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 $2.5\ MW \leq P_{NBI} + P_{ICRH} \leq 16\ MW$, with upper and lower triangularities of $-0.07 \leq \ _u \leq 0.50, 0.31 \leq \ _l \leq 0.55$, elongations $1.34 \leq \ \ \leq 1.84$, 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 [3].

Figure 1: *Poloidal cross section.*

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
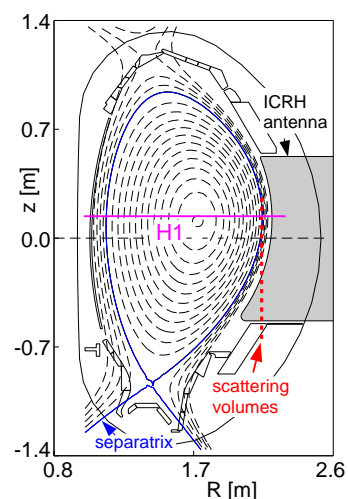
in the middle of the steep gradient region and asymmetric both further inwards (more minima),

and further outwards (more max-
ima) [2]. To compare the am-
plitudes of the large scale fluc-
tuations for different discharge
parameters the variances for the
symmetric PDFs of the nor-
malized electron density, $Var($
$n_e/\langle n_e\rangle)$, 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 rela-
tive to the separatrix with high
accuracy the radial position of
the separatrix at the outer mid-
plane, $R_{out,100}$, where the elec-

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}.*

tron 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 $_e = l_{ne}/l_{Te}$ vary between $1.3 \leq _e \leq 2.5$.

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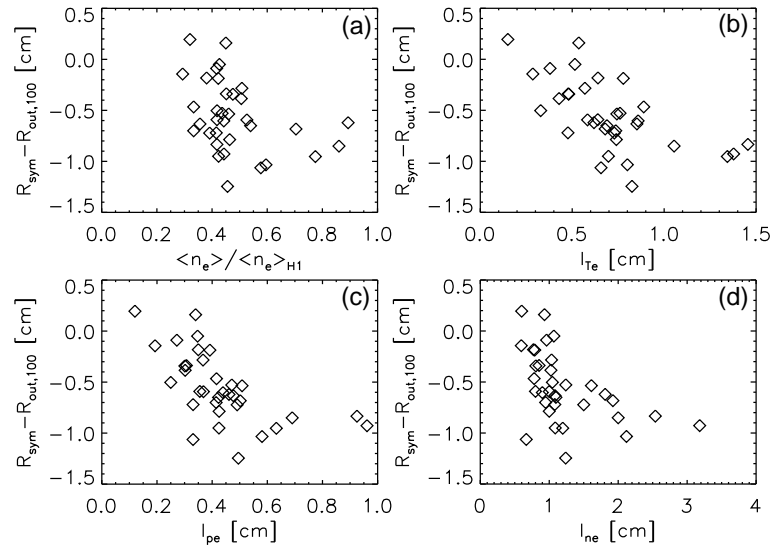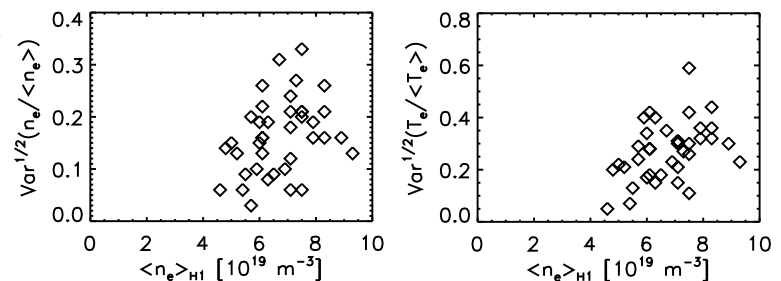the electron density: The relative

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 $\Delta R_{ne} = 2 Var^{1/2}(n_e/\langle n_e \rangle) l_{ne}$ [3]. In drift Alfvén turbulence different phenomena act on different scale lengths, which are resolved in the simulations: the ion sound gyro-radius ρ_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 $\delta_0 = (\hat{\mu}/\hat{\beta})^{1/2} \rho_S$, with C as the drift wave collisionality, ω_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, ΔR_{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 δ_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 $\Delta_h = \hat{\mu}^{1/2} C^{1/2} \omega_B^{1/2} \rho_S$, which is a hybrid scale length between ideal

