NONLINEAR SPECTRAL ANALYSIS OF PLASMA TURBULENCE

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ABSTRACT

We present a statistical analysis of strong turbulence of Langmuir and ion-sound waves resulting from beam-plasma interaction. The analysis is carried out on datasets produced by a one-dimensional numeric simulation of the Zakharov equations. Two different statistical approaches were applied to resolve the properties of the nonlinearity in the system: bispectrum analysis and Volterra model analysis. Both methods were used to identify coherent wave-wave interactions in the data and the Volterra model was furthermore employed to evaluate the energy transfers between the wave modes in case of Langmuir wave decay.

OVERVIEW OF THE ANALYSIS

The Zakharov equations [1] describe the time evolution of high-frequency oscillations of the electric field in plasma together with low frequency fluctuations of plasma density. In our work we used a one-dimensional numeric code to solve these equations for the problem of an electron beam instability. Here the energy is delivered to the system by an oscillating electron beam which excites Langmuir waves, which than decay into Langmuir waves of lower frequency and ion-sound waves. The objective of our analysis was to infer some quantitative information on this particular nonlinear three-wave decay from the simulation data. Beside this decay that can be well described in the framework of weak turbulence, other strongly-turbulent processes contribute to the evolution of the system, such as the formation of density cavities caused by modulational instability. The simultaneous appearance of these effects together with some unphysical features of the simulation introduce significant difficulties to the application of the nonlinear statistical tools.

Two first tool used in the analysis was the cross-bicoherence [2] defined in our case as

$$< E(k_1)\rho(k_2)E^*(k_1+k_2) > / \sqrt{< |E(k_1)\rho(k_2)|^2 >< |E^*(k_1+k_2)|^2 >}, \tag{1}$$

where $E(k)$ and $\rho(k)$ are the electric field and density spectra. A nonzero value of this indicates the existence of phase coupling of the three interacting waves and allows to identify the interacting wave modes.

Next we applied a parametric Volterra model [3] to quantify the energy transfer between the interacting waves. The model of the form

$$dE(k)/dt = L_k E(k) + \sum_{k=l+m} \Lambda_{klm} E(l)\rho(m), \tag{2}$$

was fitted to the data by estimating the linear and nonlinear coupling coefficients L_k and Λ_{klm}. These coefficients unambiguously determine the existence of nonlinear interaction and one can use them to compute the direction and magnitude of the nonlinear energy transfer.

We demonstrate that these methods are relevant tools for analysis of simulation datasets because of their ability to determine the properties and relative importance of different processes contributing to the dynamics of the turbulence. In the studied problem of Langmuir turbulence this means to compare the influence of the wave-wave interactions and the modulational instability.

REFERENCES

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