Physical properties of near-Earth asteroids with a low delta-v: Survey of target candidates for the Hayabusa2 mission

Sunao HASEGAWA, Daisuke KURODA, Kohei KITAZATO, Toshihiro KASUGA, Tomohiko SEKIGUCHI, Naruhsa TAKATO, Kentaro AOKI, Akira ARAI, Young-Jun CHOI, Tetsuharu FUSE, Hidekazu HANAYAMA, Takashi HATTORI, Hsiang-Yao HSIAO, Nobunari KASHIKAWA, Nobuyuki KAWAI, Kyoko KAWAKAMI, Daisuke KINOSHITA, Steve LARSON, Chi-Sheng LIN, Seidai MIYASAKA, Naoya MIURA, Shogo NAGAYAMA, Yu NAGUMO, Setsuko NISHIHARA, Yohei OHBA, Kouji OHTA, Youichi OHYAMA, Shin-ichiro OKUMURA, Yuki SARUGAKU, Yasuhiro SHIMIZU, Yuhei TAKAGI, Jun TAKAHASHI, Hiroyuki TODA, Seitaro URAKAWA, Fumihiko USUI, Makoto WATANABE, Paul WEISSMAN, Kenshi YANAGISAWA, Hongu YANG, Michitoshi YOSHIDA, Makoto YOSHIKAWA, Masateru ISHIGURO, and Masanao ABE

1 Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara 252-5210, Japan
2 Okayama Astronomical Observatory, Kyoto University, 3037-5 Honjo, Kamogata-cho, Asakuchi, Okayama 719-0232, Japan
3 Research Center for Advanced Information Science and Technology, The University of Aizu, Tsuruga, Ikki-machi, Aizu-Wakamatsu, Fukushima 965-8580, Japan
4 Public Relations Center, National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka-shi, Tokyo 181-8588, Japan
5 Department of Physics, Kyoto Sangyo University, Motoyama, Kamigamo, Kita-ku, Kyoto 603-8555, Japan
6 Department of Education, Hokkaido University of Education, 9 Hokumon, Asahikawa-shi, Hokkaido 070-8621, Japan
7 Subaru Telescope, National Astronomical Observatory of Japan, 650 North A’ohoku Place, Hilo, HI 96722, USA
8 Koyama Astronomical Observatory, Kyoto Sangyo University, Motoyama, Kamigamo, Kita-ku, Kyoto 603-8555, Japan
9 Space Science Division, Korea Astronomy and Space Science Institute, 776, Daedeokdae-ro, Yuseong-gu, Daejeon, Korea
10 Strategic Planning Department, National Institute of Information and Communications Technology, 4-2-1 Nukuikitama-chi, Koganei, Tokyo 184-8795, Japan
11 Ishigakijima Astronomical Observatory, National Astronomical Observatory of Japan, 1024-1 Arakawa, Ishigaki, Okinawa 907-0024, Japan
12 Institute of Astronomy, National Central University, 300 Zhongda Rd., Zhongli, Taoyuan City 320, Taiwan, R.O.C.
13 Department of Astronomy, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

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Abstract

Sample return from the near-Earth asteroid known as 25143 Itokawa was conducted as part of the Hayabusa mission, with a large number of scientific findings being derived from the returned samples. Following the Hayabusa mission, Hayabusa2 was planned, targeting sample return from a primitive asteroid. The primary target body of Hayabusa2 was asteroid 162173 Ryugu; however, it was also necessary to gather physical information for backup target selection. Therefore, we examined five asteroids spectroscopically, 43 asteroids spectrophotometrically, and 41 asteroids through periodic analysis. Hence, the physical properties of 74 near-Earth asteroids were obtained, which helped the Hayabusa2 backup target search and, also, furthered understanding of the physical properties of individual asteroids and their origins.

Key words: methods: observational — minor planets, asteroids: general — techniques: photometric — techniques: spectroscopic

1 Introduction

Cosmochemical, mineralogical, and petrological analyses of extraterrestrial materials such as Apollo and Luna samples, meteorites, and interplanetary dust particles have supplied important clues on their chemical composition, the temperature and pressure conditions they have encountered, and on solar sys-
tem formation, composition, and evolution. Therefore, sample return missions from major or minor planets can provide considerable scientific information compared to flyby and/or rendezvous missions.

In the 1990s, the Mu Space Engineering Spacecraft (MUSES)-C mission was implemented with the aim of successful sample return from an asteroid (Fujiiwara et al. 2000; 2004). The MUSES-C spacecraft was launched in 2003, but renamed “Hayabusa” after launch. In 2005, Hayabusa rendezvoused with the S-complex asteroid known as 25143 Itokawa and performed sample collection of material on the asteroid surface (Fujiiwara et al. 2006). Samples taken from Itokawa were brought to Earth in 2010 and analysis was performed. Those samples provided important planetary science information regarding the meteorite source, the thermal and impact history of Itokawa, the space weathering process on asteroids (Ebihara et al. 2011; Nagao et al. 2011; Nakamura et al. 2011; Noguchi et al. 2011; Tsuchiyama et al. 2011; Yurimoto et al. 2011).

Following the success of the Itokawa rendezvous performed by the Hayabusa spacecraft, a subsequent asteroid exploration project, “Hayabusa2”, was planned (Tsuda et al. 2013). The objective of the Hayabusa mission was demonstration of sample return technology; thus, the target body was an object reachable by the Mu-5 launch vehicle. The purpose of Hayabusa2, which launched in 2014 and is expected to return to Earth in 2020, is sample return from a chondritic asteroid such as a C- or D-complex body. S-complex asteroids, i.e., of the same spectral type as Itokawa, are excluded. Thus, the C-complex asteroid 162173 Ryugu was selected as the primary target of Hayabusa2. Ryugu was chosen because it is a C-complex asteroid having one of the lowest delta-v among the near-Earth asteroids (NEAs) known at the time (delta-v is the velocity adjustment needed to transfer a spacecraft from low-Earth orbit to connect with the asteroid (Shoemaker & Helin 1978)). Hayabusa2 rendezvoused with Ryugu in 2018.

Before exploration, the physical properties of the asteroid, such as the rotational period, spin vector, geometric albedo, and spectral type, must be known; hence, the spacecraft design and operation sequence for rendezvous with and sampling from the asteroid can be determined. Therefore, we performed observations to obtain the physical properties of the prospective candidates for Hayabusa (Abe, Sato, & Araki 2000; Ishibashi, Abe, & Takagi 2000a; Ishibashi, Abe, & Takagi 2000b; Ishiguro et al. 2003; Kaasalainen et al. 2003; Ohba et al. 2003; Sekiguchi et al. 2003; Cellino et al. 2003; Lederer et al. 2005; Müller et al. 2005; Müller et al. 2007; Nishihara et al. in press) and Hayabusa2 (Hasegawa et al. 2008; Müller et al. 2011; Urakawa et al. 2011; Kim et al. 2013; Ishiguro et al. 2014; Kuroda et al. 2014; Müller et al. 2017; Perna et al. 2017a).

Note that the target body of the Hayabusa mission was changed twice, with corresponding launch postponement.1 In addition, while it is necessary to know the physical characteristics of the primary target, it is also important to obtain those of backup candidates with consideration of potential mission problems. Therefore, we conducted observations to acquire the physical properties of backup target candidates for the Hayabusa2 mission.

In this paper, we report on the physical properties of the NEAs with low delta-v examined for the Hayabusa2 mission. The subsequent sections of this paper describe the observations and data reduction procedures (section 2), present the results on the asteroid physical properties (section 3), and discuss the implications of our findings (section 4).

2 Observations and data reduction procedures

The asteroid observations were performed from December 2000 to January 2015, using 10 different telescopes at eight sites in Japan and the USA, with photometry and spectroscopy observations. Five NEA spectra were recorded using the Subaru Telescope on Mt. Mauna Kea, Hawaii, USA (Minor Planet Center (MPC) code: 568) and at the Okayama Astrophysical Observatory in Okayama, Japan (MPC code: 371). Colors were recorded for 38 NEAs, along with five other asteroids, at the Kiso Observatory in Nagano, Japan (MPC code: 381); the Lulin Observatory in Nantou, Taiwan (MPC code: D35); the UH88 Telescope on Mt. Mauna Kea (MPC code: 568); the Steward Observatory on Mt. Bigelow, Arizona, USA (MPC code: 698); and the Nayoro Observatory in Hokkaido, Japan (MPC code: Q33). The lightcurves of 39 NEAs and two other asteroids were obtained at the Kiso Observatory; the Lulin Observatory; the Nayoro Observatory; the Ishigakijima Astronomical Observatory at Okinawa, Japan (MPC code: D44); the Nishihara Astronomical Observatory at Hyogo, Japan (no MPC code; 134°20'09"E, 35°01'33"N; 450 m); and the Bisei Spaceguard Center at Okayama, Japan (MPC code: 300).

2.1 Spectroscopic observations

Asteroid spectroscopic data were recorded by two different instruments mounted on different telescopes: the Faint Object Camera and Spectrograph (FOCAS) (Kashikawa et al. 2002) installed at the f/12 Cassegrain focus of the 8.2-m Subaru Telescope, and the Kyoto Okayama Optical Low-dispersion Spectrograph (KOOLS) (Ohtani et al. 1998; Ishigaki et al. 2004) attached to the f/18 Cassegrain focus of the 1.88-m telescope at the Okayama Astrophysical Observatory. Three and two spectroscopic observations of the NEAs were performed using

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1 The initial target was the E-type asteroid 4660 Nereus; the second target was the E-type asteroid 10302 1989 ML.
FOCAS and KOOLS, respectively. The nightly observation details of the spectroscopy are listed in Table 1.

Before August 2001, between September 2001 and May 2010, and after June 2010, the FOCAS instrument detector had two 2048 × 4096 STiTe ST-002A charge-coupled devices (CCDs), two 2048 × 4096 Massachusetts Institute of Technology/Lincoln Laboratory CCDs, and two 2048 × 4176 Hamamatsu Photonics CCDs, respectively. The three generations of FOCAS CCDs are of the same size, with 15 μm square pixels, and provide a 6′ circular field-of-view, with a pixel scale of 0.′′1. The 2048 × 4096 STiTe ST-002A CCD for KOOLS has 15 μm square pixels, giving a 5′ × 4.4′ field-of-view with a pixel scale of 0.′′3.

Grisms with 6500-, 7500-, and 5500- Å/mm blaze and SY47 and L600, SO58, and SY47 order-sorting filters for FOCAS spectroscopy were used for the 25143 Itokawa, 163899 2003 SD220, and 414990 2011 EM51 asteroid observations, respectively. For KOOLS spectroscopy, grisms with 6563- Å/mm blaze and a Y49 order-sorting filter were utilized.

The FOCAS and KOOLS slit lengths are 6′0 and 4′4 in the cross-wavelength direction, respectively. Note that attention must be paid to the slit width selection as atmospheric differential refraction causes erroneous classification of asteroid spectral types. The atmospheric dispersion corrector (ADC) installed in the Cassegrain unit of the Subaru Telescope can prevent flux loss errors due to atmospheric dispersion. Observations of Itokawa, 2003 SD220, and 2011 EM51 were performed using slit widths of 0.′′8, 1.′′0, and 4.′′0, respectively. Considering the orbital element ambiguity and guide error, a slightly wider slit width was employed for observation of 2011 EM51. As the 1.88-m telescope did not have ADC, it was necessary to select a wide slit for KOOLS observation; thus, a large width of 6′.0 was utilized for KOOLS.

Non-sidereal tracking was employed for the telescopes tracking the asteroids, except for the Itokawa observations, for which the data was obtained in sidereal tracking mode. In that case, the slit length direction was set as the Itokawa movement direction.

Wavelength calibration frames for FOCAS and KOOLS were acquired regularly during the night with light from thorium-argon and iron-neon hollow cathode lamps, respectively. The reflected spectrum of the target asteroid was obtained by dividing the asteroid spectrum by the solar spectrum. Hence, division by the spectrum of the observed solar analogue star having the same airmass as the asteroid yielded the reflected spectrum. This is the standard data acquisition method of asteroidal spectroscopy (e.g., Bus & Binzel 2002a). Observations between the asteroids (except Itokawa) and solar analogue stars were coordinated such that the airmass difference was less than 0.1 in each case. For Itokawa only, standard stars were observed using the spectroscopic procedures recommended for stars and galaxies. Stars with spectral models were used as standard stars for the Itokawa observation, and airmass corrections were made using the atmospheric extinction coefficients. By dividing the acquired asteroid spectrum by the solar spectrum model, the Itokawa reflection spectrum was obtained.

All data reduction for spectroscopy was performed using image reduction and analysis facilities (IRAF). A collection of flat-field images was acquired by taking a flat-field image each night during the observation period. The bias was subtracted from all spectral data. After bias subtraction, each object frame was divided by a normalized bias to correct the flat-fielding flame. The extraction of a one-dimensional spectrum from the two-dimensional images was performed using the apall function of the IRAF software. The obtained asteroid reflectance was normalized at 0.55 μm.

2 Photometric observations

Photometric observations of asteroids for colorimetry and lightcurve analyses were recorded using eight telescopes. The nightly observation details for the colorimetry and lightcurve data are summarized in Tables 2 and 3, respectively.

Sixteen colors and 27 asteroid lightcurves were obtained using the 1.05-m Schmidt telescope at the Kiso Observatory, with a 2K CCD camera having an STiTe TK2048E detector (2048 × 2048 pixels with 24 μm square pixels); this yielded an image scale of 1.′′5/pixel located in the f/3.1 Schmidt focus. The CCD field of view was 51′ × 51′. The typical seeing size was 3′′–4′′ for this observatory.

Twenty colorimetric and eight lightcurve observations were performed using the 1.02-m telescope at the Lulin Observatory (LOT), with a PI1300B CCD camera equipped with a e2v CCD36-40 detector. The format of the latter was 1340 × 1300 pixels with 20 μm square pixels, giving an image scale of 0.′′52/pixel located in the f/8.0 Cassegrain focus. The CCD field of view was 12′ × 11′. The typical seeing size was 1′′–2′′ at this observatory.

Seven colors and two lightcurves were obtained using the University of Hawaii 2.24-m telescope at the Mauna Kea Observatories (UH88). A Tektronix CCD camera yielded a 2048 × 2048 pixel CCD with 24 μm square pixels with an image scale of 0.′′22/pixel and a sky field of 7.5′ × 7.5′ in the f/10 Cassegrain focus. The typical seeing size was ~0.′′8 at this site.

