Plasma turbulence studies in the TORPEX basic plasma physics device: from concentric flux surfaces to single-null X-points

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The Toroidal Plasma Experiment (TORPEX) has so far been operated primarily as a Simple Magnetized Torus (SMT), in which helical magnetic field lines are obtained adding a small vertical magnetic field to a main toroidal component [1]. The SMT configuration features the main ingredients of a tokamak Scrape-Off Layer (SOL), with density gradients in the presence of magnetic field curvature and gradient. A toroidal in-vessel copper conductor (TC) has recently been installed in TORPEX [2], as can be seen in Fig. 1, to produce a poloidal magnetic field component.

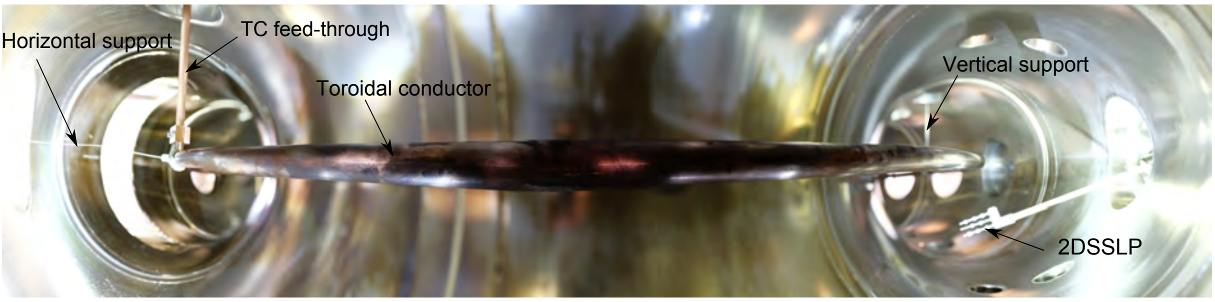

Figure 1: *Internal view of the TORPEX vacuum chamber with the toroidal conductor suspended in the center of the poloidal cross section via lateral and horizontal stainless steel wires.*

A current up to 1kA can be driven in the TC, resulting in a monotonic safety factor profile in the range $1 \div 12$ along the radial direction, with an almost constant magnetic shear of $s(r) = r/q \cdot dq/dr = 2$. A set of vertical field coils permits the creation of fusion relevant magnetic field geometries of increasing complexity, including wall-limited plasmas with a SOL on the high-field side or low-field side, as well as single or double-null X-points or magnetic snowflakes.

The first part of this paper is focused on the investigation of quasi-coherent modes and turbulence in magnetic configurations with quasi-circular concentric flux surfaces, as shown in Fig. 2-a. Quasi-coherent modes with a strong poloidal asymmetry are measured using Langmuir probes (LPs) of different geometries. A dominant localization on the bad-curvature region of the plasma volume (Fig. 2-b) suggests a ballooning nature for these instabilities. A spectral characterization at the position of maximum fluctuation amplitudes was performed. The power spectral density (PSD) indicates dominant mode frequencies in the range 15-30 kHz for the explored values of TC currents in the range $I_{TC} = 400 - 800$ A.

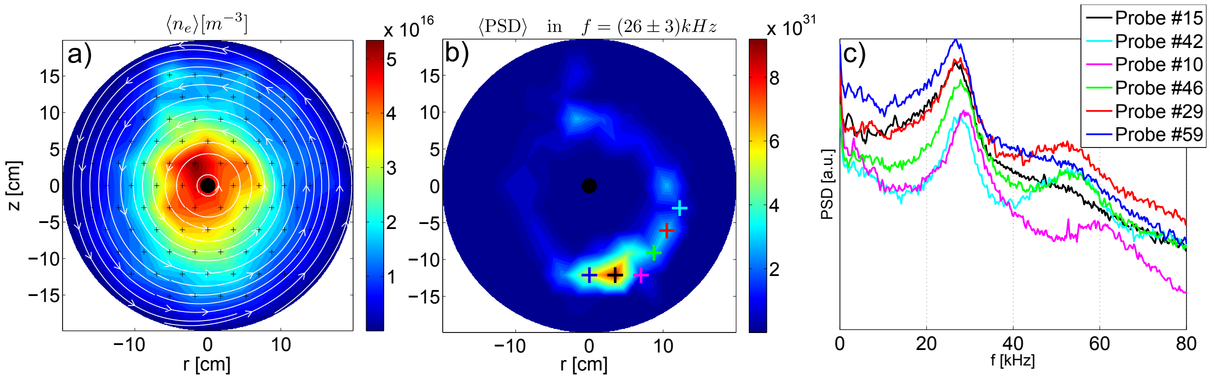

Figure 2: *Shot #59819 with 620 A in the TC. a) Time-averaged plasma density in the time-window (150-950) ms, assuming a constant electron temperature of 5 eV. b) Power spectral density of fixed LP signals averaged in the range* 26 ± 3 *kHz; the white circles indicate the probes considered for the data shown in c). c) PSDs of several fixed LPs. The black crosses in a) indicate the fixed LPs used for the plasma measurements. The black circle in the center corresponds to the TC.*

The LP PSDs for the case of 620 A is shown in Fig. 2-c. A toroidal mode number $n = 1$ was measured using a set of movable LPs (Fig. 3-a) placed at different toroidal angles, for several values of TC current (Fig. 3-b).

