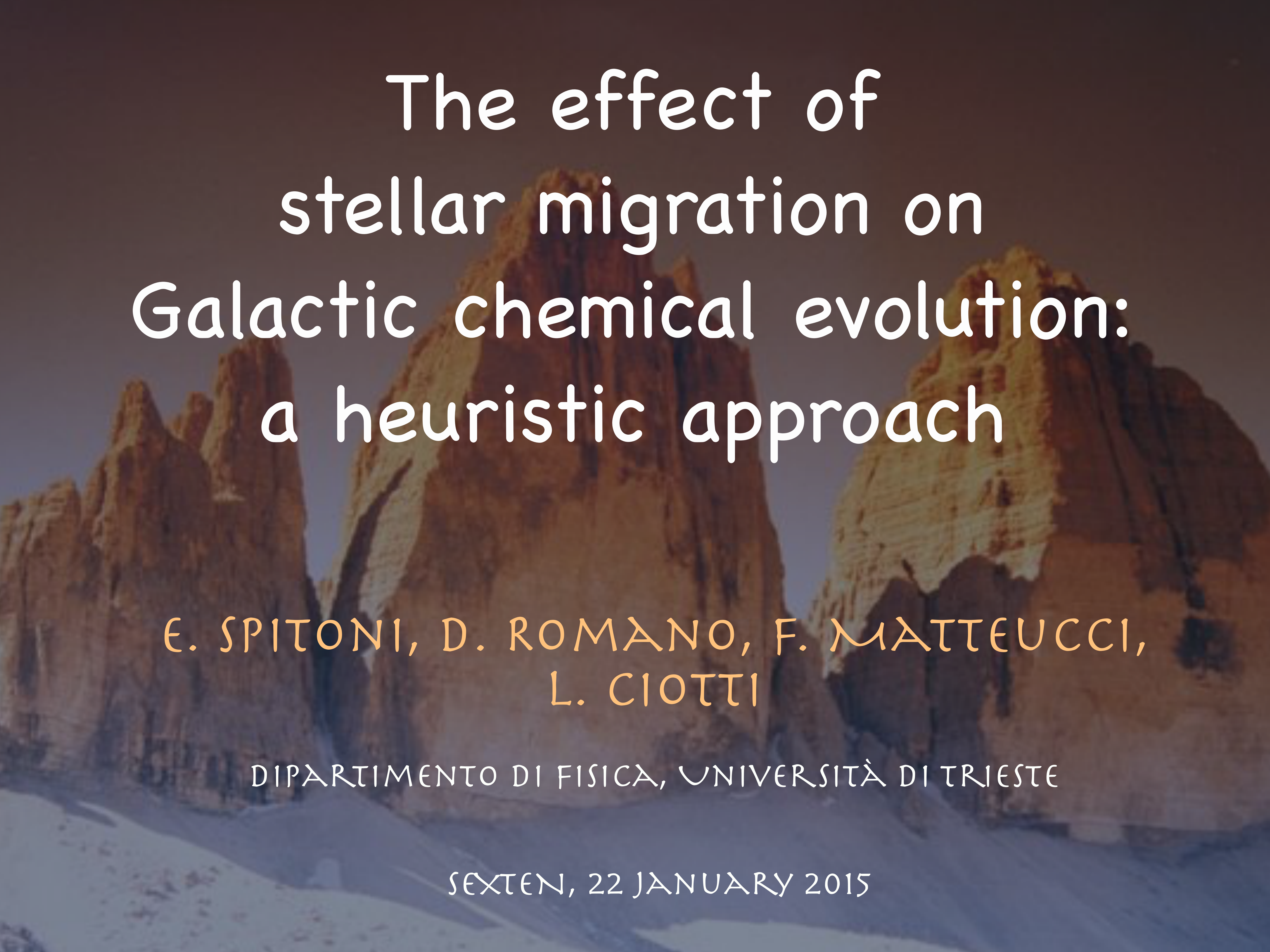


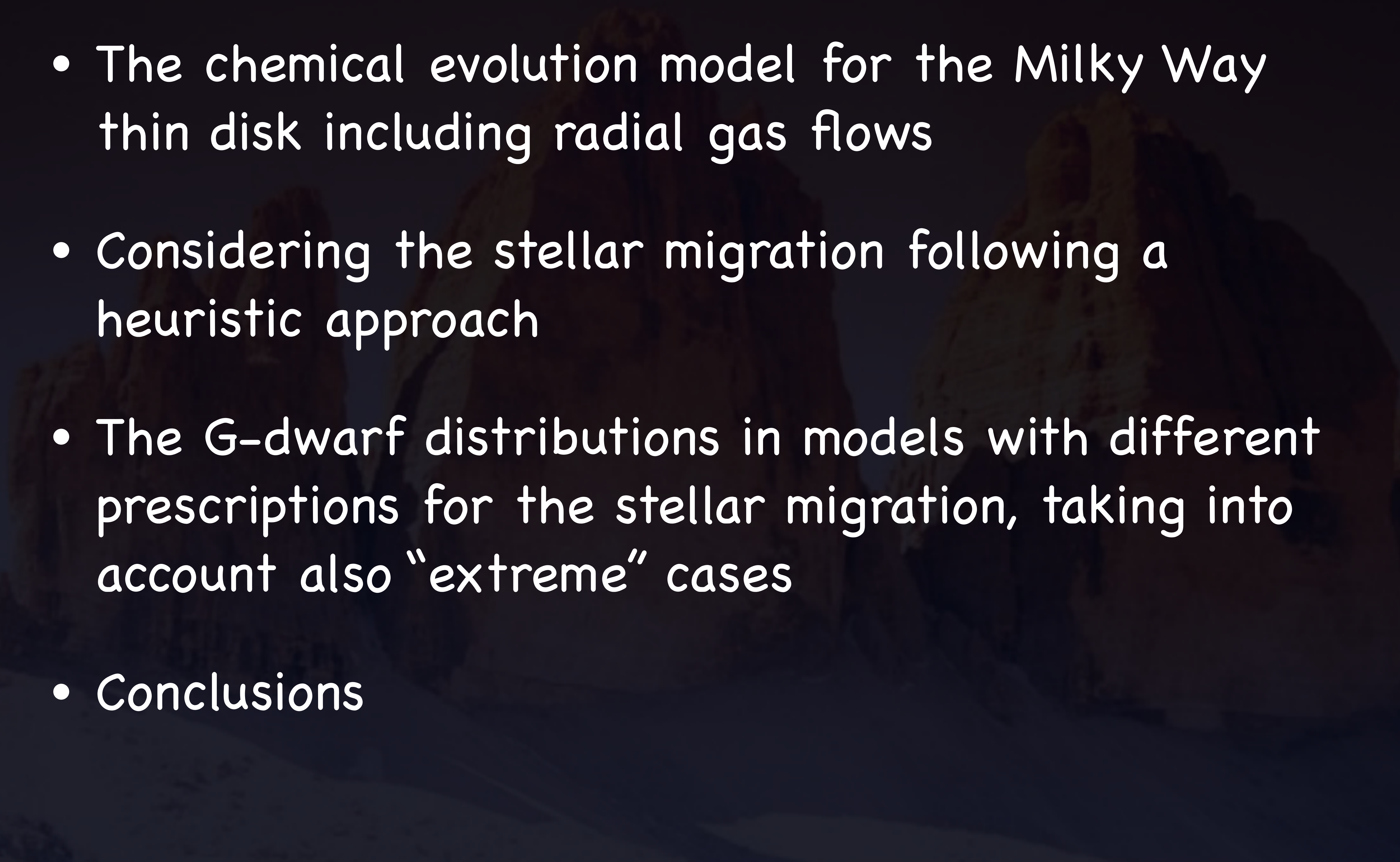
The effect of stellar migration on Galactic chemical evolution: a heuristic approach

E. SPITONI, D. ROMANO, F. MATTEUCCI,
L. CIOTTI

DIPARTIMENTO DI FISICA, UNIVERSITÀ DI TRIESTE

SEXTEN, 22 JANUARY 2015

Outline



- The chemical evolution model for the Milky Way thin disk including radial gas flows
- Considering the stellar migration following a heuristic approach
- The G-dwarf distributions in models with different prescriptions for the stellar migration, taking into account also “extreme” cases
- Conclusions

The chemical evolution model for the Milky Way thin disk

Reference model:
- i) variable SFE
- ii) Radial gas Flows

The chemical evolution model for the Milky Way thin disk

Reference model:

i) variable SFE

ii) Radial gas Flows

STELLAR MIGRATION FOLLOWING A HEURISTIC APPROACH

The chemical evolution model I

- The model assumes that the disc grows via smooth accretion of gas of primordial chemical composition. The infall law for the thin-disc is:

$$A(r,t) = a(r)e^{-\frac{t}{\tau_D}}$$

- In order to reproduce an inside-out formation of the disc, the timescale for the mass accretion is assumed to increase with the Galactic radius following the linear relation:

$$\tau_D(r) = 1.033r(\mathrm{kpc}) - 1.27\ \mathrm{Gyr}$$

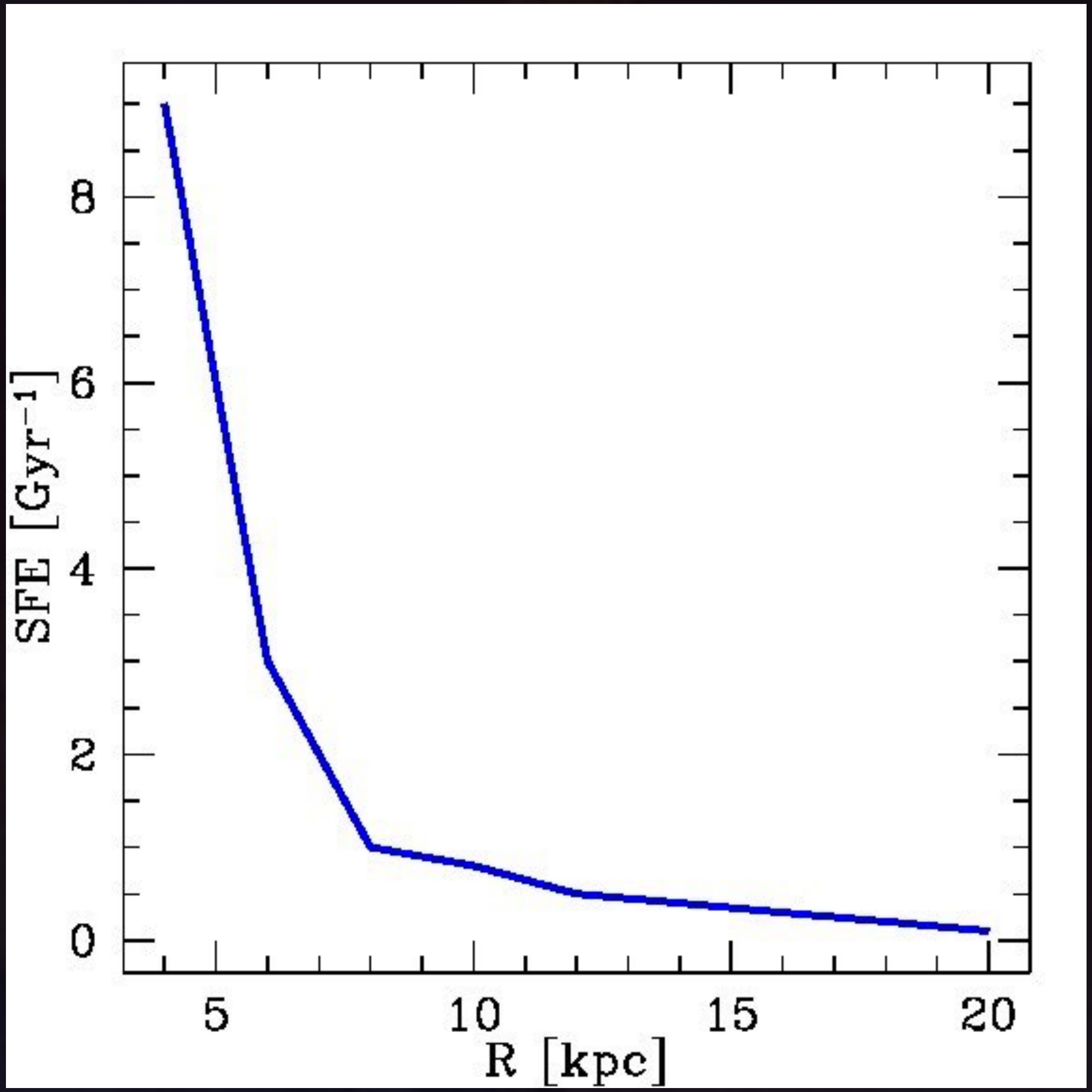
- IMF of Scalo (1986)

The chemical evolution model II

- Star formation rate

$$\psi(r,t) \propto \nu \sigma_{gas}^{k}(r,t)$$

We consider a variable star formation efficiency. The reason for this choice is related to the fact that with a constant SFE the predicted abundance ratio patterns (e.g. [O/Fe] vs [Fe/H]) do not change much from radius to radius, thus making the hypothesis of stellar migration as a solution for the observed spread rather unlikely.



The chemical evolution model II

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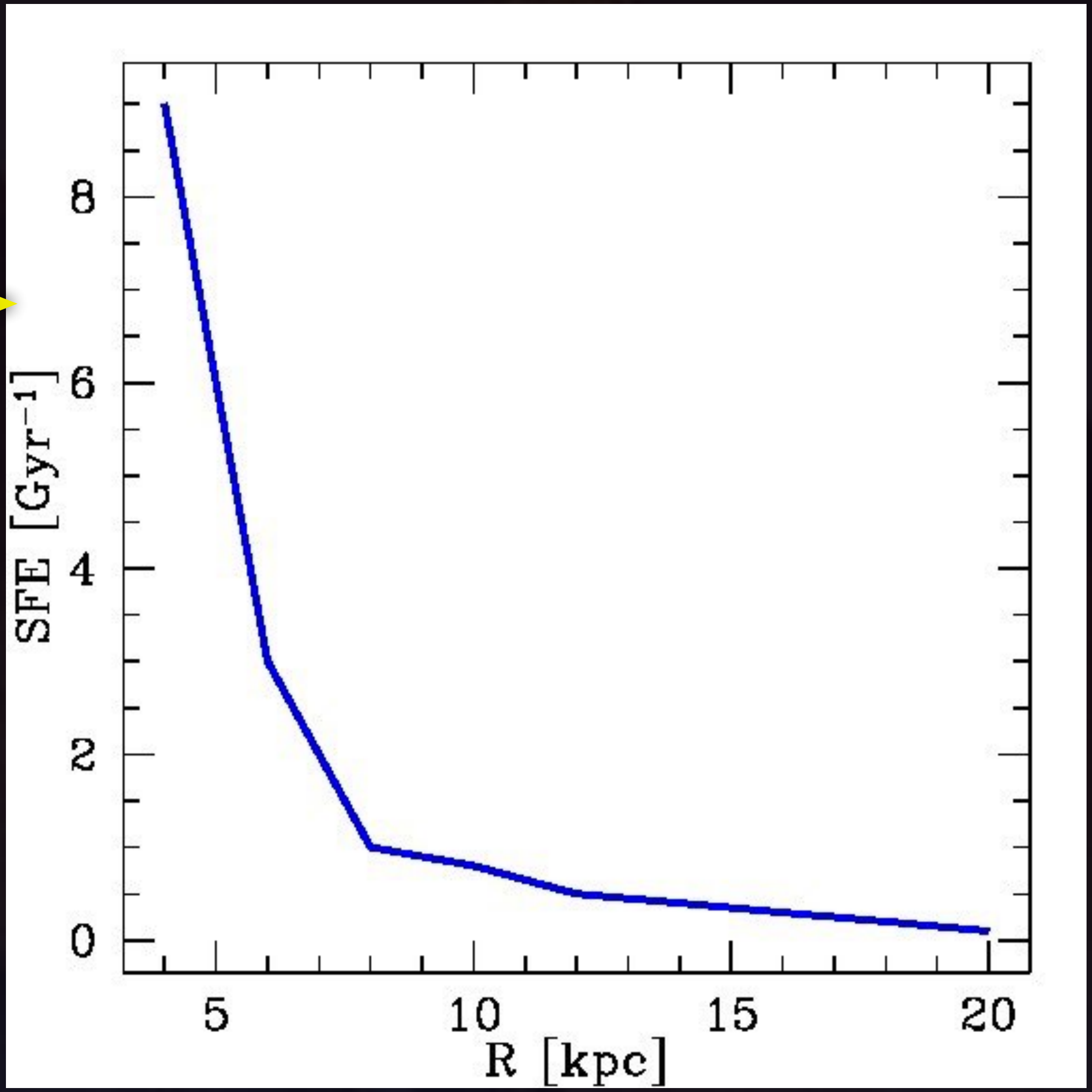


The chemical evolution model III

$$v_r \simeq -\frac{A(R,t)}{\sigma_g}\frac{(h_c - h_f)}{dh_c/dr}$$

For the MW

-1 km/s at 10 kpc

Lacey & Fall (1985)

Radial inflows of gas as a consequence of the infall

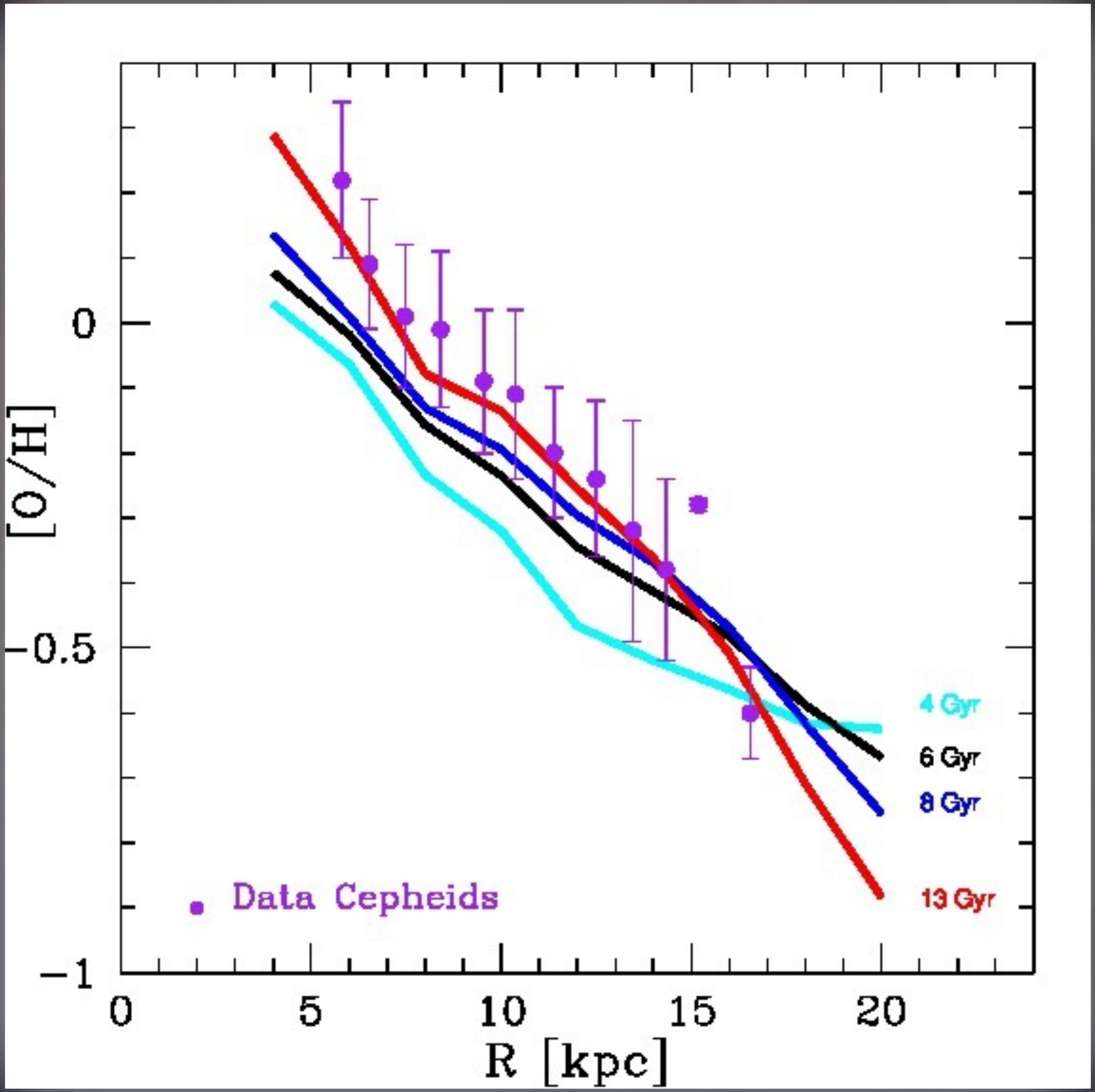
- In our reference model we implement a constant radial inflow of gas with velocity of -1 km/s following the prescriptions described in Spitoni & Matteucci (2011).

