PHOTOMETRIC BEHAVIOUR DEPENDENT ON SOLAR PHASE ANGLE AND PHYSICAL CHARACTERISTICS OF BINARY NEAR-EARTH-ASTEROID (65803) 1996 GT .
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Introduction: Photometric behavior of an asteroid is generally considered to derive from mainly changing distances from Earth and Sun, rotation causing a periodic variation of the area and/or average albedo of the visible surface, and changing solar phase angle. The goal of this study is to map out the relationships between photometric behavior and solar phase angle as accurately as possible. Furthermore we have taken near-Earth-asteroids survey of the target of the next asteroid exploratory mission (post-HAYABUSA mission) in Japan. The object observed in this study is also one of them and to reveal its physical characteristics is important purpose, too.

Asteroid of (65803) 1996 GT is an near-Earth-asteroid designed as belonging to the PHA (Potentially Hazardous Asteroid) group (*q* = 1.013 AU, *a* = 1.644 AU, *i* = 3.4 deg (MPO 53573)) and one of the most accessible asteroids by spacecraft [1]. The object was predicted from ephemeris to make a close pass by the Earth on November 2003, which represented the enhancement of the apparent brightness. We had observed the object using with Kiso 30-cm Telescope (K.3T) for long periods. During these observational periods the solar phase angle of 1996 GT had varied 40.0 to 2.0. In the past, there is little observation to obtaine the photometry of asteroids such as solar phase angle varied remarkably by a same telescope and in a continued term, and thus these data sets are very informative. In addition, we had observed the object using with 1.05-m Kiso Schmidt Telescope at UBVRI band filters and determined the color index and the taxonomic type of this asteroid.

Observations and Data Reduction: First, we had observed the asteroid 1996 GT to investigate lightcurves and photometric behavior dependent on solar phase angle for long periods from 2003 Nov. 13 to Dec. 4 using with the K.3T at mainly R-band plus I in Kiso Observatory, Japan. K.3T is a robotic telescope newly established next to the 1.05-m Kiso Schmidt Telescope at Kiso Observatory to observe the objects such as variable stars and targets of opportunity. Second, we had also taken multi-band (UBVRI) observations of 1996 GT on 2003 Dec. 1 to 4 using with the 1.05-m Kiso Schmidt Telescope with SITe 2K CCD detector at Kiso Observatory to determine its color index and taxonomic type. A detailed list of photometric observational data set is presented in Table 1. Seeing was not good and the full width of half maximum of star images were between 3 and 5 arcsec. At each observational date, Landolt standard stars were observed for calibration purpose, including solar analog stars to allow us to calculate relative reflectance value [2].

Data were reduced using the Image Reduction and Analysis Facility (IRAF) packages. The images were bias (dark; in the case of the data obtained by K.3T) subtracted and normalized by the flat field images in each band. Aperture photometry was calculated using IRAF apphot package. Relative photometry of the asteroid 1996 GT was computed through comparisons with brighter stars in each frame. The apparent magnitudes of the comparison stars were determined by observing Landolt standard stars at the same night. This obtained apparent magnitudes were converting to reduced magnitudes, m_r, which defined as

$$m_r = m_p - 5\log(\Delta r), \tag{1}$$

where m_p is the apparent magnitude, Δ is geocentric distance (AU) and *r* is heliocentric distance (AU).

Results and Discussions: Visual lightcurves of most of asteroids are semi-periodic. The strict periodicity, which is due to rotation, is interfered with changing solar phase, aspect angle, and rate of apparent motion, which result in changing lightcurve shape, mean brightness, and synodic period. Actually these effects can be eliminated in a lightcurve analysis, and an unambiguous period of rotation can usually be derived. Nevertheless, 1996 GT is not likely to apply to this lightcurve rule. Fig. 1 shows, for example, the lightcurve of 1996 GT observed on Nov. 23 using with K.3T at R-band. This figure seems to indicate that the temporal depression of brightness nearby 17 h. 1996 GT has been recently reported to be an asynchronous binary asteroid by Pravec et al. (cf. http://www.asu.cas.cz/˜ppravec/65803.htm). They have revealed the primary's rotation period (2.260 h), amplitude of the primary's rotation lightcurve (0.10 mag.), orbital period (11.90 h) and secondary-to-primary mean diameter ratio (0.2) with regard to the binary system of this object from their photometric and radar observation.

Regarding the spectral characteristics of 1996 GT, we estimated the color index U-B = 0.211 ($\pm$0.032), B-V = 0.795 ($\pm$0.016), V-R = 0.458 ($\pm$0.009), V-I = 0.820 ($\pm$0.009) from the results of UBVRI photometry. Here we used the solar values [4] and converted to relative reflectance normalized at R-band (show in Fig. 2). If this object is considered as S-type asteroid, there should be the absorption band nearby 1 micron. In addition, judging from the moderate value of spectral slope 0.45 $\pm$ 0.11 (% / 100 nm), 1996 GT may be a X-type (included E-, M-, P-types) asteroid. What has to be noticed is that these photometry had not taken at illuminated depression of the lightcurve derive from the binary system of 1996 GT.

