He, CNO abundances and (v sin i) values in He-rich stars *

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Abstract. We present projected rotational velocities distribution in He-rich stars against normal B type stars as well as the abundance analysis of light elements and their comparison with results of earlier series. The analysis is based on high-resolution observations (R=40000) collected at ESO, La Silla, Chile in the optical region and includes 11 stars, amongst them 5 new stars in comparison with an earlier sample. The distribution of projected rotational velocities shows a significant excess of slow rotators, no He-rich stars having $v \sin i > 130$ km s^{-1} at the significance level of 99.5%. Based on fully consistent LTE models, the helium abundance ranges from 0.1 (solar) to 0.4. The analysis on the new sample confirms the results of earlier paper: the light element abundances display a diverse pattern from under-solar up to above-solar values. Carbon has the same abundance in He-rich and in standard stars for cool He-rich stars, following the predictions of radiative diffusion in the presence of wind.
The star HD149363 appears rather as He-weak as based on the equivalent widths from R=40 000 spectra.

Key words: stars: abundances – stars: atmospheres – stars: chemically peculiar

1. Introduction

The He-rich stars are the most massive CP stars. Their helium abundance ranges from nearly solar to larger than unity with respect to hydrogen, and this is presently attributed to radiative diffusion in the presence of mass loss. As far as CNO elements are concerned, the models presented so far (e.g. Michaud et al., 1987) with selective mass-loss suggest normal abundances. However, these models depend on the magnetic field configuration and stellar wind strength, and one might expect that the CNO abundance pattern would depend on several parameters including effective temperature. In our paper II (Zboril and North,

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* Based on observations obtained at the European Southern Observatory, La Silla, Chile

1999) we analyzed high resolution (R=30000) spectra obtained at ESO, La Silla, Chile in 1992. The sample displays a diverse pattern from under-solar up to over-solar values for C,N,O and Mg. Carbon appears underabundant on the basis of our LTE analysis but tends to have the same abundance as that of standard stars for the coolest He-rich stars, following the model predictions. Importantly, the distribution of projected rotational velocities shows an excess of slow rotators, no He-rich star having $v \sin i >$ 130 km s^{-1}. In this contribution, we analyze additional high-resolution ESO spectra (R=40000) to obtain light element abundances and $v \sin i$ of other He-rich stars, thus enlarging the sample. The stars were selected from a variety of contributions with labelling ' He-r star'.

2. Observations

For this purpose one of us (PN) obtained high-resolution spectra (resolving power 40000) using the CAT telescope and the CES spectrograph at ESO, La Silla, Chile, on 25 - 29 June 1993 (CCD detector ESO #9), in remote control mode from Garching. Some stars are common to those published in Zboril et al. (1994). We obtained spectra of 7 completely new stars in a sample of 14 stars (Tab. 1), including normal reference stars. The spectra were obtained in two wavelength ranges: 4236-4271 Å (CNO lines), and 4001-4035 Å (He lines). Each star was measured on two consecutive nights in each wavelength range, so we cross-correlated and co-added the corresponding pairs of spectra to improve the S/N ratio. Fig. 1 compares the equivalent widths obtained in this work with those obtained in Paper II for the common stars. The widths of the helium lines show much more scatter than those of carbon. Owing to the large values of helium equivalent width, this scatter is probably significant and due to He being confined to spots.

3. Elemental abundance analysis

Basically, we used the same instrumental set-up and abundance analysis as in Paper II. The LTE synthetic spectrum method has been used as well. More specifically, the high-resolution spectra were obtained in the region 4235–4270Å for light elements in general and 4009–4035Åfor helium in particular. The former allowed us to analyse N II 4237, N II 4242 and CII 4268Ålines and SIII+OII 4254Ådoublet.

In comparison with paper I, the fully consistent LTE models were computed, i.e. with recalculated hydrostatic equilibrium: a set of model atmospheres was produced with different helium abundance and final helium abundace was determined iteratively following the observed equivalent width. The CCP7 software (Tlusty, Synspec) was used (e.g. Hubený et al., 1994). We confirm almost all stars from new sample as being helium rich, except of course, the two $v \sin i$ standards (i.e. normal reference stars), namely HD 193924 and HD 175191.

