



LIGHTCURVE AND COLOR OF NEAR-EARTH-ASTEROID 1989ML

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ABSTRACT

The asteroid of 1989ML is an Amor type near-earth-asteroid, which is one of the most accessible asteroids by spacecraft, and consequently it has been selected as a backup target of the Japanese sample return mission, MUSES-C. In January 1996, the brightness of 1989ML had been brighter than 20-magnitude in R-band and we succeeded to observe it using a 1.05-m schmidt telescope with 1K CCD detector at Kiso Observatory, Japan. From the analysis of the data obtained for four nights, it is found that the rotational period of 1989ML may be 19 or 32 hours, and the amplitude of its brightness variation is about 1 magnitude in R-band. We have performed also VRI band colorimetry and found that the color of 1989ML is similar to that of C-type asteroid.

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INTRODUCTION

About 500 near-Earth-Asteroids (NEAs) have been found up to 1998. NEAs have characters as follows. First, some NEAs are easy to be approached by spacecraft. Second, NEAs have a potential to impact to the Earth. Third, we can observe smaller sized bodies in NEAs than those in main belt asteroids (MBAs). Fourth, whether MBAs or comets are origin of NEAs is still an unsolved question.

The 1989ML is an Amor type Near-Earth-Asteroid, discovered in 1989 and rediscovered in 1992. That is one of the most accessible asteroids by spacecraft among multi-oppositional observed asteroids (Davis *et al*, 1993, Abe *et al*, 1996). In Japanese asteroid sample return mission, MUSES-C, the nominal target is 4660 Nereus, and 1989ML is the back up target (Fujiwara *et al*, 1998).

In order to optimize the mission scenario, it is significant to obtain the physical data and taxonomic type of mission target, e.g., its size, rotational state, surface material etc., from groundbased observation before launch as early as possible. Unfortunately, for 1989ML, we have no available data for its rotational period and colorimetric nature due to its faintness and few opposition chance.

OBSERVATION AND REDUCTION

We observed 1989ML using the 1.05-m Kiso schmidt telescope with 1K-CCD for four nights on 12, 13, 16 and 17 in January, 1996 during its third opposition after discovery. In Table 1, we summarize the observational environments. During our observation the apparent motion of 1989ML was about 1 arcsec/min. Seeing was not good and the full width of half maximum of star images were between 3 and 4.5 arcsec. All frames were reduced bias and normalized by flat data carefully. The

IRAF's aperture photometry technique was applied (Tody, 1986). The data for standard stars were cited from some SA-98 stars in Landolt catalogue (Landolt 1992).

Colorimetry

On January 12, we used three broad band filters, i.e. V, R, and I-bands. Exposure time was set to be 300 sec in each band. We regarded 6 frames, which consist of two exposures in each band, as one set. The standard stars were detected twice before/after each set. We took three sets from 12.5 to 15.5 UT. The brightness of 1989ML increased gradually during our observation. It is found after reducing the airmass effect that the brightness change rate was about 0.2 mag/hour in each band. We have found that a brightness of 1989ML at 14:00 UT on January 12, 1996 became 19.61(± 0.13) at V-band, 19.28(± 0.13) at R-band, and 18.97(± 0.17) at I-band respectively. Then a color of 1989ML became $(V-R)_{ML} = 0.33(\pm 0.18)$ and $(V-I)_{ML} = 0.64(\pm 0.21)$.

Light variation

On January 13, 16 and 17, we used only R-band filter to obtain the light variation of 1989ML. Exposure time was set to be 180 sec. The reason for a reduction of the exposure time from 300 sec on January 12 is to obtain more data points and better time resolved data for the lightcurve analysis. We took more than 70 frames during three nights. In order to obtain the light variation in each night, we compared the brightness of 1989ML to that of comparison stars (here after CS) in the same frame where 1989ML existed. On January 13, we could observe the standard stars as well as the field where 1989ML existed on January 12. On January 16, we also observed the field where 1989ML existed on January 13. The absolute magnitude of CS on January 13 was calculated comparing standard stars and CS by reducing airmass effect. The apparent magnitude of CS on January 16 was estimated by comparing the brightness of CS on January 13 and 16. The apparent magnitude of CS on January 17 was estimated by comparing GSC catalogue's stars in the field observed on January 16 and 17.

