DEPARTMENT OF THE INTERIOR
CANADA

HON. CHARLES STEWART, *Minister* W. W. CORY, C.M.G., *Deputy Minister*

PUBLICATIONS

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Dominion Observatory

OTTAWA

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

Vol. IX

Astrophysics

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THE CASTOR SYSTEM

BY DOUGLAS A. BARLOW

The Castor System[1] consists of a visual double star, of which the components α_1 and α_2 Geminorum are both spectroscopic binaries, and a distant companion C. The position is, R.A. $7^h\ 28^m \cdot 2$; decl. 32° 6′; magnitudes α_1 2·85, α_2 1·99, and C 9·0. Both α_1 and α_2 are of type *A;* however, the absorption in the case of the fainter is somewhat more complete, and consequently the number of measurable lines in its spectrum is greater than in that of the brighter. The companion is separated by 73″ from the primary system; it is of type *dMIe.*

On October 12, 1926, the first of a series of spectrograms was made with the one-prism spectrograph of the 15-inch equatorial of the Dominion Observatory. All plates used were Eastman 40, with the exception of the two standards, which were Eastman 33, the latter being a slower plate of finer grain. One hundred and three spectrograms were made between the above date and May 9, 1927. The plates were measured with a spectrocomparator, using standards of the respective stars.

Dr. Heber D. Curtis in his discussion[2] makes the statement that, "Although the lines in α_2 are not so distinctly defined, yet, when the proper exposure is made, the measurements seem to be somewhat more accurate on this star than on α_1". The writer finds that when measuring on the comparator α_1 is to be preferred to α_2 for accuracy. Exposures of from sixteen to twenty-four minutes and from eight to twelve minutes were required on α_1 and α_2, respectively.

α_1 Geminorum

The binary character of this component was discovered by Professor Belopolsky at Pulkowa in 1896[3]; 118 radial velocity determinations were made during the years 1894 to 1898, and an orbit determined. In the years 1904 and 1905, Heber D. Curtis investigated the star very thoroughly with the Mills spectrograph and obtained an orbit. At intervals between 1903 and 1917 J. Lehmann-Balanowskaja also made an exhaustive study of the star.[4]

The present discussion is based on the measurement of forty-two measurable spectrograms out of the forty-six obtained, four being discarded on account of weakness of stellar spectrum.

---

[1] Handbuch der Astrophysik, Band VI, p. 460.

[2] L.O.B., Vol. 4, p. 55.

[3] Bulletin, Academy of Sciences of St. Petersburg, Dec., 1896.
Memoirs, Academy of Sciences of St. Petersburg, 11, No. 4, 1900.
Ap. J., Vol. 5, p. 1, 1897.

[4] Bulletin of the Central Observatory of Russia at Pulkowa, Vol. 9, No. 93, p. 365.

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RADIAL VELOCITIES OF α_1 GEMINORUM

No.	Date	Julian Date	Velocity
	1926		km.
14717	Oct. 18	2424806·727	+30·96
22	19	807·851	−14·81
29	22	810·765	−16·59
30	22	·782	−15·18
40	28	816·724	−15·51
56	Nov. 6	825·663	−21·98
62	8	827·712	+20·80
92	Dec. 3	852·712	−15·71
14802	7	856·709	+30·07
22	23	872·665	−27·14
30	30	879·647	+18·73
	1927		
40	Jan. 8	888·699	+28·13
42	8	·715	+ 2·37
49	10	890·657	−21·93
63	21	891·654	−16·59
75	25	905·656	− 6·83
83	27	907·705	−21·01
94	Feb. 3	914·717	+14·61
14923	Mar. 1	940·711	−14·07
34	4	943·658	−10·11
42	10	949·553	− 2·85
47	11	950·654	+22·94
56	16	955·676	+ 8·50
60	17	956·664	+16·64
62	18	957·743	−28·02
65	20	959·715	+15·59
66	20	·729	+13·97
67	20	·758	+ 8·54
68	23	962·504	+11·95
70	23	·556	+17·07
71	23	·576	+ 9·94
72	23	·617	+ 5·35
74	23	·702	+ 5·50
75	23	·728	+ 6·60
76	23	·765	+ 7·23
84	25	964·686	+21·21
87	26	965·528	+11·76
90	26	·724	+ 0·16
91	27	966·653	−28·80
92	28	967·508	+13·43
96	29	968·712	− 6·90
97	30	969·518	−27·04

These were combined in normal places as follows, the phases listed being determined according to the adopted periastron and period.

