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FULL PAPER

Estimation the Energy Spectrum of Charged Particles of High-Energy Cosmic Rays

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Abstract

Main cosmic rays exceeding energy of approximately 100 TeV are examined via the cascade of particles in the EAS_s. Any explanation of these particles requires a thorough understanding of the shape of the spectrum and the variations in the overall structure of cosmic rays. The interaction of elementary particles with the nuclei of air atoms inside the atmosphere produces huge amounts of charged particles. To characterize an energy spectrum features of cascade particles, a total number of elementary particles such as electrons, muons, pions and nuclei of iron atoms within the energy range (1014-1018) eV was calculated using MATLAB program. The theoretical results were compared with experimental measurements, which showed a decent compatibility of muon - electron within the range of energies mentioned above.

Keywords: Cosmic rays, Energy spectrum, Extensive Air Showers, Knee

Introduction

An energy spectrum, all cosmic ray particles ranges from about 1 GeV to more than 1020 eV, which are the highest single particle energies in the universe. Most of these particles are ionized atomic nuclei with relativistic energies. The origin of these extraterrestrial particles is shown, and its name is Cosmic Rays (CRs). Because of its very high energy and distribution properties, cosmic rays are originally thought to be outside the galaxy. Monitoring data with high-energy rapid special response reports can be divided into two types: spectra and chemical composition [1]. The chemical composition and energy spectrum can provide cosmic rays with accurate clues regarding the propagation and acceleration the most important mechanisms active the particles in the cosmos [2, 3]. The knee's origin area is understood through the spectrum of energies, which is frequently essential to ascertain the source of cosmic rays. Numerous experiments conducted in space to obtain a direct examination of the helium and proton nucleus energy spectrum have expanded to 100 TeV, [4, 5]. Due to a decrease in flow velocity with increasing power, the measurement of cosmic rays in excess of 100 TeV, by means of experiments carried out in space, is a challenge. To produce spectrum data over Several hundred TeV via large arrays of ground air showers. By observing a knee structures in a a few PeV across the entire energy range particles cosmic radiation from numerous tests [6, 7]. The KASCADE experiment discovered the first clue that such a behavior of CR component spectra is in fact occurring [8]. Hitler's simplified model of the evolution of a pure electromagnetic cascade may be used to extract the fundamental characteristics of the cascade's development in EAS_s [9]. Even though a vast dynamic range is covered, the spectrum seems to lack structure and is best represented by broken power-laws, some of which are located in the two areas mentioned above: The energy-closed knee area is approximately E ~ 5.1015 eV [10]. The area around the ankle that was detected at energy E ~ 5.1018 eV [11]. This research aims to estimate how many charged particles there are overall in the atmosphere such as electrons, photons, pions, and muons in a knee and ankle areas within the energy range (1014-1018) eV using MATLAB program, where the experimental results confirmed this estimate of muon and electron particles at the energy levels mentioned above [12].

Importance of study

The importance lies in the study of a number of charged particles resulting from the interaction of elementary particles of cosmic rays with the nuclei of atmospheric atoms, that is, an explanation of the shape of the energy spectrum, the diversity of the total composition of cosmic rays and the conclusion of detailed information about these particles within the energy range of 1014-1018 eV in the EAS_s.

Methodology

The study of cosmic rays is one of the most important and challenging studies in the fields of astrophysics. The interaction of elementary particles within the atmosphere produces a huge amount of charged particles. To characterize the energy spectrum features of successive particles, the total number of elementary particles such as electrons, muons, ions and nuclei of iron atoms within the energy range between 1014-1018 eV was calculated using MATLAB program. The theoretical results were compared with experimental measurements [12], which showed a decent compatibility of both the muon and the electron within the range of energies above, due to the nature of the hadronic and electromagnetic interactions involved and the different decay properties of the particles in the EAS_s. Through these diagrams shows us that the photon curve of the number of charged particles is greater than the electron-muon curve of the number of protons produced on average, the first proton 1015 eV, will produce about 106 particles at sea level, 80% of which are photons, 18% electrons, 1.7% muons, and about 0.3% hadrons, which enabled us to determine the properties of key particles by estimating the energy spectrum around the knee area of cosmic rays.

