

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

(NASA-CF-143316) UV PHOTOMETRY OF ASTEROID
433 EROS (Lowell Observatory) 42 P HC \$3.75
CSCI 03A

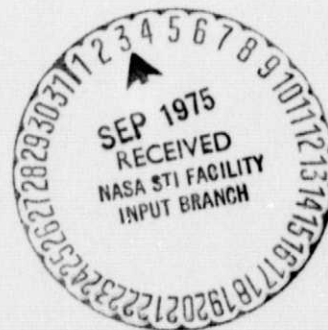
Unclas
33029

G3/89

UBV PHOTOMETRY OF ASTEROID 433 EROS

R. L. Millis, E. Bowell, and D. T. Thompson

Planetary Research Center
Lowell Observatory
Flagstaff, Arizona 86001



Four copies of manuscript submitted.

Manuscript totals 43 pages, including four Tables and eleven Figures.

RUNNING HEAD: UBV PHOTOMETRY OF EROS

Send proofs to: Dr. Robert L. Millis
Lowell Observatory
Post Office Box 1269
Flagstaff, Arizona 86001

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 $\lambda_0 = 15^\circ$ $\beta_0 = 9^\circ$.

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

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 dates¹ 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

¹U.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: $J.D. (c) = J.D. \text{ observed-light time}$. 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

Veeverka (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.

$$V(1,\alpha) = 10.85 + 0.0237 |\alpha| \quad (\text{primary maximum})$$
$$\pm 0.02 \quad \pm 0.0006$$

$$V(1,\alpha) = 10.79 + 0.0255 |\alpha| \quad (\text{secondary maximum})$$
$$\pm 0.02 \quad \pm 0.0006$$

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 $\beta_V = 0.0245 \text{ mag deg}^{-1}$. 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 1.4^m 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., $\psi = 90^\circ$), (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 astero-centric 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 astero-centric declination of the Earth $d_E (= 90^\circ - \psi)$ and that a given amplitude occurs twice during the apparition, when the aspect is $90^\circ \pm d_E$. Hence, if (α_1, δ_1) , (α_2, δ_2) are the right ascensions and declinations of Eros at aspects $90^\circ - d_E$ and $90^\circ + d_E$ respectively, and if (α_0, δ_0) is the right ascension and declination of the (northern hemisphere) pole of rotation of Eros, then

$$\tan \delta_0 = \frac{-\cos \delta_1 \cos (\alpha_1 - \alpha_0) - \cos \delta_2 \cos (\alpha_2 - \alpha_0)}{\sin \delta_1 + \sin \delta_2}$$

This equation is to be solved for α_0 , δ_0 by optimization techniques. Separate solutions were attempted for primary and secondary amplitudes, and we assumed that $\psi > 90^\circ$ ($d_E < 0^\circ$) 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_0 for each pair of geocentric positions then led to values for δ_0 . We suppose that if α_0 is correctly chosen, then the computed δ_0 will not vary with amplitude, in which case a plot of δ_0 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_0 and amplitude for all α_0 and that a determinate solution for (α_0, δ_0) exists.

The solutions are: $\alpha_0 = 0^h 42^m 8$, $\delta_0 = +14.9^\circ$ from the primary amplitudes, and $\alpha_0 = 1^h 10^m 6$, $\delta_0 = +10.3^\circ$ 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:

$$\begin{array}{lll} \alpha_0 = 0^h 42^m 8 \pm 4^m 0 & \delta_0 = +14.9^\circ \pm 3.4^\circ & (1950.0) \\ \lambda_0 = 15.4^\circ \pm 2.2^\circ & \beta_0 = +9.3^\circ \pm 3.8^\circ & (1950.0) \end{array}$$

The probable errors are estimated from the r.m.s. scatter about the least-squares line in the δ_0 , 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 nights¹ 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 deviation 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:

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

$$B-V (\alpha) = 0.884 + 0.00091 |\alpha|$$

$$\pm .005 \pm .0002$$

$$U-B (\alpha) = 0.503 + 0.00043 |\alpha|$$

$$\pm .011 \pm .0004$$

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

ORIGINAL PAGE --
OF POOR QUALITY

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

ORIGINAL PAGE IS
OF POOR QUALITY

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

ORIGINAL PAGE IS
OF POOR QUALITY

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 fraction 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^h 21^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 km² (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:

$$\begin{aligned} 1975 \text{ Jan } 24, 0^{\text{h}}21^{\text{m}} \text{ U.T. } V &= 8.009 \pm 0.012 - 0.020/\text{minute}; \\ V(1,\alpha) &= 11.843 \pm 0.012 - 0.020/\text{minute}; \\ V(1,0) &= 11.63 \pm 0.03 - 0.020/\text{minute}. \end{aligned}$$

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):

$$\log p_V = 6.244 - 0.4 V(1,0) - 2 \log D_0.$$

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 $D_0 = 11.5 \text{ km}$. 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 $D_0 = 24.8$ 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

We thank Karen Duck for assistance with data reduction. This research was supported by NASA grant NGR-03-003-001.

REFERENCES

- van den Bos, W. H., and Finsen, W. S. (1931). Physical observations of Eros. Astron. Nachr. 241, 329-334.
- Bowell, E., and Zellner, B. (1974). Polarizations of asteroids and satellites. In Planets, Stars and Nebulae Studied with Photopolarimetry (T. Gehrels, Ed.), pp. 381-404. University of Arizona Press, Tucson.
- Cailliatte, C. (1949). Sur la figure des planètes. Bull. Astron. 13, 21-83.
- Dunlap, J. L. (1972). Laboratory work on the shape of asteroids. Thesis. University of Arizona, Tucson.
- Dunlap, J. L. (1975). Lightcurves and the axis of rotation of 433 Eros. Icarus, this issue.
- Gehrels, T. (1970). Photometry of asteroids. In Surfaces and Interiors of Planets and Satellites (A. Dollfus, Ed.), pp. 317-375. Academic Press, London.
- O'Leary, B., Marsden, B., Dragon, R., Hansen, E., and McGrath, M. (1975). The occultation of Kappa Geminorum A by 433 Eros on 1975 January 24. Bull. Amer. Astron. Soc., in press.
- Roach, F. E., and Stoddard, L. G. (1938). A photoelectric light-curve of Eros. Astrophys. J. 88, 305-312.
- Taylor, B. C. (1971). Photometric observations and reductions of lightcurves of asteroids. In Physical Studies of Minor Planets (T. Gehrels, Ed.), pp. 117-131. NASA SP-267.

ORIGINAL PAGE IS
OF POOR QUALITY

Tedesco, E. F. (1975). Icarus, this issue.

Vesely, C. (1971). Summary on orientation of rotation axes. In Physical Studies of Minor Planets (T. Gehrels, Ed.), pp. 133-140. NASA SP-267.

Veverka, J. (1971). The physical meaning of phase coefficients. In Physical Studies of Minor Planets (T. Gehrels, Ed.), pp. 79-90. NASA SP-267.

Watson, F. (1937). The physical nature of Eros. Harvard College Obs. Circ. No. 419.

Wisniewski, W. (1975). Icarus, this issue.

Zellner, B., and Gradie, J. (1975). Polarization of the reflected light of asteroid 433 Eros. Icarus, this issue.

Zellner, B., Wisniewski, W., Andersson, L., and Bowell, E. (1975). Minor planets and related objects. XVIII. UBV photometry and surface composition. Astron. J., in press.

ORIGINAL PAGE -
OF POOR QUALITY

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 ^h 30 ^m 43 ^s	+50°00'.6	1.3307	0.5423	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 ^h 31 ^m 54 ^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	8.343	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

