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# Comparison of Dimensionally Similar Turbulence in TJ-K and ASDEX Upgrade

B. Nold[1], M. Maraschek[2], H.W. Müller[2], M. Ramisch[1], V. Rohde[2], U. Stroth[1]
and the ASDEX Upgrade Team[2]

[1] *Institut für Plasmaforschung, Universität Stuttgart, Germany*

[2] *Max-Planck-Institut für Plasmaphysik, Euratom Association, Garching, Germany*

## Introduction

One of the main challenges of fusion research is to acquire a better understanding of energy and particle transport. The prime transport losses are due to micro instabilities resulting in turbulence. Plasma edge turbulence has been investigated for over 30 years in various devices and significant progress has been achieved through experiments [1], theory and computation [2]. The typical properties of drift-wave turbulence have been observed in the low-temperature plasma of the torsatron TJ-K [3]. The dimensional similarity of TJ-K plasmas along with the edge of fusion devices suggests that turbulence is dominated by drift waves in both cases. This behaviour is also predicted by numerical simulations [4]. In this contribution, electrostatic fluctuations were measured in the scrape-off layer (SOL) of the divertor tokamak ASDEX Upgrade (AUG). For comparison, similar measurements were carried out in limited TJ-K plasmas. The radial dependence of statistical properties and the poloidal phase velocities of turbulent fluctuations as well as the related radial transport were also investigated.

## Experimental setups

Poloidal Langmuir probe arrays were used to measure electrostatic fluctuations on the low-field side of the tokamak ASDEX Upgrade and the torsatron TJ-K.

ASDEX Upgrade (AUG) is a midsize tokamak experiment with a poloidal divertor [5]. The Plasma is kept in an elliptical shape with major radius $R_0 = 1.65$ m and minor radius $a = 0.5$ m. The reciprocating Langmuir probe penetrated the plasma horizontally about 0.3 m above the outer midplane. The probe array consists of 9 free standing cylindrical carbon pins separated poloidally by about 3 mm. Experiments were conducted in deuterium L-mode discharges set at the lower single null (LSN) magnetic configuration. The 800 kA Ohmic discharges were operated at a low density of about $2 \times 10^{19}$ m$^{-3}$ and a toroidal magnetic field of $-2$ T.

TJ-K is a torsatron ($l = 1$, $m = 6$) with major radius $R_0 = 60$ cm [6]. The minor radius was decreased for these experiments by means of two toroidal limiter plates from $a = 10$ to 5.5 cm. The Langmuir probe array penetrated the plasma horizontally from the outer midplane. The array consists of 8 probes separated poloidally by 5 mm. The hydrogen plasma was produced with 1.8 kW ECRH at 2.45 GHz. It had a density of approximately $1 \times 10^{17}\,\mathrm{m}^{-3}$ and the magnetic field was $B = 72\,\mathrm{mT}$.

**Poloidal phase velocity**

Cross-correlation analysis of two adjacent probes revealed an abrupt switch of the poloidal phase velocity $v_\theta$ from the electron-diamagnetic drift direction in the confined plasma to the ion-diamagnetic drift direction in the SOL. Fig. 1 shows $v_\theta$ close to the separatrix in ASDEX Upgrade (top) and TJ-K (bottom). In the AUG discharges, $v_\theta$ changed from about $+3$ to less than $-5$ km/s within the radial resolution of the probes. This strong shear layer is observed for all pin combinations, while the absolute phase velocities change. The reason for this variation is not clear. It is possibly caused by the imperfect alignment of the probe array onto the flux surfaces. Therefore, the measured phase velocity can be affected by a radial component. A comparable shear layer close to the separatrix was also observed in other devices [7, 8, 9].

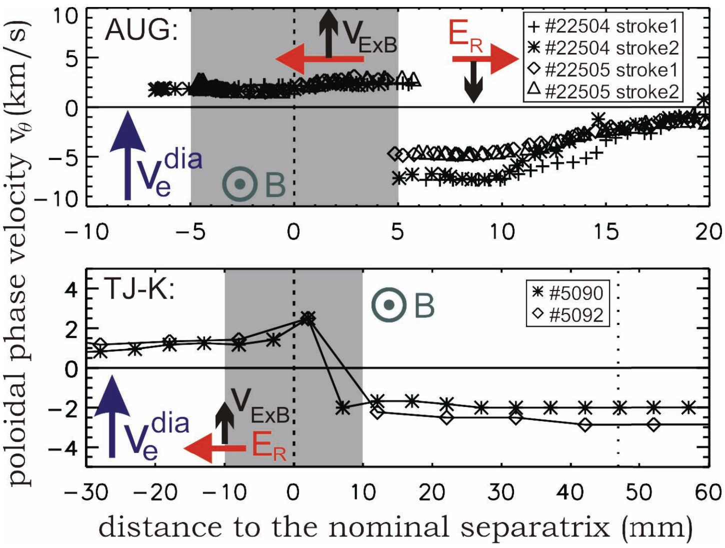


Figure 1: Poloidal phase velocity of two discharges in AUG (top) and TJ-K (bottom). The grey shadow indicates the error of the nominal separatrix position.

**Intermittency**

Intermittency is universal in magnetically confined plasmas [10, 11]. Fig. 2 shows sections of the intermittent ion-saturation current time trace from 3 different radial positions in AUG. The amplitude of the intermittent events changed from negative at the inner (left side) to positive at the outer radial position (right side). Close to the shear layer ($d \approx 5$ mm), the fluctuation amplitudes were nearly Gaussian distributed. In the bottom of Fig. 2, the probability density functions (PDFs) of the fluctuation amplitudes are compared to a Gaussian (dashed line). The fluctuation analysis revealed density "holes" in a certain range inside and density "blobs" outside the shear layer. Therefore, the positive intermittent events in the SOL do not seem to originate from far inside of the confined plasma. Rather, this points to a generation mechanism of density perturbations close to the poloidal velocity shear layer.

