

## A Basic Experiment on the Production and Identification of ETG Modes

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### Introduction and Abstract:

The electron temperature gradient (ETG) mode is believed to be one of the strongest candidates for the anomalous electron energy transport [1,2].

Using a DC bias heating scheme of the core plasma, we are able to produce a sufficiently strong electron temperature gradient for exciting ETG modes in Columbia Linear Machine (CLM). A high frequency mode thus produced has all the relevant signatures of ETG modes:  $\omega/2\pi \sim 2.3\text{MHz}$ ,  $m \sim 14-16$  and  $k_{\parallel} \sim 0.01\text{cm}^{-1}$ . The scaling of its fluctuation level with the temperature gradient scale length and the radial structure are found to be roughly consistent with theoretical expectations.

### Experimental Results:

CLM is an axisymmetric steady-state linear machine that produces a quiescent, magnetically confined, collisionless plasma. The typical plasma parameters in CLM are:  $n \sim 5 \times 10^8 - 5 \times 10^9 \text{ cm}^{-3}$ ,  $B \approx 0.1T$ ,  $T_e \approx 5 - 15\text{eV}$ , and  $T_i \approx 3 - 5\text{eV}$ . In order to measure the ETG modes, Langmuir probes with the frequency response up to  $10\text{MHz}$  and high spatial resolution ( $\sim\text{mm}$ ) are specially designed. This frequency response is enhanced by minimizing the input capacitance via placement of surface mounted mini resistor (SMD  $100k\Omega$ ) close to the probe tip.

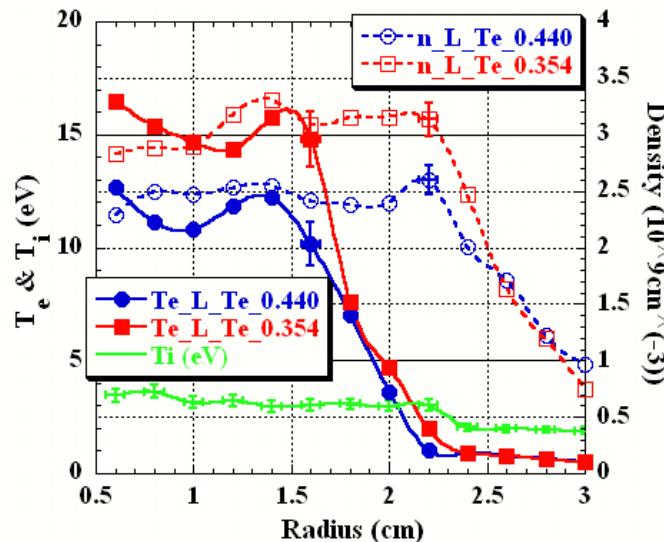


Fig. 1. Radial profiles of electron / ion temperature and plasma density.

The temperature and density profiles are shown in Fig. 1. It can be seen that a sharp electron temperature gradient is obtained while ion temperature profile is almost flat. Moreover, the density profile has no gradient within the region of strong electron temperature gradient. So the appropriate ETG drive parameter in this case is  $L_{Te}^{-1} = (dT_e / dr) / T_e$ , but not  $\eta_e = d \ln T_e / d \ln n$ .

The power spectra with many different  $L_{Te}$  have been measured, but only three of these are shown in Fig. 2. It is clear that the potential fluctuation level increases with decreasing  $L_{Te}$  as expected.

