THE SPECTROGRAPHIC ORBIT OF THE COMPANION TO RIGEL*

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ABSTRACT

The orbit of the companion of Rigel has been determined from eighteen spectrograms with a dispersion of 10 A/mm. This orbit differs little from a circle. The period is 9.860 days; the ratio of the masses of the two components, $m_2/m_1 = 0.767$; $(a_1 + a_2) \sin i = 7.771 \times 10^6$ km; and the center of mass velocity, $\gamma = +19.1$ km/sec.

No satisfactory reconciliation of the double-star observations with the spectrographic orbit seems possible at present.

The difference between the systemic velocity of the companion and the velocity of Rigel itself cannot be precisely stated but probably does not exceed 4 km/sec.

The system of Rigel is composed of star A and a companion (here called B) distant 9″.5, in position angle 201°. Their visual magnitudes are 0.34 and 6.67, respectively. No certain change in relative position has been observed in one hundred years. This fact, together with the appreciable proper motion of Rigel, is considered by S. W. Burnham[1] as evidence that Rigel and companion form a physical system.

Spectrograms of B taken in 1912, 1913, and 1934–1936 at Mount Wilson (dispersion 35 A/mm at $H\gamma$) indicated a variable radial velocity, but no satisfactory period could be obtained.

The reason for this became apparent when, in 1937, spectrograms were obtained with the coudé grating-spectrograph (second order) and 32-inch Schmidt camera. The higher dispersion—10 A/mm—clearly showed that lines from the spectra of two components are present. The difficulty with the low-dispersion plates had, therefore, been that the component lines were almost always blended. Altogether, eighteen coudé spectrograms (Table 1) have been obtained, eleven of which show satisfactory lines of the components, both of which are of spectral class B9. Although fast and relatively coarse-grained plates had to be used, numerous lines of *H*, *He* I, *Mg* II, *Si* II, *C* II, and *Ca* II were measurable in the primary spectrum. The secondary spectrum, although only slightly fainter than the primary, showed fewer lines, λ 4481 being by far the best for measurement.

These velocities, when brought to one epoch with a period of 9.860 days, are about equally divided between the two phase-intervals during which component velocities can be measured and are fairly well distributed over these intervals. More velocities would, of course, be desirable, but another observing season, at least, would be required to add a significant number. It has therefore been decided to publish an orbit based on the data in Table 1.

The period of 9.860 days is considered to be substantially correct, since it satisfactorily assembles the velocities over an interval of four years or during more than one hundred and fifty orbital revolutions. The other elements of the primary have been obtained by comparing the plotted observations with typical velocity-curves. The elements e, ω, and T are not well determined because there are too few velocities, the probable errors are fairly large, and, when the velocities are near the γ-axis, the lines of the component stars blend and do not furnish separate velocities. A circular orbit may perhaps serve as well as the orbit whose elements appear in Table 2.

The velocities of Table 1 are plotted in Figure 1 together with the velocity-curve of the primary. The velocities of the two components, measured upon eleven of the spectro-

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[1] *General Catalogue of Double Stars,* **2,** 411, 1906.

grams, yield another determination of the systemic velocity and also the ratio of the masses of the two components. The graphical method suggested by Olin C. Wilson[2] gives

TABLE 1

VELOCITIES OF RIGEL B

Plate	JD*	Phase	Velocity (Km/Sec)	
			Prim.	Sec.
Coudé 1535	2428829.994	5d318	+ 0.4	+56.2
1804	9181.035	1.399	+29.0	
1806	81.942	2.306	+23.2	
2211	9626.733	3.397	+ 2.2	+44.3
2216	27.814	4.478	− 2.5	+48.3
2221	28.756	5.420	− 1.1	+51.3
2232	48.635	5.579	− 2.4	+55.5
2237	48.844	5.788	− 1.8	+44.1
2249	57.694	4.778	− 2.5	+55.0
2297	9713.642	1.566	+28.7	
2430	9916.011	6.735	+16.9	
2436	17.012	7.736	+27.0	
2442	18.986	9.710	+52.9	−16.9
2446	20.008	0.872	+39.3	− 3.7
2502	2430036.743	9.147	+43.0	....
2613	244.006	9.350	+48.0	....
2617	274.992	0.896	+37.8	− 5.3
2691	333.823	0.567	+40.9	− 8.2

* The decimal is reckoned from noon G.M.T.

TABLE 2

ELEMENTS OF RIGEL B

Period	P	9d860
Periastron passage	T	JD 2429633.196 G.M.T.
Angle of periastron	ω	10°
Eccentricity	e	0.1
Semiamplitudes of velocity variation	K_1	25.0 km/sec
	K_2	32.6 km/sec
Systemic velocity	γ	+19.1 km/sec
	$a_1 \sin i$	3.373×10^6 km
	$a_2 \sin i$	4.398×10^6 km
	$m_1 \sin^3 i$	0.1134⊙
	$m_2 \sin^3 i$	0.0837⊙
	$\frac{m_2}{m_1}$	0.767

$\gamma = +20.5$ km/sec and $m_2/m_1 = 0.767$. This value of γ is 1.4 km/sec larger than that in Table 2. $K_2 = 32.6$ km/sec follows from the above mass ratio and K_1 of Table 2.

