The chemical evolution of the Milky Way thin disk using solar twins

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2024.12.09 Shao Qinhao

Introduction

The formation and evolution of the Milky Way are among the most important topics in modern astronomical research.

This paper focus on the thin disk formation

- Age-metallicity relation (AMR)
- Chemical trends

The study by Nissen et al. (2020) has found two populations in the age-metallicity diagram traced by nearby solar-twin stars.

The study by Ratcliffe et al. (2023) argues that radial migration and accretion events playing an important role in the chemical composition of the thin disk.

Nissen, P. E., Christensen-Dalsgaard, J., Mosumgaard, J. R., et al. 2020,A&A,640, A81

Ratcliffe, B., Minchev, I., Anders, F., et al. 2023, MNRAS, 525, 2208

Sample

The first dataset consists of HARPS-North (HARPS-N) spectra for 114 solar twins

T_{eff}: $T_{eff,\odot} \pm 200\ K, T_{eff,\odot} = 5771\ K$

$\log g$: $\log g_{\odot} \pm 0.20\ dex$, $\log g_{\odot} = 4.44\ dex$

$[Fe/H]$: $[Fe/H]_{\odot} \pm 0.3\ dex, [Fe/H]_{\odot} = 0.0\ dex$

485 solar twins

The second dataset is from 371 solar twins observed by Casali et al. (2020) with the HARPS-South (HARPS-S) spectrograph

Casali, G., Spina, L., Magrini, L., et al. 2020, A&A, 639, A127

Sample

Age determination and errors:

isochrone fitting technique in surface gravity versus effective temperature space.

$$age_{err} = 0.7Gyr$$

Determination of the R_{birth}:

This work assumes that the star-forming gas in the Milky Way is azimuthally chemically homogeneous and that the birth metallicity gradient is always linear in radius.

metallicity gradient at τ

$$[Fe\ /\ H](R_{\downarrow}birth, \boxed{\tau}) = \boxed{\nabla[Fe/H](\tau)} * R_{\downarrow}birth + \boxed{[Fe/H](0,\tau)}$$

