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## Abstract

## Full Text

*Astronomy*

I. D. Karachentsev

# Some Cosmological Consequences of Counts of Galaxies to Various Angular Diameters

*(Presented by Academician V. A. Ambartsumian, May 4, 1964)*

In 1936 Hubble published ([1]) counts of the number of galaxies to various stellar magnitudes. However, his results are burdened by considerable systematic errors, since the counts used plates taken with different telescopes and with very diverse exposures.

The appearance of a homogeneous sky survey—the Palomar Atlas—makes it possible to carry out galaxy counts in a more correct manner. In this case, as a statistical criterion of distance one may choose not stellar magnitude, but the angular diameter of the galaxy. Estimating visible diameters on the charts presents far fewer difficulties than estimating visible stellar magnitudes.

In a homogeneous, transparent, static Euclidean universe, the number of galaxies having angular diameters greater than a given fixed $d$ is, by definition, given by the expression

$$N(d) = 4\pi \int_0^\infty \varphi(D) r^2 \, dr, \tag{1}$$

where $\varphi(D)$ is the number of galaxies per unit volume with linear diameters greater than $D$. It is assumed that $\varphi(D)$ is the same in all volumes, i.e., does not depend on the distance $r$. Making in (1) the change of variables $r = Dd^{-1}$, we obtain

$$N(d) = 4\pi d^{-3} \int_0^\infty \varphi(D) D^2 \, dD = N_1 d^{-3}; \tag{2}$$

here $N_1$ is the number of galaxies on the celestial sphere with angular diameters greater than one radian.

In an expanding universe the dependence $N(d)$ is given by the relation

$$N(d) = N_1 d^{-3} (1 + z)^3, \tag{3}$$

where $z \equiv \Delta\lambda/\lambda = h\bar{D}/cd$ is the redshift of the galaxies, $c$ is the speed of light, $h$ is the Hubble parameter, and $\bar{D}$ is the mean statistical linear diameter of galaxies. Expression (3) is valid for not very large $z$, when terms of third order of smallness in the expansion in the retardation time of the light signal, $t - t_0$, may be neglected. It expresses the fact that distant parts of the Metagalaxy are observed as younger and denser; the curve $N(d)$ rises faster than in the static case.

In recent years it has been established ([2]) that galaxies have different ages and are forming at the present time. There are convincing arguments indicating that the process of formation of new galaxies is connected with ejections, fission, and decay of special cosmic objects—the nuclei of galaxies.

It is natural to assume that the increase in the number of galaxies per unit volume is proportional to their existing number $n$ and to the time interval $dt$; then $n(t) \sim e^{\alpha t}$, or

$$n(t) = n_0 e^{3\beta \frac{t-t_0}{t_0}} = n_0 e^{-3\beta z}. \tag{4}$$

where $n_0$ is the number of galaxies per unit volume in the present epoch $t_0$ in the comoving coordinate system, and the coefficient $\beta$ characterizes the rate of the division process. Thus, in the general case

$$N(d) = N_1 d^{-3} (1+z)^3 e^{-3\beta z}; \tag{5}$$

for $\beta = 0$ we have case (3), while for $\beta = 1$ the observed concentration of galaxies in the first approximation does not depend on time (a static universe and the steady-state theory).

In the presence of intergalactic attenuation of light, the pattern of the distribution $N(d)$ becomes more complicated. A decrease in the frequency of electromagnetic oscillation leads to a decrease in the received energy by a factor $(1+z)^2$. The same effect also results from the aberrational redistribution of energy over directions. The shift of the radiation maximum changes the flux by a factor $(1+z)^k$, where $k$ is calculated from the sensitivity curve of the radiation detector and from the law of the energy distribution in the galaxy spectrum. If intergalactic absorption $a$ also exists, then the change in magnitude in the first approximation may be represented in the form

$$\Delta m = 1.086(2 + 2 + k + a)z = 1.086\tau z. \tag{6}$$

Galaxies are extended objects with some distribution of brightness over the disk. By the measured diameter is meant the doubled angular distance from the center of the galaxy to a certain threshold isophote, determined by the brightness of the night sky. On the basis of photometric data ([3]), the synthetic brightness distribution in galaxies may be represented in the form

$$I(\rho) = \frac{I_0}{(1+\rho/\rho_0)^{2+\varepsilon}}, \tag{7}$$

where $\varepsilon = \varepsilon(\rho)$ is a weak function of the distance $\rho$ from the center of the galaxy; $\varepsilon$ is enclosed in the interval from 0 to 1. The change in surface brightness at each point of the galaxy according to law (6) leads to the fact that the observed (photometric) diameter of the galaxy is related to the ideal (metric) ratio by

$$\frac{d_\phi}{d_\mathrm{M}} = (1+z)^{-\tau/(2+\varepsilon)}. \tag{8}$$

Thus, the observed number of galaxies $N(d_\phi)$ is described by the system of equations

$$N(d_\phi) = N_1 d_\mathrm{M}^{-3}\left(1+\frac{h\overline{D}}{cd_\mathrm{M}}\right)^3 e^{-3\beta\frac{h\overline{D}}{cd_\mathrm{M}}}; \tag{9}$$

$$d_\phi = d_\mathrm{M}\left(1+\frac{h\overline{D}}{cd_\mathrm{M}}\right)^{-\tau/(2+\varepsilon)}.$$

Here the mean statistical diameter $\overline{D}$ is found from the dependence between the photographic magnitudes and redshifts of galaxies of the background ([4]), $m_\phi = 5\lg cz - 4^m,24$, and from the relation $m_\phi = -5\lg d + 14^m,6$ for the angular diameters of galaxies in the Palomar atlas. The calculation of $\overline{D}$ from the function $\varphi(D)$ for the Coma cluster of galaxies gives practically the same value, $\overline{D} = (25.1 \pm 0.5)$ kpc for $h = 75$ km sec$^{-1}$ Mpc$^{-1}$.

