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The EAS Size Spectrum measured at ANI Cosmic Ray Observatory in the region of Knee

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Abstract

The differential size spectrum of Extensive Air Showers (EAS) measured with the MAKET-ANI installation, located at Mt. Aragats, 3200m above the sea level, is presented. Measurements of the shower size are performed with an array of plastic scintillators as a function of the zenith angle. The knee of the EAS size spectrum is observed at $N_{e_k} = 1.76 \pm 0.05 \cdot 10^6$. The observed change of the spectral index of the size spectrum equals 0.4 ± 0.06. The comparison with data of the EAS-TOP and the KASCADE installations are performed.

1 Introduction:

The intermediate-energy region ($10^{15} - 10^{16} eV$), where pronounced structures in the charged particle spectra are observed more than forty years ago (Kulikov, 1958), is of particular interest as the Supernova (SN) driven stochastic shock acceleration mechanism (Drury, 1983; Völk, 1988) is expected to fail in this region. Several models of particle acceleration are proposed for the knee region and higher energies:

1. Supernova explosion into strong stellar winds of progenitor. Due to a reduction in acceleration efficiency at a particular rigidity the slope increases, producing the knee feature (Biermann, 1993);
2. Acceleration in single nearest SN with unique production spectra. In this case the particular nucleus with sharply defined maximal energy (proportional to charge) will be superimposed on the smeared overall Galaxy SN contribution, causing the nontrivial structures in the knee region (Berezhko,1996; Erlykin, 1997);
3. Shock acceleration in the Gamma Ray Bursters (GRB), occasionally occur inside the Galaxy (Milgrom, 1996). Only SN and GRB seems to provided required luminosity of about $5.10^{38} ergsec^{-1}$ to maintain the Galaxy CR population with energies above $10^{14} eV$ in steady state.

However, the direct evidence is lacking to support strongly this models. Measurements of the energy spectra of the individual species of the Cosmic Ray(CR) flux can provide a detailed description of the structures in knee region, revealing the rigidity cut off, inherent to Fermi acceleration, or pikes, corresponding to the individual elements fluxes from nearest SN. Now the KASCADE experiment (Klages, 1997), measuring as many characteristics of the same EAS as possible, is approaching this goal both by the statistical analysis of EAS parameter distributions (Glasstetter, 1999; Weber, 1999) and by the event-by-event analysis of each shower (Chilingarian, 1999; Haungs, 1999).

We demonstrate that such a sophisticated analysis, based on simulations with many uncertainties can be supported by the traditional EAS techniques, measuring the profiles of the individual showers. The shower size spectra measured at different altitudes will help to determine the characteristics of the knee region (beginning of the flattening, brake, beginning of the steepening) and outline possible correlations of it's shape with alternative models of CR origin. The joint analysis of the data from installations located at different altitudes will significantly enlarge the estimation accuracy of the knee shape parameters and the attenuation length of showers in the atmosphere Λ.

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2 MAKET-ANI installation:

The MAKET-ANI array (Avakyan, 1993) (fig.1)is located at Mt. Aragats at $700g/cm^2$ atmospheric depth. The electromagnetic detector is made of 92 plastic scintillators (68 with size 100x100x5 cm^3 and 24 - 30x30x5cm^3) The accuracy of particle density (A) measurement is equal to

$$\frac{\sigma_A^2}{A} \sim \frac{0.2^2}{A} + 0.07^2 + (0.02 \cdot \ln A)^2. \qquad (1)$$

