Turbulence and turbulent structures in the TORPEX device in closed field line configurations

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Introduction

TORPEX is a toroidal device dedicated to basic plasma physics investigations [1]. It features an extensive set of diagnostics and flexible plasma scenarios ideally suited to study plasma turbulence and its influence on the transport of energy and particles, both of the plasma bulk and of suprathermal components [2]. Low density and temperature plasmas (n_e~1-3x10^{16}m^{-3}, T_e~5-15eV) are produced and sustained by microwaves in the electron cyclotron (EC) range of frequencies. To date, simple magnetized toroidal (SMT) configurations have been produced by superposing a small vertical field component to a dominant toroidal magnetic field leading to helical field lines that wind around the torus and intercept the vacuum vessel at the bottom and the top. This configuration posseses the basic elements of the scrape-off layers (SOLs) of fusion confinement devices, namely magnetic field curvature, ∇B and open field lines, but it lacks the topology change between open and closed field line regions. To better mimic the SOL and edge of tokamaks, closed field line magnetic geometries have also recently been implemented using a current-carrying wire suspended in the center of the chamber. This produces a poloidal magnetic field with a rotational transform, resulting in closed magnetic field lines, allowing basic turbulence studies to be conducted in magnetic configurations of increasing complexity, and of more direct relevance to confined plasma experiments. We report here on recent progress in the fundamental understanding of turbulence and blob physics in closed field line configurations.

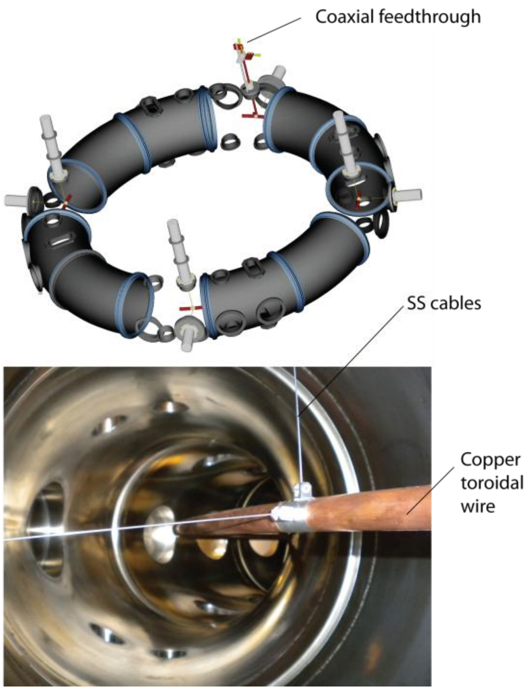

Fig. 1 *Top: Exploded CAD drawing of the toroidal wire system, including movable supports and mounting ports. Bottom: picture of the wire suspended inside the TORPEX vessel with SS suspending cables.*

