Implementing the DART impact as a benchmark for the *Rebound* Ejecta Dynamics package

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Introduction: Debris ejected off small bodies, whether caused by impact or other thermophysical processes, provides insight into the physical evolution and chemical constitution of the surface and sub-surface of those bodies. An N-body dynamics approach to debris cloud modeling can yield more details and accuracy (in terms of e.g. particle-particle interactions and differential velocity distributions) though usually requiring more computational resources.

The Python implementation of *Rebound* makes it possible to do N-body calculations at a higher temporal resolution but at a lower performance cost than most commonly used schemes (such as PKDGRAV). The *Rebound* Ejecta Dynamics package (RED) described here can increase the computational speed and reduce the CPU hours required for each simulation.

Here we expand on our previous implementations and benchmarking of RED as applied to two types of asteroid systems: a main belt asteroid (such as (596) Scheila) and a binary asteroid system (such as the Didymos system). The Didymos system is the target for the Double Asteroid Redirection Test (DART) which aims to impact the system's secondary body in an attempt to demonstrate the deflection of an asteroid.

Methodology: Effects implemented in the current version include particle size and initial velocity distributions, radiation pressure, a binary component, small body rotation, and ellipsoidal gravitational potential. Each effect is tested individually on the two types of asteroid environments.

For these benchmarking simulations, we start the debris cloud near the equator with a direct collision, perpendicular to the surface. The initial particle velocity distribution is defined as a power law in which particles closer to the center of the cone are ejected at a higher velocity. The initial input speed is multiplied by the normalized velocity factor that corresponds to the particle's radius from the center of the ejecta cone.

The varied particle size distribution is required for the implementation of solar radiation pressure. We implement a power law distribution with a large number of small particles (10^{-4} m) and a few large particles (1 m). We apply the radiation pressure as a force that acts on particles to push them away from the sun.

We approximate the target and binary as ellipsoids by expanding the ellipsoidal gravitational potential equation. Rotation about the principal axis provides a shift in the gravitational potential over time. We benchmark the binary system against the Didymos system using spherical bodies initially. Once interactions in a binary asteroid system have been tested with spherical bodies, we include ellipsoidal bodies.

Results: First, we benchmark RED by simulating clouds with no additional effects. Particles are lofted above the surface and expand evenly from the center of the cloud. When including a particle size distribution, the simulation results do not alter from the no-effects scenario unless radiation pressure is also included. In our benchmark simulations, smaller particles drift along a vector pointing away from the sun.

Next, we include ellipsoidal gravitational potential. Particles drift towards the regions of higher gravitational potential on either end of the longest axis. The rotation of the primary body increases the amount of drift due to the included centripetal force acting perpendicular to the axis of rotation.

Finally, we benchmark a binary asteroid system, consisting of two spherical components. Particles ejected from the surface nearest the binary will follow the gravitational pull of the binary as shown in Fig. 1.

Upcoming Work: The results presented here are examples of each implemented effect for the purpose of benchmarking; next, we will apply this package to questions in planetary science. Due to the increased computational speed of *Rebound*, we are able to produce a library of possible short-, medium-, and long-term ejecta evolution simulations. The beta version of RED will be published to the *Rebound* repository. A publication about this work is in review with *MNRAS.*

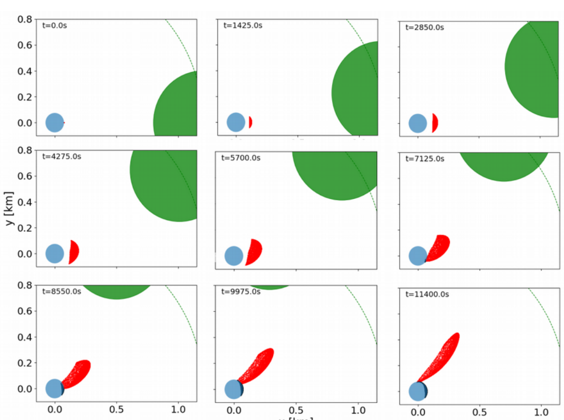

Figure 1. The Didymos system is simulated with 10^4 particles and spherical bodies. This impact models an example of the DART impact on Didymoon with gravitational influences from the primary in the Didymos system. The particles here are ejected from the equator at 70% the escape velocity of Didymoon.