No.	Phase	Velocity	Weight
1	0·023	8·50	0·4
2	0·102	14·02	0·7
3	0·182	19·47	0·5
4	0·407	29·55	0·6
5	0·618	30·07	0·3
6	0·858	22·94	0·4
7	0·928	20·80	0·3
8	1·002	14·30	0·7
9	1·057	13·51	0·6
10	1·115	11·67	0·9
11	1·194	6·88	0·8
12	1·273	− 3·54	0·5
13	1·346	− 6·90	0·4
14	1·537	−15·53	0·9
15	1·633	−16·05	0·6
16	1·806	−21·50	0·7
17	1·932	−27·14	0·2
18	2·090	−28·02	0·3
19	2·181	−27·92	0·7
20	2·355	−21·93	0·3
21	2·537	−14·89	0·5
22	2·680	− 4·16	1·0

From these normal places (omitting numbers 6 to 11, for reasons which follow), repeated orbits were obtained by experiment, using the third Henroteau method,[1] and testing each by summing the squares of the residuals until the elements given below were obtained. The period given was deduced from the observations of Curtis and the writer.

$$
\begin{aligned}
P &= 2^{d}\cdot 9283 \\
e &= 0\cdot 06 \\
\omega &= 290^{\circ}\cdot 0 \\
K &= 28\cdot 2 \text{ km.} \\
\gamma &= 0\cdot 22 \text{ km.} \\
T &= \text{J.D. } 2424888\cdot 302 \\
a \sin i &= 1{,}129{,}400 \text{ km.}
\end{aligned}
$$

Figure 1 shows this orbit with the normal places.

[1] Journal R.A.S.C., Vol. 21, p. 265 .

