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DEPARTMENT OF THE INTERIOR
CANADA

HON. CHARLES STEWART, *Minister*

W. W. CORY, C.M.G., *Deputy Minister*

PUBLICATIONS

OF THE

Dominion Observatory

OTTAWA

R. MELDRUM STEWART, M.A., *Director*

Vol. IX

Astrophysics

No. 3

A STUDY OF ZETA GEMINORUM

First Paper

BY

F. HENROTEAU, D. Sc.

OTTAWA
F. A. CLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
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GEOLOGICAL SURVEY
OF CANADA

YRÅGELI
YÄTÖN JA SOKOLO
ADAMAS TO

A STUDY OF ZETA GEMINORUM

FIRST PAPER

BY F. HENROTEAU, D.Sc.

The discovery of the variation of the light of ζ Geminorum is usually attributed to Schmidt in 1844. Before this, however, the star had been suspected of variability as mentioned by Wurm in the *Berliner Jahrbuch* for 1790 (p. 166). Several light curves of it have since been published, among which are those of E. C. Pickering,¹ Markwick,² Luizet,³ Hornig,⁴ and Guthnick.⁵ The amplitude of the photographic light curve as found by Wirtz⁶ is much larger than the visual, and Professor Guthnick also, using his photo-electric photometer and colour-screen, found a decided variation in its colour index.

The variability of the radial velocity of ζ Geminorum was discovered independently by Bélopolsky⁷ and by Campbell.⁸ The latter derived a mean radial velocity curve from a series of 44 spectrograms taken in 1898, 1899 and 1900. This curve indicates considerable departure from Keplerian orbital motion.

The radial velocities of this star which have been published up to the present are given in the following tables:—

RADIAL VELOCITIES AT OTHER OBSERVATORIES

(Bélopolsky's velocities)

Date	Julian Day	Velocity km.	Remarks
1897 Dec. 31.....	2414290.415	+32.7	
1898 Jan. 2.....	292.436	+21.2	
20.....	310.353	+37.5	
21.....	311.394	+35.3	
29.....	319.336	+22.3	
31.....	321.353	+20.5	
Feb. 17.....	338.353	+14.5	
Mar. 21.....	370.252	+22.4	
25.....	374.244	+ 5.0	
26.....	375.244	+ 0.3	
27.....	376.244	- 3.0	
28.....	377.240	-20.0	
1899 Mar. 25.....	739.240	+ 5.2	
27.....	741.248	+ 3.7	
28.....	742.277	+ 2.5	

¹ H. A., Vol. 46, 1903, p. 155.

² Jour. B. A. A., Vol. 17, 1907, p. 208.

³ A. N., Vol. 160, p. 364.

⁴ A. N., Vol. 201, p. 155.

⁵ A. N., Jubiläumsnummer, 1921.

⁶ A. N., Vol. 154, p. 336.

⁷ A. N., Vol. 149, p. 239.

⁸ Ap. J., Vol. 13, 1901, p. 90.

RADIAL VELOCITIES AT OTHER OBSERVATORIES—Concluded

(Campbell's velocities)

	Date	Julian Day	Velocity km.	Remarks
1898	Nov. 11.....	2414605.975	+19.9	
1899	Jan. 24.....	679.846	+ 0.7	
	25.....	680.875	- 1.8	
	27.....	682.841	- 2.4	
	28.....	683.841	+ 5.4	
	29.....	684.767	+13.0	
	30.....	685.826	+20.5	
		.879	+20.1	
Feb.	6.....	692.692	- 2.9	
		.737	- 2.6	
	7.....	693.675	+ 3.6	
	13.....	699.667	+ 1.7	
	15.....	701.763	- 4.3	
		.817	- 4.7	
	21.....	707.680	+17.9	
		.758	+16.3	
	22.....	708.688	+ 7.0	
		.763	+ 4.7	
April	5.....	750.650	+ 2.5	
	10.....	755.684	+12.6	
	12.....	757.701	+23.5	
	13.....	758.701	+13.3	
Sept.	12.....	910.021	+23.5	
	13.....	911.029	+14.6	
	22.....	920.000	+24.2	
	27.....	925.000	- 3.8	
Oct.	4.....	932.038	+ 5.2	
	23.....	951.996	+10.2	
	25.....	953.029	+ 2.9	
Nov.	30.....	989.017	+11.2	
Dec.	25.....	2415014.858	+ 1.3	
	26.....	015.004	+ 0.7	
		.768	0.0	
	27.....	016.962	- 6.2	
	28.....	017.008	- 5.9	
1900	Jan. 10.....	030.809	+18.9	
	15.....	035.680	+ 0.5	
	21.....	041.688	+21.2	
	29.....	049.767	+ 8.8	
	30.....	050.754	+16.2	
Feb.	6.....	057.861	- 6.7	
	7.....	058.716	- 0.4	
	11.....	062.667	+21.0	
		.779	+19.4	

(Küstner's velocities)

1912	Jan. 19.....	2419421.43	+ 5.6	
	Feb. 28.....	461.34	- 1.7	

(Lunt's velocities)

1909	Feb. 12.....	2418350	+13.7	See Ap. J., Vol. 50, p.
1914	Jan. 23.....	2420156	+ 7.9	169.
1916	Feb. 1.....	2420895	- 5.9	

Following are the radial velocities of ζ Geminorum obtained at Ottawa. The plates were measured against standard spectrograms of daylight and of Polaris; of these the latter is the more similar to that of the star, and consequently gives more reliable measures.

OTTAWA RADIAL VELOCITIES OF ζ GEMINORUM OBTAINED IN 1924

Date	Julian Day	Velocity km. Daylight	Velocity km. Polaris	Remarks
1924 Jan. 14.....	2423799.717	- 3.1	+ 0.2	
	.752	+ 0.2	- 0.4	
15.....	800.587	- 1.6	+ 0.3	
20.....	805.653	+ 3.5	+ 8.2	
23.....	808.746	- 3.0	- 1.0	
	.796	- 6.9	- 8.5	
27.....	812.580	+10.4		
31.....	816.571	+ 1.6	+ 2.7	
	.656	- 0.9	+ 2.3	
Feb. 3.....	819.630	- 7.6	- 6.8	
	.715	- 4.5	- 6.8	
8.....	824.549	+18.0	+21.9	
	.647	+17.7	+21.2	
11.....	827.569	- 2.8	- 0.2	
12.....	828.660	- 3.4	- 1.6	
13.....	829.566	- 7.7	- 5.0	
	.622	- 6.7	- 4.1	
15.....	831.533	+ 5.7	+ 5.1	
	.591	+ 4.4	+10.3	
	.654	+ 4.2	+ 9.3	
18.....	834.560	+18.4	+20.2	
	.658	+17.3	+20.2	
21.....	837.598	+ 3.4	+ 4.6	
22.....	838.517	- 2.5	+ 2.0	
	.578	- 2.2	+ 0.6	
	.653	- 0.5	+ 2.1	
24.....	840.533	- 5.5	+ 0.1	
	.583	- 2.3	- 1.8	
26.....	842.558	+13.8	+10.0	
	.632	+15.2	+18.2	Poor
28.....	844.602	.....	+20.3	
29.....	845.554	+ 7.5	+ 8.4	
	.661	+ 6.3	+11.4	
Mar. 12.....	857.558	+ 0.7	+ 2.4	
	.629	+ 1.7	+ 1.0	
13.....	858.541	- 1.6	+ 0.5	
	.606	- 4.5	+ 1.1	
17.....	862.551	+10.7	+10.7	
19.....	864.637	+25.2	+23.6	
20.....	865.581	+21.6	+21.2	
23.....	868.618	- 3.4	+ 0.5	
24.....	869.542	+ 0.4	- 5.2	
31.....	876.563	+ 6.7	+10.7	
April 2.....	878.558	+ 0.7	+ 4.7	

The velocities in the last column, together with the elements J.D. 2410639.339 + $10^d \cdot 15375$ E, have been utilized for the radial velocity curve shown in Fig. 1.

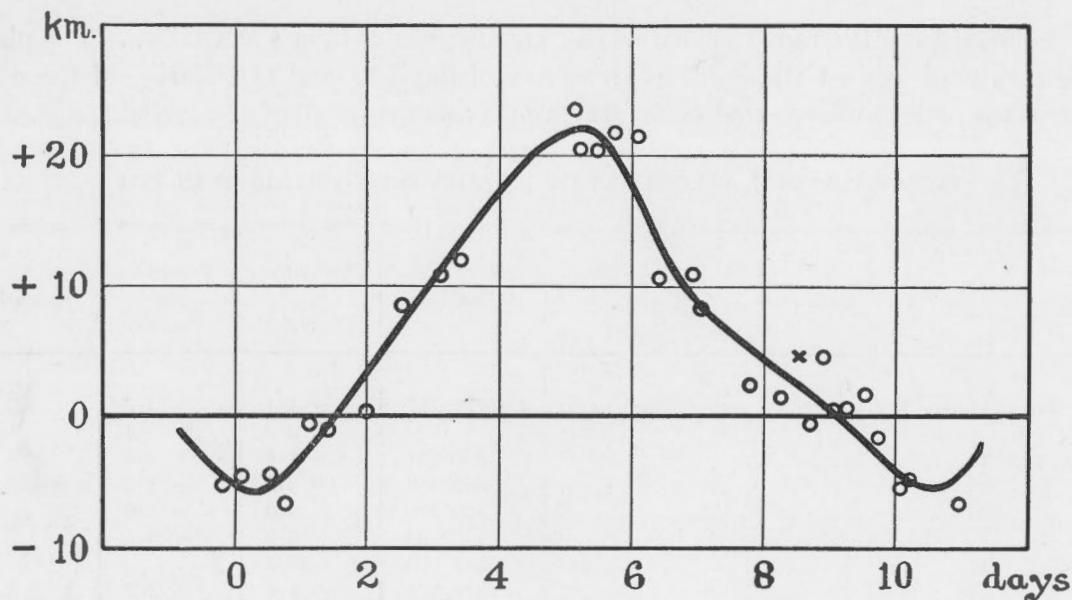


FIG. 1. Radial Velocity curve of Zeta Geminorum, 1924, Spectro-comparator measures.

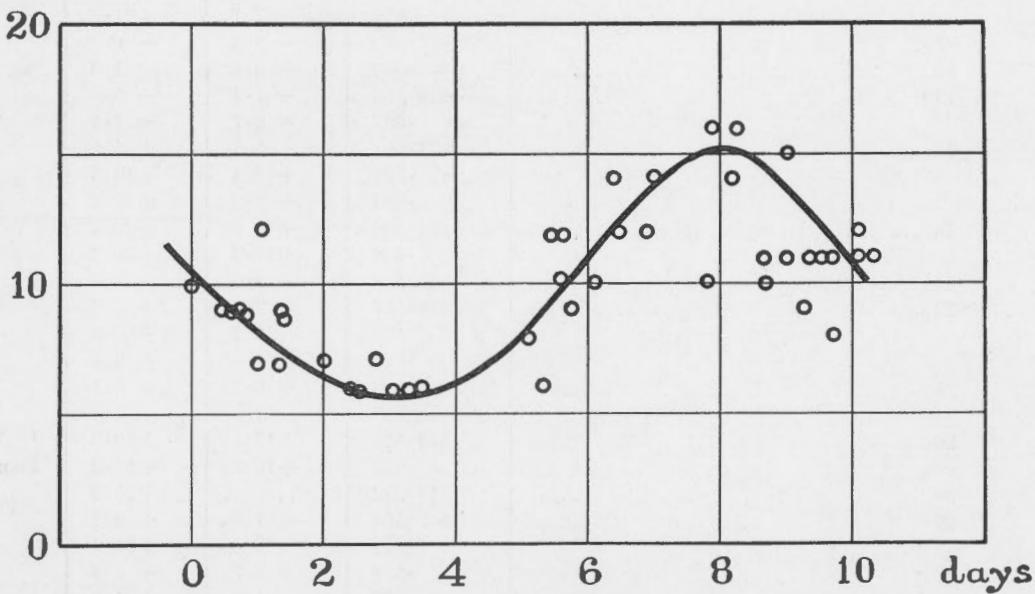
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FIG. 2. Zeta Geminorum. Variation of ratio of intensities of two close enhanced and arc lines.

VARIATION OF PERIOD

Several observers have pointed out the probability of a variation in the period of ξ Geminorum. Speaking of photometric observations Professor Mascart¹ says: "En particulier pour ξ Gémeaux la longueur de la période est depuis longtemps soupçonnée d'irregularités assez brusques et sans allure systématique reconnue; la longue série d'observations de Luizet révèle des variations de phases considérables; les observations de Moye en 1919-1920 sont concordantes tandis que en 1921, la période paraît brusquement

¹ Bul. de l'Obs. de Lyon, Vol. 4, 1922, p. 101.

