Formation and radial proagation of turbulent structures in the linear helicon device VINETA

T. Windisch[1], O. Grulke [1,2], T. Klinger [1,2]

[1] *MPI for Plasma Physics, EURATOM association, 17491 Greifswald, Germany*

[2] *EMAU University Greifswald, 17489 Greifswald, Germany*

Independent of the specific magnetic field topology, spatiotemporal turbulent structures are observed in the far plasma edge of magnetically confined plasmas and contribute mainly to the fluctuation-induced particle transport [1, 2]. Due to the radial propagation of these structures they appear as intermittent density bursts with large amplitudes ($\tilde{n}/n > 1$). While their poloidal/azimuthal propagation is mainly determined by the background $E \times B$-drift, their convective radial propagation is a self-consistent feature, which arises from a polarization of the density structure [3]. In fusion devices the polarization is caused by the curvature of the magnetic field and as a consequence the structure is dominated by interchange dynamics with $k_{||} = 0$, i.e. the structures extend along the magnetic field and appear as filaments. The polarization of the density structure leads to a dipolar potential perturbation and the resulting $E \times B$-drift propels the structure radially outwards with a typical velocity of 10% of the ion sound speed. The experimental observations in the scrape-off layer in fusion devices are in good agreement with recent theoretical models [5] and numerical simulations [6]. In fusion devices the structures develop in the turbulent plasma edge, but due to limited diagnostic access the formation process is poorly understood. Numerical simulations suggest that a transition from the interchange dynamics in the scrape-off layer (open flux surfaces) to drift-wave turbulence in the plasma edge (closed flux surfaces) is observed [7]. It is also worthwhile to note that a radial velocity shear, which naturally exist in the plasma edge region of fusion devices, may play a crucial role in the formation process.

In laboratory devices with homogeneous magnetic field topology the curvature drive for the charge polarization does not exist. But also in this situation intermittent density structures are observed in the far plasma edge, which are radially convected by a dipolar potential perturbation associated with the structure. Different mechanisms have been suggested to explain the polarization in linear devices, e.g. centrifugal forces due to a rigid body plasma rotation or the neutral wind due to different heating rates of neutrals in the plasma core and edge regions, which results in a net radial force [4].

In the present presentation the dynamics of turbulent structures in resistive drift-wave turbulence is investigated in the linearly magnetized device VINETA. Previous studies clearly revealed that

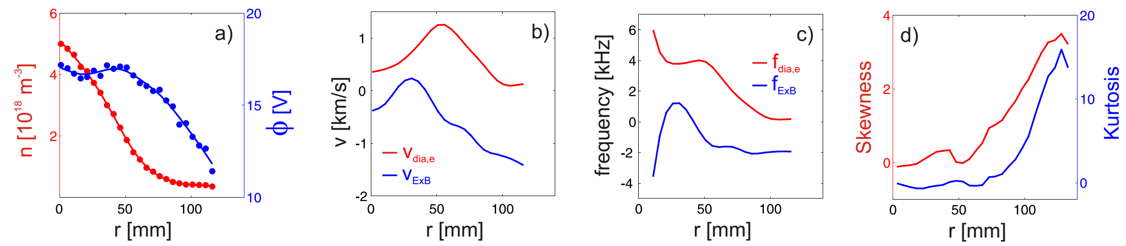

Figure 1: Time-averaged plasma density and plasma potential (a), corresponding drift velocities (b), frequencies (c) and radial evolution of skewness and kurtosis (d).

the pressure gradient driven drift-wave instability dominates in the VINETA device [8]. Plasma is produced using a helicon-wave sustained discharge with a peak density of $n \approx 10^{19}\,\mathrm{m}^{-3}$ and peak electron temperature of $T_e \approx 2-3\,\mathrm{eV}$. The ions are cold with $T_i \approx 0.5\,\mathrm{eV}$. The working gas is Argon with a typical pressure of $p = 0.1\,\mathrm{Pa}$. The Coulomb collisions $\nu_{ei}/\Omega_{ci} = 50$ and the collision rate with neutrals $\nu_{en}/\Omega_{ci} = 12$ and $\nu_{in}/\Omega_{ci} = 0.1$ are fairly high (Ω_{ci} being the ion cyclotron frequency). Time-averaged radial profiles of the plasma density and plasma potential as measured with rf-compensated Langmuir probes are shown in Fig.1a. The density has nearly a Gaussian shape with a 1/e-folding length of $r_e = 52\,\mathrm{mm}$. The plasma potential is also peaked in the center but much broader if compared to the density profile ($r_e = 144\,\mathrm{mm}$). The corresponding first order drift velocities, i.e. $E \times B$-drift $v_{E\times B}$ and the electron diamagnetic drift $v_{dia,e}$ are shown in Fig. 1b. Due to the different shapes of the profiles $v_{dia,e}$ dominates for $r < 75\,\mathrm{mm}$ and $v_{E\times B}$ for larger radii. Note that both drifts have opposite directions. The frequencies $\omega/2\pi = v/r$ are depicted in Fig.1c.

