Optical spectrum of Z UMi during its maximum light

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Using the high resolution spectrograph NES of the 6 m telescope we obtained and analysed the spectra of a R CrB type star Z UMi. The atmospheric parameters of Z UMi were estimated: $T_{\rm eff}$=5250±250 K and $\log g$=0.5$\pm$0.3. This places Z UMi among the coolest R CrB stars. We confirmed the hydrogen deficiency of Z UMi. The abundances of other elements resemble those found for the minority group of R CrB stars. We note very low iron abundance, [Fe/H]=-1.85, and an essential excess of lithium, [Li/Fe]=+1.9.

Z UMi as a R CrB star

Z UMi is associated with an IR-source IRAS 15060 + 8315. The photometric observations showed typical of R CrB stars light drop by 6^m in 1992, which lasted about 300 days. Low resolution spectra obtained during the light minimum showed only the Na I D lines in emission and the C_2 Swan system bands in absorption. No Balmer lines were detected. The hydrogen-deficient nature of Z UMi was established by Goswami et al. (1997), who used the high resolution spectra of the star during the maximum light. The CN red and violet systems and the C_2 Swan system bands were found in absorption. Weak or absent CH bands in Z UMi spectra were considered as the indicators of hydrogen deficiency. The high resolution spectrum of Z UMi during the onset of the 1997 decline was studied by Goswami et al. (1999). In this paper we present the high resolution spectra of Z UMi during its maximum light.

Observations and spectra reduction

We obtained high resolution spectra of Z UMi on March 10, 2004 (JD 2453075) with Russian 6 m telescope in combination with the Nasmyth Echelle Spectrometer equipped with a CCD camera 2052×2052 as a detector (Panchuk et al. 1999, 2002) and with an image slicer (Panchuk et al. 2003). The star was at maximum light (V≈$11\overset{m}{.}3$). The spectra covering 528–677 nm without gaps until 586 nm were reduced using the NOAO astronomical data analysis facility IRAF. The continuum was placed by fitting low order spline functions through the manually indicated points in every order. The use of image slicer results in three parallel strips of spectra in each order. These strips are wavelength shifted. Therefore all strips were reduced separately and then already linearized in the wavelength spectra were coadded. The wavelengths of the terrestial lines in the stellar spectrum were reproduced within a few 0.001 Å-s. After that all spectra of the set were coadded. As measured from the Th-Ar comparison spectra the resolution is $R \approx 42\,800$ with FWHM of comparison lines about 7 km s^{-1}.

The most remarkable spectral features in the spectrum are the weak Hα line blend with CN lines (Fig. 1) and many strong C_2 Swan system bands in absorption (Fig. 2) including (3,6) and (1,4) bandheads at 658.9 and 676.2 nm which are usually not visible in early type R carbon stars.

If these two red bands were taken into account the mean carbon abundance of Z UMi is $\log\varepsilon(\mathrm{C}) = -2.04 \pm 0.20$. Without these bands $\log\varepsilon(\mathrm{C}) = -2.10 \pm 0.1$. This means that for C_2 molecular spectrum there is no so called carbon problem (Asplund et al. 2000). For C I lines the problem is present at the level of about -0.5 dex as for all other R CrB type stars analysed up to now.

Based on metallic lines, we determined an average value of radial velocity for the moment of star's observation JD 2453075: $\mathrm{V}_r = -35.4 \pm 1.6$ km s^{-1}. From rotational lines of C_2 (0,1) band we found -35.4 ± 1.8 km s^{-1}.

