The absence of the GZK depression in the energy spectrum of the cosmic radiation

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Abstract: A resolutive assessment of the GZK suppression in the energy spectrum of the cosmic radiation around the energy of 2.1×10^{20} eV is presently feasible by the published measurements of the Auger experiment. The data indicate that the GZK kinematical effect on the hypothetical spectrum of cosmological proton is absent. In fact, the break in the spectrum observed by Auger initiates around 2×10^{19} eV reaching a reduction factor of about 3 at the energy 5×10^{19} eV with respect to a power-law continuation of the nearby energy decade, $3 \times 10^{18} - 3 \times 10^{19}$ eV with an index of 2.67. This suppression pattern is an order of magnitude below the maximum effect for GZK suppression expected at 2.1×10^{20} eV. Only the unprecedented accuracy, both systematic and statistical, of the Auger experiment makes this conclusion possible. Comments on the theoretical subterfuges appearing in the literature to elude this conclusion along with the claims for the GZK suppression by the Auger, HiRes and TA experiments are given.

Keywords: icrc2013, cosmic rays, GZK effect.

1 Introduction

The empirical evidence for the GZK suppression effect has been undulating with time and three epochs may be clearly distinguished: the long quiescent period from 1966 until to 1993 when the Fly's Eye experiment [1,2] reported an event with an energy of $(2.3-4.1) \times 10^{20}$ eV. Another event of $(1.7-2.6) \times 10^{20}$ eV detected by the Akeno-AGASA experiment [3,4] followed in 1994. The energy of these events are well above the GZK cutoff. The Akeno-AGASA Collaboration explicitly believed to have reported evidence for the absence of the GZK effect in 2001 [5]. The AGASA Collaboration found 11 events with energies above 10^{20} eV which reduced to six after reanalysis [6].

The second epoch lasted until 2006 when the HiRes Collaboration [7] observed a cutoff in the spectrum above $(5-6) \times 10^{19}$ eV with a steep slope featured by an index of 5.1 [8]. The Auger Collaboration confirmed the finding of HiRes in 2007 reporting a break in the spectrum with a harder index of about 3.3 [9]. During the second period 1993-2006, in line with the Akeno-AGASA finding, flourished a number of theoretical interpretations to explain the absence of the GZK suppression effect. The reanalysis of the Haverah Park experiment was published in this second period 1993-2006 and there is no claim for the GZK suppression since there are events around 10^{20} eV.

In 2007 commenced the third epoch which is characterized by a seeming confusion in the literature. The first reason for the confusion is that there is overwhelming evidence, that cosmic-ray sources generating the energy spectrum below the nominal threshold of 6×10^{19} eV observed at Earth are not placed at cosmological distances.

The test of the GZK suppression effect necessarily requires: (A) the presence of cosmological cosmic rays at Earth and the knowledge of some minimum features of their energy spectrum; (B) the measurements of the cosmic-ray flux below and above the energy band where the reactions, $p\gamma \to \pi^0 p$ and $p\gamma \to \pi^+ n$, are expected to carve their distinctive sign. This band is around 2.1×10^{20} eV with a lower edge 6×10^{19} eV and an upper edge of 5.3×10^{20} eV. Trivially, the two claims for the GZK suppression effect [7,8,9] have to be examined taking into account the two prerequisites: (A) and (B) .

Since there is solid empirical evidence that the cosmic rays up to 5×10^{19} eV are not cosmological, presently (2013), any deviation from a power-law spectrum with a constant index of 2.67 above 5×10^{19} eV cannot be ascribed to the GZK suppression. In other terms the condition (A) is not satisfied in the lower energy edge where the GZK effect is expected to manifest itself.

A common working hypothesis recurrent in the literature is that extragalactic sources emit a cosmic-ray spectrum with constant index, for example, in the range 2.0-2.7. This is certainly a simplifying, plausible, working assumption which consents to perform calculations but it is rather risky in energy regions not yet explored. Note that in the prerequisite (A) by the knowledge of some minimum features of the energy spectrum is currently meant a constant index of the energy spectrum emitted by the hypothetical extragalactic sources, and not a more variegated spectrum pattern.

