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UBV PHOTOMETRY OF ASTEROID 433 EROS

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ABSTRACT

UBV observations of asteroid 433 Eros were conducted on 17 nights during the winter of 1974/75. The peak-to-peak amplitude of the light curve varied from about 0.3 mag to nearly 1.4 mag. The absolute V magnitude, extrapolated to zero phase, is 10.85. Phase coefficients of 0.0245 mag/degree, 0.0009 mag/degree, and 0.0004 mag/degree were derived for V, B-V, and U-B, respectively. The zero-phase color of Eros (B-V = 0.88, U-B = 0.50) is representative of an S (silicaceous) compositional type asteroid. The color does not vary with rotation. The photometric behavior of Eros can be modeled by a cylinder with rounded ends having an axial ratio of about 2.3:1. The asteroid is rotating about a short axis with the north pole at $\lambda_o = 15°$ $\beta_o = 9°$.

I. OBSERVATIONS

UBV observations of Eros were conducted on 17 nights during the winter of 1974/75. On most nights the coverage spanned one complete rotation of the asteroid. All measurements were made using a conventional single-channel photometer equipped with standard UBV filters on the 42-inch (107-cm) telescope at Lowell Observatory's Anderson Mesa site. A dc recording system which produces both an analog record (strip chart) and a digital output via a teletype printer was employed. The photomultiplier was an EMI 6256 S cooled to -15°C.

Geocentric positions of Eros are given in Table I for each night of observation. This ephemeris was calculated using a method developed at Lowell Observatory for use in a survey program of asteroid photometry and is referred to as the method of "quasi-osculating elements." These are the elements which lead to a geocentric ephemeris in best agreement with positions given by a rigorous numerical integration that includes planetary perturbations. The quasi-osculating elements therefore differ from the true osculating elements in two important respects: they are applicable over an extended interval of time rather than at an "instantaneous" epoch only, and they contain implicitly the effects of planetary perturbations and light time.

The quasi-osculating elements for Eros were derived from the positions published in Ephemerides of Minor Planets for 1974, Leningrad 1973, and are as follows:

M	$356\overset{\circ}{.}2581$	e	0.222484
ω	$178\overset{\circ}{.}4367$	n	2016.76 arcsec/day
Ω	$303\overset{\circ}{.}8233$	a	1.45736 A.U.
i	$10\overset{\circ}{.}8230$		

The four spherical elements are referred to the mean ecliptic and equinox of 1950.0. The accuracy of the ephemeris over the interval August 1974 through July 1975 is probably better than 30 arcsec in α and δ, and 0.001 A.U. in r and Δ.

Each night, observations of Eros were interspersed with observations of one or two comparison stars. An effort was made to select stars which were near the asteroid's path on the sky and which were similar to Eros in brightness and color. However, it was not always possible to satisfy all three criteria simultaneously. The UBV magnitudes and color indices of the comparison stars as determined from observations on subsequent nights are given in the last three columns of Table II. These values are based on from one to four nights' observations as indicated in column six. The uncertainty in the magnitudes and color indices as judged from the agreement of results from different nights is estimated to be on the order of 0.01 mag. Column one contains the dates[1] on which the objects were used as comparison stars, while column two gives the catalogue numbers of those stars bright enough to be included in the Bonner Durchmusterung or Schonfeld's Southern Durchmusterung. The stars' coordinates are listed

[1]U.T. dates and times are used throughout this paper.

in columns four and five.

Typically a single measurement of the asteroid or a comparison star consisted of three ten-second integrations on the object and one ten-second integration on the sky through each of the three filters. The observations of Eros were reduced relative to those of the comparison stars using mean values for the extinction and transformation coefficients.

II. VARIATION IN BRIGHTNESS

The observed V magnitudes of Eros corrected to unit distance from the Sun and Earth are listed along with the Universal Times of the measurements (uncorrected for light time) in Table III. These data are plotted as crosses in Figures 1, 2, 3, and 4. The solid curves, which are shown for visual clarity, were drawn freehand through the same points shifted to the left and right by amounts equal to Eros' mean synodic period. The light curves in Figures 1, 2, 3, and 4 have been aligned so that the times of primary maxima (as defined below) coincide with the midpoint of the abscissa.

Maxima and Minima in the Light Curve

Table IV lists epochs of light-curve maxima and minima together with their absolute V magnitudes. Like most asteroids, the light curve of Eros passes through two maxima and two minima during each rotation. We define primary maximum as the brighter of the two maxima on the light curve of 18 October 1974, and primary minimum as the fainter of the two minima on that date. Further, in order to identify subsequent primary maxima without confusion, we suppose that they succeed each other after an interval corresponding to one synodic axial rotation of Eros. Primary minima, secondary maxima, and secondary minima are identified in a similar way. From this convention it follows that maxima and minima succeed each other cyclically in a fixed order, namely: primary maximum, primary minimum, secondary maximum, secondary minimum. In this way maxima and minima may always be related to a given rotational phase of Eros even though, as examination of Figures 1, 2, 3, and 4 and Table IV shows, primary maximum is not always the brighter of the two maxima or primary minimum the fainter of the two minima.

Times of maxima and minima were calculated from the chart record of the photoelectric signal. This analog record is at a conveniently large scale, 2 minutes per inch in time and 10 inches full-scale deflection, so that the timing of events may easily be made to $\pm 2^s$. Timing marks were established by identifying events on the chart with the clock time recorded on the teletype-writer output and are accurate to $\pm 1^s$. Hand-drawn curves were used to determine times of maximum and minimum light for each of the three filters, and this method was preferred to analytical curve fitting because decisions regarding poor data could be more easily made. The epochs listed in Table IV have been corrected for light time: J.D. (c) = J.D. observed-light time. The error ϵ is estimated from the scatter in the epoch determinations for the three filters, the curvature and regularity of the light curve, and the number of integrations used to define it; ε should be comparable to the standard deviation. The V magnitudes at maximum and minimum light should contain no significant errors due to interpolation.

From the epochs listed in Table IV it is clear that the intervals between successive maxima and minima varied considerably and in a complex manner as the apparition progressed. For example, the interval between primary maximum and primary minimum increased from 1^h19^m (0.250 synodic periods) on 18 October 1974 to 1^h35^m (0.301) on 4 January 1975, decreased to a minimum of about 1^h20^m (0.25) near 12 February, and increased again to 1^h25^m (0.268) on 19 March. The intervals between the other maxima and minima likewise varied in a complex manner. A possible explanation for these variations is given in section IV.

Absolute Magnitude and Phase Coefficient

Veverka (1971) has discussed the pitfalls which are attendant to the determination and interpretation of asteroid phase curves. It appears to us that a meaningful phase coefficient can be derived for Eros and other asteroids with large rotational brightness variation if their shapes can be approximated by a two-axis surface of revolution such as a prolate spheroid or a cylinder. Such an asteroid, rotating about a short axis, will always present the same figure and total projected area (illuminated and in shadow) near times of maximum light, regardless of aspect. In this case, changes in the brightness of the maxima corrected to unit distance can be attributed to phase effects.

In Figure 5 we have plotted the observed brightness of Eros at primary and secondary maxima, corrected to unit distance from the Sun and Earth, against solar phase angle. The straight lines, whose equations are given below, were fitted to the data by least squares.

$$V(1,\alpha) = \underset{\pm .02}{10.85} + \underset{\pm .0006}{0.0237}\,|\alpha| \qquad \text{(primary maximum)}$$

$$V(1,\alpha) = \underset{\pm .02}{10.79} + \underset{\pm .0006}{0.0255}\,|\alpha| \qquad \text{(secondary maximum)}$$

Extrapolation to zero phase of the brightness data for the secondary maximum may be unreliable in view of the apparent curvature. For the absolute magnitude of Eros at photometric maximum, extrapolated to zero phase, we therefore adopt $V_0(1,0) = 10.85$. The mean phase coefficient at the V wavelength is $\beta_V = 0.0245$ mag deg^{-1}. Eros is considerably brighter than most previously published results suggest. Taylor (1971) gives $V_0(1,0) = 11.54$.

If Eros were not symmetrical about its long axis, then its projected area at maximum light--and therefore brightness--would vary with aspect. The variation in brightness due to aspect alone would be symmetrical about an aspect of 90° (equator-on), while the variation in brightness due to solar phase angle would be symmetrical about opposition. We will show later in this paper that the aspect of Eros was 90° on about December 29, 1974, at which time the solar phase angle was 30°, while opposition occurred much later on January 21, 1975. Hence, if there were any substantial variation with aspect in the projected area of Eros at maximum light, the data in Figure 5 could not possibly be fitted by straight lines. Since the data--particularly for the primary maxima--are well fitted by straight lines, we conclude that Eros' figure can be closely approximated by a two-axis surface of revolution. We further conclude that the phase coefficient which we derived is indeed a measure of the roughness of Eros' surface.

Amplitude of the Light Curve

Figure 6 shows the peak-to-peak amplitude in the light curve plotted against Julian date. The data were calculated from the V magnitudes in Table IV. We define two measures of amplitude: magnitude at primary minimum minus magnitude at primary maximum, and magnitude at secondary minimum minus magnitude at primary minimum. We refer to these as primary and secondary amplitudes, respectively. A maximum amplitude of about $1^{m}.4$ near J.D. 2442410 (29 December 1974) is indicated.

Position of the Pole of Rotation

Many methods have been used to determine the orientation of the rotation axis of Eros, and most of these have been described by Vesely (1971). We present here a new method based on the dependence of the light-curve amplitude on the aspect angle ψ (the angle between the rotation axis and the line of sight).

We assume: (1) that the maximum amplitude in the light curve occurs when the sub-Earth point is on the rotational equator of Eros (i.e., $\psi = 90°$), (2) that Eros is bisymmetrical about its equator, (3) that there is no large-scale variegation of surface texture or albedo, and (4) that changes in the phase angle or the asterocentric declinations of the Sun and the Earth affect the magnitudes at maximum and minimum equally, and therefore do not affect the amplitude. Clearly it is unlikely that these conditions are precisely met, and so the derived position of the pole may be only approximate.

It follows from our model that the light-curve amplitude depends only on the asterocentric declination of the Earth d_E ($= 90°-\psi$) and that a given amplitude occurs twice during the apparition, when the aspect is $90° \pm d_E$. Hence, if (α_1,δ_1), (α_2,δ_2) are the right ascensions and declinations of Eros at aspects $90°-d_E$ and $90°+d_E$ respectively, and if (α_o,δ_o) is the right ascension and declination of the (northern hemisphere) pole of rotation of Eros, then

$$\tan \delta_o = \frac{-\cos \delta_1 \cos (\alpha_1-\alpha_o) - \cos \delta_2 \cos (\alpha_2-\alpha_o)}{\sin \delta_1 + \sin \delta_2}$$

This equation is to be solved for α_o, δ_o by optimization techniques. Separate solutions were attempted for primary and secondary amplitudes, and we assumed that $\psi > 90°$ ($d_E < 0°$) for dates prior to J.D. 2442410. Five amplitudes were selected (0.4, 0.6, 0.8, 1.0, and 1.2 magnitudes), and pairs of dates were computed from Figure 6 using linear interpolation. The corresponding geocentric coordinates (α_1,δ_1), (α_2,δ_2) were used in the equation above. Trial values of α_o for each pair of geocentric positions then led to values for δ_o. We suppose that if α_o is correctly chosen, then the computed δ_o will not vary with amplitude, in which case a plot of δ_o versus amplitude should result in a functional relationship with a gradient or correlation coefficient of zero. In practice it was found that fairly highly correlated linear relationships exist between δ_o and amplitude for all α_o and that a determinate solution for (α_o, δ_o) exists.

The solutions are: $\alpha_o = 0^h42^m.8$, $\delta_o = +14°.9$ from the primary amplitudes, and $\alpha_o = 1^h10^m.6$, $\delta_o = +10°.3$ from the secondary amplitudes (1950.0 coordinates are used). The difference between the two pole determinations is manifest in Figure 6 as a time displacement between the two curves: in general the primary amplitude is first to attain a given amplitude. The solution for the position of the pole derived from the secondary amplitudes is ill-conditioned because these vary with time in a somewhat irregular way after J.D. 2442410. We therefore reject the solution from the secondary amplitudes and adopt:

$$\alpha_o = 0^h42^m.8 \pm 4^m.0 \qquad \delta_o = +14°.9 \pm 3°.4 \qquad (1950.0)$$

$$\lambda_o = 15°.4 \pm 2°.2 \qquad \beta_o = +9°.3 \pm 3°.8 \qquad (1950.0)$$

The probable errors are estimated from the r.m.s. scatter about the least-squares line in the δ_o, amplitude plane.

III. UBV COLOR INDICES

In order to derive accurate color indices, it was necessary to correct for the substantial change in Eros' brightness which occurred during the time required to obtain a complete three-color set of measurements. The correction was made in the present work by fitting parabolas through each group of three successive observations in a given filter and interpolating the observed V and U intensities to the time of the B-filter measurement.

