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THE SPECTROSCOPIC ORBIT OF 56° 2617

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ABSTRACT

The star 56° 2617 is one of the absorption line O-type stars whose investigation is being undertaken at Victoria and the orbit was required to obtain the velocity of the system and the mass function. The spectrum contains practically only the Balmer lines of hydrogen and the lines of enhanced helium with traces of ordinary helium and may be assigned to the spectral class O6 with a probable temperature of 21000°K. The orbit was obtained from 28 spectra and was corrected by least-squares. The period 1·36372 days, the eccentricity 0·3336, the semi-amplitude 77·01 km., and the longitude of the apse 289°94 form the principal elements. The projected semi-axis major is 1,354,500 km. and the mass function 0·054⊙. The latter, small for a high temperature star, indicates relatively small mass unless the ratio of masses of the components or the inclination of the orbital plane is large. The velocity of the system −1·04 km. per second is so widely different from the velocity −18·5 km. given by the stationary H and K lines as to indicate that the calcium vapour cannot be connected with the star.

The star 56° 2617, R.A. $21^{h}\ 35 \cdot 9^{m}$, Dec. +57° 02′, vis. mag. 5·64, spectral class Oe5, has been announced by Rufus* as having a range of 156 km. in its velocity. R. H. Curtiss further stated in a personal letter that Rufus expected to determine the orbit. Consequently, at first only sufficient spectra were obtained to enable the spectrum to be classified but when nothing appeared for two years it seemed desirable to obtain the elements for the sake of accurate knowledge of the velocity of the system and the mass function, two elements required in the general investigation of absorption line O-type stars now in progress. Although most of these stars show a variation in velocity, this one is among the few with sufficient range to render orbital determination possible with a reasonable number of observations. Moreover, the quality of the lines for measurement is so poor that duplication of the orbit would be desirable and so no hesitation was felt about proceeding with the work.

* Ap. J. 51, 252, 1920.

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Its spectrum is classified as Oe5 in the Harvard system, and this classification, as there is no apparent emission and the Pickering lines are well marked, is correct as far as it goes. But, as H. H. Plaskett* has pointed out, this subdivision covers about as great differences of line intensities as is embraced in the classes B0 to B5, which directly follow in the Harvard system. Consequently, in his tentative scheme this star is classed as O6 from the relations of ordinary to enhanced helium and of enhanced helium to hydrogen and the temperature may be approximately assigned as 21000°K. The lines measured in the spectrum of 56°2617 consist of the Balmer series of hydrogen $H\beta$, $H\gamma$, $H\delta$ and occasionally $H\epsilon$; enhanced helium λ4686, λ4542 and occasionally λ4200; ordinary helium, λ4472 occasionally and $\lambda\lambda$4922, 4713, 4026 rarely; calcium H and K, sharp, strong and practically stationary lines. Traces of enhanced nitrogen and silicon can be seen in some of the spectra, but they are quite immeasurable. In a very few cases the enhanced helium components† of the Balmer lines have been separately measured, but generally the lines are so diffuse that this is impossible. Although there is some danger in using the measures of the blend when enhanced helium is 0·3 or 0·4, the strength of the Balmer lines, there seems generally to be a maximum on which the wire can be set to the red side of the broad diffuse line and as the resulting measures when compared with unblended lines do not indicate any appreciable displacement to the violet, it is assumed that the error introduced is negligible. Moreover, as all the lines are very diffuse and only λ4686 and λ4542 outside the Balmer lines can generally be measured, there seemed to be no recourse but to use the latter in order to bring the accidental error to a reasonable amount. The velocity measures of such spectra must necessarily be uncertain, and this is otherwise shown by the high residuals from the orbit and also by the high probable error, $\pm 13 \cdot 3$ km. per sec. of a single plate.

