

PUBLICATIONS OF THE
ASTRONOMICAL SOCIETY OF THE PACIFIC

Vol. 91

August 1979

No. 542

RECENT PERIOD CHANGES IN U CEPHEI

RICHARD C. CRAWFORD

Astronomy Department, University of California, Los Angeles

AND

EDWARD C. OLSON

Astronomy Department, University of Illinois, Urbana

Received 1979 March 8

We discuss the influence of photometric contamination accompanying recent mass-transfer events on times of minima and period changes in U Cep. We propose a simple criterion to separate disturbed and undisturbed eclipses. Using times of minima from essentially undisturbed eclipses, we find that a large period decrease occurred in early 1972, before evidence of mass transfer was observed. This decrease was followed in 1974 by a period increase of much smaller magnitude, after which the period has remained constant. We demonstrate the sporadic nature of the transfer activity from 1974 through 1977.

Key words: binaries, eclipsing—period change—mass exchange

I. Introduction

Period changes in Algol-like eclipsing binaries have been studied for many years. The classic paper by Dugan and Wright (1939) recognized erratic period increases and decreases in many systems (e.g., XZ Andromedae, ZZ Cassiopeiae, U Coronae Borealis). General discussions have since been given, for example, by Wood (1963, 1969), Herczeg (1973), and Batten (1973). Wood (1950) made the important association between sudden period changes and the presence of a Roche lobe-filling component in the system, and Plavec, Pekný, and Smetanová (1960) demonstrated the general absence of such period changes in detached systems. Herczeg (1969) was able to decompose the “great inequality” in Algol into a series of sudden period increases and decreases, with fraction period change $|\Delta P/P| \simeq 10^{-5}$. Many other studies suggest that period fluctuations are common among Algols.

Algols as a class do not show a net secular period change. The massive system U Cephei (B7 V + G8 III-IV) is an exception, exhibiting a well-defined period increase since its discovery in 1880 (Batten 1974). If mass transfer from G- to B-star is conservative, Batten showed that the mean transfer rate is $\sim 2 \times 10^{-6} M_{\odot} \text{ yr}^{-1}$. Period changes of both signs are superimposed on the general increase. Hall (1975) interpreted these changes with the theory of Biermann and Hall (1973), who suggested that mass transfer occurs at discrete

times. During a transfer event, part of the orbital angular momentum of the transferred matter is temporarily stored as rotational momentum in or near the hot component (there may also be systemic mass loss). This produces a sudden period decrease. Somewhat later, part of the stored angular momentum gradually returns to orbital motion by dissipative tidal action, causing the period to lengthen. Hall was able to represent the details of the observed—calculated time of minimum (O—C) vs. orbital cycle, E , curve with a series of upward-curving parabolas representing the intervals of period increase. These begin and end with sudden period decreases caused by eruptive mass transfer every $\sim 9 \pm 4$ years. Roughly 10^{-4} to $10^{-5} M_{\odot}$ are transferred at each eruption. The most recent of these parabolas (“ $n = 10$ ”) lasted from late 1964 to early 1972.

Several observers noted spectroscopic and photometric evidence of mass transfer and circumstellar material in U Cep in 1974 (Plavec and Polidan 1975; Batten et al. 1975; Markworth 1975; Rhombs and Fix 1976; Olson 1976a). Determination of period changes following this event offers an excellent test of the Biermann-Hall theory, and may help in understanding the dynamics of the transfer process. Hall and Keel (1977) studied the period behavior with data to 1976.8, and concluded that a period change $\Delta P/P \sim -3 \times 10^{-5}$ had occurred in early 1972. Our purpose in the present paper is to extend observations and discussions of times of

minima to late 1977, to consider in detail the influence of the distorted light curves on these times, and to refine the inferred period change(s) during this interval.

II. Observations

All photoelectric times of minima used in this paper are listed in Table Ia. The 217 visual times of minima

