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PHOTOMETRY AND SPECTROSCOPY OF THE POTENTIALLY HAZARDOUS ASTEROID 2001 YB_5 AND NEAR-EARTH ASTEROID 2001 TX_{16}

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ABSTRACT

CCD photometric observations of the two near-Earth asteroids (NEAs) 2001 YB_5 and 2001 TX_{16} were carried out in 2002 January with the 0.6/0.9 m Schmidt telescope of the National Astronomical Observatories of China (NAOC). Analysis of the light curves of these two objects reveals rotation periods of 3.20 ± 0.03 hr with amplitude 0.21 ± 0.02 mag for 2001 YB_5 and 4.8005 ± 0.0003 hr with amplitude 0.51 ± 0.01 mag for 2001 TX_{16}. Spectroscopic observations of the two NEAs were made with the NAOC 2.16 m telescope, ranging from 5000 to 9000 Å. The reflectance spectrum of 2001 YB_5 is a little bluish, with a possible weak absorption band from 8000 to 9000 Å, which is consistent with the spectra of B-type asteroids. That of 2001 TX_{16} is spectrally flat, with a shallow absorption band centered near 7000 Å, consistent with the spectra of Ch-type asteroids.

Key words: minor planets, asteroids — techniques: photometric — techniques: spectroscopic

1. INTRODUCTION

Near-Earth asteroids (NEAs), with perihelion distances (q) less than 1.3 AU, are the subjects of much interest in scientific studies for both their potential usefulness for spaceborne activities and their possible destructiveness in case of collisions with Earth (McFadden, Tholen, & Veeder 1989). The NEA 2001 TX_{16} was discovered by the JPL Near-Earth Asteroid Tracking program (NEAT) on 2001 October 13 (Helin et al. 2001a) and is a very bright object, with a maximum V magnitude of 13.8. This asteroid was once suspected of being a cometary nucleus; however, later observations revealed that it has no cometary appearance.

In addition, potentially hazardous asteroids (PHAs), which are defined based on their potential to make threateningly close approaches to Earth, are of the most immediate concern to the world. Asteroid 2001 YB_5 had a very close pass on 2002 January 7 within 0.005571 AU of Earth, approximately twice the distance to the Moon. With an Earth minimum orbit intersection distance less than 0.05 AU and an absolute magnitude (H) less than 22.0, 2001 YB_5 is considered a PHA, and thus it has attracted considerable observational attention. This object was first discovered by NEAT on 2001 December 27 (Helin et al. 2001b), with semimajor axis $a = 2.378$ AU, inclination $i = 5\overset{\circ}{.}49$, and eccentricity $e = 0.864$. Its brightness ($H = 20.6$) suggests that its size could be around 300 m.

In this paper, we present the results of photometric and spectroscopic observations of 2001 YB_5 and 2001 TX_{16}.

2. PHOTOMETRIC OBSERVATIONS

2.1. *Description and Data Reduction*

CCD photometric observations of asteroids 2001 YB_5 and 2001 TX_{16} were performed at the Xinglong Station of the National Astronomical Observatories of China (NAOC) with the 0.6/0.9 m Schmidt telescope, using the Beijing-Arizona-Taiwan-Connecticut (BATC) multicolor sky survey i filter (Fan et al. 1996; Zheng et al. 1999). The data were reduced using standard procedures, including bias subtraction and flat-fielding of the CCD images, with an automatic data reduction system named PIPELINE-I developed for the BATC multicolor sky survey (see Zheng et al. 1999 for details). During each night, five stars were chosen as comparison candidates; the most stable one, which showed the least standard deviation in its magnitudes during the night, was finally used to obtain the relative magnitude (the difference in instrumental magnitudes between the asteroid and a field comparison star) of the target asteroid. The instrumental magnitudes were determined utilizing DAOPHOT, a package within the IRAF software. Since these two asteroids all move a few degrees each day, different comparison stars were chosen on the frame for each night as necessary. To obtain a uniform data set, the offsets of all selected comparison stars were adjusted and normalized to a common zero point. Our main goal is to estimate the rotational periods of the two objects, and thus an accurate zero-point calibration is not necessary. The comparison stars that were used and the observational conditions are listed in Table 1, which contains the following information: the UT date of observation, geocentric distances Δ and heliocentric distances r, the solar phase angle of the asteroid at the time of observation, and right ascension and declination in the J2000.0 reference frame. The magnitudes of the comparison stars are from version 2.2 of the Guide Star Catalog (STScI 2001).