U.T.	V(1.00)	U.T.	V(1.00)	U.T.	V(1.00)	U.T.	V(1.00)	U.T.	V(1.00)
18 October 1974		09 ^h 01 ^m 5	12 ^m 419	09 ^h 41 ^m 0	12 ^m 601	08 ^h 30 ^m 8	11 ^m 922	09 ^h 50 ^m 0	11 ^m 305
06 ^h 30 ^m 5	12 ^m 075	09 10.5	12.399	09 46.5	12.576	08 36.1	12.001	09 53.5	11.504
06 42.0	12.138	09 17.5	12.375	09 54.2	12.533	08 41.2	12.089	09 57.6	11.509
06 54.1	12.179	09 23.9	12.299	09 58.4	12.500	08 46.5	12.185	10 04.2	11.553
07 02.2	12.195	09 35.9	12.123	10 06.1	12.415	08 51.9	12.305	10 10.5	11.572
07 13.2	12.182	09 45.8	12.031	10 11.7	12.301	08 55.8	12.394	10 14.7	11.493
07 21.3	12.139	09 53.2	11.941	10 19.2	12.144	09 01.1	12.528	10 20.8	11.477
07 33.9	12.064	10 November 1974		10 23.1	12.077	09 07.1	12.674	10 26.2	11.559
07 41.8	12.003			10 30.5	11.980	09 11.9	12.785	10 30.5	11.642
07 52.4	11.934	06 26.9	12.139	10 35.9	11.926	09 16.6	12.843	10 35.6	11.744
08 00.0	11.886	06 36.7	12.002	10 43.9	11.868	09 20.2	12.865	10 39.8	11.857
08 07.3	11.858	06 46.5	11.916	10 52.5	11.831	09 26.0	12.652	10 44.5	11.993
08 14.4	11.851	06 50.1	11.895	10 58.3	11.818	09 30.5	12.479	10 49.5	12.158
08 22.2	11.840	06 59.8	11.869	11 06.5	11.812	09 35.3	12.245	10 54.1	12.361
08 32.5	11.849	07 06.4	11.879	11 11.2	11.822	09 40.1	12.092	10 58.6	12.541
08 40.4	11.884	07 16.4	11.909	11 18.9	11.839	09 46.2	11.937	11 02.1	12.672
08 48.6	11.911	07 26.9	11.965	11 24.9	11.870	09 52.8	11.802	11 06.5	12.703
08 59.4	11.964	07 29.9	11.994	11 32.9	11.931	09 57.5	11.723	11 10.6	12.608
09 07.2	12.036	07 40.6	12.113	11 38.7	11.983	10 02.6	11.651	11 14.9	12.491
09 15.4	12.103	07 47.6	12.191	11 46.5	12.067	10 07.1	11.598	11 23.6	12.270
09 31.2	12.247	07 58.0	12.306	11 50.5	12.123	10 11.2	11.556	11 32.6	12.073
09 41.9	12.277	08 03.3	12.360	11 58.4	12.238	10 15.4	11.578	11 37.7	11.937
09 50.0	12.257	08 09.7	12.415	12 04.0	12.331	10 18.5	11.522	11 47.9	11.785
09 59.2	12.199	08 20.5	12.451	6 December 1974		10 22.4	11.505	11 47.9	11.716
10 10.1	12.125	08 27.4	12.448			10 26.4	11.503	11 52.4	11.648
10 19.7	12.044	08 37.1	12.431	07 20.8	11.789	10 30.4	11.509	11 57.1	11.576
10 27.1	11.986	08 43.3	12.396	07 28.9	11.750	10 34.3	11.521	12 01.8	11.509
10 34.7	11.951	08 52.7	12.272	07 40.3	11.728	10 39.4	11.550	12 06.4	11.462
10 45.2	11.905	09 03.7	12.125	07 48.1	11.746	10 42.3	11.571	12 11.4	11.417
10 53.0	11.902	09 10.4	12.034	07 55.9	11.788	10 46.3	11.607	12 16.1	11.387
11 02.5	11.908	09 19.4	11.955	08 03.5	11.837	10 50.2	11.658	12 21.1	11.559
11 10.5	11.941	09 22.3	11.934	08 16.0	11.954	10 54.3	11.720	12 24.5	11.358
11 21.0	11.981	09 28.7	11.891	08 23.6	12.047	10 58.9	11.804	12 29.2	11.345
11 35.9	12.044	09 38.2	11.863	08 31.2	12.162	11 03.0	11.890	12 34.0	11.341
19 October 1974		09 45.6	11.849	08 36.2	12.244	11 08.9	12.039	12 38.8	11.357
06 46.5	12.286	09 54.9	11.855	08 43.5	12.394	11 14.5	12.205	12 43.6	11.381
06 58.5	12.271	10 03.3	11.883	08 48.5	12.492	11 18.8	12.360	12 48.3	11.408
07 14.5	12.125	10 15.7	11.948	08 55.7	12.646	11 23.0	12.511	12 54.8	11.446
07 18.4	12.090	10 18.5	11.973	09 03.0	12.822	11 26.9	12.668	12 January 1975	
07 22.5	12.047	10 27.6	12.069	09 08.1	12.898	11 31.0	12.772	07 14.4	11.256
07 31.3	11.995	10 40.0	12.225	09 15.9	12.784	11 35.3	12.812	07 19.6	11.213
07 42.5	11.909	10 49.5	12.365	09 23.5	12.492	11 39.9	12.782	07 29.3	11.171
07 50.8	11.897	11 04.8	12.576	09 31.1	12.246	11 44.3	12.708	07 34.0	11.160
08 08.4	11.927	11 13.8	12.589	09 38.6	12.065	11 48.4	12.628	07 38.4	11.162
08 18.9	11.958	11 20.0	12.541	09 48.8	11.876	11 51.7	12.563	07 45.2	11.183
08 26.9	11.980	11 29.2	12.377	09 56.7	11.778	11 55.6	12.482	07 49.6	11.205
08 38.5	12.034	11 37.9	12.217	10 06.9	11.707	11 59.7	12.405	07 53.0	11.228
08 49.2	12.079	11 44.3	12.114	10 14.1	11.686	12 03.7	12.320	07 56.8	11.261
08 56.9	12.133	11 53.3	11.992	10 19.3	11.680	12 07.6	12.225	08 06.1	11.376
09 00.4	12.131	11 59.3	11.943	10 26.9	11.704	12 13.5	12.056	08 10.0	11.433
09 15.0	12.185	12 08.0	11.889	10 32.2	11.747	12 17.8	11.960	08 13.2	11.488
09 25.8	12.198	12 14.6	11.864	10 39.5	11.819	12 22.3	11.872	08 16.9	11.558
09 33.3	12.230	12 23.3	11.857	10 46.4	11.922	12 26.4	11.805	08 29.9	11.886
09 39.6	12.179	12 29.8	11.871	10 53.5	12.047	12 29.4	11.767	08 33.8	12.000
09 47.3	12.117	12 38.3	11.926	10 58.5	12.153	4 January 1975		08 36.9	12.087
09 54.7	12.047	24 November 1974		11 05.7	12.321	07 37.2	11.436	08 41.0	12.184
10 05.4	11.974			11 12.6	12.496	07 41.6	11.471	08 45.0	12.299
10 12.8	11.925	06 35.9	12.134	11 20.0	12.654	07 46.3	11.539	08 49.4	12.332
10 21.1	11.871	06 45.1	12.276	11 24.7	12.701	07 50.7	11.595	08 52.6	12.307
10 29.0	11.843	06 56.6	12.496	11 32.2	12.693	07 57.9	11.716	08 57.1	12.232
10 39.8	11.808	07 04.5	12.653	11 39.5	12.629	08 02.4	11.787	09 01.3	12.153
10 54.6	11.829	07 07.7	12.721	11 47.0	12.543	08 07.7	11.850	09 05.4	12.068
11 01.4	11.859	07 16.0	12.792	11 57.2	12.407	08 12.0	11.923	09 09.6	11.972
11 08.8	11.889	07 22.4	12.714	12 04.5	12.238	08 16.6	12.014	09 13.7	11.868
11 19.5	11.950	07 30.2	12.516	12 16.4	11.993	08 21.1	12.116	09 17.4	11.769
11 26.8	12.000	07 33.7	12.422	12 23.8	11.891	08 25.6	12.224	09 20.4	11.706
11 33.4	12.066	07 41.1	12.219	12 31.0	11.816	08 28.9	12.318	09 24.5	11.618
11 43.5	12.178	07 46.8	12.105	12 38.0	11.773	08 33.3	12.430	09 28.3	11.548
11 50.4	12.192	07 52.3	12.011	24 December 1974		08 37.7	12.523	09 31.7	11.495
8 November 1974		08 00.5	11.904			08 42.2	12.587	09 35.5	11.441
07 11.5	11.973	08 08.7	11.827	07 12.3	11.782	08 46.5	12.613	09 40.6	11.379
07 26.9	11.878	08 14.5	11.798	07 16.9	11.723	08 50.9	12.427	09 44.5	11.338
07 30.4	11.865	08 22.1	11.784	07 21.3	11.677	08 55.0	12.256	09 57.1	11.241
07 44.7	11.879	08 30.0	11.790	07 26.5	11.634	08 58.9	12.111	10 01.2	11.224
07 51.0	11.892	08 35.6	11.811	07 37.4	11.580	09 03.0	11.979	10 05.2	11.208
07 59.5	11.952	08 43.1	11.870	07 42.5	11.559	09 06.3	11.892	10 08.4	11.208
08 13.5	12.084	08 48.9	11.933	07 49.7	11.559	09 10.7	11.784	10 12.4	11.201
08 22.6	12.179	08 56.4	12.028	07 55.0	11.573	09 15.1	11.693	11 16.2	11.203
08 29.1	12.249	09 00.5	12.095	08 00.3	11.593	09 19.4	11.613	11 20.3	11.211
08 36.5	12.320	09 08.4	12.233	08 05.4	11.632	09 24.2	11.543	11 23.6	11.222
08 50.2	12.399	09 11.7	12.297	08 10.4	11.657	09 28.9	11.478	11 27.5	11.240
		09 19.5	12.438	08 15.1	11.721	09 35.0	11.409	11 31.3	11.266
		09 25.1	12.529	08 20.7	11.793	09 41.7	11.340	11 35.6	11.299
		09 33.2	12.590	08 27.0	11.873	09 45.9	11.318	11 39.1	11.330

Table III continued.

