PROCEEDINGS OF SCIENCE

The Akeno Muon Observation: A Joint Research for Near Earth Space by Japan-India Collaboration

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It is well known that the ground based observation of cosmic rays is one of the best way to investigate the effect of solar activities onto the near earth space. The GRAPES-3 muon observation is one of such kind of observation which can probe the near earth space through the galactic cosmic rays at around 0.5 AU region with a statistical precision of $\sim 0.1\,\%/\mathrm{h}$. As per the very high statistics of the GRAPES-3 muon telescope, a tiny variation of 1 % level in the cosmic ray intensity caused by the solar wind plasma and IMF related to the solar activity can be detected. The Akeno muon telescope has a similar configuration of the detection technique as the GRAPES-3 muon telescope and the energy threshold for the incoming atmospheric muons too, though the total area is about 1/7th that of the GRAPES-3. Although the low statistics of the Akeno muon telescope compared to the GRAPES-3, the field of view of the Akeno muon telescope overlaps about 20 % of that of the GRAPES-3 at 25 earth radius. Utilizing the multidirectional observational capability of both the muon telescope with overlapping field of view, global anisotropy in the cosmic rays and its precise dynamics must be resolved at a time. This kind of observation must lead to not only the investigation into the basic mechanism of the cosmic ray propagation in the IMF, but also the prompt detection of the effect of a phenomenon caused by the solar activity.

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1. Introduction

Coronal Mass Ejections (CMEs), propelled by large-scale explosive events on the solar surface such as solar flares, evolve into the magnetic clouds characterized by intense internal magnetic disturbances. It is known that as these magnetic clouds travel the interplanetary space, they cause significant fluctuations in the surrounding interplanetary magnetic fields, giving rise to anisotropy in the spatial distribution of galactic cosmic rays. Consequently, continuous monitoring of this kind of anisotropy near Earth could potentially elucidate the spatial structure of solar wind plasma and its magnetic clouds and various phenomena associated with the interplanetary magnetic field (IMF). It is further hypothesized that such observations could significantly contribute to advancements in space weather forecasting. In this study, we have been observing galactic cosmic rays of low energy that are relatively susceptible to solar activity, from the Earth. The ground based observations involve the measurement of the muon components of secondary particles produced by galactic cosmic rays in the upper atmosphere. Thus, we conducted observations using a multi-directional muon telescope employing proportional counter tubes, which provides the highest angular resolution in experiments of this kind. The Loss-cone anisotropy of galactic cosmic rays, which was anticipated to appear in the direction of the interplanetary magnetic field, was detected at the same time by both the GRAPES-3 experiment in India and the muon telescope at the Akeno Observatory of Institute for Cosmic Ray Research [2]. Through a careful analyses, it was observed that a "Precursor Decrease" occurred 5 to 24 hours prior to the arrival of the CMEs, and a very high correlation was found between the direction of the anisotropy and the IMF in 7 events ($\sim 35\,\%$) [1]. Moreover, a correlation was also observed between the intensity of the "Precursor Decrease" and the subsequent "Forbush Decrease". Further, the analysis revealed that the Loss-cone anisotropy can be observed even in the cosmic ray intensity variations on usual days, suggesting that a more detailed analysis of these phenomena is necessary for space weather forecasting. Hence, we have constructed a multi-directional muon telescope at the Akeno Observatory in Japan. With this telescope and the GRAPES-3 muon telescope in India, we are attempting to jointly observe the anisotropy of galactic cosmic rays and a phenomenon caused by the solar activity (Figure.1).

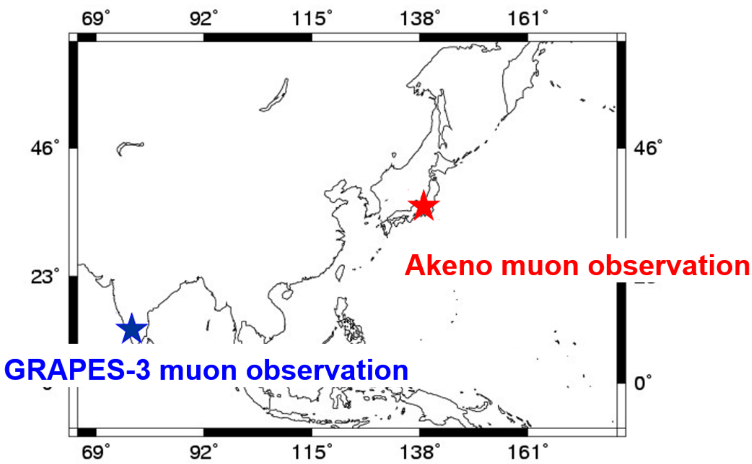

Figure 1: Japan-India joint observation for the atmospheric muons. The two observations are approximately 6,000 km apart in geographical longitude.

