time of minimum brightness. Even so, the epoch will be sharply defined; in some other methods this important feature is lacking in case of asymmetry.

Other advantages of the method are the following. Firstly, since it is completely quantitative, unambiguous results are obtained, not depending on subjective judgment as is often the case with graphical methods. Secondly, a quantitative measure of the accuracy of the epoch is obtained from the expression for the mean error. This is important for the combination of epochs, especially of those obtained photoelectrically which are often accurate to about 10 seconds. Thirdly, curvature does no harm, as it sometimes does when the branches are approximated by straight lines.

A disadvantage is that the method involves a fair amount of calculation. The risk of computing errors can, however, be removed by suitable checks. Furthermore, the writers feel that the reliability of the result does well repay the time and effort.

PHOTOELECTRIC OBSERVATIONS OF THE SHORT-PERIOD ECLIPSING VARIABLE W URSAE MAJORIS

BY K. K. KWEE

The eclipsing variable star W Ursae Majoris was observed photoelectrically at the Leiden Observatory during several nights in 1951, 1953 and 1954. Principally, times of primary minima were observed with accuracies of five to ten seconds. There seems to have been a rather abrupt change in the period from $0^d.33363699$ to $0^d.33363779$. A complete light-curve was observed in one single night in order to derive orbital elements. Evidence is present that the light-curve may be slightly variable from cycle to cycle. The secondary minimum appeared to be shifted notably from phase 0.5, but the displacement may be caused by the observed unequal maxima in the light-curve. The rectification for the sine terms in the representation of the uneclipsed light-curve was performed by division. To represent the rectified eclipse-curve it was necessary to assume an amount of additional light of about 25% of the total light of the system.

In the last section the results are discussed briefly in connection with the simplified methods of computation used.

1. *Introduction.*

The short-period eclipsing variable W Ursae Majoris has been observed photometrically many times and by several observers, since its discovery by MÜLLER and KEMPF in 1903 [1]). A complete compilation of literature up till 1942 of this star system has been given by WOODWARD [2]). After this date only some epochs of minima have been observed by KAPKO [3]) and BAV observers [4]). Of all these photometric data HUFFER's [5]) photoelectric observations of 1934 were still the most interesting and reliable ones. The final orbital elements derived from these observations have been given by PLAUT [6]). Of the spectroscopic observations those of POPPER [7]), and of STRUVE and HORAK [8]) are most up to date. From these observations a mass ratio of 2.0 can be derived, the heavier component being in front at the time of primary minimum.

2. *Observations and reductions.*

Photoelectric observations of this star have been made at the Leiden Observatory during several nights in 1951, 1953 and 1954. The original aim was to investigate changes in the period, so mainly primary minima were observed. In the night following January 23, 1954, a one-run complete light-curve was obtained, from which a set of orbital elements can be derived.

The observations were made with the 18″ Zunderman reflector. The telescope was equipped with the same photometer as A. B. MULLER used for his second series of photoelectric observations of XZ Cygni [9]). In order to get as many points as possible on the descending and ascending branches of the minima, no filters were used. The effective wave length is therefore approximately 4650 Å.

The comparison star used was HD 84142. Some data about the variable and the comparison star are given in Table 1. The spectral type of the variable was taken from STRUVE and HORAK's spectroscopic observations, while that of the comparison star was taken from the Henry Draper Catalogue. The photographic magnitudes were taken from WOODWARD's article. As the range in wave length is rather wide, because no colour filters were used, the advantage of similar spectral type was felt to be more important than the disadvantage of the rather large separation of the two stars.

The measurements were performed by pointing the telescope alternately to the comparison star and the

[1]) *Ap. J.* **17**, 201, 1903.
[2]) *Harvard Circ.* No 446, 1942.
[3]) *Astron. Circ. USSR.* No 88, 7, 1949.
[4]) *A.N.* **279**, 178, 1950.
[5]) *Ap. J.* **79**, 369, 1934.
[6]) *Pub. Kapteyn Astron. Lab. Groningen* No. 54, 1950 and No. 55, 1953.
[7]) *P.A.S.P.* **62**, 115, 1950.
[8]) *Ap. J.* **112**, 178, 1950.
[9]) *B.A.N.* **12**, 11 (No. 443), 1953.

TABLE 1

Data about the variable and the comparison star.

Star	Cat. No.	α (1900)	δ (1900)	Sp.	m_{pg}
W UMa	HD 83950	$09^h\ 36^m\ 42^s$	$+56°\ 25'$	F8p	8.15–8.95
Comparison	HD 84142	09 37 54	+58 54	F8	8.92

variable, while the sky was measured each time between two measurements of a star. The observation time needed for one cycle: variable – sky – comparison star–sky, varied from $1\frac{1}{3}$ to $2\frac{1}{2}$ minutes. In order to avoid the effect of systematic night errors, care was taken to observe in each case both branches, the descending as well as the ascending one, in one night. For the derivation of the orbital elements the whole light-curve was obtained in one single night.

