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Dynamical evolution of small bodies in the Solar System

Thesis directed by Prof. Daniel Scheeres

This thesis explores the dynamical evolution of small bodies in the Solar System. It focuses on the asteroid population but parts of the theory can be applied to other systems such as comets or Kuiper Belt objects. Small is a relative term that refers to bodies whose dynamics can be significantly perturbed by non-gravitational forces and tidal torques on timescales less than their lifetimes (for instance the collisional timescale in the Main Belt asteroid population or the sun impact timescale for the near-Earth asteroid population). Non-gravitational torques such as the YORP effect can result in the active endogenous evolution of asteroid systems; something that was not considered more than twenty years ago.

This thesis is divided into three independent studies. The first explores the dynamics of a binary systems immediately after formation from rotational fission. The rotational fission hypothesis states that a rotationally torqued asteroid will fission when the centrifugal accelerations across the body exceed gravitational attraction. Asteroids must have very little or no tensile strength for this to occur, and are often referred to as "rubble piles." A more complete description of the hypothesis and the ensuing dynamics is provided there. From that study a framework of asteroid evolution is assembled. It is determined that mass ratio is the most important factor for determining the outcome of a rotational fission event. Each observed binary morphology is tied to this evolutionary schema and the relevant timescales are assessed.

In the second study, the role of non-gravitational and tidal torques in binary asteroid systems is explored. Understanding the competition between tides and the YORP effect provides insight into the relative abundances of the different binary morphologies and the effect of planetary flybys. The interplay between tides and the BYORP effect creates dramatic evolutionary pathways that lead to interesting end states including stranded widely separated asynchronous binaries or tightly bound synchronous binaries, which occupy a revealing equilibrium. The first results of observations are reported that confirm the theoretically predicted equilibrium.

In the final study, the binary asteroid evolutionary model is embedded in a model of the entire Main Belt asteroid population. The asteroid population evolution model includes the effects of collisions as well as the YORP-induced rotational fission. The model output is favorably compared to a number of observables. This allows inferences to be made regarding the free parameters of the model including the most likely typical binary lifetimes.

These studies can be combined to create an overall picture of asteroid evolution. From only the power of sunlight, an asteroid can transform into a myriad number of different states according to a few fundamental forces.