PLANETESIMAL CAPTURE SCENARIO BY A ROTATING MARTIAN PROTO-ATMOSPHERE FOR THE ORIGIN OF MARTIAN MOONS. R. N. Matsuoka and K. Kuramoto, Faculty of science, Hokkaido University (Kita 10 Nishi 8, Kita-ku, Sapporo, Hokkaido, Japan: matryo@ep.sci.hokudai.ac.jp).

Introduction: The origin of Martian moons is enigmatic. The current Martian moons have near circular (eccentricity $e < 0.02$) and equatorial (inclination $i < 2$ deg) orbits. While a planetesimal capture scenario for the origin of Martian moons is consistent with the moons' VIS-NIR reflectance spectra that are similar to primordial carbonaceous asteroids, it faces a difficulty to explain such low-e and i orbits. Although a giant-impact scenario (e.g. [1]) has succeeded in explaining the moons' orbits with low-e and i, it has a difficulty to form moons with carbonaceous compositions because of high temperature alterations during moon formation [2]. As an attempt to explain the low-e and i orbits in the planetesimal capture scenario, the orbital energy dissipation processes of orbiting small bodies have been considered. For an energy dissipation medium, a proto-Martian atmosphere embedded in the solar nebula has been proposed [3, 4]. In previous studies, spherically symmetric and stationary atmospheres have been simply considered. While such an atmosphere can circularize circum-Mars orbits, it cannot attenuate their orbital inclination in principle. Also, in such a stationary atmosphere, since any orbiting bodies constantly receive atmospheric drag, thus orbital shrinking inevitably occurs and causes transient moons to fall to Mars. In this study, we report that a rotating atmosphere can attenuate orbital inclination of captured bodies and alleviate their orbital shrinkage. Such a rotating atmosphere may be formed by the drag of the atmosphere by rotating ancient Martian magnetism [5] and angular momentum supply to the atmosphere due to planetesimal bombardment [6].

Model: In this study, we first modelled the velocity and density distributions of rotating atmosphere, then performed orbital calculation using them for the atmospheric-drag term in the equation of motion of planetesimals and captured bodies.

Assuming an axisymmetric and isothermal atmosphere that is synchronized with the rotation of Mars inside the co-rotational radius and obeys Keplerian rotation on the outside, we derived the density distribution of rotating atmosphere analytically. The atmospheric composition is the same as the solar nebula gas. We refer this atmospheric model as "*reference rotating atmosphere*". For the derivation of atmospheric density, we set the boundary condition to connect continuously with the minimum mass solar nebula at Hill radius [7].

We performed three kinds of orbital calculation: "*capture experiment*" to investigate whether capture of planetesimal from outside of Mars' Hill sphere is possible, "*inclination experiment*" to follow the evolution of orbital inclination of captured bodies, and "*orbital shrinkage experiment*" to follow the evolution of their orbital semi-major axis. In these calculations, we used a leap-frog integrator for the gravity term and the 4^{th}-order Runge-Kutta scheme for the drag term. We set radius of planetesimal and captured bodies to 10 km (Phobos-size) and the drag coefficient to be unity [8]. The capture experiment is performed under the framework of circular restricted three-body problem. When the planetesimal reaches Mars' Hill sphere, we turn on atmospheric drag. The initial orbital eccentricity and inclination of planetesimal around the Sun is assumed to be 0 and the impact parameters to Mars are taken random. In the inclination experiment and the orbital shrinkage experiment, we considered the two-body problem consists of Mars and a captured body that initial eccentricity is 0. In these experiment, the initial orbital inclination and semi-major axis are taken as free parameters respectively. In the inclination experiment, we made calculations for the cases where the initial semi-major axis is 20,060 km (inside the co-rotational radius) and 30,000 km (outside the co-rotational radius), respectively.

Results and discussion: The capture experiment found that prograde capture rate is ~67% to the rate of direct collision onto Mars. Thus prograde cases are not so rare compared with the direct collision cases to Mars under the interaction with rotating atmosphere. Although many retrograde capture also have been observed (~1.12 times to that of direct collision rates), orbital shrinkage experiment and analytical estimate show that these retrograde bodies receive intense dragging force from the atmosphere and fall into Mars in a timescale of 1,000 yr or less (Fig. 1). This result may explain why there are only prograde moons in the current Martian system. Furthermore, we found that prograde bodies experience slower orbital shrinkage. Typical timescales of these orbital shrinkage are >100 kyr near the estimated initial orbit of Phobos just inside the corotation radius. Also, prograde bodies achieve orbital circularization and orbital inclination attenuation faster than nebula life-time (~10 Myr), with timescales of a few years and tens of kyr (Fig. 2) respectively. Moreover, the capture experiment show that the orbital radii at the time of capture include the estimated initial radii of Martian moons considering tidal orbital evolution over their ages [9].

