DYNAMICS OF THE BARYONIC COMPONENT IN HIERARCHICAL CLUSTERING UNIVERSES

Julio F. Navarro
Physics Department
University of Durham, Durham DH1 3LE, England.

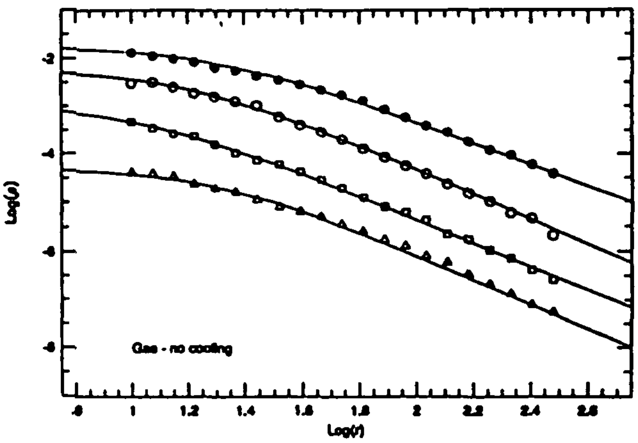
I present self-consistent 3-D simulations of the formation of virialized systems containing both gas and dark matter in a flat universe. A fully Lagrangian code based on the Smoothed Particle Hydrodynamics technique and a tree data structure has been used to evolve regions of comoving radius 2-3 Mpc. Tidal effects are included by coarse-sampling the density field of the outer regions up to a radius $\sim$ 20 Mpc. Initial conditions are set at high redshift ($z > 7$) using a standard Cold Dark Matter perturbation spectrum and a baryon mass fraction of 10% ($\Omega_b = 0.1$). Simulations in which the gas evolves either adiabatically or radiates energy at a rate determined locally by its cooling function were performed. This allows us to investigate with the same set of simulations the importance of radiative losses in the formation of galaxies and the equilibrium structure of virialized systems where cooling is very inefficient. In the absence of radiative losses, the simulations can be re-scaled to the density and radius typical of galaxy clusters. A summary of the main results follow.

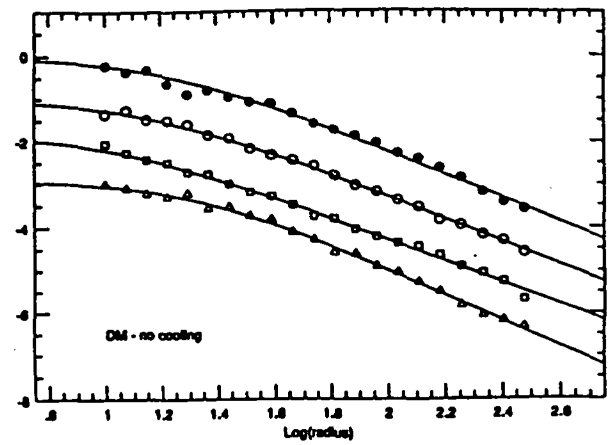
We confirm that, in the absence of radiative losses, the spatial distribution of the gas and dark matter in a virialized system is very similar. The gas and dark matter density profiles can be adequately represented by the inner parts of an isothermal sphere ($\rho \propto (1 + (r/r_{core})^{-3\beta_f/2}$, with $\beta_f \sim$ 0.7-0.9) although the gas is not completely isothermal ($T_{gas} \propto r^{-1/3}$). No evidence is found for the existence of a core radius in the gas component beyond that artificially imposed by the spatial resolution of the simulations. The average gas temperature matches well the virial temperature of the system ($\beta_T = \sigma^2_{DM}/T_{gas} \sim 1$). If an X-ray emission-weighted gas temperature is used no β discrepancy is present even after a major merger, when the system is far from equilibrium ($\beta_T \sim \beta_f$). This suggests that the β-discrepancy in galaxy clusters is not mainly due to incomplete thermalization of the gas, as previously proposed, but actually reflects either poor velocity dispersion estimates or legitimate low gas temperatures (perhaps due to the effects of cooling).

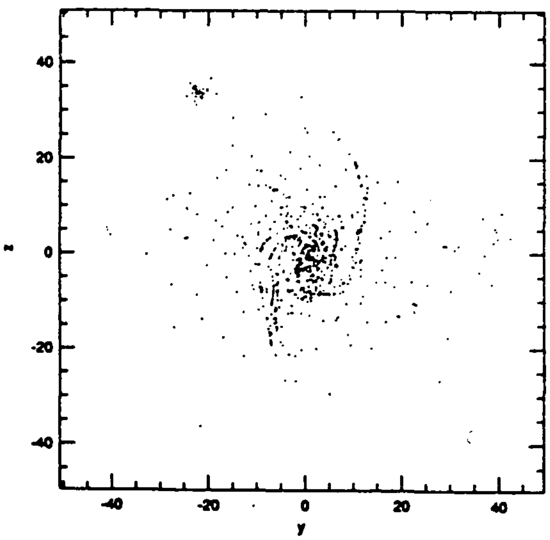
Radiative cooling is extremely important on galaxy scales. Most of the gaseous mass cools very efficiently at high redshifts and is locked up at the center of small dark matter clumps, where it rapidly settles onto centrifugally supported disk-like structures. Due to their high density, these baryonic cores are hardly disrupted by shocks and may survive longer the mergers of their surrounding dark matter halos. Simple models based on cooling radius arguments at $z = 0$ seriously underestimate the mass of these disks. In this scenario, a galactic disk grows by the mergers of dense gas clumps driven to the center by dynamical friction rather than by the quite infall of material envisaged in earlier models. This process involves a significant loss of angular momentum and large collapse factors. The rotation velocity of the disks is found to systematically overestimate the circular velocity of the surrounding halo (up to 50% for $\Omega_b = 0.1$). The surface density structure of the disks is reasonably fit by an exponential profile and its rotation velocity is flat up to $\sim$ 5 disk scale lengths, in good agreement with the observational properties of disk galaxies.

