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CHEMICAL COMPOSITION OF THE HALO MIRA-TYPE CARBON STAR V CRB

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Abstract. CNO and metal abundances have been derived for the metal-deficient carbon Mira-type star V CrB using high resolution spectra analyzed by the synthetic spectrum method. The atmosphere was calculated with continuum opacity sources and molecular opacity due to CO, CN, C_2, HCN, C_2H_2 and C_3. V CrB was found to be metal-deficient, with [Fe/H] = –2.12. The CNO abundances are log A(C) = 7.17, log A(N) = 5.3 and log A(O) = 7.13. The carbon isotopic abundance ratio is $^{12}C/^{13}C = 10.5 \pm 5.0$. Abundances of the s-process elements are enhanced. The abundance pattern is similar to other late-type CH stars. A comparison of the observed and computed near-infrared spectra indicates the need of improving the C_2H_2 opacity data.

Key words: stars: late-type, carbon, CH-type, atmospheres, individual: V CrB

1. INTRODUCTION

In a recent paper on chemical composition of metal-poor carbon stars (Kipper et al. 1996), from a preliminary analysis of a metal-poor carbon Mira-type star V CrB, we concluded that this star could not belong to the CH-type. The anonymous referee to Hartwick & Cowley's (1985) paper has noted that the spectrum of one of the CH standards in Šleivytė & Bartkevičius (1983) catalogue, HD 189711, closely resembles that of the N-type LPV V CrB, and, therefore, both of them may not be CH-type stars. On the other hand, Yamashita (1967) has classified V CrB as a probable CH star. In Table 1 the basic data of the star compiled by Šleivytė & Bartkevičius (1983) are

listed. The only published analysis of abundances in the atmosphere of V CrB has been published by Kilston (1975).

In this paper we present a more detailed analysis of the spectrum of V CrB and conclude that its chemical composition is quite close to other late-type CH stars which we have analyzed before (Kipper et al. 1996).

This analysis is mostly based on spectra obtained by C. Barnbaum with the Hamilton Echelle Spectrograph on the 3 m telescope at the Lick Observatory (Barnbaum 1994). For the near-IR region, the FTS spectrum of V CrB obtained on June, 28 1977 and kindly provided by K. H. Hinkle from KPNO archives was used.

Table 1. The basic data of V CrB = HD 141826.

V	P [d]	$B-V$	Sp	M_V	l	b	$V_{\rm rad}$ [km/s]
6.9–	352.8	4.41	N2e	−1.7	63.3	51.2	−115
−12.6			C6,2e				

2. ABUNDANCE ANALYSIS

2.1. Effective temperature

Because of great complexity of the spectra of cool carbon stars, their temperatures are quite poorly known, and no good effective temperature scale is available for C-classification. For Mira-type stars the temperatures obtained also depend on the light phase.

For V CrB a wide range of temperatures has been suggested. Here we describe these estimates in chronological order.

One of the first estimates was made by Bouigue (1954) who measured the vibrational temperatures of CN and C_2 bands in carbon stars. For V CrB he found $T_{\rm vib} = 2200$ K.

Mendoza & Johnson (1965) used the $(R+I)-(J+K)$ photometric index with calibration depending mainly on K and M giants and got $T_{\rm eff} = 2270$ K for V CrB.

Mendoza (1968), from multicolor photometry obtained $T_{\rm eff} = 1975$ K. This determination corresponds roughly to the light phase 0.5. If compared with the Mendoza & Johnson (1965) estimate, this

result shows that the effective temperature of carbon Mira-type stars strongly depends on light phase.

Baumert (1972) derived the color temperature $T_c = 2273$ K by comparing the absolute fluxes of eight-color photometry with blackbody energy distribution. Due to high galactic latitude of V CrB, the correction due to interstellar reddening estimated by Yamashita (1975) for the near-IR color temperatures is negligible.