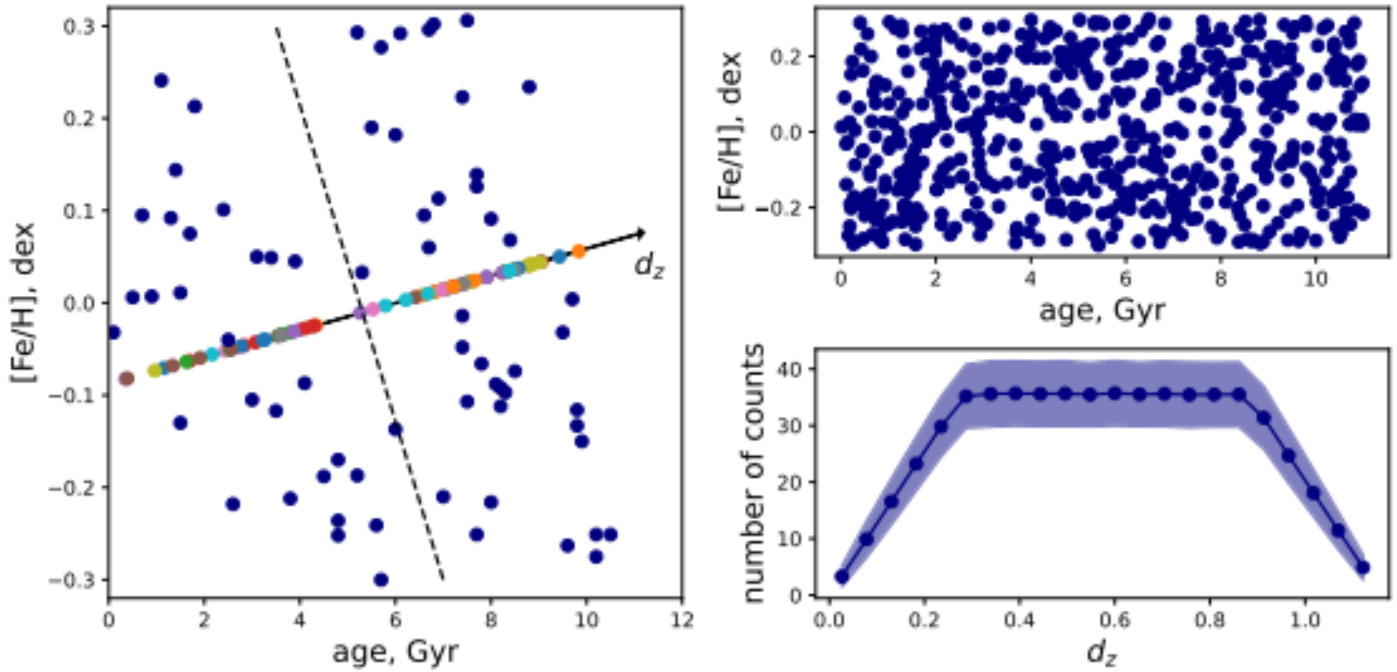
lookback time

metallicity at the MW center

$$R_{\downarrow}birth(age, [Fe\ /\ H]) = \frac{[Fe/H] - [Fe/H](0,\tau)}{\nabla[Fe/H](\tau)}$$

parameters from Ratcliffe et al. 2023, MNRAS, 525, 2208

AMR



- Left: Age-metallicity map of Nissen's data (blue dots) with the division line for two populations (black dashed line) and with d_z parameter axes (black solid