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# ABSTRACT

The eclipsing binary system UV Piscium, which is a short-period RS Canum Venaticorum-type binary system, was observed at Mt. Laguna Observatory during 1980 using the Stromgren 4-color filter system, and broad and narrow Calcium II K-line filters. A new ephemeris was calculated using only photoelectric times of minima. Four sets of orbital solutions were obtained using the Nelson-Davis-Etzel model giving reliable geometric elements for the system. The orbital separation, radii and masses of the stellar components are given in absolute units based on Popper's spectroscopic masses. The light curves exhibit small distortions in the maxima light levels which vary with phase. The system is composed of two well-detached, main sequence stars with the primary a G2 star and the secondary an early K star.

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# A PHOTOMETRIC STUDY OF THE ECLIPSING BINARY UV PISCIUM

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A Thesis

Presented to the

Faculty of

San Diego State University

---

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in

Astronomy

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by

Frank Allan Greenwood, Jr.

Spring 1981

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Approved by:

Burt Nelson _______________ 21 APRIL 1981
Date

F. L. Talbert _______________

Carl E. Oliver _______________

## ABSTRACT

The eclipsing binary system UV Piscium, which is a short-period RS Canum Venaticorum-type binary system, was observed at Mt. Laguna Observatory during 1980 using the Stromgren 4-color filter system, and broad and narrow Calcium II K-line filters. A new ephemeris was calculated using only photoelectric times of minima. Four sets of orbital solutions were obtained using the Nelson-Davis-Etzel model giving reliable geometric elements for the system. The orbital separation, radii and masses of the stellar components are given in absolute units based on Popper's spectroscopic masses. The light curves exhibit small distortions in the maxima light levels which vary with phase. The system is composed of two well-detached, main sequence stars with the primary a G2 star and the secondary an early K star.

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# Chapter 1

# INTRODUCTION

This study was undertaken in order to add to the growing accumulation of observational data on the RS Canum Venaticorum type eclipsing binary systems. This class of binaries has only in the last decade become recognized as a distinct and separate set of binary systems with its own distinct set of physical properties. Many of the systems identified as such have very sparse accumulations of data, particularly in the photometric area of observation.

## RS Canum Venaticorum Binaries

The RS Canum Venaticorum binaries have been superficially referred to as a subset of Algol-like eclipsing binaries but with some unusual properties which differentiate them from normal Algols (Morgan and Eggleton 1979`. They were specifically defined in a review paper by Hall (1976) based on their observed properties and physical characteristics. To be considered a member, a binary system must have an orbital period between one day and two weeks, a hotter component of spectral type F or G with luminosity class V or IV, and H and K emission in the spectrum outside eclipse. Hall listed 24 systems which met these criteria.

There are at least 13 properties characteristic of the RS Canum Venaticorum binaries, although no one system necessarily exhibits all of them. (1) The H and K emission is from the cooler star (or both stars). (2) The cooler star is around a spectral-luminosity class of K0 IV. (3) H$\alpha$ emission is seen outside of eclipse. (4) A wave-like distortion is present in the light curve outside of eclipse. (5) This wave migrates toward decreasing phase. (6) Additional irregular variations not due to the wave are present in the light curve. (7) One or both components has an ultraviolet excess. (8) One or both components has an infrared excess. (9) Strong centimeter radio emission has been observed in some systems. (10) Very large and irregular changes in the orbital period have been observed which cannot be explained by apsidal motion or a third orbiting body. (11) Some period variations can be correlated with the migrating wave. (12) Most systems have a mass ratio near unity. (13) Both components are detached from their respective Roche lobes.

The most conspicuous of these properties and the one which has attracted the most attention is the distortion wave in the light curve. The wave is typically a persistent, nearly sinusoidal wave which distorts the light curve both inside and outside of eclipse and renders the two maxima unequal in brightness. The wave has a period nearly equal to the system orbital period, but migrates slowly toward decreasing orbital phase. Oliver (1974) was the first to point out that these waves and their migration seem to be common to the RS Canum Venaticorum binaries in general. The migration periods have been found to range from 5 to 75 years, and the wave amplitude also fluctuates in cycles with time scales of decades (Hall 1976). The wave can be attributed to the cooler star (Biermann and Hall 1976), and the migration of it can account for the variable depth of the primary minimum and the variable displacement of the secondary minimum.

Several different explanations have been advanced to explain these distortions. One was suggested by Catalano and Rodono (1974) in which the precession of a ring or disk of circumstellar matter tilted with respect to the orbital plane produces the distortion wave. A second was expanded on by Popper (1977) which would account for the distortion by suggesting one of the stellar components is pulsating.

The third explanation, the star spot hypothesis, was actually the first one proposed (Kron 1947) and has regained prominence recently (Hall 1972; Eaton and Hall 1979). This concept has an advantage in that it organizes the stellar surface activity analogously to that observed on the Sun but on a greater scale. The concept of an active chromosphere also provides a possible explanation of many of the other observed properties of these systems including the Hα emission, H and K emission, and period changes.

In addition to the 24 systems originally listed by Hall (1976) as RS Canum Venaticorum type binaries, to which additional systems have since been added, Hall also listed two subgroups which would be classified as RS Canum Venaticorum type systems except for their periods, which fall outside of the defined range. These are the long-period and short-period groups. These systems exhibit many or all of the other characteristics common to the actual RS Canum Venaticorum binaries. Hall (1976) specifically defines the short-period group as non-contact binaries with periods less than one day in which the hotter component is of spectral-luminosity class F-G V-IV, and H and K emission is displayed in one or both components. Hall listed six systems in this group of which UV Piscium was one.

## Historical Background on UV Piscium

UV Piscium is a ninth magnitude eclipsing binary star system with a period of 0.86 days. This system was selected as having a period and observing season which would allow complete coverage of the light curve with the 41-cm Boller and Chivens telescope operated by San Diego State University at Mount Laguna Observatory during the Fall of 1980.

The variability of UV Piscium was first discovered in 1957 at the Remeis-Bamberg Observatory where it was designated BV 149. The first light curve was published by Huth (1959) based on 348 photographic plates. Huth gave a maximum light magnitude of 9.6 with a range of 0.9 and 0.2 magnitudes for the primary and secondary minima respectively, but no orbital solution was attempted. The period derived from his minima was 0.861046 days.

Subsequent light curves were investigated by Carr (1967) and Oliver (1974). Carr's light curve observed in 1966 was the first to be obtained by photoelectric means. He concluded the three light curves obtained using UBV filters resembled an Algol type system. The light curves contained an asymmetry in the light levels of 0.05 magnitudes in the two maxima at phases 0.25 and 0.75. Carr's solution of the light curves indicated that the eclipses were complete, that the primary eclipse was a transit and that the secondary was an occultation. His solution was obtained by using the procedures of Russell and Merrill (1952).

Oliver's light curve of UV Piscium was obtained in 1968 and 1969 in conjunction with observation of twenty eclipsing binary systems which exhibit Calcium II emission. Unfortunately his light curve was incomplete with no observations of the maxima between phases 0.15 and 0.40. In addition, his solution was obtained using the nomographs due to Merrill (1950) and was at odds with that of Carr. Oliver concluded that the eclipses were partial and that the primary star had the smaller radius. This conclusion was reached despite the fact that a visual inspection of his secondary eclipse observations indicates a flat bottom which would suggest a total eclipse due to an occultation.

Sadik (1979) published a comprehensive analysis of UV Piscium based on UBV photometry observed in 1977. He was able to obtain absolute elements for the system using Popper's spectroscopic elements (1976). His solution was consistent with Carr's in that the primary eclipse was due to a transit and the secondary due to an occultation. The primary was the larger of the two stars. Sadik assumed the primary to be a G2 V and the secondary a K0 IV.

The assumption of spectral types used by Sadik was apparently based on those suggested by Oliver (1974) which were derived from a color analysis of the system and the relative sizes of the two components obtained by Oliver in his study. The assumption of a subgiant class for the secondary when this star has a smaller radius than the primary is in conflict with the main sequence classification of the primary. According to the stellar radii listed in Landolt-Bornstein (Voigt 1965), a KO IV star has a typical radius of 3.0 solar radii, and a KO V star has a radius of only 0.85 solar radii. Sadik gives the radius of the secondary star as 0.929 solar radii, which would indicate it should be considered a main sequence star. Popper (1976) classified the primary as a G2 and gives a (B-V) value for the secondary of +0.91 without any luminosity classification. This (B-V) value is that derived by Oliver.

Sadik also detected an asymmetry in the light curve. He concluded that the asymmetry could be due to either a dark spot or a hot spot on the secondary. However, a hot spot was determined to more adequately explain the color dependency of the light curve asymmetry.

Based on these previous studies of UV Piscium and the current work on RS Canum Venaticorum systems, an observational program was devised using the 4-color ubvy filter system. The object of the program was to obtain three complete light curves in each filter for the months of September, October and November, 1980. From these observations a new solution to the light curve could be obtained, as well as an examination for short term asymmetrical variations in the light curves from month to month. Better information for photometric classification of the luminosity classes of the stars was also sought.

Observations were also planned using broad and narrow Calcium II K-line filters in an effort to detect any phase related emission effects.

## Chapter 2

## OBSERVATIONAL PROGRAM

The photometric observations of UV Piscium were obtained on 12 nights between 6 September and 14 December, 1980 U.T. Two additional nights of ubvy standard star observations were also obtained in this same period. These additional observations were used to determine transformation coefficients in order to tie the comparison star into the standard system.

All of the observations were obtained with the 41-cm Boller and Chivens Cassegrain reflector telescope at the Mount Laguna Observatory operated by the San Diego State University Department of Astronomy. The photometric system consisted of a single channel photometer, incorporating a dry ice cooled 1P21 photomultiplier. A 37 arc second diameter diaphragm was used on all observations except for the first night when a 72 arc second diameter diaphragm was used. This night was the first of the two standard star observation nights. The filter system consisted of the 4-color uvby interference filter system of Stromgren (1966) and a broad and narrow band filter set centered on the Calcium II K-line.

The photomultiplier signal was monitored by a

Weibrecht charge integration amplifier. Integration times of 10 seconds were used on the standard stars, but times of 40 to 50 seconds depending on the filter used were required for the program and comparison stars in order to insure good photon statistics and to keep the gain settings in a range where linearity between settings was maintained. Data recording was obtained with an automated digital system consisting of a digital voltmeter accurate to four significant digits, a digital clock set by WWV radio time signals to the nearest second, an internal timer, various code switches, a parallel to serial data converter and a teletype equipped with a paper tape punch unit.

Following completion of the observing program, the filters were measured on a Perkins-Elmer double beam spectrophotometer (Coleman 124) belonging to the San Diego State University Department of Natural Science. The mean wave-lengths of the u, v, b and y filters were found to be 3440, 4120, 4712, and 5512 Å with bandwidths of 387, 177, 172 and 232 Å respectively. These values proved to be a relatively close match to the filter system used by Crawford and Barnes (1970) to define the standard system for uvby photometry. Their mean wavelengths were 3500, 4100, 4700 and 5480 Å with bandwidths of 380, 200, 200 and 200 Å respectively.

The broad K-line filter had a mean wavelength of 3031 Å and a bandwidth of 87 Å. The narrow band K-line filter was found to have a mean wavelength at 3940 Å, but it also had a secondary transmission peak of nearly equal strength at 4000 Å. The narrow band filter also had a bandwidth of 96 Å, which exceeds that of the broad band filter. Hence, any results obtained from the K-line filters were held to be questionable at best. In addition, the K-line filters were only used during September and October, 1980, after which they were not used in order to obtain greater coverage of the light curve with the 4-color uvby filters.

The technique of differential photometry was employed for the program star. The observations were normally made repeatedly in the order sky, variable, comparison with one deflection in each of the six filters in the order y, b, v, u, broad K-line, narrow K-line. Occasionally an additional reading for a filter, particularly the u filter, was obtained to monitor for any large scale atmospheric variations such as cirrus clouds. Care was taken to insure the program star was bracketed between sky and comparison observations. Observations of the check star were interspersed with the comparison star each night in order to monitor for any variability of the comparison star. No variability was detected, which is in agreement with Sadik (1979) who used the same comparison and check stars. Table 1 summarizes the catalog data on UV Piscium, and the comparison and check stars. Spectral types and magnitude information are from the H. D. catalog for comparison purposes.

Table 1

Catalog Data

| | UV Piscium | Comparison | Check |
|---|---|---|---|
| HD | 7700 | 7997 | 7918 |
| BD | $+6^{\circ}$ 189 | $+6^{\circ}$ 197 | $+6^{\circ}$ 195 |
| GC | --- | 1596 | 1585 |
| R.A. (1900) | $1^{h}\ 11^{m}\!.7$ | $1^{h}\ 14^{m}\!.6$ | $1^{h}\ 13^{m}\!.7$ |
| Dec. (1900) | $+6^{\circ}\ 16'$ | $+6^{\circ}\ 58'$ | $+6^{\circ}\ 54'$ |
| Ptm | $9^{m}\!.1$ | $8^{m}\!.7$ | $7^{m}\!.9$ |
| Ptg | $9^{m}\!.9$ | $9^{m}\!.5$ | $8^{m}\!.7$ |
| Spectral Type | G5 | G5 | G5 |

The observational program was planned in order to obtain complete coverage of the light curve during each month of the observing season. However, due to limitations on the number of scheduled nights available and cancelled nights because of inclement weather, total monthly coverage was not achieved, but a single light curve giving complete coverage of all phases was obtained. The K-line filters were discontinued after the first two months in order to increase the number of individual uvby filter readings. This was necessitated mainly because of the long integration times required for each filter which severely limited the number of individual filter readings obtainable each night.

Four-color uvby standard stars were observed on two nights, one at the start of the observing season, 6 September, 1980 U.T., and one near the end, 11 December, 1980 U.T. On the first night, five standard stars were observed repeatedly throughout the night in the order standard, sky, standard followed by a comparison, sky sequence which was then repeated for the next standard. The filters were observed in the sequence ybvu with one observation in each filter. No averaging of the observations was performed, and each observation was treated separately. On the second night of standard observation, 13 standard stars were used and observed in the sequence sky, standard, sky followed by sky, comparison, sky sequences. The order of filter observation for the standards was yybbvvuu and the two deflections in each filter were averaged during reduction of the data.

Reduction of the observational data was performed on the San Diego State University Computer Center's IBM 1130 computer. The punched paper tape from each night's observations was converted to computer cards. These were then used as the input to the Department of Astronomy's differential photometry reduction program FOTOM. For each observation of the variable star in each filter, the program computed the Heliocentric Julian Date, the magnitude difference in the sense of variable star minus comparison star, and the orbital phase. The data consisted of 188 observations in the y filter, 187 in the b, 188 in the v and 188 in the u. In addition, 83 observations for the variable were obtained in both the broad and narrow K-line filters. The K-line observations were not used to form delta magnitudes but were used to form an index in the sense of narrow filter minus broad filter. A similar index was formed for observations taken of the comparison star.

The data for the four uvby filters are tabulated in Appendix A and includes the Heliocentric Julian Date, the phase and the magnitude difference. The phase for each observation was calculated from the equation, $PHASE = (H.J.D.-(E_o+EP))/P$, where H.J.D. is the Heliocentric Julian Date of the observation, P is the period, and E is the number of cycles which have elapsed from some base epoch, $E_o$. The ephemeris given by Huth (1959) was used with $E_o = 2428038.555$, and $P = 0.861046$ days.

FOTOM was also used to calculate color index differences of $\Delta(b-y)$ and $\Delta(u-b)$, again in the sense of (b-y) for the variable star minus the (b-y) value for the comparison star. Both of the indexes were calculated directly by subtracting the extinction corrected value of y from that of b and similarly for (u-b). It should be noted that these are not transformed color indexes on the standard system. After completion of the observing runs, the author decided not to transform the raw magnitudes to the standard system because the large integration times required often resulted in up to a five minute period between the start of a y filter observation and the ending of a u filter observation for one sequence of the variable. This fact in conjunction with the 10 to 15 minutes or more required between each variable star sequence would have required extensive interpolation in order to calculate the appropriate standard indices. Such interpolation when considered with the short period of this binary could begin to cover significant portions of the orbital phase, particularly in the phase portions during primary and secondary eclipse. Any values of the indices obtained during these phase portions would be of questionable value at best. Even the color indices formed directly from the filter magnitudes should be used with this stipulation that the values may be erroneous in the areas of the primary and secondary eclipse.

