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A High-Resolution Spectrum of the R Coronae Borealis Star V2552 Ophiuchi

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ABSTRACT. Photometry and low-resolution spectroscopy have added V2552 Oph to the rare class of R Coronae Borealis variables. We confirm this classification of V2552 Oph through a comparison of our high-resolution optical spectrum of this star and that of R CrB and other F-type members of the class. We show that V2552 Oph most closely resembles Y Mus and FH Sct, stars in which Sr, Y, and Zr are enhanced.

1. INTRODUCTION

The R Coronae Borealis variables are a select group of distinctive supergiants. A Galactic census presently recognizes no more than about 30 R CrB stars. Their special distinctions are a severe deficiency of hydrogen in their atmosphere and a propensity to fade by up to 6–8 mag at irregular and unpredictable times. The origin of the hydrogen deficiency (and other composition anomalies) and the mechanism responsible for the characteristic fading of the star remain the subjects of theoretical and observational enquiries. Given the small number of R CrB stars, one seeks to enlarge the sample in the hope that a new discovery may yield a fruitful clue to outstanding questions.

The latest addition to the R CrB census is V2552 Oph (Kazarovets et al. 2003). This star, CD $-22°12017$, was identified as an R CrB star from a light curve showing two R CrB–like fadings (Kato & Katsumi 2003). This identification was confirmed by Hesselbach, Clayton, & Smith (2002, 2003) from photometry and a low-resolution spectrum. In this paper, we report on the first high-resolution optical spectrum of V2552 Oph and show that it is remarkably similar to the spectrum of the eponym with a few striking differences.

2. OBSERVATIONS

Our spectrum of V2552 Oph was obtained on 2003 June 11 (HJD 2,452,801.809) with the McDonald Observatory's 2.7 m telescope and the 2dcoude echelle spectrograph (Tull et al. 1995) at a resolving power of 60,000. The spectrum runs from about 3800 to 10000 Å with gaps between the orders beyond 5800 Å. The signal-to-noise ratio (S/N) in the continuum is 95 or greater over much of the observed wavelength interval longward of 5500 Å. The S/N decreases to shorter wavelengths. V2552 Oph appeared to be at maximum light. Standard reductions of the CCD frames give the radial velocity of V2552 Oph as 60.5 ± 0.9 km s^{-1} from a set of 51 unblended photospheric lines.

3. V2552 OPH AND R CrB: SPECTRA AND ABUNDANCES

By inspection of the spectra, it was apparent that V2552 Oph has a spectrum remarkably similar to that of R CrB. This is illustrated in Figures 1 and 2. The similarity suggests that the stars have similar atmospheres and compositions. Lines that are of very similar strength in V2552 Oph and R CrB belong to the following atoms and ions: H I, C I, Na I, Mg I, Al I, Si I, Si II, S I, K I, Ca I, Sc II, Ti II, Fe I, Fe II, Ni I, Zn I, Ba II, and La II. The similarity for C I is a direct consequence of the fact that the neutral carbon atom is the principal contributor of continuous opacity (Schönberner 1975). The similarity for other atoms and ions with a mix of low to high excitation lines is an indication that the effective temperature ($T_{\rm eff}$), surface gravity (g), microturbulence (ξ_t), and composition are also similar for the pair of stars.

Obvious differences in line strength for atoms and ions are noted that imply differences in abundance:

1. The Li I λ6707 resonance doublet is strong in R CrB but absent from V 2552 Oph (Fig. 1).
2. The N I lines, all of high excitation, are considerably strengthened in V2552 Oph. Figure 1 shows the N I lines at 6706.1 and 6708.7 Å to be enhanced in V2552 Oph relative to R CrB.
3. The O I high-excitation and low-excitation 6363 Å [O I] lines are weaker in V2552 Oph. The fact that the low and high excitation lines are all weaker suggests that the oxygen abundance is lower for V2552 Oph.