Theoretical framework

Based at the fundamental cosmic ray energy, the quantity of charged particles has been computed for electrons, pions, and muons at the energy range 1014-1018eV, as figure.1 illustrates. The reconstructed spectrum has a skewed slope and overestimates intensity The inference of an all-particle energy spectrum undoubtedly involves bias despite the fact that the energy estimate is objective overall due to changes in the energy estimate caused by correlation between the energy resolution and a sharply declining power-law spectrum (such as, lognormal propagation) are ignored. This graphic shows that the photon curve for charged particle count is greater than the electron and muon curves for proton count.

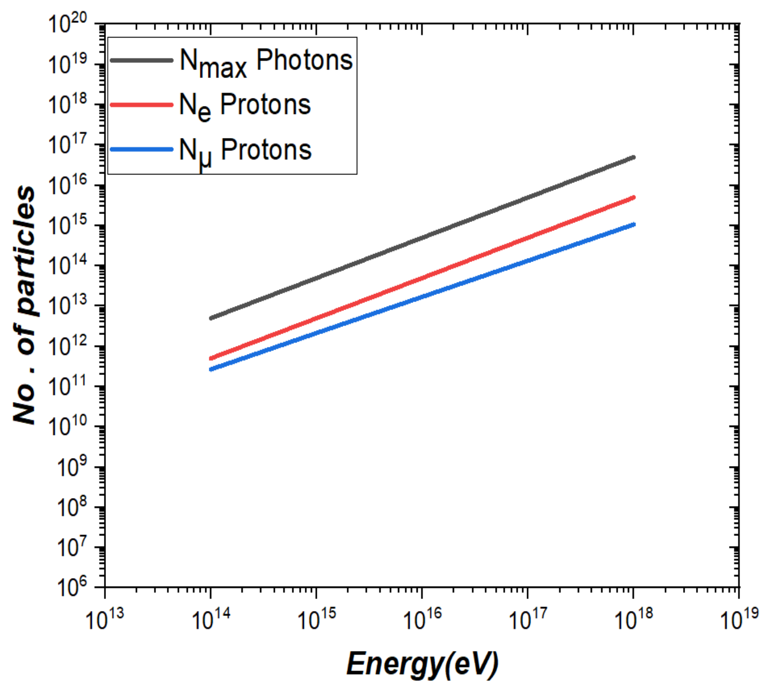
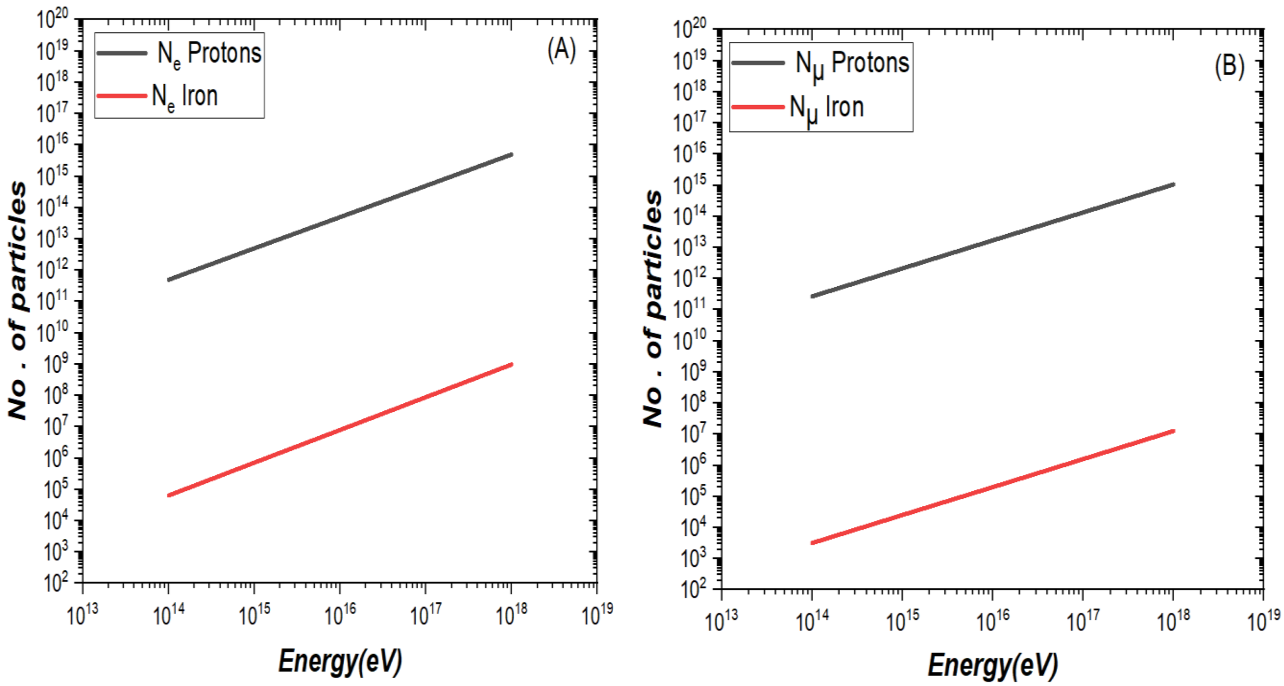


