ON THE ORBITS OF THE SPECTROSCOPIC BINARIES α ORIONIS AND α SCORPII

By JOSEPH LUNT

These two stars α Orionis and α Scorpii have the peculiarity of showing the smallest range of variation of radial velocity of any of the spectroscopic binaries for which orbits have been derived, the semi-amplitude of the velocity-curve being only 2.45 km per sec. in the case of α Orionis according to Bottlinger's elements,[1] and 2.12 km according to Halm's elements[2] in the case of α Scorpii. As these quantities are comparable with the accidental errors of the observations, it is of interest and importance to examine the evidence on which the orbits are based and to supplement it by measures of a large number of plates taken at the Cape, of which duplicate measures have, in most cases, been made by Halm and myself. It is desirable to call attention to the fact that in spite of the large number of determinations of velocity of these two stars which have been made, it is still necessary to continue the accumulation of material, as the orbits—particularly in the case of α Scorpii—are obviously in need of revision.

Ludendorff called Bottlinger's attention to the similarity of the orbits derived for these two stars, and the latter states that they are the only spectroscopic binaries of Class III*a* of which the elements are known.

The case of α Orionis is of further interest from the fact that Bottlinger has attempted to connect the variations of radial velocity with the variations of brightness of the star and suggests a relationship similar to that found to exist in the case of stars of the δ Cephei type, noting that the period and type of spectrum are very different.[3] Charles P. Olivier,[4] from a discussion of 293 observations of brightness extending over a period of nearly eleven

[1] *Astronomische Nachrichten*, **187**, 33, 1911.

[2] *Annals of the Cape Observatory*, **10**, Part III, 56*c*.

[3] *Astronomische Nachrichten*, **187**, 33, 1911.

[4] *Ibid.*, **194**, 81, 1913.

years, from 1901 to 1912, concluded that "it was quite impossible to find any regularities in the light-changes." On plotting his observations together with the velocity-determinations and theoretical velocity-curve, no connection appears to exist, and the observations negative the idea of a relationship similar to that found in the case of δ Cephei and other analogous stars.

