

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. To study the electron properties 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 strikepoint 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. The strike leg was aligned with the divertor Thomson laser to obtain measurements along a single field line, as the system was designed to do.

Once in Super-X the strikepoint 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 strike leg away from the divertor Thomson laser, it was found to have a negligible effect on the quality of the measurements produced by the diagnostic.

When a strikepoint sweep is performed it allows a 2D profile of electron temperature and density to be produced by mapping all of the Super-X datapoints to the equilibrium reconstruction at a certain time. This can be seen in Figure 1 which shows the extent of a

typical sweep performed on MAST-U. Electron density and temperature values measured in the Super-X divertor were lower than theoretical predictions [5]. It is thought that the number of neutral particles in the divertor had a significant impact on the electron density and temperature observed in the first campaign. Despite this, it can be seen that there are clear gradients in the density profiles with increasing major radius. At the typical electron temperatures (\sim eV) observed during 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.

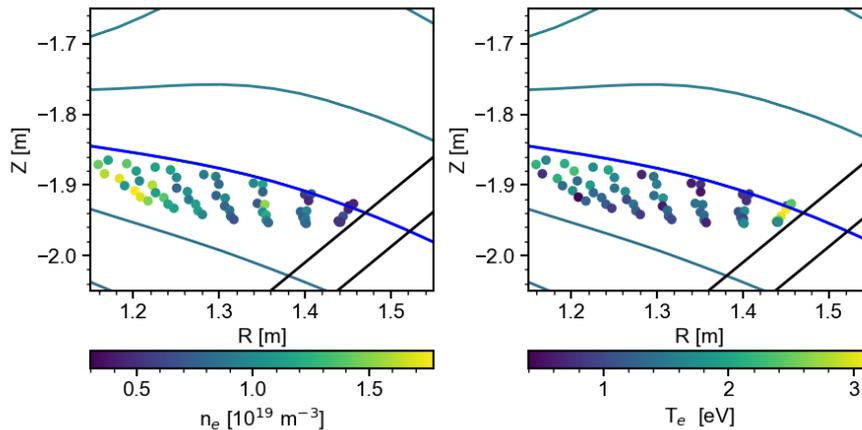


Figure 1. *Divertor Thomson scattering data from 450-750 ms with the points mapped onto the strike leg position at 600 ms for shot 45456*

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 data from the divertor Thomson system during this fuelling scan can be seen in Figure 2. With the fuelling increasing each shot there is a clear decrease in the electron temperature with increasing fuelling, as expected. Meanwhile the electron density is observed to increase for a few fuelling levels before starting to drop. This drop in density with increased fuelling, and subsequently upstream density, is indicative of detachment [6].

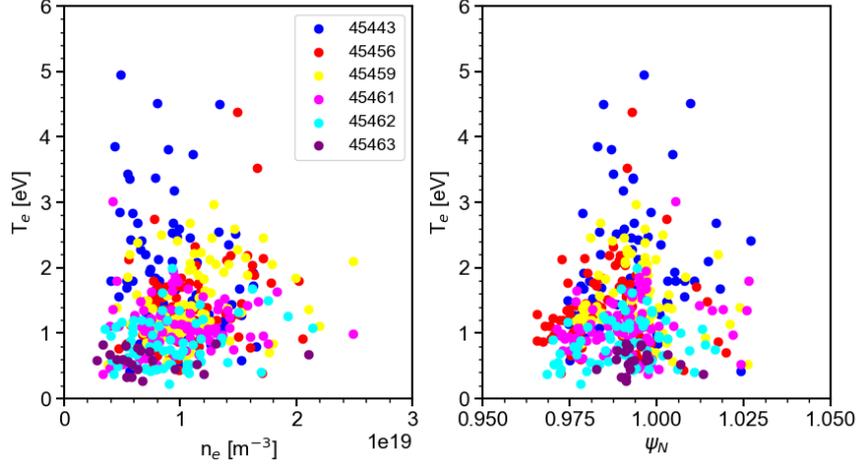


Figure 2. *Divertor Thomson data from 450-750ms between $0.95 \leq \psi_N \leq 1.05$*

Evidence of detachment can be seen in Figure 3 where the midplane (top) and divertor (bottom) electron density and temperature data is shown for the whole fuelling scan. 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. This allows comparison between the separatrix at the two regions of the plasma.

In phase 1 it is observed that the electron density at the midplane and in the divertor increases with the upstream density measured by the CO₂ interferometer. This continues until the onset of detachment where the rollover point is reached at $\sim 7 \times 10^{19} m^{-2}$. As the upstream density increases beyond the rollover value, in phase 2, a decrease in the divertor density is observed. Phase 2 is not observed at the midplane where 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.

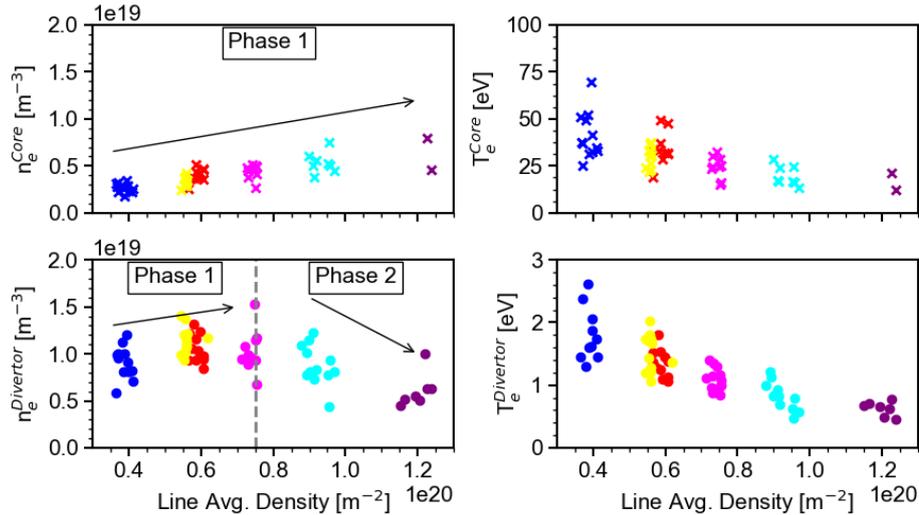


Figure 3. Average of core (top) and divertor (bottom) Thomson data between $0.95 \leq \psi_N \leq 1.05$

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 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.

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