Stars and their variability observed from space
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DO PLANET SYSTEMS INFLUENCE THE HOST STAR ATMOSPHERIC ABUNDANCES ?

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Abstract. The question of how planet formation affects the host-star atmosphere was widely discussed during the last years. We performed a comparative abundance analysis of a sample of stars with and without planets. The observed trends with condensation temperature, relative to the solar atmospheric abundances, are more closely connected to the overall metallicity of the star than to planet formation. Abundance differences for pairs of stars with and without planets but with similar metallicities in the range of −0.15 +0.34 with respect to the Sun do not show any significant trend with the condensation temperature.

Keywords: Spectroscopy, stars, atmospheric parameters, chemical abundances, exoplanets

1 Introduction

The discovery of differences between atmospheric abundances in the Sun and nearby solar twins (Meléndez et al. 2009), and in particular, of differences between abundances in solar analogs hosting giant planets and those without planets triggered massive differential abundance studies of stars hosting planets (see, for example, Schuler et al. 2011b). Meléndez et al. (2009) found a dependence of the abundance differences on the condensation temperature. Fig. 1 (left panel) represents the reconstruction of the abundance correlations found by Meléndez et al. (2009) (Fig. 5 in their paper) in slightly different form where the mean relative-to-solar atmospheric abundances in a group of solar analogs hosting planets shows a clear dependence on the condensation temperature, while the same dependence for non-planet solar analogs is weak/insignificant. The main characteristic of the observed correlation is an increase of the refractory elements relative to the volatile ones in comparison with the Sun. Abundance differences between stars without planets and those hosting giant planets also show a weak correlation with the condensation temperature (Fig. 1 – right panel). These correlations were interpreted as an influence of the planet formation on the host-star atmospheric abundances. An excellent possibility to study in detail the effects of planet formation on host-star atmospheres is provided by the differential analysis of wide binary systems in which one of the components hosts a planet and the other one does not. The best candidate is the 16 Cyg system where the secondary is a planet-hosting star (Cochran et al. 1997). I present the results of abundance analyses of both components performed with different combinations of the components' atmospheric parameters. The effect of the overall stellar metallicity on the abundance correlation with the condensation temperature is also studied.

2 Sample of stars, observations and data analysis

For the analysis we chose a sample of three pairs of stars with similar metallicities [M/H] in the range of −0.17 to +0.34 dex. One pair represents the binary system 16 Cyg. The list of the stars with the derived atmospheric parameters is given in Table 1.

Spectra were obtained with the ESPaDONs spectrograph at the Canada-France-Hawaii Telescope* (CFHT) of 16 Cyg and HD 149026 and with the Keck HiReS spectrograph (Howard et al. 2010) of the other stars. Details of the reduction procedure and atmospheric parameter determination are given by Ryabchikova et al. (2016). We used the Spectroscopy Made Easy (SME) package (Valenti & Piskunov 1996; Piskunov & Valenti 2017) with the LLmodels (Shulyak et al. 2004) grid for 16 Cyg, HD 149026, and with the MARCS model grid (Gustafsson et al. 2008) for the other stars. Abundances of 25 elements including ions were derived from the line-profile fitting of about 350 spectral lines.

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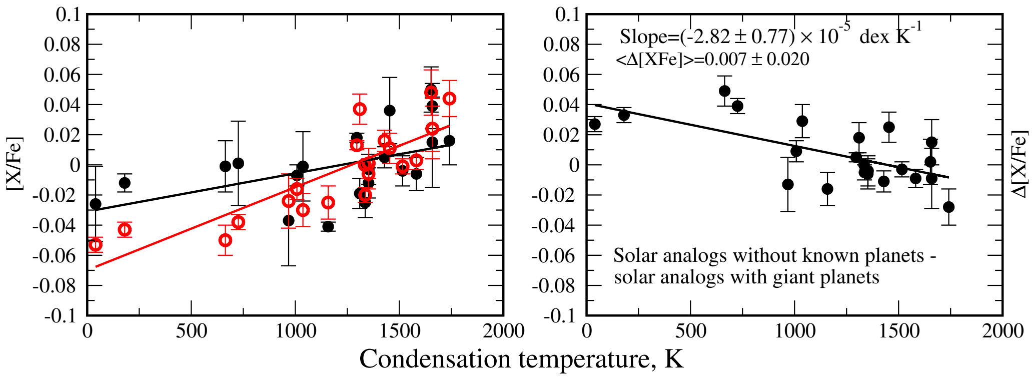

Fig. 1. Left: Differences [X/Fe] between the mean metallicity values in solar analogs and in the Sun as a function of element condensation temperature. Stars hosting planets are shown by black filled circles and those without detected planets are shown by red open circles. Linear regressions for both groups are indicated by lines. Based on the data from Fig. 5 of Meléndez et al. (2009). **Right:** Abundance differences between both groups.

Table 1. Parameters of the programme stars. The errors are given in parentheses.

