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A STUDY OF S SAGITTAE.

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INTRODUCTION.

The variability of the light of S Sagittae (known earlier as 10 Sagittae; α = $19^h51^m.5$; $\delta = +16°22'$ (1900.0); spectrum Gop) was discovered by Gore[1] in the autumn of 1885; and has been the object of study by numerous variable star observers since that time. It was found to have a variable radial velocity by Curtiss[2] from six spectrograms made in 1903 and one in 1904. It was later studied spectroscopically by Maddrill, from whose unpublished work Duncan[3] quotes the following elements:

$$K = 19 + \text{km/sec.}$$
$$e = 0.35$$
$$\omega = 69°.9$$
$$T = 1.3 \text{ days}$$
$$\text{Period} = 8.38 \text{ days}$$
$$a \sin i = 2{,}000{,}000 \text{ km.}$$

Shapley[4] included this star in his list of Cepheid variables of which he made a study regarding periodic change in spectral type, and found a range from F4 at maximum to G3 at minimum. From trigonometric measurements, Alden[5] derived a parallax of $0''.005 \pm 0''.004$, while Adams[6] gives the spectroscopic parallax as $0''.002$ and an absolute magnitude of -2.5.

Spectroscopic and magnitude observations of S Sagittae were begun in 1913 at Ann Arbor by Curtiss, who with Mellor had secured some fifty spectrograms when the study of this star was assigned to the writer in 1916. Thereafter, spectrograms

NOTE: This paper was submitted in 1923 as a dissertation in partial fulfilment of the requirements for the degree of Doctor of Philosophy, in the University of Michigan. A few additions have been made, as well as some excisions, in preparing for publication in 1932.

[1] MN *46*, 106 (1886).
[2] AphJ *20*, 231 (1904).
[3] Lick Bull *5*, 93 (1908).
[4] Mt Wils Contr *7*, 16 (1916).
[5] AJ *34*, 93 (1922).
[6] Mt Wils Contr *9*, 492 (1920).

were secured with some interruptions until 1923, for the details of which reference should be made to the journal of observations.

In the present investigation the effort has been made to analyze the complex variations found in the radial velocities of S Sagittae, and to compare the results thus found with the light curve. It was also proposed to compare the general plate velocities with those obtained from the hydrogen lines and well recognized chromospheric lines to test the possibility of differences of behavior in the absorption lines at different levels, and, further, to compare the relationships between the velocity amplitudes and phases of the velocity curve as determined from the lines of different chromospheric heights in the star's atmosphere.

The Light Variation.

A bibliography of the earlier published magnitude observations, as well as a fairly satisfactory light curve, is given by Luizet.[7] Numerous observations of the light variation of S Sagittae have since been published, by various observers. The light variation discussed in this paper is based upon a series of about two hundred magnitude observations made by Curtiss in 1913 and the following years. Normal places were formed from his manuscript data as follows:

TABLE 1. NORMAL PLACES FOR LIGHT VARIATION: CURTISS

No.	Range of phase	Mean phase	Mean Magn.	No. of Obs.
1	0.036 to 0.456	0.255	5.07	18
2	0.501 to 0.994	0.715	5.13	17
3	1.055 to 1.378	1.123	5.23	11
4	1.518 to 1.987	1.761	5.29	11
5	2.046 to 2.447	2.177	5.51	11
6	2.539 to 2.991	2.762	5.51	10
7	3.091 to 3.210	3.210	5.61	6
8	3.509 to 3.968	3.793	5.84	15
9	4.036 to 4.487	4.301	5.97	14
10	4.509 to 4.982	4.734	5.76	4
11	5.030 to 5.477	5.225	5.70	13
12	5.500 to 5.992	5.736	5.52	14
13	6.010 to 6.390	6.175	5.26	14
14	6.500 to 6.929	6.693	5.01	13
15	7.010 to 7.456	7.229	5.04	15
16	7.515 to 7.967	7.800	5.07	9
17	8.015 to 8.356	8.200	5.12	6

The earlier published results of Gore, referred to in the first paragraph of this paper, in combination with these results of Curtiss, made possible a very accurate determination of the period, giving an interval of 1,586 cycles with a resulting period of 8.381,589 days. The light curve from these normals is shown below in Figure 1.

[7] AN *168*, 341 (1905).

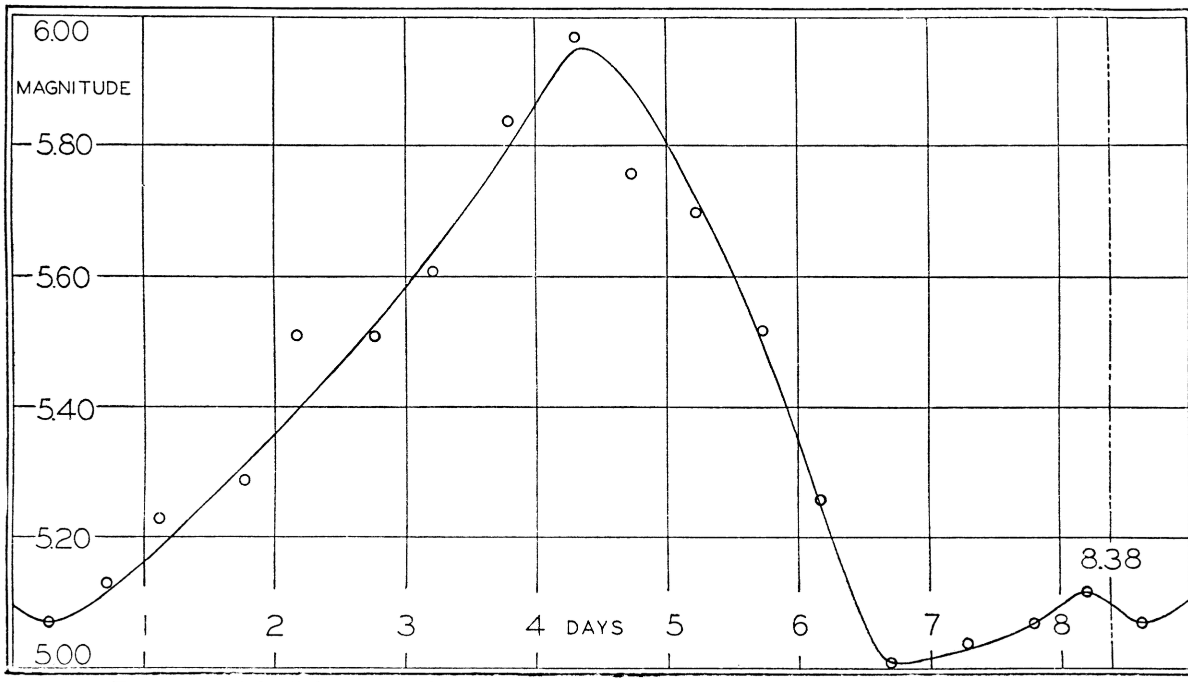

FIGURE 1. The light curve of S Sagittae, derived from observations made by R. H. Curtiss.

THE SPECTROSCOPIC DATA.

The spectrograms for this investigation were made with the single prism spectrograph attached to the 37½-inch reflector.[8] Most of the plates were made on Seed 27, a few on Seed 23, two on Seed 30, and one on Seed 60. As a result of a preliminary study of the spectrograms secured prior to 1916, evidence of variable center of mass velocity was obtained, which made desirable a series of spectrograms extending over a long period of time. Accordingly, additional plates were secured in the summer of 1916, 1917, 1918, and the spring of 1923. During the summer of 1917, an attempt was made to test out the system for short period oscillations. One series of five consecutive plates was obtained and another of four. The five plates made in 1918 and the four in 1923 were primarily for checks on the long period.

It was hoped that the radial velocities obtained in 1903 and 1904 could be included in the data, especially since they would furnish a valuable check on the long period. However, Dr. Curtiss called my attention to the fact[9] that they were taken with a spectrograph without a temperature case. In view of the relatively long exposure required for a spectrogram of this star, it was decided that the possibilities of large systematic errors in these data as well as the lack of homogeneity between them and those obtained at this observatory, rendered their use unwise in studies of the velocity of the center of mass.

[8] *These Publications*, *1*, 37 (1912).
[9] R. H. Curtiss, ApJ *20*, 231 (1904).

Methods of Reduction.

