New analysis of arrival time of successive air shower by using Erlang distribution

TAKAHIRO GONOHE,[1] NAMIKI TAKAHASHI,[1] KUNIYUKI ISHIOKA,[1] NOBUSUKE TAKAHASHI,[1]
[1]*Graduate School of Science and Technology, Hirosaki University*
taka@cc.hirosaki-u.ac.jp
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Abstract: We analyze arrival time and its direction of successive air showers in Hirosaki Air shower (AS) array. This array consists of five scintillation detectors with GPS antenna for arrival times. We have studied the features of series of air shower events (AS cluster) concentrated within short intervals of arrival time by using Erlang distribution. The Erlang distribution [7] was developed by A. K. Erlang to examine the number of telephone calls which might be made at the same time to the operators of the switching stations. The distribution is now used in the fields of stochastic processes. We report the results of analysis by Erlang and Poisson distribution.

Keywords: Air shower, AS cluster, Erlang distribution

1 Introduction

We analyze arrival time of air shower using Hirosaki AS Array which consists of 5 scintillation detectors and GPS(Location: $40^\circ 35'$ N, $140^\circ 28'$ E, 63m from sea level)[4]. By using the GPS, we can record arrival times of air showers with an accuracy of 1 micro second. Any 3-folds coincidence within 100 nano seconds is used on the trigger condition for air shower events. Each data of 3-folds coincidence, 4-folds coincidence and 5-folds coincidence are obtained by analysis of Any 3-folds coincidence. The event rate is 3600 / day. Some special successive air shower events are recorded in short term among observation data which we will be explained later. N.Ochi et al. group [2] and T.Konishi et al. [1] reported that the arrival direction of such the successive air showers tends to concentrate to the Galactic plane. Relating to their reports we analyzed similar problems by Erlang distribution. The period from April 25, 2005 to April 25, 2006 were selected for analysis. When we carry out analysis of Erlang distribution, we always use 5-folds coincidence data. In this time, the new attempt we did analysis of Erlang distribution by using each data of Any 3-folds coincidence, 3-folds coincidence, 4-folds coincidence, 5-folds coincidence.

2 Analysis by using Erlang distribution

Let us explain how to utilize the Erlang distribution for extracting the peculiar feature of successive air shower events. Here we sample successive air shower events, for example, five events. We take the time difference of No.1 event to No.5 event as first sample, that of No.2 to No.6 as the second, that of No.3 to No.7 as the third and so on. From these samples we obtain a frequency distribution of successive air shower events. In Fig.1, we compare the frequency distribution with Erlang distribution and found significant difference between observation and the expected from Erlang distribution. We found significant discrepancy in smaller time difference, as shower in Fig.1.

Erlang distribution function is following

$$f(t_k) = \frac{\beta^\gamma t_k^{\gamma-1} e^{-\beta t}}{(\gamma-1)!},$$

where, t_k is a time before k successive air shower events arrive, β is $< t_k > / \sigma_k^2$ and γ is $< t_k >^2 / \sigma_k^2$. $< t_k >$ is average of t_k and σ_k is standard deviation.

Condition of this analysis has become like this: The first, the number of successive air shower events is from 3 to 100. The second if frequency of the time difference of consecutive shower exceeds the expected more than certain times (n times) , we consider as AS cluster candidates. However, if AS cluster candidates across the same period are obtained in each data, candidates for greater ratio are chosen as AS cluster candidates. For further information is in the Table1.

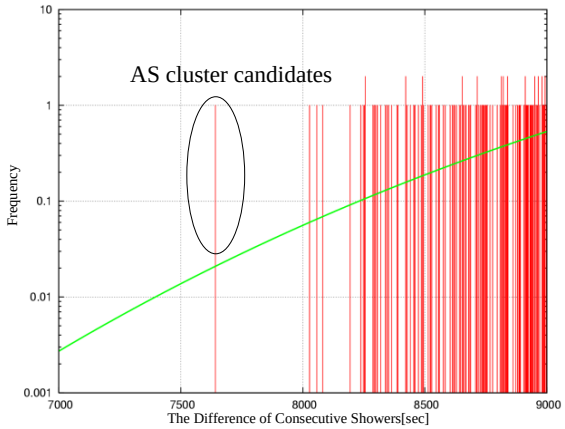


Fig1: The frequency distribution and Erlang distribution (5-folds coincidence, k =78, $< t_k >$=14256.13)

