Publications of the Astronomical Society of the Pacific
109: 796–798, 1997 July

On the Hydrogen-Deficient Nature of Z Ursae Minoris

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Received 1996 December 5; accepted 1997 April 21

ABSTRACT. Z Ursae Minoris was classified by Benson et al. (1994, AJ, 108, 247) as an R Coronae Borealis (RCB) variable star from its light variations. Hydrogen deficiency, which is a defining feature of RCB stars, was not established. To investigate this aspect we have obtained high-resolution spectra in both blue (4200–4630 Å) and red (5050–7950 Å) regions. Lines of the CH molecule (G band) at about 4300 Å, which are present in spectra of N-type carbon stars are weak or absent in the spectrum of Z UMi indicating its hydrogen-deficient nature and membership of the rare class of RCB variables.

1. INTRODUCTION

Z Ursae Minoris was first noted as a variable star by Beljawsky (1934). In the *General Catalogue of Variable Stars,* Kholopov et al. (1985–see also Jura et al. 1993) list Z UMi as a long-period Mira variable having a period $P \geqslant 400$ days. Benson et al. (1994) monitored Z UMi over a period of one year and based on their photometric and spectroscopic data classified it to be an RCB variable. A rapid decline in optical brightness of about 6 mag was the principal evidence in support of the classification. An apparent pulsation (amplitude ~ 0.5 mag with a period of 130 days) is also characteristic of RCB variables. Low-resolution spectra showed that Z UMi is a cool carbon star. Hydrogen deficiency, which is a defining characteristic feature of RCB stars was not explicitly established by Benson et al. (1994). In the present work, we discuss high-resolution spectra of Z UMi covering the spectral ranges 4200–4630 and 5010–7980 Å. Our spectra show Z UMi to be hydrogen deficient and, hence, an RCB star.

2. OBSERVATIONS AND DATA REDUCTION

High-resolution spectra of Z UMi were obtained using Sandiford Echelle Spectrograph (McCarthy et al. 1993) at the Cassegrain focus of the 2.1-m telescope at the McDonald Observatory on April 29 and 30, 1994 and April 19, 1995. The wavelength coverage was from 4200 to 4630, 5010 to 5955, and 6030 to 7980 Å. The spectral resolution is about 60,000. For comparison, a blue spectrum of the N-type carbon star UU Aur was obtained at the same resolution with the same spectrometer on March 19, 1995. The CCD data were reduced using the IRAF software package.

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3. DESCRIPTION OF THE SPECTRA

Inspection of the spectra reveals the complex combination of molecular and atomic absorption features expected of cool carbon stars. The CN Red and Violet system and the C_2 Swan bands are the dominant contributors of molecular lines. We identified a number of atomic features using the spectral atlas of the carbon stars U Hya and TX Psc by Barnbaum (1994a). Z UMi appears to be of later spectral type than the classical R0 star HD 156074, but not as late as the carbon star UU Aur (N3,C5,4). The C_2 Swan bands are much stronger in Z UMi than in HD 182040, the R1 hydrogen-deficient carbon (HdC) star. Z UMi may correspond to a spectral type of about C2 or C3.

The spectrum in the blue region was obtained to estab-

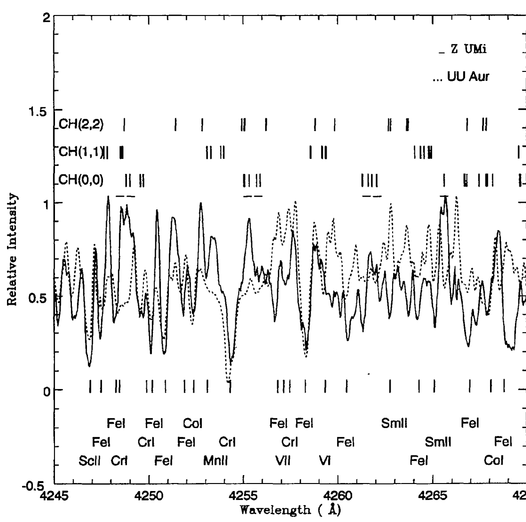

Fig. 1—Shows the comparison of the two spectra of UU Aur and Z UMi in the spectral region 4245–4270 Å. Contributions due to CH 0-0, CH 1-1, and CH 2-2 bands are indicated by separate markers for the individual bands. Horizontal markers below the CH lines indicate that CH strong regions in UU Aur are definitely CH poor in Z UMi.

