PREDICTIONS FOR THE DYNAMICAL STATE OF THE DIDYMOS SYSTEM BEFORE AND AFTER THE PLANNED DART IMPACT. H. F. Agrusa[1], D. C. Richardson[1], B. Barbee[2], W. F. Bottke[3], A. F. Cheng[4], S. Eggl[5], F. Ferrari[6], M. Hirabayashi[7], O. Karatekin[8], J. McMahon[9], S. R. Schwartz[10,11], and the DART Dynamics Working Group. [1]Department of Astronomy, University of Maryland (hagrusa@astro.umd.edu), [2]NASA Goddard Space Flight Center, [3]Southwest Research Institute, [4]Johns Hopkins University Applied Physics Laboratory, [5]Department of Aerospace Engineering, University of Illinois at Urbana-Champaign, [6]Space Research and Planetary Sciences, Physics Institute, University of Bern, [7]Department of Aerospace Engineering, Auburn University, [8]Royal Observatory of Belgium, [9]Smead Department of Aerospace Engineering Sciences, University of Colorado Boulder, [10]Planetary Science Institute, [11]Lunar and Planetary Laboratory, University of Arizona.

Introduction: NASA's Double Asteroid Redirection Test (DART) is the first full-scale demonstration of a kinetic impactor for planetary defense [1]. The spacecraft is expected to impact Dimorphos, the secondary component of the Didymos binary asteroid system, in late September of 2022. The impact will cause a reduction in the binary semimajor axis and orbital period that will be measured with ground-based observations. By measuring the change in the binary mutual orbit period, the DART mission will provide an estimate of the momentum transfer enhancement factor, β, a critical parameter that describes the additional momentum transfer generated from escaping ejecta [2]. Traveling onboard the DART spacecraft is the LICIACube spacecraft that will detach prior to impact and image both bodies with a focus on the early stages of crater formation and ejecta production as well as the backside of Dimorphos as it flies through the system [3]. Launching in 2024, ESA's Hera spacecraft will rendezvous with Didymos to further characterize the system and the effects of the DART impact [4]. Together, these three spacecraft comprise the Asteroid Impact and Deflection Assessment (AIDA) cooperation between NASA and ESA.

Here we present a summary of current predictions for the dynamical state of the Didymos system before and after the DART impact.

Didymos System Current Dynamical State:

Didymos system origin. Didymos' heliocentric semimajor axis, eccentricity, and inclination (*a, e, i*) values of (1.643 au, 0.384, 3.4°) are indicative of a body that has recently escaped the main belt [5]. The NEA population models from [5] and [6,7] both indicate that Didymos likely originated from the inner main belt near or within the ν_6 resonance between 2.1–2.5 au, although other source regions are possible. Didymos is an S-type asteroid with a geometric albedo of ~0.16, consistent with the Baptistina asteroid family, although other parent families are a possibility.

The relaxed state assumption. Due to a lack of observational evidence to indicate otherwise, dynamical studies of the Didymos system in support of DART generally assume the binary is in a relaxed state prior to impact (i.e., a circular orbit with Dimorphos' libration damped to a minimum). Ground-based observations to date indicate that Didymos' mutual orbital eccentricity is consistent with zero, although an upper limit as high as 0.05 has been reported [8,9,10]. Further, Didymos' fast rotation and top-like shape could indicate a rubble-pile structure that is more dissipative than a rigid body. This implies that mutual tides will likely have had sufficient time to damp the system to an equilibrium state in which Dimorphos is in synchronous rotation on a near-circular orbit [11]. Although current observations point toward a relaxed pre-impact dynamical state, it is still possible that this may not be the case. Observations have not yet confirmed that Dimorphos is in synchronous rotation and several mechanisms have been identified that may excite the system prior to impact, including close planetary flybys [12], meteorite impacts, and long-lived nonplanar rotation [13,14]. If, upon DART's arrival, the system is already dynamically excited, then the relaxed state assumption will need to be reevaluated.

Rigid-body Modeling of the Post-impact Dynamical State:

Rigid-body modeling. Following the methodology of [15,16], 1 year of post-impact dynamical evolution was simulated with the General Use Binary Asteroid Simulator (GUBAs), using the latest impact geometry consistent with DART's launch in November 2021 for a range of possible body shapes for Dimorphos. The results show that Dimorphos post-impact libration amplitude and attitude stability properties are highly dependent on β and its semi-axis ratios *a/b* and *b/c* and are in broad agreement with previous studies [16].

Orbit period variations. The binary orbit period is expected to be time-varying due to strong spin-orbit coupling [17]. As a result of Dimorphos' post-impact libration, angular momentum will oscillate between the mutual orbit and Dimorphos' spin state, leading to a significant variation in the orbit period. On top of the immediate orbit period change caused by DART, there will also be a time-varying component with a magnitude on the order of tens to hundreds of seconds, depending on both Dimorphos' shape and β. In addition, the orbit period variation is highly correlated with Dimorphos' libration amplitude, meaning that a measurement of the orbit period variation could indirectly constrain Dimorphos' post-impact libration amplitude.