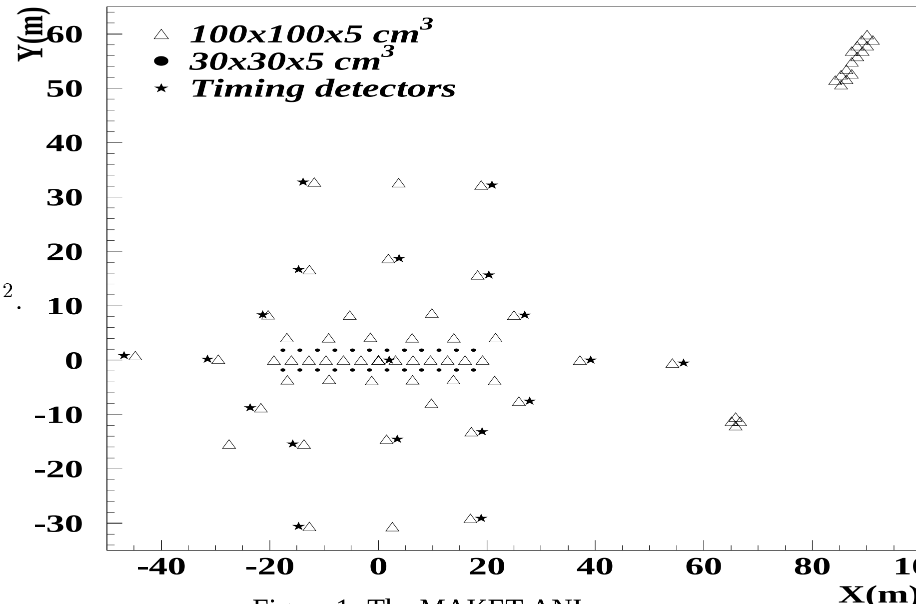

Figure 1: The MAKET-ANI array

The logarithmic ADCs provide linearity up to 10000 particles per m^2 (Hovsepyan, 1998). Arrival directions are obtained from a time of flight technique with an accuracy of $\sigma(\theta) \sim 2^o$ and $\sigma(\phi) \sim 6^o$. The EAS core location, shower size and and the age (S) parameter are measured applying of NKG-type function (Gharageozyan, 1998). The systematic uncertainties in the determination of the N_e and S parameters are $\Delta N_e \sim 10\%$ and $\Delta S \sim 0.06$. The shower axes were selected from the area, correspondent to the $96-99\%$ efficiency of registration. This rather severe selection (checked by the simulation) applied to the data file from 1997 and 1998 ($2.2 \cdot 10^6$ triggers, recorded at the effective time ~ 8000 hours) leave only $1.77 \cdot 10^5$ events for the further analysis.

3 Size Spectra in the Knee region:

If the existence of the knee is a matter of a common consensus, contradictory results about dependence of the spectral shape on the altitude and zenith angles of EAS incidence (Nagano, 1984; Danilova, 1994; Amenomori, 1996; Glasstetter, 1998; Aglietta, 1999), requires a more detailed description of the knee region shape. We implemented a procedure of iterative tuning of the upper and lower boundaries of the knee region and the knee position (Sokhoyan, 1998). The results of applying of this procedure to