The first spectrum of 56° 2617 was obtained on July 1, 1921, and the last used in the orbit on July 22, 1923. One of the 29 plates obtained in this period was inadvertently made with a slit 50 per cent wider than normal, and was not used in the solution, and two later plates made on July 30, 1923, were used only to check the correctness of the adopted period. All these plates were measured on a Gaertner micrometer engine with binocular eyepiece. The preliminary period, obtained only after some difficulty, showed some very high residuals and it was felt desirable to remeasure all the 28 spectra used in the orbit. This remeasurement was performed on the same engine, care being taken that the direction and magnitude of the residuals were unknown, in order to avoid any chance of prepossession in setting on such diffuse lines as in this spectrum. The table of observations below contains, in successive columns, the date and Julian date of the spectra, the phase from the final orbit, the velocities from the calcium lines, the separate measured velocities of the spectra from the hydrogen and helium lines with their mean, the accepted orbital velocity, and finally the residual O-C from the corrected orbit.

* Publications this Observatory, Vol. I, Nol. 30, p. 363.
† Idem, p. 335.

OBSERVATIONS OF 56° 2617

Date			Julian Date	Final Phase	Measured Velocities: Ca Lines	H and He Lines: 1st Meas.	H and He Lines: 2nd Meas.	Accepted Velocity	Residual O–C
1921	July	17	2,422,888·915	·217	−21·5	+86·0	+88·6	+87·3	+10·06
	"	31	2,902·922	·577	−24·3	− 0·6	− 1·9	− 1·2	− 2·06
	Aug.	11	2,913·898	·643	−17·2	− 3·6	+ 2·2	− 0·7	+10·86
	Oct.	20	2,983·644	·839	....	−63·2	−40·9	−52·0	− 7·77
1922	June	8	3,214·967	·330	....	+12·8	+47·6	+30·2	−23·39
	July	1	3,237·930	·110	−17·0	+87·2	+86·6	+86·9	+ 4·25
	"	4	3,240·898	·351	....	+31·4	+43·0	+37·2	−11·63
	"	11	3,247·960	·594	−18·2	−00·2	− 2·8	− 1·5	+ 0·90
	"	12	3·248·968	·238	−14·8	+81·0	+79·3	+80·2	+ 6·78
	"	19	3,255·935	·386	....	+74·7	+79·2	+77·0	+36·08
	"	20	3,256·878	1·329	....	+18·0	+41·9	+30·0	+21·40
	"	23	3,259·944	·304	−15·0	+58·2	+74·9	+66·6	+ 7·08
	Aug.	6	3,273·931	·654	−20·9	− 2·4	−21·3	−11·8	+ 1·77
	Nov.	25	3,384·735	·997	−22·0	−52·0	−50·5	−51·2	+13·00
	"	28	3,387·626	1·161	−18·4	−75·8	−87·2	−81·5	−16·29
	"	30	3,389·550	·357	−18·0	+45·8	+49·9	+47·8	+ 0·33
	Dec.	14	3,403·574	·744	−13·8	−22·7	−23·2	−23·0	+ 6·23
	"	28	3,417·596	1·128	....	−58·6	−78·5	−68·5	− 0·15
1923	June	10	3,581·928	·450	−21·6	− 5·2	−19·0	−12·1	−38·93
	"	26	3·597·863	·021	−20·1	+59·3	+64·4	+61·6	+13·46
	"	27	3,598·835	·993	−25·1	−75·2	−74·1	−74·6	−10·78
	July	3	3,604·938	·277	−18·6	+66·0	+63·2	+64·6	− 0·79
	"	11	3,612 752	·272	−25·8	+43·1	+40·6	+41·8	−19·55
	"	15	3,616·901	1·330	−14·8	+ 4·8	+16·3	+10·6	+ 1·29
	"	15	3,616·953	·019	−22·4	−20·3	−13·3	−16·8	−63·74
	"	19	3,620·851	1·189	−13·8	−33·6	−38·5	−36·0	+24·34
	"	19	3,620·958	1·296	− 7·9	−38·0	−26·2	−32·1	−17·55
	"	21	2,423,622·860	·471	−16·4	+23·3	+13·7	+18·5	− 3·84

