Overview of Turbulence and Transport Studies in the TORPEX Simple Magnetized Plasmas

A.Fasoli[1], A. Bovet[1], I. Furno[1], K. Gustafson[1], D. Iraji[1], B. Labit[1], D.Lancon[1], J. Loizu[1], P.Ricci[1], C. Theiler[1], M. Spolaore[2], N. Vianello[2], R. Cavazzana[2]

[1]*Ecole Polytechnique Fédérale de Lausanne (EPFL), Centre de Recherches en Physique des Plasmas, Association Euratom-Confédération Suisse, CH-1015 Lausanne, Switzerland*

[2]*Consorzio RFX, Associazione Euratom-ENEA sulla Fusione, Padova, Italy*

1. Introduction

Turbulence and related transport are investigated in TORPEX simple magnetised torus (SMT), in which a small vertical magnetic field is superposed on a toroidal field to form helical field lines that terminate on the vessel. As in tokamak scrape-off layers, this configuration features open field lines, ∇B, and magnetic field curvature. Plasmas of different gases are produced by microwaves with temperatures T_e~5-10eV and densities $10^{15}m^{-3} \leq n_e \leq 10^{17}m^{-3}$. Turbulence properties and effects are studied via high-resolution measurements of plasma parameters and wave fields across the plasma cross-section, using probes and non-perturbative optical imaging methods.

2. Ideal interchange mode regime

Different instabilities are identified for different plasma configurations. Increasing the vertical magnetic field, i.e. reducing the number of field line turns inside the vessel, leads to a transition from resistive to ideal interchange modes, in agreement with a 3D global fluid linear model and nonlinear simulations [1] (Fig. 1). This paper focuses on the ideal interchange regime ($k_{\parallel}$=0).

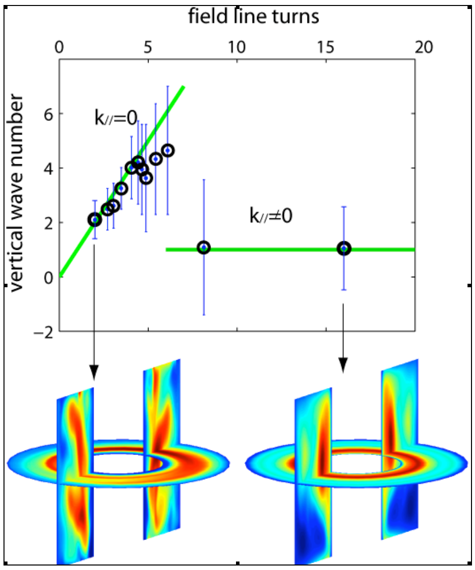

Fig. 1 *Comparison of measured wave numbers with theory predictions (green lines) and two examples of global 3D numerical simulations.*

3. Plasma blobs from interchange modes

The mechanisms behind the origin and the dynamical properties of blobs [2], regions of enhanced pressure originating from the nonlinear development of the instabilities, are elucidated. An analytical expression for the blob velocity-size distribution, including different mechanisms that reduce charge separation, i.e. cross-field ion polarization, parallel sheath currents and ion-neutral collisions, is derived. A good agreement is found for blobs observed by electrostatic probes [2], as well as for those reconstructed using a fast framing camera [3].

