NO. 18. PHOTOMETRIC STUDIES OF ASTEROIDS. X*

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ABSTRACT

Pallas was observed photoelectrically on three nights in August 1956 with the McDonald 82-inch reflector. A period of 10^h40^m has been derived. Asteroids 61 and 11 were observed on four nights in December 1959 - January 1960 with the McDonald 36-inch telescope. The period of 61 is $11^h27^m \pm 5^m$.

A brief discussion of the colors of asteroids now available is included.

This is the tenth paper in the current photometric series. The present observations were made with the 82-inch reflector of the McDonald Observatory by Kuiper in 1956 and the McDonald 36-inch telescope by Wood in 1959-60. The format and reduction routines are those of Paper IX (Gehrels and Owings, 1961; *Comm. No. 17*).

1. The Light-Curves

Pallas, No. 2

PALLAS was observed previously in the series by Kuiper on June 30, 1951, for four hours (Paper II; Groeneveld and Kuiper, 1954*a, b*). References to the photographic photometry of O. Günther on Pallas are contained in Paper II. The present observations were taken on August 26, 29, and 31, 1956, and are shown in Figures 1, 2, and 3. Passing clouds interrupted observations at around 4:00 U.T. on August 31.

The right-hand maximum of August 26 resembles the maximum observed in 1951 (Paper II). This suggests that the two maxima of the August 26 curve are not the same, i.e., that the light-curve possesses at least two maxima and two minima. Comparison of the minima shown in Figures 1-3 leads to the same conclusion.

Intercomparison between the three runs at first seems to indicate that there are two possible ways to fit the observations into a single light-curve. They follow from two alternate assumptions, namely, that the maximum on August 31, $6^h.0$ U.T., is identical with either (*a*) the maximum on August 26 at $4^h.7$ U.T., or (*b*) the maximum on August 26 at $8^h.8$ U.T. On hypothesis (*a*) the period would be a submultiple of $121^h.3$; on hypothesis (*b*), a submultiple of $117^h.2$.

On hypothesis (*a*) the shapes of the two maxima would be quite consistent, and the zero points consistent within 0.01 mag. if the differential phase effects (angles $7^\circ.9$ and $7^\circ.3$) were negligible. However, the minimum of August 29 does not fit the $7^h.3$ U.T. minimum of August 26. Accordingly, the fit of August 29, $6^h.0$ U.T., as identical with August 31, $4^h.75$ U.T., is suggested, leading to $\Delta t = 46^h.25$ as a multiple of the period. The estimated uncertainty is about $\pm 0^h.05$. The zero points of the two nights are then found to be identical if 0.01 mag. phase effects were present, in the sense that the asteroid was brighter on August 29. Hypothesis (*a*) requires, then, that a single value of the period fit the intervals $121^h.3$ and $46^h.25 \pm 0^h.05$, found above, and their difference, $75^h.05$. The period $9^h.33$, the best obtainable, gives only a rough fit and leaves a residual of $0^h.4$ for the $46^h.25$ interval. This is entirely outside the acceptable limits indicated by the observations. Accordingly, hypothesis (*a*) must be dropped.

On hypothesis (*b*) the two maxima do not agree quite as closely as on hypothesis (*a*); the maximum discrepancy occurs between August 26, $9^h.5$, and August 31, $6^h.6$ U.T., there being about 0.04 mag.

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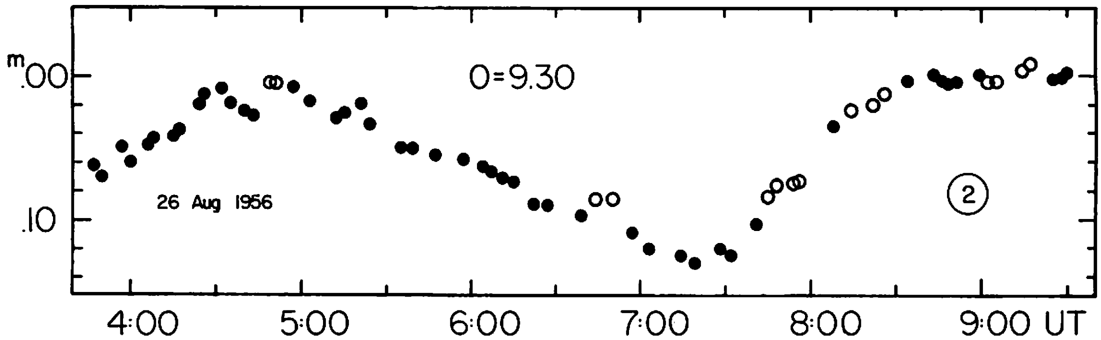

