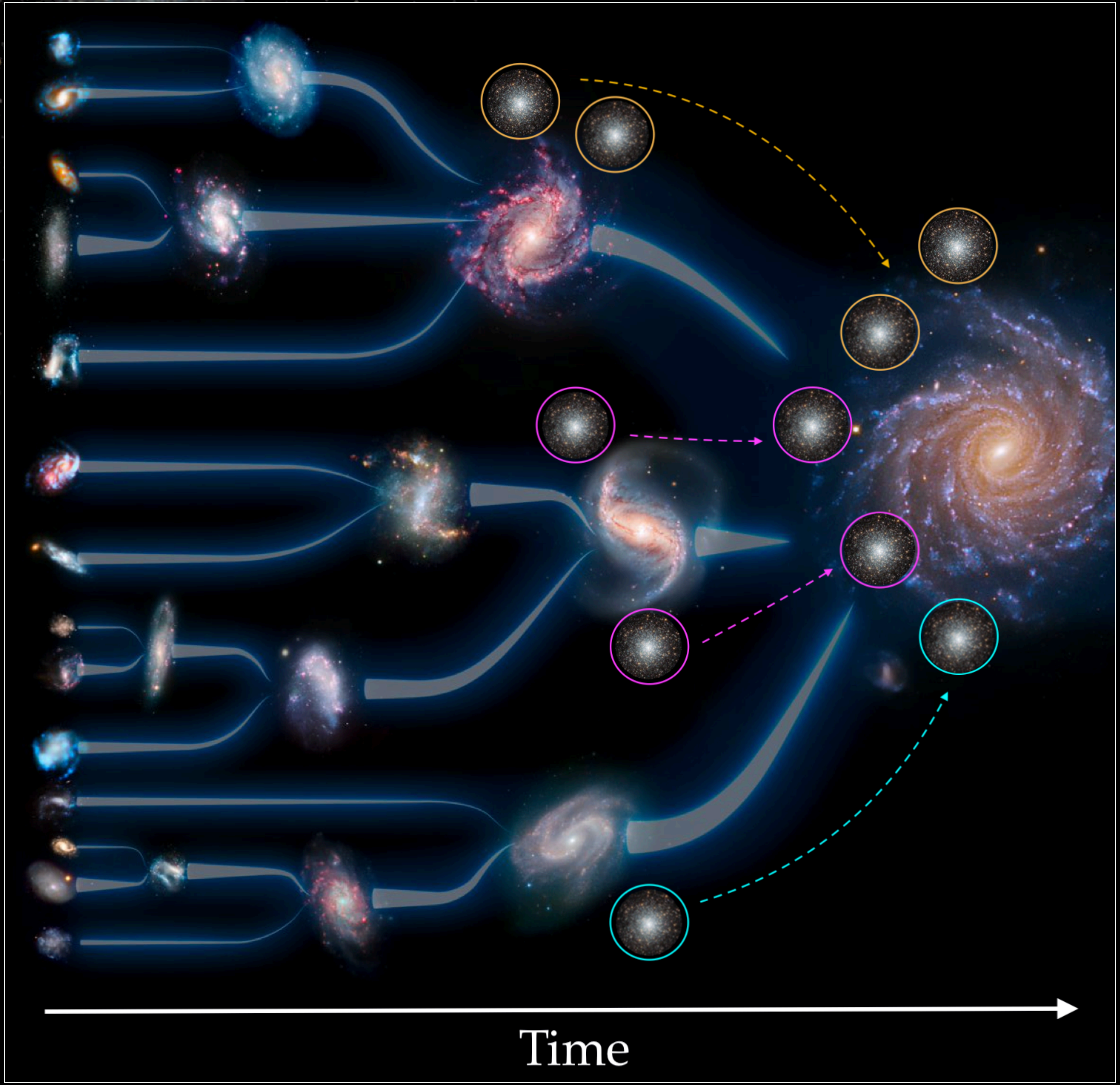

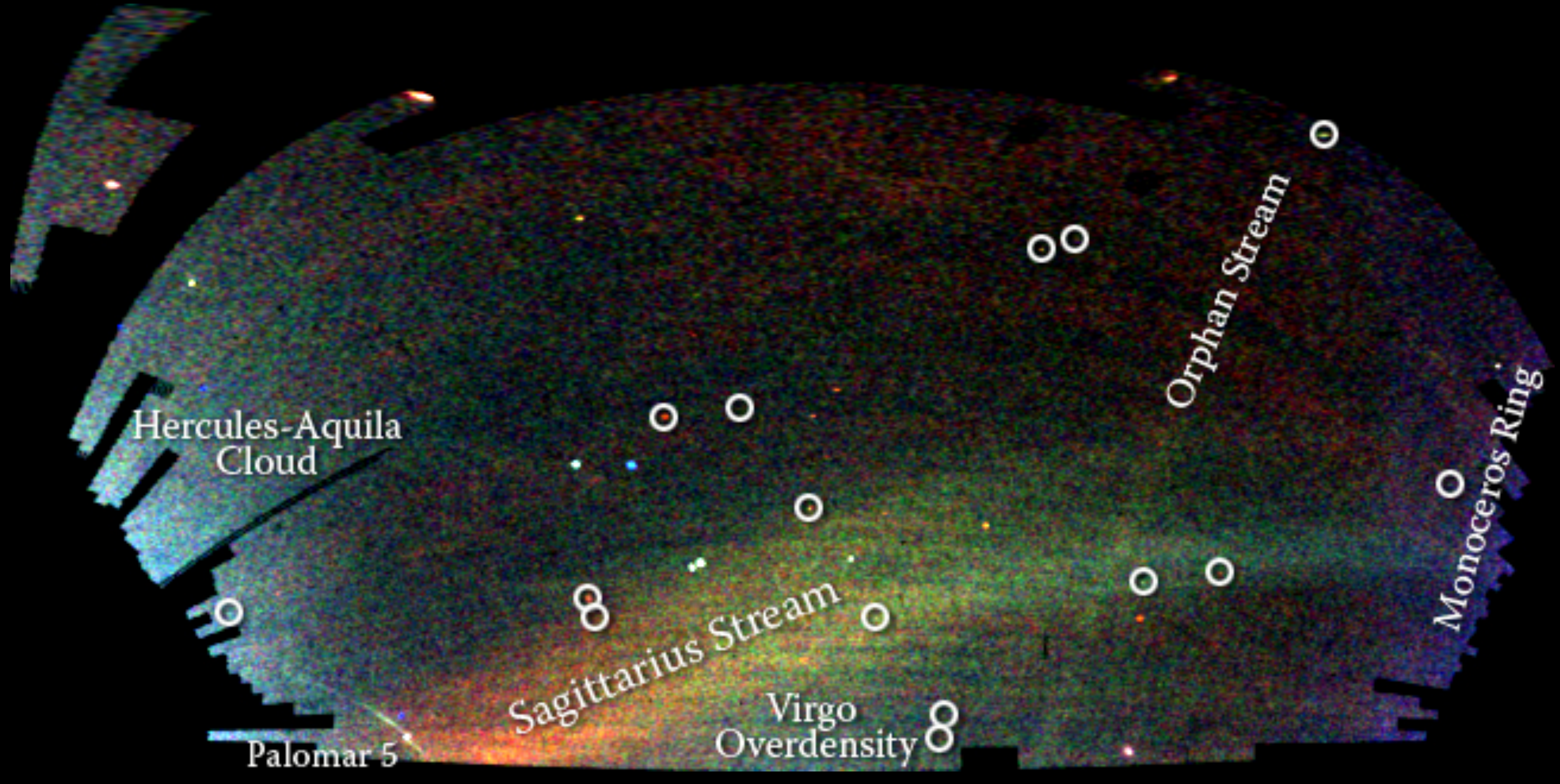

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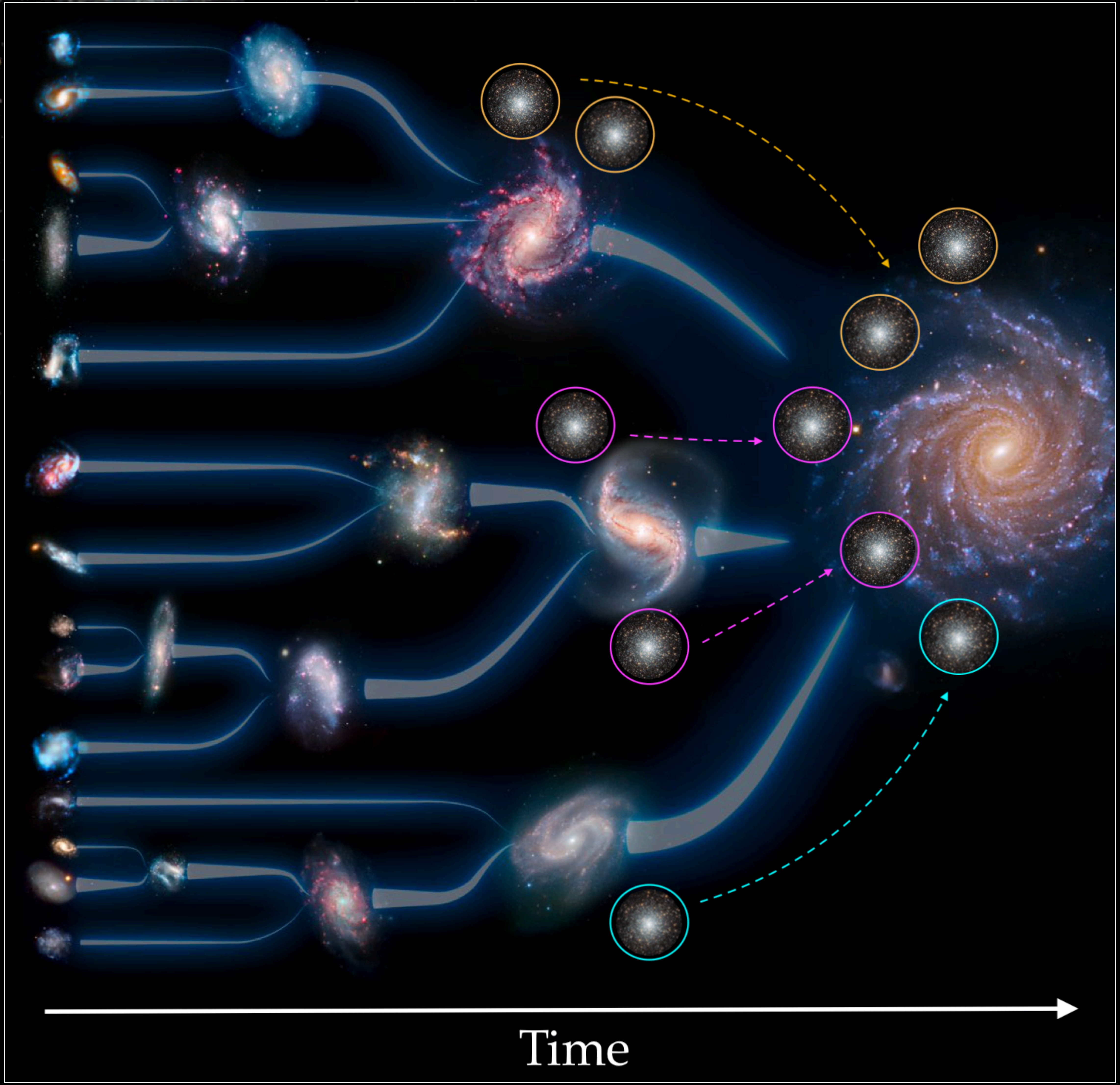

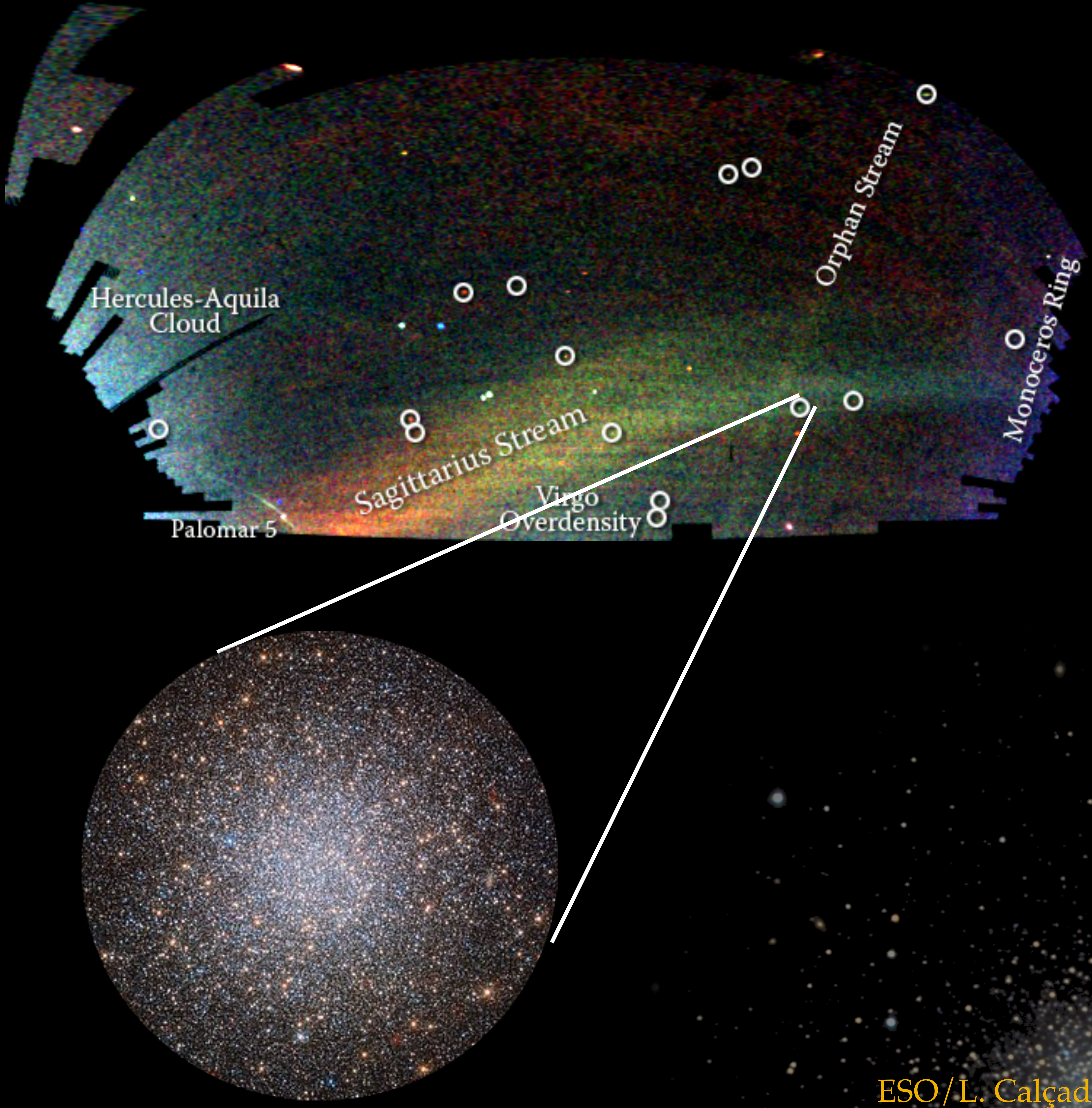

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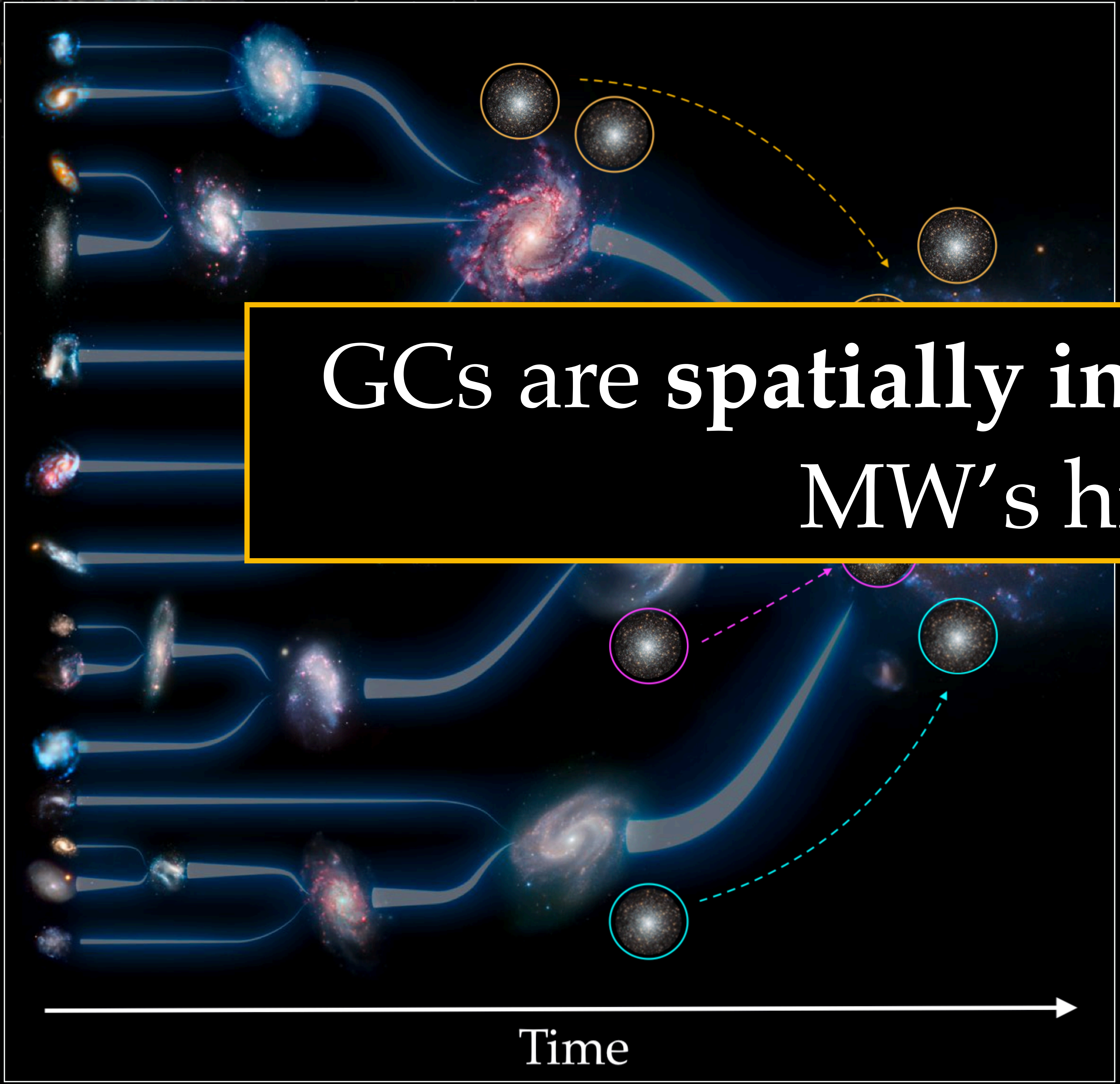
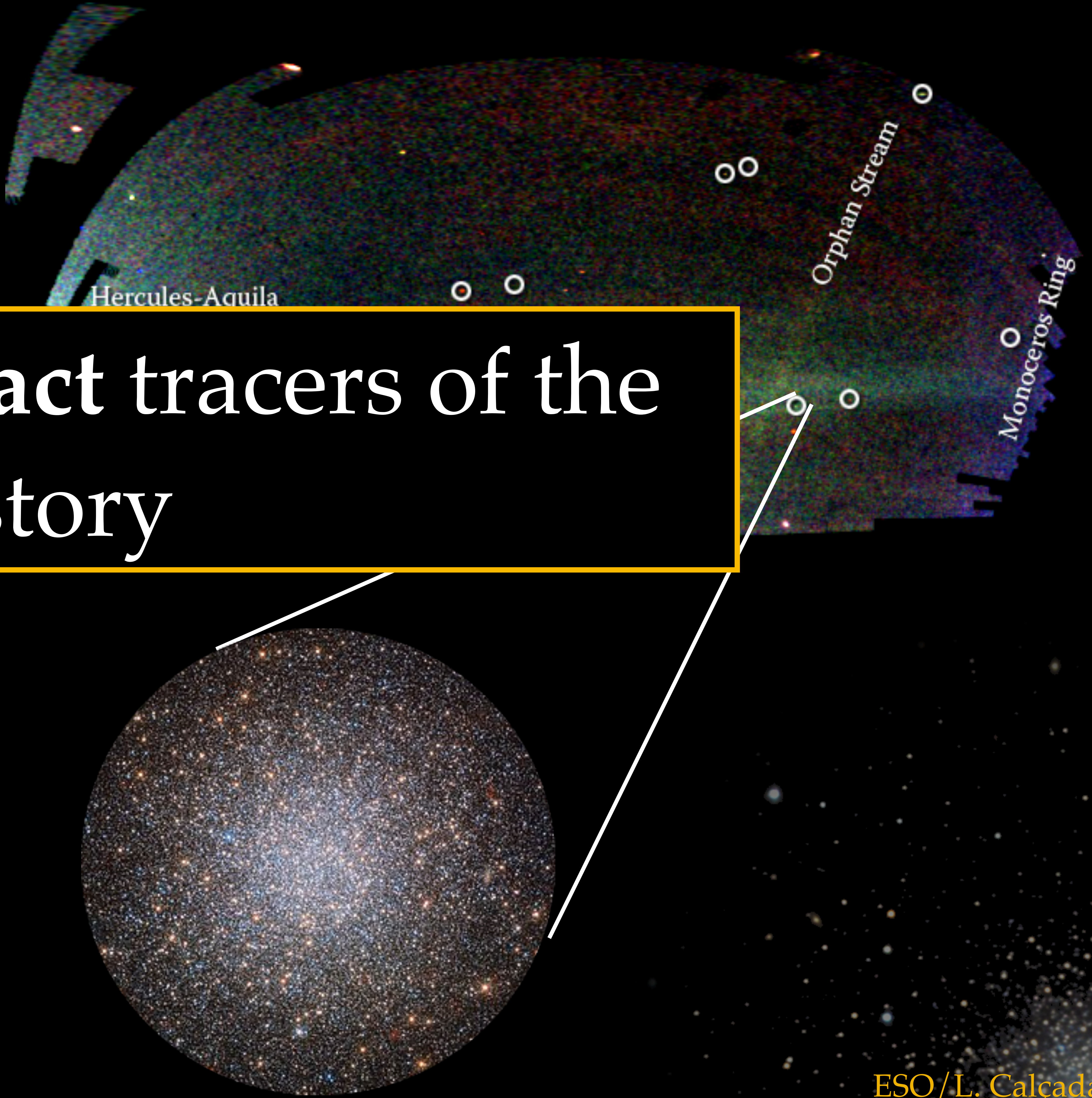


GCs are **spatially intact** tracers of the MW's history



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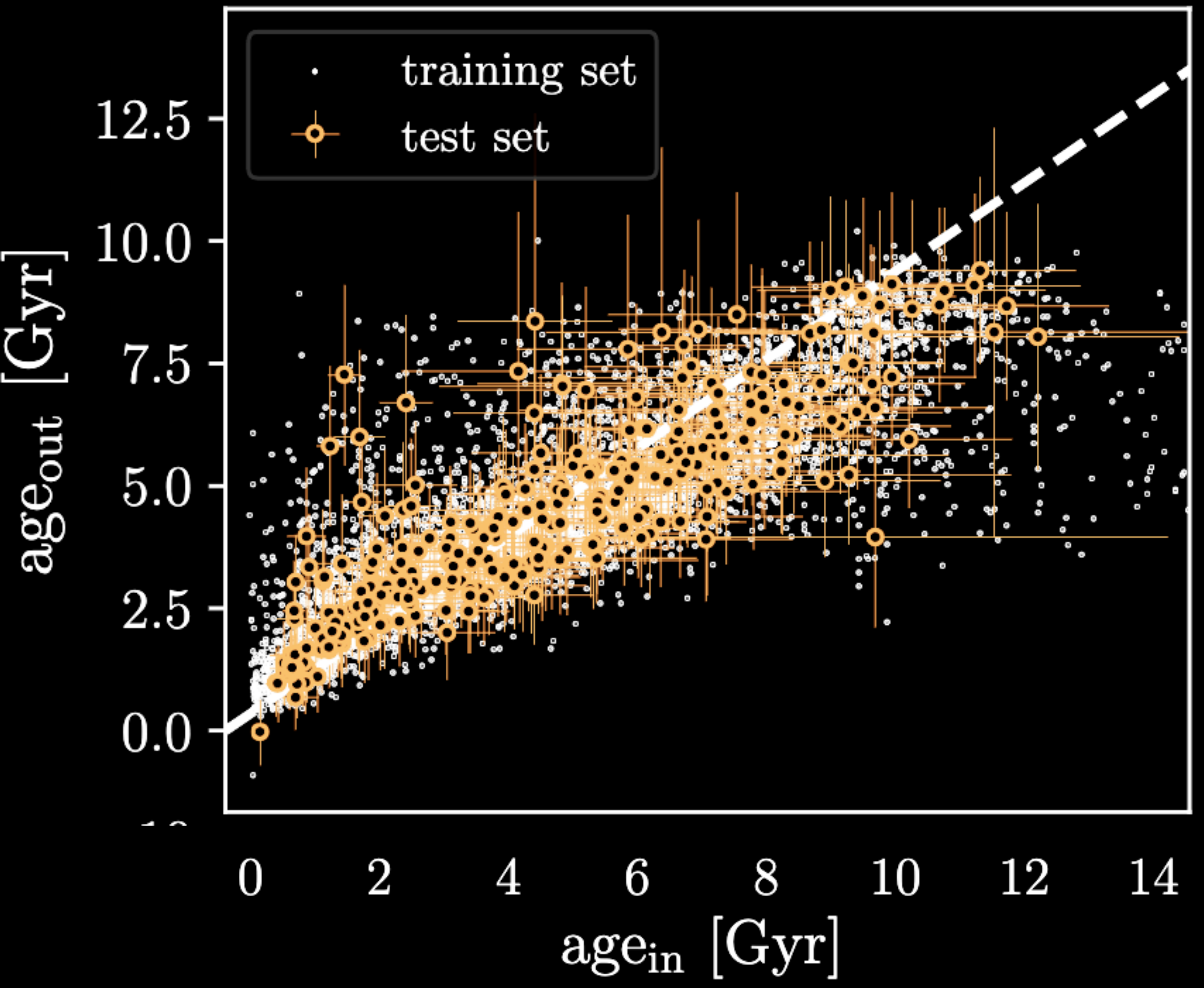
What do GCs provide that field stars do not?



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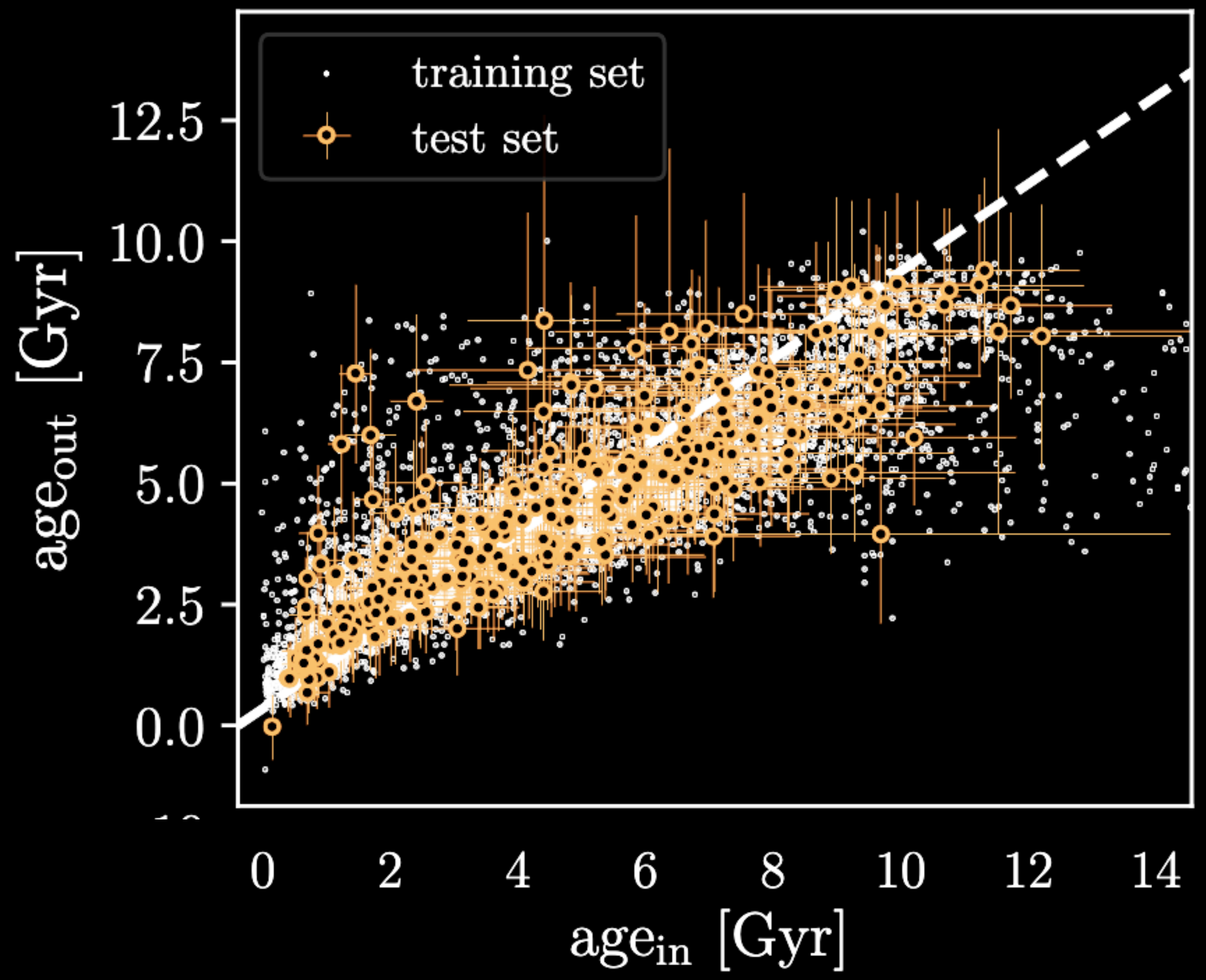

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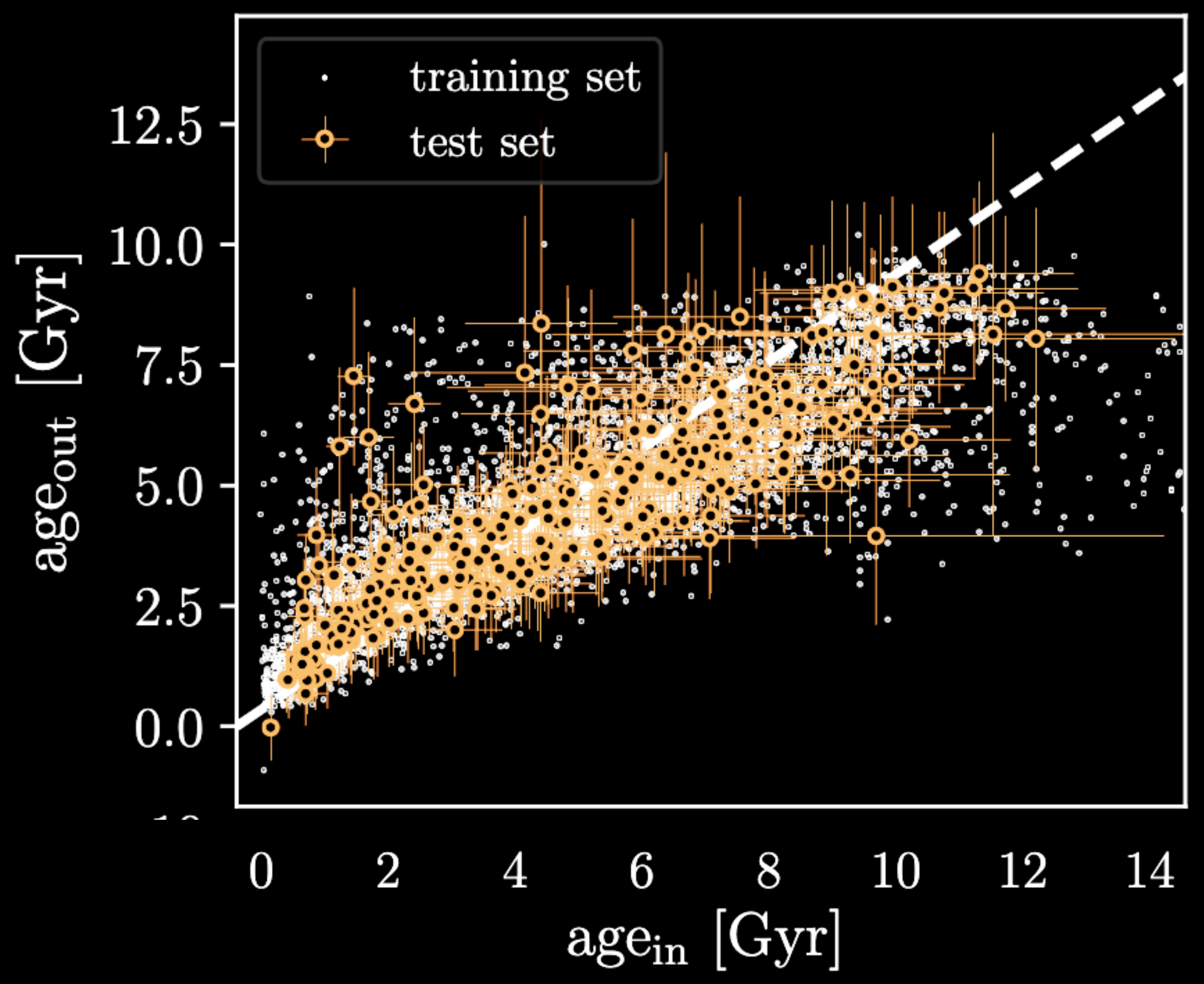

-0.5 < [Fe/H] < 0.5

10 +/- 3 Gyr

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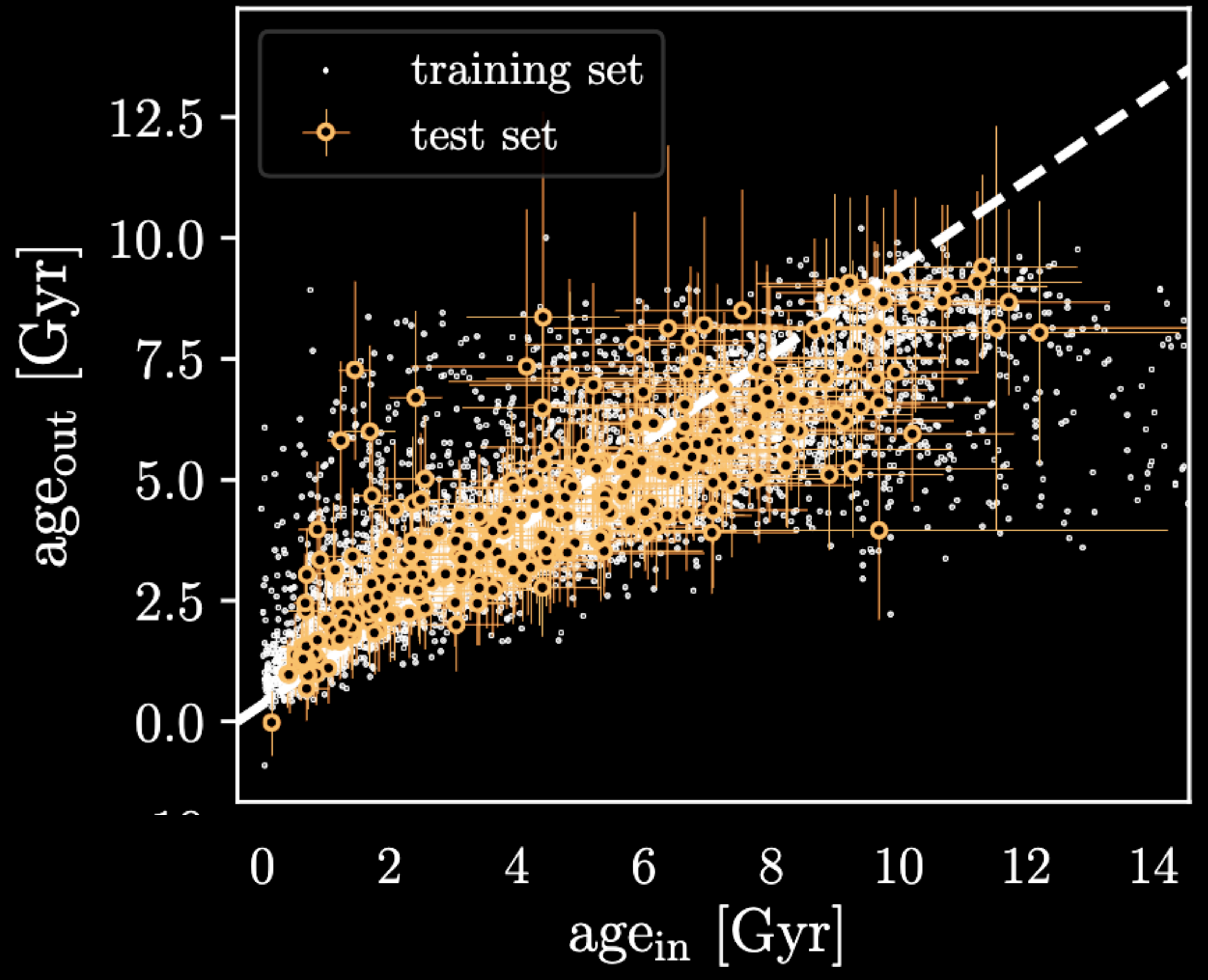

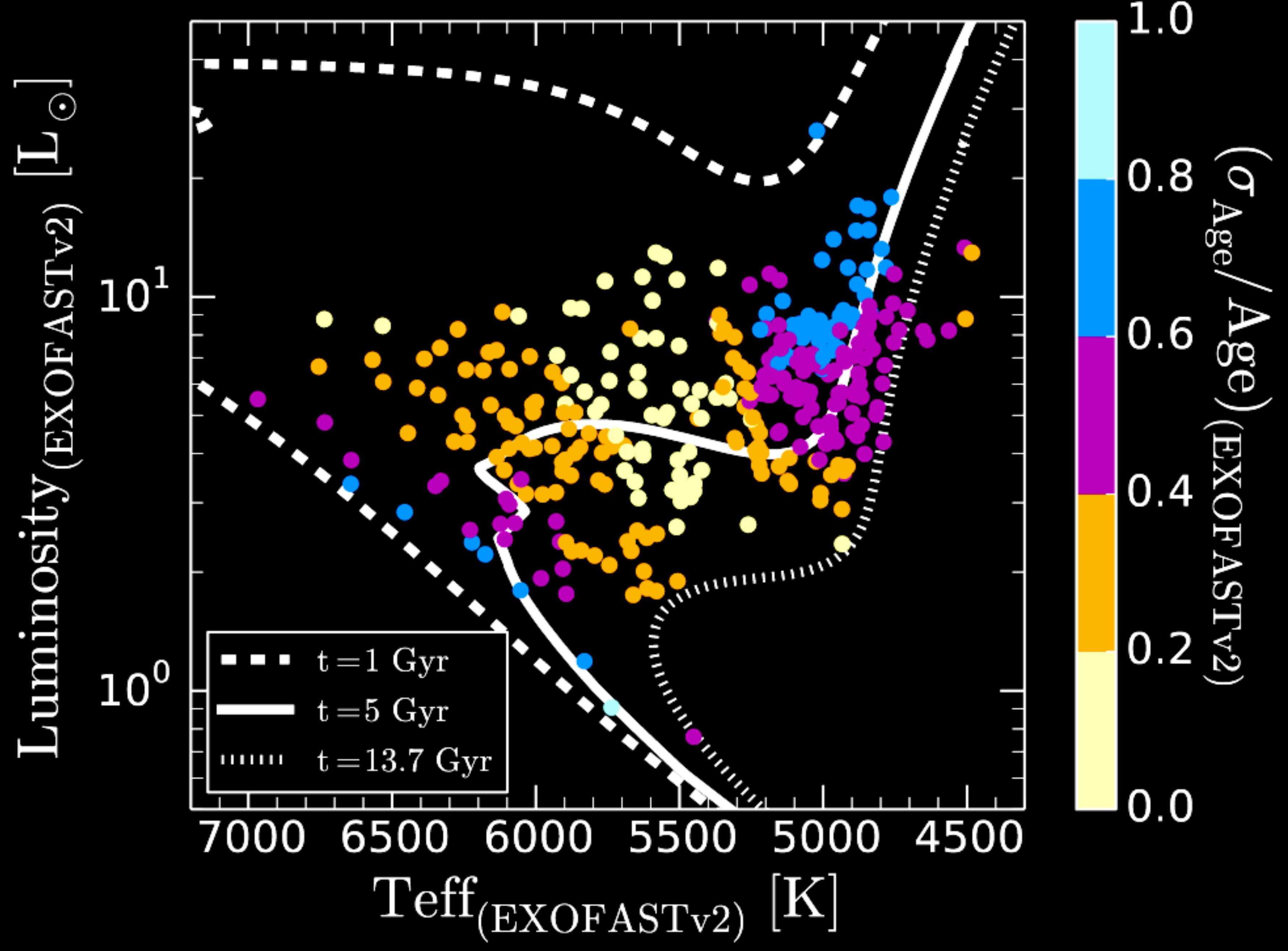

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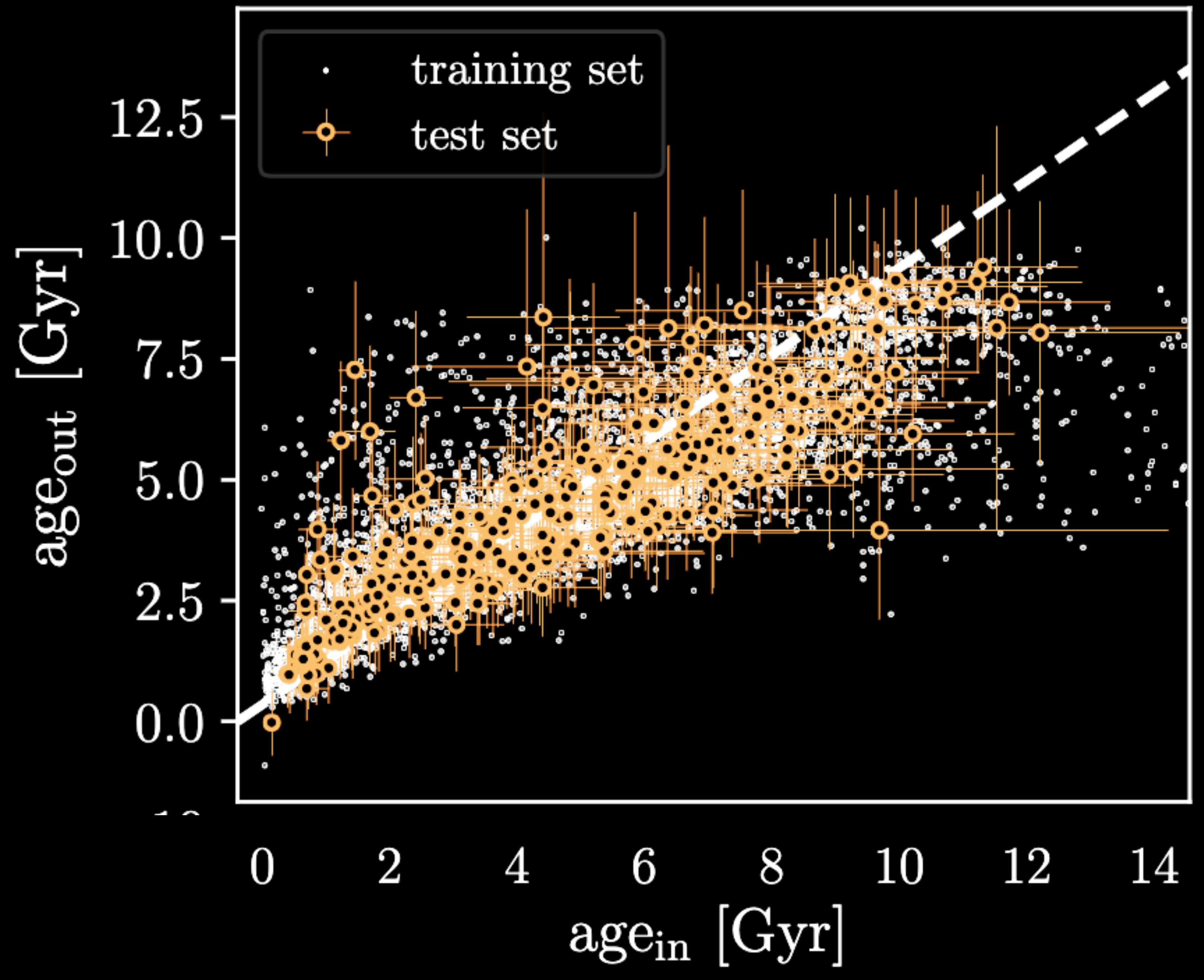

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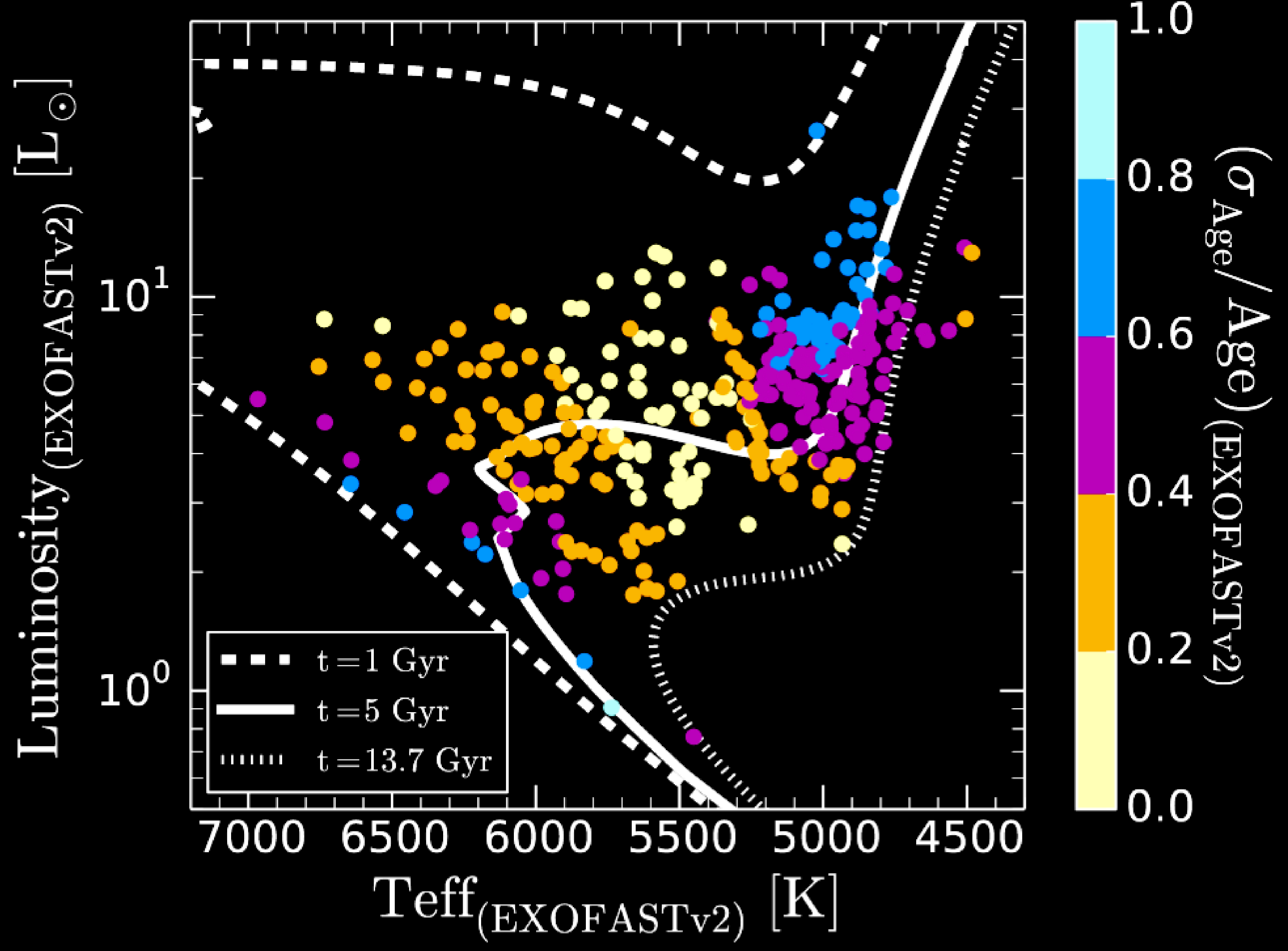

