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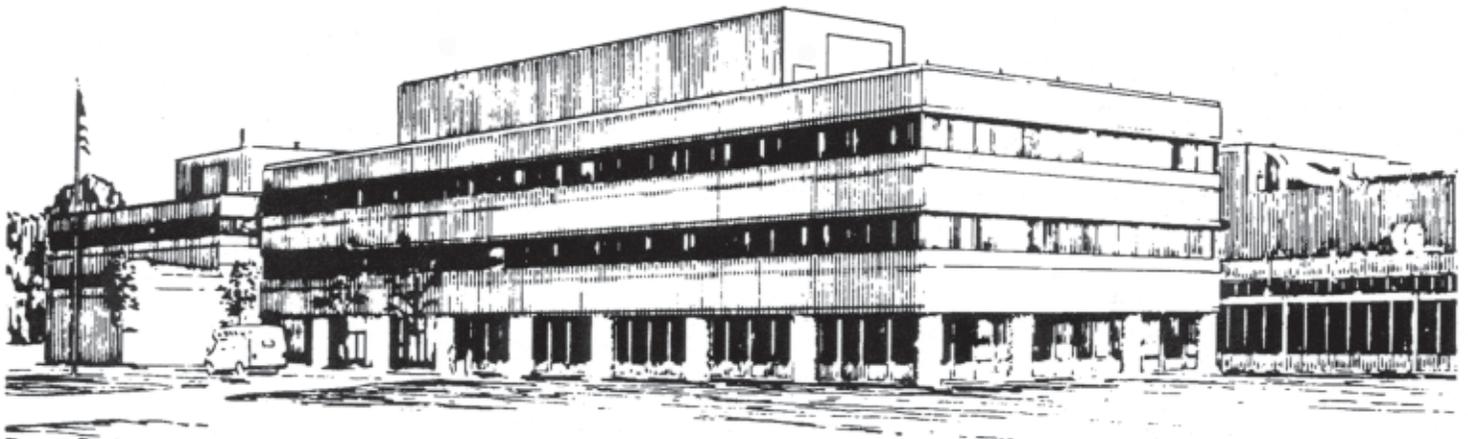
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of Microturbulence and Transport**

by

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Gyrokinetic Calculations of Microturbulence and Transport for NSTX and Alcator-CMOD H-modes

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Introduction

Recent H-mode experiments on NSTX and experiments on Alcator-CMOD which also exhibit internal transport barriers (ITB), have been examined with gyrokinetic simulations with the GS2[1,2] and GYRO[3] codes to identify the underlying key plasma parameters for control of plasma performance and ultimately, the successful operation of future reactors such as ITER. On NSTX the H-mode is characterized by remarkably good ion confinement and electron temperature profiles highly resilient in time[4]. On CMOD, an ITB with a very steep electron density profile[5] develops following off-axis RF heating and establishment of H-mode. Both experiments exhibit ion thermal confinement at the neoclassical level. Electron confinement is also good in the CMOD core.

NSTX Gyrokinetic Simulations

Linear calculations for NSTX were intended to characterize the microturbulence underlying resilient electron temperature profiles[6]. The initial simulations, at $r/a=0.25$, 0.65 and 0.8, are fully electromagnetic, follow electrons and three ion species, with the complete electron response. There are no strong ITG or ETG instabilities in the core at $r/a=0.25$ (Fig. 1) where reversed magnetic shear is calculated by EFIT, based on magnetic measurements. A new microinstability is found at $r/a=0.65$: a microtearing mode (Fig. 2). It is characterized by an odd parity electrostatic eigenfunction rotating in the electron diamagnetic direction, with a broad dispersion spectrum $0.3 < k_{\perp} \rho_s < 3$. The eigenfunction of ∇B_{\perp} has even parity and may cause high anomalous electron thermal losses[7]. At $r/a=0.8$ GS2 was used to examine the role of critical temperature gradients and the nearness to marginal stability, usually thought responsible for stiff temperature profiles. The proximity to marginal stability was investigated by scaling the observed, normalized temperature

gradients, without self-consistently recalculating plasma equilibria. At this radius the plasma profiles and magnetic geometry lead to intrinsic microturbulence above marginal stability for both ITG/TEM and ETG modes. However, neutral beam heating drives strong plasma rotation. The resulting $E \times B$ shearing rates (Fig. 1) are calculated with TRANSP. If we require $(2-3)\omega_{TG} < \omega_{ExB}$ for stability, NSTX is near marginal stability for ITG at $0.8r/a$. $\omega_{ETG} > 2\omega_{ExB}$ but it is not yet known if ω_{ExB} stabilizes ETG or microtearing modes.

