RADAR RECONNAISSANCE OF NEAR-EARTH ASTEROIDS. L. A. M. Benner[1], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109 USA, lance.benner@jpl.nasa.gov.

Radar is a very powerful astronomical technique for characterizing near-Earth objects and for refining their orbits. The Arecibo and Goldstone radars can image near-Earth asteroids (NEAs) with resolutions as fine as four meters, which greatly exceeds the finest resolution routinely available from any ground- or space-based optical telescope. Radar images reveal an object's size, shape, spin state, and features on its surface such as craters, facets, ridges, and even large boulders. Among NEAs larger than 200 m in diameter, radar imaging has revealed that ~15% are double and triple systems, that ~10% are contact binaries, and that oblate shapes with pronounced equatorial ridges are relatively common. Radar can determine the masses of binary NEAs and, in some cases, the masses of solitary NEAs through the detection of the Yarkovsky effect. Multiple opportunities for radar imaging occur annually and yield images that are exceeded in resolution only by data from spacecraft encounters.

Radar echoes from NEAs have revealed stony and metallic objects, nearly featureless spheroids, shapes that are elongated and irregular, monolithic objects, unconsolidated rubble piles, rotation periods ranging from a few minutes to several weeks, objects whose rotation is accelerating, non-principal axis rotators, and surfaces that are extraordinarily rough.

Radar is invaluable for refining orbits of potentially hazardous NEAs. Range-Doppler measurements provide astrometry with precisions as fine as 4 m in range and 1 mm/s in velocity, with a fractional precision that is orders of magnitude finer than with optical measurements. Radar astrometry can prevent objects from being lost, add centuries to the interval over which we can predict close Earth approaches, and dramatically refine collision probability estimates based on optical astrometry alone.

A sequence of radar images can be inverted to estimate an asteroid's 3D shape and spin state. This constrains its formation and evolution and permits a number of important geophysical investigations into its dynamical environment, which can be very useful for spacecraft planning and navigation.

Radar observations have supported numerous asteroid and comet spacecraft missions such as *NEAR-Shoemaker* (253 Mathilde and 433 Eros), *Hayabusa* (25143 Itokawa), *Rosetta* (21 Lutetia), *EPOXI* (103P/Hartley 2), *Dawn* (4 Vesta and 1 Ceres), *OSIRIS-REx* (101955 1999 RQ36), *CONTOUR* (2P/Encke), and *Clementine* (1620 Geographos); and contributed to mission proposals such as *Marco Polo-R* (175706 1996 FG3), *Deep Interior* (3908 Nyx), *Galahad* (175706 1996 FG3), *BASiX* (65803 Didymos), *Amor* (153591 2001 SN263), and *MAX* (99942 Apophis). In addition, radar observations are planned in 2018 for comet 46P/Wirtanen, the target of the proposed *Comet Hopper* mission, and in 2013 for NEA 2002 GT, which is under consideration for a flyby by the *Deep Impact* spacecraft in 2020.

Several significant developments have occurred at Arecibo and Goldstone since the last Asteroids, Comets, and Meteors conference in 2008. In 2010 the National Aeronautics and Space Administration (NASA) began funding the planetary radar program at Arecibo and helped prevent the observatory from closing. Arecibo replaced its generators and klystrons and has resumed transmitting ~900 kW for the first time in several years. Goldstone underwent a major refurbishment in 2010 to extend its operational lifetime by 20 years. Goldstone's imaging resolution improved by a factor of five from 18.75 m to 3.75 m, which is twice as fine as the highest resolution at Arecibo. This provides the ability to see considerably more surface detail, to spatially resolve NEAs as small as ~20 m, and it greatly improves the precision of radar ranging astrometry, which has significant ramifications for long-term orbit prediction of NEAs with diameters less than ~100 m. Significantly more time is being allocated at Arecibo and Goldstone for near-Earth objects, and as a result, the number of NEAs observed by radar is on pace to more than triple in 2012 relative to the average of the previous ten years.