U.T.	V(1,3)	U.T.	V(1,3)	U.T.	V(1,3)	U.T.	V(1,3)	U.T.	V(1,3)
12 Jan. (cont'd.)		12 ^h 24 ^m 7	11 ^m 715	05 ^h 43 ^m 5	12 ^m 022	09 ^h 29 ^m 7	11 ^m 083	05 ^h 31 ^m 5	11 ^m 122
10 ^h 43 ^m 2	11 ^m 375	12 29.3	11.801	05 44.7	17.017	09 33.1	11.076	05 54.4	11.178
10 46.6	11.419	12 30.2	11.957	05 45.9	17.054	09 36.2	11.070	05 57.3	11.179
10 50.7	11.476	12 40.0	12.060	05 47.1	11.990	09 39.3	11.073	06 00.1	11.178
10 53.8	11.519	12 46.0	12.201	05 48.8	11.966	09 42.8	11.076	06 05.1	11.183
10 58.1	11.585	12 50.6	12.114	05 50.0	11.937	09 45.8	11.081	06 06.7	11.189
11 01.4	11.638	12 52.8	12.043	05 51.3	11.908	09 49.0	11.092	06 09.7	11.217
11 05.7	11.698			05 52.7	11.873	09 52.4	11.111	06 12.5	11.228
11 09.9	11.766	19 January 1975		05 54.2	11.837	09 56.1	11.135	06 15.3	11.256
11 12.9	11.823	05 59.9	11.202	05 55.5	11.804	10 00.9	11.163	06 20.5	11.322
11 17.6	11.910	06 03.3	11.259	05 56.5	11.777	10 04.1	11.184	06 44.1	11.704
11 20.8	11.980	06 06.5	11.308	06 00.3	11.684	10 07.2	11.215	06 47.0	11.776
11 25.2	12.102	06 10.5	11.368	06 04.0	11.605	10 11.0	11.260	06 56.8	11.948
11 29.5	12.225	06 20.9	11.466	06 07.7	11.531	10 14.1	11.291	06 59.7	12.003
11 32.6	12.323	06 25.8	11.544	06 11.0	11.468	10 17.2	11.327	07 02.3	12.055
11 37.5	12.384	06 30.1	11.614	06 14.3	11.419	10 20.5	11.372	07 04.4	12.074
11 40.7	12.540	06 34.1	11.684	06 17.4	11.367	10 24.2	11.420	07 06.5	12.075
11 45.3	12.184	06 38.2	11.754	06 20.6	11.318	10 27.6	11.475	07 08.5	12.115
11 49.8	12.023	06 42.8	11.857	06 23.6	11.275	10 31.8	11.534	07 10.7	12.197
11 54.5	11.881	06 47.1	11.960	06 26.9	11.238	10 35.2	11.597	07 12.7	12.070
11 57.7	11.796	06 51.4	12.072	06 30.0	11.196	10 39.0	11.663	07 15.0	12.030
12 02.0	11.696	06 55.4	12.115	06 32.9	11.166	10 42.9	11.730	07 17.0	12.010
12 05.2	11.623	07 00.5	11.924	06 35.8	11.140	10 46.7	11.806	07 19.1	11.976
12 09.4	11.542	07 07.6	11.800	06 42.3	11.089	10 50.8	11.892	07 21.3	11.948
12 14.9	11.451	07 11.6	11.687	06 45.2	11.069	10 52.5	11.926	07 28.3	11.853
12 18.4	11.397	07 15.7	11.596	06 48.2	11.055	10 55.8	11.952	07 31.7	11.732
12 22.6	11.342	07 20.2	11.512	06 51.5	11.041	10 55.1	11.978	07 34.8	11.667
12 41.8	11.185	07 25.2	11.421	06 54.8	11.030	10 56.9	12.006	07 37.7	11.624
		07 36.1	11.257	06 57.8	11.027	10 58.2	12.011		
		07 40.5	11.204	07 00.7	11.025	10 59.5	12.016	2 February 1975	
		07 44.0	11.154	07 03.9	11.026	11 00.8	12.013	03 32.3	11.465
17 January 1975		07 49.6	11.110	07 06.8	11.033	11 02.0	12.001	03 35.2	11.433
07 44.6	11.806	07 53.9	11.081	07 09.8	11.041	11 03.5	11.976	03 37.4	11.410
07 48.7	11.698	07 58.2	11.057	07 12.7	11.054	11 05.2	11.952	03 39.4	11.387
07 56.1	11.542	08 02.4	11.038	07 15.9	11.073	11 06.5	11.919	03 41.6	11.371
08 00.7	11.469	08 06.5	11.030	07 18.8	11.089	11 07.9	11.889	03 44.3	11.345
08 04.6	11.396	08 11.2	11.024	07 21.8	11.115	11 09.2	11.854	03 46.3	11.326
08 09.1	11.328	08 15.7	11.029	07 24.7	11.140	11 10.9	11.819	03 49.5	11.304
08 14.6	11.258	08 20.5	11.044	07 27.7	11.172	11 14.6	11.734	03 54.1	11.281
08 19.5	11.200	08 29.1	11.091	07 30.6	11.206			03 57.3	11.263
08 26.8	11.133	08 33.5	11.129	07 33.7	11.245	27 January 1975		03 59.3	11.263
08 32.3	11.094	08 38.6	11.182	07 36.6	11.286	03 39.7	11.332	04 01.3	11.259
08 36.8	11.071	08 48.6	11.316	07 39.6	11.336	03 44.2	11.347	04 03.2	11.261
08 41.3	11.063	08 54.4	11.425	07 42.7	11.391	03 50.3	11.428	04 05.3	11.259
08 45.4	11.055	08 59.3	11.531	07 45.7	11.445	03 53.6	11.476	04 07.6	11.253
08 49.9	11.063	09 04.2	11.640	07 48.6	11.507	03 56.6	11.514	04 12.3	11.267
08 54.5	11.073	09 08.7	11.728	07 51.8	11.567	03 59.6	11.550	04 15.3	11.277
08 58.9	11.093	09 13.3	11.818	07 55.0	11.622	04 05.3	11.642	04 18.3	11.287
09 03.4	11.119	09 17.7	11.897	07 58.5	11.689	04 08.2	11.694	04 20.3	11.298
09 08.9	11.166	09 22.3	11.961	08 01.9	11.757	04 11.4	11.744	04 22.3	11.313
09 14.2	11.225	09 27.0	11.995	08 05.4	11.817	04 14.5	11.808	04 24.3	11.324
09 20.5	11.315	09 31.6	11.992	08 09.9	11.873	04 17.6	11.853	04 26.4	11.335
09 25.2	11.389	09 36.7	11.950	08 10.8	11.895	04 20.3	11.899	04 28.3	11.362
09 30.5	11.486	09 41.4	11.865	08 12.1	11.913	04 23.1	11.946	04 33.3	11.410
09 35.3	11.597	09 46.0	11.753	08 13.6	11.942	04 25.1	11.979	04 36.3	11.451
09 40.1	11.715	09 54.9	11.553	08 14.9	11.948	04 27.0	12.017	04 39.2	11.489
09 44.2	11.798	09 59.4	11.469	08 16.1	11.959	04 28.9	12.040	04 41.1	11.519
09 48.5	11.895	10 04.5	11.385	08 17.4	11.974	04 30.9	12.052	04 43.1	11.546
09 53.5	11.989	10 09.4	11.317	08 18.7	11.978	04 32.8	12.063	04 44.9	11.579
09 57.7	12.047	10 20.0	11.198	08 20.3	11.980	04 34.8	12.062	04 47.1	11.621
10 02.5	12.070	10 25.3	11.159	08 21.5	11.979	04 36.7	12.050	04 49.3	11.662
10 06.8	12.058	10 31.3	11.114	08 22.7	11.980	04 38.6	12.019	04 51.3	11.700
10 11.3	12.000	10 35.5	11.097	08 24.0	11.962	04 40.5	11.987	04 55.9	11.783
10 15.9	11.927	10 39.9	11.081	08 25.7	11.944	04 42.4	11.943	04 59.4	11.857
10 20.0	11.833	10 44.4	11.072	08 26.9	11.924	04 44.3	11.903	05 02.1	11.906
10 38.4	11.443	10 48.8	11.067	08 28.2	11.907	04 47.6	11.850	05 04.1	11.960
10 42.7	11.376	10 53.2	11.076	08 29.5	11.880	04 50.6	11.778	05 06.5	12.002
10 47.7	11.312	10 57.9	11.085	08 30.8	11.855	04 53.6	11.717	05 08.9	12.060
10 52.8	11.248	11 02.2	11.107	08 32.3	11.829	04 56.6	11.668	05 10.8	12.093
10 58.8	11.200	11 10.4	11.155	08 35.8	11.746	04 59.6	11.610	05 13.1	12.132
11 03.5	11.169	11 14.4	11.188	08 39.3	11.660	05 02.6	11.554	05 15.5	12.170
11 09.3	11.115	23 January 1975		08 42.4	11.591	05 05.7	11.506	05 17.5	12.182
11 14.7	11.096	05 12.8	11.495	08 45.8	11.526	05 08.5	11.456	05 19.5	12.203
11 19.6	11.081	05 18.1	11.579	08 49.0	11.469	05 11.4	11.419	05 21.4	12.208
11 24.5	11.079	05 22.1	11.645	08 52.3	11.413	05 14.7	11.362	05 23.3	12.208
11 30.2	11.089	05 27.0	11.738	08 55.3	11.364	05 17.8	11.328	05 25.3	12.195
11 32.4	11.097	05 31.5	11.821	08 58.5	11.322	05 20.8	11.291	05 27.3	12.175
11 38.7	11.125	05 34.7	11.861	09 01.7	11.278	05 23.7	11.258	05 29.2	12.151
11 49.0	11.213	05 38.2	11.951	09 04.8	11.247	05 26.8	11.227	05 31.3	12.128
11 55.8	11.283	05 39.3	11.986	09 07.7	11.214	05 30.0	11.208	05 33.6	12.095
12 01.5	11.357	05 40.7	12.004	09 11.0	11.181	05 32.9	11.179	05 35.9	12.059
12 06.5	11.424	05 42.2	12.023	09 14.0	11.158	05 38.2	11.156	05 38.6	12.014
12 11.1	11.486			09 17.4	11.135	05 41.1	11.142	05 41.2	11.972
12 15.0	11.549			09 20.4	11.114	05 43.9	11.135	05 47.4	11.840
12 19.9	11.630			09 23.3	11.102	05 46.7	11.129	05 49.9	11.794

