RADAR DISCOVERY AND CHARACTERIZATION OF BINARY ASTEROIDS

Jean-Luc Margot[(1)], M. C. Nolan[(2)], L. A. M. Benner[(3)], S. J. Ostro[(3)], R. F. Jurgens[(3)], J. D. Giorgini[(3)], M. A. Slade[(3)], E. S. Howell[(2)], D. B. Campbell[(4)]

[(1)]California Institute of Technology, MC 150-21, Pasadena, CA 91125, USA (margot@gps.caltech.edu); [(2)]National Astronomy and Ionosphere Center, HC3 Box 53995, Arecibo PR 00612, Puerto Rico; [(3)]Jet Propulsion Laboratory/Caltech, 4800 Oak Grove Drive, Pasadena, CA 91109, USA; [(4)]Department of Astronomy, Cornell University, Ithaca NY 14853

The radar instruments at Arecibo and Goldstone recently provided the first confirmed discoveries of binary asteroids in the near-Earth population. Five near-Earth objects (NEOs) have been unambiguously identified as binary systems (Ostro et al., 2000, Margot et al., 2000, Nolan et al., 2000, Benner et al., 2001, Benner et al., 2001, Nolan et al., 2002). The orbital and tidal characteristics of these systems provide direct measurements of asteroid masses and bulk densities in addition to insightful clues about asteroid internal structure. These quantities are fundamental in characterizing the physical properties of asteroids and in establishing asteroid-meteorite associations.

The binary systems observed with radar so far share similar characteristics. In delay-Doppler images, in which echo power is discriminated as a function of range from the observer and line-of-sight velocity, the signatures of two distinct components are easily observed. Both the primary and secondary components are typically resolved in range and Doppler, and their evolution in delay-Doppler space is consistent with the behavior of an orbiting binary pair. A detailed characterization of the first binary system discovered with radar is given in Margot et al., 2002. The binary systems observed to date have primary components which appear roughly spherical and have secondary/primary size ratios of about 1/3.

The observables that can be measured from radar images are as follows: 1) visible range extents which constrain the size of each component, 2) Doppler bandwidths which constrain the spin periods of both the primary and secondary, 3) range and Doppler separations as a function of time which characterize the system's total mass and orbital parameters, 4) reflex motion of the primary about the center of mass (COM) which constrains the mass ratio of the system. Although the location of the COM is initially uncertain, the process of ephemeris refinement via radar astrometry quickly leads to a very precise knowledge of its position in each image frame.

The bulk of the data analysis so far has concentrated on using the range and Doppler separations to fit for the system's total mass and orbital parameters. The model assumes that the orbital motion of the secondary takes place in a plane with an orientation that remains fixed in inertial space during the time of the observations. Such mass estimates, coupled with a detailed knowledge of the component volumes from shape modeling techniques (Hudson 1993), can lead to precise asteroid density measurements. Currently our density values rely on size estimates obtained from visual inspection of the raw radar images.

Least-squares fits of the orbital parameters yield chi-squared values of order unity. The best-fit solutions along with the formal errors of the fit and the corresponding mass and density estimates will be presented at the meeting. The general trends are as follows. The radar-observed NEA binaries have satellites orbiting at a distance of a few primary radii. Their orbital period is on the order of a day. These values yield density estimates between $\sim$1 and $\sim$2.5 g/cm^3. Initial estimates for the spin periods of the secondaries, also on the order of a day, are consistent with spin lock configurations, expected from tidal despinning timescales (Margot et al., 2002). However, because the spin periods of the primaries are typically a few hours, the systems observed to date cannot be mutually synchronous.

Reflex motion of the primary is clearly observed in the radar data sets, providing the exciting prospect of measuring the densities of NEA satellites. Improved orbital fits will incorporate the residual motion of the primary with respect to the COM and will include the mass ratio of the system as an additional parameter.

Additional improvements are expected from shape reconstruction techniques (Hudson 1993), in which a series of delay-Doppler images is inverted in a least-squares sense to provide a shape model. Apart from possibly yielding clues on formation mechanisms, shape models will significantly decrease the uncertainties associated with size/volume estimates, and this will result in considerably lower error bars on the density measurements. Given images with sufficient signal-to-noise ratio and orientational coverage, it may also be possible to infer shape and spin information for the satellites, and to derive strong conclusions regarding possible spin-orbit resonances.

Radar observations of binary asteroids constitute an emerging field which holds great promise for the future. Because the proportion of binary sytems amongst asteroids 200 m or larger is about 16% (Margot et al., 2002), binary systems will probably continue to be discovered in large numbers as part of the ongoing radar observations of NEOs. The information that can be gathered from radar data sets includes component sizes, morphologies, spin states, masses,

densities, porosities, and rigidities. The characteristics of these binary asteroids place strong constraints on their formation age and mechanisms, with significant implications for theories of tidal or impact disruption and re-accretion. Comparisons of binary systems in the near-Earth, main-belt, and Kuiper-belt populations will constrain the different dynamical and collisional regimes and will lead to a better understanding of the early stages of solar system formation and of the modern planetary environment.

REFERENCES

L. A. M. Benner, S. J. Ostro, J. D. Giorgini R. F. Jurgens, J. L. Margot, M. C. Nolan, IAU Circ. No. 7632 (2001).

L. A. M. Benner, M. C. Nolan, S. J. Ostro, J. D. Giorgini, J. L. Margot, IAU Circ. No. 7730 (2001).

R. S. Hudson, Remote Sensing Reviews 8, pp. 195-203 (1993).

J. L. Margot, M. C. Nolan, L. A. M. Benner, S. J. Ostro, R. F. Jurgens, M. A. Slade, J. D. Giorgini, D. B. Campbell, IAU Circ. No. 7503 (2000).

J. L. Margot, M. C. Nolan, L. A. M. Benner, S. J. Ostro, R. F. Jurgens, J. D. Giorgini, M. A. Slade, D. B. Campbell, Science 11 April 2002 (10.1126/science.1072094) (2002).

M. C. Nolan, J. L. Margot, E. S. Howell, L. A. M. Benner, S. J. Ostro, R. F. Jurgens, J. D. Giorgini, D. B. Campbell, IAU Circ. No. 7518 (2000).

M. C. Nolan, E. S. Howell, C. Magri, B. Beeney, D. B. Campbell, L. A. M. Benner, S. J. Ostro, J. D. Giorgini, J. L. Margot, IAU Circ. No. 7824 (2002).

S. J. Ostro, J. L. Margot, M. C. Nolan, L. A. M. Benner, R. F. Jurgens, J. D. Giorgini, IAU Circ. No. 7496 (2000).