A NEW DETERMINATION OF THE SPECTROGRAPHIC ORBIT OF CAPELLA*

OTTO STRUVE AND RUTH F. KILBY
Berkeley Astronomical Department, University of California
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ABSTRACT

The velocity-curve of the G-type component of Capella was derived from forty-two spectrograms, thirty-seven of which were obtained with the Mount Wilson coudé spectrograph and five with the Mills spectrograph of the Lick Observatory. The elements resemble those by W. Struve, except that our velocities are systematically lower by 2.3 km/sec. The final elements are: P = 104.023 days (W. Struve); $\omega = 343°.04$; T = JD 2433481.10 (phase 21.246 days); $e = 0.0147$; $K = 26.38$ km/sec; $\gamma = 29.14$ km/sec; $a \sin i$ = 37,723,300 km; $f(m) = 0.198\odot$.

TABLE 1

LIST OF STAR LINES

Adopted λ	Identification	No. of Plates	Adopted λ	Identification	No. of Plates
4006.635	*Fe*	17	4374.474	*Sc*+, *Fe*	2
4009.719	*Fe*	17	4379.240	*V*	2
4014.532	*Sc*+, *Fe*	17	4389.256	*Fe*	2
4017.129	*Fe* 7.097, *Fe* 7.161	17	4407.654	*V*	2
4017.473	⊙	17	4417.725	*Ti*+	35
4023.386	*V*+, *Co*	17	4433.232	*Fe*	36
4023.688	*Sc*	17	4442.351	*Fe*	35
4024.100	*Fe*	17	4447.730	*Fe*	35
4033.077	*Mn*	17	4455.867	*Mn* 5.817, *Ca* 5.901	35
4034.494	*Mn*	17	4457.494	*Ti* 7.439, *Mn* 7.549	35
4041.379	*Mn*	17	4461.662	*Fe*	1
4048.763	*Mn*, *Cr*	17	4468.502	*Ti*+	34
4055.553	*Mn*	17	4476.052	*Fe* 6.023, *Fe* 6.091	34
4066.986	*Fe*	17	4482.214	*Fe* 2.176, *Fe* 2.276	34
			4482.742	*Ti*, *Fe*	34
4121.327	*Co*	23	4490.780	*Fe*	2
4121.812	*Fe*, *Cr*	23			
4130.046	*Fe*	22	4515.345	*Fe*+	5
4136.530	*Fe*	23	4528.629	*Fe*	5
4139.929	*Fe*	22	4529.688	*Fe*	5
4147.677	*Fe*	21	4533.251	*Ti*	5
4153.391	*Fe*	21	4533.973	*Ti*+, *Co*	5
4158.800	*Fe*	23	4534.789	*Ti*	5
4159.188	⊙	23	4563.768	*Ti*	5
4175.645	*Fe*	18	4564.705	*V*+, *Fe*	5
			4565.520	*Cr*	5

The orbit of Capella has been determined previously by H. M. Reese,[1] at the Lick Observatory in 1901; by F. Goos,[2] at Bonn in 1908; by P. W. Merrill[3] with the inter-

* The spectrograms used in this investigation were obtained by Mr. Struve as a guest investigator at the Mount Wilson and Lick Observatories.

[1] *Lick Obs. Bull.*, 1, No. 6, 34, 1901.

[2] Dissertation, Bonn, 1908.

[3] *Ap. J.*, 56, 44, 1922.

