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Ion-Drift-Waves in the PSI-2

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1 Introduction

The ion-drift-wave (IDW) is a special solution of the general drift-wave dispersion-relation, calculated by the application of the linear-stability-analysis method on the two-fluid-equations, and was first discussed by D'Angelo and Chen [1, 2]. In almost all performed drift-wave experiments in the past, only the electron-drift-wave (EDW) was observed. Therefore, the experimental knowledge about the IDW is extremely rare. IDW's can be destabelized in the case of large finite ion-larmor-radii effects. This requires warm ions and steep gradients in the electron pressure and the radial electric field. Since the plasma in the PSI-2 (Fig. 1) fulfills these requirements, IDW's can be observed.

The PSI-2 is a stationary low pressure high current arc-discharge in an axial magnetic field. The plasma is produced between a heated cylindrical hollow cathode and a hollow anode. It drifts magnetically guided ($B = 50 \ldots 270\,\mathrm{mT}$) into different investigation chambers and forms a cylindrical plasma column with a diameter of $6 \ldots 10\,\mathrm{cm}$ and a length of about 2.5 m. In noble gases (e.g. Kr) the parameters $n_e \approx 10^{19}\,\mathrm{m}^{-3}$, $T_e \lesssim 10\,\mathrm{eV}$, $T_i \lesssim 5\,\mathrm{eV}$ can be achieved, hence the plasma is almost fully ionized. The ions are weakly magnetized (in contrast to the electrons) and their gyroradii are in the order of the plasma radius. Therefore, the ions cannot fulfill the drift-approximation, and they are almost exclusively confined by a radial self-consistent electric field, which is also responsible for the rotation of the whole plasma column [3].

2 Experimental results

Fig. 2 shows the radial profiles of a Kr-plasma determined with Langmuir-probes [4]. Since the electron pressure profile (p_e) is hollow, two regions of steep gradients exist. At the plasma edge ($r/r_0 \approx 1$) the radial electric field (E_r) changes its sign, and the resultant azimuthal macroscopic drift-velocity of the electrons ($v_{\theta_e} = v_{\theta\,\nabla p_e} + v_{\theta\,E_r}$) is strongly sheared. The maximum of v_{θ_e} coincides radially with the maximum of the floating-potential fluctuation-amplitude ($\tilde{U}_{fl}$), there where the inboard IDW is located.

This can be shown also, in the radial resolved cross-power-spectrum of U_{fl} (Fig. 3.), measured by the use of the two-point correlation technique [5]. According to the two

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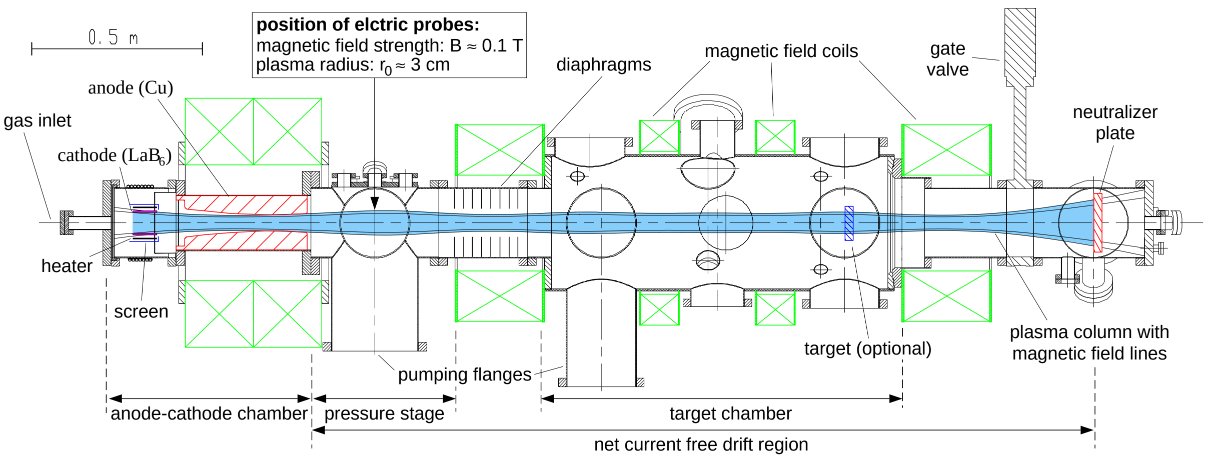

Fig. 1: The Plasma-Generator PSI-2.

