Metallicity distribution functions of halo stars:

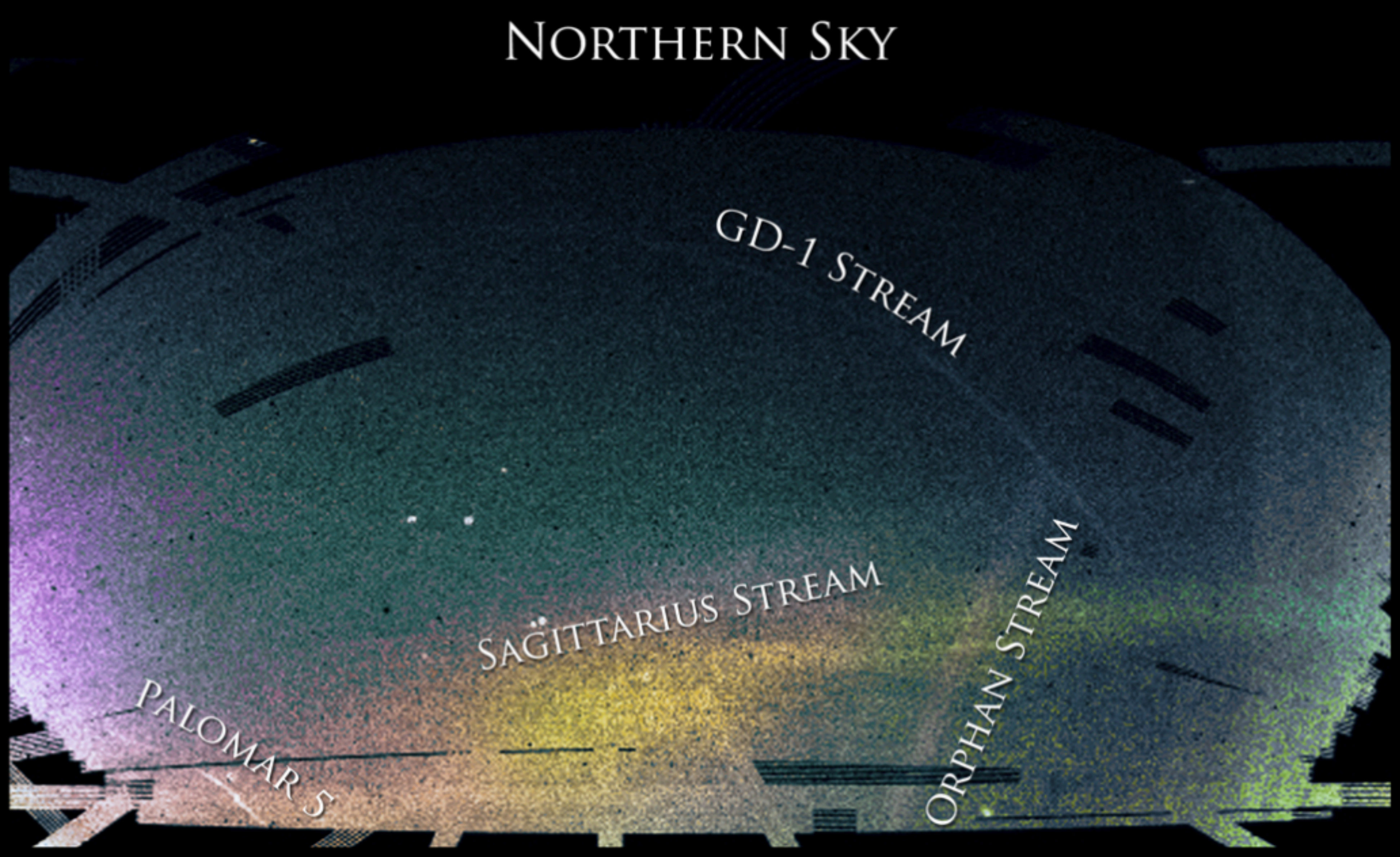
do they trace the galactic accretion history?

In collaboration with **P. Di Matteo, S. Salvadori, S. Khoperskov, G. Pagnini, M. Haywood**

Alice Mori - PhD student - **alice.mori@unifi.it**

IAUS395: Stellar populations in the Milky Way and beyond - Paraty, Brazil, November 21st 2024

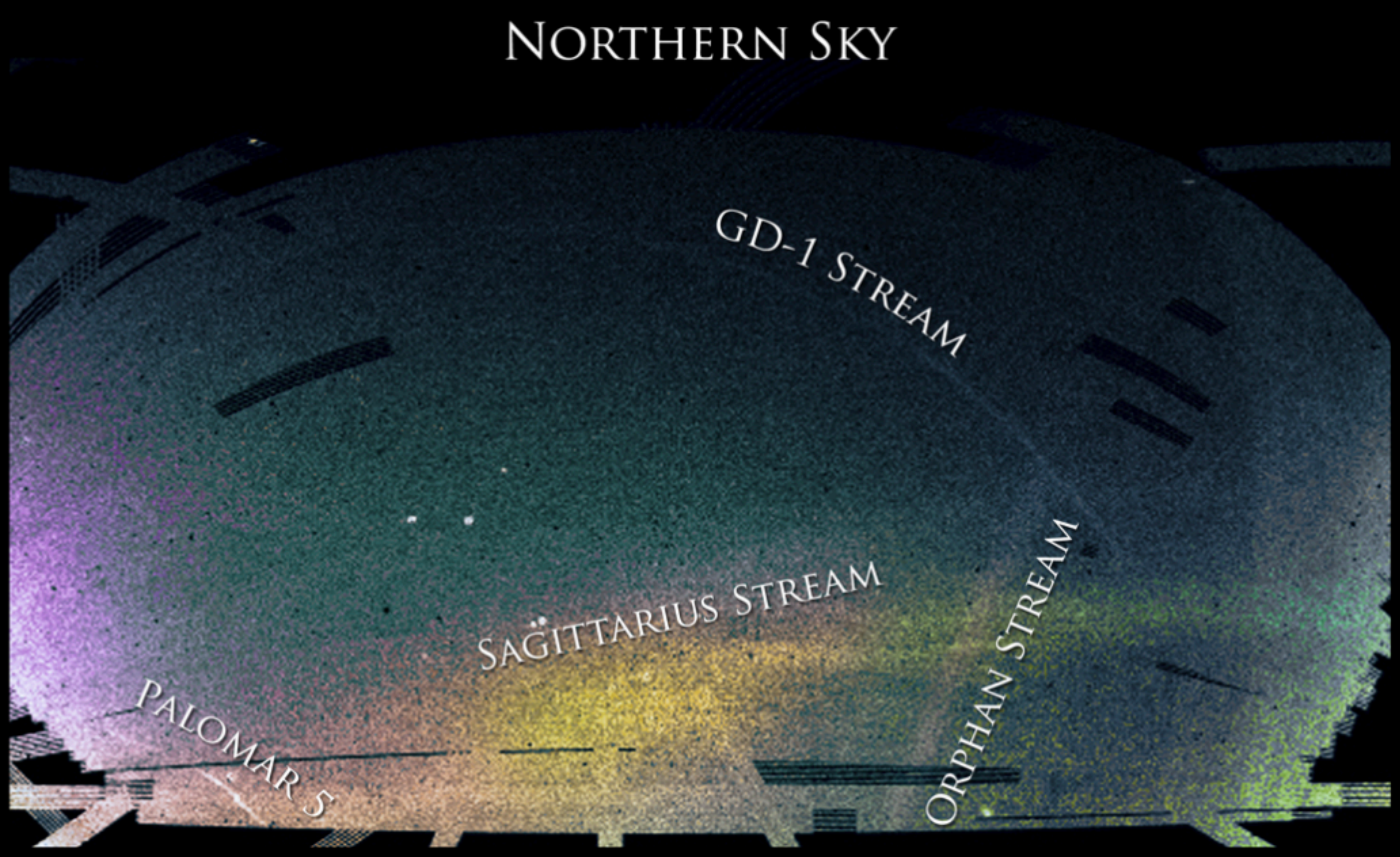
The stellar streams in the halo



Credits: SDSS DR8 / Bonaca, Giguere, Geha

Accretion history imprinted in stellar halo

The stellar streams in the halo

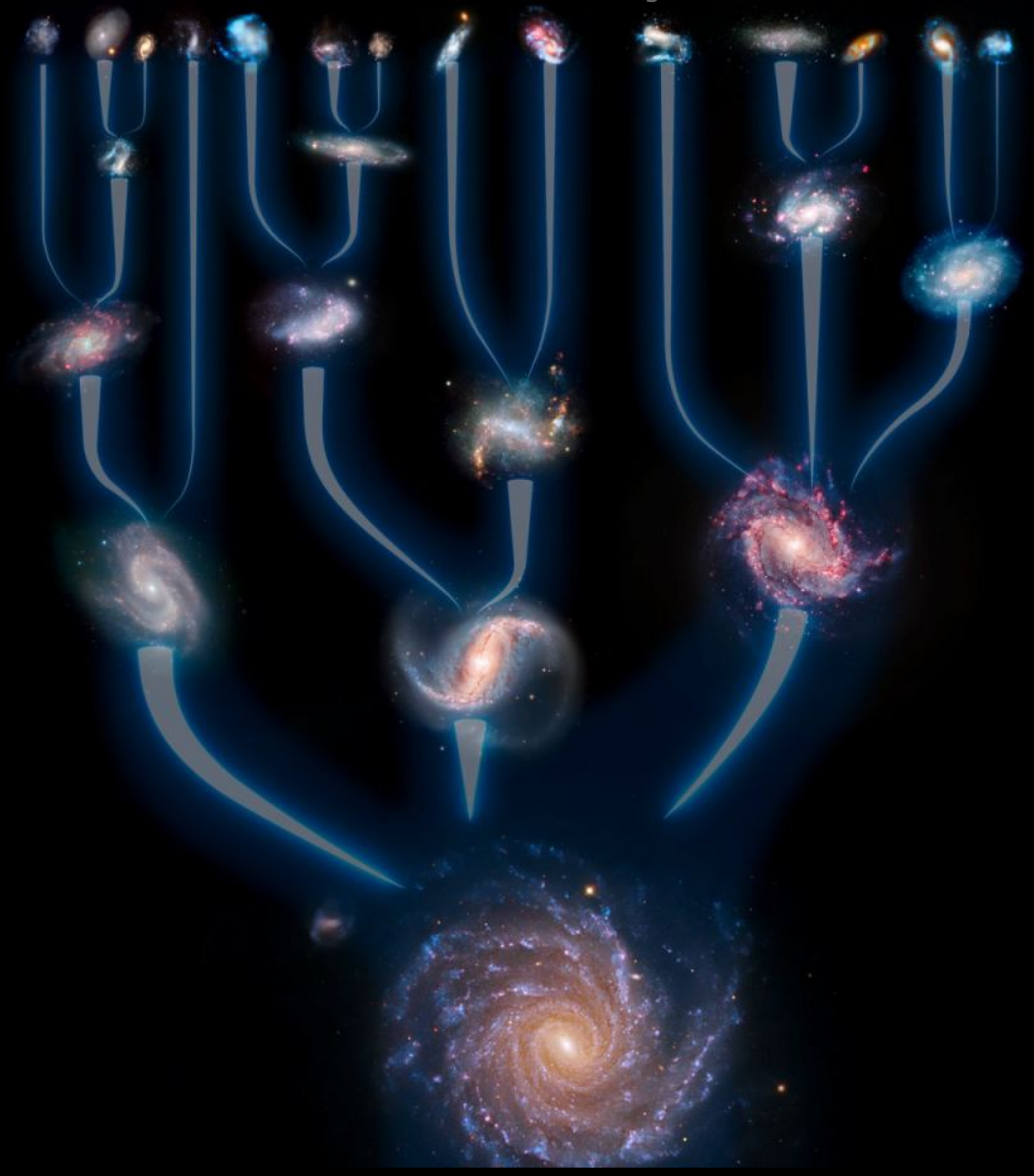


Credits: SDSS DR8 / Bonaca, Giguere, Geha

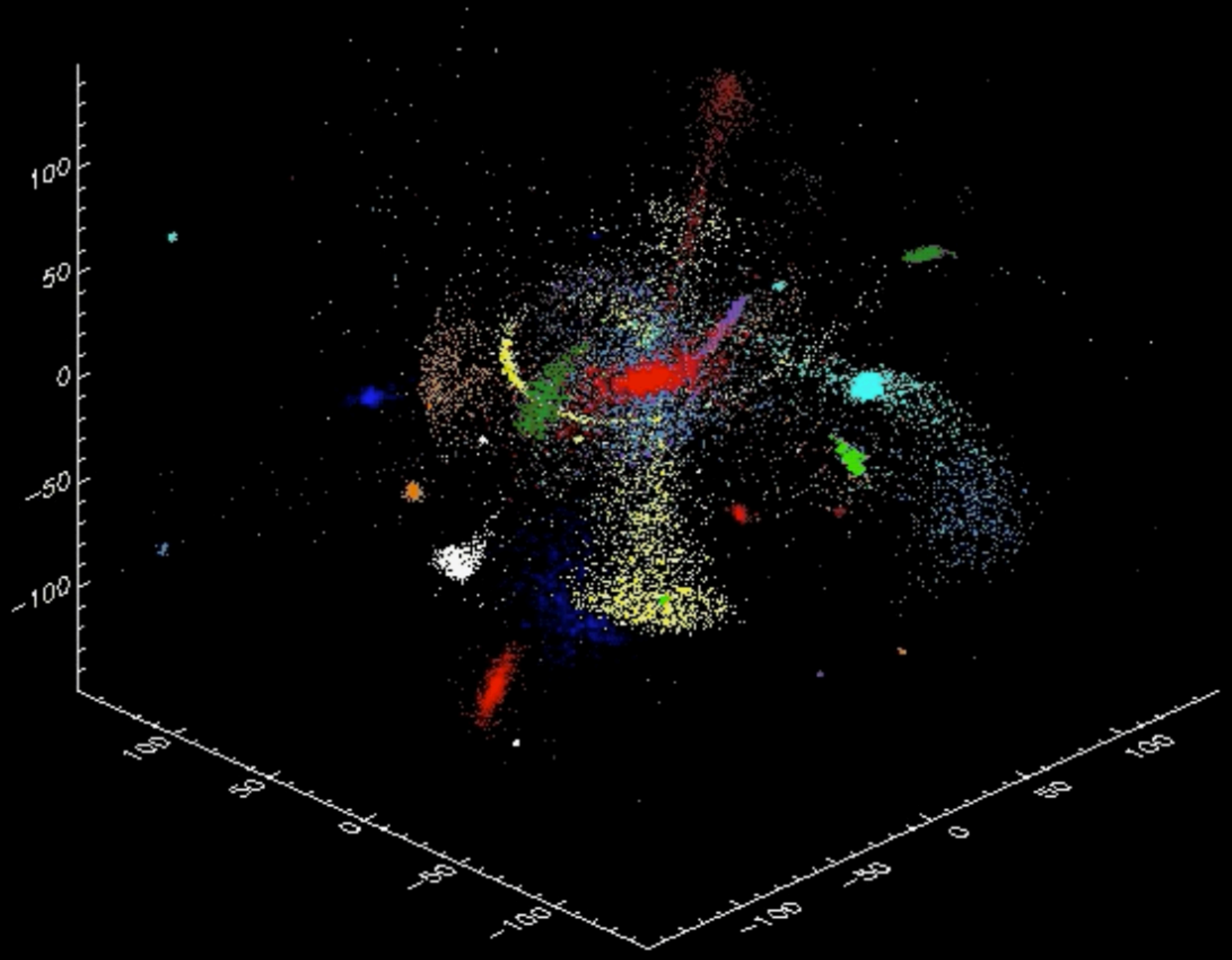
Accretion history imprinted in stellar halo

