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ON THE ORIGIN OF COSMIC RAYS

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INTRODUCTION

The current report is the seventh which we (or one of us) presented at International Conferences on Cosmic Rays beginning from the year 1955 (see [1 – 6]). Twelve years constitute a rather long term, so that a retrospective outlook on the development of representations on the origin of cosmis rays in the course of the period elapsed is of evident interest (see [1 – 6] and also [7 – 11]). It seems to us that two cases emerge then at once. On the one hand, achievements are unquestionable in the field of studies on primary cosmic rays and of problems related to astronomical aspects of their origin. Yet on the other hand, some of the very fundamental elements upon which is based the most probable galactic model of cosmic ray origin still remain obscure and lack a rigorous demonstration. This is precisely the reason

(*) O PROISKHZHDENII KOSMICHESKIKH LUCHEY why we systematically return, from report to report to what seems to be the discussion of the very same questions about the metagalactic cosmic rays, the galactic halo, the sources of cosmic rays in the Galaxy and so forth. Such a situation obviously can not induce any ill feeling, particularly among physicists. In this connection we would wish to underscore the fact that the noted insufficient definiteness of the bases of the theory of cosmic rays is in the first place the reflection of the contemporary state of the galactic and extragalactic astronomy. Much is yet obscure in these fields of astronomy, while it is extremely difficult to demonstrate the validity of a series of representations.* In this regard the question of the nature of quasars may serve as a striking example. The red shift of lines in the spectra of these objects may in principle be also explained by quasar participation in the general expansion of the Metagalaxy (cosmological hypothesis), as well as by ejection of quasars from the nucleus of the Galaxy or nearest radiogalaxies with a corresponding velocity, and finally by gravitational displacement of lines emitted by the gas situated in the central part of neutron star clusters [13]. However, we consider, alongside with most of astronomers and physicists, that the cosmological hypothesis is the only one appearing to be realistic, though it could not be demonstrated as yet, but in the last preprint obtained on this subject [13] it is, to the contrary, considered as established that quasars are located no farther than 40 Mps from the Galaxy. The respective arguments do not appear to us as being founded on a sufficient observational material; however, as far the vagueness of the question of distance to quasars goes, one must concur.

If the quasars had a truly local nature and were concretely ejected from the galactic nucleus [14], our representations about the structure and history of the Galaxy would have had to undergo radical changes. This is possibly also related to the problem of the origin of galactic cosmic rays.

Because of that the continuing discussion of the main traits of the models utilized for the origin of cosmic rays appears to be inescapable. This does not imply at all that the different models are considered as possessing equal rights. To the contrary, we invariably consider as the most probable the galactic model with halo [1 –11]. But so far, such a model not being proved as yet, the analysis of alternate possibilities remains one of the most important problems.

Thus, the pursued discussion of the most fundamental questions in the field of cosmic ray origin is indeed indispensable; at the same time, this circumstance should provoke no surprise in connection with the difficulty of the solution of a series of related astronomical problems.

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* In physics the situation is in most cases more favorable from the standpoint of the possibility of verification of theory and demonstration of the validity of either hypotheses. However, the history of the study of superconduction and verification of the theory of relativity (see, for example, [12]) and also of certain hypotheses in the region of elementary particle physics illustrate sufficiently clearly the difficulties linked also with the verification of theories and hypotheses within the field of physics.

However, there arises still one more question, namely, is there enough material accumulated during the two years elapsed after the previous conference to justify a pause upon it ? Of this we ourselves are not fully convinced. Inasmuch as there are still available a series of new data, estimates and ideas, we hope that their expounding will not prove to be superfluous and will eventually contribute to a fruitful discussion of the respective problems during the current conference.

I. METAGALACTIC COSMIC RAYS

(Uniform Model)

When speaking of the origin of cosmic rays, we shall have in mind their basic part observed near the Earth. The energy density responding to these particles (say with energy $E < 10^{14} \div 10^{15}$ ev) near the solar system is of the order $w_G \sim 10^{-12}$erg/cm^3 *. In galactic models the quantity w_G is determined by particles formed within the bounds of our Galaxy; in metagalactic theories, to the contrary, the sources of cosmic rays, to which it is referred, are situated beyond the Galaxy. At the same time, in metagalactic models the energy density of metagalactic cosmic rays is

$$w_{Mg} \sim w_G \sim 10^{-12} \text{ erg/cm}^3 \qquad (1)$$

If this estimate (1) refers to the whole metagalactic space (or, to be more precise, to a region with dimensions R of the order of the photometric radius $R_{ph} \simeq 5 \cdot 10^{27}$ cm), we shall call the corresponding model as the uniform metagalactic model. But if the estimate (1) refers only to a region with dimensions $R \ll R_{ph}$ near the Galaxy, we shall speak of local metagalactic model. In case of local group of galaxies $R \sim 10^{24}$ cm, and

$R \sim 10^{25}$ cm in "Centaur A model" (see below),
$R \sim 10^{26}$ cm for the hypothetical Local supergalaxy.

In the field of the theory of cosmic ray origin we may consider as fundamental the question of selection among three-type models, which are obvious from the above considerations and from the following scheme:

Galactic Models	Metagalactic Models	
	Uniform Model	Local Models

The arguments as evidence against metagalactic models, were brought out in the preceding report in particular [6], and we will not repeat them. We shall only pause at those assertions, which may be made more precise.

In regard to the electronic component of metagalactic cosmic rays specific conclusions may already be derived on the basis of data on isotropic cosmic X-ray radiation (see for the compilation of results ref. [18]). Utilizing these data and considering that there exists a metagalactic thermal radiation

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* The integration over the spectrum of cosmic rays observed near Earth in the period of solar activity minimum leads to the value $w_G = 0.6$ ev/cm^3

with temperature of 3°K, it is possible to obtain such an estimate for the upper energy density threshold of relativistic electrons in the Metagalactic space:

$$w_{e,\ Mg} \lesssim 3 \cdot 10^{-17}\ \text{erg/cm}^3 < w_{e,\ G} \sim 10^{-14}\ \text{erg/cm}^3. \qquad (2)$$

