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Progress in theoretical understanding of the Dimits shift and the tertiary instability of drift waves[1]

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A natural way to control turbulence in magnetic fusion devices is to take advantage of zonal flows, which form spontaneously and can reduce the turbulence level. Zonal flows can even suppress turbulence completely in a certain parameter range where drift-wave instabilities would otherwise develop. But exploiting this effect, which is known as the Dimits shift, requires understanding of its basic physics, which has been unclear. In our work [1, 2], a generic understanding of the Dimits shift in electrostatic drift-wave turbulence is obtained by studying the tertiary instability of a zonal flow within reduced turbulence models. We show that tertiary modes are localized near extrema of the zonal-flow velocity $U(x)$ with respect to the radial coordinate x. These modes can be described as quantum harmonic oscillators with complex frequencies, so their spectrum can be readily calculated. The corresponding growth rate γ_{TI} is derived within the modified Hasegawa–Wakatani model. We show that γ_{TI} equals the primary-instability growth rate plus a term that depends on the local flow "curvature" $U''(x)$; hence, the instability threshold is shifted compared to that in homogeneous turbulence. This shift is the Dimits shift, which we find explicitly in the Terry–Horton limit [3], and our analytic predictions agree well with results of numerical simulations. Our theory of the tertiary instability also extends to other turbulence models. For example, the key features of the tertiary instability of ion-temperature-gradient mode [4] are reproduced by our theory and verified by gyrokinetic simulations.

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