As the star is approximately of solar type, the method of reduction devised by Curtiss[10] was decided upon as giving velocities independent of assumed wave-lengths, eliminating sufficiently well the effect of curvature of the lines and making possible the use of a number of blends. All the spectrograms were measured on engines Nos. 2 and 4,[11] first in a direct and then in a reverse direction. Three settings were made on each line in each position and the mean of the six readings taken as the adopted value. Each line was weighted during measurement in the first position on the basis of the general character of the line and the agreement between the three settings. These weights were adjusted further on the reverse measurement. After the first series of plates were reduced, the line weights were still further adjusted from the probable errors, computed in connection with the process of rendering the lines homogeneous.

A new prism was installed before the 1914 plate was taken and this reset before the 1915 series, consequently a new standard table became necessary. It was prepared by selecting seven of the best plates made in 1916. All possible lines were measured on each of these plates and those lines selected which were measured on all five plates. The mean of the micrometer readings for these lines on the five selected plates, furnished the standard to which all subsequent measures were referred. This gave a standard table identical in origin with the plates to be measured. Five moon plates were then obtained and the mean velocity of the five standard plates referred to the moon was found to be +33.89 kms. As the moon's computed velocity for the mean time of observation was +1.1 kms., a correction of −34.99 had to be applied to each measured velocity.

Wave-Lengths Used.

Since no direct use was made of wave-lengths in this investigation, they were given minor consideration. However, it was felt that for purposes of reference the values for the lines used might well be tabulated. By means of the weighted residuals from all plates of the 1913 series for each line, corrections were obtained which rendered the lines homogeneous. Then using the Hartmann constant for the old prism, derived by Mellor,[12] the wave-lengths were computed. The differences between these and Rowland's standard values were plotted as ordinates against wave-lengths as abscissae. A smooth curve drawn through these points gave a graphical correction to the computed values. These corrected wave-lengths are tabulated in Table 2. Also in this table are found the wave-lengths to the nearest tenth of an angstrom of additional lines measured on plates made with

[10] Lick Bull *3*, 19 (1904).
[11] *These Publications* *1*, 51 (1912).
[12] Unpublished.

the new prism. Since many of the features whose wave-lengths are given in this table are blended groups of lines it will not be found in general that their wave-lengths are in agreement with individual solar lines.

TABLE 2. STAR LINES EMPLOYED.

I.A.	Element	I.A.	Element
3879.2		4242.70	Fe I
4005.34	Fe I, V II	4247.0	Fe I, Sc II
4012.8	Ti II–Fe I	4250.52	Fe I
4020.29	Mn I, Sc I, Fe I	4258.2	Fe II, Fe I
4030.66	Fe I–Ti I, Mn I	4260.46	Fe I
4033.04	Fe I, Mn I	4271.63	Fe I
4046.0	Fe I	4280.14	Cr I, Fe I, Sc II, Ti I?
4057.70	Fe I, Mg I, Co I?–Fe I	4282.66	Ca I, Fe I
4063.65	Fe I	4289.91	Ti II, Cr I, Ca I
4067.2	Fe I	4294.2	Ti II, Fe I, Zr I, Sc II
4071.71	Fe I	4302.66	Fe II, Ca I
4092.62	Fe I, V I–Ca I, Co I	4305.67	Fe I, Sr II, Ti I, Cr I, Sc II
4101.8	Hδ	4307.98	Ca I, Fe I
4118.58	Fe I, Co I	4314.70	Ti II, Fe I, Sc II
4125.92	Fe I	4320.9	Sc II, Ti II
4127.82	Fe I, V I	4325.3	Sc II, Fe I, Ti I, Ni I
4132.35	Fe I	4330.5	Ti II, Ni I
4137.26	Fe I, Ce II	4337.68	Cr I, Fe I, Ti II
4143.63	Fe I	4340.59	Hγ
4152.16	Fe I, La II, Ce II	4344.3	Ti II, Cr I
4154.38	Fe I	4351.59	Fe I, Cr I, Ti II
4156.48	Zr II, Fe I	4374.7	Sc II, Mn I, Co I–Y II
4161.4	Zr II, Sr II, Fe I, Ti II	4391.0	Fe I, Ti II
4167.48	Fe I, Mg I	4395.21	Ti II, V I
4181.96	Fe I	4400.4	Sc II, V I, Ti II
4187.3	Fe I	4404.73	Fe I
4191.4	Fe I	4408.5	Fe I, V I
4198.65	Fe I	4415.11	Fe I
4202.32	Fe I	4435.32	Ca I, Fe I
4207.12	Fe I	4443.4	Fe I, Ti II
4215.43	Sr II, Fe I	4461.70	Fe I
4227.0	Ca I, Fe I	4468.7	Ti II, Fe I
4229.78	Fe I	4481.2	Mg II, Ti I
4233.30	Fe II, Fe I	4501.2	Ti II
4235.8	Fe I	4525.5	Fe I
		4549.60	Fe II, Ti II
		4571.8	Cr I, Ti II
		4667.28	Ni I, Fe I, Ti I
		4861.14	Hβ

In the derivation of the elements, May 1.0, 1913, was taken as the epoch from which all phases were computed. It was assumed that the period of the principal velocity variation was identical with that of the light variation, an assumption that seems to have been justified in all cases of Cepheids studied. Using this period all the 1913 observations were reduced to a single cycle and normal places formed. These values were plotted and a smooth irregular curve passed through them. Velocities read off graphically from this curve were subtracted from the entire set of observations and the residuals plotted against time. The general form of the curve thus produced gave an indication of the probable length of the long period cycle as well as an indication of how the normal places should be formed. The normal places were then computed by years and the approximate long period applied to reduce all observations to a single cycle. The 1913, 1917, and 1923 series all fell on the descending branch of the curve, and the 1916 and 1918 on the ascending branch. Adjustments to the long period were then made to bring all these observations on approximately the same elliptic curve. The long period velocities read off from this curve were then subtracted from the plate velocities and the residuals used to give an improved short period curve. In this way, by a series of successive approximations, curves were obtained which fit elliptic elements for the long period variation and gave a form of irregular curve for the light period cycle that failed to change appreciably with further adjustments. A final set of normal places was then derived for the long period. These are given in Table 3 in which column one contains the number; column two, the range of phase; column three, the mean phase; column four, the mean velocity, and column five the residuals. Column six gives the number of plates and column seven the weight. This last was taken as the sum of the weights of the individual plates.

TABLE 3. NORMAL PLACES—LONG PERIOD.

No.	Range of Phase	Mean Phase	Mean Velocity	Residuals	No. Plates	Wt.
			km/sec.	km/sec.		
1	0	2.83	+ 9.0	−1.3	1	0.1
2	80.82 to 115.74	101.33	+ 8.0	0.0	6	2.5
3	117.76 to 123.74	119.31	+ 7.4	+0.6	6	2.3
4	127.72 to 128.73	133.35	+ 7.0	+1.0	7	2.0
5	144.74 to 155.61	151.02	+ 3.9	−0.2	6	2.0
6	155.66 to 165.57	160.29	+ 3.7	+0.1	6	2.6
7	165.63 to 184.59	175.66	+ 2.2	+0.1	6	2.2
8	184.64 to 188.72	186.15	+ 0.3	−0.8	8	4.8
9	191.63 to 198.75	197.88	+ 1.0	+1.3	6	2.0
10	202.62 to 204.66	203.51	− 1.7	−0.7	6	3.6
11	205.59 to 208.76	205.96	− 0.9	+0.5	8	3.2
12	213.58 to 222.88	216.26	− 1.4	+1.0	8	3.6
13	227.49 to 255.63	242.95	− 7.5	−1.5	6	2.0
14	0	275.51	− 9.8	+0.5	1	.1
15	397.84 to 404.82	398.61	−17.2	+0.7	2	.9
16	449.77 to 449.83	449.80	−12.0	−0.1	2	1.9
17	474.82 to 493.63	484.99	− 6.5	−0.1	6	4.8
18	495.85 to 506.67	502.28	− 2.8	+0.8	6	2.0
19	507.72 to 519.78	512.66	− 1.7	+0.5	6	2.0
20	523.76 to 530.83	525.74	+ 0.8	+1.2	8	4.1
21	533.64 to 539.76	536.00	+ 0.3	−0.5	6	2.8
22	544.71 to 575.65	555.56	+ 1.1	−1.6	7	3.3

