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CONSTRAINING THE MILKY WAY THICK DISK FORMATION: CHEMICAL CHARACTERIZATION OF THE THICK DISK OUTSIDE OF THE SOLAR NEIGHBOURHOOD

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Abstract. The formation of the Milky Way disk is still an open question. Many scenarios are proposed. Different formation scenarios predict different disk chemical trends. This work aims to chemically characterize the Milky Way disk inside and outside the solar neighbourhood, to better constrain its formation scenario. This is possible thanks to high resolution spectra of 200 disk stars observed using the Giraffe spectrograph on the Very Large Telescope (VLT). They were selected to have galactic altitudes $|Z|$ that cover both the thin and thick disk ($|Z|$ up to 2 kpc). The new automatic spectra analysis software SPADES (Stellar PArameters DEtermination Software, Posbic et al. 2012) was used to determine the stellar parameters, and most importantly, the elemental abundances of these stars. The distances of these stars were also determined. The metallicity distribution function of the disk using this sample was calculated. It showed a large contribution of the thick disk stars and a smooth transition at the metallicity of the thick disk/halo interface. The vertical behaviour of the metallicity distribution function was also studied. A vertical metallicity gradient in the disk of $\partial[Fe/H]/\partial|Z|$ = -0.19 ± 0.14 dex/kpc was marginally detected at the 1.4 sigma level. The [Ti/Fe] and [Ca/Fe] vs [Fe/H] trends for the stars are determined. The main result of the analysis is that the trends of [Ca/Fe] vs [Fe/H] and [Ti/Fe] vs [Fe/H] show no significant difference close (i.e. $|Z| \leq 1$ kpc) and farther away ($1 < |Z| < 2.5$ kpc) from the Galactic plane. This suggests that thick disk gas and stars have been enriched by the same proportion of type II and type I super-novae from the galactic plane up to at least 2.5 kpc. These results support thick disk formation scenarios like collapse or gas-rich accretion and disfavour a thick disk formed of stars captured during a merger event.

Keywords: Milky Way, thick disk, spectroscopy, spectral analysis

1 The Milky Way thick disk

The Milky Way is a spiral galaxy having 3 main components: the bulge, the disk and the halo. In the beginning of the 80s, stellar counts studies proposed the existence of 2 disk sub-components: the thin and the thick disk (Gilmore & Reid 1983). The formation of the Milky Way thick disk is still an open question. Many scenarios are suggested. A few examples are the accretion of the thick disk stars though a satellite (Abadi et al. 2003), the heating of a pre-existing thin disk by minor mergers (Qu et al. 2011), gas-rich accretion in the early Galaxy formation (Brook et al. 2004), stellar mixing and/or migration (Schönrich & Binney 2009).

Stars keep the chemical signature of the interstellar matter they were formed in. At the end of their lives massive stars return their nuclear products to the interstellar medium through stellar winds and supernovae, enriching it with heavier elements. The elemental abundance pattern of every generation of stars thus depends on the previous one. In principle, this allows for the star formation history of a galaxy to be traced using stellar elemental abundances (Freeman & Bland-Hawthorn 2002). To the stellar life cycles are added the different phenomena the Galaxy might have gone through: minor or major mergers, continuous gas accretion, etc... Each occurrence leaves chemical characteristics signatures upon the Galaxy and its components (e.g. relation between the elemental abundances, metallicity gradients etc...).

The work presented hereafter aims to bring new constraints to the scenarios of formation of the Milky Way thick disk using its chemical characteristics.

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2 The observations: reduction and analysis using SPADES

200 stars were selected to maximize the number of stars having $|Z| > 1$ kpc. The galactic coordinates of the centre of the observed region are $l = 357°$; $b = -39°$. The stars were observed using the multi-object VLT (Very Large Telescope) spectrograph: Giraffe. They were observed using high resolution setups: HR13 ($R = 22500$) and HR14 ($R = 28800$). No metallicity nor kinematics selections were made, and the sample is dominated by dwarfs and turn-off stars.

