Ultra High Energy Cosmic Rays from Cosmological Relics.

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Ultra High Energy Cosmic Rays (UHECR) can be a signal from very early (post-infationary) Universe. At this cosmological epoch Topological Defects (TD) and long lived superheavy (SH) particles are expected to be naturally and effectively produced. Both of these relics can produce now the particles, such as protons and photons, with energies in a great excess of what is observed in UHECR, \( E \sim 10^{10} \rightarrow 10^{11} \text{ GeV} \). The Topological Defects as the UHECR sources are critically reviewed and cosmic necklaces and monopolonia are identified as most plausible sources. The relic superheavy particles and monopolonia are shown to be clustering in the halo of our Galaxy and their decays produce UHECR without GZK cutoff. The observational signatures of both models are discussed.

1. Introduction

The observation of cosmic ray particles with energies higher than \( 10^{11} \text{ GeV} \) gives a serious challenge to the known mechanisms of acceleration. The shock acceleration in different astrophysical objects typically gives maximal energy of accelerated protons less than \((1 - 3) \cdot 10^{10} \text{ GeV}\). The unipolar induction can provide the maximal energy \( 1 \cdot 10^{11} \text{ GeV} \) only for the extreme values of the parameters. Much attention has recently been given to acceleration by ultrarelativistic shocks. The particles here can gain a tremendous increase in energy, equal to \( \Gamma^2 \), at a single reflection, where \( \Gamma \) is the Lorentz factor of the shock. However, it is known (see e.g. the simulation for pulsar relativistic wind in \[2\]) that particles entering the shock region are captured there or at least have a small probability to escape (see discussion relevant for UHECR in ref. \[3\]).

Topological defects (for a review see \[1\]) can naturally produce particles of ultrahigh energies (UHE). The pioneering observation of this possibility was made by Hill, Schramm and Walker \[10\] (for a general analysis of TD as UHE CR sources see \[1\] and for a review \[12\]). In many cases TD become unstable and decompose to constituent fields, superheavy gauge and Higgs bosons (X-particles), which then decay producing UHECR. It could happen, for example, when two segments of ordinary string, or monopole and antimonopole touch each other, when electrical current in superconducting string reaches the critical value and in some other cases.

In most cases the problem with UHECR from TD is not the maximal energy, but the fluxes. One very general reason for the low fluxes consists in the large distance between TD. A dimension scale for this distance is the Hubble distance \( H_0^{-1} \). However, in some rather exceptional cases this scale is multiplied to a small dimensionless value \( r \). If a distance between TD is larger than UHE proton attenuation length (due to the GZK effect \[13\]), then the UHE flux has an exponential cutoff.

The other general restriction to the flux of UHECR comes from the observed by EGRET extragalactic flux of gamma-ray radiation at energies between 10 \( \text{MeV} \) and 100 \( \text{GeV} \). UHE particles such as photons and electrons produce e-m cascade in the Universe, colliding with photons of background radiation (most notably microwave and radio background). Low energy part of this cascade extends down to the EGRET measurements. The cascade flux is below the EGRET limit if the energy density of the cascade photons \( \omega_{\text{cas}} \) is less than \( 2 \cdot 10^{-6} \text{ eV/cm}^3 \). On the other hand \( \omega_{\text{cas}} \) can be readily evaluated for TD from the total energy release assuming that half of it transferred to e-m cascade. Since, on the other hand the same...
energy release determines the UHECR flux, the latter is limited by the value of $\omega_{\text{cas}}$ given above.

Relic SH particles have important property of clusterization in the Galactic halo and thus UHECR produced at their decays do not have the GZK cutoff \cite{14}. The same property have monopolonium \cite{15}. The relic SH particles produce UHECR due to their decays. Their lifetime must be larger (or much larger) than the age of the Universe. For particles heavier than $10^{13} - 10^{14}$ GeV this is very restrictive condition. Even dimension-5 gravitational interaction makes the lifetime of such massive particles very short. A particle must be protected from this fast decay by some symmetry which is broken extremely weakly, for example by instanton effects \cite{14} or worm hole effects \cite{14}.

