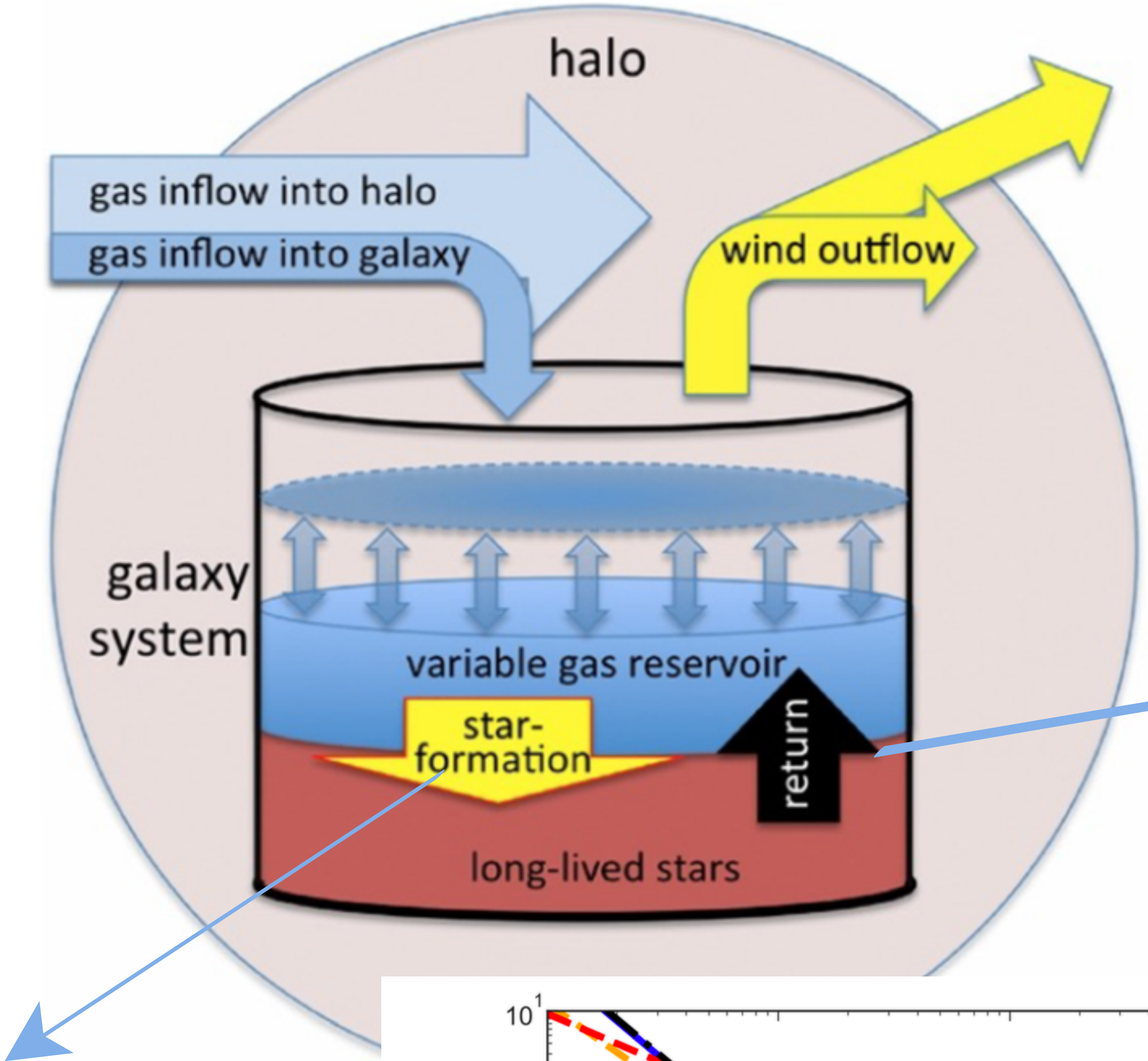
Chemical evolution of NC-elements across the Milky Way

M. Molero et al. (2023), MNRAS
co-authors: L.Magrini, F.Matteucci, D.Romano, M.Palla, G.Cescutti, C.Viscasillas Vàzquez, E.Spitoni

Introduction: chemical evolution of galaxies

$$A(t) = ae^{-t/\tau_{inf}}$$



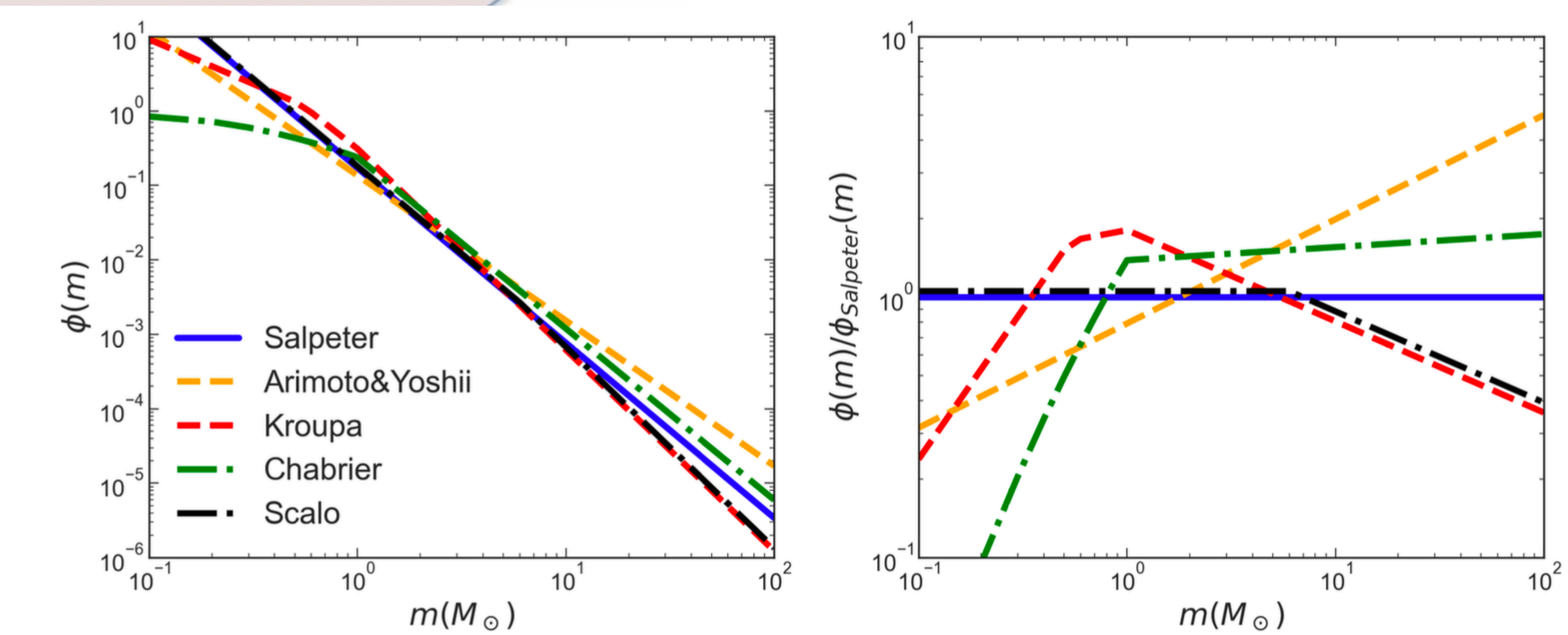
$$W(t) = -\omega\psi(t)$$

Credits: Lilly et al. (2013)

Stellar yields + stellar lifetimes

$$B(m, t) = \phi(m)\psi(t)dmdt$$

Star formation rate (SFR)



Introduction: chemical evolution of galaxies

- The evolution of the mass of gas in the form of the chemical element i

$$\dot{M}_{\mathrm{gas},i}(R,\theta,t) = -\psi(R,\theta,t)X_i(R,\theta,t) + X_{i,A}A(R,\theta,t) - X_i(R,\theta,t)W(R,\theta,t) - X_i(R,\theta,t)\dot{M}_{BH}(R,\theta,t) + \dot{R}_i(R,\theta,t)$$

Introduction: chemical evolution of galaxies

- The evolution of the mass of gas in the form of the chemical element *i*

$$\dot{M}_{\mathrm{gas},i}(R,\theta,t) = -\psi(R,\theta,t)X_i(R,\theta,t) + \underbrace{X_{i,A}A(R,\theta,t)}_{\text{accretion of gas through infall}} - \underbrace{X_i(R,\theta,t)W(R,\theta,t)}_{\text{lost of gas galactic winds}} - X_i(R,\theta,t)\dot{M}_{BH}(R,\theta,t) + \dot{R}_i(R,\theta,t)$$

accretion of gas through infall

lost of gas galactic winds

Introduction: chemical evolution of galaxies

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Introduction: chemical evolution of galaxies

- The evolution of the mass of gas in the form of the chemical element *i*

$$\dot{M}_{\mathrm{gas},i}(R,\theta,t) = -\underbrace{\psi(R,\theta,t)X_i(R,\theta,t)}_{\text{lost of gas because of SF processes}} + \underbrace{X_{i,A}A(R,\theta,t)}_{\text{accretion of gas through infall}} - \underbrace{X_i(R,\theta,t)W(R,\theta,t)}_{\text{lost of gas galactic winds}} - \underbrace{X_i(R,\theta,t)\dot{M}_{BH}(R,\theta,t)}_{\text{lost by feeding the central BH}} + \underbrace{\dot{R}_i(R,\theta,t)}_{\text{restitution of gas from stars}}$$

accretion of gas through infall

lost of gas galactic winds

lost by feeding the central BH

lost of gas because of SF processes

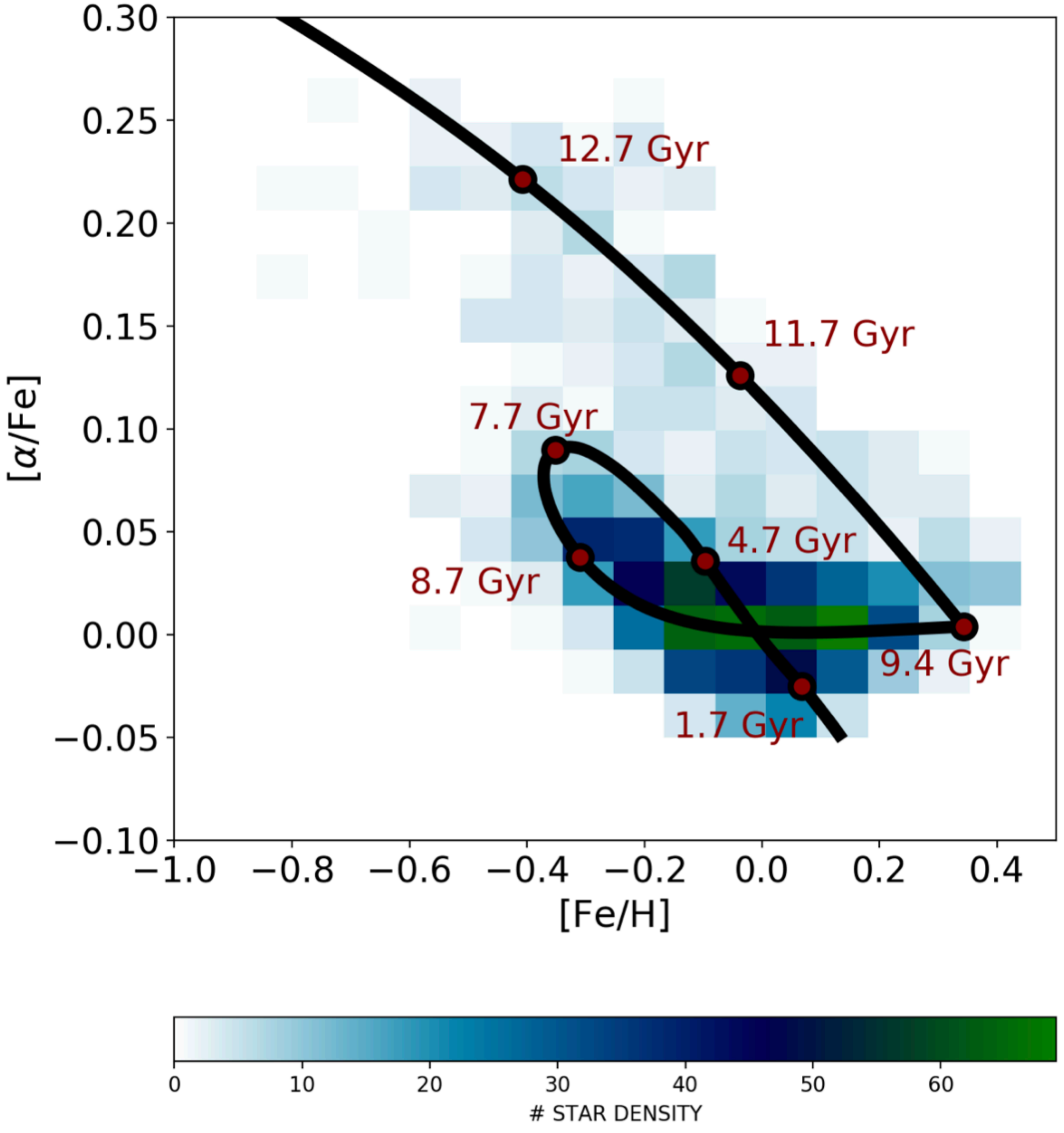
restitution of gas from stars

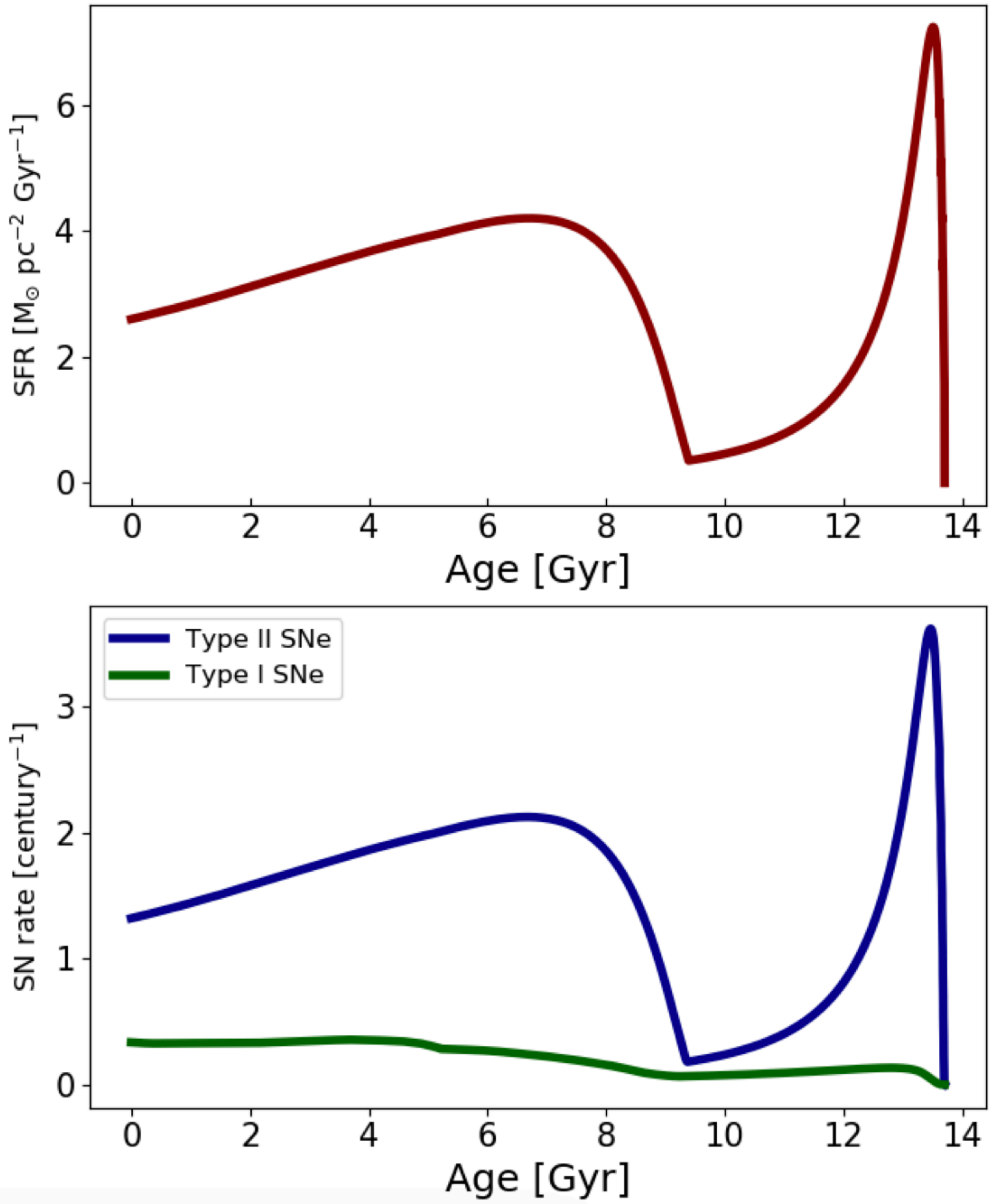
Milky Way: the disc

$$\dot{M}_{gas,i}(t,R) = -\psi(t,R)X_i(t,R) + X_{i,A}A(t,R) + \dot{R}_i(t,R)$$

$$A(t,R) = c_1 e^{-t/\tau_{D_1}} + \theta(t - t_{max})c_2 e^{-(t-t_{max})/\tau_{D_2}}, \; t_{max} = 3.25 \; Gyr$$

