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High-resolution simulations of giant impacts of terrestrial planets using a tree-Godunov-SPH method on GPU

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Smoothed Particle Hydrodynamics (SPH) method is a useful numerical tool in studying a number of astronomical and planetary science problems.
A wide variety of astrophysical and planetary science problems are studied by SPH method.
The giant impact hypothesis, one of the possible scenario of the Moon formation, is one of such a problem.
In order to examine the giant impact scenario for the Moon formation, numerical simulations of collisions between planetary embryo have been done by SPH method.
However, the problem that the current SPH method does not have resolution enough fine for debris disk is pointed out.
In the SPH method, the resolution is determined by the number of SPH particles.
To obtain high resolution, we must construct fast calculation code.

In this study, a procedure for construction of new fast SPH code is described.
We implement the following three improvements to the code.
First, we implement so-called Tree method to SPH.
While the direct search of neighbors and calculations of self-gravity among N particles require ˜$O(N^2)$ computations, the introduction of the tree method reduces the number of computations to ˜O(N log N).
Secondly, we implemented approximate Riemann solver to the SPH method, which is called the Godunov SPH.
The application of the Riemann solver enable us to simulate phenomena with strong shocks.
Furthermore, Godunov SPH method includes appropriate dissipation in solving shock flows.
The calculation time becomes 10 times faster than that of the standard SPH.
Finally, we write the SPH code to run the program on massively parallel Graphical Processing Units (GPU) supporting the NVIDIA CUDA architecture.
The calculation time of GPU is about O(10) times faster than that of CPU.

In order to check the accuracy and performance of this code, we perform two types of benchmark tests.
One is the model of the adiabatic collapse of an initially isothermal spherical gas cloud to check the performance of GPU.
We performe this test by two methods, tree Godunov SPH on GPU and tree standard SPH on CPU.
Another is the collision between planet-size objects to check the correct treatment of non-ideal EOS.
From these tests, we otain that our code is about 300 times faster than the prevailing SPH method.

By using this code, simulations with large number of particles, namely high resolution simulations, are feasible.

In future work, to obtain further improvement of the performance of GPU, we will implement memory rearrangement algorithm.
This allows us to obtain the most efficient memory bandwidth.

Keywords: giant impact, SPH, GPU