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Continuous Measurements of Upper Atmospheric Lightning Discharges by EUSO

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In this study we present possibility of continuous measurements of lightning-associated transient luminous events (TLEs) from the international space station using the Extreme Universe Space Observatory (EUSO) telescope. From global lightning data we estimated possible detection rates of lightning and TLEs. We also estimated photon numbers and optical spectra of TLEs in the near-ultraviolet region (300–400 nm) where the fluorescence emission caused by CRs exists. These results imply that EUSO has enough capabilities to monitor not only UHECRs but also global lightning and TLEs. We are developing a new-type of high-voltage divider for multi-anode photomultiplier tubes (MAPMTs) which can automatically change the gain level rapidly ($< 350\mu\text{s}$) and which enable us to carry out both UHECR and TLE observations. An electronic design and performances of the divider circuit will be presented.

1. Introduction

In the beginning of 1990's transient luminous events (TLEs) occurring above active thunderclouds were discovered [1]. TLEs excited by cloud-to-ground discharges are the discharge phenomena in the stratosphere, mesosphere and lower thermosphere and are classified into several types by their occurrence characteristics as sprites, elves and blue jets. Recently, it is demonstrated that sprites would chemically change the concentration of NO_x and HO_x in the mesosphere and lower thermosphere [2]. It is speculated that the ionization processes related to sprites and blue jets are likely to have a significant chemical impact on the ozone concentration and on the global atmosphere, particularly in the stratosphere and mesosphere. Though numbers of observational and simulation studies have been operated so far, many physical mechanisms and global occurrence rates of TLEs are still not well understood.

The main purpose of this study is to identify a link between global lightning activity, TLE activity and global change of the Earth's atmosphere. For these purposes, we need to clarify following two subjects: (1) generation mechanisms of TLEs, and (2) global occurrence rates and locations of TLEs. It is essential to carry out optical observations of TLEs from space. Thus, we started the feasibility study of lightning and TLE observations from the International Space Station (ISS) using the Extreme Universe Space Observatory (EUSO) telescope, which has not only high temporal and spatial resolution but also wide field of view (FOV). It should be noted that EUSO can provide a unique experimental opportunity to link cosmic rays and TLE's triggering.

2. Detection Rates of Lightning and TLEs by EUSO

In order to determine the feasibility of lightning observation by EUSO and to carry out the CR observation safely, it is important to evaluate the detection rates of lightning and TLEs. Using a data set of the global lightning distribution derived from electromagnetic wave measurements in the ELF/VLF range, we estimated the detection rates of lightning and TLEs. For this estimation FOV of the EUSO telescope is assumed to be

60°. In addition, the altitude and latitudinal coverage of ISS are assumed to be 430 km and $\pm 51^\circ$, respectively. It is found that the average detection rate of lightning in night time is estimated to be ~ 700 events/orbit, which becomes $\sim 1.1 \times 10^4$ events/day. If an occurrence ratio (TLEs/lightning) is $\sim 0.03\%$, the detection rate of TLEs is ~ 3 events/day, which becomes ~ 1100 events/year. Thus, it is clear that EUSO can sufficiently detect these events.

3. Photon Numbers and Spectrum of Lightning and Sprites

We estimated total photon numbers emitted by lightning and sprites at the entrance of the EUSO telescope. Figure 1 is a schematic illustration showing the observation geometry of lightning and sprites. In order to simplify the calculation, we assumed that the shape of sprite is a disk with a radius of 25 km at an altitude of 80 km and that the optical energy and duration of sprite emission is 10–100 kJ and 1 ms, respectively. Similarly, the lightning emission is assumed to be a disk with 100 km radius at 10 km altitude and to have the optical energy of 1000 kJ and duration of 200 μs . Note that these emissions are assumed to be spatially and temporally uniform. Under these assumptions, we have estimated the photon numbers from these emissions at the entrance of the EUSO telescope in one gate time unit (GTU = 2.5 μs). We also estimated the number of photons came from FOV of the single pixel of MAPMT which locates the optical axis of the telescope. The estimated photon numbers are summarized in Table 1.

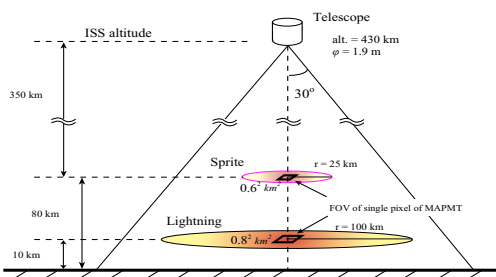


Figure 1. Schematic illustration showing the observation geometry of lightning and sprites.

Table 1. Optical energy and photon numbers at the entrance of the EUSO telescope of lightning and sprites.

	Lightning	Sprites
Optical Energy (at 300-800 nm) (kJ)	1000	10-100
Total Photon Number (ph./GTU)	8.4×10^9	$5.5 \times 10^{7-8}$
Photon Number for single-pix. (ph./pix/GTU)	1.8×10^5	$3.5 \times 10^{4-5}$

Using a relative intensity spectrum of sprites as shown in Figure 2(a) [3], we estimated a photon number spectrum at the entrance of the EUSO telescope as shown in Figure 2(b). It is found that intensity of sprites in the range of 300–400 nm is strong enough to be detected by the EUSO telescope. Such spectra are highly important while studying air showers produced by UHECRs as they would fake the fluorescence light signal in the shower development.

