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The ubiquitous zonal flows

Rameswar Singh and P H Diamond
CASS, University of California San Diego
e-mail (speaker): rsingh@ucsd.edu

Zonal flows are prevalent in nature and in laboratory experiments. In nature, zonal flows are very commonly observed in planetary atmospheres[1], liquid interior of the planets[2], in the convection zone of the sun[3], in the astrophysical disks[4], on the ocean surfaces[5]. In laboratory settings, zonal flows are routinely observed in rotating liquid experiments[6], cylindrical magnetized plasma devices[7], tokamaks[8], reversed field pinches[9] and stellarators[10]. In this pedagogical talk, we will discuss on the mechanisms of zonal flow generation, zonal flow saturation, the interplay between the zonal flow and the host turbulence and role of zonal flows on structure formation. Similarities and differences in the mechanisms of zonal flow emergence in different settings (nature and lab) will be discussed. Effects of wave - flow resonance and possibility of zonal flow hysteresis will be discussed[6].

Radial ExB shear of the zonal flow breaks up turbulent eddies, thus reducing the turbulence coherence length and turbulent transport. Zonal flows are excited by modulational instability due to negative zonal eddy viscosity[11] and the beat noise[12]. Negative eddy viscosity results from the coherent mode couplings and manifest as inverse cascade of kinetic energy. The beat noise results from the incoherent mode couplings. The interaction of zonal noise and modulations has a significant effect on feedback processes. Beat noise eliminates the power threshold for zonal flow excitation. The threshold power for L-H transition is reduced. Zonal density corrugations are excited by noise, regardless of modulational stability. The zonal density diffusivity is positive definite. Propagating corrugations manifest as avalanches. Cross-correlations between zonal flow and corrugations and their impact on turbulence saturation will be discussed.

Tangled magnetic fields, often coexisting with an ordered magnetic field, have a major impact on the turbulence and momentum transport, both in nature and laboratory magnetic confinement devices. Stochastic magnetic fields reduce zonal flow shear by dephasing the Reynolds stress. As a consequence the turbulence level and the power threshold for the L-H transition increase[13].

Zonal flow shear collapse has serious implications for limiting the operational space of the magnetic confinement devices. In particular, enhanced transport due to zonal flow collapse at high density can aggravate excitation of MARFEs or radiation driven islands due to enhanced edge cooling, which can lead to disruption of discharge[14,15]. Thus shear layer collapse can trigger the density limit phenomenology[16].

References

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