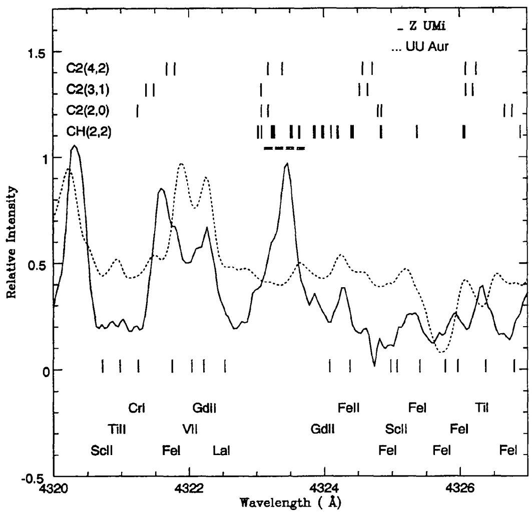

FIG. 2—Comparison of CH lines in the spectral region (4320–4327) Å in UU Aur and Z UMi. This region is dominated by Q branch heads of the CH 2-2 band. The figure shows the presence of CH lines in UU Aur and their absence in the Z UMi spectra. The high point at 4323.45 Å in Z UMi is a clear evidence for the hydrogen deficient nature of Z UMi. Horizontal markers indicate CH features that are weak or absent from Z UMi. Above the CH markers, lines of the C_2 Swan system are indicated.

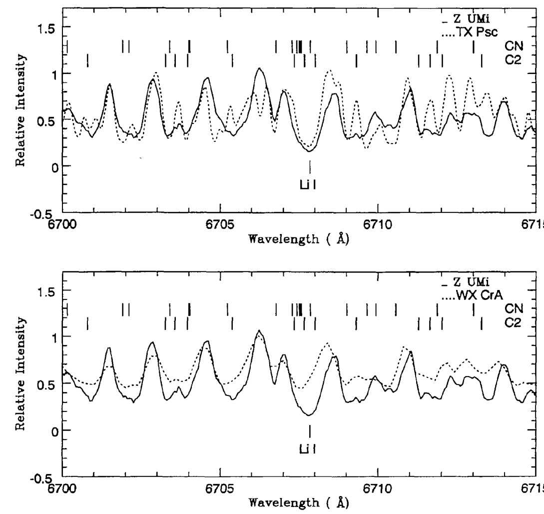

FIG. 4—Comparison of TX Psc (a Li-rich carbon star) and Z UMi in the spectral region 6700–6715 Å (upper panel). The blend of C_2, CN, and Li feature at 6707.8 Å matches in wavelength quite well. Comparison of WX CrA, a cool RCB star and Z UMi (lower panel). The figure shows the presence of Li feature at the proper wavelength in Z UMi and the absence of it in WX CrA.

lish the hydrogen deficiency through the comparison of CH lines in the spectra of Z UMi and UU Aur. We searched for CH lines in regions where C_2 lines are relatively sparse and weak. In Fig. 1 we compare UU Aur and Z UMi in the wavelength region 4245–4270 Å. Three vibrational bands—CH 0-0, CH 1-1, and CH 2-2—contribute lines in this region (Moore and Broida 1959), as indicated by markers on the figure. The regions where strong CH lines are expected are indicated by horizontal markers. These absorption features are present in UU Aur but are weak or absent in Z UMi. Some spectral features that are stronger in Z UMi than in UU Aur are due to atomic lines of heavy elements, as indicated by the possible identifications given below the spectra. Figure 2 shows the spectral region of UU Aur and Z UMi near 4320–4327 Å. This region contains the Q Branch heads of the CH 2-2 band indicated above the spectra by vertical markers. We have also indicated lines from the C_2 Swan system bands 2-0, 3-1, and 4-2 whose band heads are at 4382.15, 4371.44, and 4364.94 Å, respectively (see Fig. 3).

