THE SPECTROSCOPIC BINARY α VIRGINIS

By O. STRUVE and E. EBBIGHAUSEN

ABSTRACT

New elements are derived for Spica: $P=4.014160$ days; $e=0.10$; $\omega=40°$; $K=126.8$ km/sec.; $K_2=202$ km/sec.; $\gamma=+0.5$ km/sec.; $T=$J.D. 2426041.26. The period has been constant since 1891. The longitude of periastron seems to have advanced approximately 70° since Baker's observations in 1907–1908. The intensities of the absorption lines of both components vary; each component is strongest when its velocity is at minimum. The total absorption of the fainter component varies in a range of 1.7 to 1, while for the stronger component the range is 1.4 to 1. Three possible explanations are discussed. The interstellar K line is extremely weak.

1. The orbit of this spectroscopic binary was determined by Vogel[1] and by R. H. Baker.[2] The latter found, from measurements of eighty-three spectrograms taken in 1907 and 1908, that the period was 4.01416 days, the eccentricity 0.10 ± 0.014, and the longitude of periastron $328°\pm5°$.

Several months ago Dr. W. J. Luyten requested, in connection with his investigation of the advance of periastron in binaries,[3] that the orbit of Spica ($\alpha=13^h20^m$; $\delta=-10°38'$; mag. 1.2; sp. B2n) be redetermined at the Yerkes Observatory in order to find (1) whether the eccentricity of 0.1 is real, and (2) whether there has been an appreciable change in the longitude of periastron.

2. Spica was observed with the three-prism Bruce spectrograph in 1929 and 1930 for the purpose of determining the axial rotations of the two components.[4] New single-prism plates have been secured in 1933 and 1934, and the results, representing the unweighted means of measurements by the two authors, are given in Table I. The wave-lengths of the stellar lines used in this work are given in Table II.

3. The preliminary elements derived from these observations are shown in Table III. The agreement of our elements with those of

[1] *Pub. Potsdam Obs.*, **7**, 127, 1892.

[2] *Pub. Allegheny Obs.*, **1**, 65, 1909.

[3] *Pub. A.S.P.*, **45**, 297, 1933.

[4] O. Struve, *Ap. J.*, **72**, 1, 1930.

