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The Origin Of Phobos And Deimos By A Giant Impact

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Abstract

Despite many efforts an adequate theory describing the origin of Phobos and Deimos has not been realized. In recent years a number of separate observations suggest the possibility that the Martian satellites may have been the result of giant impact [1]. Similar to the Earth-Moon system, Mars has too much angular momentum. A planetesimal with 0.02 Mars masses must have collided with that planet early in its history in order for Mars to spin at its current rate [2]. Although subject to considerable error, current crater scaling laws and an analysis of the largest known impact basins on the Martian surface suggest that this planetesimal could have formed either the proposed 10,600 by 8,500-km-diameter Borealis basin, the 4,970-km-diameter Elysium basin, the 4,500-km-diameter Daedalia basin or, alternatively, some other basin that is no longer identifiable. It is also probable that this object impacted Mars at a velocity great enough to vaporize rock (>7 km/s), which is necessary to place large amounts of material into orbit. If material vaporized from the collision with the Mars-spinning planetesimal were placed into orbit, an accretion disk would have resulted. It is possible that as material condensed and dissipated beyond the Roche limit forming small, low-mass satellites due to gravity instabilities within the disk. Once the accretion disk dissipated, tidal forces and libration would have pulled these satellites back down toward the Martian surface. In this scenario, Phobos and Deimos would have been among the first two satellites to form, and Deimos the only satellite formed--and preserved--beyond synchronous rotation. The low mass of Phobos and Deimos is explained by the possibility that they are composed of loosely aggregated material from the accretion disk, which also implies that they do not contain any volatile elements. Their orbital eccentricity and inclination, which are the most difficult parameters to explain easily with the various capture scenarios, are the natural result of accretion from a circum-planetary disk.

1. Introduction

Since their discovery in 1877, determining the origin of Phobos and Deimos has remained problematic. Spectral analyses suggest that the composition of Phobos closely matches black or carbonaceous chondrites. This combined with other physical properties such as their shapes, low densities and low geometric albedoes has led many investigators to suggest that they are captured asteroids. However, the orbits of both moons are extremely circular and their Laplace plane is very close to the Martian equatorial plane. Captured objects would be expected to have elongate orbits with randomly oriented orbital planes. Phobos may have been able to attain its circular orbit because it experiences tidal perturbations due to its closeness to Mars, which are aided by libration. However, Deimos is too far away to experience much of either. Integration of Phobos' present eccentricity into the past indicates that it would have collided with Deimos. A number of ad hoc alternatives have been proposed to save the capture theory, including circularization of their orbits from atmospheric drag induced by an extended Martian protoatmosphere or fragmentation of a single large captured satellite during the period of heavy bombardment. However, in the former scenario the protoatmosphere would have to be in place long enough to circularize the orbits of the satellites but removed before the resulting drag pulled the satellites down to the Martian surface. In the latter scenario, referred to as "coaccretion," the distribution of particle sizes caused by fragmentation of the captured object would follow a power-law relation with the largest object approaching ~85% the size of the original object. Reaccretion of this material would occur within a few hundred orbits, and it is unlikely that only two objects the size of Phobos and Deimos would remain. Also, reaccretion of the smaller particles into several objects would result in a satellite composed of many different sized blocks. However, analysis of Phobos' libration suggests that this satellite is composed of homogenous material. Analysis of the impact history of Phobos through smooth particle hydrodynamic code modeling also supports the idea that this satellite is composed of homogenous material probably <500 m in diameter.

2. The Giant Impact Scenario

If a planet forms from ordered accretion, then a maximum prograde angular momentum is possible. Dones and Tremaine [2] showed that Mars has too much angular momentum, and thus its spin rate must have been imparted by a giant impact. If craters with asymmetric or elongate ejecta on the Martian surface are the result of satellites whose orbits slowly decayed with time (similar to present-day Phobos), then the total mass of all Martian satellites would have been -10^{20} to $\sim 10^{21}$ g [1]. Determination of how much material is placed into orbit following the formation of a giant impact is not straight-forward. A majority of material ejected ballistically from an impact that explodes below the surface of a planet either escapes into space or falls back onto the surface. Cameron and Ward [3] proposed a solution for the formation of the Earth's Moon by suggesting that large amounts of vaporized material were released during collision. Vaporization of Martian geologic material following impact with a large bolide is possible because the impact velocity must be between 7-12 km/sec to induce shock vaporization. This is slightly higher than Martian escape velocity and not an unrealistic value for an approaching planetismal. Following impact, vaporized debris rising above the surface would continue to be accelerated by gas pressure effects and gravity. This mechanism allows much more material to be accelerated into orbit than by simple ballistic emplacement (-1/2 the vaporized mass) because the debris is given an added "kick." Vapor from both the planet and impactor need to mix efficiently, however, otherwise vapor from the impactor will exceed escape velocity and vapor from the planet will not reach orbit. Thus only a narrow set of initial conditions are possible. Using a particle-in-cell hydrodynamic code, Cameron [4] found that a "successful" accretion disk formed when the velocity of the impactor slightly exceeded escape velocity and most of the vapor came from the impactor. Phobos, Deimos, and all the other satellites which may have orbited Mars in the past are only a tiny fraction of the mass of the Borealis impactor (-0.5%) [1]. For this reason alone it seems plausible that enough material from the formation of the Borealis basin could have been placed into Martian orbit as an accretion disk. There are several other proposed impact basins on Mars which may have also been capable of placing debris into Martian orbit: the 4,970-km-diameter Elysium basin and the 4,500-km-diameter Daedalia basin are among the largest. Once an accretion disk is formed, gravitational instabilities prevent the particles from clumping. Temporary mass concentrations would, however, cause a transfer in angular momentum from Mars to the accretion disk and the disk would begin to dissipate both towards the Martian surface and out towards space. Once material in the disk emerged past the Roche limit, particles in the disk would begin to accrete. Small tides raised by this body would once again cause a transfer in angular momentum, and the small satellite would begin to recede from Mars. As the accretion disk continued to dissipate another small body would form in place of the first. In the formation of the Moon, the last body to form from the accretion disk would, by necessity, be more massive than the rest. Thus this large satellite would recede from the proto-Earth faster, accrete the smaller satellites, and form the Moon. However, in the Martian scenario this last, large satellite does not form, and Mars is left with a number of small, Phobos and Deimos-size objects.

3. Summary and Conclusions

In this scenario the orbital eccentricity and inclination of both Pbobos and Deimos, which are the hardest parameters to explain in any other model, are the natural results of having formed in an accertion disk. The amount of material ejected into Martian orbit following the giant impact is calculated to be extremely low—less than 0.5% of the impacting object. Also, unlike the Earth-Moon system, it is not necessary for the accretion disk to coalescence into one massive object. Thus, it is actually *easier* for Phobos and Deimos to have formed from a giant impact than it is for the Earth’s moon.

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References

[1] Craddock, R.A.: Are Phobos and Deimos the result of a giant impact? Icarus, 211, pp. 1150-1161, 2011.
[2] Dones, L., and Tremaine, S.: Why does the Earth spin forward? Science 259, pp. 350-354, 1993
[3] Cameron, A.G.W.: The impact theory for origin of the Moon, In *Origin of the Moon*, pp. 609-616, LPI, , 1986.
[4] Cameron, A.G.W.: Formation of the pre-lunar accretion disk, Icarus, 62, pp. 319-327, 1985.