Spitoni et al. (2019/2021)

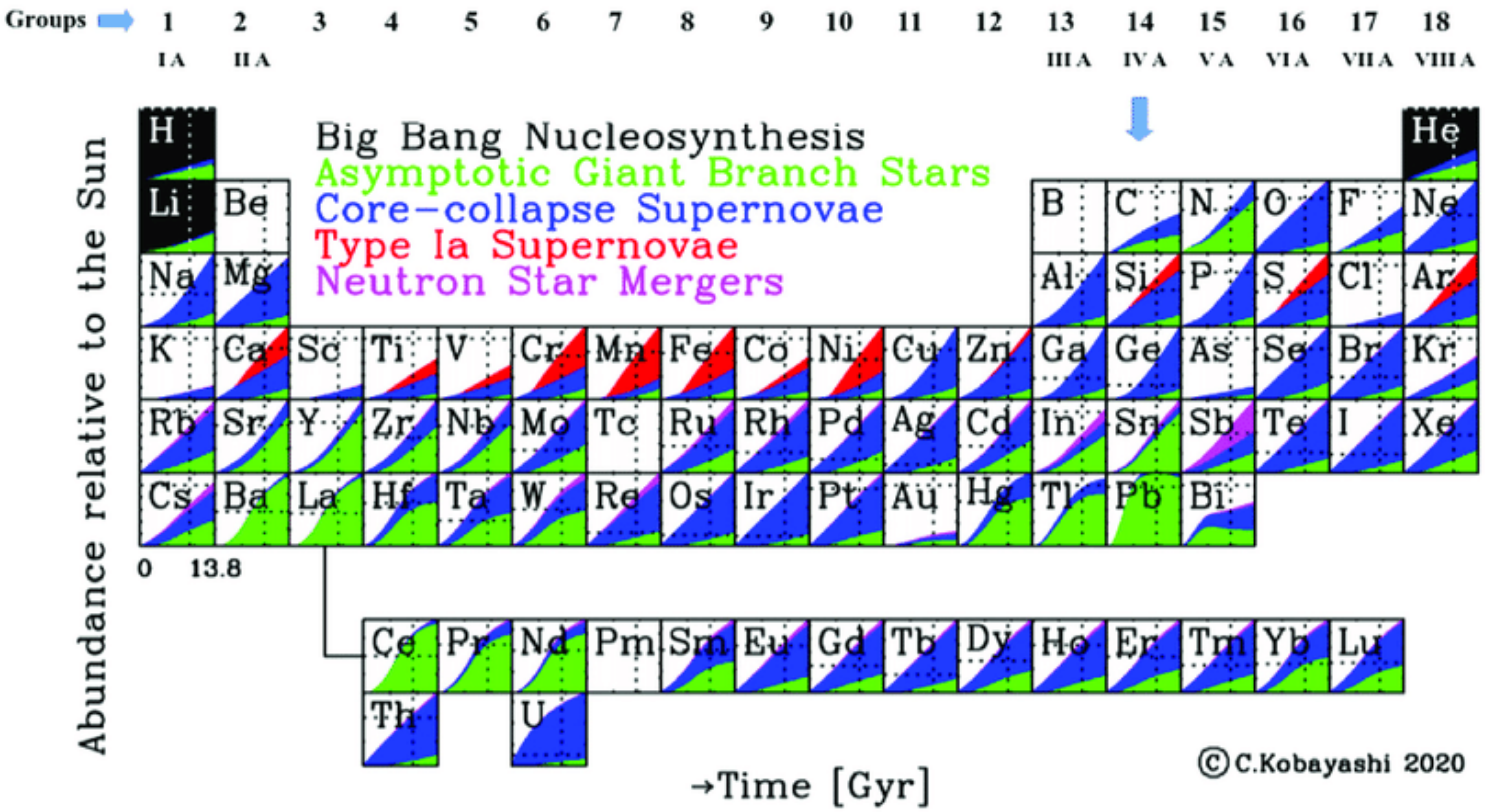




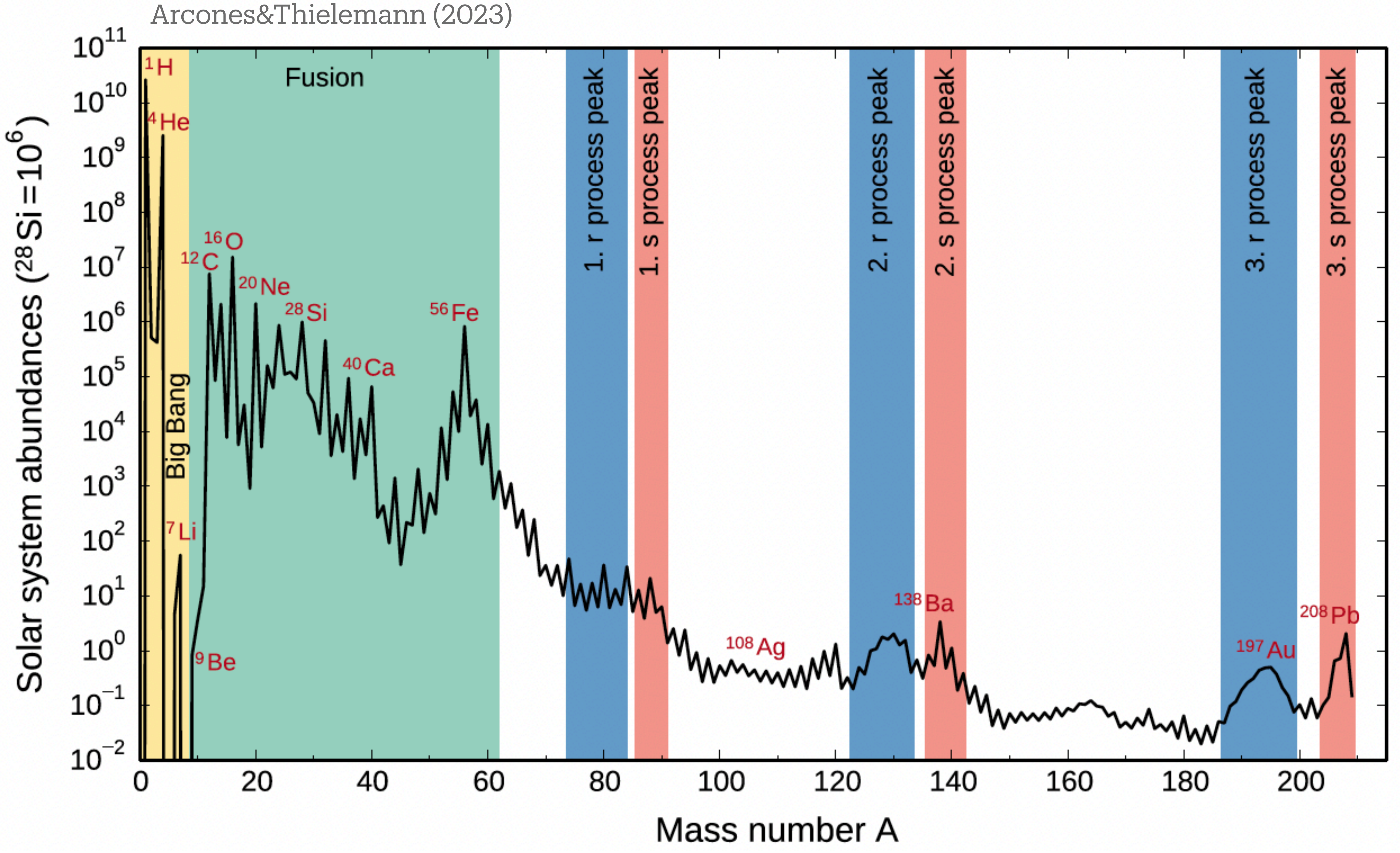
- The late accretion of pristine gas has the effect of decreasing the metallicity of each stellar population born immediately after the infall event while it has little effect on the [α/Fe] ratio

- When the SF resumes, Type II SNe produce a rise in the [α/Fe] ratio, which is then decreased and shifted towards higher metallicities due to pollution from Type Ia SNe

Introduction: chemical evolution of galaxies



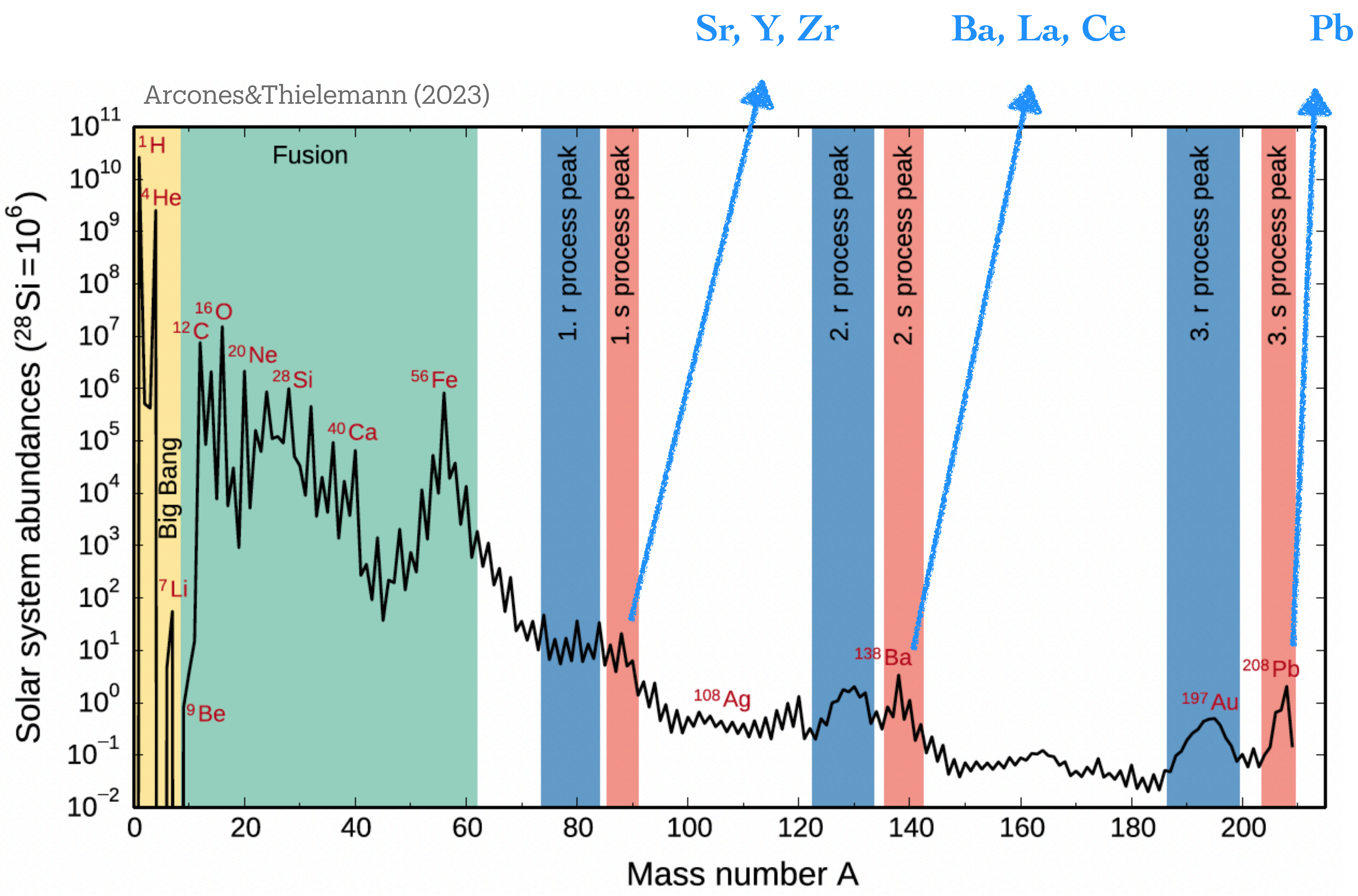
Introduction: neutron-capture elements



s-process: the unstable nuclide created by neutron capture will decay in a stable nuclide before it has time to capture another neutron

r-process: there is time for multiple neutron captures before the first β-decay occurs

Introduction: neutron-capture elements



Weak s-process: (rotating) massive stars ($M > 8\ M_\odot$)

- neutrons released from the reaction $^{22}Ne(\alpha,n)^{25}Mg$

Main s-process: Low-intermediate mass stars (LIMS, $M < 8\ M_\odot$) during the AGB phase - neutrons released from the reactions $^{13}C(\alpha,n)^{16}O$, $^{22}Ne(\alpha,n)^{25}Mg$

