ELECTRON TRANSPORT DURING H-MODE ON MAST

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Introduction

During the ELM-free H-mode on the Mega Amp Spherical Tokamak (MAST) very steep electron density (n_e) gradients are observed. The edge n_e even rises above the central value. A simple 1-D phenomenological diffusion model has been set up to simulate these so-called edge density 'ears'.

H-mode on MAST

Additional heating on MAST is provided by neutral beam injection (NBI). ELM-free H-mode periods of up to 2 energy confinement times (τ_E ~ 40 ms, [1]) have been achieved during application of ~ 600 kW NBI. The L/H-transition is followed by a clear rise in $\bar{n}_e$ and a drop in D_α emission following a sawtooth crash. Figure 1 shows an H-mode starting off with a small number of ELMs followed by an ELM-free period of ~ 30 ms. The EFIT reconstruction shows a clear increase in stored energy (β_p) for the duration of the NBI in this period.

Measurements using the single pulse, 30 point Thomson scattering (TS) diagnostic in repeated discharges show that the rise in n_e starts at the edge of the plasma and then slowly diffuses inwards, as first reported in Ref. [2]. The n_e profiles in Figure 2 are normalised according to their $\bar{n}_e$ values at the L/H-transition and compared with an L-mode profile. At the edge, the density develops a very steep gradient and can rise above the central value, causing the edges to resemble 'ears'. Similar shaped edge n_e ears have previously been observed on the prototype START experiment during very short ELM-free periods (< τ_E ~ 4 ms). The central n_e remains relatively constant. The electron temperature (T_e) does not show this behaviour. In the data considered, the electron pressure (p_e) appears to be bounded by a limiting edge pressure gradient.

Figure 3 shows video stills (mainly D_α emission) during both confinement modes overlaid with its intensity at the mid-plane. These show that the plasma edge in H-mode is much more clearly defined than in L-mode, consistent with the n_e profiles in Figure 2.

Figure 4 shows 7 horizontally viewing soft x-ray (SXR) channels below the mid-plane the positions of which are indicated in the graph. The inner channels show clear sawtooth activity, with the inversion radius just outside channel #6. The signals in channels #10 - #14 are constant before and rise during the H-mode period, consistent with the edge n_e development. After the NBI termination the plasma reduces in size which explains the fall in channel #14. The rapid drop in channel #12 follows the ELM-free/ELMy-transition, in which the edge n_e ear is lost due to some frequent ELMs. A single ELM during the H-mode, detected as a short burst of D_α, causes a

sudden drop in $\bar{n}_e$ (~ 7 %). TS measurements just after an ELM in repeated discharges show that this degrades the edge n_e ear minimally or more severely depending on the size of the ELM.

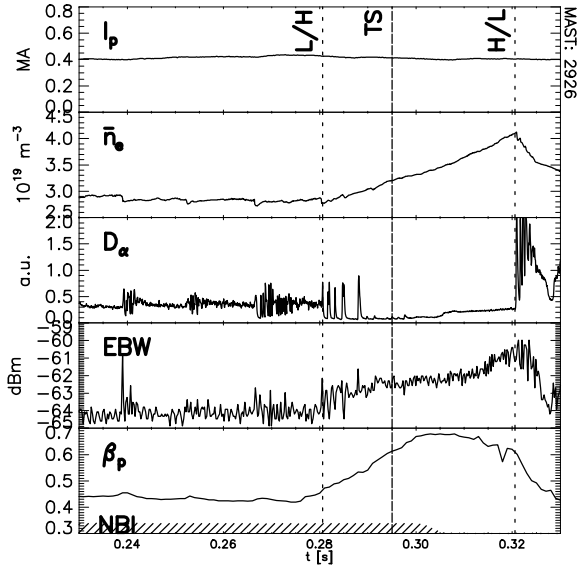

Figure 1 Time traces of plasma current (I_p), $\bar{n}_e$, D_α, EBW-emission and β_p of H-mode discharge #2926. The L/H- and H/L-transitions are indicated by the dotted lines. The dashed line indicates the time of the TS measurement.

