Astron. Astrophys. Suppl. Ser. **57**, 487-494 (1984)

A new photoelectric investigation of the W UMa system U Pegasi

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Received December 12, 1983, accepted April 19, 1984

Summary. — Over four hundred photoelectric observations of U Peg in *B* and *V* were secured with a 0.6 m reflector at Beijing Observatory in 1978. Four times of minima were determined. A period study of the times of minima from 1896 to 1980 was performed. The system was found to have a secular period decrease, $\Delta P/P$ of 1.32×10^{-10} or 4.16×10^{-3} s/yr. as well as a short term (17 years) sinusoidal oscillation with a semi-amplitude of 0.00323 day. It is suggested that oscillating term is caused by the light-time effect of an unseen third body. The third body may be an M6 main sequence star with a mass of 0.16 $M_{\odot}$. The long term secular change in period may be associated with slow mass transfer. The analysis of the 1978 light curves together with 1958 light curves of Binnendijk suggest that the system U Peg has an overcontact configuration of about 9 %. It has the characteristic of a W-type W UMa system. The photometric mass ratio, m_2/m_1, is between 3 and 2.5. If we correct the Struve *et al.* γ-velocity from 0 km/s to about − 40 km/s, the estimated spectroscopic mass ratio would agree with the photoelectric value. Based on the above assumption the absolute dimensions of U Peg are of 0.6 and 1.8 $M_{\odot}$ and of 0.8 and 1.4 $R_{\odot}$, for components 1 and 2 respectively. The physical dimensions indicate that the components are main sequence stars.

Key words : W UMa system — photometric solution — period changes — absolute dimensions — eclipsing star — close binary.

1. Introduction.

The variability of U Pegasi was discovered by Chandler (1898). Adams *et al.* (1924) classified this system as a F3 binary, but Adams *et al.* (1935) revised it to spectral type G3. In 1948 Struve *et al.* (1950) obtained 4 spectra of this system. Unfortunately, neither the dispersions nor the probable errors of these spectra were published. Two of these showed double lines. From this limited data they estimated the amplitudes of the radial velocity curves to be $K_1 = 165$ km/s and $K_2 = 205$ km/s. This led to a very uncertain spectroscopic mass ratio of 1.24. Photoelectric observations of this W UMa system were published by LaFara (1952), Huruhata *et al.* (1957) (also reported flare activity), Hinderer (1960), Binnendijk (1960), Saito (1971), Rigterink (1972) and Hogg (cf. Gordon, 1975). More complete reference of earlier work can be found in Binnendijk (1960) and will not be restated here. The light curves of this system showed variation through the years. The solutions based on the classical Russell model were published by some of the authors mentioned above, but no consistent solution was found. It is suspected that this may be due to the unstable light curve. Recently Russo *et al.* (1982) published a synthetic light curve analysis employing Binnendijk's observations (1960) by means of the Wilson and Devinney (1971) method. They derived a mass ratio, $q = m_2/m_1$ of 1.85. This value is different from the estimation of Struve *et al.* (1950).

We obtained a complete coverage of the *B* and *V* light curves of U Pegasi on October 3/4 in 1978. In the present work we shall investigate the new observations from Beijing as well as some of the published material in the literature.

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2. Observations.

The observations of U Peg were obtained with the 60 cm reflector at the Beijing Observatory. The telescope was equipped with a single channel photometer employing an EMI 6256B photomultiplier (Shen, 1967). We employed the same comparison star and check star as Binnendijk (1960), BD + 4°5038 and BD + 14°5080, respectively. Differences in magnitude between the variable and comparison star were corrected for differential extinction and transformed into the *UBV* system using the procedure outlined by Zhai and Zhang (1979).

A total of 217 pairs of *B* and *V* observations were obtained for U Peg. The probable errors are about $0^m.008$ and $0^m.009$ for *V* and *B* respectively. The observations are listed in table I, where Δm represents the magnitude difference between U Peg and the comparison star. The light curves are depicted in figure 1. The Max I and Max II are very nearly equal in brightness, while the « hump » on the ascending branch for the primary minimum, noted by Binnendijk (1960), is less pronounced in our observations.

3. Times of minima and period changes.

Four times of minima (Table II) were determined from our observations by the method of Kwee and van Woerden (1956). A collection of times of minima from 1896 to

1980 is listed in table III. Visual and photographic minima were assigned weight one, while photoelectric minima were assigned weight six. We have adopted JD.hel.2436511.66856 from Rigterink (1972) as the initial epoch. A new linear light element was derived by a weighted least-squares method, as follows :

$$\text{Min I} = \text{JD.hel.}2436511.6606 + 0.374781802\,E \,. \quad (1)$$
$$\pm\ 10 \qquad \pm\ 62$$

The residuals (O-C), calculated from the ephemeris (1) are also listed in Table III and are displayed in figure 2. The (O-C) shows a parabolic distribution but with significant scatter. This suggests that the period of U Peg may have been decreasing slowly in the past 84 years as noticed by Binnendijk (1960) and Rigterink (1972). Therefore, two further fitting tests with a weighted least-squares method were carried out. Firstly, a quadratic ephemeris was employed : the result is expressed by the following light elements :

$$\text{Min I} = \text{JD.hel.}2436511.66823 + $$
$$\pm\ 36$$
$$+ 0.374781439\,E - 2.468 \times 10^{-11}\,E^2 \,. \quad (2)$$
$$\pm\ 21 \qquad \pm\ 65$$

The fitting yields a rate of period decrease of $\Delta P/P = -1.32 \times 10^{-10}$ or 4.16×10^{-3} s/yr. The residuals from ephemeris (2), $(\text{O-C})_2$, are listed in column 4 of Table III, and are displayed in figure 3. The time variation $(\text{O-C})_2$ tends to suggest a wave-like fluctuation. If only the photoelectric observations are considered, it could be described approximately by a sinusoidal function

$$(\text{O-C})_2 = 0^{\text{d}}.323 \times 10^{-2} \sin(2\,\pi/P'\,E + 0.418\,\pi)\,, \quad (3)$$

where the oscillating period $P' = 16330$ cycles or about 17 years.