Kilston (1975) derived a quite high ionization temperature, $T_{\rm ion} = 2800$ K, and the effective temperature of $T_{\rm eff} = 2950$ K. From the molecular lines he estimated the combined vibrational-rotational temperature, $T_{\rm vib-rot} = 2700$ K.

Bergeat et al. (1976) critically revised the effective temperatures of carbon stars derived at that time. For V CrB they found the color temperature $T_c = 2250$ K for the wavelength range 0.55–1.2 μm and the effective temperature $T_{\rm eff} = 2170$ K. Their effective temperatures for carbon Mira-type stars are all lower than 2300 K.

Goebel et al. (1981) performed complete spectrophotometry of V CrB for the wavelength range 0.75–13 μm. Their observations were made roughly for the light phase 0.5. They obtained the best-fitting blackbody temperature $T_{\rm IR} = 1675$ K in the wavelength range 1.2 to 6.0 μm.

Groenewegen et al. (1992) also derived the near-IR color temperature and found $T_{\rm IR} = 1945$ K.

Tanaka et al. (1990, 1992) used low resolution FTS spectra in the 4000–7000 cm^{-1} region for carbon stars to find the near-IR color indices. For V CrB they got $T_{\rm IR} = 2300$ K.

Bergeat & Sibai (1983), using the method derived earlier (Bergrat et al. 1976), found the mean effective temperature from the existing V CrB observations to be $T_{\rm eff} = 2330$ K. They also found that depending on the light phase the effective temperature of V CrB varies up to 200 K.

We used the IR-flux method (Tsuji 1981) with the photometric data from Gezary et al. (1993) and the absolute calibration by Straižys (1977) finding $T_{\rm eff} = 2300$ K. We have eliminated from further consideration the temperature found by Kilston (1975) from the ionization equilibrium, as we believe that this equilibrium is greatly influenced by very low metal abundances of V CrB compared to normal stars. We also have not used the temperature found by Goebel et al. (1981) which corresponds to a fainter light phase than the high resolution spectra used subsequently for the abundance analysis.

Giving the highest weight to the IR-flux method, we finally adopt $T_{\rm eff} = 2250$ K.

2.2. Surface gravity

Due to severe blending of all spectral lines of the coolest carbon stars, the spectroscopic criteria cannot be used for estimation of their surface gravity. To find the surface gravity, we use the basic equation connecting gravity with the stellar mass, effective temperature and absolute bolometric magnitude (Kipper & Jørgensen 1994). If the expected error in the effective temperature is ± 100 K, the error in $\log g$ obtained using this formula is ± 0.1 dex. An error in the assumed mass of $\pm 0.2 M_\odot$ leads to the same error in $\log g$.

We choose $M_* = 0.8 M_\odot$ based on our estimates of masses of late-type CH stars (Kipper et al. 1996). This low value of the mass is also supported by the results of Groenewegen et al. (1992) who found that CH stars originate from the stars of masses 0.69–0.85 $M_\odot$.

The largest uncertainty of $\log g$ found in this way is due to the absolute bolometric magnitude. An error in $M_{\rm bol}$ of ± 1 mag leads to the error in logarithmic gravity ± 0.4 dex.

Estimates of $M_{\rm bol}$ for the N-type carbon stars of the Galaxy are of low accuracy. A few stars in open clusters indicate their $M_{\rm bol}$ from –4.4 to –5.2 (Lambert et al. 1986).

Groenewegen et al. (1992) assumed the mean bolometric magnitude of carbon stars in the Galaxy to be the same as in LMC, i.e. $M_{\rm bol} = -4.9$. Using the period-luminosity relation for carbon Mira-type stars in LMC by Feast et al. (1989) and assuming the distance modulus for the LMC to be 18.47, we get for V CrB $M_{\rm bol} = -4.5$.