Since observations of uvby standard stars had been made previous to this decision, the author still elected to transform the comparison star to the standard system. The input for the transformation was the raw magnitudes of each filter and the mean air mass for each set of individual observations. These values were computed by the FOTOM reduction programs for each night's observations.

A Fortran program was then written based on the method suggested by Crawford and Barnes (1970). This program was run on the San Diego State University Computer Center's IBM 360 computer. After the program calculated the observed indices, $(b-y)'$, $m_1'$, and $c_1'$, for the uvby system from the raw magnitudes, a set of initial extinction coefficients, K, $K_1$, $K_2$, and $K_3$, was used to calculate the extinction corrected values using the equations

$$y_{obs} = y' - KX$$

$$(b-y)_{obs} = (b-y)' - K_1X$$

$$m_1(obs) = m_1' - K_2X$$

$$c_1(obs) = c_1' - K_3X$$

where X is the mean air mass. These values were then used along with the respective values on the standard system for that star in a least square solution to determine the transformation coefficients from the equations

$$V = A + B(b-y) + y_{obs}$$

$$(b-y) = C + D(b-y)_{obs}$$

$$m_1 = E + Fm_1(obs) + J(b-y)$$

$$c_1 = G + Hc_1(obs) + I(b-y)$$

New extinction coefficients were then determined using these transformation coefficients, and the calculations were repeated until convergence of all of the coefficients was obtained.

An observational error was inadvertently made on the night of 11 December 1980. The standards were all observed at or near the zenith and did not cover a very large range of air mass. As a result, the extinction coefficients were not well determined and, hence, accurate transformation coefficients could not be calculated.

The values obtained for the transformation coefficients for the night of 6 September 1980, are listed in Table 2 along with the mean values obtained for the comparison star based on these coefficients.

Table 2

Comparison Star Transformation Values

| | | | |
|---|---|---|---|
| A | -1.6412 | I | -0.3587 |
| B | -0.0824 | K | 0.2432 |
| C | 0.9336 | $K_1$ | 0.0790 |
| D | 1.1065 | $K_2$ | 0.0789 |
| E | -0.5807 | $K_3$ | 0.1854 |
| F | 1.0789 | V (S.D.) | 8.49 (0.06) |
| J | -0.1717 | (b-y) (S.D.) | 0.61 (0.06) |
| G | 0.3490 | $m_1$ (S.D.) | 0.45 (0.08) |
| H | 0.8135 | $c_1$ (S.D.) | 0.68 (0.04) |

# Chapter 3

## EPHEMERIS CORRECTION

Two primary eclipses were observed in their entirety on two of the observing nights for UV Piscium. The phase of each observation was obtained from the ephemeris given by Huth (1959) as was discussed in the last chapter. When the magnitude difference versus phase was plotted as in Figure 3, it was immediately apparent that the times of primary and secondary minimum were shifted to the right and were not at the phase points 0.0 and 0.5 respectively as they should have been. Such a shift can normally be attributed to one of two causes, either a period change or an incorrect ephemeris.

The ephemeris for an eclipsing binary is an equation of the form

$$\text{H.J.D. (Pri. Min.)} = E_o + EP$$

which predicts the Heliocentric Julian Date, H.J.D., of the primary minimum from a base date, $E_o$, given the number of cycles, E, elapsed from $E_o$ and the period, P, of the orbit. If the ephemeris is correct, the phase of the times of primary minimum should fall at 0.0.

The ephemeris of Huth (1959)

$$\text{H.J.D. (Pri. Min.)} = 2428038.555 + 0.861046E$$

was determined from photographic determinations of eclipse timings which do not contain the greater accuracy of today's photoelectric observations. Using the ephemeris, one can calculate a predicted time of minimum, C, and with the corresponding observed time of minimum, O, can obtain the difference, (O-C), which can be plotted against either E or H.J.D. Such a plot can provide an indication of any changes which have occurred in the period of an eclipsing binary or the accuracy of the determined period. If the ephemeris is accurate with no period changes having occurred, the (O-C) plots should all fall along a horizontal line on the graph. If a period change occurs, it will appear as a sudden change in the slope of the (O-C) trend line, upward sloping for a period increase and downward sloping for a decrease. If the change in period is gradual, it will appear as a continually changing slope either up or down.

If, however, no period change has occurred, but the period was incorrectly determined to begin with, then the trend line will have a constant slope across the graph either upward or downward. An upward sloping trend line would indicate the original period was calculated too short. This appears to be the case for UV Piscium.

A search of the literature available through the San Diego State University Library and its interlibrary loan service yielded 83 timings of the primary minima plus the two from this current observational program. Seven of the photographic timings had (O-C) values as large as one-half day in magnitude. Such large values, which were on the order of half the orbital period, were considered as being due to possible observational errors and, hence, were not included in subsequent calculations. The remaining timings are plotted as (O-C)'s versus H.J.D. in Figure 1 based on the Huth ephemeris. The photographic and visual timings along with their (O-C)'s and Huth epoch numbers are listed in Appendix B. The photometric values are listed in Table 3.

Table 3

Photometric Minima of UV Piscium

| H.J.D. (2400000+) | (O-C) Huth | (O-C) This Study | Reference |
|---|---|---|---|
| 39388.87432 | +0.00984 | -0.00070 | Carr |
| 39406.95616 | +0.01082 | +0.00024 | Carr |
| 39407.81725 | +0.01087 | +0.00029 | Carr |
| 40156.92849 | +0.01209 | +0.00002 | Oliver |
| 40466.90642 | +0.01346 | +0.00077 | Oliver |
| 43053.49255 | +0.01740 | -0.00042 | Aslan |
| 43400.49515 | +0.01846 | -0.00004 | Aslan |
| 43406.52250 | +0.01849 | -0.00003 | Aslan |
| 43425.46595 | +0.01893 | +0.00037 | Aslan |
| 43463.34911 | +0.01607 | -0.00257 | Sadik |
| 43785.38345 | +0.01920 | -0.00007 | Aslan |
| 44519.85917 | +0.02268 | +0.00195 | This study |
| 44526.74563 | +0.02078 | +0.00003 | This study |

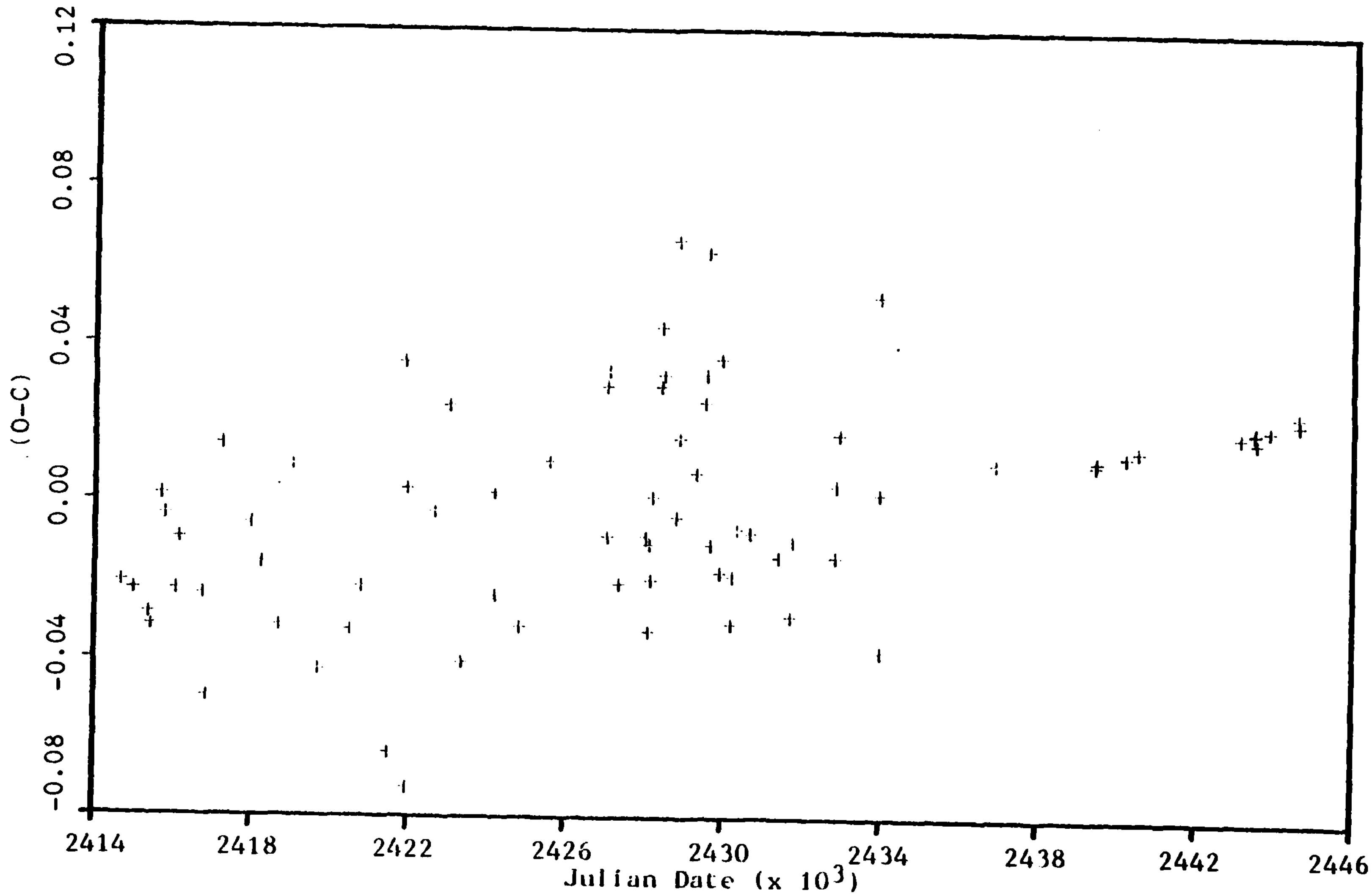


Figure 1. (O-C) Diagram of Huth Ephemeris

The timings of primary minimum for this study as well as those of Sadik (1979) and Oliver (1974) were evaluated using a program originally written by Brian Johnson for use on the IBM 1130 computer. This program solved for the minimum by reflection of the light curve about an initial estimate of the time of minimum using the method of least squares. The program was modified slightly by this author, and the values obtained for the minima observed by Sadik were checked against his values and agreed to within 0.0003 days.

An inspection of the plot reveals a large scatter in the photographic and visual (O-C) values especially when compared to the 13 photometric values which are those points after H.J.D. 2439000.0. There are no abrupt or gradual changes in period apparent from the plot, but there is a trend from lower left to upper right which is readily discernible from the photometric data points. The Huth ephemeris was determined using observations between H.J.D. 2427000 and 2435000. Due to the large scatter in this range, it is apparent that the period could have easily been calculated in error, and it is only when the very early observations and the more recent ones are included that the difference in periods becomes apparent. Aslan (1978) investigated this period difference using photometric timings obtained in 1976, 1977 and 1978 along with the timings of Huth. He failed to obtain the very early timings and attributed the differences between the Huth data and the recent observations to a period change. Again it is only in the presence of the very early observations that one realizes that the difference lies in the calculation of the original period. Carr (1967) attempted to rectify this difference, but he only had his three photometric timings available plus six photographic and visual timings from Strohmeier and Krigge (1960). He calculated an ephemeris using this data of H.J.D. = 2433155.754 + 0.861047E. Aslan determined that based on his photometric observations an appropriate ephemeris would be H.J.D. = 2428038.034 + 0.8610482E. It should be noted that both of these periods are longer than that of Huth as one would expect from the (O-C) diagram.

Based on the more complete data available, several new ephemerides were calculated by a least square fit to the equation H.J.D. = $E_o$ + PE using the epoch numbers, E, of Huth. The first ephemeris, calculated using only the photographic and visual data, was

$$\text{H.J.D.} = 2428038.55474 + 0.8610474E$$

One should note the very slight difference in the sixth decimal place of the period between this and the Huth period. If Huth had had the earlier timings available, his ephemeris would have likely been closer to this value.

A second ephemeris was calculated using all of the timings available which gave

$$H.J.D. = 2428038.55354 + 0.8610472E$$

Finally, a third ephemeris was calculated based only on the photoelectric data which was

$$H.J.D. = 2428038.54259 + 0.8610477E$$

All three of the periods differ only in the seventh decimal place, and they all fall between the two periods determined by Carr and Aslan.

A new ephemeris was then calculated using only the 13 photometric times of minimum and assigning new epoch numbers counted from a base date which was bracketed by the photometric observations. The new ephemeris is

$$H.J.D. = 2441815.30636 + 0.8610477E$$

The epoch numbers and the (O-C) values from this equation are listed in Table 3, and the (O-C)'s are plotted against H.J.D. in Figure 2.

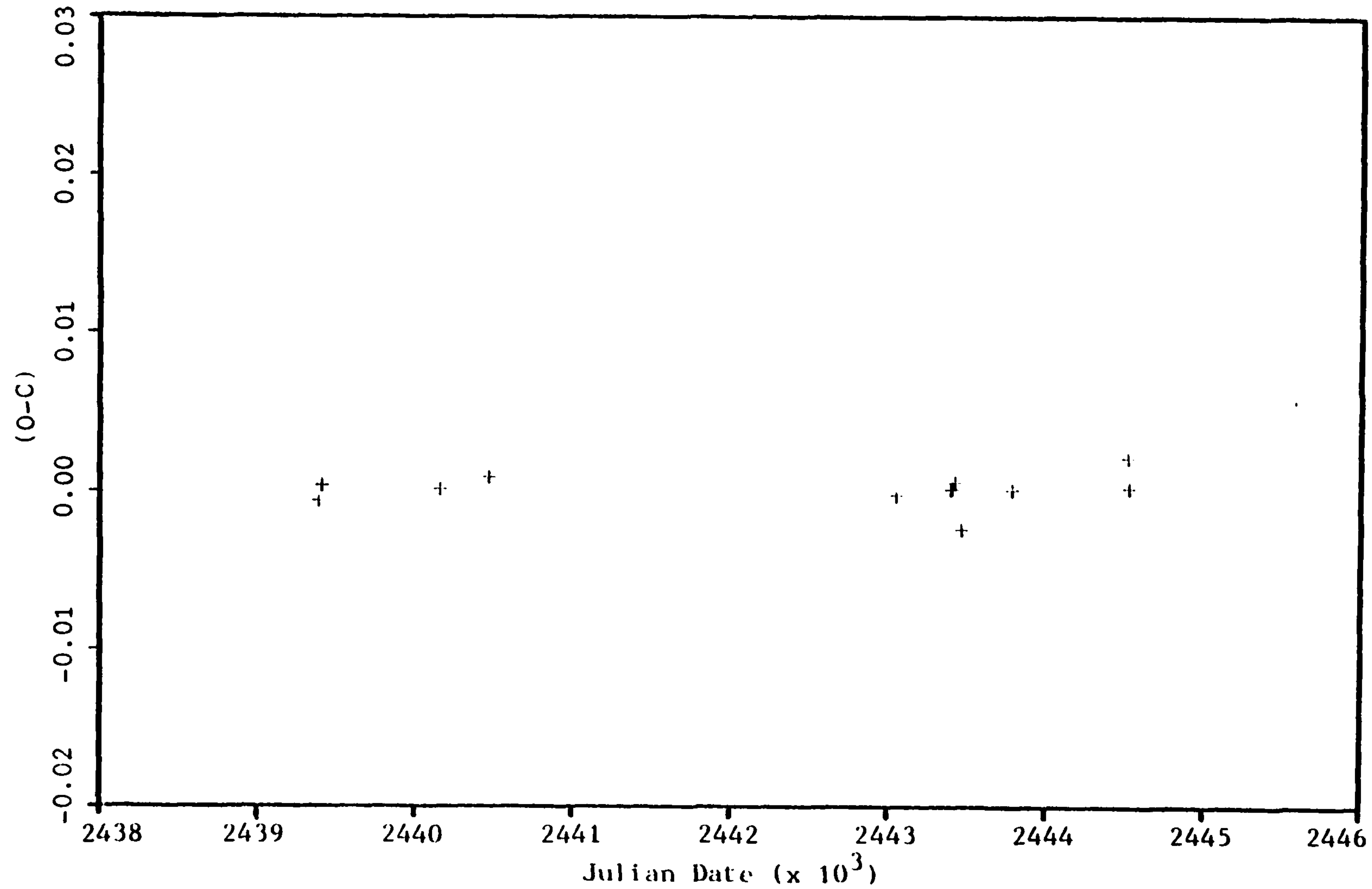


Figure 2. (O-C) Diagram of New Photometric Ephemeris

# Chapter 4

## LIGHT CURVES AND THEIR SOLUTION

Four separate and complete light curves were obtained for UV Piscium, one in each of the ubvy filters. A solution for each light curve was obtained using a synthetic light curve solution method from which an adopted solution was derived for the system.