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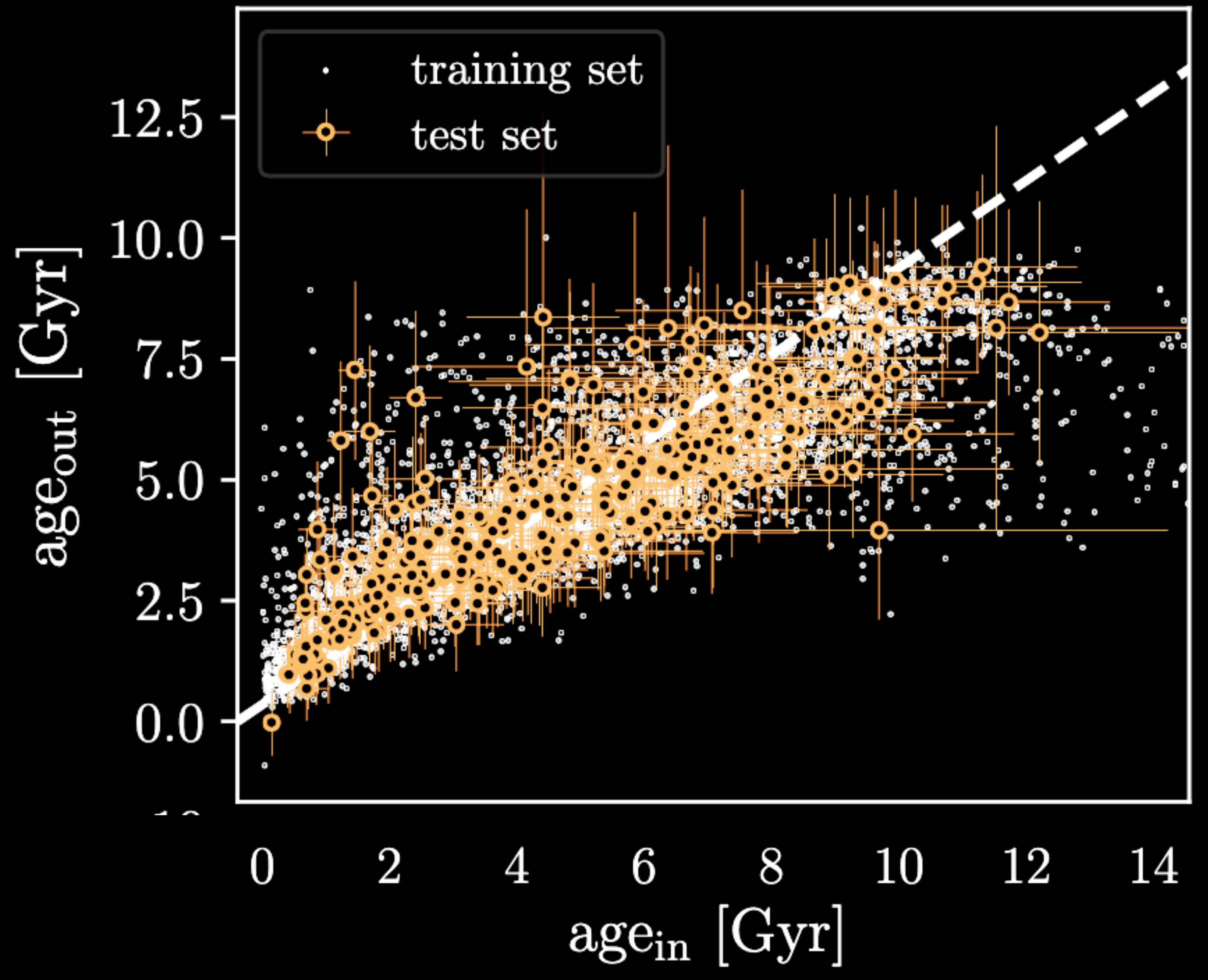

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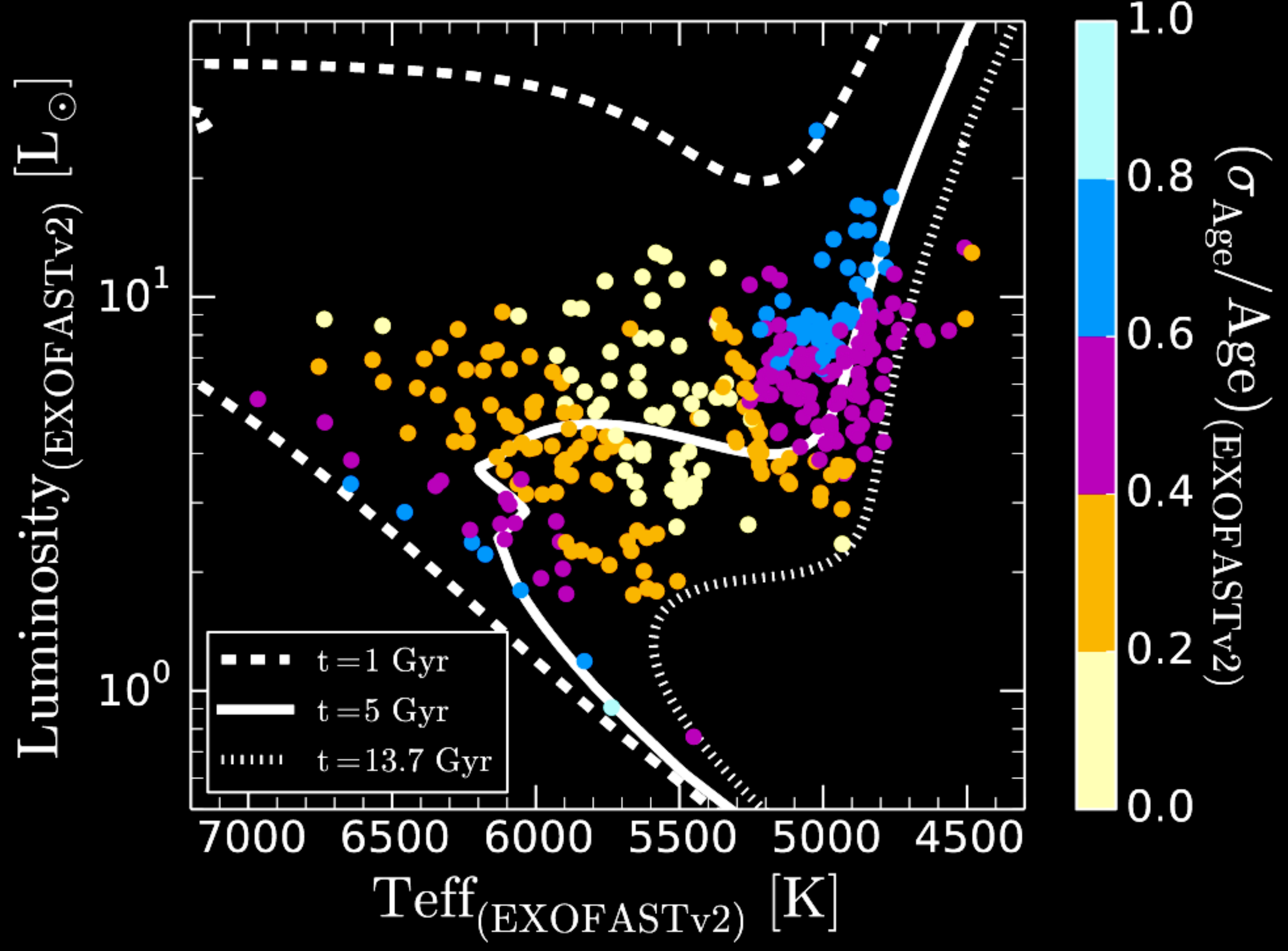

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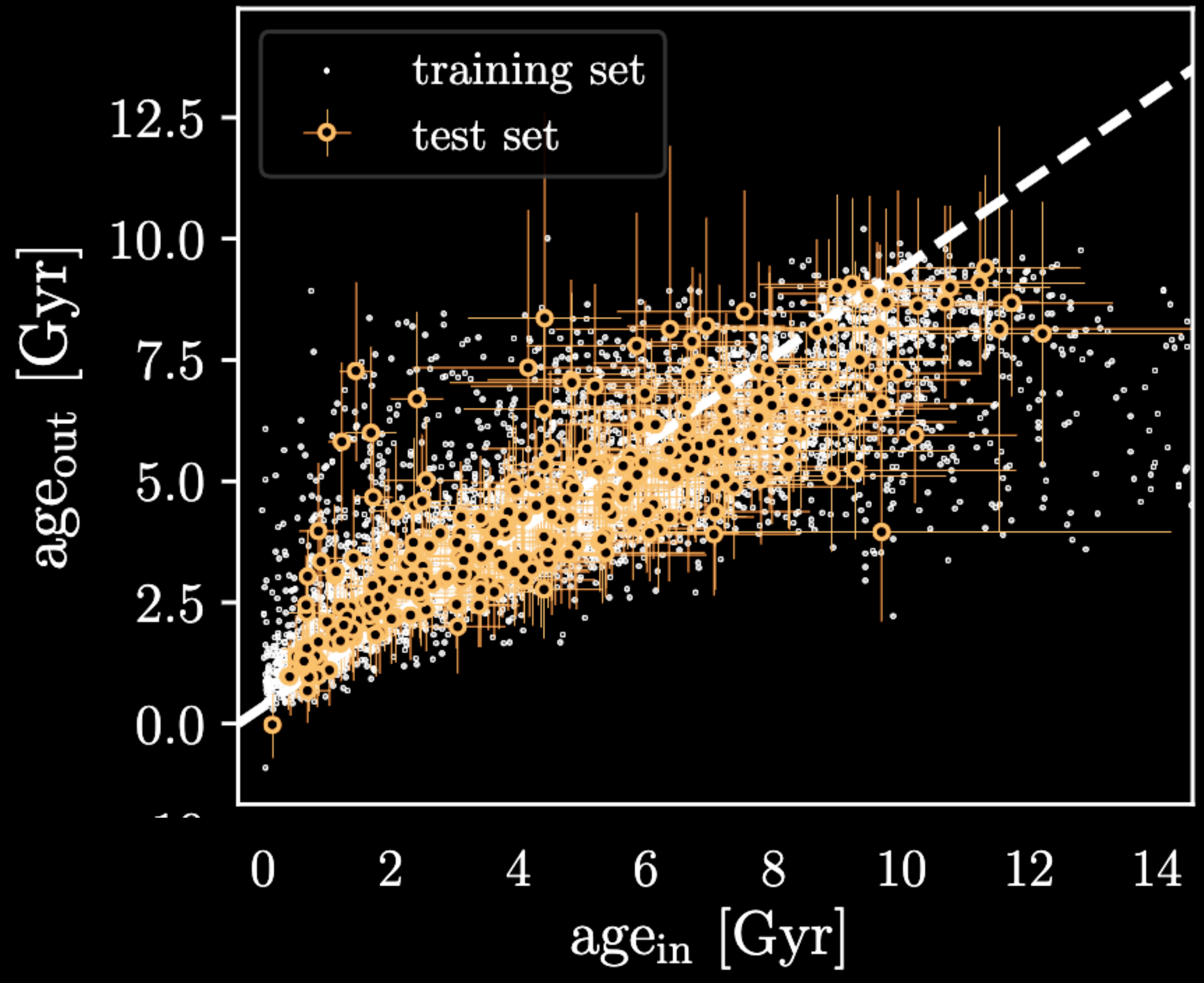

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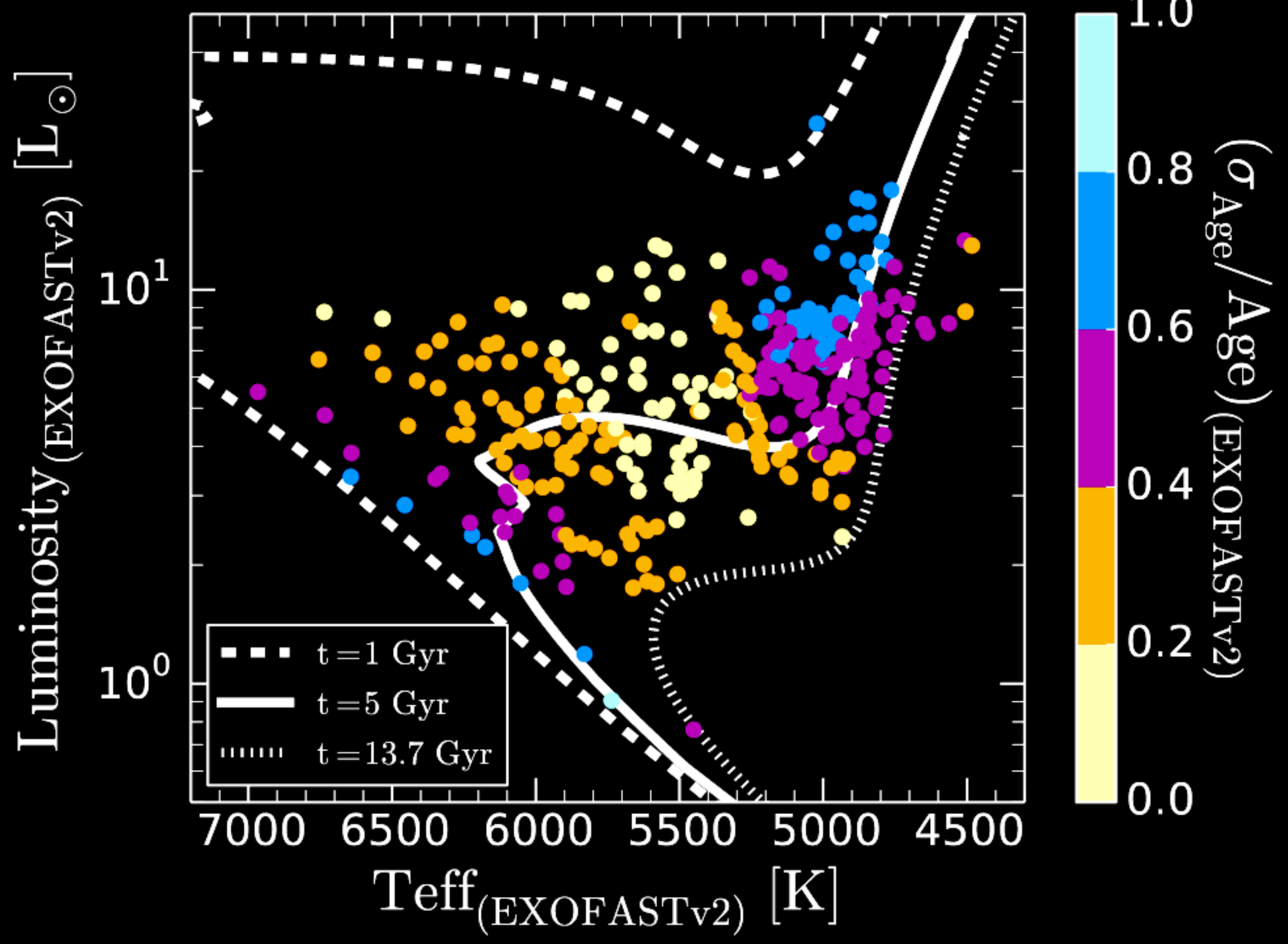

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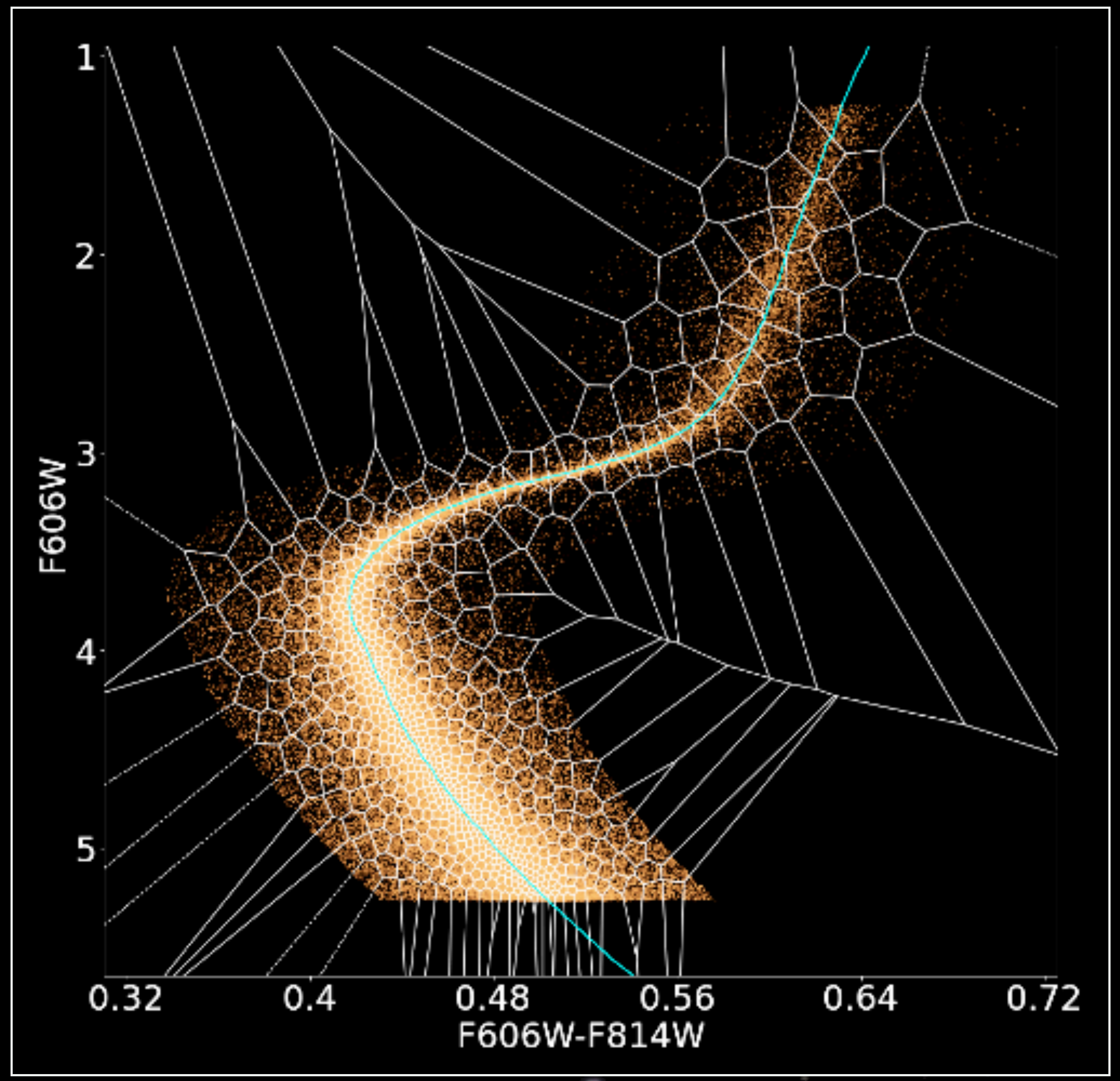

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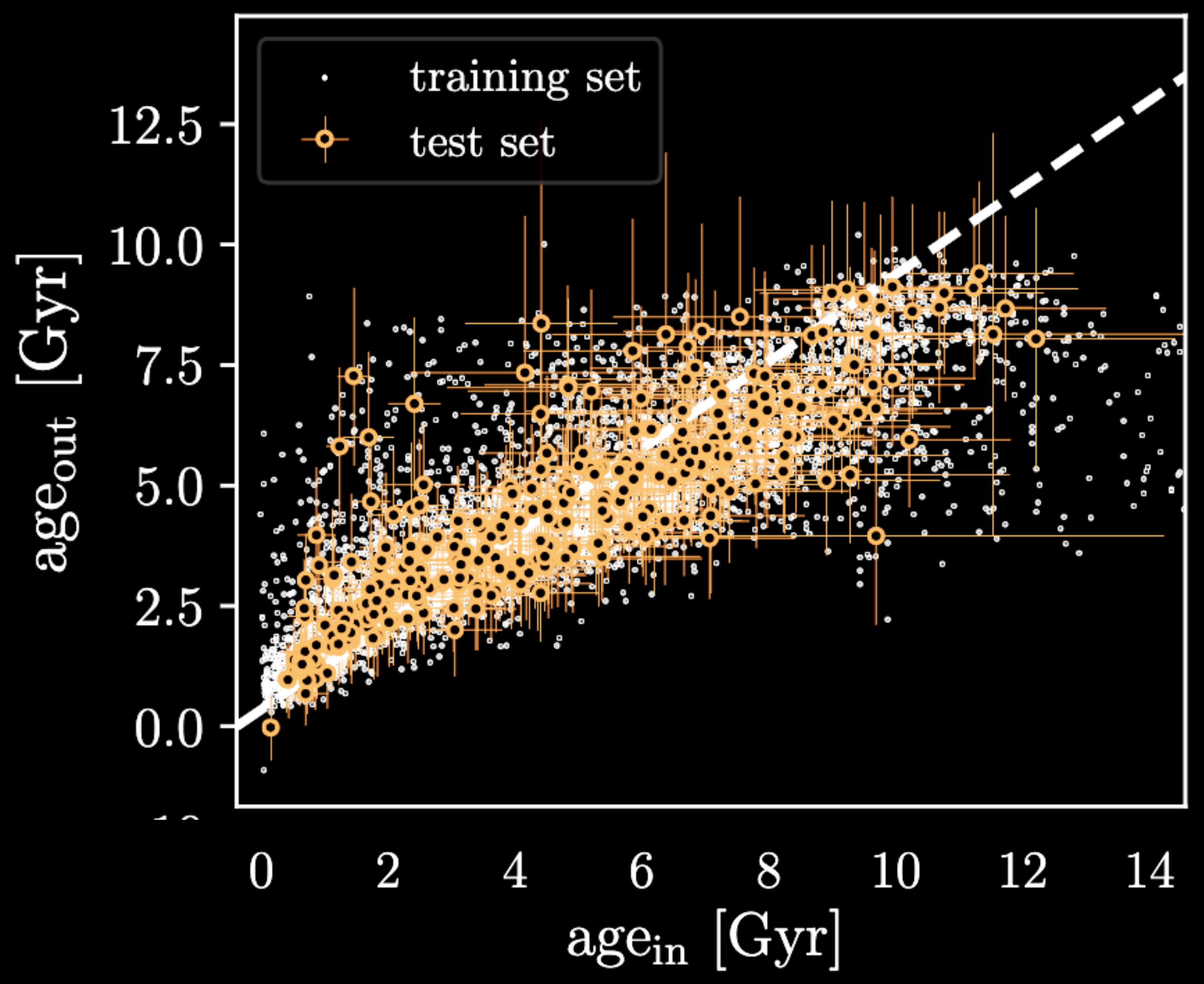

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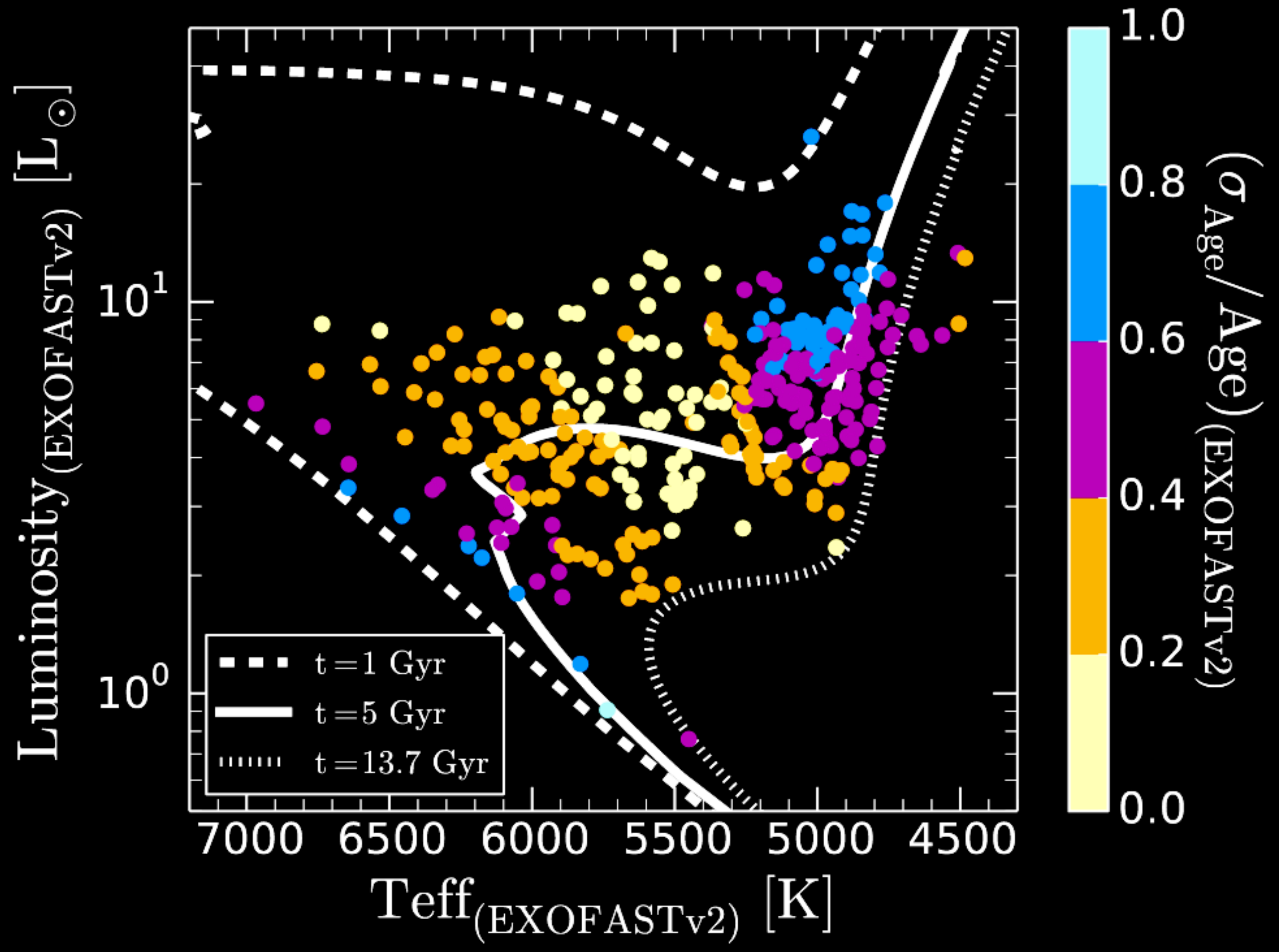

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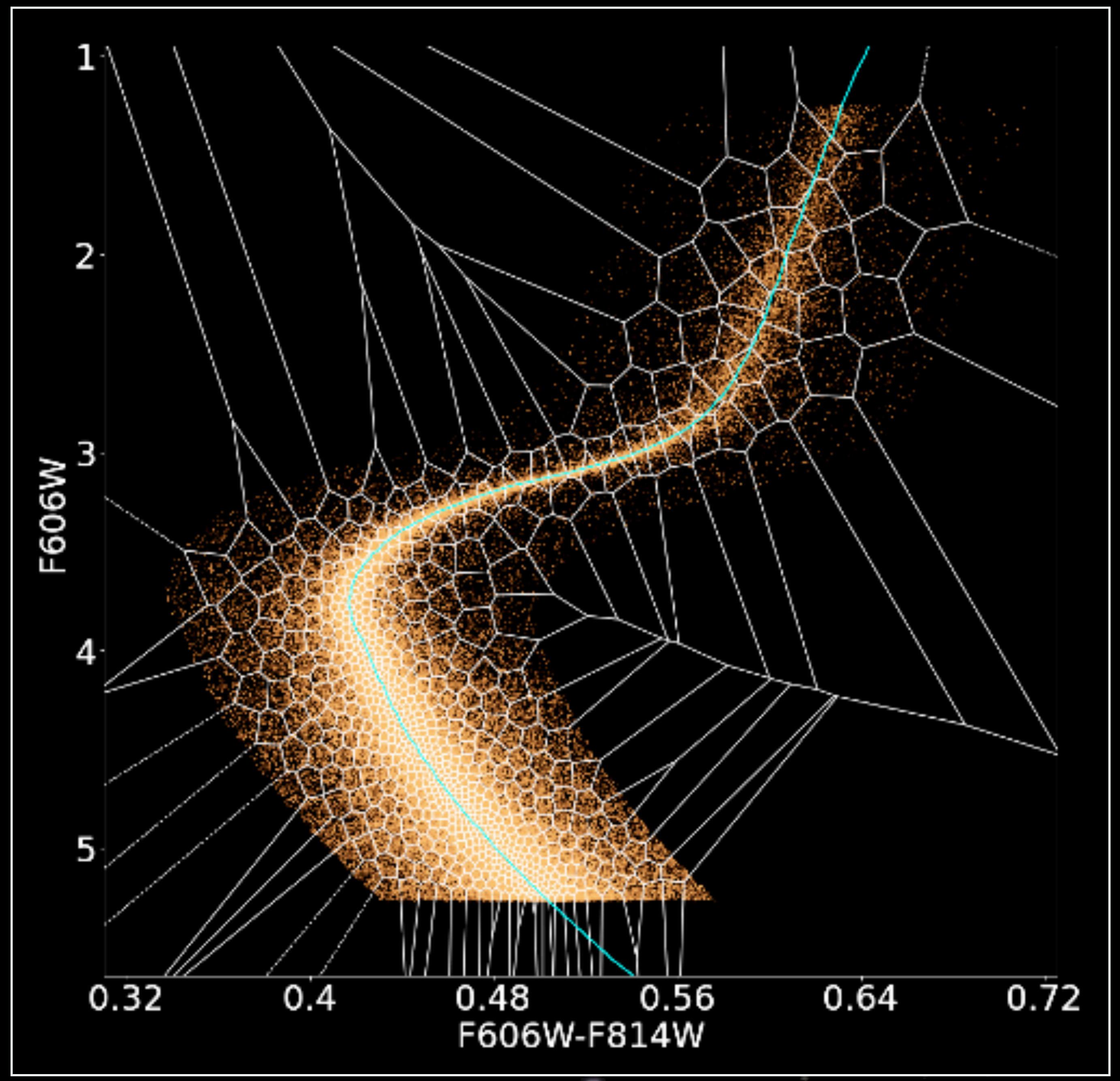
Isochrone Fitting (Ying et al. 2023)



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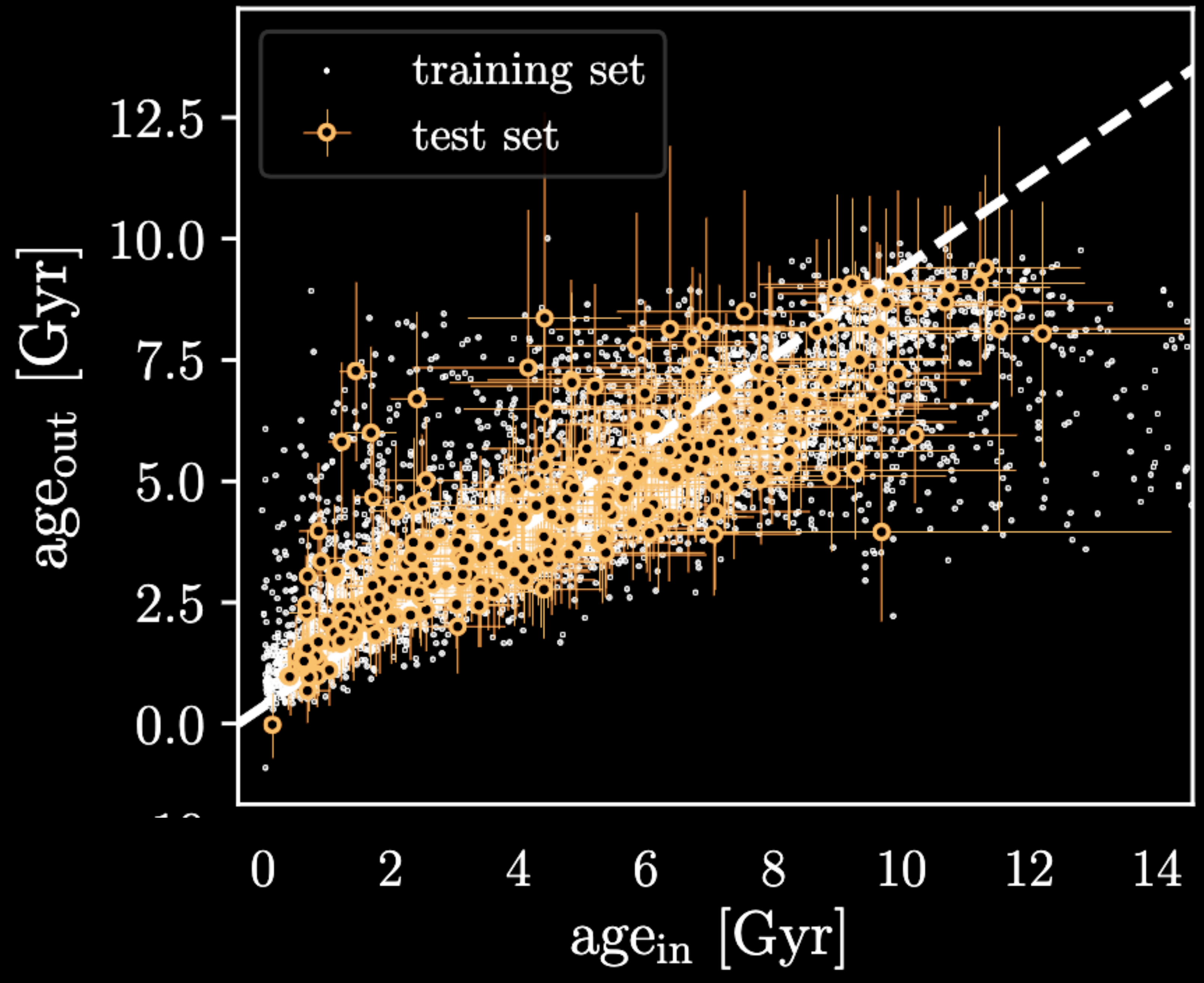

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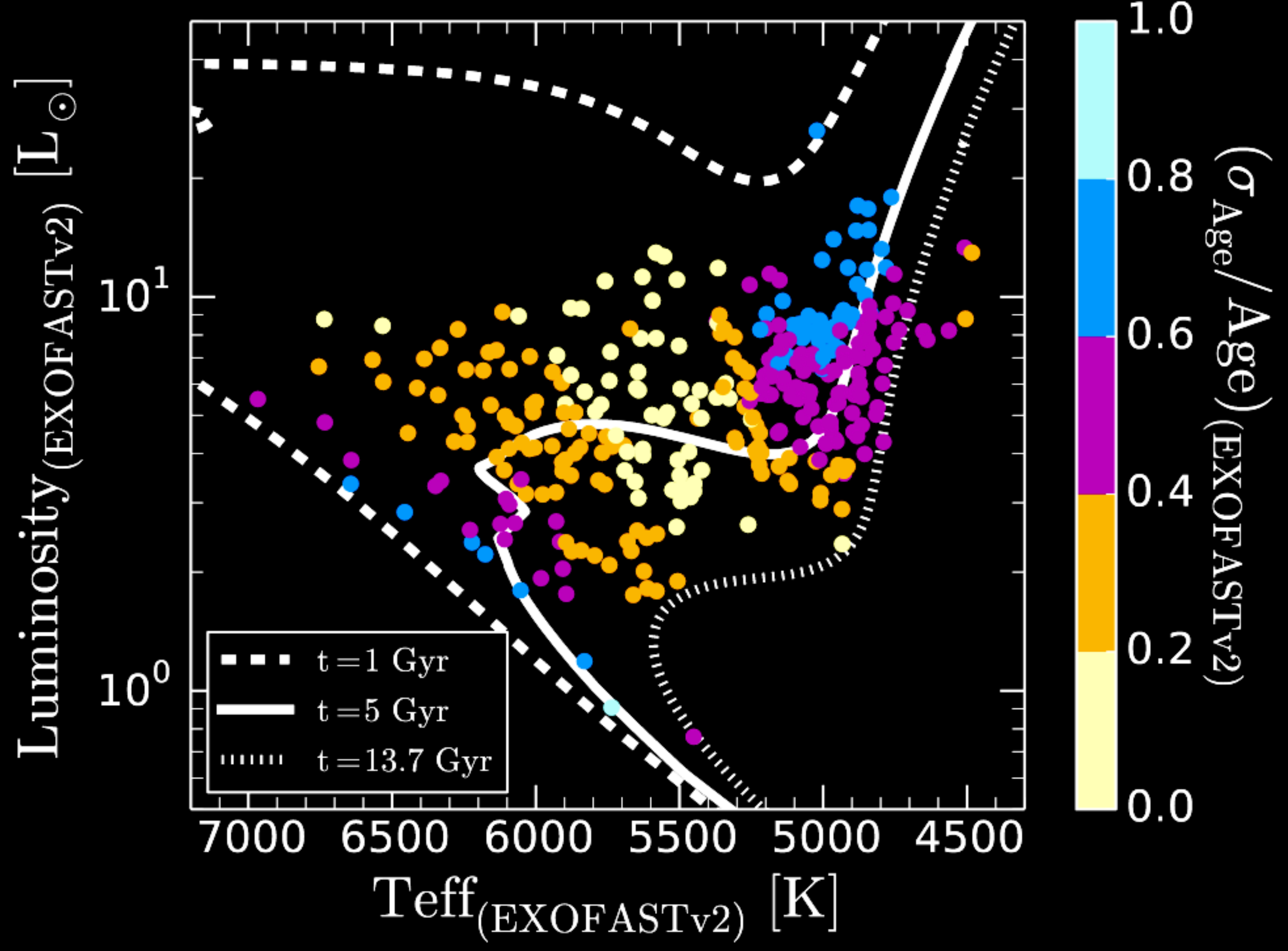

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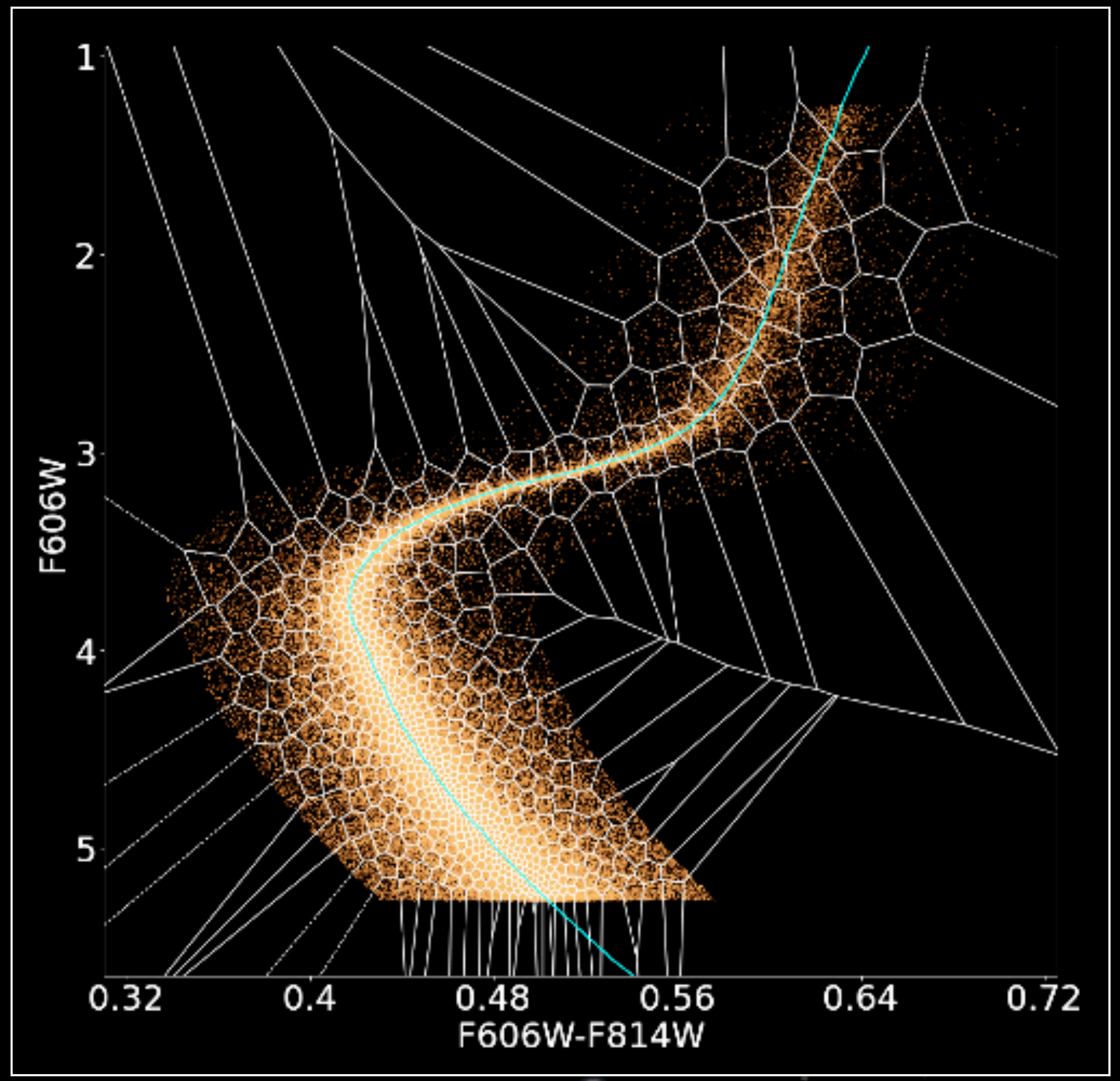

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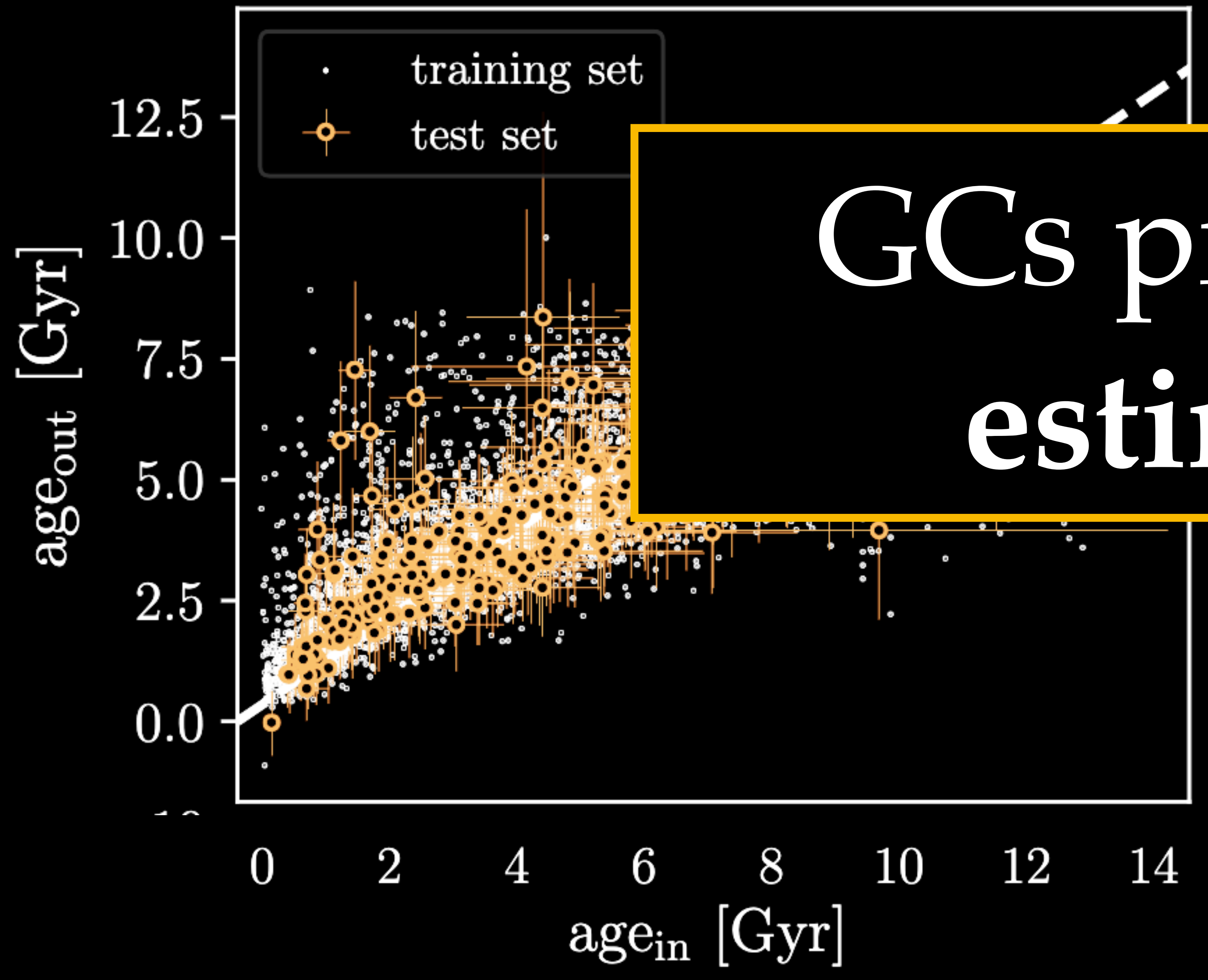

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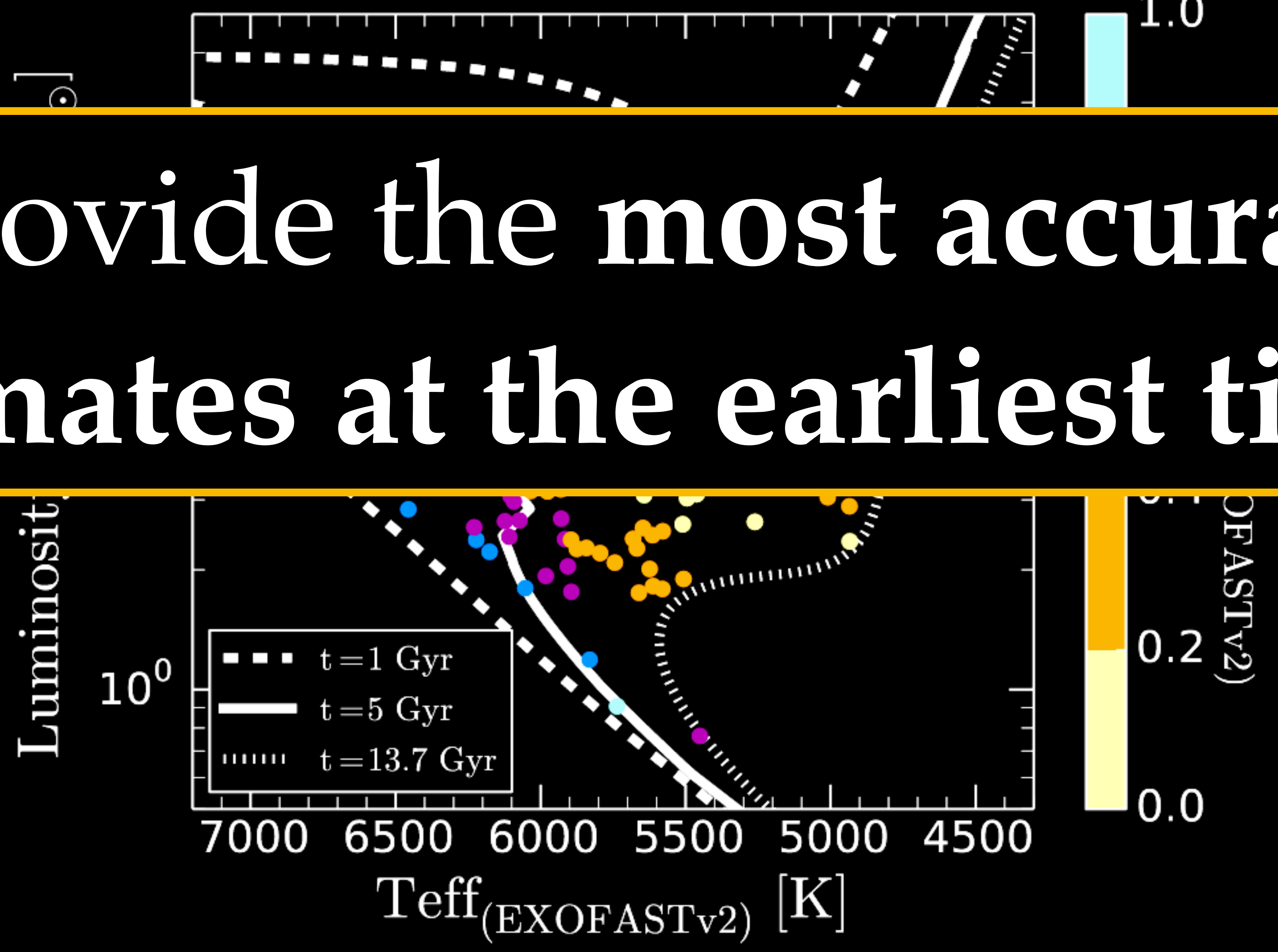

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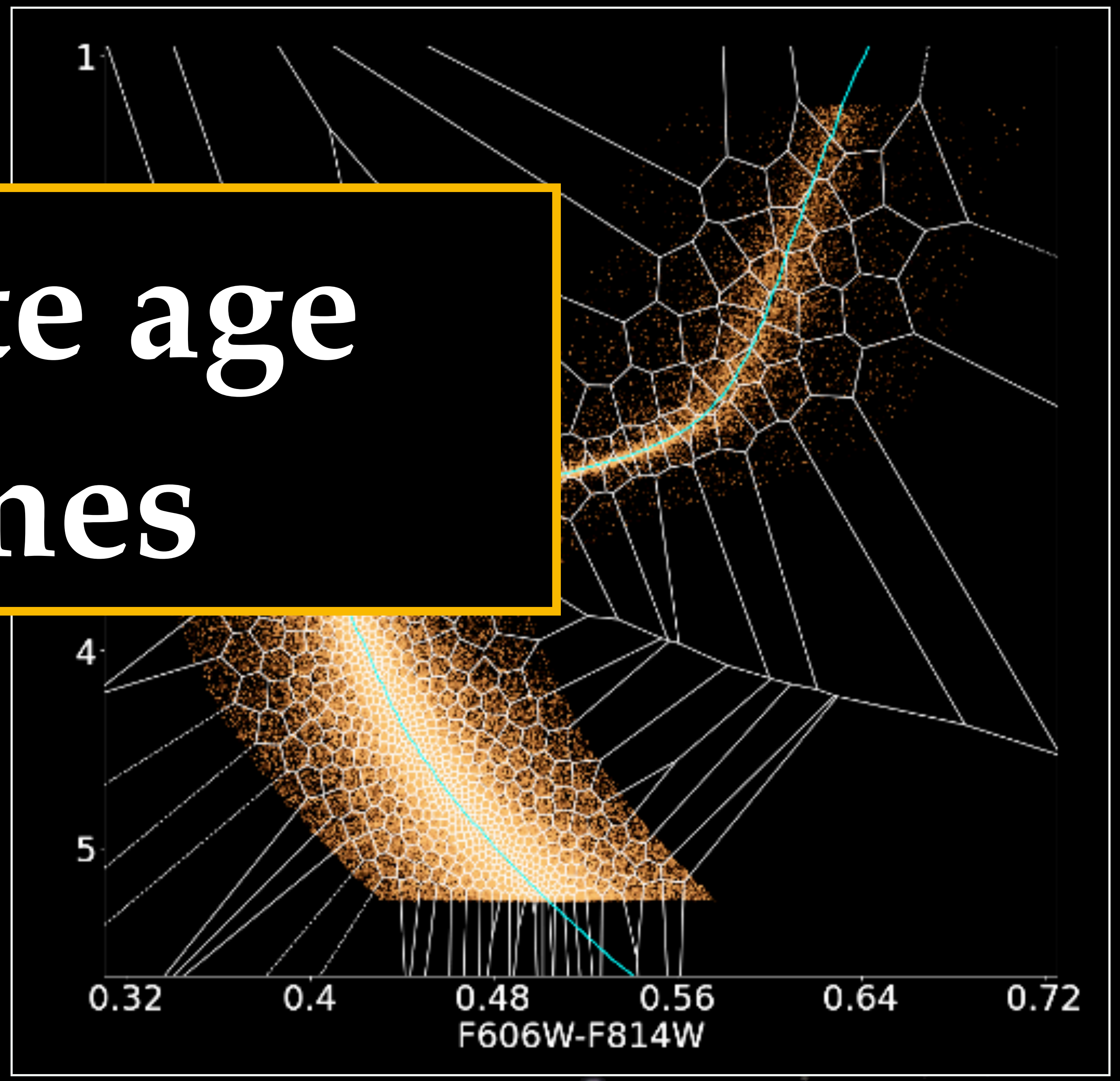

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GCs provide the **most accurate age estimates at the earliest times**

Can GCs act as Chemo-dynamical Tracers?