Lightcurves of three NEAs were recorded using the 1.05-m Murikabushi telescope at the Ishigakijima Astrophysical Observatory, equipped with an Apogee U6 camera comprising a Kodak KAF-1001E 1024 × 1024 pixel detector with 24 μm square pixels in the f/12 Cassegrain focus. The projected area was 6′2 × 6′2, which corresponded to an angular resolution of 0.′′36/pixel before 2008. After 2008, the projected area was

2 (http://ssd.jpl.nasa.gov/horizons.cgi#top).
changed to 12′3 × 12′3, corresponding to an angular resolution of 0.′72/pixel, for installation of a 0.5-time focal reducer. The typical seeing size was 1′′–2′′ at this observatory.

Three lightcurves were obtained with the 0.50-m telescope at the Okayama Astrophysical Observatory (MITSuME) (Yanagisawa et al. 2010). The data were recorded with an Apogee U6 camera with a mounted Kodak KAF-1001E 1024 × 1024 pixel detector with 24 μm square pixels in the f/6.5 Cassegrain focus. The field of view was 25.6′ × 25.6′, which corresponds to an angular resolution of 1.′5/px/pixel. The typical seeing size was 1′′–2′′ at this site.

Lightcurves for two NEAs were obtained using the 2.00-m Nayuta telescope at the Nishiharima Astronomical Observatory. The MINT imager, which was equipped with a 2068 × 2064-pixel e2V CCD230-42 detector (15 μm square pixels), was attached to the f/12 Cassegrain focus of the telescope. This system produced image dimensions of 0′′.32/pixel, yielding a field of view of 10′9 × 10′9. The typical seeing size was 1′′–2′′ at this observatory.

Color and lightcurve observations were performed using the 1.60-m Pirika Telescope at the Nayoro Observatory. Data were obtained via the NaCS instrument using the Hamamatsu CCD having 2048 × 1104 pixels with 15 μm square pixels, with an image scale of 0′′.25/pixel and a sky field of 8′4 × 4′5 in the f/12 Nasmyth focus (Nakao et al. 2014). The typical seeing size was 1′′–2′′ at this observatory.

A colorimetric observation was performed with the 1.54-m Kuiper Telescope at the Steward Observatory. The Montreal 4K (Mont4K) imager with Fairchild CCD486 detector yielded a format of 4096 × 4097 (15 μm square pixels) with an image scale of 0′′.14/pixel and a sky field of 9′7 × 9′7 in the f/13.5 Cassegrain focus. The typical seeing size was 1′′–2′′ at this site.

The asteroid lightcurves were measured at the 1.00-m telescope at the Bisei Spaceguard Center (BSGC), which is equipped with a detector consisting of four Hamamatsu Photonic CCD chips with 4096 × 2048 pixels of 15 μm square pixels, giving an image scale of 1.0/pixel located in the f/3.0 Cassegrain focus. The CCD field of view was 12′ × 11′ and the field of view of the CCD chip was 68′ × 34′. The typical seeing size was 4′′–5′′ at this observatory.

The asteroid observations were performed using non-sidereal tracking to increase the asteroid signal level as much as possible. The standard-star observation was performed with sidereal tracking. Dark and flat-field images were obtained each observational night.

For most colorimetric observations, a Johnson-Cousins filter system was utilized. A Sloan Digital Sky Survey (SDSS) filter system was used for part of the observation. To correct changes in baseline brightness due to asteroid rotation, colorimetric observations were performed by alternately exchanging the reference filter and other filters. To acquire a high signal level in a short exposure time, the RC band filter was typically used as the reference filter. Observations were conducted using such a procedure; for example, with the RC – V – RC – IC – RC – B – RC sequence. Absolute calibration for colorimetry was conducted by observing standard stars each observational night (Landolt 1992; Smith et al. 2002).

Lightcurve observations were performed using an RC or r′ band filter. To acquire the lightcurve from the difference magnitude between the asteroid and comparison stars within the same sky field, most lightcurve observations were not calibrated based on the standard stars.

The dark images for correction were constructed from a median combination of several dark frames. Stacked flat-field images for correction were created using a median combination of several flat-field frames. All photometric image frames for an individual night were bias-subtracted and flat-fielded using IRAF. The fluxes of the asteroids and of the comparison and standard stars were measured through circular apertures with diameters more than three times that of the full-width at half maximum size, using the APHOT function in the IRAF software.

As most lightcurves were obtained using relative magnitudes, the fluxes of several to dozens of comparison stars in the same frame as each asteroid were used. After eliminating the variable stars from the comparison stars, the flux difference between the asteroid and the sum of the comparisons was calculated. Some lightcurve observations were obtained from the RC band sequence for colorimetry analyses.
3 Data analysis

3.1 Periodic analysis

Before periodic analysis, the one-way light time of each observation was corrected. Similar to Hasegawa et al. (2014), the asteroid rotational periods were determined using two methods: the generalised Lomb-Scargle periodogram (GLS) (Zechmeister & Kürster 2009), which is an extension of the Lomb-Scargle periodogram (Scargle 1982), and a phase dispersion minimization method (PDM) (Stellingwerf 1978) with minimization of the sum of the squares of the adjacent data.

First, periodic analysis of the acquired lightcurve was performed with GLS. Then, periodic analysis was performed with PDM if there were more than two cycles. The rotational periods were finally determined by considering the best result yielded by the two methods. If there were insufficient data to determine the PDM, the asteroid period was determined with GLS only.

The results of the periodic analysis are presented in Table 4.
### Table 2. Colorimetric circumstances of the asteroids.

| No.  | Name     | Date         | $R_h$ [au] | $\Delta$ [au] | $\alpha$ [°] | Telescope | Filter | Band       |
|------|----------|--------------|------------|---------------|--------------|-----------|---------|------------|
| 2212 | Hephaistos | 2007.09.06   | 2.342      | 1.745         | 23.2         | UH88      | BVRC     |
| 3361 | Orpheus  | 2005.11.28   | 1.013      | 0.224         | 76.8         | LOT       | BVRC     |
| 5797 | Bivoj    | 2005.12.24   | 1.089      | 0.243         | 58.4         | Kiso      | BVRC     |
|      |          | 2005.12.28   | 1.078      | 0.236         | 60.4         |           |         |
| 11284| Belemus  | 2005.11.25   | 1.204      | 0.292         | 37.1         | LOT       | BVRC     |
|      |          | 2005.11.27   | 1.195      | 0.289         | 38.8         |           |         |
| 65679| 1989 UQ  | 2003.09.26   | 1.156      | 0.202         | 37.2         | Kiso      | BVRC     |
|      |          | 2003.09.29   | 1.157      | 0.193         | 33.6         |           |         |
|      |          | 2003.09.30   | 1.157      | 0.189         | 32.3         |           |         |
| 68278| 2001 FC7 | 2006.02.04   | 1.588      | 0.605         | 3.6          | Kiso      | BVRC     |
|      |          | 2006.02.05   | 1.589      | 0.605         | 4.1          |           |         |
| 85585| Mjolnir  | 2003.09.29   | 1.128      | 0.134         | 18.9         | Kiso      | BVRC     |
|      |          | 2003.09.30   | 1.123      | 0.129         | 18.7         |           |         |
| 136617| 1994 CC | 2007.12.03   | 1.852      | 0.883         | 8.1          | LOT       | BVRC     |
|      |          | 2007.12.06   | 1.866      | 0.907         | 10.0         |           |         |
| 136618| 1994 CN2 | 2008.02.27   | 2.193      | 1.239         | 9.3          | LOT       | BVRC     |
|      |          | 2008.02.28   | 2.193      | 1.234         | 8.7          |           |         |
|      |          | 2008.04.05   | 2.167      | 1.247         | 13.7         |           |         |
| 137799| 1999 YB | 2005.11.25   | 1.414      | 0.434         | 8.4          | LOT       | BVRC     |
|      |          | 2005.11.26   | 1.414      | 0.434         | 8.8          |           |         |
|      |          | 2005.11.27   | 1.413      | 0.435         | 9.3          |           |         |
| 138404| 2000 HA24| 2006.04.24   | 1.128      | 0.319         | 59.7         | Kiso      | BVRC     |
| 141018| 2001 WC47| 2006.12.18   | 1.382      | 0.412         | 12.2         | LOT       | BVRC     |
| 141424| 2002 CD  | 2006.12.19   | 1.378      | 0.405         | 11.2         |           |         |
| 142348| 2002 RX211| 2005.12.24  | 1.155      | 0.200         | 28.1         | Kiso      | BVCR     |
| 153591| 2001 SN263| 2008.02.28  | 1.057      | 0.075         | 26.4         | LOT       | BVRC     |
| 154007| 2002 BY  | 2007.02.21   | 1.499      | 0.532         | 13.2         | Kiso      | BVRC     |
| 159467| 2000 QK25| 2005.11.25   | 1.418      | 0.477         | 20.8         | LOT       | BVRC     |
| 161723| Ryugu    | 2007.07.22   | 1.364      | 0.493         | 37.2         | LOT       | BVRC     |
|      |          | 2007.09.04   | 1.270      | 0.287         | 21.4         | UH88      | BVRC     |
|      |          | 2007.09.12   | 1.248      | 0.269         | 23.1         | Steward   | BVRC     |
|      |          | 2007.09.13   | 1.246      | 0.268         | 23.6         |           |         |
|      |          | 2007.09.14   | 1.243      | 0.266         | 24.1         |           |         |
| 163692| 2003 CY18| 2007.12.06   | 1.814      | 0.837         | 6.0          | LOT       | BVRC     |
|      |          | 2007.12.07   | 1.818      | 0.842         | 6.2          |           |         |
| 164202| 2004 EW  | 2006.03.28   | 1.188      | 0.198         | 14.7         | LOT       | BVRC     |
|      |          | 2006.03.29   | 1.191      | 0.202         | 15.9         |           |         |
| 163899| 2003 SD220| 2006.12.21  | 0.918      | 0.337         | 91.2         | LOT       | BVRC     |
|      |          | 2006.12.22   | 0.914      | 0.337         | 91.7         |           |         |
| 170891| 2004 TY16| 2008.02.08   | 1.193      | 0.241         | 28.1         | Kiso      | BVRC     |
| 171819| 2001 FZ6 | 2007.12.07   | 1.620      | 0.684         | 16.7         | LOT       | BVRC     |
|      |          | 2007.12.08   | 1.621      | 0.683         | 16.3         |           |         |
| 172974| 2005 YW55| 2007.12.08   | 1.402      | 0.441         | 15.8         | LOT       | BVRC     |
| 206378| 2003 RB  | 2003.09.28   | 1.003      | 0.093         | 86.8         | Kiso      | BVRC     |
|      |          | 2003.09.29   | 1.003      | 0.093         | 86.4         |           |         |
Table 2. (Continued)

| No.   | Name       | Date     | $R_h$ | $\Delta$ | $\alpha$ | Telescope | Band   |
|-------|------------|----------|-------|----------|----------|-----------|--------|
| 363505| 2003 UC$_{20}$ | 2003.12.03 | 1.044 | 0.083    | 44.0     | Kiso      | BV$RcIc$ |
|       |            | 2003.12.04 | 1.043 | 0.083    | 44.5     |           |         |
|       |            | 2005.11.26 | 1.005 | 0.323    | 77.4     | LOT       |         |
| 481394| 2006 SF$_{6}$ | 2007.11.08 | 1.019 | 0.135    | 74.2     | Kiso      | BV$RcIc$ |
|       | 2001 QC$_{34}$ | 2007.09.06 | 1.279 | 0.296    | 20.7     | UH88      | BV$RcIc$ |
|       | 2004 DK$_{1}$ | 2004.04.11 | 1.088 | 0.086    | 3.4      | Kiso      | $VRcIc$ |
|       | 2004 XL$_{14}$ | 2006.12.19 | 1.010 | 0.028    | 22.5     | LOT       | BV$RcIc$ |
|       | 2005 TF     | 2005.11.28 | 1.071 | 0.164    | 55.2     | LOT       | BV$RcIc$ |
|       | 2006 GB     | 2006.04.25 | 1.074 | 0.195    | 64.6     | Kiso      | BV$Rc$  |
|       | 2007 BB$_{50}$ | 2007.02.14 | 1.337 | 0.351    | 4.5      | UH88      | BV$RcIc$ |
|       | 2007 BJ$_{29}$ | 2007.02.14 | 1.390 | 0.564    | 35.6     | UH88      | BV$RcIc$ |
|       | 2007 RV$_{9}$ | 2008.02.28 | 1.081 | 0.132    | 44.1     | LOT       | BV$RcIc$ |
|       | 2007 TU$_{24}$ | 2008.02.08 | 1.030 | 0.056    | 37.5     | Kiso      | $BRcIc$ |
|       | 2010 JV$_{34}$ | 2010.05.16 | 1.089 | 0.082    | 18.7     | Kiso      | BV$RcIc$ |
|       | 2010.05.17 | 1.080 | 0.075 | 22.5     |           |           |         |
| 852   | Wlandinenae | 2010.11.11 | 1.101 | 0.122    | 22.9     | Kiso      | BV$RcIc$ |
| 7096  | Napier     | 2005.12.28 | 3.009 | 2.327    | 15.4     | Kiso      | BV$RcIc$ |
| 22104 | 2000 LN$_{19}$ | 2013.10.23 | 1.961 | 1.014    | 12.3     | Pirika    | $gri^i$ |
| 2006  | EX$_{52}$  | 2006.12.19 | 2.615 | 1.700    | 9.9      | LOT       | BV$RcIc$ |
| 2006  | XQ$_{56}$  | 2006.12.21 | 2.619 | 1.728    | 11.3     |           |         |

