Parallel SOL transport regime in tokamak COMPASS

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Power exhaust in a tokamak fusion reactor is partly realised through energetic plasma particles heating the divertor and the first wall. The power crossing the separatrix must be distributed along the plasma-facing components without heating them to a high temperature or causing strong sputtering. This applies especially to the divertor, where particle power deposition is focused onto a narrow stripe along the strike points, figure 1. It is therefore desirable to establish a significant parallel plasma temperature gradient between *upstream*, where most of the cross-field transport is concentrated, and the divertor *targets*.

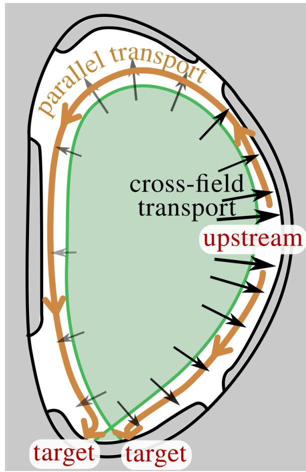

Figure 1: Schema of tokamak SOL transport.

Using the two-point model [1] as a base, the parallel temperature gradient can be quantified using the collisionality parameter, $\nu^* = 10^{-16}\frac{n_u L}{T_u^2}$: the mean number of collisions a particle undergoes on the way from upstream to target. Here L stands for flux tube length, n_u is upstream electron density, and T_u is upstream temperature.

small temperature gradient	$T_u < 1.5T_t$	$\nu^* < 10$	**sheath-limited regime**
significant temperature gradient	$T_u > 3T_t$	$\nu^* > 15$	**conduction-limited regime**

The conduction-limited regime allows for a relatively cold target plasma while keeping upstream at the same temperature.

Tokamak COMPASS is a small-sized tokamak with typical SOL collisionality of $\nu^* = 7$, but as seen in figure 2, sufficient collisionalities for the conduction-limited regime can be reached as well. This contribution investigates its SOL transport regimes by comparing the upstream and target T_e profiles, and it interprets them using the two-point model. 62 COMPASS discharges were processed and two typical representatives - of low and high collisionality - were picked for demonstration.

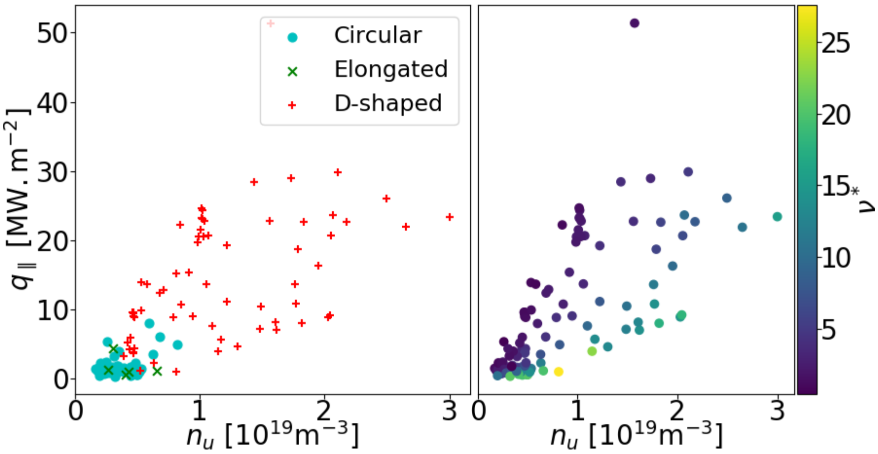

Figure 2: COMPASS operational space plotted using the separatrix heat flux $q_\parallel$ and the separatrix electron density n_u.

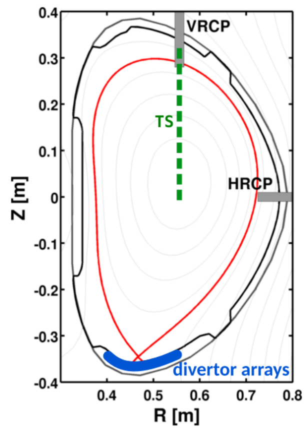

Figure 3: COMPASS T_e diagnostics.

