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V crateris - photometric elements

By

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V Crateris - Photometric Elements

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Abstract

The analysis of the photometric B and V light curves of the semi detached eclipsing binary V Crt, using Wilson - Devinney method, yielded photometric elements, including a photometric mass - ratio of 0.40. Assuming the mass of the primary component to be $1.70m_{\odot}$ (F0V), the absolute elements of V Crt are found to be $\pi_c=0.68\pi_{\odot}$, $R_h=1.77R_{\odot}$, $R_c=1.34R_{\odot}$, $\text{Log } L_h=0.87L_{\odot}$, $\text{Log } L_c=-0.06L_{\odot}$, $M_{\text{bol}, h}=2.52$, $M_{\text{bol}, c}=4.84$, $\text{Log } g_h=4.17$ and $\text{Log } g_c=4.02$. Since the secondary has already filled its Roche lobe and the primary is filling about 86% of its Roche lobe, it is suggested that in V Crt, a reverse mass transfer may start in a short time.

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1. Introduction

V Crateris (BD -15° 3260; 281.1930; P736)(V Crt) is known to be an eclipsing binary with partial eclipses. The first photoelectric study, in Johnson's B and V passbands of this system was by Sanwal et al. (1990). Qingyao (1993) reported his observations of this system in Stromgren's uvby passbands. From an analysis of these light curves, using Wilson - Devinney method, he derived elements and found V Crt to be a semi detached system (cool secondary component filling its Roche lobe) with the photometric mass - ratio, q , being equal to 0.683. According to him V Crt is a very interesting system from the evolutionary point of view, as the system may probably evolve easily into a W UMa type binary.

As we considered it useful to derive the elements and study the nature of V Crt from our (Sanwal et al. 1990) B and V light curves also, we analysed them and in the following give the results of these analysis.

2. Observations

V Crt was observed with the 1.2m reflecting telescope of the Japal-Rangapur Observatory by Sanwal et al. (1990) during March 20 - April 4, of 1972 (4 nights) and January to May of 1974(21 nights) in Johnson's B and V passbands. In all, about 870 observations in each of the B and V filters were obtained. The instrumental differential magnitudes, Δm (variable - comparison), corrected for atmospheric extinction were transformed to the standard UBV system using the transformation coefficients determined from the observations of UBV standard stars on a few nights. The star BD -16°3241 and BD -15°3256 were used as comparison and check stars, respectively. The magnitude differences (check - comparison) showed that the comparison star was constant during the period (1972 - 1974) of our observations and that the standard error of each observation was 0.^m01 both for V and B filters. The magnitude and colour of the comparison star, BD -16°3241, in the standard system, were found to be $V = 10.^m21$ and $B-V = 0.^m88$.

3. Analysis

The times of all the individual observations (B and V) of V Crt by Sanwal et al. (1990) were converted to phases using the ephemeris given by Qingyao (1993). We analysed these light curves (individual points) using Wilson - Devinney (W-D)(1971) method. For initiating the W-D programme, we used the values of a few of the required parameters given by Qingyao (1993), as initial parameters. We treated the following parameters as fixed: the temperature, $T_{e,h}$ (7500 K) of the hot component; the mass-ratio, q (0.6834) of the system; the ratio of the surface rotation rates to synchronous rotation rates, F_h and F_c ; the limb darkening coefficients, u_h and u_c ; the albedos A_h and A_c ; and the gravity darkening coefficients G_h and G_c of the hotter and cooler components, respectively. According to the principles of the W-D method, we adjusted the following parameters: the inclination, i ; the surface potentials Ω_h and Ω_c ; the relative monochromatic luminosity of the hot component L_h ; the temperature of the cool component $T_{e,c}$ and the third light l_3 . Sufficient number of runs of the DC programme was made until the sum of the residuals, $\sum W(O-C)^2$ showed a minimum and the corrections to the parameters became smaller than their probable errors. In order to check the internal consistency of the results (Popper 1984), separate solutions, for each of the V and B light curves, were made. The study of Qingyao (1993) indicated that V Crt is semi detached with the secondary filling its Roche lobe and the primary filling about 80% of its Roche lobe. Hence, to ascertain the nature of the system, we analysed the light curves using W-D method with three different codes viz; code-2(detached), code-6(contact) and code-5 (semi detached). While the analysis with code-2(detached) did not yield convergency, the analysis with both code-6(contact) and code-5(semi detached) yielded converged solutions. However, as the values of $\sum W(O-C)^2$ for the solutions with various q values for code-6 were found to be about six times larger than those obtained for code-5, we did not consider the case of contact nature for the system and proceeded further with code-5, meant for semi detached systems, only. The results of the analysis, with code-5, of individual V and B light curves are given in Table-1, cols. 2 and 3. The results indicate that the individual

Table - 1

solutions are consistent and that a combined solution for B and V is adequate to derive the system parameters.