Applying the 45° chordal method proposed by Curtiss[13] to a curve drawn through these plotted places, the following elements were derived:

$$P = 682 \text{ days}$$
$$\omega = 195°25'$$
$$e = 0.1651$$
$$T = 1914, \text{ May } 26.0 \text{ G.M.T.}$$
$$A = +10.5 \text{ km/sec.}$$
$$B = -18.8 \text{ km/sec.}$$
$$Vo = -1.8 \text{ km/sec.}$$
$$a \sin i = 136.4 \times 10^6 \text{ kms.}$$
$$\frac{m^3 \sin^3 i}{(m + m_3)^2} = 0.2180; \; (m = m_1 + m_2)$$

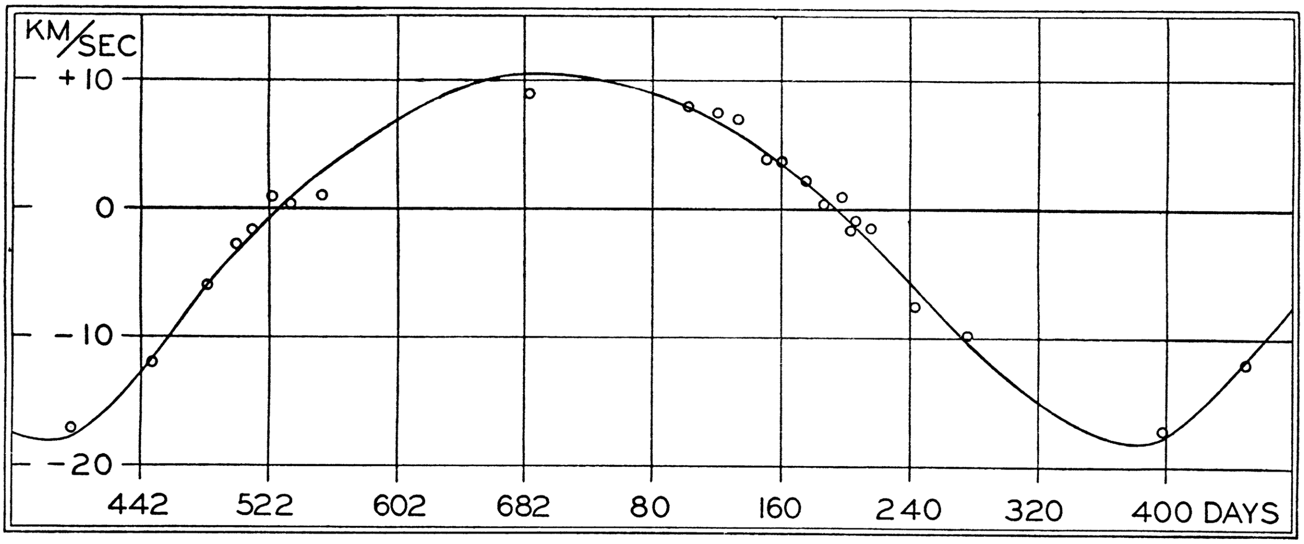

FIGURE 2. The Long Period Velocity Curve.

Figure 2 gives the elliptic curve computed from these elements together with the normal places.

The differences between plate velocities and long period velocities were then combined into normal places for the eight day cycle. These are given in Table 4 with the same arrangement of content as in Table 3. The irregularities in the observation curve drawn through these plotted normal places admitted some range of choice in selecting an elliptic curve to pass through them. However, the close resemblance between the irregularities of this velocity curve and those of

[13] Lick Bull *3*, 62 (1904).

W Sagittarii,[14] observed by Curtiss, suggested a curve which after a number of adjustments was found to be quite satisfactory.

TABLE 4. NORMAL PLACES—EIGHT DAY PERIOD.

No.	Range of Phase	Mean Phase	Mean Velocity	Residuals	No. Plates	Wt.
			km/sec.	km/sec.		
1	0.156 to 0.506	0.31	− 9.4	+2.3	15	9.2
2	1.127 to 1.437	1.22	− 5.3	+3.7	6	2.6
3	1.562 to 1.997	1.81	− 6.8	−0.4	13	6.0
4	2.128 to 2.490	2.32	− 6.0	−2.3	13	6.3
5	2.520 to 2.997	2.74	− 4.3	−2.8	11	2.9
6	3.002 to 3.570	3.31	+ 0.7	−1.4	8	2.9
7	3.653 to 3.936	3.78	+ 6.0	+0.2	7	2.6
8	4.427 to 4.791	4.68	+18.2	+4.1	4	1.8
9	5.038 to 5.417	5.38	+19.5	+2.0	7	1.5
10	5.512 to 5.993	5.79	+17.0	+1.3	7	1.9
11	6.090 to 6.399	6.25	+ 4.0	−2.2	7	3.6
12	6.423 to 6.855	6.66	− 5.9	−4.4	8	5.0
13	6.975 to 7.238	7.12	−11.7	−3.2	6	3.6
14	7.642 to 8.193	7.96	−10.6	+1.4	7	3.6

From this curve the method followed in the long period orbit gave the elements:

$$P = 8.381589 \text{ days}$$

$$\omega = 52^\circ 47'$$

$$e = 0.3385$$

$$T = 6.01 \text{ days from zero phase or 1913, May 7.01 G.M.T.}$$

$$K = 15.08 \text{ km/sec.}$$

$$a \sin i = 1.635 \times 10^6 \text{ km.}$$

$$\frac{m_1^3 \sin^3 i}{(m_1 + m_2)^2} = 0.002486$$

TABLE 5. NORMAL PLACES—FOUR DAY PERIOD.

No.	Limit of Phase	Mean Phase	Mean Velocity	Residuals	No. Plates	Wt.
			km/sec.	km/sec.		
1	0.156 to 0.506	0.31	+2.3	−0.8	15	9.2
2	0.236 to 0.600	0.49	+4.1	+1.0	4	1.8
3	0.847 to 1.226	1.17	+2.0	−0.7	7	1.5
4	1.127 to 1.437	1.22	+3.7	+1.2	6	2.6
5	1.321 to 1.802	1.60	+1.3	+0.4	7	1.9
6	1.562 to 1.997	1.81	−0.4	−0.2	13	6.0
7	1.899 to 2.208	2.06	−2.2	−0.5	7	3.6
8	2.128 to 2.490	2.32	−2.3	+0.8	13	6.3
9	2.232 to 2.664	2.47	−4.4	−0.8	8	5.0
10	2.520 to 2.997	2.74	−2.8	+0.8	11	2.9
11	2.764 to 3.047	2.93	−3.2	−0.2	6	3.6
12	3.002 to 3.570	3.31	−1.4	−0.4	8	2.9
13	3.451 to 4.002	3.77	+1.4	+0.4	7	3.6
14	3.653 to 3.936	3.78	+0.2	−0.8	7	2.6

[14] AphJ *22*, 274 (1905).

As the center of mass velocity was included in the long period elements, γ will be omitted in this and the four day cycle. In Figure 3 the full line gives the observed and the broken-line the computed representation of this cycle.

