A MODEL FOR THE THREE-DIMENSIONAL HEATING OF A PLANETESIMAL. T. D. Komacek[1], F. J. Ciesla[1], and T. M. Davison[1], [1]Department of the Geophysical Sciences, University of Chicago, Chicago IL 60637, USA (tkomacek@uchicago.edu)

Introduction: Signs of heating are widely seen in meteorites in the form of differentiation and thermal alteration. Models for the warming and cooling of planetesimals from the decay of radionuclides such as ^{26}Al have been able to match the thermal chronology and cooling rates recorded by many meteorites and thus provide constraints on the formation history of their parent bodies [e.g. 1-4].

However, not all sampled meteorite thermal histories can be matched entirely by radionuclide-based thermal models [1,5]. Hence, recent efforts have aimed to quantify the relative role of impacts on parent body thermal evolution [6] and shown that the thermal evolution of impacted regions of a young planetesimals could be comparable to that recorded by meteorites [7]. Given that impacts were common in the early solar system, modeling the thermal history of meteorite parent bodies requires accounting for the combined effects of impacts and radionuclides [8].

Previous studies of the long-term thermal evolution of planetesimals as a result of impacts have focused on head-on, or normal incidence impacts, where the impact has occurred along the line connecting the centers of the target and impacting bodies [6-8]. However, impacts are expected to occur over a range of impact angles (the most common being 45°) and will not produce axisymmetric structures. Instead, the three-dimensional structure must be considered to properly account for the thermal evolution. We have developed a model to study this thermal evolution; here we present the results of our validation tests. Our goal is to apply the methodology from [6,8] and extend it to explore three-dimensional collisions in order to better constrain the relative contributions of impacts and radionuclide heating in the thermal history of bodies from the young Solar System.

Modeling Approach: Our approach is to compute the thermal evolution of a planetesimal using a finite-volume model that solves the heat equation in three dimensions using Cartesian coordinates. The planetesimal is divided into cubes each measuring 450 meters on a side, with the model considering the full planetesimal in the x- and y-directions, but only a hemisphere in the z-direction (symmetry is assumed across the z=0 plane). Surface elements of the planetesimal are set equal to the ambient temperature in the model.

To validate our approach, we modelled the thermal evolution of a planetesimal due to internal radiogenic heating using parameters similar to what has been inferred for the H-chondrite parent body: a radius of 100 km and accretion time of 2.2 Myr after CAI formation [1]. We assumed a thermal conductivity of 2.1 W/mK, asteroidal density of 3300 kg/m^3, and specific heat capacity of 837 J/kgK, taking all values as constants to allow for comparisons of our numerical results to analytic solutions [2]. The ambient temperature was assumed to be 200 K.

Results: Figure 1 shows three snapshots of the thermal evolution of the body, displaying the radial temperature distribution at 10, 20, and 50 Ma after accretion. For comparison, the analytic solution to the thermal structure of the planetesimal is also provided. While the numerical results do not reproduce the analytic solution exactly, the difference between the two thermal profiles is minor (within 2%) and and is improved as we increase the resolution of our model—our model results approach the analytic solution as we increase the number of grid cells in the planetesimal, though at a cost of longer runtimes.

As we are modeling a spherical planetesimal, we expect that the parent body will develop an onion-shell-like structure, with highest peak temperatures found in the center of the body. Figure 2 shows how the expected thermal evolution of the parent body varies along different directions through our model planetesimal. The highest peak temperature reached by the body is ~1155 K, in close agreement to the peak temperatures found using the analytic solution presented in [2] for similar assumptions (<2% difference). Figure 2 shows the peak temperature profiles along the x- and y-axes (full diameters across 200 km of the planetesimal) and the profiles lie on top of one another, demonstrating symmetry in those directions. These profiles are in agreement with the profile along the z-axis as well, again producing the expected symmetry.

The cooling rates of materials along the x-, y-, and z-axes are also shown. The lower cooling rates in the interior, the agreement in the different directions, and the matching of the analytic solution demonstrates that our model produces the expected onion-shell structure for pure radiogenic models and thus provides an accurate description of the planetesimal thermal evolution.

Discussion: We are now modifying our code to receive inputs from the iSALE3D hydrocode, shown in Figure 3, enabling comparison of the predicted thermal histories of materials in an impacted planetesimal to inferred thermal histories of particular meteorites (cooling rates (at 773 K) and peak temperatures as in [6]). These analyses will be carried out for various impactor sizes, velocities, and impact angles to enable a variety of comparisons with cooling rates from the literature [e.g. 1,9]. Results will be presented at the meeting.

