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# Edge electron temperature and density measurements for ITER shape studies using the JET edge LIDAR system.

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## 1.Introduction.

In this paper an edge LIDAR diagnostic will be applied to characterise the pressure limit of the edge of shaped plasmas. For ITER shape studies, it is important to find out whether plasma shape has an effect on this edge pressure limit. A scan of plasma density, current and toroidal field has been performed for different plasmas with: High elongation, High triangularity (HH); High elongation, Low triangularity (HL); Low elongation, Low triangularity (LL) [1]. All discharges are additionally heated applying neutral beam injection with on average 14MW of power.

Figure 1 shows the variation in triangularity and elongation of the plasmas used in this experiment. For all three shapes a scan in density, plasma current and toroidal magnetic field has been performed (Table 1). The lines of sight of several JET diagnostics that measure $T_e$ and/or $n_e$ are drawn in the Figure. For the present study only the edge LIDAR diagnostic can be used to measure $T_e$ and $n_e$ profiles at the edge in all three cases. Edge interferometry and Lithium beams lines of sight do not cover the plasma for all three shapes. ECE suffers from density cut off at the lower magnetic fields in the scan. Finally the core LIDAR system has a too low spatial resolution.

In the following the edge LIDAR measurements will be validated using the core LIDAR, ECE radiometer, and Lithium beam measurements in plasmas where all these were able to function. Furthermore a methodology will be presented to compare the edge pedestal $T_e$ and $n_e$ values of the three shapes. And finally the edge $n_e$-$T_e$ stability diagram will be presented.

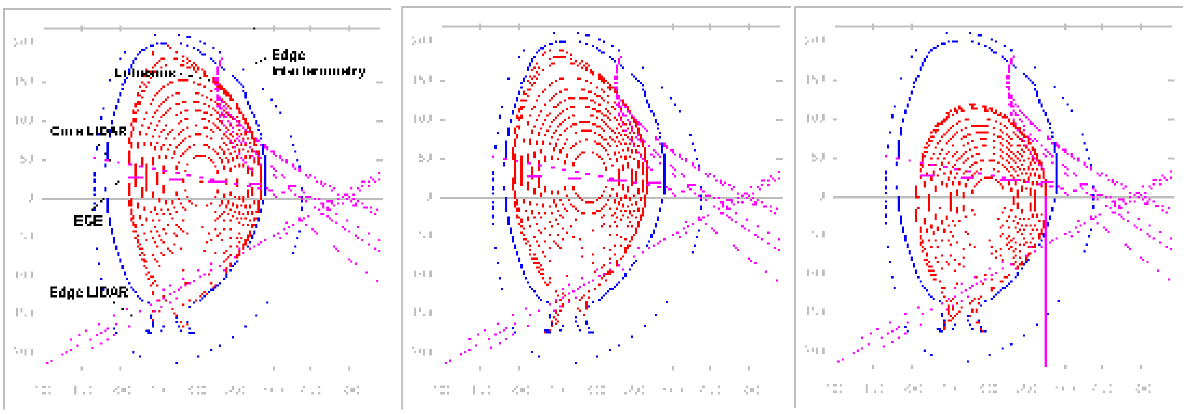


*Fig.1: The three plasma shapes used in the study: HH, HL and LL. The figure shows the lines of sight of respectively the edge LIDAR system, the main LIDAR system, ECE radiometry, the Lithium beams, and edge interferometry. Clearly the edge interferometry and the Li-beams miss the plasma for the HL and LL cases.*

*Table 1: Parameters of the ITER shape scan.*

| Shape: | $B_T$ | $I_p$ | $q_{95}$ | Elong. | Triang. | $<n_e>$ $10^{19}$ $m^{-3}$ |
|---|---|---|---|---|---|---|
| HH | 2.7 | 2.5 | 3.3 | 1.9 | 0.34 | 7.0-10.0 |
| | 2.7 | 1.8 | 3.3 | 1.9 | 0.35 | 5.0-7.0 |
| | 2.1 | 1.8 | 4.5 | 1.9 | 0.35 | 5.0-6.6 |
| HL | 1.9 | 1.8 | 3.3 | 1.8 | 0.19 | 6.0-7.1 |
| LL | 2.7 | 2.2 | 2.6 | 1.55 | 0.21 | 3.0-8.0 |
| | 2.7 | 1.8 | 3.2 | 1.55 | 0.23 | 3.0-6.7 |

2. Edge LIDAR Thomson scattering

The JET edge LIDAR system uses a 1Hz, 2 Joule, 300ps Ruby laser [2]. The laser beam is directed diagonally into the plasma just above the X-point (see Fig. 1). The spatial resolution along the laser path is 12 cm. Due to the angle of the laser beam to the flux surfaces this is transposed into an effective spatial resolution of 2-3 cm perpendicular to these surfaces at the mid-plane edge, varying with plasma configuration. The spectrometer is a four channel filter spectrometer with micro-channel plate photomultiplier detectors. Typical accuracy achieved with this diagnostic is 10 % of $T_e$ and 6% of $n_e$ at $n_e$= $3x10^{19}$ $m^{-3}$.