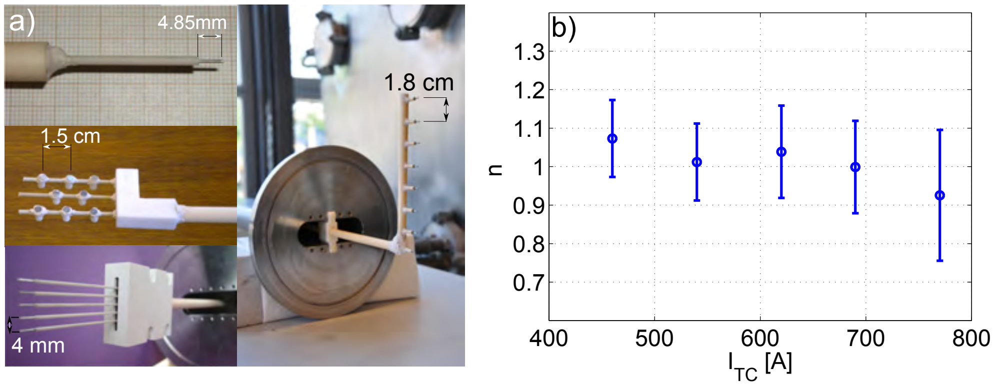

Figure 3: *a) Movable probes used for the measurement of the toroidal mode number. b) Measured toroidal mode number n for different TC currents.*

The diagnostic shown in Fig. 4, composed by a set of 44 LPs following the poloidal field lines of four perfectly circular flux surfaces, was designed to measure the poloidal mode-number m. The field aligned nature of the analysed instabilities was verified comparing the measured $m/n = m$ with the flux surface averaged safety factor $\langle q \rangle$ obtained from the calculated magnetic field, as can be seen in Fig. 4-b. The error bars of the simulated safety factor take into account the uncertainty on the position of the TC and of the diagnostic.

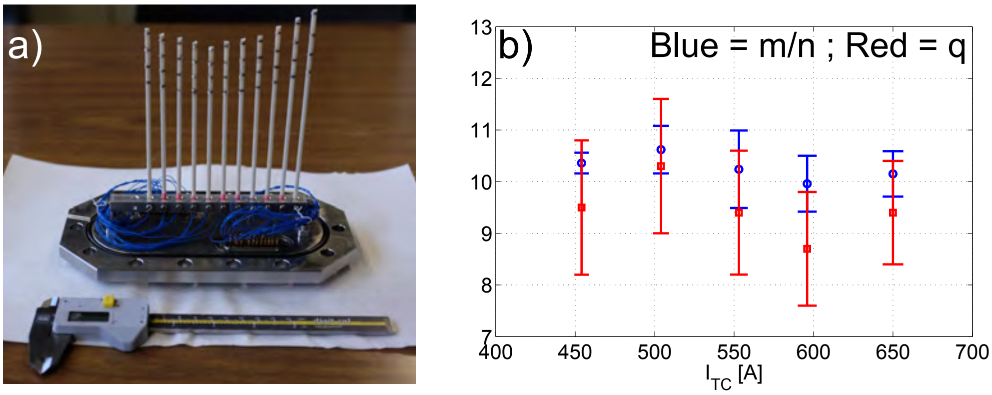

Figure 4: *a) Set of fixed LPs used for the measurement of the poloidal mode number. b) Comparison of measured* $m/n = m$ *with the simulated flux surface averaged safety factor q.*

First numerical results from the linear version of the Global Braginskii Solver (GBS) also suggest a ballooning character for the dominant instabilities, consistent with the observations.

First measurements of plasma fluctuations with a single-null X-point at approximately [r=0, z=-10] cm have been performed. A current of 600 A was used in the TC to generate the poloidal magnetic field, with an almost horizontal magnetic field obtained from the vertical field coils. A low magnetron power of 300 W was used, with a toroidal magnetic field of 820 Gauss leading to an electron cyclotron resonance position at -7 cm. This was chosen in order to generate the plasma in the region of closed flux surfaces, as presented in Fig. 5.

