ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

Astron. Astrophys. Suppl. Ser. **54**, 371-378 (1983)

Photoelectric lightcurves and rotation period of the minor planet 201 Penelope (*)

J. Surdej ([1, **]), B. Louis ([1]), N. Cramer ([2]), F. Rufener ([2]), C. Waelkens ([2]), R. Barbier ([3]) and P. V. Birch ([4])

([1]) Institut d'Astrophysique, Université de Liège, avenue de Cointe 5, B-4200 Cointe-Ougrée, Belgium
([2]) Observatoire de Genève, CH-1290 Sauverny, Switzerland
([3]) European Southern Observatory, Casilla 16317, Santiago 9, Chile
([4]) Perth Observatory, Walnut Road, Bickley, 6076, Western Australia

Received April 7, accepted July 8, 1983

Summary. — Asteroid 201 Penelope was observed photoelectrically in both the standard *UBV* and Geneva systems at ESO, Chile and Perth Observatory, Australia, between October 6 and November 7 during its 1980 opposition. An accurate synodic rotation period $P = 3^h44^m51^s.6 \pm 7^s.4$ corresponding to $0^d.15615 \pm 0^d.00009$ is derived, in good agreement with previous reported values. The lightcurve of 201 Penelope displays two distinct maxima and minima with a total amplitude $\Delta V = 0.52$ mag. This amplitude remained nearly constant during the time of our observations. Absolute magnitudes were computed with a linear extrapolation, using a mean phase coefficient $\beta_V = 0.037$ mag./deg., yielding V_0 (1, 0) = $8^m.51 \pm 0^m.01$ for the primary maximum ; mean colors were derived as $B\text{-}V = 0.70 \pm 0.01$ and $U\text{-}B = 0.23 \pm 0.02$ mag. A careful analysis of our *UBV* data indicates that the color variations reported for 201 Penelope by Surdej and Cramer (1980) were due to a failure in their reduction procedure rather than being physically real.

Key words : asteroids — minor planets — 201 Penelope — photoelectric photometry — rotation period.

1. Introduction.

On the basis of a few photoelectric observations in the *UBV* system, Bowell *et al.* (1979) have classified 201 Penelope among the CMEU-type asteroids with $B\text{-}V = 0.69$, $U\text{-}B = 0.26$ mag. and they predicted a rough value $D = 144$ km for its mean diameter. However, with the help of recent eight-color and radiometric observations, Tedesco *et al.* (1984) have established that 201 Penelope is an M class asteroid with a diameter of 70 km. Prior to 1980, no lightcurve parameters were known for this minor planet (Tedesco, 1979).

The ephemeris of minor planets for the year 1980 (I.T.A., 1980) predicted opposition for 201 Penelope on September 24 with $B = 11.6$ mag. Lambert and Africano (1980) and Surdej and Cramer (1980) have independently observed 201 Penelope to be a fast rotator with a synodic rotation period $P = 3^h44^m49^s$ and $P = 3^h44^m53^s \pm 18^s$, respectively. Furthermore, Surdej and Cramer (1980) have reported this asteroid to display noticeable color variations with rotation. With the exception of these color variations, Lagerkvist and Rickman (1981) and Lagerkvist *et al.* (1981) have published similar photometric data for 201 Penelope.

In this paper, we present the results of further photoelectric observations carried out at the European Southern Observatory (*UBV* and Geneva photometry) and at Perth Observatory (*UBV*) during the 1980 opposition.

Table I summarizes the dates of our observations, the right ascension and declination, the ecliptic longitude and latitude, the geocentric distance Δ, the heliocentric distance *r*, the phase angle α, the light time, the absolute magnitude V_0 (1, α) of the primary maximum of 201 Penelope and the number of the figure corresponding to the given date. The aspect data were computed by using the MP-programme complex designed and kindly put at our disposal by R. M. West.

When photometric data will become available during next opposition, it is very likely that photometric astrometry (Taylor, 1979) combined to all existent sets of data will enable to derive the sidereal rotation period and axis orientation of 201 Penelope.

2. Observations.

Figures 1-3 illustrate the *V* photoelectric lightcurves of 201 Penelope observed on October 6, 11 and 17, 1980 with the ESO 50 cm telescope at the European Southern Observatory, La Silla (Chile). In these and subsequent figures, no corrections have been applied for the phase and distance effects, the abscissae are U.T. without correction for light time. A single-channel photometer equipped with an EMI 6256 photomultiplier, Schott standard filters for the *UBV* magnitudes and a Pelletier cooling system was used in the pulse counting mode for the photoelectric measurements. A basic integration time of 40 s was chosen when collecting the photons through a 22 arcsec diaphragm. The general observing routine

(*) Based on observations partly collected at the European Southern Observatory, La Silla (Chile).
(**) Chercheur qualifié au Fonds National de la Recherche Scientifique (Belgique).

included frequent measurements of the asteroid, sky, comparison star and some E-region standard stars (Cousins and Stoy, 1962). The data were reduced to the standard *UBV* system in the usual way, taking into account the first and second order extinction as well as a linear color transformation.

