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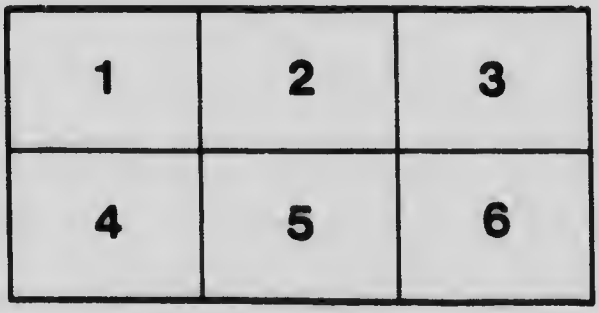

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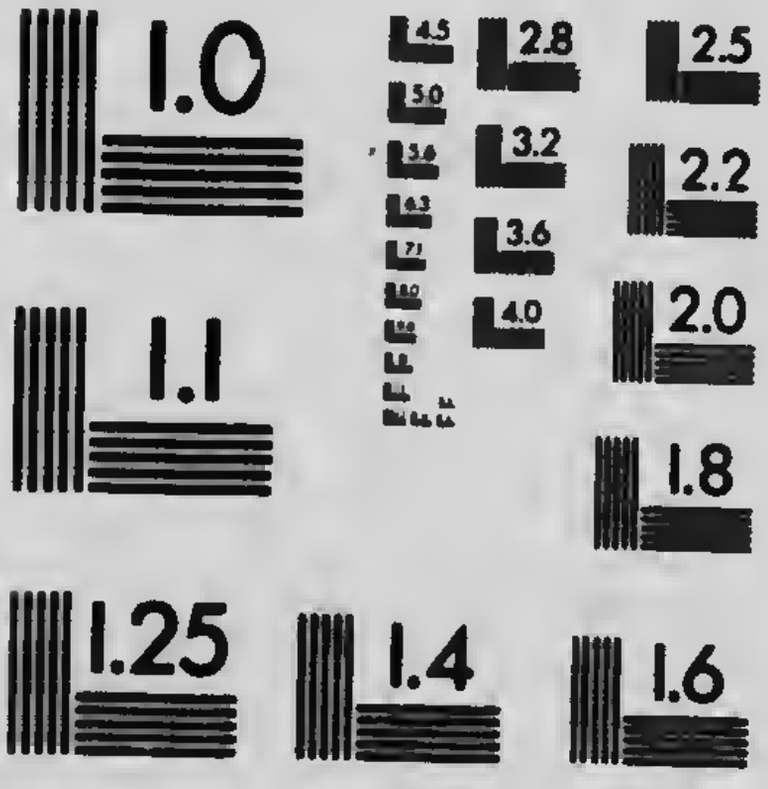

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A LONG-PERIOD SPECTROSCOPIC BINARY

BY

W. E. HARPER

DOMINION OBSERVATORY, OTTAWA

A LONG-PERIOD SPECTROSCOPIC BINARY

By W. E. Harper

THE second magnitude star γ Geminorum ($6^h\ 31^m{\cdot}9$, $\delta = +16°\ 29'$) has been under observation here since the autumn of 1906. Its radial velocity had previously been investigated by Campbell, Frost and Slipher in the years from 1899 to 1905 and it was also one of the stars which Vogel used at Potsdam when the photographic plate was first applied to work of this nature in 1888. When we consider that the two plates secured by Vogel which are used in this paper were made at the very beginning of radial velocity work the residuals of 1·5 km. for each are very small. Although a few more measures were made at Potsdam they are not used, for the reason that only the H_γ line on each was measured, and consequently the same reliance could not be placed upon them as on plates where many lines were measured.

