A PHOTOMETRIC DETERMINATION OF THE ROTATIONAL PERIOD OF PLUTO*

MERLE F. WALKER AND ROBERT HARDIE
Lowell Observatory

Owing to the fact that the image of Pluto, as seen from the earth, is essentially stellar, it has not been possible to determine its period of rotation by observations of surface features or by spectroscopic measurements. If, however, the surface of the planet is not uniform in reflectivity, it should be possible to determine the period of rotation from photometric observations of the integrated light.

Photometric observations for the purpose of determining the period of rotation of Pluto were first obtained by Kuiper[1] in 1952 and 1953 with the 82-inch McDonald reflector. While these observations gave some indication of variability, they were not adequate to determine whether a periodic variation in the light occurred. In 1954, observations of Pluto were obtained in two colors (blue and yellow) by Walker with the 60- and 100-inch reflectors at Mount Wilson, using the photometric equipment described elsewhere.[2] These observations were secured on six nights and covered an interval of eleven days. On one of these nights, February 25, Pluto was observed over an interval of five hours, during which its light was constant within about 0.005 mag. On the other nights, only a few readings on Pluto and a near-by comparison star were obtained. These again gave indications of variability but, owing to cloudy weather during the eleven-day interval, not enough observations were obtained to ascertain whether the variations were periodic.

During March and April, 1955, the authors re-examined the whole problem, carrying out an intensive program of photometric observations of Pluto with the 42-inch reflector of the Lowell Observatory. The photometer used employed a 19-stage, blue-sensitive multiplier constructed by A. Lallemand, operated without refrigeration. The primary mirror of the telescope is in poor optical condition, the light-gathering power being equivalent to about that of a 30-inch reflector. As a result, it was necessary

* Read at Pasadena meeting of the Astronomical Society of the Pacific, June 1955.

to take quite long readings on Pluto in order to obtain accurate measurements of its brightness. Usually, four deflections of about two minutes duration were taken on Pluto, alternating with three deflections of the same length on the sky. In the reductions, a set of this kind was treated as a single observation; the mean probable error of such an observation was about ±0.01 mag. under good observing conditions.

Since even under the best conditions Pluto was near the limit of visibility because of the poor quality of the image, observations made upon nights of poor seeing were of lower accuracy owing to the uncertainty in centering Pluto in the diaphragm or to the necessity of using a larger diaphragm as an alternative. On nights of good seeing a diaphragm 30 seconds of arc in diameter was used, and on some nights of poor seeing a 45-second diaphragm was substituted. With these two apertures, the portions of the deflections comprising the sky reading were about 65 and 80 percent, respectively, of the total. In order to obtain as high signal-to-noise operation as possible, the observations were made in essentially integrated light; only a Schott GG13 filter was used to cut out the ultraviolet. Since the aim was to establish a periodicity, this procedure was felt to be justified; a study of possible color variations was not attempted in 1955. The brightness of Pluto was compared with that of two near-by comparison stars, which were selected to be (1) about two magnitudes brighter than Pluto, so that only a small time would be required to observe them with an accuracy corresponding to that of a single set on Pluto; and (2) of very nearly the same color as Pluto, so that no allowance for either the differential zenith distance or the differential color terms need be made in the reductions of the observations.

The magnitudes and colors of the comparison stars were determined on the **U,B,V** system, and a conversion equation was derived from measures made on a number of standard stars through which the integrated light-measures could be expressed in terms of the **V** magnitude. For additional accuracy in comparing the 1954 and 1955 sets of observations, the two comparison stars used in 1954 were also intercompared with the two used in 1955. Both sets of comparison stars are identified in Figure 1, which is taken from a Lowell 13-inch plate. The two stars used

