Proceedings of 12th Cambridge Workshop on Cool Stars, Stellar Systems, & The Sun, 2003 University of Colorado.

Beryllium Abundances in Stars Hosting Planets

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Abstract. Very valuable information can be obtained by studying surface chemical abundances in stars with orbiting planets. Possible interactions between extrasolar planets and their parent stars can be studied using light elements as lithium and beryllium, which are excellent tracers of mixing mechanisms operating in the stellar interior. A wide sample of stars hosting planets, with spectral types in the range F7V−K0V, have been observed and their beryllium abundances derived to study in detail the effects of planets on the structure and evolution of their associated stars. Preliminary results suggest that either low-mass planet hosts are anomalously beryllium depleted stars, or theoretical evolutionary models have to be revised for stars with effective temperatures below ~ 5600 K.

1. Introduction

The number of known giant planets is growing continuously, being currently in excess of 60 (including 6 multi-planetary systems). One remarkable observed characteristic appears related to them: stars with planetary companions are considerably metal-rich when compared with single field dwarfs (González et al. 2001; Santos, Israelian, & Mayor 2001). To explain this difference two main possibilities have been suggested. The first and more traditional is based upon the fact that metals are needed to form planets: the more metals present in the proto-planetary disk, the higher the probability of forming a planet. In opposition to this view, the high metal content observed in stars with planets has also been interpreted as a sign of the accretion of high-Z material by the star sometime after it reached the main-sequence (e.g. Laughlin 2000; González et al. 2001). Although recent results seem to favour the former scenario as the key process leading to the observed metal richness of stars with planets (Santos, Israelian, & Mayor 2001), signs of accretion of planetary material have also been found (Israelian et al. 2001). The question is then turned to know how frequent

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those phenomena happen, and to how much this could have affected the observed metal contents.

To help answer these question, one particularly important element to study is beryllium (Be). Together with lithium (Li) and boron, Be is a very important tracer of the internal stellar structure and kinematics. García López & Pérez de Taoro (1998) carried out the first Be measurements in stars hosting planets: 16 Cyg A & B and 55 Cnc, followed by Deliyannis et al. (2000). Beryllium studies have one major advantage when compared with Li. Since it is burned at much higher temperatures, Be is depleted at lower rates than Li, making possible to study Be abundances in stars which have no detectable Li in their atmospheres (like intermediate-age late G- or K-type dwarfs).

In order to address this problem with a sample much larger than those previously observed, we present here a study of Be abundances in a set of 27 stars with planets and in a smaller sample of stars without known planetary companions.

2. Observations and Analysis

Observations of the Be II doublet at 3131 Å were carried out during 4 different observing runs using UVES at the 8m VLT/UT2 (ESO, Chile), UES at the 4.2m WHT and IACUB at the 2.6m NOT (both located at the Observatorio de Roque de los Muchachos, La Palma). The spectra obtained have a resolving power in the range 33000 to 70000 and S/N varying between 30 and 250.

A uniform set of stellar parameters, computed from an accurate spectroscopic analysis, has been assigned to the programme stars. The abundance analysis was done in LTE using a revised version of the code MOOG (Sneden 1973), and a grid of Kurucz (1993) ATLAS9 atmospheres. Be abundances were derived by fitting synthetic spectra to the data, using the same line-list as in García López & Pérez de Taoro (1998). Figure 1 shows two examples of this fitting. Details on the observations, data reduction and analysis can be found in Santos et al. (2001).

3. Beryllium in Stars with Planets

There are many evidences indicating that the depletion of Be is connected with the rotational history of a star. This history may also be related to the presence or not of a (massive) proto-planetary disk, and this may result in different depletion rates for stars which had different disk masses, which may have been able to form the now discovered giant planets. This could, in fact, have been the case for the pair of very similar dwarfs 16 Cyg A & B (the latter having a detected planetary companion), for which their Li abundances seem to be quite different (King et al. 1997; González 1998) but show similar amounts of Be (García López & Pérez de Taoro 1998). On the other hand, if pollution plays some role, we might also expect to detect some differences between stars with planets and stars without planets concerning light element abundances.