Model results without stellar migration

1

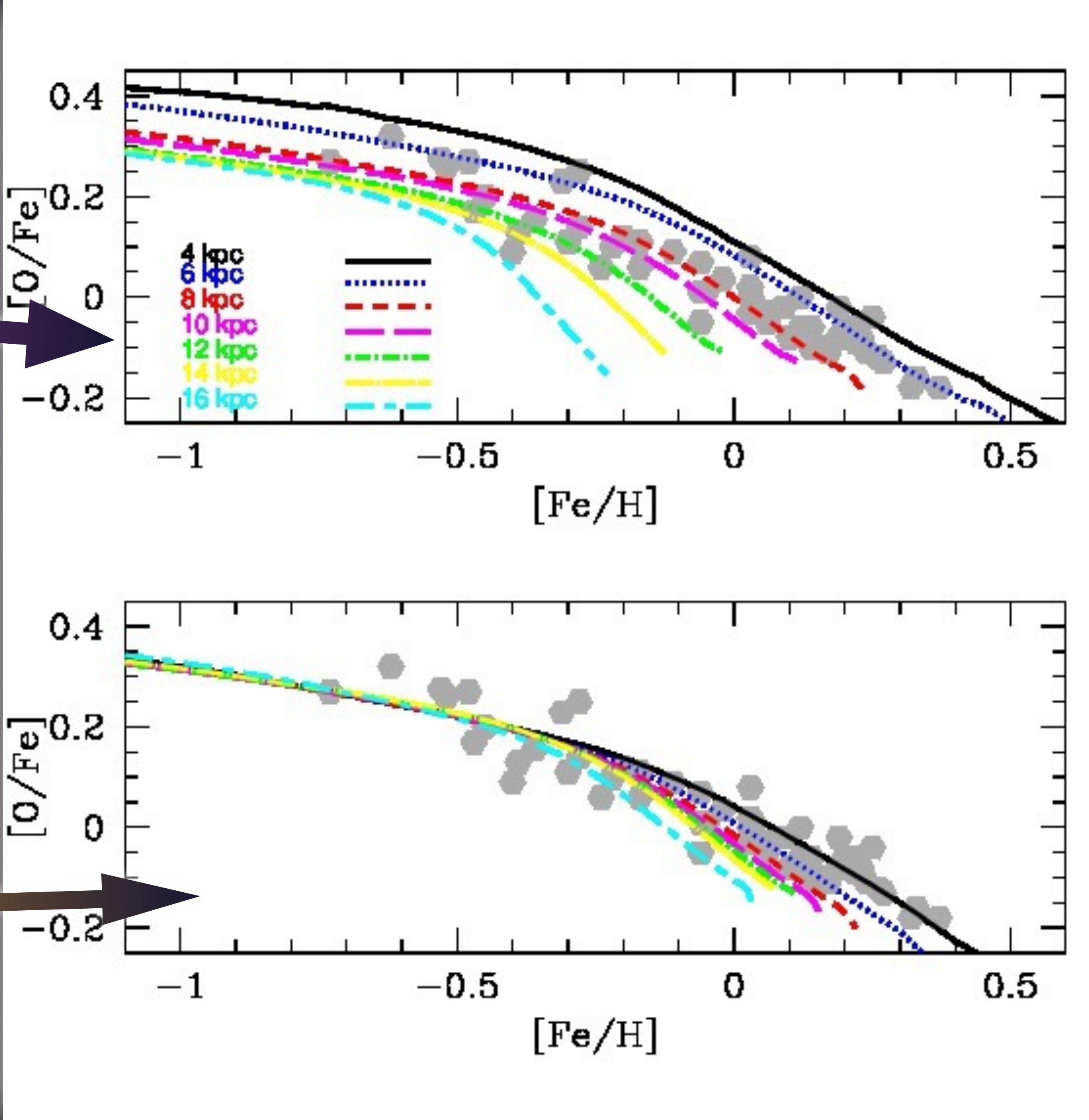
THE ABUNDANCE RADIANT

(data taken by Luck & Lambert 2011)



2

ASSUMING A VARIABLE STAR FORMATION EFFICIENCY



CONSTANT STAR FORMATION EFFICIENCY FIXED AT THE VALUE OF 1 Gyr^{-1}

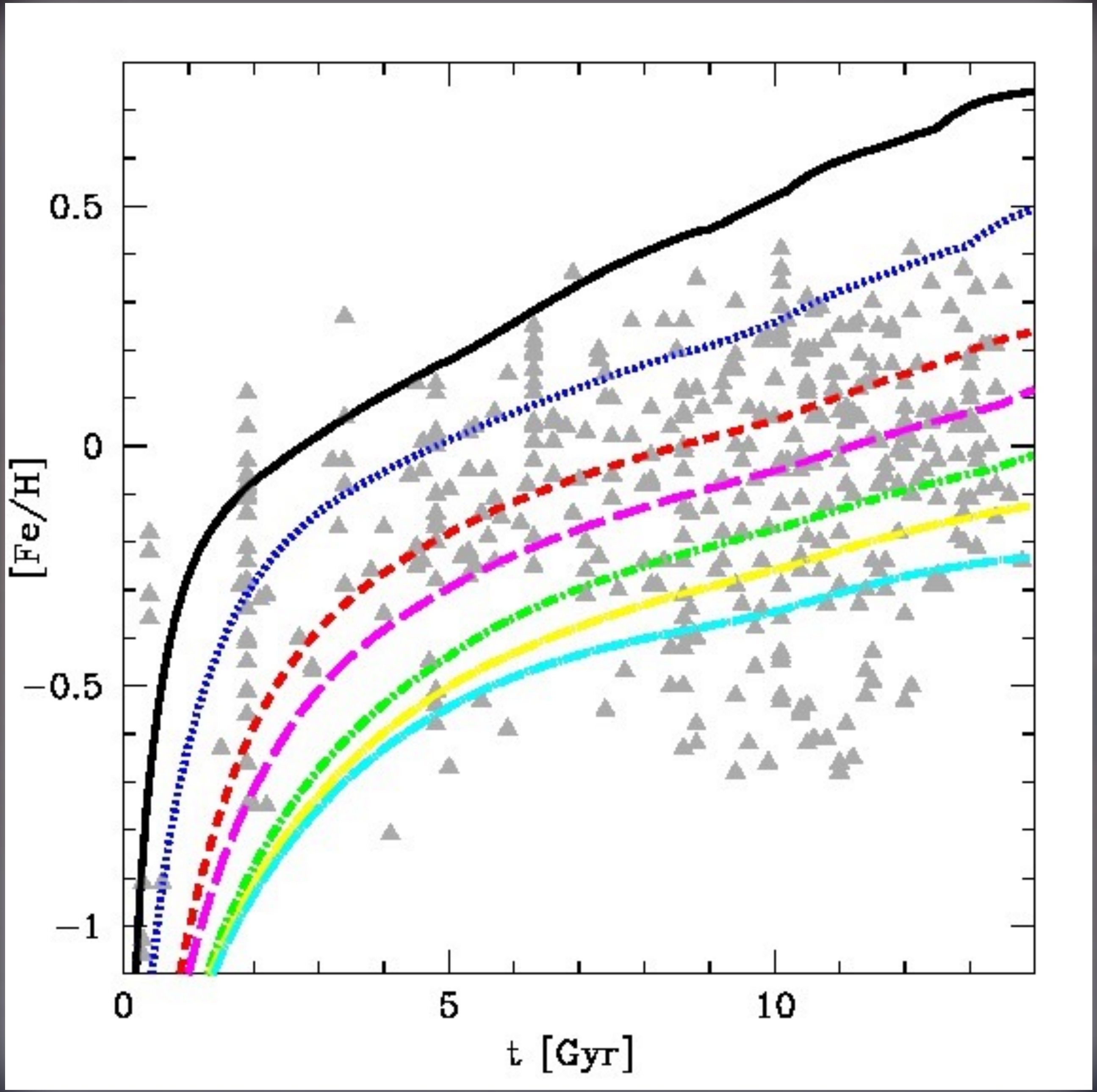
(data by Bensby et al. 2005)

The hypothesis of stellar migration as a solution for the observed spread requires necessarily a variable SFE.

The age-metallicity relation (data by Bensby et al. 2014)

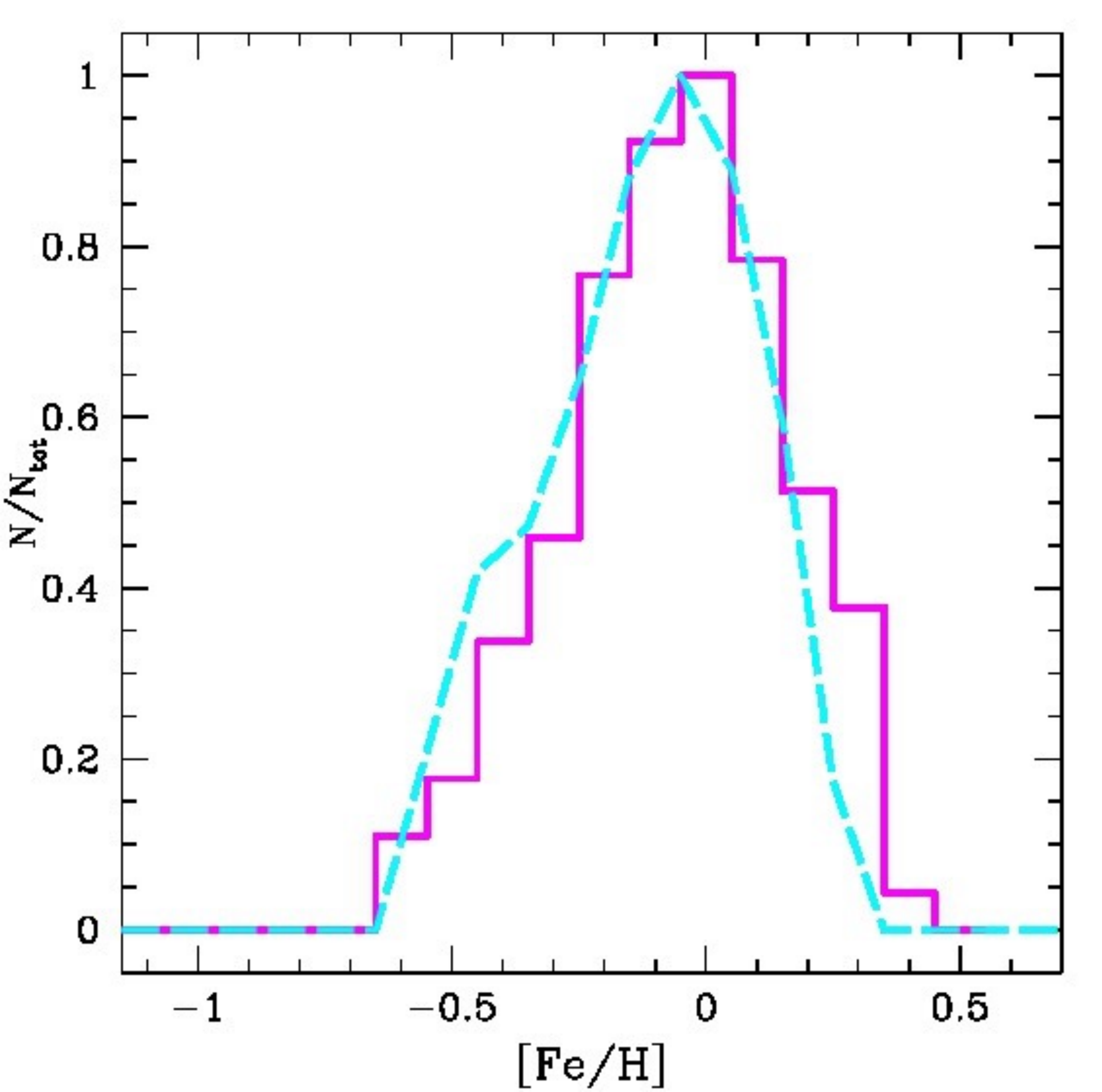
3

Other authors already claimed (e.g. Francois & Matteucci 1993; Schoenrich & Binney 2009) that the observed spread in the data can be explained with the migration of stars both from the inner and the outer regions, and we confirm their findings.



The G-dwarf distribution in the solar neighbourhood

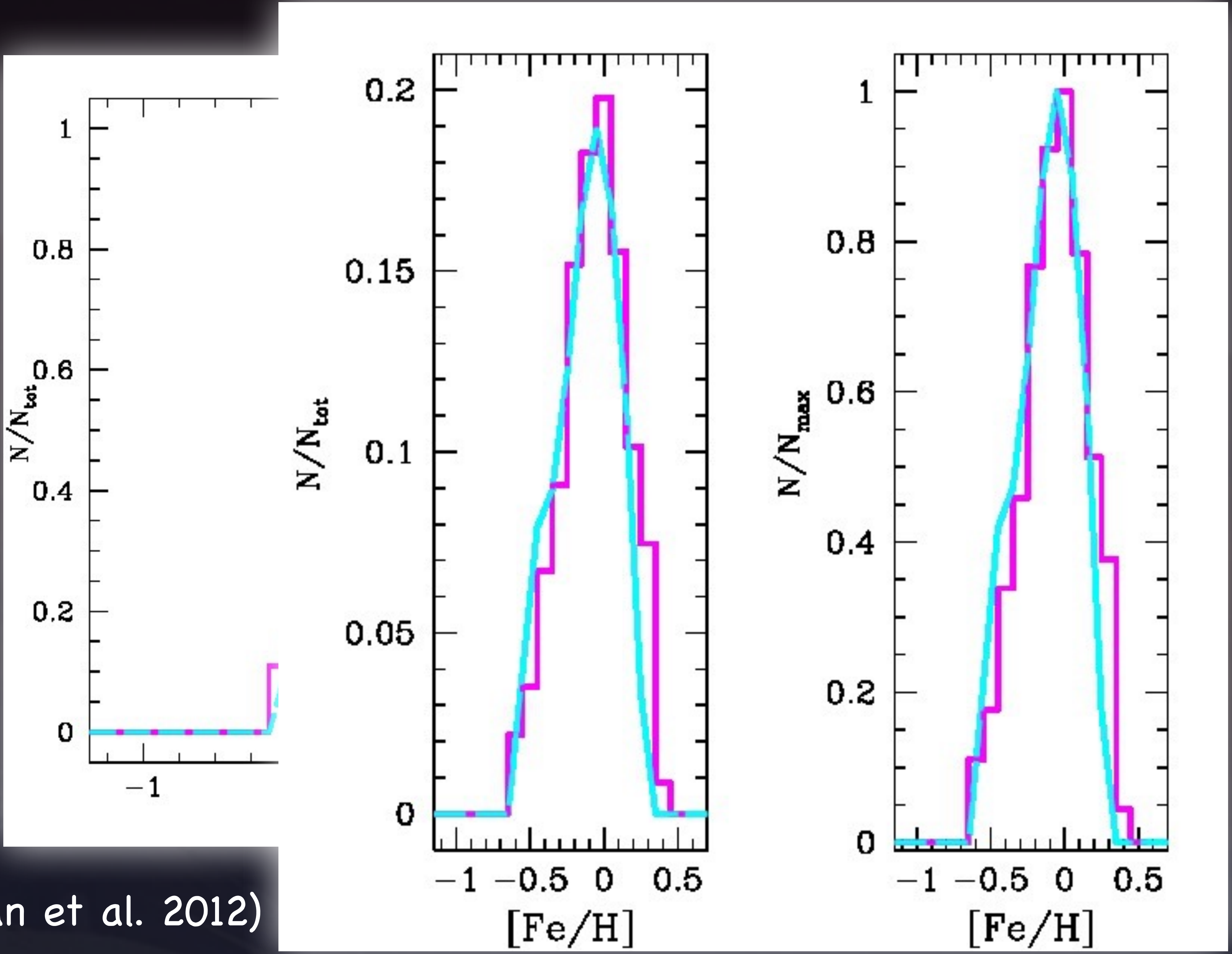
4



(data by Adibekyan et al. 2012)

The G-dwarf distribution in the solar neighbourhood

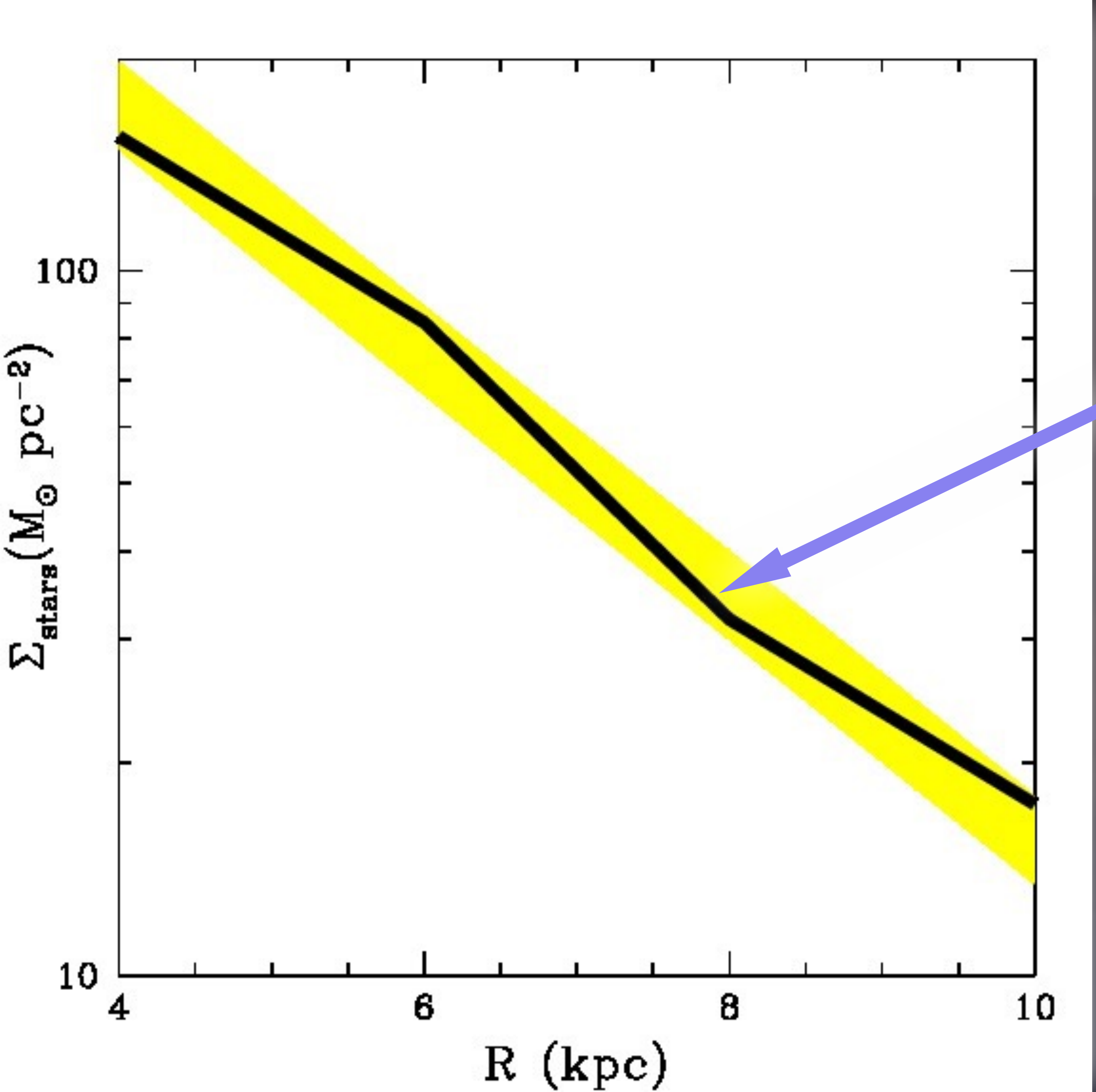
④



(data by Adibekyan et al. 2012)

