

Minor Planets and Related Objects. VI. Asteroid (110) Lydia

R. C. TAYLOR, T. GEHRELS, AND A. B. SILVESTER

Lunar and Planetary Laboratory, The University of Arizona, Tucson, Arizona

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Lydia was observed in 1958–59 at the McDonald Observatory and in 1969 at the Kitt Peak National Observatory. The lightcurve has three maxima and minima, and it shows that Lydia has an irregular shape. The synodic period is $10^h55^m36^s24\pm0^s04$ (p.e.). The absolute magnitude is $B(1,0)=8.80$, and the colors at zero phase angle are $B-V=+0.71$ and $U-B=+0.29$. The opposition effect and reddening with phase are clearly evident. A striking similarity was found among the opposition effects of Vesta, Massalia, and Lydia.

I. OBSERVATIONS

THREE asteroids were observed at the McDonald Observatory in 1958–59 specifically for the brightness-phase functions near opposition; they are (4) Vesta, (6) Hebe, and (110) Lydia. The results on Vesta are in Paper I (Gehrels 1967) and on Lydia in this paper, while we are preparing those on Hebe for a future paper in this series.

Table I lists the circumstances of the observations. They were made at the McDonald Observatory; with the 91-cm reflector: 18 October through 17 November 1958 and on 11 December 1958; with the Otto Struve 208-cm reflector: 20 November through 2 December

1958 and on 25 January 1959; these observations were made by Gehrels. An additional observation was made by R. G. Thomas with the Kitt Peak 41-cm "No. 3" reflector on 16 March 1969. A part of the reductions was made by Silvester, while Taylor was responsible for the final reductions and analysis. The observations and reductions followed the methods described in Paper I. $O-C$ corrections in 1958–59 averaged $+0^m9$ in right ascension and $+6'$ in declination.

