Broadband Photometry of the Potentially Hazardous Asteroid (153958) 2002 AM31: A Binary Near-Earth Asteroid

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Abstract

The near-Earth asteroid 153958 (2002 AM31) was discovered on January 14, 2002 by the LINEAR NEO survey (MPEC 2002-A102) in New Mexico. The object passed within 0.035 AU of the Earth on July 22 2012 and has been identified as a Potentially Hazardous Asteroid (PHA) by the IAU Minor Planet Center. We were motivated by the PHA's favorable 2012 apparition and obtained 6 nights of time-resolved Bessel BVRI photometry and 5 nights of Bessel R photometry at the JPL Table Mountain Observatory (TMO) 0.6-m telescope. We generated a solar phase curve that was used to fit a standard *H-G* model ($H_R = 18.43$, *G*=0.61). The derived *G* value was found to indicate a high optical albedo and an E-type classification. However, our observations yielded that the object's averaged broad-band colors indices ($B-R = 0.217 \pm 0.018$ mag; $V-R = 0.066 \pm 0.010$ mag, $R-I = 0.001 \pm 0.110$ mag) were most compatible with an S-type spectral classification (Bus taxonomy). This association obtained through a comparison with the 1341 asteroid spectra collected by SMASS 2 survey (Bus & Binzel 2002) and was best matched by the S-type asteroid 485 Genua. If we adopt a diameter of 0.34 km obtained by Arecibo radar imaging, then we estimate geometric albedo $p = 0.61$. Following this, we determined an Absolute V Magnitude $H = 18.50 \pm 0.02$ mag which was significantly fainter than the *H*=15.08 listed in the JPL HORIZONS database. The dispersion in the phased lightcurve suggested that 2002 AM31 was a binary system, with variations in observed flux caused by an unresolved, tidally locked secondary companion. The TMO Photometry was fitted a 2-period lightcurve model as described by Pravec et al (2000) and revealed the presence of the primary and secondary rotation periods: $P_1 = 3.206 \pm 0.004$ and $P_2 = 13.35 \pm 0.08$, respectively.

Introduction

In 1901, Andre suggested that the observed variability in the brightness of the asteroid Eros 433 may be due to the mutual eclipses of two bodies, revolving around the mutual center of mass (Merline *et al*. 2002). Andre came to this conclusion after discovering the similarity of the light curves of Eros and Lyrae. Thus, exactly 100 years after the discovery by Giuseppe Piazzi of the first asteroid (1) Ceres, the existence of satellites of some asteroids was suggested.

Although in those days, there was no direct evidence of the existence of binary asteroids, a lot of circumstantial evidence of the existence of such objects led to the idea of a large number of binary asteroids in the Solar System. Scientists also questioned the percentage ration of single and binary asteroids. The answer to that problem was closely related to the origin of binary asteroids and the stability of their motion.

Closely spaced pairs of craters of the same age on the surface of planets and satellites, including Earth, served as another evidence of the existence of binary systems. Studies have shown that it was unlikely that they were a result of a fracture of a single body just before falling due to the influence of the tidal forces and atmospheric drag. The formation of double craters could certainly be attributed to the collision of a double body with the planet. It was estimated that approximately 15% of Earth-crossing asteroids could be binaries (Bottke and Melosh, 1996).

In the 1960-70s, the research problems of double asteroids attracted a lot of attention. Such an active interest arose due to the development of modern astronomical techniques, the discovery of a large number of asteroids, and their numerous photometric observations. The main tool for finding binary asteroids in those years was the study of their light curves. The assumptions about the duality of some asteroids were made taking into account the peculiarities of their light curves, which could be explained by the presence of an asteroid's satellite. For example, the complex nature of the light curves of 24 Themis, 29 Amphitrite, and 51 Nemausa, according to the authors, points to their possible duality (Flandern *et al.*, 1979).

Finally, the idea of asteroids as single bodies deteriorated after a revolutionary discovery of a satellite of the asteroid 243 Ida by Galileo spacecraft. Since that time, the number of known binaries has risen dramatically (Merline *et al.*, 2002).

Understanding the origin and dynamics of binary and multiple asteroids as such is an important scientific task. The discovery of multiple asteroid systems allowed scientists to take a fresh look at questions regarding the origin and formation of the Solar System. Much remains unclear in the question of origin and evolution of small bodies in the Solar System. The study of multiple asteroids of different groups, along with their physical properties and dynamics, will shed light on many related issues.