The results of counts of 54 thousand galaxies near the north Galactic pole in the blue and red regions of the spectrum are presented in Figs. 1 and 2. The asymptotic value $N(d)$ fixes the constant $N_1$ and makes it possible to calculate the mean density of matter in the Metagalaxy $\rho_0$. From Fig. 1 it follows that there are $1.95\cdot10^{-2}$ galaxies per 1 Mpc$^3$. With the mean luminosity of galaxies $\overline{L} = 1.2\cdot10^{10}\ L_\odot$ and the mass-to-luminosity ratio $M/L =$

$= 7.5\,M_\odot/L_\odot$, $\bar\rho = 1.2\cdot10^{-31}$ g/cm$^3$, i.e., two orders of magnitude below the critical density. The value $3.1\cdot10^{-31}$ g/cm$^3$ obtained earlier by Oort should be reduced by a factor of $2^{1/2}$, since it has turned out that the masses of galaxies found from the virial theorem as applied to pairs of galaxies were fictitious (the pairs are nonstationary).

Fig. 1

Fig. 2

**Fig. 1.** Counts of the number of galaxies $N_c$ per square degree down to various angular diameters $d$ in the blue region of the spectrum. $d$ is expressed

in millimeters on the Palomar atlas. For each value of $N$ its mean square dispersion over different charts is indicated.

**Fig. 2.** Counts of $N_k(d)$ in the red region of the spectrum.

The solution of system (9) from the data of Figs. 1 and 2 for $\beta = 0$ gives $\tau_c = 16.3 \pm 0.8$ and $\tau_k = 12.1 \pm 0.8$. For the effective wavelengths of the blue and red spectral regions, $\lambda_c = 4170$ Å and $\lambda_k = 6450$ Å, the $k$-corrections are, respectively, $k_c = 4.2$, $k_k = 1.3$. Thus, the remaining part accounts for, respectively, $a_c = 8.1 \pm 0.8$ and $a_k = 6.8 \pm 0.8$. Such large values of the coefficient of intergalactic absorption are unacceptable for two reasons. First, the ratio of the observed density to the critical one requires an open type of Friedmann model ($q_0 < 0.5$), whereas observations give $q_0 = 3 \div 1$ ([4,5]). Allowance for intergalactic absorption considerably intensifies the contradiction: the acceleration parameter $q_0$ increases to $9 \div 11$. Second, the ratio of total absorption to selective absorption turns out to be extremely large. Scattering by metallic particles $\left(\sim \frac{1}{\lambda}\right)$ leads to the ratio

$$\gamma_k = \frac{a_c}{a_c - a_k} = 2.9.$$

For scattering by dielectrics and gases $\left(\sim \frac{1}{\lambda^4}\right)$, $\gamma_k = 1.2$, whereas from observations one obtains $\gamma_k = 6.2$.

If it is assumed that the number of galaxies increases according to law (4) with $\beta = 2$, then $\tau_c = 10.3 \pm 0.8$, $\tau_k = 5.7 \pm 0.8$. Then $a_c = 2.1$ and $a_k = 0.4$. The ratio $\gamma_k$ is equal to 1.2, i.e., it coincides with that expected for scattering by dielectrics and gases. In this case the Stebbins–Whitford effect is explained, which consists in the fact that observations ([6]) give a change of the yellow color index in the form $\Delta CI = 1.086 \cdot 3.1 \cdot z$ $(\tau_c - \tau_y = 3.1)$, while the redshift gives only $k_c - k_y = 1.8$. If the unexplained excess color $a_c - a_y = 1.3$ is attributed to scattering $\sim \frac{1}{\lambda^4}$, then $\gamma_y = 1.6$ is in good agreement with the calculated $\gamma_y = 1.65$.

Thus, counts of galaxies $N(d)$ give independent confirmation of the conclusion regarding the continuous formation of new galaxies.

Knowing the parameter $\beta = 2$, one can calculate certain observable consequences that follow from formula (4). It is known that in clusters of the Coma type young peculiar galaxies constitute about 9% of the total population (7). From their radial velocities and mutual distances, their mean age is $\sim 2 \cdot 10^8$ years. It follows from (4) that the number of galaxies formed during this time amounts precisely to 9%. Radio galaxies of the Virgo A type are still younger objects. Their age is estimated to be of the order of $10^6$ years. Substituting this value into (4), we find that there should be 1-2 radio galaxies in the Local Supercluster of galaxies. Such a frequency of occurrence of radio galaxies is close to the observed one.

**Note.** Let us note that the presence in the Palomar charts of a resolution threshold $d_p = 0.03$ mm somewhat overestimates the angular diameters of galaxies and their number at small $d$. However, taking this small effect into account can change the conclusions obtained only in the direction of strengthening them.

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Byurakan Astrophysical Observatory
Academy of Sciences of the Armenian SSR

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*Note: Figure translations are in progress. See original paper for figures.*