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The bursts of high energy events observed by the telescope array surface detector

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ABSTRACT

The Telescope Array (TA) experiment is designed to detect air showers induced by ultra high energy cosmic rays. The TA ground Surface particle Detector (TASD) observed several short-time bursts of air shower like events. These bursts are not likely due to chance coincidence between single shower events. The expectation of chance coincidence is less than 10^{-4} for five-year's observation. We checked the correlation between these bursts of events and lightning data, and found evidence for correlations in timing and position. Some features of the burst events are similar to those of a normal cosmic ray air shower, and some are not. On this paper, we report the observed bursts of air shower like events and their correlation with lightning.

1. Introduction

There have been reports about the observation of energetic radiation from thunderclouds. Some of these reports discuss the increasing rates of radiation at the ground in the presence of thunderclouds. Some of them discuss bursts of energetic radiation observed from space, known as terrestrial gamma-ray flashes (TGF) [1,2], also from aircraft [3]. They are believed to be associated with upward lightning flashes at the tops of thunderclouds. The observation of TGF on the ground was reported by Dwyer, et al. [4] Other observations of energetic radiation have been associated with individual lightning processes in the flash. The possible mechanism for some of these kinds of energetic radiation from thunderclouds is Relativistic Runaway Electron Avalanches (RREAs) or due to strong electric field on the streamer tip summarized by Dwyer, et al. [5]

Lightning is classified by the discharge region, intracloud lightning (IC), cloud to ground lightning (CG) and cloud to cloud lightning. The natural lightning flash consists of several processes, known as the stepped leader, return stroke, dart leader and subsequent return stroke. The leader direction may be up or down and of positive or negative polarity, hence there are four types of lightning for cloud to ground lightning. However, except for lightning strikes on tall objects, most lightning starts with negative charges moving downward.

Moore, et al. [6] reported the observation of the energetic radiation from stepped leaders, using NaI as a radiation detector. Dwyer, et al. [7,8] reported the observation of the energetic radiation from dart leaders, also using NaI as a radiation detector, for rocket triggered lighting. Dwyer, et al. [9] reported the observation of energetic radiation from stepped leaders, and Dwyer, et al. [10] reported association with the return stroke, also using NaI as a radiation detector, for natural cloud to ground lightning.

On the other hand, the stepped leader, the beginning of lightning, cannot start only by the electric fields in the usual thunderstorm. Therefore, it has been hypothesized that cosmic ray air showers play a role in triggering lightning by ionizing the atmosphere. In support of this, there have been several reports of energetic radiation observed with lightning.

Gurevich, et al. [11,12] reported the coincidence of air showers with lightning, using NaI and gas-counters as radiation detectors. Chilingarian, et al. [13] also reported the coincidence of air showers with lightning, using plastic scintillators. Gurevich, et al. [14] presented the results of radio emission measurements and discussed as follows. If cosmic ray air showers stimulate the electron avalanche in lightning, their observed radio event rates seem inconsistent with the flux of cosmic rays with energies estimated from the observed radio amplitudes of electron avalanche. The cosmic ray energies estimated from the avalanche amplitudes are five to six orders of magnitude higher than those estimated from the rates. Hydrometeors are introduced in an effort to overcome this inconsistency [14].

2. Observed burst events

The Telescope Array (TA) experiment, located in midwest Utah, USA(39.3N, 112.9W, Alt 1382 m), consists of two types of detector (Fig. 1). Both methods observe the high energy phenomenon known as an "air shower", which is generated by an ultra high energy cosmic ray. One instrument is atmospheric fluorescence telescope detectors and the other is ground surface particle detectors [15]. In contrast to atmospheric fluorescence which is observable during moonless nights, the TA Surface Detector (TASD) runs all day throughout the year. TASD consists of 507 plastic scintillation counters. The particle detecting part of an individual TASD counter is shown in Fig. 2. The energy deposition on this counter for a vertical muon is 2.043 MeV and the equivalent energy for trigger threshold is 0.7 MeV. The counters are deployed as a square grid array with 1.2 km spacing, and covers 680 km^2 altogether. When three adjacent detectors detect a signal, each of which corresponds to more than three particle equivalent in 8 μs, TASD judges that their signals are from an air shower, causing signal waveforms to be digitized from all detectors within ±32 μs of the trigger time [15]. The TASD is designed to detect all air showers from cosmic rays whose primary energy is more than 10^{19} eV. The average rate of shower trigger is 7.5 mHz and the expected cosmic ray energy at the threshold level is $10^{17.5}$ eV [15].

The particle detectors used in the preceding studies on introduction were mainly NaI, sometimes coupled with gas counters or plastic scintillators. The TASD uses plastic scintillator, with an area approximately 300 times larger than the NaI detectors but lacking the ability to measure the energy of individual particles. The TASD scintillator responds about 10 times faster than NaI. Whereas