TABLE 2

RADIAL VELOCITIES

Plate No.	Date	U.T.	Phase (Days)	Velocity (Km/Sec)	O−C (Km/Sec)
1	1929 Dec. 30	5:47	6.541	+38.3	−0.6
2	30	8:01	6.634	+37.9	−1.1
3	1930 Jan. 3	5:26	10.526	+43.1	−1.5
4	Sept. 2	12:29	43.774	+40.6	−1.1
5	1932 Aug. 15	11:35	29.576	+55.8	+0.6
6	15	12:30	29.614	+55.5	+0.3
7	16	12:04	30.596	+55.5	+0.6
8	1933 Aug. 10	11:55	77.520	+ 3.2	0.0
9	14	12:00	81.524	+ 3.5	−0.1
10	Sept. 5	11:30	103.503	+28.0	+0.3
11	Nov. 3	7:45	58.324	+19.6	+0.3
12	1938 Nov. 15	8:55	23.959	+57.1	+1.4
13	Oct. 16	10:55	98.065	+19.8	+0.5
14	1950 Sept. 23	12:25	88.161	+ 8.2	+0.7
15	23	12:46	88.176	+ 7.9	+0.4
16	Dec. 31	4:10	82.795	+ 3.4	−0.7
17	31	5:25	82.847	+ 2.7	−1.4
18	1951 Jan. 2	2:35	84.729	+ 3.4	−1.6
19	2	3:07	84.751	+ 3.1	−1.9
20	27	2:15	5.692	+37.0	−0.6
21	28	8:06	6.936	+39.6	+0.2
22	Feb. 19	3:47	28.756	+56.1	+0.6
23	19	4:49	28.799	+55.6	+0.1
24	20	6:35	29.872	+54.2	−0.9
25	21	4:11	30.772	+53.7	−1.1
26	Mar. 20	2:59	57.723	+19.8	−0.4
27	20	3:35	57.747	+21.0	+0.9
28	22	6:19	59.861	+17.5	+0.4
29	23	2:53	60.718	+16.8	+0.8
30	27	3:38	64.749	+11.5	+0.3
31	27	4:22	64.780	+11.8	+0.8
32	Aug. 15	12:15	102.085	+25.9	+0.5
33	16	12:14	103.085	+28.2	+1.1
34	18	12:16	1.063	+30.7	+0.4
35	Oct. 22	9:55	65.965	+ 9.3	−0.4
36	22	10:28	65.988	+ 9.6	−0.2
37	1952 Feb. 10	8:28	72.882	+ 4.7	+0.6
38	1950 Oct. 8	13:10	103.193	+29.0	+1.8
39	Nov. 5	8:32	26.977	+56.5	+0.7
40	5	8:34	26.978	+56.2	+0.3
41	12	8:40	33.982	+52.1	−0.6
42	Dec. 10	12:40	62.149	+14.7	+0.6
1c	1952 Apr. 15	4:30	33.694	+52.6	−0.3
2c	15	5:02	33.716	+52.4	−0.5
3c	16	3:16	34.642	+51.8	−0.4

ferometer in 1921; and by W. Struve[4] at Berlin-Babelsberg in 1937. In 1922 R. F. Sanford[5] concluded from the measurements of seven 60-inch spectrograms at Mount Wilson that Reese's period was not in error by more than 0.01 day, but that a decrease in the velocity of the center of mass by 0.9 km/sec was indicated.

In the present determination forty-two spectrograms were used, thirty-seven of which were obtained with the Mount Wilson coudé spectrograph and five with the Mills spectrograph of the Lick Observatory. Of the Mount Wilson plates, thirteen were prism and grating spectrograms taken by W. S. Adams and Theodore Dunham, Jr., between 1929 and 1938. The dispersion ranged between 3 and 5 A/mm. The remaining twenty-four were coudé grating spectrograms obtained from 1950 to 1952, with a dispersion of 2.8 A/mm. The Lick spectrograms were taken between August and December, 1950, with the Mills three-prism spectrograph, which has a dispersion of 10 A/mm (Nos. 38–42 in Table 2).