Hierarchical galaxy formation

Credit: ESO/L. Calçada



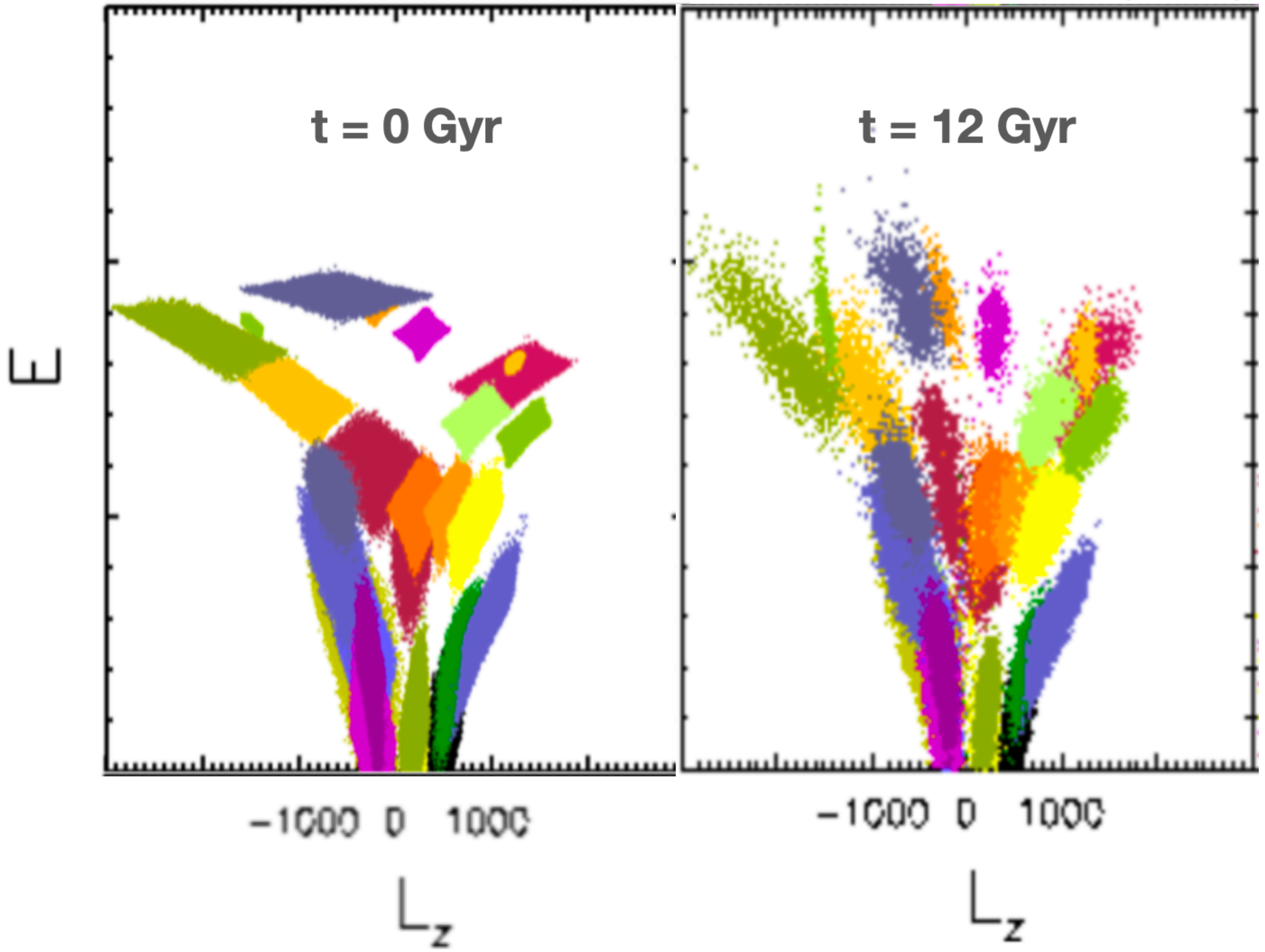
The need for Galactic Archaeology



Johnston & Bullock 2005

1. Energy-angular momentum space ($\mathbb{E} - \mathbb{L}_z$)

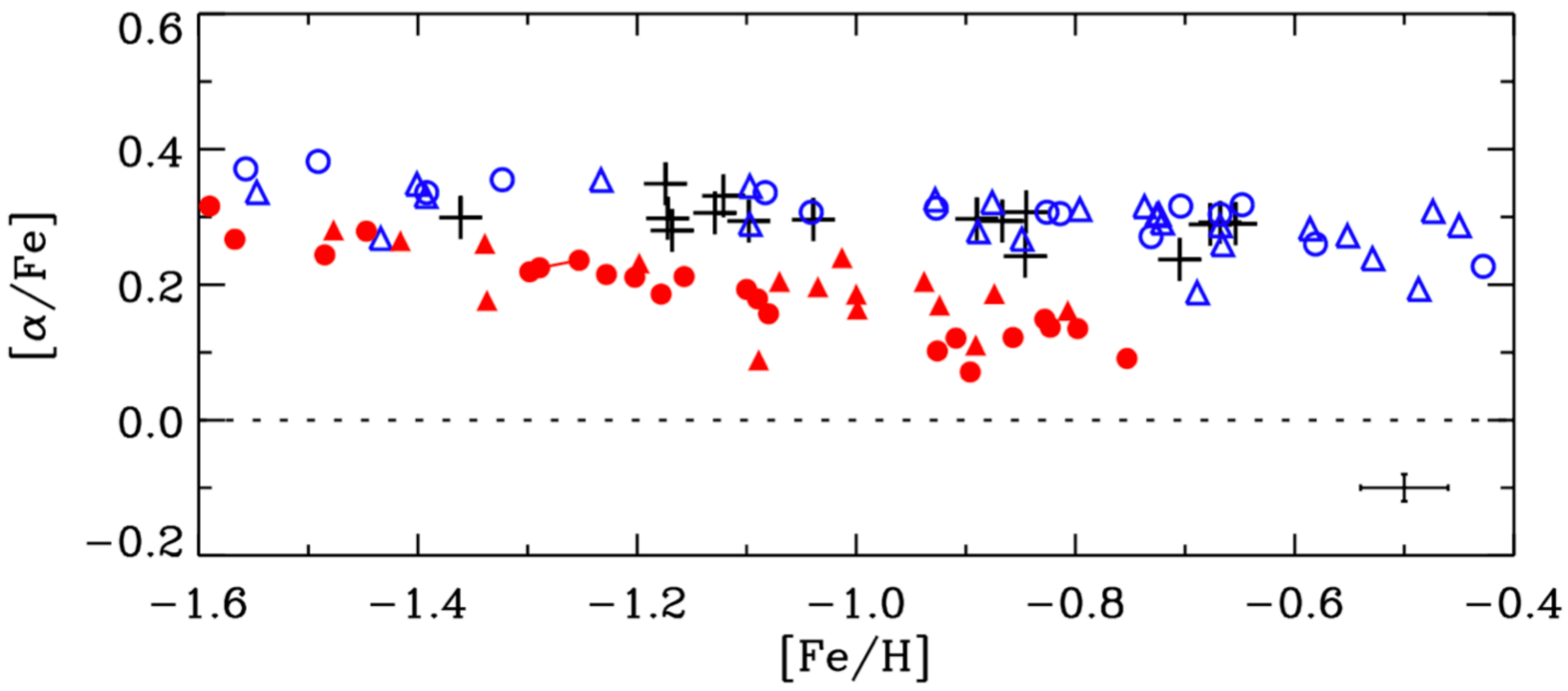
Helmi & de Zeeuw (2000)



N satellites → N clumps

2. Alpha-metallicity space

Nissen & Schuster (2010)



Different curves → different SFHs

Gaia-Sausage-Enceladus

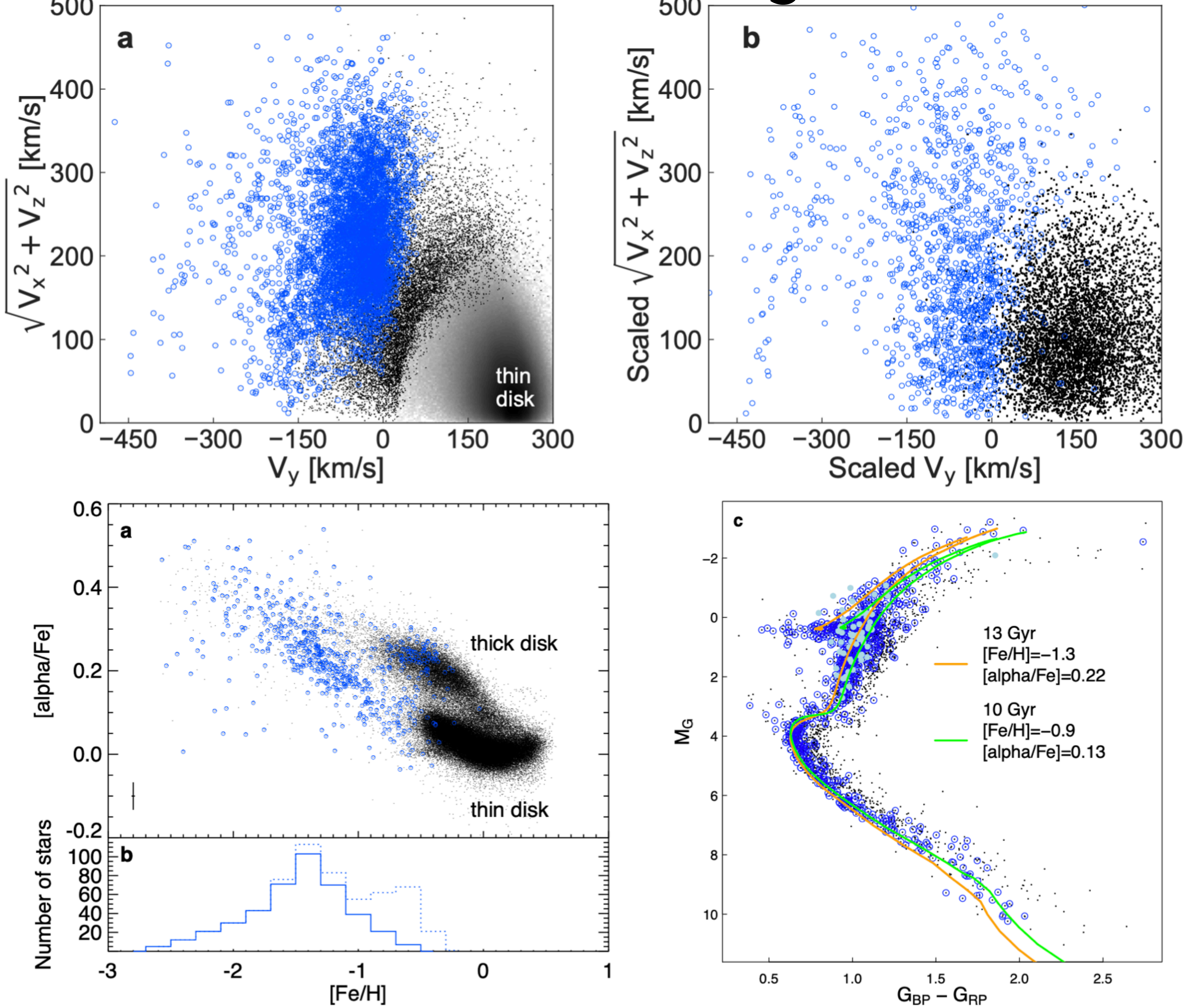
Accreted galaxy

$M_* \sim 6 \times 10^8 M_\odot$

$t_{accr} \sim 10$ Gyr ago

Gaia DR2 **data**

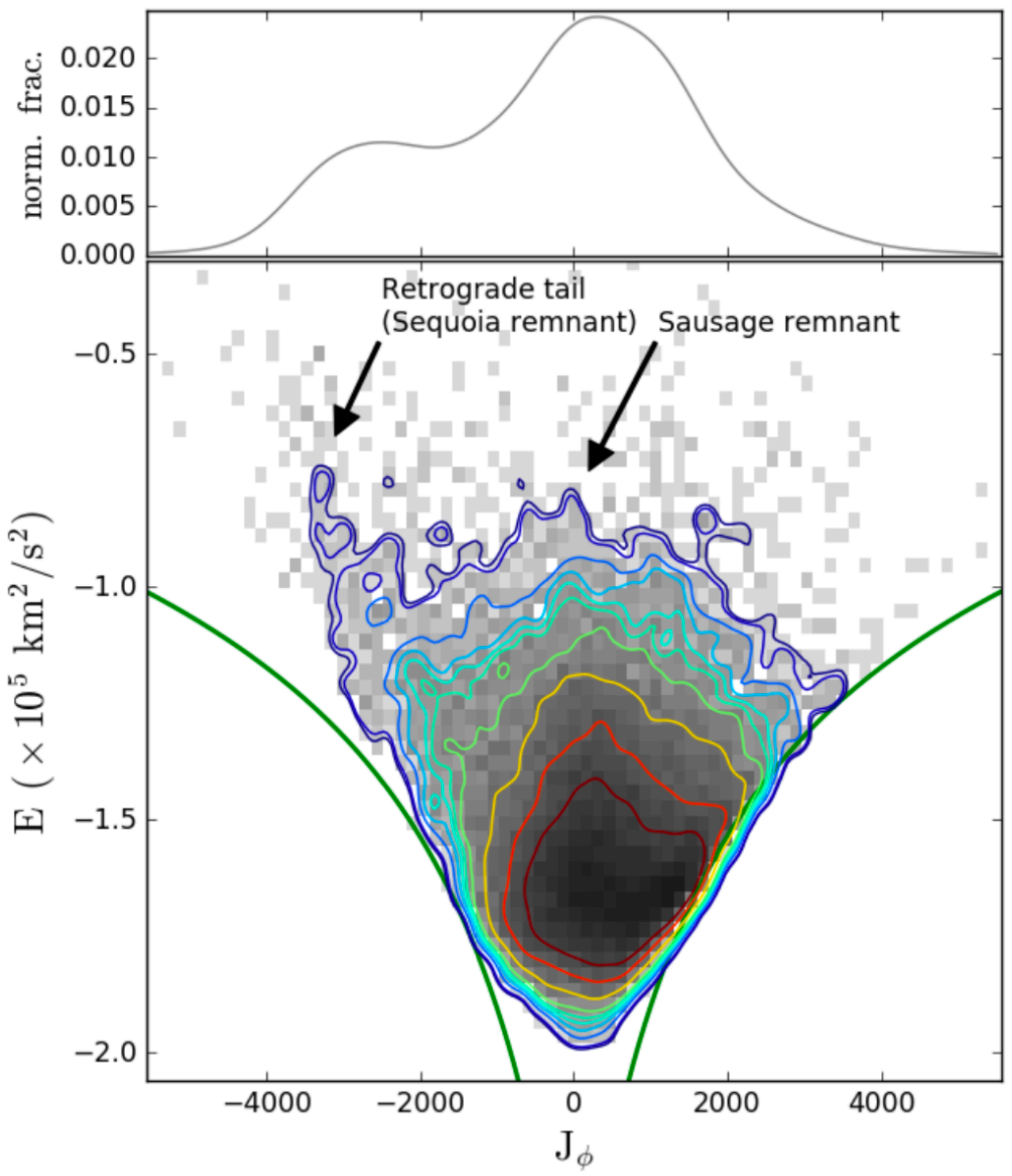
Merger **simulation**

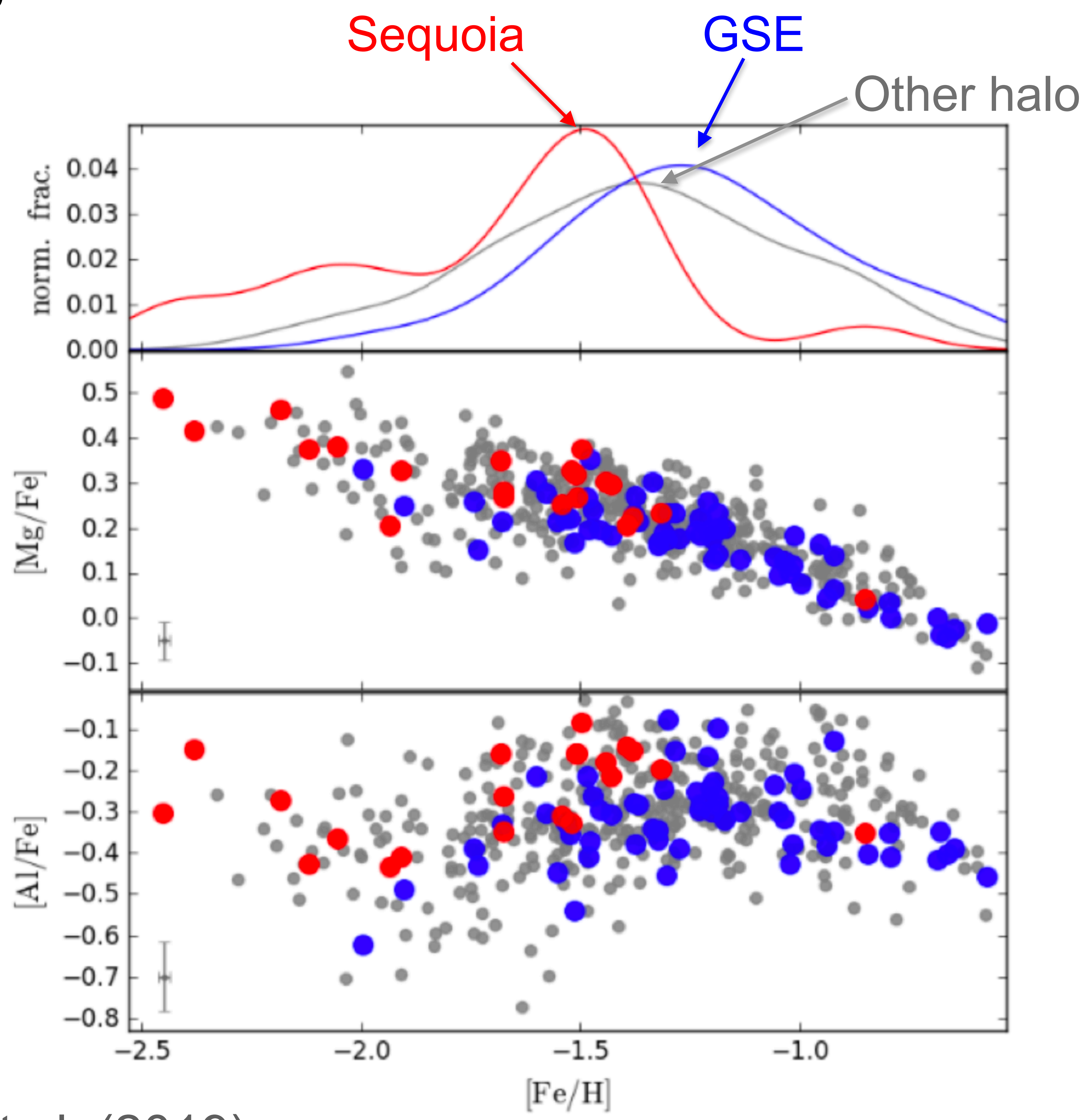


Helmi et al. (2018)

Gaia-Sausage-Enceladus & Sequoia

Metallicity Distribution Functions

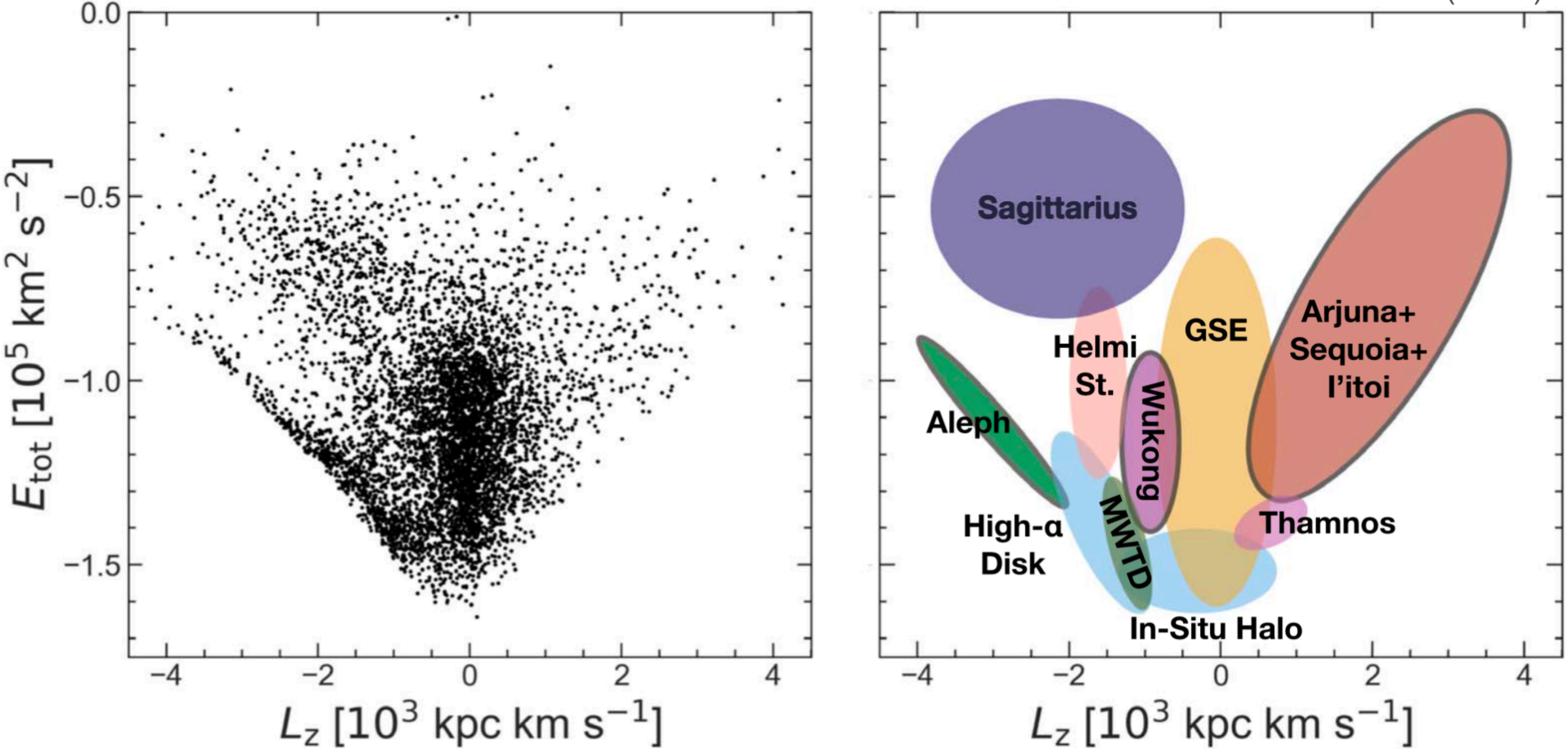




Myeong et al. (2019)

