INVESTIGATION OF LOW-FREQUENCY FLUCTUATIONS IN THE EDGE PLASMA OF ASDEX

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Introduction

Density fluctuations in the edge plasma of tokamaks in the frequency range up to a few 100 kHz have been reported for many years. A review of the earlier papers can be found in ref 1. The fluctuations are easily observed with Langmuir probes and are also visible in the H_α emission at locations with sufficient neutral gas density. High speed cine films taken on ASDEX[2] show fluctuating stripes aligned approximately parallel to the magnetic field. It has been shown that these fluctuations, which are electrostatic, cause a major part if not all of the particle transport at the plasma edge[3]. The mechanism driving these instabilities is however not yet clear.

Langmuir probe measurements and optical observations were performed on ASDEX and a comparison was made with magnetic fluctuation measurements in order to further clarify the mechanism responsible for the edge turbulence.

Radial profiles

Fig. 1 shows radial profiles of characteristic parameters in the boundary layer on the midplane outside the separatrix. They were evaluated from a radial scan of a quadruple Langmuir probe with two pins working in the ion saturation mode and two pins measuring the floating potential. All pins were located at the same radius and were arranged at the corners of a square of 2×2 mm^2. The signals were digitized with a sampling frequency of 1 MHz during an interval of 20 ms and analyzed numerically. T_e-values were taken from probe measurements with voltage sweep performed in other similar discharges. The ohmic discharges were run in deuterium at $n_e = 4.5 \cdot 10^{19}$ m^{-3}, $B_t(0) = 1.86$ Tesla and $I_p = 460$ kA resulting in $q_{cyl} = 1.96$. Assuming cross-field transport due to the E×B-drift induced by the fluctuating electric field and fluctuating density one calculates the particle flux density

$$\Gamma = \langle \tilde{n} \cdot \tilde{v} \rangle = \langle \tilde{n} \cdot \tilde{E} \times B / B^2 \rangle$$

We approximate the radial component of this expression by

$$\Gamma = \int \frac{1}{4\pi B} \, |P_{n\Phi}| \cdot \sin\alpha \cdot k(\omega) \, d\omega$$

where $P_{n\Phi}$ is the cross-power spectral density between density and potential fluctuations, α is the phase difference between density and potential fluctuations and k is the average wave number. All terms are functions of the frequency ω. Because the turbulence is strong, we have a spectrum of k-values for each value of ω which might extend from positive to negative wave numbers. In agreement with common practice k is determined from the the phase difference between the potential fluctuations measured with two different pins. This approximation may break down if the k-spectrum becomes very broad or has even two maxima at k-values with opposite sign

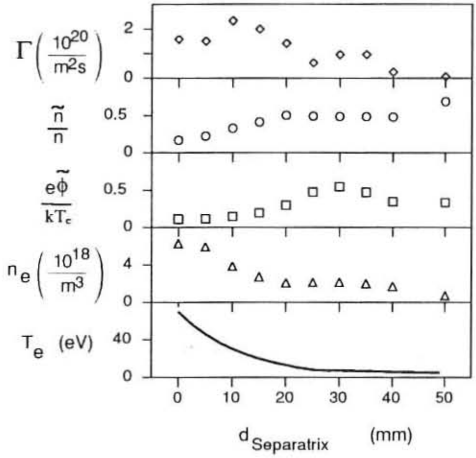

Fig.1. Radial profile of plasma parameters and fluctuation amplitudes. Top: particle flux calculated from fluctuation amplitudes.

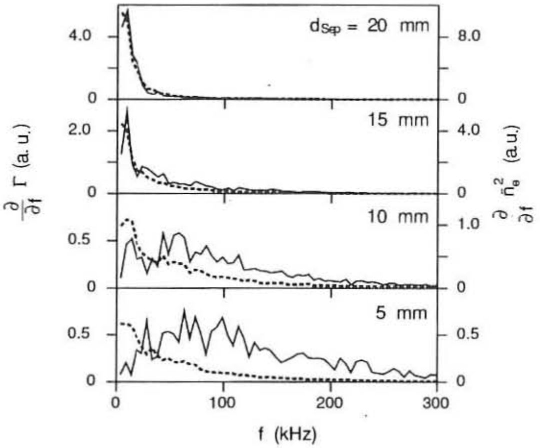

Fig. 2. Power spectra of the density fluctuations (dashed) and spectral contribution to the particle flux at various distances from separatrix.