Here $w_{e,G}$ is the energy density of the electronic component of cosmic rays in the Galaxy. We arrived at (2) assuming that the intensity of the X-ray background in the energy range $1.5 < E_X < 6$ Kev is equal to

$$I_X = 10\ \text{photons/cm}^2 \cdot \text{ster} \cdot \text{sec},$$

and the energy density of metagalactic thermal radiation is $w_T = 0.4$ ev/cm^3 ($T = 3$°K), and considering that the radiation is accumulated over the path $L = R_{ph} = 5 \cdot 10^{27}$ cm. At the same time, account is taken of electrons with $E \geqslant 7 \cdot 10^8$ ev, which are responsible for the X-ray emission with energy $E_X \geqslant 1.5$ kev. Evidently. the value of $w_{e\ Mg}$ depends on the spectrum of electrons, but this dependence is rather weak and it practically does not affect the estimate by order of magnitude (in [6] it was assumed that $T = 3.5$°K, $w_T = 0.7$ ev/cm^3 and the value $w_{e,G} < 10^{-5}$ ev/cm^3 was carried; according to [18], $w_{e,Mg} \sim 10^{-3}\ w_{e,G}$; both these results are not in contradiction with the estimate (2)). The inequality sign stands in (2), for it is not yet demonstrated that the X-ray background is the result of scattering of relativistic electrons on thermal photons (the X-ray emission of galaxies and the bremmstrahlung of the intergalactic gas may contribute to background intensity).

Thus, the energy density of the electron component of cosmic rays in the Metagalaxy is at least 300 and even much rather 10^3 times less than in the Galaxy near Earth. This conclusion does not contradict in any case the information obtained by the radio- and gamma-astronomy [6]; it is not even in contradiction with the estimate of the number of relativistic electrons hitting the intergalactic space with their origin in the galaxies (utilizing the estimate (3) below, and taking into account the energy loss, we obtain

$$w_{e,Mg} \lesssim 3 \cdot 10^{-18}\ \text{erg/cm}^3;$$

the roughness of the estimate does not allow us to still speak of contradiction with (2) or, to be more precise, with the estimate $w_{e,Mg} \sim 1 \div 3 \cdot 10^{-17}$ erg/cm^3 stemming from X-ray data).

By the same token the uniform metagalactic model is knowingly invalid relative to the electronic component (as a matter of fact, at the unique assumption of the existence of relict thermal radiation with $T = 2 \div 3$°K). Hence it is clear that the preservation of the uniform model for the proton-nuclear component is concomittantly linked with the assumption of entirely different origin of both, this and the electron components. For example, the following variant is recalled in [20]: protons and nuclei have a metagalactic origin, while the electronic component is formed in the Galaxy itself. Such "mixed" models are already appearing to us from general consideration as being quite little probable.

In reality, in a model where the electron and proton-nuclear components occupy the same volume, the total energy included in the electronic component is only 30 ÷ 100 times less than the energy contained in the proton-nuclear component. As to the losses for electrons, they are substantially higher, generally speaking than for protons and nuclei. For example, as a result, in the galactic model of origins of all cosmic rays (see below)one must inject into the proton-nuclear component an energy only 20 to 30 times greater than that required for the generation of the electronic component. (It is essential that here the electronic component in the Galaxy is knowingly not secondary and forming as a result of decay of $\pi^{\pm}$-mesons). In the remaining respects identical assumptions are sufficient to explain all the well known properties of both components. If in particular it follows from the chemical composition of the nuclear component that cosmic rays traverse a gas thickness of the order of 3 g/cm^2, the same value is acceptable also from the standpoint of the available information about the secondary (electron-positron) component of cosmic rays' electronic component (see for example, [21]). We should add here to this that even the data on solar cosmic rays and a series of theoretical considerations lead to the conclusion about the prevailing position of the proton-nuclear component by comparison with the electronic component at generation in cosmic sources. Even if in the very process of generation protons, nuclei and electrons have complete equality of rights, as this takes place for the effective acceleration mechanism considered in [22], when accounting for losses, cosmic rays originating and emerging from the sources will be impoverished in electrons.

Setting aside such an argumentation, let us recall that there exist against the uniform model and the assumption (1) linked with it for the whole Metagalaxy (for $R \lesssim R_{ph}$) a series of other objections [6, 23]. We shall pause here only on one aspect of the matter: to "fill" the Metagalaxy with cosmic rays with density (1) is extremely difficult. If one estimates the quantity of cosmic rays in galaxies and radiogalaxies in the usual manner, considering that the magnetic energy $W_m \sim (H^2/8\pi)V$ is of same order as the energy of cosmic rays $W_{cr} \sim 10^2 W_e$ (here W_e is the energy included in the electronic component), we shall arrive, even without accounting for losses and Metagalaxy expansion, at the estimate

$$w_{Mg} \lesssim 10^{-15} \div 10^{-16} \text{ erg/cm}^3. \quad (3)$$

In other words, if $W_{cr} \sim W_m$, galaxies cannot assure such an injection of cosmic rays into the metagalactic space that that would satisfy relation (1). This is why in order to streng en the uniform metagalactic model the assumption is made [24] that in radiogalaxies

$$W_{cr} \gg W_m \sim \frac{H^2}{8\pi}. \quad (4)$$

In conditions (4) the energy $W_{cr} + W_m \simeq W_{cr}$ is not the minimum possible and it may be so chosen as to assure a high value to w_{Mg}. We were led to underscore more than once (see, for example, [5, 6, 11], that the thus obtained values of W_{cr} appear to be overrated. This conclusion becomes particularly vivid if one computes [25] the energy liberation for one galaxy, required to satisfy relation (1).

Radiogalaxies belong almost without any exceptions to the number of bright elliptic galaxies of which the concentration is estimated in our epoch [26] as being

$$N_{e,b} \simeq 1.3 \cdot 10^{-4} \ (\mathrm{Mnc})^{-3} \simeq 4 \cdot 10^{-78} \ \mathrm{cm}^{-3}.$$

Let us admit that each such galaxy passed through the radiogalactic phase, while cosmic rays, forming in it, underwent no losses of any kind and were not decelerated on account of Metagalaxy expansion. Even under such assumptions in order to obtain cosmic rays with density (1), it is required that every bright elliptic galaxy inject cosmic rays with energy

$$W_{cr} \sim \frac{w_{Mg}}{N_{e,b}} \sim \frac{10^{-12}}{4 \cdot 10^{-78}} \simeq 2 \cdot 10^{65} \sim 10^{11} \ M_o c^2. \qquad (5)$$

For causes quite obvious from the above-expounded, this value is underrated and, as one may think, by one order at least. This is why in fact the estimate (5) is preserved even if one considers all galaxies as explosive and not only the bright ones (the concentration of all elliptic galaxies is

$$N_E \simeq 10^{-3} \ (\mathrm{Mnc})^{-3}$$

(see *)). But the mass of gigantic galaxies does not usually exceed 10^{12} $M_{\odot}$ and the transition into cosmic rays of the type-(5) energy appears to be excluded. The real maximum value of W_{cr} constitutes in our opinion

$$W_{cr,\ max} \sim 10^{61} \div 10^{62} \ \mathrm{ergs}.$$

For $W_{cr} \sim 3 \cdot 10^{61} \sim 10^{7} \ M_o c^2$, we have for the density w_{Mg}

$$w_{Mg} < W_{cr} \ N_{e,b} \sim 10^{-16} \ \mathrm{erg/cm}^3, \qquad (5a)$$

where the inequality sign is linked with the requirement of accounting for losses and the Metagalaxy expansion.