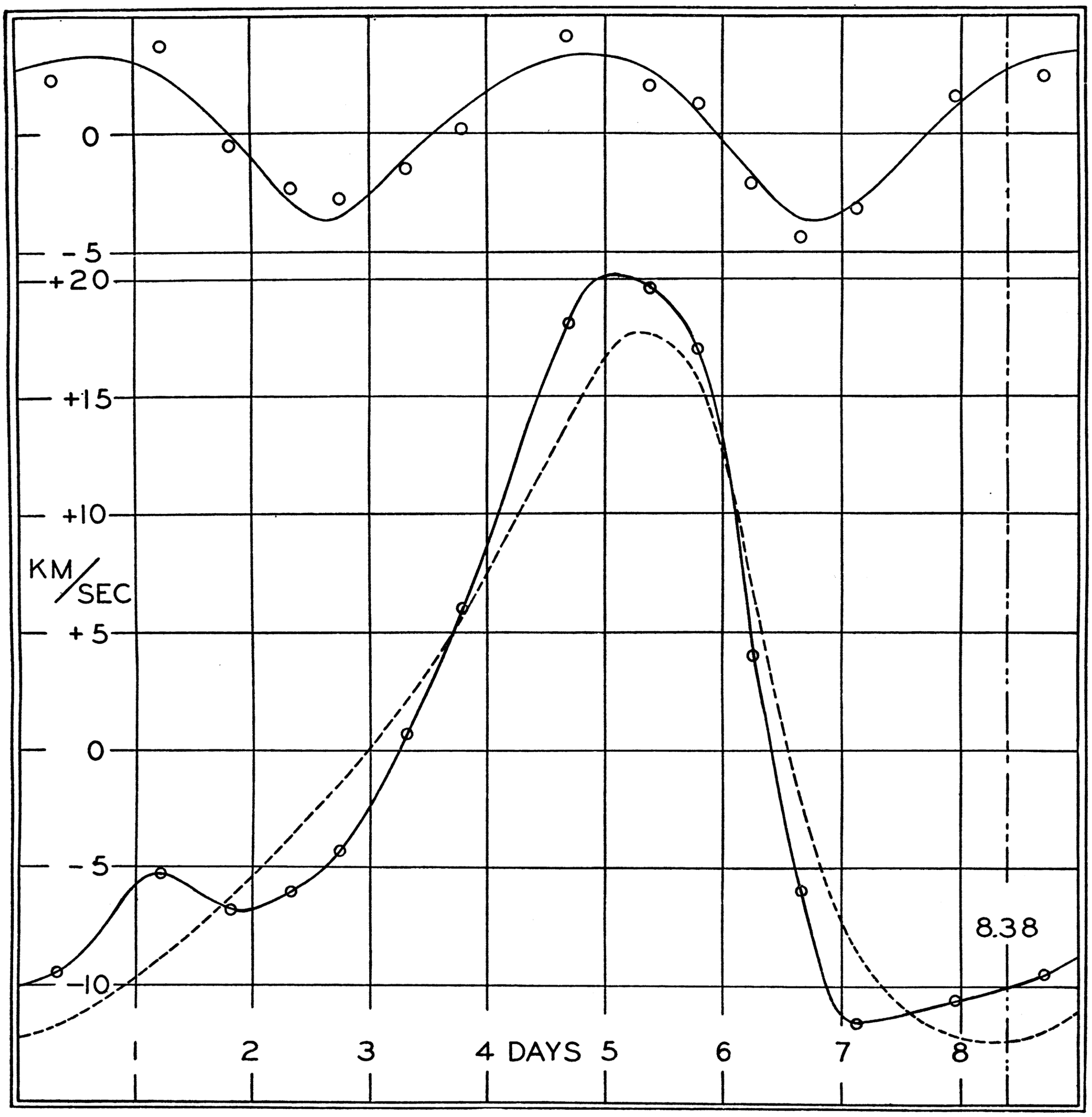

FIGURE 3. Velocity Curves of S Sagittae; 8 and 4 day Periods
Upper Curve. Secondary Oscillation
Curve of Elliptic Motion, - - - - - - - - - - - - -
Curve from Observations, ————————

The large residuals computed from the above elements were then plotted against time and found to give a well defined curve with a period equal to one half the principal cycle. These residuals were then reduced to one cycle and in order that irregularities in this oscillation might be compared with corresponding positions on the primary curve, these normals were retained for the secondary, irrespective of the overlapping phases of the observations which combined to form them. These are given in Table 5 with designations as in Tables 2 and 3 and are shown plotted in the upper part of Figure 3.

The trial and error method gave a curve to represent these normals which may be described by the following elements although it is not assumed to be due to orbital motion.

$$K = 7.4 \text{ km/sec.}$$
$$P = 4.190795 \text{ days}$$
$$\omega = 145^\circ 39'$$
$$e = 0.08974$$
$$T = 2.14 \text{ days from zero phase or 1913, May 3.14 G.M.T.}$$

Velocities at Different Levels.

In an attempt to throw some light on the question of the relative magnitudes and phases of the disturbances at different levels in the star's atmosphere, the velocities were taken out from each plate for the hydrogen lines β, γ, and δ, the chromospheric lines listed in Table 6, and the remainder of the lines.[15]

[15] It seems appropriate that a brief bibliography be given at this point relating to the general subject of velocity variations within a given spectrum and applications of the method treated in this paper.

J. Hartmann, Investigation of the Spectrum and Orbit of δ Orionis, AphJ *19*, 268 (1904). This paper announced the discovery of the "stationary" H and K lines of calcium.

W. S. Adams and H. Shapley, The Spectrum of δ Cephei, Proc NAS Wash *2*, 139 (1916). The authors segregated the velocities for individual lines as follows:—

1) A large number of enhanced lines.
2) Iron lines showing a wide range of displacement under pressure.
3) Special lines, as Hγ and 4227 A (Ca).

Due to the large number of lines available, a difference in radial velocity was definitely indicated between lines showing large pressure shifts and those characterized by small pressure shifts. Radial convection currents were assigned as the main cause.

Mary L. Heger, The Occurrence of Stationary D Lines of Sodium in the Spectroscopic Binaries β Scorpii and δ Orionis, Lick Bull *10*, 59 (1919). The behavior of the sodium lines was found to be similar to that of calcium.

R. K. Young, The Calcium Lines H and K in Early Type Stars, Dominion Aph Obs *1*, 219 (1920) RAS Can *14*, 389 (1920). A useful summary of data then available with regard to calcium lines which are stationary or which show a smaller range than the rest of the spectrum.

W. C. Rufus, A Possible Extension of the Calcium Envelope Hypothesis, RAS Can *14*, 139 (1920). The calcium envelope hypothesis which has been advanced to explain the small velocity range of H and K in certain spectroscopic binaries was tested for hydrogen by segregating the individual values for Hγ and Hδ secured by Young for χ Aurigae, and comparing them with the mean. It was found that the range of velocity determined from hydrogen alone was about 5 km/sec. less than the mean.

F. Henroteau, The Interstellar Clouds of Metallic Gases, RAS Can *15*, 62, 109 (1921). From measures made on σ Cygni, a diagram is given showing a radical displacement in radial velocity and in phase for Hϵ, in which, however, the other hydrogen lines do not share.

J. A. Aldrich, The present paper, prepared in April, 1923, was published in a brief abstract,—Radial Velocities of S Sagittae, Pop Astr *32*, 218 (1924).

W. C. Rufus, Atmospheric Pulsation of Cepheids, A New Method of Attack, Pop Astr *32*, 22 (1924).

W. C. Rufus, Atmospheric Pulsation of the Cepheid Variable Eta Aquilae, Proc NAS Wash *10*, 264 (1924), and Pop Astr *32*, 228 (1924).

R. H. Curtiss, Résumé of Remarks Concerning Recent Studies of Cepheid Variables at the Detroit Observatory, Pop Astr *32*, 471 (1924).

R. H. Curtiss, Velocity Curves from Groups of Lines of Different Chromospheric Heights in the Atmosphere of W Sagittarii, Pop Astr *32*, 547 (1924); Publ ASP *38*, 148 (1926).

TABLE 6. CHROMOSPHERIC LINES USED.

Wave-length I.A.	Element	Authority	Height in Chromosphere
4005.71	Fe I, V II	Mitchell*	800 km.
4215.72	Sr II	Mitchell	6000
4233.24	Fe II, Fe I	Lockyer**	1000
4395.12	Ti II, V I	Mitchell	2500
4501.28	Ti II	Mitchell	2500
4549.63	Ti II, Fe II	Mitchell	2500

* AphJ *38*, 424 (1913). AphJ *71*, 1 (1930).
** Tables of Wave Lengths of Enhanced Lines in the Publications of the Solar Physics Committee, 22–25, 1906.

TABLE 7. NORMAL PLACES FOR V_H, V_C AND V_R.

