A Numerical Simulation of Galaxy Subcluster Mergers

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Abstract: We present preliminary results of a 3-D numerical simulation of two merging subclusters of galaxies. By self-consistently modelling the intracluster gas and dark matter dynamics, we hope to gain insight as to how the dynamics of both relate to such observables as the cluster X-ray emission, radio source morphology, and velocity dispersions.

1. Introduction

In recent years, both X-ray and optical surveys have revealed a significant level of substructure in both the gaseous ICM and galaxy components in clusters of galaxies (Forman and Jones 1982, Beers *et al.* 1991). One possible explanation for the origin of the observed substructure is subcluster mergers (McGlynn and Fabian 1984). This is an idea which could have significant implications for theories regarding the growth of large scale structure (LSS) in the Universe. Observationally, one may gauge the significance of subcluster mergers in building LSS though comparing the number of clusters with and without signatures of a merger event. Numerical simulations such as this one will aid in the identification and interpretation of merger signatures as well as their evolution. In addition, we will be able to study the post-merger cluster environment as it relates to radio source morphology.

This experiment is being performed in 3-D using a hybrid N-Body/MHD code. The hybrid code allows the study of the self-consistent evolution of a gas component, represented by the fluid equations of hydrodynamics, in a gravitational potential defined by self-gravitating dark matter, represented by the particles of the N-Body simulation. The MHD component of the code is ZEUS-3D, an Eulerian, finite difference code developed by D. Clarke and M. Norman (Stone and Norman 1992). The N-Body component of the code is the Hernquist Treecode (Hernquist 1987).

2. The Simulation

In this simulation, two galaxy subclusters are placed initially at rest with their cores separated by 6 Mpc. The dark matter in each cluster is represented by a virialized isothermal King model distribution of particles. The dominant of the two subclusters consists of 16,000 particles while the smaller cluster consists of 2000 particles. All particles are of equal mass. The dominant cluster is scaled to 1.0×10^{15} solar masses with a velocity dispersion of 1200 km/s. The dominant cluster core and tidal radii are 0.25 and 3 Mpc, respectively. The dimensions of the smaller cluster are one half of these. Each cluster is initialized with an isothermal gas distribution in hydrostatic equilibrium with the gravitational potential defined by the dark matter particles. The temperature of the gas is a free parameter which was chosen such that the sound speed in each cluster is equal to the velocity dispersion of that cluster. This implies a gas temperature of 1.0×10^8 K in the dominant cluster and 2.6×10^7 K in the small cluster. The gas distributions are not self-gravitating. However, the total gas mass is a small fraction of the total cluster mass, less than 15% in the small cluster and less than 5% in the dominant cluster.

The hydrodynamical calculations are performed on a grid with dimensions $190 \times 60 \times 60$ corresponding to a maximum resolution of 62.5 kpc.

3. Preliminary Results

The simulation reveals the formation of multiple shock fronts expanding both parallel and perpendicular to the merger axis resulting in a complex temperature structure. Gas behind the strongest shock front is heated to 3.0×10^8 K. In addition, a pocket of the cooler gas from the small cluster may remain for a considerable time after the merger. The density contours show an elongation of the gas distribution, initially perpendicular, and eventually parallel to the merger axis. Figure 1a is a 2-D slice in density and velocity parallel to the merger axis at 1.0×10^9 yrs after the time at which the cores are coincident. At this point, the smaller cluster, having entered from the top of the figure, has passed through the core of the dominant cluster (top/center) and can be seen in the lower half of the figure. Note the clumpiness and elongation of the density distribution. Figure 1b shows the corresponding shock structure as revealed by the gas Mach number. Three shocks are evident, the strongest of which is on the merger side of the dominant cluster core.

4. Future Work

We will explore the merger parameter space with significantly improved resolution. Simulated ROSAT and EINSTEIN imagery will be generated to assist in the analysis of the x-ray data. We will also examine the evolution of cooling flows within the merger environment.

References

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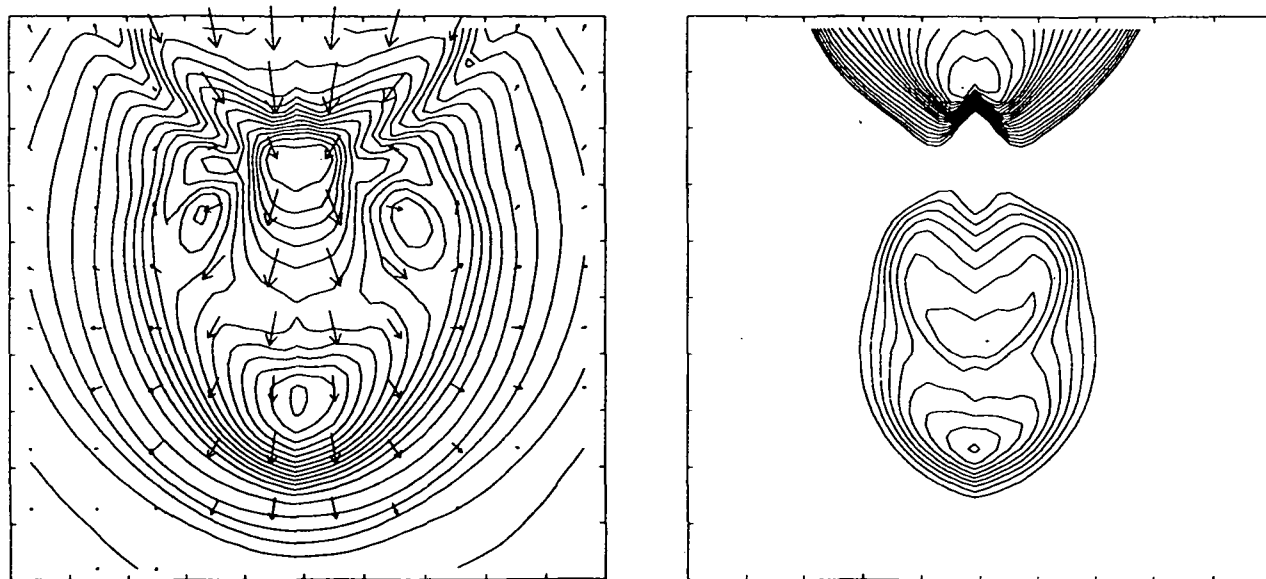Stone, J. & Norman, M. 1992, *Ap. J. Suppl.*, **80**, 791.

Figure 1. Density, velocity and Mach number shortly after the merger. The region depicted is nearly 3 Mpc on a side. The small cluster has entered from the top of the frame. a) Density contours with velocity vectors superimposed. Contours are logarithmic spaning 2 orders of magnitude. Note the clumpiness and elongation of the gas distribution. The maximum velocity corresponds to nearly 2300 km/s. b) Mach Number. Contours are linear ranging from 0.95 to 4.0.