Modeling the Evolution of Ejecta Clouds Off Small Bodies: An N-Body Particle Approach with REBOUND

Jennifer Larson[1] and Gal Sarid[2]

[1]Department of Physics, University of Central Physics, [2]Florida Space Institute, University of Central Florida

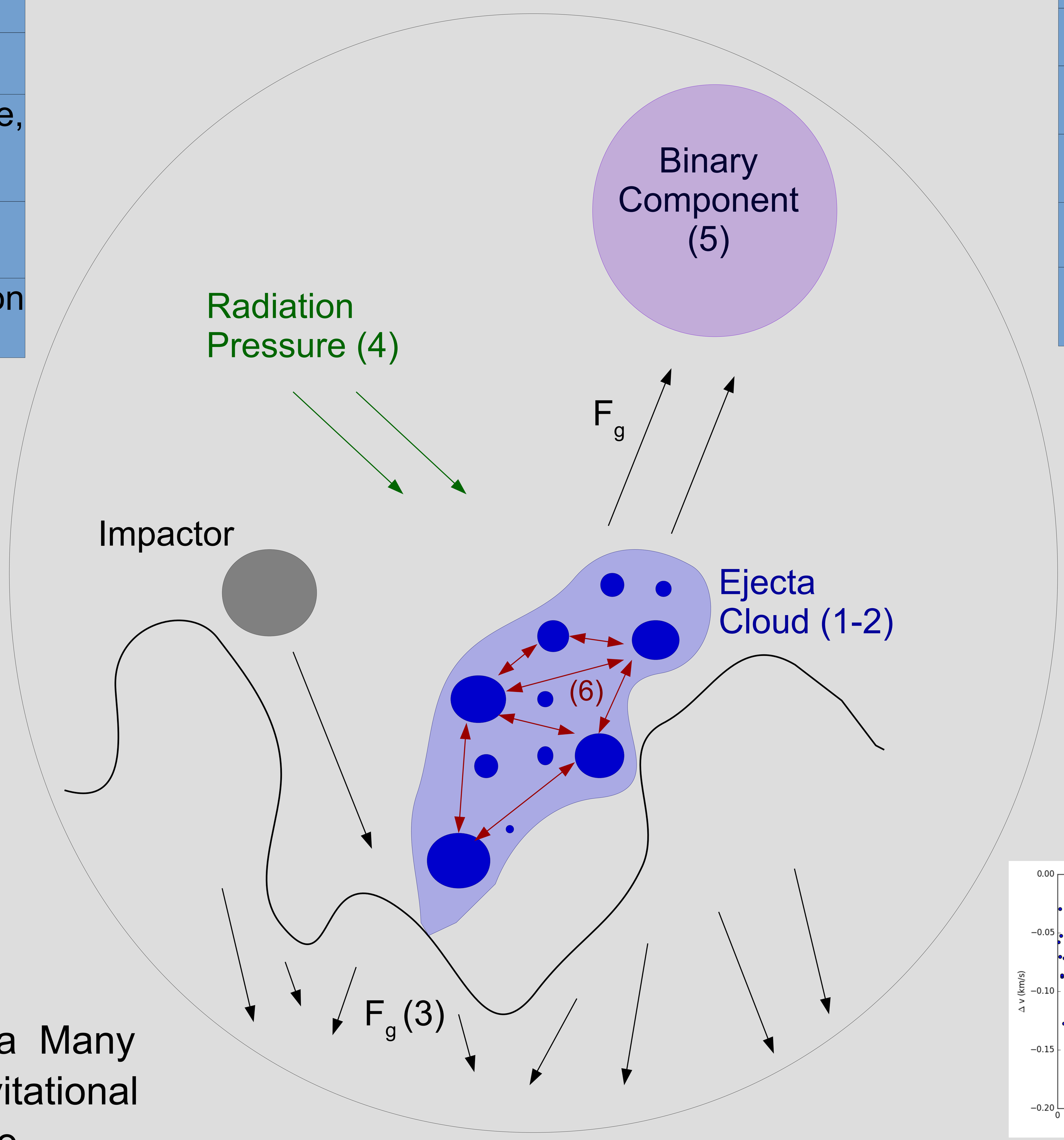
Introduction

REBOUND is an N-body integrator developed by Hanno Rein et al. [4] to model dynamical systems in astronomy such as ring systems, solar systems, dust grain interactions, etc. Here we use REBOUND to develop a model to describe the evolution of ejecta clouds off small bodies. The N-body particle approach allows us to study the microdynamics of a particle cloud with a varied size distribution of particles whereas in the hydrodynamic approach some of these finer interactions are lost [5]. Several uses for this model include but are not limited to the study of asteroid deflection, Centaur ring formation, and support for the modeling efforts for the Asteroid Impact and Deflection Assessment (AIDA) mission to predict the trajectory of the debris created by the Double Asteroid Redirection Test (DART) impact [1,2].

Methodology

We first create a REBOUND simulation using the Python module. REBOUND makes it possible to do N-body calculations at a higher temporal resolution at a lower performance cost than most commonly used schemes [3]. The Python module offers a symplectic Wisdom-Holman integrator (WHFast) [6] as well as a non-symplectic IAS15 integrator [7], which is used in this study. Units are defined as kg, km, and days. Below is a table of the effects considered in this study:

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



Reasoning and implementation of each step:

1) Place particles just above surface of target body at height based on momentum transfer. Only gravitational effects are considered.

2) Implement a size distribution of particles based on a power law. Velocity and mass distributions will also size-dependent. In addition, radiation pressure affects larger particles differently than smaller particles. Using this size distribution, we can predict size distributions of secondary craters.

