HE.2.3.07

The Possible Interpretation of Experimental Results on Cosmic Ray Particles with Energies Exceeding 10^{19} eV at ADASA Array

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ABSTRACT

Recently published experimental data of the AGASA group [1] are discussed. These data confirm the absence of a cutoff of the ultrahigh energy cosmic ray spectrum. One of the possible explanations of this result is associated with a small deviation from the special relativity theory (SRT) at Lorentz factors greater than 10^{11}. Such a generalization of SRT which is based on the Finsler-space geometry has been previously proposed in [2].

The problem of the origin of primary cosmic rays (PCR) with maximum detected energies of 10^{19}-10^{20} eV is discussed in many years. According to the most widespread viewpoint [3], the PCR in this energy region have the extragalactic origin. If their sources are at the distances of tens of Mpc from the Earth then their energy spectrum must have a cutoff at $\mathbf{E}=5\ 10^{19}$ eV associated with the photoproduction of pions on the cosmic microwave background radiation (the Greisen-Zatsepin-Kuz'min cutoff) [4]. The experimental data obtained before the FLY Eye setup and AGASA arrays had been put into operation were contraversial. The energy spectra of PCR obtained at Havera Park [5] and Sydnei arrays (SUGAR) [6] did not become steeper at $\mathbf{E}=5*10^{19}$ eV. However, Yakutsk data indicated the presence of the GZK cutoff [7].

The AGASA array has registered 461 events with the energy greater than 10^{19} eV. This statistic is significantly higher than the number of events with the same energy registered at Havera Park, Fly Eye, and Yakutsk. The energy spectrum obtained with AGASA array (see figure) is extended up to the energy of $2*10^{20}$ eV and has no a cutoff. The dashed line in figure shows the predicted spectrum of PCR from uniformly distributed extragalactic sources [3]. The AGASA results show no correlations in the arrival directions of six 10^{20} eV events with known astrophysical objects closer than 50 Mpc, which might be the sources of such particles.

The existing attempts of interpreting the absense of the GZK cutoff can be divided into two groups. The first ("physical") is based on various mechanisms of additional generation of ultrahigh energy particles, which could compensate the GZK cutoff. These models meet certain difficulties and are not discussed here (see [8-10]).

The second group of the models ("geometrical") doubts the correctness of the calculation of the GZK cutoff. As the photoproduction cross section and background radiation spectrum are knowm experimentally quite well, we here disscuss a certain modification of the Lorentz transformations (LT) with superhigh Lorentz factors $\boldsymbol{\gamma}$.