We measured the quality of each night by using the average deviation in magnitude between two corresponding comparison stars, which is also listed in the last column of Table 1. In this paper, the composite light curves have been constructed based on the method described by Harris et al. (1989). All the data were corrected for light-travel time and distance.

2.2. *Results*

Asteroid 2001 YB_5 was observed on the nights of 2002 January 3 and 4. The data were fitted with a fifth-order Fourier solution, revealing a best-fit period $P = 3.20 \pm 0.03$

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TABLE 1
Observational Conditions and Comparison Stars

Asteroid	Date (UT)	Δ (AU)	r (AU)	Phase (deg)	R.A. (J2000.0)	Decl. (J2000.0)	GSC2.2 Comparison	Dispersion (mag)
2001 YB_5........	2002 Jan 3.7	0.065	1.044	20.4	8 15 21.6	11 40 47.8	N2213231377	0.012
	2002 Jan 4.7	0.046	1.026	21.8	8 19 42.3	9 57 35.7	N2213201414	0.005
2001 TX_{16}	2002 Jan 11.6	0.495	1.441	18.4	9 24 13.3	34 16 12.2	N233322149	0.015
	2002 Jan 12.6	0.494	1.44	18.2	9 25 17.3	34 27 45.3	N233322149	0.018
	2002 Jan 14.6	0.49	1.44	17.6	9 27 27.0	34 52 01.1	N233322149	0.017
	2002 Jan 15.7	0.489	1.439	17.3	9 28 26.5	35 03 21.9	N2333221325	0.006
	2002 Jan 17.7	0.486	1.439	16.8	9 30 28.0	35 27 21.8	N2333221325	0.011

Note.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

hr with an amplitude of 0.21 ± 0.02 mag, although possible periods longer than 5 hr cannot be ruled out with these data. Because of this ambiguity in the value of the period, we give our determination a reliability code (see Harris et al. 1999) of "1." The light curve we adopted is shown in Figure 1, in which there is a relatively large dispersion among the data taken on January 3. These data probably suffered from the fast motion of this object and from the poor sky conditions on that night.

Asteroid 2001 TX_{16} was observed on five nights over the period from 2002 January 11 to 17. Because of its extreme brightness, we obtained a good fifth-order Fourier fit period of 4.8005 hr, with an error estimate of 0.0003 hr. The amplitude of the light curve is 0.51 ± 0.01 mag. The composite light curve is shown in Figure 2, which presents a double-peaked, regular shape with small dispersion.

3. SPECTROSCOPIC OBSERVATIONS AND ANALYSIS

3.1. *Data Reduction*

Spectroscopic observations of 2001 YB_5 and 2001 TX_{16} were taken with the NAOC 2.16 m telescope on 2002 January 4 at Xinglong Station. A low-resolution grating (300 lines mm^{-1}, blazed at 7000 Å) and a 3″ slit were used with a Tektronix 1024 × 1024 CCD that covers about 5000 Å from 4200 to 9200 Å, and the resolution was 9.8 Å per 2 pixels. We were compelled to truncate the spectra to avoid compromised data points shortward of 5000 Å and past 9000 Å because of low signal-to-noise ratio. The solar-analog star Hya 64 (=HD 28099; Hardorp 1978) was used to obtain the asteroid's relative reflectance spectrum. Spectral data reduction followed the procedures of the Small Main-Belt Asteroid Spectroscopic Survey (SMASS; Xu et al. 1995), using IRAF. After bias subtraction, cosmic rays were identified and removed from each image by averaging the values of the neighboring pixels. By convention, the reflectance spectra of the objects were normalized to unity at 5500 Å. Some strong absorption bands in the spectra of asteroids and Hya 64 are caused by the water and oxygen molecules in Earth's atmosphere (Cochran & Barnes 1981); these telluric features were removed to the extent possible in the final plot. Details are given by Xu et al. (1995).

