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The Contribution of Edge Fluctuations to Anomalous Transport in W7-AS

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1 Anomalous and fluctuation-induced transport

The radial particle and energy fluxes Γ_r and Q_r induced by correlated fluctuations of plasma density, temperature and poloidal electric field ("electrostatic fluctuations") in the edge plasma of toroidal confinement devices have been considered as a significant contribution to or even the main cause of the anomalous transport derived from radial density and temperature profiles. This idea has been confirmed, at least for the particle transport in most devices, by direct comparison of the radial particle flux across the last closed magnetic surface (LCMS), calculated from fluctuations of the ion saturation current $\tilde{I}_{sat}$ and the poloidal gradient of the floating potential $\tilde{\Phi}_{fl}$, with the global particle confinement time [1] or with anomalous diffusion coefficients derived from the radial profiles in an edge transport model [2]. In most cases, the comparison was done only for some standard discharge type, whereas on the TEXT tokamak the comparison was done also for variations of the discharge conditions, showing good agreement between global particle confinement time and confinement time derived from the fluctuation-induced particle flux across the LCMS, not only in magnitude but also in the changes when plasma density was varied [3].

An uncertainty is introduced into these experiments by the fact that local measurements of the radial flux had to be extrapolated to the whole flux surface to compare with global confinement times.

Since only few attempts have been made so far to measure (electron) temperature fluctuations simultaneously with $\tilde{I}_{sat}$ and $\tilde{\Phi}_{fl}$, an additional uncertainty is due to the neglect of T_e fluctuations when calculating density and plasma potential (Φ_{pl}) fluctuations from I_{sat} and Φ_{fl}. For the same reason, estimates of the radial energy transport due to electrostatic fluctuations could only be obtained making reasonable assumptions about the behaviour of $\tilde{T}_e$. Depending on the device, it was concluded that electrostatic fluctuations, respectively, could also or could not completely account for the anomalous energy transport in the plasma edge.

2 The situation on W7-AS

Whereas it is easier to measure the fluctuation-induced particle rather than energy transport, it is in contrast well known to be simpler to determine the energy confinement time, τ_E, than the particle confinement time, τ_p. While the latter may be possible in a tokamak, supposed to be toroidally symmetric, as was demonstrated in [3], it could not be achieved in a three-dimensional configuration like W7-AS. On the other hand there exist

Langmuir probe measurements in the SOL of W7-AS where the probe characteristic was swept fast (1–4 MHz) compared with typical fluctuation frequencies [4]. The conclusion of that work was that in the one type of discharge investigated ($\iota \approx 0.34$, $B = 2.5\,\mathrm{T}$, $\bar{n}_e = 1\text{–}2 \cdot 10^{19}\,\mathrm{m}^{-3}$, ECRH heating with $P = 450\,\mathrm{kW}$), the relative electron temperature amplitude was slightly lower than that of density fluctuations, that density and temperature fluctuations were almost in phase and that therefore the fluctuation-induced energy flux was approximately

$$Q_r \sim \frac{3}{2} k_B T \cdot 2 \cdot 1.5\,\Gamma_r, \tag{1}$$

the factor of 2 originating from the assumption of equal energy flux in the electron and ion channels, while the factor 1.5 arises when first correcting Γ_r for the error using I_{sat} and Φ_{fl} instead of n and Φ_{pl} fluctuations and then adding together the convective ($\langle \tilde{n} \tilde{v}_r \rangle \bar{T}$) and conductive ($\langle \tilde{T} \tilde{v}_r \rangle \bar{n}$) contributions to the energy transport.

3 Comparison between global and fluctuation-induced confinement times

Although the fast swept Langmuir probe technique could not be used in the discharges reported in this paper, we shall use eq. (1) to transform our particle transport data into energy fluxes which are then compared with the global energy confinement time.

We obtain the global energy confinement time $\tau_{E,\ global}$ from heating power P_{heat} and diamagnetic energy W_{dia} after correcting for radiation losses P_{bolo}, as the fluctuations do not have to remove that fraction of power from the plasma which already has been radiated:

