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# Study of Nonlinear Processes of Fluctuations in Laboratory Magnetized Plasmas

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Experimental techniques used to study dynamics of turbulent fluctuations in two magnetized linear plasma devices are presented. The characteristics and data requirements of wavelet-based bicoherence analysis are explained and results obtained from fast imaging data on the Mirabelle device are shown. The results reveal a temporal delay between coupling detection and power gain of a fluctuation component and show the importance of taking temporal dynamics of nonlinear processes into account. Dynamics of particle transport have been studied on PANTA and the discovered modulation of transport by coexisting modes calls for a merging of nonlinear coupling and transport studies.

## 1. Nonlinearity and Dynamics of Fluctuations

Progress in the experimental studies of turbulent processes in cylindrical magnetized plasma devices is generally centered around three axis: the search for advanced analysis tools, the use of new types of diagnostics to fulfill data requirements for analysis and eventually interpretation of results in terms of physical processes.

Concerning detection of nonlinear coupling from data of plasma fluctuations, different analysis approaches have been pursued. A recurrent mathematical quantity is the bicoherence [1]. It tests whether three fluctuation components have matching frequencies (or wave numbers) and matching phase for a long enough set of ensembles, usually taken as successive time windows. Bicoherence indicates whether the necessary conditions for nonlinear coupling are satisfied. To know if energy or enstrophy is effectively transferred between fluctuation components, the transfer coefficients can be computed for the given fluctuation regime [2]. Other methods are yet necessary to study the fine dynamics and interplay of fluctuation components. One of those is the amplitude correlation technique [3] (see also contribution 24C12 by T. Kobayashi in this conference), which is based on the assumption that the power of the nonlinearly driven mode will change later than the power of the parent mode. Another method consists in investigating sequences where power of driven fluctuations increases when coupling conditions are fulfilled. This last method requires computing possible couplings within very short time windows. This can be achieved by using wavelet bicoherence [4]. Wavelets can extract the fluctuation components of a signal for short data windows and significantly improve the temporal resolution of the results. An additional possibility is to average over a second dimension such as space instead of time, thus obtaining a quantity close to a wave number wavelet bicoherence [5]. These advanced methods require fluctuation data highly resolved in time and space.

## 3. Experimental Access to Fluctuation Data

Linear magnetized plasma devices are characterized by relatively low temperatures that allow a wide choice of diagnostics. Interesting data dimensions are time, radius, azimuthal angle and axial position. Arrays of Langmuir probes can provide good temporal resolution for several spatial points but can perturb the plasma. Azimuthal arrays, useful for investigation wave number space, usually have a fixed radial position. A non-perturbative, flexible diagnostic on linear machines is fast imaging using high sensitivity high-speed cameras. It was found on the Mirabelle device that a significant contribution to light emission results from excitation of neutral atoms by plasma electrons [6] and that light intensity is proportional to plasma density. With a high enough temporal and spatial resolution, camera data can be used instead of probe data to study turbulence.

## 4. Bicoherence Analysis on Camera Data

The wavelet wave number bicoherence has been applied to fast camera data from the linear device Mirabelle [7]. Figure 1 shows a specific moment in time when a fluctuation with azimuthal mode number m=3 is beginning to develop in the power spectrum S(m), after this mode appeared in the summed bicoherence $b^2(m)$. This kind of temporal sequences can suggest an energy transfer to the growing mode via nonlinear coupling. The corresponding camera frame is also shown in fig. 1.

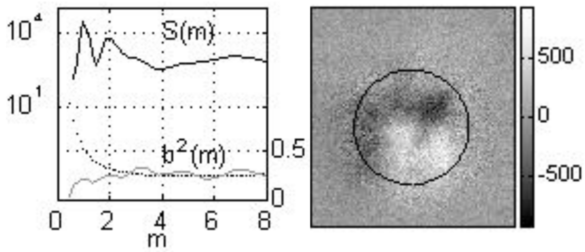


Fig.1. Wave number bicoherence and power spectrum computed from camera data on Mirabelle (left side), corresponding camera frame (right side).

The presented method's weak point, just as for the temporal wavelet bicoherence, is the doubt about independence of the considered ensembles. A repetitive record of the same sequence of events could guarantee real ensemble averaging.

## 5. Nonlinear interactions and transport

Energy transfers between different scales can influence other phenomena in plasmas such as fluctuation-induced transport. A prominent example how nonlinear interactions can influence transport is the drive of zonal flows by drift wave turbulence. A study on the PANTA showed that transport is also a non-stationary phenomenon in small linear devices even without explicit observation of detached coherent structures [8]. Figure 2 shows the time and frequency decomposed radial particle transport in the PANTA in a regime featuring a solitary-wave-like fluctuation. Transport on the frequency of the mode m=2 is modulated in time and fluctuates following an m=0 structure. The alteration of transport on one mode by another mode requires an interaction between those modes that could be detected by methods searching for nonlinear couplings. Transport and nonlinear coupling studies are planned in a wide range of discharge conditions, by using amongst others biasing of a newly installed isolated endplate.

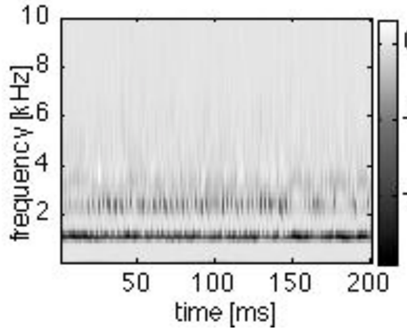


Fig.2. Frequency and time resolved transport for the PANTA solitary-wave-like regime.


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