Modelling Protogalactic Collapse and Magnetic Field Evolution with FLASH

Introduction

The αω dynamo model explains magnetic field structure and amplification in spiral galaxies.

- Field evolution attributed to amplification of toroidal and poloidal magnetic field modes by turbulence and stretching of field lines.
- Radio observations corroborate model.

Problem: the αω dynamo only explains the mechanism for amplification. A poorly understood initial “seed” field is needed to start the dynamo engine.2

Biermann Battery

The Biermann battery is a viable candidate for this seed field.

- Shocks cause ions and electrons in a plasma to separate, generating currents, and hence magnetic fields.3
- Arises naturally from shocks in protogalactic evolution.
- Can be modeled by a pure hydro simulation when the fields are very weak.
- Magnetic field, \( \mathbf{B} \), inferred from the gas dynamics, \( \omega \times \mathbf{v} \times \mathbf{r} \)
- and \( \omega = \alpha \omega \) where \( \omega \) is the vorticity, \( \mathbf{v} \) is the velocity, \( \alpha \) is a constant, \( \omega m_{\text{ion}}(1+x) \approx 10^5 G s \) and \( x \) is the ionization fraction.4 We assume \( x \) is constant and \( \leq 1 \).

The Protogalaxy Model

- A collapsing protolobe spheroid of gas. Prolate, oblate and spheroidal shapes were simulated.
- A dark matter halo simulated by \( \sim 10^6 \) particles that only interact gravitationally.
- Set in an expanding universe with cosmological parameters, \( \{ h_0 = 1, \Omega = 0.7, \sigma = 0.5 \} \)

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Simulations

Tools:

- The Tungsten cluster, a 2990 processor Linux machine, at the National Center for Supercomputing Applications. Used for high resolution protogalactic collapse simulations.
- The Tsodzil cluster. A Linux machine, 8 Intel Xeon processors, 16 GB of RAM. Used for analysis.
- FLASH, an adaptive mesh refinement (AMR) code for astrophysics.5 AMR allows the resolution to be increased in more interesting regions of the simulation.

Analytic Tests:

- An analytic result for the vorticity jump across a shock was used to check accuracy.
- The vorticity jump should follow

\[
\Delta \omega = \frac{\delta^2}{1 + \delta} \frac{\partial \mathbf{v}}{\partial \mathbf{r}},
\]

where

\[
\delta = \rho_{\text{post-shock}} / \rho_{\text{pre-shock}} - 1 \quad \text{and} \quad \rho \text{ is a density. The derivative is along a tangential distance, } \mathbf{r}, \text{ ahead and behind the shock front.}
\]

- A bow shock simulation shows that the vorticity generation is accurate to about 30%

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Future Work

- Quantitatively comparing results of the simulation to previous studies with different codes.4,6
- Analysis of prolate and oblate simulations.
- Longer term, explore later stages of protogalactic evolution with the radiative cooling and magnetohydrodynamics modules of FLASH.

References


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