RADIAL VELOCITIES OF THE FOUR STARS OF THE TRAPEZIUM IN ORION*

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ABSTRACT

Seventy-six spectrograms of the stars HD 37020, 37021, 37022, and 37023 have been obtained at the McDonald Observatory. The measures indicate that HD 37021 = BM Orionis has the following elements: $P = 6.50$ days, $\gamma = +24.0$ km/sec, $K = 81$ km/sec, $e = 0.14$, $\omega = 194°$, $T =$ JD 2430787.86. The other three stars have relatively small ranges in velocity. The mean velocities of these four stars and of θ^2 Orionis = HD 37041 exceed the velocity of the Orion nebula by 15.0 km/sec. This may be due to a gravitational red shift or to a systematic motion of the four stars through the nebula.

All four stars of the Trapezium have been announced as spectroscopic binaries. Unfortunately, the spectra of these stars are among the most difficult to measure. Not only are their absorption lines diffuse and weak, but they are complicated by the emission lines of the Orion nebula. Hence, the precision of the measurements is low, and no period has been published for any of them. The faintest star of the group, HD 37021, or star B of the multiple object θ^1 Orionis, is the known variable BM Orionis. This fact adds to the interest of the group. The spectrograms used in this work were obtained at the McDonald Observatory with the Cassegrain quartz spectrograph, equipped with a 500-mm camera. The dispersion was 40 A/mm at λ 3933. The instrument possesses a slight advantage over other spectrographs used elsewhere for the Trapezium stars: it is efficient in the ultraviolet region, so that we were always able to measure *He* I 3820 and often other violet and ultraviolet lines which are not appreciably distorted by nebular emission lines. However, these lines were not sufficient, and we have also used the other *He* I lines, λλ 4009, 4026, 4120, 4144, 4388, 4472, and occasionally a few other lines.

The purpose of the investigation was to establish, as accurately as is possible, the mean velocities of the four stars in order to find whether they agree with the velocity of the Orion nebula. The individual measurements are listed in Table 1. Stars HD 37020 and HD 37023 were measured by both authors. Star HD 37021 was measured only by Struve, and star HD 37022 was measured only by Titus. The number of lines used for each entry, when greater than one, is given just preceding the radial velocity. The scatter between the two measures is large but is fully accounted for by the extreme difficulty of the settings. The observed scatter of the mean stellar velocities of the two observers is small for HD 37020 and HD 37023. Although these measurements do not disprove the possibility that these stars are binaries, it is safe to say that their ranges in velocity are small. The mean values of all plates for each star should, therefore, give a good approximation to the velocity of the system if they are really binaries. Titus' measures of HD 37022 also show a relatively small range. No attempt has been made to derive periods for these stars, and the task would probably be hopeless without a very large amount of additional material. But Struve's measures of HD 37021—the most difficult of the four spectra—not only confirm the large range in velocity discovered by Plaskett and Pearce[2]

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[1] Dr. Titus left Yerkes Observatory on a leave of absence for war research before this paper was finished.

[2] *Pub. Dom. Ap. Obs.* Victoria, **6**, 34, 1931.

TABLE 1

RADIAL VELOCITIES IN KM/SEC

HD 37020

Date	U.T.	Stars (O. S.)	Star (J. T.)	*Ca* II (O. S.)	*Ca* II (J. T.)	Nebula (J. T.)
1943 Mar. 4.....	2:03	7 + 19	5 +15	+19	+ 4	3 +10
4.....	5:48	4 + 5	.....	.....	.....	.....
6.....	2:02	6 + 27	7 +23	− 2	.....	2 + 5
6.....	3:28	8 + 16	8 +17	+37	+28	4 +12
7.....	2:19	8 + 49	7 +40	−12	− 5	5 +14
8.....	2:28	9 + 41	6 +38	+25	+36	2 +17
9.....	1:33	8 + 43	7 +42	+37	.....	4 +23
10.....	1:29	7 + 46	6 +36	+ 8	.....	4 +15
13.....	4:24	6 + 30	7 +25	+ 6	− 5	3 +10
15.....	3:53	8 + 36	8 +43	+24	+ 7	4 +15
18.....	2:42	6 + 34	7 +40	− 3	− 2	5 +14
21.....	4:39	5 + 40	7 +40	.....	.....	5 +18
27.....	4:16	7 + 35	7 +52	+ 4	+ 1	5 +18
28.....	2:02	7 + 36	8 +36	−23	+ 1	3 +20
29.....	2:13	6 + 24	7 +21	+13	+ 8	3 − 1
Apr. 10.....	3:22	8 + 42	8 +38	+30	.....	4 +21
11.....	2:37	8 + 49	7 +49	− 6	+ 1	5 +23
12.....	3:29	8 + 70	8 +60	+34	+31	5 +21
13.....	2:40	8 + 21	6 +29	.....	.....	5 + 8
17.....	2:35	7 + 35	7 +37	.....	+ 2	3 +15
18.....	3:01	7 + 29	8 +27	−16	.....	5 + 3