ORIGINAL PAGE IS
OF POOR QUALITY

Table III continued.

U.T.	V(1,2)	U.T.	V(1,2)	U.T.	V(1,2)	U.T.	V(1,2)	U.T.	V(1,2)
2 Feb. (cont'd.)									
05 54.1	11.725	08 15.6	11.050	06 29.9	11.450	05 51.5	11.378	04 10.3	11.904
05 56.0	11.691	08 17.3	11.990	06 35.2	11.457	05 55.2	11.416	04 13.1	11.892
05 57.9	11.658	08 19.7	11.955	06 40.4	11.482	05 59.0	11.433	04 16.0	11.887
05 59.8	11.623	08 22.6	11.895	06 45.7	11.516	06 02.7	11.440	04 19.7	11.890
06 02.7	11.579	08 24.5	11.865	06 50.5	11.552	06 06.5	11.428	04 23.0	11.878
06 05.5	11.542	08 26.5	11.833	06 55.4	11.612	06 10.3	11.405	04 26.8	11.883
06 08.0	11.506	08 28.5	11.794	07 00.9	11.702	06 13.9	11.374	04 29.9	11.888
06 10.7	11.470	08 30.4	11.760	07 06.3	11.781	06 17.7	11.358	04 32.8	11.899
06 12.5	11.457	08 33.0	11.717	07 10.8	11.857	06 21.6	11.283	04 35.6	11.902
06 14.4	11.436	08 35.6	11.671	07 20.2	12.035	06 25.2	11.245	04 39.2	11.919
06 13.3	11.411	08 38.4	11.630	07 24.8	12.133	06 29.0	11.184	04 42.6	11.926
06 18.5	11.397	08 40.6	11.590	07 29.2	12.215	06 32.8	11.147	04 47.3	11.948
06 20.7	11.387	08 42.8	11.548	07 33.5	12.293	06 36.6	11.095	04 50.0	11.962
06 23.1	11.371	08 44.8	11.525	07 38.0	12.339	06 40.5	11.047	04 52.7	11.976
06 25.1	11.359	08 46.7	11.503	07 42.4	12.358	06 44.5	11.005	04 55.4	11.992
06 27.1	11.355	08 48.7	11.478	07 46.6	12.348	06 48.0	11.978	05 58.9	12.022
06 29.1	11.346	08 50.6	11.457	07 50.6	12.323	06 51.7	11.938	05 02.2	12.039
06 31.6	11.330	08 52.5	11.430	07 54.6	12.371	06 55.4	11.891	05 06.3	12.071
06 34.2	11.331	08 54.5	11.407	07 58.8	12.204	06 59.2	11.867	05 09.0	12.100
06 37.0	11.321	08 57.1	11.399	08 01.1	12.119	07 02.8	11.836	05 11.8	12.118
06 39.0	11.319	08 59.7	11.348	08 14.6	11.940	07 06.9	11.805	05 14.5	12.145
06 41.0	11.322	09 03.5	11.322	08 18.9	11.868	07 10.8	11.781	05 18.2	12.177
06 43.6	11.323	09 05.5	11.308	08 23.5	11.891	07 14.6	11.770	05 22.0	12.213
06 45.7	11.331	09 07.5	11.292	08 28.2	11.745	07 18.5	11.757	05 26.1	12.237
06 47.7	11.333	09 10.0	11.283	08 33.5	11.609	07 22.3	11.758	05 28.9	12.259
06 49.8	11.331			08 38.3	11.632	07 26.3	11.762	05 31.6	12.268
06 53.5	11.338			08 42.6	11.596	07 30.1	11.772	05 34.4	12.279
06 55.5	11.340			08 51.7	11.526	07 33.9	11.778	05 38.3	12.287
06 58.3	11.356					07 37.7	11.795	05 41.6	12.290
07 00.4	11.374					07 41.5	11.811	05 45.6	12.281
07 03.2	11.391					07 45.4	11.834	05 48.4	12.258
07 05.2	11.403					07 49.2	11.865	05 51.1	12.239
07 07.0	11.420					07 53.2	11.895	05 54.7	12.217
07 09.2	11.435					07 57.1	11.937	05 58.1	12.197
07 11.1	11.450					08 01.2	11.982	06 01.0	12.165
07 13.7	11.475					08 05.5	12.026	06 04.8	12.144
07 16.1	11.498					08 10.0	12.066	06 07.6	12.125
07 18.9	11.537					08 14.6	12.106	06 10.3	12.105
07 20.8	11.566					08 18.9	12.146	06 13.0	12.082
07 22.7	11.586					08 23.5	12.186	06 16.5	12.059
07 24.6	11.607					08 28.2	12.226	06 19.9	12.039
07 26.7	11.647					08 33.5	12.266	06 23.9	12.008
07 29.9	11.680					08 38.3	12.306	06 26.8	11.989
07 30.8	11.708					08 42.6	12.346	06 29.6	11.973
07 32.9	11.733					08 47.2	12.386	06 32.4	11.953
07 35.8	11.782					08 51.7	12.426	06 35.1	11.938
07 38.0	11.817					08 56.3	12.466	06 38.7	11.925
07 39.9	11.843					09 00.3	12.506	06 42.1	11.912
07 41.8	11.877							06 45.6	11.906
07 44.3	11.920							06 49.4	11.895
07 46.6	11.951							06 52.2	11.886
07 49.5	11.999							06 54.9	11.884
07 51.4	12.035							06 58.7	11.893
07 53.4	12.063							07 01.9	11.890
07 55.4	12.088							07 06.4	11.899
07 58.2	12.120							07 09.2	11.904
08 00.1	12.139							07 12.1	11.909
08 02.0	12.158							07 14.8	11.925
08 03.9	12.167							07 18.5	11.942
08 05.7	12.161							07 22.1	11.951
08 07.8	12.140							07 26.7	11.983
08 09.8	12.111							07 29.5	11.996
08 11.5	12.082							07 32.8	12.028

ORIGINAL PAGE IS
OF POOR QUALITY

Table IV. Epochs of light-curve maxima and minima

1974/5 U.T.	PRIMARY MAXIMUM		PRIMARY MINIMUM		SECONDARY MAXIMUM		SECONDARY MINIMUM	
	J.D. (c) -2442000 $\pm \epsilon \times 10^5$	V(1, α)	J.D. (c) -2442000 $\pm \epsilon \times 10^5$	V(1, α)	J.D. (c) -2442000 $\pm \epsilon \times 10^5$	V(1, α)	J.D. (c) -2442000 $\pm \epsilon \times 10^5$	V(1, α)
18 Oct	338.84542 \pm 139 ^a	11.831	338.90022 \pm 104	12.270	338.94844 \pm 69	11.902	338.79052 \pm 231 ^a	12.194
19 Oct	339.94199 \pm 347 ^a	11.808			339.82802 \pm 139 ^a	11.897	339.88613 \pm 347 ^a	12.195
8 Nov					359.81378 \pm 116 ^a	11.865	359.87253 \pm 128 ^a	12.419
10 Nov	361.90506 \pm 74	11.849	361.96328 \pm 28	12.599	361.79044 \pm 139 ^a	11.869	361.84858 \pm 67	12.450
					362.00966 \pm 64			
24 Nov	375.95991 \pm 16	11.812	375.79904 \pm 45	12.793	375.84672 \pm 126	11.784	375.89953 \pm 53	12.602
6 Dec	387.81705 \pm 16	11.728	387.87951 \pm 8	12.903	387.92775 \pm 45	11.680	387.97655 \pm 64	12.709
24 Dec	405.82359 \pm 130	11.559	405.88685 \pm 59	12.868	405.93376 \pm 54	11.503	405.98172 \pm 41	12.813
4 Jan	417.01758 \pm 69	11.341	416.86413 \pm 9	12.620	416.91295 \pm 64	11.304	416.96052 \pm 32	12.709
12 Jan	424.92314 \pm 89	11.201	424.98352 \pm 8	12.385	424.81613 \pm 60 ^a	11.160	424.86619 \pm 6	12.332
17 Jan	429.97174 \pm 29	11.079	430.03055 \pm 69 ^a	12.201	429.86600 \pm 116	11.655	429.91818 \pm 21	12.077
19 Jan	431.94609 \pm 140	11.067	431.78700 \pm 7	12.120	431.83969 \pm 47	11.024	431.88508 \pm 29	11.998
23 Jan	435.89905 \pm 101	11.070	435.73716 \pm 9	12.024	435.79091 \pm 42	11.025	435.84668 \pm 9	11.978
			435.95737 \pm 14 ^a	12.017				
27 Jan			439.68883 \pm 5	12.063	439.74255 \pm 50	11.122	439.79698 \pm 31	12.115

Table IV. (continued)

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

^aEpoch 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.