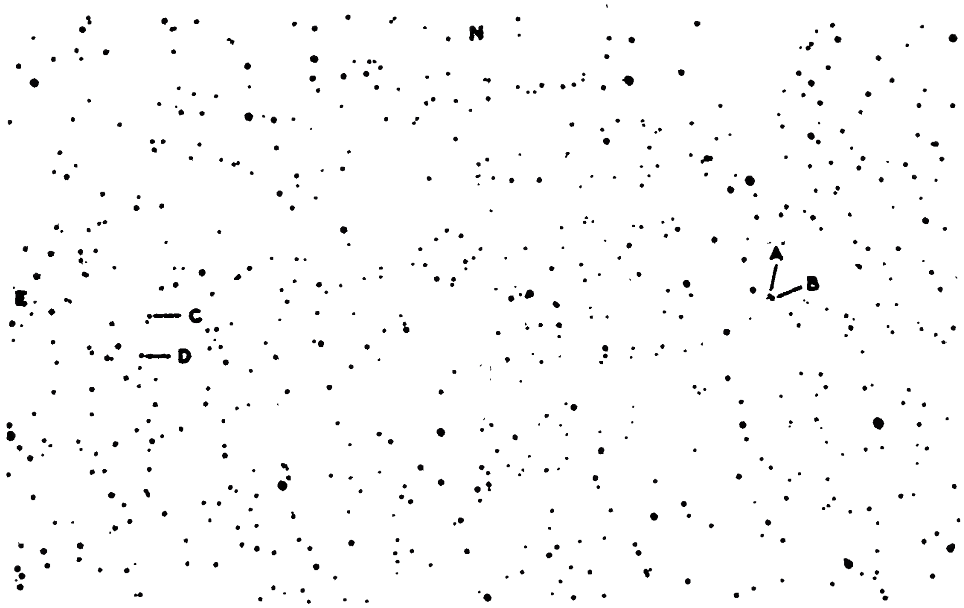

FIG. 1.—Field of Pluto in 1954 and 1955, showing the comparison stars used. From a plate taken with the 13-inch Lawrence Lowell Photographic Telescope. The scale is 89″/mm. The co-ordinates of star A are $\alpha = 9^h\,56^m\!.4$, $\delta = +23°\,14'$ (1954).

in 1954 are denoted A and B, and the 1955 stars are denoted C and D. In Table I are listed the colors and magnitudes of these

TABLE I

MAGNITUDES AND COLORS OF PLUTO AND COMPARISON STARS

Object	V	B—V	U—B
A	13.14	0.84	——
B	12.03	0.62	——
C	12.76	0.62	——
D	12.42	0.95	——
Pluto	14.90	0.79	0.26

comparison stars and Pluto; the tabulated quantities for Pluto are mean values, and the magnitude is reduced to mean opposition distance.

On five nights in March 1955, Pluto was observed over intervals of from four to seven hours in order to investigate the possibility of the occurrence of a short-period variation in light. These individual light-curves, together with the single long run obtained by Walker in 1954, are shown in Figure 2. It is quite clear that