The radial evolution of the moments skewness S and kurtosis K of the probability distribution function (PDF) of density fluctuations (Fig. 1d) clearly indicates the intermittent character of the fluctuations in the plasma edge which lead to highly non-Gaussian PDF with long positive tails for $r > 50\,\mathrm{mm}$. In the far plasma edge typical values are $S = 3$ and $K = 15$. The origin of the large amplitude bursts in the plasma edge is investigated by reconstructing the spatiotemporal dynamics using the conditional averaging technique.

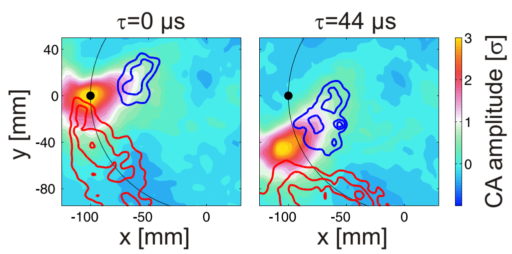

Figure 2: Conditionally averaged density and floating potential (imposed as contour lines) fluctuations for two different time lags The position of the reference probe is indicated by a black dot.

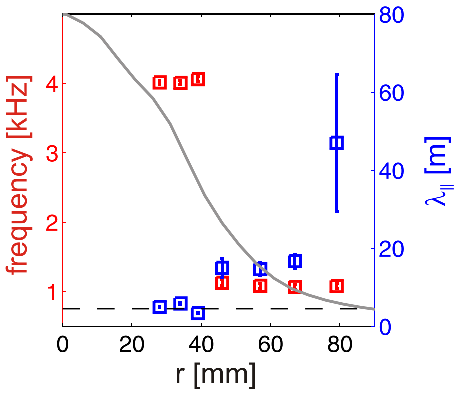

Figure 3: Radial evolution of main frequency component and parallel wavelength of density fluctuations. The dashed line indicates the machine length and the gray line the density profile

The result for the fixed reference probe located at $x = -100$ mm (indicated by a black dot) is shown in Fig. 2 for two different time lags. A turbulent structure is observed which propagates mainly azimuthally with $v_\theta = 930$ m/s ($f \approx 1.5$ kHz) but also radially with $v_r = 213$ m/s. The density structure is associated with a dipolar potential perturbation which gives rise to a $\tilde{v}_{E\times B}$-velocity directed radially outwards. The parallel wavelength $\lambda_{||}$ of the structures is shown in Fig. 3. In the plasma edge ($r > 50$ mm) $\lambda_{||}$ clearly exceeds the machine length, indicating their flute-like character. Assuming that the polarization of the turbulent structure originates from the neutral wind we can estimate the resulting radial velocity and compare it to the experimental findings. Inserting the experimentally observed peak density of turbulent structure and temperatures of $T_0^{core} = 0.05$ eV and $T_0^{edge} = 0.02$ eV for the neutral argon atoms in the core plasma and in the edge plasma, respectively, we obtain from the neutral wind model a radial structure velocity of $v_{nw} = 233$ km/s of the turbulent structure, which is in excellent agreement with the experimental findings. The contribution of the turbulent structures to the spectrum can be observed in the radial spectrogram (Fig. 4) at $f \approx 1.5$ kHz for $x < -50$ mm The spectrum peaks at $x \approx -30$ mm at a frequency 3.3 kHz (corrected for $E \times B$-Doppler shift) which is associated with quasi-coherent $m = 1$ drift mode. This is in good agreement with the Hasegawa-Mima type drift-wave dispersion relation $\omega = \omega_{dia,e}/(1 + (k_\perp \rho_s)^2) = 3.2$ kHz, where the azimuthal wavenumber $k_\perp = m/3\,\text{cm}^{-1}$ and the drift scale $\rho_s = 1.8$ cm. The spatiotemporal dynamics of the $m = 1$ is shown in Fig. 5 for two different time lags (the reference probe is located at $x = -40$ mm).