line). The solar twins projected across the d_z axis (colored points).
- Upper right: Random distribution of 600 stars.
- Lower right: Projection of the data from the upper right age-metallicity map to the d_z axis.

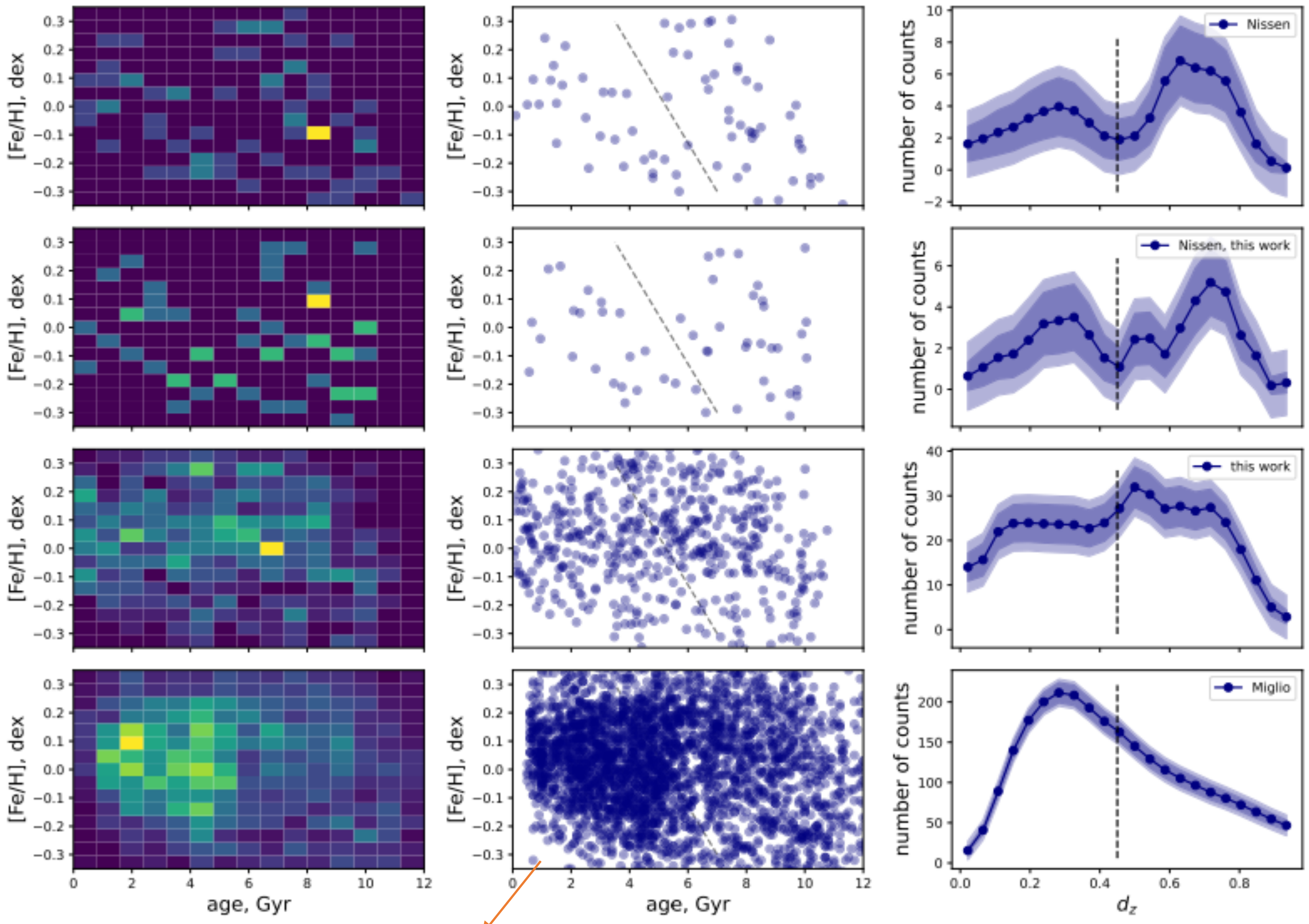
◆ The d_z axis was determined through the linear discriminant analysis algorithm trained over the ages and metallicities used by Nissen et al. (2020)