Fig. 1. The disparities between the maximal quantity of photons and the quantity of electrons and muons for elementary proton are represented by the quantity of particles in the atmosphere for each energy range as a function of fundamental energy 1014 - 1018eV.

The behavior of extremely high energy particles within the atmosphere with energies between 1014 and 1018 eV is seen in Figure 2. Figure A shows the quantity of electrons, which varies for the main protons and iron nuclei, whereas Figure B shows the quantity of muons, which varies a “protons and iron nuclei”. These variations can be attributed to the main energy and mass number of cosmic rays. The discrepancies between the maximal photon count and the electron and muon counts for iron nuclei as a function of original energy are depicted in figure C.



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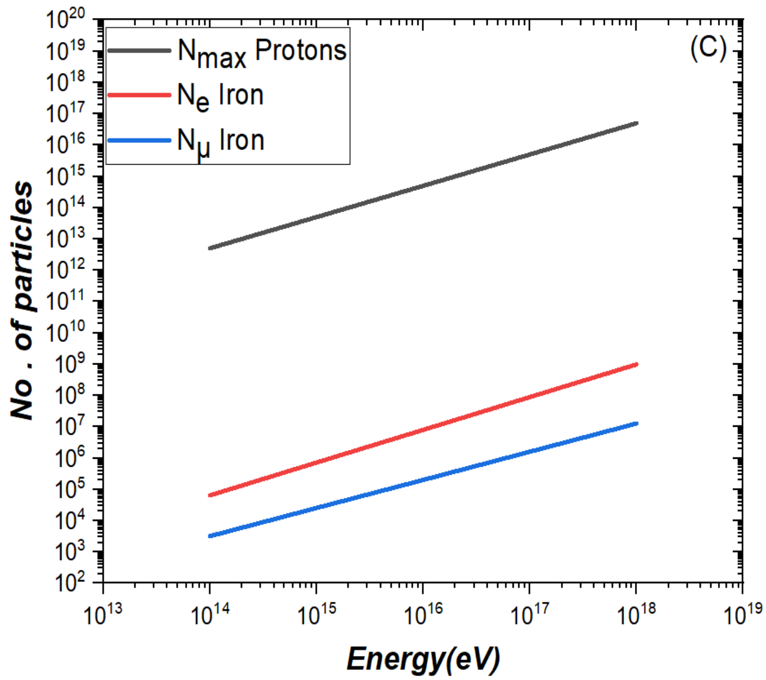

Fig. 2. The quantity of particles in the atmosphere between 1014 and 1018 eV, as a function of original energy; Fig. A shows the quantity an electrons in iron nuclei and primary protons; Fig. B indicates the quantity of muons contained in main nuclei of iron and protons; Fig. C depicts a variations in the maximum number of photons, electrons, and muons for iron nuclei.

In the energy range of 1014–1018 eV, Figure.3 illustrates how Pions' energy is dependent regarding cosmic rays' basic energy as a function of, n. Here, n represents a number of interactions, which is calculated using Equation (9), where $N_{ch}^{\pi} = 10$. Pions lose some of their energy with every interaction.