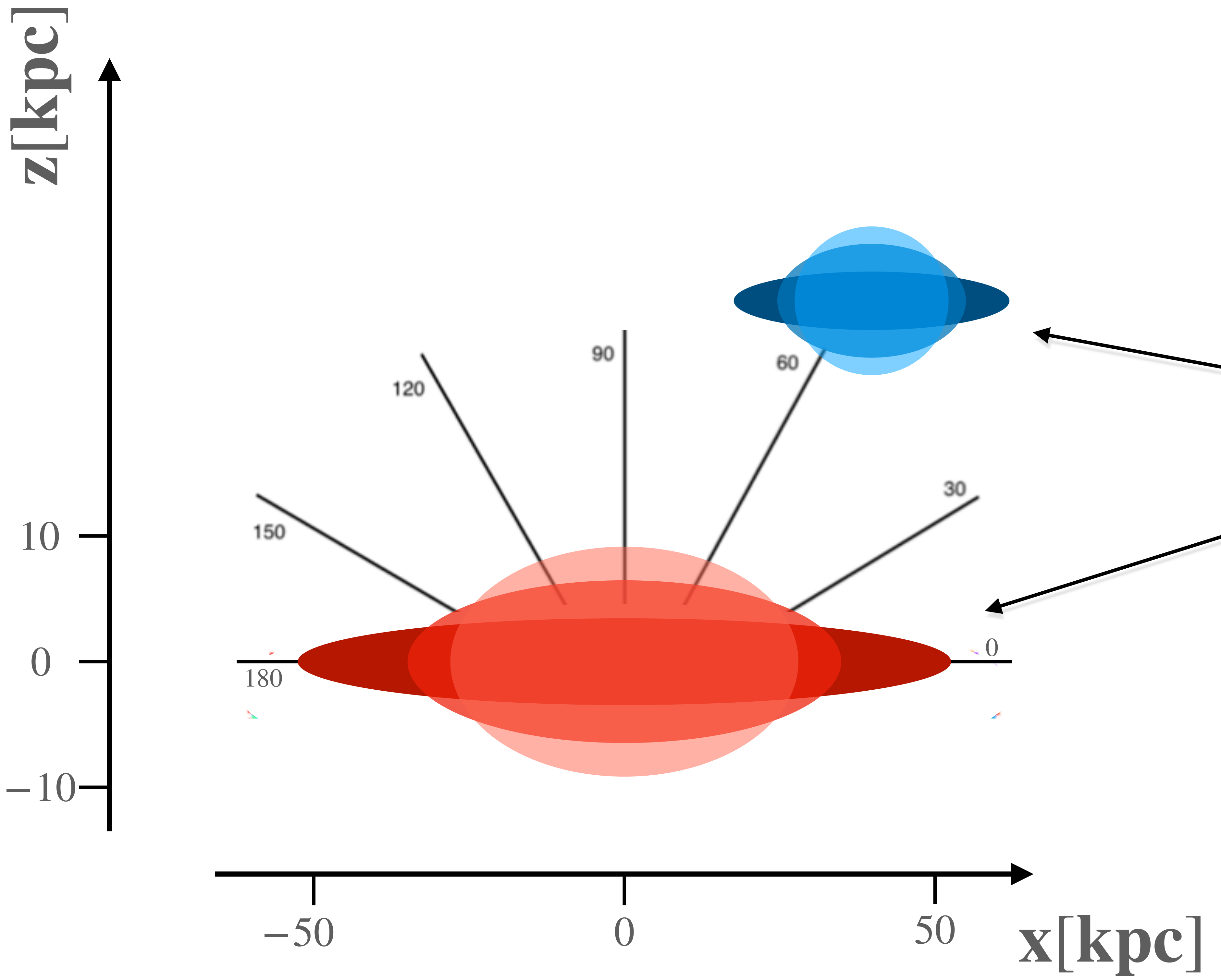
State of the art

Naidu et al. (2020)



N-body simulations set-up

MW-like galaxy accreting a satellite with mass ratio 1:10



Galaxies modelled with 3 different disc components

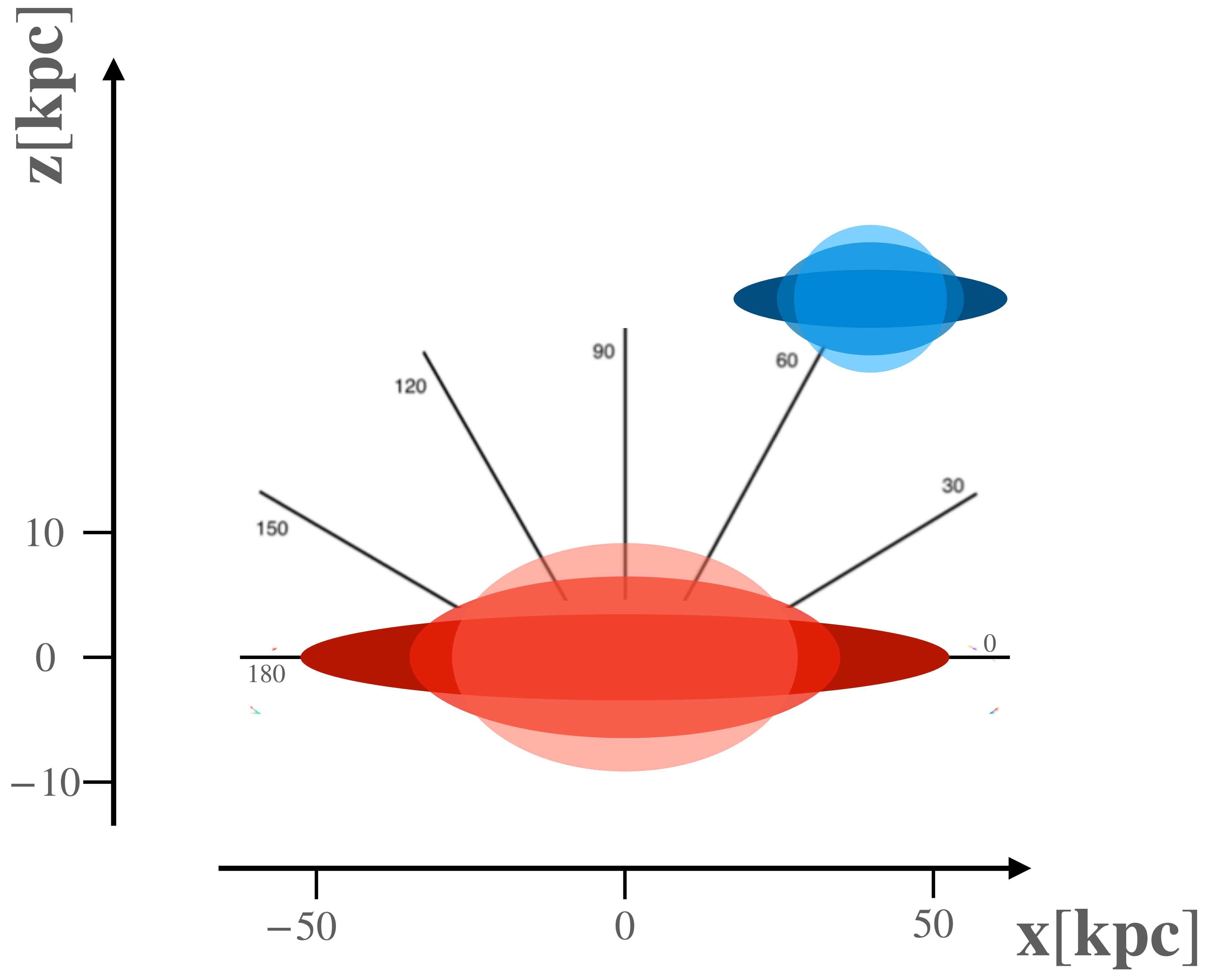
Varying the initial inclination of the satellite orbital plane wrt MW disc

$$\phi_{orb} = 0°, 30°, 60°, 90°, 120°, 150°, 180°$$

N-body simulations set-up

Abundance gradients in the MW and satellite

Mori et al. (2024)



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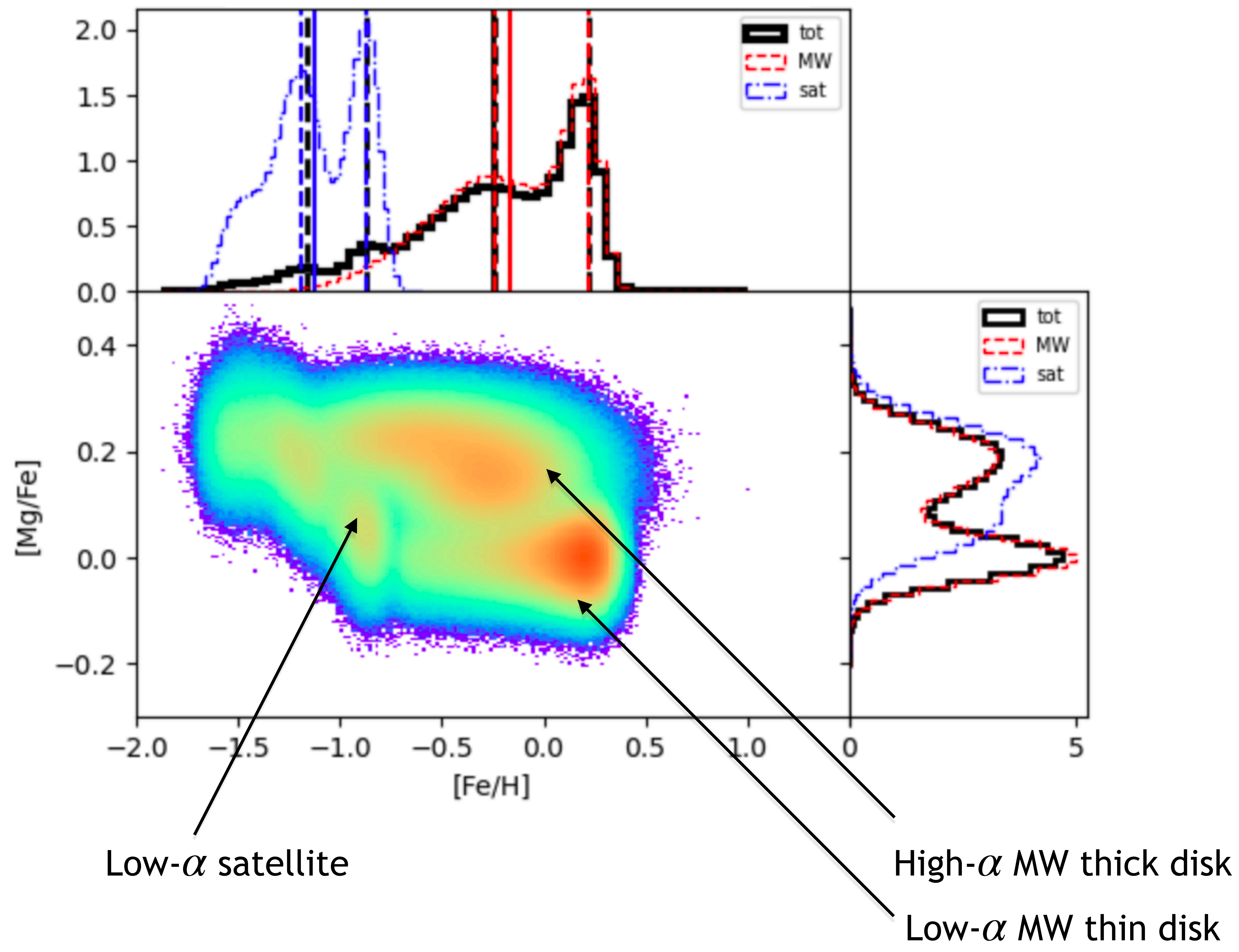
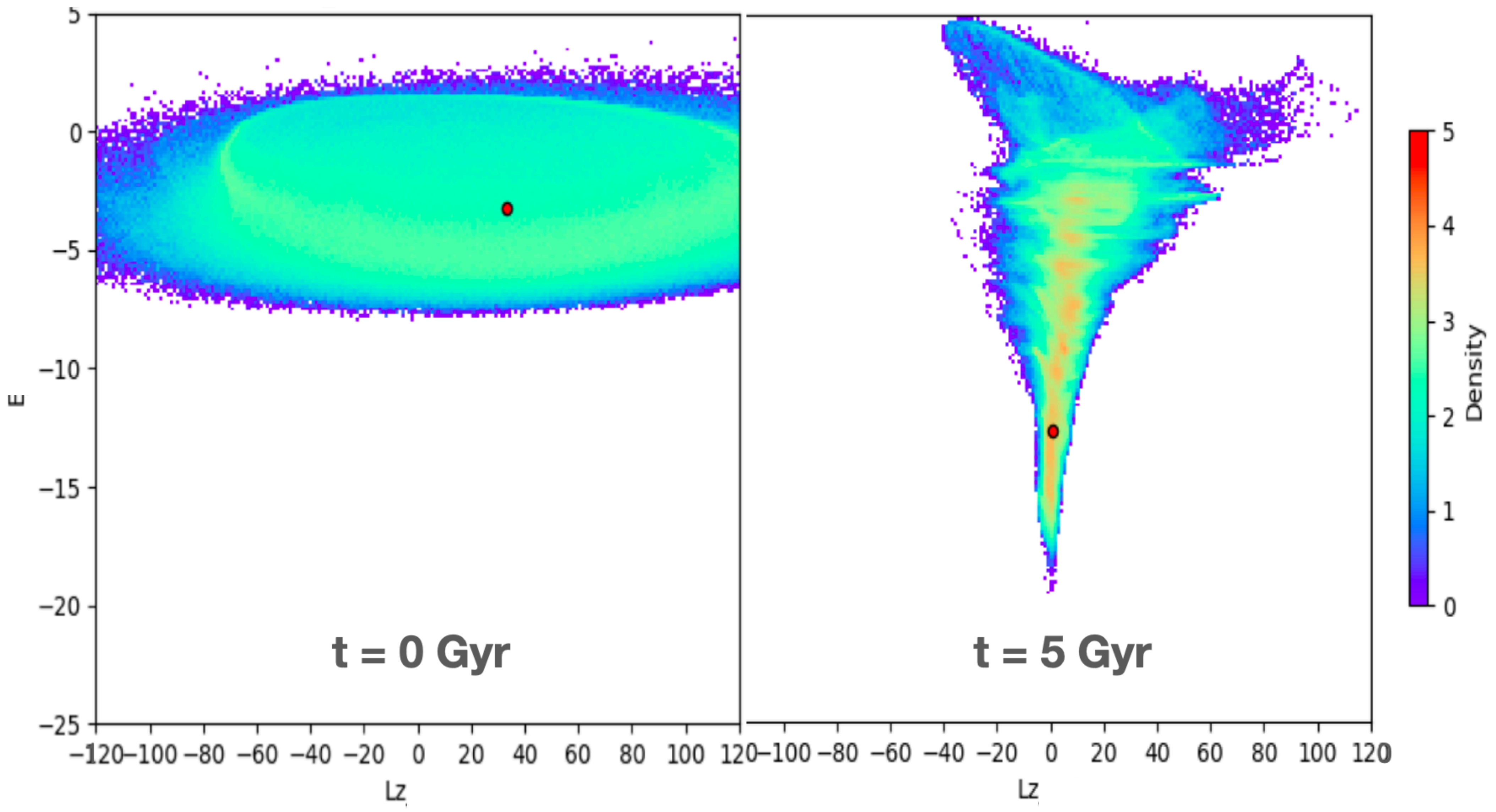


Energy-angular momentum space ($\mathbf{E} - \mathbf{L_z}$)

Mori et al. (2024)



1 satellite →N clumps

$$M_{sat} = 1/10\, M_{MW}$$

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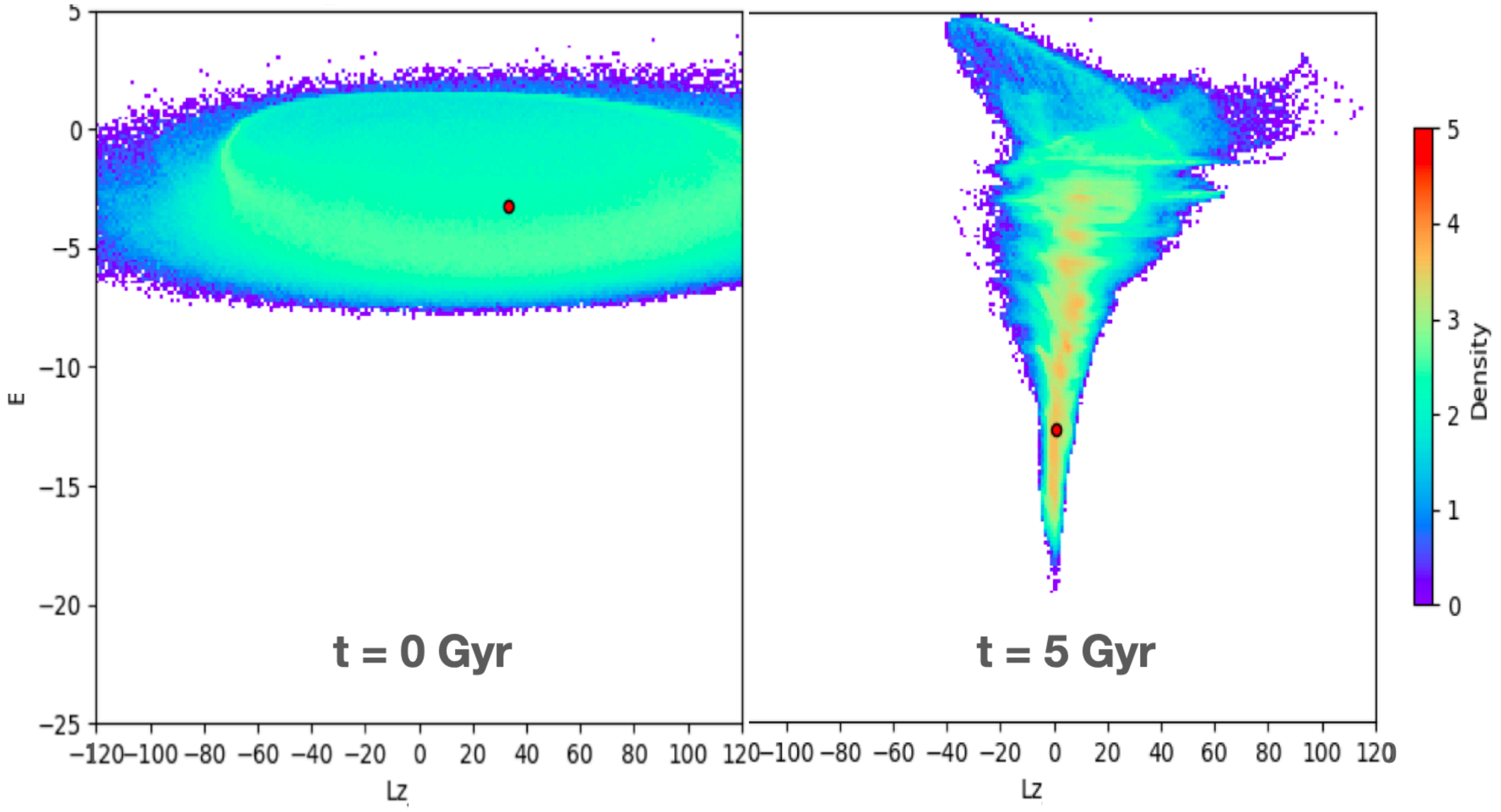
Mori et al. (2024)