Note that because of their number, the contribution to W_{Mg} by quasars can be neglected entirely (we admit here quite obviously that quasars are located at cosmological distances).

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* As was noted by G. Burbidge [19], radiogalaxies belong to the number of optically bright elliptic galaxies possibly only as a result of the very explosion. M. Schmidt (private communication) pointed out, however, that at least one half of bright elliptic galaxies must be considered as such outside their connection with the transformation into radiogalaxies (this argument is founded upon the presence in the spectra of these galaxies of Fraunhofer lines, which is evidence of stellar origin of optical emission; but, only brightness of nonstellar origin might have been enhanced as a result of explosion). By the same token the estimate (5) remains the lower threshold.

Incidently, estimate (5a) is in agreement with (3). Such must be the case if we deny ourselves the use of inequality (4). A series of considerations speak in favor of such a denial. First of all, as is well known, the total energy $W_{cr} + W_m$ is minimum at the condition

$$W_{cr} \sim W_m \quad (\text{or} \quad w_{cr} \sim \frac{H^2}{8\pi}). \qquad (6)$$

Secondly, condition (6) is natural from dynamic considerations in case of radiogalaxies and also in some other cases. Indeed, if there takes place injection of cosmic rays in some region with field H, cosmic rays will be only retained in this region so long as $w_{cr} < H^2/8\pi$; but if $w_{cr} >> H^2/8\pi$, they will be flowing out of the system more or less freely. Therefore, in the case (4), the radiating clouds in radiogalaxies must be considered as freely disintegrating (flying asunder). At the same time one should expect these clouds as being structureless, i. e., they must have a quasiuniform distribution in the concentration of cosmic rays and be characterized by the absence of somewhat sharp variations of magnetic energy density $H^2/8\pi$.

As a result of this, in conditions (4) radiating clouds must visibly be devoid of fine structure in the intensity distribution of radioemission. Observations in conditions of high angular resolution attest in the meantime to the opposite (see, for example, [27, 28]). In the radiodisk of the Galaxy this tendency, i. e. the sharp inhomogeneity ("ragged state") in the distribution of radiobrightness is expressed in a very clear fashion, as is well known. But as far as the disk is concerned, we are aware that precisely equal distribution (6) is observed in it.

Thus, it appears from all viewpoints that in our epoch (for $R < R_{ph}$) neither galaxies, nor radiogalaxies and quasars can possibly assure the observance of relation (1). Only one more possibility remains within the framework of evolutional cosmology — a powerful injection of cosmic rays in the formation stage of galaxies and quasars (for definiteness we may consider that this takes place at

$$z = \frac{\lambda - \lambda_0}{\lambda_0} \sim 3 \div 10,$$

i. e., at $t \sim 3 \div 10 \cdot 10^8$ years from the conditional beginning of Metagalaxy expansion).

Let us estimate the energy density of relict cosmic rays having formed during the formation stage of galaxies, or, to be more precise, during the stage of stellar formation.

During star formation the gravitational energy of the system decreases and, if we assume it zero in the prestellar stage, after the formation of a star with mass M and radius r the gravitational energy becomes equal by order of magnitude to $-\kappa M^2/r$. It is quite clear, moreover, that in the process of star formation only an energy $\xi(\kappa M^2/r)$ can pass to cosmic rays, where $\xi < 1$, and in all probability even $\xi << 1$. For most of stars, the energy

$\kappa M^2/ r \ll Mc^2$ and, for example, for the Sun $\kappa M^2/ r \sim 10^{-5} Mc^2$. The coefficient 10^{-5} or 10^{-4} may be considered as typical for all stars. Further, in the Metagalaxy the mean density of the matter concentrated in the stars is

$$\rho \sim 5 \cdot 10^{-31} \text{ g/cm}^3 \quad \text{or} \quad \rho c^2 \sim 4 \cdot 10^{-10} \text{ erg/cm}^3.$$

Hence it is clear that the gravitational energy yielded during star formation has a density $\sim (10^{-4} \div 10^{-5}) \cdot 4 \cdot 10^{-10} \sim 0.3 \div 3 \cdot 10^{-14}$ erg/cm^3 and an energy might have passed to cosmic rays, the density of which would be after conversion to our epoch

$$w_{Mg,r} \sim 0.3 \div 3 \cdot 10^{-14} \xi \text{ erg/cm}^3 \ll 10^{-14} \text{ erg/cm}^3. \qquad (7)$$

Even the last estimate is founded only on quite natural assumption of the validity of the inequality $\xi \ll 1$. In reality, the inequality $\xi \ll 1$ means that during star formation the energy transferring to cosmic rays is much less than the energy $\kappa M^2/ r$. For the Sun $\kappa M^2/ r \sim 10^{48}$ ergs and, if such an energy had been yielded, for example, in the lapse of time equal to $3 \cdot 10^7$ years, this would be corresponding to a power of $\sim 10^{33}$ ergs/sec, which coincides by order of magnitude with the total luminance of the Sun. Meanwhile, the power of the Sun as the source of cosmic rays is at present $u_0 \sim 10^{24}$ ergs/sec, and there is no foundations of any kind to consider it as rising by many orders at the slow contraction of the protosun. But if the question is about the stage of turbulent formation of protostars, which is precisely what was borne in mind above, it is very difficult to figure out, taking into account the quasispherical symmetry of the problem, the possibility of realization of conditions for which $\xi > 10^{-2} \div 10^{-3}$ (see also below). Therefore we much rather have

$$w_{Mg,r} < 10^{-16} \text{ erg/cm}^3. \qquad (8)$$

Above we have not yet taken into account the energy decrease of relict cosmic rays as a result of Metagalaxy expansion. Such an accounting leads to decrease of density $w_{Mg,r}$ referred to our epoch, by about one order. In this connection the estimates (7) - (8) become still more convincing (see Note 1 at the appendix). Finally, let us remark that the chemical composition of relict cosmic rays would in all probability strongly differ from the observed composition of cosmic rays near Earth. This is why the involvement of relict cosmic rays as the main component of cosmic rays in a uniform metagalactic model would have been linked with additional assumptions, even if we neglected the energy estimates, which is obviously inadmissible.