Rotational Color Variation

No evidence of rotational color variation was found on any of the 16 nights[1] that multi-filter measurements were made. Figures 7 and 8 illustrate the absence of rotational variation in the color indices of Eros on two nights separated by about seven weeks. The standard deviations of the color-index measurements on these two nights is between 0.005 mag and 0.007 mag. Certainly any variation in B-V or U-B had a peak-to-peak amplitude less than our detection threshold of 0.01 mag.

UBV Colors and Reddening with Phase

Reddening of certain asteroids with increasing solar phase angle has been reported in the literature (see, e.g., Gehrels, 1970). In Figures 9 and 10 the nightly mean color indices of Eros from the present observations (filled circles) are plotted against solar phase angle. The solid lines were fitted to these points by least squares and are described by the following expressions:

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[1]Only V measurements are available for the night of 8 November.

$$B\text{-}V\ (\alpha) = 0.884 + 0.00091\ |\alpha|$$
$$\pm .005 \quad \pm .0002$$
$$U\text{-}B\ (\alpha) = 0.503 + 0.00043\ |\alpha|$$
$$\pm .011 \quad \pm .0004$$

Reddening with phase is clearly seen in the B-V measurements and may be present in U-B.

The barred circles in Figures 9 and 10 indicate observations by E. F. Tedesco (1975) in Las Cruces, while the circled crosses denote measurements by J. L. Dunlap (1975) and W. Wisniewski (1975) in Tucson. Tedesco's data are in good agreement with the Lowell observations. The B-V measurements by Dunlap and Wisniewski are also in reasonable agreement with the present data, although the scatter is somewhat larger. The U-B measurements by the Tucson observers appear to be systematically redder by about .04 mag than the results obtained in Flagstaff and Las Cruces. This difference notwithstanding, it is quite clear that Eros' color indices are representative of an S (silicaceous) compositional type asteroid (Zellner *et al.*, 1975).

IV. THE SHAPE OF EROS

We have shown that the color of Eros does not vary with rotation, and this suggests that Eros is not mineralogically variegated on a large scale. Zellner and Gradie (1975) have shown that the polarization of Eros is constant during a rotation and have argued that both the albedo and microscale surface roughness are uniform to at least one

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part in 40. Hence, it may be concluded that the observed brightness variation is due to shape.

Because the maximum amplitude of the light curve is quite large, Eros must be an elongated body rotating about a short axis. We have already argued that the variation with phase angle of the absolute magnitude of Eros at maximum light implies a figure which is more or less symmetrical about its long axis. Clearly, a triaxial ellipsoid having the dimensions derived by Roach and Stoddard (1938) is ruled out, because the projected area of such an object seen side-on would vary greatly with aspect.

In Figure 11 we have plotted the light-curve amplitude of Eros as a function of aspect. As in Figure 6, we distinguish between primary and secondary amplitudes. Eros' aspect angle was computed assuming the pole derived above. We consider the aspect angle so calculated to be accurate to within about 3°, which is quite adequate for the purposes of the following discussion.

Computed amplitude-aspect curves for three candidate biaxial figures are also shown in Figure 11. The figures are a prolate spheroid (PS), a cylinder with hemispherical ends (HC), and a right cylinder (RC). These curves were computed on the assumption that the amplitude of such a body seen at any particular aspect angle is given simply by the ratio of the maximum to minimum projected areas, expressed in stellar magnitudes. This assumption is not completely valid because, as Veverka (1971) has pointed out, the phase coefficient of a non-spherical

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body will be different when the object is seen end-on than when seen side-on. Hence there will be some dependence of amplitude on solar phase angle. However, we expect that such dependence is not very great.

The three computed curves were normalized to a maximum amplitude of 1.2 mag by choosing axial ratios of 3.00:1, 2.54:1, and 2.35:1 for the prolate spheroid, the cylinder with hemispherical ends, and the right cylinder, respectively. Although the maximum amplitude actually observed for Eros was larger than 1.2 mag, we believe that the difference may be due to shadowing rather than the overall shape of the asteroid, as explained below. It is immediately apparent from Figure 11 that the form of the curve for a prolate spheroid is very different than that of Eros. The curve for the right cylinder appears to match Eros well over the range of aspect angles considered, and that for a cylinder with hemispherical ends matches rather less well.

When the shapes of the computed rotational light curves for the three biaxial figures seen equator-on are compared to the observed light curve of Eros near maximum amplitude, it is found that all three curves fit reasonably well, having broad maxima and narrow sharp minima. However, the rotational light curve for the right cylinder has two-peaked maxima, which is not observed. Therefore, the overall shape of Eros is well matched by a cylinder with rounded ends.

An estimate of the axial ratio of Eros may be made as follows. We consider the effect of shadowing by macroscopic irregularities on

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the side and end faces. When Eros is side-on to Earth, the total cross-sectional area is at or near maximum, and when side-on to the Sun, the area of shadows visible from Earth is near minimum. It is possible that maximum light occurs between these two positions because, when viewed side-on to Earth, a small axial rotation could result in a greater change in the area of visible shadows than the change in the total cross-sectional area. The opposite argument holds at minimum light, where the minimum cross-sectional area and the maximum shadowing have to be considered. Thus the <u>fraction</u> of the total visible area which is due to shadowing by macroscopic irregularities is greater at minimum light than at maximum, and the amplitude of the light curve is thereby increased. Therefore, in order to match the observations well, we require that the amplitude due to an approximating figure be less than that observed. Now, since the calculated curves for either of the cylinders mentioned above can be scaled up or down by increasing or decreasing the axial ratio, an upper limit may be set to the axial ratio. We find that the overall shape of Eros is well matched by a cylinder with rounded ends having an axial ratio which probably does not exceed 2.3:1. This result contrasts with the deductions of previous workers (e.g., Cailliatte, 1949) who considered that the 1.5-magnitude maximum amplitude frequently observed implies that the figure of Eros has an axial ratio of 4.0:1.

Obviously, the photometric behavior of Eros cannot be precisely modeled by any completely symmetrical geometrical figure. The primary and secondary maxima are not equally bright, and their relative brightness changes throughout the apparition. The same is true of the minima. Furthermore, as stated earlier, the time interval between successive maxima and minima changes with time in a complicated manner. Undoubtedly, these idiosyncracies of the observed light curve are the result of irregularities on the surface of Eros. Collisional processes are believed to have been important in the formation and evolution of asteroids, so a heavily cratered and otherwise irregular surface would not be unexpected for Eros. Such features will cast shadows and therefore have a significant impact on the observed light curve. It is possible, by invoking strategically located craters, to account for most of the departures of the observed amplitude-aspect curves in Figure 11 from the selected model curve. However, it is very doubtful that a unique picture of Eros can be derived in this way.

APPENDIX

Magnitude at the occultation of κ Geminorum A

On 24 January 1975 Eros occulted the 4th-magnitude star κ Gem A. This unique naked-eye event was widely observed in the northeastern United States at about 0^h21^m U.T., and timings of its duration have led to an estimate of the projected size and shape of Eros. According to O'Leary et al. (1975), the data are best fitted by an ellipse measuring 19 x 7 km^2 (preliminary values).

We have determined by interpolation the apparent V magnitude at the time of the occultation, using data from the five light curves of 17 January through 2 February 1975. The epoch of the secondary minimum immediately preceding the occultation was estimated to be 24 January, $0^h08^m35^s$ U.T. (not corrected for light time). The occultation therefore occurred on a steeply rising part of the light curve, some 12^m after secondary minimum. Allowing for the variation in the interval between successive secondary minima and taking this interval to be $5^h16^m02^s$ on 22 January, we find that the occultation took place at a rotational phase 0.0393 synodic periods after secondary minimum. V magnitudes were then calculated for the same rotational phase on the five light curves mentioned above, and these were interpolated to the occultation time. As an internal check this procedure was repeated using rotational phases measured with respect to the primary minimum and both maxima.

The result is:

1975 Jan 24, 0^h21^m U.T. V = 8.009 ± 0.012 - 0.020/minute;

V(1,α) = 11.843 ± 0.012 - 0.020/minute;

V(1,0) = 11.63 ± 0.03 - 0.020/minute.

The last term indicates the instantaneous rate at which Eros was increasing in brightness. The uncertainty in V and V(1,α) incorporates estimated errors due to rotational phase determination, interpolation, and observational scatter in the magnitudes, while the error V(1,0) is larger because of the uncertainty in extrapolating to zero phase (the phase function due to Gehrels, 1970, was used).

Geometric Albedo

The geometric albedo p_V may be calculated using a formula adapted from Bowell and Zellner (1974):

$$\log p_V = 6.244 - 0.4\ V(1,0) - 2 \log D_o .$$

The apparent dimensions given by O'Leary _et al._ (1975) indicate a projected area of 104 km^2 at the time of the occultation, which is equivalent to a circle of diameter D_o = 11.5 km. This leads to $p_V = 0.29 \pm 0.01$, where the uncertainty reflects that in V(1,0) only. However, a 1-km error in the length of the short axis would change p_V by 0.05, so that the value of p_V should be taken as indicative only.

The only other direct estimate of the size of Eros was obtained visually during a series of micrometric measurements by van den Bos and Finsen (1931). According to Watson (1937) their estimate implies a long axis of about 35 km. If we assume an axial ratio of 2.3:1, then the short axis measures about 15 km. Consideration of our two cylindrical models leads to maximum cross-sectional areas of 483 km^2 (cylinder with hemispherical ends) and 533 km^2 (right cylinder). Taking the diameters of the spheres of equal cross-sectional area to be D_o = 24.8 and 26.0 km and using the absolute magnitude derived in section II, we obtain p_V = 0.139 and 0.126, respectively. It must again be stressed that these values are indicative only.

ACKNOWLEDGEMENTS

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Table I. Ephemeris data for Eros

1974/5 U.T.	J.D. (0^h U.T.) -2442000	R.A. 1950.0	Dec. 1950.0	Heliocentric distance (A.U.)	Geocentric distance (A.U.)	Phase angle (deg.)	Light time (days)
18 Oct	338.5	$5^h30^m43^s$	+50°00'.6	1.3307	0.5493	42.39	0.00317
19 Oct	339.5	5 33 42	50 16.3	1.3276	0.5425	42.36	313
8 Nov	359.5	6 34 30	54 40.2	1.2659	0.4184	41.31	242
10 Nov	361.5	6 40 31	55 00.0	1.2600	0.4072	41.15	235
24 Nov	375.5	7 19 53	56 31.6	1.2214	0.3340	39.62	193
6 Dec	387.5	7 46 29	56 24.7	1.1923	0.2786	37.33	161
24 Dec	405.5	8 03 53	52 17.2	1.1581	0.2089	30.37	121
4 Jan	417.5	8 00 02	45 53.9	1.1439	0.1765	22.61	102
12 Jan	424.5	7 52 43	38 42.8	1.1372	0.1601	15.13	92
17 Jan	429.5	7 47 38	33 10.0	1.1346	0.1538	10.58	89
19 Jan	431.5	7 45 41	30 46.3	1.1339	0.1523	9.27	88
23 Jan	435.5	7 42 12	25 47.8	1.1332	0.1510	8.73	87
27 Jan	439.5	7 39 25	20 44.4	1.1332	0.1520	11.22	88
2 Feb	445.5	7 36 47	13 26.4	1.1349	0.1577	17.31	91
12 Feb	455.5	7 37 02	3 13.6	1.1416	0.1774	27.18	102
27 Feb	470.5	7 48 05	- 6 31.7	1.1607	0.2245	36.85	130
19 Mar	490.5	8 17 38	-12 16.2	1.2006	0.3077	42.43	0.00178

Table II. Comparison stars

Date 1974/5	B.D.	R.A. 1950.0	Dec. 1950.0	N	V	B-V	U-B
18 Oct		$5^h31^m54^s$	+50°06'.5	4	11.170	0.293	0.225
18 Oct		5 31 22	50 01.3	4	10.990	0.367	0.247
19 Oct		5 34 32	50 18.2	3	11.600	0.622	0.052
19 Oct	+50° 1208	5 34 47	50 20.4	4	8.422	1.105	0.862
8 Nov		6 35 12	54 37.4	2	11.033	1.006	0.681
8 Nov	+54° 1054	6 35 27	54 41.6	2	9.415	1.644	1.959
10 Nov		6 40 32	55 02.4	2	10.546	1.196	1.173
10 Nov	+55° 1112	6 40 18	55 06.5	2	9.990	0.279	0.078
24 Nov	+56° 1209	7 20 14	56 24.3	1	10.969	1.256	1.136
6 Dec	+56° 1241	7 47 05	56 31.4	2	8.543	1.663	1.909
6 Dec	+56° 1242	7 47 32	56 37.3	2	9.405	1.076	0.781
24 Dec	+52° 1278	8 03 27	52 08.6	2	8.876	0.443	-0.036
4 Jan	+46° 1348	7 59 36	45 45.3	2	7.936	1.048	0.985
12 Jan	+38° 1836	7 51 59	38 21.0	2	8.093	1.061	0.878
12 Jan	+38° 1834	7 51 20	38 14.5	2	8.374	0.665	0.212
17 Jan		7 47 39	32 44.1	2	10.438	0.639	0.204
19 Jan	+30° 1566	7 44 17	30 13.6	2	8.358	1.051	0.875
23 Jan	+26° 1633	7 41 05	25 54.6	4	5.332	1.551	1.852
27 Jan	+20° 1885	7 40 14	20 14.6	2	8.230	-0.054	-0.499
2 Feb	+13° 1725	7 36 51	13 00.5	2	8.929	0.624	0.175
12 Feb		7 36 08	3 00.6	3	10.095	0.885	0.600
27 Feb	- 6° 2325	7 48 04	- 6 43.0	3	9.250	0.609	0.083
19 Mar	-11° 2321	8 18 23	-12 16.2	4	9.810	1.246	1.221