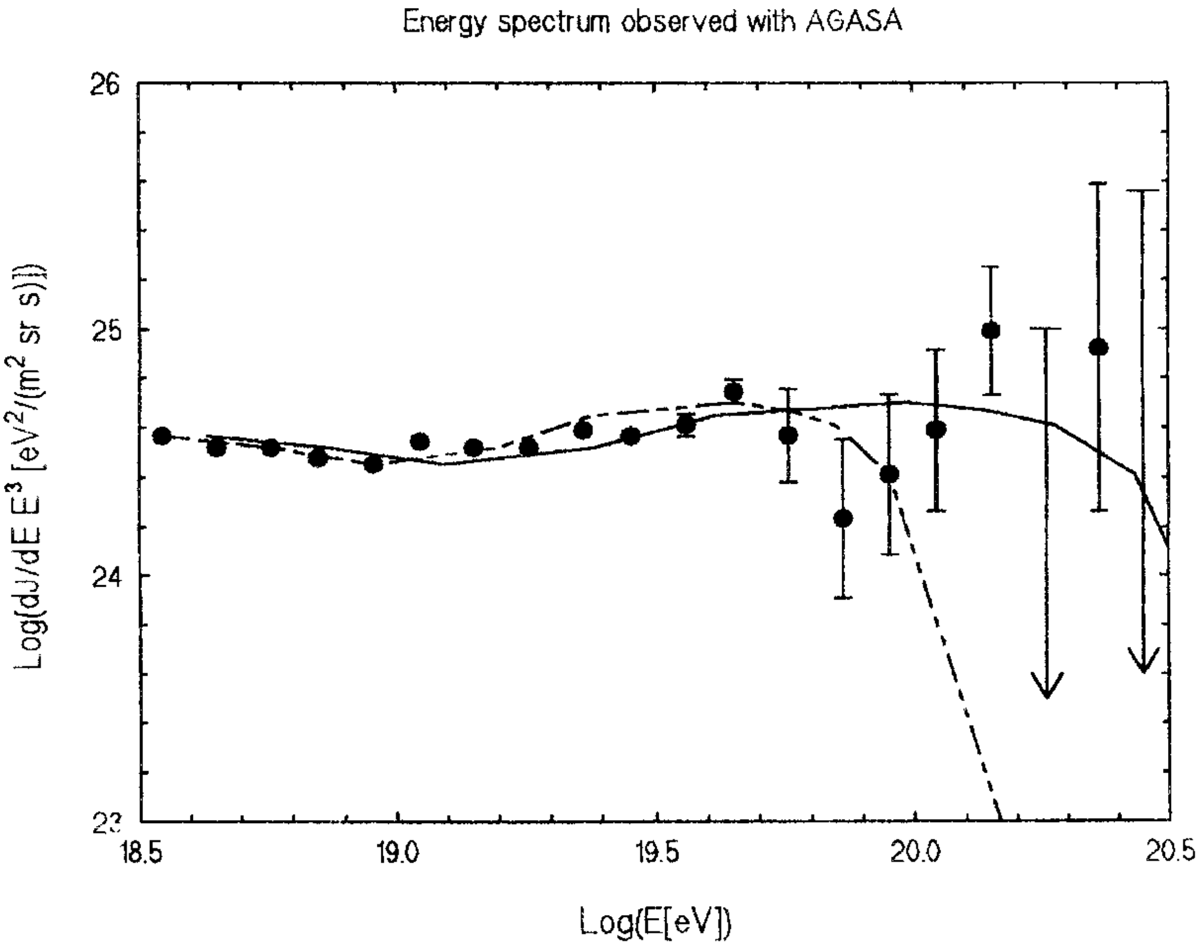
The initial point of these models is that, when calculating the photon energy in the rest system of proton, one must carry out LT with the values of $\gamma\geq\gamma_c=10^{19}$ that are by many orders of magnitude higher than those in any other experiments. This suggests that such a modification would not influence on conventional relativistic relations at not extremely large $\boldsymbol{\gamma}$. As LT are the symmetry group of the pseudo-Euclidean space, their modification implies new geometric properties of space-time and requires the basis of relativity theory to be change significantly. These models lead to the flat Finsler space [2, 11], in which the line element has the form: $\mathbf{ds = F\ ds_0}$, where $\mathbf{F}$ is a homogeneous function of zero order in the differentials of the Cartesian coordinates $\mathbf{dx}$ and $\mathbf{dt}$, $\mathbf{ds^2_0=dx^2-dt^2}$. The introduction of the Finsler metric implies that the space-time becomes anisotropic. These generalization don't exclude a violation of the relativity principle and the appearance of a preferred reference system (see, for example, [12]). We here consider two models [2, 11], in which the relativity principle is valid.