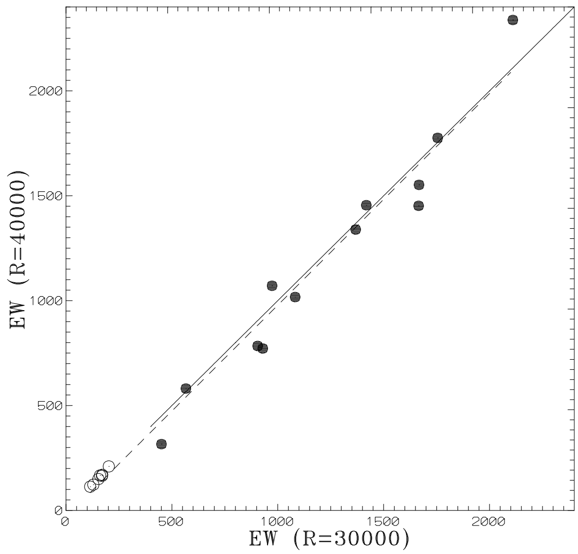


Figure 1. Comparison of equivalent widths (in mÅ) obtained in April 1992 (resolving power R=30000) and in June 1993 (R=40000) for CII 4267Å (**open dots**) and HeI 4009, 4026Å(**full dots**) lines. **Solid line**: equality, **dashed line**: best fit; *EW(R=40000)=1.00879.EW(R=30000)-30.453.*

4. CNO abundances

The abundances of light elements can be found in Tab. 1 and are displayed in Fig. 2. Note that the star HD 168785 was studied by Zboril et al. (1994), though the helium abundance was not determined. The results from the present sample basically agree well with those of paper II. The carbon diagram (Fig. 2) displays cumulative NLTE and temperature effects, i.e. the trend of carbon abundance upon effective temperature. Other authors had already noticed that carbon abundances based on the CII doublet are too low by typically 0.7 dex (e.g. Kane et al., 1980) when obtained with the LTE approximation. The NLTE effects on this line have since been shown to be considerable. Sigut (1996) discussed in detail the NLTE effect in two prominent CII spectral doublets, namely 4267 and 6578/82Å. He showed that for cool stars ($\sim$ 15000 K) the NLTE effect is negligible while for hot stars ($\geq$ 20000 K) the difference in equivalent width reaches about 30%. He compared the observed equivalent widths with his NLTE calculations and our carbon abundance trend can be explained qualitatively using Fig. 1 of his paper. Indeed, the stars cooler than about 18000 K have a nearly solar carbon abundance, while the hotter ones are all significantly underabundant, as expected from the larger equivalent width obtained from LTE calculations. The only exception is the hot star HD 149363, which seems slightly overabundant in carbon, but it does not seem to be a typical He-rich star (see

Table 1. Elemental abundances in He-rich stars (upper part of the table) and reference *vsini* stars (lower part). The DM numbers obey the HD rule. Total error bars on abundances in percent. The "*" symbol stands for earlier analysis based on R=30000 resolution (Zboril et al., 1994; Zboril and North, 1999). The spectral type extracted from Simbad database.

HD/DM	Sp.	T_{eff}	log g	He	C	N	O	$v \sin i$
—	—	[K]	—	—	x10^{-4}	x10^{-4}	x10^{-4}	[km/s]
92938*	B4V	16000	4.0	0.14±0.005	5.±1.25	—	—	125.± 4
96446*	B2III	23000	4.0	0.34± 0.005	0. 24±0.09	0.65±0.23	2.4±1.0	0.±3.
133518*	B2IV	20000	4.0	0.12±0.005	0.97±0.34	0.64±0.19	4.7±1.8	0.± 3.
-13 4383[1]	B2V	18000	4.0	0.16± 0.02	1.7±0.7	2.2±0.83	—	55.± 4.
149363[3]	B1III	30000?	4.0	∼0.06?± 0.02	6.±2.34	1.1±0.38	—	95.± 4.
149257*	B1I	25000	3.0	0.26± 0.05	0.97±0.24	0.91±0.35	—	40.± 4.
-69 2698*	B2V	25000	4.0	0.21± 0.005	0.27±0.06	0.57±0.2	—	30.± 3.
164769	B2III	23000	4.0	0.28± 0.05	1.0±0.32	1.1±0.41	—	105.±5.
168785*	B2III	23000	4.0	0.30± 0.06	0.11±0.04	0.31±0.11	0.67±0.27	14.±3.
186205	B5	17000	4.0	0.37±0.08	4.7±1.22	1.1±0.33	—	5.±3.
-43 14300[2]	B	22000	4.0	0.25± 0.04	1.7±0.68	2.0±0.84	—	2.± 3.
144218*	B2V	20000	4.0	0.08± 0.08	0.77±0.26	0.91±0.33	3.7±1.5	60.± 3.
175191	B2V	20000	4.0	0.11± 0.01	0.67±0.22	—	—	160.± 8.
193924	B2IV	19000	4.0	0.11± 0.02	0.99±0.32	0.51±0.18	1.7±0.66	20.± 3.
solar	—	—	—	0.10	3.7	1.1	6.7	—

