Is there plenty of metal-poor stars with planets in the Galactic thick disk?

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Abstract.

We performed an uniform spectroscopic analysis of 1111 FGK dwarfs observed
as part of the HARPS GTO planet search program. We applied a purely chemical
approach, based on \([\alpha/Fe]\) ratio, to distinguish the various stellar components in the
Galaxy. Apart from the well known Galactic thick and thin disks, we separated an \(\alpha\)-
enhanced stellar family at super-solar metallicities. The metal-rich high-\(\alpha\) stars have
orbits similar to the thin disk stars, but they are similar to thick disk stars in terms of
age. Our data indicate that the incidence of stars with planets are greater among the
chemically separated thick disk stars with \([Fe/H]\) \(\lesssim -0.3\) dex than they are among thin
disk stars in the same \([Fe/H]\) interval. Our results allow us to suppose that a certain
chemical composition, and not the Galactic birth place of the stars, is the causative
factor for that.

1. Introduction

Shortly, after the discovery of the first extra-solar planet [Gonzalez (1998), based on a
small sample from 8 planet-host stars (PHS), suggested that PHSs tend to be metal-rich
compared with the nearby field FGK stars which are known to hold non-planet. The
metal rich nature of the PHSs was confirmed in subsequent papers (e.g. Santos et al.
2001, 2004). Although theoretical modeling suggests that metallicity is a key param-
ter of planet formation, Haywood (2008, 2009) studying the memberships of PHSs to
different stellar populations, proposed that the presence of giant planets might be pri-
marily a function of a parameter linked to galactocentric radius (density of molecular
hydrogen), but not metallicity and the apparent correlation between metallicity and the
detection of planets is a natural consequence of that. If the rate of giant planets does not
depend on metallicity, then the core accretion theory of planet formation (e.g. Ida & Lin
2004) loses its most important observational support, and it would lend support for the
gravitational instability theory (e.g. Boss 2001).
In this proceeding we present the results for a uniform spectroscopic analysis of 1111 FGK dwarfs in order to study the frequency of the PHSs in different stellar populations.

2. The sample and elemental abundances

The sample used in this work consists of 1111 FGK stars observed within the context of the HARPS GTO programs. The spectra have a resolution of R ~ 110000 and signal-to-noise (S/N) ratio ranging from 20 to 2000. Fifty five percent of the spectra have S/N higher than 200 and about 16% of stars have S/N lower than 100.

Precise stellar parameters for all the stars were taken from Sousa et al. (2011, and references therein). Elemental abundances of refractory elements are determined for the sample stars using a differential LTE analysis relative to the Sun with the 2010 revised version of the spectral synthesis code MOOG and a grid of Kurucz ATLAS9 atmospheres (see Adibekyan et al. 2012, for details).

3. A new $\alpha$-enhanced super-solar metallicity population

Left panel of Fig. 1 shows $[\alpha/\text{Fe}]$ versus $[\text{Fe}/\text{H}]$ for the stars with $T_{\text{eff}} = T_\odot \pm 500$ K ("$\alpha$" refers to the average abundance of Mg, Si and Ti). As can be seen, the stars are clearly separated into two groups according to the content of $\alpha$ elements: the "high-$\alpha$" and the "low-$\alpha$" stars ("thin" disk). This separation highlights the well-known $\alpha$ enhancement of thick disk stars relative to the thin disk found for stars with $[\text{Fe}/\text{H}] < 0$ (e.g. Bensby et al. 2003). It is interesting to see that high-$\alpha$ stars are also divided into two subgroups: high-$\alpha$ metal-rich stars (hereafter "h$\alpha$mr"), and high-$\alpha$ metal-poor stars ("thick" disk). The kinematic separation criteria suggest (see Adibekyan et al. 2011, for details) that most of the stars in the h$\alpha$mr stellar family, such as chemically defined "thin" disk stars, have thin disk kinematics (see right panel of Fig. 1).

