*36th EPS Conference on Plasma Phys. Sofia, June 29 - July 3, 2009 ECA Vol.**33E**, P-5.213 (2009)*

Study of nonlinear mode couplings in a magnetized plasma column: Benefits of fast camera imaging

S. Oldenbürger, M. Nepal, F. Brochard, G. Bonhomme

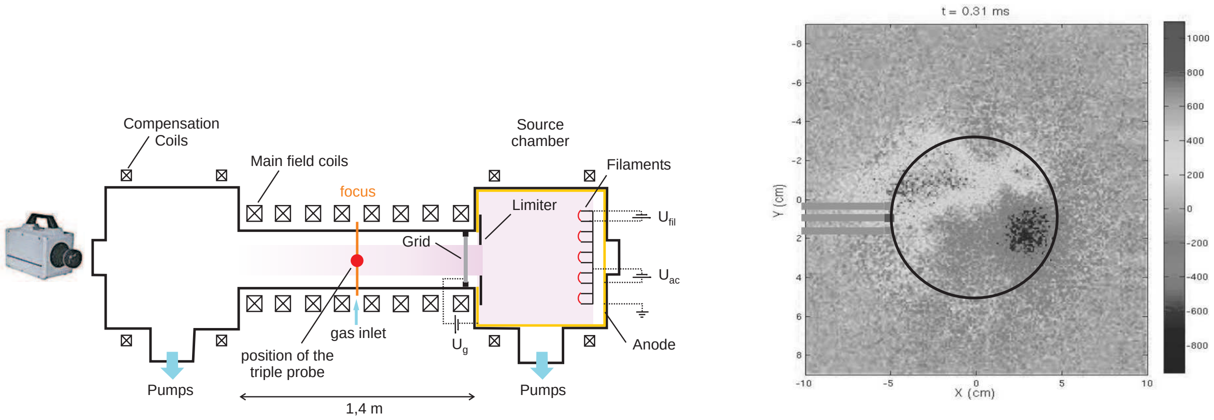
Institut Jean Lamour, UMR CNRS 7198, Département P2M, Nancy-Université,

Bd des Aiguillettes, BP 70239, F-54506 Vandoeuvre-lès-Nancy, France

The broadband spectrum of fluctuations observed in fusion plasmas can result from nonlinear high order wave-wave interactions, which can transfer the energy contained in a few modes to a multitude of modes. A nonlinear energy transfer involves at least three modes and requires a frequency and phase match between the modes. A well-known tool to measure this match is the bicoherence, which corresponds to a third order spectrum of fluctuations.

This contribution presents investigations conducted on the linear device Mirabelle. Complementary to Langmuir probe measurements, camera measurements have been used to compute wavelet bichorence. Following a short introduction of the experimental setup, first results of mode number bicoherence computation are presented. Finally the new perspectives but also the new challenges associated with the camera as a turbulence diagnostic are discussed.

In linear plasma devices with a small R/ρ_s ratio, there are a limited number of global modes with small poloidal mode number. This facilitates the study of fundamental coupling mechanisms. The low-β cylindrical magnetized plasma device Mirabelle is depicted in Fig. 1(a). The plasma is produced in a source chamber by a thermionic discharge and confined in a cylindrical section. By adjusting the acceleration voltage, the neutral gas density, the magnetic field and the potential of a grid at the entrance of the cylindrical section, the gradients in the plasma can be varied and specific plasma regimes can be selected [2]. A radially moveable Langmuir triple probe is inserted in the middle of the cylindrical section of Mirabelle. The central tip is negatively biased and records density fluctuations via the ion saturation current. The two outer tips record floating potential fluctuations. A Photron SA-1 fast camera is installed in front of a window at the end of the second chamber, which is not used for plasma production in these experiments. The focal plane is adjusted to the position of the probe tips. The recorded image pictures a cross-section of the plasma column. The frame rate for the records presented here is of 90 000 fps. One image pixel corresponds to a region of approximately 0.8 mm. In order to extract information on light intensity fluctuations, the average image of the recorded movie is subtracted from each frame. A sample frame and the position of the triple probe on the images are shown in Fig. 1(b).



(a) The Mirabelle device. (b) Image of the plasma column.

