# Global gyrokinetic ITG turbulence simulations of MAST plasmas

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## Introduction

Non-local turbulence effects are likely to be important in devices where the ratio of ion gyroradius to plasma size ($\rho_{i*}$) is large. Turbulence spreading arises from equilibrium profile variation. While the local gyrokinetic flux-tube approximation provides guidance on the linear microstability of ITG turbulence, in non-linear simulations of ITG turbulence at large $\rho_{i*}$ a global treatment of the plasma may give more insight into the transport mechanism. In this paper we will present microstability results for ion temperature gradient (ITG) modes from various gyrokinetic codes, and show global non-linear simulations of ITG turbulence in MAST.

## Experimental Plasma

For the microstabilty analysis we choose a MAST L-mode discharge #22807 at 0.25s that displays a steep ion temperature gradient at the location where there is a steep gradient in the toroidal rotation. The core has a negative magnetic shear up to $s = 0.55$ where s is the square root of the normalised poloidal flux. The ion temperature profile from the charge exchange recombination spectroscopy (CXRS), the q-profile from MSE-constrained equilibrium reconstruction and the plasma shape are shown in Fig.1. The global parameters are: $I_p$=0.88MA, $B_T$ (at $R = 1$m)=0.41T and co-heating $P_{NBI}$=3.3MW. The steep ion temperature gradient coincides with a steep gradient in the toroidal rotation profile. The value of $\rho_{i*}$ at $s$=0.5 is 1/42 in this plasma which indicates that global effects are likely to play a role in microstability studies, especially in the non-linear phase.

## Linear Microstability

To study the plasma microstability, we use three different electrostatic gyrokinetic codes. For local analysis we use the flux tube codes GS2 [1] and GYRO [2] that is run in a flux tube mode. We also run a global code ORB5 [3] to study the global effects on ITG turbulence.

We conduct an electrostatic linear study treating electrons adiabatically for simulation the equilibrium and profiles of MAST discharge #22807 neglecting flow shear and collisions.

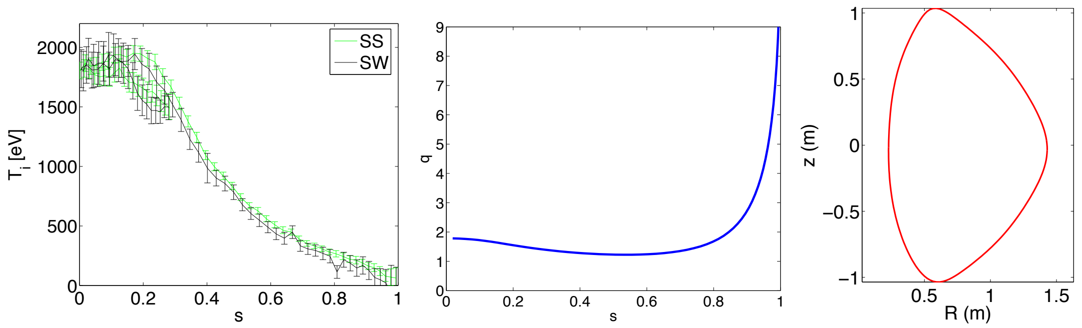


Figure 1: The ion temperature profile, q-profile and the plasma shape of the MAST discharge #22807 at 0.25s. The two measurements of ion temperature refer to the two independent neutral beams used by the CXRS system. The inboard side measurements are folded onto the outboard side in $s < 0.3$. The internal transport barrier (ITB) with steep $\nabla T_i$ is in the region $0.3 < s < 0.5$.

The flux surface in the local GYRO corresponds to $s$=0.73. The normalised growth rates are plotted in Fig. 2. The agreement between the codes is reasonably good considering that the mode location in the ORB5 simulation depends on the mode number. As can be seen in Fig. 3 the linear $n$=40 mode is localised between $s$=0.6 and $s$=0.8. An ORB5 simulation restricted to the $s < 0.6$ region finds no unstable modes. The growth rate of the fastest growing mode is slightly lower than the experimental $\mathbf{E}\times\mathbf{B}$ shearing rate.

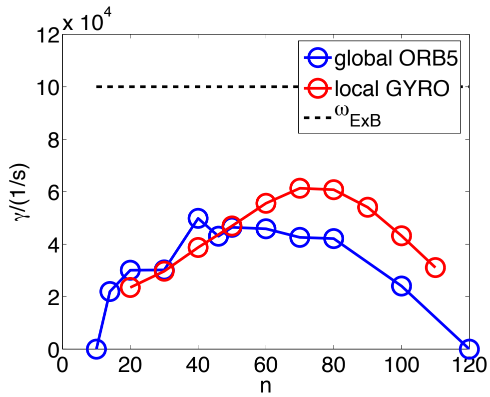


Figure 2: The linear growth rates of ITG modes in MAST discharge #22807 with a local GYRO (red) and a global ORB5 (blue) simulation without flow shear.

Including the kinetic electrons into the simulation increases the linear growth rates significantly. The comparison between local GS2 and global ORB5 linear simulations is shown in Fig. 4. The growth rates of the resulting trapped electron modes (TEM) are above the $\mathbf{E}\times\mathbf{B}$ shearing rate. The global ORB5 result without collisions is between the collisional and collisionless local GS2 result.