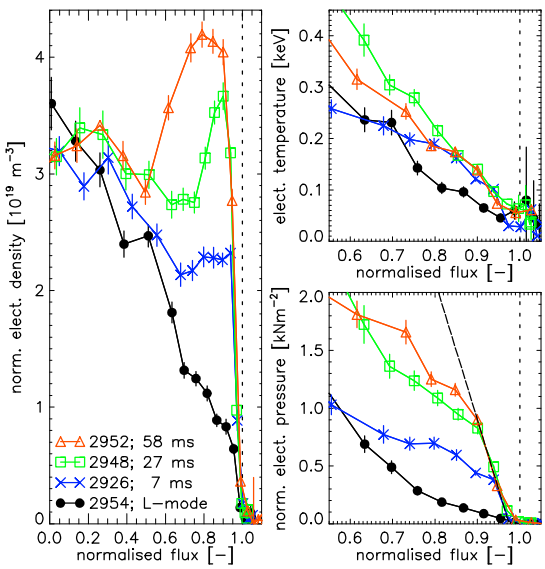

Figure 2 Profiles of n_e, T_e and p_e in 4 NBI heated discharges. Three measurements where taken at different stages of the H-mode. The time interval from the start of the ELM-free period is indicated in the graph. The n_e profiles are normalised to their average value at the L/H-transition.

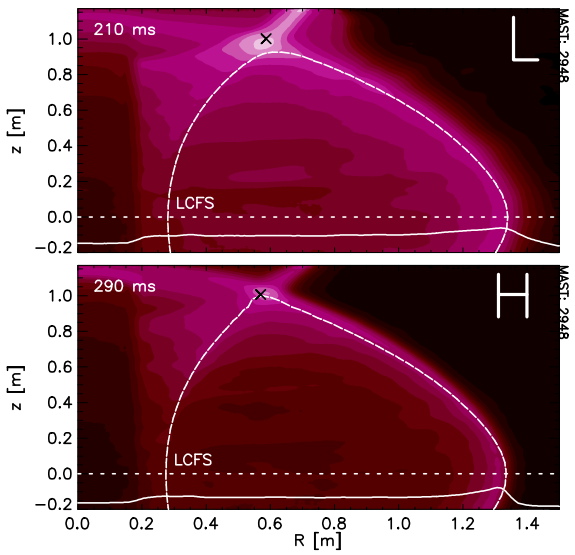

Figure 3 Video stills of the plasma #2948. The upper image shows the plasma in L-mode, the lower in H-mode. Indicated in the figure are the last closed flux surface (LCFS) and the X-point positions from EFIT. The lower trace shows the light emission at the mid-plane.

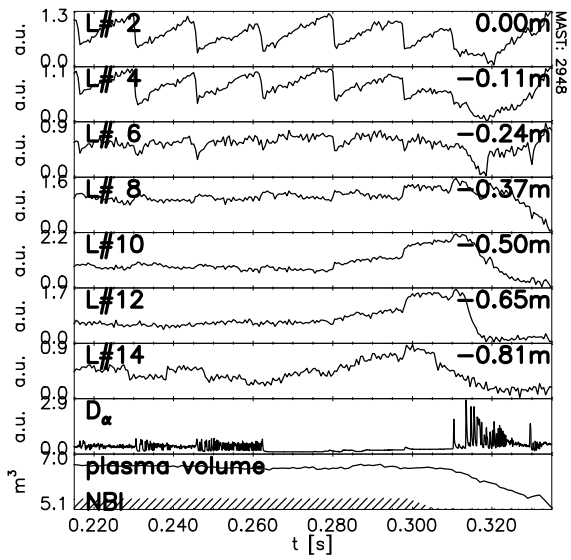

Figure 4 Lower SXR channels, D_α, plasma volume and NBI of #2948. Clear sawtooth activity is visible on the inner channels. The sawtooth inversion is close to the position of #6. The signal in outer channel #14 increases in H-mode for the duration of the NBI. Sudden steps in the signal of channel #14 are due to a diagnostic artefact.

Figure 1 also shows the 31.74 GHz signal from the electron Bernstein wave (EBW) radiometer [3]. This signal corresponds to $3\omega_{ce}$ emission at n_e around the O-mode cut-off (1.25×10^{19} m^{-3}). The rise in the emission is due to the development of the edge n_e gradient. The earliest ELMs after the L/H-transition degrade the steep gradient and lower the EBW signal. The constant higher EBW signal level follows almost immediately (< 0.5 ms $<< \tau_E$) after the L/H-transition. This indicates a rapidly established fixed steep edge n_e gradient. This is consistent with the observation in Figure 2.

In Ref. [4] it is reported that the neutral density (n_n) at the edge reduces steadily but suddenly during the H-mode period on START. This can qualitatively be explained by the increase of the edge n_e. Assuming a similar process on MAST this gives an increased electron source at the edge. The fuelling contribution of the 40 keV NBI can be neglected.