The esorex library of the ESO pipeline was used to reduce the data, more precisely the *gimasterbias, gimasterdark, gimasterflat, giwavecalibration,* and *giscience* functions (GIRAFFE Pipeline Team, 2010, "GIRAFFE Pipeline User Manual", VLT-MAN-ESO-19500-3883).

Potential binaries and variable stars were rejected. Because no stellar parameters are available for the stellar sample, a version (coded in Java) of the stellar parameters determination software TGMET (Katz 2001) determines a first estimation of the parameters $T_{\rm eff}$, $\log g$, and [Fe/H]. These values are used as a first value for the SPADES algorithm (Posbic et al. 2012). The stellar parameters ranges are limited by those of the reference grid used. This excludes another part of the stars leaving 123 stars which parameters were determined. Figure 1 gives the distribution of the stellar sample stellar parameters.

Once the stellar parameters determined, the abundances of the stars in Calcium and Titanium are calculated.

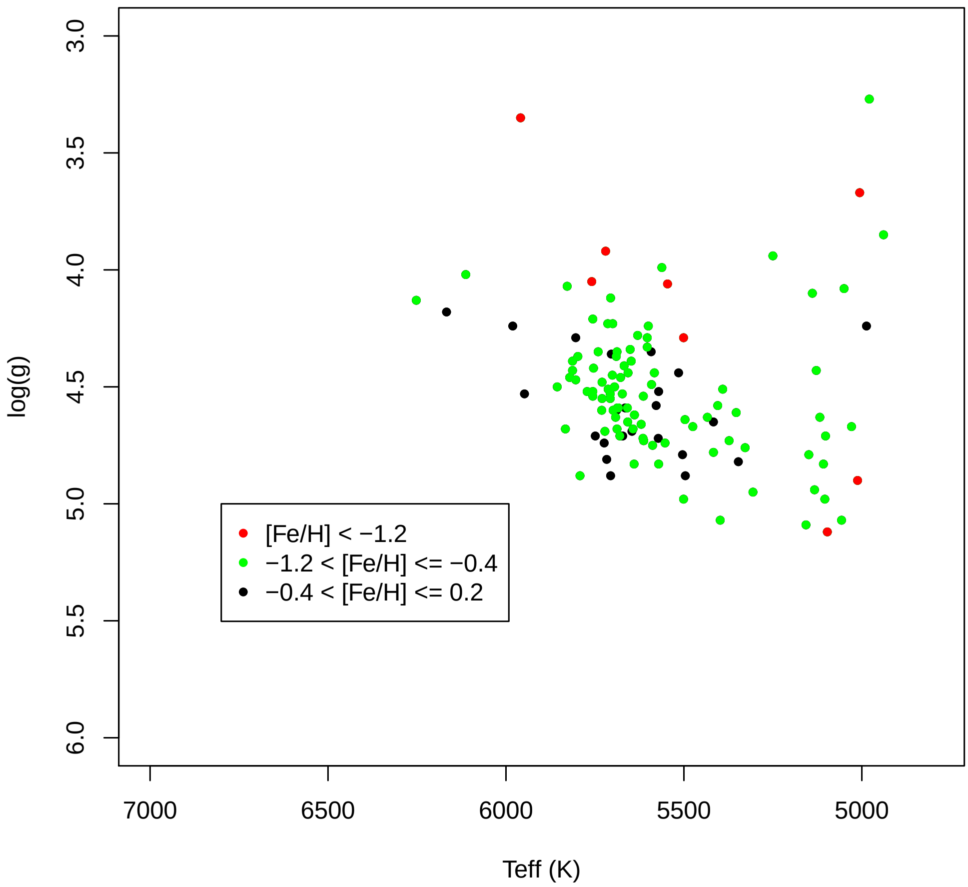

Fig. 1. The distribution of the stellar parameters of the final Giraffe stellar sample: the $T_{\rm eff}$ vs $\log g$ relation in [Fe/H] bins.