The M_V value from the catalogue by Šleivytė & Bartkevičius (1990) is -1.70. Taking the bolometric correction, $BC \approx -3.0$, estimated from the graph by Alksne et al. (1983) for spectral type C6, we get $M_{\rm bol} = -4.7$. The listed data are in good agreement and allow us to accept $\log g = -1.0$ with an error not exceeding ± 0.2 dex. In the literature, however, quite different $M_{\rm bol}$ values for V CrB can be found: Bergeat et al. (1978) give $M_{\rm bol} = -2.32$ and we obtain $M_{\rm bol} = -6.33$ using $M_V = -1.70$ and $BC = -4.63$ (Mendoza & Johnson 1965). In Kipper & Jørgensen (1994) we found that a mass around $0.8 M_\odot$ is the lower limit for the stars reaching the AGB intrinsic carbon star stage. With this mass and $T_{\rm eff} = 2250$ K, we estimated $M_{\rm bol} \approx -4.0$ from the pulsation equation (Feast et al.

1989). This estimate excludes the lower value, $M_{\rm bol} = -2.32$. Even the unlikely high mass of $2M_{\odot}$ would not give the highest luminosity listed, $M_{\rm bol} = -6.33$.

2.3. Microturbulent velocity

We used spectrum synthesis as a tool in abundance analysis, therefore, the microturbulent velocity , $\xi_{\rm t}$, is an important input parameter. It could be determined as the value which gives no dependence between the determined abundances and the equivalent widths of the lines for the element at hand.

Due to severe blending of atomic lines by molecular features in the spectrum of V CrB, the equivalent widths of the lines could be estimated only from the central depths assuming the line profiles. In the spectrum used most lines, except the strongest ones (Mg I at 518.2 nm, Na I $D_{1,2}$), have an instrumental profile.

The original continuum level of Barnbaum (1994) was used in most cases. Also, a somewhat lower resolution spectrum of V CrB obtained by V. G. Klochkova and V. E. Panchuk with the 6 m telescope on May 1, 1994, was consulted, as in that case the whole spectrum could be drawn in the same scale, what was not possible for the Lick spectra.

In this way $\xi_{\rm t} = 2.0 \pm 1.0$ km/s was found from Fe I, Ti I and La I lines. When searching for H_2 lines in cool carbon stars, Johnson et al. (1983) found that a microturbulent velocity of 3 km/s matches best the spectra of their whole sample (including V CrB).

2.4. Chemical composition for modeling

The chemical composition used for computing the atmospheric models is based on the preliminary analysis of V CrB which gives [Fe/H] ≈ -2 or even lower. Therefore, $\log A({\rm Fe}) = 5.5$ was adopted. Abundances of other elements should be adjusted to this iron abundance.

For the oxygen abundance we assume that it follows the trend observed among the field stars with decreasing metallicity: [O/Fe] ≈ -0.5 [Fe/H] down to [Fe/H] ≈ -1.0 and the constant ratio [O/Fe] $\approx +0.35$ (Wheeler et al. 1989) for lower metallicities. As a result, we adopt $\log A({\rm O}) = 7.3$. Kilston (1975) has found the carbon to oxygen abundance ratio C/O = 1.23, our preliminary result yields

C/O = 1.0. The average value of C/O = 1.1 gives $\log A(\mathrm{C}) = 7.34$. Very roughly [N/H] $\approx$ [O/H] for carbon stars (Lambert et al. 1986), and this leads to $\log A(\mathrm{N}) = 6.5$. The abundances of other elements were roughly scaled according to the data presented for stars of very low metal abundance by Pagel (1972). The chemical composition adopted for modeling is given in Table 2.

The reduced metal abundance (in particular, abundance of Na, Al and Ca) has a significant effect on the model structure due to the reduced number of electron donors. Changes in the absolute value of CNO abundances (when keeping the C/O ratio constant) cause less drastic effects on the temperature structure (Kipper & Jørgensen 1994).

Table 2. Chemical composition used for model calculations.

