Orbit perturbations due to Dimorphos's reshaping and mass loss after the DART impact

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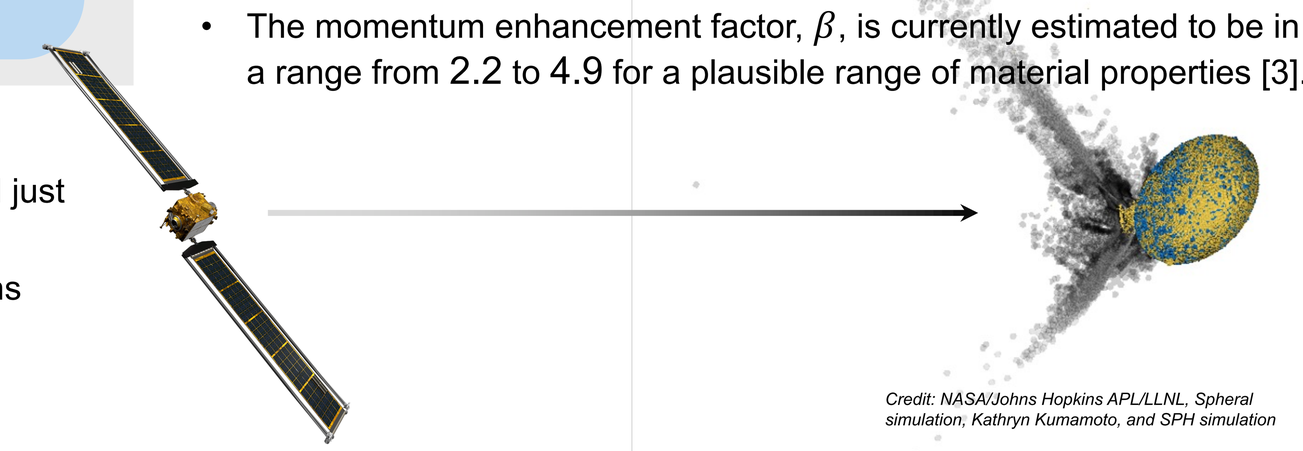
Summary

- DART impact modifies Dimorphos's shape at some magnitude.
- If the a/b axis ratio is ~1.2 – 1.3 after reshaping, the orbit period change due to reshaping could be on the order of several minutes.
- Dimorphos's mass loss due to ejecta lengthens the orbit period, counteracting the effect of reshaping.
- Out-of-plane reshaping induces significant roll libration.

DART impact on Dimorphos

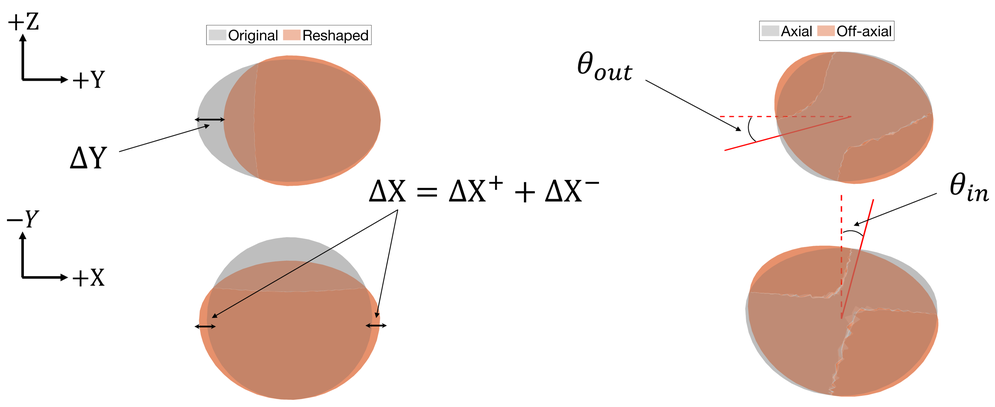
- The DART spacecraft impacted Dimorphos, smaller secondary member of the Didymos-Dimorphos binary asteroid system, with a relative speed of 6.14 km/s [1].
- The impact site was within 25 m of Dimorphos's center of figure.
- The orbit period was reduced by 33.20 ± 0.11 min (3σ) [2].
- The momentum enhancement factor, β, is currently estimated to be in a range from 2.2 to 4.9 for a plausible range of material properties [3].



Credit: NASA/Johns Hopkins APL/LLNL, Spheral simulation, Kathryn Kumamoto, and SPH simulation

Dimorphos's reshaping

- The DART impact may have induced Dimorphos's reshaping, beyond just forming a crater [4].
- Recent impact simulations and preliminary ground-based observations suggest a post-impact Dimorphos a/b axis ratio of ~1.2 – 1.3 [4, 5].
- We generate physically reasonable hypothetical shape models of reshaped Dimorphos and simulate the mutual dynamics.

