A study of a phenomena deviated from random feature in EAS energy around 100TeV with new Kinki Array

Michiyuki Chikawa[1,2]
Takeshi Goya[1], Yuichiro Morizane[1]
Hiromitsu Takama[1], Shigekazu Sakida[1], Kenji Yasui[1]
Yukihiro Kato[1], Takashi Kitamura[2]
Takeharu Konishi[1], Katsufumi Tsujies[1]
[1] *Department of Physics, Kinki University*
Higashi-Osaka, Osaka 577-8502, Japan
[2] *Research Institute for Science and Technology*
Higashi-Osaka, Osaka 577-8502, Japan

(Received November 26, 1998)

Abstract

An EAS observation system was rebuilt in July 1998 at Kinki University which consists of seven $0.25m^2$ plastic scintillators with fast PMTs. The system works well to detect EASs energy around $100TeV$ at sea level. In the observation of more than 10^3 hours, the detector records some phenomenae deviated from average feature in triggering rate, which means each series of the events has extremely small expected frequency in short term data acquisition period. For number of total events this set of consequtive events with upper limit of significant level of 3.6×10^{-2} was found. Although this is not strong evidence deviating from random Poisson distribution, but it has a value of 5σ from average rate.
The new Kinki Array is reported briefly and this phenomena is also reported in detail.

Key words: HE EAS, non-random component, consecutive EAS

1 Introduction

There have been published many reports on excess of event from expected feature in poisson random process [1, 2, 3]. One of them reported an existing of burst of 32 EASs in PeV energy within a 5 minutes time interval. They claimed the probability of such phenomena was 10^{-35} for assumption of each independent EASs[1]. And more other experiment was reported suggesting a possibility of an existing of non-random component for time separation $< 40s$ in EAS above $10^{14}eV$ in the region of specific celestial coordinate [3].

2 Experimental Set Up

Since 1989 we have been searched non-random phenomenae in extensive air showers(EAS) events from 1989 using compact detector with $CAMAC$ electronic circuit. It had four $0.25m^2$ and four $1m^2$

plastic sintillation detectors. We have been published some reports elsewhere [4]. It had been worked till the end of 1996 when some parts of electric circuit were moved to another location.
We restablished a new observation system in July 1998 at Kinki University (135.530E, 34.649N) at sea level. The system is consisting of seven $0.25m^2$ plastic scintillation detectors with PMT as the fast triggering detectors at vertice of two equilateral triangles and its centre as shown in Fig.-1. The length of sides are about $20.5m$ and $10.3m$ for large triangle and for small triangle respectively, the area is about $182.6m^2$. A block diagram of the electronic circuit is shown in Fig.-2. The data acquisition is performed by $NIM - CAMAC$ electronics which is controlled by using $CAMAC$ computer system. It also has a $CAMAC$ basesd GPS(Grobal Positioning System) module to record arrival time of the EAS in accuracy of micro-second. The trigger scheme is establish to detect the zenith angle of an EAS up to 45 degrees.
It has been worked from the begining of July 1998, although there were deficit of observations for several weeks owing to circuit trouble by a typhoon in summer, up to the present, more than 20k EAS events were recorded. In this report, about 16k events are analysed for searching non-random componet in the data of EASs.

3 Data Analysis

There are many basic data analysing to check the performnce of the detector system. For 16k events of EASs with 1228.15 hours data acquisition time, the average triggering rate is 4.61 ± 0.75 (min/ev). Frequencies of specific arrival time intervals are shown in Fig.-3(a) to (d). The triggering rates deriveing from fit to these distributions in the figure are consistent with above value within their errors. These values are consisting with previous observation system which had almost the same area with threshold energy around $10^{14}eV$. Some other triggering values for the different time intervals are calculated and shown in Table-1. In the process of data analysis, some EAS events arriving successively and we evaluate statistical quantities using statistics for these series of events. Extracted events exceed more than three σ(standard deviation:SD) are searched by scanning of all data and listed in Table-2. Table-2(a) is the number of events and their σ within 1 hour and Table-2(b) is that of within 2 hours. There is worth notice of exceeding four σ from the average number of triggering rate for 28 events within 1 hour and exceeding five σ for 52 events within 2 hours are found. Fig.-4 shows the time sequence of the events for the time of 13.00 to 16.00 on 19th July 1998. The begining of time bin is shifted to find the maximum number of events in a certain time intervals for Fig.-4. There is a position having the maximum counts for 2 hours time interval which contains 53 events. To calculate the probability for this 53 events within 2 hours, i.e. $(53-26.03)/5.06 = 5.33\sigma$, it corresponds to the probability of 2.9×10^{-7} which gives expected events of 4.6×10^{-3} to the number of total events from the accumulative normal distibution. These events are payed attention to analyse in datail for the candidate of deviating events expetd from average poisson feature.

The actual observed events within 1 hour and 2 hours are shown in Fig.-5(a), (b) and are compared with the expected events from poisson probability in Table-3. Furthemore, change of σ values as a function of the time binning is investigated by shift the begining time. They are shown in Fig-6(a) and (b). There are two peaks for the events within 2 hours. The first peak corresponds to the maximum 5.33σ. It is easy to imagine of event arrival time sequece in Fig.-4 roughly from above distributions.
The following statistical methods are adopted to the series of 53 events within 2 hours.

