Extensive Cloud Showers (ECS) – New High-Energy Phenomena Resulting from the Thunderstorm Atmospheres

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Extensive Cloud Showers (ECS) – New High-Energy Phenomena Resulting from the Thunderstorm Atmospheres

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Abstract We report the phenomenon of the *Extensive Cloud Showers (ECS)* detected by the surface particle detectors at mountain altitudes in correlation with thunderstorms. Measured microsecond duration particle bursts are first direct evidence of the electron-photon avalanches in the thunderstorm atmospheres, reaching the mountain altitudes from low located thunderclouds. In the report we present analysis of these rare events including spatial distribution, density spectra and particle energy.

1. Classification of the ECS and EAS events

Registration of the Extensive air showers (EAS) is standard technique for research of high energy Cosmic Rays (CR) accelerated in Galaxy and Universe. High-energy proton or nuclei interact in the atmosphere and born copious elementary particles comprising the electron-hadron cascade. Arrays of particle detectors (plastic or liquid scintillators, Cherenkov water tanks, etc) covering large area on earth surface detect cascade particles. Special experimental techniques are developed to recover total number of EAS particles (so-called shower size), the energy and type of primary particle [1]. The density distribution of shower particles characterized by a bell-like shape with density of particles reaching up to tens thousands per m^2 near the axes of shower.

The electron-photon cascades developing in the thunderstorm atmosphere in presence of strong electrical fields (Relativistic Runaway Electron Avalanches – RREA, previously referred as Runaway Breakdown – RB, [2,3]) cannot provide large densities on the ground and we can expect that these type of cascades (Extensive Cloud Showers (ECSs), will cover ground beneath the cloud more or less uniformly, like rain. At 19 September 2009 the shower trigger of the MAKET array for the first time registered new type of particle showers initiated in the thunderstorm above [4]. Further analysis [5] proves that thundercloud was very low above the detector (~50 m) and electrons from the RREA process reach the detector location. The estimate of cloud height for the second Thunderstorm Ground Enhancement (TGE), detected on 4 October 2010 was 150 meters; therefore very few showers reach the detector. Based on the expected systematic difference of the EAS and ECS event densities we perform a 2-way classification of showers detected at 19 September and 4 October. We compare 10-minute sample of events detected during TGE with the 10-minute sample of the pure background – EAS events measured at quiet weather. Having 2 samples, one containing the pure background and the other - signal contaminated by background we can pose the problem of the signal “purification”; i.e. select the decision boundary in the measured parameters space and perform cuts on the joint sample containing signal and background. The boundary in the space of measured characteristics (decision rule) should be optimized in a way to keep as much as possible of the signal events and suppress as much as possible background events. Obviously, we cannot keep 100% of the signal and reject all background events, because of the overlapping signal/background distributions; therefore, we have to select a compromise. Almost all of the additional MAKET triggers have mean density not exceeding 7-8 particles/m^2 [6] and we can restrict ourselves by the one-dimensional classification scheme, using only mean density of event. However, as we can see in the Figure 1 to the right from the decision line there is a population of events with rather large maximal density. We treat these events as background small EAS events with their shower axes fallen in the array. To additionally suppress such events we add the second discriminator – the maximal density within an event. Thus, the mean and maximal densities of MAKET scintillators detected the shower were used for classification. The selection procedure is visualized in the Figure 1 and 2. The showers with parameters in the region to the left from the linear decision boundary are classified as ESC events and the events to the right – as EAS events.

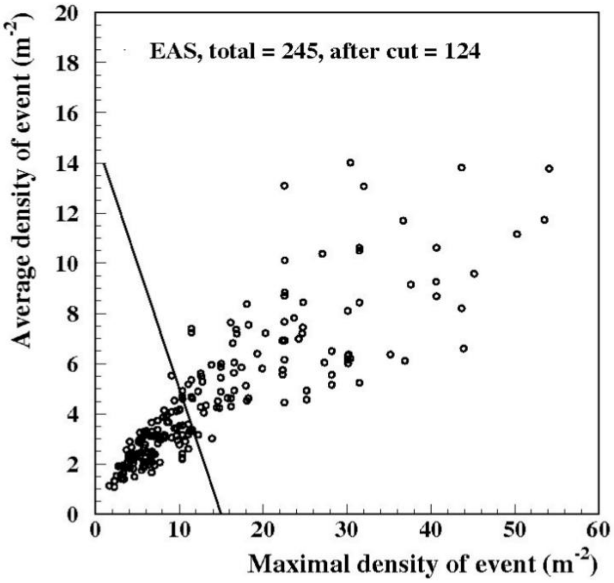

Figure 1 Scatter plot of the registered at quite weather MAKET triggers (pure EAS events).

Classification criteria suppress ~50% of the pure EAS events (121 from 245, see Figure 1) on the price of loosing ~ 25% of the joint EAS and ECS events (148 from 613, Figure 2). Therefore, in the selected sample of 465 “signal” ECS events we expect 121 background EAS events, therefore, the purity of the selected ESC sample is rather high ~75%. The 25% of contamination could not be further reduced due to large EASes with axes far from the MAKET array, which are alike ECS events. The long tails of EAS generate events with low mean and maximal densities and could not be distinguished from ECSs.

