New Developments in Momentum Transport Bifurcation Phenomenology

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Recent experimental results, including those from TCV[1] (Momentum transport bifurcation-MTB-in core as density increases in OH saturation) and JT-60U[2] (correlation of spontaneous rotation with pressure gradient for increased heating power) indicate that the phenomenology of MTB's and the buildup of spontaneous rotation is much richer than initially thought[3]. We present a new theoretical approach which encompasses these new developments and predicts others. A rigorous quasilinear calculation of the momentum flux coupled to an energy-momentum conserving wave kinetic (quasi-particle) turbulence model casts the total momentum flux as the sum of the *resonant particle* flux of parallel momentum and the *radial flux* of *parallel wave momentum*. Thus, spontaneous rotation in a region can occur by wave momentum in/out flow to/from that region. Since the resonant particle contribution is often small, we calculate the wave momentum flux using a Chapman-Enskog type expansion to obtain the wave population density. Both wave intensity gradients and electric field shearing 'wind-up' can drive a net momentum flux, the latter entering as a product with a factor of $\partial V_{gr}/\partial k_r$ - the radial compression of group velocity. Note that this factor depends on the sign of the *mode phase velocity*. Symmetry breaking is shown to enter via a number of routes. Both the TCV-type MTB (produced by change in mode propagation direction at fixed turbulence level) and the better known electric field shear induced MTB are predicted by the model, as are other novel MTB's. The modal phase and V_E' bifurcations can be represented on a single momentum "flux landscape" in $(n, \nabla p)$ space. We have applied the theory to the dynamics of intrinsic rotation at ITB formation. Finally, the basic theory, formulated for electrostatic turbulence, has been extended to address Alfvenic turbulence. The key point here is that (electromagnetic) Alfven waves support *field momentum*, which breaks the link between wave and non-resonant particle momentum.

[1] A. Bortolon, et al., Phys. Rev. Lett. 97, 235003 (2007).
[2] M. Yoshida, et al., ITPA (5/2007).
[3] J. Rice, et al., Nuclear Fusion (2007), In Press.