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# ELM Filament studies using the Edge Thomson Scattering Diagnostic on MAST

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**Introduction** Filamentary structures have been observed during ELMs on a number of tokamaks using a number of different diagnostic techniques. On MAST, pictures of the filaments have been obtained from a visible camera and the spatial structure and toroidal mode number estimated from reciprocating probe measurements [1,2]. The divertor power deposition structure of individual filaments has been observed on the ASDEX Upgrade tokamak using infrared thermography [3]. Thomson scattering (TS) data obtained on ASDEX Upgrade, shows evidence for *blob like structures* and *holes* in the $n_e$ and $T_e$ profiles inside the separatrix [4] during type I ELMs. In this paper, new results are presented on the evolution of these filaments. This paper focuses particularly on data obtained from a new edge TS system, which views the MAST outboard (low field side) pedestal region along 16 ~1cm scattering lengths. It can measure temperatures below 5eV and densities down to $1x10^{18}$ $m^{-3}$ which are below typical MAST SOL parameters. The system and its design are described in detail in [5]. Four lasers are used, which travel approximately the same beam path along a plasma major radius through the vessel midplane. During filament studies these lasers are typically used in burst mode, fired a few microseconds apart to view the evolution of a single filament. Data

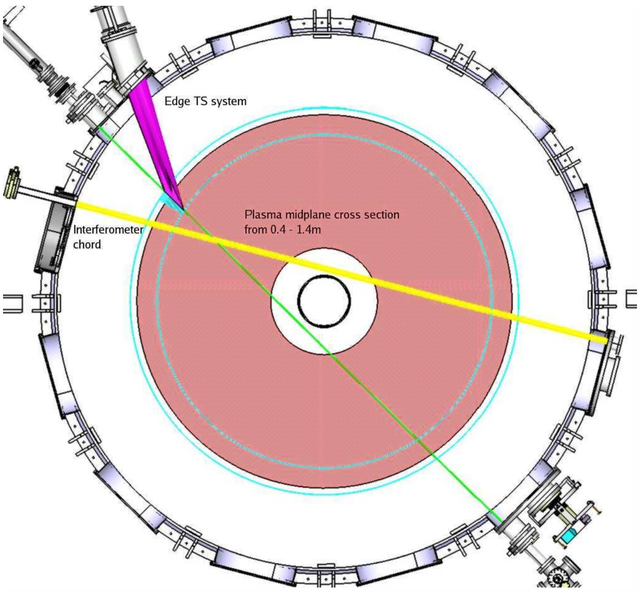


**Figure 1 - Plan view of edge Thomson scattering system optics and laser as well as interferometer chord. Plasma is shown with inner and outer radii of 0.4 and 1.4m and TS measuring between 1.29 and 1.45m.**

presented previously from TS on filaments in [1,2,4] did not achieve the spatial resolution within filaments presented here and did not produce time resolved information for the evolution of a single filamentary structure. Data from a $CO_2$ interferometer system measuring line integral density at 20μs resolution is also used. The geometry of the edge TS diagnostic and interferometer can be seen in figure 1.

**Filament Evolution** All filaments shown in figure 2 are during H-mode type I ELMs and occur during the rising edge of the divertor ELM related $D_\alpha$ pulse. For comparison, figure 2a shows typical edge profiles obtained in an H-mode inter-ELM period, these show very similar $T_e$ and $n_e$ profiles obtained from all 4 lasers, where the lasers are seperated in time by 5μs.

