GA–A27798

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AUGUST 2014

GENERAL ATOMICS

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This is a preprint of the synopsis for a paper to be presented at the Twenty-Fifth IAEA Fusion Energy Conf., October 13-18, 2014 in Saint Petersburg, Russia, and published in the *Proceedings*.

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Work supported in part by
the U.S. Department of Energy
under DE-FC02-04ER54698, DE-AC05-00OR22725, DE-FG03-97ER54415,
and the NIFS budget code NIFS11ULHH021

GENERAL ATOMICS PROJECT 30200
AUGUST 2014

Comparative Studies of Magnetic Islands and Stochastic Layers in DIII-D and LHD EX-C

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Joint experiments on the DIII-D tokamak and the LHD stellarator/heliotron have resulted in the discovery of a series of spontaneous bifurcations in the transport across the O-point of a large externally applied m/n=2/1 magnetic island as shown by heat pulse propagation measurements in Fig. 1. The mechanism for this radial transport bifurcation (including transport parallel to the stochastic magnetic field) is consistent with a transition from smooth helical (nested) island flux surfaces with a relatively strong transport barrier to a partially stochastic magnetic field with increased transport. In addition, direct measurements of the electron density and temperature inside static magnetic islands located near the edge of the plasma have revealed a non-adiabatic enhancement of the particle flux relative to the heat flux. These results provide evidence that the plasma response due to externally applied static 3D magnetic fields can produce a dynamic evolution of the magnetic field topology in the plasma under some conditions and supports the hypothesis that a toroidal nonlinear coupling of resonant modes on various rational surfaces play a role in determining the magnetic topology of the plasma. Results from these experiments demonstrate a sensitive connection between the magnetic topology generated by the plasma in response to applied 3D perturbation fields and the overall stability/confinement of the discharge.

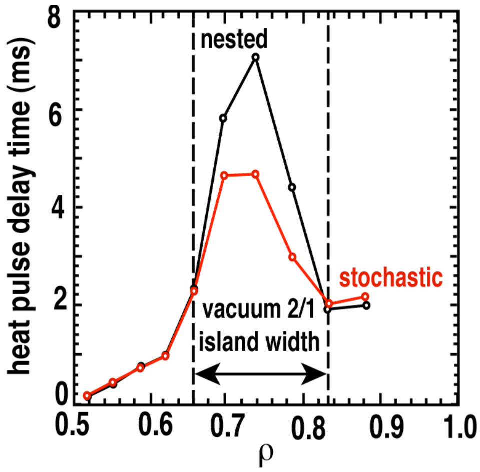

Fig. 1. Radial profile of Modulated ECH (MECH) pulse delay times showing a bifurcation of a m/n=2/1 magnetic island in DIII-D discharge 154526 from nested flux surface (black) at 2.9 s to a partially stochastic region (red) at 3.1 s.

As shown in Fig. 1, Modulated ECH (MECH) measurements, developed at LHD [1], have identify dynamic bifurcations of the transport across an m/n=2/1 magnetic island in a low rotation NBI heated DIII-D L-mode. The measurements suggest that the island O-point spontaneously transitions into a partially stochastic state during the discharge. The black curve shows an increase in the MECH delay time across a calculated island O-point located between ρ=0.65 and 0.84. This delay is due to a slowing of the heat pulse indicating the existence of reduced transport relative to that on either side of the island. The red curve was obtained a short time after the black curve in the same discharge. It suggests a change in the topology of the island consistent with a transition in a significant fraction of the outer nested island flux surfaces to a stochastic layer. Our hypothesis is that this transition occurs due to a nonlinear coupling with islands on rational surfaces that appear near edge of the discharge as the poloidal electron flow is reduced due to the drag from the 2/1 island. A flattening of the T_e profile, as measured with Thomson scattering, indicates the existence of a 4/1 island near the edge of the discharge and a time varying 3/1 island near the 95% flux surface.

