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Large scale inter-ELM fluctuations in the pedestal and the density limit in ASDEX Upgrade

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Introduction

In H mode plasmas in-between type-I edge localised modes (ELMs) [1] large scale fluctuations of the electron density and temperature were found recently in the pedestal of ASDEX Upgrade [2]. They appear in 2D poloidal snapshots of the electron density and temperature, measured by Thomson scattering, as 'blobs' and 'dips'. For the type of plasma investigated in [2] the typical relative fluctuation amplitude of the electron density was around 21%.

In this paper a set of type-I ELMy H mode plasmas with parameters covering a broad range are analysed: It is found that the relative fluctuation amplitudes in the pedestal increase with the plasma density normalised to the Greenwald density n_{GW} [3]. There are experimental hints that the perpendicular transport of particles and heat in the pedestal increases with rising relative fluctuation amplitudes of electron density and temperature. This is similar to the findings on Alcator C-Mod, where increased convective transport in the scrape-off layer was found for ohmic L mode plasmas when approaching the density limit [4].

Experimental Setup

The vertical Thomson scattering diagnostic [5] consists of a bundle of up to six vertically launched, radially staggered Nd-YAG laser beams. The scattered light is observed from the low-field side in 16 spatial channels. The whole system was shifted radially to measure low field side edge electron density and temperature profiles (Fig. 1).

The Thomson scattering data are compared to the signals of other diagnostics: The line-averaged electron density at the plasma edge including the pedestal shoulder, $\langle n_e \rangle_{H5}$, is measured by the DCN interferometer-signal H5. The neutral particle flux at the outer midplane, f_{mpl}, is measured by the ionisation gauge F14. These diagnostics are all located at different toroidal positions.

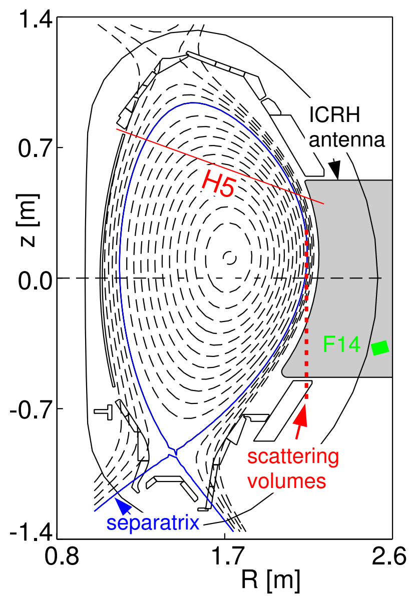

Figure 1: *Poloidal cross section.*

Results

H mode plasmas from 49 discharges heated by neutral beam co-injection (NBI) and ion cyclotron resonance heating (ICRH) with powers between $2.5\ MW \leq P_{NBI} + P_{ICRH} \leq 16\ MW$, with upper and lower triangularities of $-0.07 \leq \delta_u \leq 0.50, 0.31 \leq \delta_l \leq 0.55$, elongations $1.34 \leq \kappa \leq 1.84$, line averaged electron densities, $4.6 \leq \bar{n}_e\ [10^{19} m^{-3}] \leq 9.3$, toroidal magnetic fields $-3\ T \leq B_t \leq -1.9\ T$ and plasma currents $I_{pl}[MA] \in \{0.8, 1.0\}$ were investigated.

The probability distribution functions (PDFs) of the large scale fluctuations in the poloidally averaged radial profiles of electron density and temperature in-between ELMs were investigated in [2]: in the middle of the steep gradient region the PDFs are symmetric and asymmetric both further inwards (more minima), and further outwards (more maxima). To compare the amplitudes of the large scale fluctuations for different discharge parameters the variance of the normalised electron density, $Var(n_e/\langle n_e \rangle)$, with $\langle n_e \rangle$ as the mean value over the time interval of the evaluation, was determined at the radial position in the steep gradient region where its PDF is symmetric.

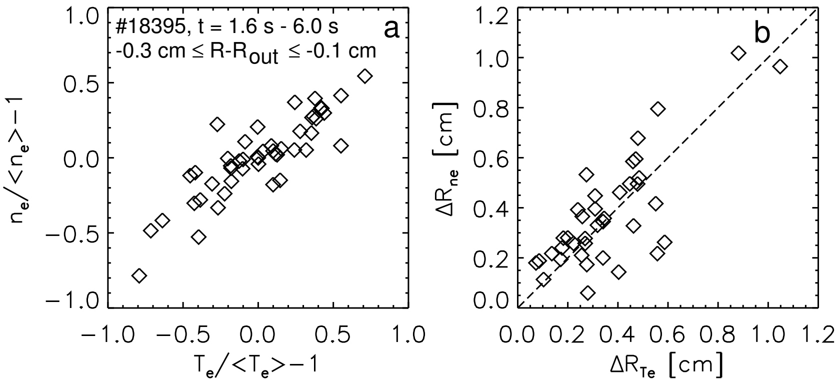

Figure 2: *The large scale fluctuations of n_e and T_e are correlated in amplitude (a) and have the same radial shifts (b).*