Table III. Observed times and reduced magnitudes

18 October 1974

U.T.	V(1,α)
$06^h30^m.5$	$12^m.075$
06 42.0	12.138
06 54.1	12.179
07 02.2	12.195
07 13.2	12.182
07 21.3	12.139
07 33.9	12.064
07 41.8	12.003
07 52.4	11.934
08 00.0	11.886
08 07.3	11.858
08 14.4	11.831
08 22.2	11.840
08 32.5	11.849
08 40.4	11.884
08 48.6	11.911
08 59.4	11.964
09 07.2	12.036
09 15.4	12.103
09 31.2	12.247
09 41.9	12.277
09 50.0	12.257
09 59.2	12.199
10 10.1	12.125
10 19.7	12.044
10 27.1	11.986
10 34.7	11.951
10 45.2	11.905
10 53.0	11.902
11 02.5	11.908
11 10.5	11.941
11 21.0	11.981
11 35.9	12.044

19 October 1974

U.T.	V(1,α)
06 46.5	12.286
06 58.5	12.271
07 14.5	12.125
07 18.4	12.090
07 22.5	12.047
07 31.3	11.995
07 42.5	11.909
07 50.8	11.897
08 08.4	11.927
08 18.9	11.958
08 26.9	11.980
08 38.5	12.034
08 49.2	12.079
08 56.9	12.133
09 00.4	12.131
09 15.0	12.185
09 25.8	12.198
09 33.3	12.230
09 39.6	12.179
09 47.3	12.117
09 54.7	12.047
10 05.4	11.974
10 12.8	11.925
10 21.1	11.871
10 29.0	11.843
10 39.8	11.808
10 54.6	11.829
11 01.4	11.859
11 08.8	11.889
11 19.5	11.950
11 26.8	12.000
11 33.4	12.066
11 43.5	12.178
11 50.4	12.192

8 November 1974

U.T.	V(1,α)
07 11.5	11.973
07 26.9	11.878
07 30.4	11.865
07 44.7	11.879
07 51.0	11.892
07 59.5	11.952
08 13.5	12.084
08 22.6	12.179
08 29.1	12.249
08 36.5	12.320
08 50.2	12.399
$09^h01^m.3$	$12^m.419$
09 10.5	12.399
09 17.5	12.375
09 23.9	12.299
09 35.9	12.123
09 43.8	12.031
09 53.2	11.941

10 November 1974

U.T.	V(1,α)
06 26.9	12.139
06 36.7	12.002
06 46.5	11.916
06 50.1	11.895
06 59.8	11.860
07 06.4	11.879
07 16.4	11.909
07 26.9	11.965
07 29.9	11.994
07 40.6	12.113
07 47.6	12.191
07 58.0	12.306
08 03.3	12.360
08 09.7	12.415
08 20.5	12.451
08 27.4	12.448
08 37.1	12.431
08 43.3	12.396
08 52.7	12.272
09 03.7	12.125
09 10.4	12.034
09 19.4	11.955
09 22.3	11.934
09 28.7	11.891
09 38.2	11.863
09 45.6	11.849
09 54.9	11.855
10 03.3	11.883
10 15.7	11.948
10 18.5	11.973
10 27.6	12.069
10 40.0	12.225
10 49.5	12.363
11 04.8	12.576
11 13.8	12.589
11 20.0	12.541
11 29.2	12.377
11 37.9	12.217
11 44.3	12.114
11 53.3	11.992
11 59.3	11.943
12 08.0	11.889
12 14.6	11.864
12 23.3	11.857
12 29.8	11.871
12 38.3	11.926

24 November 1974

U.T.	V(1,α)
06 35.9	12.134
06 45.1	12.276
06 56.6	12.496
07 04.5	12.653
07 07.7	12.721
07 16.0	12.792
07 22.4	12.714
07 30.2	12.516
07 33.7	12.422
07 41.1	12.219
07 46.8	12.105
07 52.3	12.011
08 00.5	11.904
08 08.7	11.827
08 14.5	11.798
08 22.1	11.784
08 30.0	11.790
08 35.6	11.811
08 43.1	11.870
08 48.9	11.933
08 56.4	12.028
09 00.5	12.095
09 08.4	12.233
09 11.7	12.297
09 19.5	12.438
09 25.1	12.529
09 33.2	12.590
$09^h41^m.0$	$12^m.601$
09 46.5	12.576
09 54.2	12.533
09 58.4	12.500
10 06.1	12.415
10 11.7	12.301
10 19.2	12.144
10 23.1	12.077
10 30.5	11.980
10 35.9	11.926
10 43.9	11.868
10 52.3	11.831
10 58.3	11.818
11 06.5	11.812
11 11.2	11.822
11 18.9	11.839
11 24.9	11.870
11 32.9	11.931
11 38.7	11.983
11 46.5	12.067
11 50.5	12.123
11 58.1	12.238
12 04.0	12.331

6 December 1974

U.T.	V(1,α)
07 20.8	11.789
07 28.9	11.750
07 40.3	11.728
07 48.1	11.746
07 55.9	11.788
08 03.5	11.837
08 16.0	11.954
08 23.6	12.047
08 31.2	12.162
08 36.2	12.244
08 43.3	12.394
08 48.5	12.492
08 55.7	12.646
09 03.0	12.822
09 08.1	12.898
09 15.9	12.784
09 23.3	12.492
09 31.1	12.246
09 38.6	12.065
09 48.8	11.876
09 56.7	11.778
10 06.9	11.707
10 14.1	11.686
10 19.3	11.680
10 26.9	11.704
10 32.2	11.747
10 39.3	11.819
10 46.4	11.922
10 53.5	12.047
10 58.5	12.153
11 05.7	12.321
11 12.6	12.496
11 20.0	12.654
11 24.7	12.701
11 32.2	12.693
11 39.5	12.629
11 47.0	12.543
11 57.2	12.407
12 04.5	12.238
12 16.4	11.993
12 23.8	11.891
12 31.0	11.816
12 38.0	11.773

24 December 1974

U.T.	V(1,α)
07 12.3	11.782
07 16.9	11.723
07 21.3	11.677
07 26.5	11.634
07 37.4	11.580
07 42.5	11.559
07 49.7	11.559
07 55.0	11.573
[illegible]0.3	11.593
[illegible]5.4	11.632
08 [illegible].4	11.657
08 15.1	11.721
08 20.7	11.793
08 27.0	11.873
$08^h30^m.8$	$11^m.922$
08 36.1	12.001
08 41.2	12.089
08 46.5	12.185
08 51.9	12.305
08 55.8	12.394
09 01.1	12.528
09 07.1	12.674
09 11.9	12.785
09 16.6	12.843
09 20.2	12.865
09 26.0	12.632
09 30.5	12.429
09 35.3	12.245
09 40.1	12.092
09 46.2	11.937
09 52.8	11.802
09 57.5	11.723
10 02.6	11.651
10 07.1	11.598
10 11.2	11.556
10 15.4	11.528
10 18.5	11.522
10 22.4	11.505
10 26.4	11.503
10 30.4	11.509
10 34.3	11.521
10 39.4	11.550
10 42.3	11.571
10 46.3	11.607
10 50.2	11.658
10 54.3	11.720
10 58.9	11.804
11 03.0	11.890
11 08.9	12.039
11 14.5	12.205
11 18.8	12.360
11 23.0	12.511
11 26.9	12.668
11 31.0	12.772
11 35.3	12.812
11 39.9	12.782
11 44.3	12.708
11 48.4	12.628
11 51.7	12.563
11 55.6	12.482
11 59.7	12.405
12 03.7	12.320
12 07.6	12.225
12 13.5	12.056
12 17.8	11.960
12 22.3	11.872
12 26.4	11.805
12 29.4	11.767

4 January 1975

U.T.	V(1,α)
07 37.2	11.436
07 41.6	11.471
07 46.3	11.539
07 50.7	11.595
07 57.9	11.716
08 02.4	11.787
08 07.7	11.850
08 12.0	11.923
08 16.6	12.014
08 21.1	12.116
08 25.6	12.224
08 28.9	12.318
08 33.3	12.430
08 37.7	12.523
08 42.2	12.587
08 46.5	12.613
08 50.9	12.427
08 55.0	12.256
08 58.9	12.111
09 03.0	11.979
09 06.3	11.892
09 10.7	11.784
09 15.1	11.693
09 19.4	11.613
09 24.2	11.543
09 28.9	11.478
09 35.0	11.409
09 41.7	11.340
09 45.9	11.318
$09^h50^m.0$	$11^m.305$
09 53.3	11.304
09 57.6	11.309
10 01.2	11.333
10 10.3	11.372
10 14.7	11.403
10 20.8	11.477
10 26.2	11.559
10 30.5	11.642
10 35.6	11.744
10 39.8	11.857
10 44.3	11.993
10 49.3	12.158
10 54.1	12.361
10 58.6	12.541
11 02.1	12.672
11 06.5	12.703
11 10.6	12.608
11 14.9	12.491
11 23.6	12.270
11 32.6	12.073
11 37.7	11.937
11 43.9	11.785
11 47.9	11.716
11 52.4	11.648
11 57.1	11.576
12 01.8	11.509
12 06.4	11.462
12 11.4	11.417
12 16.1	11.387
12 21.1	11.359
12 24.5	11.358
12 29.2	11.345
12 34.0	11.341
12 38.8	11.357
12 43.6	11.381
12 48.3	11.408
12 54.8	11.446

12 January 1975

U.T.	V(1,α)
07 14.4	11.256
07 19.6	11.213
07 29.3	11.171
07 34.0	11.160
07 38.4	11.162
07 45.2	11.183
07 49.6	11.205
07 53.0	11.228
07 56.8	11.261
08 06.1	11.376
08 10.0	11.433
08 13.2	11.488
08 16.9	11.558
08 29.9	11.886
08 33.8	12.000
08 36.9	12.087
08 41.0	12.184
08 45.0	12.299
08 49.4	12.332
08 52.6	12.307
08 57.1	12.232
09 01.3	12.153
09 05.4	12.068
09 09.6	11.972
09 13.7	11.868
09 17.4	11.769
09 20.4	11.706
09 24.5	11.618
09 28.3	11.548
09 31.7	11.495
09 35.5	11.441
09 40.6	11.379
09 44.5	11.338
09 57.1	11.241
10 01.2	11.224
10 05.2	11.208
10 08.4	11.208
10 12.4	11.201
11 16.2	11.203
10 20.3	11.211
10 23.6	11.222
10 27.5	11.240
10 31.3	11.266
10 35.6	11.299
10 39.1	11.330

U.T.	V(1,α)
12 Jan. (cont'd.)	
$10^{h}43^{m}.2$	$11^{m}.375$
10 46.6	11.419
10 50.7	11.476
10 53.8	11.519
10 58.1	11.585
11 01.4	11.638
11 05.7	11.698
11 09.9	11.766
11 12.9	11.823
11 17.6	11.910
11 20.8	11.986
11 25.2	12.102
11 29.5	12.225
11 32.6	12.323
11 37.5	12.384
11 40.7	12.340
11 45.3	12.184
11 49.8	12.023
11 54.5	11.881
11 57.7	11.796
12 02.0	11.696
12 05.2	11.623
12 09.4	11.542
12 14.9	11.451
12 18.4	11.397
12 22.6	11.342
12 41.8	11.18[illegible]
17 January 1975	
07 44.6	11.806
07 48.7	11.698
07 56.1	11.542
08 00.9	11.469
08 04.6	11.396
08 09.1	11.328
08 14.6	11.258
08 19.5	11.200
08 26.8	11.133
08 32.3	11.094
08 36.8	11.071
08 41.3	11.063
08 45.4	11.055
08 49.9	11.063
08 54.5	11.073
08 58.9	11.093
09 03.4	11.119
09 08.9	11.166
09 14.2	11.225
09 20.5	11.315
09 25.2	11.389
09 30.5	11.486
09 35.3	11.597
09 40.1	11.715
09 44.2	11.798
09 48.5	11.895
09 53.5	11.989
09 57.7	12.047
10 02.5	12.070
10 06.8	12.058
10 11.3	12.000
10 15.9	11.927
10 20.0	11.833
10 38.4	11.443
10 42.7	11.376
10 47.7	11.312
10 52.8	11.248
10 58.8	11.200
11 03.5	11.169
11 09.3	11.115
11 14.7	11.096
11 19.6	11.081
11 24.5	11.079
11 30.2	11.089
11 32.4	11.097
11 38.7	11.125
11 49.0	11.213
11 55.8	11.283
12 01.5	11.357
12 06.5	11.424
12 11.1	11.486
12 15.0	11.549
12 19.9	11.630