Production of both relic SH particles and TD naturally occurs in the end of inflation. Decays of inflatons most probably start in the regime of broad parametric resonance \cite{14}. It is accompanied by massive production of particles not in thermal equilibrium. At this stage ("preheating") TD can be born due to phase transitions. SH particles are produced in the varying gravitational field of the oscillating inflaton and can have now critical or subcritical density. In the end of preheating phase the thermalization of produced particles occurs, and the Universe enters the stage of reheating, when the temperature is expected to be large, $T_r \sim \sqrt{\Gamma M_p}$, where $M_p$ is the Planck mass and $\Gamma$ is the width of the inflaton decay in the regime of the broad parametric resonance. Due to large $\Gamma$ the reheating temperature is expected to be as high as $T_r \sim 10^{11} - 10^{12}$ GeV or even higher. The superheavy relic particles can be born also at the reheating phase.

Spectrum of UHE particles produced at the decays of a relic SH particles or of heavy X particles to which TD decompose, is basically the energy spectrum of QCD cascade. This spectrum, in contrast to the case of accelerated particles, is essentially non-powerlaw. It has the Gaussian peak, the maximum of which determines the multiplicity \cite{18}. For the large masses at interest the supersymmetric effects become important; they considerably change the QCD spectrum \cite{19}. The generic feature of decays of SH particles is the dominance of pion production over baryon production. It results in the dominance of UHE photons over nucleons at production, roughly as $\gamma/N \sim 10$.

Observational signature of TD is the presence of UHE photons in the primary radiation. At some energies this effect is suppressed by strong absorption on radio background \cite{15}. For the discussion and references see \cite{15}. The GZK cutoff is present, but it is weaker than in case of accelerator sources, due to the shape of QCD energy spectrum if the space distribution of the sources is the same (e.g. for necklaces).

In case of relic SH particles and monopolonia (both of them are concentrated in the halo) the signature is dominance at observation of UHE photons over nucleons. Another signature is anisotropy caused by asymmetric position of the sun in the halo.

2. Topological Defects

The following TD have been discussed as potential sources of UHE particles: superconducting strings \cite{21}, ordinary strings \cite{22}, including the cusp radiation \cite{23}, networks of monopoles connected by strings \cite{24}, necklaces \cite{25}, magnetic monopoles, or more precisely bound monopole-antimonopole pairs (monopolonium \cite{24,25}), and vortons. Monopolonia and vortons are clustering in the Galactic halo, and UHECR production is thus similar to the case of relic SH particles considered in the next section.

(i) Superconducting strings

As was first noted by Witten \cite{23}, in a wide class of elementary particle models, strings behave like superconducting wires. Moving through cosmic magnetic fields, such strings develop electric currents. Superconducting strings produce X particles when the electric current in the strings reaches the critical value. In some scenarios, e.g. \cite{29} where the current is induced by primordial magnetic field, the critical current produces strong magnetic field, in which all high energy particles degrade catastrophically in energy \cite{30}. However, for $ac$ currents there are portions of the string with large electric charge and small current. High energy particles can escape from there.
Large *ac* currents can be induced in string loops as they oscillate in galactic or extragalactic magnetic fields. Even if the string current is typically well below critical, super-critical currents can be reached in the vicinity of cusps, where the string shrinks by a large factor and density of charge carriers is greatly enhanced. In this case, X particles are emitted with large Lorentz factors.

Loops can also acquire *dc* currents at the time of formation, when they are chopped off the infinite strings. As the loops lose their energy by gravitational radiation, they shrink, the *dc* currents grow, and eventually become overcritical. There could be a variety of astrophysical mechanisms for excitation of the electric current in superconducting strings, but for all mechanisms considered so far the flux of UHE particles is smaller than the observed flux [31]. However, the number of possibilities to be explored here is very large, and more work is needed to reach a definitive conclusion.

(ii) **Ordinary strings**

There are several mechanisms by which ordinary strings can produce UHE particles.

For a special choice of initial conditions, an ordinary loop can collapse to a double line, releasing its total energy in the form of X-particles [22]. However, the probability of this mode of collapse is extremely small, and its contribution to the overall flux of UHE particles is negligible.

String loops can also produce X-particles when they self-intersect (e.g. [22]). Each intersection, however, gives only a few particles, and the corresponding flux is very small [33].

Superheavy particles with large Lorentz factors can be produced in the annihilation of cusps, when the two cusp segments overlap [23]. The energy released in a single cusp event can be quite large, but again, the resulting flux of UHE particles is too small to account for the observations [34,35].

