Parallel and simultaneous EASs at large distances due to Gerasimova-Zatsepin effects of cosmic ray heavy nuclei

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Abstract: Extensive air showers (EASs) produced by primary cosmic ray energies above the KNEE energies have been observed at multiple EAS observatories simultaneously scattered in Japan since 1996. The typical EAS array has been located at the rooftop of the buildings in the university campus, and has GPS disciplined 10 MHz oscillator which provides the UTC time stamp for each EAS event within a few μs accuracies. Searching for simultaneous and parallel EAS events at multiple EAS observatories due to Gerasimova-Zatsepin (GZ) effects have been carried out by comparing EAS arrival time stamps and directions detected by several baseline combinations of EAS arrays. The EAS pairs whose time difference and angular distance were less than 5 ms and less than 15 degree respectively, were selected and their angular distances from the solar direction and the lunar direction were examined. Consequently, significant excesses of these events in the solar direction as expected in the numerical prediction of GZ effects were not found.

Keywords: cosmic ray nuclei, Gerasimova-Zatsepin effect, large area air shower.

1 Introduction

The origin, acceleration mechanism and propagation processes of ultra-high energy cosmic rays has been a fundamental question for many decades, and it still is an unresolved mystery in the field of ultra high energy astrophysics. Above the cosmic ray primary energies of 10^{15} eV, direct measurements of cosmic ray energy and identifications of cosmic ray particle species have been impossible. In order to estimate their energy and mass compositions, the EAS observations at the sea level or high altitude mountains have been carried out. In these experiments, statistical approaches to derive cosmic ray composition are used. But, these approaches depends on the hadron interaction model because accelerator data are not available in these ultra-high energies.

The alternative approach to derive the mass composition of cosmic rays is as follows. The photo-disintegration process of cosmic ray nuclei with solar photons, allows directly exploring the mass composition of cosmic ray at energies above 10^{18} eV, if the multiple, parallel and simultaneous EAS events due to fragment particles can be registered at several observatories. This idea originally came from the idea of Zatsepin and Gerasimova [1, 2]. This process is known as the Gerasimova- Zatsepin (GZ) effect and several numerical studies of this effects have been carried out in the past two decades [3, 4, 5, 6].

To study the GZ phenomena, the Large Area Air Shower (LAAS) experiments have been established by Kitamura et al [8]. in 1995. The LAAS EAS arrays are scattered over in Japan and are located at the sea-level atmospheric depth, and they have been operated since 1996. These arrays have been synchronized with each other within the accuracy of one microsecond by using GPS-disciplined UT time stamp system. This system enables to observe both simultaneous and parallel EAS events at multiple EAS arrays. The threshold energy of primary cosmic rays in our array is around PeV. Thus, LAAS experiments are suitable for investigating the GZ events.

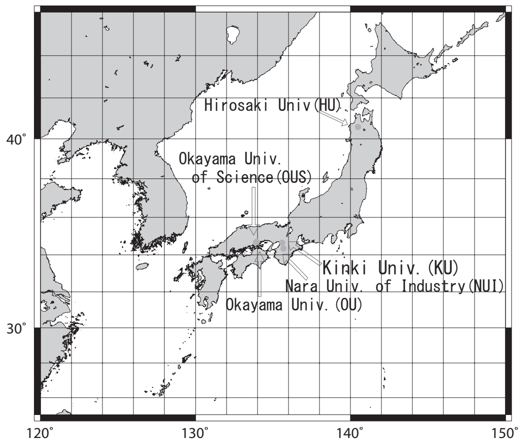

Figure 1: The geographical positions of EAS arrays with the institution names in Japan.

In this report, the LAAS experimental apparatus are briefly described. The results of data analysis for identifying the GZ candidate events are discussed.

Table 1: The geographical location and mutual distances between LAAS EAS arrays

Institute	Abbreviation	Latitude(N)	Longitude(E)	Distance[km] from		
				HU	KU	OUS
Hirosaki University	HU	40° 35'	140° 29'	-	787	872
Kinki University+	KU	34° 39'	135° 36'	787	-	152
Nara University of Industry	NUI	34° 35'	135° 41'	788	11	161
Okyama University*	OU	34° 41'	133° 55'	873	153	1
Okyama University of Science	OUS	34° 42'	133° 56'	872	152	-

+:moved to NUI and * :moved to OUS in 2008.