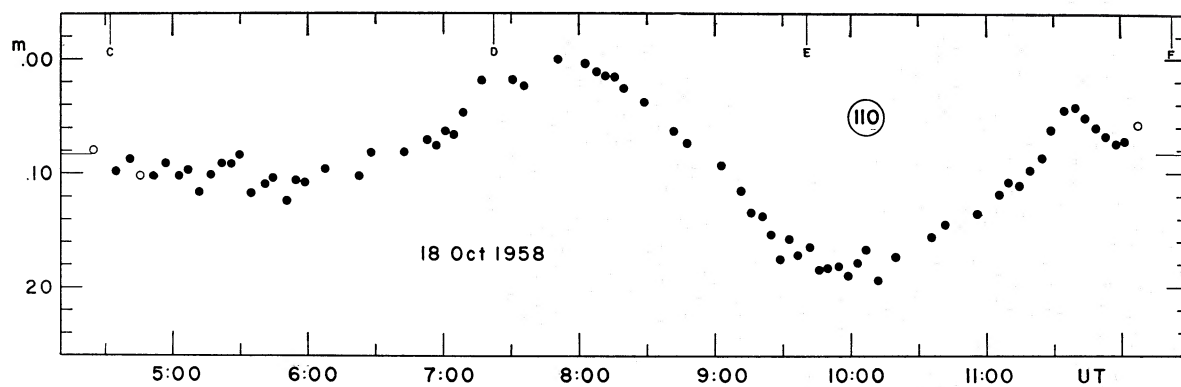
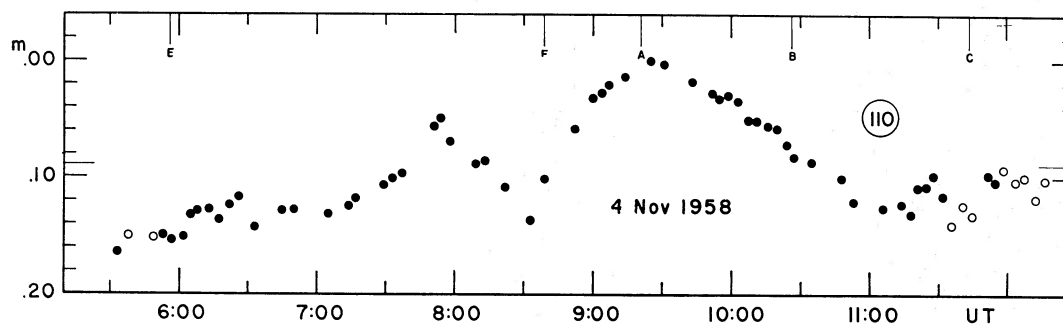
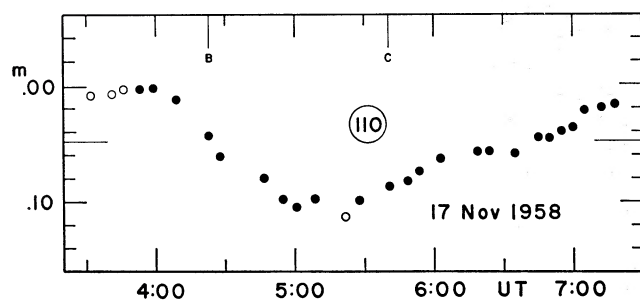
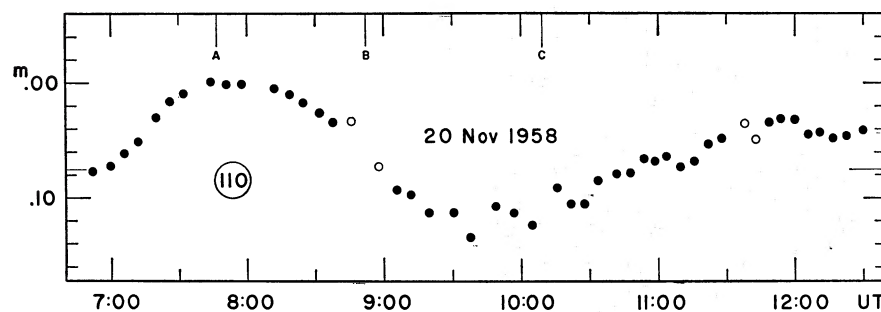
Table II gives various data for the comparison stars. Under "Scatter of comp. readings" the table gives the average deviation from a smooth curve of comparison-star magnitudes versus time.

TABLE I. Aspect data for Lydia.

Obs. date U.T.	Phase angle	Distance from Sun (a.u.)	Distance from Earth (a.u.)	Light time	R.A. 1950	Dec. 1950	Ecliptic long. 1950	lat. 1950
58.10.18	$-14^{\circ}95$ ± 0.02	2.6552 ± 0.0001	1.8419 ± 0.0001	0.01063 ± 0.00001	4^h25^m3 ± 0.2	$+21^{\circ}1'$ ± 1	$67^{\circ}98$ ± 0.03	$-0^{\circ}64$ ± 0.03
58.11.04	-8.83	2.6687	1.7340	1001	$4\ 15.4$	$+21\ 12$	65.74	-0.07
58.11.09	-6.70	2.6730	1.7147	990	$4\ 11.0$	$+21\ 12$	64.73	$+0.11$
58.11.17	-3.24	2.6798	1.6982	981	$4\ 3.3$	$+21\ 11$	62.96	$+0.43$
58.11.20	-1.79	2.6823	1.6962	980	$4\ 0.1$	$+21\ 9$	62.23	$+0.54$
58.11.25	-0.56	2.6859	1.6986	981	$3\ 55.3$	$+21\ 7$	61.12	$+0.73$
58.11.29	$+2.37$	2.6897	1.7073	986	$3\ 51.2$	$+21\ 5$	60.18	$+0.91$
58.12.02	$+3.57$	2.6915	1.7149	990	$3\ 48.8$	$+21\ 0$	59.62	$+0.94$
58.12.11	$+7.50$	2.6990	1.7565	1014	$3\ 40.4$	$+20\ 54$	57.68	$+1.28$
59.01.25	$+19.66$	2.7359	2.2275	1287	$3\ 29.4$	$+21\ 16$	55.27	$+2.24$
69.03.16	$+10.27$	2.9445	2.0527	0.01186	$9\ 58.6$	$+21\ 12$	144.40	$+8.30$

TABLE II. Comparison stars and quality of nights.