The surface stellar density

5

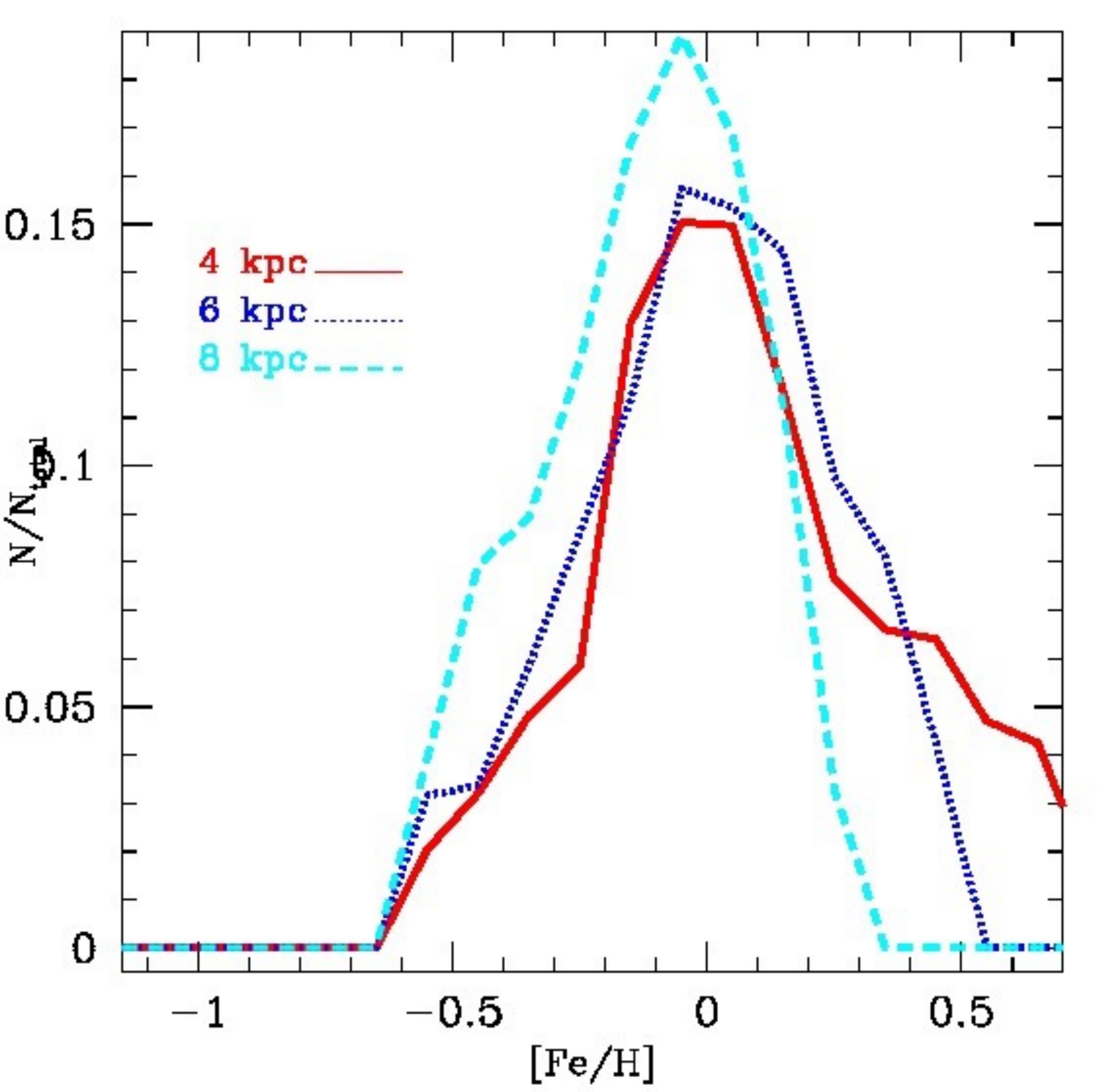


Reference model with
i) a variable SFE
ii) radial gas flow

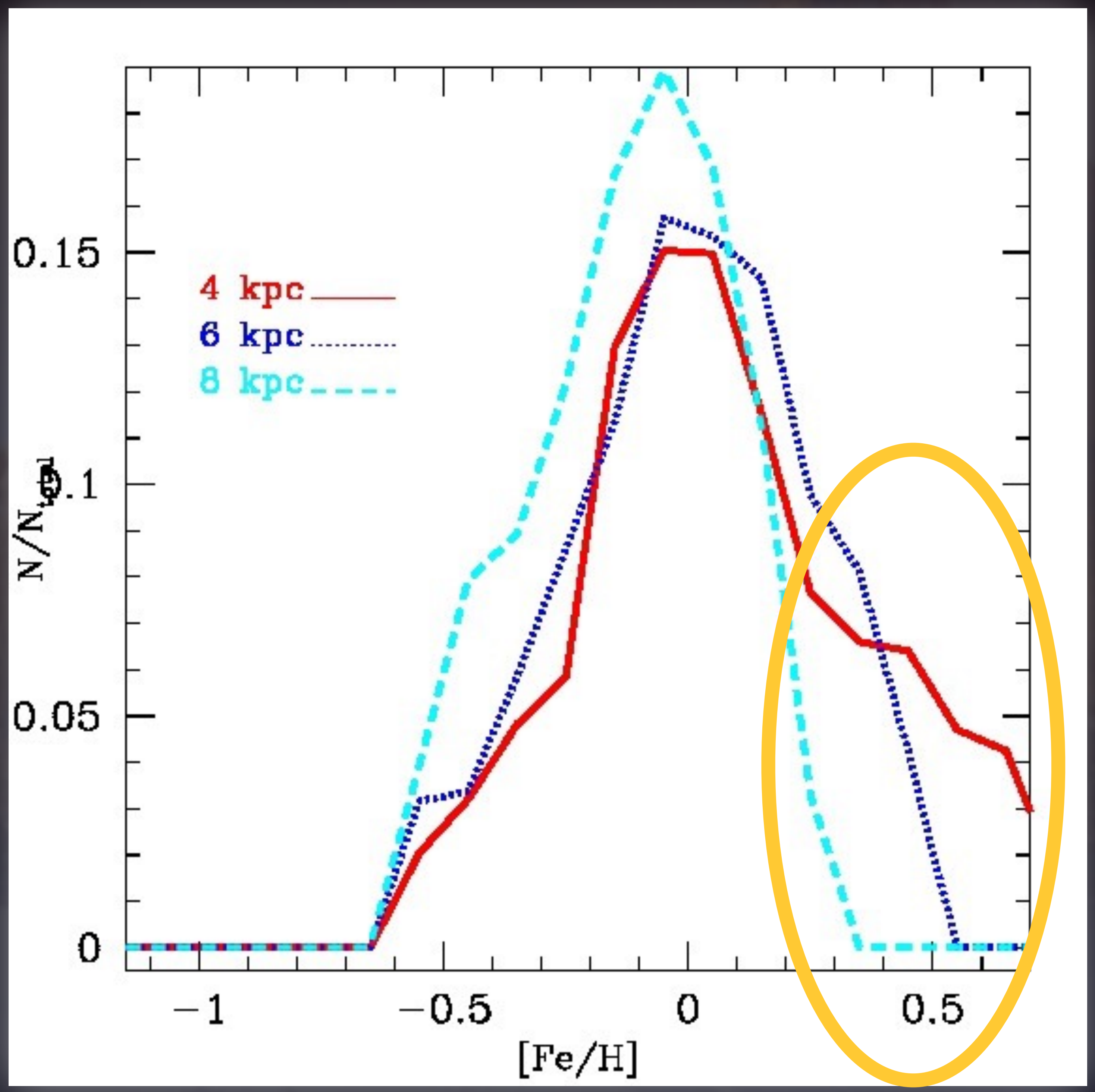
iii) NO stellar migration

DATA BY CHIAPPINI ET AL. (2001)

The G-dwarf distribution computed at 4, 6, 8 kpc



The G-dwarf distribution computed at 4, 6, 8 kpc



Prominent high metallicity tails for the G-dwarf metallicity distributions computed at 4 and 6 kpc

Including the stellar migration following a heuristic approach

- We simply move stars formed at a given radius with a certain age and with a certain metal content, to the solar vicinity following some simple rule. Following the work of Kordopatis et al. (2013), we assume as a representative value for the velocity of the stars 1 km/s^{-1}, that is $\simeq$ 1 kpc/Gyr^{-1}. To explore the velocity parameter space we also consider the cases with stellar velocities fixed at the values of 0.5 and 2 km/s^{-1}

Models	Radial gas inflow	Stellar migration	Stellar velocity
realistic case	1 km/s	10% from 4 kpc 20% from 6 kpc 60% from 8 kpc	0.5, 1, 2 km/s
extreme case 1	1 km/s	10% from 4 kpc 20% from 6 kpc NO STARS from 8 kpc	0.5, 1, 2 km/s
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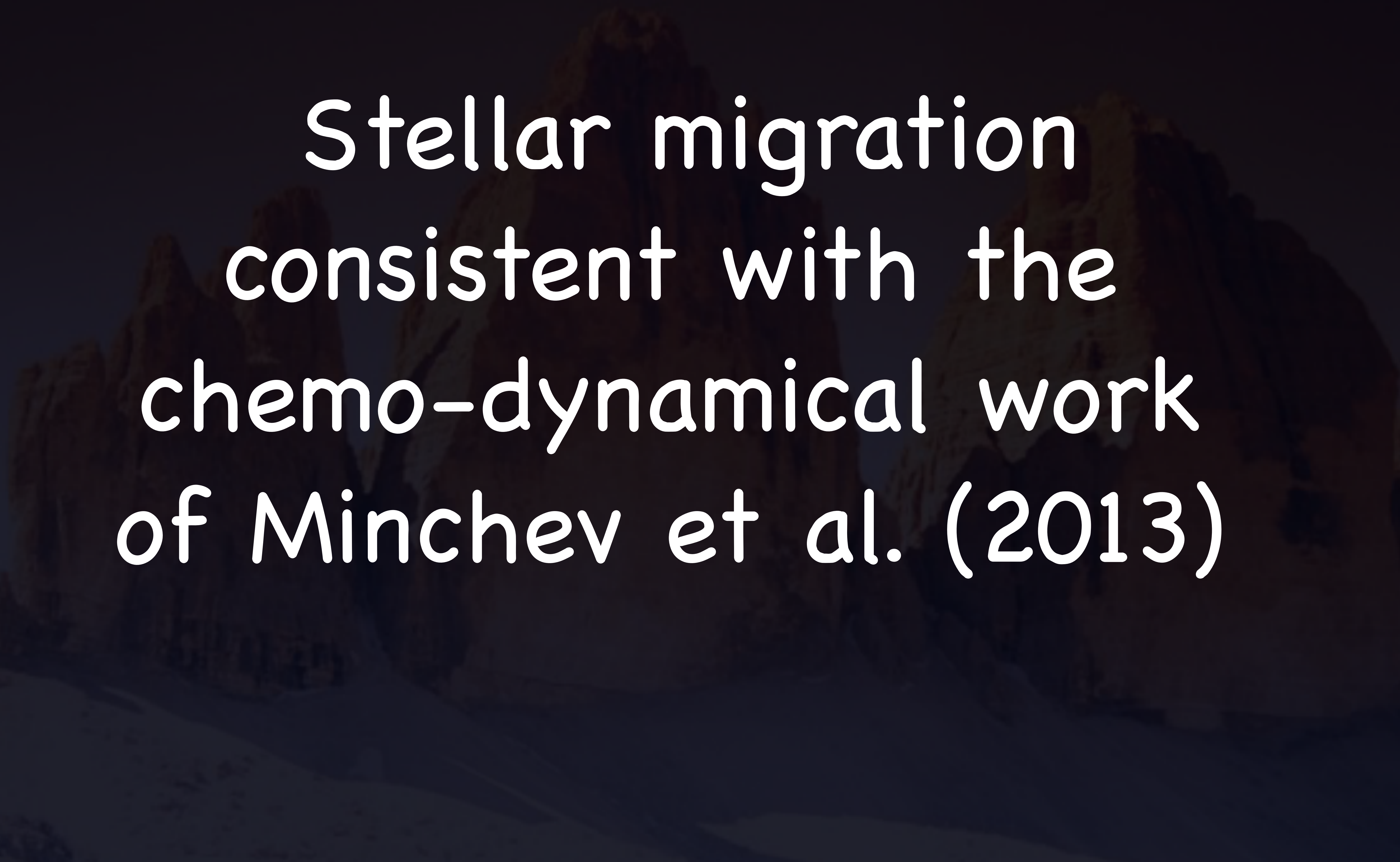

Stellar migration consistent with the chemo-dynamical work of Minchev et al. (2013)

Models	Radial gas inflow	Stellar migration	Stellar velocity
realistic case	1 km/s	10% from 4 kpc 20% from 6 kpc 60% from 8 kpc	0.5, 1, 2 km/s
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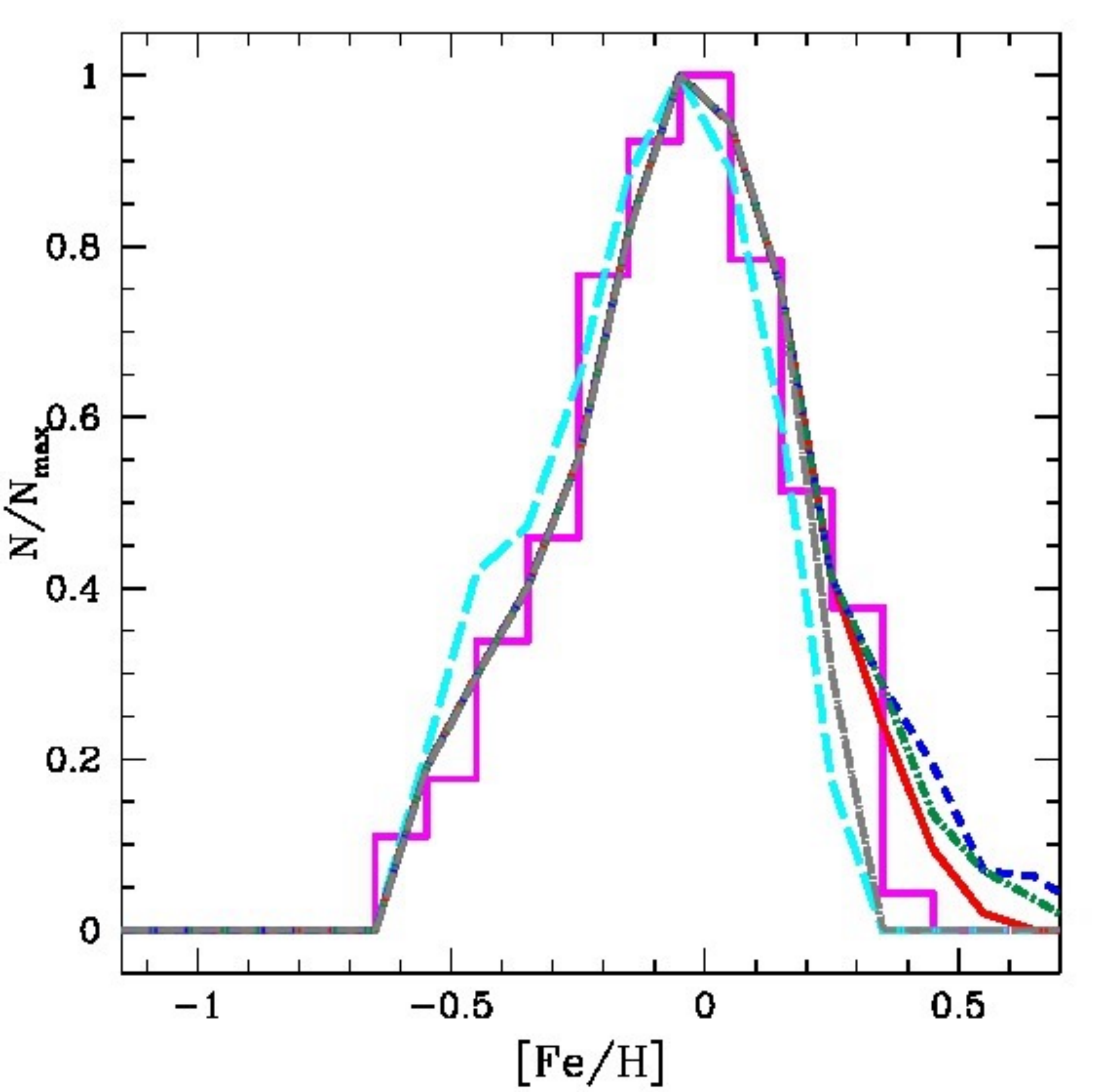
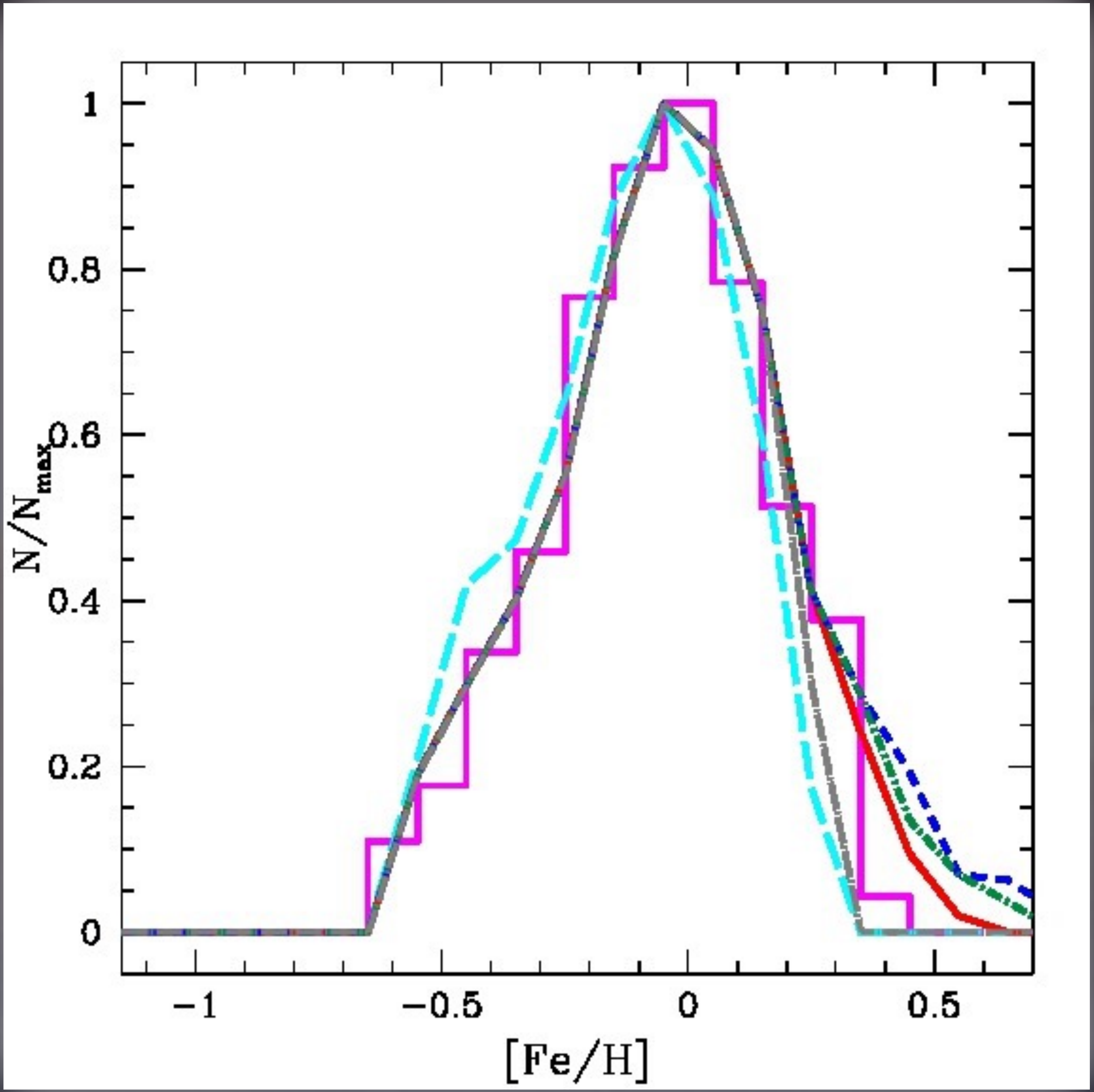
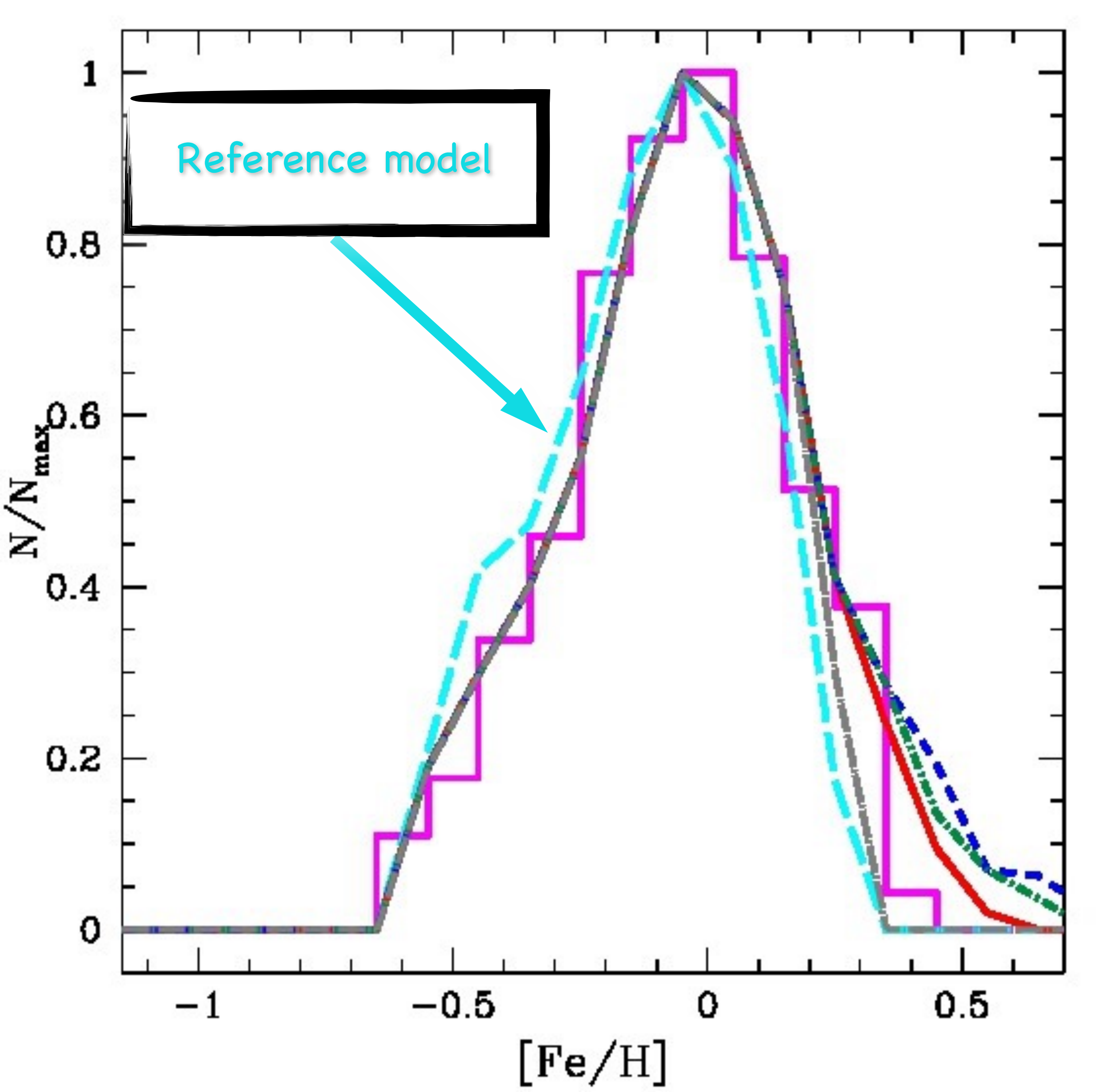
The G-dwarf distribution for the model with a stellar migration compatible with the Minchev et al (2013) results

