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# Enrichment and Heating of the Intracluster Medium by Ejection from Galaxies

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We present results of N-body + hydrodynamic simulations designed to model the formation and evolution of clusters of galaxies and intracluster gas.

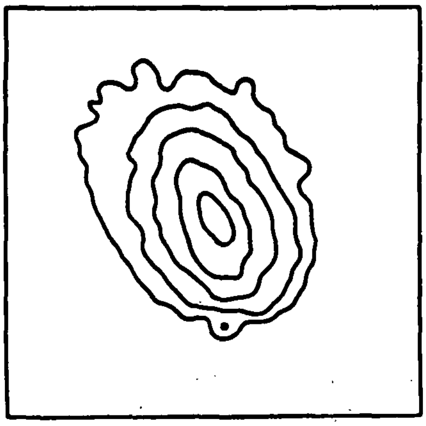
Clusters of galaxies are the largest bound, relaxed objects in the universe. They are strong x-ray emitters; this radiation originates through thermal bremsstrahlung from a diffuse plasma filling the space between cluster galaxies, the *intracluster medium* or ICM. From observations, one can infer that the mass of the ICM is comparable to or greater than the mass of all the galaxies in the cluster, and that the ratio of mass in hot gas to mass in galaxies, $M_{ICM}/M_{stars}$, increases with the richness of the cluster. If the ICM is predominantly gas left over from the galaxy formation process, why was galaxy formation more "inefficient" in rich clusters? Or, if the ICM came primarily from gas that fell into the cluster after it formed, why were rich clusters more efficient in collecting gas?

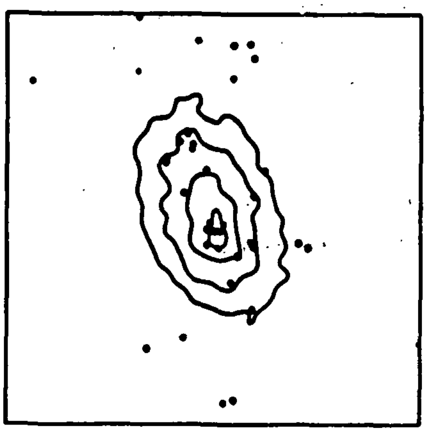
Spectroscopic studies of cluster x-ray emission show heavy element emission lines. While $M_{ICM}/M_{stars} \geq 1$ implies that most of the ICM is primordial in nature, the discovery of heavy elements indicates that some of the gas must have been processed through galaxies. Galaxy evolution thus directly impacts cluster evolution; can current theories of galaxy evolution account for the observed metallicities of galaxy clusters?

The current paradigm for evolution of the ICM involves infall of primordial gas into the cluster potential well. Gravitational collapse and shock heating then drives the gas up to observed temperatures. Recent analytical studies have examined enrichment of the ICM through supernova ejecta being blown out of galaxies as a wind, or ram-pressure stripped as galaxies plow through the ICM. We are integrating these studies with three dimensional N-body / gas dynamical evolutionary models of clusters. Our simulations follow three dynamically distinct components: cluster gas, galaxies, and dark matter. Shocks from gravitational collapse, along with mass, energy, and metal ejection from cluster galaxies, are incorporated into the models.

The initial conditions for our simulations were derived from a cold dark matter power spectrum, with a particle distribution at a redshift of 9 generated through linear theory. Galaxies are then placed in the initial conditions by-hand, using the gas mass associated with $2.5\sigma$ peaks in the density field. Our combined n-body / hydrodynamical simulation code then evolved these initial conditions to a final redshift of zero.

Radial profiles of cluster gas properties, including temperature, metallicity, and spatial distribution of ejecta were derived. Also, simulated x-ray surface brightness profiles were derived from the density and temperature data of the cluster. Despite the use of many simplifying assumptions in these early runs, results have been obtained which roughly agree with observations. In particular, iron abundances of about half solar and nearly flat temperature profiles are found within an Abell radius. Future plans for the project include refinement of our ejection algorithm. We also plan to produce a cluster catalog of reasonable size by making many simulation runs, so that systematics of cluster properties - temperature profiles, metallicities, correlations of observables - can be explored, and so that more solid predictions can be made about the expected evolution of cluster properties. This project should provide important feedback on our theories of the evolution of cluster gas, when compared with observational results from BBXRT, ROSAT, ASTRO-D, and (hopefully) AXAF.




Simulated ROSAT PSPC images of clusters grown from same initial conditions; run above includes only gas and dark matter, while run below also includes galaxies and ejection of gas. Dots on lower plot show locations of bright galaxies. Outermost isophote at same level for both plots. z is redshift of cluster; $f_{tot}$ is total counts per second in window, in the PSPC energy band; L44 is x-ray luminosity in window and in energy band, in units of $10^{44}$ ergs/s; M14 is total gas mass in the window, in units of $10^{14} M_{\odot}$.