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A SPECTROGRAPHIC STUDY OF R CANIS MAJORIS

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Abstract. New spectroscopic elements of R Canis Majoris are given in this paper, computed from 17 plates secured at the Astronomical Observatory of Merate. A new orbit has also been computed with the program by Bertiau, from 81 observations covering a period of about 40 years.

Two models of this binary system are proposed, based on two different assumptions and on a newly determined mass function. It is confirmed that the main peculiarity of this binary with regard to the mass-luminosity relation is real; there is also an evidence of mass loss from the Lagrangian point L_2 as suggested by Kitamura.

A suspected variation of the velocity V_0 of the center of mass seems to indicate the presence of a third body. The evidence is, however, not yet conclusive.

1. Introduction

R Canis Majoris was found to be variable by Sawyer (1887); but, in spite of the numerous observations made since that time, this close binary still remains one of the most puzzling eclipsing systems, so that Koch et *al.* (1963) emphasized the need of a new spectrographic, as well as photometric, study.

As is well known, the main feature of this close binary system is the fact that both components have too small masses compared to those aspected from their luminosities or spectral types if the observational aspects are the result of binary motion of two stars. An anomaly of this kind with regard to the mass-luminosity relation happens in about 15% of semi-detached systems (Kopal, 1959).

Buscombe and Morris (1958) have suggested that this eclipsing binary might be a high-velocity star, but Fringant (1956) has shown that R Canis Majoris is a slightly reddened population I star. The spectrum of the secondary component has never been observed, the one of the primary component has been classified as that of a normal Main-Sequence star of spectral type F1 by Fringant and confirmed by Kitamura (1967) from measures of the color indices: U−B=0.00 and B−V=0.33.

Photoelectric studies of this binary have been made by Wood (1946), by Koch (1960) and by Kitamura and Takahashi (1962). The light curves indicate a circular orbit but show also some asymmetry both inside and outside eclipse. Pickering (1904), and later Wendell (1909), have observed a strange 'hump' in the light curve, shortly after primary minimum, which was present on some nights and missing on others.

Variations of the period have been studied by Dugan and Wright (1939) and by Wood (1946); these authors claimed that the published material leaves no doubt that the period has abruptly shortened around 1914 and that it is still diminishing at present.

Spectrographic studies of this system have been made by Jordan (1916), by Sitterly

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(1940) and by Struve and Smith (1950); the results obtained from their observations do not agree well and there is little reason to prefer any one of the available orbits (Batten, 1967).

Lately, Kitamura (1969) has published a spectrophotometric study of this close binary, based on 20 high-dispersion plates. From a study of the residual intensities both inside and outside eclipse, from the abrupt change of period in 1914, and from the evidence of an emission component at the center of the line Ca K, Kitamura concluded that "not only the photometric asymmetry, but also the observed spectroscopic features seem to favor the assumption that both components are surrounded by gaseous matter".

2. Observations

In view of the many problems still unresolved that characterize the physical picture of this system, we have included it in our list of eclipsing binaries under observation at the Observatory of Merate for the determination of new orbits.

The observations of R Canis Majoris have begin in January 1966 and have been performed with a spectrograph giving a dispersion of 34.3 Å/mm at Hγ, attached to the 1.02 m Zeiss telescope.

Since this system has a declination of $-16\overset{\circ}{.}3$ and the latitude of Merate is $+45\overset{\circ}{.}7$ all the observations were made only around the meridian, with exposure times ranging from 60 to 150 m. Of the 25 plates secured, 17 have appeared useful to compute the 60 to 150 m. Of the 25 plates secured, 17 have appeared useful to compute the spectroscopic orbit. In Table I has been given the list of lines measured to determine the radial velocities; those marked with an asterisk are the lines listed by Petrie *et al.* (1957).

