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Investigation of Multi-scale Ion Temperature Gradient Instabilities and Turbulence in the ADITYA-U Tokamak

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Sharp density and temperature gradients are often observed in tokamaks, for example, during formation of internal transport barriers. Very sharp background gradients tend to drive short scale ion temperature gradient modes (SWITGs) unstable [1]. Because of ultra-short scales of the instability and the absence of separation of scales, neither fluid models nor flux tube based gyrokinetic models can address the stability and the concomitant transport that may ensue in such situations. Perhaps for the first time, using a global, gyrokinetic, electrostatic solver which includes nonadiabatic electrons and nonadiabatic ions, the self-consistent dynamics of SWITGs driven by very sharp background gradients, their linear & nonlinear evolution, its saturation after onset of zonal flows are addressed. Results are compared with similar studies performed using flux-tube based gyrokinetic studies [2] which were performed with adiabatic electron model.

High confinement mode plasmas are routinely produced in present day tokamaks [3]. One important aspect of this scenario is the formation of pedestal and transport barriers which reduce the transport of heat and particles from the system. Across the pedestal, plasma exhibits strong pressure gradients and therefore is a hotspot for a slew of instabilities of different flavors. Similarly, across internal transport barriers as well, the plasma exhibits steep gradients which provide free energy to small scale instabilities [4]. These barriers are created in a self-consistent manner in tokamak experiments as a result of nonlinear interaction between multi-scale structures in a tokamak. The presence of strong gradients may change the character of the conventional instabilities. For example, the ion temperature gradient mode, which is driven by the temperature gradient of ions is shown to become unstable even at wavelengths $k_\theta \rho_i$>1.0, in the presence of sharp temperature gradients [1,5]. Similarly, trapped electron modes also can manifest a shorter wavelength branch in the presence of strong gradients [6]. Such short wavelength branch of micro-instabilities is shown to be crucial for experimental parameters using gyrokinetic simulations [7]. Therefore, it is important to understand the nonlinear properties of these multi-scale modes and their contribution to the anomalous transport of particles and energy. Nonlinear flux tube simulation of short wavelength branch of the ion temperature gradient modes considering adiabatic electrons showed that the contribution from the shorter-scale modes to the total heat flux is weaker than the longer wavelength branch [2]. However, the region across the steep gradients might be very small and local flux tube calculations might not be appropriate under these conditions. The reason behind this is that the local calculations are developed on the premise that the fine-scale fluctuations by the instabilities and equilibrium quantities has disparate scale-lengths and therefore, separable. But such an assumption fails in the narrow gradient regions. This naturally calls for the necessity of global calculations that treat small scale fluctuations and large scale equilibrium variations on the same footing or in other words a multi-scale study.

In this work, we carry out global linear and nonlinear simulation studies of the longer and shorter scale ion temperature gradient mode for profiles and parameters relevant to ADITYA-U tokamak. The ADITYA-U tokamak is a small size tokamak [8] that is being upgraded to divertor configuration and is suitable for studies of micro instabilities in the presence of steep gradients. We start with a linear global gyrokinetic study for system size comparable to ADITYA-U in the electrostatic limit where β (ratio of kinetic to magnetic pressure) goes to zero. The reconstructed density and temperature profiles for ADITYA-U like circular plasma at Z=0 midplane and the safety factor and shear profiles are as shown in Fig. 1. For this equilibrium the growth rates and real frequencies are first calculated using an eigenvalue global gyrokinetic code GLOGYSTO [9] for different toroidal mode numbers to start with. This is shown in figures 2a and 2b. Figure 2c shows a typical mode structure for the electrostatic potential corresponding to the short-wavelength ITG mode for toroidal mode number (n) = 21.

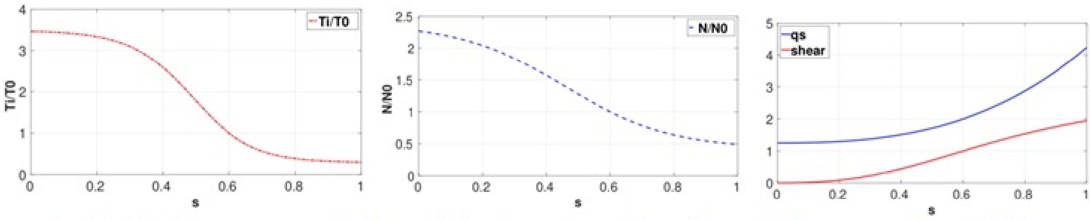

FIG. 1: Temperature (left) and density (centre) and q and shear profiles (right)

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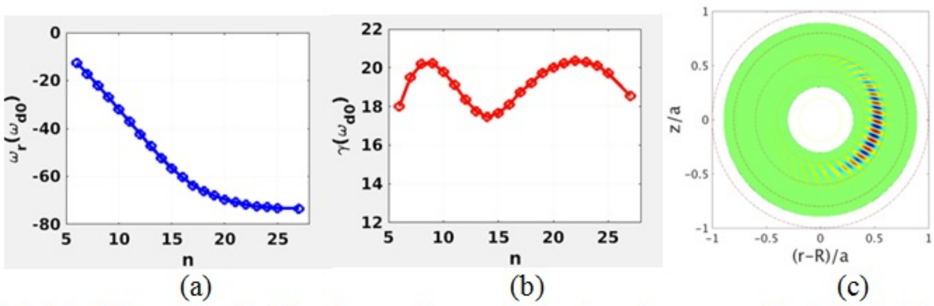

FIG. 2: Real frequency (left) and growth rates (centre) and structure for ϕ (right) for $n = 21$

Figure 2: FIG. 2: Real frequency (left) and growth rates (centre) and structure for ϕ (right) for n=21

With these results, we move forward to conduct first principle based global gyrokinetic simulations using the PIC code GTS [10]. As a first step we compare the real frequencies and growth rates calculated using GTS with those shown in Fig. 2. After this exercise, we carryout nonlinear global simulations using GTS for parameters and profiles relevant to ADITYA-U tokamak. The criteria for the simultaneous presence of short and long wavelength branches of the ITG mode for ADITYA-U plasmas are investigated. Furthermore, the dependency of the nonlinear heat flux, the effect of ExB shear on shorter-wavelength ion temperature gradient mode (SWITG), the role of non-adiabatic electrons in the presence of steep gradient using multi-scale global code GTS will be presented.

This work is performed in IPR's HPC facility ANTYA at the Institute for Plasma Research, Gandhinagar, INDIA.

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