Effects of ICRF and LHCD on SOL Density Profiles on Alcator C-Mod

C. Lau,1 G. Hanson,2 Y. Lin,1 O. Meneghini,1 S. Wukitch,1 B. Labombard,1 R. Parker,1 S. Shiraiwa,1 G. Wallace,1 J. Wilgen,2 and the Alcator C-Mod Team

1MIT Plasma Science and Fusion Center, Cambridge USA
2Oakridge National Laboratory, Oakridge USA

Abstract. A swept-frequency X-mode reflectometer has been installed on Alcator C-Mod to measure the SOL density profiles at three poloidal locations adjacent to the new Lower Hybrid Launcher. First results on density profile modifications at the LH launcher due to ICRH or LHCD non-linear effects will be presented. Experimental measurements indicate that the application of LH power creates a density depletion near the LH launcher, which is consistent with the influence of a ponderomotive force. At high $\bar{n}_e$, LH power increases the density in the far SOL. Application of low ICRF power decreases the density in front of the LH launcher, which may be consistent with ICRF sheath induced convective cells. Preliminary results, however, indicate that field line mapping and increasing ICRF power do not modify the density profile significantly.

Keywords: Scrape-off-layer, density profiles, ICRF, LH, reflectometer

PACS: 52.35.Hr, 52.55.Fa, 52.35.Mw, 52.40.Kh, 52.40.Fd

Introduction

The SOL density profile in front of the ICRF antennas and LHCD launchers is extremely critical in understanding and predicting ICRF and LHCD coupling. A X-mode reflectometer[1] has been used to measure the SOL density profiles toroidally adjacent to the new LH launcher. Specifically, density profiles modifications due to ICRF or LHCD effects will be shown here.

The reflectometer operates between 100 and 145GHz, which corresponds approximately to a density of $5 \times 10^{16}$ to $6 \times 10^{19}$ m$^{-3}$ at $B_0 = 5.4$T. It uses the differential phase technique to reduce the effects of fluctuations on the density profile measurements. Further details can be found in Ref. 1. The reflectometer measures the density at three poloidal locations adjacent to the LH launcher (Fig. 1); results shown here are from the middle pair of horns. The LH launcher also contains three pairs of Langmuir probes that can each measure the density at one location.

In this paper, all measurements were made by time averaging over many frequency sweeps in steady state plasmas, so as to minimize the effect of fluctuations, and provide the best possible time-averaged density profile. There are two large systematic error bars, however, associated with reflectometry: radial location of the first cutoff layer and accuracy of the differential phase measurement. The phase measurement, which determines the shape of the density profile, is not a significant concern since the instrumental errors in the waveguide phase are believed to be smaller than the changes
in plasma phase shown in this paper. Also, for comparisons between two density profiles, an accurate phase measurement is not essential, as the systematic phase errors will be the same for both density profiles. The determination of the first radial cutoff layer is the much more significant error. The density profile modifications due to ICRF and LHCD are very small, so other data is often needed to constrain the profiles. Since the Langmuir probes are located near the reflectometer horns, the radial error of the reflectometer measurement can be reduced by radially shifting the density profile to match the Langmuir probes. This gives an estimated 2-3 mm radial error. The Langmuir probes are fixed to the LH launcher, so the relative radial errors between density profiles should be very small. Thus, while the systematic errors may be large, the small relative errors make it possible to compare density profiles even for small density profile modifications.

![Image](image_url)

**FIGURE 1.** a) The LH Launcher, three pairs of X-mode reflectometer horns adjacent to the launcher, and six Langmuir probes on the launcher are shown on the left. b) The toroidal locations of the LH launcher and the 3 ICRF antennas are shown on the right.