Although there is a good range of velocity, about 160 km., considerable difficulty was experienced in obtaining the period and considerable time occupied in attempting to fit the observations into longer periods than the one finally selected, 1·3637 days. Even this period gave some very high residuals, much higher than can be ascribed to ordinary errors of measurement of even such diffuse lines as these. But it did not seem possible to improve upon it and the measures of three plates taken on one night showed conclusively that the period could not be less than a day and hence no submultiple of the accepted period. The only reasonable explanation of the six residuals exceeding 20 km. per second must be sought in the presence of the spectrum of the companion star. The relative displacement of the two sets of such broad and diffuse lines is too small to be apparent in the spectrum, but it is probable that at certain phases the maxima were displaced sufficiently to produce the observed residuals. This explanation seems more probable than assuming, even with such diffuse lines, that an error of measurement of 63 km. could be made. Following the usual practice, and this is especially desirable when the orbit is uncertain, the preliminary elements obtained graphically and given in the table below were corrected by least-squares by Schlesinger's method.* As it was deemed necessary to include a correction for the period it was impracticable to combine the separate observations into normal places and so the 28 observation equations given below were computed from the preliminary elements, using the mean velocities given in the table of observations. The weighting with such high residuals is important, and was estimated on the quality of the plates and agreement of the measures. The symbols in the observation and normal equations have the following magnitudes:—

$$\Gamma = \delta\gamma + e \cos \omega\delta\kappa + \mathrm{K} \cos \omega\delta e - \mathrm{K}e \sin \omega\delta\omega$$

$$\kappa = \delta \mathrm{K}$$

$$\pi = -\mathrm{K}\ \delta\omega$$

$$\epsilon = -\ \mathrm{K}\ \frac{2{\cdot}21}{1-e^2}\ \delta e$$

$$\tau = -\mathrm{K}\mu\sqrt{\frac{1+e}{1-e}}\ \frac{1}{1-e}.\delta \mathrm{T}.$$

$$m = -100\ \mathrm{K}\sqrt{\frac{1+e}{1-e}}\cdot\frac{1}{1-e}.\delta\mu$$

OBSERVATION EQUATIONS OF 56° 2617

No.	Wt.							
1	¼	1·000Γ	+ ·589κ	− ·808π	− ·300ε	− ·783τ	−2·478*m* =	−67·18
2	¾	1·000	+ ·600	− ·800	− ·306	− ·773	−2·298	+10·42
3	1	1·000	+ ·966	− ·260	− ·219	− ·203	+ ·127	+ 7·55
4	1	1·000	+ ·957	+ ·291	+ ·262	+ ·169	− ·696	+ 8·63
5	1	1·000	+ ·889	+ ·457	+ ·391	+ ·237	− ·122	+ 6·71
6	¾	1·000	+ ·797	+ ·604	+ ·477	+ ·281	+ ·877	−24·55
7	1	1·000	+ ·784	+ ·621	+ ·484	+ ·284	+ ·864	− 0·78
8	1	1·000	+ ·727	+ ·687	+ ·507	+ ·298	− ·121	+ 5·65
9	½	1·000	+ ·658	+ ·753	+ ·518	+ ·309	− ·264	−25·49
10	¾	1·000	+ ·599	+ ·800	+ ·516	+ ·314	− ·187	−13·95
11	1	1·000	+ ·577	+ ·817	+ ·513	+ ·315	+ ·280	− 1·63
12	½	1·000	+ ·497	+ ·868	+ ·494	+ ·318	− ·142	+33·73
13	¼	1·000	+ ·301	+ ·954	+ ·404	+ ·315	+ ·886	−40·34
14	¾	1·000	+ ·242	+ ·970	+ ·370	+ ·311	+1·002	− 5·11
15	¾	1·000	− ·018	+1·000	+ ·186	+ ·297	−1·181	− 4·79
16	1	1,000	− ·076	+ ·997	+ ·142	+ ·293	− ·154	− 0·61
17	¾	1·000	− ·193	+ ·981	+ ·051	+ ·284	−1·098	+ 9·58
18	¾	1·000	− ·234	+ ·972	+ ·019	+ ·282	− ·075	+ 1·23
19	¾	1·000	− ·457	+ ·890	− ·144	+ ·263	+ ·271	+ 7·16
20	¾	1·000	− ·659	+ ·752	− ·260	+ ·237	− ·751	− 6·23
21	1	1·000	− ·944	+ ·329	− ·225	+ ·134	+ ·400	− 6·88
22	½	1·000	− ·946	+ ·325	− ·223	+ ·133	+ ·112	+16·61
23	½	1·000	− ·969	− ·249	+ ·225	− ·146	− ·171	+ 1·08
24	½	1·000	− ·912	− ·410	+ ·375	− ·266	− ·232	−16·29
25	½	1·000	− ·814	− ·581	+ ·518	− ·419	−1·342	+21·68
26	½	1·000	− ·134	− ·991	+ ·393	− ·955	−3·060	−26·70
27	½	1·000	+ ·111	− ·994	+ ·147	− ·988	+ ·431	+16·46
28	¾	1·000	+ ·265	− ·986	+ ·099	− ·983	−3·110	− 7·12

