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Drift waves in the TORPEX toroidal plasma device

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Introduction

Among the wide variety of instabilities that can be excited in a toroidal magnetized plasma, gradient driven instabilities called drift waves (DW) can be unstable and evolve non linearly, leading to electrostatic turbulence. These instabilities can cause radial particle and energy transport. It is therefore important to identify DW instabilities in a plasma, to observe the spatio-temporal evolution of the related fluctuations and to link this with the theoretical results of nonlinear simulations. The TORPEX toroidal device [1] addresses this kind of issues. In this paper, we present a series of test aimed at identifying the nature of instabilities observed on TORPEX, in particular to determine whether or not an interpretation in terms of drift waves is correct. Various Langmuir probes provide local measurements of plasma density and floating potential fluctuations including the local turbulence-induced particle flux and the phase shift between density and potential [2], [3]. The effect of the neutral density on the fluctuation properties is also investigated.

Theoretical criteria to be satisfied for a drift wave

Several conditions must be satisfied by a plasma mode to be identified as a DW driven by a density gradient: 1) The maximum in density fluctuations should be located where the density gradient is the largest. 2) The frequency of the mode, in the plasma frame, must change with the density gradient length L_n, according to the dispersion relation: $\mathrm{v}_{\mathrm{phase}} = \omega_{DW}/k_y = \frac{T_e}{eB_\varphi}\frac{1}{L_n}$. 3) In the collisionless regime, density and potential fluctuations should be in phase. 4) The parallel wavenumber should be small ($k_\parallel \ll k_\perp$) but finite.

Experimental results for identification of drift waves

To verify these hypotheses, hydrogen plasmas obtained with $P_{rf} = 1kW$ of microwave power, leading to a density profile peaking close to the center of the vacuum vessel, are investigated. The magnetic configuration includes a small vertical B_z, set at the optimal value for particle confinement [4], and the main toroidal magnetic field ($B_T \leq 0.1T$). Density $n_e \sim 1 \times 10^{17} m^{-3}$, electron temperature $T_e \sim 3 \div 6eV$ and plasma potential $V_p \sim 6 \div 16V$ have been measured. In these studies, the incoming gas flux, i.e. the neutral density in the vacuum vessel, influencing the collision frequencies with neutrals, was varied. Density profiles appear to be resilient, since the density gradient length $1/L_n$ between $-10cm \le r \le +15cm$ does not change with the pressure. Only at the very edge were we able to vary the density gradient (Fig.1 upper frame).

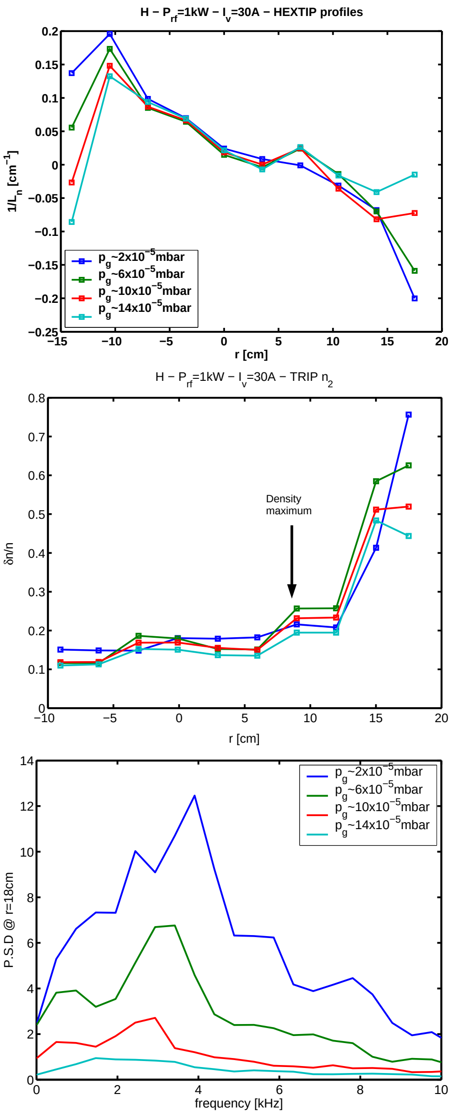

Figure 1: *Inverse density gradient length profile (top), $\tilde{n}/n$ profile (centre) and density fluctuations spectrum (bottom) for the different hydrogen gas pressure.*

