Extended electromagnetic gyrokinetic theory for tokamak pedestal

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In the pedestal, large bootstrap and Pfirsch-Schluter currents, arising from the steep pressure gradient, drive kink instabilities and enhance the drive for the peeling-ballooning modes. The latter triggers periodic plasma eruptions at the edge of a tokamak that significantly influence the pedestal properties, limiting the pedestal pressure gradient and degrading core confinement.

The conventional gyrokinetic theory usually employed to describe the physics of the pedestal is not sufficient to recover the full spectrum of ideal MHD results, e.g. it cannot capture the physics of kink modes. Indeed, it adopts a Maxwellian equilibrium and therefore does not retain the current density gradient along the magnetic field lines. These current density gradient effects can typically be ignored in a core plasma of a conventional tokamak, but must be retained in the core of a spherical tokamak plasma or in the vicinity of the pedestal of a conventional tokamak where the pressure gradient is the strongest.

In [1,2] we have developed a new electromagnetic gyrokinetic theory that captures the strong gradients in the pedestal. The particle distribution function is written in the form: $f = F + \delta f$, where F describes the equilibrium piece (in the gyrokinetic ordering), i.e. it varies on transport time scales, and δf is the fluctuating piece (the particle species indices are dropped for simplicity). To recover ideal MHD, we must retain neoclassical effects in the equilibrium distribution function and thus solve perturbatively the drift kinetic equation that describes F, expanding it in powers of $\delta = \rho_\vartheta / L \ll 1$, where ρ_ϑ is the poloidal Larmor radius and L is the characteristic size of the system. Here the leading order corresponds to the Maxwellian, employed in conventional gyrokinetics. The following order introduces the neoclassical flows (e.g. bootstrap current flows), required to recover kink physics. The gyro-angle dependent piece of the second order correction in a δ expansion must be retained as well to ensure a consistent ordering. This F is then employed to obtain the extended gyrokinetic equation for fluctuations. To solve the gyrokinetic equation for δf, we employ an expansion in $\Delta = \rho / L$, where ρ is the particle Larmor radius. In [1,2] we provide two sets of equations: (a) global, integro-differential gyrokinetic equations that allow one to capture the global properties of modes and (b) local gyrokinetic equations which employ an eikonal ansatz for the fluctuating electromagnetic field. The latter provides the theoretical formalism in a form ready for implementing in existing local gyrokinetic codes.

References:

[1] H. R. Wilson, A. V. Dudkovskaia and F. I. Parra, to be submitted (2021)
[2] A. V. Dudkovskaia, Zenodo: DOI/10.5281/zenodo.4837432