THE ECLIPSING TRIPLE SYSTEM VV ORIONIS

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RIASSUNTO. — VV Orionis (HD 36695) è un sistema triplo i cui elementi orbitali non sono ancora stati determinati in modo sufficientemente preciso; l'orbita del terzo corpo è stata data solamente da Daniel nel 1915, che ne ha calcolati gli elementi in forma approssimata. Diversi Autori hanno dato delle stime circa i valori delle masse, ottenute sotto differenti ipotesi, tuttavia non è ancora stato ottenuto un risultato definitivamente accettabile. Questi due aspetti fondamentali ed ancora non ben noti di VV Orionis ci hanno spinti ad osservare questo sistema ad eclisse e costituiscono l'argomento principale della presente memoria.

L'orbita spettroscopica della coppia principale è stata determinata da 26 osservazioni alla dispersione di 34.3 Å/mm. L'orbita del terzo corpo è invece stata calcolata da tutti i residui disponibili, che si estendono per circa 180 cicli.

Le masse sono state calcolate dalla funzione di massa da noi determinata e da una stima del rapporto delle masse della coppia principale; questa stima è dedotta dalla semi-ampiezza K_2 della secondaria, ottenuta misurando un'asimmetria nel profilo delle righe dell'idrogeno, causata dalla sovrapposizione dello spettro della secondaria sulle ali dello spettro della primaria. Una conferma sui valori così ottenuti delle masse, si è avuta dal confronto fra i raggi osservati e quelli calcolati dalle masse per stelle di sequenza principale.

SUMMARY. — VV Orionis is an eclipsing triple system whose spectroscopic parameters are not yet well known. The determination of the orbit of the third body, performed by Daniel in 1915, is rather uncertain. The masses computed by several Authors, under different hypotheses, are not in good agreement. We have observed this eclipsing system with the aim of trying to solve these open problems.

A spectroscopic orbit is computed for the primary couple, deduced from 26 plates (dispersion 34.3 Å/mm) secured at Merate from January 1966. The orbit of the third body was evaluated from all the residuals available, covering about 180 cycles.

The masses of the three bodies have been computed from the newly determined mass functions and from a rough estimate of the mass ratio of the primary couple, deduced from the semiamplitude K_2 of the secondary component. This parameter was obtained by measuring an asymmetry in the profile of the hydrogen lines due to overlapping of the secondary spectrum on the wings of the primary. A confirmation about the masses was obtained from the comparison of the observed radii with those deduced from the mass-radius relation for main sequence stars.

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1. - Introduction

Barr (1904) first observed variations in the light of VV Orionis (HD 36695) but it was only 9 years later that Hertzsprung (1913) proved the star to be an eclipsing variable; since then many observations of this system have been done, both visually and with photometers. On the contrary, the spectroscopic studies are few and this is the reason why Koch et al. (1963) have defined very desiderable a new spectroscopic study of this binary in their « Finding List for Observers of Eclipsing Binaries ».

VV Orionis is a single line binary but the luminosity of the secondary component is about 11% of the total luminosity; sometimes, however, it is possible to observe a faint trace of the secondary spectrum. The spectral types are B1 + [B5] in the catalogue by Kopal and Shapley (1956), and B2 + B9 in the catalogue by Batten (1967).

Photoelectric observations have been done by Schneller (1936), Wood (1946), Dufay (1947) and by Huffer and Kopal (1951). Scheneller's observations have been confirmed by Wood, but their orbital elements do not agree very well because, according to Wood, « the difference in elements appears to be due to numerical errors on Schneller's part ». Dufay gives the absolute elements of the system for two different mass-ratios; Huffer and Kopal also estimate masses and radii when trying to determine the limb darkening.

Spectroscopic studies have been done by Daniel (1915) and by Struve and Luyten (1949). Daniel gave evidence for a periodic variation in the residuals, which could be interpreted, according to him, « with great reserve », as due to the existence of a third body in the system, whose elements are approximately evaluated by Daniel. Struve and Luyten confirmed the variation in the residuals, but they could not determine the orbital elements of the third body because their observations cover scarcely 1/3 of the longer period. Their noteworthy result is the discovery of the secondary spectrum as a faint extension of the primary lines of hydrogen during some phases.

There is a great uncertainty in evaluating the mass ratio; various Authors give different values, ranging from $m_2/m_1 = 0.34$ according to Kopal and Shapley (1956) to $m_2/m_1 = 1.0$ according to Struve and Luyten (1949). Both Wood (1946) and Huffer and Kopal (1951) give ~ 0.5, in agreement with the mass-luminosity relation.

