

THE ORBIT OF THE SPECTROSCOPIC BINARY 43 θ^2 ORIONIS

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ABSTRACT

The period and the orbital elements of the spectroscopic binary 43 θ^2 Orionis were derived from the measurements of thirty-nine plates obtained with the Bruce spectrograph of the Yerkes Observatory. Within an interval of twenty years there seems to have been no appreciable change in the period, due to the resistance of the nebula. The velocities obtained from the emission lines of hydrogen and from the dark K line of *Ca* do not participate in the periodic shifts of the other lines. The mean velocity of these lines (emission and *Ca* K) is nearly the same as that of the nebula, and justifies the assumption that these lines are produced by the nebula. The velocity of the center of mass of the star is more than 20 km/sec. larger. The Orion nebula, as well as the calcium gases producing the stationary *Ca* line K, are nearly at rest with respect to the system of stars from which the motion of the solar system has been computed.

The orbit.— θ^2 Orionis ($\alpha = 5^h 30^m 5$; $\delta = -5^\circ 29'$ [1900]; photographic mag., 4.95, spectral type, B1n) is one of the brighter stars located in the Orion nebula. Its Bond number is 685, and its position with respect to the trapezium is about 6^s following and $100''$ south. The determination of the orbit of this star is especially interesting in connection with the question of a possible effect of the nebulous matter upon the period and upon other elements of the orbit.

The variable radial velocity of this star was announced by Messrs. Edwin B. Frost and Walter S. Adams, having been determined from four spectrograms taken in 1903 and 1904.¹ They found a range in velocity of 140 km/sec.

Further observations of θ^2 Orionis were made in 1919 by Dr. F. Henroteau at the Dominion Observatory in Ottawa.²

A short note by the writer on the bright lines of θ^2 Orionis was based on several observations made with the Bruce spectrograph of the Yerkes Observatory in 1922 and 1923.³

¹ *Astrophysical Journal*, 19, 153, 1904.

² *Publications of the Dominion Observatory*, Ottawa, 5, p. 19.

³ *Astrophysical Journal*, 58, 309, 1923.

The observations were continued at the Yerkes Observatory from October, 1923, until February, 1924, chiefly by Professor S. B. Barrett and the writer. In all, thirty-nine spectrograms could be measured for the determination of radial velocities.

The lines chiefly used for measurement, together with their wave-lengths and approximate widths, are collected in Table I.

TABLE I

STELLAR LINES			COMPARISON LINES			
Element	λ	Width	Element	λ	Element	λ
<i>Ca</i> (K).....	3933.825	0.5	<i>Ti</i>	3930.022	<i>Ti</i>	4468.663
<i>He</i>	4026.352	2.2	<i>Fe</i>	3969.413	<i>Ti</i>	4481.435
<i>Hδ.....</i>	4101.890	3.9	<i>Fe</i>	4005.408	<i>Ti</i>	4682.088
<i>He</i>	4143.928	2.2	<i>Ti</i>	4028.497	<i>Ti</i>	4856.203
<i>Hγ.....</i>	4340.634	5.0	<i>Ti</i>	4071.908	<i>Ti</i>	4885.264
<i>He</i>	4388.100	3.2	<i>Ti</i>	4132.235		
<i>He</i>	4471.676	3.2	<i>Fe</i>	4144.038		
<i>He</i>	4685.898	3.1	<i>Ti</i>	4338.084		
<i>Hβ.....</i>	4861.527	8.0	<i>Fe</i>	4383.720		

It will be noticed that all stellar lines, with the exception of *Ca* K (λ 3934), are very wide. Therefore, as was already pointed out by Professors Frost and Adams, the settings are difficult, and the internal agreement of the measurement is necessarily low. The hydrogen lines are complicated by the presence of narrow emission lines, and are therefore not suitable for accurate measurement. Although eight or nine stellar lines were measured on most of the spectrograms, it was found advisable to use for the orbit only the two helium lines λ 4472 and λ 4686. The other helium lines, as well as the hydrogen absorption lines, give substantially the same velocities, but their diffuse character makes an accurate measurement almost impossible. The *Ca* K line represents the typical case of a stationary calcium line, and the velocities derived from it had to be excluded from the orbit. They are discussed separately on page 165.

Table II contains the data of observation, together with the velocities resulting from the lines λ 4472 and λ 4686. Most of the plates were measured twice, some of them even three and four times. The weights were assumed proportional to the product of the number of times that a given plate was measured and one of the numbers,

1.0, 0.8, and 0.5, respectively, for plates designated as "good," "fair," or "poor." The first four plates were measured by E. B. Frost and W. S. Adams. The other plates were all measured by the writer. Hartmann-Cornu's dispersion formulae were computed for each spectrogram separately.