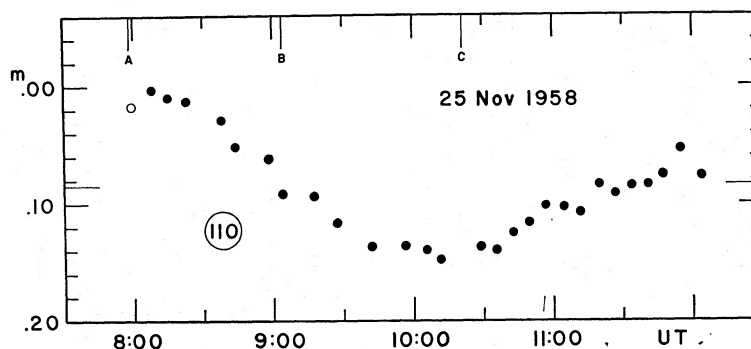
Obs. date U.T.	R.A. 1950	Dec. 1950	V (mag)	$B-V$ (mag)	Scatter of comp. readings (mag)	Remarks
58.10.18	4^h26^m1 ± 0.2	$+21^{\circ}02'$ ± 3	11.690 ± 0.006	$+0.777$ ± 0.005	± 0.005	
58.11.04	$4\ 16.2$	$21\ 11$	8.181	0.467	0.007	Cloudy and hazy most of night
58.11.09	$4\ 11.8$	$21\ 29$	11.802	0.903	0.004	One-hour lightcurve only
58.11.17	$4\ 04.6$	$21\ 22$	11.652	1.687	0.008	
58.11.20	$4\ 01.8$	$21\ 22$	11.243	1.030	0.008	Equipment trouble
58.11.25	$3\ 56.0$	$21\ 08$	12.504	0.711	0.004	
58.11.29	$3\ 52.3$	$21\ 08$	11.972	0.943	0.005	Excellent sky until stopped by clouds
58.12.02	$3\ 49.4$	$21\ 19$	9.486	1.521	0.005	
58.12.11	$3\ 41.8$	$20\ 53$	11.718	0.408	0.010	
59.01.25	$3\ 30.2$	$21\ 19$	13.492	$+0.782$	0.009	
69.03.16	$9\ 58.2$	$+21\ 18$	...	...	± 0.01	Some cirrus

FIG. 1. McDonald observations at -15° phase.FIG. 2. McDonald observations at -9° phase.FIG. 3. McDonald observations at -3° phase.FIG. 4. McDonald observations at -2° phase.

II. LIGHTCURVES AND PHASE FUNCTIONS

Figures 1–10 show the lightcurves. The McDonald observations were made using the V filter of a standard UBV photometer; each point in the figures is the

straight average of four integrations each lasting 30 to 40 sec. The short lightcurve of 9 November 1958 is not included. The Kitt Peak observations were made using a GG13 filter with averages of four integrations

FIG. 5. McDonald observations at -1° phase.

of 30 sec. Open circles are used when the probable error is greater than about 3 times that of the nightly average. "Mean V " lines were determined by planimetry and they are indicated by horizontal thin lines on the lightcurves.

Figure 11 is a calculated lightcurve for which Figs. 1-9 were superimposed as indicated by the lettered vertical bars on the top of each figure. Lydia appears to have an irregular shape. The third maximum (near 7:00) is quite pronounced.

The solid line in Fig. 11 is for an average phase angle near 8° while the dashed and dotted lines are for about 2° phase; over this small range, little variation in the shape of the lightcurve is seen although the previous findings of steeper lightcurves away from opposition (Gehrels 1956, 1967) appears confirmed.