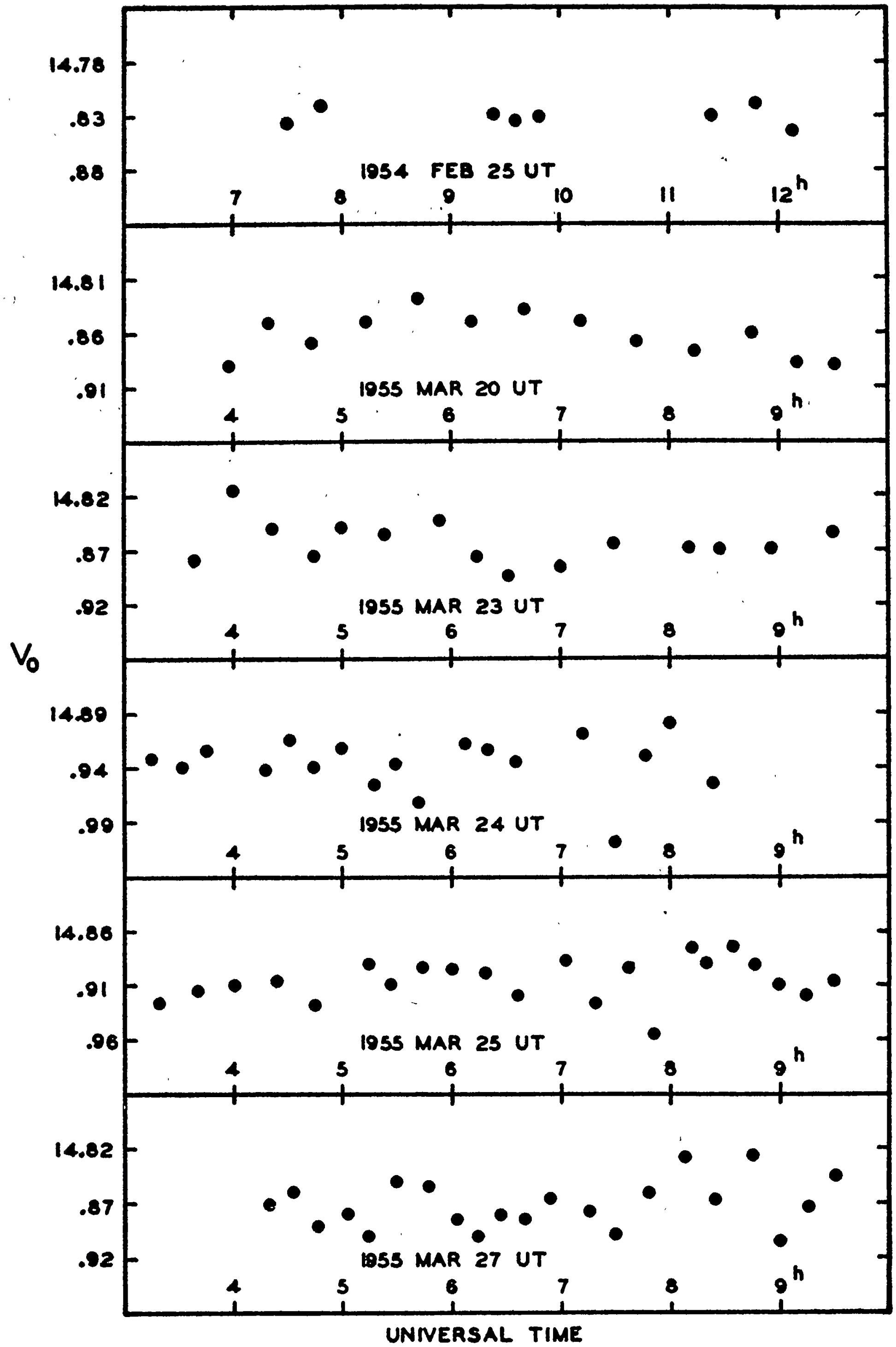

FIG. 2.—Observations of Pluto on individual nights, showing the absence of a short-period variation in light. The ordinate is the **V** magnitude reduced to mean opposition; the abscissa is Universal Time. The uppermost curve was obtained with the 100-inch Mount Wilson reflector; the other observations were made with the 42-inch Lowell reflector.

no short-period variation greater than about 0.01 mag. occurs.

On the remaining nights, Pluto was observed only sufficiently long to determine an accurate mean observation for the night. These observations show very clearly that night-to-night variations occur. In order to make certain that these variations resulted from actual changes in the brightness of Pluto and not from stars invisible to the eye (fainter than about 15th magnitude) which were included accidentally in readings on the planet or the sky, the path of Pluto was plotted accurately on a print of the region taken with the 48-inch Schmidt for the Palomar Observatory–National Geographic Sky Survey. The limiting photographic magnitude of this print is about 20. Since the apparent photographic magnitude of Pluto is about 15.3, the effects of including stars fainter than shown on the print would be less than about 0.01 mag.

Table II lists the observations of Pluto in 1954 and 1955.