Complication	Line of Investigation

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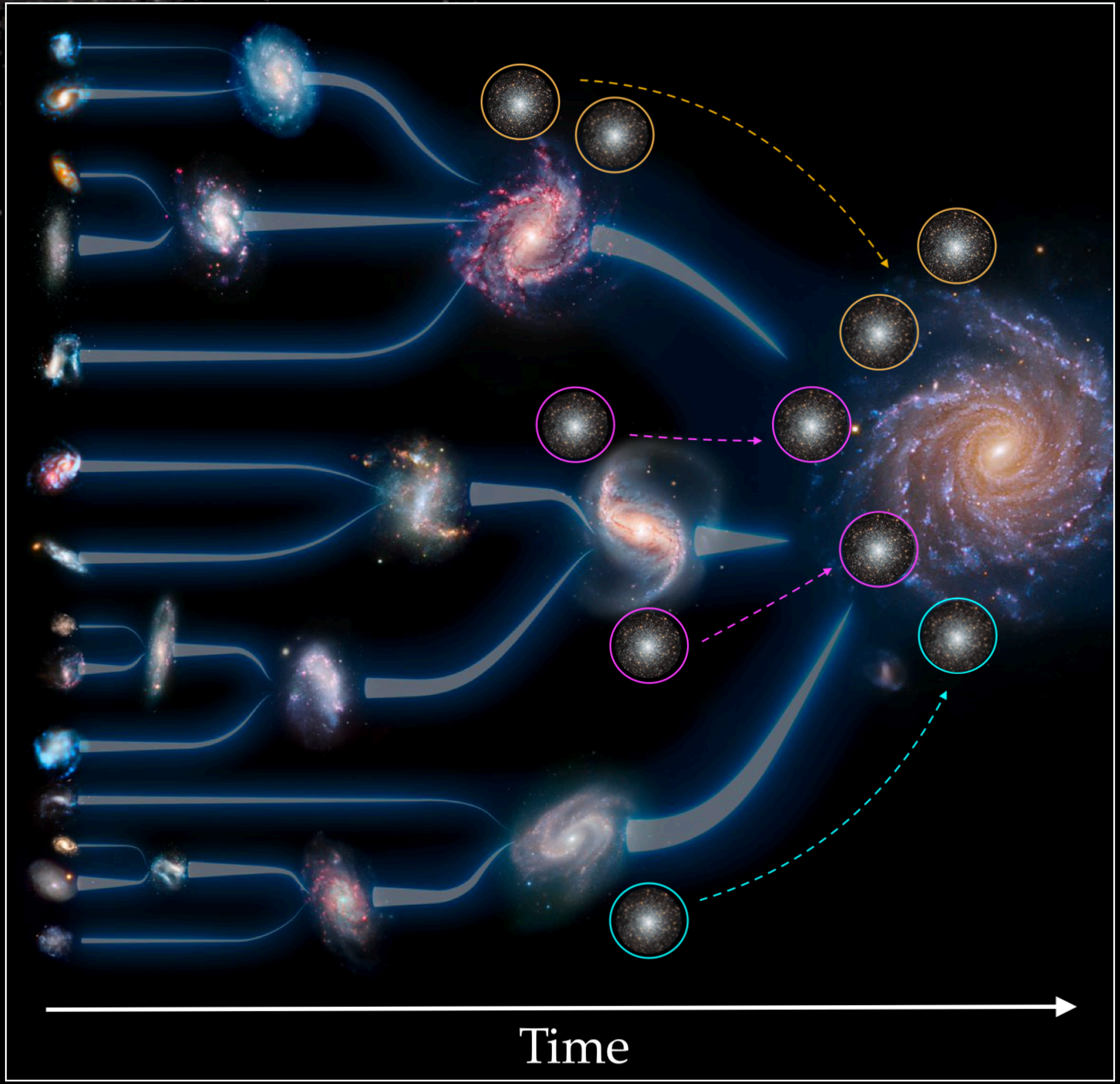
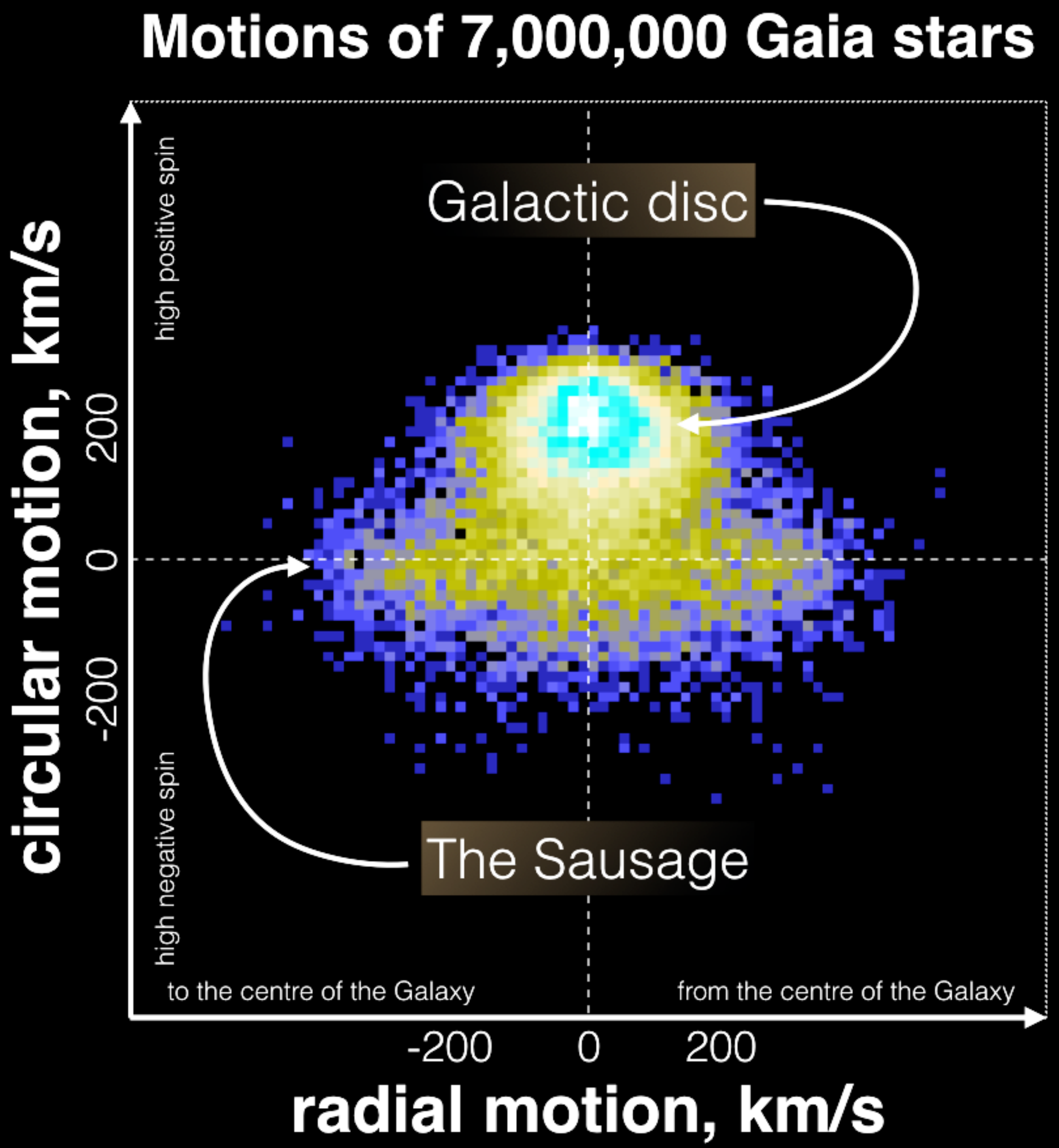
Can we use precise abundances and ages from GCs to learn about the host star formation histories?

ESO/L. Calçada

The Last Major Merger: Gaia-Sausage/Enceladus





ESO/L. Calçada, Belokurov 2018

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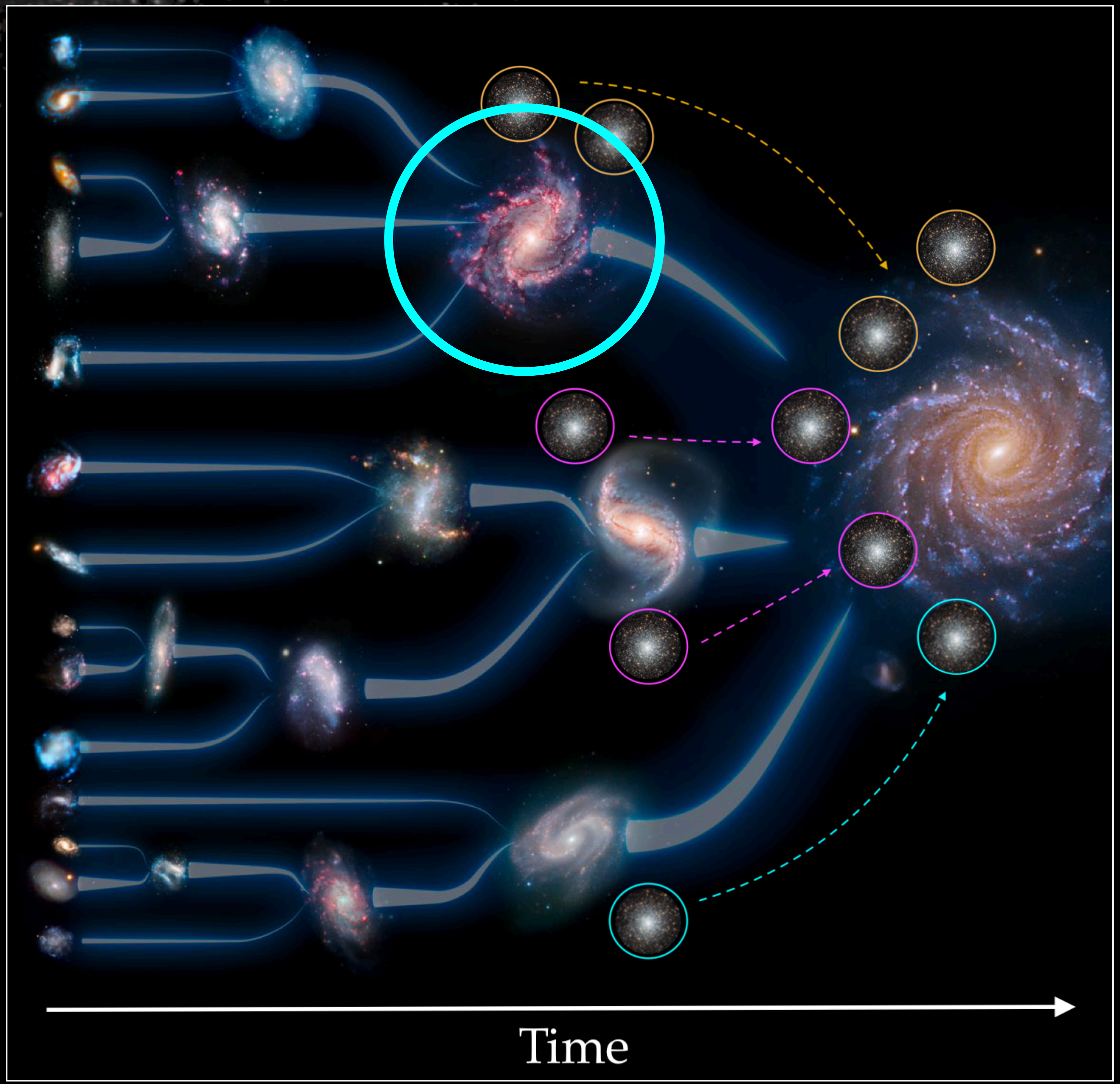

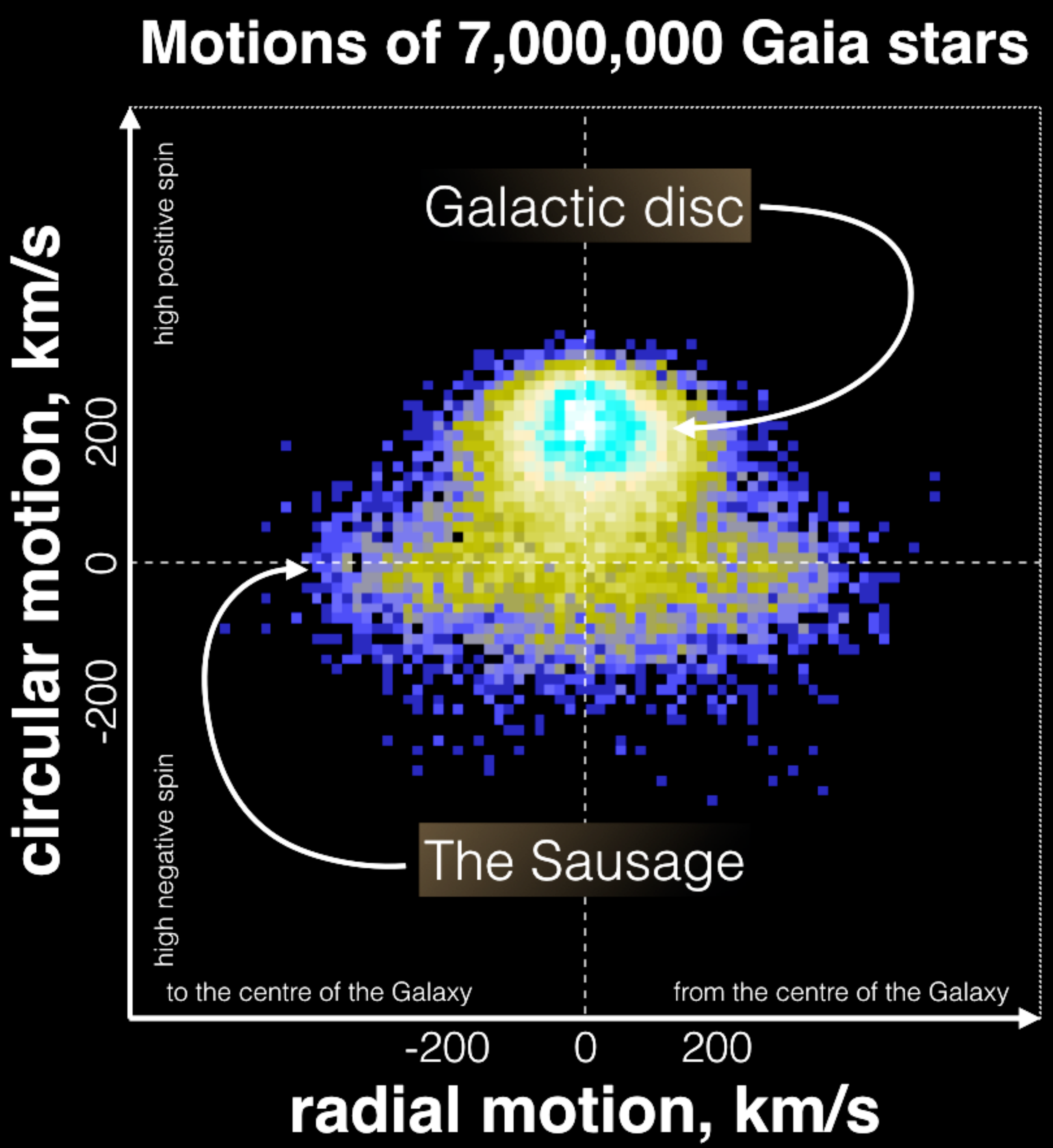

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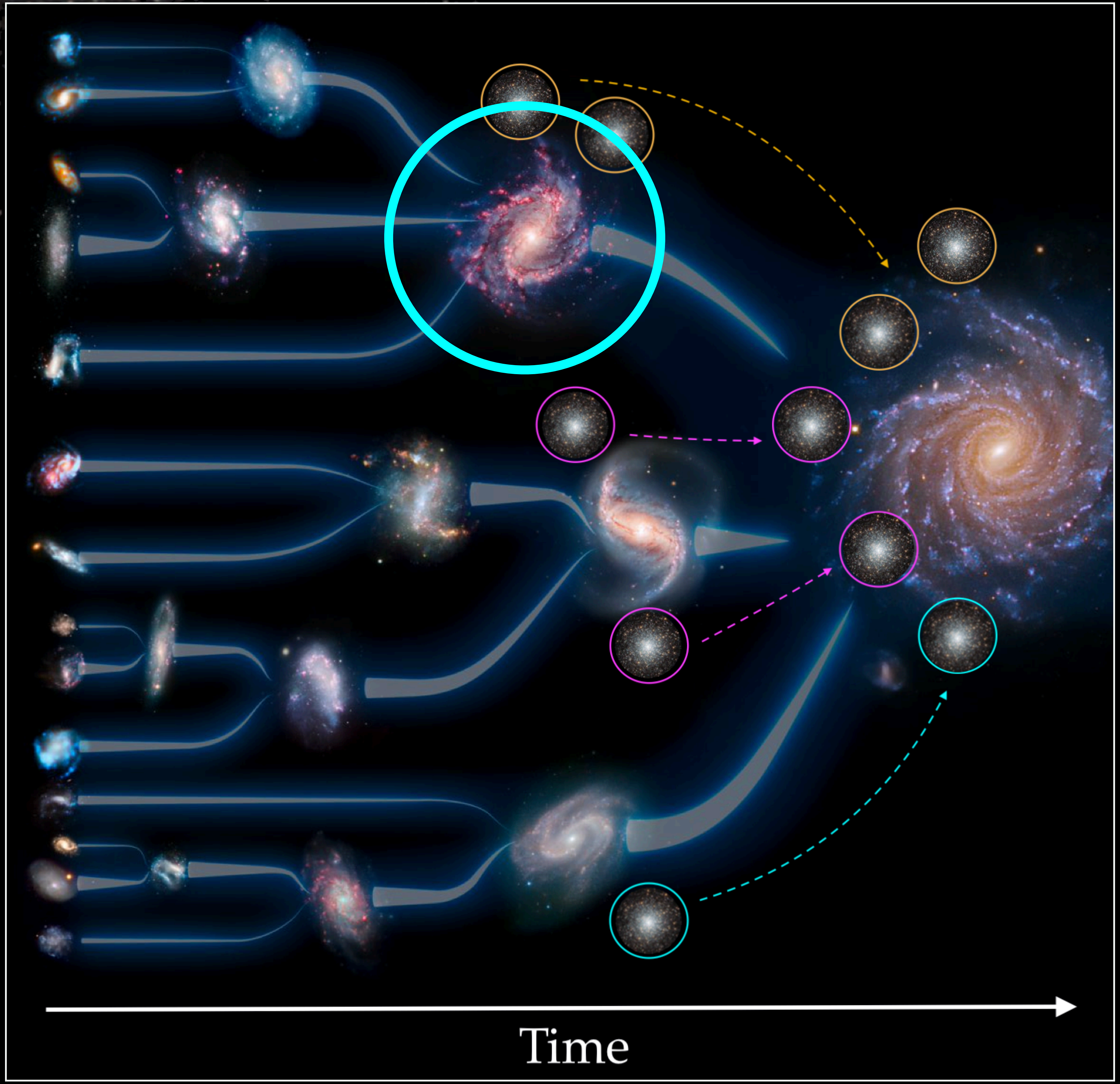

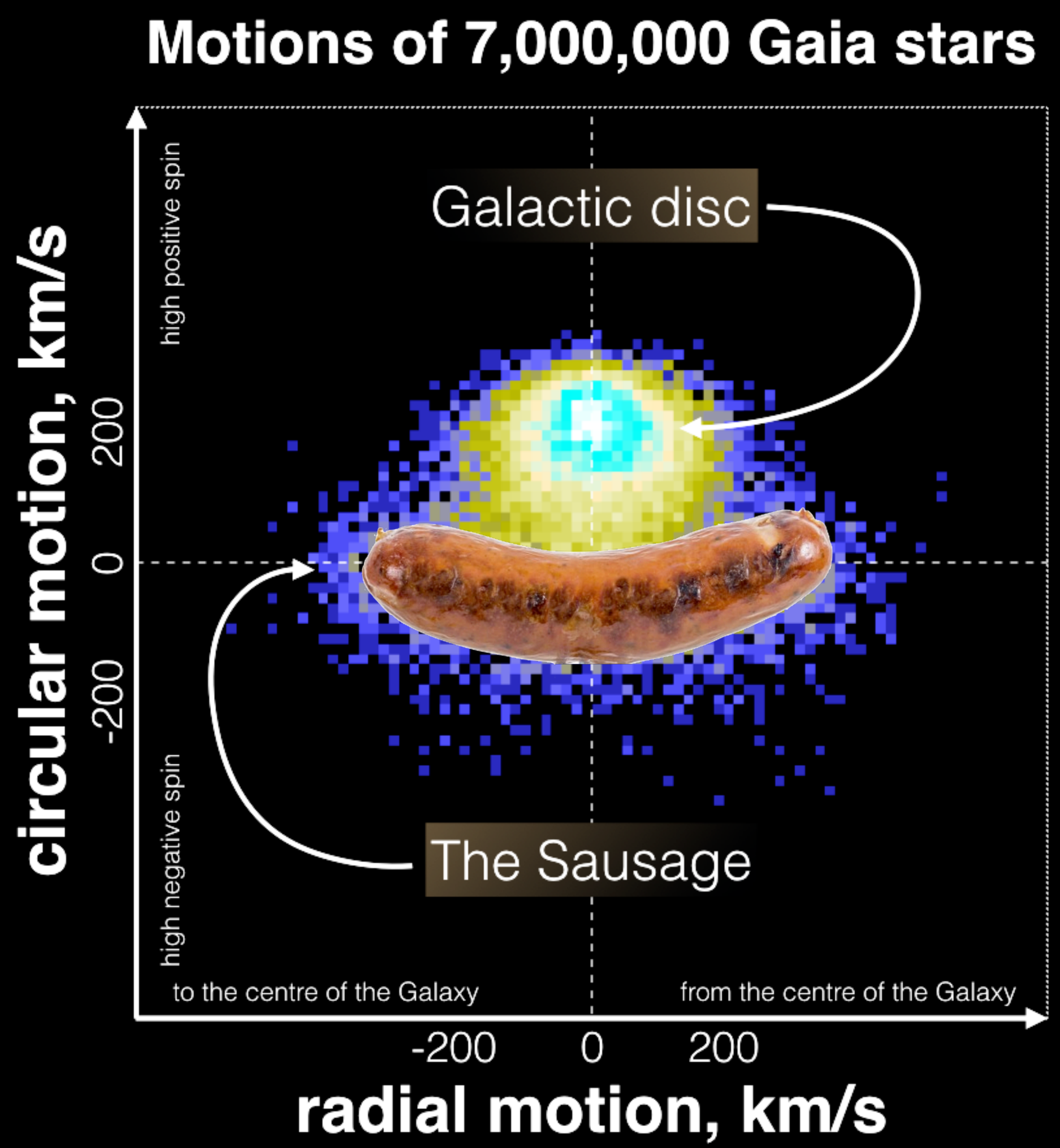

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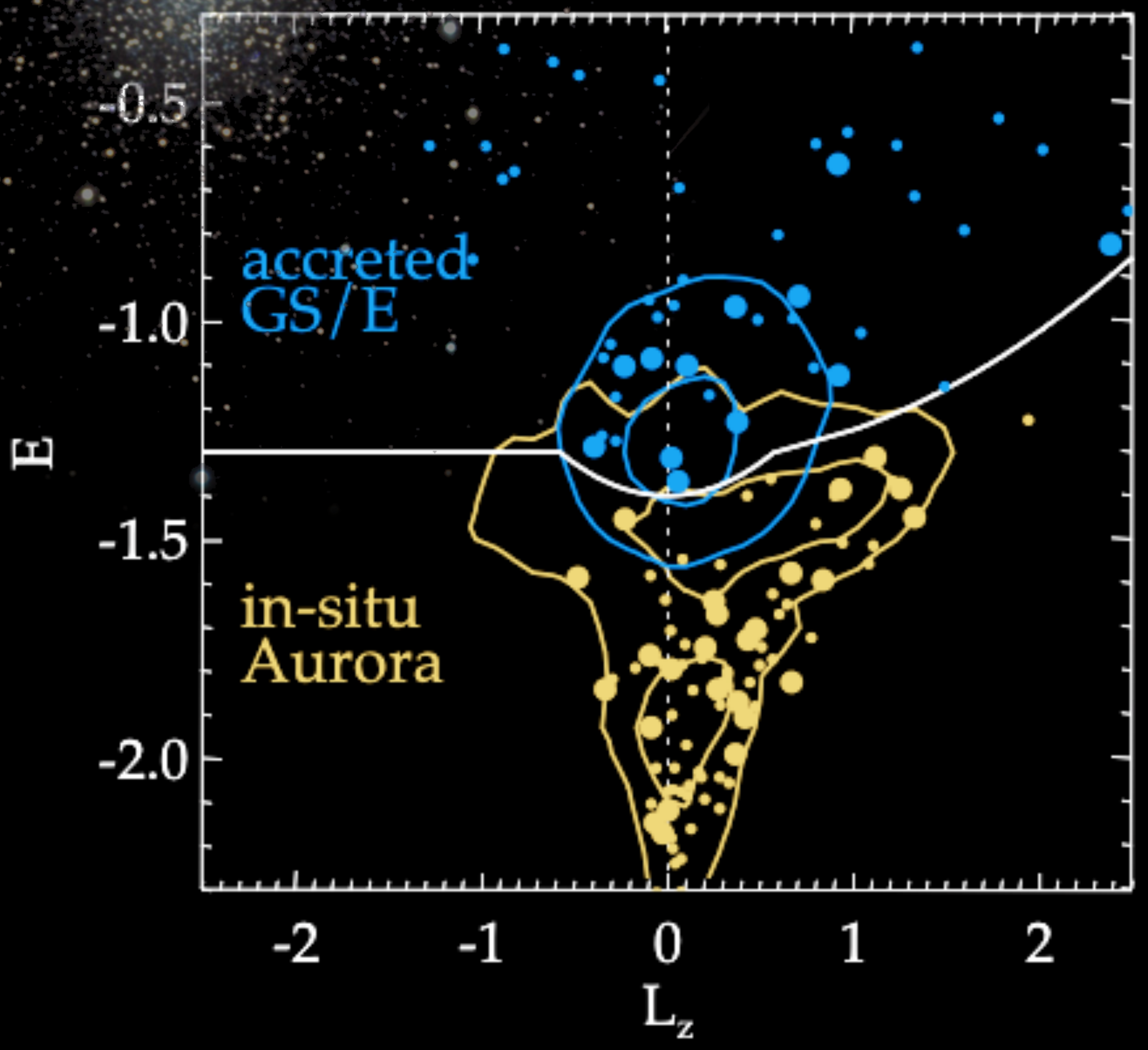
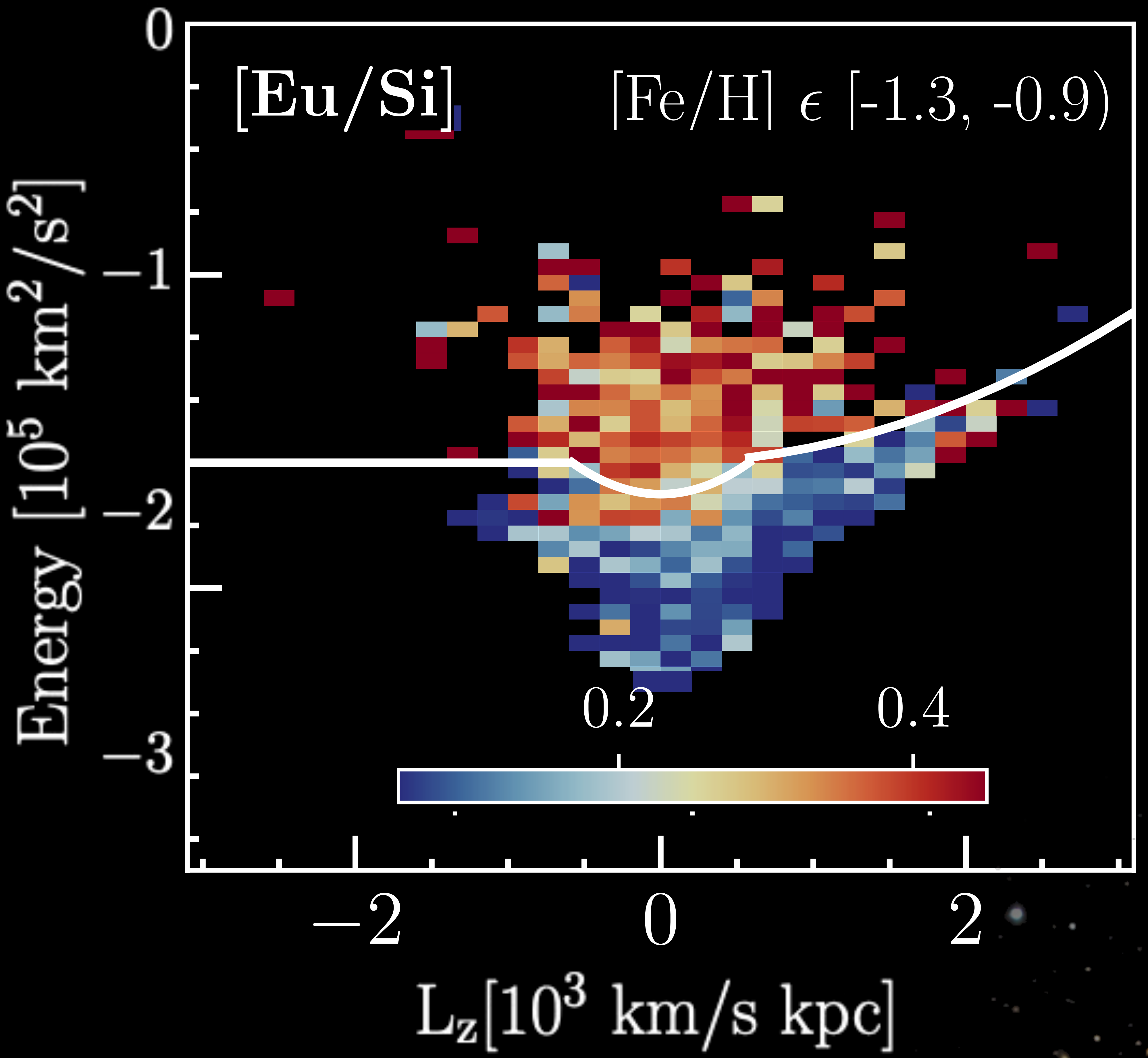
Gaia-Sausage/Enceladus in Chemical & Dynamical Space





Belokurov et al. 2022

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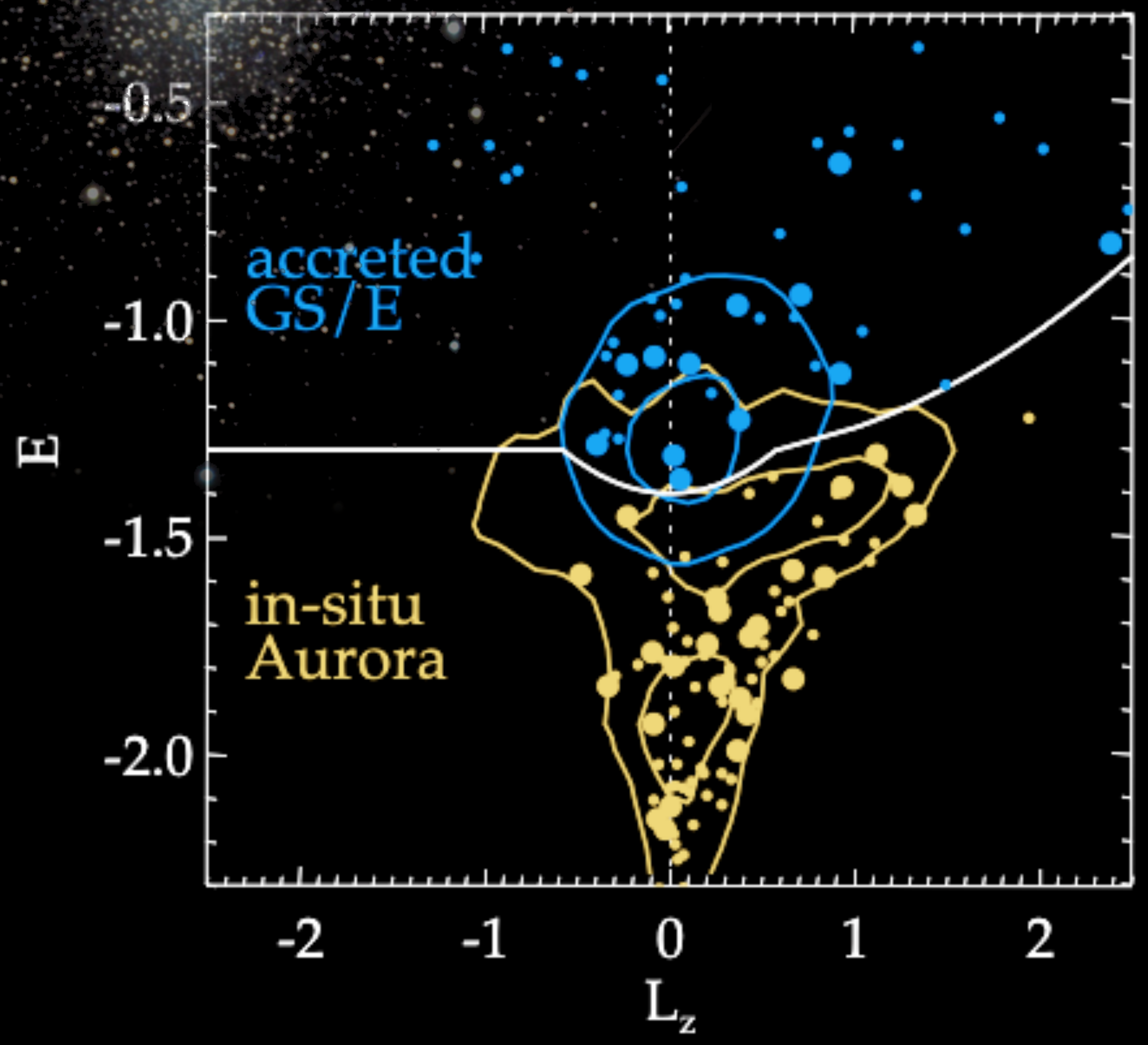

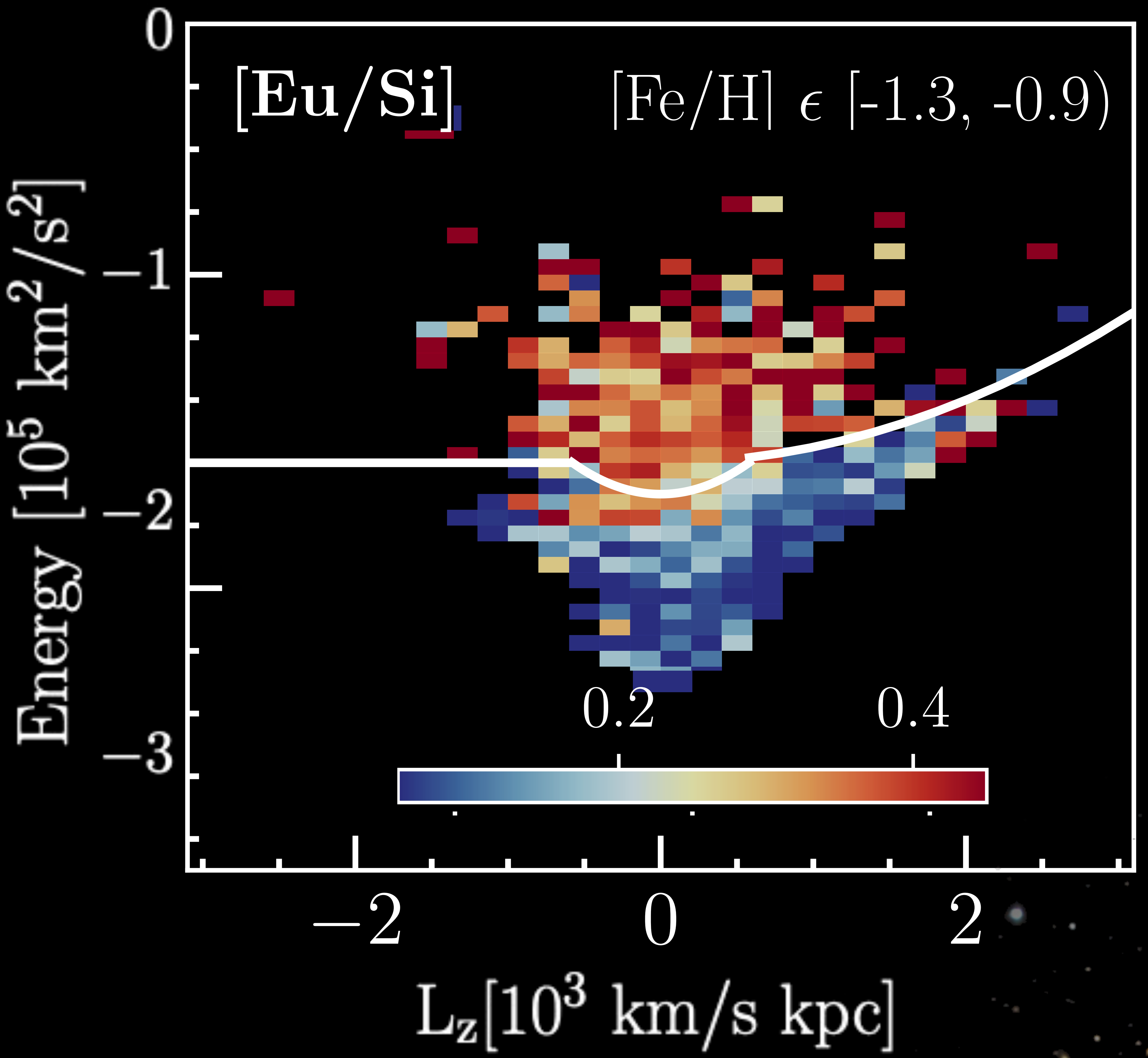

Highly radial, plunging orbits —> little net angular momentum

Belokurov et al. 2022

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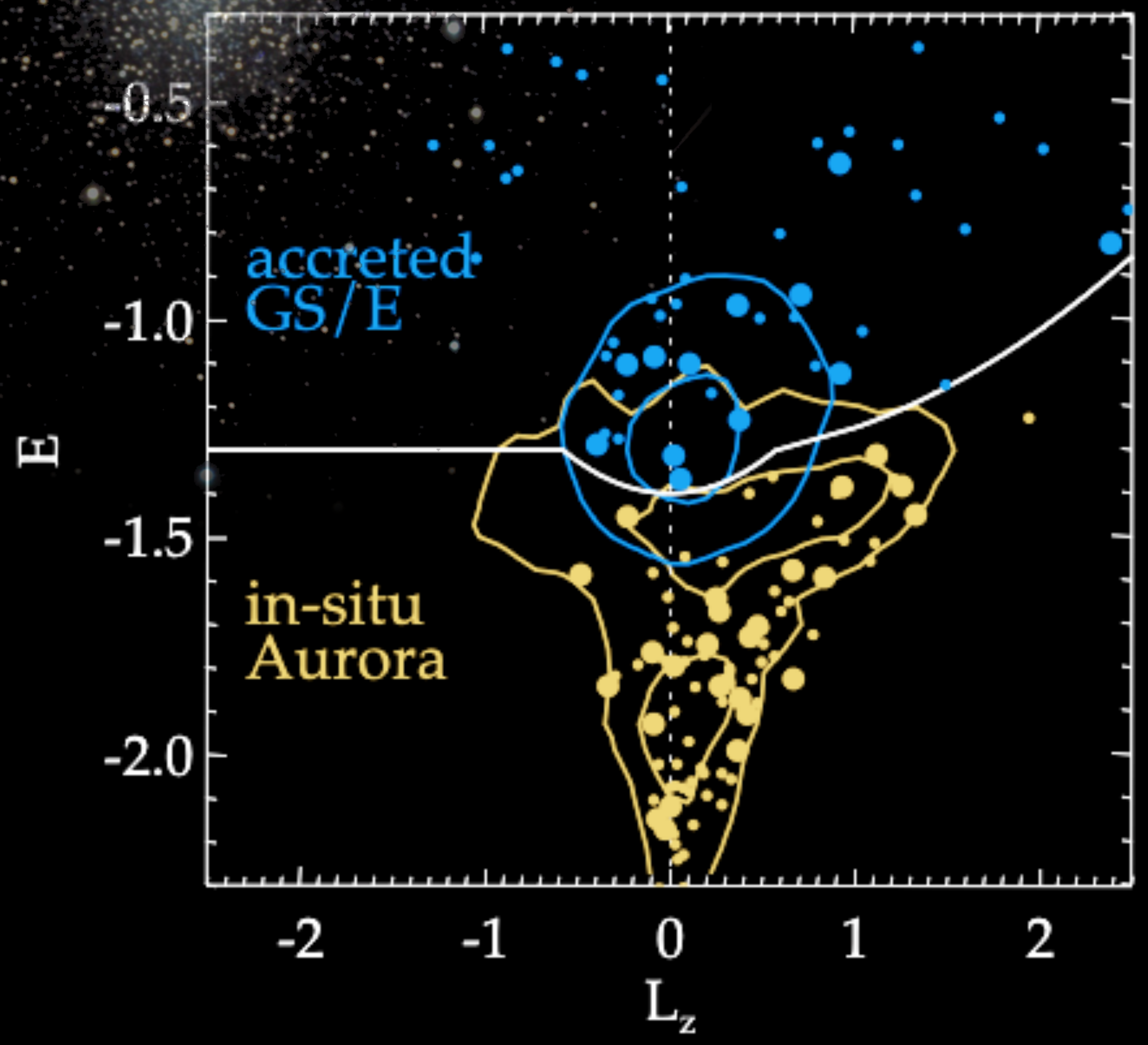