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THE ORBITS OF FIVE SPECTROSCOPIC BINARIES

BY W. E. HARPER

The stars whose orbits are determined are given in the following table.

Star	α 1900		δ 1900		Vis. Mag.	Type
	h	m	°	'		
45 Aurigae.....	6	13·7	+53	30	5·41	F5
19 Leo Minoris.....	9	51·6	41	32	5·19	F4
105 Herculis.....	18	15·1	24	24	5·49	K5
22 Vulpeculae.....	20	11·2	23	12	5·38	G7
π Cephei.....	23	04·7	+74	51	4·56	G5

45 AURIGAE

Abstract.—Twenty-eight spectrograms of single-prism dispersion and measured on the spectro-comparator against Procyon as a standard serve to determine the orbital elements. Early Lick observations assist in fixing the period at 6·5013 days. The eccentricity is .019.

This star (1900 $\alpha = 6^{\text{h}} 13^{\text{m}}.7$, $\delta = +53^{\circ} 30'$) whose visual magnitude is 5.41 and type F5, was announced as a spectroscopic binary by Campbell in the *Publications of the Astronomical Society of the Pacific* for June, 1922.

Twenty-eight spectrograms obtained with the single-prism spectrograph whose dispersion at H γ is 29 angstroms per millimetre, were made during 1922, 1923, 1924 and 1925, and these form the basis of the determination of the orbit. The plates of 1923,

April 2, and 1924, April 7, were given half weight, as in the former a very narrow spectrum was secured and in the latter the focus was not of the best. Further, the plate of 1924, November 22, has not been used at all in the determination, owing to the fact that a few minutes' exposure of an A-type star was accidentally made on the same plate.

The spectrum contains numerous well-defined lines due principally to iron, titanium, manganese, chromium and calcium. On one plate, number 8541, there were measured 153 lines between $\lambda 3941$ and $\lambda 4600$. By selecting a plate of different exposure other lines could be measured and the total increased. In the list given in *Harvard Annals*, Volume 28, page 79, which lists the lines in stars of division c, there are 183 recorded between the same limits. The great majority, though not all, of the 153 measured in this star are found in that particular list.

Through the kindness of the Lick observers the data of their seven observations were furnished, and for convenience of reference these are tabulated here. All their plates were made with the three-prism Mills spectrograph and should be very reliable. The plates have assisted materially in fixing the period accurately, but otherwise have not been made use of in the determination. A systematic difference of -3.67 km. has been added to each velocity before the residuals as shown were obtained. Our own plates were measured on the spectrocomparator against the standard plate of Procyon, number 3375, and the velocities deduced are given in the table following. The tables list the phases of the observations as based upon the final elements, and the residuals from the final curve are given in the last column. The determination does not appear wholly satisfactory, as the probable error of a plate is ± 1.89 km. per sec., larger than one might expect from single-prism plates when the character of the spectrum is considered. In the final curve the way the observations fall above and below the curve around the γ -point is suggestive of the presence of the spectrum of the second component. The last observation was made on a fine-grained plate to see if the fainter spectrum could be recorded, but no certain evidence was obtained.

LICK OBSERVATIONS OF 45 AURIGAE

Plate Number	Date	Julian Date	Phase	Velocity	Lines	O-C
9503.....	1917 Nov. 1	2,421,534.036	6 291	+24.35	30	-2.14
10507.....	1919 Jan. 25	1,984.866	2.030	+ 3.60	32	-1.85
10901.....	Sept. 25	2,227.948	4.564	-19.43	31	+1.75
10934.....	Oct. 11	2,243.942	1.054	+31.86	30	+1.94
10992.....	Nov. 10	2,273.047	4.154	-27.64	31	-0.20
11030.....	Nov. 24	2,287.052	5.156	- 6.65	30	-0.58
11082.....	Dec. 29	2,422,322.935	2.032	+ 6.58	27	+1.19

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VICTORIA OBSERVATIONS OF 45 AURIGAE

Plate Number	Date	Julian Date	Phase	Velocity	Wt.	O-C
8348.....	1922 Nov. 11	2,423,370.963	3.350	-31.2	1	-1.5
8495.....	1923 Jan. 10	3,430.865	4.741	-19.0	1	+2.0
8536.....	" 28	3,448.782	3.154	-29.6	1	-2.6
8541.....	" 31	3,451.754	6.126	+19.9	1	+0.6
8578.....	Feb. 24	3,475.780	4.147	-27.3	1	+3.7
8603.....	" 26	3,477.764	6.131	+23.0	1	+3.6
8637.....	Mar. 2	3,481.770	3.635	-32.4	1	0.0
8677.....	" 19	3,498.695	1.056	+24.4	1	-1.8
8722.....	" 26	3,505.728	1.588	+12.8	1	-1.4
8723.....	" 26	3,505.745	1.605	+11.9	1	-1.9
8762.....	" 30	3,509.771	5.631	+ 5.3	1	+0.3
8775.....	April 2	3,512.653	2.012	+ 6.6	$\frac{1}{2}$	+4.4
8776.....	" 2	3,512.666	2.025	+ 6.2	$\frac{1}{2}$	+4.2
8808.....	" 9	3,519.719	2.576	-18.7	1	-5.0
8809.....	" 9	3,519.732	2.589	-16.6	1	-2.3
9706.....	1924 Mar. 3	3,848.702	6.494	+28.8	1	+2.2
9721.....	" 10	3,855.721	.511	+32.9	1	+2.1
9742.....	" 14	3,859.712	4.502	-26.3	1	-0.3
9828.....	April 7	3,883.681	2.466	- 5.5	$\frac{1}{2}$	+5.2
9829.....	" 7	3,883.708	2.493	- 3.4	$\frac{1}{2}$	+8.1
10859.....	Oct. 10	4,069.020	5.768	+ 6.4	1	-2.6
10942.....	Nov. 22	4,112.908	4.147	-24.5		
11101.....	Dec. 23	4,143.918	2.651	-14.2	1	+1.5
11175.....	1925 Jan. 23	4,174.794	1.020	+25.3	1	-1.4
11214.....	Feb. 14	4,196.730	3.452	-33.5	1	-2.3
11226.....	" 24	4,205.734	5.955	+10.0	1	-4.4
11260.....	Mar. 6	4,216.730	3.948	-33.0	1	-0.5
11320.....	" 16	2,424,226.702	.918	+28.0	1	-0.2

From the first few plates it was seen that the period was in the neighbourhood of 6.5 days. Our later observations defined this more closely and with the aid of the Lick results a definite value of 6.5013 days was established. Preliminary elements were then adopted as follows.

PRELIMINARY ELEMENTS

$$P = 6.5013 \text{ days}$$

$$e = .04$$

$$\omega = 354^\circ$$

$$K = 32.3 \text{ km.}$$

$$\gamma = -0.7 \text{ km.}$$

$$T = \text{J.D. } 2,423,634.597$$

The observations were grouped into 16 normal places and observation equations were built up according to the usual Lehman-Filhés form, connecting the residuals with the elements K, e, ω and T. In these equations

$$x = \delta \gamma$$

$$y = \delta K$$

$$z = K \cdot \delta e$$

$$u = K \cdot \delta \omega$$

$$v = 31.292 \delta T$$

NORMAL PLACES

	Mean Phase	Mean Velocity	Wt.	O-C			Mean Phase	Mean Velocity	Wt.	O-C	
				Prel.	Final					Prel.	Final
1	1.038	+24.85	2	-3.7	-1.66	9	4.502	-26.30	1	-0.8	-0.28
2	1.597	+12.40	2	-3.0	-1.92	10	4.741	-19.00	1	+1.6	+2.01
3	2.019	+ 6.40	1	+3.8	+4.47	11	5.631	+ 5.30	1	+0.5	+0.34
4	2.479	- 4.20	1	+7.0	+6.97	12	5.861	+ 8.20	2	-3.8	-3.64
5	2.605	-16.50	3	-1.8	-1.81	13	6.129	+21.40	2	+1.7	+2.29
6	3.252	-30.40	2	-2.5	-1.74	14	6.494	+28.80	1	+0.9	+2.23
7	3.543	-32.95	2	-2.0	-1.09	15	7.511	+32.90	1	0.0	+2.14
8	4.047	-30.15	2	+0.8	+1.74	16	7.918	+28.00	1	-2.3	-0.19

OBSERVATION EQUATIONS

1.....	1.000x	+ .904y	+ .389z	+ .499u	+ .537v	+3.7 = 0
2.....	1.000	+ .497	- .679	+ .885	+ .914	+3.0
3.....	1.000	+ .101	-1.002	+ .994	+ .994	-3.8
4.....	1.000	- .326	- .644	+ .926	+ .897	-7.0
5.....	1.000	- .433	- .450	+ .877	+ .843	+1.8
6.....	1.000	- .843	+ .648	+ .466	+ .435	+2.5
7.....	1.000	- .934	+ .939	+ .223	+ .209	+2.0
8.....	1.000	- .936	+ .856	- .224	- .203	-0.8
9.....	1.000	- .767	+ .211	- .595	- .556	+0.8
10.....	1.000	- .617	- .227	- .758	- .719	-1.6
11.....	1.000	+ .170	- .946	- .995	-1.010	-0.5
12.....	1.000	+ .394	- .695	- .939	- .970	+3.8
13.....	1.000	+ .631	- .219	- .811	- .852	-1.7
14.....	1.000	+ .885	+ .511	- .538	- .574	-0.9
15.....	1.000	+1.040	+ .998	- .025	- .023	0.0
16.....	1.000	+ .959	+ .602	+ .390	+ .422	+2.3

From these were formed the normal equations

$$\begin{aligned}
 25.000x - & .428y + .631z + 2.228u + 2.100v + 19.700 = 0 \\
 12.613 - & 2.668 - 1.479 - 1.419 + 5.328 \\
 & 10.991 - .367 - .256 + 7.712 \\
 & 12.287 + 12.338 + 5.291 \\
 & 12.405 + 5.513
 \end{aligned}$$

from which there resulted the corrections as follows:

$$\begin{aligned}
 \delta\gamma &= -0.82 \text{ km.} \\
 \delta K &= -0.56 \text{ km.} \\
 \delta e &= -0.021 \\
 \delta\omega &= -23^\circ.40 \\
 \delta T &= -0.431 \text{ days}
 \end{aligned}$$

The corrections for ω and T are large, but uncertainty in their determination is always present when the eccentricity is as low as in this case, resulting as it does in almost identical coefficients in the observation and normal equations for these two elements. Had either element been considered fixed, as is often done, the correction to the other would have been vanishingly small.

The sum of the squares of the residuals for the normal places was reduced from 184.5 to 156.6, or about 15 per cent, and satisfactory agreement existed between equation and ephemeris residuals.

FINAL ELEMENTS

$$\begin{aligned}
 P &= 6.5013 \text{ days} \\
 e &= .019 \pm .026 \\
 \omega &= 330^\circ.60 \pm 40^\circ.85 \\
 \gamma &= -1.52 \text{ km.} \pm 0.57 \text{ km.} \\
 K &= 31.74 \text{ km.} \pm 1.08 \text{ km.} \\
 T &= \text{J.D. } 2,423,634.166 \pm 0.741 \text{ day} \\
 a \sin i &= 2,837,000 \text{ km.}
 \end{aligned}$$

The graph shown (Fig. 1) represents the final elements with the observations as grouped.

