

Beryllium abundances in parent stars of extrasolar planets: 16 Cygni A & B and ρ^1 Cancri*

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Abstract. The $^9\text{Be II } \lambda 3131 \text{ \AA}$ doublet has been observed in the solar-type stars 16 Cyg A & B and in the late G-type star ρ^1 Cnc, to derive their beryllium abundances. 16 Cyg A & B show similar (solar) beryllium abundances while 16 Cyg B, which has been proposed to have a planetary companion of $\sim 2 M_{\text{Jup}}$, is known to be depleted in lithium by a factor larger than 6 with respect to 16 Cyg A. Differences in their rotational histories which could induce different rates of internal mixing of material, and the ingestion of a similar planet by 16 Cyg A are discussed as potential explanations. The existence of two other solar-type stars which are candidates to harbour planetary-mass companions and which show lithium and beryllium abundances close to those of 16 Cyg A, requires a more detailed inspection of the peculiarities of the 16 Cyg system.

For ρ^1 Cnc, which is the coolest known object candidate to harbour a planetary-mass companion ($M > 0.85 M_{\text{Jup}}$), we establish a precise upper limit for its beryllium abundance, showing a strong Be depletion which constrains the available mixing mechanisms. Observations of similar stars without companions are required to assess the potential effects of the planetary companion on the observed depletion. It has been recently claimed that ρ^1 Cnc appears to be a subgiant. If this were the case, the observed strong Li and Be depletions could be explained by a dilution process taking place during its post-main sequence evolution.

Key words: stars: individual: 16 Cyg A,B – stars: individual: ρ^1 Cnc – stars: abundances – stars: evolution – planetary systems

1. Introduction

In very recent years, several stars have been proposed to have planetary companions on the basis of measured precise radial velocity variations. This field of research is experiencing rapid development, and updated reviews of the present situation can

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* Based on observations made with the Nordic Optical and William Herschel Telescopes, which are operated on the island of La Palma by the NOT Scientific Association and the Isaac Newton Group, respectively, in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias.

be found in the proceedings of the workshop on *Brown Dwarfs and Extrasolar Planets* edited by Rebolo et al. (1998) and in *The Extrasolar Planets Encyclopaedia*¹ by J. Schneider.

Once a solar-type star has been suggested to harbour a planetary-mass companion, it is interesting to investigate any similarities with the Sun, as well as to find possible differences with respect to other single stars. Chemical abundances are among the most important parameters to be compared and, in particular, precise abundances of light elements such as lithium and beryllium (easy to destroy by (p, α) nuclear reactions when the temperature reaches $\sim 2.5 \times 10^6$ and $\sim 3.5 \times 10^6$ K, respectively) combined with the abundances of other elements which are not so readily destroyed in stellar interiors, should help to understand how the presence of planets may affect the chemical composition of their parent stars. Gonzalez (1997, 1998) has derived the overall metallicities as well as abundances of different elements (including lithium) for a wide sample of proposed parent stars, finding that four of the known systems show a metallicity significantly higher than the solar value.

A peculiar system such as 16 Cyg A & B, formed by twin solar-type stars of which only one has an orbiting planet (Cochran et al. 1997), is an especially suitable candidate to perform a detailed abundance study. Gonzalez (1998) found that both stars have a similar metallicity with a value slightly larger than solar, and confirmed independently a previous result of King et al. (1997a) that 16 Cyg B (the star with a suspected planet) is strongly depleted in lithium with respect to 16 Cyg A. The knowledge of their beryllium abundances is of potential value in quantifying the possible influence of a planetary companion on the mixing mechanisms operating in the stellar interior.

ρ^1 Cnc is a star with spectral type G8V, and is the coolest known object which is a candidate to have a planetary companion. Following Gonzalez (1998), this star falls into the group having roughly Jupiter-mass companions with small circular orbits and very metal-rich parent stars. Dominik et al. (1998) have shown recently that the planetary system of ρ^1 Cnc also hosts a Vega-like disk of dust, evidenced by an infrared excess at 60 μm . The star is very depleted in lithium and its beryllium abundance could be compared with existing upper limits

¹ <http://wwwusr.obspm.fr/planets/>

measured in younger stars with similar effective temperatures (García López et al. 1995a).

In this paper we derive the beryllium abundances of the 16 Cyg system and of ρ^1 Cnc by comparing observations with spectral syntheses of the $^9\text{Be II } \lambda 3131 \text{ \AA}$ doublet. We use those, together with their published lithium values, as well as with available abundances for other stars (with and without suggested planetary companions), and discuss briefly possible effects of planets on processes taking place in their structure and evolution.