Table1:List of data used in this analysis

Data condition	n times	Data number
Any 3-folds coincidence	10	1223743
3-folds coincidence	10	773843
4-folds coincidence	30	289018
5-folds coincidence	40	160882

The AS cluster candidates data obtained in this way which are showed in Fig2 and Table2.

Table2: Detail of AS cluster candidates with Erlang distribution

Any 3-folds coincidence

No.	arrival time(UTC Date-Time)	*events(k)*	average time[sec]	elapsed time[sec]
1	2005/05/04-07:49:05~07:49:28	11	243.70	22.85
2	2005/05/25-03:28:57~03:31:48	30	706.73	170.43
3	2006/03/30-19:10:17~19:10:30	10	219.33	13.49

3-folds coincidence

No.	arrival time(UTC Date-Time)	*events(k)*	average time[sec]	elapsed time[sec]
4	2005/05/06-12:04:15~12:16:23	46	1734.23	728.11
5	2005/05/25-03:28:57~03:31:16	20	732.21	138.46
6	2005/10/22-09:43:13~09:53:22	41	1541.53	608.34

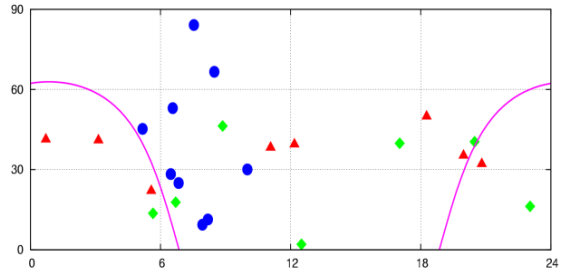
4-folds coincidence

No.	arrival time(UTC Date-Time)	*events(k)*	average time[sec]	elapsed time[sec]
7	2005/07/06-13:58:35~13:59:42	9	825.34	66.70
8	2005/12/19-11:00:09~11:08:51	21	2063.40	521.60
9	2006/03/28-21:13:20~22:21:45	85	8667.28	4105.57

5-folds coincidence

No.	arrival time(UTC Date-Time)	*events(k)*	average time[sec]	elapsed time[sec]
10	2005/07/02-19:32:13~19:42:31	16	2778.60	618.11
11	2005/07/06-14:14:29~16:21:50	78	14256.13	7641.08
12	2005/08/08-07:32:11~07:34:13	9	1482.02	122.29
13	2005/12/09-21:16:52~21:26:48	16	2778.60	595.79

No.1



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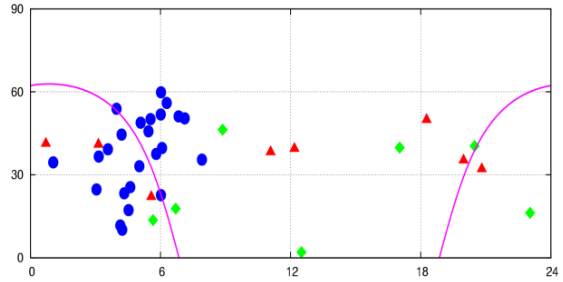

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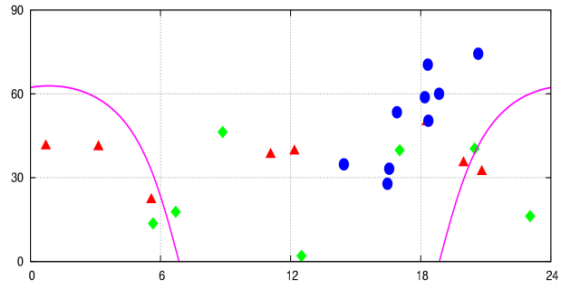

