LHCD driven reversed shear plasmas on Alcator C-Mod

S. Shiraiwa[1], P. T. Bonoli[1], I. Faust[1], A. Hubbard[1], O. Meneghini[1],R. R. Parker[1], A. E. Schmidt[1], G. M. Wallace[1], J.R. Wilson[2], and S. Scott[2], R. Mumgaard[1]

[1]*Plasma Science Fusion Center, MIT, MA, USA*

[2]*Princeton Plasma Physics Laboratory, NJ, USA*

A goal of LHCD on Alcator C-Mod is to provide a current profile control tool to explore a high bootstrap current, advanced tokamak (AT) plasma regime [1, 2]. One way to approach the AT regime is to produce a strong reversed shear profile by LHCD and to exploit a spontaneous development of an internal transport barrier (ITB) [3, 4], which increases bootstrap current. Key issues in developing such an operational scenario include to predict current profile modification by LHCD and its effect on core transport. To assess these issues, we performed LHCD experiments in relatively low density, where average density is about $0.5 \cdot 10^{20}m^{-3}$, fully non-inductive regime. In some of these discharges, we observed spontaneous ITB development. In this paper, we presents these ITB transitions observed in LHCD plasmas on Alcator C-Mod and the initial result of a transport modeling using the TRANSP/LSC code.

Figure 1 shows an example of an ITB discharge. Total 0.9 MW of LHCD power at 4.6GHz LHCD was injected from 0.9 s to 1.4s to a plasma with 440 kA of plasma current and the line averaged density of $6.5 \cdot 10^{19}m^{-3}$, and the plasma was sustained nearly fully non-inductively. As shown in Fig. 1 (c), an abrupt increase of the central temperature occurred (ITB transition) at around 1.2 s. At the same time, the soft X-ray emission from the central region of plasma was observed to increase. Figure 2 compares the temperature and density profiles before and during the ITB phase. The temperature profile shows a steep gradient around r/a = 0.2. On the other hand, there is no change in the density profile.

In this discharge, the sawtooth activity was suppressed at 1.0 s, and is not considered a direct cause of the transition. Indeed, under the same discharge condition, the transition to the improved confinement regime was consistently observed about 200-300 ms after the LH turn-on, which is about the same as the current diffusion time. Also, the transition did not occur, when a lower LHCD phasing was used and the LHCD driven current was expected to be more peaked at the center. Moreover, this high temperature period often ended before the LHCD turn-off (ITB collapse). Figure 1. (e) shows the soft X-ray emission profile just before the ITB collapse. Characteristic oscillations were observed to grow towards the ITB collapse, which is likely to be m=2 mode activity. These experimental observations suggest that the current profile modified by LHCD played a key role to the transition to ITB phase and the MHD activity leading to its collapse.

To better understand the evolution of current profile during LHCD, we performed TRANSP/LSC simulations of one of ITB discharges. In this simulation, the LCS code, a ray-tracing code coupled with a 1-D (in the parallel velocity) Fokker-Planck calculation, was used to predict LHCD power deposition and driven current profile. Constant Z_{eff} was used, which was chosen to match the loop voltage in the Ohmic phase between simulation and experiment.

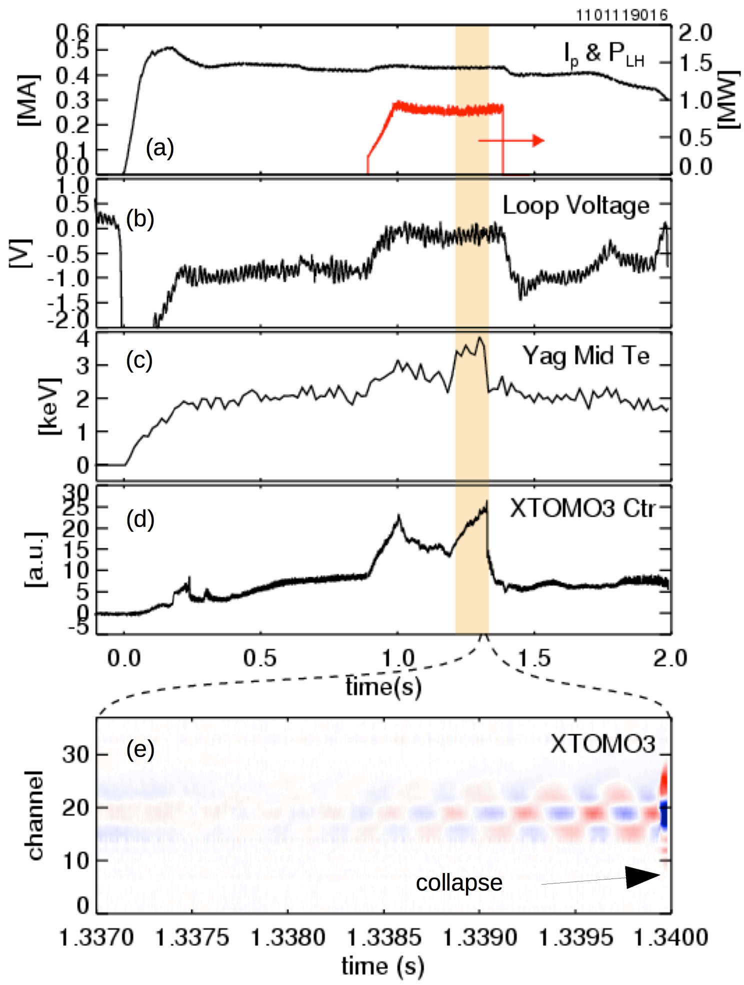

Fig 1: Fig 1: A typical ITB discharge on Alcator C-Mod. (a) plasma current and LHCD power, (b) loop voltage, (c) the central temperature measured by Thomson scattering, (d) soft X-ray emission, and (e) expanded view of soft X-ray emission profile before ITB collapse. $N_{//} = 1.9$ was used for LHCD antenna phasing.