The *V* photoelectric magnitudes recorded for 201 Penelope on October 8, 14 and 30, 1980 with the 70 cm Swiss telescope on La Silla are displayed in figures 4-6. These measurements were performed in the Geneva observatory system (Rufener, 1981) with a photometer working in the pulse counting mode and recording quasi-simultaneously the seven colors (Burnet, 1976).

Finally, figures 7-9 illustrate the instrumental V' lightcurves obtained with the Lowell-Perth 60 cm reflector on October 29, 30 and November 7, 1980 at Perth Observatory. Only extinction corrections have been applied to these measurements. Each data point corresponds to the mean of 3 × 10 seconds of integration, with sky readings subtracted. The data recording system is fully described by Millis *et al.* (1974).

3. Lightcurves and rotation period.

Figures 10, 11 and 12 represent the mean composite lightcurves of 201 Penelope constructed from the three different sets of observations — i.e. October 6, 11, 17 (*UBV,* ESO), October 8, 14, 30 (Geneva, ESO) and October 29, 30, November 7, 1980 (V', Perth Observatory) — when taking into account the distance (see table I), phase (a mean phase coefficient $\beta = 0.037$ mag./deg. leading to the best fitting) and light time effects. In each of these figures, the horizontal line refers to a mean magnitude level, the areas enclosed by the composite lightcurve above and below that line being equal.

We see from these figures that a full cycle of light variations consists of two distinct maxima M_1, M_2 and minima m_1, m_2, almost equally spaced in time ($\Delta M_1\, m_1 = 0.28$, $\Delta m_1\, M_2 = 0.23$, $\Delta M_2\, m_2 = 0.24$ and $\Delta m_2\, M_1 = 0.24$ along the phase axis in Figs. 10-12). The total amplitude of the *V* lightcurve is easily derived to be $\Delta V = 0.52$ mag. Within the measurement uncertainties, this amplitude is found to remain constant during all our observations (cf. Lagerkvist *et al.*, 1981). Although the Perth data seem to indicate a larger total amplitude (see Fig. 12), comparison between figure 6 and figures 7-9 suggests that several bad measurements occurring around the minima m_1 and m_2 are responsible for this effect. With respect to the mean magnitude level, the amplitudes of the different extrema are − 0.264, − 0.146, 0.184 and 0.261 mag. for M_1, M_2, m_1 and m_2, respectively.

As usually, these gross characteristics of 201 Penelope's lightcurve are the best interpreted as being due to the changing shape of the asteroid during its rotation. Let us notice the presence of a small hump in the lightcurve of 201 Penelope located near the rotational phase 0.3 (see Figs. 10-12). This feature can also be identified in the mean composite lightcurve published by Lagerkvist *et al.* (1981). It is very likely that such a feature results from near-specular reflection from a rather small flat area (cf. Van Houten, 1965).

Table II contains the epochs — corrected for light time — of the different extrema appearing in the *V* lightcurve of 201 Penelope. Assigning weights proportional to the number of cycles elapsed between two similar extrema, we derive the following synodic rotation periods

$$P_{M_1} = 3^{\mathrm{h}}44^{\mathrm{m}}51\overset{\mathrm{s}}{.}7 \pm 7\overset{\mathrm{s}}{.}1\,,$$
$$P_{M_2} = 3\;44\;52.2 \quad 7.4\,,$$
$$P_{m_1} = 3\;44\;50.9 \quad 4.8\,,$$

and

$$P_{m_2} = 3\;44\;51.5 \quad 9.5\,,$$

leading to

$$P = 3^{\mathrm{h}}44^{\mathrm{m}}51\overset{\mathrm{s}}{.}6 \pm 7\overset{\mathrm{s}}{.}4 \text{ or } 0\overset{\mathrm{d}}{.}15615 \pm 0\overset{\mathrm{d}}{.}00009$$

for the mean synodic rotation period of 201 Penelope. As outlined by Lambert and Africano (1980), this value constitutes the second shortest rotation period observed for a main-belt asteroid.

Using the technique of photometric astrometry (Taylor, 1979), we have made trials for deriving the pole orientation, sidereal period and sense of rotation of this asteroid. Due to the high spin rate of 201 Penelope and taking into account — for different orientations of the pole — the variation of the longitude of the subearth point as well as that of the time shift (see Eq. 1 in Taylor, 1979), we find that the sidereal rotation period of 201 Penelope should differ from the synodic one by 0.4 s, at most. Therefore, the too large uncertainty ($\sigma \sim 7$ s) affecting the value of P precludes from deriving intrinsic properties of the rotation. Such a task should become feasible when photometric data from another opposition will be available.

