

Subpopulations in the solar neighborhood using precise manual abundances in solar twins

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Abstract. We aim to identify subpopulations in the solar neighborhood through precise manual abundances in solar twins, and to assess how the Sun fits in among the solar twins. The sample consists of 79 stars plus the Sun, whose abundances are from Bedell et al. (2018), and parameters and ages from Spina et al. (2018), both using spectra obtained from the HARPS spectrograph at ESO's LaSilla Observatory. In the first stage, we analyzed the abundance pattern of solar twins, where it was possible to differentiate three subpopulations: copper-rich, copper-poor, and sodium-poor. Next, through the quadratic sum of the relative deviations, we discovered that the Sun is part of the copper-rich subpopulation.

Resumo. Nosso objetivo é identificar subpopulações na vizinhança solar por meio de abundâncias manuais precisas em gêmeas solares, e verificar como o Sol se encaixa entre as gêmeas solares. A amostra consta de 79 estrelas gêmeas solares mais o Sol, cujas abundâncias são de Bedell et al. (2018), e parâmetros e idades de Spina et al. (2018), ambos utilizando espectros obtidos do espectrógrafo HARPS no Observatório LaSilla do ESO. Na primeira etapa, analisamos o padrão de abundância das gêmeas solares, onde foi possível diferenciar três subpopulações, as ricas em cobre, as pobres em cobre e as pobres em sódio. A seguir, através da soma quadrática dos desvios relativos descobrimos que o Sol faz parte da subpopulação rica em cobre.

Keywords. Stars: abundances – Stars: solar-type – Stars: evolution

1. Introduction

This research explores the use of high precision stellar abundances (at the level of 0.01 dex), made possible through a direct comparison between solar twins and the Sun.

Solar twins are a subclass of solar-type stars, with atmospheric parameters similar to those of the Sun, with a difference of up to $\pm 100\text{K}$ in effective temperature, ± 0.1 dex in both surface gravity and metallicity ($[\text{Fe}/\text{H}]$).

The abundance of stars can reflect the chemical composition of the interstellar medium (ISM) when they were born. As successive generations of stars enrich the ISM, the stellar abundance pattern depends on when the star was born, meaning that chemical abundances depend on the age of the star. Furthermore, there is a dependence on the Galactocentric distance, since the innermost regions of the Milky Way have a higher star formation rate, thus reaching higher metallicities more quickly.

Therefore, analyzing possible subpopulations in the abundance pattern of solar twins, is of paramount importance for discovering the galactic origin of the Sun, since they are stars very similar to it.

2. Methods and Results

The sample consists of 79 solar twins plus the Sun, whose abundances are from Bedell et al. (2018), and stellar parameters and ages from Spina et al. (2018), both using spectra obtained from the HARPS spectrograph at ESO's La Silla Observatory. In both studies the analysis was performed by the line-by-line differential method, which cancels systematic errors by comparing the abundance measured in each line of the target star with the abundance of the same line of the reference star, in this case the Sun. For this reason, the abundances are precise.

The first step was to analyze the abundance pattern of solar twins by age, as well as metallicity by age. Next, it was necessary to differentiate the stars of the Galactic thick disk from

those of the thin disk, as seen in Fig. 1, since those of the thick disk are very old and possibly predate the rise of the Galactic thin disk population. For this, we used the equation taken from Shejeelammal, J., et al. (2024), which defines the limit as:

$$\begin{aligned} [\text{Mg}/\text{Fe}] &= +0.19 \text{ for } [\text{Fe}/\text{H}] \leq -0.6, \\ [\text{Mg}/\text{Fe}] &= -0.217 \times [\text{Fe}/\text{H}] + 0.06 \text{ for } -0.6 < [\text{Fe}/\text{H}] \leq 0, \\ \text{and } [\text{Mg}/\text{Fe}] &= +0.06 \text{ para } [\text{Fe}/\text{H}] > 0. \end{aligned}$$

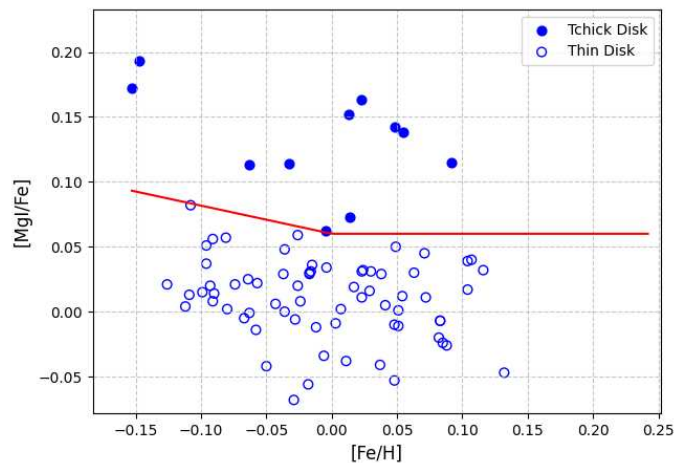


FIGURE 1. Separation between stars in the thick disk and thin disk.