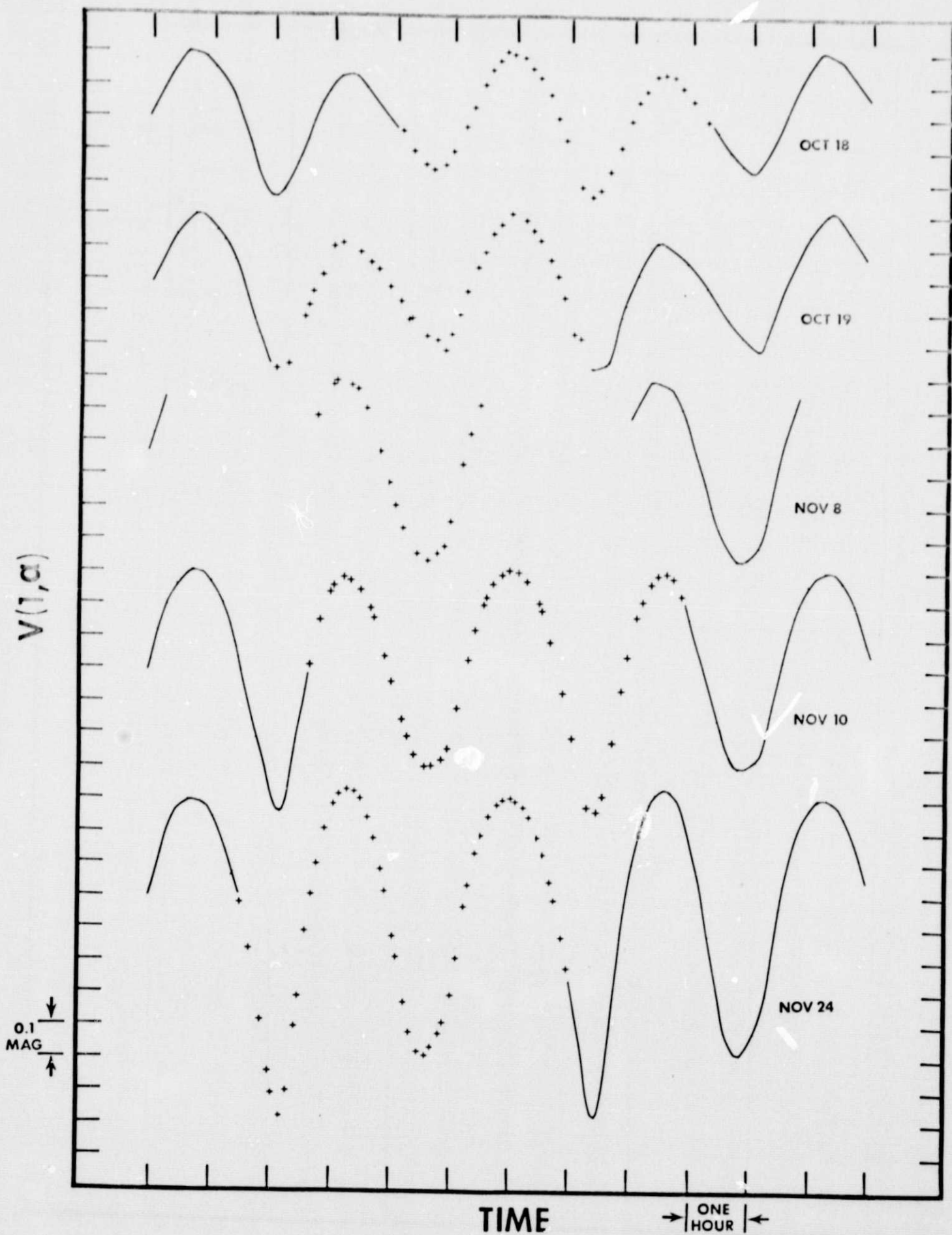
The observed V magnitudes of the comparison star are also given as an indication of the photometric quality of the night. Note that the measurements of Eros' brightness are plotted on a compressed scale.

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 Wisniewski (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 Wisniewski (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 $\psi > 90^\circ$, and open symbols to $\psi < 90^\circ$. Computed amplitude-aspect curves are identified as follows: PS prolate spheroid, CH cylinder with hemispherical ends, and RC right cylinder.



