Investigation of cross-field transport in a linear magnetized plasma using emissive probes

G. Bousselin[1], J. Grünwald[2], C. Brandt[3], N. Lemoine[1], G. Bonhomme[1]

[1]Institut Jean Lamour, Nancy-Université, Vandœuvre-lès-Nancy, France

[2]Institute for Ion Physics and Applied Physics, University of Innsbruck, Innsbruck, Austria

[3]Max-Planck-Institut für Plasmaphysik, Greifswald, Germany

1. Introduction

Turbulence of low frequency instabilities in confined magnetized plasma is assumed to be responsible of an anomalous particle and energy transport perpendicular to the magnetic field. In order to improve the efficiency of controlled fusion, this anomalous transport has to be reduced. In the linear magnetized plasma device Mirabelle, both drift wave and flute mode instabilities can develop in the plasma column [1][2]. Cohabitation of density and plasma potential fluctuations is responsible of a net convective transport.

The plasma density and its fluctuations are usually recorded from the ion saturation current I_{is} to a cold Langmuir probe. In a Maxwellian plasma, the plasma potential Φ_p can be measured indirectly with cold probes using the inflection point of the first derivative of the current-voltage characteristic. It can be also calculated from the following relation between the floating potential V_{fl} and Φ_p (knowing T_e):

$$\Phi_p = V_{fl} + \frac{k_B T_e}{e} \ln\left(\frac{(1-\gamma_e)I_{es}}{(1+\gamma_i)I_{is}} \right) \qquad (1)$$

$I_{es/is}$ are the electron/ion saturation current respectively, T_e the electron temperature, $\gamma_{e/i}$ the secondary electron/ion emission coefficient and k_B the Boltzmann constant.

The evaluation of plasma potential fluctuations is indirect as well. They are often considered to be equal to those of the floating potential in the limit of small temperature fluctuations.

An emissive probe consists of a small Tungsten wire loop heated by an external DC current. For a sufficient heating current, the probe starts to emit electrons and this electron emission current I_{em} is adding to the plasma current. Then the relation (1) becomes:

$$\Phi_p = V_{fl}{}^{em} + \frac{k_B T_e}{e} \ln\left(\frac{(1-\gamma_e)I_{es}}{(1+\gamma_i)I_{is} + I_{em}} \right) \qquad (2)$$

By increasing I_{em}, the second term in (2) decreases and the floating potential of the emissive probe tends to Φ_p. When $I_{em} = I_{es} - I_{is}$, $V_{fl}{}^{em}$ reaches $\Phi_{p.}$ It is sufficient to measure the emissive probe floating potential to directly measure Φ_p and its fluctuations[3].

In this paper, we present measurements of cross-field transport obtained with a probe array consisting of several emissive and cold Langmuir probes used to record simultaneously plasma potential and density fluctuations. The induced turbulent transport is computed using spectral analysis based on a wavelet transform.

2. Experimental setup

Experiments are conducted on the low-β linear magnetized plasma device Mirabelle, sketched on Fig. 1. Plasma is produced in one source chamber by a thermionic discharge. Plasma diffuses in the linear section and is confined by an axial magnetic field up to 120 mT. With a limiter at the entrance of the column, flutes modes instability driven by a strong $\mathbf{E} \times \mathbf{B}$ shear at low magnetic field can be observed. Drift waves are dominant at higher magnetic field. Depending on the discharge parameters plasma fluctuations can be periodic or turbulent.
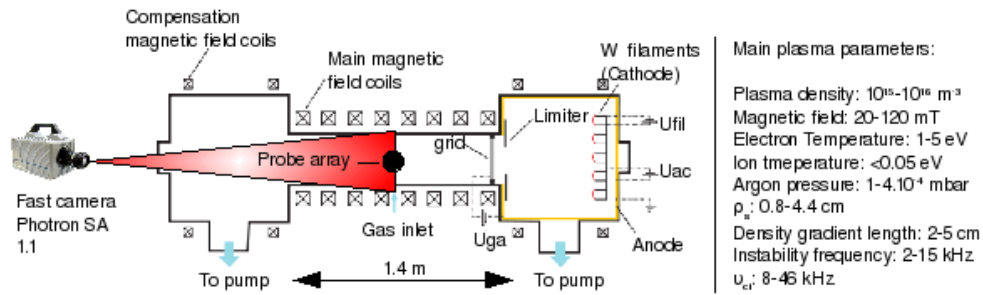

Figure 1 : Scheme of the linear magnetized plasma device Mirabelle

A radially movable probe array (Fig. 2) consisting of four emissive probes and two cylindrical cold Langmuir probes is located in the central part of the column. Φ_p and its fluctuations are recorded with the two inner heated emissive probes. Then poloidal electric field fluctuations are
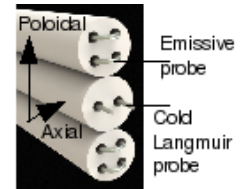

Figure 2 : Probe array

calculated by $\tilde{E}(t) = \left(\overset{em1}{\tilde{\Phi}_p}(t) - \overset{em2}{\tilde{\Phi}_p}(t) \right) \Big/ d$, with d being the distance between the probes.