3.2. *Analysis and Results*

A cubic spline function was used to fit the spectra of the asteroids; 41 data points ranging from 5000 to 9000 Å with an interval of 100 Å were obtained. The "spectral distances" $D_x = [\sum_{n=1}^{k} (X_n - Y_n)^2]^{1/2}$ between the two asteroids and the 1341 asteroids of SMASS II (Binzel et al. 2001) were calculated, where D_x is the "spectral distance" between the unclassified spectrum X and a classified spectrum Y, and n represents the individual channels making up the spectrum with k being the total number of channels. The method is described in Yang et al. (2003).

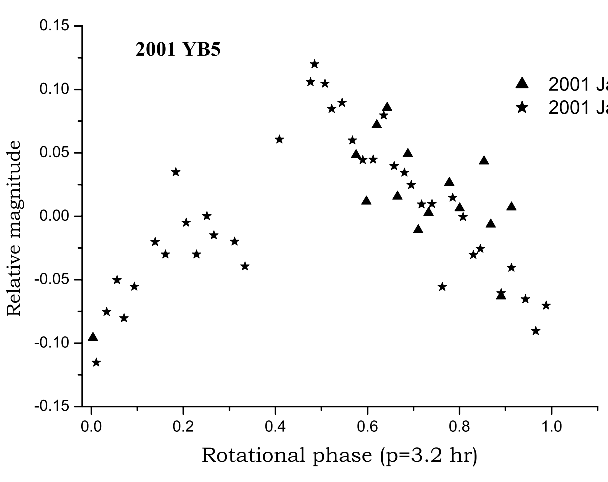

Fig. 1.—Composite light curve of 2001 YB_5. Zero phase corresponds to UT 2002 January 4.81.

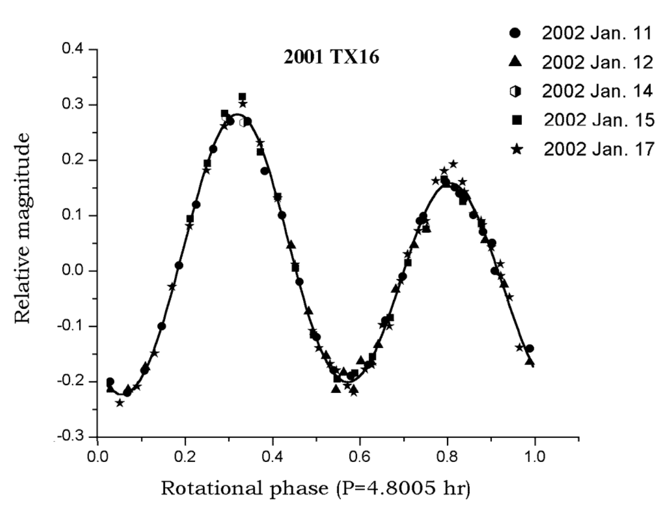

Fig. 2.—Composite light curve of 2001 TX_{16}. Zero phase corresponds to UT 2002 January 17.74.

TABLE 2

SMASS II Asteroids with Minimum "Spectral Distances" to 2001 YB_5

No. (1)	Name (2)	Class. (3)	Spectral Distance (4)
1............................	(555) Norma	B	0.0585
2............................	(5690) 1992 EU	B	0.0791
3............................	(3581) Alvarez	B	0.1126
4............................	(767) Bondia	B	0.1906
5............................	(7110) 1983 XH_1	Ch	0.1924
6............................	(6500) Kodaira	B	0.2018
7............................	(2382) Nonie	B	0.2064
8............................	(4156) 1988 BE	Cgh	0.2068
9............................	(62) Erato	Ch	0.2091
10..........................	(383) Janina	B	0.2097

TABLE 3

SMASS II Asteroids with Minimum "Spectral Distances" to 2001 TX_{16}

No. (1)	Name (2)	Class. (3)	Spectral Distance (4)
1............................	(177) Irma	Ch	0.0629
2............................	(104) Klymene	Ch	0.0684
⋮	⋮	⋮	⋮
27..........................	(934) Thuringia	Ch	0.1038
28..........................	(706) Hirundo	Cgh	0.1049
40..........................	(895) Helio	B	0.1171

The results of comparing the two NEAs with all the asteroids of SMASS II are listed in Tables 2 and 3. In Table 2, column (1) lists a sequential identifier assigned according to increasing spectral distance of the SMASS II asteroids from 2001 YB_5. Column (2) lists the corresponding SMASS II asteroids, and column (3) lists the classifications of those SMASS II asteroids. Values of the spectral distance are listed in column (4). Table 3 is arranged in the same way.