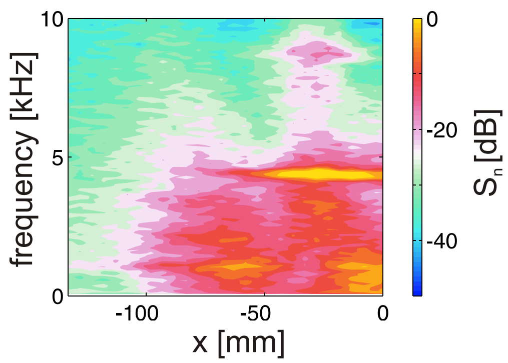

Figure 4: Radial spectrogram of density fluctuations (Doppler-shifted).

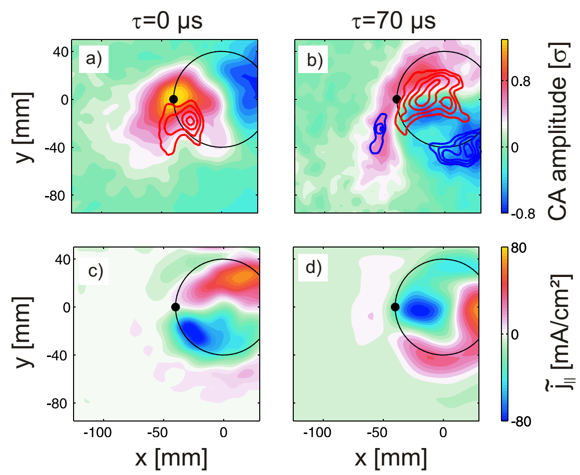

Figure 5: Conditionally averaged density and floating potential (imposed as contour lines) fluctuations (a,b) for two different time lags and the corresponding fluctuating parallel current $\tilde{j}_{||}$ (c,d).

One clearly observes the $m = 1$ drift mode, which propagates clockwise in the direction of the electron diamagnetic drift. In contrast to the turbulent structures the drift-wave has a parallel wavelength (cf. Fig. 3 for $r < 50$ mm), indicating their three-dimensional character. The intrinsic fluctuating parallel current $\tilde{j}_{||}$ (Fig. 5c,d) lags behind the density density perturbation and gives rise to the potential perturbation with a phase shift $\delta(\tilde{n}, \tilde{\phi}) \approx \pi/4$. The resulting fluctuating $\tilde{v}_{E\times B}$-velocity transports plasma from the positive $m = 1$ density perturbation radially outwards (Fig. 5b). For consecutive time lags the structure gets disconnected from the drift mode. A careful analysis of Fig. 5b reveals that the turbulent structure is connected with a negative potential perturbation. This can be explained by a the local increase of the electron temperature, which leads to a decrease of the floating potential. When the structure is disconnected from the $m = 1$ drift mode it's azimuthal propagation is solely determined by the background $E \times B$-drift with a frequency of $f \approx 1 - 1.5$ kHz for $x < -50$ mm. The diamagnetic drift has no influence on the azimuthal propagation. This explains the relatively sharp transition in the spectra to the lower frequencies at this position (cf. Figs. 3,4).

References

[1] Zweben S. J. *et al.*, *Nucl. Fusion* 44, 134 (2004).

[2] Windisch T *et al.*, *Phys. Plasmas* 13, 122303 (2006).

[3] Krasheninnikov S. I., *Phys. Lett. A* 283, 368 (2001).

[4] Krasheninnikov S. I. and Smolyakov A. I., *Phys. Plasmas* 10, 3020 (2003).

[5] Myra J. R. *et al.*, *Phys. Plasmas* 13, 092509 (2006).

[6] Garcia O. E. *et al.*, *Phys. Plasmas* 13, 082309 (2006).

[7] Ribeiro T.T. and Scott B., *Plasma Phys. Controlled Fusion* 47, 1657 (2005).

[8] Schröder C *et al.*, *Phys. Plasmas* 12, 042103 (2005).