Capture of satellite precursors and their orbital evolution by a rotating Martian proto-atmosphere

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Mars has two satellites: Phobos and Deimos. Their reflectance spectrum and bulk densities are similar to those of primordial carbonacious asteroids, which suggests "capture scenario" for the origin of martian satellites.

Phobos and Deimos have low-eccentricity and low-inclination orbits. If capture scenario is correct, their orbital features suggest that they experienced dissipation processes of their orbital energy. In previous studies, a static Martian proto-atmosphere produced by the gravitationally bound nebula gas has been proposed (Hunten 1979; Sasaki 1990). Such a static atmosphere, however, cannot attenuate orbital inclination and would cause the decay of the orbital radii, and prevent the formation of a satellite unless dissipation processes of proto-atmosphere are introduced. In this study, we focused on the possibility of a rotating Martian proto-atmosphere which is expected to attenuate the orbital inclination of a captured body while preventing its orbital shrinkage. Such a rotating atmosphere may form due to the gravitational acquisition of solar nebula gas preserving the angular momentum originally possessed and the transport of the angular momentum from a rotating Mars. In our model of a rotating atmosphere, the density distribution is analytically obtained assuming an isothermal atmosphere that is synchronized with the rotation of Mars inside the stationary orbital radii and obeys Keplerian rotation on the outside. To investigate the probability of capture and orbital evolution of small bodies, we performed orbital calculations using the density and velocity distributions for the rotating atmosphere model.

Numerical experiments to see the capture processes of small bodies from the outside of the Mars' Hill sphere are conducted under the framework of restricted three-body problem under the interaction with the rotating atmosphere. We found that prograde capture cases are not as rare as direct collision cases under the rotating atmosphere, but cases of retrograde capture also have been observed. Two-body orbital calculations and analytical estimate show that the retrograde bodies constantly receive dragging force from the rotating atmosphere and fall into Mars in a time scale of 1,000 yr or less. This may explain why there are only prograde satellites in the current Martian satellite system. Moreover, prograde bodies show slow orbital shrinkage with typical timescale > 100 kyr. Also, the orbital relaxation of a prograde body proceeds with timescales of tens of Myr and a few years for attenuation of inclination and eccentricity, respectively. These timescales are much shorter than the nebula life-time (~10 Myr). The orbital radii at the time of capture include the estimated initial orbital radii of Phobos and Deimos considering tidal evolution over their ages. Therefore, it is found that the capture of small bodies by a rotating Martian proto-atmosphere can explain the orbit of the current Martian satellites.

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