Of the four Lick observations two were made in 1899, one in 1904 and one in 1905. The 1904 plate showed variability in velocity and the star was announced as a spectroscopic binary in the *Astrophysical Journal* for March, 1905. The Yerkes Observatory made three plates in 1901 which showed no variation in velocity and one in 1904 which did. The Lowell Observatory have a plate in each of 1902 and 1903 and four in 1905. As the 1905 plates were all made within a month and are only approximate results, they can not be considered as better than two definite measures. For some reason the 1902 plate does not agree with our curve there being a residual of 9 km. in a well defined part of the curve, while the 1903 plate has a residual of 3 or 4 km., but in a part of the curve which is not so well defined and which will require more observations to fill up the gap. As none of the other plates used gave residuals greater than 2 km. these

two plates were excluded from the final determination of the orbit. Just at this point it may be stated that Slipher, using the data just outlined, which is given in the table of "Early Measures," discussed the star's variable velocity in *Astrophysical Journal*, Vol. XXII., page 84, and suggested for it a period of three and one-half years. The observational data was, however, entirely too meagre, I think, to bear out any suggested period. The period herein determined, approximately six years, is no multiple of that suggested by Slipher and the writer feels that though the number of observations is greatly increased they are yet too few to make a rigid determination of the elements. Those given here suit the observations remarkably well however.

Twenty plates were made here with the Universal three-prism spectrograph from December, 1906, to April, 1907. These were measured and reduced by the writer, using the long interpolation method of Hartmann. As twenty or more star lines on each were measured, a considerable amount of labor was thus expended on them. This work availed little so far as the star itself was concerned, but, possibly, helped to show that some instrumental errors had not yet been overcome and a new spectrograph was accordingly designed for radial velocity work alone. The plates with the Universal instrument have, therefore, not been used in this discussion.

The new three-prism spectrograph, IIIL, was ready in May, 1907, and spectrograms of the star were again made. During the season of 1910 the spectrograph was changed quite frequently, as a short form of camera was being experimented on, and no plates with the long focus camera were made. There were made, however, two with camera designated III S and one with camera designated III R, but as the dispersion of these was only about one half as great as the III L, they could not be considered by any means as reliable as the other, and hence they have not been used. It is unfortunate that a continued series of plates with III L were not made that season as they would fall around the maximum of the curve and round out an otherwise incomplete set. The plates then that are used in this discussion were all

made with spectrograph III L, whose linear dispersion at H_γ is 10·1 tenth-metres per millimetre. The measures of these are given in the table. Quite a number of these results are the means of two measures. Nearly all the plates were measured by the writer, but independent measures were made on several by other observers, Messrs. Westland, Cannon and Parker, and there was good agreement in the results obtained The phases are reckoned from the corrected value of periastron passage, Julian Day 2,4.0,101·6, using the period 2175 days.

EARLY MEASURES

Observatory	Date	Julian Date	Phase	Velocity	Wt. Assigned	Residual
Potsdam	1888, Dec. 14	2,410,986·5	896·4	− 18·1	½	+ 0·5
Potsdam	1889, Jan. 6	1,009·5		14·2	½	
Lick	1899, Sept. 21	4,919·9	468·3	15·4	1	− 1·0
Lick	Oct. 24	4,952·9	501·3	15·1	1	− 0·4
Yerkes	1901, Nov. 15	5,704·8	1253·2	15·4	1	+ 0·3
Yerkes	Nov. 20	5,709·8	1258·2	14·9	1	+ 0·8
Yerkes	Nov. 27	5,716·8	1265·2	16·4	1	− 0·7
Lick	1904, Jan. 27	6,507·8	2056·2	4·7	1	+ 0·1
Yerkes	Dec. 6	6,821·8	195·2	8·7	1	+ 0·2
Lick	1905, Feb. 13	6,890·7	264·1	10·4	1	+ 0·2
Lowell	1905, Mar. 10	6,915·7	294·1	11·	½	− 0·2
Lowell	Mar. 20	6,925·7		12·	½	
Lowell	Apr. 6	6,942·6	319·5	11·	½	+ 0·4
Lowell	Apr. 13	2,416,949·6		11·8	½	