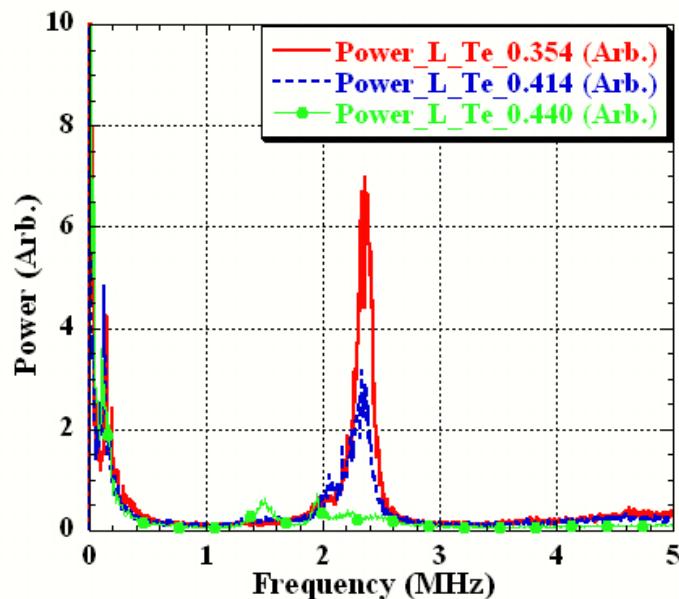


Fig. 2. Power Spectra of potential fluctuation with different  $L_{Te}$

For ETG modes, the azimuthal wave number is much larger than the parallel wave number, as typical of drift waves. We measure the azimuthal wave number via the two very close probe tips of twin probes aligned in the circumferential direction. If the distance between the two tips of the twin probes is  $l$ , the azimuthal wave number can be calculated as  $m = 2\pi r \phi_{\max} / (360l)$ . In our case,  $\phi_{\max} \approx 130^\circ$ ,  $r \approx 1.9\text{cm}$  and  $l \approx 0.28\text{cm}$ , so  $m$  can be found as  $\sim 15$ , which corresponds to  $k_{\perp} \rho_e \approx 0.05$ .

From the phase measurement we can also see that there are about 3 modes with different  $m$  hidden inside the peak ( $m=14, 15, 16$ ) in the power spectrum (Fig. 3). The negative sign of the phase shift corresponds to the electron diamagnetic direction, which is appropriate for ETG modes.

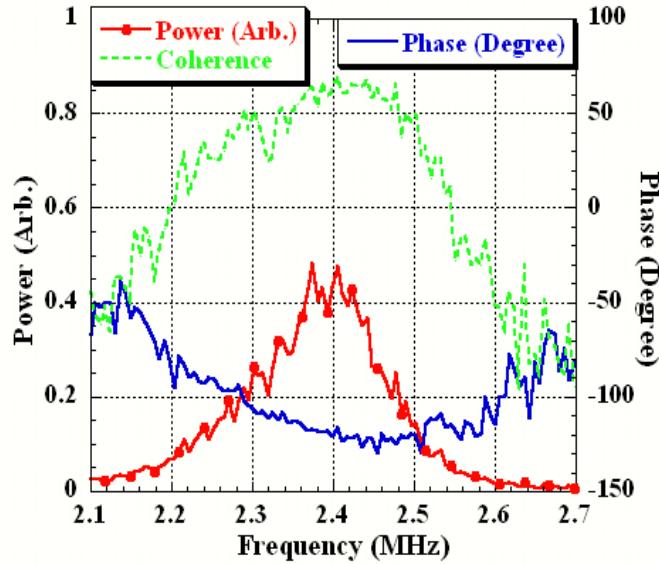


Fig. 3. Measurement of the azimuthal wave number.

In CLM, the azimuthal Doppler shift due to the equilibrium electric field is about  $m \cdot \omega_{\bar{E} \times \bar{B}} / 2\pi \sim m \cdot 135 \times 10^3 \sim 2\text{MHz}$  for  $m \approx 15$ . After subtracting the Doppler shift from the frequency detected in the lab frame, we obtain the frequency in the plasma frame as  $f_{\text{plasma frame}} = f_{\text{lab frame}} - m \cdot f_{\bar{E} \times \bar{B}}$ . From the peak in the spectrum we observe (see Fig. 2), the frequency of the mode in the lab frame  $f_{\text{lab frame}}$  is larger than  $m \cdot f_{\bar{E} \times \bar{B}}$ , which yields the frequency in the plasma frame to be about  $+0.3\text{MHz}$ . The positive sign of the frequency suggest this mode propagates in the same direction as the mode in the lab frame, i.e. the electron diamagnetic direction, which in CLM is the same as the ExB direction. This is appropriate for the ETG mode.

From the measurement of phase difference of two axially displaced probes, we find the parallel wave length to be  $\sim 600\text{cm}$ , about 4 times the CLM machine length, similar to our ITG finding. From this we can estimate than  $k_{\parallel} \approx 0.01\text{cm}^{-1}$ , which is much smaller than  $k_{\perp} \approx 7\text{cm}^{-1}$ .