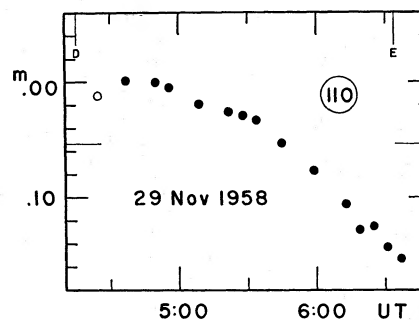
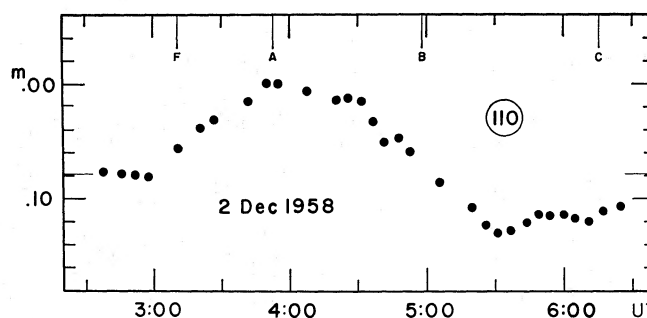
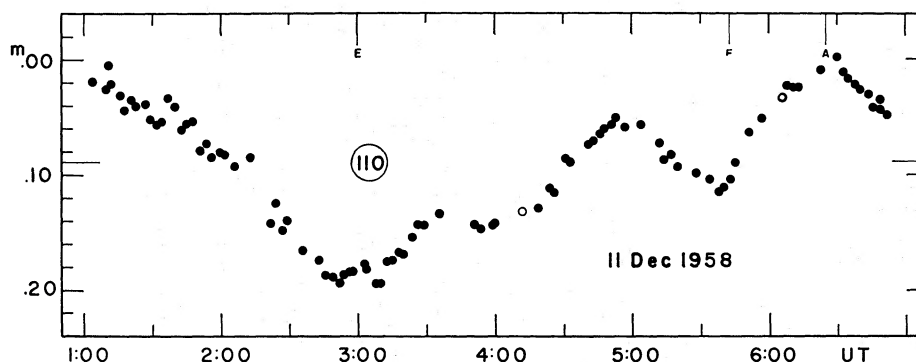
FIG. 6. McDonald observations at $+2^\circ$ phase.

Table III contains the nightly averages of the UBV results. For each number a relative weight is estimated; usually about six transfer measurements were made

FIG. 7. McDonald observations at $+4^\circ$ phase.FIG. 8. McDonald observations at $+8^\circ$ phase.

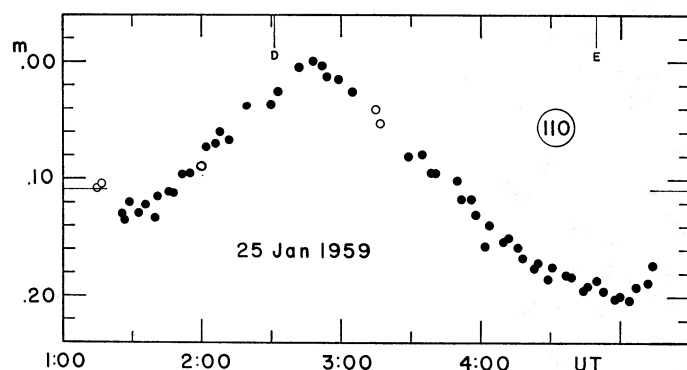


FIG. 9. McDonald observations at +20° phase.

