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# Transport Improvement Near Low Order Rational $q$ Surfaces in DIII-D* EX-C

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As fusion energy research progresses to burning plasma experiments it will be important to understand how to access regimes of improved confinement. In many magnetic fusion devices improvements in transport have been observed near low-order rational $q$ surfaces, often leading to the formation of internal transport barriers. Experiments to advance the physics understanding of this phenomenon have been performed in DIII-D by examining closely the timing and spatial structure of the transport changes near integer $q$. Experimental results and GYRO code calculations point to the role of local zonal flow generation near $q_{min}$ magnetic structure.

In DIII-D, the effects of crossing integer $q$ values are most readily seen in low density, neutral beam heated, negative central shear discharges where the minimum in $q$, $q_{min}$, is typically at the half radius, r/a ~ 0.5. In these discharges, transient or enduring increases in ion and electron temperature are observed as $q_{min}$ traverses integer values as shown in Fig. 1. At the $q_{min}$ = 2 crossing an internal transport barrier forms for the ions. These results are similar to those reported in other tokamaks [1].

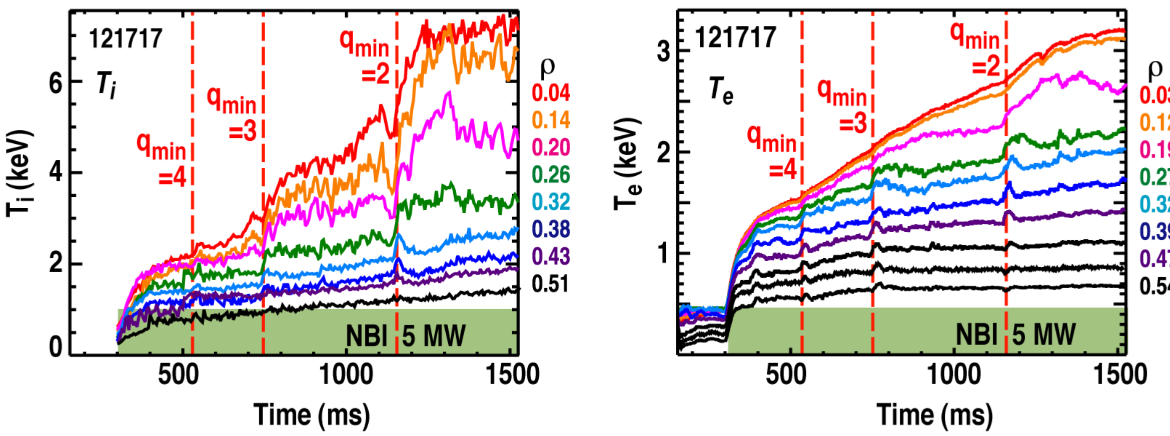


Fig. 1. Ion and electron temperature time histories for a DIII-D discharge with transport changes occurring as integer $q_{min}$ surfaces are crossed.

The timing of the transport changes relative to the appearance of the rational surface has been measured carefully in DIII-D experiments and is key to understanding the underlying physics. The evolution of the $q$ profile is determined accurately with a combination of MSE-

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constrained EFITs and observation of reverse shear Alfvén eigenmodes (RSAE) [2]. The transport changes can be closely followed by observing the $T_e$ gradient evolution using pairs of adjacent ECE channels. The measurements show that the temperature gradient increase begins 5-20 ms before the crossing of $q_{min}$ = integer, and for the case of a transient change in transport, the elevated gradient remains for a comparable interval afterwards. A typical example of the $T_e$ gradient changes around $q_{min} = 2$ is shown in Fig. 2 with the gradient amplitude expressed in terms of $a/L_{Te} = (a/T_e)dT_e/dR$.