Stars without planets				Stars with planets			
Star	$T_{\rm eff}$,K	$\log g$	[M/H]	Star	$T_{\rm eff}$,K	$\log g$	[M/H]
HD 107211	5789(80)	4.20(29)	0.34(06)	HD 149026	6074(82)	4.18(29)	0.24(06)
16 Cyg A	5829(39)	4.30(11)	0.09(03)	16 Cyg B	5773(40)	4.38(09)	0.07(03)
HD 209203	6160(80)	4.29(29)	-0.17(09)	HD 50554	5972(80)	4.31(30)	-0.12(07)

3 Abundance correlations

3.1 16 Cyg

First, we consider the binary system 16 Cyg, which has nearly identical components with atmospheric parameters close to the solar ones. In this case we can perform a differential analysis of the components directly not involving the Sun to see if there is any abundance difference between component 16 Cyg A without planet and 16 Cyg B hosting a giant planet. Note, that both components are considered to have formed from the same material.

In 2011, Ramírez et al. (2011) and Schuler et al. (2011a) performed abundance analyses of the 16 Cyg system. They found a correlation of the abundances with the condensation temperature in both components similar to that shown in Fig. 1 (left panel) but no correlation in abundance differences between components A and B. Later, a very careful abundance study of 16 Cyg was performed by Tucci Maia et al. (2014); Maia et al. (2019). They found abundance correlations in both components as well as a correlation of abundance difference with condensation temperature. Their results are represented in Fig. 2 (left panel). Atmospheric parameters derived in both papers are given in Table 2. We also add $T_{\rm eff}$ obtained from interferometry (White et al. 2013) and $\log g$ obtained from asteroseismology (Metcalfe et al. 2015) as independent parameter determinations through direct methods. Then we performed abundance analyses of the components of 16 Cyg by the methods given above using our spectroscopically determined atmospheric parameters and those derived by the direct methods. Note that we employed the same spectra as Tucci Maia et al. (2014). Differential abundances (averaged line-by-line differences) as a function of the condensation temperature are shown in Fig. 2. The plots demonstrate the variations of the slope of the linear correlation with the temperature difference between the components. While $T_{\rm eff}$ of the primary is practically the same in all investigations, 5834±4 K, for the secondary we have a range of $5750 \leq T_{\rm eff} \leq 5809$. With the largest temperature difference of 80 K, derived by Tucci Maia et al. (2014), we have a positive correlation, while the interferometric estimates give us the minimal temperature difference, 30 K, and produce a negative correlation. Our own analysis results in a temperature difference of 56 K, and any correlation is practical absent. If the overall abundance difference of 0.02 dex found by us is considered significant, the planet formation around 16 Cyg B has resulted in a negligible depletion of the atmosphere of 16 Cyg B in all elements.

Table 2. Parameters of the 16 Cyg system from different studies

	$T_{\rm eff}$,K	$\log g$	[M/H]	$T_{\rm eff}$,K	$\log g$	[M/H]	$T_{\rm eff}$,K	$\log g$
16 Cyg A	5830(11)	4.30(02)	0.101(008)	5834(5)	4.330(013)	0.103(005)	5839(42)	4.292(003)
16 Cyg B	5751(11)	4.35(02)	0.054(008)	5749(4)	4.360(011)	0.052(003)	5809(39)	4.358(002)
Reference		1			2		3	4

References: (1) Tucci Maia et al. (2014); (2) Maia et al. (2019); (3) White et al. (2013); (4) Metcalfe et al. (2015)

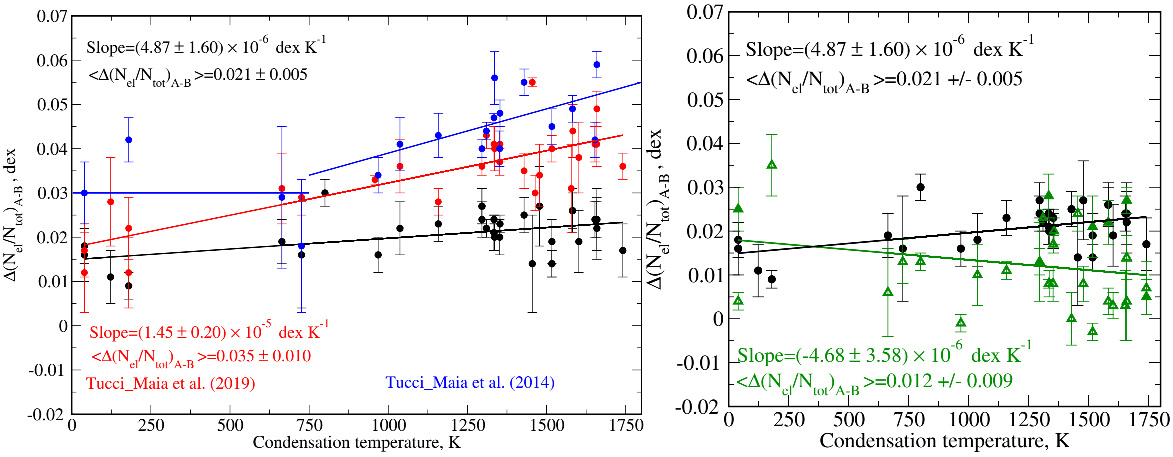

Fig. 2. Left: Differential abundances in the 16 Cyg system as a function of the condensation temperature. Results of the present study are shown by filled black circles, while blue and red filled circles represent the results from Tucci Maia et al. (2014) and Maia et al. (2019), respectively. Linear regression lines, the slopes and the mean abundance differences are indicated by the corresponding colours. The masses of the planets are given. **Right:** Same as left panel except for atmospheric parameters determined by the direct methods of interferometry and asteroseismology (green triangles).

