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Radar observations and characterization of a selection of potentially hazardous asteroids

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Abstract

We present physical characterizations of a selection of potentially hazardous asteroids (PHAs) observed using the Arecibo planetary radar systems in 2018-2019. For example, in 2018, the Arecibo planetary radar program detected 70 near-Earth asteroids (NEAs), including 25 PHAs, and obtained radar images for 18 of them. By May 1st, 2019, the program had observed 31 NEAs including 8 PHAs. Some of the highlighted targets include 66391 (1999 KW4), 2017 YE5 and 163899 (2003 SD220), but in this paper we focus on targets that have received less exposure despite good-quality data. From 2018, we include 2017 VR12, 2015 DP155, 398188 Agni, 144332 (2004 DV24), 2016 AZ8, and 523788 (2015 FP118). In 2019, we have observed PHA 522684 (2016 JP) and intend to add to the list 68950 (2002 QF15), 90403 (2003 YE45), 454094 (2013 BZ45), 141593 (2002 HK12), and 153814 (2001 WN5). We will report observed sizes, satellites (if detected), spin rates, polarization measurements that are indicative of the near-surface structure, and effective electric permittivities when the range resolution of images allows.

1. Introduction

The U.S. Congress has mandated NASA to search, track, and characterize all near-Earth asteroids that are larger than 140 m across. Arecibo Observatory's planetary radar program is part of this effort, observing annually about 100 near-Earth asteroids, of which 20-40 per year are PHAs. Planetary radar observations provide post-discovery high-precision orbital refinement and physical characterization. Arecibo's S-band (2380 MHz, 12.6 cm) planetary radar system is the most powerful and active planetary radar in the world with up to 1 MW of output power and a telescope aperture with a diameter of 305 m.

2. Methods

In a typical radar observation, we transmit a circularly polarized signal, and receive it in both the opposite circular (OC) and the same circular (SC) polarization. We measure the Doppler broadening of the signal; the Doppler frequency bandwidth depends on the target's apparent spin rate (P), apparent diameter (D), the latitude of the nearest edge (δ) at the time of the observation, and the wavelength of the transmitted signal (λ)

$$B = \frac{4\pi D \cos(\delta)}{\lambda P} \quad (1)$$

We can also use phase-coded signals that allow us to display the echo in a delay-Doppler space, where each pixel corresponds to a specific signal round-trip delay and Doppler shift. Despite a north-south ambiguity, the visible extent of the target sets strong constraints on the size of the target, and can allow the detection of potential satellites and features that cannot be detected by any other ground-based method. We will also add lightcurve data where applicable to add information on the spin rate and size estimate of the target. Estimating the sizes of asteroids from radar images can help us derive the visual albedos that are needed for estimating asteroid sizes from their absolute magnitude.

The received power (P_{rx}) can be used to measure the radar cross section (σ) of the target:

$$\sigma = \frac{(4\pi)^3 R^4 P_{rx}}{\lambda^2 G_A^2 P_{tx}}, \quad (2)$$

where R is the distance to the target, P_{tx} is the transmitted power, and G_A is the antenna gain [1]. The radar cross section in a specific polarization normalized with the projected area (A_{proj}) of the target at the time of the observation gives the radar albedo:

$$\hat{\sigma} = \frac{\sigma}{A_{\mathrm{proj}}}. \quad (3)$$

This parameter is descriptive of the average reflectivity of a unit area of the asteroid's surface, and can be used

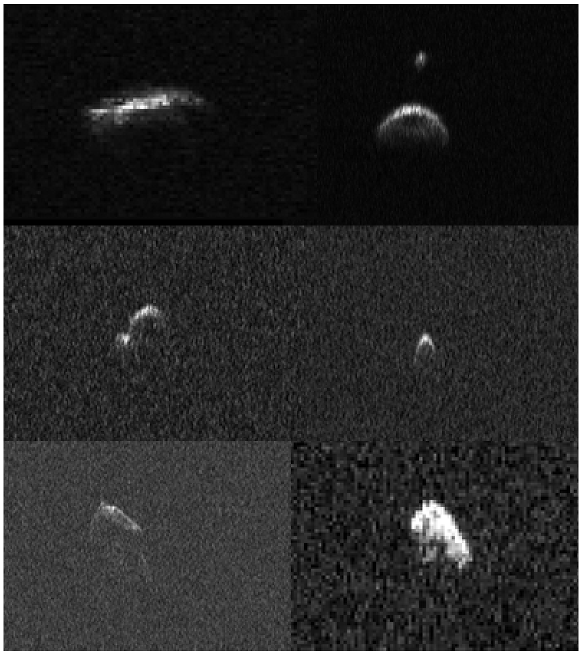

Figure 1: Delay-Doppler images of six near-Earth asteroids included in this paper. On the left, from the top down: 2015 DP155, 398188 Agni, and 144332 (2004 DV24). On the right, from the top down: 2016 AZ8, 523788 (2015 FP118), and 2017 VR12. The vertical (range) resolution is 7.5 m/pixel. Image courtesy: Arecibo Observatory/NASA/NSF.

to find clues on the mineralogy and structure of the surface [2]. The ratio of the radar cross sections, or the circular polarization ratio $\mu_C = \sigma_{SC}/\sigma_{OC}$, can be used as a first-order estimate of the surface roughness of the asteroid [1].

3. Targets

Figure 1 shows a compilation of delay-Doppler images of six of the included targets: 2015 DP155, 398188 Agni, 144332 (2004 DV24), 2016 AZ8, 523788 (2015 FP118), and 2017 VR12. The vertical resolutions are 7.5 m/pixel in all the images. In addition, we will include 522684 (2016 JP), 68950 (2002 QF15), 90403 (2003 YE45), 454094 (2013 BZ45), 141593 (2002 HK12), and 153814 (2001 WN5) if observed successfully.

4. Results

For the targets observed by April 2019, we find a diverse set of PHAs that are binaries, such as 2016 AZ8, contact binaries, such as 398188 Agni, rounded with a possible equatorial ridge, such as 2016 JP, or irregular, possibly rubble pile asteroids such as 2017 VR12. For example, as reported in Virkki et al. [3], 2016 AZ8 has a diameter 420 $\pm$ 60 m and a secondary that is about 180 $\pm$ 30 m long. This implies a visual albedo of 4 $\pm$ 1 % when the absolute magnitude is 21.0. The system was observed near maximum range separation along the line of sight at 420 $\pm$ 45 m, which is a lower bound on the mutual-orbit scale due to possible projection effects. Echo bandwidths place upper bounds on the rotation periods of the primary and secondary of 7 and 40 hours, also subject to projection effects.

The taxonomic type is not known for most of the targets included here but all of their measured circular polarization ratios are comparable to typical values observed for S- and C-complex asteroids (from 0.1 to 0.3). A very high observed value of μ_C could be indicative of an E-type asteroid [4].

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