◆ While studying the distribution of stars across d_z one should also consider the geometrical effects of that projection due to the edges of the dataset under consideration：

Samples were randomly distributed into this box with metal abundances from 0.3 to -0.3 and ages from 0-12 Gyr. , the shape of the $d_z$parameter distribution is not linear.

sklearn.discriminant_analysis.LinearDiscriminantAnalysis

AMR



This dataset is composed of red giant and red clump stars with APOGEE metallicity measurements and asteroseismic high-accuracy ages.

- AMR for three different datasets:

[1] Nissen's dataset (72 stars, top row) ;
[2] stars that are in common between the Nissen dataset and this work's(52 stars, second row) ;
[3] solar twins in this work (485 stars, third row) ;
[4] dataset from Miglio et al. (2021) (2785 stars, bottom row).

- The right column represents the d_z separation parameter where the vertical dashed line represents the location of the Nissen's data drop, the dark blue region is the measurement uncertainty, and the light blue region is the quadratic sum of measurement and statistical uncertainty.

Miglio, A., Chiappini, C., Mackereth, J. T., et al. 2021, A&A, 645, A85

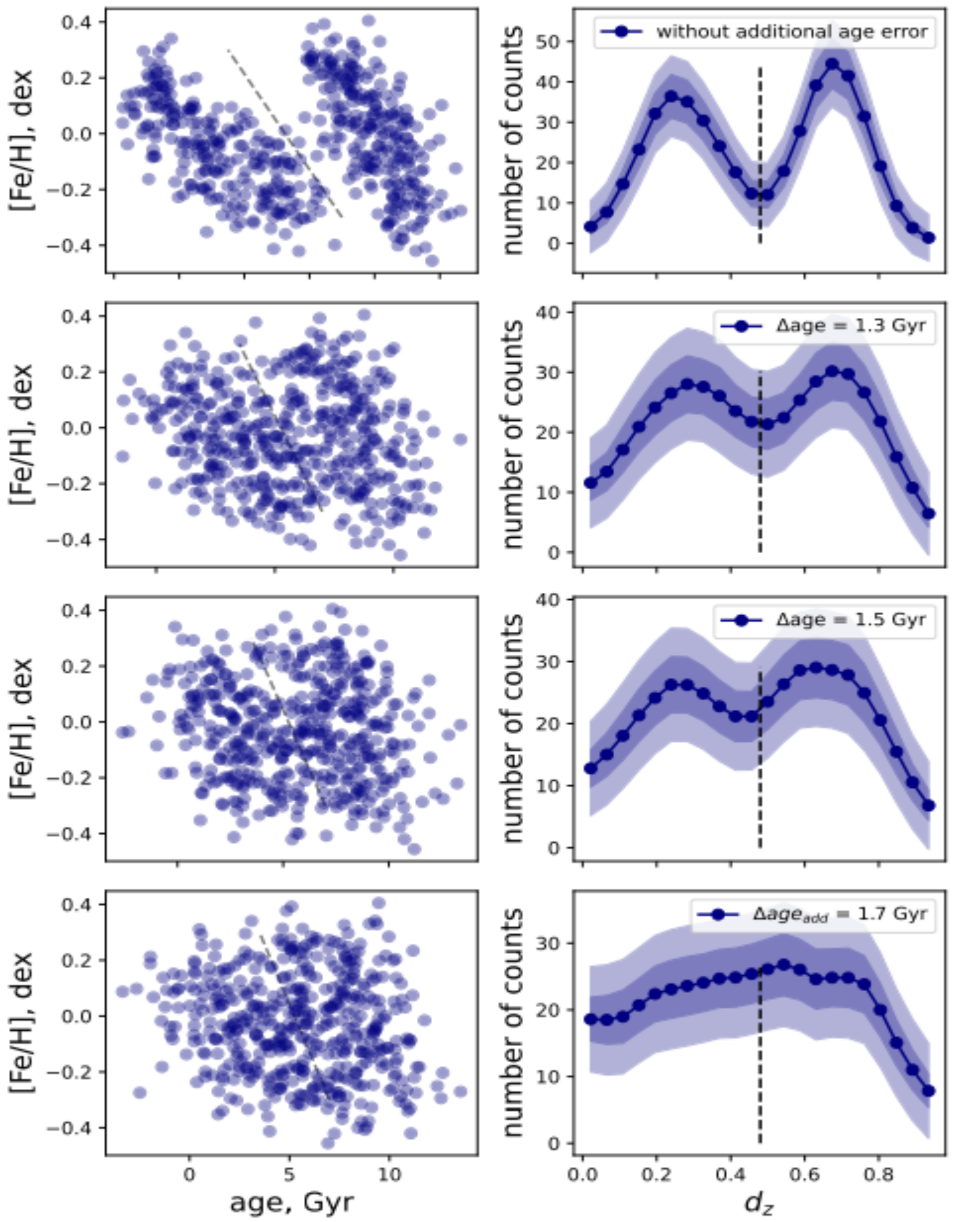
AMR

Is the segregation ambiguous because it does not take into account additional age uncertainty?

