Gyrokinetic Simulation of Tokamak Edge Plasmas

Yong Xiao[1], Taige Zhang[1], Chen Zhao[1], and Zhihong Lin[2,3]

[1]Institute for Fusion Theory and Simulation, ZhejiangUniversity, Hangzhou, 310027, China
[2]Department of Physics and Astronomy, University of California, Irvine, CA92697, U.S.A
[3]Fusion Simulation Center, PekingUniversity, Beijing, 100871, China

E-mail contact of main author: yxiao@zju.edu.cn

Abstract. It has been recently discovered that the trapped electron mode (TEM) may play an important role in the H mode edge plasma for domestic tokamaks such as EAST and HL-2A. The stability and transport for TEM for the edge parameters are studied using large scale gyrokinetic particle simulations. The gyrokinetic simulation reveals the parametric dependences on the wavelength and collisionality. The ballooning mode structure of this instability is found un-conventional with peaking at up and down side of the poloidal plane for the steep gradient H mode edge. The frequency stair case is found for the linear dispersion, which can be understood as a jump between different branches of the linear eigenmode.

1. Introduction

It is generally believed that the microturbulence leads to the anomalous transport[1] observed in experiments. For low-β and high temperature toroidal plasmas, electrostatic modes may play a dominant role in driving turbulent transport. The ion temperature gradient (ITG) mode[1][2] and collisionless trapped electron mode (CTEM)[3] are two prominent candidates accounting for ion and electron turbulent transport respectively. After several decades' development, massively parallel gyrokinetic simulation based on first-principles has emerged as a major tool to investigate the complicated physics of the turbulent transport[4]. The global gyrokinetic code GTC is one of the major turbulence simulation codes that are doing active frontier research in magnetic fusion plasmas.

The EAST tokamak is one of the major superconductor tokamaks in fusion research. With it successful H mode operation, the EAST tokamak has recently carried out many interesting physics studies in microturbulence. One of them is the discovery of electron coherent mode (ECM) in the tokamak edge, which is identified by the gyrokinetic continuum simulation as the dissipative trapped electron mode (DTEM). In this work, we import the real plasma profiles and equilibrium magnetic field from the EAST discharge #38300. And we then use the GTC code to carry out a gyrokinetic particle simulation, which shows that linear instability has a weak dependence on the electron collisions for the applied parameters. The frequency staircase in the linear dispersion is discovered and the underlying physics is discussed.

The remainder of this paper is organized as follows. In Section 2, we describe the simulation parameters used for this case of EAST discharge #38300. In Section 3, the main simulation results are illustrated. In the last section, we discuss simulation results and a summary is given.

2. Simulation Parameters

Employing the global gyrokinetic particle code GTC, we carry out an electrostatic simulation for the EAST tokamak with discharge #38300, where no significant magnetic fluctuations are observed in experiments. The relevant tokamak parameters are listed as follows: The major radius $R_0 = 1.9m$, The minor radius $a = 0.41m$, the magnetic field on axis $B_0 = 1.73T$, and deuterium is the major ion species. The simulation domain is set at the steep gradient pedestal region, i.e., $0.78a \sim 0.97a$. The plasma profiles computed by IMFIT are shown in Fig. 1(a-d). The plasma parameters at the peak gradient position ($r = 0.93a$) are: $T_e = 250eV$; the safety factor $q = 3.81$, which corresponds to an effective collisional frequency $\nu_e* = \frac{\nu_{ei} q R_0}{\nu_{te} \varepsilon^{3/2}} = 0.95$, where $\nu_{te} = \sqrt{T_e / m_e}$. The equilibrium magnetic field configuration and plasma profiles are taken from EFIT equilibrium reconstruction [5][6]. In addition, the electron temperature at the pedestal top, i.e. $T_e = 400eV$ (corresponding to $\nu_e* = 0.38$), is also used in a second simulation to account for the temperature variation in the pedestal. A uniform particle loading method is used to carry out the simulations below[7].