$V(1,\alpha)$

0.1
MAG

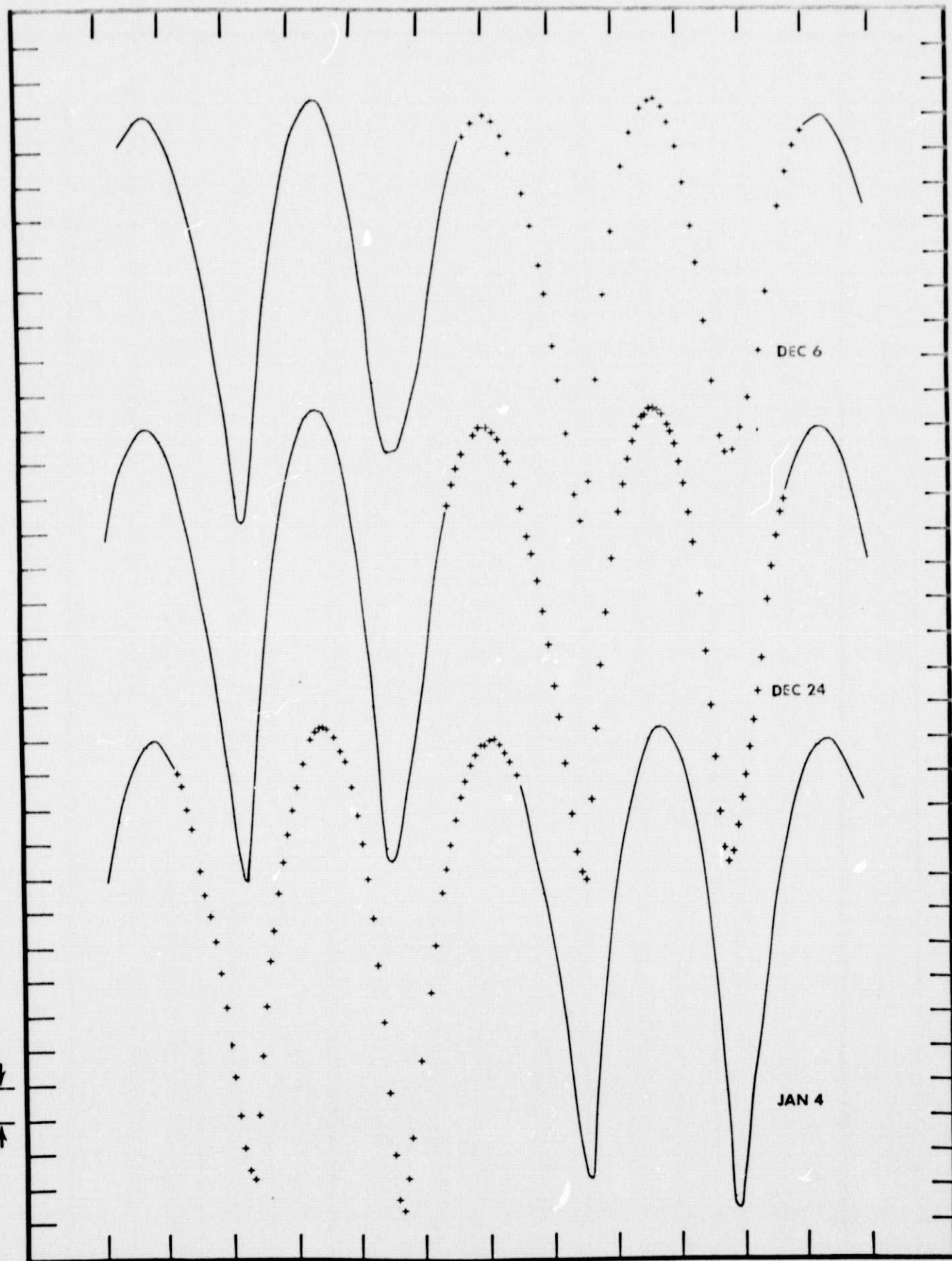
TIME

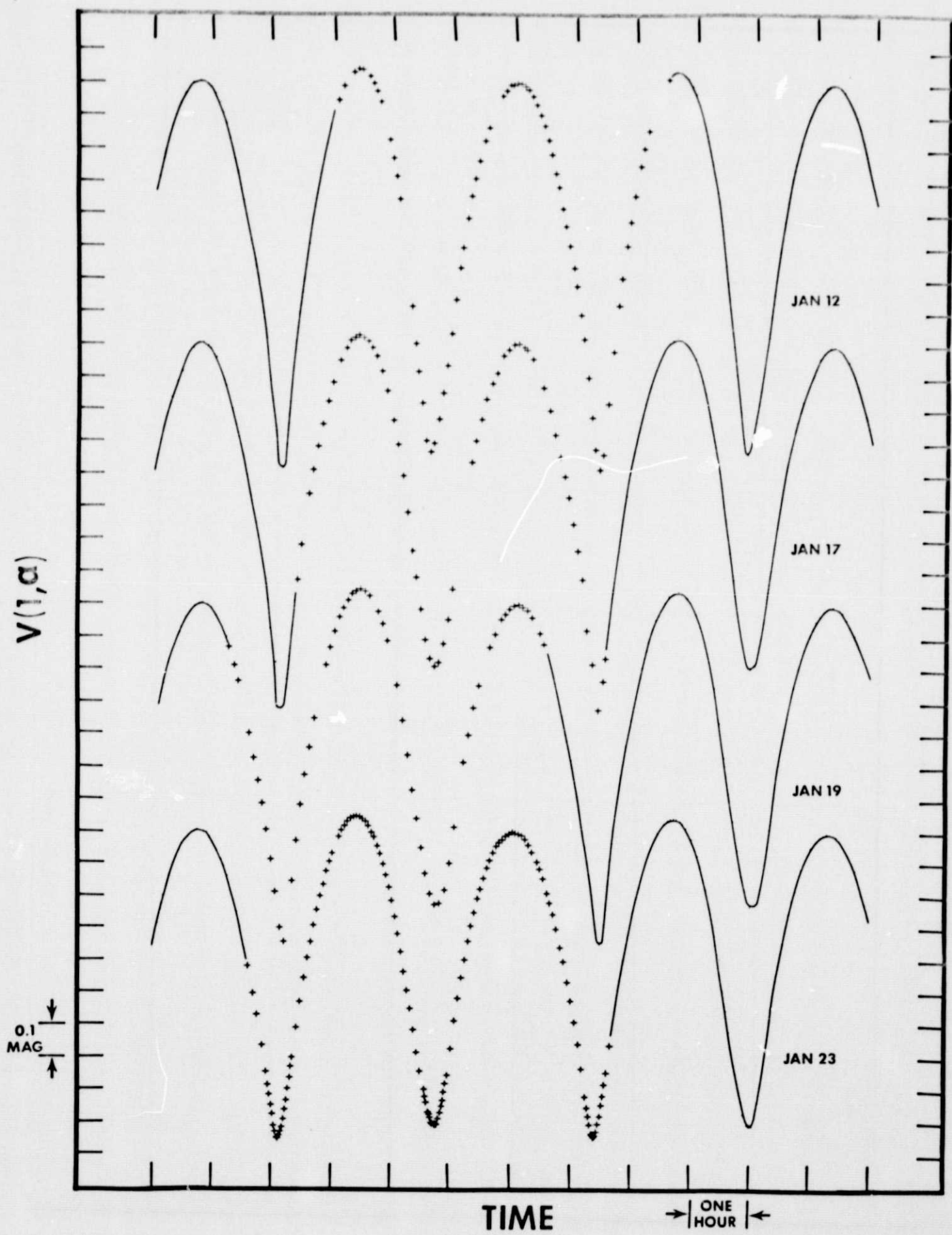
ONE
HOUR

DEC 6

DEC 24

JAN 4





$V(1, \alpha)$

0.1
MAG

JAN 27

