Final Technical Report

Integrated Study of the Nonlinear Dynamics of Collisional Drift Turbulence

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Abstract:

An existing linear magnetized plasma device, the Controlled Shear Decorrelation experiment (CSDX) was used to study the transition from a state of coherent wave like activity to a state of turbulent activity using the magnetic field and thus magnetization of the plasma as the control parameter. The results show the onset of coherent drift waves consistent with linear stability analysis. As the magnetization is raised, at first multiple harmonics appear, consistent with wave steepening. This period is then followed by the beginning of nonlinear interactions between different wave modes, which then results in the formation of narrow frequency but distributed azimuthal wave number fluctuations that are consistent with the formation of long-lived coherent nonlinear structures within the plasmas. These structures, termed quasicohherent modes, persist as the magnetic field is raised. Measurements of turbulent momentum flux indicate that the plasma is also forming an azimuthally symmetric radially sheared fluid flow that is nonlinearly driven by smaller scaled turbulent fluctuations. Further increases in the magnetic field result in the breakup of the quasicohherent mode, and the clear formation of the sheared flow. Numerical simulations of the experiment reproduce the formation of the sheared flow via a vortex merging process, and confirm that the experiment is providing the first clear experimental evidence of the formation of sheared zonal flows from drift turbulent fluctuations in a magnetized plasma.

Milestones Achieved:

2004: Controlled transition to state of drift turbulence achieved in the CSDX device.

2005: Initial evidence of the existence of a sheared zonal flow in the CSDX experiment.

2006: Measurements of turbulent stress and comparison against measured sheared flows

2006-07: Numerical simulations confirm essential picture of turbulent-driven shear flow in experiment.

Conclusions and Next Steps:

The experiment provided the world's first direct demonstration of shear flow formation from turbulence in a magnetized plasma, confirming theoretical predictions. Results should be followed up by parametric studies of this physics e.g. at different power inputs, neutral gas operating pressures, ion masses and magnetic fields. In particular the evolution of the shear flow and the turbulent flow drive should be studied across these ranges of parameters. If financial resources were to permit, direct flow visualization using e.g. a fast camera would provide additional insight into the mechanisms of flow organization, and should be complemented by direct, unobtrusive and unambiguous measurements of flow using laser induced fluorescence techniques. Finally, these techniques should be complemented by the development of fourier-domain (Frequency and wavenumber) approaches to determine which spatial scales interaction to cause the formation of the zonal flow. These techniques would then be transferrable to large-scale fusion experiments, where they could be used to provide a better understanding of zonal flow formation in these systems, and to determine if such physics play an important role e.g. in the transition from low-mode confinement to high-mode confinement – a topic that is essential for the basic operational mode of the ITER magnetic fusion experiment.

List of Publications Arising from this Project:

1. Holland, C., Tynan, G. R., McKee, G. R. & Fonck, R. J. Investigation of the time-delay estimation method for turbulent velocity inference. *Rev. Sci. Instrum.* **75**, 4278-4280, doi:10.1063/1.1787574 (2004).
2. McKee, G. R. *et al.* Turbulence velocimetry of density fluctuation imaging data. *Rev. Sci. Instrum.* **75**, 3490-3492, doi:10.1063/1.1790043 (2004).
3. Tynan, G. R. *et al.* Radially sheared azimuthal flows and turbulent transport in a cylindrical plasma. *Phys. Plasmas* **11**, 5195-5203, doi:10.1063/1.1794752 (2004).
4. Burin, M. J., Tynan, G. R., Antar, G. Y., Crocker, N. A. & Holland, C. On the transition to drift turbulence in a magnetized plasma column. *Phys. Plasmas* **12**, 14, doi:052320 10.1063/1.1889443 (2005).
5. Holland, C. *et al.* Observation of turbulent-driven shear flow in a cylindrical laboratory plasma device. *Phys. Rev. Lett.* **96**, 4, doi:195002 10.1103/PhysRevLett.96.195001 (2006).
6. Itoh, K. *et al.* Physics of zonal flows. *Phys. Plasmas* **13**, 11, doi:055502 10.1063/1.2178779 (2006).
7. Tynan, G. R. *et al.* Observation of turbulent-driven shear flow in a cylindrical laboratory plasma device. *Plasma Phys. Control. Fusion* **48**, S51-S73, doi:10.1088/0741-3335/48/4/s05 (2006).
8. Holland, C. *et al.* Numerical simulations of collisional drift-wave turbulence in a magnetized plasma column. *Plasma Phys. Control. Fusion* **49**, A109-A119, doi:10.1088/0741-3335/49/5a/s09 (2007)