The star intensities on the recordings of the Brown recorder, from which the sky intensities were subtracted, were read off with accuracies of about 0.5 per cent, and the magnitude differences $(m_v - m_c)$ were finally derived in three decimals. The times were measured accurately in seconds and were finally computed in five decimals of a Julian day, after reduction to the sun had been applied. Corrections for differential extinction were made. The extinction coefficients used resulted from investigations of the intensity changes of the comparison star during the night, assuming that the sensitivity of the multiplier and of the amplifier were constant. This assumption can safely be made, as was apparent from recordings of an artificial standard light-source, consisting of a small spot of radio-active paint, which was measured at the beginning and the end of an observing night on several occasions. The resulting extinction coefficients for the different nights are given in the second column of Table 2. The individual observations are shown in Table 6; the first column gives the times in Heliocentric Julian days, and the second column gives the differences in magnitude corrected for differential extinction.

3. *Changes of period.*

The method used for the derivation of the epochs of the minima is described in a separate paper by H. VAN WOERDEN and the author, preceding this article. In Table 2 the resulting epochs are given. Column 3 gives the epochs of minimum expressed in

TABLE 2

New observed minima.

Date	k	Min. Hel. J. D.	m.e.	$2n+1$	N	$O-C$
	m		d			d
October 23, 1951	0.7	2433943.61155	0.00010	67	64	+0.00010
October 24, 1951	0.5	2433944.61230	0.00007	77	75	−0.00006
December 13, 1951	0.7	2433994.65800	0.00007	75	72	−0.00003
April 21, 1953	0.5	2434489.44288	0.00005	75	76	+0.00002
January 16, 1954	0.6	2434759.68933	0.00010	51	54	−0.00014
January 23, 1954	0.46	2434766.36224	0.00006	47	48	+0.00002

Heliocentric Julian days; column 4 gives their mean errors, derived as described in the paper mentioned; column 5 shows the total number of interpolated magnitudes used for the derivation of the epoch; and the total number of observed magnitudes used for the formation of the interpolated magnitudes is given in column 6. The number N was chosen thus that for each minimum the same phase interval was used. The total phase interval from which the minimum times were derived, was each time about $0^d.07$.

A least-squares solution from the data of Table 2 gives the following linear formula for the times of the primary minima:

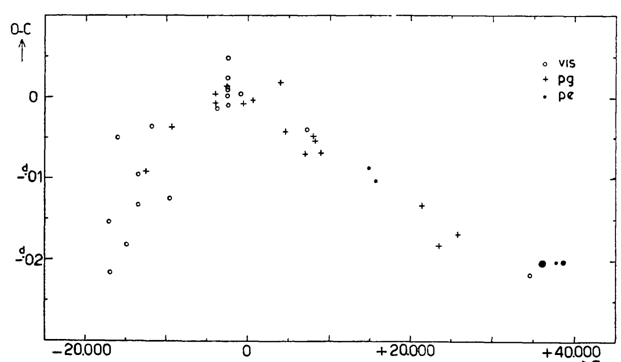
$$\text{Min.} = \text{Hel J. D. } 2434489.44286 + 0^d.33363779\,E.$$
$$\pm\ 0.00003 \pm 0\ .00000003\ \text{m.e.}$$

In Figure 1 the residuals in time of all observed minima are shown. The residuals refer to WOODWARD's formula:

$$\text{Min.} = \text{Hel. J. D. } 2421856.9401 + 0^d.333637665\,E$$

and were taken from her Table II, p. 6. Only the primary minima are shown in the figure. The epochs

FIGURE 1



Time residuals of minima of W Ursae Majoris using WOODWARD's formula.

TABLE 3

Primary minima to be added to WOODWARD's Table II.

Min. J. D. (hel)	m.e.	epoch	$O-C$	authority
	d		d	
2430455.43316	0.00022	+25772	−0.01684	KAPKO
2433386.4352	0.0014	+34557	−0.0217	POHL-BAV
2433943.61155	0.00010	+36227	−0.02024	KWEE
2433944.61230	0.00007	+36230	−0.02040	KWEE
2433994.65800	0.00007	+36380	−0.02035	KWEE
2434489.44288	0.00005	+37863	−0.02019	KWEE
2434759.68933	0.00010	+38673	−0.02019	KWEE
2434766.36224	0.00006	+38693	−0.02003	KWEE

of minimum added to WOODWARD's list are given in Table 3. The observed minima of KAPKO and the BAV observers were reduced by means of least-squares solutions to the mean epochs given in this table; their mean errors, as shown in column 2, were computed from their internal deviations.