Observations by artificial satellites are exceptionally beneficial because they are located within the interplanetary space, allowing the direct measurement of physical quantities, such as solar wind velocity and interplanetary magnetic field. However, to understand the global structure of the interplanetary magnetic field, simultaneous observations by a multitude of satellites are required. This could imply that, with observations from only a few satellites, it is difficult to differentiate between temporal variations of the magnetic field structure and spatial variations due to the movement of the satellites' positions. In contrast, the large area muon telescope using proportional counter tubes used in this study is capable of capturing variations in the intensity of galactic cosmic rays coming from multiple directions, even as a single detector. Moreover, these detectors are independently operated at locations thousands of kilometers apart on the surface of the earth. By the simultaneous observations, not only the area covered by the telescopes increase, enhancing statistical precision and data reliability, but the combination of the Earth's rotation and the multidirectional observation of the detector also allows us to separate and analyze spatial and temporal variations in the intensity of galactic cosmic rays. Therefore, it enables us to investigate the three-dimensional structure of the interplanetary magnetic field that causes these cosmic ray intensity variations. Of course, in this study, there is still an uncertainty in the investigation of phenomena because we are observing the interplanetary magnetic field using cosmic rays as a probe. Therefore, it is necessary to analyze in conjunction with observational results from satellites and other observational equipments too.

In the space weather aspect, large-scale coronal mass ejections, caused by solar flare event, can induce rapid decreases in intensity of galactic cosmic rays (called Forbush decreases) and geomagnetic disturbances (called geomagnetic storms). These not only cause damage to man-made space crafts operating in outer space, such as satellites, but can also occasionally trigger significant blackouts on Earth, considerably affecting daily life for human being. Therefore, forecasting the arrival of magnetic storms is not only beneficial for protection of the infrastructure from a geomagnetic storm but also aids in acquiring valuable basic data for the physical processes of interplanetary space, which is a focus of recent research on space weather forecasting. Additionally, such data are useful as basic information for verifying the impact of solar activity on variations in the electromagnetic environment of interplanetary space. They also serve as essential data for investigating the possibility that such variations could become factors in changes in the Earth's environment.

2. Akeno muon telescope

The Akeno Muon Telescope operates at the Akeno Observatory of the Institute for Cosmic Ray Research consisting of three muon detectors. Each detector is installed within a concrete building located outside the Akeno observatory campus, called Muon Station. The concrete building of the Muon Station has a concrete ceiling and walls with a thickness of about 2 m, providing 1 GeV energy threshold for vertically incoming muons. The muon detectors are constructed with a 4-layer structure comprising proportional counter tubes, with the upper and lower layers arranged orthogonally to each other. This configuration allows us to record muon tracks with an angular resolution of about 10°. This technique is similar to that used in the GRAPES-3 muon telescope in India. The proportional counter tubes utilized at the Akeno Observatory have dimensions of 10 cm × 10 cm × 500 cm and contain P10 gas in it. Inside the proportional counter tubes, tungsten wires are placed at center, and a high voltage of about 2,800 V is applied to it. The atmospheric muons passing through the proportional counter tubes ionize the internal gas and generate electrical signals. The electrical signals produced by the proportional counter tubes have magnitudes proportional to the energy lost by the muons through ionization of the gas inside the counters (Figure.2). Within the 4-layer structure, a 30 cm spacer is installed between the lower two layers and the upper two layers (Figure.2). This provides the Akeno muon telescope with the same angular resolution and field of view as GRAPES-3 muon telescope. The concrete buildings of Muon Station are located outside the Akeno Observatory campus and are named M1, M5, and M8 (Figure.3), approximately 200 meters apart from each other in sequential order (Figure.4). The field of view of the muon detectors is finely divided into 169 directions based on the direction of the incoming muons. Depending on the specific phenomenon interested, the field of view may be coarsely divided into 9 directions. The 9-direction in the field of view is named accordingly, with NW, N, NE, W, V, E, SW, S, and SE representing each direction (Figure.2). The area of each detector is 25 m^2, resulting in a total detection area of 75 m^2 for the three detectors. This represents 1/7th of the muon detection area of the GRAPES-3 muon telescope [3]. The field of view of the Akeno muon telescope at point of 25 Earth radius, overlapping about 20 % with that of GRAPES-3 muon telescope. This enables the simultaneous capture of space weather phenomena occurring outside the Earth's magnetosphere, interplanetary space.