Parameters and model atmosphere

Tenenbaum et al. (2005) accepted $T_{\rm eff} \approx 5000\,{\rm K}$ for Z UMi on the basis of CO bands visibility. With the temperature close to 5000 K, the mean $M_{\rm bol}$=-5 ± 1 and mass $\mathcal{M}/\mathcal{M}_{\odot} = 0.7 \pm 0.2$ of R CrB stars (Asplund et al. 2000) the surface gravity will be close to $\log g = 0.5 \pm 0.3$. Tenenbaum et al. (2005) found that there is very little difference in the strengths of CO absorption bands if $\log g = 0.5$ and 1.5. The value $\xi_{\rm t} = 5\,{\rm km\,s^{-1}}$ we choose close to the mean value of cooler R CrB stars. The model atmospheres for this analysis were computed with a modified version of MARCS program (Gustafsson et al. 1975) with updated opacities. The opacities from continuum sources, molecules CO, CN, C_2, HCN, C_2H_2 and C_3, and the metallic lines were taken into account. The line opacities were treated in opacity sampling approximation (Jørgensen et al. 1992). Synthesizing the spectral region with the C_2 Swan system (0,1) band head we found that the computed C_2 rotational lines were too strong. The quite slight reduction of the input carbon abundance to $\log \varepsilon({\rm C}) = -2.2$ and higher temperature (5250 K) gave the acceptable fit. Therefore the further analysis was performed with the model 5250/0.5 (C/He=0.006). We estimate the error in $T_{\rm eff}$ about 250 K.

Elemental abundances

Determining the abundances from individual spectral lines is extremely ambiguous in the case of Z UMi. There are no lines belonging to atomic species, which are not blended with molecular lines, and therefore no equivalent widths could be measured and the procedures like determining the microturbulence parameter $\xi_{\rm t}$, adjusting $T_{\rm eff}$ using abundance versus excitation potential and $\log g$ determination using ionization equilibrium, are not applicable. Synthesizing the spectra only the upper limit of abundances could be found. As the lines, which could be used in this case are strong, the errors due to the errors in the structure of model atmosphere could not be estimated. Also, the error in the accepted microturbulence parameter $\xi_{\rm t}$ of about $1\,{\rm km\,s^{-1}}$ translates directly into abundance errors greater than ± 0.3 dex. The oscillator strengths of used metallic lines in Bell's line-list were replaced with the solar ones by Thevenin (1989, 1990). The found abundances are listed in Table. We found that the hydrogen abundance could not exceed 10^{-5} by synthesizing the Hα line blend with CN lines (Fig. 1). Few (5) lines of N I show that $\log \varepsilon({\rm N}) \geq -3.1$. This is in accord with the N abundance found from CN bands. The oxygen abundance from 7 O I lines including [O I] lines at 630.02 and 636.39 nm is $\log \varepsilon({\rm O}) = -3.45 \pm 0.30$. The iron abundance from Fe I and Fe II lines $\log \varepsilon({\rm Fe}) = -5.9 \pm 0.3$ is very low. The almost coinciding abundances from Fe I (-5.93) and Fe II (-5.87) indicates that the combination of $T_{\rm eff}$ and $\log g$ is not too far from the reality. As earlier Goswami et al. (1997), we note that the Li I line at 670.78 nm is clearly present and we estimate $\log \varepsilon({\rm Li}) \approx 3.3$ and [Li/Fe]=1.9. It means that Z UMi is indeed the "Li-rich" R CrB star.