Detection

Binary asteroids can be detected with adaptive optics observations, with radar Doppler imaging, or with the help of satellites. Nowadays, one of the most promising methods of detection of binary NEAs, and especially Main Belt binary systems, is a study of their light curves. Brightness fluctuations of an asteroid are caused by a large number of factors, such as rotation of a non-spherical body, inhomogeneous surface albedo, presence of mutual eclipses, shadowing in the system of two bodies, etc. Typically, the light curve of an asteroid, which is used to determine the duality of the asteroid, consists of two light oscillation periods. The short period is due to the rotation of the non-spherical primary component, the long period is the composed light properties that can be explained by mutual events (occultation/eclipses).

As described by Merline *et al*. (2002), there are certain challenges connected with light curve observations of binary systems. Certain orbital properties, such as primaries rotating at a different rate than the secondaries and favorable geometric conditions, when Sun and Earth are close to the mutual orbital plane of the binary system, play the key role in detection of binary systems via light curve observations. Also, in order to determine a two-period light curve, the system must have multiple eclipses/occultation. In addition, the secondaries must be approximately ~20% of the binaries. This method favors near-Earth asteroids (NEAs), where most of the systems remain asynchronous for a long period of time after their formation.

Data obtained via photometric observations of an asynchronous binary, reduced to unit Heliocentric and Geocentric distances and to a zero phase angle, consist of two or more periodic components co-added linearly into a combined light curve. It can be represented as a linear addition of two Fourier series:

$$F(t) = F_1(t) + F_2(t) \qquad (1)$$

$$F(t) = \bar{C}_0 + \sum_{k=1}^{m} [C_{1k} \cos \frac{2\pi k}{P_1}(t - t_0) + S_{1k} \sin \frac{2\pi k}{P_1}(t - t_0)]$$
$$+ \sum_{k=1}^{m} [C_{2k} \cos \frac{2\pi k}{P_2}(t - t_0) + S_{2k} \sin \frac{2\pi k}{P_2}(t - t_0)] \quad , \qquad (2)$$

where $F_j(t)$ is the flux at time t, $\bar{C}_0$ is the mean reduced light light flux, C_{ij} and S_{ij} are the Fourier coefficients, P_j are the periods of the components, t_0 is the zero-point time, *m* is the maximum significant order (Pravec et al. 2006). In theory, the short-period component is used to model the shape of the primary body. The long-period component shows the mutual events and the secondary rotation light curve. The produced periods are synodic due to the motion of the system with respect to Earth and Sun.

A LINEAR NEO survey done in New Mexico discovered the near-Earth asteroid 2002 AM31 on January 14, 2002. On July 22, 2012 (153958) 2002 AM31 made a close approach to the Earth at a distance of 0.035 AU. The asteroid has been designated as a Potentially Hazardous Asteroid by the Minor Planet Center. We present a photometric analysis of our observations and suggest that 2002 AM31 is a binary system.

Methods

Observations of the Apollo asteroid 2002 AM31 were performed using the telescope of the TMO, Table Mountain Observatory (code: 673): the 0.6 meter f/16 Ritchey-Chretien reflector equipped with a thermoelectrically cooled 2K SI CCD camera. The observational circumstances are summarized in Table I. The columns give the date of the observation to the nearest hundredth of a day referred to the mid-time of each observing night, target apparent heliocentric distance (*r*) and geocentric distance (Δ) in AU, solar phase angle in degrees and visual magnitude as computed by the JPL HORIZONS ephemeris service. Absolute calibrations were done in the Bessel BVRI system using photometric standard stars from Landolt (1992) in order to calculate atmospheric extinction and zero-point offset. The science images were bias and flat-field corrected before they were used to measure the magnitudes. IRAF, Image Reduction and Analysis Facility, was used for the aperture photometric analysis. On the nights with good photometric quality observations were carried out through Bessel

