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Orbit of the spectroscopic binary b Persei

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Abstract. New spectroscopic orbital elements have been derived for the close binary system b Persei. The period is improved to 1·527360 days. Earlier observations by Cannon (1914), Harper (1930) and Heard (1938) have been reanalysed and the reality of the variations in the orbital elements is established. The change in ω indicates an aspidal motion period of about 60 years. Changes in some of the orbital elements may be due to the distortion of the radial velocity curve by gas streams present in the system. In view of the flaring radio emission detected from this system and the variations of the orbital elements, we believe that the close binary system b Persei is in an active mass transfer phase.

Keywords. Close binary systems; apsidal motion; mass transfer; spectroscopic orbit.

1. Introduction

The binary nature of b Persei was first detected by Campbell in 1910. Cannon (1914) derived its orbit using 36 plates taken at Ottawa during the years 1910 and 1911. The orbit was reinvestigated by Harper (1930) and Heard (1938). Cannon detected a secondary spectrum and deduced a mass ratio of 3·6: 1. However, both Harper and Heard found no trace of the secondary spectrum on the Victoria and Yerkes plates respectively. We also do not find any evidence for the presence of the secondary spectrum.

The photometric study by Stebbins (1923) showed the system to be an ellipsoidal variable with an amplitude of 0·06 magnitude in the visual region. Recently, Hjellming and Wade (1973) detected faint intermittent radio emission from b Persei with characteristics of the radio emission similar to those seen in the close binary systems β Persei, β Lyrae and α Scorpii B.

2. Observations

Forty spectrograms of b Persei were taken on Eastman-Kodak 103 a–0 emulsion during the period January-February 1973 with a grating spectrograph attached to the Cassegrain focus of the 102 cm reflector at Kavalur. The projected slit width was 20 microns and the spectra had a dispersion of 47 Å/mm at H_γ. All the plates were measured by one observer (RR) with an Abbe comparator. These spectra cover a wavelength range from λ 3,700–λ 4,600. The wavelengths used for radial velocity measurements are listed in table 1. The successive columns in table 2

Table 1. Wavelength used for radial velocity measurement

Wavelength Å	Line	Wavelength Å	Line
4481·228	Mg II	3933·664	Ca II K
4340·468	H_γ	3889·060	H_8
4101·737	H_δ	3835·400	H_9
3970·074	H_ϵ	3797·910	H_{10}

give the plate number, the heliocentric Julian day of observation, the phase computed from T, the time of periastron passage. the measured radial velocity reduced to the sun. the number of lines measured on each plate, and the residuals computed from the final elements.

3. The period

Cannon (1914) found the period of the system to be 1·52732 days. Stebbins (1923) from his photometry found the primary minimum to occur 0·033 day later than that predicted from Cannon's period. The discordance between the light curve and the prediction is accounted for by a correction of + 0·000013 day to Cannon's period. Harper (1930) found that his observations and earlier ones can best be represented by a period of 1·52738 days. Combining the earlier epochs of observation with ours, we find that a period of 1·527360 days represents all the observations satisfactorily and hence have used this value in our subsequent calculations. The orbital period of the system does not seem to have changed during the last 63 years.

4. The orbital elements

The preliminary elements obtained by the method of Lehman-Filhes were corrected by a least squares solution following Sterne (1941). All observations listed in table 2 were given equal weight and were used in the least squares analysis. This solution yielded a value of eccentricity ($e = 0·09$) that differed much from zero and hence we performed a second least squares solution by the method of Schlesinger (1908). However, we adopted Sterne's suggestion (Sterne 1941) to replace T by T_0, the time at which the mean longitude ($\omega + M$) is zero. Table 3 shows the preliminary values. the first solution and the final solution of the orbital elements. The computed curve using the final solution is shown as a solid line in figure 1, and the individually observed radial velocities are plotted as filled circles.

5. Discussion

In order to compare the new orbit with earlier orbit determinations, we have reanalysed the data of Harper (1930) and Heard (1938) according to Sterne's method. Since Cannon's orbit showed large eccentricity, his data were reanalysed according to the method of Schlesinger (1908), again replacing T by T_0. The revised period of 1·527360 days was used in all computations and the orbital elements given by the respective authors were used as preliminary elements. The orbital elements recomputed by us and those given by Harper (1930) and Heard (1938) differ only

