THE INTERNAL STRUCTURE OF PROTOCLUSTERS AND THE FORMATION OF GALAXIES

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We give a short review of the general picture and main features of the formation of galaxies and clusters of galaxies on the basis of the adiabatic theory. Detailed discussions of these questions are published in references 1-6. Some related problems of the formation and development of large scale structure in the Universe according to the same theory are considered in Zeldovich's report.

The general picture of the theory under consideration is as follows:

(i) For redshifts $z > 10^5$, there are small density and velocity perturbations having a monotonic (e.g. power-law) spectrum.

(ii) For redshifts $10^5 > z > z_{rec} \approx 10^3$, large scale perturbations grow whereas small scale perturbations are dissipated; a characteristic length arises and this determines the future processes of galaxy formation.

(iii) For redshifts $10^3 > z \gtrsim 15$ following recombination, the perturbations grow, preserving their form.

(iv) For redshifts $15 > z > 10$, the non-linear stages begin; the first "pancakes" are formed although the mean square density perturbations $((\delta\rho/\rho)^2)^{\frac{1}{2}}$ are less than 1. At the same time protoclusters of rich clusters like Coma, Perseus, and Virgo begin to form.

(v) For redshifts $10 > z > 1$ to 2, the bulk of the matter ($\sim 70\%$) turns into "pancakes". The central part of a "pancake" cools and fragments into small clouds while the "pancake" grows as a whole. At the same time these small clouds cluster forming larger complexes, which then develop into galaxies.

In this report we concentrate on the late stages of evolution of "pancakes". We recall briefly the general features of the formation and evolution of pancakes. Zeldovich has shown that the growth of perturbations results in the origin of one-dimensional gas structures which are thin and very dense; we call them pancakes. Gas layers fall onto these

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pancakes and lose their velocity in shock waves. Kinetic energy is transformed into heat and the gas acquires a high temperature. The dense central part of the pancake cools rapidly due to radiation, but the out-lying layers remain hot up to the present epoch.

In spite of the fact that the motion outside pancakes was without vorticity, inside pancakes the motion acquires a component of vorticity. We believe that thermal instabilities in the cooling medium moving with vorticity results in the formation of cool gas glouds moving in the hot gas. In this case the local density is much greater than the mean density. "Mean temperature" means the temperature of the hot gas or the temperature associated with the motion of cool clouds. The masses and sizes of the clouds are determined by their thermal conductivity and by the turbulence in the hot gas.

It is very important that the pressure in the shock front is greater than the self-gravitation of the "pancake". The pressure decreases with time and determines the evolution of cool matter.

It should also be remembered that the thickness of the pancake, its temperature, density and so on depend on radial coordinates and change with time. We would like to point out that the final results which may be compared with observation need an analysis of the problem as a whole.

Galaxies are formed by the clustering of cool clouds which formed due to thermal instability and turbulence. A galaxy was never at any stage a homogeneous gas cloud; the first stars can form in the cool clouds before the origin of the galaxy. But it is necessary to emphasize that both turbulence and cool clouds are a secondary phenomenon; they arise inside the pancakes and their parameters are closely related to the parameters of the pancakes.

We would like to give a short summary of the results we have obtained within the framework of the "pancake theory" of galaxy formation which can be compared with observation.

(1) The masses of galaxies formed in pancakes depend on their radial coordinates. We can derive an approximate mass function of galaxies

$$\frac{dN_g}{dM_g} \propto M_g^{-\nu} ; \quad \nu = 1 \div 1.5, \quad 10^8 < \frac{M_g}{M_\odot} < 10^{11}.$$

(2) We can derive an approximate mass-angular momentum relation

$$\mu_g \simeq 10^{30} \, (M_g/10^{11} \, M_\odot)^{2/3},$$

where μ_g is angular momentum per unit mass.

(3) We can obtain the mass function of clusters of galaxies

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$$\frac{dN_{cl}}{dM_{cl}} \propto M_{cl}^{5}\ e^{-(M_{cl}+3M_{o})^{2}/8M_{o}^{2}},$$

$M > M_o$ and $M_o = 10^{15}M_{\odot}$.

(4) In this picture we can also explain the existence of hot gas in rich clusters as well as HI clouds in superclusters of galaxies, for example in the Local Supercluster.

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DISCUSSION

Efstathiou: I would like to make a comment concerning the pancake theory. This morning Dr Jones presented the results of our work on the tidal torque theory. The value of the parameter λ obtained is a scale-independent quantity and so should apply to pancakes as well as proto-galaxies. If these pancakes then dissipate a lot of energy during their collapse, one might be in danger of producing a rotation-dominated pancake contrary to observations.

Silk: How did you obtain your mass function of galaxies and of galaxy clusters?

Doroshkevich: The mass function is a result of numerical calculations.

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