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Experimental studies of intermittency and turbulent transport in linear and toroidal magnetized plasmas

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Turbulent transport is an important mixing mechanism in plasmas, in nature as well as in laboratory experiments, also fusion related experiments. Systematic studies of turbulent diffusion due to low frequency electrostatic fluctuations were carried out in linear Q-machine plasmas and in discharge plasmas as well. A characteristic feature of many experimental conditions is that a broad spectrum of magnetic field aligned turbulent low frequency electrostatic fluctuations is excited, although the instabilities driving the turbulence can be different from one experiment to another. The space-time evolution of large scale coherent structures is identified and their contribution to the turbulent transport determined.

1. Introduction

Turbulent transport of magnetized plasma is found to be important in nature as well as many laboratory experiments, fusion related studies in particular [1,2]. The dominant transport mechanism is in many cases low frequency electrostatic waves that are strongly magnetic field aligned. When all characteristic frequencies are below the ion cyclotron frequency, $\omega << \Omega_{ci}$, we can associate the fluctuating cross-field plasma velocity with the $\boldsymbol{E}_0\times\boldsymbol{B}_0/B_0^2$-velocity, and the fluctuating plasma flux becomes $\boldsymbol{\Gamma} = n\boldsymbol{E}\times\boldsymbol{B}_0/B_0^2$. Polarization drifts are of the order of $(<\omega>/\Omega_{ci})E/B$, and are often ignored.

Turbulent transport due to low frequency electrostatic waves has been studied in several different types of magnetized plasma experiments, linear devices as well as toroidal experiments. A characteristic feature of many experimental conditions is that a broad spectrum of magnetic field aligned turbulent fluctuations is excited. In their basic form the driving mechanisms are assumed to be drift-wave instabilities, but in most cases the analytical model has to be modified by including Kelvin-Helholtz or velocity shear instabilities in addition to the effects of centrifugal forces caused by bulk plasma rotations. The turbulence can usually not be described as a Gaussian random process, in part because it is dominated by randomly occurring large coherent structures. The space-time evolution of such large scale structures has been identified by conditional sampling techniques [3] in linear discharge plasmas and Q-machine plasmas [4,5], as well as in toroidal devices [6,7], and their contribution to the turbulent transport determined. A significant part of the turbulent plasma flux is caused by these large structures, and the transport can not in general be characterized as classical diffusion.

2. Experimental conditions

Some early studies of anomalous transport due to low frequency electrostatic turbulence were carried out in, for instance, strongly magnetized linear Q-machine plasmas [4]. Here not only the average plasma flux was determined, but also the amplitude probability density of the fluctuating radial plasma flux. An experimental set-up with single ended operation is shown schematically in Fig. 1. In this case the radial DC electric field is localized to the inhomogeneous scrape-off layer, and the resulting $\boldsymbol{E}_0\times\boldsymbol{B}_0/B_0^2$-velocity has the appearance of a narrow "jet" propagating across the magnetic field lines in the azimuthal direction as shown in Fig. 1.

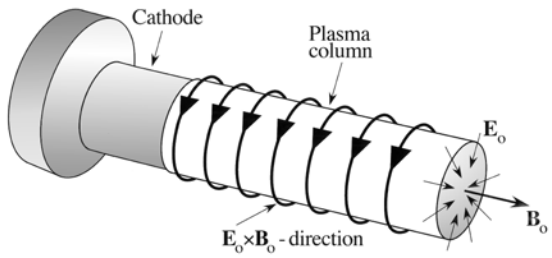

Fig.1. Schematic diagram of a Q-machine plasma column for single ended conditions. The localized radial electric field at the scrape-off layer gives rise to a strongly sheared azimuthal $\boldsymbol{E}_0\times\boldsymbol{B}_0/B_0^2$-velocity.

Fluctuations in the plasma density n and the electrostatic potential were detected by Langmuir probes. The azimuthal component E_θ of the electric field was deduced by the potential difference of two closely space probes. The probes detected local floating potentials, but at theses low frequencies, we can assume the results to be representative also for the fluctuating plasma potential. It was explicitly demonstrated that the dominant contribution to the electrostatic fluctuations came from perturbations having long wavelength components along the magnetic field. On the basis of the observed E_θ and n variations, the radial component Γ_r of the turbulent plasma flux was obtained. A typical probability density for the plasma flux is shown in Fig. 2, where we note that the average value $\langle\Gamma_r\rangle \equiv \Gamma_0 \neq 0$. While the probability densities for E_θ and n can be approximated by zero-mean Gaussian distributions, we find that $P(\Gamma_r)$ is significantly different from a Gaussian distribution, characterized in particular by a long "tail". It seems that this form is generic for the turbulent transport in several devices, also some toroidally magnetized plasma without a toroidal transform [6,7]. We anticipate that this form of the flux-probability density is an indicator of turbulent transport caused by large sporadically occurring coherent structures. The loss of plasma is due mostly to bursts, and not to diffusive losses as described by Fick's law.