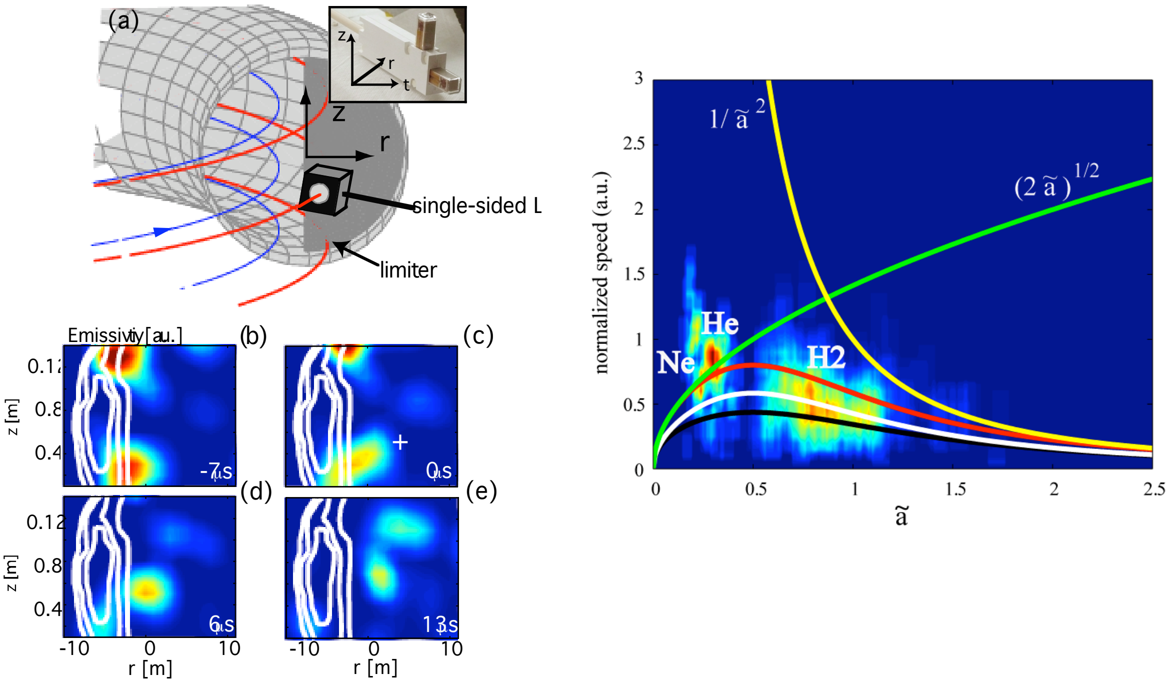

Fig. 2 *Left: (a) Sketch of the experimental set-up for the measurement of blob dynamics, showing the metal limiter fixing the blob boundary conditions, and the current measuring probes. (b)-(e): Tomographically inverted fast framing camera images of the evolution of the blobs generated from interchange modes. Rigth: Normalised speed-size joint probability reconstructed from the camera images, i.e. fully non-perturbatively and with high spatial resolution (<1.5cm).*

The latter are shown in Fig. 2, which illustrates the capability of the fast framing imaging system to reconstruct details of blob dynamics, and the diagnostics used to measure the profiles of the blob field-aligned currents [4]. The current measurements and the fact that a similar blob size-speed scaling is extracted from numerical simulations based on a 2D fluid model [5] confirm the interpretation of the mechanisms regulating the blob motion.

4. Plasma blob control

Once the mechanisms behind the generation and the motion of blobs are elucidated, methods to influence the blob dynamics are devised, e.g. by varying the blob connection length or by creating ad hoc ExB flow patterns using biased electrodes. A sketch of the bias electrodes installed on a metal limiter to this aim is shown in Fig. 3, together with one of the first demonstrations of an effect of the biased limiter on blob propagation [6].

5. Interaction between supra-thermal ions and turbulence

Turbulence can affect, in addition to the plasma bulk, transport and confinement of supra-thermal components, such as fusion generated α's. Detailed studies of the phase space transport mechanisms of supra-thermal ions in the presence of well diagnosed waves and turbulence are possible in TORPEX. The fast ions are injected using a Lithium source with varying energy and beam current, which can be moved across the plasma cross section. Space, time and energy resolved data can be obtained by modulating the fast ion beam, by varying the injection angle and by changing the distance between fast ion source and detector [7].

