Scale lengths of inter-ELM fluctuations in the pedestal of ASDEX Upgrade

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Introduction

In H mode plasmas in-between type-I edge localized modes (ELMs) [1] large scale fluctuations of 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 (TS), as ‘blobs’ and ‘dips’. In this paper a set of type-I ELMy H mode plasmas with parameters covering a broad range are analysed to find scalings for the observed fluctuations. Additionally the heat transport is investigated by analysing the electron heat diffusivity in the pedestal.

Experimental Setup

The vertical TS diagnostic consists of a bundle of up to six vertically launched, radially staggered Nd-YAG laser beams. The whole system was shifted radially to measure low field side edge electron density and temperature profiles with 10 spatial channels (Fig. 1). The TS data are compared to the line-averaged electron density, $\langle n_e \rangle_{H1}$, with an integration path including the plasma core, $\langle n_e \rangle_{H1}$, which is measured by the DCN-interferometer. Both diagnostics are located at different toroidal positions.

Results

H mode plasmas from 49 discharges heated by neutral beam co-injection (NBI) and ion cyclotron resonance heating (ICRH) with powers between $2.5 \text{ MW} \leq P_{\text{NBI}} + P_{\text{ICRH}} \leq 16 \text{ MW}$, 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, $4.6 \leq \bar{n}_e \ [10^{19} \text{ m}^{-3}] \leq 9.3$, toroidal magnetic fields $-3 \ T \leq B_t \leq -1.9 \ T$ and plasma currents $I_{\text{pl}} [\text{MA}] \in \{0.8, 1.0\}$ were investigated [3].

The probability distribution functions (PDFs) of the large scale fluctuations in the poloidally averaged radial profiles of electron density and temperature in-between ELMs are symmetric.
in the middle of the steep gradient region and asymmetric both further inwards (more minima),
and further outwards (more maxima) [2]. To compare the amplitudes of the large scale fluctuations for
different discharge parameters the variances for the symmetric PDFs of the normalized electron density,
$Var\left(\frac{n_e}{\langle n_e \rangle}\right)$, with $\langle n_e \rangle$ as the mean value over the time interval of
evaluation, are determined. For estimating the radial positions of the symmetric histograms relative
to the separatrix with high accuracy the radial position of the separatrix at the outer midplane, $R_{out,100}$, where the
electron temperature, measured by TS, is around 100 eV, is used [4]. The radial positions $R_{sym} - R_{out,100}$
of the symmetric histograms are localized where the local electron density, averaged in
the poloidal direction and in time, normalized to the line integral is $\langle n_e \rangle / \langle n_e \rangle_{H1} > 0.3$ (fig. 2a).
They correlate best with the smallest gradient scale lengths of the pedestal, e. g. with the gradient
scale lengths of electron pressure $l_{pe}$, and temperature $l_{Te}$, but less good with the larger
gradient scale length of the electron density $l_{ne}$ (fig. 2b-d). Note that the corresponding values
of $\eta_e = l_{ne}/l_{Te}$ vary between $1.3 \leq \eta_e \leq 2.5$.

The fluctuations of electron density and temperature are highly correlated [3]. The data set of
the electron density and temperature fluctuations includes plasmas of quite different heating
powers, plasma shapes and magnetic fields. A strong correlation is, however, already found with
the electron density: The relative

Figure 2: The radial positions $R_{sym} - R_{out,100}$ of the symmetric histograms are localized where $\langle n_e \rangle / \langle n_e \rangle_{H1} > 0.3$
and correlate best with the pressure gradient length $l_{pe}$.

Figure 3: Variances of the electron density and temperature fluctuations versus the line density $\langle n_e \rangle_{H1}$.
fluctuation amplitudes of the electron density and temperature rise with the line averaged electron density $\langle n_e \rangle_{H1}$ (fig 3).

Based on simulations of drift wave turbulence the radial diameters of the fluctuating structures in the electron density can be estimated by $\Delta R_{ne} = 2 \text{Var}^{1/2}(n_e/\langle n_e \rangle)_{ne}$ [3]. In drift Alfvén turbulence different phenomena act on different scale lengths, which are resolved in the simulations: the ion sound gyro-radius $\rho_s$, the collisional limit of drift waves $\Delta_d = C^{1/2} \rho_s$, the scale length of resistive ballooning $L_0 = 2 \pi C^{1/2} \omega_B^{1/4} \rho_s$ and the collisionless skin depth $\sigma_0 = (\hat{\mu}/\hat{\beta})^{1/2} \rho_s$, with $C$ as the drift wave collisionality, $\omega_B$ the magnetic curvature parameter, $\hat{\beta}$ the drift Alfvén parameter, and $\hat{\mu}$ as the normalized mass ratio [5].

The measured radial diameters of the electron density fluctuations, $\Delta R_{ne}$ correlate already quite well with the scale length of the collisional limit of drift waves (fig. 4a) and with the scale length of resistive ballooning, $L_0$ (fig. 4b), but not with the collisionless skin depth $\sigma_0$ (fig. 4c). Especially for the larger values of $\Delta R_{ne}/\rho_s$ an even better correlation is obtained with the empirically constructed scale length $\Delta_h = \hat{\beta}^{1/2} C^{1/2} \omega_B^{1/4} \rho_s$, which is a hybrid scale length between ideal and resistive MHD (fig. 4d). The ideal MHD part, $\hat{\beta}^{1/2} \omega_B^{1/4}$, tends to enlarge the spatial diameters of the fluctuating structures [5].

In the following it is assumed that mainly the electron heat conductivity determines the heat transport in the pedestal. The perpendicular electron heat conductivity $\chi_{\perp}$ can then be estimated from the perpendicular heat flux $P_{\text{heat}} - P_{\text{rad}} = \lambda \langle n_e \rangle \chi_{\perp} d\langle T_e \rangle/dR$, with $P_{\text{heat}}$ as the total applied heating power and $P_{\text{rad}}$ as the power lost by radiation as determined from bolometry. The local electron density $\langle n_e \rangle$ and electron temperature gradient $d\langle T_e \rangle/dR$ are taken from the poloidally and time averaged background profiles containing the large scale fluctuations and which are measured by Thomson scattering. It is also assumed that the heat flux extends mainly over an area of $A \approx 10 \, m^2$ on the low field side of the plasma. For iden-
tifying the spatial scales of the electron heat diffusion, the electron heat diffusivity $\chi_e$ normalized to the usually used Gyro-Bohm diffusivity $D_{GB}$ is used here. Good ordering of the normalized electron heat diffusivities $\chi_e/D_{GB}$ is found for the scale length of the collisional limit of drift waves $\Delta_d$ (fig. 5a) and for the scale length of resistive ballooning $L_0$ (fig 5b). This was also found in theoretical simulations: the energy transport scales in the same way for both the collisional limit of drift waves and resistive ballooning turbulence [6]. There is increasing scatter of the normalized heat conductivity towards the smaller values of the scale lengths in figures 5a, b. When plotting the normalized electron heat diffusivity versus the collisionless skin depth $\sigma_0$ a quite good correlation is found also for the small collisionless skin depths $\sigma_0 < \rho_S$. Only a very small correlation is found between the normalized heat diffusivity and the hybrid scale $\Delta_h$, which is the scale length of the electron density and temperature fluctuations.

**Summary and Conclusion**

While the dynamics of ideal and resistive MHD are found experimentally in the scale lengths of the electron density and temperature fluctuations, the heat transport by the electrons takes place on smaller scales down to the collisionless skin depth $\sigma_0$.

**References**


