Implantation of Martian Materials in the Inner Solar System by a Mega Impact on Mars

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The rare asteroids, called A-type asteroids, orbit within the Hungarian region and within the main asteroid belt region. They have olivine-rich spectral features [DeMeo&Carry 2013]. Their origin is still under debate even though some could be mantle materials fragmented and ejected by a catastrophic impact of differentiated primordial asteroid [Sanchez et al. 2014]. On the other hand, olivine is a major mineral of the Martian upper mantle with ~60 wt% [e.g. Bertka&Fei 1997, Zuber 2001]. Also, at the surface of Martian grabens, such as Nili Fossae, an olivine-rich signature is detected [Hoefen et al. 2003, Mustard et al. 2009].

Recent studies showed that a giant impact may occur on Mars and it produced Mars-orbiting debris from which Martian moons, Phobos and Deimos, acreete [Rosenblatt et al. 2016, Hesselbrock&Minton 2017, Hyodo et al. 2017, Canup&Salmon 2018]. Recently, Polishook et al. (2017) suggested that such Martian-moon forming impact may also produce debris that escapes from Mars’ gravitational field, and some of them may have delivered to the 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 [Hyodo&Genda 2018, ApJL] that investigated the compositional and thermodynamic properties of the impact ejecta produced by a giant impact that forms Martian moons [Hyodo et al. 2017]. We also present their mass and heliocentric orbits and discuss the possibility of forming rare A-type asteroids.

We perform high-resolution SPH simulations of Mars' giant 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). We found that the giant impact produced the following escaping debris [Hyodo&Genda 2018, ApJL]:

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% [Elkins-Tanton et al. 2003] and thus ($Mg_{0.75}$, $Fe_{0.25}$) SiO_4olivine solid solution as a major mineral of the Martian upper mantle, solidus and liquidus temperatures are about 1850 K and 2000 K [Bowen&Schairer 1935]. 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).

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 nominal collision velocity between existing asteroid is ~5km/s [Bottke et al. 1994]. 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 [Kurosawa&Genda 2018] and thus the timing of the giant impact on Mars may be recorded in some chondrite.

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