FEB 2

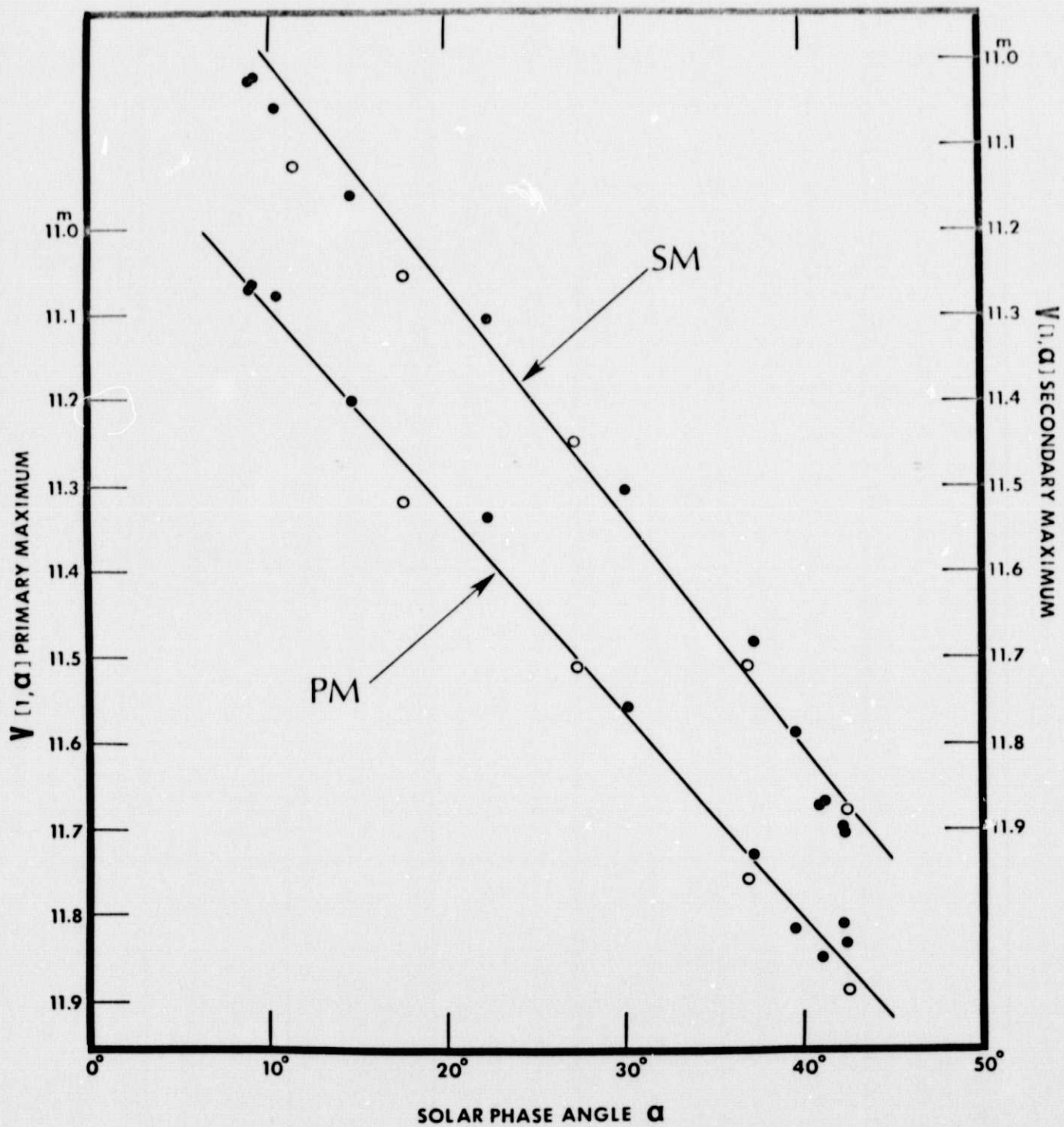
FEB 12

FEB 27

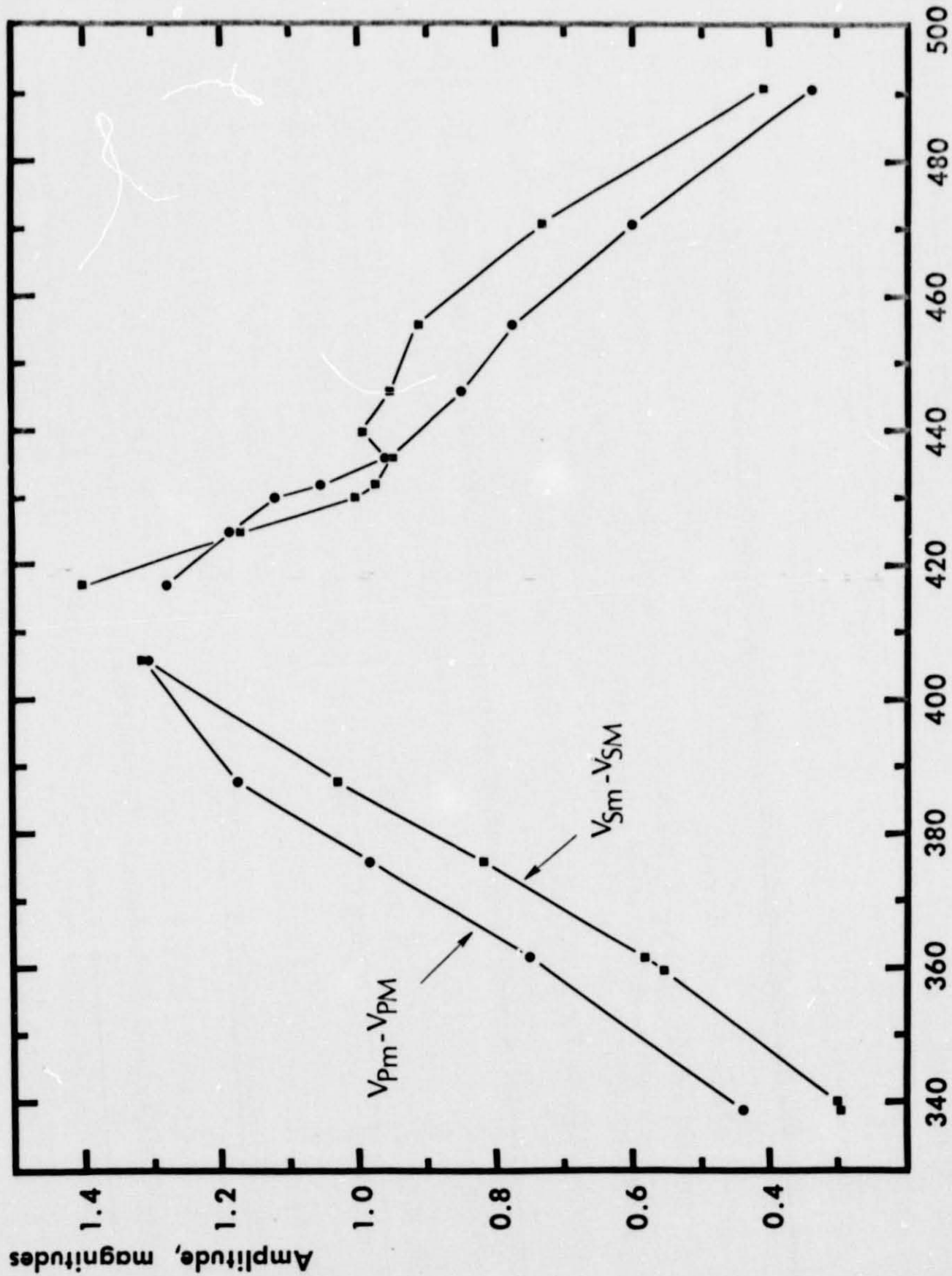
MAR 19

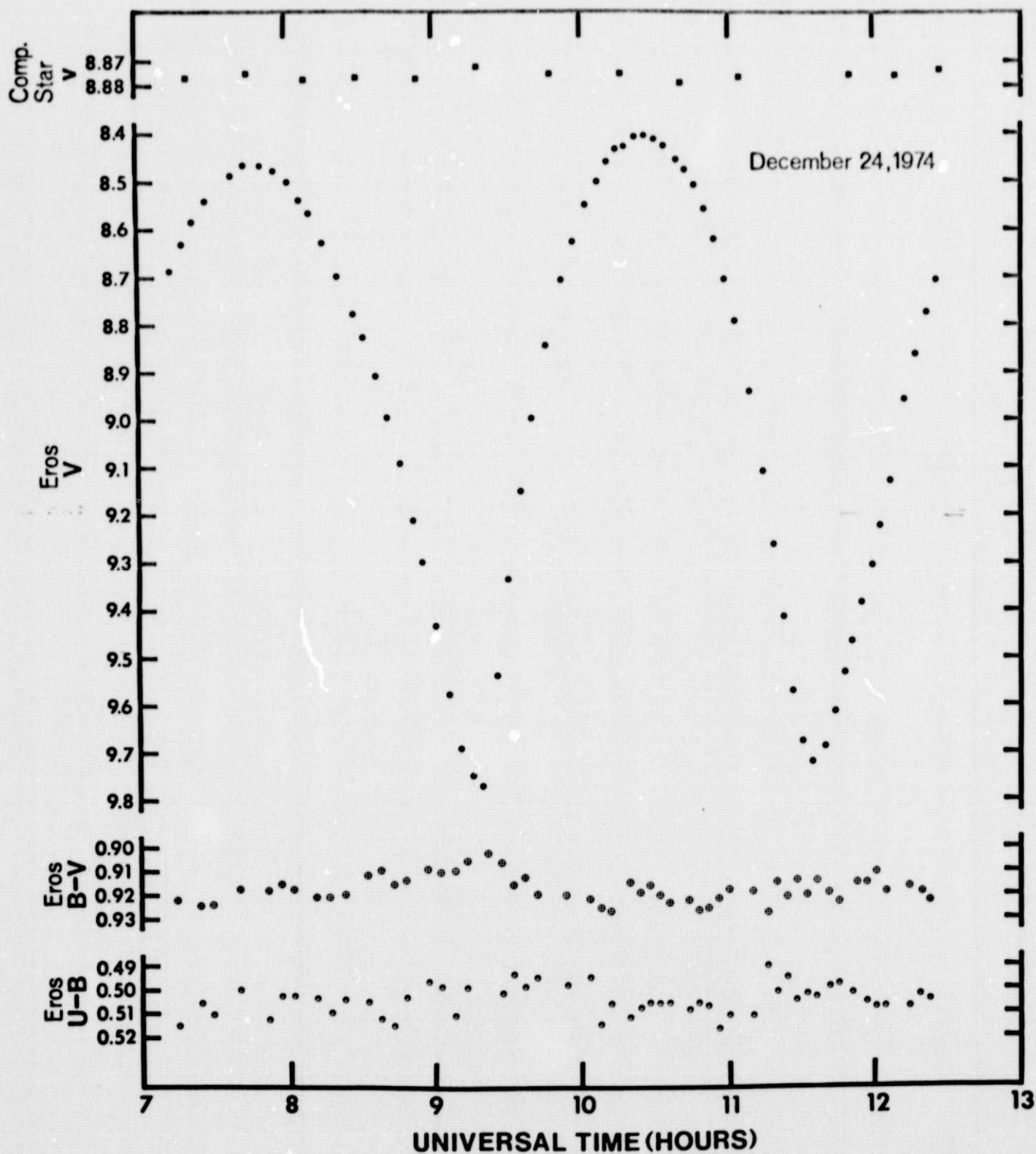
TIME

