IS DZ ANDROMEDAE AN R CORONAE BOREALIS VARIABLE?

By Aruna Goswami and N. Kameswara Rao
Indian Institute of Astrophysics, Bangalore

and David L. Lambert
Department of Astronomy, University of Texas at Austin

The variable star DZ Andromedae has been suspected to be an R Coronae Borealis variable. Our analysis of a high-resolution spectrum shows that the star has been misclassified: the spectrum resembles that of a K giant. We have determined the stellar parameters — effective temperature, surface gravity, and microturbulence — using model atmospheres. Abundances derived for a range of light elements, many Fe-peak elements, and a few s-process elements indicate a near-solar composition for DZ And.

Introduction

DZ And was discovered as a variable star by Thomas Cragg[1]. Cragg's visual observations showed the star at a maximum magnitude of about 9·6 except that on two occasions it was found to be fainter than 13·5. Based on this light variation and a 'weak' spectrogram obtained at maximum light, Cragg remarked that "evidence is strong that this is a magnitude 10 RCrB star with a range of more than 4 magnitudes".

RCrB stars are hydrogen deficient, but Orlov & Rodríguez[2], in the briefest of reports, noted the presence of 'normal' hydrogen lines in DZ And's spectrum and assigned the spectral type K0. Absence of atomic and molecular carbon lines was also noted. Spectrograms obtained by Rao[3] with the 40-inch telescope at Kavalur also showed strong Hα in absorption. Deep declines characteristic of RCrB stars have not been reported since the discovery paper. Mattei[4] noted that in 1973 DZ And showed no significant variation in brightness. It was presumably these assorted snippets of information that led Clayton[5] in his recent review to place DZ And in a list of stars that are not RCrB stars but which were once assigned to the class.

Although these observations challenge the identification of DZ And as an RCrB variable, they are not conclusive. Since the hydrogen lines of normal stars are highly saturated, a moderate hydrogen deficiency may not be obvious at low spectral resolution. In addition, RCrB stars with a low frequency of the class' characteristic declines may not be observed to vary for long periods. An analysis of high-resolution spectra to determine the chemical composition seemed certain to provide unambiguous information on the evolutionary status of DZ And. We present here the first study of the chemical composition of this star based on high-resolution spectra.

Observations and data reduction

High-resolution spectra of DZ And were obtained on 1996 July 24 using *2dcoudé*, a cross-dispersed echelle spectrograph at the coudé focus of the McDonald Observatory's 2·7-m telescope[6]. The wavelength coverage is from

3800–10 000Å with complete coverage up to about 5700Å and partial coverage to longer wavelengths. The spectral resolution is about 60 000. The CCD data were reduced using the spectroscopic reduction package ECHELLE of the IRAF software package. The two spectra, each of 30 minutes exposure, were combined to increase the signal-to-noise ratio. Th-Ar hollow-cathode lamp exposures taken immediately before and after the stellar exposures were used for wavelength calibration. A pseudo-continuum was determined for each order using the highest points in the order considered to be free of stellar lines. Spectra were reduced to a normalized continuum using spline-interpolated values for the pseudo-continuum.

Description of the spectrum

DZ And's spectrum resembles that of a K giant as comparison with the spectrum of Arcturus[7] clearly shows. Fig. 1 depicts a portion of DZ And's spectrum near 6155Å with lines of Na I, Ca I, and Fe I identified. Fig. 2 shows the Hα profile. The C I lines that are so strong and prevalent in spectra of the typical RCrB star are weak. Although the low effective temperature may be partly responsible for their weakness, we note that the lines are of a similar strength or weaker than the same lines in Arcturus' spectrum: *e.g.*, the line at 5380·3Å has an equivalent width of about 23 mÅ in DZ And and 24 mÅ in Arcturus[8], and other C I lines at 4770, 6587, and 6671Å listed by Mäckle *et al.*[8] are not seen in DZ And's spectrum. In addition, the leading C_2 Swan bandhead at 5165Å is weakly present in DZ And's spectrum, comparable to that in Arcturus' spectrum. Mäckle *et al.*[8] estimated the carbon abundance of Arcturus to be

