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SEARCH OF SELF-ORGANIZED CRITICALITY IN VLF CHORUS OBSERVED BY MAGION-5

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Abstract. We consider the VLF emissions observed by MAGION-5 in the morning sector. The chorus emissions in dynamic spectra in the range of time scales 0.1-10 Hz look like a self-similar set. The scaling features in chorus observation have been tested. It was found that the distribution of time between chorus is power-law with the exponent d=2.0÷2.3. It was found that fluctuations in hiss at the same frequencies have the similar shape of distribution, but for the plasmaspheric hiss such distribution is different. We suppose that the similar power-law distribution for chorus and hiss could be a result of the same mechanism of self-organization in the magnetospheric plasma.

Introduction

Lately, there were broadly discussed properties of systems of self-organized criticality (SOC) and analogies of processes, taking place in such systems, with processes going on in various natural phenomena (Bak, 1997). Such approach finds application in the investigation of processes in the magnetospheric plasma as well (Milovanov et al., 1996; Uritski and Pudovkin, 1998). Usually attributes of a SOC state are believed to be the power form of the spectrum of fluctuations of some characteristic of the system. ($1/f^a$ spectrum) or probability distribution of the value of some characteristic. In other words, one can consider the self-similarity (self-affinity) of some characteristic of the system as a criterion of the SOC state.

In this paper we try to find the SOC state in the near-earth plasma of radiation belts. As a result of cyclotron interaction of radiation belts' energetic electrons with low-frequency waves the dissipation of radiation belts energy occurs; at the same time electrons with energies of 10-100 keV are precipitated into the upper atmosphere and various types of VLF emissions are generated. In this paper we analyze VLF/ELF chorus emissions, that present a sequence of elements, increasing by frequency in the frequency range of 10^2-10^4 Hz and duration of 0.1-1 sec. VLF/ELF chorus emissions in the morning sector are closely related to magnetospheric substorms, injection of energetic electrons from the tail into the inner magnetosphere, to precipitation of energetic electrons and, thus, to the dynamics of radiation belts (Bespalov and Trakhtengerts, 1986). Characteristics of VLF choruses, measured by MAGION-5 satellite using a magnetic antenna near the equatorial area at invariant latitudes of 10-30^0 in the morning sector (Titova et al., 2000) were analyzed in the paper. The data are digitized at the frequency of 44.1 kHz 8-bit values of the magnetic component of VLF emissions during the MAGION-5 satellite pass over the Panskaya Ves receiving station.

The incentive for the present study was the fact that spectrograms of VLF chorus emissions, obtained with different time resolution visually look very much alike. In other words, in spectrograms with low time resolution the elements, which seem elementary, will form the structure, which is found out in each of them at the enhancement of the resolution. If it is really so then the sequence of chorus elements statistically is a self-affinity set.

For chorus emissions, observed by the satellite, we considered a limited range of time scales, namely, from 0.1 to 10 sec. The time of about 0.1 sec in spectrograms corresponds to typical duration of chorus elements at the fixed frequencies, whereas the time intervals of 10 sec obviously exceed the time of chorus elements taking place during the considered MAGION-5 passes. Usually chorus emissions were observed ~ 10 min per pass within the range of L-shells 3-6 (Fig.1).

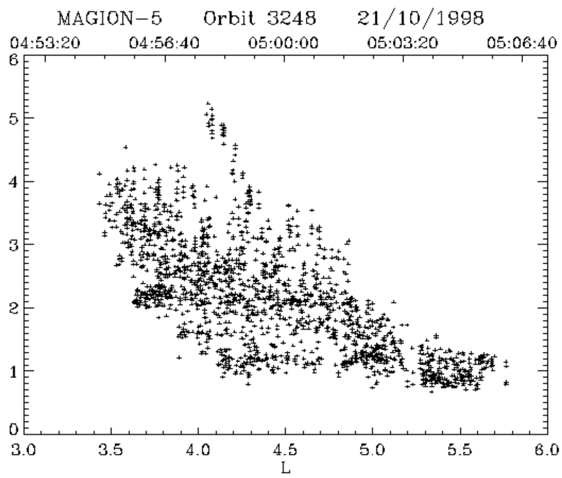

Fig.1. Distribution of the mean frequency of VLF choruses along the MAGION-5 trajectory in 3248 orbit. 1894 choruses marked.