### Density Profile Effects due to ICRF power

Alcator C-Mod has 3 ICRF antennas (Fig. 1 right): two 2-strap antennas and a 4-strap antenna that are located 36, 72, and 144° away toroidally from the LH launcher, respectively. A typical density profile modification for a low ICRF power (150kW) discharge is presented in Fig. 2a). Fig. 2b) shows a blowup of the density profile near the LH Launcher. Addition of ICRF consistently decreases the density a couple of mm in front of the LH launcher and usually increases the density further away from the launcher. The shape of the density profile also changes substantially in front of the LH launcher. This density decrease and density profile shape change is reminiscent of reflectometer results on TFTR[2], in which a RF sheath induced convective cell model was used to explain the experimental data[3].

Experiments to date, however, indicate that increasing ICRF power up to 1MW, changing the plasma current, or using a different ICRF antenna does not have a strong effect on the SOL density profiles. In front of the LH launcher, the density consistently decreases with ICRF power, but increasing ICRF power does not seem to further modify the profile in a strong or predictable way. Different currents and
different antennas have also been tried, and the density decrease in front of the LH launcher has been observed even when the active ICRF antenna is not mapped to the reflectometer horns. More work needs to be done verify this preliminary conclusion.

**Density Profile Effects due to LH Power**

The effects of LH on the SOL density profiles strongly depend on $\bar{n}_e$. Fig.3) shows a density profile for $\bar{n}_e$ of .8, 1, and $1.4 \times 10^{20} \text{ m}^{-3}$. For all three densities, density profiles with and without LH power are plotted. When LH is applied, the density drops in front of the LH launcher for all line averaged densities. A sub-mm slow wave evanescent layer ($2.6 \times 10^{17} \text{ m}^{-3}$ for 4.6GHz LH waves) appears to be created in the lowest density case, while no evanescent layer is observed at higher densities. As $\bar{n}_e$ is increased, LH power also increases the density a few mm in front of the LH launcher. This density increase is most pronounced for the highest density case. It needs to be noted again that all experimentally measured profiles have a systematic large radial error bar possibly up to 3mm. This will not change the general trends between the density profiles, but obviously makes the measurement of the vacuum gap questionable. Lower hybrid coupling simulations, however, were done for a range of densities with low (watts) and high (350kW) LH power, which shows reasonable agreement with the experimentally measured LH reflection coefficients [2]. This gives some more confidence in the density measurement, as a .5mm radial shift for all the radial profiles will drastically change the simulated LH reflection coefficients.

Possible physical mechanisms for the LH induced changes to the density profiles are ponderomotive force, ionization, and vortex structures. Ponderomotive forces, which decreases the density, have been hypothesized to explain LH coupling results in JET[4], Tore Supra[5], and Asdex[6]. Possible effects of ionization were reported in JET[4] and effects of vortex structure in Asdex[6]. Ponderomotive forces do not depend on density, which might explain why the density profile decreases in front of the LH launcher for all $\bar{n}_e$. Ionization effects, which increase with density, may explain why the LH induced density increase is most prominent at high $\bar{n}_e$. Vortex structures could also play a role in affecting the density at this poloidal location. Recent simulations on
Alcator C-Mod[7] indicate that ponderomotive forces could be consistent with the density profile changes. The current model currently somewhat under-predicts the experimentally measured density profile, so ionization or vortex structures may need to be included in the model for better agreement.

FIGURE 3. Density profiles with 350kW LH power (solid) and without LH power (dashed) are shown for three different line averaged densities of .8, 1 and 1.4x10^{20} m^{-3}.

Discussion

Nonlinear modifications due to ICRF and LHCD have been observed using a X-mode reflectometer located besides the LH launcher. For both application of ICRF and LHCD powers, the density decreases in front of the LH launcher for a wide range of plasma parameters. At high densities, LHCD power also increases the density a few mm away from the LH launcher.

ACKNOWLEDGMENTS

This work was supported by U.S DoE under awards DE-AC05-00OR22725 and DE-FC02-99ER54512.

REFERENCES

7. Meneghini O. et al., this conference