Stars with and without planets: Where do they come from?

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Abstract. A long and thorough investigation of chemical abundances of planet-hosting stars that lasted for more than a decade has finally beared fruit. We explore a sample of 148 solar-like stars to search for a possible correlation between the slopes of the abundance trends versus condensation temperature (known as the T_c slope) both with stellar parameters and Galactic orbital parameters in order to understand the nature of the peculiar chemical signatures of these stars and the possible connection with planet formation. We find that the T_c slope correlates at a significant level (at more than 4σ) with the stellar age and the stellar surface gravity. We also find tentative evidence that the T_c slope correlates with the mean galactocentric distance of the stars (R_{mean}), suggesting that stars that originated in the inner Galaxy have fewer refractory elements relative to the volatile ones. We found that the chemical "peculiarities" (small refractory-to-volatile ratio) of planet-hosting stars is merely a reflection of their older age and their inner Galaxy origin. We conclude that the stellar age and probably Galactic birth place are key to establish the abundances of some specific elements.

1. Introduction

Dozen of studies during the last decade explored the connection between stellar and planetary properties. Naturally, this connection is found to be bidirectional: stellar properties play an important role on planet formation and evolution (e.g. stellar metallicity-giant planet frequency - Gonzalez (1997); Santos et al. (2001)), and the planet formation may have an impact on stellar properties (e.g. extra depletion of lithium in planet-hosting stars - Israelian et al. (2009); Delgado Mena et al. (2014)).

After the first planets discovered, astronomers have been also trying to understand if the stars hosting planets are chemically peculiar (in terms of individual elements) and even to search for chemical signatures of planet formation on the hosting stars atmospheres. For the first part the most significant result was recently obtained by Adibekyan et al. (2012a,b) who found that most of the metal-poor planet hosts are enhanced in α-elements. For the second part (chemical imprints of planet formation) the results are still feeding a lively debate.

Several studies suggested that the chemical abundance trend with the condensation temperature, T_c, is a signature of terrestrial planet formation (e.g. Meléndez et al. 2009; Ramírez et al. 2009). In particular, that the Sun shows "peculiar" chemical abundances because of the presence of the terrestrial planets in our solar system (Meléndez et al. 2009). Although these conclusions have been strongly debated in other studies (e.g. González Hernández et al. 2010, 2013, hereafter GH10,13), the main reason of the observed chemical "peculiarities" was not identified.

Here we explore the origin of the trend observed between [X/H] (or [X/Fe]) and T_c using a sample of 148 solar-like stars from GH10,13. The more detailed analysis and complete results are presented in Adibekyan et al. (2014).

2. Data

Our initial sample is a combination of two samples of solar analogs (95 stars) and "hot" analogs (61 stars) taken from GH10,13. We have cross-matched this sample with the Geneva-Copenhagen Survey sample (GCS- Nordström et al. 2004), for which Casagrande et al. (2011) provides the Galactic orbital parameters, the space velocity components, and the ages of 148 of the stars considered in our study[1]. Fifty-seven of these stars are planet hosts, while for the remaining 91 no planetary companion has been detected up to now.

The stellar atmospheric parameters and the slopes of the Δ[X/Fe]$_{SUN-star}$ versus T_c were derived using very high-quality HARPS spectra[2]. Twenty-five elements from C (Z = 6) to Eu (Z = 63) have been used for this analysis. These slopes are corrected for the Galactic chemical evolution trends as discussed in GH10,13.

The stars in the sample have effective temperatures 5604 $K \leq T_{eff} \leq 6374$ K, metallicites -0.29 $\leq$ [Fe/H] $\leq$ 0.38 dex, and surface gravities 4.14 $\leq \log g \leq$ 4.63 dex. Throughout the paper we defined solar analogs as stars with; T_{eff} = 5777$\pm$200 K; logg = 4.44$\pm$0.20 dex;

[1]Throughout the paper, BASTI expectation ages are used as suggested by Casagrande et al. (2011).

[2]Zero slope means solar chemical composition, and a positive slope corresponds to a smaller refractory-to-volatile ratio compared to the Sun.

[Fe/H] = 0.0±0.2 dex. Fifteen out of 58 solar analogs in this sample are known to be orbited by planets.