Data analysis

Since initial broadband VLF data include various telemetric lines and some parasite signals, such traditional technique of identification of SOC state criteria as Fourier analysis of the spectrum of amplitude variations within the entire frequency band of the initial signal can not be applied in this case. That is why we used two approaches to the preliminary data processing for the analysis.

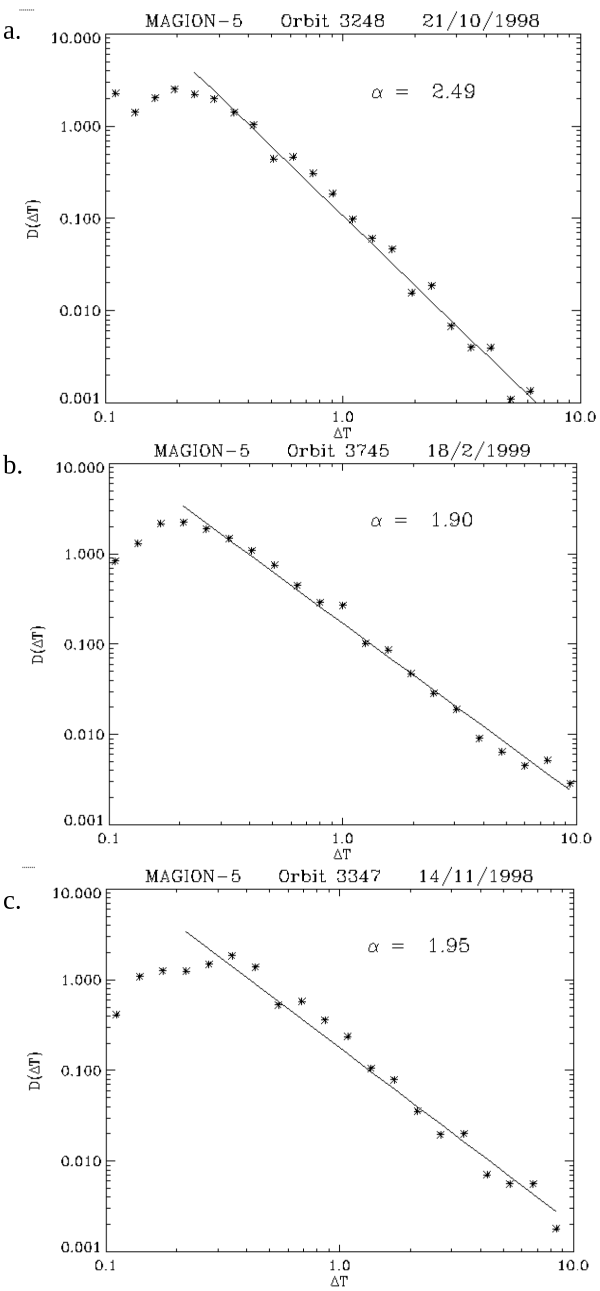

Fig.2. Distribution of times between appearances of chorus elements: a) 3248 orbit, 1894 choruses; b) 3745 orbit, 1179 choruses; c) 3347 orbit, 583 choruses.