TABLE I

OBSERVATIONS OF α VIRGINIS

Date	U.T.	Velocity I	Velocity II	Quality	Date	U.T.	Velocity I	Velocity II	Quality
1929 Dec. 31	11h14m	+131.4	....	p	1934 Apr. 10	5h42m	+113.0	−174.7	g
1930 Feb. 14	7 50	− 20.6	....	p	1934 Apr. 12	6 18	−119.8	+188.9	g
1930 Mar. 3	8 05	−124.0	+196.3	g	1934 Apr. 16	7 02	−106.5	+170.8	g
1930 Mar. 8	7 30	+ 6.1	....	g	1934 Apr. 26	3 35	+ 52.0	....	g
1930 Mar. 20	6 52	− 6.8	....	g	1934 Apr. 26	4 11	+ 61.6	....	p
1930 Mar. 31	6 41	− 88.8	+200.2	g	1934 Apr. 30	4 49	+ 83.9	−161.9	g
1930 Apr. 19	3 38	+ 11.2	....	g	1934 Apr. 30	5 09	+ 88.0	−140.4	g
1930 Apr. 22	4 40	+122.2	−172.8	g	1934 May 2	5 53	−110.7	+173.8	g
1930 Apr. 22	5 46	+106.5	−170.2	g	1934 May 2	6 09	−111.0	+162.7	g
1930 Apr. 22	6 53	+101.8	−182.4	g	1934 May 4	6 07	+ 90.8	−165.8	g
1930 Apr. 24	4 28	−111.7	+188.5	g	1934 May 4	6 28	+ 88.4	−132.4	p
1930 Apr. 24	5 35	−113.0	+181.3	g	1934 May 8	4 21	+ 66.6	− 98.2	g
1930 Apr. 26	3 25	+111.8	−176.9	g	1934 May 8	4 36	+ 64.3	− 96.4	g
1930 Apr. 26	4 33	+106.2	−167.4	g	1934 May 14	3 59	−102.8	+165.6	g
1930 May 1	3 25	− 10.5	....	p	1934 May 14	4 23	−115.2	+139.2	g
1930 May 3	2 56	− 61.1	....	g	1934 May 16	3 49	+ 39.8	....	g
1930 May 6	3 41	−109.5	+176.1	g	1934 May 16	4 14	+ 44.9	....	g
1930 May 8	2 54	+ 83.3	−135.5	f	1934 May 18	3 58	−102.1	+154.6	g
1930 May 8	4 01	+107.0	−181.2	g	1934 May 19	4 00	− 88.0	+123.3	g
1930 May 10	2 43	−103.8	+170.4	p	1934 May 27	1 56	−114.2	+151.1	g
1930 May 10	3 15	−103.4	+168.6	p	1934 May 28	4 35	+ 43.7	....	g
1933 Nov. 28	12 23	+ 34.6	....	g	1934 May 30	1 48	− 78.8	....	g
1933 Nov. 30	11 45	−100.7	....	p	1934 June 5	4 41	+ 46.6	....	f
1933 Nov. 30	12 00	− 98.8	....	p	1934 June 5	4 56	+ 39.9	....	f
1933 Nov. 30	12 11	− 86.4	....	p	1934 June 7	2 01	− 61.8	....	g
1933 Nov. 30	12 17	− 81.7	....	p	1934 June 10	2 05	+142.8	−199.6	p
1933 Dec. 18	12 44	+ 18.8	....	g	1934 June 11	1 56	− 54.9	+ 82.9	g
1933 Dec. 27	10 32	+124.3	−221.7	g	1934 June 13	3 08	+ 9.7	....	g
1933 Dec. 27	11 02	+130.8	−211.9	g	1934 June 25	1 57	− 8.2	....	g
1934 Jan. 16	11 30	+144.0	−203.5	g	1934 June 25	2 09	− 7.4	....	g
1934 Jan. 20	9 20	+137.5	−195.1	g	1934 June 27	2 49	− 58.4	....	g
1934 Jan. 21	12 29	− 27.3	....	g	1934 June 29	2 05	− 3.4	....	g
1934 Jan. 27	12 37	− 2.4	....	g	1934 June 30	1 53	+134.6	−196.8	f
1934 Jan. 30	11 44	−111.2	+181.2	g	1934 June 30	2 01	+139.8	−215.8	g
1934 Jan. 30	12 04	−111.2	+181.9	g	1934 June 30	2 14	+133.5	−211.7	g
1934 Feb. 21	9 24	+130.2	−198.2	g	1934 June 30	2 25	+138.5	−208.8	g
1934 Feb. 23	9 33	−114.0	+177.4	g	1934 June 30	2 36	+124.8	−217.8	g
1934 Feb. 23	9 51	−115.2	+179.6	g	1934 June 30	2 54	+133.8	−190.3	g
1934 Feb. 23	12 14	−107.8	....	p	1934 June 30	3 30	+112.1	−209.3	p
1934 Feb. 24	6 21	− 17.9	....	g	1934 June 30	4 18	+113.2	−201.5	p
1934 Feb. 24	6 45	− 17.5	....	g	1934 July 2	2 04	−108.2	+178.8	g
1934 Feb. 27	7 47	−116.2	+174.8	f	1934 July 2	2 17	−122.2	+158.4	g
1934 Mar. 9	7 57	+116.1	−192.2	g	1934 July 2	2 29	−110.6	+153.6	g
1934 Mar. 9	10 05	+136.6	−215.3	g	1934 July 3	2 12	− 5.8	....	g
1934 Mar. 10	7 11	+ 9.2	....	g	1934 July 4	2 10	+131.6	−214.0	f
1934 Mar. 13	7 02	+117.0	−193.8	g	1934 July 12	2 04	+139.0	−194.9	g
1934 Mar. 13	7 52	+120.1	−207.6	g	1934 July 12	2 14	+136.2	−206.8	g
1934 Mar. 19	7 29	−115.9	+197.0	g	1934 July 14	2 07	−113.4	+165.6	g
1934 Mar. 19	7 46	−114.0	+182.9	g	1934 July 14	2 30	−107.7	+171.6	g
1934 Apr. 10	5 28	+107.2	−173.9	g					