Because of the complexity of the period of U Peg, we adopted the following light elements for phase calculation for our 1978 observations :

$$\text{Min I} = \text{JD.hel.}2443785.04296 + 0^{\text{d}}.37478048\,E \,.$$

The phases are listed together with the observations in table I.

4. Photometric solution.

A total of 217 observations in both B and V were combined into fifty-five normal points, and were weighted according to the number of individual observations combined to form a normal point. Judging by the shape of the light curves we started our computing analysis with a contact configuration (Mode 3, Leung and Wilson, 1977). The following adjustable parameters were employed ; inclination i, temperature of component 2, T_2 (star eclipse at secondary minimum) ; surface potential of the stars, $\Omega_1 = \Omega_2$; and luminosity of component 1, L_1 (yellow), and L_1 (blue). Based on a spectral type F3, we adopted a polar effective temperature $T_1 = 7000$ K ; gravitation darkening coefficients $g_1 = g_2 = 0.5$; bolometric albedos $A_1 = A_2 = 0.5$; and limb darkening coefficients $X_1 = X_2 = 0.60$ in V, and $X_1 = X_2 = 0.72$ in B. The luminosities were calculated according to the Planck function in the computing code. Both B and V light curves were used simultaneously in deriving a photometric solution.

After a series of convergent tests were executed at many assumed fixed-mass ratios, $q = (1.24, 1.50, 1.85, 2.0, 2.5, 3.0, \text{and } 3.5)$, a preliminary solution with mass ratio equal to 3.0 was found at minimum Σ (the sum of the weighted squares of residuals between the calculated light curve and the observations). A plot of Σ *vs.* q is shown in figure 4. With the preliminary solution at $q = 3.0$ we expanded the number of adjustable parameters to include the A's, g's, X's, and q. In deriving our final set of parameters we divided the adjustable parameters into two groups : the first group containing A_1 (= A_2), g_1 (= g_2), X_1 (= X_2) in V, and X_1 (= X_2) in B ; and the second group containing i, Ω_1 (= Ω_2), q, T_2, and L_1. Differential corrections were computed alternatively for these two groups of parameters until a new solution was obtained. The parameters of the final adopted solution are listed in table IV. The theoretical light curves are shown as smooth curves in figure 1. The agreement between the observed and the computed light curves is good except for the primary minimum in V.

Our new solution indicates that the system of U Peg has an overcontact configuration (Fig. 5) of 9.4 %. It has the characteristics of a W type W UMa system. The photometric mass ratio derived is equal to 3.01. This value seems quite large compared to the spectroscopic estimate of 1.24 of Struve *et al.* (1950) and also larger than the photometric value of 1.85 of Russo *et al.* (1982). At this point, we decided to reanalyze Binnendijk's 1958 observations. We obtained solutions at assumed fixed mass ratios of 1.85 (value obtained by Russo *et al.*), 2.0, 2.8, and 3.0. Again, all these solutions indicate that the configuration of U Peg is overcontact. A plot of the residuals Σ *vs.* q of these solutions is shown at the bottom portion of figure 4. The best Σ is at 2.5 instead of 1.85 as suggested by Russo *et al.* (1982). The difference corresponds to 0.15 in the reciprocal (i.e. m_1/m_2) mass ratio of the components, which is not a serious disagreement. In this paper we adopt a q value of 2.5 for Binnendijk's observations.

5. Mass ratio and estimates of absolute dimensions.

It appears that there is a controversy regarding the mass ratio of U Peg. The photometric values are 3.01 (based on our light curves) and 2.50 (based on Binnendijk's observations) for the 1978 and 1958 observations respectively. The corresponding reciprocal mass ratios, m_1/m_2, of the above are 0.33 and 0.40 respectively. The difference is only 0.07 which is of no major significance. Thus, we conclude that the mass ratio lies between 3 and 2.5 (or 0.33 and 0.4 for reciprocal ratios).

In eclipsing systems, the determination of the differential temperature between the components is very reliable (chiefly as a function of the relative depths of the eclipses). In table IV, the temperature difference is less than 400 K, which suggests that both components have a very similar spectral type (F3). Therefore when the spectrum is single-lined (i.e. near eclipses) it would be very difficult to identify the individual spectra of the components. We believe that Struve *et al.* (1950) misidentified the spectra at phase 0.029 (i.e. on