Summarizing, we see that the uniform metagalactic model of the origin of cosmic rays encounters most serious objections, and within the framework of well known representations and of evolutional cosmology it is impossible. This conclusion might be waved, as it seems to us, only in case of radical change of opinions in the field of extragalactic astronomy and, for example, with recognition of the validity of stationary cosmological model. All the present day tendency in the development in the fields of astronomy and cosmology appear, however, to directed in the opposide side, and it seems, in particular, that the stationary cosmological model is more and more improbable, if not altogether rejected.

2. METAGALACTIC COSMIC RAYS

(Local Models)

In local metagalactic models the region filled with cosmic rays of high intensity (condition (1)) has dimensions $R \ll R_{ph} \simeq 5 \cdot 10^{27}$ cm. However, no indications of any kind exist that would point to some peculiar activity of galaxies situated near our own Galaxy. To the contrary, here the density of galaxies and radiogalaxies is in general no higher than average. This is why the considerations of energy expounded above fully refer also to a series of local theories. Let us admit, for example, that there is question about a hypothetical Local supergalaxy with volume $V \sim 10^{77}$ cm^3. There are in this region $\sim 10^4$ galaxies and in order to accumulate cosmic rays with density $w_{Mg} \sim 10^{-12}$ erg/cm^3 each of these galaxies must inject cosmic rays with energy $W_{cr} \sim 10^{61}$ ergs, even if we neglect the particle leakage from the system and its expansion. But this means that each galaxy passed through the radiogalactic phase, and that furthermore it must have belonged to radiogalaxies of the most powerful type. In the meantime, as already underscored, radiogalaxies are only those bright elliptic galaxies, of which there are very few in the Local supergalaxy. A difficulty arises also in quasistationary local models, which is connected with the retainment of cosmic rays. For such a retainment to be possible the magnetic field must be sufficiently intense and quasi-closed. But such an assumption has in itself no foundations of any kind, and, if there is also question of explanation of the origin of the electronic component within the bounds of the Local supergalaxy, it is in contradiction with radioastronomical data (see, for example, [5]).

Incidently, in the application to the electronic component of cosmic rays on local metagalctic models there is superimposed a hard limitation when accounting for the existence of relict thermal radiation with T = 3°K. In reality in the course of motion in a time τ in a radiation field with energy density w_r and a chaotic magnetic field with intensity H, the energy of the electron is

$$E < E_{max}(\tau) = \frac{1}{\beta\tau} = \frac{1.56 \cdot 10^{13}}{(w_T + \frac{H^2}{8\pi})\,\tau\,(\mathrm{sec})}\ \mathrm{ev}, \qquad \beta = \frac{32\pi e^4}{9m^4c^7}\left(w_T + \frac{H^2}{8\pi}\right), \tag{9}$$

where $w_T + H^2/8\pi$ is measured in ergs/cm^3.

Hence it is clear that during observation near Earth of an electron with energy E, it may be asserted that even moving rectilinearly with velocity $v \simeq c$, it could not cover a path R greater than

$$R_{max} = c\tau = \frac{4.7 \cdot 10^{23}}{(w_T + H^2/8\pi)E(\mathrm{ev})}\ \mathrm{cm}. \tag{10}$$

At $w_T = 0.4$ ev/cm^3 = $6.4 \cdot 10^{-13}$ erg/cm^3, and neglecting the magnetic bremmstrahlung losses in the field H, we have

$$R_{max} \simeq \frac{7 \cdot 10^{35}}{E\ (ev)}\ cm. \qquad (11)$$

Particles with $E \simeq 3 \cdot 10^{10}$ ev are known to be observed in the composition of the electronic component of cosmic rays at the Earth (see the latest compilations of data in [21, 29], and possibly even to $2 \div 4 \cdot 10^{11}$ ev (see [30]). At $E = 3 \cdot 10^{10}$ ev, $R_{max} \simeq 2 \cdot 10^{25}$ cm in accord with (11). However, in fact the estimate (11) is clearly overrated. First of all, it is difficult to conceive that the motion of particles in the metagalactic space is rectilinear. Even in a field $H \sim 10^{-9}$ the curvature radius of particle trajectory with energy $E \sim 3 \cdot 10^{10}$ ev is $r = E/300H \sim 10^{17}$ cm, and consequently, such a field already is susceptible to radically modify the trajectory of particles. One may think that the "by-pass factor", linked with the influence of the intergalactic magnetic field lowers the estimate (11) by at least one order of magnitude. First, when moving from the intergalactic space toward the Earth electron must cover a certain path in the Galaxy. Here even the losses per time unit are somewhere nearly three times higher than in the intergalactic space ($w_{tot} = w_T + w_{opt} + H^2/8\pi \sim 2 \cdot 10^{-12}$ erg/cm^3) and the field is more entangled. Because of this the electron will be moving in the Galaxy (from its "boundaries" to Earth) for a time $T > 10^7$ years. At $\tau = 10^7$ years $= 3 \cdot 10^{14}$ sec and $w_{tot} = 2 \cdot 10^{-12}$ erg/sec, according to (9) $E_{max} = 2 \cdot 10^{10}$ ev, i. e., extragalactic electrons with $E > 2 \cdot 10^{10}$ ev are generally incapable of reaching the Earth. Analogous considerations compel us to believe that for sources of electrons with $E > 10^{10}$ ev

$$R_{max} < \frac{10^{35}}{E\ (ev)} < 10^{25}\ cm. \qquad (12)$$

The distance to Centaur A radiogalaxy, which is closest to us, is

$$R_{CG} = 3.8\ Mps \simeq 10^{25}\ cm.$$

Therefore, the sources of the electronic component of cosmic rays in the Galaxy must be by metagalactic scales doubly local ($R < 10^{25}$ cm $\sim 10^{-3} R_{ph}$; this estimate is not in contradiction with X-ray data either).

But even such a possibility is of very little probability.