References: [1] Harrison K. P. and Grimm R. E. (2010) *GCA, 74,* 5410-5423. [2] Hevey P. J. and Sanders I. S. (2006) *M&PS, 41,* 95-106. [3] Trieloff M. et al. (2003) *Nature, 422,* 502-506. [4] Kleine T. et al. (2008) *E&PSL 270,* 106-118. [5] Schulz T. et al. (2012) *GCA, 85*, 200-212. [6] Davison T. M. et al. (2012) *GCA, 95*, 252-269. [7] Davison T. M. (2011) *PhD Thesis*. [8] Ciesla F. J. et al. (2013) *M&PS,* Submitted. [9] Taylor G.J. et al. (1987) *Icarus*, *69,* 1-13.

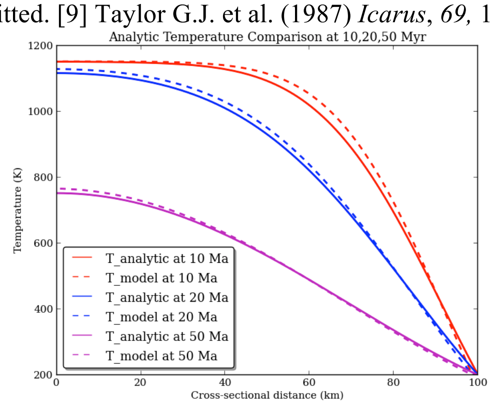

Figure 1: Radial comparison of model and analytic [2] temperature distributions at 10 (red), 20 (blue), and 50 (magenta) Myr after formation of the H Chondrite parent body. While slight differences exist, there is good general agreement between the analytic and numerical models.

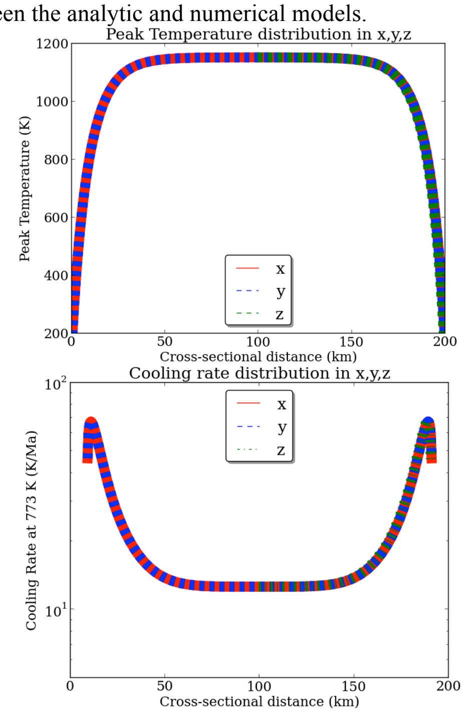

Figure 2: Top: Profiles of the peak temperature reached by materials in the planetesimal in x,y,z directions at the end of the model time. The peak temperatures found for the line drawn along the x-axis (red) overlap with that along the y-axis (green) as expected due to symmetry. The temperature along the z-axis (blue) is also shown, but only for a radius rather than a full diameter as we model only a hemisphere. Bottom: Profiles of the cooling rate in K/Ma at the end of the model timeframe through the center of the planetesimal.

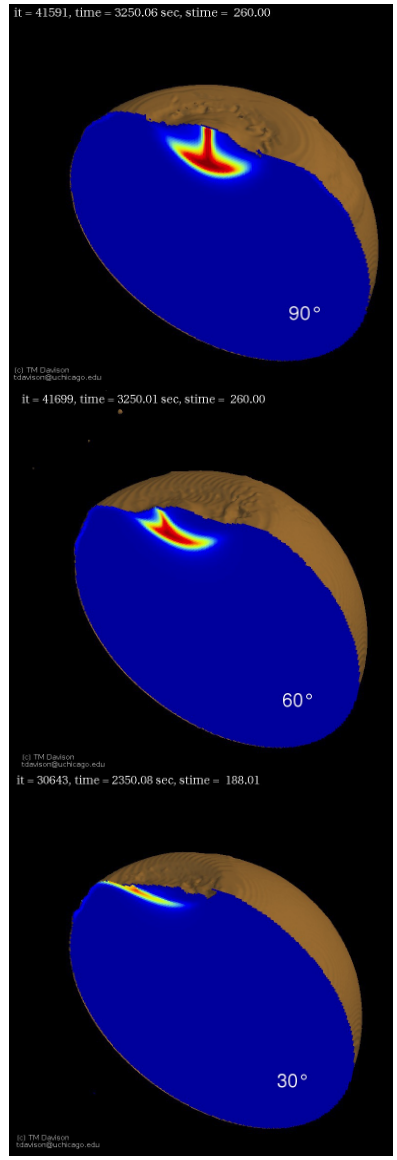

Figure 3: iSALE3D runs of a 10 km impactor into a 100 km target at 4 km/s at various impact angles. The colors indicate post-impact temperatures of materials in the planetesimal (red indicates highest temperatures while blue displays lowest). Our 3D thermal model will be applied to quantify the differences in thermal evolution for materials in these different cases.