Table 2. Radial velocities of b Persei

Plate No.	Hel. J.D.	Phase (period)	V km/sec	No. of lines measured	(O–C) km/sec
	2441700+				
1720	00·086	·964	−22·1	6	−14·0
1721	00·097	·971	−18·1	5	− 8·2
1733	01·177	·678	+57·5	3	− 8·3
1741	02·147	·313	+21·7	3	− 1·3
1742	02·164	·324	+25·8	4	− 0·1
1743	02·178	·334	+20·6	4	− 7·8
1744	02·196	·346	+30·9	4	− 0·6
1745	02·214	·357	+27·4	4	− 6·9
1751	03·088	·936	+ 6·4	7	+ 4·7
1752	03·150	·970	−12·2	5	− 2·6
1753	03·170	·093	−11·3	6	+ 1·4
1754	03·201	·003	− 8·7	5	+ 8·0
1758	04·073	·574	+64·0	7	− 4·9
1759	04·084	·581	+68·6	7	− 0·6
1760	04·095	·588	+69·3	5	− 0·1
1761	04·107	·596	+60·5	5	− 9·0
1770	05·069	·226	− 5·5	6	− 5·3
1771	05·080	·233	+ 5·3	4	+ 3·8
1772	05·085	·237	+ 0·8	4	− 1·7
1773	05·098	·245	+ 1·7	5	− 3·0
1792	16·162	·489	+71·7	5	+10·7
1793	16·190	·507	+73·0	5	+ 9·6
1801	17·168	·148	−18·0	3	− 1·0
1802	17·193	·164	−10·4	3	+ 3·8
1836	25·095	·338	+17·5	4	−11·9
1844	26·165	·038	−22·6	6	− 1·1
1851	27·076	·635	+76·8	4	+ 7·9
1862	28·065	·282	+34·2	5	+19·5
1863	28·090	·298	+24·9	5	+ 5·9
1875	29·065	·937	− 9·5	5	− 8·9
1876	29·079	·946	+ 5·8	4	+ 9·1
1886	30·063	·590	+63·9	6	− 5·5
1887	30·086	·606	+75·6	5	+ 6·0
1893	31·055	·240	− 4·2	5	− 7·5
1894	31·071	·251	+ 8·3	6	+ 2·2
1902	32·068	·904	+ 17·5	6	+ 7·7
1919	34·059	·207	− 6·6	7	− 1·6
1920	34·074	·217	− 1·2	5	+ 2·1
1935	35·056	·859	+30·7	5	+ 6·5
1936	35·067	·867	+ 21·1	5	− 0·6

Table 3. Orbital elements of b Persei

Orbital elements		Preliminary (Method of Lehman-Filhes)	First solution (Sterne's method)	Final solution (Schlesinger's method)
V_0	..	25·9 km/sec	26·7±0·9 km/sec	26·92±0·87 km/sec
K	..	46·5 km/sec	45·8±1·3 km/sec	46·38±1·46 km/sec
e	..	0·06	0·090±0·026	0·090±0·025
ω	..	239°·8	165°·2±16·3	147°·8±15·6
T_0	..	J.D. 2441699·483	J.D. 2441699·514 ±0·009	J.D. 2441699·514 ±0·008

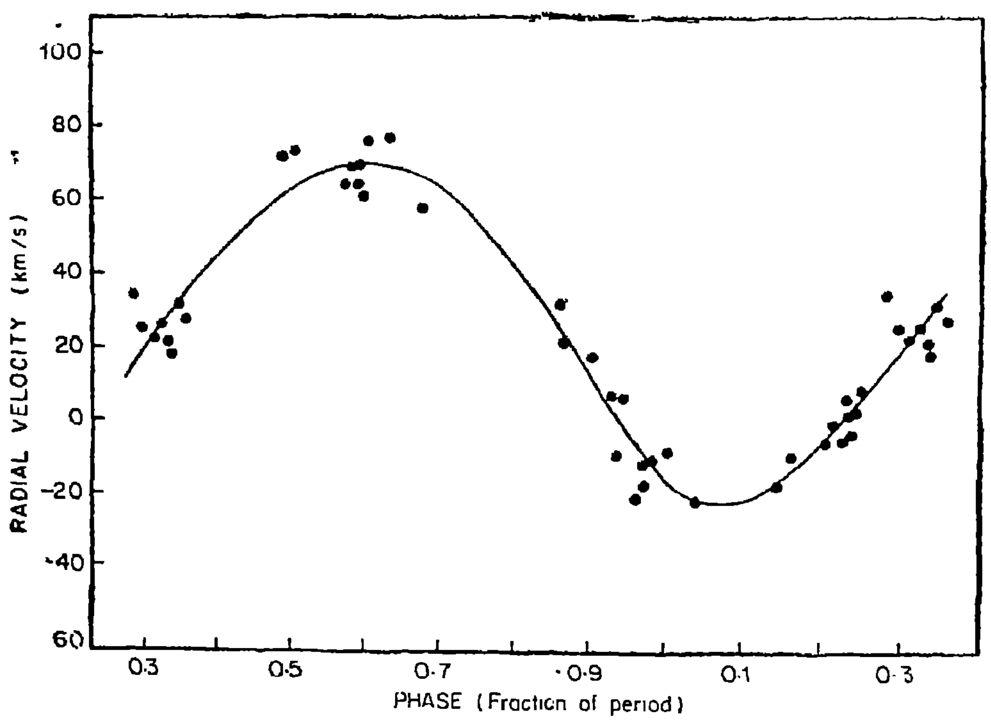

Figure 1. Radial velocity curve of b Persei.

in ω and T, while the orbital elements determined by Cannon (1914) and those computed by us using his data are practically the same. The recomputed orbital elements are listed in table 4, together with the orbital elements derived from our data for comparison.

