The effect of grain growth on star formation in low-metallicity collapsing gas clouds

Gen Chiaki[1], Takaya Nozawa,[2,3] Naoki Yoshida[1,2], Raffaella Schneider[4], Kazuyuki Omukai[5], Marco Limongi[2,4], and Alessandro Chieffi[6]

[1]*University of Tokyo, Japan,* [2]*Kavli IPMU, Japan,* [3]*NAOJ, Japan,* [4]*INAF/OAR, Italy,* [5]*Tohoku University, Japan,* [6]*INAF/IASF, Italy*

Recent studies have revealed that first stars (Population III or Pop III stars), which are formed in metal-free gas clouds, are predominantly massive (several 10–1000 $M_\odot$). On the other hand, present-day stars are typically solar- or subsolar-mass. Some researchers have investigated the transition of stellar mass scale. Omukai et al.(2005) perform one-zone semi-analytic collapse calculations. They show that additional gas cooling, other than primordial elements, owing to heat transfer from hot gas to cold dust can trigger gas fragmentation at high densities ($n_\mathrm{H} = 10^{12}$–10^{15} cm^{-3}). They therefore conclude that low-mass fragments can be formed at metallicities $Z > 10^{-5.5}\ Z_\odot$. However, they assume that the fraction of heavy elements condensed into the solid phase (depletion factor) is fixed to the value in the local universe (~ 0.5). Dust grains in the early universe is supplied mainly by supernovae because their progenitors have short lifetime less than the cosmic age where mass transition would occur. Grains are also destroyed by reverse shocks penetrating in supernova ejecta, where grains are formed. Theoretical approaches show that the depletion factor is at least 0.01. Observations of damped Lyman alpha systems also reveal that this ratio is below the present-day value in the metal-deficient environments. Then, Schneider et al.(2006, 2012) study the fragment properties of clouds, setting the initial dust amount self-consistently calculated by their Pop III supernova models. They find that the critical condition can be described as the dust-to-gas mass ratio to trigger the dust-induced fragmentation. This means that the critical metallicity depends on supernova models (the initial depletion factor). So far, the dust amount is assumed to be fixed in the course of collapse. However, Nozawa et al.(2012) find that accretion of heavy elements in the gas phase onto dust grains (grain growth) can alter the thermal properties of gas even with the small initial depletion factor in metal-deficient clouds.

We perform one-zone collapse calculations, taking grain growth into consideration in order to reveal its effect on the cloud fragmentation. We employ the dust models (composition and size distribution predicted by early supernova models) as the initial condition of our calculations with low-metallicity. We find that growth of dust grains can enhance dust cooling especially for the small initial depletion factor (~ 0.01), and the critical metallicity is altered to smaller value. Also, the dependence of the critical metallicity on the initial depletion factor becomes milder.