### Light Curves

Each of the light curves was plotted on a large scale as magnitude difference versus phase. These plots are reproduced in Figures 3, 4, 5, and 6 on a smaller scale, one for each filter. A number of initial conclusions can be drawn from an inspection of the light curves.

The orbit of the system is very close to being circular, which can be seen from the phase displacement of the secondary minimum relative to the primary, just one-half of the total cycle. If the phase error was removed as was discussed in Chapter 3, the two minima would occur at phases of 0.5 and 0.0 respectively.

The shape of the eclipse bottoms can reveal the type of eclipse taking place. The primary is deep and sharp indicating it is due to either a partial eclipse or a transit. It is also much deeper than the secondary

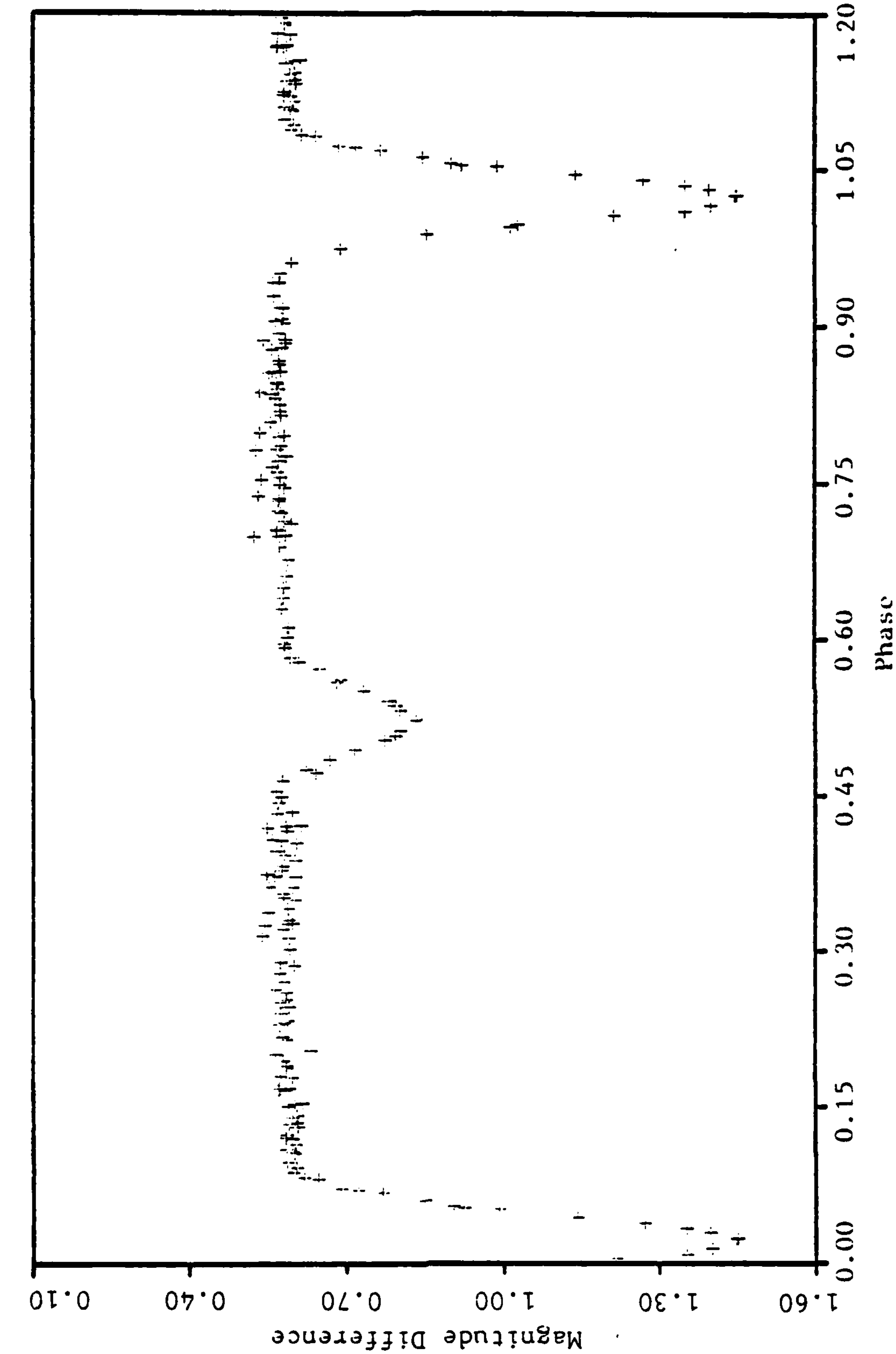


Figure 3. Light Curve, y Filter

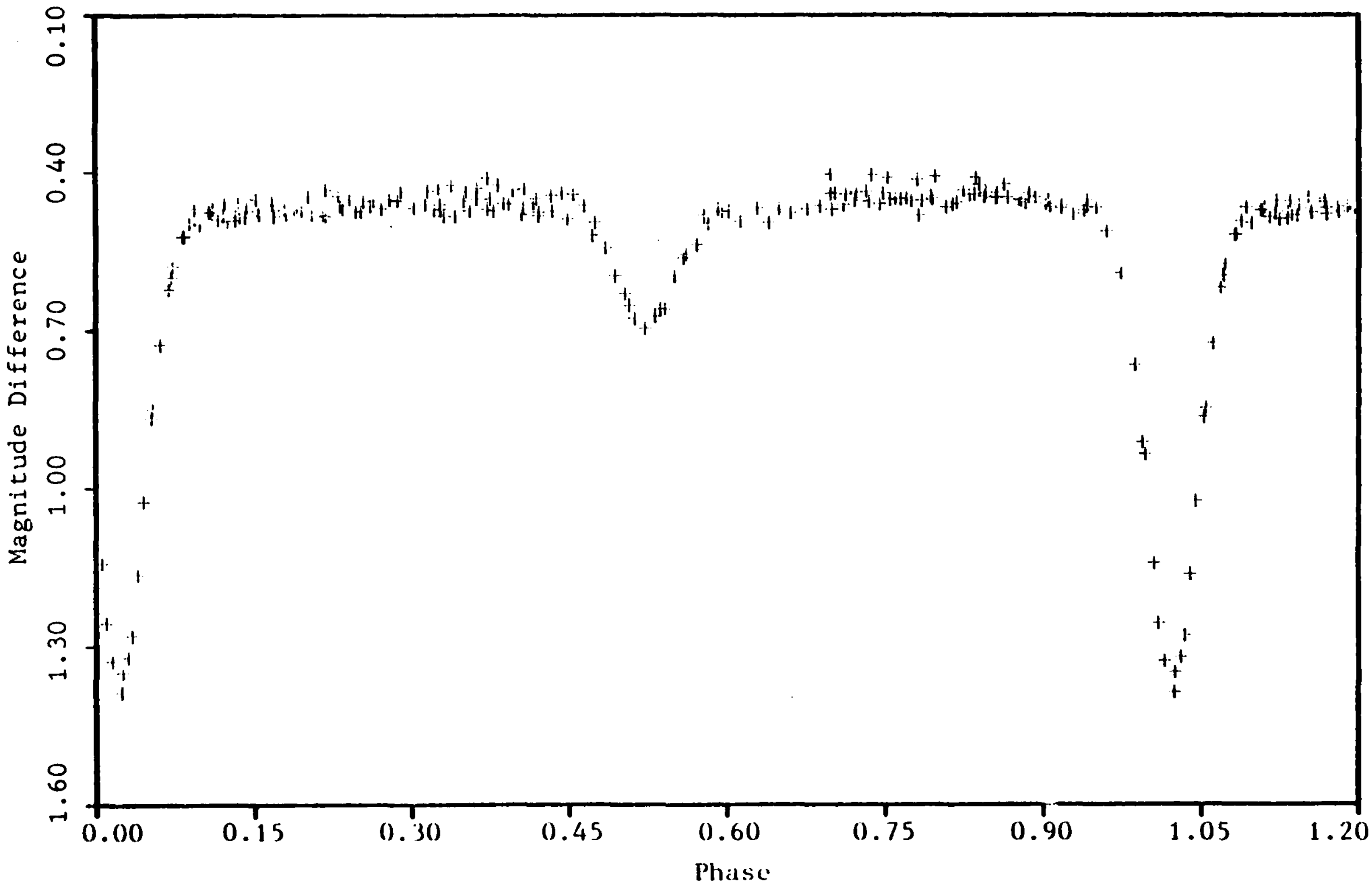


Figure 4. Light Curve, b Filter

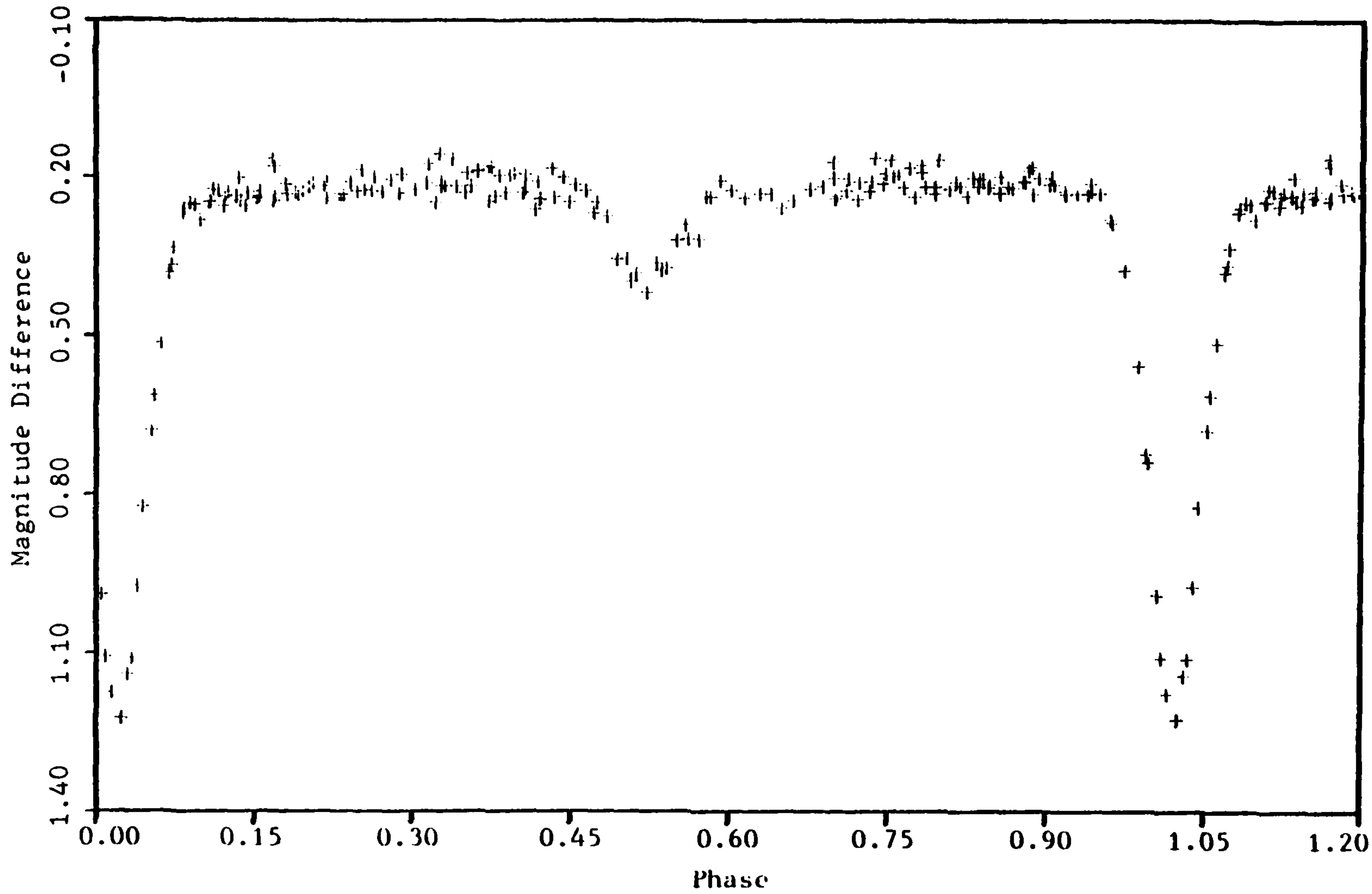


Figure 5. Light Curve, v Filter

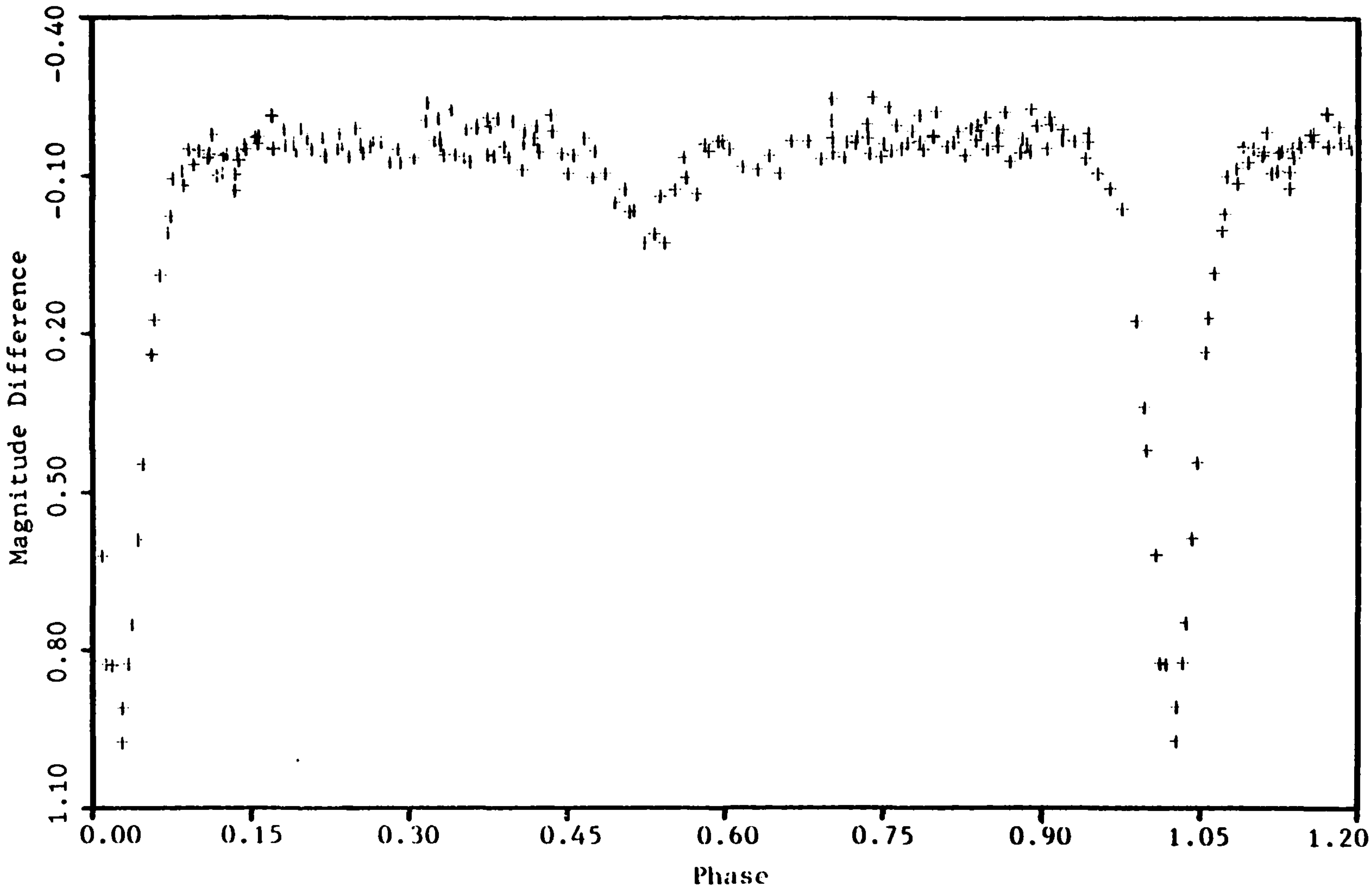


Figure 6. Light Curve, u Filter

eclipse, indicating the primary star is probably much hotter than the secondary. The primary eclipse also becomes progressively deeper going from the y filter toward shorter wavelengths in the u filter. The depths range from about 0.86 magnitude to about 1.1. Just the opposite effect is observed in the secondary eclipse, again indicating the large temperature difference. Here the depths range from about 0.25 magnitude in the y filter to about 0.17 in the u filter. These depths of the eclipses are in excellent agreement with those obtained by Sadik, Oliver and Carr. The shape of the secondary eclipse is not as sharply defined at minimum as the primary is. The scarcity of observations in each curve at the minimum point makes it difficult to definitely conclude if the eclipse is a partial or complete eclipse. However, there does seem to be an indication of a flat bottom in the u and v filters. Such a flat bottom would indicate an occultation which would suggest, along with the inspection of the primary eclipse, that the primary star is the larger one in the system. This would also indicate that the inclination of the orbit is very close to 90 degrees. The duration of an eclipse is about two and one-half hours.

