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Initial TORPEX results of plasma production, confinement and fluctuation studies

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Experimental configuration

TORPEX (TORoidal Plasma EXperiment) [1, 2] is a toroidal device for basic plasma physics research, with major radius $R = 1$m; minor radius $a = 0.2$m; toroidal and vertical magnetic field, $B_{tor} < 0.1$T, $B_v < 5$mT. Plasmas are generated by a microwave power source that can deliver up to 50kW at a frequency $\nu_{RF} = 2.45$GHz, modulated with frequencies up to 20kHz, during a typical discharge length of 100ms. Plasmas with densities of $n \sim 10^{17}\text{m}^{-3}$, electron temperature $T_e \sim 5 \rightarrow 10$eV and plasma potential $\sim 10 \rightarrow 30$V, measured by electrostatic probes, are typical.

First experimental campaigns have focused on basic plasma production and confinement mechanisms as well as on the physics of fluctuations driven in the region of density and temperature gradients. The ultimate goal of this work is to improve understanding and control capability of plasma turbulence and related transport.
The plasma confinement is optimised by superimposing a small vertical component over the dominant toroidal magnetic field [3]. The spiral-shaped field lines allow particles to partially short-circuit the vertical electric field E_z driven by charge dependent ∇B and curvature drifts. Coulomb collisions limit this short-circuiting effect, allowing the formation of an equilibrium characterised by a finite value of E_z. The competition between two loss mechanisms, the radial $\mathbf{E} \times \mathbf{B}$ drift ($\propto B_z^{-2}$) and the direct particle loss at the intersection of the field lines with the vacuum vessel ($\propto |B_z|$), leads to an optimal value of B_z, for which the confinement time is maximum.

Plasma production

Plasmas are created by microwaves in the electron cyclotron (EC) range of frequencies injected in O-mode polarisation from the low field side (LFS). The ionisation process is initiated at the EC layer by electrons accelerated resonantly by the wave field. Once the plasma is formed, due to the low value of T_e, the injected waves are subject to weak single pass absorption at R_{EC}. The transmitted waves are reflected by the vessel walls and contain a mix of O- and X- polarisations. At the upper hybrid layer R_{UH}, the X-mode encounters a resonance, where the electric field can accelerate electrons to energies above the ionisation potential.