Low ω_i and high ω_e in NSTX #108730 could be understood to arise from stable ITG and unstable ETG and microtearing modes. With reversed shear, no unstable modes are found in the core, but if magnetic shear is not reversed ETG may be unstable there. $E \times B$ shear is too weak to definitely stabilize ITG and lead to low ω_i . Resolution of this may be found by including better impurity data with GS2 and/or ω^* -stabilization effects, to be examined with GYRO. Nonlinear simulations are in progress.

CMOD Gyrokinetic Simulations

GS2 simulations of CMOD are focussed at the internal transport barrier (ITB) trigger time, just before a steep density profile is established. Linear calculations showed stable long wavelength turbulence at the ITB region, without invoking suppression by $E \times B$ shear[8]. Nonlinear simulation of the CMOD plasma shows quiescent microturbulence in the ITG range of frequencies in the barrier region, just before ITB formation (Fig. 3). These nonlinear calculations are electrostatic, rather than electromagnetic, which makes little difference in low ω , linear gyrokinetic simulations for CMOD. The simulations use four values of k_\perp and 23 values of k_r . In the plasma core, weak turbulence is predicted, with saturation occurring with the development of a Geodesic Acoustic Mode (GAM) (Fig. 3) at 77 kHz. A high frequency core mode at 80 kHz for a similar experiment has been found with ECE[9]. The simulation mode is a stable mode of the plasma, excited as a damped computational mode, and which may be driven unstable by RF heating. The only well resolved linearly unstable mode is an ITG mode at about 50kHz, outside the ITB region.

Identification of the driving forces responsible for drift wave microstability in the barrier region before the ITB appears, has been explored by examining the effects of increased gradients for the electron, ion, impurity density and temperatures as well as magnetic shear. It is found that increases in the normalized electron temperature gradient cause the largest destabilization of the ITG mode in the barrier region at the trigger time. This suggests that the ITB is triggered by reduction in the normalized electron temperature

gradient driving force for the ITG/TEM microstability when off-axis RF heats the plasma locally. Reduced instability growth rates predicted at the barrier are consistent with the observed reduced transport[10]. GYRO simulations are found in good qualitative agreement with GS2 for the CMOD case, for linear, flux-tube, electromagnetic simulations including kinetic electrons but without impurities or noncircular magnetic geometry.

Conclusions

For the most part, gyrokinetic simulations of the NSTX and CMOD H-mode ITB experiments support the picture of unstable ITG(ETG) microturbulence driving high $\chi_i(\chi_e)$, and that suppressed ITG causes reduced particle transport and improved χ_i . However, the present GS2 flux-tube microstability analysis disagrees with the above picture in two respects. At the NSTX edge, ITG may be unstable, yet transport analysis finds low χ_i [6]. In addition, ETG is stable in the core, but high χ_e is observed[6]. We have identified a long anticipated, microturbulent mode with tearing parity on NSTX in the ITG-TEM range of frequencies. The mode is driven by electron dynamics and, along with ETG, may cause high χ_e . Nonlinear calculations for CMOD confirm initial linear simulations, which predicted ITG drift mode stability in the barrier region just before ITB formation. Future experiments on both devices will include MSE measurements of $q(r)$ as well as fluctuation data, to refine predictions for microturbulence.

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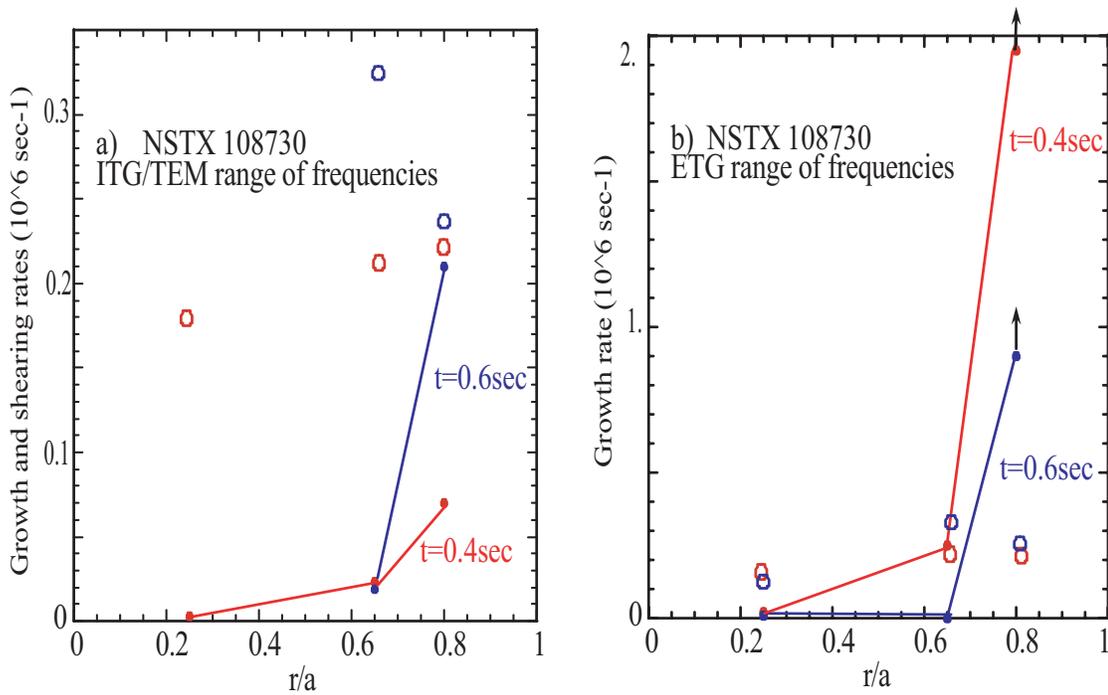