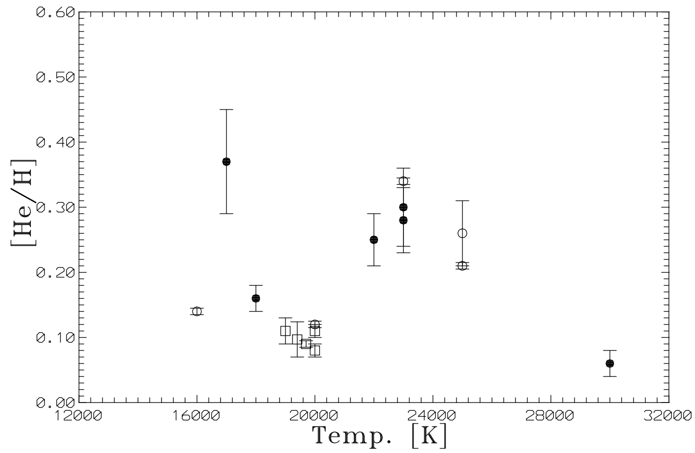
Note: [1,3] Atmospheric parameters from Kilkenny and Buse (1992), [2] Dufton et al. (1993).

below). Even though Sigut's NLTE equivalent widths are clearly more realistic than LTE ones, they seem still larger than the observed ones (by various sources in the literature, as well as by us) by 10 percent at least, so it is difficult to conclude the absolute C abundances obtained from this line only. In any case, our work does not show any clear difference between the C abundance of He-rich stars, compared to that of normal ones.

We found peculiar abundances for the star HD 149363. This object can probably not be hotter, since the light element abundances would then become strongly overabundant. On the other hand, a cooler atmosphere would not reflect the estimates from Kilkenny and Busse (1992) based on a Kiel diagram, hydrogen line profiles and Kurucz model atmospheres (see section on HD 149363). The other diagrams display the fact that solar abundances for N, O are the upper limit with few exceptions. Concerning nitrogen, the phenomenon of "nitrogen-rich stars" does exist (Gies et al. 1992), but our overabundances do not exceed the 3σ limit; therefore, our stars can not be assigned definitely to this group.

5. Projected rotational velocity distribution

In this section the projected rotational velocity distribution is examined together with the results from our Paper II. We have updated the $v \sin i$ distribution, as well as the cumulative one, the latter being compared with that of normal BV-III stars (Wolff et al., 1982). A Kolmogorov-Smirnov test applied to both cumulative



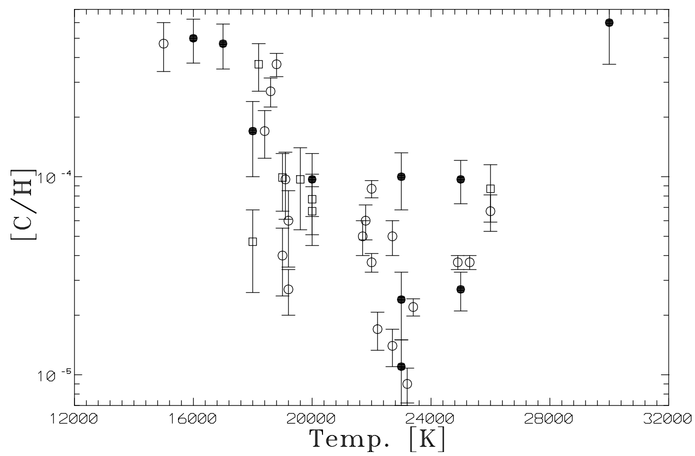


Figure 2. Stellar abundance defined as [N(elem.)/N(H)] versus effective temperature - **helium and carbon**. Key to symbols: **open circle**: data for He-rich stars, Zboril and North (1999) and Zboril et al. (1994) (Tab. 1), **full circles**: present sample, **open squares**: reference stars, present sample and Zboril et al. (1994).

distributions showed a significant difference between them, in the sense that the He-rich stars are clearly slower rotators than normal B-type ones: no He-rich star has $v \sin i > 130$ km s^{-1}. There is no evidence of any dependence on spectral type, confirming the result found in Paper II. The only star exceeding the limit is HD 175191, a reference star and $v \sin i$ standard (Slettebak et al., 1975). Merging the rotational velocity values from paper II and those from the present paper, the KS test applied to the cumulative distributions (Fig. 5) showed, at a significance level of 99.5%, that He-rich stars are slow rotators. Therefore, this fact is now well established.

