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ON THE POST-IMPACT SPIN STATE OF THE SECONDARY COMPONENT OF THE DIDYMOS-DIMORPHOS BINARY ASTEROID SYSTEM

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The Didymos binary asteroid is the target of NASA's Double Asteroid Redirection Test (DART) mission, the first demonstration of the kinetic impactor technique for planetary defense [1], and of the ESA Hera mission that will rendezvous with Didymos to fully characterise the system as well as DART's outcome [2]. In the fall of 2022, the

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DART spacecraft will impact Dimorphos, the secondary component of the binary, resulting in a mutual orbit period change that can be measured from the ground to infer the momentum transfer efficiency, which is commonly referred to as "beta" (β). The change in orbit period and eccentricity (which depend on β) and Dimorphos's shape (which is poorly constrained) are expected to have a significant influence on the post-impact spin and orbital dynamics of Dimorphos [3].

Name	Resonance
$\mathcal{R}_1$	$\omega_{\text{lib}} = 2\omega_{\text{prc}}$
$\mathcal{R}_2$	$n = 2\omega_{\text{prc}}$
$\mathcal{R}_3$	$n = 2\omega_{\text{lib}}$
$\mathcal{R}_4$	$\omega_{\text{lib}} = n$

Table 1: ω_{lib} is the free libration frequency of the secondary, n is the mean motion, and ω_{prc} is the natural precession frequency of the secondary.

Treating Dimorphos as a uniform triaxial ellipsoid, we explored the influence of its axial ratios and β on its post-impact spin state. We consider the outcomes from a simplified planar impact, where the DART momentum is transferred entirely within the mutual orbit plane and opposite of Dimorphos's motion (the actual impact will have a small nonplanar component). First, we developed a purely analytic model to quantify Dimorphos's attitude stability as a function of its shape. Then, we conducted attitude dynamics simulations with a simplified 3D spin-orbit model, accounting for Dimorphos's shape and Didymos's oblateness, to understand the underlying dynamical structure of the system. Finally, we used the General Use Binary Asteroid Simulator [4] (GUBAS) to perform high-fidelity Full Rigid Two-Body Problem (FR2BP) simulations to understand the effect of full coupling between the body spins and mutual orbit.[1]

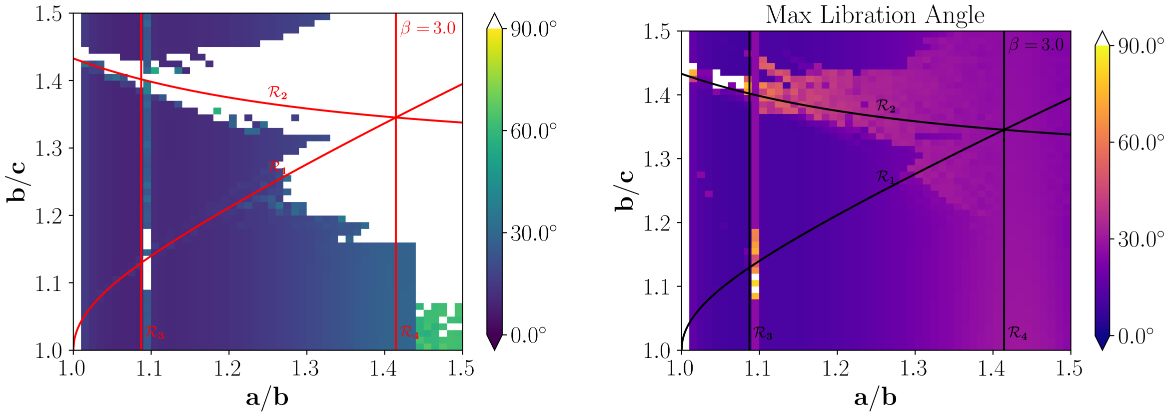
Both simulation codes reproduce various expected resonances between the mean motion and Dimorphos's libration and spin precession frequencies, which are listed on Table 1. On short timescales, the two codes agree quite well. However, the simplified 3D attitude simulations indicate that many possible shapes of Dimorphos would break from synchronous rotation, even for a moderate value of $\beta = 3$ within a year of the impact (Fig. 1a). However, the FR2BP results show that this is unlikely unless β is a bit larger, around ~ 5. The difference between these two results is a consequence of full spin-orbit coupling in the FR2BP code. However, the post-impact libration amplitude is still quite large, exceeding $\sim 40^\circ$ for $\beta = 3$ when spin-orbit coupling is accounted for (Fig. 1b).

The results of both simulation codes show that most shapes of Dimorphos will become attitude unstable, and, using standard dynamical systems techniques (i.e. Fast Lyapunov Indicators), we show that it can evolve chaotically. We compare these results to the analytic model prediction of resonances and stability. The change in mutual orbit period is largely unaffected by Dimorphos's post-impact spin state, meaning a chaotic tumbling state does not affect the mission's ability to meet its Level 1 requirements.

Comments:

Oral presentation preferred.

[1] https://github.com/alex-b-davis/gubas



(a) Simplified 3D Model, $\beta = 3$ **(b) GUBAS, $\beta = 3$**

Figure 1: The maximum libration amplitude over a one-year simulation as a function of the axial ratios a/b and b/c. Fig. 1a shows the result from the simplified 3D model and Fig. 1b shows the result from the GUBAS simulation code. The predicted resonances that drive the attitude instability are overlayed on these plots and defined on Table 1. Cases in which the libration angle exceeds 90° are indicated in white. These are considered to have broken from synchronous rotation.

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