Filling factor dependence of the thermal conductivity understood from the graph structure of dust aggregates

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Previous studies (Arakawa *et al*. 2017; 2019) revealed that the thermal conductivity through the solid network of dust aggregates is proportional to the square of the filling factor. However, the reason why the thermal conductivity is given by the power-law function of the filling factor was still unclear. In order to understand the physical reason of this power-law dependence, we need to investigate the geometric structure of highly porous dust aggregates.
In this study, we study the graph structure of fractal aggregates called BCCA aggregates (e.g., Meakin 1991). The fractal dimension of BCCA aggregates is approximately 1.9 (e.g., Okuzumi *et al.* 2009) and the graph structure of BCCA aggregates is classified as a tree. Then the gyration radius r_g and the filling factor ϕ is connected by the following equation, $r_g \simeq \phi^{-1/(3-1.9)}$, and the number of the heat conduction path per unit area, σ, is given by $\sigma \simeq \phi^{2/(3-1.9)}$ for BCCA aggregates. In addition, we calculated the graph-theoretical distances of monomer grains within a BCCA aggregate. We found that the root mean square of the graph-theoretical distance d is given by $d \simeq r_g^{1.2}$. Therefore, the thermal conductivity of BCCA aggregates is proportional to $\sigma r_g / d \simeq \phi^2$.

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