

## EDGE ION TEMPERATURE GRADIENTS IN H-MODE DISCHARGES

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### Introduction

Understanding the processes that sustain the edge transport barrier (ETB) in H-mode plasmas is necessary for reliable scaling to next step tokamaks. In particular, the temperature at the top of the barrier sets the boundary condition for the level of turbulent transport in the plasma core. Moreover, the mechanisms that connect particle and heat transport in the electron channel and the ion channel are not yet completely clear. In this investigation experimentally determined electron and ion edge temperature gradients of H-mode discharges are compared. Selected experimental results are modelled with the 2D fluid code B2.5 to gain insight into the transport processes within the ETB.

### Experimental setup and results

Ion temperature ( $T_i$ ) profiles in the ETB region of H-mode discharges in the ASDEX Upgrade tokamak have been measured by means of Lithium beam charge exchange spectroscopy [1]. Here a 40 keV neutral Lithium beam serves as electron donor for the charge exchange process with fully stripped He impurity ions:  $\text{He}^{2+} + \text{Li}^0 \rightarrow \text{He}^{+*} + \text{Li}^+$ . The subsequent radiation of the HeII (4-3) transition is measured with two Czerny Turner spectrometers coupled to frame transfer CCD cameras via up to 18 lines of sight. From the Doppler width of the line  $T_i$  is derived. The data cover a region of normalised poloidal radius between  $\rho_{\text{pol}} = 0.9$  and  $\rho_{\text{pol}} = 1.01$  with a spatial resolution of 6 mm. The frame rate of the CCD cameras was set to 4 ms. During ELMs the intensity of the passive HeII line increases by a factor of 2 to 3 due to the increased He recycling, disturbing the weak active charge exchange contribution. Therefore, the CCD frames containing such high passive signals during ELMs have to be omitted from evaluation. In order to retain enough useful frames in between ELMs, the measurements are restricted to type I ELMy H-modes with ELM frequencies less than 100 Hz and a constant phase for about 2 seconds. Because of the small active CX-signal, weak He gas fuelling was applied to some of the discharges, leading to a He concentration ( $n_{\text{He}^{2+}}/n_e$ ) of  $\sim 10\%$ . Figure 1 shows the ion temperature profiles of both the core CXRS system using the CVI (8-7) transition and the edge Li-beam CXRS system using the HeII (4-3) transition for discharge #21160,  $t=5-7$  s.

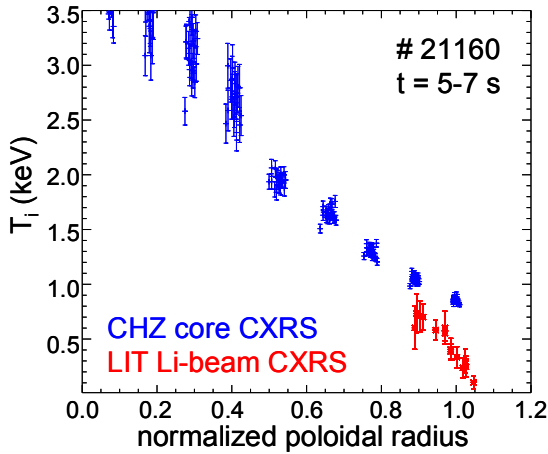


Figure 1: Measured ion temperature profile for shot #21160,  $t=5-7$  s. The blue data points are from the core CXRS diagnostic, the red points from Li-beam CXRS edge diagnostic.

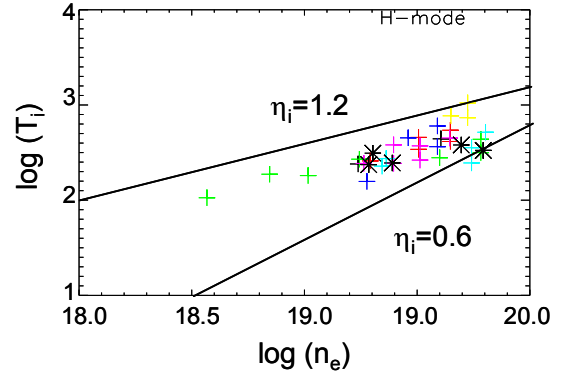


Figure 2: Double logarithmic plot of  $T_i$  vs  $n_e$  for 6 different H-mode discharges. Only data in the ETB,  $0.96 < \rho_{pol} < 1.01$  are taken. The solid lines show gradients of 0.6 and 1.2 to guide the eye to the values determined as minimum and maximum for  $\eta_i$ .

