ONE BODY, TWO BODY, SMALL BODY, N-BODY: EJECTA DYNAMICS IN THE ENVIRONMENT OF SINGLE AND BINARY ASTEROIDS J. Larson[1] and G. Sarid[2], [1]Department of Physics, University of Central Florida, [2]Florida Space Institute, University of Central Florida.

Introduction: Many previous models of ejecta clouds off of small bodies use hydrodynamic models and scaling relations by [1] and [2]. However, hydrodynamic models lose the fine particle-particle interactions that N-body calculations are capable of [3]. Using an N-body approach we are able to track the trajectories of individual particles.

This study expands off of [4] by applying the ejecta dynamics model presented there to the Didymos system and the impact on asteroid (596) Scheila. While future work will involve more specific applications of this model to the Didymos system as a part of preliminary calculations for the Double Asteroid Redirection Test (DART) [5,6], here we use the Didymos system as an example to test the accuracy of each effect acting on the particles. This model is also compared to ejecta modeling results of the impact on asteroid (596) Scheila [7,8].

First, we outline the effects implemented into this model. Next, we apply our model to the Didymos system. Finally, we discuss the results of this study as well as future applications of this model.

Methodology: The *Rebound* python module is an N-body integrator developed by [9]. *Rebound* allows for faster and more accurate integrations at lower performance cost than other N-body integrators such as *Mercury* [10]. [4] used this integrator to develop a model for impacts off small bodies. The N-body particle approach to modeling ejecta dynamics allows for the tracing of finer interactions between particles than in hydrodynamic models.

Table 1 outlines the effects added to this model. These effects are listed in the order that they were added to this model. Each of these effects are shown individually as well as the cumulative effects for both the Didymos system and the (596) Scheila impact.

Physical and orbital parameters for both the Didymos system and asteroid (596) Scheila are obtained from the JPL Horizons Database. We chose the Didymos system due to its binary component as well as its proximity to the sun so particles would be influenced by solar radiation forces. Asteroid (596) Scheila was chosen due to the observations and models of the impact that occurred on the asteroid. These images and models provide a baseline to compare the accuracy of our model against [7,8]. For the asteroid (596) Scheila simulations we simply attempt to match our results to previous models. Also, (596) Scheila is close to the maximum asteroid size (approximately 150 km in diameter) on which particle dynamics close to the surface are heavily determined by the oblateness of the body rather than primarily being determined by surface features [10].

Each simulation is set up to be in a target body-centric frame of reference such that the body from which the ejecta leaves is both stationary and at the center of the planetary system; therefore, the orbital elements provided in Table 2 are to ensure the correct conversion from the helio-centric frame to the target body-centric reference frame. Three reference frames (one for the ecliptic plane frame of reference, one for the coordinates on the target body, and one to describe the ejecta cone off the surface) are defined in fig. 1. Figure 1a shows how the coordinate frames are defined for an ellipsoidal target body, which can be rotated and tilted relative to the ecliptic plane. Unprimed coordinates belonging to the ecliptic plane frame of reference make up the primary reference frame and all coordinates input to or output from the *Rebound* simulation are given in the unprimed target body/ecliptic plane reference frame. Primed coordinates represent the target body reference frame, which is a secondary frame of reference. Figure 1b shows zooms in on the target body to show how the primed target body reference frame relates to the third reference frame of the ejecta cone. This final reference frame describes the coordinates that define the shape of the ejecta cone as if the cone was on an infinite plane with the base of the cone at the origin.

The location of the impact event on the target body is given in spherical coordinates by the radius of the target body at that spot, a latitude, a longitude, and the initial height of the particles above the surface of the body. The particles are required to start a small distance above the surface of the body to avoid computational complications that arise when particles are initially placed directly on the body's surface. In such a case particles are likely to be counted as having already landed back on the body and are removed from the simulation.

The target body shape is determined by the three axes *a*, *b*, and *c* that define a triaxial ellipsoid. Therefore, particles experience a different net force than for a spherical target body depending on their longitude and latitude. Particles' positions and velocities are recorded as they land back on the target body as well as the binary component. In this way we can develop a size distribution of particles on both the target body as well as the binary.

We test four different particle configurations (shown in Table 2) that are tested on each asteroid system. Each particle configuration varies either in ejecta cone opening angle or initial velocity. The initial particle velocities are some fraction of the escape velocity for the target body. Particles are initially placed at height *h* above the surface of the asteroid in a thin disk. The radius of this disk is calculated based on the disk height and the opening angle of the ejecta cone. [12,13] model the evolution of ejecta cones based on analytic studies and laboratory experiments. Theses studies help characterize the distribution of particles and particle velocities throughout the disk.