TABLE II

Plate	Date	G.M.T.	Observer	J.D. Red. to Epoch 2423700 +	Velocity	Weight
IB 240.....	1903, Dec. 31	14 ^h 38 ^m	F, S	56.644	+ 87.1	3.0
247.....	1904, Jan. 2	14 15	A, S	58.628	84.6	1.6
258.....	1904, Jan. 23	12 49	A, F, S	58.539	+ 42.5	3.2
273.....	1904, Jan. 29	13 13	F, S	43.527	- 48.2	2.0
517.....	1905, Feb. 13	14 30	F, S	46.058	+ 9.5	0.2
1302.....	1907, Dec. 30	16 58	Fox, S	44.711	- 21.9	0.5
1313.....	1908, Jan. 7	15 46	L, S	52.661	+ 79.4	0.8
1352.....	1908, Jan. 20	14 15	B, S	44.569	- 11.3	0.5
1405.....	1908, Feb. 3	14 34	B, S	58.582	+ 8.5	1.0
6423/1...	1922, Feb. 20	13 47	B, S	58.473	81.7	0.8
6423/2...	1922, Feb. 20	14 27	B, S	58.501	91.1	0.8
6788.....	1923, Mar. 2	14 34	B, S	54.984	78.5	1.6
6794.....	1923, Mar. 7	15 23	B, S	60.108	28.5	2.0
6810.....	1923, Mar. 16	14 00	σ , S	47.931	25.4	1.0
6824.....	1923, Mar. 23	14 12	B, S	54.980	96.1	3.0
6831.....	1923, Mar. 26	14 02	B, S	57.933	+ 59.7	1.6
6840.....	1923, Mar. 30	13 51	B, S	61.925	- 29.9	1.0
IR 7146.....	1923, Oct. 2	22 39	B, S	38.002	+ 35.6	0.5
7161.....	1923, Oct. 7	21 33	B, S	42.956	- 60.4	1.6
7167.....	1923, Oct. 14	21 03	B, S	49.955	+ 61.6	1.6
7173.....	1923, Oct. 20	20 37	σ , S	55.917	100.1	1.0
7183.....	1923, Oct. 21	21 41	B, S	56.961	85.2	1.0
7191.....	1923, Oct. 22	20 58	σ , S	57.932	64.1	2.0
7201.....	1923, Nov. 6	19 33	σ , S	51.844	112.1	1.0
7210.....	1923, Nov. 10	20 04	B, σ , S	55.865	+119.0	1.6
7227.....	1923, Nov. 17	19 48	B, σ , S	41.825	- 82.6	2.0
7236.....	1923, Dec. 2	17.10	B, S	56.715	+111.2	1.6
7248.....	1923, Dec. 15	18 42	σ , S	48.750	51.0	2.0
7265.....	1924, Jan. 5	16 10	σ , S	48.616	70.6	2.0
7268.....	1924, Jan. 6	16 38	B, S	49.635	71.6	1.0
7274.....	1924, Jan. 12	14 23	σ , S	55.541	102.8	2.0
7276.....	1924, Jan. 12	17.50	σ , S	55.685	+105.6	2.0
7283.....	1924, Jan. 19	14 14	B, σ , S	41.506	- 74.8	1.0
7285.....	1924, Jan. 19	17.38	σ , S	41.648	64.1	1.0
7291.....	1924, Jan. 20	14 51	B, σ , S	42.532	- 92.6	1.6
7297.....	1924, Jan. 26	13 17	B, σ , S	48.466	+ 58.4	2.0
7299.....	1924, Jan. 26	16 08	σ , S	48.585	+ 73.4	1.0
7308.....	1924, Feb. 10	13 04	B, S	42.428	- 95.5	1.0
7310.....	1924, Feb. 10	16 14	B, S	42.560	- 84.4	1.0

In the column "Observer" the following designations are used: F=E. B. Frost; A=W. S. Adams; Fox=Philip Fox; L=O. J. Lee; B=S. B. Barrett; σ =Otto Struve; S=F. R. Sullivan.

On account of the inaccuracy of the individual measures, the plates were grouped and the following thirteen normal velocities were formed.

