# ON THE ORIGIN OF THE VOIDS

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In the past few years the large scale structure and dynamics of the galaxy distributions have been studied intensively, mainly by means of red-shift surveys. From these surveys it seems that the distribution of galaxies is characterised by large, empty voids of (20 - 40) $h_{100}^{-1}$ Mpc in diameter with a typical density contrast of $\delta \sim -(0.7 - 0.8)$.

The mere existence of the voids poses a severe challenge to all theories of the formation of galactic systems. In particular, it seems to be difficult to reconcile the observed structure with the gravitational instability theory in a large $\Omega_0$(i.e. $\Omega_0 \lesssim 1.0$) Universe. The point is that if a void of radius $d_0$ is to be formed via random fluctuations, galaxies should have large peculiar velocities, $v_P \sim d_0 H_0^{-1} = v_H(d_0)$ for $\Omega_0 = 1$. (For $\Omega_0 < 1$ linear theory predicts $v_P \sim d_0 H_0^{-1} \Omega_0^{0.6}$.) These large peculiar velocities are not observed. Now, suppose that the progenitors of the voids are negative density perturbations in which $\delta$ is smoothly varying, such that the gravitational force field acts, mainly, radially outwards from some center. Under these conditions the average distance travelled is only $d_0/4$, about one third of the random motion value, $7/8\ d_0$. In this case the peculiar velocities are expected to be much less than in the random case.

Our basic claim is that such a structure is a natural consequence of a combined spectrum of adiabatic and isothermal perturbations. The adiabatic component is truncated on scales less than $M_D \sim (10^{13} - 10^{15}) M_\odot$ where $M_D$ is the damping mass, while the isothermal perturbations may be the "seeds" from which structure on scales less than $M_D$ has evolved. In the following discussion we concentrate only on the adiabatic component. A truncated density perturbation power spectrum implies a wiggly covariance function, $\xi(r)$. As the density excess $\delta(r)$, around sufficiently high density maxima (minima) is proportional to $\xi(r)$, out to some coherence radius, it should be nearly spherically symmetric and manifests a wiggly structure.

*G. O. Abell and G. Chincarini (eds.), Early Evolution of the Universe and Its Present Structure, 203–206.*

The main point is that while high positive density peaks are the progenitors of rich clusters, negative amplitude density troughs are the progenitors of the voids. These high negative density peaks are surrounded by shells of positive $\delta$. As the density contrast within the voids decreases the density excess of the shell increases. There is a coherent flow of galaxies, formed within the void, to its boundaries, i.e. to the shells.

The dynamical evolution of the voids has been investigated by means of a spherical shells model. The power spectrum of the primordial adiabatic component is assumed to be some power law truncated at $k_D$. At the initial epoch the spherical shells system is assumed to have a density excess profile given by: $\delta(r) = \delta_o \xi(r)$, ($\xi(r)$ is normalized so as to make $\xi(0) = 1$) and an initial Hubble-like expansion velocity field. Thus, specifying $\Omega_o, H_o$, the initial epoch, $\delta_o$ and the perturbations power spectrum index, n, the perculiar velocity and density field at the present epoch is calculated.

