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Edge E_r Structure and the ∇B Drift Effect on L–H Transition

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INTRODUCTION

For many years, experimentalists have searched for a critical edge parameter at the L-H transition by slowly raising the input power until a transition occurred [1]. Since many plasma parameters are correlated with the input power, it is difficult to identify parameters that are changing due to power balance from those that may be related to the L-H transition.

We have adopted a different approach by changing the proximity to the L-H threshold while keeping the input power constant. In DIII–D, the H–mode power threshold changes from approximately 1 MW when the ion ∇B drift is toward the X-point, to over 5 MW when the ion ∇B drift is away from the X-point. By comparing plasma conditions at fixed power for both directions of the ion ∇B drift direction, we hope to more clearly identify conditions related to the transition and not just those associated with power balance.

This paper reports on the differences and similarities of the edge and divertor plasmas when the only operational difference is the direction of the toroidal field. The midplane edge profiles of temperature and density were found to be nearly identical, independent of the ion ∇B drift direction. The amplitudes of the edge density and plasma potential fluctuations were also very similar. Differences were observed in the edge radial electric field and the plasma near the X-point region. The radial position of the X-point was also found to be important in determining the power threshold. Therefore, the sign and structure of E_r as well as plasma conditions near the X-point may be important in determining the power threshold.

EDGE REGION

Measurements of the edge E_r from charge exchange recombination spectroscopy (CER) and Langmuir probe measurements indicate that for low power L–mode plasmas, E_r changes sign when the toroidal field direction is changed [Fig. 1(f)]. The L–mode edge E_r is positive at 5–10 keV/m when the ion ∇B drift is toward the X-point, and it is negative at about the same value when the ion ∇B drift is away from the X-point. At fixed power just below threshold when the ion ∇B drift is toward the X-point, all the other measured edge parameters, including the edge temperature, the temperature gradient, and the density, remain approximately the same [Fig. 1(a–e)]. The edge T_i was slightly higher when the ∇B drift was away from the X-point but the difference was small and close to the measurement error. Edge density and plasma potential fluctuation measurements using reflectometry and Langmuir probes showed little difference in the fluctuation amplitudes, suggesting that the turbulent transport is similar in both cases. The reflectometry measurements did, however, show a difference in the average frequency of the fluctuations. One interpretation of this result is that the difference frequencies correspond to different flow velocities of the background plasmas. These results

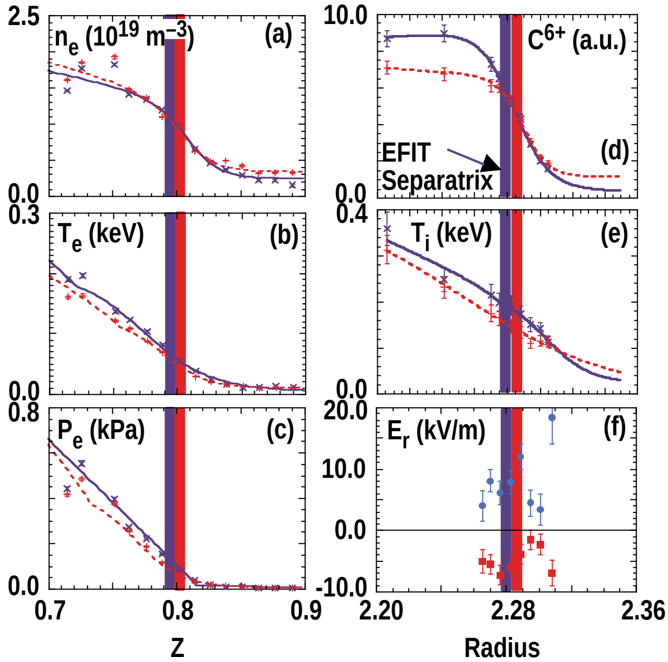

Fig. 1. Edge profiles of (a) n_e (b) T_e (c) P_e measured by Thomson scattering and (d) C^{6+} density (e) T_i (f) E_r measured by CER for ∇B drift towards (blue) and away (red) from the X–point. Basic plasma parameters were I_p = 1 MA, B = 2.1T, n_el = $2.5{\times}10^{19}$ m^{-3}, lower single null, total input power (NBI + Ohmic) 1 MW. The error bars for the Thomson measurements are small as a result of averaging 42 profiles.

indicate that additional physics, other than those involving the local edge profiles of n_e, T_e and T_i near the plasma midplane, are needed to describe the L–H transition.

