J160-012 **Room: 203** **Time: May 27 11:21-11:33**

Development of a numerical method for multi-phase flow by a particle method and its application to metal droplets in magma ocean

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Computation of multiphase flows is complex, not only because fluid properties are discontinuous across the interface between the different fluids, but also because surface tension is often an important player in the dynamics. The treatment of surface tension requires the knowledge of the shape of the interface, which of course evolves with the flow.

Free surfaces are treated naturally by Lagrangian descriptions of fluids. Smoothed particle hydrodynamics (SPH) is a Lagrangian method often used in the context of astrophysical fluid dynamics. In this method, matter is decomposed in a number of particles, each being represented by a kernel function which can overlap those of others. Each quantity, including density is obtained by summing the kernels. It allows to treat both very large deformations of interfaces and density variations, both being important ingredients of accretion dynamics. On the other hand, it is not very appropriate to incompressible situations.

We use another fully Lagrangian method, termed the moving-particle semi-implicit (MPS) method (Koshizuka and oka, 1996), that is well suited to modeling of incompressible flows. As in SPH, a discrete number of particles is used and each quantity at each point is obtained by summing that of neighbouring particles to which a weight is attributed. However, particles are forbidden to overlap in MPS by using radius dependent weight functions that are infinite at the center. The density increase is so drastic when particles try to overlap that strong repulsive pressure forces arise. However, there has been no model for MPS method to treat surface tension by continuous approach in 3-D space. We developed a new model that can treat surface tension in 3-D space. The model is a hybrid of MPS method and SPH.

We show a benchmark test of a breakup of a falling droplet into a vortex ring form by viscous deformation. In this system, the viscous ratio between the outer fluid and inner fluid is rather critical for whether a breakup occur or not and we compare the result with the experiment carried out by Baumann et al., 1992. We also show the interactions of many droplets including fragmentations and coalescences under gravity. The size and the velocity distributions are governed by the physical processes, which is controlled by the Reynolds number of droplets. This system can be used as the model of the separation of metal from silicate in the process of the evolution of the Earth.