32ND INTERNATIONAL COSMIC RAY CONFERENCE, BEIJING 2011

The Anisotropy of Cosmic Ray Pursued with Chaos Analysis

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DOI: 10.7529/ICRC2011/V01/0406

Abstract: The time series data of air shower size obtained by Nishimura-Kamata-Greisen formula are analyzed by the fractal dimension analysis to select the chaotic time series groups in the air shower events observed in 2004, 2005 and 2006. The events with the primary energy around 10^{15}eV in the selected time series groups seem to have the anisotropy of arrival direction around 11h, 5h and 21h of right ascension. The anisotropy of the right ascension of chaotic events seems to have the dependence on the value of fractal dimension. The result suggests that the chaotic gamma-ray groups arrive the earth sometimes from particular active galaxies.

Keywords: chaos, fractal dimension, anisotropy of chaotic feature

1 Chaos Analysis of Time Series Data of Air Shower Size

The time series data of the air shower arrival time interval have been regarded as the random sequence. We found the chaotic feature and it's anisotropy in it [1]. In this report, the object of analysis is developed to the time series data of air shower size to reach the information of the dynamics of the generation of chaotic cosmic rays. The air shower size is calculated by Nishimura-Kamata-Greisen formula [2] $f(x)=c(s)x^{s-2}(x+1)^{s-4.5}$. In this formula, f(x) is the lateral distribution function of electrons in air shower, s is the age parameter and x is equivalent to the distance between the centre of air shower and the scintillation counter. The fractal dimension analysis is executed with Grassberger-Procaccia method [3,4] for every 300 continuous events whose duration is about 12h, shifting the first event by 3 events for each analysis. Figure 1 shows a diagram of the analysis of the chaotic 300 time series of air shower size which is embedded in 11 dimensional phase space. D_m value is defined by $d\ln C_m/d\ln r$, where C_m is the number of the pair of vector point embedded for each 11 continuous time series data and r is the pair distance. In the case of chaotic time series, D_m has the constant value D in some finite range of r as shown in the formula $C_m \propto r^D$.

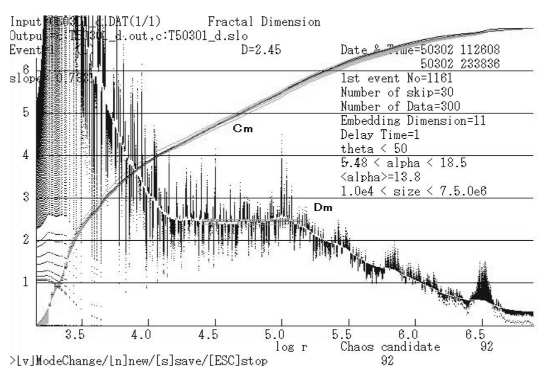

Figure 1. The example of the diagram of the fractal dimension analysis for the 300 chaotic time series of air showers.

The maximum size of analyzed air showers is decided to be $7.5\text{x}10^6$, because it brings the maximum detection frequency of the chaotic group as shown in figure 2.

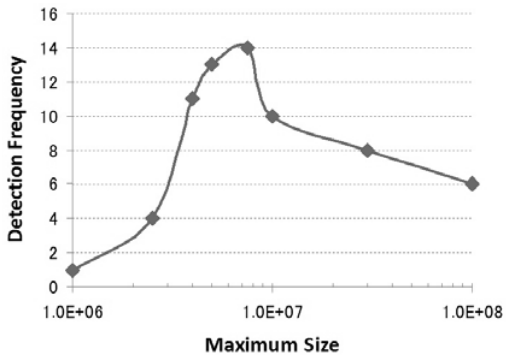

Figure 2. The maximum size for the chaos analysis vs. the detection frequency of chaotic group in the air showers observed from Jul. to Dec. in 2005 at Osaka.

The analysis is also executed for the embedded dimension 9, and the chaotic time series are decided under the condition that they have similar fractal dimension for both embedded dimension. The chaotic 39 groups in Osaka and 18 groups in Nara are detected in about 240 thousands (Osaka) and 126 thousands (Nara) time series observed in 2005. The average fractal dimension is 2.5 (Osaka, the range: 1.8-3.1) and 2.1 (Nara, the range: 1.4-2.8). The maximum Lyapunov exponent of these chaotic time series is simulated with Wolf's method [5] getting the positive convergent value larger than 0.3. This is another evidence for the chaotic feature of the time series. The every artificial data which are made by randomizing the sequence of original time series lose completely the chaotic feature. This result indicates that the original time series are not the color noises (the surrogate data test)[6].

2 The Anisotropy of the Chaotic Feature of Time Series Data of Air Shower Size

Figure 2 suggests that the contribution of the primary cosmic rays which have the energy larger than $4.0\text{x}10^{15}$eV and smaller than $7.5\text{x}10^{15}$eV (Chaos-Size) to the chaotic feature is dominant. Therefore, the right ascension distribution is studied for the air showers with Chaos-Size in the chaotic groups detected in each 3 months or 1 year. The fractal dimension dependency of the right ascension distribution is also studied.

