NUMERICAL SIMULATIONS OF THE COLLISIONAL EVOLUTION OF COMETESIMALS

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Introduction: To further our understanding of the initial conditions that produced our solar system we have begun to model the chemical and physical evolution of Oort Cloud comets and Kuiper Belt Objects (KBOs): the oldest, most volatile-rich, and most pristine objects in our solar system. Comets and KBOs are nearly as old as the Solar System and are the remnant building blocks of planets; thus they provide fundamental information about the initial conditions for the formation of planets. The parent bodies of KBOs were most likely formed in the outer regions of the Solar System while comets were most likely scattered into their current orbits by the giant planets. Neither comets nor KBOs have been perfectly preserved. Their surfaces have been weathered by high-energy particles, photons, and micrometeorites. Furthermore, impacts within the Kuiper Belt and between cometesimals (proto-comets) before scattering to the Oort Cloud are likely to have significantly altered the bulk chemical and physical properties from their initial state. We have begun conducting direct numerical simulations of collisions between cometesimals to investigate the evolution of the bulk properties of these objects. Our long-term goal is to determine the composition of the early protoplanetary nebula by modeling the evolution of cometesimals into present-day comets.

Numerical Method: The simulations are conducted using a shock physics code, **CTH** [1], which is coupled to an *N*-body gravity code, **pkdgrav** [2-4]. This method allows detailed modeling of the impact including heating, phase changes, and mixing of material as well as late term gravitational reaccumulation [Fig. 1].

CTH is a well tested Eulerian grid code that includes adaptive mesh refinement [Fig. 1a-b], which allows for the detailed modeling of impacts and cratering events. CTH also has the capability of modeling heating, multiple materials, mixed materials, and phase changes.

Once the initial shock wave and accompanying refractory wave have progressed through the target it is no longer necessary or practical to continue the simulation with CTH. At this point most of the shock induced physics is complete and gravity is the dominant force. Thus, the last output of CTH is run through a translator in order to convert the Eulerian grid data into Lagrangian particles, creating initial conditions for pkdgrav [Fig. 1c]. The late term gravitational evolution of the post-impact material is modeled under the constraints of self-gravity and physical collisions. The material of the original target and projectile are modeled as indestructible spheres that collide with one another inelastically. The particles cannot be fractured nor can they merge with one another.

Tests: We have conducted a series of catastrophic disruption tests between single material asteroid-like bodies. We compare the amount of specific energy necessary to create a largest post-collision remnant of 50% the original system mass using our hybridized method with previous studies using different numerical methods [5-6]. Previous methods have not followed the gravitational reaccumulation; thus, in these cases the largest post-collision remnant is determined by ballistic equations. In our simulations the mass of the largest post-collision remnant is measured directly.

These tests have confirmed that our hybridized method produces similar results to other methods in single material asteroid collisions.

Future Work: We are now working on tracking the location of the most highly shocked material after a collision event. This study will determine the compositional distribution on the surface and interiors of the collision remnants, which may help explain the color diversity in the Kuiper Belt when surface weathering is taken into account. Future work will investigate the effect of various internal configurations of ice, basalt, and porosity on collision outcome with a primary goal to determine the level of devolatilization from collisional evolution. This future study will help to explain why none of the four comet nuclei that have been observed in detail (Tempel 1, Wild 2, Borrelly, and Halley) look similar either in surface features or shape.

Conclusions: New hybridized shock-*N*-body simulations will allow us to constrain the composition of the protoplanetary nebula of our own solar system. These simulations will show how small bodies in our solar system evolve, and will assist the interpretation of data from the Stardust mission, and to explain the diversity of objects in the Kuiper Belt.