2. Observations and data reduction

The observations were carried out in several runs conducted at the 2.6 m Nordic Optical (NOT) and 4.2 m William Herschel (WHT) telescopes of the Observatorio del Roque de los Muchachos (La Palma), using the IACUB (McKeith et al. 1993) and Utrecht Echelle (UES) spectrographs, respectively. Table 1 lists the stars observed, dates, and telescopes. Most of the observations were performed at the NOT and only two exposures of 1200 s each were devoted to 16 Cyg B at the WHT. ρ^1 Cnc and 16 Cyg A were observed with IACUB using a slit width of ~ 0.7 arc sec which provided spectra with a resolution $R = \lambda/\Delta\lambda \sim 40000$ recorded using a 1024×1024 ($19 \mu\text{m}$) Thomson blue-coated CCD, while the slit width used to observe 16 Cyg B at the NOT was ~ 0.8 arc sec and the resolution $R \sim 33000$. IACUB is an un-crossed echelle spectrograph and the order corresponding to the Be II doublet was isolated using an interference filter centered at $\lambda 3131 \text{ \AA}$, with a FWHM of 45 \AA , and a maximum transmission of 64%. The UES observations of 16 Cyg B were performed using the E79 grating, a slit width of ~ 1 arc sec, $R \sim 50000$, and recorded with a 2048×2048 ($24 \mu\text{m}$) SITe CCD. Eleven spectral orders were available on the detector, the bluest one with useful signal containing the Be II doublet.

Data reductions were performed by standard procedures using routines included in the IRAF² suite of programs. Final signal-to-noise ratios (S/N) achieved in the pseudo-continuum surrounding the Be II doublet are listed in Table 1. Technical problems with the UES and the low elevation of the object during the observations (airmass $\sim 2 - 3$) prevented the achievement of a better spectrum of 16 Cyg B with the WHT. Due to the absence of ThAr lines available for these observations, wavelength calibrations were carried out using photospheric lines present in the stellar spectra whose values were taken from the Moore et al. (1966) solar atlas. Second-order polynomial fits were applied, using 11–18 lines, to give calibrations with rms scatter between 0.004 and 0.011 \AA . Dispersions of 0.017 and $0.035 \text{ \AA pixel}^{-1}$ were obtained for ρ^1 Cnc and 16 Cyg A & B, respectively, with IACUB (with a binning of two pixels in the spectral direction for the latter cases), while a disper-

sion of $0.033 \text{ \AA pixel}^{-1}$ corresponded to the UES spectrum of 16 Cyg B.

3. Spectral synthesis

Stellar parameters were taken from the detailed abundance analysis carried out by Gonzalez (1998). Adopted effective temperatures (T_{eff}), surface gravities ($\log g$), and metallicities ($[\text{Fe}/\text{H}]$) are listed in Table 2. Typical errors associated with these quantities are $\pm 100 \text{ K}$ for T_{eff} and ± 0.1 dex for both $\log g$ and $[\text{Fe}/\text{H}]$. A solar oxygen abundance $\log \text{N}(\text{O}) = 8.93$ (Anders & Grevesse 1989; where $\log \text{N}(\text{X}) = \log (\text{X}/\text{H}) + 12$) was taken, in all cases. Small changes of this abundance (like the updated solar value $\log \text{N}(\text{O}) = 8.87$ by Grevesse & Noels 1996), which affect the OH lines located in the Be II region, do not alter significantly the comparison between observed and synthetic spectra.

The beryllium abundance analysis was performed by spectral synthesis fitting to the $^9\text{Be II } \lambda 3131.065 \text{ \AA}$ line, which is weaker but more isolated than its companion at $\lambda 3130.421 \text{ \AA}$. Synthetic spectra were computed using the code WITA2, a UNIX-based version of code ABEL6 (Pavlenko 1991), which computes LTE atomic and molecular line profiles, and the model photospheres were interpolated for the adopted stellar parameters within a grid of ATLAS9 models (computed without overshooting) provided by Kurucz (1992). Details of the line list employed (which is adjusted to reproduce the solar spectrum and uses accurate oscillator strengths for the Be II lines), the absence of significant NLTE effects on the derived abundance (< 0.1 dex), and the low sensitivity of the observed feature to changes in the beryllium abundance for low T_{eff} values were shown in García López et al. (1995a,b).