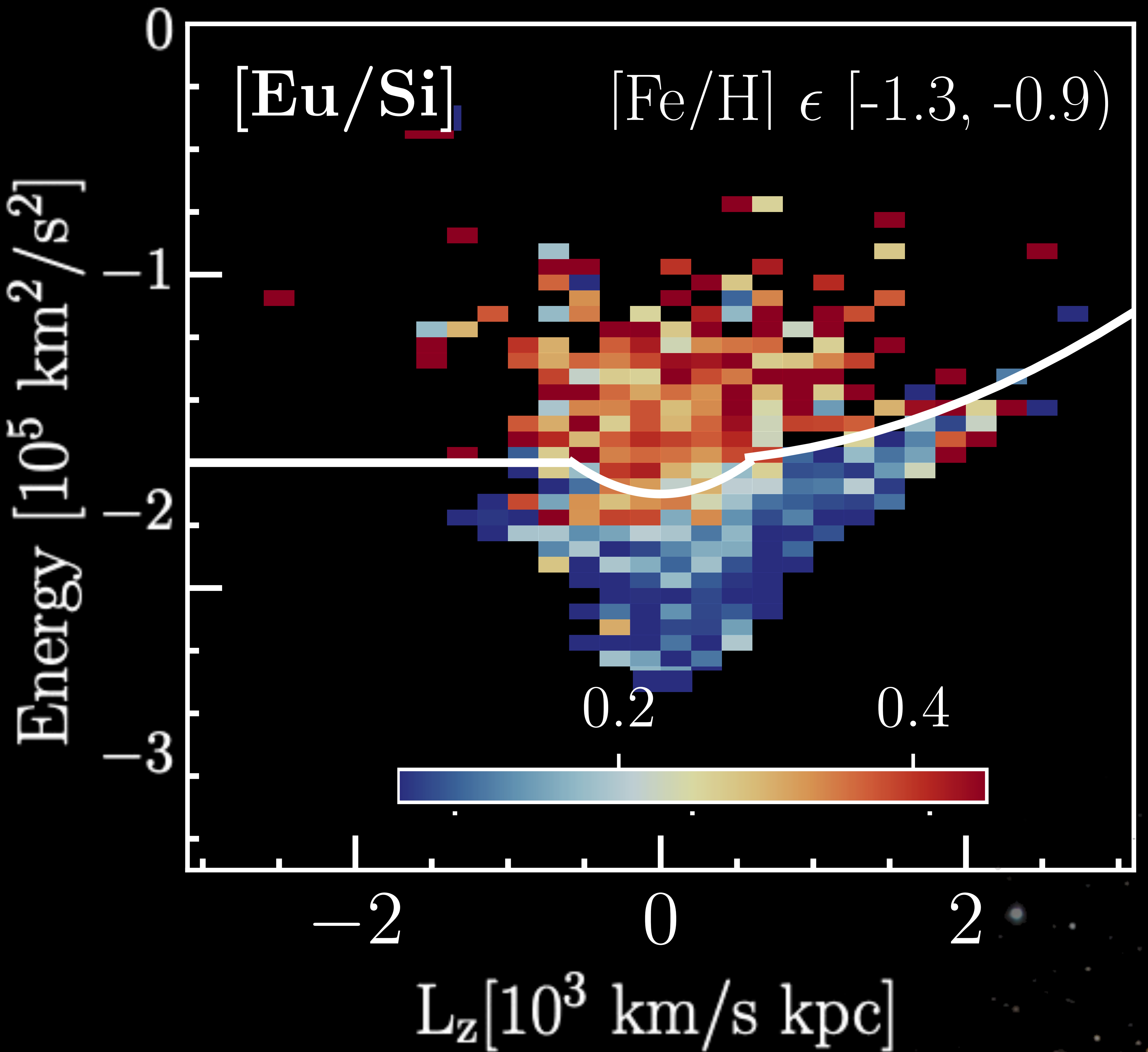

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[Si/Fe] depletion, [Eu/Fe] enhancement

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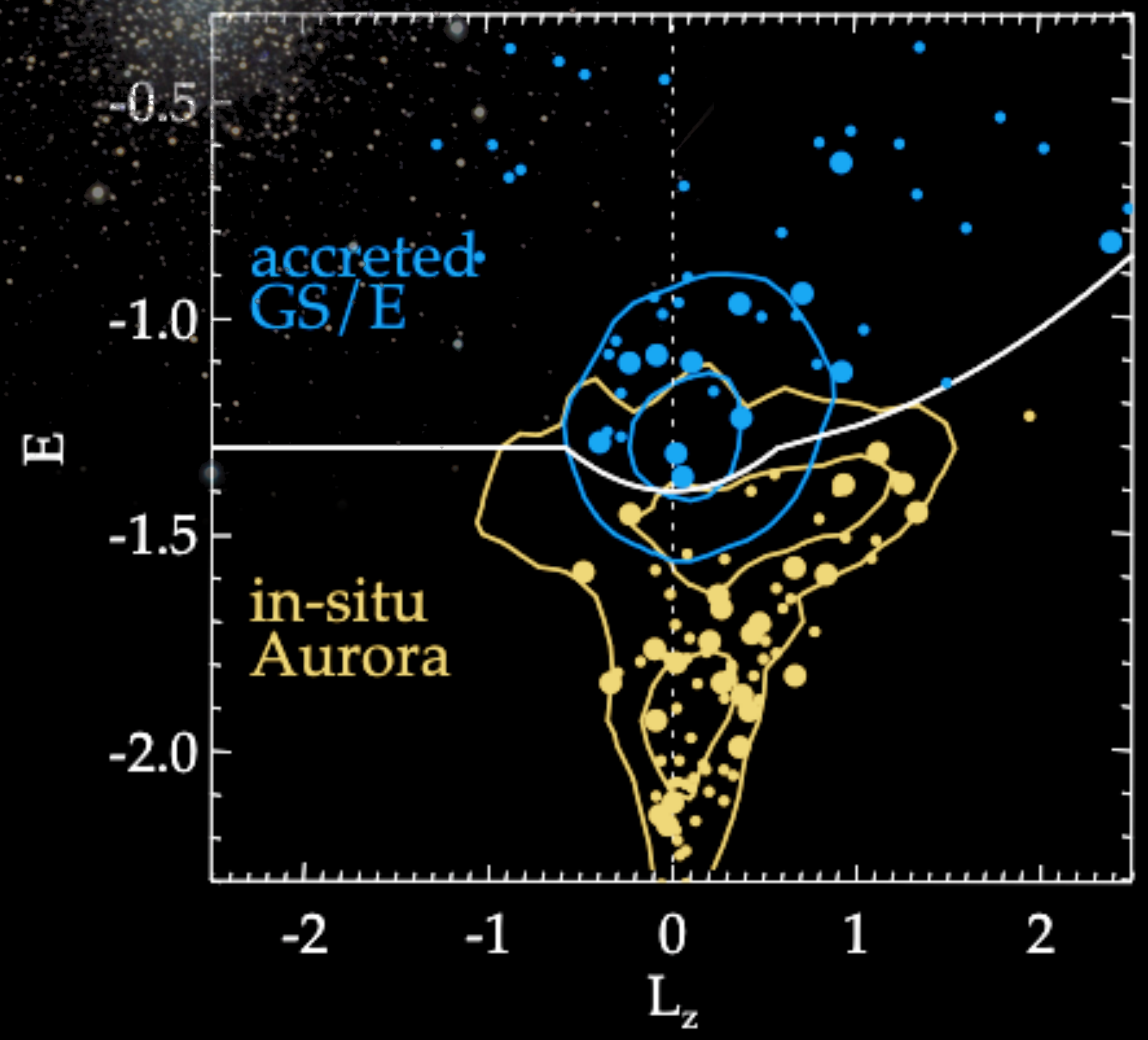

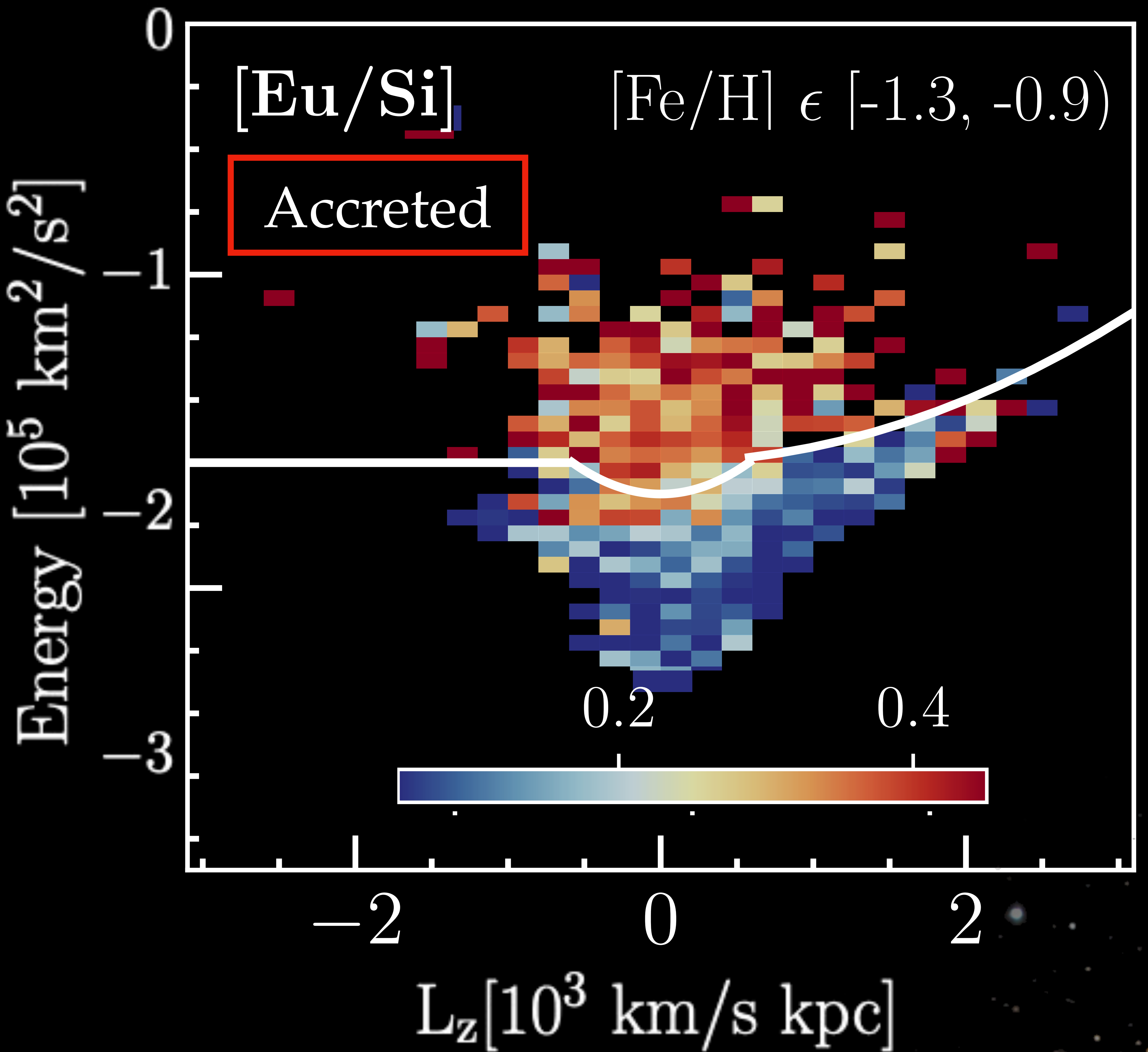

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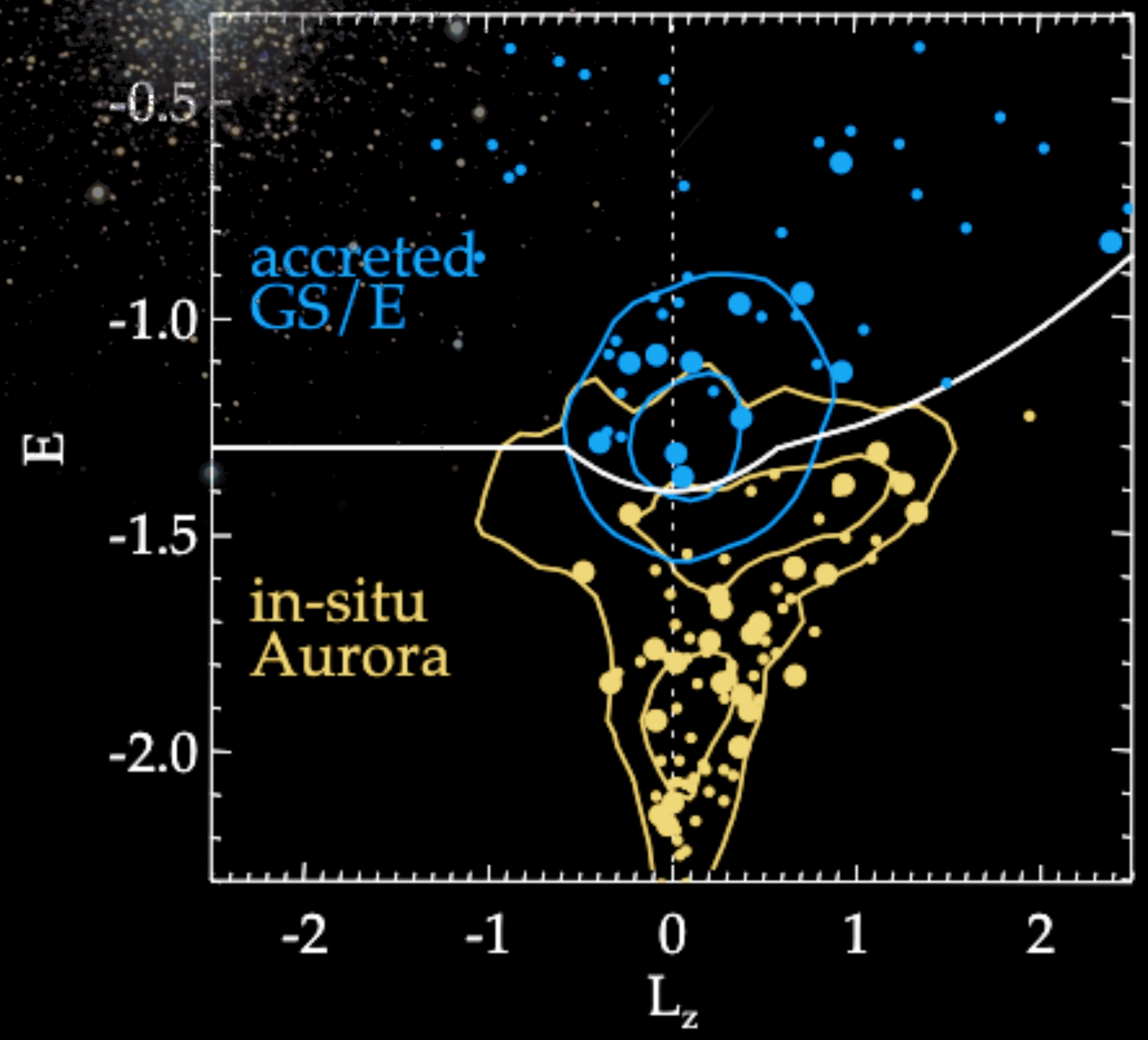

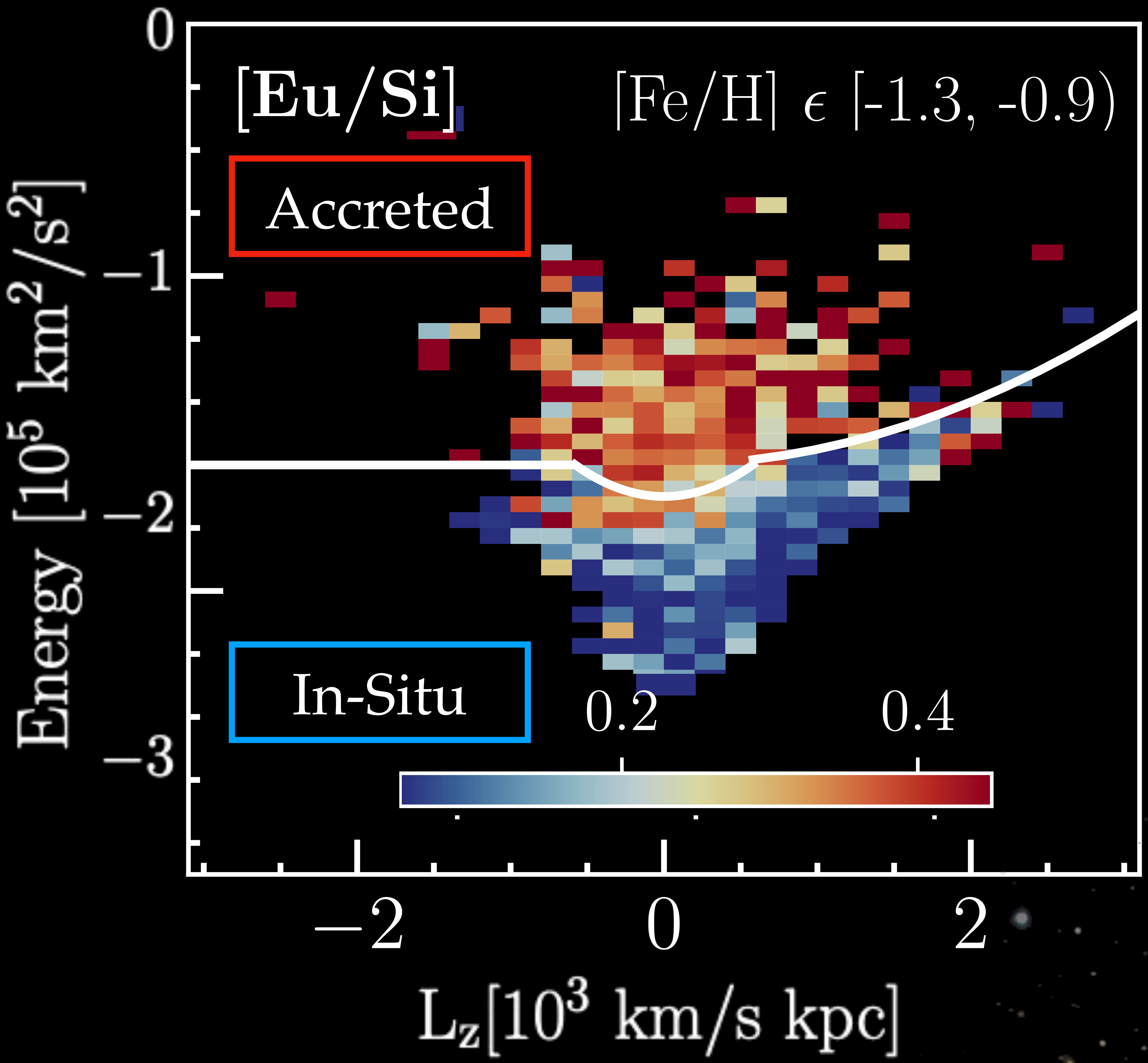

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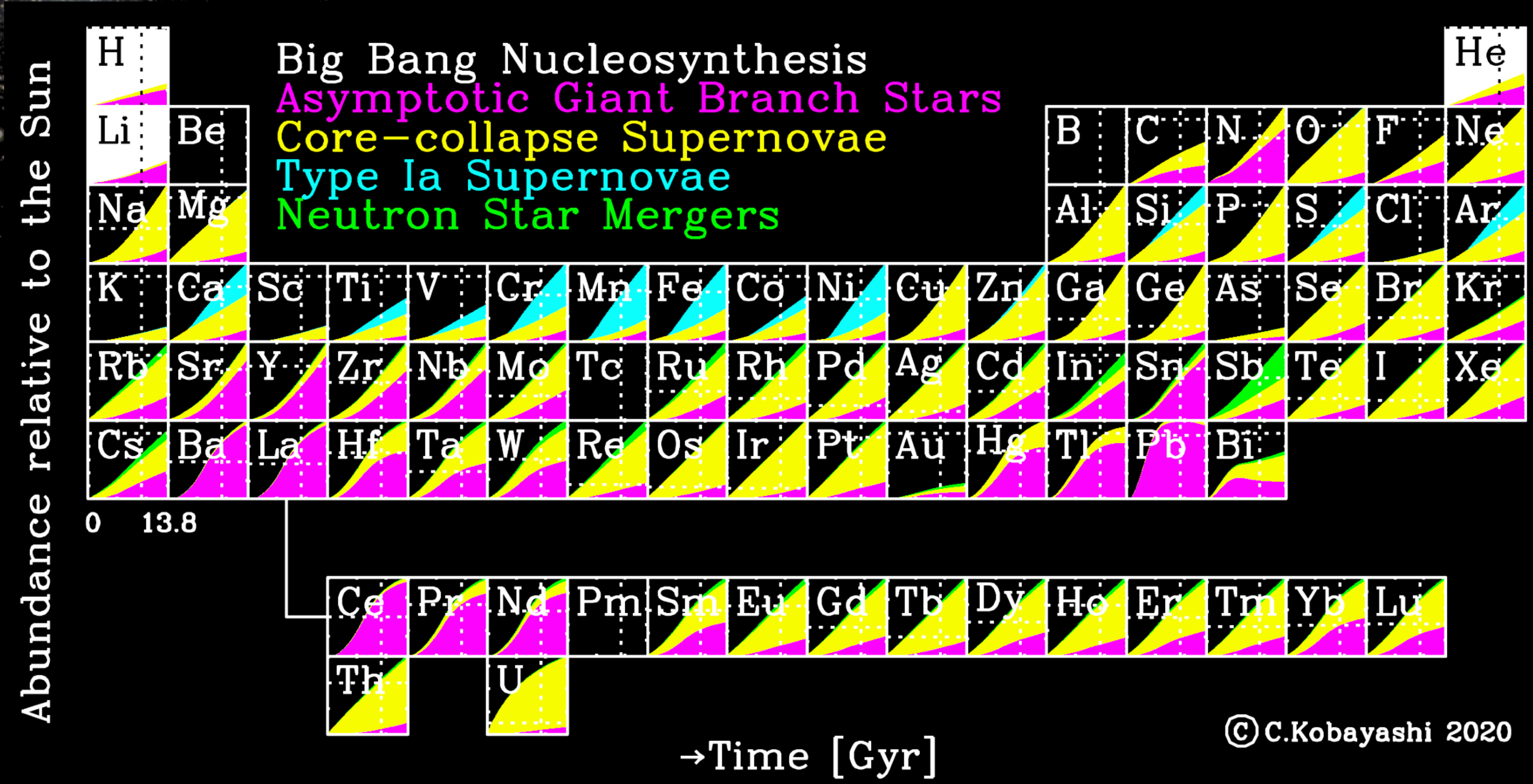
Nucleosythentic Sites and Signatures



Kobayashi, Karakas & Lugaro, 2020

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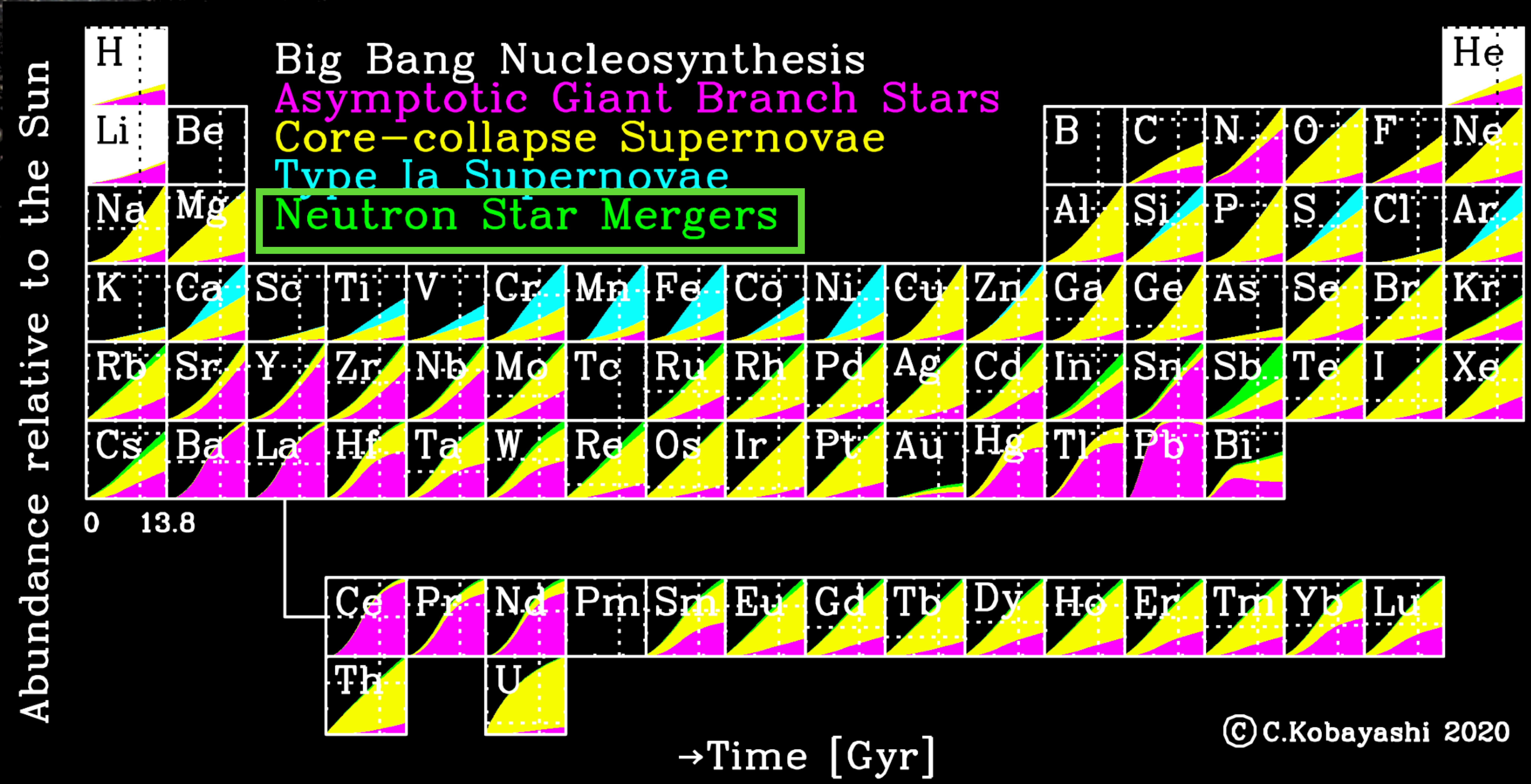

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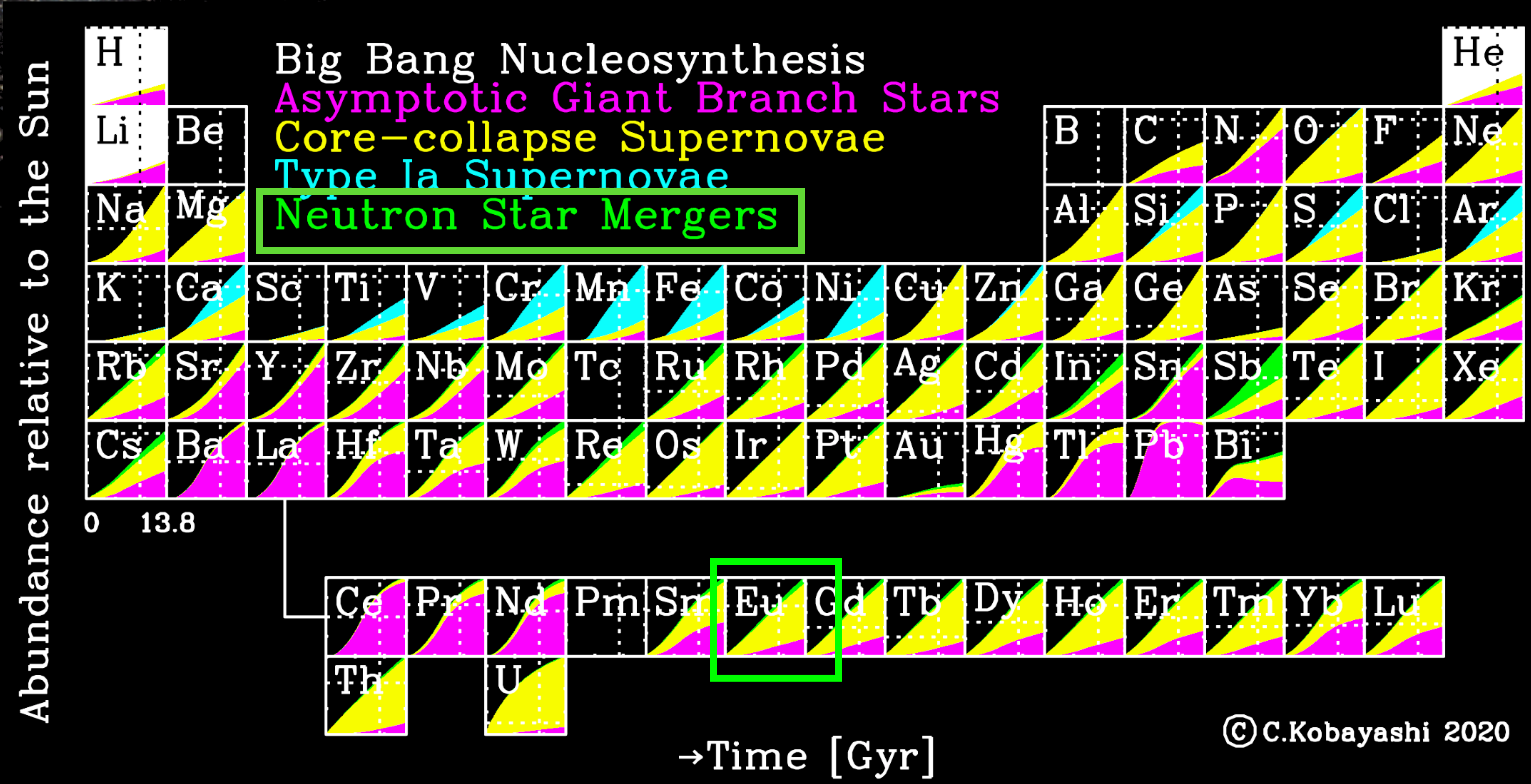

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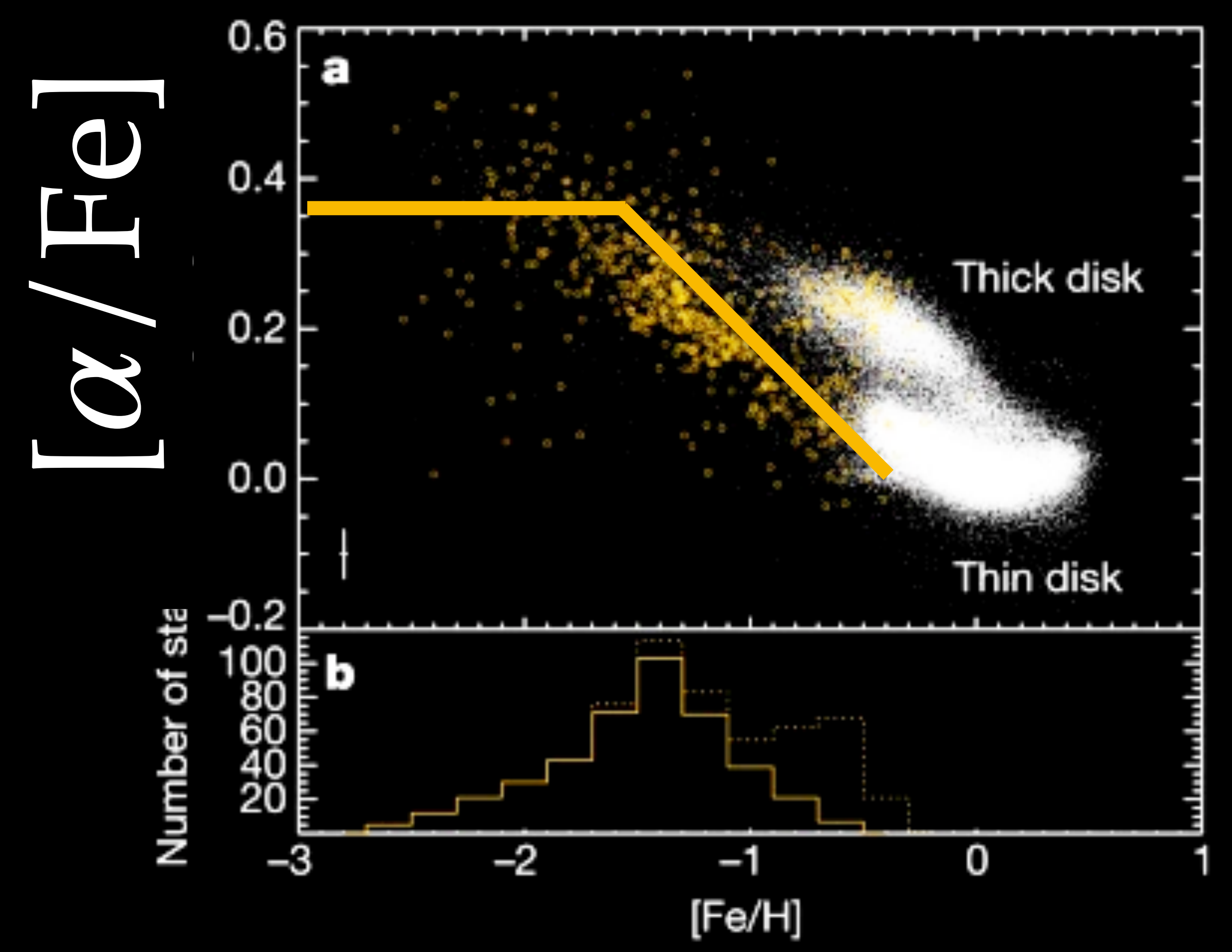
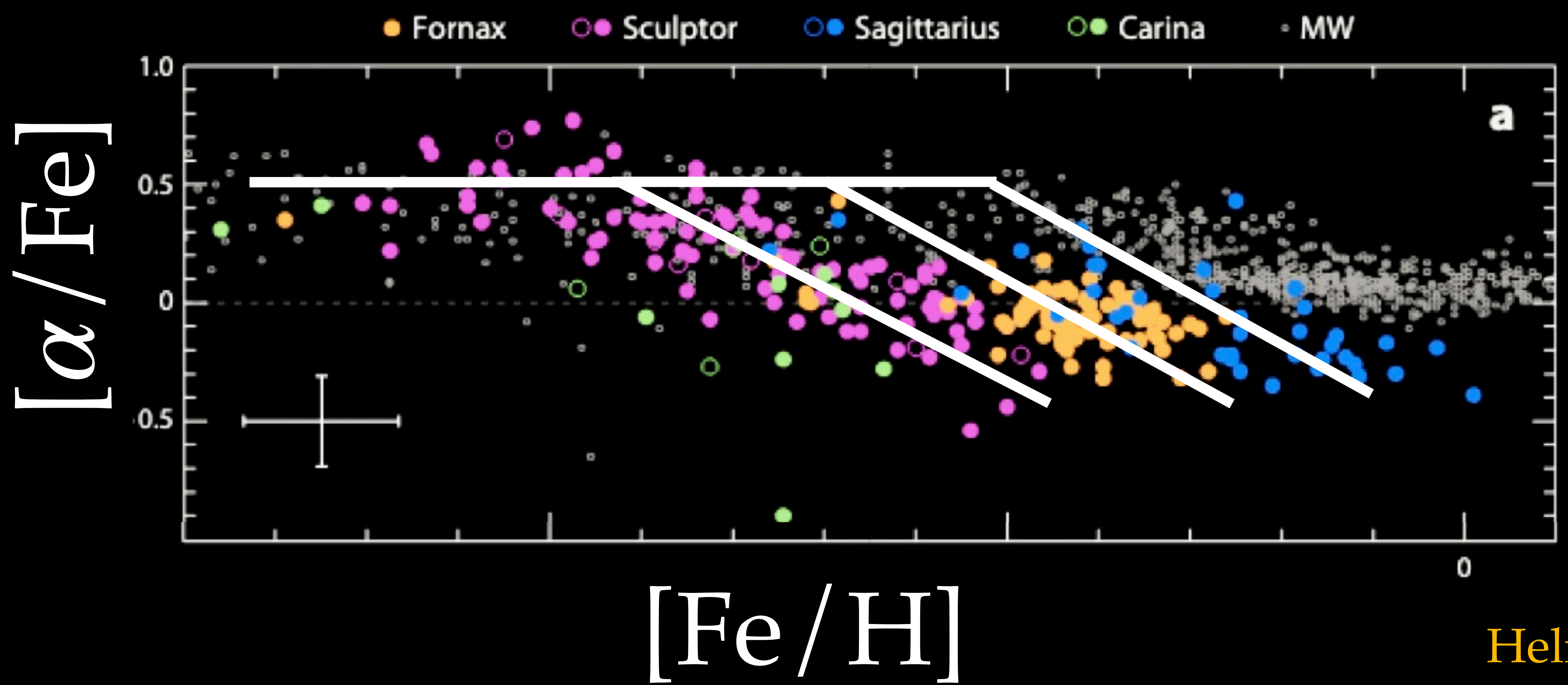
Gaia-Sausage-Enceladus has a unique signature in [Eu/α]





Helmi et al. 2018, Tolstoy et al. 2009 Matsuno et al. 2021, Aguado et al. 2021

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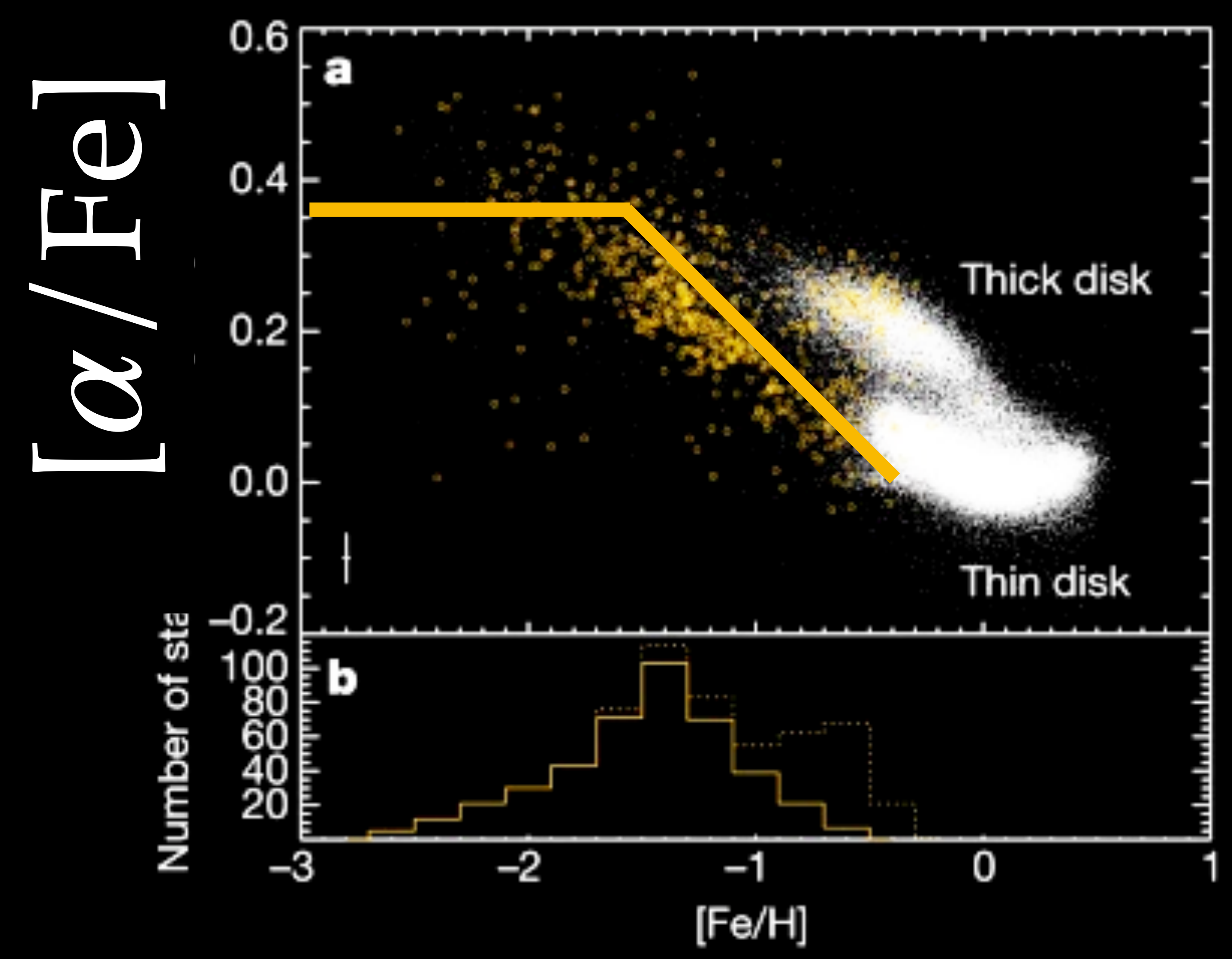
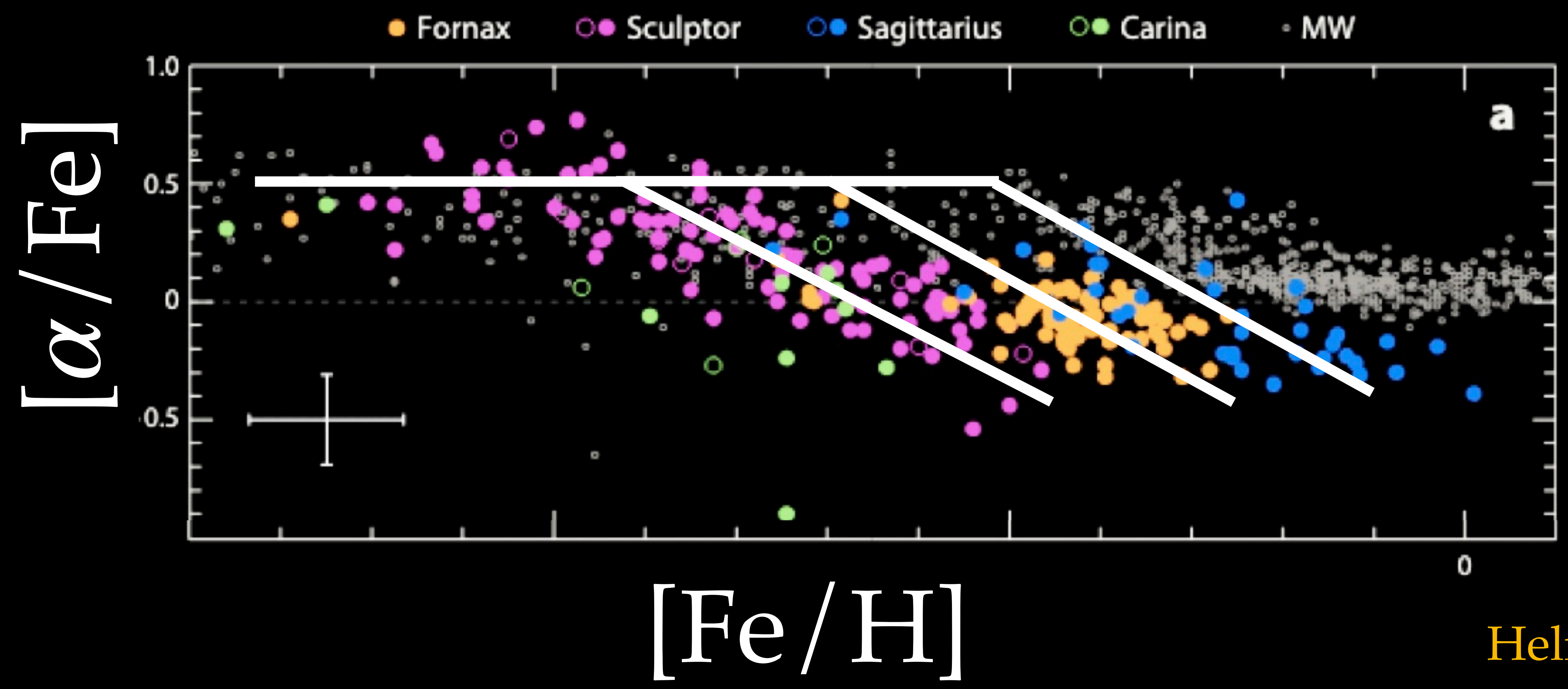


[α/Fe] encodes star formation history



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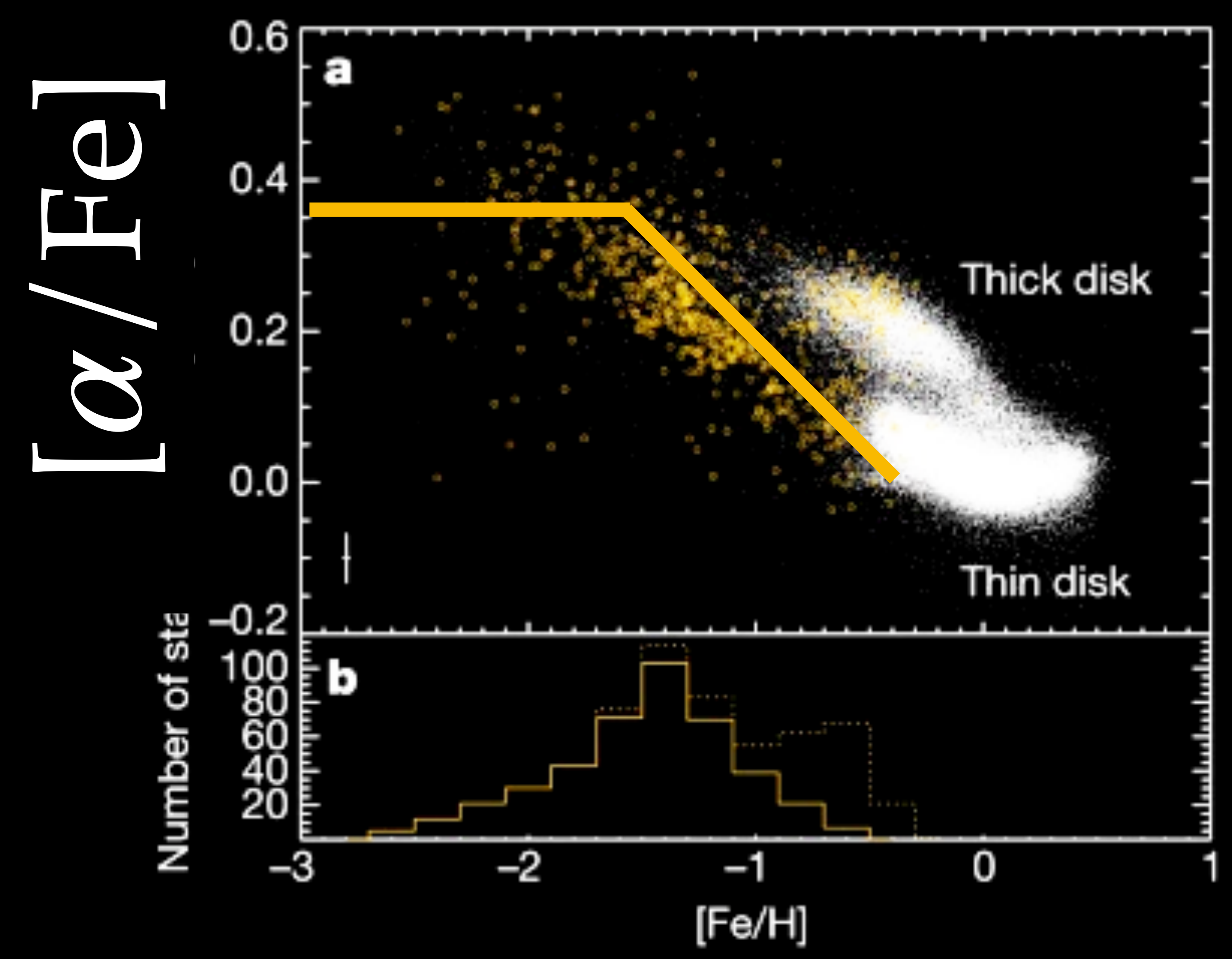