HD 37021

Date	U.T.	Star (O. S.)	*Ca* II (O. S.)	Nebula (O. S.)	Phase	
1943 Mar. 4.....	1:31	4 − 72	.....	4 +22	0.00	
4.....	5:15	5 − 65	−12	4 +19	0.16	
5.....	2:34	5 − 9	+49	4 + 8	1.05	
6.....	1:43	4 + 2	.....	4 +14	2.01	
6.....	3:06	5 + 43	.....	4 +15	2.07	
7.....	1:49	4 +111	+25	4 +24	3.02	
8.....	2:00	3 + 88	.....	3 +32	4.02	
9.....	2:06	2 − 40	.....	4 +25	5.03	
9.....	2:35	3 + 42	+13	4 +23	5.05	
10.....	2:04	4 − 57	.....	4 +17	6.03	
10.....	2:40	5 − 45	+31	4 +18	6.05	
13.....	3:58	4 + 83	.....	4 +14	2.61	
13.....	5:06	3 +117	.....	4 +23	2.65	
14.....	4:40	5 + 88	+ 6	4 +14	3.63	
15.....	3:20	3 + 64	.....	4 +14	4.58	
18.....	3:54	4 − 22	.....	4 +19	1.10	
21.....	3:58	3 + 78	+16	4 + 8	4.11	
26.....	3:43	4 + 74	+37	4 +19	2.59	
27.....	3:36	4 + 93	.....	4 +23	3.59	
28.....	2:36	5 + 54	+44	4 +13	4.55	
29.....	2:55	5 − 54	− 8	4 +12	5.56	
Apr. 10.....	2:42	5 + 61	+46	4 +15	4.55	
12.....	2:50	5 − 68	+16	4 +14	0.06	

TABLE 1—*Continued*

HD 37022

Date	U.T.	Star (J. T.)	*Ca* II (J. T.)	Nebula (J. T.)		
1943 Mar. 6	2:18	6 + 14	− 9	−19		
7	1:22	7 + 41	.....	−13		
9	1:21	6 + 41	+34	+10		
10	1:20	8 + 30	+19	+19		
13	4:42	8 + 42	+19	+10		
28	3:22	6 + 23	+ 5	+ 2		
29	2:03	7 + 54	.....	− 9		
Apr. 10	3:56	5 + 39	+22	−24		
11	2:15	8 + 47	.....	+ 7		
12	3:58	5 + 51	.....	+ 4		
13	2:18	7 + 43	+16	+19		
17	2:20	8 + 31	.....	+ 8		
18	2:15	10 + 41	+33	− 2		
18	3:21	6 + 27	+44	− 3		

