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Investigation of cross-field transport in a linear magnetized plasma

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Introduction

In magnetic confined plasmas, the particle and energy cross-field transport towards the wall is still a major challenge. Particularly intermittent transport events (so-called "blobs") through the scrape-off-layer can cause damages to the wall materials as well as to the quality of plasma confinement. Low frequency gradient driven instabilities, which can be investigated with small scale devices, play a prominent role in non-diffusive transport. Transport measurements in a small device like Mirabelle [1] lead to a better understanding of the origin and characteristics of plasma instabilities and their associated convective transport. The field of transport measurements in magnetized plasmas is subject to continuous improvement of the experimental and analyzing tools. The state-of-the-art already implies the use of analyzing methods resolved in time, space and frequency. A further step is the combination of several diagnostics such as probes and fast cameras.

The first part of this contribution describes the linear plasma device Mirabelle. A second part focuses on the convective transport measurements performed with triple probes and the wavelet based data analysis. The following section describes the use of a fast camera to investigate the plasma dynamics. Finally, the enhancements needed to improve the comparison between camera and probe measurements are presented.

Experimental device

The experimental investigations are performed on the low-β cylindrical magnetized plasma device Mirabelle. The device is composed of a central cylindrical section and a source chamber in which argon plasma is produced by a thermionic discharge. The plasma is confined magnetically within the central section. It is possible to observe regular to weakly turbulent states for several types of instabilities, i.e. drift waves and flute modes, by adjusting the plasma gradients and especially the radial electric field that acts on the rotation of the plasma column [2]. This can be done by varying the bias of a grid mounted at the entrance of the central section or by adding a limiter between the cylindrical section and the source chamber.

Probe measurements

In the presence of a plasma potential perturbation, local fluctuating poloidal electric fields arise. In the presence of the main magnetic field, this leads to a radial transport $\Gamma = v_{\tilde{E}\times B} \cdot \tilde{n}$ ($\tilde{n}$ denotes the density fluctuations and $\tilde{E}$ the poloidal field fluctuations).

In previous works, transport has in general been computed by using mean values of the density and the electric field fluctuations, in some cases frequency resolution of transport has been studied by using Fourier-methods. However, these methods are not adapted for instabilities with co-existing modes and non stationary regimes. Hence, wavelet-based methods are used here, which make it possible to extract information not only about the average transport amplitude but also about its evolution in time [3]. The convective transport is calculated as follows:

$$\Gamma(f,t) = \frac{2}{B}\,|\tilde{n}(f,t)\tilde{E}^*(f,t)|\,\cos(\arg(\tilde{n}(f,t)\tilde{E}^*(f,t))),$$

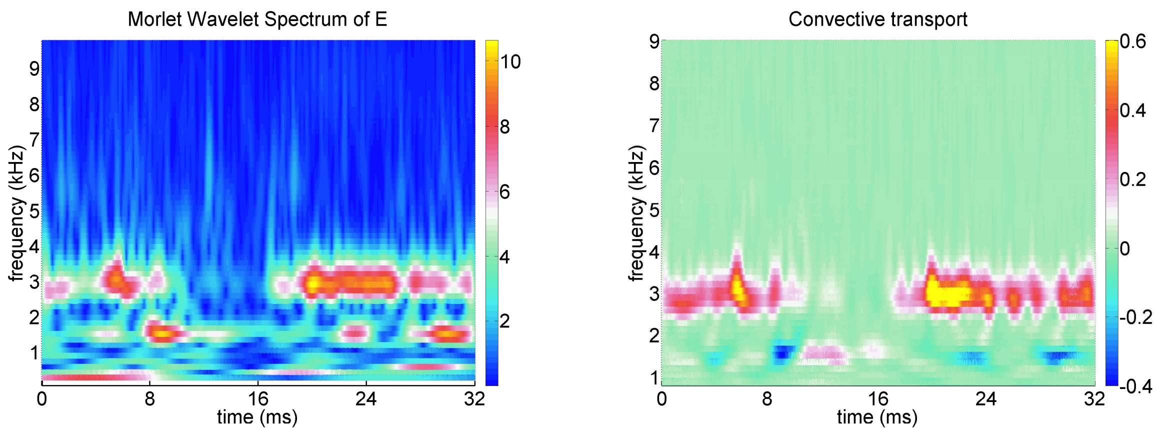
where $|\tilde{n}(f,t)\tilde{E}^*(f,t)|$ is the time resolved cross power spectrum and $\arg(\tilde{n}(f,t)\tilde{E}^*(f,t))$ is the cross phase between the density and the electric field fluctuations. Alternatively, the time-windowed cross-coherence is used to get statistically robust estimations.