Figure 1: The experimental setup and a sample image recorded with the fast camera. The average image has been subtracted in order to visualize light fluctuations. The position of the triple probe and a virtual circle passing through the probe's position are indicated.

Synchronized recordings of the ion saturation current measured by the central Langmuir probe and the light intensity on the pixel corresponding to the probe's position show a good agreement. The finding that their cross-correlation shows no phase lag corroborates the assumption that the electronic temperature fluctuations in Mirabelle do not influence the collected light intensity.

The wavelet bicoherence has been computed according to the expressions presented in [3]: $B^w(f_1, f_2) = \int_T \; W(f_3,t)^* \; W(f_1,t) \; W(f_2,t) \; dt$ for $f_1 + f_2 = f_3$. The summed squared auto-bicoherence is given by: $b^2(f_3) = \frac{1}{S_f} \sum_{f_1,f_2} [B(f_1, f_2)]^2$, where S_f is the number of summands with $f_3 = f_1 + f_2$. These quantities are high, if a phase match exists, i.e. if $\varphi_1 + \varphi_2 = \varphi_3 + \; cst$. The frequency bicoherence plot computed from the light intensity time series is very similar to the bicoherence plot constructed from the density time series measured with the probe, as expected from the good agreement between light intensity recordings and density measurements. In the case of global poloidal modes, the mode number bicoherence is particularly interesting. In a study using measurements with a poloidal probe array in the VINETA device, Brochard *et al.* [4] observed a rise of the summed bicoherence located on a given mode, shortly before this mode gained power in the spectrum. The high bicoherence could in this case be linked to an energy transfer to the mode. It was possible to observe a similar sequence by using camera measurements on Mirabelle. The light fluctuations have been extracted from pixels arranged on a circle, as sketched in Fig. 1(b), in order to simulate poloidal measurements. Figure 2 shows the summed squared wavelet auto-bicoherence and the power spectrum computed on three successive camera images. In the first image, a high bicoherence peak, indicated by the arrow, can

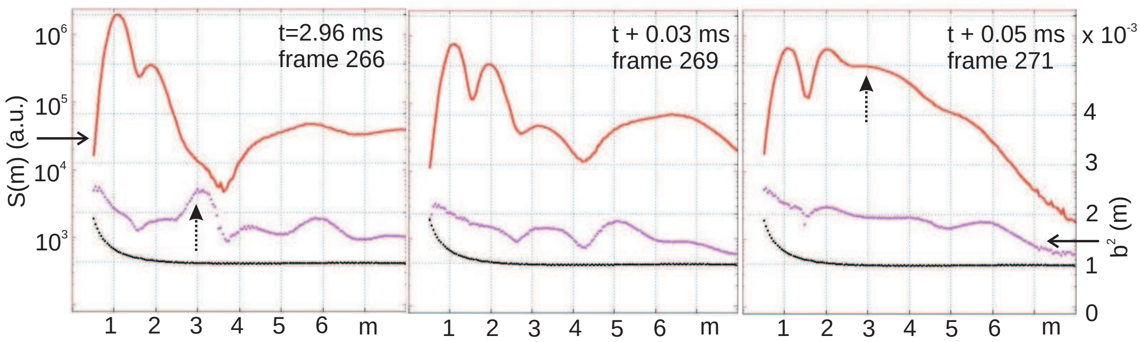
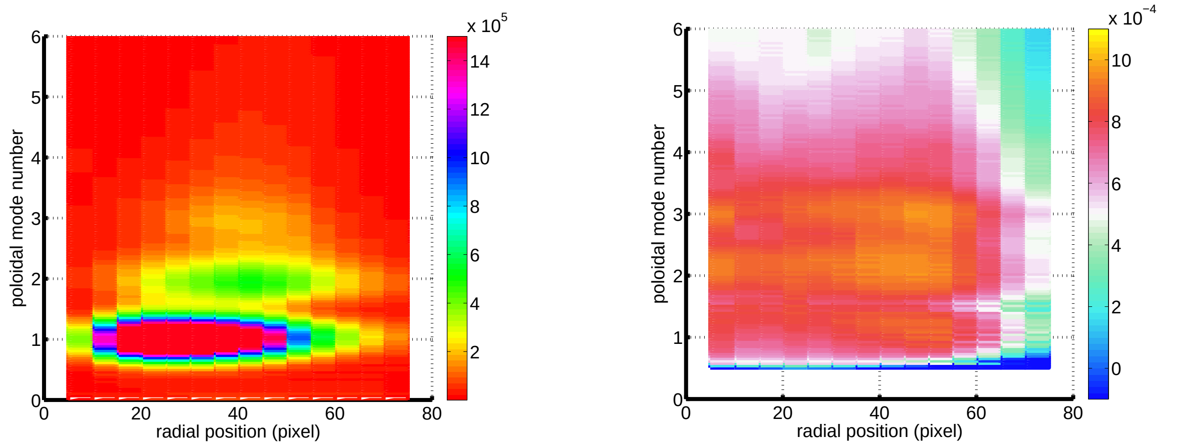


