PDC2023
Vienna, Austria

Ongoing and Upcoming Mission Highlights

A FIRST ASSESSMENT ON THE ORIGIN OF DIDYMOS AND DIMORPHOS, NASA's DART MISSION TARGETS

Fabio Ferrari(1), Harrison F. Agrusa(2)(3), Yun Zhang(2), Olivier S. Barnouin(4), R. Terik Daly(4), Andrew F. Cheng(4), Carolyn M. Ernst(4), Masatoshi Hirabayashi(5), Seth A. Jacobson(6), Martin Jutzi(7), Alice Lucchetti(8), Patrick Michel(3), Naomi Murdoch(9), Ryota Nakano(5), Maurizio Pajola(8), Eric E. Palmer(10), Sabina D. Raducan(7), Derek C. Richardson(2), Colas Robin(9), Stefania Soldini(11), Filippo Tusberti(8), Ronald-Louis Ballouz(4), Brent W. Barbee(12), Adriano Campo Bagatin(13), Ioannis Gkolias(14), Josh Lyzhoft(12), Jay McMahon(15), Alex J. Meyer(15), Paul Sánchez(15), Daniel J. Scheeres(15), Paolo Tanga(3), Kleomenis Tsiganis(14), Stavro Ivanovski(16), Stephen R. Schwartz(10), Andrew S. Rivkin(4), Nancy L. Chabot(4) and the DART Investigation Team

(1) *Department of Aerospace Science and Technology, Politecnico di Milano, Italy*
(2) *University of Maryland, College Park, MD, USA*
(3) *Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Nice, France*
(4) *Johns Hopkins University Applied Physics Laboratory, USA*
(5) *Auburn University, Auburn, AL, USA*
(6) *Michigan State University, East Lansing, MI, USA*
(7) *Space Research and Planetary Sciences, University of Bern, Switzerland*
(8) *INAF-Osservatorio Astronomico di Padova, Italy*
(9) *Institut Supérieur de l'Aéronautique et de l'Espace (ISAE-SUPAERO), Université de Toulouse, Toulouse, France*
(10) *Planetary Science Institute, Tucson, AZ, USA*
(11) *University of Liverpool, UK*
(12) *NASA/Goddard Space Flight Center*
(13) *IUFACyT-DFISTS, Universidad de Alicante, Spain*
(14) *Aristotle University of Thessaloniki, Greece*
(15) *University of Colorado Boulder, CO, USA*
(16) *INAF - Osservatorio Astronomico di Trieste*

Keywords: *DART, Didymos, Dimorphos, origin, kinetic impact*

ABSTRACT

On September 26th, 2022, NASA's Double Asteroid Redirection Test (DART) performed the first full-scale demonstration of kinetic impact for planetary defense purposes, by impacting at high speed the asteroid Dimorphos, the secondary component of (65803) Didymos binary system. Before impact, DART provided exceptional close-up images of both Didymos and Dimorphos, revealing that both asteroids have oblate shapes and rocky surfaces [1].
We perform here a first assessment of formation and evolutionary paths that may have led to the observed, pre-impact state of the Didymos system. We account for asteroids' internal structures that are consistent with their observed asteroid shapes

and the geomorphological features appearing on their surfaces. Key parameters to this analysis are the bulk densities of the two asteroids, which have a high uncertainty and currently estimated in the range 2100–2700 kg/m^3 (one sigma) [1], and their spin rate, which is directly constrained for the Didymos primary only (2.260 h) [2], and has not been measured for Dimorphos, for which is typically assumed to equal its orbit period (11.92 h).
We use N-body discrete-element codes to reproduce the dynamical evolution of Didymos and Dimorphos, which are modelled as loosely consolidated self-gravitating (rubble-pile) aggregates [3]. We investigate evolutionary processes that may have led to the formation of Dimorphos, such as major fission events, mass shedding or transport within the binary system, and their possible causes, such as slow reshaping due to YORP-driven spin change, or abrupt reshaping due to meteoritic impacts [4,5,6].
Preliminary model results suggest that both Didymos and Dimorphos may have a rubble-pile inner structure, as this appears consistent with both dynamical simulations and preliminary geological assessments of their surfaces.
In particular, a rubble-pile Didymos is structurally stable when assuming a bulk density of 2700 kg/m^3 (the higher-end of pre-impact density estimates), or for a smaller density, in the presence of some structural coherence in the inner part of the asteroid [7,8]. Such coherence might be provided by grain interlocking and/or a small cohesion level (few Pa) between rubble-pile constituents, or by a small (30–50% volume) inner rigid core. Also, numerical simulations show that reshaping processes on Didymos imply mass movements from mid-latitudes to the equator, where particles would be only tenuously bound to Didymos [9]. This appears consistent with the equatorial region of Didymos, which, compared to the mid-latitude region, appears smoother and less boulder-rich, suggesting materials might have been shed from the equator due to Didymos's high spin rate [10].
Under the assumption of tidally locked behavior, Dimorphos has a sensibly lower spin rate compared to Didymos, and this makes Dimorphos's shape stable at any density value within the estimated one-sigma uncertainty range. From a dynamical perspective, Dimorphos's shape would be stable even with a fully-fragmented interior and in the absence of cohesion/interlocking. A major source of dynamical perturbation is provided by the presence of Didymos, which makes Dimorphos's shape unstable at distances smaller than 900–1000 m (depending on the bulk density, and in absence of internal strength). A preliminary assessment shows that Dimorphos would disrupt under Didymos-induced tides at distances closer than 500–600 m, and would have a more elongated shape in the range 600–900 m. The ESA Hera mission will provide detailed measurements of key properties, including internal ones, during its rendezvous with Didymos through close proximity operations of the spacecraft and its two Cubesats Milani and Juventas in 2027, allowing us to check our predictions [11].

References: [1] Daly et al., 2022 (submitted). [2] Thomas et al., 2022 (submitted). [3] Agrusa et al., 2022, PSJ. [4] Richardson et al., 2022, PSJ. [5] Nakano et al., 2022, PSJ. [6] Hirabayashi et al., 2022, PSJ. [7] Ferrari & Tanga 2022, Icarus. [8] Hirabayashi et al, 2015, ApJ. [9] Sánchez, Scheeres, 2018, Icarus. [10] Tardivel et al, 2018, Icarus. [11] Michel et al., 2022, PSJ.

****

Comments: *Oral presentation preferred, will be attending in person*