Fig. 1 Growth rates in the ITG/TEM (a) and ETG (b) range of wavelengths for the fastest growing mode at 0.4 seconds and 0.6 seconds in NSTX H-mode, at 0.25 r/a , 0.65 r/a and 0.8 r/a . The open circles denote the ExB shearing rate. The ITG are intrinsically stable or are stabilized by shearing except possibly near the plasma edge, at $r/a=0.8$. ETG modes are stable in the core and not stabilized by shearing at 0.8 r/a . Microtearing parity eigenfunction identified at 0.65 r/a in the ITG/TEM range of wavelengths.

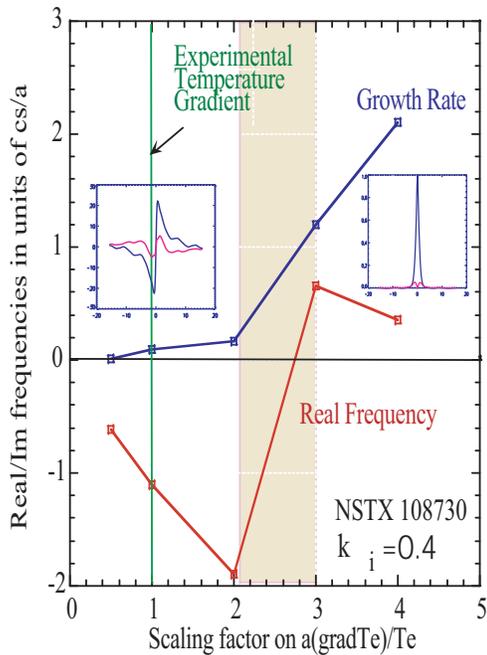


Fig. 2 At 0.65 r/a in the ITG/TEM range of wavelengths a microtearing instability is found, driven by electron temperature gradient. If all other gradients=0, mode structure is unchanged and growth rate decreases by 10%. Without collisions or with increased electron temperature gradient, fastest growing mode is ITG. Insets: microtearing, ITG electrostatic eigenfunctions.

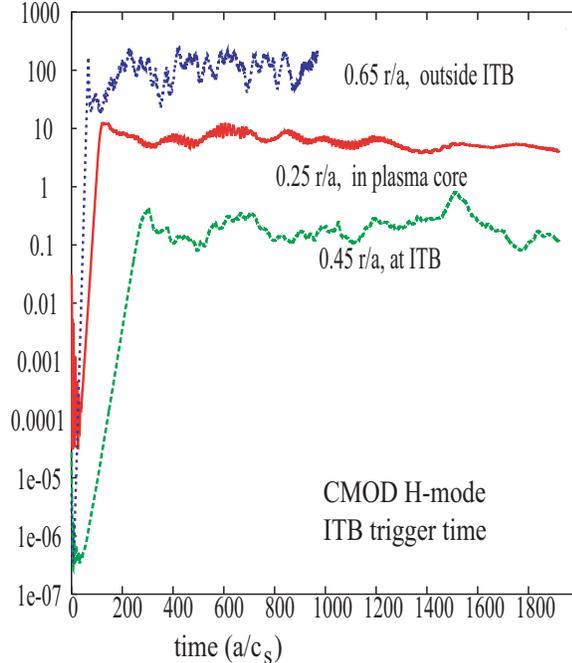


Fig. 3 Nonlinear, electrostatic simulations of CMOD before the ITB show the linear phase, followed by saturation. At the ITB region, the volume-integrated magnitude of the square of the fluctuation potential is reduced by two orders of magnitude, and by one order of magnitude in the plasma core, compared to the ITG unstable region outside the plasma core. A GAM mode develops in the plasma core.

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