Radar investigations of near-Earth asteroids at Arecibo and Goldstone

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Radar observations are a powerful technique to study near-Earth asteroids (NEAs). The Arecibo and Goldstone planetary radars can provide delay-Doppler images that can directly resolve surface features such as concavities, hills, ridges, and boulders. Goldstone's 3.75-m resolution capability is invaluable when attempting to image NEAs with diameters smaller than 50 m. To date, over 430 near-Earth asteroids and 136 main-belt asteroids have been observed with radar. 80 % of the radar-detected NEAs have been observed within the last 10 years. The radar detection rate in the last three years has tripled relative to the average in the previous decade due to an increase in funding and greater scheduling flexibility.

Currently, ∼400 observing hours per year at Goldstone and ∼600 observing hours per year at Arecibo are devoted to observing asteroids. We strive to observe all strong and moderately strong imaging targets, Yarkovsky drift candidates, NEOWISE targets, asteroids with very low perihelia that can be used to measure solar oblateness, and as many other detectable asteroids as resources allow. We also regularly attempt to observe any asteroid that is flagged by the Near-Earth Object Human Spaceflight Accessible Targets Study (NHATS) list (http://neo.jpl.nasa.gov/nhats/). To date, we have observed more than 60 NHATS objects at Arecibo and Goldstone.

In the past three years, ∼1/3 of the detected asteroids were targets of opportunity (TOOs), some of which we observed within 24 h from when the discoveries were announced. Many TOOs are small, rapidly moving objects that are detectable by radar only within few lunar distances. Radar astrometry is particularly important for these asteroids because they are too faint to be followed for long with optical telescopes. A radar-range measurement often secures their orbit for decades or centuries, where otherwise the object would be lost and require rediscovery. In one of the extreme cases, two delay and two Doppler measurements from Goldstone prevented a newly discovered potentially hazardous asteroid (PHA) 2014 CU_{13} from being lost. The measurements also extended its Earth-encounter predictability by 1000 years. Radar observations of objects that are closer than ∼4 lunar distances (∼10.3 seconds RTT, round-trip-time for signal) previously required coordination between two stations (one for transmit and one for receive) due to the short RTT and need to physically switch between transmit and receive configurations. However, the switching process has been accelerated and recent observations of 2013 XY_8 have shown that Goldstone can now conduct monostatic observations with RTTs of ∼5 seconds. This provides much stronger signal-to-noise ratios for very close targets.

With the rapidly growing number of radar detections, some population trends are emerging. The latest statistics show that the fraction of contact binaries has grown to ∼14 % and is now comparable to that of true binaries in the NEA population with diameters larger than 200 m. We are also starting to capture what may be the tail ends of certain sub-populations. For example, we have found two very small binary systems, 2003 SS_{84} and 2004 FG_{11}, that have primaries < 200 m in diameter; we have also found that 2005 AY_{28} and 2013 JR_{28} are contact binaries in the same size range. These objects are at the boundary between gravitationally bound "rubble piles" and strength-dominated, possibly monolithic objects. The NEAs are a very diverse population, in which we continue to discover unusual objects. It is difficult to anticipate what the future radar observations may uncover, but surprises are likely.