Cold Flows versus Virial Shock Heating in Galaxy Formation

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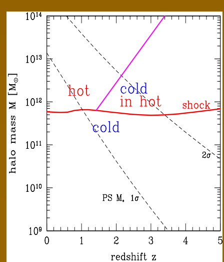
Abstract

Cosmological simulations confirm the predictions for a critical halo mass with an important role in shaping up the main galaxy properties at low and high redshifts. Below this mass, galaxies are built by cold flows associated with efficient star formation. Above this mass, cooling and star formation are shut down by shock-heating triggered feedback. Massive galaxies at high redshifts are built by cold flows penetrating hot halos.

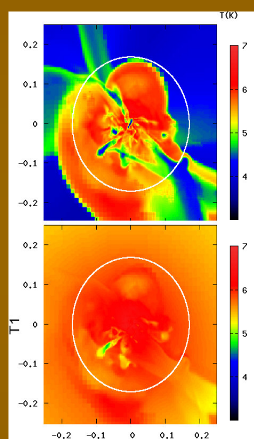
Introduction

The basic picture of galaxy formation (Rees & Ostriker 1977, Silk 1977, White & Rees 1978) utilizes the assumption that as gas falls into halos, it passes through the virial shock which heats it to it's virial temperature. We find that in the presence of significant cooling, the gas below the shock cannot support itself and falls inward on a dynamic timescale. In this case the shock cannot propagate outwards and stays at the disc. The gas then accretes via cold flows.

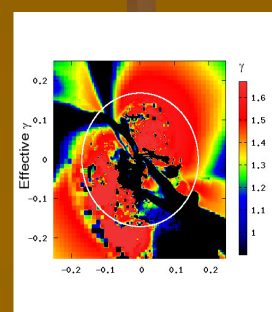
This can be quantified (Birnboim & Dekel, MNRAS, 345, 349) into a stability criterion which depends on the ratio between the cooling rate and the contraction rate. When converted to global halo parameters this criterion becomes a critical mass below which no gas can heat due to virial shocks. This critical halo mass ($5\cdot10^{11}$ solar masses) depends weakly on the redshift (Dekel and Birnboim, astro-ph/0412300).



The critical mass for existence of a virial shock (red line). The area between the pink line and the red line marks the coexistence between a hot spherical component and cold filaments feeding the galaxies. The black lines are the typical M_* masses. Thus, the typical halo at z>1 will not have a virial shock.



Actual temperature (top panel) and post shock temperature (bottom panel) of the same $3\cdot10^{11}$ solar mass halo in the ART simulation. The shock is clearly visible in the actual temperature but is erased in the smooth, post shock temperature, proving that our transformation is consistent with the numerical simulation of the shock.



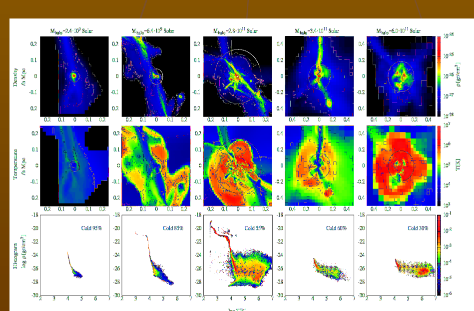
Colormap of the effective gamma which is the stability parameter of the gas derived in our previous work. The critical value lies between 0.9 – 1.4 depending on the geometry of the problem. For this halo, the hot sphere is stable for for a virial shock while the filament, being denser, are still unstable. No shock is predicted in these filaments until they hit the disc.

Methods

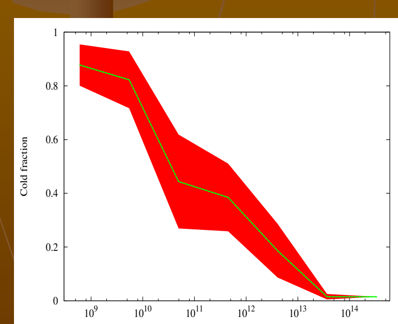
A novel technique for determining the stability of complex 3D configuration was derived and tested on 3D halos. It involves converting all the local thermodynamic variables (density, temperature, energy) into their post shock values, assuming that a shock occurred there. Then, the stability criterion was applied to 3D cosmological hydrodynamic simulations performed by Andrey Kravtsov and a prediction of what gas will be able to form a shock was generated. This values correlates well with the gas that actually shocks. This analysis is done for each distinct halo in the simulation to calculate average halo properties.

Results

The transition between cold flows and hot accretion is seen between 10^{11} – 10^{12} solar masses as is predicted by the stability analysis. The spread is larger than seen in spherical simulations due to the large geometrical configurations. A good correlation is found between the unstable fraction of gas predicted and the cold fraction found. This feature may help explaining the bimodality, help SAMs and have observational impact.



A selection of halos from the ART simulations, by Andrey Kravtsov, presenting a sequence of halos from cold to hot. Top row is density, middle row – temperature, bottom row – mass histogram of the gas in the halos sorted according to temperature and density. As the halos become larger in mass, the cold fraction of gas decreases until no cold component is present.



The Cold-fraction/Mass relation for a compilation of all the halos in redshifts 1-4 of the ART hydrodynamic simulation. The transition between 10^{11} – 10^{12} solar mass of halo is smooth due to the 3D effects of filaments and mergers taking place.