U.T.	V(1,α)
$12^{h}24^{m}.7$	$11^{m}.715$
12 29.3	11.801
12 [illegible]	11.957
12 40.0	12.060
12 46.0	12.201
12 50.6	12.114
12 52.8	12.043
19 January 1975	
05 59.9	11.202
06 05.3	11.259
06 09.5	11.308
06 20.9	11.466
06 25.8	11.544
06 30.1	11.614
06 34.1	11.684
06 38.2	11.761
06 42.8	11.857
06 47.1	11.960
06 51.4	12.072
06 55.4	12.115
07 03.3	11.924
07 07.6	11.800
07 11.6	11.687
07 15.7	11.596
07 20.2	11.512
07 25.2	11.421
07 36.1	11.257
07 40.5	11.204
07 44.9	11.154
07 49.6	11.110
07 53.9	11.081
07 58.2	11.057
08 02.4	11.038
08 06.5	11.030
08 11.2	11.024
08 15.7	11.029
08 20.5	11.044
08 29.1	11.091
08 33.5	11.129
08 38.6	11.182
08 48.6	11.316
08 54.4	11.425
08 59.3	11.531
09 04.2	11.640
09 08.7	11.728
09 13.3	11.818
09 17.7	11.897
09 22.3	11.961
09 27.0	11.995
09 31.6	11.992
09 36.7	11.950
09 41.4	11.865
09 46.0	11.753
09 54.9	11.553
09 59.4	11.469
10 04.5	11.385
10 09.4	11.317
10 20.0	11.198
10 25.3	11.159
10 31.3	11.114
10 35.5	11.097
10 39.9	11.081
10 44.4	11.072
10 48.8	11.067
10 53.2	11.076
10 57.9	11.085
11 02.2	11.107
11 10.4	11.155
11 14.4	11.188
23 January 1975	
05 12.8	11.495
05 18.1	11.579
05 22.1	11.645
05 27.0	11.738
05 31.5	11.821
05 33.4	11.861
05 34.7	11.890
05 36.3	11.923
05 37.8	11.951
05 39.3	11.986
05 40.7	12.004
05 42.2	12.023

U.T.	V(1,α)
$05^{h}43^{m}.5$	$12^{m}.024$
05 44.7	12.017
05 45.9	12.004
05 47.1	11.990
05 48.8	11.966
05 50.0	11.937
05 51.3	11.908
05 52.7	11.873
05 54.2	11.837
05 55.5	11.804
05 56.5	11.777
06 00.3	11.684
06 04.0	11.605
06 07.7	11.531
06 11.0	11.468
06 14.3	11.419
06 17.4	11.367
06 20.6	11.318
06 23.6	11.275
06 26.9	11.238
06 30.0	11.196
06 32.9	11.166
06 35.8	11.140
06 42.3	11.089
06 45.2	11.069
06 48.2	11.055
06 51.5	11.041
06 54.8	11.030
06 57.8	11.027
07 00.7	11.025
07 03.9	11.026
07 06.8	11.033
07 09.8	11.041
07 12.7	11.054
07 15.9	11.073
07 18.8	11.089
07 21.8	11.115
07 24.7	11.140
07 27.7	11.172
07 30.6	11.206
07 33.7	11.245
07 36.6	11.286
07 39.6	11.336
07 42.7	11.391
07 45.7	11.445
07 48.6	11.507
07 51.8	11.567
07 55.0	11.622
07 58.5	11.689
08 01.9	11.757
08 05.4	11.817
08 09.9	11.873
08 10.8	11.895
08 12.1	11.913
08 13.6	11.942
08 14.9	11.948
08 16.1	11.959
08 17.4	11.974
08 18.7	11.978
08 20.3	11.980
08 21.5	11.979
08 22.7	11.980
08 24.0	11.962
08 25.7	11.944
08 26.9	11.924
08 28.2	11.907
08 29.5	11.880
08 30.8	11.855
08 32.3	11.829
08 35.8	11.746
08 39.3	11.660
08 42.4	11.591
08 45.8	11.526
08 49.0	11.469
08 52.3	11.413
08 55.3	11.364
08 58.[illegible]	11.322
09 01.7	11.278
09 04.8	11.247
09 07.7	11.214
09 11.0	11.181
09 14.0	11.158
09 17.4	11.135
09 20.4	11.114
09 23.3	11.102
09 26.3	11.094

U.T.	V(1,α)
$09^{h}29^{m}.7$	$11^{m}.083$
09 33.1	11.076
09 36.2	11.070
09 39.3	11.073
09 42.8	11.076
09 45.8	11.081
09 49.0	11.092
09 52.4	11.111
09 56.1	11.13[illegible]
10 00.9	11.163
10 04.1	11.184
10 07.2	11.215
10 11.0	11.260
10 14.1	11.291
10 17.2	11.327
10 20.5	11.372
10 24.2	11.430
10 27.6	11.475
10 31.8	11.534
10 35.2	11.597
10 39.0	11.663
10 42.9	11.730
10 46.7	11.806
10 50.8	11.892
10 52.5	11.926
10 53.8	11.952
10 55.1	11.978
10 56.9	12.006
10 58.2	12.011
10 59.5	12.016
11 00.8	12.013
11 02.0	12.001
11 03.5	11.976
11 05.2	11.952
11 06.5	11.919
11 07.9	11.889
11 09.2	11.854
11 10.9	11.819
11 14.6	11.734
27 January 1975	
03 39.7	11.332
03 44.2	11.347
03 50.3	11.428
03 53.6	11.476
03 56.6	11.514
03 59.6	11.550
04 05.3	11.642
04 08.2	11.694
04 11.4	11.744
04 14.5	11.808
04 17.6	11.853
04 20.3	11.899
04 23.1	11.946
04 25.1	11.979
04 27.0	12.017
04 28.9	12.040
04 30.9	12.052
04 32.8	12.063
04 34.8	12.062
04 36.7	12.050
04 38.6	12.019
04 40.5	11.987
04 42.4	11.943
04 44.3	11.903
04 47.6	11.850
04 50.6	11.778
04 53.6	11.717
04 56.6	11.668
04 59.6	11.610
05 02.6	11.554
05 05.7	11.506
05 08.5	11.456
05 11.4	11.419
05 14.7	11.362
05 17.8	11.328
05 20.8	11.291
05 23.7	11.258
05 26.8	11.227
05 30.0	11.208
05 32.9	11.179
05 38.2	11.156
05 41.1	11.142
05 43.9	11.135
05 46.7	11.129

U.T.	V(1,α)
$05^{h}51^{m}.5$	$11^{m}.122$
05 54.4	11.128
05 57.3	11.139
06 00.1	11.178
06 03.1	11.183
06 06.7	11.189
06 09.7	11.217
06 12.5	11.228
06 15.3	11.256
06 20.5	11.322
06 41.1	11.704
06 47.0	11.776
06 56.8	11.948
06 59.7	12.003
07 02.3	12.055
07 04.4	12.074
07 06.5	12.075
07 08.5	12.115
07 10.7	12.097
07 12.7	12.070
07 15.0	12.030
07 17.0	12.010
07 19.1	11.976
07 21.3	11.948
07 28.3	11.853
07 31.7	11.732
07 34.8	11.667
07 37.7	11.624
2 February 1975	
03 32.3	11.468
03 35.2	11.433
03 37.4	11.410
03 39.4	11.387
03 41.6	11.371
03 44.3	11.345
03 46.3	11.326
03 49.5	11.304
03 54.1	11.281
03 57.3	11.263
03 59.3	11.263
04 01.3	11.259
04 03.2	11.261
04 05.3	11.259
04 07.6	11.253
04 12.3	11.267
04 15.3	11.277
04 18.3	11.287
04 20.3	11.298
04 22.3	11.313
04 24.3	11.324
04 26.4	11.335
04 28.3	11.362
04 33.3	11.410
04 36.3	11.451
04 39.2	11.489
04 41.1	11.519
04 43.1	11.546
04 44.9	11.579
04 47.1	11.621
04 49.3	11.662
04 51.3	11.700
04 55.9	11.783
04 59.4	11.857
05 02.1	11.906
05 04.1	11.960
05 06.5	12.002
05 08.9	12.060
05 10.8	12.093
05 13.1	12.132
05 15.5	12.170
05 17.5	12.182
05 19.5	12.203
05 21.4	12.208
05 23.3	12.208
05 25.3	12.195
05 27.3	12.175
05 29.2	12.151
05 31.3	12.128
05 33.6	12.095
05 35.9	12.059
05 38.6	12.014
05 41.2	11.972
05 47.4	11.840
05 49.9	11.794

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U.T.	V(1,α)
2 Feb. (cont'd.)	
05 54.1	11.725
05 56.0	11.691
05 57.9	11.658
05 59.8	11.623
06 02.7	11.579
06 05.5	11.542
06 08.0	11.506
06 10.7	11.470
06 12.5	11.457
06 14.4	11.436
06 13.3	11.411
06 18.5	11.397
06 20.7	11.387
06 23.1	11.371
06 25.1	11.359
06 27.1	11.355
06 29.1	11.346
06 31.6	11.330
06 34.2	11.331
06 37.0	11.321
06 39.0	11.319
06 41.0	11.322
06 43.6	11.323
06 45.7	11.331
06 47.7	11.333
06 49.8	11.331
06 53.5	11.338
06 55.5	11.340
06 58.3	11.356
07 00.4	11.374
07 03.2	11.391
07 05.2	11.403
07 07.0	11.420
07 09.2	11.435
07 11.1	11.450
07 13.7	11.475
07 16.1	11.498
07 18.9	11.537
07 20.8	11.556
07 22.7	11.586
07 24.6	11.607
07 26.7	11.647
07 29.9	11.680
07 30.8	11.708
07 32.9	11.733
07 35.8	11.782
07 38.0	11.817
07 39.9	11.843
07 41.8	11.877
07 44.3	11.920
07 46.6	11.951
07 49.5	11.999
07 51.4	12.035
07 53.4	12.063
07 55.4	12.088
07 58.2	12.120
08 00.1	12.139
08 02.0	12.158
08 03.9	12.167
08 05.7	12.161
08 07.8	12.140
08 09.8	12.111
08 11.5	12.082

U.T.	V(1,α)
08 13.6	12.050
08 17.3	11.990
08 19.7	11.955
08 22.6	11.895
08 24.5	11.863
08 26.5	11.833
08 28.5	11.794
08 30.4	11.760
08 33.0	11.717
08 35.6	11.671
08 38.4	11.630
08 40.6	11.590
08 42.8	11.548
08 44.8	11.525
08 46.7	11.503
08 48.7	11.478
08 50.6	11.452
08 52.5	11.430
08 54.5	11.407
08 57.1	11.399
08 59.7	11.348
09 03.3	11.322
09 05.5	11.308
09 07.3	11.292
09 10.0	11.283
[illegible] February 1975	
03 21.5	11.627
03 25.8	11.585
03 30.1	11.559
03 36.5	11.528
03 40.7	11.516
03 45.1	11.510
03 49.5	11.513
03 53.7	11.520
03 58.3	11.537
04 02.3	11.551
04 07.7	11.582
04 12.0	11.656
04 22.0	11.715
04 33.6	11.863
04 38.5	11.930
04 42.7	11.996
04 46.6	12.049
04 51.4	12.117
04 57.2	12.192
05 01.5	12.252
05 05.9	12.283
05 10.2	12.276
05 14.5	12.243
05 18.9	12.189
05 24.1	12.121
05 28.6	12.062
05 33.7	11.984
05 38.3	11.920
05 43.5	11.838
05 48.2	11.773
05 56.8	11.648
06 01.2	11.602
06 05.6	11.561
06 10.5	11.520
06 15.5	11.486
06 20.0	11.462
06 24.9	11.453

U.T.	V(1,α)
06 29.9	11.450
06 35.2	11.457
06 40.4	11.482
06 45.7	11.516
06 50.5	11.552
06 55.4	11.612
07 00.9	11.702
07 06.3	11.781
07 10.8	11.857
07 20.2	12.035
07 24.8	12.133
07 29.2	12.215
07 33.5	12.293
07 38.0	12.339
07 42.4	12.358
07 46.6	12.348
07 50.6	12.323
07 54.6	12.271
07 58.8	12.204
08 01.1	12.119
08 14.6	11.940
08 18.9	11.868
08 23.5	11.801
08 28.2	11.745
08 33.5	11.669
08 38.3	11.632
08 42.6	11.596
08 51.7	11.526
27 February 1975	
03 34.8	12.328
03 39.7	12.278
03 43.7	12.244
03 47.3	12.209
03 51.1	12.173
03 56.7	12.115
04 00.8	12.072
04 04.6	12.031
04 08.4	11.999
04 12.6	11.949
04 16.6	11.908
04 20.4	11.861
04 24.2	11.833
04 28.0	11.796
04 31.7	11.770
04 35.1	11.750
04 39.2	11.732
04 43.2	11.720
04 47.0	11.710
04 50.7	11.716
04 54.8	11.722
05 02.6	11.758
05 06.4	11.781
05 10.2	11.815
05 13.9	11.850
05 17.6	11.893
05 21.4	11.935
05 25.1	11.980
05 28.7	12.033
05 32.4	12.059
05 36.2	12.163
[illegible] 40.0	12.220
05 43.8	12.274
05 47.8	12.336