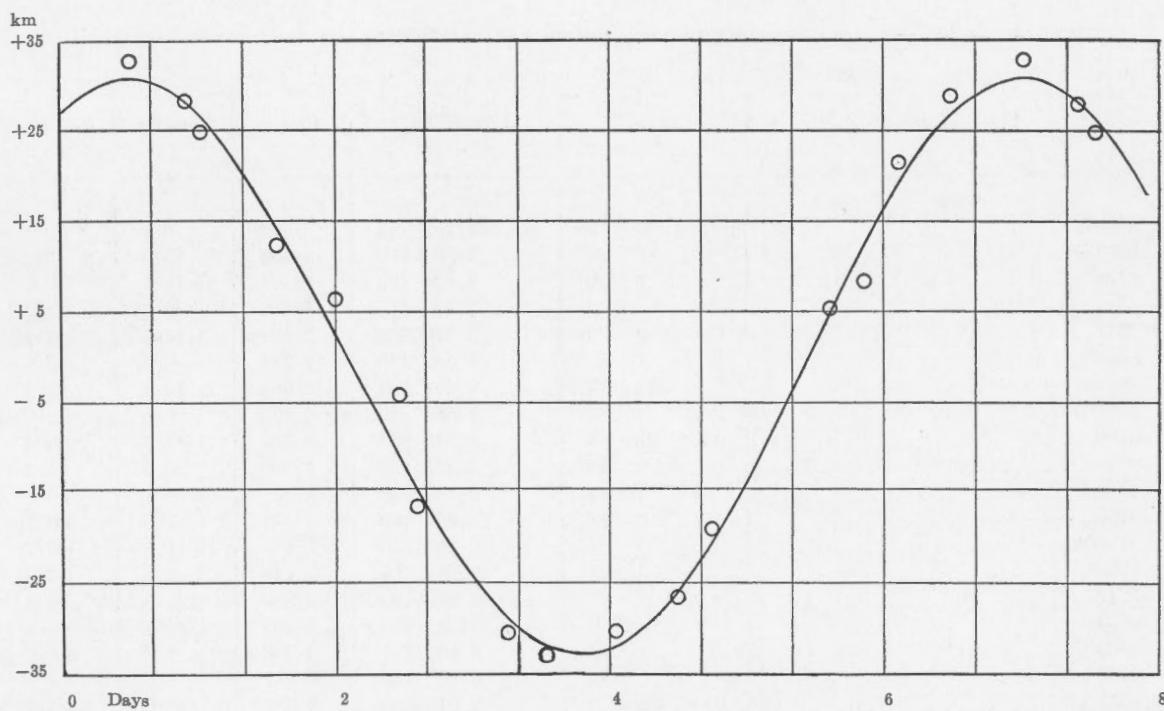


FIG. 1—Radial Velocity Curve of 45 Aurigae

In our absolute magnitude work we found from the ratios of six pairs of lines an absolute magnitude of +1.5 for this star corresponding to a parallax of 0''.016.

In the foregoing the dates are given in Greenwich Mean Time as used prior to 1925.

Dominion Astrophysical Observatory,
Victoria, B.C.

March, 1925.

19 LEO MINORIS

Abstract.—Thirty-three spectrograms of this star obtained in 1923, 1924 and 1925 with the single-prism spectrograph serve to determine the orbital elements. Its spectrum is F4 and the plates were measured on the spectrocomparator against Procyon as a standard. The probable error of a plate is ± 1.2 km./sec. The period is 9.283 days and the eccentricity small.

The star 19 Leo Minoris, Boss 2665 (1900 $\omega = 9^{\text{h}} 51^{\text{m}}.6$, $\delta = +41^{\circ} 32'$), visual magnitude 5.19 and type F4, was noted to be a spectroscopic binary from the first two plates made in 1923. A total of 33 plates have been obtained with the single-prism spectrograph, and these serve as the basis for the determination of the orbital elements. The lines of the F4 spectrum are well defined and the plates were measured against Procyon on the spectrocomparator. As the star is bright the plates are all well exposed and, while two are slightly inferior to the rest, they have all been weighted equally in the solution. The probable error of a plate on the basis of the final elements is ± 1.2 km./sec. and is quite satisfactory.

OBSERVATIONS OF 19 LEO MINORIS

Plate Number	Date	Julian Date	Phase	Velocity	Residual O-C
8680.....	1923 Mar. 19	2,423,498.773	.178	+ 6.2	+0.4
8702.....	" 24	3,503.779	5.184	-25.3	-0.2
8726.....	" 26	3,505.796	7.201	-11.7	-0.2
8779.....	April 2	3,512.717	4.839	-26.5	-1.3
8811.....	" 9	3,519.763	2.602	-11.7	+0.1
8866.....	" 23	3,533.725	7.281	- 9.9	+0.6
8943.....	May 7	3,547.694	2.684	-14.1	-1.4
8977.....	" 22	3,562.716	8.423	- 0.9	-1.3
9709.....	1924 Mar. 3	3,848.843	6.777	-15.3	+0.4
9725.....	" 10	3,855.839	4.490	-26.6	-1.8
9744.....	" 14	3,859.780	8.431	+ 0.1	-0.4
9767.....	" 17	3,862.793	2.161	- 7.6	-0.1
9785.....	" 22	3,867.740	7.108	-11.7	+0.7
9799.....	" 24	3,869.780	9.148	+ 8.0	+3.3
9813.....	" 28	3,873.795	3.880	-22.8	-0.4
9831.....	April 8	3,884.765	5.567	-24.4	-0.4
9838.....	" 14	3,890.737	2.256	- 6.6	+1.8
9850.....	" 21	3,897.758	9.277	+ 5.6	+0.5
9935.....	May 9	3,915.693	8.646	- 1.2	-3.5
9978.....	" 19	3,925.705	.092	+ 3.4	-2.1
10008.....	" 23	3,929.700	4.087	-26.0	-2.5
10055.....	June 2	3,939.705	4.809	-22.9	+2.4
10108.....	" 16	3,953.724	.262	+ 8.0	+2.5
10164.....	" 26	3,963.722	.977	- 0.8	-3.6
11105.....	Dec. 24	4,144.008	4.886	-27.3	-2.0
11141.....	1925 Jan. 9	4,160.955	3.267	-14.7	+3.5
11185.....	" 24	4,174.964	7.993	- 2.6	+0.6
11263.....	Mar. 6	4,216.775	3.389	-17.7	+1.4
11310.....	" 14	4,224.840	2.171	- 8.6	-1.0
11323.....	" 16	4,226.799	4.130	-23.1	+0.6
11346.....	" 22	4,232.912	.960	+ 1.7	-1.3
11388.....	" 30	4,240.851	8.899	+ 4.6	+0.9
11415.....	April 6	2,424,247.661	6.426	-16.7	+2.0

The period was quite early seen to be about 9.3 days, and a value of 9.283 was established from the first two years' observations. It has not been necessary to change this for the 1925 series. The preliminary elements adopted from graphical methods follow.

PRELIMINARY ELEMENTS

$$\begin{aligned}P &= 9.283 \text{ days} \\e &= .10 \\ \omega &= 345^\circ \\ \gamma &= -10.75 \text{ km.} \\ K &= 16.0 \text{ km.} \\ T &= \text{J.D. } 2,423,498.500\end{aligned}$$

The observations were grouped into 17 normal places and observation equations built up in the usual way connecting the elements with the residuals for the normal places.

NORMAL PLACES

	Mean Phase		Mean Velocity	Wt.	Residual O-C	
	Prel.	Final			Prel.	Final
1.....	8.994	8.899	+ 4.6	1	-0.2	+0.9
2.....	.079	9.267	+ 5.7	3	-0.8	+0.7
3.....	.315	.220	+ 7.1	2	+0.3	+1.9
4.....	1.064	.969	+ 0.4	2	-3.6	-2.5
5.....	2.291	2.196	- 7.6	3	+0.3	+0.3
6.....	2.738	2.643	-12.9	2	-0.4	-0.4
7.....	3.423	3.328	-16.2	2	+2.3	+2.5
8.....	4.127	4.032	-24.0	3	-1.2	-0.8
9.....	4.585	4.490	-26.6	1	-2.1	-1.8
10.....	4.940	4.845	-25.6	3	-0.5	-0.3
11.....	5.279	5.184	-25.3	1	-0.2	-0.2
12.....	5.662	5.567	-24.4	1	0.0	-0.4
13.....	6.521	6.426	-16.7	1	+3.3	+2.0
14.....	7.038	6.943	-13.5	2	+2.1	+0.5
15.....	7.336	7.241	-10.8	2	+1.7	+0.2
16.....	8.088	7.993	- 2.6	1	+1.2	+0.6
17.....	8.595	8.500	- 0.7	3	-2.3	-1.9

In the observation equations the following substitutions have been made in the Lehmann-Filhés coefficients.

$$\begin{aligned}x &= \delta\gamma \\y &= \delta K \\z &= K \cdot \delta e \\u &= K \cdot \delta\omega \\v &= 10.994 \cdot \delta T\end{aligned}$$

OBSERVATION EQUATIONS OF 19 LEO MINORIS

							Wt.
1.....	1.000x	+ .974y	+ .725z	- .506u	- .578v	+ 0.2	= 0 1
2.....	1.000	+1.078	+1.239	- .220	- .235	+ 0.8	3
3.....	1.000	+1.097	+ .966	- .026	000	- 0.3	2
4.....	1.000	+ .920	+ .064	+ .542	+ .644	+ 3.6	2
5.....	1.000	+ .181	- .998	+ .970	+ .961	- 0.3	3
6.....	1.000	- .107	- .759	+ .953	+ .893	+ 0.4	2
7.....	1.000	- .482	- .043	+ .789	+ .694	- 2.3	2
8.....	1.000	- .756	+ .681	+ .496	+ .427	+ 1.2	3
9.....	1.000	- .860	+ .949	+ .263	+ .234	+ 2.1	1
10.....	1.000	- .899	+ .996	+ .068	+ .076	+ 0.5	3
11.....	1.000	- .899	+ .903	- .120	- .077	+ 0.2	1
12.....	1.000	- .854	+ .640	- .335	- .259	0.0	1
13.....	1.000	- .302	- .853	- .943	- .890	- 2.1	2
14.....	1.000	- .109	-1.013	-1.004	- .989	- 1.7	2
15.....	1.000	+ .434	- .642	- .968	-1.052	- 1.2	1
16.....	1.000	+ .773	+ .132	- .763	- .866	+ 2.3	3
17.....	1.000	- .580	- .321	- .762	- .670	- 3.3	1

From these there resulted the following normal equations:—

$$\begin{aligned}
 33.000x + 1.380y + 5.128z - 1.153u - 6.609v + 6.700 &= 0 \\
 18.061 + 1.154 - 2.799 - 2.882 + 13.026 \\
 21.716 - .234 - .349 + 19.376 \\
 14.878 + 14.723 + 7.752 \\
 14.696 + 7.340
 \end{aligned}$$

which gave corrections as follows:—

$$\begin{aligned}
 \delta\gamma &= - .03 \text{ km.} \\
 \delta K &= - .76 \text{ km.} \\
 \delta e &= - .052 \\
 \delta \omega &= + 6^\circ.09 \\
 \delta T &= + .095 \text{ days}
 \end{aligned}$$

The sum of the squares of the residuals for the normal places was reduced from 91.2 to 56.6 and satisfactory agreement existed between equation and ephemeris residuals, the numerical average being 0.04 km.

The final elements, then, with their probable errors are the following:

FINAL ELEMENTS

$$\begin{aligned}
 P &= 9.283 \text{ days} \\
 e &= .048 \pm .020 \\
 \omega &= 351^\circ.09 \pm 14^\circ.95 \\
 \gamma &= -10.78 \pm 0.26 \text{ km.} \\
 K &= 15.24 \pm 0.35 \text{ km.} \\
 T &= \text{J.D. } 2,423,498.595 \pm 0.383 \text{ day} \\
 a \sin i &= 1,943,130 \text{ km.}
 \end{aligned}$$

The graph (Fig. 2) represents the final elements and the grouped observations are shown.

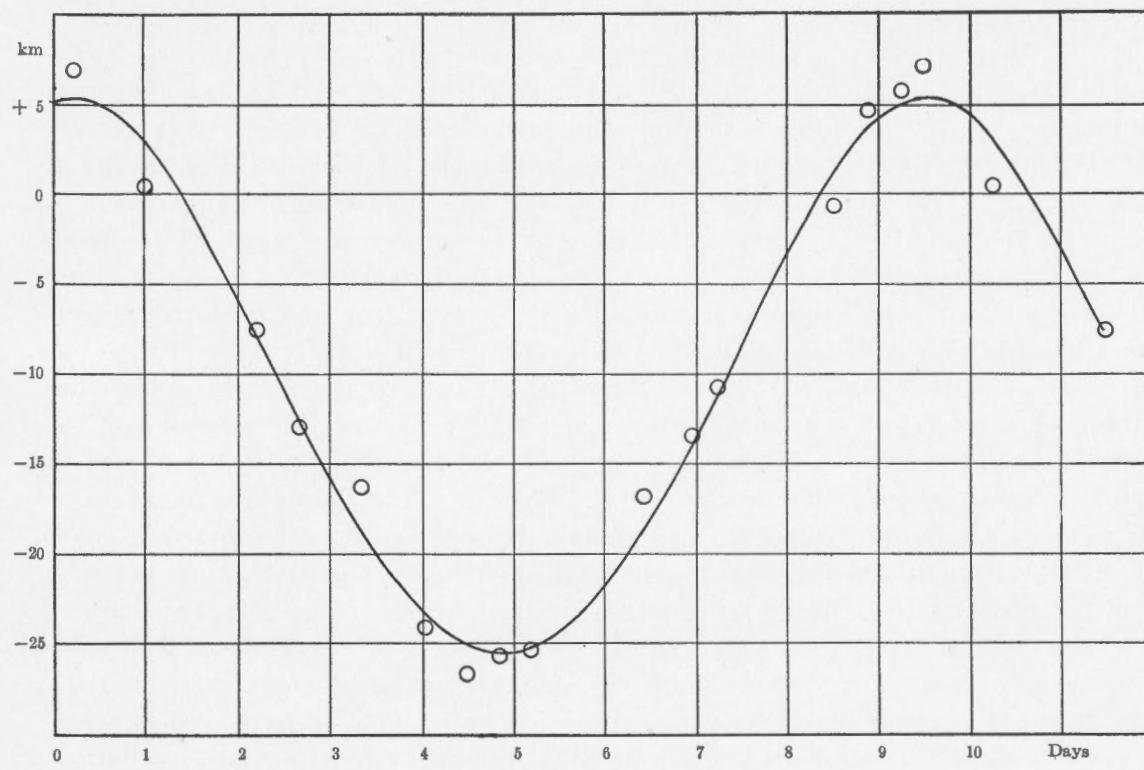


FIG. 2.—Radial Velocity Curve of 19 Leo Minoris

All times are expressed in Greenwich Mean Time as used prior to 1925.