1) Fluctuations radial location: The central frame on Fig.1 shows the radial profile of the rms of density fluctuations normalized to the equilibrium density, $\tilde{n}/n$. Contrary to the $1/L_n$ profile, the profile of normalized fluctuations is clearly not symmetric about the density maximum. This may be due to the destabilizing effect of the magnetic field lines curvature. *2) Mode frequency* vs *density gradient:* Despite the large Doppler effect, the density fluctuation spectrum (Fig.1 lower frame) reveals that the frequency of the observed coherent mode shifts to lower frequencies when the gradient flattens at the plasma edge, region of strong fluctuations. *3) Phase shift between density and potential:* Assuming that temperature fluctuations can be neglected, we identify the plasma potential fluctuations with the directly measured floating potential fluctuations. First, we estimate the coherence between density and floating potential fluctuations. This is larger than 0.8 in the outer regions, is constant with the pressure and decreases in the central region as the neutral density increases. In a region where the drive for instability is weak, fluctuations are less correlated because of collisions with neutrals. The phase difference between density and potential fluctuations is calculated where the coherence exceeds 0.75, between 1 and 4kHz. As shown on Fig.2, this condition excludes the central region. Nevertheless, it is clear that the phase difference in the region of instability is almost 0 and never reaches $\pi/2$ or π which would suggest a flute-like or a Kelvin-Helmholtz-like nature for the instability, respectively. *4) Parallel wavenumber estimation:* With two Langmuir probes spaced in the toroidal direction by 1.8 cm, we estimate the toroidal wavenumber identified as $k_{\parallel}$ $(B_z \ll B_{\varphi})$, using a statistical two-point correlation technique. The wavenumber spectra for two radial positions are plotted on Fig.2 . In the region of low fluctuation intensity, the spectral dispersion is too large to allow an estimate of $k_{\parallel}$. But where

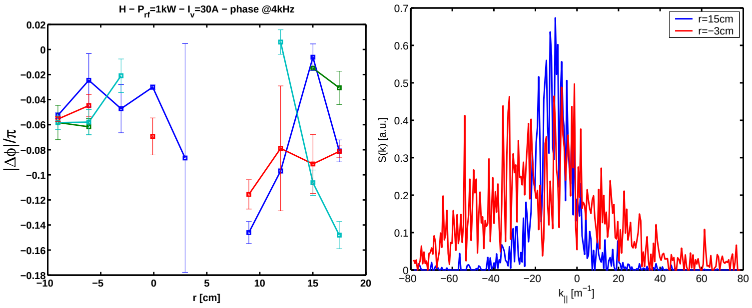

Figure 2: *Estimated phase shift between potential and density (righ) and parallel wavenumber spectrum (left) for the different hydrogen gas pressure.*

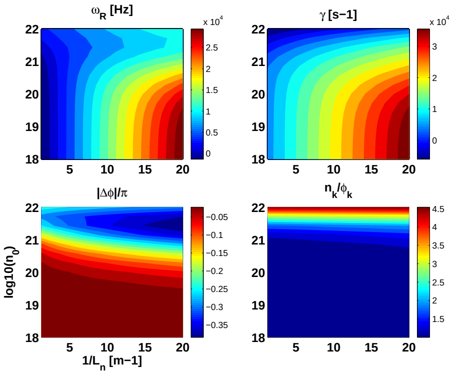

Figure 3: *Frequency, growth rate, phase shift and amplitude variations with $1/L_n$ and n_0 predicted by a linearized dispersion relation.*

the fluctuations are strong, the spectral dispersion is reduced and a finite parallel wavenumber is found: $k_{||} \sim -10m^{-1}$. Therefore, the observed features of the low-frequency peak do not contradict any of the four general points mentioned in the introduction for drift wave identification. However, in microwave produced plasmas an additional issue needs to be addressed. As the plasma production is linked to a local upper hybrid resonance, it may lead to a low frequency oscillation in the plasma in two ways. First, it can produce a non propagating disturbance via the local nonlinear coupling between the microwave power and the plasma density. The measured propagation properties of the low frequency fluctuations seem incompatible with this mechanism. Second, nonlinear wave-wave interactions at the resonant layer can lead to the excitation of low frequency waves, for example via parametric decays [5]. As in our experimental conditions the upper hybrid layer is close to the maximum density gradient, where the fluctuation amplitude is maximum, a direct role of the microwaves in the excitation of the observed instabilities cannot be excluded. In addition, in case in which the microwave power is modulated [3], the measured spectra indicate a modulation of the low frequency oscillation at the same frequency. The significance of this effect will be assessed in future dedicated experiments in which the depth and frequency of the modulation of the microwave power will be varied systematically.