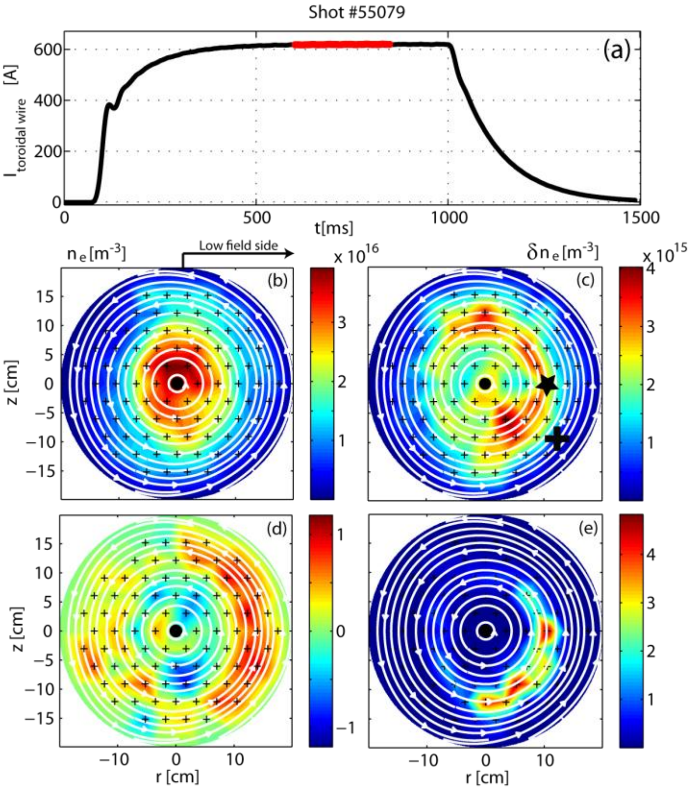

Fig. 2 *(a) Time evolution of the current in the toroidal wire during a discharge. Poloidal profiles of time-averaged electron density,* n_e*, signals (b), standard deviation (c) and skewness (d) of fluctuating* n_e *signals. (e) Poloidal profile of the standard deviation of* n_e *signals filtered in the frequency range [16.1-22.7] kHz, where the amplitude of dominant mode peaks. Closed flux surfaces are represented by the white contours.*

Experimental setup and results

An exploded view of the toroidal wire system is shown in Fig. 1(a), together with a picture of the wire installed inside the TORPEX vacuum chamber in Fig 1(b). The copper wire has 1cm radius and is suspended by three insulated 1mm diameter stainless steel wires and a vertical coaxial copper feed-through. This is also used to connect the toroidal wire to an external power supply. The wire can be moved vertically to achieve different magnetic configurations, including single- and double-null configurations, or be removed from the plasma region to re-establish SMT operation. A 1kA-10V power supply, whose output dynamics is limited to a maximum slew rate of ~1400A/sec, allows reaching a maximum flat top current in approximately 300ms. Water-cooling is used for the portion of the conductors embedded in the vertical coaxial feed-through, which has a reduced copper section of ~1cm^2. The flat top current duration is limited by the Ohmic heating of the wire with almost pure radiative cooling in vacuum. Typically 100 discharges per day, with a flat top duration of approximately 1s, can be safely performed without overheating the wire, thus insuring data statistics similar to that of present SMT configurations.

The time evolution of the wire current in a typical discharge is represented in Fig. 2(a) with a flat top current of ~620A. A vertical magnetic field $B_z \sim 2$G is used to produce magnetic flux surfaces that are almost circular and centred around the geometrical centre of the device. The plasma is produced, as in the SMT configuration, by injecting microwaves from the low field side at 2.45GHz, corresponding to the EC resonance frequency. The toroidal field is adjusted such that the EC resonance is well inside the vacuum vessel (in this case at r = -0.085m) and the microwave power is kept at a minimum level, about 250W.

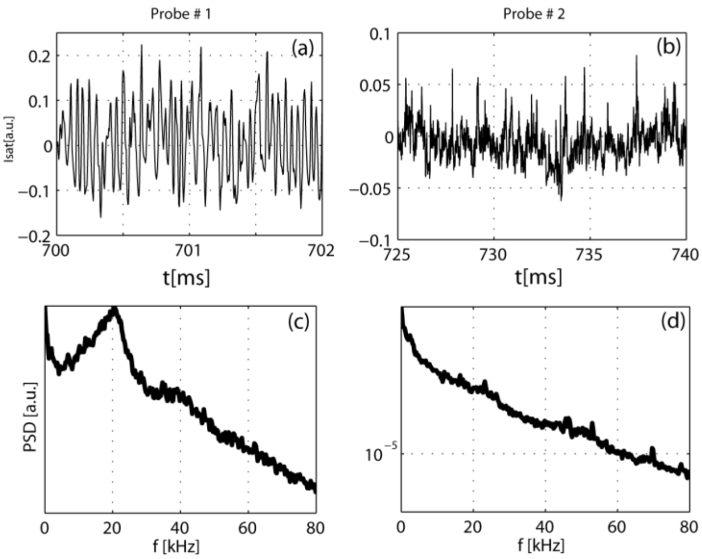

Fig. 3 *Time series of ion saturation signals (a, b) at the two locations indicated in Fig. 2(d) show coherent oscillations where the fluctuations peak (black star) and intermittent bursts at the edge on the low field side (black cross). Also shown are the respective power spectral densities (c, d).*

Figure 2(b) show 2D profiles of the time-averaged electron density (assuming T_e=5 eV), obtained from an array of 85 Langmuir probes, which provides a complete coverage of the poloidal cross section [3]. On the same figure, the almost circular magnetic flux surfaces, computed from the measured currents in the coils and in the toroidal wire, are also shown. The measurements clearly indicate the creation of almost circular symmetric n_e profiles centred on the magnetic axis during the flat top phase of the discharge.

