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The Binary Yarkovsky Effect: A New Mechanism for Changing the Mutual Orbits of Asynchronous Binary Asteroids.

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1. Introduction

Binary asteroids are found throughout the Solar System at a wide range of size scales. Their formation mechanisms are also diverse. Km-sized systems are generally thought to form by rotational disruption of the primary resulting from radiative torque, large main-belt systems are thought to form by collisions, while binaries in the Kuiper Belt are thought to be primordial, forming directly from the streaming instability. This study primarily focuses on ~ km-sized binaries found among both the near-Earth asteroids (NEAs) and main-belt asteroids (MBAs). These systems are small and close enough to the Sun that radiation forces play an important role in their long-term evolution. Understanding their long-term dynamics is crucial to trace back their evolution and estimate their lifetime, which also provides information on physical properties and geologic structures of asteroids.

It is widely accepted that the long-term dynamics of binaries are dominated by tides and the Binary YORP (BYORP) effect, which is a radiative torque that modifies the orbit of the secondary asteroid (Cuk & Burns, 2005). Tidal dissipation can either drive the secondary outward or inward, depending on whether the secondary's mean motion is slower or faster than the primary's spin (Murray & Dermott, 1999).

In this work, we investigate the Yarkovsky effect that has been largely overlooked in the context of the long-term evolution of binary asteroids. The Yarkovsky effect, which is the radiation force raised on the afternoon side of a rotating object, has been well studied for single asteroids (Vokrouhlicky, 1999). However, its impact on binary asteroids remains less explored.

2. Results

The Yarkovsky effect on a binary consists of two components: the Yarkovsky-Schach (YS) effect and the planetary Yarkovsky effect. The YS effect is caused by: (1) elimination of the satellite irradiation by sunlight when it is located in the primary shadow; and (2) the related asymmetric thermal cooling and heating of the secondary after it enters and exits the shadow (in fact, there is also a similar effect on the primary related by the shadow of the secondary, but this produces smaller dynamical perturbation). This effect was noticed for binary asteroids too, but not studied in detail yet (Vokrouhlicky et al, 2005). The planetary Yarkovsky effect is simply the Yarkovsky effect caused by the primary's radiation instead of the Sun.

We find that for prograde secondaries ($\varepsilon < 90^o$), the Yarkovsky effect tends to drive the secondary towards the synchronous orbit a_{syn} determined by n = ω, while for retrograde secondaries (ε > 90°), the Yarkovsky effect always drives the secondary outward until it leaves the system. The timescale for the orbital migration of the Yarkovsky effect is roughly 0.1 Myrs, depending on the physical properties of the binary. This brings us new insights about the mechanism of the synchronization of binary asteroids and the underlying reason why the majority of binary asteroids are found to be in synchronous states. Our calculations also predict that the secondary asteroids with spin periods shorter than 4.3 hours (the orbital period around the Roche limit) will fall into the Roche limit quickly driven by the Yarkovsky effect and then get tidally disrupted, reshaped or accreted on the primary. In addition, some asynchronous binaries might be in the Yarkovsky-tide equilibrium state where the orbit does not drift, but such a state may be quickly broken by the YORP effect or tides. For retrograde secondaries, the Yarkovsky effect would drive them outward until they leave the binary system due to planetary perturbations or collisions, producing asteroid pairs. In this scenario, the two components of the asteroid pair would exhibit opposite spin directions.

We found that the synchronization of the Dinkinesh-Selam system discovered by the Lucy spacecraft could be due to the Yarkovsky effect, considering that tides are weak for such a distant secondary. In addition, we calculated the possible Yarkovsky effect on Didymos-Dimorphos system in its state following the impact of the NASA DART mission, which might have perturbed it into an asynchronous state. The Yarkovsky-induced semimajor axis drift rate is ~7.6 cm/yr. This could be examined by in-situ observation conducted by the space mission ESA Hera during its rendezvous with Didymos in late 2026.

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