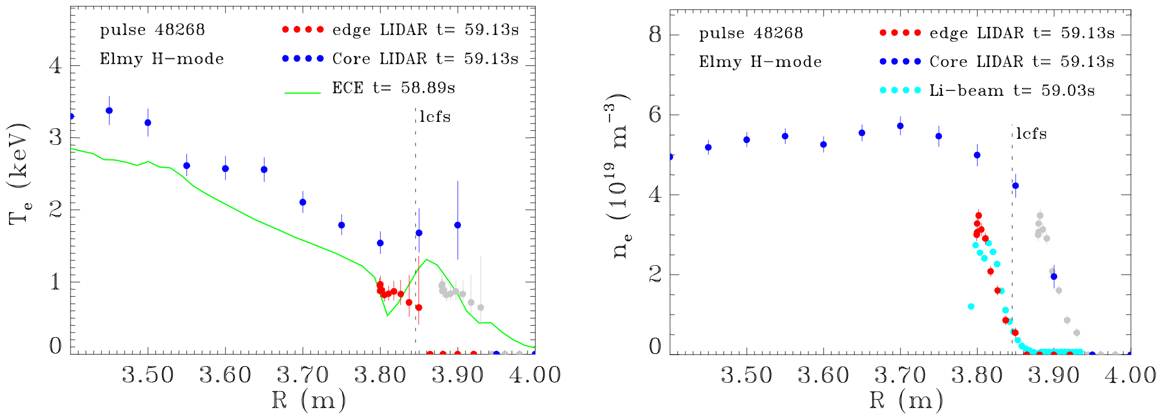


*Fig 2: $T_e$ and $n_e$ profiles for an Elmy H-mode discharge. The $T_e$ profile shows ECE (green), core LIDAR (blue) and edge LIDAR (red). The hump in the ECE $T_e$ data at R>3.8 m is due to relativistic shine-through. The drop at 3.8 m is believed to be real and to represent the pedestal in $T_e$. In grey the shifted edge LIDAR data is plotted to match the core LIDAR data. The $n_e$ profile shows Lithium beam, core and edge LIDAR data. Lithium beam and edge LIDAR data agree remarkably well, whereas the core LIDAR data again seems shifted. Again the shifted edge LIDAR data is plotted in grey. The last closed flux surface by the JET-EFIT code is indicated by a dotted line marked lcfs .*

3. Validation of Edge LIDAR data

For the comparison of different diagnostics the data is mapped to the midplane of the plasma using the magnetic reconstruction as shown in Fig. 1. Figure 2 shows the temperature and density profiles for an Elmy H-mode discharge. The profiles of $T_e$ show that the ECE and edge LIDAR measurements agree very well at the onset of the knee in the ECE $T_e$ profile. From this onset (what is believed to be the pedestal of the profile) the ECE profile drops

towards zero, whereas the edge LIDAR profile does not show this marked drop in $T_e$. The core LIDAR data agrees with the other two diagnostics but seems to be shifted.
This shift between the core LIDAR data and other data is better observed in the density. The shift is 8 cm for both $n_e$ and $T_e$ and is systematically present for all additionally heated discharges in JET. The figure also shows that the edge $n_e$ profiles measured by Li-beams and edge LIDAR agree remarkably well.

The difference between ECE and edge LIDAR could be explained by assuming that the pedestal measurement recorded by ECE is limited by the ECE spatial resolution, i.e. the gradient is much steeper than observed by ECE. This steep gradient then is not resolved by the edge LIDAR diagnostic.

The problem of the shift in position between main LIDAR and other diagnostics lies in the reconstruction of the flux surfaces (Fig. 1) or the position calibration of core LIDAR. The core LIDAR system is the only diagnostic in this comparison that does not rely on mapping on the flux surfaces.

## 4. Determining Te and ne at the pedestal

For our current study we want to use the edge LIDAR data to compare the edge pedestal of differently shaped Elmy H-mode plasmas. For this analysis edge LIDAR data is selected away from ELMs.To give an estimate of the pedestal $T_e$ and $n_e$ values a constant pedestal width of 5 cm is assumed. Then a linear fit to the edge LIDAR data is performed and the value of Te and ne at 5 cm inward form the last closed flux surface is recorded as the edge pedestal value (Fig. 2). Of course this method is not very exact in terms of determining the $T_e$ and $n_e$ values at the pedestal, but it is a systematic way of comparing edge pedestals in different discharges.