Figure 2 shows a plot of Be as a function of effective temperature ($T_{\rm eff}$). Superposed with the measurements are a set of Yale beryllium depletion isochrones from Pinsonneault, Kawaler, & Demarque (1990) for solar metallicity and an

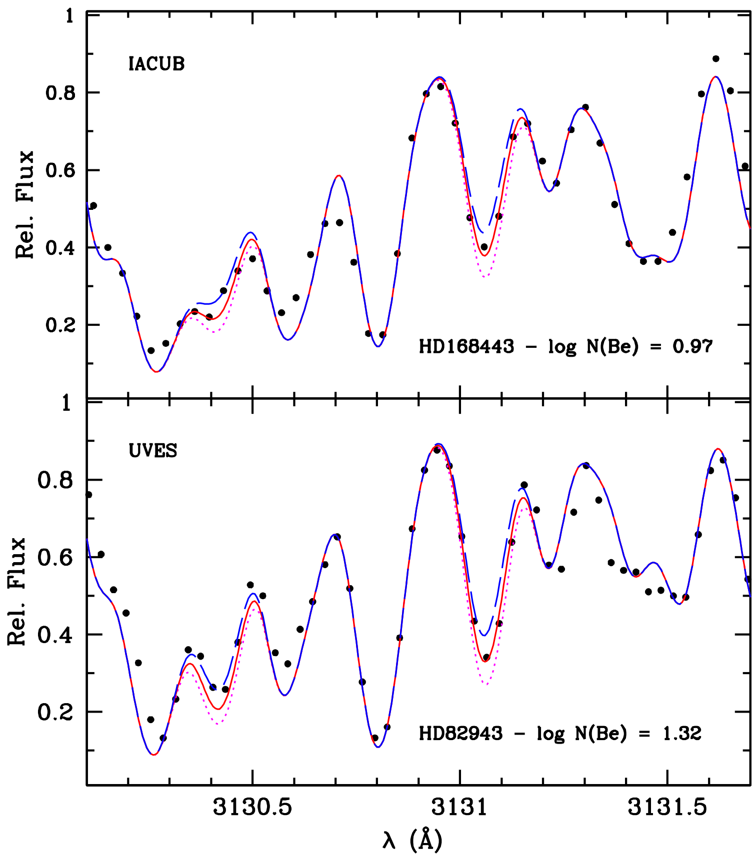

Figure 1. Spectra for two of the observed stars in the Be II line region (dots), and three spectral syntheses with different Be abundances, corresponding to the best fit and to changes of ± 0.2 dex, respectively.

age of 1.7 Gyr. An initial abundance $\log \mathrm{N(Be)} = 1.29$ (where $\log \mathrm{N(Be)} = \log(\mathrm{Be/H}) + 12$), between solar (1.15) and meteoritic (1.42), was selected. One interesting detail comes out immediately from the figure: four of the stars (HD 38529, 14 Her, Gl 86, and 55 Cnc), all of them planet hosts in the temperature interval between 5150 K and 5700 K, show only upper limits. While for HD 38529 the Be depletion may be explained by the fact that this star is already leaving the main-sequence (its low surface gravity and its position in the HR-diagram show it to be evolved), for the three remaining objects no simple explanations seem possible.

As it can be seen from Figure 2, rotating models do not predict significant burning at temperatures around 5200 K. Furthermore, for temperatures between about 5600 and 6200 K the dispersion in $\log \mathrm{N(Be)}$ is remarkably small, and abundances seem to be consistent with the model predictions, but the general trend for lower temperatures follows a slow decrease with decreasing temperature. Under the assumption that no difference exists between stars with and