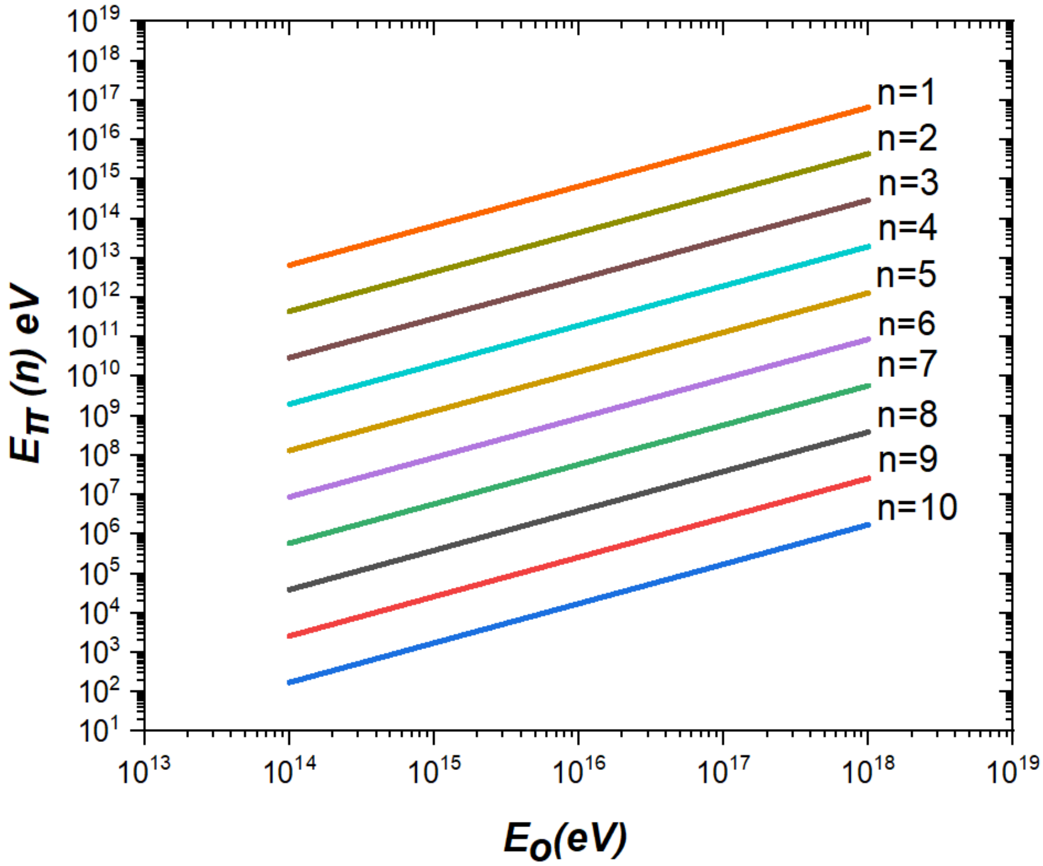

Fig.3 . The relationship, using Eq. (9) with $N_{ch}^{\pi} = 10$, in the energy range 1014 - 1018eV between the fundamental energy and the energy of pions.

In this figure 4, the experimental results CASA-MIA [12] in energy reconstruction based on the number of electrons and muons for the shower size in the energy range 1014-1018 eV that showed a decent compatibility between electron and muon within the range of primary energies are presented.