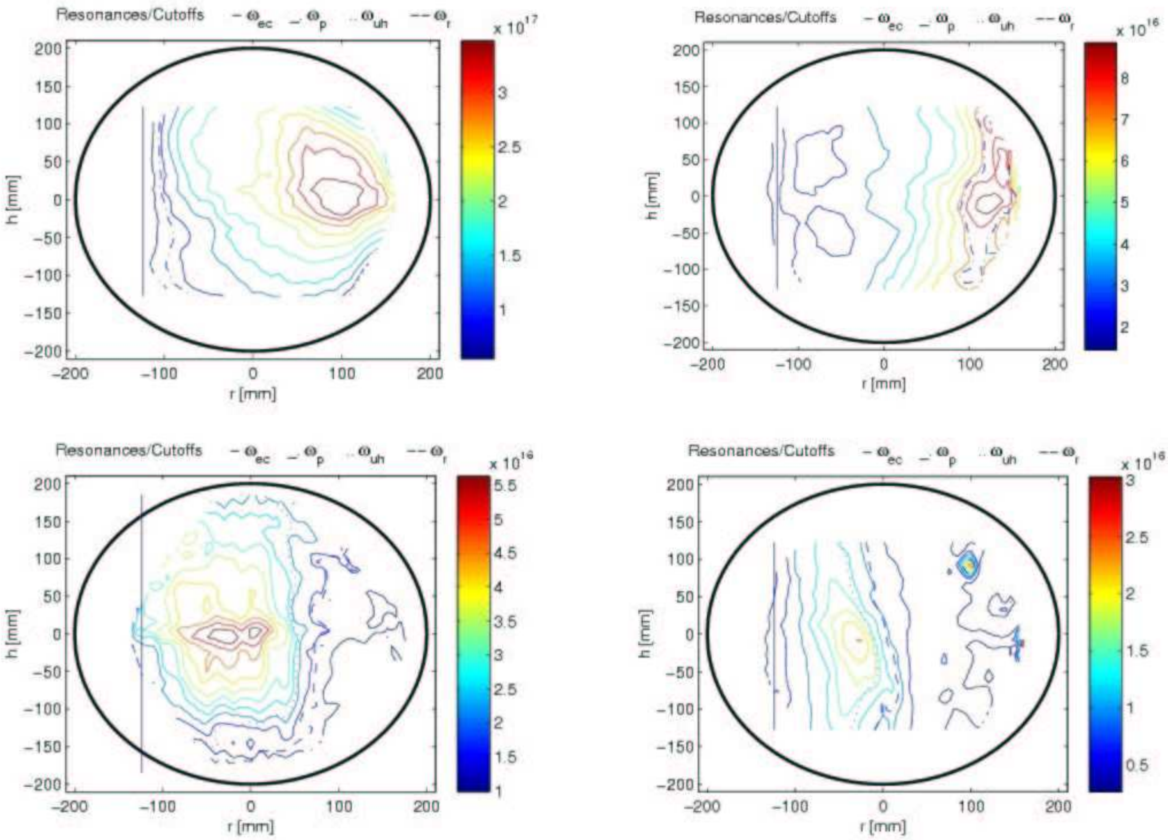

Figure 1: *Argon (left) & Hydrogen plasma density profiles,* 10*kW (top) &* 500*W*

As a consequence, the density is expected to increase at the UH layer. As ω_{UH} depends on n, the profile should extend from R_{EC} to R_{UH}, shifting to the LFS as the microwave power is increased. Such an effect is clearly observed both in Hydrogen and Argon plasmas, as shown in Figure 1. As the steady-state profile is the result of a balance between the plasma production and the mechanisms leading to an equilibrium, the maximum of the density does not necessarily peak at the UH layer, and may include over dense regions.

The over-dense region is observed to be wider in Argon plasmas, with a higher density and a more peaked profile, than in Hydrogen.

In order to assess the effect of absorption at ω_{UH}, experiments with modulated EC power were performed (square wave modulation at 600Hz, with a duty cycle of 33% and $P_{RF} = 1 \rightarrow 1.5$kW).

This allows the separation of the fast ionisation and absorption processes from the slower mechanisms that lead to the plasma equilibrium. Figure 2 shows that the increase in $n(r,h,t)$ caused by the increase in the EC power is localised at the UH layer, confirming the role of the UH resonance in the ionisation process.

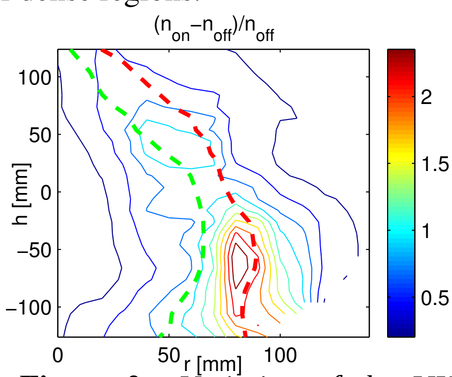

Figure 2: *Variation of the UH position during plasma modulation experiments (Green/red:low/high power)*

In some experimental regimes, with relatively large toroidal field and microwave power, large oscillations with frequencies $6-12$kHz are observed in both the absorbed power (estimated from measurements of injected/reflected microwave power) and density (Figure 3). The two quantities appear strongly correlated, with relative phases and amplitudes of the density oscillations depending on the spatial location. The coupling between density and absorbed power may be mediated by the UH resonance, via the absorption and ionisation mechanisms discussed above: as the density is increased, the UH layer moves outward, absorbing the injected power at the plasma edge and preventing it from reaching the plasma core, where the density would then tend to decrease. The time scale for such decrease should be related to the characteristic time for the relaxation of the density at different locations. The measured oscillation periods are in fact observed to be of the same order of the estimated particle confinement time.

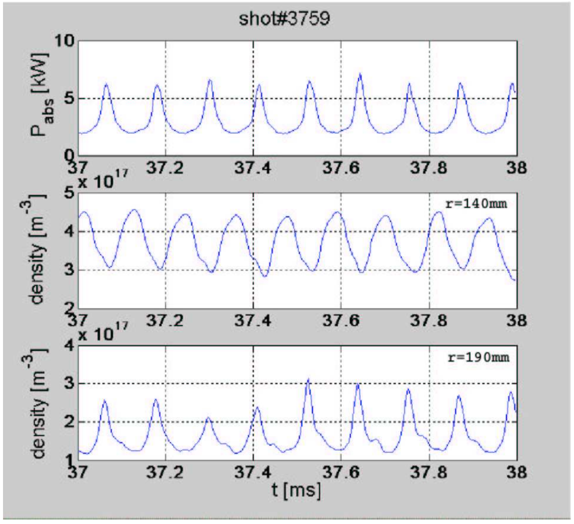

Figure 3: *Coupling between density and absorbed power*

Coherent modes & turbulent structures

Depending on the experimental conditions, low frequency (much lower than the ion cyclotron frequency) coherent modes and turbulent regimes have been observed in the spectra of density fluctuations (Figure 4). In Argon plasmas, modes with frequency $f = 8.34kHz$ and wave-number $k_\theta = 0.6cm^{-1}$ have been measured, propagating in the electron diamagnetic direction with a phase velocity $v_\theta = 860m/s$. This value is comparable with the drift velocity estimated from the background parameters, $1.1 \pm 0.4km/s$.