Element	Abundance	Element	Abundance
H	12.00	Si	5.90
He	10.99	S	5.50
C	7.34	K	3.20
N	6.50	Ca	4.60
O	7.30	Ti	3.30
Ne	6.60	Cr	4.00
Na	4.60	Fe	5.50
Mg	6.10	Ni	4.30
Al	4.40		

2.5. Model atmospheres

There is no doubt that accurate and detailed chemical analyses of Mira-type spectra require sophisticated dynamical models since the velocity stratification may strongly alter the profiles and the equivalent widths of lines (Scholz 1992). In the case of V CrB, however, the amplitude of shocks is only about 11.4 km/s, i.e. lower than in the M or S Mira-type stars, where it can reach about 30 km/s (Sanford 1950). The hot zone directly behind the propagating shock front is hopefully optically transparent and very thin. It does not affect the equilibrium temperature stratification and the absorption spectrum of the photosphere (Bessell et al. 1996). The shock could alter the partial pressures of molecules with low dissociation energy, such as H_2 (Pierce 1994). The presence of quite strong H_2 4712.9 cm^{-1} line

in the spectrum of V CrB supports the assumption of relatively mild influence of shocks on the absorption spectrum.

Taking into account the above considerations and the fact that dynamical atmospheric models for the metal-poor carbon Mira-type stars are not available, we used static models.

The new metal-deficient model atmospheres with the opacity as complete as possible were computed for V CrB in the way described in Kipper & Jørgensen (1994). The program used is an improved version of the MARCS program (Gustafsson et al. 1975) with updated opacities. Opacities from continuum sources and the molecules CO, CN, C_2, HCN, C_2H_2 and C_3 were included.

Goebel et al. (1981), when analyzing their 0.75–13 μm infrared spectrophotometry of V CrB, have stressed that its spectrum is dominated by bands of HCN and C_2H_2 molecules and that the calculations of model atmospheres cannot be attempted without inclusion of these molecules. As it was noted, these molecules were included in the present models. The molecular opacities were treated in the opacity sampling (OS) approximation and included 5365 points throughout the spectrum equally spaced in wavenumber inside each of six intervals covering the wavelength region from 125 nm to 25 μm.

The data for computing opacities in these OS points were taken for CO from Goorvitch (1994), for C_2 from Querci et al. (1974), for CN from Jørgensen & Larsson (1990), for HCN from Jørgensen et al. (1985), for C_2H_2 from the unpublished work of Jørgensen (1982) and for C_3 from Jørgensen et al. (1989).

In Fig. 1 the synthetic spectrum computed at OS points for the used model $(T_{\rm eff}, \log g, Z/Z_\odot) = (2250, -1, 0.001)$ and the 2250 K blackbody flux curve are plotted. Shifted up from this spectrum (multiplying by 20), the near-IR fluxes from Goebel et al. (1981) are also plotted, together with the 1675 K blackbody fitted in the same way as in the case of the Goebel et al. data. The positions of the strongest molecular bands are also indicated.

The qualitative fit of the calculated and observed near-IR spectra is quite close except for the 2.14 μ C_2H_2 band which is strong in the calculated spectrum and not observed at all. One has to bear in mind that the opacity sampling spectra cannot be compared directly with observations and only a rough idea, how the molecular bands behave, can be obtained. For this reason and remembering that the calculated spectrum corresponds to the light maximum and the observed data are taken near the visual minimum, a quantitative

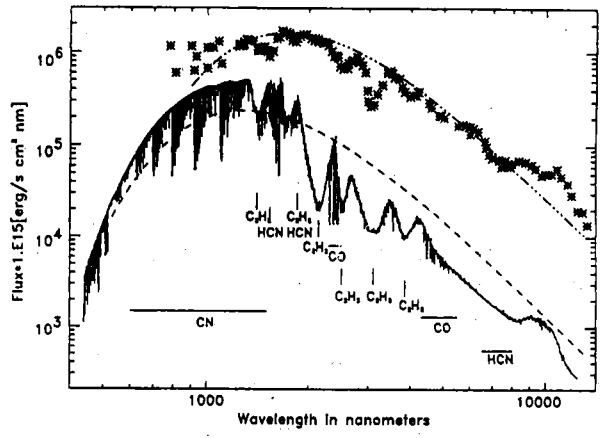

Fig. 1. The computed and observed spectra of V CrB. Full line: the computed spectrum for the accepted model (2250, −1, 0.01), dashed line: the 2250 K blackbody flux curve, asterisks: the near-IR spectrum of V CrB by Goebel et al. (1981), dash-dotted line: the 1675 K blackbody flux curve. The last two are shifted up by a factor of 20. The flux units correspond to the model spectrum.

