Search for chemical clocks with TESS and APOGEE

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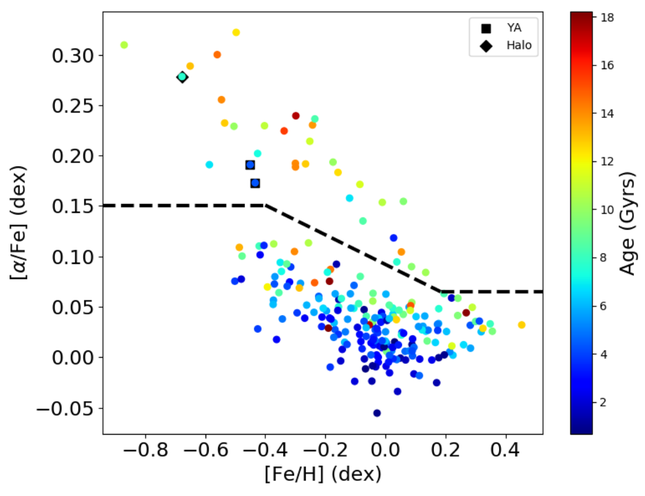
Rationale

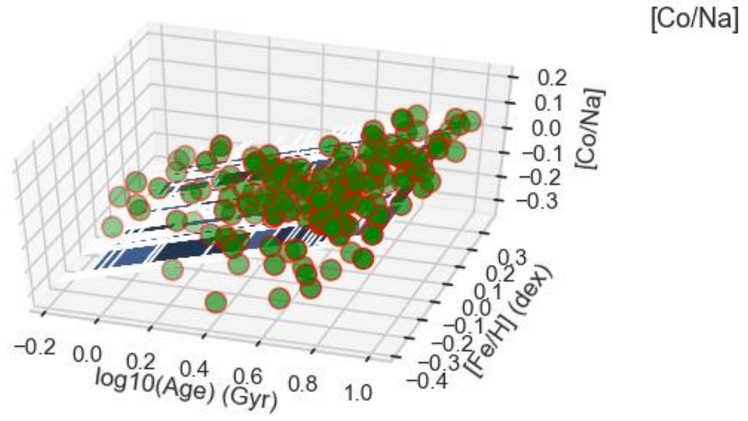
- **A chemical clock** is an abundance ratio of two chemical species correlated with the age of a population of stars. Such a ratio permits the direct dating of a star solely based on its photospheric chemical abundance.
- Sample of **TESS red giants branch stars** extracted from Mackereth et al (2021) (see Fig 1). It embodies a spatial extension of almost 2 kpc inside the galactic disc. The chemical abundances for these stars are obtained with **APOGEE 2 DR16** pipeline(Jönsson et al. 2020).
- Our study is motivated by a mean **relative uncertainty on ages of 20%** thanks to the precise mass and radii asteroseismic data from Elsworth et al. (2020)**.** Such reliability in individual stellar ages estimation combined with a wide range of chemical abundances **(19 chemical species**) has never been reached before in the infrared (H band) for the S/N and spectral resolution of APOGEE in such a wide sky area.



- **Fig1: [α/Fe] vs [Fe/H] dichotomy plane.** Ratio between alpha elements (Mg, Si) and iron compared to the metallicity**.** Age displayed as a colour code. Almost all the stars belong to the galactic disc. Sample chemically separated in high-alpha and low -alpha abundance (dashed black line) based on a Gaussian mixture process. Two stars are apparently young and alpha-rich (black squares). One belongs to the Halo (black diamond).

Assessing age and abundance correlations

- We used **the Spearman coefficient (ρ)** for our correlation computation since it quantifies the credibility of a monotonic relationship between two variables.
- To get a significant number of chemical clock candidates among **the low-alpha stars**, we set a **threshold at ρ≥ |0.3|.** We got a first category displaying **negative correlation values** and a second category revealing **positive values.**
- Following the approach of Delgado Mena et al. (2019), we computed **several types of multi-linear regressions of [X/Y]** abundance ratios to take into account the **limitation of [Fe/H]** on chemical clock dating**.** As a matter of fact, the authors demonstrated for some chemical elements the slopes of the [X/Fe]-age relations display very different trends depending on the metallicity.



- **Fig2: A plot of a multi-linear regression.** Graphical representation of the multi-linear regression of the [Co/Na] abundance ratio against the age and the metallicity of the low alpha stars in the sample.

References:

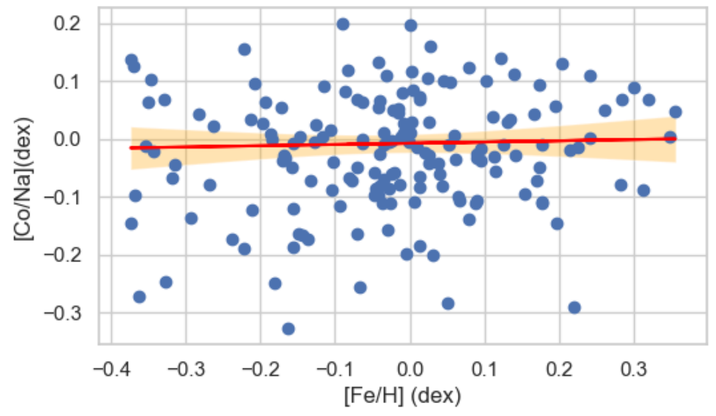
Mackereth, J. T., Miglio, A., Elsworth, Y., et al. 2021, MNRAS, 502, 1947
Jönsson, H., Holtzman, J. A., Allende Prieto, C., et al. 2020, AJ, 160, 120
Elsworth Y., Themeßl N., Hekker S., Chaplin W., 2020, Res Notes Am. Astron. Soc., 4, 177
Delgado Mena, E., Tsantaki, M., Adibekyan, V. Z., et al. 2017, A&A, 606, A94

Results

- We ranked our chemical clock candidates according to two statistics quality coefficients: The adjusted coefficient of determination (adj R2) that takes into account the number of input variables contrary to the R2 that increases with the number of fitting variables. The reduced chi-squared is a measure of the goodness of the fit. Its expectation value is 1. It follows the chi-square statistic. This statistic measures both the spread of the data and the accuracy of the fit..
- Our candidates include the element Cobalt, unconsidered in previous studies in the visible band.
- We found a new set of chemical clocks which **seem to not depend on metallicity : [Co/Na]** and **[Ni/Na]** (0.4<[Fe/H]<0.4 dex).

Work in progress

- We are assessing the **possibility of the non-universality of chemical clocks** with regards to their birth radius in our large available region of space. It would mean that age-abundance relationships would not be applicable for all stars independently of their birth location.



- **Fig3: Projected plot along the age dimension of the multi-linear regression. Projected version** plot of figure 2 with [X/Y] abundance in dex compared to the [Fe/H] in dex. This reveals that the [Co/Na] is **insensitive** to metallicity.