Search for large-scale coincidences of EAS in LAAS experiment

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Abstract

To search for signals from extreme short bursts in the universe, we have performed the large-scale coincidence analysis, using EAS data from five stations of the Large Area Air Shower (LAAS) group. By comparing arrival times and arrival directions of EAS detected at distant stations, coincident and parallel EAS pairs were extracted out of a sea of background cosmic rays. One of them was intriguingly observed from directions consistent with the Crab Nebula, a previously reported UHE γ-ray source. The preliminary results reported here allow the analysis techniques to be tested and demonstrate the potential of observations with the full operation of the network detector system as a cosmic ray interferometer.

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pp. 191–194

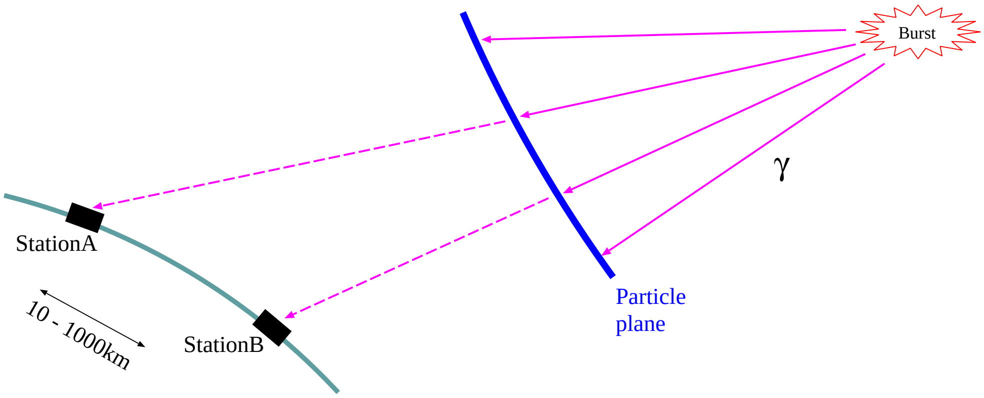

Fig. 1. A hypothetical sketch of a coincident and parallel EAS event observed by the LAAS system.

1. Introduction

The Large Area Air Shower (LAAS) experiment is searching for correlations in UHE cosmic rays over a very large area, using eleven compact air shower arrays scattered over Japan. As one of such correlations, large-scale coincidences of EAS are studied in this report. We search for pairs or groups of coincident and parallel EAS observed by stations separated by 1–900km, as illustrated in Fig. 1. Possible sources for such events include very short bursts of active stars, γ-ray bursts and decay products from EHE cosmic rays ("the GZ effect" [2]). Our earlier results on this topic can be found elsewhere [3]. Recently, the Baksan group reported the detection of short bursts of Mrk 501 by employing an analytical procedure similar with that described here [1]. Their result also demonstrates the potential of this analytical scheme to detect burst signals.

2. Experiment and Data

Details of the LAAS project are given in [3, 4]. In this paper we use EAS data taken at five stations of the LAAS group, as listed in Table 1. Each station has 4–8 scintillation counters and a GPS receiver, which provides time stamps of EAS triggers with accuracy of 1μs. The stations are separated by 1.1–873km from each other, much larger than a lateral span of EAS induced by UHE cosmic rays; thus we treat datasets from different stations as independent. The counter arrangement and the trigger condition of OU and OUS1 arrays were modified twice, so we have three datasets for these stations each. Simulated by the CORSIKA code, the angular accuracy of the arrays is 7–10° and the mean energy of detected EAS is 600–1000 TeV [3]. For the analysis, the shower restriction of $\theta \leq 45°$ is applied.

Table 1. The LAAS stations and data. († EAS with $\theta \leq 45°$).

	Dist. (km) from		Trig. rate	# of counters		
Station	OU	KU1	(/24h)†	Total	Trig.	Data period
HU	873	787	566	5	5	11/1998 – 05/2002
NUI-a	162	11	304	7	7	08/1996 – 07/1998
NUI-b	162	11	439	7	7	11/1998 – 05/2002
KU1	153	—	446	5	5	09/1996 – 05/2002
OUS1-a	1	152	727	4	4	09/1996 – 11/1997
OUS1-b	1	152	308	8	8	11/1997 – 01/1999
OUS1-c	1	152	722	8	4	01/1999 – 05/2002
OU-a	—	153	565	8	5	09/1996 – 12/1999
OU-az	—	153	1162	8	3	01/2000 – 03/2000
OU-b	—	153	1295	8	3	04/2000 – 05/2002