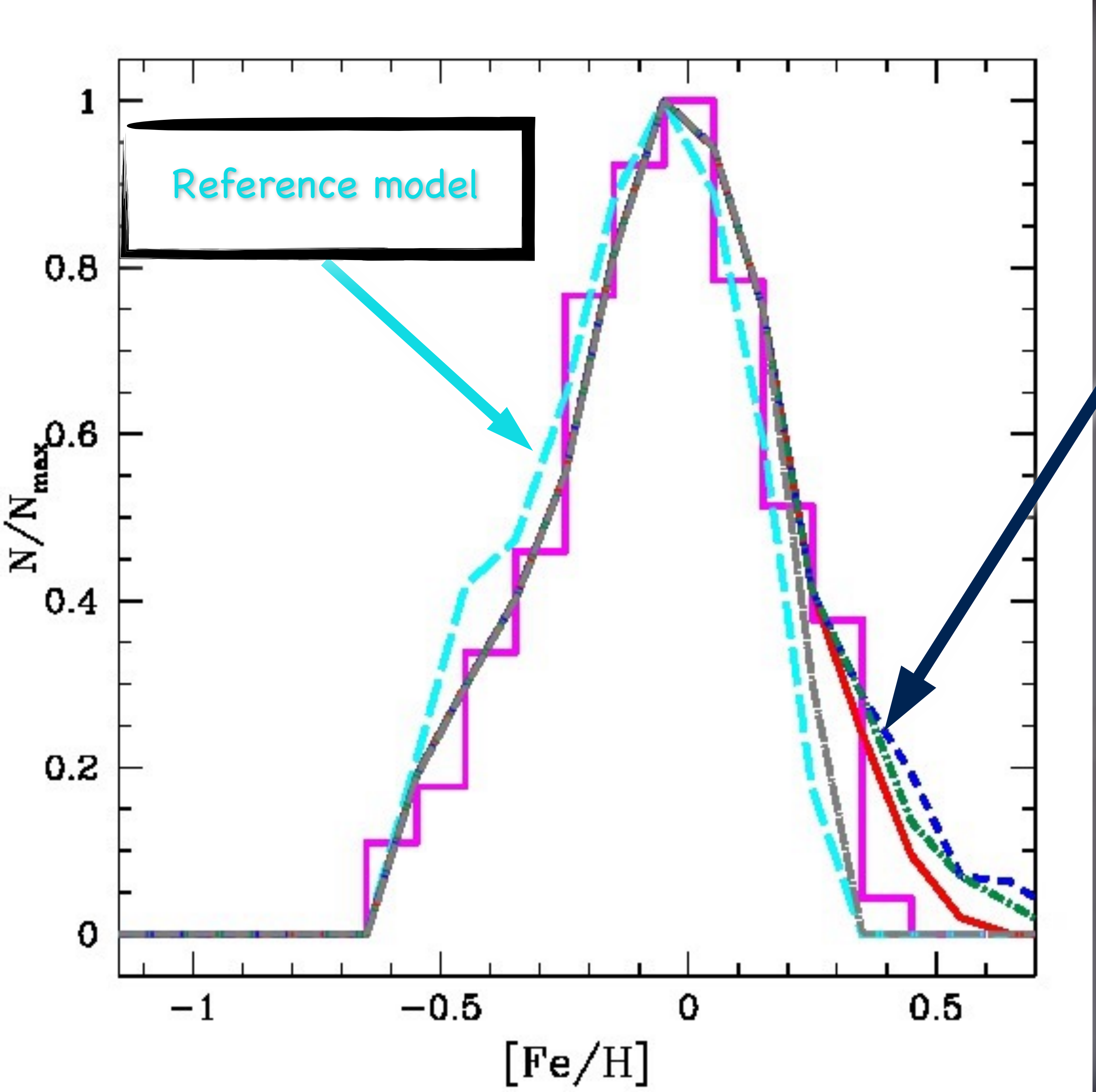


realistic case

10% from 4 kpc
20% from 6 kpc
60% from 8 kpc

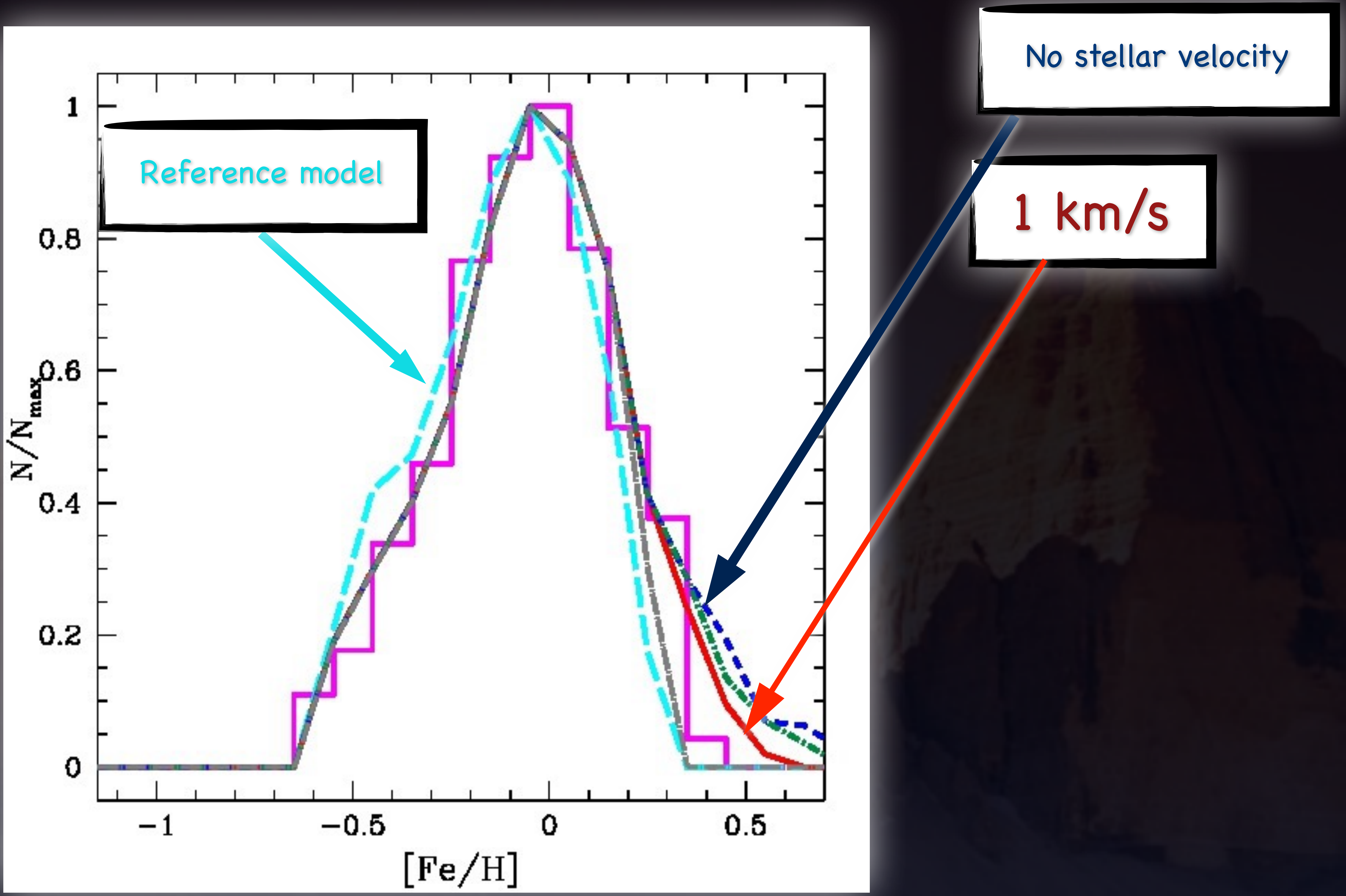

1
0.8
0.6
0.4
0.2
0
N/N_{max}
−1
−0.5
0
0.5
[Fe/H]


Reference model
1
0.8
0.6
0.4
0.2
0
N/N_max
−1
−0.5
0
0.5
[Fe/H]



Reference model

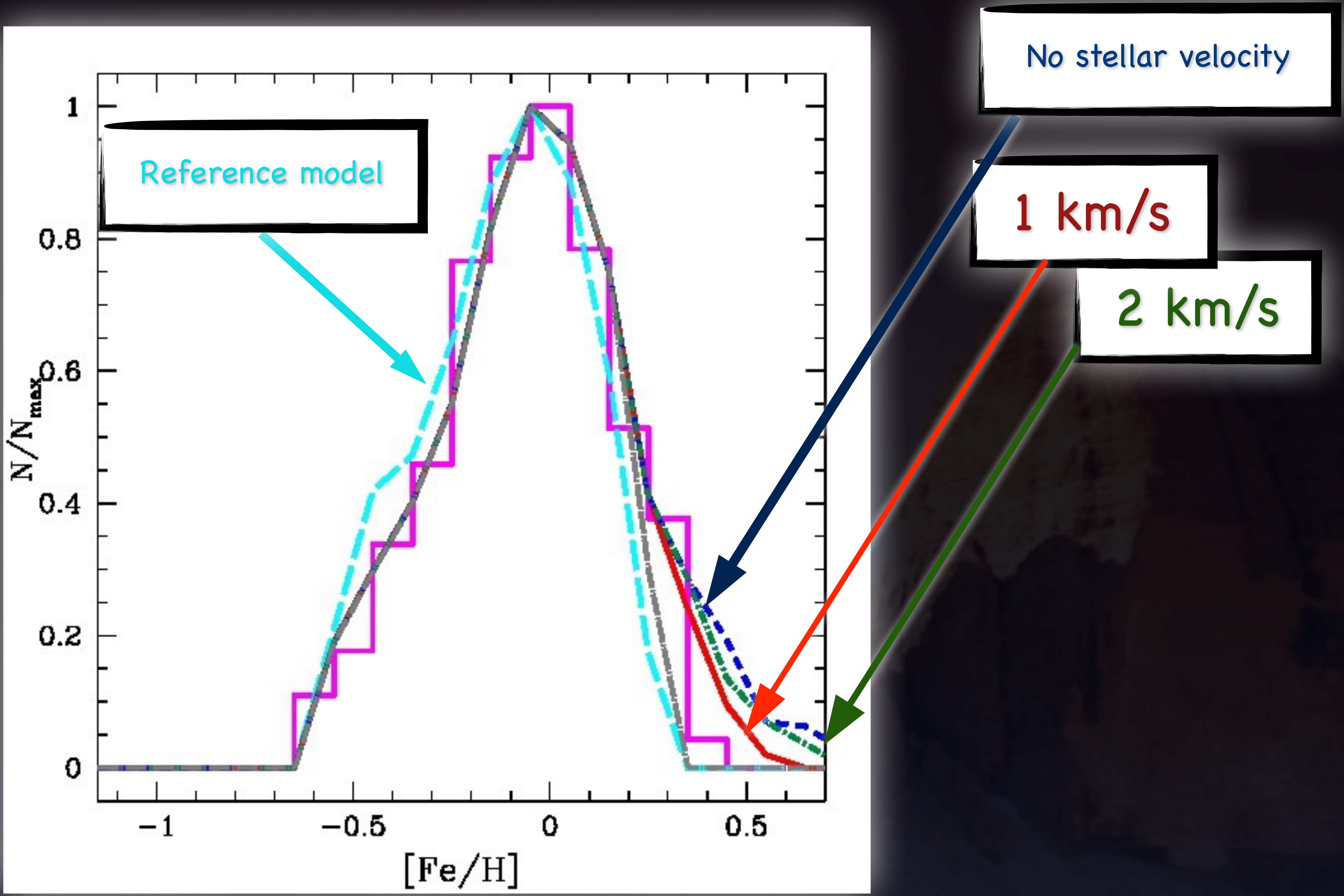
No stellar velocity



Reference model

No stellar velocity

1 km/s

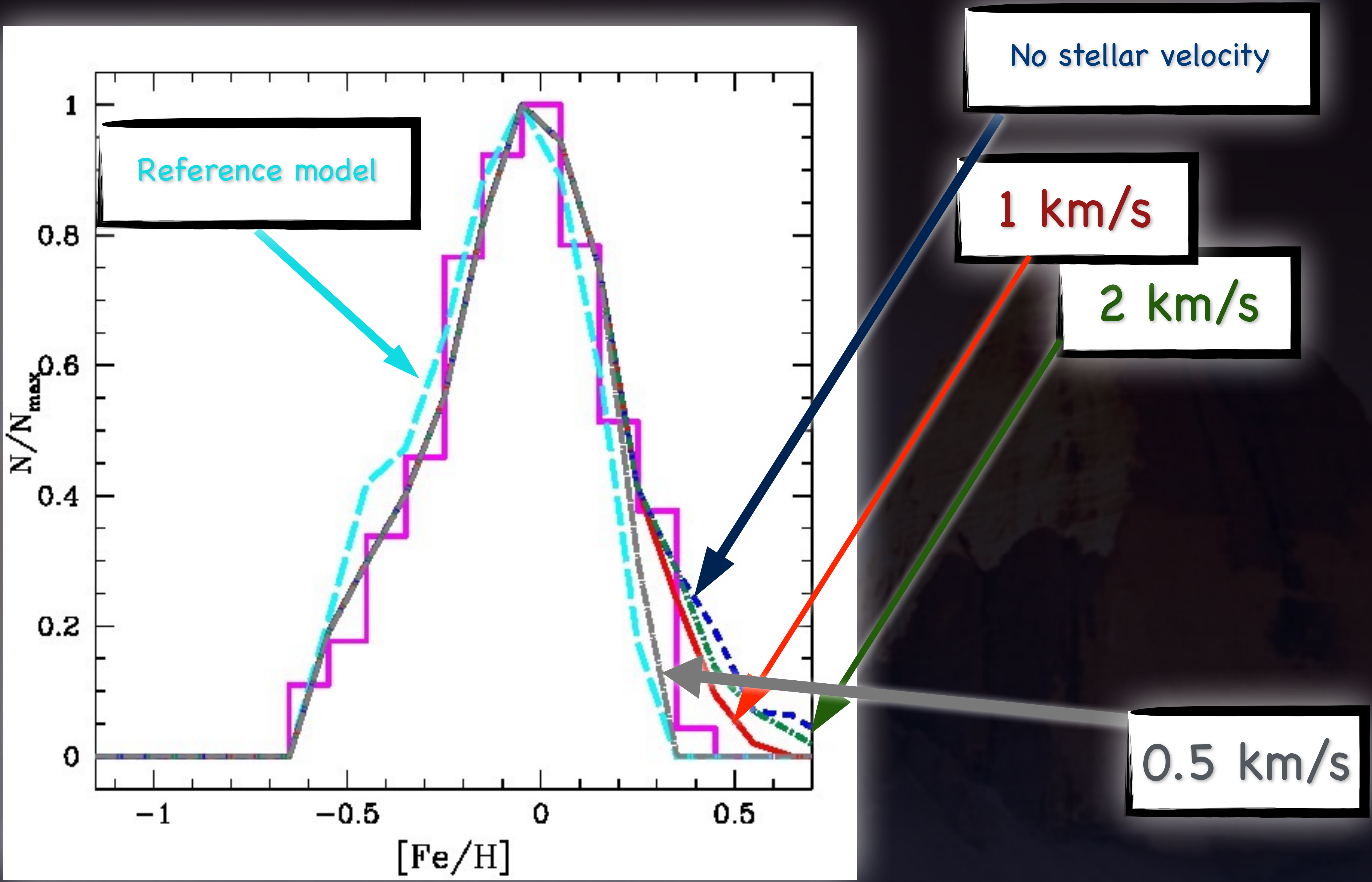


Reference model

No stellar velocity

1 km/s

2 km/s



Reference model

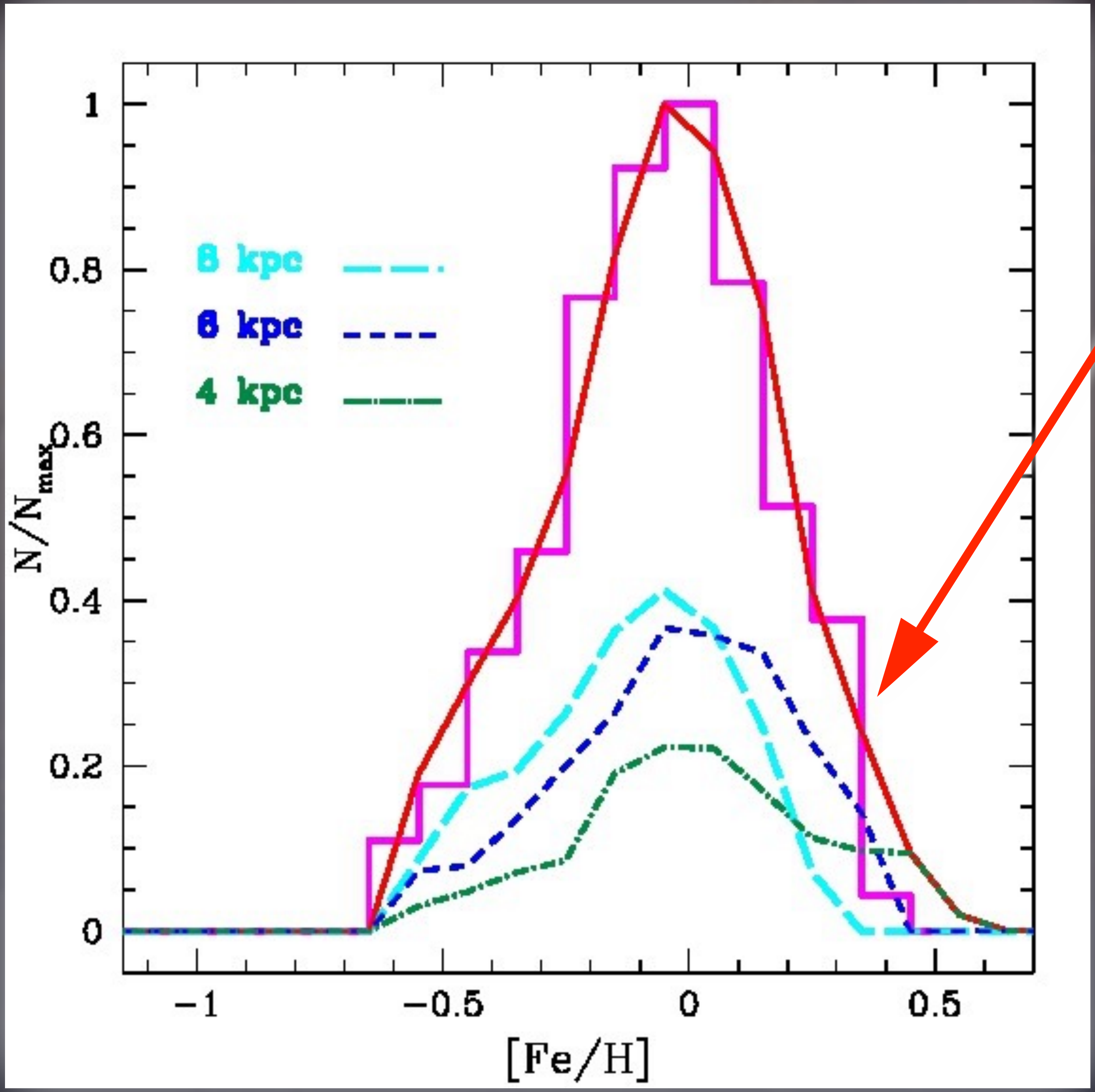
No stellar velocity

1 km/s

2 km/s

0.5 km/s

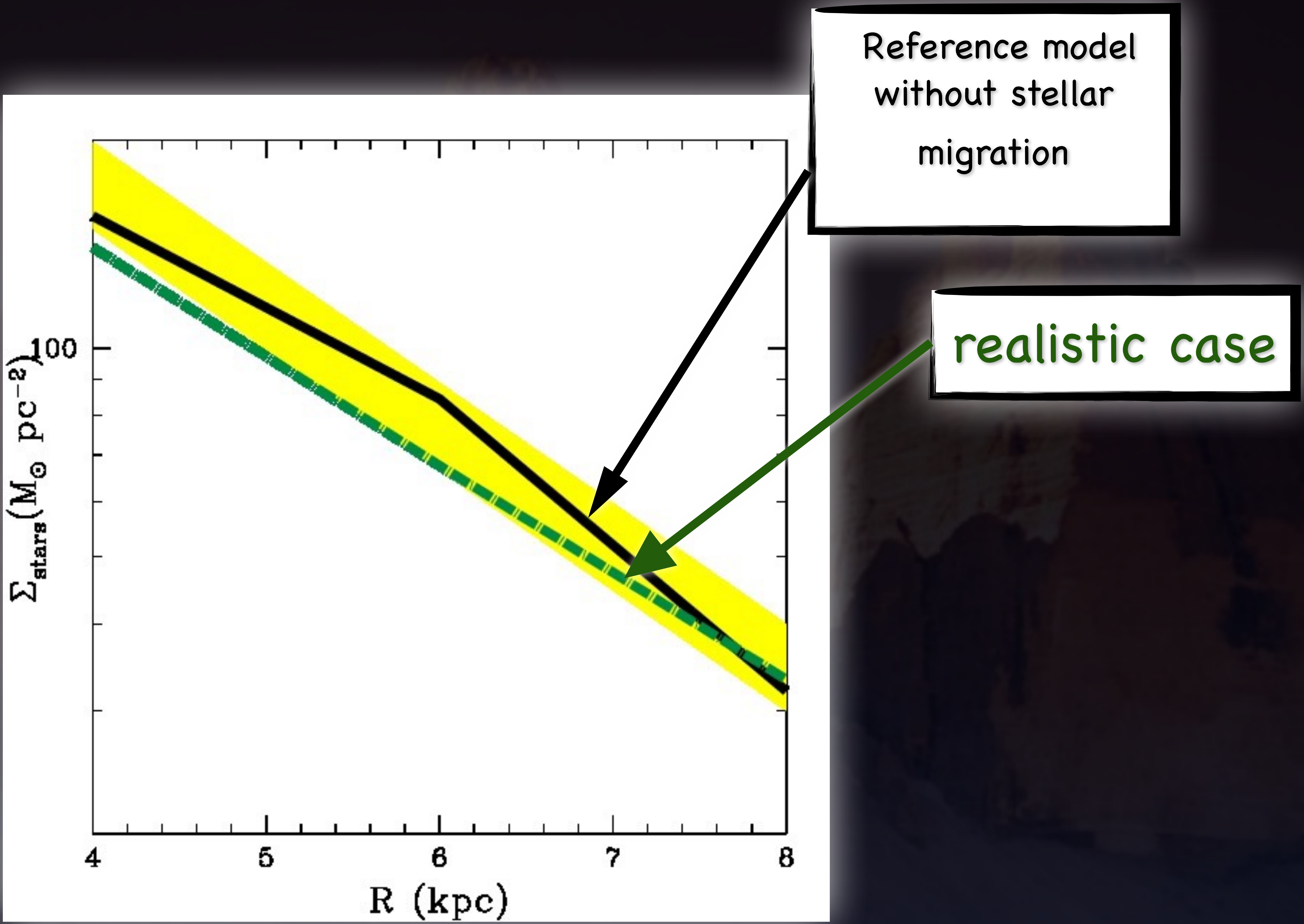
Contribution of the stars born at 4 kpc, 6 kpc which end up in the solar neighborhood as well as the ones born in situ at 8 kpc.