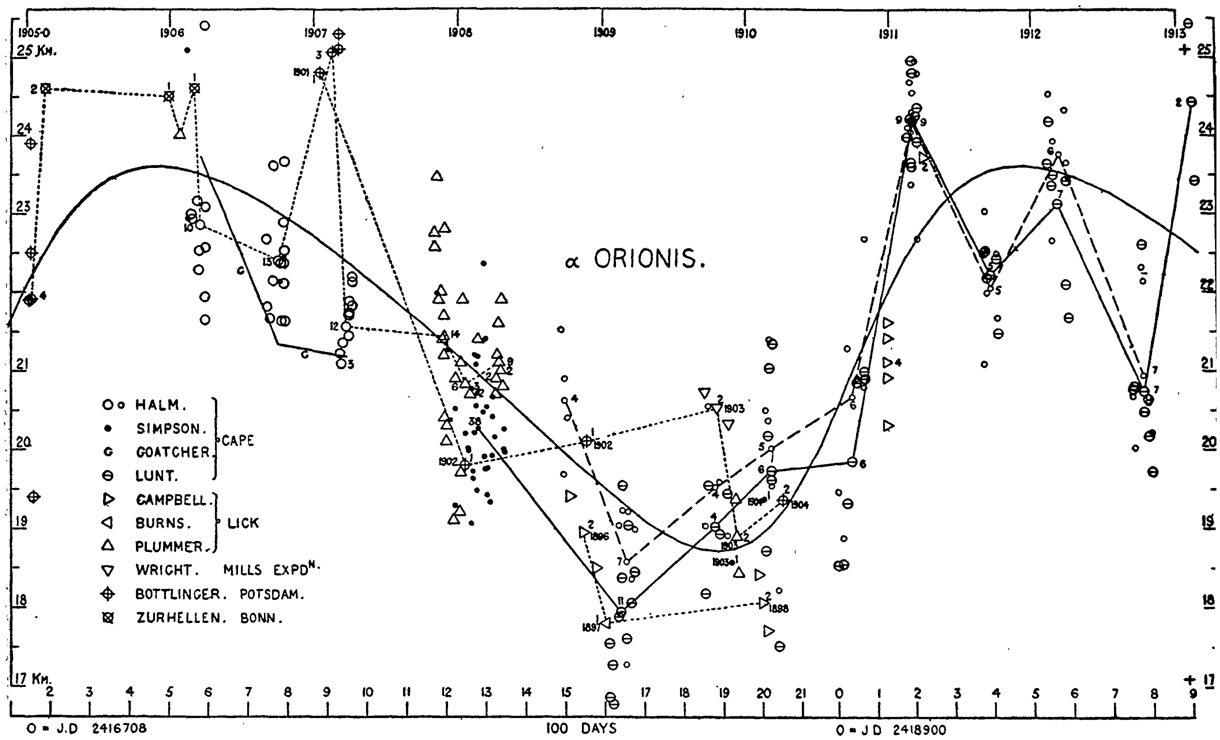

FIG. 1

In order to exhibit the facts as regards the determination of the orbits in a graphic manner, two charts have been prepared which clearly show the present position of the problem and indicate what further work is necessary in order to arrive at a satisfactory solution. The original charts were made on millimeter-squared paper on a large scale, viz., 1 cm = 0.2 km, 1 cm = 40 days, and were reduced photographically to a convenient size for the pages of the *Journal*.

α ORIONIS

In Fig. 1 the sinuous line represents the theoretical velocity-curve derived from the elements by Bottlinger. The individual observations on which the orbit is based are shown, and the means of each group are connected by the fine broken line, the number of plates in each group being denoted by numerals at each of the connected points. The observations of different observers are differentiated in the diagram and they are divided into three periods, viz., 1896–1898, 1901–1904, and 1905–1913. The observations in the first two periods are denoted by dates at the mean points in the diagram. To the rest of the observations the dates at the head of the diagram and the 100-day scale at the foot of the diagram apply. Included in the additional observations here given are 38 measures by Simpson[1]—published after the appearance of Bottlinger's paper—from plates taken at about the same time as Plummer's series. Halm's measures, mainly duplicating those of the same plates measured by me but using a different standard plate, are indicated by the coarse broken line from 1908 to 1912, my measures being indicated by a continuous line. The continuous line 1906–1907 represents the means of Goatcher's measures,[2] on the Zeiss comparator, of the same plates measured by Halm on the Hartmann comparator.

It is apparent from the diagram that no point on the velocity-curve can be satisfactorily fixed by the measures of only one or two plates, and that Bottlinger's determinations of the important maximum and minimum points of the curve are weak, inasmuch as they depend on scanty and non-homogeneous material. The later observations, depending on a larger number of plates, indicate that the minimum is earlier and lower than Bottlinger's orbit demands and that the maximum is earlier and higher. Whether the pronounced departures from simple orbital motion which are so strikingly shown in the duplicate measures of the same plates by Halm and myself are real, and analogous to those regarded as established by Campbell in the case of ζ Geminorum, or whether they are instrumental in origin, is a point which can be settled only by further observations, preferably at different observatories with different instruments.

It is evident from Bottlinger's measures of the Potsdam plates, from Plummer's measures of the Lick plates, and from measures of

[1] *Annals of the Cape Observatory*, 10, Part III, 91*c*. [2] *Ibid.*, 10, Part I, 54.

the Cape plates by various observers that isolated observations are of little value in determining orbits of binaries showing such small amplitude, but groups of ten or twelve plates a few months apart, particularly at maximum and minimum, are much needed. Plummer's series of measures of Lick plates and Simpson's of Cape plates at about the same epoch afford a good opportunity of comparing results and indicate a difference Lick−Cape of 0.64 km.

In the period from December 17, 1907, to April 23, 1908:

Plummer	17 plates = 20.88 km	Mean phase	1291^d
Simpson	36 " = 20.24 "	" "	1286^d

In determining orbits of stars such as these, with such a small variation in velocity, there is some danger in combining heterogeneous material from different observatories when corrections have to be applied to bring them into agreement.

Campbell records that fifteen observations by Belopolsky at Pulkowo in 1898 and 1899 on the average are 6 km above his values for ζ Geminorum. Bottlinger applied a correction of 2 km to the Potsdam and Bonn plates, but Küstner and Zurhellen, from observations of the starlike mountain peaks near the lunar terminator, arrive at a correction of only 1 km. Zurhellen's values would therefore be 1 km higher than is shown in the diagram. It is not considered advisable to attempt to revise Bottlinger's elements until further observations are secured.

The observations are given in Table I.

The measures of forty-four plates by Simpson are published in the *Annals of the Cape Observatory*, **10**, Part I, 54. The six measures of three Lick plates, 1910–1911, are published in *Lick Observatory Bulletin*, **6**, 144. One plate taken on December 21, 1910, was measured independently by Miss Hobe and Messrs. Burns, Wilson, and Young, and two plates taken on March 27 and 28, 1911, were measured by Miss Hobe. In the diagram these are marked as Campbell plates.