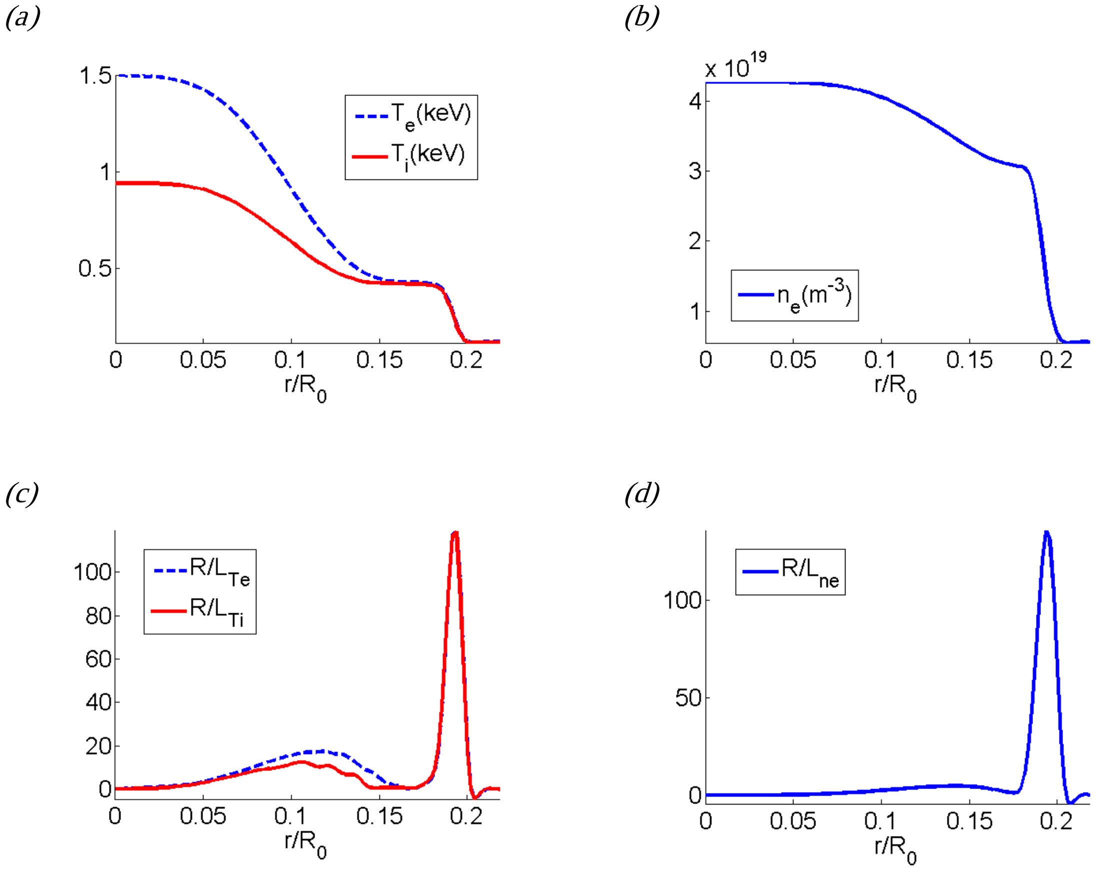

FIG. 1. The plasma profiles for EAST discharge #38300: (a) ion and electron temperature; (b) electron density; (c) ion and electron density; (d) electron density gradient.

3. Simulation Results

With the preceding parameters, an electron mode is found by simulation to propagate in the electron diamagnetic direction. The linear dispersion is shown in Fig. 2 with both real frequency and growth rate varying with poloidal wavelength $k_\theta \rho_i$. A frequency staircase is observed and the frequency of the lowest stair is about 30~40kHz. However, the linear growth rate increases monotonically with poloidal mode number. For both linear frequency and growth rate, the collisions do not show a significant effect on the instability, as shown by Fig. 2 (a,b), which is inconsistent with previous results [8]. In addition, Fig. 2(c, d) shows that the linear growth and real frequency becomes higher for higher temperature, which implies that the frequency may follow C_s/R_0 scaling.