TABLE III

J.D.	Velocity	Weight	O.-C.*	O.-C.†
3741.660.....	- 76.0	0.5	+13.2	+ 0.1
3742.619.....	81.7	0.7	+ 0.2	- 3.6
3744.269.....	- 37.6	.4	- 7.0	- 4.6
3746.992.....	+ 20.1	0.2	17.5	- 8.5
3748.604.....	61.9	1.0	1.2	+ 2.0
3749.785.....	64.3	0.3	-12.8	-13.3
3752.252.....	97.6	.2	+ 2.9	- 3.4
3754.962.....	110.0	.6	10.5	+ 3.3
3755.752.....	107.2	.9	10.5	+ 3.8
3756.773.....	93.6	.8	+ 3.7	- 1.3
3757.933.....	62.2	0.5	-13.6	-15.7
3758.545.....	55.6	1.0	- 8.7	+ 6.2
3760.325.....	+ 12.7	0.5	+ 7.9	+ 6.3

* From the preliminary elements.

† From the final elements.

After a number of attempts the period was found to be

$$P = 21.029 \text{ days.}$$

There seems to have been no appreciable change in the period within the past twenty years for which observations are available. During this interval of time the binary has completed 350 revolutions.

Preliminary elements were determined by the graphical method of Lehmann-Filhés. The residuals appeared to be rather large, and a least-squares solution was carried through with the use of Schlesinger's tables and formulae.¹ The results are collected below. Further refinements did not seem necessary on account of the unavoidable inaccuracy of the measurements.

TABLE IV
THE ELEMENTS

	Preliminary	Corrections	Final	Probable Errors
γ	+35.7 km/sec.	(+1.1)	+36.8 km/sec.	
τ	21 ^d 029	Adopted	21 ^d 029	
e	0.35	-0.08	0.27	± 0.02
K	95.0 km/sec.	-1.3 km/sec.	93.7 km/sec.	± 3.6 km/sec.
ω	157 ^o 2	-2 ^o 5	154 ^o 7	$\pm 3o2$
T	-2423741 ^d 300	+0 ^d 062	3741 ^d 362	$\pm 0d314$
$a \sin i$	27,000,000 km		27,000,000 km	

¹ Publications of the Allegheny Observatory, 1, 33.

The probable error of one normal velocity of weight unity is ± 4.1 km/sec. The value of $[p\Delta^2]$ was reduced from 595.8 to 292.3. The velocity-curve below represents the corrected orbit.

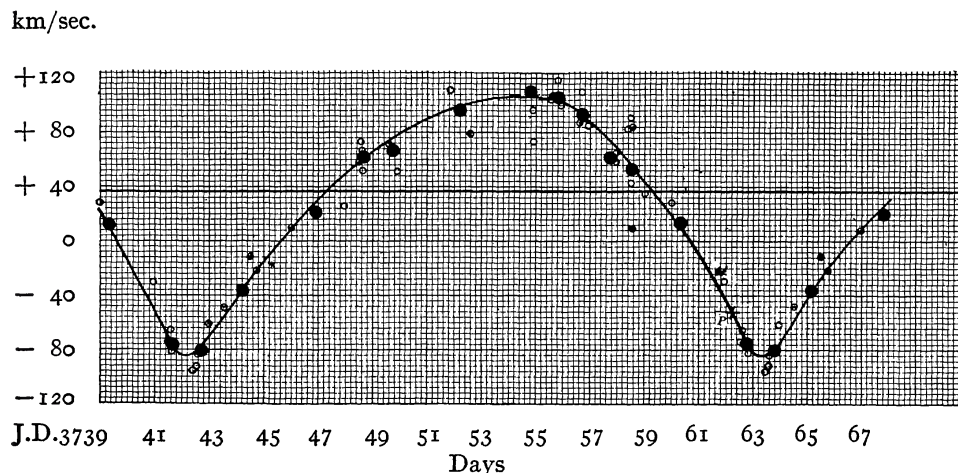


FIG. 1.—Velocity curve of 43 θ^2 Orionis

- Velocities determined in 1922-1924
- ⊙ Velocities determined in 1903-1908
- Normal velocities

The value of K is decidedly greater than for an average binary having a period of twenty-one days. A glance at the curve on page 170 of this issue, giving the relation between P and K for 144 known spectroscopic binaries, shows that an average binary, having a period of twenty-one days, should have a value of K of the order of 45 km/sec. In the case of θ^2 Orionis, K is more than twice as large. This divergence cannot be explained as a result of inclination only, since in an average spectroscopic binary this inclination is such that $(\sin^3 i)_{av.} = 0.65$. Therefore, even under the assumption that $i = 90^\circ$, K cannot amount to as much as 94 km/sec. It is also improbable that the mass ratio in this star is much larger than the average ($m_2/m_1 = 0.8$). Only lines due to the stronger component of the binary (m_1) appear on our plates. This makes it probable that $m_2 < m_1$ and, accordingly, the probability is small that $m_2/m_1 > 0.8$. The large value of K must evidently be attributed to a large total mass of the star, which may easily amount to as much as ten to twenty times the mass of the sun.