Using the derived luminosities (Table-1), the magnitude and colour of the comparison star [V=10.21, B-V=0.88] and the corresponding differential magnitudes for unit luminosity at the quadrature [V=+0.124, B= -0.330], we derived the colour (B-V) of the primary, hot component to be 0.36. According to Qingyao(1993) the space reddening, E(b-y), is equal to 0.044. From the relation

$$E(b-y) = 0.70 E(B-V) \quad (1)$$

of Crawford et al. (1970), a reddening correction of 0.^m06 was derived for the (B-V) colour. From this, we obtained the reddening free colour of the primary component to be (B-V)_o=0.30, which corresponds to an average temperature of 7160±100 K (Allen 1976, Popper 1980, Schmidt-Kaler 1982). Hence, as stated above, a combined solution for B and V colours with T_{e,h}=7160 and q=0.6834 as fixed parameters was made. The average parameters derived from the individual solutions (Table-1, cols. 2 and 3) were used as preliminary elements for the combined solution. In order to find an improved value for the mass-ratio, q, we made additional solutions (combined B and V) by keeping T_{e,h}(7160 K) and q(0.2, 0.25, 0.30, 0.35, 0.375, 0.40, 0.425, 0.45, 0.50, 0.60, 0.80 and 1.00) as fixed parameters. From a plot of the resulting $\sum W(O-C)^2$ and q it is noticed that the minimum occurs at q=0.40.

The results of the combined solution with q=0.40 and in which A_c, x_h, x_c were treated as additional variable parameters are given in Table-1, col. 4. One can notice that ℓ_3 is absent in both the colours in the individual as well as in the combined solutions. The theoretical curves obtained from the elements given in Table-1, col. 4 are shown in Figures 1a and 1b as solid lines. In these figures, the

Figures 1a, b

filled circles represent the individual observations of Sanwal et al.(1990). The fit of the theoretical curves to the observations is quite satisfactory except around 0.8 to 0.9 and 0.54 to 0.64 phases where the observations indicate large scatter (more in B than in V). As the (O-C)'s obtained from the original unphased data has not shown any time variability, we attribute this large scatter to the presence of gases or gas streams in the system. As no spectroscopic studies are available, evidence for the presence of gases in the system is lacking. Since the system is semi detached with the secondary filling its lobe, one can presume mass loss from this component which will be a source of gases in the system. The presence of gases affecting the light curves of the semi detached systems of TT Hya(Vivekananda Rao & Sarma 1994), HU Tau(Parthasarathy et al. 1995), R CMa(Sarma et al. 1996) and EU Hya(Vivekananda Rao et al. 1996) was already reported.

4. Absolute Elements

Using the derived luminosities(Table-1, col. 4), the differential magnitudes, Δm , at the quadrature and the standard values of the magnitudes of the comparison star in both the passbands(section 3), we derived the magnitudes and colours of the individual components. These values are as given in Table-2. As discussed in section 3, the reddening correction, $E(B-V)$ is equal to 0.06 and hence the reddening free colours of the

Table -2

primary and secondary components are $(B-V)_0=0.31$ and 0.84 respectively. The colour of the primary corresponds to a temperature of 7120 ± 100 K which in turn corresponds to a spectral type of F0(Allen 1976, Popper 1980, Schmidt-Kaler 1982). The above temperature agrees quite well with that of the fixed temperature 7160 ± 100 K used for the primary component in the analysis. This confirms that our analysis with fixed $T_{e,h}(7160$ K) and $q(0.40)$ yielded results akin to the reddening free data. The $(B-V)_0$ of 0.84 for the secondary component corresponds to a spectral type of K0V or G4III and its derived temperature of 4820 K(Table-1, col. 4) suggests a spectral type of K2V or G7III(Allen 1976; Popper 1980; Schmidt-Kaler 1982). There is a small discrepancy between the

spectral types derived from the colour and effective temperature. This could be attributed to the use of Planck's law in the W-D programme while in the case of stars one has to take into consideration the model atmospheres appropriate for each spectral type. Keeping in view the bigger sizes(radii) of both the components(see the following) we adopted a spectral type of F0V-IV for the primary and G4-7V-IV for the secondary component. Qingyao(1993) suggested the spectral types of A8V and G9V for the primary and secondary components respectively.

Since no spectroscopic studies exist for this system, neither the spectral types nor the individual masses of the components are presently available. Hence it is difficult to get reliable absolute elements for the components. However, to get approximate dimensions and masses of the components, we assumed the primary F0V component to obey the spectral type- mass relation of the normal main sequence stars(Allen 1976). From this assumption one gets a mass of $1.70m_{\odot}$ for the primary component. From the presently

derived mass-ratio, $m_c/m_h=q=0.40$ and the assumed mass of $1.70m_{\odot}$ for m_h , one gets a mass of $0.68m_{\odot}$ for the secondary component.