3. Correlations with T_c slope

We searched for possible correlations between the T_c slope and, in turn, atmospheric parameters, and also Galactic orbital parameters and age, in order to understand which is/are the main factor(s) possibly responsible for the abundance trends with T_c.

3.1 T_c slope against stellar parameters and age

After a detailed analysis, we found that the T_c trend strongly relates (at more than 4σ) with the surface gravity and stellar age (see Figure 1): old stars are more "depleted" in refractory elements (smaller refractory-to-volatile ratios) than their younger counterparts. At the same time we found no significant correlation of the T_c slope with other stellar parameters.

Since for FGK dwarf stars in the main sequence one does not expect significant changes in their atmospheric chemical abundances with age, we are led to believe that the observed correlation is likely to reflect the chemical evolution in the Galaxy. We note that this is the simplest assumption we can make based on our limited current knowledge of stellar evolution, and we caution the reader that there might be other effects that could severely affect the composition of stars as a function of age .

3.2 T_c slope and Galactic orbital parameters

Moving one step further, we found a tentative evidence that the T_c slopes correlate also with the mean galactocentric distance of the stars (R_{mean}), which we use as a proxy of the birth radii (see Figure 2)[3]. This trend is indicating that stars which have originated in the inner Galaxy have less refractory elements relative to the volatiles. This result qualitatively agrees with the recent observations of Galactic abundance gradients by Lemasle et al. (2013), where the authors used young Galactic Cepheids for the gradient derivations.

3.3 Tc slope and planets

Following our definition of solar analogs, we found that the average of the T_c slope for planet hosting solar analogs is greater (0.012±0.31) than that of their non-host counterparts (-0.16±0.34). The Kolmogorov-Smirnov (K-S) statistics predict the ≈ 0.21 probability (P_{KS}) that these two subsamples came from the same underlying distribution for T_c slope. At the same time, the same statistics predict a $P_{KS} \approx 0.20$ probability that they stem from the same underlying age distributions. The latter can be seen in Figure 1: most of the planet-hosting stars tend to be relatively old (> 5 Gyr). Moreover, planet host and non-host samples show a different distribution of $R_{mean} - P_{KS} \approx 0.007$. As can also be seen in Figure 2, 66% planet hosts have R_{mean} smaller than 7.5 kpc (where slopes are usually high) and only 37% of stars without detected planets have similarly low R_{mean} values. Clearly the two subsamples are not consistent with respect to the mean galactocentric distance and age. Interestingly,

[3] Several studies have shown that the mean of the apo- and pericentric distances, R_{mean}, are good indicators of the stellar birthplace (e.g. Grenon 1987; Edvardsson et al. 1993)

Haywood (2009) has already shown that (giant) planet host stars tend to have smaller R_{mean} and probably originate in the inner disk, which follow the same direction as our findings.

These results suggest that the difference in T_c slopes observed for solar analogs with and without planets is then probably due to the differences in their "birth places" and birth moment.

4. Conclusion

Our findings lead us to two interesting conclusions i) The solar analogues with planets in the solar neighborhood mostly come from the inner Galaxy (because of still unknown reason) and ii) the age and galactic birth place are the main factors responsible for the abundance ratio of refractory to volatile elements in the stars.

Acknowledgements. This work was supported by the European Research Council/European Community under the FP7 through Starting Grant agreement number 239953. V.Zh.A., S.G.S., and E.D.M are supported by grants SFRH/BPD/70574/2010, SFRH/BPD/47611/2008, and SFRH/BPD/76606/2011 from the FCT (Portugal), respectively. NCS also acknowledges support in the form of a Investigador FCT contract funded by FCT/MCTES (Portugal) and POPH/FSE (EC). G.I., S.B.L, and J.I.G.H. acknowledge financial support from the Spanish Ministry project MINECO AYA2011-29060, and J.I.G.H. also received support from the Spanish Ministry of Economy and Competitiveness (MINECO) under the 2011 Severo Ochoa Program MINECO SEV-2011-0187. PF is supported by the FCT and POPH/FSE (EC) through an Investigador FCT contract with application reference IF/01037/2013 and POPH/FSE (EC) by FEDER funding through the program "Programa Operacional de Factores de Competitividade - COMPETE.