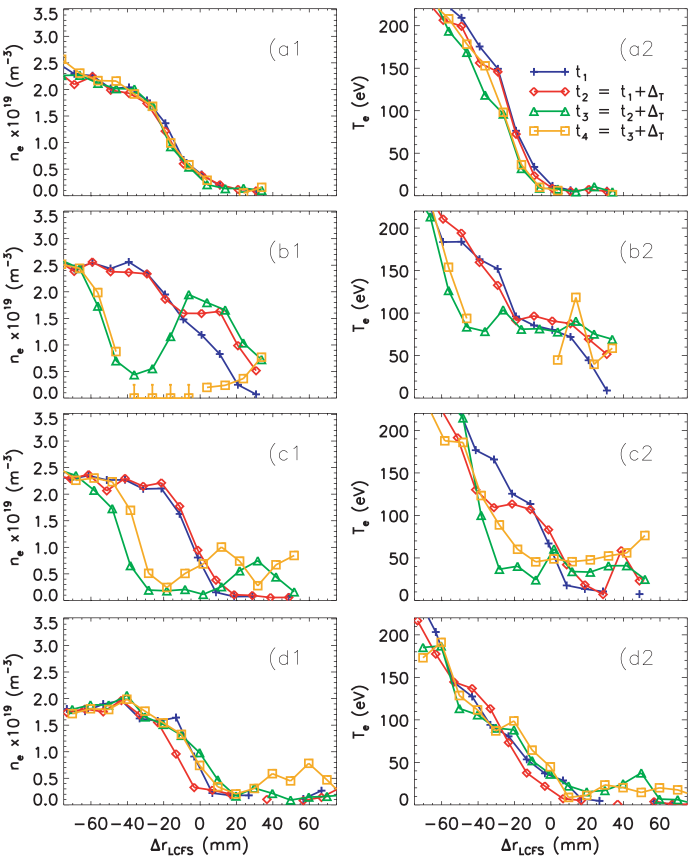


**Figure 2 - ELM filaments observed using lasers in burst mode 5μs apart. a) shows a profile obtained in an inter-ELM H-mode period, b-d) show filaments observed during ELMs classified according to distance of the filament from the pre-ELM last closed flux surface.**

Expulsion of a filamentary structure is seen in figure 2b. The first profile shows a bulge in the $n_e$ profile relative to the inter ELM H-mode profile. The electron temperature at $r_{LCFS}$+10mm is 70eV, which is lower than pedestal temperatures (~120eV) but much higher than scrape off layer temperatures of 5-10eV. The second profile shows the movement of this structure further out. The third profile shows a large density ‘hole’ inside the pre-ELM LCFS and a large filamentary structure outside the main plasma. The peak density of this filamentary structure is close the pre-ELM pedestal density, the temperature is relatively constant in the structure and similar to that in the plasma between the structure and the core. The final timeslice in figure 2b shows no evidence of plasma connecting the filament to the core at the midplane. Since the TS system minimum measurement parameters are low, it is likely that no plasma exists in this region and the structure is detached at the midplane. The temperature in the structure is very high relative to that in the SOL. Figure 2b indicates a filament radial velocity of at least 10kms$^{-1}$. When filaments are observed at large $\Delta r_{LCFS}$, the position of the edge pedestal is similar to the pre-ELM edge pedestal. Filaments observed when part of the filament is inside the pre-ELM last closed flux surface show large indentations to the position of the $T_e$ and $n_e$ pedestals, as in figure 2c. Figure 2d, shows a filament that has detached from the plasma and exists far from the pre-ELM last closed flux surface. Its temperature has dropped close to that of the SOL.

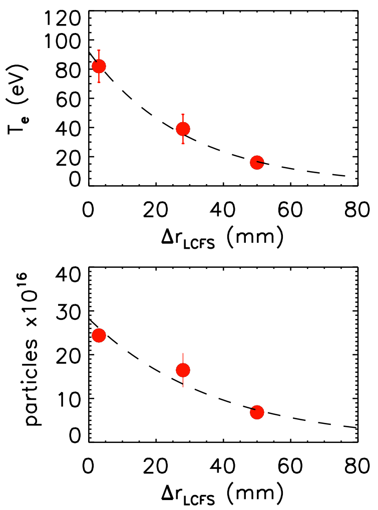


**Figure 3 – Filament temperature and number of particles plotted against filament center distance from the pre-ELM last closed flux surface.**

**Filament parameter fall-off** The temperature and number of particles contained in the filaments (calculated assuming circular filament cross section and filament length from fast camera data as in [6]) fall off rapidly as the filament moves from the last closed flux surface (figure 3). The decay length of filament temperature is measured as ~3cm and the decay length of number of particles contained in the filament is ~4cm. The fall-off of the electron energy content of filaments may be inferred from these results. In [7], peak density and peak temperature radial fall–off were obtained on the DIII-D tokamak using probe data and are in a similar range.