Baker is excellent, except in the case of ω and T. The velocity-curve is unsymmetrical, and ω seems to have advanced approximately

TABLE II

STAR LINES

He I 4009.27	*C* II 4267.16	*Si* III 4552.61
He I 4026.19	*H*γ 4340.47	*Si* III 4567.82
*H*δ 4101.74	*He* I 4387.93	*Si* III 4574.74
He I 4120.81	*He* I 4471.48	*H*β 4861.33
He I 4143.76	*Mg* II 4481.23	

70°. A further analysis of this advance in periastron will be undertaken by Dr. Luyten.

TABLE III

ORBITAL ELEMENTS

	Struve and Ebbighausen	Baker
P	4.014160 days	4.01416 days
e	0.10	0.10
T	J.D. 2426041.26	1908 Jan. 14.846
ω	40°	328°
K_1	126.8 km/sec.	126.1 km/sec.
γ	+0.5 km/sec.	+1.6 km/sec.
$a_1 \sin i$	6,965,000 km	6,930,000 km
K_2	202 km/sec.	207.8 km/sec.
$a_2 \sin i$	11,096,000 km	11,400,000 km
m_2/m_1	0.63	0.61
Minimum velocity	J.D. 2426038.72	J.D. 2417958.29

Figure 1 shows the velocity-curves by Baker and by the authors. Zero phase corresponds to the Yerkes time of periastron passage. Baker's curve was adjusted in phase to correspond to the Yerkes curve at $V=\gamma$. The blended observations are unreliable for the determination of the orbit; the fainter component markedly displaces the blended line toward the γ-axis.

4. Plotting the individual observations by Vogel and by Baker with the latter's period, we find the following three epochs of minimum velocity:

Series	Minimum Velocity
Vogel, 1890–1891	J.D. 2411495.42
Baker, 1907–1908	2417958.29
Yerkes, 1929–1934	2426038.72