Figure 3 shows the right ascension distribution of air showers in Chaos-Size for the chaotic groups detected in 2005 at Osaka, with fractal dimension not smaller than 2.5.

In the same way, Figure 4 shows the case with fractal dimension smaller than 2.5 for the chaotic groups detected in 2006 at Osaka. Thinking of the results of the chaos in the time series of arrival time interval reported [1] in 2003, the preference around 5h, 11h and 21h seems to be remarkable. The precision of the right ascension calculation for each event is 1.0h.

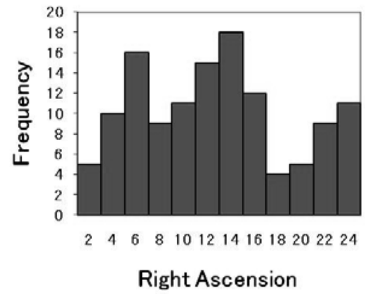

Figure 3. The right ascension distribution of chaotic air shower groups which has the primary energy around 10^{15}eV observed in 2005 at Osaka. The fractal dimensions are larger than or equal to 2.5.

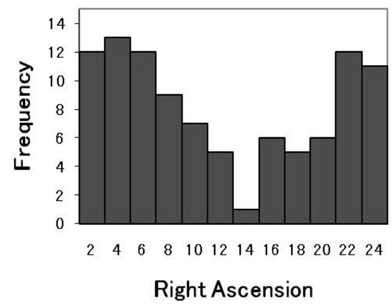

Figure 4. The right ascension distribution of chaotic air shower groups which has the primary energy around 10^{15}eV observed in 2006 at Osaka. The fractal dimensions are smaller than 2.5.

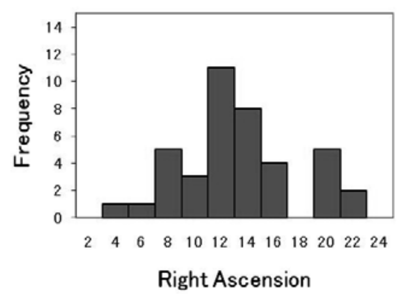

Figure 5. The right ascension distribution of chaotic air shower events which have primary energy around 10^{15}eV observed at Osaka from Jul. to Sep.in 2005.

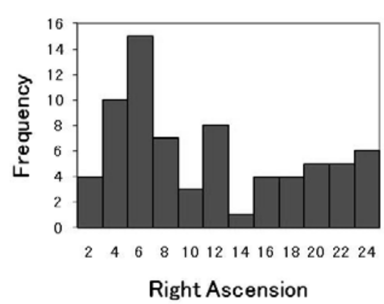

Figure 6. The right ascension distribution of chaotic air shower events which have primary energy around 10^{15}eV observed at Osaka from Oct. to Dec. in 2005.

Figure 5 shows the right ascension distribution of air showers in Chaos-Size in the chaotic groups with fractal dimension not smaller than 2.5 detected from Jul. to Sep. in 2005 at Osaka.

Figure 6 shows the right ascension distribution of the chaotic groups with fractal dimension smaller than 2.5 detected from Oct. to Dec. in 2005 at Osaka. The right ascension of air showers in Chaos Size for the chaotic groups which have fractal dimension not smaller than 2.5 approximately prefers to the direction around 11h. On the other hand, the right ascension distribution of the chaotic groups which have fractal dimension smaller than 2.5 approximately prefer to the direction around 5h or 21h. In the case of air shower data observed at Nara, the rate of events in Chaos-Size is smaller than that of Osaka. Therefore the detection frequency is relatively small, however the right ascension in Chaos-Size of chaotic groups detected in 2005 approximately prefer to around 11h and 21h as shown in Figure 7.

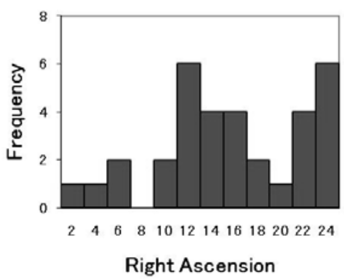

Figure 7. The right ascension distribution of chaotic air shower events which have primary energy around 10^{15}eV observed at Nara in 2005.

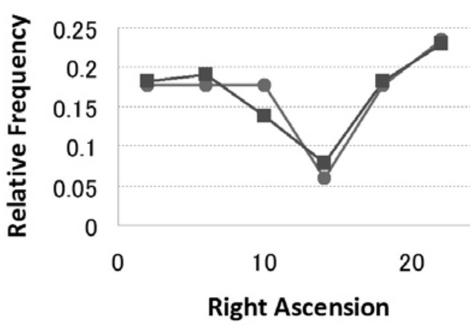

Figure 8. The right ascension distribution of the chaotic air shower Observed in 2004 at Nara (blue circle) and Osaka (magenta square).