In Figs. 2(c) and 2(d), the 2D profiles of n_e fluctuations (standard deviation of the signal up to the system Nyquist frequency, i.e. in the range 0-125kHz) and of the skewness *S* (normalized third order moment of the probability density function of n_e signals) show that the character of the fluctuations changes significantly across the poloidal cross section of the device. The poloidal profile of the fluctuation amplitude reveals the presence of instabilities in the region of strong gradients, with a ballooning character, i.e. larger amplitudes on the low field side, in the region of unfavourable curvature. Figure 3 shows a n_e signal measured in the region of maximum fluctuations at the position indicated by the star in Fig. 2(c), together with the respective power spectral density (psd). Density fluctuations are dominated by coherent oscillations as confirmed by the psd in Fig. 3(b) that peaks around a frequency of ~20 kHz. This coherent oscillation is characterized by an even stronger ballooning character than the fluctuation standard deviation, as shown in Fig. 2(e). Using a two-point correlation technique to compute the statistical dispersion relation [4], we measure a vertical wave number k_z ~90 m^{-1} at the midplane at $r=10$cm, where the fluctuations in the frequency range [16.1-22.7] kHz have their maximum. This corresponds to a poloidal $m \sim 9$ mode number. Across the region of maximum mode amplitude moving radially outwards, the skewness becomes positive and the fluctuation spectrum is broad and exempt from coherent modes, as shown by a n_e signal and its psd in Fig. 3(b, d). This suggests the presence of intermittent blobs radially propagating and transporting particles and heat into the low field side region.

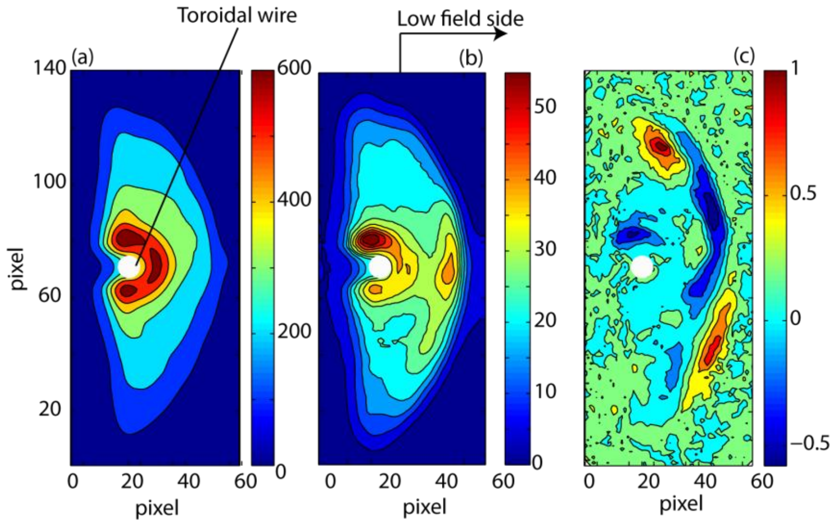

Fig. 4 *Visible light emission recorded by a fast framing camera from a tangential view. (a) time-averaged emission, (b) fluctuating emission, (c) skewness of the fluctuations.*

A Photron Ultima APX-RS fast framing camera is also used to complement the set of Langmuir probe measurements, allowing comparisons of statistical and spectral properties of visible light and electrostatic fluctuations [5]. The present plasma is imaged from a tangential view that covers the low field side region where the electrostatic fluctuations peak. A maximum acquisition frequency of 50 kHz was used with a reduced chip size of 60x140 pixels. The results are presented in Fig. 4, which shows (a) the time-averaged profile of the visible light emission, (b) the standard deviation of the fluctuation and (c) their skewness.

Although limited by line-integration effects, the skewness profile in Fig 4(c) is consistent with the electrostatic measurements in Fig. 3(d), thus confirming the presence of intermittent events localized at the edge of the plasma on the low field side (positive skewness).

The new toroidal wire system allows the production of magnetic geometries with single and double magnetic null-lines, as well as, for particular combinations of currents in the existing set of poloidal coils, snowflake divertor configurations [6]. More complex geometries with multiple fully 3D X-points and/or magnetic ergodic/chaotic surfaces could also be generated by additional ad-hoc coils installed inside the TORPEX vessel. This system will also allow basic investigations of the interaction of thermal plasma and suprathermal particles with instabilities and turbulence in magnetic configurations of increasing complexity.

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References

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