DISK ACCRETION EFFICIENCY IN A MULTIPLE-IMPACT LUNAR ORIGIN SCENARIO. J. Salmon[1] and R. M. Canup[1], [1]Southwest Research Institute, Planetary Science Directorate, 1050 Walnut Street – Suite 300, Boulder, CO 80302, USA (julien@boulder.swri.edu).

Introduction: The origin of Earth's Moon remains uncertain. The leading hypothesis relies on the Moon accumulating from an impact-generated disk. Recently, [1] proposed an alternative scenario in which the Moon forms progressively via multiple smaller impacts. Each impact results in the formation of a "moonlet", and the Moon results from the consecutive merging of several moonlets. These impacts produce much smaller disks, of order 0.1-1M_L, which are much smaller than in other impact scenarios [2,3]. The mass of the moonlet formed from such disks iwas estimated in [1] using a standard analytical prescription from [8]. In [2] we revised this expression using a more accurate numerical modeling of the protolunar disk, and found that the mass of the moon that would form from a given disk would be generally much smaller than predicted by [8], especially at large specific angular momentum $\left(J_{spec} \geq 1\right)$. The evolution of a < 1$M_L$ disk has not been studied in detail, so it is not clear if predictions from [4] or [2] would be accurate in this context. The initial mass and position of each "moonlet" are essential parameters for their subsequent tidal evolution and for whether moonlets formed by subsequent impacts will merge to grow the Moon. It has also implications for the number of moonlets, and thus the total number of impacts, that may be required to grow a lunar-mass object, which may affect the probability of success in this scenario.

Numerical model: We model the disk's evolution using a hybrid numerical model [2,3]. The code includes viscous spreading of a Roche-interior disk, resonant interactions between the disk and outer moonlets, and formation of new objects at the Roche limit. We neglect tidal interactions as those processes affect the system on much longer timescales.

Accretion simulations: We have performed a suite of numerical simulations to study the accretion of a moonlet from disks similar to those produced by the impacts considered in [1]. The initial structure of the disk is adapted from that of the disk shown in Figure 6 of [1] (R. Rufu, personal communication). We consider disks with a total mass $0.1 - 1M_L$, with 30-50% inside the Roche limit, and a surface density profile for the outer disk $\sigma \propto r^{-\alpha}$ with $\alpha = 2 - 3$. The outer disk is composed of 600 bodies with an outer edge from $5 - 9R_\oplus$. The produced disks have $0.99 \leq J_{spec} \leq 1.2$, while [1] finds disks with $0.7 \leq J_{spec} \leq 1.14$.

Figure 1 shows the mass of the largest object at 10^4 years as a function of the disk's specific angular momentum. Black triangles are results from a set of 60 simulations, while the red crosses are from the canonical case [2] and are shown for reference. The black lines are the analytical estimates from [4], considering either that 0 or 5% of the disk's mass escapes the system (continuous and dashed line, respectively). The blue lines are revised analytical estimates from [2].

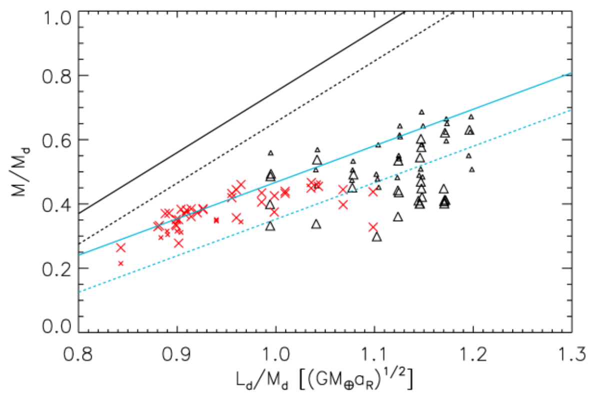

Figure 1: Ratio of the mass of the largest body at t = 10^4 years to the initial disk mass, as a function of the disk's specific angular momentum. Black triangles are results from the new set of simulations. Red crosses are from canonical disks [2] and are shown for reference. Small symbols are cases where the mass of the second largest body is at least 20% that of the largest one. In those cases we added the mass of the two bodies, since tidal evolution could cause them to merge later on. The black solid and dashed lines are analytical estimates from [4] assuming 0 or 5% of the disk's mass escapes, respectively. Blue lines are our revised analytical estimates from [2].

We find good agreement between our numerical results and our revised analytical. While our simulations do not cover the full range of possible disk J_{spec}, it appears that disks with $J_{spec} \geq 0.99$ would form a moonlet whose mass is about a factor of ~2 smaller than predicted by [4]. If that trend continues at smaller J_{spec}, it is possible that twice as many impacts as estimated in [1] could be needed to form a lunar-mass object. This may affect the likelihood of a multiple-moon scenario, as a larger number of impacts having struck the Earth is unlikely.

References: [1] Rufu, R, Aharonson, O, Perets, Hagai B (2016) *Nat. Geosc.* 10, 89-94. [2] Salmon, J., Canup, R. M. (2012) *ApJ 70*, 83. [3] Salmon, J., Canup, R. M. (2014) *Phil. Trans. R. Soc. A* 372: 20130256. [4] Ida, S., Canup, R. M., Stewart, G. R. (1997) *Nature*, 389, 353-357.