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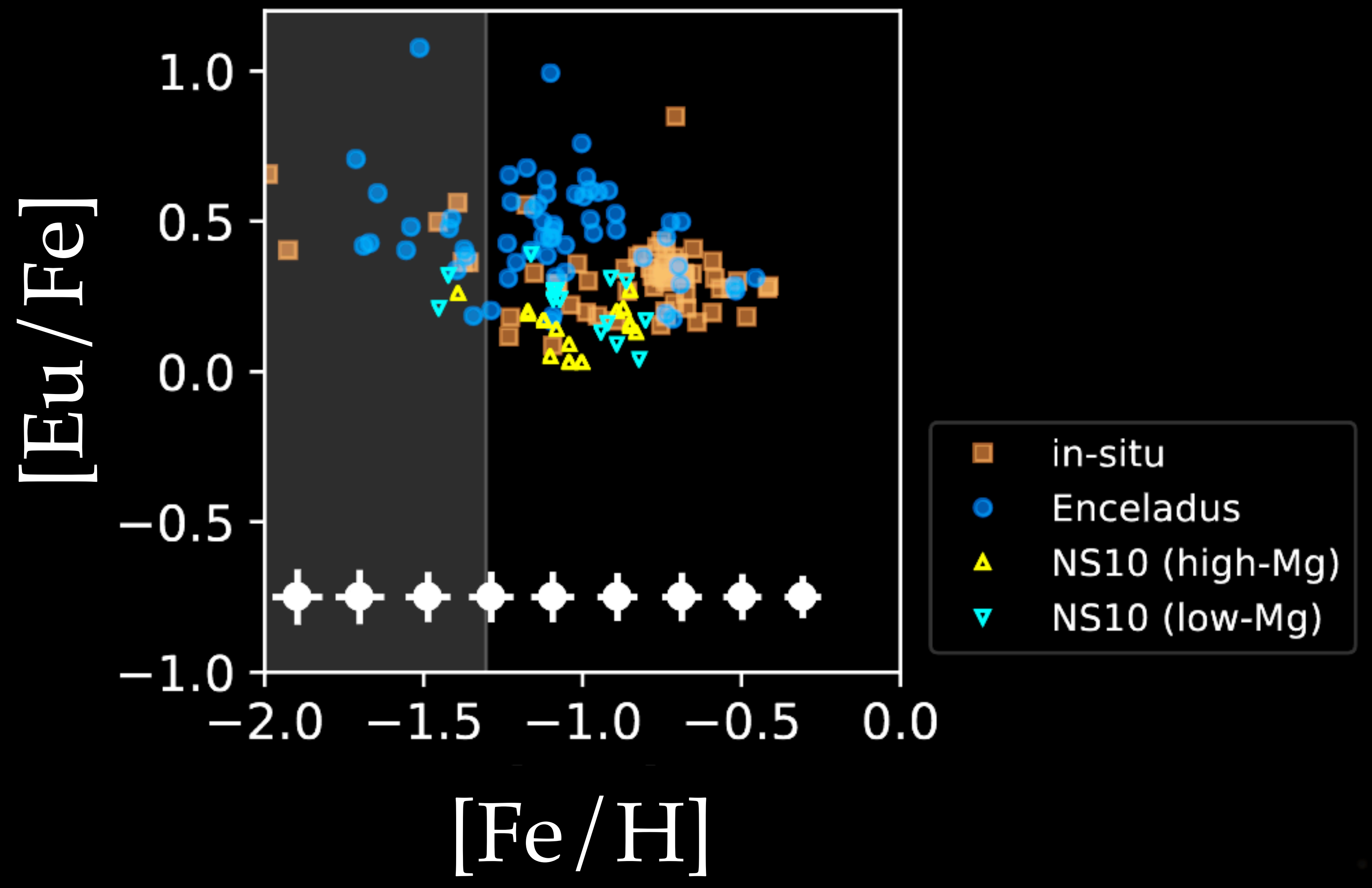

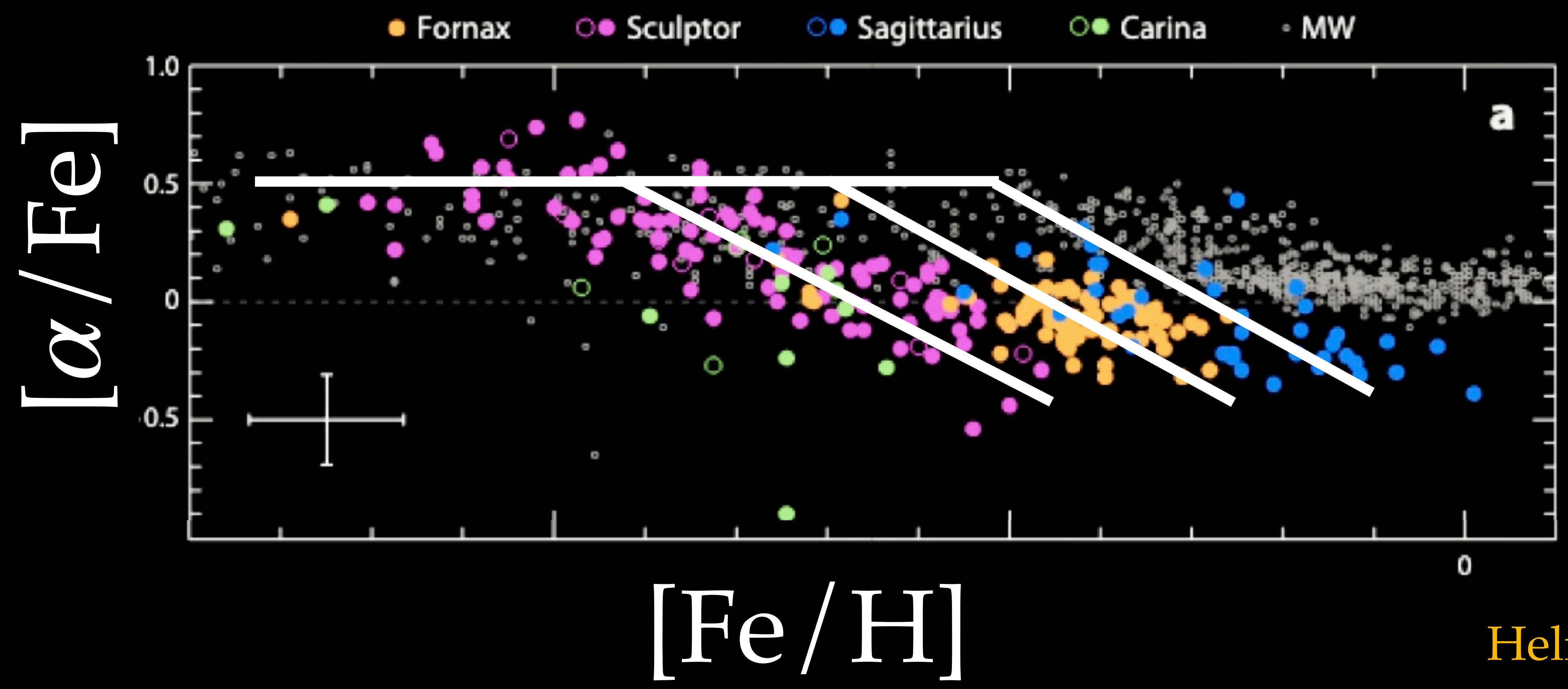

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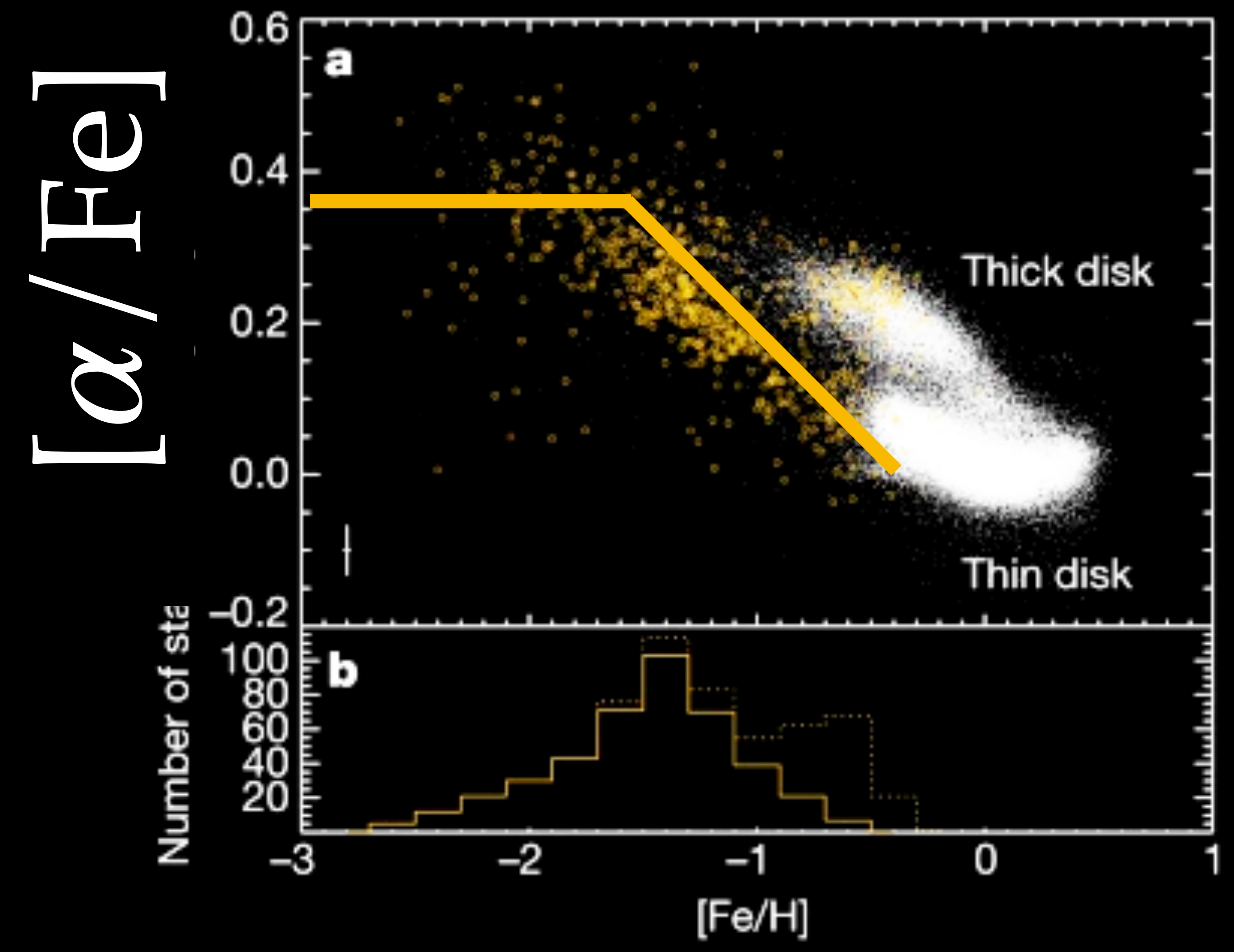

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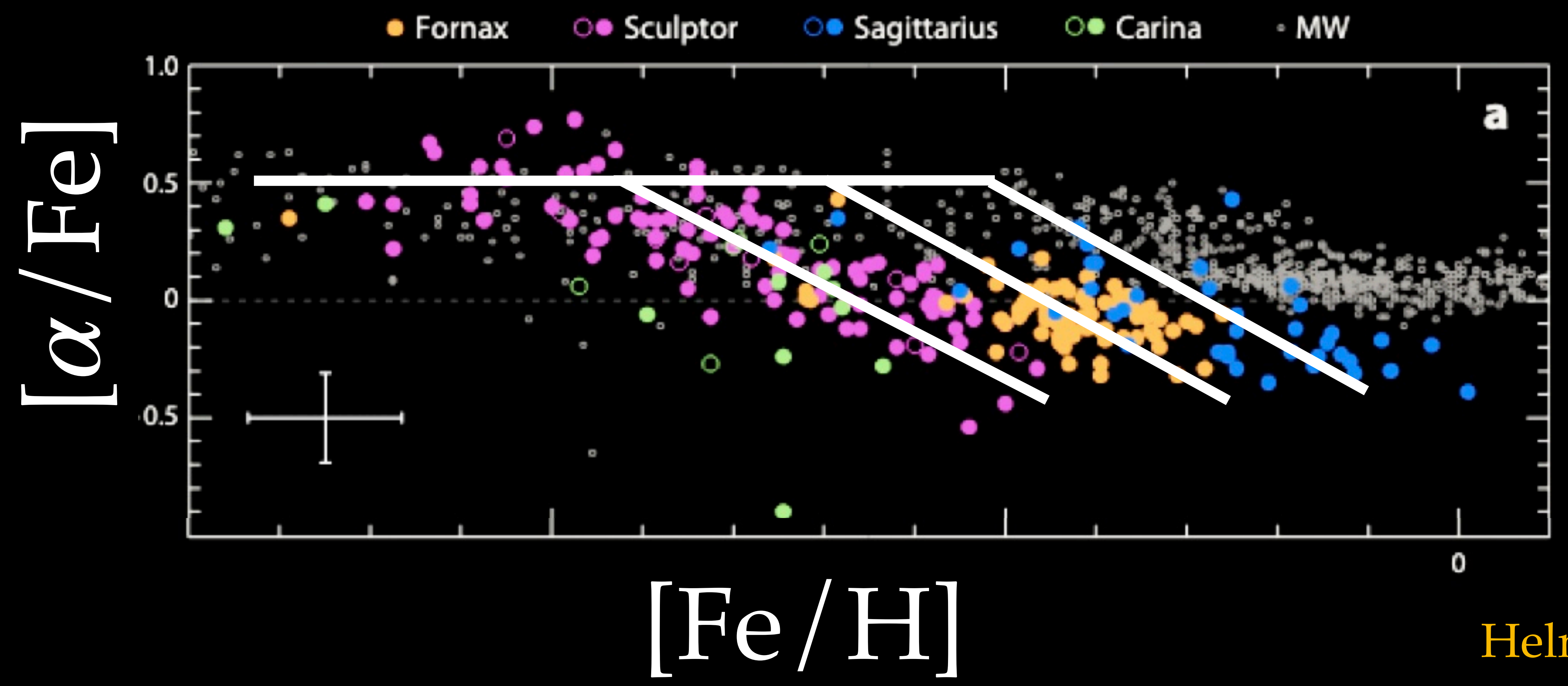

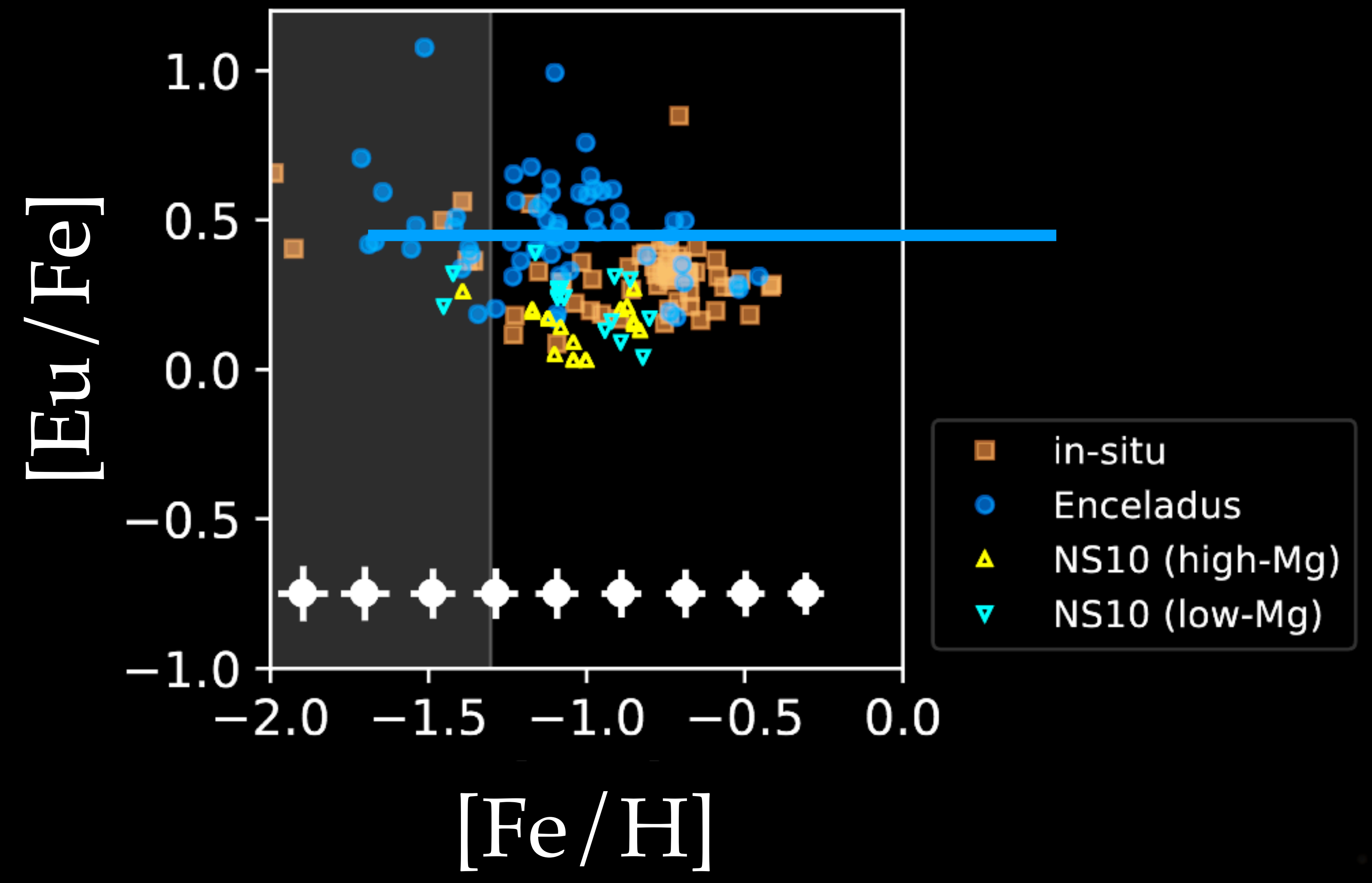

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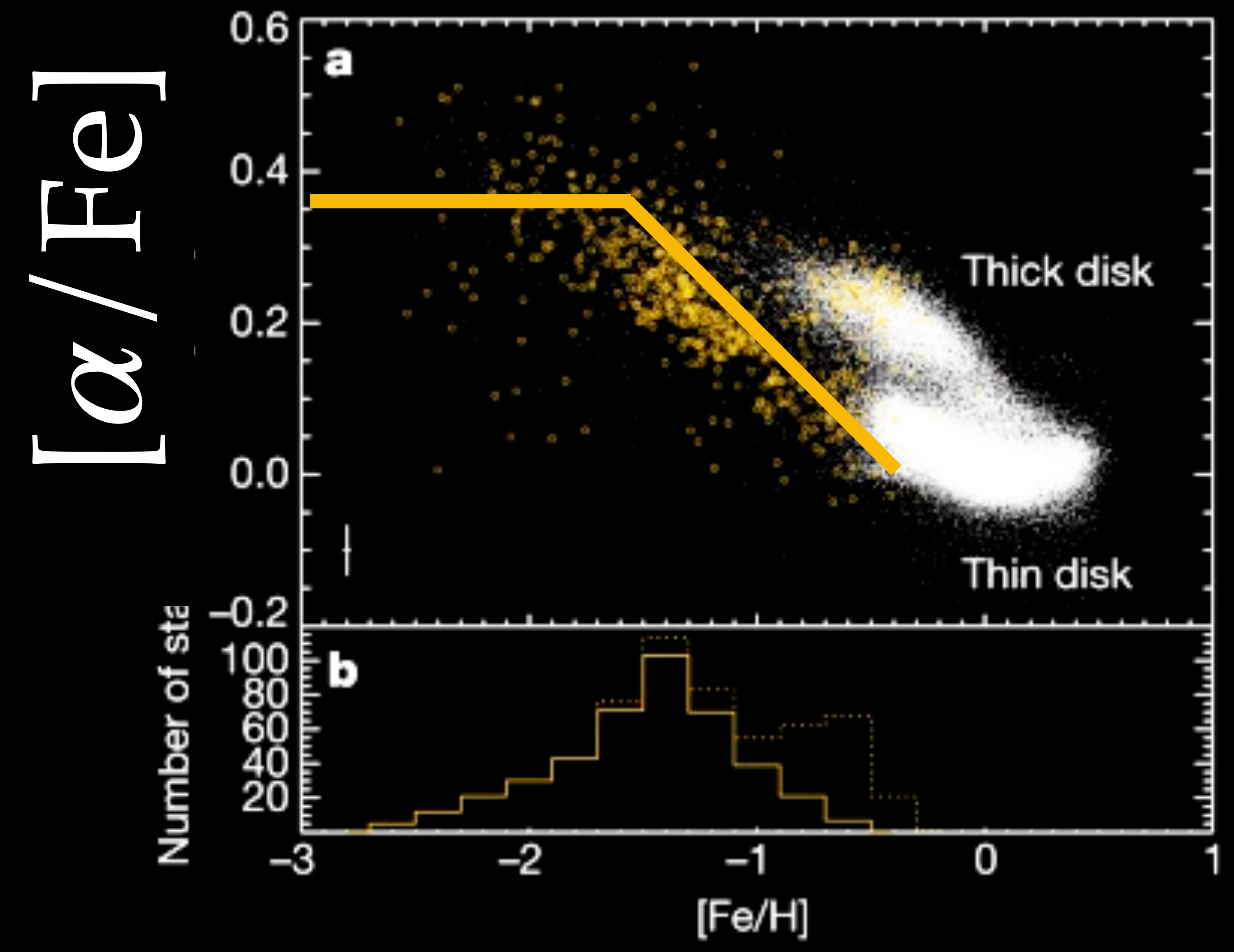
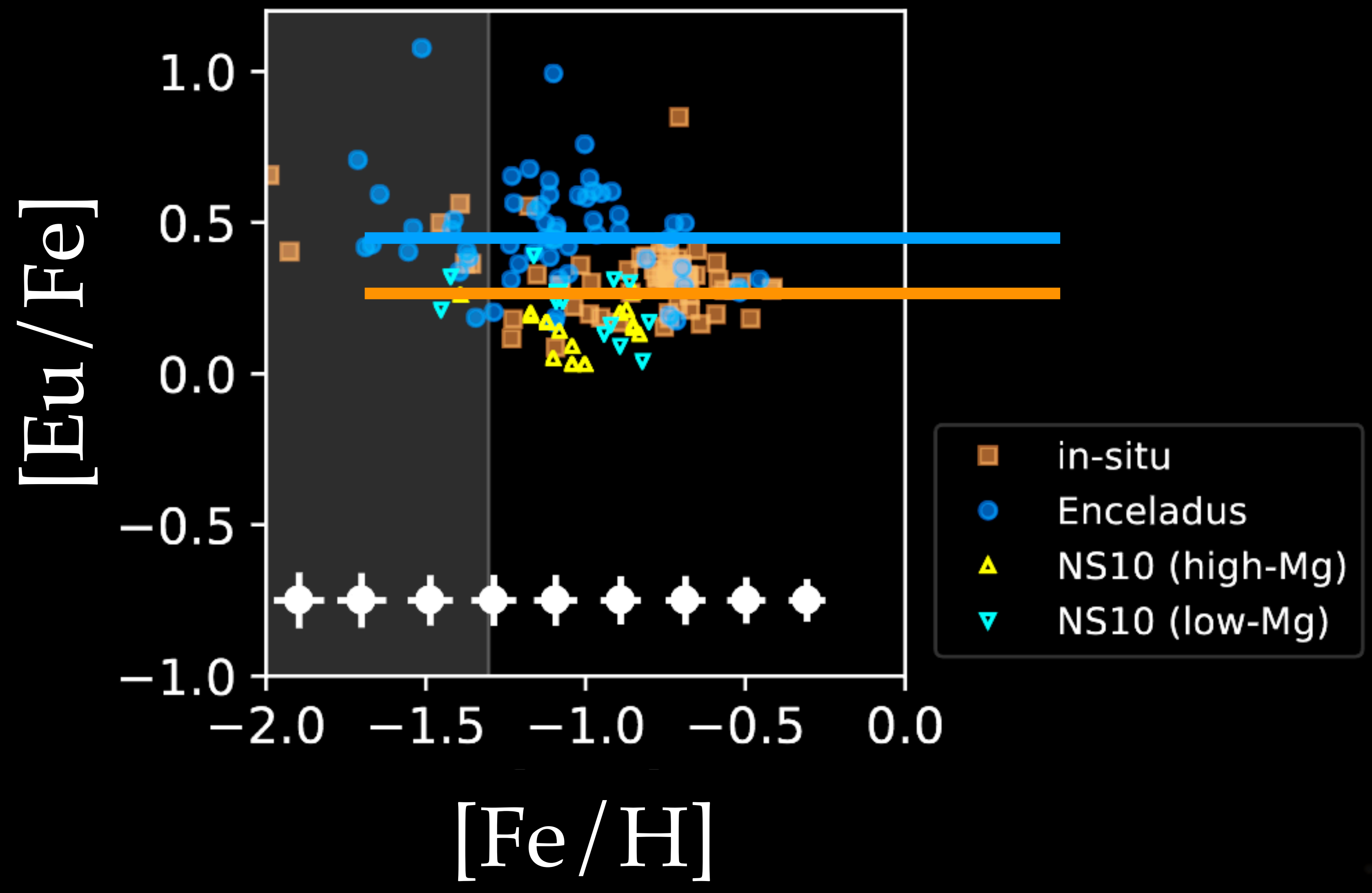
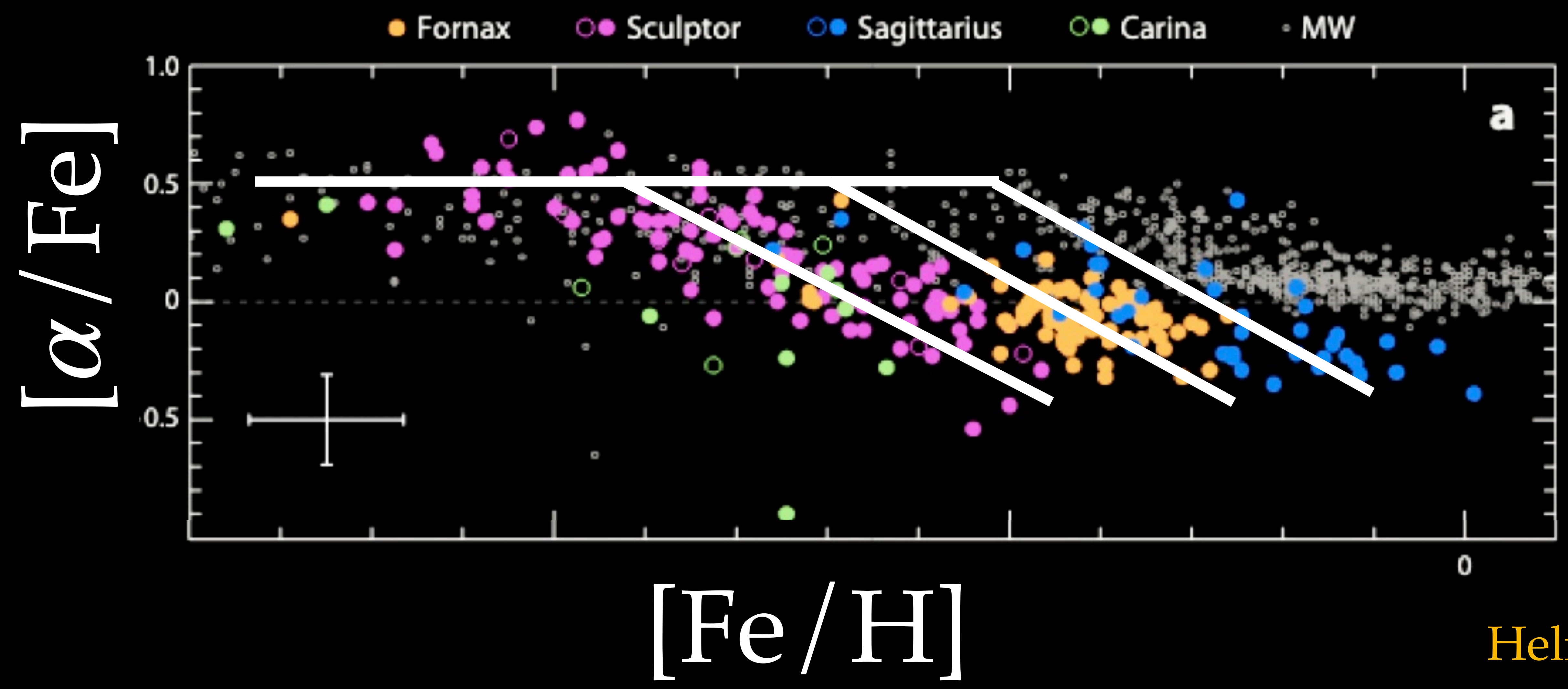


[α/Fe] encodes star formation history





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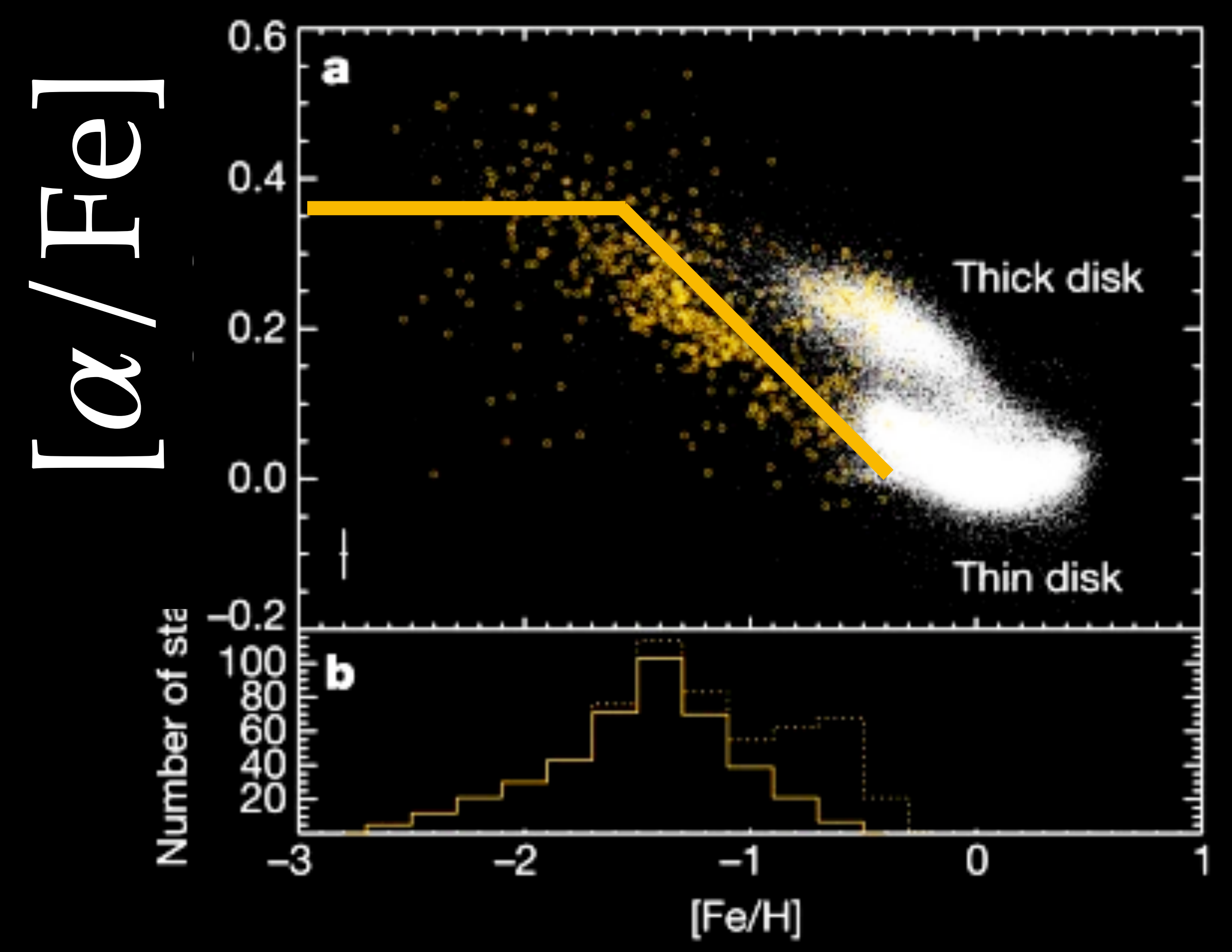

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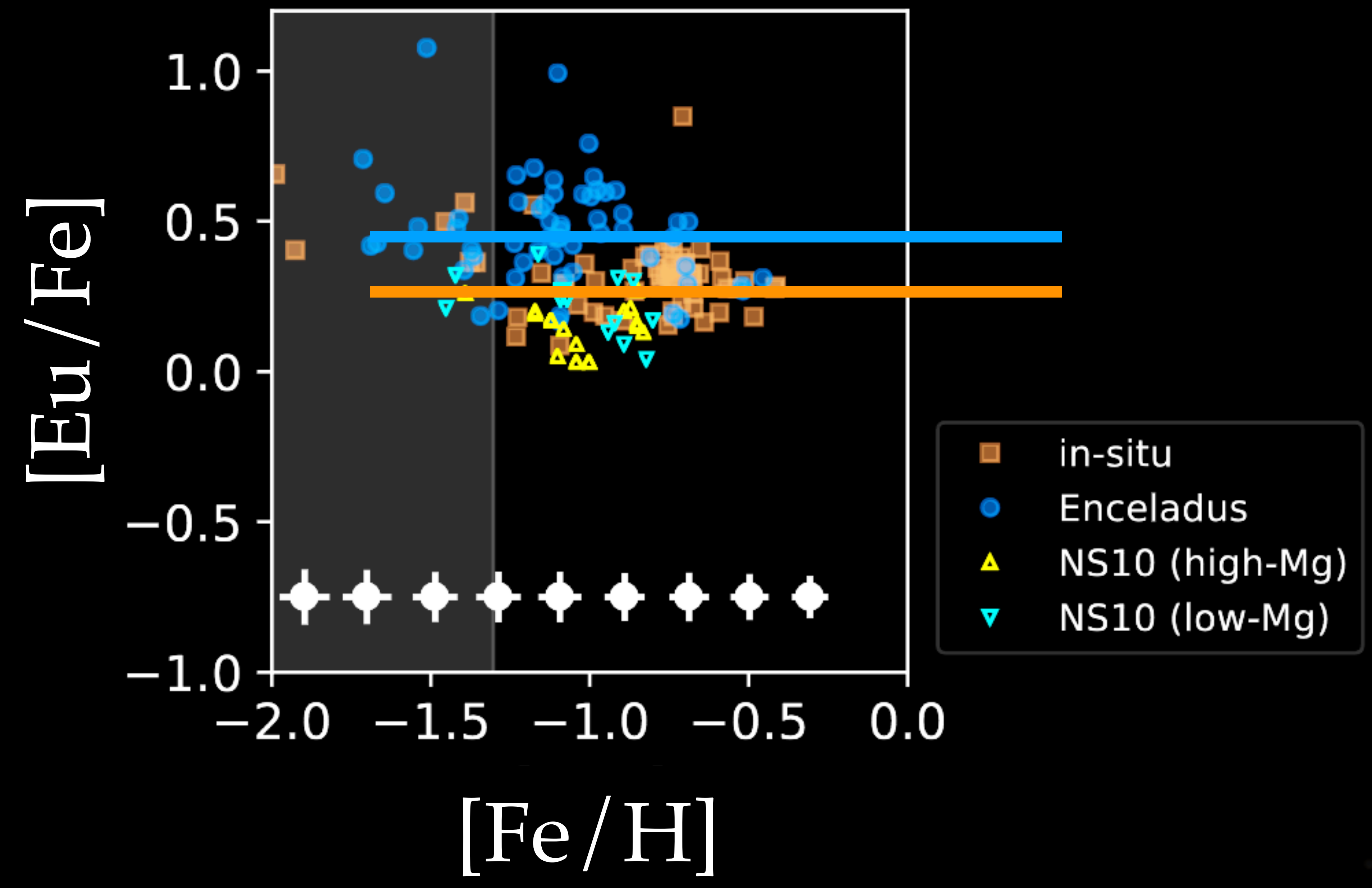

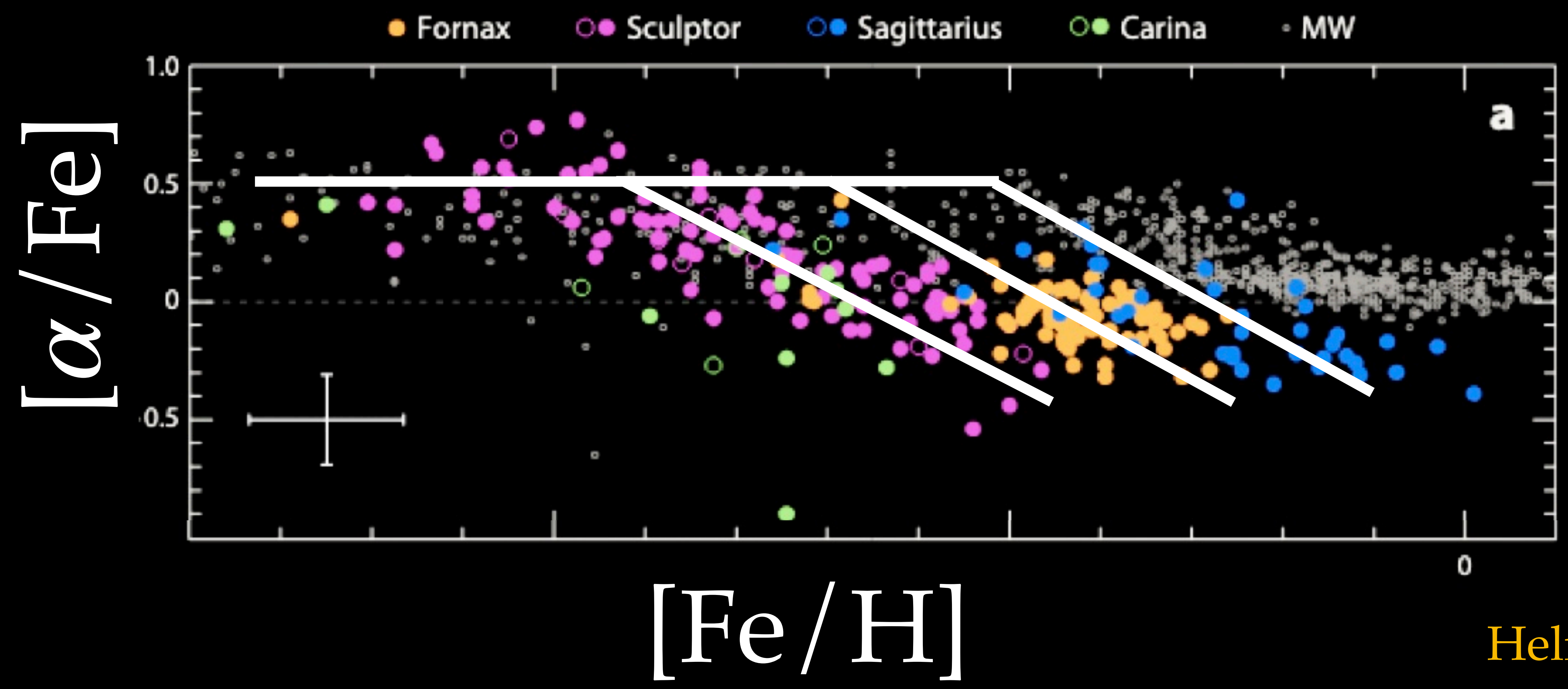

[Eu/Fe] encodes information on rare channels and mixing timescales

Helmi et al. 2018, Tolstoy et al. 2009 Matsuno et al. 2021, Aguado et al. 2021

Can GCs act as Chemo-dynamical Tracers?

Complication	Line of Investigation

ESO/L. Calçada

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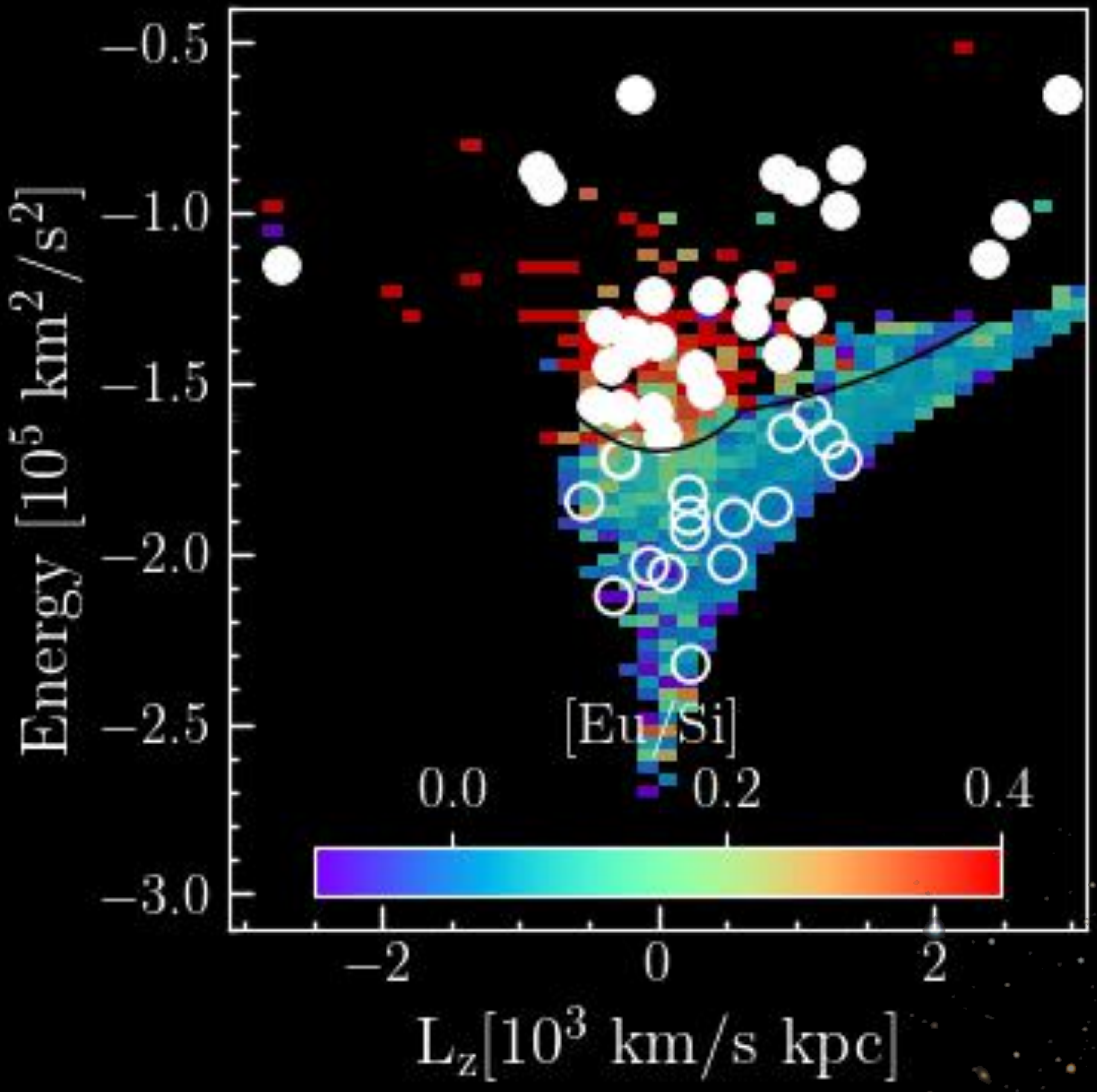
Globular Cluster Compilation



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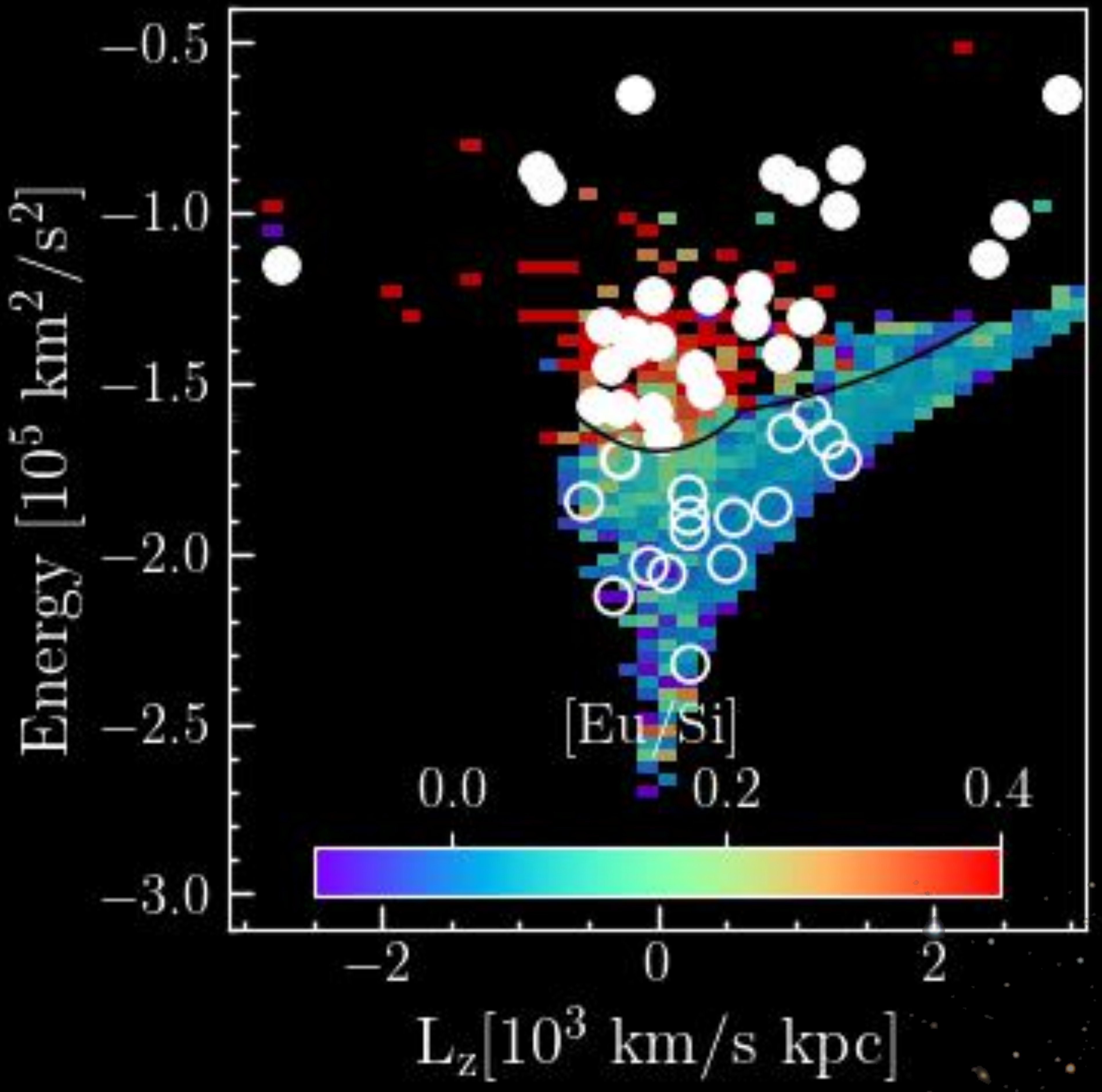