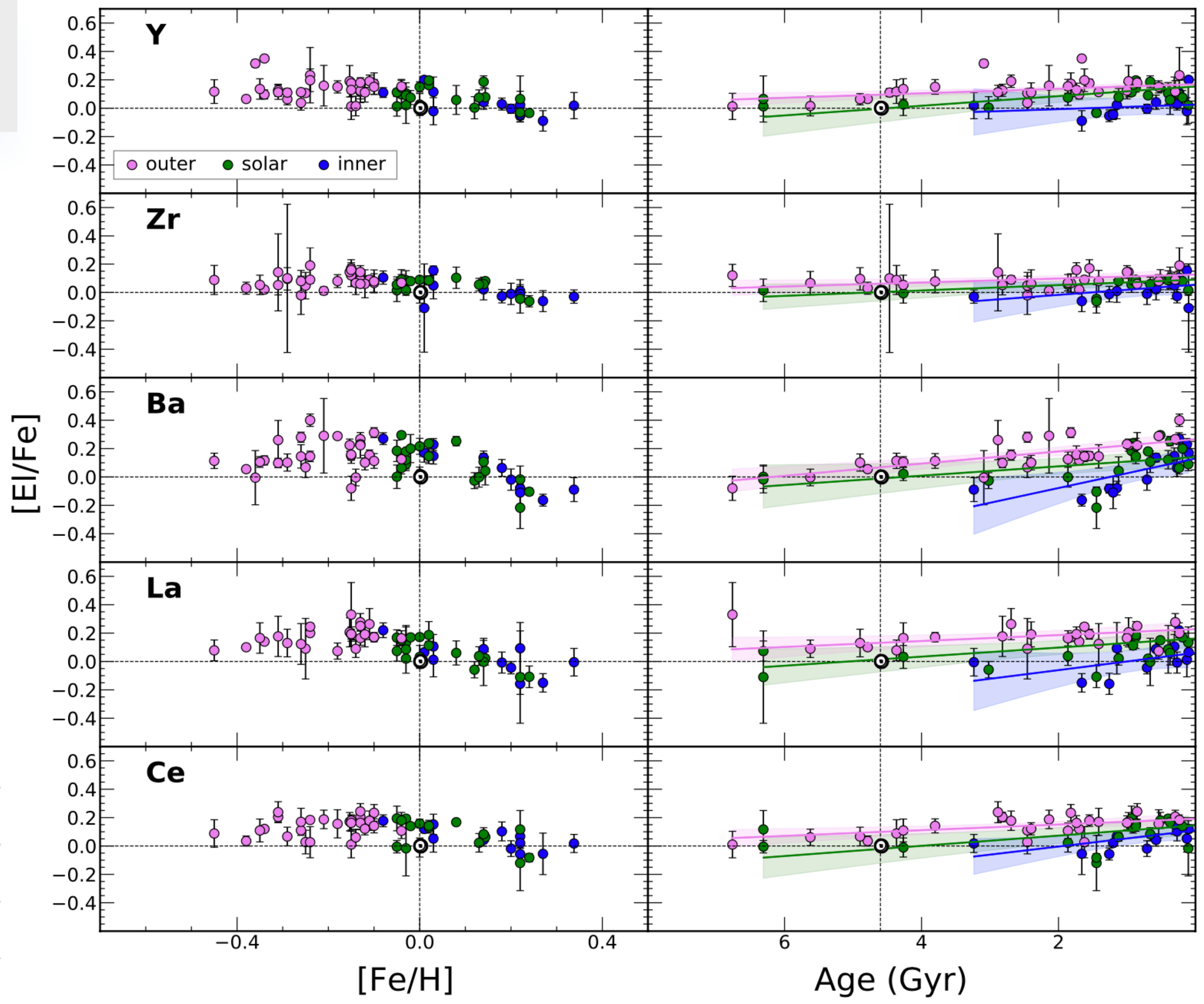
Strong s-process: Low-metallicity low-mass AGB stars - neutrons released from the reactions $^{13}C(\alpha,n)^{16}O$, $^{22}Ne(\alpha,n)^{25}Mg$

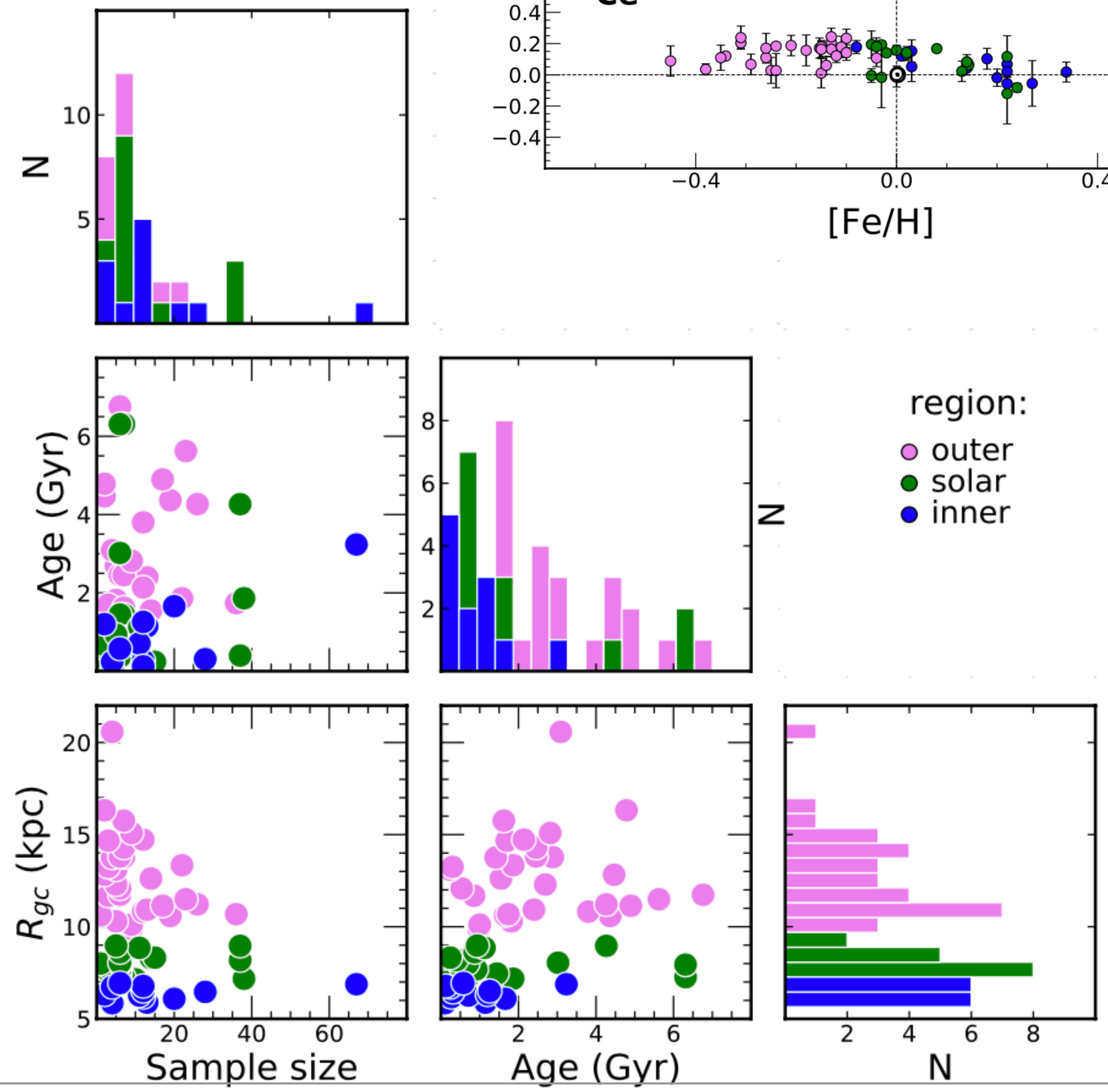
Observational data-set

- Data from the 6th data-release (iDR6) of the *Gaia*-ESO survey

- Two sets: 62 OCs (precise measurement of their ages, distances and chemical composition, but are limited in the metallicity range their span) and 3975 field stars

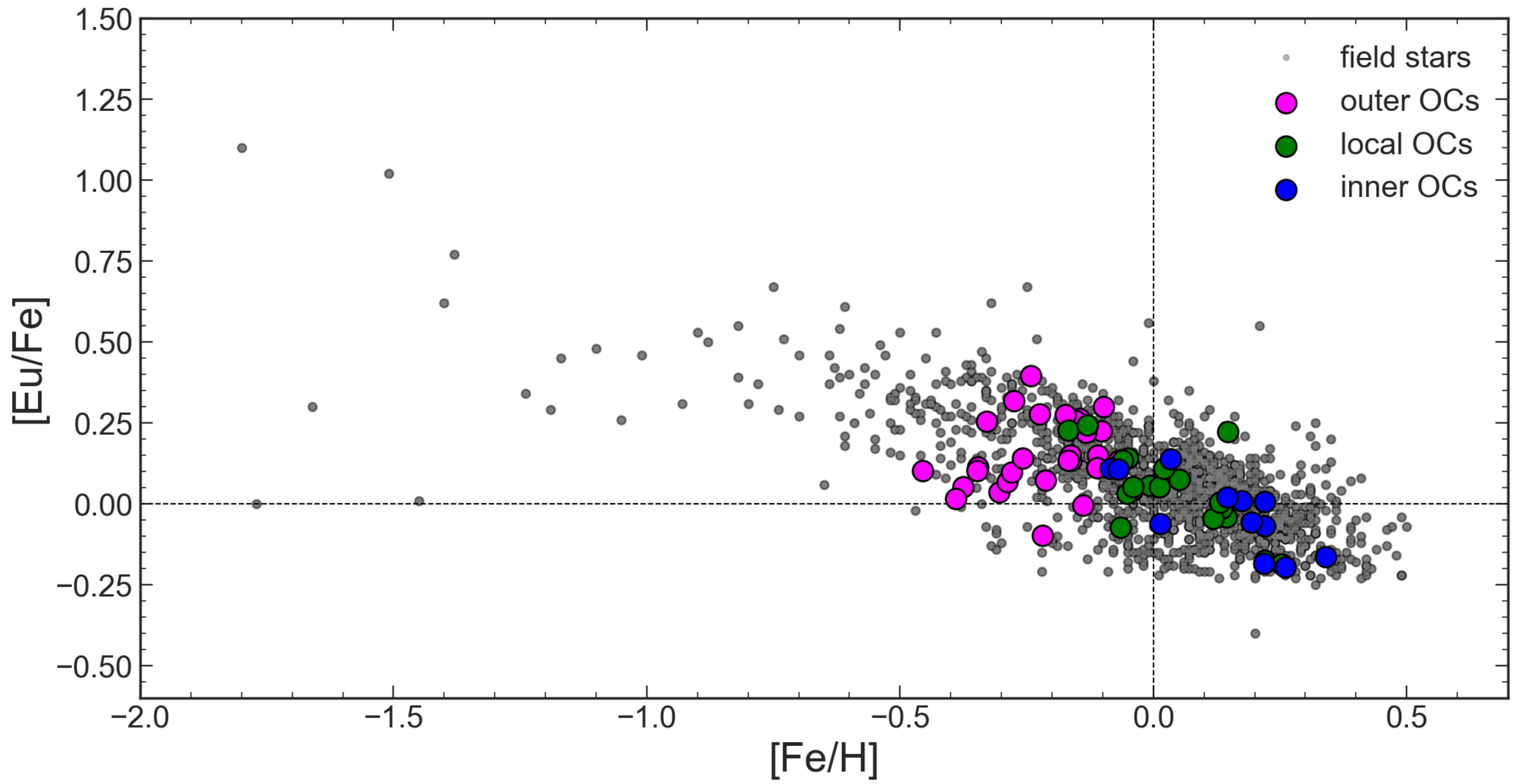
- S-process elements: Y, Zr, La, Ba, Ce
  R-process and mixed elements: Eu, Nd, Mo, Pr

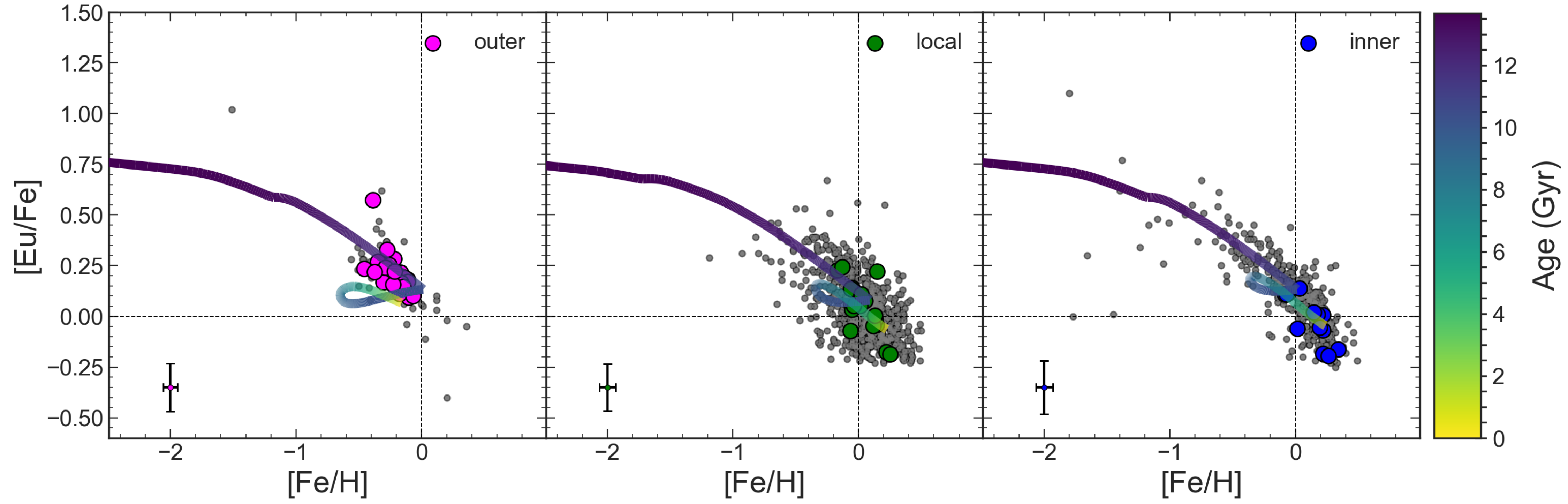




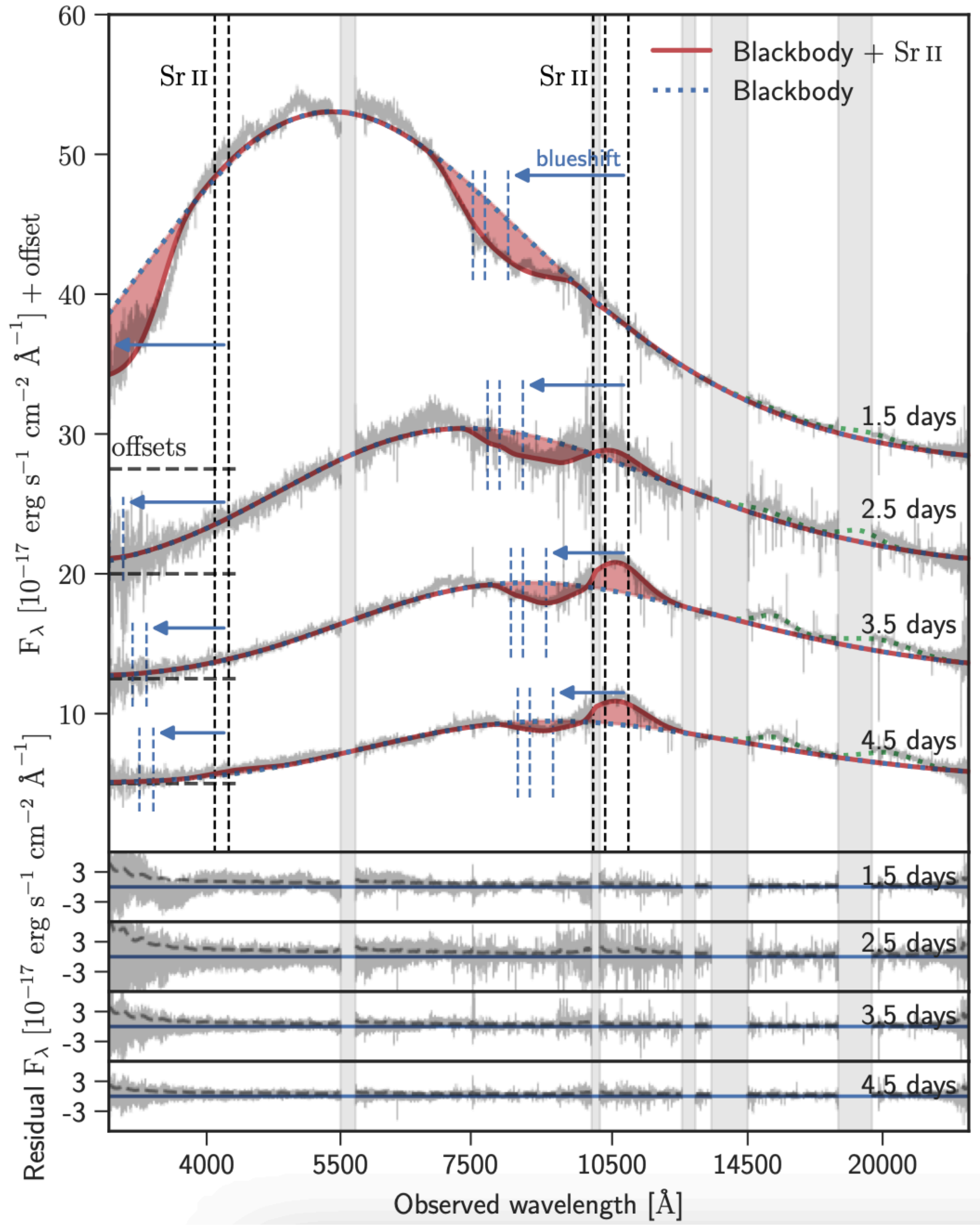
Viscasillas Vàzquez et al. (2022)

