A Grid Search on the Fates of the Ejecta Produced by the AIDA Impact on the Secondary of (65803) Didymos

Yang Yu¹, Patrick Michel⁴

¹Beihang University, 100191 Beijing, China (yyuyang thu@gmail.com), ²Université Côte d’Azur, Observatoire de la Côte d’Azur, CNRS, Lagrange Laboratory, CS 42429, 06304 Nice Cedex 4, France (michel p oca eu).

Introduction

One of the purposes of the Asteroid Impact & Deflection Assessment (AIDA) space project is to understand the post-dynamics of the ejecta cloud produced by a hypervelocity impact on the secondary of the binary asteroid (65803) Didymos. The sub-sequent dynamics of the debris ejected from the impact site is crucial information for the mission design as well as for the discussion on the origin of binary asteroids. In particular, the high-velocity impact on the secondary of the binary system may cause irreversible damage to a companion spacecraft, and the evolution of the ejecta cloud essentially depends on the initial distribution and the chaotic nature of the particles. In previous studies [1-2], compatible models for both components of Didymos were derived from existing measurements and the combination of radar and photometric observations. The excavation flow properties model (EFPM) was developed and applied to track the ejecta plume from an impact and its hypothetical impact sites for the NASA-DART spacecraft were evaluated in terms of the particles of different fates [3]. As a preliminary work supported by the NERSC project, we developed a numerical method to achieve full-scale simulations of the ejecta cloud composed of huge number of particles [4]. Here this method is applied to more general cases. A grid search was organized under the AIDA impact scenario, showing how the ejecta fate depends on two key factors: the ejection speed vₑ and launching site. The distribution of the ejecta fates reveals some evolution features of the ejecta cloud, which are summarised as below.

Key points in this poster:

- Temporarily trapped ejecta that orbits around the binary only exists for a modest ejection speed range 4.0 < vₑ < 42.0 cm/s, beyond which the orbital behaviors become simplified.
- The amount of ejecta accreted on the primary peaks around vₑ = 12.0 cm/s, and the accreting latitude (on the primary) is correlated with the re-impact speed.
- The proportions of ejecta accreted on the primary and orbiting around the binary system show consistent trend of variation as a function of vₑ.
- Two mechanisms dominate the accretion on the secondary: the mean motion resonance with the secondary’s orbit produces long-term quasi-periodic re-accretion peaks over days to weeks, and the impact site that intercepts the mutual orbit can produce a rapid re-accretion peak that is not recurrent as the former.
- The polar orbits and retrograde orbits show survival advantages as predicted, and the debris-vacuum area is confirmed to exist for arbitrary initialization of the ejecta, which emerges in a time after the impact.

Grid Search Scheme

Two key factors that strongly affect the trajectory of an individual piece of ejecta are the ejection speed vₑ and the launching site on the surface of Didymos (λ, φ) (represented in local longitude and latitude). The initial configurations of the binary components were determined to be the latest version of the reference model of (65803) Didymos. The retrograde solution of the mutual orbit was adopted to obtain the heliocentric orientation of the binary system (Fig. 1).

Figure 1: The initial configurations of Didymos system obtained in the celestial coordinate system.

Figure 1 also defines the body-fixed frames of the primary and secondary, which are aligned tangent to the orbits in terms of the principal moments of inertia. The geographic coordinate systems of the binary components are defined as like; xₚ defines the equatorial plane, +zₚ points to longitude φ, +yₚ points to the eastern hemisphere, and in the right-hand convention, -z points to the North Pole. The grid search set up 45 groups of simulations, each includes 100,000 ejecta particles sampled over the globe of the secondary and given a uniform ejection speed, i.e., 25 vₑ values in total were examined, ranging from 4.0 cm/s to 550.0 cm/s. The scheme aims at an ergodic attempt to sweep a wide range of parameter range and the results will be presented as a function of vₑ and (λ, φ).

Properties of the Ejecta Accreted on the Binary Components

The fate for ejecta launched from the surface of the secondary is classified into 7 types: Early escape (EE) — Ejecta escapes prior to its first periastron passage to the binary system; Late escape (LE) — Ejecta escapes after its first periastron passage to the binary; Early accretion on the primary (EAP) — Ejecta impacts on the surface of the primary prior to its first periastron passage to it; Early accretion on the secondary (EAS) — Ejecta impacts on the surface of the primary after its first periastron passage to it; Late accretion on the secondary (LAS) — Ejecta impacts on the surface of Didymos after re-impacting from its SOI. Surviving orbits (SO) — Till specified time, ejecta has neither been recycled nor ejected out of the binary system.