After analyzing the abundance patterns, it was possible to identify three subpopulations (some examples are shown in Fig. 2):

- Copper-rich (Cu-rich) stars, which are those above the fit of the $[\text{Cu}/\text{Fe}]$ versus age plot;
- Copper-poor (Cu-poor) stars, which are those below the fit;

- And sodium-poor (Na-poor) stars, which are old ($\geq 6\text{Gyr}$) and below the fit of the $[\text{Na}/\text{Fe}]$ versus age graph.

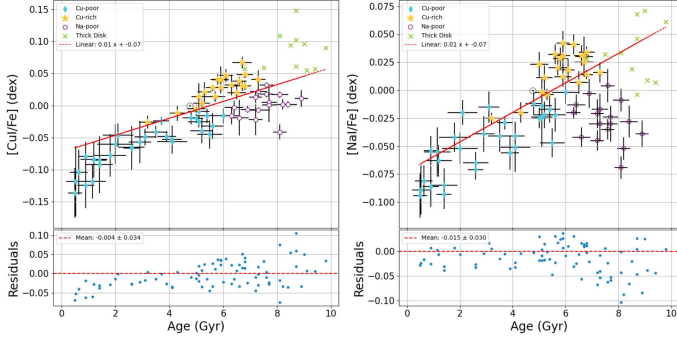


FIGURE 2. Plots of the global fit between abundances and ages for $[\text{Cu}/\text{Fe}]$ and $[\text{Na}/\text{Fe}]$.

With these subpopulations defined, fits were made for each (e.g., Fig. 3). Then, it was possible to calculate Deviations and Relative Deviations to compare which subpopulation the Sun belongs to. The equations are:

$$D = (O - E) \text{ (for Deviation)} \quad (1)$$

$$Dr = \frac{(O - E)}{e_m} \text{ (for Relative Deviation)} \quad (2)$$

Where:

O = observed value ($[X/Fe] = 0$)

E = fit for the age Sun ($4.6x + b$)

e_m = mean error for each subpopulation

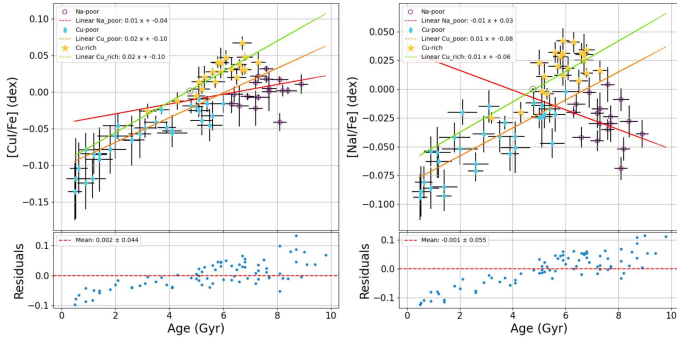


FIGURE 3. Plots of the fits between abundances and age for each subpopulation in $[\text{Cu}/\text{Fe}]$ and $[\text{Na}/\text{Fe}]$.

For a better analysis, the Deviation and Relative Deviation were graphically represented as a function of the atomic number of elements, as shown in Fig. 4. In order to determine to which population the Sun belongs, we performed a quadratic sum of the relative deviations of each subpopulation, obtaining the following results: 148.2 for Na-poor, 96.4 for Cu-poor and 40.1 for Cu-rich. Thus, we propose that the Sun belongs to the copper-rich group, since this was the group that presented the smallest deviation relative to the Sun.

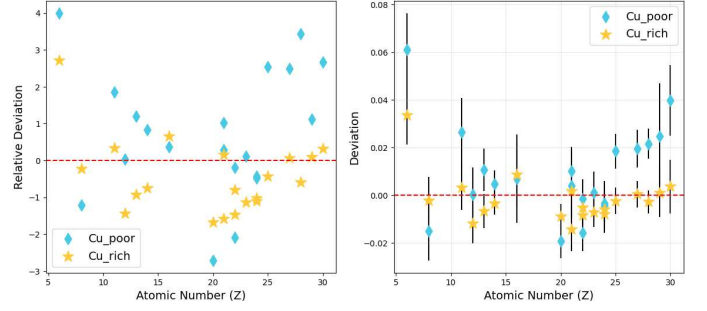


FIGURE 4. Plots of Relative Deviation (left) and Deviation (right) versus the atomic number for all chemical elements analyzed.

3. Conclusion

The behaviour of abundance vs. age was analyzed for 79 solar twins and the Sun, whose spectra were obtained from the HARPS spectrograph. This made it possible to distinguish three subpopulations: sodium-poor, copper-poor and copper-rich, to which the sun seems to belong. Knowing which group the Sun belongs to can help us understand where the Sun originated, as it likely migrated from the inner Milky Way (e.g., Wielen et al. (1996); Dantas et al. (2025)), but its exact birth radius is still unknown.

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References

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