[Eu/Fe] vs. [Fe/H] in the disk

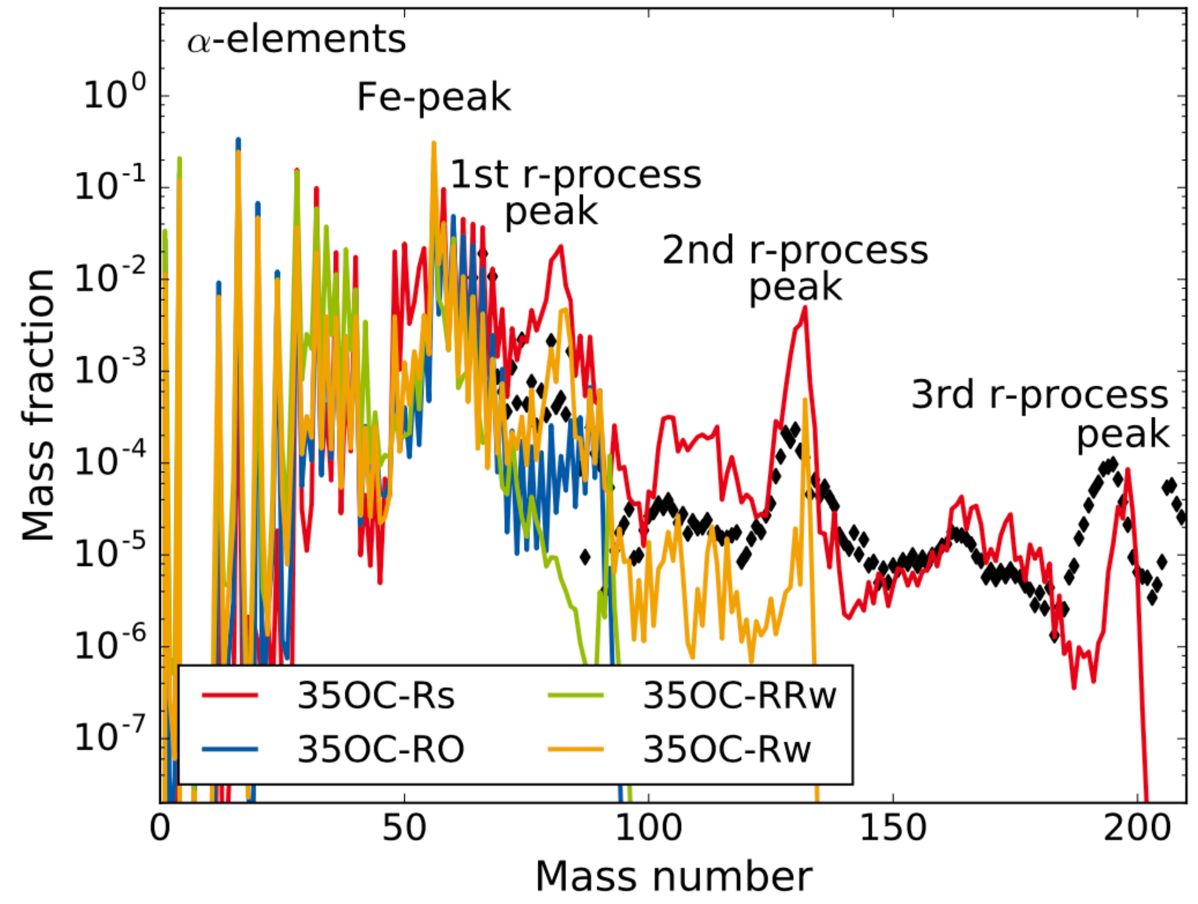




Watson et al. (2019)



Reichert et al. (2021)



R-process

I. MNS with a DTD - rate fine-tuned to that of Abbott et al. (2021) - $Y^{MNS}_{Eu} = 3.0 \times 10^{-6}\ M_{\odot}$

II. MR-SNe - assumed to be 20% of stars with 10-25 $M_{\odot}$ initial mass - $Y^{MR-SNe}_{Eu} = 4.69 \times 10^{-7}\ M_{\odot}$

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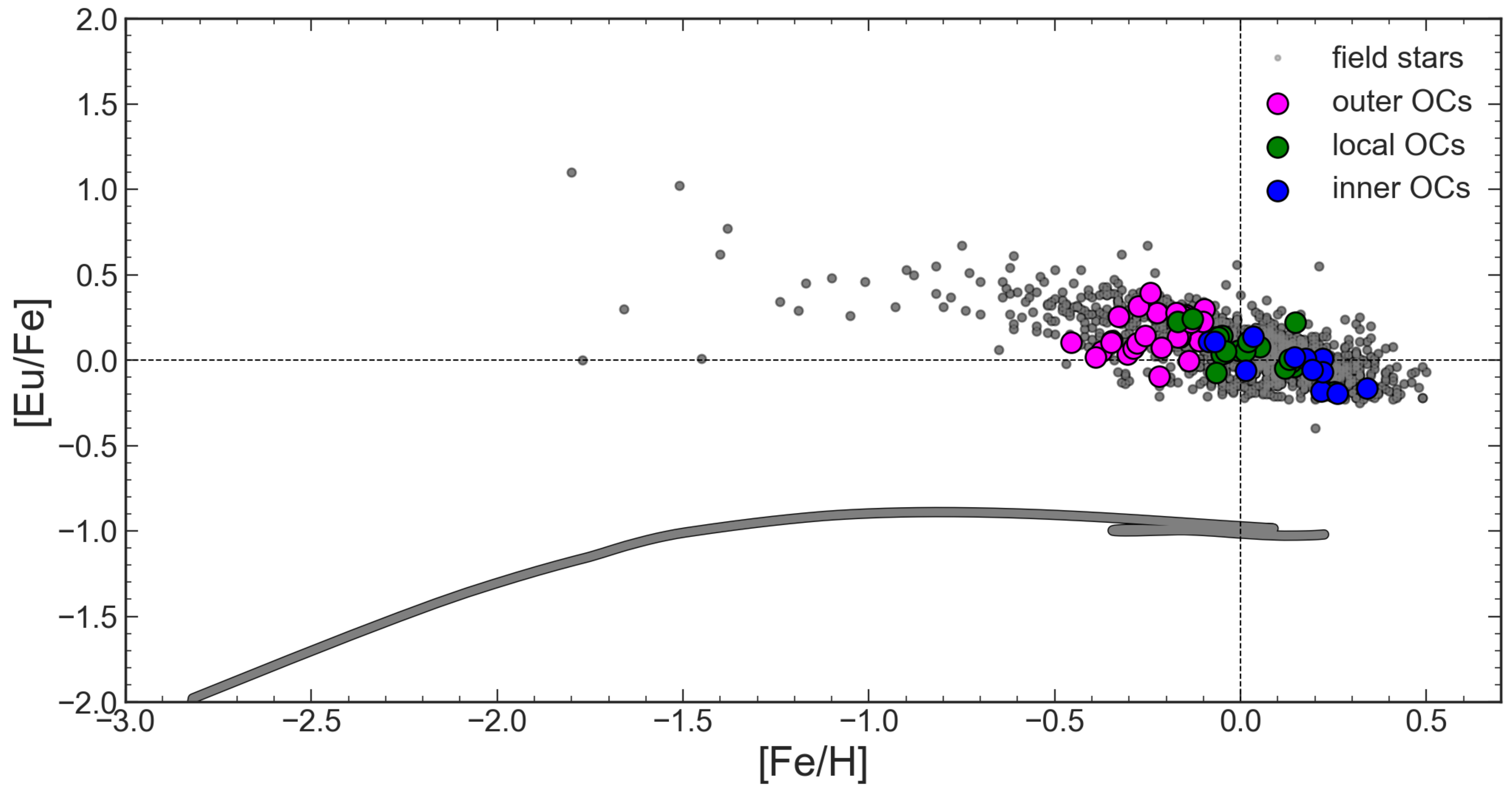

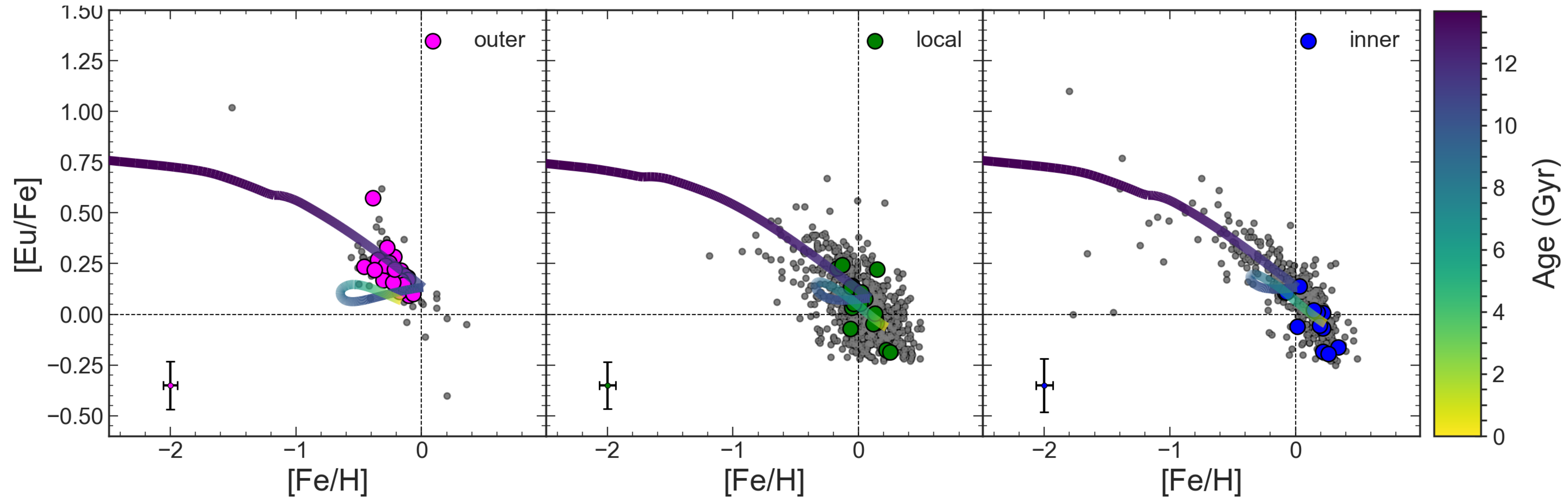

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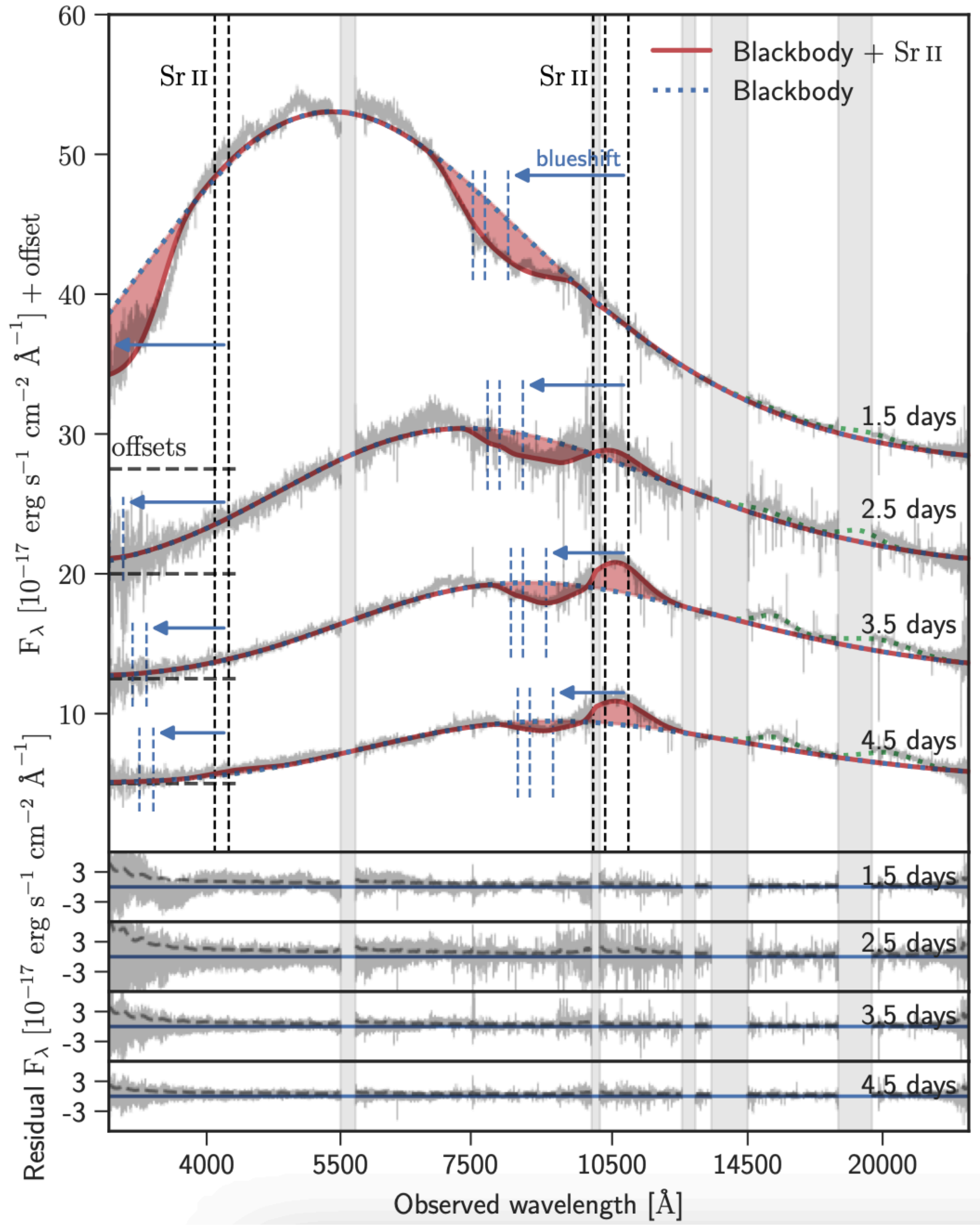

