A 120 MPC SCALE IN THE UNIVERSE

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1. Introduction

Galaxies are not distributed randomly but are concentrated within elongated filamentary chains which consist of groups and clusters of galaxies; the space between filaments is devoid of galaxies. Such distribution can be called cellular (Jõeveer and Einasto, 1978; Zeldovich et al., 1982): a cell is a large low-density region surrounded by superclusters. Examples are the Northern Local Void surrounded by the Local, Coma and Hercules superclusters (Lindner et al., 1995), and the Bootes void (Kirshner et al., 1981) surrounded by the Hercules and Bootes superclusters. Superclusters and voids form a continuous network of alternating high- and low-density regions; the mean diameter of voids between clusters in the supercluster-void network is about $100 \, h^{-1}_{100} \text{Mpc}$ (Zeldovich et al., 1982).

It is not clear whether superclusters and voids form a regular or irregular network. According to the classical paradigm of the formation of large scale structure the distribution of density waves is Gaussian on all scales, and thus the supercluster-void network should have a random character. The observed network was formed by density waves of a wavelength range corresponding to the scale of the network. Therefore, it was a great surprise when it was found that the distribution of high-density regions along pencil beams around the northern and southern Galactic poles is fairly regular: high- and low-density alternate with rather constant step of $128 \, h^{-1}_{100} \text{Mpc}$ (Broadhurst et al., 1990). The regularity of the structure is so far well established only in the direction of Galactic polar caps, while in other directions the regularity is much less pronounced. In order to find the degree of the global regularity of the supercluster-void network 3-dimensional data of the distribution of high-density regions are needed. For this purpose Abell-ACO clusters of galaxies (Abell, 1958; Abell et al., 1989) can be used. These clusters cover the whole celestial sphere outside the Milky...
Way zone of avoidance. Here I give a summary of our principal results, a more detailed analysis is published elsewhere.

2. Distribution of clusters of galaxies

The distribution of clusters of galaxies located in very rich superclusters with at least 8 member-clusters is shown in Figure 1 (Einasto et al., 1994; Einasto, 1995; Einasto et al., 1997b), see also (Tully et al., 1992). This Figure shows clearly that high-density regions are separated from each other by a fairly constant intervals of $\approx 120 h^{-1}_{100} \text{Mpc};$ in other words, they form a quasi-regular network of superclusters and voids.

We supplemented this qualitative description by a quantitative analysis, using the power spectrum of clusters of galaxies (Einasto et al., 1997a). On short wavelengths the spectrum can be approximated by a power law with index $n = -1.8.$ On wavenumber $k_0 = 0.05 h_{100} \text{Mpc}^{-1}$ it has a sharp peak; this wavenumber corresponds to the wavelength $\lambda_0 = 2\pi/k_0 = 120 h^{-1}_{100} \text{Mpc}.$ On longer scales the error corridor of the spectrum is large and here the spectrum is compatible with the Harrison-Zeldovich spectrum of power index $n = 1.$

The presence of a sharp maximum in the power spectrum of matter is
the main finding of our study of the distribution of clusters of galaxies. Our result has found independent support from other data (Landy et al., 1996; Gaztanaga and Baugh, 1997; Peacock, 1997; Retzlaff, 1997). Comparison with simple toy models shows that a peaked power spectrum is possible only if high-density regions form a quasiregular rectangular network (Einasto et al., 1997d; Einasto et al., 1997c). In this case the correlation function of objects located in high-density regions is oscillating. Evidence for an oscillating cluster correlation function has been accumulating already for some time (Kopylov et al., 1988; Mo et al., 1992; Einasto and Gramann, 1993; Fetisova et al., 1993).

3. Comparison with CMB data

The angular power spectrum of the cosmic microwave background (CMB) has been measured by a number of teams. We compared the CMB spectrum with optical data using three models for the power spectrum: (a) a scale-free initial spectrum, (b) a double power law approximation to the cluster spectrum, and (c) a spectrum based on the observed cluster spectrum. For a set of cosmological parameters, we calculate the matter transfer function, and the matter and radiation power spectra for all three models (Atrio-Barandela et al., 1997). We assume the Universe has a flat geometry. In calculations we used the package CMBFAST (Seljak and Zaldarriaga, 1996). To estimate the goodness of a particular set of cosmological parameters we calculate the parameter $\chi^2$ for all three principal models, see Figure 2.