The two outer emissive probes are used as references. Density fluctuations ñ are simultaneously recorded by Langmuir probes and can be observed by a fast camera (up to 100 kHz) to distinguish the dynamics of the instabilities.

3. Cross-field transport analysis

The fluctuation-induced radial transport is defined as: $\Gamma_r = \langle \tilde{n} \tilde{v}_{E \times B} \rangle = \langle \tilde{n} \tilde{E}_\theta \rangle / B$. Because the fluctuations are polychromatic, it is important to compute Γ_r as a function of the different frequencies to understand which part of the spectrum has the biggest influence. The transport

can be expressed by the cross-correlation between $\tilde{n}$ and $\tilde{E}$. In turn, the cross-correlation can be written using the Fourier transform of the cross-spectrum $S_{\tilde{n},\tilde{E}}(\omega)$. Then the global transport is the integral over each frequency component given by:

$$\Gamma(\omega) = \frac{2}{B}\mathbb{R}\left(S_{\tilde{n},\tilde{E}}(\omega)\right) = \frac{2}{B}\left|S_{\tilde{n},\tilde{E}}(\omega)\right|\cos\left(\varphi_{\tilde{n},\tilde{E}}\right) \qquad (3)$$

In order to follow the complex time evolution of the transport, we are computing the cross-spectrum by using wavelet transform.

$$\Gamma(\omega,t) = \frac{2}{B}\left|W_{\tilde{n}}(\omega,t)W_{\tilde{E}}^{*}(\omega,t)\right|\cos(\varphi_{W_{\tilde{n}}(\omega,t)} - \varphi_{W_{\tilde{E}}(\omega,t)}) \qquad (4)$$

$W_{\tilde{n}}(\omega,t) = \int \tilde{n}(\tau).\psi^{\omega,t}(\tau)d\tau$ is the wavelet transform of ñ (or $\tilde{E}$) using continuous complex Morlet wavelets, $\left|W_{\tilde{n}}(\omega,t)W_{\tilde{E}}^{*}(\omega,t)\right|$ the cross power, $\varphi_{W_{\tilde{n}}(\omega,t)} - \varphi_{W_{\tilde{E}}(\omega,t)}$ the cross phase.

4. Results

Both cold and emissive probes were used to measure radial transport in a regular m=2 flute mode regime. The corresponding spatiotemporal dynamics and mean profiles are presented in Fig. 3. Cross-field transport results at several radial positions are shown in Fig. 4.
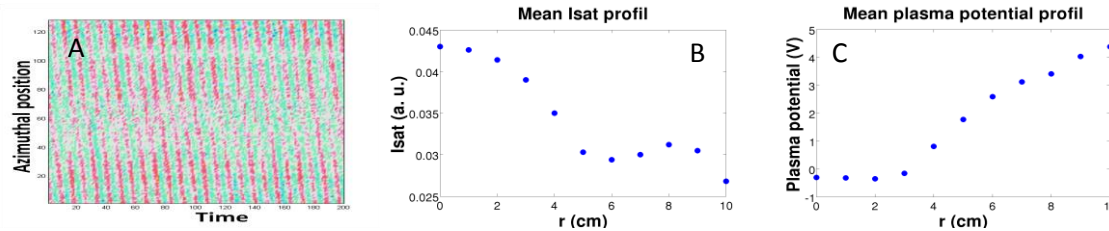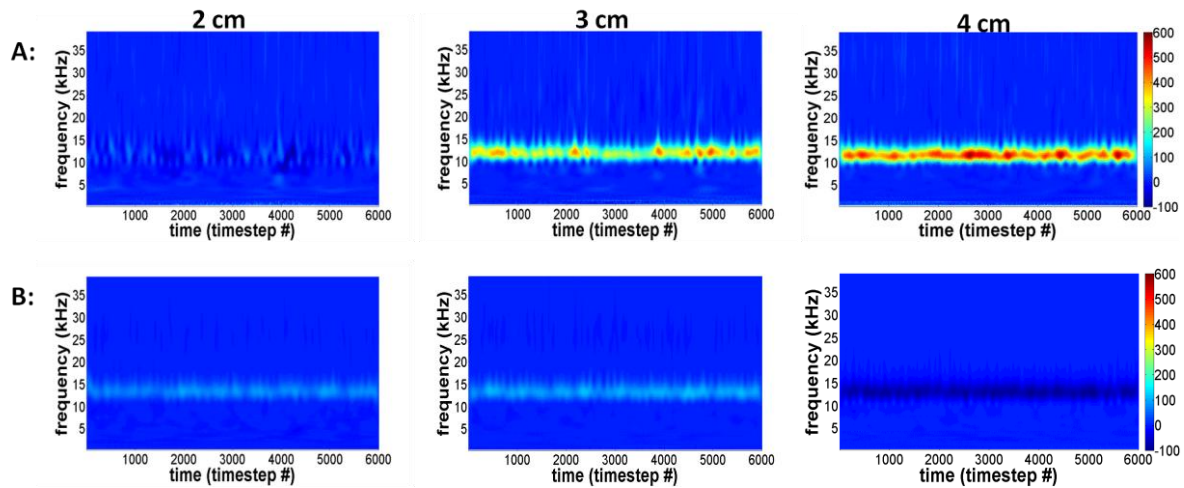

