CN status of a sample of galactic OB supergiants

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Abstract: In our search for evidence for the CNO processed material in the atmospheres of galactic OB supergiants we measured the equivalent widths of photospheric lines in their high-resolution *IUE* spectra. A sample of 36 stars was investigated and the lines He II 1640 Å, C III 1247 Å, N IV 1718 Å and O IV 1339 Å were studied. All ions show a well-defined dependence on effective temperature. Comparison of stars with questionable CN status with normal stars gives evidence for a decrease in equivalent widths of C III and O IV lines accompanied by an increase in equivalent widths of N IV and He II lines, which leads to abundance differences.

1 Introduction

Evolutionary theories predict that some massive stars should show variations in their surface abundances indicative of CNO core-processed material being present in the photosphere. Some models (Schaller et al. 1992) imply that massive stars can evolve through blue loops, developing as main sequence-BSG-RSG-BSG stars. In that case two populations of BSG are postulated: the pre-RSG which would be chemically normal and the post-RSG which would show evidence of nucleosynthetically processed material in their atmospheres. Classical models of stellar evolution generally predict that only very massive stars with masses $\geq 60 M_{\odot}$ lose enough mass via stellar wind to show CNO enriched material, while still on the main sequence (Chiosi and Maeder 1986). Stars of lower mass show CNO processed material in their atmospheres in the later phases of their evolution, after the first dredge-up.
Recent investigations on the effect of stellar rotation on the structure and evolution of massive stars show that early atmospheric contamination can occur by mixing with the stellar interior, the contamination being more important as both, the stellar mass and the initial rotational velocity increase. This would remove the need for blue loops to explain the OBN/OBC phenomenon (Meynet and Maeder 2000).
In this work we have looked for abundance-deviations in a sample of 36 galactic OB supergiants. For some of our program stars the CN status has been estimated from optical spectra (McErlean et al. 1999; Lennon et al. 1993; Walborn 1976; Wollaert 1988; Takeda 1994; Takeda and Hidai 1995; Villamariz et al. 2002.). We have derived the CN status of the whole sample by analyzing the He, C, N and O ultraviolet lines.

Table1. Program stars:

No.	HD no.	Spectral type	T_{eff}/K	Name	Association	SWP	CN normal stars
1	207198	O9 Ib/II	32000		Cep OB2	25981	
2	30614	O9,5 Ia	30000	α Cam	NGC 1502	2591	
3	209975	O9,5 Ib	30000	19 Cep	Cep OB2	36503	
4	167264	O9,7 Iab	27500	15 Sgr	Sgr OB7	4368	
5	37128	B0 Ia	25000	ε Ori	Ori OB1	6727	
6	204172	B0,2 Ia	23500	69 Cyg	Cyg OB4	48946	
7	38771	B0,5 Ia	22000	κ Ori	Ori OB1	30178	
8	192422	B0,5 Ib	22000		Cyg OB1	51893	
9	213087	B0,5 Ib	22000	26 Cep	Cep OB1	2736	
10	2905	BC0,7 Ia	21000	κ Cas	Cas OB14	54038	
11	13854	B1 Iab	20000		Per OB1	2737	
12	24398	B1 Ib	20000	ζ Per	Per OB2	9685	x
13	190603	B1,5 Ia+	19000		Vul OB2	1822	
14	193183	B1,5 Ib	19000		Cyg OB1	52716	
15	13841	B1,5 Ib	19000		Per OB1	18512	
16	14143	B2 Ia	17500		Per OB1	9435	
17	14818	B2 Ia	17500	10 Per	Per OB1	9416	
18	41117	B2 Ia	17500	χ^2 Ori	Gem OB1	40669	
19	206165	B2 Ib	17500	9 Cep	Cep OB2	4406	x
20	13866	B2 Ib	17500		Per OB1	18513	x
21	31327	B2 II	17500		Aur OB1	21280	
22	198478	B2,5 Ia	16000	55 Cyg	Cyg OB7	36938	x
23	42087	B2,5 Ib	16000	3 Gem	Gem OB1	8646	
24	14134	B3 Ia	15000		Per OB1	46882	
25	53138	B3 Ia	15000	o^2 CMa	Coll 121	7193	x
26	225094	B3 Ia	15000		Cas OB5	18688	
27	36371	B4 Iab	14300	χ Aur	Aur OB1	2945	x
28	58350	B5 Ia	13500	η CMa	Coll 121	30198	x
29	164353	B5 II	13500	67 Oph	Sct OB2	4267	x
30	191243	B5 II	13500		Cyg OB3	7737	x
31	13267	B6 Ia	12900	5 Per	Per OB1	51892	x
32	12301	B7 II	12400	53 Cas		4265	x
33	34085	B8 Ia	11500	β Ori	Ori OB1	32727	
34	199478	B8 Ia	11500		NGC 6991	15552	x
35	208501	B8 Ib	11500	13 Cep	Cep OB2	4217	
36	21291	B9 Ia	10800		Cam OB1	8087	