The heliocentric distance ($R_h$), geocentric distance ($\Delta$), and phase angle ($\alpha$) for asteroid observation were obtained from the NASA JPL HORIZON ephemeris generator system.²
Table 3. Lightcurve observational circumstances of the asteroids

| No. | Name       | Date       | Duration | $R_n^*$ | $\Delta^*$ | $\alpha^*$ | Telescope |
|-----|------------|------------|----------|---------|------------|------------|-----------|
| 433 | Eros       | 2005.01.08 | 3.54     | 1.134   | 0.420      | 58.6       | MITSuME   |
|     |            | 2005.01.09 | 3.27     | 1.135   | 0.418      | 58.5       |           |
| 1943| Anteros    | 2007.02.20 | 1.89     | 1.492   | 0.420      | 58.6       | Kiso      |
|     |            | 2007.02.21 | 1.46     | 1.488   | 1.002      | 41.3       |           |
|     |            | 2009.08.17 | 6.56     | 1.450   | 0.503      | 24.1       |           |
|     |            | 2009.08.19 | 0.47     | 1.458   | 0.504      | 22.8       |           |
|     |            | 2009.08.20 | 3.07     | 1.462   | 0.505      | 22.1       |           |
| 5797| Bivoj      | 2005.12.22 | 1.59     | 1.095   | 0.247      | 57.3       | Kiso      |
|     |            | 2005.12.24 | 2.33     | 1.089   | 0.243      | 58.4       |           |
|     |            | 2005.12.26 | 2.48     | 1.083   | 0.240      | 59.5       |           |
|     |            | 2007.02.20 | 1.54     | 1.078   | 0.236      | 60.4       |           |
| 11284| Belenus   | 2005.11.25 | 2.38     | 1.204   | 0.292      | 37.1       | LOT       |
| 14402| 1991 DB   | 2009.01.18 | 1.07     | 1.335   | 0.444      | 31.6       | LOT       |
|     |            | 2009.01.20 | 4.75     | 1.323   | 0.424      | 31.1       |           |
|     |            | 2009.01.21 | 6.68     | 1.318   | 0.416      | 30.9       |           |
|     |            | 2009.01.22 | 5.52     | 1.312   | 0.407      | 30.7       |           |
|     |            | 2009.02.25 | 3.97     | 1.139   | 0.162      | 21.4       | Kiso      |
|     |            | 2009.02.28 | 0.83     | 1.125   | 0.147      | 22.3       |           |
|     |            | 2009.03.01 | 6.20     | 1.122   | 0.144      | 22.8       |           |
|     |            | 2009.03.02 | 1.37     | 1.118   | 0.140      | 23.4       |           |
| 68278| 2001 FC7  | 2006.02.04 | 3.96     | 1.588   | 0.605      | 3.6        | Kiso      |
|     |            | 2006.02.05 | 8.10     | 1.589   | 0.605      | 4.1        |           |
| 85585| Mjolnir   | 2003.09.27 | 4.27     | 1.139   | 0.146      | 19.5       | Kiso      |
|     |            | 2003.09.28 | 5.11     | 1.134   | 0.141      | 19.2       |           |
|     |            | 2003.09.29 | 4.33     | 1.128   | 0.134      | 18.9       |           |
|     |            | 2003.09.30 | 1.58     | 1.123   | 0.129      | 18.7       |           |
| 85867| 1999 BY9  | 2009.01.18 | 5.49     | 1.374   | 0.521      | 33.6       | LOT       |
|     |            | 2009.01.19 | 0.19     | 1.372   | 0.513      | 33.3       |           |
|     |            | 2009.01.20 | 0.56     | 1.369   | 0.507      | 33.1       |           |
|     |            | 2009.01.21 | 3.55     | 1.366   | 0.500      | 32.9       |           |
|     |            | 2009.01.22 | 2.25     | 1.364   | 0.495      | 32.7       |           |
| 89136| 2001 US16 | 2012.10.19 | 5.86     | 1.574   | 0.583      | 6.2        | Nayuta    |
|     |            | 2012.10.20 | 6.03     | 1.576   | 0.587      | 6.9        |           |
| 136618| 1994 CN2  | 2006.03.29 | 7.80     | 2.183   | 1.238      | 11.2       | LOT       |
|     |            | 2008.02.26 | 6.22     | 2.194   | 1.244      | 9.8        |           |
| 137799| 1999 YB   | 2008.10.30 | 3.45     | 1.420   | 0.432      | 7.3        | Kiso      |
|     |            | 2008.10.31 | 1.46     | 1.420   | 0.431      | 6.4        |           |
|     |            | 2008.11.01 | 6.84     | 1.420   | 0.431      | 5.8        |           |
|     |            | 2008.11.03 | 4.67     | 1.420   | 0.430      | 4.2        |           |
| 138175| 2000 EE104| 2007.02.20 | 1.46     | 1.258   | 0.284      | 16.4       | Kiso      |
|     |            | 2007.02.21 | 7.31     | 1.256   | 0.283      | 16.9       |           |
| 138404| 2000 HA24 | 2006.04.24 | 3.38     | 1.128   | 0.319      | 59.7       | Kiso      |
|     |            | 2006.04.28 | 1.08     | 1.149   | 0.343      | 57.5       |           |
|     |            | 2006.04.29 | 3.04     | 1.153   | 0.349      | 57.0       |           |
| 141018| 2001 WC47 | 2006.11.28 | 2.20     | 1.451   | 0.549      | 25.9       | Kiso      |
| 142348| 2002 RX211| 2005.12.22 | 4.00     | 1.150   | 0.194      | 28.3       | Kiso      |
|     |            | 2005.12.24 | 1.59     | 1.155   | 0.200      | 28.1       |           |
Table 3. (Continued)

| No.   | Name     | Date       | Duration | $R_0$   | $\Delta$ | $\alpha$ | Telescope |
|-------|----------|------------|----------|---------|----------|----------|-----------|
| 152560| 1991 BN  | 2005.12.26 | 3.41     | 1.162   | 0.207    | 27.8     | LOT       |
|       |          | 2005.12.28 | 1.92     | 1.167   | 0.213    | 27.7     |           |
| 153591| 2001 SN$_{263}$ | 2008.02.28 | 0.97     | 1.057   | 0.075    | 26.4     | LOT       |
| 154007| 2002 BY  | 2007.02.16 | 8.42     | 1.521   | 0.568    | 16.1     | Kiso      |
|       |          | 2007.02.19 | 8.07     | 1.508   | 0.547    | 14.5     |           |
|       |          | 2007.02.20 | 4.52     | 1.504   | 0.540    | 13.9     |           |
|       |          | 2007.02.21 | 5.00     | 1.499   | 0.532    | 13.2     |           |
|       |          | 2007.04.11 | 2.78     | 1.294   | 0.358    | 30.5     | Murikabushi |
|       |          | 2007.04.12 | 1.24     | 1.291   | 0.357    | 31.1     |           |
|       |          | 2007.04.19 | 4.13     | 1.268   | 0.356    | 36.4     |           |
| 154991| Vinciguerra | 2007.01.13 | 5.66     | 1.192   | 0.329    | 44.2     | Kiso      |
|       |          | 2007.01.14 | 4.98     | 1.190   | 0.325    | 44.3     |           |
|       |          | 2007.01.15 | 5.39     | 1.188   | 0.321    | 44.3     |           |
| 159402| 1999 AP$_{10}$ | 2009.09.16 | 1.60     | 1.187   | 0.190    | 16.1     | MITSuME   |
|       |          | 2009.09.17 | 4.85     | 1.180   | 0.184    | 16.9     |           |
|       |          | 2009.09.18 | 4.19     | 1.174   | 0.179    | 17.8     |           |
|       |          | 2009.09.19 | 3.25     | 1.168   | 0.174    | 18.6     |           |
|       |          | 2009.09.20 | 4.73     | 1.162   | 0.169    | 19.5     |           |
|       |          | 2009.10.15 | 6.18     | 1.044   | 0.079    | 52.1     |           |
|       |          | 2009.10.17 | 6.32     | 1.038   | 0.077    | 55.9     |           |
|       |          | 2009.10.18 | 6.13     | 1.035   | 0.077    | 57.8     |           |
|       |          | 2009.10.20 | 6.31     | 1.030   | 0.076    | 61.5     |           |
|       |          | 2009.12.12 | 3.41     | 1.120   | 0.230    | 48.9     | Kiso      |
|       |          | 2009.12.13 | 1.84     | 1.126   | 0.233    | 47.9     |           |
|       |          | 2009.12.14 | 4.42     | 1.132   | 0.237    | 46.8     |           |
| 159467| 2000 QK$_{25}$ | 2005.12.24 | 0.92     | 1.513   | 0.545    | 11.2     | Kiso      |
|       |          | 2005.12.28 | 1.15     | 1.528   | 0.568    | 13.1     |           |
| 162567| 2000 RW$_{37}$ | 2008.02.06 | 3.05     | 0.968   | 0.081    | 100.5    | Kiso      |
|       |          | 2008.02.07 | 2.20     | 0.970   | 0.079    | 99.3     |           |
|       |          | 2008.02.08 | 0.12     | 0.973   | 0.077    | 98.0     |           |
| 163000| 2001 SW$_{169}$ | 2008.09.26 | 4.64     | 1.220   | 0.228    | 15.6     | Kiso      |
|       |          | 2008.09.27 | 1.84     | 1.221   | 0.231    | 16.6     |           |
|       |          | 2008.10.30 | 5.13     | 1.246   | 0.353    | 38.0     |           |
|       |          | 2008.11.01 | 6.06     | 1.248   | 0.362    | 38.8     |           |
| 163899| 2003 SD$_{220}$ | 2006.11.28 | 1.38     | 0.974   | 0.359    | 81.4     | Kiso      |
| 164202| 2004 EW  | 2005.03.05 | 1.12     | 1.091   | 0.099    | 1.5      | LOT       |
|       |          | 2005.03.07 | 5.77     | 1.099   | 0.107    | 4.0      |           |
|       |          | 2006.03.28 | 5.94     | 1.188   | 0.198    | 14.7     |           |
|       |          | 2006.03.29 | 6.97     | 1.191   | 0.202    | 15.9     |           |
| 190491| 2000 FJ$_{10}$ | 2014.08.12 | 3.06     | 1.327   | 0.328    | 14.8     | UH88      |
|       |          | 2014.08.13 | 5.99     | 1.323   | 0.326    | 15.2     |           |
|       |          | 2014.08.14 | 4.75     | 1.320   | 0.324    | 15.9     |           |
|       |          | 2014.08.15 | 3.46     | 1.317   | 0.322    | 16.5     |           |
| 225312| 1996 XB$_{27}$ | 2014.08.12 | 2.83     | 1.163   | 0.251    | 48.3     | UH88      |
|       |          | 2014.08.13 | 3.92     | 1.164   | 0.255    | 48.4     |           |
|       |          | 2014.08.14 | 1.08     | 1.165   | 0.258    | 48.6     |           |
|       |          | 2014.08.15 | 3.67     | 1.166   | 0.261    | 48.7     |           |
Table 3. (Continued)

| No.  | Name       | Date      | Duration | \(R_h\) | \(\Delta\) | \(\alpha\) | Telescope   |
|------|------------|-----------|----------|---------|-----------|-----------|-------------|
| 250697 | 2005 QY\(_{151}\) | 2010.11.10 | 2.73     | 1.065   | 0.205    | 64.0      | Kiso        |
|       |            | 2010.11.11 | 0.67     | 1.056   | 0.203    | 65.7      |             |
| 253062 | 2002 TC\(_{70}\) | 2013.02.19 | 8.26     | 1.570   | 0.582    | 1.5       | Nayuta      |
|       |            | 2013.02.20 | 5.63     | 1.568   | 0.580    | 1.1       |             |
| 341843 | 2008 EV\(_5\) | 2009.01.22 | 1.73     | 1.028   | 0.081    | 55.5      | LOT         |
|       |            | 2009.03.01 | 2.36     | 1.038   | 0.166    | 69.1      | Kiso        |
|       |            | 2009.03.02 | 1.71     | 1.038   | 0.168    | 69.4      |             |
| 357439 | 2004 BL\(_{86}\) | 2015.01.28 | 6.68     | 1.000   | 0.018    | 33.7      | MITSuME     |
|       |            | 2015.01.31 | 6.98     | 1.015   | 0.046    | 47.9      |             |
| 416186 | 2002 TD\(_{60}\) | 2006.11.24 | 2.08     | 1.114   | 0.300    | 57.7      | Kiso        |
| 451157 | 2009 SQ\(_{104}\) | 2013.05.01 | 5.92     | 1.062   | 0.083    | 47.7      | BSGC        |
|       |            | 2013.05.07 | 4.42     | 1.087   | 0.103    | 38.6      |             |
|       |            | 2013.05.09 | 4.41     | 1.095   | 0.110    | 36.9      | Pirika      |
|       |            | 2013.05.10 | 3.01     | 1.099   | 0.113    | 36.1      |             |
|       |            | 2013.05.17 | 4.15     | 1.130   | 0.145    | 33.0      | Murikabushi |
|       |            | 2013.05.18 | 3.09     | 1.134   | 0.150    | 32.8      |             |
| 2004 QJ\(_7\) | 2011.11.03 | 4.27     | 1.104   | 0.238    | 56.3      | Kiso        |
| 2005 JU\(_{108}\) | 2005.08.29 | 4.44     | 1.269   | 0.280    | 19.8      | Kiso        |
|       |            | 2005.08.31 | 0.49     | 1.278   | 0.286    | 17.9      |             |
| 2005 TF | 2005.12.27 | 2.60     | 1.130   | 0.215    | 42.9      | Kiso        |
|       |            | 2005.12.28 | 1.16     | 1.135   | 0.218    | 41.9      |             |
| 2006 GB | 2006.04.25 | 1.12     | 1.074   | 0.195    | 64.6      | Kiso        |
|       |            | 2006.04.27 | 1.16     | 1.078   | 0.203    | 64.2      |             |
|       |            | 2006.04.28 | 0.48     | 1.081   | 0.208    | 64.0      |             |
|       |            | 2006.04.29 | 0.64     | 1.082   | 0.212    | 63.9      |             |
| 2007 FK\(_1\) | 2007.05.07 | 6.28     | 1.081   | 0.094    | 38.2      | Murikabushi |
|       |            | 2007.05.08 | 3.00     | 1.079   | 0.092    | 39.3      |             |
|       |            | 2007.05.09 | 7.59     | 1.076   | 0.089    | 40.6      |             |
|       |            | 2007.05.10 | 6.37     | 1.073   | 0.087    | 41.7      |             |
|       |            | 2007.05.11 | 4.13     | 1.071   | 0.085    | 42.9      |             |
|       |            | 2007.05.12 | 6.56     | 1.068   | 0.083    | 44.2      |             |
|       |            | 2007.05.13 | 5.16     | 1.066   | 0.082    | 45.4      |             |
| 2010 JV\(_{34}\) | 2010.05.16 | 6.14     | 1.089   | 0.082    | 18.7      | Kiso        |
|       |            | 2010.05.17 | 4.83     | 1.080   | 0.075    | 22.5      |             |
| 11739 | Baton Rouge | 2007.12.13 | 4.51     | 3.181   | 2.204    | 2.5       | Kiso        |
| 19483 | 1998 HA\(_{116}\) | 2009.02.26 | 3.11     | 2.141   | 1.223    | 13.8      | Kiso        |
|       |            | 2009.02.28 | 3.17     | 2.142   | 1.242    | 14.7      |             |

