Arecibo and Goldstone Radar Imaging of Near-Earth Asteroids

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Radar is the most powerful astronomical technique for studying the physical properties of near-Earth objects (NEAs) and for refining their orbits.

Radar imaging can achieve resolutions as fine as several meters per pixel that can turn unresolved points in optical telescopes into detailed, geologic entities. The resolutions obtainable with delay-Doppler radar images can be surpassed only by spacecraft missions but at enormously greater cost. Delay-Doppler radar images reveal an object's size, shape, spin state, topography, and whether or not it is a binary or triple system. Radar can determine the masses of binary NEAs (using Kepler's 3rd law) and solitary NEAs (through detection of the Yarkovsky effect), and is sensitive to surface roughness, porosity, and metal abundance.

Radar echoes from NEAs have revealed both stony and metallic objects, featureless spheroids and shapes that are elongated and irregular, objects that must be monolithic pieces of rock and objects that must be unconsolidated rubble piles, small-scale morphology ranging from smoother than the lunar surface to rougher than the rockiest terrain on Earth, correlations between surface roughness and taxonomic class, objects with craters and linear structures, rotation periods ranging from a few minutes to several weeks, objects whose rotation periods are accelerating, non-principal axis spin states, contact binaries, and binary and triple systems. Radar has become the primary technique for the discovery of binary and triple NEAs, and has shown that contact binaries and binaries comprise at least 25% of the NEA population larger than 200 m in diameter. High-resolution radar imaging has revealed that pronounced equatorial ridges are common among rapidly rotating NEAs. Radar observations led to the first detection of the Yarkovsky and YORP effects.

Radar is invaluable for refining orbits of potentially hazardous NEAs. Range-Doppler measurements provide line-of-sight positional astrometry with precision finer than 10 m in range and 1 mm/s in velocity, and with a fractional precision typically 100 to 1000 times finer than with optical measurements. Radar astrometry obtained shortly after an asteroid's discovery adds decades or centuries to the interval over which we can predict close Earth approaches and dramatically refines collision probability estimates based on optical astrometry alone. For an object on an impact trajectory, simulations have shown that radar astrometry can provide an average of several years more advance notice of an impact than if radar observations were not available.

Sequences of radar images can be inverted to reconstruct an object's 3D shape and spin state, which provide clues to its geologic origin and evolution. Once a shape is available, it provides an opportunity for detailed investigations of the object's dynamical environment such as gravitational slopes and orbits close to the surface, which can constrain the distribution of regolith and reveal regions that must be bare rock, and reduce the risk and cost for planning spacecraft rendezvous and sample return missions.

Currently, 20-30 NEAs are being observed annually, yielding detailed images and with hundreds to thousands of pixels on each target. To date, 252 near-Earth asteroids and 13 comets have been detected with radar, and of these, about 50 are contact binaries or binaries. Shape models have been estimated for about 25 objects and data for dozens of other objects are available that are suitable for shape inversion.