In experiment, SOL T_e profiles were measured by two reciprocating probes (HRCP and VRCP), two divertor probe arrays, and the Thomson scattering (TS) diagnostic (figure 3). Beside TS [2], two methods of T_e measurement were employed: the floating ball-pen and Langmuir probe technique, where $T_e = (V_{BPP} - V_{LP})/\alpha$ (HRCP, VRCP, new divertor array) [3][4], and the first-derivative probe technique (old divertor array) [5].

The two divertor arrays were compared to one another and to the two-point model. There were several results, some of which are shown in figure 5. To begin, for low ν^*, the new array agrees with the two-point model ($T_u = T_t$), while the old array measures a lower temperature. In contrast, the two arrays agree throughout the high ν^* SOL, in the far SOL they even agree with the two-point model. Lastly, the electron energy distribution function, measured by the old array, is bimaxwellian throughout the SOL for low ν^* but becomes maxwellian in high ν^* with the exception of the strike point vicinity. It would follow that in high collisionalities the two arrays are interchangeable, and for low collisionalities the new divertor array is favourable. However, the method used here (T_e profile comparison) is extremely dependent on the mapping correction Δ, which is discussed in the following paragraph. Due to the random error in Δ, which can be up to several millimeters, the latter conclusion is not definitive.

In order to compare T_e profiles measured at different poloidal angles, the profiles must first be mapped along the magnetic flux surfaces to the outer midplane (OMP). However, the EFIT reconstruction used on tokamak COMPASS exhibits systematic errors which are dependent on the plasma shape. Assuming that the real separatrix shape follows figure 4, an OMP mapping correction is devised here.

Several methods of calculating a suitable mapping correction were tested in a statistical analysis of the COMPASS discharge database. Three of them displayed a 95% correlation while adhering to a 1:1 dependence. The first of these methods assumes poloidal symmetry of T_e profiles, and determines the mapping correction Δ by shifting the mapped VRCP profile so that it matches the HRCP T_e profile. The second method then assumes that the velocity shear layer (VSL), $E_r = 0$, lies on the same magnetic surface on the top and on the OMP. Lastly, the same was assumed for the boundary between the near and far SOL, which was detected by fitting the RCP T_e profile with a double exponenial. These methods are independent while consistently yielding the same results. Thus the suggested EFIT mapping correction was based on the most widely applicable one of them. The correction has three degrees of accuracy, depending on RCP data availability:

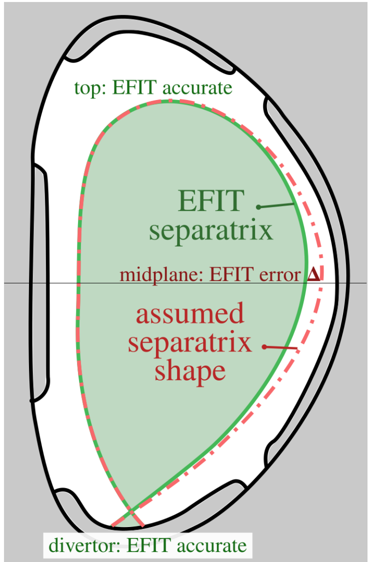

Figure 4: Separatrix position assumptions.

1. Both HRCP and VRCP measurement available: $\Delta = R_{VSL,HRCP} - R^{mapped}_{VSL,VRCP}$
2. Only HRCP measurement available: $\Delta = 0.77\left(R^{HRCP}_{VSL} - R^{EFIT}_{separatrix}\right) + 0.3$ cm
3. No RCP data: $\Delta = \begin{cases} (-0.9 \pm 0.4) \text{ cm} & \text{for circular plasmas} \\ (1.2 \pm 0.7) \text{ cm} & \text{for D-shaped plasmas} \end{cases}$