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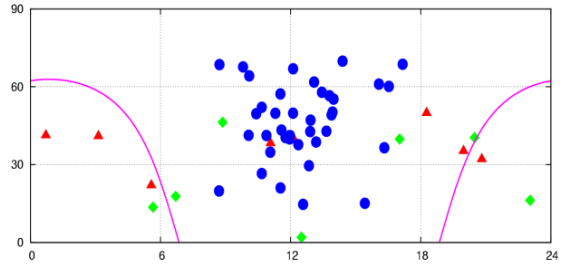

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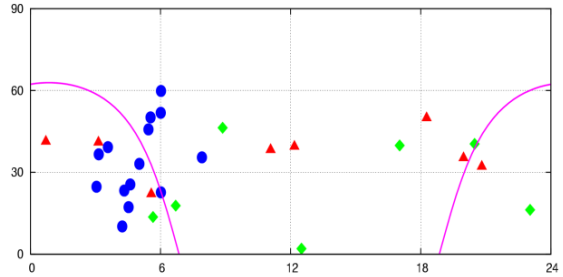

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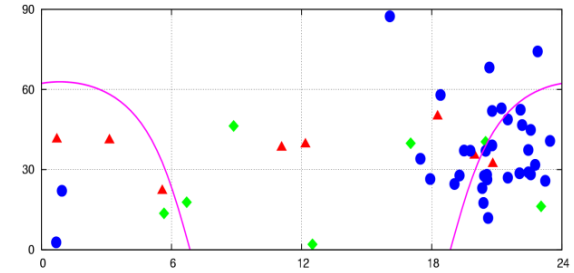

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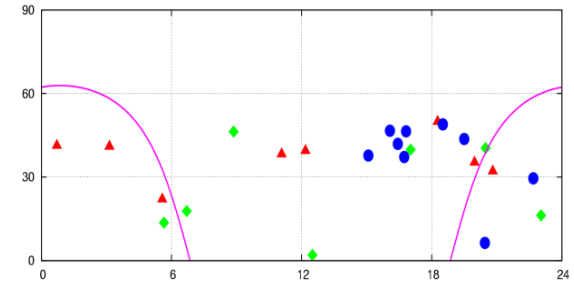

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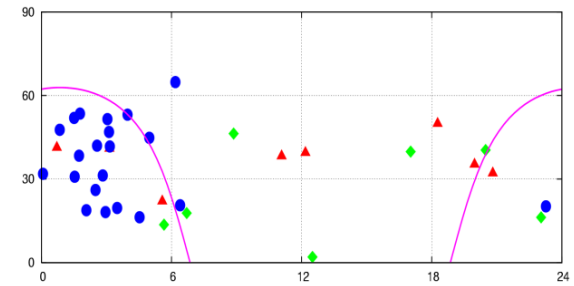

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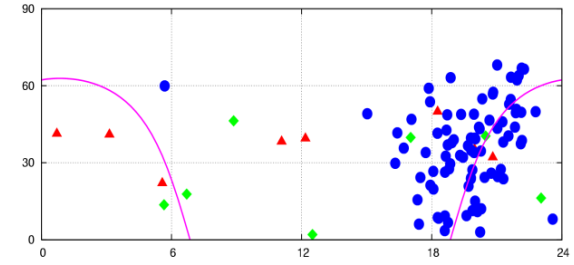

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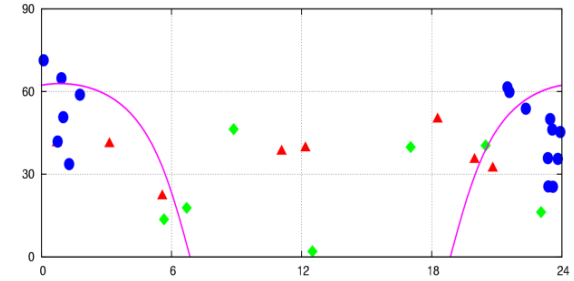