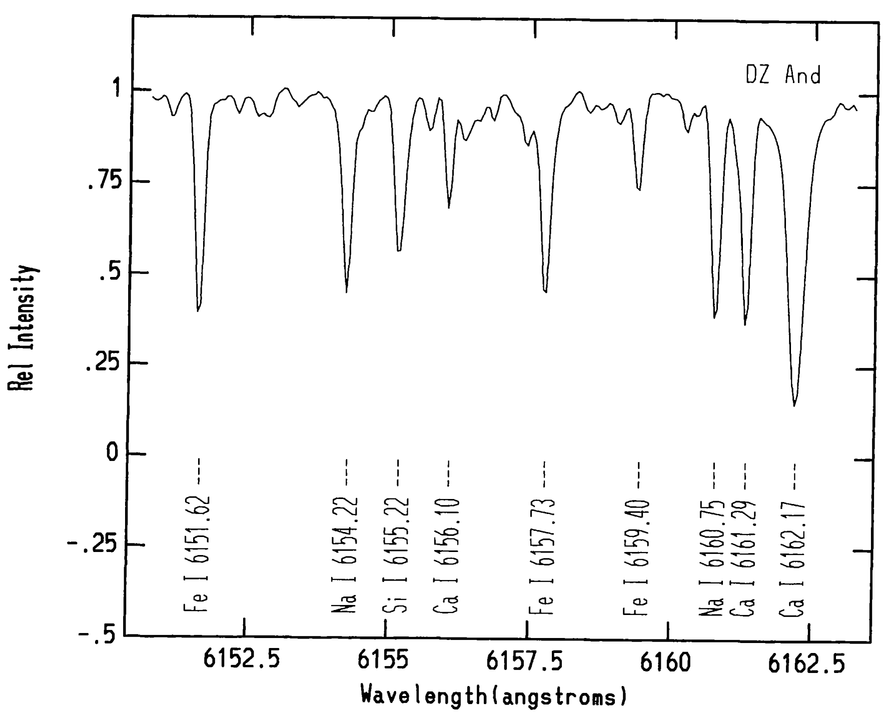

FIG. 1

The region (6150–6163)Å in DZ And showing lines of Na I, Ca I, Si I, and Fe I.

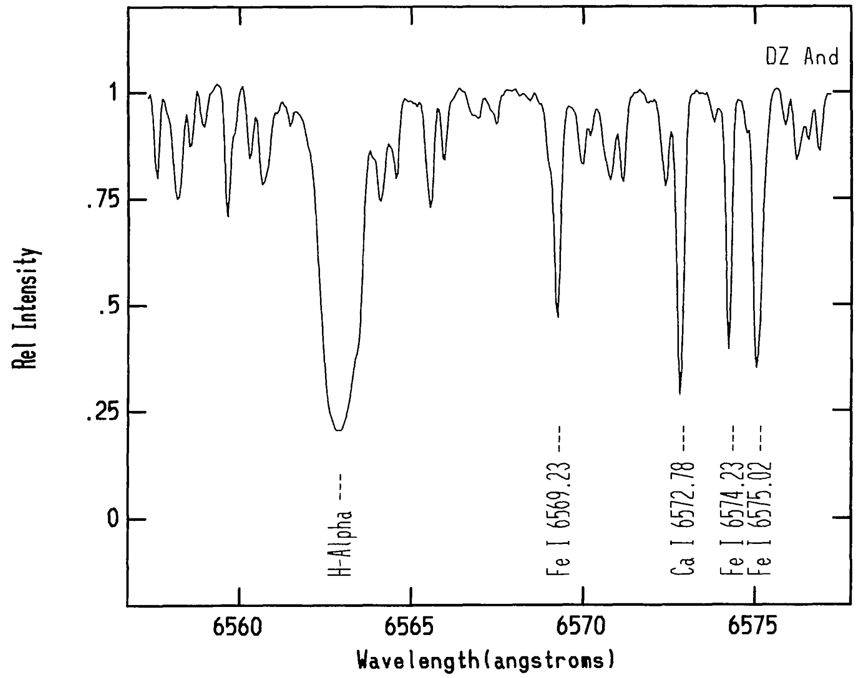

FIG. 2

The Hα profile in DZ And.