The Cape measures were made on a Hartmann spectrocomparator. Halm used plate 3453 of α Orionis as standard plate, the shift of which has been taken provisionally as +45.81 km, the mean of three comparisons with the plate 2145 of α Tauri used as

TABLE I

α ORIONIS

PLATE NO.	DATE	PHASE*	RADIAL VELOCITY		L.—H.
			Lunt	Halm	
			km	km	km
1901	1908 Sept. 14	1491^{d}	....	+21.52	
1909	21	98	....	19.68	
1913	22	99	....	20.90	
1922	30	1507	....	20.40	
	Mean, 4 plates....	1499	....	20.62	
2117	1909 Jan. 13	1612	+17.55	....	
2123	14	13	16.87	....	
2146	21	20	17.28	....	
2159	23	22	16.77	....	
2207	Feb. 6	36	17.88	19.03	
2226	15	45	18.37	17.92	
2229	16	46	19.53	19.22	
2244	25	55	17.60	17.28	
2258	Mar. 2	60	19.03	19.20	
2271	10	68	18.05	18.35	
2282	19	77	18.44	18.98	
	Mean, 11 plates....	1641	17.94	....	
	Mean, 7 plates....	1655	....	18.57	−0.63
2501	1909 Sept. 15	1857	18.17	19.02	
2515	22	64	19.53	20.54	
2542	Oct. 20	92	18.92	19.58	
2566	Nov. 9	1912	19.43	18.90	
	Mean, 4 plates....	1881	19.01	19.51	−0.50
2675	1910 Feb. 15	2010	18.71	20.49	
2683	22	17	20.16	20.36	
2689	25	20	21.02	21.39	
2694	Mar. 1	24	19.60	19.53	
2705	5	28	21.33	....	
2707	19	42	17.51	18.21	
	Mean, 5 plates.....	2023	....	20.00	
	Mean, 6 plates.....	2024	19.72	....	−0.28
2796	1910 Aug. 19	3	18.52	19.45	
2806	Sept. 2	17	18.54	18.87	
2818	13	28	19.31	21.28	
2840	Oct. 6	51	20.84	20.89	
2852	25	70	20.98	20.79	
2855	28	73	20.89	22.67	
	Mean, 6 plates.....	40^{d}	+19.85	+20.66	−0.81

*Zero phase is taken as J. D. 2416708 = 1904 August 15, and the period as 2192 days.

TABLE I—*Continued*

Plate No.	Date	Phase	Radial Velocity		L.—H.
			Lunt	Halm	
			km	km	km
3008	1911 Feb. 16	184d	+23.97	+24.09	
3021	22	190	24.20	24.67	
3024	24	192	23.64	24.03	
3027	25	193	23.59	23.36	
3029	27	195	24.95	24.54	
3032	Mar. 1	197	24.79	24.29	
3042	8	204	24.24	24.94	
3048	11	207	23.90	22.67	
3049	13	209	24.34	24.78	
	Mean, 9 plates	197	24.18	24.15	+0.03
3260	1911 Aug. 28	377	22.49	21.08	
3265	31	380	22.51	23.02	
3268	Sept. 5	385	22.17	21.98	
3283	29	409	22.41	22.47	
3290	Oct. 2	412	21.47	21.66	
	Mean, 5 plates	393	22.21	22.04	+0.17
3453	1912 Feb. 6	539	23.63	Standard	
3470	12	545	24.17	24.53	
3480	17	550	23.35	22.65	
3489	21	554	23.49	23.92	
3499	23	556†	26.94†	27.36†	
3547	Mar. 23	585	22.09	24.32	
3553	25	587	23.41	23.65	
3567	29	591	21.67	23.45	
	Mean, 7 plates	564	23.12	....	
	Mean, 6 plates	569	....	23.75	−0.63
3796	1912 Sept. 6	752	20.77	20.67	
3803	10	756	....	20.02	
3825	29	775	20.80	22.31	
3830	30	776	22.60	....	
3835	Oct. 4	780	20.48	22.14	
3847	14	790	20.64	20.60	
3849	15	791	20.17	20.66	
3864	23	799	19.72	20.21	
	Mean, 7 plates	780	20.74	....	
	Mean, 7 plates	778	....	+20.94	−0.20
3969	1913 Feb. 3	902	25.43	....	
3973	14	913	23.42	....	
	Mean, 2 plates	907d	+24.43	....	