It has been recently argued [33] that long strings lose most of their energy not by production of closed loops, as it is generally believed, but by direct emission of heavy X-particles. If correct, this claim will change dramatically the standard picture of string evolution. It has been also suggested that the decay products of particles produced in this way can explain the observed flux of UHECR [35,36]. However, as it is argued in ref [15], numerical simulations described in [35] allow an alternative interpretation not connected with UHE particle production.

But even if the conclusions of [35] were correct, the particle production mechanism suggested in that paper cannot explain the observed flux of UHE particles. If particles are emitted directly from long strings, then the distance between UHE particle sources is of the order of the Hubble distance $H^{-1}$, $D \sim H^{-1} \gg R_p$, where $R_p$ is the proton attenuation length in the microwave background radiation. In this case UHECR flux has an exponential cutoff at energy $E \sim 3 \cdot 10^{10}$ GeV. In the case of accidental proximity of a string to the observer, the flux is strongly anisotropic. A fine-tuning in the position of the observer is needed to reconcile both requirements.

(iii) **Network of monopoles connected by strings**

The sequence of phase transitions

$$G \rightarrow H \times U(1) \rightarrow H \times Z_N$$

(1)

results in the formation of monopole-string networks in which each monopole is attached to N strings. Most of the monopoles and most of the strings belong to one infinite network. The evolution of networks is expected to be scale-invariant with a characteristic distance between monopoles $d = \kappa t$, where $t$ is the age of Universe and $\kappa = const$. The production of UHE particles are considered in [24]. Each string attached to a monopole pulls it with a force equal to the string tension, $\mu = \eta_s^2$, where $\eta_s$ is the symmetry breaking vev of strings. Then monopoles have a typical acceleration $a \sim \mu / m$, energy $E \sim \mu d$ and Lorentz factor $\Gamma_m \sim \mu d / m$, where $m$ is the mass of the monopole. Monopole moving with acceleration can, in principle, radiate gauge quanta, such as photons, gluons and weak gauge bosons, if the mass of gauge quantum (or the virtuality $Q^2$ in the case of gluon) is smaller than the monopole acceleration. The typical energy of radiated quanta in this case is $\epsilon \sim \Gamma_m a$. This energy can be much higher than what is observed in UHECR. However, the produced flux (see [33]) is much smaller than the observed one.

(iv) **Vortons**
Vortons are charge and current carrying loops of superconducting string stabilized by their angular momentum [27]. Although classically stable, vortons decay by gradually losing charge carriers through quantum tunneling. Their lifetime, however, can be greater than the present age of the universe, in which case the escaping X-particles will produce a flux of cosmic rays. The X-particle mass is set by the symmetry breaking scale $\eta_X$ of string superconductivity.

The number density of vortons formed in the early universe is rather uncertain. According to the analysis in Ref. [28], vortons are overproduced in models with $\eta_X > 10^9 GeV$, so all such models have to be ruled out. In that case, vortons cannot contribute to the flux of UHECR. However, an alternative analysis [39] suggests that the excluded range is $10^6 GeV < \eta_X < 10^{12} GeV$, while for $\eta_X \gg 10^{12} GeV$ vorton formation is strongly suppressed. This allows a window for potentially interesting vorton densities with $\eta_X \sim 10^{12} - 10^{13} GeV$.

Like monopolia and SH relic particles, vortons are clustering in the Galactic halo and UHECR production and spectra are similar in these three cases.

(iv) Necklaces.

Necklaces are hybrid TD corresponding to the case $N = 2$ in Eq. (1), i.e. to the case when each monopole is attached to two strings. This system resembles “ordinary” cosmic strings, except the strings look like necklaces with monopoles playing the role of beads. The evolution of necklaces depends strongly on the parameter

$$ r = m/\mu d, \quad (2) $$

where $d$ is the average separation between monopoles and antimonopoles along the strings. As it is argued in Ref. [25], necklaces might evolve to configurations with $r \gg 1$, though numerical simulations are needed to confirm this conclusion. Monopoles and antimonopoles trapped in the necklaces inevitably annihilate in the end, producing first the heavy Higgs and gauge bosons ($X$-particles) and then hadrons. The rate of $X$-particle production can be estimated as [25]

$$ \dot{n}_X \sim \frac{r^2 \mu}{t^2 m_X}. \quad (3) $$

Restriction due to e-m cascade radiation demands the cascade energy density $\omega_{cas} \leq 2 \cdot 10^{-6} eV/cm^3$. The cascade energy density produced by necklaces can be calculated as