For definiteness less us pause at the local metagalactic model "Centaur A" in which the sources of cosmic rays is the center of Centaur A. The path from this source to us will be covered for a time

$$\tau > R_{CG} / v \sim 10^{15}\ sec \quad (v < 10^{10}\ cm/sec)$$

and near Earth $E_{max} < 10^{10}$ ev. No such sharp cutoff in the spectrum of electrons is observed. In order to fill a volume $V \sim R^3_{CG} \sim 10^{75}$ cm^3 with density $w_e \sim 10^{-14}$ erg/cm^3 , Centaur A must inject into the electronic component only an energy $W_e \sim w_e V \sim 10^{61}$ ergs, and syill more when accounting for the losses. Finally, during electron inflow into the Galaxy from without, electrons with such a high energy would be mainly emitting in the halo or at radiodisk boundary, and the density of energy $w_{e,G}$ at Galaxy periphery would be higher than near Earth. But we must concede that this question is quantitative; however, there are still no radioastronomical indications of any kind in regard to the validity of such a pattern. To the contrary, all the data known to us agree with the assumption that the energy density of the electronic component and its hardness do not increase from the center of the disk toward the periphery (halo), at the very least.

As already pointed out, it appears to be at least unnatural to consider in any metagalactic models the sources of electrons and nuclei (including protons) as different and occupying different regions. If nevertheless we apply the local model, and, to be more precise, the'Centaur A model' only for the proton-nuclear component, the validities of the assumption, required for it, are extremely little probable just the same. Thus, for filling a volume $V \sim 10^{75}$ cm^3 with density $w_{Mg} \sim 10^{-12}$ erg/cm^3, Centaur A must inject into the cosmic rays an energy $W_{cr} \sim 10^{63}$ ergs. Meanwhile, according to standard estimates (see, for example, [11]) $W_{cr} \sim 10^{59}$ ergs. Furthermore, even during the gravitational collapse the energy liberation beyond does not exceed 1%, while for transformation into cosmic rays it is hardly possible to attain an efficiency greater than 10^{-3}. This means that during the collapse of the mass M, an energy $W_{cr} \lesssim 10^{-3}$ Mc^2 $\sim 10^{51}$ $(M/M_\odot)$ ergs will transfer to cosmic rays. Hence, for $W_{cr} \sim 10^{63}$, the mass $M \sim 10^{12}$ $M_\odot$, while the mass of the whole galaxy Centaur A constitutes $M \simeq 2 \cdot 10^{11}$ $M_\odot$.

Note also that the "Centaur A model" would be essentially nonstationary, which meets with a series of objections (see Section 3.1).

It may be generally stated that local metagalactic models are met with the most serious difficulties. It is true that they visibly can not be rejected with the same degree of definiteness as the uniform model. We nevertheless assume that local models might draw attention only in the case of validity of the hypothesis on local nature of quasars.

In the plan of experimental investigations the subsequent analysis of the question of metagalactic models must be conducted in different directions. Data on the metagalactic cosmic rays and more particularly on their electronic component may be refined by the gamma-, X-ray, or radioastronomical methods. Let us then stress the fact that γ-rays from the decay of π°-mesons contribute information on the proton-nuclear component generating mesons. It follows from the well known threshold [31] for the flux of observed γ-rays that the intensity of cosmic rays in the metagalactic space is not higher than in the Galaxy (for details see [11, 23]). This is why the increase of sensitivity by one or, more particularly, by two orders, might already directly corroborate the validity of the inequality $w_{Mg} << w_G$. Unfortunately, we must then know the coccentration of metagalactic gas (above we started from the assumption that in our epoch the mean concentration of metagalactic gas is $n \sim 10^{-5}$ cm^{-3}; however, in fact the question of the value of $\underline{n}$ still remains open). It follows from the above that the possibilities opening the further study of the electronic component are clear, particularly for energies $E > 10^{10}$ ev. Obvious also is the importance of the study of the spectrum and of chemical composition of cosmic rays with $E > 10^{15} \div 10^{17}$ ev. In this region a substantial contribution of the metagalactic component is not only possible but highly probable.

If we could succeed in clearly separating the metagalactic component of cosmic rays at ultrahigh energies, we might obtain, as a result of the well known extrapolation, information on metagalactic cosmic rays of lower energy too. Finally, let us recall the determination of the degree of anisotropy of cosmic rays

$$\delta = \frac{I_{max} \quad I_{min}}{I_{max} + I_{min}} .$$

From theoretical considerations one should expect in the galactic model an anisotropy $\delta \sim 10^{-3}$ [11], whereupon the intensity is maximum in the direction toward the galactic center. According to the available data (the last work in this field being ref.[32]) such an anisotropy is precisely the one observed. However, the effect is so small that the question still cannot be considered as resolved and subsequent measurements in wide energy range are quite important. In their idea anisotropy measurements are one of the most direct ways to distinguish metagalactic models from the galactic ones. Indeed, in the first case cosmic rays must flow into the Galaxy from without, and the intensity in the direction toward the galactic center or in a close direction must be minimum. But in galactic models the anisotropy sign is opposite (see above). Unfortunately, the real situation may become substantially more complex in connection with the influence of the magnetic field in the galactic arm near the solar system. It appears to us, however, quite little probable that the local field might change the anisotropy sign. By the same token a reliable determination of the latter, though still not providing a final solution, would contribute to it a great deal.

3. GALACTIC MODELS

3.1. MODELS DISCUSSED

By assumption, in galactic models, cosmic rays having formed near Earth were formed in the Galaxy; to be more precise, we refer here to the basic part of cosmic rays. The distinction between the various galactic models amounts in the first place to the selection of dimensions of the region filled with cosmic rays and to the choice of sources. The situation clearly emerges from the following Table:

MODEL	Region filled with cosmic rays (with $w_G \sim 10^{-12}$ erg/cm^3)	Time dependence	Basic sources
with halo	halo ($R \sim 3 \div 5 \cdot 10^{22}$ cm)	Quasistationary pattern	Supernovae "minor" explosions of the galactoc nucleus
disk model	disk ($R \sim 5 \cdot 10^{22}$ cm, $h \lesssim 2 \cdot 10^{21}$ cm)		
Nonstationary model	?	strong variations for the time $T \lesssim 10^8$ y.	"major" explosions of the galactic nucl.

Arguments against the hypothesis on "major" explosions of the galactic nucleus, and therefore also on the nonstationary model were already brought forth more than once [6, 11, 23]. We thus shall limit ourselves by the remark that a "major" explosion would much rather have destroyed the spiral structure of the Galaxy, transferring it into the category of radiogalaxies. Meanwhile, radiogalaxies are only elliptical galaxies. Evidence against the "major" explosion is constituted by the absence of the corresponding intensity variations of cosmic rays, the existence of electrons with high energy (the electrons would also not "survive" long enough), the absence of anostorpy of cosmic rays and the data on the dependence of the relative number of L-nuclei on energy. Obviously, had the quasars been found to be ejected from the nucleus of the Galaxy [14], all these arguments would be unconvincing. But such a hypothesis on the nature of quasars is not even realistic within the framework of our representations on the local nature of quasars [13].