2 Observational data

Among 36 stars from our program (Table 1) there are 12 stars to which a normal CN status has been assigned (McErlean et al. 1999, Prinja 1990, Wollaert et al. 1988 and Walborn 1976). In order to get a better mean relation for normal stars, we extended the sample of normal supergiants by adding 7 stars from Wollaert et al. (1988): HD 210809 (O9 Iab), HD 188209 (O9,5 Iab), HD 218915 (O9,5 Iab), HD 149038 (O9,7 Iab), HD 91969 (B0 Ia), HD 122879 (B0 Ia), HD 154090 (B0,7 Ia). Other stars from our sample show deviations in equivalent widths from the mean relation defined by normal supergiants as a function of their spectral type. The calibration of the effective temperature scale was adopted from Lennon et al. (1993).

3 Results

For the lines located on the shoulder of the curve of growth the deviations of equivalent widths from those of the normal supergiants, ΔlogW (Figure 3.), can be turned into logaritmic abundance deviations, ΔlogA, by multiplication with a factor 2 or larger (Wollaert et al. 1988). Thus the plot in Fig. 3 corresponds to logaritmic abundance deviations in relative units. The method allows an estimate of limit values, i.e. only lower limits for the overabundances and upper limits for the underabundances can be determined.

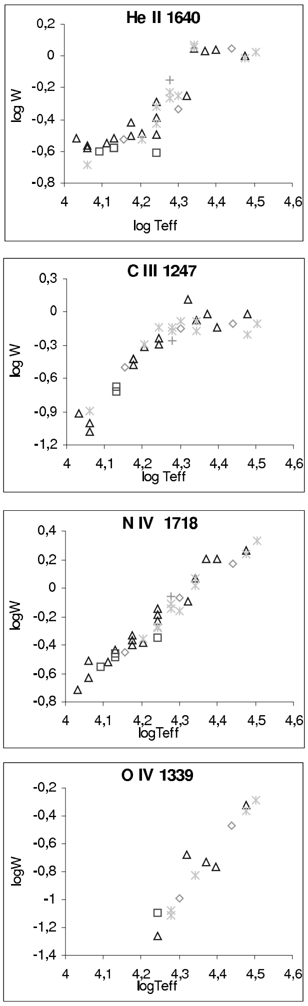

Figure 1: Equivalent widths vs. logT_{eff} for the He, C, N and O lines. The luminosities are marked by the following simbols: $+$ Ia+, $\triangle$ Ia, $\diamond$ Iab, $*$ Ib, $\square$ II.

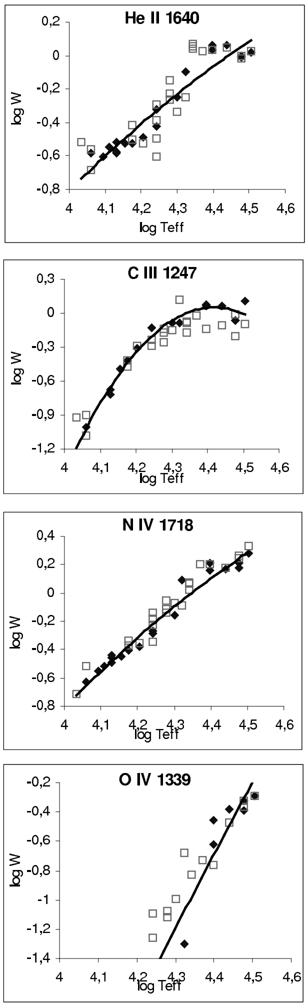

Figure 2: The solid line in the logW vs. logT_{eff} plot is defined by normal supergiants which are marked by filled diamonds, while open squares represent all other program stars.

