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Structural Stability of Asteroids

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This thesis develops a technique for analyzing the internal structure of an irregularly shaped asteroid. This research focuses on asteroid (216) Kleopatra, a few-hundred-kilometer-sized main belt asteroid spinning about its maximum moment of inertia axis with a rotation period of 5.385 hours [97], to motivate the techniques. While Ostro et al. [117] reported its dog bone-like shape, estimation of its size has been actively discussed. There are at least three different size estimates: Ostro et al. [117], Descamps et al. [36], and Marchis et al. [102]. Descamps et al. [36] reported that (216) Kleopatra has satellites and obtained the mass of this object. This research consists of determination of possible failure modes of (216) Kleopatra and its subsequent detailed stress analysis, with each part including an estimation of the internal structure. The first part of this thesis considers the failure mode of Kleopatra and evaluates the size from it. Possible failure modes are modeled as either material shedding from the surface or plastic failure of the internal structure. The surface shedding condition is met when a zero-velocity curve with the same energy level as one of the dynamical equilibrium points attaches to the surface at the slowest spin period, while the plastic failure condition is characterized by extending the theorem by Holsapple (2008) that the yield condition of the averaged stress over the whole volume is identical to an upper bound for global failure. The prime result shows that while surface shedding does not occur at the current spin period and thus cannot result in the formation of the satellites, the neck may be situated near its plastic deformation state. From the failure condition, we also find that the size estimated by Descamps et al. (2011) is the most structurally stable. The second part of this thesis discusses finite element analyses with an assumption of an elastic-perfectly plastic material and a non-associated flow rule. The yield condition is modeled as the Drucker-Prager yield criterion, which is a smooth shear-pressure dependent condition. The result shows that the failure mode highly depends on

the body size. As the body size increases, the failure mode transits from a compression-oriented mode to a tension-oriented mode. This asteroid should have a cohesive strength of at least 200 kPa to keep its original shape, although we argue that its cohesion may be less. In addition, the upper bound technique for structural failure and the dynamical analysis for surface shedding are also applied to 21 different shapes to determine their failure modes (either surface shedding or structural failure) on the assumption of zero-cohesion. Finally, we apply these concepts to analyze the breakup event of main belt comet P/2013 R3.