THERMAL CONDUCTIVITY OF BIFRACTAL AGGREGATES: THEORETICAL INTERPRETATION.

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Introduction: Understanding the thermal conductivity of dust aggregates is important for numerous topics in planetary science: for example, the thermal evolution of planetesimals is controlled by the thermal conductivity of dust aggregates [e.g., 1], the near-surface temperature distribution of comets and asteroids also depends on the thermal conductivity of surface dust layers [e.g., 2]. The thermal conductivity of dust aggregates depends on many physical parameters (e.g., the temperature, porosity, composition, radius of monomer grains), and there are many experimental [e.g., 3] and numerical [e.g., 4−6] studies on the thermal conductivity of dust aggregates. Recently, we revealed that the thermal conductivity through the solid network of dust aggregates is approximately proportional to the square of the filling factor [5,6]. However, the reason why the thermal conductivity is given by the power-law function of the filling factor was not yet revealed.

Theoretical prediction: Here we investigate the geometric structure of highly porous and fractal dust aggregates. We study the graph structure of fractal aggregates formed by the ballistic cluster-cluster aggregation process (hereafter BCCA; [7]) to understand the origin of this power-law dependence. It is known that the fractal dimension of BCCA aggregates is approximately 1.9 [e.g., 8] and the graph structure of BCCA aggregates is classified as a tree. Therefore the gyration radius R_{gyr} and the filling factor ϕ must be connected by the equation, $R_{\mathrm{gyr}} \sim \phi^{-1/(3-1.9)}$, and the number of the heat conduction path per unit area, σ, would be given by $\sigma \sim \phi^{2/(3-1.9)}$ for BCCA aggregates. The internal structure of compressed BCCA aggregates is bifractal: the fractal dimension is 3 for a large-scale structure but is 1.9 for a small-scale structure [9]. Therefore, we can predict the filling factor dependence of the thermal conductivity of compressed BCCA aggregates if we know the relation between the mean geodesic distance and the gyration radius of a BCCA aggregate.

Results. We calculated the geodesic distances of monomer grains within a BCCA aggregate. We found that the root mean square of the geodesic distance D_{rms} is given by $D_{\mathrm{rms}} \sim R_{\mathrm{gyr}}^{1.3}$ (Figure 1). The thermal conductivity of BCCA aggregates is inversely proportional to the geodesic distance per the gyration radius, $D_{\mathrm{rms}}/R_{\mathrm{gyr}}$, and is proportional to the number of the heat conduction path per unit area, σ. Therefore, the thermal conductivity of compressed BCCA aggregates f is proportional to $f \sim \phi^{2.1}$, as shown in Figure 2.

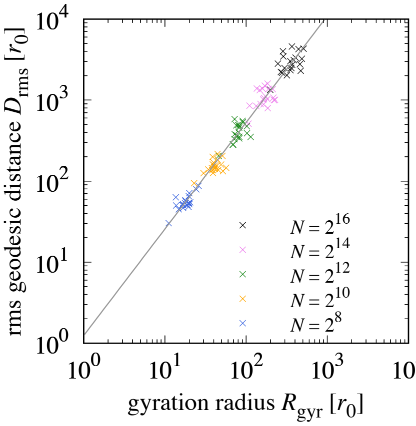

Figure 1. The mean geodesic distance D_{rms} and the gyration radius R_{gyr}. The number of monomer grains is $N = 2^8$–2^{16}.

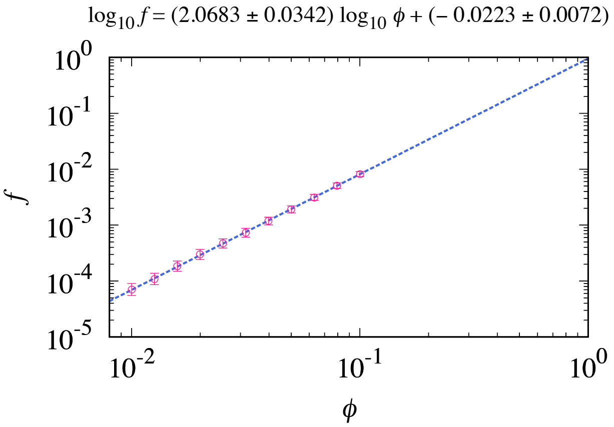

Figure 2. The normalized thermal conductivity f and the filling factor ϕ. The definition of f is described in Arakawa *et al.* [5,6].

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