1 km/s

Our model is entirely consistent with Minchev et al. (2013) results in terms of the G-dwarf metallicity distribution

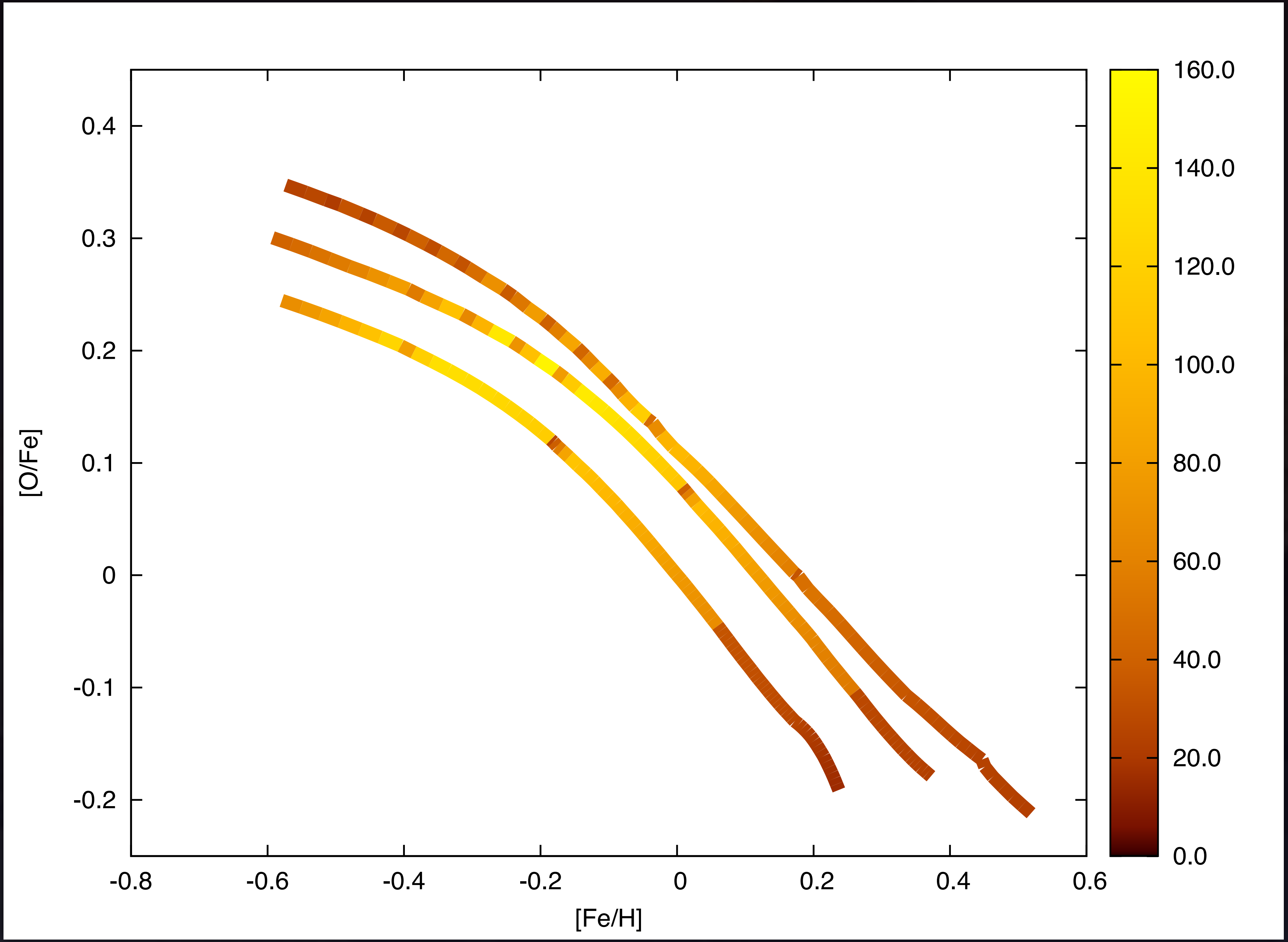
The surface stellar density



Reference model without stellar migration

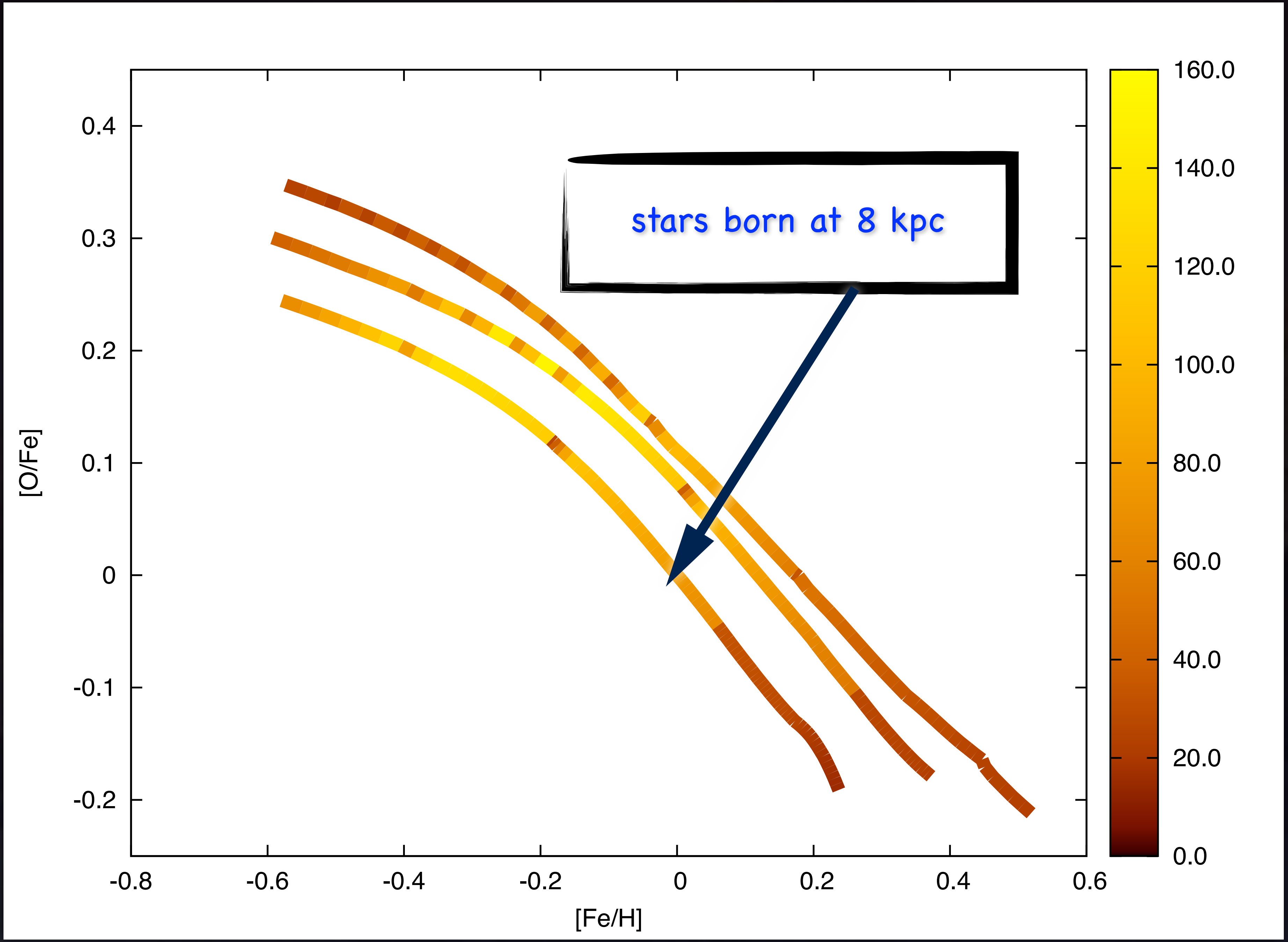
realistic case

[O/Fe] vs [Fe/H] in the solar neighbourhood (Minchev case + stellar velocity 1 km/s)



10^6 STARS

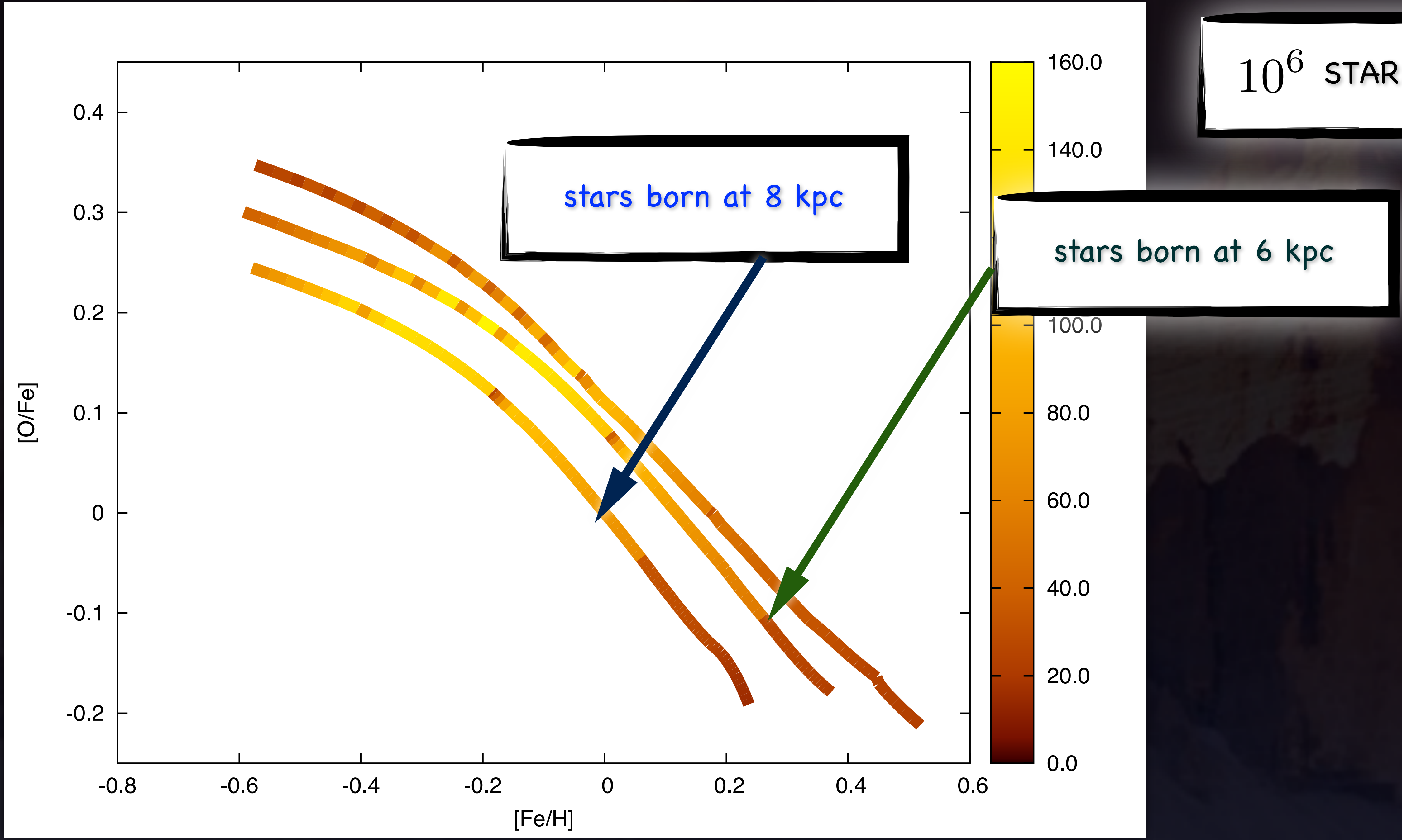
[O/Fe] vs [Fe/H] in the solar neighbourhood (Minchev case + stellar velocity 1 km/s)



stars born at 8 kpc

10^6 STARS

[O/Fe] vs [Fe/H] in the solar neighbourhood (Minchev case + stellar velocity 1 km/s)

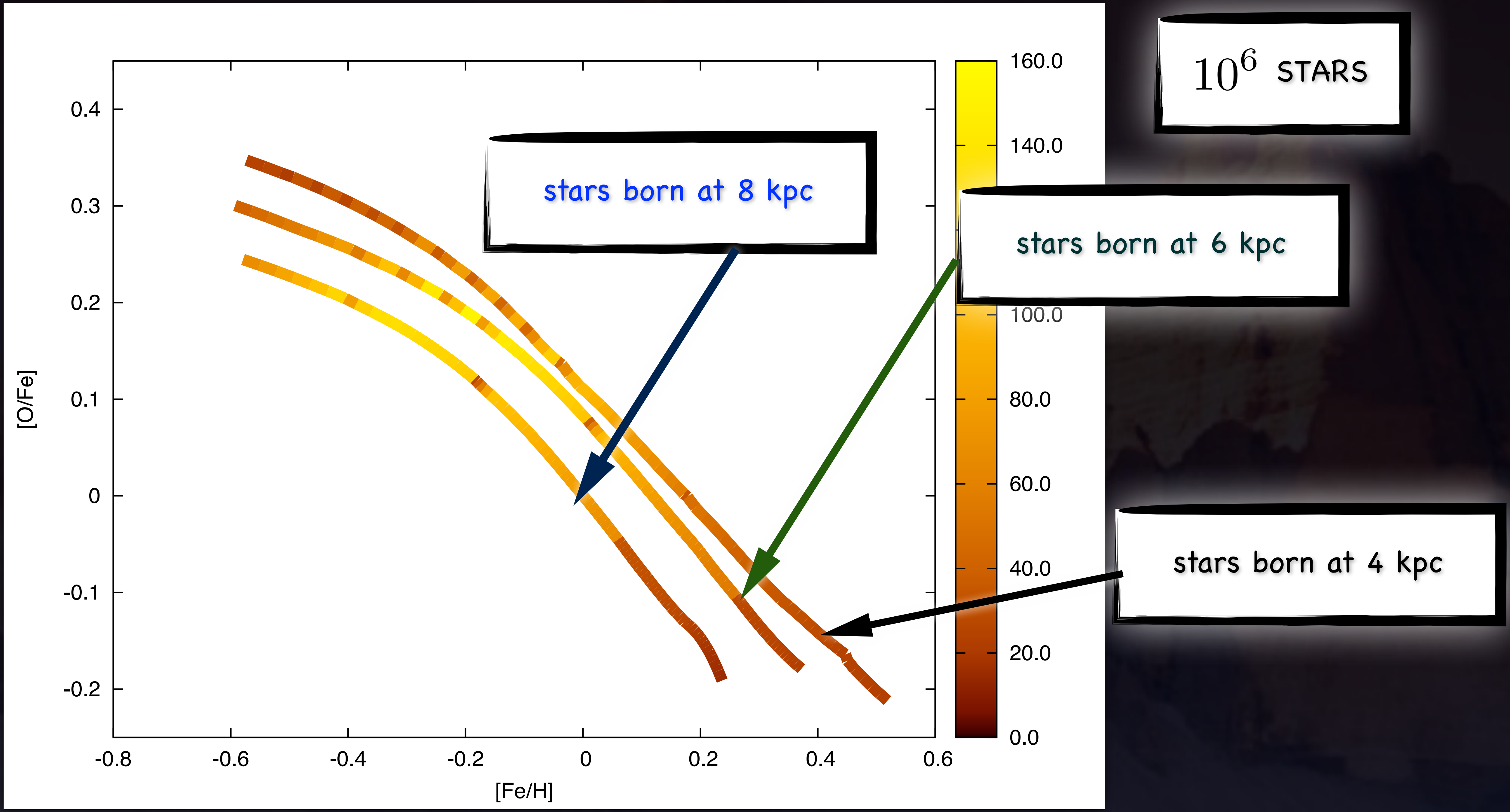


stars born at 8 kpc

stars born at 6 kpc

10^6 STARS

[O/Fe] vs [Fe/H] in the solar neighbourhood (Minchev case + stellar velocity 1 km/s)