Fig. 1. Observations of 2 Pallas

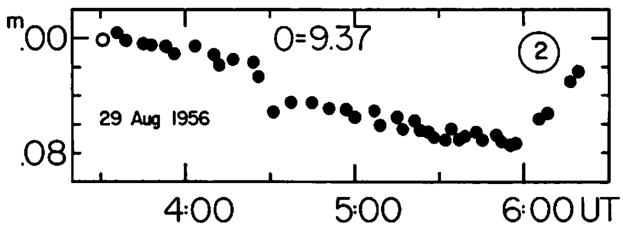

Fig. 2. Observations of 2 Pallas

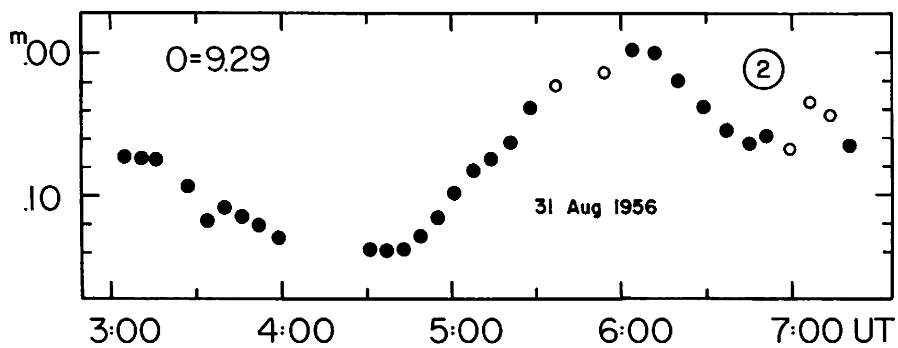

Fig. 3. Observations of 2 Pallas

between two groups of three points each. However, because of the time interval of five days some real differences in the light-curve may have developed. The zero points fit perfectly if the asteroid were 0.01 mag. fainter on August 31, which is reasonable. The August 29 minimum now fits only in one position on the light-curve; the epoch is estimated by superposition of the zero points. Then August 29 at $7^{h}.0$ U.T. corresponds in phase to August 26, $4^{h}.23$ U.T., yielding the interval $74^{h}.77$ for a multiple of the period. Combined with the interval of $117^{h}.2$ found before, a third interval of $42^{h}.43$ is found. Only one value of the period fits these numbers, namely $P = 10^{h}.655$. The computed intervals are then $42^{h}.62$, $74^{h}.58$, and $117^{h}.2$.

The difference of $0^{h}.19$ in the 74^{h} interval appears, upon re-examination of the data, to be entirely acceptable since it leads to a shift in the zero point of less than 0.01 mag. (The $117^{h}.2$ interval is based on direct superposition of well-observed maxima and is therefore more precise.)

A final check of the $10^{h}40^{m}$ period is made by inspection of the composite light-curve. A gap of $1^{h}.4$ is left, but a plausible extrapolation will close it and provide an acceptable fit between the magnitudes at the ends of the curve. The period $10^{h}40^{m}$ is therefore adopted as the only one compatible with the data. It is also compatible with the estimate given in Paper II. The composite light-curve so derived is shown in Figure 4. Additional long runs on Pallas are still regarded as desirable to provide verification of the period. The estimated uncertainty of the period is ± 0.01 hour.

Pallas was re-observed for colors along with three primary *UBV* standards on September 4, 1956. The colors are listed in Table 1 and are in good agreement with the less precise values determined on the nights of the light-curves.