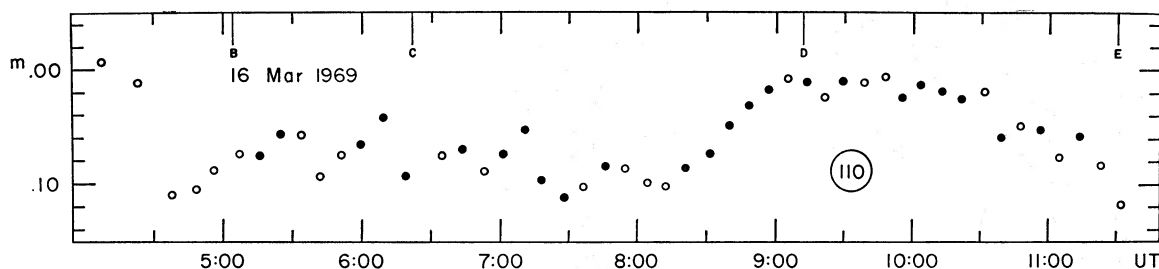


FIG. 10. Kitt Peak observations at +10° phase.

per night. No *UBV* transfers were made for the light-curve of 1969.

Figure 12 shows the magnitudes and colors as functions of the orbital phase angle. The opposition effect (viz. Sec. IV) and reddening with phase are clearly seen.

In calculating the phase functions, linear relations were assumed (only the data from nights with phase angles greater than 8° were used for the *V* filter). The results are:

$$V(1,\alpha) = 8.09 + 0.032|\alpha|,$$

$$B - V = +0.706 + 0.0016|\alpha|,$$

$$U - B = +0.287 + 0.0025|\alpha|.$$

The straight lines of Fig. 12 show these relations (the different ordinate scales should be noted).

TABLE IV. Observed epochs and synodic periods.

Obs. date 1958-9 U.T.	Observed U.T.	J.D.(c) 2436000+	Interval	Number of cycles	P_{syn}
Oct. 18	13 ^h 5 ^m	49540345	16 ^d 8451	37	04455 272
	±1	±0.0006	±0.0005		
Nov. 4	9 21	511.8796	5.0077	11	245
Nov. 9	9 32	516.8873	7.7404	17	318
Nov. 17	3 18	524.6277	3.1868	7	257
Nov. 20	7 47	527.8145	5.0076	11	236
Nov. 25	7 58	532.8221	4.0979	9	322
Nov. 29	10 19	536.9200	2.7319	6	317
Dec. 2	3 53	539.6519	9.1054	20	270
Dec. 11	6 25	548.7573	45.0729	99	282
Jan. 25	8 14	593.8302			

TABLE III. *UBV* observations of Lydia.

Obs. date U.T.	$\langle V(1,\alpha) \rangle$ (mag) wt.	$\langle B - V \rangle$ (mag) wt.	$\langle U - B \rangle$ (mag) wt.
58.10.18	8.585 2	+0.719 3	+0.317 2
58.11.04	8.383 1	0.722 3	0.298 4
58.11.09	8.300 1	0.700 1	0.334 1
58.11.17	8.120 1	0.697 2	0.305 3
58.11.20	8.011 1	0.707 1	0.263 2
58.11.25	7.868 1	0.682 1	0.251 3
58.11.29	8.025 1	0.730 1	0.322 3
58.12.02	8.127 3	0.722 4	0.318 4
58.12.11	8.322 1	0.713 3	0.275 2
59.01.25	8.738 1	0.747 2	0.342 2

TABLE V. Calculated amplitudes of Lydia.

Date	Above mean <i>V</i>	Below mean <i>V</i>	Amplitude (mag)
58.10.18	0.080	0.112	0.19
58.11.04	0.087	0.075	0.16
58.11.09	0.082	0.078	0.16
58.11.17	0.078	0.085	0.16
58.11.20	0.076	0.088	0.16
58.11.25	0.079	0.094	0.17
58.11.29	0.079	0.099	0.18
58.12.02	0.079	0.102	0.18
58.12.11	0.084	0.108	0.19
59.01.25	0.109	0.095	0.20
69.03.16	...	...	0.11

