Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

PPS025-P05 Room:Convention Hall Time:May 23 10:30-13:00

Planetesimal Bow Shocks: A Heating Mechanism for Chondrule Formation II

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We simulated the bow shock excited around the planetesimal moving with supersonic velocity relative to the nebula gas, and examined whether dust grains are heated enough to melt and become chondrules.

Chondrules are millimeter sized spherical silicate particles that constitute up to 80% of chondrite in volume. Although they must have experienced heating and then melting to account for their spherical shapes and their textures, the heating source remains to be solved. Some kind of heating events must have happened in their formation age, about 4.56 billion years ago, because the temperature of the nebula gas was a few hundred kelvins at that time, which is too low to melt dust grains.

The shock wave heating model is the one of the ideas for the heating mechanism, which explains the observational constraints for chondrule formation properly. However, no reliable sources of shocks are still confirmed.

In this study, we focused on the planetesimal bow shock as the source of the shock. The idea of the bow shock excited by the supersonic planetesimal with respect to the nebula gas is offered by Hood (1998) and Weidenschilling et al. (1998) and the only numerical study so far for the planetesimal bow shock is conducted by Ciesla et al. (2004). They simulated the bow shocks in two-dimensional Cartesian coordinate system, regarding the planetesimal as a cylinder, and calculated the thermal history of a dust grain in one dimensional shock model by using the shock properties given by their simulation.

In order to analyze quantitatively the possibility of the planetesimal bow shock for chondrule formation, we conducted hydrodynamic simulations in axisymmetric spherical coordinate system, regarding a planetesimal as a sphere, and calculated the thermal history of a dust grain along its trajectory with various impact parameters. The flow around the supersonic planetesimal was simulated by using the ZEUS-2D code (Stones & Norman 1992) with various velocities, densities and planetesimal sizes.

As a result, we restricted the possible chondrule formation region in the gas density - gas relative velocity parameter space. In addition, we found the possible impact parameter range in which dust grains could melt. By using these results, we estimated the total amount of chondrules that could be made by planetesimal bow shocks. About one earth mass of dust grains could be heated to melting point by bow shocks under the scenario that supersonic planetesimals with high eccentricity was excited by Jovian resonances (Marzari & Weidenschilling 2002). We concluded that the planetesimal bow shocks are still possible chondrule formation site.

Keywords: planetesimal, shock wave, chondrule