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Period study of the Algol-type eclipsing binary—R Canis Majoris

K. R. Radhakrishnan, K. D. Abhyankar and M. B. K. Sarma
Centre of Advanced Study in Astronomy, Osmania University, Hyderabad 500007

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Abstract. Photoelectric observations of the Algol-type eclipsing binary R Canis Majoris during three consequtive observing seasons of 1979–82 gave a total of ten primary minima in each of the V and B passbands and nine in the U passband. The $(O - C)$ curve obtained by using these minima and those available in the literature indicates that the period changes noticed in R CMa are due to light-time effect. The elements of the light-time orbit are determined. The mass of the third body is derived to be $\approx 0.5\ M_{\odot}$ for i values ranging from 60° to 90°. The low mass and the absence of significant light contribution suggests that the third body may be an M dwarf or a white dwarf.

Key words : eclipsing binary—R CMa—triple system

1. Introduction

R Canis Majoris (BD $-16°2898$) was found to be an eclipsing binary by Sawyer (1887). From his visual observations, Dugan (1924) found an abrupt shortening in the period of this system during 1914. This was confirmed by Dugan & Wright (1939) and Wood (1946). Wood had also found evidence for further shortening of the period. Koch (1960), from his photoelectric observations and the earlier published times of minima, felt that the $(O - C)$ curve could be represented either by two straight lines or by a sine curve of semi-amplitude of $0^{d}.032$. He, however, concluded that 'since the secondary eclipse has always been located at the half-period point and the absorption lines from a third body have never been detected, the period is probably intrinsically variable'. Guinan (1977), using his photoelectric times of minima along with all those published up to that time, showed that the $(O - C)$ curve can be represented by two straight lines corresponding to two constant periods before and after the abrupt change in 1914. Since we had obtained ten photoelectric times of primary minima, it was decided to investigate the cause for the period change in this system.

2. Observations

R CMa was observed by us photoelectrically on 14 nights during 1979–80 through standard *V* and *B* passbands with the 31-cm refractor of the Nizamiah observatory using an unrefrigirated EMI 9502 *B* photomultiplier. During the observing seasons 1980–81 and 1981–82, this system was observed on 34 nights on the 1.2m-reflecting telescope of the the Japal-Rangapur observatory using an unrefrigirated EMI 6256B photomultiplier. The output from these photomultipliers was amplified by a GR 1230A DC amplifier and recorded by a Honeywell Brown stripchart recorder. HD 56405 was used as comparison star and HD 56310 as check star. The observations of the comparison star were used for determining the nightly extinction coefficients. By observing many standard stars, the instrumental Δm (variable — comparison) values in each passband were converted to the standard system (Radhakrishnan & Sarma 1982). The constancy of Δm (HD 56310 – HD 56405) has suggested that the comparison star remained constant during the period of our observations within $0^m.01$ in *B* and *V*, and $0^m.02$ in *U* passband.

The times of primary minima determined from the observations using Kwee & van Woerden's (1956) method are listed in table 1 which also includes all other published times of minima.

Table 1. R CMa : Photoelectric and visual times of minima

Times of minima HJD 2400000 +	No. of cycles *E*	$(O-C)$	Weight	Reference
10368.9940	−17666	−.0384	v 1	1
10562.1140	−17496	−.0285	v 1	1
10664.3470	−17406	−.0303	v 1	1
11425.4370	−16736	−.0214	v 1	1
11993.3910	−16236	−.0384	v 1	1
12527.3030	−15766	−.0191	v 1	1
13242.9558	−15136	−.0105	v 1	1
14333.4540	−14176	−.0158	v 1	1
14447.0560	−14076	−.0080	v 1	1
14878.7180	−13696	−.0040	v 1	1
15810.2070	−12876	+.0126	v 1	1
18309.2920	−10676	+.0253	v 1	1
19615.6310	− 9526	+.0310	v 1	1
19849.6340	− 9320	+.0300	v 1	1
20138.1570	− 9066	+.0237	v 1	1
20513.0290	− 8736	+.0348	v 1	1
21278.6460	− 8062	+.0270	v 1	1
21648.9830	− 7736	+.0469	v 1	1
22029.5020	− 7401	+.0253	v 1	1
22030.6380	− 7400	+.0254	v 1	1
22558.8490	− 6935	+.0234	v 1	1
22765.5900	− 6753	+.0229	v 1	1
23098 4210	− 6460	+.0229	v 1	1
23406.2530	− 6189	+.0147	v 1	1
23442.6090	− 6157	+.0205	v 1	1
23866.3210	− 5784	+.0262	v 1	1
24667.1390	− 5079	+.0051	v 1	1
25052 2350	− 4740	+.0167	v 1	1
25320.3190	− 4504	+.0184	v 1	1
25650.8780	− 4213	+.0183	v 1	1
25990.5200	− 3914	+.0137	v 1	1
26014.3800	− 3893	+.0189	v 1	1
26027.9990	− 3881	+.0066	v 1	1