Dominion Astrophysical Observatory,
Victoria, B.C.

April 10, 1925.

105 HERCULIS

Abstract.—Twenty-five spectrograms of this K-type star were obtained with the single-prism spectrograph since April, 1922, and upon these a solution of the orbit is based. The period adopted is 478 days, but this is uncertain to the extent of a few days, as the observations cover only two cycles. The eccentricity is .398 with semi-amplitude 16.07 km./sec.

The star 105 Herculis (1900 $\alpha = 18^{\text{h}} 15^{\text{m}}.1$, $\delta = +24^{\circ} 24'$) whose visual magnitude is 5.49 and type K5, was first observed here on April 17, 1922. A total of 25 plates has been secured with the single-prism spectrograph and these serve as the basis for the determination of the orbit of this spectroscopic binary. In our parallax work we gave the type as K2, but the best exposed plate, made probably since that type was assigned, shows it to be closer to K5 which Harvard gives for the star.

The plates as a whole are much inferior to our average run and the writer accepts the responsibility for such being the case. The star seems unusually red and it so happened that on many of the nights when the star was observed it was more or less hazy, resulting in a weakened spectrum in the violet. The plates were measured on the spectrocomparator against Arcturus as a standard, and the velocities deduced with the weights assigned are given in the table of observations. The phases are based on the final value of periastron passage with the period 478 days and the residuals are scaled from the curve shown which represents the final elements. The elements are not to be considered as definite for, owing to the fact that only two cycles of the period are covered, the period must be uncertain to the extent of a few days. Observations will be taken here in future years to improve the value of the period and by means of which it is hoped to lessen the probable errors of the elements. These are rather high due to the probable error of a plate being ± 2.0 km. per second and also to the small range in velocity variation.

OBSERVATIONS OF 105 HERCULIS

Plate Number	Date	Julian Date	Phase	Velocity	Wt.	O-C
7470.....	1922 April 17	2,423,162.001	99.35	- 2.7	3	-0.7
7622.....	May 28	3,203.867	141.22	- 7.8	3	-5.0
8254.....	Oct. 27	3,355.650	293.00	-21.2	2	-7.0
8284.....	Nov. 2	3,361.625	298.98	-11.4	2	+2.7
8308.....	" 8	3,367.572	304.92	-11.4	3	+3.4
8709.....	1923 Mar. 25	3,504.007	441.36	-34.3	3	-0.3
8875.....	April 23	3,533.971	471.32	-26.6	3	+3.5
8950.....	May 7	3,547.906	7.26	-21.8	2	+2.3
8971.....	" 19	3,559.942	19.29	-19.5	3	-0.6
9026.....	June 6	3,577.891	37.24	-11.6	2	-1.0
9084.....	" 25	3,596.846	56.20	-7.3	3	-1.6
9190.....	July 20	3,621.827	81.18	-4.3	3	-1.6
9304.....	Aug. 17	3,649.742	109.09	-0.7	3	+1.3
9493.....	Oct. 8	3,701.613	160.96	-3.4	3	+0.2
9941.....	1924 May 9	3,915.937	375.29	-22.0	3	+2.1
10065.....	June 2	3,939.950	399.30	-28.3	3	-0.2
10198.....	" 30	3,967.895	427.24	-38.8	1	-6.0
10242.....	July 7	3,974.780	434.13	-34.1	3	-0.5
10534.....	Aug. 25	4,023.699	5.05	-21.6	3	+3.6
10634.....	Sept. 8	4,037.729	19.08	-23.7	3	-5.2
10906.....	Oct. 27	4,086.592	67.94	+ 0.1	3	+4.0
10908.....	" 31	4,090.587	71.94	- 2.8	3	+0.6
10944.....	Nov. 24	4,114.558	95.91	+ 3.4	2	+5.4
11430.....	1925 April 6	4,247.978	229.33	- 8.2	3	-0.2
11503.....	" 13	2,424,254.981	236.33	- 8.6	2	-0.3

NORMAL PLACES

	Mean Phase Final	Mean Velocity	Wt.	O-C	
				Prel.	Final
1.....	102.14	-0.42	.8	+2.40	+1.62
2.....	151.09	5.60	.6	-2.18	-2.50
3.....	232.13	8.36	.5	- .30	- .10
4.....	299.82	14.20	.7	- .17	+ .15
5.....	375.29	22.00	.3	+1.94	+2.12
6.....	399.30	28.30	.3	- .35	- .22
7.....	436.24	34.86	.7	-1.72	-1.18
8.....	471.32	26.60	.3	+2.09	+3.47
9.....	13.16	21.64	1.1	-1.26	- .57
10.....	37.24	11.60	.2	- .43	-1.01
11.....	56.20	7.30	.3	- .61	-1.59
12.....	73.69	-2.67	.9	+1.69	+ .67

PRELIMINARY ELEMENTS

$$\begin{array}{ll} P = 478 \text{ days} & \gamma = -14.30 \text{ km.} \\ e = .38 & K = 15.35 \text{ km.} \\ \omega = 230^\circ & T = \text{J.D. } 2,423,536.09 \end{array}$$

From graphical methods the foregoing preliminary elements were adopted and then a set of observation equations according to the form of Lehmann-Filhés was built up connecting the five elements γ , K , e , ω and T with the residuals for the grouped observations. In these observation equations, weighted as above, the following substitutions were made for the sake of homogeneity.

$$\begin{array}{ll} x = \delta\gamma & u = -K.\delta\omega \\ y = \delta K & v = .25495 \delta T \\ z = K.\delta e & \end{array}$$

OBSERVATION EQUATIONS FOR 105 HERCULIS

1.....	1.000x	+ .748y	- .420z	- .415w	- .080v	-2.40	= 0
2.....	1.000	+ .709	- .961	+ .013	+ .139	+2.18	
3.....	1.000	+ .407	- .659	+ .470	+ .292	+ .30	
4.....	1.000	+ .018	+ .141	+ .676	+ .414	+ .17	
5.....	1.000	- .628	+1.106	+ .634	+ .628	-1.94	
6.....	1.000	- .889	+1.060	+ .475	+ .668	+ .35	
7.....	1.000	-1.227	- .232	- .105	+ .260	+1.72	
8.....	1.000	- .937	- .778	-1.010	-1.372	-2.09	
9.....	1.000	- .396	+ .750	-1.277	-1.735	+1.26	
10.....	1.000	+ .204	+1.420	-1.183	-1.185	+ .43	
11.....	1.000	+ .496	+ .940	- .962	- .693	+ .61	
12.....	1.000	+ .648	+ .340	- .740	- .376	-1.69	

These gave the following normal equations:—

$$\begin{array}{ccccccccc} 6.700x & - & .018y & + & .806z & - & 2.258u & - & 2.078v & - & .109 = 0 \\ 3.136 & - & .795 & - & .074 & + & .326 & - & 2.488 \\ & & 3.237 & - & 1.229 & - & 1.485 & - & .043 \\ & & & & 3.914 & + & 4.071 & + & .229 \\ & & & & & & 4.906 & - & .755 \end{array}$$

which resulted in the following corrections to the elements:—

$$\begin{aligned}\delta\gamma &= -0.06 \text{ km.} \\ \delta K &= +0.72 \text{ km.} \\ \delta e &= +0.018 \\ \delta\omega &= +4^\circ.47 \\ \delta T &= +4.56 \text{ days}\end{aligned}$$

The sum of the squares of the residuals for the normal places was reduced a small amount from 16.54 to 13.53 and good agreement existed between equation and ephemeris residuals, none being greater than .06.

The following, then, are the elements as determined for the present.

FINAL ELEMENTS

$$\begin{aligned}P &= 478 \text{ days} \\ e &= 0.398 \pm 0.038 \\ \omega &= 234^\circ.47 \pm 5^\circ.11 \\ \gamma &= -14.36 \text{ km.} \pm 0.41 \text{ km.} \\ K &= 16.07 \text{ km.} \pm 0.57 \text{ km.} \\ T &= \text{J.D. } 2,423,540.65 \pm 4.75 \\ a \sin i &= 96,904,000 \text{ km.}\end{aligned}$$

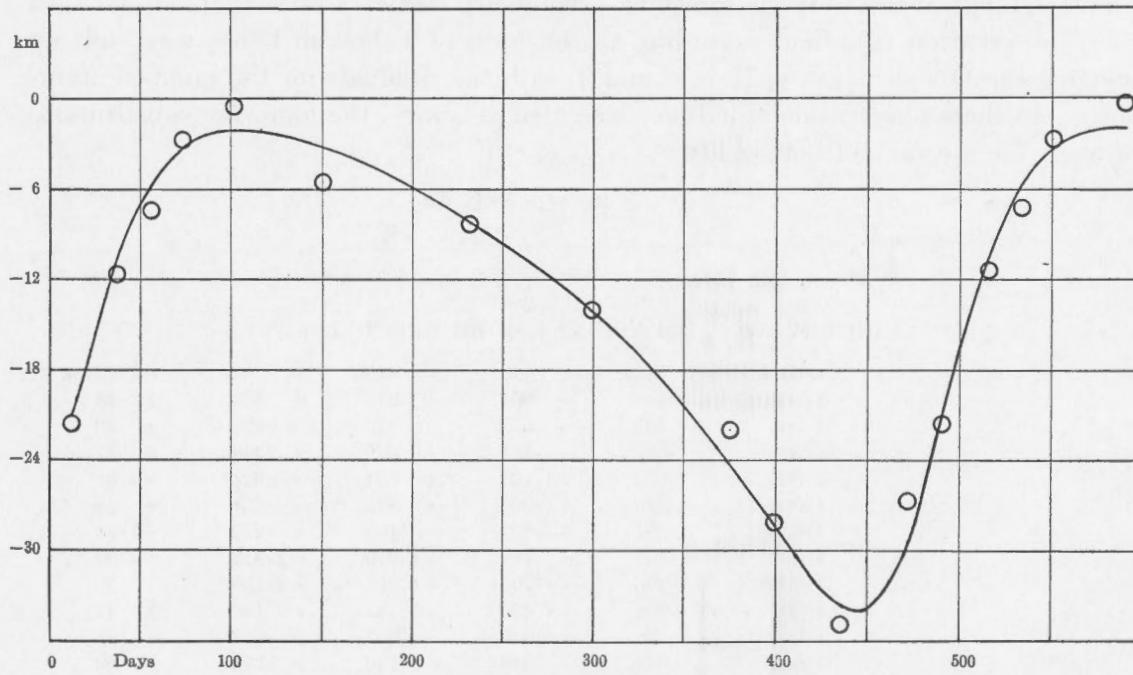


FIG. 3.—Radial Velocity Curve of 105 Herculis

In the foregoing the times are given in Greenwich Mean Time in the sense used prior to 1925.

Dominion Astrophysical Observatory,
Victoria, B.C.

April 24, 1925.

22 VULPECULAE

Abstract.—Twenty-seven spectrograms of this star whose visual magnitude is 5·4 and type G7 are made the basis of a determination of its spectroscopic orbit. The period is 251 days, the eccentricity .042 and the probable error of a plate $\pm 1\cdot0$ km. per sec.

Observations were begun on this star, whose right ascension is $20^{\text{h}} 11^{\text{m}} \cdot 2$ and declination $+23^{\circ} 12'$, in the year 1922 and twenty-seven spectrograms have been secured on which to base a determination of the orbital elements. The value obtained for the period was 251·0 days, and the observations, while not uniformly distributed over the period, are nevertheless sufficiently so to ensure a fair determination of the elements.