No.	Range of Phase	$Phase_H$	V_H	No. of Plates	Wt.	$Phase_C$	V_C	No. of Plates	Wt.	$Phase_R$	V_R	No. of Plates	Wt.
			km/sec.				km/sec.				km/sec.		
1	0.156 to 0.506	0.33	−10.2	15	66	0.31	− 9.5	15	156	0.31	− 8.5	15	1026
2	1.127 to 1.437	1.26	− 8.2	4	14	1.20	− 7.5	6	60	1.21	− 5.6	6	385
3	1.562 to 1.997	1.74	− 9.6	12	47	1.77	− 1.8	13	123	1.74	− 7.0	13	1100
4	2.128 to 2.490	2.31	−10.7	12	43	2.31	− 8.6	13	121	2.31	− 6.5	13	704
5	2.520 to 2.997	2.73	− 7.3	11	35	2.77	− 6.6	11	94	2.72	− 4.2	11	471
6	3.002 to 3.570	3.32	− 4.8	7	27	3.31	+ 0.9	8	62	3.31	− 1.9	8	428
7	3.653 to 3.936	3.75	− 3.4	7	31	3.76	+ 3.9	7	72	3.75	+ 6.5	7	385
8	4.427 to 4.791	4.63	+10.6	4	12	4.62	+18.8	4	39	4.67	+19.9	4	262
9	5.038 to 5.417	5.33	+29.8	5	13	5.31	+22.2	7	64	5.34	+18.6	7	273
10	5.512 to 5.993	5.76	+13.2	5	15	5.74	+18.1	7	41	5.77	+15.7	7	232
11	6.090 to 6.399	6.26	+12.4	6	31	6.21	+ 5.5	7	69	6.34	+ 3.6	7	590
12	6.423 to 6.855	6.68	− 3.8	8	37	6.63	− 4.6	8	85	6.57	− 6.4	8	545
13	6.975 to 7.238	7.14	−13.8	6	39	7.13	−12.3	6	67	7.17	−11.2	6	444
14	7.642 to 8.193	7.95	−10.8	7	29	7.98	−11.4	7	74	7.95	−10.6	7	501

HAZEL M. LOSH, The Spectrum of Zeta Tauri, *These Publications*, *4*, 1 (1931). Written in 1924; variations found.

W. C. RUFUS, Xi Persei, a Deviation from Elliptic Motion, abstract, Pop Astr *33*, 300 (1924). A systematic deviation was found that could not satisfactorily be interpreted as orbital motion, and was attributed to atmospheric effects.

W. C. RUFUS, Atmospheric Motion in Zeta Geminorum, abstract, Pop Astr *34*, 242 (1926).

D. W. LEE, Motion in the Atmosphere of Eta Aquilae, University of Michigan thesis (1926), unpublished. Abstract in Pop Astr *34*, 622 (1926).

T. S. JACOBSEN, A Re-Determination of the Radial Velocity Curves of Certain Cepheid Variable Stars, Lick Bull *12*, 138 (1926). In δ Cephei the velocity differences found show no relation to phase and are not regarded as established; a slight high minus low effect is not very definitely indicated for η Aquilae.

R. F. SANFORD, On the Radial Velocity and Spectrum of the Cepheid Variable T Monocerotis, AphJ *66*, 170 (1927). Slight variations indicated.

O. L. DUSTHEIMER, A Study of the Spectrographic Observations of Phi Persei, University of Michigan thesis (1927), unpublished. No appreciable difference found between curves for Hδ, Hγ, and He.

F. HENROTEAU, A Study of Zeta Geminorum. Dominion Obs *9*, 107 (1927). No difference found for lines of different levels.

F. HENROTEAU, A Study of Eta Aquilae, Dominion Obs *9*, 129 (1928). Results in general agreement with those of Jacobsen; ionized lines give about 10 km/sec. larger range than low level lines.

V. HASE, Velocity Curves of Zeta Geminorum in Lines of Different Heights in the Chromosphere. Pulkovo Mitth *11*, 6, 345 (1928). Three groups of lines of different heights were tested, but no appreciable differences were found.

P. W. MERRILL, The Spectrum of B.D. +11° 4673, AphJ *69*, 330 (1929). A puzzling spectrum of most irregular behavior; "The immediate outcome of this investigation is an example of what a stellar atmosphere can do." Large differences in amplitude and phase relations are definitely indicated. Four groups of lines can not be reconciled as to behavior: namely, (1) H; (2) He I and N II; (3) Al III; (4) Ti II, Fe II, and (Fe II). The first four elements in order of atomic weight have amplitudes of about 18 km/sec., while the remaining three elements have amplitudes of about 8 km/sec. There are also marked phase differences.

H. S. MENDENHALL, A Spectrographic Study of Beta Cephei, Lick Bull *14*, 133 (1930). No certain evidence of relative displacement found.

W. J. WILLIAMS, A Spectrographic Study of P Cygni, University of Michigan thesis (1930), unpublished. Velocity of star apparently constant, though large systematic differences were found in velocities of different lines.

W. C. RUFUS, Lag of Phase at High Levels in Zeta Geminorum, abstract, Pop Astr *39*, 20 (1931). Re-groups Mlle. Hase's data and obtains results indicating differences of behavior in lines of different levels.

These values were then formed into normal places and are listed in Table 7 in which columns one and two correspond to the same columns in Table 5, column three gives the phase for the hydrogen lines and column four the corresponding

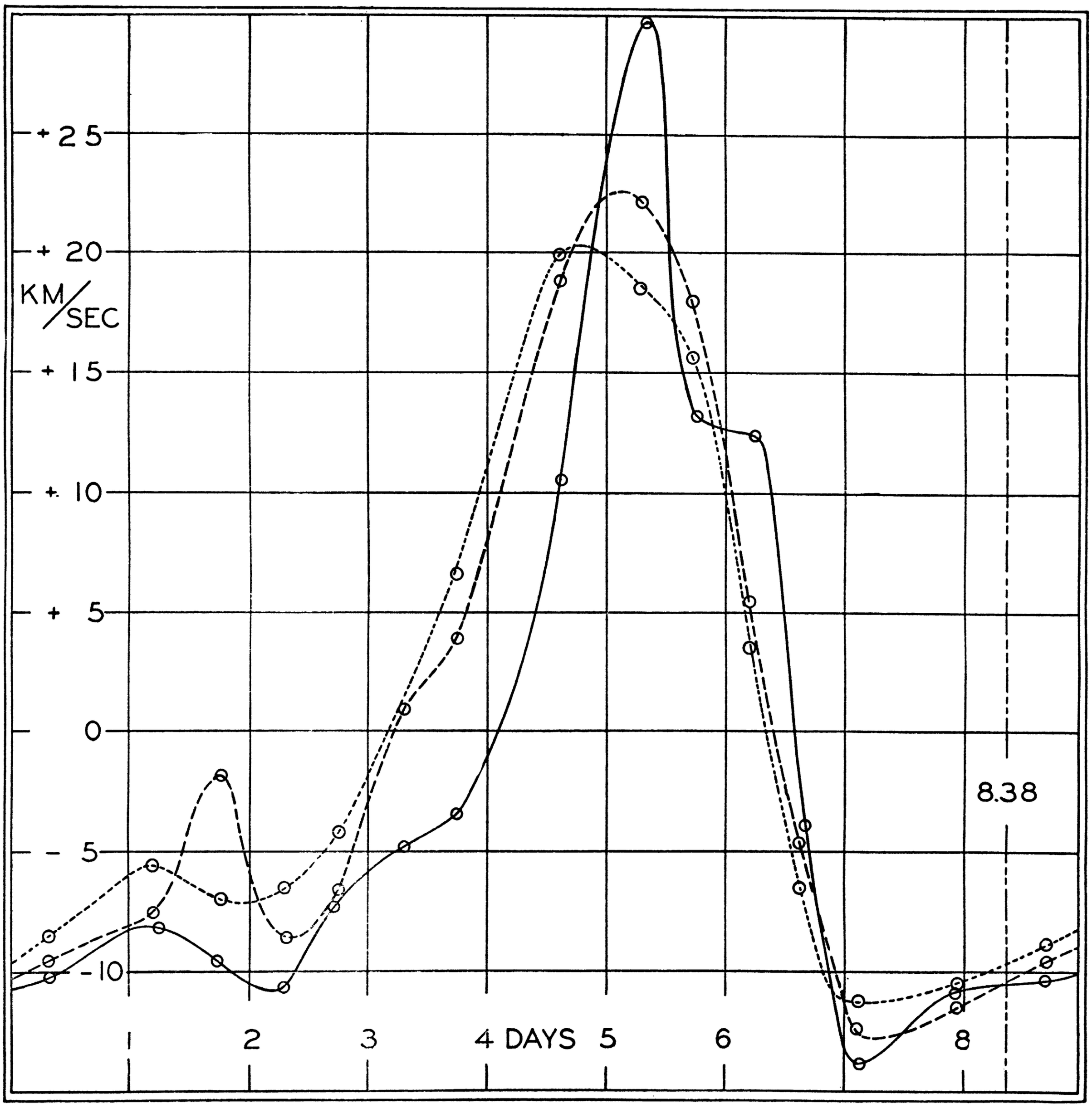

FIGURE 4. Velocity Curves for Hydrogen, Chromospheric and Reversing Layer Lines.
Hydrogen, ...
Chromosphere, - - - - - - - - - - - - -
Reversing Layer, ————————

velocities, column five the number of plates represented and column six the weights. Columns seven, eight, nine and ten and columns eleven, twelve, thirteen and fourteen contain corresponding data for the chromospheric and remaining lines.