(*Continued*)

Table 1. (*Continued*)

Times of minima HJD 2400000 +	No. of cycles *E*	(*O–C*)	Weight	Reference
26753.8560	– 3242	–.0033	v 1	1
26994.6880	– 3030	+.0090	v 1	1
28596.3573	– 1620	+.0001	v 1	2
28922.3745	– 1333	+.0019	v 1	2
29301.7760	– 999	–.0012	pe 10	1
29308.5900	– 993	–.0028	pe 10	1
29309.7270	– 992	–.0018	pe 10	1
29660.7280	– 683	–.0068	v 1	1
30035.5850	– 353	–.0107	v 1	1
32999.2350	+ 2256	–.0333	v 1	2
33367.3200	2580	+.0065	v 1	2
34453.2710	3536	–.0030	v 1	2
34454.4040	3537	–.0059	v 1	2
34481.6617	3561	–.0109	pe 10	2
35515.3600	4471	–.0197	pe 10	2
35534.3675	4488	–·0153	pe 10	2
36958.0038	5741	–.0222	pe 10	3
36959.1426	5742	–.0194	pe 10	3
36982.9953	5763	–.0215	pe 10	3
39140.1442	7662	–.0264	pe 10	4
39163.9998	7683	–.0256	pe 10	4
39169.6780	7688	–.0271	pe 10	5
39533.1790	8008	–.0275	pe 10	6
39802.4030	8245	–.0217	pe 10	6
39822.8460	8263	–.0257	v 1	7
39863.7380	8299	–.0276	v 1	7
39870.5310	8305	–.0503	v 1	7
39872.8170	8307	–.0361	v 1	7
39875.0980	8309	–.0270	pe 10	8
39896.6700	8328	–.0379	v 1	7
39904.6320	8335	–.0275	v 1	7
39905.7720	8336	–.0235	v 1	7
39912.5770	8342	–.0341	v 1	7
39912.5920	8342	–.0191	v 1	7
39912.5843	8342	–.0268	pe 10	7
39929.6370	8357	–.0132	v 1	7
39935.3070	8362	–.0230	pe 10	9
39954.5960	8379	–.0450	v 1	7
40288.5780	8673	–.0299	v 1	7
40313.5710	8695	–.0276	v 1	7
40582.7830	8932	–.0339	v 1	7
40964.4660	9268	–.0274	pe 10	10
40971.2820	9274	–.0270	pe 10	11
40979.2340	9281	– 0266	pe 10	11
40995.1390	9295	–.0248	pe 10	11
40996.2710	9296	–.0288	pe 10	11
41725.5330	9938	–.0415	v 1	12
41765.3070	9973	–.0255	v 1	12
42059.5100	10232	–.0314	v 1	13
42092.4520	10261	–.0318	v 1	14
42099.2710	10267	–.0284	v 1	15
42100.4000	10268	–.0353	v 1	15
42116.3040	10282	–.0345	v 1	15
42402.5780	10534	–.0179	v 1	16
42426.4190	10555	–.0317	v 1	17
42426.4220	10555	–.0287	v 1	18
42467.3000	10591	–.0446	v 1	19
42785.3670	10871	–.0414	v 1	20
42802.4340	10886	–.0135	v 1	21
42802.4320	10886	–.0155	v 1	22
42826.2770	10907	–.0253	v 1	23
42820.5936	10902	–.0290	pe 10	24

(*Continued*)

Table 1. (*Continued*)