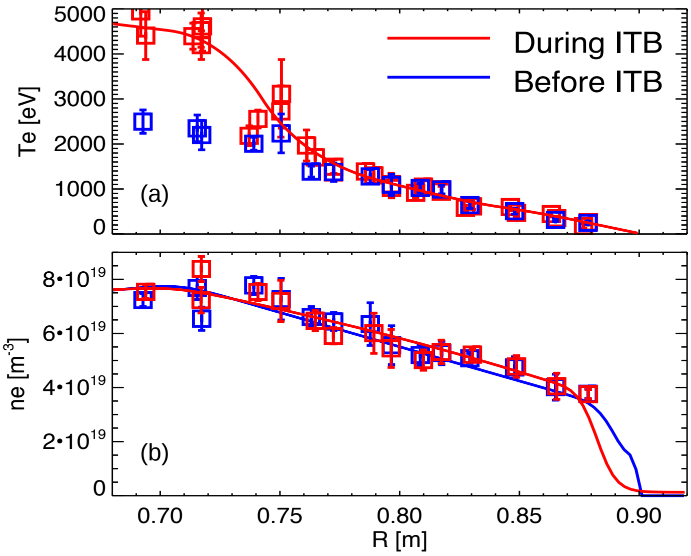

Fig 2: Comparison of temperature and density profiles before (blue) and during (red) ITB phase.

Figure 3 (left) shows the time evolution of current profiles during LHCD. It is shown that the LHCD driven currents are broad and modify a peaked current profile to a hollow profile. Two profiles of total current reconstructed by EFIT using MSE pitch angle measurements and pressure profile measurements as constraints are overlaid, showing good agreement. As a result, the central safety factor increased as shown in Fig 3. (right), and shear

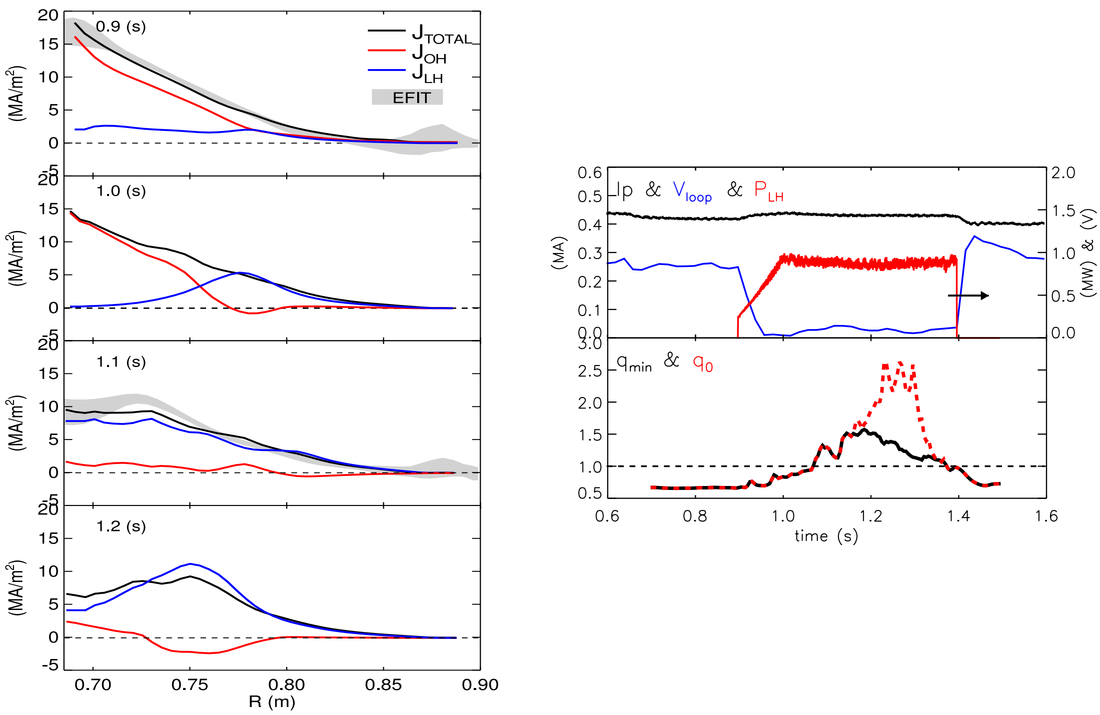

Fig 3: TRANSP/LSC simulation of the discharge shown in Fig. 1. (left) the profiles of OH, LH, and total currents during LHCD. The EFIT reconstruction was constrained by MSE pitch angle and pressure measurements. (right) time evolutions of the current, loop voltage, LHCD power, the central safety factor and the minimum safety factor.

reversal, indicated by $q_{min} < q_0$, occurred around 1.2 s, which is when the ITB development was observed in the experiment. Also, the location of q_{min} was consistent with the location where the steep gradient was formed in T_e profile.

In summary, the first LHCD driven ITB plasma obtained on Alcator C-Mod is presented. These ITB formation was characterized by an abrupt increase in the temperature profile in the core region, and no change was observed in the density profile. Prediction of current profile evolution using TRANSP/LSC has good agreement with equilibrium reconstruction and shows that the reversed shear profile was achieved by off-axis LHCD when the ITB transition occurred. Further analysis and direct measurement of core turbulence is planned to understand the ITB formation physics.

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Reference

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