10^6 STARS

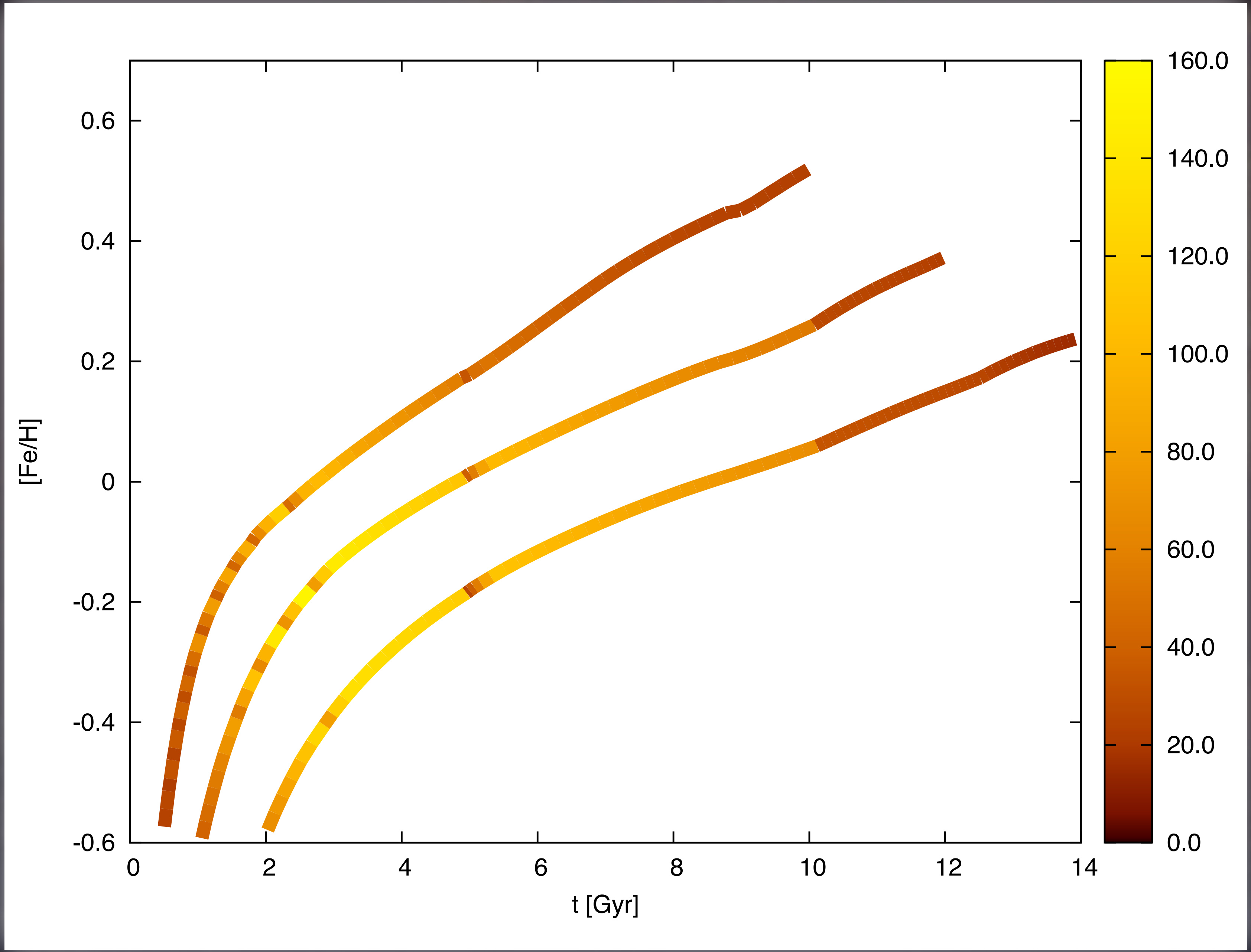
stars born at 8 kpc

stars born at 6 kpc

stars born at 4 kpc

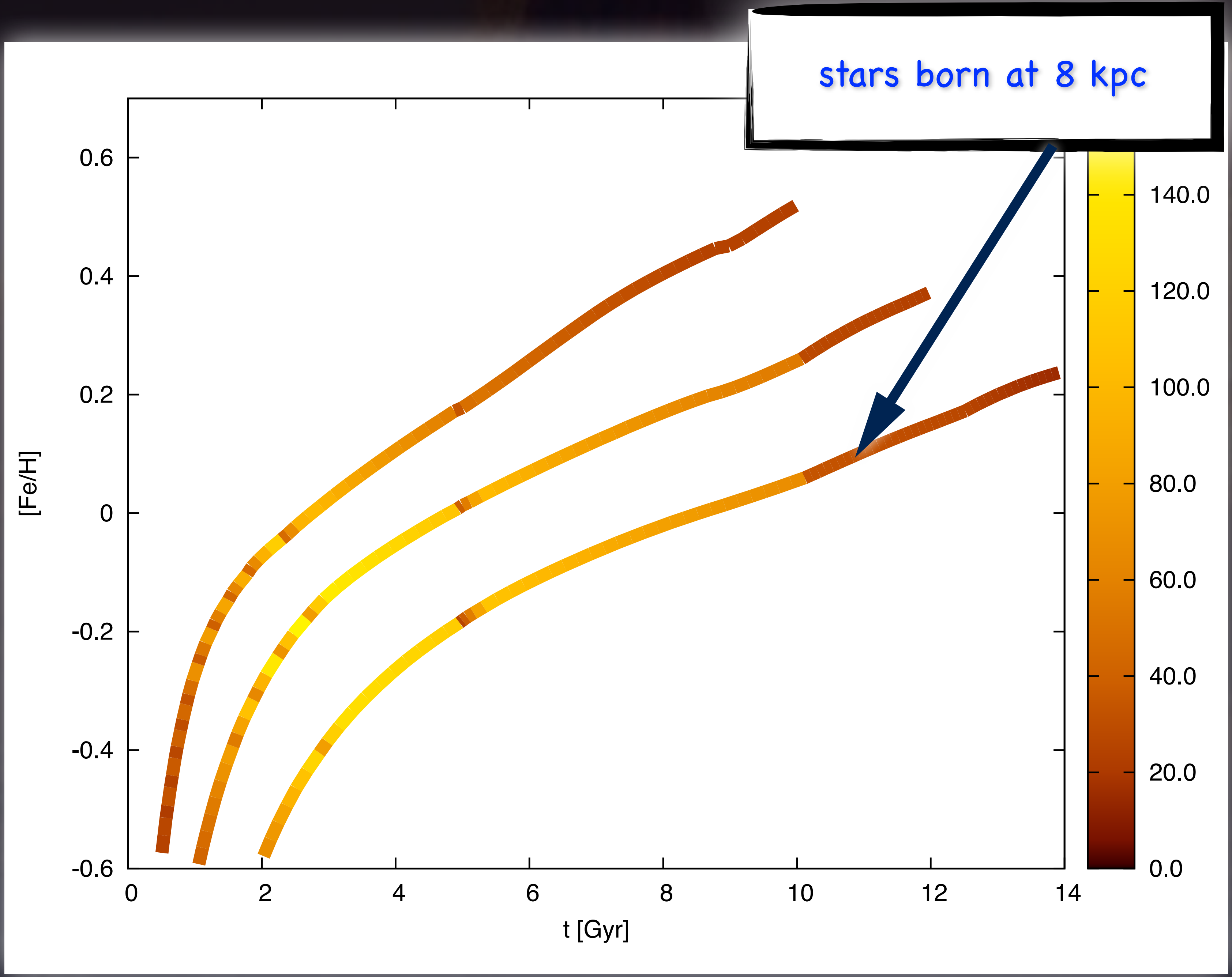
Age-metallicity relation in the solar neighborhood (Minchev case + stellar velocity 1 km/s)

10^6 STARS



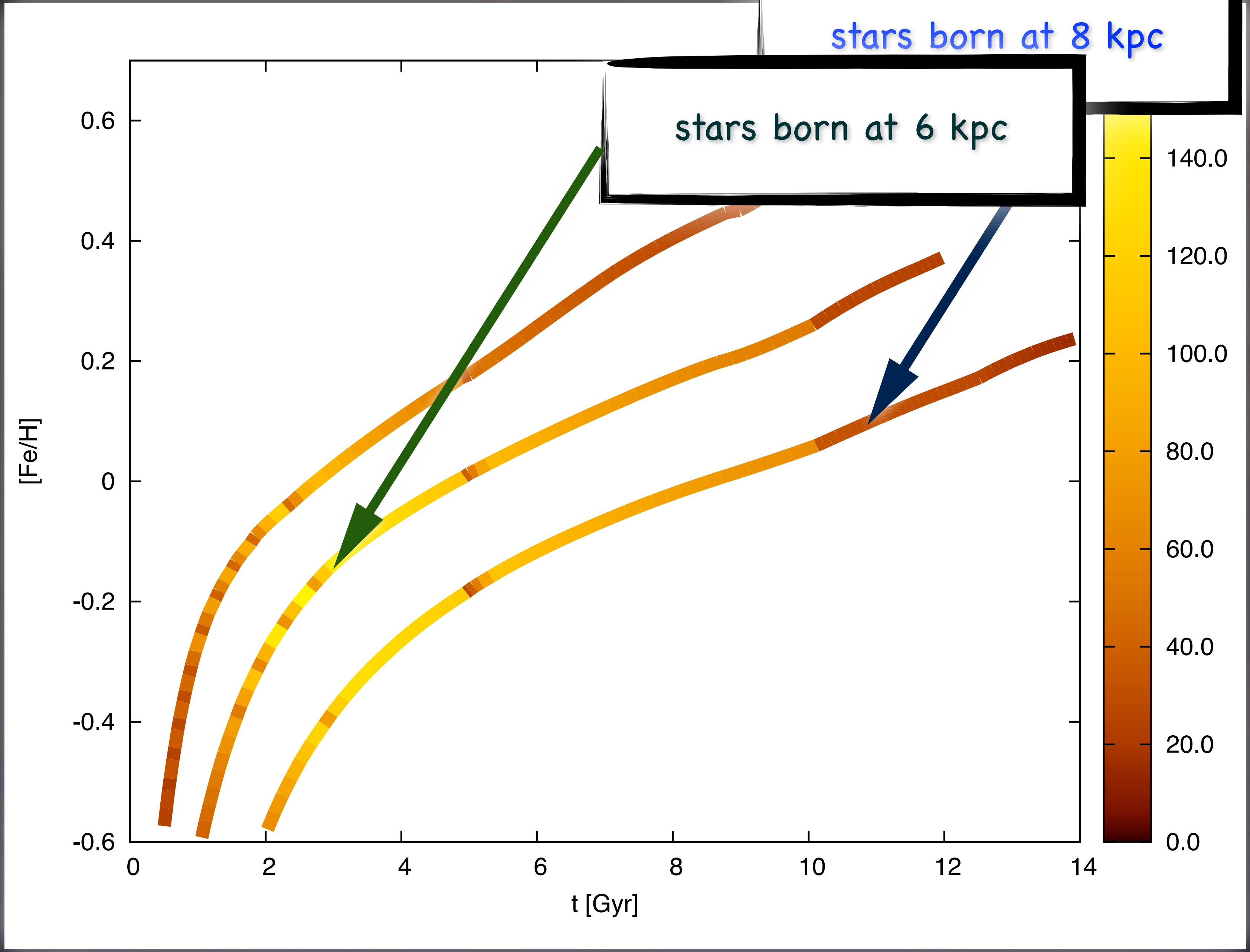
Age-metallicity relation in the solar neighborhood (Minchev case + stellar velocity 1 km/s)

10^6 STARS


stars born at 8 kpc

Age-metallicity relation in the solar neighborhood (Minchev case + stellar velocity 1 km/s)

10^6 STARS

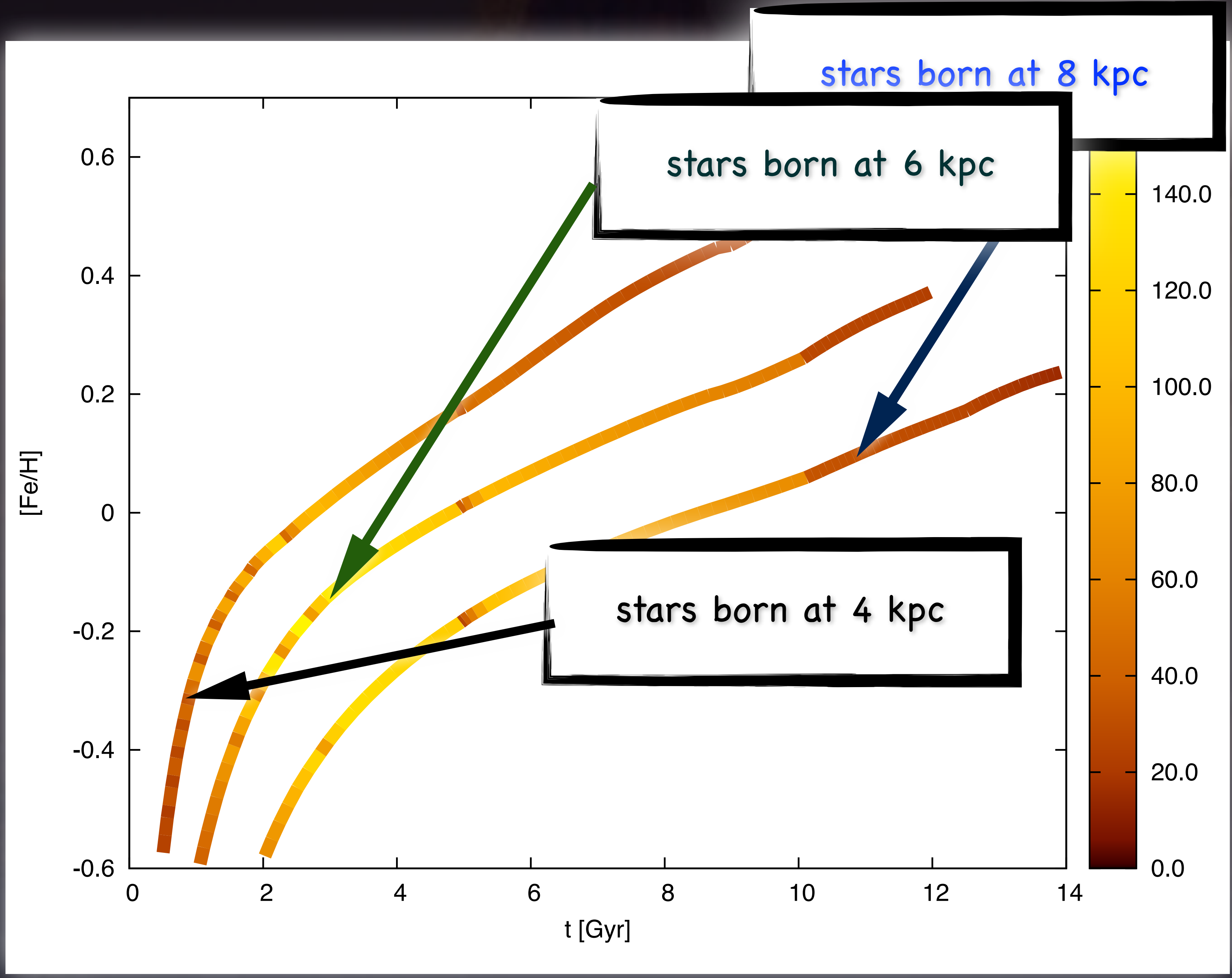


stars born at 8 kpc

stars born at 6 kpc

Age-metallicity relation in the solar neighborhood (Minchev case + stellar velocity 1 km/s)

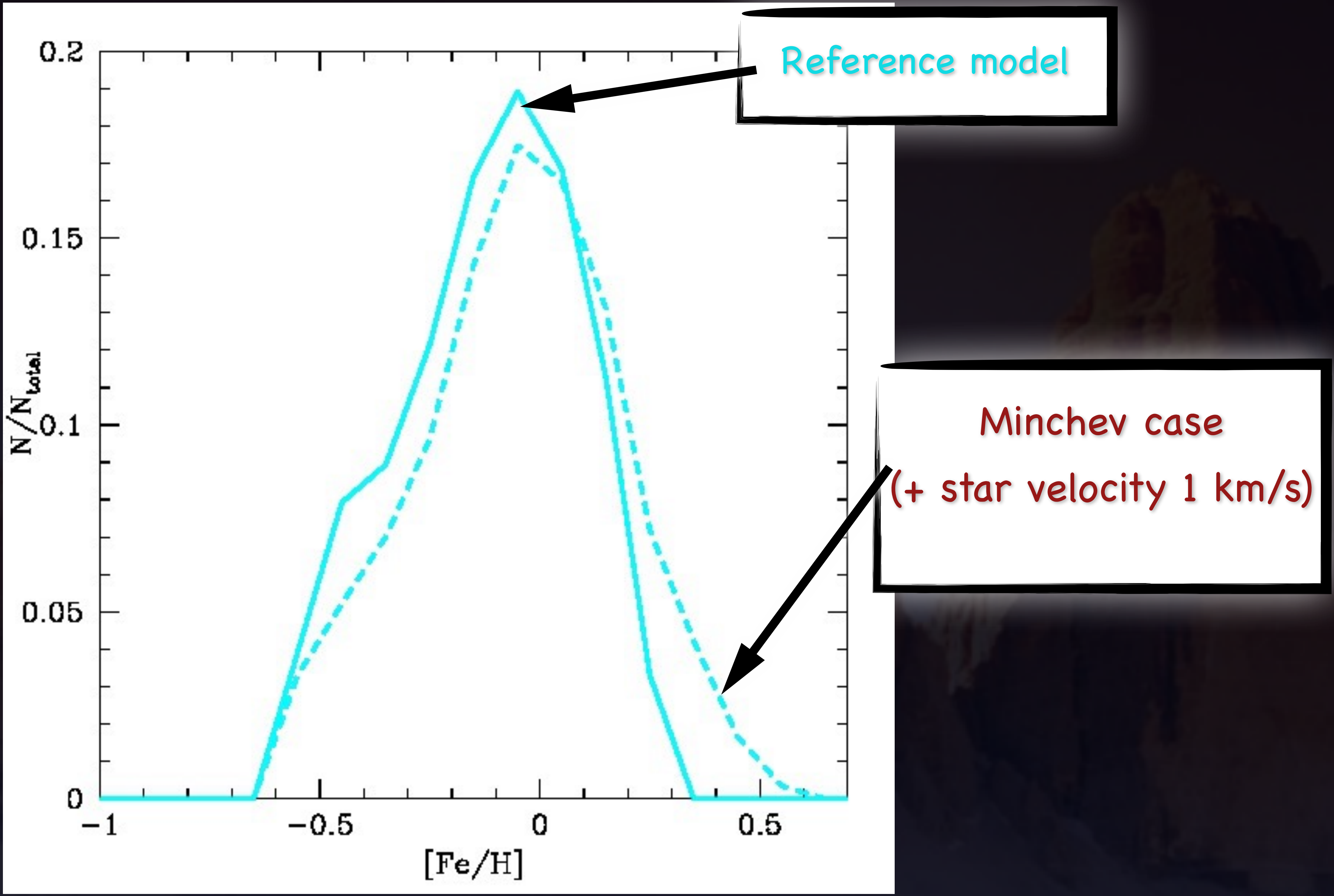
10^6 STARS



stars born at 8 kpc

stars born at 6 kpc

stars born at 4 kpc

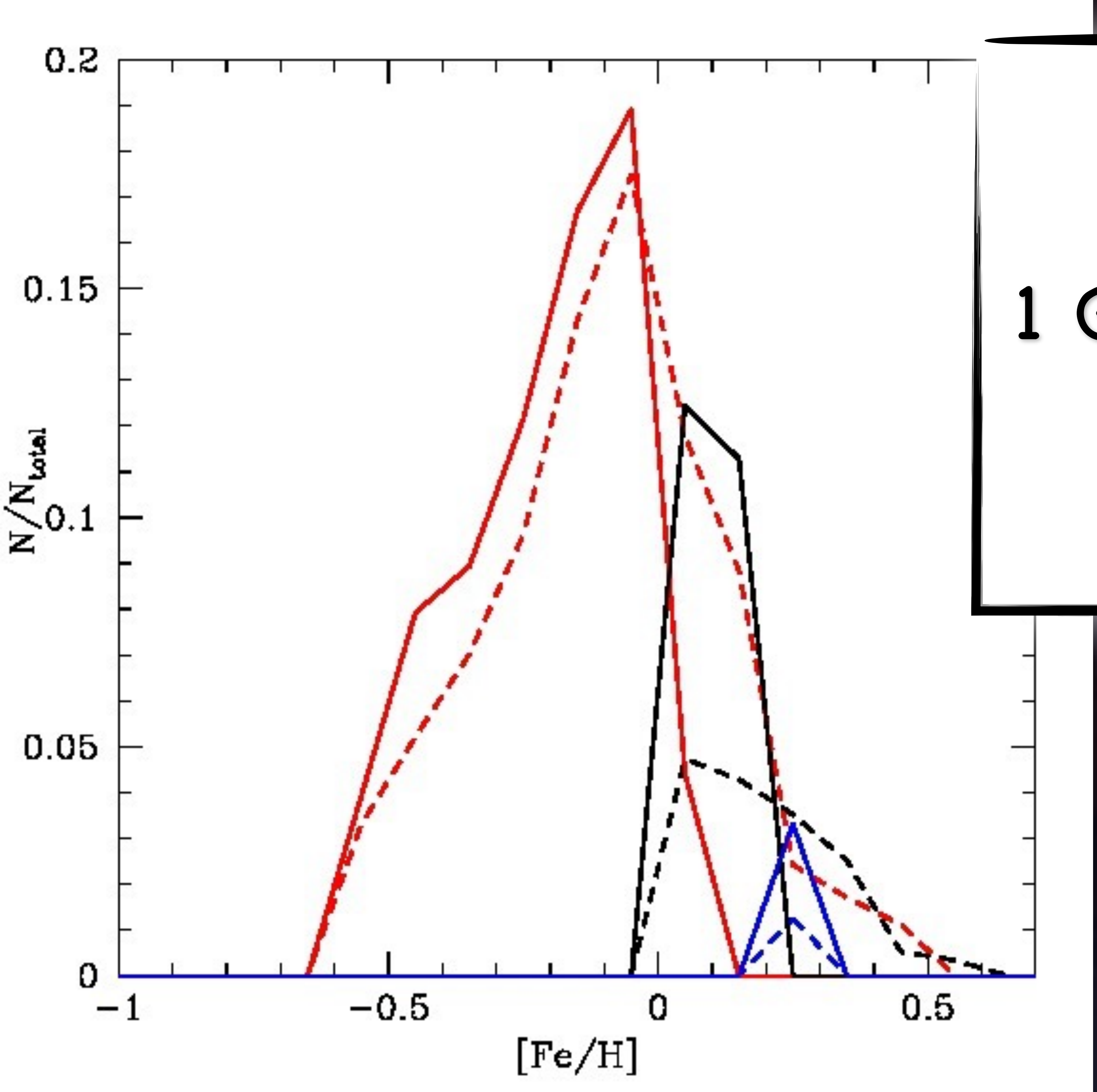


Reference model

Minchev case

(+ star velocity 1 km/s)

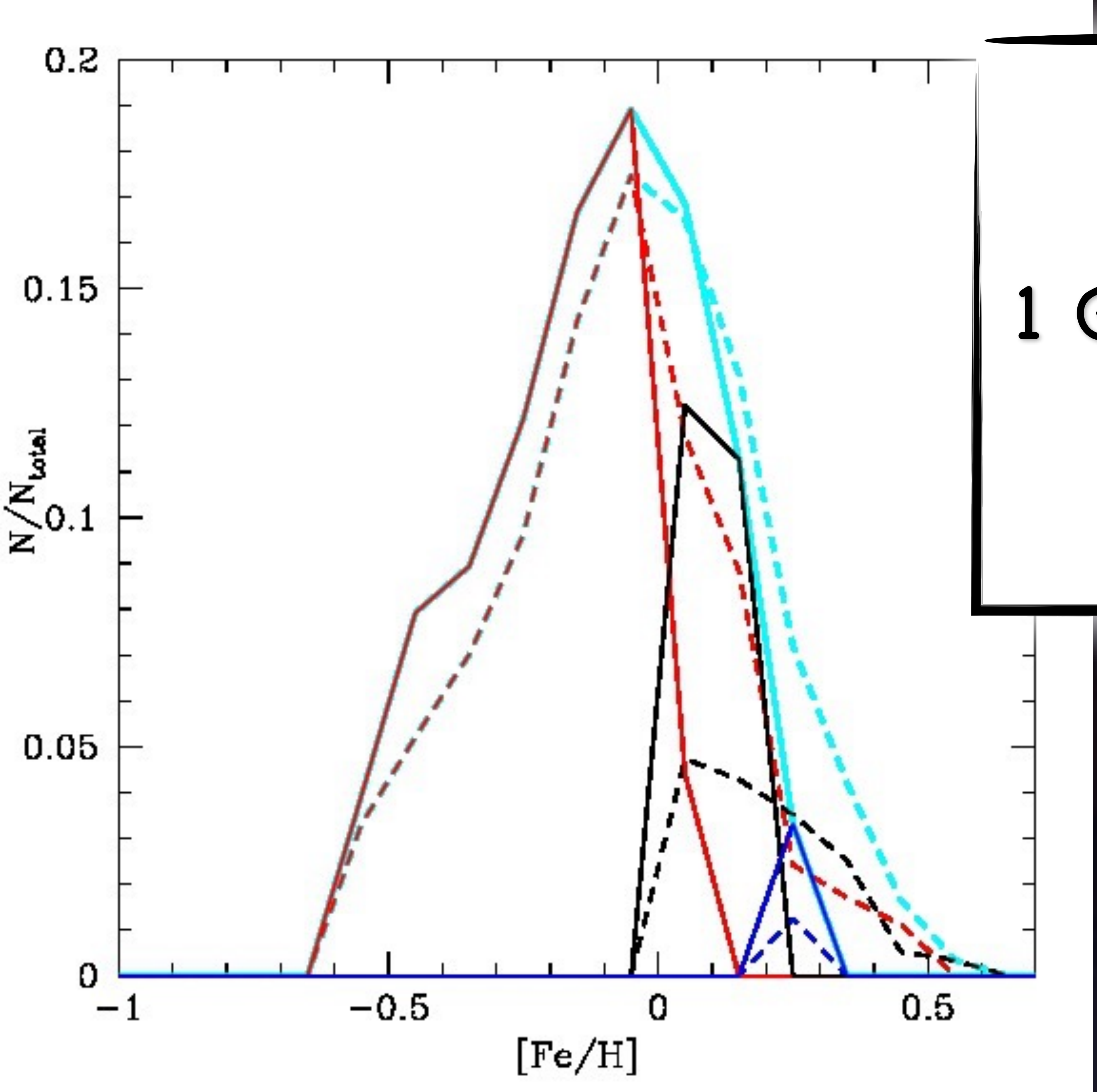
The G-dwarf distribution for different ages of stars



ages < 1 Gyr

1 Gyr < ages < 5 Gyr

ages > 5 Gyr



ages < 1 Gyr
1 Gyr < ages < 5 Gyr
ages > 5 Gyr

Percentages of stars in different age bins

%	Reference model	Minchev case
ages<1 Gyr	3.30	1.25
1 Gyr<ages<5 Gyr	23.75	15.93
ages>5 Gyr	72.95	82.82

