CHONDRULE MELTING VIA TRANSIENT HEATING EVENTS. G. S. Swint, L. S. Matthews, and T. W. Hyde, Space Physics Theory Group, Department of Physics, Baylor University, Waco, TX 76798-7316, USA.

Introduction

Meteoric evidence suggests that particles in the protoplanetary nebula were subjected to intense, but brief, periods of heat. This paper introduces a numerical simulation for rapid heating events in protoplanetary disks. Early results showing the possible effects of such events are provided.

Background and Evidence

Current planetary formation theories hold that planet formation begins with the coagulation of dust in an accretion disk around a protostar. This process of coagulation and condensation formed dust grains. In turn, the dust grains coagulated to form planetesimals, 1 to 10 km-sized bodies which were the direct precursors to planets. Some meteorites today are relics of the pre-planetesimal stages of our solar system's formation. Studies of these primitive meteorites yield valuable data about the structure and formation of the planetesimals.

Chondritic meteorites are characterized by the inclusion chondrules, spherical droplets about 1 mm in size which can account for up to 80% of a meteor's total mass. Age, chemical composition, and textural properties indicate that chondrules formed in the planetary nebula. Their spherical shape indicates that at some point they had been molten; this required temperatures around 1800 K[2].

However, most chondrules have non-glassy textures. This suggests chondrules were not melted completely. Also, nucleation sites for crystallization are still present. This requires that both the heating and cooling of the chondrule take place rapidly. Chondrules exhibit a lack of isotopic variation, as would be expected had the droplets been molten for a long period of time, or simply been formed through condensation. Furthermore, FeS is present in chondrules. Due to its low vaporization temperatures, the nebula where the chondrules were formed must have had an ambient temperature less than 700 K[1].

This evidence indicates that chondrules were present in a cool nebula. At some point, the chondrule is rapidly heated to temperatures above 1800 K and then cools rapidly. This scenario is supported by the presence of once molten rims on 1 cm sized calcium-aluminum rich inclusions which are also found in primitive meteorites. Laboratory experiments show that the cooling time for a chondrule is on the orders of hours. Therefore, the heating of the chondrule must have taken place in a time on the order of minutes or seconds[2].

The melting of such particles significantly changes their properties. Primarily, the heating events would have melted any aggregates of material into spherical droplets. This reduces the open structure of the aggregates to a compact spherical form. Also, charge distribution on the aggregates is dependent on shape, but spherical particles have a uniform surface charge.

Numerical Simulation

To accurately model the coagulation of dust grains in a protoplanetary environment, it is necessary to keep track of a large number of particles while noting collisions that result in sticking. In the current study, this was accomplished using a numerical model based on the Box_Tree code[3]. The Box_Tree code models a ring or disk by first dividing it into self-similar patches orbiting the planet or star, where the box size is much greater than the radial mean excursions of the constituent dust grains. Boundary conditions are met using twenty-six ghost boxes. A tree code is incorporated into the Box_Tree routine to allow it to deal with gravitational and electrostatic interactions between the particles. A full treatment of rigid body dynamics, including rotation, is possible allowing for both cluster trajectories and the orientation of fractal aggregates to be determined.

Heating events in this model were assumed to be instantaneous so that no collisions took place during the heating event. It was assumed that all particles would melt completely into spherical droplets, that no particles were vaporized, and that increased temperatures did not alter particle charges by boiling off electrons. Angular momentum was simply conserved in the transition from aggregate to sphere.

Results

Preliminary runs were made on particles initially ranging in size from 1 to 6 microns. This is about 10^3 times smaller than chondrules, which must be built up from condensates and micron size particles. All particles were initially spheres. With fractal agglomeration allowed, there were far fewer and much larger particles than simple spherical merging (Figure 1 a, b). Inclusion of heating in the simulation resulted in many more particles than with only the fractal agglomeration, but fewer than the simple merging of first case (Figure 1a, b, c).

