First Results of SOL Reflectometer on Alcator C-Mod

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Highlights

• Results from SOL reflectometer
  – Electronics and waveguide calibrations have been done (HTPD 2010)
  – Data analysis routines have been written (2010-2011)
  – Data accumulated from late 2010 to 2012

• First Data shows poloidal asymmetries and toroidal asymmetries in density profiles (bulk of this poster)
  – Due to differences in private SOL
  – Due to intentional localized gas puffing
  – Due to application of LHRF power

• Current and Future Work
  – Understand the mechanisms for these local density profile modifications and their relationship to LHRF coupling
  – Use reflectometer horns close to ICRF antenna to study effects of ICRF power on SOL density profiles
Background
ICRF and LHRF coupling is determined by the density profile

- Cold plasmas near antenna
- Magnetic field is well known
- Density profile is main unknown knob
  - distance to cutoff
  - density gradient after cutoff
- Increasing ICRF and LHRF power can affect density profiles, which in turn could impact coupling
  - Suggestive evidence can be seen in high power LH experiments
• Use X-mode frequency R-cutoff from 100-146GHz
  – Yields density range of $5 \times 10^{16}$ to $6 \times 10^{19}$ m$^{-3}$ at $B_0 = 5.4$T
• Each measurement is average of 25 sweeps at 40μs per sweep.
• Measurement at one of three pairs of horns (only one horn for each discharge) at top, middle, and bottom of LH Launcher
• LH launcher and attached limiter and diagnostics can move in and out radially
Radial offset errors in Density Profile Inversion is dominant error source

\[ \phi(\omega) = 2 \frac{\omega}{c} \int_{r_0}^{r(\omega)} Ndr - \pi / 2 \]

\[ r(\omega) = r_0 - \frac{c}{\pi} \int_0^{\omega} \frac{d\phi}{d\omega'} \frac{d\omega'}{(\omega^2 - \omega'^2)^{1/2}} \]

\[ r(\omega_{i+1}) = r_0 - f(\phi_i, \phi_{i-1}, \omega_i, \omega_{i-1}, r(\omega_i), r(\omega_{i-1}), ..., B(r)) \]

- .1% error in B ~ 1mm error in \( r_0 \)
- Errors in \( \omega_0 \) also contribute
- Density profile is shifted to match Langmuir probe data
  - Reduces error to estimated 2 to 3mm

Reflectometer equation

O-Mode

X-mode: (Bottolier-Curtet)
Phase errors are another contribution to error source

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- Largest contribution to \( f(...) \) is phase measurement.
- Systematic phase errors can occur (phase drifts, structure?, others?), especially for large density gradients
- Statistical errors in \( f(...) \) are dependent on plasma density fluctuations, differential phase technique etc.; they are often small after averaging over many sweeps
- Inversion errors can propagate through to \( f(...) \), especially at low densities. They are usually small.
Typical Raw Data (phase and amplitude) is shown.

Beat frequency ($d\phi/dt$) can be related to group delay ($d\phi/d\omega$) by the user controlled sweep speed ($d\omega/dt$).
Comparision between Scanning Langmuir probes and SOL reflectometer in ohmic discharges is reasonable, especially in common SOL. Shading indicates +/- 1 standard deviation of the radial errors. This is purely statistical and does not indicate systematic errors (including relative radial errors between profiles).

Note the disagreement in the behind the plasma limiter, presumably due to differences toroidally.
Localized measurements within port is important since LH launcher can move radially in and out and thus create different density profiles.

Graph on left compares two identical discharges at different LH launcher locations.

Profiles agree in near SOL and disagrees behind plasma limiter. It is interesting that it disagrees in front of the LH Launcher in both cases, indicating that connection length may not the only issue (differences in recycling, source?).
Effects of Localized Gas Puffing
LH camera can see effects of localized gas puffing

• Localized gas puff installed at top and bottom locations adjacent to LH launcher
• Top reflectometer horns (shown in yellow) is used for this set of discharges
• Objective is use gas puff to improve antenna performance without affect global plasma performance.
Density profile is modified by top gas puff as measured by top reflectometer horn.

There is some global changes due to the increase in line averaged density, but there are also clear local SOL density profile modifications due to the localized gas puff.
Density profile is not modified by bottom gas puff as measured by top reflectometer horn. Density profile modification is indeed local, as top reflectometer horn sees a much stronger effect from top gas puff.

More work will be done in the future for this.
Effects of LHRF Power
“Stripes” are routinely seen during LHRF discharges.

- This data was taken piggyback during LH discharges.
- Only 1 reflectometer horn can be used for each discharge.
Middle horn is near stripe, so it sees large change during LH operation.
Bottom horn (not near stripes) does not see nearly as large of a change during LHRF operation.
Top horn sees small changes during LHRF operation
Reflectometer Horn is closer to $n_{||}=1.9$ stripe than $n_{||}=1.4$ stripe, which explains differences in SOL density profile with different $n_{||}$.
Data from 2010/2011 indicates that behavior may be stronger at higher densities and higher LH power.

No data exists during high density, high power LH discharges for top and bottom horn. Effects with LH power are much more apparent at high densities.
Note that it’s extremely hard to believe that ionization is the only physical mechanism here due to the large change in density profiles behind the LH launcher.
Conclusions

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