# UHE Cosmic Ray Energy Spectrum Derived From Gauhati University Mini Array Data

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**Abstract**
The Gauhati University Mini Array of eight plastic scintillators of carpet area 2m$^2$ has been operated since September 1996. The array detects giant EAS by the method of time spread measurement of secondary particles. We have analyzed the data recorded by the array through April 1998. The paper presents the derived energy spectrum above primary energy E= $10^{16.9}$ eV. The differential energy spectrum observed by the Mini Array is j(E)= $10^{24.01} \times E^{-2.98\pm0.1} m^{-2} sr^{-1} s^{-1} eV^{-1}$.

## 1 Introduction:

Every well determined feature of the cosmic ray energy spectrum will have considerable impact on theories of the origin, acceleration, and propagation of cosmic rays. The shape of the energy spectrum below $10^{17}$eV is widely considered to be well established although there is still some disagreement about the details around the knee ( Lloyd-Evans, 1991). To detect the UHE cosmic ray and for derivation of the energy spectrum, collection of enough air shower data is necessary which requires a large number of ground based detectors covering a wide area ( several km$^2$ ). But Prof. J. Linsley suggested a low cost method requiring a few closely packed detectors capable of measuring arrival time spread of individual shower particles ( Linsley, 1986). We utilize the idea and a Mini array detector has been setup in the Physics Department , Gauhati University. This detector array is specially designed to measure, both the charge particle density and their arrival time at the detector level. The details about the method is presented elsewhere ( Bezboruah, Boruah and Boruah, 1999).This paper presents the energy spectrum derived from the experimental data collected by the set up.

## 2 The Experiment:

The signals from the eight plastic scintillation detectors are amplified and then discriminated to provide corresponding logic signals. The discriminated output is then individually shaped into narrow pulses of 20nS width and OR'ed together to give a serial pulse train and fed to the Digital Storage Oscilloscope ( Tektronix , TDS520, 500MHz , 500MSamples per sec ), 100MHz time digitizer and to trigger unit. The trigger circuit senses the incoming pulse train and generates the necessary trigger pulse. Once triggered, the oscilloscope trace and the 100MHz time digitizer are stopped and the recorded data is then transferred to the PC ( 486DX2 ) via GPIB and RS232 interface respectively. The microprocessor ( µP, 8086 ) monitors the status of the detectors at a predetermined interval . The details about the data acquisition system is presented elsewhere ( Bezboruah, Boruah and Boruah, 1998).

## 4 Data Selection Criteria :

A mini array should be able to pick out the very few large air shower events from a swarm of irrelevant events including the counter noises, the background soft radiations and small air showers. In order to eliminate the large number of small air showers a minimum time spread has to be assigned. For a Mini Array of $2m^2$ area, a minimum acceptable shower size of $7.5\times10^6$ requires a minimum time spread $\sigma_1 = 100$ nS .

## 5 Experimental Results:

Data have been collected during October, 1996 to April, 1998. Most of the data collected do not belong to true large shower events. The data are reduced by the selection process and by visual inspection. True large shower events with a time spread of shower front $\sigma \geq 100$nS and with local particle densities $\rho \geq 1.5/m^2$ are collected and analysed. They belong to showers of sizes, $N \geq 7.5\times10^6$.

## 6 Energy Spectrum:

The differential energy spectrum considering the events above threshold $\rho_1$=1.5/$m^2$ ) is shown in the fig.1. The spectrum becomes steeper around $10^{17.3}$ eV and flattens around $10^{18.2}$eV and forms a dip. We divide our Mini Array energy spectrum into three energy ranges and fit them to a power law in each region ( Table B ). Table B also lists the overall fit. All the fits were done with the least squares fitting. A comparison has also been done between the least-squares fitting and chi square fitting. In general the two methods agree. To show the significance of the dip the number of events expected from the overall fit (normalized to the observed number of events at $10^{17.3}$ eV ). The expected number of events between $10^{17.3}$ eV and $10^{18.2}$ eV is 1423.99 while the observed number is 1237. The significance of the deficit is 4.96$\sigma$. To show the significance of flattening above $10^{18.2}$eV, we use the normalization and slope from the total fit upto $10^{18.4}$ eV. The total number of events observed above this energy is 337 while the expected number of events is 144.75. The significance of this excess is 15.98$\sigma$.

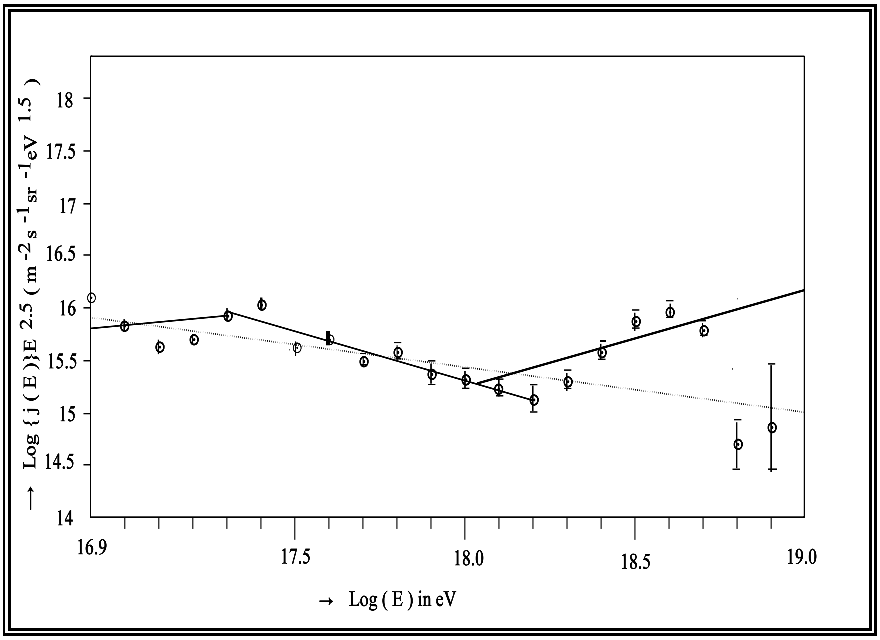


**Fig.1: Mini Array Differential Energy Spectrum . Points Data. Dashed Line : Best Fit in Each Region. Dotted Line : Best Fit Upto $10^{18.4}$ eV.**