The large scale fluctuations of electron density and temperature are in phase, which is seen when plotting the relative fluctuations of electron density versus those of the electron temperature for one discharge (fig. 2a). The relative amplitudes of the electron temperature fluctuations are larger than for the

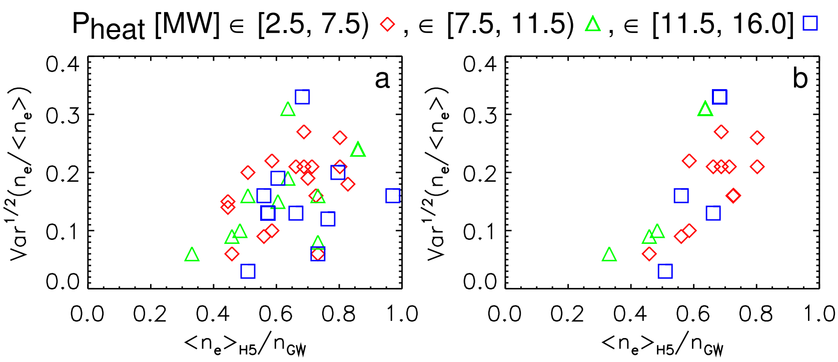

Figure 3: *Relative amplitudes of the large scale fluctuations versus normalised edge density for $I_{pl}[MA] \in \{0.8, 1.0\}$ (a), and $I_{pl} = 1.0\ MA$ (b), and different total heating powers P_{heat}.*

electron density (fig. 2a). This correlates with the usual finding that the gradient length of the electron temperature, l_{Te}, is smaller than for the electron density, l_{ne}. The effective radial shifts of the electron density fluctuations, $\Delta R_{ne} = 2\ Var^{1/2}(n_e/\langle n_e\rangle)\ l_{ne}$, are correlated with the analogously defined radial shifts ΔR_{T_e} of the electron temperature fluctuations and both are of the same size (fig. 2b). These radial shifts have the same size as the radial widths of the fluctuations in electron density and temperature, seen in the 2D poloidal snapshots [2]. These fluctuations apparently move macroscopic plasma volumes radially with respect to their positions in the unperturbed profile.

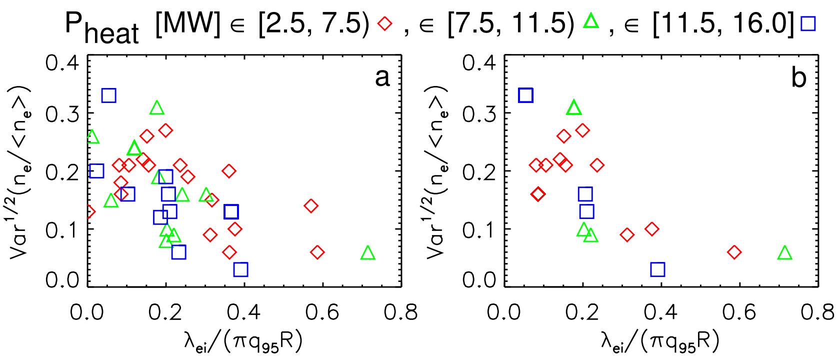

Figure 4: $Var^{1/2}(n_e\langle n_e\rangle)$ *versus* $\lambda_{ei}/(\pi q_{95}R)$ *for* $I_{pl}[MA] \in \{0.8, 1.0\}$ *(a), and* $I_{pl} = 1.0\ MA$ *(b) and different* P_{heat}.

The relative amplitudes of the large scale fluctuations increase with the line-averaged edge density $\langle n_e\rangle_{H5}$, normalised to the Greenwald density [3] $n_{GW} = I_{pl}/(\pi a^2)$ with $a = 0.5\ m$ as the minor radius of the ASDEX Upgrade plasma (fig. 3a). For a single plasma current and thus a single Greenwald density a near linear increase of $Var^{0.5}(n_e/\langle n_e\rangle)$ with the normalised density $\langle n_e\rangle_{H5}/n_{GW}$ is found (fig. 3b), especially for low total heating powers P_{heat}.

