Study of near SOL decay lengths in AUG under attached and detached divertor conditions

H J. Sun[1], E. Wolfrum[1], B. Kurzan[1], T. Eich[1], K. Lackner[1], A. Scarabosio[1], O. Kardaun[1], M. Faitsch[1], S. Potzel[1], U. Stroth[1,2] and the ASDEX Upgrade Team

[1] *Max Planck Institute for Plasma Physics, Boltzmannstr. 2, 85748 Garching, Germany*

[2] *Physik-Department E28, Technische Universität München, 85747 Garching, Germany*

1. Introduction

A series of studies of the power flux in the divertor target regions for attached plasmas have been made using Infrared (IR) camera measurements in high confinement mode (H-mode) plasmas [1] [2] [3] [4] [5] [6] and in low confinement mode (L-mode) plasmas [7] [8]. Classical electron heat conduction relates power decay width $\lambda_{q_{\parallel e}}$ and the temperature decay width, $\lambda_{T_{e,u}}$ through the well know results $\lambda_{q_{\parallel e}} = \frac{2}{7}\lambda_{T_{e,u}}$. A Previous study of H-mode plasma under attached condition showed that this relation is consistent with the upstream Te and target IR data [9]. This has also been validated by comparing measurements from the Thomson Scattering (TS) system and IR camera for the same discharges in L-mode plasma [10]. Due to the instrumental constraints, the measurements based on IR thermography used to establish the scalings come from attached divertor discharges over a limited range of operating parameters compared to conditions expected on ITER at high performance. Direct measurements of the upstream decay lengths can provide important complementary information for understanding the SOL physics.

2. Experimental results

2.1 Simple model relates $\lambda_{q_{\parallel e}}$ and $\lambda_{T_{e,u}}$ in both confinement regimes

Previous empirical study [2] [8], based on downstream IR measurements, found that $\lambda_{q_{\parallel e}}$ in ASDEX Upgrade discharges could be well described by the following scalings:

$$\lambda_{q_{\parallel e}} = (0.78 \pm 0.69) B_T^{-0.63\pm1.05} q_{\mathrm{cyl}}^{1.14\pm0.81} P_{sol}^{-0.05\pm0.31} \text{ for H-mode attached plasma}$$

and $$\lambda_{q_{\parallel e}} = (1.45 \pm 0.13) B_T^{-0.78} q_{\mathrm{cyl}}^{1.07\pm0.07} P_{sol}^{-0.14\pm0.05} \text{ for L-mode attached plasma}$$

Here, $\lambda_{q_{\parallel e}}$ is measured in mm; B_T in Tesla; q_{cyl} is the cylindrical safety factor; and P_{sol} is measured in MW. To test the consistency between the IR and the TS measurements, the above empirical scalings can be compared with measured results. In figure 1, it can be seen that, given the uncertainties between different diagnostics, the results are consistent with classical electron conduction: $\lambda_{T_{e,u}} = \frac{7}{2}\lambda_{q_{\parallel e}}$, relating the upstream gradient length to the decay width of the power flux entering the diverted region in the conduction-limited regime.

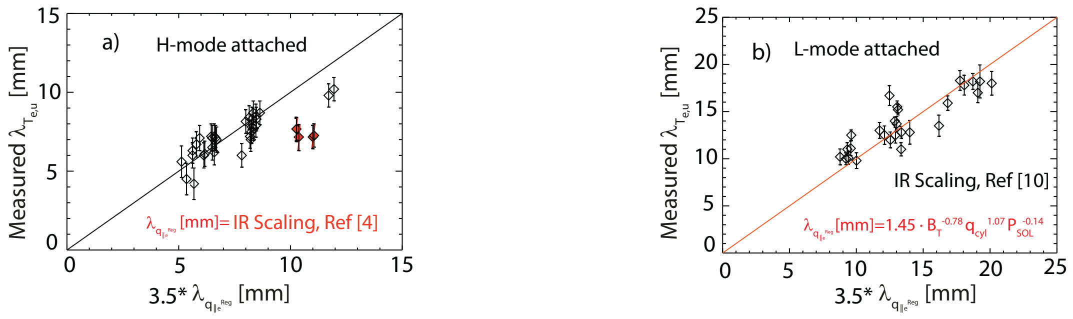

Figure 1. $\lambda_{T_{e,u}}$ from TS measurements against (a) 3.5* $\lambda_{q_{\parallel e,reg}}$scaling from downstream IR measurement for H-mode attached plasma; (b)3.5*$\lambda_{q_{\parallel e,reg}}$ scaling from IR measurements for L-mode attached plasma.

