Parent stars of extrasolar planets – XII. Additional evidence for trends with $v \sin i$, condensation temperature and chromospheric activity

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ABSTRACT

Several recent studies have reported differences in $v \sin i$, abundance–condensation temperature trends and chromospheric activity between samples of stars with and without Doppler-detected planets. These findings have been disputed, and the status of these results remains uncertain. We evaluate these claims using additional published data and find support for all three.

Key words: stars: abundances – planetary systems.

1 INTRODUCTION

Stars with planets (SWPs) detected with the Doppler method have been shown to be more metal rich (Gonzalez 1997; Santos, Israeli & Mayor 2001; Valenti & Fischer 2005) and more massive (Laws et al. 2003; Johnson et al. 2010) as a group when compared to similar stars without detected planets (non-SWPs). Recently, SWP and non-SWPs have also been reported to differ in $v \sin i$ (Gonzalez 2008; Gonzalez, Carlson & Tobin 2010a), abundance–condensation temperature ($T_c$) trends (Melendez et al. 2009; Ramirez, Melendez & Asplund 2009; Gonzalez, Carlson & Tobin 2010b; Ramirez et al. 2010), Li abundance (Gonzalez 2008; Israelian et al. 2009; Gonzalez & Asplund 2009; Gonzalez, Carlson & Tobin 2010b; Ramirez et al. 2010) and chromospheric activity (Gonzalez 2008), but each of these findings has been disputed. Alves, Do Nascimento & de Madeiros (2010) did not find a significant difference in $v \sin i$ between their samples of SWPs and non-SWPs. Baumann et al. (2010) found the Li abundance distributions to be indistinguishable between their samples of solar analogue SWPs and non-SWPs. Gonzalez Hernandez et al. (2010) do not find a significant difference in abundance–$T_c$ trends between their samples of solar analogue SWPs and non-SWPs. Finally, Canto Martins et al. (2011) do not find a significant difference in chromospheric activity between their samples of SWPs and non-SWPs.

The purpose of the present study is to revisit these controversies using published data and the method of analysis described in our recent series of papers (Gonzalez 2008; Gonzalez et al. 2010a,b). The paper is organized as follows. In Section 2 we compare the $v \sin i$ distributions between SWPs and non-SWPs. In Section 3 we examine abundance–$T_c$ trends. We compare chromospheric activity in Section 4. We summarize our results in Section 5.

2 $v \sin i$

Gonzalez (2008) and Gonzalez et al. (2010a) compared $v \sin i$ values of SWPs and non-SWPs using two samples. One of the samples was based on the extensive data set of Valenti & Fischer (2005), which remains the best data for comparing SWP and non-SWP $v \sin i$ values. However, since we completed our most recent analysis using their data, many new exoplanets have been discovered. The presence of undiscovered planets among the non-SWPs has been a source of unavoidable systematic error, but it is one that is becoming less important as new planets are discovered.

The full sample of stars from Valenti & Fischer (2005) contains 1040 dwarfs; at the time of the paper’s publication 85 of these stars with $T_{\text{eff}} > 5500 \text{ K}$ were known to host Doppler-detected planets. To form our subsample, we first calculated the absolute visual magnitudes using the recalibrated Hipparcos parallaxes and then excluded those stars with a parallax value less than 10 times the parallax error. Next, we excluded stars with $T_{\text{eff}} < 5500 \text{ K}$ and $T_{\text{eff}} > 6450 \text{ K}$; this is slightly broader than the range we had used in Gonzalez et al. (2010a), 5550–6250 K. Our final sample contains 99 SWPs and 627 non-SWPs. This compares to 82 SWPs and 594 non-SWPs used in Gonzalez et al. (2010a).1

We applied our method of analysis described in Gonzalez (2008) and Gonzalez et al. (2010a) to the present data. In brief, we calculated a weighted-average difference between the $v \sin i$ value of an SWP and the $v \sin i$ values of all the comparison stars using the inverse square of the $\Delta_1$ index as the weight. The $\Delta_1$ index is a measure of the distance between two stars in $T_{\text{eff}}$–log g–[Fe/H]–$M_V$ parameter space. We have made one minor change to this procedure compared to our previous studies. Previously, we had used [Fe/H] as one of the parameters needed to calculate the $\Delta_1$ index. However, using [Fe/H] could lead to a systematic error when thick disc stars are in the sample, since they have a different value of [$\alpha$/Fe] compared to thin disc stars. When we are considering the possible dependence of planet formation on composition, [M/H] is a better index to use than [Fe/H] (Gonzalez 2009). Therefore, we have replaced [Fe/H] with [M/H] when calculating the $\Delta_1$ index.

1 Note that the numbers of SWPs and non-SWPs in the present study with $5550 < T_{\text{eff}} < 6250 \text{ K}$ are 93 and 578, respectively.
We show in Fig. 1(a) the bias-corrected weighted-average $v\sin i$ differences between the SWP and non-SWP samples ($\Delta v\sin i$). We corrected the $\Delta v\sin i$ values for bias in the same way as described in Gonzalez et al. (2010a). Briefly, the method involves splitting the non-SWP sample into two subsamples. We then calculated $\Delta v\sin i$ values from these subsamples in the same way as was done with the original SWP and non-SWP samples. Any trends in these $\Delta v\sin i$ values with $T_{\text{eff}}$ are considered biases. The results presented in Fig. 1(a) resemble those in fig. 12 of Gonzalez et al. (2010a), which was also based on the data of Valenti & Fischer (2005). As in Gonzalez et al. (2010a), we subtracted the average linear bias trend from the non-SWP $\Delta v\sin i-T_{\text{eff}}$ data from the SWP $\Delta v\sin i$ values. However, as is evident in fig. 11 of Gonzalez et al. (2010a), the required bias correction is not quite linear with $T_{\text{eff}}$.