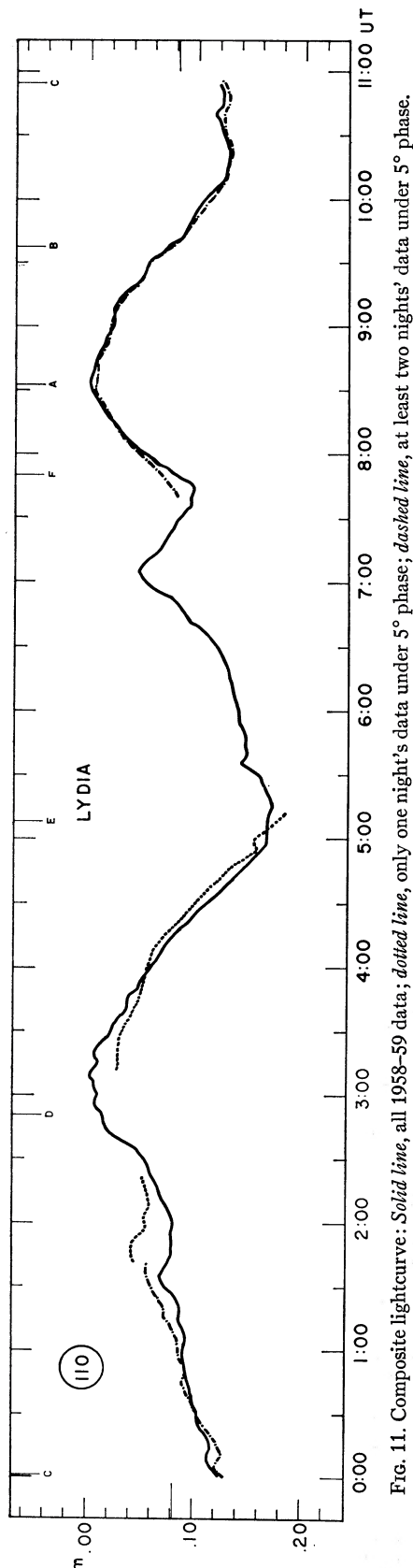


FIG. 11. Composite lightcurve: *Solid line*, all 1958-59 data; *dotted line*, only one night's data under 5° phase; *dashed line*, at least two nights' data under 5° phase.

No color change ($U-V$) over the surface of Lydia was found which may indicate that the lightcurve is caused mostly by shape.

III. THE PERIOD OF ROTATION

Table IV contains the epochs of maximum light (marked in Figs. 1-9 by the vertical lines labeled "A" with the corresponding Julian Date after correction for light time). A least-squares routine, with weights according to the number of cycles, gives a synodic period of $10^h55^m36^s.24 \pm 0^s.04$ (p.e.).

Table V gives the amplitudes obtained by plotting the height and depth of each lightcurve with reference to the mean V line. Amplitudes of incomplete lightcurves were determined by linear interpolation and adjacent lightcurve fitting. The amplitude in 1958-59 was 0.18 mag on the average, and it was 0.11 mag in 1969, which indicates a closer polar aspect in 1969.

An attempt was made to determine the true period and orientation of the pole using photometric astrom-

TABLE VI. Ecliptic longitude and latitude, as seen from Lydia of the subearth point, the subsolar point, and the apparent center of light.

Epoch	Subearth		Subsolar		Lightcenter	
	long.	lat.	long.	lat.	long.	lat.
58.10.18	247°98	+0°64	222°13	+0°28	247°16	+0°62
58.11.04	245.74	+0.07	230.90	+0.03	245.45	+0.07
58.11.09	244.73	-0.11	233.63	-0.04	244.56	-0.11
58.11.17	242.96	-0.43	237.57	-0.17	242.93	-0.43
58.11.20	242.23	-0.54	239.25	-0.21	242.21	-0.54
58.11.25	241.12	-0.74	241.92	-0.29	241.12	-0.74
58.11.29	240.18	-0.91	244.09	-0.35	240.20	-0.90
58.12.02	239.62	-0.94	245.56	-0.37	239.66	-0.94
58.12.11	237.68	-1.28	250.37	-0.51	237.89	-1.26
59.01.25	235.27	-2.24	273.94	-1.22	236.69	-2.18
69.03.16	324.40	-8.30	342.67	-3.53	324.75	-8.12

