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Balloon-borne measurement of UV nightglow and clouds for the JEM-EUSO mission

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Abstract: Ultra-high energy cosmic rays (UHECRs) above 100 EeV have been observed with several experiments. Their origin and propagation mechanism are still in mystery mainly due to the low statistics. In order to observe UHECRs with sufficient statistics, the JEM-EUSO mission is going on. In the JEM-EUSO mission, fluorescence and Čerenkov light from the extensive air showers induced by UHECRs are observed with a telescope attached to the International Space Station. It is important to study the background (BG) intensity in near UV region (300-400nm) seen from the JEM-EUSO telescope. We launched a balloon at Sanriku Balloon Center of JAXA to investigate the nightglow and the clouds on August 29, 2005. The upward and downward nightglow were measured in the eight near UV bands and the cloud images were recorded with an infrared thermography. In this paper, the detail of the experiment and the results will be reported.

Introduction

In order to study the sources and the propagation mechanisms of the ultra-high energy cosmic rays (UHECRs), the JEM-EUSO mission [1] is going on. The fluorescence and Čerenkov light from the extensive air showers induced by UHECRs will be observed by the telescope attached to the International Space Station flying at the altitude of ∼400 km. BG light in near UV region (300-400 nm) viewing from the satellite orbit is important for the JEM-EUSO observation. So far, several balloons have been launched [2, 3] for the BG study in clear nights for the experiments like JEM-EUSO. Cloud has so high albedo that the BG light level may increase. For the study of the correlation between the BG light and the cloud, We launched a balloon in Japan in August, 2005.

Instrument

The schematic figure of the whole instrument is shown in Figure 1. The whole instrument is installed in a pressure-resistant vessel with 30 cm in diameter and 40 cm in height. It consists of two parts, the module for the BG light observation and that for cloud observation. An infrared thermography, TVS-200 (Nippon Avionics Co.,Ltd.) is used for the cloud observation, looking down below the balloon. The field of view is $30^\circ \times 22^\circ$ and the sensitive wavelength is 8∼14 μm. The image of temperature distribution is recorded into the compact flash (CF) memory card every two minute. If there is cloud, its temperature reflect that of surrounding atmosphere. If we have a temperature distribution as a function of height, the height of the cloud can be derived.

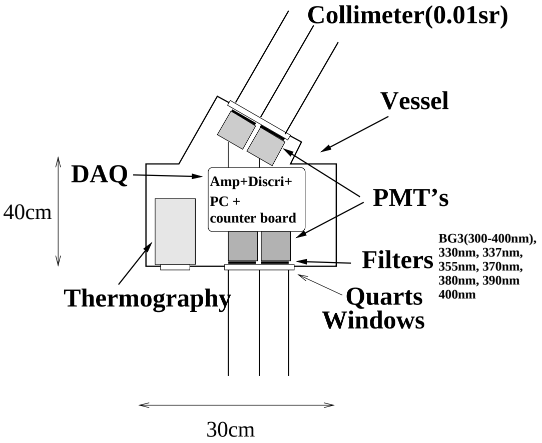

Figure 1: Schematic figure of the instrument for the BG and cloud observation on balloon.

Four multi-anode photomultiplier tubes (MAPMTs) with sixteen anodes, R8900-M16, developed for the EUSO mission, are used for the BG light detection, with collimeters of 0.01 sr FoV. PMTs are operated with the gain around 10^6. HV modules supplying the power to the PMTs are the candidates selected for the EUSO experiment. Two PMTs are attached to see upward, and the other two downward. The central wavelengths of the seven narrow band filters are 330, 337, 355, 370, 380, 390, 400 nm with the bandwidths of $\sim$10 nm for the spectroscopic data, and a BG3 filter (300-400 nm) is also used for the total amount of light in the interested UV range. Four filters each are attached to the surface of the PMT. The signals from PMT anodes are measured with photon-counting method with 16 bit counters and the counts are stored into a CF memory card by the on-board computer (PC). As the counts are not proportional to the number of incident photons, calibration curves were obtained with a 375 nm LED in the laboratory ahead of the observation, with which the observed counts were converted in the analysis.

A part of the photon counting data, the video signal from the thermography and the house keeping data (pressure and temperatures in the vessel) were sent via the telemetry for monitoring.