The bright lines.—On our early plates emission lines were found only in the case of $H\beta$. Later plates, especially those taken with the new camera lens of the Bruce spectrograph, designated by IR, show that emission lines appear also occasionally on $H\gamma$, and in one or two instances also on $H\delta$. These emission lines are not always visible, and the variability of their intensity was pointed out last year.¹ It can now be shown that this variability is purely an effect of background. The bright lines—black on the plates—are visible only when they are superposed over the absorption lines due to the star. Since they do not participate in the periodic shifts of the absorption lines, but show a stationary velocity, they are sometimes superposed over the background of the continuous spectrum, on account of the large amplitude of the velocity variation of the absorption lines. When this happens, they are not visible, because the contrast is not sufficient to bring them out on a photograph. However, their presence is clearly demonstrated by the fact that they vitiate the velocities obtained from the hydrogen absorption lines, making the measured velocities greater near maximum and smaller near minimum. There seems to be no doubt that the bright lines are due to the Orion nebula. The mean velocity obtained from all plates on which bright $H\beta$ and $H\gamma$ had been measured is $+17.6$ km/sec. A plate of the Orion nebula, taken near θ^2 Orionis, gave a velocity of $+16.5$ km/sec. This agreement is as good as can be expected. The nebular lines do not appear on our plates of θ^2 Orionis. From a comparison with the spectrum of θ^1 Orionis, where $Nu \lambda 5007$ is decidedly stronger than $H\beta$, we should expect to see the nebulum line in the spectrum of θ^2 Orionis, even though it is superposed on the continuous spectrum of the star. Its absence is apparently due to the weakening of the nebular lines in the outer regions of the nebula, as compared with the hydrogen lines. This effect was first noticed by W. W. Campbell² and later confirmed by C. Runge.³

Direct photographs of the Orion nebula show a small condensation around θ^2 Orionis, in which the star is placed somewhat eccentrically.

¹ *Astrophysical Journal*, 58, 139, 1923. ² *Ibid.*, 9, 312, 1899.

³ *Ibid.*, 8, 32, 1898; *Astronomische Nachrichten*, 145, 227, 1897.

The Ca line K.—The velocities obtained from the line λ 3934 were reduced with the same period as that found from the other lines, and plotted together with the velocities from the emission lines of hydrogen. There appears to be no connection between the period of 21.029 days and the velocities of either the line K or the emission lines. However, some of the plates give values for the calcium lines which deviate considerably from the average, and remeasurement did not remove these discrepancies. Table V contains the results of the measurements.

TABLE V

Plate	Vel.	Plate	Vel.	Plate	Vel.
6794.....	+15.2	7227.....	+24.7	7283.....	+25.5
6810.....	15.5	7248.....	8.9	7285.....	+13.4
6824.....	45.2	7265.....	15.2	7291.....	— 3.3
6831.....	10.3	7268.....	9.4	7297.....	— 1.9
6840.....	24.6	7274.....	0.7	7299.....	+ 1.6
7183.....	+ 5.3	7276.....	+10.2	7308.....	+ 7.7

The mean of these velocities is +12.7 km/sec., which is very close to the velocity of the Orion nebula in this region. The difference between these two velocities lies within the errors of measurement. Therefore, the writer is inclined to believe that the calcium atmosphere surrounding the star is the Orion nebula. Whether or not the variations illustrated in Table V are real cannot be decided from the material at hand. On most of our plates the region around λ 3934 is somewhat underexposed, and this may produce errors in the interpretation of the line. On the other hand, all plates indicated by the letters "IR" were taken with the new camera lens of the Bruce spectrograph (designed by Dr. F. E. Ross), which gives best definition near λ 3900, the definition being almost as good in the region of λ 4800 and only a little less sharp in the center of the plate, near λ 4500.

The velocity of the center of mass of the star is +37 km/sec., which is quite different from the velocities of the nebula (+16.5 km/sec.), the emission lines of hydrogen (+17.6 km/sec.), and the sharp calcium line (+12.7 km/sec.).

In connection with Dr. J. S. Plaskett's recent paper on stationary calcium clouds in space,¹ it may be stated that the component of the solar motion in the direction of the Orion nebula amounts to about 18 km/sec. Therefore, the various velocities corrected for the motion of the solar system would be as follows:

TABLE VI

θ^2 Orionis (center of mass).....	+ 19 km/sec.
Hydrogen emission lines.....	$\pm$ 0 km/sec.
Orion nebula.....	- 2 km/sec.
Calcium K (stationary)	- 5 km/sec.

YERKES OBSERVATORY

February 19, 1924

¹ *Monthly Notices of the Royal Astronomical Society*, **84**, 80, 1923.