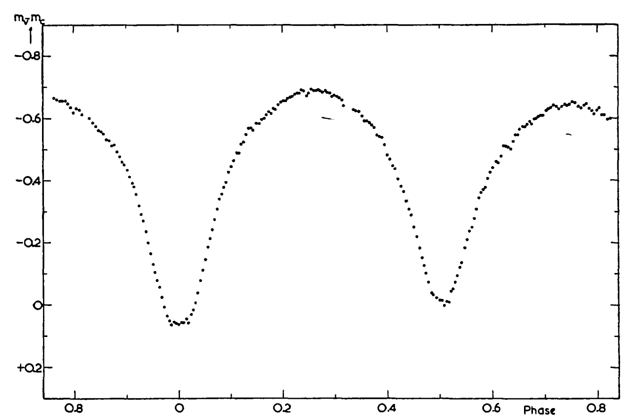
From Figure 1 it can be seen that the period is beginning to lengthen again. However, it is not yet possible to derive a secondary period. The observed change in the period may be a result of a slow continual variation in the period, as well as of a sudden change around Julian day 2432250 ($E = + 31150$). Such a sudden change in the period, as might also have occurred at Julian day 2420981 ($E = - 2626$) according to WOODWARD, may point to dynamic instability which, as is shown by WOOD [1]), may be found in such close systems. We shall postpone further discussion of this point until section 5, where also the orbital elements derived in section 4 will be discussed.

4. *New orbital elements.*

On the night of January 23rd, 1954, a long series of observations was obtained from $19^h\,40^m$ till $28^h\,10^m$ MET. As the period of the variable star is nearly exactly eight hours, all phases of the light-curve were covered, and even a small overlap of about thirty minutes was obtained. The total number of single observations of the variable star was 220.

The corrections for differential extinction were important only during the first four hours of observation. An investigation of the variations in intensity of the comparison star showed a constant extinction coefficient $k = 0^m.46$ for this part of the night. After midnight the extinction coefficient increased slowly to $k = 0^m.55$, but the total differential corrections were less than $0^m.002$ for these parts of the light-curve. It should be noted, however, that after correction for differential extinction had been applied, the overlapping parts of the light-curve still showed a shift of $0^m.014$; in the beginning of the night the star was brighter than at the end. This discrepancy cannot be removed by assuming small variations in the extinction coefficient, unless it is reduced to half of its original value, which is contradicted by the observations of the comparison star. It would seem, therefore, that the shift is real, and that the light-curve is variable from cycle to cycle. However, more accurate observations are required to establish this phenomenon with certainty.

FIGURE 2



Individual observations of W Ursae Majoris on January 23, 1954.

In Figure 2 the observed magnitudes, corrected for differential extinction are shown. A remarkable feature of the light-curve is that the maximum following primary minimum is higher by $0^m.035$ than the one following secondary minimum. This had already been noted in the earlier observations, and is thus confirmed here once more.

The phases of the observed magnitudes were computed with the formula:

$$\text{Phase} = \frac{\text{Hel. J. D.} - 2434766.36224}{0.333637},$$

which was accurate enough for the whole observed light-curve. The epoch of the secondary minimum was then derived in the same way as the primary minima in section 3, with $(2n + 1) = 45$ and $N = 40$, and over an interval in phase of $0^P.1760$:

$$\text{Phase of sec. min.} = 0^P.50435 \pm 0^P.00032 \text{ m.e.}$$

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[1]) *Ap. J.* **112**, 196, 1950.

As we see, the deviation of this secondary minimum from phase 0.5 is very pronounced compared with its mean error, and is even much larger than was suspected by HUFFER in 1934. Ascribing the whole of this deviation to orbital eccentricity, and assuming the inclination to be 90°, we obtain

$$e \cos\omega = +0.0068 \pm 0.0005 \text{ m.e.},$$

e and ω representing respectively the orbital eccentricity and the longitude of the periastron. It is doubtful, however, if orbital eccentricity is the main cause of this deviation, for, after correcting the light-curve for the unequal maxima as indicated below, the displacement of the secondary minimum from half a period after primary minimum reduces to only one fifth of its original value.

A satisfactory representation of the light-variation between the eclipses is given by:

$$\begin{aligned} l_v/l_c = 1.6268 &- 0.0108 \cos\vartheta - 0.2254 \cos 2\vartheta + \\ \pm 0.0026 &\pm 0.0027 \qquad\quad \pm 0.0036 \\ &+ 0.0325 \sin\vartheta - 0.0088 \sin 2\vartheta, \\ &\pm 0.0012 \qquad\quad \pm 0.0016 \text{ m.e.} \end{aligned}$$

where l_v/l_c represents the intensity of the variable star in terms of that of the comparison star. The cosine terms may be accounted for by reflection and ellipticity effects of the components. As, however, the origin of the sine terms remains unknown, satisfactory rectification for these terms is impossible. The simple assumption that the complications giving rise to these terms affect the brightness of both components in the same proportion but produce no asymmetry of shape or of surface brightness, leads, according to RUSSELL [1]), to a rectification by the formula:

$$j = \frac{l_v/l_c + 0.0176 + 0.0108 \cos\vartheta + 0.0044 \cos 2\vartheta}{1.6444 - 0.2211 \cos 2\vartheta + 0.0325 \sin\vartheta - 0.0088 \sin 2\vartheta},$$

where PLAUT's results from HUFFER's older observations were used for the computation of the other reflection terms.