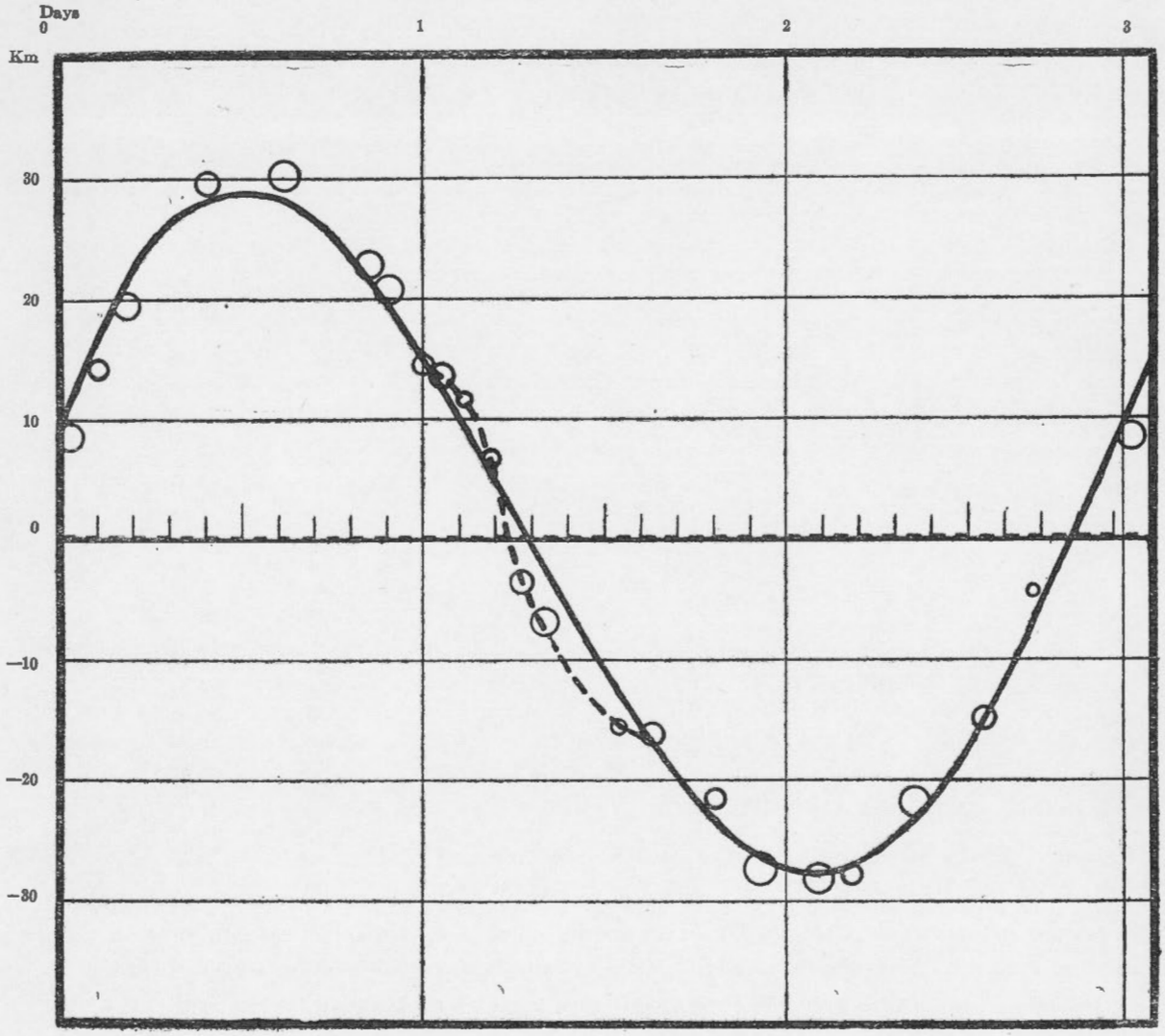

Fig. 1—Orbit of α_1 Geminorum

Following is a list of orbits which have been determined,—complete in so far as the writer is aware.

Author	Epoch	K	γ	ω	e	$a \sin i$	T J.D.
		km.	km.				
Belopolsky	1896	33·43	−4·1	82·0	0·12	1,336,400	2,413,559·00
L.–B.	1903·2, I	31·99	−1·2	14·4	0·02	1,287,500	6,136·24
Curtis	1904·7	31·76	−1·0	102·5	0·01	1,279,900	6,828·057
L.–B.	1905·7, II	30·13	−1·0	250·2	0·09	1,208,500	6,870·29
L.–B.	1910·0, III	29·19	−1·8	351·3	0·03	1,174,800	8,364·58
L.–B.	1912·9, IV	26·84	−2·6	86·5	0·05	1,080,200	9,454·72
L.–B.	1914·8, V	28·67	0·8	283·3	0·05	1,153,400	2,420,176·70
L.–B.	1916·8 VI	26·47	−9·3	35·7	0·04	1,065,100	0,927·24
Barlow	1926·9	28·2	0·2	290·0	0·06	1,129,400	4,888·302

Dr. Belopolsky considered a rotation in the line of apsides probable, having arrived at this idea by a classification of his observations into three groups which gave different elements. He assigned a period of 1,502 days, but he did not consider the observational data sufficient for a definitive decision as to the reality of this change. The writer agrees with Mrs. Lehmann-Balanowskaja in her conclusion that, considering the clearly small eccentricity of the orbit and the consequent opportunity for error, the attempt to define the variation may be wisely abandoned for the present. Dr. Belopolsky gives as period 2·934050 days.

Dr. Curtis' orbit was obtained from a series of 32 plates; his period 2·928285 days, was determined by using the maxima and minima given by Belopolsky in 1896-9 in connection with his own of 1904-5.

Between 1904 and 1917, 147 plates were secured at Pulkowa. These were divided into six sets and six orbits were determined by Mrs. Lehmann-Balanowskaja. By using the ascending and descending nodes she computed a mean period of 2·928308 days. She suggests that there may be a continuous variation in the amplitude, and offers the following relation:

$$K = 29{\cdot}13 - 0{\cdot}34\ (t - 1910{\cdot}0)$$

Referring to fig. 1, particular attention is called to the peculiarity in the descending branch of the curve. This made its appearance early in the investigation, and care was taken to accumulate a greater number of observations at this phase, with the result shown, the points in that vicinity being each the weighted mean of a number of observations. On account of this peculiarity, normal places 6 to 11 were omitted from the process of determination of elements, as being under the possible influence of a slight eclipse.