**Density Integral fluctuations** The interferometer measures line integral density ( $N_e = \int n_e dl$ ) through the midplane of the plasma across two plasma diameters as indicated in figure 1. Figure 4 shows a time trace of the interferometer through 2 ELMs, whose timing may be seen from the accompanying divertor $D_\alpha$ trace. The dashed red line indicates the timing of the Thomson scattering system sample seen in figure 2b. The filaments are seen to rotate toroidally by the fast camera at speeds of order 10kms$^{-1}$ in the co-current direction (counter clockwise from the TS line of sight to the interferometer line of sight in figure 1). The distance along the circumference of the plasma outboard edge between the two diagnostics is ~26cm and the interferometer samples at 20μs, corresponding to 20cm for an edge moving at 10kms$^{-1}$. Since the interferometer sample rate is of the same order as the time for the plasma edge to rotate between the two diagnostics, it is likely the ~1.1% $N_e$ dip of a single time sample, after the TS time in figure 5, prior to the

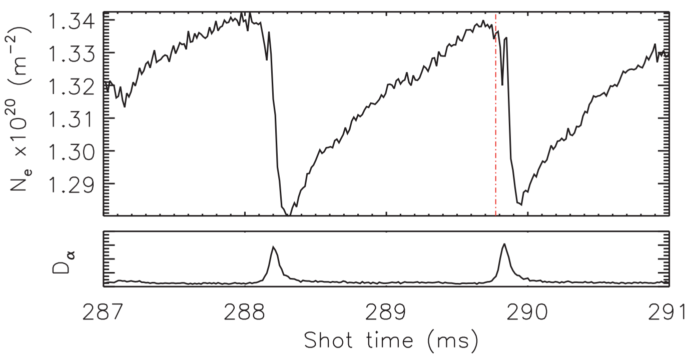


**Figure 4 –Single time point fluctuations seen during ELMs particle losses in interferometer data.**

ELM crash, is the same filament/indentation event seen by the two diagnostics. This filament/indentation related dip is much larger than interferometer noise level, a similar but smaller dip is seen in the previous ELM. The density integral measurement during the ELMs in figure 4 can be seen to rise ~4% over the ~3ms inter-ELM period and subsequently fall a similar amount over a period of ~200µs. From the TS $n_e$ data in figure 2b line integral measurements over the interferometer path length may be estimated, the $N_e$ fluctuations are calculated to be +0.2% -0.6% and -1.9% at $t_2$, $t_3$, $t_4$ respectively, relative to $N_e$ at $t_1$. These fluctuation levels agree well with the interferometer measurements.

**Conclusions** First TS profiles showing with good radial resolution through type I ELMing filaments have been obtained with multiple time slices showing the evolution of a single filament. As the filament moves from the edge of the plasma it creates a *hole* inside the pre-ELM LCFS, also observed in [4]. Radial velocities of the filaments are significantly higher than those previously measured, at least in the initial phase of filament evolution. Filament $T_e$ and particle content fall-off with distance from the last closed flux surface has been measured for MAST type I ELMing filaments. Determination of the scaling of filament energy content and filament energy content fall-off length will determine the power loadings on wall components on future devices. Important observations from the interferometer data indicate that the filaments are born before the $N_e$ loss, exist during the loss and single time slice dips in $N_e$ interpreted as *indentations* correspond with the TS evidence of toroidally local edge perturbations.

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