Finally, making use of the magnitudes $V_0\,(1, \alpha)$ calculated for the primary maximum M_1 at unit distances (i.e. for $r\Delta = 1$) and phase angles $\alpha > 8°$ (see table I plus the values published by Lagerkvist *et al.*, 1981), we derive

$$\beta_V = 0.037 \pm 0.003 \text{ mag./deg.}$$

for the mean phase coefficient of 201 Penelope, and

$$V_0\,(1, 0) = 8\overset{\mathrm{m}}{.}51 \pm 0\overset{\mathrm{m}}{.}01$$

for the absolute magnitude of the primary maximum M_1. The mean absolute magnitude is similarly found to be

$$\bar{V}(1, 0) = 8\overset{\mathrm{m}}{.}78 \pm 0\overset{\mathrm{m}}{.}01\,.$$

4. The absence of color variations.

Surdej and Cramer (1980) have reported the detection of noticeable color (*B-V, U-B*) variations during the rotation of 201 Penelope. Figures 13 and 14 illustrate the mean composite *B-V* and *U-B* color curves constructed from observations that were recorded on October 6, 11 and 17, 1980 at ESO. A rough evaluation of the Geneva observations performed on October 8 and 14 seemed to confirm these findings. However, low-resolution spectrophotometry (IDS) carried out on October 30 with the ESO 1.5 m telescope as well as available reduced data in the Geneva photometric system contradicted our preliminary results. The different techniques adopted during the observing and reduction procedures in both the *UBV* and Geneva photometric systems suffice to account for the observed discrepancies. Indeed, because of the quasi-simultaneity in the reading of the color measurements with the Geneva photometer, one has the right to assign one time to a complete set of seven magnitudes. In the *UBV* system, each color integration is measured separately, with a time interval of approximately 40 s between two consecutive measurements. It follows that if the rate of light variation is high enough, the colors measured during consecutive intervals of 40 s will not refer anymore to a unique configuration of the asteroid and this is exactly what occurred for the color measurements shown in figures 13 and 14. Using the *V* measurements in figure 10 and adopting a time delay of 40 s (resp. 80 s) between two consecutive *B*, *V* (*U*, *B*) color integrations, we have succeeded in correctly simulating the color variations displayed in figures 13 and 14 (Louis, 1982). The color indices of 201 Penelope are finally measured to be :

$$B\text{-}V = 0.70 \pm 0.01 \text{ and } U\text{-}B = 0.23 \pm 0.02 \text{ mag.}$$

out of 186 measurements in the *UBV* system, and

$$U = 1.45 \pm 0.06,\ V = 0.09 \pm 0.02,\ B_1 = 1.11 \pm 0.04,$$
$$B_2 = 1.29 \pm 0.04,\ V_1 = 0.84 \pm 0.03 \text{ and } G = 1.11 \pm 0.03 \text{ mag.}$$

out of 235 measurements in the Geneva system. None of these color indices shows variation exceeding the mean scatter. Table III includes the identification as well as magnitudes and colors of the comparison stars measured during our observations.

Among all asteroids observed photometrically, there remain nine objects which are potential candidates for showing color variations with rotation (Schober and Schroll, 1981). However, it cannot be excluded that cases similar to 201 Penelope are present in this sample. For instance, the color variations reported by Lustig and Dvorak (1975) for 71 Niobe have not been confirmed by Harris (Tedesco, 1983). We plan to check in the near future such possible inconsistencies for 71 Niobe and other minor planets in terms of spurious effects inherent to the observing and/or reduction procedure(s).

Acknowledgements.

It is a pleasure for us to thank the referee, Dr. E. F. Tedesco, for some of his valuable comments as well as unpublished information.

