

Geophysical Constraints on Asteroids from Groundbased Radar

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Radar has provided otherwise unavailable physical information about some 200 asteroids [1]. Measurements of echo power as a function of time delay (range) and Doppler frequency (radial velocity) provide two-dimensional images with resolution as fine as ~ 10 m. Such images can be used to construct geologically detailed three-dimensional models, to define the rotation state precisely, to measure surface structural characteristics, and to constrain the object's internal density distribution.

Asteroids stand apart from rocks and planets, because their short-range strength and long-range gravity achieve an intricate mechanical balance that is not well understood and is different for each object [2]. Moreover, sooner or later, the success or failure of explosive deflection or destruction of an Earth-threatening asteroid will depend in part on the object's interior configuration of fractures and macroporosity [3]; the apparently considerable macroporosity of many asteroids [4] would make short-notice mitigation very difficult [5]. The common km-sized asteroids that are the focus of NASA's "Spaceguard Survey" might exist in a no-man's land where neither gravity nor strength predominates, and may be stranger than ever imagined [2]. Given the following radar results for specific near-Earth asteroids (NEAs) and main-belt asteroids (MBAs), consider the geophysical implications for collisional history, spin state evolution, and interior configuration.

NEA Toutatis [6,7] is in a slow, excited rotation state, with a dissipation timescale longer than the age of the solar system. The asteroid's principal moments of inertia are in ratios within 3% of 3.19 and 3.01, and the inertia tensor is indistinguishable from that of a homogeneous body; such information has yet to be determined for any other asteroid except Eros and probably is impossible to acquire in a fast spacecraft flyby. The object's linear features suggest fractures and perhaps internal blockiness and macro-porosity [8] at 100-m-to-km scales. A strong dichotomy between the gravitational slope distributions on the asteroid's two lobes suggests that they are fragments of a precursor body that was disrupted in a sub-catastrophic collision. Their reunion may have been at least partially responsible for Toutatis' unusual rotation state [7].

NEAs Castalia [9], Mithra [10], Bacchus [11], and 2002 FC appear to be contact binaries, a natural by product of tidal fission or damped low-speed collisions [8]. With a length/width ratio 2.76 ± 0.21 , the porpoise-shaped NEA Geographos is the most elongated solar system object imaged so far [12], possibly the outcome of tidal stretching of an unconsolidated precursor during a close planetary encounter [13]. The very high radar reflectivity of the ~ 200 -km, dogbone-shaped MBA Kleopatra indicates a metallic composition [14]; the interior may be unconsolidated. The 2-km object 1986 DA is even more radar reflective and is the leading candidate for a metallic NEA [15]. The carbonaceous chondritic NEA 1998 KY26 is a spheroid with a diameter of about 30 m [16] and a rotation period of 11 min, which is too rapid for it to consist of multiple components bound together just by their mutual gravitational attraction. Very strong, detailed images of NEA 1999 RQ36 reveal a rapidly rotating, almost featureless spheroid [17].

Radar has revealed six NEAs to be binary systems [18 and refs. therein; 19]. Delay-Doppler images of 2000 DP107 reveal a 800-m primary and a 300-m secondary. The orbital period of 1.767 d and semimajor axis of 2620 ± 160 m yield a bulk density of 1.7 ± 1.1 g/cc for the primary. DP107 and other radar-imaged binary NEAs have spheroidal primaries spinning near the breakup point for strengthless bodies. Some 1/6 of the tens of thousands of NEAs larger than 200 m in diameter may be binary systems.

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