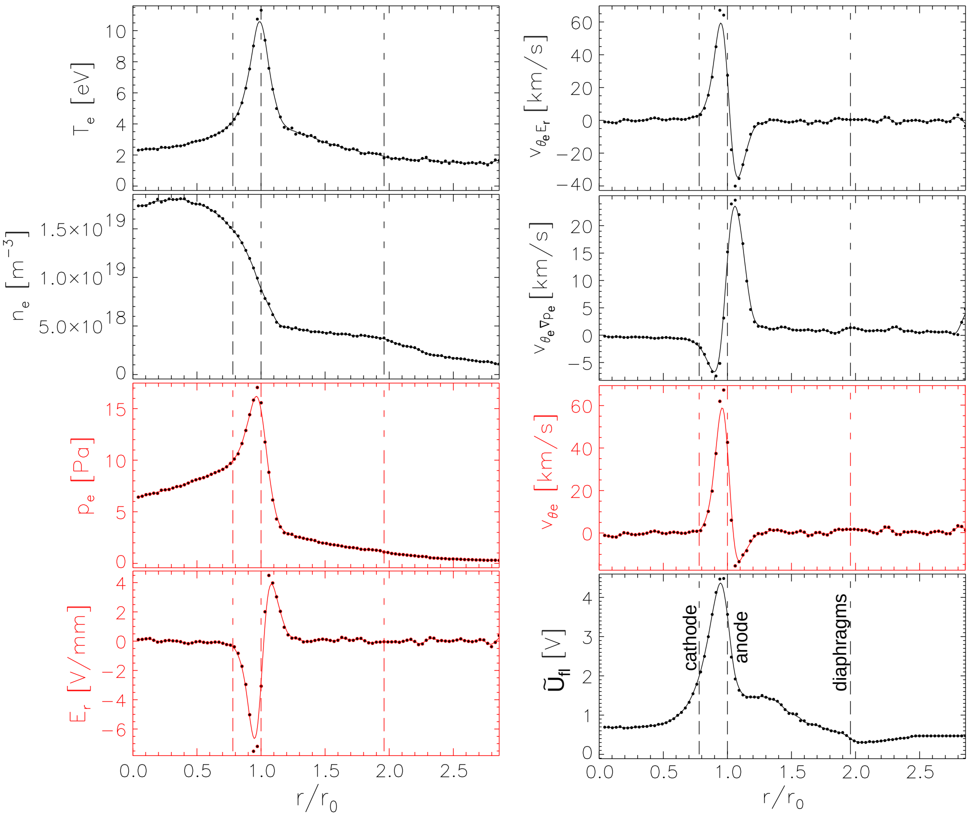

Fig. 2: Radial profiles of a Kr-plasma.

extrema of v_{θ_e}, two IDW-mode-series exist simultaneously. For the inboard IDW's a nearly linear azimuthal dispersion-relation ($\omega(k_\theta) = v_{ph}k_\theta$) was found, using the cross-phase-spectrum ($k_\theta(\omega) = \varphi_{12}(\omega)/\Delta x$) to calculate the wavenumber-frequency-spectrum of U_{fl} (Fig. 4). From the slope of $\omega(k_\theta)$ a azimuthal phase-velocity of about 2 km/s can be determined, which is nearly the same as the spectroscopical measured azimuthal macroscopic drift-velocity of the ions [6].

Additional to the electric probes, an end-on CCD-camera, looking through the hollow anode-cathode-unit along the plasma-axis, was used for the observation of the spatio-temporal structure of the plasma cross-section (Fig. 5). Because of the hollow p_e- and (therefore) intensity-profile, only the inboard IDW can be observed. The analysis of these images delivers a dominant mode-number of $m_\theta = 5$ and a azimuthal phase-velocity of about 2 km/s (with the same direction), consistently to the results of the probes. Furthermore, the mode-structure of the IDW can also be seen in the spectral emission of the neutrals [7]. This indicates, that the IDW-dynamics leads to an azimuthal periodic radial-displacement ($r(\theta) - r_m$) of the formerly annular $p_e(r_m)$-distribution. The drift-surfaces of the electrons (and ions because quasi-neutrality) are modified through the electrostatic potential of the IDW. Graphically, a displacement-amplitude of $\tilde{r}_m \approx 1$ mm can be determined from the CCD-images [7].

