Orbital evolution of Martian moons by rotating Martian proto-atmosphere with low angular momentum

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Martian moons, Phobos and Deimos has radii about several km to 10 km, and irregular shapes. Their low albedos and reflectance spectra are similar to those of primitive carbonaceous asteroid which supports "capture scenario" for their origin.

In previous studies considering the capture due to energy dissipation by gas drag from the Martian proto-atmosphere caused by the gravitational bound of the nebula gas, it is possible to circularize the moons' orbit (Hunten 1979, Sasaki 1990). While this spherically symmetric atmospheric structure can make moon's orbit circular, it is impossible to attenuate the orbital inclination of the moon. Also, the satellite constantly receives atmospheric drag and cause moons to fall into Mars eventually. Although the giant impact theory (e.g. Rosenblatt+ 2016) explains such moons' orbital feature, it is difficult to form moons with carbonaceous composition because of high temperature environment during moon formation. On the other hand, in context of capture scenario, Matsuoka & Kuramoto (2018, JpGU) considered the atmospheric rotation and showed that the attenuation of inclination occurred and the orbital shrinking was inhibited. However, since this atmosphere has extremely large angular momentum (1.3 times the Martian spin anugular momentum) due to Keplerian rotation beyond the co-rotational radii, thus it seems difficult to realize to form. Also, there is a problem that moons are formed and stay beyond Deimos' orbit. In this study, we construct models of rotating atmosphere with much small anugular momentm and show that it is more advantageous in explaining the orbital features of the current Martian moons.

This study assumed that atmospheric rotation is limited within the Bondi radii and the velocity field is modeled as follows so that the rotational velocity becomes continuous by changes with distance. (1) Mars surface to co-rotational radii R_C: co-rotational atmosphere with Mars' spin. (2) co-rotational radii to Bondi radii R_B: attenuated atmospheric rotation with distance given by $v(r)=((R_B-r)/(R_B-R_C))^{\Gamma} v_K(r)$ (v_K is a Keplerian velocity, Γ is a constant which we set unity in this study). (3) Bondi radii to Hill radii: stationary atmosphere connecting nebula at Hill radii. Such atmosphere can be regarded as a case that has not enough angular momentum to make Keplerian rotation outside the co-rotational radii. The density field of the atmosphere was determined by the balance of centrifugal force by this velocity field, Mars gravity and pressure gradient, and the drag force by these velocity field and density field were given to the equation of motion of moons. This atmosphere has low angular momentum of only 0.14 % of the Martian spin angular momentum.

In numerical experiments, moons have the inward radial velocity component in all regions, but the orbital shrinkage is suppressed near the co-rotational radii due to small speed difference between moons and atmosphere. The typical timescale of attenuation of semi-major axes of Phobos size moons is the order of 10^4 yr or more. This timescale sharply increased as approaching the co-rotational radii, indicating that the moons stay well in this region. This result naturally explains the initial position near the co-rotational radii of moons before tidal orbital evolution. Since there is a speed difference between moons and the atmosphere even if the inclination takes small value, the attenuation of inclination occurs efficiently. In contrast to timescale of inclination decay derived in our previous study that is rapidly increasing with the

decay of inclination, timescale derived in this study has an upper limit of several thousand years for a Phobos size moon. This result explains small orbital inclination of the current Martian moons. Such tendencies are recognized in the same way when Γ has different positive values, and in the cases of the Deimos size moons, such orbital evolution occur more rapidly than those of Phobos size moons.

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