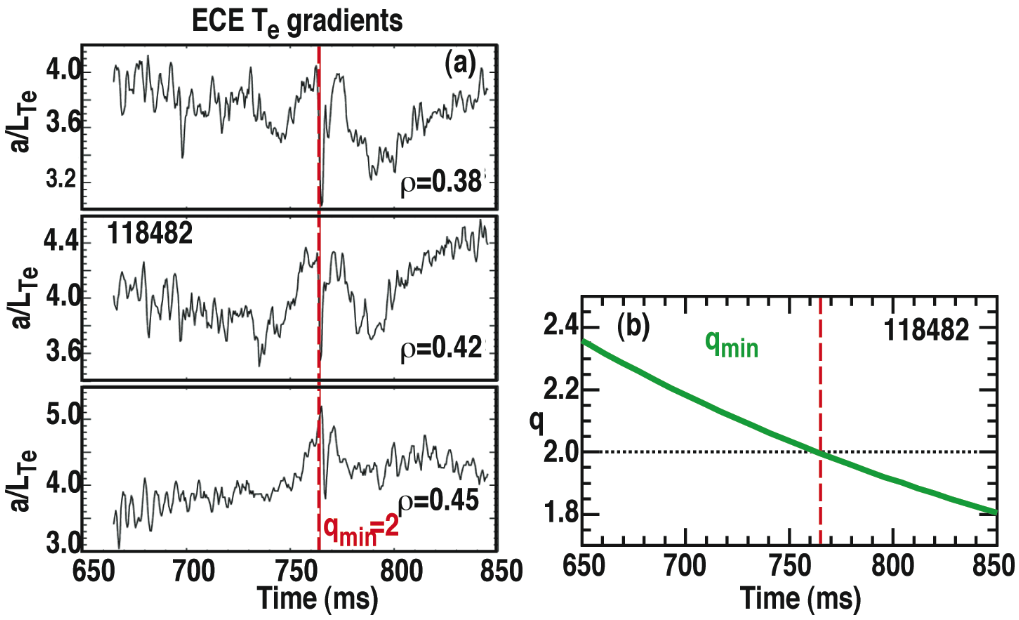


Fig. 2. (a) Time evolution of the electron temperature gradient for three locations in the vicinity of $q_{min} = 2$ showing an increase in the gradient prior to the integer $q$ crossing. (b) $q_{min}$ time history derived from an exponential fit to MSE-EFIT and RSAE mode data.

One implication of the timing of the temperature increases is that the transport changes are not caused by the effects of magnetic reconnection since the changes occur before the integer $q$ surface comes into the plasma. Also, in discharges with low heating power, no low frequency mode activity is seen in the magnetic probe signals near the time of integer $q$. High frequency modes, such as fast ion driven Alfvén eigenmodes, are not believed to be playing a role because in discharges with no measurable fast ion mode activity, the electron temperature behavior is the same.

The measured $T_e$ gradient evolution shown in Fig. 2 is in agreement with GYRO code simulations predicting profile corrugations near low-order rational $q$ surfaces [3]. These profile corrugations are zonal flow structures that occur due to the gap in rational surfaces near integer $q$. They are expected to be large for the case of strong turbulence and negative central shear as in the DIII-D experiments.

The temperature changes at integer $q$ occur with simultaneous transient reductions in low-k turbulent fluctuation levels. Also, a localized burst in the poloidal velocity of the turbulence at the $q_{min}$ radius has been detected with the beam emission spectroscopy diagnostic. Both of these observations are consistent with the zonal flow structure picture of transport reduction. For plasmas where the input power is large enough that the integer $q$ crossing leads to an ITB, we believe the ITB is triggered by the localized zonal-flow-induced changes to transport that increase the ExB shearing to the point to yield sustained turbulence suppression.

[1] J.W. Conner, *et al.*, Nucl. Fusion **44**, R1 (2004).
[2] R. Nazikian, *et al.*, Proc. of the 20th IAEA Fusion Energy Conf. (Vilamoura, Portugal, 2004).
[3] R.E. Waltz, *et al.*, Nucl. Fusion **45**, 741 (2005).