



Investigation of multifractal nature of floating potential fluctuations obtained from a dc glow discharge magnetized plasma

Pankaj Kumar Shaw^{*}, Debajyoti Saha, Sabuj Ghosh, M.S. Janaki, A.N. Sekar Iyengar

Plasma Physics Division, Saha Institute of Nuclear Physics, 1/AF, Bidhannagar, Kolkata-700064, India

HIGHLIGHTS

- Plasma floating potential fluctuations are multifractal in nature.
- Role of magnetic field on the multifractal spectrum is investigated.
- Strength of multifractality decrease with the increase in magnetic field strength.
- Multifractality is due to the significant contribution of long range correlation.

ARTICLE INFO

Article history:

Received 26 July 2016

Received in revised form 31 October 2016

Available online 21 November 2016

Keywords:

Glow discharge Plasma

Floating potential fluctuation

Multifractality

Chaos

Multifractal detrended fluctuation analysis

ABSTRACT

In this paper, multifractal detrended fluctuation analysis (MF-DFA) has been used to analyze the floating potential fluctuations obtained with a Langmuir probe from a dc glow discharge magnetized plasma device. The generalized Hurst exponents ($h(q)$), local fluctuation function ($F_q(s)$), the Rényi exponents ($\tau(q)$) and the multifractal spectrum $F(\alpha)$ have been calculated by applying the MF-DFA method. The result of the MF-DFA shows the multifractal nature of these fluctuations. We have investigated the influence of magnetic field on the multifractal nature of the fluctuations and it is seen that degree of multifractality is reduced with the increase in the magnetic field strength. The values of $h(q)$ have been restricted between 0.7 and 1 for the magnetized fluctuations. This result is evidence of the existence of long-range correlations in the fluctuations. Furthermore, we employed shuffle and surrogate approaches to analyze the origins of multifractality. Comparing the MF-DFA results for the data set to those for shuffled and surrogate series, we have found that its multifractal nature is due to the existence of significant long-term correlation.

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1. Introduction

Plasma fluctuations measured in a dc glow discharge plasma and other plasma devices are mostly complex and multiscale in nature [1,2]. The complexity and multiscale nature varies little from one condition of measurement to another. When a magnetic field is applied, the system dynamics, i.e. the fluctuations, becomes more complex due to generation of various magnetized plasma modes like cyclotron modes, $E \times B$ drift in addition to unmagnetized plasma modes. These fluctuations

^{*} Corresponding author.

E-mail address: pankaj.shaw@saha.ac.in (P.K. Shaw).

also exhibit chaotic behavior and recognized to acquire self-similarity and also manifest strong fluctuations of all possible scales [3–5]. Since the fractality appears as a universal property of the complex systems, so, it is worthwhile to investigate the multifractal dynamics of the plasma which is also a complex system. The concept of multifractality is of great importance for space plasmas [6] because it allows us to look at intermittent turbulence in the solar wind [7]. It is also very important in the study of tokamak plasma turbulence [8]. Many attempt have been made to recover the observed scaling exponents, using multifractal phenomenological models of turbulence describing distribution of the energy flux between cascading eddies at various scales [9]. Multifractal dynamics for plasma edge electrostatic turbulence has been investigated using wavelet transform modulus maxima (WTMM) [10]. Here, multifractal detrended fluctuation analysis [11] (MF-DFA) technique is deployed to investigate the multifractal dynamics of floating potential fluctuations obtained from the glow discharge plasma device. MF-DFA method is based on the generalization of the detrended fluctuation analysis [12–14] (DFA), and is able to determine the multifractal scaling behavior of a signal. MF-DFA, is a fairly robust and powerful technique for detection of the multifractality, has been applied successfully in diverse fields such as sunspot time series [15], traffic time series [16], stock market data [17], EEG signals [18], heart rate data [19], geophysical data [20], earthquake data [21] and many others [22, 23]. MF-DFA technique is also employed in the field of plasma to detect the multifractality in intermittent fluctuations of discharge plasma [24] and tokamak edge plasma fluctuations [25] etc.

In the present study, the floating potential fluctuations obtained from dc glow discharge magnetized plasma are studied using Lyapunov exponent, MF-DFA technique and power spectrum analysis. The main focus is on the investigation of long range correlation nature and multifractal properties of the fluctuations. We have also carried out on how the multifractal nature of the fluctuation changes with the application of axial magnetic field. Generally, long range correlation in the time series data and fatness of the probability density function (PDF) of the time series are the two principle sources of the multifractality in that time series. Here, we have compared the MF-DFA results for the data sets to those for shuffled and surrogate series to find out the source of multifractality in the fluctuations.

The rest of the paper is organized as follows: In Section 2, a brief description of MF-DFA technique is provided. Experimental setup is described in the Section 3. Detail discussion about the nature of observed floating potential fluctuations, the results obtained by applying MF-DFA on the fluctuations and the calculation of the multifractal spectrum are provided in the Section 4. Conclusion and summary of the results are presented in Section 5.

2. Methodology: multifractal detrended fluctuation analysis

The multifractal detrended fluctuation analysis (MF-DFA) technique is the modified version of detrended fluctuation analysis (DFA) used to detect multifractal properties of time series. The MF-DFA consists of five steps. For a given time series x_k of length N , steps for MF-DFA are given below [15]:

1. Determine the profile of underline time series:

$$Y(i) \equiv \sum_{k=1}^i [x_k - \langle x \rangle] \quad i = 1, 2, \dots, N. \quad (1)$$

2. Divide the profile $Y(i)$ into $N_s \equiv \text{int}(N/s)$ non-overlapping segments of equal lengths s . In general, length N of the series is not a multiple of the timescale s , so, a short part at the end of the profile may remain. In order not to disregard this part of the series, the same procedure is repeated starting from the opposite end. Thereby, $2N_s$ segments are obtained altogether.
3. Compute the local trend for each of the $2N_s$ segments by a least squares fit of the series. Then determine the variance

$$F^2(s, \nu) \equiv \frac{1}{s} \sum_{i=1}^s \{Y[(\nu - 1)s + i] - y_\nu(i)\}^2, \quad \nu = 1, 2, \dots, N_s \quad (2)$$

and

$$F^2(s, \nu) \equiv \frac{1}{s} \sum_{i=1}^s \{Y[N - (\nu - N_s)s + i] - y_\nu(i)\}^2, \quad \nu = N_s + 1, N_s + 2, \dots, 2N_s \quad (3)$$

where $y_\nu(i)$ is a fitting polynomial in segment ν . Linear, quadratic, cubic or higher order polynomials can be used in the fitting procedure. Usually, a linear function is selected for fitting the function [26].

4. Average over all segments to obtain the q th-order fluctuation function, given by

$$F_q(s) \equiv \left\{ \frac{1}{2N_s} \sum_{\nu=1}^{2N_s} [F^2(s, \nu)]^{q/2} \right\}^{1/q}. \quad (4)$$

5. Determine the scaling behavior of the fluctuation functions by analyzing log–log plots of $F_q(s)$ versus s for each value of q . If the series x_k are long range power law correlated, $F_q(s)$ increases as a power law for large values of s ,

$$F_q(s) \sim s^{h(q)}. \quad (5)$$

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