The time series of density and electric field are measured by means of a radially movable Langmuir triple probe. The central tip is negatively biased and records density fluctuations whereas the two outer tips record floating potential fluctuations. When temperature variations are neglected, the electric field is given by the floating potential gradient. The time series are decomposed on a Morlet wavelet basis and the cross power and cross phase is computed using directly the wavelet coefficients.

To illustrate this method, Fig.1(a) displays the wavelet transform of the electric field fluctuations recorded at the edge of the plasma column in a regime with high grid voltage. Two intermittent frequency bands appear at 1,5 kHz and at 3 kHz, both are candidates to induce convective transport. As can be seen in Fig.1(b), the computed transport does indeed appear intermittently at the two frequencies. Moreover, the wavelet computation shows that the direction of the transport, which is dependent on the phase difference between density and electric field fluctuations, is opposite for the two modes. This example illustrates the intermittent and non-monochromatic nature of the observed instabilities and the need for a transport analysis, that conserves time and frequency information.

Fast camera imaging

A fast camera is set up in front of vacuum windows at each side of the Mirabelle device. By focusing on a cross-section inside the cylindrical section, light intensity fluctuations in a



(a) Wavelet transform of $\tilde{E}$.

(b) Wavelet calculated transport.

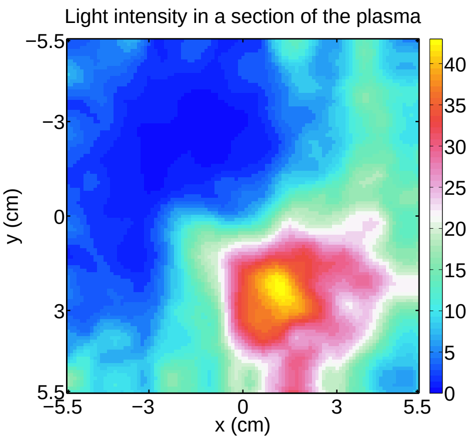
Figure 1: Example of transport analysis on probe measurements at the edge of the cylindrical section of Mirabelle.

whole section of the plasma column are recorded. The fluctuations in light intensity are linked to the fluctuations of plasma density, thus providing a visualization of the density fluctuations dynamics [4]. The camera record and the probe data acquisition can be triggered to obtain simultaneous measurements. The rather weak light intensity as well as the cloudy shape of the structures request efficient image analysis methods. The images have been processed as follows: first, an average frame is subtracted from the images. Second, the frames are denoised by using a two dimensional wavelet decomposition and by recomposing the images discarding small scale information. Optionally, in a third step the images are smoothed. A processed camera frame is shown in Fig.2(a), depicting a regular m=1 mode. Probe measurements performed for the same regime at different radial positions show important and continuous transport at the frequency of the m=1 mode. Transport averaged over time and frequency as a function of the radial position is shown in figure Fig.2(b). The transport reaches its maximum value at 3 cm. This correspond to the position of the structure recorded by the camera.

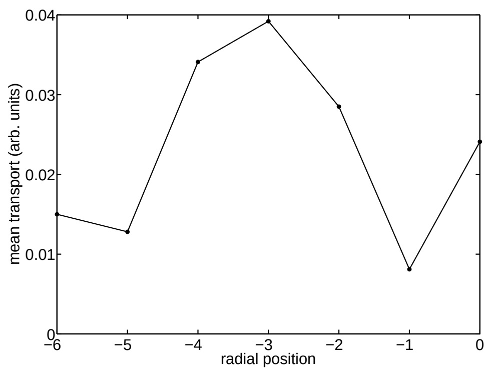
Summary and Perspectives

The methods used to assess transport in the Mirabelle device have been presented. An example of triple probe measurements illustrated the need for time and frequency resolved analysis. A first comparison between fast camera images and probe measurements showed coherency between the detected transport and a visible structure.

The radially movable triple probe provides a single point measurement of convective transport at a given radial position. To access the global flux, a probe array should be used that covers the whole circumference of the plasma. This would also enhance the comparison between the



(a) Fast camera image after processing.



(b) Mean transport for different radial positions. Position 0 corresponds to the center of the column.

Figure 2: Imaging of a m=1 regular spiral mode and transport at different radial positions.

camera images and the probe data. A circular probe array with adjustable radial extension is therefore under construction.

As a further prospect, it should be considered to investigate the influence of instability control on the convective transport. The Mirabelle device can be equipped with a multiple plate exciter to apply an open-loop control to the plasma instabilities [5]. Alternatively, a cylindrical tube can be used to stabilize weakly turbulent instabilities with a TDAS-control. The advanced combination of probe measurements and camera images can improve the understanding of the effect of extern control on the plasma behavior.

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