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E and L_z are not generally conserved quantities, when very massive satellites are concerned

See also Jean-Baptiste+17, Khoperskov+23, Pagnini+23

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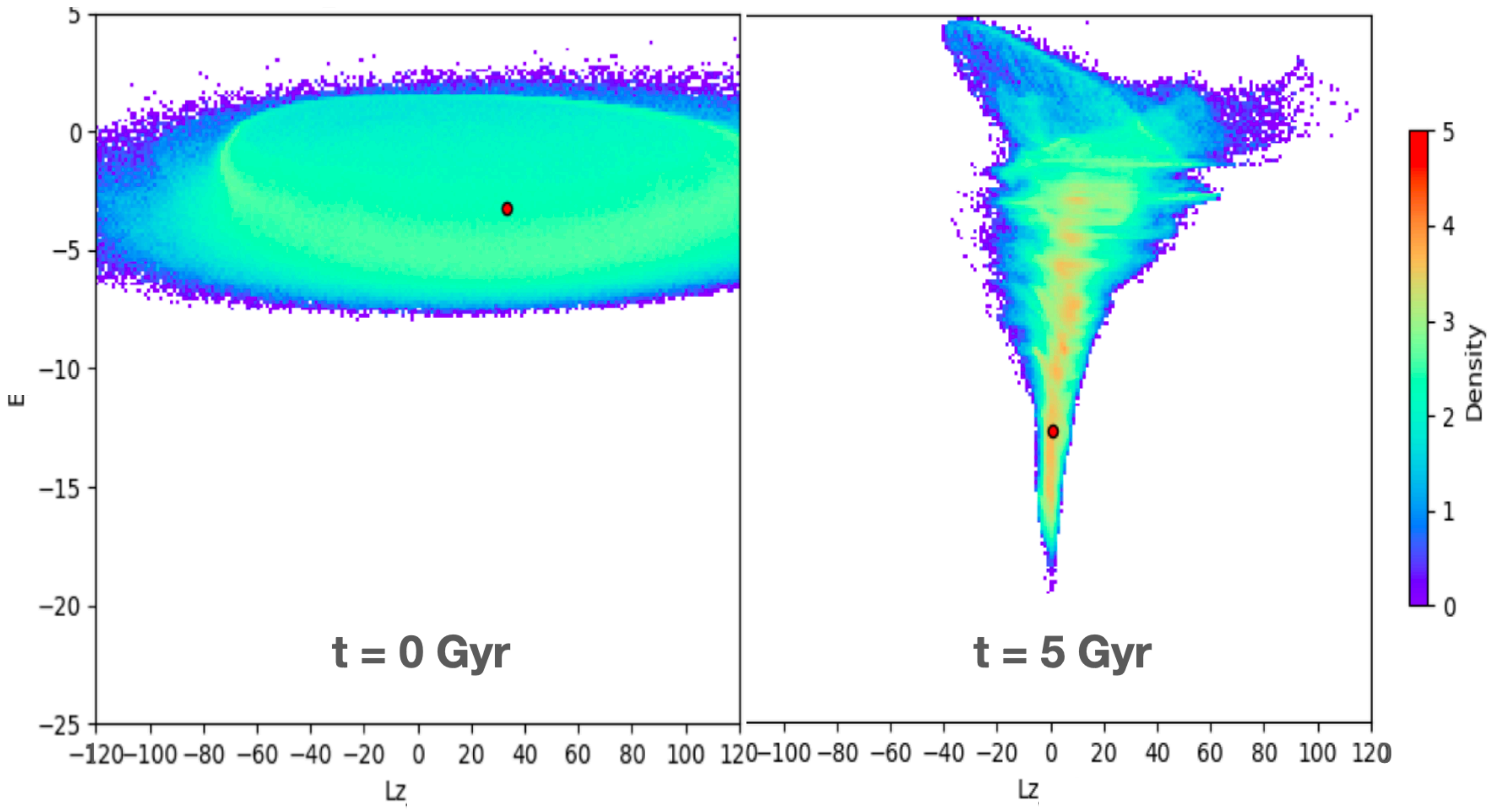
Mori et al. (2024)



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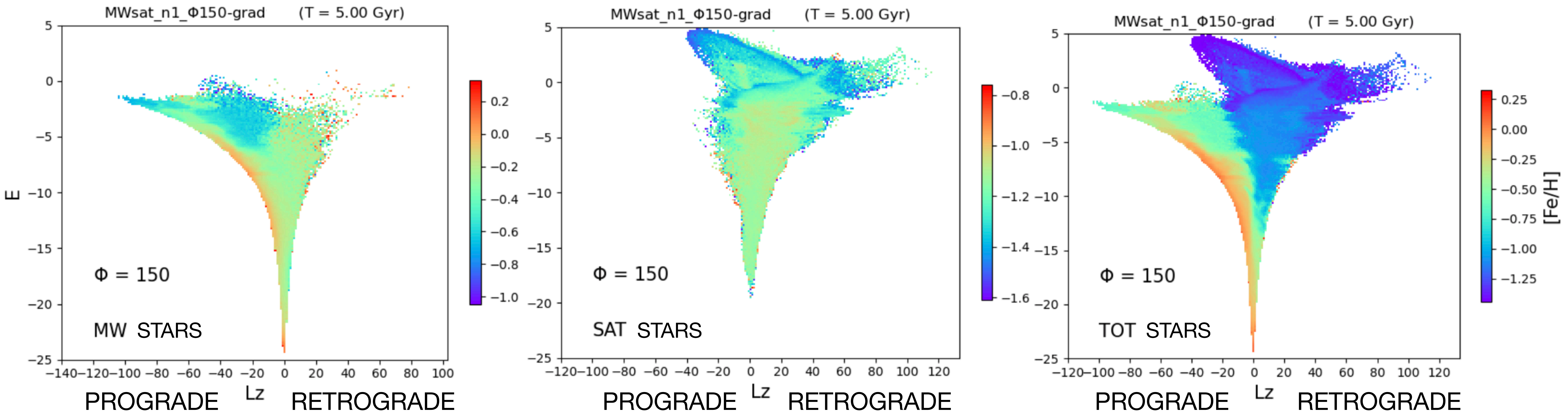
Kinematic heating of disc stars (together with the accreted stars) → formation of the stellar halo

Metallicity patterns in $\mathbf{E - L_z}$ space

Mori et al. (2024)



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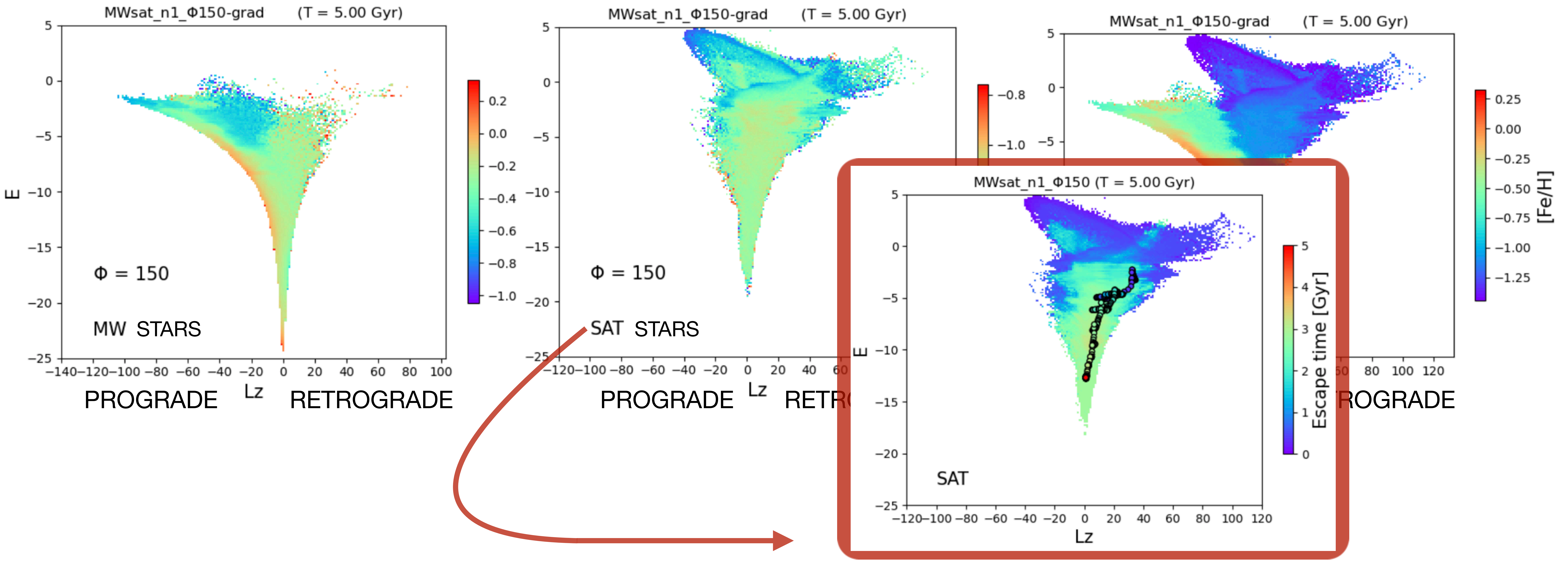

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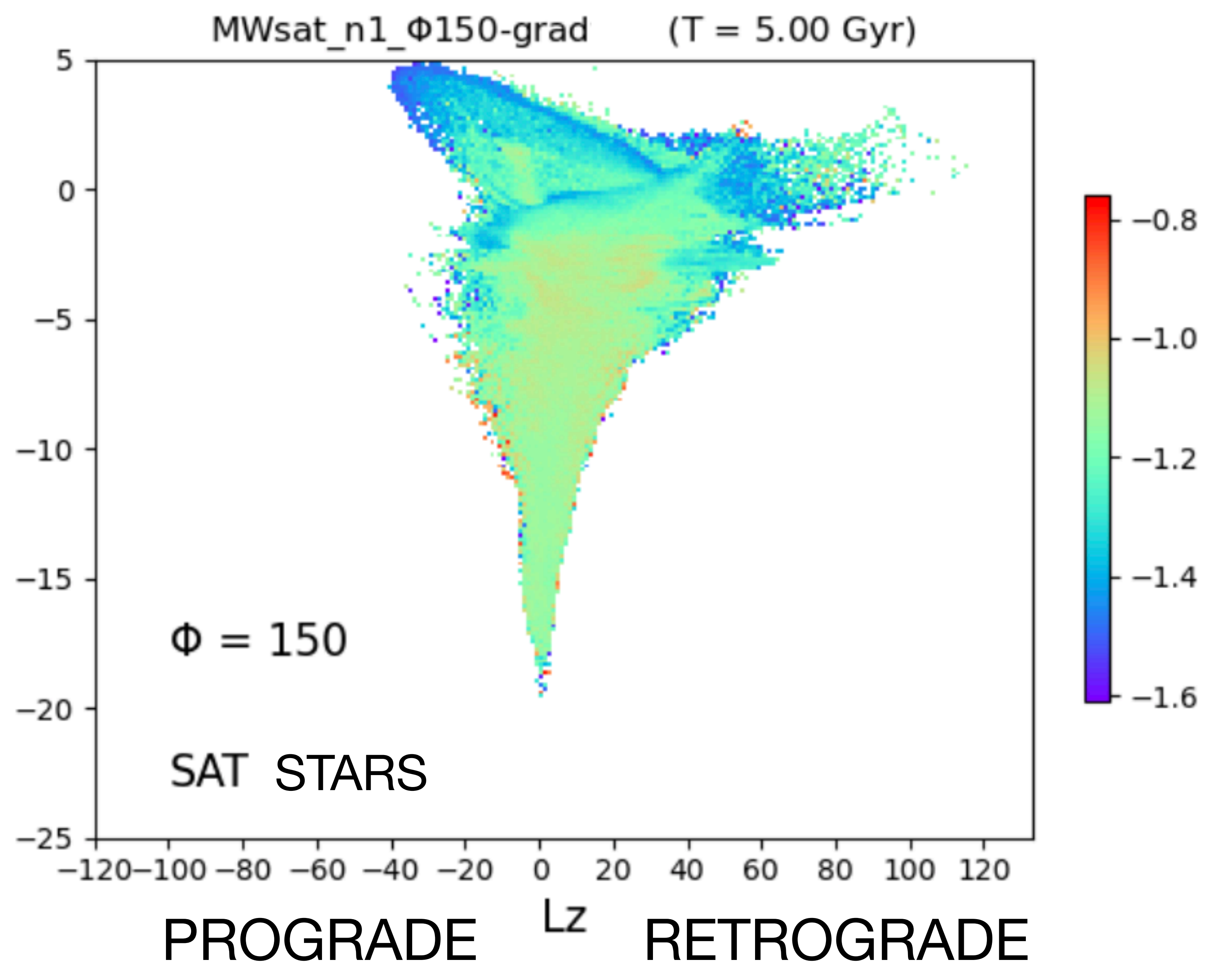
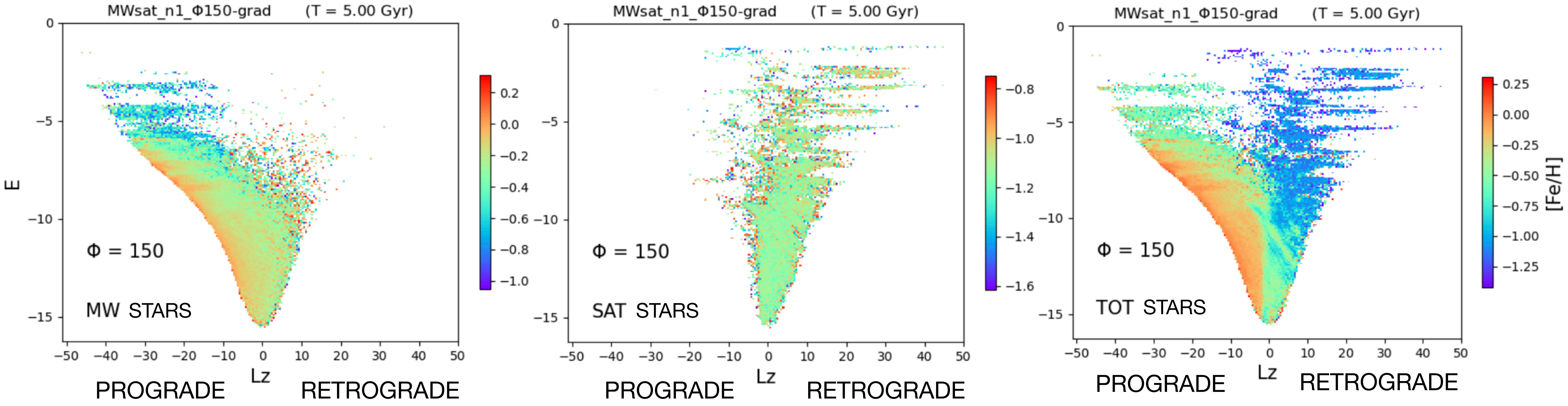


Accreted stars with **different [Fe/H]** end up in **different regions** of the $E - L_z$ space:
the **higher E** ones are on average **more metal-poor** than the ones that end up more gravitationally bound

Solar neighbourhood

Mori et al. (2024)