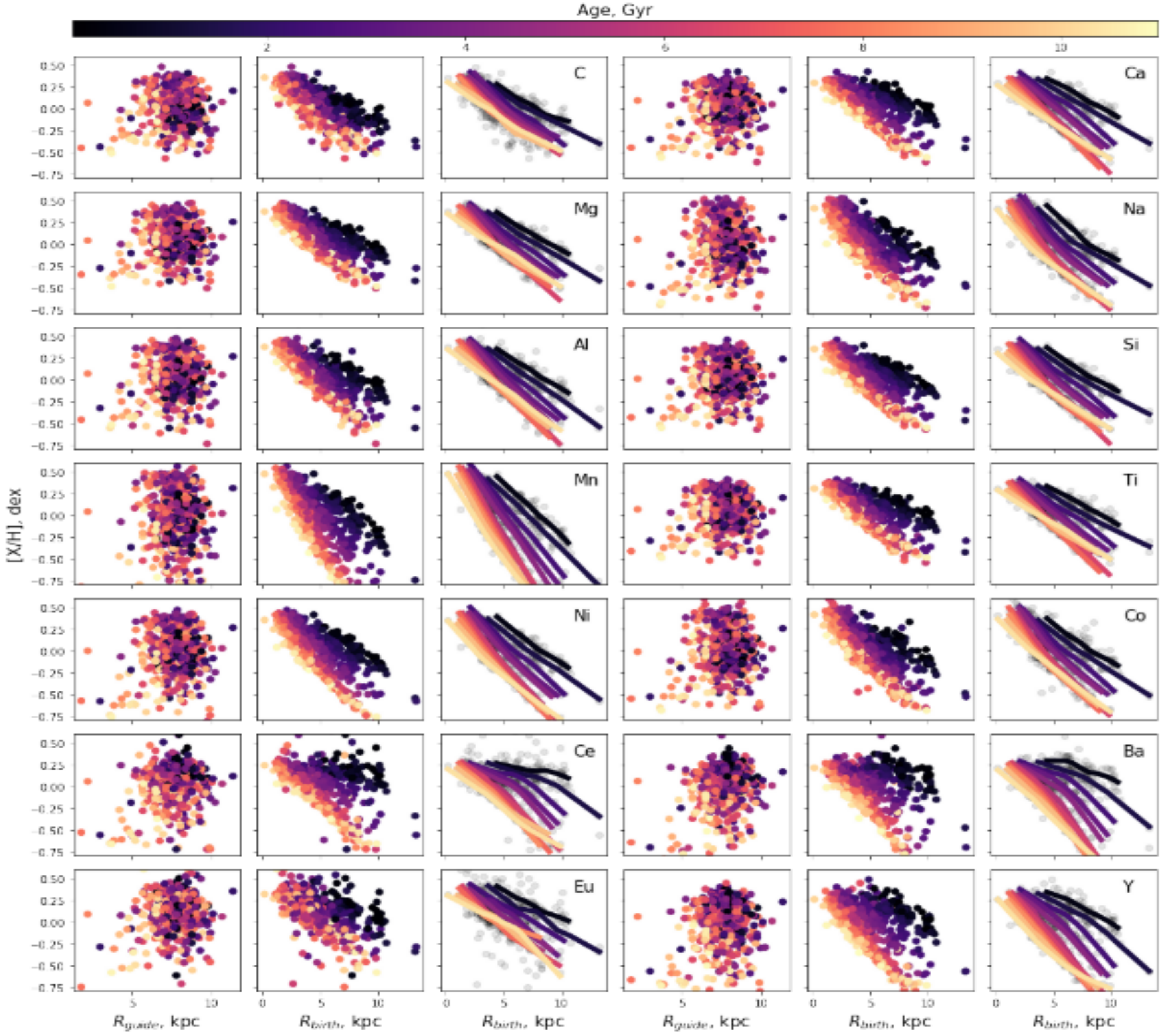
This work selected three main distribution points in each of the two populations of the Nissen et al. dataset and randomly created Gaussian-distributed patches. ($\sigma_{age} = 0.7, \sigma_{Fe/H} = 0.1$)

- The first row of figure shows the case where the additional age uncertainty has not been taken into account.
- The second, third, and fourth rows of figure are considering different additional age errors of 1.3, 1.5, and 1.7.

So they need at least 1.7 Gyr of additional unaccounted error in age to eliminate any signature of double populations.