After the rectification had been made, both minima appeared to be shifted from their original phases. This was to be expected on account of the sine terms included in the rectification formula.

The epochs were redetermined and the results are:

primary min. rectified $= 0^P.00086 \pm 0^P.00023$ m.e.
secondary „ „ $= 0^P.50165 \pm 0^P.00040$ „ ,

from which a remaining eccentricity effect of

$$e \cos\omega = +0.0012 \pm 0.0006 \text{ m.e.},$$

can be derived. The rectified depths of the minima reduced to:

rectified depth:
primary minimum: $1 - j_1 = 0.3114 \pm 0.0012$ m.e.
secondary „ : $1 - j_2 = 0.2832 \pm 0.0026$ „ .

In view of the uncertainty of the method of rectification, any correction for orbital eccentricity remains provisional. So, in the following computations, the eccentricity effects have been neglected except for a constant shift in phase of both minima, corresponding to the newly determined epochs.

It is very likely that the causes underlying the sine terms in the representation of the light-variation between the eclipses also have affected the coefficients of the cosine terms. The coefficient of the cos 2ϑ-term cannot, therefore, give a reliable determination of the mean ellipticity coefficient z of the components. For the following computations this coefficient z has been estimated according to theoretical computations based on PLAUT's older elements. This value was $z = 0.103$; it should be noted that the value derived from the light-curve should have been $z = 0.163$.

The orbital elements were computed using the well-known equations of condition:

$$\frac{\cos^2 i}{a_2^2} + \frac{\sin^2 i}{a_2^2} \sin^2\vartheta_i = (1 + kp_i)^2 (1 - z \cos^2\vartheta_i).$$

The final elements were computed by IRWIN's differential method [2]). All the solutions were made with assumed limb-darkening coefficients $u = 0.8$ for both components, corresponding to their late spectral types and to the effective wave length used.

First a solution was tried based on PLAUT's older orbital elements, partial eclipses being assumed. However both minima showed inadmissible systematic deviations from this solution. Furthermore, differential corrections applied only to the primary minimum strongly pointed to a larger value of k, the ratio of the semi-major axes of the components, and to a minimum value of $\cos^2 i$, where i is the inclination of the orbit. The latter indication means that one of the eclipses must be total. This is in agreement with the light-curve, where at primary minimum a fairly constant intensity may be detected. It is however in contradiction with the shallowness of both minima, which pointed either to a partial eclipse, or to a total eclipse with a smaller value of k! This difficulty might be overcome by assuming a certain amount of additional light in the rectified light-curve, so that $L_1 + L_2 < 1$. The light-curve could then be explained by a total eclipse at primary minimum as well as by a larger value of k.

To simplify the final solutions as much as possible, and according to the above mentioned tendency of

[1]) *Ap. J.* **108**, 388, 1948.
[2]) *Ap. J.* **106**, 380, 1947.

$\cos^2 i$ to a minimum value, the inclination i was taken to be 90°. Furthermore an accurate value for L_1 can be found from the constant intensity during total eclipse in the primary minimum, while L_2 is related to L_1 and k by KOPAL's formula [1]):

$$L_2 = \frac{L_1}{k^2\, Y(k, -1)} \times \frac{1 - \lambda_2}{1 - \lambda_1},$$

from which also ΔL_2 can be expressed in Δk, or, by definition of k, also in Δa_1 and Δa_2. So from IRWIN's method of solution by differential corrections, which originally included the unknowns ΔL_1, ΔL_2, Δa_1, Δa_2, $\Delta(\cos^2 i)$, Δu_1, and Δu_2, only two, Δa_1 and Δa_2, remained in the final solution. The results of this solution are given in Table 4. The residuals of the observations from this solution are also given in Table 6, column 3.

TABLE 4
Final elements

Adopted elements:

z_m	$= 0.103$
u_1	$= 0.8$
u_2	$= 0.8$
i	$= 90°$
K_1	$= 250$ km/sec
K_2	$= 125$ km/sec
e	$= 0.00$
P	$= 0^d.33363779$

Derived elements (errors given are mean errors):

$1 - j_1$	$= 0.3114 \pm 0.0012$
$1 - j_2$	$= 0.2832 \pm 0.0026$
$1 - \lambda_1$	$= 0.3114 \pm 0.0012$
$1 - \lambda_2$	$= 0.2686 \pm 0.0036$
L_1	$= 0.3114 \pm 0.0012$
L_2	$= 0.4317 \pm 0.0073$
L_3	$= 0.2569$
J_1/J_2	$= 1.317 \pm 0.018$
a_1	$= 0.3136 \pm 0.0018$
a_2	$= 0.4239 \pm 0.0013$
b_1	$= 0.2970$
b_2	$= 0.4015$
k	$= 0.740 \pm 0.004$
r	$= 1.720 \times 10^6$ km
a_1	$= 0.540 \times 10^6$ km
a_2	$= 0.729 \times 10^6$ km
μ_1	$= 0.609\ \mu_\odot$
μ_2	$= 1.218\ \mu_\odot$

Mean deviation of one observation:

	m
during primary minimum	± 0.005
during secondary minimum	± 0.008
between the eclipses.	± 0.007
averaged over the whole light-curve . . .	± 0.007

[1]) Harv. Obs. Monog. No. 8: Z. KOPAL, 'The computation of elements of eclipsing binary systems', p. 53, formulae 3.57 and 3.57a, 1950.