Times of minima HJD 2400000 +	No. of cycles E	$(O-C)$	Weight	Reference
42826.2860	10907	−.0163	v 1	25
42835.3480	10915	−.0418	v 1	20
42835.3680	10915	−.0218	v 1	21
43161.3770	11202	−.0281	v 1	26
43162.5140	11203	−.0271	v 1	26
43186.3610	11224	−.0349	v 1	27
43202.2720	11238	−.0271	v 1	28
43203.3960	11239	−.0390	v 1	28
43219.3120	11253	−.0262	v 1	28
43430.5770	11439	−.0464	v 1	29
43512.3790	11511	−.0322	v 1	30
43513.5130	11512	−.0342	v 1	31
43587.3580	11577	−.0254	v 1	32
43595.2960	11584	−.0390	v 1	32
43612.3370	11599	−.0371	v I	32
43880.4240	11835	−.0324	v 1	33
43888.3700	11842	−.0380	v 1	34
43905.4160	11857	−.0311	v 1	34
43946.3060	11893	−.0350	v 1	35
43971.2940	11915	−.0378	v 1	36
44255.2833	12165	−.0340	pe 10	37
44281.4030	12188	−.0409	v 1	38
44606 2980	12474	−.0253	pe 10	39
44607.4321	12475	−.0272	pe 10	39
44647.1932	12510	−.0240	pe 10	39
44648.3283	12511	−.0249	pe 10	39
44649.4610	12512	−.0281	v 1	40
44664.2298	12525	−.0266	pe 10	39
44672.1842	12532	−.0238	pe 10	39
44998.1982	12819	−.0251	pe 10	39
44999.3289	12820	−.0304	pe 10	39
45015.2383	12834	−.0241	pe 10	39

v = visual pe = photoelectric
$(O-C)$ refer to the ephemeris – 2430436.5832 + $1^d.13594197\ E$

References : 1. Wood (1946); 2. Koch (1960); 3. Kitamura & Takahashi (1962); 4. Sato (1971); 5. Robinson (1967); 6· Charyulu (1969); 7. Baldwin (1973); 8. Guinan (1977); 9. Kizilirmak & Pohl (1970); 10. Kizilirmak & Phol (1972); 11. Sarma (1972); 12. Mallama (1973); 13. Locher (1974); 14. Peter (1974); 15. Locher (1974); 16. Locher (1975); 17. Locher (1975); 18. Peter (1975); 19. Peter (1975); 20. Peter (1976); 21. Locher (1976); 22. Tuboly (1976); 23. Zajacz (1976); 24. Mallama *et al.* (1977); 25. Fenyvesi (1976); 26. Poretti (1977); 27. Hevesi (1977); 28. Poretti (1977); 29. Locher (1977); 30. Poretti (1978); 31. Pampaloni (1978); 32. Poretti (1978); 33. Poretti (1979); 34. Pampaloni (1979); 35. German (1979); 36. Poretti (1979); 37. Radhakrishnan & Sarma (1982); 38. Pampaloni (1980); 39. Present work; 40. Boistel (1981).

3. $(O - C)$ Curve

There are a total of 33 photoelectric and 94 visual observations. These times of minima were fitted to the following ephemeris of Guinan (1977)

$$\text{HJD Prim. minimum} : 242,0213.133 + 1^d.13593872\ E \qquad \ldots(1)$$

The $(O - C)$ curve obtained this way is shown in figure 1. It is seen that the $(O - C)$ curve is almost sinusoidal with small distortion. Such a type of $(O - C)$ variation in a binary may be caused either by apsidal motion or by light-time orbit due to a third body. Apsidal motion is caused by motion in an eccentric orbit wherein the secondary minima are shifted periodically from their mean position of 180° and their $(O - C)$ would shift opposite to those of primary minima. The