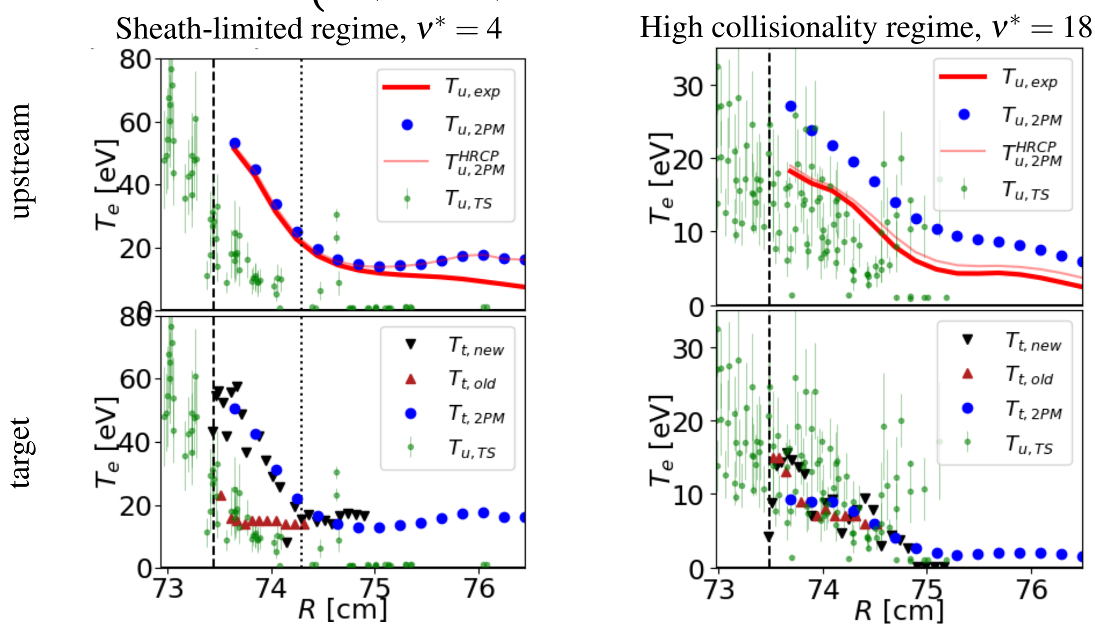

Figure 5: Electron temperature profiles as measured by the HRCP, the two divertor arrays, and the Thomson scattering, and output of the two-point model using n_u, $q_\parallel$, and L profiles.

Finally, T_e profiles were mapped from the top and the divertor to the OMP, and compared. Figure 5 shows the T_e profile comparison for two selected discharges. The low ν^* discharge represents the sheath-limited regime, with no temperature gradient between upstream and target. The two-point model reproduces the HRCP and the new divertor array profiles well, however, the old divertor array does not agree with the rest of the diagnostics nor the two-point model.

On first glance, the high collisionality discharge fails to develop the characteristic parallel temperature gradient. However, the two-point model prediction is not entirely straightforward to interpret in this case. One of the control variables of this model is the connection length L, the distance between upstream and target. The HRCP head effectively acts as target, reducing L to zero locally. Assuming that the other two control variables, $q_{\|}$ and n_u, are not affected by the probe's presence, the two-point model yields different T_u for the HRCP and for an unperturbed plasma. As figure 5 shows, this perturbation has the form of cooling the SOL. The effect is weak in the hot, sheath-limited SOL, but in high collisionalities the cooling can reach up to a factor of two according to the two-point model. Whether this truly occurs may be confirmed by a non-invasive diagnostic such as the Thomson scattering, however, the mapping accuracy of this diagnostic is uncertain (random error up to 1 cm) and the SOL T_e profiles feature much scatter. Further precision improvement would be required in order to draw a more definite conclusion.

In summary, this contribution investigated parallel T_e profiles, aiming to characterise the typical SOL transport regime of tokamak COMPASS. To this end, five various diagnostics were employed, with the (dis)agreement between the two divertor arrays specifically addressed. After developing a reliable method for performing mapping to the OMP, T_e profiles at various locations along the flux tube were compared. The COMPASS SOL was shown to be typically in the sheath-limited regime, with low collisionalities and flat parallel temperature profiles. Collisionalities $\nu^* > 15$ can be reached, but the corresponding parallel T_e gradient was not found. This may possibly be attributed to the probe cooling the surrounding plasma.

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