December 12.157, in their Table III). According to our solution in table IV, Star 1 (star eclipsed at primary minimum in our notation, or component II in their notation) is fainter than star 2 by a factor of 2. At phase 0.03 with an inclination of 76° and partial eclipse, the intensity ratio l_2/l_1 is a factor of 10. Therefore, the velocity at this phase should belong to star 2 (their component I) instead of star 1 as suggested by Struve *et al.* At phase 0.54, our solution gives an intensity ratio l_2/l_1 which is nearly 2. Therefore the velocity at this phase belongs also to star 2 which was correctly identified by Struve *et al.* (1950). The corrected spectroscopic observations are shown in figure 6. In their paper, the γ velocity was chosen at 0 km/s (indicated by the broken straight line in the diagram) which gave a mass ratio $m_2/m_1 = 1.24$. If the photometric mass ratio actually lies between 3.0 and 2.5, the γ velocity should be around − 40 km/s (indicated by the solid straight line in Fig. 6). The computed radial velocity curves based on the photometric result are shown as solid smooth curves in the same diagram. With the very limited spectroscopic observations available, the fitting is satisfactory. In any case, a new spectroscopic study is highly recommended for U Peg to determine the value of the mass ratio.

If we adopt the following parameters : γ-velocity = − 40 km/s, K_1 = 260 km/s, K_2 = 100 km/s, and $q = 2.6$ (i.e. the solution shown in Fig. 6), along with the solution in table IV, we can estimate the absolute dimensions of this contact system. The physical dimensions estimated are listed in table V. In light of the uncertainty associated with the mass ratio the probable errors are not presented in the table. Both components have radii corresponding to main sequence stars (see Table V).

6. Discussion.

6.1 CHANGES IN THE SHAPE OF THE LIGHT CURVE. — The light curve of U Peg has undergone noticeable changes in shape since it was first observed photoelectrically by LaFara (1952) in 1949 and 1950. The brightness at the maxima and the minima are summarized in figure 7. It appears that Max I is relatively stable, of the order $0^m.01$ to $0^m.02$, within the observational errors. The variation of Max II is more noticeable. The largest changes occur at the minima, especially in Min II. The origin of the variations is unknown. It could arise from activity on the surface of the common envelope or from the material surrounding the system. The occurrence of variable light curves among W UMa systems is fairly common. The most obvious examples are VW Cep and SW Lac.

6.2 SHORT-TERM MODULATION AND SECULAR PERIOD CHANGES. — It is unlikely that the short-term (17 years) fluctuation (Eq. (3)) is responsible for changes in the light curves of U Peg, since the variation in figure 7 does not appear to reflect such a periodicity. In figure 3, both the primary and secondary minima follow the same 17 year cycle and the amplitude of the modulation is 0.0032 days. It is suggested that this sinusoidal fluctuation may be due to the light-time effect caused by a third body. If we assume a circular orbit for the triple system it would lead to a mass function (Kruszewski, 1966) $f(m_3) = 0.00062\ M_\odot\ [= m_3 \sin^3 i' / (m_1 + m_2 + m_3)^2]$. If we assume the range of the inclination i' to be from 90° to 70°, we obtain a mass range for the third body, from $0.16 \leq m_3 \leq 0.17\ m_\odot$. This corresponds to about the mass of an M6 star. Since the solution in table IV does not require an l_3, we conclude that the M6 star must be a main sequence dwarf star rather than a giant or supergiant star.

It is suspected that the secular period changes may be associated with slow on-going mass exchange between the components. This is a very complicated effect in contact systems and it is beyond the scope of this paper.

Acknowledgements.

We would like to express our appreciation to the Academia Sinica and the U.S. National Science foundation grant INT 8120404 for the support of this joint research.

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TABLE Ia. — *BV observations of U Pegasi.*

