A Critique of the Energy Estimates made of Ultra High Energy Cosmic Rays detected by the Yakutsk array

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Abstract

Several inconsistencies between experimental features observed at the Yakutsk array and at other scintillator arrays are pointed out. It is argued that some properties of the recording methods used at the Yakutsk array may be responsible for the differences. The estimates of the energy and flux of the highest energy cosmic rays recorded at Yakutsk are, as a result, probably too low.

1. Introduction

There is continuing interest in the question of the structure of the cosmic ray spectrum in the energy region near to 10^{20} eV. Conflicting experimental evidence has been offered as to whether there is, or is not, a steeping of the spectrum near 10^{20} eV [1,19]. It is by no means certain how to resolve this dilemma: it may be necessary to wait for greatly increased statistics from the Auger Observatory. However, in recent papers, a number of data interpreters have claimed that the evidence is already sufficient to establish the existence of the GZK cut-off. In particular, Berezinsky et al [6] and Bahcall and Waxman [4] have argued that a combination of data from Fly's Eye, Yakutsk and HiRes are to be believed rather than the data from the AGASA experiment. It is argued [4,6] that the Yakutsk data, from an exposure about half that of AGASA, do provide clear evidence for a cut-off. In [6] a detailed analysis of features of the GZK cut-off is given based on these data. It is the purpose of this note to show that there may be technical problems with the Yakutsk data collection system that make it probable that this claim is incorrect. The line of argument does not rely on derivation of primary energies from the observational data.

2. Comparison of Experimental Data and the Yakutsk recording system.

A comparison of the rate of events recorded at Yakutsk (exposure 824 km^2 year sr [11]) against that seen at AGASA (1649 km^2 year sr [19]) is revealing. Both groups have used, as the measured 'ground parameter', the scintillator density at 600 m from the shower axis, S(600). S(600) is adopted because it is

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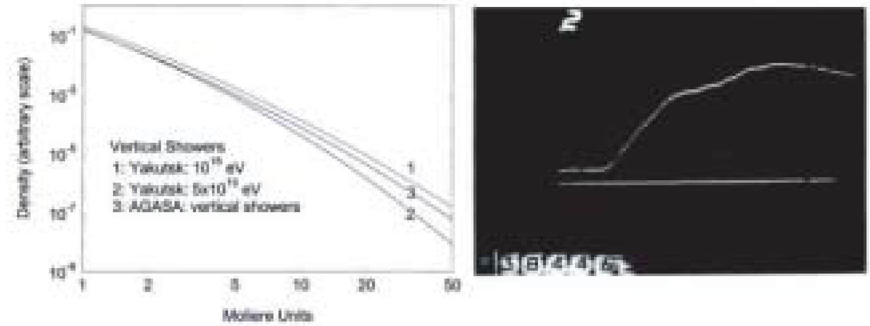

Fig. 1. LH: The lateral distributions for vertical showers at Yakutsk [2] and AGASA [19]. RH: Response of 2.2 m^2 of scintillator to a 9° shower of 5×10^{19} eV at 1177 m from the axis. The density is 4.9 m^{-2}: the pulse length is 4μs.

an accurately measurable quantity, depending little on detailed knowledge of the lateral distribution function. The choice of S(600) is related to the spacing of the detectors in the array [14]: that this quantity has also been shown, by model calculations, to be closely proportional to the primary energy *is an additional bonus*. It is necessary to correct the values of S(600) for the different temperatures and pressures at the observation levels of the arrays, before a comparison of the rates of events can be made [13,18]. These factors lead to an adjustment of 0.64 between AGASA and Yakutsk, the S(600) values being smaller at the latter array, for the same primary energy. For showers that would have S(600) = 100 m^{-2} at Yakutsk, the integral rates from the two arrays are

Yakutsk rate = 0.024 ± 0.005 km^2 y sr, based on 20 events.
AGASA rate = 0.064 ± 0.006 km^2 y sr, based on 106 events.