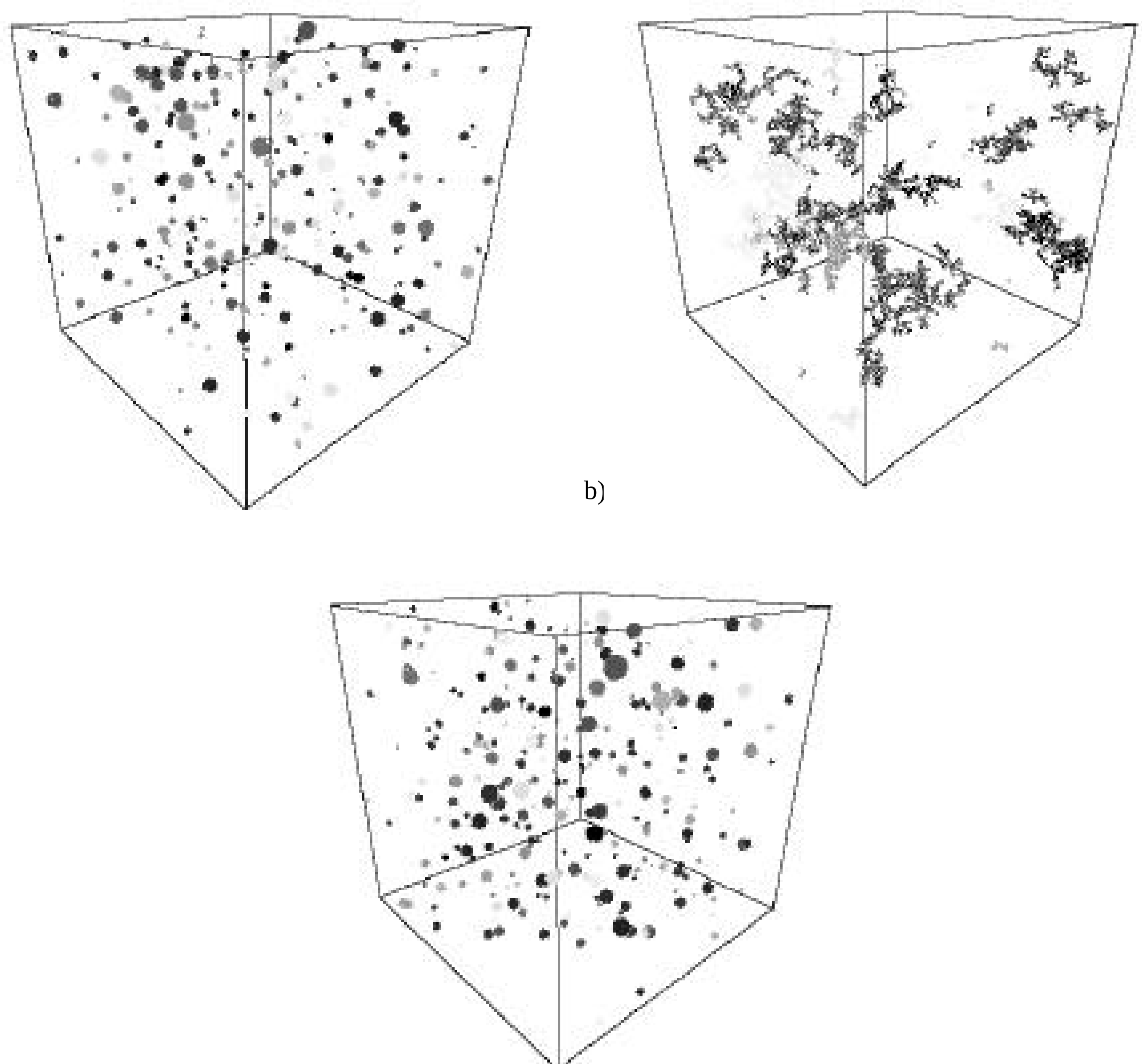
Future simulations should only incorporate the heating events after the aggregates have been allowed to grow to the proper size. The possibility of the change in electrostatic charge should also be taken into account. The frequency and time of the heating events should be studied as well.

References

(1) Boss, Alan P., Hot Times in the Solar Nebula, *Nature*. 377:578-579, 1995.

(2) Morfill, G. E., G. H. Spruit, and E. H. Levy, Physical Processes and Conditions Associated with the Formation of Protoplanetary Disks, in *Protostars and Planets III*, ed. E.H. Levy, and J. I. Lunine, The University of Arizona Press, 939, 1993.

(3) Richardson, Derek C., A Self-Consistent Numerical Treatment of Fractal Aggregate Dynamics, *Icarus*, 115, 320-335, 1995.



a) b) c)

Figure 1. Coagulation of 5600 dust particles. **a)** Only spherical particles allowed as a result of collisions. There were 314 resultant bodies and no aggregates. The average particle mass was 8.06e-12. **b)** Fractal agglomeration allowed. There were 60 resultant bodies of which 53 were aggregates. The average body mass was 42.2e-12. **c)** Fractal agglomeration allowed, and 12 transient heating events occurred. There were 282 resultant bodies with an average mass of 8.98e-12. 16 bodies were aggregates.