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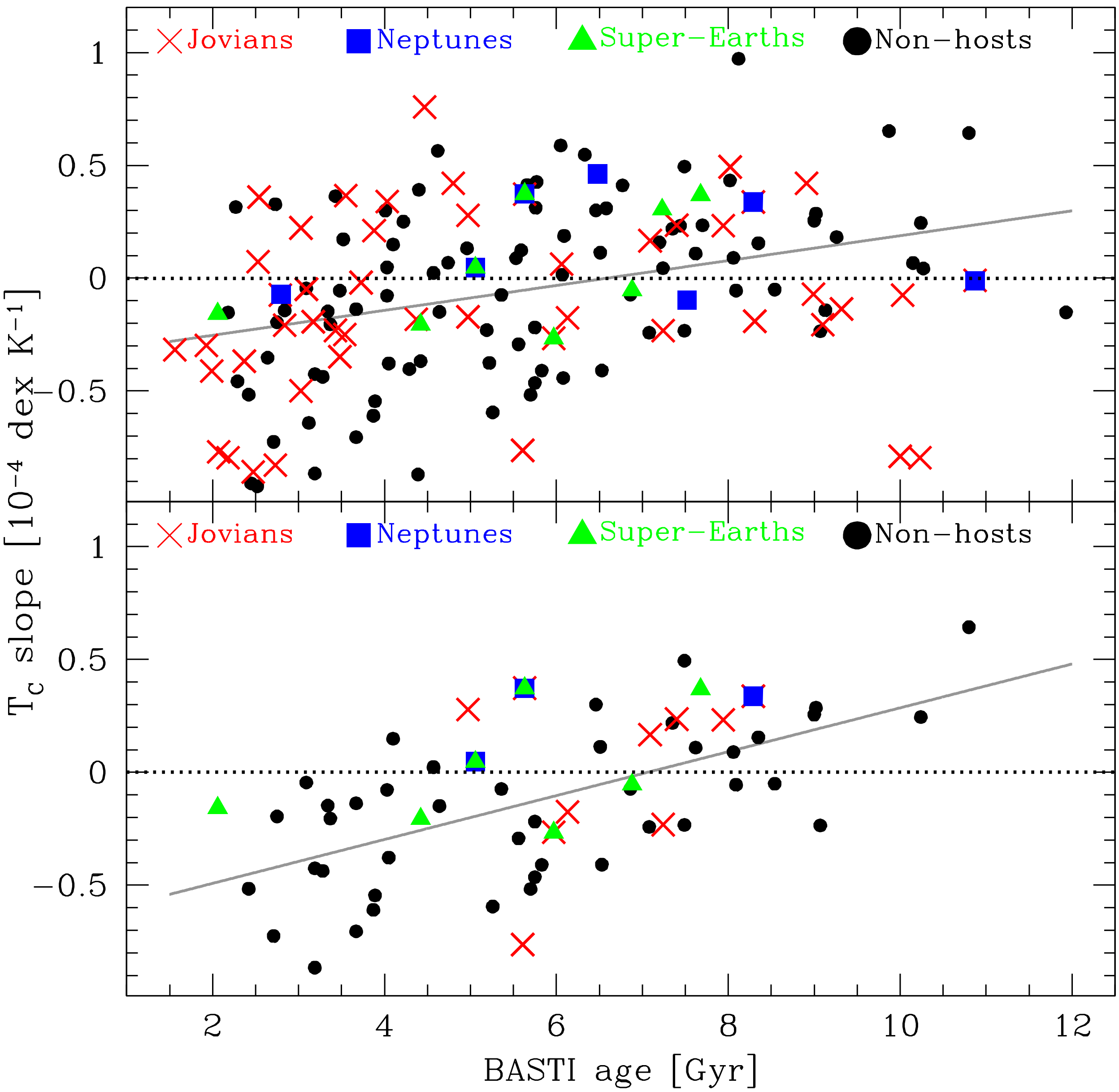

Figure .1: T_c slopes versus ages for the full sample (*top*) and for the solar analogs (*bottom*). Gray solid lines provide linear fits to the data points.