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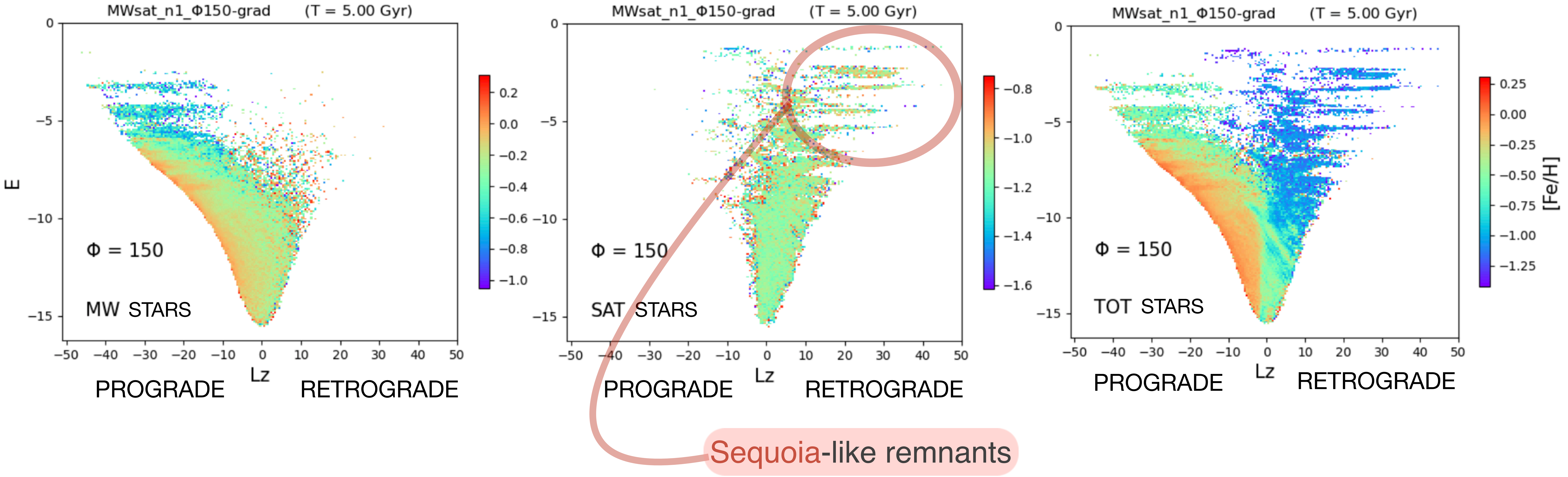
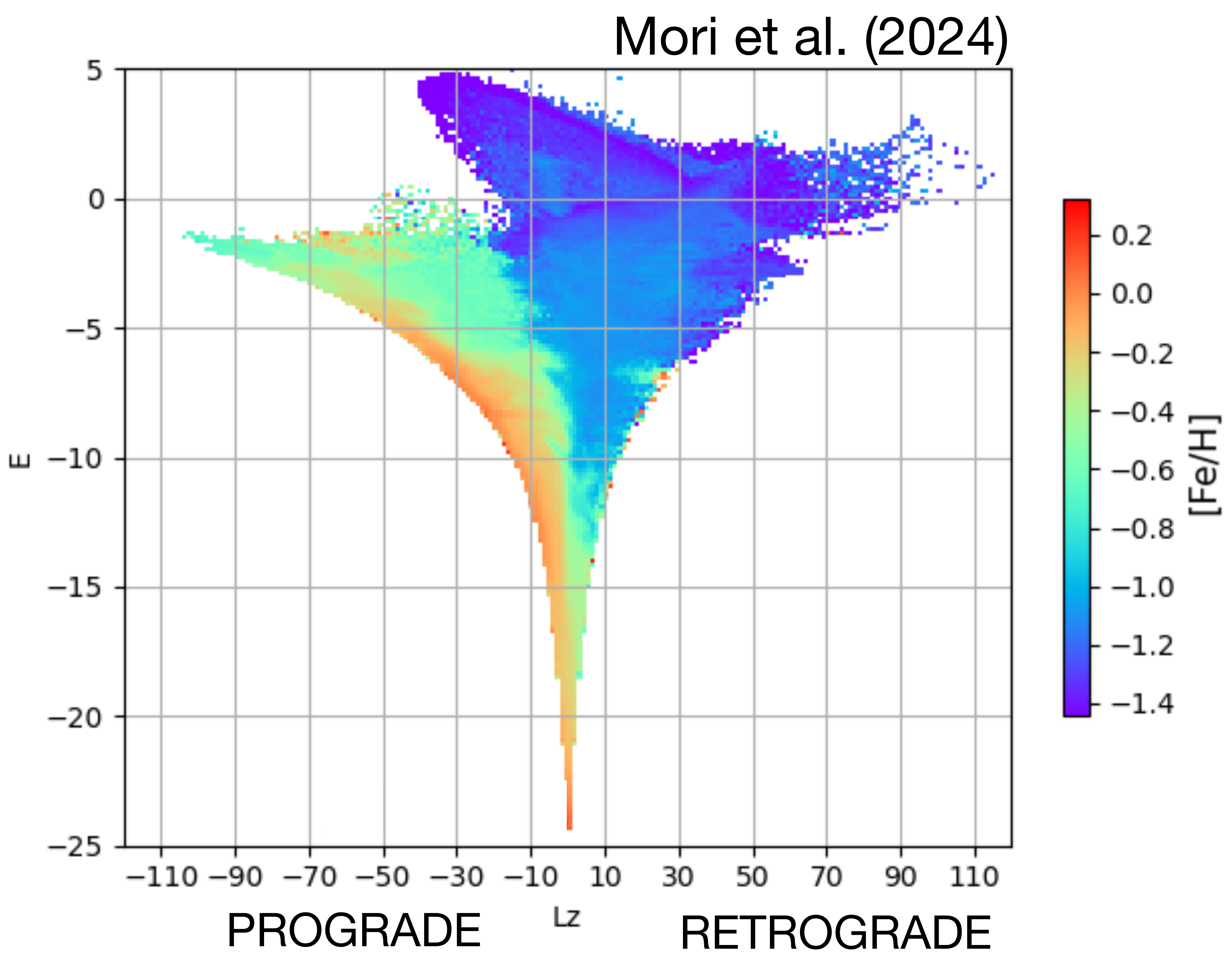
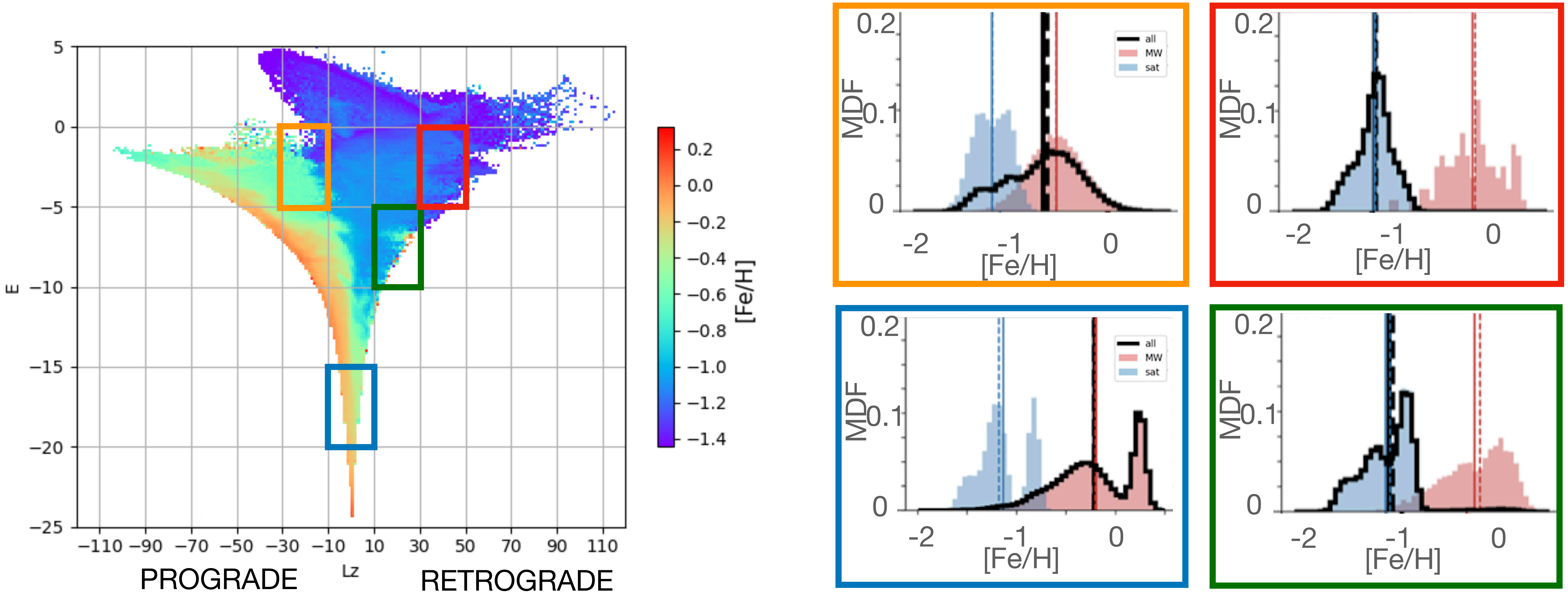


Different MDFs ⟷ different satellites?



Different MDFs ⟷ different satellites?

adapted from Mori et al. (2024)



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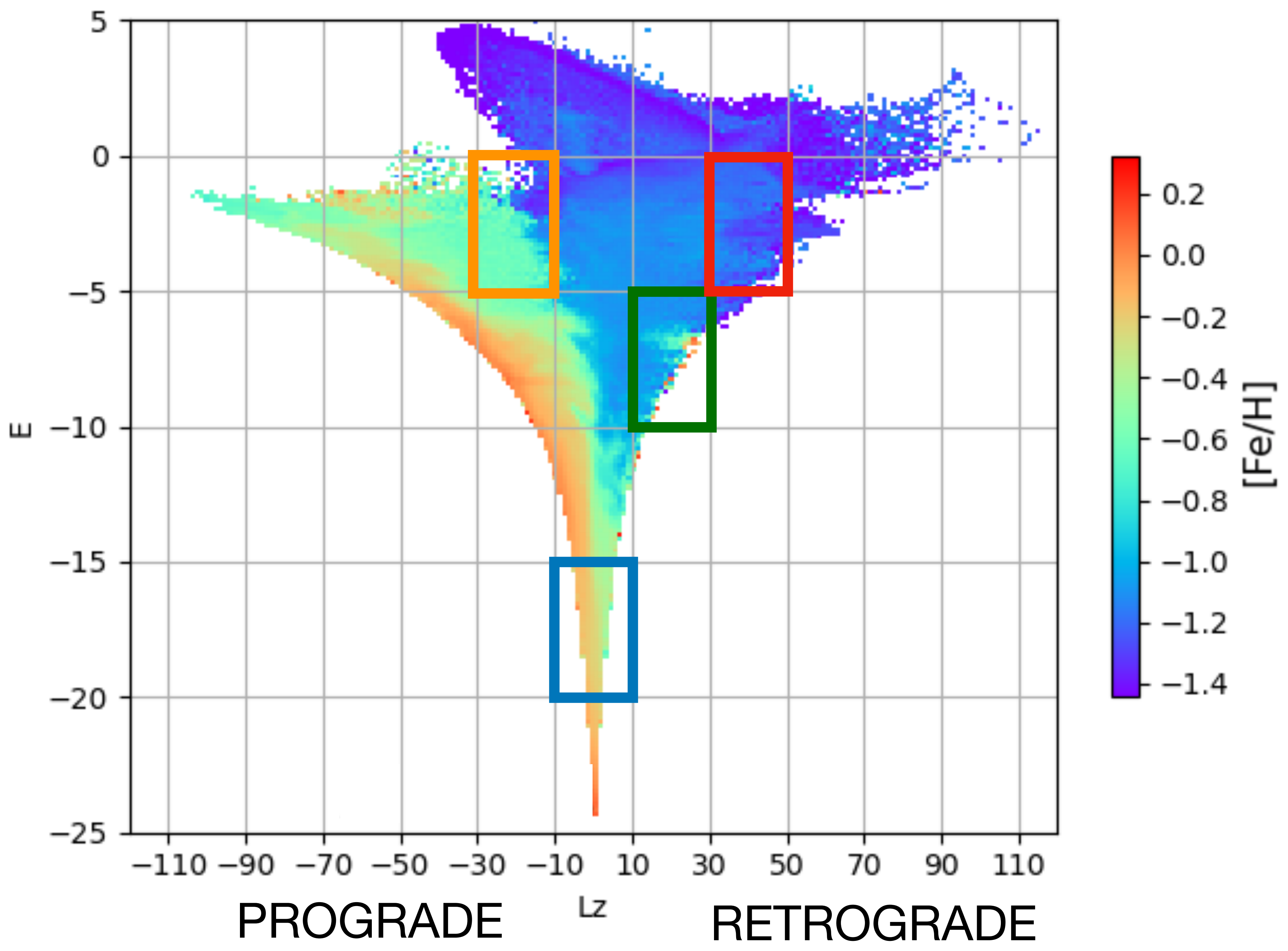
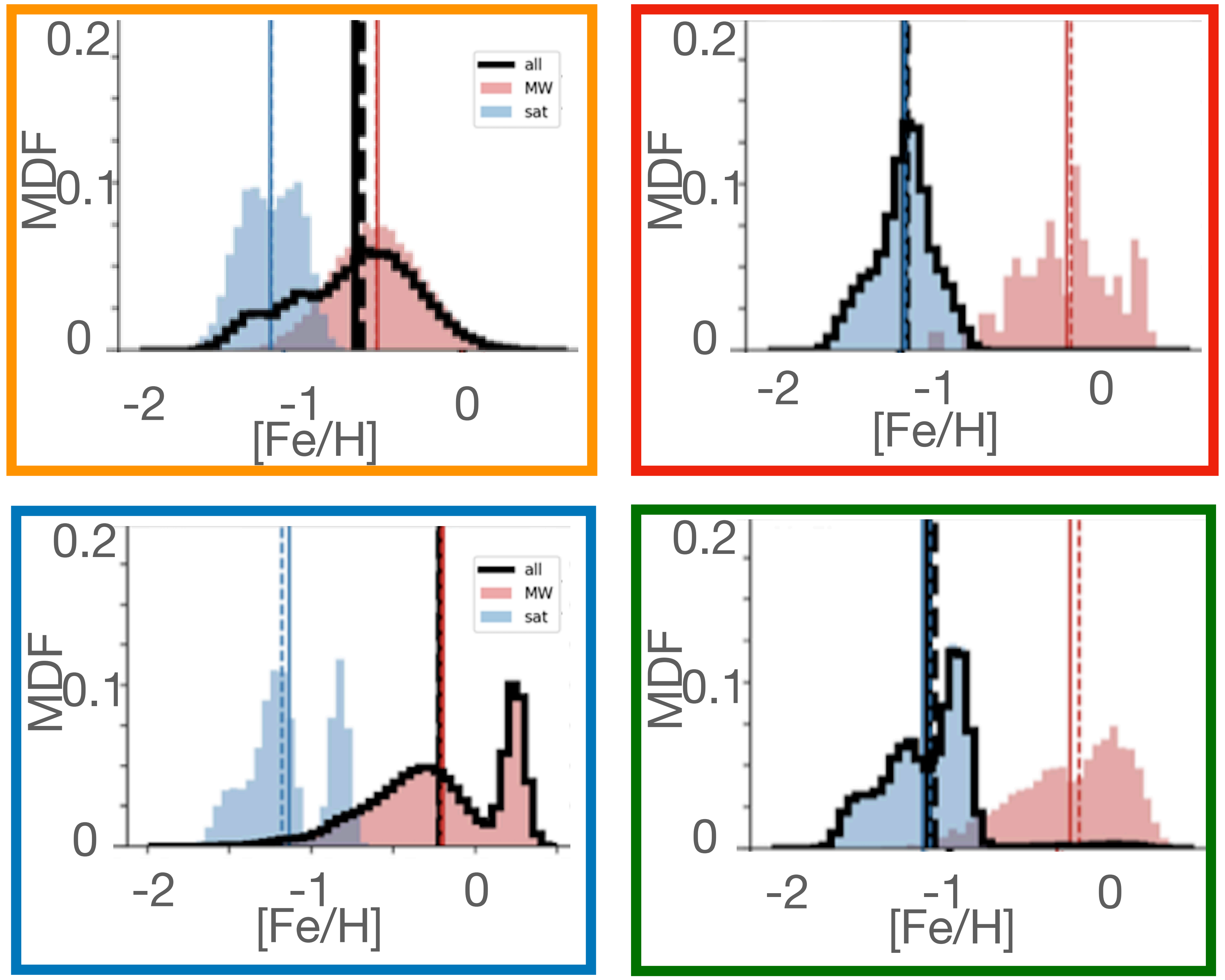




One satellite gives rise to **different MDFs** in **different regions** of the $E - L_z$ space!

Mass-metallicity relation

The Astrophysical Journal, 901:48 (32pp), 2020 September 20 Naidu et al.

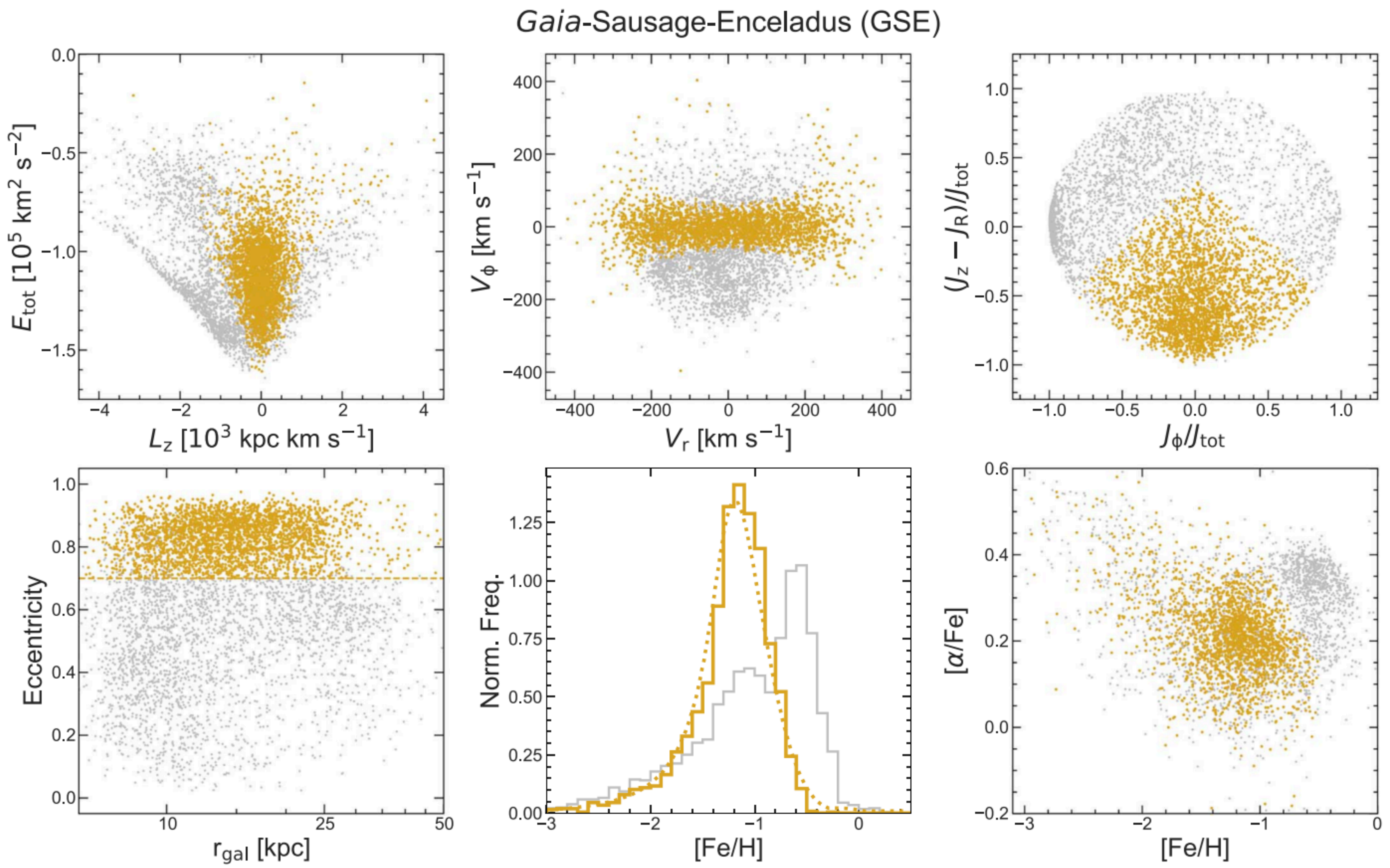


Figure 11. Gaia–Sausage–Enceladus (GSE, gold) in chemodynamical space. Panels are as in Figure 3, except for the top right, which shows the distribution of stars in action space. GSE is selected on eccentricity ($e > 0.7$) motivated by the dense population of stars in the bottom-left panel. The smooth, unimodal MDF is well fit by a simple chemical evolution model (dotted line in the MDF panel) that also reproduces the tail to low [Fe/H]. The highly eccentric GSE stars map to various projections of phase space as overdensities at $L_z \sim 0$, $V_\phi \sim 0$, and J_z–$J_R < 0$.