\* The heliocentric distance (\(R_h\)), geocentric distance (\(\Delta\)), and phase angle (\(\alpha\)) for asteroid observation were obtained from the NASA JPL HORIZON ephemeris generator system.\(^2\)
Table 4. Physical properties of the asteroids.

| No. | Name       | Orbital group | $\Delta V^*$ [km s$^{-1}$] | $H^*$ [mag] | Visible tax* | B-D tax* | RP [hr], this study | RP [hr], literature* | Geometric albedo* | SC/OC ratio* |
|-----|------------|---------------|----------------------------|-------------|--------------|----------|---------------------|---------------------|-------------------|-------------|
| 433 | Eros       | Amor          | 6.069                      | 11.2        | (S) (Sw)     | 5.26     | $5.2703 \pm 0.00002$ | $0.27 \pm 0.01$     | 0.28              |
| 1943| Anteros    | Amor          | 5.391                      | 15.8        | (S) (S)      | 2.869$^\dagger$ | $2.8692 \pm 0.0006$ | 0.15 $\pm$ 0.08   | –                 |
| 2212| Hephaisota | Apollo        | 10.242                     | 13.9        | S/D Sq       | –        | (>20)               | (0.19 $\pm$ 0.02)  | –                 |
| 3361| Orpheus    | Apollo        | 5.541                      | 19.0        | V (Q)        | –        | (3.58)              | (0.36 $\pm$ 0.14)  | –                 |
| 5797| Biboj      | Amor          | 5.741                      | 18.8        | S/D, {Q}     | 2.706$^\dagger$ | $2.706 \pm 0.003$ | –                 | –                 |
| 9950| ESA        | Amor          | 7.557                      | 16.1        | S Sw        | –        | (6.712 $\pm$ 0.005) | (0.10 $\pm$ 0.05)  | –                 |
| 11284| Belenus    | Amor          | 5.800                      | 18.2        | Q           | ~5.7     | $5.43 \pm 0.02$     | (0.25 $\pm$ 0.19)  | –                 |
| 14402| 1991DB     | Amor          | 5.948                      | 18.7        | (C) Ch      | 2.261    | $2.261 \pm 0.00006$ | (0.14 $\pm$ 0.06)  | –                 |
| 25143| Itokawá   | Apollo        | 4.632                      | 19.2        | S (Sqw)     | –        | (12.1324 $\pm$ 0.0001) | (0.29 $\pm$ 0.03) | (0.27) |
| 65679| 1989UQ     | Aten          | 6.405                      | 19.5        | C/B C       | –        | (7.748 $\pm$ 0.001) | (0.03 $\pm$ 0.01)  | –                 |
| 68278| 2001FC$^7$| Amor          | 5.784                      | 18.4        | X Xc        | 4.230$^\dagger$ | $4.230 \pm 0.002$ | (0.09 $\pm$ 0.02)  | –                 |
| 85585| Mjöllnir  | Apollo        | 5.608                      | 21.6        | A/D S       | 11.6     | $11.6 \pm 0.04$     | –                   | –                 |
| 85867| 1999BY$^9$| Amor          | 6.368                      | 18.0        | (Q) {Q}     | >16       | (>25)               | –                   | –                 |
| 89136| 2001US$^{16}$| Apollo      | 4.428                      | 20.2        | (Sq/Sr)     | –        | (14.3 $\pm$ 0.3)   | (14.39)            | (0.39)            |
| 136617| 1994CC    | Apollo        | 5.379                      | 17.7        | D/S indet.  | –        | (2.3886 $\pm$ 0.00009) | (<0.38)            | (0.50)            |
| 136618| 1994CN$^2$| Amor          | 5.159                      | 16.7        | D/S –       | 13.0     | $13.0 \pm 0.0002$  | –                   | (0.47 $\pm$ 0.23) |
| 136923| 1998JH$^2$| Amor          | 6.699                      | 16.2        | (S) {S}     | –        | (15.7 $\pm$ 1.0)   | –                   | –                 |
| 137799| 1999YB    | Amor          | 5.889                      | 18.5        | S Sq        | 9.43     | $9.39 \pm 0.05$    | (0.31 $\pm$ 0.21)  | –                 |
| 138175| 2000EE$^{104}$| Apollo | 6.537                      | 20.3        | – {Xn}      | 7.6     | $7.6 \pm 0.04$     | (~8)                | (0.18 $\pm$ 0.05) | (1.1) |
| 138404| 2000HA$^{24}$| Apollo     | 5.813                      | 19.1        | A/S/D S     | 3.777$^\dagger$ | (3.7768 $\pm$ 0.2) | –                   | –                 |
| 141018| 2001WC$^{47}$| Amor        | 4.800                      | 18.9        | Q Sq        | 16.75$^\dagger$ | (16.747 $\pm$ 0.006) | –                   | –                 |
| 141424| 2002CD    | Aten          | 5.602                      | 20.5        | B B        | –        | –                   | –                   | –                 |
| 142348| 2002RX$^{211}$| Amor      | 6.332                      | 18.1        | S/A Sw      | 5.067    | $5.0689 \pm 0.006$ | –                   | –                 |
| 152560| 1991BN    | Apollo        | 5.560                      | 19.1        | (Q) {Q}     | 3.49     | $3.49 \pm 0.04$    | –                   | (0.38 $\pm$ 0.25) | (0.27) |
| 153591| 2001SN$^{263}$| Amor       | 5.963                      | 16.9        | B/C Cb     | 3.426$^\dagger$ | (3.4256 $\pm$ 0.002) | –                   | (0.05 $\pm$ 0.02) | (0.16) |
| 154007| 2002BY    | Amor          | 6.069                      | 17.9        | X Xc       | 14.91    | $14.91 \pm 0.003$  | –                   | –                 |
| 154991| Vinciguerra| Amor          | 5.915                      | 18.4        | (Q) –       | 3.385    | $3.385 \pm 0.0009$ | –                   | –                 |
| 159402| 1999AP$^{10}$| Apollo     | 6.429                      | 16.1        | (Sa) Sw     | 7.911    | $7.911 \pm 0.0001$ | (7.908 $\pm$ 0.001) | (0.34 $\pm$ 0.17) |
| 159467| 2000QK$^{25}$| Amor        | 6.617                      | 18.2        | Q –         | >3       | –                   | –                   | –                 |
| 162173| Ryugu      | Apollo        | 4.646                      | 19.3        | C/B C      | –        | (7.6311)           | (0.05 $\pm$ 0.01)  | –                 |
| 162567| 2000RW$^{37}$| Apollo    | 6.154                      | 19.9        | (C) –       | 2.439    | $2.439 \pm 0.007$  | –                   | (0.17 $\pm$ 0.03) |
| 163000| 2001SW$^{169}$| Amor       | 5.257                      | 19.2        | (S/Sr/Sq)  | 69.97$^\dagger$ | (69.97 $\pm$ 0.05) | –                   | –                 |
| No.  | Name     | Group | \(\Delta V\) | \(H\) | Visible | B-D | RP, this study | RP, literature | Albedo | SC/OC |
|------|----------|-------|---------------|-------|---------|-----|---------------|---------------|--------|-------|
| 163692 | 2003 CY\(_{18}\) | Apollo | 5.724 | 18.0 | X/C | – | – | – | (0.20) |
| 163899 | 2003 SD\(_{220}\) | Aten | 7.855 | 17.3 | S/D, S | Sw | 285\(^{1}\) | \((\sim 285)\) | (0.31 ± 0.04) | – |
| 164202 | 2004 EW | Aten | 6.730 | 20.8 | C/B | Xn | 11.11 ± 0.0002 | – | (0.35 ± 0.18) | – |
| 170891 | 2004 TY\(_{16}\) | Amor | 6.578 | 16.9 | S/D | D | – | (2.795 ± 0.002) | – | – |
| 171819 | 2001 FZ\(_{6}\) | Amor | 6.520 | 18.3 | V | V | – | (15.24 ± 0.04) | – | – |
| 172974 | 2005 YW\(_{55}\) | Amor | 6.379 | 19.3 | S/D | – | – | (0.30 ± 0.24) | – | – |
| 190491 | 2000 FJ\(_{10}\) | Apollo | 4.553 | 20.9 | (S) | – | – | – | – |
| 206378 | 2003 RB | Apollo | 5.510 | 18.7 | S/A | Sw | – | (37.5 ± 0.2) | (0.44 ± 0.19) | – |
| 214869 | 2007 PA\(_{8}\) | Apollo | 6.797 | 16.4 | (Q/O) | {Sq} | – | (102 ± 5) | (0.29 ± 0.08) | (0.29) |
| 225312 | 1996 XB\(_{27}\) | Amor | 4.755 | 21.7 | (D), {S/D} | – | 1.195 ± 0.002 | – | (0.48 ± 0.26) | – |
| 341843 | 2008 EV\(_{5}\) | Aten | 5.633 | 20.0 | (C) | {B} | 3.725\(^{1}\) | \((3.725 ± 0.001)\) | (0.10 ± 0.31) | (0.40) |
| 357439 | 2004 BL\(_{86}\) | Apollo | 8.458 | 19.4 | (V) | (V) | 2.572 ± 0.001 | \((2.620)\) | \((~ 0.25)\) | – |
| 363505 | 2003 UC\(_{20}\) | Aten | 8.715 | 18.1 | B/C | Cb | – | – | (0.03 ± 0.01) | (0.21) |
| 414990 | 2011 EM\(_{31}\) | Apollo | 5.213 | 21.9 | A/S | – | – | – | – |
| 416186 | 2002 TD\(_{60}\) | Amor | 5.373 | 19.3 | (S) | {Sw} | 2.851\(^{1}\) | \((2.8513 ± 0.0001)\) | (0.50 ± 0.35) | (0.41) |
| 471240 | 2011 BT\(_{15}\) | Apollo | 4.975 | 21.7 | (A) | {Sw} | – | \((0.109138 ± 0.000002)\) | – | – |
| 481394 | 2006 SF\(_{6}\) | Aten | 6.802 | 19.9 | A/S/D | – | – | – | (0.21 ± 0.15) | – |
| 2001 QC\(_{34}\) | Apollo | 4.972 | 20.1 | S/X, {Q} | – | – | – | (0.27 ± 0.19) | – |
| 2004 DK\(_{1}\) | Amor | 5.627 | 21.0 | S/D/A | – | – | – | – |
| 2004 QJ\(_{7}\) | Apollo | 6.159 | 18.5 | – | (Q) | 1.28 ± 0.02 | – | – | – |
| 2004 XL\(_{14}\) | Aten | 12.436 | 21.2 | X/D/S | Xk | – | – | (0.15 ± 0.10) | (0.49) |
| 2005 JU\(_{108}\) | Amor | 8.436 | 19.7 | (C) | – | 5.34 ± 0.03 | – | – | – |
| 2005 TF | Amor | 5.899 | 20.2 | Q | Sqw | 2.57\(^{1}\) | \((2.57 ± 0.005)\) | – | – |
| 2006 GB | Aten | 6.341 | 20.3 | Q/X/S/D | – | >2.5 | – | – | – |
| 2007 BB\(_{30}\) | Amor | 8.436 | 18.5 | S/D | – | – | – | – | – |
| 2007 BJ\(_{29}\) | Apollo | 9.970 | 18.8 | Q | – | – | – | – | – |
| 2007 FK\(_{4}\) | Amor | 6.570 | 20.2 | – | – | 17.11 ± 0.05 | – | – | – |
| 2007 RV\(_{9}\) | Apollo | 6.624 | 20.2 | Q/S | – | – | – | – | – |
| 2007 TU\(_{24}\) | Apollo | 6.093 | 20.3 | Q | – | – | \((~ 26)\) | – | (0.37) |
| 2010 JV\(_{34}\) | Apollo | 6.754 | 20.8 | Q/C | – | 2.783 | – | (0.17 ± 0.04) | – |
| No.   | Name      | Group   | $\Delta V$ | $H$ | Visible | B-D | RP, this study | RP, literature | Albedo | SC/OC |
|-------|-----------|---------|------------|-----|---------|-----|----------------|----------------|--------|-------|
| 2010 TC$_{55}$ | Amor    | 8.350   | 20.3       | A/S | –       | –   | (2.446 ± 0.04) | –              | –      | –     |
| 2013 NJ            | Apollo  | 4.908   | 22.0       | V/Q | Q       | –   | (2.02 ± 0.05)  | –              | –      | –     |
| 852   | Wladilena | Inner MBA | 10.0   | S   | –       | –   | (4.6133 ± 0.0003) | (0.28 ± 0.01)  | –      | –     |
| 7096  | Napier    | Mars-crosser | 15.1   | C   | –       | –   | –              | (0.05 ± 0.01)  | –      | –     |
| 11739 | Baton Rouge | Hilda    | 12.0   | D   | –       | –   | 4.8 ± 0.3      | –              | (0.08 ± 0.01)  | –     |
| 19483 | 1998 HA$_{116}$ | Inner MBA | 13.9   | –   | –       | –   | 2.619 ± 0.004  | (2.6259 ± 0.0002) | –      | –     |
| 22104 | 2000 LN$_{19}$ | Middle MBA | 13.5   | X/C | –       | –   | –              | (0.13 ± 0.02)  | –      | –     |
| 2006 EX$_{52}$     | Damocloid | 14.6   | D         | –   | –       | –   | –              | –              | –      | –     |
| 2006 XQ$_{56}$     | Cybele    | 17.9   | D         | –   | –       | –    | (0.03 ± 0.03)  | –              | –      | –     |

$^*$The delta-v for transfer from low-Earth orbit to rendezvous was obtained from the NASA Near-Earth Asteroid Delta-V for Spacecraft Rendezvous database. $^3$H is the absolute magnitude taken from the MPC databases. $^4$The character or value in parentheses is that given in the literature. The bold-type character in braces is the spectral type classified using data in the literature only. The italic value of the geometric albedo was obtained by combining the absolute magnitude with the size from the radar. $^5$As a result of the inferiority of the observed data, the rotational period value is that given in the literature.
3.2 Spectral classification

The asteroid colorimetric data were converted to reflectance data using the solar color (Ramírez et al. 2012). Spectral classification of the observed visible spectroscopic and spectrophotometric asteroidal data was performed using the Tholen taxonomy (Tholen 1984). Although the spectral data contained sufficient wavelength coverage for classification, they were ultimately insufficient for classification purposes. This was because the spectrophotometric data discussed in this study incorporated less than five colors. Therefore, classification based on spectrophotometric data involved selection of possible spectral types within the error range. The Tholen taxonomy results are listed in Table 4.