References

BOWELL, E., GEHRELS, T., ZELLNER, B. : 1979, in *Asteroids,* ed. T. Gehrels (The University of Arizona Press, Tucson) p. 1108.
BURNET, M. : 1976, *Etude et réalisation d'un photomètre différentiel commandé par ordinateur.* Thèse n° 235 présentée au département d'électricité, Ecole Polytechnique Fédérale de Lausanne.
COUSINS, A. W. J., STOY, R. H. : 1962, *R. Obs. Bull.* **49.**
I.T.A. : 1980, *Ephemeris of Minor Planets for 1980,* Inst. of Theoretical Astronomy, Leningrad, ed. by S. Lavrov.
LAGERKVIST, C.-I., RICKMAN, H. : 1981, *The Moon and the Planets* **24,** 437.
LAGERKVIST, C.-I., RICKMAN, H., SCALTRITI, F., ZAPPALA, V. : 1981, *Astron. Astrophys.* **104,** 148.
LAMBERT, J. V., AFRICANO, J. : 1980, *IAUC* 3523.
LOUIS, B. : 1982, *Photométrie des Astéroïdes,* Mémoire de licence, Université de Liège, Faculté des Sciences.
LUSTIG, G., DVORAK, R. : 1975, *Acta Phys. Austr.* **43,** 89.
MILLIS, R. L., THOMPSON, D. T., HARRIS, B. J., BIRCH, P., SEFTON, R. : 1974, *Icarus* **23,** 425.
RUFENER, F. : 1981, *Astron. Astrophys. Suppl. Ser.* **45,** 207.
SCHOBER, H. J., SCHROLL, A. : 1981, in the *Proceedings of the Sixth European Regional Meeting in Astronomy,* Dubrovnik.
SURDEJ, J., CRAMER, N. : 1980, *IAUC* 3527.
TAYLOR, R. C. : 1979, in *Asteroids,* ed. T. Gehrels (The University of Arizona Press, Tucson) p. 480.
TEDESCO, E. F. : 1979, in *Asteroids,* ed. T. Gehrels (The University of Arizona Press, Tucson) p. 1098.
TEDESCO, E. F. : 1983, private communication.
TEDESCO, E. F., GRADIE, J. C., THOLEN, D. J. : 1984, *Icarus,* to be submitted.
VAN HOUTEN, C. J. : 1965, *Hemel Dampkring* **63,** 162.

TABLE I. — *Aspect data, light times, reduced magnitudes and figure numbers for the minor planet 201 Penelope.*

Date of observation (0^hU.T.)	R.A. (1950.0)	Decl. (1950.0)	λ (1950.0)	β (1950.0)	Δ (A.U.)	r (A.U.)	α	Light time	$V_o(1,\alpha)$	Figure(s)
Oct.6,1980	$23^h52^m55^s$	-5°46'45"	356°.073	-4°.597	1.2534	2.2285	7°.5	$0^d.00724$	$8^m.78$	1
8,	23 51 42	-5 59 14	355.711	-4.667	1.2627	2.2302	8.5	0.00729	8.83	4
11,	23 50 00	-6 16 30	355.207	-4.762	1.2786	2.2330	9.9	0.00738	8.88	2
14,	23 48 30	-6 31 52	354.762	-4.849	1.2964	2.2358	11.3	0.00749	8.94	5
17,	23 47 11	-6 45 14	354.371	-4.923	1.3163	2.2387	12.6	0.00760	8.96	3
29,	23 44 11	-7 17 41	353.470	-5.122	1.4133	2.2510	17.2	0.00816	-	7
30,	23 44 07	-7 18 52	353.447	-5.133	1.4226	2.2521	17.5	0.00822	9.16	6,8
Nov.7,	23 44 29	-7 19 56	353.523	-5.186	1.5022	2.2612	19.9	0.00868	-	9

TABLE II. — *Epochs of the extrema for 201 Penelope.*

Epoch (1) (U.T.,1980)	Extremum	Epoch (1) (U.T.,1980)	Extremum	Epoch (1) (U.T.,1980)	Extremum
UBV/ESO		Geneva/ESO		V'/Perth	
Oct.6, $0^h.67 \pm 0^h.07$	M_2	Oct.8, $2^h.41 \pm 0^h.07$	m_2	Oct.29, $12^h.62 \pm 0^h.07$	M_1
1.64	m_2	3.28	M_1	13.70	m_1
2.54	M_1	4.35	m_1	14.56	M_2
3.65	m_1	5.22	M_2		
4.47	M_2			Oct.30, 14.05	m_2
5.42	m_2	Oct.14,1.62	M_1	15.02	M_1
6.30	M_1	2.76	m_1	16.07	m_1
7.40	m_1	3.63	M_2	16.97	M_2
		4.56	m_2		
Oct.11,1.54	m_2	5.46	M_1	Nov.7, 13.07	m_2
2.45	M_1			14.04	M_1
3.57	m_1	Oct.30,1.82	M_2	15.07	m_1
4.34	M_2	2.76	m_2	15.96	M_2
5.29	m_2	3.66	M_1	16.98	m_2
6.21	M_1	4.80	m_1		
Oct.17,0.88	M_1				
1.95	m_1				
2.76	M_2				

(1) corrected for light time

TABLE III. — *Magnitudes and colors of the comparison stars.*

Star	Magnitudes and colors
Comp. A-ESO not catalogued R.A.=$23^h52^m52^s$ Decl.=-5°56'10" (1950.0)	V=11.284±0.005, B-V=0.524±0.007 and U-B=-0.016 ±0.008 mag. (50 measurements on October 6,11 and 17, 1980)
Comp. B-Geneva HD 221675	m_V=11.296±0.008, U=1.237±0.021, V=0.307±0.013, B1=1.018±0.018, B2=1.355±0.019, V1=1.042±0.018 and G=1.360±0.019 mag. (36 measurements on October 8 and 14, 1980)
Comp. C-Geneva	m_V=10.341±0.009, U=1.413±0.021, V=0.124±0.010, B1=1.106±0.017, B2=1.290±0.017, V1=0.868±0.014 and G=1.153±0.015 mag. (19 measurements on October 30, 1980)

