# The Evolution of Binary Asteroids Formed by Spin Fission

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**Motivation:** Binary asteroid systems comprise a significant fraction ($\sim 16\%$) of the Near-Earth asteroid (NEA) population [1]. Many of these systems are a-synchronous binaries–the secondary is tidally locked, but the primary has a spin rate faster than the orbit rate. Observed a-synchronous systems have low mass ratios and a distinctive primary shape characterized by an equatorial bulge. Several theories exist that attempt to explain this binary population by a Yarkovsky-OKeefe-Radzievskii-Paddack (YORP)-induced fission process [2, 3]. The mechanics of such a process are not fully understood, and current theories do not fully explain the extant data. This includes common-origin asteroids, which are asteroid pairs that are not currently gravitationally bound together, but have nearly identical solar orbits and appear to have an inter-related past [4] and high mass ratio systems such as Hermes (whose apparent lack of abundance may be due to observational bias).

**Background:** If the asteroid is modeled as a "rubble pile", a collection of gravitationally bound boulders with a distribution of size scales and very little tensile strength between them, increasing the spin rate via YORP leads to an eventual spin-fission of the components, as determined by the largest separation of component mass centers [5]. Friction from the tidal deformation of the binary members will dissipate energy and evolve the orbit and spin states of the bodies. However, current theory to model and predict such tidal dissipation and orbital evolution requires a quasi-steady state approximation [6].

**Method:** We numerically integrate the equations of motion of the binary system, modeling each body as a triaxial ellipsoid. For simplicity, all motion is constrained to a plane. Our model applies instantaneous tidal torques to both members of the binary system to determine energy dissipation. The systems begin at the spin-fission limit with contact along the largest axes of each body and will evolve towards their tidally locked orbital equilibrium states due to energy dissipation from tides, all the while conserving angular momentum [7].

**Results:** Fig. 1 shows a sample of our data demonstrating the evolution of 20 systems over a 500 year period resulting in significant tidal energy dissipation. 100 percent energy dissipation would place the system in the orbital relative equilibrium. Fitted power laws were used to extrapolate the evolution of the system to the orbital relative equilibrium state and determine a timescale for that evolution. Fig. 2 shows these timescales as a function of mass ratio, along with a fitted power law showing a clear trend as a function of the system's mass ratio. For many systems this process takes between 10 and 100 kyrs, relatively short compared to the proposed YORP and BYORP timescales [8, 9]. Most systems evolve to the tidally locked state, however low mass ratio systems ($< 0.2$) have positive energy and generally escape from each other in short time spans. Fig. 3 is a plot of the maximum separation distance between the primary and secondary for a range of mass and shape ratios evolved over 100 years. The spherical Hill radius for these systems at 1 AU is $\sim 80.5$ primary radii and thus low mass systems quickly disrupt, implying that

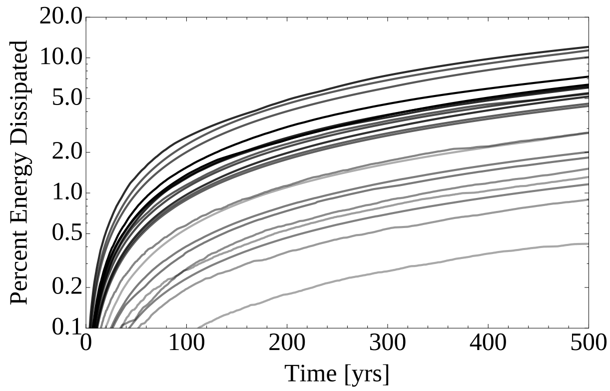


Figure 1: Energy dissipation of different systems. The darker the line, the larger the mass ratio.

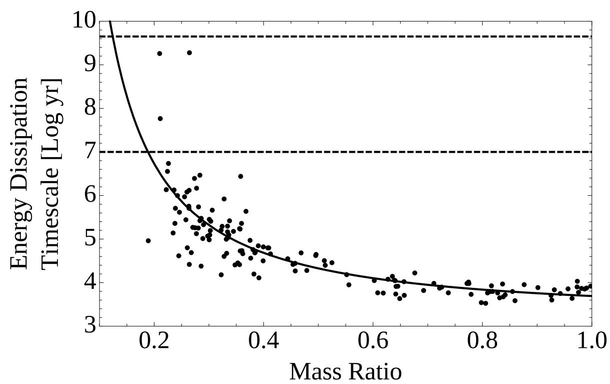


Figure 2: Timescales for modeled systems to reach orbital relative equilibrium. The curve is a numerical fit to the data. The lower dashed line indicates the lifetime of a typical Near-Earth asteroid. The upper dashed line indicates the age of the solar system.