Using Kepler's 3rd law

$$A^3=74.55(m_h+m_c)P^2 \quad (2)$$

and with a period of $0.^d7020357$ (Qingyao 1993), one gets $A=4.44 R_{\odot}$ as the separation of the components. From the derived average fractional radii [$r=(r_{\text{pole}}+r_{\text{side}}+r_{\text{back}}/3)$] of 0.398 and 0.301 for the primary and secondary components respectively, one gets $Ar_h=R_h=1.77R_{\odot}$ and $Ar_c=R_c=1.34R_{\odot}$. The above derived radius of the primary component, R_h , is larger than that of $1.35R_{\odot}$ of a normal F0V star(Allen 1976). This may be due to the evolution of the primary which is filling about 86% of its Roche lobe($r^*_h=0.462$ for $q=0.40$; Plavec & Kratochvil 1964). The system parameters are as given in Table-2.

The bolometric corrections are from Popper(1980). According to Buser & Kurucz(1978) a star with a (B-V) colour of 0.31 and log g of 4.17 should have a temperature of about 7200 K. This agrees quite well, within the errors of assumed parameters, with the temperatures of 7160 ± 100 K used by us for the primary component in our analysis. For comparison, the elements of V Crt as derived by us and Qingyao(1993) are given in Table-3.

Table-3

5. Conclusions

A comparison of the presently derived parameters with those of Qingyao(1993) shows that while our analysis indicates the primary eclipse to be a transit ($r_h > r_c$), that of Qingyao indicates it to be an occultation($r_c > r_h$). This uncertainty in the nature of the primary eclipse may have arisen because of the almost equal sizes of the components and the eclipses being partial. From the present analysis of the B and V light curves, we obtained a photometric mass-ratio of 0.4 which differs from the mass-ratio of 0.683 derived by Qingyao from his uvby light curves. Since both the studies used W-D method for the analysis, this large discrepancy in the q values is more significant. In order to find whether this discrepancy is due to the choice of fixed and free parameters used in the analysis, we made another solution, as before, of our data with $T_{e,h}$ fixed at 7500 K used by Qingyao in his analysis. The parameters x_h , x_c , A_c , G_h and G_c were all kept free. The resulting $\sum W(O-C)^2$ showed a minimum again at about 0.4. Hence it is concluded that the discrepancy in the values of q may be due to the data itself.

Our observed B and V light curves of V Crt (Figures 1a and 1b) have the appearance of normal Algol type binary light curves without any peculiarities. These light curves do not show the O'Connell effect that is apparent in the uvby light curves of Qingyao. This suggests that what ever might be the source responsible for this effect, was not present during the period(1972-74) of our observations. Qingyao attributed this effect to spot activity on the cool secondary component. In such as case, before analysing his original observations for elements, Qingyao should have corrected them for the effects of

spottedness. It is well known that analysis of light curves distorted by photometric waves caused by spots generally yield unreliable elements and this may be a possible reason for Qingyao to get a mass-ratio much different from that derived by us. Another factor that one has to remember in this context is that the present method of determining photometric mass-ratio would have been considerably more favourable, if the primary eclipse were total, as it is in a number of similar systems, but not in V Cr. Unless spectroscopic studies are available, one cannot ascertain which one of the above photometric mass-ratios is closer to the spectroscopic value.

A comparison of the positions of the primary and secondary components with single stars in the $\log m$ versus $\log L$, $\log T$ and $\log R$ relations (ZAMS) showed that the primary component is of the same luminosity and temperature but bigger in size when compared to stars of the same mass. The secondary has the same temperature but is overluminous (1.7^m) and bigger when compared to stars of the same mass. In the H-R diagram ($\log T_e$ versus $\log L$, ZAMS) both the components are above but near the ZAMS suggesting that both of them have left the main sequence. Thus our solution makes V Cr a typical Algol binary with one difference. Due to the short period (0.70^d) of the system, the primary component is almost filling its Roche lobe and it may give rise to reverse mass transfer very shortly. These conclusions are tentative and spectroscopic studies of this system are urgently needed for an understanding of its properties.