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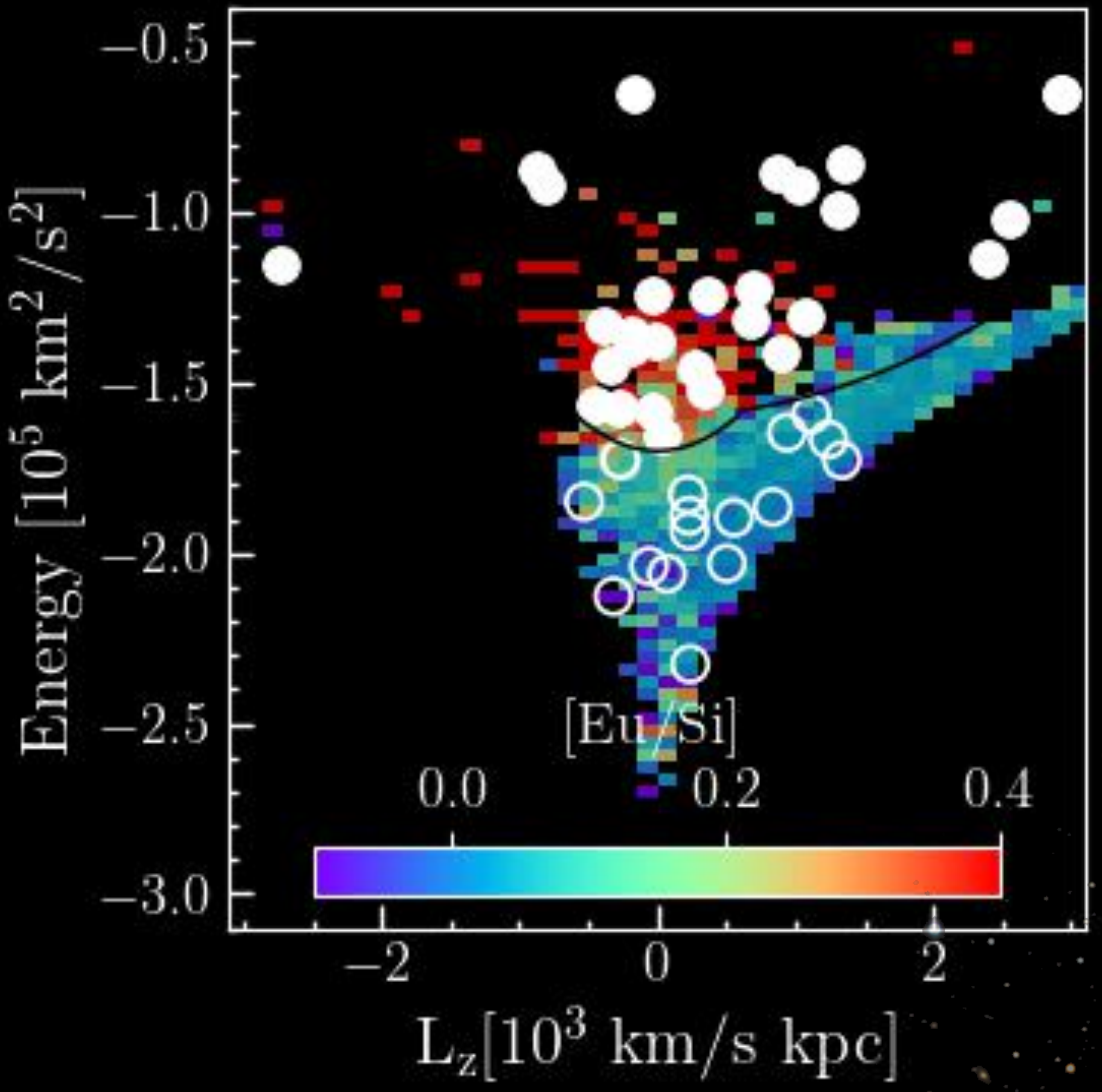

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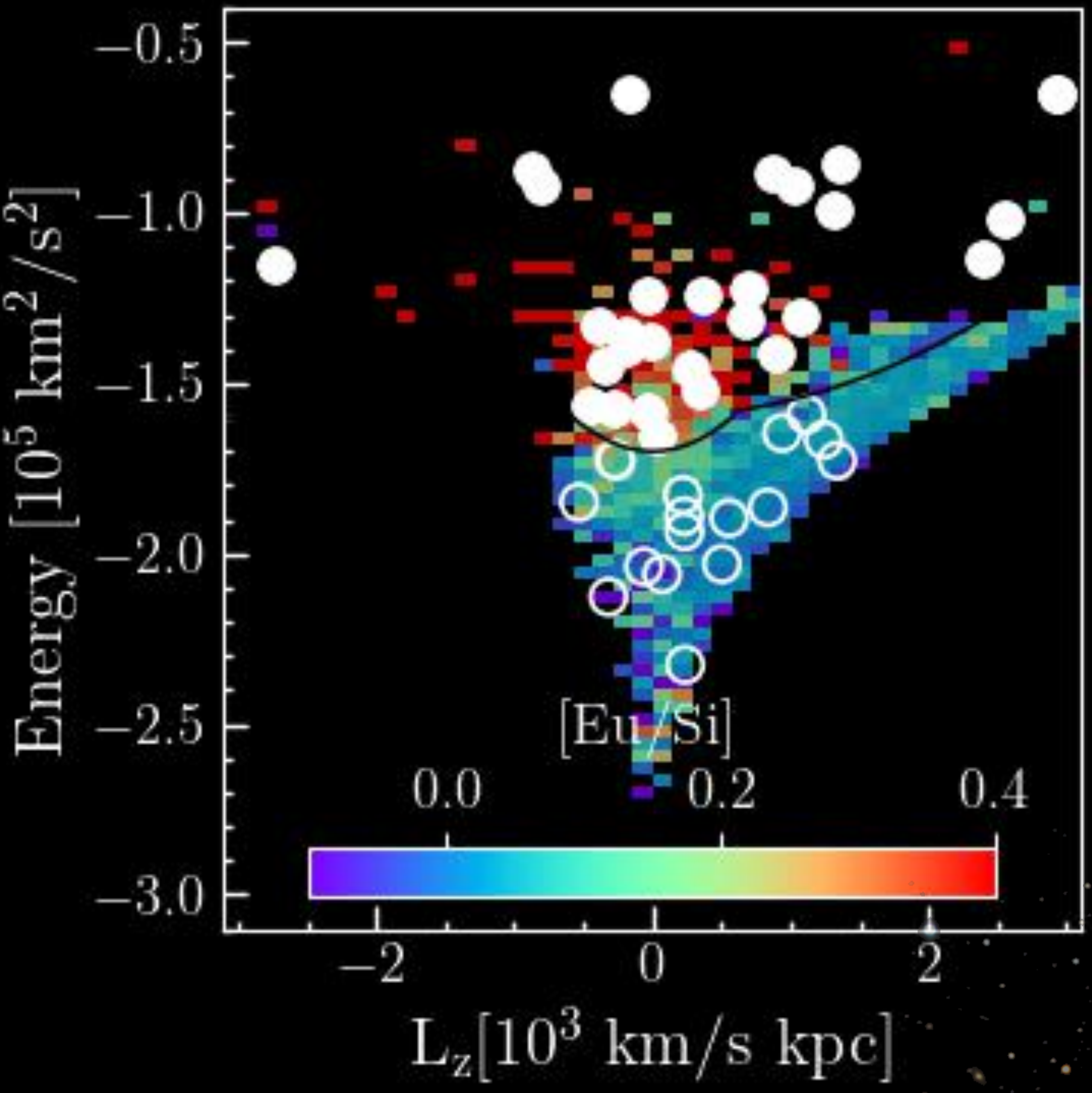

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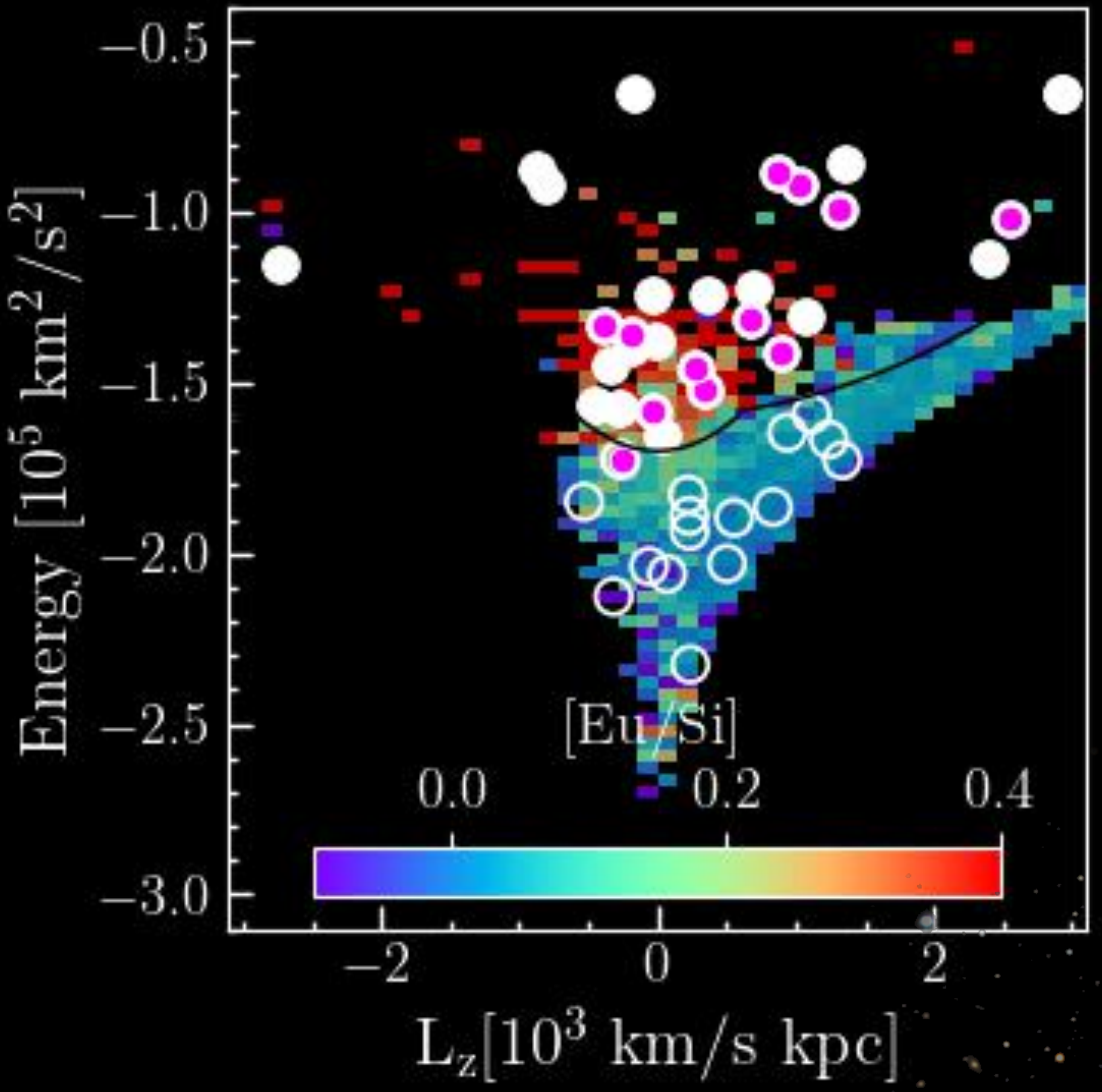

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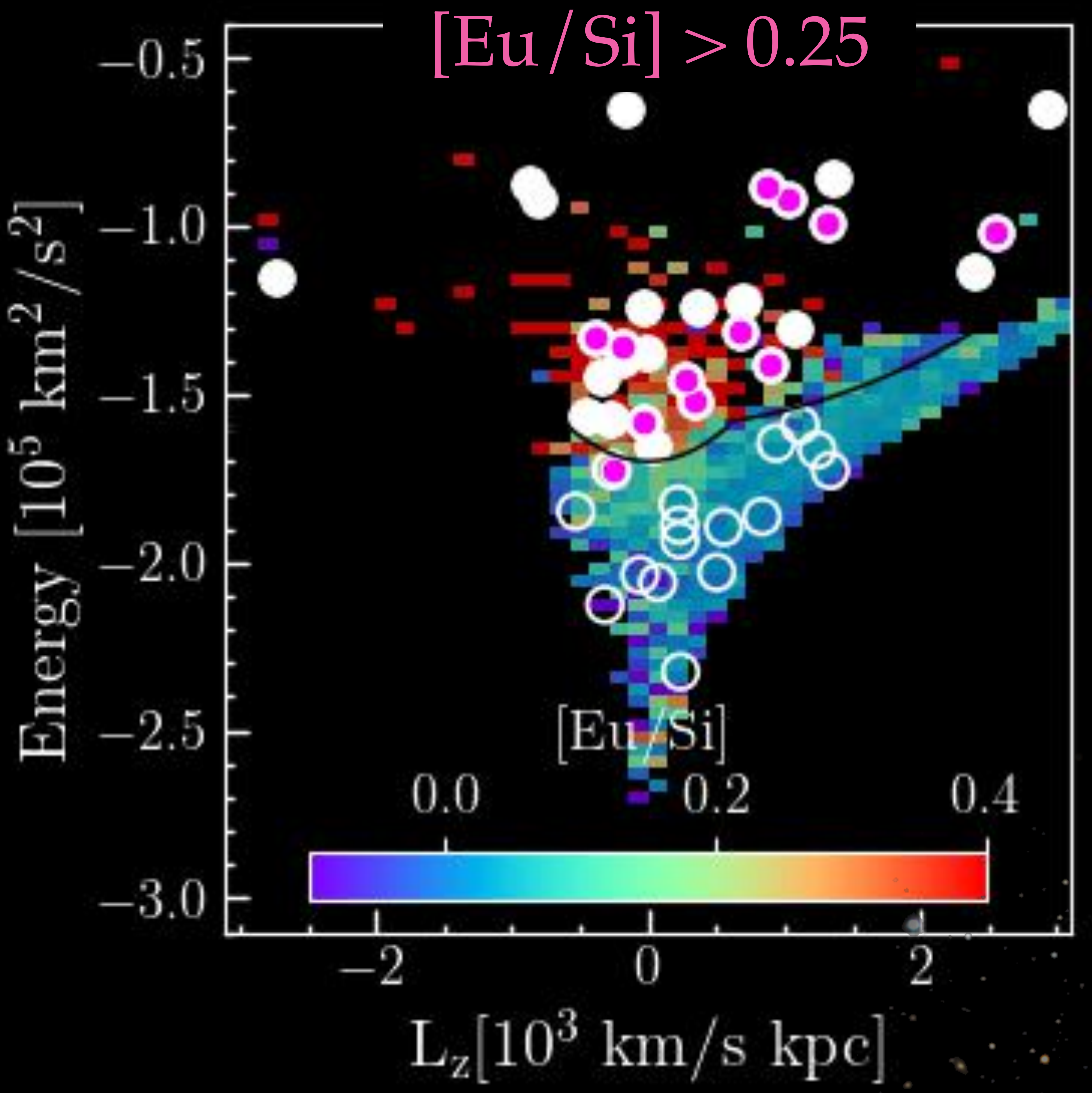

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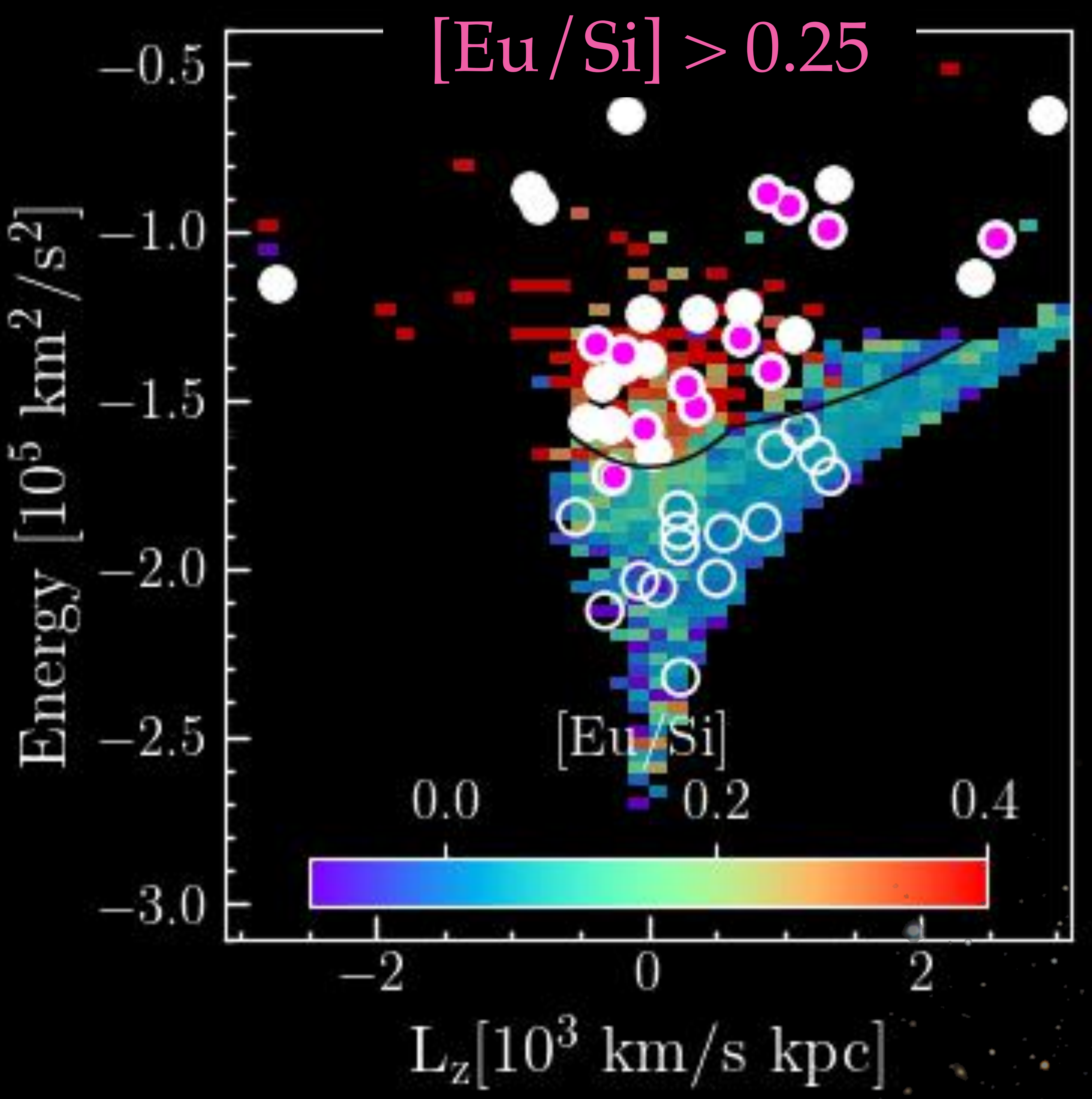

Accreted GCs light up in [Eu/Si] -> a chemical tag?

See also Koch-Hansen et al. 2021 and Monty et al. 2023b

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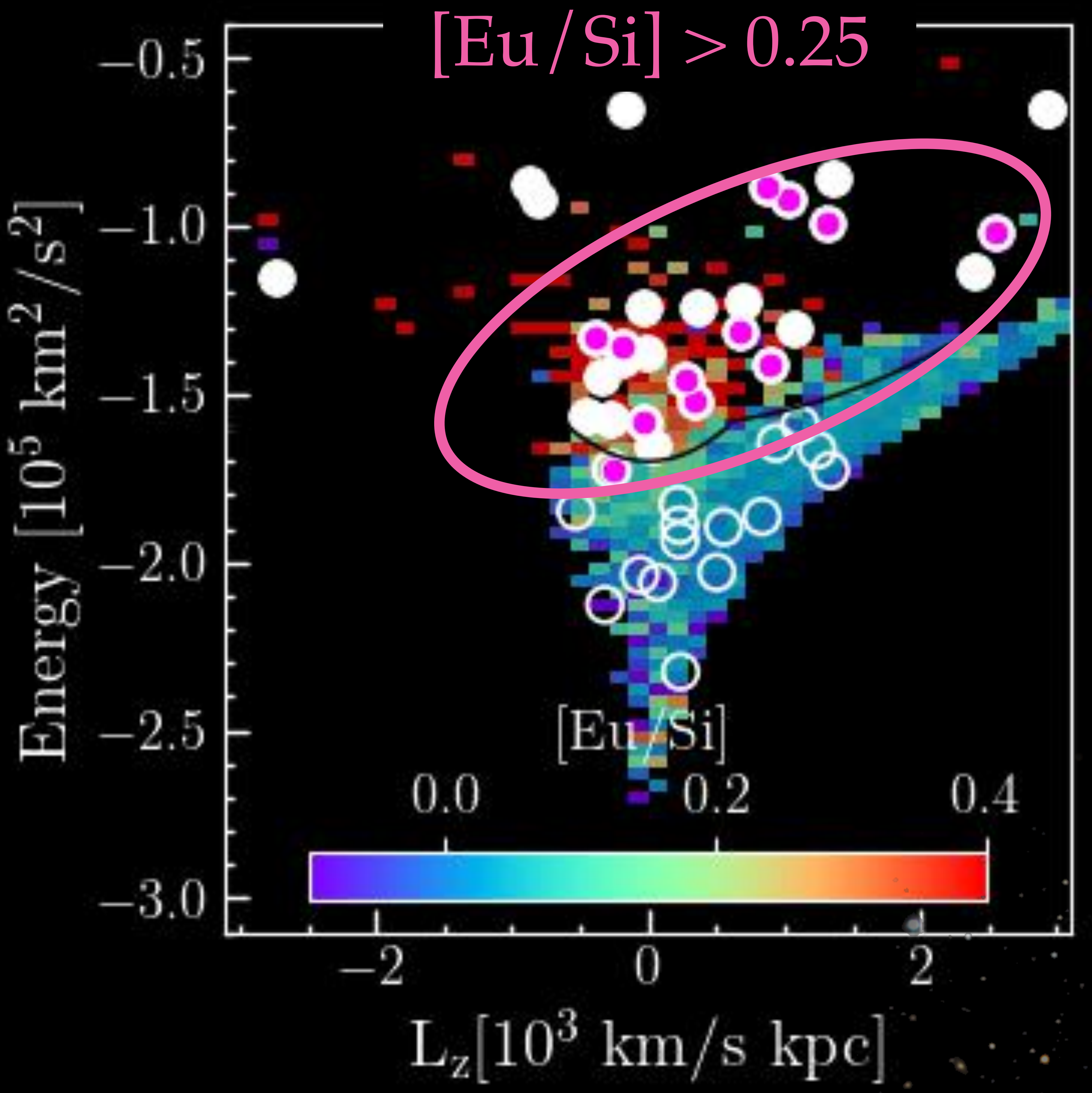

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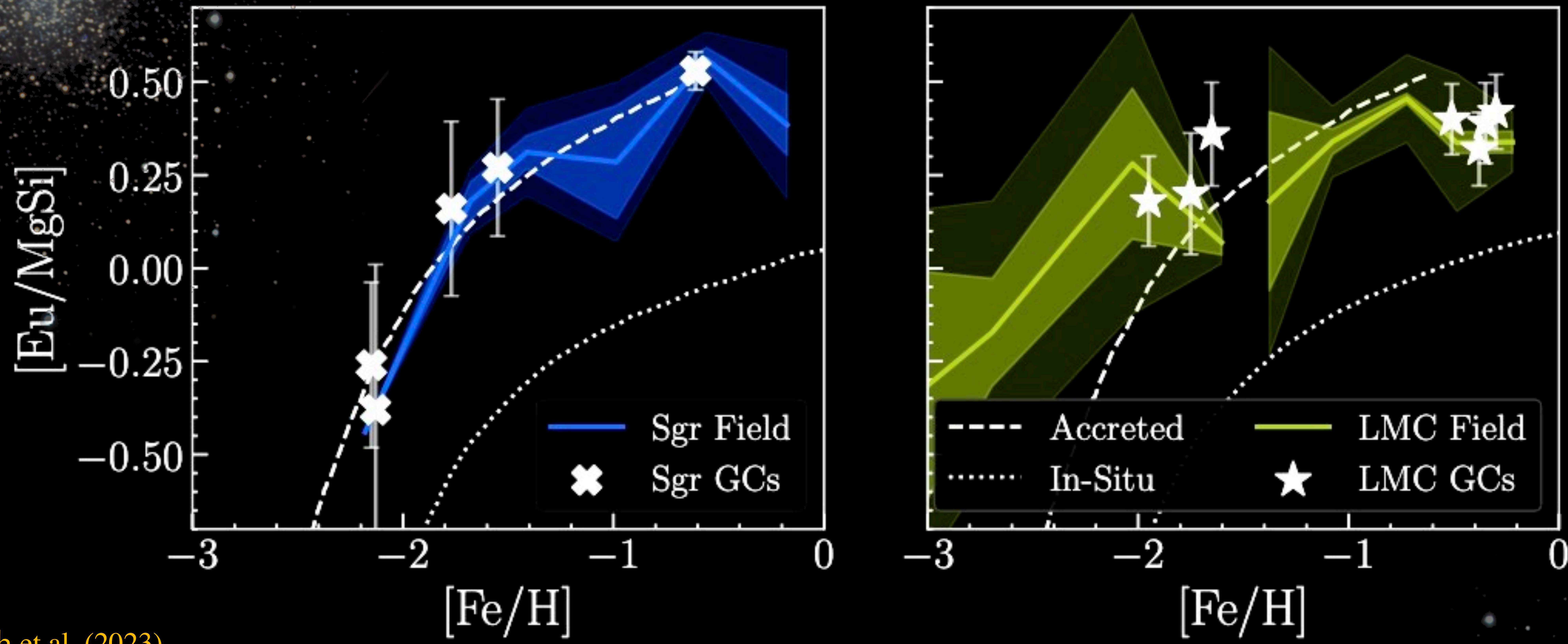
ESO/L. Calçada

Globular clusters trace the r-process evolution of their hosts



Data from: Oh et al. (2023), Reggiani et al. (2021), Van der Swaelmen et al. (2013), Pompéia et al. (2008), Mucciarelli et al. (2008) and Mucciarelli et al. (2010) a, Reichart et al. 2020

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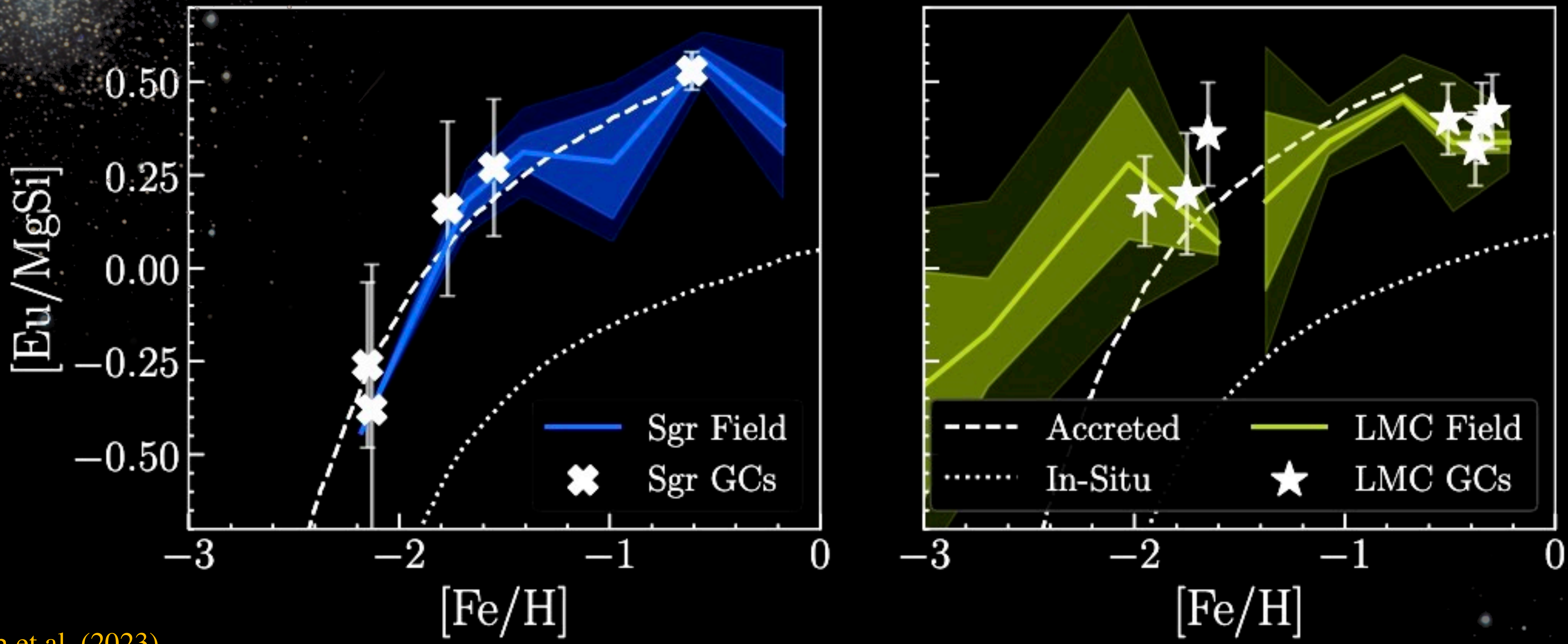

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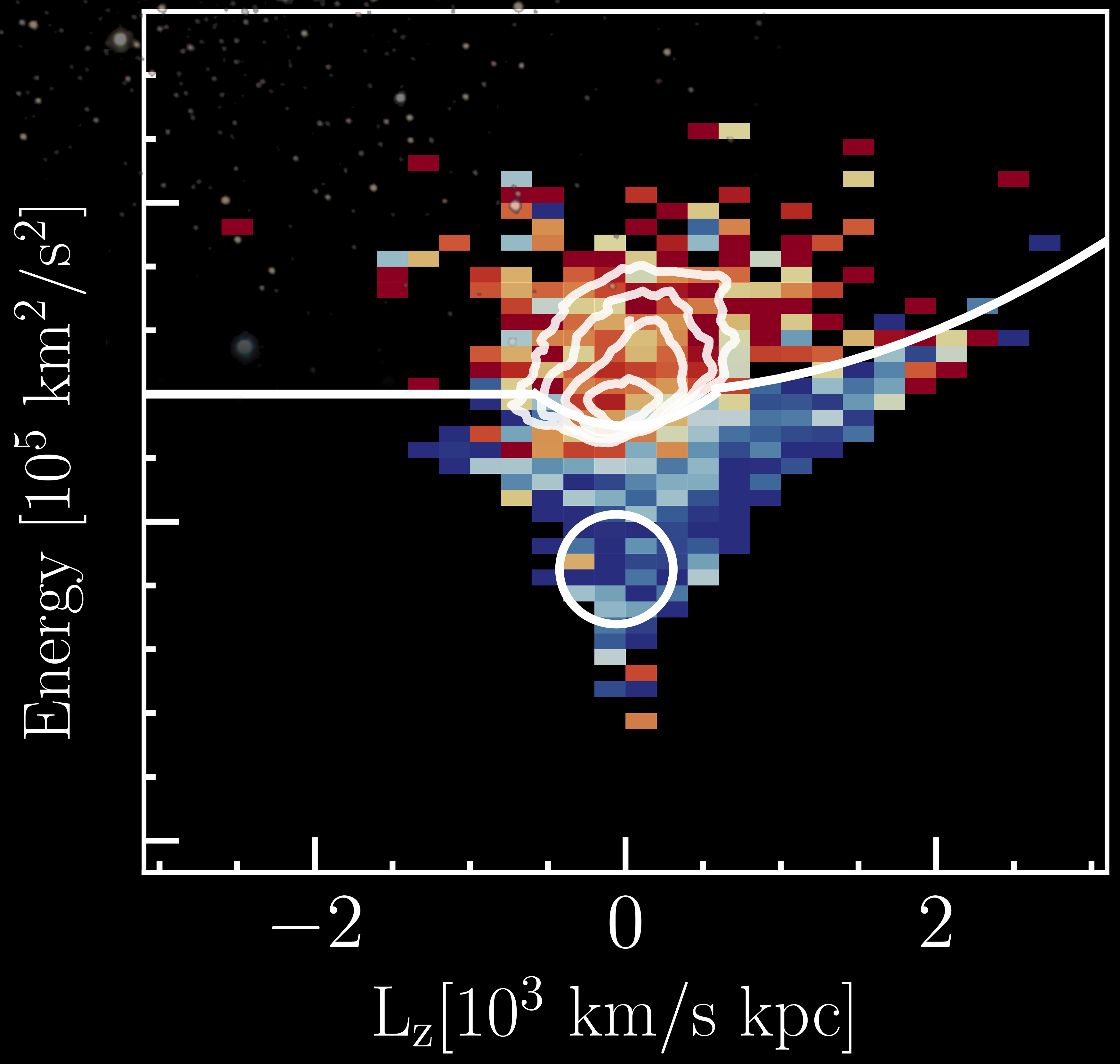
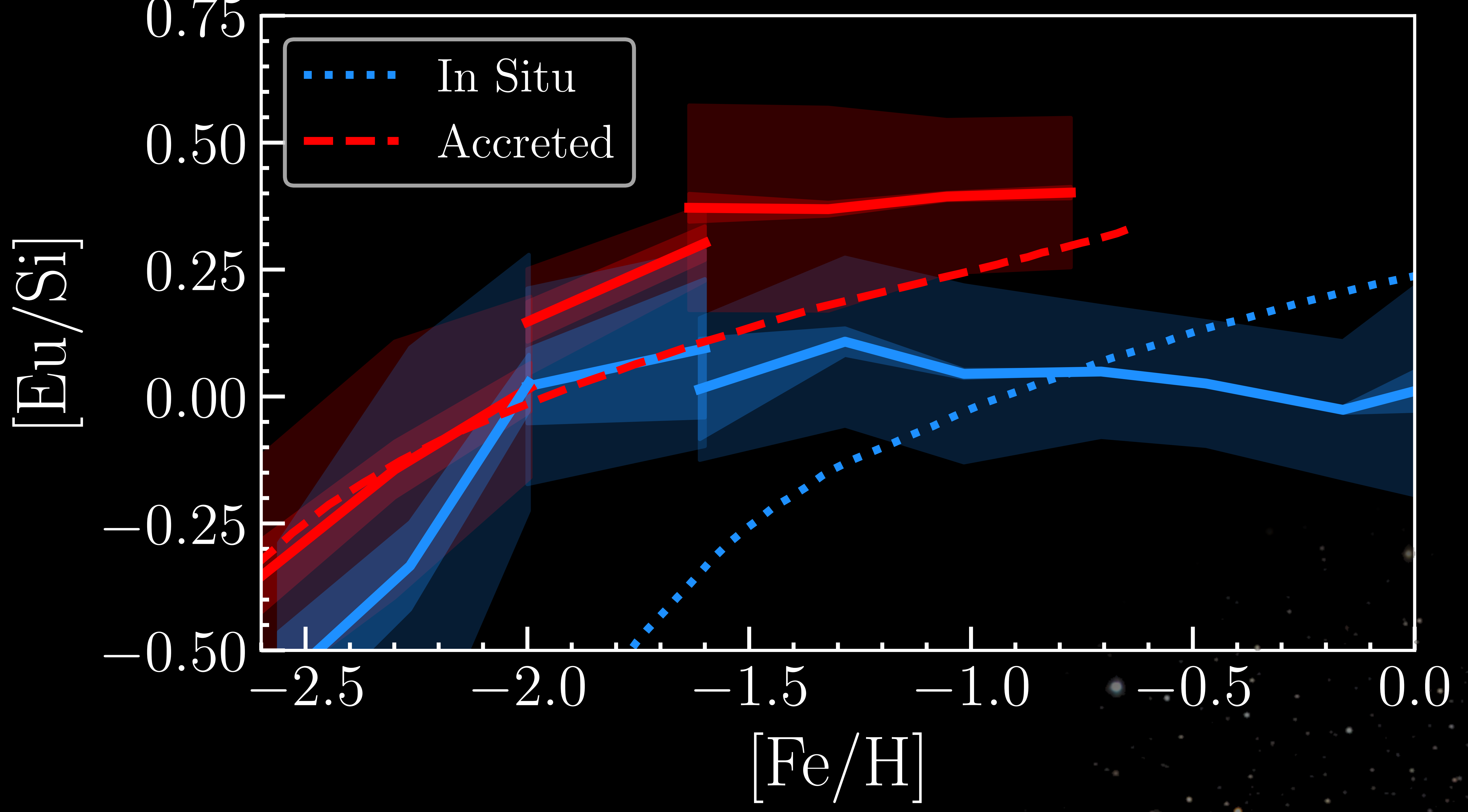
Globular clusters trace the chemical evolution of their hosts in [Eu/α] across metallicity

Monty et al. 2024

Hints that the difference in [Eu/Si] extends to all metallicities





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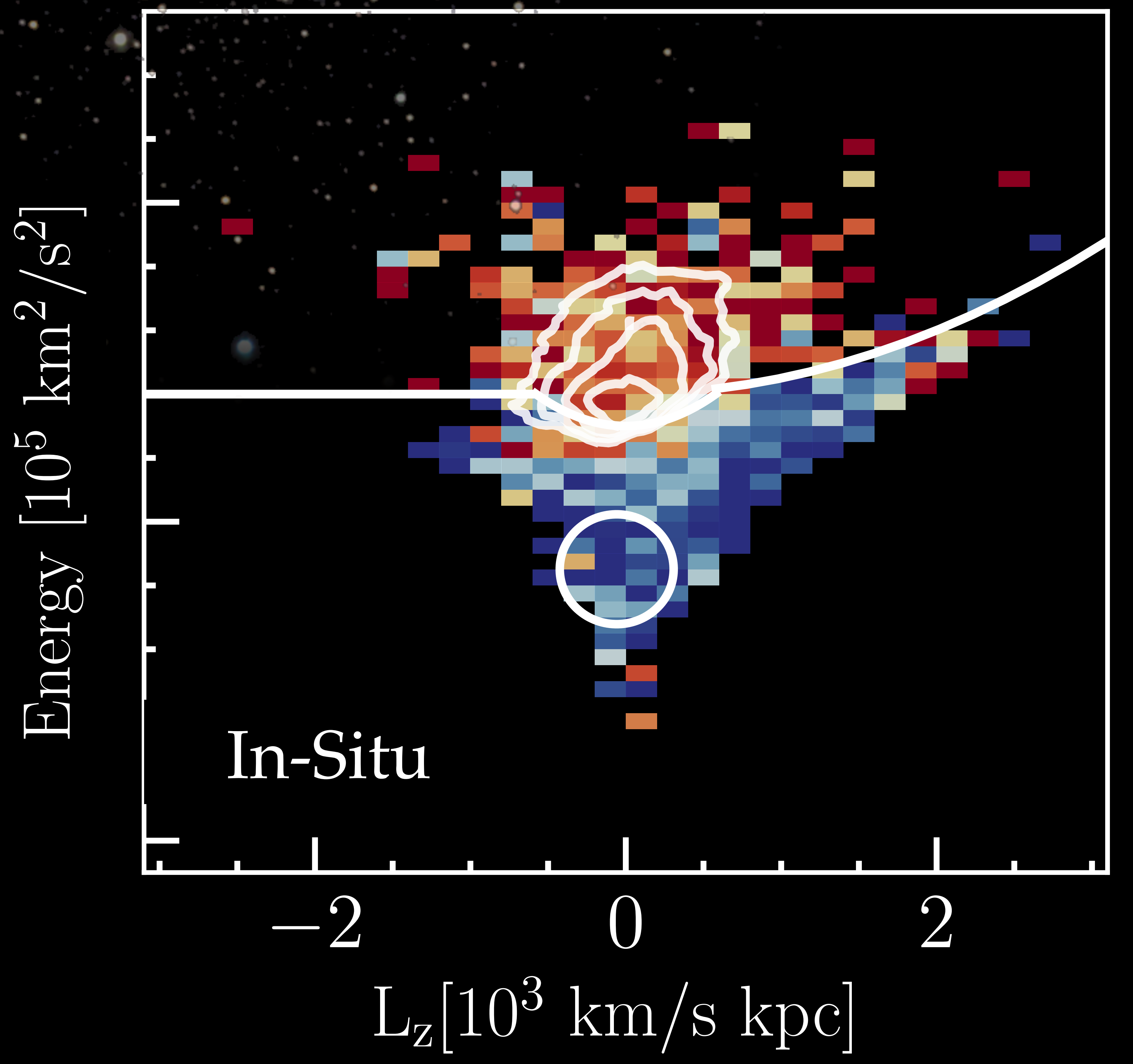

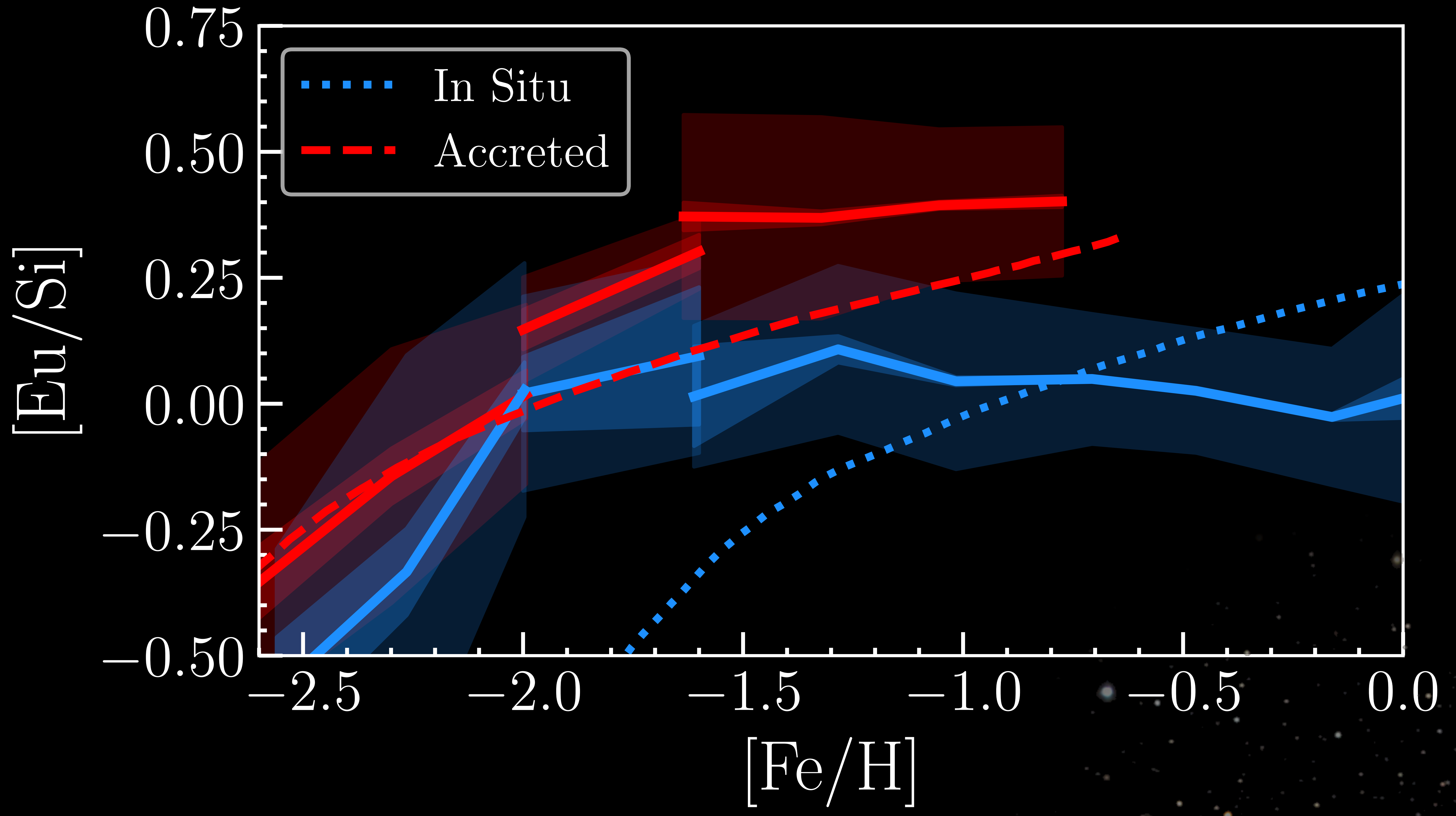

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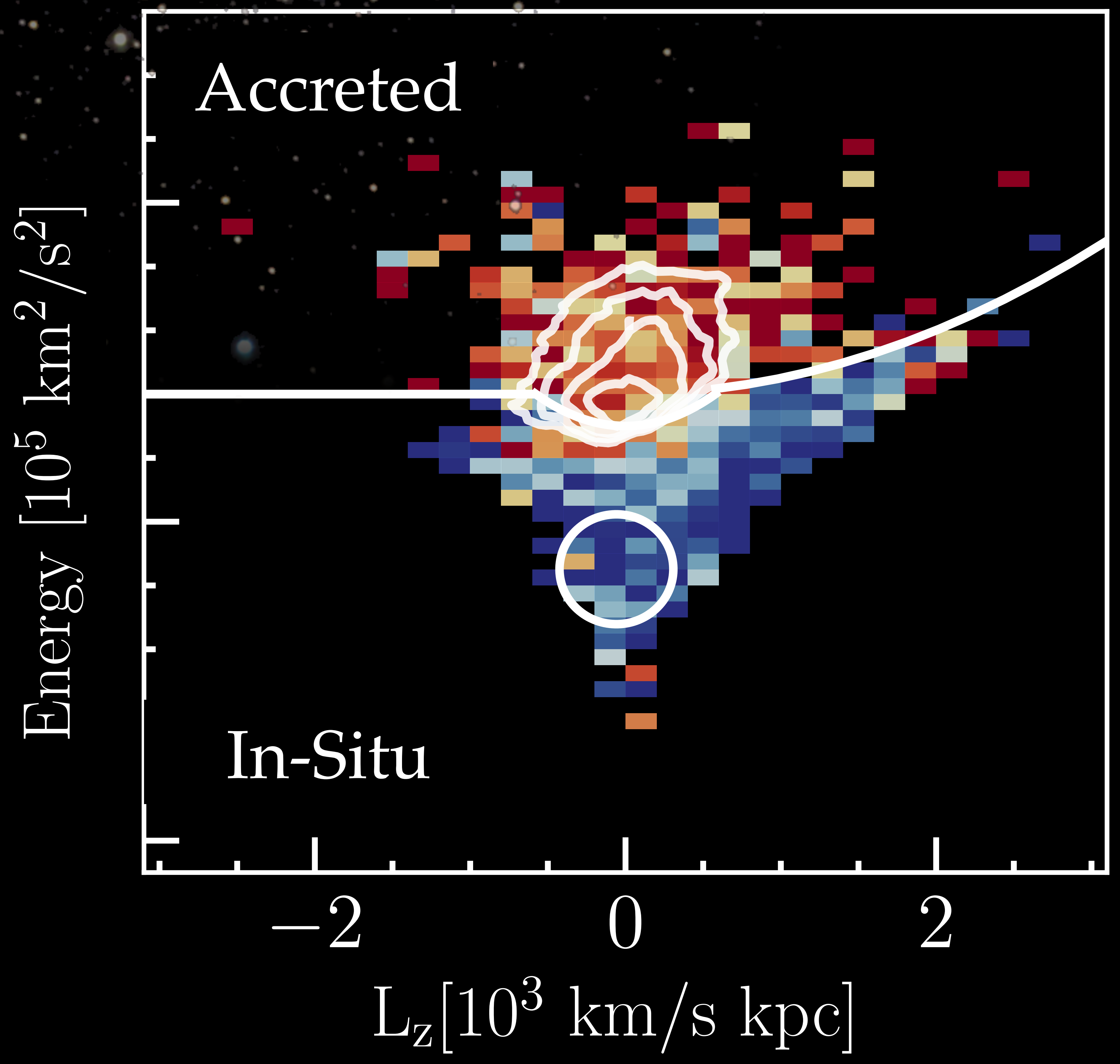