2 Experiments

2.1 Array setup

The LAAS experiments [7, 10] are the joint projects of compact EAS arrays maintained at multiple institutes in Japan. These arrays are deployed in Japan from 34° N to 40° N and 134° E to 140° E shown in Fig. 1. Those mutual baselines are ranging from 0.1 km to 1000 km. The geographical location and mutual distances from the specified EAS arrays are listed in Table 1. In the fifth to the seventh columns of Table 1, we specified mutual distances measured from HU(Hirosaki University), KU(Kinki University) and OUS(Okayama University of Science) sites respectively.

In each institute, the EAS arrays are located at the rooftop of buildings in university campus. The array typically consists of eight plastic scintillation detectors whose size is $50 \times 50\,\mathrm{cm}^2 \times 5\,\mathrm{cm}$. The detectors are deployed over a rooftop area of approximately $200\,\mathrm{m}^2$.

The data acquisition system is triggered when each of more than 3 detectors are hit within 100ns time window. The relative arrival times of EAS front particles are digitized with a CAMAC TDC (Kaizuworks Model 3780) with the resolution of 40 ps. The local density of EAS particles is digitized with a CAMAC ADC (Lecroy Model 2249W), of which dynamic range is limited to less than 10 particles. The typical trigger frequency is about 0.1 to 0.5 Hz at each array. The time stamp of each EAS event is registered by using a CAMAC GPS timing module (Kaizuworks Model 3850A), which maintains GPS-disciplined oscillator of 10 MHz frequency and provide the accuracy of UT time stamp less than 1μs at each EAS array.

The EAS arrival direction is determined by fitting the plane equation to EAS particle arrival times calculated from TDC values. It is unlikely that the EAS core location and shower size could be obtained, because of the limitation of EAS array dimensions and ADC dynamic ranges. Thus, the arrival direction angle and UT time stamp of each EAS event are analyzed in the following physics analysis.

2.2 Extension of LAAS arrays in Okayama area

The LAAS group has operated several EAS arrays in Okayama University (OU) and Okayama University of Science (OUS). One array was set up in the campus of OU and three arrays have been deployed in that of OUS which are abbreviated as OU, OUS1, OUS2 and OUS3, respectively. The distance between OU array and OUS arrays is almost 1 km, and the mutual distances between OUS arrays are about one hundred meter. It was expected that ultra-high energy EAS might be detected by both OU array and some of OUS arrays, and relatively higher energy EAS could hit multiple EAS arrays among the OUS arrays.

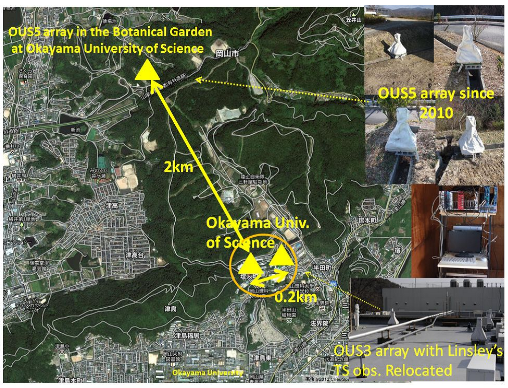

Figure 2: LAAS EAS arrays in Okayama University of Science. Most distant EAS array(OUS5) is located at 2 km distance away from the university campus in the Botanical garden of Okayana University of Science.

In 2006, to constrain the zenith angle distribution of primary cosmic rays observed by OUS1, the OUS4 array were constructed in the ground floor of four-storied building in the OUS campus. The OUS4 can select EAS events of which zenith angle is less than 23.5deg. The OUS1 and OUS4 can measure the EAS size and dispersion of the arrival time of EAS particles. These data can determine EAS energy by using Linsley's time structure method [9, 11]. Because of shutting down the the OU array in 2008, the new OUS5 arrays were constructed in the Botanical garden of Okayama University of Science, shown in Fig. 2, of which distance from OUS campus is about 2 kilometers. The mutual combination of these five EAS arrays can provide primary energy information ranging from PeV to EeV to search the coincidence of EAS events.