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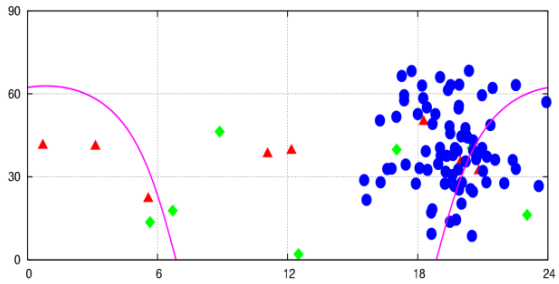

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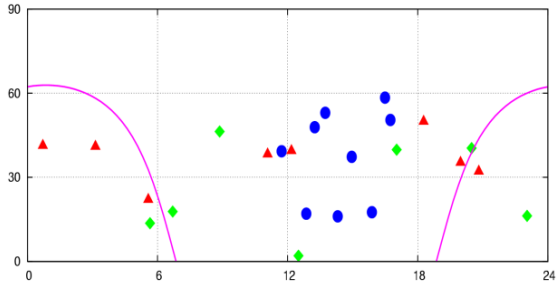

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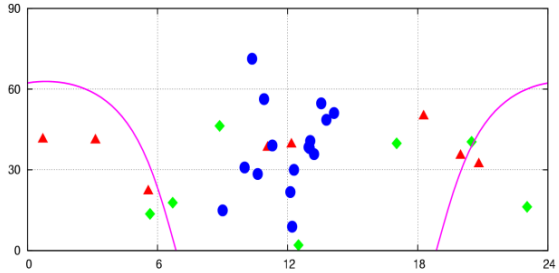

Fig2: Arrival direction of AS cluster with mainly resources of x-ray(triangle) and gamma-ray(rhombus)

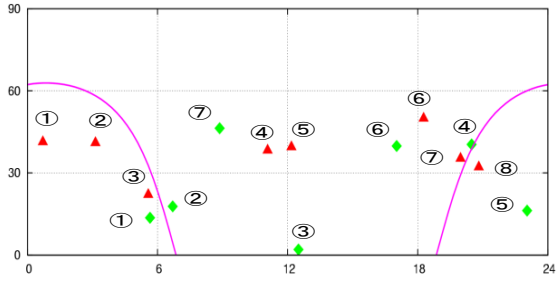

Fig3: Mainly resources of x-ray and gamma-ray,
Symbols of triangle: mainly resources of x-ray,
①M31, ②Algol,③Crab Nebula,④Mkn421,⑤NGC4151, ⑥AM Her, ⑦Cyg X1, ⑧Cygnus loop (q.v. [6]).
Symbols of rhombus: mainly resources of gamma-ray,
① 3EG J0530+1323, ② 3EG J0633+1751, ③ 3EG J1229+0210, ④3EG J2020+4017, ⑤3EG J2254+1601, ⑥TeV 1654+3946, ⑦TeV 0852-4622 (q.v.[6]).

3 Consideration of AS cluster events

In Table2, AS cluster events at random which are independent of time. And in Fig2 the arrival direction is concentrated in particular direction. Some of these are in galactic plane and the others from other than the direction of galactic plane. The various stars are concentrated in galactic plane. On the other hand, gamma-ray and x-ray resources in various places (Fig3). By the way, Smith. et al.[5] described that AS cluster in only short term are existing. However, there are AS cluster in longer term in our results of analysis.

4 Consideration of Erlang distribution procedure and method of this analysis

There are two algorithm of Erlang distribution and Poisson distribution to get the AS cluster candidates. Nevertheless, we reported only analysis results of Erlang distribution. Because, Erlang distribution procedure is more useful than Poisson distribution procedure. There are two parameters by which one analyzes the events concerned, with constant time interval and searching of the total time interval in the case of Poisson distribution, while there is only one parameter, the time difference between successive air shower events. We consider that analysis of data for each condition are effective for obtaining more AS cluster candidates data , because the data is fewer and it is difficult to get the data.

5 Conclusion

We consider AS cluster are mainly gamma-ray and x-ray which are no effect of magnetic field. And, AS cluster are not only in short term but also in long term. There may be larger events because we analyzed to only 100 events in this time. Finally, using Erlang distribution, we could get the AS cluster candidates without missing them.

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