Parthenope, No. 11

Observations of Parthenope have been previously published (Paper VII; van Houten-Groeneveld and van Houten, 1958). Six hours of observations on January 1, 1960 (Fig. 5) show a flat minimum of at least 2½ hours' duration. The minimum shows a marked change from the one-hour minimum observed in 1956, though the maximum range of both years is about the same. On the basis of the previously estimated length of the period, 10^h40^m, the observations of January 2 (Fig. 6) show a part of the light-curve not previously observed. This conclusion is confirmed by direct superposition of Figures 5 and 6 which show differences in detail. Since there is no apparent overlap between the January 1 and 2 runs, a precise period cannot be obtained, but no contradiction is found with the earlier estimate of 10^h40^m.

No change in range between the 1956 and 1960 observations is indicated. However, not enough of the complete light-curve has been covered to derive total amplitudes as needed for a determination of the pole of rotation.

Four transfers of asteroid and comparison star to the Praesepe and Pleiades standards were made during the night of January 2. This provided a check on possible variability of the comparison star. In fact, this star was found to decrease in brightness by 0.1 mag. during the interval of observation. Its magnitude (reduced to outside atmosphere with an adopted extinction coefficient) fits a sloping straight line with a p.e. of ± 0.035 mag., which is consistent with the probable error of a single transfer. Accordingly, the asteroid light-curve has been corrected for this change in the comparison star. Since the four transfers included the asteroid, direct magnitudes for it are available at these epochs which provide a check on the reduction procedure. The V and $B-V$ in Table 3 are the mean magnitude and color of the comparison star at 7:00 U.T., the average during the time of the light-curve observations.

If the period estimate is correct, two full-night runs on alternate nights should give a precise period determination.

Danaë, No. 61

Danaë was observed for the first time in this series on two consecutive nights, December 27 and 28, 1959 (Figs. 7, 8). Two different maxima were found on the ten-hour run of December 27; from the combined data the period of rotation is found to be $11^h27^m \pm 5^m$.

Two different comparison stars were used on the long run of December 27. The change-over occurred near the meridian, and a magnitude difference was determined at that time. As a check these stars were re-observed on the next night. No variation was found. The gap near 9:00 U.T. on December 28 resulted from the asteroid's passing a field star.

The superposition of the December 28 run onto the December 27 plot showed only one possible fit. The magnitudes were also compatible, there being a difference of about 0.01 mag. between the runs, about half of which is accounted for by the increased distance on December 28. The combined data are

TABLE 1
SUMMARY OF OBSERVATIONS

No.	Obs. Date U.T.	V of Zero	$B-V$	$U-B$	Range	Mean V	g	Fig.
			m	m	m			
2	8/26/56	9.30	......	......	0.14	9.35 *	4.63 *	1
	8/29/56	9.37	......	......	.09	......	......	2
	8/31/56	9.29	......	......	.15	9.36 *	4.61 *	3
	9/ 4/56	......	+0.65	+0.27	......	......	......	....
11	1/ 1/60	10.223	.800	.358:	.10	10.277*	7.010*	5
	1/ 2/60	10.195	.819	.422	.12	10.260*	6.969*	6
61	12/27/59	12.139	.850	.455	.31	12.258†	8.037†	7
	12/28/59	12.157	0.850	0.412	0.29	12.264*	8.039*	8

* Mean over night's run.
† Mean over full period.

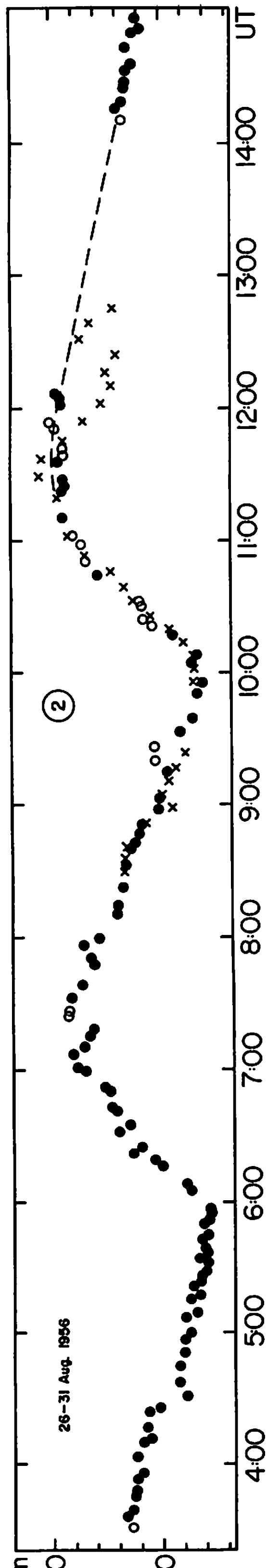

Fig. 4. Composite light-curve of 2 Pallas. Abscissae are times of August 29. Some observations of August 29 are repeated at far right. August 31 observations are shown as crosses.