3 Data Analysis

In order to search simultaneous EAS events at multiple sites within one kilometer baseline in Okayama area, the analysis of time differences of EAS pairs are used. By applying these procedures to LAAS long baseline observations and adopting event selection criteria predicted by numerical approaches, it will enable to identify simultaneous EAS events at long baseline EAS sites. Therefore, we have applied the following event selection criteria for our observation data:

1. the number of coincidence counters was larger than 5 corresponding to the threshold energy of 5 PeV,

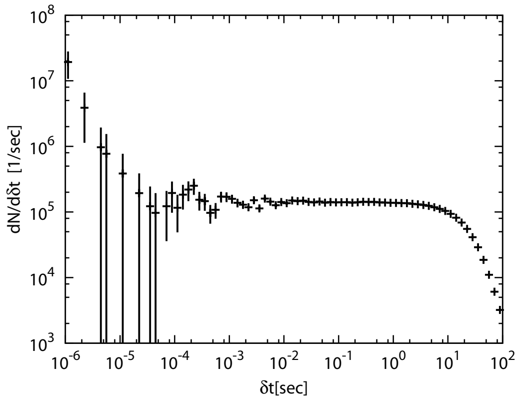

Figure 3: Observed time difference distribution between OU and OUS(1km distance)

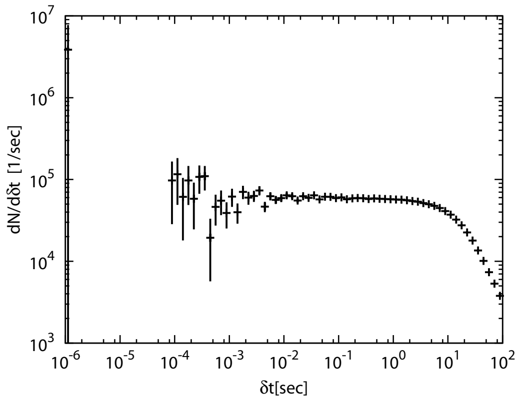

Figure 4: Observed time difference distribution between KU/NUI and OU/OUS(180 km distance)

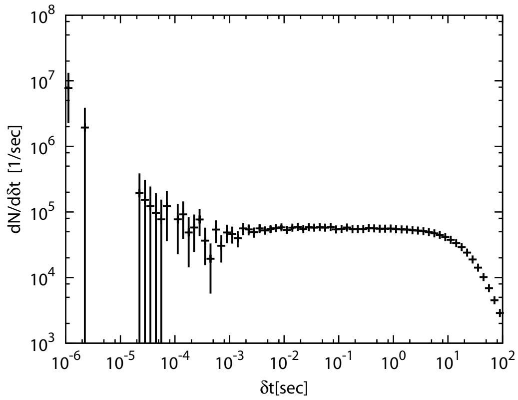

Figure 5: Observed time difference distribution between HU-KU/NUI/OU/OUS (800 km distance)

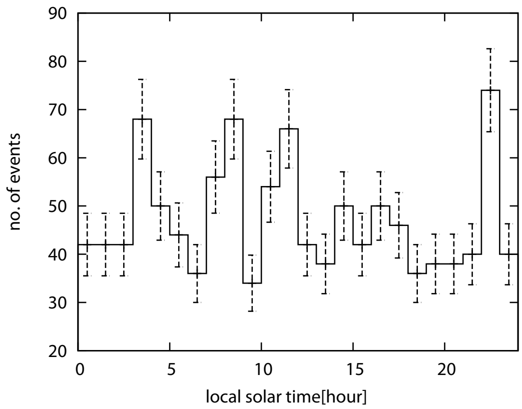

Figure 6: Arrival time distribution of long baseline event pairs in local solar time

2. the baseline lengths were limited to more than hundred km,

3. the time difference of EAS events were smaller than 5 ms which came from the mutual geographical locations of EAS sites.

The data period is from Sept. 1996 to Nov. 2011.

4 Results

To obtain the candidates of GZ event, the condition described in Sec. 3 were applied for data analysis. The obtained time difference distributions are shown in Figs. 3, 4 and 5. These exponential decreasing is expected from the randomness of EAS arrival time distributions. While statistical fluctuations are seen in the time range below several ms time differences, the small enhancement of EAS pairs are observed even in the large baseline cases.

In this analysis, we selected 1120 EAS event pairs as GZ candidate events within the time difference window of five millisecond from the combination of EAS arrays between HU and KU/NUI/OU/OUS.

According to simulation studies, the possibilities of GZ event depends on the angle between solar direction and the direction of cosmic ray travel when EAS pairs arrived at the earth, and they might maximize when the solar direction is equal to the direction of cosmic ray travel. We examined the selected GZ candidate's arrival time as a function of local solar time shown in Fig. 6. The frequency of GZ candidate events distributed uniformly instead of expected maximizations at the solar direction and the anti-solar direction . Some double peak structures are also seen int the midday time and the midnight time. Although these structures are not significant statistically, they are located around expected enhancements of GZ effects. To compare the non-solar variation, we calculated the event rate as a function of local sidereal time shown in Fig. 7. The GZ event rate also seems to be uniform as a function of local sidereal time.