OTTAWA MEASURES OF γ GEMINORUM

Plate	Date	Julian Date	Phase	Velocity	No. of Lines	Wt.	Residual
1099	1907, Oct. 8	2,417,857·9	1231·3	− 15·9	13	1	0·0
1255	1908, Jan. 22	7,963·5	1336·9	14·7	16	1	+ 0·5
1293	Jan. 27	7,968·8	1342·2	15·5	17	1	− 0·3
1305	Jan. 29	7,970·8	1344·2	13·8	16	1	+ 1·3
1330	Feb. 17	7,989·8	1363·2	16·9	17	1	− 1·8
1307	Feb. 28	8,000·7	1374·1	14·4	15	1	+ 0·5
1453	Apr. 3	8,035·7	1409·1	15·5	15	1	− 0·8
1872	Sept. 7	8,192·9	1566·3	12·6	10	1	+ 0·5
2074	Dec. 23	8,299·7	1673·1	10·4	14	1	+ 1·2
2208	1909, Jan. 30	8,337·7	1711·1	12·9	16	1	− 1·8
2281	Feb. 17	8,355·7	1729.1	11·9	14	1	− 1·1
2287	Feb. 20	8,358·7	1732·1	9·9	11	1	+ 0·8
2395	Mar. 20	8,386·7	1760·1	9·5	15	1	+ 0·7
3971	1911, Jan. 28	9,065·8	264·2	11·4	13	1	− 0·8
4734	Dec. 19	9,390·9	589·3	15·2	13	1	+ 0·3
4830	1912, Feb. 8	2,419,441·8	640·2	− 16·3	15	1	− 0·4

The spectrum is of the Sirian type, having many fine metallic lines of iron and titanium as well as the hydrogen series. The following table contains the lines most frequently measured.

LINES IN γ GEMINORUM

Element	Wave-Length	Element	Wave-Length
Fe	4584·018	Ti	4468·663
Ti	4572·156	Ti	4443·970
Ti	4563·939	Fe	4404·927
Cr	4558·827	Ti-V-Fe	4395·286
Fe-Cr	4556·202	Cr-Mg.	4352·006
Fe-Ti	4549·766	Ti	4340·634
Ti	4534·139	Fe	4325·039
Fe-Ti	4522·855	Fe	4308·081
Ti	4515·508	Ti	4300·211
Ti	4508·455	Fe	4294·290
Ti	4501·448	Fe	4233·328
Mg.	4481·400		

It has been the writer's custom for some time past to obtain wave-lengths for each star by itself, making the sum of the velocity residuals equal to zero. In the case of this star a summary of the residuals given by each line from the velocity

accepted for the plate shows that some slight changes might be made in the wave-lengths and better agreement secured among the lines themselves. The revised velocities would not be materially different, as the differences in the long run would tend to balance one another, and the procedure has not been carried out. A sample of the residuals is given in the accompanying table for the nine lines most frequently used, the order indicating the frequency of measurement.

RESIDUALS FROM LINES

Line	Average Numerical Residual	Average Algebraic Residual	Line	Average Numerical Residual	Average Algebraic Residual
3959	2·3	+ 0·8	4522	2·7	+ 1·4
[illegible]	1·9	− 1·4	4501	2·2	1·6
4384	5·1	− 1·7	4395	5·0	+ 3·7
4352	2·9	+ 0·8	4508	2·6	− 2·0
4308	2·5	+ 1·2			

A plot of our own observations seemed to indicate a period of about six years. The early observations were now brought forward using periods of 2270, 2200 and 2160 days. The latter seemed to suit the reliable observations, best and it was accordingly used. Graphical values for the elements were obtained in the usual way.

Preliminary Elements

P = 2160 days
e = ·35
ω = 0°
K = 6·5 km.
γ = − 12·27 km.
T = J. D. 2,410,036·0

Although, as previously stated, there was a gap in the curve requiring further observations to fill up, yet it seemed desirable to make a least squares solution of all the dependable measures to date. For purposes of grouping, the very early observations at Potsdam were weighted one-half as were also the Lowell approximate measuress, while all others including our own were each

weighted unity. In the Table of Normal Places groups 1–9 inclusive represent our own observations, groups 10–16 those of other observatories.

