Development of SPH toward a three-dimensional simulation of an icy moon with internal ocean

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There are some traces of existence of internal ocean in some icy moons, such as a plumes of vapor of Europa and Enceladus. This suggests that there is a region of liquid water beneath the surface ice shell. Since liquid water would be essential for the origin of life, it is important to understand the development of internal ocean, especially the temperature distribution/evolution inside the icy moons. It is considered that the balance between the tidal heating caused by tidal acceleration and radiative cooling sustains liquid water beneath the surface of an icy moon. We aim to simulate tidal heating an internal ocean of an icy moon by 3-dimensional numerical fluid calculations using Smoothed Particle Hydrodynamics (SPH) method. The SPH method is a particle-based method for simulations of fluid dynamics and commonly used for problems involving fracture or large deformation. We added viscosity and thermal conduction terms into the governing equations of SPH. However, we found two problems in calculating the rigid body rotation by using SPH including viscous term: (1) With the conventional formulation of viscosity, unwanted viscosity force prevent the rotation. (2) There is an artificial internal energy partitioning in the layered structure, which is due to the formulation of standard SPH. In order to resolve the former problem, we modified the formulation of viscosity and verified that unwanted viscous force is suppressed by it. For the latter problem, we introduced Density Independent SPH (DISPH), which was developed to improve the behavior of discontinuous surface. In addition, by using the algorithm to define the surface of a fluid using the particle method, we introduced cooling by radiation from the satellite surface. Also, we introduced an equation of state that takes phase transitions into account. According to the above modifications, we have developed the SPH method that introduces all the necessary physical processes (viscosity, conduction, radiative cooling and phase transition) to simulate the evolution of an internal ocean of an icy moon. As future works, we are planning to perform two patterns of calculations: (1) Application to the hypothetical system and perform parameter study, simulating by assigning different value to semi major axis, eccentricity, obliquity, mass of icy moon, etc… and analyze the effect on internal structure. (2) Application to icy moons in solar system (Europa, Enceladus) and reveal the internal structure of them.

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