The magnitude of CSs on each night are about 14 mag in R-band and the magnitude error is about 0.06 mag on January 12, 13, and 16, and 0.15 mag on January 17.

A light variation of 1989ML is shown in Fig. 1 and Fig. 2. The data detected in different bands on January 12 are translated to the magnitude in R-band.

Table 1. Observational Circumstances of 1989ML

Date (UT)	r (AU)	R (AU)	Phase (deg)	R.A. (2000.0)	Dec. (2000.0)
96 Jan 12.0	1.443	0.477	12.9	8 ^h 52 ^m .96	+20 ^d 34 ^m .6
96 Jan 13.0	1.442	0.474	11.9	8 ^h 51 ^m .36	+20 ^d 49 ^m .5
96 Jan 16.0	1.441	0.466	9.1	8 ^h 46 ^m .24	+21 ^d 35 ^m .2
96 Jan 17.0	1.441	0.464	8.2	8 ^h 44 ^m .43	+21 ^d 50 ^m .6

r: heliocentric distance, R: geocentric distance

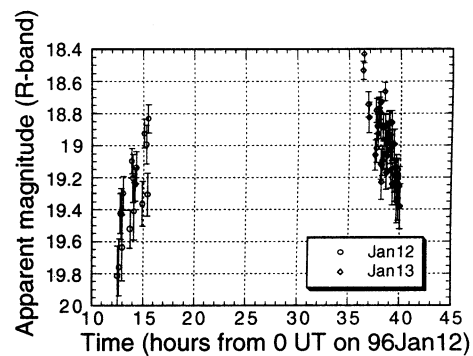


Fig. 1. Apparent magnitude of 1989ML in R-band on January 12 and 13, 1996.

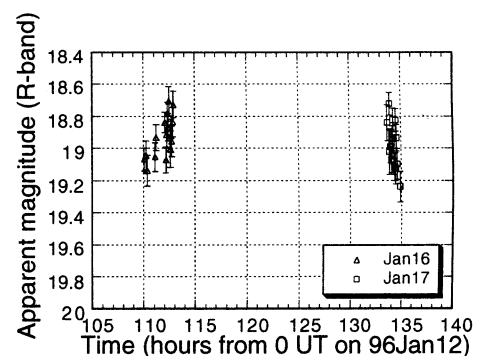


Fig. 2. Apparent magnitude of 1989ML in R-band on January 16 and 17, 1996.

RESULTS AND DISCUSSION

Assuming that the solar color is $(V-R)_s = 0.367$ and $(V-I)_s = 0.705$, we can obtain the color of reflectance by 1989ML. That is, the R-band and I-band reflectance normalized at V-band are $0.97(+0.18/-0.15)$ and $0.94(+0.20/-0.17)$, respectively. We plot the color of 1989ML in VRI color map in Fig. 3. In this figure the color of other major taxonomic type asteroid is derived from Xu et al. (1995). Although an error bar is very large, it is found that the color of 1989ML is dropped in the region for C-type asteroids.

We applied the data in Fig. 1 and Fig. 2 to the spectrum analysis method by Lomb cited in Press et al. (1994) after translating them to the absolute magnitude assuming 1989ML's slope parameter $G=0.15$. Fig. 4 shows the result of periodogram. The most reliable period is found from Fig.4 to be 15.9 hours and the second candidate is 9.5 hours. We checked the same data by an independent analysis using a phase dispersion minimization method (Lafleur and Kinman 1965) and obtained the same period basically. Since the light variation curve of most asteroids has two minima and two maxima during one rotational period, we regards the rotational period of 1989ML as 31.8 hours or 19.0 hours.

If the light variation of the asteroid is caused by only the change of the projected surface area and the shape of asteroid is assumed to be triaxial ellipsoid, we can obtain the best model for lightcurve to fit our observation. We shows the best model to explain our observation in Fig. 5 as dotted curve, where the rotational period is set to be 31.8 hours.