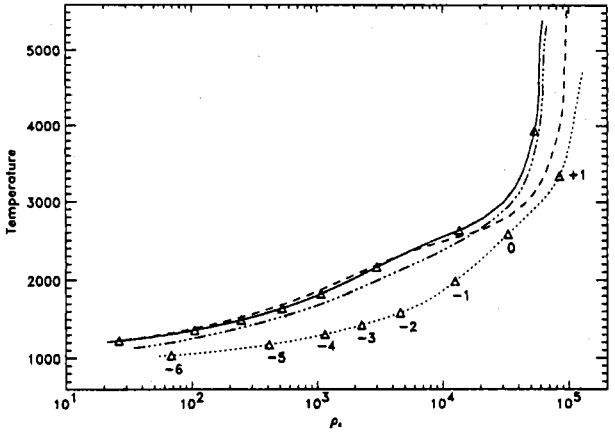

Fig. 2. The temperature structure in some models calculated for V CrB. Plotted is the temperature versus the mass loading, ρ_x. The full line is for the adopted model (2250, −1, 0.01), the dotted line is for the model without C_2H_2, the dashed line is for the model with lower (by 0.5 dex) $\log g$ and the dash-dotted line is for the model with the opacity in 2.14 μm C_2H_2 band excluded. For the first two models the points with logarithms of the Rosseland mean optical depth from −6 to 1 are also indicated (triangles).

fit was not attempted. Also, construction of atmospheric models of carbon stars for effective temperatures below 2000 K seems to be not feasible.

At the same time, the opacity due to C_2H_2 is very important in formation of the temperature structure in the atmospheres of carbon stars. In Fig. 2 the temperature distributions in some models are plotted. If the opacity due to C_2H_2 is completely excluded, the model will be much more compact compared to the case when it is included. Even the exclusion of only the 2.14 μm band changes the temperature structure. However, the temperature structure of the model with excluded C_2H_2 2.14 μm band will lead to abundances about 0.1 dex lower compared to the accepted model, which is small change compared to other errors (see Section 2.6).

To decrease the intensity of the C_2H_2 bands, one should decrease the partial pressure of this molecule in the outer atmospheric layers. This could be done either by decreasing the surface gravity or by increasing the temperature. If the effective temperature is raised, it merely shifts the temperature distribution, and such models are therefore not plotted. The lowering of the surface gravity leads to a model which mimics the model with still lower metallicity. The reasonable higher effective temperature, $T_{\rm eff} = 2600$ K, or the lower surface gravity, $\log g = -1.5$, will not lead to models which better describe the near-IR spectrum of V CrB. The absence of the 2.14 μm band in the observed near-IR spectrum, which corresponds to much lower temperature (1675 K), shows that the reason for too strong C_2H_2 bands in the synthetic spectrum is not in too low temperature chosen for the modeling. One of the possibilities to reduce the strength of C_2H_2 can be the presence of the chromosphere. Again, a quite strong H_2 line in the spectrum of V CrB suggests that this is not the case.

The C_2H_2 2.14 μm band is also excessively strong throughout the light period in the OS-spectra computed by Höfner (1996) for the exploratory dynamical atmospheric models of V CrB, similarly to the dynamical models of other carbon-rich long period variables (Höfner et al. 1995). In the new C_2H_2 OS-tables calculated by Jørgensen (1996) the 2 μm band is almost absent.

