# Physics of the collisionless microtearing mode

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## 1. Introduction

Microtearing modes (MTMs) are a type of small scale instability caused by a sheared magnetic field in magnetised plasma. In tokamak geometry they are localised in the vicinity of rational flux surfaces and are characterised by short wavelength perpendicular to the magnetic field and a tearing parity in the magnetic potential. They can be extremely unstable in some circumstances [1]. MTMs impact electron transport and edge turbulence [1]. Therefore, understanding the driving mechanism is important for improving tokamak confinement.

Early theories in simplified slab geometry have found that MTMs are driven by an electron temperature gradient [2,3]. The role of energy dependence of the collision frequency suggests that they are unstable in semi-collisional plasmas whilst stable in either high or low collision frequencies [3]. However, recent gyrokinetic numerical simulation results have revealed an unstable MTM in *collisionless* tokamak plasmas [1]. As modern tokamaks, including ITER, are more frequently operated in collisionless conditions, it is vital to understand the mechanism. In this work, we have studied the equivalent slab geometry using a full gyrokinetic simulation code GS2 (Gyrokinetic Simulations project) [4] and have found MTMs in the collisionless limit to be unstable even in the *slab* geometry. In section 2 the simulation results are benchmarked with existing theory and the difference validated. In sections 3 and 4 we show our research progress on finding the most probable driving mechanism for the collisionless MTM.

## 2. Identifying the collisionless MTM in slab geometry simulations

Existing MTM theory in slab geometry [2,3] finds stability in the collisionless limit, based on a reduced set of fluid eigenmode equations and a limited number of numerical solutions. We have recovered those results, as shown with solid lines in Figure 1, where we have confirmed that in slab geometry MTMs are driven by the electron temperature gradient $\eta_e$ and stabilised at low collision frequency. The dots are simulation results obtained from GS2 gyrokinetic simulations using the same parameters. These gyrokinetic results are consistent with the reduced fluid theory at high collision frequencies, but find an unstable mode even in the limit of low collision frequencies.

We seek to identify the collisionless instability mechanism and confirm if it is a physical result or numerical artefact. The mode structures measured in GS2 simulations are shown in

Figure 2. The collisionless instability is well-converged and has the same tearing parity in magnetic potential and even parity in electrostatic potential as for collisional MTMs. Although the mode structure for the electrostatic potential is much wider, the collisionless instability in our GS2 simulation is an MTM.

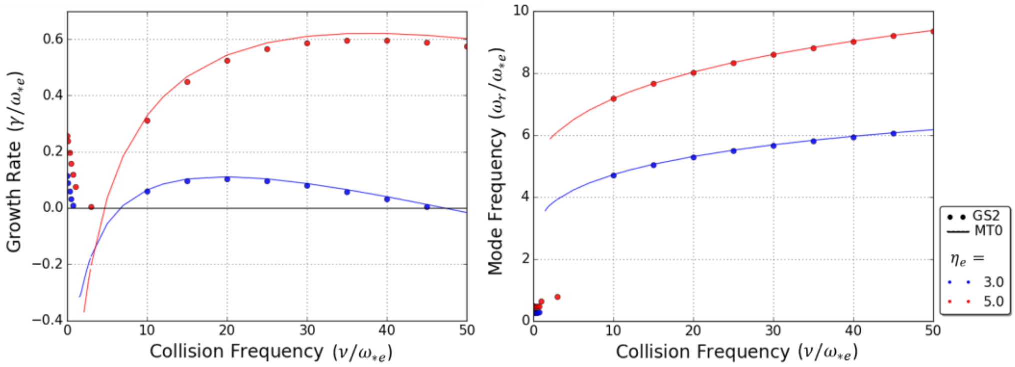


Figure 1: The solid lines show our results for growth rate and mode frequency from the solution of the reduced fluid eigenmode theory [3], and the dots are gyrokinetic simulation results from the GS2 code. Note the discontinuous mode frequency predicted at low collision frequency by GS2 implies a transition to a new branch. Parameters for the results are $k_y\rho_i = 0.3$, $\beta = 0.01$ and $L_n/L_s = 0.05$. $k_y\rho_i$ is the perpendicular wavenumber normalised to the ion Larmor radius. $\eta_e = L_n/L_T$ and $L_n$, $L_T$ and $L_s$ are scale lengths of density gradient, temperature gradient and magnetic shearing, respectively. $\nu/\omega_{*e}$ is the electron collision frequency normalised to the electron diamagnetic frequency.