[C/H] = −0·7 ± 0·15. From the spectral resemblance of DZ And's spectra to Arcturus, we suggest a carbon abundance in DZ And similar to that in Arcturus. The C_2 bands are a distinctive mark of the cooler RCrB stars — see, for example, the spectrum of Z UMi in Goswami *et al.*[9]. The qualitative impression of the spectrum is that DZ And is a K giant of near-solar metallicity with a normal hydrogen and carbon content.

An estimate of the luminosity class is obtainable from the width of the Hα profile. On correction for the instrumental profile, the full width at half maximum of the Hα line is found to be 59 ± 4 km s^{-1}, comparable to 66·8 km s^{-1} reported for Arcturus[10]. From the width-luminosity calibration offered by Kraft *et al.*[10] we derived the luminosity class of DZ And to be III. K2 III is a possible spectral classification, a result consistent with the spectral similarity of DZ And and Arcturus.

The radial velocity of DZ And was measured using several unblended lines. The mean heliocentric radial velocity on HJD 2450288·91 was v_r = 13·3 ± 1·5 km s^{-1}.

Analysis

The abundance analysis uses a set of model atmospheres and equivalent widths of selected lines. A selection of Fe I and Fe II lines from the analysis of Arcturus[8] was used in a routine procedure to determine the stellar parameters: the effective temperature, T_{eff}, the surface gravity, g, the microturbulence velocity, v_t, and the metallicity [Fe/H]. Firstly, the microturbulence velocity was estimated by requiring the derived abundances to be independent of the strength of the lines. The microturbulence velocity at which lines falling on the linear

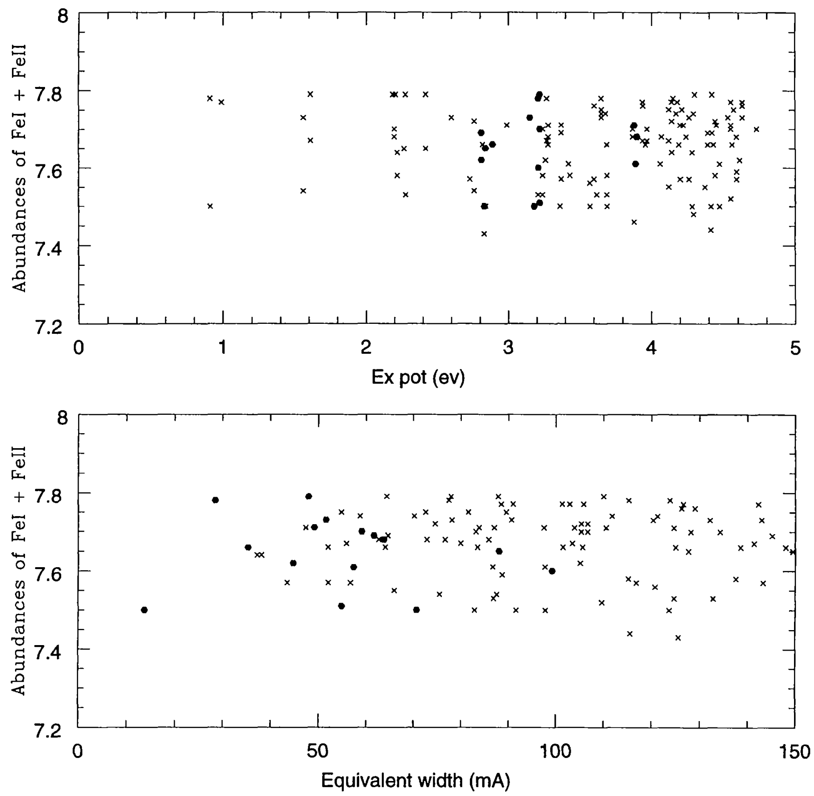

FIG. 3

The iron abundance of DZ And shown for individual Fe I and Fe II lines as a function of a line's equivalent width and the lower excitation potential. The cross marks indicate Fe I and filled circles Fe II

and flat portions of the curve-of-growth yield the same abundance value is an estimate of v_t. The temperature is then adjusted such that the derived abundances are independent of the excitation potential of the lines. The temperature at which this condition is achieved gives an estimate of T_{eff}. The surface gravity is obtained from the ionization balance between Fe I and Fe II lines. Model atmospheres were selected from a grid computed using the MARCS code[11].