For this reason, we also corrected for bias using a second method. We calculated the $v\sin i$ difference values in increments of 100 K using the non-SWP sample and applied these offsets to the $v\sin i$ differences between the SWPs and non-SWPs. We show the results of this approach in Fig. 1(b). The overall pattern is similar to that in Fig. 1(a), but the distribution of $v\sin i$ differences is flatter between 5500 and 6000 K. The average $\Delta v\sin i$ value for the data plotted in Fig. 1(b) between these two temperatures is $-0.46 \pm 0.96$ (s.e.) $\pm 0.11$ (s.e.m.) km s$^{-1}$. The corresponding average $\Delta v\sin i$ value determined by Gonzalez et al. (2010a) from the Valenti & Fischer (2005) data is $-0.66 \pm 1.08$ (s.e.) $\pm 0.13$ (s.e.m.) km s$^{-1}$ (for $T_{\text{eff}} = 5550$–$6000$ K).

### 3 TRENDS WITH $T_{\text{eff}}$

Valenti & Fischer (2005) reported the abundances of five elements: Na, Si, Ti, Fe and Ni. While this is a small number of elements for our analysis, their $T_{\text{eff}}$ values span nearly the same range as the more extensive set of elements employed by Gonzalez et al. (2010b).

In addition, the Valenti & Fischer (2005) data set is large and the abundances have small uncertainties. The samples of SWPs and non-SWPs we use in these sections are the same ones we used for the $v\sin i$ analysis above.

We calculated the abundance–$T_{\text{eff}}$ slope for each star with simple linear least squares. We then calculated the weighted-average $[X/H]_c-T_{\text{eff}}$ differences between the SWPs and non-SWPs using the same procedure as described above. However, in this case the bias corrections are small, allowing us to adjust the data with a simple linear fit, as in Gonzalez et al. (2010b). We show the corrected data in Fig. 2. It resembles the data in fig. 2 of Gonzalez et al. (2010b).

Gonzalez et al. (2010b) also confirmed the discovery by Melendez et al. (2009) that the more metal-rich SWPs display more negative $[X/H]_c-T_{\text{eff}}$ slopes than non-SWPs, while more metal-poor SWPs do not. We find very similar patterns in the current data, which we show in Fig. 3.

### 4 CHROMOSPHERIC ACTIVITY

Isaacson & Fischer (2010) present chromospheric activity measurements of more than 2600 stars on the California Planet Search Program. In particular, they tabulate median values of log $R_{\text{HK}}$, which we use in the following analyses. We cross-referenced their data with the Valenti & Fischer (2005) data and excluded stars with $T_{\text{eff}} < 5500$ K and $T_{\text{eff}} > 6420$ K; we also applied the same parallax quality cut used above in our $v\sin i$ analysis. These cuts resulted in samples of 63 SWPs and 364 non-SWPs. We calculated weighted differences in log $R_{\text{HK}}$ using these two samples and corrected for bias using the same method used to produce Fig. 1. We show the results in Fig. 4.

The differences between the SWPs and non-SWPs are readily apparent in Fig. 4(a). However, we should be cautious in how we interpret this result. The SWP log $R_{\text{HK}}$ values range from $-5.117$ to $-4.610$, while they range from $-5.206$ to $-3.879$ for the non-SWPs. The apparent negative differences in log $R_{\text{HK}}$ for the majority of SWPs, then, could be due, in part, to the excess number of active
There are far fewer SWPs with negative mean differences in log $R'_{\text{HK}}$ in Fig. 4(b) compared to Fig. 4(a). However, a trend is still evident. A linear least-squares fit to the data yields a slope of $(1.33 \pm 0.58) \times 10^{-4}$ K$^{-1}$; the mean weighted difference is zero at $T_{\text{eff}} = 5925$ K. The Pearson correlation coefficient for the data in Fig. 4(b) is 0.283. This translates into a 5 per cent probability that the trend is due to chance alone.

The truth should lie somewhere between Figs 4(a) and (b). While the more conservative cut in log $R'_{\text{HK}}$ values employed in preparing Fig. 4(b) excludes stars that are much more active than any SWPs in our sample, it probably also excludes some stars whose log $R'_{\text{HK}}$ values would not prevent Doppler detection of planets. For instance, HD 22049 has a log $R'_{\text{HK}}$ value near $-4.5$, 0.1 unit larger than our cut-off.

We do not know why our conclusions are different from those of Canto Martins et al. (2011), but we do note some differences with their study. First, our samples are very different; we employ a much larger sample of non-SWPs. Secondly, our method of analysis compares SWPs to non-SWPs with similar physical parameters, including age. The log $R'_{\text{HK}}$ index is known to be sensitive to age. Perhaps the difference we uncovered between SWPs and non-SWPs is too subtle to detect with other statistical approaches.

5 CONCLUSIONS

Using an updated version of the method of analysis described in (Gonzalez 2008) and Gonzalez et al. (2010a,b), we have verified that there are significant differences in $v\sin i$, abundance–$T_C$ trends and chromospheric activity between SWPs and non-SWPs. We employed high-quality data from the literature, taking into account new planets that have been discovered since the data were originally published.

We have verified that SWPs have significantly smaller values of $v\sin i$, abundance–$T_C$ slope and $R'_{\text{HK}}$ compared to otherwise similar non-SWPs. For the case of the abundance–$T_C$ slope differences, we also verified that they are significant when comparing stars with $[\text{M/H}] > 0.10$, but not for more metal-poor stars. It is also notable that all three parameters display the largest differences between the SWP and non-SWP samples for $T_{\text{eff}}$ less than about 5900 K.

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