TABLE I

Measured spectral lines

3933.68*	Ca II	4290.03	Cr, Ti II
3956.68*	Fe, Ca, Ti, Ce II	4307.90	Ti II, Fe
4005.53*	Fe	4325.76	Fe
4024.78	Fe, Fe II, Ti II	4337.05	Fe
4030.65*	Mn, Fe, Cr II, Ti	4340.48*	Hγ
4045.59*	Fe, Co, Mn	4351.76	Fe II
4063.36*	Fe	4383.55	Fe
4067.05	Ni II	4395.03	Ti II
4071.56*	Fe, Cr II	4404.73	Fe, Fe
4101.75*	Hδ	4443.80	Ti II
4132.31*	Fe, Ca, Ti II, Fe	4481.44*	Mg II, Fe, Cr II
4143.50	Fe	4501.27	Ti II
4167.26	Mg	4528.62	Fe
4215.52	Sr II	4534.02	Ti II, Fe II
4226.56*	Ca, Ti II, Fe	4549.60	Ti II, Fe II
4233.31	Fe II, Fe, Cr II	4563.76	Ti II
4250.51	Fe, Fe	4602.94	Fe
4260.48	Fe	4666.99	Ni
4271.54	Fe, Fe	4859.75	Fe
4282.41	Fe	4861.33	Hβ

TABLE II

Radial velocities of R Canis Majoris

Plate no.	Julian day	Phase	Velocity	Weight
2259	2439131.506	0.404	−49.79 ± 1.66 (p.e.)	0.60
2265	132.513	0.291	−74.48 ± 2.60	0.38
2272	133.502	0.162	−51.26 ± 2.58	0.39
2544	818.618	0.289	−70.08 ± 2.64	0.38
2557	838.586	0.868	−29.70 ± 3.36	0.30
2603	845.630	0.069	−50.13 ± 4.27	0.23
2615	864.512	0.691	−26.78 ± 1.62	0.62
2618	871.476	0.822	−31.88 ± 2.04	0.49
2620	871.561	0.897	−35.00 ± 2.68	0.37
2641	927.394	0.048	−42.13 ± 2.25	0.44
2648	929.315	0.738	−25.30 ± 2.91	0.34
2650	930.407	0.700	−24.73 ± 7.36	0.14
2707	2440242.458	0.408	−50.89 ± 2.62	0.38
2708	242.514	0.457	−46.24 ± 3.36	0.30
2714	245.442	0.035	−42.06 ± 3.89	0.26
2715	245.523	0.106	−59.85 ± 2.51	0.40
2734	259.437	0.356	−67.42 ± 2.83	0.35

Table II contains the following observed data; its successive columns indicate: number of the plate, epoch of observation in Julian days, phase after primary minimum computed from Koch's ephemeris, observed radial velocity with probable error, weight ($w = 1/\text{p.e.}$).

3. Results

The radial velocities curve of this system is shown on Figure 1.

In view of a large scatter of the observations and following the example of Struve and Smith, we have not undertaken a solution by least squares. During primary eclipse there is a systematic deviation of the observations from the assumed circular

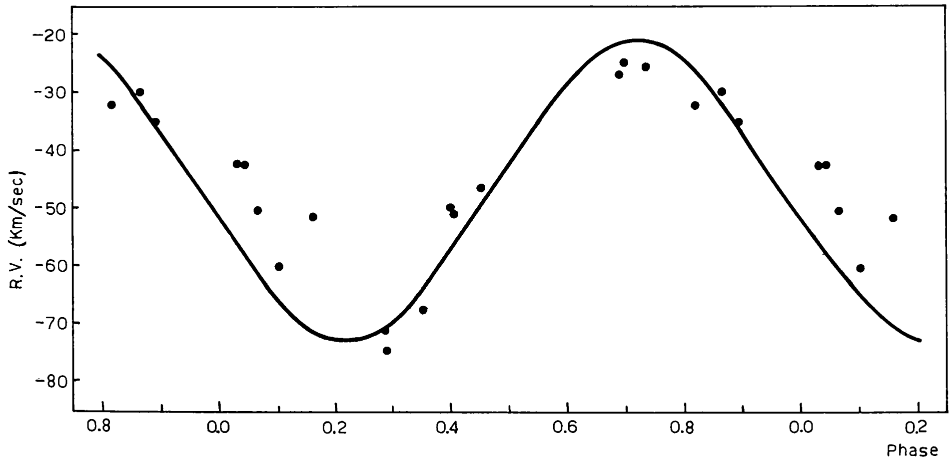

Fig. 1. Radial-velocity curve of R Canis Majoris.

orbit; this deviation may, however, be due to rotation and is present also in the work of Struve and Smith.