TABLE Ia
PHOTOELECTRIC TIMES OF MINIMUM LIGHT

JD - 2440000	Epoch Number	O-C (days)	References	JD - 2440000	Epoch Number	O-C (days)	Reference
86.4908	720	-0.0007	Kizilirmak & Pohl 1970	2367.6590c	1635	0.0350	Markworth 1978
101.4483	726	-0.0015	Kizilirmak & Pohl 1970	2377.6246c	1639	0.0284	Olson 1976b
136.3542	740	0.0019	Kizilirmak & Pohl 1970	2452.4170	1669	0.0296	Pohl & Kizilirmak 1976
141.3350	742	-0.0034	Kizilirmak & Pohl 1970	2462.3927	1673	0.0331	Surkova 1975
213.6372	771	0.0006	Bakos & Tremko 1973	2651.8644	1749	0.0337	Crawford 1979
228.5925	777	-0.0024	Bakos & Tremko 1973	2661.8384c	1753	0.0355	McNamara 1976
233.5810	779	0.0001	Bakos & Tremko 1973	2671.8086	1757	0.0336	Crawford 1979
243.5555	783	0.0024	Bakos & Tremko 1977	2676.7956	1759	0.0345	Crawford 1979
273.4695	795	-0.0001	Surkova 1970	2676.7959	1759	0.0348	Batten 1975
440.5195	862	0.0162	Bakos & Tremko 1973	2681.7825	1761	0.0353	Batten 1975
512.8046	891	0.0031	Scarfe et al. 1973	2696.7421c	1767	0.0367	Present work
644.9351	944	0.0024	Hall 1973	2706.7154c	1771	0.0378	McNamara 1976
679.8413	958	0.0060	Hall 1973	2706.7160	1771	0.0384	Hall & Keel 1977
809.4802	1010	0.0068	Kizilirmak & Pohl 1971	2711.7000	1773	0.0363	Hall & Keel 1977
854.3560	1028	0.0079	Kizilirmak & Pohl 1971	2711.7007c	1773	0.0370	Present work
874.3009	1036	0.0084	Kizilirmak & Pohl 1971	2716.6879c	1775	0.0381	Present work
1190.9261	1163	0.0174	Scarfe et al. 1973	2731.6400	1781	0.0320	Hall & Keel 1977
1198.4067	1166	0.0189	Todoran 1973	2736.6281	1783	0.0340	Hall & Keel 1977
1203.3925	1168	0.0186	Pohl & Kizilirmak 1972	2806.4320	1811	0.0327	Pohl & Kizilirmak 1977
1210.8706	1171	0.0176	Scarfe et al. 1973	2816.4050	1815	0.0336	Bakos & Tremko 1977
1215.8567	1173	0.0176	Scarfe et al. 1973	2873.7445c	1838	0.0331	Present work
1218.3500	1174	0.0179	Todoran 1973	2878.7316c	1840	0.0342	Present work
1223.3360	1176	0.0178	Todoran 1973	2903.6705c	1850	0.0426	Markworth 1978
1395.3610	1245	0.0230	Kizilirmak & Pohl 1974	2963.4980	1874	0.0372	Pohl & Kizilirmak 1977
1512.5340	1292	0.0230	Braune & Mundry 1973	3010.8735	1893	0.0449	Crawford 1979
1719.4651	1375	0.0317	Bakos & Tremko 1977	3015.8566	1895	0.0419	Crawford 1979
1901.4641	1448	0.0387	Bakos & Tremko 1977	3020.8368	1897	0.0360	Crawford 1979
1938.8476	1463	0.0266	Scarfe et al. 1973	3025.8218c	1899	0.0349	Present work
1948.8207a	1467	0.0276	Coyne 1974	3030.8093	1901	0.0364	Scarfe 1976
2267.9330b	1595	0.0306	Plavec & Polidan 1974	3035.7952	1903	0.0362	Crawford 1979
2302.8402	1609	0.0352	Batten & Plavec 1974	3055.7392	1911	0.0358	Hall & Keel 1977
2307.8280	1611	0.0369	Batten & Plavec 1974	3080.6714c	1921	0.0376	Present work
2312.8095	1613	0.0324	Batten & Plavec 1974	3090.6422c	1925	0.0363	Present work
2317.7950	1615	0.0318	Batten & Plavec 1974	3202.8311	1970	0.0383	Crawford 1979
2322.7858c	1617	0.0365	Olson 1976b	3207.8187	1972	0.0398	Crawford 1979
2327.7697	1619	0.0343	Batten & Plavec 1974	3364.8824	2035	0.0420	Crawford 1979
2337.7364c	1623	0.0289	Olson 1976b	3379.8377	2041	0.0390	Crawford 1979
2342.7239	1625	0.0303	Batten 1975	3389.8102	2045	0.0394	Crawford 1979
2342.7242c	1625	0.0306	Present work	3409.7625c	2053	0.0473	Present work
2347.7144c	1627	0.0347	Olson 1976b	3429.6990c	2061	0.0395	Present work
2362.6696c	1633	0.0316	Markworth 1978	3459.6165c	2073	0.0405	Present work

Notes: a) very uncertain--minimal ingress coverage

b) incorrectly given in the reference

c) determined by method of Kwee and Van Woerden (1956) by present authors

available to us were separated into 18 groups; their mean E , (O–C), and epoch range are listed in Table Ib. E and (O–C) are calculated with the ephemeris $\text{HJD min I} = 2438291.5020 + 2.493\,0410\,E$ (Kukarkin et al. 1969). The authors obtained *uvby* observations with the 61-cm Ojai, the no. 4 41-cm Kitt Peak National Observatory, and the 102-cm Prairie Observatory reflectors. Observing procedures have previously been described (Crawford 1979; Olson 1976b). Ultraviolet light curves were the most highly distorted, and were excluded from the adopted times of minima.

III. Analysis

The (O–C) values from Table I are plotted as a function of E in Figure 1. Photoelectrically measured (PE) values are plotted as circles, while the visual (V)

determinations, averages of about 12 individual minima each, are plotted as diamonds. The mean error of a PE result is typically $\sim \pm 0.0003$ day. Single V times vary in quality, depending on the number of observed points. By comparing V and PE times of the same eclipse, we find that errors of the former range from ± 0.006 to ± 0.002 day. The lower value agrees with the estimate of Mallama (1974) for good determinations. The most realistic typical error is $\sim \pm 0.004$ day. Each V point in Figure 1 therefore has an error $\sim \pm 0.001$ day, except where variations due to variable activity have entered the means.