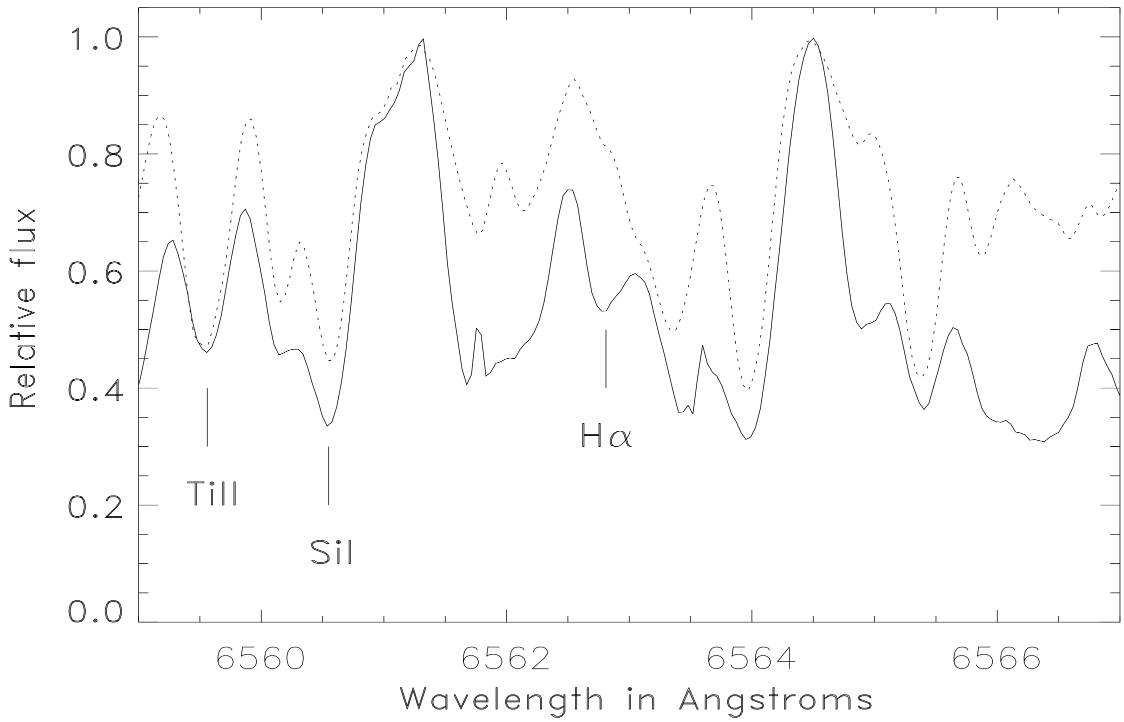

Fig. 1. Comparison of the spectra of Z UMi (full line) and HD 182040 (dotted line) near the Hα line. The lines of Ti II and Si I are also indicated. All other lines belong to CN.