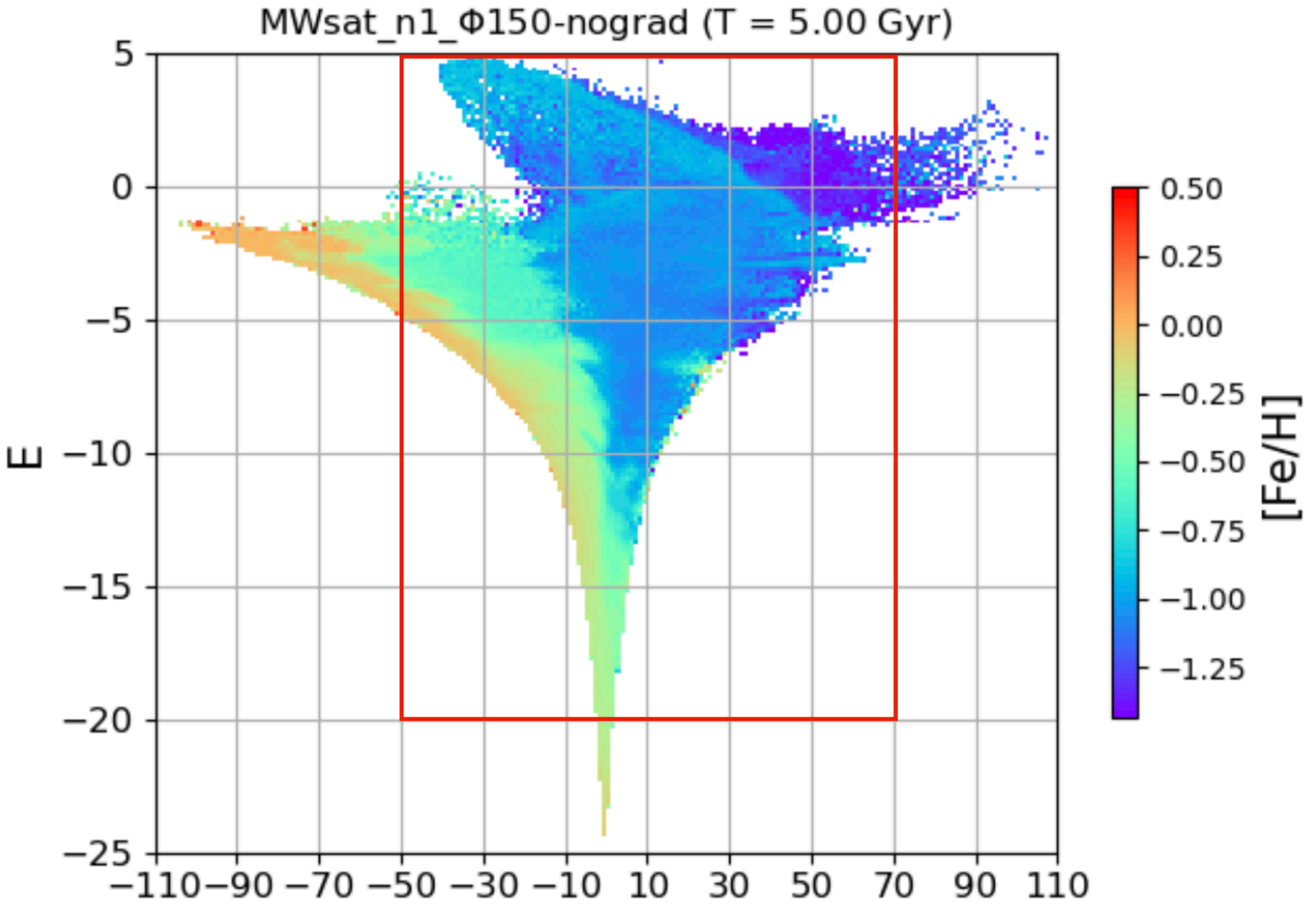
$$< [\mathrm{Fe/H}] > = (-1.69 \pm 0.04) + (0.30 \pm 0.02)\log\left(\frac{M_*}{10^6 M_\odot}\right)$$

Kirby et al. 2013

Reconstructing a possible accretion history from $E - L_z$ and MDFs

Mass-metallicity relation

Mori et al. (2024)



MDF mean values:

$\downarrow E; L_z \rightarrow$	$(-50, -30)$	$(-30, -10)$	$(-10, 10)$	$(10, 30)$	$(30, 50)$	$(50, 70)$
(0,5)	-0.90	-1.01	-1.01	-0.99	-1.13	-1.36
(-5,0)	-0.19	-0.69	-1.04	-1.05	-1.04	-1.05
(-10,-5)	-0.09	-0.18	-0.72	-1.06	-1.16	-
(-15,-10)	-	-0.17	-0.29	-0.96	-	-
(-20,-15)	-	-	-0.29	-	-	-

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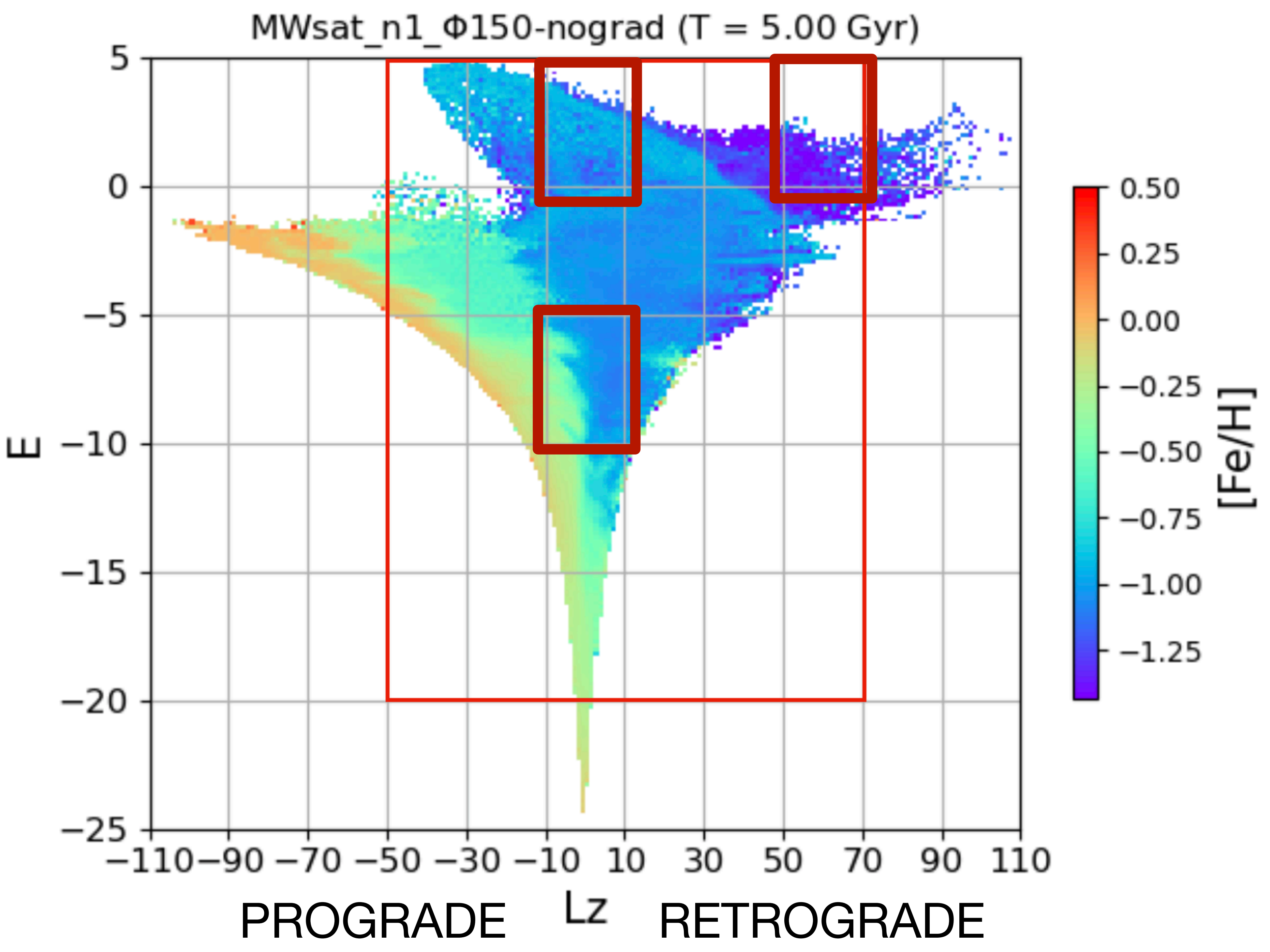

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Mass-metallicity relation

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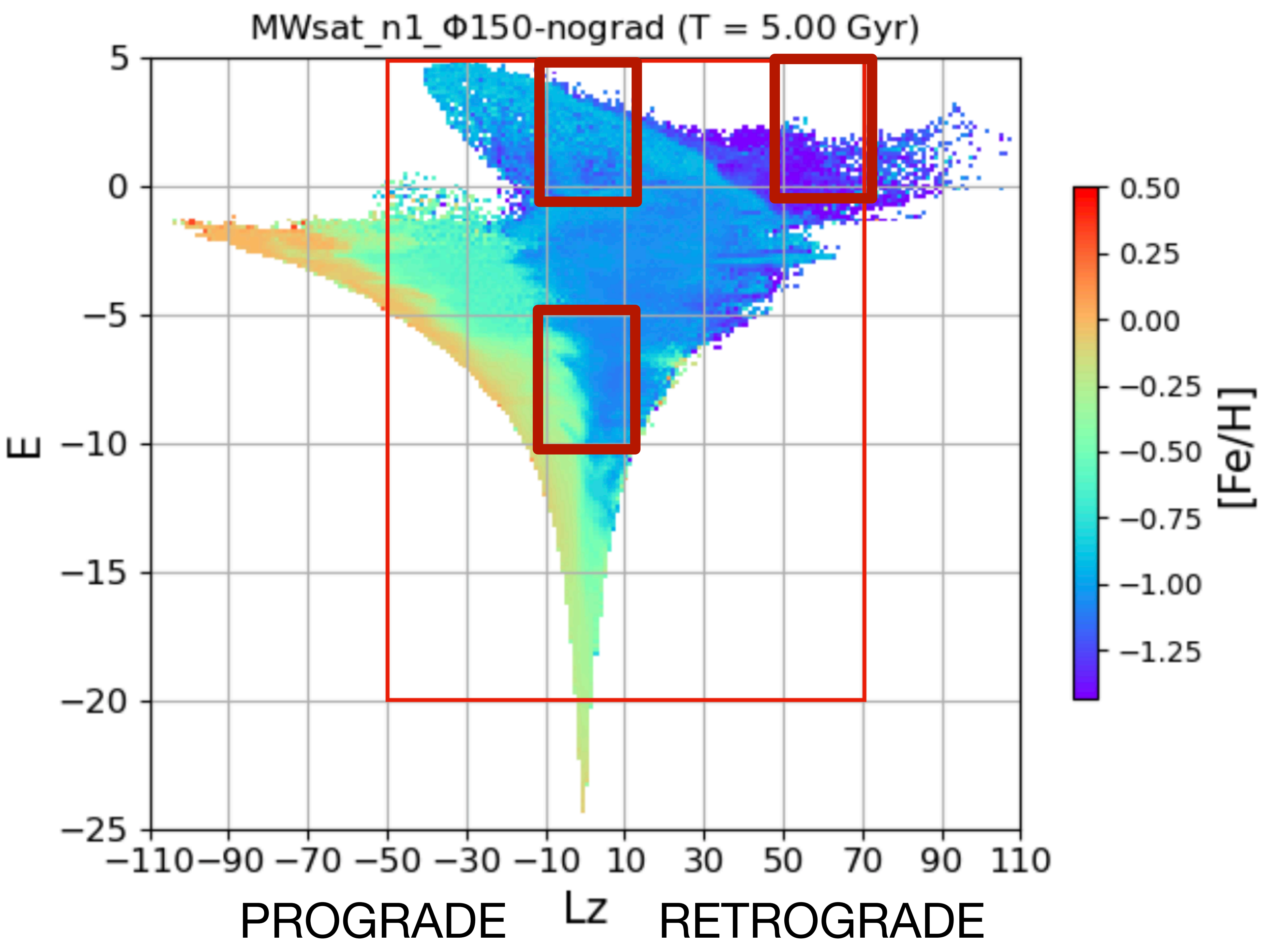

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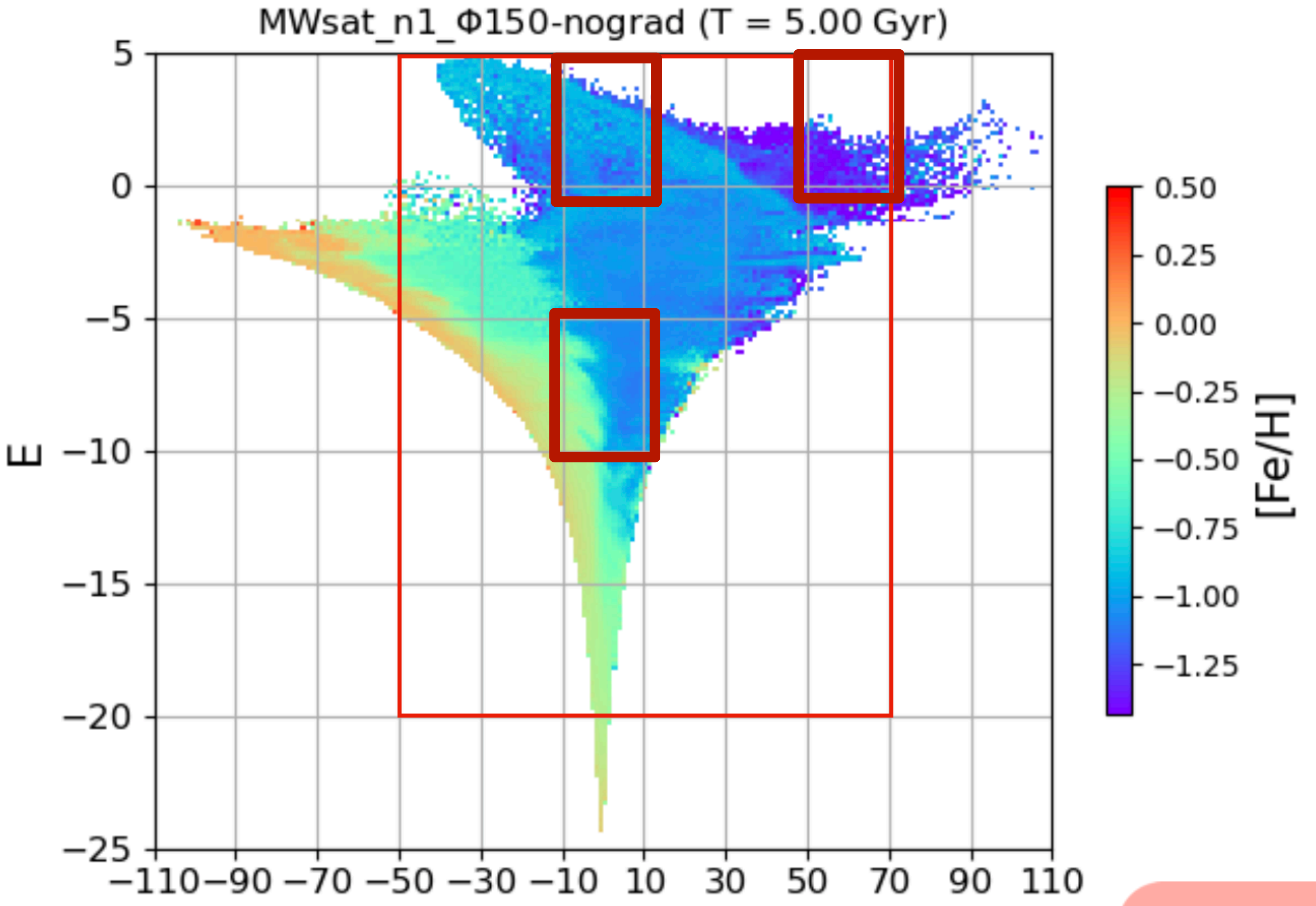
Different mean metallicities of the MDFs → different satellites masses in different regions!