(standing waves). The particle flux determined by this method is plotted at the top of Fig. 1. Its maximum agrees roughly with the value which is estimated assuming uniformity over the surface and a particle confinement time equal to half of the energy confinement time. The non-monotonic decay with distance from the separatrix is unexpected. It might be explained by problems with the approximation explained above or with a slight toroidal asymmetry of the configuration causing magnetic islands.

The power spectrum of the density fluctuations and the integrand in the formula for the particle flux are shown in Fig. 2 for different distances from the separatrix. For a distance of 2 cm or larger (not shown here) the spectra are restricted to frequencies below about 20 kHz and the different frequencies contribute to the transport corresponding to the fluctuation amplitude. Closer to the separatrix the fluctuation spectrum extends to higher frequencies, but the maximum remains at low frequencies. The maximum contribution to the transport in this zone comes from higher frequencies. Very low frequencies do not contribute substantially to the transport despite their high amplitude. It is not yet clear whether this change indicates the existence of two different modes or is merely caused by the strong variation of the plasma parameters and of the magnetic shear in the vicinity of the separatrix.

Close to the separatrix one observes an abrupt change of the sign of k, i.e. of the average propagation velocity of the fluctuations. Further outside the fluctuations propagate in the diamagnetic ion drift direction. With increasing distance from the separatrix the propagation velocity decreases. The observations are consistent with the assumption that the propagation corresponds essentially to a plasma rotation due to the radial electric field. A propagation with the electron diamagnetic drift velocity relative to the moving plasma may be superimposed[4].

Correlation parallel and perpendicular to the magnetic field

Langmuir probes and optical observations were used to determine the correlation of the fluctuations in the directions parallel and perpendicular to the magnetic field. Optical observations were performed in the vicinity of a gas puffing valve to get sufficient H_α-light. Optical fibres connected to photomultipliers were imaged on the surface of the discharge. This method averages over the edge plasma in radial direction but permits qualitative measurements in a very flexible way.

Good correlation has been found along the magnetic field between the midplane and the divertor over a distance of about 12 m. Two probes each with two tips operating in the ion saturation mode were positioned on the same flux surface, one on the midplane and one in the upper divertor chamber. The toroidal field was varied in tiny steps until correlation between both probes was found. Field calculations with the Gourdon-code were used to determine the starting conditions. Fig.3 shows the results. The column on the left shows coherence spectra between two different signals (dashed, left scale), and the phase difference. The column on the right displays the equivalent cross-correlation functions. The first row shows coherence γ, phase angle α and cross–correlation function φ between the two tips in the divertor. Below the same functions between the two tips on the midplane are shown. In both cases the tips are positioned with a small distance perpendicular to the toroidal field. For this reason the phase shift is not zero, but increases with