* Pub. Allegheny Observatory, I, p. 33.

From these observation equations the following normals were computed:—

$20 \cdot 000\Gamma$	$+3 \cdot 480\kappa$	$+7 \cdot 225\pi$	$+3 \cdot 860\epsilon$	$+ \cdot 786\tau$	$-77 \cdot 064m$	=	$-23 \cdot 01$
	$+8 \cdot 772$	$+1 \cdot 373$	$+2 \cdot 200$	$+ \cdot 644$	$+ \cdot 132$	=	$-8 \cdot 298$
		$+11 \cdot 772$	$+2 \cdot 285$	$+5 \cdot 518$	$+5 \cdot 356$	=	$-1 \cdot 192$
			$+2 \cdot 405$	$+ \cdot 850$	$+ \cdot 047$	=	$-12 \cdot 545$
				$+3 \cdot 522$	$+5 \cdot 621$	=	$+7 \cdot 045$
					$+24 \cdot 035$	=	$+38 \cdot 089$

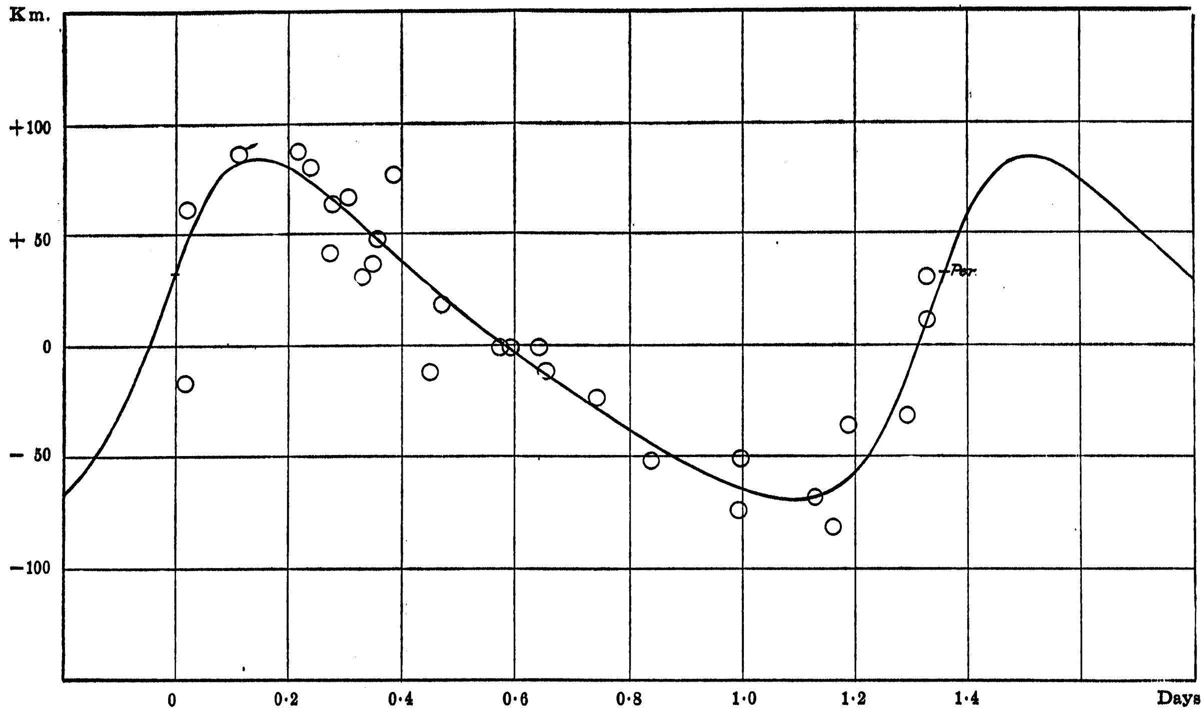
The solution of these normal equations and the determination of the weights gives the following values of the unknowns, from which the corrections to the elements with their probable errors at once follow.

