*Rapid Communications*

# Observation of Electron Temperature Profiles with Bulged Regions around the $\iota$ = 1 Magnetic Surface of the Large Helical Device

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A highly space-resolved Thomson scattering system installed on the large helical device revealed that the electron temperature profile of the plasma occasionally has bulged regions at the location where the iota is close to 1.

**Keywords:**
LHD, magnetic island, electron temperature profile, Thomson scattering

In toroidal plasma, a set of nested magnetic surfaces (magnetic configuration) ‘tells’ plasma how to behave, and the plasma, in turn, ‘tells’ the magnetic configuration how to change. This mutual interaction between a magnetic configuration and plasma is of a particular interest in plasma physics. The most prominent example of such involves a magnetic island, which is a topological defect imbedded in the otherwise almost complete magnetic configuration. A magnetic island usually deteriorates the global energy confinement because it scarcely has the resistance against the heat flow from the inner to the outer regions bypassing the magnetic island. It is usually believed that the $T_e$ profile across a magnetic island is flat, which implies that there is no heat source inside the island and/or that the island’s confinement ability is very low. However, this is not necessarily the case a priority. Indeed, a magnetic island may have a set of nested magnetic surfaces inside, and hence will have a high energy confinement, giving bulged $T_e$ profile if a tiny amount of heat source is present. LIDAR Thomson scattering diagnostic on JET revealed [1] small structures at the locations where the safety factor $q$ (= $1/\iota$) is simple rational numbers. Although some of the structures presented in the figures seem to be a bulge (hump), they are not convincing enough because of the poor spatial resolution and large error bars of the diagnostic. In this *rapid communication*, we show examples of $T_e$ profiles that do have bulged regions near the $\iota$ = 1 surface, and discuss their implications.

The $T_e$ profiles along the major radius on the $Z = 0$ plane at a horizontally elongated section (4-O) of the LHD plasmas are obtained by a repetitive (10-150 Hz) multi-channel (200) Thomson scattering system [2]. The key that makes it possible to convincingly claim the significance of a structure on $T_e$ profiles is the spatial resolution that takes into account of the cross talk among the spatial channels and the magnitude of errors (error bars). If the laser beam size were negligibly small, the light collected by neighboring channels would be independent of each other. However, in practice, the finite size of the beam introduces cross talk between the neighboring channels (‘defocused blur cross talk’). This cross talk is less than 10% at most. The separation $\Delta$ between the scattering volumes is dependent on the scattering position $R_{sc}$: $\Delta$(3.6 m) = 1.8 cm, $\Delta$(4.6 m) = 1.3 cm. Errors in $T_e$ arise mainly from the shot noise, excess noise, and plasma light fluctuation. The shot noise and the plasma light fluctuation can be estimated with sufficient accuracy based on the scattered and background signals. The excess noise, which is intrinsic to the avalanche process in the detectors, enhances the shot noise and makes the error estimate somewhat complex. To alleviate this problem we calibrate the enhancement factor using ~1,000 $T_e$ profiles obtained from a long duration discharge. Thus by settling the key issues, though not yet completely, and examining the raw data carefully, we convincingly show examples of $T_e$ profiles.

Figure 1(A) shows a $T_e$ profile with bulges around the location where $\iota$ = 1 (vertical lines), at which the well-identified $m/n$ = 1/1 island is intentionally enhanced by the LID coil [3]. Here, the plasma was created by ECH and sustained by NBI in a static magnetic configuration specified by $B$ = 2.8 T, $R_{ax}$ = 3.6 m, $\gamma$ = 1.245, $B_q$ = 100% and $I_{LID}$(6O) = 1,938 A [4]. The evolution of diamagnetic energy ($W_p$), absorbed NBI power ($P_{nbi}$) and line average density ($n_e$) are shown in Fig. 1(C). The $T_e$ profiles around the $\iota$ = 1 regions occasionally change as shown in Fig. 1(B). The statistical error bars (1 standard deviation) in (A) and (B) are less than the size of the plot-symbol; however, some systematic errors have not yet been removed. The bulges at the inner ($R$~4.34