Evidence in favour of the eclipse is found in a publication by P. Guthnick and R. Prager,[6] "Photoelektrische Untersuchungen an Spektroskopischen Doppelsternen und an Planeten". An account is given of the installation of a photo-electric photometer and investigations therewith, including that of Castor. The measurements of magnitude were of the entire system, with results as follows:

M (Maximum), 1914 April 18·78 G.M.T. 2·92825 E
M – m (Minimum), $1^d{\cdot}5$
M $0^m{\cdot}35$; m $0^m{\cdot}44$

This change in combined magnitude corresponds to a change of $0^m{\cdot}28$ in the fainter component, whose magnitude is $2^m{\cdot}85$

The Guthnick light curve tends to raise some doubts as to the apparent simplicity of the system. The occurrence of an eclipse is neither definitely indicated, nor definitely excluded. Furthermore, it is clear that if this epoch of minimum be taken to be that of eclipse, we have a useful check upon the number of periods elapsed between the epochs of Curtis and the writer, that is a check upon the period given.

Taking the natural phase of eclipse, that is, when $v + \omega = 90°$, the following epochs are obtained:

Curtis, J. D. 2,416,830·895
Barlow, 2,424,889·583.

[6] Berlin-Babelsburg Publications, Band 1, Heft 1.

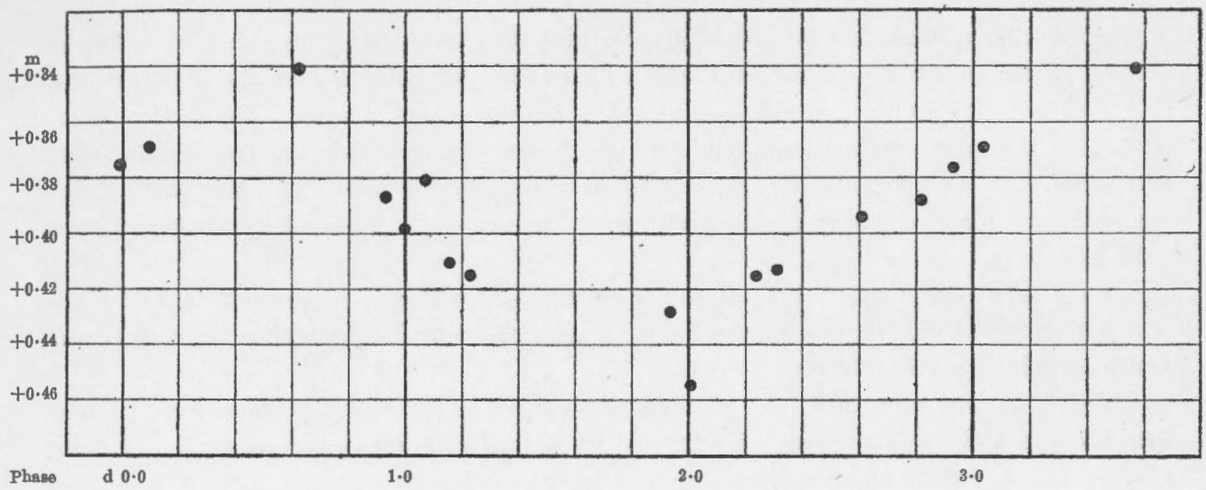

Fig. 2—Guthnick Light—Curve of α_1 Geminorum

($m = \alpha_1$ Geminorum—α Leonis)

The epoch of light minimum of the Guthnick curve is J.D. 2,420,245·280.

A period of $2^d \cdot 928302$ is indicated. The improvement on the period $2^d \cdot 928308$ being thus practically negligible. The difference between the Guthnick light-minimum and the date of assumed eclipse ($v+\omega = 90°$) for that particular revolution is $0^d \cdot 015$, which, in view of the curve, and the lack of accuracy with which the time of minimum is determinable, is remarkably small. The writer feels safe in adopting a period of 2·9283 days.