3.2 Metallicity effect

From six selected stars, we formed three pairs by metallicity. The results of the pairwise differential analyses are plotted on Fig. 3. One can see large abundance variations (relative to the Sun) with the condensation temperature for high-metallicity stars and a de facto absence of such variations for low-metallicity stars, independently of the presence of a planet. At the same time, line-by-line abundance differences between stars with and without planets do not show any significant dependence on the condensation temperature, and their average values simply reflect differences in overall stellar metallicity.

4 Conclusions

Our analysis shows that the observed variations of the atmospheric abundances (relative to the Sun) with condensation temperature are similar for the planet/non-planet stars of similar metallicities. The amplitude of these variations depends on the metallicity, coming close to zero at low metallicity. We did not find any significant trends in atmospheric abundances differences with the condensation temperature for stars having giant planets and without detected planets. We propose that the observed abundance trends are rather connected with the overall metallicity of the star than with planet formation, although more extensive studies are required to support this result.

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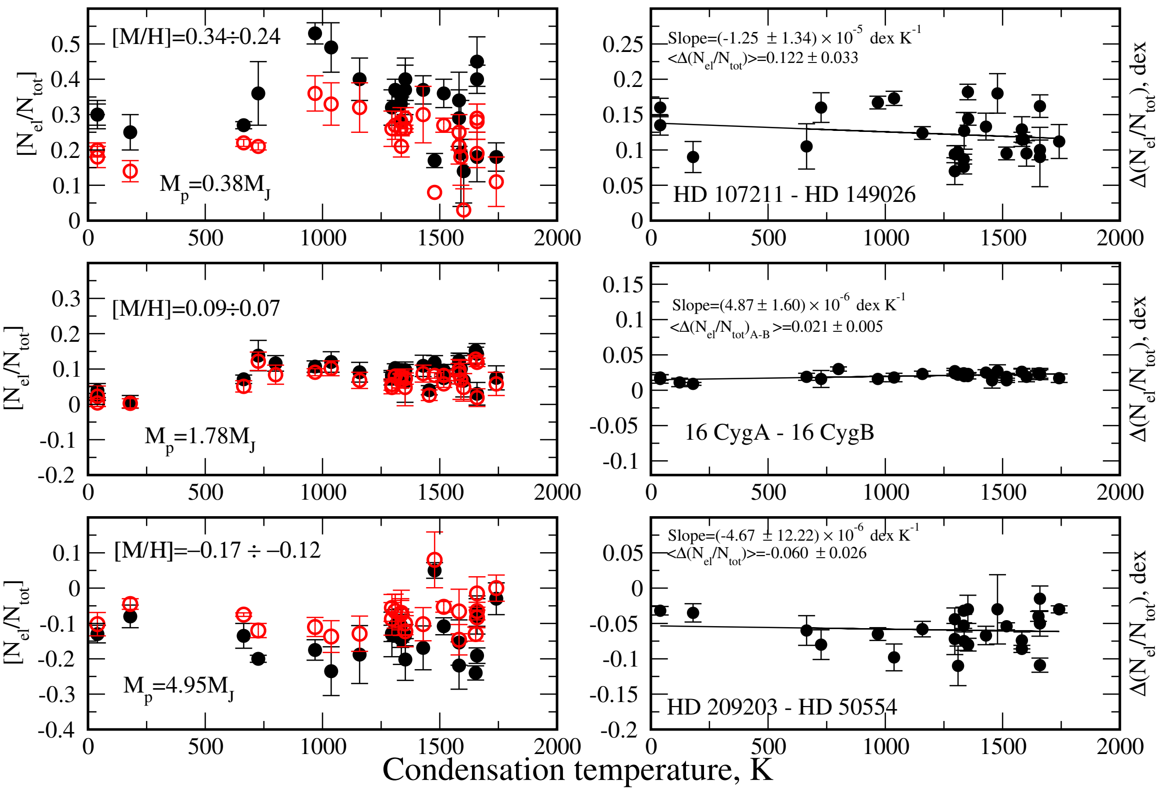

Fig. 3. Left: Differential atmospheric abundances of the programme stars relative to the Sun as a function of condensation temperature. Star without detected planets are shown by filled black circles, those with giant planets by open red circles. **Right:** Line-by-line differences between stars without detected planets and with giant planets as a function of the condensation temperature. The slopes and mean difference are given for each pair of stars.

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