Mass-metallicity relation

Mori et al. (2024)



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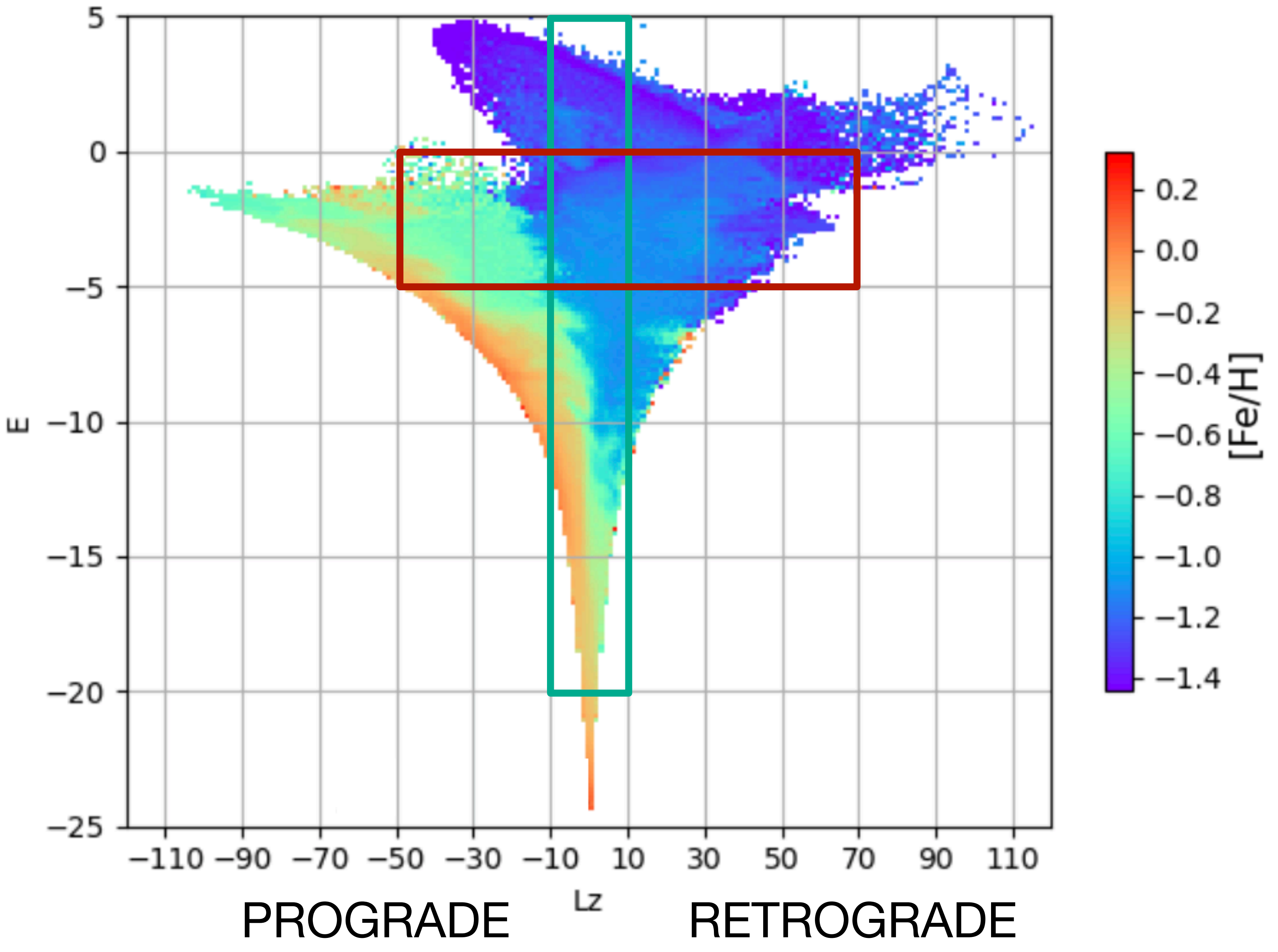
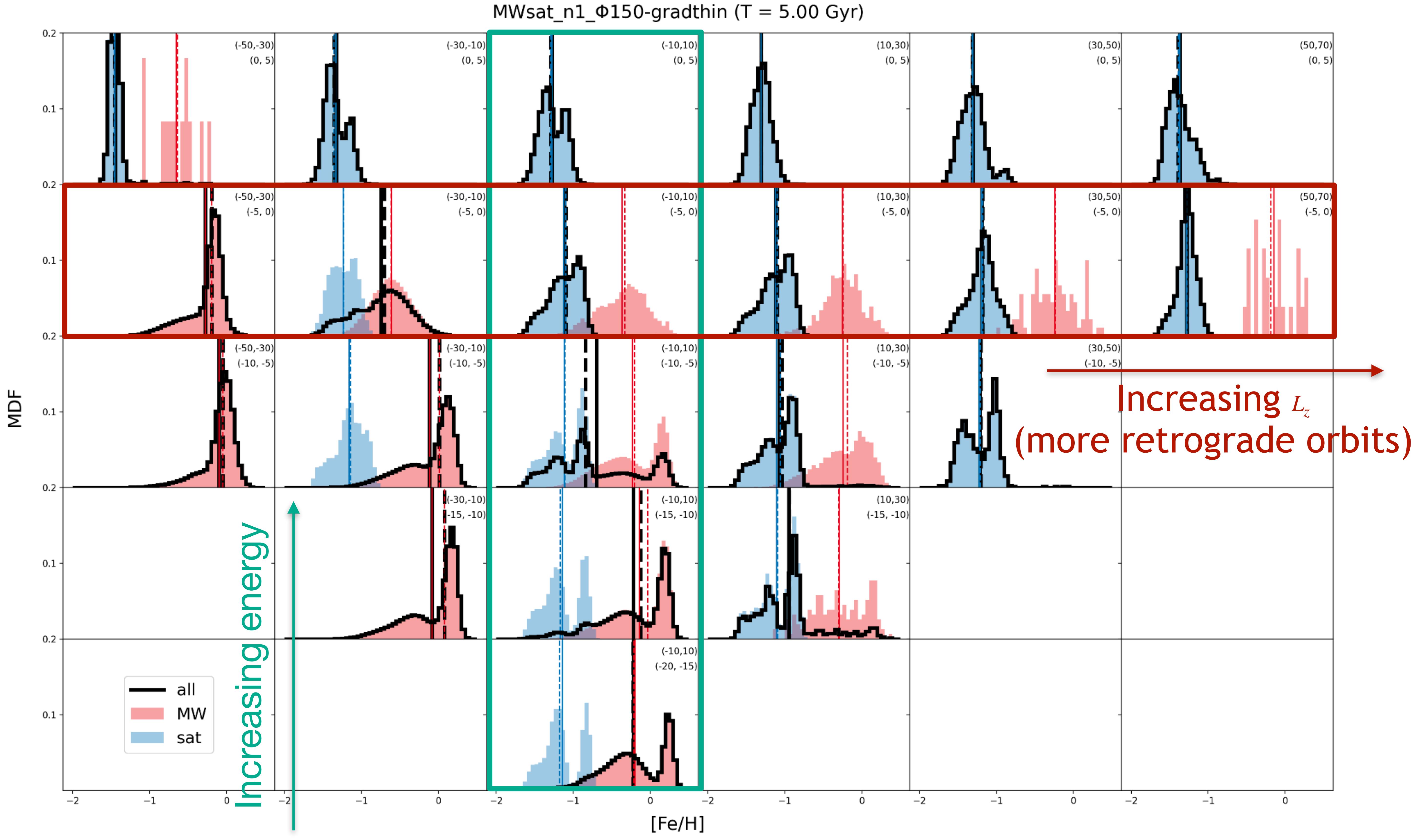
Bias for the accretion history of the MW towards

- over-estimation of the number of accretion events
- and un under-estimation of the relative masses

MDF trends in the $\mathbf{E} - \mathbf{L_z}$ space

Mori et al. (2024)





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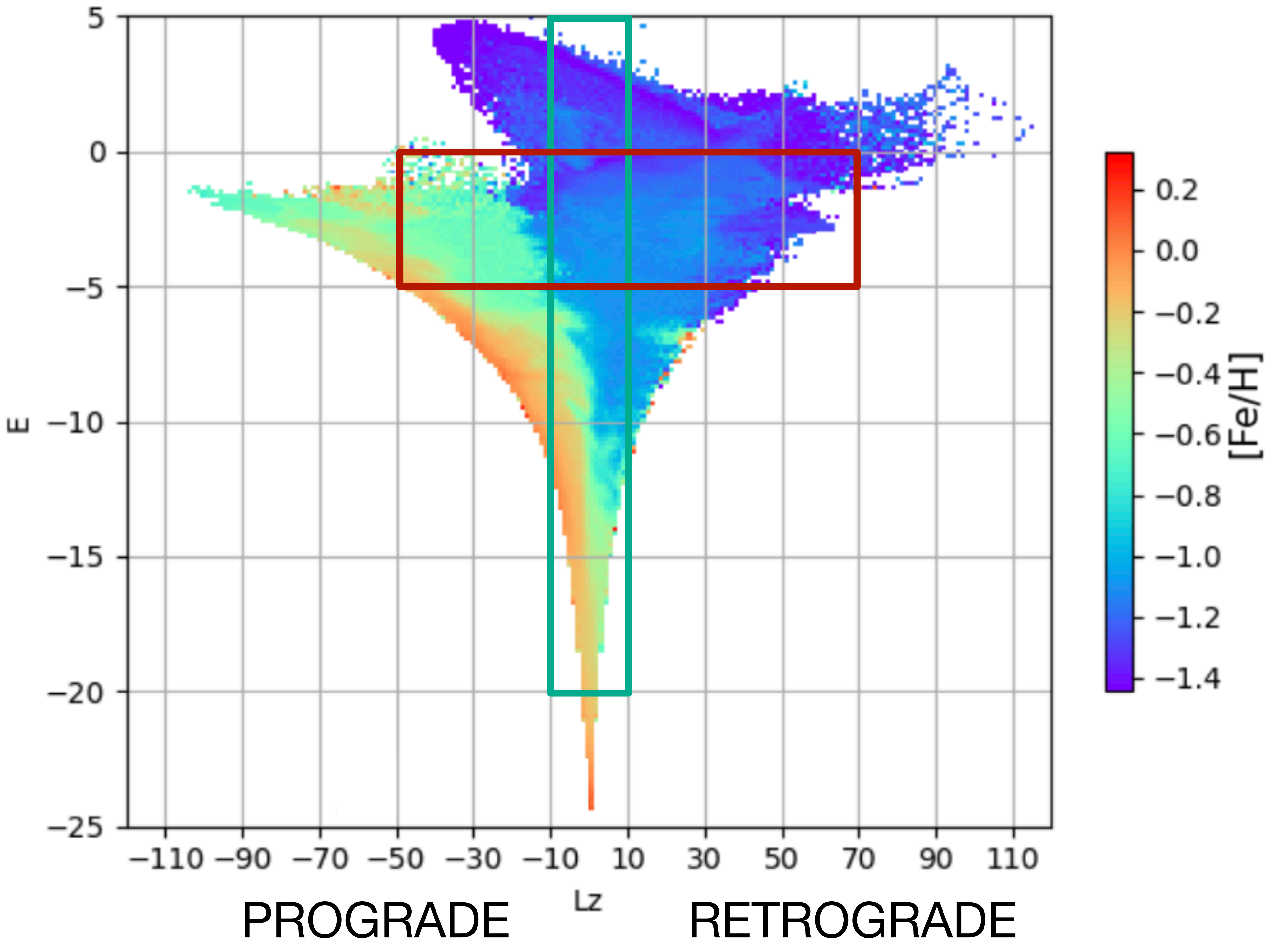
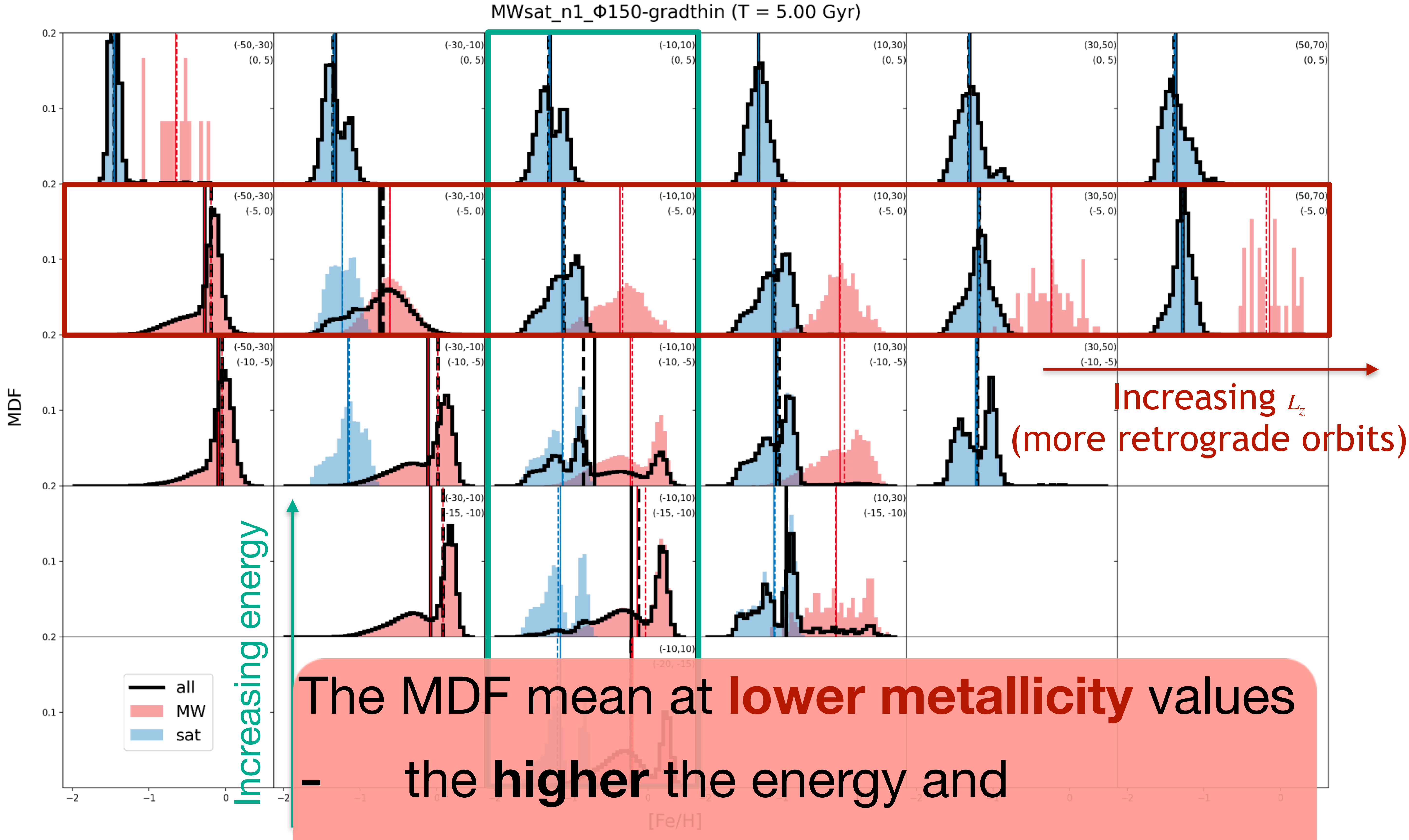




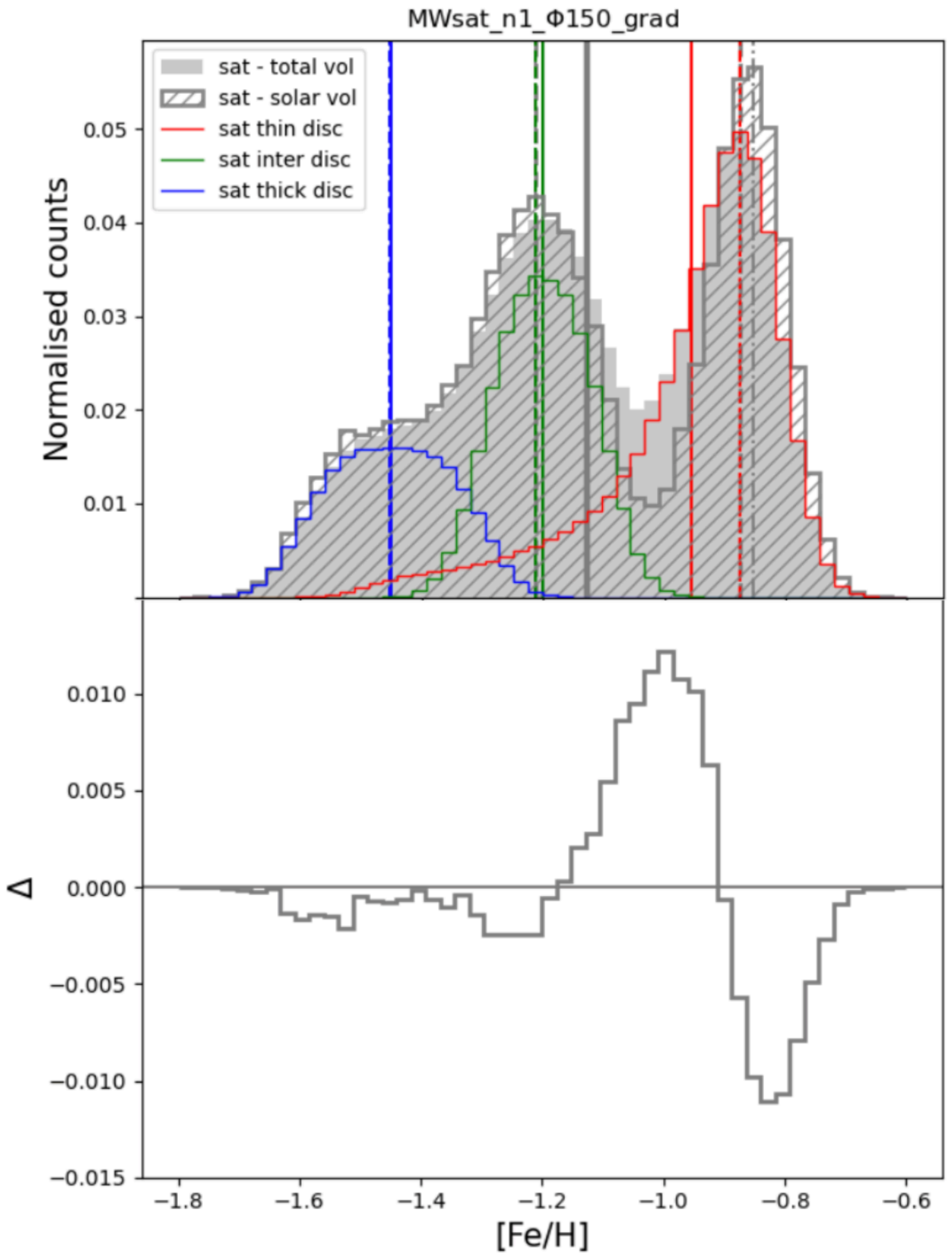
The MDF mean at **lower metallicity** values

- the **higher** the energy and
- the **greater** the angular momentum

MDF in a solar-like volume

Mori et al. (2024)

Is it representative of the global one?