HD 37023

Date	U.T.	Star (O. S.)	Star (J. T.)	*Ca* II (O. S.)	*Ca* II (J. T.)	Nebula (J. T.)
1943 Mar. 4	2:04	6 + 32	6 +31	+25	.....	4 +28
6	2:12	7 + 34	6 +29	+40	+37	1 +36
6	3:38	6 + 49	5 +30	+31	+19	3 +21
7	2:32	7 + 36	6 +41	+34	+22	4 + 8
8	2:38	7 + 36	6 +31	+37	.....	3 +20
9	1:43	7 + 45	7 +42	+40	+31	3 +32
10	1:40	7 + 40	5 +30	+25	+16	3 +21
13	4:35	7 + 38	5 +24	+19	+22	4 + 8
15	4:10	7 + 38	6 +27	+16	+13	4 +18
18	3:06	7 + 41	7 +32	−14	.....	4 +15
21	4:58	7 + 48	7 +48	+13	.....	2 +18
28	3:10	7 + 42	6 +36	+ 7	+44	3 +14
29	2:29	7 + 40	7 +46	+14	+23	2 +23
Apr. 10	3:42	7 + 30	6 +18	+24	+ 6	4 +11
11	3:08	6 + 22	6 +15	+49	.....	5 +15
12	3:47	5 + 17	6 + 7	.....	.....	3 +30
13	3:13	6 + 27	5 +10	+16	.....	5 +9
18	2:32	7 + 33	7 +22	+32	+17	4 +11

at Victoria but establish beyond doubt that the period is approximately 6.50 days.[3] The phases in Table 1 were computed by setting the epoch of the first plate, JD 2430787.56, as zero. The velocity-curve is shown in Figure 1. In spite of the large scatter, the character of the curve is well established, and the elements derived from it by a graphical procedure are given in Table 2.

The variable star BM Orionis has been the subject of considerable controversy among astronomers. It has recently been regarded as an irregular variable, possibly of the kind

[3] At the Cincinnati meeting of the A.A.S., McLaughlin asked whether the period could be close to one day. Our observations do not exclude this, but the duration of the light minimum is reported to be 23.5 hours.

associated with nebulae.[4] But Hartwig[5] had announced in 1920 the value $P = 6.4754$ days, and there can now be little question that this period is identical with the one found spectroscopically. The photometric observations of this star are especially difficult, as has been shown by Parkhurst,[6] who was unable to find a variation in excess of a quarter of a magnitude on 103 photographs of the Orion nebula taken with the Yerkes 40-inch refractor. The last issue of the *Katalog und Ephemeriden Veränderlicher Sterne* by H. Schneller available to me (1940) lists BM Orionis as an Algol-type star with

$$\text{Minimum} = 2422717.342 + 6.47075E\,.$$

The light at maximum is given as 8.1 mag., and the depth of primary eclipse is 0.61 mag. The duration of this eclipse is 23.5 hours; there is no secondary minimum. Apparently no accurate light-curve has been published.

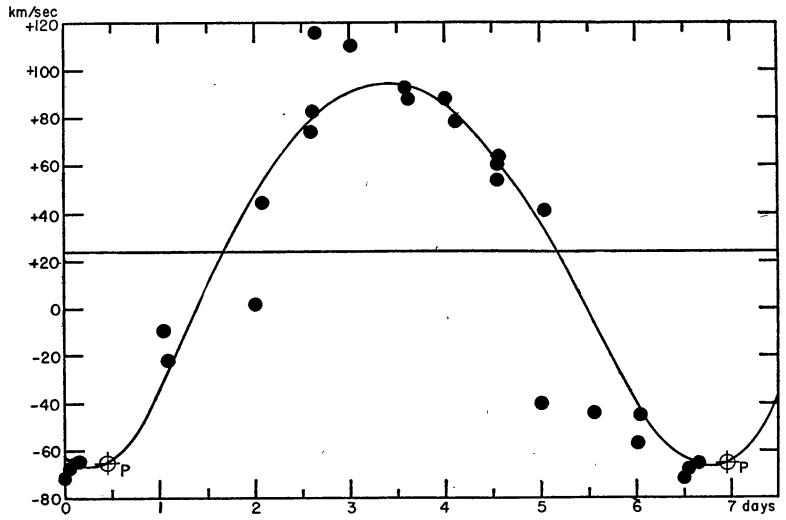

FIG. 1.—Velocity curve of HD 37021

TABLE 2

ORBITAL ELEMENTS OF HD 37021 = BM ORIONIS

$P = 6.50$ days	$T =$ JD 2430787.86 = phase 0.30 days
$\gamma = +24.0$ km/sec	$a \sin i = 7 \times 10^6$ km
$K = 81$ km/sec	$\dfrac{m_2^3}{(m_1 + m_2)^2} \sin^3 i = 0.35\odot$
$e = 0.14$	
$\omega = 194°$	

The summarized results of the radial velocity measurements are given in Table 3, where the star θ^2 Orionis = HD 37041 has been added from the recent orbit by Münch[7] and the earlier one by Struve.[8] The last column contains the stellar radial velocities of Moore's catalogue,[9] and the spectral types are those determined at Victoria.