In addition, asteroid classification in terms of the Bus-DeMeo taxonomy (DeMeo et al. 2009) was performed through a combination of the observed visible data and near-infrared data reported in the literature, where classification had not already been performed. An online tool\(^5\) was used to classify the asteroids according to the updated BusDeMeo taxonomy\(^5\). The Bus-DeMeo taxonomy results are listed in Table 4.

4 Results

4.1 Near-Earth asteroids

In addition to the asteroids observed in this study, information updates from the previous study (Kuroda et al. 2014) are also presented below.

4.1.1 433 Eros

Asteroid 433 Eros (1898 DQ) belongs to the Amor group, has a delta-\(v\) of 6.069 km s\(^{-1}\), and was first rendezvoused with a spacecraft (NEAR-Shoemaker) (e.g., Yeomans et al. 2000). Eros is classified as S-type in the Tholen taxonomy (Tholen 1984), the Bus taxonomy (Bus & Binzel 2002b), and the Bus-DeMeo taxonomy (Thomas et al. 2014). The asteroid albedo is 0.27 (Usui et al. 2011) and it has a radar echo circular polarization ratio (SC/OC) of 0.28 (Benner et al. 2008). Campa (1938) first reported the Eros rotational period, and many studies have since been performed on this property. The accurate rotational period was reported to be 5.27026 hr with NEAR-Shoemaker (Yeomans et al. 2000). Lightcurve observations of Eros were conducted during its apparition in January 2005, and a rotational period of 5.26 hr was obtained (Fig. 1). The result obtained in this study is in agreement with the previous report.

4.1.2 1943 Anteros

Asteroid 1943 Anteros (1973 EC) is a member of the Amor group and has a delta-\(v\) of 5.391 km s\(^{-1}\). It was classified as S-type by Tholen (1984), L-type by Binzel et al. (2001a), and S-type by DeMeo et al. (2009). The albedo of this asteroid has been estimated to be 0.15 (Trilling et al. 2010). An accurate rotational period of 2.8692 hr has been reported for Anteros (Warner 2017c). For periodic analysis, Anteros was observed during its apparition in February 2007 and August 2009. However, the rotational period could not be determined in this study because of the lack of data for periodic analysis. The value of the rotational period was quoted from Warner (2017c) (Fig. 1).

4.1.3 2212 Hephaistos

Asteroid 2212 Hephaistos (1978 SB) is a member of the Apollo group and has a delta-\(v\) of 10.242 km s\(^{-1}\). The albedo is 0.19 (Usui et al. 2011) and Pravec et al. (1997) have reported that the asteroid has a rotational period of more than 20 hr. Visible colorimetric, visible spectroscopic, and near-infrared spectroscopic data of the asteroid are reported in Pravec et al. (1997) and Tedesco 2005\(^7\), Luu & Jewitt (1990), and de León et al. (2010) and DeMeo, Binzel, & Lockhart (2014). DeMeo, Binzel, & Lockhart (2014) have demonstrated that Hephaistos is an Sq-Q-type asteroid using near-infrared data only. Colorimetric observation for Hephaistos was performed during its apparition in September 2007. The spectrophotometric data in this study allowed classification of this asteroid to S/D-type (Fig. 2). This asteroid was classified as Sq-type in combination with the visible and infrared data. Several spectra including those from the literature were compared in this work. The spectra are roughly coincident, but there are slight differences in shape.

4.1.4 3361 Orpheus

Asteroid 3361 Orpheus (1982 HR) has an Apollo-type orbit with a delta-\(v\) of 5.541 km s\(^{-1}\). The geometric albedo is 0.36 (Mainzer et al. 2011) and the rotation period is reported as 3.58 hr (Wisniewski 1991). Wisniewski (1991) and DeMeo, Binzel, & Lockhart (2014) have classified the asteroid as V- and Q-type, respectively. Colorimetric observation for Orpheus was conducted during its apparition in September 2005. In this study, the asteroid was classified as V-type using spectrophotometric data (Fig. 2).

4.1.5 5797 Bivoj

Asteroid 5797 Bivoj (1980 AA) has a delta-\(v\) of 5.741 km s\(^{-1}\) belongs to the Amor group. A rotational period of 2.706 hr has been reported for Bivoj (Mottola et al. 1995). Photometric observations of this asteroid were performed during its apparition.
Fig. 1. Composite rotational lightcurves of asteroids.
Fig. 1. (continued)
Fig. 2. Spectra of asteroids.
Fig. 2. (continued)
tion in December 2005 and February 2006. Because of a lack of lightcurve data to conduct periodic analysis, the rotational period of the asteroid could not be determined in this study. The value of the rotational period was cited from Mottola et al. (1995) (Fig. 1). Visible colorimetric observations were performed (Harris & Young 1989; McFadden, Gaffey, & McCord 1984). From the colorimetric data in this study, the asteroid was categorized as S/D-type. Although classification was not performed by McFadden, Gaffey, & McCord (1984), the classification in this work was conducted using the data reported by McFadden, Gaffey, & McCord (1984), because the wavelength range considered in that work was wider than that of the present study. This asteroid was classified as Q-type.

4.1.6 9950 ESA
Asteroid 9950 ESA (1990 VB) is a member of the Amor group and has a delta-v of 7.575 km s$^{-1}$. Warner (2014a) showed that ESA has a rotational period of 6.712 hr. Further, the albedo is 0.10 (Trilling et al. 2010). Spectroscopic observation for ESA was performed during its apparition in December 2013. The asteroid was classified as S-type using visible data (Fig. 2). In addition, by combining the visible data in this study and the near-infrared data in the Database of The MIT-University of Hawaii-Infrared Telescope Facility (MIT-UH-IRTF) Joint Campaign for Near-Earth Object (NEO) Spectral Reconnaissance (SMASS)$^8$, the asteroid was classified as Sw-type.

4.1.7 11284 Belenus
Asteroid 11284 Belenus (1990 BA), belongs to the Amor group and has a delta-v of 5.800 km s$^{-1}$. A rotational period of 5.43 hr was reported by Hicks et al. (2013). The NEOSurvey website$^9$ reports that Belenus has a geometric albedo of 0.25. Belenus was observed during its apparition in November 2005. The asteroid rotational period was determined to be 5.7 hr from its lightcurve (Fig. 1). The results of this study are in somewhat good agreement with past reports. Belenus was classified as S-type (Hicks et al. 2013; Lin et al. 2018). The spectrophotometric data obtained in this study indicate a Q-type asteroid (Fig. 2). A combination of the visible data acquired in this study and near-infrared SMASS data$^8$ also indicates a Q-type asteroid.

4.1.8 14402 1991 DB
Asteroid 14402 1991 DB with a delta-v of 5.948 km s$^{-1}$ is assigned to the Amor group. The asteroid was classified as C-type in the Bus taxonomy (Binzel et al. 2004b) and C-type in the Bus-DeMeo taxonomy (Thomas et al. 2014). The albedo of 1991 DB is 0.14 (Delbó et al. 2003) and the rotational period is reported to be 2.266 hr on the Ondrejov Asteroid Photometry Project website$^{10}$ (Pravec web). Lightcurve observations of 1991 DB were conducted during its apparition between January and March 2009, and a rotational period of 2.261 hr was obtained (Fig. 1). The result obtained in this study is in agreement with the previous report.

4.1.9 25143 Itokawa
Asteroid 25143 Itokawa (1998 SF$_{36}$), which has a delta-v of 4.632 km s$^{-1}$, is a member of the Apollo group. Itokawa was the first asteroid in which a sample return was conducted by a spacecraft (Hayabusa) (Fujiwara et al. 2006). The albedo of this asteroid has been estimated to be 0.29 (Müller, Hasegawa, & Usui 2014) and the asteroid has an SC/OC of 0.27 (Benner et al. 2008). A rotational period of 12.1324 hr has been reported (Nishihara et al. in press). Spectroscopic and spectrophotometric data for Itokawa have been reported in Binzel et al. (2001b), Ishiguro et al. (2003), Lowry et al. (2005), de León et al. (2006), Abell et al. (2007), Davies et al. (2007), and Carry et al. (2016), and this asteroid was classified as Sqw-type in the Bus-DeMeo taxonomy (Thomas et al. 2014; Hasegawa et al. 2017). Itokawa was spectrally observed during its apparition in December 2000. The spectroscopic data acquired in this study yielded a classification as S-type (Fig. 2). Several spectra including those from the literature were obtained and compared; the spectra are roughly coincident, but there are slight differences in shape.

4.1.10 65679 1989 UQ
Asteroid 65679 1989 UQ has an Aten-type orbit with a delta-v of 6.405 km s$^{-1}$. The geometric albedo of the asteroid is 0.03 (Mainzer et al. 2012) and the rotation period is reported as 7.748 hr (Pravec web$^{10}$). The asteroid has been classified as B- and C-type by Binzel et al. (2004a) using visible data and by Thomas et al. (2014) using near-infrared data, respectively. Colorimetric observation for 1989 UQ was conducted during its apparition in September 2005. In this study, the asteroid was classified as a B/C-type asteroid using spectrophotometric data (Fig. 2). A combination of the visible data and near-infrared SMASS data$^8$ also indicated a C-type asteroid. Several spectra including those from the literature were obtained and compared. The spectra are roughly coincident, but there are slight differences in its shape.

4.1.11 68278 2001 FC$_7$
Asteroid 68278 2001 FC$_7$ is a member of the Amor group and has a delta-v of 5.784 km s$^{-1}$. The albedo is 0.09 (Mainzer et al. 2012). Photometric observations of the asteroid were performed during its apparition in February 2006. Monteiro et al. (2017) reported that 2001 FC$_7$ has a rotational period of 4.230 hr. The rotational period, however, could not be determined in this study because there were insufficient data for rotational analysis. The spectrophotometric and spectroscopic data of the

\begin{itemize}
  \item $^8$ (http://smass.mit.edu/minus.html).
  \item $^9$ (http://neareartheastobjects.nau.edu/neosurvey/).
  \item $^{10}$ (http://www.asu.cas.cz/ppravec/neo.htm).
\end{itemize}
asteroid are reported in Carvano et al. (2010) and de León et al. (2010). From the colorimetric data considered in this study, this asteroid was classified as X-type (Fig. 2). Further, this asteroid was classified as Xc-type based on a combination of the visible and infrared data. Several spectra including those from the literature were obtained and compared. The spectra are roughly coincident, but there are slight differences in shape.

4.1.12 85585 Mjolnir
Asteroid 85585 Mjolnir (1998 FG₉) with a delta-υ of 5.608 km s⁻¹ belongs to the Apollo group. Photometric observations of Mjolnir were performed during its apparition in September 2003. A rotational period of 11.6 hr was obtained (Fig. 1). From the spectrophotometric data acquired in this study, the asteroid was categorized as A/D-type (Fig. 2). Moreover, based on a combination of the visible data obtained in this study and near-infrared data from SMASS⁸, the asteroid was classified as S-type (Fig. 2).

4.1.13 85867 1999 BY⁹
Asteroid 85867 1999 BY⁹ is a member of the Amor group and has a delta-υ of 6.368 km s⁻¹. Koehn et al. (2014) has shown that this asteroid has a rotational period of more than 25 hr. Lightcurve observations of 1999 BY⁹ were performed during its apparition in January 2009, and a rotational period of more than 16 hr was obtained (Fig. 1). As classification of this asteroid was not performed in de León et al. (2010), the classification reported in this study was conducted using their data. Hence, this asteroid was classified as Q-type (Fig. 2).

4.1.14 89136 2001 US₁₆
Asteroid 89136 2001 US₁₆ belongs to the Apollo group and has a delta-υ of 4.428 km s⁻¹. The asteroid has an SC/OC of 0.39 (Benner et al. 2008) and has been classified as Sq/Sr-type Kuroda et al. (2014). The rotational period of 2001 US₁₆ was shown to be 14.39 hr (Pravec web¹⁰). The asteroid was observed during its apparition in October 2012, and a rotational period of 14.3 hr was acquired (Fig. 1). The result of this study is consistent with the previous report.

4.1.15 136617 1994 CC
Asteroid 136617 1994 CC, with a delta-υ of 5.379 km s⁻¹, is a member of the Apollo group. Brozović et al. (2011) has reported that this asteroid, which has an SC/OC of 0.50 and a rotational period of 2.3886 hr, is a triple system composed of three bodies of 0.62, 0.11, and 0.08 km in diameter. Combining the diameter obtained from radar investigation and the absolute magnitude yields a geometric albedo value of 0.38 in this asteroid. This asteroid was classified as Sq-, Sa-, and S-type by Brozović et al. (2011), Thomas et al. (2014), and Carry et al. (2016), respectively. 1994 CC was observed during its apparition in February and April 2008. The asteroid was classified as D/S-type based on spectrophotometric data in this study (Fig. 2). Based on a combination of the visible and near infrared data, the classification of 1994 CC in terms of the Bus-DeMeo taxonomy was “indeterminate”.

4.1.16 136618 1994 CN²
Asteroid 136618 1994 CN² is a member of the Apollo group and has a delta-υ of 5.159 km s⁻¹. The albedo of this asteroid is 0.47 (Trilling et al. 2016). Carvano et al. (2010) reported that the asteroid is S-type on the surface. Photometric observations for 1994 CN² were performed during its apparition in March 2006 and February and April 2008. A rotational period of 13.0 hr was obtained (Fig. 1). The spectrophotometric data of this study indicated a classification of S/D-type (Fig. 2). S-type asteroids typically have an albedo of more than 0.1 (Hasegawa et al. 2017); therefore, based on its albedo, this asteroid is constrained to S-type.

4.1.17 136923 1998 JH²
Asteroid 136923 1998 JH² has an Amor-type orbit with a delta-υ of 6.699 km s⁻¹. The rotation period is reported to be 15.7 hr (Vaduvescu et al. 2017). Carry et al. (2016), Kuroda et al. (2014), and DeMeo, Binzel, & Lockhart (2014) classified this asteroid as D-, S-, and Sq/Q-type, respectively. As visible and near-infrared spectra of the asteroid had already been acquired, the Bus-DeMeo taxonomy was considered based on both datasets in this study. This asteroid is S-type (Fig. 2).

4.1.18 137799 1999 YB
Asteroid 137799 1999 YB with a delta-υ of 5.889 km s⁻¹ belongs to the Amor group. The value of the asteroid albedo is given as 0.31 on the NEOSurvey website⁹. A rotational period of 9.39 hr has been reported for 1999 YB (Warner 2015). Evans & Tabachnik (2002) showed that 1999 YB is possibly a long-lived asteroid, as it has low eccentricity and inclination and is not planet-crossing between Earth and Mars. Photometric observations of the asteroid were acquired, but the Bus-DeMeo taxonomy was considered based on both datasets in this study. This asteroid is S-type (Fig. 2).