(A) the Chebyshev's inequality expression
The Chebyshev's inequality gaves an upper limit of the probability. The probability for observing any specific number of counts given the Poisson probability with a mean of x_0 and standard deviation σ is calculated by the Chebyshev's theorem which gives an upper limit of the probability for the frequency of exceed $k\sigma$ as following:

$$Prob(|x - x_0|) > k\sigma) \leq 1/k^2.$$

In this case,

$$x_0 = m = 4.61 = \sigma^2$$

i.e. $\sigma = \sqrt{m} = 5.06, k\sigma = 53 - 26.03$ events, therefore, $k = 5.33$

$$Prob(|x - x_0| > 52) = (1/5.33)^2 = 0.036.$$

This value corresponds to the significance level of 3.6%.

(B) cumulative Poisson probailiy:
The cumulative Poisson probabilty function is defined by

$$P_x(< k) = 1 - P(k, x)$$

whereis $P_x(< k)$ is the probability that the number of Poisson random events occurring will be between 0 and $k - 1$ inclusive, x is the mean number, $P(k, x)$ is the imcomplete gamma function [5].
The calculated values of the cummulative Poisson probabiliy with the real data are given in Table-3(a) and (b).

4 Summary

The upper limit of significant level of $\alpha = 3.6 \times 10^{-2}$, that is, the confidence level of 96% is obtained to accept an hypothesis for 52 events within 2 hours deviating from random Poisson process. From cumulative Poisson probability, the number of expected events 1.28×10^{-3} is obtained for the total events. Although this value is not strong evidence deviating from random phenomena. However, if we assume the normal distribution for the errors of triggering rate, the probability of order of 10^{-7} might be obtained.
For validity of the candidate in detail, there needs some other statistical methods and also needs to improve statistics of the data.

There is a topics of some gamma-ray bursts(GRBs) coming from a soft gamma-ray repeater(SGR), Magnetar SGR1900+14, on 27th August 1998 [6]. We tried to find a possibility of event excess from random distribution but no excess was found in the data at the time. We are keeping to watch the EAS events due to GRBs from the Magnetars.

References

[1] GR Smith, MOgmen, E Buller, S Standil: Phys. Rev. Lett.50, 2110(1983)

[2] DJ Fegan, B McBreen, C O'Sullivan: Phys. Rev. Lett.51, 2341(1983)

[3] CL Bhat, ML Sapru, CL Kaul: Nature 146, 288(1980)

[4] M Chikawa et al.: Proc. 21st ICRC(Adelaide), OG10.3-1(1990)
K Tsuji et al.: J. of Faculty of Sci. and Tech.(Kinki University) 26, (1990)
M Chikawa et al.: Proc. 22nd ICRC(Dublin), HE 3.1.12(1991)
M Chikawa et al.: Proc. 23rd ICRC(Calgary), Vol.4, 219(1993)
M Chikawa et al.: Proc. 24th ICRC(Rome), Vol. 2, OG6.3.1, 780(1995)

[5] WH Press et al.: Numerical Recipes in C, Cambridge University Press, 1988

[6] http://www.magnetar.com/

6.51 ± 2.47	evs./30min.
13.01 ± 3.55	evs./hr.
26.03 ± 5.06	evs./2hrs.

Table-1: EAS events triggering rates.

(a)

date	time	events	$\sigma/30min.$
1998/07/11	00:21:56-01:51:56	15	3.33
1998/07/11	00:51:56-02:21:56	16	3.72
1998/07/11	01:21:56-02:51:56	16	3.72
1998/07/17	01:51:56-03:21:56	15	3.33
1998/07/19	02:21:56-03:51:56	18	4.50
1998/07/24	02:51:56-04:21:56	15	3.33
1998/08/01	03:21:56-04:51:56	15	3.33
1998/08/03	03:51:56-05:21:56	15	3.33
1998/08/29	04:21:56-05:51:56	15	3.33
1998/08/31	04:51:56-06:21:56	16	3.72
1998/09/04	05:21:56-06:51:56	15	3.33
1998/09/15	05:51:56-07:21:56	15	3.33

(b)

date	time	events	$\sigma/hr.$
1998/07/11	01:21:56-02:21:56	26	3.60
1998/07/16	13:55:31-14:55:31	24	3.04
1998/07/19	13:34:01-14:34:01	30	4.79
1998/07/19	14:55:31-15:55:31	24	3.04
1998/07/24	21:29:37-22:29:37	2	-3.05
1998/08/04	00:09:31-01:09:31	2	-3.05
1998/08/04	02:09:31-03:09:31	2	-3.05
1998/09/02	21:17:08-22:17:08	2	-3.05
1998/09/16	18:16:28-19:16:28	24	3.04
1998/09/16	20:16:28-21:16:28	24	3.04
1998/09/16	22:16:28-23:16:28	30	4.71