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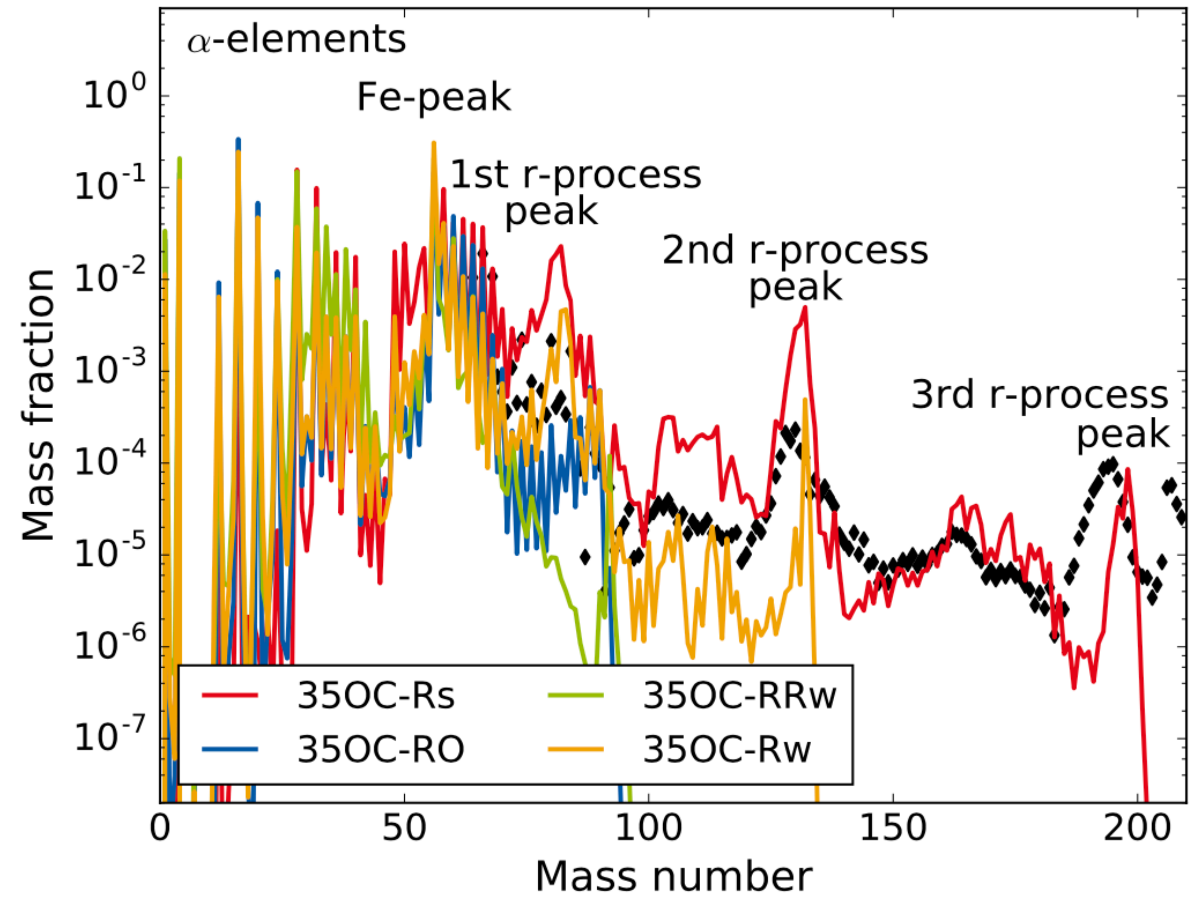

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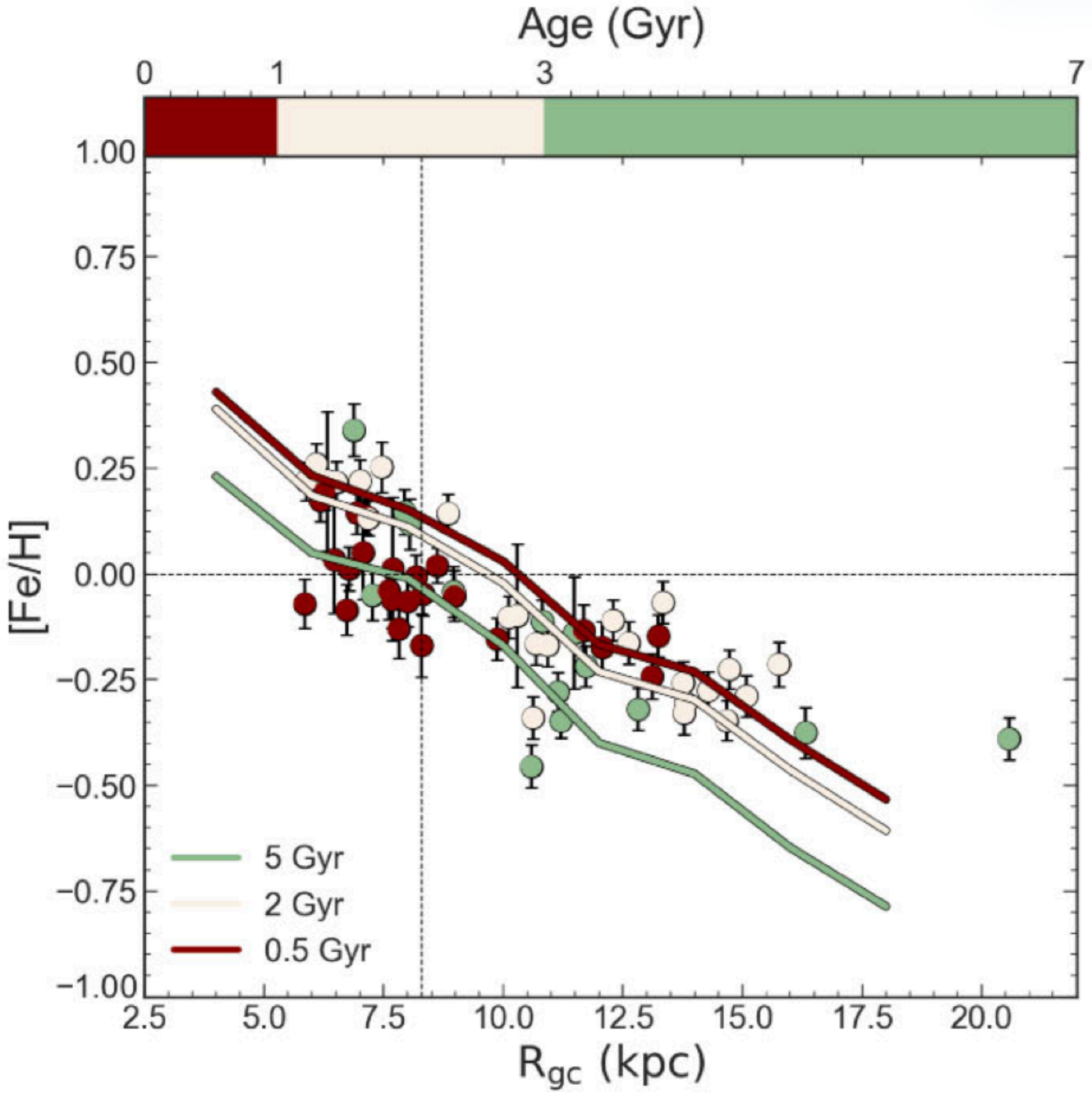
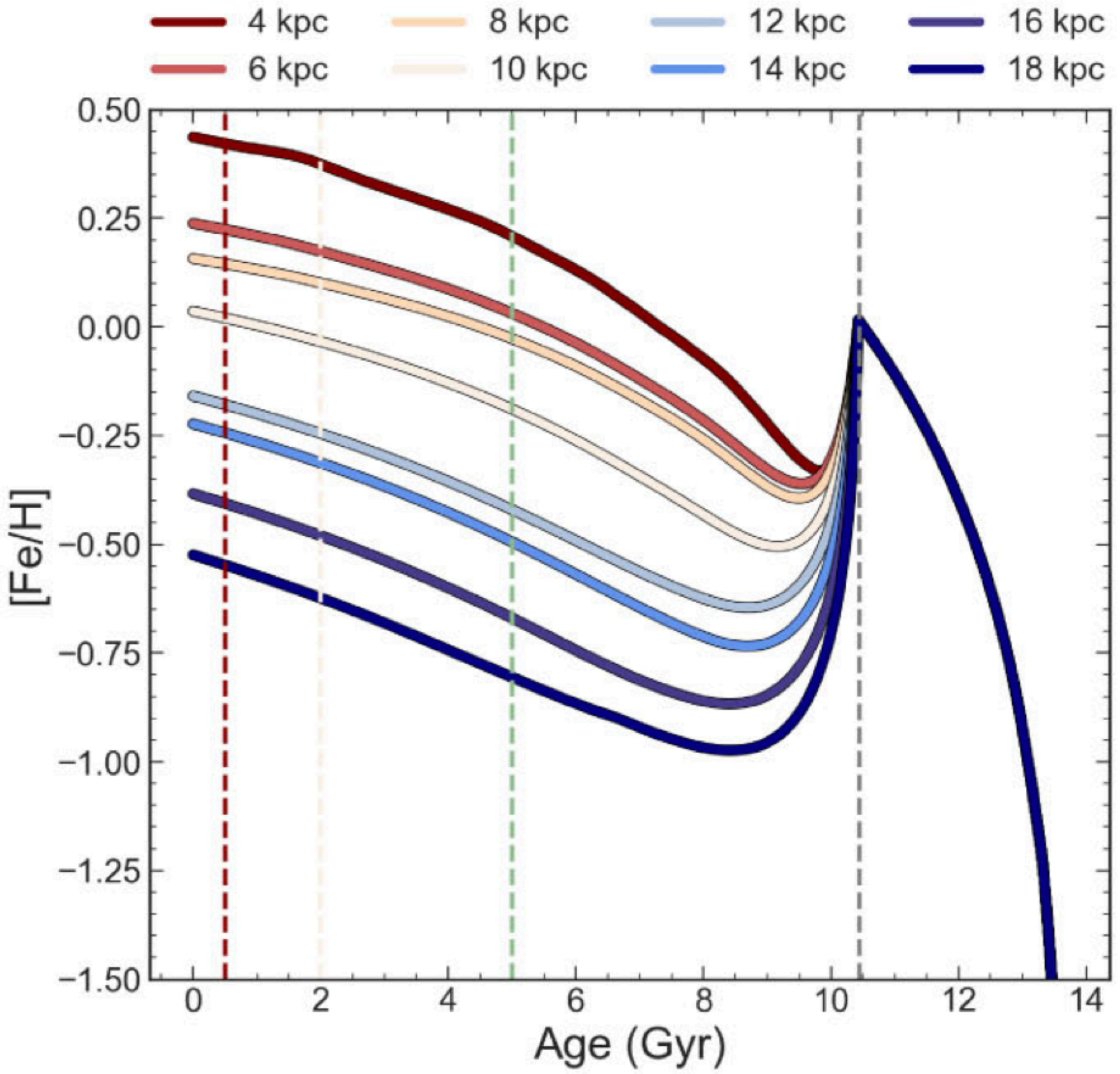
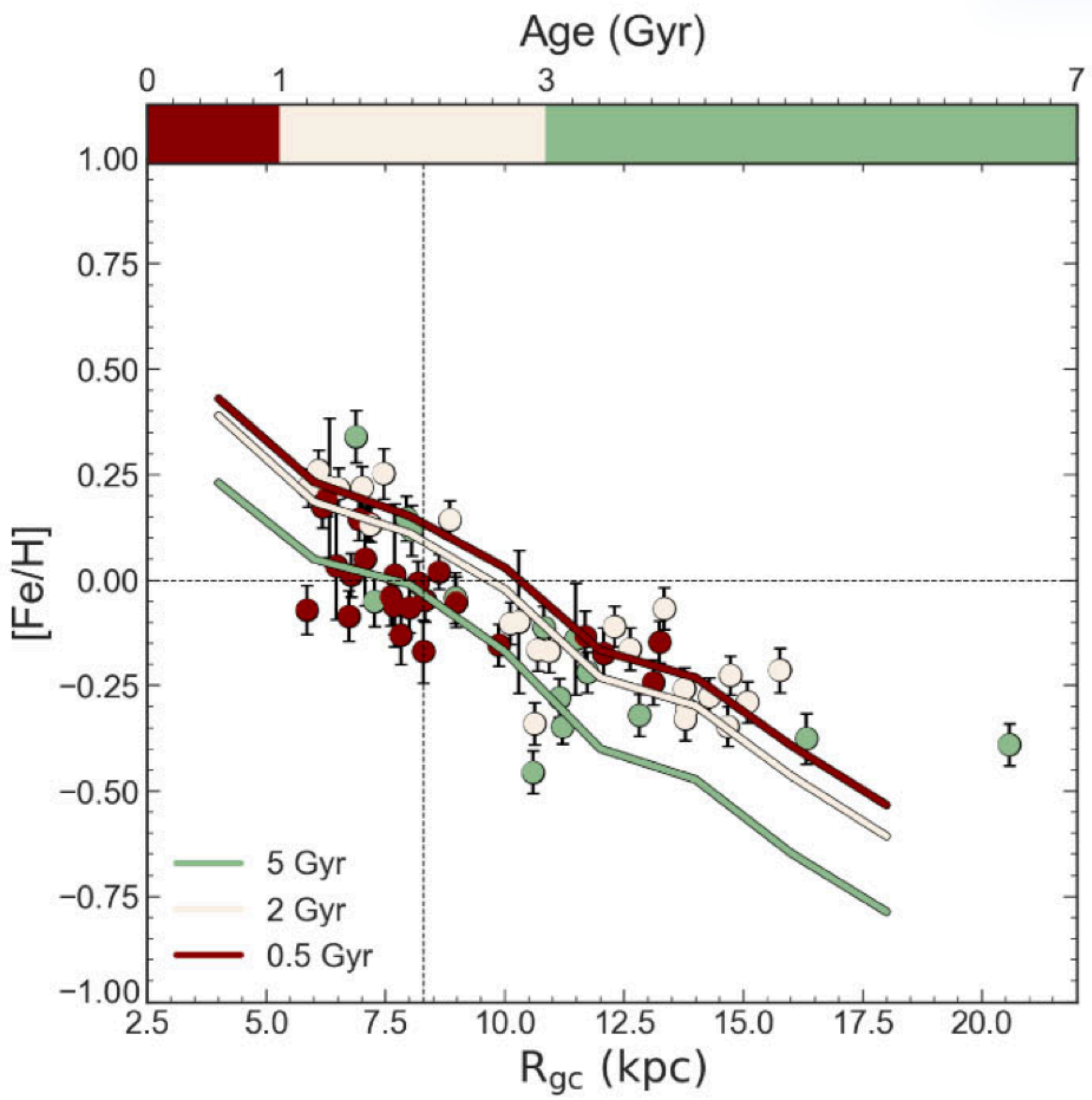
Milky Way: the disc - gradients of elements

