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ELECTRON TEMPERATURE CRITICAL GRADIENT AND TRANSPORT STIFFNESS

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GENERAL ATOMICS

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Electron Temperature Critical Gradient and Transport Stiffness

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Using the flexible electron cyclotron heating (ECH) systems at DIII-D, a critical electron temperature gradient has been found in the electron heat fluxes and stiffness at various radii in L-mode plasmas. The TGLF reduced turbulent transport model [1] and full gyrokinetic GYRO model [2] do well to obtain the observed critical gradients and stiffnesses, but they do not do well at predicting the absolute level of transport. In fact they predict too little transport, sometimes referred to as the L-mode edge transport shortfall. Although the best fusion performance is obtained in H-mode, an L-mode phase must be passed through to obtain H-mode, during which the center stack flux is consumed most rapidly; hence, it is vital that turbulent transport models properly predict L-mode transport so that flux consumption can also be properly modeled.

In DIII-D the electron temperature critical gradient and transport stiffness are measured by changing the electron heat flux through a surface, while maintaining the total heat flow into the plasma. One such scan around ρ=0.71, where ρ is the normalized toroidal flux coordinate, is shown in Fig. 1(a). The TGLF predicted electron heat diffusivities, multiplied by 4, are also shown. Of particular interest is that there is a break in the slope of diffusivity vs gradient at the same gradient for both TGLF and experiment. This suggests that TGLF is computing the critical gradient and stiffness (sensitivity of diffusivity to gradient) correctly, but is missing some level of baseline transport proportional to the electron temperature gradient.

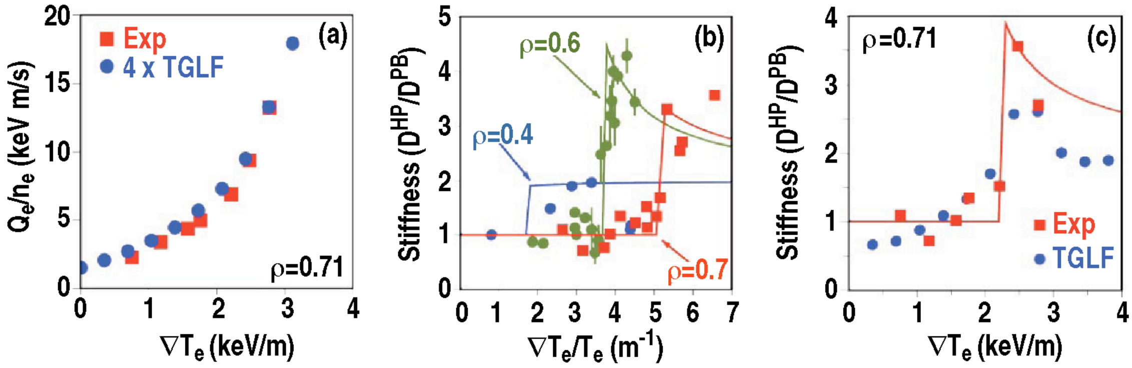

Fig. 1. (a) Electron heat diffusivity vs temperature gradient: inferred experimental diffusivity (■) and TGLF predicted diffusivity (●), multiplied by a factor of 4. (b) Electron heat transport stiffness (ratio of heat pulse diffusivity to power balance diffusivity) at ρ=0.4, 0.6, and 0.71 vs inverse electron temperature gradient scale length. (c) Experimentally inferred (■) and TGLF computed (●) stiffness at ρ=0.71. The solid lines in (b) and (c) are the stiffnesses resulting from fits to a simple critical gradient model of the diffusivities.

The temperature gradient-diffusivity scans are accomplished operationally by aiming ECH gyrotrons either inside or outside of a surface, and changing the aiming of one gyrotron at a time from inside to outside, shot to shot. There is always a single gyrotron modulated at 28 Hz outside of the surface of interest. This modulated gyrotron allows for the measurement of the heat pulse diffusivity D^{HP}. The ratio of D^{HP} to the power balance diffusivity D^{PB} is the plasma stiffness. For a regime such as neoclassical, where the heat flux is linearly proportional to the temperature gradient (with no offset), the stiffness is 1. There can be a critical gradient above which the flux is no longer proportional to the gradient; the stiffness will then jump above 1. The experimentally inferred electron transport stiffness for various radii is shown in Fig. 1(b). Consistent with a critical gradient paradigm, the stiffness at each radius starts around 1 and jumps up above 1 at a critical gradient. The value of the critical gradient depends on the radial location in the plasma. The TGLF predicted stiffness for ρ_N=0.71 is shown in Fig. 1(c), and is comparable to the experimentally inferred stiffness there.

Additionally, long-wavelength electron temperature fluctuations were measured at ρ=0.6 using the Correlated Electron Cyclotron Emission (CECE) diagnostic, shown in Fig. 2(a). The different symbols correspond to different heating configurations, either with only ECH heating [3] or ECH and neutral beam injection (NBI) heating, which significantly increases the plasma rotation and rotational shear. These measured fluctuations can be compared to the GYRO predicted fluctuations shown as solid symbols. It is interesting that although GYRO does reasonably well at predicting the fluxes [Fig. 2(b)], it substantially underpredicts the fluctuations, while still exhibiting a critical gradient similar to the measured fluctuations.

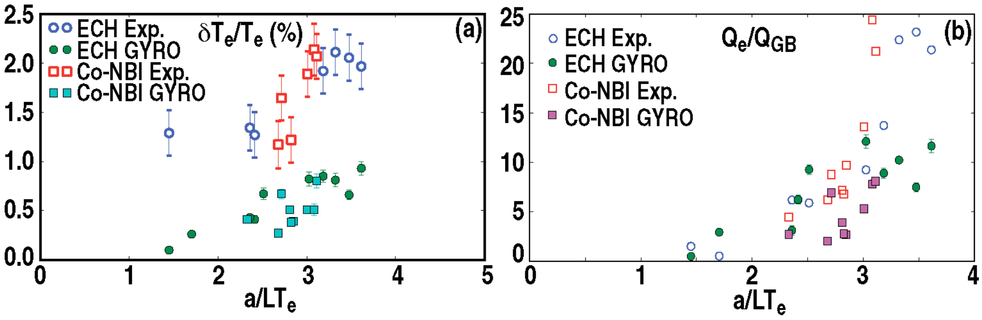

Fig. 2. (a) Normalized electron temperature fluctuations at ρ_N=0.6 vs normalized inverse electron temperature gradient scale length as measured by the CECE diagnostic (○,□) or predicted by GYRO (●,■). (b) GyroBohm normalized electron energy fluxes at ρ_N=0.6 as inferred from power balance calculations (○,□) or predicted by GYRO (●,■) vs normalized inverse electron temperature gradient scale length.

In conclusion, the electron temperature gradient dependence of electron heat fluxes and temperature fluctuations has been measured in DIII-D. The critical gradients and stiffnesses compare favorably with TGLF and GYRO predictions; however, there is a clear shortfall of absolute transport in the outer regions of these L-mode discharges. Future work is investigating the role of shorter wavelength modes in producing transport at the lower wave numbers here considered as a mechanism for resolution of this discrepancy. Resolution is vital to be able to model future devices with confidence.

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