Prior to $E \sim 1300$, the scatter of all points is fairly small. The one discordant point, $E = 862$, has been discussed by Bakos and Tremko (1974) and Hall (1973). Omitting this point, the least-squares parabola for the PE and V minima for $E = 700$ –1250 is $\text{HJD min I} =$

TABLE Ib
MEANS OF VISUAL TIMES OF MINIMUM LIGHT

Mean Epoch	O–C (days)	Number of Times	Epoch Range	Reference
736.3	–0.0017	12	720–750	1,2,3
808.5	–0.0001	6	799–838	4,5,6
885.0	0.0020	15	856–911	6,7,8,9
962.9	0.0078	10	925–1002	10,11,12
1021.5	0.0075	19	1006–1030	10,13,14,15
1156.9	0.0175	17	1114–1185	16,17,18
1242.3	0.0220	10	1227–1256	16,19,20,21,22
1311.8	0.0223	12	1292–1326	20,22,23,24,25
1395.0	0.0285	9	1384–1416	26,27,28
1454.9	0.0330	14	1436–1464	29,30,31,32
1508.7	0.0358	9	1481–1550	32,33,34,35,36
1614.7	0.0312	24	1582–1645	27,32,36,37,38,39
1677.4	0.0291	7	1655–1702	40,41,42
1749.5	0.0334	15	1724–1789	39,42,43
1851.1	0.0356	14	1803–1894	42,44,45,46
1939.6	0.0388	8	1925–1955	47,48,49
2012.8	0.0373	9	1973–2028	50,51
2104.9	0.0391	7	2065–2158	52,53,54

References:

- | | | |
|------------------|-----------------------|-----------------------|
| 1 IBVS #394 | 19 IBVS #637 | 37 BBSAG #16 |
| 2 ORION 13 #109 | 20 J BRIT AA 83 452 | 38 BBSAG #17 |
| 3 ORION 14 #110 | 21 BBSAG #2 | 39 IBVS #1249 |
| 4 ORION 14 #112 | 22 AN 294 225 | 40 BBSAG #20 |
| 5 ORION 14 #113 | 23 BBSAG #4 | 41 BBSAG #21 |
| 6 IBVS #795 | 24 BBSAG #5 | 42 PC (M BALDWIN) |
| 7 ORION 14 #114 | 25 BBSAG #6 | 43 BBSAG #23 |
| 8 ORION 14 #115 | 26 BBSAG #8 | 44 BBSAG #26 |
| 9 ORION 28 #116 | 27 AN 298 121 | 45 BBSAG #28 |
| 10 JAAVSO 4 86 | 28 BBSAG #9 | 46 BBSAG #29 |
| 11 ORION 28 #118 | 29 BBSAG #10 | 47 BBSAG #31 |
| 12 IBVS #501 | 30 BBSAG #11 | 48 IBVS #1335 |
| 13 ORION 28 #120 | 31 MVS SONNEBERG 7 32 | 49 MVS SONNEBERG 8 #2 |
| 14 AN 294 123 | 32 J BRIT AA 85 445 | 50 BBSAG #33 |
| 15 ORION 28 #121 | 33 JAAVSO 5 84 | 51 BBSAG #34 |
| 16 JAAVSO 5 29 | 34 BBSAG #13 | 52 BBSAG #35 |
| 17 ORION 29 #126 | 35 BBSAG #14 | 53 BBSAG #36 |
| 18 ORION 29 #127 | 36 JAAVSO 6 24 | 54 BBSAG #37 |

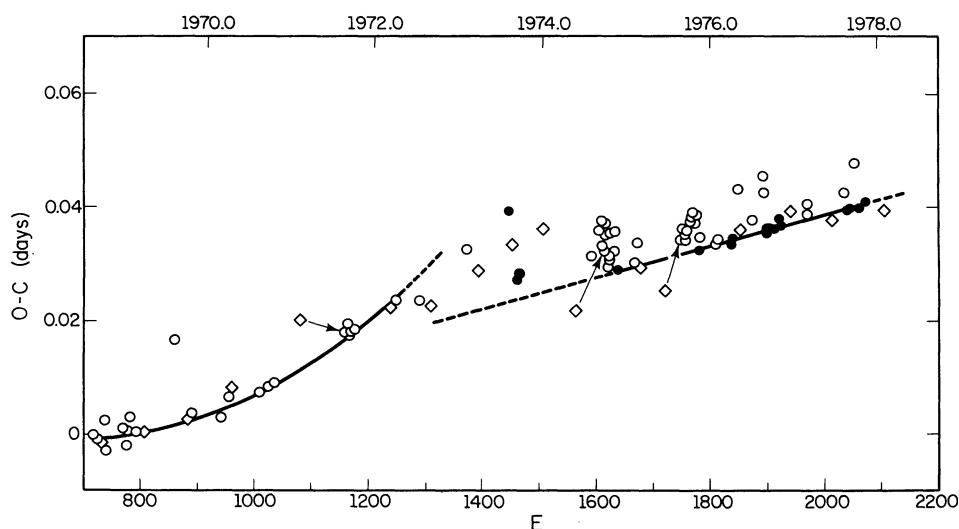


FIG. 1—Observed minus calculated times of minima for U Cep. Circles are photoelectric determinations, and filled circles are eclipses for $E > 1300$ judged by the criterion on d to be essentially free of circumstellar contamination. Each diamond is a mean of about 12 visual determinations.

$2438291.5312 \pm 0.0101 + (2.4929478 \pm 0.0000214)E + (7.12 \pm 1.11) \times 10^{-8} E^2$. Later points show notably larger scatter; many were derived from highly distorted primary eclipses during periods of elevated mass transfer. In spite of this scatter, Hall and Keel were able to show that the period had decreased to ~ 2.493061 days. Our analysis of 55 PE minima for $E = 1463$ –2073 yields $P = 2.4930617 \pm 0.0000024$ days, so clearly a period decrease has occurred.