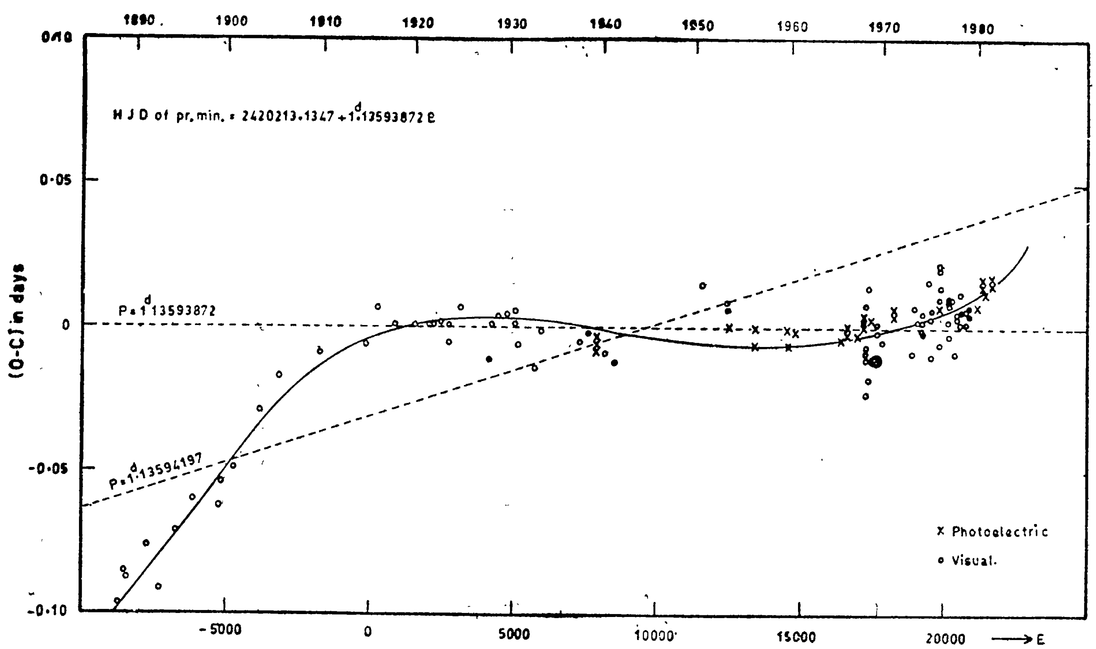

Figure 1. R CMa : The $O-C$ curve obtained using Guinan's second ephemeris.

secondary minima of R CMa are very shallow, making accurate determination of their times difficult and hence these are never published. But in all the previous studies as well as our own, the secondary has always been found to occur at 0.5 phase. Our spectroscopic investigations as well as those of others have shown the orbit of R CMa to be nearly circular, thus eliminating apsidal motion as one of the causes for period changes in R CMa. Hence the period changes exhibited by R CMa can be attributed to the presence of a third body in the system.

4. Light-time orbit

The elements of the light-time orbit are determined from the $O-C$ *versus* epoch curve, using Irwin's (1952) method. The $(O-C)=0$ line is redrawn in such a way as to equalize the amplitudes of the $(O-C)$ variation on either side. This axis corresponding to $P = 1^d.13594197$ is the true binary period as seen from the centre of mass of the triple system and is shown in figure 1 by the slant dashed line. According to Irwin (1952), the light-time effect τ which is the value of $(O-C)$ for the ephemeris corresponding to the centre of mass of the system is given by

$$\tau = \frac{K}{\sqrt{1-e^2\cos^2\omega}}\left\{\frac{1-e^2}{1+e\cos\nu}\sin(\nu+\omega)+e\sin\omega\right\}, \qquad \ldots(2)$$

where
$$K = \frac{\tau_{\max}-\tau_{\min}}{2} = \frac{a\sin i\sqrt{1-e^2\cos^2\omega}}{2.590\times10^{10}} \qquad \ldots(3)$$

is the semi-amplitude of the $(O-C)$ variation, τ is in days and a, the semimajor axis of the light-time orbit, is in kilometers; e is the eccentricity and ω the longitude of periastron and ν the true anomaly. Using the (e, ω) tables of Irwin (1952) and his graphical method, the light-time orbital elements are derived as