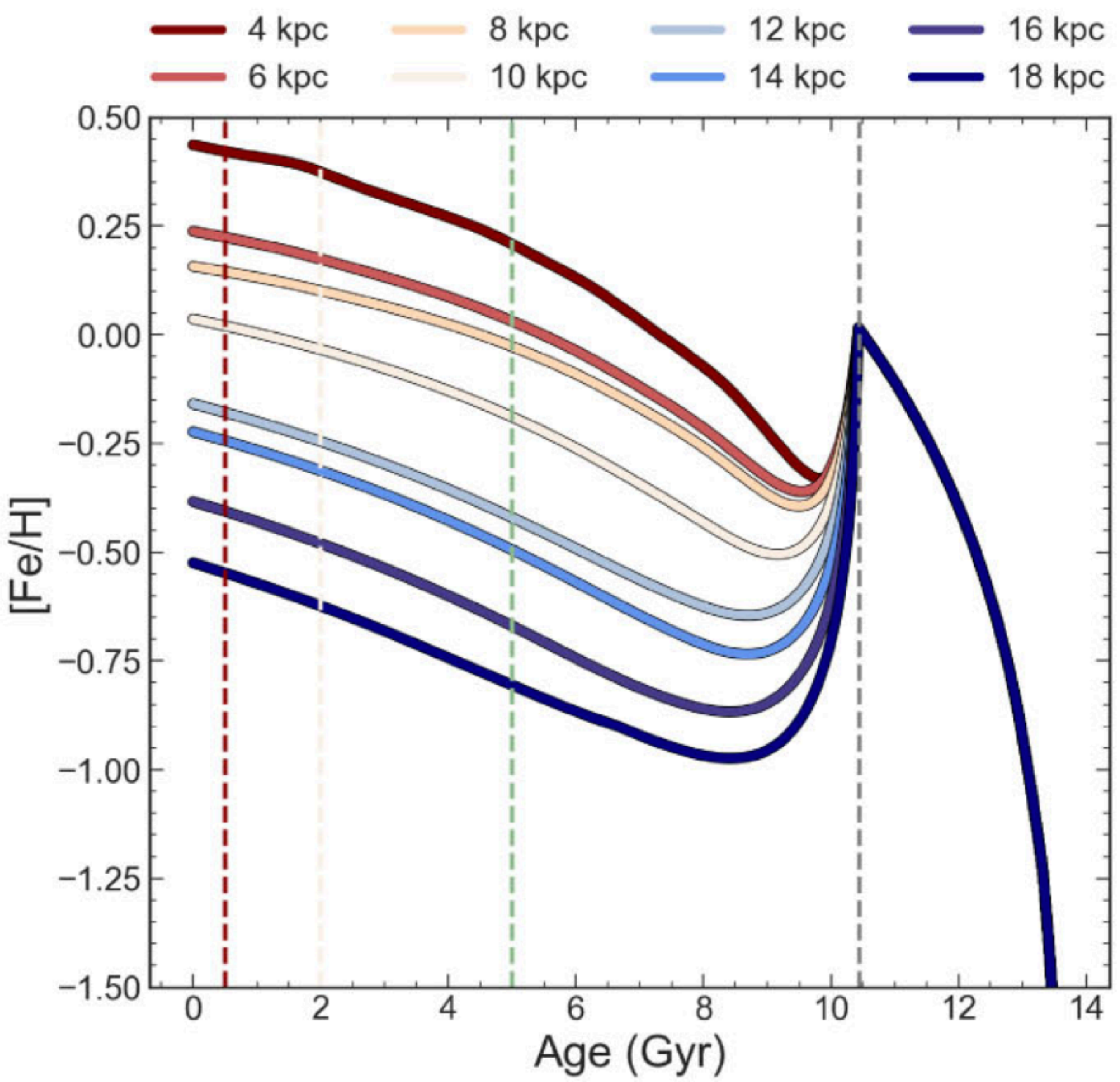




Inside-out + variable SF efficiency

Milky Way: the disc - gradients of elements

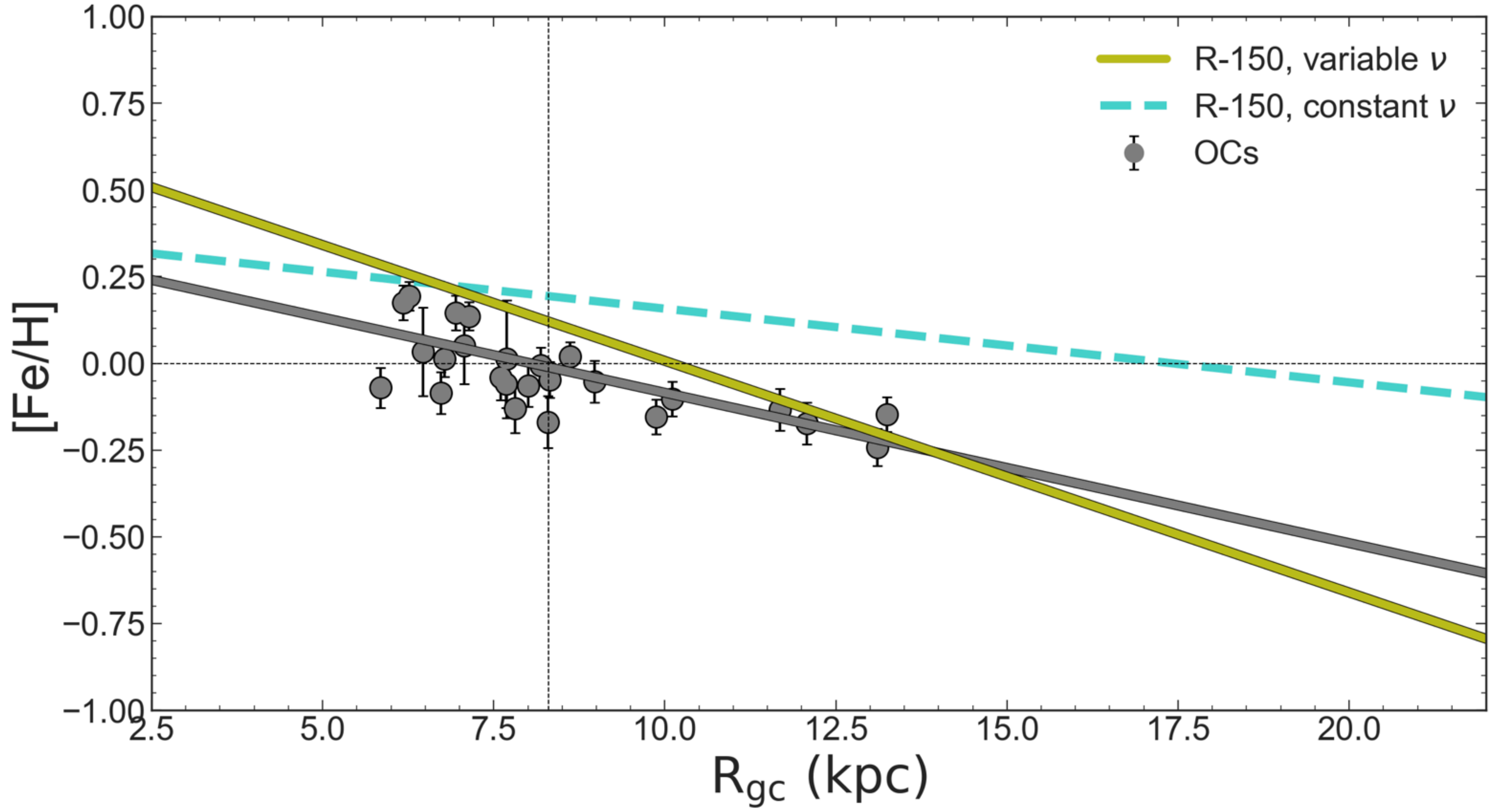




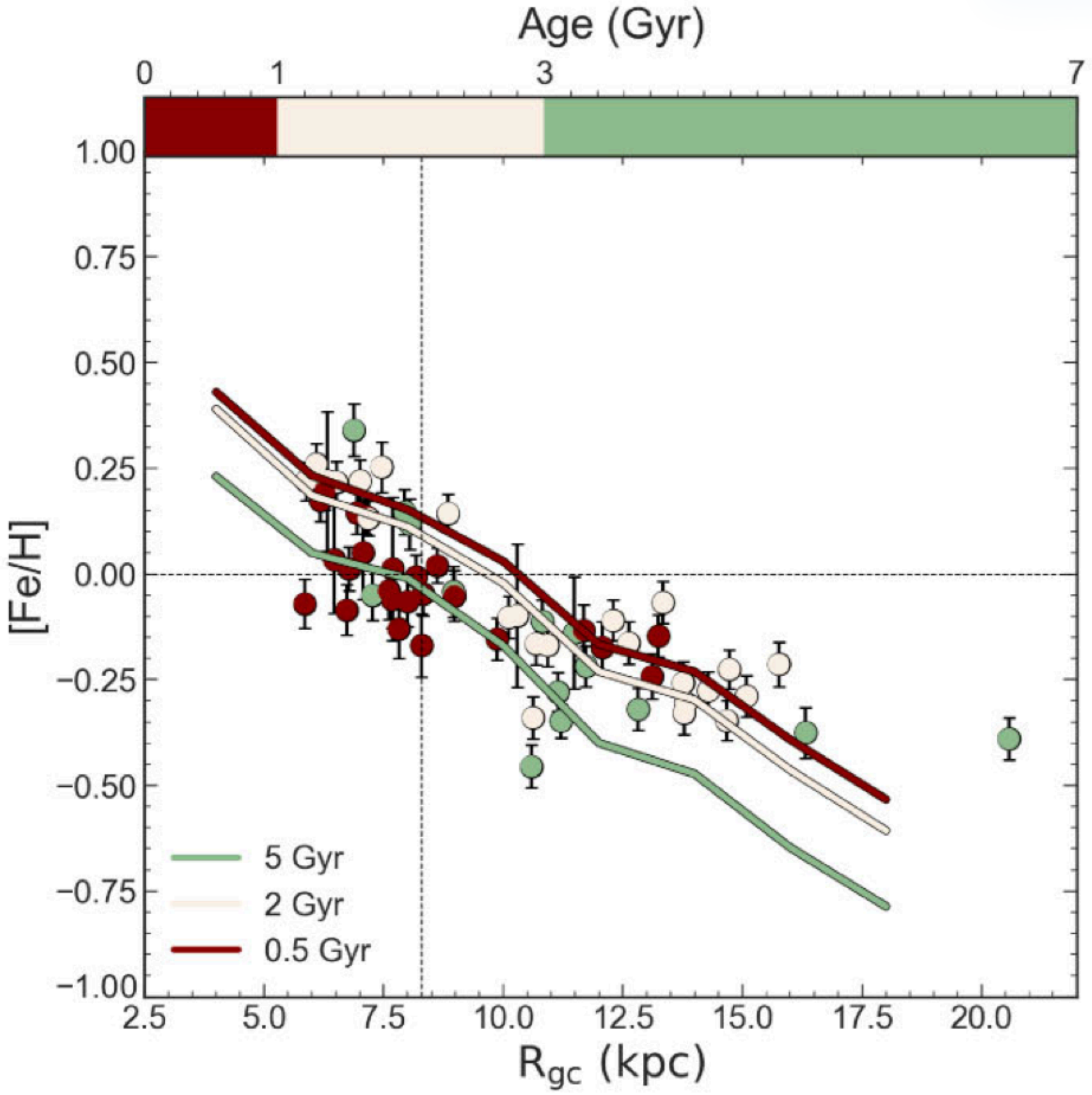
Inside-out + variable SF efficiency

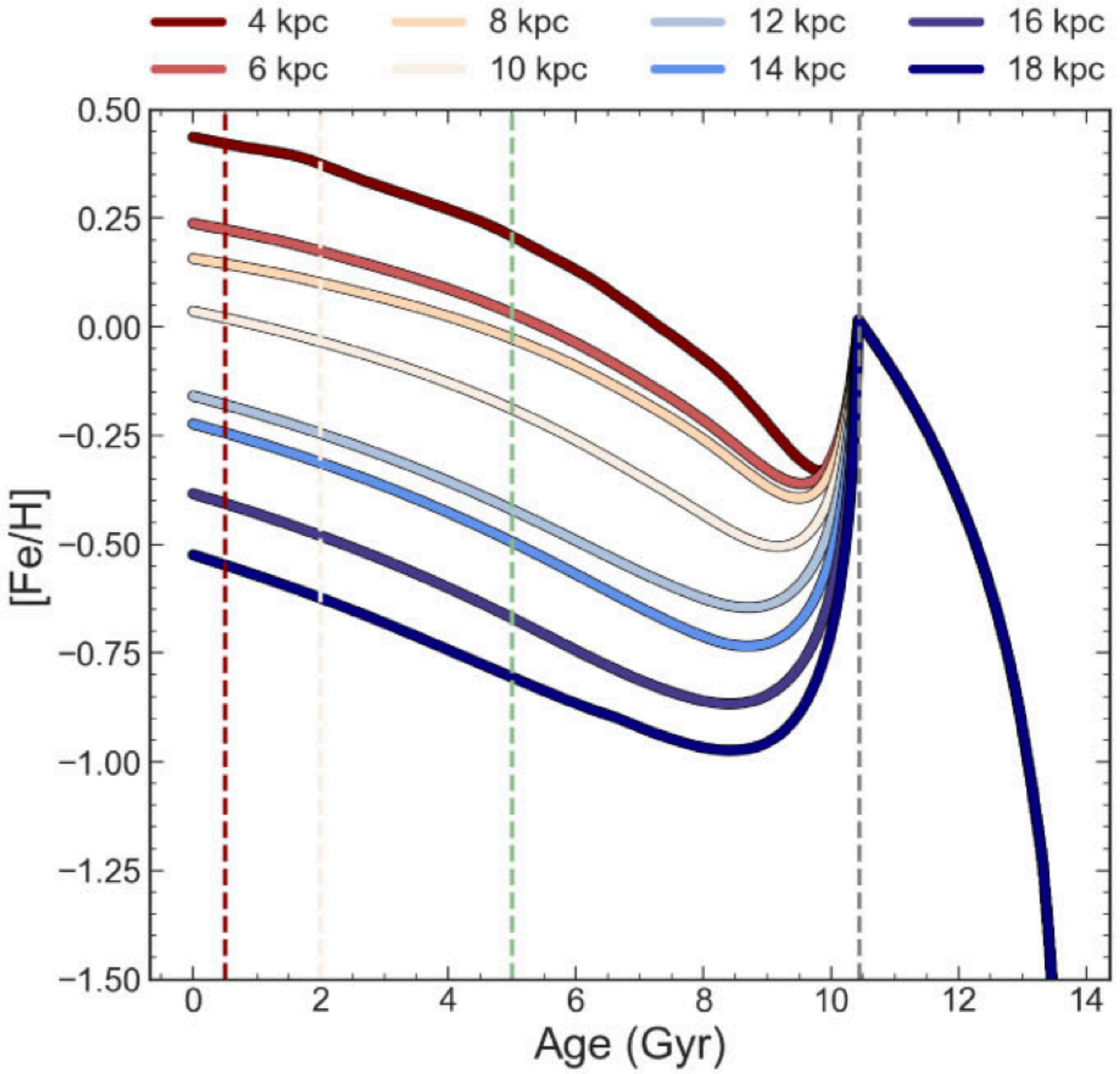
$$[Fe/H] = -0.054(\pm 0.004) \times R_{GC} + 0.474(\pm 0.045)$$