U.T.	V(1,α)
05 51.5	12.378
05 55.2	12.416
05 59.0	12.433
06 02.7	12.440
06 06.5	12.428
06 10.3	12.405
06 13.9	12.374
06 17.7	12.338
06 21.6	12.283
06 25.2	12.245
06 29.0	12.184
06 32.8	12.147
06 36.6	12.095
06 40.5	12.047
06 41.3	12.005
06 48.0	11.978
06 51.7	11.938
06 55.4	11.891
06 59.2	11.867
07 02.8	11.836
07 06.9	11.805
07 10.8	11.781
07 14.6	11.770
07 18.5	11.757
07 22.3	11.758
07 26.3	11.762
07 30.1	11.772
07 33.9	11.778
07 37.7	11.795
07 41.5	11.811
07 45.4	11.834
07 49.2	11.865
07 53.2	11.895
07 57.1	11.937
08 01.2	11.982
08 05.5	12.026
08 31.6	12.300
08 37.2	12.326
08 43.8	12.334
08 47.2	12.322
08 50.5	12.294
08 53.9	12.272
08 57.1	12.248
09 00.3	12.234
19 March 1975	
02 45.3	12.208
02 49.6	12.216
02 53.7	12.220
02 56.5	12.215
02 59.4	12.210
03 10.5	12.193
03 23.2	12.131
03 27.3	12.107
03 30.7	12.085
03 33.6	12.067
03 36.5	12.066
03 46.8	12.013
03 50.7	12.005
03 53.6	11.989
03 56.4	11.964
03 59.2	11.948
04 02.9	11.937
04 06.4	11.912

U.T.	V(1,α)
04 10.3	11.904
04 13.1	11.892
04 16.0	11.887
04 19.7	11.890
04 23.0	11.878
04 26.8	11.883
04 29.9	11.888
04 32.8	11.899
04 35.6	11.902
04 39.2	11.919
04 42.6	11.926
04 47.3	11.948
04 50.0	11.962
04 52.7	11.976
04 55.4	11.992
04 58.9	12.022
05 02.2	12.039
05 06.3	12.071
05 09.0	12.100
05 11.8	12.118
05 14.5	12.145
05 18.2	12.177
05 22.0	12.213
05 26.1	12.237
05 28.9	12.259
05 31.6	12.268
05 34.4	12.279
05 38.3	12.287
05 41.6	12 290
05 45.6	12.281
05 48.4	12.258
05 51.1	12.239
05 54.7	12.217
05 58.1	12.197
06 02.0	12.165
06 04.8	12.144
06 07.6	12.125
06 10.3	12.105
06 13.0	12.082
06 16.5	12.059
06 19.9	12.039
06 23.9	12.008
06 26.8	11.989
06 29.6	11.973
06 32.4	11.953
06 35.1	11.938
06 38.7	11.925
06 42.1	11.912
06 46.6	11.906
06 49.4	11.895
06 52.2	11.886
06 54.9	11.884
06 58.7	11.893
07 01.9	11.890
07 06.4	11.899
07 09.2	11.904
07 12.1	11.909
07 14.8	11.925
07 18.5	11.942
07 22.1	11.951
07 26.7	11.983
07 29.5	11.996
07 32.8	12.028

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Table IV. Epochs of light-curve maxima and minima

1974/5 U.T.	PRIMARY MAXIMUM J.D. (c) -2442000 ± ε x 10^5	V(1,α)	PRIMARY MINIMUM J.D. (c) -2442000 ± ε x 10^5	V(1,α)	SECONDARY MAXIMUM J.D. (c) -2442000 ± ε x 10^5	V(1,α)	SECONDARY MINIMUM J.D. (c) -2442000 ± ε x 10^5	V(1,α)
18 Oct	338.84542 ± 139[a]	11.831	338.90022 ± 104	12.270	338.94844 ± 69	11.902	338.79052 ± 231[a]	12.194
19 Oct	339.94199 ± 347[a]	11.808			339.82802 ± 139[a]	11.897	339.88613 ± 347[a]	12.195
8 Nov					359.81378 ± 116[a]	11.865	359.87253 ± 128[a]	12.419
10 Nov	361.90506 ± 74	11.849	361.96328 ± 28	12.599	361.79044 ± 139[a]	11.869	361.84858 ± 67	12.450
					362.00966 ± 64			
24 Nov	375.95991 ± 16	11.812	375.79904 ± 45	12.793	375.84672 ± 126	11.784	375.89953 ± 53	12.602
6 Dec	387.81705 ± 16	11.728	387.87951 ± 8	12.903	387.92775 ± 45	11.680	387.97655 ± 64	12.709
24 Dec	405.82359 ± 130	11.559	405.88685 ± 59	12.868	405.93376 ± 54	11.503	405.98172 ± 41	12.813
4 Jan	417.01758 ± 69	11.341	416.86413 ± 9	12.620	416.91295 ± 64	11.304	416.96052 ± 32	12.709
12 Jan	424.92314 ± 89	11.201	424.98352 ± 8	12.385	424.81613 ± 69[a]	11.160	424.86619 ± 6	12.332
17 Jan	429.97174 ± 29	11.079	430.03055 ± 69[a]	12.201	429.86600 ± 116	11.055	429.91818 ± 21	12.077
19 Jan	431.94609 ± 140	11.067	431.78700 ± 7	12.120	431.83969 ± 47	11.024	431.89508 ± 29	11.998
23 Jan	435.89905 ± 101	11.070	435.73716 ± 9	12.024	435.79091 ± 42	11.025	435.84668 ± 9	11.978
			435.95737 ± 14[a]	12.017				
27 Jan			439.68883 ± 5	12.063	439.74255 ± 50	11.122	439.79698 ± 31	12.115

Table IV. (continued)

1974/5 U.T.	PRIMARY MAXIMUM J.D. (c) -2442000 $\pm \epsilon \times 10^5$	PRIMARY MAXIMUM $V(1,\alpha)$	PRIMARY MINIMUM J.D. (c) -2442000 $\pm \epsilon \times 10^5$	PRIMARY MINIMUM $V(1,\alpha)$	SECONDARY MAXIMUM J.D. (c) -2442000 $\pm \epsilon \times 10^5$	SECONDARY MAXIMUM $V(1,\alpha)$	SECONDARY MINIMUM J.D. (c) -2442000 $\pm \epsilon \times 10^5$	SECONDARY MINIMUM $V(1,\alpha)$
2 Feb	445.77662 ± 17	11.319	445.83543 ± 9	12.167	445.67008 ± 22	11.253	445.72237 ± 5	12.208
12 Feb	455.65659 ± 6	11.510	455.71225 ± 6	12.283	455.76720 ± 37	11.450	455.82056 ± 39	12.364
27 Feb	470.80369 ± 41	11.757	470.86394 ± 95	12.354	470.70007 ± 150	11.710	470.74962 ± 27	12.443
19 Mar	490.78105 ± 190	11.884	490.62030 ± 115	12.220	490.67972 ± 53	11.878	490.73450 ± 94	12.287

[a]Epoch determined from V filter record only.

FIGURE CAPTIONS

Figure 1. V light curves of 433 Eros. The crosses are the actual observed points. The curves were drawn freehand through the same points shifted to the left and right by amounts equal to Eros' mean synodic period. The time of primary maximum coincides with the midpoint of the abscissa. Magnitudes are corrected to unit heliocentric and geocentric distances.

Figure 2. Caption as Figure 1.

Figure 3. Caption as Figure 1.

Figure 4. Caption as Figure 1.

Figure 5. Brightness of Eros at the primary maximum (PM) and secondary maximum (SM) of the light curve plotted as a function of solar phase angle. Filled circles denote points obtained prior to opposition; open circles are observations after opposition. The straight lines were fitted to the data by least squares.

Figure 6. Primary (filled circles) and secondary (filled squares) amplitude of Eros' light curve plotted against Julian date.

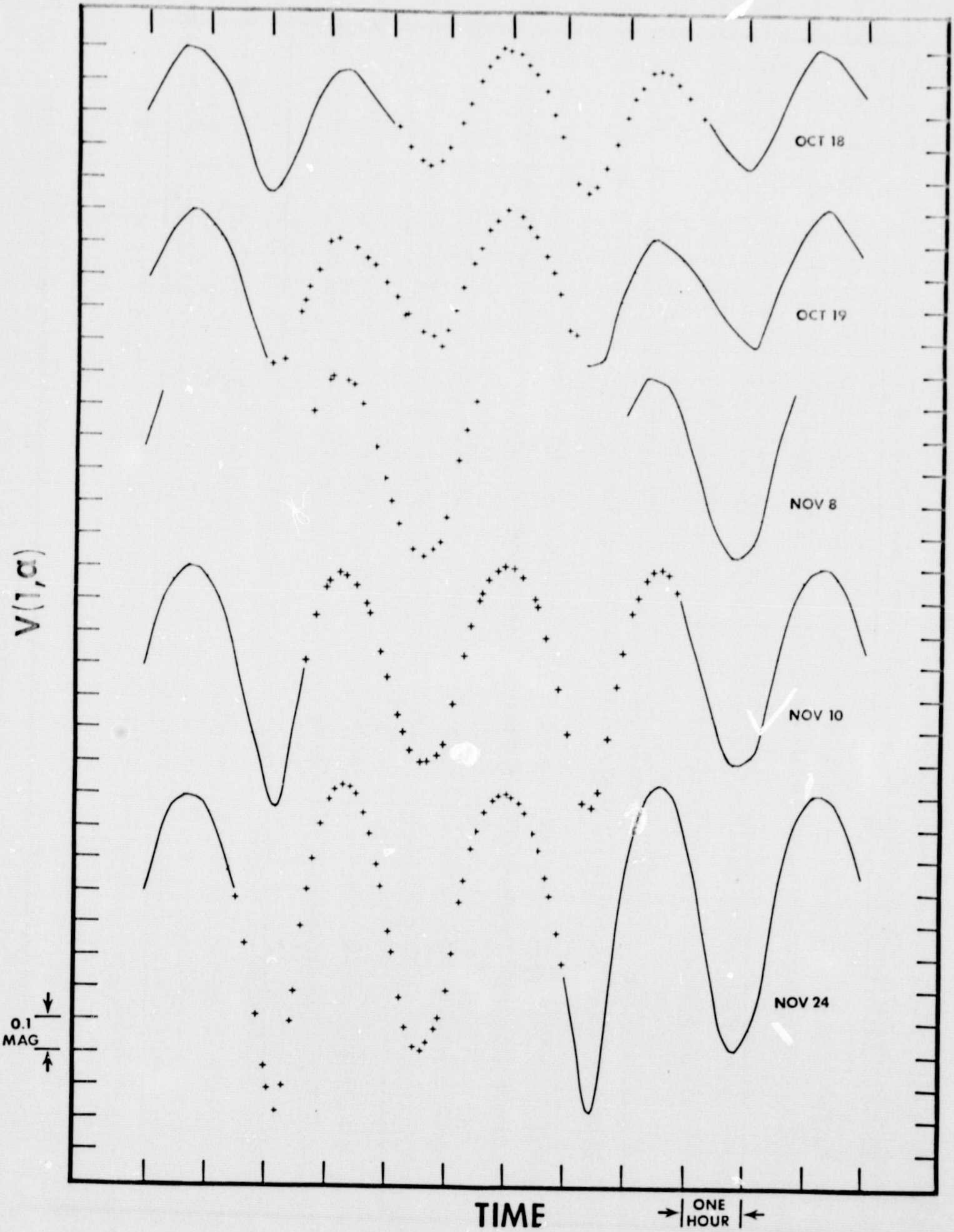
Figure 7. Observed V magnitudes and color indices of Eros from December 24, 1974, plotted as a function of Universal Time. The observed V magnitudes of the comparison star are also given as an indication of the photometric quality of the night. Note that the measurements of Eros' brightness are plotted on a compressed scale.

Figure 8. Observed V magnitudes and color indices of Eros from February 12, 1975, plotted as a function of Universal Time. The observed V magnitudes of the comparison star are also given as an indication of the photometric quality of the night. Note that the measurements of Eros' brightness are plotted on a compressed scale.