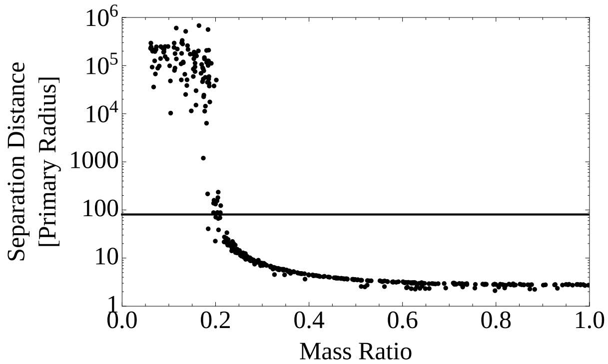


Figure 3: The maximum separation distance between bodies in units of the primary radii. The line indicates the Hill radius of the system at 1 AU.

YORP induced fission could be a significant source of common-origins asteroids. Before the systems become unbound, the secondary of each system is often spun up–an effect driven by the spin-orbit coupling from the expanded gravitational potentials. If the secondary is itself a "rubble pile", it will undergo spin fission. The most conservative requirement for fissioning is the fissioning of a massless test particle on the surface. Bodies with higher mass ratios will always fission at lower spin rates [2]. Fig. 4 shows the results from evolving 88 low

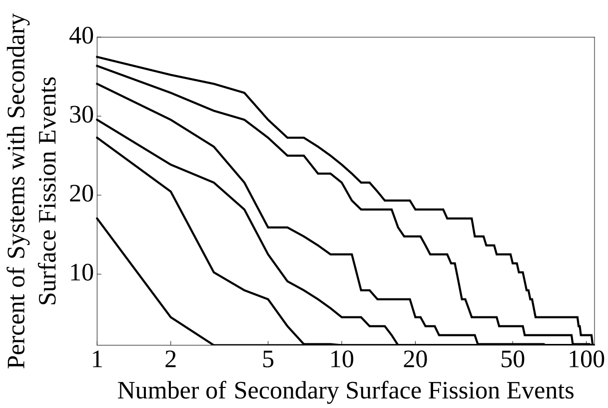


Figure 4: Percent of low mass ratio systems ($\mu < 0.2$) to have secondary surface fission events. Each curve represents a cumulative total number of events for a different time length (the uppermost curve is 100 days, then in descending order 50, 20, 10, 5, and 2 days).

mass ratio ($< 0.2$) systems for 1 year. More than a third of the systems in this short amount of time undergo at least one surface fission event, while $10\%$ of these systems undergo more than 50 such events. We hypothesize that almost all low mass secondaries will undergo some sort of spin fission if they remain in orbit long enough. Secondary fission occurs when the orbit of the system is at pericenter and the location of the fission is on the interior (primary facing) side of the secondary. Dynamically modeled test particles will strike the primary after fissioning from the secondary providing material for the observed equatorial bulge of a-synchronous systems. The material deposited on the primary will also transfer angular momentum, which has the effect of both stabilizing the orbit of the secondary and increasing the spin of the primary. Such systems should mimic the observed a-synchronous binaries. Without this mechanism all secondaries would escape from low mass ratio systems.

**Discussion:** The initial component size distribution and configuration within the parent body will determine the mass ratio of the spin-fissioned system and consequently the evolutionary course of the system. High mass ratio systems evolve quickly to their tidally locked orbital equilibrium states. From these states binary YORP (BYORP) may play an important role in their expansion–creating more common-origin systems–or contraction–creating contact binaries. The secondaries of low mass ratio systems quickly escape–creating common-origin systems, however many go through a secondary fission process that can stabilize the system–creating a-synchronous binaries. These results imply additional constraints to the proposed assembly of a secondary in orbit. These secondaries must form in a "sweet spot", far enough from the primary to avoid most of the spin-orbit coupling that results in both the system disruption and secondary fission, but close enough so most of the mass shed from the primary remains in an orbit suitable for accretion.

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**References**

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