The spectrum is of type G7 and the plates have been measured on the spectro-comparator using α Boötis, No. 2702, as a standard plate. The table following contains the phases reckoned from the time of periastron, the velocities, the weights assigned the plates and the residual for each from the curve representing the final elements. Through a slip the weight 1 was used for the first plate, whereas it should have been 2, but any correction would be negligible.

OBSERVATIONS OF 22 VULPECULAE

Plate	Date	Julian Date	Phase	Velocity	Wt.	O-C
7852.....	1922 July 28	2,423,264.866	100·016	-24·1	1	+1·5
8009.....	Aug. 28	3,295·739	130·889	-8·0	3	-0·4
8027.....	Sept. 1	3,299·802	134·952	-2·9	3	+2·8
8052.....	" 7	3,305·815	140·965	-5·8	3	-2·4
8078.....	" 10	3,308·766	143·916	-2·4	2	-0·1
8136.....	" 16	3,314·798	149·948	-3·6	2	-3·1
8213.....	Oct. 9	3,337·699	170·849	+4·3	3	+1·8
8255.....	" 27	3,355·697	190·847	+0·6	3	+1·8
8337.....	Nov. 11	3,370·571	205·721	-6·8	3	+0·8
8379.....	" 14	3,373·650	208·800	-12·1	2	-2·5
8954.....	1923 May 7	3,547·989	132·139	-6·7	2	+0·5
9086.....	June 25	3,596·908	181·058	+1·8	3	+0·3
9192.....	July 20	3,621·871	206·021	-7·6	3	+0·3
9306.....	Aug. 17	3,649·798	233·948	-27·1	3	-0·7
9495.....	Oct. 8	3,701·667	34·817	-50·6	3	+0·4
9526.....	" 12	3,705·671	38·821	-49·6	2	+1·7
9539.....	" 22	3,715·594	48·744	-51·8	3	-1·1
10066.....	1924 June 2	3,939·964	22·114	-48·4	2	+0·4
10247.....	July 7	3,974·884	57·034	-50·7	3	-2·5
10331.....	" 21	3,988·844	70·994	-41·5	3	+1·0
10536.....	Aug. 25	4,023·758	105·908	-19·8	3	+2·1
10623.....	Sept. 6	4,035·753	117·903	-15·4	3	-0·8
10725.....	" 15	4,044·718	126·868	-9·3	3	+0·7
10778.....	" 26	4,055·694	137·844	-4·4	3	+0·1
10850.....	Oct. 9	4,068·723	150·873	-1·6	3	-1·2
10910.....	" 31	4,090·670	172·820	+2·3	2	-0·2
10945.....	Nov. 24	2,424,114·600	196·750	-2·1	2	+1·3

NORMAL PLACES OF 22 VULPECULAE

—	Mean Phase	Mean Velocity	Wt.	Residual O-C	
				Prel.	Final
1.....	100.016	-24.10	1	+1.67	+1.52
2.....	105.908	-19.80	3	+2.30	+2.10
3.....	117.903	-15.40	3	-0.48	-0.76
4.....	129.694	-8.16	8	+0.38	+0.08
5.....	137.920	-4.37	9	+0.37	+0.07
6.....	148.621	-2.40	7	-1.63	-1.63
7.....	172.837	+3.50	5	+0.73	+0.89
8.....	185.952	+1.20	6	+0.19	+0.64
9.....	202.133	-4.92	5	0.00	+0.73
10.....	207.135	-9.40	5	-1.89	-1.07
11.....	233.948	-27.10	3	-1.47	-0.70
12.....	22.114	-48.40	2	+0.26	+0.43
13.....	36.419	-50.20	6	+0.97	+1.06
14.....	52.889	-51.25	5	-1.94	-1.85
15.....	70.994	-41.50	3	+0.98	+1.04

The observations were grouped into 15 normal places on the basis of phase. A value of the period of 251.0 days seemed most satisfactory and while there are only four cycles covered by the observations and this value may be in error by as much as a day, it was not considered that any great improvement would result by including the period in the least-squares solution. Moreover, as the eccentricity was small it was necessary to consider either T or ω fixed, and the former was the element taken as fixed.

PRELIMINARY ELEMENTS

$$\begin{array}{ll} P = 251.0 \text{ days} & \gamma = -23.52 \text{ km.} \\ e = .05 & K = 27.0 \text{ km.} \\ \omega = 120^\circ & T = \text{J.D. } 2,423,415.850 \end{array}$$

With these, observation equations were built up connecting the residuals with the four elements, e , ω , γ and K and for homogeneity the following substitutions were made:

$$\begin{array}{ll} x = \delta\gamma & z = K \delta e \\ y = \delta K & u = -K \cdot \delta\omega \end{array}$$

OBSERVATION EQUATIONS OF 22 VULPECULAE

1.....	1.000x	- .083y	+ .140z	- .955u	-1.67	= 0
2.....	1.000	+ .053	- .027	- .954	-2.30	
3.....	1.000	+ .319	- .336	- .896	+0.48	
4.....	1.000	+ .555	- .578	- .771	-0.38	
5.....	1.000	+ .696	- .701	- .650	-0.37	
6.....	1.000	+ .843	- .785	- .454	+1.63	
7.....	1.000	+ .974	- .435	+ .090	-0.73	
8.....	1.000	+ .909	+ .155	+ .402	-0.19	
9.....	1.000	+ .689	+1.029	+ .743	.00	
10.....	1.000	+ .593	+1.235	+ .829	+1.89	
11.....	1.000	- .078	+ .811	+1.042	+1.47	
12.....	1.000	+ .931	-1.186	+ .467	-0.26	
13.....	1.000	-1.024	- .386	+ .097	-0.97	
14.....	1.000	- .955	+ .280	- .323	+1.94	
15.....	1.000	- .702	+ .698	- .693	-0.98	

These resulted in the following normal equations:—

$$\begin{aligned}
 7.100x + 1.932y - .540z - 1.047u + 1.031 &= 0 \\
 3.995 - .508 - .178 + .286 \\
 3.322 + 1.935 + 1.498 \\
 2.907 + 1.541
 \end{aligned}$$

from which the following corrections were obtained:—

$$\delta\gamma = - .23 \text{ km.}$$

$$\delta K = - .01 \text{ km.}$$

$$\delta e = - .008$$

$$\delta \omega = + 1^\circ .0$$

The following, then, are the final elements obtained, with their probable errors attached.

FINAL ELEMENTS

$$\begin{aligned}
 P &= 251.0 \text{ days} \\
 e &= .042 \pm .015 \\
 \omega &= 121^\circ .0 \pm 0^\circ .93 \\
 \gamma &= -23.75 \text{ km.} \pm 0.24 \text{ km.} \\
 K &= 26.99 \text{ km.} \pm 0.31 \text{ km.} \\
 T &= \text{J.D. } 2,423,415.850 \\
 a \sin i &= 93,072,000 \text{ km.}
 \end{aligned}$$

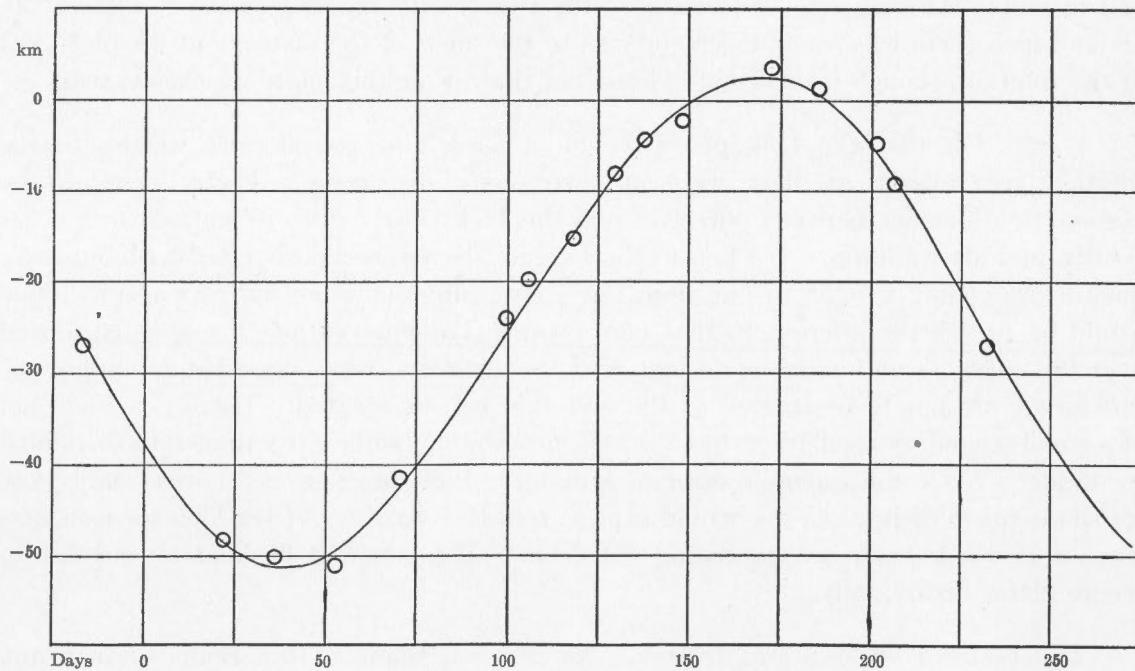


FIG. 4.—Radial Velocity Curve of 22 Vulpeculae

The curve (Fig. 4) accompanying represents the final elements, and on it are shown the observations as grouped.

Dominion Astrophysical Observatory,
Victoria, B.C.

Dec. 8, 1924.

π CEPHEI

Abstract.—Twenty-three spectrograms taken with the single-prism spectrograph and measured on the spectrocomparator against the sky as a standard, were made the basis of the determination of the elements. Five observations taken 25 years ago at the Lick Observatory were made use of also and fixed the period as 556.2 days. The semi-amplitude is 23.02 km. and the eccentricity 0.281.

The star π Cephei (1900 $\alpha = 23^{\text{h}} 04^{\text{m}}.7$, $-\delta = +74^{\circ} 51'$, visual magnitude 4.56 and type G5) was announced¹ as a spectroscopic binary from the Lick Observatory from five plates taken in the years 1899 and 1900. The results of four plates made at the Bonn Observatory in the years 1909 and 1912 have since been published² as well as two of Hnatek³ at Vienna in 1913. For convenience of reference all are given in the table of observations.

The star is a long period visual binary listed as number 12196 in Burnham's catalogue. While the separation at present is less than a second of arc, yet the yellow component to which the present discussion relates is over two magnitudes brighter than the fainter and hence the measures should not be vitiated to any appreciable degree by the light from the fainter star.

The star has been observed here with the single-prism instrument since the beginning of 1922. The measures have been made on the comparator against the sky as a standard and in many cases against Arcturus also, the two results agreeing closely. Plate 8030, about which there was some uncertainty as to the focus of the instrument was not used in the solution, though its residual is less than that of another plate which was used.

It was felt that the Lick plates would, if used, add considerable weight to the solution, particularly as they were of three-prism dispersion. There seems to be systematic difference between ourselves and the Lick Observatory as judged from other results, and after adding -1.5 km. to their values they were incorporated with our own. Such a proceeding is open to question, but a determination from our own results alone would be very little different to that here given. The observations are not distributed over the curve as uniformly as desired, and the elements, while regarded as closely approximate, are not to be treated as the best that can be secured. There is a suspicion of a small secondary oscillation, but the measures are not sufficiently numerous or refined to decide. While the probable error of a plate, ± 1.58 km. per sec., is reasonably low for single-prism dispersion, one would expect from the character of the lines for measurement a probable error not exceeding ± 1.0 km. The star will be kept on our list to secure plates occasionally.

The table of observations follows. No use was made of the Bonn and Vienna single-prism results, though the residuals from our curve are tabulated and are exceedingly small for the Bonn Observatory.

¹ Ap. J. Vol. 14 p. 138

² A.N. 4750.