2 The data compared with the expected GZK effect

Measurements by radio telescopes, which can observe photons in the band 1 mm 100 meters, and infrared measurements prove the existence of photons with a black-body spectrum with a peak energy of 6.76×10^{-4} eV. The reference temperature is 2.725 *absolute degrees* and the related photon density ρ is 411 photons/cm^3. These photons do populate the cosmic space everywhere. The impact of the two reactions, $p\gamma \to \pi^0 p$ and $p\gamma \to \pi^+ n$, on the energy spectrum of the hypothetical cosmological protons above 6×10^{19} eV is maximized around 2.1×10^{20} eV. These extreme energies have been observed by a number of exper-

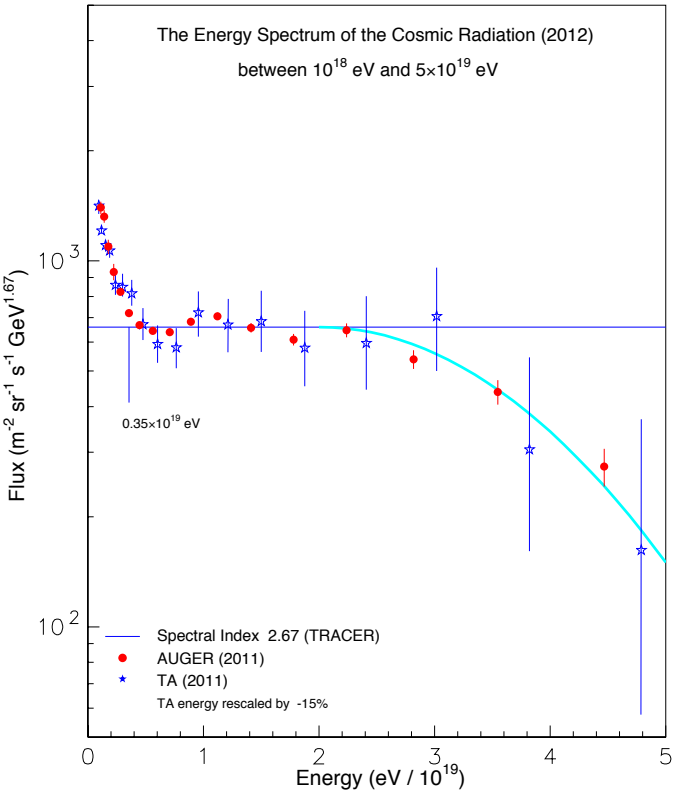

Fig. 1: Energy spectrum of the cosmic radiation in a linear scale of energy measured by the Auger experiment (*red dots*) [9] in the energy interval $(1-5)\times 10^{19}$ eV interpolated by a power law with a constant index $\gamma = 2.67$ (*horizontal blue curve*). The turquoise curve is a simple parabolic deviation from the power law with $\gamma = 2.67$ starting at 2×10^{19} eV and passing through the Auger data points above 2×10^{19} eV. The energy spectrum of the TA experiment [12] is also reported (*blue stars*) with rescaled energy (-15 percent) in order to join the Auger data points.

iments also with rescaled event energies after appropriate reanalysis of the data.

In the following the thresholds for the two reactions above and the approximate distances of the extragalactic sources emitting cosmic nuclei are crudely determined. Presently (2013), the approximate values of these two parameters and the observed heavy chemical composition in the energy range $(1-50)\times 10^{18}$ eV make fictitious the GZK suppression test.

The black-body spectrum may be divided in a central region limited by the low and high energies E_1 and E_3, respectively, 2.55×10^{-4} eV and 12.4×10^{-4} eV. The energy $E_2 = 6.76\times 10^{-4}$ eV corresponds to the maximum of the black-body distribution while E_1 and E_3 label the energies where the distribution descends by half from its maximum value. The low lateral region of the black-body spectrum $\varepsilon_\gamma \leq E_1$ occupies only 5 per cent of the entire distribution while the high lateral region $\varepsilon_\gamma \geq E_3$ more than 25 per cent. Crudely an estimate of the threshold may be calculated by setting $\varepsilon_\gamma = E_3$ and it results, $(5-6)\times 10^{19}$ eV.

A cosmic-ray proton of energy E_P colliding with a cosmic background photon of energy ε_γ has an equivalent energy given by : $E_\gamma = (E_P/m_P)\ \varepsilon_\gamma\ (1-cos\theta)$ where θ is the angle between the directions of motion of the two particles before collisions. If the energy E_γ is between 1 and 2 GeV in the center-of-mass system the cross sections are about $\sigma = 200\times 10^{-27}\ cm^2$ for $\sqrt{s} = (1.2-1.5)$ GeV.

