ACCRETION OF THE MOON FROM AN IMPACT GENERATED DISK; R. M. Canup, H. F. Levison, G. R. Stewart and L. W. Esposito

In a recent work, we presented the first numerical calculations of accretion of an impact-generated protolunar disk into a single large Moon [1]. Our calculations were based on the model developed by Canup and Esposito to describe accretion in the Roche zones around the giant planets [2]. Previous numerical simulations (e.g. [3]) of a large impact event predict the formation of a disk of material centered near or within the Roche limit ($\sim 2.9R_E$). A natural expectation based on results in [2] and comparison with the satellite systems of the outer planets would be for multiple small moons to arise from such a protolunar disk. Multiple moonlets could accrete to form a single Moon if they evolved into crossing orbits due to tidal interaction with the Earth. This would occur if the innermost moonlet in the disk were also the most massive, so that it evolved outward at the relatively fastest rate and swept up all exterior material. The analysis in [1], which included both moonlet accretion and orbital evolution, demonstrates that forming massive moonlets in the inner disk near the Roche limit is extremely difficult. An Earth system with multiple moons is the final result unless some particularly severe constraints on initial conditions in the disk are met. We found that a disk with a lunar mass of material exterior to $a \sim 3.5 - 4R_E$ or an extremely steep radial surface density profile at the onset of collisional growth is required for a single, lunar-sized body to result from accretion of silicate density material in a protolunar disk. The former corresponds most closely to disks produced by impactors with nearly twice the mass of Mars and about twice the angular momentum of the current Earth/Moon system.

The possible effects of resonances between moonlets were not modeled in [2], and so we have recently begun investigations to determine if accretion of a smaller inner body by a larger exterior protomoon could be aided by eccentricity excitation during capture into mean motion resonances. We have added perturbations due to the potential of a tidal bulge raised on the Earth by an orbiting body to the Levison and Duncan mixed-variable symplectic integrator, SWIFT [4]. Evolution of the semi-major axis, eccentricity, and inclination of orbiting bodies due to the tidal bulge potential are all included, in addition to the mutual interactions among the primary and all orbiting moonlets. Although our study is in its preliminary stages, we have found that the 2:1 mean motion resonance can effectively excite an inner moonlet into a crossing orbit with an exterior perturber for a mass ratio between the inner and outer moonlet of 0.1. Figure 1 is a typical result. If further work demonstrates that such an effect is also present between moonlets with smaller mass ratios, the constraints found in [2] could be somewhat eased. However, enough mass would still have to be initially ejected into orbits with $a > 3.5 - 4R_E$ to allow for the outer perturbing moonlet to accrete, and so disks formed by high angular momentum impactors still seem to be favored.


© Lunar and Planetary Institute • Provided by the NASA Astrophysics Data System
Figure 1: The evolution of two moonlets in Earth orbit. The outer and inner moonlets have masses of $10^{25}$ and $10^{24}$ g respectively, and evolve outward as they tidally interact with the Earth. Lines 1 and 2 are the 2:1 and 3:2 mean motion resonances; lines 3 and 4 are the semi-major axes of the inner and outer moonlets. The shaded regions surrounding the semi-major axes curves represent the maximum radial extent of the orbits at periapse and apoapse. The excitation of the eccentricities causes the moonlets to occupy crossing orbits after about 60,000 years.