We think a new spectroscopic study of this eclipsing system would be very interesting, as one could thus give a precise determination of the orbit of the third body, and a better evaluation of the mass ratio.

2. - Observations

With the aim of contributing to the solution of these two fundamental aspects in the dynamics of VV Orionis, we included this triple system in the list of eclipsing binaries observed at the Observatory of Merate for determining new orbits.

We began the observations in January 1966, securing 26 plates (dispersion 34.3 Å/mm at H_γ) whose data are given in Table I; the phases are computed from the period by DUFAY (1947), the weights are computed from the probable errors, whose mean value is ± 4.5 km/sec.

Table II gives the lines measured to compute the radial velocities; the lines marked with an asterisk are those listed by PETRIE (1953).

3. - RESULTS

The orbital elements have been computed by means of the Fortran programme by BERTIAU (1967). Table III gives the residuals (O-C), together with their phases computed from the longer period shown in Table IV.

We determined accurately the orbit of the third body, with the program by Bertiau, by making use of all the residuals available, related to a number of observations in the last 55 years and thus covering nearly 180 cycles of the third body. Table IV gives the results of our determination, together with the approximate values by Daniel in 1915 (in parenthesis).

It has been possible, by means of the residuals, to correct the radial velocities of the primary component and to compute the improved orbital elements. Table V gives the preliminary and the corrected values, together with their probable errors.

Fig. 1 gives the final radial velocity curve; the dots represent the velocities corrected for the effect of the third body. The residuals for the modified orbit are given in column (O-C)' of Table III.

With the aim of determining the amplitude K_2 of the secondary component we examined the profile of the hydrogen lines from the microphotometer tracings of some plates, secured at phases when the radial velocity is maximum or minimum. Fig. 2 gives part of the microphotometer tracings of two plates secured at phases 0.119 and 0.633.

As one can easily see from Fig. 2, the line profiles are asymmetric, namely the blue (red) side is wider when the primary receeds (approaches). This effect is undoubtedly due to the overlapping of the secondary spectrum on the wings of the primary when the difference in radial velocities is large. To determine the relative Doppler shifts we tried to separate the contribution of the two components, by measuring the maximum asymmetry in the tracings. The uncertainty in the method is undoubtedly very large, nevertheless we can tentatively give an estimate of 320 km/sec for the parameter K_2 relative to the hydrogen lines, obtained as a mean value of 6 tracings. Consequently, an approximate value of $m_2/m_1 = 0.44$ is thus determined without introducing any external assumption.

TABLE I

plate n.	Julian day	phase	rad. veloc.	weight
2275	2439139.393	0.000	− 69.1	0.30
2276	154.340	.062	− 86.9	.20
2292	188.360	.966	− 5.3	.15
2314	201.315	.687	+176.5	.20
2382	459.435	.465	+ 70.0	.40
2383	459.550	.539	+123.2	.45
2405	483.441	.623	+144.3	.40
2437	536.249	.175	− 90.6	.25
2439	536.350	.243	− 84.0	.20
2441	537.297	.880	+ 42.9	.35
2454	572.287	.437	+ 36.1	.30
2613	864.435	.119	−103.6	.20
2705	2440242.361	.550	+100.6	.20
2706	242.394	.572	+108.2	.90
2713	245.380	.582	+151.6	.40
2716	246.377	.254	−114.8	.15
2717	246.426	.286	− 73.9	.25
2719	248.372	.597	+119.5	.75
2720	248.422	.631	+148.3	.30
2721	248.467	.661	+167.4	.20
2722	248.507	.688	+154.5	.10
2723	251.397	.633	+165.0	.15
2724	251.442	.664	+147.7	.20
2727	252.275	.224	−114.1	.20
2729	252.380	.295	− 83.9	.15
2733	259.365	.998	− 71.7	.35

TABLE II - Measured star lines.

element	wavelength	element	wavelength
H 13	3734.37	H_δ	4101.77*
H 12	3750.15	He I	4120.84*
H 11	3770.63	Si II	4128.05*
H 10	3797.90	Si II	4130.88*
He I	3819.76	He I	4143.76
H 9	3835.39	Ca II	4267.17*
H 8	3889.05	H_γ	4340.47*
He I	3926.53	He I	4387.93*
Ca II K	3933.67*	He I	4471.48*
H_ε	3970.07*	Mg II	4481.23*
N II	3994.99*	Si III	4552.62*
He I	4009.27	Si III	4567.84*
He I	4026.14*	H_β	4861.33*
O II	4069.77*		