The computed spectrum between 5 and 8 μm is featureless and similar in this respect to the observed spectrum, except of the observed 7 μm band. This band was attributed by Goebel et al. (1981) to the joint effect of HCN, C_2H_2 and possibly CS. The reason for the

depression in the calculated spectrum between 4.5 and 8.5 μm is the broad C_2H_2 band in the OS data used. At 8 μm and longwards the observed flux shows an excess emission which, however, is not so evident if compared with the model spectrum, instead of the blackbody curve. In the synthetic spectrum this bump is just the undisturbed photospheric continuum and is visible only due to contrast with the end of the broad depression at 8.5 μm. In the observed spectrum there is an additional excess at 10–13 μm which is not reproduced in the synthetic spectrum. In the synthetic spectrum the contribution of dust shell was not taken into account. The presence of a bump in the synthetic spectrum in 8.5–10 μm region shows that there is no need for the graphite dust to explain the observed "emission" in that region. The presence of graphite was suggested by Goebel et al. (1981) for explaining the raising continuum shortwards of SiC emission which is confined to the 10–13 μm range in all carbon stars.

2.6. Abundances

The abundances were found by fitting the calculated spectra to the observed ones by eye (Fig. 3). As it is explained in Section 2.3, the continuum drawn by Barnbaum (1994) was used, with the corrections applied from the inspection of a slightly lower resolution spectrum.

The profiles of all lines, except of the strongest ones, were assumed to be instrumental and, therefore, if the line was found to be wider, it was treated as a blend. The instrumental broadening itself was determined using the terrestrial O_2 lines. These lines in the spectral region 686.5–690.6 nm lead to the instrumental broadening of 13 km/s. For a few relatively unblended lines the observed profile is quite well described by instrumental profile and, therefore, no extra broadening (e.g. from macroturbulence) was applied.

The individual metal lines were fitted, not the spectral regions. This gave a possibility to estimate the internal errors presented in Table 3. For C_2 and CO, however, the 5 nm regions were fitted.

The carbon to oxygen abundance ratio was estimated from the fits of the C_2 bands in the spectral region shorter than 570 nm. The oxygen and carbon abundances were estimated from the CO first-overtone lines in the region 4324–4366 cm^{-1} with the assumption that the C/O ratio was already fixed by fits of the C_2 bands in the visual region. The nitrogen abundance was found from the CN

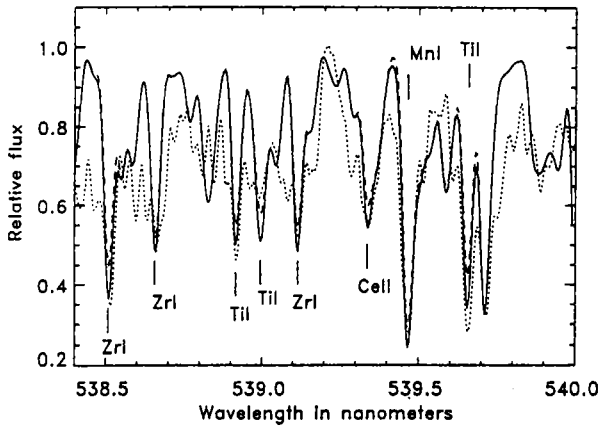

Fig. 3. The observed spectrum of V CrB (dotted line) together with two synthetic spectra (full and dashed lines). Some identifications are indicated. For computing the spectrum, plotted by a dashed line, the abundances of indicated elements were reduced by 0.5 dex.

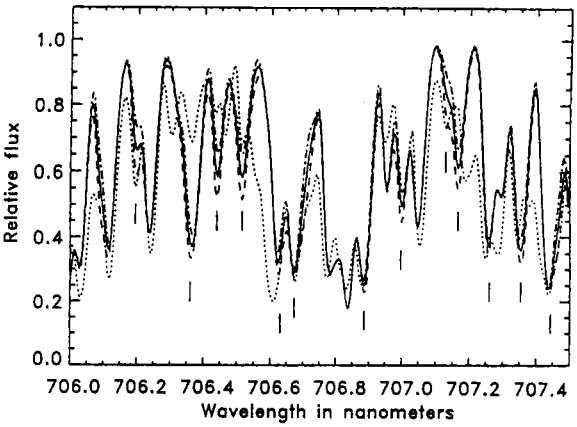

Fig. 4. One of the regions used for determining the carbon isotopic abundance ratio, $^{12}C/^{13}C$. The observed spectrum is plotted by the dotted line. The full line corresponds to $^{12}C/^{13}C = 10$, the dashed line to 5 and the dash-dotted line for 20.

