Simulation methods and visualization tools for MHD simulations in a sphere

*Akira Kageyama[1], Kumiko Hori[1], Naohisa Sakamoto[1]

1. Graduate School of System Informatics, Kobe University

In recent years, we have been developing a set of simulation and visualization tools for magnetohydrodynamics (MHD) simulations in the spherical geometry. The adopted numerical scheme is a finite-difference method on the Yin-Yang-Zhong grid [1], which is an overset grid system in the spherical geometry.

The codes are written in Fortran 2003 or in eFortran [2], which is a dialect of Fortran 2008 language. The features of eFortran include; the period "." as the member access operator; block comments, addition/subtraction/multiplication assignment, pre-defined and user-defined aliases, automatic check of "implicit none" call, "just once" block, and "skip" block. We have developed a preprocessor to convert the dialect into the legitimate Fortran. It is a simple text converter in Python that keeps the line numbers of the input dialect and the output standard codes.

We have performed MHD simulations of relaxation process in a sphere [5]. Since the spherical geometry is free from the lateral dynamic pressure on the spherical boundary, we can observe MHD relaxation process in which flow and the magnetic field coexist. Intriguing structures of magnetic/flow fields are observed after relaxations.

One of interesting applications of the spherical MHD solver is the spherical shell convection with resistive inner core. Magnetic field generated by dynamo process in the convective spherical layer can diffuse into the inner solid core. We have solved slowly rotating spherical thin shell convection system and confirmed that the resistive inner core plays important roles to keep the dynamo operating in convection rolls in the ring- or spiral-shape.

We have also applied the Yin-Yang-Zhong simulation code to simulate MHD flows in a precessing sphere. We have confirmed that magnetic field is generated in spherical precession flows in some parameter regimes that are reported in previous studies. The structure and the generation mechanism of the magnetic field is analyzed in detail.

For the visualization purposes, we have developed two kinds of visualization tools for simulation data produced on the Yin-Yang or Yin-Yang-Zhong grid : (a) Two dimensional (cross sectional) in-situ visualization library with vector graphics format (EPS) [3], and (b) three dimensional visualization methods based on an advanced visualization framework KVS (Kyoto Visualization System) [4].

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