The eclipses appear to be well defined and symmetrical about the minimum except for the secondary in the u filter, which can be attributed mostly to scatter in the observations. Both the ingress and egress from the eclipse are relatively well defined. This would indicate any oblateness in the two stars is relatively small. Hence, there is little tidal distortion present even with the small orbit and close proximity of the stars. Except for a series of observations in the phase ranges from 0.3 to 0.5 and 0.7 to 0.9, which will be discussed later, both maxima are well defined, relatively flat and of the same magnitude in each. It appears that the type of assymmetry noted by Carr and Sadik is not present in these observations. The observational scatter is on the order of 0.3-0.4 magnitude but increases to about 0.6-0.8 magnitude in the u filter. Any reflection effect present is relatively small.

Figures 7 and 8 show the color curves $\Delta(b-y)$ and $\Delta(u-b)$ obtained from these observations. The $\Delta(b-y)$ curve shows almost no difference in or out of eclipse. There is a slight reddening of the color during the primary eclipse as would be expected, but it is not pronounced. The $\Delta(u-b)$ color curve shows a pronounced difference during eclipse, and provides a definite indication of the spectral difference in the two stars, with the secondary being the cooler star.

Figures 9 and 10 are the Calcium II K-line plots for UV Piscium and the comparison star respectively. As was noted in Chapter 2, the information obtainable

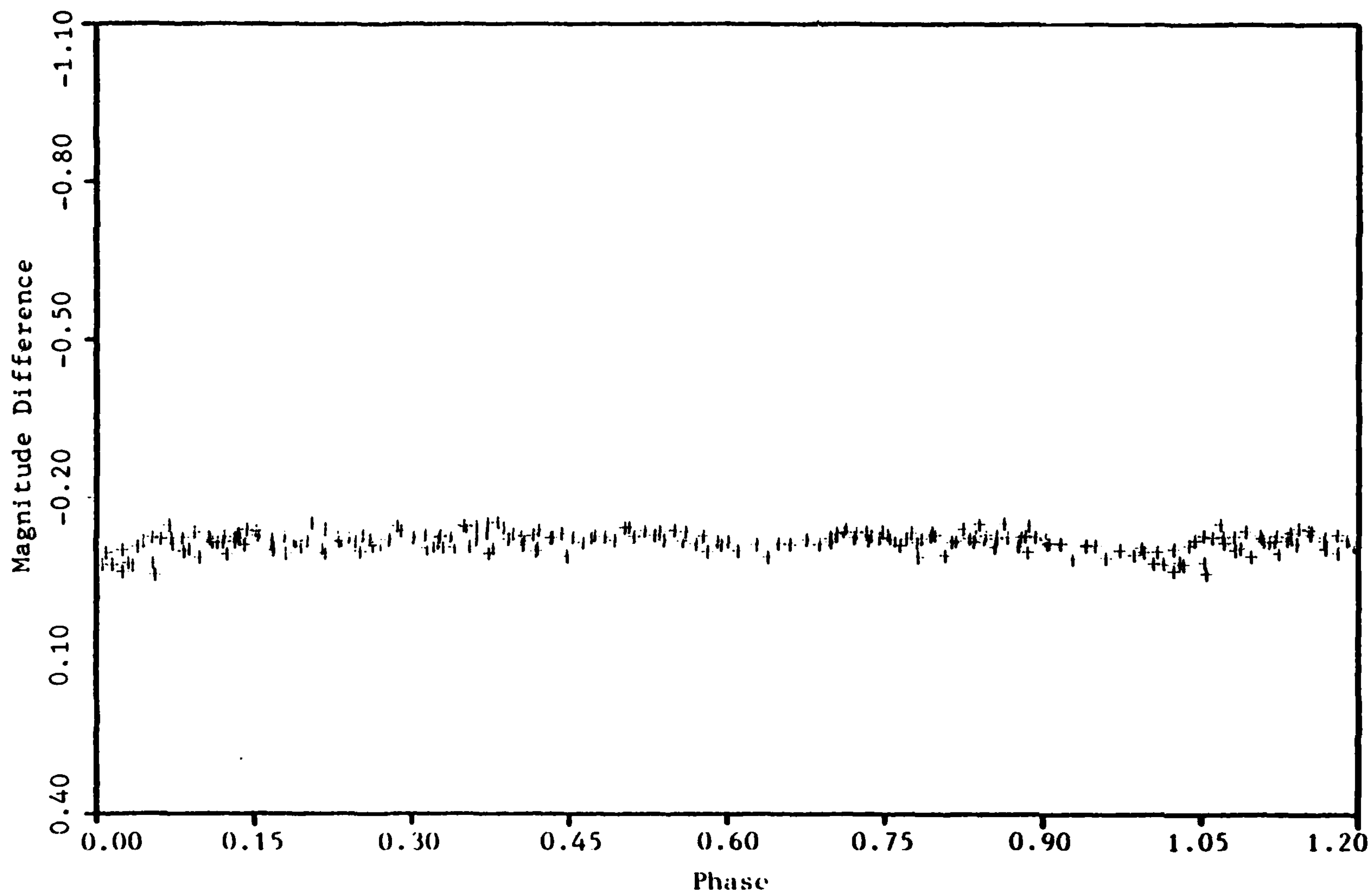


Figure 7. Δ(b-y) Curve

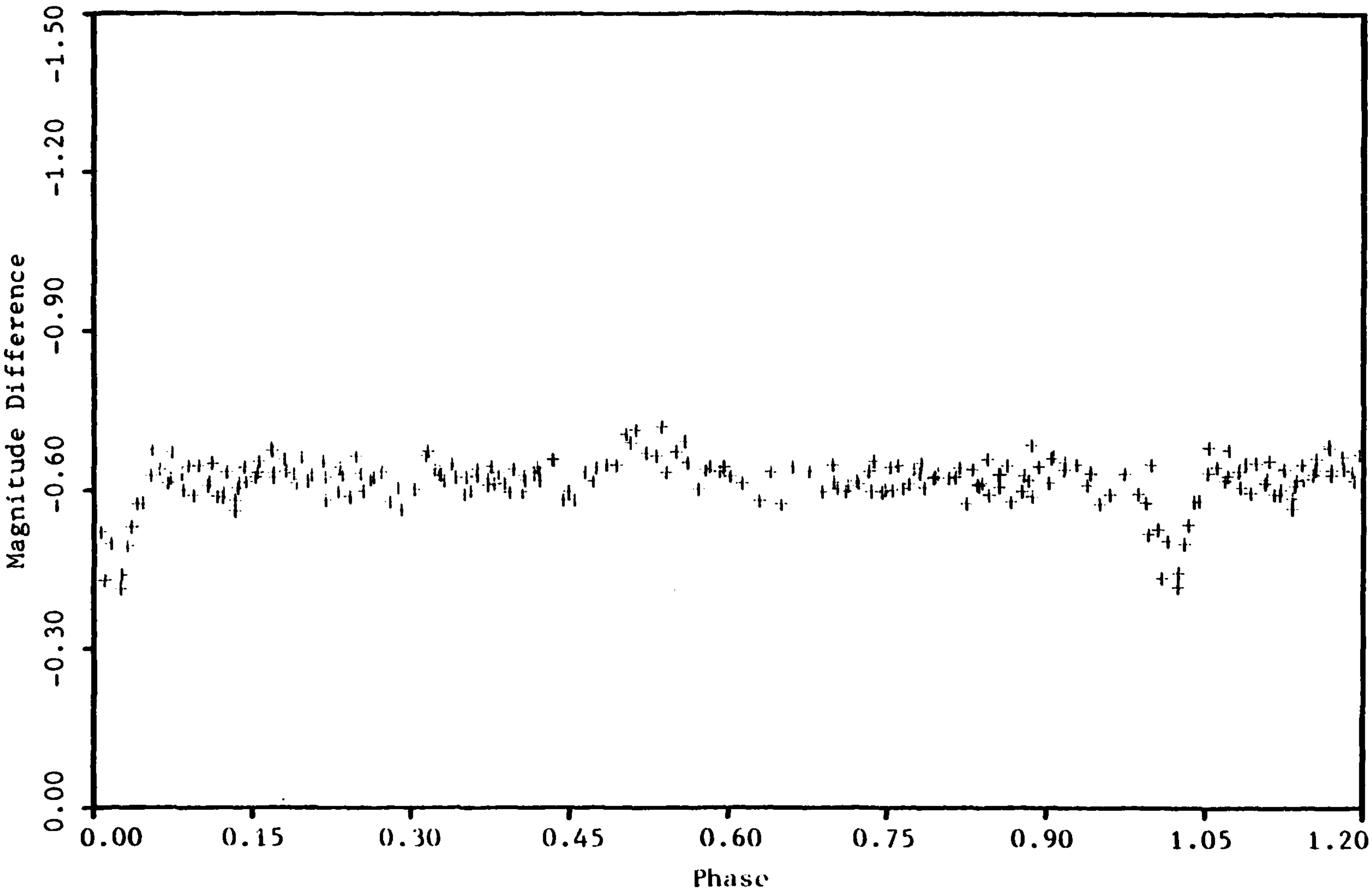


Figure 8. Δ(u-b) Curve

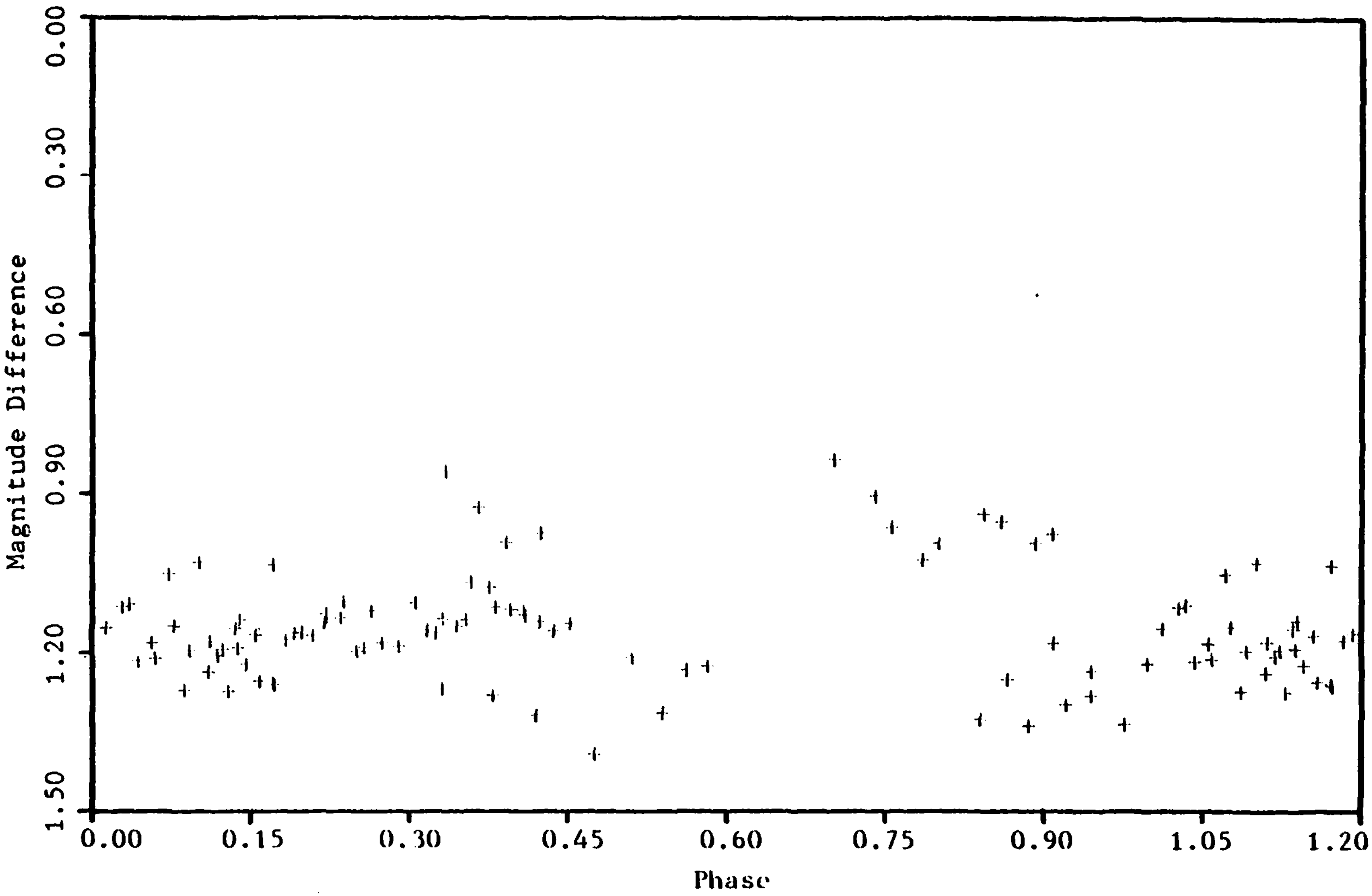


Figure 9. Calcium II K-Line for UV Piscium

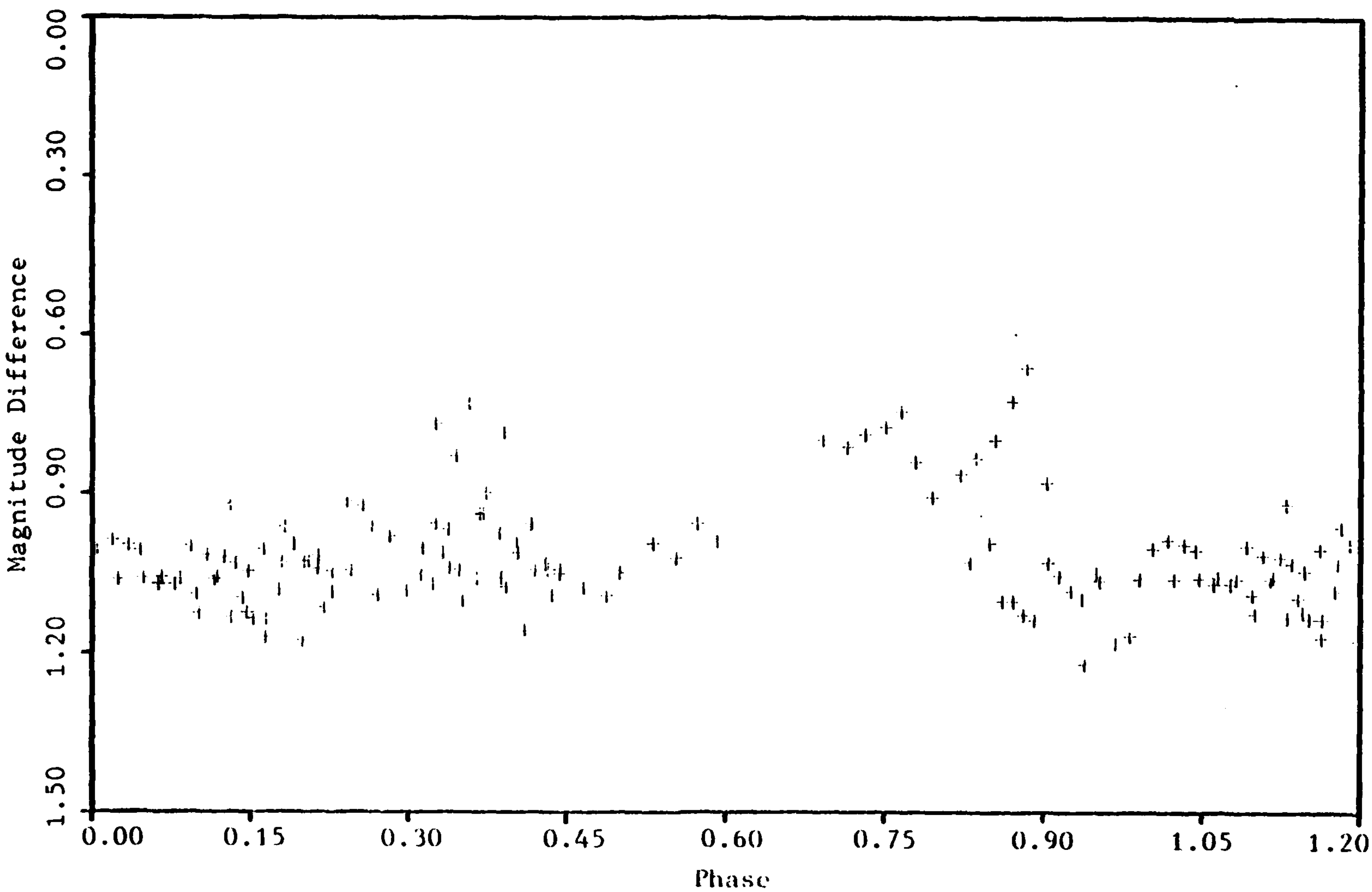


Figure 10. Calcium II K-Line for Comparison

from the K-line is questionable due to filter irregularities. This is born out by the two diagrams. There is a very large amount of scatter, and no trends relative to phase can be discerned. In addition, the data points at phase 0.4 and 0.7-0.8, which fall above the general level of the star points, correspond to the similar sets of points on the comparison star plots. Both respective phase sets were observed on the same nights. The comparison star phase values were assigned by time interpolation between the respective phases of variable observations on each night. Hence, these variations can be attributed to possible atmospheric transmission differences from night to night. A plot of the points by month of observation also revealed no apparent differences.