The cross sections σ for the aforementioned reactions above threshold are about $120\times 10^{-27}\ cm^2$, and therefore the length of a photon column L_γ necessary to make a p γ collision is $1/\sigma\rho$ where ρ is the photon density. This length is about 6.5 *Megaparsec*. By a collision cosmic protons loose a fraction of their initial energy estimated by others (see, for example, ref. 10) and they never disappear. Secondary protons accumulate to energies close and lower than the initial one, E_P.

The cross sections for photodisintegration of cosmic nuclei on the cosmic background radiation delimit the distance of the sources from the solar system. The distance of the sources emitting intermediate and heavy nuclei is certainly limited to a few *Megaparsec* [11].

The energy spectrum measured by the Auger experiment is shown in figure 1 (red dots). The horizontal blue line is just a visual guide which relates low energy data with an spectral index of 2.67 [13] to high energy Auger data which happen to have a comparable spectral index of about 2.67. The absence of the GZK is evident by the linear scale of energy of figure 1: the deviation from the horizontal line initiates well below the threshold expected at 6×10^{19} eV. It commences at $(2.0-2.5)\times 10^{19}$ eV.

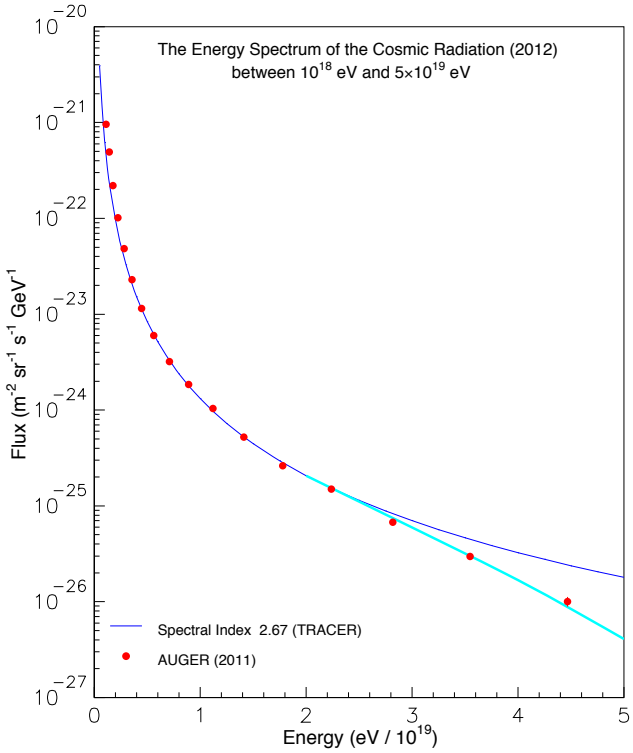

Fig. 2: Energy spectrum of the cosmic radiation measured by the Auger experiment (*red dots*) [9] in the energy interval $(1-5)\times 10^{19}$ eV interpolated by a power law with a constant index $\gamma = 2.67$ (*blue curve*). The divarication in the energy interval $(2.0-2.5)\times 10^{19}$ eV from the extrapolated spectrum is signalled by the turquoise curve constrained by the Auger data points.

Figure 2 reports the energy spectrum in the range $10^{18}-10^{19}$ eV. The power-law interpolation (thin blue curve) with an index of 2.67 is imposed through the data. The turquoise curve represents a parabolic deviation from the power-law interpolation, equal to that shown in figure 1. Again it is patent that the deviation initiates at $(2.0-2.5)\times 10^{19}$ eV.

3 The test of the GZK suppression in the range $5\times 10^{19}-1.4\times 10^{20}$ eV

The time evolution of the energy spectrum of the hypothetical cosmological protons due to the cosmic expansion would diminish the thresholds of the reactions, $p\gamma \to \pi^0 p$ and $p\gamma \to \pi^+ n$. This circumstance was considered in the original paper by Kenneth Greisen in 1966 [10] . In principle this correction is necessary if the black-body spectrum in the past had been more energetic than the present one but the empirical evidence for that is missing. Adopting this correction just as a numerical game, a major conflict between predictions and data developes : the shift of the threshold below $(5-6)\times 10^{19}$ eV drags on the abrupt fall in the cosmic ray spectrum (GZK effect) to an energy region below 2.1×10^{20} eV. But this energy shift creates a major problem because the energy region $(5-10)\times 10^{19}$ eV is populated by dozens of events.