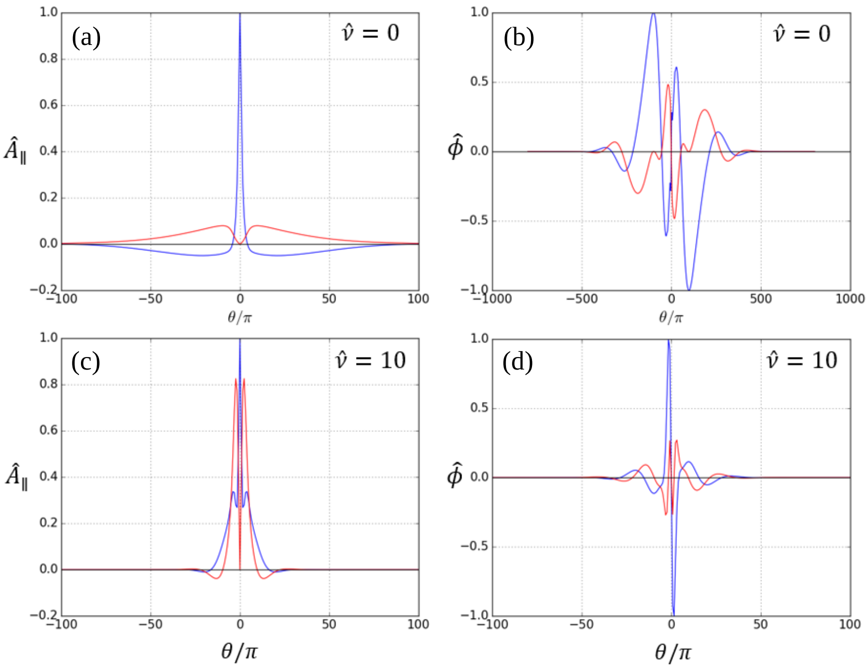


Figure 2: Mode structures provided by GS2 simulations showing parallel magnetic potential $\hat{A}_\parallel$ [(a) and (c)] and electrostatic potential $\hat{\phi}$ [(b) and (d)] of the instabilities shown in Figure 1 at $\nu/\omega_{*e} = 0$ [(a) and (b)] and $\nu/\omega_{*e} = 10$ [(c) and (d)]. The blue lines are real part and the red lines are the imaginary part. $\theta$ is along the perpendicular direction in Fourier space. These mode structures show that both the instabilities are MTM and the collisionless one has a broader structure.

## 3. Identifying the missing physics in the existing theory

To identify the driving mechanism for the collisionless MTM, we have re-derived the fluid slab eigenmode equations from gyrokinetic theory to evaluate the assumptions required. Taking only electron collisions into account, as for the GS2 simulations, we found that there are two key assumptions related to the ion response, namely $|\omega| \gg k_\parallel v_i$ and $k_x \rho_i \ll 1$. Here, $\omega$ is the mode frequency, $k_\parallel = k_y x / L_s$, $v_i$ is ion thermal velocity and $k_x$ is perpendicular wave number across the slab direction.

The first assumption ignores the parallel ion density dynamics and the second one enables ion finite Larmor radius effects to be treated perturbatively. We employ the GS2 solutions to evaluate the validity of these assumptions, finding that both are marginally acceptable for the collisional branch but the latter one does not hold for the collisionless branch, as shown in Figure 3. Indeed, even $k_x \rho_e$ becomes significant for the collisionless branch.