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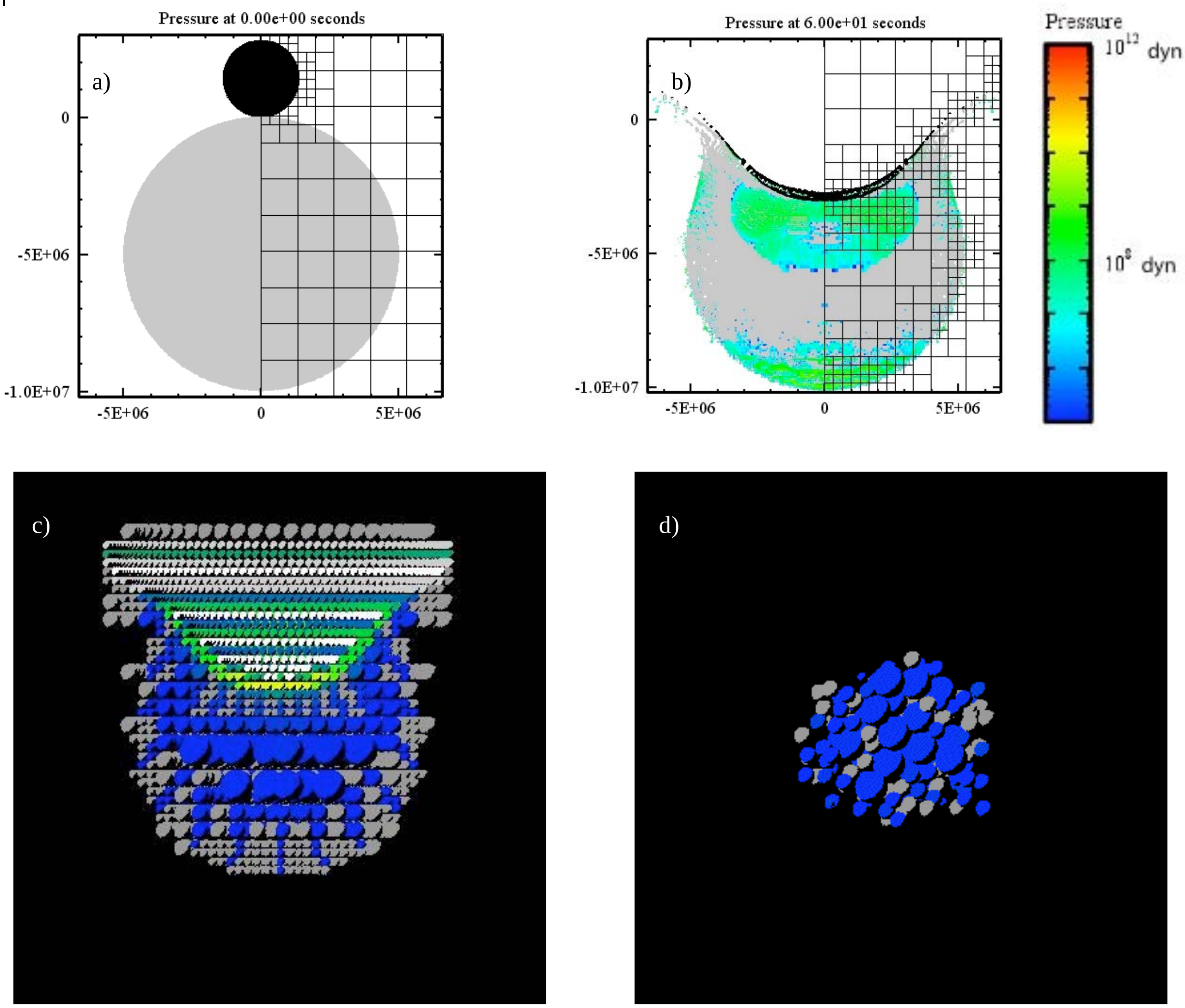

Fig. 1: An example of a hybridized impact simulation between two basalt spheres. Time increases from a) to d). Frames a) and b) are modeled using the shock physics code CTH in 2-D cylindrical symmetry, frames c) and d) are modeled using the 3-D *N*-body gravity code pkdgrav. Frame a) shows the initial condition in CTH. The grey sphere is a 50-km radius target, the black sphere is a 14-km radius projectile with an impact speed of 1.8 km/s. The grid on the right hand side of the frame represents the initial grid. Frame b) shows the result of the impact after 60 seconds. The hot color map shows the areas of highest pressure between 10^5 (blue) and 10^9 dynes (green). Frame c) shows frame b) converted into N-body particles and represents the transition from CTH to the gravity code pkdgrav. The colored particles represent grid blocks that contained Lagrangian tracer particles. These particles are color coded with respect to peak pressure attained over the first 60 seconds after impact (yellow = high pressure, blue = low pressure). Frame d) shows the largest post-collision remnant after about ten hours, at which point the remnant has a mass just under 50% the total system mass. In frames c) and d) the objects have been cut in half to reveal their interiors.