These values are shown plotted in Figure 4. The dotted line shows the hydrogen velocities, the broken line those for the chromospheric gases and the full line the velocities for the remaining and presumably low level gases.

Although, as has been pointed out, the results must be considered as provisional in character, yet the following facts seem to be indicated: first, there is a greater range of velocities for the higher gases, the range decreasing systematically through the three groups studied; second, there is a slight indication of corresponding lag of phases, the lower gases passing through the cycle first followed by the chromospheric and lastly the hydrogen; third, there may possibly be a decided increase in irregularities in the upper gases although this is undoubtedly due in part to the difference in the number of measurements represented; fourth, although there are variations in phase and amplitudes between the velocities of the different levels, the general similarity of the curves representing these quantities gives unmistakable evidence that the observed absorption all takes place in the atmosphere of the star; fifth, there is apparently a direct relation between the different level velocities and the light variations as developed in the following discussion.

By way of summarizing the results which have been secured, a Journal of Observations is given below in Table 8. This assembles in tabular form, not only the observations which have been used in the discussion, but also the residuals secured from the period and sub-periods adopted.

In this table column one contains the plate number; column two the observer, designated as follows: C, Curtiss; M, Mellor; H, Henroteau; R, Rufus; and A, Aldrich. Column three gives the date expressed in Greenwich mean time; column four, the number of lines measured; column five, the weight of the plates computed from the inverse square of the probable error. Column six gives the velocity of the plate, corrected for the standard table velocity and reduced to the sun. Column seven contains the phase in the 682 day orbit, designated as Ph. No. 1; column eight the corresponding computed velocity. Columns nine and ten, eleven and twelve give like data for the eight and four day cycles. In the last column the difference between the observed value of the velocity and the sum of the computed values is given.

TABLE 8. JOURNAL OF OBSERVATIONS.

Plate No.	Obs.	Date G.M.T.	No. Lines Meas.	Wt.	Obs. Plate Vel.	Computed						O-C
						Ph. 1	Vel. 1	Ph. 2	Vel. 2	Ph. 3	Vel. 3	
		1913			km/sec.		km/sec.		km/sec.		km/sec.	km/sec.
1829	C	May 3.833	11	1	− 5.7	2.83	− 0.1	2.83	− 0.6	2.83	−3.3	−1.7
2115	C	July 20.817	28	4	+17.8	80.82	− 1.6	5.39	+18.2	1.20	+2.5	−1.3
2141	C	26.813	33	3	0.0	86.81	− 1.9	3.00	+ 0.3	3.00	−2.6	+4.2
2170	C	Aug. 2.760	41	4	− 8.1	93.76	− 2.1	1.56	− 7.4	1.56	+0.9	+0.5
2174	M	4.756	12	2	− 3.1	95.76	− 2.2	3.56	+ 4.3	3.56	−0.1	−5.1
2235	C	23.754	33	6	+15.0	114.75	− 3.6	5.79	+16.6	1.00	+2.9	−0.9
2242	C	24.743	40	6	−13.5	115.74	− 3.6	6.78	− 3.2	2.59	−3.7	−3.0
2260	C	26.758	41	6	−14.5	117.56	− 3.7	0.42	−11.2	0.42	+2.9	−2.5
2261	C	26.803	24	3	−10.7	117.80	− 3.8	0.46	−11.0	0.46	+3.0	+1.9
2270	C	28.705	25	3	− 8.5	119.71	− 3.9	2.36	− 3.2	2.36	−3.2	+1.8
2271	C	28.751	33	6	− 6.2	119.75	− 3.9	2.41	− 2.8	2.41	−3.4	+3.8
2275	M	29.707	34	4	− 1.8	120.71	− 4.0	3.37	+ 2.8	3.37	−0.9	+0.2
2287	M	Sept. 1.741	15	1	− 4.3	123.74	− 4.1	6.40	+ 3.6	2.21	−2.5	−1.3
2294	M	5.721	22	2	−15.3	127.72	− 4.5	2.00	− 5.2	2.00	−1.4	−3.7
2296	M	6.726	24	3	− 5.6	128.73	− 4.6	3.00	+ 0.2	3.00	−2.6	+1.3
2300	M	9.717	19	3	+ 7.7	131.72	− 4.8	5.99	+12.3	1.80	−0.4	−0.2
2313	C	13.722	12	2	−11.4	135.72	− 5.0	1.62	− 7.0	1.62	+0.6	0.0
2315	C	14.625	30	4	− 9.4	136.63	− 5.1	2.52	− 2.5	2.52	−3.6	+1.7
2316	C	14.701	25	3	− 9.8	136.70	− 5.1	2.60	− 2.0	2.60	−3.7	+1.0
2318	M	22.738	27	2	− 4.1	144.74	− 5.8	2.25	− 3.8	2.25	−2.7	+8.2
2328	M	26.662	25	3	− 3.2	148.66	− 6.1	6.18	+ 8.0	1.99	−1.4	−4.0
2334	M	27.646	34	4	−17.8	149.65	− 6.2	7.16	− 8.6	2.97	−2.7	−0.4
2335	M	27.699	31	4	−22.1	149.70	− 6.2	7.21	− 9.0	3.02	−2.5	−4.5
2339	M	Oct. 1.677	20	1	−12.0	153.68	− 6.6	2.81	− 0.8	2.81	−3.4	−1.2
2340	M	3.609	41	6	+13.1	155.61	− 6.7	4.74	+14.8	0.55	+3.1	+2.0
2341	M	3.660	36	5	+15.9	155.66	− 6.7	4.78	+14.8	0.59	+3.1	+4.6
2356	M	6.664	32	3	−19.7	158.66	− 7.1	7.80	−11.9	3.61	+0.2	−1.0
2357	M	6.703	31	3	−19.5	158.70	− 7.1	7.83	−11.9	3.64	+0.3	−0.8
2361	C	9.588	27	6	−16.0	161.59	− 7.3	2.34	− 3.4	2.34	−3.2	−2.1
2377	C	12.647	31	3	+15.4	164.67	− 7.6	5.42	+18.2	1.23	+2.4	+2.4
2383	M	13.572	38	4	− 6.8	165.57	− 7.6	6.32	+ 5.0	2.13	−2.2	−2.1
2384	M	13.627	36	6	− 8.6	165.63	− 7.6	6.38	+ 3.8	2.19	−2.4	−2.4
2393	C	18.608	26	2	−13.3	170.61	− 8.1	2.98	+ 0.3	2.98	−2.7	−2.8
2400	C	25.608	33	4	−16.3	177.61	− 8.8	1.59	− 7.0	1.59	+0.7	−1.2
2401	C	25.672	26	3	−13.7	177.67	− 8.8	1.66	− 6.5	1.66	+0.3	+1.3
2409	C	30.629	22	3	−14.9	182.63	− 9.4	6.62	− 0.2	2.43	−3.4	−1.8
2412	C	Nov. 1.590	34	4	−14.8	184.59	− 9.6	0.20	−13.0	0.20	+2.4	+5.4
2413	C	1.644	34	4	−18.4	184.64	− 9.6	0.25	−11.4	0.25	+2.5	+0.1
2424	M	4.581	22	4	−13.6	187.58	− 9.8	3.19	+ 1.4	3.79	−1.7	−3.6
2468	C	Dec. 8.491	28	3	− 7.1	221.49	−13.8	3.57	+ 4.2	3.57	0.0	+2.4
2495	C	14.493	31	4	−20.8	227.49	−14.6	1.19	− 8.8	1.19	+2.5	0.0
2518	C	21.496	30	3	−21.5	234.50	−15.6	8.19	−12.0	4.00	+1.8	+4.2
		1914										
2822	C	June 2.844	39	8	−21.8	397.84	−28.6	3.91	+ 7.0	3.91	+1.4	−1.7
2833	C	9.820	6	1	−24.5	404.82	−28.6	2.50	− 2.5	2.50	−3.6	+9.6
		1915										
3415	C	Dec. 14.507	19	1	−26.7	275.51	−21.2	2.00	− 5.2	2.00	−1.5	+1.1
		1916										
3511	M	June 5.773	51	9	−31.2	449.77	−22.4	0.26	−11.5	0.26	+2.6	+0.1
3512	M	5.827	51	10	−31.6	449.83	−22.4	0.31	−11.4	0.31	+2.7	−0.6
3537	M	30.816	51	9	−27.1	474.82	−18.6	0.16	−11.6	0.16	+2.3	+0.8
3556	C	July 6.750	51	10	− 8.8	480.75	−17.6	6.09	+10.2	1.90	−0.9	−0.4
3562	M	10.711	50	8	−25.6	484.71	−17.1	1.67	− 6.5	1.67	+0.3	−2.4