Percentages of stars in different age bins

%	Reference model	Minchev case
ages<1 Gyr	3.30	1.25
1 Gyr<ages<5 Gyr	23.75	15.93
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Extreme cases for the stellar migration

Models	Radial gas inflow	Stellar migration	Stellar velocity
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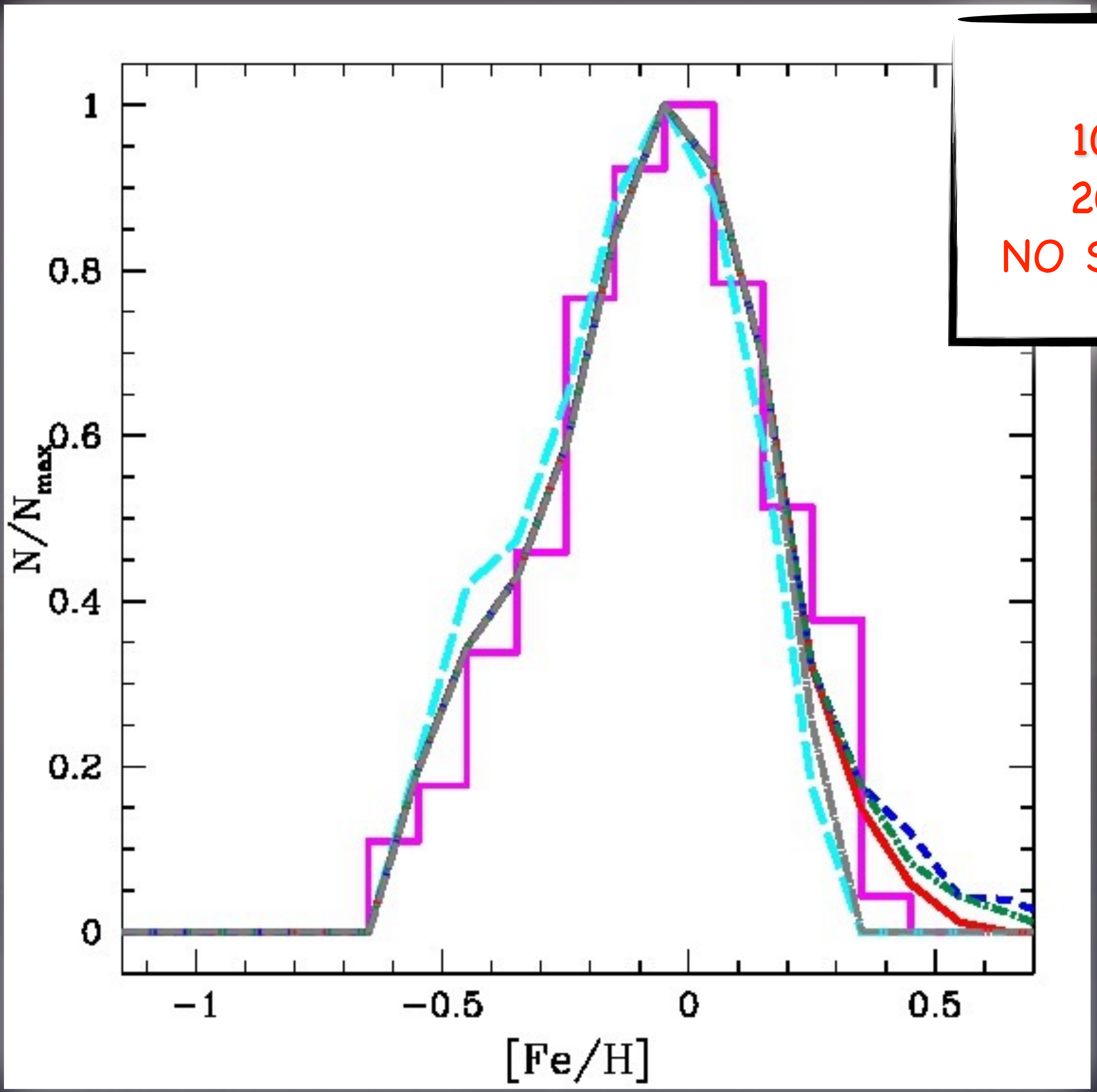
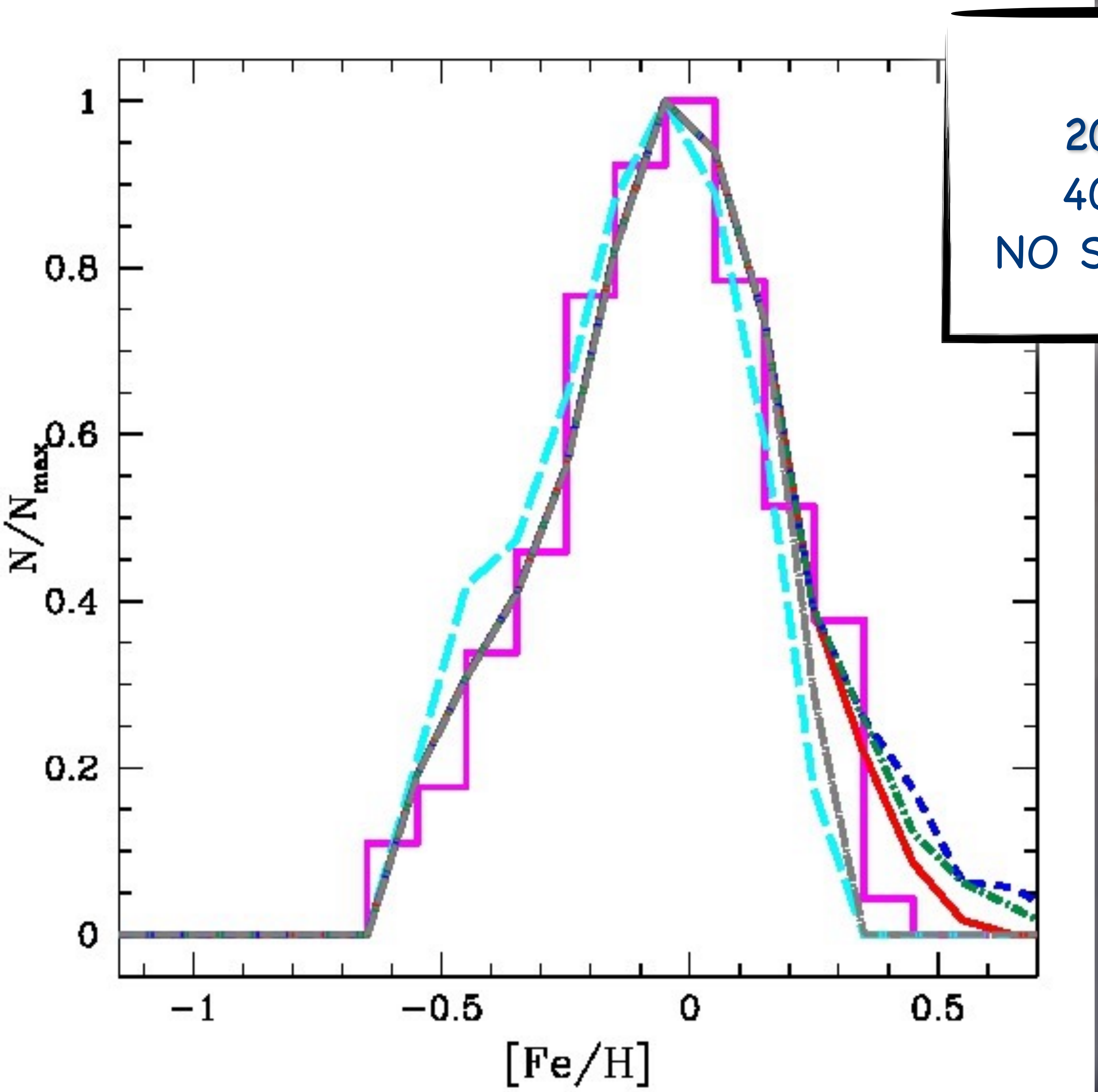


case 1

10% from 4 kpc

20% from 6 kpc

NO STARS from 8 kpc



case 2

20% from 4 kpc

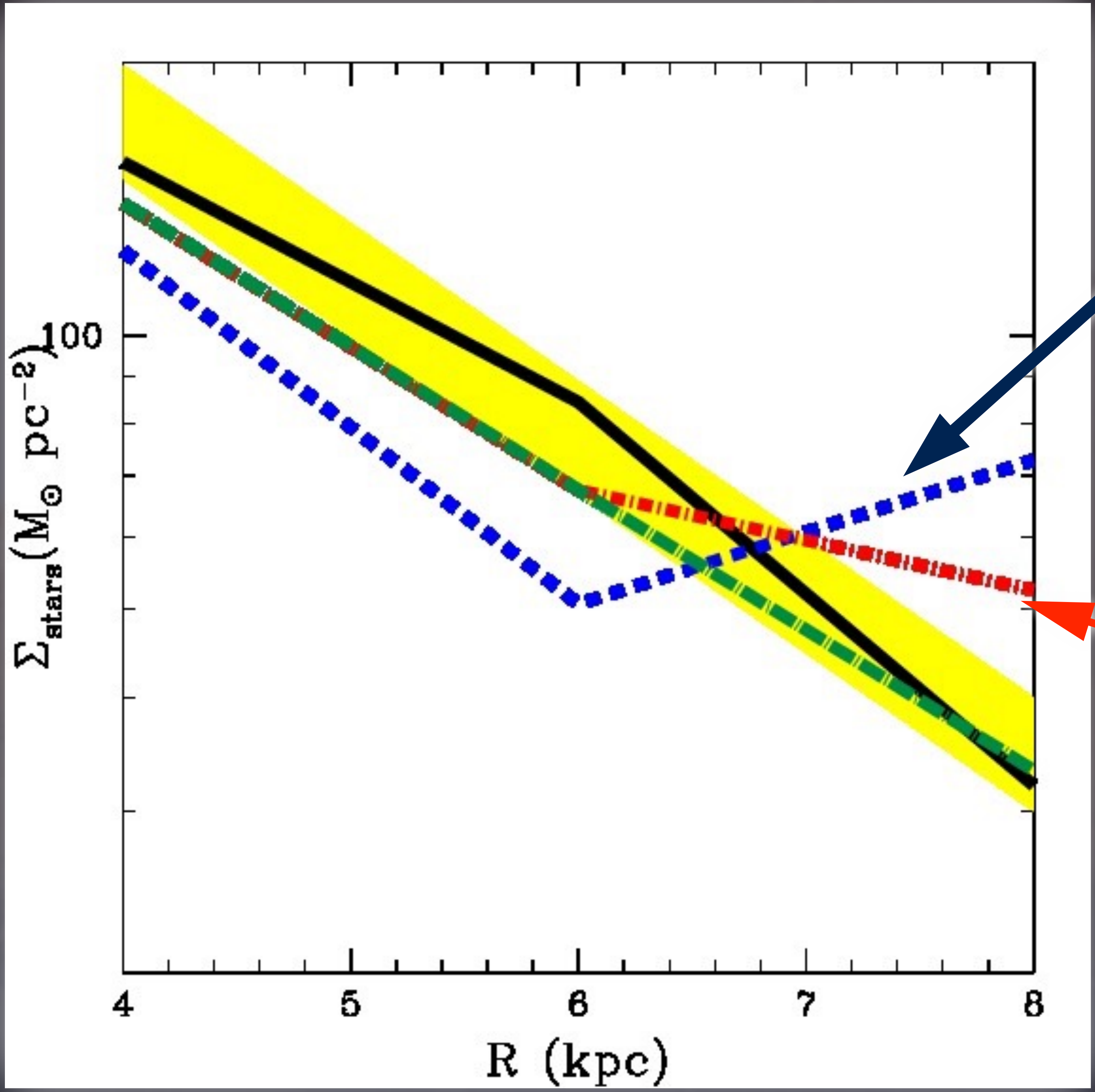
40% from 6 kpc

NO STARS from 8 kpc

As found adopting the more realistic model described in Minchev case, the effect of the extreme cases 1 and 2 stellar migration is to increase the high-metallicity tail of the distribution, thus improving the agreement with the data obtained without migration

BUT...

The surface stellar density



case 2

20% from 4 kpc

40% from 6 kpc

NO STARS from 8 kpc

case 1

10% from 4 kpc

20% from 6 kpc

NO STARS from 8 kpc

On the other hand, we see that the stellar surface mass density is drastically modified by the stellar migration in both cases 1) and 2) (considering the velocity of the stars of 1 km/s in the radial direction), and the observational data are not fitted anymore.

We also test the “really extreme” case 3), where all stars born at 4 kpc and 6 kpc are supposed to end up in the solar neighborhood:

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We also test the "really extreme" case 3), where all stars born at 4 kpc and 6 kpc are supposed to end up in the solar neighborhood:

Models	Radial gas inflow	Stellar migration	Stellar velocity
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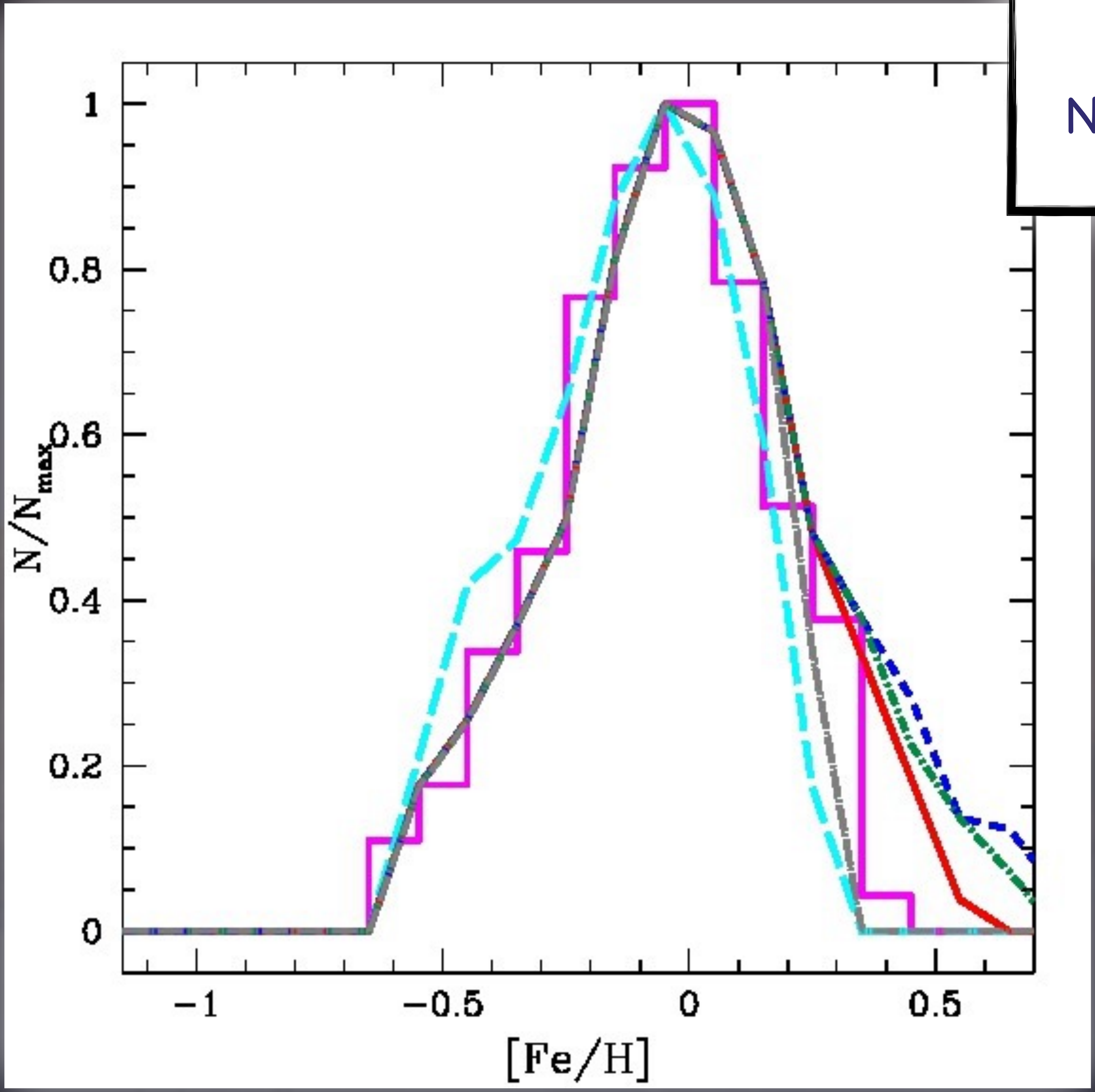


