Cosmic rays at ultrahigh energies

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Abstract. In this paper, the nature of the origin of cosmic rays is considered. By studying the chemical composition, the intensity of cosmic rays is determined. And when collisions with the nuclei of the interstellar medium, unstable particles appear. The astronomical role of cosmic rays and the probable galactic model of the origin of cosmic rays have been clarified. The results of the chemical composition of cosmic rays are obtained. It is shown that: a) cosmic rays are mostly located in the Galaxy; b) the Virgo supercluster is a metagalactic model in which the main part of the proton-nuclear component forms superclusters; c) the metagalactic model differs from the galactic one in the energy density of cosmic rays. Models of the origin of cosmic rays in the region of energies up to 1017 Ev, the most preferred model is one that assumes an increase in multiplicity. The energy density of cosmic rays is determined. The dependences of the average number of muons on the number of electrons in the shower and the energy spectrum of muons in the shower are found. Depending on where the main sources of cosmic rays are located, the following models of cosmic rays are shown: solar, galactic and metagalactic, and galactic models have several modifications and differ from halo and disk models, since cosmic rays fill a quasi-spherical volume.

Keywords: Cosmic rays · Astrophysics · Galactic · Metagalaxy · Spectrum · Radio emission · Cosmic rays · Ultrahigh energies.

1. Introduction

The purpose of this paper is to consider models of the origin of cosmic rays in the region of ultrahigh energies

To achieve this goal explored the model, we investigated a model of cosmic rays in a galaxy "trapped" in a quasi-stationary manner. For this model, the main source of om origin of cosmic rays are supernovae. However, the model does not solve the problem of the origin of cosmic rays (Kostin et al., 2019; Kozlov, 2022).

By studying the chemical composition, the intensity of cosmic rays was determined. And when colliding with the nuclei of the interstellar medium, unstable particles appear: π-mesons that decay with the emission of gamma rays.

2. Materials and method

Using the magnetic field H, we can find the intensity, synchrotron radiation spectrum, and energy density - $W_{c\,r,}$ (Urusova and Temirbolatova, 2020).

We calculated the energy density for the Earth, which are respectively:

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$$Wcr — Xr\ Wcr \sim 102\ Wcr,\ e \sim 10\text{-}18Erg/m^3. \tag{1}$$

If we take into account the equal distribution of energy by "degrees of freedom", we have obtained that the field strength, H, is quasi-isotropic:

$$H^2 \div 8\pi = x_H,\ X_H \sim 2, \tag{2}$$

Further, knowing that:

$$x_r = W_{cr} \div W_{cr,e}\ u\ X_H = H^2 \div 8\pi wcr.. \tag{3}$$

$$x_r \sim 102 \text{ and } X_H \sim 2, \tag{4}$$

received:

$$W_{cr} \sim 1050—1055\ Erg. \tag{5}$$

Depending on where the main sources of cosmic rays are located, there are the following types of models: solar, galactic, and Meta galactic.

Calculating the intensity of cosmic **gamma** rays in meta galactic models and knowing the density of the medium, we determinede the energy density - W_{cr}, which is equal to:

$$W_{cr},\ Mg \ll W_{cr},\ G \equiv W_{cr} \sim 10^{-18} Erg/m^3, \tag{6}$$

Moreover, cosmic rays uniformly fill the super cluster (Kitaev-Smyk, 2019).

The inconsistency of the Meta galactic model follows from the fact that the expression is valid outside the Galaxy:

$$W_{cr},\ Mg \ll W_{cr}\cdot, \tag{7}$$

$$W_{cr},\ MC \approx W_{cr},\ Mg \approx W_{cr}. \tag{8}$$

From expression (8) follows:

$$F_y E \approx 2.710 - 11^{-11} \frac{photons}{m^2} sec. \tag{9}$$

Studies have shown that galactic models have several modifications and differ from halo and disk models, since cosmic rays fill a quasi-spherical volume equal to:

$$R \sim (3 - 5) \times 10^{10-20} m,\ T_{cr,h} \sim \frac{R^2}{2D} \sim (1 - 3) \times 10^8\ years, \tag{10}$$

where R is the volume radius, $T_{cr,h}$- Lifetime.

Using the expression (10), we can calculate:

$$D \sim \frac{lv}{3} \sim 10^{25} m^2 sec^{-1},\ L \sim 10^{21} m. \tag{11}$$

Supernovae-pulsars are located in a galactic disk with a half-thickness of, $_{h8\sim}$(3-5) × 10^{10-20}m. This means that the gas in the Galaxy is concentrated in a disk with a thickness of:

$$h_g \sim\ 100 - 150\, nc \sim (3\text{-}5) \times 10^{20}\, \text{м}. \tag{12}$$

This model is related to the dynamics of a system containing cosmic rays, gas, and magnetic fields, and the cosmic rays entrap the field and cause a turbulent motion. Then, the source area is surrounded by cosmic rays, where the intensity is very high, and the transition is made to intergalactic space at a large distance from the source area, it is equal to:

$$h_{d\sim (1\ -\ 3)\times 10^{19} m,} \tag{13}$$

$$h_s \sim 3\times 10^{10-18} m.. \tag{14}$$

And for the halo, respectively, at a distance of:

$$h_h \sim R \sim (1\ -\ 5)\times 10^{10-20}\ m \tag{15}$$

For relativistic electrons given, taking into account the additional losses, the size of the cosmic ray halo is much smaller.