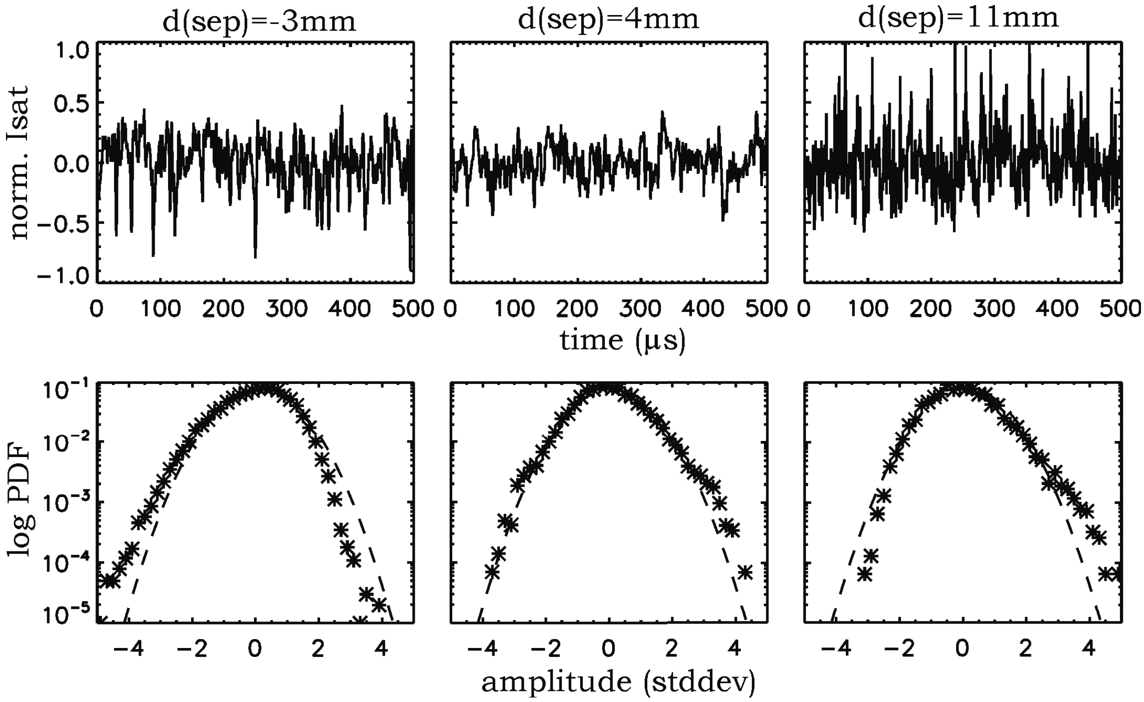


Figure 2: Top: $I_{sat}$ fluctuations measured at different radial positions in AUG. Bottom: PDFs compared to a Gaussian (dashed).

## Cross-phase and transport

Cross-phase and transport were investigated using three probes, one measuring $\tilde{I}_{sat}$ poloidally in-between two floating-potential probes. Density and poloidal electric-field fluctuations were calculated from this measurement while temperature fluctuations were neglected. The average phase relation between density and poloidal electric-field fluctuations of ASDEX Upgrade is shown in Fig. 3. It was found close to $\pi/2$ throughout the entire radial range. Indicating density and potential fluctuations are almost in phase, a behavior expected for drift-wave instabilities. The radial variation of the net local turbulent transport $\Gamma = \langle \tilde{n}(t)\tilde{E}_\theta(t)/B \rangle_t$ was also investigated. Inward transport was found close to the shear layer ($d \approx 5\,\mathrm{mm}$) in AUG, whereas outward transport was observed further inside and in the far SOL. Transport in TJ-K shows similar features that were first seen at high frequencies in TJ-K biasing experiments [12].

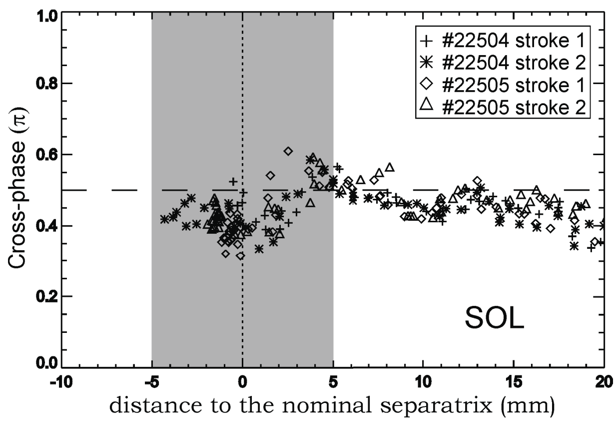


Figure 3: Radial profile of the cross phase between $\tilde{I}_{sat}$ and $\tilde{E}_\theta$ in AUG.

## Conclusions

The results from Langmuir probe measurements in the edge of ASDEX Upgrade and limited TJ-K discharges showed similarities which can provide support for the concept of dimensional similarity. Of particular interest were the plasma dynamics in the vicinity of the separatrix, where an abrupt change of the phase velocity direction was observed. The asymmetric amplitude distribution of intermittent events is an indicator for density blobs in the SOL and density holes in a certain range of the confined plasma. The cross-phase between density and electric-field fluctuations had drift-wave characteristics. Net radial inward transport was observed close to the velocity shear layer in ASDEX Upgrade.

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