4.1.19 138175 2000 EE₁₀⁴
Asteroid 138175 2000 EE₁₀⁴ is a member of the Apollo group and has a delta-υ of 6.537 km s⁻¹. A rotational period of ~8 hr, size of ~0.2 km, and SC/OC polarization ratio of 1.1 were obtained using radar observations (Howell et al. 2001). An albedo
of 0.18 for the asteroid was obtained from information on the size and absolute magnitude. Lightcurve observations for the asteroid were performed during its apparition in February 2007. The rotational period of the asteroid was determined to be 7.6 hr from its lightcurve (Fig. 1). From the near-infrared data in the SMASS database, the asteroid was classified as Xn-type (Fig. 2). Previously, Benner et al. (2008) noted that an E-type asteroid has the highest SC/OC ratio. The values of the circular polarization ratios and geometric albedo for the asteroid are not contradictory to classification of the asteroid as Xn-type.

4.1.20 138404 2000 HA₄₂₄
Asteroid 138404 2000 HA₄₂₄ is a member of the Apollo group and has a delta-υ of 5.813 km s⁻¹. The rotational period of 3.7768 hr was shown in Hayes-Gehlke et al. (2017). Further, 2000 HA₄₂₄ was observed during its apparition in April 2006. The rotational period, however, could not be obtained in this study because of a lack of lightcurve data for periodic analysis. Instead, the rotational period was quoted from Hayes-Gehlke et al. (2017) (Fig. 1). The asteroid was classified as S-type with visible (Sanchez et al. 2013) and near-infrared spectra (DeMeo, Binzel, & Lockhart 2014). The spectrophotometric data in this study yielded an asteroid of A/S/D-type (Fig. 2). A combination of the visible and near-infrared data also indicated an S-type asteroid.

4.1.21 141018 2001 WC₄₇
Asteroid 141018 2001 WC₄₇, with a delta-υ of 4.800 km s⁻¹, is a member of the Amor group. The rotational period was reported to be 16.747 hr in Warner (2012). Photometric observations of 2001 WC₄₇ were performed during its apparition in November and December 2006. As there were insufficient data for periodic analysis, the rotational period of the asteroid could not be decided in this study. The value of the rotational period was cited from Warner (2012) (Fig. 1). Spectroscopic observations were performed (Kuroda et al. 2014; de León et al. 2010). From the colorimetric data in this study, the asteroid was categorized as Q-type. From a combination of the visible data in this study and the near-infrared data in the SMASS database, the asteroid was classified as Sq-type. Several spectra including those from the literature were obtained and compared. The spectra are roughly coincident, but there are slight differences in shape.

4.1.22 141424 2002 CD
Asteroid 141424 2002 CD, which a delta-υ of 5.602 km s⁻¹, is a member of the Apollo group. This asteroid was colorimetrically observed during its apparition in March 2006. The spectrophotometric data obtained in this study allowed classification of the asteroid as B-type (Fig. 2). Additionally, the asteroid class was determined to be B-type based on a combination of the visible spectrophotometric data and near-infrared data from SMASS.

4.1.23 142348 2002 RX₂₁₁
Asteroid 142348 2002 RX₂₁₁ has an Amor-type orbit with a delta-υ of 6.332 km s⁻¹. Higgins et al. (2006) reported that 2002 RX₂₁₁ has a rotational period of 5.0689 hr. Photometric observations of 2002 RX₂₁₁ were conducted during its apparition in December 2005. A rotational period of 5.067 h was acquired in this study (Fig. 1), which is consistent with the literature. The asteroid was classified as being S-complex (DeMeo, Binzel, & Lockhart 2014). The colorimetric acquired data in this study allowed classification of this asteroid as S/A-type (Fig. 2). A combination of the visible and near-infrared data indicated an Sw-type asteroid.

4.1.24 152560 1991 BN
Asteroid 152560 1991 BN is a member of the Amor group and has a delta-υ of 5.560 km s⁻¹. The albedo of the asteroid is 0.38 (Trilling et al. 2016) and it has an SC/OC of 0.27 (Benner et al. 2008). Visible and near-infrared spectroscopic data for this asteroid are reported in Binzel et al. (2004b) and Lazzerini et al. (2005), respectively. Through a combination of the visible data and infrared data in the literature, this asteroid was classified as Q-type (Fig. 2). Lightcurve observations for the asteroid were performed during its apparition in December 2009, and a rotational period of 3.49 hr was obtained (Fig. 1).

4.1.25 153591 2001 SN₂₆₃
Asteroid 153591 2001 SN₂₆₃ with a delta-υ of 5.963 km s⁻¹ belongs to the Amor group. The asteroid has been confirmed as a triple system, having three bodies of 2.5, 0.8, and 0.4 km in diameter (Becker et al. 2015). The SC/OC ratio and geometric albedo of the triple asteroid are 0.16 (Becker et al. 2015) and 0.05 (Delbo et al. 2011), respectively. Becker et al. (2015) showed that the asteroid has a rotational period of 3.4256 hr. Photometric observations were performed during its apparition in February 2008. The rotational period, however, could not be determined in this study because of the short time period spanned by the data for periodic analysis. The value of the rotational period was taken from Becker et al. (2015)(Fig. 1). 2001 SN₂₆₃ has been classified as B-type (Carvano et al. 2010; Perna et al. 2014; Becker et al. 2015). From the spectrophotometric data obtained in this study, the asteroid was categorized as B/C-type (Fig. 2). Moreover, the combination of the visible data acquired in this study and near-infrared data from the SMASS database allowed classification of the asteroid as Cb-type. Several spectra including those from the literature were obtained and compared. These spectra are roughly coincident, but there are slight differences in its shape.

4.1.26 154007 2002 BY
Asteroid 154007 2002 BY is a member of the Amor group and has a delta-υ of 6.069 km s⁻¹. Photometric observations of
the asteroid were performed during its apparition in February and April 2007. A rotational period of 14.91 hr was obtained (Fig. 1). This asteroid was classified as X-type using visible spectrophotometric data (Fig. 2). From a combination of the visible data and infrared data from SMASS\(^5\), the asteroid was categorized as Xc-type.

4.1.27 154991 Vinciguerra
Asteroid 154991 Vinciguerra (2005 BX\(_{26}\)) belongs to the Amor group and has a delta-\(\nu\) of 5.915 km s\(^{-1}\). This asteroid was in the Q taxonomic class (Carry et al. 2016). Vinciguerra was observed during its apparition in January 2009, with a rotational period of 3.835 hr being acquired (Fig. 1).

4.1.28 159402 1999 AP\(_{10}\)
Asteroid 159402 1999 AP\(_{10}\), belongs to the Apollo group and has a delta-\(\nu\) of 6.429 km s\(^{-1}\). 1999 AP\(_{10}\) was classified as S-type in the Tholen taxonomy (Ye 2011), Sa-type in the Bus taxonomy (Hicks, Lowry, & Weissman 2009), and Sq-type in the Bus-DeMeo taxonomy (Thomas et al. 2014). The asteroid albedo was 0.34 (Trilling et al. 2010). The accurate rotational period was reported to be 7.908 hr (Franco et al. 2010). Lightcurve observations of the asteroid were conducted during its apparition in September, October, and December 2009, and a rotational period of 7.911 hr was obtained (Fig. 1). The result obtained in this study is agreement with the previous report.

4.1.29 159467 2000 QK\(_{25}\)
The asteroid 159467 2000 QK\(_{25}\) is a member of the Amor group and has a delta-\(\nu\) of 6.617 km s\(^{-1}\). For periodic analysis, the asteroid was observed during its apparition in December 2005, and a rotational period of more than 2.5 hr was obtained (Fig. 1). Colorimetric observations for the asteroid were conducted during its apparition in November 2005. The asteroid was classified as Q-type using spectrophotometric data in this study (Fig. 2).

4.1.30 162173 Ryugu
Asteroid 162173 Ryugu (1999 JU\(_3\)) is a member of the Apollo group and has a delta-\(\nu\) of 4.646 km s\(^{-1}\). This asteroid is the target body of the Hayabusa2 mission (Tsuda et al. 2013). The albedo and rotational period of this asteroid have been estimated to be 0.05 and 7.6311 hr, respectively (Müller et al. 2017). The spectroscopic data of the asteroid are reported in Binzel et al. (2001a), Vilas (2008), Lazzaro et al. (2013), Moskovitz et al. (2013), Pinilla-Alonso et al. (2013), and Perna et al. (2016), and indicate that Ryugu is a C-complex asteroid. Colorimetric observations for the asteroid were performed during its apparition in July and September 2007. The spectrophotometric data obtained in this study allowed classification of this asteroid as C/B-type (Fig. 2).

4.1.31 162567 2000 RW\(_{37}\)
Asteroid 162567 2000 RW\(_{37}\) has an Apollo-type orbit with a delta-\(\nu\) of 6.154 km s\(^{-1}\). The geometric albedo of the asteroid is 0.17 (Nugent et al. 2015). Binzel et al. (2004b) classified the asteroid as C-type. Lightcurve observations for 2000 RW\(_{37}\) were conducted during its apparition in February 2008. A rotational period of 2.439 hr was acquired (Fig. 1).

4.1.32 163000 2001 SW\(_{169}\)
Asteroid 163000 2001 SW\(_{169}\) with a delta-\(\nu\) of 5.257 km s\(^{-1}\) belongs to the Amor group. A rotational period of 69.97 hr was reported for 2001 SW\(_{169}\) (Stephens 2016). An asteroid with low eccentricity and inclination that is not planet-crossing between the Earth and Mars indicates possible long life (Evans & Tabachnik 2002). Lightcurve observations of the asteroid were performed during its apparition in September, October, and November 2008. The long duration lightcurve data for the asteroid were insufficient; thus, the rotational period of the asteroid could not be decided in this study (Fig. 1). Carvano et al. (2010), Kuroda et al. (2014), and DeMeo, Binzel, & Lockhart 2014 classified the asteroid as S-, S/Sr/Sq-type, and S-complex, respectively. In combination with the visible data and infrared data in the literature, 2001 SW\(_{169}\) was classified as Sw-type (Fig. 2).

4.1.33 163692 2003 CY\(_{18}\)
Asteroid 163692 2003 CY\(_{18}\) is a member of the Apollo group and has a delta-\(\nu\) of 5.724 km s\(^{-1}\). The asteroid has an SC/OC of 0.20 (Benner et al. 2008). Colorimetric observations for 2003 CY\(_{18}\) was performed during its apparition in December 2007. The asteroid was classified as X/C-type using visible data (Fig. 2).

4.1.34 163899 2003 SD\(_{220}\)
Asteroid 163899 2003 SD\(_{220}\) belongs to the Aten group and has a delta-\(\nu\) of 7.855 km s\(^{-1}\). It is reported that the asteroid has a geometric albedo of 0.31 in Nugent et al. (2016). A rotational period of 285 hr has been reported (Warner 2016b). 2003 SD\(_{220}\) was observed during its apparition in November and December 2006. However, the rotational period could not be determined in this study because of the lack of data for periodic analysis (Fig. 1). 2003 SD\(_{220}\) was classified as S/Sr- and Sr-type (DeMeo, Binzel, & Lockhart 2014; Perna et al. 2016). The spectrophotometric and spectroscopic data acquired in this study yielded asteroid classifications of S/D- and S-type, respectively (Fig. 2). A combination of the visible data acquired in this study and the near-infrared data obtained in DeMeo, Binzel, & Lockhart (2014) also indicated Sw-type.
4.1.35 164202 2004 EW
Asteroid 164202 2004 EW with a delta-\(v\) of 6.730 km s\(^{-1}\) is classified as the Aten group. The albedo of 2004 EW is 0.35 (Trilling et al. 2010). The asteroid was classified as being X-type (Perna et al. 2018). Photometric observations of 2004 EW were conducted during its apparition in March 2005 and 2006. The spectrophotometric data of this study yielded classification of the asteroid as C/B-type (Fig. 2). A combination of the visible data acquired in this study and the near-infrared data of the SMASS database\(^8\) allowed classification of the asteroid as Xn-type. A rotational period of 11.11 hr was obtained (Fig. 1).

4.1.36 170891 2004 FY\(_{16}\)
Asteroid 170891 2004 FY\(_{16}\), which has a delta-\(v\) 6.578 km s\(^{-1}\), is a member of the Amor group. The rotational period of this asteroid has been estimated to be 2.795 hr (Carbognani 2008). Using the colorimetric data acquired in this study, the asteroid was categorized as S/D-type (Fig. 2). A combination of the visible data and the near-infrared SMASS data\(^8\) indicated a D-type asteroid.

4.1.37 171819 2001 FZ\(_6\)
Asteroid 2001 FZ\(_6\) has an Amor-type orbit with a delta-\(v\) of 6.520 km s\(^{-1}\). The rotation period has been reported as 15.24 hr (Warner 2017b). Colorimetric observations for 2001 FZ\(_6\) were conducted during its apparition in December 2007. The asteroid was classified as V-type using the spectrophotometric data obtained in this study (Fig. 2). A combination of the acquired visible data and the near-infrared SMASS data\(^8\) also indicated a V-type asteroid.

4.1.38 172974 2005 YW\(_{55}\)
Asteroid 172974 2005 YW\(_{55}\) is a member of the Amor group and has delta-\(v\) of 6.379 km s\(^{-1}\). The geometric albedo of the asteroid is 0.30 (Mueller et al. 2011). Colorimetric observations for the asteroid were performed during its apparition in February 2008. The colorimetric data obtained in this study yielded classification of this asteroid as S/D-type (Fig. 2). The classification of this asteroid could be constrained to S-type through consideration of the albedo.

4.1.39 190491 2000 FJ\(_{10}\)
Asteroid 190491 2000 FJ\(_{10}\) with a delta-\(v\) of 4.553 km s\(^{-1}\) belongs to the Apollo group. Christou et al. (2012) reported that the asteroid has an S-type surface and a rotational period of more than 2 hr. Lightcurve observations were performed for 2000 FJ\(_{10}\) during its apparition in August 2014. A rotational period of 2.456 hr was obtained (Fig. 1), which is consistent with the literature.

4.1.40 206378 2003 RB
Asteroid 206378 2003 RB is a member of the Apollo group and has a delta-\(v\) of 5.510 km s\(^{-1}\). Warner (2016a) showed that the asteroid has a rotational period of 37.5 hr, with an albedo of 0.44 (Nugent et al. 2016). Colorimetric observations of 2003 RB were performed during its apparition in September 2009, and it was classified as S/A-type. Moreover, the combination of the visible data acquired in this study and the near-infrared data in the SMASS database\(^8\) allowed the asteroid to be classified as Sw-type.

