WHAT MAY SUPERCLUSTERS TELL US ABOUT GALAXY FORMATION?

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ABSTRACT: The structure and dynamical properties of superclusters (SC's) may help us distinguish between various scenarios for galaxy formation. N-body simulations and analytic estimates show that (contrary to a common belief) a nondissipative pancake scenario can explain the observed flattening of SC's. Then, the disk-halo structure of the Local SC (LSC) and its velocity field suggest that galaxies form before SC's and not necessarily as a result of a dissipative gas collapse to SC pancakes. A confrontation of the simulations with the data indicates that the LSC has collapsed along its short axis only after $z \sim 1$.

Observations of SC's, and of the LSC in particular, are approaching a stage where quantitative comparisons with formation theories may be attempted, and let me mention here such an attempt. Two extreme scenarios are commonly discussed: a) the clustering picture where structure evolves hierarchically from small to large, starting from isothermal perturbations, and where the clustering of galaxies is gradual and dissipationless, and b) the dissipative pancake picture where structure evolves from large to small via fragmentation of SC's. In the latter, large scale adiabatic perturbations (of baryons and/or of massive neutrinos) that survive damping are the progenitors of all structure, and formation of highly asymmetric SC's is a natural outcome because of the large-scale asphericity of the velocity field. If the collapsing material is gaseous, dissipation produces a thin, dense pancake (or string) that fragments to form galaxies, but it is hard to explain in this picture the presence of many galaxies very far from the SC plane in which they are assumed to be born. Yet, a non-dissipative pancake scenario, which is a combination of the two scenarios, is also possible: galaxies may already exist during the collapse of SC's as an outcome of small-scale perturbations, and they cross the SC plane (or line) with little dissipation to form a thicker pancake while some of them still populate the SC halo. By studying nondissipative pancakes, and comparing with the LSC, we estimate the degree of dissipation required to explain the observed flattening (Dekel, 1983a).

An N-body simulation of Sc formation is illustrated by a sequence of snapshots in Fig. 1. An initially Hubble expanding, spherical system of a comoving radius ℓ ($\ell_{18} \equiv \ell/18\mathrm{Mpc}$), which corresponds to the critical

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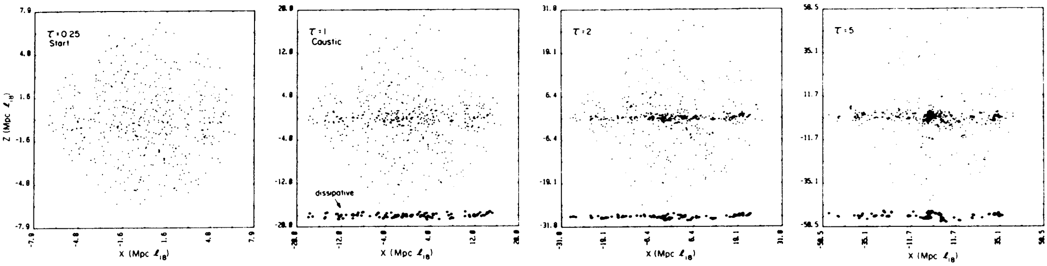

Figure 1. Edge-on, comoving snapshots.

damping length, is perturbed adiabatically in one direction (a sin wave in Z) and is assumed to evolve in the linear regime according to the approximation of Zeldovich (1970). The slight flattening in the initial state (time $\tau=0.25$) is associated with a systematic peculiar flow toward the XY plane which leads to focusing of trajectories of 20% of the particles in a thin pancake at $\tau=1$. The relative flattening is not transient! It becomes even more pronounced after $\tau=1$, even when the absolute thickness grows again (the thickness is eventually affected by subclustering).

The nondissipative flattening and cooling is primarily due to the expansion in the orthogonal directions. When the period of oscillation of a particle about the plane becomes small in comparison with the expansion time scale, there is an adiabatic invariant approximated by $h(\tau)v(\tau)\cong$const., where h and v are some mean values of the height and the velocity of the particle above the plane. Combine that with a mean gravitational field of an infinite uniform disk that is proportional to the disk surface density, $\mu(\tau)$, and obtain in time $h\propto v^{-1}\propto\mu^{-1/3}\propto R^{2/3}$, where R is the expanding length scale in the plane, i.e., the pancake becomes flatter like $h/R\propto R^{-1/3}$.

The flattening in the numerical models is found to resemble that of the LSC (Tully 1981 and references therein) near the focusing time $\tau=1$, and it becomes much flatter later. The fit is insensitive to fine details in the models, such as the exact peculiar velocity of our galaxy toward Virgo or the degree of subclustering. A similar result is obtained for observed external SC's, which means that the nondissipative pancake scenario can account for the observed flattening of SC's in general and that dissipation is not required. The velocity field in the LSC (Dekel 1983b) and the subclustering (Dekel 1982; 1983c) are found to be consistent with this scenario also. Hence, galaxies may have formed before SC's, and not necessarily as a result of their collapse which could have been very recent ($z<1$) and nondissipative.

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