EXPLORING THE POST-IMPACT PROPERTIES OF COLLISIONAL REMNANTS IN THE EARLY SOLAR SYSTEM. R. J. Lyons[1], F. J. Ciesla[1], T. M. Davison[2], G. S. Collins[2] , [1]The Department of the Geophysical Sciences, The University of Chicago, Chicago, Illinois, USA (rjlyons@uchicago.edu), [2]Impacts & Astromaterials Research Centre, Department of Earth Science &Engineering, Imperial College London, London, UK.

Introduction: Planetesimal collisions were energetic and frequent events during the first ~100 Myr of Solar System history [1]. The timing, impactor size, and velocities of these collisions would have been determined by the orbits of the giant planets and mass of the planetesimal swarm from which the terrestrial planets formed, and understanding the types of collisions which occurred during this time may help us constrain the dynamic state of the young Solar System.

A record of collisons is preserved in those planetesimals which remain behind as asteroids today and serve as meteorite parent bodies. Early collisions have been invoked to explain the thermal evolution of meteoritic materials that cannot be explained by radiogenic heating alone and for the mixing/juxtaposition of materials of different thermal histories in a given sample [2-7]. Unfortunately, while collisions are believed to be responsible for these features, it is unclear what collisional parameters would produce features consistent with the observed petrologies and chronologies.

Previously, we investigated the thermal evolution of relatively low-energy impacts (< 1% the energy needed for disruption) into planetesimals that occurred in the first ~100 Myr of Solar System history [2, 3]. In such cases, mass loss from the impactor and target was minimal, and the impacts led either to localized heating which could drive metamorphism in small volumes of a target [2] or exposure of otherwise-buried materials to space which would have accelerated cooling of radiogenically heated bodies [3]. However, more energetic collisions are likely to have occurred which would have led to significant erosion or disruption of the target body, with significant ejection of mass and possible reaccumulation into an altered planetesimal. This type of evolution has been invoked to explain the evolution of meteorites such as the Iron IA/Winonaites [4,5] and Iron IIE [7].

In order to quantitatively investigate the thermal evolution caused by energetic planetesimals collisions in the early Solar System, we are using the iSALE hydrocode to simulate the shock processing that occurs during and immediately after the collision (heating, acceleration of materials). We then are adapting the REBOUND particle code [8] to follow the dynamical evolution of the remaining target and and all ejected material to determine the provenance and relative positions of materials that reside in the final body. This is a similar approach to that outlined in Leinhardt and Stewart (2009) [9]. Our goal is to determine the types of collisions which would have occurred in the early Solar System, as evidenced by meteorite parent bodies, and use this information to constrain the dynamical evolution of the early Solar System. Here we describe the progress made toward that goal.

REBOUND: REBOUND is an N-body particle-based code similar to *pkdgrav* [9-11], which tracks the motions of a large number of rigid spheres as they interact with one another gravitationally and through collisions. Particles are initially definied as having a mass, radius, position, and velocity, but no internal evolution (shock heating, fragmentation, etc.) is allowed to occur. Collisions can be treated as being elastic, inelastic (with a defined coefficient of restitution) each of which results in bouncing of the particles, or as resulting in perfect merging of the two particles, where two colliding particles are replaced with a single particle of equivalent mass and volume.

As an initial step in the development of this project, we compared the outcome of a simulation performed with REBOUND to one that used the particle pkdgrav as described in Leinhardt et al. (2000) [10]. Specifically, we modeled the collisions between rubble pile asteroids at various speeds and impact angles. We followed the same methodology as [10] and carried out a series of runs using the same initial conditions and parameters as defined in their study. We see similar final masses and mixing of the impacting bodies as found in [10].

Combining iSALE and REBOUND: Having verified that REBOUND could reproduce the results of Leinhardt et al. (2000), we then applied it to follow the post-impact dynamical evolution of materials from an iSALE simulation. The iSALE simulation for a given collision scenario was run until the shock wave from the impact had dissipated in the target body. The final states of all materials in the simulation were then taken as the initial conditions for a REBOUND run, with particle properties defined for each grid cell in the iSALE simulation: radius, mass, position, and velocity.

Here we report the runs for an a combined iSALE-REBOUND simulation of a 10 km body striking a 100 km target at 45 degree angle at 8 km/s. Figure 2 shows snapshots of the immediate post-impact state of the planetesimal using the iSALE code. The planetesimal is assumed to have been heated by radioactivity for 5 Myr at the time of the collision. The initial set-up of the REBOUND simulation is shown, with the outer 35 km of the body colored as red spheres, along with a snapshot 5 minutes into the model run. The large blue sphere at the center results from the perfect merging of the low velocity materials in the target as the run proceeded. Ejected materials which, are largely red and thus originate from the outer portion of the target, fan away from the body, colliding with one another and evolving dynamically under the influence of all mass in the simulation.

Future Plans: We are currently investigating a suite of impact scenarios in iSALE, varying impactor size, velocity, and angle of impact, as well as target size and thermal structure. Our goal is to determine the fate of all materials involved in a collision, and to determine the physical state of those materials which reaccrete to serve as parent bodies of meteorites. We will specifically note the temperature distribution of the materials in those products and follow the subsequent thermal evolution. We will also consider differentiated bodies and the fate of mantles and cores. Ultimately, our model predictions will be compared to meteoritic data to constrain the collisions that occurred in the early Solar System.