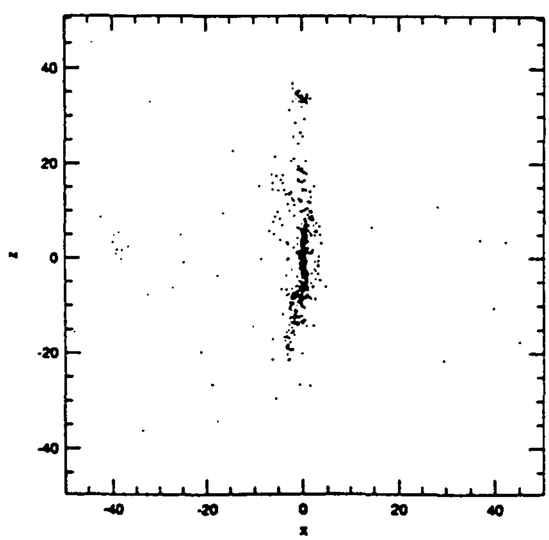
Star formation can be added in a realistic manner because the thermodynamical properties of the gas are known everywhere, although uncertainties regarding the efficiency of supernovae feedback can not be avoided. Most major galaxies formed through mergers of smaller subunits at recent redshifts ($z < 3$). The derived star formation rates (SFR) were about three times higher at $z \sim 1$ than at the present time, lending support to the interpretation of excess blue counts as due to evolution in both galaxy number density and average star formation rates. The stellar content of halos which have undergone a recent merger ($z < 0.5$) have dynamical and chemical properties which compare favourably with observations of elliptical galaxies.

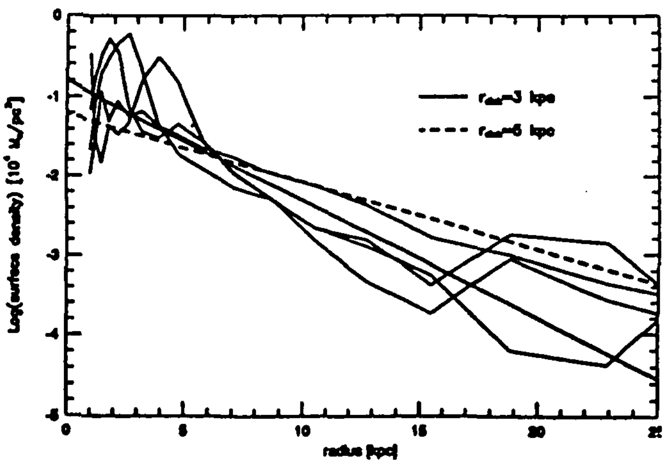
Figures: 1st row) Gas and dark matter density profiles together with isothermal β model fits (no cooling). 2nd row) Face-on and edge-on views of a gaseous disk at $z = 0$. Box is 100 kpc across (with cooling). 3rd row) Surface density profiles with exponential fits with disk scale lengths 3 and 5 kpc (inner 25 kpc). Rotation velocity of the disk and circular velocity of the system (inner 100 kpc). Insert is a blow-up of the inner 30 kpc.

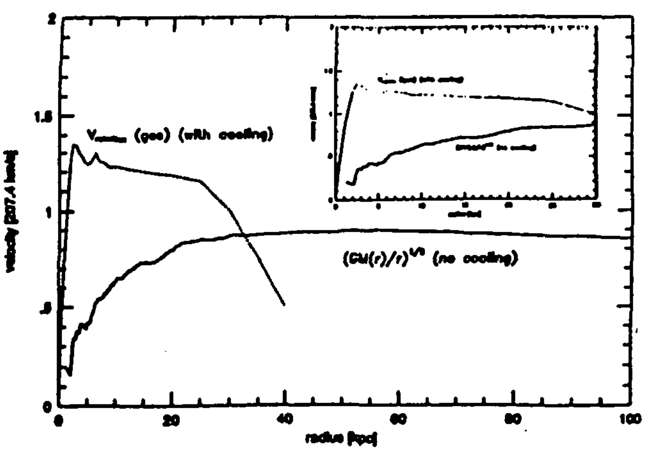

Gas - no cooling
Log(r)


DM - no cooling
Log(radius)


y
z


x
z


radius [kpc]


radius [kpc]