3 Potential model of the IDW

The measured periodic potential fluctuations can be interpreted as a rotating azimuthal periodic charge-density distribution $\sigma_m(r,\theta) = -\tilde{\sigma}_m \sin(m\theta)\delta(r - r_m)$, located at the mode-radius r_m. With Poisson's Eq. $\Delta\phi(\vec{r}) = -\rho(\vec{r})/\epsilon$ the potential (Fig. 6)

$$\phi_m(r,\theta) = -\tilde{\phi}_m \left(\frac{r}{r_m}\right)^{\pm m} \sin(m\theta) \quad \text{with:} \begin{Bmatrix} + : \ 0 \le r \le r_m \\ - : \ r_m \le r < \infty \end{Bmatrix} \tag{1}$$

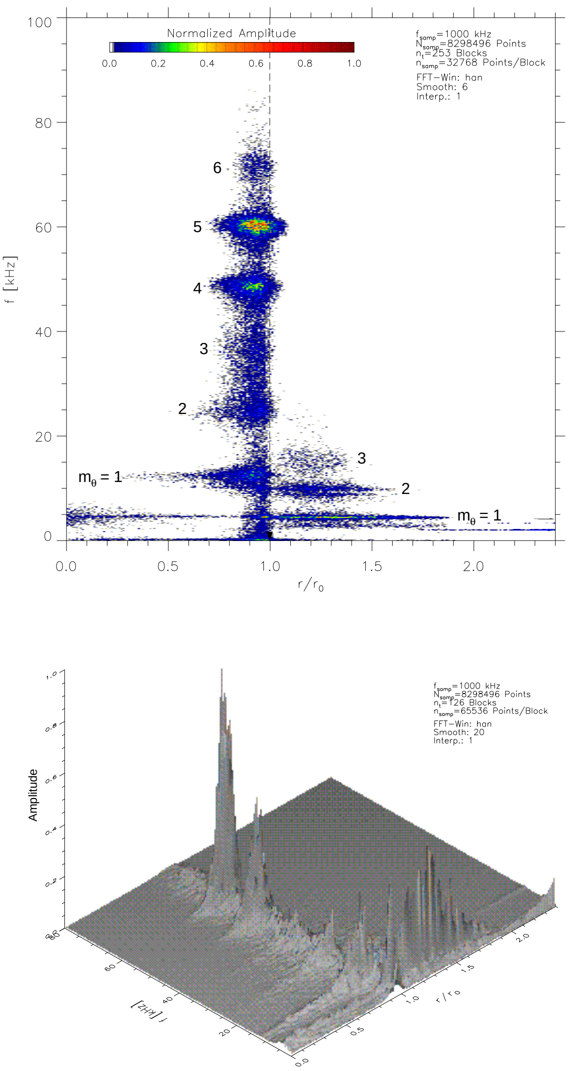

Fig. 3: Cross-power-spectrum of U_{fl}.