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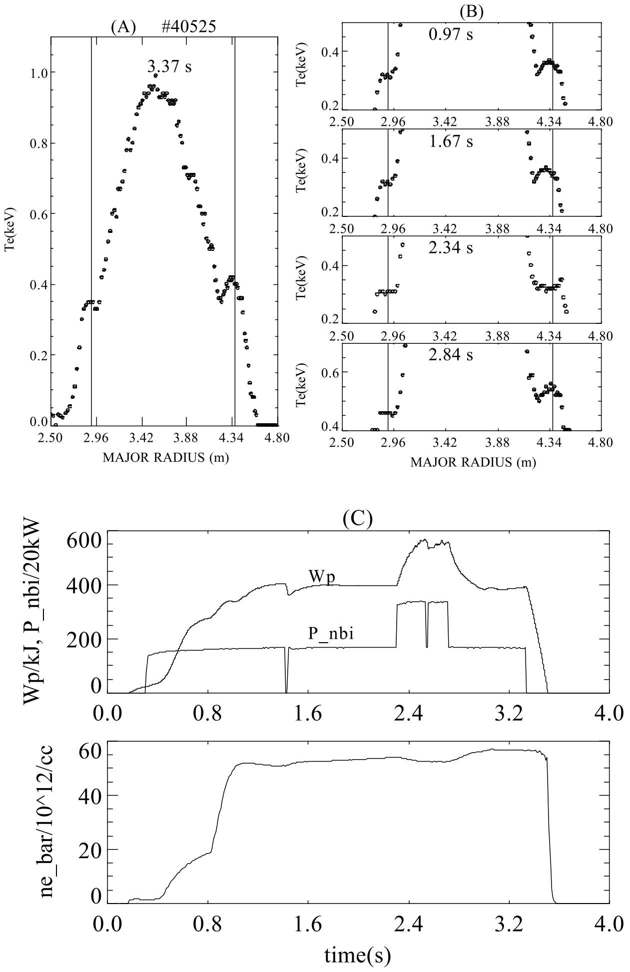

Fig. 1 (A) $T_e$ profile with bulges around $\iota = 1$ (vertical lines). (B) $T_e$ profile around $\iota = 1$ at various instants. (C) Evolutions of $W_p$, $P_{nbi}$ and $n_e$. NBI#1 is active between 0.27–2.7 s, and NBI#3 is between 2.3–3.3 s.

m) and the outer ($R$~2.85 m) $\iota = 1$ regions imply that heat is certainly deposited and confined inside the island. Another bit of evidence strongly supporting this implication is that the $T_e$ at the outer side bulge is higher than that at the inner side, which is reasonable if the magnetic island has its O-point at the outer side as the vacuum magnetic island does. Even if bulged shapes are not clearly seen due to poor data quality, differences in $T_e$ between the in-and-out sides are occasionally observed, indicating that island heating is a rather common phenomenon. The sizes of the bulges depend on the heating configuration: on average, the bulge is larger when the plasma is heated by NBI#3 than by NBI#1, which is reasonable in considering the volume commonly occupied by the neutral beam and the island. The bulges sometimes shrink and become flat regions though plasma and heating conditions are almost constant in time. An explanation for this is that the island may take various energy confinement states, ranging from the lowest state (flat profile) to a higher one (bulged profile). Another possible explanation, or rather a speculation, is that the plasma is ‘struggling’ to find a way to accomplish ‘self-healing’ [5] by fluctuating the topology of the island. The information obtained by the present 1-dimensional $T_e$ profile is quite insufficient for understanding the island that is intrinsically of a 3-dimensional nature. Plasma physics seems to require further development in diagnostics. If the island is preferentially heated, for example, by ECH, it will provide us opportunities to study Heliac plasma in LHD.

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