TABLE III

plate n.	(O-C)	phase	(O-C)'
2276	+12.0	0.000	+ 7.8
2275	− 1.0	.129	− 0.7
2292	+37.1	.294	+37.0
2314	+17.8	.405	+19.8
2382	+13.3	.633	+ 9.9
2383	+12.5	.634	+11.3
2405	− 6.7	.846	−14.7
2437	+17.3	.296	+16.8
2439	+ 3.9	.297	− 1.6
2441	− 0.6	.305	− 6.9
2454	− 1.1	.607	+ 2.0
2613	+ 5.1	.128	−11.8
2705	− 5.5	.390	− 7.4
2706	−11.6	.390	−12.6
2713	+26.1	.416	+26.6
2716	−24.6	.425	−18.9
2717	+ 1.5	.425	+ 4.8
2719	−13.6	.442	−11.8
2720	+ 0.8	.442	+ 3.5
2721	+11.4	.443	+14.5
2722	− 4.9	.443	− 0.7
2723	+16.5	.468	+19.7
2724	− 8.9	.468	− 3.1
2727	−13.7	.476	− 4.8
2729	−12.8	.476	− 9.1
2733	−23.9	.532	−12.1

TABLE IV

Present work	Daniel
$K = 16 \pm 5$ km/sec	(13.0)
$V_o = 1 \pm 4$ km/sec	
$e = 0.3$	(0.3)
$\omega = 46° \pm 2°$	
$T_o = 2419827 \pm 10$	(1913, Febr. 20)
$P = 115.874 \pm 0.014$ d	(120)
$a \operatorname{sen} i = 24 \times 10^6$ km	(20, 460, 000)
$f(m) = 0.041$ ⊙	

TABLE V

Element	Preliminary value	Corrected value
K (km/sec)	135.1 ± 9.3	139.9 ± 8.8
V_o (km/sec)	20.0 ± 8.1	26.3 ± 7.7
e	0.069	0.077
ω (°)	61.3 ± 3.1	84.3 ± 2.7
T_o	2440251.71	2440251.80
a sen i (10^6 km)	2.75	2.85
f(m) (☉)	0.377	0.418
P (d)	1.4854	1.4854

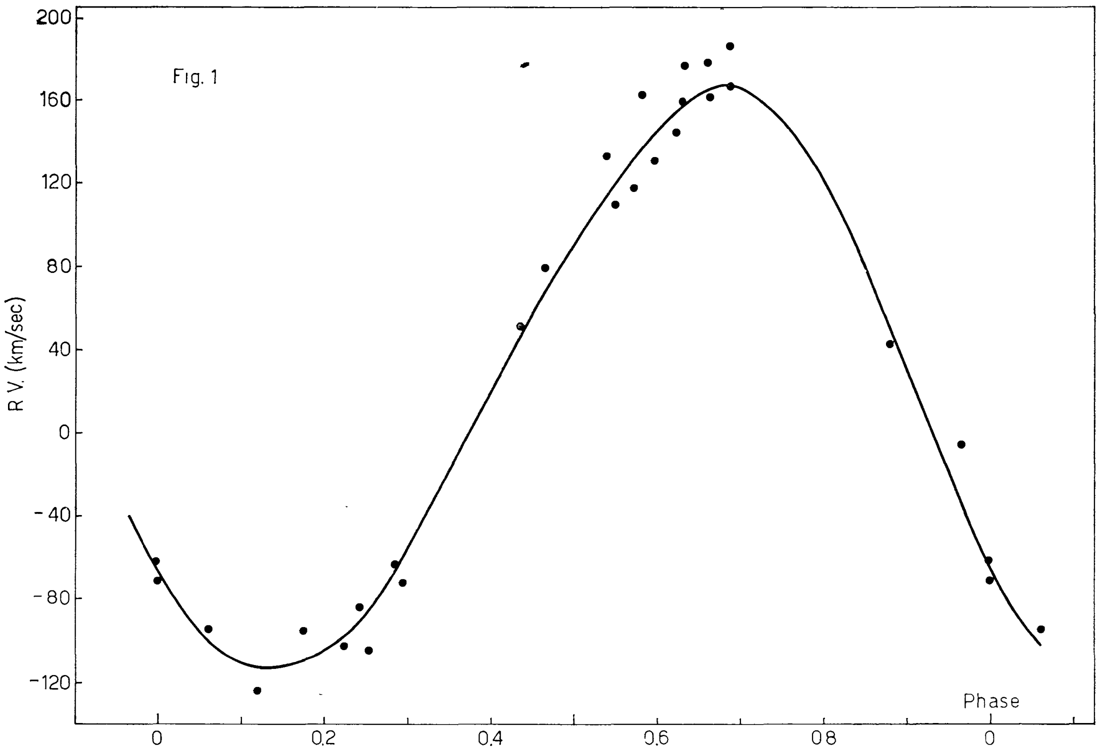

FIG. 1
Final radial velocities curve.