(c)

date	time	events	$\sigma/2hrs.$
1998/07/13	23:21:56-01:21:56	9	-3.33
1998/07/14	23:21:56-01:21:56	10	-3.14
1998/07/19	13:34:01-15:34:01	53	5.33
1998/07/25	22:29:37-00:29:37	10	-3.14
1998/07/29	00:29:37-02:29:37	8	-3.53
1998/07/30	21:09:31-23:09:31	9	-3.33
1998/07/31	21:09:31-23:09:31	10	-3.14
1998/07/31	23:09:31-01:09:31	7	-3.72
1998/08/03	01:09:31-03:09:31	10	-3.14
1998/08/03	13:09:31-15:09:31	43	3.32
1998/09/12	23:50:20-01:50:20	9	-3.33
1998/09/13	05:50:20-07:50:20	42	3.13
1998/09/14	13:50:20-17:50:20	42	3.13
1998/09/16	17:16:28-19:16:28	44	3.52
1998/09/16	19:16:28-21:16:28	44	3.52
1998/09/16	21:16:28-23:16:28	44	3.52
1998/09/19	23:16:28-01:16:28	9	-3.33

Table-2(a): List of excess events greater than 3σ (a) within 30 min, (b) within 1 hour, and (c) within 2 hours time interval.

time interval : 3600 [sec] event : 16000 [events]
trig. rate : m= 12.99 (min/ev), exp (-m) =2.2899e-006

i	evs.	relative	poisson	fitted evs	raw/pred	P (<i)	1-P (<I)
0	0	0.00e+000	2.29e-006	2.82e-003	0.00e+000		
1	0	0.00e+000	2.97e-005	3.66e-002	0.00e+000	2.29e-006	1.00e+000
2	4	3.25e-003	1.93e-004	2.38e-001	1.68e+001	3.20e-005	1.00e+000
3	9	7.31e-003	8.36e-004	1.03e+000	8.74e+000	2.25e-004	1.00e+000
4	25	2.03e-002	2.71e-003	3.34e+000	7.48e+000	1.06e-003	9.99e-001
5	17	1.38e-002	7.05e-003	8.69e+000	1.96e+000	3.78e-003	9.96e-001
6	33	2.68e-002	1.53e-002	1.88e+001	1.76e+000	1.08e-002	9.89e-001
7	49	3.98e-002	2.83e-002	3.49e+001	1.40e+000	2.61e-002	9.74e-001
8	51	4.14e-002	4.60e-002	5.66e+001	9.01e-001	5.44e-002	9.46e-001
9	76	6.17e-002	6.63e-002	8.17e+001	9.30e-001	1.00e-001	9.00e-001
10	82	6.66e-002	8.61e-002	1.06e+002	7.73e-001	1.67e-001	8.33e-001
11	109	8.85e-002	1.02e-001	1.25e+002	8.70e-001	2.53e-001	7.47e-001
12	112	9.09e-002	1.10e-001	1.36e+002	8.26e-001	3.54e-001	6.46e-001
13	116	9.42e-002	1.10e-001	1.35e+002	8.56e-001	4.65e-001	5.35e-001
14	96	7.79e-002	1.02e-001	1.26e+002	7.64e-001	5.74e-001	4.26e-001
15	95	7.71e-002	8.83e-002	1.09e+002	8.73e-001	6.76e-001	3.24e-001
16	98	7.95e-002	7.17e-002	8.83e+001	1.11e+000	7.65e-001	2.35e-001
17	73	5.93e-002	5.48e-002	6.75e+001	1.08e+000	8.36e-001	1.64e-001
18	59	4.79e-002	3.95e-002	4.87e+001	1.21e+000	8.91e-001	1.09e-001
19	42	3.41e-002	2.70e-002	3.33e+001	1.26e+000	9.31e-001	6.93e-002
20	35	2.84e-002	1.75e-002	2.16e+001	1.62e+000	9.58e-001	4.23e-002
21	19	1.54e-002	1.08e-002	1.34e+001	1.42e+000	9.75e-001	2.48e-002
22	16	1.30e-002	6.40e-003	7.89e+000	2.03e+000	9.86e-001	1.39e-002
23	9	7.31e-003	3.61e-003	4.45e+000	2.02e+000	9.92e-001	7.54e-003
24	4	3.25e-003	1.96e-003	2.41e+000	1.66e+000	9.96e-001	3.92e-003
25	0	0.00e+000	1.02e-003	1.25e+000	0.00e+000	9.98e-001	1.97e-003
26	1	8.12e-004	5.07e-004	6.25e-001	1.60e+000	9.99e-001	9.53e-004
27	0	0.00e+000	2.44e-004	3.01e-001	0.00e+000	1.00e+000	4.45e-004
28	1	8.12e-004	1.13e-004	1.39e-001	7.17e+000	1.00e+000	2.01e-004
29	0	0.00e+000	5.07e-005	6.25e-002	0.00e+000	1.00e+000	8.79e-005
30	1	8.12e-004	2.19e-005	2.70e-002	3.70e+001	1.00e+000	3.72e-005
31	0	0.00e+000	9.20e-006	1.13e-002	0.00e+000	1.00e+000	1.53e-005
32	0	0.00e+000	3.73e-006	4.60e-003	0.00e+000	1.00e+000	6.08e-006
33	0	0.00e+000	1.47e-006	1.81e-003	0.00e+000	1.00e+000	2.35e-006
34	0	0.00e+000	5.61e-007	6.91e-004	0.00e+000	1.00e+000	8.84e-007
35	0	0.00e+000	2.08e-007	2.56e-004	0.00e+000	1.00e+000	3.23e-007
36	0	0.00e+000	7.51e-008	9.25e-005	0.00e+000	1.00e+000	1.15e-007
37	0	0.00e+000	2.64e-008	3.25e-005	0.00e+000	1.00e+000	3.98e-008
38	0	0.00e+000	9.01e-009	1.11e-005	0.00e+000	1.00e+000	1.34e-008
39	0	0.00e+000	3.00e-009	3.70e-006	0.00e+000	1.00e+000	4.42e-009
40	0	0.00e+000	9.74e-010	1.20e-006	0.00e+000	1.00e+000	1.42e-009
total	1232	1.00e+000	1.00e+000	1.23e+003			

