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Abstract

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MEAN RADIATION DENSITY IN THE METAGALAXY AND SOME QUESTIONS OF RELATIVISTIC COSMOLOGY

(Presented by Academician Ya. B. Zel' dovich on 11 X 1963)

The paper is devoted to calculating the mean density of electromagnetic radiation in the Metagalaxy and its spectral distribution. Comparison of the calculations with observations may provide information on a number of important questions in cosmology and astrophysics. First, it will make it possible to determine the character of the evolution of galaxies and to estimate the values of the basic parameters of cosmological theories. Second, it will be possible to obtain information about the state of matter at the early stages of expansion of the Metagalaxy. Finally, data on the radiation density in the Metagalaxy are important for analyzing possible processes occurring in interstellar and intergalactic space.

If galaxies had always shone with the same intensity, had no relative velocities, and filled a finite volume in empty Euclidean space, then the observed radiation density would differ from the energy density at the surfaces of the sources by the dilution factor—the fraction of the surface of the celestial sphere occupied by the sources. The spectral distribution of the energy would be the same as that of the sources.

In reality the spectrum received is affected by such factors as the recession of galaxies, the evolution of their luminosity, the difference of the metric of space from the Euclidean one, and the presence of diffuse matter in intergalactic space.

The present calculation has been carried out on the basis of the Friedmann cosmological model. The computations were performed analogously to McVittie [^1]. For the Hubble constant H_0 the value 100 km/sec $\cdot$ Mpc [^2] was adopted. In accordance with this value of H_0, Oort' s data [^3] for the mass/luminosity ratio of galaxies M/L and the density of luminous matter (galaxies) ρ_L were corrected. For these quantities we adopted $M/L = 28\, M_\odot/L_\odot$ and $\rho_L = 5 \cdot 10^{-31}$ g/cm^3. The calculations were carried out for the following variants of assumptions about the mean density $\bar{\rho}$ and the equation of state of matter in the Metagalaxy:

1) The principal fraction of the mass of the Metagalaxy is concentrated in galaxies: $\bar{\rho} = \rho_L = 5 \cdot 10^{-31}$ g/cm^3. The equation of state is $P = 0$.

2) A large amount of intergalactic matter is assumed (gas; dust; possibly, objects difficult to observe). The mean density is equal to the critical density $\rho_k = 3H_0^2/8\pi x$: $\bar{\rho} = \rho_k = 1.86 \cdot 10^{-29}$ g/cm^3. The equation of state is $P = 0$.

3) The presence in the Metagalaxy of a large number of neutrinos is assumed. $\bar{\rho} = \rho_k = 1.86 \cdot 10^{-29}$ g/cm^3. The equation of state is $P = \bar{\rho}c^2/3$.

The work has been done under the assumption of complete transparency of the intergalactic medium. The presence of only scattering diffuse matter changes nothing in an isotropic radiation field. The possible influence of absorption of light by intergalactic dust, with subsequent reradiation at other frequencies, will be investigated in another paper.

If galaxies formed no earlier than the epoch when $\bar{\rho}$ was of the order of 10^{-26} g/cm^3, then the mutual screening of galaxies has a negligibly small effect on

results of the calculation. Finally, possible deviations in the distribution of matter from a strictly homogeneous one, which, as Ya. B. Zel' dovich has shown, substantially affect the brightness of individual distant galaxies, do not affect the value of the mean radiation density.

Analysis of observational data on the relative distribution of galaxies of different types and on the composition of their stellar populations in them [(4,5)] shows that the distribution of energy in the radiation spectrum of a unit volume of the Metagalaxy can be approximated in the optical and infrared regions by the sum of two Planck curves with temperatures $T_1 = 10\,000°$K (type I stellar population) and $T_2 = 5000°$K (type II stellar population) and with equal integral intensity at the present time. In the radio region the radiation of galaxies is determined by nonthermal processes. Its spectrum has the form $dE = A\nu^{-0.9}d\nu$. The quantity A can be calculated from Brown' s data [(6)]. Only the radio emission of normal galaxies was taken into account.

At present there are no reliable data on the evolution of galaxies. Here we shall give the results of calculations for the following variants of assumptions about the evolution of the luminosity of galaxies:

1) Galaxies shine from the moment when the mean distance between them $\bar{l}$ was 10 times smaller than the present $\bar{l}_0$, i.e. $x \equiv \bar{l}/\bar{l}_0 = 0.1$. The luminosity of galaxies is constant.

2) Galaxies shine from the moment when $x = 0.1$. The luminosity of type I stellar population ($T_1 = 10\,000°$K) evolves according to the law $L = L_0 x^{0.645} e^{6.5x}$. The luminosity of type II stellar population is constant.

3) Galaxies shine from the moment when $x = 0.3$. The luminosity of galaxies is constant.