$$m = +1 \cdot 037 \quad \text{whence} \quad \delta\mu = -0 \cdot 000067$$
$$\tau = +11 \cdot 921 \qquad \delta T = +0 \cdot 01847 \text{ days} \pm \cdot 033$$
$$\epsilon = -7 \cdot 222 \qquad \delta e = +0 \cdot 3336 \pm \cdot 0402$$
$$\pi = -6 \cdot 641 \qquad \delta\omega = +4^{\circ} \cdot 94 \pm 8^{\circ} \cdot 48$$
$$\kappa = +0 \cdot 007 \qquad \delta K = +0 \cdot 007 \text{ km.} \pm 3 \cdot 04$$
$$\Gamma = +2 \cdot 539 \qquad \delta\gamma = -0 \cdot 06$$

The preliminary and final values of the elements are given in the table below, and it is seen that the solution did not materially change the graphically determined elements. A plot of the velocity curve with the single observations shown as small circles gives graphical evidence of the uncertainty of the measures.

Element		Preliminary	Final
Period	P	1·3637 days	1·36372 ± ·00006 days
Eccentricity	e	0·30	0·3336 ± ·0402
Semi amplitude	K	77·0 km.	77·01 ± 3·04 km.
Longitude of Apse	ω	285°·0	289°·94 ± 8°·48
Time of Periastron	T	3300·533 J.D.	3300·551 ± ·033 J.D.
Velocity of System	γ	− 0·98 km.	−1·04 km. per sec.

The sum of the squares of the residuals was reduced by the solution from 4572 to 4242. The probable error of an observation of unit weight is $\pm 9 \cdot 7$ km. and of a single plate $\pm 13 \cdot 3$ km. per second. The mean velocity from the calcium lines, H and K, considered as constant in velocity, is $-18 \cdot 5 \pm 0 \cdot 61$ km. per second, while the probable error of a single plate from the calcium lines is $\pm 2 \cdot 9$ km. per second. It seems probable, therefore, that these lines as usual in stars "earlier" than B3, do not share in the oscillations of the hydrogen and helium lines, and the difference in the velocity of the system and of the calcium lines, $17 \cdot 5$ km., seems to preclude the possibility of the calcium vapour in this star being connected with the system.



Velocity Curve of 56° 2617

The value of the projected semi-axis major, $a \sin i$, is 1,354,500 km. and of the mass function $\frac{m_2^3}{(m_1 + m_2)^2} \sin^3 i$ is .054 ⊙. It will be of interest to see what ratio of the masses of the components or what angle of inclination of the orbit plane will make this relatively small mass function bring the masses to the order of magnitude usually assigned to this class. A ratio of masses of four to one and an average value of the inclination, $\sin i = 0 \cdot 6$, give masses 25 and 6·25 times the sun, while if we assume a ratio of mass of two to one, which is reasonable when the second spectrum does not show, an inclination of 77° will give masses 20 and 10 times the sun. Such masses, which are of about the order expected in these high temperature stars, do not, therefore, call for impossible or even improbable conditions of relative mass or of inclination.

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