The Lick plates were measured in the region between λ 4501 and λ 4572. On all the twenty-four Mount Wilson grating spectrograms, and on seven of the thirteen prism

TABLE 3

NORMAL VELOCITIES

No.	Wt.	Plates	Mean Phase (Days)	Velocity (Km/Sec)	O−C (Km/Sec)
1.....	2	20, 1, 2, 21	6.314	+38.1	−0.5
2.....	1	3	10.526	+43.1	−1.5
3.....	1	12	23.959	+57.1	+1.4
4.....	2	39, 40, 22, 23, 5	28.276	+56.0	+0.4
5.....	2	6, 24, 7, 25, 41	30.772	+54.4	−0.3
6.....	1	4	43.774	+40.5	−1.1
7.....	2	26, 27, 11, 28, 29	59.221	+18.4	+0.4
8.....	2	42, 30, 31, 35, 36	65.000	+10.9	+0.1
9.....	1	37	72.882	+ 4.7	+0.3
10.....	1	8	77.520	+ 3.2	0.0
11.....	2	9, 16, 17, 18, 19	83.138	+ 3.2	−1.0
12.....	1.4	14, 15	88.169	+ 8.0	+0.6
13.....	1	13	98.065	+19.8	+0.5
14.....	2	32, 33, 38, 10, 34	103.586	+28.6	+0.8

spectrograms, two or three regions were measured. A list of the lines in each region is given in Table 1. Because of the peculiar suppression of the strong lines of *Fe* I, *Mg* I, *Ti* II, etc., in the G-type component,[6] the lines selected were chosen from the large number of faint absorption features belonging to the G star which are in no way complicated by the presence of the F-component.

Table 2 shows the final radial velocities and the values of O−C resulting from least-squares solutions. The plates were grouped into 14 normal places, as shown in Table 3, together with the residuals resulting from the final least-squares solution. The weight assigned to each normal place was roughly the square root of the number of observations included.

The orbit of this star is so nearly circular that ω and e are not well determined. Preliminary values of γ and K were found by the Lehmann-Filhés graphical method, and various preliminary elements were tried. The period had been determined accurately by

[4] *Zs. f. Ap.*, **17**, 61, 1939.

[5] *Pub. A.S.P.*, **34**, 178, 1922.

[6] *Ap. J.*, in press.

TABLE 4

ORBITAL ELEMENTS OF G-TYPE COMPONENT OF CAPELLA

Element	Reese (1896–1900)	Probable Error	Goos (1905–1907)	W. Struve (1935–1937)	Mean Error	Merrill (1920–1921)	O.S. and R.K. (1929–1952)	Mean Error
P	104.022 days	± 0.024 day	104.035 days	104.023 days	.....	104.022 days	104.023 days	.....
ω	117°.3	±18°.3	(Reese)	358°.14	±29°.83	114°.30	343°.04	±16°.22
T (JD)	2414899.5	± 5.3 days	(Reese)	2428076.000	± 8.599 days	2422596.79	2433481.10 ($21^{d}.246$)	± 5.01 days
e	0.0164	± 0.0055	(Reese)	0.0155	± 0.0094	0.0086	0.0147	± 0.0048
K	25.76 km/sec	± 0.12 km/sec	26.5 km/sec	26.05 km/sec	± 0.24 km/sec	.....	26.38 km/sec	± 0.10 km/sec
γ	+30.17 km/sec	± 0.104 km/sec	+30.79 km/sec	+31.43 km/sec	.....	.....	+29.14 km/sec	± 0.12 km/sec
$a \sin i$	36,847,900 km	.....	37,906,400 km	37,258,000 km	.....	.....	37,723,300 km	.....
i	.....	.....	.....	.....	.....	−41°.08	.....	.....
$f(m)$	.....	.....	.....	.....	.....	.....	0.198 ⊙	.....

Reese and W. Struve; Struve's value, 104.023 days, was adopted and not corrected in our solution.

A least-squares solution was made, using the method of T. Sterne[7] (in which the preliminary orbit is circular) with the initial values:

P = 104.023 days, γ = 29.25 km/sec,
T_0 = JD 2433486.200 (phase 26.344 days), K = 27.15 km/sec.