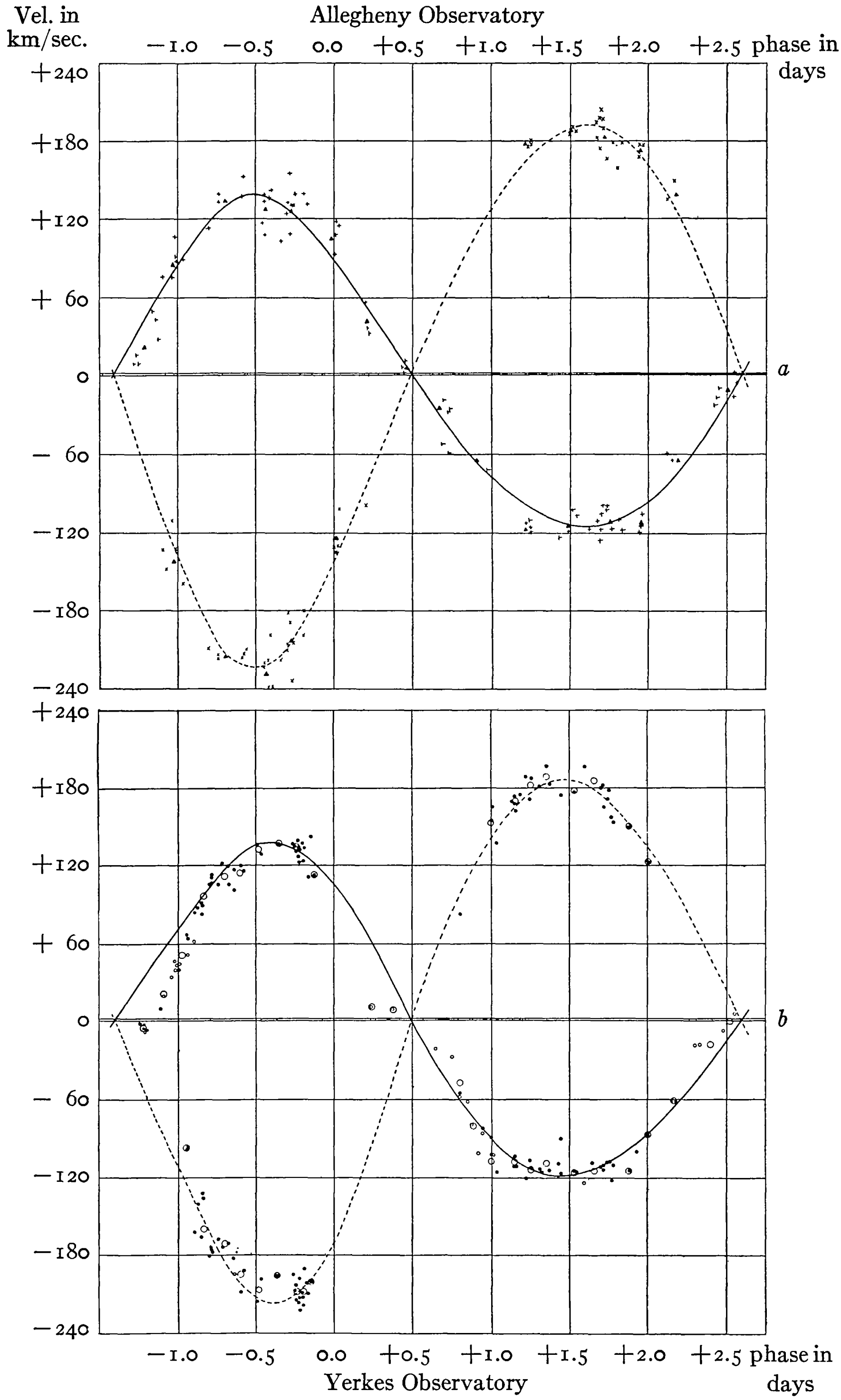
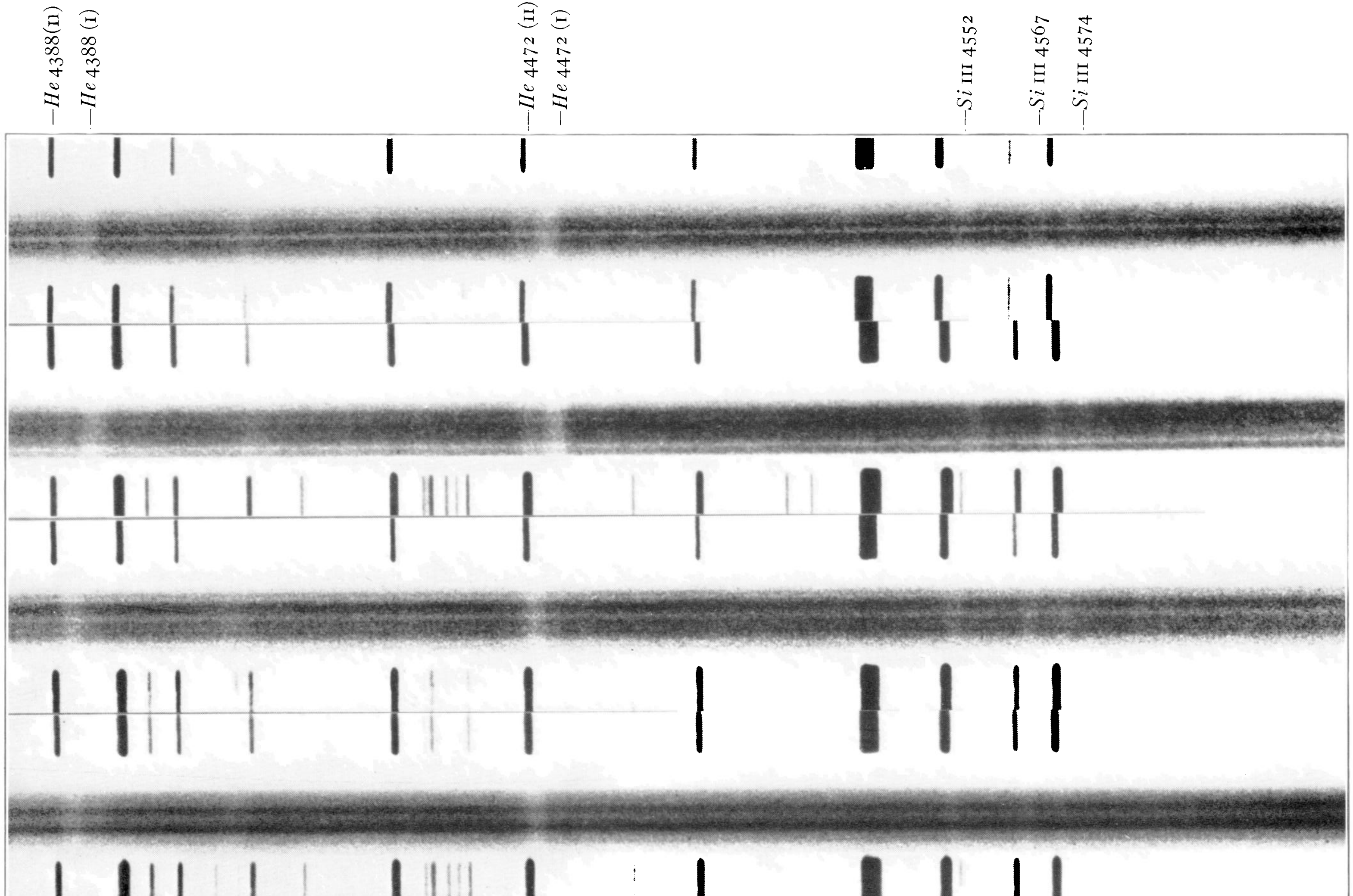