## 7 Discussion and Conclusion :

Considering all the densities and shower front thicknesses above the threshold, energy spectrum as shown in fig.1 is obtained with an overall spectral slope of -2.85 ( Table A ). This value is lower than that calculated by other large groups ( Table B ) ( Bird, Cobrato, Dai et al.). The over estimation in the higher energy side may be due to inclusion of some delayed particles, which are not real part of the true shower front and thereby falsely increasing the thickness of the shower front. This

## TABLE A

NORMALIZATION AND SPECTRAL SLOPE OF j(E)

| Energy Range ( eV ) | Power Index | $\chi 2$ | Log ( normalization) | Normalized at ( eV ) |
|---|---|---|---|---|
| $10^{16.9}$ - $10^{18.9}$ | -2.85 ± .12 | 98.95 | -29.29 | $10^{18}$ |
| $10^{16.9}$ - $10^{17.3}$ | -2.93 ± .62 | 12.06 | -29.46 | $10^{18}$ |
| $10^{17.3}$ - $10^{18.2}$ | -3.44 ± .11 | 14.30 | -29.68 | $10^{18}$ |
| $10^{18.2}$ - $10^{18.9}$ | -3.07± .78 | 21.83 | -30.83 | $10^{18.5}$ |
| $10^{16.9}$ - $10^{18.4}$ | -2.98 ± .10 | 56.30 | -31.12 | $10^{18.5}$ |

## TABLE B

SPECTRUM SLOPES

| Experiment | Slope | Energy Range (eV) |
|---|---|---|
| Haverah Park | $3.14^{+0.05}_{-0.06}$ | $10^{17.6}$ - $10^{20.0}$ |
| Akeno | 3.04 ± 0.04 | $10^{15.7}$ - $10^{19.8}$ |
| Akeno ( Array 1 ) | 3.24 ± 0.18 | $10^{17.8}$ - $10^{18.8}$ |
| Akeno ( Array 20 ) | 3.16 ± 0.08 | $10^{18.3}$ - $10^{19.0}$ |
| Yakutsk | 3.23 ± 0.08 | $10^{18.3}$ - $10^{19.0}$ |
| Fly's Eye ( Mono ) | 3.07 ± 0.01 | $10^{17.3}$ - $10^{19.6}$ |
| Fly's Eye (Stereo) | 3.18 ± 0.02 | $10^{17.3}$ - $10^{19.6}$ |
| Mini Array | 2.98 ± 0.10 | $10^{16.9}$ - $10^{18.4}$ |

gives an over estimation of the core distance, leading to higher energy estimation for a given particle density. Hence we consider the overall spectrum for Mini Array upto $10^{18.4}$ eV with a slope of -2.98 ± .10 which is in reasonable agreement with that calculated by the other groups. The differential energy spectrum corresponding to best fit (least squares fitting) in the energy region $10^{16.9}$ eV to $10^{18.4}$ eV is derived as :

$$j ( E ) = 10^{24.01} \times E^{- 2.98 \pm .10} \ m^{-2} \ sr^{-1} \ s^{-1} \ eV^{-1}$$

**TABLE C**

THE DIP

| Experiment | Slope before the Dip | First slope in the Dip | Second Slope in the Dip |
|---|---|---|---|
| Akeno | 3.02 ± 0.03 ( $10^{15.7}$ - $10^{17.8}$) | 3.16 ± 0.08 ( $10^{17.8}$-$10^{18.8}$) | 2.80 ± 0.3 ( $10^{18.8}$ - $10^{19.8}$ ) |
| Haverah Park | 3.01 ± 0.02 ( $10^{17.48}$-$10^{17.6}$) | 3.24 ± 0.07 ($10^{176}$-$10^{18.6}$) | $2.70^{+0.18}_{--0.17}$ ( > $10^{19}$ ) |
| Fly'sEye(Stereo) | 3.01 ± 0.06 ( $10^{17.3}$- $10^{17.6}$ ) | 3.01 ± 0.06 ($10^{17.3}$-$10^{17.6}$ ) | 2.71 ± 0.10 ($10^{18.5}$-$10^{19.0}$) |
| Mini Array | 2.93 ± 0.62( $10^{16.9}$ - $10^{17.3}$ ) | 3.44± 0.11 ($10^{17.6}$-$0^{18.2}$ ) | 3.07 ± 0.78 ($10^{18.2}$-$10^{18.9}$) |

A dip is clearly seen from the Mini Array energy spectrum as also observed by other groups. There is qualitative agreement in the spectral changes. TableC lists the slopes over a relatively short energy range given by the experiments of various other groups of workers.

The spectral break at $10^{17.3}$ eV is due to a possible change in cosmic ray composition from predominantly light to predominantly heavy. The break at the position of dip ($10^{18.2}$ eV) indicates a possible change from galactic to extragalactic origin or possibility of a new cosmic ray source.

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