Properties of Microtearing Turbulence in the H-Mode Pedestal

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Recent work on microturbulence under tokamak H-mode [1] pedestal conditions revealed the essential contributions of non-MHD-like instability drive to transport characteristics necessary to explain pedestal evolution [2]. To summarize, heat and particle diffusivities from kinetic-ballooning-mode (KBM) turbulence [3, 4] alone cannot be the only transport mechanism during the inter-ELM phase (where ELM denotes edge-localized modes), as – assuming a weak density source relative to the heat source – the density profile will be modified on shorter time scales than the temperature profiles, resulting in KBM stabilization. Instead, other instabilities will take over, which drive stronger heat than particle diffusivities. Due to the presence of $E \times B$ shear, two primary candidates are microtearing (MT) [5, 6, 7] and electron-temperature-gradient (ETG) [8, 9] modes.

The importance of MT turbulence and transport under pedestal conditions has been elucidated in, e.g., Ref. [10]. Expanding on this effort, in the present work, a similar but – in order to ensure numerical robustness – simplified scenario is investigated, based on the DIII-D H-mode discharge #98889 as described in Ref. [11]. Specifically, ions are treated as adiabatic, a local flux-tube approximation is employed, and the magnetic geometry is reduced to circular, concentric flux surfaces.

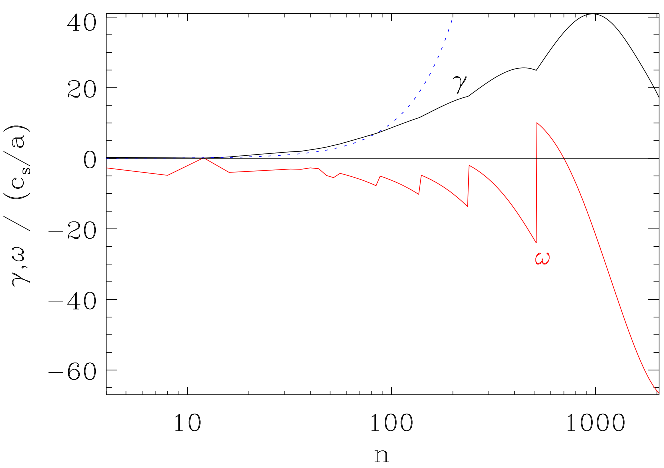

Figure 1: *Linear growth rate (black) and frequency (red) spectra. The dotted blue line corresponds to $\gamma \propto n^2 \propto k_y^2$ scaling.*

The resulting instability picture is shown in Fig. 1, where growth rates and frequencies are depicted for a large range of toroidal mode numbers, beginning at $n = 4$. Notably, the dominant eigenmode at the lowest two wavenumbers is a semi-collisional MT mode, with slab-like features—i.e., with an extended envelope in ballooning space. At smaller scales, a variety of ETG branches is observed, spanning a large range of wavenumbers; for these branches, mode peaking at substantial finite radial wavenumber k_x is a common feature. Note that, in general, a number of subdominantly unstable modes exist at each wavenumber.

Indicated in the figure by a dotted blue line is the basic quasilinear scaling with the squared toroidal wavenumber k_y^2. Naively, one may expect growth rates lower than this curve to contribute little to overall flux.

Initial nonlinear gyrokinetic [12] simulations with the GENE code [8] clearly demonstrate that this intuition is inaccurate, as shown in Fig. 2. Importantly, this simulation was only run for about one ion transit time, thus preventing coupling of the ETG-scale dynamics to the MT turbulence; the latter had already saturated based on a single-scale simulation, which was then continued including electron scales. Shown as solid lines are preliminary multi-scale heat fluxes: the MT-driven blue electron electromagnetic flux Q_e^{em} peaking at low k_y reaches levels comparable to those of the ETG-driven electron electrostatic flux Q_e^{es} peaking at high k_y, as shown in black. Note that the fluxes in the figure are multiplied by the wavenumber to allow for direct visual comparison due to the varying spectral density resulting from the logarithmic k_y axis.

The corresponding ion-scale fluxes are shown as dashed lines; considering the limited temporal statistics during the multi-scale phase, little change of flux is seen in either channel. By comparison, more significant impact is observed for the ETG turbulence (the data shown here as dotted lines was rescaled to account for the altered spectral density). Overall high-k_y flux is reduced in the presence of MT, likely a consequence of low-k zonal flows. Furthermore, the spectral pile-up seen at $k_y \approx 2$ is prevented by the larger simulation domain in the multi-scale case.

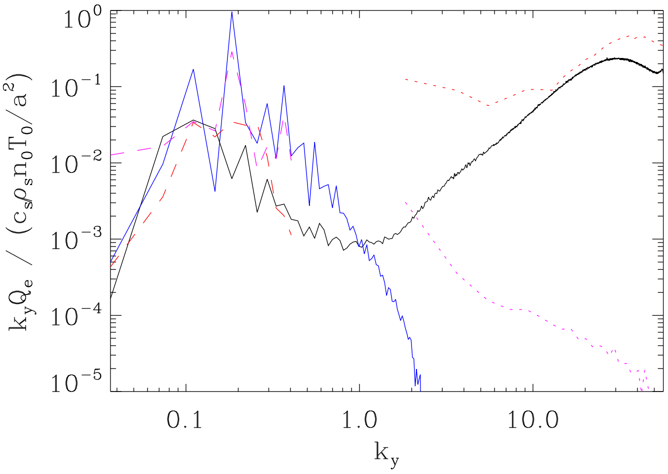

Figure 2: *Spectra of the electromagnetic (blue and pink) and electrostatic (black and red) flux channels. Solid lines correspond to multi-scale results, while dashed (dotted) lines show data for low-k_y-range (high-k_y-range) single-scale simulations.*

In terms of pedestal evolution, the reduced ETG heat flux can be thought to be offset by the addition of the MT flux component. One may predict, however, that RMP fields – which can deteriorate zonal flows [13, 14, 15] – would counteract the MT impact and boost ETG fluxes. Explicit simulations of this scenario are underway and will be presented in a future publication.

The fact the modifications to the turbulence and transport of the inter-ELM pedestal system occur as a consequence of cross-scale interactions introduces a complication into ongoing efforts to construct reduced models of pedestal MT-ETG transport.

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