TABLE II

PHOTOMETRIC OBSERVATIONS OF PLUTO IN 1954 AND 1955

JD	V_0	PE_i	B—V	JD	V_0	PE_i
2434000+				2435000+		
797.96*	14.85	.005	0.78	193.78	14.87	.002
798.92*	14.83	.002	0.79	194.66	14.84	.011
799.91*	14.85	.005	0.80	196.67	14.93	.005
800.88†	14.94	.003	0.78	197.89	14.95	.010
807.89*	14.96	.005	0.79	198.92	14.90	.003
808.87*	14.91	.005	0.80	210.79	14.94	.007
2435000+				211.73	14.91	.004
186.79	14.86	.002		212.86	14.92‡	.008
189.79	14.87	.002		213.82	14.85	.006
190.71	14.94	.002		215.70	14.93	.003
191.79	14.91	.002		217.68	14.91	.005

* 100-inch Mount Wilson reflector.

† 60-inch Mount Wilson reflector.

‡ This observation may be about 0.04 magnitude too faint owing to the probable inclusion of a star of about 18th magnitude in the sky reading. It has been corrected to 14.88 in Fig. 3.

The first column contains the date of observation. The second column gives the average value of the **V** magnitude of Pluto for each night, reduced to mean opposition, ($\mathbf{V}_0$). The third column contains the internal probable errors of the **V** observations for each night. The external probable errors are, of course, larger than the figures given; consequently the tabulated values should be regarded only as approximate, relative weights. The last column gives the color measurements of Pluto made in 1954. The probable errors of these colors are about 1.4 times those given for the values of $\mathbf{V}_0$, since both magnitudes and colors were measured differentially.

With the possibility of a short-period variation eliminated, it became clear from the observations on successive nights that a periodic variation in the light does indeed occur, with a range of about 0.1 mag. and a period between 6.0 and 6.5 days. Returning to the 1954 observations, we found that they could be combined with the 1955 observations according to a number of possible periods which are tabulated in Table III. The estimated

TABLE III

POSSIBLE ROTATIONAL PERIODS FOR PLUTO FROM 1954 AND 1955 DATA

Days	Days
6.185	6.600
6.285	6.710
6.390	6.825
6.495	

accuracy of these values is about ±0.005 day.

In order to obtain a definitive value of the period, Kuiper has kindly turned over to the authors a portion of his 1953 observations for inclusion here. These are tabulated in Table IV,

TABLE IV

PHOTOMETRIC OBSERVATIONS OF PLUTO IN 1953*

JD	$\mathbf{V}_0$	JD	$\mathbf{V}_0$
2434470.75	14.97	2434475.62	15.01
471.65	14.89	476.63	14.98
474.65	14.99	477.62	14.90

* These observations were obtained by Kuiper with the 82-inch McDonald reflector.

and are of undetermined weight with respect to those in Table II. If these are combined with a period of about six days, it appears that they define the minimum portion of the light-curve; they are all, however, systematically fainter than the values found in 1954 and 1955 at the minimum of the variation, so that in combining Kuiper's data with the more recent observations, an arbitrary zero-point correction of —0.05 mag. has been applied to his measures. Using his data, we may select a period from Table III which fits all the observations from 1953 to 1955; this is the value 6.390 days with an estimated accuracy of ± 0.003 day. Figure 3