5. *Discussion.*

As was stated in section 3, the observed changes in period can be interpreted as a slow continual variation as well as by a variation with two discrete jumps. The first interpretation may be explained by a dynamically stable as well as by a dynamically unstable system, according to whether the variation will be periodic or irregular. The second interpretation however points inevitably to dynamic instability.

The problem of dynamic instability in very close binary systems has been extensively studied by KUIPER in his interpretation of β Lyrae [2]) and by WOOD [3]). In Table 3a of his article, KUIPER gave the stability limits for the dimensions of the components for several mass ratios. In Table 5 we have quoted these limits for a system with a mass ratio equal to 2. Comparing these data with the observed dimensions, we find that, although the latter fall quite within KUIPER's limiting values, the stability margin for the minor axes is not very large.

We must be careful, however, in the interpretation of the elements derived in section 4. Although the derived mean errors are very small, they depend very much on assumptions and idealized models.

The first point to mention is the value to be taken for the mean coefficient of ellipticity of the components. Whereas the convex maxima of the light-curve gave a value of $z = 0.163$, for the reason given in section 4, we had preferred to adopt PLAUT's theoretical value 0.103, based on the static theory of the tides. However the formulae used by PLAUT only contained the first-order effects, and they are valid for small values of a_1 and a_2 (e.g. smaller than 0.25). In our case the dimensions of the components turned out to be much larger, so, strictly speaking, the approximation was not valid, and the assumed value of $z = 0.103$ must be considered with much reserve.

A second point concerns the process of rectification. As was stated in section 4, the rectification for the sine terms in the light-curve between the minima remains provisional, as the origin of these terms is not known. With the assumption stated there, the observed light-curve was corrected for these terms by division. If however these sine terms originate from surrounding gas clouds as in the case of β Lyrae, the rectification will be much more complicated. No general methods have been published yet to solve such a problem. It may be noted in this connection, that STRUVE and HORAK's spectroscopic observations showed Ca emissions, which may point to the existence of surrounding gas clouds, and, furthermore, the additional light, necessary to make the depths of the

[2]) *Ap. J.* **93**, 133, 1941.
[3]) *Ap. J.* **112**, 196, 1950.

TABLE 5

Observed dimensions of the components and their theoretical limits.

Dimension	Heavier component		Lighter component	
	Limit	Obs.	Limit	Obs.
Outer major equatorial semi-axis a'	0.468	0.4239	0.346	0.3136
Inner major equatorial semi-axis a''	0.571		0.429	
Minor equatorial semi-axis b	0.440	0.4015	0.313	0.2970
Polar semi-axis c	0.414		0.300	

minima fit the solution derived from the form of the light-curve, may also arise from these clouds.

The third critical point is the additional light assumed in section 4. This assumption was based on the disagreement of the depths of the minima with the form of the rectified eclipse curve. Both features naturally depend strongly on the rectification process, which, as is stated above, remained highly tentative. The amount of additional light needed turns out to be rather large however (ca. 25%), and we doubt whether this can be ascribed to a wrong rectification. It should also be noted that the system of W Ursae Majoris has an optical component of the 13th magnitude. The light of this component contributes only one or two per cent to the total light of the system, which can be neglected in view of the much larger amount discussed above.

To conclude we can summarize the present results and conclusions as follows:

a. The period has increased since HUFFER made his photoelectric observations in 1934. The possibility that this increase resulted from an abrupt change in the period may not be entirely ruled out.

b. The analysis of the complete light-curve resulted in the following conclusions:

1. The first maximum is higher than the second.
2. The secondary minimum comes at phase 0.50435; this apparent shift from mid-phase may however be a result of the unequal maxima.
3. The primary minimum represents a total eclipse.
4. To explain the rectified light-curve additional light of about 25% of the total light of the system was needed.
5. The computed dimensions of the components are about 10% less than the stability limits of the system.