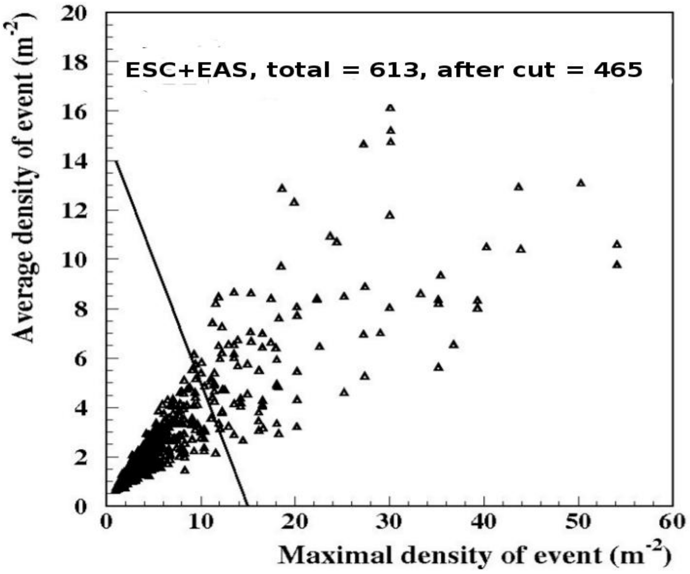

Figure 2 Two-way classification of the showers detected at 19 September, 2009 and 4 October 2010 during thunderstorms.

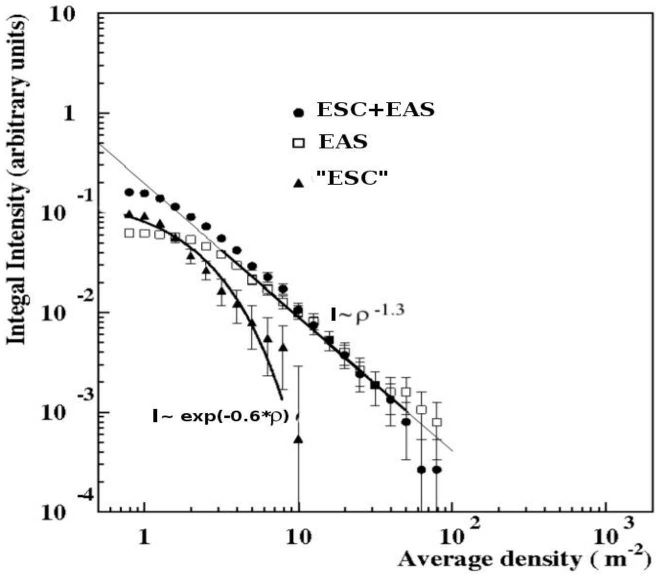

Figure 3 Integral density distribution of the events from the joint ESC+EAS, statistically reconstructed ESC and pure EAS classes.

Further evidence of the difference of two classes of the events is apparent from the Figure 3. As we can see in the Figure 3 the density distribution (ρ) of EAS events follows a power law as many other distributions generically connected with population of the galactic cosmic rays falling on the atmosphere. In contrast, the density distribution of the ESC events follows an exponential curve, as expected from an avalanche process. The average value of the mean density of EAS and ECS samples are ~6 and 2.5 particles/m^2 correspondingly. The density spectra of the joint ECS+EAS sample and pure EAS sample are drastically different in the region of small densities (less than 7-8 particles/m^2) and identical for higher densities.

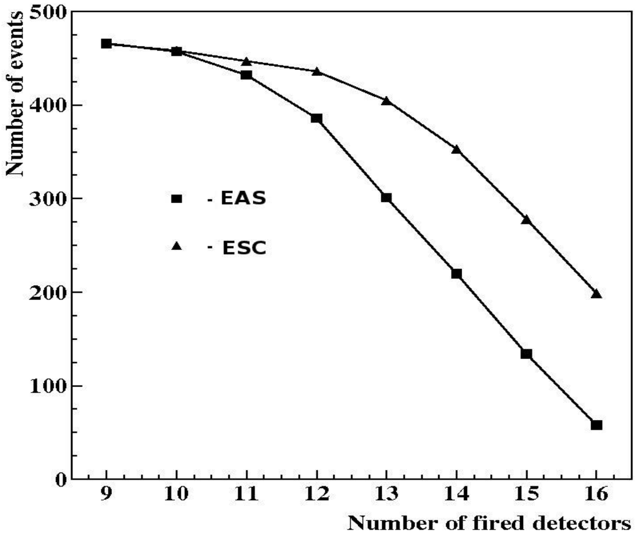

Figure 4 Numbers of events detected with 9 to 16 scintillators of the MAKET array for the two classes of events, both containing 465 events at MAKET trigger conditions (9 scintillators from 16 fired).

In the off-line analysis we require more than 9 scintillators (hardware trigger condition) to be fired; consequently the number of events diminish with the requirement of enlarging of the number of scintillators with signal above threshold. However, the “speed” of the decrease of events significantly differs for the EAS and ECS samples, as one can see in the Figure 4. Number of EAS events is fast fallen (from 465 at trigger to 50 when all 16 scintillators are required). This can be explained by the small sizes of the EAS at rather low MAKET array threshold energies ~50 TeV. The number of ECS events is decreasing much slower. Therefore, we can state that there is no experimental evidence that the spatial elongation of the ECS events is less than 1000 m^2 (limit caused by the finite size of MAKET detector). The slow decrease of detection efficiency of ECL events with increasing the area of particle collection can be explained by the finite efficiency of plastic scintillators only.
The time-distribution of the ECS events allows estimating the upper limit of the individual event duration to be 50 microseconds [6].

2. Conclusion

We discover new energetic atmospheric phenomena, Extensive Cloud Showers (ECSs), for the first time unambiguously proving existence of the RREA process tightly connected with the gamma ray bursts detected by orbiting gamma-ray observatories, i.e. Terrestrial gamma flashes [7].

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