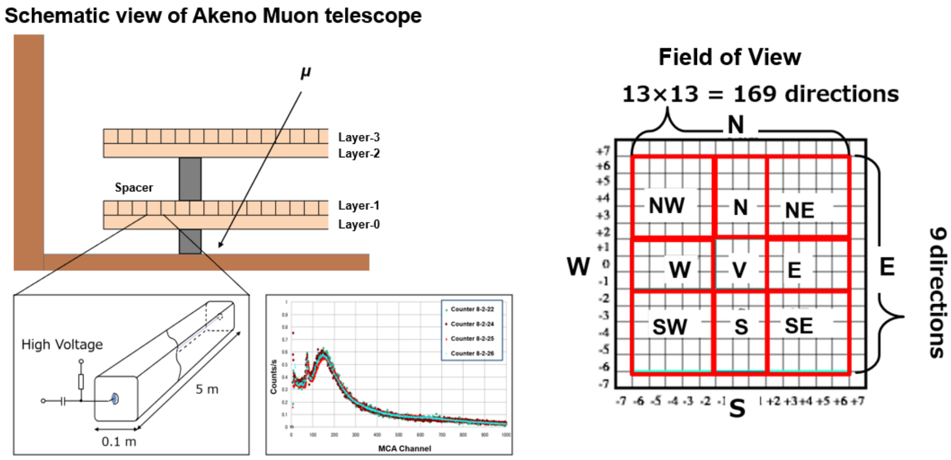

Figure 2: The schematic view of the Akeno muon telescope and its field of view with 169 directional bins and 9 directional bins. Proportional counter tubes used in the muon telescope are made of steel with 2.3 mm thickness filled with P10 gas. The pulse hight distributions show a clear single muon peak. A 30 cm thickness spacer are placed between the upper layer (Layer-2,3) and the lower layer (Layer-0,1).

3. Joint observation

Taking advantage of the overlapping field of views, both the GRAPES-3 muon telescope and the Akeno muon telescope conduct continuous observations. These two observations are located about 6,000 km apart, with a geographic longitude separation of 60 degrees (equivalent to 3.5

Figure 3: Three muon detectors are in operation at Akeno in Japan. They are housed in separate concrete buildings with 2 m thickness walls, called Muon Station. Each station can operate independently.

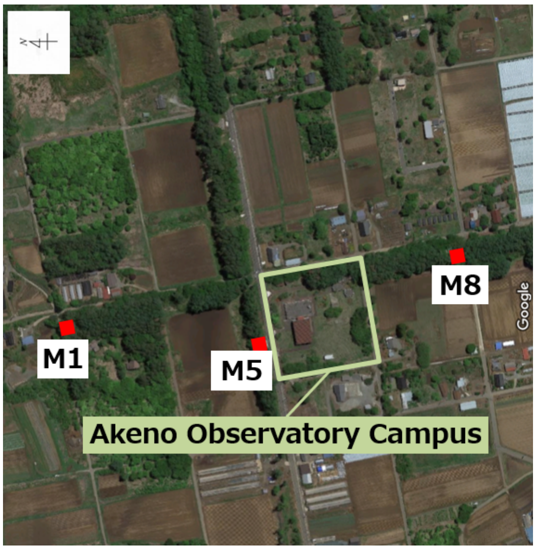

Figure 4: Whole view of the Akeno muon observation. Each Muon Station is installed outside the campus of Akeno observatory, with 200 meter distances between the stations in a north-south direction.

hours). This allows for the separation of the spatial structure and temporal variations of widespread phenomena at near Earth space that would be challenging to capture using a single telescope. As we mentioned in the Introduction section, the Loss-cone anisotropy of galactic cosmic rays, which was anticipated to appear in the direction of the interplanetary magnetic field, was detected at the same time by both the GRAPES-3 muon telescope in India and the muon telescope at the Akeno Observatory of Institute for Cosmic Ray Research [2]. With these Japan-India joint observations, recently we have successfully detected a phenomenon (Forbush Decrease) in which the intensity of cosmic rays decreases due to the M1 class flare that occurred on November 1, 2021 (Figure.5). Figure.5 illustrates the Forbush Decrease observed by the GRAPES-3 muon telescope and the Akeno muon telescope. The intensity of cosmic rays, as observed by both telescopes, shows a decrease over several days, followed by a subsequent recovery. In Figure5, the field of view of the muon telescope is divided into 9 directions, displaying the variations in cosmic ray intensity at each direction. The overlapping regions between the eastern field of view (NE, E, SE) of the GRAPES-3 muon telescope and the western field of view (NW, W, SW) of the Akeno muon telescope indicate that both telescopes are capturing the same variations in intensity. This observation shows that although the Akeno muon observation have lower statistical precision, when combined with the GRAPES-3 muon observations, it leads to an overall improvement in the observational accuracy and reliability.