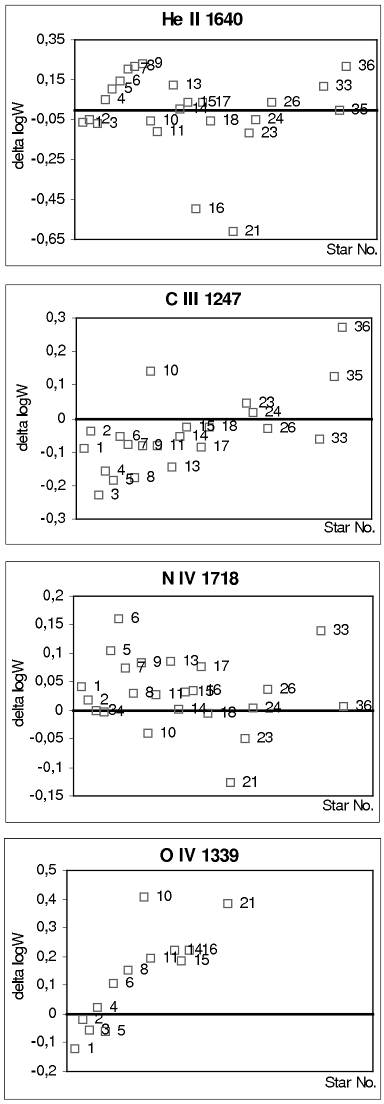

Figure 3: Deviations in equivalent widths from the mean relation defined by normal supergiants as a function of their T_{eff}. The stars are marked by numbers in agreement with assignments in Table 1.

4 Discussion

Our results show, as expected, increased helium and nitrogen abundances, accompanied by decreased carbon. Normal or moderate enrichment in nitrogen accompanied by underabundant helium observed in stars no. 1, 2, 3, 11, 24 can be explained by rotating evolutionary models: they predict that helium enrichment appeared later in the stellar atmosphere, while CNO abundance changes were already present. This might be the reason why no clear correlation between helium overabundance and CNO contamination has been found.
However, the star no. 36 gives evidence of a remarkable proportion between helium and carbon abundances, while a few other program stars show a weak correlation of helium with carbon

lines, as reported also by Lennon et al (1993).
Oxygen is showing strange overabundances in the stars no. 6, 8, 11, 14, 15, 16 which are more or less underabundant in carbon and moderatly overabundant in nitrogen. More attention should be paid to this problem, which might result from the small number of normal stars for which oxygen lines could have been measured, leading to a rather poor determination of the trend line.
One of the general predictions of the stellar evolution calculations is that the most luminous supergiants of a given spectral type should show the strongest contamination by CNO processed material, providing that they have passed through the RSG stage. Such trend is found here for the spectral type B1,5, where one Ia supergiant (No. 13) shows stronger helium and nitrogen lines and a weaker carbon line than two Ib supergiants (No. 14, 15) of the same spectral type. For the spectral type B2 we can only say that one B2 II supergiant (No. 21) shows lower helium and nitrogen lines than the three B2 Ia supergiants (No. 16, 17, 18). At B8 one Ia star (No. 33) shows stronger helium and weaker carbon line than one Ib star (No. 35). The same B8 Ia star (No. 33) shows a very strong nitrogen line, while no nitrogen line was measured in the B8 Ib (No. 35) stellar spectrum.
According to Lennon et al. (1993), it is possible that all supergiants have atmospheres enriched by CNO processed material. In our sample, only three stars (No. 10, 21, 23) are nitrogen deficient. Eight stars from the sample (No. 1, 2, 3, 10, 11, 18, 23, 24) show helium deficiency which could be explained as a result of rotational effects mentioned before.
Enhanced line strengths might confirm the presence of the CNO processed material in the atmospheres, but it does not necessarily give evidence of later stages of evolution. It could have been dredged-up during a red supergiant stage, but it also could have been mixed to the surface at an early stage of evolution because of stellar rotation. On the other hand, line strengths can be affected by atmospherical structure rather than by abundance anomalies.
The results shown here are quite preliminary. An appropriate model atmosphere in the UV would lead to a more reliable interpretation.

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