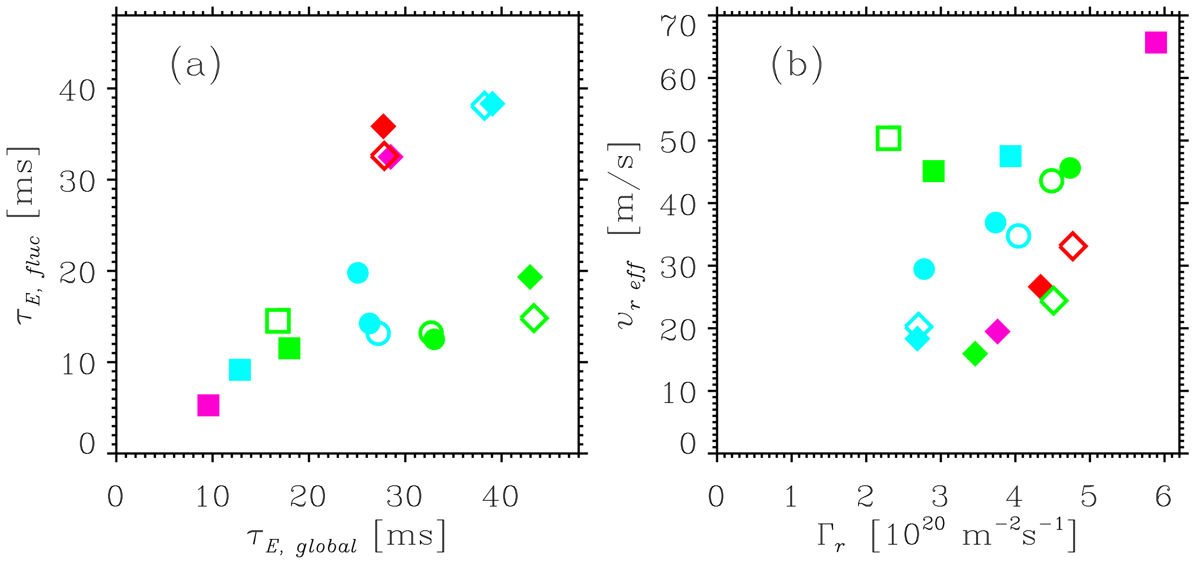
$$\tau_{E,\ global} = \frac{W_{dia}}{P_{heat} - P_{bolo}}$$

For the I_{sat} and Φ_{fl} fluctuation measurements, a poloidal array of 19 Langmuir probes with 2 mm probe separation was used, and the radial flux was averaged over the positions of several I_{sat} tips and over time windows of 8–12 ms during the radial reciprocation of the probe. The most critical task is the determination of the radial position of the LCMS since, in the presence of steep gradients of density, temperature and also of the radial flux, an error of a few mm would render the comparison between different discharges impossible. We use several indicators like the position of the vacuum LCMS and the location of the velocity shear layer of the fluctuations to determine this position in a consistent way between different discharges. We then calculate

$$\tau_{E,\ fluc} = \frac{W_{dia}}{Q_r A_{LCMS}}$$

where Q_r is taken from eq. (1), and A_{LCMS} is the surface area of the LCMS.

The comparison between $\tau_{E,\ global}$ and $\tau_{E,\ fluc}$ is shown in fig. (a) for a series of discharges with different plasma density and heating power. The order of magnitude of the energy confinement times calculated in the two different ways is in good agreement. The general tendency of increasing global energy confinement time with increasing plasma density is reproduced by $\tau_{E,\ fluc}$ as well. For the medium and high density discharges at low heating power, however, the fluctuation-induced transport is larger ($\tau_{E,\ fluc}$ is smaller) than expected from the global confinement, whereas for the other discharges, at fixed density, the confinement degradation with increasing heating power is again reproduced by $\tau_{E,\ fluc}$.



(a) Comparison between global energy confinement time $\tau_{E,\, global}$ and energy confinement time derived from the fluctuation-induced transport across the LCMS. Different symbols are for different line-averaged density — squares: $1.7 \cdot 10^{19}\,\mathrm{m}^{-3}$; circles: $3.4 \cdot 10^{19}\,\mathrm{m}^{-3}$; diamonds: $6.8 \cdot 10^{19}\,\mathrm{m}^{-3}$. Different colours are for different heating power — green: 180 kW, blue: 270 kW, magenta: 380 kW and red: 540 kW. Full symbols are for the inwards movement of the reciprocating probe, open symbols for the outwards movement. (b) Effective radial velocity as defined in eq. (3) versus radial particle flux; symbols are the same as in (a). Note the reduction of $v_{r\,eff}$ with increasing plasma density.