$$ \omega_{cas} = \frac{1}{2} \int_0^{t_0} \int_0^{r_0} \frac{1}{3} \left( \frac{1}{1 + z} \right)^4 = \frac{3}{4} \int_0^{r_0} \frac{r_0^2 \mu}{t_0^2} \quad (4) $$

where $r_0 \approx 0.5$ is a fraction of total energy release transferred to the cascade. The separation between necklaces is given by [22] $D \sim r^{-1/2} t_0$ for large $r$. Since $r^2 \mu$ is limited by cascade radiation, Eq. (4), one can obtain a lower limit on the separation $D$ between necklaces as

$$ D \sim \left( \frac{3 f_\pi \mu}{4 \pi \omega_{cas}} \right)^{1/4} t_0 > 10(\mu/10^6 GeV^2)^{1/4} kpc, \quad (5) $$

Thus, necklaces can give a realistic example of the case when separation between sources is small and the Universe can be assumed uniformly filled by the sources.

The fluxes of UHE protons and photons are shown in Fig.1 according to calculations of Ref. [25]. Due to absorption of UHE photons the proton-induced EAS from necklaces strongly dominate over those induced by photons at all energies except $E > 3 \cdot 10^{11} GeV$ (see Fig.1), where photon-induced showers can comprise an appreciable fraction of the total rate. The dashed, dotted and solid lines in Fig.1 correspond to the masses of $X$-particles $10^{14} GeV$, $10^{15} GeV$ and $10^{16} GeV$, respectively. The values of $r^2 \mu$ used to fit these curves to the data are $7.1 \cdot 10^{27} GeV^2$, $6.0 \cdot 10^{27} GeV^2$ and $6.3 \cdot 10^{27} GeV^2$, respectively. They correspond to the cascade density $\omega_{cas}$ equal to $1.5 \cdot 10^{-6} eV/cm^3$, $1.2 \cdot 10^{-6} eV/cm^3$ and $1.3 \cdot 10^{-6} eV/cm^3$, respectively, all less than the allowed cascade energy density for which we adopt the conservative value $\omega_{cas} = 2 \cdot 10^{-6} eV/cm^3$.

For energy lower than $1 \cdot 10^{10} GeV$, the presence of another component with a cutoff at $E \sim 1 \cdot 10^{10} GeV$.
10^{10} \text{ GeV} \) is assumed. It can be generated, for example, by jets from AGN [40], which naturally have a cutoff at this energy.

3. Relic Superheavy Particles

Production of relic SH particles occurs in time varying gravitational field of oscillating inflaton [41,42]. SH particle must be lighter than inflaton, otherwise the relic density of SH particles is exponentially suppressed. Since inflaton has to be lighter than \( 10^{13} \text{ GeV} \) to produce the required spectrum of primordial density fluctuations, this scale gives the upper limit to the mass of SH relic particle. In this scenario SH particles can provide the critical density of the Universe.

Several other plausible mechanisms were identified in [44], including thermal production at the reheating stage, production through the decay of inflaton field at the end of the preheating phase and through the decay of hybrid topological defects, such as monopoles connected by strings or walls bounded by strings.

We shall start our short description with the non-equilibrium thermal production.

For the thermal production, temperatures comparable to \( m_X \) are needed. In the case of a heavy decaying gravitino, the reheating temperature \( T_R \) (which is the highest temperature relevant for the considered problem) is severely limited to value below \( 10^8 - 10^{10} \text{ GeV} \), depending on the gravitino mass (see Ref. [43] and references therein). On the other hand, in models with dynamically broken supersymmetry, the lightest supersymmetric particle is the gravitino. Gravitinos with mass \( m_{3/2} \lesssim 1 \text{ keV} \) interact relatively strongly with the thermal bath, thus decoupling relatively late, and it can be the CDM particle [44]. In this scenario all phenomenological constraints on \( T_R \) (including the decay of the second lightest supersymmetric particle) disappear and one can assume \( T_R \sim 10^{11} - 10^{12} \text{ GeV} \). In this range of temperatures, SH particles are not in thermal equilibrium.