JD Hel. 2443780.0+	Phase	Δm_V	JD Hel. 2443780.0+	Phase	Δm_V	JD Hel. 2443780.0+	Phase	Δm_V	JD Hel 2443780.0+	Phase	ΔM_B
4.9668	0.7968	0.017	5.1129	0.1866	0.043	5.2503	0.5531	0.339	4.9674	0.7984	0.077
.9749	.8183	.031	.1154	.1934	.038	.2512	.5557	.346	.9752	.8193	.099
.9816	.8363	.057	.1164	.1960	.032	.2533	.5612	.316	.9821	.8377	.122
.9828	.8394	.075	.1187	.2020	.028	.2543	.5638	.303	.9833	.8407	.138
.9843	.8435	.071	.1196	.2045	.031	.2564	.5696	.294	.9848	.8448	.139
.9870	.8506	.139:	.1220	.2108	.010	.2574	.5720	.266	.9874	.8517	.155
.9881	.8537	.144:	.1229	.2132	.009	.2596	.5781	.253	.9886	.8550	.166
.9908	.8609	.112	.1275	.2255	.004	.2605	.5804	.246	.9914	.8623	.169
.9921	.8642	.114	.1300	.2322	.005	.2632	.5876	.222	.9924	.8651	.183
.9946	.8709	.118	.1313	.2356	.002	.2642	.5902	.208	.9951	.8723	.185
.9958	.8741	.117	.1333	.2410	-.001	.2667	.5969	.187	.9963	.8756	.194
.9986	.8815	.152	.1341	.2431	-.002	.2675	.5990	.183	.9991	.8830	.214
.9996	.8844	.152	.1362	.2487	.000	.2716	.6101	.156	5.0001	.8857	.226
5.0020	.8907	.166	.1369	.2506	.001	.2730	.6137	.152	.0025	.8919	.228
.0029	.8931	.169	.1392	.2567	-.004	.2759	.6215	.135	.0034	.8945	.238
.0055	.8999	.192	.1402	.2593	.001	.2768	.6240	.121	.0060	.9012	.264
.0064	.9025	.200	.1424	.2653	.002	.2788	.6292	.108	.0069	.9039	.273
.0090	.9094	.230	.1437	.2688	-.001	.2799	.6321	.114	.0094	.9105	.305
.0102	.9127	.241	.1459	.2747	.000	.2820	.6378	.100	.0108	.9142	.313
.0128	.9196	.268	.1469	.2772	.003	.2830	.6405	.095	.0133	.9210	.342
.0140	.9226	.283	.1491	.2832	.002	.2851	.6461	.094	.0145	.9240	.355
.0163	.9288	.306	.1501	.2858	.007	.2861	.6487	.087	.0167	.9300	.381
.0172	.9312	.323	.1522	.2915	.004	.2886	.6554	.083	.0176	.9322	.398
.0195	.9374	.346	.1533	.2944	.000	.2897	.6584	.082	.0200	.9388	.424
.0208	.9409	.364	.1555	.3003	.000	.2920	.6644	.074	.0212	.9420	.445
.0231	.9470	.397	.1565	.3029	.018	.2928	.6665	.064	.0236	.9482	.482
.0240	.9494	.407	.1611	.3152	.021	.2953	.6732	.059	.0244	.9505	.490
.0262	.9553	.437	.1639	.3227	.029	.2962	.6758	.047	.0268	.9568	.518
.0273	.9583	.441	.1647	.3249	.032	.3004	.6869	.037	.0278	.9596	.533
.0295	.9641	.477	.1670	.3309	.046	.3026	.6928	.026	.0301	.9658	.553
.0307	.9672	.485	.1680	.3336	.050	.3035	.6953	.021	.0312	.9685	.571
.0331	.9736	.511	.1702	.3395	.052	.3058	.7013	.010	.0335	.9748	.597
.0340	.9762	.514	.1713	.3424	.058	.3067	.7037	.014	.0345	.9774	.609
.0366	.9831	.537	.1733	.3477	.064	.3085	.7086	.015	.0370	.9841	.615
.0380	.9867	.546	.1740	.3497	.069	.3100	.7126	.018	.0380	.9867	.634
.0399	.9919	.558	.1763	.3558	.077	.3123	.7185	.008	.0408	.9942	.643
.0414	.9957	.563	.1772	.3582	.080	.3131	.7209	.008	.0417	.9967	.647
.0440	.0029	.567	.1794	.3641	.091	.3152	.7265	.009	.0445	.0041	.644
.0451	.0056	.558	.1803	.3665	.090	.3160	.7286	.005	.0455	.0068	.644
.0472	.0113	.549	.1822	.3715	.088	.3183	.7345	.000	.0477	.0127	.635
.0481	.0139	.541	.1833	.3745	.098	.3190	.7365	.003	.0486	.0150	.625
.0505	.0201	.530	.1854	.3800	.112	.3209	.7417	.005	.0509	.0211	.617
.0513	.0223	.522	.1862	.3822	.131	.3216	.7436	-.003	.0517	.0234	.605
.0533	.0277	.506	.1884	.3881	.138	.3238	.7494	.000	.0538	.0290	.585
.0543	.0302	.501	.1893	.3904	.147	.3247	.7518	.000	.0548	.0315	.572
.0566	.0365	.479	.1916	.3967	.160	.3267	.7572	.003	.0571	.0377	.552
.0576	.0389	.455	.1924	.3986	.158	.3278	.7599	.000	.0580	.4000	.545
.0598	.0450	.436	.1949	.4055	.176	.3300	.7658	.004	.0602	.0460	.514
.0606	.0471	.426	.1961	.4085	.195	.3308	.7681	-.002	.0611	.0484	.498
.0629	.0532	.396	.1985	.4151	.209	.3331	.7742	.001	.0633	.0543	.463
.0637	.0554	.380	.1994	.4173	.220	.3343	.7773	.000	.0642	.0567	.451
.0661	.0617	.351	.2014	.4229	.235	.3366	.7835	.004	.0666	.0632	.420
.0670	.0642	.334	.2023	.4253	.249	.3375	.7860	.014	.0675	.0654	.409
.0693	.0702	.311	.2044	.4308	.267	.3444	.8042	.028	.0697	.0713	.379
.0702	.0726	.307	.2057	.4341	.278	.3525	.8260	.042	.0706	.0738	.365
.0724	.0785	.273	.2096	.4445	.316	.3534	.8284	.048	.0729	.0797	.340
.0733	.0809	.273	.2120	.4510	.345	.3567	.8371	.056	.0737	.0821	.335
.0760	.0880	.237	.2129	.4534	.358				.0764	.0891	.302
.0773	.0915	.225	.2150	.4590	.374				.0777	.0927	.292
.0795	.0974	.202	.2157	.4610	.375				.0799	.0986	.276
.0806	.1003	.210	.2177	.4663	.401				.0810	.1015	.267
.0826	.1059	.183	.2187	.4689	.411				.0831	.1070	.247
.0835	.1082	.166	.2210	.4750	.441				.0840	.1096	.241
.0858	.1144	.151	.2219	.4773	.443				.0862	.1155	.217
.0867	.1167	.148	.2245	.4845	.462				.0872	.1179	.214
.0888	.1224	.142	.2255	.4869	.472				.0892	.1234	.205
.0896	.1245	.138	.2277	.4929	.477				.0900	.1256	.199
.0917	.1301	.125	.2285	.4950	.475				.0923	.1316	.191
.0928	.1330	.124	.2305	.5005	.480				.0933	.1343	.188
.0957	.1408	.109	.2314	.5029	.477				.0961	.1419	.173
.0967	.1433	.104	.2335	.5083	.476				.0970	.1443	.168
.0988	.1490	.094	.2343	.5105	.475				.0993	.1504	.162
.0998	.1516	.089	.2366	.5166	.469				.1002	.1526	.158
.1024	.1586	.084	.2374	.5189	.463				.1029	.1598	.139
.1032	.1608	.084	.2399	.5255	.446				.1037	.1620	.148
.1056	.1672	.066	.2423	.5319	.433				.1062	.1687	.132
.1067	.1702	.066	.2444	.5376	.407				.1071	.1712	.128
.1088	.1758	.055	.2452	.5396	.396				.1094	.1772	.121
.1098	.1783	.053	.2473	.5451	.374				.1101	.1793	.122
.1120	.1843	.046	.2480	.5470	.361				.1125	.1856	.114