(a)

timeinterval : 7200 [sec] event : 16000 [events]
trig. rate : m= 25.85 (min/ev), exp (-m) =5.9470e-012

i	evs.	relative	poisson	fitted evs	raw/pred	P (<i)	1-P
0	0	0.00e+000	5.95e-012	3.68e-009	0.00e+000		
1	0	0.00e+000	1.54e-010	9.52e-008	0.00e+000	5.95e-012	1.00e+000
2	0	0.00e+000	1.99e-009	1.23e-006	0.00e+000	1.60e-010	1.00e+000
3	1	1.62e-003	1.71e-008	1.06e-005	9.44e+004	2.15e-009	1.00e+000
4	0	0.00e+000	1.11e-007	6.85e-005	0.00e+000	1.93e-008	1.00e+000
5	0	0.00e+000	5.72e-007	3.54e-004	0.00e+000	1.30e-007	1.00e+000
6	0	0.00e+000	2.46e-006	1.52e-003	0.00e+000	7.02e-007	1.00e+000
7	3	4.85e-003	9.10e-006	5.63e-003	5.33e+002	3.17e-006	1.00e+000
8	1	1.62e-003	2.94e-005	1.82e-002	5.50e+001	1.23e-005	1.00e+000
9	6	9.69e-003	8.44e-005	5.22e-002	1.15e+002	4.17e-005	1.00e+000
10	5	8.08e-003	2.18e-004	1.35e-001	3.70e+001	1.26e-004	1.00e+000
11	3	4.85e-003	5.13e-004	3.17e-001	9.45e+000	3.44e-004	1.00e+000
12	10	1.62e-002	1.10e-003	6.84e-001	1.46e+001	8.57e-004	9.99e-001
13	10	1.62e-002	2.20e-003	1.36e+000	7.36e+000	1.96e-003	9.98e-001
14	8	1.29e-002	4.05e-003	2.51e+000	3.19e+000	4.16e-003	9.96e-001
15	13	2.10e-002	6.99e-003	4.32e+000	3.01e+000	8.21e-003	9.92e-001
16	10	1.62e-002	1.13e-002	6.99e+000	1.43e+000	1.52e-002	9.85e-001
17	9	1.45e-002	1.72e-002	1.06e+001	8.47e-001	2.65e-002	9.74e-001
18	14	2.26e-002	2.46e-002	1.53e+001	9.18e-001	4.36e-002	9.56e-001
19	14	2.26e-002	3.35e-002	2.08e+001	6.75e-001	6.83e-002	9.32e-001
20	19	3.07e-002	4.33e-002	2.68e+001	7.08e-001	1.02e-001	8.98e-001
21	20	3.23e-002	5.33e-002	3.30e+001	6.06e-001	1.45e-001	8.55e-001
22	22	3.55e-002	6.27e-002	3.88e+001	5.67e-001	1.98e-001	8.02e-001
23	33	5.33e-002	7.04e-002	4.36e+001	7.57e-001	2.61e-001	7.39e-001
24	36	5.82e-002	7.58e-002	4.69e+001	7.67e-001	3.32e-001	6.68e-001
25	51	8.24e-002	7.84e-002	4.85e+001	1.05e+000	4.07e-001	5.93e-001
26	29	4.68e-002	7.80e-002	4.83e+001	6.01e-001	4.86e-001	5.14e-001
27	42	6.79e-002	7.46e-002	4.62e+001	9.09e-001	5.64e-001	4.36e-001
28	41	6.62e-002	6.89e-002	4.26e+001	9.61e-001	6.38e-001	3.62e-001
29	37	5.98e-002	6.14e-002	3.80e+001	9.73e-001	7.07e-001	2.93e-001
30	36	5.82e-002	5.29e-002	3.27e+001	1.10e+000	7.69e-001	2.31e-001
31	18	2.91e-002	4.41e-002	2.73e+001	6.59e-001	8.22e-001	1.78e-001
32	22	3.55e-002	3.56e-002	2.21e+001	9.97e-001	8.66e-001	1.34e-001
33	22	3.55e-002	2.79e-002	1.73e+001	1.27e+000	9.01e-001	9.87e-002
34	23	3.72e-002	2.12e-002	1.31e+001	1.75e+000	9.29e-001	7.08e-002
35	13	2.10e-002	1.57e-002	9.70e+000	1.34e+000	9.50e-001	4.95e-002
36	16	2.58e-002	1.13e-002	6.96e+000	2.30e+000	9.66e-001	3.39e-002
37	8	1.29e-002	7.86e-003	4.87e+000	1.64e+000	9.77e-001	2.26e-002
38	8	1.29e-002	5.35e-003	3.31e+000	2.42e+000	9.85e-001	1.48e-002
39	3	4.85e-003	3.54e-003	2.19e+000	1.37e+000	9.91e-001	9.41e-003
40	5	8.08e-003	2.29e-003	1.42e+000	3.53e+000	9.94e-001	5.87e-003
41	0	0.00e+000	1.44e-003	8.94e-001	0.00e+000	9.96e-001	3.58e-003
42	2	3.23e-003	8.88e-004	5.50e-001	3.64e+000	9.98e-001	2.14e-003
43	2	3.23e-003	5.34e-004	3.31e-001	6.05e+000	9.99e-001	1.25e-003
44	3	4.85e-003	3.14e-004	1.94e-001	1.54e+001	9.99e-001	7.13e-004
45	0	0.00e+000	1.80e-004	1.12e-001	0.00e+000	1.00e+000	3.99e-004
46	0	0.00e+000	1.01e-004	6.27e-002	0.00e+000	1.00e+000	2.19e-004
47	0	0.00e+000	5.57e-005	3.45e-002	0.00e+000	1.00e+000	1.18e-004
48	0	0.00e+000	3.00e-005	1.86e-002	0.00e+000	1.00e+000	6.21e-005
49	0	0.00e+000	1.58e-005	9.79e-003	0.00e+000	1.00e+000	3.21e-005
50	0	0.00e+000	8.18e-006	5.06e-003	0.00e+000	1.00e+000	1.63e-005
51	0	0.00e+000	4.15e-006	2.57e-003	0.00e+000	1.00e+000	8.11e-006
52	1	1.62e-003	2.06e-006	1.28e-003	7.84e+002	1.00e+000	3.96e-006
53	0	0.00e+000	1.00e-006	6.22e-004	0.00e+000	1.00e+000	1.90e-006
54	0	0.00e+000	4.81e-007	2.98e-004	0.00e+000	1.00e+000	8.96e-007
55	0	0.00e+000	2.26e-007	1.40e-004	0.00e+000	1.00e+000	4.15e-007
total	619	1.00e+000	1.00e+000	6.19e+002			