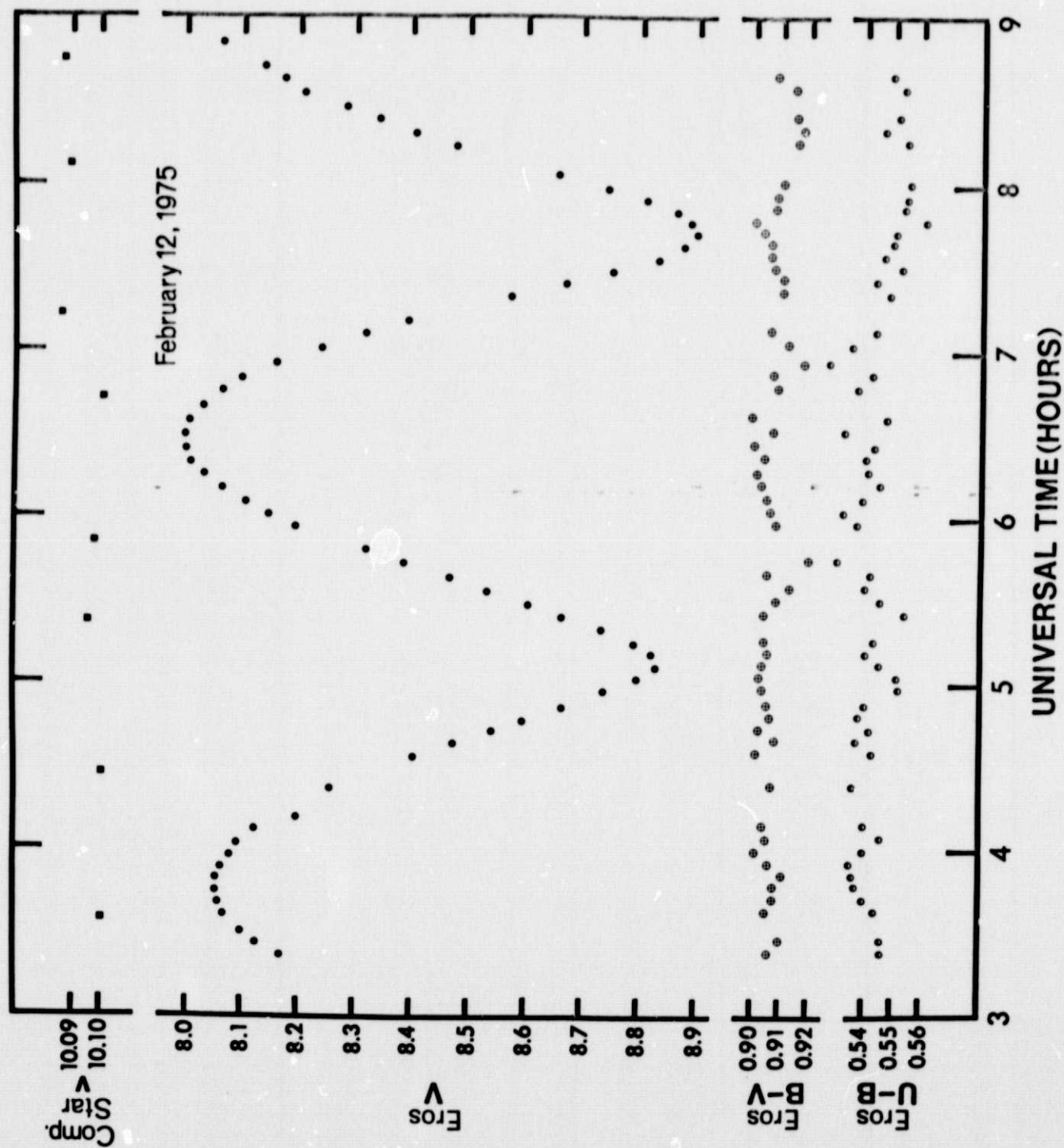
ONE
HOUR

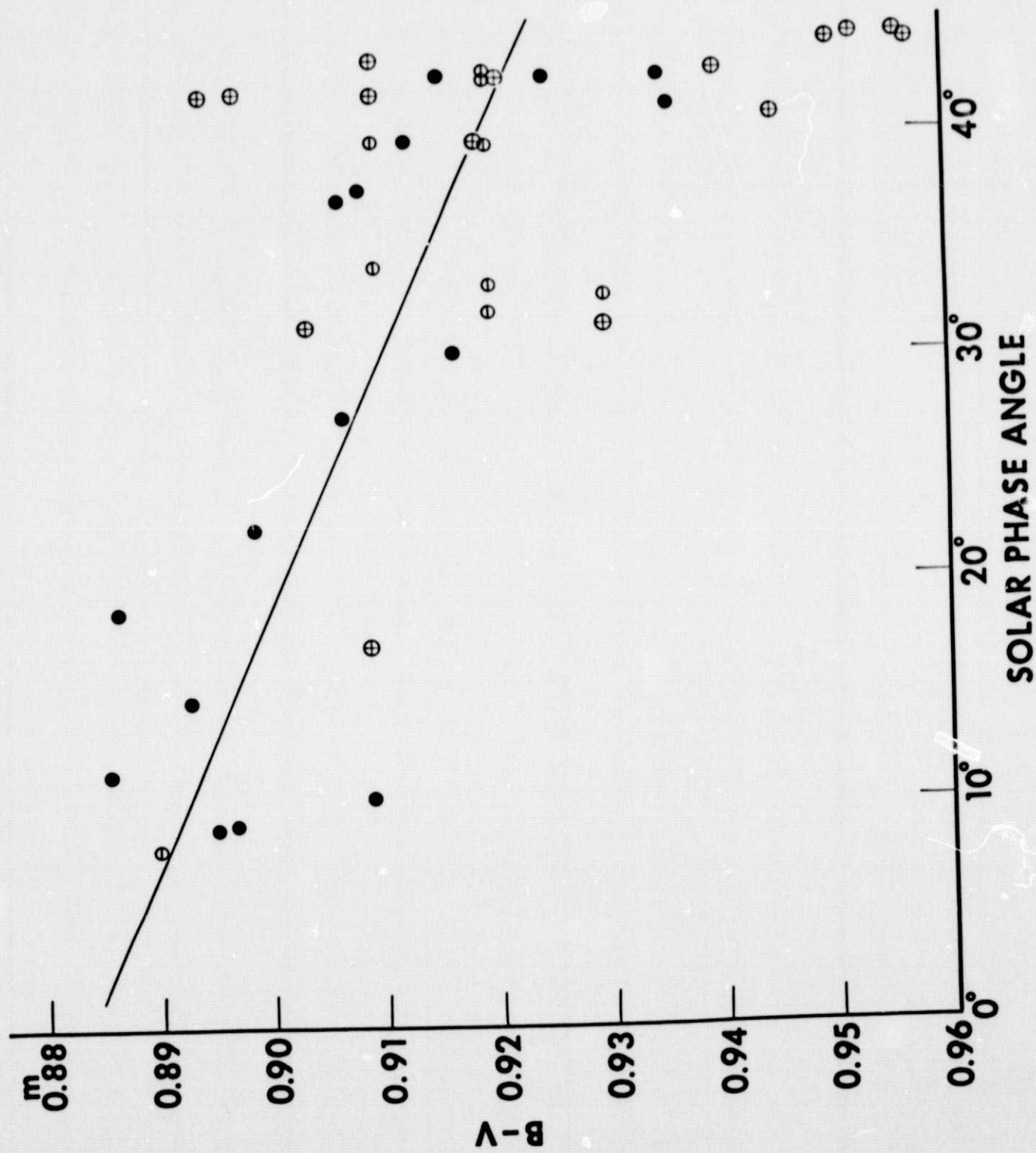


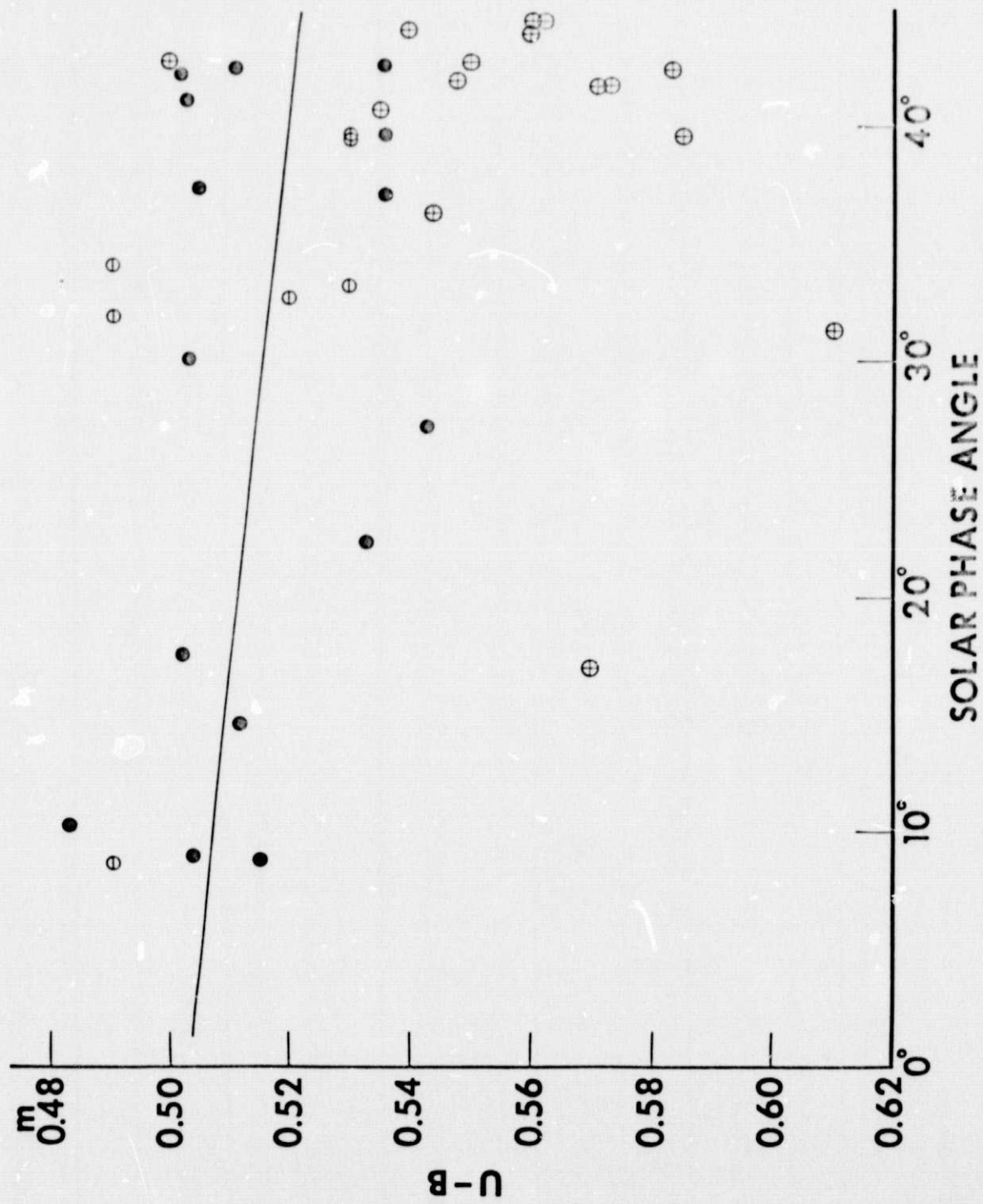
Millis et al. Figure 5











Millis et al. Figure 10.