The change with time of the intensity of radio emission was assumed to be the same as for the luminosity of type I stellar population for all three variants.

Fig. 2. Dependence of the energy flux density of the Metagalaxy in the photographic region on redshift. The ordinate gives the fraction of the total flux supplied by galaxies with ν_0/ν less than the given value (ν_0 and ν are the received and emitted frequencies, respectively). The curve was calculated under assumption 1) on the evolution of luminosity. Circles are observational data.

Figure 1: Fig. 2. Dependence of the energy flux density of the Metagalaxy in the photographic region on redshift. The ordinate gives the fraction of the total flux supplied by galaxies with ν_0/ν less than the given value (ν_0 and ν are the received and emitted frequencies, respectively). The curve was calculated under assumption 1) on the evolution of luminosity. Circles are observational data.

Fig. 1. Spectrum of the Metagalaxy.
A–$\rho = \rho_L = 5 \cdot 10^{-31}$ g/cm^3, $P = 0$;
B–$\rho = \rho_k = 1.86 \times 10^{-29}$ g/cm^3, $P = 0$;
V–$\rho = \rho_k = 1.86 \cdot 10^{-29}$ g/cm^3, $P = \bar{\rho}c^2/3$;
a–under assumption 1) on the evolution of the luminosity of galaxies (see text);
b–under assumption 2);
v–under assumption 3);
g–under the assumption of absence of motion of galaxies and of their evolution; galaxies uniformly fill a sphere of radius c/H_0 in empty Euclidean space;
d–equilibrium Planck radiation with $T = 1^\circ$K. Crosses–experimental points.

Some of the calculated spectra of the Metagalaxy are shown in Fig. 1. The influence of the evolution of the luminosity of galaxies and of the moment of origin is evident.

galaxies and the law of expansion of the Metagalaxy. A detailed analysis of the influence of these factors on the adopted spectrum of the radiation of the Metagalaxy will be given in another paper. It should be noted, however, that measurements in a narrow frequency interval do not make it possible to choose between the adopted models. Measurements over the entire spectrum are needed. The frequency ranges $5 \cdot 10^{10} \div 5 \cdot 10^{11}$ Hz and $10^{13} \div 5 \cdot 10^{14}$ Hz may be noted as the most interesting. In the first region the influence of the law of expansion of the Metagalaxy is substantial, whereas in the second region the evolution of the luminosity of galaxies has a stronger effect.

Fig. 2. Dependence of the energy flux density of the Metagalaxy in the photographic region on redshift. The ordinate gives the fraction of the total flux supplied by galaxies with ν_0/ν less than the given value (ν_0 and ν are the received and emitted frequencies, respectively). The curve was calculated under assumption 1) on the evolution of luminosity. Circles are observational data.

Experimentally, the extragalactic component of the night-sky glow has been poorly studied. Only in the photographic region have Bokulevich ([7]) made estimates on the basis of Hubble’ s galaxy counts ([8]). The value obtained by him ($\sim 2.2 \cdot 10^{-20}$ erg/cm^2·Hz·sec·ster., with extrapolation of the counts to 8^m) agrees well with our calculated value $(0.7 \div 2.4) \cdot 10^{-20}$ erg/cm^2·Hz·sec·ster. The dependence of the observed energy flux density in the photographic region on the redshift of galaxies, according to data ([7,9]), also agrees with the calculation (Fig. 2). This shows that the assumptions made about the radiation spectrum per unit volume of the Metagalaxy are close to reality.

The appearance of the spectrum at $\nu < 5 \cdot 10^{11}$ Hz is decisively affected by the evolution of the luminosity of galaxies in the radio range, which is poorly known. According to data ([10,11]), at $\nu = 10^8$ Hz the brightness temperature of the extragalactic component of the sky glow is 100—200° K, which corresponds to a flux $(4.5 \div 9) \cdot 10^{-19}$ erg/cm^2·Hz·sec·ster. The calculations give $(0.24 \div 2) \cdot 10^{-20}$ erg/cm^2·Hz·sec·ster. The difference is probably due to the strong role of the evolutionary effect.

Measurements in the frequency range $10^9 \div 5 \cdot 10^{10}$ Hz are very important for an experimental test of Gamow' s theory ([12]). The astronomical consequences of this theory are analyzed in detail in the work of Zel' dovich ([13]). According to Gamow' s theory, at present an equilibrium Planck radiation with temperature $1 \div 10°$ K should be observed. In Fig. 1, B shows the curve for $T = 1°$ K. Measurements ([14]) at frequency $\nu = 2.4 \cdot 10^9$ Hz give a temperature of $2.3 \pm 0.2°$ K, which coincides with the theoretically calculated atmospheric noise (2.4° K). Additional measurements in this region (preferably from artificial Earth satellites) will help finally to decide the question of the validity of Gamow' s theory.

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