We refine this analysis by rejecting those eclipses with distorted light curves. All workers agree that distorted curves show an apparent duration of totality, d , lower than its normal value of ~ 0.09 day. This effect is usually traced to circumstellar material around the B-star. In this paper we require that “undisturbed” light curves have $d \gtrsim 0.075$ day. Light-curve distortion makes it difficult to determine apparent times of second and third contacts, t_2 and t_3 , with precision. We take these times at the “breaks” in the y , b , and v light curves, recognizing that in the interval d many eclipses show definite curvature. Undisturbed eclipses for $E > 1300$ are plotted as filled circles in Figure 1. These eclipses for $E > \sim 1600$ accurately define the lower envelope of the points. It is evident that photometric contamination can delay the apparent time of minimum by as much as ~ 0.01 day. A similar conclusion has been reached by Bakos and Tremko (1977), and follows from published light curves (Olson, 1976a) and from Crawford (1979). The 14 undisturbed minima from $E = 1639$ to 2073 define a linear relation of small scatter; we suggest that this relation gives the true period during this time. The linear least-squares solution yields the “undisturbed ephemeris” HJD min I = $2438291.4858 \pm 0.0027 + (2.4930683 \pm$

$0.0000014)E$, predicting a mean error per minimum of ± 0.0006 day. A parabolic least-squares fit does not reduce the mean fitting error.

The most recent example of a disturbed eclipse occurred at $E = 2053$ (1977 September 23). This eclipse occurred ~ 0.007 day late relative to the new ephemeris. Figure 2 shows the y light curve (unfortunately not observed during totality) of September 23 (circles) and the undisturbed eclipses of October 13 (squares) and November 12 (triangles). The solid curve is the best estimate of the truly undisturbed symmetrical light curve, obtained by reflecting the egress branch around mideclipse (Olson 1979). The well-known depressed ingress shoulder is apparent at phase < 0.96 .

Apparent duration of totality, d , is related to $(O-C)$'s derived from the undisturbed ephemeris as shown in Figure 3. This interval is fairly well-determined ($\sim \pm 0.002$ day) for long- d eclipses, but is less certain ($\sim \pm 0.01$ day) for the more disturbed eclipses. Considering these uncertainties, the $d, (O-C)$ relation is fairly well-defined. Excess light during ingress exceeds that during egress. The hot spot produced by the impact of the mass-transferring stream on the B-star is visible before second contact, and contributes to delays in the apparent times of minima. The excess light at second contact usually exceeds that at third contact, reflecting an asymmetry in the distribution of the circumstellar material that further delays times of minima and reduces d . The nature of this excess light and the radial extent of the circumstellar material has recently been discussed by Crawford (1979). As a result of this photometric contamination, there are no small- d , small- $(O-C)$ points in Figure 3. Considering the variability of light curve shapes near mideclipse, we do not rec-

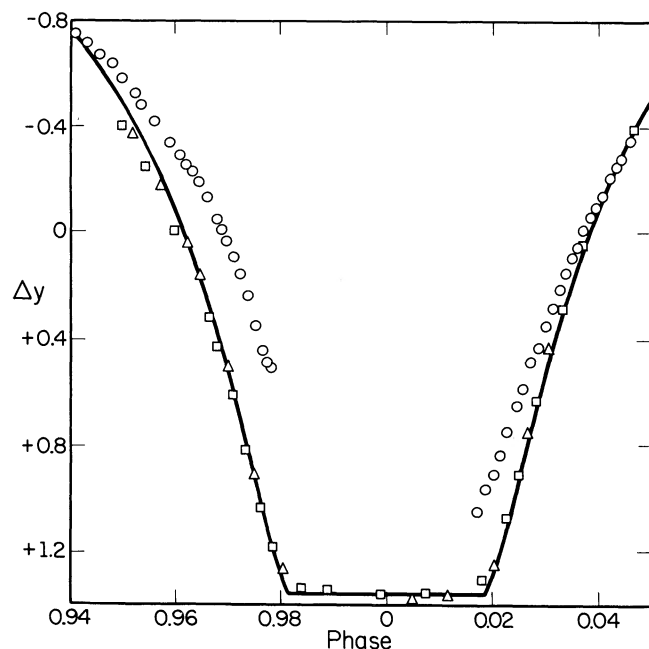


FIG. 2—Recent primary eclipse curves of U Cep. Circles: 1977 September 23 ($E = 2053$); squares: 1977 October 13 ($E = 2061$); triangles: 1977 November 12 ($E = 2073$). Solid curve, best estimate of symmetrical, undisturbed eclipse curve.

ommend that this relation be used to “correct” times of minima for photometric contamination. The correlation of Figure 3 does suggest that (O–C)’s from an ephemeris representing undisturbed eclipses are a good indicator of the degree of photometric disturbance. Selection of $d \geq 0.075$ day as the criterion for undisturbed eclipses is based mainly on this relation. Qualitative estimates of photometric contamination by Olson (1976a) correlate well with (O–C).

Figure 4 shows the apparent times of second contact t_2 (squares), mideclipse t_0 (diamonds), and third contact t_3 (octagons), relative to times of minima calculated with the undisturbed ephemeris. Forty-three eclipses for which at least t_2 or t_3 is available are plotted. The correlation of Figure 3 is evident in this plot, with large $t_3 - t_2$ associated with small delays in t_0 . In cases where t_0 is late, the interval $t_0 - t_2$ is usually shorter than $t_3 - t_0$. This implies that the excess light in disturbed eclipses is usually greater near second than third contact, which is consistent with the September 23 light curves of Figure 2. The circumstellar matter is therefore asymmetrically distributed around the B-star. The fact that t_2 and t_3 remain within the intervals of true second to third contacts predicted by the undisturbed ephemeris suggests that this ephemeris cannot