Decrease in the energy of the primary particle between the secondary particles leads to a slow development of the cascade of nuclear-active particles, resulting in the fraction of muons in the shower (see Fig. 1) is too small in comparison with the experimental results (Konyukhov, 2019; Levitan et al, 2018).

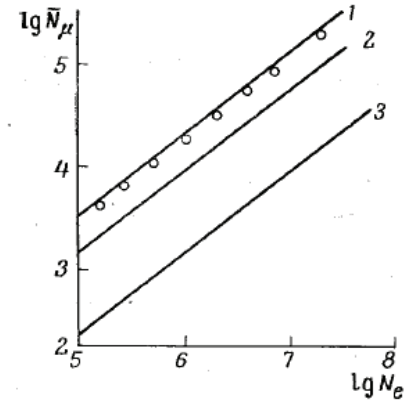

Fig. 1. Dependence of the average number of muons ($E_{\mu}>^{10-10}$ *sV)* on the number of electrons in the shower.

However, it should be emphasized that the experimental data were obtained on a small-area installation that directly measures only 15-20% of the total number of rain particles. In addition, the interpretation of experimental results can be significantly influenced by taking into account the transverse momenta of pion, which increases fluctuations in the spatial distribution function of particles (Lyashchenko, 2020; Marov, 2018; Minat, 2020). Therefore, it is desirable to conduct a similar experiment at high altitude using a device with continuous sensitivity up to distances from the rain axis of ~ 100 *m.*

Since (high multiplicity model) If the IMM assumes a sharp increase in multiplicity in the energy rang of ~ 10 $^{10-14}$ *eV,* then within the framework of this model, we should expect irregularities in the dependence of various shower characteristics on the primary energy (Subeto, 2019; Panasyuk, 2019; Priz, 2019).

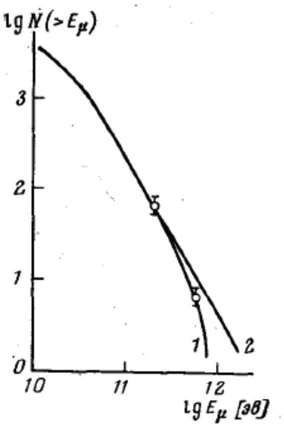

Fig. 2. Energy spectrum of muons in a shower with Ne=2·10 5^5.

At the transition to high altitudes the spectrum irregularity in terms of N_e. It is observed at high values *of ne,* but its range significantly decreases, which is a consequence of approaching the maximum shower.

According to the MVM, the energy spectrum of muons in broad atmospheric showers (EAS) should be torsion) at $E_\mu \sim (2 - 10)\ {-}^{10-11}$ *eV,* while the energy spectrum of muons calculated using the usual model does not give such a result (see Fig. 2).

In the description of p*(R)* by an approximation of the form p*(R)~1/*Rn, the exponent n *n*increases by 0.4 when $N_{e\ changes}$ from^{107} to^{109}, while the corresponding calculations give a change *in n* of only 0.15 and 0.10 for the conventional model and MVM, respectively. Therefore, to explain the observed dependence, it is necessary to assume a scaling model, and the transition from the MVM or conventional model to the scaling model should take place at an energy of$^{10-17-10-18}$-10^{18} *eV* (Rozhenkov, 2018; Cheredov, 2019).

On the other hand, the value of the conversion coefficient *K /(E)* from the number of particles in the shower to the primary energy obtained turns out to be 30-50% higher than it is possible to obtain in the IMM framework, and 2.5 times higher than in the conventional model.

As for other experimental data available in this energy range, they can be consistent with both the usual model and the high multiplicity model.

Thus, in the region of energies up $10^{\text{to } 10-17}$Ev.However, the model that assumes multiplicity growth with an energy *of the type n~* E_0^{E0} , $more\ preferable$ where as for energies above 10 $-^{10-17}$ *eV*, the situation seems unclear, and therefore additional experimental verification of both the value of the conversion coefficient *K(E)* and the dependence of the type of the spatial distribution function on the shower power is necessary.