BVRI filters to determine the mean values of the color indices for the entire surface of the asteroid. The obtained results were compared to the 1341 catalogued asteroid spectra in the SMASS II, Small Main Belt Asteroid Spectroscopic Survey, the database introduced by Shelte J. Bus and Richard Binzel, as well as the ECAS, Eight Color Asteroid Survey, proposed by David J. Tholen (Bus & Binzel 2002). Since we observed 2002 AM31 at a wide range of solar phase angles, we could generate its phase curve. As described in Bowell et al. (1989) the H-G phase relation was used to describe the reduced magnitude *H(a)* as the function of a changing solar phase angle:

$$H(a)=H-2.5\log(1-G)\Phi_1(a)+G\Phi_2(a) \quad , \qquad (3)$$

where H is the absolute magnitude at a zero phase angle, Φ_1 , Φ_2 are the functions of the phase angle, G is a "slope parameter" that describes the shape of the phase curve. The solar phase curve was used to determine the mean absolute magnitude of the object and the geometrical albedo of the asteroid. The lightcurves have been plotted relative to the Bessel R band. The time of observations was corrected by light-time to correct for the varying relative distance between the observer and a target. The combined lightcurve was separated by fitting a two-period Fourier series.

Results

We observed asteroid 2002 AM31 at TMO and obtained six nights of Bessel BVRI broadband photometry and five nights of Bessel R-band photometry. From our data, we obtained mean colors: $B-R=0.217\pm0.018$ mag $V-R=0.066\pm0.010$ mag, $R-I=0.001\pm0.11$ mag. Our colors match consistently with S type Spectral Classification (Bus Taxonomy), as summarized in Table 2. Using the H-G model to fit the solar phase curve we determined it's absolute magnitude (H_R) to be 18.43 mag, and the slope parameter G=0.61, as shown in Figure 1. Our derived G value is indicative of a high optical albedo and E type spectral classification. An Absolute Magnitude $H_v=18.50\pm0.02$ mag, significantly fainter than the $H_V=15.08$ mag reported in the JPL Small-Body Database Browser. If we adopt a diameter of 0.34 km obtained by the Arecibo imaging results from July 12, 2012 we estimate an albedo ρ=0.61 (Lance & Benner, 2012). The dispersion in the phased lightcurve suggested that AM31 was a binary system, with variations in observed flux caused by an unresolved, tidally locked secondary companion. The rotational period of the primary body is $P_1=3.206\pm0.004$ hr. The long-period component showed both mutual events and a rotational period of the secondary. We estimated $P_2=13.35\pm0.08$ hr. Plots for each are included in Figure 2.

Future Research

The observational study of asteroid 2002 AM31 revealed that it is a binary system. The 3D shape analysis will be subject of a future paper. Additional radar imaging of 2002 AM31 was planned at Goldstone and Arecibo radar observatories. The next opportunity to observe 2002 AM31 will be on July 2032 when the asteroid will approach the Earth at a similar distance.

Tables and Figures

Table 1: Observational circumstances.

UT DATE	r [AU]	delta [AU]	Phase [deg]	V [mag]	Filters	OBSERVERS
2012 06 16.23	1.221	0.220	19.4	16.3	R	Teague, Strojia
2012 06 17.22	1.215	0.214	19.6	16.2	BVRI	Dombroski,Davtyan
2012 06 19.24	1.202	0.200	20.1	16.1	BVRI	Davtyan, Dombroski
2012 06 21.27	1.189	0.187	20.9	15.9	BVRI	Dombroski, Davtyan
2012 06 23.30	1.176	0.174	21.9	15.8	R	Hicks
2012 06 24.27	1.170	0.168	22.4	15.7	R	Hicks
2012 07 06.26	1.098	0.099	33.4	14.8	R	Davtyan, Dombroski
2012 07 07.40	1.092	0.093	35.0	14.7	R	Hicks
2012 07 08.26	1.087	0.089	36.3	14.6	BVRI	Dombroski, Davtyan
2012 07 20.40	1.024	0.038	76.4	13.8	BVRI	Strojia, Teague
2012 07 21.37	1.020	0.036	82.9	13.9	BVRI	Teague, Strojia

Table 2: Best-fit SMASS II spectral analogs.

