GIANT IMPACTS BETWEEN ROTATING BODIES IN AN EULERIAN CODE. A. C. Pepper[1], S. J. Lock[2], E. J. Davies[1], S. T. Stewart[1], [1]Department of Earth and Planetary Sciences, U. of California, Davis (acpepper@ucdavis.edu), [2]Division of Geological and Planetary Sciences, California Institute of Technology.

Introduction: During the late stages of terrestrial planet formation, giant impacts influence the composition and dynamics of the growing planets [1]. To study these processes, the motion and deformation of the bodies are modeled using hydrocodes [e.g., 2, 3]. These codes come in two main varieties: particle-based and mesh-based. Particle-based methods, notably SPH, are much more common due to their computational efficiency. Mesh-based codes have their own advantages (e.g. greater resolution across shock fronts), thus both are needed to study different aspects of collisional processes during planet formation.

In giant impact simulations, establishing initial conditions requires high resolution structural models of the colliding bodies. When calculating impacts in mesh-based codes, methods have been developed to initialize spherical bodies in gravitational equilibrium. However, it is expected that most bodies were rapidly rotating during accretion [4] and this can have a significant effect on the impact outcome and the properties of the post-impact body [5, 6, 7]. Impactors with significant angular momenta, are not well approximated by gravitationally equilibrated spheres and currently there are no robust techniques for initializing rotating planets in mesh-based codes. It has therefore not been possible to use mesh-based codes to accurately model and study impacts between rotating bodies.

Here, we present a method for initializing oblate spinning bodies in CTH, a mesh-based code [8], using the recently-developed HERCULES (Highly Eccentric Rotating Concentric U (potential) Layers Equilibrium Structure) program [6]. Furthermore, we examine the errors introduced during advection of material through the mesh and discuss resolution requirements for conducting physically accurate giant impact simulations.

Methods: CTH is an Eulerian, shock physics code that has been previously used to simulate giant impacts with realistic equations of state [9,10]. Like many Eulerian codes, CTH used Adaptive Mesh Refinement (AMR) wherein the blocks that compose the grid are subdivided recursively. To initialize oblate bodies in CTH, we first calculated the structure of an isolated, rotating planet using the HERCULES code. HERCULES uses potential field theory methods to calculate the equilibrium structure of bodies by modeling the body as a series of concentric, overlapping, constant-density spheroids, as shown schematically at the top of Figure 1. The regions in-between concentric spheroids define 3D shells, that we will call layers, which are homogeneous in density, pressure, and temperature.

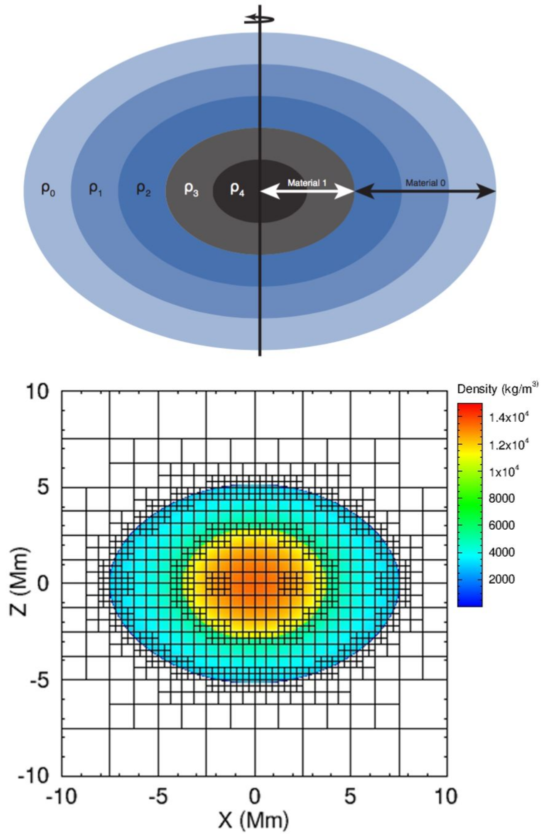

Fig 1: Example structure of a rotating Earth-mass planet. The top figure shows schematically how bodies are represented in HERCULES: as an ensemble of concentric spheroids. Not shown in the figure are the surface points which compose each of these spheroids. The bottom figure depicts a cross-section of the body, perpendicular to the rotation axis, after initialization in CTH. This particular body has an angular momentum of $2L_{EM}$, where $L_{EM} = 3.5 \times 10^{34}$ kg m^{-2} s^{-1} is the angular momentum of the present Earth-Moon system, a rotational period of ~3 hr, and a flattening of 0.31. The solid black lines in the figure trace the boundaries between blocks in CTH's mesh. Each block is a cube of 8x8x8 cells.