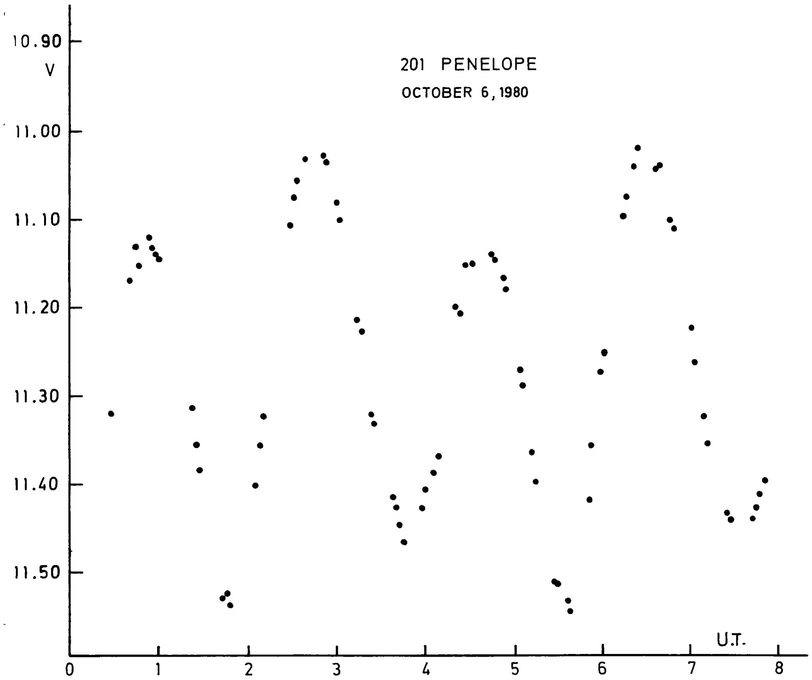

FIGURE 1. — *V* lightcurve of 201 Penelope on October 6, 1980.

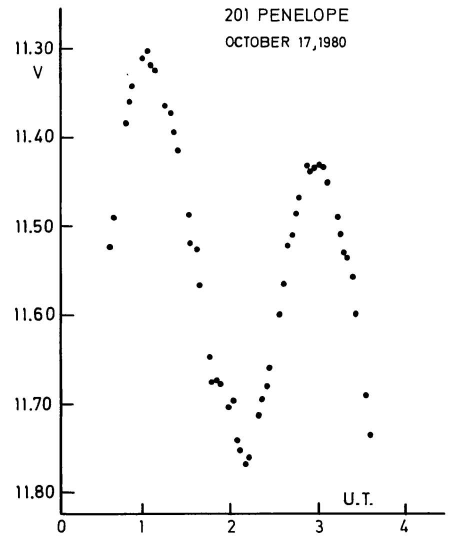

FIGURE 3. — *V* lightcurve of 201 Penelope on October 17, 1980.

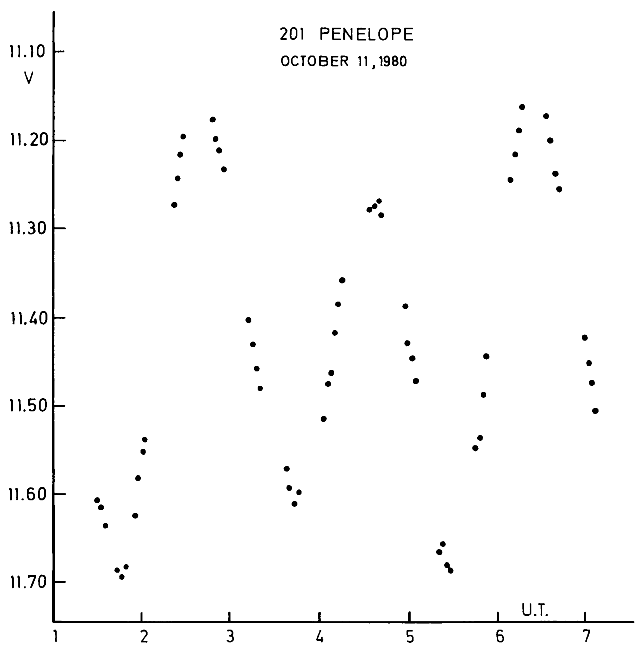

FIGURE 2. — *V* lightcurve of 201 Penelope on October 11, 1980.