MISFIT	OBJECT NAME	TAXONOMIC (THOLEN)	CLASS (BUS)
1.173	907 Rhoda	C	Xk
1.186	485 Genua		S
1.376	471 Papagena	S	S
1.630	196 Philomela	S	S
1.665	116 Sirona	S	S
1.769	742 Edisona	S	K

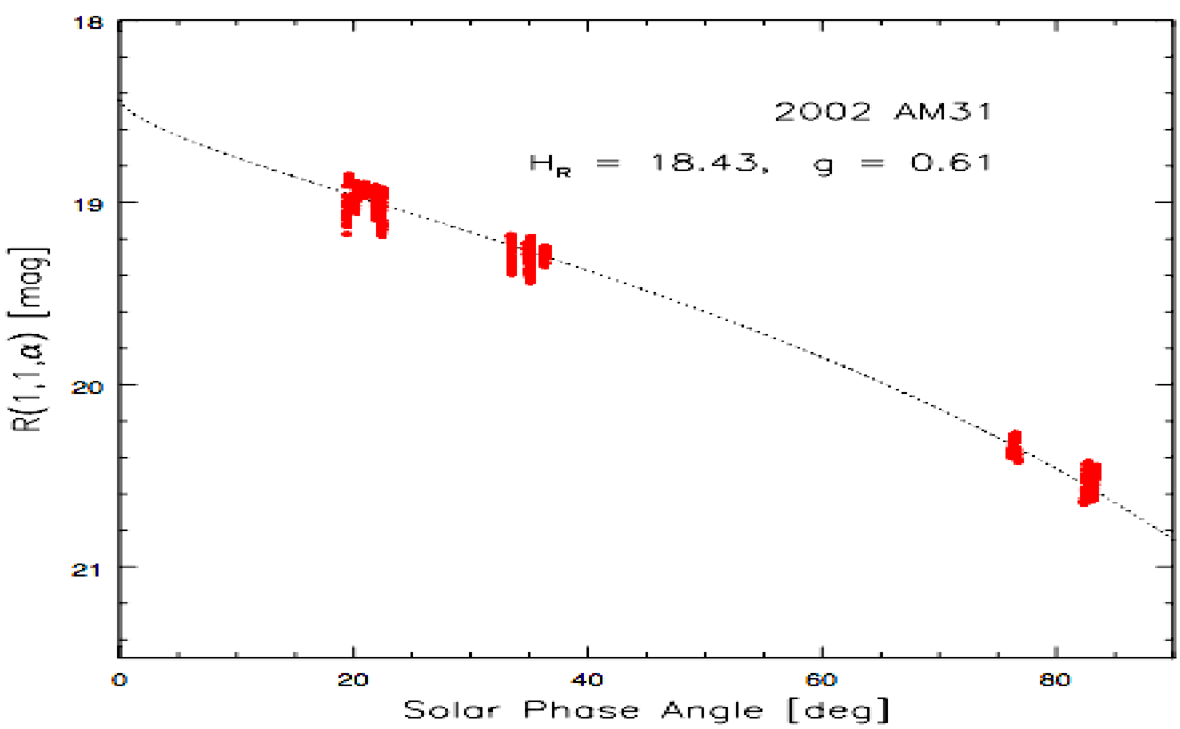

Figure 1: Solar phase curve of (153958) 2002 AM31