4.1.41 214869 2007 PA\(_8\)
Asteroid 214869 2007 PA\(_8\) belongs to the Apollo group and has a delta-\(v\) of 6.797 km s\(^{-1}\). The albedo of 2007 PA\(_8\) is 0.29 (Fornasier, Belskaya, & Perna, D. 2015). The asteroid has an SC/OC of 0.29 and the rotational period was shown to be 102 hr (Brozović et al. 2017). Brozović et al. (2017) reported that this asteroid is in non-principal axis rotation and a short-axis mode precession with average period of 102 hr and oscillation about the long axis of 493 hr. Spectrophotometric and spectroscopic observations of the asteroid were conducted in Hicks et al. (2012), Lin et al. (2018), Nedelcu et al. (2014), Fornasier, Belskaya, & Perna, D. (2015), Sanchez et al. (2015), and Perna et al. (2016). Through a combination of the visible data reported by Kuroda et al. (2014) and the infrared data of the SMASS database\(^8\), this asteroid was classified as Sq-type (Fig. 2). Several spectra including those from the literature were obtained and compared. The spectra are roughly coincident, but there are slight differences in its shape.

4.1.42 225312 1996 XB\(_{27}\)
Asteroid 225312 1996 XB\(_{27}\) belongs to the Amor group and has a delta-\(v\) of 4.755 km s\(^{-1}\). It has been noted that this asteroid is possibly long-lived because of its low eccentricity and inclination, and because it does not cross the orbits of either the Earth or Mars (Evans & Tabachnik 1999, 2002). The albedo of the asteroid is 0.48 (Mueller et al. 2011). 1996 XB\(_{27}\) was classified as being D-type (Carr et al. 2016). Considering the albedo distribution of D-type asteroids (Hasegawa et al. 2017), the value of the albedo and the classification result are contradictory. This asteroid was classified as S/D-type using SDSS data in this study (Fig. 2). Taking the albedo value into consideration, the preferable classification of this asteroid is S-type. Lightcurve observations for 1996 XB\(_{27}\) were performed during its apparition in August 2014. A rotational period of 1.195 hr was obtained (Fig. 1). Thus, 1996 XB\(_{27}\) is a fast rotator.

4.1.43 250697 2005 QY\(_{151}\)
Asteroid 250697 2005 QY\(_{151}\) is a member of the Apollo group and has a delta-\(v\) of 7.006 km s\(^{-1}\). This asteroid was observed during its apparition in November 2010 and its rotational period
was determined to be more than 11 h from its lightcurve (Fig. 1).

4.1.44 253062 2002 TC$_{70}$
Asteroid 253062 2002 TC$_{70}$ is a member of the Amor group and has a delta-$v$ of 4.886 km s$^{-1}$. Kuroda et al. (2014) reported that 2002 TC$_{70}$ is Sq/Q-type. Lightcurve observations for 2002 TC$_{70}$ were performed during its apparition in February 2013. A rotational period of $\sim$17 hr was acquired (Fig. 1).

4.1.45 341843 2008 EV$_5$
Asteroid 341843 2008 EV$_5$ has a Aten-type orbit with a delta-$v$ of 5.633 km s$^{-1}$. The asteroid albedo is 0.10 (Mainzer et al. 2011) and the asteroid has an SC/OC of 0.40 (Busch et al. 2011). The rotation period is reported to be 3.725 hr (Galád et al. 2009). Lightcurve observations of 2008 EV$_5$ were performed during its apparition in January and March 2009. Because the lightcurve data were not sufficient for periodic analysis, the rotational period of the asteroid could not be determined in this study. The value of the rotational period was cited from Galád et al. (2009) (Fig. 1). The colorimetric and spectroscopic data of the asteroid are reported in Somers et al. (2010) and Reddy et al. (2012), respectively. As classification was not performed in Reddy et al. (2012), classification was conducted in this study; hence, the asteroid was classified as B-type. As the albedo value for 2008 EV$_5$ lies within the albedo distribution range of B-type asteroids (Hasegawa et al. 2017), this classification result is consistent with the spectral type inferred from the albedo value.

4.1.46 357439 2004 BL$_{86}$
Asteroid 357439 2004 BL$_{86}$, with a delta-$v$ of 8.458 km s$^{-1}$, belongs to the Apollo group. A combination of the diameter obtained from the absolute magnitude and the size determined using radar (Benner et al. 2015) yields a geometric albedo value of 0.25 in this asteroid. Benner et al. (2015) showed that 2004 BL$_{86}$ is a binary system composed of a primary body and satellite of 0.35 and 0.07 km in diameter, respectively. The asteroid was classified as V-type (Birlan et al. 2015; Franco 2015; Reddy et al. 2015) and the rotational period was reported to be 2.620 hr (Reddy et al. 2015). Lightcurve observations of 2004 BL$_{86}$ were conducted during its apparition in January 2015, and a rotational period of 2.572 hr was obtained (Fig. 1). The phase angle changed by approximately 10 degrees in three days of the observation period. While correction was made in consideration of this, the rotation period was 2.568 hr. The corrected result is in agreement with past reports.

4.1.47 363505 2003 UC$_{20}$
Asteroid 363505 2003 UC$_{20}$ is a member of the Aten group and has a delta-$v$ of 8.715 km s$^{-1}$. This asteroid has an albedo of 0.03 (Nugent et al. 2015), with an SC/OC value of 0.21 (Benner et al. 2008). Colorimetric observation for 2003 UC$_{20}$ was performed during its apparition in November 2005. The asteroid was classified as B/C-type based on visible data (Fig. 2). By combining the visible data acquired in this study and the near-infrared data in the SMass database, the asteroid was classified as Cb-type.

4.1.48 414990 2011 EM$_{15}$
Asteroid 414990 2011 EM$_{15}$ belongs to the Apollo group and has a delta-$v$ of 5.213 km s$^{-1}$. Spectroscopic observation of the asteroid was performed during its apparition in February 2014. The spectrum in this study indicated an A/S-type asteroid (Fig. 2).

4.1.49 416186 2002 TD$_{60}$
Asteroid 416186 2002 TD$_{60}$ with a delta-$v$ of 5.373 km s$^{-1}$ is a member of the Amor group. The albedo of this asteroid has been estimated to be 0.05 according to the NEOSurvey website. This asteroid has an SC/OC of 0.41 (Benner et al. 2008), and it has been noted that 2002 TD$_{60}$ is a tumbling asteroid with two rotational periods of 2.8513 and 6.783 hr (Pravec et al. 2005). Lightcurve observations of 2002 TD$_{60}$ were performed during its apparition in November 2006. The short-period value of the rotational period given in Pravec et al. (2005) was utilized (Fig. 1). The asteroid was classified as S-type in terms of the Bus taxonomy (Lazzarin et al. 2005). As (Lazzarin et al. 2005) did not classify this asteroid using the Bus-DeMeo taxonomy, it was classified as Sw-type for that taxonomy in this study.

4.1.50 451157 2009 SQ$_{104}$
Asteroid 451157 2009 SQ$_{104}$, which has a delta-$v$ of 4.879 km s$^{-1}$, is a member of the Apollo group. Spectroscopic data of 2009 SQ$_{104}$ were reported in Kuroda et al. (2014). A combination of the visible data of Kuroda et al. (2014) and the SMass near-infrared data also indicated an Sq-type asteroid (Fig. 2). 2009 SQ$_{104}$ was observed during its apparition in May 2005. A rotational period of 6.974 hr was obtained (Fig. 1).

4.1.51 471240 2011 BT$_{15}$
Asteroid 471240 2011 BT$_{15}$ has an Apollo-type orbit with a delta-$v$ of 4.975 km s$^{-1}$. The rotation period is reported as 0.109138 hr (Warner 2014b), which indicates that the asteroid is a fast rotator. The asteroid was classified as A-type (Kuroda et al. 2014). Based on a combination of the visible data of Kuroda et al. (2014) and the SMass infrared data, this asteroid was classified as Sw-type (Fig. 2).

4.1.52 481394 2006 SF$_6$
Asteroid 481394 2006 SF$_6$ belongs to the Aten group and has a delta-$v$ of 6.802 km s$^{-1}$. The albedo is 0.21, from the
NEOSurvey website. Colorimetric observation for the asteroid was performed during its apparition in November 2007. The spectrophotometric data obtained in this study allowed classification of this asteroid to A/S/D-type (Fig. 2). The classification of this asteroid could be constrained to A/S type in consideration of its albedo value.

4.1.53 2001 QC$_{34}$
Asteroid 2001 QC$_{34}$ with a delta-$v$ of 4.972 km s$^{-1}$ belongs to the Apollo group. The albedo of this asteroid is estimated as 0.27 on the NEOSurvey website. Colorimetric and spectroscopic data for the asteroid were obtained by Dandy, Fitzsimmons, & Collander-Brown (2003) and Carry et al. (2016) and Vilas (2008), respectively. Photometric observations for 2001 QC$_{34}$ were performed during its apparition in September 2007. From the spectrophotometric data in this study, the asteroid was categorized as S/X-type (Fig. 2). Using spectroscopic data (Vilas 2008), this asteroid was classified as Q-type.

4.1.54 2004 DK$_{3}$
The asteroid 2004 DK$_{3}$ is a member of the Amor group and has the delta-$v$ of 5.627 km s$^{-1}$. Colorimetric observations of 2004 DK$_{3}$ were performed during its apparition in April 2004. This asteroid was classified as S/D/A-type.

4.1.55 2004 QJ$_{7}$
Asteroid 2004 QJ$_{7}$ belongs to the Apollo group and has a delta-$v$ of 6.159 km s$^{-1}$. The asteroid was classified as Q-type (DeMeo, Binzel, & Lockhart 2014). 2004 QJ$_{7}$ was observed during its apparition in November 2011 and a rotational period of 1.28 hr was acquired (Fig. 1). This asteroid is a fast rotator.

4.1.56 2004 XL$_{14}$
Asteroid 2004 XL$_{14}$ belongs to the Aten group and has a delta-$v$ of 12.436 km s$^{-1}$. The albedo is 0.15 according to the NEOSurvey website. The SC/OC is 0.49 (Benner et al. 2008). Colorimetric observations of 2004 XL$_{14}$ were conducted during its apparition in December 2006. The spectrophotometric data obtained in this study allowed classification of this asteroid as X/D/S-type (Fig. 2). Moreover, the asteroid was classified as Xk-type based on a combination of the visible data in this study and the infrared data of the SMASS database.

4.1.57 2005 JU$_{108}$
Asteroid 2005 JU$_{108}$ is a member of the Amor group and has a delta-$v$ of 8.436 km s$^{-1}$. This asteroid has been classified as C-type (Carry et al. 2016). Lightcurve observations for 2005 JU$_{108}$ were performed during its apparition in August 2015, and a rotational period of 5.34 hr was obtained (Fig. 1).

4.1.58 2005 TF
Asteroid 2005 TF is a member of the Amor group and has a delta-$v$ of 5.899 km s$^{-1}$. A rotational period of 2.8692 hr has been reported for this asteroid (Warner 2017a). 2005 TF was observed during its apparition in November and December 2005. The rotational period could not be obtained in this study because insufficient data were acquired for periodic analysis. Thus, the value of the rotational period was quoted from Warner (2017a) (Fig. 1). The spectrophotometric data in this study allowed classification of this asteroid as Q-type (Fig. 2). This asteroid was also classified as Sqw-type based on a combination of the visible data acquired in this study and the SMASS near-infrared data.

4.1.59 2006 GB
Asteroid 2006 GB has an Aten-type orbit with a delta-$v$ of 6.341 km s$^{-1}$. Photometric observation for 2006 GB was conducted during its apparition in April 2006. A rotational period of more than 2.5 hr was obtained (Fig. 1). The asteroid was classified as Q/X/S/D-type using the spectrophotometric data acquired in this study (Fig. 2).

4.1.60 2007 BB$_{50}$
Asteroid 2007 BB$_{50}$ with a delta-$v$ of 8.436 km s$^{-1}$ belongs to the Amor group. Colorimetric observation of 2007 BB$_{50}$ was performed during its apparition in February 2007. This asteroid was classified as S/D-type (Fig. 2).

4.1.61 2007 BJ$_{29}$
Asteroid 2007 BJ$_{29}$ is a member of the Apollo group and has a delta-$v$ of 9.970 km s$^{-1}$. Colorimetric observation for the asteroid was performed during its apparition in February 2007. The asteroid was classified as Q-type based on the visible data acquired in this study (Fig. 2).

4.1.62 2007 FK$_{1}$
Asteroid 2007 FK$_{1}$ belongs to the Amor group and has a delta-$v$ of 6.570 km s$^{-1}$. 2007 FK$_{1}$ was observed during its apparition in May 2007. The rotational period of the asteroid was determined as 17.11 hr from its lightcurve (Fig. 1).

4.1.63 2007 RV$_{9}$
Asteroid 2007 RV$_{9}$ with a delta-$v$ of 6.624 km s$^{-1}$ is assigned to the Apollo group. Colorimetric observations of 2007 RV$_{9}$ were conducted during its apparition in February 2008. The spectrophotometric data obtained in this study indicated an asteroid of Q/S-type (Fig. 2).

4.1.64 2007 TU$_{24}$
Asteroid 2007 TU$_{24}$, which has a delta-$v$ of 6.093 km s$^{-1}$, is a member of the Apollo group. Rotational periods of $\sim$26 hr are...
reported on the Pravec website\textsuperscript{10}. The SC/OC of the asteroid is 0.37 (Benner et al. 2008). Photometric data in the V and $R_C$ bands are reported in Betzler et al. (2008), and 2007 TU\textsubscript{24} was colorimetrically observed during its apparition in February 2008. The spectrophotometric data obtained in this study and those reported in Betzler et al. (2008) allowed classification of this asteroid as Q-type (Fig. 2).

\section*{4.1.65 2010 J\textsubscript{V}34}

Asteroid 2010 J\textsubscript{V}34 has an Apollo-type orbit with a delta-$v$ of 6.754 km s$^{-1}$. The geometric albedo of the asteroid is 0.17 (Mainzer et al. 2014). Photometric observations for 2010 J\textsubscript{V}34 were conducted during its apparition in May 2005. A rotational period of 2.783 hr was acquired (Fig. 1). The asteroid was classified as Q/C-type using spectrophotometric data in this study (Fig. 2). Taking the value of its albedo into consideration, this asteroid classification was preferred to be Q-type.