α_2 Geminorum

The variation in the radial velocity of this brighter component of Castor was discovered in October, 1905, by Dr. Curtis, and from a series of 40 observations an orbit was computed.[7]

Between the years 1909 and 1916 thirty-eight plates were made by A. A. Belopolsky at Pulkowa, and the investigation was pursued by V. Rossowskaja.[8]

The writer knows of no subsequent investigations other than the present.

Advantage was taken of all clear weather between October 12, 1926, and May 9, 1927, to make the 48 observations listed below. All measurements were made on the comparator, except that of 15064. The measurable lines in this spectrum, are as a rule, decidedly faint. There are obvious discrepancies from the smooth curve, but great care was taken in measurement, and many plates were re-measured with no appreciable change. The fact that the range is less than half that of α_1 renders these discrepancies more obvious.

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[7] L. O. B., Vol. IV, p. 55, 1897.

[8] Pulkowa Bulletin, Vol. 10, p. 192.

RADIAL VELOCITIES OF α_2 GEMINORUM

No.	Date	Julian Date	Velocity
	1926		
14690	Oct. 12	2424800·728	+17·91
91	12	·736	+ 9·17
92	12	·750	+14·33
14700	14	802·728	+ 0·99
01	14	·740	+ 9·32
02	14	·744	+ 9·32
18	18	806·737	−10·66
21	19	807·835	+ 0·69
23	19	·864	+ 3·85
28	22	810·752	+ 7·21
31	22	·864	+ 8·22
41	28	816·734	− 7·67
47	30	818·728	+13·37
55	Nov. 6	825·655	− 9·99
93	Dec. 3	852·729	−14·97
14803	7	856·728	+ 7·73
04	7	·741	+ 3·61
09	15	864·751	+13·03
21	23	872·654	+ 8·68
41	23	·709	− 6·50
	1927		
53	Jan. 11	891·550	+16·62
64	21	901·698	+15·29
68	23	903·658	+ 2·44
76	25	905·749	+ 5·76
82	27	907·686	− 5·89
93	Feb. 3	914·702	+ 2·04
98	5	916·624	− 8·38
14908	11	922·763	+ 2·72
10	13	924·660	− 3·37
19	28	939·726	+ 7·66
24	Mar. 1	940·722	+ 4·33
35	4	943·706	− 4·74
39	5	944·647	−11·87
48	11	950·665	+ 4·57
50	12	951·578	− 0·19
55	16	955·665	+11·57
64	19	959·494	+ 6·99
79	24	963·586	−13·46
85	25	964·710	+ 6·59
86	26	965·509	+15·56
95	29	968·664	+ 4·56
99	30	969·658	+ 2·90
15064	April 28	998·536	− 3·38
72	May 3	2425003·557	+16·07
73	3	·615	+14·90
86	9	009·574	− 9·39
87	9	·588	− 9·36
88	9	·598	− 8·60

These were combined in normal places as follows:

No.	Phase	Velocity	Weight
1	0·027	+ 3·85	0·2
2	0·072	+ 6·69	0·2
3	0·252	+ 9·96	0·3
4	0·795	+16·03	0·3
5	1·625	+13·86	0·6
6	2·096	+13·85	0·7
7	2·860	+ 6·89	0·9
8	3·572	+ 3·23	0·5
9	4·122	+ 5·21	1·0
10	4·474	+ 4·57	0·2
11	5·020	+ 2·90	0·2
12	5·398	+ 1·05	0·3
13	6·198	− 3·38	0·4
14	6·739	− 4·74	0·2
15	7·084	− 6·50	0·2
16	7·328	− 8·38	0·1
17	7·643	− 8·55	0·3
18	8·075	−11·09	1·0
19	8·595	− 9·99	0·1
20	8·897	− 7·67	0·1
21	9·222	+ 0·69	0·1

From these normal places a curve was drawn and a first orbit obtained by the third Henroteau method. With the sum of the squares as criterion, this was adjusted by experiment until the following orbit was obtained.

$$
\begin{aligned}
P &= 9^{d}\cdot 2236 \\
e &= 0\cdot 50 \\
K &= 13\cdot 4 \text{ km.} \\
\gamma &= 2\cdot 66 \text{ km.} \\
\omega &= 267^{\circ}\cdot 8 \\
T &= \text{J.D. } 2{,}424{,}890\cdot 849 \\
a \sin i &= 1{,}103{,}900 \text{ km.}
\end{aligned}
$$

Dr. Curtis gives 9·218826 days for the period and Rossowskaja 9·2189. The period given in the list of elements was obtained from the epochs of Curtis and the writer.