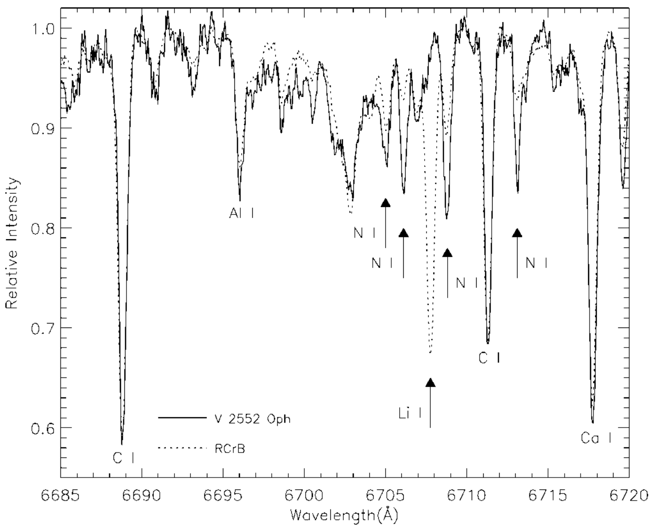

FIG. 1.—Spectra of V2552 Oph and R CrB in the interval 6685–6720 Å. Many lines are the same strength in the two spectra, but remarkable differences are seen and marked by an arrow: N I lines are much stronger in V2552 Oph, but Li I is strong in R CrB but absent from V2552 Oph.

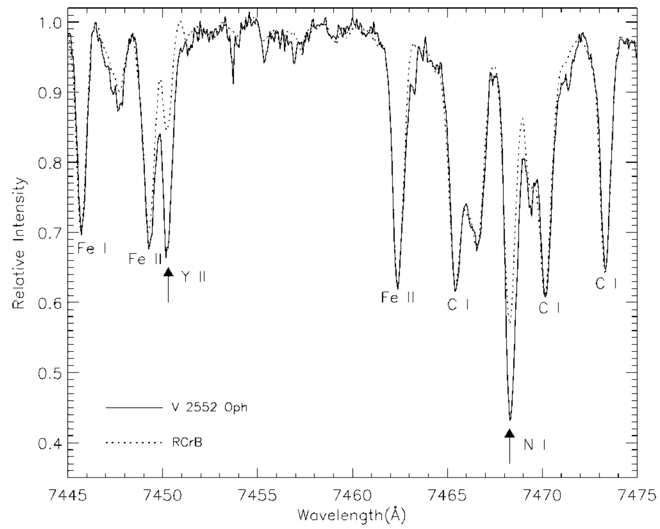

FIG. 2.—Spectra of V2552 Oph and R CrB in the interval 7445–7475 Å. Many lines are the same strength in the two spectra, but remarkable differences are seen and marked by an arrow: the N I line at 7468 Å and the Y II line at 7450 Å are much stronger in V2552 Oph.

4. Lines of Sr II, Y II, and Zr II are much stronger in V2552 Oph (Fig. 2).

The lines of the C_2 Swan bands are much weaker in V2552 Oph than in R CrB. The rotational excitation of the C_2 molecules is representative of the photosphere.

An abundance analysis of V2552 Oph and R CrB was made using the family of model atmospheres employed by Asplund et al. (2000). The R CrB spectrum is one obtained in 1995 August with the 2dcoude at the same spectral resolution as our spectrum of V2552 Oph. In light of the spectral similarities, we adopted as the initial (and final) model one with the atmospheric parameters chosen by Asplund et al. for R CrB: $T_{\rm eff} = 6750$ K, $\log g = 0.5$ cgs, and $\xi_t = 7$ km s^{-1}, and an assumed ratio C/He = 0.01 by number of atoms. Standard spectroscopic checks for $T_{\rm eff}$, g, and ξ_t confirm the adopted parameters to be appropriate for V2552 Oph. Results of the abundance analysis are given in Table 1, where we list results for V2552 Oph and R CrB from our spectra and results for R CrB from Asplund et al. Selection of lines and atomic data (i.e., the *gf*-value of a line) are taken largely from Asplund et al. For a few Fe I lines, *gf*-values were taken from Reddy et al. (2003). In general, the same lines were used for both stars, and hence the abundance analyses are accurate in a differential sense. There is very good agreement between the two R CrB analyses; the difference seen for oxygen and barium is due to an improved selection of lines in the case of oxygen and to an erroneous equivalent width for one Ba II line used in Asplund et al.'s analysis.