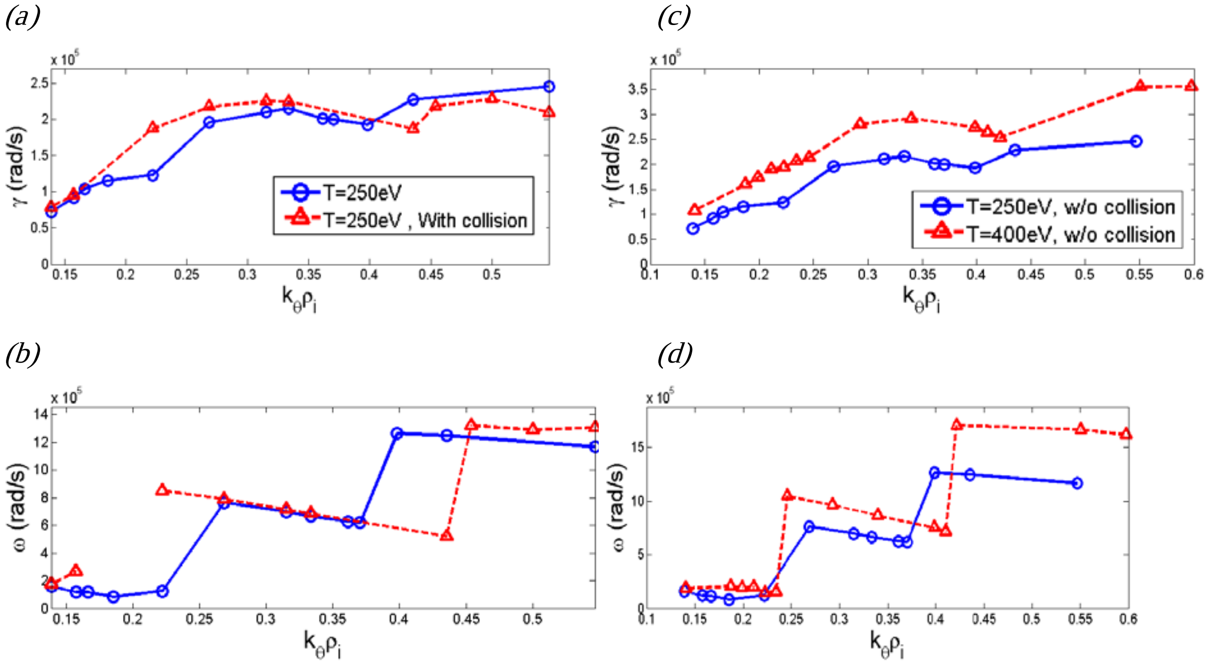
(a) (c) (b) (d)

FIG. 2. Linear dispersion relationcomparisonat the pedestal top and peak gradient position: (a) Real frequency and (b) growth rate for Te=250eV with or without collisions; (c) Real frequency and (d) growth rate with different electron temperatures(250eV and 400eV).

Next we show the linear mode structure on the poloidal mode structure. As shown in Fig. 3, the linear eigenmode demonstrates an unconventional ballooning structure [9], which peaks at $\theta = \pm\frac{\pi}{2}$ for $n=17$, $\theta=\frac{5\pi}{4}$ for $n=34$, and $\theta=\frac{\pi}{4}$ for $n=59$.