Figure 3: A/ Spatiotemporal dynamic, B-C/ Mean n_e and Φ_p profiles

Transport is mainly governed by a single frequency at 11 kHz and shows only very small variations in time. However its amplitude and direction vary depending on the probes used. Emissive probe measurements are consistent with density and potential profiles. Radial flux is directed outward and increases with the distance from the center. Maximum transport is located where gradients are maximum. The transport measured with cold probes is weaker. It undergoes a sign change at 4cm where n_e and Φ_p gradients are maximum. This unexpected transport direction is the result of a cross-phase $\varphi_{\tilde{n}\tilde{E}}$ which exceeds $\pi/2$. At the same position, $\varphi_{\tilde{n}\tilde{E}}$ from emissive probes is around $\pi/6$. This phase mismatch is observed at each position and can be the result of the temperature fluctuations omission when using cold probes. The cross power which weights the absolute value of the transport is different according to the probes used. In general, the cross power obtained with emissive probes is the highest.

Figure 4 : Cross-field transport measurements with emissive probes (A) and cold probes (B)

A weakly turbulent flute mode regime is shown on Fig. 5 with its spatiotemporal dynamic and the cross-field transport measured with both cold and emissive probes at maximum gradients. In both case, the coexistence of two modes at 9 and 15 kHz is responsible for net transport puffs. Thanks to the wavelet decomposition, this intermittent transport can be clearly observed. The cross power for each mode with both cold and emissive probes are similar.
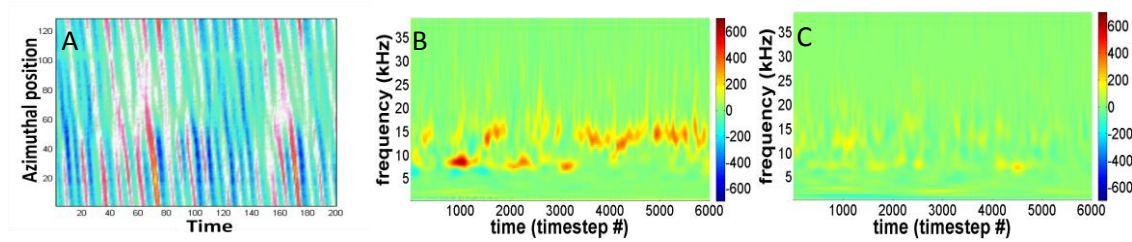

Figure 5 : Spatiotemporal dynamic (A), Radial transport with emissive (B)-cold probes (C)

The difference in the absolute transport value resides in the fact that the cross phase measured with cold probes is near 0.4π whereas it is 0.1π for emissive probes.

5. Conclusion

First cross-field transport measurements using emissive probes have been performed in Mirabelle device. Coherent results have been obtained with emissive probes but absolute value and direction of the radial flux differ depending on the probes used. The cross power seems to be under-estimated using cold probes. Cross phase mismatch induces a transport sign change. $\tilde{T}_e$ seems to influence the amplitude and direction of the radial flux.

References

[1]   F. Brochard, E. Gravier, G. Bonhomme, Phys. Plasmas **12**, 062104 (2005)
[2]   S. Oldenbürger, Ph.D. thesis, Institut Jean Lamour, Vandoeuvre-lès-Nancy (2010)
[3]   R. Schrittwieser, C. Ionita, P. Balan, et al. Plasma. Phys. Control. Fusion **50**, 055004 (2008)