TABLE Ib. — *BV observations of U Pegasi.*

JD Hel. 2443780.0+	Phase	Δm_B	2443780.0+	Phase	Δm_B	2443780.0+	Phase	Δm_B	2443780.0+	Phase	Δm_B
5.1133	0.1878	0.108	5.1830	0.3736	0.173	5.2507	0.5542	0.408	5.3194	0.7375	0.045
.1159	.1947	.100	.1858	.3810	.183	.2516	.5567	.399	.3213	.7427	.054
.1168	.1970	.093	.1866	.3832	.191	.2538	.5626	.386	.3220	.7446	.049
.1192	.2034	.088	.1889	.3893	.205	.2547	.5651	.373	.3243	.7506	.052
.1201	.2058	.087	.1898	.3917	.212	.2569	.5709	.350	.3251	.7527	.055
.1224	.2120	.081	.1919	.3975	.228	.2577	.5731	.333	.3272	.7585	.051
.1233	.2144	.072	.1928	.3998	.236	.2601	.5793	.314	.3283	.7613	.047
.1280	.2268	.068	.1956	.4073	.262	.2609	.5816	.299	.3304	.7670	.056
.1306	.2338	.061	.1965	.4096	.263	.2637	.5890	.278	.3313	.7694	.054
.1316	.2366	.057	.1989	.4162	.278	.2646	.5914	.274	.3336	.7756	.055
.1336	.2419	.057	.1998	.4184	.293	.2671	.5979	.258	.3348	.7787	.067
.1345	.2444	.057	.2019	.4241	.314	.2680	.6003	.247	.3370	.7847	.067
.1365	.2496	.058	.2027	.4263	.318	.2721	.6113	.219	.3380	.7872	.066
.1374	.2518	.062	.2050	.4323	.338	.2736	.6153	.210	.3450	.8059	.094
.1397	.2580	.059	.2060	.4351	.351	.2764	.6228	.188	.3529	.8271	.102
.1406	.2604	.055	.2101	.4458	.394	.2771	.6248	.185	.3539	.8297	.110
.1430	.2669	.059	.2124	.4522	.419	.2793	.6305	.171	.3571	.8382	.109
.1442	.2700	.055	.2133	.4545	.436	.2803	.6334	.170			
.1463	.2758	.052	.2154	.4600	.453	.2825	.6392	.151			
.1474	.2787	.053	.2161	.4619	.455	.2834	.6415	.153			
.1496	.2846	.055	.2181	.4674	.473	.2856	.6474	.151			
.1505	.2870	.060	.2193	.4704	.489	.2866	.6501	.141			
.1528	.2930	.061	.2214	.4762	.510	.2889	.6563	.135			
.1537	.2955	.060	.2222	.4783	.518	.2902	.6598	.128			
.1559	.3014	.065	.2250	.4858	.537	.2924	.6655	.123			
.1574	.3055	.072	.2258	.4879	.539	.2931	.6675	.116			
.1618	.3170	.087	.2281	.4939	.553	.2958	.6745	.098			
.1644	.3239	.093	.2289	.4961	.548	.2966	.6767	.098			
.1652	.3261	.098	.2310	.5017	.560	.3009	.6882	.092			
.1674	.3320	.109	.2319	.5040	.558	.3031	.6941	.088			
.1685	.3349	.111	.2339	.5094	.550	.3040	.6966	.081			
.1707	.3409	.120	.2347	.5116	.545	.3063	.7025	.070			
.1717	.3434	.122	.2370	.5177	.542	.3070	.7046	.068			
.1737	.3488	.129	.2379	.5202	.537	.3091	.7100	.061			
.1746	.3511	.131	.2405	.5270	.513	.3105	.7139	.068			
.1767	.3569	.146	.2428	.5331	.498	.3127	.7197	.061			
.1776	.3593	.149	.2448	.5386	.480	.3136	.7220	.062			
.1799	.3653	.163	.2456	.5408	.465	.3157	.7277	.057			
.1806	.3673	.165	.2476	.5461	.441	.3165	.7298	.047			
.1826	.3726	.163	.2485	.5484	.432	.3186	.7356	.047			

TABLE II. — *Times of light minimum.*

Min.	m.e.	Color	Ref.
J. D. hel. 2443700.0+			
85.04296	0.00005	V	Pri.
85.04316	.00008	B	Pri.
85.23126	.00008	V	Sec.
85.23115	.00023	B	Sec.