TABLE OF NORMAL PLACES

	Mean Phase Preliminary	Mean Vel.	Wt.	O-C Preliminary	Mean Phase Corrected	O-C Corrected
1	1394·7	− 15·30	2	+ ·43	1284·1	+ ·24
2	1453·8	14·65	2	+ ·74	1343 2	+ ·50
3	1479·2	15·65	2	− ·44	1368·6	− ·68
4	1598·3	14·05	2	+ ·07	1487·7	− ·12
5	1802·7	11·65	2	− ·52	1692·1	− ·31
6	1841·2	10·90	2	− ·58	1730·6	− ·19
7	1870·7	9·50	1	+ ·15	1760·1	+ ·71
8	389·8	11·40	1	+ ·35	264·2	− ·79
9	740·3	15·75	2	− ·15	614·8	− ·04
10	962·0	16·10	1	+ ·29	896·4	+ ·55
11	580·4	15·25	2	− ·88	484·8	− ·75
12	1354·5	15·57	3	+ ·36	1258·9	+ ·12
13	2151·8	4·70	1	− 1·19	2056·2	+ ·11
14	340·2	9·55	2	+ 1·24	229·6	+ ·21
15	404·7	11·50	1	+ ·52	294·1	− ·21
16	430·1	11·40	1	+ 1·04	319·5	+ ·44

Observation equations using the differential form of Lehmann-Filhés were built up and transformed into normals from which the following corrections were obtained.

$$\delta\gamma = - \cdot 01 \text{ km.}$$
$$\delta K = - \cdot 38 \text{ km.}$$
$$\delta e = - \cdot 052$$
$$\delta\omega = + 16^\circ \cdot 31$$
$$\delta P = + 15 \cdot 0 \text{ days}$$
$$\delta T = + 65 \cdot 6 \text{ days.}$$

Using the corrected value of the period, 2175 days, the observations were again grouped as in column 6 of the table, and residuals obtained which were in general smaller than the previous ones. The value for Σpvv for the preliminary elements was 11·1 and for the corrected elements 4·7. Using all the measures the probable error of a plate obtained from the last two columns of the measures is ± 0·55 km. per sec. This is extremely small for a star of this type when we consider that

the plates were secured by five different equipments, and one cannot but feel that the good agreement is somewhat of a chance result. This is all the more likely when we note the probable errors of the determined quantities which appear with the corrected values of the elements. Some of them are of considerable magnitude, and it will be necessary to obtain more measures after a few years to fill up the gap at the maximum of the curve. The elements as corrected, with probable errors, are as follows:

Corrected Elements

$P = 2175 \pm 22{\cdot}85$ days
$e = {\cdot}298 \pm {\cdot}026$
$\omega = 16°{\cdot}31 \pm 6°{\cdot}16$
$K = 6{\cdot}12$ km. $\pm$ ·28 km.
$\gamma = -12{\cdot}28$ km. $\pm$ ·13 km.
$A = 7{\cdot}87$ km.
$B = 4{\cdot}37$ km.
$T =$ J. D. $2{,}410{,}101{\cdot}6 \pm 96{\cdot}81$ km.
$a \sin i = 174{,}720{,}000$ km.

This star is unique in being one of the longest period binaries known. With the exception of α Orionis, a late solar type star, which has recently been shown* to have a period approximately the same, but whose orbital elements have not been definitely determined, no other spectroscopic binary has nearly such a long period. The other binaries of this type have periods ranging from a fraction of a day up to one hundred days. In the case of Sirius the period is 49·3 years, but it was not from spectroscopic but from visual observations that this was determined.