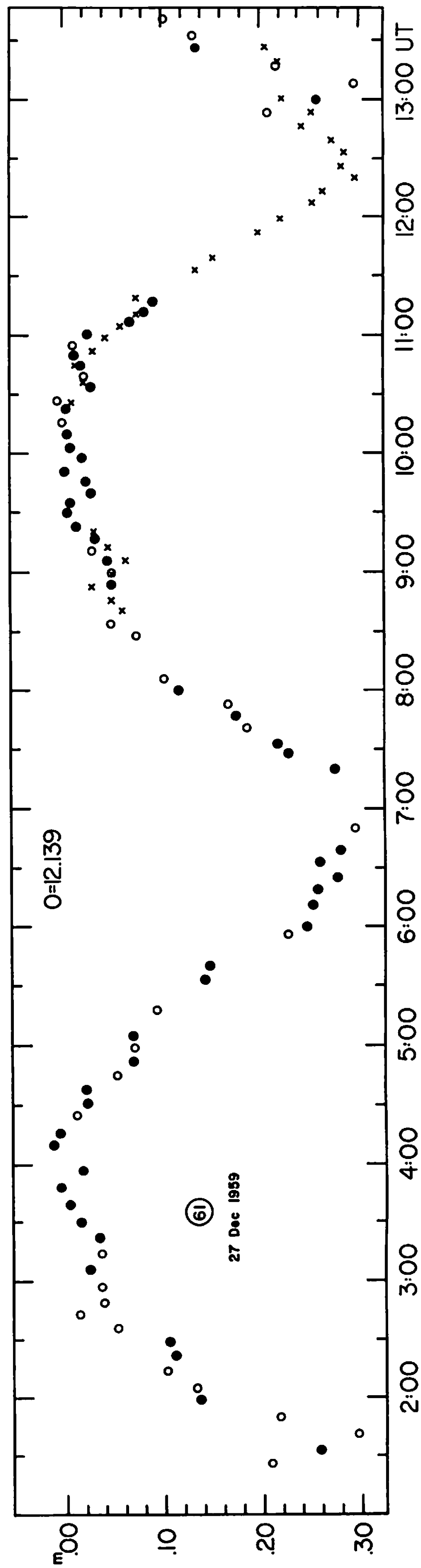

Fig. 7. Light-curve of 61 Danaë. The observations beyond 11:20 U.T. are those of December 28, 1959, reduced to December 27, 1959, and plotted as crosses.