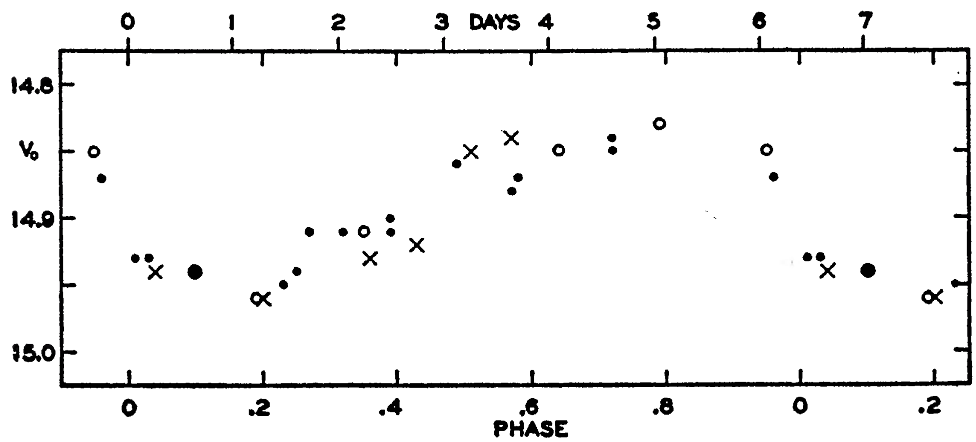

FIG. 3.—Observations of Pluto combined according to the elements: JD 2434800.26 + 6.390*E* days. The dots represent the 1955 observations; the circles, observations made in 1954; and the crosses, observations made in 1953. The ordinate is the **V** magnitude reduced to mean opposition; the abscissa is the phase in the six-day period.

shows how this period fits the observations. Since the descending branch of the light-curve appears to be the steepest, we have chosen the phase when it reaches the magnitude $\mathbf{V}_0 = 14.90$ as a convenient zero-point to provide the following elements of the light-variation:

$$\text{JD } 2434800.26 \pm .06 + 6.390E \pm .003E.$$

The color observations made in 1954 indicate that there is probably no color variation larger than about 0.005 mag. during the period of rotation; the data are too few to enable us to determine whether a smaller color variation occurs.

The 1954 observations, although rather few, suggest that the shape and amplitude of the light-curve was essentially the same then as in 1955. This, together with the fact that all of the observations for 1953, 1954, and 1955 can be fitted with a constant period, suggests that we are observing the actual surface of the planet and not a cloud layer. This is actually what one would expect, in view of the extremely low surface temperature and probable small size of Pluto.

The long period of rotation observed for Pluto is undoubtedly related to its origin and evolutionary history. An interesting interpretation, due to Kuiper,[3] is that such a period indicates that Pluto originated as a satellite of Neptune and not as a planet. Future observations of the light-variation of Pluto will be of importance in establishing whether or not the shape of the light-curve is really unvarying and also whether the amplitude is a function of the position of the planet in its orbit, as this might provide some clue to the inclination of its axis of rotation to the plane of its orbit. Clearly we cannot determine the inclination of the rotational axis to the line of sight from the present observations; but the fact that the integrated light reflected from Pluto changes by as much as 0.1 mag. as the planet rotates suggests that, at the present time, Pluto is seen more nearly equator-on than pole-on. Mars provides the only other case of an equator-on planet whose surface is visible and which has been observed photoelectrically. The light-variation of Mars resulting from rotation has a range of 0.1**V** mag.[4] Ranges up to 0.4 mag. are observed for some of the asteroids, but these larger amplitudes might be expected since many asteroids are irregular in shape.[5] While the surface conditions of Pluto without doubt differ greatly from those of Mars or the asteroids, the fact that Mars seen equator-on also reveals a variation of 0.1 mag. would appear to strengthen our conclusion that Pluto is seen more nearly equator-on.

It is a pleasure to thank Dr. Kuiper for permission to use some of his data in advance of publication and for several stimulating discussions of this problem. We also thank Dr. G. Van Biesbroeck for taking a plate of the field of Pluto for us with the 82-inch McDonald reflector.

---

[1] G. P. Kuiper, private communication.
[2] M. F. Walker, *Pub. A.S.P.*, **66**, 71, 1954.
[3] G. P. Kuiper, *Proc. Nat. Acad. Sci.*, **39**, 1153, 1953.
[4] H. L. Johnson and A. J. Gardiner, *Pub. A.S.P.*, **67**, 74, 1955.
[5] I. Groeneveld and G. P. Kuiper, *Ap. J.*, **120**, 200, 1954.