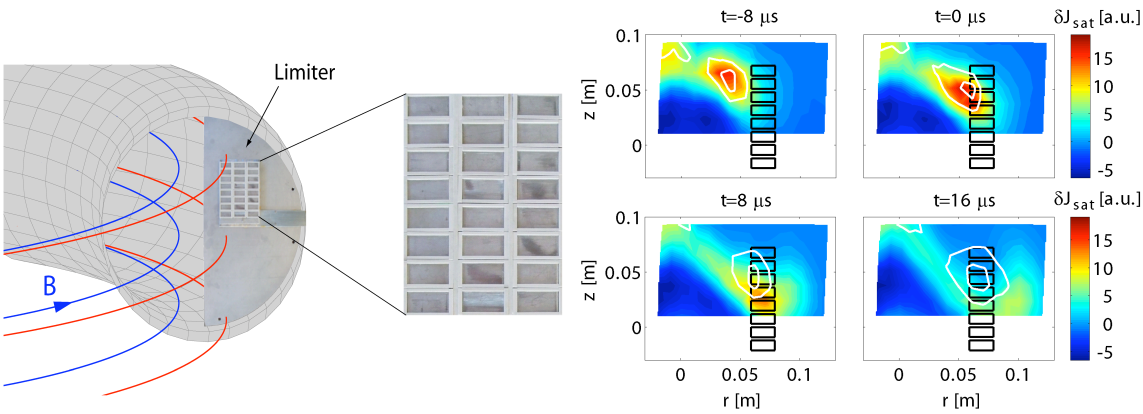

Fig. 3 Left: The biasing setup in TORPEX. 24 independent electrodes are installed on the metal limiter. Right: Sequence of frames showing the effect of biasing on blob propagation. White contours show the propagation of a blob without biasing. Color plots show the average blob evolution when a vertical stripe of electrodes, indicated by black rectangles, is biased to 30V with respect to ground.

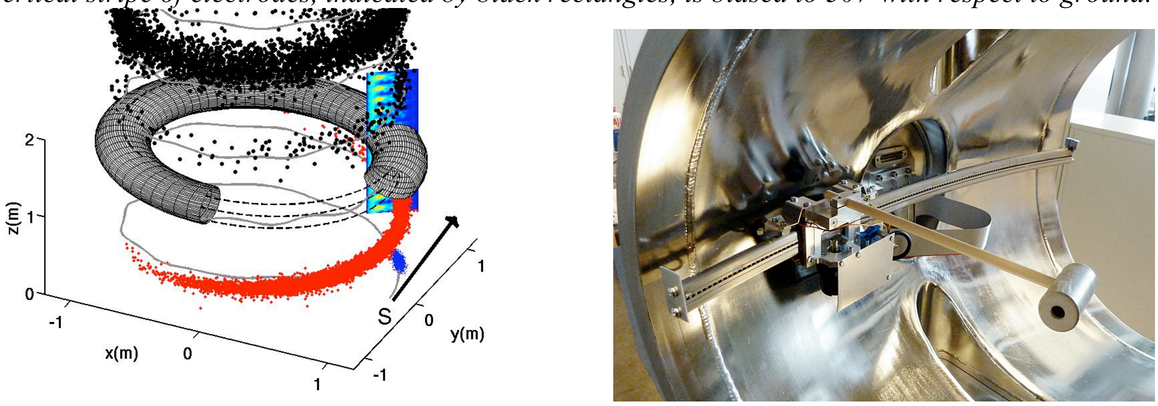

Fig. 4 Left: trajectories of Li6+ ions at 300eV) in TORPEX turbulent fields. A single trajectory (gray line) is shown along with a population of ions at an early time (blue points), and two later times (red and black points). Right: picture of the recently developed toroidally moving system allowing for a continuous variation of the source/detector distance, installed in one of the TORPEX mobile sectors.

To provide a theoretical interpretation frame, we treat fast ions as test particles and integrate their equations of motion in the simulated turbulent fields. Trajectories such as those shown in Fig. 4(left) are produced, which are coupled with a synthetic diagnostic to compare simulation results directly with TORPEX data. By continuously varying distances between source and detector (see Fig. 4), information about the fast ion transport mechanism is extracted in different turbulence regimes and for different ratios of ion energy to plasma temperature.