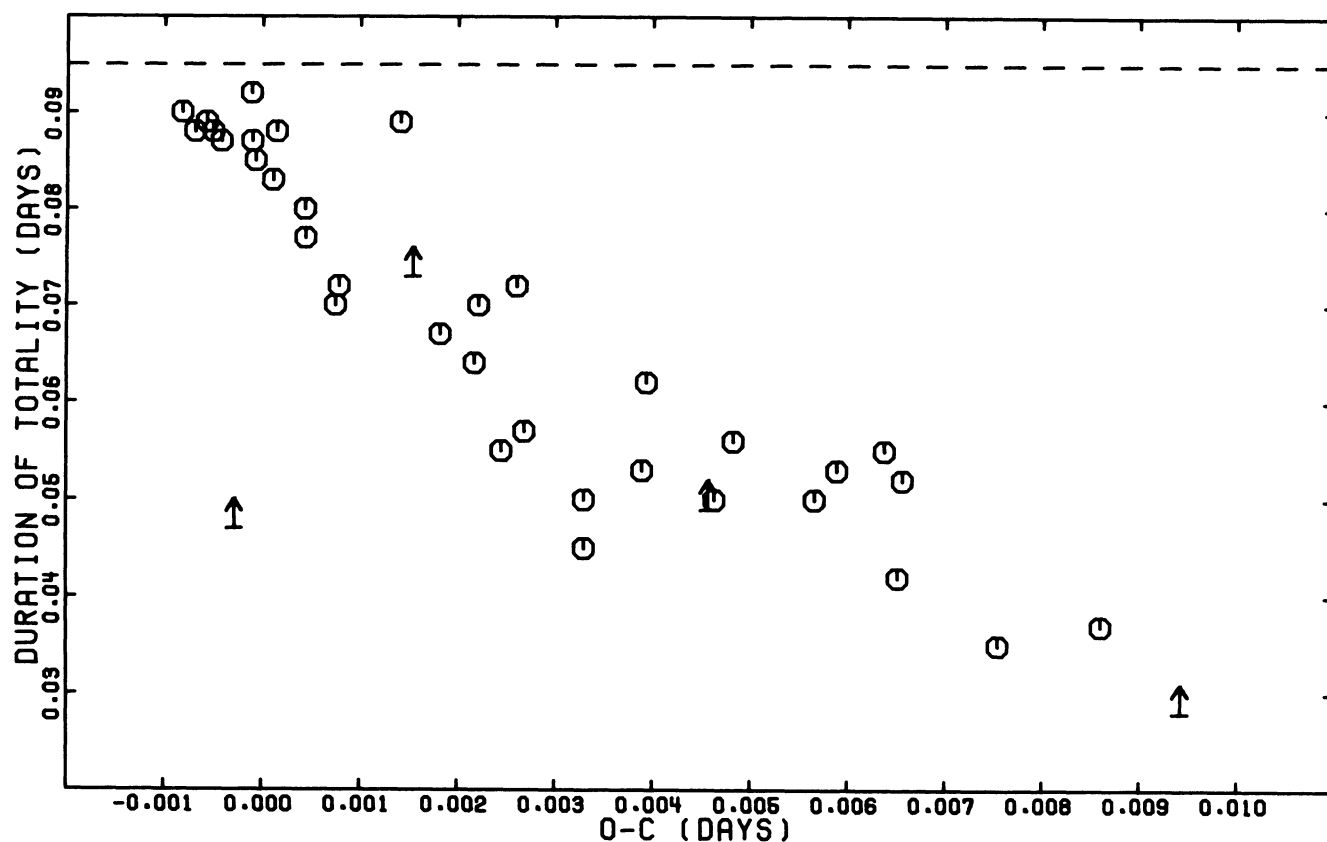


FIG. 3—Relation between apparent duration of totality and (O–C) derived from the undisturbed ephemeris (see text) of U Cep. The dashed line corresponds to times of internal contacts of $\sim \pm 0.019P$.