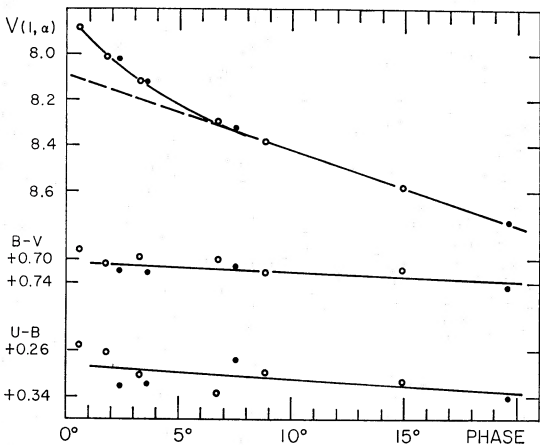


FIG. 12. Phase functions of Lydia. *Abscissas*, the orbital phase angle in degrees. *Ordinates*, *top curve*: the observed magnitudes (V on the UBV system) reduced to unit distances from the Sun and the Earth; *middle curve*, the $B-V$ colors; *bottom curve*, the $U-B$ colors. *Open circles* are before and *filled circles* after opposition.

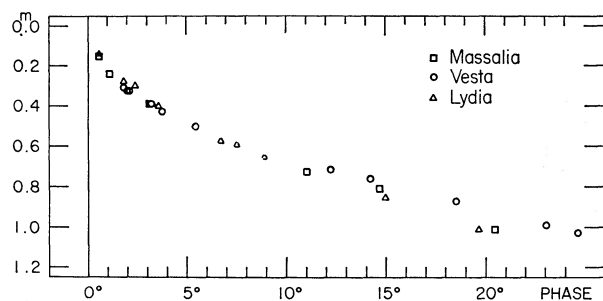


FIG. 13. Magnitude-phase relations of three asteroids.

etry (Paper I and refined in Sec. VII of Paper IV), but a wider range of observations of lightcenter coordinates is needed. Table VI gives the present ecliptic coordinates on Lydia for a future determination of the pole.

IV. THE OPPOSITION EFFECT

A pronounced nonlinear increase in brightness from about 8° phase to 0° phase, was found for (20) Massalia (Gehrels 1956). Lydia shows that same opposition effect. Figure 13 is a plot for Massalia, Vesta, and Lydia, of V magnitude versus phase angle; corrections were applied to adjust for the differences in brightness. There is a striking similarity of the opposition effect of these three asteroids.

We plotted the values of B and U as a function of phase, for Vesta as well as for Lydia, and these curves superpose to within the precision of the measurements. The opposition effect therefore appears to be independent of wavelength.

It would be of interest to observe additional asteroids and satellites at small phase angles. This should be done for faint asteroids that presumably are collision products, as well as for the brighter ones that may have

originated by accretion. In the Palomar-Leiden Survey (Van Houten *et al.* 1970), an indication was found—from photographic photometry—that the opposition effect is the same for faint as for bright asteroids, while the former have a steeper phase function beyond 8° phase. We found that the opposition effect of Fig. 13 is not the same as that of the Moon or Mars.

Laboratory studies by Hapke and others indicate that the opposition effect is due to internal blocking and shadowing effects, i.e., the effect is related to texture more than to composition. [Veverka (1970) has a detailed discussion of the opposition effect.] The similarity of opposition effects is then explained by the fact that different asteroids, which may have different compositions, have had the same bombardment by small particles (and solar wind). If the opposition effect could be shown to be independent of distance from the Sun, this could be an indication of cometary rather than asteroidal origin of the small particles. The opposition effect should, therefore, be observed for bright and faint asteroids of various values of the semi-major axes, including the Trojans.

ACKNOWLEDGMENTS

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