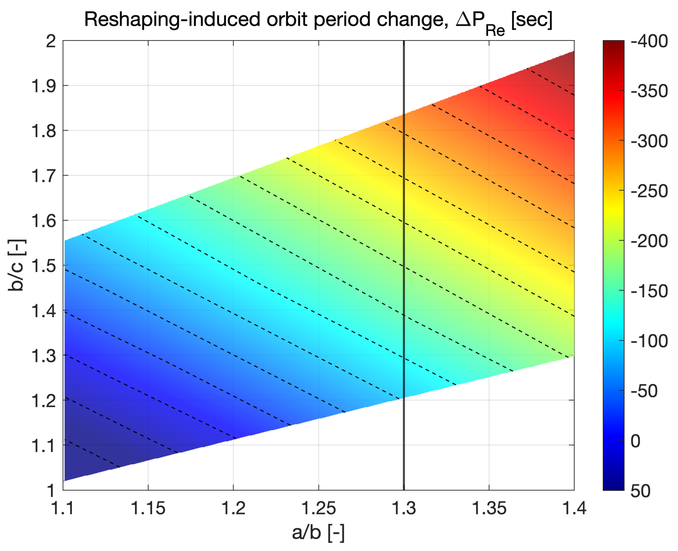


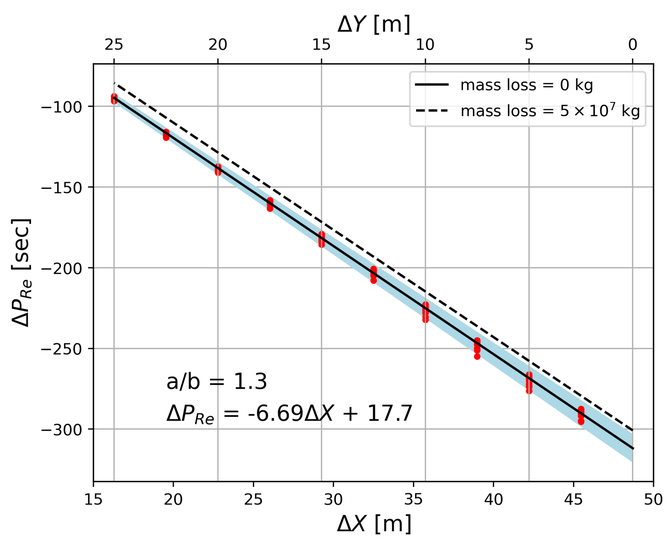
Dimorphos's mass loss due to ejecta

- Images from LICIACube and HST show that a significant amount of material was ejected after the impact [6, 7].
- Material with sufficiently high ejection speeds escaped the system, while material with low ejection speeds could be redistributed back onto Dimorphos, contributing to the reshaping of Dimorphos [8].
- A recent study suggests that the total mass of the ejected materials is at least 10^7 kg (i.e., ~0.3% of Dimorphos's original mass) [9].

Orbit period change due to reshaping and mass loss

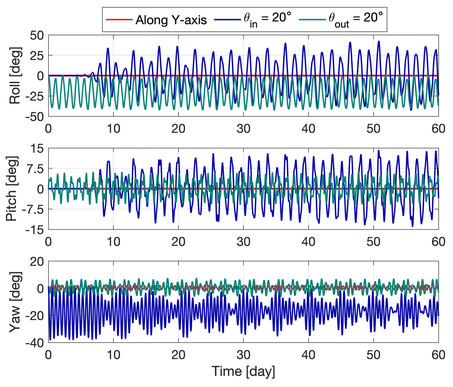
- Dimorphos's reshaping generally reduces the orbit period.
- If a/b = 1.2 ~ 1.3 as suggested by ground-based observations, the reshaping-induced orbit period change, ΔP_{Re}, could be up to ~300 sec.
- ΔP_{Re} is almost unaffected by asymmetry in reshaping magnitude along X and Z axes.
- Reshaping is more important than mass loss, which naturally lengthens the orbit period.
- Mass loss in excess of ~10^7 kg will make the apparent effect of reshaping smaller.

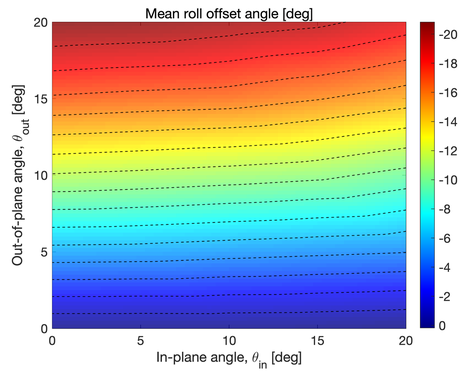




Off-axial reshaping and Dimorphos's rotation state

- Off-axial reshaping results in a deviation from the original direction.
- In-plane reshaping significantly affects all three libration angles.
- Out-of-plane reshaping induces a considerable roll libration.





Further refinement of the β estimation

- The uncertainties of the physical properties of Didymos and Dimorphos mainly dominate the current uncertainty of β [e.g., 3].
- Accounting for reshaping generally reduces β.
  → e.g., β for a/b = 1.3 ranges from 3.02 to 3.35, depending on the magnitude of reshaping, which is smaller than the current estimate of β for ρ_B = 2400 kg/m^3, 3.61 [1].
- As better constraints are placed on the physical properties of the bodies, including the effects of reshaping and mass loss becomes more important.
- When ESA's Hera fully characterizes the system in 2027, the effects of reshaping and mass loss should be included for the most accurate β.

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