2.2 **A single scaling or separate scalings for H-mode and L-mode regimes?**

The previous study based on IR measurement and the first experimental observation from TS system shows that the dependences of $\lambda_{T_{e,u}}$ on primary parameters are similar in H and L-mode regimes. In the following analysis, it will be assumed that $\lambda_{T_{e,u}}$ have the same parametric dependencies in both H and L-mode regimes. Following previous analyses, log-linear regressions were made using the form $\lambda_{T_{e,u}} = C \cdot B_T^{C_B} \cdot q_{95}^{C_q} \cdot P_{sol}^{C_P}$. To study the degree to which H- and L-mode regimes differ, two different approaches will be taken: firstly, assuming a single scaling for both regimes, i.e. $C_H = C_{L,}$; secondly, assuming different scalings between these two regimes, i.e. $C_H \neq C_L$.

Assuming a single scaling for both regimes, a fit to the combined H-mode and L-mode attached plasma dataset gives the scaling:

$$\lambda_{T_{e,u}} = 3.32 \cdot q_{95}^{0.64\pm0.13} P_{sol}^{-0.32\pm0.05} B_T^{0.23\pm0.35}. \qquad (1)$$

The regression has a fit quality of R^2 = 0.87 (RMSE: 13%). As shown in figure 2 (a), the dataset is well represented by the scaling with no obvious systematic deviations. The dataset combining both H-mode and L-mode regimes, considerably extends the range of P_{sol}, resulting in a dependence with much smaller uncertainty. However, it should be emphasized that the B_T dependence still has a large uncertainty due to the small variation in B_T, as for the previous IR and TS based ASDEX Upgrade datasets.

Assuming different coefficient but identical parametric dependences for H- and L-mode plasmas, a log-linear regression over the combined dataset gives the following best fit scaling:

$$\lambda_{T_{e,u}} = C_{H,L} q_{95}^{0.75\pm0.12} P_{sol}^{-0.15\pm0.06} B_T^{0.11\pm0.24} \; (C_H = 2.4; C_L = 3.53) \qquad (2)$$

This regression has a fit quality of R^2 = 0.95 (RMSE: 9%). As shown in figure 2(b), the dataset is as expected somewhat better represented by this scaling.

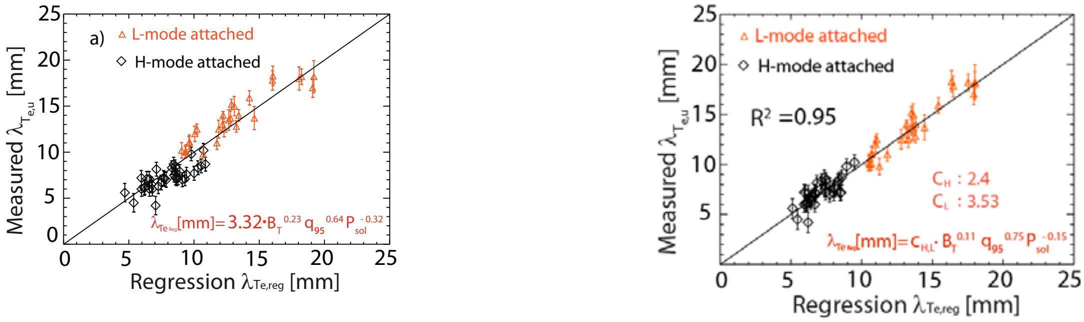

Figure 2. Measured $\lambda_{T_{e,u}}$against (a) a single scaling for both H and L-mode regimes, (b) the scaling with different coefficients both regimes.

Based on the classical Spitzer-Harm conduction, the equation below can be used to estimate the separatrix temperature, $T_{e,u}$ [2]:

$$T_{e,u} \cong \left(\frac{7}{2}\frac{(P_{sol}/A_{q_\parallel})L}{\kappa_{0e}}\right)^{2/7}. \qquad (3)$$

Here, the simplified relation $L = \pi R q_{95}$ is used to calculate the connection length and $A_{q_\parallel} = 4\pi R \lambda_q B_\theta / B_T$ is the surface area for the parallel power flux. $\lambda_{q_{\parallel e}} = \frac{2}{7}\lambda_{T_{e,u}}$ is used to calculate $A_{q_\parallel}$. Applying equation 3 to the scaling in equation 1 gives $\lambda_{T_{e,u}} \propto q_{95}^{0.95} T_{e,u}^{-0.85}$, which is close to the simple form $\lambda_{T_{e,u}} \propto q_{95} T_{e,u}^{-1}$ (black dotted line) and equation 2 gives $\lambda_{T_{e,u}} \propto C_{H,L} q_{95}^{0.91} T_{e,u}^{-0.46}$, which is close to $\lambda_{T_{e,u}} \propto C_{H,L} q_{95} T_{e,u}^{-0.5}$(blue dashed line), as illustrated in figure 3(a). However, there is no obvious correlation with $n_{e,u}$, as shown in figure 3(b). A simple relation based on power balance and Spitzer-Harm conduction is used to derive the perpendicular heat transport coefficient, $\chi_\perp \propto n_{e,u}^{-1} \lambda_{T_{e,u}}^2 q_{95}^{-2} T_{e,u}^{5/2}$. Combining this relation with $\lambda_{T_{e,u}} \propto q_{95} T_{e,u}^{-1}$, gives $\chi_\perp \propto T_e^{1/2}/n_e$, while with the expression $\lambda_{T_{e,u}} \propto C_{H,L} q_{95} T_{e,u}^{-0.5}$, gives $\chi_\perp \propto \frac{C_{H,L}^{\chi} T_e^{3/2}}{n_e}$ (C_H^χ for H-mode plasma, C_L^χ for L-mode plasma).