Didymos heliocentric orbit. The DART spacecraft and any momentum carried by ejecta leaving the system will contribute to a small change in the heliocentric orbit of the Didymos system. This change may be measurable through a combination of ground-based observations and Hera measurements. Although measuring a change to Didymos' heliocentric orbit is not required to meet DART mission objectives, it may be useful to further constrain the effect of the DART impact and the physical properties of the system [18].

Rubble-Pile Modeling of the Post-impact Dynamical State.

The role of internal structure on the dynamics. A series of 1-year post-impact simulations was conducted using PKDGRAV, a granular *N*-body code that allows for the treatment of one or both bodies as a rubble pile. In most scenarios—an approximately ellipsoidal Dimorphos with moderate β values—these simulations broadly agree with equivalent rigid-body simulations over DART-relevant timescales (several months to years). Although this effort is still in progress, this indicates that the faster rigid-body simulations are likely adequate for capturing the evolution of the system following the DART impact. This remains to be seen for timescales exceeding a few years, where a dedicated orbital evolution code may be required to properly account for secular evolution such as tides and the binary YORP effect (BYORP).

The possibility of body-reshaping–induced perturbations to the mutual orbit. The possibility of shape changes to either Didymos or Dimorphos (or both) caused by the DART impact and their resulting dynamical effects are also explored. Dimorphos can reshape due to the cratering process [19]. On the other hand, ejected material from Dimorphos could reach the surface of Didymos, potentially triggering a reshaping process due to Didymos' near-critical rotation rate and potential structural sensitivity [20]. Reshaping in these events would change the mutual gravity field, and alter the resulting orbital period. For example, if Didymos reshapes by 70 cm along its spin axis, earth-based observations may detect the resulting orbital change [21]. In order to conserve angular momentum, such a deformation would lead to a decrease in Didymos' spin rate that would be readily measurable via lightcurves. The effect on the mutual orbit period due to a deformation of Dimorphos is also explored [22].

Secular Evolutionary Effects: There are also longer-term secular effects of note. The BYORP and tidal parameters for the system are still poorly constrained, due to a lack of a shape model for Dimorphos and a limited understanding of tidal processes in rubble piles. Based on shape models provided by DART approach imagery, it will be possible to compute the BYORP coefficient for the Didymos system (which will be significantly improved with the Hera mission). A measurement of the BYORP coefficient combined with the system's known mean anomaly drift will provide a better understanding of the relative contributions of BYORP and tides to the mutual orbit evolution. Of course, this gets complicated by the DART impact itself, which will alter the shape of Dimorphos and therefore change the BYORP coefficient. In addition, if DART triggers chaotic rotation in Dimorphos, it would shut off BYORP entirely [13,16].

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References:

[1] Cheng, A. F., et al. 2018, Planet. Space Sci., 157, 104. [2] Rivkin, A. S., et al. 2021, Planetary Science Journal, 2, 173. [3] Dotto, E., et al. 2021, Planet. Space Sci., 199, 105185. [4] Michel, P., et al. 2018, Advances in Space Research, 62, 2261. [5] Bottke, W. F., et al. 2002, Icarus, 156, 399. [6] Granvik, M., et al. 2016, Nature, 530, 303. [7] Granvik, M., & Brown, P. 2018, Icarus, 311, 271. [8] Scheirich, P., & Pravec, P. 2009, Icarus, 200, 531. [9] Fang, J., & Margot, J.-L. 2012, AJ, 143, 24. [10] Naidu, S., et al. 2020, Icarus, 113777. [11] Goldreich, P., & Sari, R. 2009, 691, 54. [12] Meyer, A. J., & Scheeres, D. J. 2021, Icarus, 367, 114554. [13] Cuk, M., Jacobson, S. A., & Walsh, K. J. 2021, PSJ, 2, 231. [14] Quillen, A. C., LaBarca, A., & Chen, Y. 2022, Icarus, 374, 114826. [15] Agrusa, H. F., et al. 2020, Icarus, 349, 113849. [16] Agrusa, H. F., et al. 2021, Icarus, 370, 114624. [17] Meyer, A. J., et al. 2021, Planetary Science Journal, 2, 242. [18] Makadia, R., Eggl, S. & Fahnestock. E. 2021, DPS Abstracts, Abstract #113.08. [19] Raducan, S. & Jutzi, M. 2022, PSJ (Submitted) [20] Zhang, Y., et al. 2021, Icarus, 362, 114433. [21] Hirabayashi, M., et al. 2017, MNRS, 472, 1641. [22] Nakano, R., et al. 2022, PSJ (Submitted).