The relative right ascension distributions of chaotic air shower events in Chaos Range observed at Osaka and Nara are compared in Figure 8. It indicates the nearly coincidence between the chaos phenomena detected at two different station at a distance 11km.

Another evidence of the existence of the chaotic cosmic rays extending to large area is shown in Figure 9. The slope of the plateau area in Figure 1 indicates the degree of the chaotic feature. The left graph in Figure 9 shows the fluctuation of the slope of D_m curve for each 150 time series of the shower size whose duration is about 6 hour observed in 8 days Mar. 2005 at Nara. The result of FFT analysis of this fluctuation data is shown in right graph. It has a peak at the period 1 day. It shows the situation that the chaotic series of cosmic rays are arriving in large area and they are detected at a station on the earth which rotates with 1 day period.

The arrival time coincidence between far-off stations has been studied also by Large Area Air Shower (LAAS) group [7,8]. The coincidence events whose difference of arrival time is less than 200 micro-seconds are detected for 6100 thousands events observed from 1996 to 2002 at five different stations of LAAS group. The result is shown in Figure 10. The coincidence events detected at around 5h and 12h of right ascension which agree with the result of the chaos analysis. It should be regarded that these results coincide with the report of the Tibet AS γ Collaboration [9].

3 Conclusion

The chaos analysis to study the cosmic rays is to sort out the low entropy group of the cosmic ray time series expecting that a group of time series include the cosmic rays which have same origin and the correlation between each other. The fractal dimensions are detected in about 5 percent duration of the time series of air shower size observed from 2004 to 2006 at Osaka and Nara stations. The right ascension of the air shower which has dominant size, from 4.0×10^{15}eV to 7.5×10^{15}eV as primary energy in these chaotic groups seems to have the anisotropy preferring to around 5h, 11h and 21h. This result is supported also by the anisotropy of the coincidence events observed at five far-off stations for 7 years till 2002 and also by the result of chaos analysis for the time series of the air shower arrival time interval [1]. Moreover, the anisotropy of the right ascension of chaotic events seems to have the dependence on the value of fractal dimension. The right ascension of the chaotic air shower group which has the higher fractal dimension seems to prefer to the direction around 11h. This suggests that the dynamics of the production of cosmic rays arriving from the direction 11h is more complex. The likeliest candidate of the cosmic ray which has the anisotropy of detected right ascension is gamma ray, so the chaos analysis may have the chance to pursue the 100TeV gamma rays from active galactic nuclei like Mrk421 or supernova remnant like Cyg-x1. If they should be protons, we may assume a nonlinear proton re-accelerator or attenuator like a magnetic cloud or dark matter which are located near the solar system at a distance of a few light years in the particular directions.

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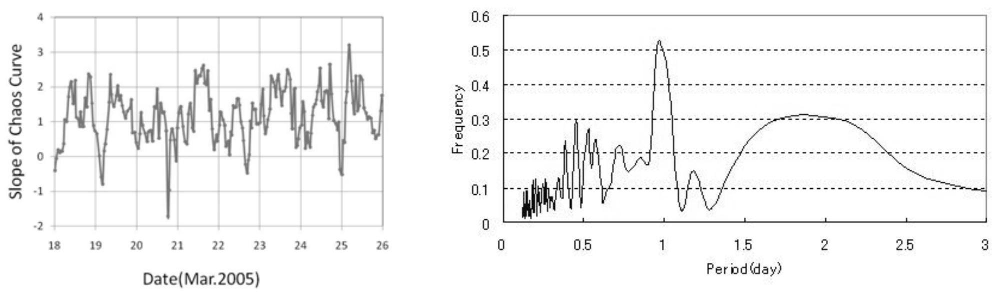

Figure 9. The FFT analysis of the fluctuation of chaotic feature on fractal dimension analysis for the energy time series data observed during Mar.18 and Mar.28 in 2005 at Nara.

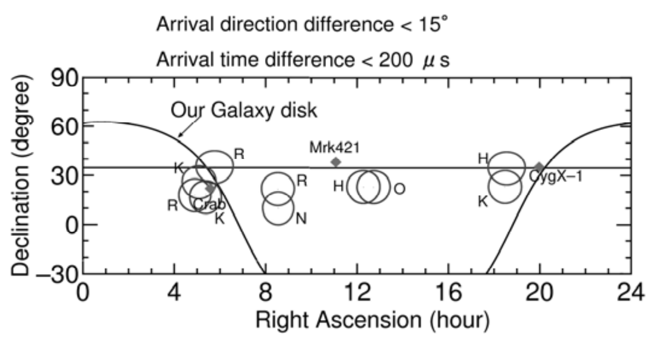

Figure 10. The right ascension and declination distribution of coincidence events observed in 5 stations of LAAS group. H: Hirosaki Univ., K: Kinki Univ., N: Nara-Sangyo Univ., O: Okayama Univ., R: Okayama Univ. of Science. The Distances between the stations are H-K: 787km, O-H: 873km, R-N: 161km and R-K: 152km.