4 Decomposition of the radial flux

To determine due to which quantities changes in Γ_r occur, $\tilde{I}_{sat}$ and $\tilde{\Phi}_{fl}$ were transformed into the frequency domain. The transforms will be denoted by $I_{sat}(f)$ and $\Phi_{fl}(f)$. If $E_\theta(f)$ is the poloidal electric field in the frequency domain, $\sum_f \Gamma_r(f) = \sum_f E_\theta^*(f)\, I_{sat}(f)/B$, and the real part of $\sum_f \Gamma_r(f)$ is the time-averaged radial particle flux. We now decompose $\sum_f E_\theta^*(f)\, I_{sat}(f)$ into components,

$$\sum_f E_\theta^*(f)\, I_{sat}(f) = \bar{n} \left(\sqrt{\sum_f |I_{sat}(f)|^2 / \bar{n}} \right) \left(\sqrt{\sum_f |\Phi_{fl}(f)|^2} \right) \bar{k}\, \bar{\gamma}\, e^{i\bar{\alpha}}, \qquad (2)$$

by defining an "average poloidal wavenumber" of the Φ_{fl} fluctuations

$$\bar{k} \equiv \frac{\sqrt{\sum_f |E_\theta^*(f)|^2}}{\sqrt{\sum_f |\Phi_{fl}(f)|^2}},$$

an "average coherency" between I_{sat} and E_θ fluctuations

$$\bar{\gamma} \equiv \frac{|\sum_f E_\theta^*(f)\, I_{sat}(f)|}{\sqrt{\sum_f |E_\theta(f)|^2}\, \sqrt{\sum_f |I_{sat}(f)|^2}}$$

and an "average phase angle" between I_{sat} and E_θ fluctuations

$$\bar{\alpha} \equiv \arg \left(\sum_f E_\theta^*(f)\, I_{sat}(f) \right)$$

($\bar{n}$ is calculated from $\bar{I}_{sat}$ and $\bar{T}_e$ assuming $T_e = T_i$ and neglecting $\tilde{T}_e$).

If we compare the contributions of the individual factors on the right hand side of eq. (2) for the discharges analysed so far, no distinct parameter dependence of any one of them is found, except for $\bar{n}$, which is correlated with the line averaged density. Only the product of all these factors without $\bar{n}$ shows a clear dependence on density. The real part of this product is the "effective radial velocity" $v_{r\,eff}$ defined by

$$\Gamma_r = \langle \tilde{n}\, \tilde{v}_r \rangle \equiv \bar{n}\, v_{r\,eff}, \tag{3}$$

and it is plotted versus Γ_r in fig. (b): $v_{r\,eff}$ decreases with increasing density.

5 Conclusions

The radial particle flux due to electrostatic fluctuations across the LCMS has been used to calculate the energy confinement time $\tau_{E,\,fluc}$, assuming poloidal and toroidal symmetry and using information on the behaviour of electron temperature fluctuations obtained in earlier experiments. For the first time in a stellarator, $\tau_{E,\,fluc}$ has been compared with the global energy confinement time $\tau_{E,\,global}$ for different discharge conditions. Not only the magnitudes of $\tau_{E,\,fluc}$ and $\tau_{E,\,global}$ agree very well, also the general scaling is similar when plasma density and heating power are varied.

Changes in the radial particle flux under different discharge conditions cannot be attributed to a single one out of the factors determining the flux, like $\tilde{I}_{sat}$ amplitude, $\tilde{\Phi}_{fl}$ amplitude, poloidal scale of the fluctuations or coherency or phase angle between $\tilde{I}_{sat}$ and $\tilde{\Phi}_{fl}$, but all these factors act together.

The simultaneous measurement of $\tilde{I}_{sat}$, $\tilde{T}_e$ and $\tilde{\Phi}$ up to the LCMS and the investigation of the behaviour of $\tilde{T}_e$ for a variation of discharge conditions, as well as the influence of variations of further discharge parameters like the magnetic field or rotational transform remain open tasks.

[1] S. J. Levinson et al., Nucl. Fusion **24** (1984) 527.
A. Rudyj, PhD thesis, IPP Garching report III/160 (1990).
C. Hidalgo et al., 17th EPS vol. 14B, part III (1990) 1353.
G. Vayakis, PhD thesis, AEA Fusion Report 123 (1991).

[2] S. J. Zweben and R. W. Gould, Nucl. Fusion **25** (1985) 171.
R. A. Moyer et al., J. Nucl. Mater. **241-243** (1997) 633.

[3] W. L. Rowan et al., Nucl. Fusion **27** (1987) 1105.

[4] U. Pfeiffer et al., Contrib. Plasma Phys. **38** (1998) 134.