Island-induced transport barrier due to turbulence-driven Vortex-Flow

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We predict a new state of plasma self-organization in presence of magnetic islands, namely turbulence-driven island Vortex-Flows, which are non-axisymmetric flows. The interaction between an ExB sheared Vortex-Flow and the Drift-Wave (DW) turbulence driving it is derived in presence of a coherent static magnetic island, based on Ref. [1]. The turbulence is driven by a 3D density profile due to quasi-linear island-induced profile flattening. The Drift-Waves thus follow the local electron diamagnetic direction along the island. The metrix tensor is introduced, making the analysis transparent in island geometry. An extended Charney-Hasegawa-Mima [2] equation describes the DW turbulence-Vortex Flow interaction, from which a wave-kinetic equation is obtained in island geometry. This yields a DW-Vortex Flow predator-prey model which predicts a nonlinear threshold for island Vortex-Flow formation. The Vortex-Flow threshold decreases as the inverse-square of the island width (normalized to the gyroradius), which shows that the turbulence around wider islands may more easily drive flows. Our previous turbulence-driven Vortex-Flow Predator-Prey model [3] is extended to include the coupling to the island pressure gradient and associated mean Vortex-Flow.The turbulence-driven Vortex-Flow is driven by nonlinear coupling to turbulence, and damped by viscous dissipation, whereas the mean Vortex-Flow is set by the island pressure gradient via a generalization of radial force balance to the island topology. The island pressure gradient is driven by the heat source Q, and suppressed by turbulence due to quasilinear flattening. The role of the mean Vortex-Flow is to lock-in the transition to the ITB-like state, by analogy with the L-H transition.The dynamics of turbulence, turbulence-driven Vortex-Flow energy and island pressure gradient are shown [Fig 1]. Here, the heat source is constant in time corresponding to the flat-top regime while the island-width is slowly ramped up (black line), as in the experiment [4] which triggers the transition to the ITB-like regime, once the threshold island-width is reached. The model predicts that the island-width threshold is proportional to ρ (rho star), which is favorable for future devices like ITER. Once the island-width threshold is reached, the following observations can be made, based on this predator-prey model: i) The turbulence (blue) starts to be suppressed, ii) The turbulence-driven Vortex-Flow energy (red) increases. The island-averaged pressure gradient (and associated mean Vortex-Flow) increases (yellow), which correspond to the island-induced ITB.

References

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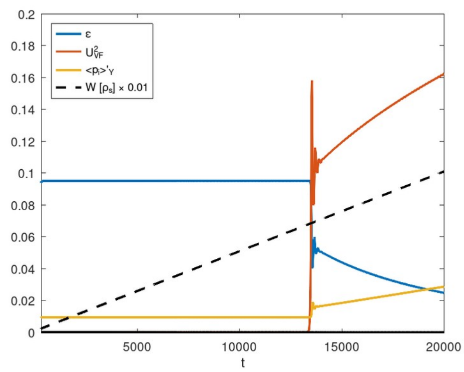

Fig. 1: dynamics of the island Vortex-Flow predator-prey model