We note, that we are interested in such negative (density peak) perturbations that, were they positive, would have formed at present superclusters and rich clusters whose central density contrast is $\delta_{RC} \sim (10^3 - 10^4)$. The initial epoch was taken to be $Z_i = 10^3$, and the present density profiles and peculiar velocity fields were calculated for $0.1 < \Omega_o < 1.0$ and $-1.5 < n < 1.5$ as a function of r (in units of $(1+Z_i)k_D^{-1}$). A void ($\delta < 0$) is formed surrounded by a shell of positive $\delta$ only for $n > -1$. For positive (density peak) perturbations that reach $\delta > \delta_{RC}$ at the present epoch, the negative counterparts reach $\delta < -0.85$ ($\Omega_o = 1.0$), $\delta < -0.75$ ($\Omega_o = 0.45$) and $\delta < -0.65$($\Omega_o = 0.1$) in their centers. A typical void has a central density contrast of order $\delta \sim -(0.8 - 0.9)$ and is surrounded by a shell with a positive density excess of $\delta \sim (1.0 - 10)$. The thickness of the shell is $\sim (10 - 20)\%$ of the radius of the void. Negative (density peak) perturbations form voids with a radius 10 times larger than that of clusters that would have formed from their positive counterpart. The density field is, relatively insensitive to $\Omega_o$, compared to the velocity field which is a rather sensitive function of $\Omega_o$. In a void of $\delta \sim -(0.8 - 0.9)$ the maximal relative peculiar velocities galaxies would have is of the order of $(v_p/v_H) \sim (0.4 - 0.5)$ for $\Omega_o = 1$, $\sim (0.2 - 0.25)$ for $\Omega_o = 0.45$ and $\lesssim 0.09$ for $\Omega_o = 0.1$. These values should be compared with the values of 1, 0.62 and 0.25, respectively, for the random motion scenario.

$\Omega_o$ can be inferred from studying the dynamics of galaxies on scales larger than $\sim 10\ h^{-1}$ Mpc in two independent ways. One way is from the velocity field of galaxies in superclusters e.g. the Virgo supercluster, the other is from the dynamics of the voids in the galaxy distribution as described above. If these two independent estimates of $\Omega_o$ are found to be consistent it will give a major support to the support to the dissipationless gravitational instability theory.

## Discussion

*Bonometto:* I) Is the value of n you quote the one after recombination?
II) Do you take into account the spike around the Jeans mass (prior to recombination) and the change of slope above it?

*Hoffman:* I) Yes.
II) No, as the scales considered here are smaller than the Jeans scale prior to the recombination epoch.

*Inagaki:* I) In your calculation, how does the void evolve? Does it evolve self-similarly? Recently Bill Saslaw and his research student developed a theory concerning voids based on equilibrium statistical mechanics. Their theory agrees excellently with N-body simulations. What do you think about it?
II) In a spherical model the gravitational force is always towards the center. There is no mutual attraction between shells. I am afraid that the result is quite different if you remove the assumption of spherical symmetry. What do you think about it? Have you compared your results with those of N-body simulations?

*Hoffman:* I) The evolution is self-similar only until $\delta\rho/\rho$ becomes appreciable. After that it is strongly nonlinear, as the formation of the ridges shows.
II) Yes, N-body calculations can show the effect of small-scale fluctuations on the development of the mean large-scale structure. In particular, the ridges might thicken in some places and not in others; this possibility is omitted in spherical calculations.

*Thompson:* I would like to point out that your assumption that the M/L ratio increases with increasing scale is an uncertain one. It is, for the most part, only an assumption, since dynamical data on large scales (2 to 10 Mpc) is very sparse. In a paper to be presented later in this session, I will show evidence for a low M/L ratio over large scales.

*Hoffman:* The basic prediction of the M/L model (Hoffman et al., 1982, Ap. J., 262, 413) is that M/L is a nondecreasing function of scale. This seems to be confirmed by most of the observational data (see also Dr. Harms' paper in these Proceedings). The scale on which M/L reaches its asymptotic value depends on $\Omega_0$.

*Huchra:* I'd like to add to Laird Thompson's comment. In the groups and clusters we've analyzed in the CfA survey, there is no evidence for M/L increasing on the large scale -- binaries, groups and clusters all give M/L $\sim$ 100 to 200.

*Hoffman:* The main feature of the Hoffman et al. (1982) model is that M/L is a nondecreasing function of the linear scale. The results quoted by Dr. Huchra are consistent with the model for a $\Omega_0 \sim 0.1$ universe. For any reasonable values of $\Omega_0$, M/L is constant over scales larger than a few Mpc and hence the voids are devoid of matter. The $v_P/v_H$ field depends strongly on the limiting value of M/L, i.e., $\Omega_o$.