Kinetic Stability Analysis and Collisionless Damping of Zonal Flows*

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Abstract

The crucial role played by zonal flows in regulating the saturation level of drift wave turbulence and ultimately of turbulent transport (see, e.g., Ref. [1]), has brought significant attention on determining the amount of zonal flow which can be spontaneously generated by the turbulence itself before zonal flows become unstable as well due to Kelvin Helmholtz (KH)–like mode excitations [2, 3]. In this framework, drift waves are the “primary” instability and spontaneously generate zonal flows, the “secondary”, which can be limited in amplitude by the onset of “tertiary” KH–like modes [2, 3]. The “tertiary” instability has been proposed as explanation for the nonlinear upshift of the critical Ion Temperature Gradient (ITG) driven turbulence threshold [4].

In the present work, we present a kinetic stability analysis of the “tertiary” KH–like modes and determine the threshold condition for their excitation, i.e. the maximum allowable level of zonal flows spontaneously generated by drift wave turbulence. In other words, our work represents extensions of previous studies [2, 3], which are limited to fluid descriptions of the “tertiary” modes and therefore valid in the strongly unstable domain. In the present theoretical framework, we argue that the long lived saturated zonal flow structures, spontaneously generated in ITG turbulence [5, 6], can be considered as generators of *neighboring nonlinear equilibria*, whose stability we analyze with respect to low frequency drift waves with $|k_\perp| \gg |k_z|$, $2\pi/|k_\perp|$ and $2\pi/|k_z|$ being, respectively, drift wave and zonal flow wavelengths.

In toroidal geometry, we demonstrate the crucial role played by trapped as well as barely circulating particles in setting the “tertiary” instability threshold, due to the fact that the characteristic frequency of the KH–like modes is smaller than the typical thermal ion bounce frequency. Starting from the nonlinear gyrokinetic equation [7], we derive the quasineutrality condition for low frequency, long wavelength drift waves in the form of an integral equation [3], whose solution in the local limit gives us a simple estimate for the threshold condition of the “tertiary” instability. Considerations of anomalous collisionless “viscous” damping of the zonal flows via the “tertiary” instability will also be presented.

References

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