Role of collisions on the drift wave mode

A way to affect the plasma production is to vary the collision frequency with neutrals, which can modify the parallel dynamics of the primary fast electrons. This has been done for the same type of hydrogen plasmas discussed above. The frequency of electron-neutral collisions has been varied by a factor of 7 ($4 \times 10^4 \leq \nu_{e,n} \leq 28 \times 10^4 s^{-1}$). As it can be seen on Figs.1&2, the spectral properties of fluctuations are not affected by this change. A possible explanation is that, in hydrogen plasmas, Coulomb collisions are dominant for the thermal electrons, which determine the profiles. As a guideline for interpreting these experiments, a two-field model [7] has

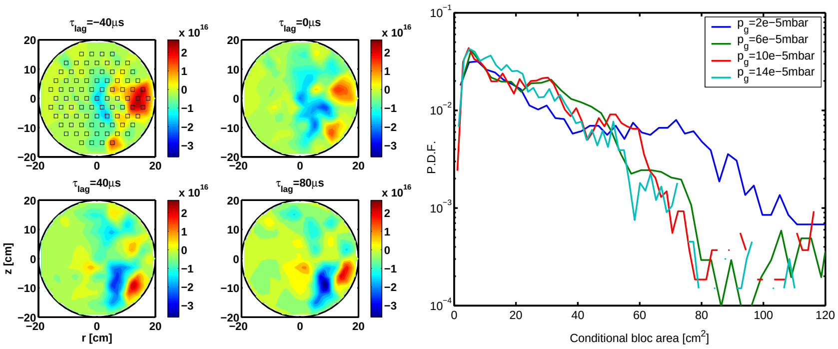

Figure 4: *Example of 2D visualization of density fluctuations (left) and probability density function of "conditional area" of density blobs (right)*

been linearized and the resulting dispersion relation investigated. This model includes the main ingredients to study drift waves: density gradient and magnetic field curvature. It also contains cross-field dissipation, controlled by the collision frequencies $\nu_{\alpha,n}$ and parallel dynamics for electrons, controlled by $1/\nu_{e,n}$. Coulomb collisions are not included. This model predicts that for the TORPEX plasma parameters, flute modes ($k_{||} = 0$) are stable while resistive drift wave modes ($k_{||} \neq 0$ and collisions) are always unstable even in the favorable curvature region. Fig.3 shows that for a typical experimental density gradient ($1/L_n \sim 10m^{-1}$), drift waves can be fully stabilized for a neutral gas pressure greater than $10^{21}m^{-3}$. According to the dispersion relation, drift waves in argon plasmas can be stabilized with neutral densities around $10^{19}m^{-3}$, which will be the subject of future experiments.

Role of collisions on spatio-temporal structures

Even if collisions with neutrals have no effect on the wave linear properties, one can look at the spatio-temporal evolution of these fluctuations which includes nonlinear effects. To this aim, the conditional average sampling [6] was applied to this set of data. As an illustration, a 2D reconstruction of density fluctuations for four different delays is plotted on Fig.4. Density fluctuations have been interpolated to the whole cross-section assuming they are vanishing at the vacuum vessel. Density blobs, i.e. spatially localized strong density fluctuations, essentially located in the low field side region where fluctuations are maxima, propagate in the $E \times B$ direction ($\mathrm{v}_{E\times B} \leq 1.5 \times 10^3 m.s^{-1}$). Using a contouring algorithm, we can isolate approximately 10 blobs per time frame and per value of pressure and then compute their "conditional area" to provide the probability density function as shown on Fig.4 for each gas pressure. We see that the probability of having spatially extended "conditional density fluctuation blobs" is higher for lower gas pressure. This is in agreement with the observation that the radial and poloidal correlation lengths decrease with the collisions.

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