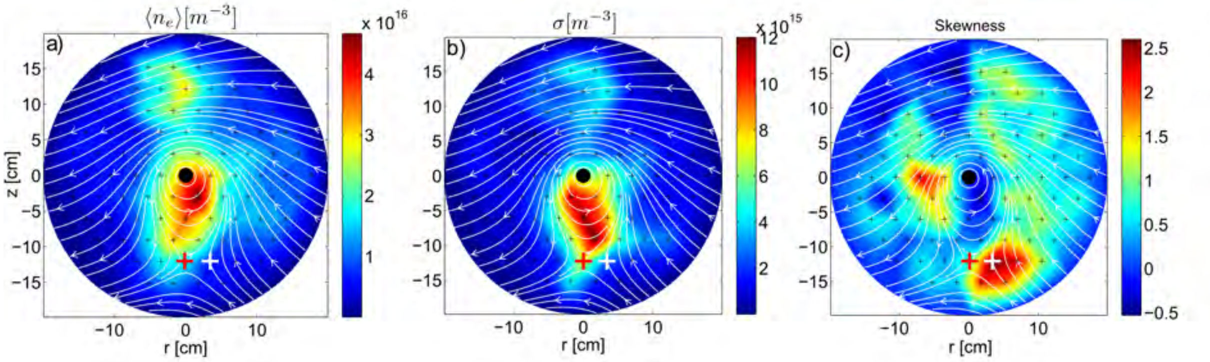

Figure 5: *a) Time averaged plasma density in the time-window (150-950) ms, assuming a constant electron temperature of 5 eV. b) Standard deviation. c) Skewness. The TC is indicated in black in the center, the black crosses correspond to the fixed LPs used for the measurements, while the red and black crosses refer to the probes analysed in Fig. 6.*

The analysis of plasma fluctuations indicates the presence of quasi-coherent modes close to the X-point with a region of high skewness on the low field side of the X-point, as can be seen in Fig. 5-c. This is confirmed by the PSD and the probability distribution function (PDF) of two fixed LPs (#59 - #15) located, respectively, at [r=0, z=-12] cm and [r=3.5, z=-12] cm (Fig. 6).

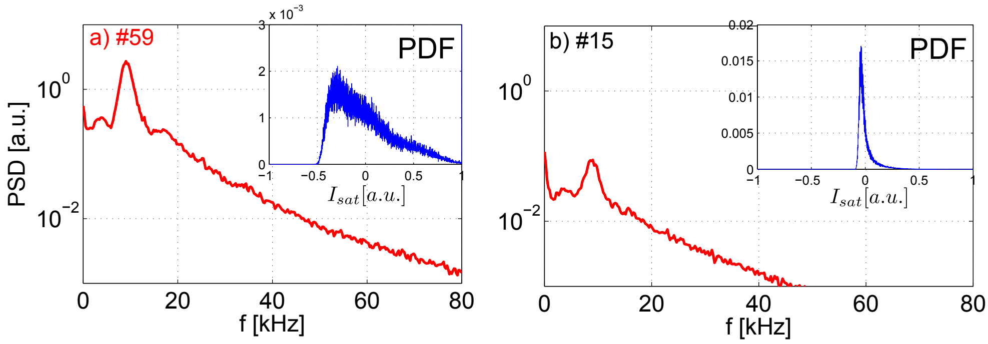

Figure 6: *PSD and PDF of I_{sat} signals for the LPs* #59 *and* #15.

The dynamics of the corresponding quasi-coherent structures is presented in Fig. 7. Two snapshots of 2D plasma fluctuation signals resulting from the Conditional Averaged Sampling technique applied on the 2DSSLP using as a trigger a signal from a fixed probe located at [r=-1, z=-9.5] cm are shown here. The mode seems to stretch as it evolves upward counter-clockwise, resulting in the detachment of a blob, which radially propagates outward, as indicated in Fig. 7. This dynamics present similarities with the blob-formation mechanism investigated in the SMT [3]. Further investigations will be performed to study the effect of an X-point on blob dynamics.

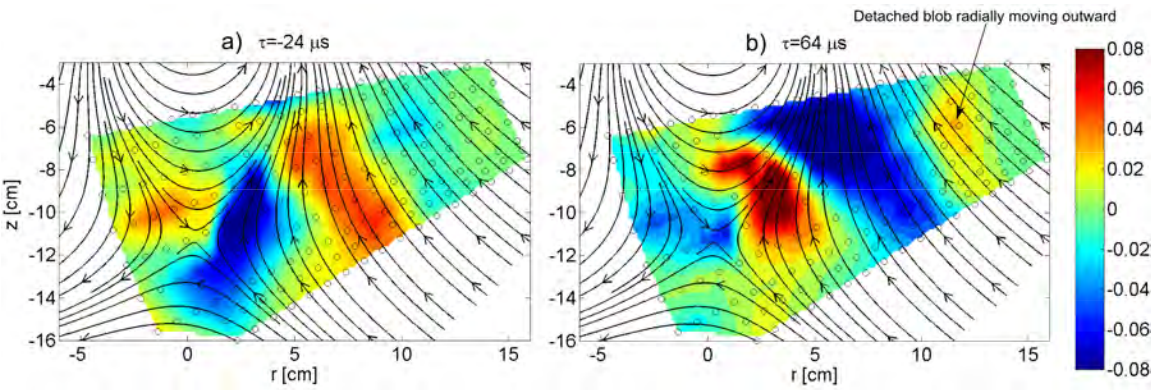

Figure 7: *Time snapshots of 2D plasma fluctuations resulting from the Conditional Averaged Sampling technique on a 2D-movable LP data, using as trigger a fixed probe located at [r=-1, z=-9.5] cm.*

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References

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