If \( T_R < m_X \), the density \( n_X \) of X-particles produced during the reheating phase at time \( t_R \) due to \( a + \bar{a} \to X + \bar{X} \) is easily estimated as

\[ n_X(t_R) \sim N_n n_a^2 \sigma_X t_R \exp(-2m_X/T_R), \]

where \( N_n \) is the number of flavors which participate in the production of X-particles, \( n_a \) is the density of \( a \)-particles and \( \sigma_X \) is the production cross-section. The density of X-particles at the present epoch can be found by the standard procedure of calculating the ratio \( n_X/s \), where \( s \) is the entropy density. Then for \( m_X \sim 1 \cdot 10^{13} \text{ GeV} \) and \( \xi_X \) in the wide range of values \( 10^{-8} - 10^{-4} \), the required reheating temperature is \( T_R \sim 3 \cdot 10^{11} \text{ GeV} \).

In the second scenario mentioned above, non-equilibrium inflaton decay, X-particles are usually overproduced and a second period of inflation is needed to suppress their density.

Finally, X-particles could be produced by TD such as strings or textures. Particle production occurs at string intersections or in collapsing texture knots. The evolution of defects is scale invariant, and roughly a constant number of particles \( \nu \) is produced per horizon volume \( t^3 \) per Hubble time \( t \). (\( \nu \sim 1 \) for textures and \( \nu \gg 1 \) for strings.) The main contribution to the X-particle density is given by the earliest epoch, soon after defect formation, and we find \( \xi_X \sim 10^{-6} \nu (m_X/10^{13} \text{ GeV}) (T_f/10^{10} \text{ GeV})^3 \),

Figure 1. Proton and gamma-ray fluxes from necklaces. High (\( \gamma \)-high) and low (\( \gamma \)-low) photon fluxes correspond to two extreme cases of gamma-ray absorption. The fluxes are given for \( m_X = 1 \cdot 10^{14} \text{ GeV} \) (dashed lines), \( m_X = 1 \cdot 10^{15} \text{ GeV} \) (dotted lines) and \( m_X = 1 \cdot 10^{16} \text{ GeV} \) (solid lines).
where $T_f$ is the defect formation temperature. Defects of energy scale $\eta \geq m_X$ could be formed at a phase transition at or slightly before the end of inflation. In the former case, $T_f \sim T_R$, while in the latter case defects should be considered as ”formed” when their typical separation becomes smaller than $t$ (hence $T_f < T_R$).

X-particles can also be produced by hybrid topological defects: monopoles connected by strings or walls bound by strings. The required values of $n_X/s$ can be obtained for a wide range of defect parameters.

Lifetime of SH particle has to be larger (or much larger) than age of the Universe. Even gravitational interactions, if unsuppressed, make the lifetime of X-particle with mass $m_X \sim 10^{13} - 10^{14}$ GeV much shorter. Some (weakly broken) symmetry is needed to protect X-particle from the fast decay. Such symmetries indeed exist, e.g. discrete gauge symmetries. If such symmetry is very weakly broken by e.g. wormhole effects [14] or decay is caused by instanton effects [16], X-particle can have the desired lifetime. The detailed analysis of the gauge discrete symmetries was recently performed in [45]. There were found the cases when allowed non-renormalizable operators for a decay of X-particle are suppressed by high power of the Planck mass. In this case the lifetime of X-particle can be larger than the age of the Universe.

The realistic example of long-lived SH particle, the crypton, is given in [16]. Like in the case above, decay of crypton is suppressed by high power of the Planck mass.

Energy spectrum of decaying particles from DM halo has no GZK cutoff [14] and photons dominate in the flux. The energy spectrum was calculated using QCD Monte Carlo simulation ”Herwig” [17] and as limiting QCD spectrum with supersymmetric particles taken into account [18]. The spectrum, as calculated in [18], is shown in Fig.2.

4. Signatures

In contrast to acceleration astrophysical sources, TD production spectrum is enhanced by UHE photons. Though UHE photons are absorbed stronger than UHE protons (antiprotons), the photons can dominate at some energies or at least $\gamma/p$ ratio in case of TD is much larger than in case of acceleration sources [18]. This signature can be discussed quantitatively for necklaces, probably the only extragalactic TD which satisfy the observational constraints. At large value of $r = m/\mu d > 10^7$ necklaces have a small separation $D < R_\gamma$, where $R_\gamma$ is an absorption length for UHE photons. They are characterized by a small fraction of photon-induced EAS at energies $10^{10} - 10^{11}$ GeV. However, this fraction increases with energy and becomes considerable at the highest energies.