Following are the three orbits for comparison purposes:

Author	Epoch	K	γ	ω	e	$a \sin i$	T
Curtis	1904·7	13·557	6·20	265·353	0·5033	1,485,000	2,416,746·385
Rossowskaja	1910·3	13·92	6·18	266·98	0·5	1,523,000	2,418,786·307
Barlow	1926·9	13·4	2·66	267·8	0·50	1,103,900	2,424,890·849

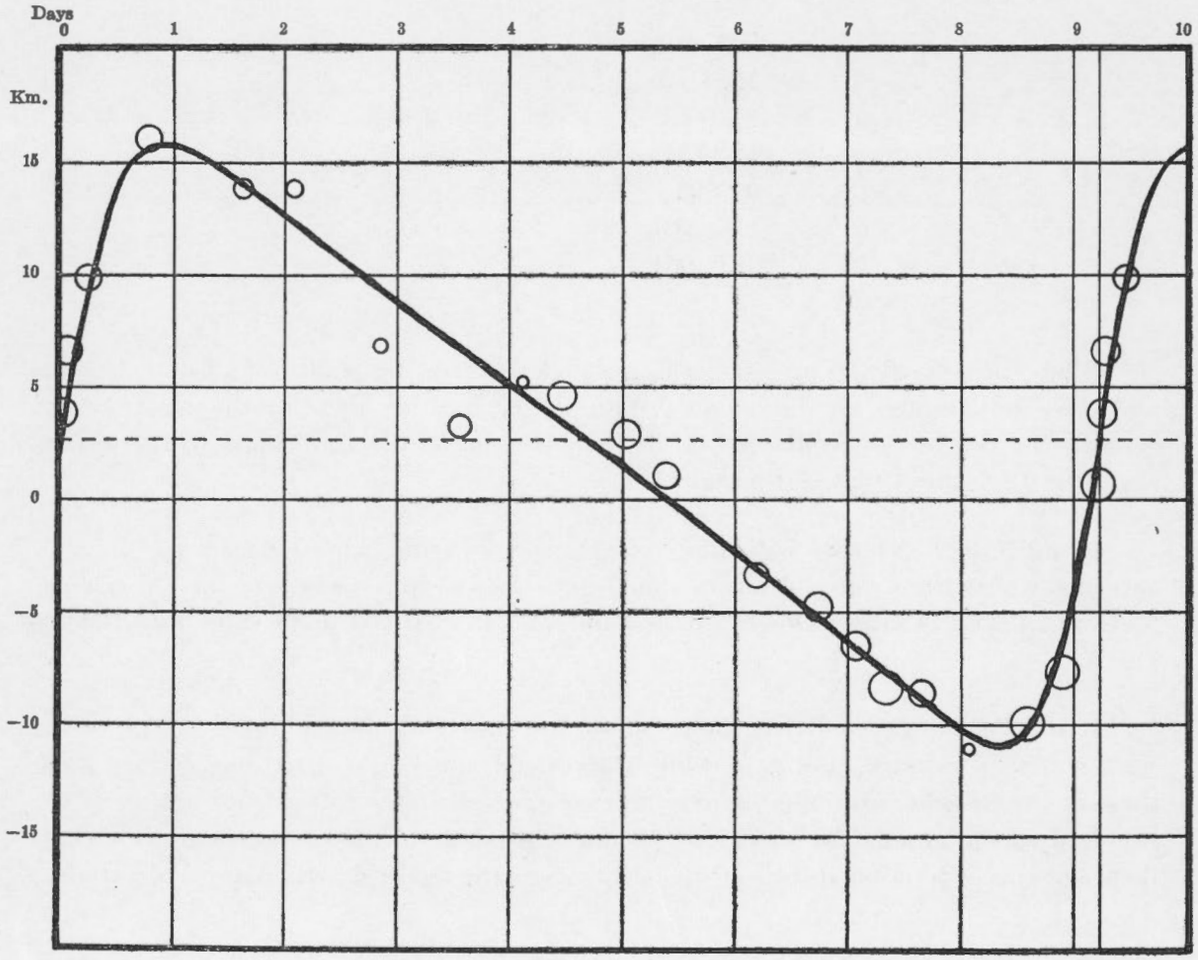

Fig. 3—Orbit of α_2 Geminorum

Dr. Curtis obtained a curve of great smoothness, with no large residuals. Commenting upon the extremes in eccentricity of the two components, he says: "This extraordinary difference seems, by the accepted theories of stellar evolution, to indicate that the brighter component is the older, and that the fainter is, spectroscopically speaking, a binary of relatively recent origin". One would expect the effect of tides to be noticeable in a system of such high eccentricity; but without data of greater accuracy than at present available nothing definite can be determined.

The Visual Orbit

Castor was discovered to be a double star by Bradley and Pound in 1719. Since then, although it has been frequently observed, its orbit has not been definitely determined. Many orbits have been published, all different; for the present discussion, the elements given by Rabe[9] are adopted:

[9] Astr. Nach., Vol. 216, p. 49.

P = 306·28 years
T = 1954·728 A.D.
a = 6″·060
n = 1°·1754
e = 0·5593
i = 113°·207
ω = 278°·031
Ω = 32°·546

When Curtis made his investigation, Doberck had recently published a list of elements and these he adopted for discussion. With these, and his own for the spectroscopic systems, he derived a parallax of 0″·05. On this basis, the total mass of the system would be 12·7 times that of the Sun.

Using Rabe's elements with those of Curtis, the writer finds a parallax of 0″·075, agreeing well with a later determination from photographs made at the Allegheny, McCormick, and Dearborn Observatories, namely 0″·077 ± 0·004, and a value of 12,189,000 km. for $a_1\ a_2$.