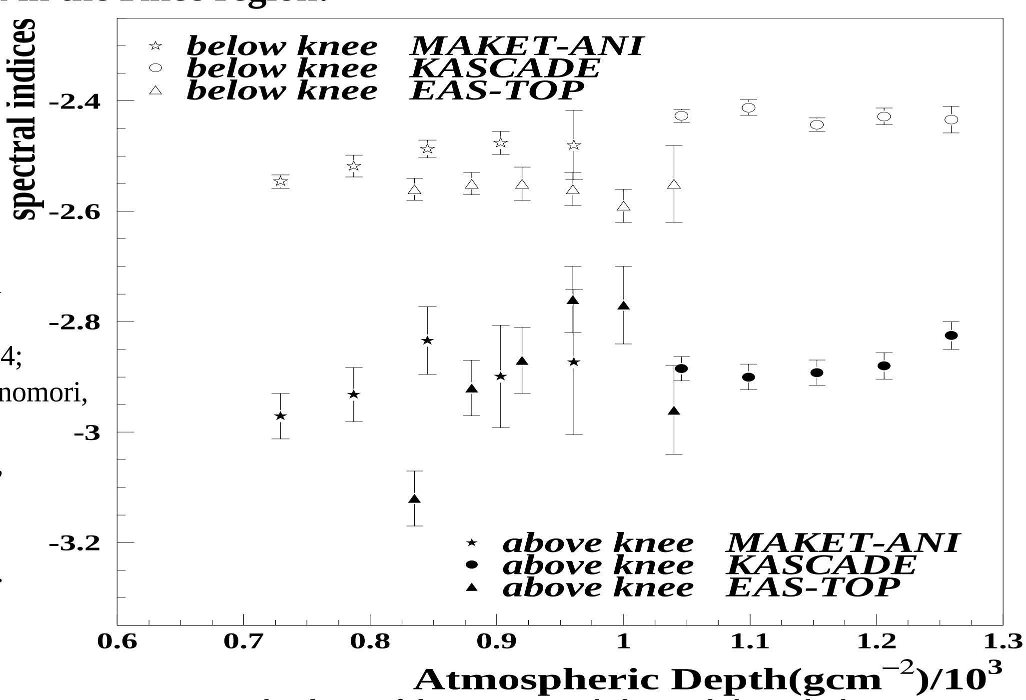

Figure 2: The slopes of the size spectra below and above the knee

the MAKET-ANI data, and the spectral slopes obtained by the KASCADE (Glasstetter, 1998) and EAS-TOP (Aglietta, 1999) experiments are depicted in fig. 2. Then one and the same procedure for the knee region and knee point determination was applied to the MAKET-ANI and KASCADE intensity tables measured in different intervals of zenith angle. To obtain the estimates of the attenuation length of showers in the atmosphere (Λ) four methods were used:

1. By fitting the angular dependence of a differential intensities for many groups of showers fallen in different N_e intervals we estimate the attenuation length of EAS intensity (λ_N) (Ohta, 1979). And then obtain Λ using the approximation given in (EAS TOP, 1997) (we assume that interaction cross section varies slowly with energy): $$\Lambda \sim 1.6\lambda_N; \qquad (2)$$
2. By the "Constant Intensity Cut" (CIC) technique (Nagano, 1984), assuming that the intensity $I(> N_{e_k})$ is constant with accuracy of $\sim 20\%$ (Aglietta, 1999);
3. By fitting the knee position (N_{e_k}) "attenuation" with respect to the zenith angle (the accuracy of the latter isn't enough due to limited number of angular bins and poor statistics for large zenith angles);
4. By joining the MAKET-ANI and KASCADE experiments data we enlarge twice the "effective" atmospheric depths range and increase significantly the accuracy of the EAS attenuation length estimate (compare the third and the fourth lines of table 1). Notice also in fig. 3, where by the small squares the knee positions determined by the MAKET-ANI ($700gcm^{-2}$) and KASCADE($1020gcm^{-2}$) data are denoted.

	$\Lambda^{MAKET-ANI}(gcm^{-2})$	$\Lambda^{EAS-TOP}(gcm^{-2})$
1	203 ± 6	219 ± 3
2	188 ± 11	222 ± 3
3	278 ± 76	257 ± 80
4	225 ± 12	

Table 1: The Estimates of the Attenuation Length of Showers in the Atmosphere, (numbers in the first column corresponds to the ones in the enumeration list above), EAS-TOP results from (Aglietta, 1999)