(b)

Table-3: Lists of the number of events againt frequency for (a) 1 hour, and (b) 2 hours time interval. The real experimental data are compared with the number of expected events from the prediction of Poisson distribution. The cumulative Poisson probability, $P(< i)$, and its complementary probability, $1 - P$, are also listed.

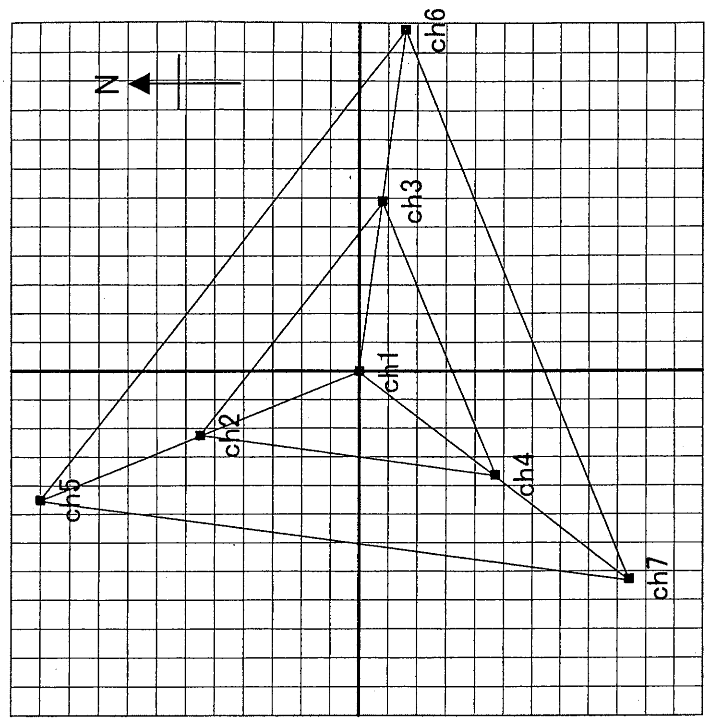

Fig.-1: The new Kinki Array was rebuilt. The arrangement of seven plastic scintillation detectors are shown. A lattice length is $1m$.