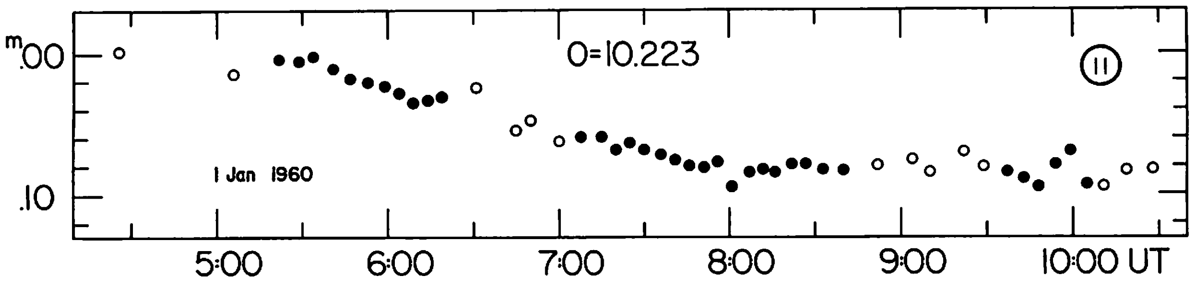

Fig. 5. Observations of 11 Parthenope

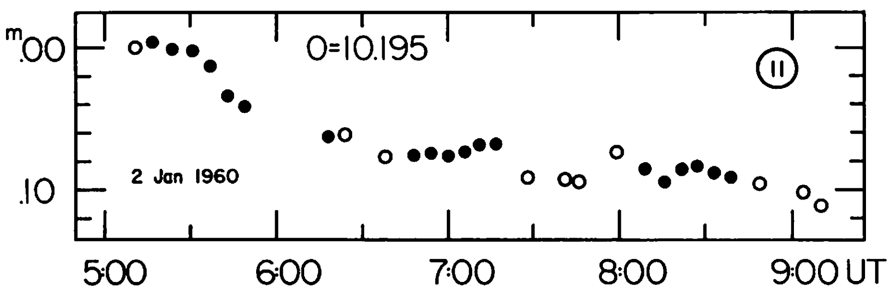

Fig. 6. Observations of 11 Parthenope

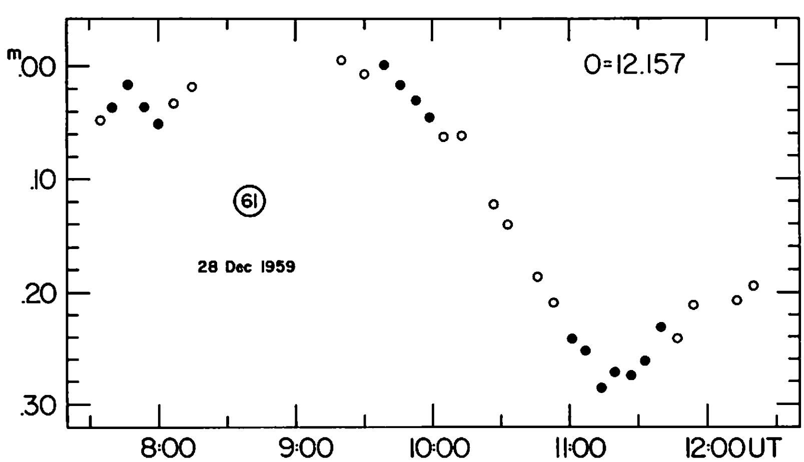

Fig. 8. Observations of 61 Danaë

TABLE 2
ASPECT DATA FOR THE ASTEROIDS

No.	Obs. Date U.T.	Phase Angle	log r	log ρ	Light-time	R.A.	Decl.	λ	β
		°			m	h m	° ′	°	°
2	8/26/56	7.3	.5277	.3854	20.21	21 15	+ 9 10	324	+24
	8/29/56	7.6	.5274	.3860	20.23	21 13	+ 8 37	323	+23
	8/31/56	7.9	.5272	.3870	20.28	21 11	+ 8 13	323	+23
11	1/ 1/60	6.5	.4143	.2151	13.65	05 29.6	+18 55	82	−04
	1/ 2/60	6.9	.4144	.2164	13.69	05 28.7	+18 57		
61	12/27/59	7.3	.4855	.3284	17.72	06 18.3	+46 38	03	+23
	12/28/59	7.3	.4857	.3289	17.74	06 16.4	+46 37		

