Formation of Phobos and Deimos via a Giant Impact

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Based on the paper by Citron et al. (2015)

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Abstract

Giant impacts during late stages of planet formation can explain a variety of solar system phenomenon. The most well known theory is the the formation of Earth's moon via giant impact (Hartmann & Davis (1975), Cameron & Ward (1976)). Giant impacts can also explain Mercury's thin mantle, through large grazing impacts (Asphaug & Reufer (2014)). A giant impact may have formed the Pluto-Charon system as well as Pluto's smaller moons (Canup (2011)) Finally, the motivaiton for this work is that the Martian moons, Phobos and Deimos, could have formed from a giant impact. The Mars Express mission found results consistent with the idea of in-situ formation of the Martian moons for two primary reasons (Witasse et al. (2014)). First, minerals were detected on Phobos that are also found on the surface of Mars. Second, they found the density (1.87 g cm^{-3}) and porosity ($\sim 30\%$) of Phobos to be inconsistent with the capture model, as such an object would likely break up during capture. Furthermore, both Phobos and Deimos have nearly circular orbits and small inclinations. Although tidal forces could have circularized Phobos, the tides on Deimos are not strong enough to have circularized it. However, in the giant impact scenario, we would expect both of the moons to have circular orbits with low inclinations (Rosenblatt & Charnoz (2012)).

In this work, the authors do a series of SPH calculations of a massive object impacting a Mars sized planets to explore the mass that would be ejected into a satellite forming disk. The initial conditions are constistent with Marinova et al. (2008), to explore whether the one giant impact could have caused the martian hemispheric dochotomy and the formation of the martian moons. The impact scenario is a Mars sized target with an iron core and an olivine mantle being hit by basalt body. The impactor has a nominal mass of $M_{imp} = 0.026 M_{\mars}$ and impact velocity of 6 km/s. The goal of these simulations was to study the mass of the intial debris disk as a function of impactor mass, velocity, and impact angle. Previous work has inferred the total mass of past and present martian satellites, by assuming that some fraction of the elongated Martian craters formed from short-lived satellite impacts (Schultz & Lutz-Garihan (1984)). These types of estimates make a lot of assumptions and can only used as an order of magnitured estimates. Even conservative estimates of M_{sat} are nearly two orders of magnitude greater than the mass Phobos, meaning that Mars likely had many satellites in the past. Craddock (2011) estimated that about half of the mass of a debris disk (M_d) produced by a giant impact would go into forming satellites (M_{sat}). In a more sophisticated study of a circum-Mars debris disk, Rosenblatt & Charnoz (2012) found that you need $M_d \sim 100 M_{sat}$. In this work, the authors found that a Borealis-scale impactor may capable of producing a debris disk large enough to form both Phobos and Deimos, although a more sphisticated study of the debris disk formed from their simulation is necessary.

To extend their work, I will repeat some of their simulations with `spheral++`, a parallel Adaptive Smoothed Particle Hydrodynamics with an oct-tree based N-body solver (Owen (2018)). The code can model solids and fluids as well as damage and fractures. I will try to match the initial conditions as best as possible, and see how our results vary. The debris disk formed by Citron et al. (2015) only contains ~ 280 particles although they are representing Mars with $\sim 3 \times 10^5$ SPH particles. I would like to repeat their simulations at higher resolution, because I think a robust result should have far more particles in the debris disk. Because `spheral++` can use an adaptive smoothing length, I can have much higher resolution near the surface of Mars. With the adaptive smoothing length, I should be able to do have a higher resolution impact and debris disk for the same number (or even less) SPH particles.

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