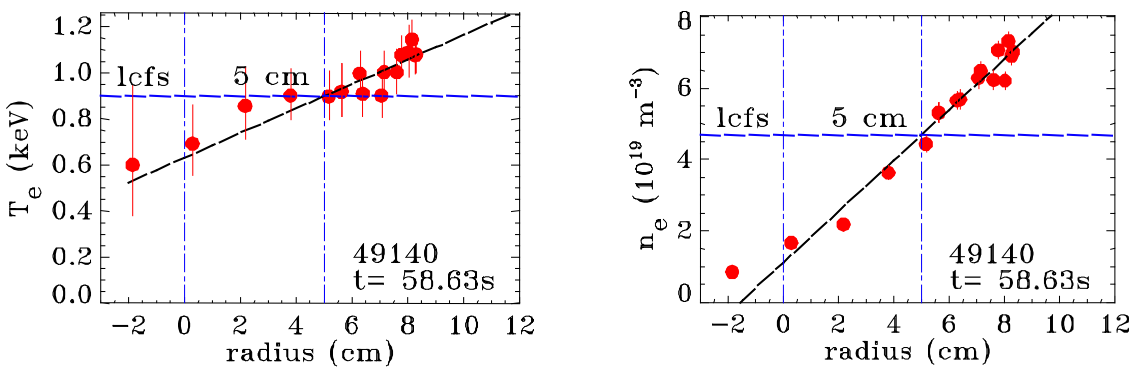


*Fig 3: Estimation of the edge pedestal values for $T_e$ and $n_e$. In this case the values are resp. $T_e$= 0.90 keV and $n_e$= 4.6x$10^{19}$ $m^{-3}$.*

## 5. Edge $n_e$ and $T_e$ diagram for the ITER shape study plasmas.

The edge pedestal values using the technique described in Fig.3 are plotted in an $n_e$-$T_e$ diagram showing the pressure limit of the discharges (Fig.4). The data are grouped in the categories as described in table 1. From Fig.4 it can be concluded that the stability limit shifts to higher values of $n_e$ and $T_e$ if the plasma current increases. (Compare HH low and high current and LL low and high current.) This is what is expected and validates the method. The figure also shows a clear distinction between the LL and HH discharges. Unfortunately not enough HL data is available to separate the effect of elongation and triangularity. From other data it was found that elongation has a stronger effect on improving confinement then triangularity has [1].

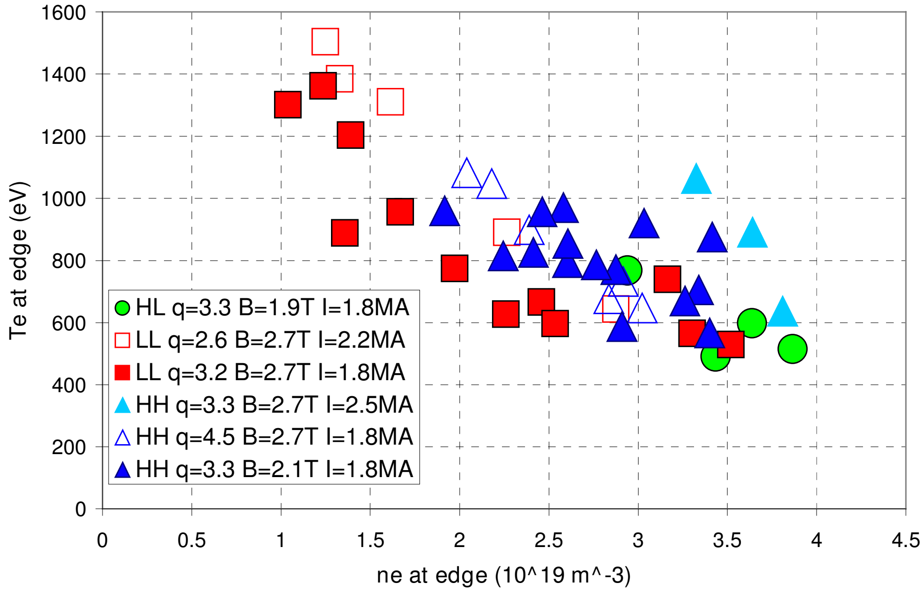


*Fig.4: $n_e$ and $T_e$ diagram for the ITER shape study. The $n_e$ and $T_e$ are the values at 5 cm inward to the last closed flux surface as explained in the previous section. The spread of points of one condition (same shape and current) is an indication of the error in the measurements. The figure shows that plasma current has a clear effect on the pressure limit. There also is a clear distinction between the points of the LL and HH discharges at similar $I_p$.*

5. Conclusions

Edge LIDAR produces data that is consistent with data from ECE radiometry, Li-beams and the core LIDAR system. The pedestal at the edge measured by ECE is not resolved by the edge LIDAR diagnostic. This indicates that the pedestal is likely to be steeper than shown by ECE.

The core LIDAR data is shifted compared to measurement by other diagnostics. The explanation for this discrepancy either lies in a misinterpretation of the position of the LCFS by the magnetic reconstruction code (EFIT), or in a faulty time of flight calibration of the core LIDAR measurements. The discrepancy in position is systematically the same for JET additionally heated discharges and is 8 cm.

Plasmas with high elongation and high triangularity have higher edge pressure limits than plasmas with low elongation and low triangularity. Unfortunately not enough data is available of plasmas with high elongation and low triangularity to conclude from this method which of the two has the largest effect on edge pressure limit.

References


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