The reflectance spectrum of 2001 YB_5 obtained from our observations is linear and slightly bluish over the 5000–9000 Å wavelength region, with a possible weak absorption band from 8000 to 9000 Å (see Fig. 3; the spectra of 2001 YB_5 and 2001 TX_{16} shown in Figs. 3 and 4 were smoothed by binning in 25 Å increments). These linear and bluish characteristics are similar to those of B-type asteroids, as described by Bus & Binzel (2002), though as shown in Table 2, there are certain resemblances to Ch- and Cgh-type asteroids as well. Since 2001 YB_5 does not show an absorption feature near 7000 Å (see Fig. 3), the confusion with Ch- and Cgh-type asteroids may be due to the lack of spectral information shortward of 5000 Å and to the contribution of noise. Thus, we classify 2001 YB_5 as a B-type asteroid.

The spectrum of 2001 TX_{16} is linear, with a shallow absorption band centered shortward of 7000 Å (see Fig. 4). The slope of this object resembles a Ch-type asteroid spectrum (Bus & Binzel 2002). In Table 3 the first 27 asteroids, with the minimum spectral distances, are all Ch-type asteroids, which distinguishes 2001 TX_{16} from the other types clearly. Therefore we classify 2001 TX_{16} as a Ch-type asteroid.

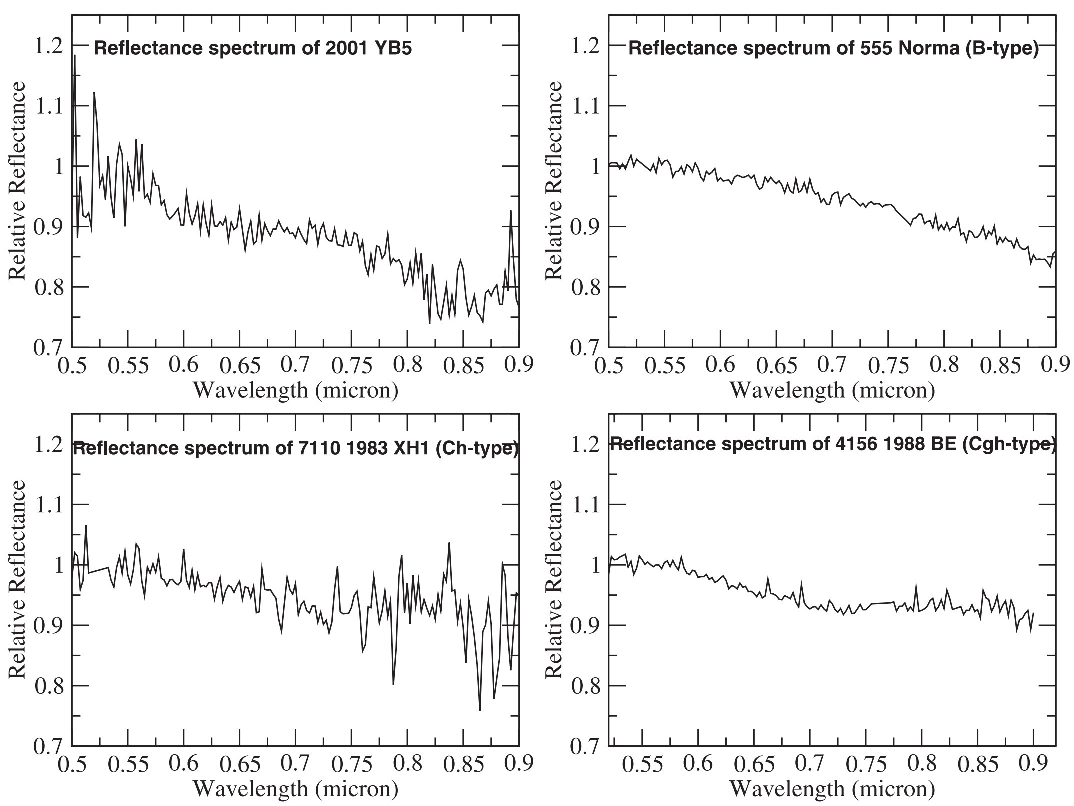

Fig. 3.—Reflectance spectra of 2001 YB_5 and SMASS II asteroids of similar spectral type