Moreover, we estimated slope parameter *G* of 1996 GT using IAU Two-Parameter *H*, *G* Magnitude System [5]. The mean V-band magnitude of an asteroid can be calculated from the formula

$$H(\alpha) = H - 2.5log[(1-G)\Phi_1(\alpha) + G\Phi_2(\alpha)], \tag{2}$$

where $H(\alpha)$ is the V-band magnitude, at solar phase angle α, reduced to unit heliocentric and geocentric distances; H is the absolute magnitude. G is the slope parameter. Φ_1 and Φ_2 are two specified phase functions (cf. [5]). Here assuming the equation apply to R-band, we calculated R-band absolute magnitude. As results, we obtained the value of $H_R = 17.70 \pm 0.03$ and $G = 0.20 \pm 0.02$ (Fig. 3). And we converted the H_R to V-band absolute magnitude H_V by our leading color index of 1996 GT. We calculated the value of geometric albedo with [6]

$$D(km) = 10^{-H_V/5} 1329/\sqrt{p_v}. \qquad (3)$$

Here we use the primary's and secondary's diameters of 1996 GT derived from the radar observation of Pravec et al. As results, the value of geometric albedo p_v is 0.147. According to [7] and [8], B-, C-, D-, F-, G-, P-, and T-type asteroids have $G = 0.09 \pm 0.09$ and lower geometric albedos ranging from 0.02 to 0.11. M-type have $G = 0.21 \pm 0.06$ and moderate geometric albedos from 0.10 to 0.18. The S- and Q- types have $G = 0.23 \pm 0.11$ and geometric albedos from 0.10 to 0.22. High albedo asteroids in the E, R, V classes have $G = 0.42 \pm 0.08$ and geometric albedos from 0.25 to 0.60. Therefore 1996 GT may be interpreted as particularly M-type among X-type. This interpretation may be proved more clearly by the reflectance derived from the radar observation.

Conclusions: In summary, we have derived the color index and predicted the taxonomic type of 1996 GT asteroid from its spectral slope, slope parameter G and geometric albedo p_v. The lightcurve of this object represented the feature of binary system as same as Pravec et al. reported. Finally, ground-based observations have accumulated a vast amount of information on asteroids in various respects, while *in-situ* asteroid observation by spacecrafts provide many of the essential information for determining physical characteristic of asteroids. If 1996 GT is correctly a M-type asteroid, this type asteroid is rare among accessible asteroids by spacecraft and this object would be expected to the target of the next asteroid exploratory mission.

References: [1] Abe (2003) *Proceedings of* 24^{th} *the Solar System Symposium in ISAS* 89-92. [2] Landoldt A. U. (1992) *Astron. J.* **104,** 340-371. [3] Lang K. (1992) *Astrophysical Formulae 2.* New York: Springer-Verlag. [4] Howell E. (1995) Ph.D. thesis, Univ. of Arizona. [5] Bowell E. B. et al. (1989) In *Asteroids II* pp. 524-556. [6] Harris A. W. and Harris A. W. (1997) *Icarus* **126,** 450-454. [7] Harris A. W. and Young J. (1988) *Bull. Am. Astron. Soc.* **20,** 865. [8] Verbischer A. J. and Veverka J. (1995) *Icarus* **115,** 369-373.

Data Set	UT Date	Telescope
RI Photometry	11/13,14,16-18, 21-23,25-27/03, & 12/1-4/03	K.3T
BVRI Photometry	12/1,2,4/03	Kiso 1.05-m Schmidt
UBVRI Photometry	12/3/03	Kiso 1.05-m Schmidt

Table 1: Observational summary for (65801) 1996 GT.

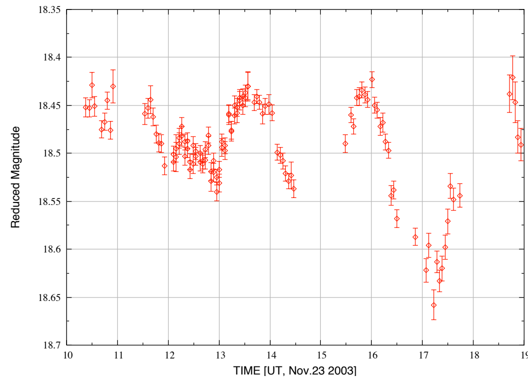

Figure 1: Lightcurve of 1996 GT, taken on Nov. 23 2003 using with K.3T at R-band.

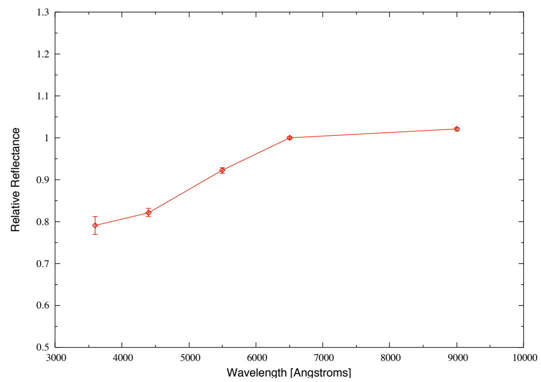

Figure 2: Relative reflectance of 1996 GT normalized at R-band.

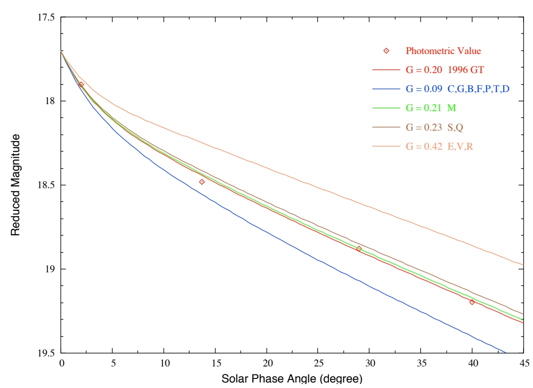

Figure 3: Solar phase angle behavior of 1996 GT at R-band. Phase curves derived from various slope parameter G are also presented to compare.