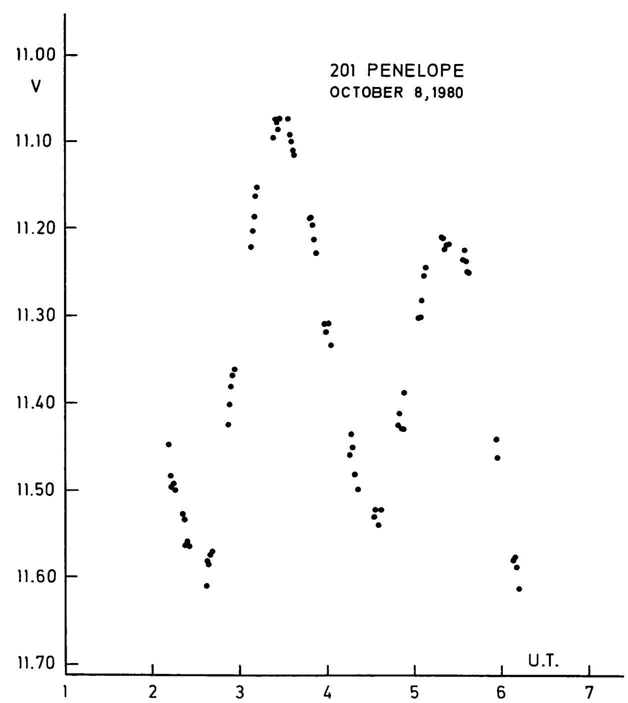

FIGURE 4. — *V* lightcurve of 201 Penelope on October 8, 1980.

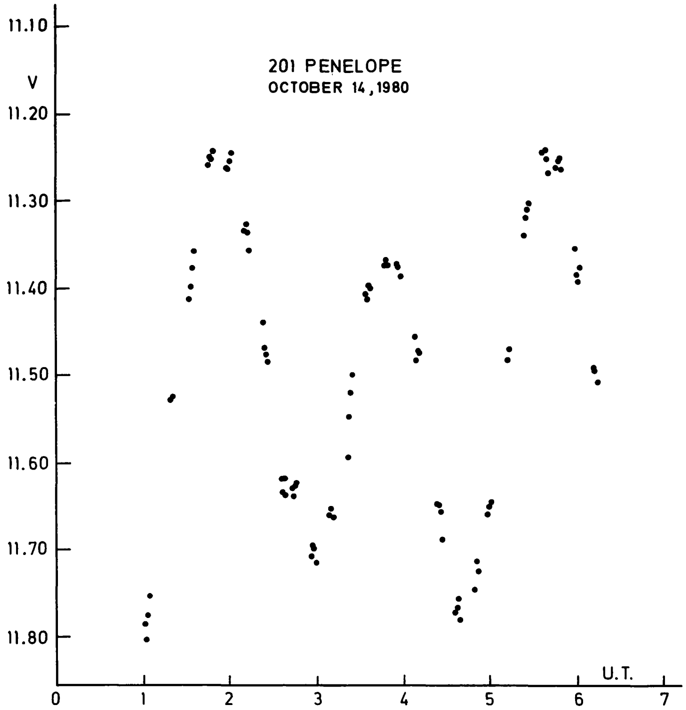

FIGURE 5. — V lightcurve of 201 Penelope on October 14, 1980.

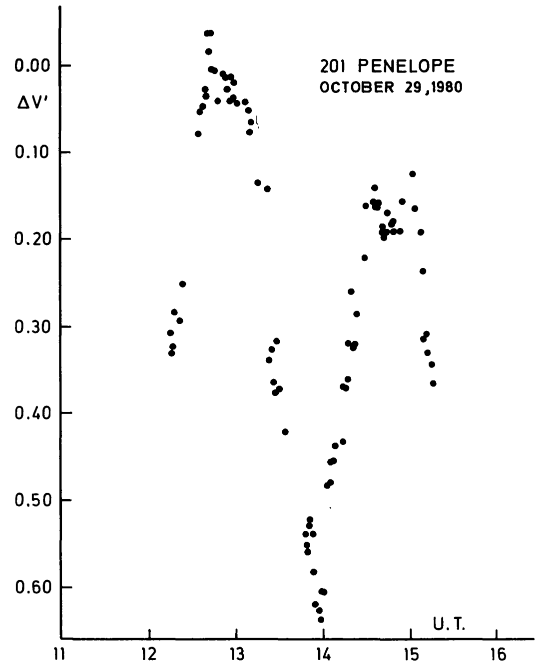

FIGURE 7. — V' lightcurve of 201 Penelope on October 29, 1980.