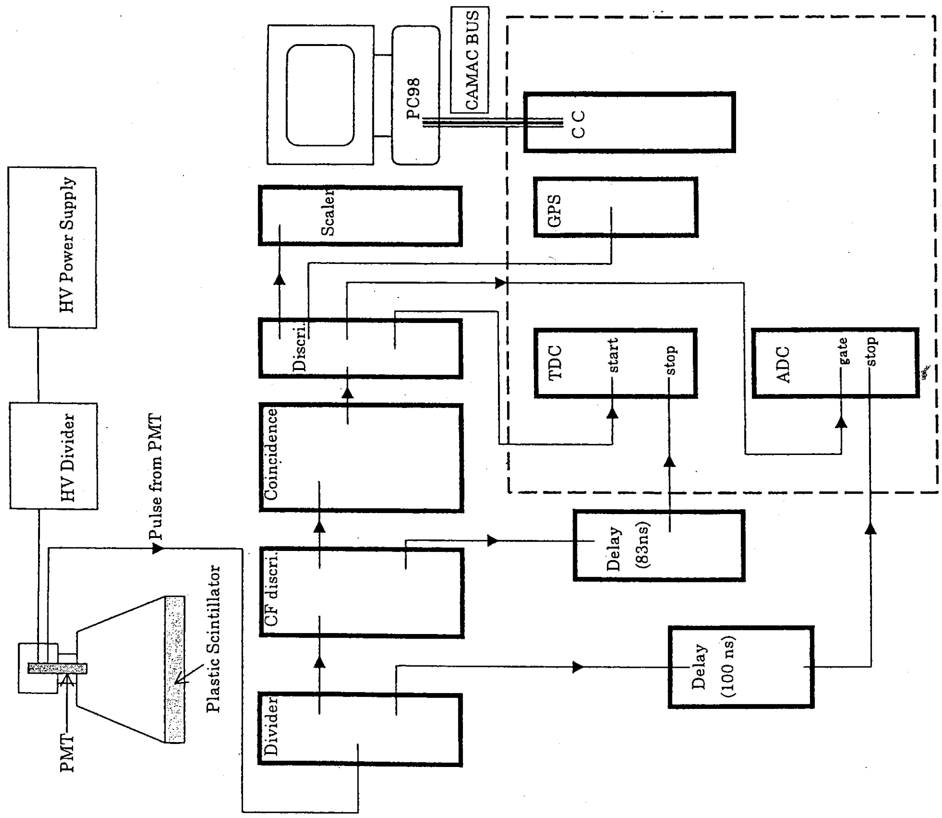

Fig.-2: The block diagram of the detection system which is consists of $NIM - CAMAC$ electronic circuit.