FIG. 1.—(*a*) Allegheny Observatory velocity-curve: + stronger component; × weaker component; ⊢ blended lines; ▲ normal points; (*b*) Yerkes Observatory velocity-curve: ● complete observations; ∘ blended lines; ○ normal points.

1934ApJ....80..365S

PLATE V



SPECTRUM OF α VIRGINIS

a) 1934 Jan. 16, 11^{h}30^m U.T. (phase 3^{d}75); *b*) 1934 July 12, 2^h:14^m U.T. (phase 3^{d}74); *c*) 1934 May 2, 6^{h}09^m U.T. (phase 1^{d}16); *d*) 1934 March 19, 7^{h}46^m U.T. (phase 1^{d}37).

The total number of revolutions between the first epoch and the last is 3623. The corresponding period is 4.014160 days, in exact agreement with Baker. Using this value, we find that the number of revolutions between the second and the last epoch is 2013. The computed interval is 8080.50 days, while the observed interval is 8080.43 days. The difference is 0.07 day, which, spread over two epochs, is not large enough to be detected with certainty. We thus conclude that, within the precision of the measurements, the period has been constant between 1890 and 1934.

5. In the course of this investigation we found a remarkable periodic change in the relative intensities of the two absorption components of Spica. Generally speaking, the fainter component is much less intense with respect to the brighter when the former recedes from the sun and the latter approaches it (Pl. V).

Whether this phenomenon was caused by a change in the fainter component alone, or by changes in both components, could only be ascertained by a careful examination of the entire material.

The effect is seen best when the two components are completely separated. At our request Miss Lois T. Slocum has made estimates of the line intensities for all plates on which the radial velocity of the primary component is $\lesssim \pm 80$ km/sec. The corresponding intervals of phase are approximately 3.2–0.1 day and 0.9–2.0 day. The estimates were made on an arbitrary scale. For the faint component *He* 4472 was estimated. The strong component of this line is unsuitable because of its great intensity. Accordingly, the *Si* III line 4552 was used for the strong component. By means of several microphotometer tracings the estimates were later converted into total absorptions expressed in A-units of complete darkness. The calibration was found to be

Estimate	0	1	2	3	4
Total absorption in A	0.10	0.12	0.17	0.24	0.38

The results[5] of the estimates are given in Table IV.

Both components vary, but the variation is appreciably greater for the fainter component.

[5] The values given in Table IV are tentative. The measurement of faint diffuse lines is difficult and the probable errors are large.