Table 1 shows that for many elements, there is an uncanny match of the abundances for V2552 Oph and R CrB: differences

TABLE 1
ELEMENTAL ABUNDANCES FOR V2552 OPH AND R CrB

	R CrB				
SPECIES	Asplund et al.	This Paper	V2552 Oph	n[a]	SUN[b]
H I	6.9	6.86	6.66	1, 1	12.00
Li I	2.8	2.55	<0.96	1, 1	3.35
C I	9.2	9.11 ± 0.25	9.05 ± 0.24	16, 17	8.46
N I	8.4	8.42 ± 0.44	8.96 ± 0.28	5, 8	7.90
O I	9.0	8.60 ± 0.37	7.96 ± 0.21	6, 6	8.76
Na I	6.1	6.11 ± 0.05	6.14 ± 0.12	3, 3	6.37
Mg I		6.81 ± 0.26	6.77 ± 0.09	2, 2	7.62
Al I	5.8	5.76 ± 0.13	5.78 ± 0.11	2, 2	6.54
Si I	7.2	6.97 ± 0.21	6.97 ± 0.22	4, 5	7.61
Si II		7.34 ± 0.15	7.67 ± 0.28	2, 2	...
S I	6.8	6.70 ± 0.13	6.77 ± 0.09	7, 7	7.26
K I		4.77	4.48	1, 1	5.18
Ca I	5.3	5.32 ± 0.33	5.34 ± 0.27	5, 4	6.41
Sc II		2.89 ± 0.30	2.91 ± 0.23	3, 3	3.15
Ti II		4.05 ± 0.30	4.11 ± 0.37	2, 2	5.07
Fe I	6.5	6.40 ± 0.24	6.37 ± 0.27	20, 21	7.54
Fe II		6.40 ± 0.13	6.42 ± 0.09	10, 10	...
Ni I	5.5	5.49 ± 0.11	5.55 ± 0.18	4, 5	6.29
Cu I			3.95 ± 0.16	2, 2	4.34
Zn I		4.16	4.31	1, 1	4.70
Sr II			4.28	1	2.99
Y II	1.5	1.55 ± 0.18	2.29 ± 0.09	3, 3	2.28
Zr II		1.84 ± 0.19	2.25 ± 0.19	3, 3	2.67
Ba II	1.6	1.13 ± 0.16	1.03 ± 0.09	3, 3	2.25
La II		0.64 ± 0.38	0.63 ± 0.43	2, 2	1.25

[a] Number of lines used in the analyses (a, b), where a and b are the number of lines used for R CrB and V2552 Oph, respectively.

[b] Recommended abundances for the solar system from Lodders (2003; her Table 2).

are 0.05 dex or less in many cases. This degree of similarity is surely fortuitous. Abundance differences for N, Y, and Zr average about 0.6 dex in favor of V2552 Oph, and the difference for O is 0.6 dex in favor of R CrB.

4. V2552 OPH AMONG THE R CrBs

If classified by composition, the F–G type R CrB stars belong to one of two classes: a majority and a minority class (Lambert & Rao 1994). The minority R CrB stars are marked by an approximately solar Si abundance and a severe Fe deficiency or, equivalently, an extraordinarily high Si/Fe; see Lambert & Rao (1994) and Asplund et al. (2000) for a fuller characterization of the minority class. Majority members have a solar or slightly subsolar Si abundance and a mild Fe deficiency resulting in a less unusual Si/Fe ratio ([Si/Fe] $\simeq +0.5$). V2552 Oph with [Si/Fe] $= +0.5$ and a 1 dex Fe underabundance becomes the newest member of the majority.

Within the majority, there are significant abundance differences for some elements, notably those few elements for which V2552 Oph and R CrB differ: Li, N, O, Sr, Y, and Zr. Except for a coupling of Sr, Y, and Zr, these elements do not vary in a correlated manner. Among majority R CrBs previously analyzed, Y Mus and FH Sct closely resemble V2552 Oph in composition across the elements from H to La. In particular, the trio have no detectable Li, similar low abundances of O, and high Sr, Y, and Zr abundances (relative to Fe and to Ba and La). We refer the reader to Asplund et al. (2000) for a discussion of what may be learned from the compositions about the origins of these variable stars.

