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On Binary Asteroids: Dynamics, Formation and Parameter Estimation

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Binary asteroids make up roughly 16% of the near Earth and Main Belt asteroid populations, while an estimated 50% of Kuiper Belt objects are believed to be binary or multi-body systems. Their abundance and unique dynamics have gained the interest of planetary scientists and mission planners alike as potential targets for future study and exploration. Several missions to binaries have already been announced, such as the DART and Hera missions to Didymos, the Lucy mission flyby of Jupiter Trojan 617 Patroclus, and the Janus mission flybys of 1996 FG3 and 1991 VH. The success of these missions and others will require a thorough understanding of binary dynamics, their formation processes, and robust navigation techniques. This thesis attempts to expand the toolsets available for the study and exploration of binary systems by implementing high fidelity dynamics models, exploring their dynamical structure, formation processes, mass parameter observability, and navigation approaches. We begin by developing an arbitrary shape and order implementation of the coupled attitude and orbit dynamics of binary asteroids, otherwise known as the Full Two-Body Problem (F2BP). Dynamical systems theory techniques are then applied to identify the equilibria of the F2BP and their associated dynamical structure. We apply these dynamical tools first to binary asteroid formation and evolution; where we study the statistical fate of a representative set of low and high mass ratio binary asteroids as they evolve from their initial fission. Next the sensitivity of the stable doubly synchronous equilibrium to the binary mass parameters is investigated to understand the remote observability of mass parameters from measurements of the binary dynamics alone. Finally, a consider covariance analysis is developed for an in-situ spacecraft estimating the masses, inertias, and higher order parameters of a target binary.

Throughout the thesis we identify many new behaviors of these complex dynamical systems and propose new techniques for their study. We first identify and map the manifolds about the

stable doubly synchronous equilibrium and characterize the breakdown of the unstable doubly synchronous equilibrium as barrier to recollision and successful binary fission. In the area of binary formation and evolution we note the importance of nonplanar dynamics in the fate of ejected secondary asteroids and the fission of captured secondaries. We prove the mathematical feasibility of remote mass parameter estimation, while identifying technical challenges that may limit its implementation. Expanding this analysis to an in-situ spacecraft, we are able to characterize the sensitivity of the dynamics to estimated mass parameters; identifying trends and characteristics in their relative importance and effect.