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References

- Allen, C. W. 1976, *Astrophysical Quantities*, 3rd edn. (London: Athlone press)
- Buser, R., Kurucz, R. L. 1978, *A&A*, **70**, 555
- Crawford, D. L., Glasky, J. W., Perry, C. L. 1970, *AJ*, **75**, 822
- Parthasarathy, M., Sarma, M. B. K., Vivekananda Rao, P. 1995, *A&A*, **297**, 359
- Plavec, M., Kratochvil, P. 1964, *Bull. Astron. Inst. Czechoslovakia*, **15**, 165
- Popper, D. M. 1980, *ARA&A*, **18**, 115
- Popper, D. M. 1984, *AJ*, **89**, 132
- Qingyao, Liu. 1993, *A&AS*, **101**, 49
- Sanwal, N. B., Sarma, M. B. K., Vivekananda Rao, P., Parthasarathy, M. 1990, *Contrib. Nizamiah and JR Obs.*, No.24
- Sarma, M. B. K., Vivekananda Rao, P., Abhyankar, K. D. 1996, *ApJ*, **458**, 371
- Schmidt-Kaler, T. H. 1982, in *Landolt Bornstein, New Series, Vol. 2b*, ed. K. Schaifers and H. H. Vogt (New York: Springer), 453
- Vivekananda Rao, P., Sarma, M. B. K. 1994, *Bull. Astron. Soc. India*, **22**, 451
- Vivekananda Rao, P., Sarma, M. B. K., Abhyankar, K. D. 1996, *PASP*, **108**, 967
- Wilson, R. E., Devinney, E. J. 1971, *ApJ*, **166**, 605

Table - 1

V Cr1: Elements obtained from the solution of individual light curves using W-D method, keeping $T_{e,h} = 7500$ K and $q = 0.6834$ along with the combined VB solution for $q = 0.40$. Both $T_{e,h}$ and q are treated as fixed parameters.

Element		V	B	Combined VB solution q(0.40)
1		2	3	4
* $T_{e,h}$	K	7500	7500	7160
$T_{e,c}$	K	4903	4883	4820±20
* q		0.6834	0.6834	0.40
i°		73.18	73.18	76.84±0.04
r_h	pole	0.3331	0.3331	0.3825±0.0010
	point	0.3699	0.3699	0.4292±0.0011
	side	0.3443	0.3443	0.3992±0.0011
	back	0.3578	0.3578	0.4132±0.0010
r_c	pole	0.3247	0.3247	0.2825±0.0029
	point	0.4609	0.4609	0.4070±0.0032
	side	0.3397	0.3397	0.2945±0.0029
	back	0.3717	0.3717	0.3272±0.0031
L_h		0.8508	0.9042	V 0.8946±0.0550
				B 0.9318±0.0457
L_c		0.1492	0.0958	V 0.1054
				B 0.0682
$+\ell_3$		0.0±0.0002	0.0±0.0002	V 0.0±0.0002
				B 0.0±0.0002
* F_h		1.0	1.0	1.0
* F_c		1.0	1.0	1.0
x_h		0.641	0.740	V 0.659
				B 0.750
x_c		0.667	0.890	V 0.708
				B 0.951
* A_h		1.0	1.0	1.0
A_c		0.5	0.5	0.52
* G_h		0.25	0.25	0.25
* G_c		0.08	0.08	0.08

* Fixed parameters

+ In units of total system light at phase 0.25

Table -2
V Crt: Properties of the components of V Crt

Parameter	Hot Component	Cool Component
V	10.46	12.78
B	10.83	13.68
B-V	0.37	0.90
(B-V) ₀	0.31	0.84
Sp. type	F0V-IV	G4-7V-IV
A/ R _☉	4.4	
Mass($m_{☉}$)	1.70*	0.68
Radius(R _☉)	1.77	1.34
Log L/ L _☉	0.87	-0.06
M _{bol}	2.52	4.84
M _v	2.53	5.18
log g	4.17	4.02

* Assumed

Table - 3
V Crt: Comparison of elements obtained
from Qingyao's and present studies

Parameter	Qingyao (1993)	Present studies
1	2	3
$T_{e,h}$ K	7500*	7160*
$T_{e,c}$ K	5008	4820
q	0.683	0.40
i°	73.08	76.84
r_h	0.33	0.398 ^a
r_c	0.35	0.301 ^a
$\text{Log } L_h/L_\odot$	0.75	0.87
$\text{Log } L_c/L_\odot$	0.19	-0.06
m_{v_h}	1.55*	1.70*
m_{v_c}	1.05	0.68
R_h	1.51	1.77
R_c	1.58	1.34
$\log g_h$	4.26	4.17
$\log g_c$	4.04	4.02
Sp.type (Pri)	A8V	F0V-IV
(Sec)	G9V	G4-7V-IV

*Assumed value

$$^a r = r_{\text{pole}} + r_{\text{side}} + r_{\text{back}} / 3$$

Captions to Figures

Figure 1a: V Crt: Light curves in V and B passbands in the phase range of 0.70 to 0.30. Filled circles represents observations and the solid lines represent theoretical curves computed from the elements given in col.4 of Table-1.

Figure 1b: V Crt: Same as Figure 1a for the phase range of 0.20 to 0.80.

Fig. 1. Dependence of the calculated and experimental curves on the parameter Δ for the elements given in Col. A of Table 1.

Fig 1b: Same as Fig 1a for the phase range of 0.20 to 0.80.