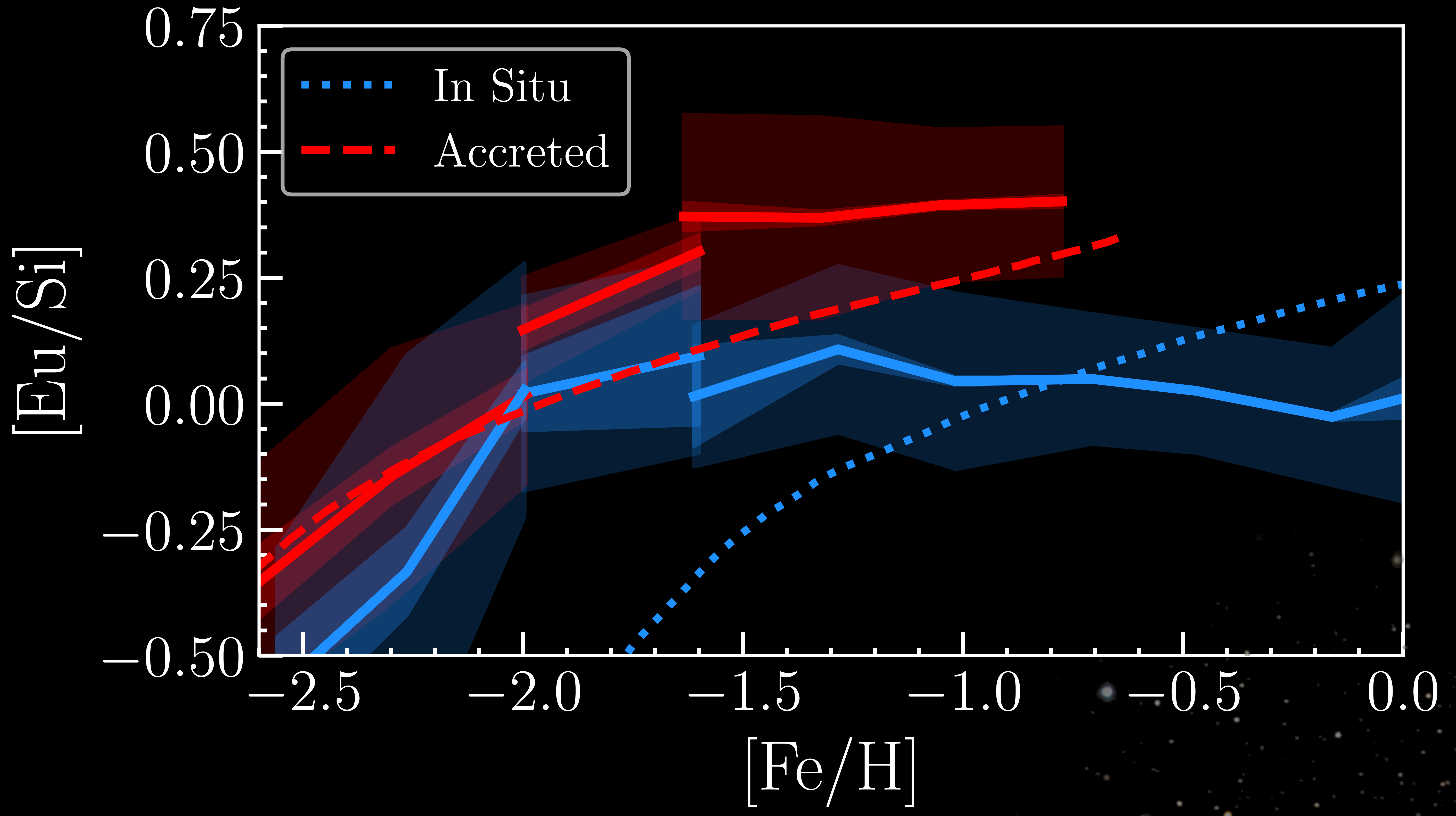

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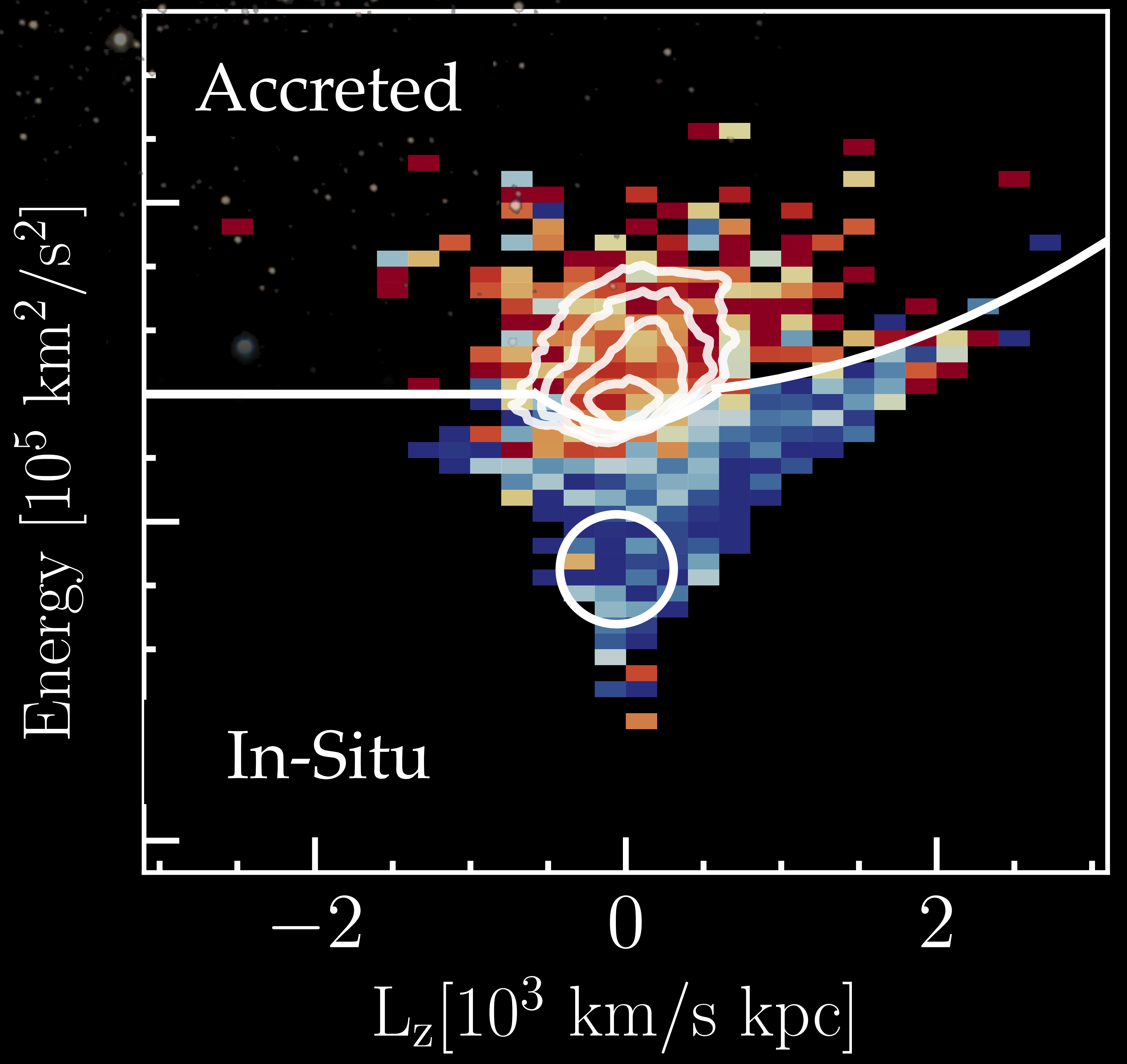
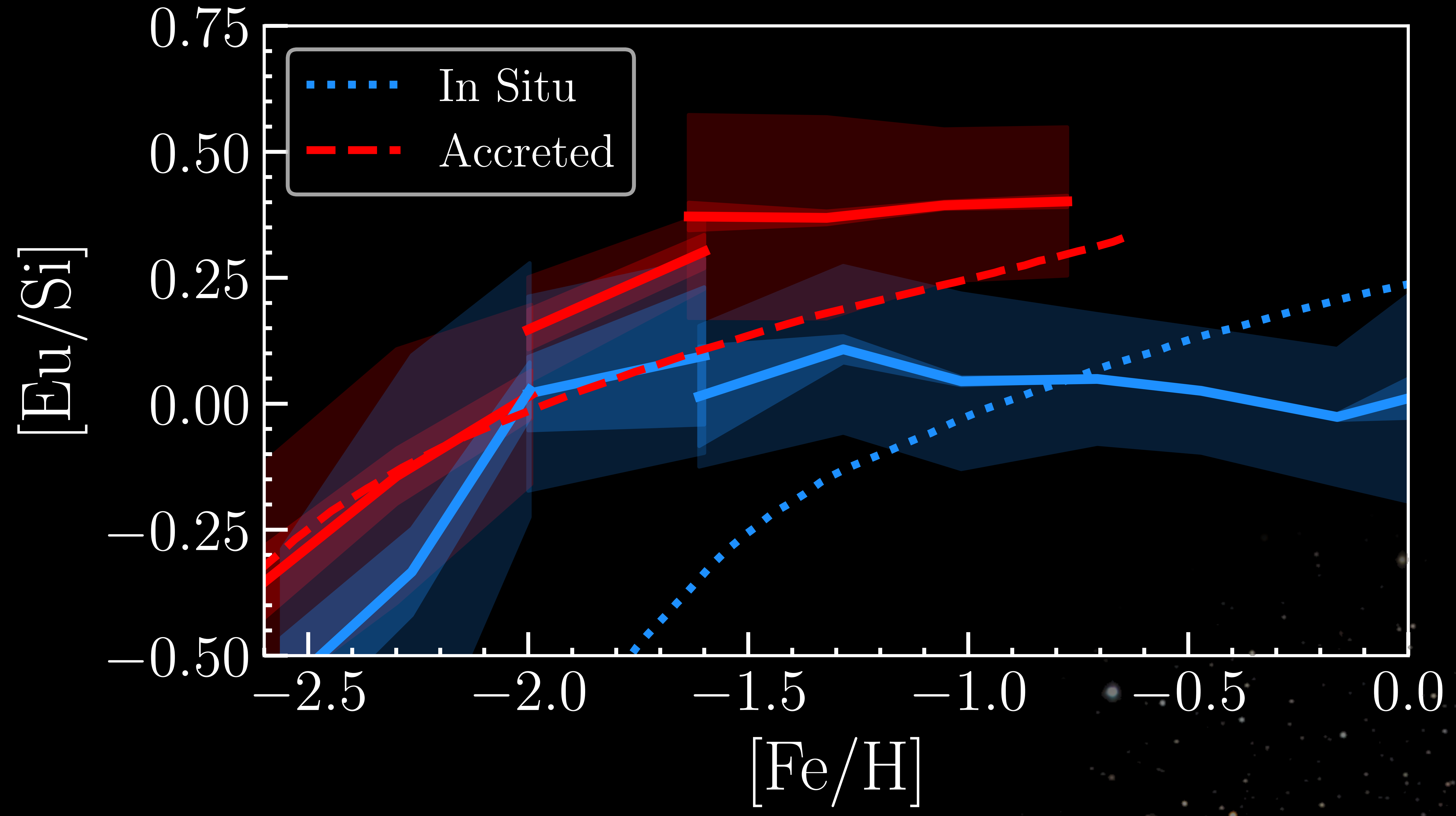


Different equilibrium levels in [Eu/Si]



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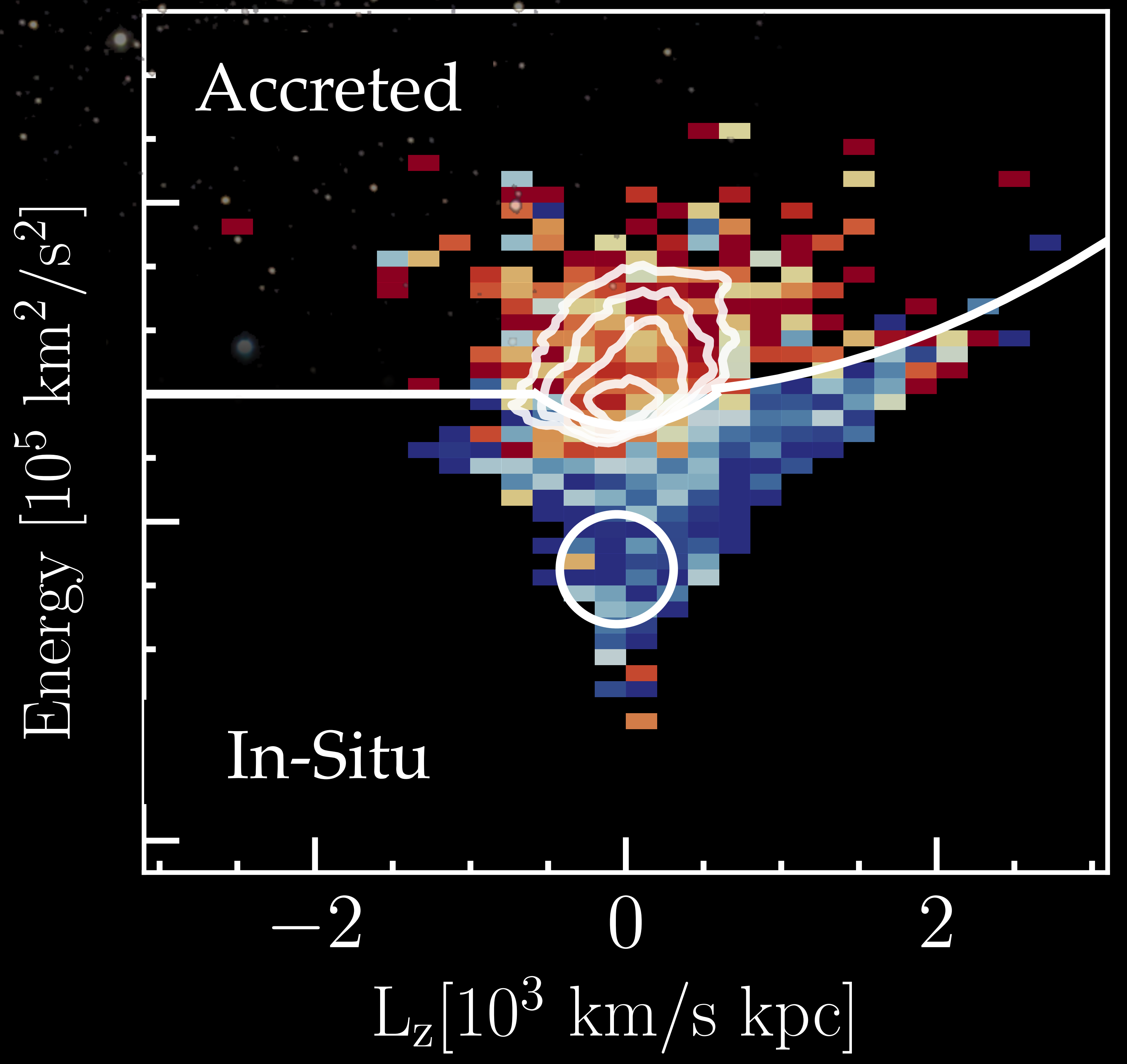

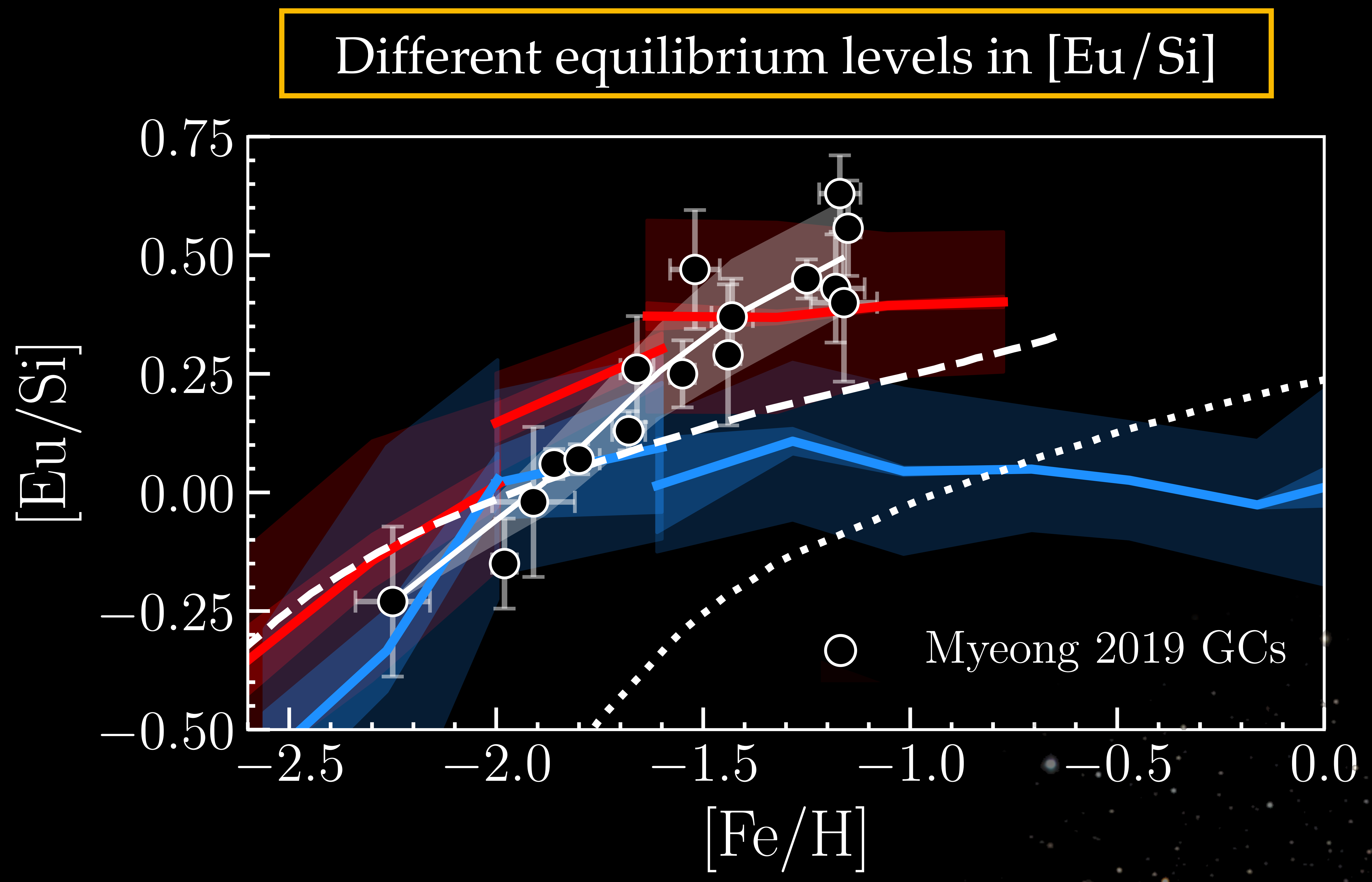

Monty et al. 2024

Can GCs act as Chrono-chemo-dynamical Tracers?

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GCs are incredibly chemically complex	Does a chemical tag exist between GCs and their host galaxies?	
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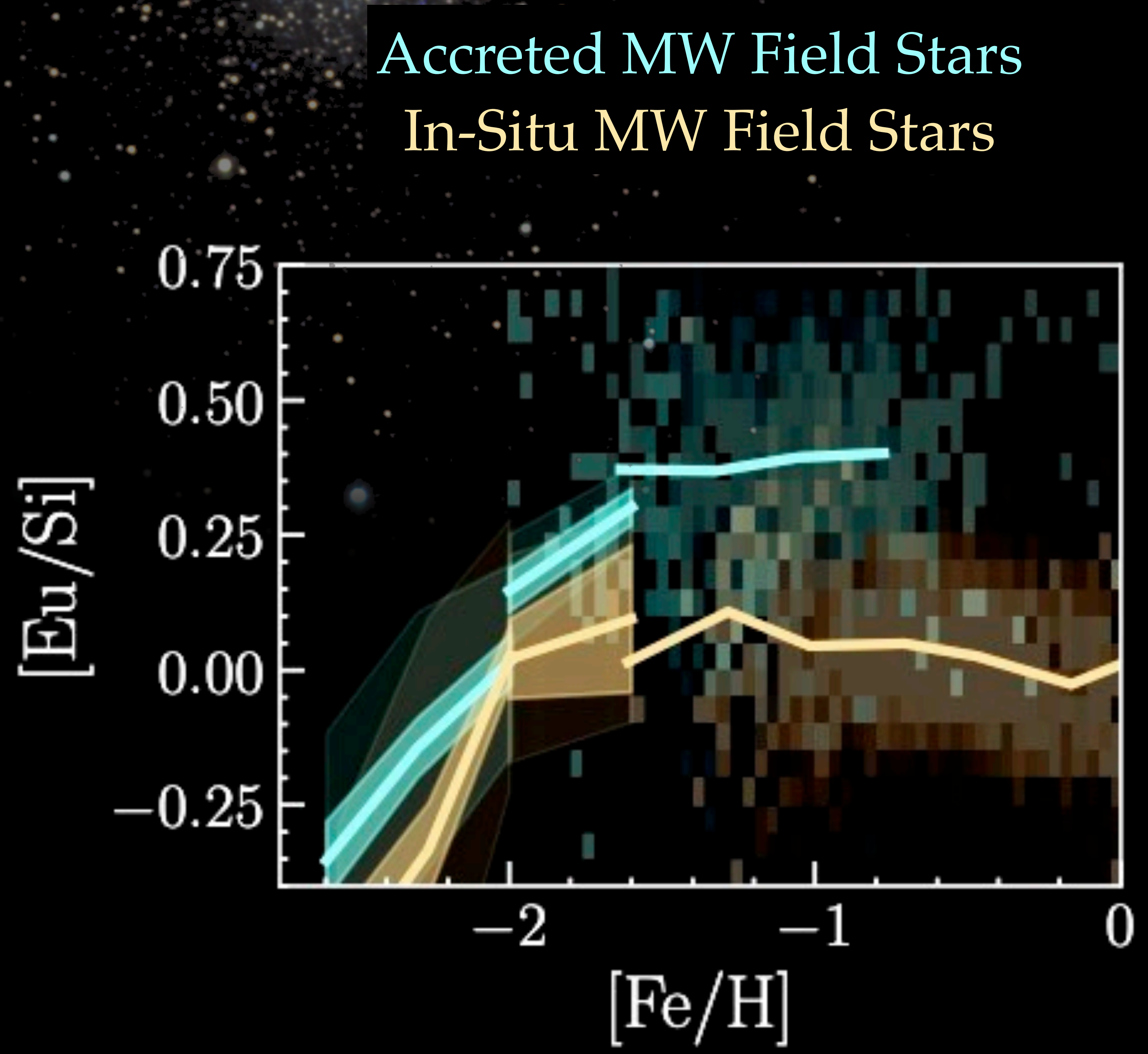
GCs as **sub-Gyr timers** of the chemical evolution of the GSE dwarf galaxy

GCs associated with the last major merger time its chemical evolution



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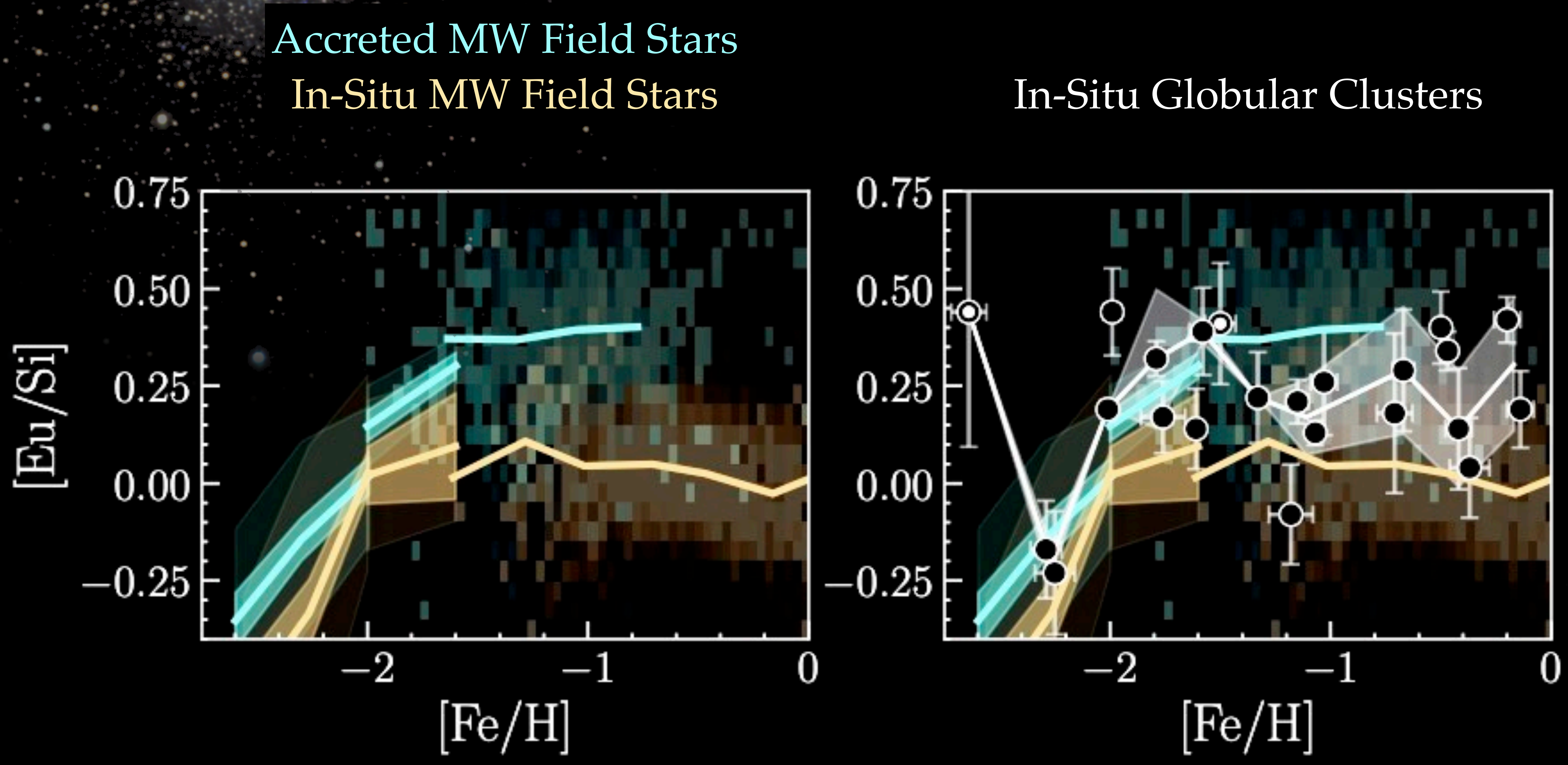

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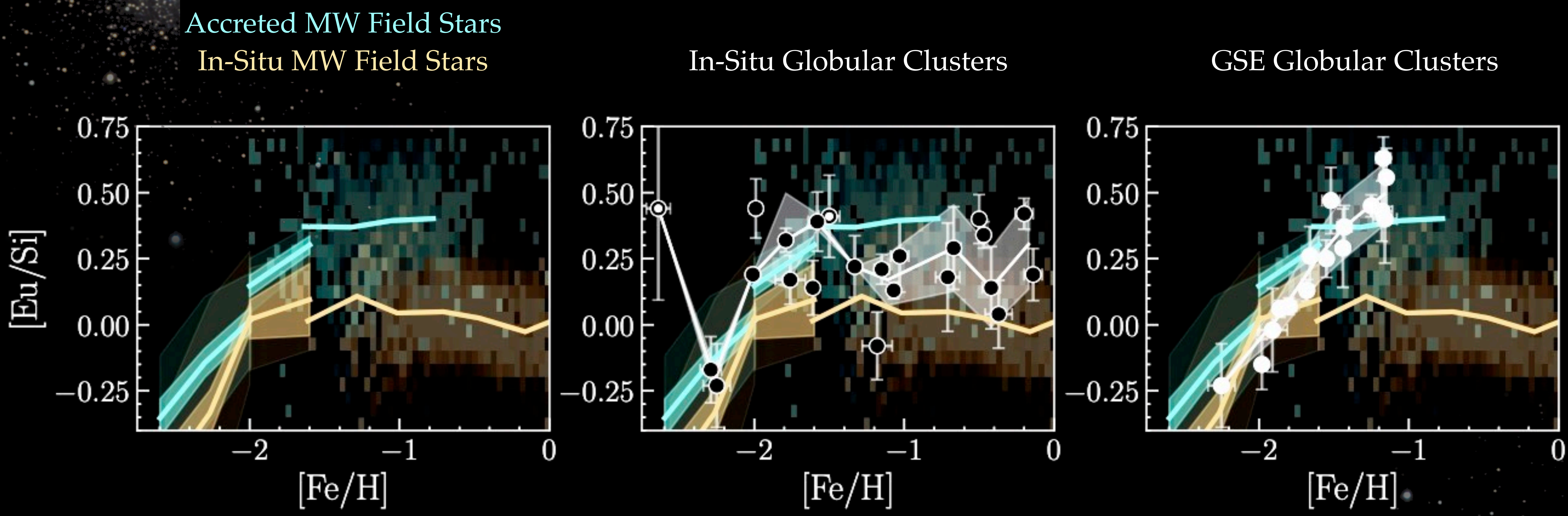

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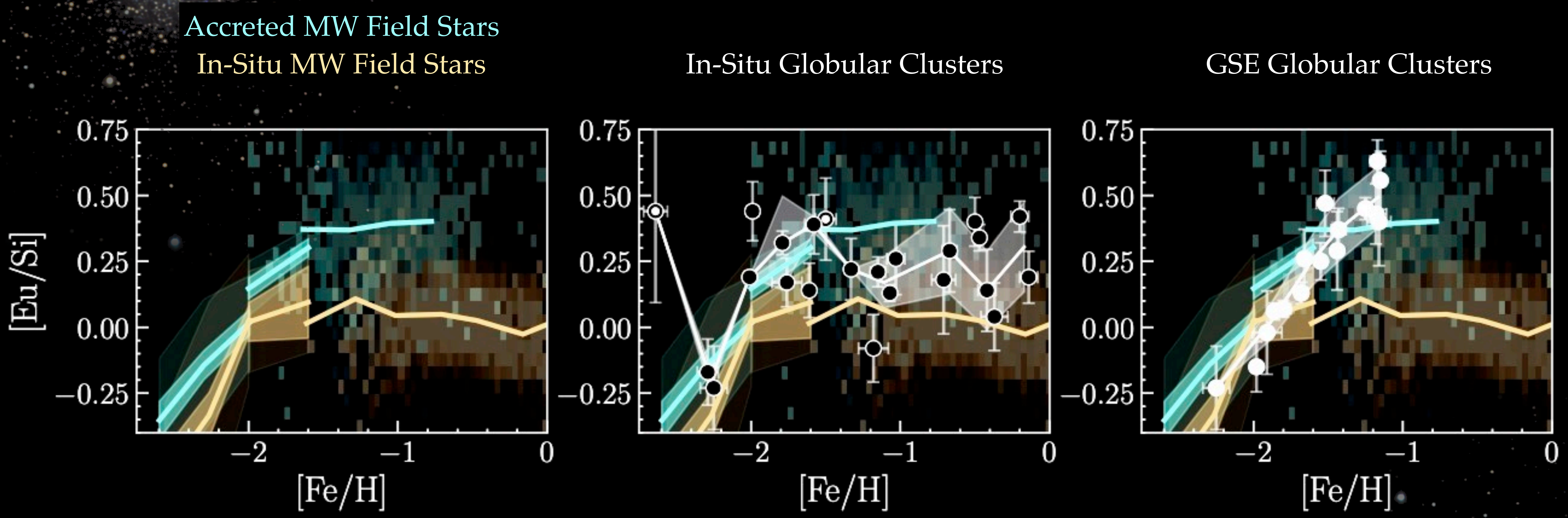

The GSE GCs form the tightest sequence in [Eu/Si] seen as of yet
[Eu/Si] rise of 0.75 dex in GSE takes place over 2 Gyr

Summary

See arXiv: 2405. 8963 for more details

Summary

1. GCs trace the star formation histories of their hosts at all times in the ratio of [Eu/α]

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    2. **Delay time for neutron star mergers (destruction timescales for NSM progenitors in GCs?)**

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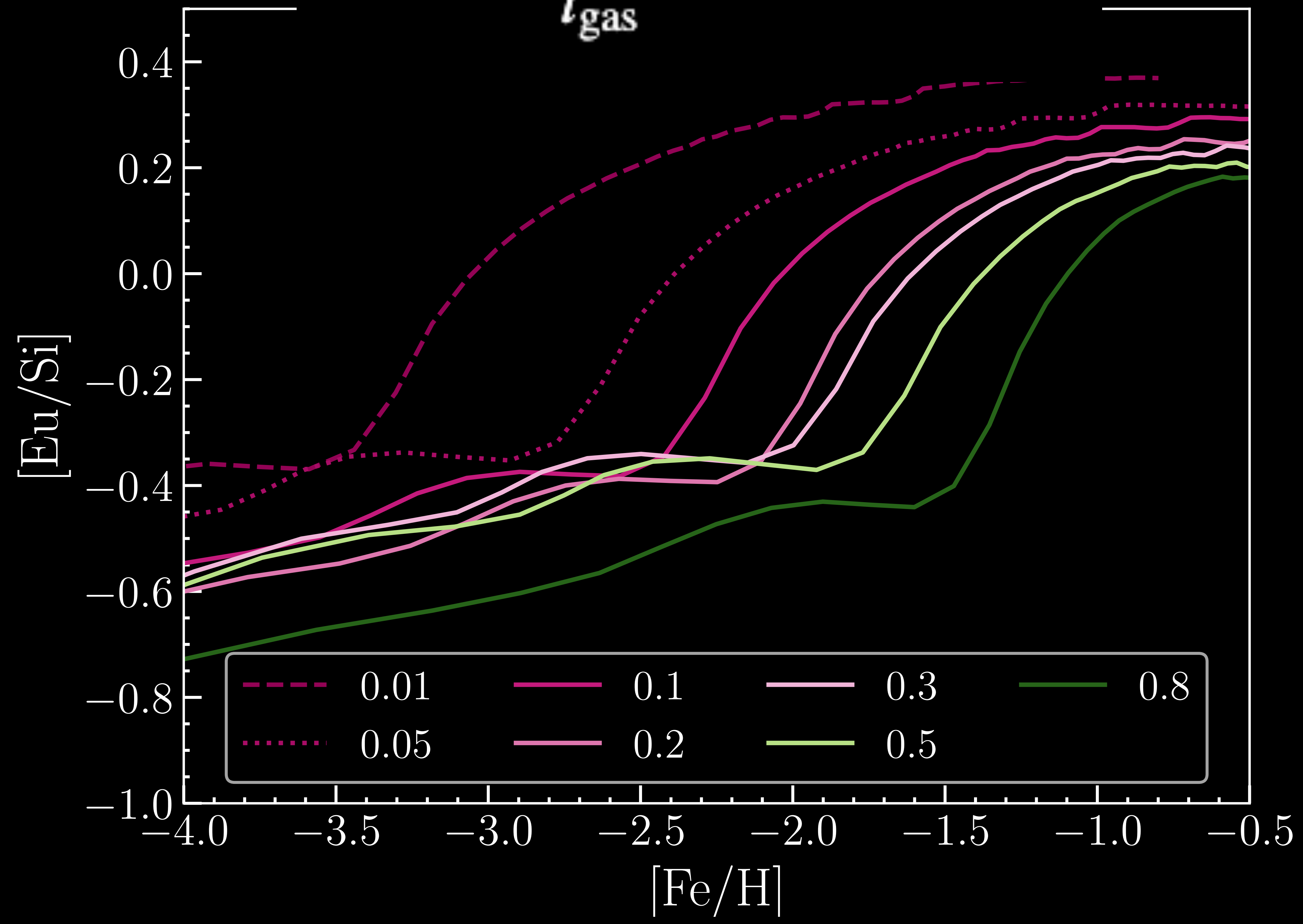
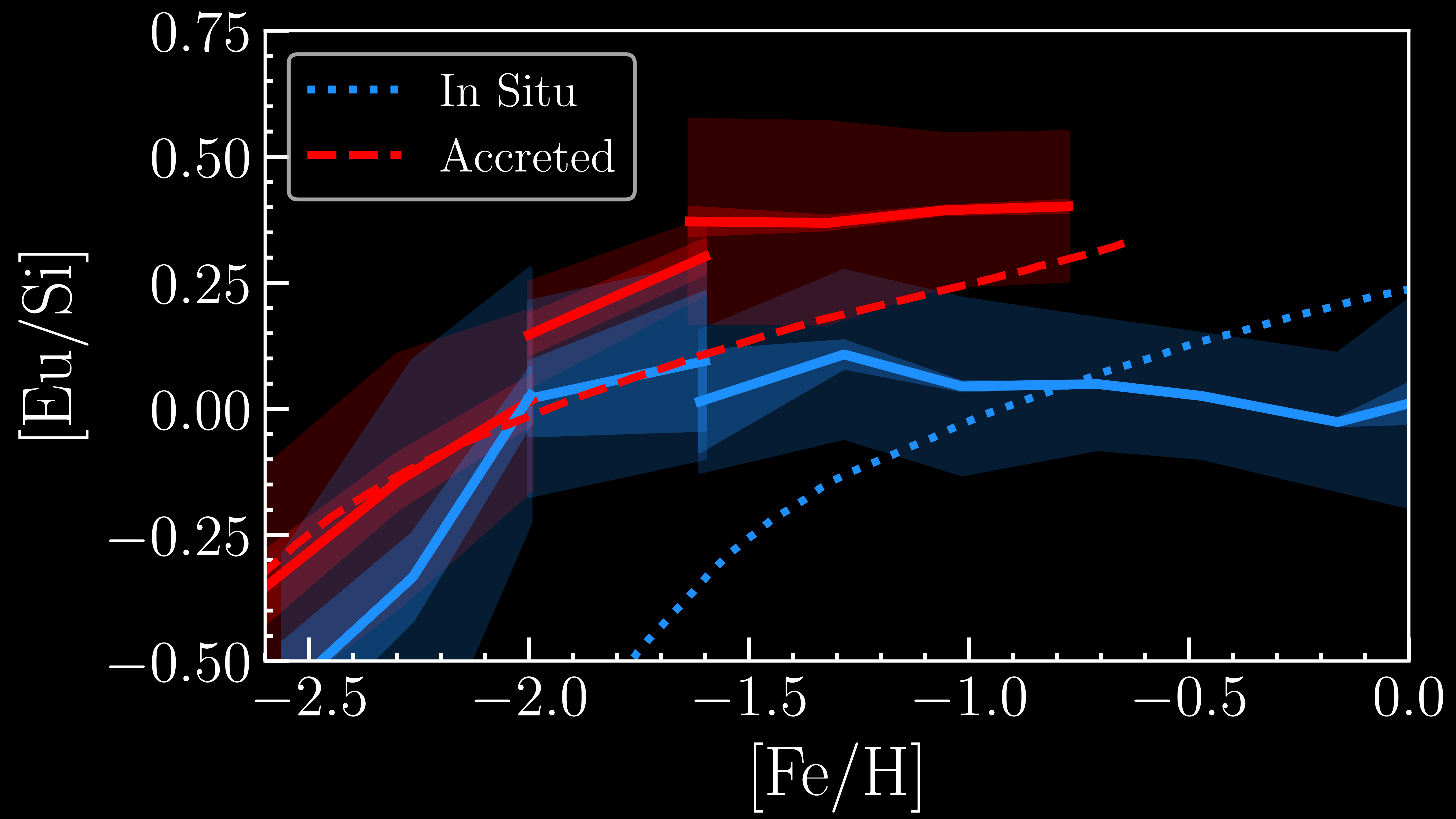
Extra Slides

Lessons from Field Stars: Star Formation Efficiency Alone Cannot Explain the Different Plateaus

$$\mathrm{SFR} = \frac{1}{t_{\mathrm{gas}}} M_{\mathrm{gas}} = \mathrm{SFE} \cdot M_{\mathrm{gas}}$$





Monty et al. in-prep

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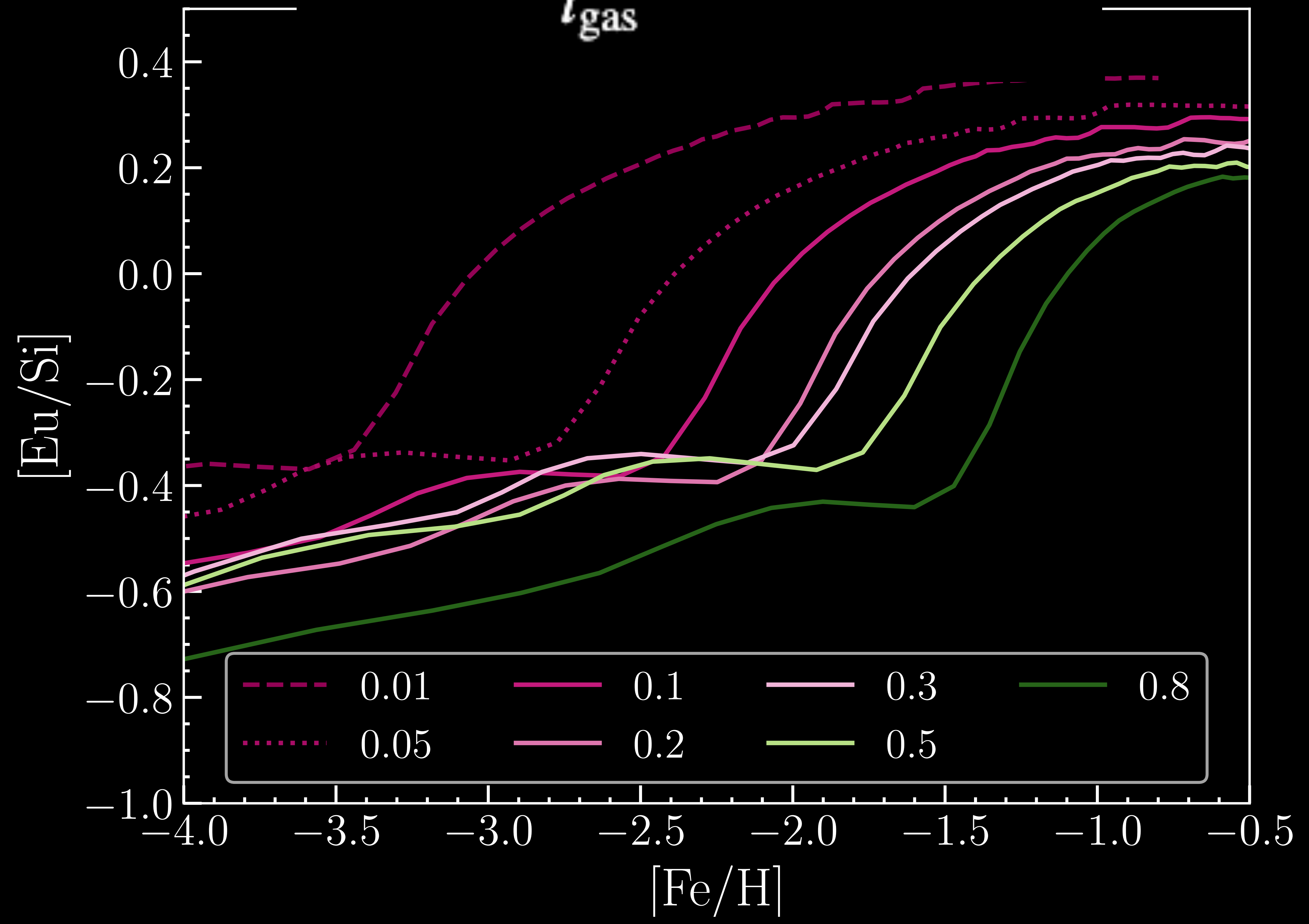
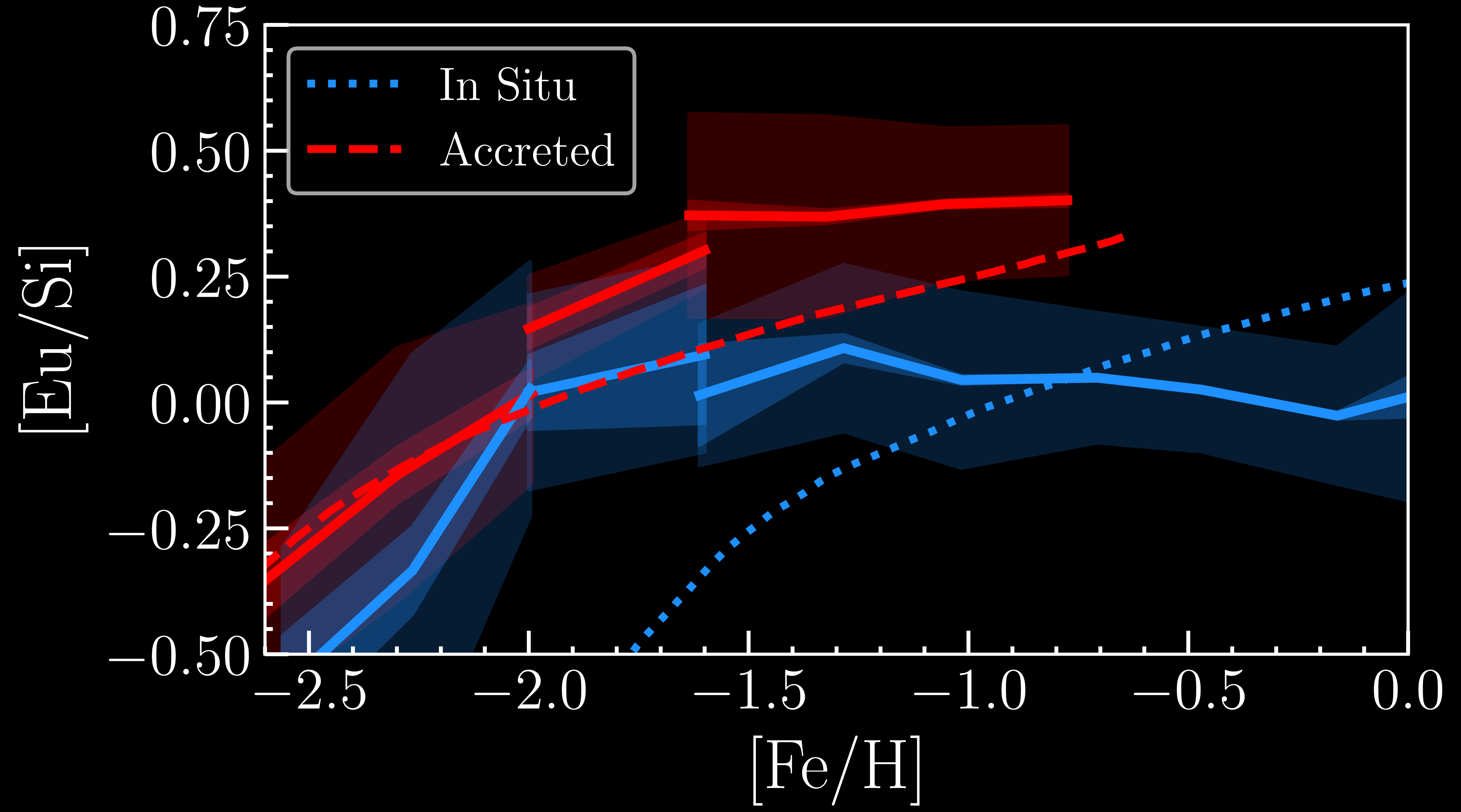