We also examined the orbital evolution of captured bodies under the atmosphere in which the co-rotational angular momentum with the spin of Mars is leaked to the region beyond the corotational radius to the Bondi radius. The velocity distribution of this "*AM-leaking atmosphere*" is assumed to be co-rotation with the Mars spin inside the co-rotational radius, attenuated velocity given by $\left(\frac{r_B - r}{r_B - r_C}\right)^{1/2} v_K(r)$ in the region from the co-rotational radius to the Bondi radius, and stationary beyond. Here r is the distance from the Mars spin axis and $v_K(r)$ is the Keplerian velocity around Mars. In such a rotating atmosphere, despite having a lower angular momentum than modelled above, orbits of captured bodies evolve so as to be long-lived near the co-rotational radius, which can also cause a attenuation of orbital inclination (Figs. 3, 4). Furthermore, bodies captured outer region migrate to the co-rotational radius. This allows formation of moons with low-*e* and *i* near the co-rotational radius, consistent with the orbital features of the current Martian moons at the time of formation.

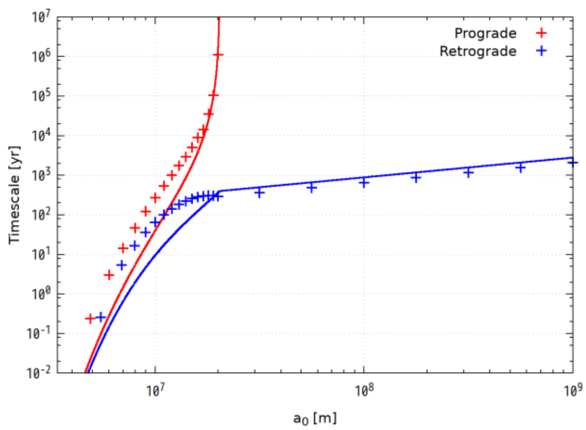

Fig. 1: The relationship between initial semi-major axis and timescale of orbital shrinkage in the reference rotating atmosphere. The analytical estimates and numerical results are shown with solid curves and points, respectively (red: prograde, blue: retrograde).

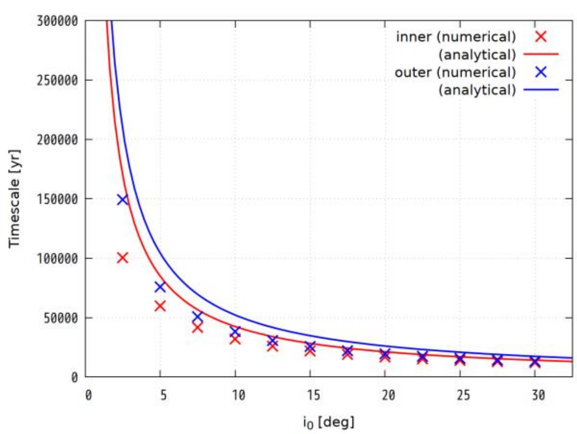

Fig. 2: The relationship between initial orbital inclination and timescale of the attenuation of inclination in the reference rotating atmosphere. The analytical estimates and numerical results are shown with solid curves and points, respectively, for inner bodies (*a* = 20,060 km, red) and outer bodies (*a* = 30,000 km, blue).

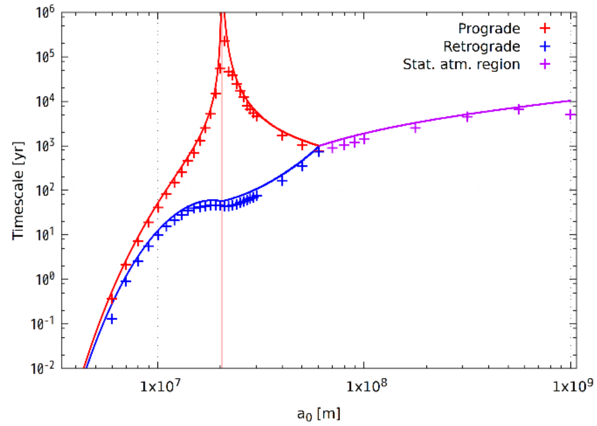

Fig. 3: The relationship between initial semi-major axis and timescale of orbital shrinkage of prograde moons in the AM-leaking atmosphere. The analytical estimates and numerical results are shown with solid curves and points, respectively (red: prograde, blue: retrograde). The purple solid lines and points show the timescale in the region of stationary atmosphere. In this region, relative velocities to the atmosphere are equal regardless of prograde or retrograde. The pink vertical solid line indicates co-rotational radius.

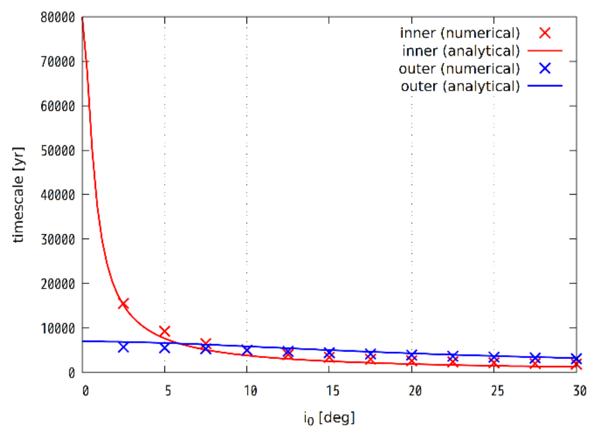

Fig. 4: The relationship between initial orbital inclination and timescale of the attenuation of inclination in the AM-leaking atmosphere. The analytical estimates and numerical results are shown with solid curves and points, respectively, for inner bodies (*a* = 20,060 km, red) and outer bodies (*a* = 30,000 km, blue).

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