Figure 2 shows the effects of a hydrogen pellet injected into an edge static m/n=1/1 magnetic island produced by the LHD RMP coil. Here, the deposition of the pellet inside the island O-point results in a non-adiabatic evolution of the electron density and temperature. In this experiment pellets were periodically injected into the O- and ×-point of a large island as well as into plasmas with no RMP induced islands. The island electron density decay rate $\gamma_{isl}=\Delta n_e/\Delta t$ was measured using a line-integrated CO_2 laser imaging interferometer in each of these cases and charge exchange recombination data was obtained which provides information on changes in the toroidal and poloidal flows, impurity pressure gradients and radial electric fields. It was found that the electron density decay rate goes through two separate phases in all cases. There is a fast exponential decay during the first 80 ms followed by a much slower decay. During the initial electron density decay, for a pellet placed inside the island O-point and with γ_{isl} averaged over the first 80 ms, γ_{isl} was found to be $7.5\text{x}10^{20}$ $m^{-3}s^{-1}$. This is about a factor of 2 larger than the initial γ_{isl} with a pellet injected into an ×-point or with a pellet in a discharge with no RMP.

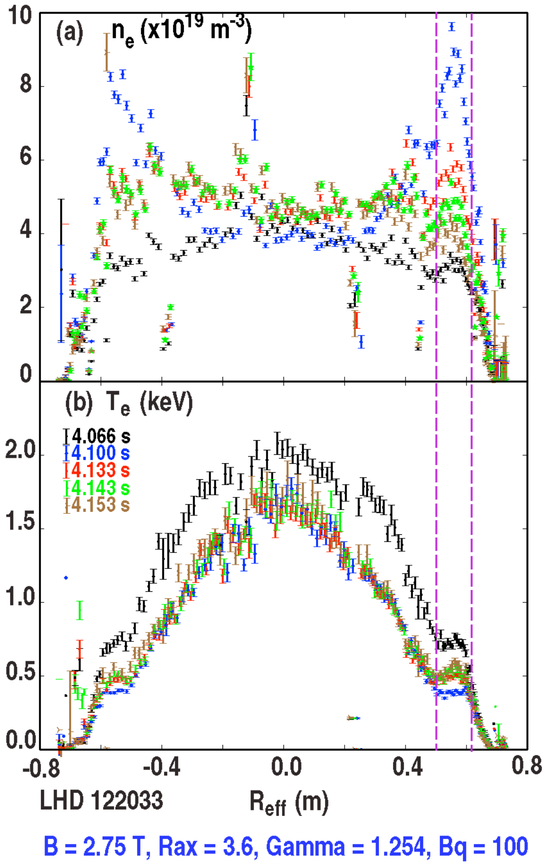

Fig. 2. Profiles of (a) n_e and (b) T_e after the injection of an H pellet t = 4.09 s in LHD.

In this experiment, radial profiles of the electron density and temperature were measured at discrete time intervals with the LHD Thomson scattering system. As shown in Fig. 2(a), the electron density inside the island increases from $3\text{x}10^{19}$ m^{-3} at 4.07 s, just before a pellet is injected into the outer edge of the discharge, to $8.4\text{x}10^{19}$ m^{-3} at 4.10 s just after the pellet is injected. This shows that the peak density inside the island can exceed the central density in the discharge by at least a factor of 2.2. It is noted that some of the pellet mass is carried across the island and deposited on flux surfaces closer to the core of the plasma. This produces a smaller secondary peak in the density profile at R_{eff} = 0.4 m. During the initial fast density decay between 4.10 and 4.13 s this smaller density peak located on the inboard side of the island shows a significantly slower decay rate than that inside the island O-point. A characteristic flattening of the T_e profile across the island is seen in Fig. 2(b). After the pellet enters the island O-point at 4.10 s the entire T_e profile drops by about 250 eV. As the density in the island O-point drops, between 4.10 and 4.15 s, T_e remains relatively constant indicating a non-adiabatic change in the pressure inside the island due a higher electron particle transport than heat transport.

Data from both MECH and island pellet experiments are providing valuable insight into the structure/dynamics of islands and transport due to the islands that can be used to determine whether the islands are screened or amplified in diverted H-mode plasma and if they are involved in modifying the stability of the peeling-ballooning modes that are believed to be responsible for ELMs.

This work was supported in part by the US Department of Energy under DE-FC02-04ER54698, DE-AC05-00OR22725, DE-FG03-97ER54415, and the NIFS budget code NIFS11ULHH021.

[1] K. Ida, *et al.*, New Journal of Phys. **15**, 013061 (2013).