$$-0.065(\pm 0.003)$$



Milky Way: the disc - gradients of elements





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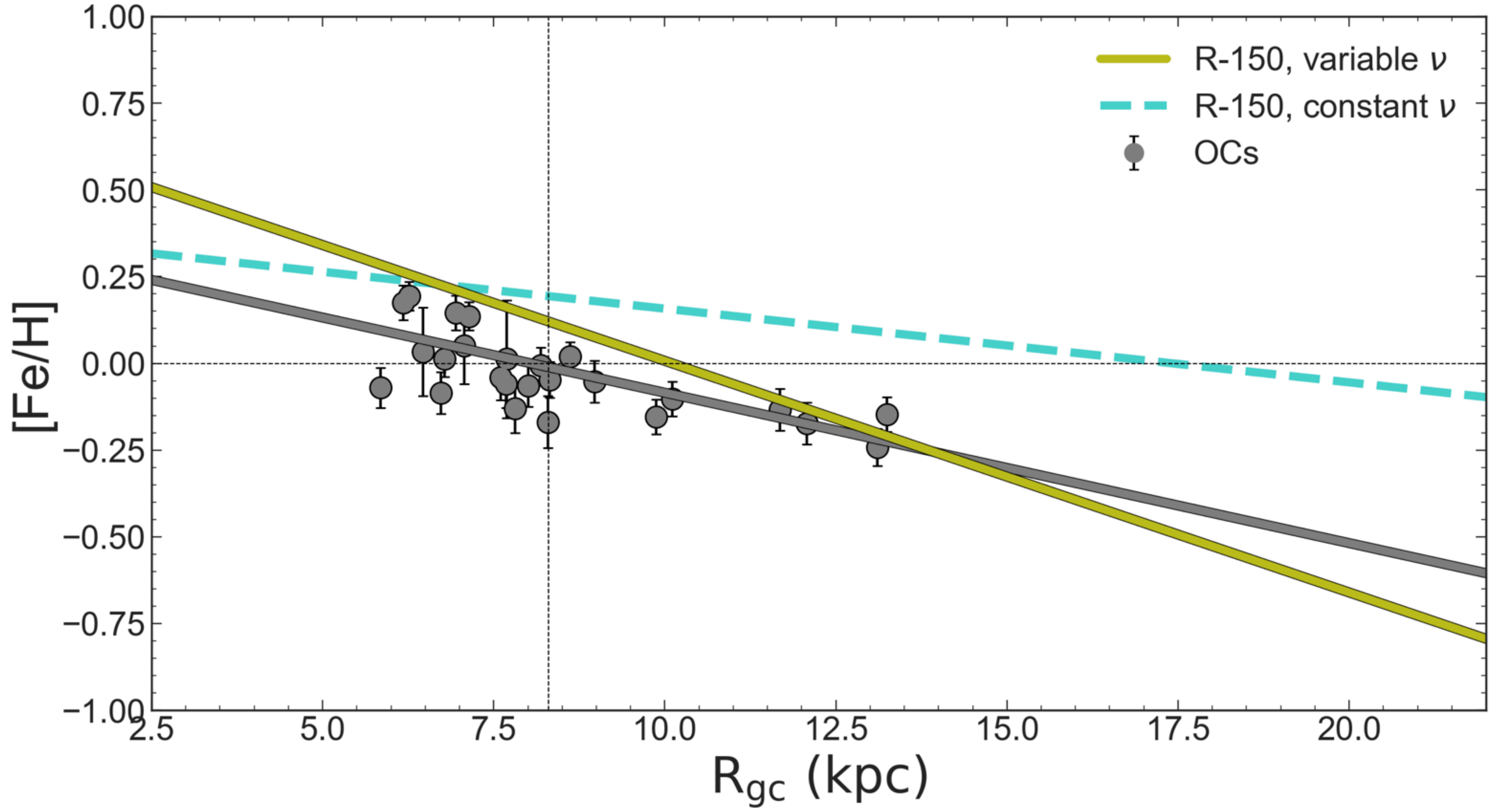
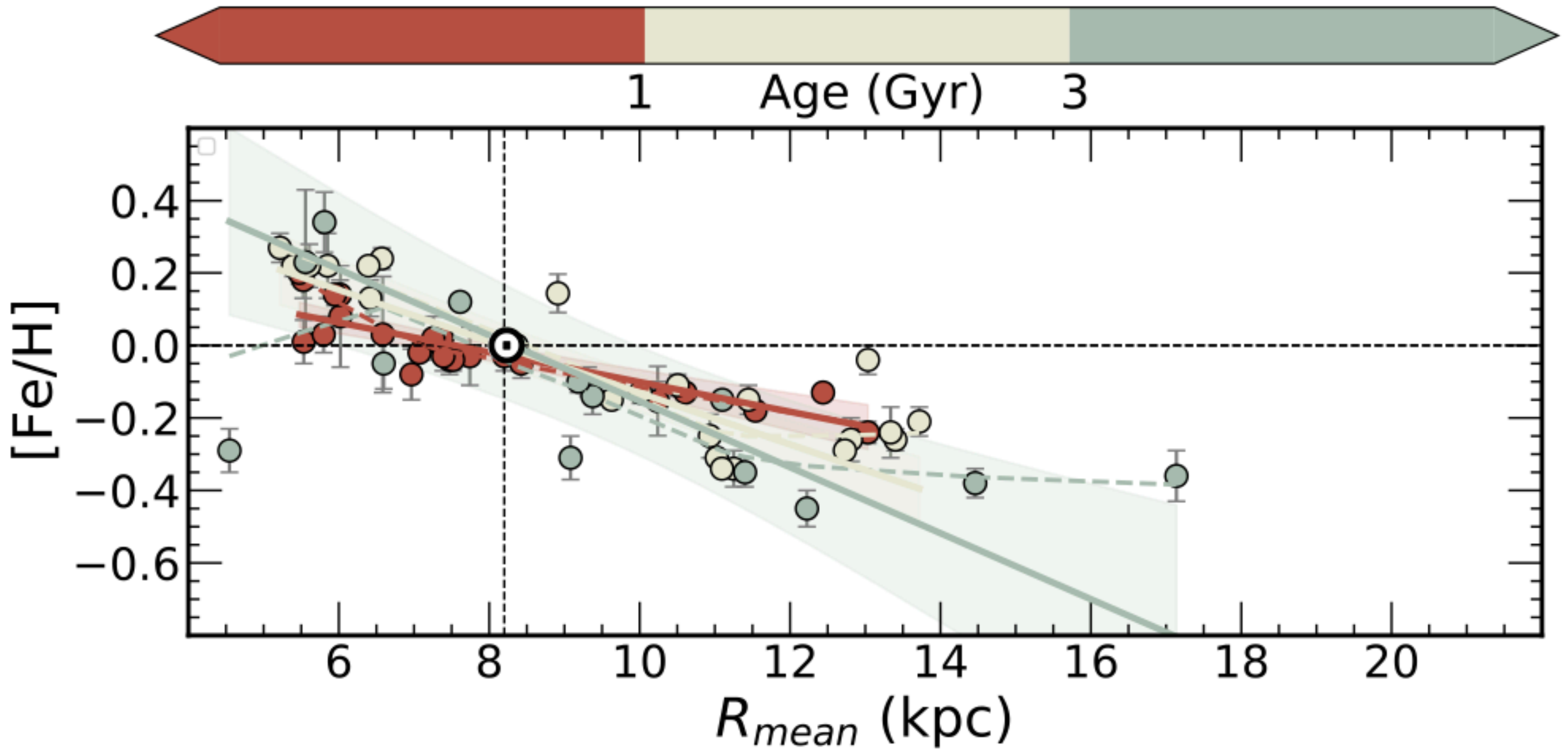
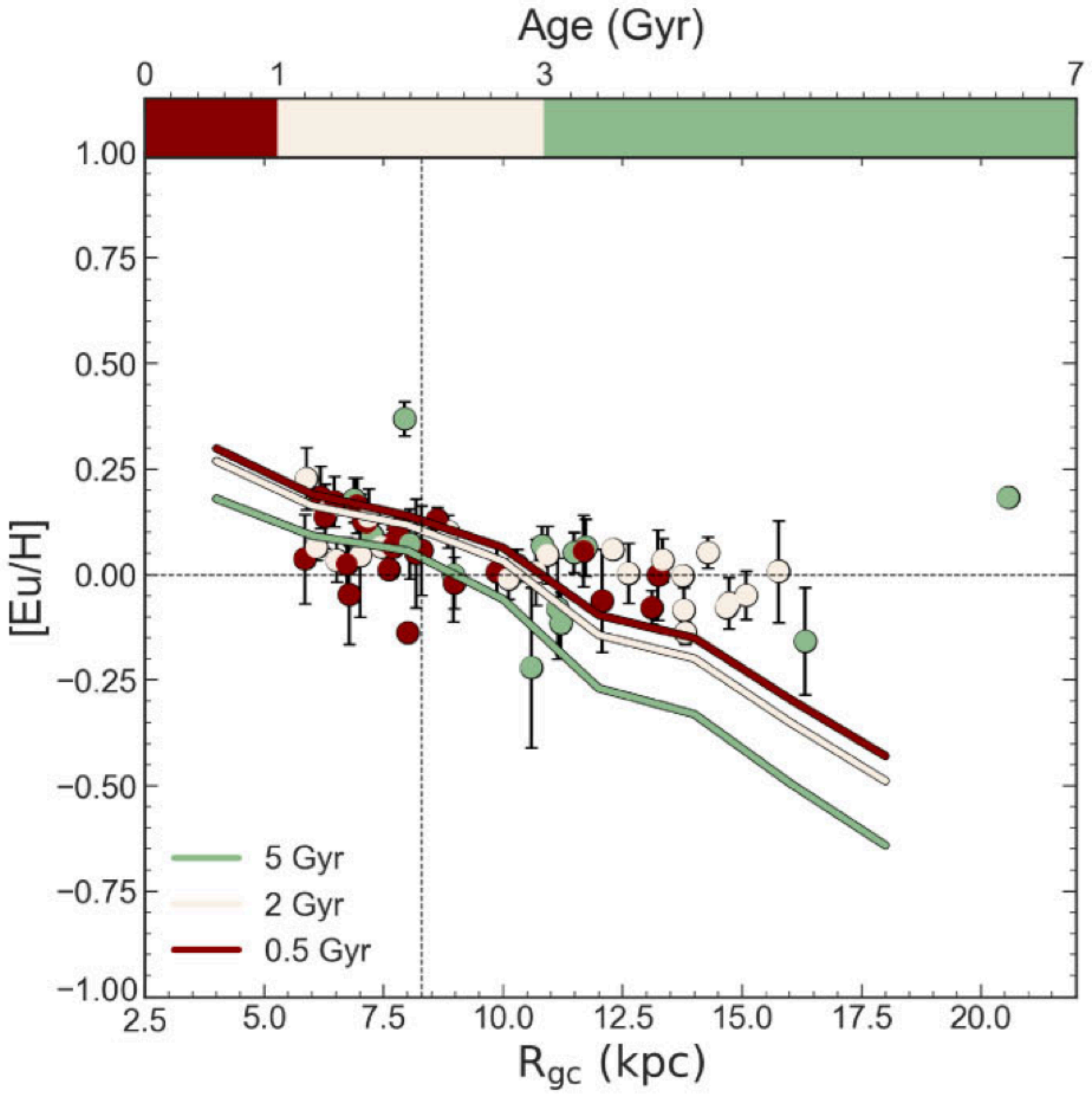


$$[\mathrm{Fe/H}] = -0.060(\pm 0.005) \times R_{mean} + 0.481(\pm 0.050)$$



Orbits computed with GALPY code with MWPotential 2014 (Bovy+15)