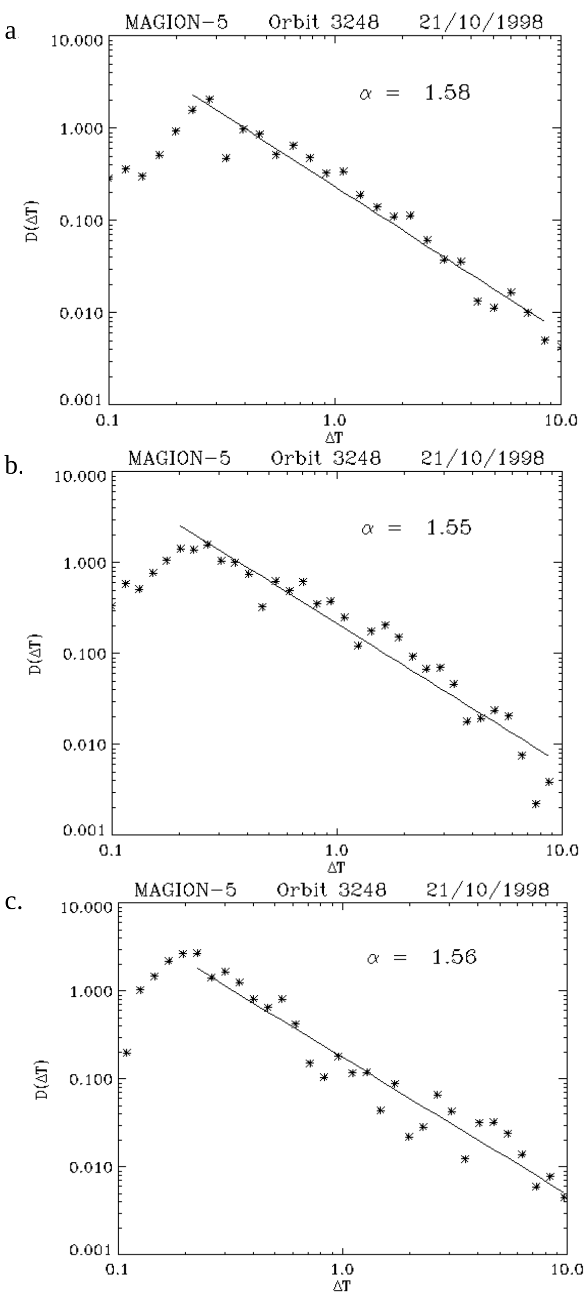

Fig.3. Distribution of times between appearances of chorus elements with mean frequencies from a narrow range: a). 0.8-1.3 kHz; b). 1.9-2.4 kHz; c). 3.0-4.0 kHz.

First approach

Chorus elements were marked manually in the spectrogram, time and frequency of the beginning and end of chorus elements were marked. Fig.1 gives an example of dependency of the mean frequency of the marked chorus elements along the MAGION-5 trajectory in 3248 orbit. In spite of the fact, that chorus elements can only be marked subjectively (all weak and short elements are almost impossible to be marked), this approach still gives us an opportunity to construct statistical distributions for sufficiently intense chorus elements.

In order to check the suggestion on statistical self-affinity of a set of choruses, the distribution of times between appearances of chorus elements were constructed. For three orbits 3248, 3745 and 3347 these distributions are given in Fig.2 In all these cases distributions are close to the $1/f^a$ form, where a=2.0÷2.5. All choruses marked within 1-5 kHz frequency range were taken into consideration.

Fig.2. Distribution of times between appearances of chorus elements: a) 3248 orbit, 1894 choruses; b) 3745 orbit, 1179 choruses; c) 3347 orbit, 583 choruses.