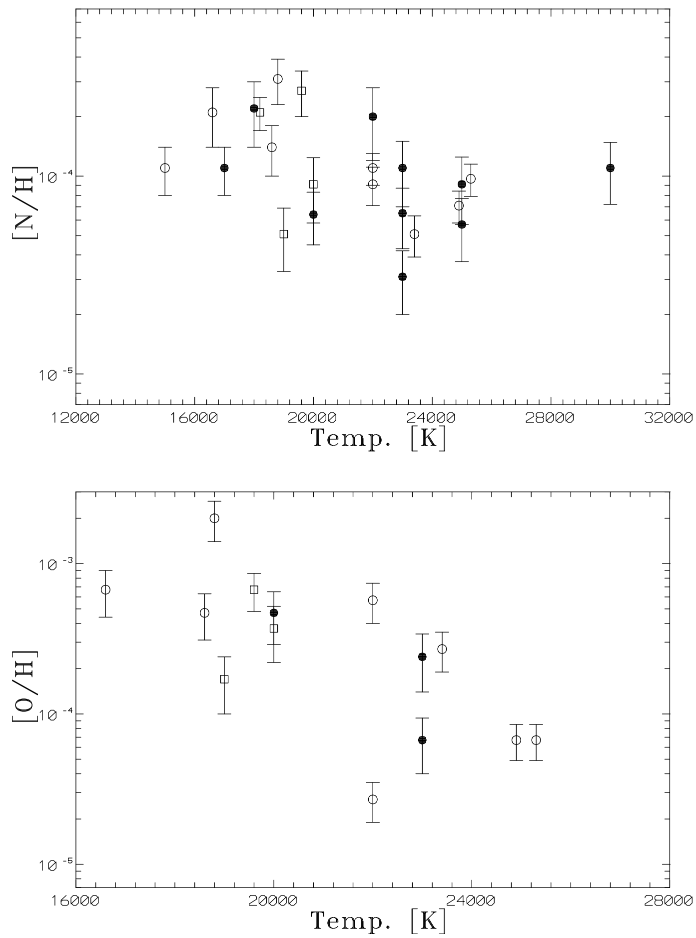


Figure 3. Stellar abundance versus effective temperature - **nitrogen and oxygen**. Key to symbols: **open circles**: data for He-rich stars, Zboril and North (1999), **full circles**: present sample.

6. The star HD 149363

Helium was estimated as underabundant relative to hydrogen, based on fully consistent LTE models, i.e. with recalculated hydrostatic equilibrium. On the contrary, Kilkenny and Busse (1992) assigned the He-rich status to this star, on the basis of low resolution spectra ($\sim 50 \mathring{A}\ \mathrm{mm}^{-1}$). In addition, it is clear from Tab. 1 and Fig. 2 that its carbon abundance does not match the overall trend. We checked the atmospheric parameters estimated by the authors, who used low-resolution spectra and uvby photometry obtained at SAAO, by looking at *UBV* photometry, Geneva photometry and IUE records. The temperature

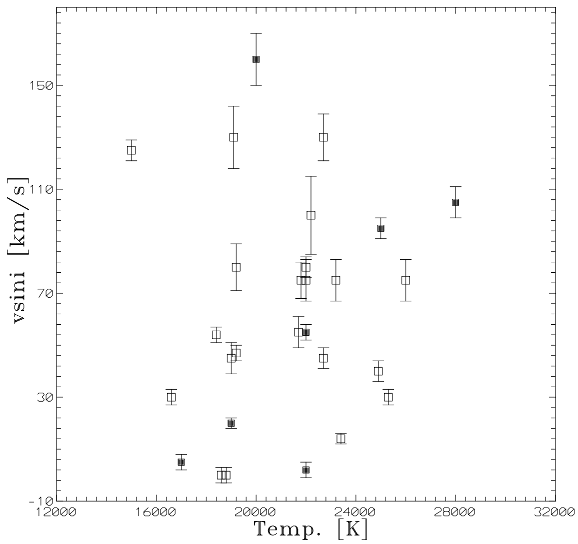


Figure 4. The projected rotational velocities distribution. **Open square**: Zboril and North (1999), **full square**: present sample. See text.