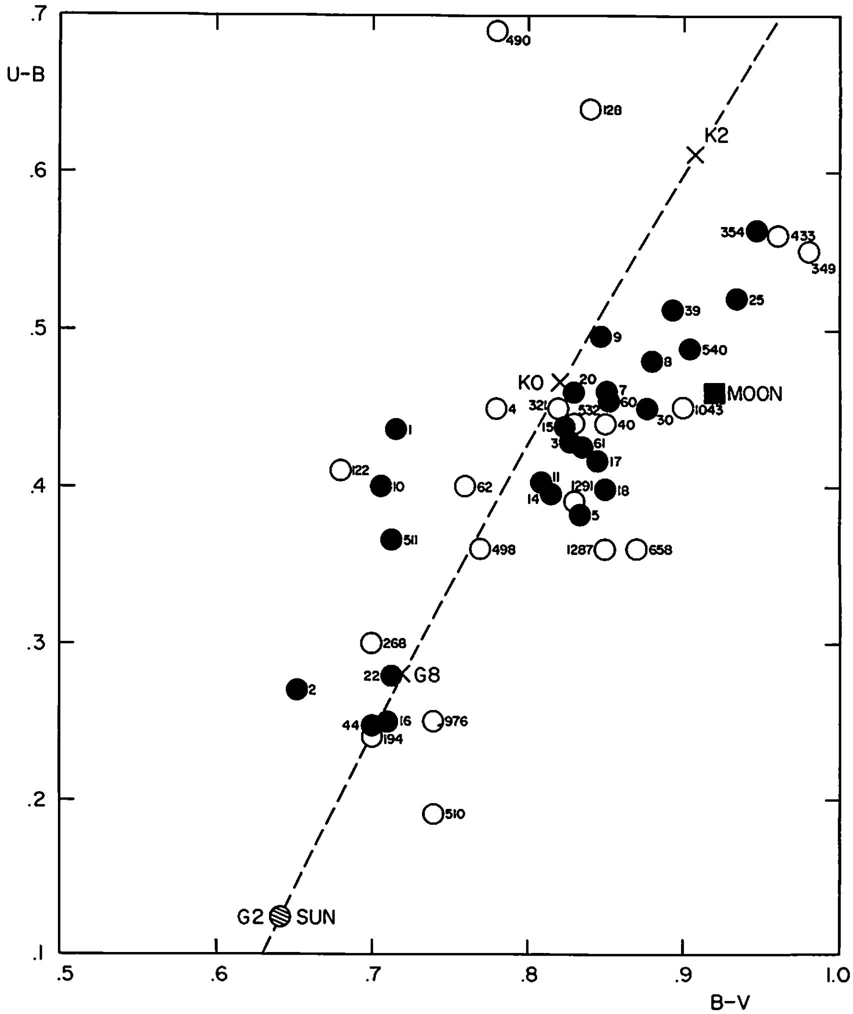

Fig. 9. *UBV* colors of asteroids compared to main-sequence stars (line). Approximate position of Sun is at G2.

TABLE 3
COMPARISON STARS AND QUALITY OF THE NIGHTS

Used for Asteroid No.	Obs. Date U.T.	R.A. 1959	Decl. 1959	V	$B-V$	Scatter of Comp. Readings	Remarks
		h m	° ′	m	m	m	
11	1/ 1/60	5 30.1	+18 50	10.348	+1.121	0.004	Wind, good night
	1/ 2/60	5 28.9	+18 53	11.393:	0.527:	.008	Stopped by clouds
61	12/27/59	6 18.7	+46 39	12.043	0.417	.007	Some dust and wind
	12/27/59	6 17.7	+46 37	11.787	0.974	.007	
	12/28/59	6 16.4	+46 37	12.587	1.131	0.005	Fair night

shown in Figure 7, which uses the time scale of December 27 and shows the December 28 observations as crosses.

The fact that a period as long as 11½ hours was found unambiguously from observations on two nights only, may be attributed to the long run of December 27. The value of long continuous runs in asteroid photometry is again illustrated.

2. *The Colors*

The format and main sequence of Figure 9 are taken from Paper II; the colors are from Papers IX and X and the Yerkes Survey (Kuiper *et al.*, 1958, Table 9). The addition of 28 new asteroids to the plot does not change the overall features of the earlier plot except perhaps that the concentration toward $B-V=0.82$ and $U-B=0.44$ is more evident. The avoidance of the upper-left and lower-right areas of the plot remains. The data first used showed one outstanding exception, No. 540. Dr. Gehrels has recently re-observed this object and allowed us to include his measures:

No. 540, November 10, 1961, $B-V=+0.904$; $U-B=+0.488$; Mean $V=13.91$; and $g=11.34$.

On the average the asteroids fall about 1½ times as far from the sun in $U-B$ as they do in $B-V$. This shows that the albedo of the asteroids continues to decrease into the ultraviolet, i.e., the color is slightly yellowish, like the moon.

$U-V$ when plotted against the absolute magnitude g shows no correlation. This indicates that for the asteroids there exists no color-size relationship. This is perhaps not surprising in view of the fact that the smaller asteroids increase in number so rapidly with decreasing dimensions (cf. *Survey*, Kuiper *et al.*, 1958) that the total cross-section of each successively fainter magnitude group increases by a factor of the order of two. Hence, collisions with the smallest asteroids are by far the most numerous. Consequently, the largest- and the medium-sized asteroids presumably have similar surface structures, both being determined by the impacts of small bodies.

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