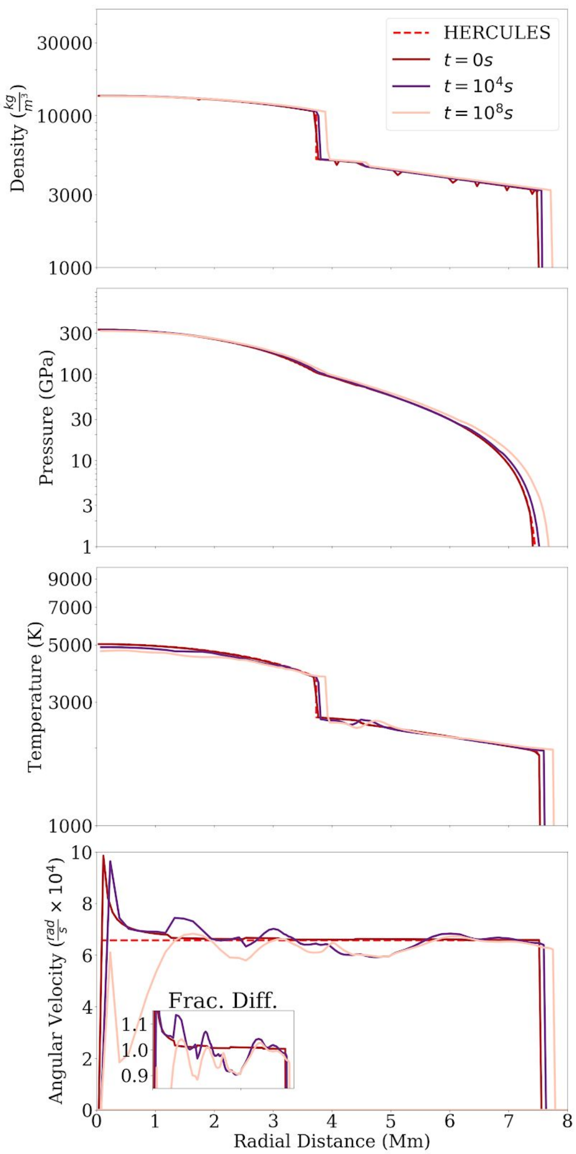

Fig 2: Evolution of density, pressure, temperature, and angular velocity of a rotating body in CTH. The curves labeled HERCULES display the direct output of HERCULES. The curves labeled t = 0 s correspond to the the body after initialization in CTH. The inset plot in the angular velocity panel displays the angular velocity of the CTH calculation normalized to the bulk rotation rate of the HERCULES initial state.

To transfer the thermodynamic structure of a planet into CTH, we inserted polygons with the shape, density and temperature of each HERCULES layer into CTH using our new HOTCI (HERCULES Output To CTH Input) package. We found that roundoff errors produced unsatisfactory results when pressure and density were the insertion variables.

To ensure that each layer is fully resolved, the maximum cell width in CTH was constrained to be significantly smaller than the minimal HERCULES layer width.

For our calculations, we initialized bodies that were one third iron core by mass, with a forsterite mantle. We used the M-ANEOS forsterite equation of state for the silicate mantle [9,11] and the ANEOS equation of state for the iron core [10].

Results: To test the robustness of our initialization process, we studied the evolution of isolated, rotating planets in CTH. Figure 2 shows the evolution of the internal structure of an example, rapidly-rotating, Earth-mass body. We found that if sufficiently high resolution was used, both for the HERCULES planet and for the CTH mesh, the initialized planets were relatively stable over timescales on the order of a few hours, which is sufficient for a giant impact simulation. Stability requires at least 100 layers in HERCULES, a cell-width to radius ratio no less than 1:32 across the material interfaces in CTH, and the finest spatial resolution possible in CTH's self-gravity calculation.

Minor artifacts develop at the boundaries between the initialized layers as the structure adjusts, but these artifacts dissipate after only a few minutes. Over time scales on the order of a day, the center of mass of the body drifts away from its starting location as oscillations in both total energy and radial profile grow.

Summary: We have developed a new technique for initializing rotating bodies in the CTH Eulerian shock-physics code. The initialized bodies are stable over several hours, more than sufficient for modeling giant impacts between rapidly-rotating bodies. Using this routine, we will perform example calculations of giant impact collisions with pre-impact rotation in CTH and compare them to simulations performed using the smoothed particle hydrodynamics code GADGET2, which has previously been used to study such collisions [5, 7].

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