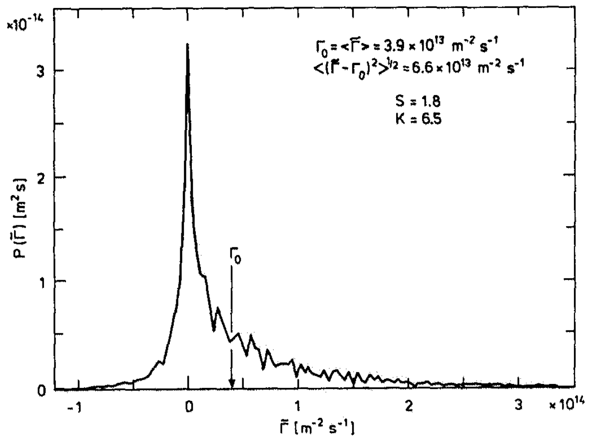

Fig.2. Example of probability density (PDF) for the fluctuating radial component of the bulk $n\boldsymbol{E}\times\boldsymbol{B}_0/B_0^2$-plasma transport [5]. The average plasma flux component is indicated by Γ_0.

3. Coherent structures and intermittency

In order to obtain evidence of the space-time evolution of large coherent structures conditional sampling techniques have been used [3-7]. In cases where the plasma flow conditions could be controlled [5] it was demonstrated that these structures could take the form of monopolar or dipolar vortices in a plane perpendicular to $\boldsymbol{B}_0$. The characteristics of the structures and the associated turbulent transport depended on the plasma conditions, the shear of the flow in particular [5,8].

The presence of large structures is a sign of significant intermittent features of the turbulence. Intermittency is usually analyzed in terms of higher order structure functions. As an alternative analysis of intermittent features of the flux signal we suggest the use of excess statistics [9], i.e. a study of the durations of time intervals where the turbulent plasma flux exceeds some prescribed threshold level. We believe this definition to be particularly useful for studies of confinement of hot plasmas: it can here be important to distinguish many short plasma bursts from a few long ones. Although the accumulated time in the bursts can be the same, their consequences will be different as far as, for instance, the heat load on a confining wall is concerned. With many short bursts there can be time for the wall to cool down between bursts, while it need not be so for long bursts, even when they are few. We consider the flux signal obtained from laboratory experiments and analyze the distribution of the time intervals spent above some prescribed reference level. It can be demonstrated that analytical models for the excess-time statistics require information not found in the flux probability density $P(\Gamma_r)$. A relatively simple, yet useful, model is derived which can be expressed in terms of the joint probability density $P(\Gamma_r, d\Gamma_r/dt)$ of the fluctuating flux signal $\Gamma_r(t)$ and its time derivative $d\Gamma_r(t)/dt$. As a reference non-intermittent case we take a Gaussian random signal, and obtain analytical estimates for this reference case. The results can be useful also for other related problems dealing with random processes.

References

[1] P. C. Liewer: Nucl. Fusion, **25** (1985) 543–621.
[2] D. A. D'Ippolito, J. R. Myra, and S. J. Zweben: Phys. Plasmas, **18** (2011) 060501.
[3] H. Johnsen, H. L. Pécseli, and J. Trulsen: Phys. Fluids **30** (1987) 2239–2254.
[4] T. Huld, S. Iizuka, H. L. Pécseli, and J. Juul Rasmussen: Plasma Phys. Control. Fusion, **30** (1988) 1297–1318.
[5] T. Huld, A. H. Nielsen, H. L. Pécseli, and J. Juul Rasmussen: Phys. Fluids B **3** (1991) 1609-1625.
[6] F. J. Øynes, O-M. Olsen, H. L. Pécseli, Å. Fredriksen, and K. Rypdal: Phys. Rev. E, **57** (1998) 2242–2255.
[7] Å. Fredriksen, C. Riccardi, L. Cartegni, and H. Pécseli: Plasma Phys. Contr. Fusion, **45** (2003) 721–733.
[8] K. Kamataki, et al.: Plasma Phys. Contr. Fusion, **50** (2008) 035011.
[9] L. Fattorini, Å. Fredriksen, H. L. Pécseli, C. Riccardi, and J. K. Trulsen: (2011) to be submitted.