![Figure 1](image.png)

Figure 1. Left – $[\alpha/\text{Fe}]$ versus $[\text{Fe}/\text{H}]$ for all stars with $T_{\text{eff}} = T_\odot \pm 500$ K. Open circles refer to "thick" disk and dotes refer to "thin" disk stars, respectively. Crosses refer to the metal-rich high-$\alpha$ stars. Right – The $[\text{Fe}/\text{H}]$ and $[\alpha/\text{Fe}]$ separation histograms for the $\alpha$-enhanced stars.
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Studying the orbital parameters and ages of the three chemically separated groups we observe that metal-rich high-\(\alpha\) (\(h_{\alpha}mr\)) and the "thick" disk stars are on average older than chemically defined "thin" disk stars. Simultaneously the \(h_{\alpha}mr\) stars, such as "thin" disk stars have nearly circular orbits, close to the Galactic plane. Although the present observations suggest that \(h_{\alpha}mr\) stars (high-\(\alpha\), metal rich) may have originated from the inner disk (e.g. inner thick-disk members), they do not allow us to exclude the possibility that they represent a whole new Galactic population. More observations are needed to resolve this uncertainty.

4. Planet-host stars in different stellar "families"

In our sample we have 135 planet hosts and 976 stars with no known orbiting planet. The left panel of Fig. 2 shows the distribution of planet-host and non-host stars in the \([\alpha/Fe] vs [Fe/H]\) space. In the high metallicity region ([Fe/H] > 0) the frequency of Jovian host stars which are also enhanced by \(\alpha\) elements is higher (30.0 ± 8.3 %) than the one for the hosts with low-\(\alpha\) content (19.6 ± 2.2 %).

![Figure 2. \([\alpha/Fe] versus [Fe/H] and [\alpha/Fe] versus [Ref/Fe] for the total sample. The symbols for non host stars are the same as in Fig. 1. Black dots represent the non-host stars, red squares refer to the Jovian hosts and blue triangles refer to the stars hosting exclusively Neptunians and super-Earths.](image)

Higher frequency rate of PHSs is observed in the "very" metal-poor region ([Fe/H] \(\lesssim\) -0.3), where 8 hosts from 10 have high \([\alpha/Fe]\) values (see also Adibekyan et al., 2012b submitted to A&A). The aforementioned \(\alpha\)-enhanced hosts are belonging to chemically defined "thick" disk, and the remaining 2 to the "thin" disk. Interestingly, this thin/thick proportion changes dramatically when we apply a purely kinematic approach to separate the thin and thick discs. The kinematical separation suggests that 6 or 3 host are from the thick disc, 4 or 6 stars belong to thin disc and 1 or 2 stars can be classified as transition stars depending on the kinematic criteria used - [Bensby et al. (2003)] or [Reddy et al. (2006)], respectively. Note that the plenty of Jovian hosts in the thick disk were reported in Haywood (2008, 2009).

In the Fe-poor regime it is difficult to conclude what is the main reason that most of the PHSs lie in the high-\(\alpha\)/thick-disk region. Following to [Gonzalez (2009), and con-
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Considering "Ref" index which quantifies the mass abundances of Mg, Si and Fe, instead of $[\text{Fe}/\text{H}]$, we can see that the observed plenty of metal-poor PHSs in the thick disc "disappears": most metal-poor planet host stars in the thick disc have the same [Ref/H] distribution as their thin disc counterparts. Moreover, our data show that planet host stars start to have high [$\alpha$/Fe] ratios at lower metallicites when they still belong to the thin disc (see also Adibekyan et al., 2012b submitted to A&A).

Our results allow us to suppose that the certain chemical composition and not the Galactic birth place is the determining factor that most of the metal-poor PHSs lie in the high-\(\alpha\)/thick-disk region. These results also suggest that in general, metals other than iron may also have an important contribution to planet formation if the amount of iron is insufficient to easily form a planet. Five stars out of 8 \(\alpha\)-enhanced metal-poor PHSs are orbiting low mass planets which indicates the importance of the \(\alpha\) elements in the formation of Neptune-like planets in the metal-poor domain.

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