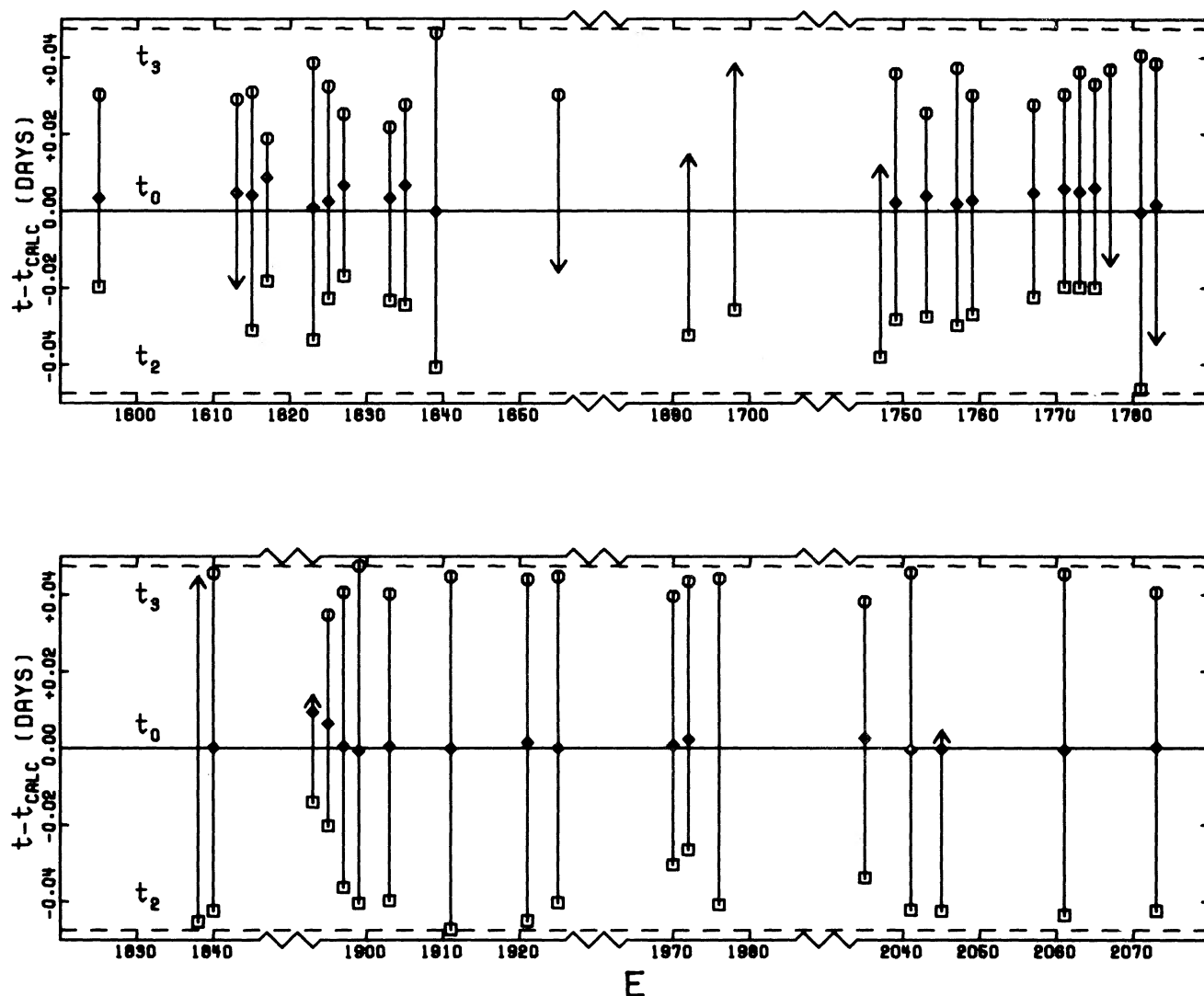


FIG. 4—(O—C)'s for second contact (squares), mid-eclipse (diamonds), and third contact (octagons) derived from the undisturbed ephemeris of U Cep. Dashed lines correspond to times of internal contacts of $\sim \pm 0.019P$.

be grossly in error.

Figure 5 is an expanded partial plot of PE (O—C) showing remarkably erratic variations in the photometric disturbance (and, presumably, in the mass-transfer rate). This figure is based on the undisturbed ephemeris, and covers the interval $E = 1595$ (1974 August 8) to $E = 1925$ (1976 November 8). Because of its 2.5-day period, eclipses of U Cep can be observed on a single night from a given location in windows separated by six months. Since most of the observations of Figures 4 and 5 were made in North America, the record has large gaps. It is possible that full time resolution of the variations has not been achieved because only alternate eclipses occur at night from a given location. Evidently photometric contamination of primary eclipses often decayed in a time as short as ~ 10 days, reflecting the rapid turn-off of mass transfer and sub-

sequent disk collapse. Sporadic transfer events have occurred for about four years, but the fraction of observed eclipses that are nearly undisturbed has increased since the end of 1975.

Finally, we consider period changes that have occurred since $E \sim 1100$ (Fig. 1). Hall and Keel (1977) argued that one sudden period decrease occurred in early 1972 ($E \sim 1250$). We differ only in our own use of undisturbed minima, in the addition of 10 PE minima ($E = 1921$ to 2073), and in the use of the visual means of Table Ib.

We first note that in the interval $E \sim 1640$ –2100 the period of U Cep, defined by the undisturbed eclipses, remained sensibly constant (the solid line segment of Fig. 1). The period was in fact more nearly constant than during the preceding “parabolic” phase. This is true in spite of pronounced, fluctuating photo-

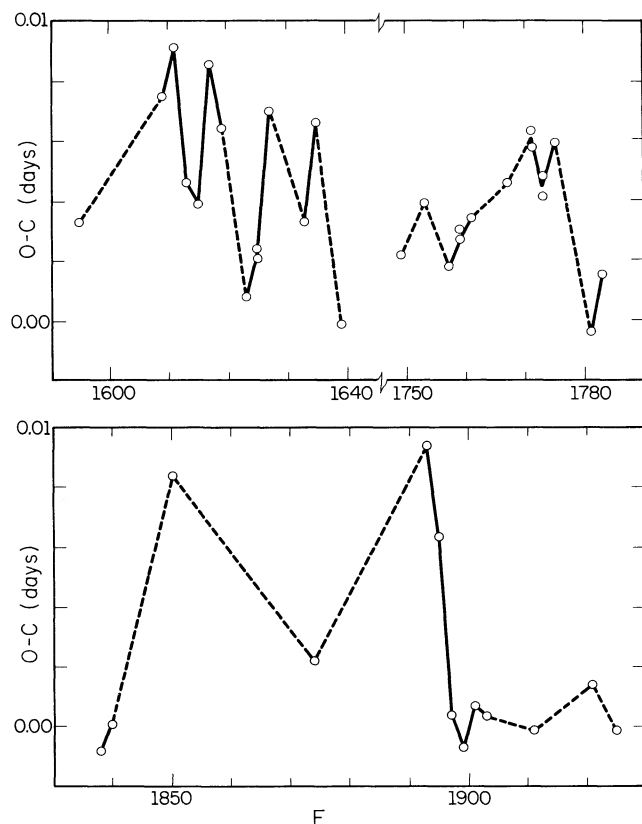


FIG. 5—Expanded plot of $(O-C)$ of times of minima of U Cep, derived from the undisturbed ephemeris. Solid lines connect eclipses observed at five-day intervals (the smallest eclipse interval observable from a given location).