The model with halo and the disk model differ in the first place by the choice of volume occupied by cosmic rays. If in the first case this volume is

$$V_h \sim R^3 \sim 10^{68}\ cm^3,$$

in the second case it will be

$$V_d \sim R^2 h \sim 10^{67}\ cm^3.$$

In correspondence with this the total energy of cosmic rays in the Galaxy differs in b th models by one order:

$$W_h \sim w_G V_h \sim 10^{56}\ ergs, \qquad W_d \sim w_G V_d \sim 10^{55}\ ergs \qquad (13)$$

The power of cosmic ray injection, required for sustaining the quasistationary pattern in the disk model will, however, be in all probability higher than in the model with halo. This is linked with the fact that the escape time of particles is lesser in the disk model than in the model with halo. Thus, if we take advantage of the diffusion pattern with a certain effective diffusion coefficient D, the escape time for the disk model is

$$T_d \sim h^2/2D \sim 10^5 \text{ years for a disk half thickness } h/2 \sim 10^{21}\ cm, \text{ and } D \sim 10^{29}\ cm^2\ sec^{-1} \text{ (see [11]).}$$

For a halo with $R \sim 3 \cdot 10^{22}$, the value of D being the same, it will be already

$$T_h \sim R^2/2D \sim 10^8 \text{ years.}$$

For these values in the disk model the power of the sources will be

$$U_d \sim W_d / T_d \sim 10^{43}\ ergs/sec$$

which exceeds by two orders the power of sources in models with halo. But the main fact is that such a powerful injection is extremely difficult to assure. The value $T_d \sim 10^5$ years can not be accepted on account of considerations on the chemical composition of cosmic rays and on the degree of their anisotropy (for details, see [23]).

Therefore, the disk model is inescapably linked with the assumption of rather good retention of cosmic rays in the disk, so that $T_d \gtrsim 10^7$ years. But even in the assumed layer with thickness $h \simeq 2 \cdot 10^{21} \simeq 800$ nc, which responds to the radiodisk [33], it is very difficult to assure a good retention of cosmic rays. Thus, to the value $T_d \sim 10^7$ years responds the effective diffusion coefficient $D = lv/3 \sim 10^{27}$ and it means that the effective path length $l < 0.3$ nc, inasmuch as the particle motion velocity along the field is $v \sim 10^{10}$ cm/sec and it is extremely difficult to assure a strong deflection of particles over $l \lesssim 0.3$ nc.* However, here the decisive question is that of the existence of Galaxy halo, for in its absence, as a certain region filled with a field with $H > 10^{-6}$, cosmic rays cannot hold in this region either.

3.2. PROBLEM OF THE HALO

The question of halo was found to be to some extent made more complex in connection with the mixing of two notions: about the "physical halo" and the "radiohalo" (see [34]). In the optical disk of the Galaxy $H \sim 10^{-5}$, the gas is disposed in a layer with thickness $h_g \sim 200$ nc and density $\rho_g \sim 10^{-24}$ g/cm^3. It is probable that in the intergalactic space, within the bounds of the Local group of galaxies, $H \lesssim 10^{-7} \div 10^{-8}$ and $\rho \lesssim 10^{-28}$g/cm^3. Thus, what is the character of transition between these two regions ? The existence of a more or less sharp transition is little probable a priori and the hypothesis on the "physical halo" is simply reduced to the assumption that the transitional region has dimensions $R \gg h_g \sim 3 \cdot 10^{20}$ cm.

Because both the consideration on the retention of cosmic rays and on certain dynamic and other effects (see [1], 35 37]), such an assumption is natural. Moreover, the presence of physical halo may be considered as demonstrated, inasmuch as the thickness of the observed Galaxy radiodisk is $h = h_r \sim 2 \cdot 10^{21}$ cm (see [33] and above). This, however, remains in the shadow, inasmuch as the galactic halo is often identified with radiohalo, understanding by the latter a quasispherical radioemitting region with radius $R \sim 10 - 15$ Knc $\simeq 3 \div 5 \cdot 10^{22}$ cm, surrounding the galactic disk. The question of existence of such a radiohalo is in reality still open. But the whole series of arguments in favor of the presence of radiohalo may already be brought forth now. Thus, in the direction toward the galactic pole the effective radioemission temperature is $T_b \simeq 100$°K, the frequency being $\nu = 180$ Mc. Utilizing this value or the data for other frequencies, it is easy to see that relativistic electrons with concentrations observed near Earth, will provide such an emission if they fill a halo with $R \simeq 10 - 15$ knc and a field $H \simeq 3 \cdot 10^{-6}$ [21, 23, 29, 38]). At the same time, the spectral index $\alpha = 0.5 \div 0.7$ leads to a differential spectrum of electrons with index $\gamma = 2\alpha + 1 = 2 \div 2.5$, which is not in contradiction with the data on the electronic component near the Earth.

But if we consider that radiohalo is absent, the observed quasispherical radioemission component must be considered as metagalactic. Meanwhile all the estimates known to us lead for the metagalactic component to the values $T_{b,\,Mg} \lesssim 20 - 30$° for the frequency $\nu = 180$ Mc/sec. Thus, the renunication of radiohalo is tantamount to the entirely unfounded assumption of the presence of the corresponding metagalactic emission.

* since the distance between clouds in the disk $l_0 \sim 100$ nc.

But the only thing that incites us to doubt about the existence of radiohalo is the absence of clearly expressed angular dependence of radioemission (asymmetrical position of the solar system necessarily leading for a symmetric halo relative to Galaxy center to a specific dependence of radioemission intensity on direction [33]). But measurements of angular dependence are complicated on account of a series of circumstances, so that in this respect the pattern is not clear. Obviously, by the same token the existence of radiohalo is not established, without being, however, in any way rejected. Incidently, the existence of radiohalo with $R \sim 3$ Knc and $H \simeq 3 \cdot 10^{-6}$ knowingly would not contradict even the above data on the dependence of intensity on direction.

By virtue of the above the radiohalo near the Galaxy appears to be quite probable (near galaxy M31 the presence of radiohalo is considered as established, particularly in long waves).