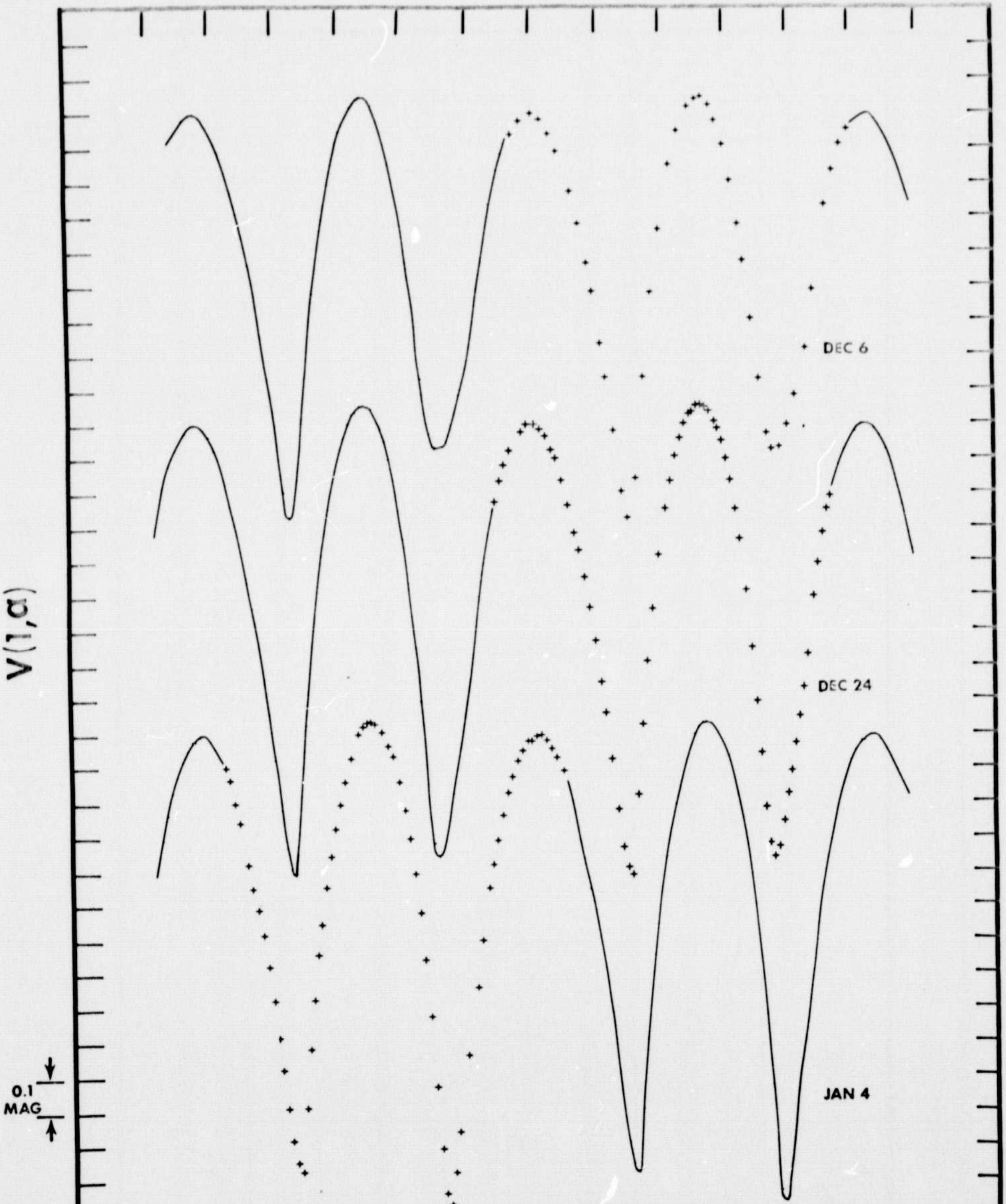
Figure 9. The B-V color index of Eros as a function of solar phase angle. The filled circles denote the present observations from Lowell. The circled crosses are observations by Dunlap (1975) and Wisneiwski (1975) from Tucson, while the barred circles refer to measurements by Tedesco (1975) from Las Cruces. The straight line was fitted by least squares to the Lowell data.

Figure 10. The U-B color index of Eros as a function of solar phase angle. The filled circles denote the present observations from Lowell. The circled crosses are observations by Dunlap (1975) and Wisneiwski (1975) from Tucson, while the barred circles refer to measurements by Tedesco (1975) from Las Cruces. The straight line was fitted by least squares to the Lowell data.

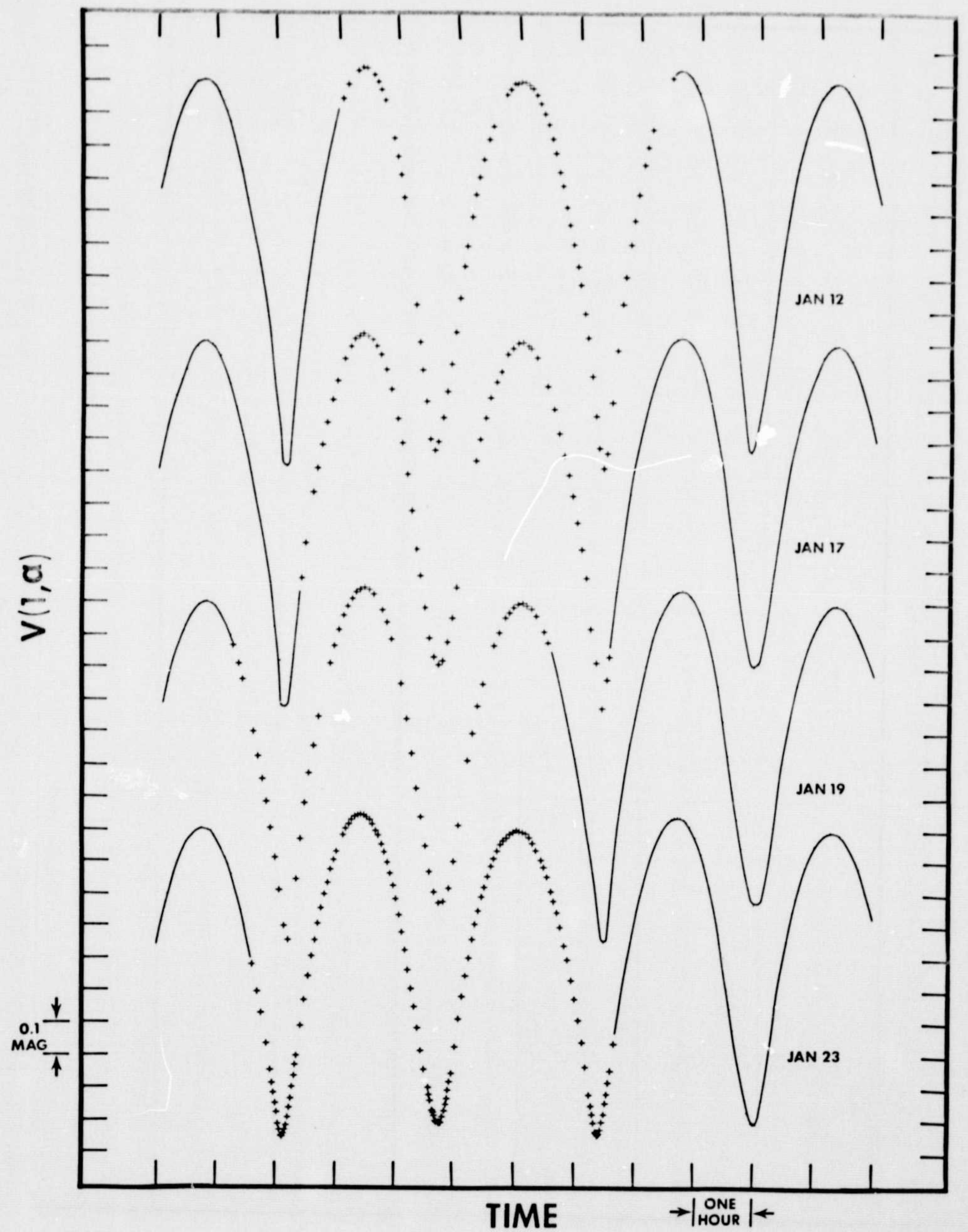
Figure 11. Primary (circles) and secondary (squares) amplitude of the light curve of Eros plotted as a function of aspect ψ (lower ordinate) and Julian date (upper ordinate). Filled symbols pertain to $\psi > 90°$, and open symbols to $\psi < 90°$. Computed amplitude-aspect curves are identified as follows: PS prolate spheroid, CH cylinder with hemispherical ends, and RC right cylinder.