metric disturbances signaling mass transfer and producing spuriously large $(O-C)$'s. The upper envelope of the point scatter hardly changed, so individual minima were delayed by comparably large amounts (up to 0.008 day) throughout this range. The character of the photometric disturbance remained qualitatively the same, and similar to that of Figure 2. Let "clearly disturbed" eclipses have apparent times of minima more than 0.001 day later than the undisturbed time. The fraction of such eclipses drops from ~ 0.7 to ~ 0.3 during this interval. The activity decline is therefore in the number of disturbed eclipses rather than in the peak intensity of the disturbance. The statistics are perhaps best for the 1.1-year interval $E = 1639$ –1800, where 10 of 14 eclipses were clearly disturbed.

Figure 1 suggests that the period decrease joining parabolic and linear segments probably occurred during a 2.4 year "transition interval" $E \sim 1250$ to 1639. It is not clear how such a period change could be produced by activity of the same nature as that following 1639. Mass transfer may have been more rapid and nearly continuous during this interval, and qualitatively different photometric effects may have occurred.

Unfortunately, few photoelectric observations were

made until the end of the transition period, and a clear picture of activity cannot be drawn. The scatter in $(O-C)$ may have been slightly greater, but clear evidence for more consistent or intense events of the type seen after $E \sim 1600$ is lacking. Several minima for which photoelectric data were available to us ($E = 1448, 1463, 1467$) in fact satisfy our criterion on d for undisturbed eclipses. Egress was not observed for $E = 1375$, setting a lower limit $d \sim 0.065$ day. However, the point $E = 1448$, $(O-C) = +0.0387$ day, (Bakos and Tremko 1977, 1978) lies at or above the upper envelope of the scatter in Figure 1. The value of $d \sim 0.075$ day, at the lower limit of our criterion for undisturbed eclipses. It may therefore be an example of the qualitatively different disturbance mentioned above and, in spite of its large d , may have a spuriously large $(O-C)$. The B -light curve of this eclipse was compared to our best estimate of the undisturbed curve obtained by interpolation between the four-color b and v curves (Olson 1979). Totality was flat and within 0.01 magnitude of the undisturbed light level of the G-star. Over most of the observed magnitude range, the light curve was uniformly narrower than normal by ~ 0.015 day (the difference between the observed and the truly unperturbed d). This in itself is atypical of later disturbed light curves (see Fig. 2). We evidently lack sufficient data to judge if the d -criterion is always valid in the transition interval, and this uncertainty is a caveat in the following discussion.

The only evidence for a typically disturbed eclipse in the transition interval prior to $E = 1595$ is the comment of R. Harvin (ref. 34, Table Ib) that no constant phase was present during the eclipse at $E = 1495$. The visual mean at $E = 1508.7$, which includes the Harvin observation, is at the upper envelope of scatter in Figure 1. All subsequent visual means fall much closer to the times given by the undisturbed ephemeris. Thus we infer that unusually persistent photometric disturbances of the type observed at $E > 1600$ may have been present around $E \sim 1500$, and may have been the forerunner of all subsequent activity.

We consider two simple possibilities to describe the period evolution of U Cep joining the parabolic and linear segments of Figure 1. The first requires that a single sudden period decrease occurred near $E \sim 1140$ where the extrapolated linear portion intersects the parabola. Difficulties are that (1) several later eclipses show no evidence of photometric contamination, and (2) the $(O-C)$'s of undisturbed eclipses $E = 1463$ and 1467 require special explanation. The second and preferred possibility requires a period decrease $\Delta P/P \sim -3 \times 10^{-5}$ near $E = 1230$, followed by a period increase $\Delta P/P \sim +6 \times 10^{-6}$ near $E = 1600$. The period decrease is close to that proposed by Hall and Keel

(1977). The undisturbed eclipses are accommodated, and the period increase may be explained by mass transfer associated with activity toward the end of the transition interval. The absence of photometric contamination near the epoch of proposed period decrease remains a problem. Naftilan (1975) did report hydrogen-line emission in April 1972 ($E \sim 1252$). Until more complete observations of additional period changes are available, we tentatively conclude that most of the pronounced photoelectric and spectroscopic anomalies recently observed in U Cep were not directly associated with the large period changes. Thus, the total mass of the matter responsible for the disturbances may not be gravitationally significant.

As far as they go, these observations are consistent with the Bierman-Hall theory. Future observations of undisturbed eclipses will indicate if a gradual period increase is occurring, as required by the theory. The next major period decrease may occur around 1981; only persistent efforts will produce useful observations of this event. Given the information that spectroscopic and photometric observations may reveal about the dynamics of mass transfer and possible mass loss from the system, the attempt is well worthwhile.