A selection of Fe I lines covering a range in excitation potential (1·0–5·0 eV) and equivalent widths (20–160 mÅ) was used to determine T_{eff} and v_t. Fig. 3 shows the plot of derived Fe abundances as a function of equivalent width and excitation potential for Fe I and Fe II lines. The surface gravity was found by requiring that the Fe I lines and Fe II lines give the same Fe abundance. (The Ti I and Ti II lines were similarly used.) The gf-values for the Fe I and Fe II lines were taken from Fuhr *et al.*[12] and Lambert *et al.*[13].

We determined the parameters for DZ And to be T_{eff} = 4400 K, log g = 2·0 cgs units and v_t = 1·75 km s^{-1}. The Fe and Ti ionization loci in the T_{eff} – log g plane are almost coincident. Since the observed $U - B$ and $B - V$ colours indicate that the star is not affected by interstellar reddening, an estimate of the effective temperature is made from photometric colours[3] based on Johnson's[14] calibration: a temperature of 4350K is indicated, in good agreement with the spectroscopic result. The accuracies in T_{eff}, log g, and v_t are respectively $\Delta T_{eff} \sim \pm$ 2000K, Δlog $g \sim \pm$ 0·25 cgs units, and $\Delta v_t \sim \pm$ 0·5 km s^{-1}.

Weak unblended lines of many elements were measured and used in the abundance analysis. The gf-values for elements V to Ni are also adopted from Fuhr *et al.*[12] and Martin *et al.*[15] when available. The gf-values for other elements were taken from a tape compiled by R. E. Luck (private communication); these are based when possible on experimental determinations of high quality. We assumed that DZ And has the standard He abundance of the MARCS grid (He/H = 0·1) and used the model atmosphere computed for [M/H] = 0·0.

Abundances

Mean abundances are given in Table I. The standard deviation is about 0·10 dex for Fe where we could measure many lines. For other elements the standard deviation ranges up to 0·4 dex.

Our analysis suggests almost solar abundance for most of the elements, including Fe. Reference meteoritic abundances are taken from Grevesse *et al.*[16]. DZ And appears slightly metal-rich ([Fe/H] ~ 0·1) relative to the Sun. Relative abundances are generally as expected for stars of near-solar metallicity, *i.e.*, [X/Fe] ≃ 0·0 — see Table I where we give not only the abundance log ε (X), and [X/H] but also [X/Fe]. In computing this latter quantity, we use the Fe I-

TABLE I

Chemical composition of DZ Andromedae

Element	*Z*	*log ε*	*No of lines*	*Meteorites*[a] *log ε*	*[X/H]*	*[X/Fe]*
Na I	11	6·79 ± 0·07	2	6·32	+0·47	+0·33
Mg I	12	7·67 ± 0·12	3	7·58	+0·09	−0·05
Al I	13	6·43 ± 0·11	2	6·49	−0·06	−0·20
Si I	14	7·98 ± 0·08	8	7·56	+0·42	+0·28
Ca I	20	6·41 ± 0·11	23	6·35	+0·06	−0·08
Sc I	21	3·10 ± 0·36	2	3·10	0·00	−0·14
Sc II	21	3·21 ± 0·28	5	3·10	+0·11	−0·18
Ti I	22	5·00 ± 0·16	27	4·94	+0·06	−0·08
Ti II	22	5·10 ± 0·18	9	4·94	+0·16	−0·13
V I	23	4·26 ± 0·15	17	4·02	+0·24	+0·10
Cr I	24	5·78 ± 0·12	21	5·69	+0·09	−0·05
Cr II	24	5·93 ± 0·15	2	5·69	+0·24	−0·05
Mn I	25	5·76 ± 0·11	4	5·53	+0·23	+0·09
Fe I	26	7·64 ± 0·10	127	7·50	+0·14	
Fe II	26	7·79 ± 0·10	16	7·50	+0·29	
Co I	27	5·37 ± 0·11	7	4·91	+0·46	+0·32
Ni I	28	6·48 ± 0·18	63	6·25	+0·23	+0·09
Zn I	30	5·10 ± 0·04	2	4·67	+0·43	+0·29
Sr I	38	2·58	1	2·92	−0·34	−0·48
Y I	39	2·21	1	2·23	−0·02	−0·16
Y II	39	2·36 ± 0·19	9	2·23	+0·13	−0·16
Zr I	40	2·35 ± 0·07	7	2·61	−0·26	−0·40
Zr II	40	2·48 ± 0·26	2	2·61	−0·13	−0·42
Mo I	42	2·19 ± 0·03	2	1·97	+0·22	+0·08
Ba II	56	2·19 ± 0·40	2	2·22	−0·03	−0·32
La II	57	1·30 ± 0·28	3	1·22	+0·08	−0·21
Ce II	58	1·73 ± 0·13	5	1·63	+0·10	−0·19
Nd II	60	1·58 ± 0·26	5	1·49	+0·09	−0·20
Eu IV	63	0·66 ± 0·00	2	0·55	+0·11	−0·18