Table III contains the results of the present work, together with all spectroscopic elements up to this time computed for this system.

The small value of the mass-function computed in the present work confirms once again the peculiarity of this binary system with regard to the mass-luminosity relation.

TABLE III

Element	Jordan	Sitterly	Struve-Smith	Present work
e	0.138	0.013	0.000	0.000
V_0 (km/sec)	-39.7	-34.8	-42.5	-45.5
K (km/sec)	28.6	24.0	31.5	26.0
$a \sin i$ (10^6 km)	0.443	0.374	0.491	0.406
$f(m)$ (in ○)	0.0027	0.0016	0.0037	0.0021

In Table IV we have given the orbital elements of R Canis Majoris deduced from all the observations done after the year of the shortening of the period (1914), computed by means of the program by Bertiau (1967), previously adapted to the computer IBM 7040 (Galeotti and Guerrero, 1968).

TABLE IV

$K = 25.07 \pm 2.61$ km/sec
$V_0 = 39.80 \pm 2.20$ km/sec
$P = 1.1359 \pm 0.0015$ d
$f(m) = 0.0020$ ○

$e = 0.046 \pm 0.104$
$\omega = 149.°77 \pm 1.85$
$T_0 =$ J.D. 2432891.510 ± 0.018
$a \sin i = 0.391 \times 10^6$ km

4. Discussion

The scatter in the velocity curves of the different authors is always large and the results obtained do not agree well; the uncertainties in the mass-function and in the eccentricity are very large. Sitterly, after discussion of his material, concluded that the eccentricity is equal to zero or very small; but the observations of Jordan do not agree with a circular orbit.

The orbital elements given in Table IV may be considered to be the best available ones, as they cover a period of about 40 years and have been computed by least-squares from some 81 observations. From the mass-function so computed, and assuming (Kitamura, 1969) for the primary component a normal F1 main sequence mass of $1.7_{\odot}$, we can deduce a mass ratio of 0.12. If we compare this value of the mass ratio with those of the 83 eclipsing binaries listed in the Kopal and Shapley (1956) catalogue, we conclude that R Canis Majoris may be the system with the smallest known mass ratio.

We have compared the fractional radii, taken as the mean values of the results from the observations by Wood, by Koch, and by Kitamura and Takahashi, with the dimensions of the innermost and outermost Lagrangian lobes, taken from the work by Plavec and Kratochvíl (1964) for the mass ratio 0.12 (Table V).

TABLE V

$r_1 = 0.30$	$r_2 = 0.26$
$y_{11} = 0.58$	$y_{12} = 0.21$
$y_{21} = 0.61$	$y_{22} = 0.24$

We notice immediately, that while the primary component is well inside the innermost lobe, the radius of the secondary component seems larger than the outermost lobe, so confirming the results obtained by Sahade (1963), and by Kitamura (1969). This conclusion, however, may be explained if we remember that the Roche model is based on certain assumptions. The first of these assumptions states that the two bodies are considered as mass points; and this may not be the case for R Canis Majoris.

If, on the contrary, we assume that the secondary component fills exactly its Roche limit, the system must have a total mass of only $0.31_{\odot}$, with a mass ratio of 0.24. I think that the model that we deduce from this last assumption is unlikely and that we must prefer the previous assumption.

Gaseous matter may surely be present anywhere, between the two Lagrangian lobes and should be much denser around the secondary component, which, undoubtedly, fills its Roche limit. From these models of R Canis Majoris we deduce that a mass loss should occur through the Lagrangian point L_2 and the system must be surrounded by gaseous matter, as suggested by Kitamura (1969).

Finally, we wish to remark that the velocity V_0 of the center of mass has diminished in comparison with the previous determinations (see Table III), and that the last three observations seem to satisfy to a linear variation of 0.3 km/sec per year. Nevertheless, the variation, if any, may be cyclic with a very long period, including the value obtained by Jordan before 1914. This variation does not seem to be of instrumental origin, because of its amount and of its regular trend. If it is real, we can argue that R Canis Majoris is a triple system with very long secondary period or that the mechanism of mass loss acts as an acceleration of the center of mass from the time when the period commenced to diminish. At any rate, further observations are needed to confirm this variation.

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