



Quantum numerical computation of the classical kinetic equation by quantum computer: new method for the Boltzmann equation in 6D collisionless plasma

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Auroras occur in the magnetosphere-ionosphere coupling system. The system is the region where the high-field weak ionized gas system and the collisionless plasma system are coupled through magnetic field lines. In this system, plasma density gradients, etc., occur on much smaller scales than in ideal magnetohydrodynamics (MHD), requiring first-principles equations that can be applied to multiple scales. In the field of space plasma physics, including auroral electron acceleration mechanism research, with the development of computers, research using kinetic equations such as the Vlasov-Maxwell equation (collisionless Boltzmann-Maxwell equation) (e.g. [1]). are dominant in the field. The equations are first-principles equations that describe the motion of a three-dimensional plasma particle in terms of a six-dimensional state distribution function. To simulate the auroral electron acceleration mechanism in the magnetosphere-ionosphere coupling system, collisional interactions between particles as well as 3D wave-particle interactions are essential. However, higher-order numerical calculations of the collisional Boltzmann equation are not realistic even with state-of-the-art supercomputers since the computational cost is extremely high.

Recent advances in quantum computer research have shown that quantum algorithms provide exponential speedups over classical algorithms (e.g. [2]). For the solution of advection partial differential equations, the superiority of quantum algorithms for the two-dimensional Navier-Stokes equations using the lattice Boltzmann method (D2Q5 model) [3] and the two-dimensional neutral particle collisionless Boltzmann equations [4] was also revealed.

Therefore, we developed a quantum algorithm for the six-dimensional Boltzmann equation for collisionless plasmas. The time-space evolution of the six-dimensional state distribution function with the addition of velocity space was calculated with reference to techniques such as conversion gates from classical information to quantum information, quantum walks, and probability amplitude addition circuits used in the quantum algorithm for the Navier-Stokes equations. The most important advantage of the quantum computer is the parallelization of grid information in the spatial direction into a single state function through massively parallelization. Its computational complexity is $O(\log_2 N)$ faster than $O(N^6)$ of a similar classical algorithm (N : the number of grids in a direction).

The goal of this project is to construct the quantum algorithm (6D Boltzmann-Maxwell equations for collisional plasmas) that simulates the auroral electron acceleration mechanism.

In this presentation, the quantum algorithm constructed in the First stage. will be explained, and the obtained quantum numerical results will be compared and discussed with those obtained by the classical algorithm, with a view to the future.

References

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