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What Limits Zonal Flow Saturation in (nearly) Collisionless Drift-Wave Turbulence?

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Drift wave – zonal flow turbulence is self-regulating and often modeled as a predator-prey system. A key question that remains is how zonal shears are regulated in the case of weak frictional damping. Zonal flow stability and its implications are key concerns.

One might naively think that zonal flow instability is determined by Rayleigh's criterion.[1] However, realistic values of electron adiabaticity tell us that Rayleigh-Kuo (RK) is the correct stability criterion.[2] RK's criterion states that for zonal flow instability to occur, it is necessary for the total mean potential vorticity gradient to vanish locally. Here, in the Hasegawa-Wakatani system, mean potential vorticity gradient is defined as such: $\nabla(\langle PV\rangle) = \nabla(\langle n\rangle - \nabla^2\langle \phi\rangle)$.

To see the effects of zonal flow instabilities on zonal shears and turbulence levels, we utilize the energy ratio between zonal flows and drift waves. We define the quantity R = Zonal Flow Energy / Drift Wave Energy. $R < 1$ characterizes a state of weak zonal flows and strong turbulence. $R >> 1$ constitutes a Dimits Shift-like state, where most of the energy is transferred to zonal flows. Here, "zonal" means k_θ and $k_z = 0$ and "drift wave" means k_θ and $k_z \neq 0$. The parts of this energy ratio are calculated via integration on simulations utilizing the Hasegawa-Wakatani equations.[3]

Distributions of R vs. $\nabla(\langle PV\rangle)$ are then plotted for varying values of frictional damping (μ), for frozen $\nabla(\langle n\rangle)$ (for simplicity). Results for three different values of μ are plotted in Figure 1 below.

The results indicate that for lower damping, areas in the zonal flow with $R < 1$ centralize at $\nabla(\langle PV\rangle) = 0$, in accord with the RK criterion. Higher damping cases stray from this structure, indicating that RK stability is not the governing physics.

Ongoing work is concerned with variable $\nabla(\langle n\rangle)$ to analyze staircase-like structures. We speculate that high $\nabla(\langle n\rangle)$ can explain stable staircase structures through the RK criterion, i.e. – strong shear layers support steepened $\nabla(\langle n\rangle)$ while large $\nabla(\langle n\rangle)$ in turn maintains the stability of the shear layers. This research was supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences, under Award Number DE-FG02-04ER54738.

References

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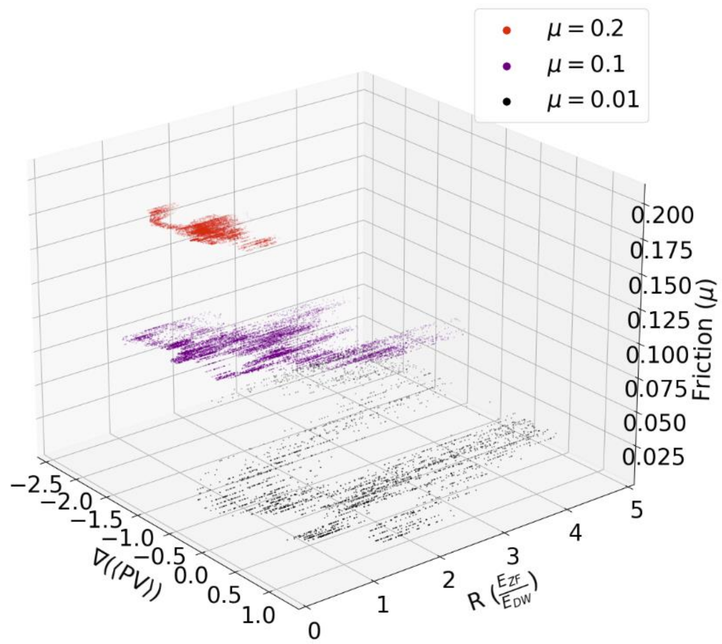

Figure 1: 3D plot of R vs. $\nabla(\langle PV\rangle)$ for three different values of μ. As frictional damping is increased, both the zonal flow energy of the system and the variance along the $\nabla(\langle PV\rangle)$ and R axes drastically decrease.