Figure 4: *Plot of the measured radial diameters ΔR_{ne} versus typical scale lengths of the underlying turbulence.*

and resistive MHD (fig. 4d). The ideal MHD part, $\hat{\mu}^{1/2} \omega_B^{1/4}$, 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 $P_{heat} - P_{rad} = A \langle n_e \rangle \chi_\perp d\langle T_e \rangle/dR$, with P_{heat} as the total applied heating power and P_{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 scatttering. 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-
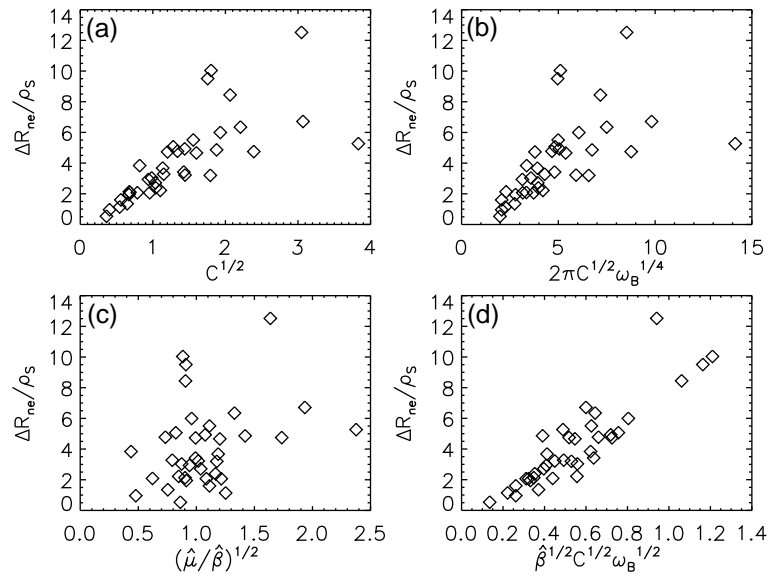
tifying the spatial scales of the electron heat diffusion, the electron heat diffusivity χ_e normalized to the usually used Gyro-Bohm diffusivity D_{GB} is used here. Good ordering of the normalized electron heat diffusivities χ_e/D_{GB} is found for the scale length of the collisional limit of drift waves Δ_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 σ_0 a quite good correlation is found also for the small collisionless skin d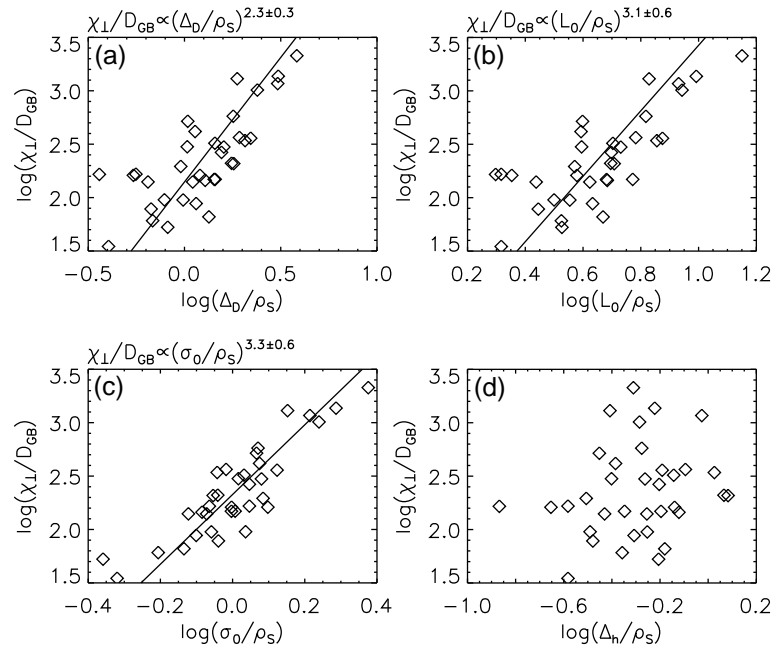epths $\sigma_0 < \rho_s$. Only a very small correlation is found between the normalized heat diffusivity and the hybrid scale Δ_h, which is the scale length of the electron density and temperature fluctuations.

Figure 5: *Plot of the measured electron heat diffusivities χ_e versus typical scale lengths of the underlying turbulence.*

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 σ_0.

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