Arecibo and Goldstone radar evidence for boulders on near-Earth asteroids

L. Benner[1], M. Nolan[2], M. Brozovic[1], P. Taylor[2], M. Busch[3], E. Howell[2], J. Margot[4], J. Giorgini[1], A. Springmann[2], S. Naidu[4], C. Magri[5], and M. Shepard[6]

[1]Jet Propulsion Laboratory, California Institute of Technology
[2]NAIC-Arecibo Observatory
[3]SETI Institute
[4]University of California, Los Angeles
[5]University of Maine at Farmington
[6]Bloomsburg University

Delay-Doppler radar observations of numerous near-Earth asteroids (NEAs) since 1999 have revealed many small groups of radar-bright pixels in some of the highest signal-to-noise ratio (SNR) images obtained at Arecibo and Goldstone. Many of the spots remain observable as the asteroids rotate through tens of degrees. The bright pixels are not receiver noise, self noise, or artifacts, but are real features. Clusters of bright pixels appear primarily in high-resolution radar images with resolutions of 4–19 m/pixel and usually span a few rows and columns or less, indicating that these are surface features a few tens of meters in extent or smaller. Many clusters appear near the trailing edges of the images and are adjacent to and up range from radar shadows, implying the presence of small-scale topography. To date, small groups of bright pixels have been seen on at least ten NEAs observed at high resolution, such as (in chronological order of radar detection) (101955) Bennu, (33342) 1998 WT_{24}, (100085) 1992 UY_4, (374851) 2006 VV_2, (341843) 2008 EV_5, (136849) 1998 CS_1, (308635) 2005 YU_{55}, (214869) 2007 PA_8, (4179) Toutatis, and 2014 BR_{57}. Of these objects, Toutatis is the largest, with a long axis of 4.6 km, and 2004 BR_{57} is the smallest, with a diameter of about 80 m. These objects also span a considerable dynamic range of shapes, spin states, and spectral classes.

What causes the radar-bright pixels? Radar albedo correlates positively with increasing near-surface density, so relatively bright echoes can result from scattering off surface and near-surface features with higher densities than their surroundings. Bright echoes can also be generated by specular reflections from relatively flat surfaces oriented nearly perpendicular to the radar line-of-sight. Many of these features are located near the radar terminator where the radar line-of-sight is at grazing incidence angles, which tends to highlight small-scale topography. We suggest that a plausible interpretation for these particular observations is that the bright pixels are echoes from surface and near-surface boulders, which have been seen on each of the three near-Earth asteroids imaged by spacecraft: (433) Eros (NEAR-Shoemaker), (25143) Itokawa (Hayabusa), and (4179) Toutatis (Chang'e 2). These asteroids have also been imaged by radar, but the resolutions and/or signal-to-noise ratios were insufficient to reveal possible boulders. Bright spots were not evident in radar images of Toutatis obtained between 1992–2008, but following an upgrade in Goldstone's finest resolution from 19 to 4 m/pixel in 2010, a modest number of spots became visible in Goldstone images of Toutatis obtained in 2012. The prevalence of small radar bright spots on numerous NEAs establishes that features consistent with boulders can be detected in delay-Doppler radar images of particularly high-SNR targets and that these features are relatively common on near-Earth asteroid surfaces.