3. Analyses and Results

3.1. Search for coincident EAS

First we search for coincident EAS pairs/groups by comparing arrival time differences (TD). For each combination of 2–5 stations, TD of any EAS pair/group (one EAS from each station) are calculated with accuracy of 1μs. In case of 3–5 stations, the maximal TD in the EAS group is taken as the TD of the group. Then the distribution of TD is produced and excess of very small TD events is searched. This procedure is carried out independently for 85 station-combinations. As an example, Fig. 2. (left) shows the TD distribution for KU1–HU (histogram). As expected from chance coincidences, the distribution decays with TD exponentially. No significant excess of small-TD events is found from any station-combinations. However, in some cases we can see extraordinarily small-TD events, as is shown in Fig. 2. (left) by the arrow. Events (A), (B) in Table 2. are such events selected by this analysis. p in Table 2. is the chance probability calculated from the slope of the chance coincidence distribution. P is the resultant chance probability taking into account the number of station-pairs. No single event has enough significance to claim the detection of correlated EAS.

3.2. Search for coincident and parallel EAS

Next we pick up EAS pairs/groups with small angular distances (AD) in addition to small TD. The analytical procedure is the same as the above one, but only EAS pairs/groups with AD$\leq 10°$ are accepted to the TD distribution. In case of 3–5 stations, the maximal AD in the EAS group is taken as the AD of the group. As an example, Fig. 2. (right) shows the TD distribution for OUS1-b–

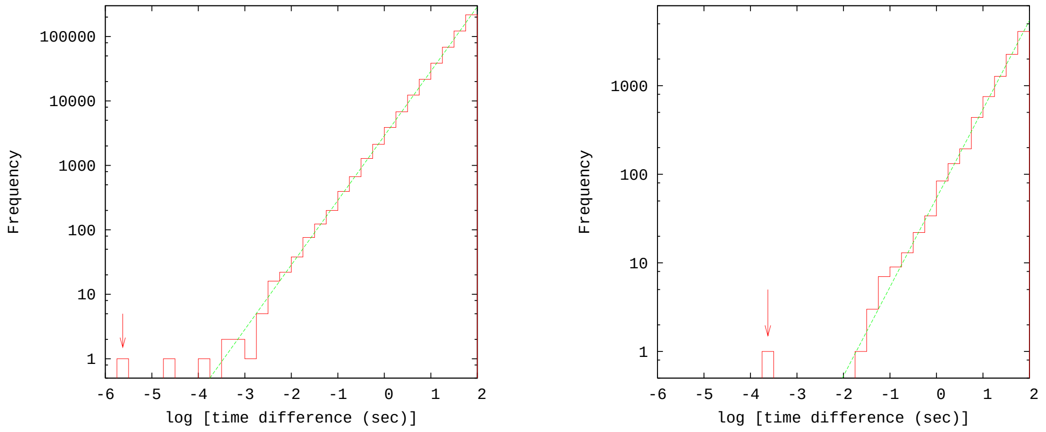

Fig. 2. TD distribution for KU1-HU (left) and OUS1-b–KU1 (right) under AD≤ 10°.

Table 2. The parameters of correlated EAS candidates.

ID	TD (sec)	AD (°)	Stations	Date,Time	α	δ	θ	p	P
A	0.000003	39	HU	10/16/2001	154	55	22	0.020	0.82
			$\hookrightarrow$KU1	3425.63979	159	11	28		
B	0.000007	23	OUS1-c	12/12/2001	244	30	6	0.11	> 0.9
			$\hookrightarrow$OU-b	8085.06994	267	45	17		
C	0.000195	6	OUS1-b	09/24/1998	85	16	19	0.025	0.88
			$\hookrightarrow$KU1	73332.795	81	19	16		
D	1.691356	8	NUI-b	01/14/1999	187	19	21	0.15	> 0.9
			$\hookrightarrow$KU1	74821.	183	26	18		
			$\hookrightarrow$OU-a		188	23	16		

KU1 (histogram) under restriction of AD≤ 10°. Events (C), (D) in Table 2. are extraordinarily small-TD events picked by this analysis. No event is significant enough, but we note that the event (C) was intriguingly detected from directions consistent with the Crab Nebula. If it is confirmed that this feature is caused by UHE γ-rays from the Crab, a strong constraint would be imposed on the emission mechanism of the object. Part of this work was supported by the Frontier Project of the Ministry of Education, Science, Sports and Culture of Japan.

4. References

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