Results: Both the Didymos system and asteroid (596) Scheila are used as test cases for each effect in Table 1. The addition of a particle size distribution allows the particles to be influenced by solar radiation, which is dependent on the radius of the particle. Particles influenced by solar radiation experience an additional drag in the radial direction from the sun. Figure 2 shows an example of 10^4 particles ejected off an asteroid like Didymos before adding its binary component. Particles vary in size with radii from 10^{-4} to 1 cm and are influenced by the radiation pressure. The particles drift rather than continue in a straight path radially from the surface of the body.

Changing the shape of the asteroid from spherical to ellipsoidal will also cause particles to drift. Depending on the starting location of the ejecta, particles will feel an uneven gravitational attraction. This will cause particles to drift towards the region of higher gravity.

Adding a binary component to the system adds additional gravitational forces close to the body. We expect particles to curve in their orbits to either collide with the binary, fly by the binary, or fall back on the surface of the target body.

Future Work: The results of this study demonstrate the capabilities of the model proposed by [4] including the addition of non-axisymmectric gravity, a binary component, and radiation pressure for two test cases: the Didymos system and the asteroid (596) Scheila impact. In addition to further modeling for the DART mission, future work includes implementing a function to facilitate particle-particle interactions. This function would determine whether two colliding particles stick together or bounce off of each other based on the relative velocities of the particles.

References: [1] Housen K. R. et al. (1983). *J. Geophys. Res., 88*, 2485–2499. [2] Holsapple K. R. (1993). *Ann. Rev. Earth Planet. Sci., 21*, 333–373. [3] Artemieva N. (2008) *Large Meteorite Impacts and Planet. Evo. IV,* 3082. [4] Larson J. and Sarid G. (2017) *LPS XLVIII*, 2829. [5] Cheng A. F. et al. (2016) *Planet. & Space Sci., 121*, 27-35. [6] Schwartz S. R. et al. (2016) *Advances in Spae Research, 57,* 1832-1846. [7] Jewitt D. et al. (2011) *ApJ Letters, 733,* L4. [8] Ishiguro M. et al. (2011) *ApJ Letters, 741*, L24. [9] Rein H. and Liu S.-F. (2012) *A & A, 537,* A128. [10] Rein H. and Tamayo D. (2017) *Mon. Not. R. Astron. Soc., 467*, 2377-2383. [11] Hilton J. L. (2002) *Asteroids III, 1,* 103-112. [12] Cintala M. J. et al. (1999) *Meteorit. Planet. Sci., 34,* 605-623. [13] Richardson J. E. et al. (2007) *Icarus, 190,* 357-390.

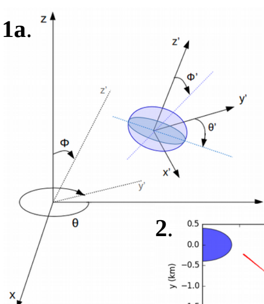
Order	Effect
1	Develop basic model of particles being ejected from small body (compare to (596) Scheila observations)
2	Determine size distribution of particles
3	Implement non-axisymmetric gravity
4	Implement radiation pressure effects (dependent on particle size, material, porosity, and shape)
5	Apply to binary/triple systems
6	Allow particle-particle interactions using *Rebound's* collision function

Table 1. List of effects implemented into model in the order that they have been added to the model. The addition of particle-particle interactions is a part of a future project.

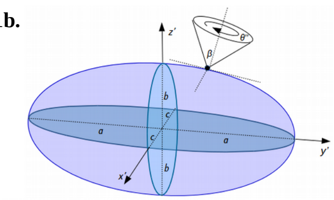
Simulation	A	B	C	D
Number of Particles	1e5	1e5	1e5	1e5
Particle Radii [cm]	10^{-4} to 1	10^{-4} to 1	10^{-4} to 1	10^{-4} to 1
Initial Velocity [m s^{-1}]	0.9 v_{esc}	0.9 v_{esc}	0.9 v_{esc}	0.5 v_{esc}
Opening Angle (β)	45°	30°	60°	45°

Table 2. Particle parameters for the four simulation variations. Simulations A, B, and C vary in opening angle. Simulation D has the same opening angle as simulation A but varies in initial particle velocity.

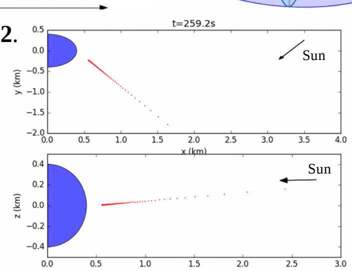
1a.



1b.



2.



Figures. 1(a) The unprimed coordinate system is the frame in which the ecliptic plane exists. **1(b)** A zoomed in image of the target body's primed coordinate system. The ejecta cone's shape is defined by the opening angle (β) and the position about the cone (θ″). **2** An example of 10^4 particles ejected from Didymos at the escape velocity with β=45° and are influenced by radiation pressure from the sun. The black arrows point towards the position of the sun.