Examination of Figs. 1 and 2 as well as the rest of the blue spectrum of Z UMi shows the CH lines to be much

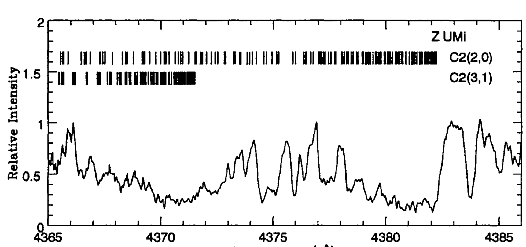

FIG. 3—The spectral region 4365–4385 Å in Z UMi. The region is dominated by C_2 Swan system 2-0 and 3-1 bands.

weaker than they are in UU Aur. Indeed, we are not convinced that CH is a contributor to Z UMi's spectrum. For normal late-type stars, the CH bands decrease in strength with decreasing effective temperature. Z UMi appears to be of an earlier spectral type than UU Aur yet has much weaker CH lines. Hence, we conclude the star must be hydrogen deficient, as implied by its photometric classification as an RCB variable. (Absence of Hα from the red spectrum is not strong evidence of hydrogen deficiency. The line is not seen in absorption in N-type stars but may be seen in emission occasionally.)

An interesting feature of the red spectrum is the presence of Li I at 6707.8 Å. This is shown by Fig. 4 where we compare the spectra of Z UMi, TX Psc, and WX CrA. TX Psc is an N-type carbon star with a Li abundance which is approximately that expected for a red giant whose convective envelope diluted the star's main-sequence surface reservoir of lithium (Denn et al. 1991). It is *not* a Li-rich carbon star like WZ Cas. WX CrA like Z UMi is a cool RCB star.[2] The spectrum of WX CrA shows an absorption feature at 6707.5 Å that is a blend of CN and C_2 (Denn et al. 1991; Lambert et al. 1993; Barnbaum 1994b). Relative to WX CrA, Z UMi clearly shows excess absorption at the wavelength expected of Li I. There is a close correspondence between the spectrum of Z UMi and TX Psc.[3] This similarity also shows lithium to be present as Denn *et al.* could not fit the spectrum of TX Psc without a contribution from the Li I resonance lines.

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[2]The spectrum of WX CrA was obtained at the Cerro Tololo Inter-American Observatory with the Cassegrain echelle spectrometer at the 4-m telescope with a spectral resolution 0.3 Å and S/N ratio ~ 100.

[3]The spectrum of TX Psc from Denn et al. (1991) was obtained at the McDonald Observatory at a resolution of 100,000.

The C_2 Swan bands are well represented in our spectra of Z UMi. All of the expected band heads are present. We find no evidence for isotopic ($^{12}C^{13}C$) bands. Unfortunately, the 1-0 band at 4737 Å was not observed. It is this band that most directly gives an estimate of the $^{12}C/^{13}C$ ratio as the $^{12}C^{13}C$ band lies to the red of the blue-degraded $^{12}C_2$ band. Nonetheless, it seems likely that Z UMi is ^{13}C poor like the HdCs.

Atomic lines of several elements from sodium to gadolinium have been identified. Judged by their intensities in Z UMi and UU Aur, we expect the relative elemental abundances for Z UMi and UU Aur to be similar. In particular, the *s*-process elements do not have the unusual relative abundances so obvious from the line intensities for the cool RCB U Aqr (Bond et al. 1979).

The radial velocity of the star has been measured from several relatively unblended atomic lines in spectra obtained on 1994 April and 1995 April. To within the errors of measurement the velocity was the same on the two occasions: the mean value is -37 ± 2 km s^{-1}.

4. CONCLUDING REMARKS

Our high-resolution spectra show, by inspection, that Z UMi lacks the CH lines that are clearly seen in the N-type carbon stars. On this basis, we conclude the star is hydrogen deficient and so confirm Benson *et al.*'s suggestion that Z UMi is a cool RCB variable.

A secondary feature of interest is the presence of the Li I 6707 Å resonance doublet. An abundance analysis with appropriate model atmospheres will be necessary to derive the lithium abundance. Lithium is present in some RCBs and HdC stars. Keenan and Greenstein (1963) first showed lithium to be present in R CrB. Three other warm RCBs are known to show lithium (Lambert and Rao 1994). One HdC also shows a prominent Li I doublet (Warner 1967). It is, however, unclear if Z UMi should be classed with the "Li-rich" warm RCBs. The star is much cooler so that more lithium is neutral and quite a low abundance could translate to a detectable Li I doublet. Certainly, the N-type carbon stars such as TX Psc have a much lower lithium abundance than the warm RCBs with a prominent Li I doublet.

Aruna Goswami acknowledges the Council of Scientific and Industrial Research, New Delhi, for financial assistance through scientists' pool scheme. We thank Dr. Earle Luck for providing the spectrum of TX Psc. This work was supported in part by the National Science Foundation (Grant AST-9315124) and the Robert A. Welch Foundation of Houston, TX.

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