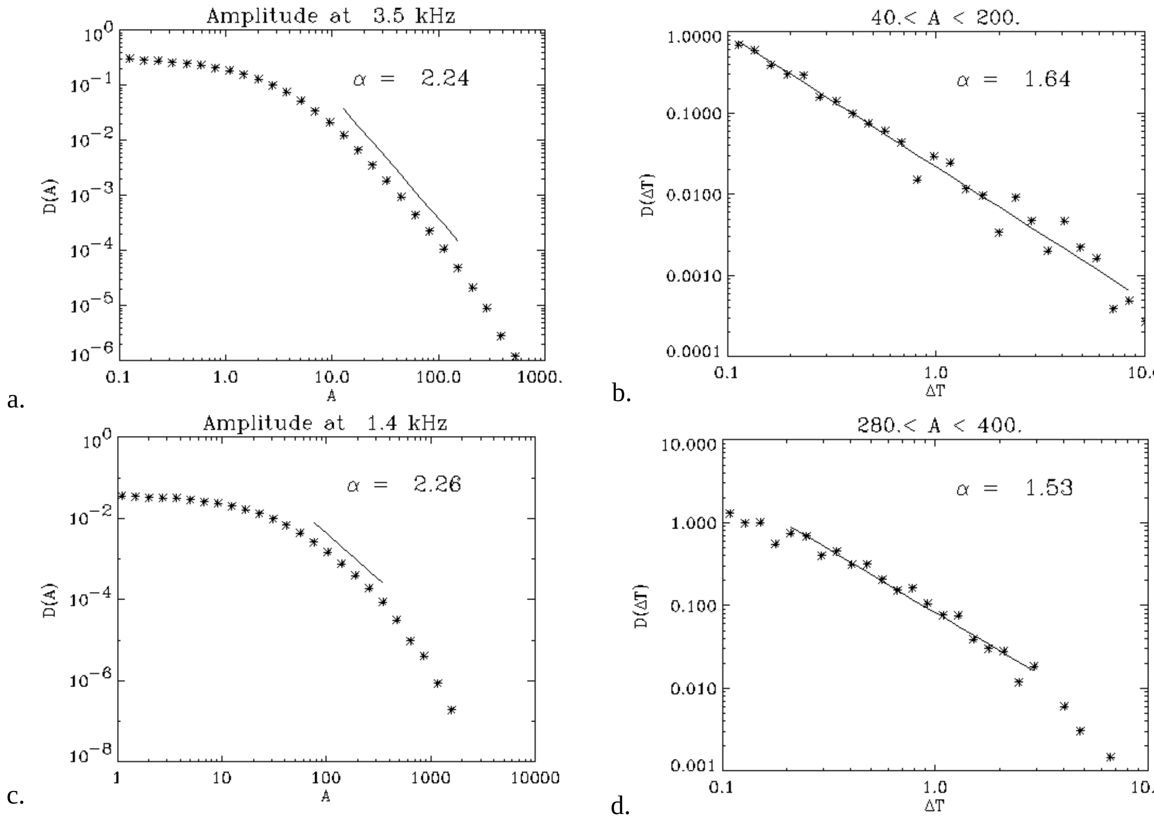

Fig.4. MAGION-5 data at the orbit 3248 (choruses). The left column: distribution of VLF amplitude at selected frequency (top row - for 3.5 kHz; bottim row - for 1.4 kHz). The right column: distribution of interval between the occurrencies of amplitudes in the marked region.

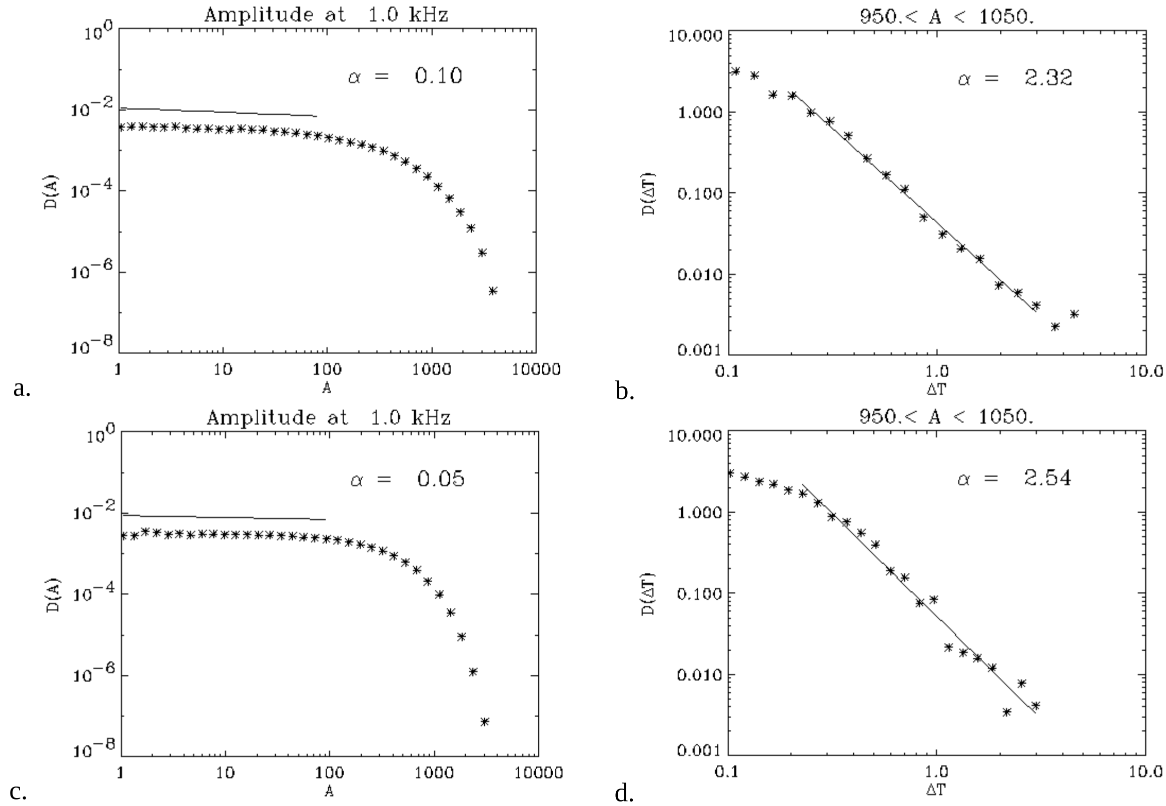

Fig.5. MAGION-5 data for hisses: the top row - orbit 3340; the bottom row - orbit 3252. Left column: distribution of VLF amplitude at 1 kHz. Right column: distribution of the interval between the occurrences of amplitudes in the marked region.