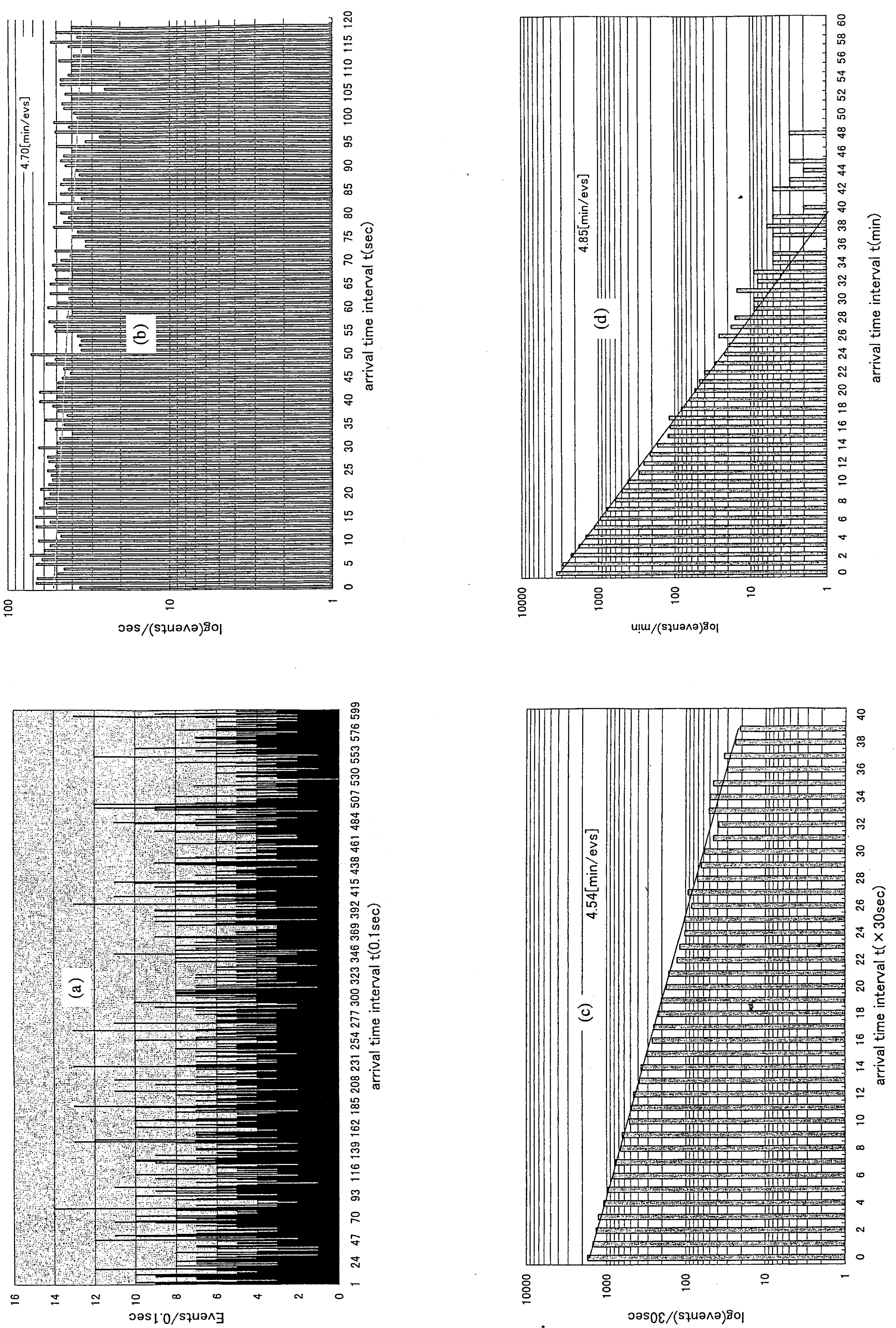

Fig.-3: The distributions of EAS arrival time interval for intervals of (a) 0.1sec, (b) 1sec, (c) 30sec, and (d) 1min.

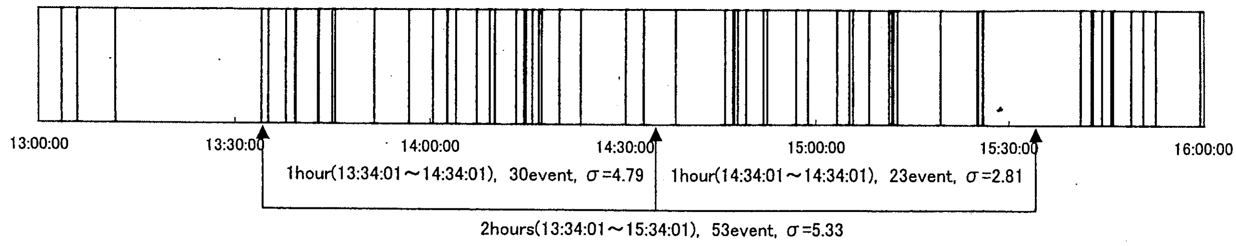

Fig.-4: The time sequence of events for exceeding 5σ within 2 hours is shown. It contains a series of 53 events in the indicated period. Also deviding to 1 hour region is shown. It include 30 events corresponding to 4.79σThese are phenomenae of the maximum consecutive events in the Table-2(b) and (c).