\section*{4.1.66 2010 T\textsubscript{C}55}

Asteroid 2010 T\textsubscript{C}55 is a member of the Amor group and has a delta-$v$ of 8.350 km s$^{-1}$. Previously, Statler et al. (2013) reported that 2010 T\textsubscript{C}55 has a rotational period of 2.446 hr. Colorimetric observations for the asteroid were performed during its apparition in November 2010. The colorimetric data acquired in this study allowed classification of this asteroid as A/S-type (Fig. 2).

\section*{4.1.67 2013 NJ}

Asteroid 2013 NJ, having a delta-$v$ of 4.908 km s$^{-1}$, belongs to the Apollo group. A rotational period of 2.02 hr has been reported (Thirouin et al. 2016). Spectroscopic observation for 2013 NJ was performed during its apparition in December 2013. Further, from the spectroscopic data obtained in this study, the asteroid was categorized as V/Q-type (Fig. 2). Moreover, based on a combination of the visible data obtained in this study and the near-infrared data of the SMASS database\textsuperscript{8}, the asteroid was classified as Q-type.

\section*{4.2 Asteroids other than NEAs}

The asteroid results given in this section are by-products of observations of the NEAs.

\subsection*{4.2.1 852 Wladilena}

Asteroid 852 Wladilena (1916 S27) is an inner main-belt asteroid. Harris et al. (1999) showed that this asteroid has a rotational period of 4.6133 hr. The Wladilena albedo is 0.28 (Usui et al. 2011). Colorimetric observations of this asteroid were performed during its apparition in December 2005. This asteroid was classified as S-type (Fig. 2).

\subsection*{4.2.2 7096 Napier}

Asteroid 7096 Napier (1992 VM) is a member of the group of Mars-crossing asteroids. Napier is reported to have a geometric albedo of 0.05 (Usui et al. 2011). This asteroid was observed during its apparition in February 2007. From the spectrophotometric data in this study, this asteroid was classified as C-type (Fig. 2).

\subsection*{4.2.3 11739 Baton Rouge}

Asteroid 11739 Baton Rouge (1998 SG\textsubscript{27}) is a member of the Hilda dynamical group. The albedo of this asteroid is 0.08 (Grav et al. 2012). Near-infrared colorimetric data of the asteroid are shown in Popescu et al. (2016). Based on the classification in Popescu et al. (2016), this asteroid is D/T-type (D-complex). Lightcurve observations of Baton Rouge were conducted during its apparition in December 2007, and a rotational period of 4.8 hr was obtained (Fig. 1).

\subsection*{4.2.4 19483 1998 HA\textsubscript{116}}

Asteroid 19483 1998 HA\textsubscript{116} is an inner main-belt asteroid. A rotational period of 2.6259 hr is reported for this asteroid on the Pravec webpage\textsuperscript{10}. A rotational period of 2.619 hr was acquired (Fig. 1). The result is consistent with those in the literature.

\subsection*{4.2.5 22104 2000 LN\textsubscript{19}}

Asteroid 2000 LN\textsubscript{19} is a middle main-belt asteroid, with an albedo of 0.13 (Masiero et al. 2011). Near-infrared colorimetric data of the asteroid are reported in Popescu et al. (2016). The spectrophotometric data acquired in this study allowed classification of this asteroid as X/C-complex (Fig. 2). Additionally, this asteroid was preferred to be X-type by considering both the albedo value and the near-infrared infrared data (Popescu et al. 2016).

\subsection*{4.2.6 2006 EX\textsubscript{52}}

Asteroid 2006 EX\textsubscript{52} has a Halley- or long-period comet-type orbit. Licandro et al. (2018) classified the asteroid as D-type. Colorimetric observations for 2006 EX\textsubscript{52} were conducted during its apparition in December 2006. The asteroid was classified as a D-type asteroid using spectrophotometric data in this study (Fig. 2).

\subsection*{4.2.7 2006 XQ\textsubscript{56}}

Asteroid 2006 XQ\textsubscript{56} belongs to the Cybele dynamical group. The asteroid albedo has been estimated to be 0.03 (Nugent et al. 2015). Colorimetric observations of 2006 XQ\textsubscript{56} were performed during its apparition in February 2007. From the colorimetric data in this study, the asteroid was categorized as D-type.
5 Discussion

The asteroid classification performed in this study was mainly conducted using $BVR_{C1}$ colorimetric data. Using the filter system, C-type asteroids and other types can be classified in cases of low-SN data. However, it is difficult to distinguish between S- and D-type asteroids (e.g., Bivoj: classified as S/D in this study; 1998 JH2: D in Carry et al. (2016) but S in Kuroda et al. (2014); 2000 HA$_{246}$: A/S/D in this study; 2003 SD$_{220}$: S/D and S in this study; 2004 TY$_{156}$: S/D and D in this study; 1996 XB$_{27}$: D in Carry et al. (2016) and S in this study). In the Tholen and Bus taxonomies, data in the wavelength range of approximately 0.8 to 1.0 $\mu$m are required in order to determine the presence or absence of S-type olivine and pyroxene characteristic absorption. Using data for the $I_C$ band only, there are cases in which absorption cannot be detected. In particular, it should be noted that there is a limit to classification in the case of low-SN data in colorimetric photometry.

It is known that there are few asteroids with periods shorter than 2.2 hr. A possible reason for this is that rubble-pile asteroids with periods faster than 2.2 hr break apart (Pravec & Harris 2000). Therefore, fast rotators with rotational rate exceeding 2.2 hr are considered to be monoliths. The fast rotators encountered in this study are all S-complex asteroids (1996 XB$_{27}$; 2011 BT$_{15}$; 2004 QI$_{17}$; 2013 NJ). 2004 QI$_{17}$ and 2013 NJ have spectra that have not been reddened, but 2011 BT$_{15}$ has a very reddish spectrum compared to Itokawa and Eros, which are expected to have ordinary chondritic materials (Trombka et al. 1997; Nakamura et al. 2011). Consequently, 2011 BT$_{15}$ may be made of a fragment of weathered stony-iron meteorite rather than weathered ordinary chondrite.

In this study, 1994 CC was classified as “indeterminate”. Reddy et al. (2011) has shown that this asteroid is an olivine-dominated NEA with known composition. Although an A-type asteroid is olivine rich, it is characterized by strong reddening. In contrast, 1994 CC is not weathered. The classification of this asteroid may have been deemed indeterminate because there are no non-weathered olivine rich asteroids in the Bus-DeMeo taxonomy. The spectrum of 1994 CC matches the spectra of brachinites, which are olivine-rich acondrites and shergottites, according to the Modeling for Asteroids (M4AST) tool$^{11}$ (Popescu, Birlan, & Nedelcu 2012). Ultimately, 1994 CC was found to be an olivine-dominated object that had not undergone space weathering. The surface of Itokawa is weathered, but the surface age is reported to be of the order of thousands of years (Sasaki & Hiroi 2015; Keller, Berger, & Christofferse 2015; Harries et al. 2016). Hence, it is presumed that the surface exposure age of 1994 CC is less than thousands of years.

2013 NJ, which is a Q-type asteroid, is characteristic in that the absorption width of 1 $\mu$m extends to the shorter wavelength side. According to the M4AST tool$^{11}$, Almahata Sitta is a meteorite with a spectral pattern corresponding to 2013 NJ. Almahata Sitta mainly consists of olivine and pyroxene, which is a kind of anomalous polymict ureilite. Also, its spectrum is similar to the spectrum of Appleby Bridge, which is LL6 chondrite from the Reflectance Experiment Laboratory (RELAB) database. Like 1994 CC, 2013 NJ has a tendency not to exhibit space weathering. The surface exposure age of the asteroid may be estimated to be less than thousands of years.

Evans & Tabachnik (2002) showed that the candidates for long-lived asteroids in the near-Earth region are 1999 YB (S-type), 2001 SW$_{169}$ (Sw-type), and 1996 XB$_{27}$ (S-type), in addition to 10302 1989 ML (E-type) (Mueller, Harris, & Fitzsimmons 2007), 52381 1993 HA (D-type) (Penna et al. 2017b), 138911 2001 AE$_{2}$ (S-type) (Thomas et al. 2014), and 2000 AE$_{205}$ (S-type) (Binzel et al. 2001a). Previously, Rossi, Marzari, & Scheeres (2009) demonstrated via calculation that the NEA rotation distribution is dispersed by the Yarkovsky-O’Keefe-Radzievskii-Paddack (YORP) effect. The asteroid rotation periods in this region are also dispersed (2001 SW$_{169}$: 69.97 h; 2001 AE$_{2}$: 15.88 h (Warner 2018); 1989 ML: 19 h (Abe, Sato, & Araki 2000); 1999 YB: 9.39 h; 1993 HA: 4.107 h (Penna et al. 2017b); 1996 XB$_{27}$: 1.195 h). Bottke et al. (2007) has noted that these asteroids may be temporarily trapped in this region. It has been inferred that asteroids that remain longer in this area are easier to spin up and down, because they experience more YORP effects. As they have extreme rotation periods, 1996 XB$_{27}$ and 2001 SW$_{169}$ are likely to be long-lived asteroids. The YORP effect depends strongly on the pole orientation. If they are long-lived they may be driven to the stable obliquity states which could be tested.

The spectral distributions of asteroids having both low delta-$v$ of less than 6 km s$^{-1}$ and absolute magnitudes not exceeding 21, while being reachable by the Hayabusa2 spacecraft, were extracted in this work. For this purpose, the classification catalog created in this study and those of the following works were used: Binzel et al. (2001a); Binzel et al. (2004a); Binzel et al. (2004b); Carry et al. (2016); Christou et al. (2012); Clark et al. (2011); Dandy, Fitzsimmons, & Collarder-Brown (2003); de León et al. (2010); DeMeo, Binzel, & Lockhart (2014); Hasegawa et al. (2017); Hicks et al. (2012); Ieva et al. (2018); Kuroda et al. (2014); Lazzarin et al. (2005); Lin et al. (2018); Moskovitz et al. (2013); Perna et al. (2014); Perna et al. (2016); Perna et al. (2018); Tholen (1984); Thomas et al. (2014); Xu et al. (1995). The spectral classification procedure provided a total of 91 asteroids, composed of 11 C-complexes, 60 S-complexes, and 20 others (11 C-complex, 6 D-complex, and 3 V-type). Number of the S-complex, C-complex, and other asteroid were found to be 66, 12, and 22, respectively. The results are consistent with those of Kuroda et al. (2014), within the statistical error range, and imply that the NEAs with low delta-$v$ reachable by Hayabusa2 originate from the specific inner main-
belt region, which consists of a $\nu_6$ secular resonance vicinity, a 3:1 mean-motion resonance vicinity, and an intermediate-source Mars-crossing region. In particular, the NEAs appear to have been supplied through the $\nu_6$ resonance. This is supported by Bottke et al. (2002).

Detailed analysis of the Hayabusa2-reachable asteroids classified as C- and S-complexes revealed that there are six B-types and five C-types among the C-complexes and 33 Q-types among the S-complexes, including Sq-types, 17 S-types, and 10 others. The number of B-types is approximately one tenth that of the C-types (based on Hasegawa et al. 2017), and the number of Q-types is less than five percent the number of S-types (Lin et al. 2015) for the main-belt asteroids. Obviously, the distributions of the Q/S ratio and B/C ratio of the main belt region differ among asteroids with low delta-$\nu$. In accordance with this result, the spectrum of an asteroid in the near-Earth region turns bluish. It is believed that the spectrum changes from a reddish (S-type) spectrum to bluish (Q-type) as the surface layer is refreshed through various mechanisms (e.g., Binzel et al. 2010; Polishook et al. 2014; Delbo et al. 2014). However, the surface-layer refreshing mechanism cannot explain the change of B/C-type, as the spectra of aqueously altered carbonaceous chondrites have been found to be bluish under weathering in experiment (Matsuoka et al. 2015; Lantz et al. 2017).

A large range of thermal inertia values is observed within the similar size ranges between 10 and 100 km in diameter, and this result implies that asteroids with sizes exceeding 10 km are covered in fine and mature particles (Hanus et al. 2018). In addition, NEAs not covered with fine regoliths were found. By combining the maximum polarization degree and the geometric albedo, Ishiguro et al. (2017) and Ito et al. (2018) showed the existence of particles with diameters exceeding several hundreds of micrometers on asteroid surfaces. Binzel et al. (2015) argued that the redness and blueness of the spectrum of asteroid 101955 Bennu indicate finer and coarser grain sizes, respectively, based on laboratory measurements. From observation with the UH88 Telescope, Ryugu was classified as C-type; however, this asteroid was classified as B-type based on LOT and Steward observations. It was also shown that 162173 Ryugu has B- and C-type spectra on the surface (de León et al. 2018). In addition, some asteroids (Hephaistos; Itokawa; 1989 UQ; 2001 FC7; 2001 WC47; 2001 SN203; 2007 PA8) were seen to have varying spectra. In fact, it has been confirmed that the grain size of the 25143 Itokawa surface differs (Fujiwara et al. 2006). This indicates that these objects have surface variability. In particular, the spectra of 2001 FC7, 2001 SN203, and 2007 PA8 are both blue and red. Similarly to Bennu, these spectra imply that these asteroids have separate surface regions dominated by finer and coarser grain materials or boulders. Existence of coarser grain material on the surface of NEAs may explain the B/C-type ratio of NEAs.

On the other hands, the Polana-Eulalia family of the inner asteroid belt, which has low eccentricity and phase angle, has an almost equal proportion of B- and C-type asteroids (de León et al. 2018). Previously, Walsh et al. (2013) suggested that the major contributors of primitive NEAs could be the Eulalia and new Polana family. It is also possible that most of the C-complex NEAs accessible by Hayabusa2 are from this family.

### 6 Conclusions

Observations of 74 NEAs have elucidated the physical characteristics of low delta-$\nu$ bodies for sample return missions such as Hayabusa2.

- Among the asteroids observed in this study, the C-type asteroids reachable by Hayabusa2 are 153591 2001 SN$_{263}$ and 341843 2008 EV$_{31}$.
- In this study, it was found that visible colorimetric observations such as the $BVR_{C}I_{C}$ filter system are not very suitable for taxonomic classification, especially for classification of D- and S-type asteroids.
- The B/C ratio of the near-asteroids is equal to approximately one and differs from that of the asteroids in the main belt. There are two plausible reasons for this difference. One is related to the particle size of the regoliths on the asteroid surfaces, and the other is that the asteroids are reflected to the composition of the family from which the asteroid originated.

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