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Semi-analytical Methods of Orbit Propagation for Near-Earth Asteroids

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The long-term dynamics of Near-Earth Objects (NEOs) are driven by the secular perturbations of the solar system and the presence of planetary close encounters. Close encounters with the inner solar system planets cause the orbits of NEOs to become chaotic, thus we study their long-term evolution stochastically. We combine analytical solutions of the long-term secular perturbations with the numerical evaluation of close encounters, allowing the rapid propagation of NEO orbit trajectories. Using the semi-analytical propagation tool we obtain statistics of the orbit long-term dynamics, characterizing their stochastic behavior.

Many of the physical properties of NEOs evolve over time. This evolution is usually coupled with the orbit evolution through close encounters, long-term effects, or at least conditioned by the location of the asteroid within the solar system. Planetary close encounters excite the relative orbits of binary asteroids. Using the semi-analytical propagation we gather statistics of the close encounters. Combined with models for the excitation of binaries we compute the probability of experiencing encounters that disrupt binary systems. We conduct this analysis for the NASA Janus and NASA/APL DART mission targets.

The rotational state of asteroids evolves under thermal torques or YORP effect. This effect depends on the obliquity, the angle between the spin pole and the orbit plane. YORP theories predict that the spin poles is torqued into equilibrium obliquities of 0, 90 or 180 degrees. Modeling the obliquity component of the torque while propagating the orbit with the semi-analytical model we obtain oscillations in obliquity that are near but offset from the equilibrium configurations.

We characterize the long-term impact hazard of asteroids by propagation of the Minimum Orbit Intersection Distance (MOID). The MOID limits the closest encounters that can occur and its uncertainty grows much slower than the overall uncertainty in the position of asteroids. Thus, we can extend the timescales of typical impact characterization analyses. We combine analytical estimates of the intrinsic probability of collision with the propagation of the orbits to rank the km-sized NEO population and PHAs, large asteroids ($H < 22$) currently with an Earth MOID < 0.05au.

The analytical theories of planetary close encounters assume a constant MOID to find keyholes, regions that lead to a future impact. We analyze different models for the evolution of the MOID as corrections to the analytical theory. We find that the short-period oscillations and shallow encounters play a significant role in the definition of keyholes, as the variations can be in the order of tens of Earth Radii in a few years.