DIVERTOR REGION

Changes in the power threshold are correlated with changes in the plasma conditions near the X-point and divertor region. When the ion ∇B drift is toward the X-point, there is a higher electron density just below the X-point, a higher electron temperature along the outer divertor leg, and a higher electron pressure above the X-point than when the ∇B drift is away from the X-point. A map of electron pressure made from a composite of Thomson scattering measurements along a vertical chord in the divertor region during a radial scan of the X-point is shown in Fig. 2. Under otherwise steady conditions, an L–H transition occurred when the X-point was moved to the largest radial position of this scan (Fig. 3). These results suggest

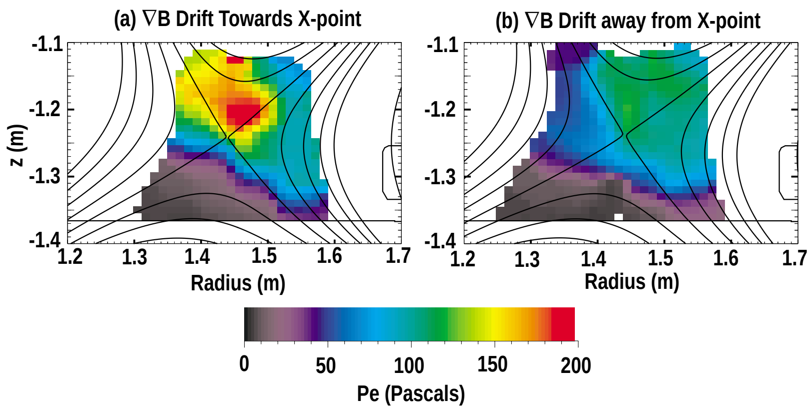

Fig. 2. Electron pressure near the X-point region for (a) B drift towards the X-point, (b) B drift away from the X-point.

that physics associated with the X-point region may play a key role in determining the edge E_r and the H–mode power threshold.

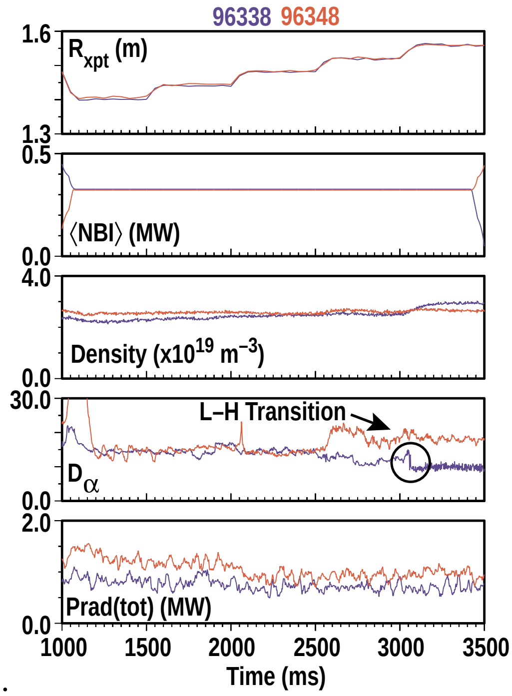

Fig 3. Time traces of (a) the X-point radial position, (b) NBI power (c) line-averaged density (d) D_α radiation from the divertor region (e) total radiated power, for two discharges showing an L–H transition at 3050 ms when the ∇B drift is toward the X-point (blue), that does not occur when the ∇B drift is away from the X–point (red).

HIGH THRESHOLD CASE

As the power is increased to 5 MW (just below threshold) when the ion ∇B drift is away from the X-point, the edge temperature and temperature gradient roughly doubles (Fig. 4). The divertor conditions also change dramatically, with the local high-pressure region above the X-point disappearing as the entire core plasma pressure increases. These results support the hypothesis that it is not the local edge profiles of n_e, T_e and T_i near the plasma midplane that determines the conditions for the L–H transition. It also suggests that although the divertor conditions influence the L–H transition, the divertor does not contain the only essential parameters for the transition. At this power level, the toroidal angular momentum input from the neutral beams becomes important and the radial electric field changes from being negative in the scrape-off-layer to +20 kV/m just inside the separatrix. This shear in E_r may be a component in the suppression of the turbulence at the L–H transition [2].

The L–H threshold condition can not be characterized by a simple value of the edge E_r shear. As shown in Fig. 4(f), the shear in E_r at high power when the ∇B drift is away from the X–point is much greater than the E_r shear at low power when the ∇B drift is towards the X-point. Since the amplitude of the edge turbulence also increases with heating power, the value of E_r shear required to stabilize the turbulence should also increase.