Three-dimensional space is assumed in [2] to be isotropic, and the metric function **F** depends only on $\mathbf{dt/ds_0}$. In the model [11], the space is anisotropic and characterized by the vector **n** having the same Cartezian coordinates in all equivalent reference systems. If the Finsler metric is given the generalized relativistic dynamics can be developed by using the conventional calculus of variations. In the two models, the energy-momentum relation has the form: $\mathbf{f\,(E^2-p^2)=m^2c^4}$, where **f** is a homogeneous function of zero order in the energy-momentum components, which is determined by the metric function **F**. The transformations that conserve this form are referred to as generalized LT for energy-momentum. In the model [2], the generalized LT of energy-momentum and space-time are canonical, isomorphic to the conventional LT, and, thus, conserve the form of dynamic canonical equations. In this case, energy-momentum components transform not linearly, while the generalized LT of a space-time point are linear but their coefficients depend on the energy-momentum of the probe particle at this point. The subsequent development of this model is based on the tensor analysis for the canonical (contact) transformations.

Omitting the general cumbersome formulas, we consider only the generalized LT of the photon energy-momentum $\mathbf{k = \hbar\omega\,(1, n)}$ from the laboratory system **K** into the reference system **K'** moving conterwise to the vector **n** with the velocity **V** (the rest system for the high-energy proton). In the system **K'**, the photon energy is $\hbar\omega' = 2\ \hbar\omega\ \gamma\ D(\gamma)$. In the model [11], the function $\mathbf{D(\gamma)=\{\gamma(1-vn/c)\}^{-r}}$, where **r** is a small dimensionless constant characterizing the degree of anisotropy. In the model [2], $\mathbf{D(\gamma)=f(\gamma)^{1/2}}$, with the power series expansion of **D** taking the form: $\mathbf{D(\gamma)=1-a\,\gamma^4}+\ldots$, where **a** is a small constant. Besides, $\mathbf{D(\gamma>>\gamma_c)=D(\infty)<\infty}$.

The main factor determining the value of the GZK cutoff is the exponent of the Planck distribution of backdround photons $\mathbf{H=exp(-\hbar\omega/kT)}$, where $\mathbf{kT}=10^{-4}$ eV. In the rest system of proton, for $\hbar\omega'=m_\pi\,c^2$ = 140 MeV", the both models yield: $\mathbf{H=exp(-m_\pi\,c^2\,/kT\ 2\,\gamma\,D(\gamma))}$. Thus, in this case, the net result is the substitution of γ by $\gamma\,D(\gamma)$, i.e., a scaling of extremely large Lorentz factors. If the function $\mathbf{D(\gamma)}$ in the region $\gamma>\gamma_c$ becomes small compared to unity then the factor **H** decreases and, correspondingly, this leads to deviation from the conventional GZK calculations. According to [2], it follows from this that $\mathbf{a}=\gamma_c^{-4}=10^{-44}$. This value might be associated with the gravitational effect or fluctuations in the stochastic-space theory. The finiteness of the asymptotic value of $\mathbf{D(\infty)}$ implies that the onset of the GZK cutoff shifts along the energy scale and is determined by the condition $\gamma_c'=\gamma_c D(\gamma_c)$. The solid curve in figure shows an example of such calculations for $\gamma_c' = 10\,\gamma_c$; this value is quite admissible in the model [2]. To estimate $\mathbf{D(\gamma)}$ in the model [11], we take into account that the microwave background radiation is isotropic; therefore, the mean value $\mathbf{<nv>=0}$ and the upper estimate of **D** is about of γ^{-r}. To shift the cutoff energy by a factor **S** in the region $\gamma>>\gamma_c$, it is necessary to assume that $\mathbf{r=-log(S)/log(\gamma_c)=-1}$ (for **S**=10). Such a large anisotropy parameter is inadmissible in this model because the experimental estimates give $\mathbf{r=10^{-8}}$ [11].

Thus, the model [2] can describe the absence of the GZK cutoff by shifting the cutoff energy by a factor "S". This implies that $\gamma_c'=\gamma_c\cdot S$. On the other hand, because of a weak γ dependence in the model [11], we have to introduce an inadmissibly large value of the anisotropy parameter.


Energy spectrum observed with AGASA
26
25
24
23
18.5
19.0
19.5
20.0
20.5
Log(dJ/dE E^3 [eV^2/(m^2 sr s)])
Log(E[eV])

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