We have attempted to plot the estimated intensities against phase within each of the phase intervals. There is no systematic difference within these intervals. In other words, the maximum and minimum intensities of each component coincide, within the rather limited precision of the estimates, with the minimum and maximum velocities of each component.

A test of possible secular changes in the intensities was also made, but the result was negative. The observed variations appear to repeat themselves precisely with the period of the binary.

An examination of the plates taken when the two components are blended showed that in phase interval 2.3–3.0 days the fainter component is usually seen as a rather narrow line superimposed over

TABLE IV

	Estimate	Total Absorption
STRONG COMPONENT, λ 4552		
Positive velocity of strong component > +80 km/sec.	2.0	0.17 A
Negative velocity of strong component < −80 km/sec.	3.0	0.24
Ratio	...	1.4
FAINT COMPONENT, λ 4472		
Positive velocity of strong component > +80 km/sec.	2.6	0.20
Negative velocity of strong component < −80 km/sec.	0.9	0.12
Ratio	...	1.7

the wing of the broader and stronger component. In the phase interval 0.2–0.8 day this is not so clearly shown, but there are only a few good plates and the result is therefore not decisive. We suspect that the total intensities of the blended lines are slightly stronger in phase interval 2.3–3.0 days than in phase interval 0.2–0.8 day.

We also suspect that the contour of the stronger component is not always that demanded by the rotational effect, but that occasionally the edges of the line are steeper than would be expected. Unfortunately, our single-prism spectrograms, though taken on a high-contrast emulsion and properly widened, do not suffice to bring out clearly these details in the line contours. This work will be continued with the use of three-prism spectrograms.

The contour of the fainter component is narrow when its velocity is positive. This feature has already been discussed by Struve.[4] It should be noted, however, that in his work on the rotational velocities of the components of α Virginis, he used only spectrograms on which the faint component was displaced toward the red. Our new plates indicate that the contour of the fainter component is not so narrow when its velocity is negative, although even then it is not nearly as wide as the stronger component. In view of this variation in line width, the ratio of the diameters found by Struve from the relative widths of the two components cannot be regarded as definitely established.

6. The phenomenon which we have described in section 5 resembles that discovered by Bailey[6] in the spectrum of the binary μ^1 Scorpii. A brief description of this was given by Miss Cannon,[7]

TABLE V

	P	K_1	e	ω	Variation in Line Intensity
μ^1 Scorpii	1^d446	200?km	0.05	190°	Strong
V Puppis	1.454	300?	.08	72	Strong
π Scorpii	1.571	138	.05	90	Suspected
σ Aquilae	1.950	164	.0	....	Absent
2 Lacertae	2.616	80	.01	180	Suspected
α Virginis	4.014	127	0.10	40	Average

and a complete study has recently been published by Miss Maury.[8] The latter also discovered a similar variation in the lines of V Puppis.[9]

From Miss Maury's description it appears certain that the variations in the intensities of the two components of μ^1 Scorpii and of V Puppis greatly exceed those of α Virginis.

The fact that three spectroscopic binaries of short period and large amplitude of velocity show the same phenomenon suggests that it may be caused by similar physical changes in close double stars.

In Table V we have listed several short-period spectroscopic binaries of class B having double lines. Evidently the variations are not correlated in any simple manner with either period or amplitude. They are certainly much weaker in π Scorpii than in V Puppis and

[6] *Harvard Circ.*, 11, 1896.

[7] *Harvard Ann.*, 28, Part II, remark 73.

[8] *Ibid.*, 84, 169, 1920.

[9] *Ibid.*, p. 178.

in μ^1 Scorpii. They are not related to ω, which is 190° in μ^1 Scorpii and 40° in α Virginis, and are therefore not an effect of periastron like the one recently discovered by Morgan in μ Sagittarii[10] and later verified by him with the help of a large amount of new material. This latter effect produces striking changes in the stronger helium lines near periastron. It should be remembered, however, that for μ Sagittarii, $P = 180$ days, $e = 0.45$, so that obviously this is an entirely different phenomenon from that observed in α Virginis.