It is of particular importance for the following to underscore still one more case. The assertion of absence of radiohalo near the Galaxy would imply the absence of quasispherical region with $R \gtrsim 10$ knc, which is the source of radioemission with $T_b > 20 - 30°$ (at $\nu = 180$ Mc). But hence would follow only a rather feeble limitation upon the parameters of physical halo. In reality, the radioemission intensity is proportional to

$$H^{\frac{\gamma + 1}{2}}.$$

If at $H = 3 \cdot 10^{-6}$ the intensity of radioemission from the halo responds to the temperature $T_b = 100°$, at $\gamma = 2$ and $H = 10^{-6}$ the temperature will already be $T_b \simeq 20°$ and the radioastronomers would be concluding that radiohalo is absent. Meanwhile the physical halo $R \sim 10 \div 15$ knc and $H \simeq 10^{-6}$ still radically differs in the sense of influence on the cosmic rays from the metagalactic region with $H < 10^{-7}$ oe.

Summarizing, one may assert that any data attesting against the possibility of selection of galactic model of origin of cosmic rays utilizing the assumption of existence of physical halo with $R \sim 10 - 15$ knc, are absent. To the contrary, the alternative quasistationary — the disk model, encounters difficulties and is significantly less probable.

3.3. THE MOST PROBABLE MODEL

We therefore consider as most probable the galactic model with halo, which was discussed earlier more than once. Because of the above, we shall bring forth the parameters of this model without detailed explanations.

Galactic Model with Halo.

Radius: $R \sim 3 \div 5 \cdot 10^{22}$ cm; volume : $V \sim 10^{68}$ cm^3; energy of cosmic rays: $W_{cr} \sim 10^{56}$ ergs; escape time of particles from the system: $T \sim 3 \cdot 10^8$ years; power of sources $u \sim W_{cr}/T \sim 10^{40}$ ergs/sec.

<u>The pattern is quasistationary</u> (variation of mean intensity in the system $< 10\%$ for a time $T \sim 1 \div 3 \cdot 10^8$ years).

<u>For the electronic component</u>: $w_e \sim 10^{54}$ ergs, $T_e \sim 10^8$ years, $U_e \sim$ $\sim W_e/T_e \sim 3 \cdot 10^{38}$ ergs/sec.

<u>Basic Sources</u>: supernovae and, possibly, "minor" galactic nucleus explosions.

Toward the boundaries of halo (for $R > 10$ knc) the energy density w_G in galactic models must drop. This is why the value $W_{cr} \sim w_c V$ must, for example, result to be equal to $3 \cdot 10^{55}$ ergs. The lifetime T for protons and nuclei may also be lowered, but in the model discussed we still have $T > 10^8$ y. By the same token, $U \sim 3 \cdot 10^{39} \div 3 \cdot 10^{40}$ are the reasonable limits reflecting the inaccuracy of the parameters. The characteristic lifetime of electrons T_e is less than the lifeti e T in connection with the losses, whereupon the latter rise with the energy, and must be taken into account during more precise calculations.

The respective calculations conducted by us are exposed in Section 17 of the book ref. [11]. Inasmuch as the new computations of such type, taking into account the latest data, are still unfinished, we shall limit ourselves here to two remarks. Calculations of [38] are not in contradiction with our own, provided we take into account that the data utilized by us on the intensity of nonthermal radioemission were averaged over the hemisphere in the direction of the galactic anticenter. Such an intensity is 2.5 times higher than in the direction toward the galactic pole. As already mentioned, when choosing the value $T = 100°$, the electrons observed near Earth will provide the required radiation for a halo with parameters $R \sim 10 \div 15$ and $H \sim 3 \cdot 10^{-6}$ Our calculations [11] for the number of secondary electrons coincide with those of [39] in respect to the contribution by the proton component of cosmic rays, provided we assume for the mean concentration of hydrogen in the entire volume of the Galaxy, including the halo, the value $n = 0.01$ cm^{-3}. The discrepancy between [11] and [39] is linked with the fact that in [39], a value $1.5 \div 3$ greater of the density is unjustifiably utilized; moreover, in our opinion the role of αp-collisions is also strongly overrated*.

On the whole the data on the electronic component appear to be quite compatible with the model discussed (see [5, 11, 21, 23, 29, 34 and 38 - 40]). The same may be said about all known to us data on the proton-nuclear component. However, in a series of cases the experimental data are inaccurate, while the calculations are either imprecise, or insufficiently specific. This is why the model with halo may not yet be considered as demonstrated, and the more so if we take into account the noted state of the very problem of halo.

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* It is admitted in [39], that at proton collision with a helium nucleus the interaction takes place with one nucleon of the nucleus. However, it is assumed in contradiction with this that the energy of generated mesons in αp-collisions is about four times greater than at $p\alpha$-collisions for one and the same energy per nucleon in the incident particle.

For the subsequent work it would be very important to ascertain the dimensions of the halo. One may think that the solution of this problem will be obtained already by the radiomethod (separation of the emission component responding to radiohalo). If in this way the very foundations of the model are found to be entirely reliable, main attention will be drawn by the quantitative calculations (chemical composition, secondary electrons and positrons, γ-rays, anisotropy) and their comparison with observations, and also the study of the sources of cosmic rays themselves.

3.4 PROBLEM OF SOURCES

The choice of model, and concretely, of a galactic model with halo, imposes on the sources of cosmic rays specific conditions, fixing in the first place the power of injection. However, by the same token the sources themselves cannot yet be considered as unambiguously indicated. In other words, for a complete description, or rather sufficiently complete, it is necessary to make more precise the choice of sources, and subsequently work out a theory of sources. The problem of sources was discussed more than once. At the same time bursts of supernovae were considered at the outset as the fundamental source (see [1-4, 7-9]), while during the latest years a possible substantial role was ascribed to "minor" explosions of the galactic nucleus (see [5, 6, 11, 20, 23]). Such a situation prevails at present.

According to the latest data [41], supernovae burst in the Galaxy once in 50 years, as an average, that is $1.5 \cdot 10^9$ sec. This is why the mean energy, which must be transferred to cosmic rays during the burst of one supernova must constitute

$$W_{Sn} = 1.5 \cdot 10^9 U \sim 10^{49} \text{ ergs}$$

(for total injection power $U = 10^{40}$ ergs/sec). As is well known the value $W_{Sn} \sim 10^{49}$ ergs is quite possible.