Chemical Trends



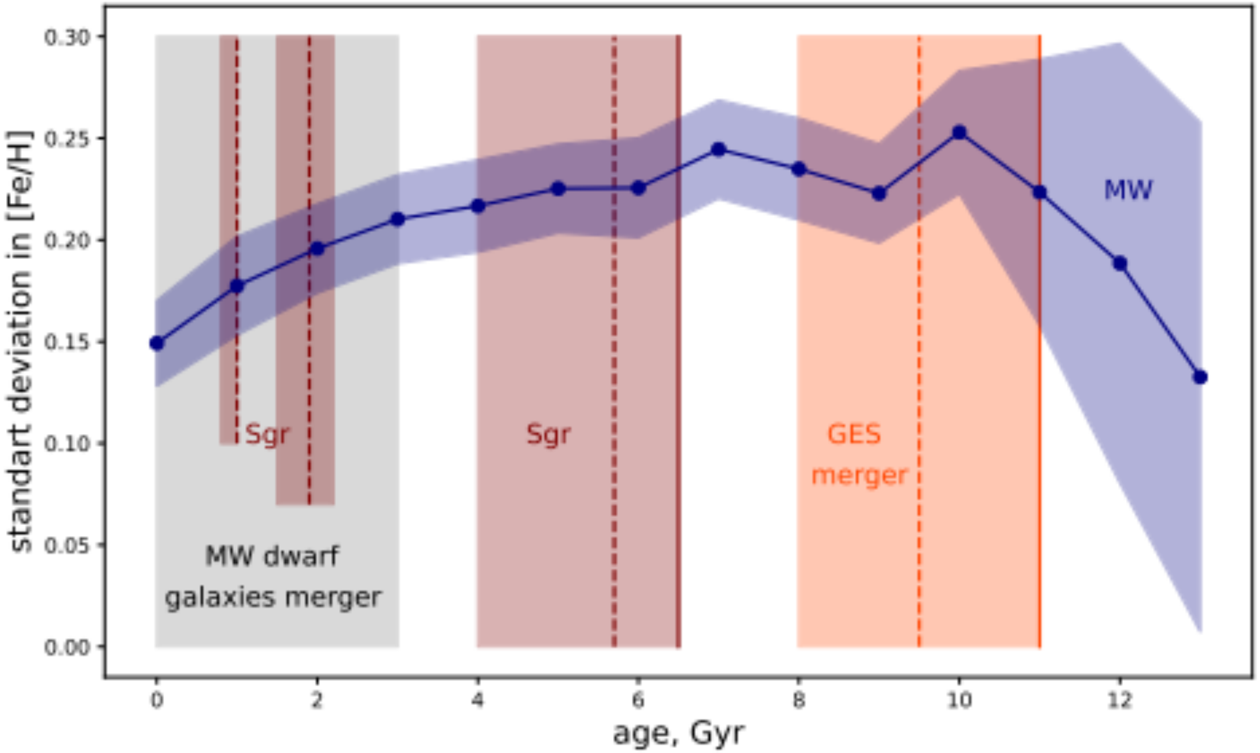
- Chemical trends for 14 elements with guiding and birth radii (Rguide, Rbirth) color-coded by age. In the third and sixth columns the trend lines were obtained by locally weighted scatterplot smoothing (LOWESS).

It can be found that stars of different ages are well distinguished in the birth radius, indicating that the radial migration of stars can well explain the basic age-chemistry dependences.

However, a slight overlap is partially present at the 4-6 Gyr and 8-12 Gyr age ranges. The most plausible mechanism for this would be that the Milky Way experiences accretion.

Chemical Trends

This work suggests that it may be due to the effects of the GES accretion event, as well as the effects of the sgr pericenter channel on the formation of the Galactic disk and on other channels in Galactic dwarf galaxies.



- Metallicity standard deviation vs. age trend of the stars under investigation (blue line for main trend; blue region for measurement uncertainty).
- Orange: GES accretion event; red: Sgr; gray: mergers of the Milky Way dwarf galaxies.
- The solid vertical lines show the beginning of the merger, and the dashed vertical lines show the peak of star formation corresponding to a particular accretion event.

Conclusion

- They used a new parameter to test the AMR separation into two groups for solar twins in the solar vicinity. In the process, they took into account all possible sources of errors and did not detect a separation. For Nissen et al. (2020), the separation was caused by the statistical bias.

- They also studied the dependence of chemical abundance with guiding and birth radii and age. The mixed star populations for the guiding radius transform into well-separated trends for the birth radius. This means that radial migration, which is the basis of the birth radii determination, explains well the star’s chemical distribution, but the conclusion that radial migration alone does not explain all the features in the Milky Way formation history.

Thanks