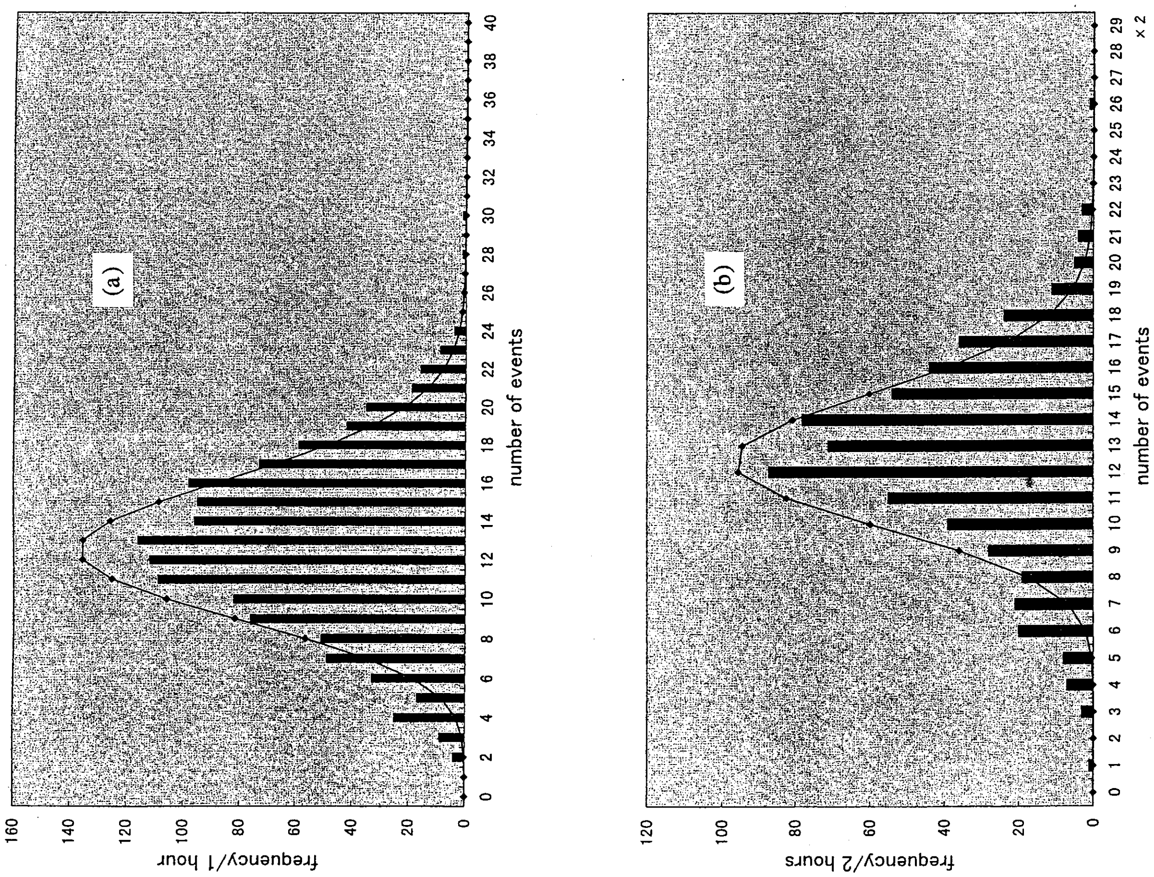

Fig.-5: The distributions of the number of events vs. frequency for (a) 1 hour time interval, and (b) 2 hours time interval. The expected events from the prediction of Poisson distribution are also drawn.

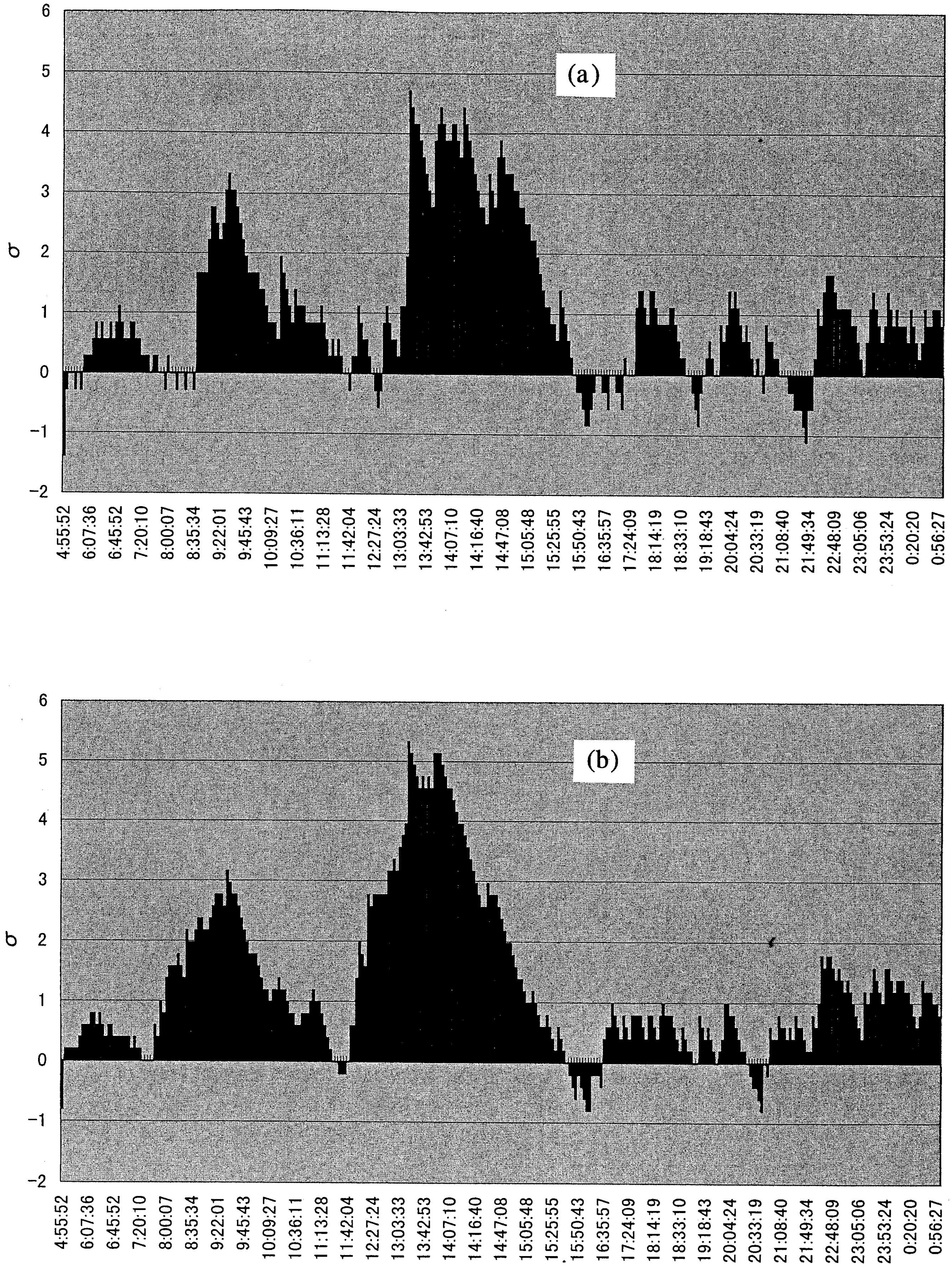

Fig.-6: The distributions of σ values as a function of the begining time for (a) 1 hour time interval, and (b) 2 hours time interval.