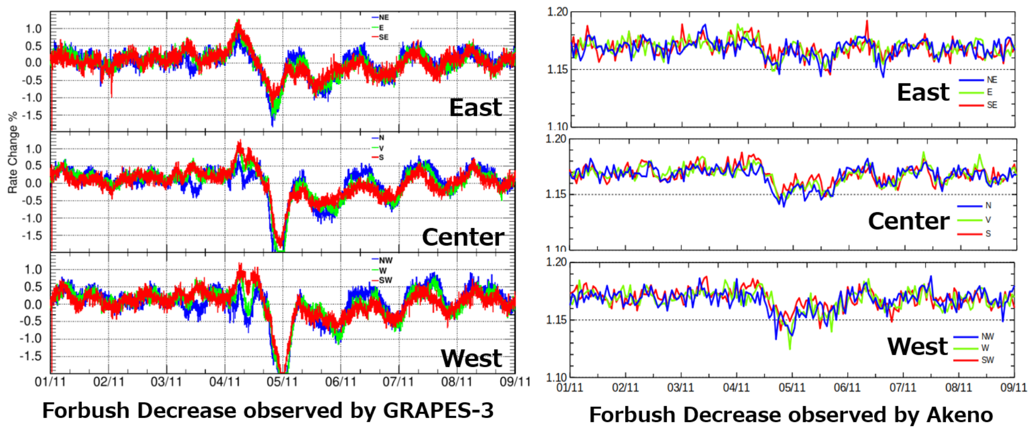

Figure 5: Space weather events captured by Japan-India muon observations. The Forbush Decrease (FD) caused by the M1 class flare that occurred on November 1, 2021 was detected by both the telescope. The left figure represents the FD detected by the GRAPES-3 in India . The right figure represents the FD detected by the Akeno Muon observation in Japan.

4. Summary

We are operating multi-directional muon telescopes using the proportional counter tubes for the three muon stations (M1, M5, M8) at the Akeno Observatory, Japan. With these telescopes and the GRAPES-3 muon telescope in India, we are attempting to jointly observe the anisotropy of galactic cosmic rays and a space weather related phenomenon caused by the solar activity. The GRAPES-3 muon telescope can probe near earth space through the galactic cosmic rays at around 0.5 AU region with a statistical precision of $\sim$ 0.1 %/h. As per the very high statistics of the GRAPES-3 muon telescope, a tiny variation of 1 % level in the cosmic ray intensity caused by the solar wind plasma and IMF related to the solar activity can be detected. Although the GRAPES-3 muon observation exhibit excellent statistical and angular resolution, there are some limitations to single-point observations, making it challenging to observe phenomena with structures extending beyond the field of view of the telescope and separate their temporal and spatial characteristics. Thanks to the field of view of the Akeno muon telescope at 25 earth radius, overlapping with that of GRAPES-3 muon telescope, it becomes possible to overcome these difficulties. The Akeno muon telescope has a similar configuration of the detection technique as the GRAPES-3 muon telescope and the energy threshold for the incoming atmospheric muons too, though the total area is about 1/7th that of the GRAPES-3. Although the low statistics of the Akeno muon telescope compared to the GRAPES-3, the field of view of the Akeno muon telescope overlaps about 20 % of that of the GRAPES-3 at 25 earth radius. Utilizing the multidirectional observational capability of both the muon telescope with overlapping field of view, global anisotropy in the cosmic rays and its precise dynamics must be resolved at a time. This kind of observation must lead to not only the investigation into the basic mechanism of the cosmic ray propagation in the IMF, but also the prompt detection of the effect of a phenomenon caused by the solar activity. The combination of both India (GRAPES-3 muon telescope) and Japan (Akeno muon telescope) is expected to provide a clearer understanding of the three-dimensional structure of solar wind effects in interplanetary space.

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