A.N. 197, p. 187

OBSERVATIONS OF π CEPHEI

Observatory Plate No.	Date	Julian Date	Phase	Velocity	O-C
Lick III.....	1899 Aug. 8	2,414,875.9	193.37	-33.0	+0.6
"	" 23	4,890.9	208.37	-36.0	-1.4
"	" 29*	4,896.9	214.37	-37.0	-2.0
"	1900 Oct. 7	5,300.9	62.17	-5.0	+1.0
"	Dec. 24	5,378.9	140.17	-23.0	+4.0
Bonn I.....	1909 Oct. 24	8,604.32	28.39	+3.1	-1.6
"	1912 Sept. 26	9,672.39	540.26	+8.9	-0.4
"	Oct. 9	9,685.34	553.21	+11.0	+1.2
"	Oct. 11	2,419,687.36	555.23	+8.8	-1.0
Vienna I.....	1913 Oct. 31	2,420,072.332	384.00	-20.3	+7.9
"	Nov. 21	0,093.308	404.98	-28.5	-3.5
Victoria—					
6975.....	1922 Jan. 6	2,423,061.594	36.07	+3.8	+1.4
8030.....	Sept. 1	3,299.869	274.34	-30.8	+4.9
8258.....	Oct. 27	3,355.772	330.24	-37.2	-3.3
8286.....	Nov. 2	3,361.672	336.14	-34.3	-0.9
8307.....	" 5	3,364.772	339.24	-32.5	+0.7
8311.....	" 8	3,367.664	342.14	-27.6	+5.4
8433.....	" 27	3,386.687	361.16	-28.4	+2.4
8497.....	1923 Jan. 13	3,433.594	408.07	-24.8	-0.1
9312.....	Aug. 17	3,649.969	68.24	-10.6	-2.0
9501.....	Oct. 8	3,701.848	120.12	-18.8	+4.2
9566.....	" 26	3,719.772	138.04	-25.6	+0.9
10250.....	1924 July 7	3,974.959	393.23	-27.7	-1.0
10334.....	" 21	3,988.961	407.23	-26.0	-1.3
10571.....	Aug. 29	4,027.895	446.17	-20.0	-3.3
10610.....	Sept. 3	4,032.925	451.20	-13.6	+1.9
10627.....	" 6	4,035.909	454.18	-12.3	+1.9
10636.....	" 8	4,037.876	456.15	-15.4	-1.4
10727.....	" 15	4,044.821	463.09	-10.8	+1.0
10853.....	Oct. 9	4,068.832	487.10	-5.8	-1.3
10989.....	Nov. 28	4,118.723	537.00	+7.5	-1.3
11030.....	Dec. 8	4,128.716	546.99	+11.0	+1.3
11092.....	" 23	4,143.638	5.71	+10.7	+1.4
11197.....	1925 Feb. 9	2,424,191.590	53.66	-7.3	-3.6

All the plates were considered of equal weight and some occurring at or about the same phase were grouped as shown in the table of normal places. The mean phases there listed are based on the final elements.

NORMAL PLACES FOR π CEPHEI

	Phase	Velocity	Wt.	O-C			Phase	Velocity	Wt.	O-C	
				Prel.	Final					Prel.	Final
1	36.07	+3.8	1	-0.3	+1.4	10	377.20	-28.0	2	+0.7	+1.1
2	57.92	-6.9	2	-2.4	-1.9	11	407.65	-25.4	2	-1.3	-0.7
3	68.24	-10.6	1	-2.2	-2.0	12	448.67	-16.8	2	-1.2	-1.0
4	129.08	-22.2	2	+4.5	+2.8	13	455.17	-13.8	2	+0.1	+0.2
5	140.17	-24.5	1	+4.3	+2.5	14	463.09	-10.8	1	+1.0	+1.0
6	193.37	-34.5	1	+0.5	-0.9	15	487.10	-5.8	1	-1.0	-1.3
7	211.37	-38.0	2	-2.0	-3.2	16	537.00	+7.5	1	-1.8	-1.3
8	333.19	-35.8	2	-2.5	-2.1	17	546.99	+11.0	1	+0.2	+1.3
9	340.69	-30.0	2	+2.7	+3.1	18	5.71	+10.7	1	-0.3	+1.4

Graphical methods in use here gave the following preliminary values of the elements.

$$\begin{aligned}P &= 556.2 \text{ days} \\e &= .30 \\ \omega &= 15^\circ \\K &= 24.0 \text{ km.} \\ \gamma &= -19.75 \text{ km.} \\T &= \text{J.D. } 2,414,138.0\end{aligned}$$

In the observation equations which were built up the following substitutions were made.

$$\begin{aligned}x &= \delta\gamma \\y &= \delta K \\z &= K \cdot \delta e \\u &= -K \cdot \delta\omega \\v &= [9.49460] \delta T\end{aligned}$$

OBSERVATION EQUATIONS FOR π CEPHEI

								Wt.
1.....	1.000x	+ .996y	+ .086z	+ .786u	+1.124v	+0.3	= 0	1
2.....	1.000	+ .634	- .867	+1.017	+1.290	+2.4		2
3.....	1.000	+ .472	-1.111	+1.061	+1.253	+2.2		1
4.....	1.000	- .289	- .624	+ .893	+ .653	+4.5		2
5.....	1.000	- .378	- .393	+ .822	+ .550	-4.3		1
6.....	1.000	- .635	+ .520	+ .458	+ .220	-0.5		1
7.....	1.000	- .677	+ .725	+ .332	+ .139	-2.0		2
8.....	1.000	- .566	+ .697	- .438	- .262	+2.5		2
9.....	1.000	- .540	+ .625	- .480	- .286	+2.7		2
10.....	1.000	- .374	+ .175	- .670	- .420	-0.7		2
11.....	1.000	- .180	- .307	- .805	- .558	+1.3		2
12.....	1.000	+ .175	- .952	- .915	- .786	+1.2		2
13.....	1.000	+ .245	-1.031	- .921	- .825	-0.1		2
14.....	1.000	+ .332	-1.107	- .921	- .873	-1.0		1
15.....	1.000	+ .624	-1.125	- .865	- .988	+1.0		1
16.....	1.000	+1.212	+ .385	- .308	- .591	+1.8		1
17.....	1.000	+1.272	+ .760	- .111	- .305	-0.2		1
18.....	1.000	+1.282	+1.010	- .207	+ .218	+0.3		1

There resulted the following normal equations:—

$$\begin{aligned}27.000x + 2.033y - 4.093z - 2.845u - 1.502v + 2.400 &= 0 \\10.629 - 3.002 + .945 + 1.145 + 9.334 \\15.176 + 1.097 + .262 + 1.180 \\14.669 + 13.491 - 6.200 \\13.505 - 1.913\end{aligned}$$

from which the following corrections resulted:

$$\begin{aligned}\delta\gamma &= + .12 \text{ km.} \\\delta K &= - .98 \text{ km.} \\\delta e &= - .019 \\\delta\omega &= -9^\circ.30 \\\delta T &= -11.67 \text{ days}\end{aligned}$$

so that the final elements, with their probable errors attached are as follows:—

FINAL ELEMENTS

$$\begin{aligned}
 P &= 556.2 \text{ days} \\
 e &= .281 \pm .020 \\
 \omega &= 5^\circ.70 \pm 4^\circ.21 \\
 K &= 23.02 \text{ km.} \pm 0.59 \text{ km.} \\
 \gamma &= -19.63 \text{ km.} \pm 0.37 \text{ km.} \\
 T &= \text{J.D. } 2,414,126.33 \pm 5.83 \text{ days} \\
 a \sin i &= 168,970,000 \text{ km.}
 \end{aligned}$$

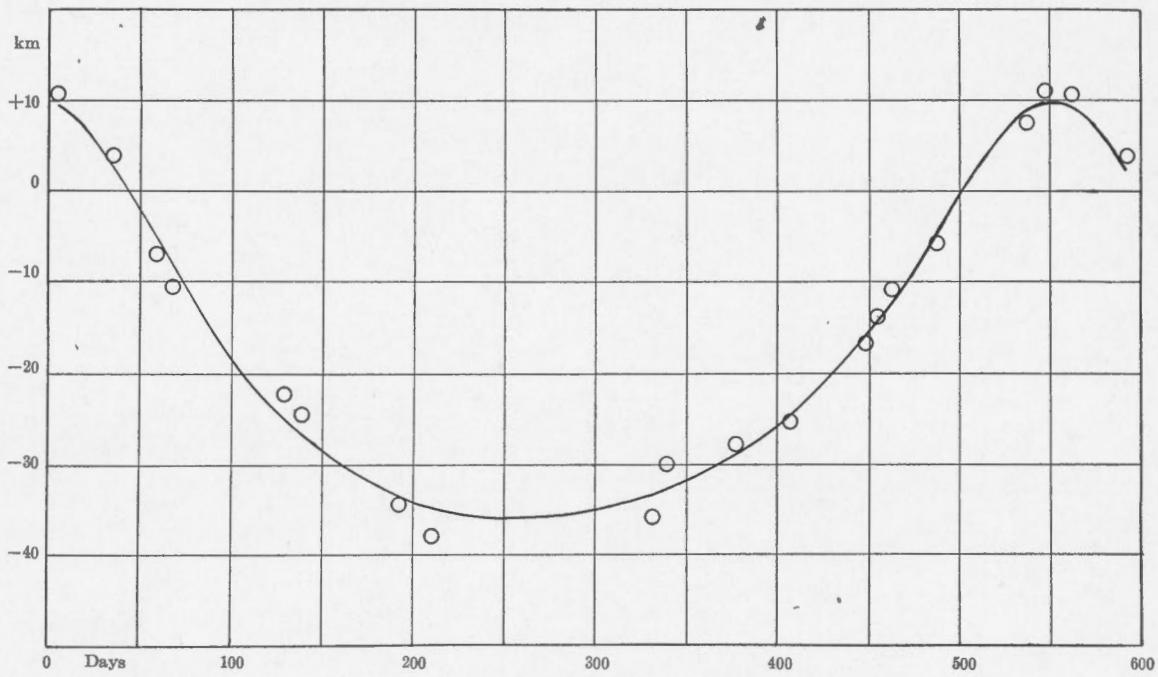
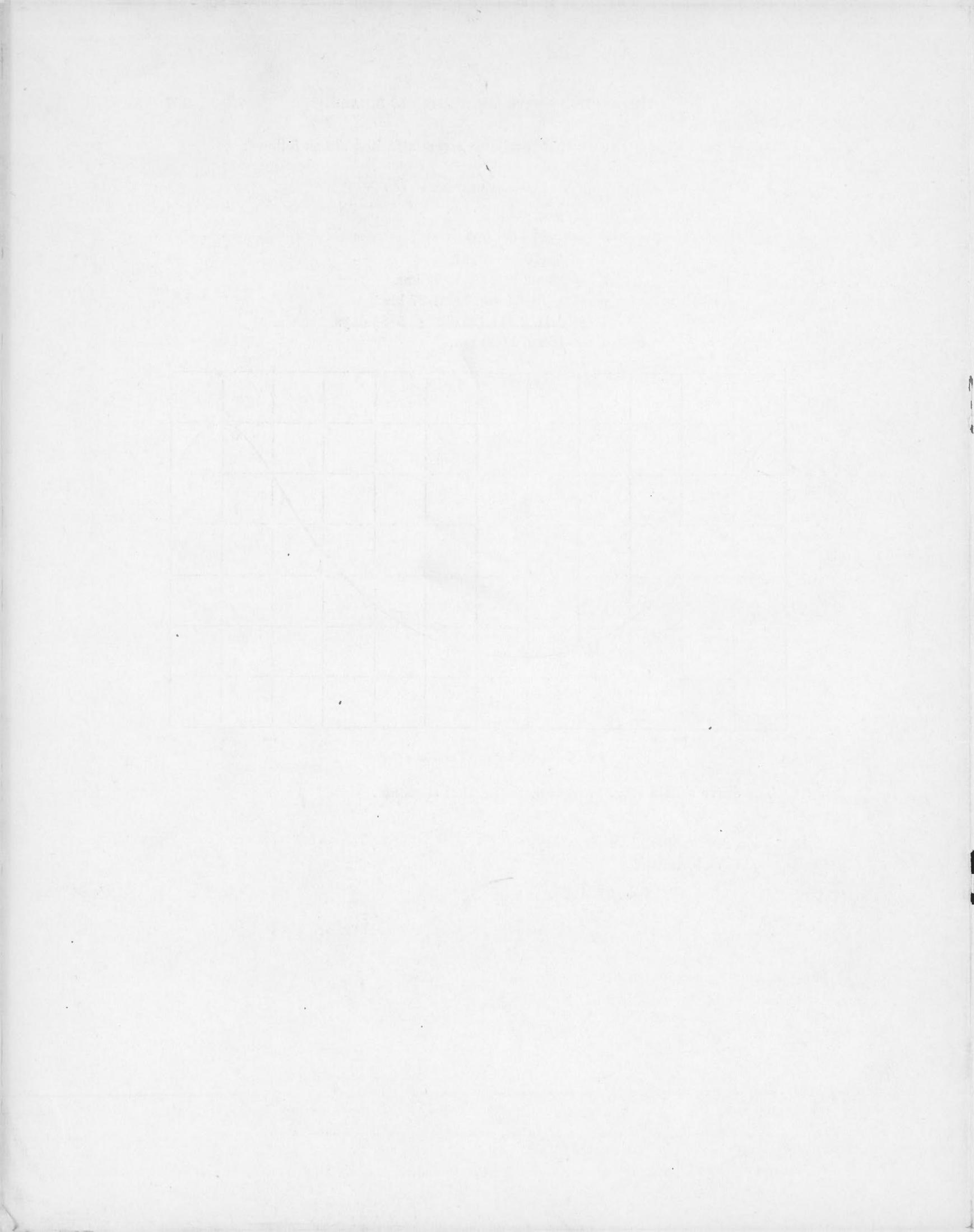


FIG. 5.—Radial Velocity Curve of π Cephei

The curve shown (Fig. 5) represents the final elements.