3.1. 16 Cyg A and B

The values of the parameters adopted for 16 Cyg A & B are very close to the solar values. Fig. 1 shows the comparison between observed and synthetic spectra for the Sun and 16 Cyg A & B. The solar spectrum, with a resolution $R \sim 50000$, was obtained by observing the Moon with the combination WHT+UES in a previous campaign during April 1995. Synthetic spectra have been convolved with gaussians with the appropriate FWHMs to reproduce the different instrumental profiles. A beryllium abundance $\log \text{N}(\text{Be}) = 1.15$ (Chmielewski et al. 1975; Anders & Grevesse 1989) reproduces very well the observed solar $^9\text{Be II } \lambda 3131.065 \text{ \AA}$ line, while this is not the case for other surrounding lines (including the $^9\text{Be II } \lambda 3130.420 \text{ \AA}$ line), and provides a fiducial comparison for the quality of the best fit which can be achieved for solar-type stars. García López et al. (1995b) illustrate the high sensitivity of solar synthetic spectra to changes in the beryllium abundance. The best fit to the observed weak Be II line for 16 Cyg A indicates an abundance of $\log \text{N}(\text{Be}) = 1.10$, i.e. a beryllium abundance not significantly different from solar. Changes of $\pm 250 \text{ K}$ in T_{eff} , ± 0.3 dex in $\log g$, and ± 0.2 dex in $[\text{Fe}/\text{H}]$ imply variations of ± 0.05 , ± 0.2 , and ± 0.05 dex, respectively, in the solar Be abundance (García López et al. 1995b). The corresponding maximum uncertainties for the parameters

² IRAF is distributed by National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation, USA.

Table 1. Stars observed

Star	Name	V	$B - V$	Telescope	Date	Exp. time (s)	S/N
HR 3522	ρ^1 Cnc	5.95	0.87	NOT	19/11/1996	3600	35
HR 7503	16 Cyg A	5.96	0.64	NOT	19/07/1997	1800	35
HR 7504	16 Cyg B	6.20	0.66	NOT	22/07/1997	1800	30
				WHT	13/11/1997	2400	15

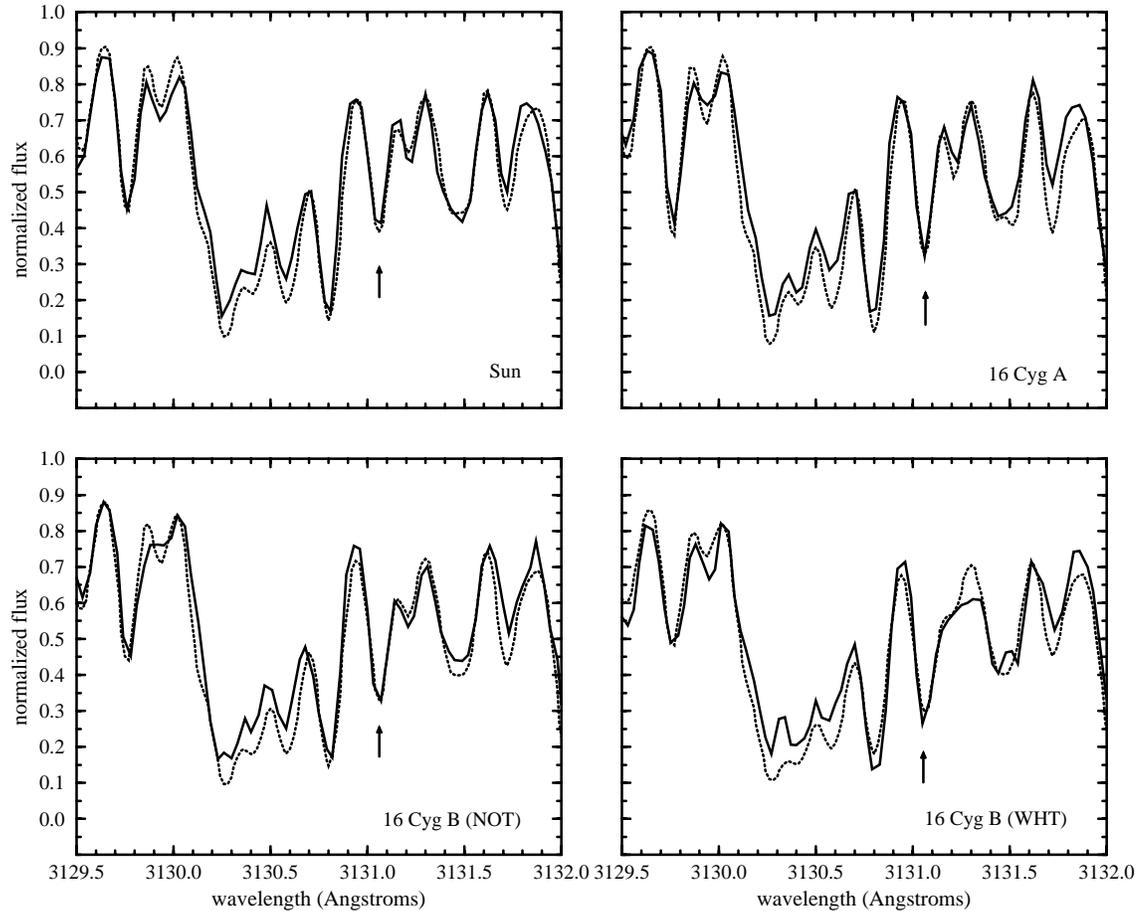


Fig. 1. Best fit of synthetic spectra (dotted line) to the observations (solid line) of the Sun and 16 Cyg A & B. Two independent spectra of 16 Cyg B obtained at the NOT and WHT, respectively, are shown in the lower panels. Beryllium abundances have been derived from the fitting to the (indicated) ${}^9\text{Be II } \lambda 3131.065 \text{ \AA}$ line.

adopted for 16 Cyg A are ± 0.05 , ± 0.1 , and ± 0.05 dex, respectively. Including an additional 0.05 dex abundance error induced by the uncertainty in locating the pseudo-continuum around the Be II doublet, and another 0.1 dex induced by the uncertainty associated with the available S/N, the final error resulting from combining these errors in quadrature amounts ± 0.17 dex.