A decrease of the relative fluctuation amplitudes of the electron density in the pedestal is found with increasing local electron-ion mean free path, $\lambda_{ei} \sim T_e^2/n_e$, over connection length, $\pi q_{95}R$, between the inboard and outboard midplane (fig. 4).

In general heat is transported by radiation, conduction and convection. For investigating the influence of the large scale fluctuations on the perpendicular heat-flux, however, here a simplified ansatz is used by estimating an effective perpendicular heat diffusivity $\chi_\perp$ in the pedestal from $P_{heat} - P_{rad} = A\ n_e\ \chi_\perp dT_e/dR$ with P_{heat} as the total heating power, P_{rad} as the power lost by radiation, and n_e and dT_e/dR of the background profiles, averaged over the large scale fluctuations. The local heat flux is assumed to extent over an area of $A \approx 10\ m^2$ of the plasma surface on the low field side. With increasing electron temperature the perpendicular heat diffusivity $\chi_\perp$ decreases, which is opposite to Bohm diffusivity, $\chi_B = T_e/(16eB_t)$ (fig. 5a). The relative amplitudes of the electron density fluctuations decrease also with rising T_e (fig. 5b). Thus the perpendicular heat diffusivity increases slightly with the electron density fluctuations (fig. 5c), indicating that already on the closed magnetic surfaces in the pedestal the fluctuations contribute to the perpendicular heat transport.

A clear increase of the neutral particle flux in the outer midplane, f_{mpl}, with relative amplitudes of the fluctuations of the electron density, $Var^{1/2}(n_e/\langle n_e\rangle)$, is found (fig. 5d). The number of data points here is smaller than in the previous plots, because f_{mpl} is not available for each investigated discharge.

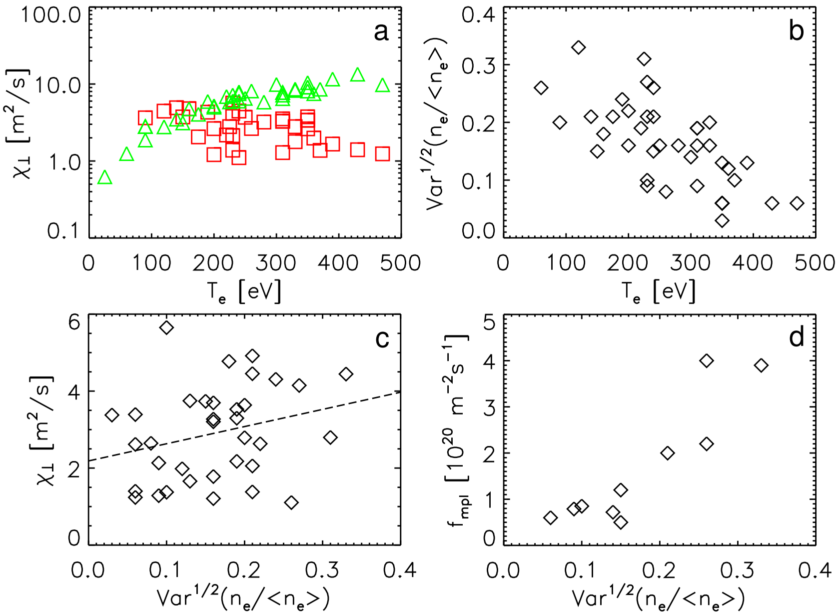

Figure 5: $\chi_\perp$ *(red squares) decreases with* T_e*, which is opposite to* χ_B *(green triangles) (a).* $Var^{1/2}(n_e/\langle n_e\rangle)$ *decreases with increasing* T_e *(b).* $\chi_\perp$ *increases slightly with* $Var^{1/2}(n_e/\langle n_e\rangle$ *as shown by a fit to the data (c).* f_{mpl} *increases with* $Var^{1/2}(n_e/\langle n_e\rangle)$ *(d).*

Discussion

It is now tried to interpret the experimental findings: Since the fluctuation amplitudes of electron density and temperature in the pedestal are correlated (fig. 2a) and the radial shifts ΔR_{ne} and ΔR_{Te} of these fluctuations are the same (fig. 2b), the fluctuations can be seen as macroscopic volumes confining plasmas of either higher, or lower electron density and temperature, than the background plasma, as was already found in [2]. The perpendicular heat diffusivity and particle transport increase with the amplitudes of these large scale fluctuations (fig. 5) acting as convection cells. The amplitudes of these fluctuations increase with increasing density normalised to the Greenwald density (fig. 3), with decreasing temperature (fig. 5b), or with decreasing mean free path over connection length (fig. 4), i. e. with increasing collisionality.

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