TABLE 6

Individual observations

J. D. Hel.	$m_v - m_c$	J. D. Hel.	$m_v - m_c$	J. D. Hel.	$m_v - m_c$	J. D. Hel.	$m_v - m_c$	J. D. Hel.	$m_v - m_c$
J.D. 2433943		d	m	d	m	d	m	d	m
d	m	·59477	−.122	·62241	+.018	·64710	−.441	·54886	−.609
·56590	−.521	·59594	−.097	·62337	+.002	·64799	−.440	·54999	−.600
·56806	−.513	·59703	−.062	·62425	−.025	·64901	−.451	·55099	−.594
·56946	−.500	·59817	−.035	·62525	−.041	·65012	−.444	·55222	−.586
·57073	−.496	·59974	−.008	·62617	−.071	·65118	−.474	·55340	−.591
·57210	−.475	·60086	+.029	·62716	−.079	·65212	−.499	·55428	−.585
·57336	−.473	·60215	+.038	·62807	−.122	·65303	−.492	·55534	−.591
·57502	−.461	·60348	+.042	·62902	−.138	·65407	−.495	·55674	−.590
·57632	−.443	·60459	+.085	·62998	−.173	·65512	−.511	·55765	−.577
·57738	−.419	·60563	+.090	·63101	−.185			·55850	−.565
·57848	−.405	·60695	+.100	·63206	−.211	J.D. 2433944		·55930	−.564
·57968	−.398	·60798	+.069	·63308	−.229	d	m	·56025	−.558
·58085	−.398	·60901	+.073	·63406	−.230	·50983	−.638	·56123	−.551
·58207	−.385	·61025	+.086	·63508	−.261	·51064	−.635	·56218	−.562
·58321	−.357	·61142	+.082	·63609	−.281	·51195	−.646	·56304	−.549
·58442	−.321	·61266	+.078	·63707	−.294	·51300	−.628	·56388	−.543
·58585	−.292	·61386	+.105	·63811	−.321	·51404	−.639	·56486	−.524
·58735	−.277	·61510	+.092	·63922	−.325	·51525	−.655	·56577	−.530
·58846	−.259	·61638	+.079	·64030	−.351	·51646	−.655	·56671	−.521
·58958	−.229	·61741	+.060	·64217	−.383	·51778	−.643	·56762	−.519
·59053	−.216	·61847	+.063	·64316	−.376	·51911	−.657	·56857	−.524
·59169	−.183	·61945	+.047	·64412	−.407	·52017	−.649	·56959	−.507
·59280	−.166	·62046	+.052	·64515	−.421	·52120	−.656	·57084	−.490
·59380	−.136	·62155	+.026	·64614	−.433	·52342	−.655	·57169	−.496

Table 6 (*continued*)