Figure 2: Sequence showing the power spectrum and summed squared auto-bicoherence computed from camera images at three points in time. The lowest black curve gives the bicoherence noise level inherent to the computation method.

be seen on the mode $m = 3$, whereas the mode is weak in the power spectrum. On the second image, this mode appears in the power spectrum and its power increases even more in the third frame, as indicated by a second arrow.

When poloidal probe arrays are used, the probe tips have to be ajusted to a given radius and can therefore usually only measure the bicoherence at a fixed radius. The camera however records the whole cross-section of the column with a good spatial resolution. It is possible to analyze several radial positions from the same movie and to obtain information about simultaneous coupling events at different radii. Figure 3 shows the radial evolution of the power spectrum and summed squared auto-bicoherence computed from camera images. Although this plots can be computed for every single movie frame, the plots shown in figure 3 have been averaged over 300 frames. The mode number spectrum in Fig. 3(a) shows that the higher mode numbers are located at slightly outer radial positions, as predicted from various numerical studies, e.g. [5]. The maximum of bicoherence for all modes is found at a radial position of about 50 pixels, which corresponds to the position of the m = 3 mode, see Fig. 3(b). The localization of the maximum bicoherence doesn't seem to follow the position of the maximum power spectrum. This is especially striking for the m = 1 mode.

Camera measurements feature an inherent benefit, which is the high spatial resolution. The records give the density fluctuations simultaneously in a whole cross-section of the plasma column without perturbation of the plasma. Their main drawbacks are linked to the low signal strength and the poor temporal resolution. The frame rate is high enough for the visualization of the instabilities in the Mirabelle device, which have frequencies in the range of 1-15 kHz, but it is too low for a good statistical analysis of short-time phenomena like energy transfers between modes. Therefore the correlation between bicoherence peaks and peaks in the power



(a) Poloidal mode number spectrum as a function of radius.

(b) Summed squared auto-bicoherence as a function of radius.

Figure 3: Radial evolution of the power spectrum and summed squared auto-bicoherence computed from camera images. One pixel corresponds to circa 0.8 mm

spectrum could not be established unambiguously. The use of a light intensifier would permit higher frame rates as well as the investigation of less bright plasma regimes.

The Mirabelle device is equipped with an octupolar exciter, which can be used to control turbulence and a study of the turbulent transport in different regimes is being conducted. The bicoherence analysis on camera measurements can provide information on nonlinear couplings and could give further insight in the mechanisms of turbulence, especially if it was coupled with transport studies.

This work, supported by the European Community under the contract of Association between EURATOM, CEA, and the French Research Federation for fusion studies, was carried out within the framework of the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commision. Financial support was also received from the French National Research Agency through contracts ANR-08-JCJC-0068-01 and ANR-07-BLAN-0187.

References

[1] T. Pierre, G. Leclert and F. Braun, Rev. Sci. Instrum., **58**, 6-11, (1987)

[2] F. Brochard, E. Gravier and G. Bonhomme, Phys. Plasmas **12**, 062104, (2005)

[3] B. Ph. van Milligen et al., Phys. Plasmas **2**, 3017, (1995)

[4] F. Brochard et al., Phys. Plasmas **13**, 122305, (2006)

[5] R.F. Ellis and E. Marden-Marshall, Phys. Fluids **22**, 2137, (1979)