The beryllium abundance derived from a similar analysis applied to the spectrum of 16 Cyg B observed with NOT+IACUB is $\log N(\text{Be}) = 1.30 \pm 0.17$, slightly larger than that derived for 16 Cyg A but compatible with it and the solar value within the error bars. This shows that while there is a difference of a factor 6 (at least) in the lithium abundances of both stars (listed in Table 2, and taken from Gonzalez 1998), there is no indication of

beryllium depletion among them. A service observation of 16 Cyg A & B was requested at the WHT aimed at improving the S/N obtained with the NOT and better constraining the slight difference in Be abundance between the two stars. However, technical problems with the UES and the restriction imposed at the time of the observation by the coordinates of the objects allowed us to obtain only one final low-S/N spectrum for 16 Cyg B. The UES spectrum shown in Fig. 1 has been smoothed slightly, and the synthetic spectrum overplotted was computed with an abundance of $\log N(\text{Be}) = 1.6$.

Table 2. Stellar parameters and lithium & beryllium abundances

Star	T_{eff} (K)	$\log g$	[Fe/H]	$\log N(\text{Li})$	$\log N(\text{Be})$
ρ^1 Cnc	5150 ^a	4.15 ^a	0.29 ^a	$< -0.04^a$	$< 0.55^b$
16 Cyg A	5750 ^a	4.20 ^a	0.11 ^a	1.24 ^a	1.10 ± 0.17^b
16 Cyg B	5700 ^a	4.35 ^a	0.06 ^a	$< 0.46^a$	1.30 ± 0.17^b
70 Vir	5538 ^c	4.02 ^c	-0.04 ^c	1.79 ^c	0.86 ± 0.22^c
HD 114762	5865 ^c	4.31 ^c	-0.66 ^c	1.94 ^c	0.95 ± 0.33^c
ν And	6050 ^d	4.0 ^d	0.06 ^d	2.15 ^d	0.90 ^d
τ Boo	6390 ^d	3.8 ^d	0.30 ^d	$< 0.6^d$	$< 0.05^d$

Data taken from Gonzalez (1998; *a*), this work (*b*), Stephens et al. (1997; *c*), and Boesgaard & Lavery (1986; *d*).

3.2. ρ^1 Cnc

The low effective temperature of this star makes its beryllium abundance analysis more difficult and uncertain. García López et al. (1995a) studied the sensitivity of the observed Be II λ 3131.065 Å feature to the beryllium abundance in late-type stars belonging to the Hyades open cluster and the Ursa Major Group (UMaG), and found that this sensitivity decreases with decreasing T_{eff} . A line of another element which is blended with the Be line becomes very important for cool stars, clearly dominating the feature when the temperature drops below ~ 5000 K. They tentatively identified the perturbing line as Mn I λ 3131.037 Å, and Primas et al. (1997) and King et al. (1997b) also found evidence of such a blend in their analyses of α Cen A & B, but suggesting different blending features. As a result of this limitation, García López et al. derived reliable beryllium abundances only for three Hyades stars with $5700 \geq T_{\text{eff}} \geq 5200$ K, and established upper limits for the cooler stars in their sample. On the other hand, García López (1996) investigated the potential use of ^9Be I lines to overcome the uncertainties associated with the Be II line at low effective temperatures, finding that the best candidate (λ 2348.609 Å, not observable from the ground) would not provide reliable abundances.

Fig. 2 shows the comparison between the observed spectrum of ρ^1 Cnc and several synthetic spectra computed with different Be abundances and the stellar parameters listed in Table 2. As seen in the upper panel, the fit of the synthetic spectrum to the observed one is not as good as for solar-like stars (Fig. 1); a value $\log N(\text{Be}) = 0.1$ reproduces the observed feature. The lower panel is a zoom of the region surrounding the Be II λ 3131.065 Å line, and the observed spectrum is represented by photon statistics error bars to better demonstrate the sensitivity of the observed feature to changes in beryllium abundance. Five synthetic spectra, computed without beryllium and with $\log N(\text{Be}) = 0.1, 0.3, 0.5,$ and $0.7,$ respectively, are also shown. Although the spectrum computed with $\log N(\text{Be}) = 0.1$ reproduces the observations, the spectrum without beryllium is well included within the error bars suggesting that an upper limit instead of a measurement is a more prudent result here. This upper limit could be as high as $\log N(\text{Be}) = 0.5$ given the S/N in the points defining the line itself. An additional 0.15 dex uncertainty is induced by the errors in the adopted stellar parameters

