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Roles of shock-induced ionization due to >10km/s impacts on evolution of silicate vapor clouds

Kosuke Kurosawa[1*], Seiji Sugita[1], Toshihiko Kadono[2], Keisuke Shigemori[2], Yoichiro Hironaka[2], Norimasa Ozaki[3], Akiyuki Shiroshita[2], Yuichiro Cho[4], Tatsuhiro Sakaiya[5], Shinsuke Fujioka[2], Shogo Tachibana[4], Vinci Tommaso[6], Takafumi Matsui[7]

[1]Grad. Sch. of Fr. Sci., Univ. of Tokyo, [2]ILE, Osaka Univ., [3]Grad. Sch. of Eng., Osaka Univ., [4]Grad. Sch. of Sci., Univ. of Tokyo, [5]Grad. Sch. of Sci., Osaka Univ., [6]LULI, Ecole Polytech, [7]PERC/Chitech

Introduction: Generation of impact-induced silicate vapor clouds may have played important roles in the origin of the Moon [1, 2], prebiotic organic synthesis [3], and atmospheric erosion on the early Mars [4]. Such impact-driven processes, however, have not been understood well because energy partitioning process during impacts is still unknown. Silicates are expected to become dense plasmas due to intense impact compression. Laboratory experiments are practically the only way to investigate thermodynamic behavior of shock-induced silicate plasmas because physical properties of dense plasmas exhibit strong material dependences.

Experiments: We conducted shock-compression experiments at ILE of Osaka University and carried out in-situ spectroscopic observations of silicate vaporization from the end of compression phase to adiabatic expansion to understand energy partitioning process during hypervelocity impacts. The laser intensity is 150 TW/cm^2. The peak shock pressure is about 1 TPa. Diopside was used as targets. The flash from shock-heated silicates was observed with a spectrograph connected to a streak camera (Hamamatsu, C7700).

Results: We obtained a time-resolved emission spectrum from shock-heated silicates. We observed the change in emission spectrum from strong blackbody radiation into a number of emission lines. We carried out Planck function fitting of the strong continuum at immediately after the laser shot to estimate the peak shock temperature, resulting in 2.0×10^4K. We analyzed a number of emission lines to estimate the time evolution of temperature T and electron number density ne of the shock-induced silicate vapor cloud. We conducted spectral line fitting of observed emission lines using theoretical synthetic spectra with different T and FWHM. We can obtain the $n_e$of the silicate vapor cloud using the FWHM [5].

Discussion: We calculate peak shock temperature with the Dulong-Petit limit of isochoric specific heat, suggesting that it should be 6×10^4K at 1 TPa. The obtained peak shock temperature is much smaller than the theoretical prediction. The origin of this difference may result from a rise in the isochoric specific heat due to endothermic processes, such as structural change and ionization. The observed ionic emission lines strongly support this idea. Although the silicate vapor cloud was expected to expand into vacuum rapidly, the T at 25 - 50 ns after the laser shot is close to the peak shock temperature. In contrast, $n_e$drastically decreases at the same time, suggesting that exothermic effect due to electron recombination may play an important role on thermodynamic evolution of silicate vapor clouds. Thus, the results of the present study shows that electrons may work as an energy reservoir in energy partitioning during impacts via ionization and electron recombination. The rise in the isochoric specific heat due to ionization causes much more entropy gain during impacts that controls the degree of vaporization of shock-heated silicates [6]. It is one of the most important parameters in the giant impact hypothesis [1, 2]. Theoretical calculations indicate that too large mass of silicate vapor prevents growth of the proto Moon in the circum-terrestrial silicate disk [1, 7]. Thus, impact-induced ionization may drastically change the fertile range of impact conditions to form a large moon around the proto-Earth after a giant impact.

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