It will be remembered that these figures are functions, among other things, of the centre-of-mass velocity, and that while those determined by Curtis may be accepted, those of the present determination rest, in each case, entirely on the measurement of the standard spectrogram. The figures which might result from the use of these would not, then, serve as criteria for Rabe's orbital elements or the recent determinations of parallax.

Castor C

This companion is distant 73″ from Castor, in position angle 165°, and it has the same parallax and proper motion. The apparent magnitude is 9·0. From a spectrogram made on March 15, 1916, at Mount Wilson, it was discovered to be a binary star, having two spectra of about equal brightness and closely similar, with both absorption and emission lines. Thirty-five spectrograms were made by A. H. Joy and R. F. Sanford[10] with results as follows:

P = 0^d·814266
K_2 = 114·0 km. sec.
K_1 = 126·7 km. sec.
T = J.D. 2,423,746·524
γ = 4·3 km. sec.
$(a_1+a_2)\sin i$ = 2,695,000 km.
$m \sin^3 i$ = 0·63 ⊙
$m_2 \sin^3 i$ = 0·57 ⊙

[10] Mount Wilson Obs. Contributions, Ap. J., Vol. 64, 1926.

H. Van Gent published a paper giving an account of a photometric investigation of Castor C[11] showing it to be an eclipsing system; the results of his computation are as follows, assuming the orbit to be circular:

Min. J.D. 2,424,595·4105 + 0·81430 E
$\pm$ 0·0015 $\pm$ 0·00024
radius of each component, r = 406,000 km.
distance between centres, a = 2,581,000 km.
average mass, $\frac{M_1 + M_2}{2}$ = 0·518 $\odot$
density d = 2·596 $\odot$

This density is much above the average for spectroscopic binaries. A surface temperature of 3,500° has been computed, distinguishing the components as dwarf stars.[12]

In concluding, the writer wishes to express his acknowledgment of the co-operation of Dr. Henroteau and Mr. J. F. Frédette in taking some of the spectra, and of the advice and assistance of the former throughout.

DOMINION OBSERVATORY, OTTAWA.
March, 1928.

[11] Bulletin Astr. Inst. Netherlands, Vol. 3, No. 97, 1926
[12] L'Astronomie, October 1927, p. 482.