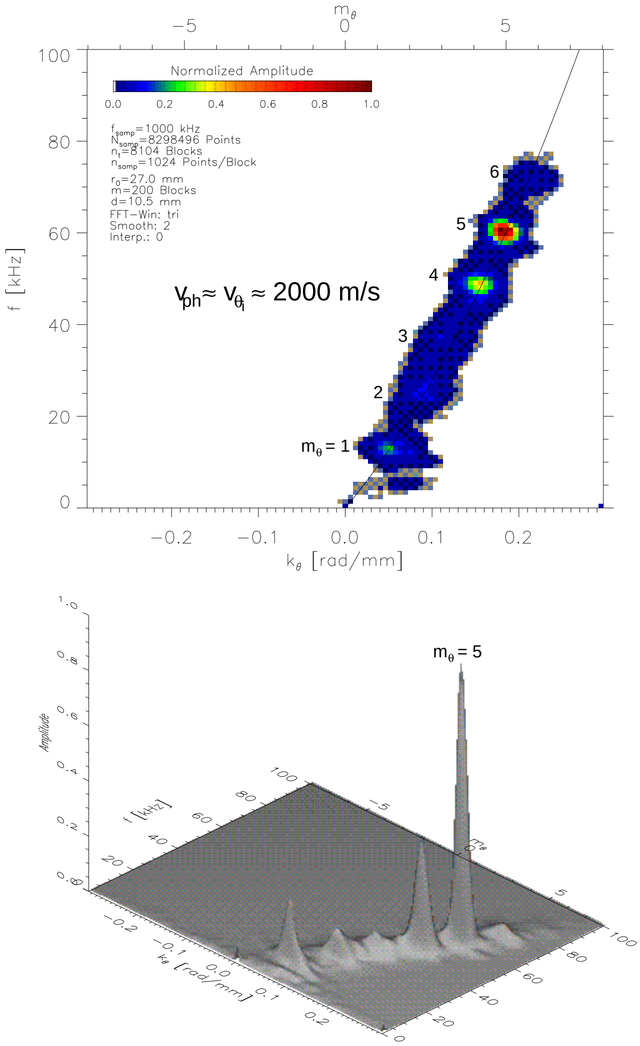

Fig. 4: Wavenumber-frequency-spectrum of U_{fl} (azim. dispersion-relation of the inboard IDW).

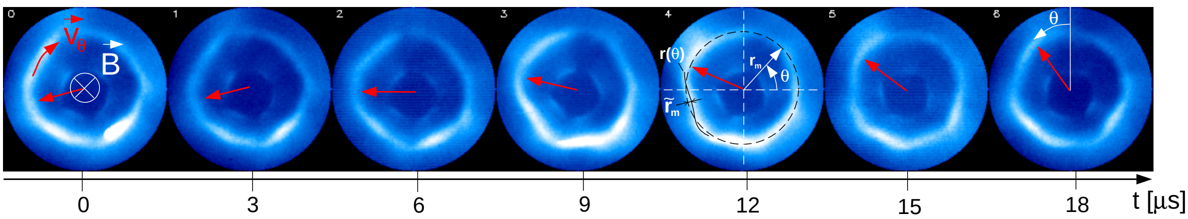

Fig. 5: Sequence of CCD-images of the plasma cross-section in the full visible spectral range. The directions of the rotation of the IDW, the electrons and the ions are identical, and are right-handed to $\vec{B}$, due to the $\vec{E} \times \vec{B}$-motion with $E_r < 0$ at the position of the inboard IDW.