† Plate rejected.

standard plate by Lunt. The plate of α Tauri has a shift of +77.38 km, as determined by comparison with twenty solar plates. Halm's measures may require a further correction when the shift of his standard plate is better determined.

α SCORPII

The diagram of velocities, Fig. 2, is self-explanatory and the same general remarks apply as in the case of α Orionis. Halm's

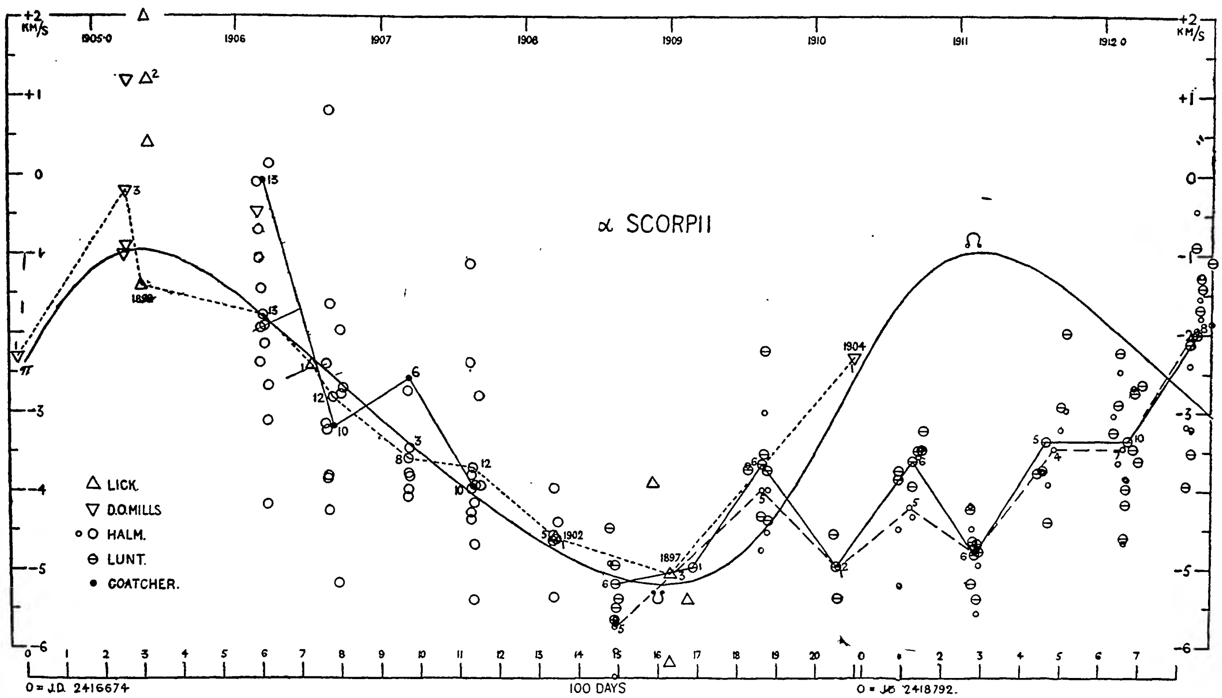

Fig. 2

published measures are confined to a part of the downward branch of the velocity-curve covering a period of a little over two years and comprising fifty plates. The individual measures of groups of twelve or thirteen plates show fluctuations which in range exceed the total variation of velocity required by the orbit derived, and show that measures of isolated plates are of little or no value in fixing a point on the velocity-curve. The remaining and major part of the velocity-curve depends on only nine plates, five secured at Lick and four by the Southern Mills Expedition at Santiago. The apex of the curve depends on approximate measures of three