Offsets of $\Delta[Ca/Fe] = 0.073$ dex and $\Delta[Ti/Fe] = 0.08$ dex were applied to adjust our abundance scales to the scales of Takeda (2007). The offsets were derived from 5 S4N spectra (Posbic et al. 2012), analysed with SPADES and for which Takeda (2007) provide Ca, Ti and Fe abundances.

The distances (thus the galactic altitude $|Z|$) of the stars are calculated using an isochrones based method.

3 Results

The Metallicity Distribution Function was examined. The possible presence of a vertical metallicity gradient was assessed. To detect and quantify this gradient, the mean [Fe/H] by bins of $|Z|$ were calculated. The mean $|Z|$ of each bin as a function of the mean [Fe/H] of each bin are plotted in Figure 2 along with the calculated error bars. Once a linear regression is used, a mildly significant metallicity gradient with increasing $|Z|$ of a value of -0.19 ± 0.14 dex/kpc is calculated.

The relations between [Ca/Fe] (resp. [Ti/Fe]) and [Fe/H] both near ($|Z| < 1$ kpc) and at large distance ($1 \leq |Z|$ kpc) from the Galactic plane were analysed. These relations are plotted in Figure 3, in black for stars having $|Z| < 1$ kpc and in red for the stars at higher altitudes. No significant difference between the chemical trends inside ($|Z| < 1$ kpc) and outside ($1 \leq |Z|$ kpc) the solar neighbourhood can be detected.

