Formation Of Protoplanets From Planetesimals

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Planetary accretion from planetesimals to protoplanets is investigated using three-dimensional N-body simulations. The effect of gas drag due to solar nebula is included and realistic-sized planetesimals with the standard material density is used, with which the growth time scale of planetesimals is realistic. In agreement with the earlier works (Kokubo and Ida 1996, 1998, *Icarus*) that investigated gas-free accretion of planetesimals with enlarged sizes, it is found that a bimodal protoplanet-planetesimal system is formed through runaway and oligarchic growth. In the intermediate accretion stage, the growth mode of planetesimals is runaway growth where the mass distribution relaxes into isolated runaway bodies and the continuous power-law mass distribution with $dn_{\rm c}/dm \propto m^{\alpha}$, where $n_{\rm c}$ is the cumulative number of bodies and $\alpha \simeq -2.5$. While thinning out some runaway bodies, the growth mode shifts to oligarchic growth where larger protoplanets tend to grow more slowly than smaller ones, while the growth of protoplanets is still faster than that of planetesimals. The orbital separations of the protoplanets are kept wider than about 5 Hill radii of the protoplanets through orbital repulsion. In the late accretion stage, similar-sized protoplanets grow, while most planetesimals remain small. In 500000 years, protoplanets with mass 10^{26}g are formed at 1AU.