# Coordinated Experimental and Computational Search for Zonal Flow Characteristics

POSTER

I. Cziegler[1*], L. Howlett[1], A. Malcolm-Neale[1], S. Thomas[1], Y. Enters[1], S. Biggs-Fox[1], D. Dickinson[1], S. Freethy[2], A. Field[2], D. Dunai[3]

[1] York Plasma Institute, University of York, York, UK

[2] UK Atomic Energy Authority, Culham, UK

[3] Centre for Energy Research, Budapest, Hungary

Turbulence has long been known to dominate cross-field transport in toroidal magnetic confinement devices. The role of turbulence driven large-scale flows, i.e. zonal flows (ZF), in the self-organisation of turbulence and thus in the quality of global confinement has extensive theoretical support and an increasing amount of experimental evidence. Despite this, definitive experimental identification of ZFs and analysis of several of their key features have been lacking in the field. We report a coordinated effort of theory, improved metrics in computation and experimental diagnostics, as well as upgraded velocimetry in support of ZF analysis.

Previous experimental studies have suffered from a range of limitations from insufficient temporal resolution through sensitivity and specificity of flow velocimetry data to the restricted spatial domain in which to evaluate defining nonlinear characteristics. An extensive analysis of cross-correlation time delay estimation (CCTDE) techniques is shown in which several new methods are developed for reducing the fail rate of velocimetry while optimising temporal resolution using the 2MHz sampling rate of the MAST(-U) beam emission spectroscopy (BES) system. The resulting spectrum of velocity fluctuations shows a non-trivial dependence on the average flow with realistic PDF of input signals. CCTDE is used to show geodesic-acoustic modes (GAM) in MAST and compared with magnetic components. The applicability to measurements of nonlinearity is shown from edge turbulence measurements. Furthermore, a dynamic time warping (DTW) method was tested to characterise its range of usefulness. Testing included an analysis of time resolution with various distributions of signals and signal to noise ratios, sensitivity to shear, robustness against the barberpole illusion and the effect of oversampling. Taken together, these tests highlight the areas in which prior ZF experiments have been unsatisfactory. On the theoretical side, we report the development of a method to study the poloidal structure of the nonlinear spectral energy transfer of zonal flow drive. The method is applied to local nonlinear gyrokinetic simulations of tokamak core ion temperature gradient (ITG) turbulence using cyclone base case parameters in concentric circular flux surface geometry. It is found that the transfer of energy into the zonal flows is similar to the turbulent activity level in both poloidal structure and temporal behaviour. This information provides strong support for spatially localised measurements.

This work was supported in part by Engineering and Physical Sciences Research Council grants EP/R034737/1, EP/L01663X/1 and EP/T012250/1.

*corresponding author: istvan.cziegler@york.ac.uk