lines in the region longer than 700 nm. From the same region the estimates of the carbon isotopic ratio, $^{12}C/^{13}C$, were made (Fig. 4).

For synthesizing the spectra, we have used a program developed from the widely known program WIDTH5 for the standard LTE analysis (Kurucz 1970).

Table 3. Chemical composition of V CrB.

Elem.	log$A$	[E/H]	[E/Fe]	Number of lines	Ref. gf
C	7.17	−1.4	0.75		
N	5.3	−2.7	−0.5		
O	7.13	−1.8	0.4		
Ca	4.2±0.5	−2.1	0.0	10	B
Sc	1.3±0.3	−1.8	0.3	5	B
Ti	3.2±0.2	−1.8	0.3	35	B(T)
V	2.8±0.2	−1.3	0.8	26	B
Cr	2.6±0.4	−3.1	−1.0	7	B
Mn	4.2±0.6	−1.2	0.9	7	B
Fe	5.55±0.27	−2.12		27	B
Co	4.2±0.4	−0.8	1.0	12	B
Ni	4.6±0.6	−1.7	0.4	9	B
Cu	3.0	−1.1	1.0	1	B
Sr	1.4±0.8	−1.5	0.6	3	B
Y	2.0±0.9	−0.1	2.0	6	B
Zr	2.7±0.3	−0.1	2.0	29	B
Nb	1.1±0.4	−0.9	1.2	10	B
Mo	1.7	−0.5	1.6	2	B
Ba	1.5	−0.6	1.5	2	T
La	1.0±0.6	−0.1	2.0	12	B
Ce	2.4±0.5	0.8	2.9	8	B
Pr	1.2±0.3	0.4	2.5	4	B
Nd	0.3±1.0	−0.9	1.2	6	B
Sm	−0.6±0.7	−1.3	0.8	5	B
Eu	−0.5±0.7	−1.2	0.9	3	B
Gd	−0.3±0.4	−1.4	0.7	7	B
Lu	0.2	−0.6	1.5	1	B
Hf	0.9±0.5	0	2.1	5	B
Th	0.2±0.5	0	2.1	5	B
U	0.5±0.5	0.1	2.0	10	B

For the spectral region $\lambda < 700$ nm we used the line list compiled by Bell (1976) with some modifications of oscillator strengths for metal lines according to Thevenin (1989). In Table 3 the references to used oscillator strengths are indicated as B (Bell 1976), T (Thevenin 1989), and B(T) are Bell's log gf values with zero-point shifted according to Thevenin. For computing the CN spectrum we

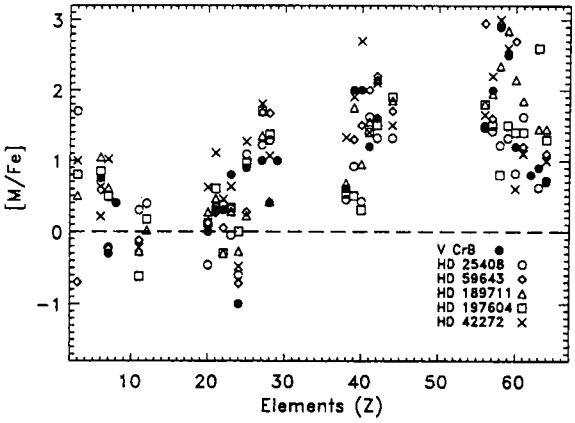

Fig. 5. The abundances relative to iron, [M/Fe], in the atmospheres of V CrB and other late-type CH stars analyzed earlier.

used the data from the SCAN-CN tape (Jørgensen & Larsson 1990) and for CO near-IR lines the data by Goorvitch (1994).