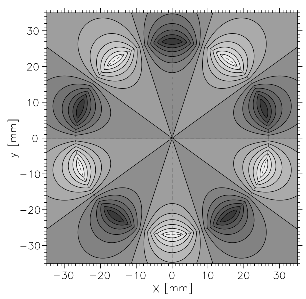

Fig. 6: $\phi_5(r, \theta)$

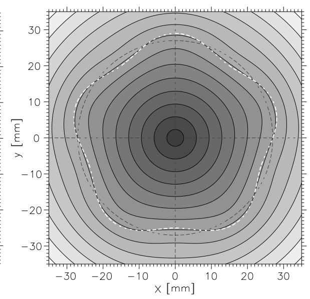

Fig. 7: $\Phi_5(r, \theta)$

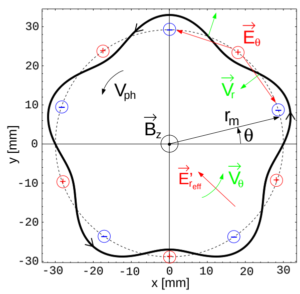

Fig. 8: Drift-surface

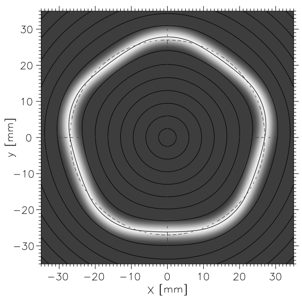

Fig. 9: Intensity$\sim p_e$

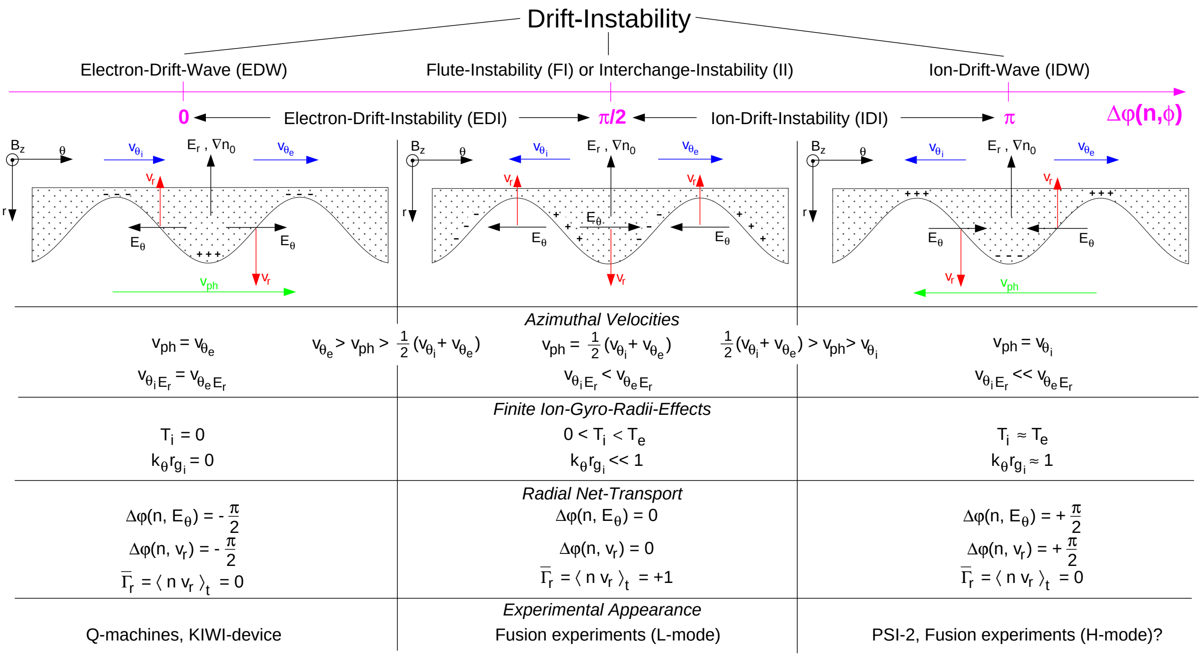

Fig. 10: Classification-scheme of the drift-instabilities.

can be calculated. For simplicity E_r can be assumed as constant, hence the total potential is $\Phi_m(r,\theta) = \phi_m(r,\theta) - E_r r$ (Fig. 7). With some mathematics, a equation for the drift-surface at r_m (Fig. 8)

$$r(\theta) = r_m - \tilde{r}_m \sin(m\theta) \quad , \ \tilde{r}_m = \frac{\tilde{\phi}_m}{E'_{r_{eff}}(r_m)} \approx \frac{\tilde{U}_{fl}(r_m)}{E'_{r_{eff}}(r_m)} \approx \frac{5\,\mathrm{V}}{-5\,\mathrm{V/mm}} \approx -1\,\mathrm{mm} \qquad (2)$$

can be calculated. Independet from the analysis of the CCD-images, this relation delivers the same value for $|\tilde{r}_m|$, so the potential model of the IDW is confirmed. Furthermore, the observed intensity-distribution of the $m = 5$ mode (Fig. 5) can be reproduced with a approximated GAUSSIAN-p_e-profile that follows this drift-surface (Fig. 9).

4 Conclusions

The drift-waves observed in the PSI-2 are identified as IDW's, because their azimuthal dispersion-relation is found to be nearly linear, and their resultant azimuthal phase velocity is approximately equal to the azimuthal ion drift velocity ($\omega(k_\theta) \approx v_{\theta_i} k_\theta$). Because of the high parallel conductivity, the parallel wave numbers are found to be nearly zero [7]. Hence, it is a IDW with a flute-like shape. Furthermore, the potential fluctuations always lag behind the density fluctuations with a phase shift of $\Delta\varphi(n,\phi) \approx \pi$ [7], according to the classification-scheme of the drift-instabilities (Fig. 10). Therefrom it can be shown, that IDW's are only unstable if $\Delta\varphi(n,\phi)$ is slightly smaller than π, and that the radial net transport ($\bar{\Gamma}_r$) is proportional to $\sin\Delta\varphi(n,\phi)$. Thus, one question arises: What is the value of $\Delta\varphi(n,\phi)$ at the plasma-edge in a fusion experiment during the H-mode?

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