5. INTERSTELLAR AND CIRCUMSTELLAR GAS

Absorption components of likely interstellar origin are present in the Na D lines (Fig. 3). Stellar Na D lines at +60 km s^{-1} are accompanied by strong components extending from −10.5 to 0.0 km s^{-1}. The strongest components are seen in the K I λ7699 line at −7.1 and −0.6 km s^{-1}. Diffuse interstellar bands are present in V2552 Oph's spectrum at 5780, 6284, 6379, and 6613 Å. Adopting the wavelengths given by Herbig (1995), we calculate a heliocentric velocity of about −7 km s^{-1} from these bands. Herbig's (1993) relation between the equivalent width of a diffuse interstellar band and reddening gives $E(B-V) = 0.4$ for V2552 Oph.

This estimate, the apparent visual magnitude ($V = 10.7$; Kato & Katsumi 2003) combined with the absolute magnitude ($M_V = -5$) for an F-type R CrB star in the LMC (Alcock et al. 2001), puts V2552 Oph at a distance of about 7.7 kpc. At this distance, interstellar gas following Galactic rotation has a heliocentric velocity of about −11 km s^{-1}. This velocity shifts to the red for smaller distances: it is −2.3 km s^{-1} for a distance of 1.1 kpc. The similarity between this range of predicted velocities and the measured velocities suggests that the Na D and K I sharp components and the diffuse interstellar bands at velocities of −10 to 0 km s^{-1} are interstellar in origin.

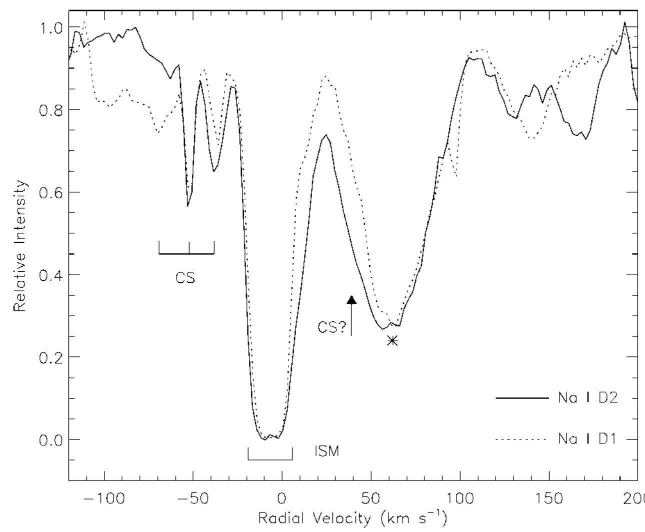

FIG. 3.—Na D1 and D2 lines in V2552 Oph. The stellar line at +60 km s^{-1} is identified. A broad multicomponent interstellar feature is indicated (see text). High-velocity sharp circumstellar (CS) lines are marked. There is also a probable CS component just to the blue of the stellar line and marked as CS?.

In addition to the interstellar components, there are sharp components in the Na D lines at −38.4 and −52.9 km s^{-1} and a weak one at −69.0 km s^{-1}. These are possibly of circumstellar origin. If so, they represent clouds expanding away from the star at −98, −113, and −129 km s^{-1}. These velocities exceed the surface escape velocity for an R CrB star. If it is assumed that the two stronger components represent gas ejected at the time of the deep double minimum reported by Kato & Katsumi (2003), the radial distances traveled are 93 and 135 stellar radii, respectively, where a stellar radius is estimated at 80 solar radii. Such high-velocity ejections are commonly seen following a deep minimum.

6. CIRCUMSTELLAR DUST

Declines of the R CrB stars are caused by soot clouds in front of the star. A characteristic of the stars is an infrared excess from circumstellar dust (Feast et al. 1997). Many R CrB stars show an infrared excess at the *K* band. Most have an infrared excess at longer wavelengths. A few have a strong excess at 60 and 100 μm from very cold dust in an extended shell (Rao & Nandy 1986; Walker 1986).