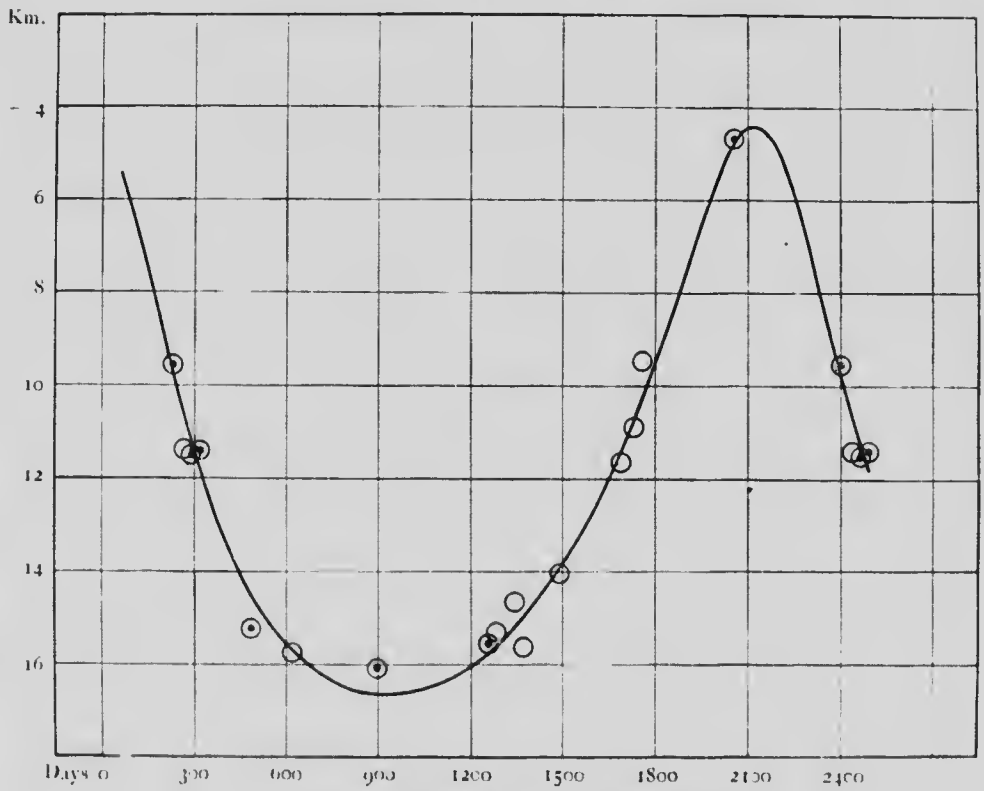
The periods of visual binaries in general are very large when compared with those of spectroscopic binaries but there are some with relatively short periods. Thus we have

κ Pegasi	11·37 years,
13 Ceti	7·42 years,
δ Equulei	5·70 years,

* *A. N.* 4467.

the last one of these has a shorter period than the star under consideration. So that we may say of γ Geminorum that it bridges over the gap between the periods of the longest spectroscopic and the shortest visual binary.

The plates were all of Seed 27 emulsion. One fine grained plate has since been made, but on none does a second spectrum show. The companion star would, of course, need to be of small mass relatively to the principal star in order that there might be sufficient separation of the lines to be resolved on our plates. Possibly near the time of next periastron passage, which occurs



VELOCITY CURVE OF γ GEMINORUM

at the beginning of 1916, some high dispersion equipment may record the fainter component spectrum. If the star should prove to be a visual binary, and we combined the spectrographic measures of the relative velocity of the two components in the line of sight with the orbit data from micrometric measures, we would have an indirect means of determining the parallax of the star. So far as is known to the writer no values of the parallax of this star by any method have been published.

The curve shown represents the elements as corrected. The plain circles represent our own observations grouped, while the circles with dark centres the grouped measures of other observatories.

It is with some hesitation that the foregoing elements are submitted. Owing to the paucity of observations around the peak of the curve we cannot regard these elements as definite, but they can be regarded, I think, as fairly approximate. It is just possible that this discussion may result in some unpublished measures of this star's radial velocity being brought to light.

A good share of the credit for this determination of the orbital elements should be given to those observatories who made the early observations, without which our own measures would be inadequate.

DOMINION OBSERVATORY,
OTTAWA, CANADA,
April, 1912.