Relic SH particles, as well as monopolonia and vortons, have the enhanced density in the Galactic halo. The signature of this relics is absence of the GZK cutoff, dominance of UHE gamma radiation at observation and anisotropy due to non-central position of the Sun in the DM halo. Anisotropy is the strongest signature of the DM halo model. It is most noticeable as the difference in fluxes between directions to Galactic Center and Anticenter. Since Galactic Center is
not observed by any of existing now detectors, anisotropy for them is less pronounced, but can be detected if the halo component becomes dominant at $E \sim (1-3) \cdot 10^{19}$ eV. In case the halo component is responsible only for the events at $E \geq 1 \cdot 10^{20}$ eV as recent AGASA data suggest, statistics is too small for the predicted anisotropy and this problem will be left for the Auger detector in the southern hemisphere.

**UHE photons** as primaries can be also tested by the existing detectors. The search for photon induced showers is not an easy experimental task. It is known (see e.g. Ref.[51]) that the muon content of the photon-induced showers at very high energies is very similar to that in proton-induced showers. However, some difference in the muon content between these two cases is expected and may be used to distinguish between them observationally.

Fly’s Eye detector is the most effective one in distinguishing between the photon and proton induced showers. This detector is able to reconstruct the development of the shower in the atmosphere [52], which is different for photon and proton induced showers. The analysis [53] of the highest energy shower $E \sim 3 \cdot 10^{20}$ eV detected by Fly’s Eye detector disfavors its photon production. The future HiRes detector [54] will reliably distinguish the photon and proton induced showers.

The Landau-Pomeranchuk-Migdal (LPM) effect [55] and the absorption of photons in the geomagnetic field are two other important phenomena which affect the detection of UHE photons [51,56]: (see [57] for a recent discussion). The LPM effect reduces the cross-sections of electromagnetic interactions at very high energies. However, if a primary photon approaches the Earth in a direction characterized by a large perpendicular component of the geomagnetic field, the photon likely decays into electron and positron [51,56]. Each of them emits a synchrotron photon, and as a result a bunch of photons strikes the Earth atmosphere. The LPM effect, which strongly depends on energy, is thus suppressed. If, on the other hand, a photon moves along the magnetic field, it does not decay, and LPM effect makes shower development in the atmosphere very slow. At extremely high energies the maximum of the showers can be so close to the Earth surface that it becomes ”unobservable” [57].

5. Conclusions

Topological Defects and relic quasistable SH particles are effectively produced in the post-inflationary Universe and can produce now UHE particles (photons and (anti)nucleons) with energies higher than observed now in UHECR.

The fluxes from most known TD are too small to explain the observations. The plausible candidates are necklaces and monopolonia (the latter by observational properties are similar to relic SH particles). The fluxes from extragalactic TD are restricted by e-m cascade radiation. The energy spectrum of UHE (anti)protons from TD have less pronounced GZK cutoff than from acceleration sources, because of the QCD production spectrum, which is much different from the power-law energy spectrum. The signature of extragalactic TD is presence of UHE photons in the primary radiation. Absorption of UHE photons on radiobackground considerably diminishes the fraction of photon induced showers at observation.

Relic SH particles (and monopolonia) are concentrated in the Galactic halo and their energy spectrum does not exhibit the GZK cutoff. UHE photon flux is $\sim 10$ times higher than that of protons. Detectable anisotropy is expected, especially the difference of fluxes between Galactic Center and Anticenter.

Therefore, both sources, TD and relic SH particles, have very distinct experimental predictions, which can be tested with help of present detectors, but most reliably - with the future detectors, such as the Auger detector in the south hemisphere [50] and HiRes[54].

This paper is based on the talk given at 10th Int. Symposium on Very High Energy Cosmic Ray Interaction, July 12-17,1998. The new publications which appeared since that time is not included in this review. Most important of them is the new data of the AGASA detector at ener-
gies higher than $1 \cdot 10^{20}$ eV. As shown in Fig.2 they can be interpreted as existence of two components of UHECR, one with the GZK cutoff and another - without it and extending to energies $(2 - 3) \cdot 10^{20}$ eV. In this case the DM halo component (relic SH particles) have to be responsible only for $E > 1 \cdot 10^{20}$ eV part of the spectrum.

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