Importance of Dust Evolution to the H_2 and CO Abundances in Galaxies

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We present our recent efforts of clarifying the important role of dust in H_2 and CO formation in galaxies. Since stars form in molecular clouds, tracing molecular gas in galaxies is important in revealing how galaxies convert gas to stars. Molecular gas is usually observed by CO emission. The CO-to-H_2 conversion factor ($X_{\rm CO}$) is known to correlate with the metallicity (Z) (e.g., Bolatto et al. 2013). The *dust abundance*, which is related to the metallicity, is responsible for this correlation through dust shielding of dissociating photons and H_2 formation on dust surfaces. Thus, we investigate how the relation between dust-to-gas ratio and metallicity ($\mathcal{D}$–Z relation) affects the H_2 and CO abundances (and $X_{\rm CO}$) of a 'molecular' cloud (Hirashita & Harada 2017). For the $\mathcal{D}$–Z relation, we adopt a dust evolution model developed in our previous work (Hirashita 2015), which treats the evolution of not only dust abundance but also grain sizes in a galaxy. Shielding of dissociating photons and H_2 formation on dust are solved consistently with the dust abundance and grain sizes. As a consequence, our models predict consistent metallicity dependence of $X_{\rm CO}$ with observational data of nearby galaxies. Among various processes driving dust evolution, dust growth by the accretion of gas-phase metals has the largest impact on the $X_{\rm CO}$–Z relation. We also find that dust condensation in stellar ejecta has a dramatic impact on the H_2 abundance at low metallicities ($\lesssim 0.1\ \mathrm{Z}_\odot$), relevant for damped Lyman α systems and nearby dwarf galaxies, and that the grain size dependence of H_2 formation rate is also important at low metallicities.

We further implement the above framework into hydrodynamical simulation of a galaxy (Chen, Hirashita, et al. 2017), thereby clarifying how the star formation law (relation between the surface densities of molecular gas mass and star formation rate) changes as a function of galaxy age and metallicity. The simulation treats the dust evolution consistently with the physical properties of the ISM, and the formation of H_2 and CO are treated by post-processing. Because of inefficient molecule formation at low metallicity ($\lesssim 0.4\ \mathrm{Z}_\odot$), the star formation law is not established at young ages, especially if the molecular gas is traced by CO. We also find that the grain size distribution is important for the CO abundance; thus, if we trace the star formation law by CO, dust evolution should be carefully discussed. In summary, the results of the simulation indicate that the establishment of a star formation law is strongly regulated by dust evolution.