4. - DISCUSSION

Making use of the newly determined mass-ratio, of the mass-function previously determined by us and assuming an inclination $i = 84^\circ.3$ as given by KOPAL

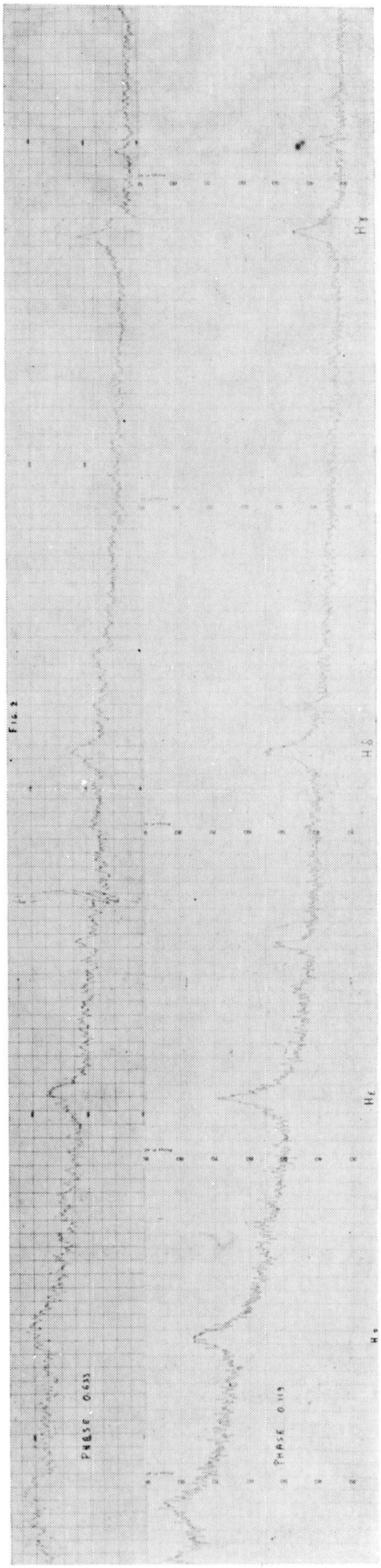

FIG. 2
Microphotometer tracings of two plates at phases 0.119 and 0.633.

and SHAPLEY (1956) we computed the masses of the two principal bodies:

$$M_1 = 10.2 \odot \qquad M_2 = 4.5 \odot$$

Our results agree very well with those by WOOD (1946), who gives a mass ratio m_2/m_1 within the limiting values 0.50 and 0.40, those by Hertzsprung-Dufay who consider the two mass ratios 0.50 and 0.33 and with that by HUFFER and KOPAL (1951) who give a value of 0.50 from the best agreement with the mass-luminosity relation. On the contrary, the masses obtained by us are much larger than those computed by STRUVE and LUYTEN (1949) who estimated a mass-ratio of the order of 1.0 by measuring tracings with a much less prominent asymmetry than our in the hydrogen line profiles.

We then verified that the two principal bodies do not exceed their Roche limit, by comparing the photometric fractional radii with the Lagrangian lobes computed by PLAVEC and KRATOCHVIL (1964) for a mass ratio 0.44, without taking into account the influence of the third body. We can thus confirm that the two principal bodies form indeed a detached system.

From the mass function of the third body, and assuming its orbit complanar with that of the primary couple we determined its mass: $2.3_\odot$. This result appears somewhat larger than the value estimated by KOPAL and SHAPLEY (1956) under the hypothesis of a mass function 0.024, deduced from the work by DANIEL (1915).

Table VI gives the absolute geometric parameters deduced by combining the photometric elements of KOPAL and SHAPLEY (1956) with our spectroscopic data. We give also some characteristic parameters of normal main sequence stars, taken from ALLEN (1955), with masses equal to those of the three bodies of VV Orionis.

TABLE VI

	I°	II°	III°
$M/M_\odot$	10.2	4.5	2.3
a (10^6 km)	2.86	6.56	155.76
$(R/R_\odot)_{obs}$	5.2	2.6	
$(R/R_\odot)_{thr}$	5.0	3.2	1.9
$M_V/M_{V\odot}$	−2.4	−0.3	+1.5
Spectral type	B 2	B 7	A 3

If the system really satisfies the mass-radius relation for main sequence stars, the very good agreement between the radii computed from the masses and those observed gives an indirect confirmation about the values of the masses obtained by us.

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