TABLE IV. — *Photometric solution of U Pegasi (1978).*

	V (5500Å)	B (4500Å)
$L_1/(L_1+L_2)$	0.314 ±0.001	0.324 ±0.001
$X_1=X_2$	0.62 ±0.01	0.73 ±0.01
$q=m_2/m_1$	3.012±0.002	
i	76°.1 ±0°.1	
$A_1=A_2$	0.50 ±0.02	
$g_1=g_2$	0.48 ±0.02	
$\Omega_1=\Omega_2$	6.574±0.003	
Ωinn	6.632**	
Ωout	6.013**	
Over-cont.	9.4%	
	Comp.1.	Comp.2.
r(pole)	0.2724±0.0002	0.4515±0.0002
r(side)	0.2839±0.0002	0.4837±0.0003
r(back)	0.3196±0.0004	0.5112±0.0003
T °K	7000*	6617 ±7

* Assumed; ** Theoretical values.

TABLE V. — *Estimated absolute dimensions of U Pegasi.*

A (separation)	2.9 $R_\odot$
R1	0.8 $R_\odot$
R2	1.4 $R_\odot$
M1	0.6 $M_\odot$
M2	1.8 $M_\odot$
$R1_{m.s.}$*	0.7 $R_\odot$
$R2_{m.s.}$*	1.4 $R_\odot$

* main sequence radius according to its mass (Allen, 1973)

TABLE III. — *O-C of the times of light minima for U Pegasi (1896-1980).*

Min.=JD.hel. 2400000.0+	E	$(O-C)_1$ $.10^{-2}$	$(O-C)_2$ $.10^{-2}$	Ref.	Min.=JD.hel. 2400000.0+	E	$(O-C)_1$ $.10^{-2}$	$(O-C)_2$ $.10^{-2}$	Ref.
13514.619	-61361	-5.54	0.76	1.	40831.7729	11527	0.25	0.23	pe.2.
3542.531	-61286.5	-6.47	-0.19		0832.7122	11529.5	0.48	0.47	pe.
3830.561	-60518	-5.45	0.63		0837.7692	11543	0.23	0.21	pe.
4907.682	-57644	-5.64	-0.29		0888.7399	11679	0.26	0.26	pe.
5021.237	-57341	-6.03	-0.76		0891.7381	11687	0.26	0.26	pe.
20072.594	-43863	-1.24	1.15		0892.6763	11689.5	0.38	0.38	pe.
0756.751	-42037.5	-1.96	0.11		0893.8008	11692.5	0.40	0.40	pe.
1130.598	-41040	-1.74	0.16		42302.420	15451	0.58	0.96	5.
3735.340	-34090	-0.90	-0.03		2347.3879	15571	-0.01	0.39	pe.6.
7744.393	-23393	0.31	0.05		2359.398	15603	1.69	2.10	7.
8521.321	-21320	0.84	0.43		2714.309	16550	0.96	1.47	8.
9522.736	-18648	0.64	0.06		2741.2810	16622	-0.27	0.25	pe.6.
30260.679	-16679	0.41	-0.27		2777.244	16718	-1.88	-1.34	5.
0260.866	-16678.5	0.37	-0.31		43012.445	17345.5	0.66	1.27	8.
3182.8561	- 8882	0.75	-0.14	pe.	3012.438	17345.5	-0.04	0.57	9.
3190.7262	- 8861	0.71	-0.18	pe.	3015.435	17353.5	-0.16	0.45	8.
3190.9132	- 8860.5	0.68	-0.21	pe.	3020.679	17367.5	-0.46	0.16	10.
3202.7181	- 8829	0.60	-0.29	pe.	3021.6134	17370	-0.71	-0.10	pe.
3230.6408	- 8754.5	0.75	-0.14	pe.	3024.612	17378	-0.68	-0.06	
3244.5075	- 8717.5	0.73	-0.17	pe.	3078.403	17521.5	-0.31	0.93	11.
3255.5630	- 8688	0.67	-0.22	pe.	3142.292	17692	-0.82	-0.17	9.
3558.7624	- 7879	0.76	-0.13	pe.	3785.0431	19407	-0.79	0.08	pe.12.
3561.7592	- 7871	0.62	-0.28	pe.	3785.2312	19407.5	-0.72	0.15	pe.
3924.5497	- 6903	0.79	-0.11	pe.	3789.353	19418.5	-0.80	0.07	pe.13.
3998.9448	- 6704.5	0.88	-0.02	pe.	44469.3857	21233	-1.69	-0.57	pe.14.
4303.4545	- 5892	0.83	-0.06	pe.	4490.3786	21289	-1.18	-0.05	pe.
4685.3586	- 4873	0.97	0.09	pe.	4500.4922	21316	-1.73	-0.60	pe.15.
6481.6864	- 80	0.83	0.07	pe.	4501.4295	21318.5	-1.70	-0.56	pe.
6483.7490	- 74.5	0.96	0.20	pe.	4502.5554	21321.5	-1.54	-0.41	pe.
6484.6839	- 72	0.76	-0.01	pe.	4503.4923	21324	-1.55	-0.41	pe.
6508.6702	- 8	0.79	0.02	pe.	4504.6165	21327	-1.56	-0.43	pe.
6511.6688	0	0.82	0.06	pe.					
6515.6057	10.5	0.99	0.23	pe.					
7636.0099	3000	0.39	-0.24	pe.2.					
8689.7081	5811.5	0.31	-0.16	pe.3.					
8691.7693	5817	0.30	-0.17	pe.					
8692.7072	5819.5	0.39	-0.08	pe.					
40206.260	9858	0.04	-0.13	4.					
0826.9010	11514	0.27	0.26	pe.2.					
0827.8396	11516.5	0.44	0.42	pe.					