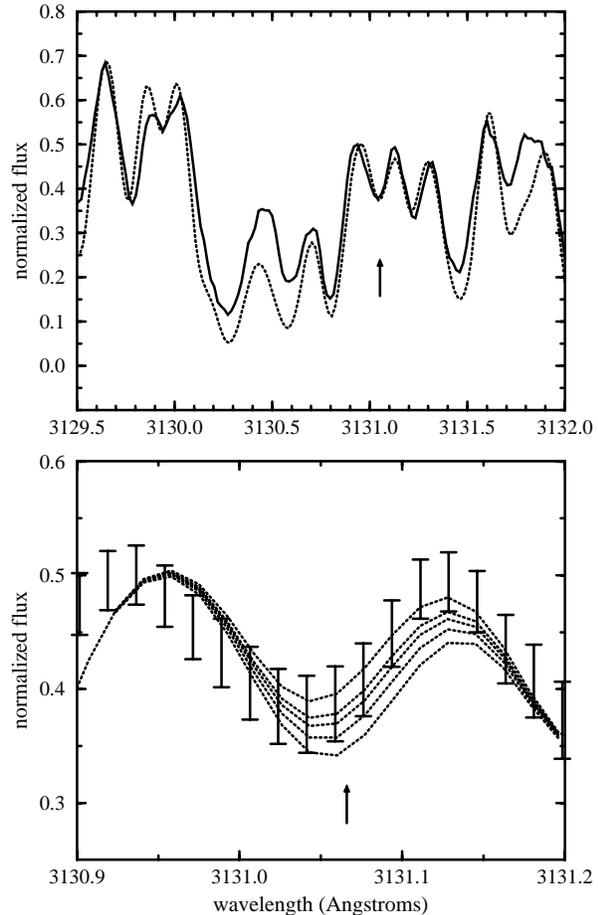


Fig. 2. Upper panel: best fit of a synthetic spectrum (dotted line) to the observations of ρ^1 Cnc, indicating an abundance $\log N(\text{Be}) = 0.1$. Lower panel: zoom of the region surrounding the Be II λ 3131.065 Å line. The observed spectrum is represented by photon statistics error bars. Five synthetic spectra (dotted lines), computed without beryllium and $\log N(\text{Be}) = 0.1, 0.3, 0.5,$ and $0.7,$ respectively, show the low sensitivity of the observed feature to changes in the beryllium abundance of the synthetic profiles, and indicate that only an upper limit can be derived.

(mainly $\log g$), 0.1 dex is associated with the uncertainty in locating the pseudo-continuum, and, finally, we consider an error of 0.1 dex related to an uncertainty of ± 0.2 dex in the estimated $\log gf$ value for the Mn I line which blends strongly the Be II line at this effective temperature. Combining these uncertainties in quadrature, our conservative upper limit for the beryllium abundance of ρ^1 Cnc is $\log N(\text{Be}) < 0.55$.

4. Discussion

4.1. 16 Cyg A and B

The lithium and beryllium abundances of 16 Cyg A are very similar to those of the Sun and α Cen A, another well known solar analog. Adopting $T_{\text{eff}} = 5800$ K, $\log g = 4.31$, and $[\text{Fe}/\text{H}] = +0.24$ for α Cen A (Chmielewski et al. 1992), King et al. (1997a) found $\log N(\text{Li}) = 1.37 \pm 0.06$ and King et al.

(1997b) derived $\log N(\text{Be}) = 1.32 \pm 0.15$ for this star. Primas et al. (1997) obtained $\log N(\text{Be}) = 1.21 \pm 0.09$ using the same effective temperature and slightly different gravity and metallicity ($\log g = 4.40$ and $[\text{Fe}/\text{H}] = +0.10$). Stephens et al. (1997) derived Li and Be abundances for a large sample of F- and G-type main-sequence (MS) stars. Two of the stars studied by Stephens et al. have also been proposed to have very-massive planetary companions: 70 Vir (HR 5072) and HD 114762, with $M_{\text{planet}} > 9 M_{\text{Jup}}$ and $> 10 M_{\text{Jup}}$, respectively, following Gonzalez (1998). The effective temperatures and Li & Be abundances assigned by Stephens et al. to these stars are listed in Table 2, and it can be seen that they do not show the same dramatic Li depletion as does 16 Cyg B. There are two additional parent stars with available Be abundances: ν And and τ Boo, studied by Boesgaard & Lavery (1986) using photographic spectra. These stars are the hottest parent stars found up to now. τ Boo, with an effective temperature of 6390 K assigned by Boesgaard & Lavery, is located well into the so called “Li gap” of the F-type stars (Boesgaard & Tripicco 1986) and shows significant Li and Be depletions, while ν And (with $T_{\text{eff}} \sim 6050$ K and close to the red edge of the gap) has kept large amounts of both elements (see Table 2).