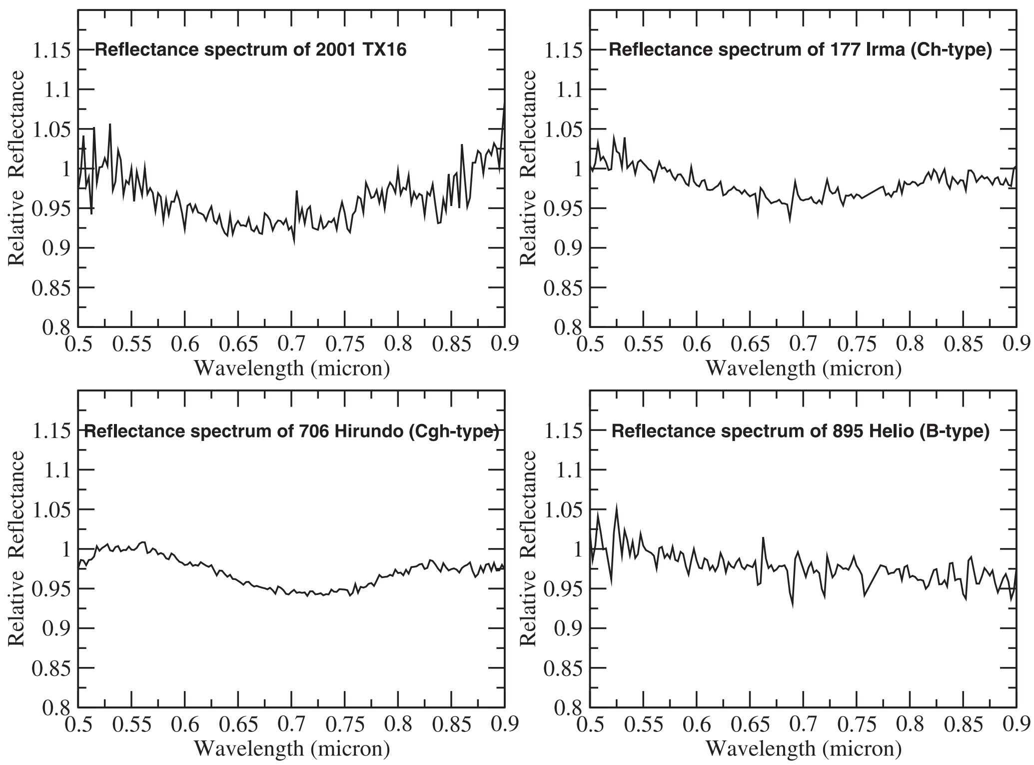

FIG. 4.—Reflectance spectra of 2001 TX_{16} and SMASS II asteroids of similar spectral type

4. DISCUSSION

Some asteroids have been found to have an absorption feature centered near 7000 Å with a width of about 250 Å, attributed to an $Fe^{+2} \rightarrow Fe^{+3}$ charge transfer transition in oxidized Fe found in phyllosilicate, one of the hydrated minerals (Vilas & Gaffey 1989; Rivkin et al. 2002). Low-albedo asteroids associated with hydrated minerals are common among the main-belt asteroids (Rivkin et al. 2002). However, compared against the list of NEAs with known spectral classifications given by Binzel et al. (2002), which lists only six B-type asteroids and 17 C-types (including subclasses among 231 NEAs, it is obvious that these asteroids are relatively rare among NEAs. In addition, there is no Ch-type NEA reported in the Binzel et al. list, and thus 2001 TX_{16} might be a rare find—an NEA with the 7000 Å phyllosilicate absorption feature.

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