Simulation of Turbulence and Magnetic Field Evolution in Astrophysical Plasmas

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Introduction: Background

Galaxy clusters are the largest gravitationally bound objects in the Universe. A characteristic cluster contains hundreds of galaxies spread over ~3 megaparsecs, or roughly 10^8 light years, and contain over 10^14 times more mass than the sun.

Cosmological Simulations

Unfortunately, it is not possible to construct one’s own galaxy cluster in a laboratory and watch it evolve. Even if it were, one would have to wait around for several billion years for the experiment to finish! Astrophysicists resort to the next best option to help understand the observed phenomena: computational simulation. The image in Fig. 2 shows a rendering of a detailed simulation of the merger of two clusters, shown readily by the bright regions in the density (top left). The magnetic field strength is expected to look like the shown “blob”, while an indicator of turbulence is shown in the bottom right. It is important for these simulations to understand exactly the interplay between the magnetic field and the dynamic, turbulent ICM.

Turbulence and Fields

The study of the evolution of a magnetic field containing turbulent plasma can be performed through computational simulations allowing for control and variation of a wide range of parameters governing the turbulence, plasma, and magnetic field. We have conducted six simulations of a plasma system driven by turbulent motions with varying initial magnetic field conditions. Outlined here are two simulations each containing an initial magnetic field that averages to zero across the system, called “zero mean background”, or ZMB. The difference lies in the initial structures at which they are present, with ZMB04 originating in scales 1/2 that of ZMB04.

Magnetohydrodynamic Simulations

In turbulence, the field lines of the magnetic field are stretched and pulled. This stretching action increases the energy contained within the field and increases the strength of the field. This is the mechanism by which the field evolves.

Magnetic Field Strength

Regardless of initial structure, there is a significant difference between the evolution of the two simulations. The scale structure of the initial magnetic field is important for its evolution. Below is a quick summary of results:

- More complex, twisting structures formed earlier in ZMB04, as the turbulence more quickly inputs energy into the magnetic field.
- Because of this, for ZMB04, field strength evolves roughly twice as fast as that in ZMB06.
- Regardless of initial structure, simulations reach similar final equilibrium states (t=200 in Fig. 4).

The early evolution of the magnetic fields here are most important, and most applicable to the current observed state of galaxy clusters. With further work, the results of these additional simulations will be directly applicable to the observed properties of cluster magnetic fields.

Results and Conclusions

From the plots in Fig. 4, there is a significant difference between the evolution of the two simulations. The scale structure of the initial magnetic field is important for its evolution. Below is a quick summary of results:

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Further information

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