An inspection of table 4, reveals significant variations in ω and T. The change in ω is about 6° per year. If we interpret this as due to a rotation of the line of apsides we get an apsidal motion period of about 60 years. Even though the change in ω does not seem to be uniform and the smallness of the value of e makes the determination of ω a little uncertain, it is clearly seen that the change in ω is quite rapid and the line of apsides seems to have made one complete rotation since the first orbit determination by Cannon in 1914.

The variation in the systemic velocity V is quite significant. The systematic dif-

Table 4. The orbit of b Persei at different epochs

Orbital Element/Epoch	Cannon 1911·04	Harper 1930·10	Heard 1935·24	Kodaikanal 1973·10
P ..	1·527360 days	1·527360 days	1·527360 days	1·527360 days
V_0	22·54±0·57 km/sec	12·71±0·51 km/sec	19·94±0·90 km/sec	26·92±0·87 km/sec
K ..	42·53±1·15 km/sec	38·10±0·61 km/sec	43·11±1·51 km/sec	46·38±1·46 km/sec
ϵ ..	0·21±0·02	0·068±0·035	0·040±0·027	0·090±0·025
ω ..	154°·5	338°·1±27·3	283°·98±29·0	147°·8±15·6
T ..	J.D. 2418956·172±0·032	J.D. 2418957·033±0·116	J.D. 2418956·814±0·120	J.D. 2418956·223±0·085
T_0 ..	J.D. 2418955·496±0·006	J.D. 2418955·599±0·005	J.D. 2418955·609±0·006	J.D. 2418955·596±0 008
$a \sin i$ ..	873327 km	798364 km	904704 km	970200 km
$f(m)$ ..	0·011	0·008	0·013	0·015

Velocities measured with our spectrograph reproduce the values in Wilson's catalogue within a kilometer. Hence, any systematic differences present in the radial velocity measurements of the four observatories should be less than $\pm$ 2 km/sec, while the variation in systematic velocity V ranges over 14 km/sec. One can normally interpret this change as arising from the effects of the presence of a third body in the system. However, when one couples this with a variation in K of 8 km/sec and a change in orbital eccentricity from 0·21 to 0·05 over an interval of twenty years, one becomes aware of the manifestation of temporal gaseous streams that can subtly distort line profiles to give velocities unrepresentative of the dynamical behaviour of the principal components.

An inspection of table 4, reveals that the variation of V and K are linearly correlated with the value of ω. The effect of gas streams on the observed radial velocity seems to be dependant on the orientation of the orbit with respect to the observer. The computed residuals of H_γ and H_δ show large negative residuals from phase 0·6 to 0·0 on the descending branch of the radial velocity curve while such an effect is almost absent in H_8, H_9 and Ca II K 3933 is completely free from it. These effects can be understood in terms of gas streams flowing through the inner lagrangian point L_1, from the primary component towards the secondary. The absolute magnitude of b Persei lies in the range 0·2 to 1·6 magnitudes (Olson 1968). This, together with the orbital elements derived in this study and the mass ratio of 3·6: 1 given by Cannon (1914) lead us to believe that it is the primary component which has filled up its roche lobe. The gas streams flowing from the inner lagrangian point L_1 from the primary towards the secondary seen projected against the primary would lead to distortion of the descending branch of the radial velocity curve. It must be mentioned, however, that no trace of emission is seen in the spectrogram employed in the present study. A few spectra obtained at a dispersion of 17Å/mm in the red do not indicate emission in H_α either. However, microphotometric tracings of these spectra do suggest a slight asymmetry of the line profiles near phase 0·15 and 0·50. High dispersion spectra would be required to confirm these findings.

Hjellming and Wade (1973) have recently detected flaring radio emission from b Persei. They found the characteristics of the radio emission to be similar to those detected from β Persei, β Lyrae, α Scorpii B, and more recently from AR Lacertae (Hjellming and Blankenship 1973). In all these systems, it appears that the radio emission is associated with the primary component. In the case of β Persei, β Lyrae and AR Lacertae there is clear observational evidence for the presence of gas streams in these systems. The non-thermal radio emission from these binary systems is interpreted by Jones and Wolf (1973) as due to the gravitational energy liberated as mass falls on to the surface of the receptor star. The recent detection of radio emission and the optical observation presented here indicate that b Persei is in the mass transfer phase. Optical observations of the spectrum of β Persei by Bolton (1972) during the time covered by radio measurements, have shown significant changes in the profiles of hydrogen lines and also in the K line of Ca II. This phenomenon occurs simultaneously with strong radio flaring. A similar process may prevail in the close binary system b Persei from time to

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