The most notable aspect of the light curves is the absence of the general asymmetry between the maxima, which was noted previously by Carr and Sadik. However, there is a complication present in each light curve in the maxima between phases 0.30 to 0.45 and 0.70 to 0.80. The scatter in the individual points is greater in these areas than the rest of the maxima. Plots of the data by each month indicated that this scatter is due to vertical shifts of the general level of the maxima from one month to another. The phase region 0.30 to 0.45 was observed on three separate nights, each in a different month, 14 September, 9 October and 4 November, 1980.

The first two nights' observations were at the general level of the maxima, but the observations from 4 November were shifted vertically upward above the average maxima level in all four light curves. Similarly, the phase region from 0.70 to 0.80 was observed on the nights of 11 September, 6 November and 14 December, 1980. Again the observations from November and December were at the general level of the maxima, but the September observations were shifted vertically above the maxima level in all four light curves. Carr also alluded to such vertical shifts in his data when plots for individual nights were made. However, both his and Sadik's observations were made over a short period of time, less than one month, and could not show any shift in the distortions from month to month.

From the $\Delta(b-y)$ values, a mean level for the two maxima was determined. They were -0.119 and -0.120 magnitude for the first and second maxima respectively. The standard deviation for both was 0.014 magnitude. These values excluded the two nights of observations where the distortions were present. The mean $\Delta(b-y)$ level was then determined for the two nights of shifted observations. They were -0.126 and -0.123 magnitude for the first and second maxima respectively. Although both of these means fall within one standard deviation of the mean maximum levels, the fact that all of the observations of these two nights are above the general level is of significant interest. The values indicate that the distortions are probably due to an enhancement of the light levels received from the binary. Such an enhancement could be caused by either an increase in brightness due to a hot spot or to a localized increase in brightness due to a reduction in the surface coverage by dark spots on one or both stars.

The lack of complete coverage of the light curve from month to month precludes any definite conclusion on movement of the distortion in phase along the curve. However, an inspection of the monthly observations of different parts of the light curve relative to the position of the distortions suggested a retrograde movement in phase of the distortion along the light curve. Such a movement toward decreasing phase is a characteristic of the wave distortions in RS Canum Venaticorum type light curves but on a much shorter time scale.

## Solution of the Light Curve

The light curve solutions were obtained using a synthetic solution method. The method is based on the model developed by Nelson and Davis (1972). Corrections and additions to that model were made by Etzel (1975) and incorporated into a computer program EBOP (Eclipsing Binary Orbit Program). Further revisions of the model, now referred to as the Nelson-Davis-Etzel model (NDE), are contained in version 12 of the program which was used in this solution. The program was run on the IBM 360 computer.

The NDE model has been demonstrated by Popper and Etzel (1981) as an excellent model for the analysis of the light curves of well-detached eclipsing binaries. UV Piscium is such a system although some small oblateness of the components due to their close proximity can be expected. The NDE model incorporates the effects of oblateness after that of Binnendijk (1960) for a simple biaxial (rotational) ellipsoid and adds these effects into a simple spherical-limb-darkened model to match the observations. Reflection is treated essentially the same as in the simple, uniformly illuminated hemisphere model given by Binnendijk (1960). The amount of reflection effect is also assumed to be small in the NDE model.

The model parameters used in the solution are listed in Table 4. Initial values for the parameters were selected from those of Sadik (1979). The value of the radius of the primary star, $r_p$, is in terms of the semi-major axis of the orbit. Theoretical values of limb darkening were interpolated from the tables by Grygar, et al., (1972) for each filter, assuming main sequence G2 and K0 stars. Gravity darkening was set

Table 4

Model Parameters

| Symbol | Definition |
| --- | --- |
| $J_s$ | Central Surface Brightness of Secondary ($J_p = 1$) |
| $r_p$ | Equivalent Spherical Radius of Primary |
| k | Ratio of Radii (spherical, $k = r_s/r_p$) |
| $u_p$ | Limb Darkening of Primary |
| $u_s$ | Limb Darkening of Secondary |
| i | Orbital Inclination (Degrees) |
| $e\cos\omega$<br>$e\sin\omega$ | Orbital Eccentricity and Longitude of Periastron |
| $y_p$ | Gravity Darkening of Primary |
| $y_s$ | Gravity Darkening of Secondary |
| $S_p$ | Reflected Light from Primary |
| $S_s$ | Reflected Light from Secondary |
| q | Mass Ratio ($q = M_s/M_p$) |
| t | Tidal Lead/Lag Angle of Stellar Axes |
| $L_3$ | Third (Extra) Light |
| $\Delta\theta$ | Phase Correction for Epoch Error |
| SFACT | Luminosity Scaling Factor |

at zero due to the small oblateness of this system and late-type stars. Unit weights were used for all observations. The value of q used, 0.75, is that given by Popper (1976). Both t and $L_3$ were set to zero. The phase correction $\Delta\theta$ was calculated for each light curve to shift the primary minimum to phase 0.0. The variable SFACT is the luminosity normalization factor which equates the brightness of the theoretical light curve to the observed curve.

The adopted solution in each filter was arrived at after a large number of computer runs in each filter. The primary criteria for solution acceptance were convergence of any one solution and minimization of the sum of the square of the residuals, $\Sigma(o-c)^2$. Initial solutions were obtained for $e\cos\omega$ and $e\sin\omega$. The values of e obtained indicated e was less than 0.01. Hence, all subsequent solutions were made with $e\cos\omega$ and $e\sin\omega$ set to zero.

Solutions were then obtained using various combinations of the parameters as variables while others were held constant until the adopted solutions were obtained in each filter. These values are listed in Table 5 along with their standard errors when available. Also listed are the oblateness $\varepsilon$, semi-major axis a and semi-minor axis b of each star, the fractional system luminosity L of each component at quadrature, and the

Table 5

Solution Values and Standard Errors

| Variable | y | b | v | u |
|---|---|---|---|---|
| $J_s$ | 0.383<br>.012 | 0.357<br>.014 | 0.262<br>.015 | 0.221<br>.021 |
| $r_p$ | 0.2422<br>.0030 | 0.2475<br>.0032 | 0.2519<br>.0036 | 0.2427<br>.0055 |
| $r_s$ | 0.1866 | 0.1877 | 0.1901 | 0.1867 |
| k | 0.7707<br>.0080 | 0.7585<br>.0146 | 0.7547<br>.0085 | 0.7691<br>.0138 |
| $u_p$ | 0.61 | 0.70 | 0.82 | 0.86 |
| $u_s$ | 0.72 | 0.85 | 0.96 | 1.00 |
| i | 88.13<br>.50 | 89.32<br>1.56 | 89.15<br>1.34 | 88.45<br>1.00 |
| $S_p$ | 0.0041 | 0.0039 | 0.0030 | 0.0025 |
| $S_s$ | 0.0112 | 0.0116 | 0.0124 | 0.0122 |
| $\Delta\theta$ | -0.02307<br>.00034 | -0.02339<br>.00037 | -0.02353<br>.00041 | -0.02346<br>.00058 |
| $\epsilon_p$ | 0.0158 | 0.0168 | 0.0177 | 0.0159 |
| $\epsilon_s$ | 0.0129 | 0.0131 | 0.0136 | 0.0129 |
| $a_p$ | 0.2448 | 0.2503 | 0.2549 | 0.2453 |
| $a_s$ | 0.1883 | 0.1894 | 0.1919 | 0.1883 |
| $b_p$ | 0.2409 | 0.2461 | 0.2504 | 0.2414 |
| $b_s$ | 0.1858 | 0.1869 | 0.1893 | 0.1859 |
| $L_p$ | 0.8218 | 0.8392 | 0.8776 | 0.8911 |
| $L_s$ | 0.1782 | 0.1608 | 0.1224 | 0.1089 |
| S.E. 1 | 0.0147 | 0.0156 | 0.0185 | 0.0275 |

standard error of one observation s.e.1. Table 6 lists the mean values obtained from the adopted solutions. These values agree closely to those obtained by both Carr and Sadik.

Table 6

Mean Values and Standard Deviations

| Parameter | Value | S.D. |
|---|---|---|
| $\varepsilon_p$ | 0.0166 | 0.0009 |
| $a_p$ | 0.2488 | 0.0048 |
| $b_p$ | 0.2447 | 0.0045 |
| $\varepsilon_s$ | 0.0131 | 0.0003 |
| $a_s$ | 0.1895 | 0.0017 |
| $b_s$ | 0.1870 | 0.0016 |
| $i$ | 88.76 | 0.57 |
| $r_p$ | 0.2461 | 0.0046 |
| $r_s$ | 0.1878 | 0.0016 |
| $k$ | 0.7633 | 0.0079 |

Two further checks were made on the adopted solution. One was a check on the limb darkening coefficients. The solutions were tested for incremental changes in limb darkening away from the theoretical values. No significant change occurred in the residuals as measured by the $\Sigma(o-c)^2$'s; hence, it was concluded that the solutions were not sensitive to variations in limb darkening.

A test was also made to check the solution against changes in k. The value of k was ranged from 0.70 to 0.82 in order to check the effect on the residuals. In the range from 0.74 to 0.78 for k, the residuals increased less than 5%, and remained less than 10% different in the range from 0.73 to 0.79. This suggests that the true value of k is probably in the range from 0.74 to 0.78, which is in excellent agreement with the more formal standard error of k in Table 5 but gives a more definitive range within which k is located.

## Chapter 5

## CONCLUSION

The absolute parameters of the orbit and stars can now be obtained from the adopted solution values listed in Table 6. Popper (1976) gives the minimum masses for the system, $M_j \sin i$, as $1.2 M_\odot$ for the primary and $0.9 M_\odot$ for the secondary, which he determined from spectroscopic observations. Using the value of i from Table 6, the absolute masses were calculated and are listed in Table 7.

Table 7

Absolute Parameters

| Parameter | Value |
|---|---|
| $M_p$ | $1.201\ M_\odot$ |
| $M_s$ | $0.901\ M_\odot$ |
| a | $4.879\ R_\odot$ |
| $R_p$ | $1.201\ R_\odot$ |
| $R_s$ | $0.916\ R_\odot$ |
| $R_{crit(p)}$ | $1.971\ R_\odot$ |
| $R_{crit(s)}$ | $1.737\ R_\odot$ |

Table 7 also lists the values for the radius of the orbit, a, and the stellar radii, $R_p$ and $R_s$. The orbital radius can be found from Kepler's third law

$$a^3 = (74.5445)P^2(M_1 + M_2)$$

where the units are solar radii for a, days for P and solar masses for $M_1$ and $M_2$. The individual stellar radii, $R_j$, in terms of solar radii can then be obtained using the relation

$$R_j = ar_j$$

With these previously obtained values, it is now possible to determine the size of the critical Roche lobes for this system. Plavec (1970) gives the following algorithm for determining the Roche lobes given the mass ratio of the system:

$$r_{crit(j)} = 0.38 + 0.20\log(\frac{M_j}{M_{3-j}})$$

where $r_{crit(j)}$ is in units of the separation of the stars, a. The values of the Roche lobes in absolute units are given in Table 7 and can be compared to the respective stellar radii. Both stars fill less than 75% of their respective Roche lobes. The primary and secondary fill 61% and 53% of the respective lobes. Hence, this system is a well detached system.

There is an ambiguity as to the spectral-luminosity classification of this system, especially of the secondary star. The spectral class of the primary has been determined by Popper (1976) as G2, and the secondary was classified on the basis of light curve determined colors by Oliver as a K0. As a check on these values, an estimate of the stellar colors was made from this study, but it must be emphasized that these are not definitive due to problems referred to earlier in transforming the colors. However, with this stipulation in mind, the (b-y) color on the standard system of the primary, determined from that of the midpoint of the secondary eclipse when only light from the primary is observed is 0.46. That of the secondary star, although contaminated slightly by the primary during the primary eclipse, is 0.52. These values, when compared to those given by Popper (1980) for main sequence stars, place the primary as a late G and the secondary as an early K star. If the primary is in fact a G2 star, it may be slightly evolved above the main sequence, but it definitely is not a subgiant as can be seen by its small radius. Similarly, the secondary may be an early K star, but it also is definitely not a subgiant due to its small radius as was alluded to in Chapter 1. Hence, this system should be classified as two main sequence stars with the primary a G2 and the secondary an early K star.

Two significant questions concerning the wave distortion in the light curve remain to be resolved. The first concerns whether the distortion when present is really an enhancement of the light output. This question should be addresed by an attempt to specifically define a non-distorted level for the out of eclipse maxima. Any distortion then observed could be referenced to a well defined non-distorted maximum level to determine if it really is an enhancement.

The second question concerns the movement of the distortion from month to month. Is this a real movement of one distortion wave or the appearance at different phase positions of several individual distortions? Also, is the motion prograde or retrograde? Both of these areas of investigation could be addressed by an observing program designed to observe the entire light curve during a two week period or less and then comparing several such curves obtained in one observing season, with particular emphasis on detailed observations of the maxima. Such a program should also be carried out, if possible, on a telescope larger than the 41-cm telescope used in this study due to the magnitude range of UV Piscium.

In conclusion, UV Piscium has been found to be a well detached binary composed of two main sequence stars of spectral class G2 and early K. The light curves are well defined with very little distortion, except for a small wave distortion in the maxima, and their solutions have permitted reliable absolute elements to be determined.