We particularly urge visual observers to search carefully for, and to report promptly (to E.C.O.), distorted eclipse curves. To aid in this effort, we give the quiescent visual eclipse curve of U Cep in Table II. The

TABLE II
QUIESCENT VISUAL ECLIPSE CURVE

Time From Mid-Eclipse (hours)	Orbital Phase	V*
-4.0	0.9331	7.05
-3.5	0.9415	7.22
-3.0	0.9499	7.44
-2.5	0.9582	7.75
-2.0	0.9666	8.18
-1.5	0.9749	8.80
-1.0	0.9833	9.23
-0.5	0.9916	9.24
0.5	0.0084	9.24
1.0	0.0167	9.24
1.5	0.0251	8.82
2.0	0.0334	8.18
2.5	0.0418	7.72
3.0	0.0501	7.41
3.5	0.0585	7.17
4.0	0.0669	7.01

* Johnson system, assuming $V(\text{HD } 6006) = 7.89$.

typical depressed ingress shoulder, mentioned above, accounts for the slight asymmetry of the eclipse. Variations larger than 0.1 magnitude from eclipse to eclipse have been seen in the light level during totality, and are probably caused by variations of the G-star. Such variations, as well as the absence of the nominal interval of constant light, should be monitored. Variations could occur in times as short as the dynamical time scale (a few days).

We thank Marvin Baldwin, Alan Batten, Norman Markworth, D. H. McNamara, G. Bakos, J. Tremko, and Colin Scarfe for supplying observations in advance of publication. Drake Deming, William Hartkopf, and Richard Karman assisted with observations at Prairie Observatory. This research was partially supported by National Science Foundation grant 76-24639 to E.C.O.

REFERENCES

- Bakos, G. A., and Tremko, J. 1973, *Bull. Astr. Inst. Czechoslovakia* 24, 298.
 ——— 1974, *I.A.U. Inf. Bull. Var. Stars*, No. 869.
 ——— 1977, *J.R.A.S. Canada* 71, 234.
 ——— 1978 (private communication).
 Batten, A. H. 1973, *Binary and Multiple Systems of Stars* (Oxford: Pergamon Press).
 ——— 1974, *Pub. Dominion Astrophys. Obs.* 14, 191.
 ——— 1975 (private communication).
 Batten, A. H., and Plavec, M. 1974, *I.A.U. Inf. Bull. Var. Stars* No. 940.
 Batten, A. H., Fischer, W. A., Baldwin, B. W., and Scarfe, C. D. 1975, *Nature*, 253, 174.
 Biermann, P., and Hall, D. S. 1973, *Astr. and Ap.* 27, 249.
 Braune, W., and Mundry, E. 1973, *Astr. Nachrichten* 294, 225.
 Coyne, G. V. 1974, *Recherche Astr.* 8, 475.
 Crawford, R. C., 1979, *Pub. A.S.P.* 91, 111.
 Dugan, R. S., and Wright, F. W. 1939, *Contr. Princeton Univ. Obs.* No. 19.
 Hall, D. S. 1973, *I.A.U. Inf. Bull. Var. Stars* No. 847.
 ——— 1975, *Acta Astr.* 25, 1.
 Hall, D. S., and Keel, W. C. 1977, *Acta Astr.* 27, 167.
 Herczeg, T. 1969, in *Non-Periodic Phenomena in Variable Stars*, L. Detre, ed. (Dordrecht: Reidel), p. 465.
 ——— 1973, in *Extended Atmospheres and Circumstellar Matter in Spectroscopic Binary Systems*, I.A.U. Symposium No. 51, A. H. Batten, ed. (Dordrecht: Reidel), p. 181.
 Kizilirmak, A., and Pohl, E. 1970, *I.A.U. Inf. Bull. Var. Stars* No. 456.
 ——— 1971, *ibid.* No. 530.
 ——— 1974, *ibid.* No. 937.
 Kukarkin, B. V., Kholopov, P. N., Efremov, Yu. N., Kukarkina, N. P., Kurochkin, N. E., Medvedeva, G. I., Perova, N. B., Federovich, V. P., Frolov, M. S. 1969, *General Catalogue of Variable Stars* (Moscow).
 Kwee, K. K., and Van Woerden, H. 1956, *Bull. Astr. Inst. Netherlands* 12, 327.
 Mallama, A. D. 1974, *Journal A.A.V.S.O.* 3, 11.
 Markworth, N. L. 1975, *Bull. A.A.S.* 7, 338.
 ——— 1978 (private communication).
 McNamara, D. H. 1976 (private communication).
 Naftilan, S. A. 1975, *Pub. A.S.P.* 87, 321.
 Olson, E. C. 1976a, *Ap. J.* 204, 141.
 ——— 1976b, *Ap. J. Suppl.* 31, 1.

- 1979 (in preparation).
- Plavec, M., and Polidan, R. S. 1975, *Nature* 253, 173.
- Plavec, M., Pekný, Z., and Smetanová, M. 1960, *Bull. Astr. Inst. Czechoslovakia* 11, 180.
- Pohl, E., and Kizilirmak, A. 1972, *I.A.U. Inf. Bull. Var. Stars* No. 647.
- 1976, *ibid.* No. 1163.
- 1977, *ibid.* No. 1358.
- Rhombs, C. G., and Fix, J. D. 1976, *Ap. J.* 209, 821.
- Scarfe, C. D. 1976 (private communication).
- Scarfe, C. D., Niehaus, R. J., Barlow, D. J., and Baldwin, B. W. 1973, *I.A.U. Inf. Bull. Var. Stars* No. 844.
- Surkova, L. P. 1970, *I.A.U. Inf. Bull. Var. Stars* No. 501.
- 1975, *Astr. Tsirk.* 882, 5.
- Todoran, I. 1973, *I.A.U. Inf. Bull. Var. Stars* No. 775.
- Wood, F. B. 1950, *Ap. J.* 112, 196.
- 1963, in *Basic Astronomical Data*, K. Aa. Strand, ed. (Chicago: University of Chicago Press), p. 370.
- 1969, in *Non-Periodic Phenomena in Variable Stars*, L. Detre, ed. (Dordrecht: Reidel), p. 429.