All these results imply that EUSO has enough capabilities to monitor not only UHECRs but also global light-

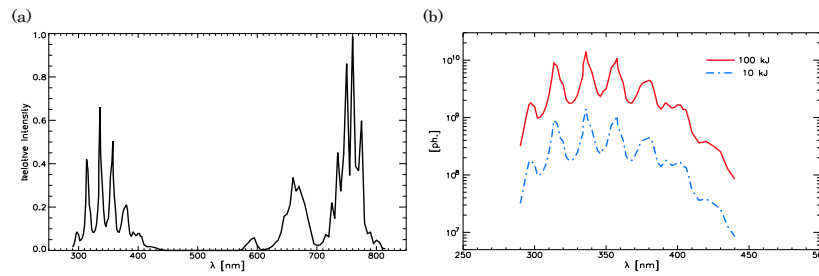


Figure 2. (a) Relative optical intensity spectrum of sprites [3]. (b) Estimated photon number spectrum of sprites in the range of 290–440 nm at the entrance of the EUSO telescope at ISS. Note that the atmospheric transmission is supposed to be 1.0

ning and TLEs. However, the photon numbers of lightning and sprites are 2-3 order bigger than that of the extensive air showers generated by UHECRs whose energy is 1.0×10^{20} eV. Since the gain level of MAPMTs is 10^6 to detect a weak air shower emission, anode signals would be saturated when the MAPMT looks at such strong lighting flashes. Moreover, these lightning flashes may cause considerable damage to MAPMTs. Thus, we need to provide the focal surface detector with some gain controlling unit which can reduce the gain level of MAPMTs as soon as EUSO observes lightning and TLEs. For this purpose, we are now developing a new high-voltage divider circuit for MAPMTs with an auto-gain controlling system.

4. Auto-Gain Controller for MAPMTs

Figure 3 is the schematic diagram showing the high-voltage divider for MAPMT with auto-gain controlling system. In this divider circuit we employ photo-MOS relay semiconductors (Matsushita - AQV258). This photo-MOS relay has the output voltage resistance of 1500 V and can switch the voltage level within 350 μ s with extremely low power consumption of <15 mW.

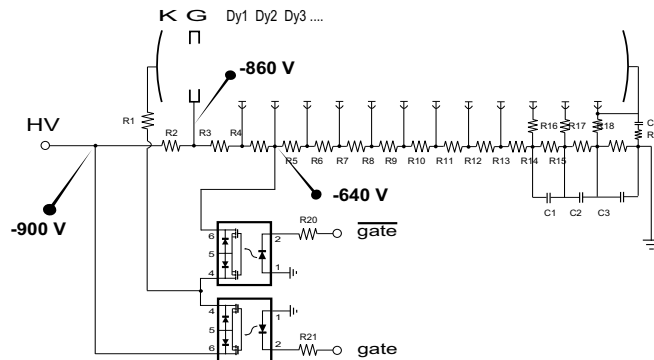


Figure 3. Schematic diagram of the high-voltage divider circuit for MAPMTs with an auto-gain controlling system.

One photo-MOS relay is connected to the -900 V high voltage which is directly provided by the high voltage generating unit at the focal surface and the other is connected to the -640 V voltage at the third dynode of MAPMT. The timing and duration of these voltage switching is controlled by the gate and off-gate signals

which are generated by a gate generator and are inputted into these relays. Using this circuit, we can switch the voltage level at the MAPMT photocathode from -900 V to -640 V. When the voltage level at the photocathode is -900 V, photoelectrons can be amplified at the following dynodes. To the contrary, when the voltage level at the photocathode is -640 V, most of photoelectrons will be shielded because the voltage level at photocathode is larger than that at the MAPMT grid. Then, we can reduce the MAPMT gain. We have developed an engineering model of this divider circuit and tested its function.

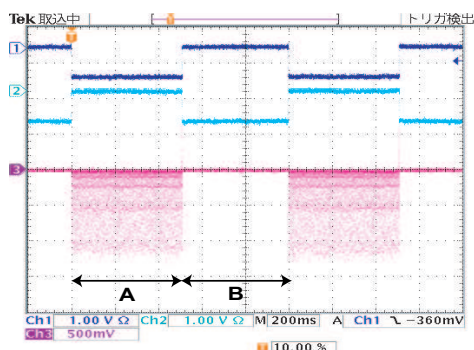


Figure 4. Plots of gate, off-gate and anode signal from top to bottom. In the time interval indicated by “A” and “B”, the voltage level at the photocathode is -900 V and -640V, respectively.

Figure 4 shows the plots of gate, off-gate and anode signal from top to bottom, respectively. Note that the gate and off-gate signals are switched every 500 ms by a function generator in this measurement. It is clear that the gain level of MAPMT is dramatically reduced in the time period “B”, when the voltage level at the photocathode is -640 V. We measured the reduction rate of the gain level and found it to be $\sim 1/200$. Thus, we confirmed that this gain control system is effective to reduce the MAPMT gain. The next development is to set the gain reduction rate to be $1/1000$. We performed the radiation test for the photo-MOS relays and confirmed that these semiconductors can endure in the space environment [4].

5. Summary

We have performed the feasibility study of lightning and TLE observation by EUSO. We have estimated the detection rates of lightning and TLEs and found that EUSO will detect these events with sufficient rates and enough photon numbers. We are developing an engineering model of a new divider circuit with the auto gain controlling system. Using photo-MOS relays, we confirmed that the system can reduce the MAPMT gain level. This result is a great step forward for the EUSO lightning observation.

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