Milky Way: the disc - gradients of elements



$$[\mathrm{Eu/H}] = -0.019(\pm 0.003) \times R_{GC} + 0.245(\pm 0.030)$$

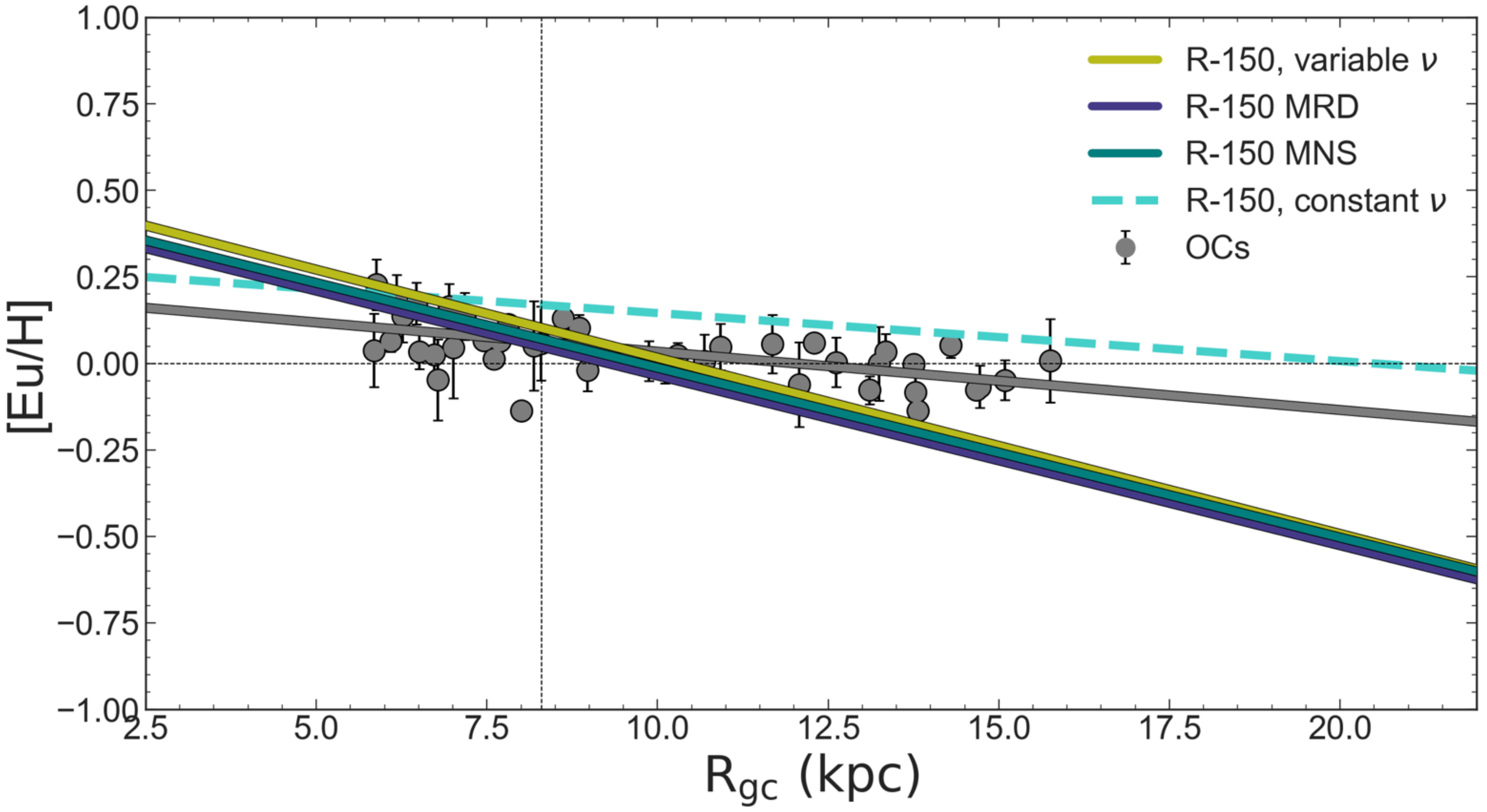
$-0.051(\pm 0.003)$ MNS + MRD

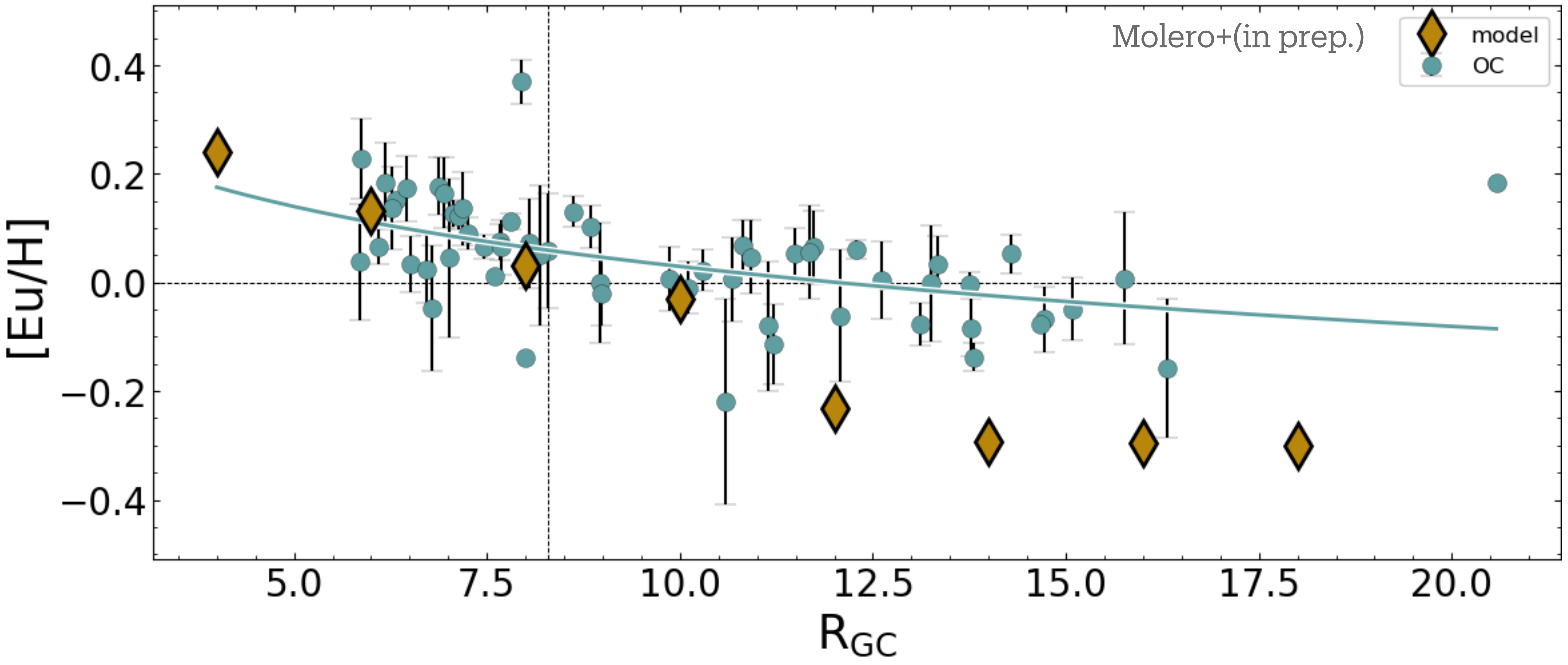
$-0.049(\pm 0.003)$ only MRD

$-0.049(\pm 0.003)$ only MNS without DTD

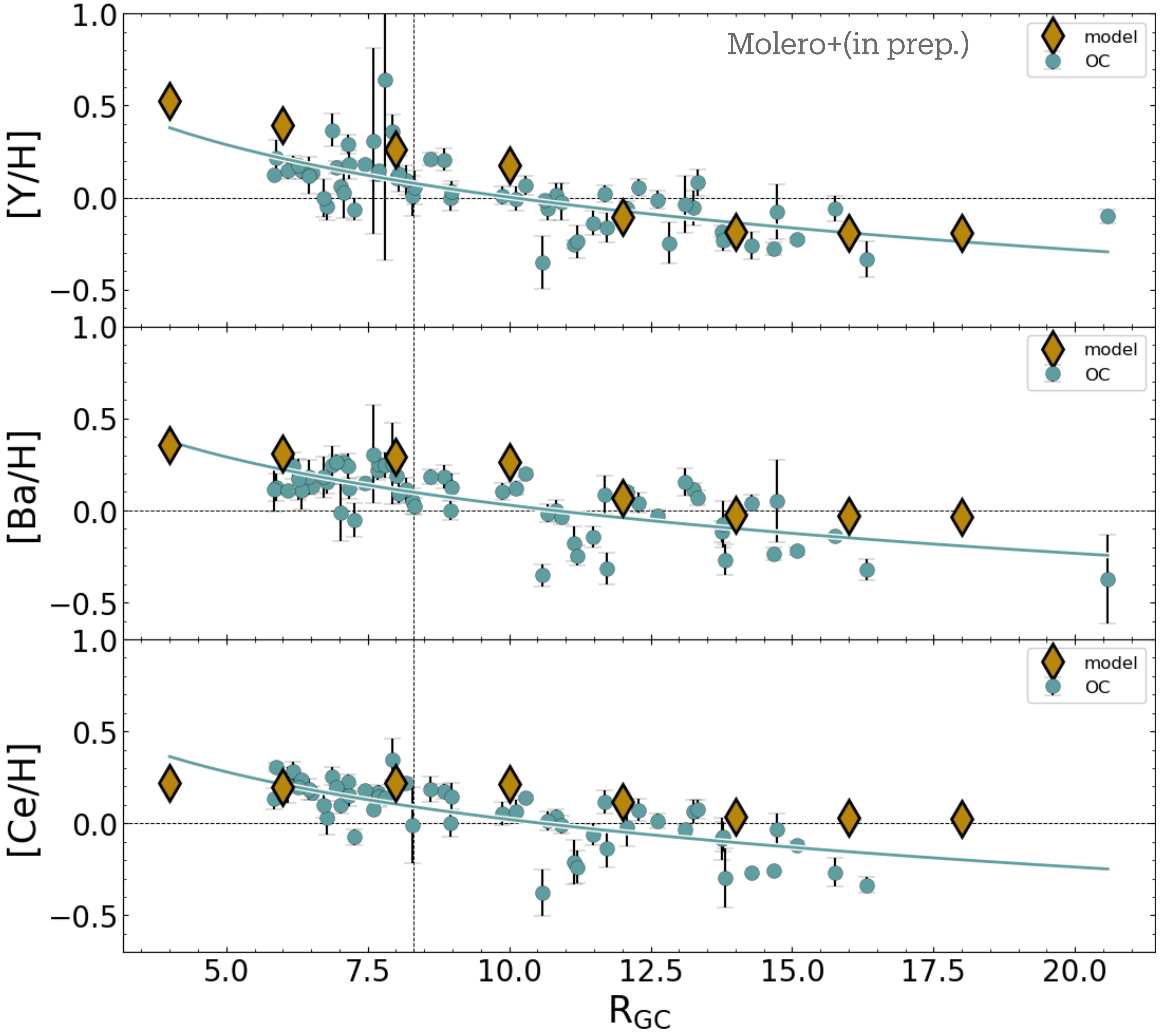
The predicted Eu gradient is **too steep**, independently on how quickly the production of Eu is

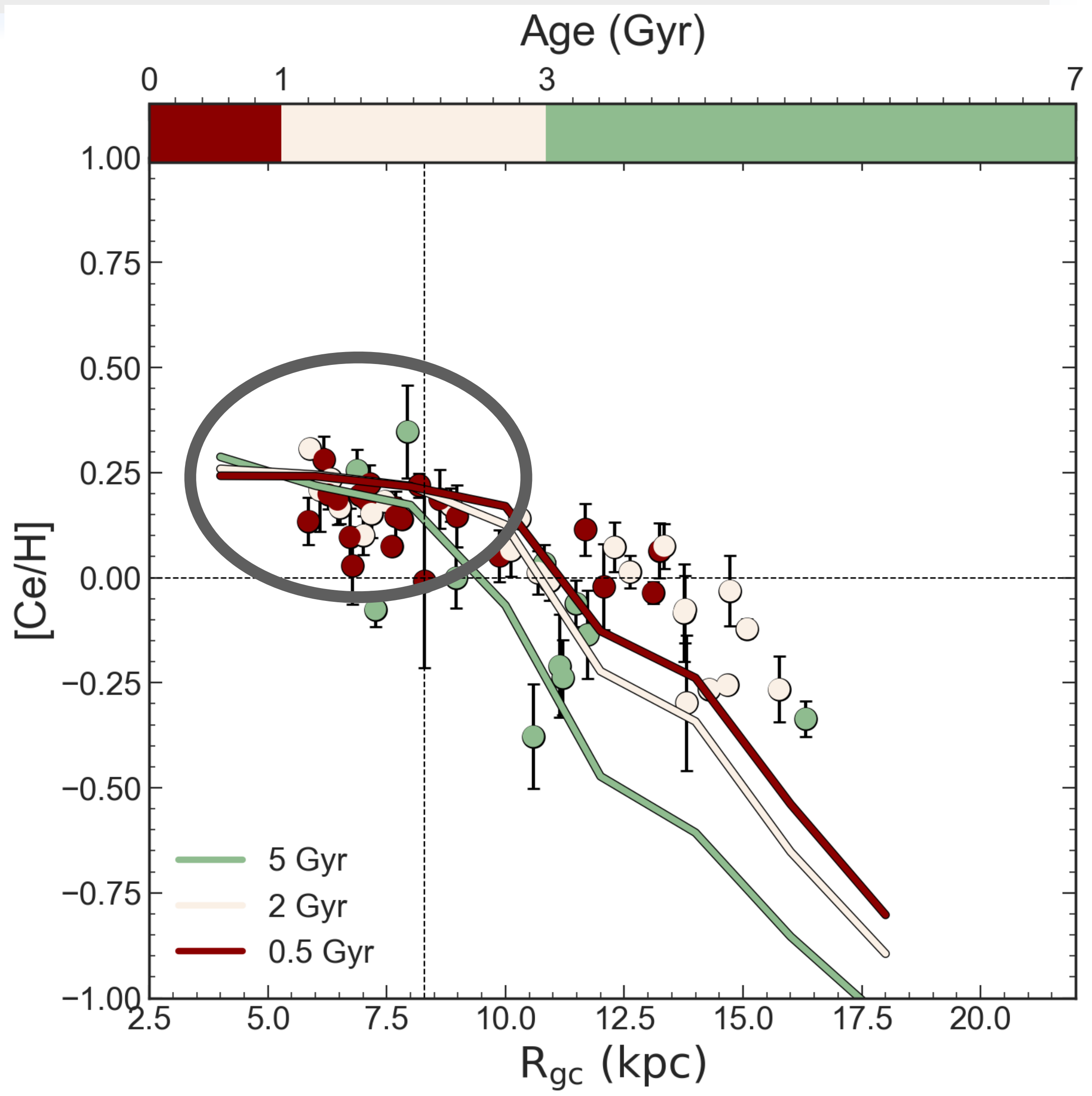
Even by using R_{mean} instead of R_{GC} the <u>OCs gets rearranged in the [Eu/H] vs. R diagram</u>, but the overall gradient does not change

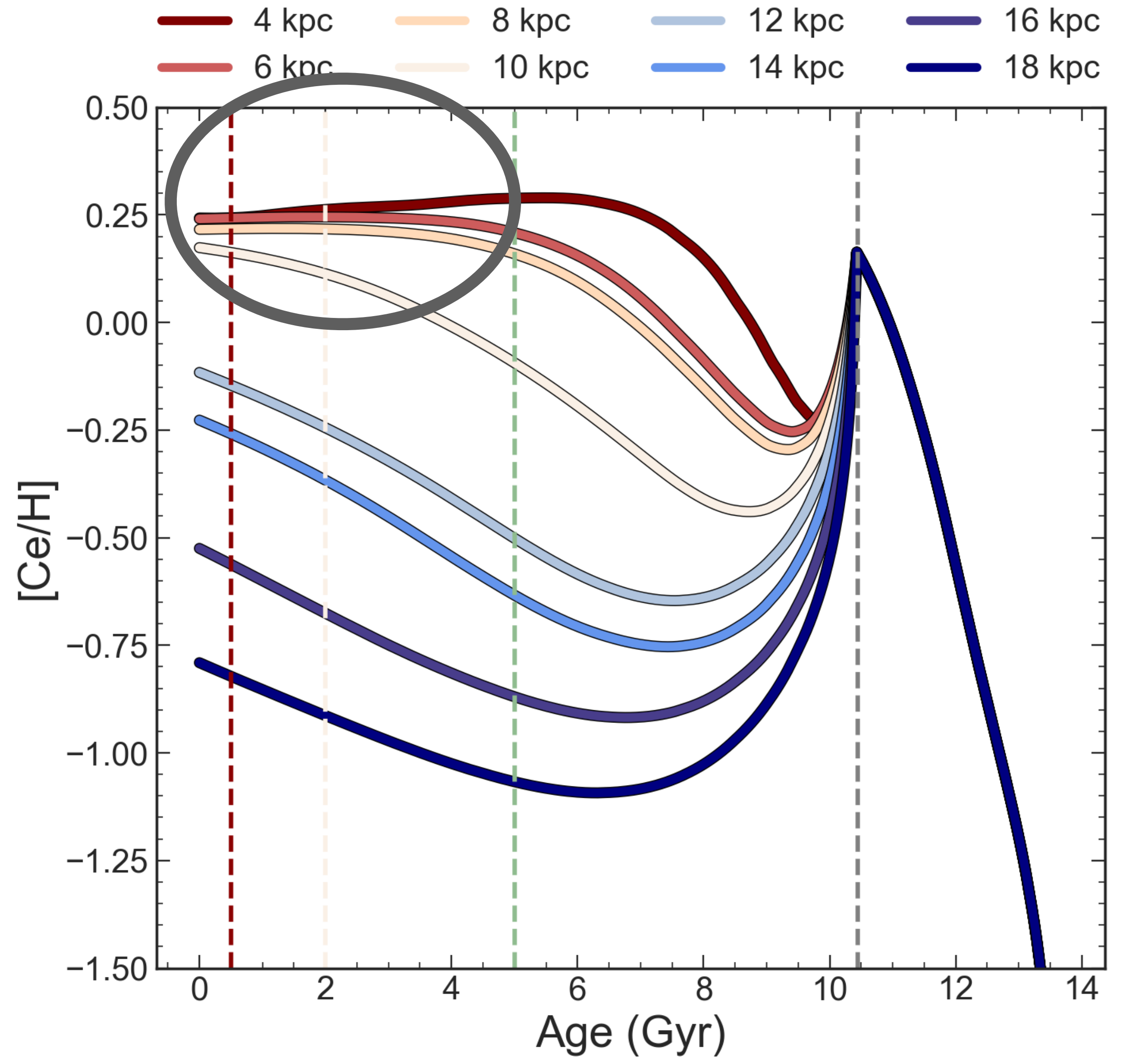




Milky Way: the disc - gradients of elements







According to Casali et al. (2023), this is the effect of having a stronger SF in the inner region than in the outer ones

Due to the effect of AGB which contributions reach a maximum value faster in the inner region than in the outer ones

S-process

I. AGB stars with yields from the non-rotational set of the FRUITY database (Cristallo et al. 2009; 2011; 2015).

II. Rotating (IRV = 0, 150, 300 km/s) massive stars with yields from Limongi&Chieffi (2018).

Summary & Conclusions

- 9 chemical species (Y, Zr, Ba, La, Ce, Eu, Mo, Nd, Pr) observed with the *Gaia*-ESO survey in the MW disc.

r-process

I. MNS with a DTD - rate fine-tuned to that of Abbott et al. (2021) - $Y_{Eu}^{MNS} = 3.0 \times 10^{-6}\ M_{\odot}$

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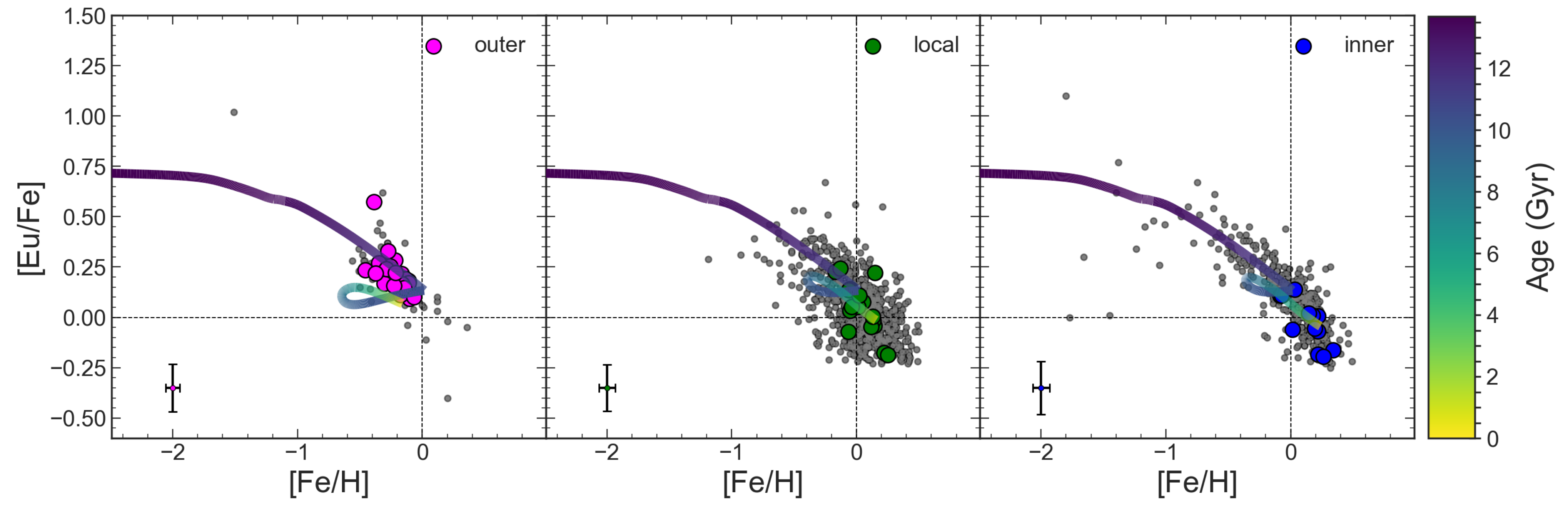
- We well reproduce the [Eu/Fe] vs. [Fe/H] both in the inner, solar and outer regions. However, the quick source completely dominates the production of Eu.



- The predicted present day slope of the [Fe/H] gradient is -0.067 ± 0.003 dex kpc^{-1}, in agreement with recent slopes from OCs samples as well as with the adopted dataset, if the observed gradient is computed by adopting the guiding radius.

- The observed flat slope of the [Eu/H] gradient is not reproduced by our model, independently of how quick the production of Eu is assumed to be. The agreement does not improve by adopting the guiding radii of the OCs.