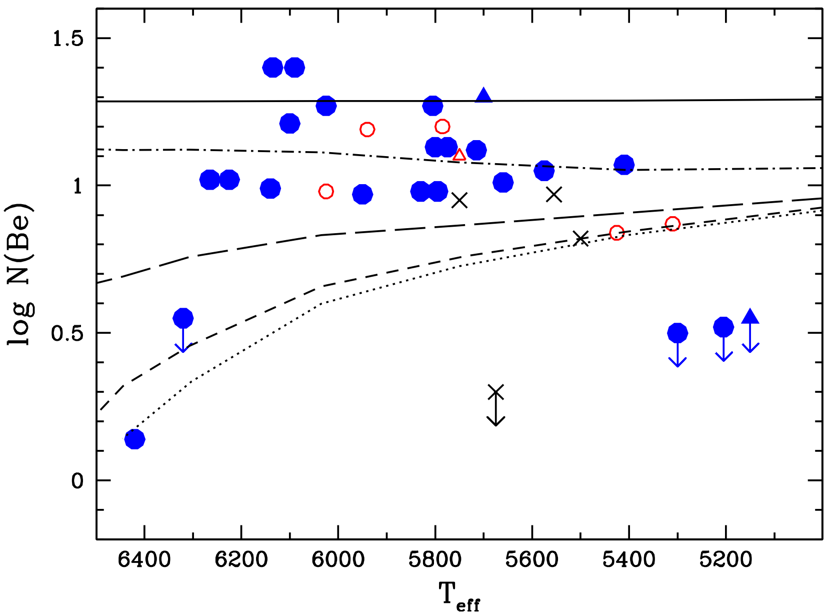

Figure 2. Be abundances for stars with planets (blue filled symbols) and stars without detected planetary companions (red open symbols) as a function of $T_{\rm eff}$. Circles represent the stars studied in this work, while triangles denote the three objects taken from the study of García López & Pérez de Taoro (1998). Stars with surface gravities $\log g < 4.1$ are denoted by crosses (all planet hosts). Superposed are the Be depletion isochrones (case A) of Pinsonneault et al. (1990) for solar metallicity and an age of 1.7 Gyr. From top to bottom, the lines represent a standard model (solid line), and 4 models with different initial angular momentum.

without giant planets, either the trend is due to some metallicity or age effect, or it is simply telling us that the models are not able to reproduce the observations for temperatures below ~ 5600 K.

One possible explanation for the abundances of the three most discrepant objects could be their ages. 55 Cnc and Gl 86 seem to be quite old, with isochrone ages higher than 15 Gyr. This is not the case for 14 Her, with an age around ~ 6 Gyr. Furthermore, there is a star (HD 222335, without detected giant planet) with about the same temperature, similar age ($\sim 5-6$ Gyr) but much higher Be abundance. Can a metallicity effect explain the observed difference? The star 14 Her is one of the most metal rich stars in the sample ([Fe/H]$= +0.50$), and HD 222335 is a more normal dwarf with [Fe/H]$= -0.10$. But a counter-example does exist: Gl 86, only about 100 K cooler, has a value of [Fe/H]$= -0.20$. Unfortunately, no theoretical isochrones for Be depletion are available for high metallicities, and it is not clear whether a difference of $+0.5$ dex in metallicity can or cannot induce significantly different Be depletion rates for this temperature range.

Although not conclusive, the evidences discussed above strongly suggest that a bona-fide explanation for the observed Be abundances may pass by some inconsistencies in the models. However, one should not remain indifferent to the fact that the three objects mentioned above are all planet host stars. This may also suggest that some other physical process, like angular momentum transfer between the proto-planetary disk and the star may have induced extra-mixing. Unfortunately only the addition of more objects to the plot, and in particular the determination of Be abundances for a larger sample of non-planet host dwarfs with $T_{\rm eff} < 5600$ K will permit to better settle down this question. On the other hand, although still very preliminary, the current result may also argue against pollution as the key process leading to the metallicity excess of stars with planets. Rather, if some difference exists between both populations, it is in the wrong sense, since the three cases described above may suggest that planet hosts stars are more beryllium poor.

4. Lithium vs. Beryllium

When comparing Be and Li abundances for all stars with both measurements available and $T_{\rm eff} < 6300$ K (to avoid objects belonging to the so-called *"Li gap"* present among F-type stars), we find no clear trends. The only interesting, but expected, result is that there are no stars having depleted much of their Be but that are still Li rich. Again, no significant difference is seen between planet hosts and non-planet hosts stars.

Work is in progress to enlarge considerably the number of measurements on both populations of stars.

Acknowledgments. The data presented here were obtained using the William Herschel and Nordic Optical telescopes (operated by the Isaac Newton Group and jointly by Denmark, Finland, Iceland, and Norway, respectively, in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias), as well as with the VLT/UT2 telescope (ESO, Chile).

This research was partially supported by the Spanish DGES under project PB98-0531-C02-02. We wish to thank the Swiss National Science Foundation (FNSRS) for the continuous support to this project. Support from Fundação para a Ciência e Tecnologia, Portugal, is gratefully acknowledged. Financial support has also been provided by the Italian Ministry of University, Scientific Research and Technology (MURST).

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