References: [1] T. M. Davison et al. (2013) MaPS 48, 1894-1918. [2] T. M. Davison et al. (2012) GCA 95, 252-269. [3] F. J. Ciesla et al. (2013) MaPS 48, 2559-2576. [4] Benedix et al. (2000) MaPS 35, 1127-1141. [5] Schulz et al. (2012) GCA 85, 200-212. [6] Scott et al. (2014) GCA 136, 13-37. [7] A. Ruzicka and M Hutson (2009) GCA 74, 394-433. [8] H. Rein and S. -F. Liu (2012) A&A 537, A128. [9] Z. M. Leinhardt and S. T. Stewart (2009) Icarus 199, 542-559. [10] Z. M. Leinhardt et al. (2000) Icarus 146, 133-151.

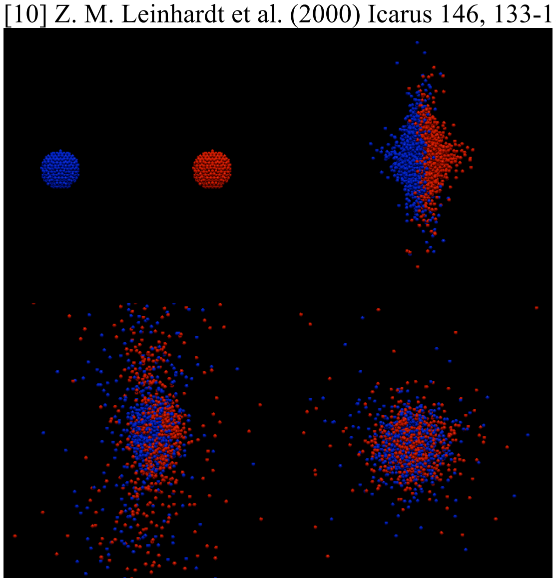

Figure 1: Different stages of evolution for a rubble pile collision modeled with REBOUND following [10] Initial conditions are shown in the upper left, while the upper right shows a period shortly after impact. The lower panels show the gradual reaccumulation of a body which is a mix of the fragments from the original rubble piles, while some debris is lost.

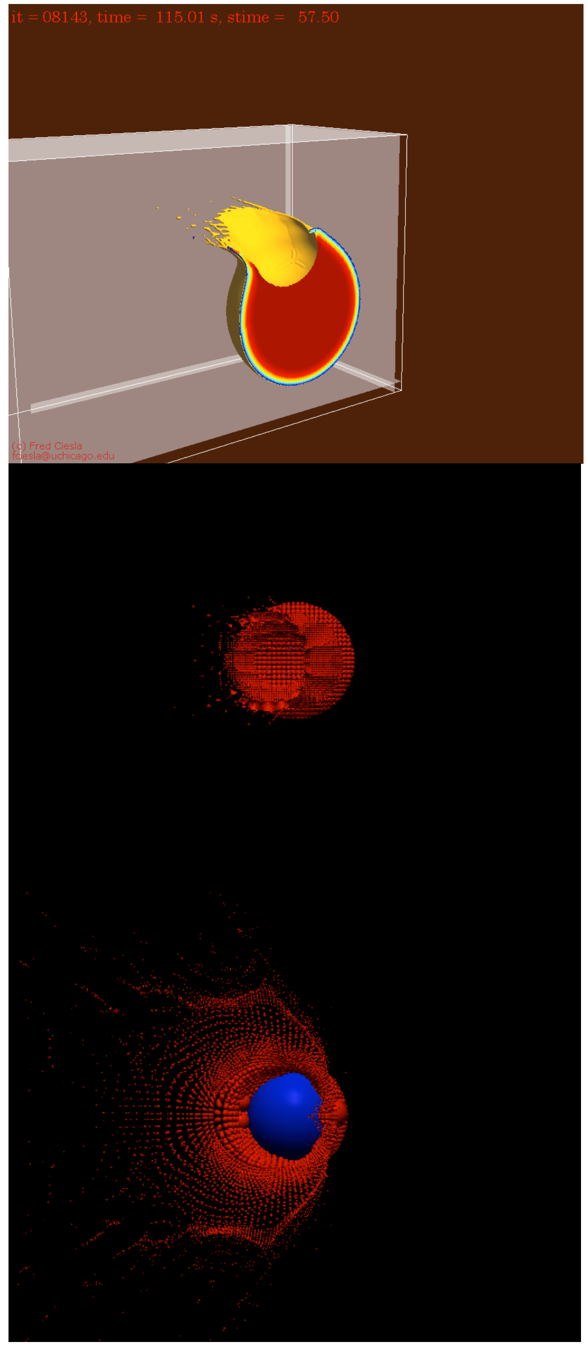

Figure 2: Top panel: iSALE simulation of an impact into a radiogenically warmed planetesimal (colors correspond to material temperature. Middle panel: Initial conditions for REBOUND run based on the iSALE simulation; outer 35 km of target is colored red. Bottom: Distribution of particles 5 minutes into the REBOUND simulation. Blue sphere represents low velocity interior of the target.