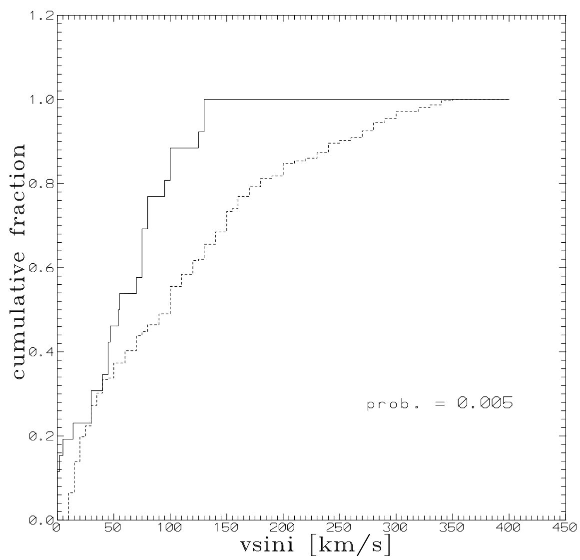


Figure 5. Cumulative distributions of normal and He-rich stars. **Solid line:** He-rich stars, **dashed line:** normal B0-5III-V stars of Wolff et al. (1982).

derived from *UBV* colours, however, is not very reliable due to reddening. Using Geneva photometry calibrated by Künzli et al. (1997), one obtains the following atmospheric parameters: $T_{\rm eff} = 30000$ K, $\log g = 4.0$. The synthetic UV fluxes computed from an LTE model atmosphere ($T_{\rm eff} = 30000$, $\log g = 4.0$) match the IUE records well. Thus, assuming the atmospheric parameters adopted by Kilkenny and Busse (1992) are true ($T_{\rm eff} = 31000$, $\log g = 3.8$), as confirmed by the above discussion, the star would belong to the He-weak group of chemically peculiar stars, rather than to the He-rich group.

The total equivalent width of He I 4009+4026 pair measured on our spectra is 1070 mÅ. The authors clearly overestimated the equivalent widths for helium using low-dispersion spectra and thus He-rich status. On the other hand, the carbon abundance is rather unusual (Fig. 2) and measurements of the hydrogen line profiles and other portions of spectra would put another useful constraint on the parameters of this star.

7. Conclusions

Based on LTE model atmospheres and high-resolution spectra, we have presented an abundance analysis of 7 new stars from a sample of 14 stars. Preliminary analysis of the remaining stars had been performed by Zboril et al. (1994) and a more complete analysis was published by Zboril and North (1999). Having used a standard synthetic spectrum method we achieved the following results:

- lack of fast rotators with a confidence level of 99.5%
- helium abundances from 0.1 (solar) up to 0.4
- given the atomic data a possible diverse pattern of abundances, preferably under-solar
- the hot star HD 149363 may be He-weak

The analysis of all spectra presented in this work and in Paper II highlighted a very significant lack of fast rotators and a considerable tendency towards under-solar abundances of carbon according to LTE models. This apparent underabundance is due to the well-known sensitivity of the C II 4267Å line to NLTE effects, and is the same for both He-rich and normal stars. The helium abundance seems to be spread from 0.1 up to 0.4 and (only in the cases of strong emissions) the abundance reaches a larger value (~0.8), based on fully consistent LTE models, i.e. with recalculated hydrostatic equilibrium. The helium abundance spread may be modulated by other phenomena (magnetic geometry and aspect, degree of both horizontal and vertical stratification, stellar wind, overall emission strength as derived from photometry and/or hydrogen lines etc.). Noticeably, the helium rich atmosphere does not seem to have a widely different structure to a normal one, judging from the shape and equivalent width of lines formed at or near the continuum forming region, but this fact should be checked carefully on a larger sample of photospheric lines.

The atmosphere of HD 149363 may not fulfill standard conditions as defined by LTE model atmospheres, whether Kurucz's ones or fully consistent with recalculation of hydrostatic equilibrium, and would require high-resolution spectra to match and study line forming and continuum forming regions.

The next papers in this series will concentrate on more realistic abundances derived from echelle spectra, vertical and azimuthal aspects of helium abundance and the environmental studies of He-rich stars.

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