The material is hardly sufficient to permit a complete interpretation of these variations. Three possible mechanisms suggest themselves:

a) The phenomenon resembles that postulated many years ago by Duncan for the explanation of the light-curves of Cepheid variables.[11] The two components are supposed to have identical periods of rotation and orbital revolution. Their motion in a resisting medium would heat the advancing side of each component, thus causing a variation in the intensities of the two continuous spectra.

According to this hypothesis, the variation is entirely due to changes in the continuous spectra and not to the lines themselves. The amount of absorbing matter is considered equal in all four spectra. This presupposes, of course, that the spectral types of the two components are the same. Let the total absorptions of the lines be $A_1' = A_2' = A_1'' = A_2'' = A$, and let the intensities of the continuous spectra of the two sides of component one be C_1' and C_2' while the intensities of the continuous spectra of component two are designated C_1'' and C_2'', for the fainter and the brighter side, respectively. The observed continuous spectrum is $C_1' + C_1''$ when the velocity of the primary is negative and $C_2' + C_2''$ when the velocity of the primary is positive. The observed intensities of the four lines are

$$\frac{AC_1'}{C_1'+C_1''} = a\,; \qquad \frac{AC_1''}{C_1'+C_1''} = b\,; \qquad \frac{AC_2'}{C_2'+C_2''} = d\,; \qquad \frac{AC_2''}{C_2'+C_2''} = e\,.$$

[10] *Ap. J.*, 75, 407, 1932.

[11] This hypothesis has, of course, been abandoned in so far as the Cepheids are concerned.

The data in Table IV give

$$\frac{a}{d}=1.4\;;\qquad \frac{e}{b}=1.7\;.$$

Furthermore, Struve[4] found

$$\frac{a}{b}=8.8\;.$$

It is, of course, obvious that the observations can give only the two ratios C_1'/C_1'' and C_2'/C_2''. We cannot derive C_1'/C_2'. In other words, the observed intensities depend upon the ratios of intensity of the bright side of the primary to the faint side of the secondary, and of the faint side of primary to the bright side of the secondary, but they tell us nothing concerning the quantity $m=C_1'/C_2'$. If m is known from other data, then we also know C_1''/C_2''.

It is seen that

$$\frac{C_1'}{C_1''}=\frac{a}{b}=8.8\;.$$

Forming

$$\frac{a}{d}=1.4=\frac{1+\dfrac{C_2''}{C_2'}}{1.11}\quad\text{and}\quad\frac{e}{b}=1.7=\frac{9.8}{\left(\dfrac{C_2'}{C_2''}+1\right)}\;,$$

we find two values of C_2''/C_2':

$$\frac{C_2'}{C_2''}=1.8\;;\qquad \frac{C_2'}{C_2''}=4.8\;,$$

which are inconsistent with one another. We conclude that the observations given in Table IV are not consistent with the hypothesis $A_1'=A_2'$; $A_1''=A_2''$. This may, however, be due to the lack of precision in our observations.

We shall tentatively adopt $C_2'/C_2''=3.5$. Supposing next that the stronger component does not vary at all ($m=1$), we find $C_2''/C_1'=2.5$. The bright side of the companion is 2.5 times more intense than the faint side.

The spectral class of each of the two components is B2, corresponding roughly to $T''=15{,}000°$ K. Computing from Planck's law the temperature corresponding to an increase in $J(\lambda)=C_1\lambda^{-5}(e^{C_2/\lambda T}-1)^{-1}$ by a factor of 2.5, we find for $\lambda=5000$ A

$$T'=25{,}000° \text{ K} .$$

Such a large difference between T' and T'' should produce a marked difference in the spectral types of the two sides of the companion, which is contrary to observation.

Another objection to hypothesis (*a*) is the mechanical difficulty of accounting for so large a difference in temperature. The energy required is so enormous that the density of the resisting medium would have to be much greater than could be reconciled with the fact noted in section 4, that the period has been constant to within at least 0.00001 day (or 1 sec.) in an interval of forty-four years.[12]

b) It might be suggested that the variation of the intensities is caused by the reflection effect in a close binary. Eddington[13] has given a formula for computing the amount of light reflected from the companion, when C'/C'' and $\varphi=R_2/a=$radius of companion/distance of centers are known. For several eclipsing variables the brighter side of the companion is twice as intense as the fainter side. For α Virginis R_2/a is not accurately known, but, assuming a reasonable value for this ratio, it seems probable that the reflected light would make an important contribution to the total brightness of the companion.

