The role of dust in the early Universe

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Dust grains play crucial roles in the star formation processes through the H_2 formation on dust grains and the transition from Population III (Pop III) to Population II (Pop II) stars by dust cooling. First, in order to explore role of dust in first galaxies, we develop one-zone galaxy formation model in which we include a novel implementation of dust size evolution and the resulting H_2 formation on dust grains (D.Y. et al. 2011, ApJ). Then, we apply our model to study cosmic star formation rate (SFR) and reionization history, taking into account the initial mass function (IMF) transition from Pop III to Pop II due to dust cooling (D.Y. et al. 2012a, b, in preparation). We treat consistently the following processes in the model: (i) the formation and size evolution of dust by SNe, (ii) the time-dependent chemical reaction networks including H_2 formation both on the surface of the grains and in the gas phase, (iii) the SFR which is proportional to H_2 mass, (iv) Dark matter (DM) halo evolution due to the hierarchical merger tree and (v) the IMF transition from Pop III to Pop II due to dust cooling.

In our galaxy model, we find that the star formation efficiencies in the high-redshift galaxies are much lower than those in present-day galaxies and that the H_2 formation is suppressed by dust destruction, especially by the reverse shocks in SN remnants. At the galaxy age of ~ 0.8 Gyr, in galaxy models with virial mass $M_{vir} = 10^9 M_{sun}$ and formation redshift $z_{vir} = 10$, the molecular fraction is 2.5 orders of magnitude less in the model with dust destruction by both reverse and forward shocks than that in the model without dust destruction.

Applying our galaxy model, we show that the stellar mass fraction for redshift $5 < z < 10$ is roughly an increasing function of host halo mass, M_{vir}. This is because H_2 formation on dust grains is more efficient in more massive galaxies, and the scaling of stellar mass fraction with host halo mass $\log(M_{vir}(z = 5)/M_{sun}) = (9 - 11)$, rapidly evolves during redshift, $5 < z < 10$. The stellar mass fractions have a large scatter, since star formation efficiency in these galaxies depends on H_2 formation on dust grains and can be suppressed by the primordial gas accretion. We discuss the reionization history considering the IMF transition from Pop III to Pop II due to dust cooling.