3. Results

1) Cosmic rays are mostly located in the Galaxy.
2) The Virgo supercluster is a meta galactic model in which the main part of the proton-nuclear component forms a supercluster.
3) The meta galactic model differs from the galactic one by the energy density of cosmic rays: $W_{cr},\ Mg \ll W_{cr}$, G $\equiv W_{cr} \sim 10 - 12^{-12}\ Erg/cm3^3$

4) The radius, lifetime, volume, energy density of cosmic rays, energy density of cosmic rays in the Galaxy, and power in the region of capture of quasi-spherical halos are respectively equal to:

$$R\sim (3 - 5)\times 10^{10-20} m, T_{cr,\,h}\sim \frac{R^2}{2D}\sim(1 - 3)\times 10^{8}\, years,$$

$$D\sim \frac{lv}{3}\sim 10^{25}\, m^{2}\, sec^{-1},\ L\sim 10^{21} m$$

$$h_8\sim (3\text{-}5)\times 10^{10-20} m$$

$$h_g\sim 100 - 150\, n\, c\sim (3\text{-}5)\times 10^{20} \text{м}.$$

5) Models of the origin of cosmic rays in the energy range up to 10^{17} The most preferred model is that which assumes multiplicity growth with an energy of the type n~ $E_0^{0.5}$.

The halo model is related to the dynamics of a system containing cosmic rays, gas, and magnetic fields, with cosmic rays dragging the field along with them and emanate causing turbulent motion. Then, the source area is surrounded by cosmic rays, where the intensity is very high, and the transition is carried out to intergalactic space at a large distance from the source area equal to:

$$h_{d\sim (1 - 3)\times 10^{19} m,}$$

$$h_s\sim 3\times 10^{10-18} m.$$

And for the halo, respectively, at a distance of:

$$h_h\sim R\sim(1 - 5)\times 10^{10-20}\, m$$

For relativistic electrons, taking into account the additional losses, the size of the cosmic ray halo is much smaller.

And for the electronic component, respectively, it is equal to:

$$W_{cr,e}\sim 10^{54}\, Erg.$$

6) In the field of energies up to 10^{17} The most preferred model is that which assumes multiplicity growth with an energy of the type n~ $E_0^{0.5}$.

7) Dependencies found: the average number of muons (E μ > 1010 s V) as a function of the number of electrons in the shower and the energy spectrum of muons in the shower with $Ne=2\cdot 10^5$ (see Fig. 1 and Fig. 2).

The considered models are the most probable, which are obtained on the basis of studies and observations of the intensity of radio emission.

4. Discussion

It is problematic to model cosmic radiation at ultrahigh energies, since there is a large arbitrariness in the choice of parameters for the model of the elementary act of nuclear interaction.

Until recently, the above-mentioned arbitrariness existed in almost the entire field of energies that make the main contribution to the development of EAS. However, significant progress made in recent years at accelerators has made it possible to obtain data on nuclear interactions up to energies of $2*10^{10-12}$ *eV* for *pp*-interaction sand up to 3 $*10^{1011}$ *eV* for *N*n interactions, up to energies that are very significant for the development of a broad shower. Thus, the boundary of the region where arbitrariness in the choice of parameters of an elementary act begins has now been pushed back to approximately$^{10-13}$ *eV.* Since EAS originating from primary energies less $10^{\text{than } 10-17}$ *eV* have been studied in incomparably more detail than in the region of higher energies, it is advisable to consider separately the development of EAS and the nature of nuclear interactions in the region of energies less than and greater $10^{\text{than } 10-17}$ *eV.*

The most serious reason for the proposal of a high multiplicity model (MVM) was a significant discrepancy between the experimental intensity of EAS at a depth of ~200 $g * cm^{-2}$ and calculations based on the SCR model.

Experimental data on EAS in the region of extremely high energies (above 10^{10-17} *eV)* are contradictory.

On the one hand, there are data, the interpretation of which requires a transition to a model where the maximum shower development would be closer to sea level than in the usual model with $n\sim E_0^{0.25}$.

5. Conclusion

The results of the study showed that: a) cosmic rays are mostly located in the Galaxy; b) the super cluster in Virgo is a meta galactic model in which the main part of the proton - nuclear component forms superclusters; c) the meta galactic model differs from the galactic one by the energy density of cosmic rays: W_{cr}, $Mg \ll W_{cr}$, G $\equiv W_{cr} \sim 10 - 12^{-12} Erg/cm3^{3}$

Models of the origin of cosmic rays in the energy range up to 10^{17} The most preferred model is that which assumes multiplicity growth with an energy of the type $n\sim E_0^{0.5}$.

The density, p – adius, lifetime, volume, energy density of cosmic rays, energy density of cosmic rays in the Galaxy, and power in the region of capture of the a-quasi- spherical and electron components, respectively, are determined .

Dependencies found: the average number of muons ($E_{\mu} > 10^{10}$ *s V) as a function* of the number of electrons in the shower and the energy spectrum of muons in the shower with $Ne=2\cdot10^{5}$.

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