The results shown in Table 3 are of great interest. The radial velocities of all five stars are greatly in excess of the radial velocities of the Orion nebula determined from

[4] C. and S. Gaposchkin, *Variable Stars*, pp. 30–31, 302–303, Cambridge, 1938.

[5] *Geschichte und Literatur der Veränderlichen Sterne*, **3**, 82, 1922.

[6] *Pop. Astr.*, **27**, 578, 1919; *Ap. J.*, **53**, 317, 1921.

[7] *Ap. J.*, **98**, 229, 1943. [8] *Ap. J.*, **60**, 159, 1924. [9] *Pub. Lick Obs.*, **18**, 46, 1932.

the same plates. The best available average velocity of the Orion nebula is +17.5 km/sec.[10] It is improbable that these stars are passing through the nebula and are not physically associated with it. The appearance of the Trapezium in the midst of a small hollow within the nebula would appear to rule this out. Hence it is possible that the systematic difference of

Stars *minus* Nebula = +15.0 km/sec

should be interpreted as a gravitational red shift. The masses of the five stars are probably very large, and there is no reason why they should not have a red shift similar to those of the massive Trumpler stars in clusters,[11] which range from +5 to +15 km/sec.

TABLE 3

RADIAL VELOCITIES OF STARS IN TRAPEZIUM (θ^1 AND θ^2 ORIONIS)

STAR	DESIGNATION	SP.	MAG.	RADIAL VELOCITIES									
				Star			Nebula			Interstellar *Ca* II			Moore Star
				V	P.E.	No.	*V*	P.E.	No.	*V*	P.E.	No.	
HD 37020.....	θ^1 Ori A	B2	6.8	+34.3	±1.9	21	+14.0	±1.0	20	+ 9.5	±2.1	18	+32 ± 4
HD 37021.....	θ^1 Ori B	B2	7.9	+24.0	.....	23	+17.6	±0.8	23	+22.0	±3.1	12	−24 ±18
HD 37022.....	θ^1 Ori C	O7*k*	5.4	+37.4	±2.0	14	+ 0.5	±2.3	14	+20.3	±2.9	9	+23.1± 1.8
HD 37023.....	θ^1 Ori D	B0	6.8	+32.4	±1.5	18	+18.8	±1.3	18	+23.0	±1.7	17	+27 ± 3
HD 37041.....	θ^2 Ori A	O9*k*	5.2	+34.5	±0.7	22	+17.6	.....	....	+18.9	±3.5	12	+36.8

It is suggestive that the smallest red shift is observed in the case of HD 37021—the faintest and presumably least massive star of the group—while the two largest red shifts occur in the two brightest stars. It is, of course, not possible to prove the physical connection of the Orion stars with the nebula, but the component of the solar motion in the direction of Orion is about 18 km. The nebula is, therefore, approximately at rest with respect to the solar system, while the stars show a systematic velocity of recession from the solar system of the order of 15 km/sec. If this amount is interpreted as an effect of galactic rotation, the corresponding distance of the group of stars would be about 1000 parsecs, which is probably not consistent with the distance of the Orion nebula. It should also be noted that the interstellar *Ca* II lines of the five stars in Table 3 give an average value of about +20 km/sec. Subtracting the solar motion, we obtain a residual motion of only +2 km/sec to be attributed to galactic rotation. Twice this amount, or +4 km/sec, might be expected for the galactic-rotation component of the five stars. But it is difficult to account for anything like +15 km/sec. Hence, the only two alternatives are gravitational red shift or a systematic motion of the stars through the nebula.

[10] J. H. Moore, *Pub. Lick Obs.*, **18**, 213, 1932.

[11] *Pub. A.S.P.*, **47**, 254, 1935.