To assess the infrared excess of V2552 Oph, we searched the 2MASS All-Sky Catalog of Point Sources (Cutri et al. 2003) for V2552 Oph's presence at *J*, *H*, and *K*. A source was found coincident to within 0$''$.4 with V2552 Oph's position on an *ESO R*-band frame. The 2MASS magnitudes are $J = 8.69$, $H = 8.39$, and $K = 8.16$. The $J-H$ and $H-K$ color indices, after correction for interstellar reddening corresponding to $E(B-V) = 0.41$, lie on the blackbody color-color plot at about the temperature of the photosphere; i.e., there is no infrared excess detectable at *J*, *H*, and *K*. V2552 Oph could not be located in the *IRAS* Faint Source Catalog.

V2552 Oph is one of few R CrB stars not to show an excess in these bands. In this respect, it is similar to Y Mus (Feast 1997). Kilkenny & Whittet (1984) did find an infrared excess for Y Mus at 5 and 10 μm. The absence for Y Mus of an infrared excess at *K* and shorter wavelengths has been linked to the fact that the last minimum occurred several decades ago; i.e., recent soot production has ceased or been reduced to low levels. This explanation is not easily transferred to V2552 Oph, which has experienced one or two fadings recently. It is presumably nothing more than a coincidence that V2552 Oph resembles Y Mus both in a lack of infrared excess at *K* and in composition.

7. CONCLUDING REMARKS

Addition of V2552 Oph to the rare class of R CrB variables is attributable to the Japanese amateur astronomer K. Haseda, whose announcement identifying the star as a variable included the suggestion that it might be an R CrB variable.[1] Our high-resolution spectrum fully confirms the identification of V2552 Oph from photometry and low-resolution spectroscopy that the star is an R CrB variable. We show that it is a member of the majority class of these variables, as introduced by Lambert & Rao (1994). Within that class, V2552 Oph closely resembles Y Mus and FH Sct in showing a below-average oxygen abundance and an above-average abundance of Sr, Y, and Zr. In this respect, V2552 Oph confirms the spectrum of compositions offered by the majority stars but provides no novel clues to the origins of the anomalous compositions of these remarkable variables. Perhaps the next discovered R CrB variable will be the Rosetta Stone needed to unlock the chain tying the abundances to the origins of these stars.

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[1] http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/alert6000/msg00226.html.

REFERENCES

Alcock, C., et al. 2001, ApJ, 554, 298

Asplund, M., Gustafsson, B., Lambert, D. L., & Rao, N. K. 2000, A&A, 353, 287

Cutri, R. M., et al. 2003, Vizier On-line Data Catalog II/246

Feast, M. W. 1997, MNRAS, 285, 339

Feast, M. W., Carter, B. S., Roberts, G., Marang, F., & Catchpole, R. M. 1997, MNRAS, 285, 317

Herbig, G. H. 1993, ApJ, 407, 142

———. 1995, ARA&A, 33, 19

Hesselbach, E., Clayton, G. C., & Smith, P. S. 2002, BAAS, 34, 1128

———. 2003, PASP, 115, 1301

Kato, T., & Katsumi, H. 2003, Inf. Bull. Variable Stars, 5417, 1

Kazarovets, E. V., Kireeva, N. N., Samus, N. N., & Durlevich, O. V. 2003, Inf. Bull. Variable Stars, 5422, 1

Kilkenny, D., & Whittet, D. C. B. 1984, MNRAS, 208, 25

Lambert, D. L., & Rao, N. K. 1994, J. Astrophys. Astron., 15, 47

Lodders, K. 2003, ApJ, 591, 1220

Rao, N. K., & Nandy, K. 1986, MNRAS, 222, 357

Reddy, B. E., Tomkin, J., Lambert, D. L., & Allende Prieto, C. 2003, MNRAS, 340, 304

Schönberner, D. 1975, A&A, 44, 383

Tull, R. G., MacQueen, P. J., Sneden, C., & Lambert, D. L. 1995, PASP, 107, 251

Walker, H. J. 1986, in Hydrogen-deficient Stars and Related Objects, ed. K. Hunger et al. (Dordrecht: Reidel), 407