Modelling of edge n_e ears

A steeping of the edge n_e gradient during H-mode is generally explained as the result of a locally reduced diffusivity; the so-call edge transport barrier (ETB). A change of the edge transport on a time scale much shorter than τ_E from the start of the L/H-transition could explain the fast establishment of the edge n_e gradient as follows from the EBW measurements (Figure 1) and the immediate steady rise of the $\bar{n}_e$. The formation of the positive n_e gradient on the inside of the edge n_e ear could subsequently be the result of slow inward diffusion and/or an increase of the edge electron source as a result of the increased ionisation rate at the edge. To test these hypotheses a simple 1-D phenomenological diffusion model has been developed for the electron transport during H-mode on MAST. Particle conservation can be defined by:

$$\frac{\partial n_e}{\partial t} + \nabla \cdot \Gamma = S$$

where S is the radially (r) dependent electron source term. $S(r)$ is assumed to be very peaked just inside the separatrix, based on the observation of a peaked D_α profile (Figure 3, [4]). The particle flux (Γ) assumes a diffusion coefficient (D):

$$\Gamma = -D \nabla n_e$$

$D(r)$ is derived from $n_e(r)$ and $S(r)$ in the L-mode phase which is considered stationary. This defines D_L and S_L. In the ELM-free H-mode the diffusivity in a narrow edge region is set to $D_{ETB} < D_L$. The H-mode is generally ended by a sequence of ELMs during which the ear degrades and n_e drops rapidly. This is modelled by setting $D = D_{ELM} > D_L$ in the ETB region during the ELM. In the simulation the n_e profile of discharge #2948 (27 ms into the ELM-free H-mode) is developed from the n_e profile in L-mode, #2954 (Figure 2), in time steps of 10 μs. Values for D_{ETB} and D_{ELM} are adjusted to match the simulated profiles to the measurements. Also $S(r)$ is optimised similarly. Initially only an ETB of $D_{ETB} = 0.3 \times D_L$ is introduced during the ELM-free H-mode. Figure 5 shows that in this case only an n_e pedestal is produced after 27 ms. The size of the pedestal varies with S_L and D_{ETB}. In the second scenario the electron source changes in time

proportionally to changes in n_e due to the ETB, thus simulating an increase in the ionisation rate. Figure 6 now shows a reproduction of the measured data. Diffusivity profiles resulting from the model are shown in Figure 7. During the H-mode $D \sim 0.5$ ms^{-2} within the separatrix. This relates to a global particle confinement time $\tau_p \sim 2\tau_E$ estimated for parabolic n_e profiles.

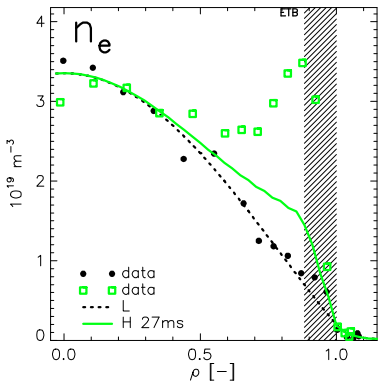

Figure 5 Simulation (lines) of n_e 27 ms into ELM-free H-mode compared to the TS data (symbols). In the model only an ETB at the location of the shaped area is introduced.

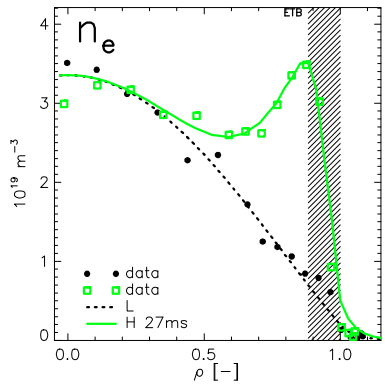

Figure 6 Simulation (lines) of n_e 27 ms into ELM-free H-mode compared to the TS data (symbols). In the model an ETB is introduced and the electron source rises proportional to n_e.

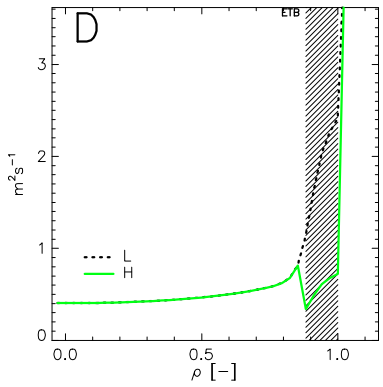

Figure 7 D profiles in L-mode (dashed line) and H-mode (solid line). The transport during the H-mode has dropped 70 % in the ETB region, indicated by the shaded area.

Conclusion

Observations of the edge n_e ear during the ELM-free H-mode on MAST have been well reproduced in simulations using a simple 1-D phenomenological diffusion model. This model shows that the edge n_e ear can be formed by the combination of an edge transport barrier and an enhanced electron source. This model gives an essentially flat $D(r)$ within the separatrix during H-mode.

In future, modelling of the electron source and n_n will follow from measurements with the newly installed D_α camera on MAST. This will help to improve the quality of the model and therefore lead to a better description of the edge n_e ear phenomena.

References

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Acknowledgements

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