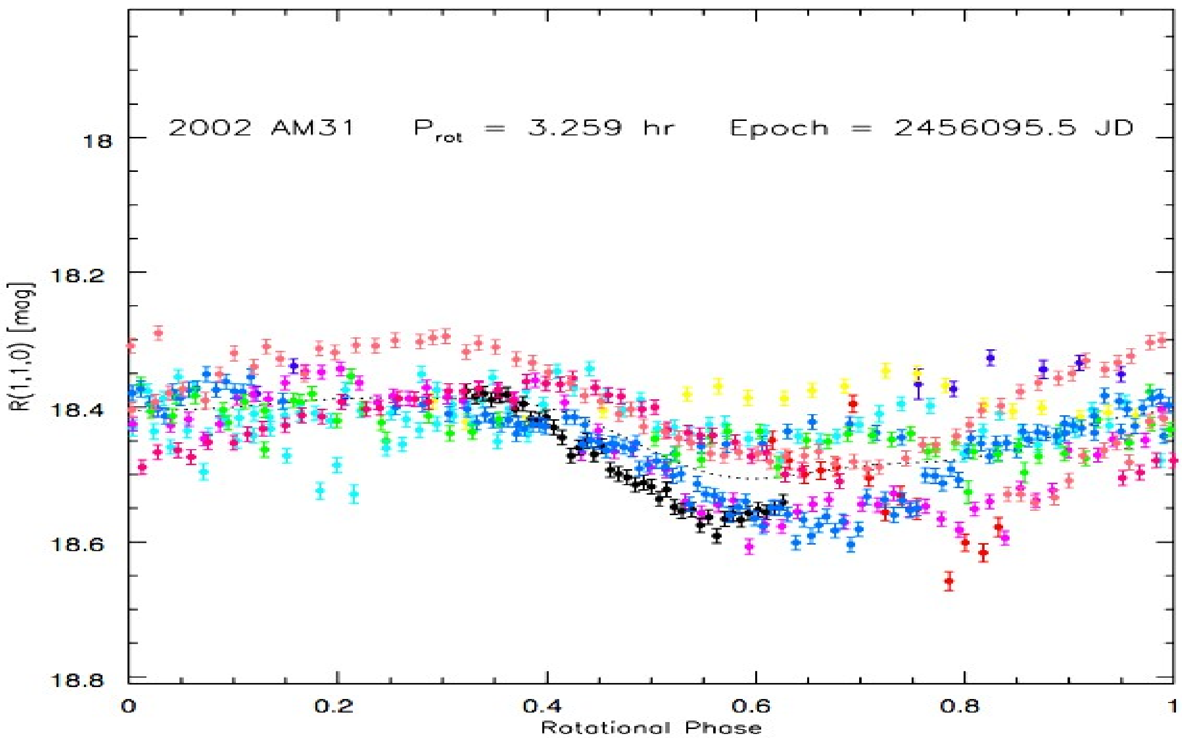

Figure 2: Phased lightcurve of (153958) 2002 AM31

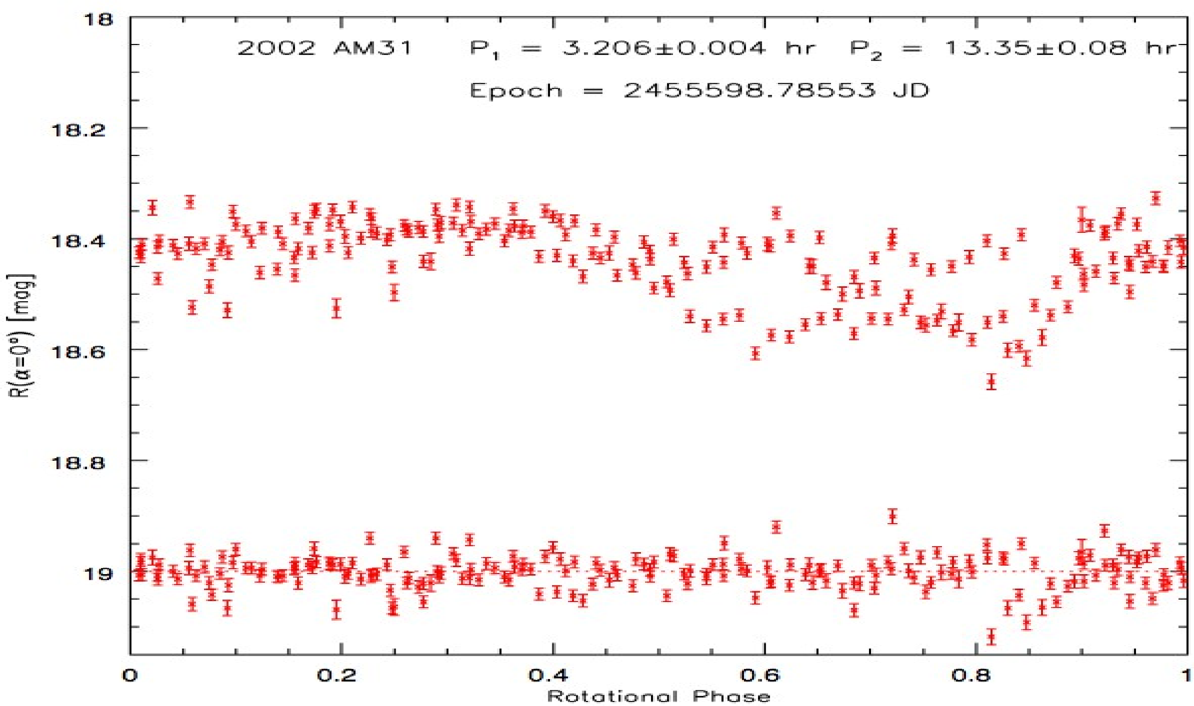

Figure 3: Two-period lightcurve of (153958) 2002 AM31

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