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APPENDICES

# APPENDIX A

| [illegible] | [illegible] DATA | Y-FILTER |
|---|---|---|
| [illegible] | PHASE FRACTION | MAGNITUDE DIFFERENCE |
| [illegible] | 0.37422 | 0.55012 |
| [illegible] | 0.41284 | 0.58973 |
| [illegible] | 0.44848 | 0.57522 |
| [illegible] | 0.47440 | 0.64417 |
| [illegible] | [illegible] | 0.79594 |
| [illegible] | [illegible] | 0.79695 |
| [illegible] | [illegible] | 0.64596 |
| [illegible] | 0.57733 | 0.61365 |
| [illegible] | 0.63797 | 0.52802 |
| [illegible] | 0.73706 | 0.53591 |
| [illegible] | 0.75457 | 0.54201 |
| [illegible] | 0.73100 | 0.55131 |
| [illegible] | 0.73760 | 0.55869 |
| [illegible] | [illegible] | 0.57415 |
| [illegible] | [illegible] | 0.56317 |
| [illegible] | [illegible] | 0.54561 |
| [illegible] | [illegible] | 0.56793 |
| [illegible] | 0.16709 | 0.57205 |
| [illegible] | 0.29528 | 0.53364 |
| [illegible] | 0.32690 | 0.58744 |
| [illegible] | 0.34976 | 0.60382 |
| [illegible] | 0.37199 | 0.60455 |
| [illegible] | 0.33781 | 0.60455 |
| [illegible] | 0.40445 | 0.60737 |
| [illegible] | 0.42092 | 0.61601 |
| [illegible] | [illegible] | 0.59140 |
| [illegible] | 0.45205 | 0.59937 |
| [illegible] | 0.03042 | 1.39772 |
| [illegible] | [illegible] | 0.92585 |
| [illegible] | [illegible] | 0.90544 |
| [illegible] | 0.07254 | 0.59119 |
| [illegible] | [illegible] | [illegible] |
| [illegible] | 0.10795 | [illegible] |
| [illegible] | [illegible] | 0.58673 |
| [illegible] | 0.14118 | 0.59780 |
| [illegible] | 0.21357 | 0.58639 |
| [illegible] | 0.23400 | 0.58957 |
| [illegible] | 0.25407 | 0.58627 |
| [illegible] | 0.27097 | 0.58255 |
| [illegible] | 0.29632 | 0.60215 |
| [illegible] | [illegible] | 0.59371 |
| [illegible] | 0.32132 | 0.58102 |
| [illegible] | [illegible] | 0.53901 |

| UV PISCIUM | PHOTOELECTRIC DATA | Y-FILTER |
|---|---|---|
| H.J.D. 2400000+ | PHASE FRACTION | MAGNITUDE DIFFERENCE |
| 44519.71360 | 0.86309 | 0.57603 |
| 44519.73605 | 0.88334 | 0.58697 |
| 44519.73615 | 0.90667 | 0.58097 |
| 44519.75360 | 0.91755 | 0.57776 |
| 44519.75520 | 0.94165 | 0.57695 |
| 44519.85150 | 0.99425 | 1.01799 |
| 44519.84445 | 0.00924 | 1.35215 |
| 44519.85795 | 0.02447 | 1.44695 |
| 44519.87042 | 0.03941 | 1.27209 |
| 44519.88193 | 0.05272 | 0.99325 |
| 44519.90580 | 0.06872 | 0.77095 |
| 44519.91315 | 0.08120 | 0.62035 |
| 44519.92184 | 0.09902 | 0.54774 |
| 44519.95560 | 0.11523 | 0.60406 |
| [illegible] | 0.13209 | 0.60891 |
| 44521.67453 | 0.13466 | 0.59171 |
| [illegible] | 0.15176 | 0.58990 |
| 44521.70277 | 0.16746 | 0.58516 |
| 44521.71809 | 0.18055 | 0.57456 |
| 44521.72678 | 0.19527 | 0.58091 |
| 44521.74636 | 0.21508 | 0.58013 |
| [illegible] | 0.23194 | 0.58285 |
| 44521.77173 | 0.24709 | 0.59234 |
| [illegible] | 0.26103 | 0.58752 |
| [illegible] | 0.31339 | 0.59172 |
| [illegible] | 0.32754 | 0.59924 |
| [illegible] | 0.34170 | 0.59045 |
| [illegible] | 0.35569 | 0.59120 |
| [illegible] | 0.37020 | 0.57693 |
| [illegible] | 0.39265 | 0.58364 |
| [illegible] | 0.40650 | 0.57305 |
| [illegible] | 0.42040 | 0.58676 |
| [illegible] | 0.43409 | 0.59387 |
| [illegible] | 0.94147 | 0.55454 |
| [illegible] | 0.97378 | 0.64337 |
| [illegible] | 0.98702 | 0.85805 |
| [illegible] | 0.99642 | 1.03269 |
| [illegible] | 0.00552 | 1.21639 |
| [illegible] | 0.01504 | 1.40138 |
| [illegible] | 0.02490 | 1.45054 |
| [illegible] | 0.03429 | 1.35228 |
| [illegible] | 0.04468 | 1.14270 |
| [illegible] | 0.05115 | 0.85122 |

| [illegible] | PHOTOELECTRIC DATA | Y-FILTER |
|---|---|---|
| [illegible] | PHASE FRACTION | MAGNITUDE DIFFERENCE |
| [illegible] | 0.07117 | 0.72345 |
| [illegible] | 0.08187 | 0.64728 |
| [illegible] | 0.09296 | 0.60569 |
| [illegible] | 0.10651 | 0.60261 |
| [illegible] | 0.12028 | 0.59644 |
| [illegible] | 0.13604 | 0.60735 |
| [illegible] | 0.15480 | 0.61715 |
| [illegible] | 0.16699 | 0.59147 |
| [illegible] | 0.1[illegible]044 | 0.58749 |
| [illegible] | 0.11032 | 0.58633 |
| [illegible] | 0.12165 | 0.58519 |
| [illegible] | 0.13210 | 0.60353 |
| [illegible] | 0.14278 | 0.60696 |
| [illegible] | 0.15387 | 0.60279 |
| [illegible] | 0.16675 | 0.57406 |
| [illegible] | 0.17720 | 0.59837 |
| [illegible] | 0.19069 | 0.58736 |
| [illegible] | 0.20146 | 0.56629 |
| [illegible] | 0.21806 | 0.575[illegible]9 |
| [illegible] | 0.23017 | 0.57361 |
| [illegible] | 0.24106 | 0.57665 |
| [illegible] | 0.25171 | 0.57398 |
| [illegible] | 0.26376 | 0.56540 |
| [illegible] | 0.27939 | 0.57424 |
| [illegible] | 0.28985 | 0.57621 |
| [illegible] | 0.31344 | 0.54142 |
| [illegible] | 0.32553 | 0.54556 |
| [illegible] | 0.33787 | 0.55257 |
| [illegible] | 0.35196 | 0.54280 |
| [illegible] | 0.36219 | 0.55404 |
| [illegible] | 0.37236 | 0.56503 |
| [illegible] | 0.39221 | 0.57977 |
| [illegible] | 0.39654 | 0.56722 |
| [illegible] | 0.40738 | 0.56056 |
| [illegible] | 0.41856 | 0.55066 |
| [illegible] | 0.43249 | 0.56955 |
| [illegible] | 0.44304 | 0.57263 |
| [illegible] | 0.45598 | 0.56882 |
| [illegible] | 0.46492 | 0.58026 |
| [illegible] | 0.47450 | 0.62535 |
| [illegible] | 0.48418 | 0.67025 |
| [illegible] | 0.49375 | 0.71784 |
| [illegible] | 0.50808 | 0.77541 |

[illegible] ELECTRIC DATA Y-FILTER

| [illegible] 2440000+ | PHASE FRACTION | MAGNITUDE DIFFERENCE |
|---|---|---|
| [illegible] | 0.51206 | 0.60521 |
| [illegible] | 0.52207 | 0.83529 |
| [illegible] | 0.53149 | 0.80479 |
| [illegible] | 0.54078 | 0.78139 |
| [illegible] | 0.55039 | 0.73653 |
| [illegible] | 0.56106 | 0.69290 |
| [illegible] | 0.57125 | 0.65117 |
| [illegible] | 0.58227 | 0.59672 |
| [illegible] | 0.59165 | 0.58680 |
| [illegible] | 0.60193 | 0.59107 |
| [illegible] | 0.59534 | 0.58497 |
| [illegible] | 0.61127 | 0.59353 |
| [illegible] | 0.62894 | 0.58002 |
| [illegible] | 0.63964 | 0.58359 |
| [illegible] | 0.64943 | 0.58404 |
| [illegible] | 0.66060 | 0.58984 |
| [illegible] | 0.67627 | 0.59210 |
| [illegible] | 0.68838 | 0.57684 |
| [illegible] | 0.69954 | 0.58794 |
| [illegible] | 0.71059 | 0.57916 |
| [illegible] | 0.72116 | 0.57910 |
| [illegible] | 0.73478 | 0.57579 |
| [illegible] | 0.74512 | 0.58499 |
| [illegible] | 0.75500 | 0.57755 |
| [illegible] | 0.76485 | 0.56239 |
| [illegible] | 0.77506 | 0.58879 |
| [illegible] | 0.78513 | 0.57650 |
| [illegible] | 0.79492 | 0.58572 |
| [illegible] | 0.81415 | 0.57903 |
| [illegible] | 0.82454 | 0.57690 |
| [illegible] | 0.83489 | 0.56024 |
| [illegible] | 0.84590 | 0.57086 |
| [illegible] | 0.85991 | 0.57483 |
| [illegible] | 0.86657 | 0.57493 |
| [illegible] | 0.87732 | 0.56177 |
| [illegible] | 0.88681 | 0.58843 |
| [illegible] | 0.69571 | 0.57087 |
| [illegible] | 0.70425 | 0.57194 |
| [illegible] | 0.70526 | 0.57151 |
| [illegible] | 0.71300 | 0.58554 |
| [illegible] | 0.72291 | 0.57323 |
| [illegible] | 0.73260 | 0.57459 |
| [illegible] | 0.74808 | 0.57701 |

UV PISCIUM PHOTOELECTRIC DATA Y-FILTER

| H.J.D. 2440000+ | PHASE FRACTION | MAGNITUDE DIFFERENCE |
|---|---|---|
| 4527.65286 | 0.75999 | 0.57213 |
| 4527.66170 | 0.77076 | 0.57394 |
| 4527.67141 | 0.78193 | 0.57142 |
| 4527.68155 | 0.79366 | 0.57493 |
| 4527.69370 | 0.80732 | 0.55919 |
| 4527.70286 | 0.81605 | 0.57719 |
| 4527.71312 | 0.83051 | 0.56231 |
| 4527.72504 | 0.84437 | 0.57103 |
| 4527.73490 | 0.85494 | 0.55649 |
| 4527.75513 | 0.87922 | 0.58112 |
| 4527.76305 | 0.89225 | 0.57520 |
| 4527.77306 | 0.89261 | 0.56373 |
| 4527.78775 | 0.91708 | 0.58341 |
| 4527.79745 | 0.92651 | 0.56624 |
| 4527.81609 | 0.95026 | 0.57826 |
| 4527.82491 | 0.96027 | 0.59983 |

[illegible] [illegible]ELECTRIC DATA B-FILTER

| [illegible] | PHASE FRACTION | MAGNITUDE DIFFERENCE |
|---|---|---|
| 44471.7[illegible] | 0.37560 | 0.45360 |
| 44471.7[illegible] | 0.41652 | 0.46157 |
| 44471.[illegible] | 0.44924 | 0.49112 |
| 44471.[illegible] | 0.47246 | 0.52176 |
| 44471.[illegible] | 0.50770 | 0.65614 |
| 44471.[illegible] | 0.53696 | 0.66306 |
| 44471.[illegible] | 0.55926 | 0.56617 |
| 44471.[illegible] | 0.57861 | 0.45465 |
| 44473.74579 | 0.69234 | 0.40765 |
| 44473.77[illegible] | 0.73800 | 0.40929 |
| 44473.7[illegible] | 0.75332 | 0.41414 |
| 44473.8171[illegible] | 0.77173 | 0.41408 |
| 44473.[illegible] | 0.79834 | 0.41269 |
| 44473.[illegible] | 0.84[illegible]30 | 0.42750 |
| 44473.[illegible] | 0.85692 | 0.44328 |
| 44473.[illegible] | 0.88695 | 0.45116 |
| 44474.[illegible] | 0.90555 | 0.45723 |
| 44475.7[illegible] | 0.15786 | 0.45678 |
| 44475.7[illegible] | 0.29612 | 0.46200 |
| 44475.[illegible] | 0.32771 | 0.46360 |
| 44475.[illegible] | 0.35056 | 0.45718 |
| 44475.[illegible] | 0.37290 | 0.47250 |
| 44475.[illegible] | 0.38370 | 0.46195 |
| 44475.[illegible] | 0.40531 | 0.40333 |
| 44475.[illegible] | 0.42192 | 0.47364 |
| 44497.7[illegible] | 0.83158 | 0.49595 |
| 44497.7[illegible] | 0.84272 | 0.45337 |
| [illegible] | 0.03112 | 1.52157 |
| [illegible] | 0.05466 | 0.85091 |
| [illegible] | 0.07536 | 0.57944 |
| [illegible] | 0.09395 | 0.49757 |
| [illegible] | 0.11365 | 0.47743 |
| [illegible] | 0.12839 | 0.49404 |
| [illegible] | 0.14194 | 0.49735 |
| [illegible] | 0.21630 | 0.44299 |
| [illegible] | 0.23497 | 0.47207 |
| [illegible] | 0.25490 | 0.45751 |
| [illegible] | 0.27193 | 0.47172 |
| [illegible] | 0.28757 | 0.45674 |
| [illegible] | 0.30319 | 0.47006 |
| [illegible] | 0.32255 | 0.47397 |
| [illegible] | 0.33699 | 0.41432 |
| [illegible] | 0.36375 | 0.42742 |

[illegible] PISCIUM PHOTOELECTRIC DATA B-FILTER

| H.J.D. 2440000+ | PHASE FRACTION | MAGNITUDE DIFFERENCE |
|---|---|---|
| [illegible] | 0.88402 | 0.46209 |
| [illegible] | 0.90741 | 0.46293 |
| [illegible] | 0.91623 | 0.46773 |
| [illegible] | 0.94233 | 0.46975 |
| [illegible] | 0.99493 | 0.91497 |
| [illegible] | 0.00391 | 1.25690 |
| [illegible] | 0.02512 | 1.33775 |
| [illegible] | 0.04017 | 1.16523 |
| [illegible] | 0.05339 | 0.86787 |
| [illegible] | 0.06947 | 0.62372 |
| [illegible] | 0.08397 | 0.52214 |
| [illegible] | 0.09871 | 0.50096 |
| [illegible] | 0.11490 | 0.49030 |
| [illegible] | 0.13269 | 0.49275 |
| [illegible] | 0.13546 | 0.46069 |
| [illegible] | 0.15242 | 0.45316 |
| [illegible] | 0.16815 | 0.46267 |
| [illegible] | 0.18418 | 0.48063 |
| [illegible] | 0.19692 | 0.47394 |
| [illegible] | 0.21877 | 0.48581 |
| [illegible] | 0.23257 | 0.46578 |
| [illegible] | 0.24784 | 0.47552 |
| [illegible] | 0.26168 | 0.46661 |
| [illegible] | 0.31402 | 0.46357 |
| [illegible] | 0.32921 | 0.47120 |
| [illegible] | 0.34237 | 0.48605 |
| [illegible] | 0.35635 | 0.47583 |
| [illegible] | 0.37398 | 0.47592 |
| [illegible] | 0.38527 | 0.45325 |
| [illegible] | 0.39725 | 0.45291 |
| [illegible] | 0.42184 | 0.48503 |
| [illegible] | 0.43478 | 0.47570 |
| [illegible] | 0.91235 | 0.45753 |
| [illegible] | 0.97450 | 0.59535 |
| [illegible] | 0.99770 | 1.75496 |
| [illegible] | 0.99406 | 1.43767 |
| [illegible] | 0.00619 | 1.14545 |
| [illegible] | 0.01572 | 1.32965 |
| [illegible] | 0.02556 | 1.35017 |
| [illegible] | 0.03396 | 1.23071 |
| [illegible] | 0.04535 | 1.02643 |
| [illegible] | 0.06131 | 0.72983 |
| [illegible] | 0.07267 | 1.60164 |

[illegible] PYROELECTRIC DATA [illegible]-FILTER

| [illegible] | PHASE FRACTION | MAGNITUDE DIFFERENCE |
|---|---|---|
| [illegible] | 0.08254 | 0.52349 |
| [illegible] | 0.09360 | 0.47171 |
| [illegible] | 0.10715 | 0.47450 |
| [illegible] | 0.12112 | 0.46345 |
| [illegible] | 0.13671 | 0.46626 |
| [illegible] | 0.15545 | 0.46225 |
| [illegible] | 0.16963 | 0.46530 |
| [illegible] | 0.14912 | 0.47064 |
| [illegible] | 0.11111 | 0.47160 |
| [illegible] | 0.12239 | 0.45956 |
| [illegible] | 0.13295 | 0.47363 |
| [illegible] | 0.14362 | 0.46795 |
| [illegible] | 0.15454 | 0.47483 |
| [illegible] | 0.16944 | 0.47513 |
| [illegible] | 0.17947 | 0.47154 |
| [illegible] | 0.19136 | 0.46708 |
| [illegible] | 0.20215 | 0.44736 |
| [illegible] | 0.21372 | 0.46587 |
| [illegible] | 0.23096 | 0.44729 |
| [illegible] | 0.24171 | 0.45510 |
| [illegible] | 0.25256 | 0.47594 |
| [illegible] | 0.26442 | 0.45655 |
| [illegible] | [illegible] | [illegible] |
| [illegible] | 0.29345 | 0.44017 |
| [illegible] | 0.31603 | 0.43795 |
| [illegible] | 0.32626 | 0.43215 |
| [illegible] | 0.33361 | 0.42735 |
| [illegible] | 0.35266 | [illegible] |
| [illegible] | [illegible] | 0.45364 |
| [illegible] | [illegible] | 0.41434 |
| [illegible] | [illegible] | 0.42594 |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | 0.46475 |
| [illegible] | [illegible] | 0.46291 |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | 0.44220 |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |
| [illegible] | 0.47515 | [illegible] |
| [illegible] | [illegible] | 0.51597 |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |

[illegible] P[illegible]ELECTRIC DATA A-FILTER

| [illegible] | PHASE FRACTION | MAGNITUDE DIFFERENCE |
|---|---|---|
| [illegible] | 0.52279 | 0.69922 |
| [illegible] | 0.53213 | 0.67720 |
| [illegible] | 0.54144 | 0.66285 |
| [illegible] | 0.55101 | 0.59991 |
| [illegible] | 0.56179 | 0.55915 |
| [illegible] | 0.57195 | 0.53970 |
| [illegible] | 0.58293 | 0.50041 |
| [illegible] | 0.59229 | 0.47282 |
| [illegible] | 0.60250 | 0.47714 |
| [illegible] | [illegible] | 0.47714 |
| [illegible] | 0.61349 | 0.43636 |
| [illegible] | 0.62961 | 0.47085 |
| [illegible] | 0.64034 | 0.48930 |
| [illegible] | 0.65009 | 0.47246 |
| [illegible] | 0.66126 | 0.48014 |
| [illegible] | 0.67701 | 0.47332 |
| [illegible] | 0.68998 | 0.46702 |
| [illegible] | 0.70026 | 0.47374 |
| [illegible] | 0.71127 | 0.46514 |
| [illegible] | 0.72180 | 0.45726 |
| [illegible] | 0.73342 | 0.45824 |
| [illegible] | 0.74530 | 0.46336 |
| [illegible] | 0.75565 | 0.45525 |
| [illegible] | 0.76551 | 0.45465 |
| [illegible] | 0.77575 | 0.45777 |
| [illegible] | 0.78584 | 0.45757 |
| [illegible] | 0.79564 | 0.45410 |
| [illegible] | 0.81490 | 0.46450 |
| [illegible] | 0.82525 | 0.43813 |
| [illegible] | 0.83572 | 0.44572 |
| [illegible] | 0.84465 | 0.44985 |
| [illegible] | 0.85665 | 0.45201 |
| [illegible] | 0.86722 | 0.45193 |
| [illegible] | 0.87200 | 0.45604 |
| [illegible] | 0.88746 | 0.44415 |
| [illegible] | 0.69965 | 0.44377 |
| [illegible] | 0.70359 | 0.44276 |
| [illegible] | 0.71370 | 0.44563 |
| [illegible] | 0.72359 | 0.44132 |
| [illegible] | 0.73324 | 0.44950 |
| [illegible] | 0.74479 | 0.44500 |
| [illegible] | 0.76072 | 0.45357 |
| [illegible] | 0.77140 | 0.45289 |

[illegible] PHOTOELECTRIC DATA B-FILTER

| H.J.D. 2440000+ | PHASE FRACTION | MAGNITUDE DIFFERENCE |
|---|---|---|
| 44[illegible]7.67311 | 0.73241 | 0.48520 |
| [illegible]7.[illegible] | 0.7[illegible]438 | 0.44922 |
| [illegible]7.[illegible] | 0.[illegible]570 | 0.47614 |
| [illegible]7.7[illegible] | 0.[illegible]73 | 0.46104 |
| [illegible]7.7[illegible] | 0.[illegible]116 | 0.44735 |
| [illegible]7.72[illegible] | 0.[illegible]522 | 0.45040 |
| [illegible]7.7[illegible] | 0.[illegible]569 | 0.45185 |
| [illegible]7.7[illegible]79 | 0.[illegible]999 | 0.45777 |
| [illegible]87.7[illegible] | 0.[illegible]654 | 0.45206 |
| [illegible]7.77[illegible] | 0.[illegible]29 | 0.46442 |
| [illegible]7.7[illegible] | 0.[illegible]1773 | 0.47263 |
| [illegible]7.7[illegible]4 | 0.[illegible]18 | 0.48394 |
| [illegible]7.[illegible]2 | 0.93[illegible]49 | 0.47750 |
| 44[illegible]7.[illegible] | 0.[illegible]096 | 0.47163 |
| [illegible]7.[illegible]7 | 0.[illegible]91 | 0.51600 |

BV PISCIUM PHOTOELECTRIC DATA V-FILTER

| H.J.D. 2440000+ | PHASE FRACTION | MAGNITUDE DIFFERENCE |
|---|---|---|
| 4491.74597 | 0.37629 | 0.14451 |
| 4491.76149 | 0.41779 | 0.26456 |
| 4491.80048 | 0.45005 | 0.25092 |
| 4491.82940 | 0.47328 | 0.27193 |
| 4491.[illegible] | 0.50844 | 0.40040 |
| 4491.[illegible] | 0.53792 | 0.37970 |
| 4491.90412 | 0.55997 | 0.29403 |
| 4491.92077 | 0.57935 | 0.24012 |
| 4493.74152 | 0.69969 | 0.17544 |
| 4493.7[illegible] | 0.73875 | 0.15745 |
| 4493.7[illegible] | 0.75417 | 0.17093 |
| 4493.[illegible] | 0.73526 | 0.19139 |
| 4493.[illegible] | 0.79907 | 0.17146 |
| 4493.[illegible] | 0.81106 | 0.20707 |
| 4493.[illegible] | 0.85766 | 0.20434 |
| 4493.[illegible] | 0.89745 | 0.18542 |
| 4493.[illegible] | 0.99624 | 0.20397 |
| 4493.7[illegible] | 0.14674 | 0.15915 |
| 4493.7[illegible] | 0.29694 | 0.21452 |
| 4493.[illegible] | 0.32659 | 0.22112 |
| 4493.[illegible] | 0.35125 | 0.23306 |
| 4493.[illegible] | 0.37568 | 0.24932 |
| 4493.[illegible] | 0.39956 | 0.23329 |
| 4493.[illegible] | 0.40909 | 0.25277 |
| 4493.[illegible] | 0.42252 | 0.24411 |
| 4497.7[illegible] | 0.38228 | 0.21927 |
| 4497.7[illegible] | 0.36842 | 0.19293 |
| 4511.[illegible] | 0.03191 | 1.14322 |
| 4514.71[illegible] | 0.05650 | 0.61644 |
| 4514.7[illegible] | 0.07414 | 0.35747 |
| 4514.74740 | 0.09967 | 0.25179 |
| 4514.7[illegible] | 0.11947 | 0.24875 |
| 4514.77[illegible] | 0.12799 | 0.23222 |
| 4514.7[illegible] | 0.14274 | 0.23646 |
| 4514.[illegible] | 0.21715 | 0.21989 |
| 4514.[illegible] | 0.23571 | 0.23592 |
| 4514.[illegible] | 0.25559 | 0.22354 |
| 4514.[illegible] | 0.27262 | 0.23103 |
| 4514.[illegible] | 0.29847 | 0.23422 |
| 4514.[illegible] | 0.30591 | 0.22711 |
| 4514.[illegible] | 0.32627 | 0.25163 |
| 4514.[illegible] | 0.33772 | 0.20740 |
| 4515.71[illegible] | 0.36442 | 0.22255 |

| [illegible] | PHOTOELECTRIC DATA | V-FILTER |
|---|---|---|
| [illegible] | PHASE FRACTION | MAGNITUDE DIFFERENCE |
| 44519.75722 | 0.88472 | 0.19190 |
| 44519.75774 | 0.89914 | 0.21766 |
| 44519.75675 | 0.91901 | 0.23604 |
| [illegible] | 0.94591 | 0.23081 |
| [illegible] | 0.97565 | 0.72609 |
| [illegible] | 0.01069 | 1.10992 |
| [illegible] | 0.02536 | 1.22528 |
| [illegible] | 0.04049 | 0.97539 |
| [illegible] | 0.05430 | 0.64207 |
| [illegible] | 0.07028 | 0.38377 |
| [illegible] | 0.08436 | 0.26191 |
| [illegible] | 0.09984 | 0.28368 |
| [illegible] | 0.11659 | 0.22856 |
| [illegible] | 0.13535 | 0.23747 |
| [illegible] | 0.13511 | 0.20487 |
| [illegible] | 0.15515 | 0.24315 |
| [illegible] | 0.16086 | 0.24313 |
| [illegible] | 0.18147 | 0.23569 |
| [illegible] | 0.19672 | 0.22955 |
| [illegible] | 0.21960 | 0.24314 |
| [illegible] | 0.23323 | 0.25615 |
| [illegible] | 0.24654 | 0.23912 |
| [illegible] | 0.26437 | 0.22656 |
| [illegible] | 0.31442 | 0.21511 |
| [illegible] | 0.32901 | 0.21315 |
| [illegible] | 0.34517 | 0.22084 |
| [illegible] | 0.35792 | 0.21927 |
| [illegible] | 0.37797 | 0.23961 |
| [illegible] | 0.39409 | 0.19981 |
| [illegible] | 0.40795 | 0.22495 |
| [illegible] | 0.42177 | 0.24517 |
| [illegible] | 0.43547 | 0.24088 |
| [illegible] | 0.84518 | 0.21644 |
| [illegible] | 0.87539 | 0.37323 |
| [illegible] | 0.93035 | 0.56029 |
| [illegible] | 0.99775 | 0.74165 |
| [illegible] | 0.00636 | 0.99167 |
| [illegible] | 0.01542 | 1.17744 |
| [illegible] | 0.02350 | 1.22687 |
| [illegible] | 0.03066 | 1.11245 |
| [illegible] | 0.04601 | 0.32569 |
| [illegible] | 0.05351 | 0.51597 |
| [illegible] | 0.07277 | 0.36995 |

[illegible] PHOTOELECTRIC DATA V-FILTER

| H.J.D. 2440000+ | PHASE FRACTION | MAGNITUDE DIFFERENCE |
|---|---|---|
| 44526.79659 | 0.08331 | 0.27073 |
| 44526.80612 | 0.09437 | 0.25516 |
| 44526.81775 | 0.10788 | 0.25020 |
| 44526.82375 | 0.12182 | 0.25614 |
| 44526.84329 | 0.13754 | 0.24760 |
| 44526.85941 | 0.15627 | 0.23004 |
| 44526.87154 | 0.17036 | 0.24084 |
| 44526.88376 | 0.18989 | 0.23153 |
| 44545.76429 | 0.11201 | 0.22622 |
| 44545.77394 | 0.12310 | 0.24036 |
| 44545.78305 | 0.13373 | 0.23965 |
| 44545.79214 | 0.14435 | 0.23273 |
| 44545.80163 | 0.15537 | 0.23976 |
| 44545.81482 | 0.17022 | 0.19288 |
| 44545.82836 | 0.18060 | 0.21662 |
| 44545.83526 | 0.19211 | 0.25525 |
| 44545.84972 | 0.20286 | 0.22169 |
| 44545.85714 | 0.21984 | 0.20302 |
| 44545.86726 | 0.23159 | 0.23590 |
| 44545.87657 | 0.24240 | 0.21520 |
| 44545.88595 | 0.25029 | 0.18964 |
| 44545.89616 | 0.26512 | 0.20259 |
| 44545.90986 | 0.28082 | 0.20670 |
| 44545.91957 | 0.29119 | 0.19663 |
| 44547.68271 | 0.31679 | 0.17395 |
| 44547.67152 | 0.32701 | 0.16035 |
| 44547.68916 | 0.33937 | 0.16956 |
| 44547.69817 | 0.35334 | 0.19517 |
| 44547.70881 | 0.36358 | 0.19000 |
| 44547.71177 | 0.37375 | 0.18511 |
| 44547.72[illegible] | 0.38679 | 0.20075 |
| [illegible] | 0.39790 | 0.19621 |
| [illegible] | 0.41079 | 0.19451 |
| [illegible] | 0.42321 | 0.21910 |
| [illegible] | 0.43349 | 0.19716 |
| [illegible] | 0.44689 | 0.20346 |
| [illegible] | 0.45931 | 0.21624 |
| [illegible] | 0.46852 | 0.22035 |
| [illegible] | [illegible] | 0.25186 |
| [illegible] | [illegible] | 0.27703 |
| [illegible] | 0.48709 | [illegible] |
| [illegible] | [illegible] | [illegible] |
| [illegible] | 0.51047 | [illegible] |

RW PISCIUM PHOTOELECTRIC DATA V-FILTER

| H.J.D. 2440000+ | PHASE FRACTION | MAGNITUDE DIFFERENCE |
|---|---|---|
| 44547.84063 | 0.52342 | 0.42120 |
| 44547.84371 | 0.53280 | 0.36576 |
| 44547.[illegible]677 | 0.54217 | 0.37473 |
| 44547.[illegible] | 0.55172 | 0.32303 |
| 44547.[illegible] | 0.5624[illegible] | 0.32075 |
| 44547.[illegible] | 0.57269 | 0.32063 |
| 44547.[illegible] | 0.58359 | 0.24122 |
| 44547.[illegible] | 0.59297 | 0.21064 |
| 44547.[illegible] | 0.60320 | 0.22244 |
| [illegible] | 0.61595 | 0.24323 |
| [illegible] | 0.63033 | 0.23490 |
| [illegible] | 0.64105 | 0.23559 |
| [illegible] | 0.65084 | 0.26137 |
| [illegible] | 0.66206 | 0.24653 |
| [illegible] | 0.67771 | 0.22646 |
| [illegible].70[illegible] | 0.69286 | 0.22201 |
| [illegible].71[illegible] | 0.70099 | 0.24355 |
| [illegible].72[illegible] | 0.71202 | 0.22957 |
| [illegible] | 0.72261 | 0.24476 |
| [illegible].74[illegible] | 0.73614 | 0.21199 |
| [illegible] | 0.74963 | 0.21611 |
| [illegible] | 0.75637 | 0.20154 |
| [illegible].77174 | 0.76617 | 0.22281 |
| [illegible] | 0.77[illegible]47 | 0.24095 |
| [illegible] | 0.78[illegible]60 | 0.22269 |
| [illegible] | 0.79641 | 0.22174 |
| [illegible] | 0.81550 | 0.21342 |
| [illegible] | 0.82506 | 0.23945 |
| [illegible] | 0.83[illegible]50 | 0.22197 |
| [illegible] | 0.84736 | 0.21455 |
| [illegible] | 0.85723 | 0.23503 |
| [illegible] | 0.86682 | 0.22479 |
| [illegible] | [illegible] | 0.21163 |
| [illegible] | [illegible]19 | 0.23593 |
| [illegible] | 0.70041 | 0.20595 |
| [illegible] | 0.70279 | 0.2[illegible]875 |
| [illegible] | 0.71440 | 0.22549 |
| [illegible] | 0.72426 | 0.21255 |
| [illegible] | 0.73594 | 0.22983 |
| [illegible] | 0.74955 | 0.19752 |
| [illegible] | 0.741[illegible] | 0.19647 |
| [illegible] | 0.77210 | 0.18397 |
| [illegible] | 0.7[illegible]335 | 0.19447 |

[illegible] PHOTOELECTRIC DATA V-FILTER

| H.J.D. 2440000+ | PHASE FRACTION | MAGNITUDE DIFFERENCE |
|---|---|---|
| 44597.68070 | 0.79511 | 0.22311 |
| 44597.69381 | 0.79596 | 0.23519 |
| 44597.69506 | 0.80947 | 0.22693 |
| 44597.70351 | 0.81940 | 0.22060 |
| 44597.71470 | 0.83190 | 0.20522 |
| 44597.72452 | 0.84609 | 0.22366 |
| 44597.73546 | 0.85639 | 0.23344 |
| 44597.75640 | 0.88074 | 0.21282 |
| 44597.76[illegible]02 | 0.89420 | 0.20595 |
| 44597.77647 | 0.90401 | 0.21775 |
| 44597.78[illegible] | 0.91844 | 0.23047 |
| 44597.79[illegible]78 | 0.92938 | 0.23466 |
| 44597.80757 | 0.94024 | 0.23625 |
| 44597.81752 | 0.95168 | 0.23552 |
| 44597.82[illegible]04 | 0.96159 | 0.24358 |
| 44597.82744 | 0.96343 | 0.29020 |