POLOIDAL VELOCITY SHEAR

Recent measurements of spatially resolved edge density fluctuations using beam emission spectroscopy (BES) show a large change in the poloidal group velocity of the fluctuations when the X-point location was changed while B was held fixed (Fig. 5). At 5 cm inside the separatrix, the poloidal group velocity is positive in both cases. When the ion ∇B drift is toward the X-point, the velocity reverses direction near the separatrix, creating a high shear region. When the ion ∇B drift is away from the X-point, the velocity remains nearly constant. These results are also confirmed by correlation reflectometry measurements. A leading theory of improved edge confinement in H–mode is flow shear stabilization of turbulence [3]. When the flow shear reaches a critical value, the turbulence is suppressed and radial transport is reduced. These results suggest that it may be the shear in the edge poloidal group velocity of the turbulence that is important in determining the L–H transition and the power threshold.

DISCUSSION AND SUMMARY

Changing the direction of B causes up to a five-fold increase in the L–H power threshold but does not significantly alter the edge profiles of density and temperature near the plasma midplane. These results indicate that additional physics, other than those involving the local

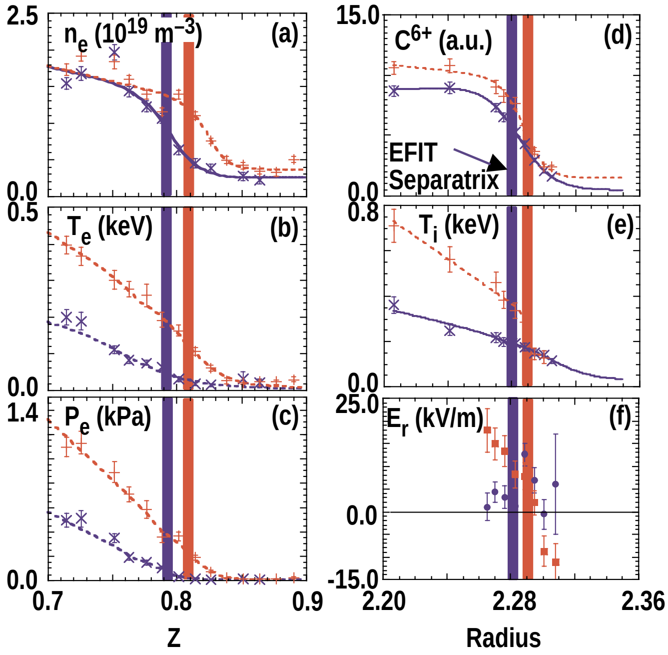

Fig. 4. Edge profiles of (a) n_e (b) T_e (c) P_e (d) C^{6+} (e) T_i (f) E_r for two discharges at power levels just below threshold. Basic plasma parameters were I_p = 1 MA, B = 2.1 T, n_e = 2.5×10^{19} m^{-3}, lower single null. For the ∇B drift towards the X–point (blue), P_{tot} = 1 MW, the ∇B drift away from the X–point (red), P_{tot} = 5 MW.

edge profiles of n_e, T_e and T_i near the plasma midplane, are needed to describe the L–H transition. The plasma conditions near the X-point show substantial changes when the direction of B is changed, suggesting that physics associated with the X-point region may play a key role in determining the H–mode power threshold. However, L–H transitions occur for very different X-point and divertor plasma conditions, indicating that although the divertor conditions influence the L–H transition, the divertor does not contain the only essential parameters for the transition. It appears that the conditions leading to an L–H transition involve a complex process that can be influenced by many different parameters. Characterizing this complex interplay between the generation of flow shear at the plasma edge, the heating power, and the plasma configuration is the subject of future work.

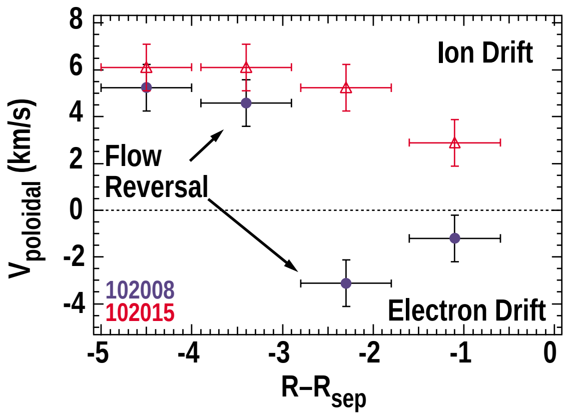

Fig. 5. Poloidal group velocity of edge density fluctuations measured by beam emission spectroscopy. ∇B drift towards the X–point (blue) and away from the X–point (red).

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