J. D. Hel.	$m_v - m_c$	J. D. Hel.	$m_v - m_c$	J. D. Hel.	$m_v - m_c$	J. D. Hel.	$m_v - m_c$	J. D. Hel.	$m_v - m_c$
J.D. 2433944		d	m	d	m	d	m	d	m
d	m	.63198	−.185	.63209	−.301	.69259	−.433	.39948	−.507
.57259	−.487	.63327	−.221	.63295	−.287	.69357	−.444	.40046	−.497
.57349	−.475	.63415	−.218	.63389	−.262	.69453	−.444	.40148	−.485
.57451	−.452	.63521	−.251	.63478	−.241	.69536	−.447	.40243	−.485
.57548	−.451	.63596	−.270	.63569	−.232	.69646	−.478	.40354	−.475
.57635	−.441	.63683	−.280	.63663	−.199	.69746	−.474	.40473	−.468
.57723	−.416	.63773	−.268	.63760	−.187	.69832	−.484	.40612	−.452
.57814	−.419	.63861	−.300	.63847	−.171	.69923	−.488	.40694	−.439
.57949	−.417	.63943	−.322	.63949	−.137	.70005	−.494	.40788	−.425
.58039	−.395	.64058	−.360	.64038	−.131			.40870	−.416
.58118	−.390	.64144	−.354	.64133	−.106	J.D. 2434489		.40968	−.405
.58209	−.367	.64239	−.366	.64258	−.071	d	m	.41058	−.403
.58300	−.360	.64325	−.377	.64369	−.049	.35162	−.644	.41143	−.401
.58415	−.344	.64405	−.388	.64473	−.014	.35264	−.637	.41223	−.383
.58516	−.332	.64494	−.395	.64587	+.007	.35368	−.641	.41312	−.373
.58618	−.305	.64626	−.410	.64682	+.028	.35488	−.634	.41406	−.349
.58707	−.295	.64715	−.423	.64773	+.049	.35595	−.634	.41495	−.343
.58802	−.269	.64814	−.445	.64884	+.070	.35696	−.635	.41589	−.317
.58894	−.261	.64906	−.445	.65005	+.091	.35791	−.634	.41670	−.304
.58994	−.235	.65008	−.466	.65108	+.092	.35883	−.638	.41780	−.287
.59092	−.220	.65128	−.454	.65220	+.104	.35981	−.642	.41874	−.259
.59224	−.188	.65231	−.470	.65318	+.096	.36074	−.642	.41966	−.258
.59326	−.174	.65353	−.482	.65414	+.100	.36165	−.638	.42060	−.236
.59410	−.155	.65431	−.490	.65523	+.096	.36261	−.630	.42157	−.219
.59509	−.130	.65510	−.510	.65626	+.109	.36390	−.645	.42243	−.196
.59595	−.100	.65596	−.533	.65727	+.104	.36537	−.630	.42327	−.167
.59697	−.064	.65675	−.495	.65832	+.113	.36631	−.638	.42423	−.166
.59795	−.067	.65763	−.511	.65932	+.092	.36719	−.642	.42514	−.142
.59879	−.041	.65850	−.516	.66047	+.109	.36825	−.638	.42606	−.116
.59967	−.023	.65986	−.531	.66140	+.092	.36912	−.632	.42710	−.102
.60073	−.002	.66081	−.538	.66242	+.105	.36996	−.623	.42806	−.082
.60157	+.055	.66166	−.535	.66336	+.101	.37097	−.623	.42898	−.058
.60248	+.040	.66254	−.534	.66430	+.097	.37190	−.626	.43007	−.032
.60340	+.052	.66338	−.522	.66522	+.081	.37282	−.626	.43105	−.007
.60443	+.068	.66417	−.559	.66624	+.071	.37358	−.622	.43206	+.018
.60557	+.091	.66503	−.562	.66726	+.063	.37444	−.622	.43299	+.036
.60668	+.091	.66579	−.568	.66811	+.033	.37536	−.614	.43390	+.040
.60761	+.076			.66913	+.015	.37627	−.618	.43493	+.056
.60897	+.093	J.D. 2433994		.67028	+.007	.37714	−.615	.43592	+.070
.60983	+.081	d	m	.67128	−.021	.37804	−.612	.43686	+.078
.61081	+.085	.56223	−.655	.67214	−.049	.37926	−.611	.43779	+.083
.61181	+.092	.56355	−.667	.67296	−.075	.38077	−.618	.43876	+.086
.61278	+.098	.56438	−.662	.67388	−.094	.38164	−.602	.43994	+.072
.61368	+.088	.56581	−.655	.67501	−.117	.38253	−.595	.44140	+.071
.61462	+.068	.56695	−.650	.67599	−.131	.38343	−.583	.44239	+.083
.61550	+.101	.56804	−.664	.67683	−.151	.38440	−.582	.44331	+.071
.61637	+.087	.56913	−.659	.67771	−.170	.38531	−.582	.44425	+.075
.61745	+.092	.57030	−.668	.67856	−.203	.38610	−.578	.44493	+.079
.61958	+.086	.57137	−.664	.67947	−.208	.38686	−.582	.44563	+.079
.62047	+.073	.61821	−.480	.68023	−.227	.38763	−.574	.44642	+.091
.62136	+.057	.61951	−.464	.68116	−.227	.38847	−.570	.44734	+.095
.62222	+.046	.62075	−.477	.68211	−.258	.38939	−.562	.44820	+.095
.62309	+.022	.62172	−.452	.68308	−.262	.39024	−.566	.44927	+.079
.62399	−.004	.62275	−.444	.68382	−.295	.39109	−.554	.45027	+.075
.62487	−.023	.62391	−.429	.68484	−.305	.39202	−.549	.45120	+.055
.62574	−.051	.62486	−.417	.68590	−.326	.39295	−.558	.45211	+.044
.62655	−.061	.62573	−.411	.68682	−.338	.39382	−.538	.45276	+.025
.62748	−.079	.62668	−.389	.68778	−.343	.39473	−.538	.45350	+.021
.62837	−.115	.62798	−.370	.68867	−.370	.39571	−.533	.45430	−.001
.62927	−.115	.62889	−.348	.68957	−.393	.39651	−.536	.45535	−.020
.63016	−.124	.62994	−.326	.69068	−.386	.39739	−.517	.45639	−.052
.63110	−.149	.63126	−.311	.69163	−.403	.39846	−.509	.45739	−.064

TABLE 6 (*continued*)

