Reproduction of chondrule size distribution by shock-wave heating model: dust size distribution in solar nebula

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Chondrules are mm-sized, once-molten, spherical-shaped grains mainly composed of silicate material. They are considered to have formed from dust particles that were heated and melted through flash heating events in the solar nebula and cooled again to solidify in a short period of time. The chondrule sizes are concentrated at around 300 - 900 micron. Shock-wave heating model is one of the plausible models for chondrule formation. This model can explain the peak temperature experienced by chondrules in the formation process (e.g., Iida et al. 2001). The purpose of this study is to investigate how the chondrule size distribution is reproduced in the framework of the shock-wave heating model.

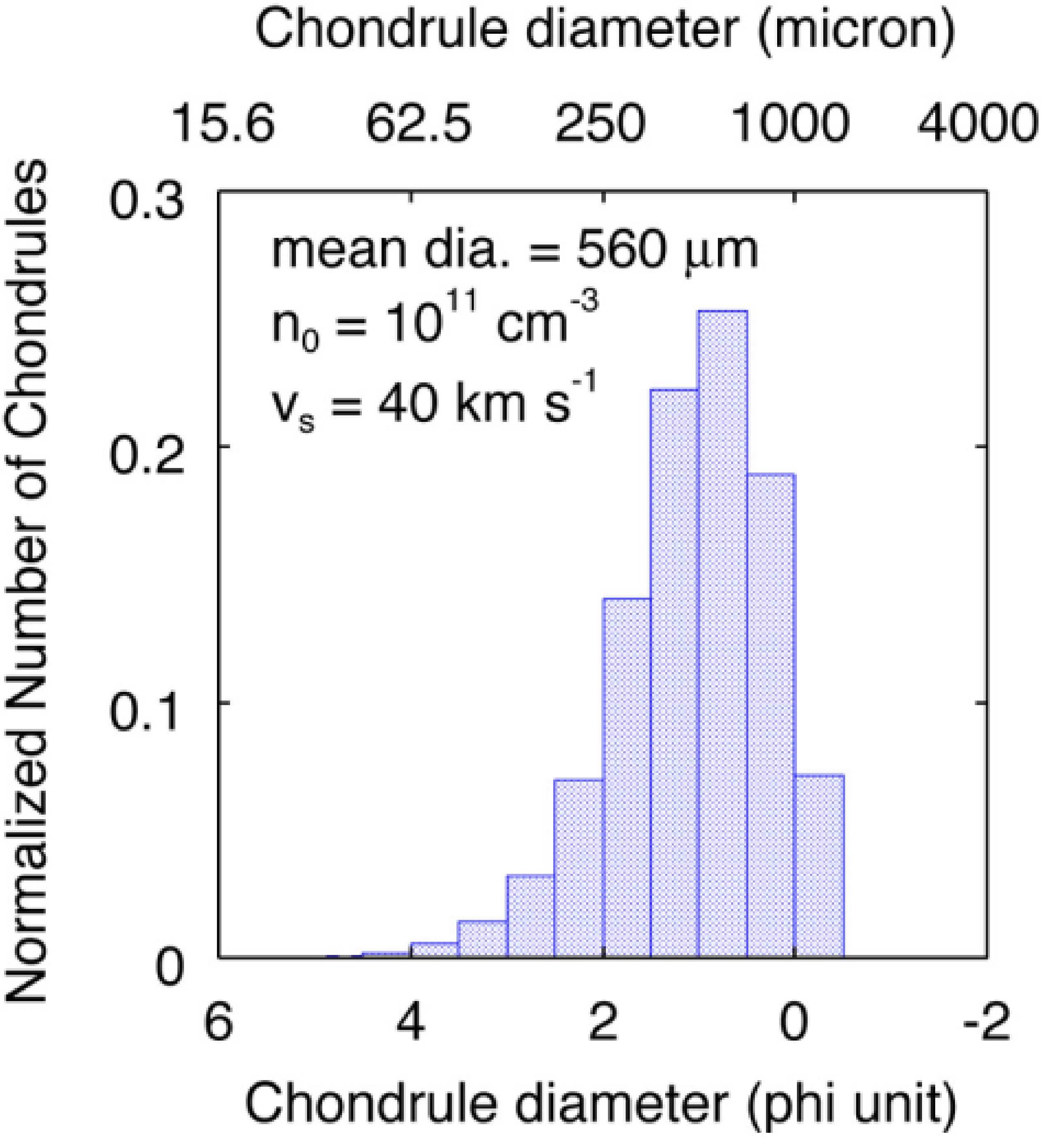
While the dust particles are heated, they shrink due to the evaporation. Therefore, the radii of formed chondrules are smaller than those of precursor dust particles (Miura & Nakamoto 2004). Another important effect is a fragmentation of molten dust particles by the ram pressure (Susa & Nakamoto 2002). There is a critical radius above which the molten particles cannot maintain their body by its own surface tension. In order to consider the chondrule size distribution, above two effects should be taken into consideration.

For numerical calculation, we model above problems as below. We assume that the postshock gas flow is steady, one-dimensional, and plane parallel. We consistently solve equations of hydrodynamics and non-equilibrium gas-phase chemical reactions. It is very important to solve the chemical reactions because it is not only indispensable for estimating heating/cooling rates for gas, but also for evaluating the evaporation rate of dust particles (which depends on the partial pressure of hydrogen molecules). For dust particles, we simultaneously calculate the equations of motion, energy, and shrinkage by the evaporation. It is assumed that the dust particles whose temperatures exceed the melting point and which do not evaporate completely can form chondrules. It is also assumed that the molten dust particles which fragment by the ram pressure cannot form chondrules for simplicity.

To reproduce the chondrule size distribution, it is needed to assume the size distribution of precursor dust particles. In this study, we calculate for two cases; a power-law distributions and a lognormal distribution. We compare the calculated chondrule size distributions with the measured ones. Though the majority of chondrule size data has been derived from thin-section measurements, the method has a bias associated with the measurement of three-dimensional objects in two dimensions. A method for correcting measured chondrule size distribution for the bias is described in Eisenhour (1996). In our study, using this correcting method, we virtually observe the calculated results of chondrule sizes.

From our calculation results, we find that the size distribution of chondrules in ordinary chondrites can be hardly reproduced from the power-law distribution. We also find that it is possible to reproduce from the lognormal distribution. In this case, the size distribution of formed chondrules is very similar to that of the precursor dust particles. Examples of suitable shock parameters (shock velocity vs, preshock gas number density n0) are (i) vs ~ 40 km/s at n0 ~ 10^11 cm^-3, or (ii) vs ~ 8 km/s at n0 ~ 10^14 cm^-3. The values (i) are consistent with a protoplanetary disk that is gravitationally unstable (Desch & Connolly 2002), and the values (ii) may be explained by the shock waves induced by X-ray flare in upper solar nebula.

Another possibility for the narrow-ranged chondrule size distribution is the size selection after some chondrule forming events. After chondrule forming events, formed chondrule must unite with other sub-micron dust particles (matrix component) and grow to be chondrites. According our study, measured chondrule size distribution may be directly reflecting the size distribution of chondrule precursor dust particles.



Chondrule diameter (micron)
15.6
62.5
250
1000
4000
Normalized Number of Chondrules
0.3
0.2
0.1
0
mean dia. = 560 μm
n0 = 10^11 cm^-3
vs = 40 km s^-1
6
4
2
0
-2
Chondrule diameter (phi unit)