Observation

The balloon was launched past 18 o'clock on August 29th, 2005 (JST) at Sanriku Balloon Center, Japan Aerospace Exploration Agency (JAXA), which is located in Iwate prefecture, Japan (141.8°E, 39.2°N). Figure 2 shows the track of the balloon by GPS. The total flight duration was about 7 hours. Around 21^h30^m, the balloon reached its highest point and switched to the level flight at about 33 km high. The data of the thermography was taken from the time of the launch and the BG light observation started past 20 o'clock. At the launch time, the sky was clear. From 22 o'clock some clouds started to be seen in the thermography images. Until the end of the observation, small pieces of cloud moved through the FoV intermittently. The gondola was rotating with the period of $\sim$1 minute during the level flight. At 0^h27^m, the observation was stopped. The balloon was cut and the gondola fell onto the sea. They were successfully collected in the next morning.

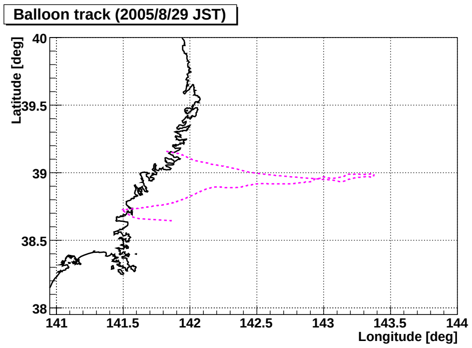

Figure 2: Track of the balloon (broken line).

Results

Figure 3 shows the sample images of the thermography. The left panel is that just after the launch, so that the launching pad can be seen. The center one is in the middle of the observation period. The mesh-like image in the surrounding part of the picture is the net covering the gondola. The blue part with a bar at the lower right corner is the VLF antenna of the other experiment loaded on the same

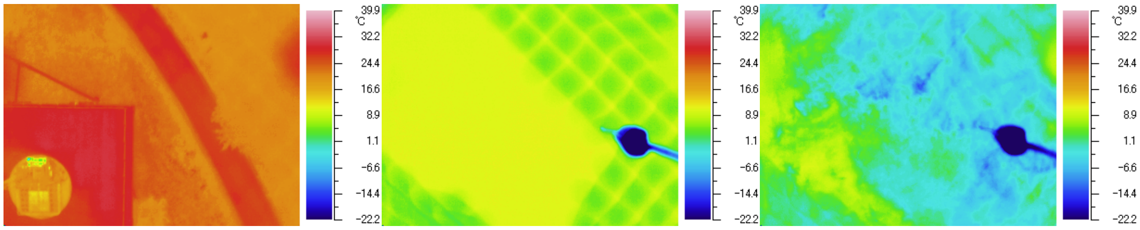

Figure 3: Sample Infrared images in flight. left:just after the launch. center:21^h30^m. right:23^h55^m.

balloon. The right panel in Figure 3 is an example of cloud image. Figure 4 shows the variation of the temperature in the center of FoV of the thermography. After the launch, it decreases gradually and after 2 hours it becomes almost constant around 10 °C. After 22 o'clock, the minimal temperature varies between -10 °C and 0 °C. This can be understood as that small pieces of clouds were passing through in the FoV (Figure 3 right).

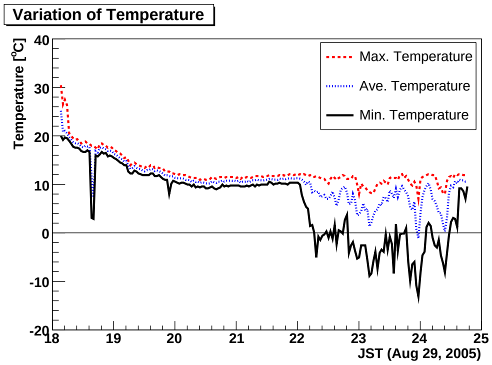

Figure 4: Variation of temperature in the center area of the FoV of the thermography.

If we consider the minimal temperature in the FoV as the cloud top temperature and use the temperature distribution as a function of height measured at 21 o'clock on the same day above Sendai (a city, ∼100 km away from the balloon center)[4], the estimated height is $4 \sim 6$ km, taking into account the attenuation of infrared in the atmosphere. This height is compared with those by the Himawari6 instrument for the weather observation on the Japanese satellite, MTSAT-1R[5], and by MODIS sensor[6] on the Aqua satellite[7] (We call them as Himawari and MODIS, respectively hereafter.). The Himawari images are available[8] for every hour on that day except a few hours in the eclipse of the satellite. The MODIS MOD06 level2 data is available from the NASA's site for just after the observation period (1^h30^m on the 30th) and provides the physical data such as temperature, pressure, height, optical thickness of the cloud. The cloud top height derived from the Himawari image is $4 \sim 4.5$ km, which is consistent with our result. The height from the MODIS data is $8 \sim 9$ km, which is different from our or Himawari result. According to the MODIS level2 data, the thickness of the cloud is thin. Therefore, the difference in the cloud height will be due to the assumption for the analysis of our and Himawari's data that the clouds are thick enough and then the emissivity of the cloud is 1. The derived sea surface temperatures agree among three data, around 24°C.