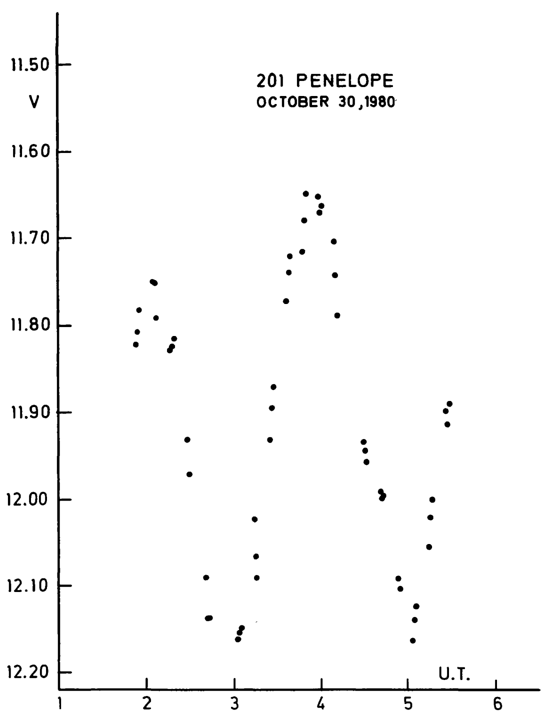

FIGURE 6. — V lightcurve of 201 Penelope on October 30, 1980.

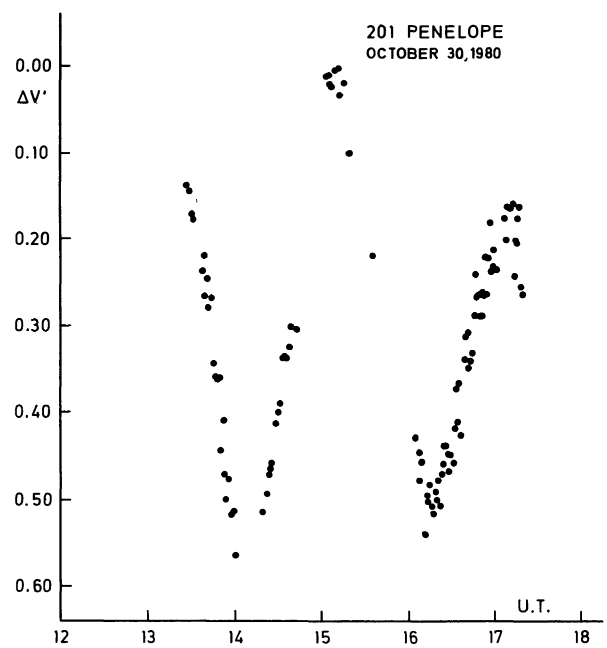

FIGURE 8. — V' lightcurve of 201 Penelope on October 30, 1980.

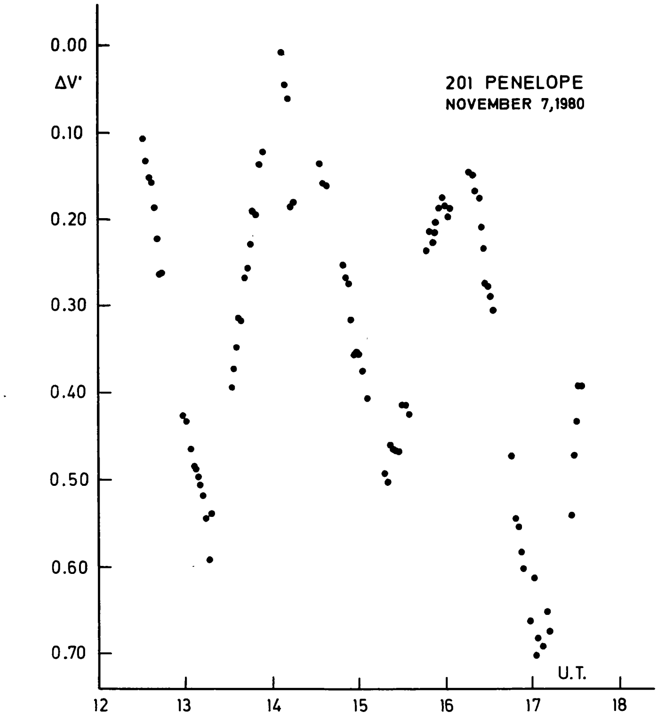

FIGURE 9. — V' lightcurve of 201 Penelope on November 7, 1980.

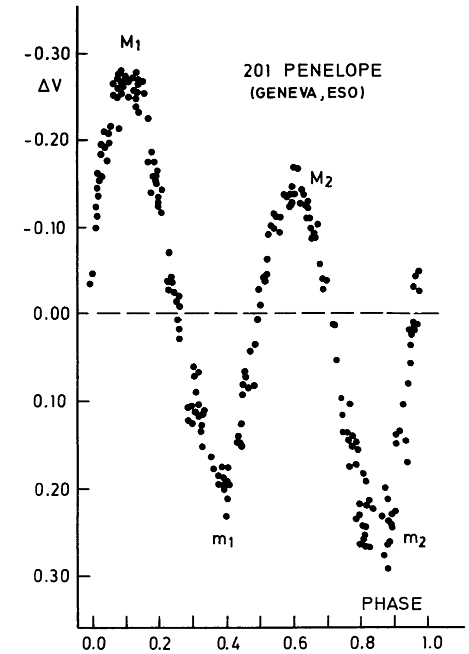

FIGURE 11. — Composite lightcurve of 201 Penelope from observations recorded on October 8, 14 and 30, 1980 with the Geneva 70 cm telescope.