Most of the stars studied by Stephens et al. in the interval $T_{\text{eff}} \sim 5700 - 5800$ K show lithium abundances in the range $\log N(\text{Li}) \sim 1.6$ to 2.4 and beryllium abundances between 1.0 and 1.3; two stars show Li abundances at 1.41 and 1.71, and some Be depletion at 0.68 ± 0.26 and 0.86 ± 0.13 , respectively; and there is also one star, HD 160693, which appears to be depleted in both Li (< 1.14) and Be (0.42 ± 0.22). The only two objects in that sample which show somewhat similar behaviour to 16 Cyg B are HR 483 and HR 1729. These have solar beryllium abundance but are significantly hotter ($T_{\text{eff}} \sim 5860$ and 5930 K, respectively) and have very-high upper limits for lithium ($\log N(\text{Li}) < 1.85$ and < 1.76), which make them also compatible with an object like 16 Cyg A. This distribution of abundances can be seen in Fig. 3, where we have plotted Be against Li abundances for stars cooler than ~ 6060 K (to avoid the large scatter observed for the abundances of the hotter stars -Stephens et al. 1997; García López et al. 1998-), including α Cen A & B as well as the Hyades and UMaG stars studied by García López et al. (1995a). Tables 2 and 3 list the data used to produce Fig. 3. Note that there is a difference of about three orders of magnitude in the lithium abundances plotted in the figure, while the corresponding beryllium range is ~ 1 dex. Although the stellar parameters employed to derive the abundances for the different samples are not homogeneous and detailed star to star comparisons cannot be made, Fig. 3 shows that there are not significant differences between stars with and without massive planetary companions, with the exception of 16 Cyg B.

Gonzalez (1998) estimated an age of 9 ± 2 Gyr for 16 Cyg A & B using stellar evolution grids. If the difference in lithium abundances between the two stars (which have kept a similar Be abundance) is caused by a slow mixing mechanism, which transports the material from the base of the outer convection zone to the Li burning layer, associated with the angular momentum loss (as suggested by King et al. 1997a), the stars must

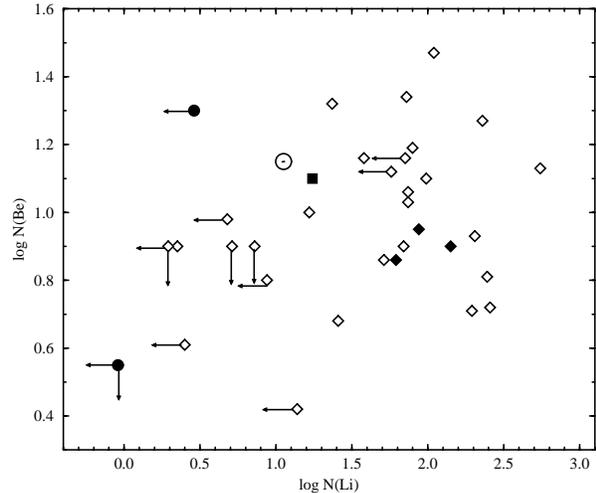


Fig. 3. Beryllium against lithium abundances for stars cooler than ~ 6060 K. Filled circles: parent stars with Be abundances derived in this work; filled square: 16 Cyg A; filled diamonds: parent stars with Be abundances taken from Stephens et al. (1997) and Boesgaard & Lavery (1986); open diamonds: single stars with Be abundances taken from the literature (García López et al. 1995a; King et al. 1997a,b; Primas et al. 1997; Stephens et al. 1997); the solar abundances are marked with the standard symbol.

have had a different angular momentum history (i.e. different initial angular momenta or different loss rates). This would also be the case if the differences in lithium abundance were related to changes in the stellar structure induced by different rotation rates during the pre-MS phase (Martín & Claret 1996). Cochran et al. (1997) suggest that the difference in rotation rate or angular momentum loss between the two stars could be associated with the existence of a massive proto-planetary disk around 16 Cyg B while the star was in its pre-MS phase (giving rise to the present $\sim 2 M_{\text{Jup}}$ orbiting planet), which would have served to brake the stellar rotation and induced a more rapid Li depletion compared to 16 Cyg A, which would have lacked a similar disk and kept a faster rotation rate. Apart from explaining how a system such as 16 Cyg A & B, with only one star surrounded by a massive proto-planetary disk can be formed, one must also show why the Li depletion is not so severe in 70 Vir and HD 114762 with more massive planetary companions and greater ages (8.5 ± 1 and 14 ± 2 Gyr, respectively; Gonzalez 1998). A possible explanation could lie in the large eccentric orbits of the planetary companions to these stars, with proto-planetary disks which could have then had a smaller effect on the pre-MS stellar rotation rates. Although the companion to 16 Cyg B also presents a very-high orbital eccentricity, it is possible that it has been altered from a more circular one by gravitational perturbation due to 16 Cyg A (Mazeh et al. 1997). In addition, a check has to be made on whether or not the mixing mechanisms proposed predict correctly the observed abundances. From Fig. 11 of Stephens et al. (1997), it seems that the rotationally-induced model of Deliyannis & Pinsonneault (1993) predicts significant Li differences and similar (solar) beryllium abundances for stars with $T_{\text{eff}} \sim 5700$ K, an age of 4 Gyr, and a difference of 20 km