1. AJ.,65,88,1958; 2. AJ.,77,319,1972; 3. IBVS.,1010; 4. IBVS.,328; 5. Contr. of the Copernicus Obs. and Planet in Brno, 20; 6. IBVS.,1200; 7. IBVS.,978; 8. IBVS.,1190; 9. AN.,300,165,1979; 10. IBVS.,1249; 11. AN.,301,329,1980; 12. Ours; 13. IBVS.,1924; 14. IBVS.,1908; 15. IBVS.,2026.

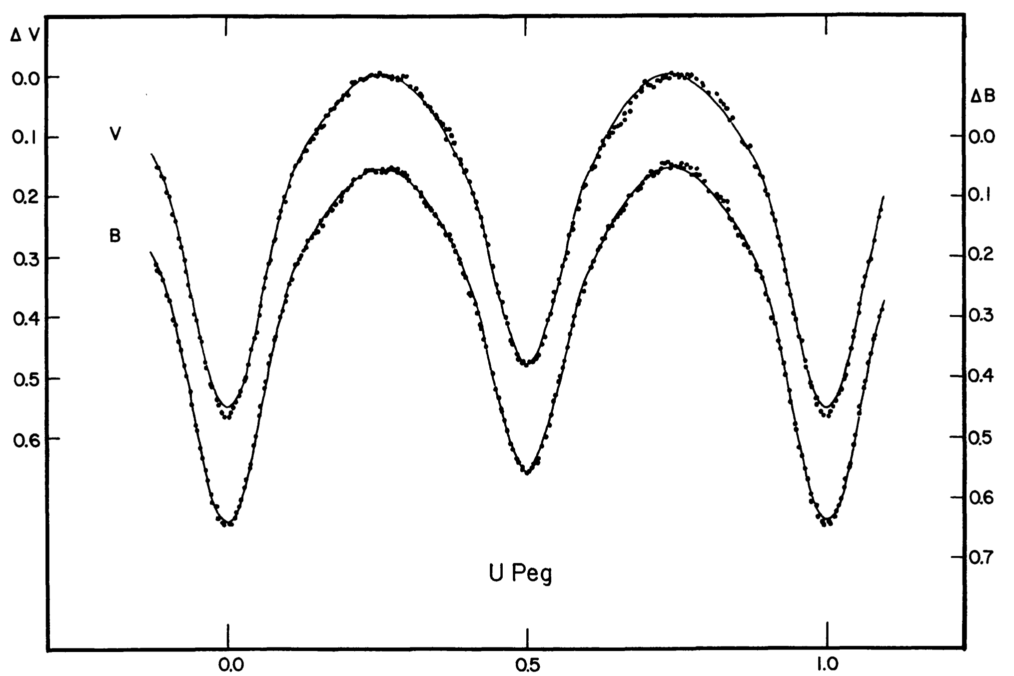

FIGURE 1. — *B* and *V* light curves of U Pegasi. Points are observations and the solid curves represent the theoretical light curves calculated from the parameters in table IV.

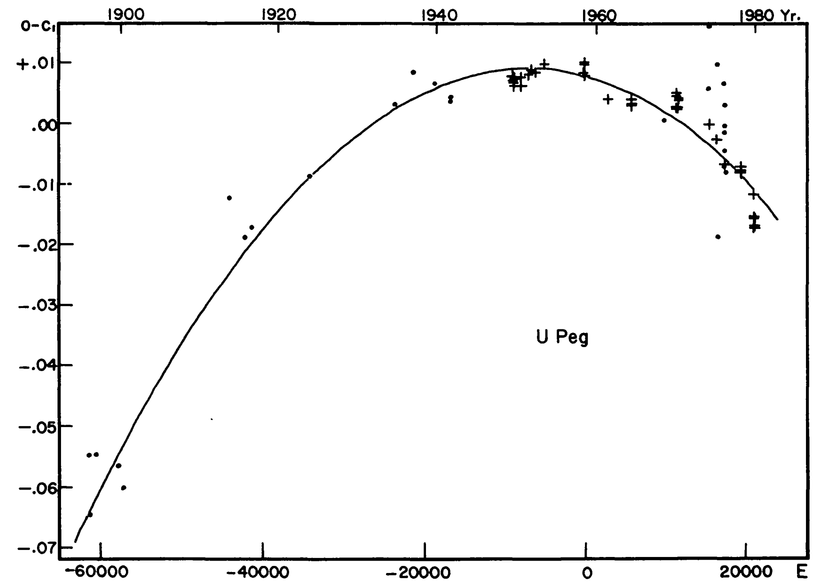

FIGURE 2. — $(O\text{-}C)_1$ of the times of light minimum and long term variation of the period of U Pegasi. Dots represent visual and photographic observations. Crosses are photoelectric observations.