If the two components are spherical, or if they are ellipsoids having their major axes in the line joining their centers, then the reflection effect at both quadratures is the same and the fainter component should be strongest at opposition. The observations prove that the effect at the two quadratures is not the same.

If there is no equality in the periods of rotation and revolution, tidal lag will cause the major axes to be displaced from the line

[12] It is easy to apply to the present case the argument advanced by H. Poincaré (*Leçons sur les hypothèses cosmogoniques*, p. 194, 1913) against the meteoric hypothesis of the maintenance of the sun's heat.

[13] *Internal Constitution of Stars* (German ed.), p. 263, 1928.

joining the centers.[14] In that case the reflection effect will not be the same in the two quadratures. However, maximum and minimum line intensity should occur somewhere between quadrature and opposition, and not at quadrature as observed.

Furthermore, the ellipticity of the components of close binaries is usually small, and while the reflection effect in the companion may be observable in opposition, it will produce but little difference in the two quadratures. The ellipticity of α Virginis has not been determined, but Stebbins[15] found a probable variation in light amounting to about 0.10 mag. Judging from the somewhat similar case of the variable π^5 Orionis for which Stebbins[16] finds an elongation of only a little more than 5 per cent, we can conclude that the ellipticity of the stronger component in α Virginis is insufficient to cause the observed variation in the line intensities. There remains, however, the possibility recently discussed by K. Walter,[17] that the ellipticity of the fainter component is different from that of the stronger.

c) The third hypothesis attributes the changes to an actual increase of absorbing gas on the advancing side of each component. There is no theoretical explanation for this increased thickness, but, accepting it as a working hypothesis, we estimate that the amount of material on the advancing side of the reversing layer of each component is roughly twice that on the receding side.

7. The peculiar variations in the intensities of the components make it somewhat uncertain whether the position of each component as measured under the microscope is actually a true measure of the velocity of the center of gravity of each star. It is possible that the contour of each component is unsymmetrical and that the amount of asymmetry varies. In that case a spurious eccentricity may easily be introduced into the orbit.

However, there is at present no real reason to suspect such a spurious effect. The value of ω in α Virginis is 40°, while in μ^1 Scorpii it is 190° and in V Puppis, 72°. Apparently the eccentricity

[14] J. H. Jeans, *Astronomy and Cosmogony*, p. 286, 1928.

[15] *Ap. J.*, **39**, 478, 1914.

[16] *Ibid.*, **51**, 218, 1920.

[17] *Veröff. Sternwarte Königsberg*, No. 2, 1931; *ibid.*, No. 3, 1933.

of the orbit is not caused by the spurious shifts of unsymmetrical lines, for otherwise we should expect that ω would be the same in all stars, and that, furthermore, e would be larger in μ^1 Scorpii and in V Puppis than in α Virginis, since in the two former stars the intensities vary over a much larger range than in the latter.

Another argument in favor of the reality of e is the variation in ω detected in α Virginis.

8. The interstellar calcium line in α Virginis is exceptionally weak. We have taken a Process plate with the spectrum widened several millimeters. The interstellar line is barely visible, and its intensity leads us to expect that the distance of α Virginis is small. Assuming the density of the interstellar cloud to be uniform, the distance of the star could hardly exceed 100 parsecs, and should probably be in the neighborhood of 50 parsecs.

The galactic latitude of α Virginis is $+50°$, and it is therefore possible that the density of the interstellar calcium should not be considered uniform.

9. In presenting this brief study of the orbit and the spectral changes of α Virginis, we have attempted to emphasize the importance of a careful study of known spectroscopic binaries. Not only do the orbital elements merit a redetermination, but physical changes have now been established in these close double stars which are still extremely puzzling.

We are indebted to Miss Slocum for the estimates of the line intensities.

YERKES OBSERVATORY
August 27, 1934