Table 3. Stars without massive planetary companions plotted in Fig. 3

Star	T_{eff} (K)	$\log N(\text{Li})$	$\log N(\text{Be})$	Reference
HR 219	5883	1.90	1.19	1
HR 483	5862	<1.85	1.16	1
HD 30649	5716	1.71	0.86	1
HR 1729	5931	<1.76	1.12	1
HR 3064	5941	2.04	1.47	1
HD 65583	5328	<0.94	0.80	1
HR 4845	5830	1.87	1.06	1
HR 5914	5801	2.36	1.27	1
HR 6060	5809	1.58	1.16	1
HD 148816	5833	1.84	0.90	1
HR 6189	6058	2.41	0.72	1
HR 6349	6028	2.74	1.13	1
HD 157089	5739	1.87	1.03	1
HD 160693	5701	<1.14	0.42	1
HR 6775	5955	2.31	0.93	1
HD 18499	5725	1.41	0.68	1
HD 195633	5864	2.29	0.71	1
HD 208906	5940	2.39	0.81	1
HR 9088	5377	<0.68	0.98	1
HR 9107	5574	1.86	1.34	1
α Cen A	5800	1.37	1.32	2,3
α Cen B	5350	<0.40	0.61	4,5
vB 17	5635	1.99	1.10	6
vB 21	5250	0.35	0.90	6
vB 26	5465	1.22	1.00	6
vB 46	5065	<0.29	<0.90	6
HD 41593	5140	0.86	<0.90	6
HD 109011A	4760	0.71	<0.90	6
HD 110463	4800	0.71	<0.90	6

References: (1) Stephens et al. (1997); (2) King et al. (1997a); (3) King et al. (1997b); (4) Chmielewski et al. (1992); (5) Primas et al. (1997); (6) García López et al. (1995a).

s^{-1} in their initial equatorial velocity. However, it is not clear from the figure what would be the predictions for stars of considerably greater ages (in the range $\sim 8 - 14$ Gyr).

Furthermore, long-period orbiting planets of small mass, like the planets of the solar system, could also be able to induce some lithium depletion but are not easy to detect with the currently available observing facilities, making so very difficult to complete separate a priori the stars with and without “Li-depleting” planets.

Alternatively, the fact that we do not find stars with lithium and beryllium abundances comparable to those of 16 Cyg B (while it is common to find other stars with orbiting planets behaving like 16 Cyg A) could be telling us something about the chemical enrichment of stars with planetary companions. Orbital migration of planets formed at large radii and transported inwards by tidal interactions with the proto-planetary disk could occur (Lin et al. 1996), and would result in adding metal-rich material to the parent star. The degree of chemical enrichment would depend on the fraction of the star over which the accreted material is distributed, which is linked to the age and evolution-

ary stage of the parent star. Laughlin & Adams (1997) predict that solar-type stars with maximum disk lifetimes of ~ 10 Myr should have virtually no metallicity enhancement, while more massive stars (early F- to late A-type, with shallower convection zones) could experience more significant chemical enrichments. Gonzalez (1998) discusses the possibility that 16 Cyg A could have had in the past a planetary companion like that of 16 Cyg B, but which was engulfed by its parent star after the time needed to disturb the companion of 16 Cyg B from its original circular orbit. This could have increased its observed lithium abundance (which survives in the outer fraction of the stellar interior where the temperature is lower than $\sim 2.5 \times 10^6$ K) without changing significantly (< 0.1 dex) the overall stellar metallicity, but what would be its effect on the beryllium abundance? It will be interesting to perform detailed computations simulating the accretion of planets of different sizes onto parent stars with different masses at different evolutionary stages, to obtain better estimates of the possible enrichment of light elements. However, if this were the explanation of the abundances observed for 16 Cyg A & B, what would be the peculiarities of this system which cause it to differ from parent stars with similar effective temperatures, such as 51 Peg, 47 UMa, HD 114762, the Sun, or even the cooler 70 Vir and hotter ν And, which do not show such dramatic lithium depletion? New interesting challenges are open for detailed stellar structure and evolution studies.