In Figure 3 we compare matter power spectra and temperature anisotropy spectra for our three basic models with the data. The cosmological parameters were chosen to reproduce the CMB data (Netterfield et al., 1997). We see that the temperature anisotropy spectra are very similar in the range of multipoles observed in Saskatoon. In other words, the present CMB data are not sufficient to discriminate between models. The matter power spectra are also similar on short wavelengths but on medium and long scales they are very different. The scale-free model with large cosmological constant has a broad maximum at large wavenumber ($k \approx 0.01 \, h_{100} \, \text{Mpc}^{-1}$); the maximum of the first acoustic oscillation occurs at $k \approx 0.1 \, h_{100} \, \text{Mpc}^{-1}$ and is of rather small relative amplitude. Both scales are outside the allowed range of the observed spike in the cluster spectrum: $k_0 = 0.052 \pm 0.005 \, h_{100} \, \text{Mpc}^{-1}$ (Einasto et al., 1997a). No combination of cosmological parameters can reproduce the spike at $k = k_0$: the existence of a broad maximum is an intrinsic property of all scale-free models. Thus the observed spike is not related to acoustic oscillations in the baryon–photon plasma as assumed by Szalay (1997) but must have a different origin. On the other hand, the cluster and double power law spectra fit the observed cluster spectrum by
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Figure 2. Goodness-of-fit contours of $\chi^2$ at 68% and 95% confidence level. The $\chi^2$ statistics measures the deviation of the expected temperature anisotropy amplitude of a given model from the Saskatoon data. The first row displays the results for the scale free model; the second row for the double power law model; and the lowest row for the cluster spectrum based model. In the first column we plot models with varying Hubble constant and baryon fraction for a spectral index $n = 1$ at large scales and no cosmological constant. In the middle column the same diagrams were repeated for $n = 1.2$. Dashed lines indicate the nucleosynthesis bounds. The last column displays the results for models with different values of the cosmological constant. On all these models, the age of the Universe was chosen to be 14 Gyr.

construction and reproduce the CMB data, i.e they fit equally well both datasets.

Thus the comparison of optical and CMB data brings us to the conclusion that CMB data are not in conflict with the presence of a spike in the
Figure 3. Comparison of matter power spectra and radiation temperature anisotropies with cluster and CMB data. Dots with 1σ error bars give the observations: the measured cluster spectrum (Einasto et al. 1997a) in the left panel and the Saskatoon data on CMB temperature anisotropies (Netterfield et al. 1997) in the right panel. The scale-free model spectra (short-dashed lines) were computed using the following parameters: $h = 0.6$, $\Omega_b = 0.07$, $\Omega_c = 0.23$, and $\Omega_\Lambda = 0.7$. The cluster spectrum (solid lines) was calculated using $h = 0.6$, $\Omega_b = 0.08$, $\Omega_c = 0.92$, and $\Omega_\Lambda = 0$; and the double power law models (long-dashed) using $h = 0.6$, $\Omega_b = 0.05$, $\Omega_c = 0.95$, and $\Omega_\Lambda = 0$. To compare matter power spectra and observations we used a bias factor $b_{cl} \approx 3$ for cluster spectrum.

matter power spectrum, and that the present combined cluster and CMB data favour models with a built-in scale in the initial spectrum. We repeat that a regular supercluster-void network can be formed only by a power spectrum with a sharp maximum (Einasto et al., 1997d). As noted by Szalay (1997) correlated phases are also crucial to form a regular network of high- and low-density regions.

Double inflation models provide a possible scenario where the formation of a spike could have taken place. One version of a double inflation model is suggested by Starobinsky (1992). This model produces a spectrum rather similar to the initial spectrum found from data (Atrio-Barandela et al., 1997). The study of the distribution of matter on large scales is of crucial importance since it could provide a direct test of more complicated models of inflation.

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