The resulting abundances are presented in Table 3. They are also plotted in Fig. 5 together with the abundances found for the other late-type CH stars. The quoted errors correspond to the confidence level of 95 %. These are the formal errors derived from differing results for various lines. The errors are rather large due to heavy blending and therefore only the central parts of medium and strong lines were fitted. The systematic errors from the uncertainties in the assumed effective temperature (±200 K), surface gravity (±0.5 dex) and the microturbulent velocity (±1.0 km/s) are expected not to exceed ±0.4 dex, the largest of these errors being due to uncertainty in the microturbulent velocity (Kipper et al. 1996).

The carbon to oxygen abundance ratio is determined with quite low error from the intensity of C_2 bands, C/O= 1.09 ± 0.01, but the absolute values of C and O abundances are very uncertain. The lines of the first overtone bands in the 4323–4366 cm^{-1} region, which were used to fix these abundances, are quite strong and therefore the errors amount to ±0.5 dex. The same applies to the nitrogen abundance. The value given in Table 3 corresponds to the dissociation energy of CN $D_0(CN) = 7.77$ eV (Costes & Naulin 1994).

The carbon isotopic abundance ratio, $^{12}C/^{13}C$, found from 22 ^{13}CN lines in the region 703.3–707.4 nm is 10.5 ± 5.0.

We could not confirm the lithium abundance for V CrB found by Boffin et al. (1993), $\log A(\mathrm{Li}) = -1.0$. Instead the lithium was found to be nearly absent ($\log A(\mathrm{Li}) = -2.5$), in accordance with the result by Torres-Peimbert & Wallerstein (1966).

The presence of ^{99}Tc, a short-living isotope, is believed to indicate recent enrichment of s-process elements. The abundance of technetium usually is established by the resonance lines of Tc I near 425 nm. Unfortunately, the used observations do not cover the blue spectral region. In addition, Tc I has two intercombination lines at 592.447 nm and 608.523 nm. The spectra used in this work include the last line. However, this Tc I line is hopelessly blended by a Ti I line at 608.526 nm (Smith & Wallerstein 1983). We were not able to synthesize properly this spectral region for estimating the contribution of the Ti I line and other lines in this blend due to the absence of many observed lines in our list. Using the representative spectra of stars, containing technetium in their atmospheres (Barnbaum et al. 1991), we could only estimate that the presence of Tc in V CrB is possible. To look for the second intercombination line at 592.447 nm we used the echelle spectrum obtained by Klochkova and Panchuk and described in p. 439. For this spectral region our line list is also not as complete as desired. We were able, however, to estimate the upper limit of the technetium abundance: $\log A(\mathrm{Tc}) \leq -0.5$.

3. CONCLUSIONS

The element abundances in the atmosphere of V CrB derived in this work do not differ considerably from the abundances found previously for other late-type CH stars (Kipper et al. 1996). Therefore we conclude that V CrB is a CH star, and this solves a discussion described in the introduction about the classification of this important star. Using the arguments outlined in our previous work (Kipper & Jørgensen 1994, Kipper et al. 1996) we conclude that V CrB most likely has formed as an intrinsic carbon star.

We found that no graphite dust shell, suggested by Goebel et al. (1981), is needed for explaining of the spectrum of V CrB in the 8–15 μm region. However, some SiC dust can be at the limit of detectability. The mass-loss from V CrB, estimated by Groenewegen et al. (1992) from CO data, is one of the lowest in their sample of carbon stars, $\dot{M} = 2 \cdot 10^{-7}\ M_{\odot}/\mathrm{yr}$, what supports our result.

Difficulties in the detailed fitting of the near-IR fluxes of the computed and observed spectra from 1.5 to 8 μm indicate the need for improving the C_2H_2 opacity data for this region.

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