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MULTI-SCALE/MULTI-FIELD TURBULENCE MEASUREMENTS TO RIGOROUSLY TEST GYROKINETIC SIMULATION PREDICTIONS ON THE DIII-D TOKAMAK

by

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A series of carefully designed experiments on DIII-D have taken advantage of the exceptional set of turbulence and profile diagnostics to rigorously test gyrokinetic turbulence simulations. Though still in the early stages, these studies are already producing new and interesting results. It is found that predictions of transport and fluctuation levels in the mid-core region (0.4<ρ<0.75) are often in better agreement with experiment than those in either the outer region (ρ≥0.75), where edge effects may become important, or with those in the inner region (ρ≤0.3) where some of the scale length assumptions in the gyrokinetic formulation may become less reliable. Furthermore, some simulations exhibit a suppression of long wavelength modes and a resulting unphysical buildup of fluctuation energy at higher *k* requiring extension to successively higher *k* ranges and potentially requiring fully coupled low through high *k* simulation. These validation studies are crucial in developing confidence in a first-principles based predictive capability for ITER.

New measurement capabilities since the last IAEA 2008 meeting include local, wavenumber resolved TEM scale $\tilde{n}$, fluctuating turbulence flows, density-temperature ($n_e T_e$) turbulence crossphase, as well as previously available ITG and ETG scale n_e and low-*k* T_e fluctuations. The novel measurement of the $n_e T_e$ crossphase is important in gyrokinetic validation studies since it represents the relationship between two different fluctuating fields (it is also closely related to the crossphases that determine the turbulent transport) and since it can be directly compared to simulation at a fundamental level. The unique array of multi-field, multi-scale turbulence measurements has been utilized to study a wide range of target plasmas with excellent spatial coverage (r/a~0.55–0.85).

We have conducted a series of plasma experiments which (a) take advantage of DIII-D's diagnostic, heating, and plasma control capabilities, (b) address significant plasma physics target states, and (c) utilize simulation capabilities both before and after the experiment with the a priori simulations central to the experimental design process. The target plasmas are designed to address plasma parameters that have a large plasma response such that both experiment and simulation show significant variations. Examples of these parameters are T_e/T_i, electron temperature scale length L_{Te}, and plasma elongation κ. These experiments feature multiple measures of similar parameters, reduction of uncertainties in radial profiles via repeat shots and/or plasma jogs, repeat shots to acquire full fluctuation profiles, plasmas designed for full diagnostic access (e.g. magnetic field chosen for full ECE access), etc. and have provided new and more complete data sets for validation studies of gyrokinetic simulations. The new and significant results are:

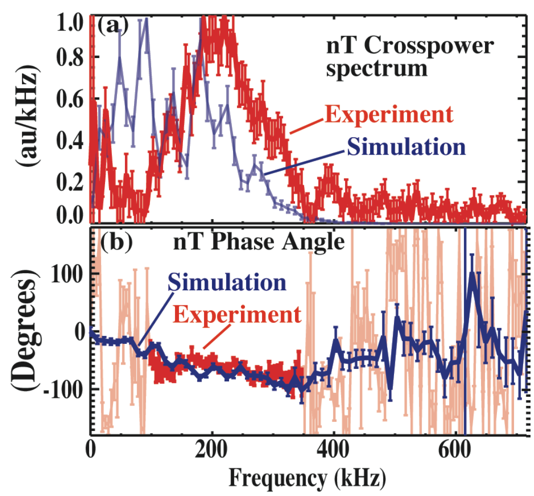

Fig. 1. Experimental *nT* crosspower showing significant fluctuation activity only in the range 100-350 kHz. (b) Comparison between measured *nT* crossphase and nonlinear GYRO simulations showing quantitative agreement in the range 100-350 kHz where the cross power is significant [1]. The *nT* phase measurement outside this range is shown however error bars are large due to the very small power levels.

(1) In plasmas heated with ECH to vary T_e, agreement is observed between $n_e T_e$ turbulence crossphase measurements and from the nolinear gyrokinetic GYRO code [1] (Fig. 1 and Ref. [2]). Experimentally, the frequency range 100-350 kHz (Fig. 1) is the region of significant temperature fluctuation activity as well as the largest cross coherence between the density and temperature fluctuations. Interestingly, in this case the simulated power flows are underestimated

by ~3 for the ion channel and overestimated by ~50% for the electron channel (experimental power flow error bars are ~10% [2]).

(2) For plasmas where electron mode physics is tested by making electron modes (TEM and ETG) dominant over ion modes (ITG), intermediate TEM/ETG scale $\tilde{n}$ decreases with decreasing a/L_{Te} as predicted (Fig. 2) [3]. However, higher a/L_{Te} plasmas showed a surprising, and unpredicted, opposite response. In addition, changes in local electron temperature fluctuations (at ρ=0.64) are observed as a/L_{Te} is changed consistent with nonlinear GYRO simulations even though these same simulations do not predict the observed opposite response of intermediate-k $\tilde{n}$. At this radius, global GYRO simulations of electron thermal diffusivities agree within uncertainties, while the simulated ion diffusivities are low by ~50% (experimental error bars on the ion diffusivities are ~12%).

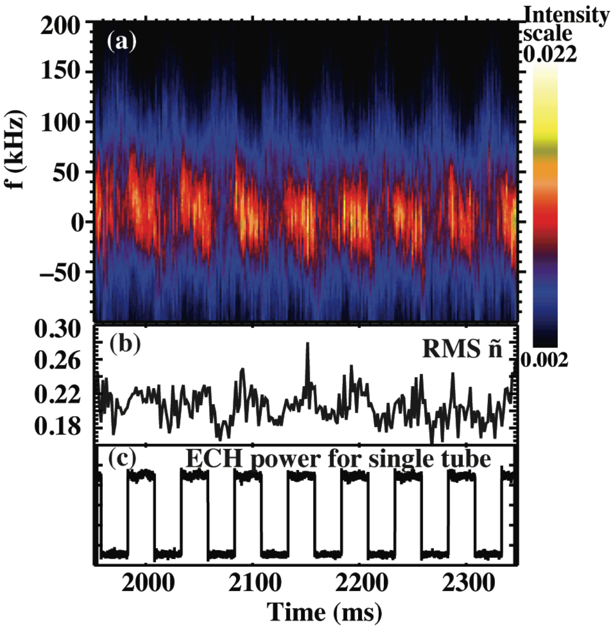

Fig. 2. (a) Power spectral plot of intermediate-k ñ levels showing amplitude modulation due to modulation of local a/L_{Te}. (b) Corresponding RMS intermediate-k ñ levels. (c) ECH power from single gyrotron tube with high level corresponding to local high a/L_{Te} level (low level corresponds to local low level) [3].

(3) For plasmas with elongation (κ) scans, measured thermal transport and low-k fluctuations (n_e and T_e) decrease with increasing κ consistent with general predictions. Initial GYRO simulations indicate rough agreement with measured turbulence, as well as strong intermediate and high-k modes at high κ.

These studies are focused on the testing and validation of a wide range of gyrokinetic turbulence codes/simulations. The simulation codes utilized to-date include GYRO, and more recently GTC [4] and GYSELA [5] have begun to enter the process. Through this ongoing validation activity, where experimental measurement is compared with simulation prediction, the design of suitably rigorous experiments for testing code predictions has steadily improved. This process has also resulted in improvement in the turbulence simulation model itself (improved rotation model, generalized geometry), while also highlighting the critical importance of utilizing accurate synthetic diagnostics [6].

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