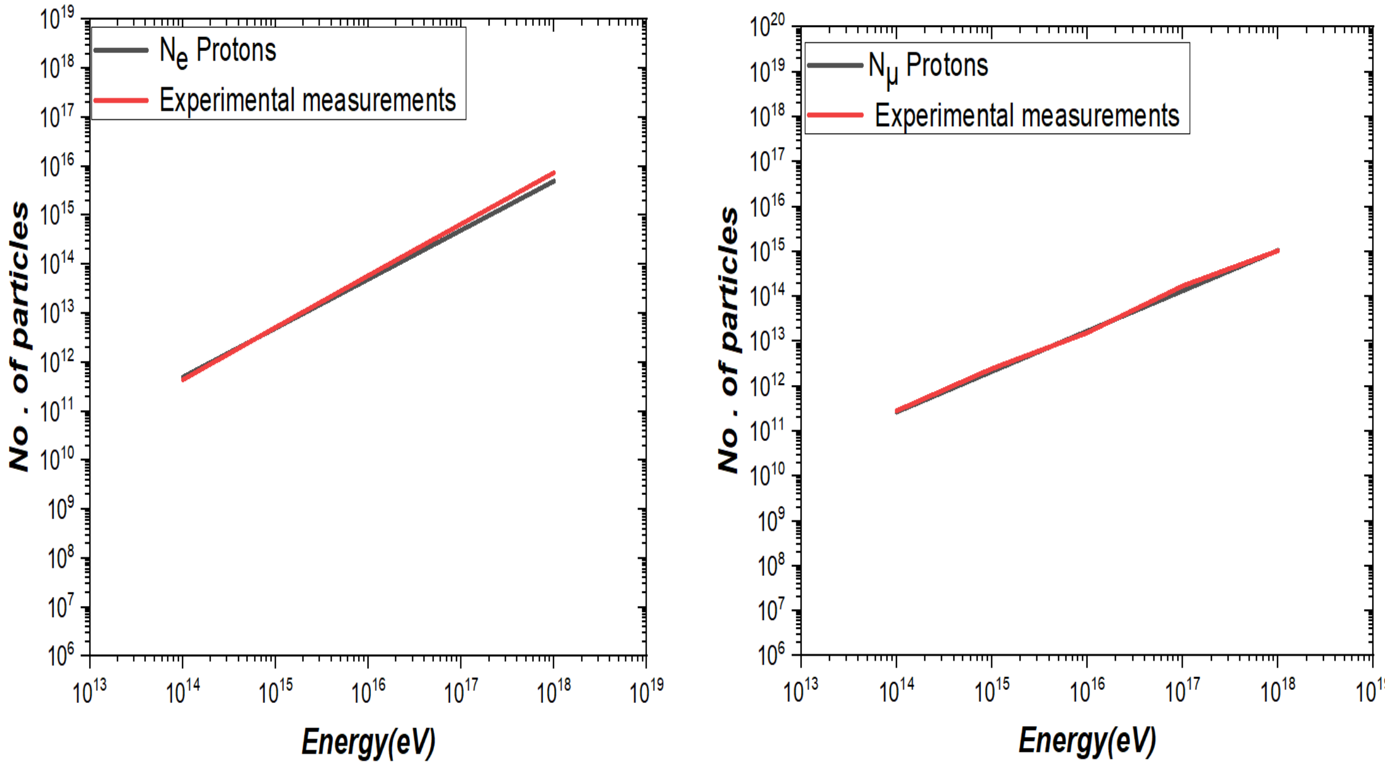

Fig 4. It presents the experimental results [12] of the quantity of electrons and muons in relation to an initial energy and their comparison with theoretical data within the energy range 1014-1018 eV.

We can see in figure 1. The number of charged particles of photons, electrons, and muons in the energy range 1014-1018 eV, which based on the initial cosmic ray energy, where the quantity of charged particles increases with the increase of the initial energy. In figure 2, we find that the behavior of particles relative to protons and iron nuclei differs at high energies due to the number of mass and initial energy on which these particles depend. In figure 3. The pion's energy that depend regarding the main energy as a function of, *n* in energy range 1014-1018 eV, the more reactions *n* pions lose part of their energy in each reaction, where *n* is the number of reactions. Figure 4. Experimental CASA-MIA [12] measurements of a number of electrons-muons charged particles in the energy range 1014-1018 eV with the theoretical data showing a decent compatibility of both electrons and muons within the range of the above energies.

Results

An EAS_s is a series of secondary particles formed from the interaction between primary cosmic radiation with high energy (such as P, C, He, Fe, etc) with the nuclei of atmospheric atoms such as (N, Ar, O, etc) [13]. Due to the nature of the hadronic and electromagnetic interactions involved and the decay properties of the various particles. At the average proton 1015 eV, approximately 106 particles will be produced at sea level, 80% protons, 18% electrons, 1.7% muoms, and about 0.3hadrons.Neutrinos will also be produced by degrading weak particles, but remain invisible through normal EAS experiments[14]. Every generation of EAS develops with its secondary particles carrying less energy per particle than the one before it. Particle count rises to the shower maximum, or X_{max}, at which point the particles' energy is insufficient to generate new ones [15]. The portion of hadronic energy is as follows:

$$E_h = N_\mu \xi_c^\pi \qquad 1$$

Where $\xi_c^\pi$is a critical energy for pions, and(N_μ) is a quantity of muons, which is equivalent to pions(N_π); $N_\mu$is stated as [16, 17]:

$$N_\mu = \left(\frac{E_0}{\xi_c^\pi}\right)^\beta \qquad 2$$

With A = atomic mass number; ξ_c^π*=20 GeV; β=0.90,*

$$N_\mu = \left(\frac{E_0}{\xi_c^\pi}\right)^\beta A^{1-\beta} \approx 1.69 \times 10^4 A^{0.10} \left(\frac{E_0}{1PeV}\right)^{0.90} \qquad 3$$