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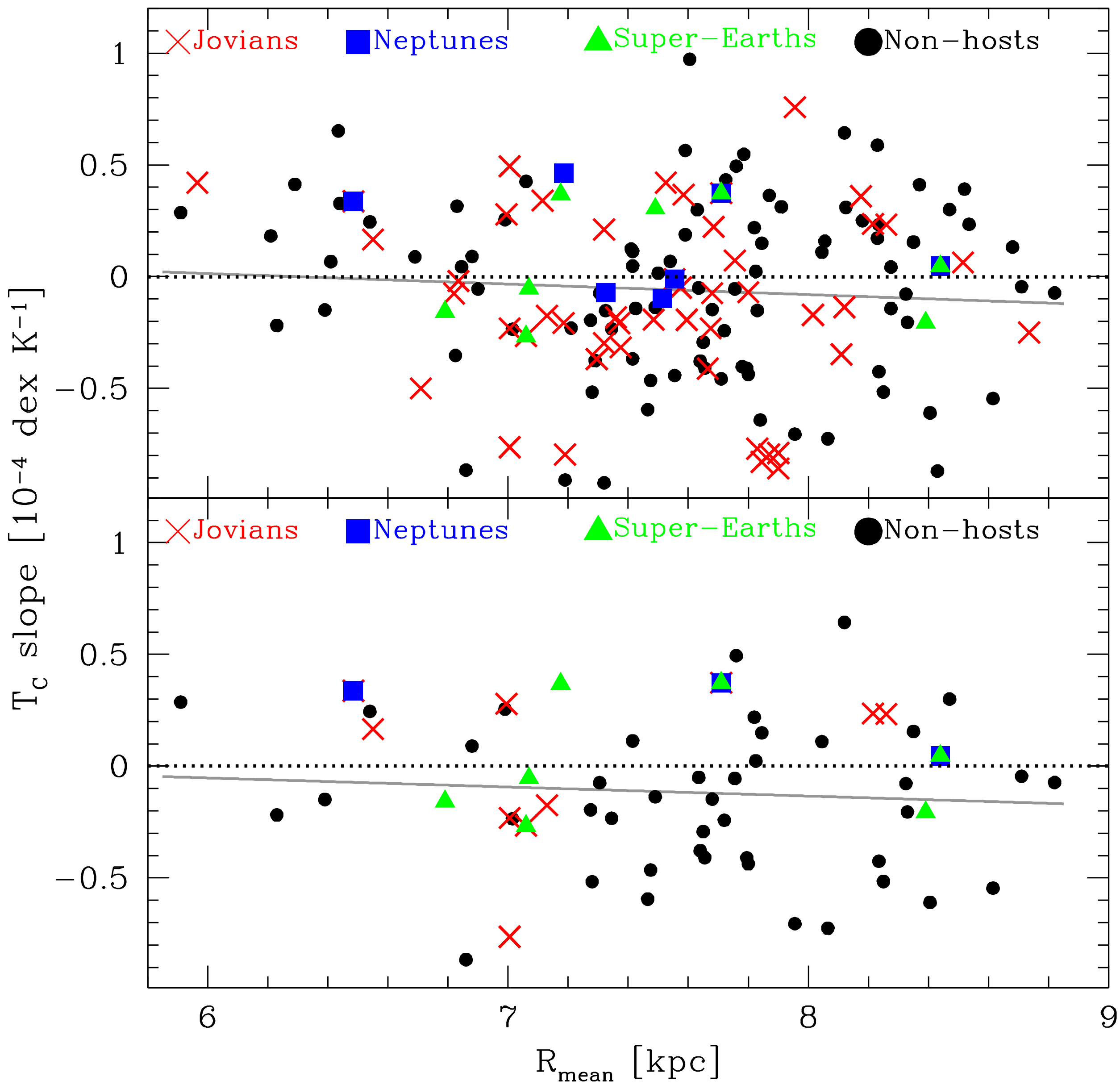

Figure .2: T_c slopes versus R_{mean} for the full sample (top) and for the solar analogs (bottom). Gray solid lines provide linear fits to the data points.