[illegible] PISCIUM PHOTOELECTRIC DATA U-FILTER

| H.J.D. 2400000+ | PHASE FRACTION | MAGNITUDE DIFFERENCE |
|---|---|---|
| 44491.74672 | 0.37716 | -0.18970 |
| 44491.76285 | 0.41866 | -0.16830 |
| 44491.81019 | 0.45089 | -0.10142 |
| 44491.[illegible] | 0.47914 | -0.09362 |
| [illegible] | 0.50356 | -0.02865 |
| [illegible] | 0.53865 | -0.03743 |
| [illegible] | 0.56099 | -0.12979 |
| [illegible] | 0.59085 | -0.15619 |
| 44493.74731 | 0.72063 | -0.24071 |
| 44493.76017 | 0.73969 | -0.24274 |
| 44493.79410 | 0.75590 | -0.22462 |
| [illegible] | 0.77420 | -0.20951 |
| [illegible] | 0.79990 | -0.21635 |
| [illegible] | 0.84184 | -0.17959 |
| [illegible] | 0.85848 | -0.19003 |
| [illegible] | 0.88970 | -0.22055 |
| [illegible] | 0.90705 | -0.20489 |
| [illegible] | 0.17020 | -0.20376 |
| 44496.75716 | 0.20779 | -0.14791 |
| [illegible] | 0.32921 | -0.16939 |
| [illegible] | 0.35205 | -0.13234 |
| [illegible] | 0.37454 | -0.13709 |
| [illegible] | 0.39069 | -0.15133 |
| [illegible] | 0.40706 | -0.10835 |
| [illegible] | 0.42551 | -0.14150 |
| [illegible] | 0.33510 | -0.13586 |
| [illegible] | 0.36419 | -0.13613 |
| [illegible] | 0.03233 | 0.32519 |
| [illegible] | 0.05742 | 0.17497 |
| [illegible] | 0.07522 | -0.09202 |
| [illegible] | 0.09043 | -0.14952 |
| [illegible] | 0.11021 | -0.13464 |
| [illegible] | 0.12665 | -0.15990 |
| [illegible] | 0.14351 | -0.15597 |
| [illegible] | 0.21001 | -0.17190 |
| [illegible] | 0.23655 | -0.15569 |
| [illegible] | 0.25640 | -0.14030 |
| [illegible] | 0.27544 | -0.15145 |
| [illegible] | 0.29023 | -0.14731 |
| [illegible] | 0.30472 | -0.13066 |
| [illegible] | 0.32416 | -0.15329 |
| [illegible] | 0.33909 | -0.19077 |
| [illegible] | 0.36510 | -0.21481 |

| [illegible] | PHOTOELECTRIC DATA | V-FILTER |
|---|---|---|
| HEL. J.D. 2440000+ | PHASE FRACTION | MAGNITUDE DIFFERENCE |
| 4519.75705 | 0.88546 | -0.15245 |
| 4519.75795 | 0.90380 | -0.19123 |
| 4519.75779 | 0.91977 | -0.13145 |
| 4519.75893 | 0.94375 | -0.15770 |
| 4519.83877 | 0.98632 | 0.34248 |
| 4519.84099 | 0.01137 | 0.82650 |
| 4519.85984 | 0.02655 | 0.97332 |
| 4519.87291 | 0.04150 | 0.59103 |
| 4519.88993 | 0.05501 | 0.24045 |
| 4519.89755 | 0.07095 | 0.00934 |
| 4519.90991 | 0.08528 | -0.07885 |
| 4519.92272 | 0.10016 | -0.14520 |
| 4519.93752 | 0.11734 | -0.09821 |
| 4519.95199 | 0.13403 | -0.16920 |
| 4521.67377 | 0.13680 | -0.19414 |
| 4521.69103 | 0.15325 | -0.17056 |
| 4521.70434 | 0.16952 | -0.21169 |
| 4521.71575 | 0.19252 | -0.15585 |
| 4521.72040 | 0.19746 | -0.18759 |
| 4521.74124 | 0.22027 | -0.13838 |
| 4521.75370 | 0.23396 | -0.17587 |
| 4521.77507 | 0.24934 | -0.19704 |
| 4521.78596 | 0.26306 | -0.15801 |
| 4521.80809 | 0.31591 | -0.20129 |
| 4521.84287 | 0.32986 | -0.15514 |
| 4521.85489 | 0.34373 | -0.13706 |
| 4521.86661 | 0.35777 | -0.12298 |
| 4521.88875 | 0.38063 | -0.13460 |
| 4521.90342 | 0.39468 | -0.13913 |
| 4521.91645 | 0.40866 | -0.15798 |
| 4521.93297 | 0.42239 | -0.15547 |
| 4521.95417 | 0.43621 | -0.18066 |
| 4523.67652 | 0.94586 | -0.17407 |
| 4523.70419 | 0.97593 | -0.03205 |
| 4523.71984 | 0.98907 | 0.18062 |
| 4523.72344 | 0.99339 | 0.42405 |
| 4523.73118 | 0.00755 | 0.62162 |
| 4523.75275 | 0.01708 | 0.82847 |
| 4523.74911 | 0.02700 | 0.90940 |
| 4523.76614 | 0.03655 | 0.75085 |
| 4523.77637 | 0.04670 | 0.44785 |
| 4523.77972 | 0.05423 | 0.09035 |
| [illegible] | 0.07585 | -0.02155 |

[illegible]ELECTRIC DATA J-FILTER

| [illegible] | PHASE FRACTION | MAGNITUDE DIFFERENCE |
|---|---|---|
| [illegible].79720 | 0.03402 | -0.10751 |
| [illegible] | 0.09578 | -0.11892 |
| [illegible] | 0.10859 | -0.13213 |
| [illegible] | 0.12252 | -0.10272 |
| [illegible] | 0.13329 | -0.12733 |
| [illegible] | 0.15697 | -0.17216 |
| [illegible].57215 | 0.17107 | -0.17611 |
| [illegible] | 0.19055 | -0.15044 |
| [illegible].75591 | 0.21294 | -0.17539 |
| [illegible].77440 | 0.12321 | -0.13605 |
| [illegible].75360 | 0.13450 | -0.10016 |
| [illegible].79270 | 0.14509 | -0.14789 |
| [illegible] | 0.15626 | -0.15344 |
| [illegible] | 0.17092 | -0.15058 |
| [illegible] | 0.18127 | -0.13621 |
| [illegible] | 0.19232 | -0.14591 |
| [illegible] | 0.20357 | -0.16961 |
| [illegible] | 0.22074 | -0.13411 |
| [illegible].58771 | 0.23235 | -0.14910 |
| [illegible].57717 | 0.24510 | -0.13381 |
| [illegible] | 0.25399 | -0.15670 |
| [illegible].83634 | 0.26594 | -0.16709 |
| [illegible].71097 | 0.28155 | -0.12302 |
| [illegible].41315 | 0.29187 | -0.12223 |
| [illegible].85375 | 0.31751 | -0.23468 |
| [illegible] | 0.32777 | -0.20511 |
| [illegible] | 0.34020 | -0.22192 |
| [illegible] | 0.35405 | -0.14537 |
| [illegible].70359 | 0.36426 | -0.19295 |
| [illegible].71274 | 0.37447 | -0.20345 |
| [illegible].72192 | 0.38458 | -0.20533 |
| [illegible].75717 | 0.39461 | -0.20034 |
| [illegible] | 0.40944 | -0.13319 |
| [illegible] | [illegible] | -0.17066 |
| [illegible] | 0.43479 | -0.21105 |
| [illegible].77311 | 0.44503 | -0.13907 |
| [illegible].78274 | 0.45613 | -0.13576 |
| [illegible].79141 | 0.46625 | -0.16769 |
| [illegible] | 0.47652 | -0.14377 |
| [illegible] | 0.48546 | -0.10126 |
| [illegible] | 0.49374 | -0.04635 |
| [illegible] | 0.50506 | -0.07066 |
| [illegible] | 0.51417 | -0.05166 |

[illegible] PHOTOELECTRIC DATA U-FILTER

| [illegible] 2440000+ | PHASE FRACTION | MAGNITUDE DIFFERENCE |
|---|---|---|
| [illegible] | 0.52411 | 0.02495 |
| [illegible] | 0.53347 | 0.01319 |
| [illegible] | 0.54294 | 0.03031 |
| [illegible] | 0.55242 | -0.06924 |
| [illegible] | 0.56315 | -0.09195 |
| [illegible] | 0.57343 | -0.09135 |
| [illegible] | 0.58439 | -0.14197 |
| [illegible] | 0.59369 | -0.16104 |
| [illegible] | 0.60396 | -0.14710 |
| [illegible] | 0.59733 | -0.16251 |
| [illegible] | 0.61668 | -0.11359 |
| [illegible] | 0.63104 | -0.10807 |
| [illegible] | 0.64179 | -0.13417 |
| [illegible] | 0.65156 | -0.10062 |
| [illegible] | 0.66271 | -0.16142 |
| [illegible] | 0.67845 | -0.16054 |
| [illegible] | 0.69054 | -0.12771 |
| [illegible] | 0.70167 | -0.13676 |
| [illegible] | 0.71270 | -0.13027 |
| [illegible] | 0.72339 | -0.15716 |
| [illegible] | 0.73686 | -0.13664 |
| [illegible] | 0.74740 | -0.13055 |
| [illegible] | 0.75711 | -0.14186 |
| [illegible] | 0.76689 | -0.14582 |
| [illegible] | 0.77715 | -0.17929 |
| [illegible] | 0.78746 | -0.14462 |
| [illegible] | 0.79720 | -0.16456 |
| [illegible] | 0.81626 | -0.15766 |
| [illegible] | 0.82675 | -0.13331 |
| [illegible] | 0.83728 | -0.16127 |
| [illegible] | 0.84904 | -0.14514 |
| [illegible] | 0.85793 | -0.15035 |
| [illegible] | 0.86947 | -0.12187 |
| [illegible] | 0.87938 | -0.13409 |
| [illegible] | 0.88690 | -0.14004 |
| [illegible] | 0.70107 | -0.19966 |
| [illegible] | 0.71174 | -0.16647 |
| [illegible] | 0.71514 | -0.15927 |
| [illegible] | 0.72494 | -0.16916 |
| [illegible] | 0.73472 | -0.19196 |
| [illegible] | 0.73545 | -0.16611 |
| [illegible] | 0.73027 | -0.15471 |
| [illegible] | 0.74219 | -0.13962 |

| RV PISCIUM | PHOTOELECTRIC DATA | U-FILTER |
|---|---|---|
| H.J.D. 2440000+ | PHASE FRACTION | MAGNITUDE DIFFERENCE |
| 44587.[illegible] | 0.77279 | -0.15722 |
| 44587.67377 | 0.79428 | -0.16044 |
| 44587.69415 | 0.79676 | -0.17106 |
| 44587.69577 | 0.81029 | -0.14990 |
| 44587.7[illegible] | 0.82015 | -0.17771 |
| 44587.71[illegible] | 0.83269 | -0.13479 |
| 44587.727[illegible] | 0.84668 | -0.20444 |
| 44587.73[illegible] | 0.85723 | -0.17513 |
| 44587.757[illegible] | 0.88144 | -0.16511 |
| 44587.7[illegible] | 0.[illegible]3489 | -0.18456 |
| 44587.777[illegible] | 0.90476 | -0.14632 |
| 44587.7[illegible] | 0.91914 | -0.16210 |
| 44587.7[illegible] | 0.93059 | -0.15042 |
| 44587.[illegible] | 0.94093 | -0.12761 |
| 44587.[illegible] | 0.95245 | -0.09555 |
| 44587.[illegible] | 0.96414 | -0.07030 |

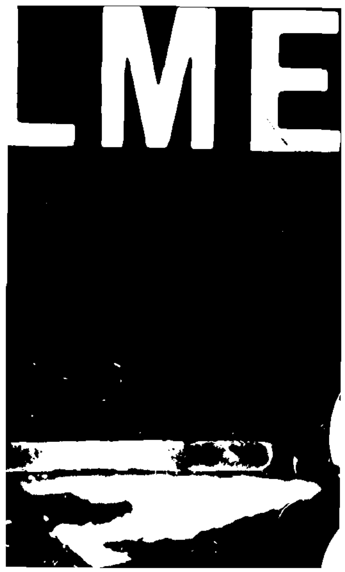
# APPENDIX B

## TIMINGS OF PRIMARY MINIMUM

| H.J.D. 2400000+ | EPOCH NUMBER (HUTH) | (O-C) (HUTH) |
|---|---|---|
| 14666.470 | -15530 | -0.021 |
| 14991.630 | -15164 | -0.023 |
| 15372.539 | -14710 | -0.029 |
| 15434.032 | -14638 | -0.032 |
| 15664.769 | -14366 | +0.001 |
| 15763.479 | -14256 | -0.004 |
| 16059.660 | -13912 | -0.023 |
| 16134.084 | -13825 | -0.010 |
| 16746.774 | -13114 | -0.024 |
| 16959.045 | -12393 | -0.050 |
| 17412.039 | -12573 | +0.014 |
| 17469.709 | -12274 | -0.576 |
| 17969.477 | -11694 | -0.006 |
| 18227.701 | -11394 | -0.016 |
| 18607.563 | -10960 | -0.032 |
| 19004.636 | -10496 | +0.009 |
| 19335.783 | - 9793 | -0.043 |
| 20434.565 | - 8773 | -0.053 |
| 20730.722 | - 8443 | -0.022 |
| 21430.765 | - 7616 | -0.064 |
| 21513.564 | - 7514 | -0.529 |
| 21846.809 | - 7191 | +0.035 |
| 21939.635 | - 7148 | +0.003 |
| 21945.582 | - 7075 | -0.073 |
| 22621.712 | - 6291 | -0.003 |
| 22993.710 | - 5859 | +0.024 |
| 23327.731 | - 5471 | -0.041 |
| 24134.574 | - 4534 | +0.002 |
| 24165.546 | - 4498 | -0.024 |
| 24763.796 | - 3773 | -0.032 |
| 25527.755 | - 2916 | +0.010 |
| 25912.743 | - 1417 | +0.510 |
| 26473.003 | - 1530 | +0.401 |
| 26759.025 | - 1223 | +0.029 |
| 27001.439 | - 1201 | -0.009 |
| 27071.609 | - 1166 | +0.033 |
| 27713.033 | - 842 | -0.021 |
| 27792.037 | - 51 | -0.009 |
| 28017.798 | 54 | -0.033 |
| 28030.737 | 49 | -0.011 |
| 28125.062 | 132 | -0.020 |
| 28156.519 | 137 | +0.001 |
| 28363.647 | 331 | +0.029 |

TIMINGS OF PRIMARY MINIMUM

| H.J.D. 2400000+ | EPOCH NUMBER (HUTH) | (O-C) (HUTH) |
|---|---|---|
| 28373.546 | 399 | +0.044 |
| 28429.502 | 454 | +0.032 |
| 28761.530 | 840 | -0.004 |
| 28774.315 | 855 | +0.066 |
| 28837.022 | 928 | +0.016 |
| 29155.047 | 1299 | -0.407 |
| 29267.275 | 1427 | +0.007 |
| 29486.559 | 1662 | +0.025 |
| 29514.420 | 1744 | +0.032 |
| 29527.567 | 1729 | +0.063 |
| 29625.313 | 1844 | -0.011 |
| 29873.592 | 2137 | -0.018 |
| 29895.728 | 2159 | +0.036 |
| 29937.689 | 2206 | -0.413 |
| 30175.640 | 2482 | -0.031 |
| 30467.511 | 2519 | -0.019 |
| 30318.598 | 2678 | -0.007 |
| 30643.377 | 3051 | -0.008 |
| 31330.734 | 3856 | -0.014 |
| 31687.039 | 4239 | -0.029 |
| 31725.544 | 4282 | -0.010 |
| 32504.431 | 5535 | -0.014 |
| 32820.608 | 5554 | +0.004 |
| 32874.673 | 5622 | +0.017 |
| 33743.697 | 6394 | -0.386 |
| 33916.331 | 6792 | +0.052 |
| 33979.565 | 6824 | +0.002 |
| 33779.263 | 6359 | -0.038 |
| 36833.510 | 10234 | +0.010 |


LME