The factor of 2.7 between the rates at an energy of $\sim 3.4 \times 10^{19}$ eV [19] is highly significant. A similar evaluation at an S(600) only $\sqrt{2}$ greater reveals that the AGASA integral rate, based on 38 events, is 4.7 times the Yakutsk rate (4 events). These facts suggest that the Yakutsk array is failing to register large events, as has been remarked before [8].

The lateral distribution functions for vertical showers at Yakutsk and AGASA, [11,19] are shown in figure 1(LH). The Yakutsk function for the highest energies is much steeper than that found at AGASA, contrary to expectation.

It is to be expected that the steepness of the lateral distribution function will increase with energy. If the mass composition remains constant, the depth of maximum will become closer to the observation level. The dependence of the steepness of the lateral distribution on energy has only been obtained accurately with arrays, in which some of the detectors are spaced close together [9,16]. For the Volcano Ranch array the steepness parameter was found to increase by only (0.07±0.03) per decade. For a similar parameter measured using the Yakutsk array, a value of 0.15 per decade is reported, without uncertainties. At the AGASA array no variation of the steepness parameter with energy has been found.

The only event recorded by the Yakutsk array with an energy above 10^{20} eV has a zenith angle of 58.9°. Two estimates of the energy have been made [3, 10]. Thin scintillators have inherently poor sensitivity to events of such a zenith angle.

These 4 experimental facts may have a common explanation that lies in the recording system used for the Yakutsk detectors. Details are given in [7,12]. In addition, signals are registered only when coincidences are seen between two detectors, 2 m^2 scintillators spaced 90 cm apart, within a resolving time of 1.2 μs. The fidelity of the systems is strongly dependent on the time spread of the shower front, which has not been reported for the detectors of the Yakutsk array. An integration time of 1 or 2 μs was used on different detectors: it seems certain that these are insufficiently long to collect the entire signal at the large distances that are important when measuring the properties of the largest showers. The spreads have been recorded in some large events at Volcano Ranch [17] and at AGASA [15,19], and in a short run with scintillators at Haverah Park [8]. All these measurements show that a substantial fraction of the signal arises after 1 μs, with the fraction increasing with distance. The signal recorded by 2.2 m^2 of scintillator at Haverah Park is shown in figure 1(RH). In this pulse only about 65% of the signal has arrived after 1 μs and about 80% after 2 μs. The Haverah Park array was at a very similar altitude to Yakutsk so that effects of similar magnitude must be present at Yakutsk. It has been known for many years [5] that signals in water tanks are very much less spread in time at zenith angles of 60° than for vertical showers, and this will also be the case with scintillators because of the dominance of the muons in the shower signal. The Yakutsk event of 58.9° is rich in muons: further, at one scintillator 960 m from the core, the half width of the arrival times was 200 ns [10].

3. Conclusions

The steepness of the lateral distribution, and the rapid increase of steepening with energy, can be understood, at least qualitatively, because the Yakutsk recording system cannot record the full signal size at large axial distances. Preliminary analysis of the effect of this, using estimates of the shower front thickness from Haverah Park, suggest that the 'ground parameter', S(600), may be underestimated by $\sim 25\%$ at the highest energies. Additionally, it seems probable that the short coincidence window must lead to a loss of triggers at Yakutsk. This fact must make it difficult to estimate the collecting area for showers where the cores have fallen outside of the array, as has been done at Yakutsk [11]. It is striking that the one event claimed to have an energy above 10^{20} eV is of large zenith angle. Here the time spread of the pulses was short so that neither the resolving time nor the integration time will have been factors in evaluating it.

In my view, there are sufficient experimental questions about the Yakutsk methods for it to be unwise to infer evidence of a cut-off from the Yakutsk data, as some have done [4,6]. These have nothing to do with primary energy evaluation from simulations.

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5. References

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