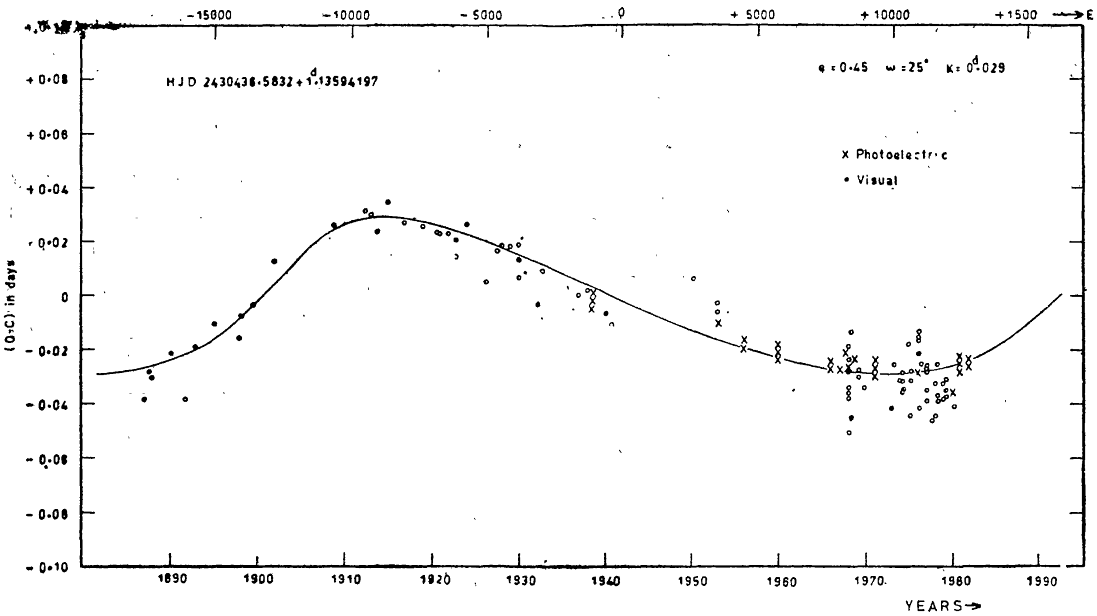

Figure 2. R CMa : The new $(O-C)$ diagram. The new continuous line represents the theoretical curve obtained with the adopted third body orbital elements.

$$P = 91.44 \text{ yr}$$
$$e = 0.45 \pm 0.08 \text{ (s.e)}$$
$$\omega = 25^\circ \pm 30^\circ \text{ (s.e)}$$
$$K = 0^d.031 \text{ (preliminary)}$$
$$= 0^d.029 \text{ (corrected)} \pm 0.001 \text{ (s.e)}$$

With the preliminary elements, only the semi-amplitude is corrected by a least squares solution given by

$$\Delta K = \Sigma W_i \Delta\tau \left(\frac{\Delta\tau}{\Delta K}\right) \Big/ \Sigma W_i \left(\frac{\Delta\tau}{\Delta K}\right)^2 \qquad \ldots(4)$$

Here the W_i are weights appropriate to different observations : one to visual observations and ten to photoelectric observations. The correction to K was found to be $-0^d.002$ thus giving the corrected $K = 0^d.029$. From this '$a \sin i$' was found to be 8.23×10^8 km. A theoretical $(O - C)$ curve is calculated with these elements and is shown as solid line in figure 2. The open circles in this figure denote the visual observations and the crosses the photoelectric observations. The fit of the theoretical curve to the observed $(O - C)$ points is seen to be satisfactory.

5. Discussion

R CMa is a single-lined spectroscopic binary and from combining the spectroscopic data of ours (Radhakrishnan 1983) with that of Jordan (1916), Sitterly (1940) and Struve *et al.* (1950), a mass function $f(m) = 0.00251 \pm 0.00014\ M_\odot$ is derived. The primary component is found to be a normal F2 V star. Assuming the mass of this star to be 1.52 $M_\odot$ (Allen 1976), the total mass of the double system is found to be $1.719 \pm 0.003\ M_\odot$. With this value of the binary mass, the mass function of the triple system is found to be 0.02 $M_\odot$. The mass of the third body is found to be 0.54 $M_\odot$ for an orbital inclination of 60° and 0.46 $M_\odot$ for an orbital inclination of 90°. The star of such a low mass can either be an *M* dwarf or a white dwarf. The measured parallax of 0″.024 ± 0.004 (Guinan 1983) places R CMa at a distance of 43 ± 7 pc. At this distance, the maximum angular seperation of the third body from the binary would be about 0″.7. Since our observations were obtained with a 20 arcsec diaphragm, the third body would always remain in the diaphragm. However, its light contribution should be negligible in the *V*, *B* and *U* passbands. Its contribution should be measurable in the infrared if the third body is an *M* dwarf, and in the ultraviolet if it is a white dwarf. Observations in the far-infrared and extreme UV may shed light on the real nature of this body. Speckle interferometry of the system, may resolve the third body and confirm its actual presence.

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