All models converge



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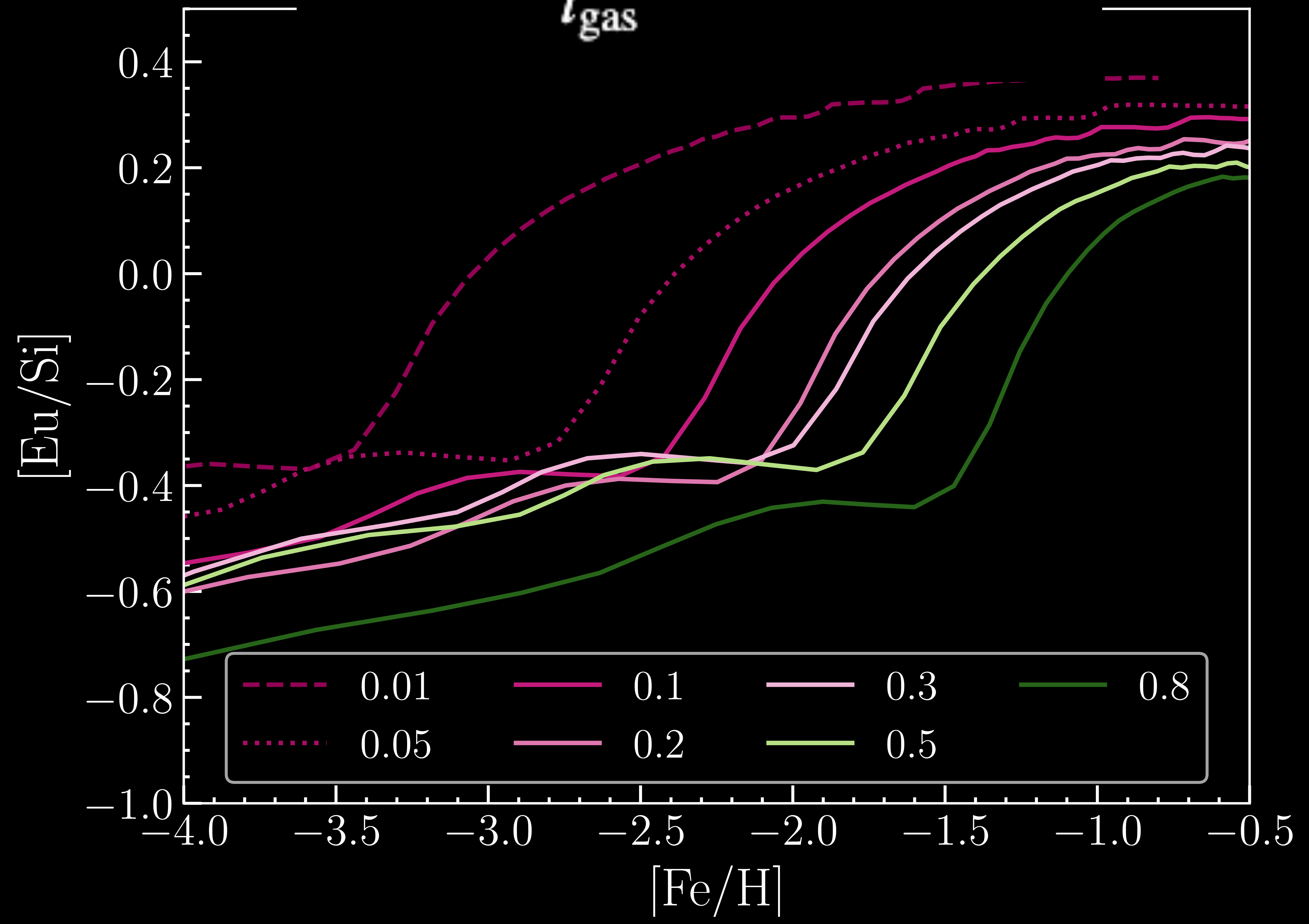
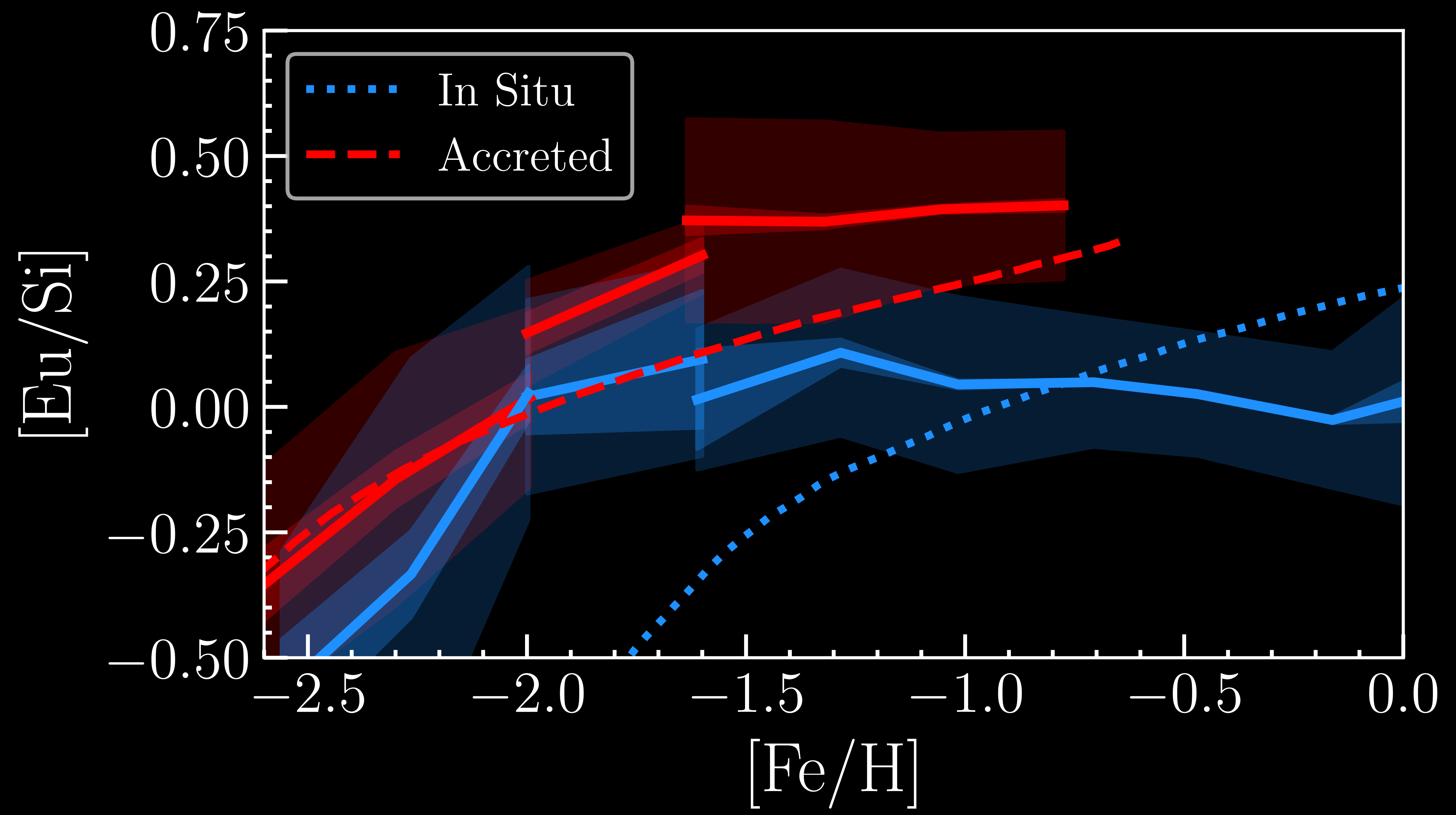


All models converge

The MW and GSE continue to diverge -> differences SFE not enough to explain offset



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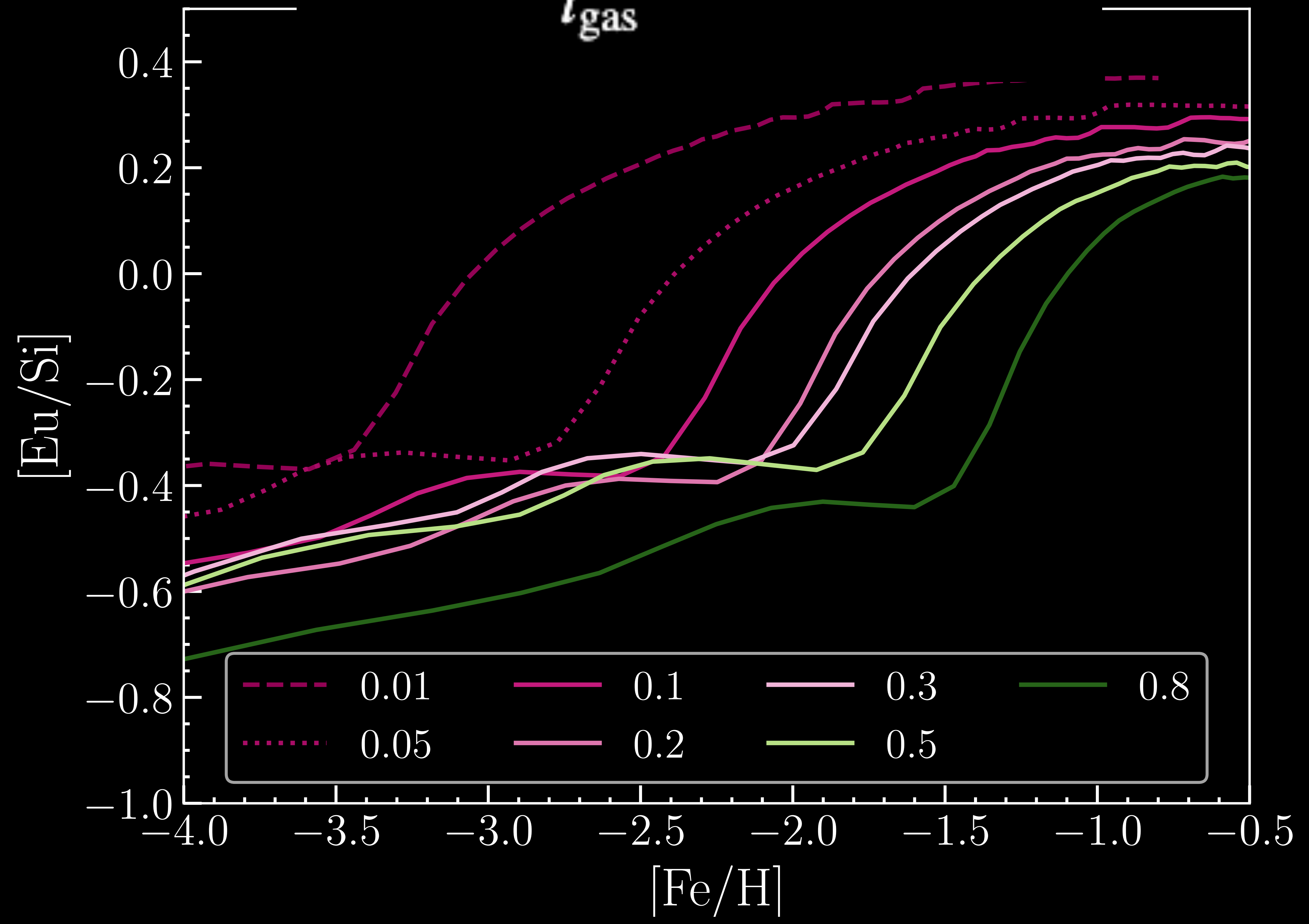

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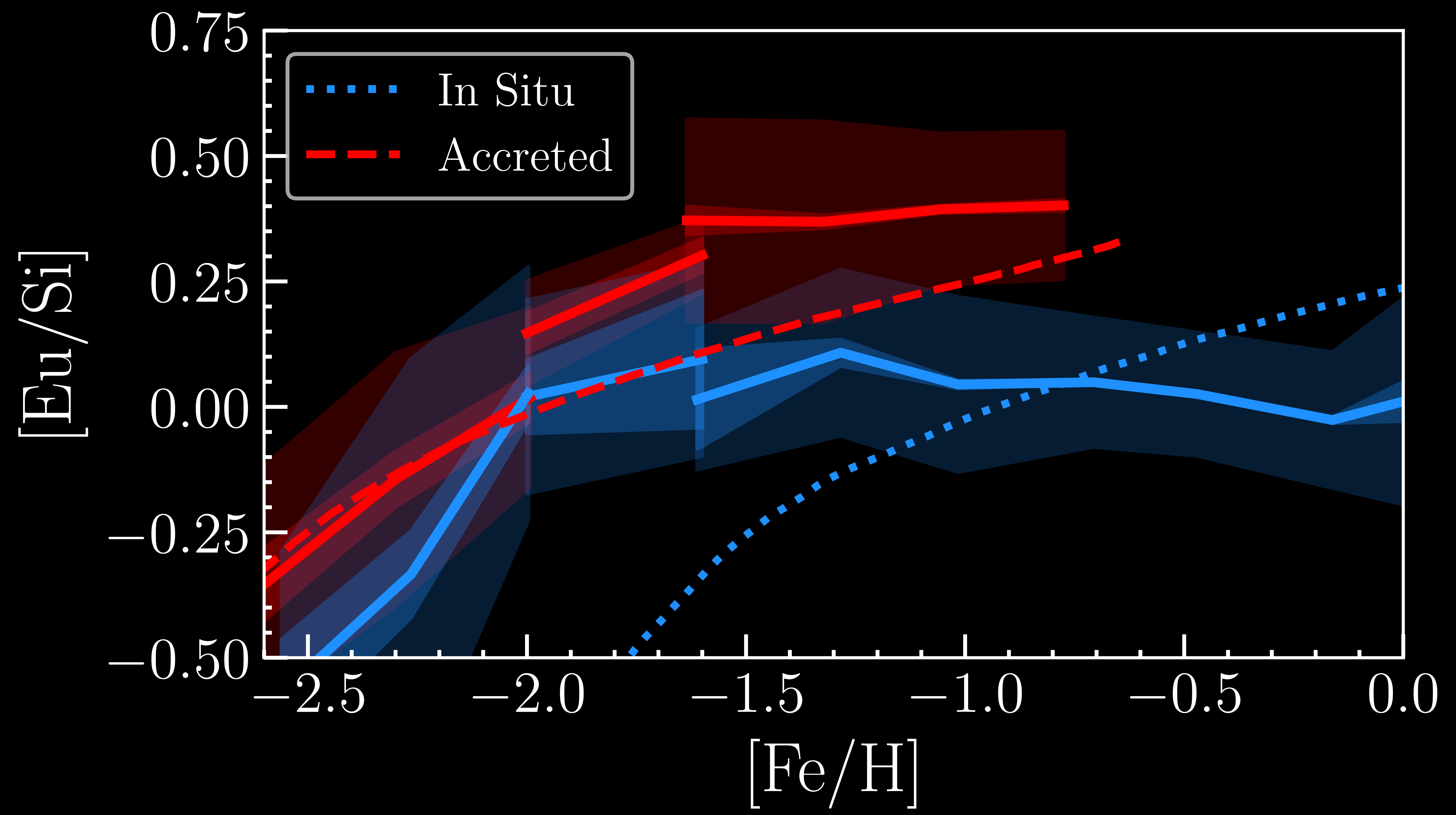
NSM ejecta likely transported and mixed differently in dwarf galaxies



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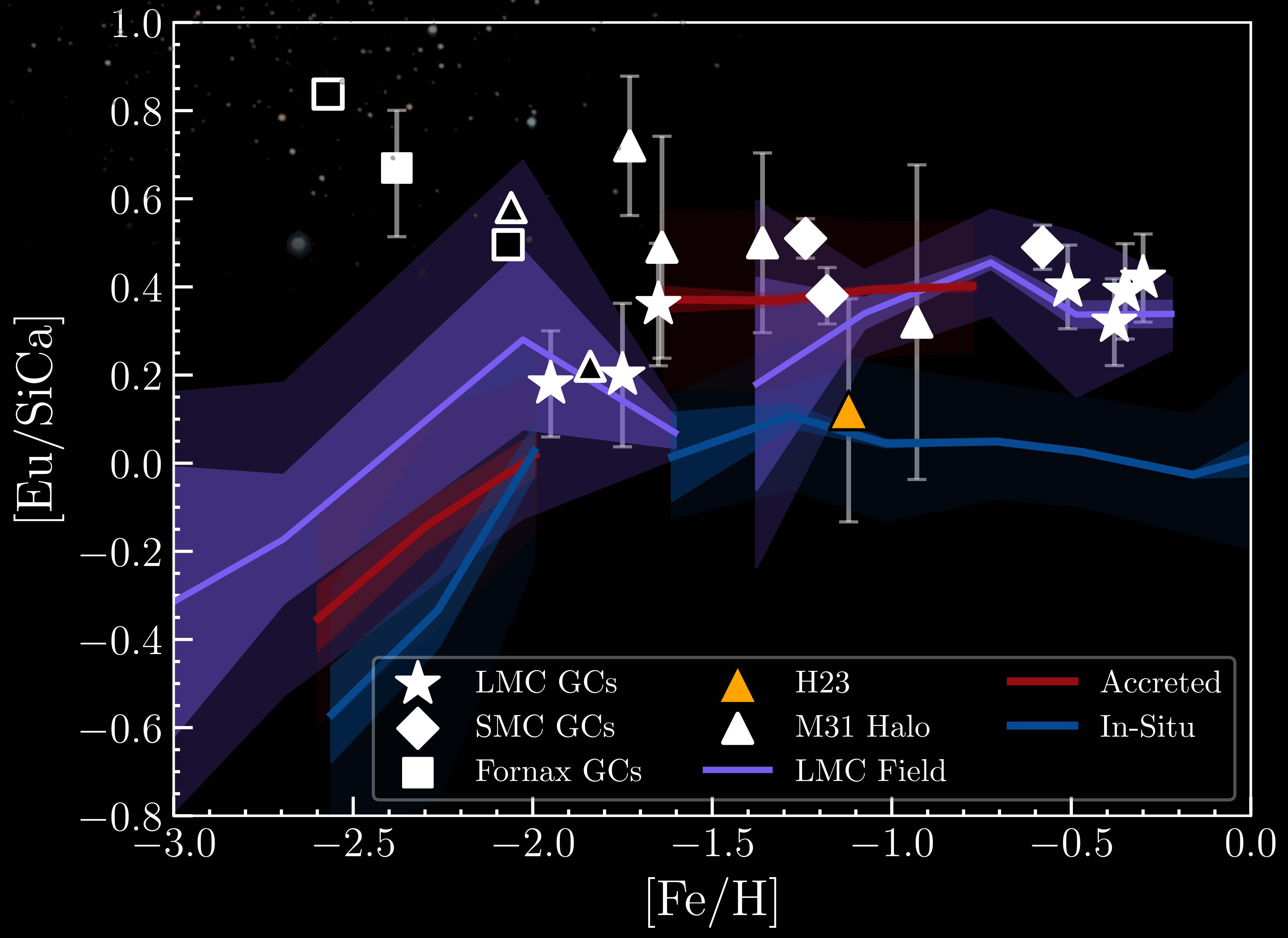
Bonus: [Eu/Si] could be used to perform Extra-galactic Archaeology



Sakari et al. 2015

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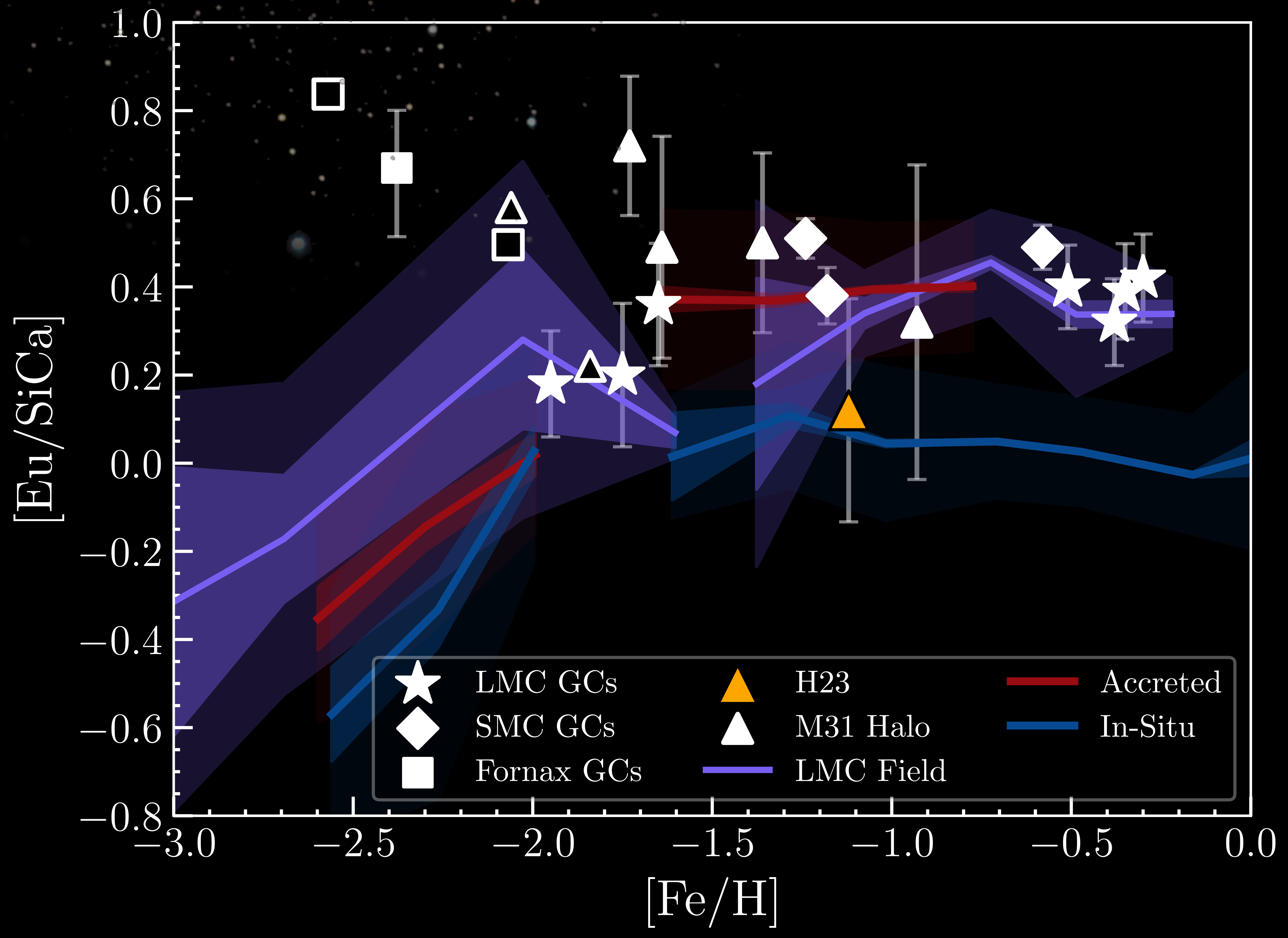

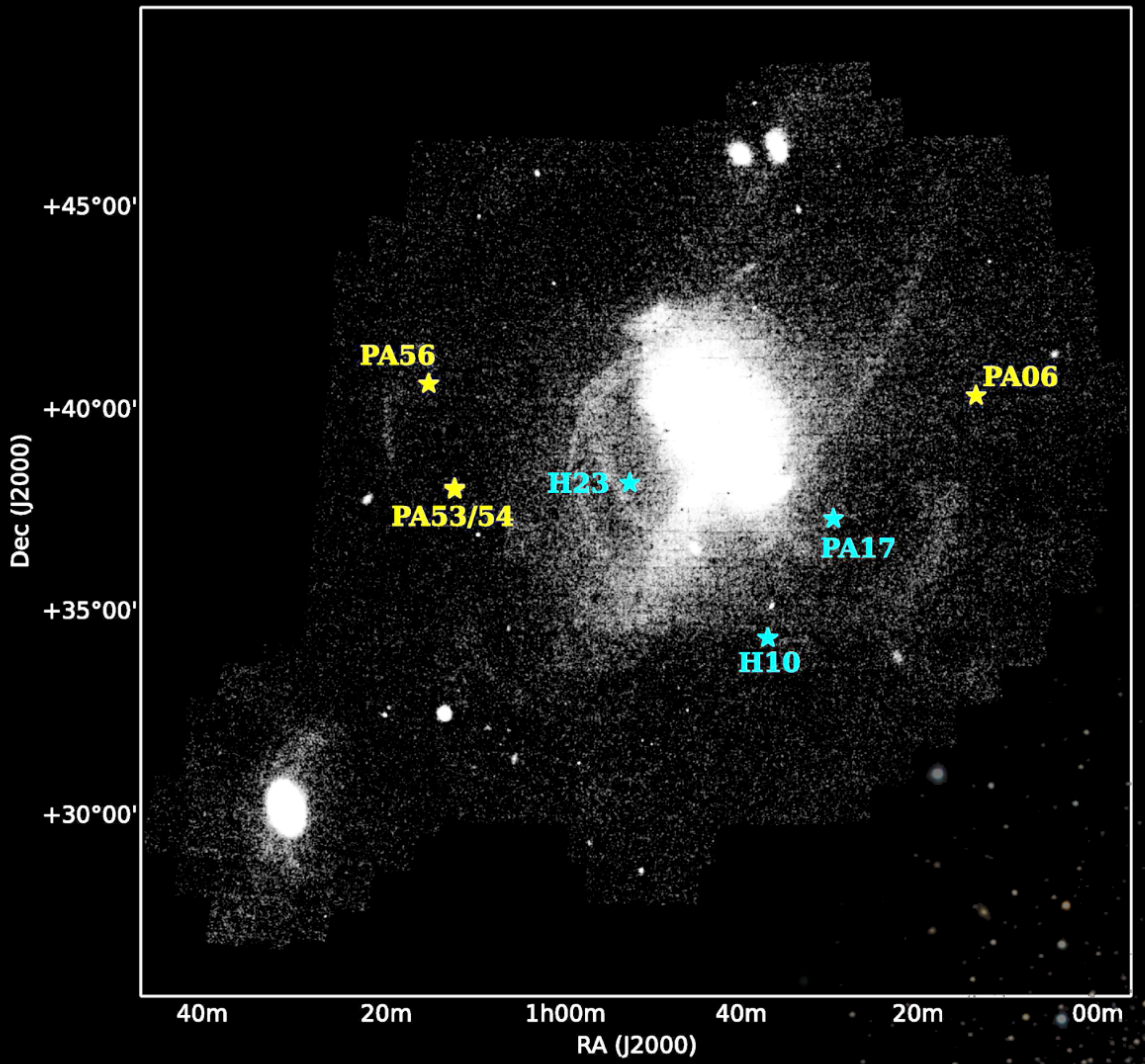

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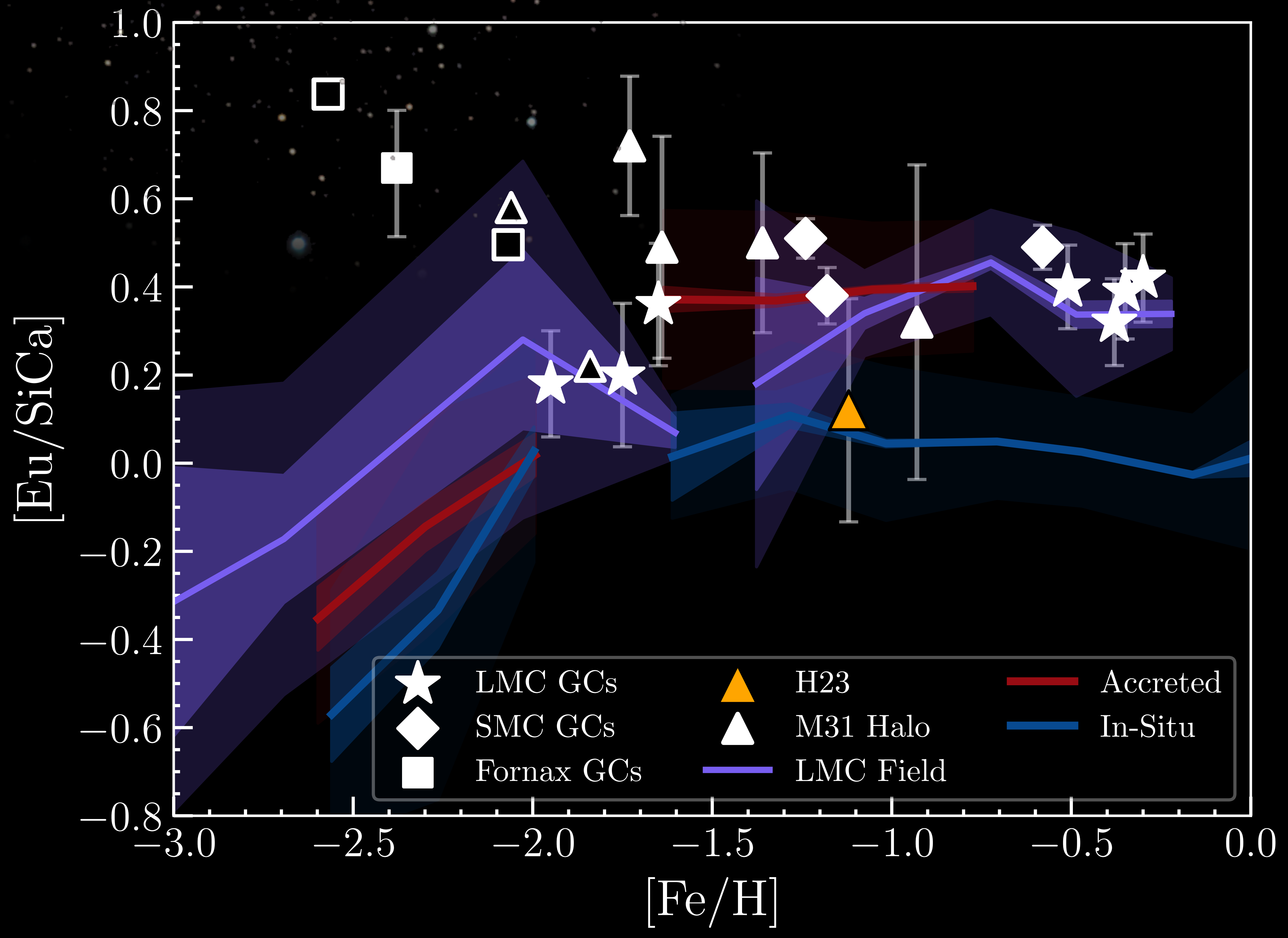

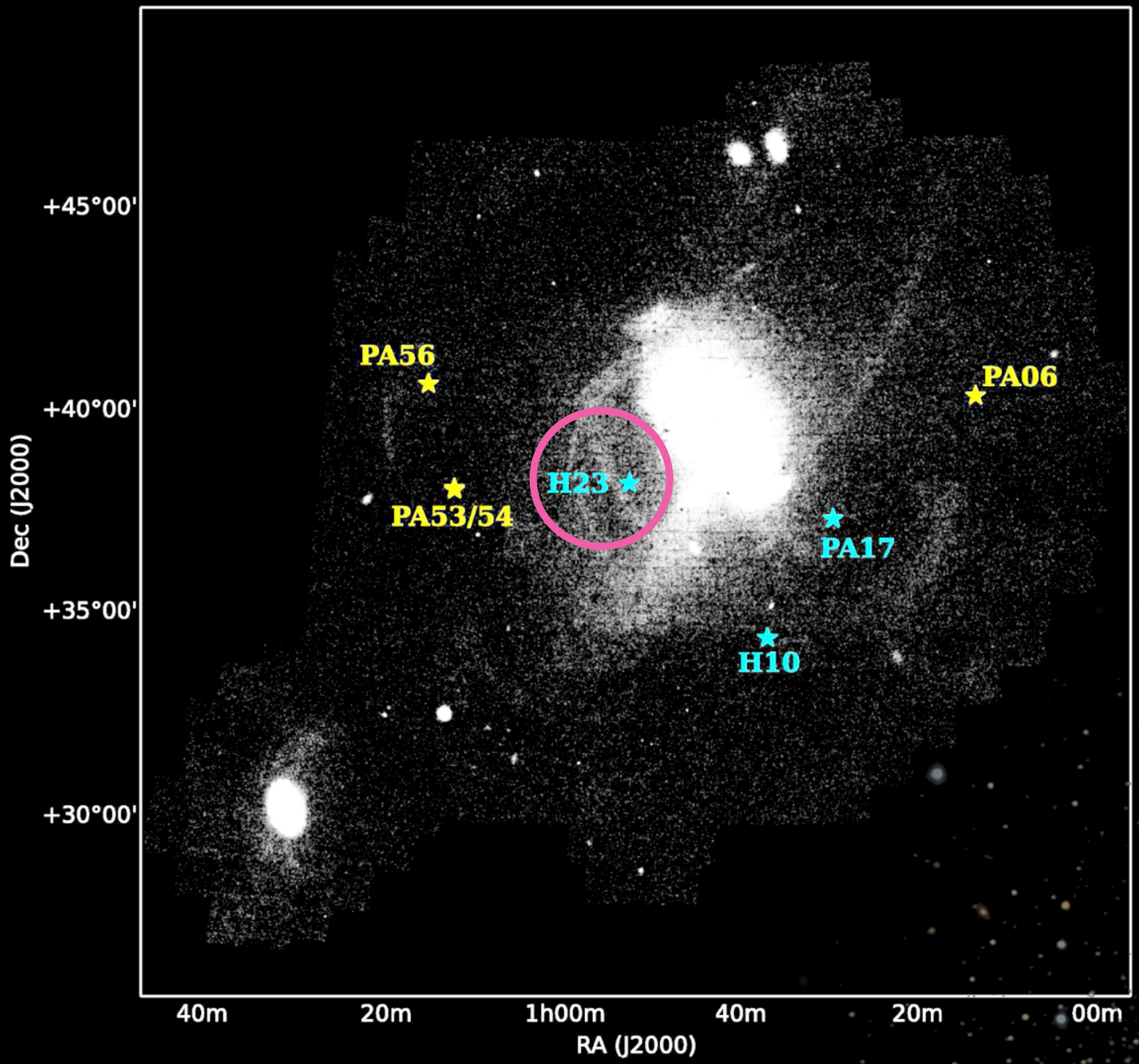

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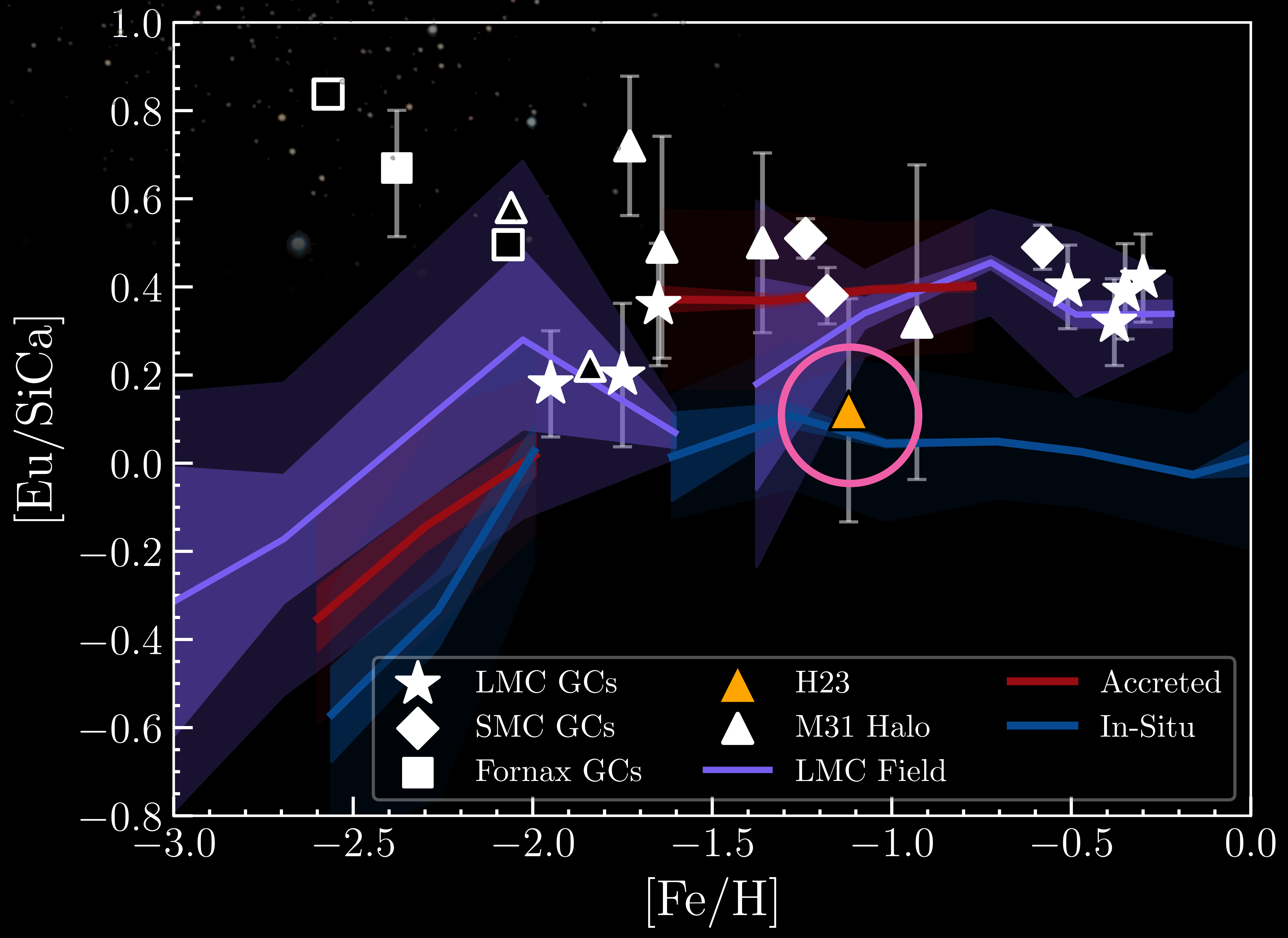

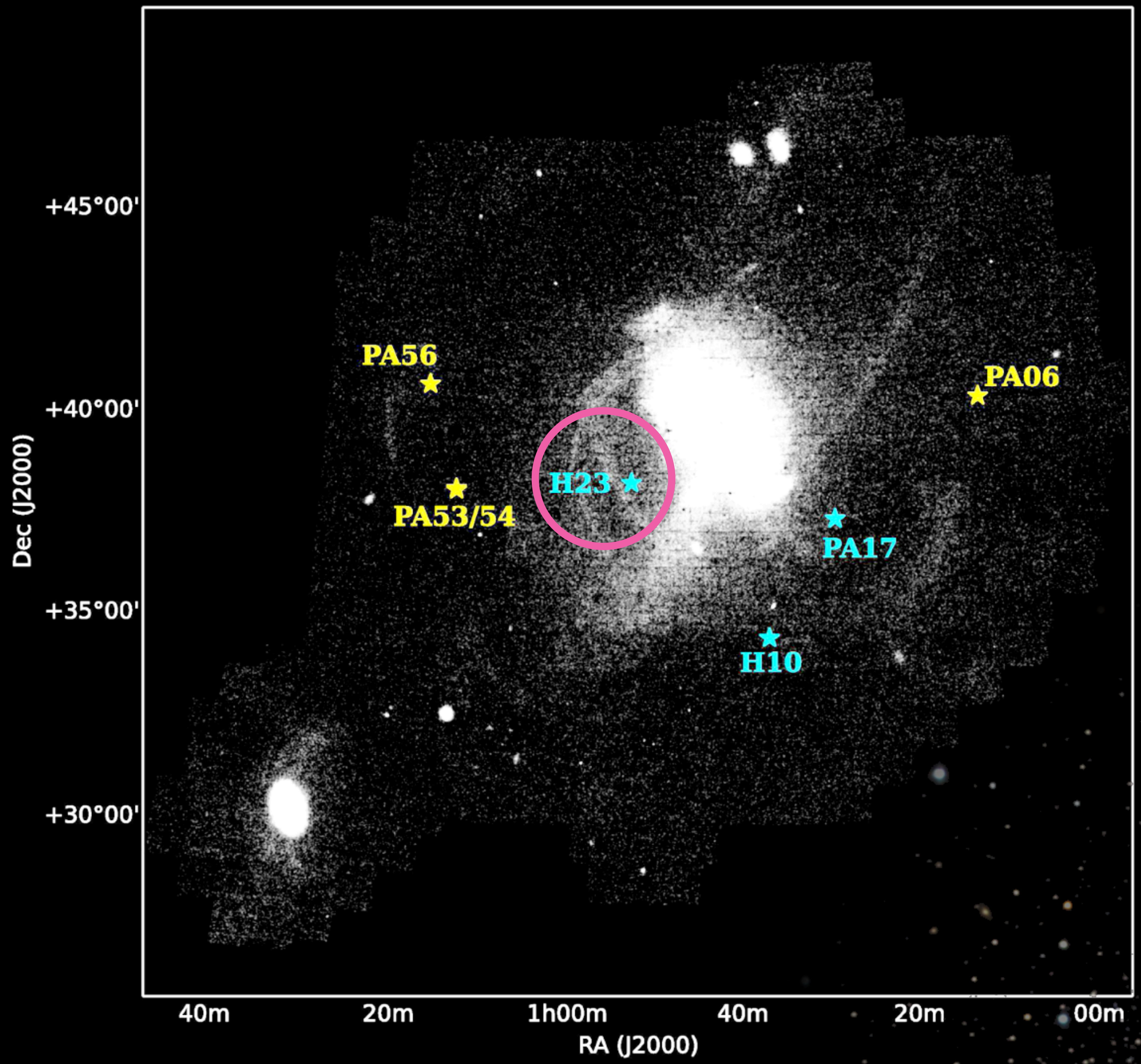

Sakari et al. 2015

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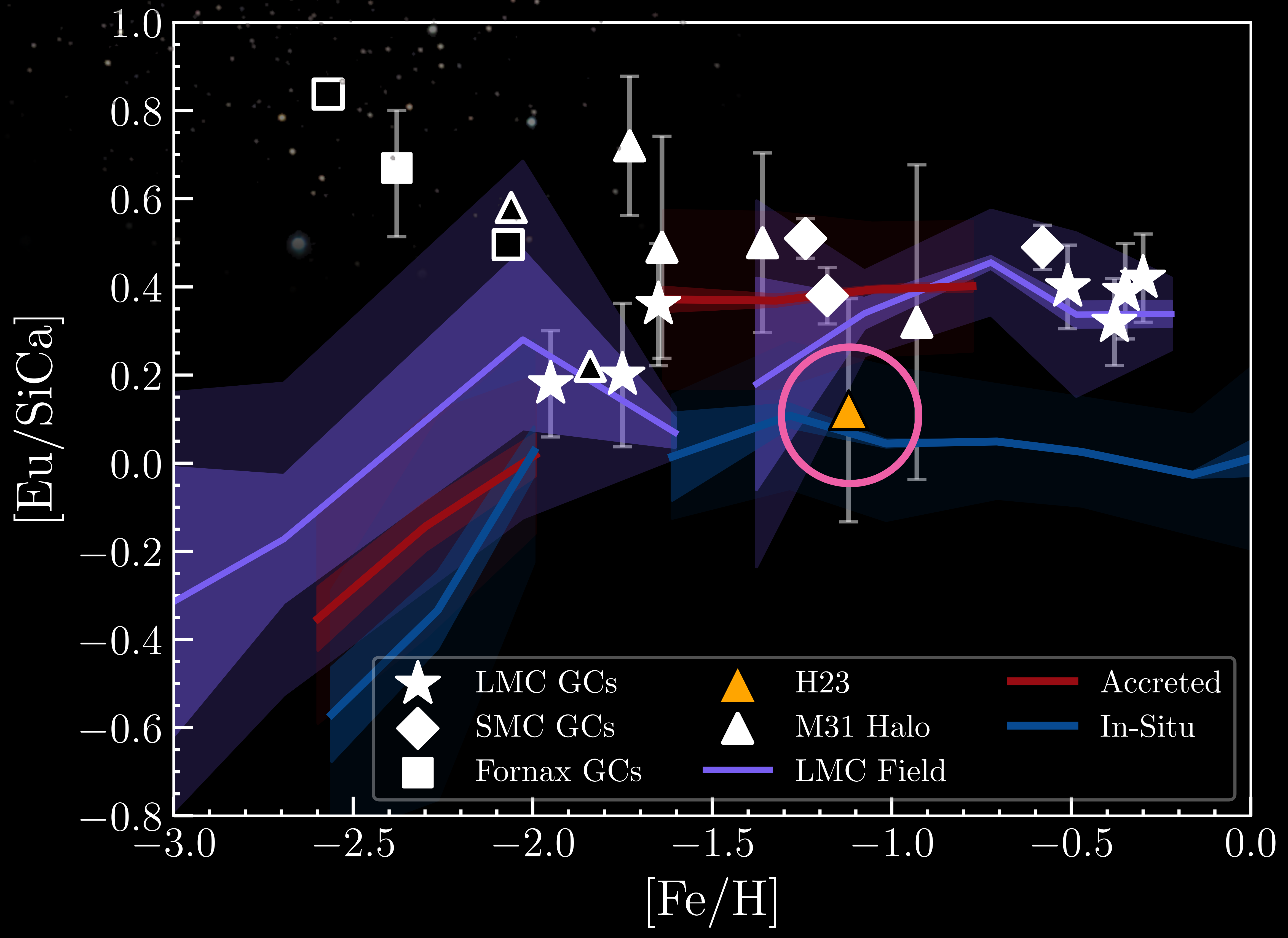
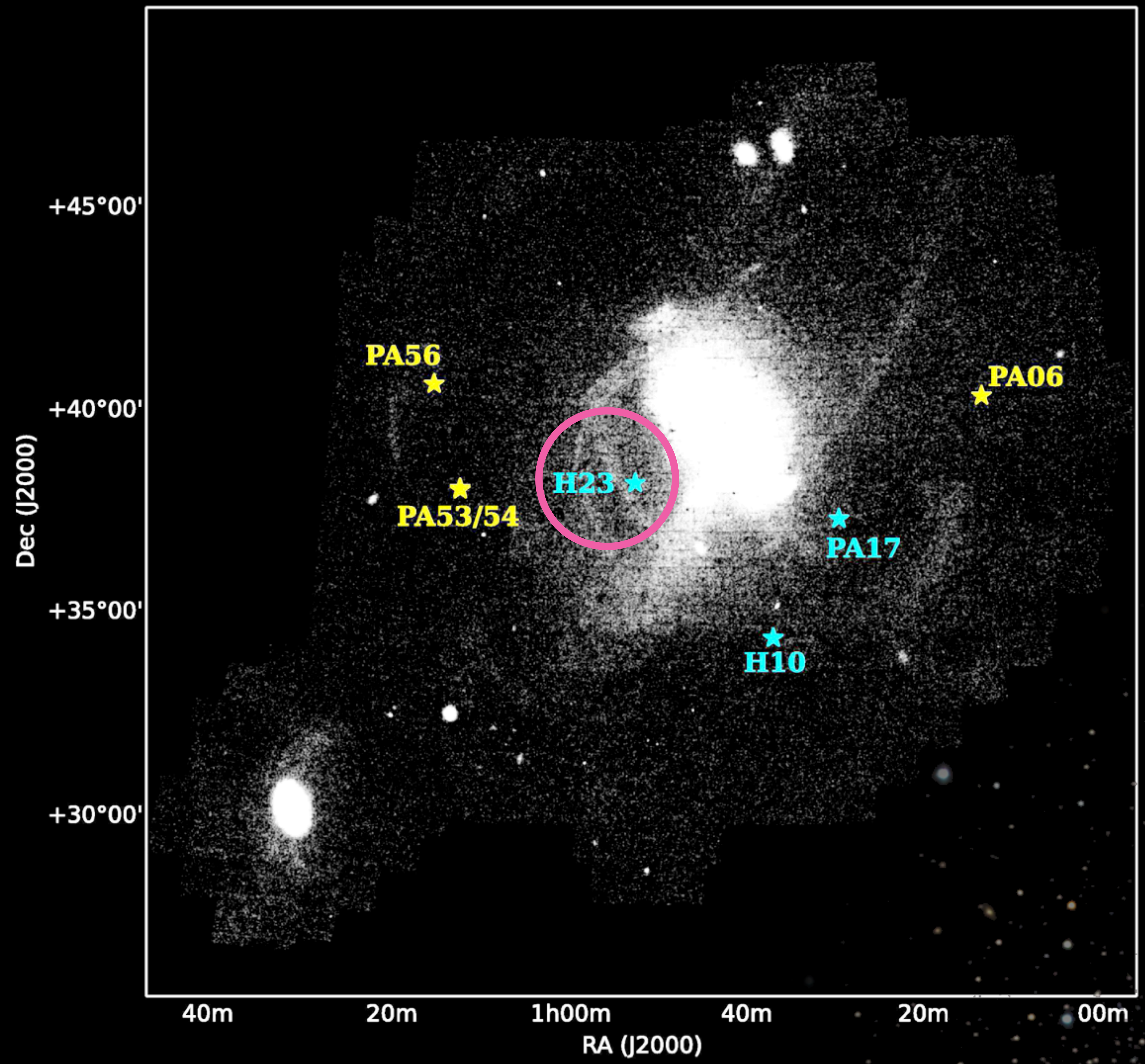
Most likely in-situ GC which formed alongside M31





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