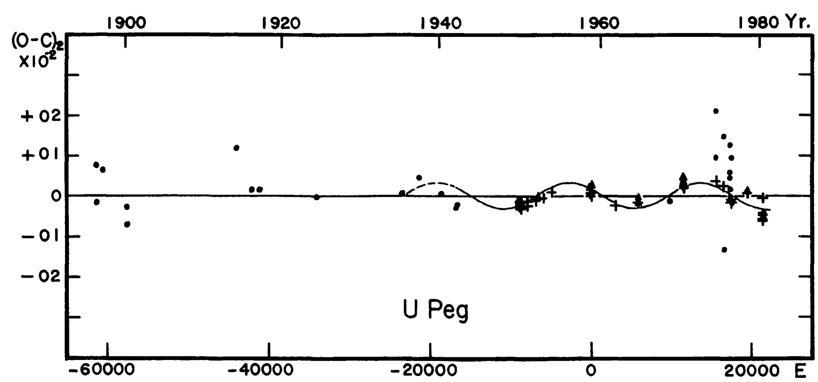

FIGURE 3. — $(O\text{-}C)_2$ of the times of light minimum and short term fluctuation of the period of U Pegasi. Dots represent visual and photographic observations. Crosses and triangles are primary and secondary minima of the photoelectric observations, respectively.

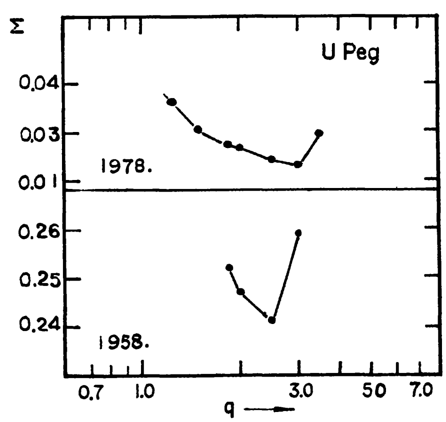

FIGURE 4. — The sum of weighted squares of residuals Σ as a function of mass ratio $q = m_2/m_1$.

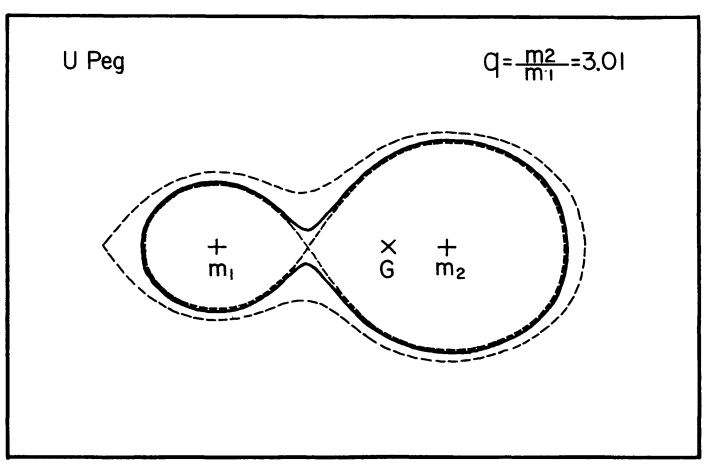

FIGURE 5. — Configuration of U Pegasi.

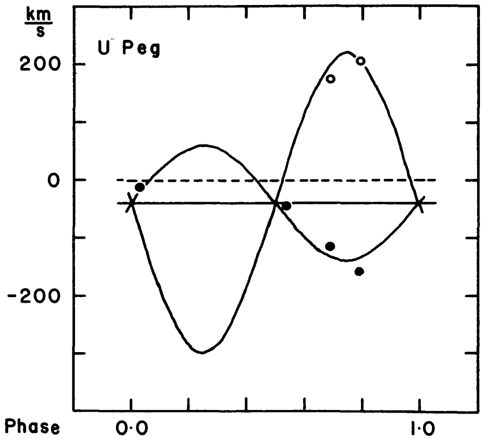

FIGURE 6. — Radial velocities measured by Struve *et al.* (1950). Solid circles represent star 2, and circles represent star 1. Straight line designates the revised γ-velocity and the broken straight line designates the previously adopted γ-velocity. The solid curves represent the radial velocity curves of the components.

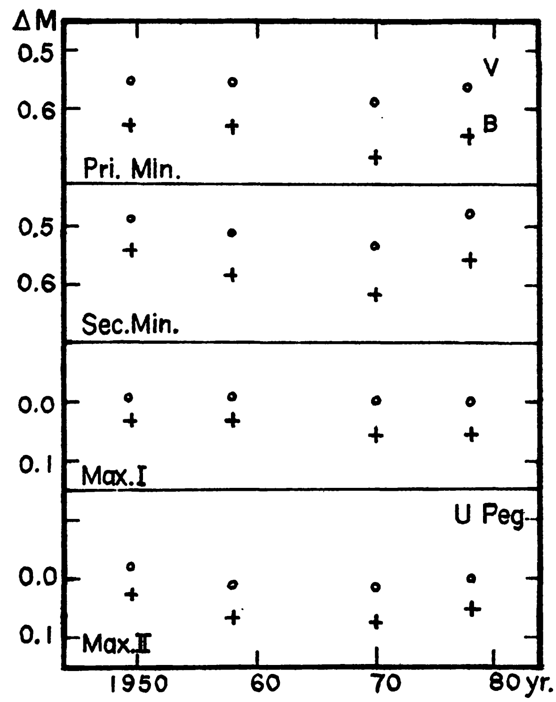

FIGURE 7. — Variation sampling of the light curves of U Pegasi from the observations by LaFara (1952), Binnendijk (1960), Rigterink (1972) and Zhai *et al.* (this paper).