Finally, we examined the seasonal variation of GZ candidate events were shown in Fig. 8. Simulation study suggested that the high altitude season of the Sun could yield high probability of GZ event creations. The obtained data shows large structure due to atmospheric pressure variation.

5 Conclusion

The LAAS project has carried out GZ candidate searches with GPS synchronized arrays by selectiong both arrival directions of EAS and time differences of EAS pairs. We applied 14deg angular distance restriction and five millisecond time differences to select EAS events in this analysis and we have finally analyzed 1120 EAS pairs when the distance between arrays were more than 150 km. These extension of EAS array combinations to long baseline EAS

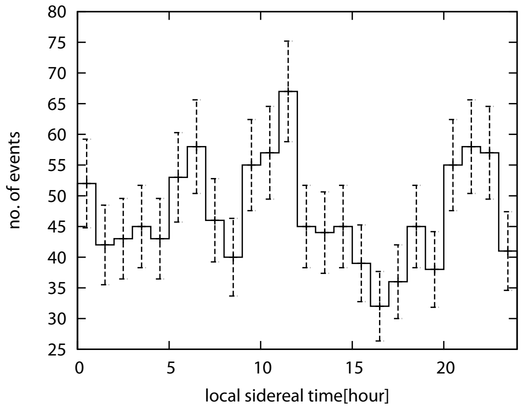

Figure 7: Arrival time distribution of long baseline event pairs in local sidereal time

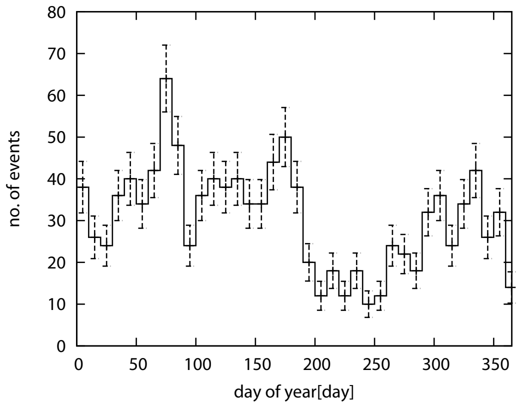

Figure 8: Yearly variation of long baseline event pairs

sites allows searching simultaneous EAS events. Using LAAS's one decade observation data, we have selected EAS pairs like Gerasimova-Zatsepin effects under the limitation of time differences of EAS pairs.

We compare obtained angular distance distributions around the solar position as a function of local solar time. The significant excesses in solar direction and anti-solar direction were not found, and the distribution seems to be uniform. However, some structure can be seen around local midday time and midnight time in local solar time analysis. The obtained GZ pair distribution as a function of local sidereal time however seems to be more uniform.

References

[1] G. Zatsepin, Dokl. Akad. Nauk. SSSR, 1950, 80, 557-578.
[2] N. Gerasimova and G. Zatsepin, Soviet Phys., 1960,JETP 11, 899.
[3] G. Medina-Tanco and A. Watson, Astropart. Phys., 1999,10, 157-164. doi: 10.1016/j.nuclphysbps.2005.07.015
[4] L. Epele, S. Mollerach and E. Roulet, J. of High Energy Phys., 1999, 3, 17-31. doi: 10.1088/1126-6708/1999/03/017
[5] Y. Fujiwara et al., Nucl. Phys. B(Proc. Suppl.), 2006, 151, 481-484. doi:10.1016/j.nuclphysbps.2005.07.084
[6] S. Lafébre, H. Falcke, J. H́orandel, and J. Kuijpers, A & A, 2008, 485 1, 1-4. doi: 10.1051/0004-6361:200809468
[7] N. Ochi et al., J. Phys. G:Nucl. Part. Phys., 2003, 29, 1169-1180. doi:10.1088/0954-3899/29/6/316
[8] T. Kitamura et at., Atropart. Phys., 1997, 6, 279-291. doi:10.1016/S0927-6505(96)00062-X
[9] H. Matsumoto et al., Nucl. Inst. Method A, 2010, 614, 475-482. doi:10.1016/nima.2009.12.080
[10] A. Iyono et al., Astrophys. Space Sci. Trans., 7, 327-333, 2011 doi:10.5194/astra-7-327-2011
[11] Astrophys. Space Sci. Trans., 7, 335-344, 2011 doi:10.5194/astra-7-335-2011