Dominion Astrophysical Observatory,
Victoria. B.C.

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en avance." Chandler has given a period of $10^d \cdot 15382$, Guthnick a period of $10^d \cdot 15457$, while in the *Vierteljahrsschrift* catalogue the elements of variation are given as:—

$$J.D. 2410639 \cdot 339 + 10^d \cdot 15375 E + 0^d \cdot 62 \sin(0^\circ \cdot 112 E + 116^\circ \cdot 5).$$

On account of the uncertainty of ordinary visual and photographic observations and the difficulty of determining accurate maxima and minima, it does not seem advisable to place much confidence in periods determined from photometric observations unless these cover long intervals of time and are of precision such as obtained with the photo-electric photometer.

Radial velocities are more reliable. Jacobsen, who obtained twenty-one of these (as yet unpublished) between March 5 and May 15, 1923, found that a period of $10^d \cdot 15258$ connected Campbell's observations with his. The same period connects Campbell's observations with ours, but it does not appear to fit Küstner's observations and certainly not those of Lunt. There is thus found a variation of period within a few years.

VELOCITIES FROM INDIVIDUAL LINES

A new method of analyzing variable radial velocity data by a systematic study of line displacements from different elements and at different levels of a star's atmosphere has been developed recently by Dr. W. Carl Rufus of the Detroit Observatory. This method has already given important results in the case of some of the brighter Cepheid variables, in which a motion of pulsation of the star appears to be indicated. Among the papers treating of this may be mentioned:—"Atmospheric Pulsation of Cepheids, A Method of Attack," by Carl Rufus,¹ "Atmospheric Pulsation of η Aquilae," by W. Carl Rufus,² "Atmospheric Pulsation of the Cepheid Variable η Aquilae," by W. Carl Rufus,³ "Résumé of remarks concerning recent studies of Cepheid variables at the Detroit Observatory," by R. H. Curtiss,⁴ "Velocity-curves from groups of lines of different chromospheric heights in the atmosphere of W. Sagittarii," by R. H. Curtiss,⁵ "Radial Velocities of S. Sagittae," abstract by J. A. Aldrich.⁶

Considering the important influence that these results might have on the theory of Cepheids it was thought that an investigation of ζ Geminorum would be of value, especially for lines originating in different levels of its atmosphere.

All the plates of ζ Geminorum were, therefore, measured again directly on a Toepfer measuring engine, in both direct and reversed positions as usual. The velocities obtained for individual lines, after correction for the earth's motion, are given in the following tables. In these tables each plate is indicated by its Julian date, under which is given the phase computed from the formula

$$J.D. 2410639 \cdot 339 + 10^d \cdot 15375 E$$

In the first column the approximate wave-lengths of the spectral lines are given, preceded by the symbols of the elements which are thought to produce them; in the second column are given the heights of these elements in the chromosphere of the Sun as determined by Professor S. A. Mitchell⁷. Resulting curves obtained for lines of high, medium and low level, as well as for the mean of all the lines, are given in figures 3, 4, 5 and 6. There is apparently no marked variation of amplitude from one curve to another.

¹ Pop. Ast., Vol. 32, 1924, p. 22.

² Pop. Ast., Vol. 32, 1924, p. 228.

³ Proc. Nat. Acad. Sc., Vol. 10, 1924, p. 264.

⁴ Pop. Ast., Vol. 32, 1924, p. 471.

⁵ Pop. Ast., Vol. 32, 1924, p. 547.

⁶ Pop. Ast., Vol. 32, 1924, p. 218.

⁷ Ap. J., Vol. 38, 1913, p. 407.

Julian Day		799.7		805.7		808.7		808.8		819.7		824.5		824.6	
Phase		1.12		7.05		10.15		0.05		0.80		5.64		5.74	
Wave lengths	Chromo-spheric height km.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.
Fe. 4191.7	550	+6.8	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	+17.3	2
Zr. 4209.1	550	-1.5	2	+20.1	2	.....	.....	.....	.....	-7.3	1	+18.4	1	+21.3	2
Sr. 4215.7	6000	+0.2	2	.....	.....	.....	.....	-4.6	1	-2.5	1	+17.3	2	+21.3	2
Ca. 4226.9	5000	0.0	2	+9.4	1	.....	.....	.....	.....	.....	.....	.....	.....	+18.0	2
Fe. 4233.8	400	+8.5	1	.....	.....	.....	.....	-4.6	1	.....	.....	.....	.....	+25.7	3
Fe. 4260.6	600	+5.2	5	+13.9	3	.....	.....	-11.2	1	-9.0	2	+14.6	3	+19.8	7
Fe. 4308.0	750	+0.3	2	+4.0	2	.....	.....	.....	.....	+0.3	2	+25.9	2	+25.8	2
Ti. 4313.0	600	+1.0	1	+1.4	3	-5.8	1	-8.2	3	-8.9	1	+22.6	2	+23.6	2
Sc. 4321.0	800	-3.2	6	+7.1	5	-1.2	1	-10.2	2	-0.9	1	+18.3	3	+20.4	3
Fe. 4325.9	900	.....	.....	-2.1	2	.....	.....	.....	.....	-2.4	1	+19.2	2	+24.7	2
Y. 4375.1	550	-0.3	3	+10.7	3	.....	.....	.....	.....	-4.4	3	+27.4	3	+27.3	3
Fe. 4383.7	1600	-2.8	5	+8.3	2	.....	.....	-7.6	2	.....	.....	+22.8	2	.....	.....
Fe. 4404.9	800	-5.2	3	+12.1	4	+3.2	3	.....	4	-2.0	2	+23.5	4	+22.2	4
Fe. 4415.3	500	-1.9	3	+9.5	2	+3.0	1	-5.4	2	-5.8	4	+20.9	3	+23.2	2
Ca. 4455.0	500	-7.6	2	+9.1	2	.....	.....	-9.0	4	.....	.....	.....	.....	.....	.....
? 4464.6	500	+1.7	1	+1.3	6	-0.5	2	-6.8	3	+0.5	2	+14.7	3	+18.3	2
Ti. 4468.7	1500	+2.3	3	+8.1	3	.....	.....	+7.5	3	+1.1	2	+25.2	3	+25.1	4
Ti. 4501.4	1600	-8.6	1	+12.6	1	+9.6	4	+5.6	2	-17.3	3	+24.0	2	+22.6	2
Fe. 4508.5	600	-1.3	1	+13.7	1	-6.0	2	-1.0	4	-1.0	1	+17.6	4	+21.3	2
Ti. 4549.7	1300	+3.9	4	+6.2	5	+3.2	4	-9.8	3	+6.0	5	+26.2	4	+19.5	4
Ti. 4563.9	1200	-6.5	1	+9.1	2	+0.7	1	-0.7	3	-0.6	1	+20.0	2	+13.3	3
Ti. 4572.2	1200	-1.2	3	+9.2	2	-7.2	2	-8.6	3	-8.4	2	+9.6	4	+25.5	2

Julian Day		828.7		831.6		831.7		834.6		834.7		838.6			
Phase		9.75		2.53		2.59		5.50		5.60		9.52			
Wave lengths	Chromo-spheric height km.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.
Fe. 4191.7	550	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	-0.5	1	.....	.....
Zr. 4209.1	550	.....	.....	-6.0	2	+4.0	3	+21.4	3	+20.4	2	+5.7	1	.....	.....
Sr. 4215.7	6000	.....	.....	.....	.....	+9.0	1	+20.4	1	+25.6	1	+2.4	2	.....	.....
Ca. 4226.9	5000	.....	.....	.....	.....	.....	.....	.....	.....	+22.2	1	-5.0	3	.....	.....
Fe. 4233.8	400	.....	.....	.....	.....	-0.2	1	.....	.....	.....	.....	+4.7	1	.....	.....
Fe. 4260.6	600	.....	.....	+10.6	2	+5.1	1	+29.3	3	+20.1	3	+5.9	4	.....	.....
Fe. 4308.0	750	.....	.....	+13.0	1	+7.4	3	+17.5	3	+23.0	1	-0.5	5	.....	.....
Ti. 4313.0	600	.....	.....	+15.1	1	+8.3	4	+24.0	3	+25.2	1	-0.8	4	.....	.....
Sc. 4321.0	800	+9.6	3	+12.0	2	+8.5	4	+18.7	2	+18.7	2	+3.9	6	.....	.....
Fe. 4325.9	900	+0.5	1	+5.0	1	+3.8	2	+19.6	4	+21.9	4	+4.7	3	.....	.....
Y. 4375.1	550	.....	.....	+12.8	1	-11.5	3	+21.0	2	+25.7	2	+5.6	6	.....	.....
Fe. 4383.7	1600	.....	.....	.....	.....	-0.2	4	+26.9	1	+25.8	3	+6.7	1	.....	.....
Fe. 4404.9	800	-8.2	4	+9.8	2	+1.3	5	+25.4	4	+19.4	4	+0.1	6	.....	.....
Fe. 4415.3	500	-4.9	1	+7.2	1	-0.1	5	+13.2	2	+20.4	3	+2.2	2	.....	.....
Ca. 4455.0	500	-7.8	1	+1.0	4	+8.2	3	+8.5	2	+20.0	4	-0.4	2	.....	.....
? 4464.6	500	-0.9	2	.....	.....	+2.9	4	+13.1	1	+11.9	2	+3.0	1	.....	.....
Ti. 4468.7	1500	.....	.....	+12.3	4	+9.7	4	+29.8	4	+20.0	4	+3.6	2	.....	.....
Ti. 4501.4	1600	-3.3	.....	.....	.....	-3.2	2	+22.5	1	.....	.....	+2.0	4	.....	.....
Fe. 4508.5	600	+5.4	3	+14.6	1	+5.5	4	.....	.....	+16.5	1	+3.1	4	.....	.....
Ti. 4549.7	1300	-7.2	2	+3.6	4	-0.5	4	+24.7	3	+24.8	6	+3.6	3	.....	.....
Ti. 4563.9	1200	.....	.....	+6.4	1	+2.4	3	+22.5	1	+16.0	1	+10.5	2	.....	.....
Ti. 4572.2	1200	+1.0	1	.....	.....	+1.2	4	+22.8	2	+20.2	2	+6.8	1	.....	.....