TABLE 8. JOURNAL OF OBSERVATIONS—*Continued.*

Plate No.	Obs.	Date G.M.T.	No. Lines Meas.	Wt.	Obs. Plate Vel.	Computed						O-C
						Ph. 1	Vel. 1	Ph. 2	Vel. 2	Ph. 3	Vel. 3	
		1916			km/sec.		km/sec.		km/sec.		km/sec.	km/sec.
3568	H	July 15.792	51	9	−19.2	489.79	−16.3	6.75	− 2.7	2.56	−3.7	+3.5
3570	A	18.653	42	7	−20.9	492.65	−15.9	1.23	− 8.5	1.23	+2.4	+1.1
3574	A	19.628	37	4	−27.8	493.63	−15.8	2.21	− 4.0	2.21	−2.6	−5.4
3580	A	21.850	25	3	+ 1.2	495.85	−15.4	4.43	+11.8	0.24.	+2.5	+2.3
3581	A	22.812	35	4	+ 7.8	496.81	−15.3	5.38	+18.0	1.19	+2.5	+2.5
3594	C	27.722	32	3	−18.7	501.72	−14.6	1.91	− 5.6	1.91	−1.0	+2.4
3597	A	29.681	28	3	− 6.0	503.68	−14.3	3.87	+ 6.8	3.87	+1.3	+0.3
3598	A	29.750	16	1	− 6.7	503.75	−14.3	3.94	+ 7.8	3.94	+1.6	−1.8
3604	H	Aug. 1.669	42	7	−22.1	506.67	−13.9	6.68	− 4.6	2.67	−3.7	+0.1
3608	H	2.720	28	3	−26.4	507.72	−13.7	7.91	−11.8	3.72	+0.7	−1.6
3609	A	5.625	38	7	−20.9	510.63	−13.2	2.43	− 2.8	2.43	−3.5	−1.4
3610	A	5.792	27	2	−23.2	510.79	−13.2	2.60	− 2.0	2.60	−3.7	−4.4
3612	A	8.708	26	3	+ 4.8	513.71	−12.8	5.51	+18.0	1.32	+2.0	−2.4
3613	A	8.771	11	1	+16.2	513.77	−12.8	5.57	+17.9	1.38	+1.8	+9.4
3619	H	14.782	20	4	− 3.8	519.78	−12.0	3.20	+ 1.6	3.20	−1.7	+8.2
3626	A	18.760	50	8	−18.6	523.76	−11 4	7.18	− 8.7	2.99	−2.6	+4.1
3627	A	18.816	33	5	−22.6	523.82	−11.4	7.24	− 9.2	3.05	−2.3	+0.2
3632	A	19.667	45	9	−20.2	524.67	−11 2	8.09	−11.9	3.90	+1.4	+1.5
3633	A	19.725	47	8	−18.5	524.73	−11.2	8.15	−12.0	3.96	+1.6	+3.1
3652	A	25.753	15	1	+11.3	530.75	−10.5	5.79	+16.6	1.60	+0.7	+4.6
3653	A	25.833	21	1	+ 1.0	530.83	−10.5	5.87	+15.0	1.68	+0.2	−3.7
3656	A	28.642	49	8	−19.2	533.64	−10.1	0.30	−11.4	0.30	+2.7	−0.4
3658	A	28.799	44	5	−17.8	533.80	−10.1	0.46	−11.1	0.46	+3.0	+0.4
3660	A	29.778	25	2	−15.6	534.78	−10.0	1.44	− 7.7	1.44	+1.5	+0.6
3670	A	Sept. 3.695	51	9	− 8.3	539.70	− 9.4	6.35	+ 4.4	2.16	−2.3	−1.1
3671	A	3.764	15	1	−21.1	539.76	− 9.4	6.42	+ 3.3	2.23	−2.6	−12.4
3675	A	8.706	40	3	−15.9	544.71	− 8.8	2.98	+ 0.2	2.98	−2.6	−4.8
3676	A	8.764	27	3	−12.3	544.76	− 8.8	3.04	+ 0.6	3.04	−2.4	−1.8
3681	A	12.698	52	8	−19.9	548.70	− 8.3	6.98	− 6.6	2.79	−3.5	−1.5
3682	A	12.760	40	7	−19.4	548.76	− 8.3	7.04	− 7.3	2.85	−3.2	−0.5
3696	A	22.743	27	4	−10.2	558.74	− 7.2	0.26	−11.5	0.26	+2.5	+5.9
		1917										
3939	C	June 6.675	37	3	+11.5	134.03	− 4.8	6.11	+ 9.8	1.92	−1.0	+7.5
3949	A	July 27.675	43	8	−12.6	184.68	− 9.6	6.46	+ 2.3	2.27	−2.8	−2.5
3950	A	27.764	46	8	−15.6	184.76	− 9.6	6.55	+ 0.8	2.36	−3.2	−3.6
3951	A	27.827	36	7	−11.9	184.83	− 9.6	6.62	− 0.2	2.43	−3.4	+1.4
3952	A	30.719	35	4	−16.4	187.72	− 9.8	1.13	− 8.8	1.13	+2.7	−0.4
3953	A	30.793	43	8	−12.6	187.79	− 9.8	1.20	− 8.7	1.20	+2.5	+3.4
3954	A	31.722	38	5	−19.8	188.72	−10.0	2.13	− 4.6	2.13	−2.2	−3.1
3955	A	Aug. 3.632	19	1	+ 6.3	191.63	−10.3	5.04	+17.2	0.85	+3.1	−3.7
3956	A	9.681	37	6	−13.6	197.68	−11.0	2.71	− 1.4	2.71	−3.6	+2.4
3957	A	9.764	29	3	−15.2	197.76	−11.0	2.79	− 0.9	2.79	−3.5	+0.2
3958	A	10.629	39	5	− 6.3	198.63	−11.1	3.65	+ 5.0	3.65	+0.3	−0.6
3959	A	10.697	38	4	− 2.8	198.70	−11.1	3.72	+ 5.6	3.72	+0.7	+2.1
3960	A	10.748	19	1	− 6.4	198.75	−11.1	3.77	+ 6.0	3.77	−0.9	−2.2
3961	A	14.618	41	7	−25.7	202.62	−11.4	7.64	−11.2	3.45	−0.6	−2.5
3963	A	15.604	42	8	−20.6	203.60	−11.6	0.25	−11.4	0.25	+2.5	−0.1
3964	A	15.668	41	7	−23.8	203.67	−11.6	0.32	−11.3	0.32	+2.7	−3.6
3965	A	15.729	40	8	−20.0	203.73	−11.6	0.37	−11.2	0.37	+2.8	+0.0
3966	A	15.793	31	5	−19.2	203.79	−11.6	0.44	−11.1	0.44	−2.9	+0.6
3967	A	16.660	15	1	−26.5	204.66	−11.7	1.30	− 8.3	1.30	+2.1	−8.6
3968	A	17.594	45	7	−17.8	205.59	−12.0	2.23	− 4.0	2.23	−2.6	+0.7