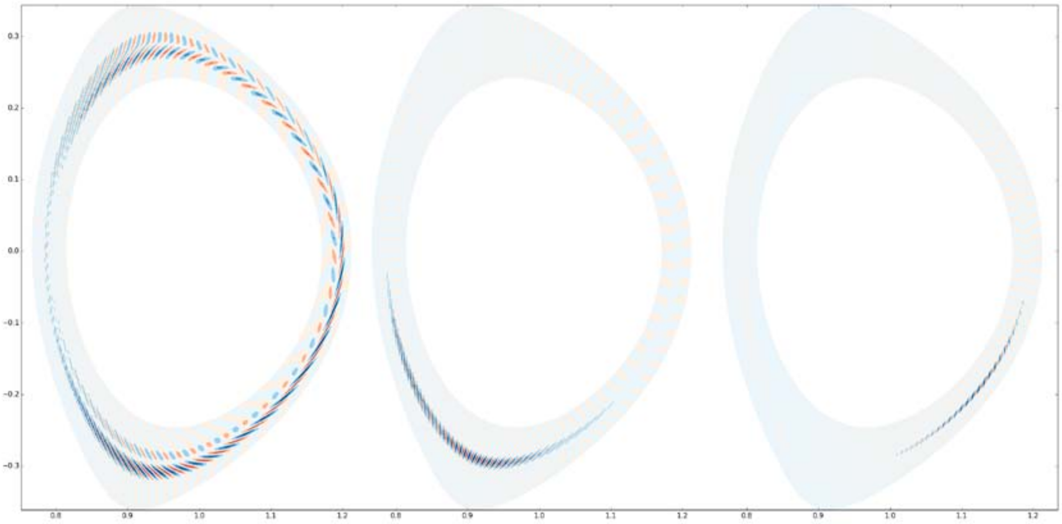

FIG. 3.The snapshot of poloidal mode structure for n=17, 34 and 59, where Te=250eV.

Then we reduce the peak value of ion and election temperature and density gradient respectively. With the ion temperature gradient reducing to $R_0/L_{Ti}=2.2$, the election gradient reducing to $R_0/L_{Te}=6.9$, and the density gradient reducing to $R_0/L_n=2.2$ and $R_0/L_n=6.8$ respectively, the simulation shows that the density gradient make a great impact on the linear dispersion relation. As shown in Fig. 4, when density gradient reduced, the frequency staircase disappeared. And the frequency staircase still exists when election or ion temperature gradient reduced. The instability disappears when using adiabatic election in simulation.

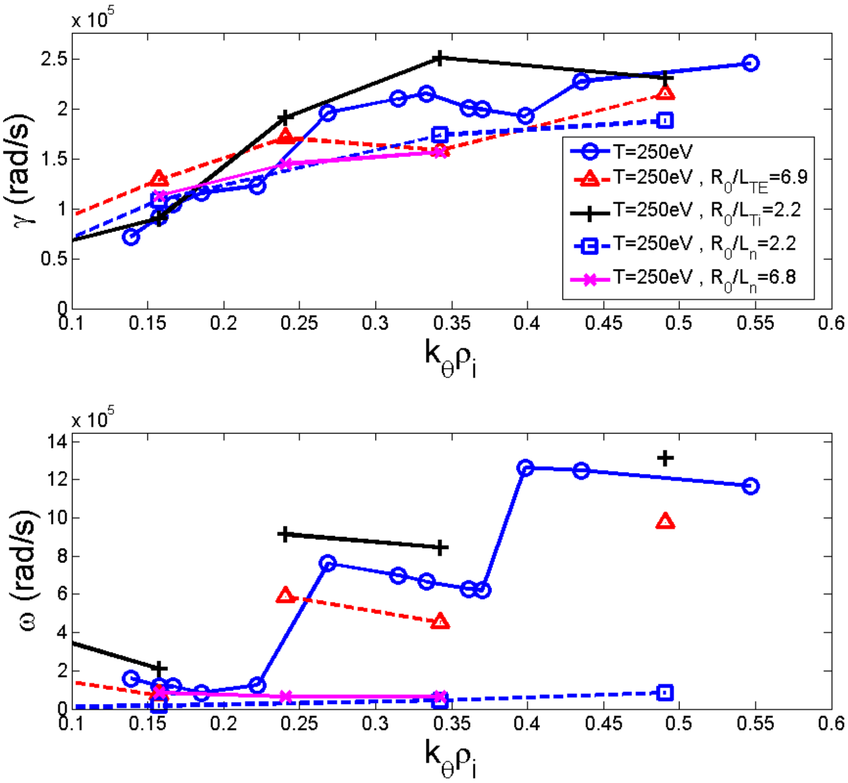

FIG. 4. Linear dispersion relation of different temperature and density peak gradients.

4. Discussion and summary

In this paper, we use real EAST equilibrium and gyrokinetic simulation by the GTC code to explore the electron coherent mode observed in the EAST experiment. However, we find the collisions play a damping effect in the linear instability. The mode becomes unstable for short wavelength. A frequency stair case is found for the linear dispersion relation. This is due to fact that with wavelength becomes shorter, the linear frequency becomes larger. The instability may jump from the TEM mode to the ubiquitous mode, where different branches of the dispersion exist.

Acknowledgments

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