Thomson scattering measurements in MAST-U Super-X divertor plasmas

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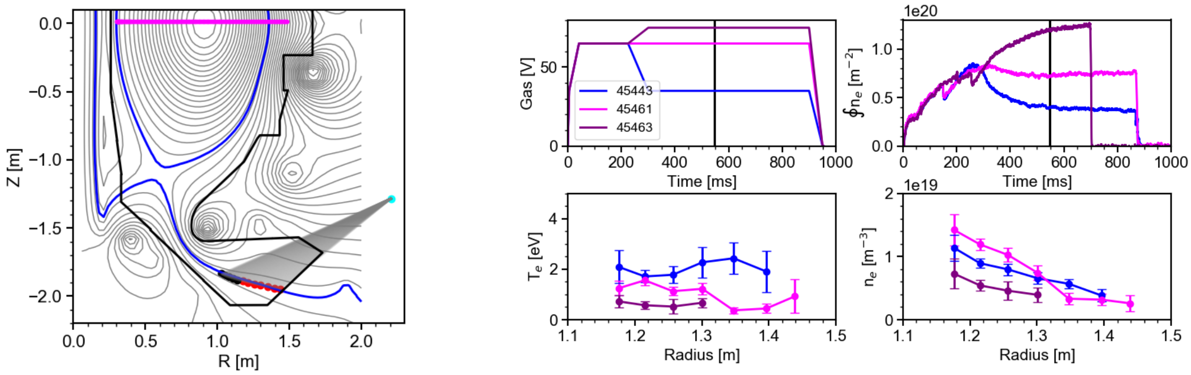
In 2021 MAST-U completed its first physics campaign. A goal of the campaign was to characterise the detachment threshold in the Super-X divertor. The core [1, 2] and divertor [3, 4] Thomson scattering systems were used to measure electron properties surrounding the midplane and divertor separatrix respectively. These diagnostics are part of a suite of systems diagnosing MAST-U plasmas to study the plasma exhaust. Properties such as gas fuelling, fuelling location and magnetic flux expansion were investigated to study the detachment onset. In this work only plasmas fuelled at a constant rate from the high field side midplane will be presented.

Super-X Divertor Thomson Profiles

A 600 kA L-mode Super-X divertor scenario was developed during the first campaign with high field side midplane fuelling. The strike point was swept from a conventional divertor configuration out to the Super-X at 450 ms where it was held until 750 ms before the plasma went into rampdown. A plasma equilibrium from a typical Super-X plasma can be seen in Figure 1(a). The divertor leg was aligned with the Thomson laser to obtain measurements along a single field line, as the system was designed to do. A typical radial profile from the diagnostic can be seen in Figure 1(b).

Once in Super-X the strike point can be swept across the divertor tile. This allows comparison with diagnostics such as Langmuir probes which have a number of probe arrays at various toroidal locations on the divertor tile. This sweep was performed for a number of MAST-U plasmas. Even though the sweep moves the position of the divertor leg away from the Thomson laser, good measurements were still produced by the diagnostic.

Electron density and temperature values measured in the Super-X divertor, seen in Figure 2, were lower expected based on the operational limits of the system. Despite this, it can be seen that there are clear gradients in the density profiles with increasing major radius towards the target. At the typical electron temperatures (∼eV) observed during



(a) **(b)**

Figure 1. *(a) Magnetic equilibrium from 45465 at 500 ms showing core (magenta) and divertor (red and black) Thomson scattering spatial points from divertor collection cell (cyan). (b) Divertor Thomson profiles at 545 ms as the divertor moves from attached (45443) to onset of detachment (45461) to detached (45463)*

this campaign it was too cold to see any significant gradient in the temperature profile. These gradients are expected when electron temperatures approach 10 eV during higher power Super-X experiments carried out in future campaigns.

Detachment Measurements

A fuelling scan from the high field side midplane was carried out over a number of plasma shots in order to reach divertor detachment. The parameter space from the divertor Thomson system during this fuelling scan can be seen in Figure 2. With an increase in fuelling there is a clear decrease in the electron temperature. Meanwhile the electron density is observed to increase for a few fuelling levels before starting to drop. This drop in density with increased fuelling is indicative of detachment [5].