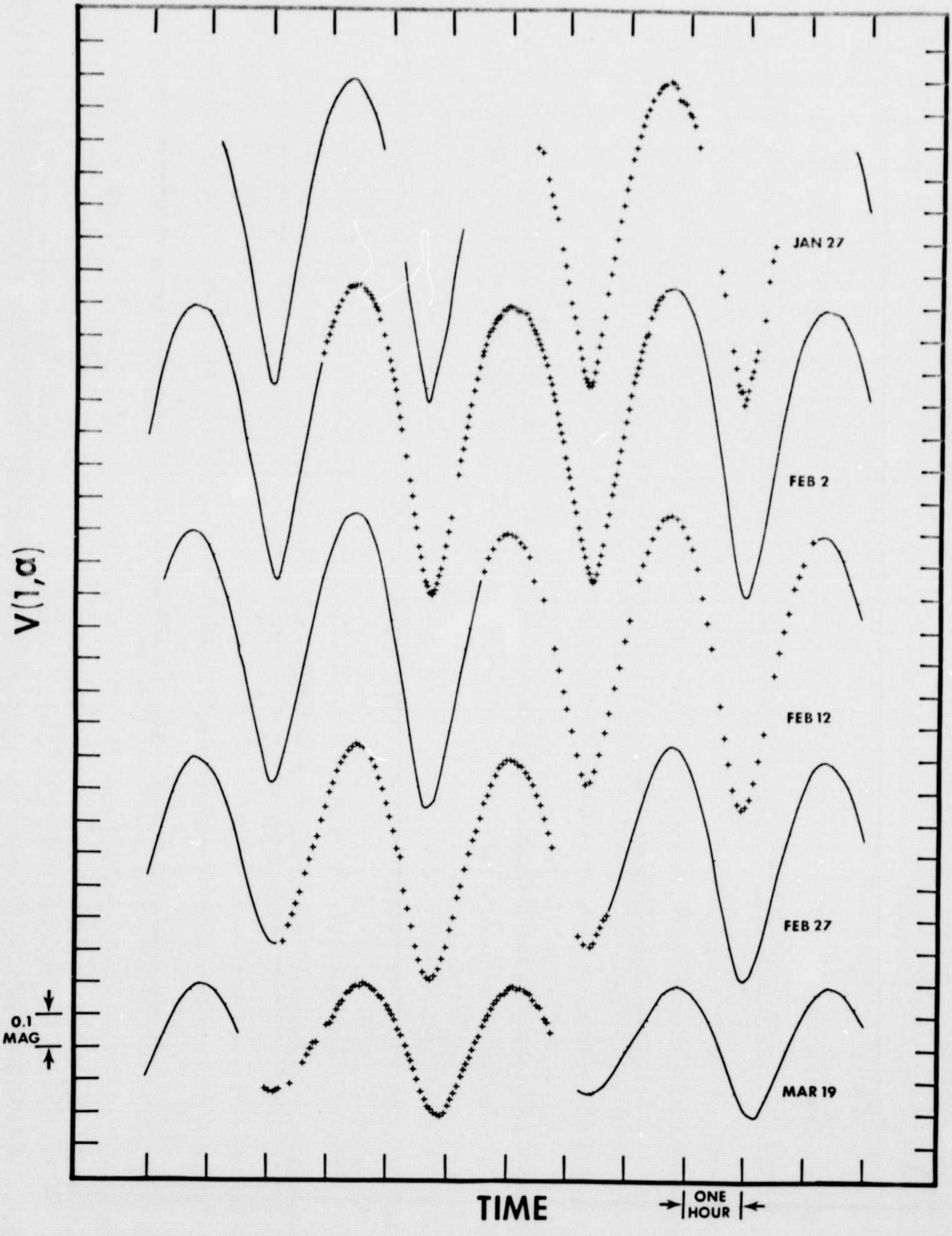
Millis et al. Figure 1



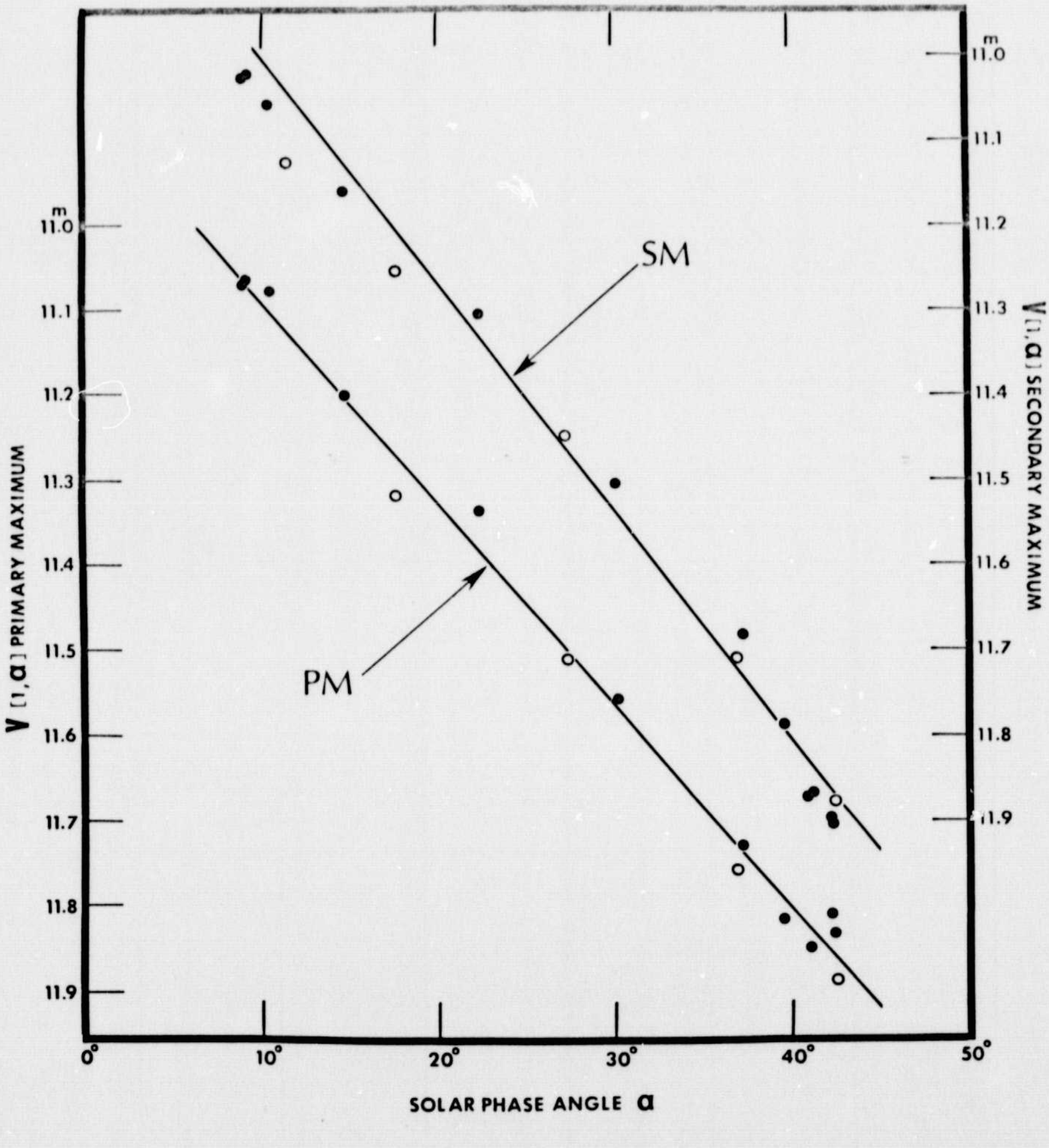
Millis et al. Figu



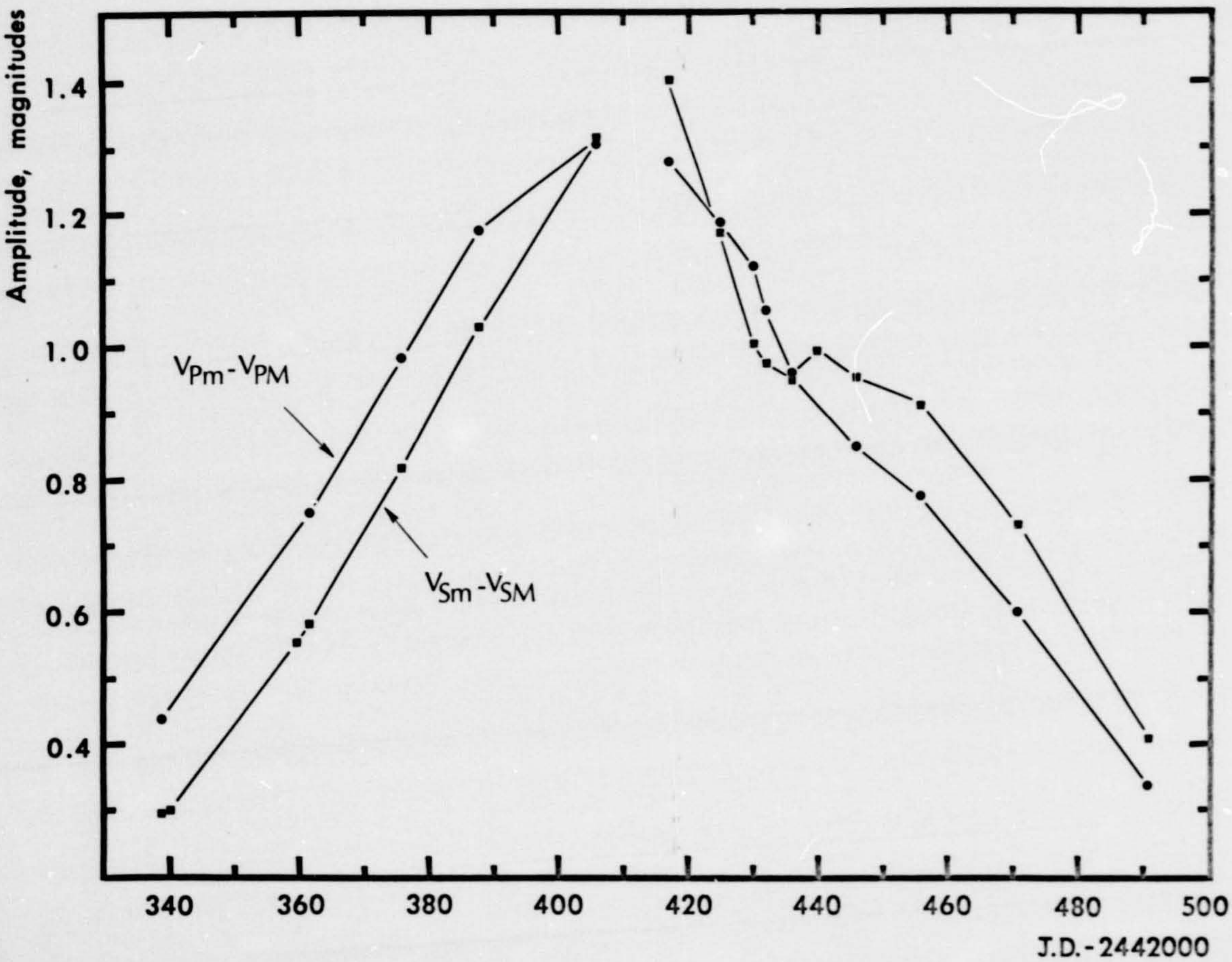
Millis et al. Figure 3



Millis et al. Figure 6



Millis et al. Figure 5


Amplitude, magnitudes
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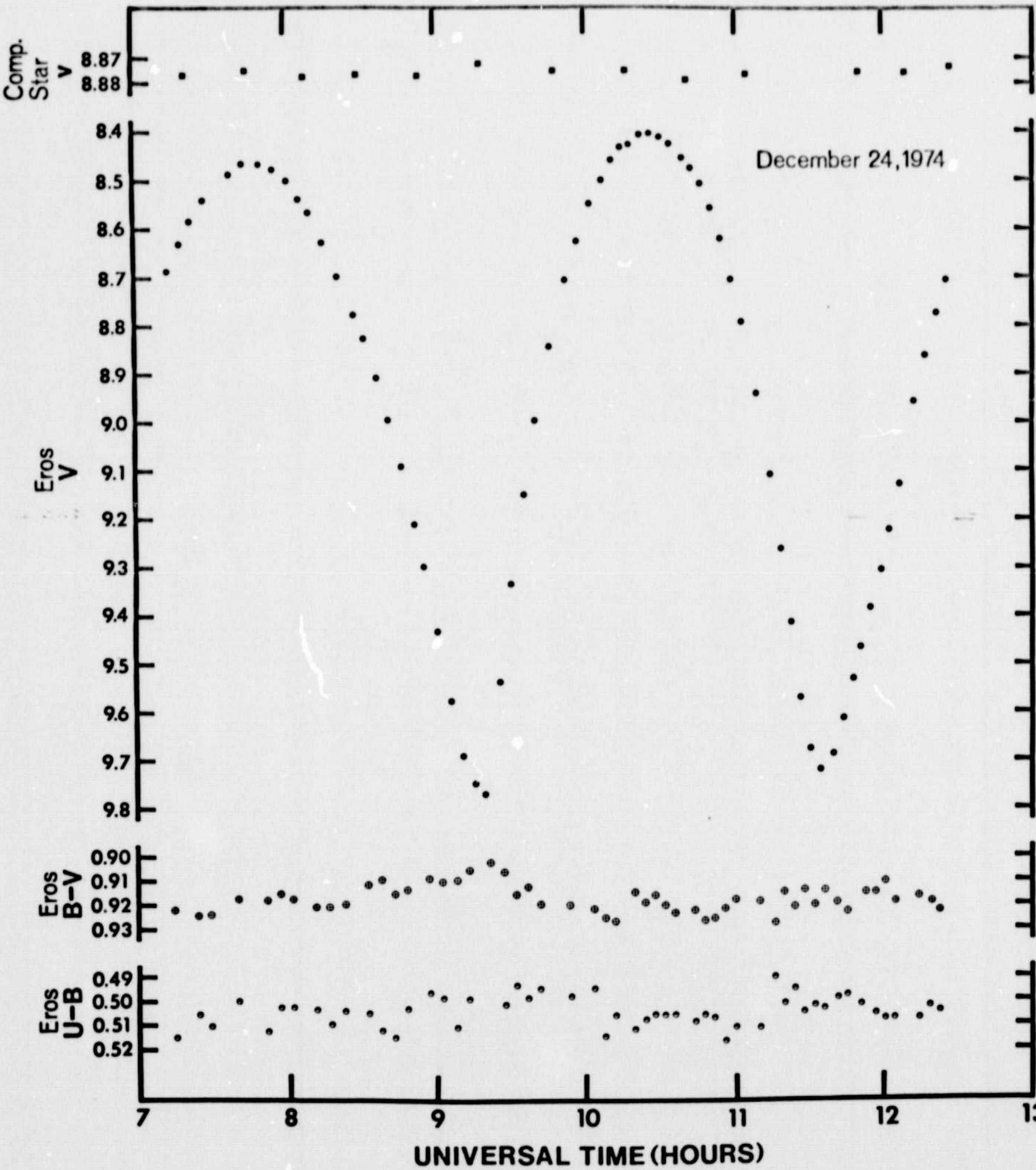
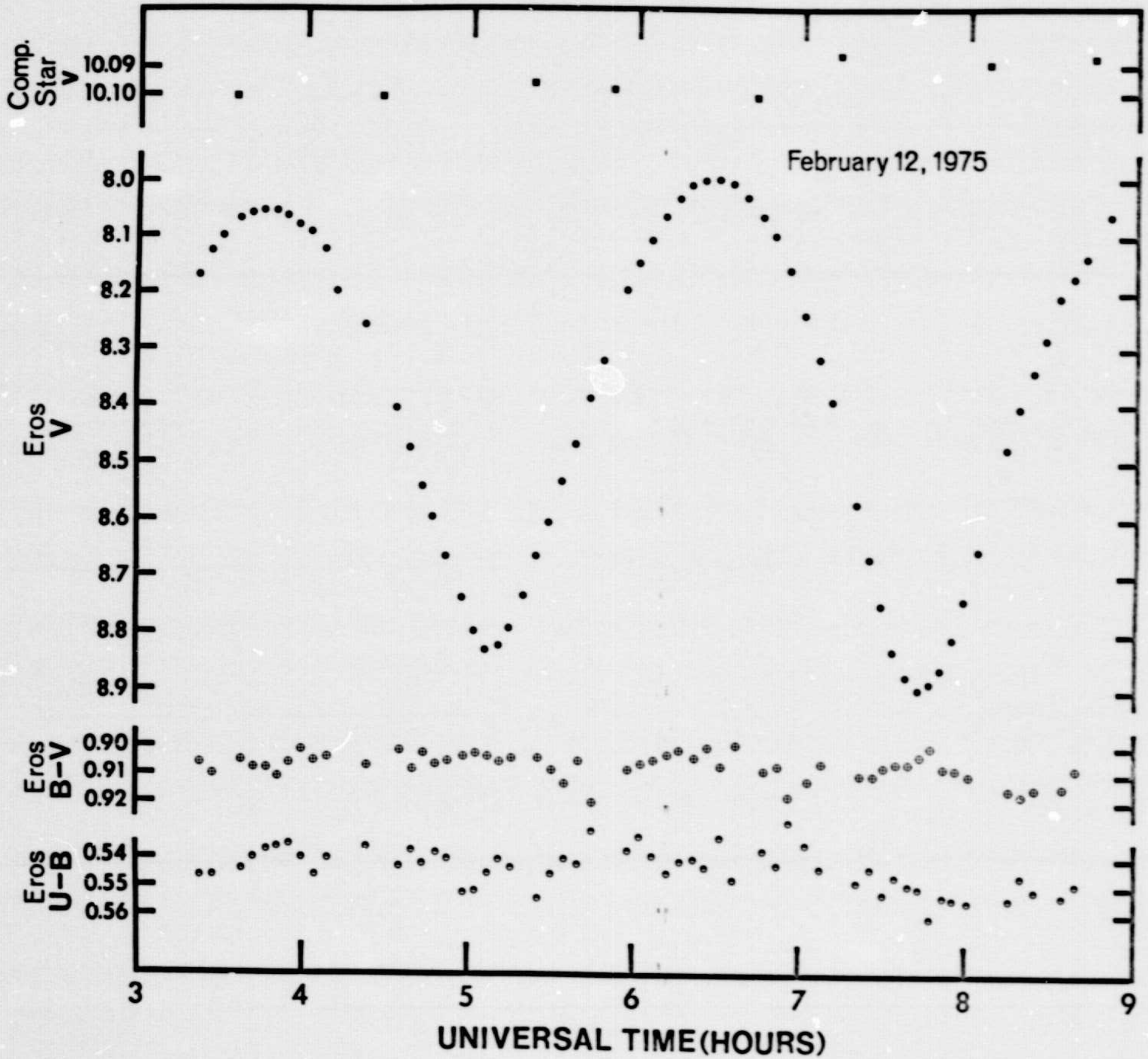
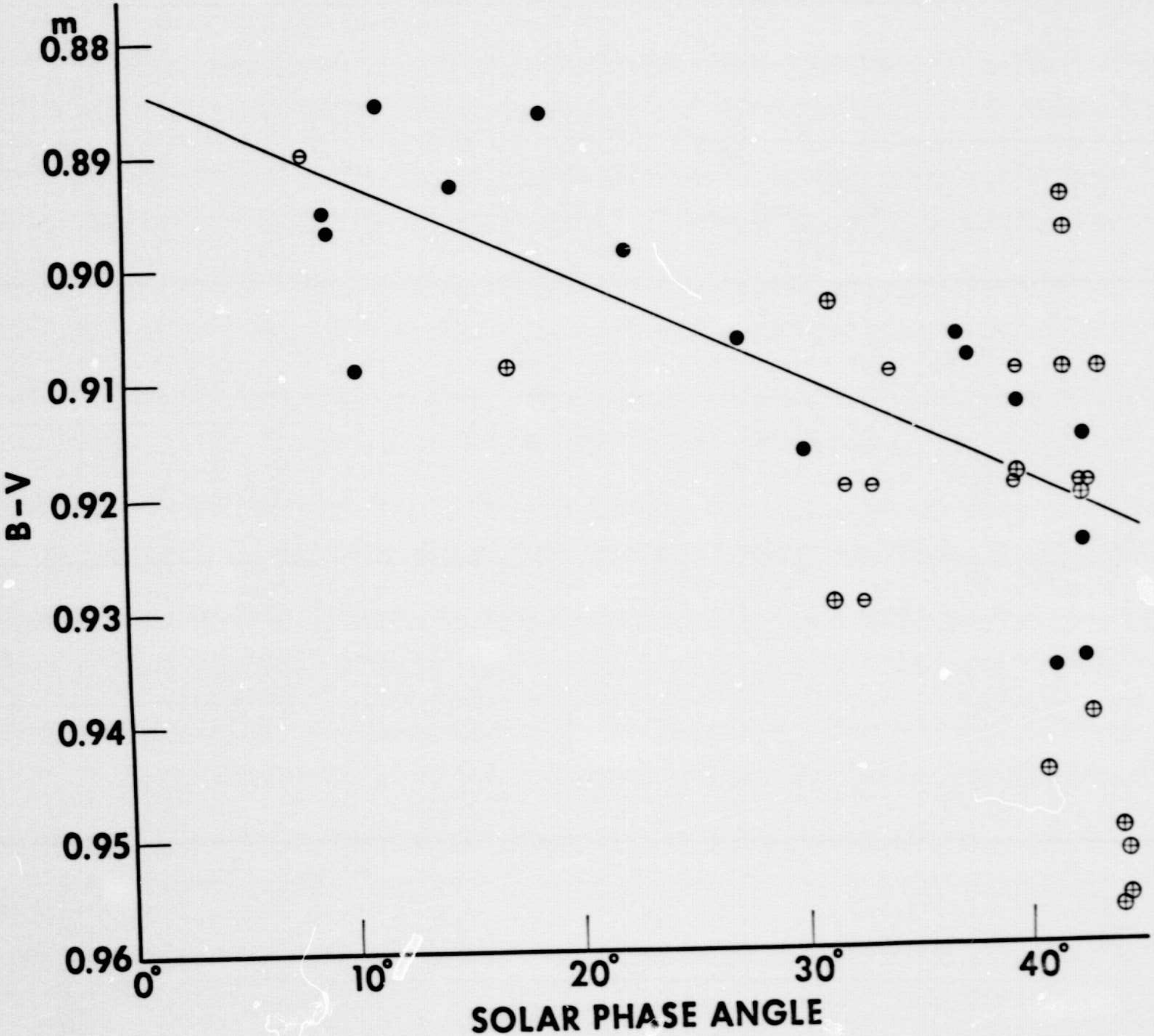
1.2
1.0
0.8
0.6
0.4
340
360
380
400
420
440
460
480
500
J.D.-2442000
$V_{Pm}-V_{PM}$
$V_{Sm}-V_{SM}$