Julian Day		840.5		840.6		842.6		845.6		845.7		857.6	
Phase		1.32		1.37		3.35		6.34		6.45		8.19	
Wave lengths	Chromo-spheric height km.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.
Fe. 4191.7	550	.....	.....	.....	.....	.....	.....	+ 3.3	1	.....	.....	.....	.....
Zr. 4209.1	550	.....	.....	.....	.....	.....	.....	+ 7.6	3	+ 8.4	2	.....	.....
Sr. 4215.7	6000	- 2.2	1	+ 3.5	1	.....	.....	+16.7	2	+12.4	3	.....	.....
Ca. 4226.9	5000	.....	.....	.....	.....	.....	.....	+12.4	1	+14.2	1	.....	.....
Fe. 4233.8	400	.....	.....	.....	.....	.....	.....	+16.0	3	+12.7	3	.....	.....
Fe. 4260.6	600	- 4.2	3	+ 0.9	2	.....	.....	+14.3	3	+14.0	4	.....	.....
Fe. 4308.0	750	- 2.2	3	- 8.9	3	.....	.....	+ 9.4	3	+10.3	2	+ 8.6	1
Ti. 4313.0	600	+ 4.2	6	+ 5.2	2	.....	.....	+ 8.2	3	+ 3.5	5	+ 0.8	2
Sc. 4321.0	800	0.0	3	- 0.1	1	+14.8	1	+11.7	3	+ 9.2	4	- 2.4	3
Fe. 4325.9	900	.....	.....	- 7.2	2	.....	.....	+12.6	3	+10.1	4	.....	.....
Y. 4375.1	550	- 0.8	2	- 2.0	1	.....	.....	+ 9.2	3	+12.5	3	+ 1.6	1
Fe. 4383.7	1600	.....	.....	.....	.....	.....	.....	+15.1	4	+10.2	1	.....	.....
Fe. 4404.9	800	+ 9.0	4	- 5.4	6	+22.6	2	+ 9.8	2	+10.8	2	+ 2.1	1
Fe. 4415.3	500	+ 5.5	3	- 2.0	3	+35.5	2	+10.8	2	+12.9	4	- 4.1	2
Fe. 4455.0	500	+ 4.0	2	+ 0.2	2	+ 9.4	2	- 0.1	1	+ 0.9	2	- 9.2	1
? 4464.6	500	+18.5	4	+14.7	2	+17.8	2	.....	.....	+11.7	2	- 1.0	1
Ti. 4468.7	1500	- 4.4	3	+ 5.4	3	.....	.....	+ 7.6	4	+ 3.6	4	- 17.7	1
Ti. 4501.4	1600	+ 6.5	1	- 7.6	1	+15.9	1	+15.0	1	+ 7.2	4	-13.6	1
Fe. 4508.5	600	+ 6.4	1	+ 2.4	1	.....	.....	+ 7.3	2	+ 9.6	2	.....	.....
Ti. 4549.7	1300	+ 8.3	4	- 2.3	4	+18.1	1	+10.6	2	- 0.1	5	- 2.8	1
Ti. 4563.9	1200	- 4.6	2	- 2.1	1	.....	.....	.....	.....	+16.0	1	+ 1.4	1
Ti. 4572.2	1200	- 5.8	1	+ 2.1	3	+ 1.5	2	.....	.....	- 3.6	2	- 7.7	1
Julian Day		857.6		858.6		868.6		869.5		876.6		878.6	
Phase		8.26		9.17		9.10		10.02		6.88		8.88	
Wave lengths	Chromo-spheric height km.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.	Vel. km.	Wt.
Fe. 4191.7	550	.....	.....	.....	.....	.....	.....	- 5.4	3	+ 9.2	1	- 0.9	2
Zr. 4209.1	550	.....	.....	+ 1.4	3	.....	.....	- 2.2	2	+14.7	4	+13.6	1
Sr. 4215.7	6000	.....	.....	+ 9.5	1	.....	.....	- 4.4	3	+ 7.5	2	+ 2.3	4
Ca. 4226.9	5000	.....	.....	.....	.....	.....	.....	- 8.8	2	+10.3	1	+ 5.1	3
Fe. 4233.8	400	.....	.....	.....	.....	.....	.....	- 6.3	2	+ 7.8	3	+ 0.4	3
Fe. 4260.6	600	.....	.....	+ 0.6	1	- 9.5	3	- 6.3	3	+14.4	2	+ 3.8	3
Fe. 4308.0	750	.....	.....	+ 8.5	1	- 3.0	1	- 4.1	4	+12.0	3	+ 7.5	2
Ti. 4313.0	600	.....	.....	- 2.7	1	+ 4.6	1	- 5.4	6	+ 6.3	4	+10.8	2
Sc. 4321.0	800	+ 1.9	2	- 3.6	1	+ 1.4	1	- 5.2	7	+ 5.5	6	+ 2.1	6
Fe. 4325.9	900	.....	.....	- 1.7	2	- 3.3	2	- 5.5	4	+10.8	4	+ 1.2	4
Y. 4375.1	550	.....	.....	+ 6.1	2	+11.5	1	- 2.4	4	.....	.....	+ 7.5	6
Fe. 4383.7	1600	.....	.....	.....	.....	.....	.....	-11.8	2	+14.6	2	+ 4.0	6
Fe. 4404.9	800	+ 7.9	2	+ 1.9	3	+ 3.9	2	- 7.9	4	+13.0	3	+ 3.2	3
Fe. 4415.3	500	+ 7.6	1	+ 4.1	1	.....	.....	- 7.0	4	+ 6.8	3	+15.1	2
Ca. 4455.0	500	+12.8	1	+ 0.5	2	.....	.....	- 9.7	1	+10.7	4	+ 0.9	1
? 4464.6	500	- 3.6	1	+ 2.6	4	- 5.2	2	-16.3	2	+ 0.6	6	+13.0	1
Ti. 4468.7	1500	.....	.....	.....	.....	.....	.....	-10.7	3	+ 7.4	3	- 5.0	2
Ti. 4501.4	1600	+ 5.6	1	- 3.4	2	+ 1.4	1	- 4.9	3	+12.4	1	+ 7.3	1
Fe. 4508.5	600	+ 2.9	1	+ 0.3	2	- 8.9	2	- 8.9	2	.....	.....	- 1.7	1
Ti. 4549.7	1300	- 4.3	2	+ 4.8	4	- 7.2	3	- 7.2	3	+ 5.4	3	+ 5.4	5
Ti. 4563.9	1200	.....	.....	+ 1.2	3	- 3.0	3	- 3.0	3	+ 8.4	1	+ 8.4	2
Ti. 4572.2	1200	- 1.2	3	- 6.6	1	- 5.5	3	- 5.5	3	+12.7	5	+12.7	2

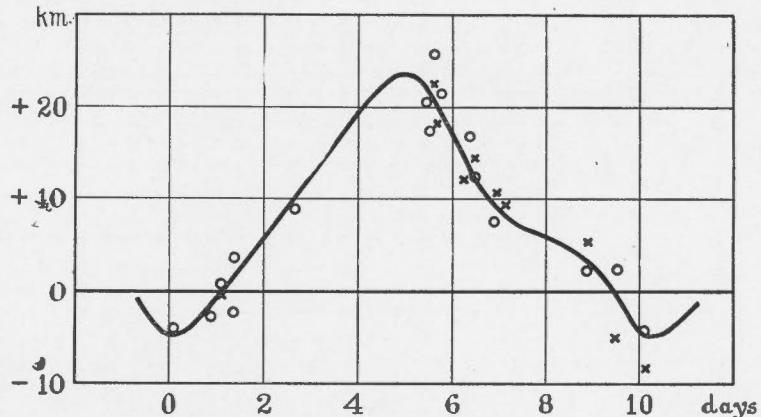


FIG. 3. Zeta Geminorum. Direct measures of two lines
 $O = 4215.73$ 6000 km. level in Sun's chromosphere.
 $X = 4226.90$ 5000 km. level in Sun's chromosphere.

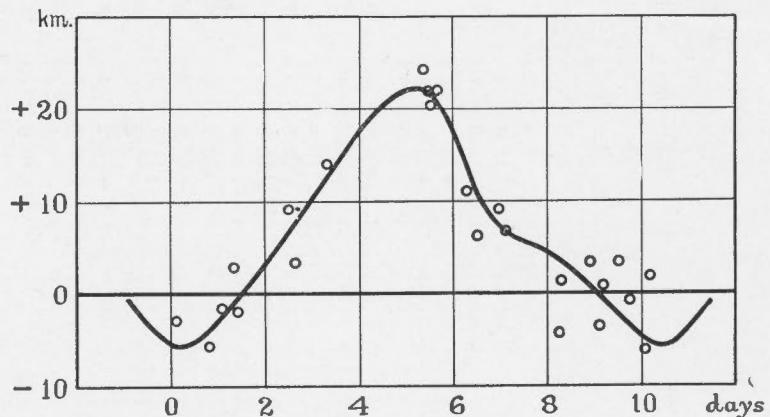


FIG. 4. Zeta Geminorum. Direct measures of ten lines
 800–1600 km. level in Sun's chromosphere.

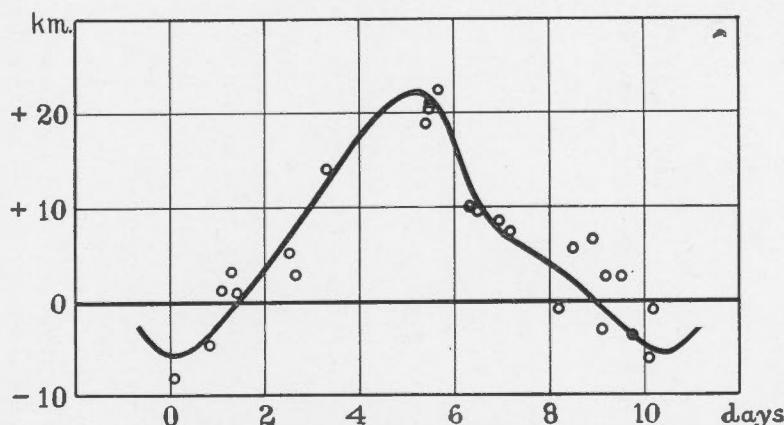


FIG. 5. Zeta Geminorum. Direct measures of ten lines all below 800 km. level in Sun's chromosphere.

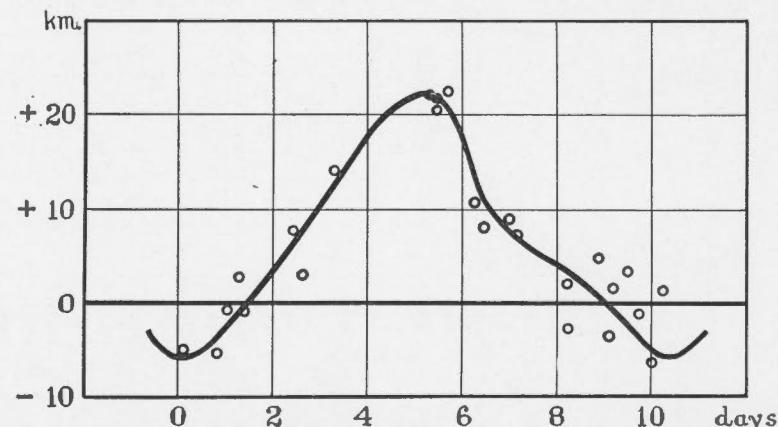


FIG. 6. Zeta Geminorum. Direct measures of twenty lines up to 1600 km. level in Sun's chromosphere.

VARIATION OF SPECTRAL CLASS

The intensity of the titanium enhanced line 4534·139 relative to that of the titanium arc line 4534·953 has been estimated in the spectrograms of ζ Geminorum. These two lines, from the fact that they are so close together and so sensitive to variation of spectral class, afford perhaps the best criterion for the determination of this variation. They have already given satisfactory results in the cases of δ Cephei and α Ursae Minoris.¹ While both lines actually vary, the intensity of the arc line was throughout assumed as 10, and that of the enhanced line estimated in terms of it. The intensities given in the following table are therefore essentially ratios.

Date, 1924	Phase	Enhanced Ti 4534·139 Intensity	Date, 1924	Phase	Enhanced Ti 4534·139 Intensity
Jan. 14.....	1·12	12	Feb. 22.....	9·48	11
14.....	1·13	7	22.....	9·52	11
15.....	2·00	7	22.....	9·60	11
20.....	7·05	14	24.....	1·32	9
23.....	10·15	11	24.....	1·37	7
23.....	0·05	10	26.....	3·35	6
31.....	7·83	10	26.....	3·42	6
31.....	7·91	16	28.....	5·39	6
Feb. 3.....	0·64	9	29.....	6·34	14
3.....	0·80	9	29.....	6·45	12
8.....	5·64	10	Mar. 12.....	8·19	14
8.....	5·74	9	12.....	8·26	16
11.....	8·65	11	13.....	9·17	11
12.....	9·75	8	13.....	9·23	9
13.....	0·50	9	17.....	3·03	6
13.....	0·60	9	19.....	5·12	8
15.....	2·51	6	20.....	6·07	10
15.....	2·53	6	23.....	9·10	15
15.....	2·59	7	24.....	10·02	12
18.....	5·50	12	24.....	10·08	11
18.....	5·60	12	31.....	6·88	12
21.....	8·62	10			

All these estimates were made at one sitting, and with no knowledge of the phases corresponding to individual spectrograms. The results are plotted on the accompanying curve (Fig. 2). This curve shows that for ζ Geminorum the maximum and minimum of the enhanced lines occur, respectively, about one-quarter of the period before and after maximum light. This result is in agreement with that found by the writer for α Ursae Minoris, which is also a Geminid, but in direct contrast with what was obtained for δ Cephei, and for many other variables of the δ Cephei type.²

¹ Pub. Dom. Obs., Vol. IX, No. 1, pp. 52 and 61.
² Mt. Wilson Contrib., Vol. 7, p. 1.

CONCLUSION

To sum up it may be said that in ζ Geminorum all lines apparently give the same radial velocities, while for η Aquilae, which was also investigated by us as well as by Professor Rufus, this is not the case; that in ζ Geminorum and α Ursae Minoris, which are the two brightest Geminids so far investigated, the maximum ionization seems to occur about one-quarter of the period before maximum light and the minimum ionization one-quarter of the period after. Although both the Geminids and stars strictly of the δ Cephei type are giant stars, or stars of very low density, the phenomena occurring in the first are somewhat different from those in the second.

The co-operation of Messrs. J. F. Frédette and R. Callander in the work of observing and measuring is here acknowledged.

DOMINION OBSERVATORY, OTTAWA,
March, 1925.