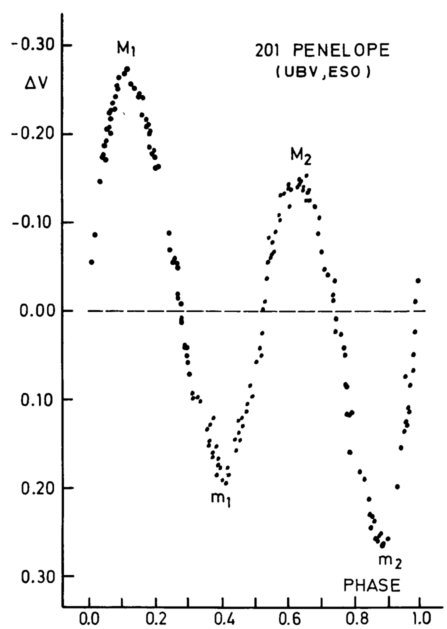

FIGURE 10. — Composite lightcurve of 201 Penelope from observations recorded on October 6, 11 and 17, 1980 with the ESO 50 cm telescope.

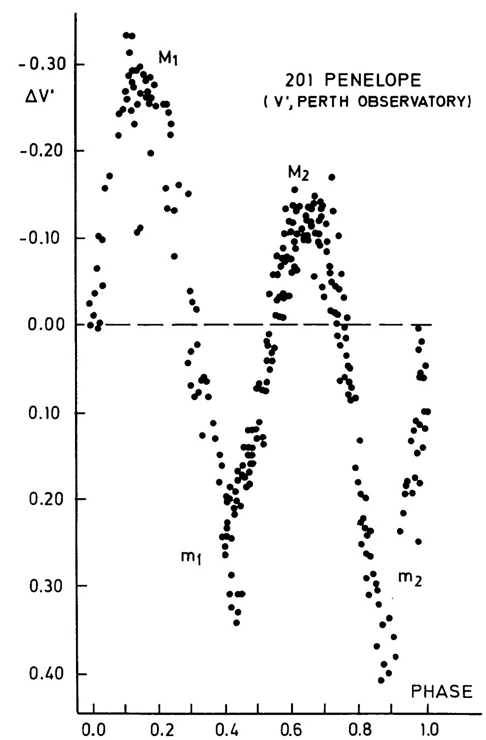

FIGURE 12. — Composite lightcurve of 201 Penelope from observations recorded on October 29, 30 and November 7, 1980 with the Lowell-Perth 60 cm telescope.

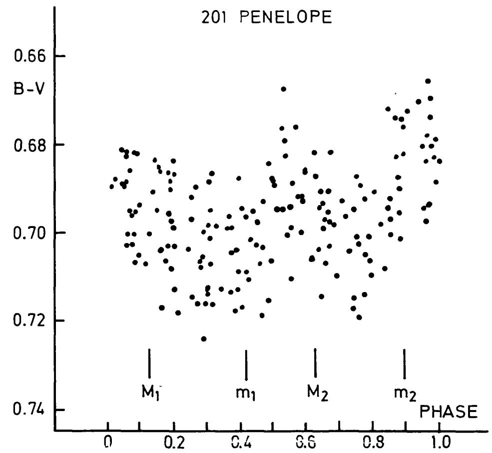

FIGURE 13. — Mean composite *B-V* color curve of 201 Penelope from observations recorded on October 6, 11 and 17, 1980 with the ESO 50 cm telescope.

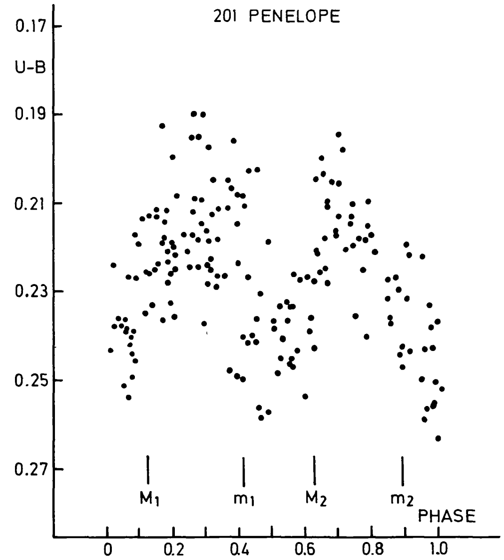

FIGURE 14. — Mean composite *U-B* color curve of 201 Penelope from observations recorded on October 6, 11 and 17, 1980 with the ESO 50 cm telescope.