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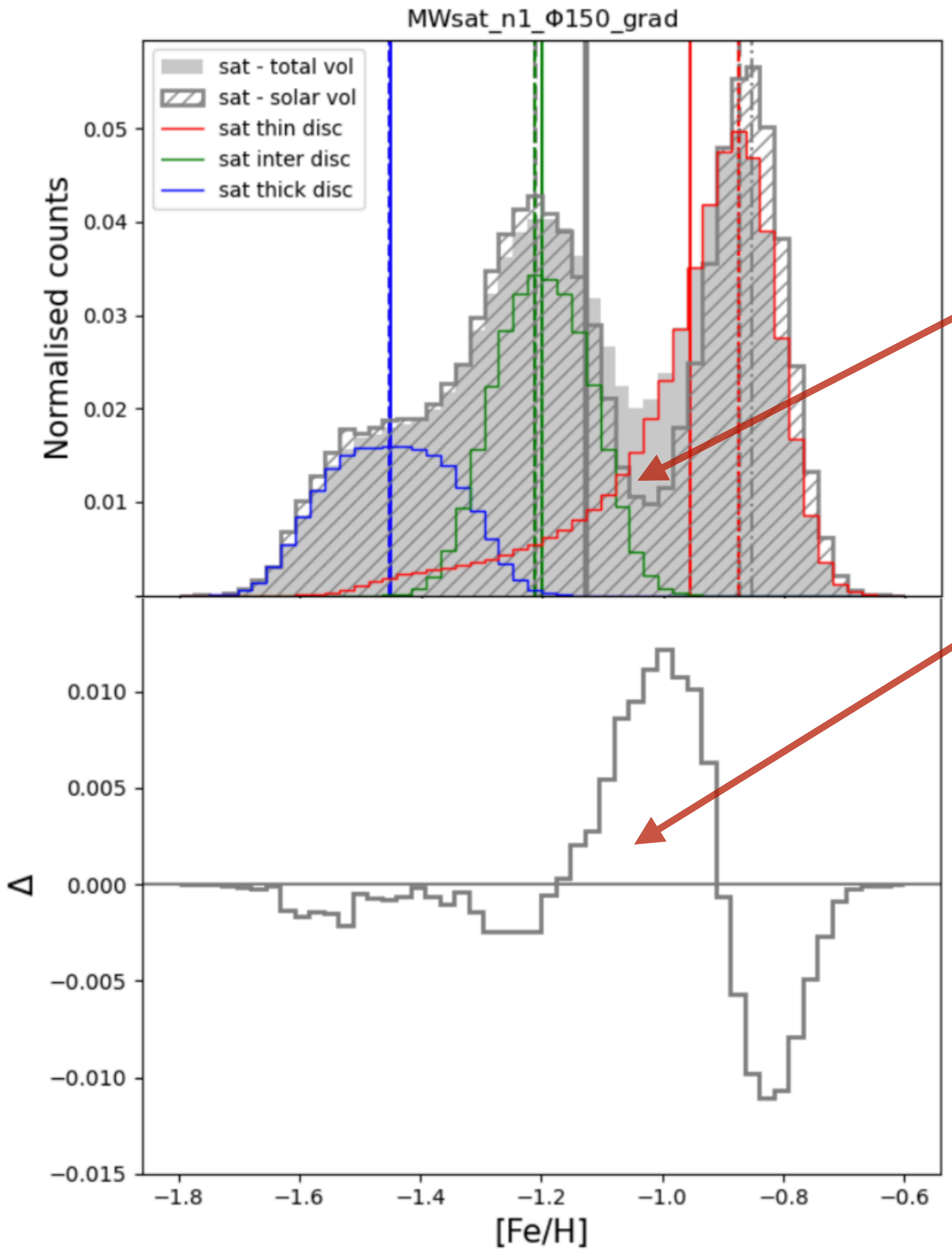

Mori et al. (2024)

we cannot capture the most metal-poor accreted stars found at very high energies

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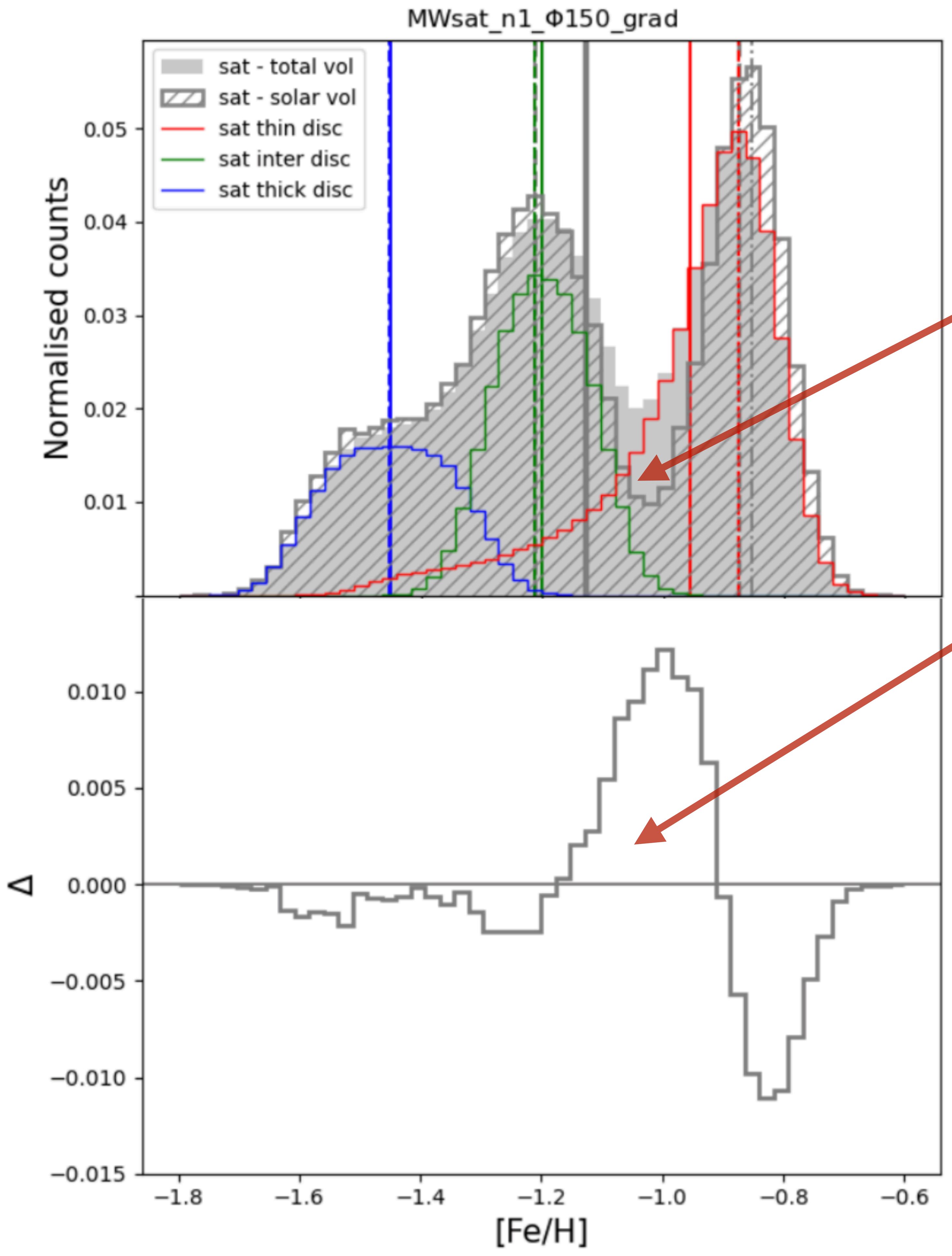


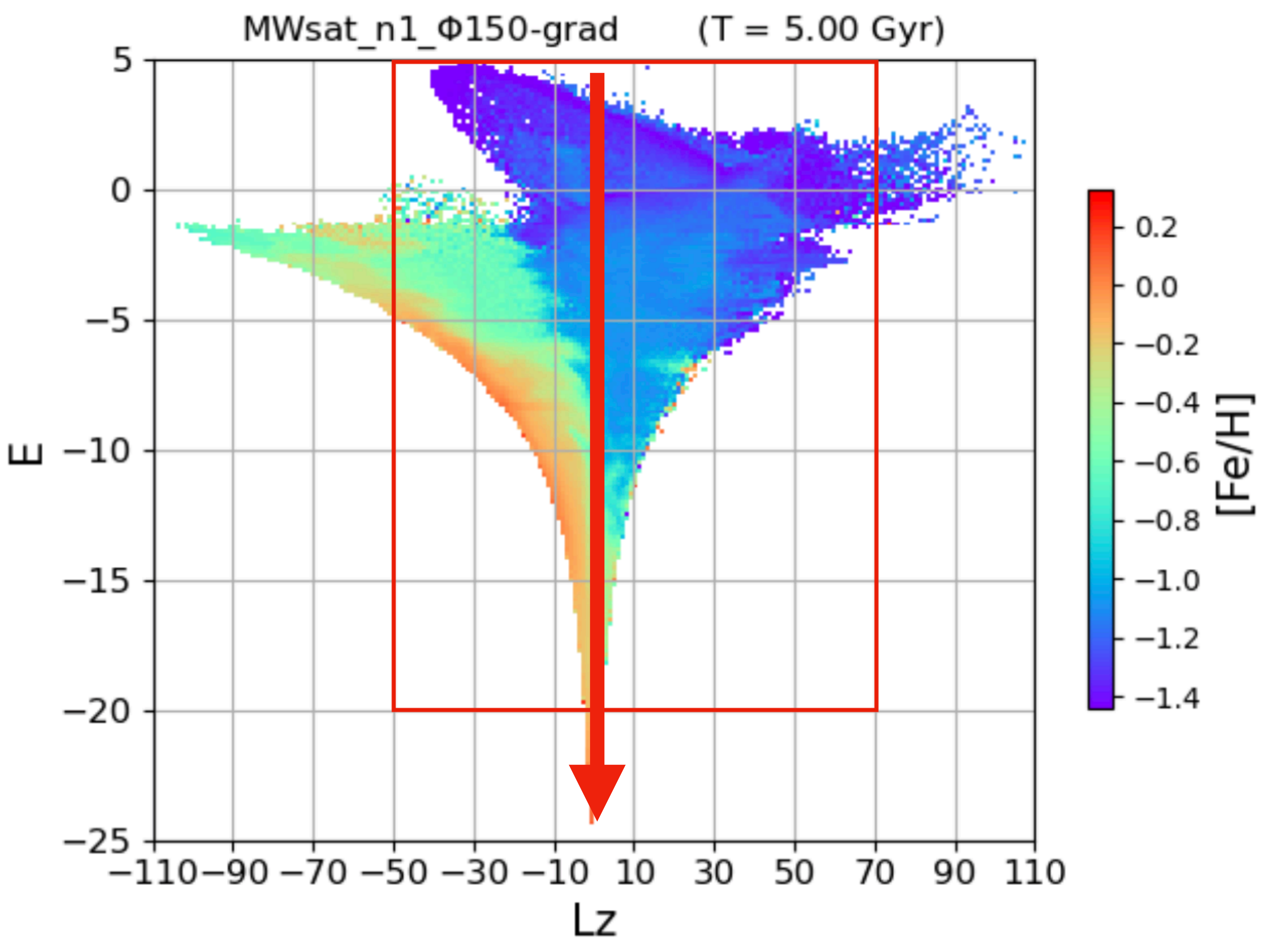
Mori et al. (2024)

we cannot capture the most metal-poor accreted stars found at very high energies

The MDF of the GSE may still exhibit biases

Initial condition in the satellite imprints

Relation between metallicity gradient in the satellite and in the $\mathbf{E-L_z}$



Alice Mori | IAUS395: Stellar populations in the MW and beyond | Paraty, Brazil 21/11/24

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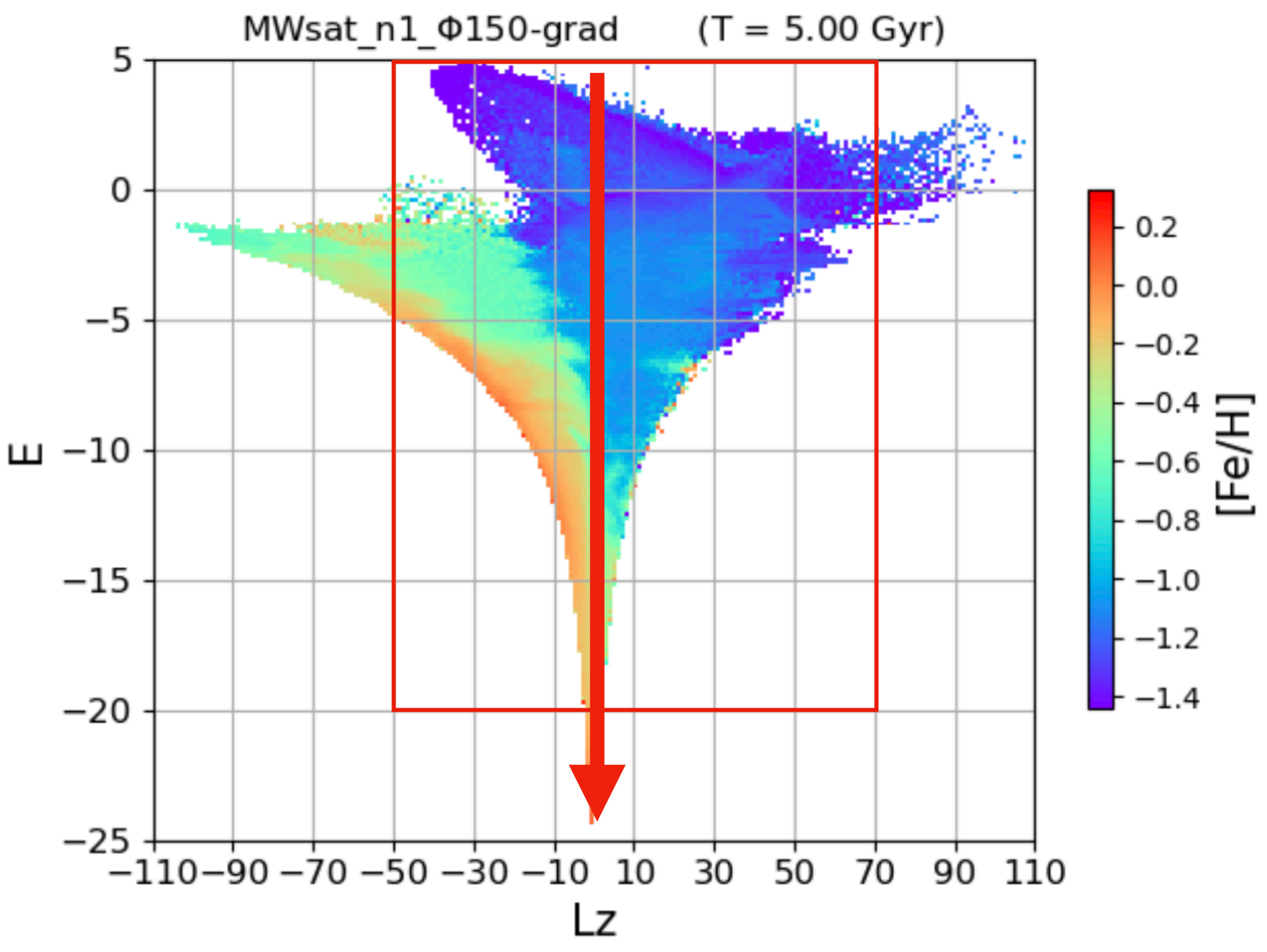

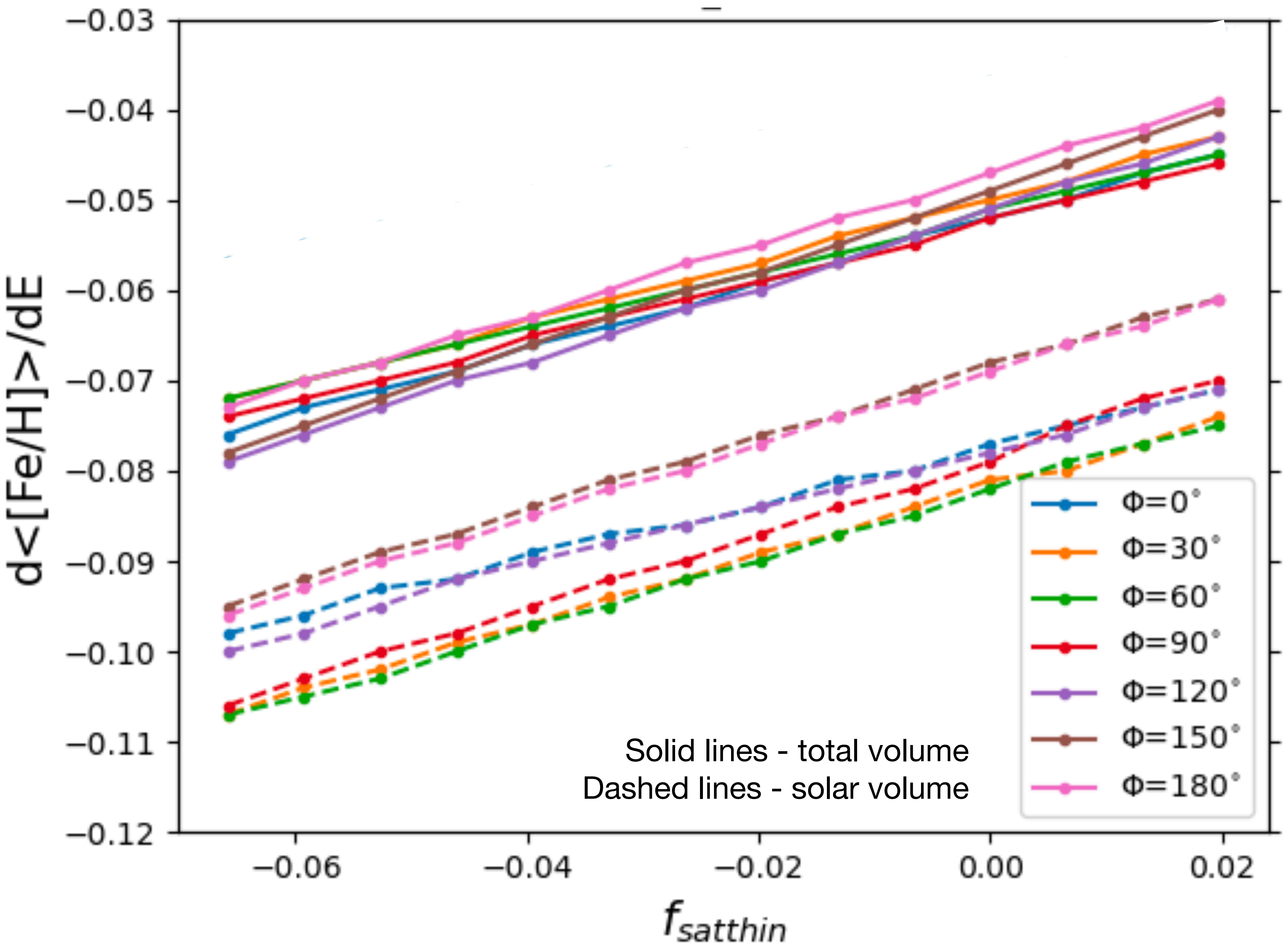

Conclusions

Thank you for your attention!

- Accreted stars from ~1:10 mass ratio satellites redistribute in a **wide range** of E and Lz (Jean-Baptiste+17; Koppelman+20; Amarante+22; Khoperskov+23c)
- Stars at higher E are on average **more metal-poor** than those that end up to be more bound (Amarante+22; Khoperskov+23a,d).

- Satellite stars with different metallicities can be deposited in different regions of the *E* – *Lz*, so a single ~1:10 merger can manifest with **different MDFs**, in different regions of the *E* – *Lz*.
- **Clumps** with different *E*, *Lz* and metallicities may be interpreted as originating from different satellites, but our analysis shows that these interpretations are **not physically motivated**.

- Reconstructing the Galactic accretion history through **mass-metallicity** relations using the MDF mean values of single $E - L_z$ clumps can be very **misleading.**
- Over-estimation of the number of accretions and under-estimation of the associated masses.

- In a **solar**-like volume, we cannot capture anymore the very metal-poor accreted stars from the outskirts of the satellite which are found at very high energies.
- This implies that the **MDF** of the **GSE** may still exhibit **biases**.

- From the metallicity **gradient in the E – Lz** space as a function of E one can retrieve information about the initial conditions of the **radial metallicity gradient in the satellite**.

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