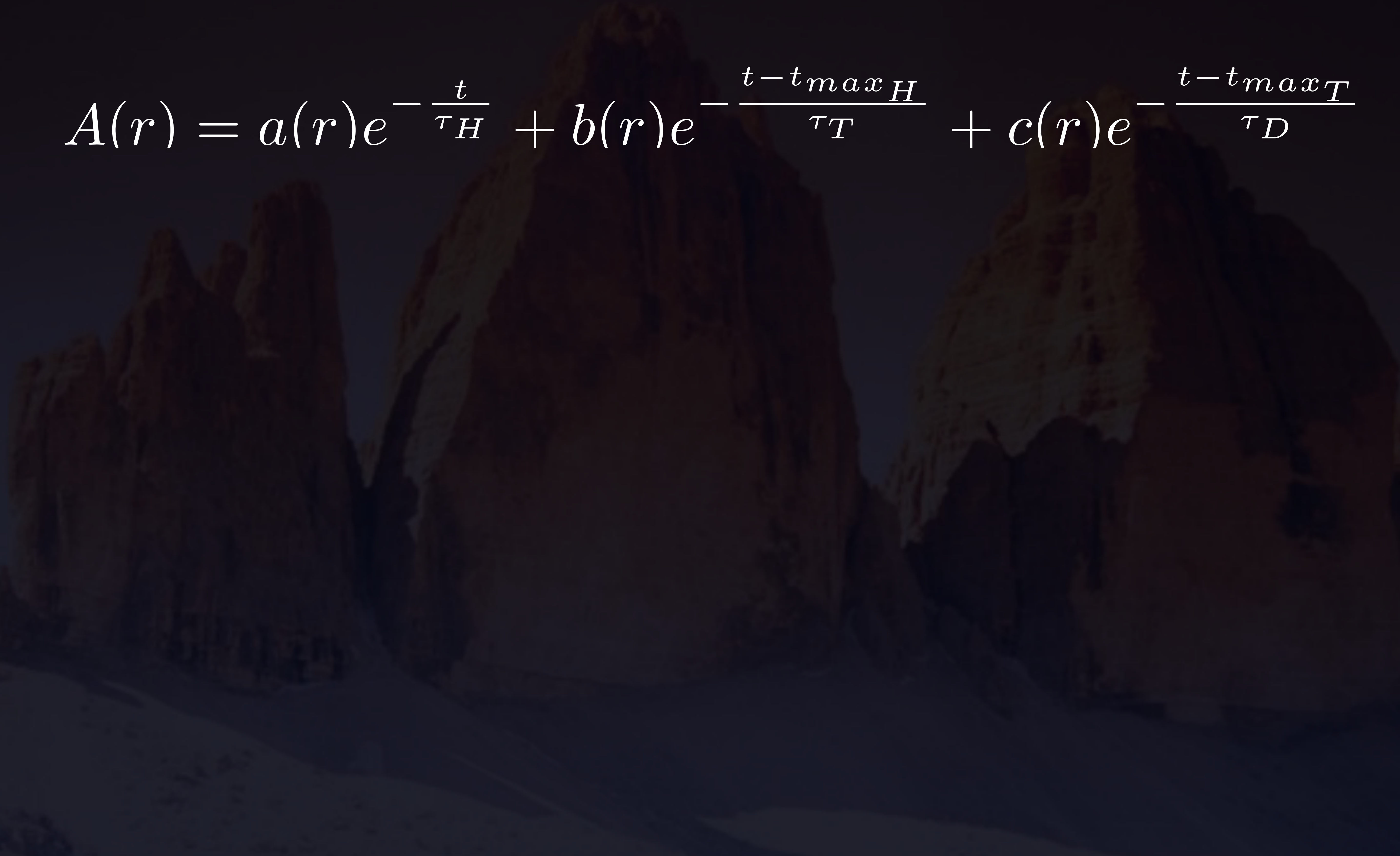
case 3

100% from 4 kpc
100% from 6 kpc
NO STARS from 8 kpc

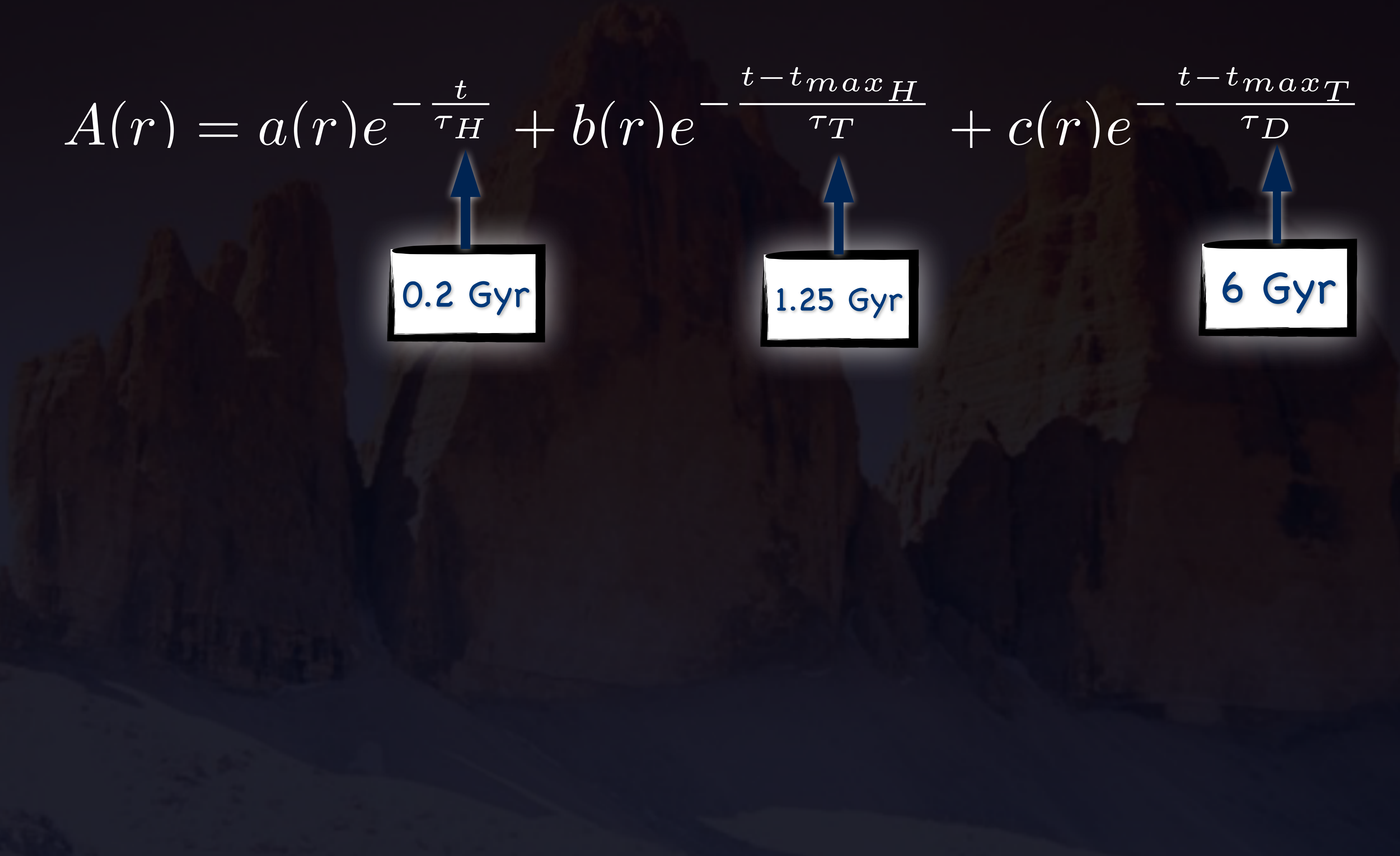
EVEN IN THIS EXTREME CASE THE G-DWARF DIAGRAM IS NOT SUBSTANTIALLY AFFECTED

The three infall model of Micali et al. (2013)

$$A(r) = a(r)e^{-\frac{t}{\tau_H}} + b(r)e^{-\frac{t-t_{max_H}}{\tau_T}} + c(r)e^{-\frac{t-t_{max_T}}{\tau_D}}$$



The three infall model of Micali et al. (2013)



$$A(r) = a(r)e^{-\frac{t}{\tau_H}} + b(r)e^{-\frac{t-t_{max_H}}{\tau_T}} + c(r)e^{-\frac{t-t_{max_T}}{\tau_D}}$$

τ_H: 0.2 Gyr

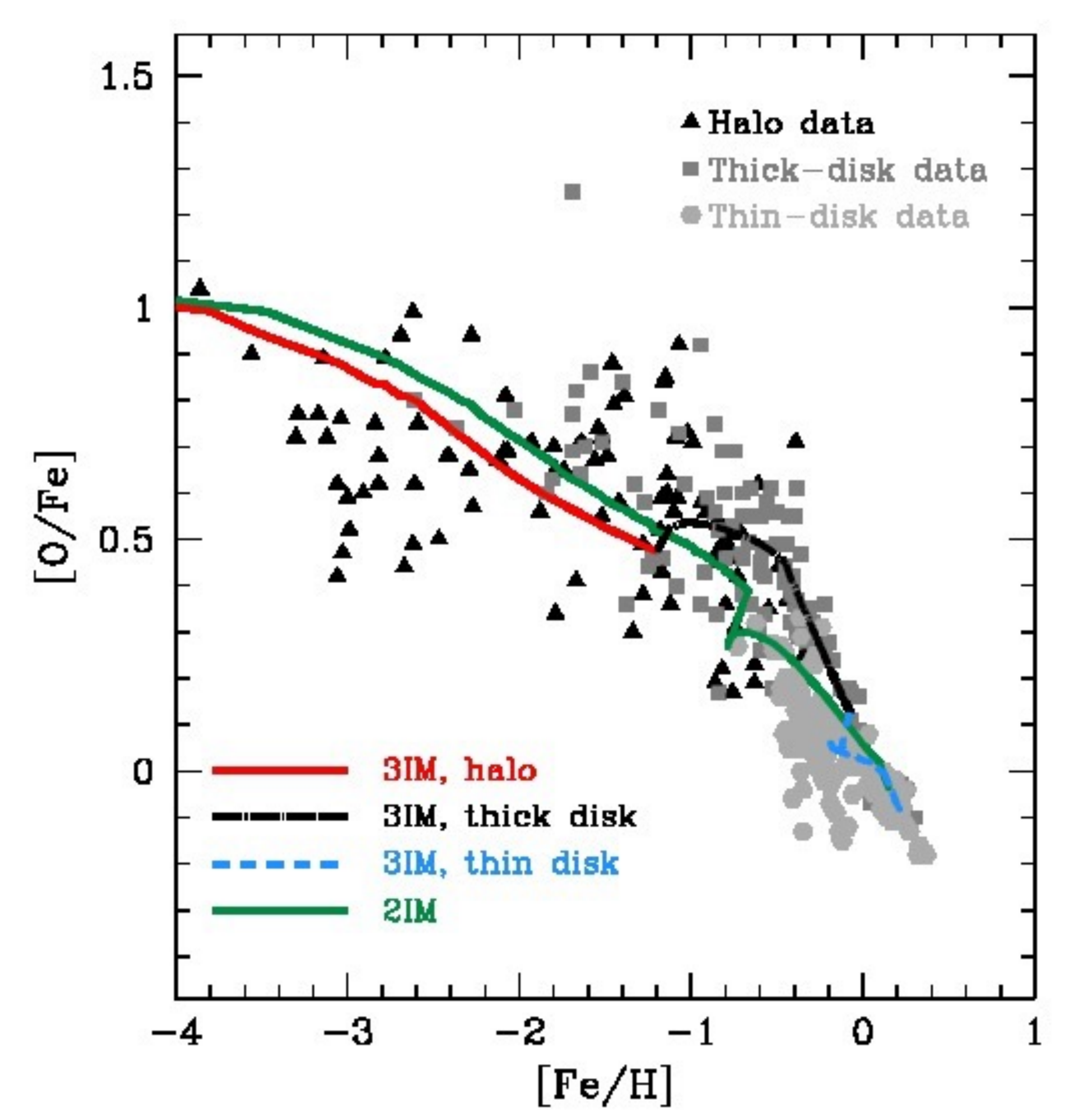
τ_T: 1.25 Gyr

τ_D: 6 Gyr

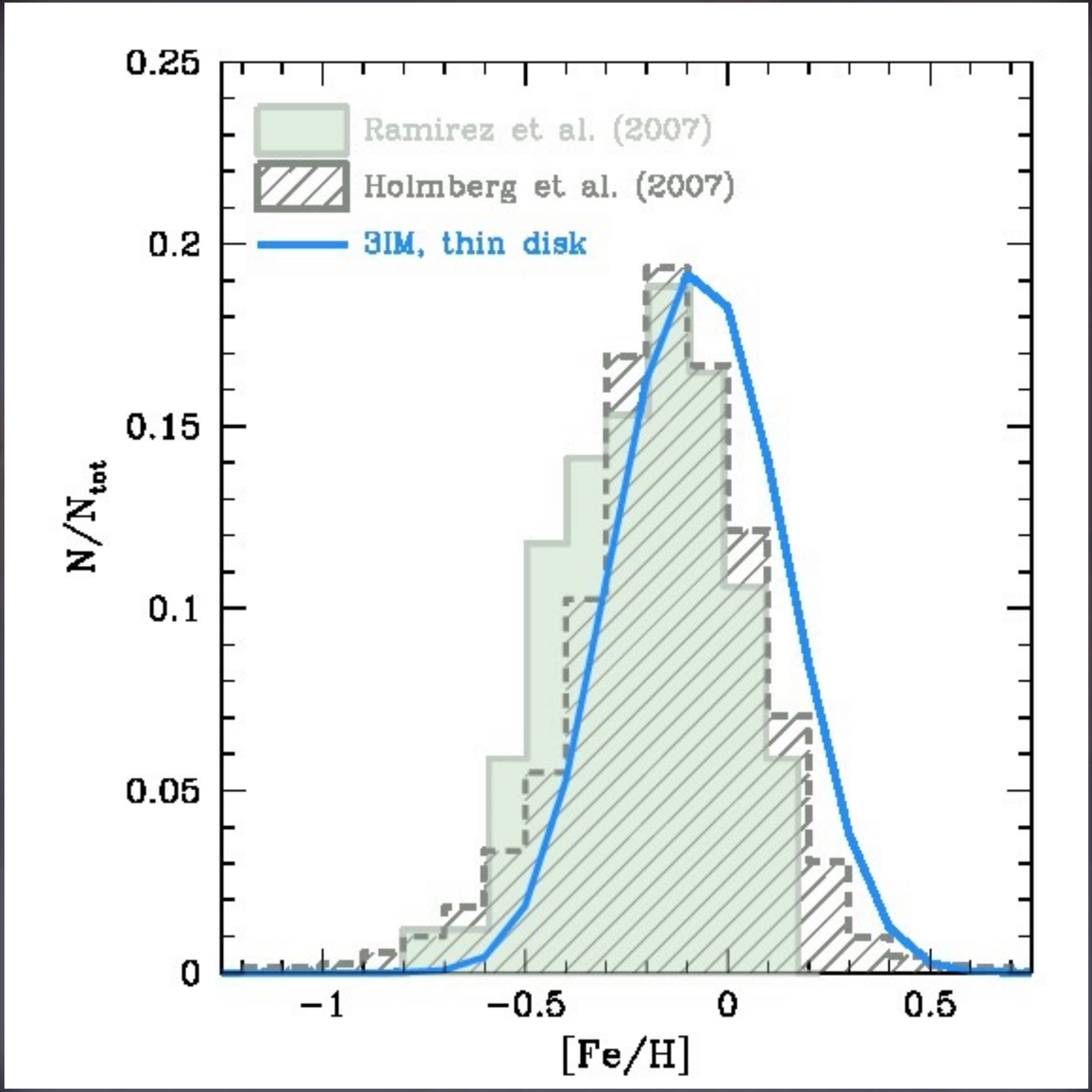
The three infall model of Micali et al. (2013)

$$A(r) = a(r)e^{-\frac{t}{\tau_H}} + b(r)e^{-\frac{t-t_{max_H}}{\tau_T}} + c(r)e^{-\frac{t-t_{max_T}}{\tau_D}}$$

6 Gyr



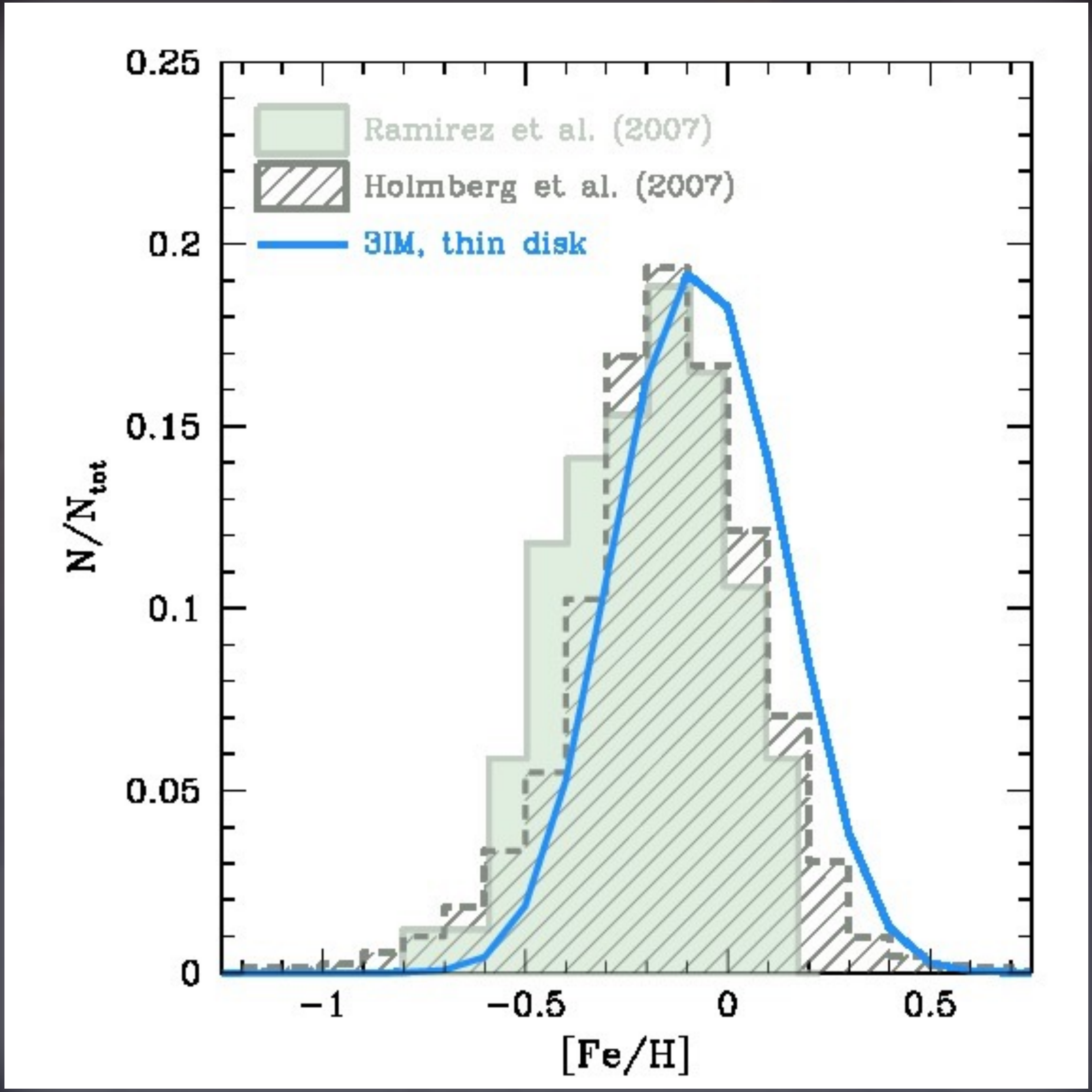
The three infall model of Micali et al. (2013)



$$\tau_D = 6\ \mathrm{Gyr}$$

Threshold in the gas density for the SF assumed to be 7 $M_\odot\,pc^{-2}$

The three infall model of Micali et al. (2013)

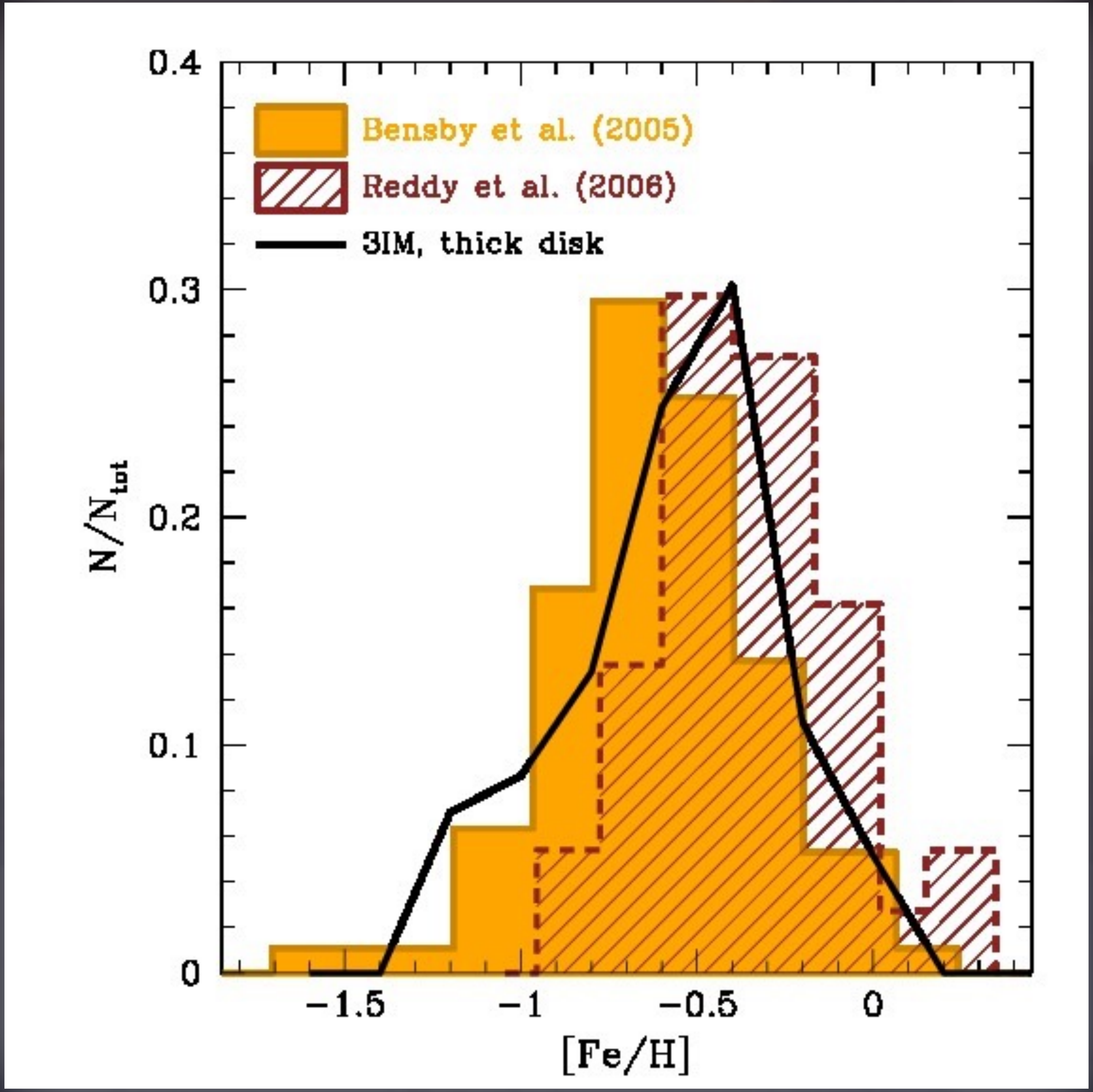


$$\tau_D = 6 \text{ Gyr}$$

Threshold in the gas density for the SF assumed to be 7 $M_\odot pc^{-2}$

Without any stellar migration they are able to reproduce the high-metallicity tail

G-dwarf distribution for the thick disk (Micali et al. 2013)



$$\tau_T = 1.25\ \mathrm{Gyr}$$

Threshold in the gas density for the SF assumed to be 5 $M_\odot pc^{-2}$

Conclusions

- The chemical evolution model for the thin disc of the Milky Way with a variable SFE and a constant radial gas inflow without stellar migration is able to well fit the majority of the observables.

- Including a stellar migration which follows the prescriptions given by results of the chemo-dynamical model of Minchev et. al. (2013), and taking into account star velocities of 1 km/s , we are able to reproduce very well the high metallicity tail in the G-dwarf distribution for thin disk stars.

- Considering "extreme" cases of migration where the stars born in situ at 8 kpc cannot migrate outwards, the G-dwarf distribution is not substantially modified. In general, the effect of the migration is just to slightly increase the right tail of the distribution.

- Therefore, we can conclude that the G-dwarf distribution is not a very sensitive diagnostic to quantify the migration of stars.