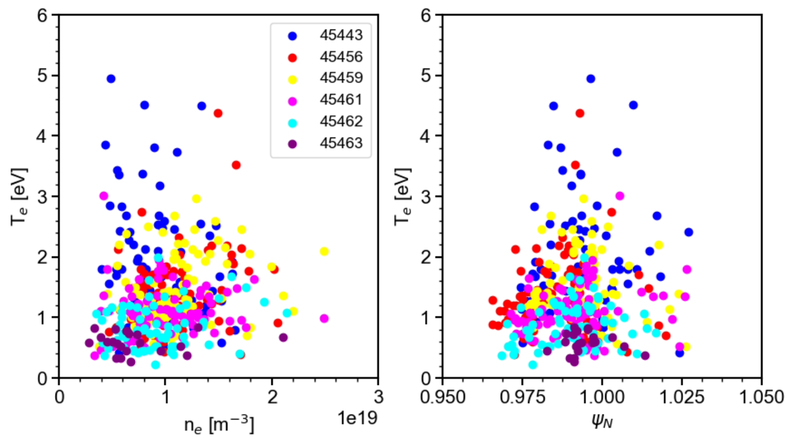


Figure 2. *Divertor Thomson data from 450-750ms between 0.95 $\leq \psi_N \leq$ 1.05*

Evidence of detachment can be seen in Figure 3 where the midplane (top) and divertor (middle) electron density and temperature data is shown for the whole fuelling scan as well as the ratio between the two systems (bottom). To compare the two systems the average of the data is taken for $0.95 \leq \psi_N \leq 1.05$ where ψ_N is the normalised poloidal flux. For the divertor Thomson system all of the spatial points are within this limit due to the divertor leg alignment. The average across the same poloidal flux space allows comparison between the separatrix at the two regions of the plasma.

To explain Figure 3 the plot is divided into two regions separated by the rollover point. Before reaching rollover it is observed that the electron density at the midplane and in the divertor increases with the upstream density measured by the CO_2 interferometer. This continues until the onset of detachment where rollover is reached at $\sim 7 \times 10^{19}\,m^{-2}$. As the upstream density increases beyond the rollover value a decrease in the divertor density is observed. In contrast, at the midplane, the electron density continues to increase with the upstream density measured by the interferometer.

Conversely, the midplane electron temperature is observed to decrease with the upstream density. The same behaviour is observed in the divertor throughout the fuelling scan. As a result the electron pressure is not being conserved beyond the point of rollover.

This is an encouraging result for MAST-U as a rollover is observed during first operation of the Super-X divertor and during low power L-mode plasmas. Observing the rollover in the divertor Thomson diagnostic data will aid comparisons between this system and other divertor diagnostics such as Langmuir probes, IR cameras and multi-wavelength spectroscopy systems for exhaust analysis in future experiments.

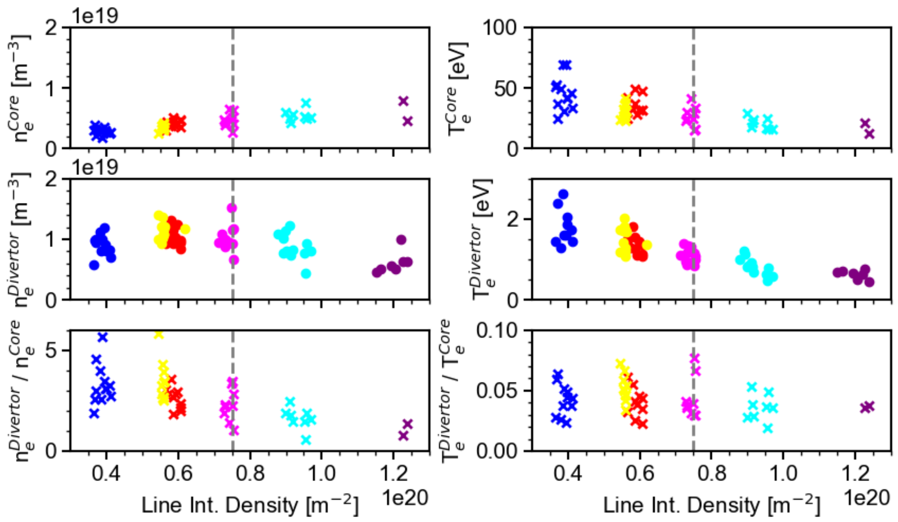


Figure 3. *Average of core (top) and divertor (middle) Thomson data and the ratio of the two (bottom) for data between $0.95 \leq \psi_N \leq 1.05$ for divertor Thomson laser pulses*

Conclusions

The MAST-U divertor Thomson system has demonstrated divertor electron density and temperature measurements down to $\sim 1 \times 10^{18}\, m^{-3}$ and $0.5\,\mathrm{eV}$ respectively. It has shown its suitability to measure the point of divertor rollover and aid comparison with other diagnostics operating in the divertor. With the comparison of midplane scrape-off layer profiles from the core Thomson system the effect of the divertor configuration on the core plasma can also be investigated. This will be important in future physics campaigns when the power crossing the separatrix is increased and the Super-X scenarios are pushed into H-mode operation.

Acknowledgments

This work was funded partly by the United Kingdom Engineering and Physical Sciences Research Council under Grant No. [EP/W006839/1]. This work was partly funded by the University of Liverpool. This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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