The mean distance and mass functions are in Table 2. The smallest value of the distance of the centers, $a_1 + a_2$ (for $i = 90°$) is 7.771×10^6 km. There seems to be no evi-

[2] *Mt. W. Contr.*, No. 640; *Ap. J.*, **93**, 29, 1941.

dence of variability in the light of B, and hence it may be concluded that i is not close to 90°. Although the mass-luminosity relation might be assumed and i derived thereby, this is mere speculation; it would be much more to the point to be able to derive independently a value for i and thus contribute new evidence on the mass-luminosity relation.

Burnham[1] has made the following interesting comments about the companion of Rigel, which he calls BC:

> In 1889 and 1890 it [the companion of Rigel] was certainly single with the 36-inch, with the highest powers under the very best conditions. If the distance had been as much as 0″05, it would have been noticed on some of these occasions with the large refractor. At this time it seemed at least possible that the observed elongation was not real and that it was not double after all. Later the duplicity was fully confirmed by Aitken and Hussey with the 36-inch refractor at Mount Hamilton. Since that time these observers, at my special request, have examined this star at frequent intervals. The distance is probably always under 0″2 and apparently this lasts but a short time. The components are so nearly equal that the quadrants given by the different observers have no significance and all are subject to a correction of 180°. That this pair is in very rapid motion cannot be doubted and the period may be shorter than that of any known pair.

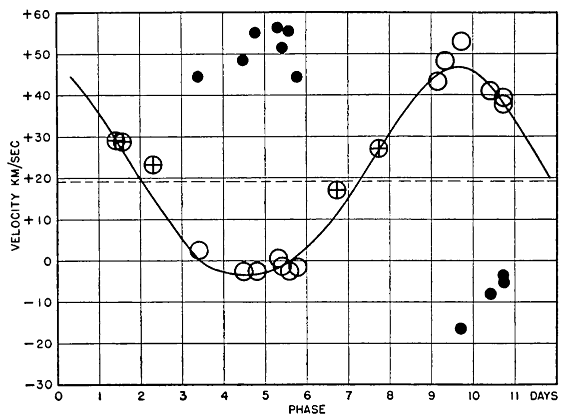

FIG. 1.—Radial velocities of the companion to Rigel (Table 1). Circles indicate the primary; dots, the secondary. The velocity-curve of the primary is that given by the elements of Table 2. The velocity of the system is shown by the broken horizontal line. Phases are reckoned from periastron.

To this statement may be added these remarks by R. G. Aitken: "I have no hesitation in stating that the star was certainly double in 1898–99 and in 1911. The measures in January, 1903, I think are also reliable."[3] His measures range from a separation of 0″18–0″12 in 1898–1899 to 0″09–0″05 in 1903.

These observations naturally raise the question whether the visual pair and the spectroscopic binary are identical. This seems quite untenable, for a separation of the two components of the visual double even as large as 0″1 and a reasonable parallax of Rigel cannot be reconciled with the values of $a_1 \sin i$ and $a_2 \sin i$ without making i exceedingly small and, therefore, m_1 and m_2 far larger than can possibly be admitted.

Of course, it is possible to assume that Rigel's companion is triple, composed of the spectroscopic binary and another star. This, however, would require that the third star be considerably fainter than either component of the spectroscopic binary. This is contrary to the evidence of the double-star observers who have found the two visual components to be equal. Furthermore, the value of γ for the spectroscopic binary would then be expected to undergo changes as the binary and the third star revolved around

[3] *Pub. Lick Obs.*, 12, 39, 1914.

their common center of mass. If Burnham's conclusion concerning a very short period is correct, this change in γ should manifest itself in the time covered by our observations. But neither the coudé velocities nor the earlier low-dispersion velocities show any certain variation in γ. The double-star and spectroscopic observations of Rigel's companion are still to be reconciled.

As has been stated, Burnham considered the relative fixity of A and B, together with the proper motion of A, as evidence that the stars form a physical system. It would be of interest to know how the systemic velocity of B and the velocity of A compare.

The velocity of Rigel according to the catalogue of radial velocities by J. H. Moore[4] is +23.6 km/sec—a value 4.5 km/sec larger than the systemic velocity of the companion, B. Other comparisons are afforded by twenty-two spectrograms photographed at Mount Wilson with a dispersion of 2.9 A/mm on Cramer Contrast plates. The following mean velocities have been obtained:

Lines	Km/Sec
H	+22.9
He	+20.0
Si II, *C* II, *Fe* II, *Mg* II	+17.0

The mean for *H* is in good agreement with the catalogue value. But O. Struve[5] found the absorption $H\alpha$ line to be accompanied by emission and shifted about an angstrom to the violet. Mount Wilson observations show that the emission varies and that the absorption line $H\alpha$ is displaced through a considerable range on various plates. Although emission has not been detected with other *H* lines, it is conceivable that their positions may be affected. Hence these lines may not furnish the true radial velocity of Rigel.

The mean for *He* rests upon measures of the wide and shallow *He* lines, which, however, are measurable with fair precision on these high-dispersion plates.

Since the lines of the ionized elements are relatively sharp, they probably yield the most reliable value for the radial velocity.

The systemic velocity of B is within 2 km/sec of the mean velocity of Rigel, whether derived from the lines of *He* or from those of the ionized elements. Thus Burnham's conclusion that A and B form a physical pair is confirmed.

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[4] *Pub. Lick Obs.*, **18**, 41, 1932.

[5] *Ap. J.*, **77**, 67, 226, 1933.