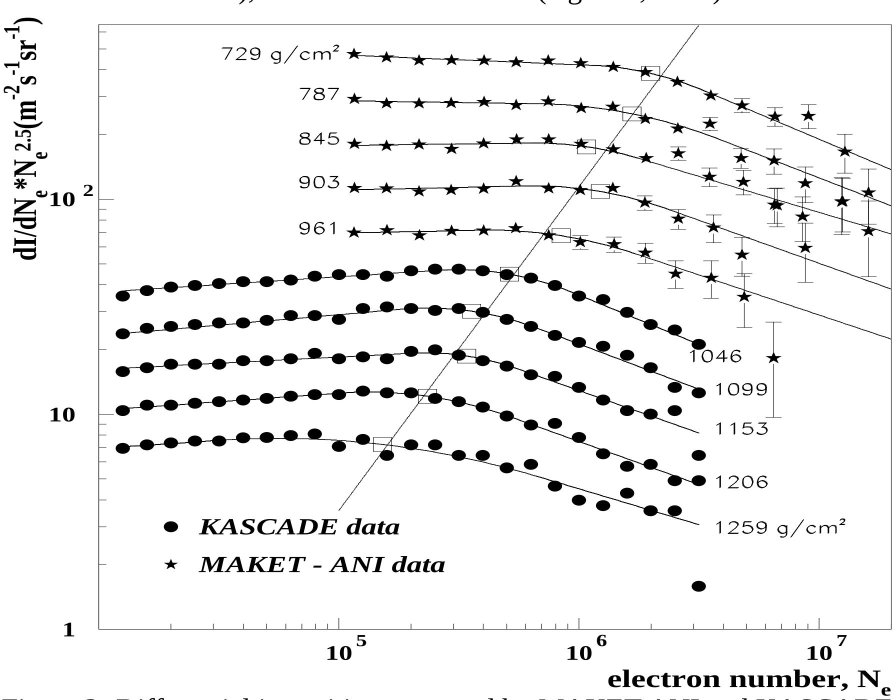

Figure 3: Differential intensities measured by MAKET ANI and KASCADE

4 Conclusion:

The summary of the Size Spectra characteristics measured on the altitude 3200m by the MAKET-ANI installation of Aragats Cosmic Ray Observatory in zenith angle range ($0° - 45°$) are posted in the table 2. The changes of spectral slopes are apparent for each interval of zenith angles at a N_{e_k} value, shifted with atmospheric depth (see fig. 3). The joint analysis of MAKET-ANI and KASCADE data allows to consider the atmospheric depths interval from 700 to 1285 gcm^{-2} and significantly improve the accuracy of the attenuation length estimate.

$I(10^5 < N_e < (1.17) \cdot 10^6)$	$(8.07 \pm 0.14) \cdot 10^{-11} (N_e/10^5)^{\gamma_1}$
$I(N_e > (2.57) \cdot 10^6)$	$(2.94 \pm 0.41) \cdot 10^{-13} (N_e/10^6)^{\gamma_2}$
γ_1	-2.54 ± 0.012
γ_2	-2.94 ± 0.042
$\Delta(N_{e_k})$	$(1.17 \pm 0.035) \cdot 10^6$ - $(2.57 \pm 0.064) \cdot 10^6$
N_{e_k}	$(1.76 \pm 0.05) \cdot 10^6$
$I(N_{e_k})$	$(5.3 \pm 0.12) \cdot 10^{-14}$

Table 2: The Summary of the Measured Fluxes and Knee Region Parameters, Zenith Angles Range of ($0° - 45°$), Altitude 3200m (intensities are given in $m^{-2}sec^{-1}sr^{-1}$ units)

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References

Aglietta M.et al., 1999, *Astropart. Phys.* , **10**, 1
Amenomori M., et al., 1996, *Astrophys. Journal* , **461**, 408
Avakyan V.V. et al., 1993, *Jadernaya Fiz.* , **56**, 182
Hovsepyan G.G. et al., Proc. ANI98, FZKA 6215, (Nor-Amberd, 1998) 45
Berezhko E.G. et al., *JETF* , **82**, 1996, 1
Biermann P.L., 1993, *A. & A.* , **271**, 649
Chilingarian A. et al., Proc. 26th ICRC (Salt Lake City, 1999), HE 2.2.04
Danilova E.V. et.al., 1994,*Izv. RAN, Ser. Fiz.* , **58**, 67
Drury L.O'C, 1993, *Rep. Prog. Phys.* , **46**, 973
Erlykin A.D., Wolfendale A.W., 1997, *J. Phys. G* , **23**, 979
Haungs A., et al., Proc. 26th ICRC (Salt Lake City, 1999), HE 2.2.02
Gharageozyan G.V. et al., Proc. ANI98, FZKA 6215, (Nor-Amberd, 1998) 51
Glasstetter R., et al., Proc. 16th ECRS (Alcala, 1998), 564
Glasstetter R., et al., Proc. 26th ICRC (Salt Lake City, 1999), HE 2.2.03
Klages H.O.,et al., 1997, *Nucl. Phys.* **52B**, 92
Kulikov G.V. et.al., 1959, *JETF* , **35**, 441
Milgrom M., Usov V., 1996, *Astropart. Phys.* **4**, 365
Nagano M., et. all., 1984, *G:Nucl. Phys.* , **10**, 27
Ohta K., et al., Proc. 16th ICRC (Kyoto, 1979), 177
Sokhoyan S.H. et al., Proc. ANI98, FZKA 6215, (Nor-Amberd, 1998) 55
The EAS TOP Collaboration,Proc. 25th ICRC (Durban, 1997), v.4, 125
Weber J.H., et al., Proc. 26th ICRC (Salt Lake City, 1999), HE 2.2.42
Völk, et.al., 1988, *Astr.J.Lett.* **333**, L65