6. Summary and outlook

Significant progress has been made in the understanding of the nature of turbulence and its effects in a simple magnetized torus, a paradigm for the edge of magnetically confined fusion plasmas. Preparations are under way to extend these investigations to magnetic configurations of increasing complexity. In addition to the SMT configuration (Fig. 5a), we will develop configurations with twisted field lines (Fig. 5a), in which a poloidal field will be generated by a current driven in a copper wire running along the toroidal direction. The twist of the magnetic field line can be easily controlled by the amount of current driven in the wire by external 1kA-10V power supplies. The flat top will last approximately 200ms, with no need for active cooling of the wire, which will be suspended inside the vacuum chamber through insulated stainless steel wires. More complex geometries with multiple fully 3D X-points and/or magnetic ergodic surfaces will also be generated by ad-hoc coils installed inside the TORPEX vessel (see Fig.5c). Turbulence measurements in this kind of topology will be of particular interest for phenomena associated with magnetic reconnection and for the crucial edge region in magnetically confined fusion plasmas.

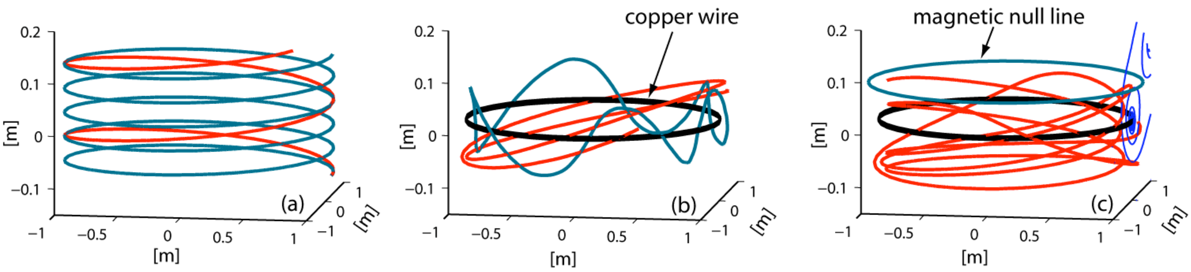

Fig. 5*: Magnetic geometries on TORPEX. (a) Present setup: two different SMT configurations having open field lines with different pitch (red and blue lines); (b) Magnetic configurations with twisted field lines; (c) Example of a complex magnetic configuration with a null-line (blue line).*

At present, the TORPEX plasma production relies on EC and UH resonances, which limits the range of magnetic fields and β that can be operated and, in turn, precludes changing significantly the ion sound gyroradius, an important parameter for turbulence. To extend the operating parameter space in TORPEX, the range of toroidal magnetic fields, the plasma density, and the density radial scale length/gradient in particular, two internal radio frequency helicon sources will be developed. Increasing the density will also allow us to increase the plasma β and access scenarios in which electromagnetic turbulence can play a role.

This work was partly supported by the Fonds National Suisse pour la Recherche Scientifique.

References

[1] P.Ricci et al., Phys. Rev. Lett. 104, 145001, 2010; A. Fasoli et al. Plasma Phys. Contr. Fusion 52, 124020, 2010.
[2] I.Furno et al., Phys. Rev. Lett. 100, 055004, 2008; C.Theiler et al., Phys. Rev. Lett. 103, 065001, 2009.
[3] D.Iraji et al., Rev. Sci. Instrum., 79, 10F508, 2008; D.Iraji, EPFL PhD Thesis 5073, 2011.
[4] I.Furno et al., Phys. Rev. Lett. 106, 245001, 2011.
[5] I.Furno et al., submitted for publication on Plasma Phys. Contr. Fusion, 2011.
[6] C.Theiler et al., Physics of Plasmas 18, 055901, 2011.
[7] G. Plyushchev, EPFL PhD Thesis 4543 (2009); A.Fasoli et al., Plasma Phys. Contr. Fusion 52, 124020, 2010.