Due to the dependence of the phase velocity on the gradient length scale [4], and the measured value of the component of the wave-number along the toroidal direction ($k_{||} \ll k_\theta$), the modes can be identified as drift waves.

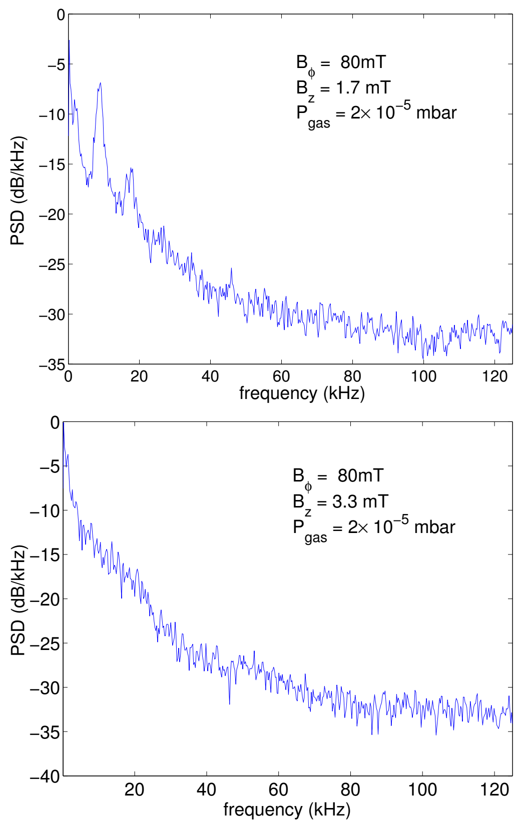

Figure 4: *Frequency spectra of density fluctuations in Argon plasma: coherent (top) and turbulent case (bottom)*

The Conditional Average Sampling technique [5], applied to data from Langmuir probes, has revealed the existence of structures in the density, propagating in the poloidal plane along the $\mathbf{E} \times \mathbf{B}$ direction with velocity $v \approx 500m/s$ (Figure 5).

Diagnostic plans

In order to characterise the plasma fluctuations and turbulent structures and to determine the physical mechanisms that lead to their formation, high spatial and temporal resolution diagnostics are needed. Several are envisaged for the next campaign.

For the measurement of density and potential fluctuations, a 92 tip Langmuir probe array covering the entire poloidal section has been designed and is under construction. The spatial resolution is about $\sim$ 3.5cm and has a high temporal resolution of 400kHz. A 3-tip Langmuir probe for detecting density and potential fluctuations with high temporal ($10MHz$) resolution will also be installed to measure the fluctuation-induced particle flux over a plane perpendicular to the toroidal magnetic field.

A study of the feasibility of optical imaging techniques has just been completed. Initial results from a fast photomultiplier detector coupled to an optical fibre, suggest that the photon levels are sufficient for different optical techniques. This will allow the use of a fast camera imaging system, 40 – 100k frames/sec, for observing the fluctuations in the visible light emission from neutrals due to T_e fluctuations. Possible extensions to velocity-dependent imaging techniques based on laser induced fluorescence are also envisaged.

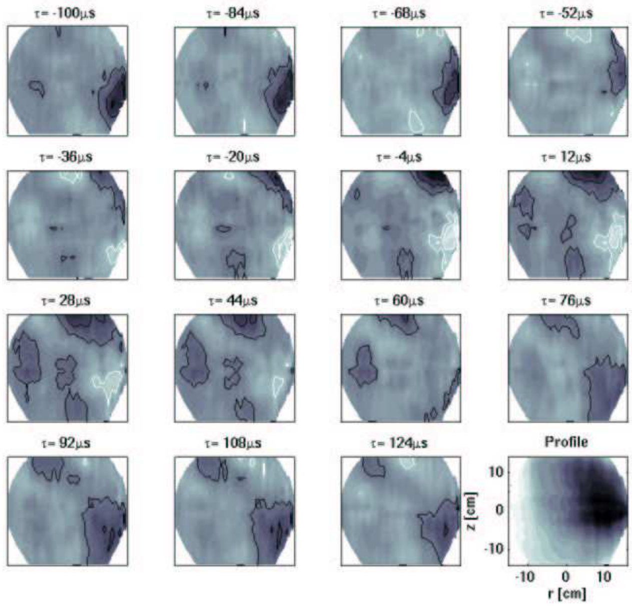

Figure 5: *Blobs / structures moving with time and their projection in the poloidal plane*

Acknowledgements

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