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Effect of Planetary Encounters on Binary Asteroids

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1. Why are some near-Earth binaries eccentric?

The binary nature of near-Earth asteroids (NEAs) is generally discovered by planetary radar (24 out of 37 as of May 2011) during a close approach to Earth, which can provide detailed physical and orbital information about the binary. Previous studies have found that approximately ∼16% of NEAs larger than 200 meters in diameter have satellites [1,2]. Orbital solutions of the small number of well-characterized NEA binaries indicate that approximately one-third of them have eccentric mutual orbits with $e \geq 0.2$. Accordingly, we seek an explanation for the origin of these eccentricities.

Processes that may modify the eccentricities of NEA binaries include tidal evolution, radiation effects such as binary YORP (BYORP), and close planetary encounters. Assuming a low-density, "rubble pile" composition of an asteroid, tidal evolution will tend to damp eccentricities [3,4]. The BYORP effect occurs when a non-spherical, synchronously rotating satellite's orbital angular momentum changes in response to its asymmetrical re-radiation of sunlight [5]. This radiation perturbation requires synchronous rotators, and most of the observed eccentric NEA binaries are not synchronously locked. In this work, we investigate the orbital effects and timescales of planetary flyby encounters for all well-characterized NEA binaries.

2. Single Planetary Encounter

We perform N-body numerical integrations to examine the orbital perturbations due to a single hyperbolic flyby between an Earth-sized terrestrial body and an NEA binary. Our initial conditions (masses and separations) are based on all well-characterized NEA binaries and the simulations begin with binaries in circular mutual orbits. After an encounter, possible outcomes include an intact, stable binary system or instability marked by either collision or ejection of the secondary. We record the final eccentricities of stable encounters. Simulations are repeated to thoroughly examine encounter geometries, distances, and velocities for all well-characterized NEA binaries.

Our results show that close planetary encounters can easily excite the eccentricities of binaries to values of $e \geq 0.2$. For instance, NEA binary 2003 YT1 has been reported to be eccentric [6] and we find that its eccentricity can be excited to $e \geq 0.2$ as far away as encounter distances of ∼25 Earth radii (see Figure 1).

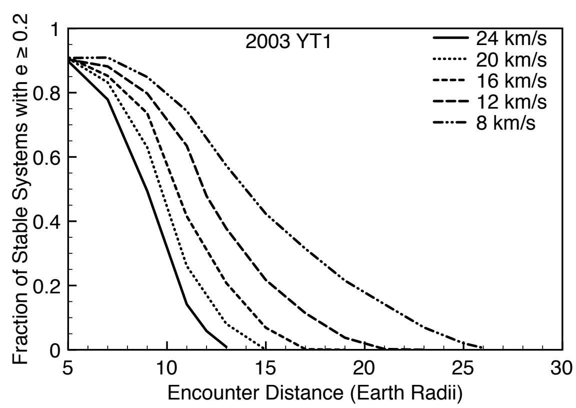

Figure 1: NEA Binary 2003 YT1 is observed to be eccentric, and we find that a single planetary flyby can excite the eccentricity of its mutual orbit at various encounter velocities (8, 12, 16, 20, and 24 km/s). We plot the fraction of stable encounters with excited ($e \geq 0.2$) mutual orbits.

3. Frequency of Planetary Encounters

We determine the frequency of close planetary encounters with terrestrial planets. The timescale of close encounters are dependent on the NEA's past evolutionary path to its current heliocentric orbit. Accordingly, we follow a previous method [7] of integrating test particles from three efficient source regions for NEAs: ν_6 secular resonance with Saturn, 3:1 meanmotion resonance with Jupiter, and Mars-crossing regions. As the test particles migrate into near-Earth space, we find test particles whose heliocentric orbits closely match those of well-characterized NEA binaries. We use an Opik-type code [8] to evaluate the time evolution of the matching test particles' encounter probability with terrestrial planets. We find that close encounters capable of increasing a binary's eccentricity can take place on 10^5 - 10^7 year timescales.

4. Summary

Binary systems represent a sizeable fraction of near-Earth asteroids and about one-third of them have been found with mutual orbits of e ≥ 0.2, whose origins are unknown. We conduct a numerical investigation to test the hypothesis that close scattering encounters by terrestrial planets have excited the orbital eccentricities of near-Earth binaries to their currently observed values. We will present results for all well-characterized NEA binaries, and from this ensemble we will draw conclusions about the effects of planetary encounters and the origin of eccentricities.

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