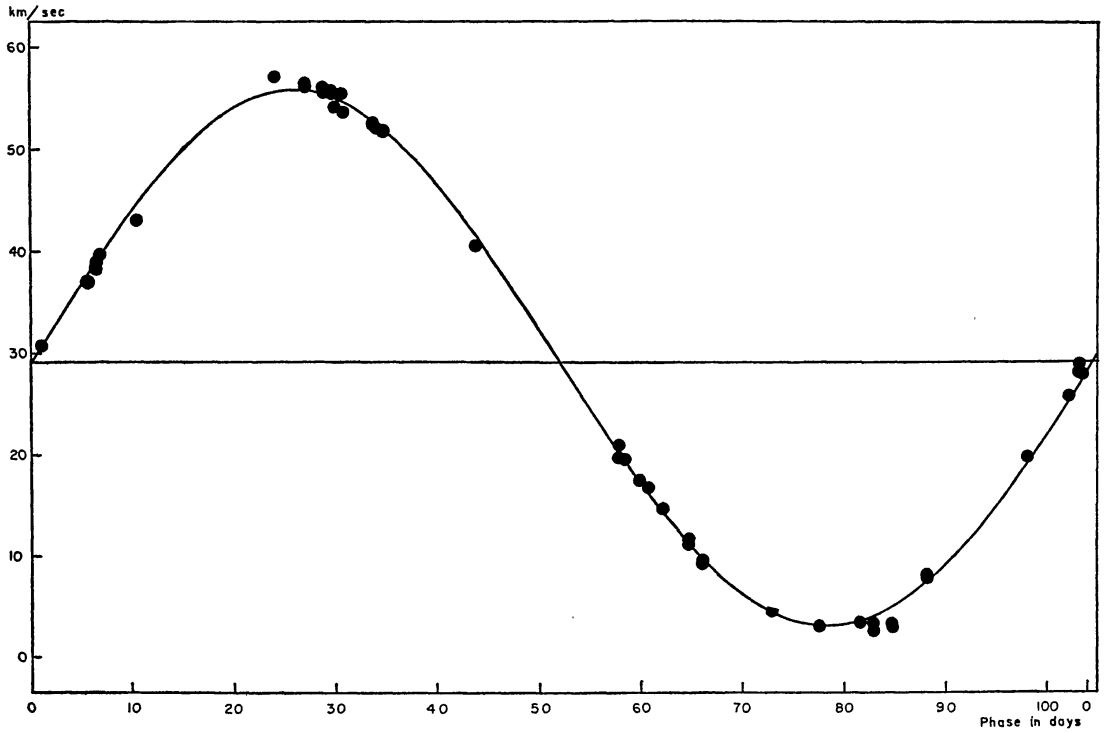

FIG. 1.—New velocity-curve of Capella with Mount Wilson and Lick observations

The value of T_0, the time of nodal passage, was, of course, read from the observed curve. The resulting preliminary elements were

ω = 339°.56 T = 20.248 days
e = 0.0138 γ = 29.14 km/sec
K = 26.37 km/sec
Zero epoch = JD 2433549.856.

The values of e and ω are similar to those of W. Struve.

From these elements a second least-squares solution was made, using Schlesinger's method as modified by Paddock[8] for small eccentricity. The final elements and their mean square errors are given in Table 4. The value of $\Sigma\Delta v^2$, which is 29.2 for the single observations, was not altered appreciably by the second least-squares solution. The mean square error of a single normal point is $\pm$0.77 km/sec, and that of a single plate is $\pm$0.89 km/sec. Figure 1 shows the new velocity-curve. Three check observations obtained after the computations had been concluded are also shown in Figure 1; they are listed at the end of Table 2, with the letter "c."

[7] Harvard Reprint No. 222 (*Proc. Nat. Acad. Sci.*, **27**, 175, 1941).

[8] *Lick Obs. Bull.*, No. 274, 1915.