The fluxes of the BG light are derived as the converted counts divided by the gate time, the solid angle of the collimeter, the area of the PMT pixel, the transmittance of the filters and the detection efficiency of the PMTs. Here, the converted count is calculated from the observed signal count with the calibration curve obtained in the laboratory. Figure 5 shows the BG light rate from above and below the balloon. The average light intensity from above is almost constant, but with large fluctuation. The intensity from below is low and constant at first, and gradually increases with the moon elevation higher. In the lower panel of Figure 5, a small peak can be seen a few minutes to 24 o'clock. This time corresponds to that of the right panel of Figure 3, so that the peak can be interpreted as a scattering of the moon light by the cloud below the balloon.

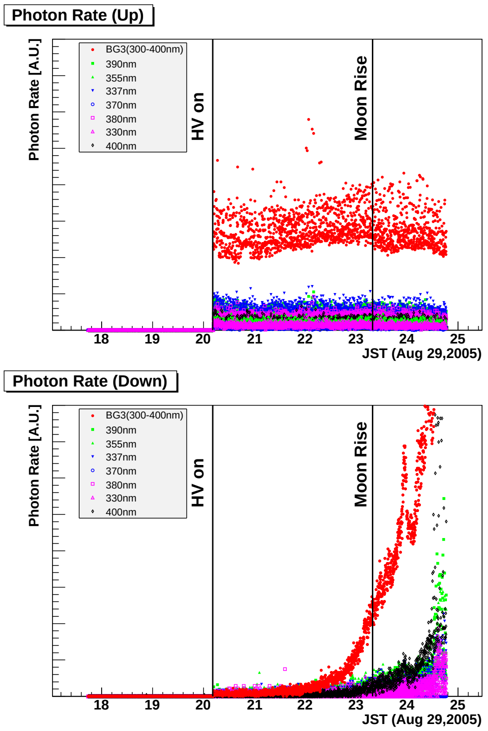

Figure 5: Time variation of the night sky light in near UV region (300$\sim$400 nm) per unit area, angle and time from above the balloon. The upper panel shows the BG light from above the balloon and the lower panel shows the BG light from below. Filled red circles (largest counts) show the count through BG3 filter for 300-400 nm in wavelength and the other markers show the counts those through the seven narrow band filters in the same wavelength range.

According to the summary paper about the diffuse night sky background[9], the main components are the zodiacal light, the diffuse star (and galaxy) light and the airglow. As the JEM-EUSO will fly at the altitude $\sim$400 km, the airglow, which occurs around 100 km, will be seen in the FoV of the JEM-EUSO, but the other two components can not been seen. The contribution from the zodiacal light and the diffuse star light is evaluated using the data in Ref.[9]. Similar structure of the fluctuation of the light intensity from above the balloon is reproduced. That is, most of the fluctuation can be explained by seeing the bright and dark part of the sky with the rotation of the balloon gondola with the period of $\sim$1 min. Comparing our result on the flux in the moonless night with the previous measurements, the flux from above is larger than that by the NIGHTGLOW experiment[3] and that from below is smaller than those by the NIGHTGLOW and BaBy[2] experiments. This may be due to that the airglow intensity was stronger in our observation, but another observation near Japan will be necessary for confirmation.

Summary

We had 4.5 hour observation of BG light and clouds on balloon on August 29th and 30th, 2005 (JST) at Sanriku, Japan. The estimated cloud height was between 4km and 6km, which is consistent with that derived from the MTSAT-1R data, 4 to 4.5km. But that from the MODIS/Aqua level2 data was 8 to 9km. The reason of this inconsistency may be due to the assumption that the cloud emissivity is 1 in the former two analysis. The BG light rate in a moonless night is larger from above and smaller from below compared to the previous balloon observations. The effect of clouds on the background level has not been clear yet, because the clouds started to appear just before the moon rise. In order to make it clear the effect, more detailed analysis or the observation at moonless night is necessary.

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