While there is still a discrepancy between the outermost channels of the core system and the innermost channels of the edge system, the  $T_i$  gradient is considerably steeper in the ETB region than in the core. The typical H-mode edge structure, the so-called pedestal, can thus also be seen in the  $T_i$  profiles. For a variety of such discharges with the pedestal top densities varying between  $5$  to  $8 \cdot 10^{19} \text{ m}^{-3}$ , edge profile data have been collected from various diagnostics, i.e. edge Thomson scattering for electron temperature ( $T_e$ ) and electron density ( $n_e$ ), ECE for  $T_e$  and the Lithium beam diagnostic for  $n_e$ . In the steep edge gradient region, i.e. between  $\rho_{pol}=0.96$  and  $\rho_{pol}=1.01$ , the ratio of density gradient length and temperature gradient length,  $\eta$ , has been determined for electrons and ions. With the gradient length  $L_x$  being defined as  $L_x = |1/x \, dx/dr|^{-1}$ , we can write  $\eta = L_n/L_T = d(\ln T)/d(\ln n)$ . By fitting a straight line to a double logarithmic plot of  $T$  versus  $n$ ,  $\eta$  can be determined in a simple way. Figure 2 shows such a plot for 6 different discharges, where the ion density ( $n_i$ ) is replaced by  $n_e$ , assuming that there is a constant factor between  $n_e$  and  $n_i$ . While  $\eta_e$  is found to be about 2 in agreement with previous results [2] at ASDEX Upgrade,  $\eta_i$  is determined to be between 0.6 and 1.2 in the investigated discharges. The two lines marked  $\eta_i = 0.6$  and 1.2 are not fits to the data, but are meant as a guide to the eye, marking the minimum and maximum  $\eta_i$  derived. As the onset of ion temperature gradient (ITG) modes is expected to occur for  $\eta_i = 1-2$  [3], no significant anomalous transport is expected for ions in the ETB region.



To achieve this excellent match between experiment and modelling, profiles for particle and heat transport coefficients are used, which are shown in figure 4. While for the particle diffusion coefficient  $D$  and electron heat transport coefficient  $\chi_e$  anomalous values across the whole radial region are necessary to model the experiment, the ion heat transport coefficient  $\chi_i$  can be set to neoclassical values in the ETB region. As can be seen in figure 4, the barrier region extends 2.5 cm inwards from the separatrix. Also in this region, the ratio of the banana width to the minimum gradient length of all profiles stays well below one, which is a condition for the validity of neoclassical transport models. Although the neutrals are simply treated as a fluid, i.e. no kinetic treatment is applied, the modelled data match the measured  $H_\alpha$  and CIII radiation in the divertor within a factor of 2, being in surprisingly good agreement.

## Conclusions

In ASDEX Upgrade H-mode discharges with ELM frequencies  $< 100$  Hz the ion and electron temperature gradient lengths differ by around a factor of 2. While  $\eta_e$  is found to be around 2,  $\eta_i$  is between 0.6 and 1.2. Therefore it is unlikely that ion temperature gradient driven modes occur. This is supported by B2.5 modelling of such an H-mode discharge, because the mid-plane profiles can be simulated with the ion heat transport coefficient set to neoclassical values in the ETB region.

## References

- [1] M. Reich et al, Plasma Phys. Control. Fusion 46 (2004) 797
- [2] J. Neuhauser et al, Plasma Phys. Control. Fusion 44 (2002) 855,  
A. Kallenbach et al, Nucl. Fusion 43 (2003) 573
- [3] B. Scott, New J. Phys. 4 (2002) 52
- [4] R. Schneider et al, Contrib. Plasma Phys. 46 (2006) 3
- [5] A. Peeters, Phys. Plasmas 7 (2000) 268
- [6] L.D. Horton et al, Nucl. Fusion 45 (2005) 856