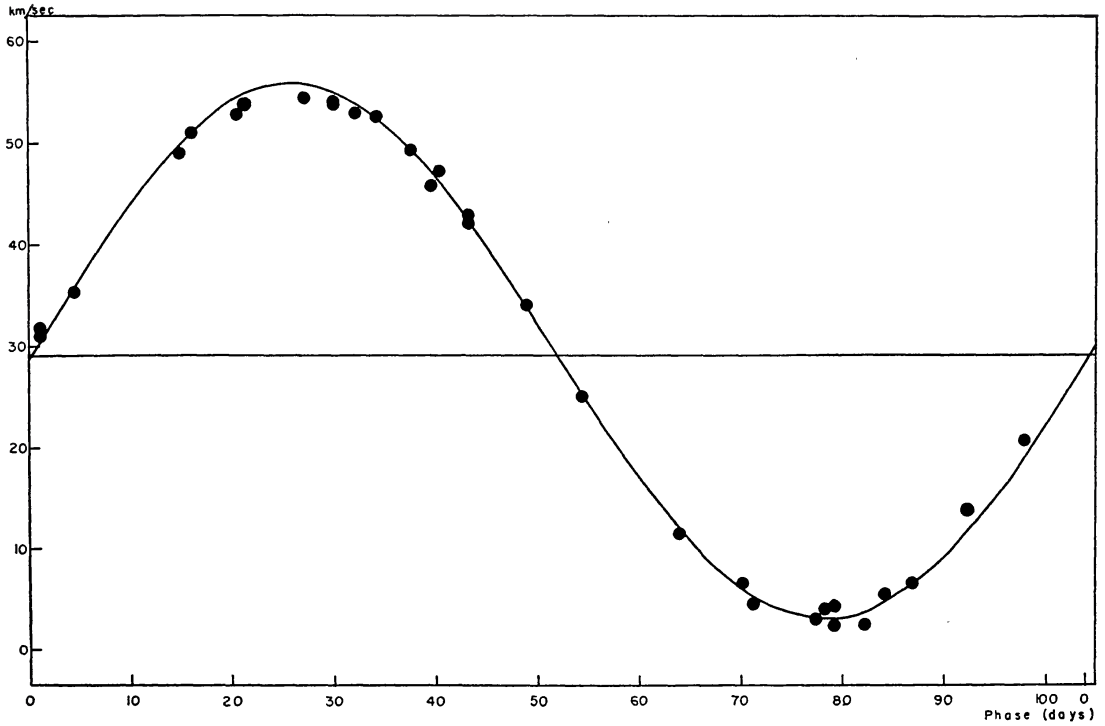

FIG. 2.—New velocity-curve of Capella with Reese's old Lick observations

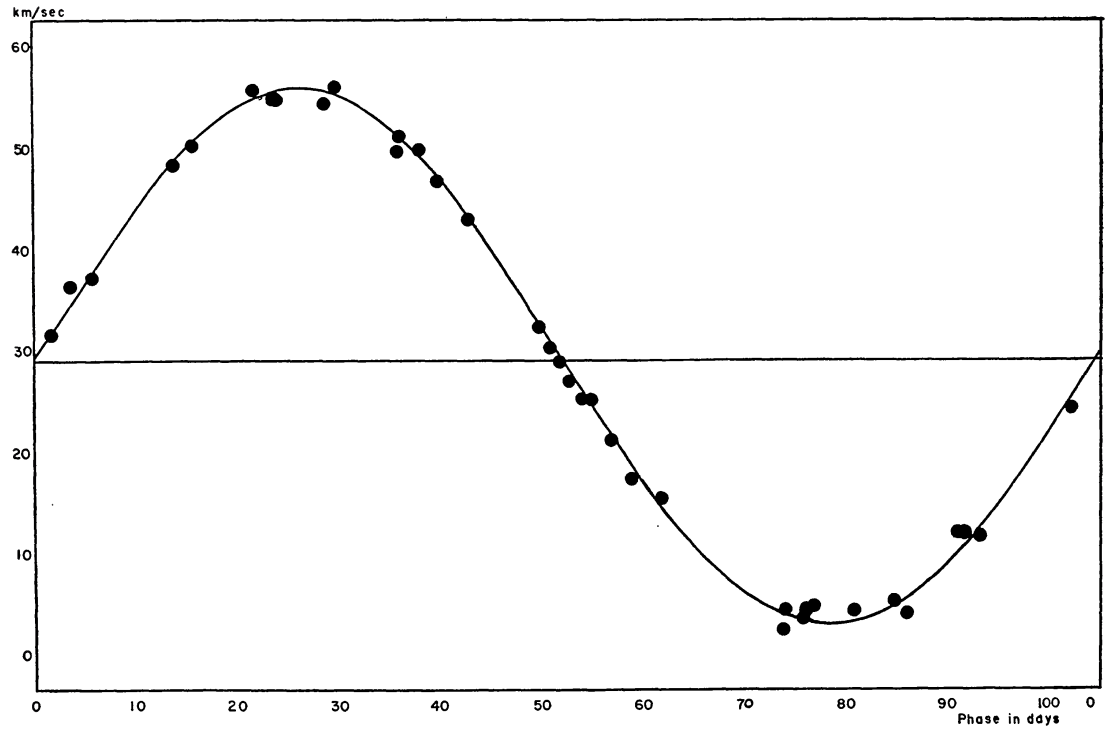

FIG. 3.—New velocity-curve of Capella with W. Struve's Berlin-Babelsberg observations

The departures of the observations from the curve just before maximum and just after minimum may represent deviations from elliptical motion. Every effort was made to fit them by trying various preliminary elements and by means of the least-squares solution, but no improvement was possible. The deviation near maximum is represented by only one plate. The four conspicuous deviations near minimum represent observations which were all made within a few days at Mount Wilson; without further check we cannot be certain that there is a real departure from elliptical motion.

Figures 2 and 3 are comparisons of our velocity-curve with the observations by Reese and W. Struve, respectively. In both comparisons the observations have been shifted vertically to allow for the rather large differences in γ; and the phases given in W. Struve's paper have been corrected for the fact that they were based on a period and zero epoch slightly different from his final ones. The new curve fits both Reese's and W. Struve's observations.