[a]From Grevesse, Noels & Sauval[16]

based abundance for elemental abundances derived from neutral lines of predominantly ionized species, and the Fe II-based abundance for elemental abundances derived from ionized lines. The estimated error in [X/Fe] is small and lies in a range of $\pm 0\cdot 1$ dex to $\pm 0\cdot 4$ dex. With the exception of Si I, Co I, and Zr I, the [X/Fe] ratios for species represented by three or more lines are zero to within the experimental error (say $\pm$ 0·1 dex). Si and Co may be over-abundant ([X/Fe] $\sim$ 0·3 to 0·5) and Zr underabundant ([Zr/Fe] $\sim$ $-0\cdot 4$). A few elements based on just one or two lines may have slightly anomalous abundances. The overabundance of Si, also Na and Zn, appears not to be due to choice of gf-values because our chosen data reproduce the abundances reported by Mäckle *et al.*[8] when we use a model atmosphere for Arcturus and the equivalent widths listed by Mäckle *et al.*[8].

Concluding remarks

DZ And shows the characteristics of a normal K2 III star. Its composition is nearly solar. Hydrogen is likely of normal abundance. Carbon is not obviously enhanced. In short, the star's composition is not consistent with membership of the RCrB class. Normal K giants are not known to vary in brightness and are certainly not known to experience RCrB-like declines. The cause of light variations (if real) reported by Cragg[1] appears to be a mystery.

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References

(1) T. Cragg, *PASP*, **73**, 453, 1961.
(2) M. Ya. Orlov & M. H. Rodríguez in V. E. Sherwood & L. Plaut (eds.), *Variable Stars and Stellar Evolution*, (Reidel, Dordrecht), p. 159, 1975.
(3) N. K. Rao, *ApSS*, **70**, 489, 1980.
(4) J. A. Mattei, *JRASCan*, **68**, 112, 1974.
(5) G. C. Clayton, *PASP*, **108**, 225, 1996.
(6) R. G. Tull *et al.*, *PASP*, **107**, 251, 1995.
(7) R. F. Griffin, *A Photometric Atlas of the Spectrum of Arcturus* λλ 3600–8825Å (Cambridge Philosophical Society, Cambridge), 1968.
(8) R. Mäckle, R. Griffin & H. Holweger, *A&AS*, **19**, 303, 1975.
(9) A. Goswami, N. K. Rao & D. L. Lambert, *PASP*, **109**, 796, 1997.
(10) R. P. Kraft, G. W. Preston & S. C. Wolff, *ApJ*, **140**, 235, 1964.
(11) B. Gustafsson *et al.*, *A&A*, **42**, 407, 1975.
(12) J. R. Fuhr, G. A. Martin & W. L. Wiese, *J. Phys. Chem. Ref. Data*, **17**, No. 4, 1988.
(13) D. L. Lambert *et al.*, *ApJS*, **103**, 183, 1996.
(14) H. L. Johnson, *ARAA*, **4**, 193, 1966.
(15) G. A. Martin, J. R. Fuhr & W. L. Wiese, *J. Phys. Chem. Ref. Data*, **17**, No. 3, 1988.
(16) N. Grevesse, A. Noels & A. J. Sauval, in S. S. Holt & G. Sonneborn (eds.), *Cosmic Abundances* (ASP Conference Series, no. 99) (ASP, San Francisco), 1996, p. 117.