Figure 2: The distribution of the ejecta fates. The maps show the fates of sampled particles pictured against the launching sites for different ejection speeds. (a) 20.0 cm/s (b) 31.0 cm/s (c) 41.0 cm/s (d) 51.0 cm/s.

Figure 2 presents the results of the grid search. The distribution of ejecta fates proves to be complex within a closed range, 4.0 < vₑ < 42.0 cm/s. Beyond this range, if vₑ > 4.0 cm/s, all ejecta are trapped in the mean motion resonance of the secondary and get re-accreted within 1.14 hr, if vₑ > 42.0 cm/s, the trajectories of sampled particles tend to be radiating in longitude (ε-points), leading to a rapid cleanup of ejecta from the vicinity of Didymos, except for a small fraction of the trajectories that are geometrically blocked by the primary. The proportion of ejecta in EAS/LAS shows a monotonic increase with vₑ, and that in EAP/LAS shows a general decrease. The proportion of EAP/LAP is found to be positively correlated with that of SO.

The complex patterns in the maps (Fig. 2) reveal an intrinsic structure that represents the global orbital behaviors of sampled particles. Two mechanisms prove to play a strong role in the evolution of the ejecta: the fixed and in mean motion resonance with the secondary’s orbit produce long-term quasi-periodic re-accretion peaks over at least a couple of days after the impact; Secondary, ejecta on non-rotating orbits that intercept the mutual orbit produce a rapid re-accretion peak that is not recurrent as the resonant case. The "hitting effect" occurs in both mechanisms, which is a source of chaotic motion as ejecta with similar initial conditions can then have very different fates.

Distribution of the Survived Orbiting Ejecta after 2 Months

The plane of longitude of ascending node (L.A.N.) vs. inclination shows a remarkable dependence of the survived orbits (60 days posterior to the impact) on the ejection speed; particles of the same vₑ value are classified into groups of similar initial conditions can then have very different fates. Two mechanisms prove to play a strong role in the evolution of the ejecta: the fixed and in mean motion resonance with the secondary’s orbit produce long-term quasi-periodic re-accretion peaks over at least a couple of days after the impact; Secondary, ejecta on non-rotating orbits that intercept the mutual orbit produce a rapid re-accretion peak that is not recurrent as the resonant case. The "hitting effect" occurs in both mechanisms, which is a source of chaotic motion as ejecta with similar initial conditions can then have very different fates.

We also find the occurrence of low-speed re-impacts are limited to low latitudes of the Primary, e.g., re-impacts below 15cm/s reside in [0°, 30°N], etc. And the polar areas are only reachable by re-impacts of a narrow speed range around 10.0 cm/s (a modest value).

Figure 3: The ranges of relative re-impact speeds on the primary (R.S.P) and the secondary (R.S.S) is a function of the ejection speed.

Figure 3 shows the results of the grid search. The re-impact speed largely increases as the ejection speed (for both binary components, see Fig. 3). The wide range of R.S.P is a result of the fast autorotation of the primary, which produces a ~ 30 cm/s convected velocity at the equator. We clarify the fast rotation can lead to very different re-impact speeds even for the debris ejected from very close launching sites and velocities. We also find the occurrence of low-speed re-impacts are limited to low latitudes of the Primary, e.g., -impacts below 15 cm/s reside in [0°, 30°N], etc. And the polar areas are only reachable by re-impacts of a narrow speed range around 10.0 cm/s (a modest value).

Figure 4: The longitude of ascending node vs. inclination plane of SO particles after 2 months. The labeled tertilems (a-h) indicate the clumps of survived orbits from different ejection speeds (6-38 cm/s), respectively.

We checked the population of survived orbits in different inclinations, and found 39% of them fall in [28°, 187°] (retrograde, nearly equatorial orbits), consist mostly of particles with low vₑ values, and 36% fall in [0°, 129°] (nearly polar orbits). Only 5% reside below [7°] (propagate nearly equatorial orbits), mostly composed of particles with large vₑ values that exhibit highly eccentric orbits after ejected.

References