Radiation-pressure-driven dust transport to galaxy halos at high redshift

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Dust is known to exist in a wide volume in the Universe, not only in the interstellar medium (ISM) but also in the circum-galactic and intergalactic medium (CGM and IGM) (e.g., Ménard et al. 2010, MNRAS, 405, 1025). Since dust in the CGM and IGM affects the opacity toward distant objects in the Universe (Aguirre 1999, ApJ, 512, L19), it is important to clarify the origin and evolution of dust in the entire cosmic volume. Dust in the CGM is also of fundamental importance in the total dust budget in galaxies and in the Universe, since Ménard et al. (2010) estimate that the dust mass in a galaxy halo is on average comparable to that in a galaxy disc. Moreover, as Inoue & Kamaya (2003, MNRAS, 341, L7) argued, dust could affect the thermal state of the IGM through photoelectric heating. However, the origin of dust in galaxy halos or in the CGM is still a mystery.

When did the CGM and IGM start to be enriched with dust? Recent sensitive observations by ALMA have found some dusty "normal" galaxies at $z > 7$ (e.g., Watson et al. 2015, Nature, 519, 327). These galaxies could be the first sources of the dust in the IGM and CGM. We investigate if the radiation pressure in high-redshift ($z \sim 10$) galaxies can efficiently transport dust to halos. To clarify the first dust enrichment of galaxy halos in the early Universe, we solve the motion of a dust grain considering radiation pressure, gas drag, and gravity in the vertical direction of the galactic disc. Radiation pressure is estimated in a consistent manner with the stellar spectra and dust extinction. As a consequence, we find that dust grains with radii $a \sim 0.1$ μm successfully escape from the galactic disc if the ongoing star formation episode converts more than 15 per cent of the baryon content into stars and lasts $\gtrsim 30$ Myr, while larger and smaller grains are trapped in the disc because of gravity and gas drag, respectively. We also show that grain charge significantly enhances gas drag at a few–10 scale heights of the galactic disc, where the grain velocities are suppressed to ~ 1 km s^{-1}. There is an optimum dust-to-gas ratio ($\sim 10^{-3}$) in the galactic disc and an optimum virial mass $\sim 10^{10}$–10^{11} $M_\odot$ for the transport of $a \sim 0.1$ μm grains to the halo. We conclude that early dust enrichment of galaxy halos at $z \gtrsim 10$ is important for the origin of dust in the CGM.

Finally, we discuss other mechanisms of injecting dust into the IGM and CGM based on our recent simulations (Hou et al. 2017, MNRAS, 469, 870; Aoyama et al. 2018, MNRAS, 478, 4905). Each model has each prediction on the typical grain size in the IGM, so that we compare our previous constraints on the grain radii in the CGM and IGM (Hirashita & Lin 2019, Planetary and Space Science, in press) with various theoretical predictions.