Accretion Phenomena and Related Outflows, IAU Colloquium 163
ASP Conference Series, Vol. 121, 1997
D.T. Wickramasinghe, L. Ferrario, and G.V. Bicknell, eds.

A Magnetohydrodynamic Model of Galaxy Formation

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Abstract. We present a full 3D model of galaxy formation, incorporating for the first time magnetohydrodynamical effects. By this means we hope to simulate the creation of active galactic nuclei, including jets. Preliminary results are encouraging.

1. Introduction

We are developing a model for the formation of active galactic nuclei, beginning with a primordial cloud and following the collapse through to the production of a centrally condensed object producing jets and surrounded by a galactic disc with a realistic field configuration. This ambitious aim requires a full self-gravitating magnetohydrodynamic (MHD) calculation in three dimensions, also including the effects of a turbulent dynamo.

2. The model

Clearly the range of scale lengths we wish to investigate is extremely large, and this necessitates the use of a Lagrangian technique, free from the constraints of an imposed grid, and naturally adaptive to give the highest resolution only where it is needed. We use a version of TREESPH (Hernquist & Katz 1989) which combines hierarchical tree gravity with smoothed particle hydrodynamics (SPH). We also use SPH to calculate the magnetic field configuration and its back reaction on the gas dynamics.

Incorporating MHD into a SPH framework has posed two major problems, although we now believe that both have been resolved satisfactorily. The first was to ensure the stability of the simulation, in particular the Lorentz force calculation. The second was to restrict $\nabla.\mathbf{B}$ to acceptable values. It is not unfortunately possible within SPH to constrain $\nabla.\mathbf{B} = 0$, but with use of a suitable form for the induction equation and careful choice of the parameters controlling the resolution of the simulation we can restrict $\nabla.\mathbf{B}$ to values which are dynamically insignificant.

Typical simulations commence with a uniform, rotating sphere comprised of both gas and collisionless dark matter (with gas particles constituting 10% of the total mass and 75% of the particle number). A uniform magnetic field of strength 10^{-16} T is applied perpendicular to the rotation axis; such a field strength is consistent with observational constraints (Kronberg et al. 1992) and theoretical predictions (Ratra 1992).

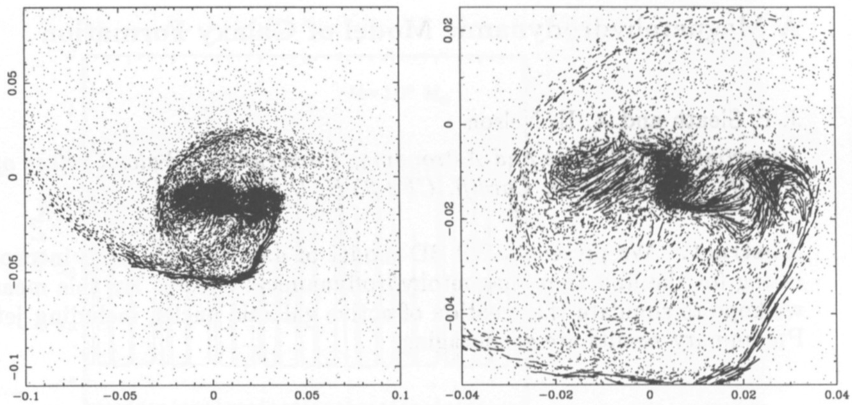

Figure 1. Results from an 18 000 particle simulation after ~1.5Gyr, viewed along the rotation axis. All particles along the line of sight, together with their associated magnetic field vectors, are shown.

3. Results

Results are still preliminary at this stage, but nonetheless encouraging. In the simulation shown (Fig. 1) we see that a galactic sized object is formed with a well-defined barred spiral structure superimposed on a thin disc. The magnetic field lies parallel to the arms in accordance with observations (Beck & Hoernes 1996) and has increased in strength by about two orders of magnitude. This is somewhat lower than the field strengths observed in galactic discs (Fitt & Alexander 1993), reflecting the short time for which this simulation has been run and the lack of any dynamo action – the increase in the field is due solely to the frozen-in field being transported by the gas.

4. Future developments

The next important development will be to relax the ideal MHD approximation by including dissipation and the effects of an $\alpha\omega$-dynamo, the latter resulting in a poloidal field component. With increased resolution, obtained by using more particles and/or weighting the particles such that there are more present in the central volume, it is hoped that this will permit us to create and resolve the outflows/jets from the central region which we observe in active galactic nuclei.

References

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https://doi.org/10.1017/S0252921100044055 Published online by Cambridge University Press