Collapsing Low-metallicity Gas Clouds with the Growth of Dust Grains

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Dust grains in the early universe are considered to be crucial for star formation in the early universe. It is considered that the transition of typical stellar mass scale in the early universe is caused by dust. The additional cooling channel other than primordial element can reduce the Jeans mass of collapsing gas clouds. Dust cooling works when gas density is high so that the Jeans mass is further reduced. In the early universe, dust grains are supplied mainly by supernovae. In supernovae, heavy elements are partly part from grains after reverse shocks pass through ejecta, where grains form. We consider the collapsing gas has the same abundance pattern and dust amount as a metal-free supernova. In low-metallicity clouds, dust cooling is inefficient if dust-to-metal ratio is small. However, accretion of heavy elements onto grains (grain growth) can enhance dust cooling and can even modify the fragmentation properties of metal-deficient clouds. We investigate the effect of grain growth on the fragmentation condition in gas clouds by one-zone calculation of collapsing clouds with metallicity 10^{-6}—10^{-3} $Z_{\rm sun}$. We set abundance pattern of heavy elements and abundance of dust grains obtained by calculations of metal-free supernovae. As a result, for progenitor models with large amount of carbon, growth of carbon grains can enhance dust cooling even if the initial dust-to-metal ratio is small. The critical metallicity above which dust cooling is efficiency is $Z_{\rm crit} \sim 10^{-5.5} Z_{\rm sun}$ regardless of initial dust-to-metal ratio. On the other hand, for models with high abundance of silicon, the effect of silicate grains is comparable to carbon. Smaller amount of silicate grains can survive the passage of reverse shocks than carbon. The critical metallicity is $Z_{\rm crit} \sim 10^{-5.5} Z_{\rm sun}$ for models with smaller effect of reverse shock, and $Z_{\rm crit} \sim 10^{-4.5} Z_{\rm sun}$ for the other cases.