The existence of "minor" explosions of the galactic nucleus may at present be considered as rather probable not only by virtue of analogy with other galaxies, but also according to data bearing on the motions in the central region of the Galaxy [42]. The mean power of injection $U \sim 10^{40}$ ergs/sec may be assured, for example, if in the course of a single burst an energy $W_n \sim 3 \cdot 10^{54}$ ergs $\sim M_0 c^2$ is transferred to cosmic rays and the bursts recur every 10^7 years. The galactic nucleus was recently revealed in the infrared [43], whereupon the total power (luminance) of the source constituted $8 \cdot 10^{40}$ ergs/sec. Such a luminance is about $2 \cdot 10^7$ times higher than that of the Sun. One may believe, according to a series of considerations, that the mass of the nucleus is $M \sim 3 \cdot 10^7 M_\odot$. To the explosion of the galactic nucleus responds some kind of instability or even the Collapse. The energy transfer to cosmic rays, that is $W_n \sim 3 \cdot 10^{54}$ ergs is then possible even at very low effectiveness of the acceleration (it should be sufficient to recall that for a nucleus with the indicated mass $Mc^2 > 5 \cdot 10^{61}$ ergs, and for some models of quasars the liberation of energy reaches 10^{-3} Mc^2). If the main part of cosmic rays was accelerated as a result of nucleus explosions (note that 30 explosions with $W_n \sim 3 \cdot 10^{54}$ ergs must obviously take place in order to accumulate the energy $W_{CR} \sim 10^{56}$ergs) one might expect some nonstationary state, i. e. intensity variations. However, if this variation reaches only 3 percent, as in the example brought out, it can hardly be noticed. The same may be said in respect to other well known methods.(see the annotation 2 at the Appendix). Therefore, it is clear that the separation of the contributions from supernovae and the galactic nucleus explosions will not be easy to reliably perform. It should be noted at the same time that high efficiency of supernovae as injectors of relavistic particles is already established, whereas in respect to Galaxy nucleus explosions there prevails a total uncertainty. This is why supernovae remain the most probable candidate for the role of basic sources of cosmic rays in the Galaxy.

CONCLUSION

For the period elapsed since the London Conference of 1965 no somewhat quite specific data have appeared, which would affect the estimate of the general state of the problem of origin of cosmic rays. Substantial progress was achieved, however, in regard to the study of the electronic component. If the relict metagalactic thermal radiation with $T \simeq 3°K$ exists, and it is very difficult to doubt about it despite the absence of measurements in waves $\lambda < 1.5$ cm, the uniform metagalactic model of the origin of the electronic component is excluded. The local metagalactic models still are not completely excluded, but tough limitations are superimposed upon them, particularly if there is question of electrons with energy $E > 10^{10}$ ev. The assumption of different origin of the electron and proton-nuclear components of cosmic rays (for not too high energies) is already assumed little probable from general considerations. In conjunction with what was said earlier we see in this one of the basic arguments against metagalactic models for the proton-nuclear component. Another argument, no less important, is based upon considerations on energy. Thus, within the framework of evolutional cosmology the uniform metagalactic model appears to us as already impossible from these energetic considerations. Though less specifically, the same can be said of the "Centaur A model" and of some other local models. As a matter of fact, some local metagalactic model or a nonstationary galactic model appear possible only in the assumption that gigantic explosions took place relatively recently ($T < 10^8$ years) in the nucleus of the Galaxy or in the nuclei of closest galaxies (for Centaur A there is question of injection of cosmic rays with energy $W_{CR} \sim 10^{63}$ ergs, for which a mass $M > 10^{12} M_{\odot}$ must collapse). For such or similar hypotheses we see no real foundations of any kind. Even if quasars were found to be having a local nature, they would fail to provide us with a guarantee in regard to the validity of local metagalactic or nonstationary galactic models of origin of cosmic rays, Obviously, at the same time the establishment of local nature of quasars (despite the arguments of [13], we still consider this question as open) would modify the situation and would make the models referred to significantly more probable.

Among the galactic models the one with halo is most probable. We see no contradictions of any kind or difficulties in this model, but it still is not demonstrated and sufficiently worked out in many respects, amd particularly from the quantitative viewpoint and taking into account the latest data (see annotation 3 in the Appendix).

On the strength of all the above-expounded it is clear that we shall still be compelled to return, time and again, to the very same questions about metagalactic cosmic rays, galactic halo and the sources of cosmic rays. The introduction of final clarity, of the demonstration of the validity of a series of postulates in this round of questions will be attained with great difficulty and will require a long time, which is unfortunate. We assume at the same time that the history of the investigation of the problem of the origin of cosmic rays for the past 15 years does not provide any basis for skepticism, and, to the contrary, it is evidence of a real progress.

**** THE END ****

ANNOTATIONS

1. (to page 8). If we take into account the possible formation of cosmic rays during explosions of galactic nuclei, then too estimate (7) will be preserved in essence. Assume that during explosions of nuclei a mass of the order $\zeta \sim 10^{-2} \div 10^{-3}$ of the total mass of galaxies participates. Then, with out taking into account the losses and the expansion of the region occupied by cosmic rays,

$$w_{Mg,r} \sim \zeta\xi \cdot \rho c^2 \sim 4 \cdot 10^{-15} \div 4 \cdot 10^{-16} \text{ for } \xi \sim 10^{-3}.$$

The role of the expansion and of the losses is great in this case and, for our epoch, estimate (8) is again valid.

2. (To page 18). The above-said does not refer to high-energy electrons. If the last explosion of Galaxy nucleus took place 10^7 years ago (a lesser value is extremely little probable), the electrons, then accelerated, cannot now have an energy greater than $E_{max} \simeq 3 \cdot 10^{10}$ ev/cm. [9] for $w_T + H^2/8\pi \sim 2 \cdot 10^{-12}$ erg/cm^3 and $\tau = 3 \cdot 10^{14}$ sec . But if we postulate for this case H 10^{-5}, which is more probable, $E_{max} \simeq 10^{10}$ ev. We did not take into account the electron motion time from nucleus to Earth. At diffusive propagation with $\mathfrak{D} \sim 10^{29}$ this time is $T \sim R^2/2\mathfrak{D} \sim 10^8$ years and $E_{max} \simeq 1 \div 3 \cdot 10^9$ ev (this argument is evidently valid also in the case when the nucleus generates electrons all the iime).

3. (To page 18) Attempt to construct a quantitative theory of origin of cosmic rays was made in ch."Y" of the boor ref.[11]. Now we are undertaking the preparation of the second edition of this book and to the corresponding revision of all calculations in the light of new information.

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