S2-4 Fusion Plasma Simulation and Computation Science in the Future
核融合プラズマシミュレーションと次世代計算科学

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Plasma physics has directed its attention to the potential power of computer simulation as a powerful methodology of science since the twilight of the evolution of computer. With the great help of noticeable progress in supercomputer, investigation of fusion plasmas through computer simulation has been deepened significantly. For future direction of computer simulation, it's important to develop an algorism that solves accurately processes in each scale layer while exchanging necessary information between layers.

1. Introduction

Plasma physics has directed its attention to the potential power of computer simulation as a powerful methodology of science since the twilight of the evolution of computer. In particular, it has been trying to capture the nature of plasmas fully in a self-consistent manner as much as possible by using large-scale computer simulation method. This is because complex natures that are often expressed as nonlinearity, nonequilibrium, and openness are considered to be essential in describing behavior of plasmas. Remarkable properties, such as self-organization or structure formation, are very often observed in such systems, and plasma has been found to be an exemplar of those properties. Those natures require cultivation of new methodology to understand the mechanism of processes that is beyond conventional methods in physics. Fusion plasma physics is not an exception, which is a branch of plasma physics. Due to existence of strong gradient in various parameters and influx/outflux of energy with external region, fusion plasmas have been found to reveal itself variety of remarkable phenomena. With the great help of noticeable progress in supercomputer, investigation of fusion plasmas through computer simulation has been deepened significantly.

Nowadays computer simulation aims to give good prediction of real fusion plasma experiments, which contributes to effisient execution of experiments as well as reduction of construction costs for new devices. The properties of plasma are so complicated that we need to develop further sophisticated modeling to realize precise prediction for overall behavior of plasmas, however.

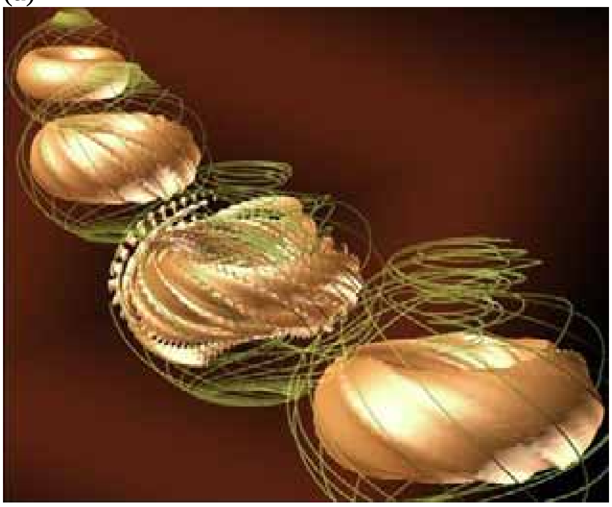
2. Prospect of Fusion Plasma Simulation

The problem is whether or not we could give good prediction of fusion plasmas if performance of computer is enhanced. It is true that we can have finer grid points as well as longer time evolution when computer performance is increased. In this way, phenomena in a specific scale of space and time can be investigated more accurately. It's important to continue this effort.

It has been recognized recently, however, that various scales of space and time appear in actual fusion plasmas, which consist of macroscale and microscale (ion and electron), and they are not independent. Conventional approach of plasma physics has been based on an assumption that physics processes can be split into several layers of scale, and overall nature can be captured if physics of each layer is understood. In actual plasma phenomena, the interaction between different scale layers may not be able to be neglected, even if it is weak. The weak interaction could change the processes drastically when it is accumulated. The challenge is to develop a new method that can treat multiple layer structure simultaneously and self-consistently. The difference in time scale between macro and micro scale can be extended to 10 to the 8^{th} in fusion plasmas, and it is understood immediately that a model that try to cover all scales in one equation and grid system is not realistic. For future direction of computer simulation, it's important to develop an algorism that solves accurately processes in each layer while exchanging necessary information between layers. The multiple layer structure is not specific in fusion plasmas, but is quite universal in all fields of natural science as well as social science. The algorism that is developed in plasma physics can be exported to other fields in science.

Shown in Fig.1 is a possible example of interaction between macroscale and microscale phenomena. Figure 1 (a) shows global evolution of Internal Reconnection Event that is observed in spherical tokamak experiments [1]. As the name indicates, magnetic reconnection plays important role in the processes. MHD simulation is executed in Fig.1 (a). For a case of higher temperature confinement, collisionless reconnection is supposed to be important in the mechanism of reconnection, which is not fully described by the MHD model. Shown in Fig.1 (b) is a microscale simulation of the collisionless reconnection [2], which reveals detailed physics around the X points of reconnection. Self-consistent combination of those two simulations can clarify the overall behavior of the plasma.

(a)



(b)

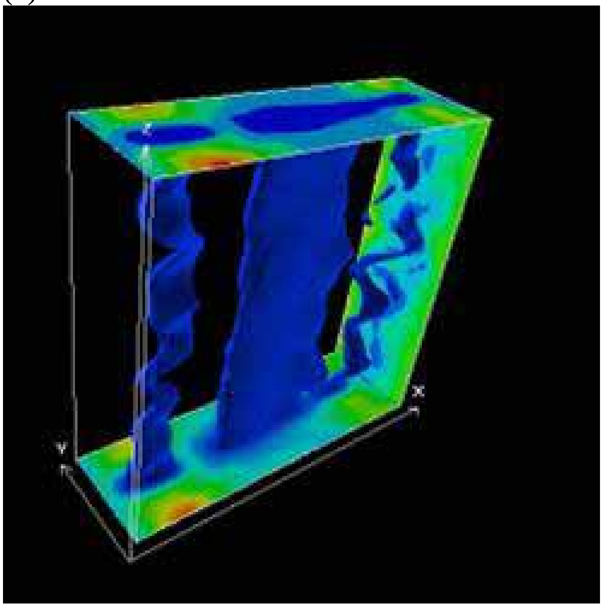


Fig.1 (a) Macroscale MHD simulation of Internal Reconnection Event in spherical tokamak [1]. (b) Microscale simulation of collisionless magnetic reconnection [2].

3. Discussion

Numerical analysis technique of linear stability for fusion plasmas has been developed to a highly sophisticated level. Nonlinear simulation for each layer of scale has revealed many exciting processes. Nevertheless, we believe it’s a time to open doorway to investigate physics of multi scale layers. A lot of surprises may be waiting.

In many fields of science, computer simulation is now considered to be the third method of science following experiment and theory. We have proposed to call it “simulation science”, in which we aim to search for truth that can be reached only through computer simulation.

For the purpose of pursuing simulation science, it’s also important to organize a simulation researcher group that consists of intensive interaction among researchers on simulation, computer usage, algorism, and theory. Collaboration with surrounding researchers is another important factor.

The Earth Simulator is a bright star of hope for simulation science. It has kept the world record of performance for more than two and half years. A good combination of computer vendor and simulation researcher would create a new era of simulation science.

Acknowledgments

I acknowledge discussions with simulation researchers at NIFS.

References

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[2] R.Horiuchi et al, Comp. Phys. Comm (2004) in press.