RADAR OBSERVATIONS OF NEAR-EARTH ASTEROIDS FROM ARECIBO AND GOLDSTONE. P. A. Taylor[1], J. E. Richardson[1], E. G. Rivera-Valentín[1], L. A. Rodriguez-Ford[1], L. F. Zambrano-Marin[1], M. C. Nolan[2], E. S. Howell[2], L. A. M. Benner[3], M. Brozovic[3], S. P. Naidu[3], J. S. Jao[3], C. G. Lee[3], J. D. Giorgini[3], M. W. Busch[4], S. E. Marshall[5], J. L. Margot[6], Adam H. Greenberg[6], F. D. Ghigo[7], M. K. Shepard[8], and J. T. Schmelz[1]; [1]Arecibo Observatory, Universities Space Research Association, HC 3 Box 53995, Arecibo, PR 00612 (*ptaylor@naic.edu*); [2]Lunar and Planetary Laboratory, University of Arizona; [3]Jet Propulsion Laboratory, California Institute of Technology; [4]SETI Institute; [5]Cornell University; [6]University of California, Los Angeles; [7]National Radio Astronomy Observatory; [8]Bloomsburg University.

Introduction: The Arecibo S-band (2.38 GHz, 12.6 cm, 1 MW) planetary radar system at the 305-m William E. Gordon Telescope in Puerto Rico and the Goldstone Solar System Radar complex (X band: 8.56 GHz, 3.5 cm, 450 kW on the DSS-14 70-m antenna; C band: 7.19 GHz, 4.2 cm, 80 kW on the DSS-13 34-m antenna) in California are the most active planetary radar facilities in the world. Radar observations are critical for identifying those objects that may present a hazard to Earth and providing detailed physical characterizations in terms of size, shape, spin, and surface-property (reflectivity, polarization, geologic features and sometimes composition and density) information. In fact, radar investigations of many near-Earth objects are roughly equivalent, in their science content, to space flyby missions, but at a cost orders of magnitude less.

Technical Capabilities: While Arecibo is more sensitive partly due to its sheer size, the Goldstone telescopes are more maneuverable and can achieve finer spatial resolution for objects that come close enough to Earth, as fine as 3.75 m (testing at 1.875 m is underway) compared to 7.5 m at Arecibo. Range-Doppler radar measurements provide line-of-sight positional astrometry, orthogonal and complementary to optical plane-of-sky astrometry, with precision as fine as $\sim$10 m in range and $\sim$1 mm/s in velocity with a fractional precision 100 to 1000 times finer than that of typical optical measurements. Radar astrometry routinely extends our ability to accurately predict the trajectories of asteroids for decades or centuries into the future, often preventing newly discovered objects from being lost. Two-dimensional range-Doppler images that resolve the target spatially along the line of sight and in frequency (velocity) space reveal its basic shape and surface features that, given sufficient orientational coverage, may be inverted to provide a full three-dimensional shape model and complete spin-state description. Collaborations with the 100-m Green Bank Telescope and elements of the Very Long Baseline Array maximize the scientific return on observing campaigns by providing additional sensitivity and resolution for imaging and constraining spin states, respectively.

Current Research: In 2015, Arecibo and Goldstone combined to detect 108 near-Earth asteroids (95 at Arecibo, 39 at Goldstone, and 26 with both facilities), one-third of which are designated as potentially hazardous to Earth. Additionally, about one in four asteroids detected are of interest to NASA as dynamically accessible for future missions, the so-called NHATS-compliant objects. Put in perspective, the 108 asteroids detected in 2015 were 15% of all asteroids detected with radar since 1968; 50% of all radar detections have occurred since 2012.

We will present a sampling of the asteroid zoo collected by radar over the past calendar year. The immense variety in the near-Earth asteroid population is clear, from the $\sim$2-meter 2015 TC_{25} that rotates in $\sim$2 minutes to the elongated, multi-kilometer (163899) 2003 SD_{220} that rotates once every $\sim$12 days. Shapes vary from spheroids, such as the pareidolia-inspired "skull" 2015 TB_{145}, to the unexpectedly irregular, epitomized by (436724) 2011 UW_{158}, reminiscent of an unshelled walnut. Binaries, such as (357439) 2004 BL_{86}, occur in about one in six near-Earth asteroids over 200 meters in diameter, while peanut-shaped bodies, such as (85989) 1999 JD_{6}, occur just as often.

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