TABLE 8. JOURNAL OF OBSERVATIONS—*Continued.*

Plate No.	Obs.	Date G.M.T.	No. Lines Meas.	Wt.	Obs. Plate Vel.	Computed						O-C
						Ph. 1	Vel. 1	Ph. 2	Vel. 2	Ph. 3	Vel. 3	
		1917			km/sec.		km/sec.		km/sec.		km/sec.	km/sec.
3969	A	Aug. 17.660	42	8	−17.4	205.66	−12.0	2.30	− 3.6	2.30	−3.0	+1.1
3970	A	17.722	44	7	−15.2	205.72	−12.0	2.36	− 3.2	2.36	−3.2	+3.2
3971	A	17.785	37	4	−17.8	205.79	−12.0	2.43	− 2.9	2.43	−3.4	+0.6
3972	A	17.847	13	3	−15.2	205.85	−12.0	2.49	− 2.5	2.49	−3.6	+2.8
3973	A	20.635	21	1	− 3.9	208.64	−12.2	5.28	+17.9	1.09	+2.8	−12.3
3974	A	20.697	16	1	+13.5	208.70	−12.2	5.34	+18.0	1.15	+2.6	+5.1
3975	A	20.761	11	1	− 0.1	208.76	−12.2	5.40	+18.0	1.21	+2.5	−8.4
3976	A	25.580	44	8	−17.3	213.58	−12.8	1.84	− 6.0	1.84	−0.6	+2.1
3977	A	25.644	45	8	−17.4	213.64	−12.8	1.91	− 5.6	1.91	−1.0	+1.9
3978	A	25.706	46	9	−15.7	213.71	−12.8	1.97	− 5.3	1.97	−1.2	+3.6
3982	R	Sept. 19.625	15	1	−24.3	238.63	−16.1	1.74	− 6.4	1.74	−0.1	−1.8
3983	R	21.560	37	4	−12.1	240.56	−16.3	3.67	+ 5.2	3.67	+0.4	−1.4
3987	A	Oct. 6.561	41	8	−32.2	255.56	−18.3	1.91	− 5.6	1.91	−0.8	−7.5
3988	A	6.626	23	2	−20.6	255.63	−18.3	1.98	− 5.2	1.98	−1.4	+4.4
		1918										
5052	R	July 5.717	28	4	+ 4.6	527.72	−11.0	5.86	+15.1	1.67	+0.3	+0.2
5059	A	8.750	47	5	−11.8	530.75	−10.5	0.51	−10.9	0.51	+3.0	+6.5
5062	A	12.703	39	4	+ 2.4	534.70	−10.0	4.46	+14.6	0.27	+2.6	−4.8
5118	A	Aug. 19.656	27	2	−23.1	572.66	− 5.7	0.51	−10.9	0.51	+3.0	−9.5
5119	A	22.649	41	6	− 4.6	575.65	− 5.4	3.50	+ 3.8	3.50	−0.3	−2.7
		1923										
6103	A	Apr. 10.826	13	1	−26.0	221.81	−13.9	2.58	− 2.0	2.58	−3.7	−6.4
6104	A	10.892	34	2	−19.4	221.89	−13.9	2.66	− 1.6	2.66	−3.7	−0.2
6115	A	11.826	43	3	−15.0	222.81	−14.0	3.58	+ 4.5	3.58	+0.1	−5.6
6116	A	11.889	45	2	−13.3	222.88	−14.0	3.65	+ 5.0	3.65	−0.4	−4.7

Discussion of the Results.

It is not the purpose of this study to consider the general question of Cepheid variation nor is any particular theory assumed in formulating the results of the investigation. For purposes of numerical description the variations have been described in terms of elliptic elements which are found to fit the observations to a degree of accuracy consistent with the probable errors of the observations.

A comparison of the light and velocity curves, assuming orbital motion, exhibits the following relationships: Maximum light occurs 0.8 day after periastron passage, 0.43 day after zero velocity referred to the center of mass on the descending branch and 0.45 day before the maximum velocity of approach. The minimum of light occurs 1.12 days after the zero velocity referred to the center of mass, in passing from recession to approach, and 0.7 day before the maximum velocity recession. The general similarity of the light and velocity curves, even to the minor irregularities, as noted by Curtiss[16] in his study of W Sagittarii and suggested for this star in his study of the "Possible Characteristics of Cepheid Variable Stars," seems to be well authenticated as a comparative study of my velocity curve and Curtiss' light curve will show. Two points of maximum disturbance

[16] *These Publications 1*, 104 (1913).

appear on the curves showing the velocities for the different levels of the star's atmosphere. The first is a hydrogen disturbance at the point of periastron and the second a disturbance in the chromospheric gases at the time of apastron.

Considered from the point of view of atmospheric pulsations, it will be noted that the point of maximum expansion between the hydrogen and chromospheric layers occurs at 5.03 days, the point of maximum expansion between the chromospheric and reversing layers at 4.72 days and, if we can proceed by extrapolation, the point of maximum expansion between the reversing layer and photosphere will come near 4.4 days. At this point the temperature of the radiating surface would be lowest in the cycle and it would give off a minimum radiation due to temperature. This coincides with the minimum on the light curve. The time of maximum compression between the hydrogen and chromospheric gases comes within 0.06 day of the maximum compression between the chromospheric and reversing layers. Maximum compression in the photospheric layer must occur near the same phase. Thus maximum radiation and near minimum absorption should occur at the phase 6.8 days. This again coincides with the phase of maximum light. Thus it appears that the major variations in the eight day cycle may be accounted for by the hypothesis of atmospheric pulsation. For the minor irregularities, a very marked temporary contraction between the reversing and chromospheric layers at 1.8 days corresponds to a slight secondary maximum light at the same phase but a more pronounced secondary maximum from 2.5 to 3.5 days in the light curve has no corresponding cause in the relative velocities. Again the secondary minimum from 7 to 8.5 days and the pronounced secondary maximum at 0.3 days seem to be without adequate explanation. Apparently then, the pulsation theory may be adequate to account for the major variations in the light cycle but fails in the present limited application to account for the minor irregularities.

From planimetric measurements of the velocity curves it appears that the reversing layer reaches a maximum distance of 6×10^6 km. from its neutral position. Assuming a surface radiation comparable to that of the sun, the star's diameter will be in the vicinity of 25×10^6 km. It would thus appear that on the pulsation theory alone the extent of movement is nearly half the radius of the star. A return to the orbital theory of a motion about the center of mass due to a small close satellite or protuberance to account for a part of the observed velocities would simplify the explanation at this point and would help to account for the short period velocity variation.

A new problem presents itself in the differential center of mass velocities observed for groups of lines at different levels. Were these irregular, they might be thought of as accidental, due to the limited number of lines represented, but they produce a progressive effect even more pronounced than the lag of phase or differential velocity range. The chromospheric layer has a velocity of approach, with respect to the reversing layer, of 0.56 km/sec., and the hydrogen layer has a corresponding velocity of 2.40 km/sec. As each layer partakes of the same cyclic movement, all are unquestionably attached to the same nucleus. It seems, then, that the only explanation is that the observed velocities are not all due to the Doppler effect. Systematic displacements of star lines referred to solar lines are surely present and may account for some of the observed effect. Also atmospheric circulation may be an important factor.

Summary and Conclusions.

The following results have been obtained as a result of this study:

A long period variation of 682 days was discovered and elements for the orbit of the primary body with respect to the center of mass of the system were determined.

The residual velocities, after the long period variation was allowed for, were resolved into two components one of which was represented by an elliptic motion equal in period to the principal light cycle and the other by a slightly eccentric motion in a period of half that length. Elements were derived for each of these cycles.

A new period of the light variation was derived from the observations of Curtiss and Gore.

Attention was called to the general similarity between the light and velocity curves even in the minor variations and the close resemblances of the variation curves of this star to those of W Sagittarii, as derived by Curtiss, were pointed out.

Strong evidence was obtained of a systematic variation in magnitude and phase of the velocities at different levels in the star's atmosphere.

A differential center of mass velocity was observed for the different levels and the bearing of the different findings on the atmospheric pulsation and orbital motion theories discussed.

In conclusion the writer wishes to acknowledge his obligations to former Director Hussey for the privilege of the Observatory as well as for his personal interest and help during the progress of the work. He wishes also to acknowledge his indebtedness to the late Director R. H. Curtiss under whose immediate supervision this work was done. Thanks are also extended to Dr. W. C. Rufus and other members of the staff for aid in securing the spectrograms and for helpful suggestions during the work.

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