Deep Impact on Close-in Super-Earths: Atmospheric Escape and Material Mixing

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A violent collision between two objects is thought to occur repeatedly at the advanced stage of planet formation. In the Solar System, a giant impact is believed to be closely-related to a moon-forming event and the origin of highly-tilting Uranus. Recently, the *Kepler* telescope has revealed that close-in super-Earths, namely 1–10 Earth-mass planets orbiting within 0.1 AU, are common and abundant in the Milky Way. They are likely to have experienced giant impacts as well while migrating inward their host stars via disk-planet interactions. A mass-radius relation for transiting super-Earths suggests that some of them are rocky planets with no atmosphere, whereas super-Earths with thick atmospheres of < 10 wt % exist. Such a diversity of their bulk compositions should reflect formation processes, one of which could be a giant impact.

We performed three-dimensional hydrodynamic simulations of a giant impact between a super-Earth and an Earth-sized planet using Cray XC30 at NAOJ and examined an impact-driven atmospheric loss and a thermal state and material mixing inside a target planet after the impact [1]. Figure 1 shows that snapshots of two giant impact simulations: (top) a low-velocity head-on collision (v_{esc}) on 4.3 $M_\oplus$ and (bottom) a high-velocity one ($3v_{esc}$) on 10 $M_\oplus$. We assumed that each target has a rocky/iron core surrounded by a H/He atmosphere of 7.5 wt % and the projectile is a naked rocky/iron core.

In a high-velocity case, the atmosphere heated by a propagating shock wave expands beyond the Hill radius of a target, and then escapes from it rapidly. A hot and well-mixed interior triggers vigorous convection. On the other hand, a low-velocity collision allows a target to retain a large fraction of its original atmosphere and produce a non-uniform distribution of chemical compositions inside itself, which leads to an inefficient heat transport (e.g. double-diffusive convection). Collisional histories of super-Earths can strongly affect thermal evolution as post-formation processes. Also, giant impact would be one of key factors that cause the diversity of bulk compositions as seen in the mass-radius relation of transiting super-Earths.

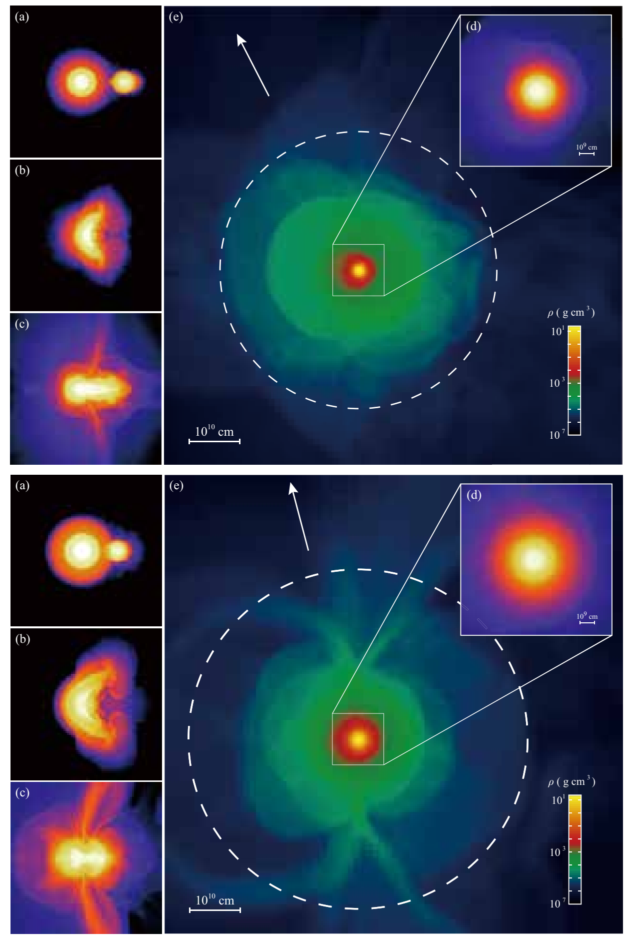

Figure 1: Snapshots of two giant impact simulations on a close-in super-Earth orbiting at 0.1 AU around 1 $M_\oplus$. (Top) a low-velocity collision : the density distribution across slices in the planets' orbital plane (a) before the impact, (b) immediately after, (c) at 1.56 hours, and (d) at 18 hours after the impact. (Bottom) a high-velocity collision : panels (a)–(d) are snapshots taken at the start of the impact, at 15 minutes, at 1.5 hr and at 21.5 hr after the impact, respectively. The dashed circle overplotted on the planet indicates its Hill sphere. The parent star is in the direction of the white arrow.

Reference

[1] Liu, S. -F., Hori, Y., Lin, D. N. C., Asphaug, E.: 2015, *ApJ*, **812**, 164.