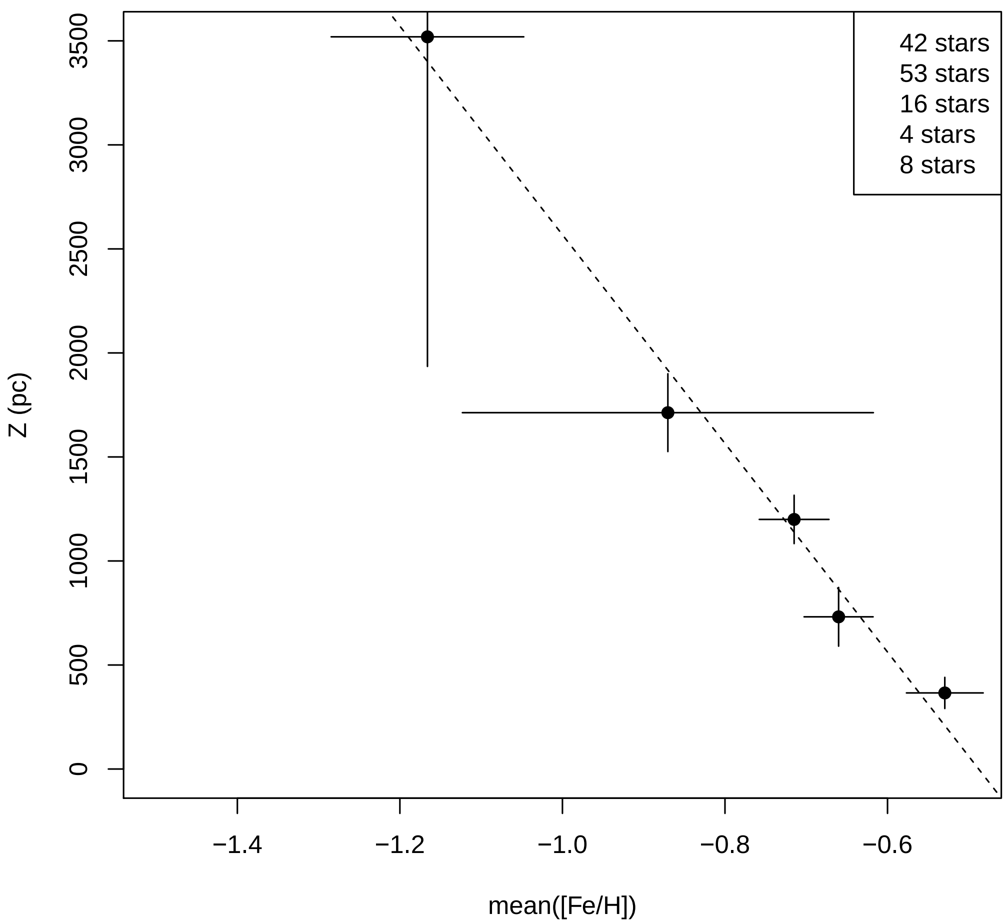

Fig. 2. The mean $|Z|$ of each bin as a function of the mean [Fe/H] of each bin.

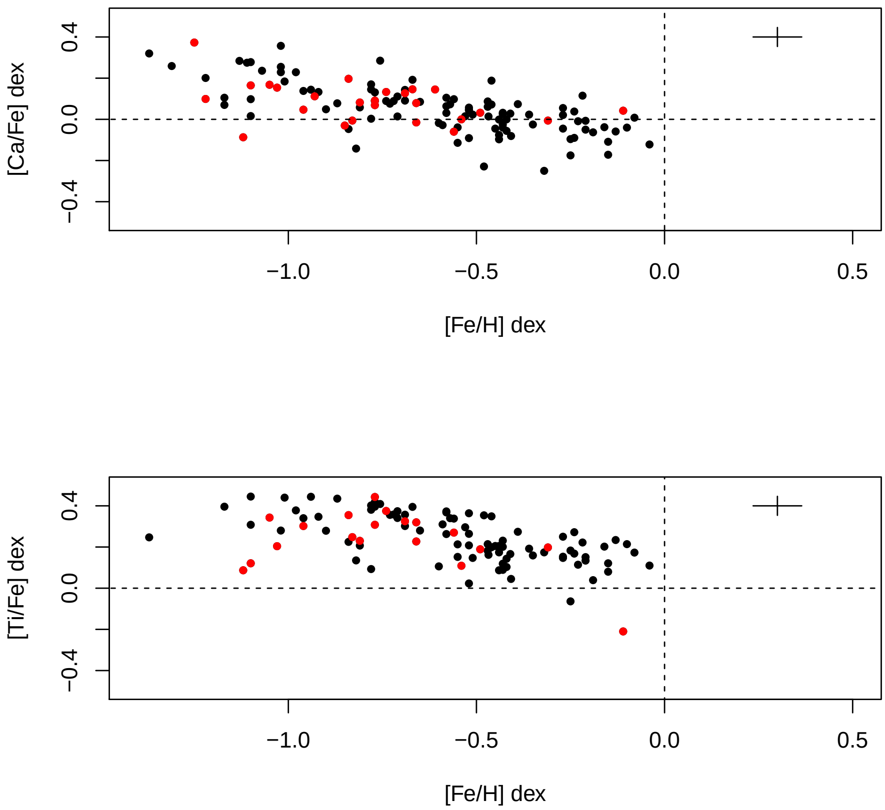

Fig. 3. $[Ca/Fe]$ versus $[Fe/H]$ (top) and $[Ti/Fe]$ versus $[Fe/H]$ (bottom), both near ($|Z| < 1$ kpc in black) and at large distance ($|Z| \geq 1$ kpc in red) from the Galactic plane

Finally the results were confronted to different thick disk formation scenarios. The two constraints[i] considered together, favour (quasi-)monolithic collapse, gas-rich building blocs scenarios or dynamical heating by minor merger(s), while the vertical metallicity gradient would disfavour a thick disk formed of stars captured during a merger event.

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[i]The suspected vertical gradient in the thick disk dominated sample, and the similarity between the abundance trends inside and outside the solar neighbourhood