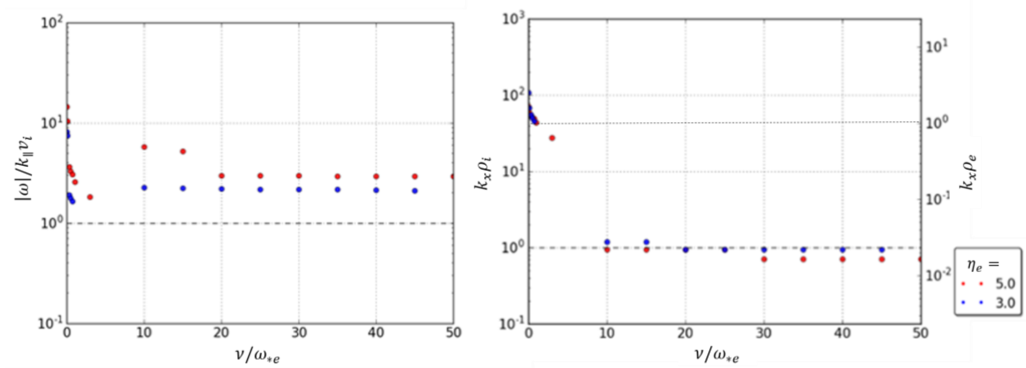


Figure 3: Validity of the two assumptions at different collision frequencies showing that the assumption $k_x \rho_i \ll 1$ does not hold for the collisionless branch. Related parameters are consistent with previous figures.

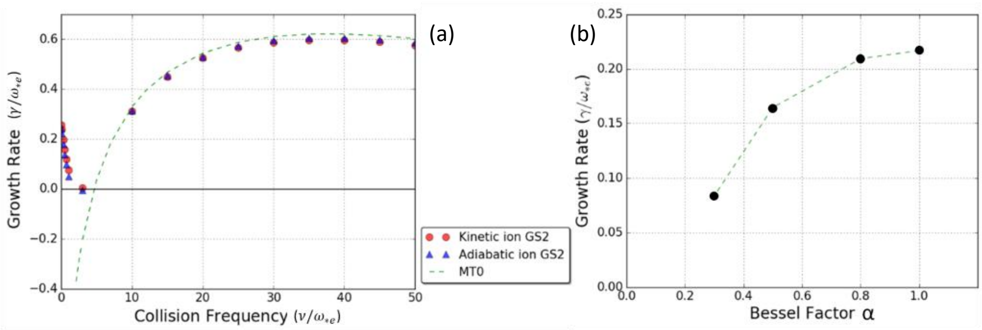


Figure 4: (a) GS2 simulations with kinetic ion or adiabatic ion options, compared to the fluid slab mode (MT0). (b) GS2 simulation results for collisionless MTM with adiabatic ions showing the destabilising effect of electron FLR. We have set $\eta_e = 5.0$, with $\nu/\omega_{*e} = 0.1$ for (b).

We confirm that the relevant physics is associated with the electrons by repeating the GS2 simulations with adiabatic ions (see Fig 4(a)). We find that the instability persists, leading us to focus on finite electron Larmor radius effects as the possible drive of the collisionless MTM. To test this hypothesis, we introduce an artificial parameter, α, in GS2 which scales the size of the electron FLR effects in the Bessel function of the simulations; we refer to α as the Bessel factor. In the original GS2 simulation the Bessel factor $\alpha = 1$. Ignoring electron FLR effects is equivalent to $\alpha \to 0$. By varying the Bessel factor for the collisionless MTM, adopting adiabatic ions for simplicity, we confirm the destabilising effect of electron FLR at low collision frequencies in figure 4(b). In contrast, we find that for the collisional MTM the electron FLR effects have no impact.

**4. Discussion on the physics of driving mechanism**

GS2 simulations in slab geometry have shown a strong impact from the electron FLR effects on the collisionless MTM, which is absent in the fluid slab models for MTMs. Taking electron FLR effects into account in the derivation of an extended fluid theory, we have found extra terms associated with parallel magnetic potential. The solution of the resulting model will be compared with GS2 in future work to confirm quantitatively the physics mechanism of the collisionless mode, and to assess the relevance in toroidal geometry.

**5. Conclusion and future work**

In this paper, we have found a new *collisionless* MTM instability in *slab* geometry using the full gyrokinetic simulation code GS2. We have provided evidence to show that the driving mechanism most likely comes from the electron FLR effects associated with the magnetic potential. The development of the new gyrofluid eigenmode equations retaining electron FLR is in progress.

We note a recent related study in [5] reported several driving mechanisms requiring finite collision frequency. We aim to probe the connection to the collisionless instability found here in the future.

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**References**

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