3) Implement shape and mass distribution of central body. Input a Many small bodies have irregular shapes that cause variations in gravitational forces that affect ejecta particles [11,12]. Also, we implement the rotation of the central body. This alters the shape and mass distributions.

4) Poynting-Robertson drag and other radiation pressure effects create a deceleration on the motion of the particles. This can be implemented in REBOUND by adding an external force.

5) Binary and triple components add external gravitational forces that are close enough to the particles to have a significant influence on the trajectories [13].

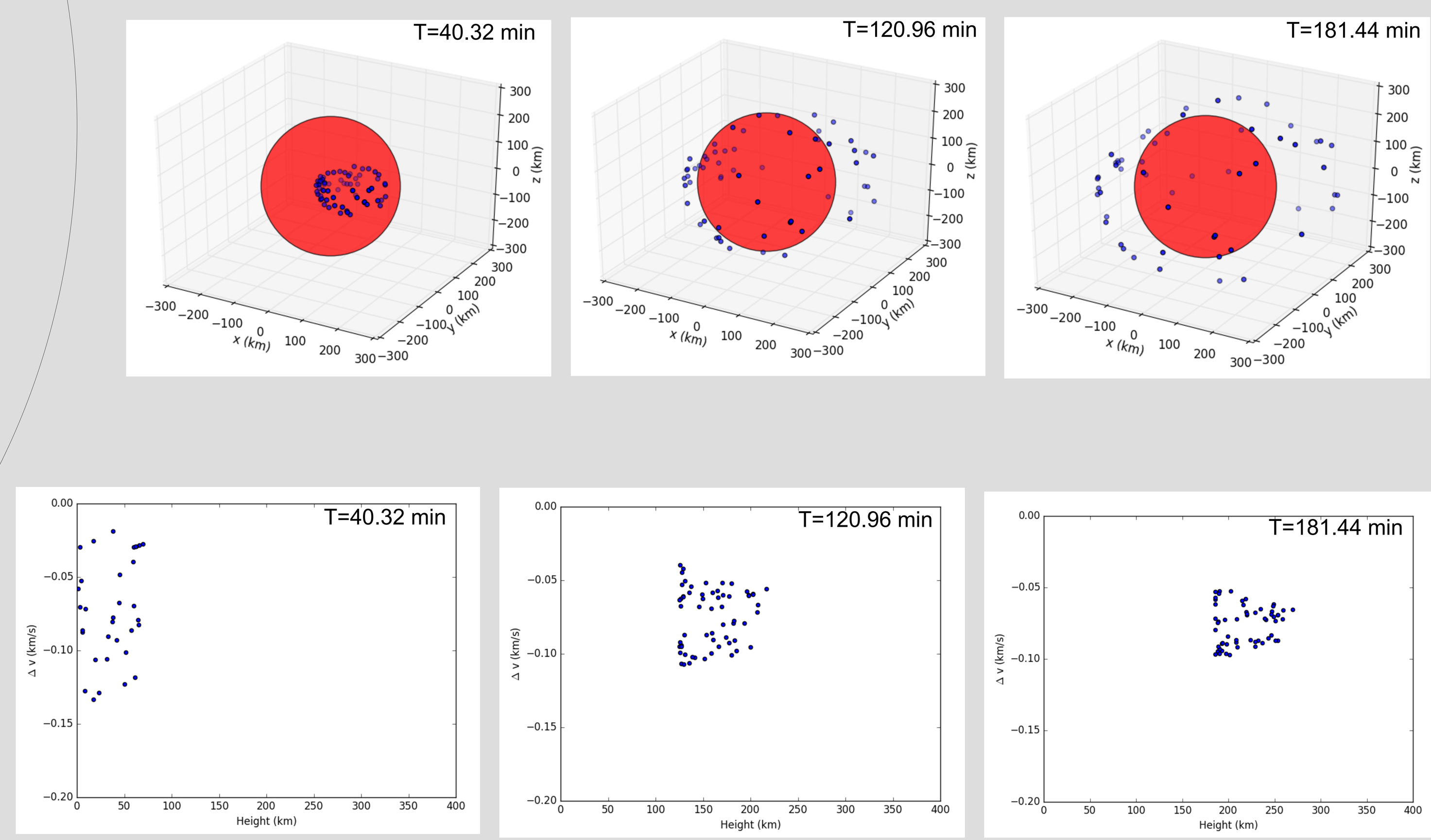
6) Particles in an ejecta cloud may interact with each other through collisions. We consider two types of collisions:
- particles merge completely
- particles ricochet off each other and do not merge at all
- partial disruption of particles

Example Calculation

To test our model, we implement conditions similar to the (596) Scheila impact [8,9]. Particles are ejected from the surface in a cone with a half-opening angle of 45° [9]. When particles collide with the surface of the target body, they are removed from the simulation. This example focuses on the ejection of the particles from the target body without considering external perturbations. The total timescale of this example is approximately 8 hours long. Below is a table of initial conditions for this example:

Parameter	Initial Value
Impactor Diameter (L)	20 m [14]
Impactor Velocity (v_i)	5 km s^{-1} [14]
Initial Particle Height	0.3 m
Target Body Radius	79.9 km [15]
Initial Particle Speed (v_{exc} for (596) Scheila)	75 m s^{-1} [9]
Target Body Semi-major Axis	2.5 AU [15]
Maximum Angle of Ejecta Cone (Φ)	45° from vertical [9]
Number of Particles	100

Here we show the ejection of particles and the dispersion versus separation for our model using the initial conditions described above.



Conclusions

- Our current model is able to eject a cone of particles from a small body using the REBOUND Python module.
- While the current model only considers the gravitational perturbations from a spherical target body and the surrounding solar system, future work will implement other effects such as radiation and non-axisymmetric gravity.

References

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