In Table 4 the final elements are compared with the elements derived by others. It is interesting that our elements resemble so closely those of W. Struve. It is especially striking that our value of ω is so near to that of W. Struve and so different from that of Reese. The latter is, however, supported by Merrill's determination with the interferometer. It should, however, be noted that Merrill[3] has stated that, "by taking T = 2,422,563.76, $\omega = 0.0°$, $e = 0.01$, the residuals in distance are considerably reduced, while those in angle are somewhat increased. With a circular orbit the representation is also very good." It would be of interest to secure a new set of measurements with the interferometer.

The differences in center-of-mass velocity are not definitely explained; our γ is 2.3 km/sec lower than that of W. Struve, and 1.0 km/sec below Reese's. To detect a possible systematic error in our observations, two spectrograms of the standard-velocity star Arcturus were taken on February 10, 1952, at almost the same time as plate No. 37 of Capella. Measurement of the same lines that were used for Capella yielded the mean velocity -5.74 km/sec, which agrees well with the accurate value, -5.62 km/sec, determined with the same instrument by Adams[9] in 1941. (The I.A.U. standard value, -5.1 km/sec, has not been revised since 1928.[10])

The systematic error of the prewar radial velocities obtained by W. Struve with Professor P. Guthnick's spectrograph attached to the 50-inch reflector, has never been determined. It is therefore not now possible to conclude that the γ-velocity is variable.

[9] *Ap. J.*, **93**, 11, 1941.

[10] *Trans. I.A.U.*, **3**, 171, 1928; *ibid.*, **7**, 311, 1950.