The data on the chemical composition of the cosmic radiation in the interval $10^{18}-4.12\times 10^{19}$ eV indicate that the flux contains a substantial admixture of intermediate and heavy nuclei. This statement results by four independent methods of measurements of the chemical composition achieved by the Auger Observatory. In the energy band $5\times 10^{19}-1.4\times 10^{20}$ eV populated by events of the highest energy (Auger data), the experimental test of the GZK suppression is in principle feasible, since the abundance of heavy nuclei is not measured (or measured but not yet published). An extragalactic acceleration mechanism could manifest itself in this band, $5\times 10^{19}-1.4\times 10^{20}$ eV providing protons or nuclei or admixtures of light and heavy nuclei. In principle cosmological protons might dominate this energy band, but more realistically, still galactic cosmic-ray sources have to be considered (see Section 10 of ref. 14).

Figure 3 shows the cosmic-ray spectrum measured by the Auger Collaboration [9] purposely shown in a linear scale of energy. The spectrum seems to diminish by steps, and not by a sharp cutoff. If the chemical composition of the cosmic radiation continues to becomes heavier and heavier, not only in the explored range $10^{18}-4.12\times 10^{19}$ eV, but also in the range, $5\times 10^{19}-1.4\times 10^{20}$ eV, a simple inference may be drawn. Light elements disappear with rates higher than heavy elements as energy increases. If the chemical composition attains a pure iron content at 1.4×10^{20} eV (data point with the highest energy in figure 3) or even above this energy, it is obvious that cosmic rays are still galactic even in the range $5\times 10^{19}-1.4\times 10^{20}$ eV. In this case the experimental test for the GZK suppression,

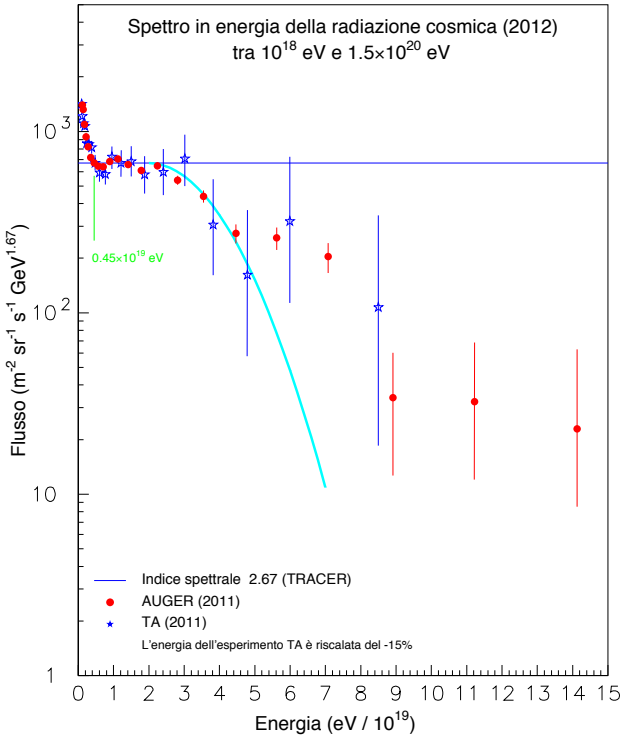

Fig. 3: Measurements of the energy spectrum of the cosmic radiation in the energy interval $(1-15)\times 10^{19}$ eV in a linear scale of energy measured by the Auger and TA Collaborations [9,12]. The horizontal straight line is only a visual guide which indicates a cosmic-ray spectrum obtained by a power-law extrapolation at constant index of 2.67 [13] from very low energies. The turquoise curve is the same parabolic deviation shown in figures 1 and 2. The cosmic-ray flux seems to decrease by steps and not by an abrupt descend as conceived in the GZK depression effect. The degradation of the spectrum by steps above $(2-2.5)\times 10^{19}$ eV might be due to the *Failure of Injection to the Galactic Accelerator* (*FIGA*) as described in a forthcoming paper. The distinctive characteristic feature of the *FIGA effect* is that heavy and ultraheavy cosmic ions outnumber light ions (protons and He nuclei) up to 5.6×10^{20} eV where the galactic accelerator definitely ceases to perform.

which is undefined below 5×10^{19}, remains vague even in this energy interval.

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