TABLE II

α Scorpii

Plate No.	Date	Phase*	Radial Velocity		L.—H.
			Lunt	Halm	
			km	km	
1786	1908 July 30	1479[d]	−4.48	−4.93	
1807	Aug. 10	1490	5.65	6.38	
1813	11	91	5.18	5.70	
1816	12	92	4.95	5.65	
1822	13	93	5.50	6.05	
1846	21	1501	5.38	Standard	
	Mean, 5 plates	1489	....	5.74	
	Mean, 6 plates	1491	5.19	....	+0.55
2247	1909 Feb. 25	1689	5.38†	....	
2414	July 15	1829	3.73	3.67	
2456	Aug. 17	62	4.33	4.76	
2464	26	71	3.53	....	
2468	27	72	2.22	3.00	
2475	Sept. 2	78	3.74	4.53	
2481	3	79	4.38	3.99	
	Mean, 5 plates	1864	....	3.99	
	Mean, 6 plates	1865	3.66	....	+0.33
2682	1910 Feb. 20	2049	4.56	....	
2698	Mar. 1	2058	5.38	4.97	0.00
	Mean, 2 plates	2054	4.97	....	
2774	1910 Aug. 2	94	3.85	4.49	
2777	3	95	3.74	5.22	
2809	Sept. 6	129	3.94	4.33	
2825	21	144	3.49	3.56	
2831	29	152	3.48	3.47	
2835	Oct. 4	157	3.23	....	
	Mean, 5 plates	123	....	4.21	
	Mean, 6 plates	129	3.62	....	+0.59
2969	1911 Jan. 31	276	4.24	4.19	
2975	Feb. 2	278	5.19	4.49	
2990	6	282	4.65	4.72	
3003	15	291	5.39	5.57	
3010	16	292	4.68	4.74	
3014	20	296	4.78	4.95	
	Mean, 6 plates	286[d]	−4.82	−4.78	−0.04

* Zero phase taken as J.D. 2416674 = 1904 July 12, and the period as 2118 days.

† Radial velocity 4.98 in diagram in error.

TABLE II—*Continued*

Plate No.	Date	Phase	Radial Velocity		L.—H.
			Lunt	Halm	
			km	km	km
3231	1911 July 18	444^d	−3.77	....	
3240	31	457	3.73	−3.74	
3245	Aug. 14	471	4.40	3.91	
3278	Sept. 15	503	2.92	3.22	
3280	29	517	1.99	2.97	
	Mean, 5 plates	478‡	3.36	....	
	Mean, 4 plates	487	....	3.46	+0.10
3443	1912 Jan. 29	639	3.25	3.04	
3462	Feb. 8	649	2.89	3.64	
3473	12	653	2.23	2.48	
3495	22	663	4.60	4.67	
3505	27	668	4.17	3.84	
3508	28	669	3.97	3.85	
3542	Mar. 17	687	3.46	....	
3545	21	691	2.74	2.68	
3568	31	701	3.62	....	
3570	April 8	709	2.64	....	
	Mean, 7 plates	662	....	3.46	
	Mean, 10 plates	673	3.36	....	+0.10
3739	1912 July 29	821	3.94	3.18	
3756	Aug. 7	830	2.12	2.40	
3763	10	833	3.51	3.21	
3768	19	842	0.90	0.45	
3782	30	853	1.69	1.55	
3789	Sept. 2	856	1.29	1.80	
3792	6	860	1.42	1.25	
3827	39	884	1.09	1.87	
	Mean, 8 plates	847^d	−2.00	−1.96	−0.04

‡ Phase shown as 465 days in error.

Santiago plates—mean, −0.2 km per sec.—and one Lick plate belonging to a previous period. Two other Lick plates which place the observed maximum at +1.2 km have been left out of account, but if these are included and the revised[1] values of the three Santiago plates are used, the mean of the five 1905 plates is 1.09 km above the theoretical maximum of the curve, and the two Lick plates place it 2.16 km above the curve, leaving the maximum very uncertain. The minimum of the curve depends on three Lick plates taken in 1897, and the period depends mainly on the

[1] *Publications of the Lick Observatory*, **9**, 257.

coincidence in velocity between one Lick plate at 1902.4 and five Cape plates at 1908.2, giving a period of 5.8 years. On the ascending branch of the curve there is only a single Lick plate.

The velocity-curve derived from measures of fifty plates from July, 1908 to October, 1912—subsequent to the first series measured by Halm—does not follow the course prescribed for it by the orbit, but indicates that the maximum of the curve had not then been reached. It indicates that the period must be lengthened very considerably and that a satisfactory orbit cannot be derived until the observations are extended to give a determination of the apex of the curve. In view of the small range of variability it is desirable to secure observations in groups of plates, say ten to twelve, at intervals of four to six months, and that the observations should be duplicated at different observatories.

The observations are given in Table II.

Halm used Plate 1846 of α Scorpii as standard plate.

Lunt used Plate 2145 of α Tauri as standard plate.

Shift of 1846 taken as +23.43 km, the mean of four comparisons with plate 2145. Shift of 2145 taken as +77.38 km, the mean of comparisons with twenty solar plates. Halm's measures may require a further correction when the shift of his standard plate is better determined.

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