3. Summary

By comparing upstream temperature decay width, $\lambda_{T_{e,u}}$, with the scaling of the SOL power decay width, $\lambda_{q_{\parallel e}}$, based on the downstream IR measurements, it is found that a simple relation based on classical electron conduction can relate $\lambda_{T_{e,u}}$ and $\lambda_{q_{\parallel e}}$ well. The combined dataset can be described by both a single scaling and a separate scaling for H- and L-mode. For the single scaling, a strong inverse dependence of, $\lambda_{T_{e,u}}$ on the separatrix temperature,

$T_{e,u}$, is found, suggesting the classical parallel Spitzer-Harm conductivity as dominant mechanism controlling the SOL width in both L-mode and H-mode over a large set of plasma parameters. This dependence on $T_{e,u}$ explains why, for the same global plasma parameters, $\lambda_{q_{\parallel e}}$ in L-mode is approximately twice that in H-mode. The single scaling for both H- and L-mode, implies a common form of perpendicular heat transport coefficient, $\chi_{\perp} \propto C^{\chi}_{HL} T_e^{1/2} / n_e$ ($C^{\chi}_{HL}$for both H- and L-mode plasma). However, the possibility of the separate scalings for different regimes also exits, which gives results similar to those previously reported for the H-mode, but here the wider SOL width for L-mode plasmas is explained simply by the larger premultiplying coefficient. Using different coefficients for H- and L-mode plasmas, gives $\chi_{\perp} \propto C^{\chi}_{H,L} T_e^{3/2} / n_e$ (C^{χ}_{H} for H-mode plasma and C^{χ}_{L} for L-mode plasma). Based on the dataset of this paper, there is no significant evidence for any of the two models. Further experiments are required to give a definitive answer.

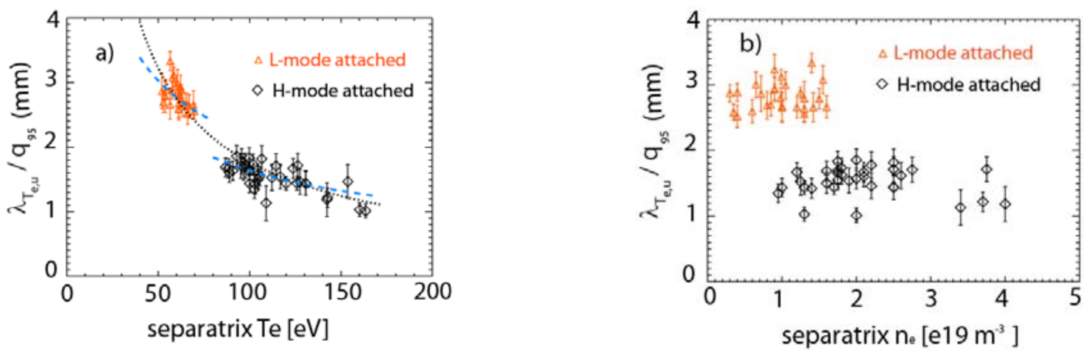

Figure 3. $\lambda_{T_{e,u}}$, normalized by q_{95} against (a) separatrix $T_{e,u}$ and (b) density $n_{e,u}$.

References

[1] T. Eich et al, *Phys. Rev. Lett.*, vol. 107, p. 215001, 2011.

[2] T. Eich et al, *J. Nucl. Mater.*, vol. 438, p. S72, 2013.

[3] M. Makowski et al, *Phys. Plasmas*, vol. 19, p. 056122, 2012.

[4] T. Gray et al, *J. Nucl. Mater.*, vol. 415, p. S360, 2011.

[5] A. J. Thornton et al, *J. Nucl. Mater.*, vol. 438, p. S360, 2011.

[6] B. La Bombard, *Phys. Plasma*, vol. 18, p. 056104, 2011.

[7] A. Scarabosio et al, *J.Nucl.Mater.*, vol. 438, p. S426, 2013.

[8] B. Sieglin, *Plasma Phys. Control. Fusion*, vol. 58, p. 055015, 2016.

[9] H. J. Sun et al, Plasma Phys. Contr. Fusion, vol. 57, p. 125011, 2015.

[10] M. Faitsch et al, Plasma Phys.Control.Fusion, vol. 57, p. 075005, 2015.