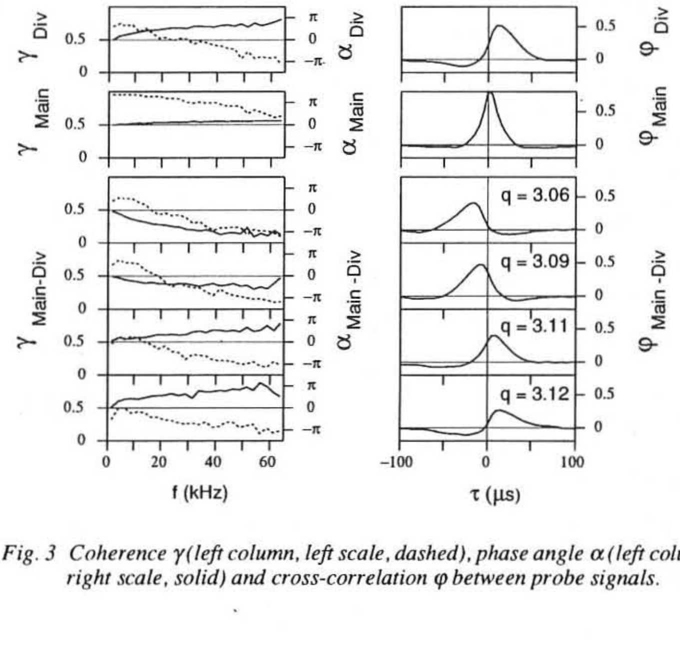

Fig. 3 Coherence γ(left column, left scale, dashed), phase angle α (left column, right scale, solid) and cross-correlation φ between probe signals.

the frequency, and the coherence decreases. The four rows at the bottom show correlations between one divertor tip and one tip on the midplane at different values of q_{cyl} indicated at the right. Maximum coherence and no phase shift (no delay) are observed between $q_{cyl} = 3.09$ and 3.11. Within the accuracy of the measurement of currents the same field line passes through both probes under these conditions. A very small angle of propagation, as expected for drift waves, cannot be excluded because of the limited accuracy of the q-measurement. The phase plots in Fig. 3 indicate however that the fluctuations propagate exactly in the same direction, as we would not observe a simultaneous change of the sign of the phase for all frequencies at the same q-value. This appears to be extremely unlikely if the line of constant phase would not coincide with the field line.

The picture of good correlation along the field lines is confirmed by the observation that the profiles of $\tilde{n}/n$ are similar in the divertor and on the midplane.

The four rows at the bottom of Fig. 3 look very similar to measurements performed in the same poloidal plane with different probes or optical channels. While the fluctuations are extremely well correlated along the magnetic field lines the peak value of the cross-correlation function decreases to less than half of the maximum over a poloidal distance of 1.5 cm.

Parameter studies

Systematic parameter studies have been performed with the optical method only. The evaluations are still on the way. Up to now the following facts can be stated.

- The poloidal propagation velocity determined from the delay of the correlation maximum over a fixed distance d varies with $d^{-0.5}$.
- The poloidal propagation velocity scales like $I_p/(n_e \cdot B_t^{2.5})$.
- The edge frequency of the power spectrum decreases strongly with increasing toroidal field.
- The fluctuations are detected only on the low field side of the torus during double null discharges. During single null discharges the fluctuations are also observed on the high field side. We conclude that the origin of the fluctuations is on the low field side. In single null discharges they can propagate along the magnetic field to the high field side.

Discussion

A comparison with magnetic fluctuation measurements indicates, that close to the separatrix the magnetic fluctuations originate from the same mechanism as the electrostatic fluctuations described above. The transport estimated from the magnetic fluctuations[5] is by far smaller than that induced by electric field fluctuations. One should therefore concentrate on electrostatic modes to explain the transport in the plasma edge. In the past it has not been sufficiently taken into account that the field lines outside the separatrix or the limiter edge are not closed. This fact might suppress drift modes and permit MHD instabilities of the flute type because line tying is not perfect. With probes one observes a sheath potential at the target plates which increases the sheath resistivity substantially so that the pressure gradient can drive instabilities in the region of unfavourable curvature. All the observations described above agree with the assumption of flute modes. More work is however necessary to confirm this picture.

References

1 P. C. Liewer, Nucl. Fusion 25, 543 (1985)
2 H. Niedermeyer, IPP Annual Report 1981, p. 10
3 W. L .Rowan, C. C. Klepper, Ch. P. Ritz et al, Nucl. Fusion 27, 1105 (1987)
4 Ch. P. Ritz, R. D. Bengtson, S. J. Levinson, and E. J. Powers, Physics Fluids 27, 2956 (1984)
5 A. B. Rechester and M. N .Rosenbluth, Phys. Rev. Letters 40, 38 (1978)