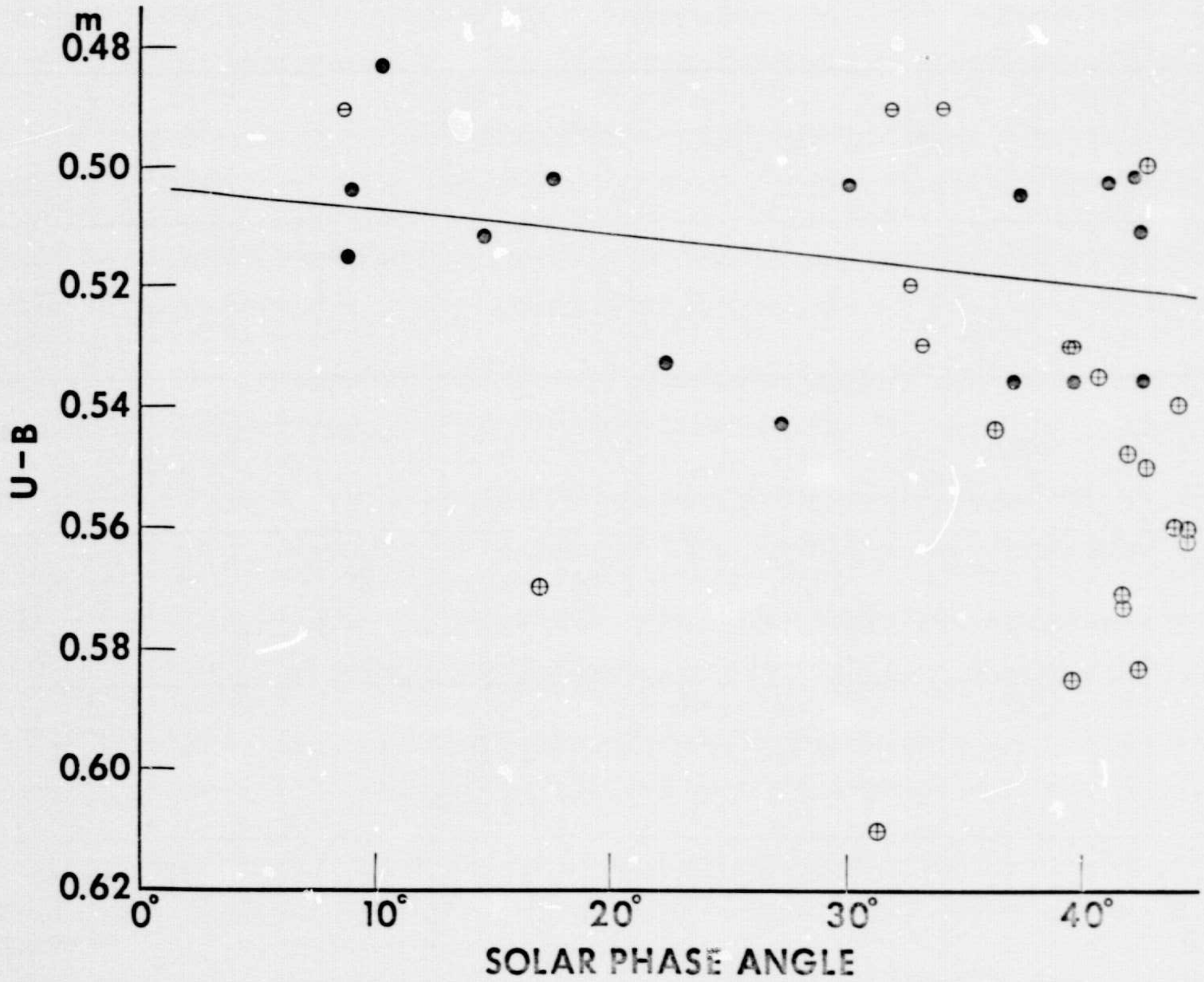
Millis et al. Figure 7



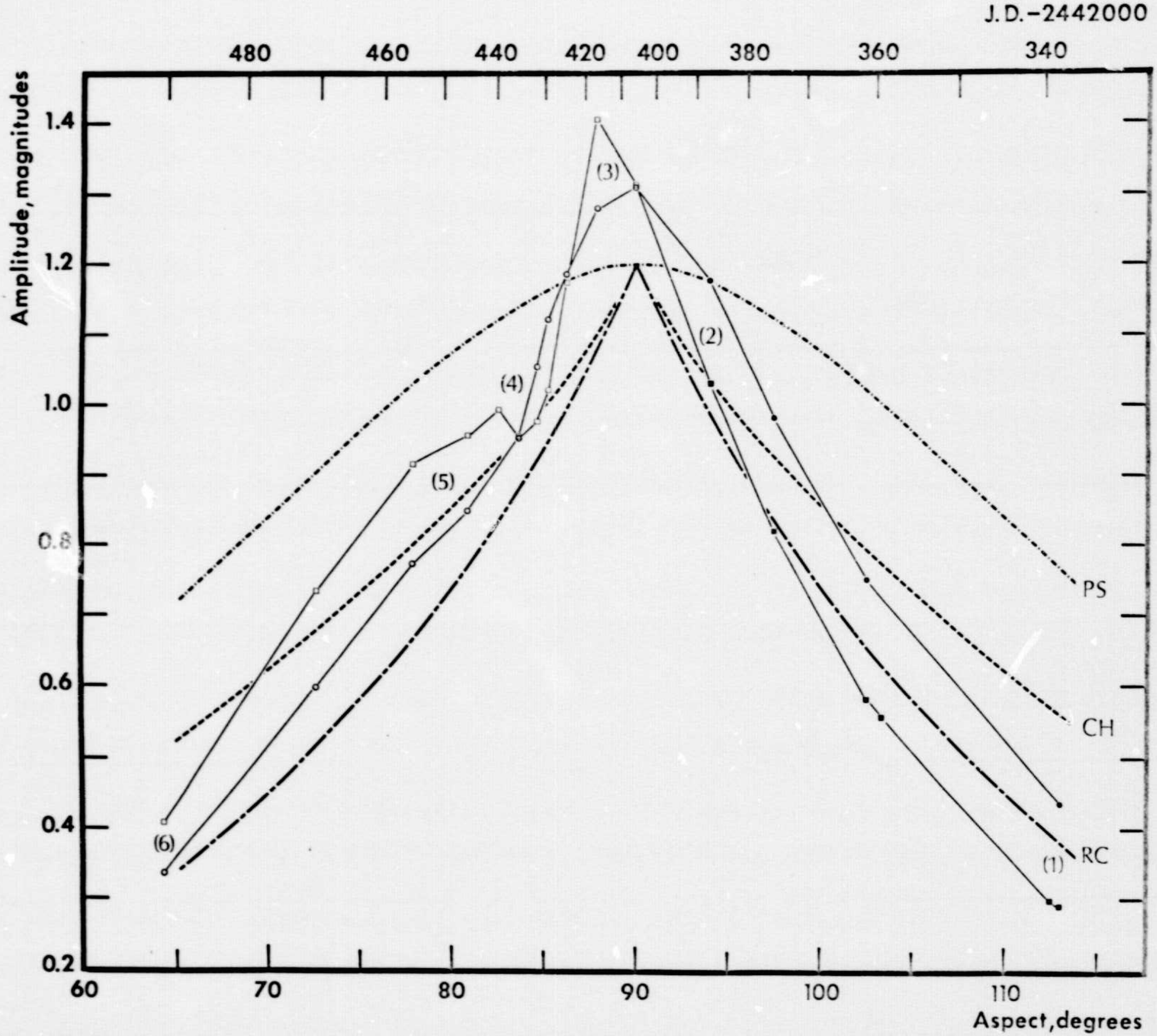
Millis et al. Figure 8



Millis et al. Figure 9



Millis et al. Figure 10.



Millis et al. Figure 11