In Fig. 5, the amplitude of model curve is about 1.0 mag and its maximum brightness is about 2.6 times of minimum brightness. In order to derive an axis ratio about the asteroid, we have to take into account the effect of non-geometrical scattering at non-zero phase angle. We used empirical relations (Zappala *et al.*, 1990) to deduce the axis ratio from our observations. Since the dynamically stable rotation is the rotation around the shortest axis, assuming observed aspect angle of 90 degree, the ratio of the longest axis to the intermediate axis (here after a/b) is derived 2.2. Binzel *et al.* (1992) reported on the corrected mean amplitude of light variation of NEAs and similar sized (diameter less than 5 kilometers) MBAs. Estimated mean a/b s are 1.5 and 1.7 respectively using the relation between

a/b and the corrected amplitude calculated by Binzel and Sauter (1992). If our observed aspect angle is not 90 degree, our estimated a/b becomes larger than 2.2. This suggests that the 1989ML has a very elongated shape.

We also checked the axis ratio based on the rotational period of 19.0 hours. In this case, the error is larger than that in the case of rotation period of 31.8 hours. The amplitude of model curve, however, becomes about 0.6 mag and the resulting axis ratio is about 1.7.

We show the summary of our results in Table 2.

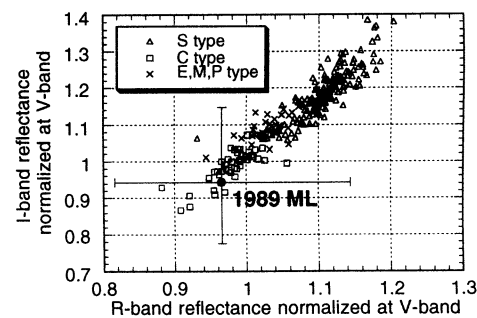


Fig. 3. Reflectance color of 1989ML and those of other major taxonomic type asteroids. The reflectance data of major taxonomic asteroids are derived from Xu et al. (1995).

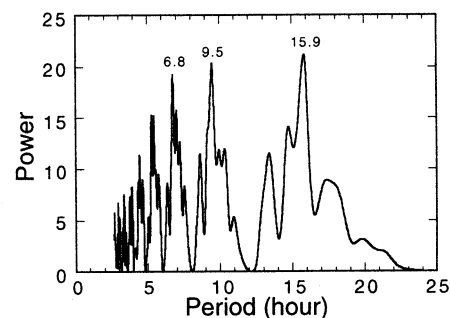


Fig. 4. Spectral power vs. a rotational period of 1989ML for our observations with the Lomb method.

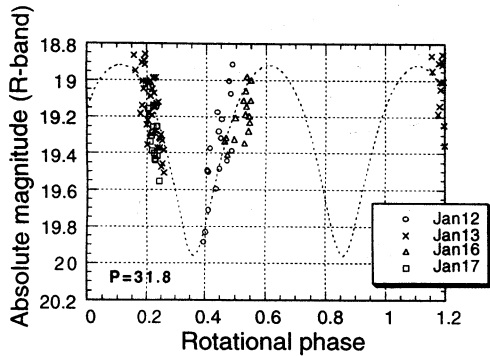


Fig. 5. A comparison of our observations with a light variation of 1989ML estimated by a model of its rotational period of 31.8 hours with an amplitude of 1.0 mag.

Table 2. Summary of Results

Color	(V-R) _{ML}	0.33 +/- 0.18 mag
	(V-I) _{ML}	0.64 +/- 0.21 mag
Reflectance normalized at V-band *		
	R-band	0.97 (0.87~1.15)
	I-band	0.94 (0.78~1.15)
Taxonomic type		C-type (?)
Rotational period		31.8 hour
**Amplitude of light variation		1.0 mag
** (max / min) of brightness		2.6
***Aspect ratio (a/b)		2.2
**Mean H _v -magnitude		19.7 mag

* Assuming solar color (V-R)_s=0.367, (V-I)_s=0.705

** Estimated by fitting light curve

*** Assuming that the aspect angle is 90 deg and the solar phase correction is ruled by Zappala et al. (1990).

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