A One Hundred Million SPH Particle Simulation of the Moon Forming Impact

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We have performed a Smoothed Particle Hydrodynamics (SPH) simulation of the Moon-forming impact using 10^8 particles. SPH codes are well-suited to computing gravitational interactions in 3D, tracking provenance, and are guaranteed to conserve mass, so are the usual choice for studying this problem. Furthermore, the well-tested Hashed Oct-Tree (HOT) code [1, 2] that we use has been parallelized to work efficiently on multiprocessor machines with distributed memory. This means that large numbers of particles can be used with a time integration scheme that conserves both energy and angular momentum to much better than 1%.

Our simulation contains 100 times more particles than in the state-of-the-art simulations published to date, which typically deploy a few million particles [3, 4, 5, 6, 7] This simulation has achieved spatial resolutions on the order of $\sim$30 km in the planet and a few hundred kilometres in the Moon-forming disk. These resolutions are almost an order of magnitude finer than in any of the aforementioned published simulations.

A careful reading of a very recent study of resolution-dependence of Moon-forming impact simulations [7] shows that at least two important constraints on impact outcomes – the iron content of the Moon-forming disk and the amount of material with orbits lying wholly beyond the Roche limit – have not converged to numerically stable limits in 10^6 particle simulations (nor in Eulerian simulations of comparable spatial resolution). Higher resolution is required to address these issues by (i) vertically resolving the disk, and (ii) reducing numerical viscosity into the estimated range of physical viscosities. We have applied mature algorithms, common in the fiel of cosmology, to find bound objects within the Moon-forming impact disk and produce the mass function of these 'moonlets' at different times. This will shed light on the temporal evolution of the Moon-forming disk sub-structure and the eventual fate of such objects. Earlier work, with lower resolution simulations, suggests that these bound objects are short lived while our high resolution simulation seems to show that these substructures can survive for most of the history of the Moon-forming disk.

In Figure 1, we present three snapshots of the Moon Forming Impact. The initial Mars-sized object arrives from the upper-right, making initial contact with the proto-Earth. In the centre, the "impactor" and initial debris approaches for a secondary collision. In the bottom row, the cores of the proto-planets have merged, leaving an orbiting stream of iron-poor material and a vapour cloud that evolves to form the Moon.

References

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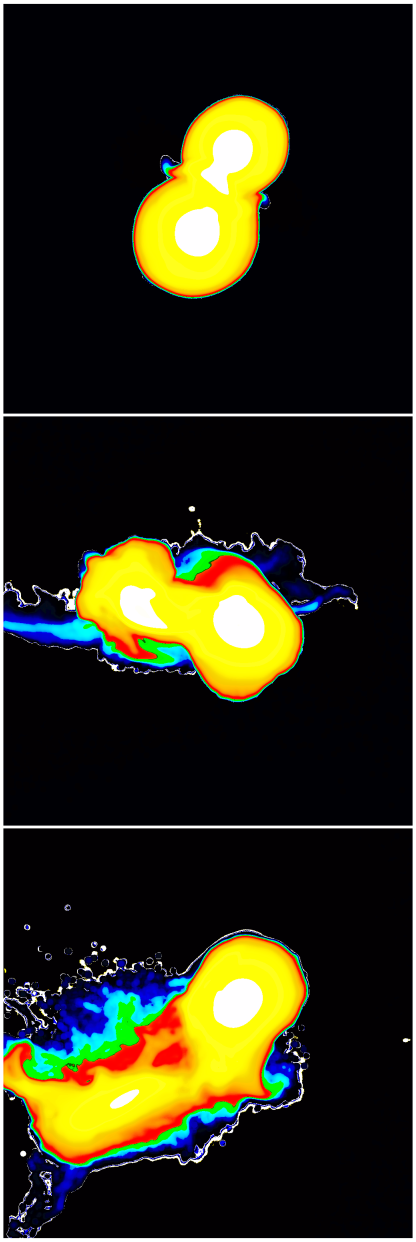

Figure 1: Snap shots of a planetary collision simulation with 10^8 SPH particles. Colours represent the logarithm of the projected density. The images are chronologically ordered from the top to the bottom. This simulation used 100 million particles, a Tillotson (1962) Equation of State (EOS) [8] and was evolved for $\sim$5 hr after the Giant Impact taking place.

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