As one can see from Fig.1, mean frequencies of registered choruses tend to gather near certain frequencies. One may suggest, that choruses, clustering near one frequency, have a common localized generation source. That is why it is of special interest to us to analyze time distributions between chorus elements near those frequencies. The results are given in Fig. 3. One can see, that as the frequency band gets narrow, the form of distribution of times between appearances of chorus elements remains exponential, whereas the **a**-value becomes less (Fig.3).

Fig.3. Distribution of times between appearances of chorus elements with mean frequencies from a narrow range: a). 0.8-1.3 kHz; b). 1.9-2.4 kHz; c). 3.0-4.0 kHz.

Second approach

We considered the time dependency of the amplitude at certain selected frequencies, crossing the sequence of chorus elements in the spectrogram. One may assume, that intervals, during which the amplitude exceeds a certain threshold value at the given frequency, correspond to chorus elements. It turned out, that the density of the amplitude distribution at the selected frequency also had a region of the $1/f^a$ form. It is manifested the most for high frequencies (Fig. 4a). For those chorus elements, that have an amplitude from this region, the time distribution between appearances of chorus elements, is the same as the one, given in Fig. 4b. Amplitudes range for constructing this one and analogous distributions (Fig. 4d and Fig. 5 b-d) was chosen the way the total number of elements was ~2000.

At lower frequencies the $1/f^a$ form area is less manifested within the amplitude distribution, due to the increase of random noise level (Fig. 4 c-d).

The analysis of amplitude of VLF signal within the narrow frequency range allows us to compare the characteristics of chorus emissions to the ones of VLF hiss fluctuations, for which it is impossible to mark any certain discrete structure in the spectrogram. We chose two types of hiss for comparison with choruses; hiss in the morning sector, observed after the plasmopause on L-shells, about 4-5 simultaneously with choruses emissions at high frequencies (orbit 3240) and plasmosphere hiss, observed inside the plasmosphere at L<4 (orbit 3252).

Fig. 5 also displays examples of processing for those orbits as well. Dependencies D(A) (distribution of the amplitude at the given frequency) are shown in the same figure on the left. Corresponding time distributions between signal appearances are given on the right.

From Fig. 4 and 5 (left columns) one can see:

1). In events of an intense chorus without noise (orbit 3248 at the frequency of 3500 Hz) the density of amplitude distribution decreases as $1/f^a$, where $a=2.2\div2.3$, Fig.4a.

2). The amplitude distribution at the frequency of 1 kHz in the plasmosphere hiss (orbit 3252) is close to the uniform one with a sharp decrease at high frequencies, Fig. 5 c.

3). In events of hiss and noisy choruses at frequencies 1.0-1.4 kHz amplitude distributions are intermediate between events 1 and 2, Fig. 4 c and Fig. 5 c.

From the right column of Fig.4 and 5, one can see, that in events of choruses (orbit 3248) of time distribution between appearance of elements near the selected frequency has a decrease $1/f^a$, where $a=1.5\div1.7$. For orbits 3240 and 3252 (hisses) the distribution decreases much faster (a>2.0).

Conclusions

After the data by MAGION-5, it is shown, that in the morning sector at L=3-4 the sequence of chorus elements has properties, that may be an evidence of the SOC state of plasma in the area of their generation.

First, intervals between chorus elements within the range of 0.1-10 sec have the distribution of the form $1/f^a$, while for chorus elements at the selected frequency a<2.0. Such form of distribution between events is an evidence of the state of 'punctuated equilibrium'. The examples of such state (Bak,1997; Bak and Paczuski, 1995) known from literature, give **a**~1.6.

Second, the distribution of choruses' amplitudes at the selected frequency have a power-law region with **a** = 2.2÷2.3. At high frequencies this region is manifested better, than at low ones, where the noise interferes heavily.

The comparison of characteristics of chorus emissions with the characteristics of hisses revealed their difference. For instance, the distribution of amplitudes at the frequency of 1 kHz in the plasmosphere hiss is of a purely noise nature, e.g. close to the uniform one with sharp decrease at high frequencies.

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