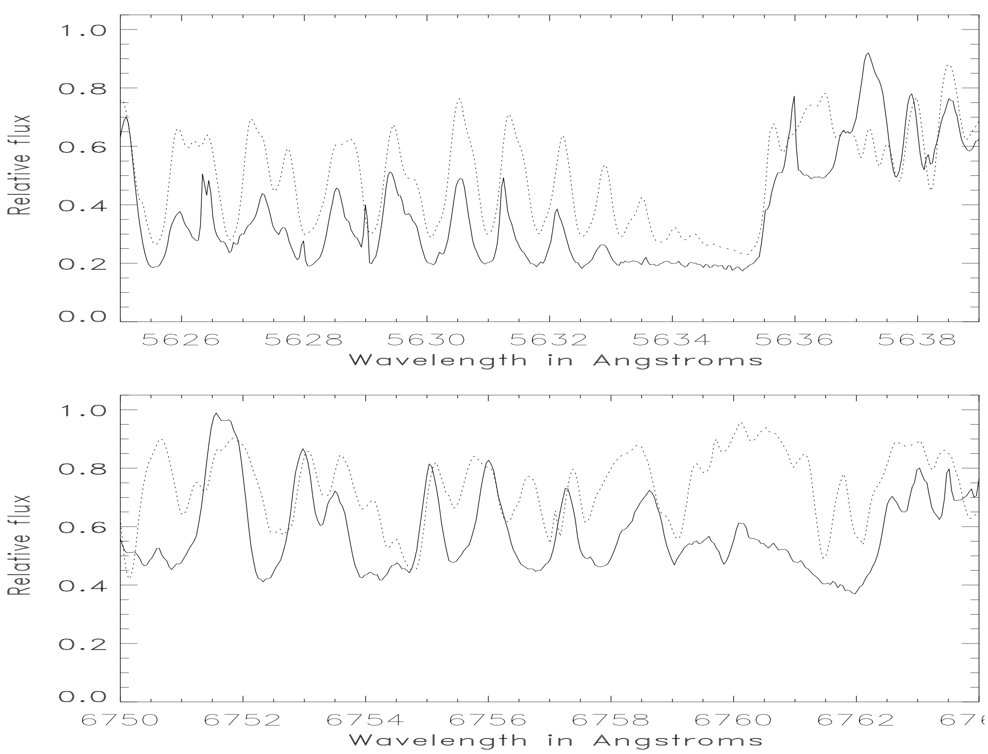

Fig. 2. Comparison of the spectra of Z UMi (full line) and HD 182040 (dotted line) near the C_2 (0,1) 563.550 and 676.1 nm bandheads. The C_2 Swan bands in Z UMi spectrum are much stronger than in HD 182040 indicating lower temperature.

Chemical composition of Z UMi, of the majority and minority groups of R CrB stars (Asplund et al. 2000), and the Sun (normalized to $\log \Sigma \mu_i A_i = 12.15$). The [El/Fe] spread in R CrB stars is given in parentheses.

El.	$\log\varepsilon$ Sun[1]	$\log\varepsilon$ Z UMi	[El/Fe] Z UMi	[El/Fe] R CrB maj.	[El/Fe] R CrB min.	Remarks
H	12.00	$\leq 10^{-5}$				
Li	3.25[2]	3.3	1.9	$-0.1(0.8)$	0.0(0.5)	
C	8.39	9.5 ± 0.2				C_2 bands
N	7.78	8.4 ± 0.5	2.5	1.7(0.3)	1.9(0.7)	CN bands
O	8.66	8.1 ± 0.3	1.3	0.6(0.6)	1.5(0.6)	7[3] O I and [O I]
Na	6.17	4.5	0.2	1.0(0.3)	1.6(0.2)	1 Na I
Mg	7.53	5.9	0.2	0.1(0.3)	$-0.2(0.3)$	1 Mg I
Al	6.37	5.8	1.3	0.6(0.3)	0.9(0.2)	2 Al I
Si	7.51	6.5 ± 0.5	0.8	0.6(0.3)	1.6(0.3)	8 Si I
Ca	6.31	3.9 ± 0.4	-0.9	0.3(0.2)	0.2(0.2)	3 Ca I
Sc	3.05	1.5 ± 0.5	0.3	0.7(0.6)	1.5(0.1)	9 Sc II
Ti	4.90	4.2 ± 0.2	1.2	0.1(0.4)	0.5(1.0)	6 Ti I
		3.2	0.2			2 Ti II
Cr	5.64	4.0 ± 0.3	0.2			7 Cr II
Fe	7.45	5.6 ± 0.3				77 Fe I
						20 Fe II
Co	4.92	4.2 ± 0.3	1.1			4 Co I
Ni	6.25	4.9 ± 0.3	0.5	0.6(0.2)	1.1(0.3)	4 Ni I
Y	2.24	0.8	0.4	0.8(0.6)	1.2(0.8)	1 Y II
Ba	2.17	0.0	-0.3	0.3(0.4)	0.6(0.2)	1 Ba II
La	1.13	0.3	1.0	1.3(0.5)	1.1(0.1)	2 La II

[1] Asplund et al. (2005), relative to $\log\varepsilon(\mathrm{H})$,
[2] Meteoritic value,
[3] Number of used lines.

Conclusions

We found that Z UMi is one of the coolest R CrB star with its $T_{\mathrm{eff}} \approx 5250$ K. The coolest known R CrB stars S Aps, WX CrA, and U Aqr have $T_{\mathrm{eff}} \approx 5000$ K. The declines of these stars are very slow and much more symmetrical than the R CrB stars declines (Alcock et al. 2001). We conclude that the chemical composition of Z UMi resembles that of minority group R CrB stars. Similarly to V CrA, VZ Sgr, and V3795 Sgr it is very metal-poor. Nitrogen is overabundant as in majority group and V CrA from the minority group.

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