J. D. Hel.	m_v-m_c	J. D. Hel.	m_v-m_c	J. D. Hel.	m_v-m_c	J. D. Hel.	m_v-m_c	J. D. Hel.	m_v-m_c
J.D. 2434489		d	m	d	m	d	m	d	m
d	m	.48680	−.511	.61321	−.619	.65366	−.452	.69151	+.055
.45844	−.083	.48732	−.521	.61451	−.634	.65481	−.432	.69277	+.072
.45937	−.117	.48861	−.526	.61559	−.636	.65609	−.418	.69417	+.062
.46026	−.132	.48950	−.526	.61682	−.611	.65740	−.415	.69561	+.056
.46109	−.158	.49056	−.543	.61827	−.636	.65867	−.389	.69683	+.041
.46202	−.179	.49158	−.556	.61986	−.594	.66003	−.368	.69837	+.046
.46309	−.185	.49240	−.547	.62126	−.618	.66125	−.337	.69998	+.020
.46395	−.214	.49338	−.556	.62253	−.606	.66232	−.329	.70151	−.054
.46487	−.226	.49437	−.571	.62360	−.607	.66368	−.325	.70308	−.073
.46560	−.247	.49534	−.566	.62471	−.611	.66507	−.292	.70486	−.106
.46641	−.259	.49627	−.575	.62592	−.596	.66633	−.279	.70617	−.125
.46733	−.282	.49727	−.575	.62701	−.596	.66754	−.239	.70799	−.164
.46822	−.306	.49827	−.572	.62826	−.605	.66871	−.217	.70969	−.215
.46921	−.313	.49928	−.572	.62951	−.605	.66982	−.195	.71105	−.249
.47042	−.325	.50022	−.598	.63125	−.579	.67122	−.163	.71227	−.256
.47166	−.347	.50119	−.601	.63258	−.576	.67240	−.137	.71360	−.286
.47319	−.373	.50227	−.596	.63412	−.572	.67363	−.122	.71495	−.323
.47397	−.381	.50325	−.611	.63561	−.550	.67492	−.094	.71655	−.346
.47475	−.395	.50419	−.602	.63666	−.565	.67604	−.055	.71798	−.371
.47564	−.409			.63786	−.542	.67705	−.049	.71942	−.389
.47670	−.415	J.D. 2434759		.63949	−.548	.67824	−.013	.72094	−.414
.47760	−.433	d	m	.64074	−.548	.67939	+.021	.72230	−.429
.47872	−.442	.60262	−.643	.64204	−.538	.68062	+.065	.72371	−.457
.47979	−.460	.60425	−.658	.64321	−.528	.68198	+.051	.72537	−.466
.48084	−.466	.60569	−.648	.64426	−.522	.68319	+.061	.72704	−.488
.48189	−.483	.60709	−.657	.64550	−.526	.68437	+.092	.72863	−.490
.48292	−.501	.60843	−.651	.64665	−.502	.68591	+.075	.73027	−.522
.48382	−.492	.60970	−.641	.64793	−.462	.68732	+.090	.73198	−.510
.48499	−.497	.61095	−.654	.64909	−.465	.68883	+.045	.73339	−.523
.48600	−.511	.61207	−.640	.65166	−.462	.69023	+.055		

J. D. Hel.	m_v-m_c	$O-C$	J. D. Hel.	m_v-m_c	$O-C$	J. D. Hel.	m_v-m_c	$O-C$	J. D. Hel.	m_v-m_c	$O-C$
J.D. 2434766			d	m	m	d	m	m	d	m	m
d	m	m	.32935	−.434	+.004	.36837	+.057	+.004	.40867	−.569	−.010
.28276	−.664	−.014	.33081	−.411	+.002	.37007	+.030	−.008	.41014	−.563	+.005
.28455	−.659	−.010	.33227	−.391	+.001	.37145	+.016	−.001	.41212	−.585	−.006
.28652	−.655	−.010	.33366	−.380	−.009	.37290	−.007	+.003	.41413	−.583	+.006
.28835	−.655	−.011	.33515	−.356	−.009	.37426	−.039	−.003	.41578	−.596	+.002
.29018	−.655	−.014	.33674	−.318	+.002	.37619	−.077	.000	.41717	−.600	+.006
.29177	−.646	−.009	.33817	−.290	+.004	.37762	−.111	−.002	.41866	−.612	+.001
.29349	−.633	−.000	.33977	−.269	−.004	.37913	−.144	−.002	.42021	−.621	−.001
.29558	−.619	+.009	.34131	−.234	−.002	.38072	−.185	−.006	.42176	−.616	+.011
.29717	−.632	−.010	.34280	−.198	+.004	.38213	−.211	−.002	.42302	−.632	.000
.29922	−.627	−.011	.34433	−.164	+.006	.38357	−.240	−.002	.42452	−.628	+.011
.30088	−.612	−.001	.34576	−.129	+.010	.38520	−.274	−.002	.42601	−.644	+.001
.30564	−.600	−.010	.34714	−.103	+.006	.38666	−.308	−.007	.42772	−.652	−.001
.30762	−.585	−.002	.34856	−.077	.000	.38823	−.340	−.011	.42927	−.656	.000
.30954	−.573	.000	.35001	−.056	−.008	.38968	−.355	.000	.43085	−.656	+.004
.31132	−.562	+.002	.35147	−.022	−.004	.39099	−.377	+.002	.43214	−.664	+.002
.31282	−.557	.000	.35290	+.009	.000	.39249	−.393	+.008	.43367	−.668	+.001
.31444	−.549	−.001	.35463	+.036	−.001	.39423	−.426	+.001	.43514	−.671	+.002
.31599	−.531	+.009	.35608	+.052	.000	.39588	−.444	+.005	.43667	−.677	−.001
.31788	−.528	+.001	.35748	+.064	+.007	.39765	−.464	+.006	.43832	−.681	−.001
.31950	−.511	+.009	.35889	+.056	−.002	.39946	−.489	+.002	.43952	−.681	+.001
.32124	−.515	−.005	.36042	+.060	+.001	.40091	−.488	+.017	.44080	−.692	−.009
.32293	−.492	+.006	.36198	+.063	+.004	.40232	−.517	.000	.44243	−.689	−.005
.32455	−.477	+.006	.36385	+.056	−.002	.40389	−.524	+.005	.44404	−.671	+.016
.32623	−.460	+.007	.36526	+.056	−.001	.40543	−.548	−.008	.44549	−.682	+.005
.32776	−.450	.000	.36698	+.045	−.010	.40712	−.568	−.018	.44722	−.693	−.005