Considering a shower that is started through the energy of a single photon E_0. When there is energy in every particle ξ_c^e,which denotes a critical energy for electrons, the cascade achieves its maximum size $N = N_{max}$. N is the overall size of the shower for photons, and electrons, and it is expressed as [18]:

$$N_{max} = \frac{E_0}{\xi_c^e} \qquad 4$$

The electron count at shower maximum is expressed as [16]:

$$N_e^{max} = \frac{N_{max}}{g} = \frac{E_0}{g\xi_c^e} \qquad 5$$

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Where g is the correction factor and is dependent on the energy threshold and electron and photon detection efficiency of the detectors. The relationship determines the number of electrons for $E_{em}=E_o$ [16, 19]:

$$N_e = \frac{E_{em}}{g\xi_c^e} \quad 6$$

$$N_e \approx 10^6 \left(\frac{E_0}{1PeV}\right)^{\alpha_1} \quad 7$$

Where $\alpha_1 = 1.03;\ \alpha_2 = 1.046;$

$$N_e \approx 5.95 \times 10^5 A^{1-\alpha_2} \left(\frac{E_0}{1PeV}\right)^{\alpha_2} \quad 8$$

After n atmospheric layers, a single cosmic ray proton with energy E_o enters the atmosphere, and we find that$N_\pi = (N_{ch}^\pi)^n$, where $N_{ch}^\pi$is the entire count of charged pions. With equal split of energy assumed upon particle formation, the entire amount of energy these pions carry is$(2/3)^n E_o$. Electromagnetic showers from π^0decays have absorbed the remaining original energyE_o. Consequently, in atmospheric layer n, each charged pion has an energy of [18, 20]:

$$E_\pi = \frac{E_0}{\left(\frac{3}{2}N_{ch}^\pi\right)^n} \quad 9$$

The quantity of interactions required to reach$E_\pi = \xi_c^\pi$therefore Eq. (9) becomes:

$$\xi_c^\pi = \frac{E_0}{\left(\frac{3}{2}N_{ch}^\pi\right)^n} \quad 10$$

Thus:

$$n\ ln\left(\frac{3}{2}N_{ch}^\pi\right) = ln\left[\frac{E_0}{\xi_c^\pi}\right] \quad 11$$

Following a specific number of $n = n_c$ across generations, therefore Eq. (11) turns into:

$$n_c = \frac{ln[E_0/\xi_c^{\pi}]}{ln(\frac{3}{2}N_{ch}^{\pi})} \qquad 12$$

With$N_{ch}^{\pi} = 10$; Eq. (12) becomes:

$$n_c = 0.85\, log_{10}[E_0/\xi_c^{\pi}] \qquad 13$$

Conclusion

The estimation within the energy spectrum of charged particles at high energies of cosmic rays was characterized in this work. By obtaining the number of secondary particles such as photons, muons, electrons and pions in the EAS calculated in the energy range 1014-1018 eV for the proton and the primary iron. We can determine the properties of the main particles by estimating the energy spectrum around the knee and ankle region of cosmic rays by comparing it with the experimental measurements of CASA-MIA of electron-muon charged particles observed in the above energy range. In an effort to reduce several systematic uncertainties, especially the KASCADE experiment, looks for relationships among an greater quantity of EAS_s measurables. Generally, because there are only substantial ground-based detector installations, the results degrade, viewing EAS_s, can produce data from experiments due to a low flux from cosmic rays above 1 PeV. Rather, by comprehensive systematic examinations, it has discovered and quantified the underlying limits and suggested additional improvements. While there is conjecture that a spectrum may stretch past the GZK cutoff, there's currently no experimental evidence to confirm the source or cosmic origin of this GZK radiation. A characteristics due to this finding reveal a genuine enigma at the forefront of natural science with significant cosmic implications.

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