4.2. ρ^1 Cnc

Although only an upper limit, to the best of our knowledge this value represents the first evidence of significant beryllium depletion in the coolest MS stars measured. King et al. (1997b) and Primas et al. (1997) derived $\log N(\text{Be}) < 1.17$ and $\log N(\text{Be}) = 0.61 \pm 0.28$ for α Cen B adopting, respectively, $T_{\text{eff}} = 5325$ and 5350 K, while the upper limit established by García López et al. (1995a) for one Hyades and three UMaG late-type stars with $4760 \geq T_{\text{eff}} \geq 5140$ K was $\log N(\text{Be}) < 0.9$, close to the solar abundance. The effective temperature adopted by García López et al. for the UMaG star HD 41593 is the same as that adopted here for ρ^1 Cnc. The analysis of HD 41593 shows that a similar low beryllium abundance is compatible with the observed spectrum, but its low S/N (~ 15) makes it also compatible with a larger abundance.

The stellar parameters derived by Gonzalez (1998) for ρ^1 Cnc place the star in the subgiant region of the HR diagram, confirming previous claims in this direction. However, the age derived for the star using theoretical isochrones turns to be $\gg 16$ Gyr, i.e. much greater than the accepted age of the universe. If ρ^1 Cnc were indeed a subgiant star, the observed Li and Be depletions could be due to a dilution effect taking place once the star has evolved off the MS and the convection zone deepens and mixes Li- and Be-rich material with Li- and Be-free material from the inner region. Strong Li and Be depletions have been found by Boesgaard & Chesley (1976) among several late G- and early K-type subgiants, which appear to agree with theoretical predictions for dilution.

A possible alternative explanation suggested by Gonzalez (1998) is that ρ^1 Cnc is an unresolved stellar binary viewed nearly pole-on, and this could be tested by searching for variations in the line profile shapes. The very-low lithium abundance of ρ^1 Cnc is compatible with strong depletion experienced by an old late G-type MS star (~ 5 Gyr, Baliunas et al. 1997 based on Ca II H & K chromospheric activity), as predicted by extrapolating the 4 Gyr Li isochrones of the rotating models of Deliyannis & Pinsonneault (1993) presented in Fig. 11 of Stephens et al. (1997). Extrapolating the corresponding Be isochrones in the figure may not give an adequate prediction of the Be abundance for ρ^1 Cnc, because strong Be depletion may occur for effective temperatures much cooler than those considered in the plot. Indeed, older rotating models computed by Pinsonneault et al. (1990; case A), which include angular momentum loss, predict beryllium depletions of 0.23 to 0.45 dex for 0.8–0.9 M_{\odot} stars ($T_{\text{eff}} \sim 5000 - 5400$ K) at 1.7 Gyr (the greatest age considered), with initial angular momenta in the range $1.6 \times 10^{49} - 5 \times 10^{50}$ $\text{gr cm}^{-2} \text{s}^{-1}$. Other angular momentum loss and internal redistribution properties (cases labeled as B to F) predict similar Be depletions at that age. The strong Be depletion observed in ρ^1 Cnc would therefore set a very significant constraint on the theoretical models. Other old and cool stars which are not suspected to have a companion planet should be observed to distinguish any possible planetary influence on the Be abundance of ρ^1 Cnc.

5. Conclusions

Beryllium abundances have been derived for the solar-like stars 16 Cyg A & B and the cooler object ρ^1 Cnc, for which there are published values of their lithium abundances. 16 Cyg B and ρ^1 Cnc are candidates to be parents of extrasolar planets, and by measuring their Be abundances we aim at studying the potential dependence on the presence of planetary companions of detailed processes operating in their structure and evolution.

16 Cyg A & B show very similar Be abundances, which are compatible with the solar value, while the lithium abundance of 16 Cyg B is at least a factor 6 smaller than that of 16 Cyg A. Different rates of mixing of material in their interiors associated with different angular momentum histories, as well as the hypothetical ingestion of a planetary companion by 16 Cyg A are discussed as potential explanations. The existence of two other solar-like parent stars, whose Li (and Be) does not show strong depletion, i.e. whose behaviour is like 16 Cyg A, the Sun and the majority of similar stars with Li and Be abundances available, implies that the 16 Cyg system requires special observational and theoretical attention.

A low upper limit has been derived for the beryllium abundance of ρ^1 Cnc. This is the first time a precise limit has been set and that such strong Be depletion has been observed in a late G-/early K-type MS star. This measurement clearly constrains the depletion predictions of the available mixing mechanisms, but requires observation of planet-free stars with similar age and spectral type to discard the potential effects of the planetary companion on the Li and Be depletions. Claims have also been made indicating that ρ^1 Cnc appears to be a subgiant. If this were

the case, its strong Li and Be depletions could be explained by a dilution process taking place during its post-MS evolution.

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