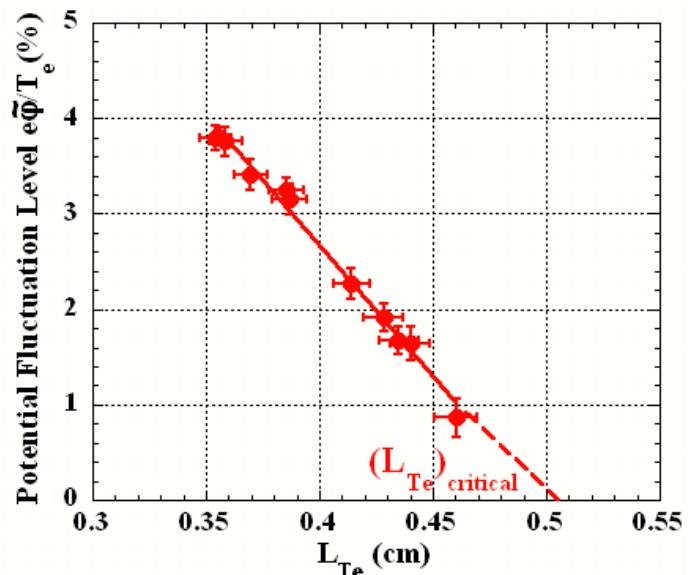


Fig. 4. Potential fluctuation level v.s.  $L_{Te}$ .

The temperature gradient length  $L_{Te}$  is varied via D.C. accelerating voltage and discharge current. As we mentioned before, the potential fluctuation level increases with decreasing of  $L_{Te}$ , a trend in agreement with theory and simulation results. In Fig. 4 we show the potential fluctuation scaling v.s.  $L_{Te}$ , as expected of ETG modes.

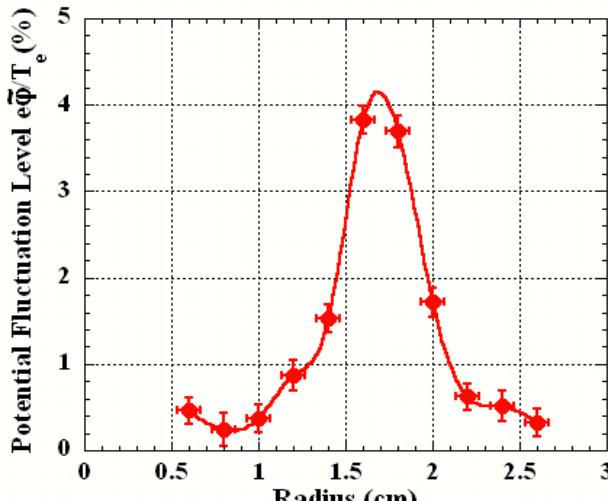


Fig. 5. Radial profiles of potential fluctuation level.

Finally, we show the radial profile of fluctuation amplitude in Fig. 5. The maximum fluctuation level is located at the point of the sharpest electron temperature gradient ( $L_{Te}$  smallest), as expected. The fluctuation level is near the noise level in the center and close to the edge of the plasma, where the electron temperature gradient is very weak, consistent with the fact that a weak gradient cannot drive the mode.

## Conclusion:

In conclusion, with radially localized D.C. bias heating and appropriate discharge current, desired electron temperature radial profiles with a range of  $L_{Te}$  are obtained, sufficient for exciting ETG modes. Potential fluctuations at  $\sim 2.3\text{MHz}$  are correlated with a sharp electron temperature gradient. This frequency is consistent with the theoretical estimation of the ETG mode. The modes have the azimuthal wave number  $m \sim 14-16$  ( $k_{\perp}\rho_e \ll 1, k_{\perp}\rho_i > 1$ ) and propagate in the electron diamagnetic direction. These modes have  $k_{\parallel} \ll k_{\perp}$ , characteristic of drift waves. The potential fluctuation of the modes increases with decreasing  $L_{Te}$  as expected and the radial location of the maximum amplitude of the mode coincides with the steepest electron temperature gradient. With all the parametric signatures described above, this may be the first direct and definitive production and identification of ETG modes.

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## Reference:

- [1] W. Dorland, F. Jenko and M. Kotschenreuther and B.N. Rogers, *Phys. Rev. Lett.* 85, 5579 (2000)
- [2] R.E. Waltz, J. Candy and M. Fahey, *Phys. Plasmas*, 14, 056116 (2007)