Extended gyrokinetic theory for the tokamak H-mode pedestal

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The conventional gyrokinetic theory, typically employed in the pedestal, is not sufficient to capture the features of the current density gradient physics, including the physics of kink modes. This is because it is typically based on a Maxwellian equilibrium independent of the sign of the velocity component parallel to the magnetic field. The kink mode drive is proportional to $j'_{\parallel}/n$, where $j'_{\parallel}$ is the radial derivative of the parallel current density and n is the toroidal mode number, and thus is ordered out from conventional gyrokinetics and ideal MHD, which is justified in a core plasma. However, $j'_{\parallel}$ is large in the pedestal due to a large fraction of bootstrap current, i.e. the steep pressure gradient there, and thus must be retained in the model.

The electromagnetic gyrokinetic theory has been extended to capture these effects [1]. The particle distribution function is split as $f = F + \delta f$ with F describing the equilibrium solution (in gyrokinetic ordering) and δf being associated with fluctuations: $\nabla_{\parallel}\delta f \sim \delta f/L$ along and $|\boldsymbol{\nabla}_{\perp}\delta f| \sim \delta f/\rho$ across equilibrium magnetic field lines, where L is the system size and ρ is the particle gyro-radius. To recover the kink mode physics, one needs to retain the current density in the equilibrium distribution, associated with the neoclassical currents, and hence solve for F perturbatively, expanding it in powers of $\delta = \rho_{\vartheta}/L \ll 1$, where ρ_{ϑ} is the poloidal Larmor radius. The leading order solution is the Maxwellian, employed in conventional gyrokinetics. The following two orders provide contributions to neoclassical flows, including the bootstrap current due to the steep pressure gradient in the pedestal and required to capture features of the kink mode physics and the current related terms in ideal MHD. The gyro-angle dependent part of the second order correction in a δ expansion has to be retained in F as well to ensure consistent ordering. F is then used to derive the extended gyrokinetic equation for fluctuations. To obtain δf, the second small parameter is introduced, $\Delta = \rho/L \ll 1$, and the corresponding expansion is applied.

This provides an improved gyrokinetic theory in the presence of large pressure gradients relevant for microinstabilities that drive turbulence in the core of a spherical tokamak plasma or the edge pedestal region of a conventional tokamak.

References

[1] A.V. Dudkovskaia, H.R. Wilson and F.I. Parra, to be submitted (2022)