Formation of rotating Martian proto-atmosphere caused by magnetic torque and implications for the orbital evolution of Martian moons

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The Martian moon, Phobos and Deimos have small radii (about several to 10 km) and irregular shapes, low albedo, and reflectance spectra similar to those of primordial carbonaceous asteroids. From these features, “capture scenario” for their origin has been proposed.

However, it is difficult to explain their near circular and equatorial orbits by a simple capture scenario. Although the giant impact hypothesis (e.g. Rosenblatt et al. 2016) well explains the orbital features of Martian moons, it appears incompatible with the primordial carbonaceous composition suggested from the reflectance spectra because moons experience high temperature environment (~2,000 K) during such formation process (Hyodo et al. 2018). In order to explain the orbital features of Martian moons in the framework of the capture scenario, drag due to Martian proto-atmosphere formed by gravitational bound of the solar nebula gas, has been proposed as an orbital energy dissipation medium for the orbital evolution of moons. In previous studies (Hunten 1979; Sasaki 1990), the case of spherically symmetric and stationary proto-atmosphere has been examined. It was proven that orbits of moons can be circularized, but their inclination cannot be attenuated in principle. The case for rotating proto-atmosphere was studied in Matsuoka and Kuramoto (2018; 2019, JpGU). The case that rotational velocity decays with a power law of distance beyond the co-rotational radius, inclination of moons attenuates efficiently with a short time scale of 10^4 yr, and the moon formation near the co-rotational radii (Burns 1990) can be explained. However, in these studies, the rotational velocity is artificially given, and the source of angular momentum and the validity of atmospheric structure has not been sufficiently examined.

In this study, the evolution of the atmospheric rotational velocity structure is examined by considering the interaction with spinning dipole magnetic field which may exist in Mars as a source of the atmospheric angular momentum. Even in the region near Mars, if the atmosphere is dusty, it is weakly ionized by the decay of radionuclide, and the rotating Martian magnetic field can transfer angular momentum to the atmosphere. Since the torque received by the atmosphere depends on the magnetic flux density in the field strength, therefore the rotational velocity distribution strongly depends on the distance. Under the radionuclide ratio ^{40}K/H of 1.5×10^{-10} (Consolmagno and Jopikii 1979) and Martian equatorial magnetic field strength of 10 G, the atmosphere within the co-rotational radii can be co-rotated with Mars within the timescale of the order of 10^4 -10^5 yr, and the atmosphere can rotate to the region of ten and several Martian radius within the proto-planetary disk lifetime (~10^7 yr). This indicates that the Martian magnetic field is a possible angular momentum source for rotating atmospheres that can efficiently cause orbital evolution of captured small bodies to near circular, low inclination orbits.

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