DISTRIBUTION OF MARTIAN MATERIALS IN THE INNER SOLAR SYSTEM BY A GIANT IMPACT ON MARS

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Introduction: The rare asteroids, called A-type asteroids, orbit within the Hungarian region (~7% of the total mass) and within the main asteroid belt region (~0.4%). They have olivine-rich spectral features [1]. Their origin is still unclear even though some could be mantle materials fragmented and ejected by a catastrophic impact of differentiated primordial asteroid [2]. On the oter hand, olivine is a major mineral of the Martian upper mantle with ~60 wt% [3,4]. Also, at the surface of Martian grabens, such as Nili Fossae, an olivine-rich signature is detected [5,6].

Recent stidies showed that a giant impact may occur on Mars and it produced a Mars-orbiting debris from which Martian moons, Phobos and Deimos, acreete [7,8,9,10]. Recently, Polishook et al. (2017) [11] suggested that such Martian-moon forming impact may also produce a debris that escape from Mars' gravitational field, and some of them may have delivered to asteroid region. However, quantitative arguments such as mass, composition and orbits of the impact ejecta have been not studied yet.

In this talk, we will present our recent work [12] that investigated the compositional and thermodynamic properties of the impact ejecta produced by a giant impact that forms Martian moons [9]. We also present their mass and heliocentric orbits, and discuss the possibility of forming rare A-type asteroids.

Method: We performed high-resolution smoothed particle hydrodynamics (SPH) giant impact simulations that produce Martian-moons forming debris disks (typical impact parameters: impactor mass of ~0.03 mass of Mars, impact velocity of ~6 km/s and impact angle of 45 degrees) [9]. The total number of SPH particles in the simulation is $N=3\times10^5$ or 3×10^6. The initial entropy of Mars and the impactor is set to be 2000 J K^{-1} kg^{-1}, which corresponds to ~680 K at the surface of Mars (see more details in Hyodo & Genda 2018, ApJL [12]).

In this work, we focus on the SPH particles that are not gravitationally bound to Mars after the impact (particles that escape from Mars gravity). Then, using the data of the escaping particles obtained from our SPH simulations, we calculated Sun-centered orbits of the ejected particles (semimajor axis, eccentricity and inclination).

Results: SPH simulations show that our canonical impact (impactor mass of ~0.03 mass of Mars, impact velocity of ~6 km/s and impact angle of 45 degrees without pre-impact Martian spin) produces the following escaping debris [12]:

1. Mass of ~10^{-2} M_{Mars}
2. ~20wt% originates from Mars and the rest originates from the impactor
3. ~50% of the Martian material originates from Martian mantle (between 50 and 200 km in depth)
4. Temperature ranges between 1000 and 4000K with a peak around 2000 K

Assuming the Mg# (=Mg/(Mg+Fe) in mol) of bulk silicate Mars of ~75% [13] and thus $(Mg_{0.75}, Fe_{0.25})SiO_4$ olivine solid solution as a major mineral of the Martian upper mantle, solidus and liquidus temperatures are about 1850 K and 2000 K [14]. Then, using our SPH simulations, we found that ~10% of escaping Martian mantle debris does not melt but ~70% of the debris completely melts. In the case of partial melting (2000 K), ~20% of the Martian mantle debris avoids melting and thus they would preserve their primitive minerarogy. Hence, the unmelted Martian mantle material (olivine-rich material) is estimated to be about ~2% of the total ejected mass (~1.7×10^{20} kg). This mass is much larger than those of current A-type asteroids found in the Hungarian region (~2.8×10^{15} kg) and the current main asteroid belt (~8.9×10^{18} kg; [1]).

The orbits of the ejected particles are distributed between ~0.5-3.0 AU with eccentricity upto ~0.6 and inclination up to ~0.3 radian. Detailed stidues on the long-term evolution of the debris is required but the initial orbits of the debris shows that they can easily reach the asteroid belt region and thus unmelted Martian mantle material (a maximum of ~2% of the total debris mass) is potentially expected to settle into stable orbits as rare A-type asteroids found in the Hungarian and main asteroid belt regions.

We also expect that the debris hit the pre-existing asteroids with impact velocity larger than 5 km/s. The niminal collision velocity between existing asteroid is ~5km/s [15]. Such high velocity collision between the debris and pre-existing asteroid may record a reset of ^{40}Ar–^{39}Ar age and/or impact melts [16] and thus the timing of the giant impact on Mars may be recorded in some chondrite.

All these physical and chemical theoretical predictions would be useful for testing the giant impact hypothesis on Mars. Future observations and planetary explorations including a sample return mission would be important.

References:

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