In the earlier local flux tube studies of ITG modes in MAST using the GS2 code it was found that L-mode plasmas are unstable with growth rates below the experimental $\mathbf{E}\times\mathbf{B}$ shearing rate [4]. However it was also found that for the experimental sheared flow with $\omega_{E\times B}$ exceeding the maximum ITG growth rate by about 50% the linear mode was fully stabilised.

We repeat the flow shear stabilisation study for the new L-mode (#22807) discharge but use

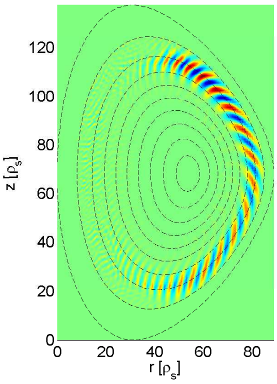


Figure 3: The mode structure of $\phi$ for $n$=40 ITG mode without flow.

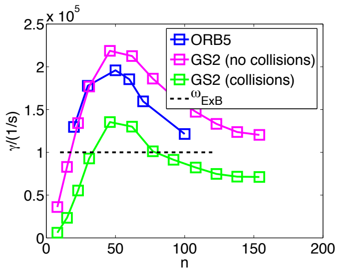


Figure 4: The linear growth rates of TEM modes as a function of $n$.

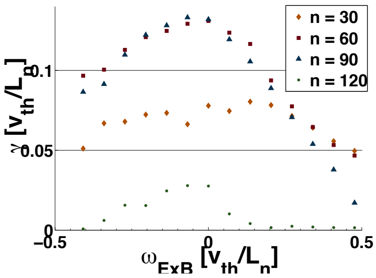


Figure 5: The linear growth rates of ITG modes with adiabatic electrons as a function of the $\mathbf{E}\times\mathbf{B}$ shearing rate.

the global ORB5 code. In this study, we assume a linear equilibrium radial electric field profile across the plasma with $\mathbf{E_r} = 0$ at s=0.5. The growth rate as a function of $\mathbf{E}\times\mathbf{B}$ shearing rate is plotted in Fig. 5. The first thing to note is that the stabilising effect of the flow shear is not symmetric with respect to direction of the flow shear or the sign of $\omega_{E\times B}$. At small negative value of $\omega_{E\times B}$ the flow shear is actually destabilising.

Furthermore, the required amount of flow shear to stabilise any mode is considerably more than the growth rate of the mode without the flow shear. Also the spectrum of the unstable mode changes with the flow shear. The mode with the fastest growth rate in the static case is stabilised more effectively than the low-$k_y\rho_i$ modes. A similar shift in the unstable spectrum with flow shear is also found in local GS2 simulations with kinetic electrons.

**Non-linear Gyrokinetic Simulations**

While the flux tube approach can be helpful for local linear studies, its assumptions of invariance of the equilibrium and profiles inside the simulation region, become invalid at high $\rho^*$. Furthermore a global approach is required to study turbulence spreading from unstable to originally stable regions.

While it is possible to run ORB5 non-linearly by letting the profiles relax due to the turbulence, the only way to obtain information about the steady state turbulent fluxes is to describe sources and sinks. They act as localised heating and cooling keeping the profiles close to the initial values. This method is described in detail in [5]. In non-linear simulations we run ORB5 with 200 million tracers and a grid of $N_s \times N_\chi \times N_\phi = 64 \times 512 \times 256$. The numerical noise level stays below 5% in the non-linear phase.

We compare the heat flux of the non-linear simulations with the experimental level calculated by TRANSP. According to TRANSP the ion transport in this discharge is consistent with the neoclassical level despite the steep temperature gradient. In the non-linear ORB5 simulations with adiabatic electrons and without flow shear we find that using the experimental temperature profiles the ion heat flux is indeed very low. However, increasing the temperature gradients slightly, the transport increases significantly above the neoclassical level. This can be seen in Fig. 6. In addition we find the turbulence spreads from the linearly unstable region of $s = 0.6 - 0.8$ further towards the core during the non-linear phase. The peak of the heat flux during the non-linear phase is actually not the location of the linear mode. At the same time the turbulence spectrum shifts to longer wave lengths peaking at $n \approx 25$.

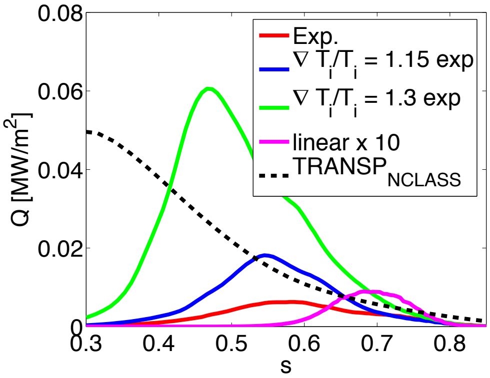


Figure 6: The radial heat flux as a function of radius for varying temperature gradient length. The linear case shows location of the linear mode. The dashed line shows the neoclassical flux.

## Conclusions

Global gyrokinetic linear analysis of ITG modes in MAST L-mode discharge with a global code ORB5 shows that to stabilise the linear ITG modes requires that $\omega_{E\times B}$ is 4-10 times larger than $\gamma_{ITG}$. In the non-linear simulations we find that experimental $\nabla T_i/T_i$ in MAST L-mode plasma even with an ITB and without flow shear is too small to produce significant turbulent ion transport.

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