9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Impact of transport ordering breakdown on plasma currents and transports in a tokamak

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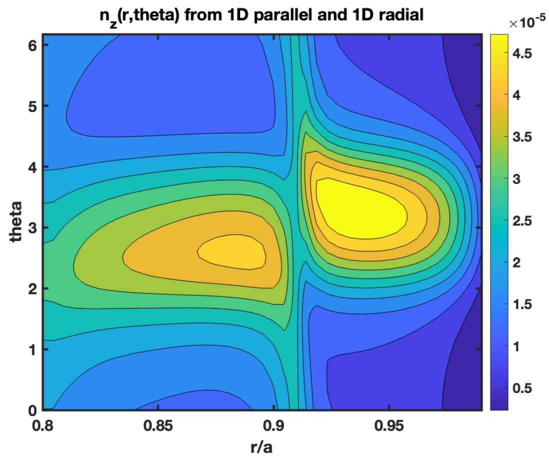
Since the transport time scale in a modern tokamak is longer than both the collision time and the microscale turbulence eddy turnover time, the ion and electron distribution functions are very close to a Maxwellian. Deviations from the Maxwellian are typically of the order of a small parameter, ρ_i^*, the ratio of the ion Larmor radius to the machine size. To determine the fluid quantities (density, average velocity, and temperature) in the Maxwellian, the poloidally and temporally averaged neoclassical and turbulent fluxes are balanced with various particle, momentum, and energy sources. This balances between the sources and fluxes are achieved on the transport time scale, which is approximately $1/\rho_i^{*2}$ times longer than the collision time and the eddy turnover time. Furthermore, because the parallel streaming is generally much faster than magnetic and ExB driftts, the fluid quantities tend to be poloidally uniform. Due to these time separations, 1D radial transport equations are likely sufficient to evolve the fluid quantities.

However, in this study, we present two examples where this time scale separation breaks down. First, we found that high-Z impurities in the pedestal can experience 2D (radial and poloidal) transport on a time scale comparable to both the parallel dynamics and the perpendicular turbulent and classical transport. This occurs due to the steep density and temperature gradients in the pedestal and the high friction associated with large Z. When the impurity charge number is sufficiently large, such that $Z^2 \nu_{ii}^* \rho_i^* \sim 1$, the impurity density evolution is influenced simultaneously by radial and poloidal motion. Figure 1-(b) shows a 2D contour plot of impurity density from our 2D formulation for a JET tungsten case [1], which is different from the poloidal asymmetry predicted by the conventional theory [2] based on separate 1D parallel momentum and radial equations, shown in Figure 1-(a).

As a second example, we demonstrate that the radial and poloidal localization of heating source can lead to a breakdown of the conventional ordering. In the conventional ordering, the RF heating source was predicted to modify the Bootstrap current only indirectly through changes to the background distribution, resulting in a small net current change due to a cancellation between positive and negative changes in radial gradients of the background distribution function around the heating location. However, when the source intensity is sufficiently large (>1MW/m^3) due to radial and poloidal localization, the quasilinear velocity diffusion by RF waves can be included in the first-order drift kinetic equation. For ions, the quasilinear velocity diffusion rate can become comparable to the parallel streaming and collision rates, allowing wave-particle interactions to directly modify the neoclassical distribution and bootstrap currents. We found that ion cyclotron heating likely reduces the existing bootstrap current by interfering with pitch-angle scattering of the trapped particles. In other conditions of radial temperature gradient and wave parallel refractive index, the wave can enhance the bootstrap current, offering a promising synergy between RF-driven current and bootstrap current.

(a)



(b)

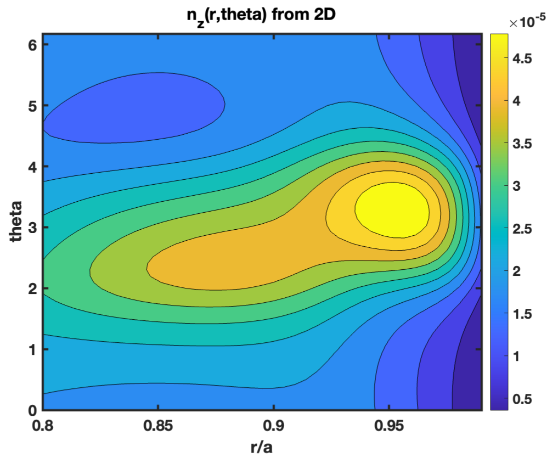


Figure 1. 2D contour plot of tungsten impurity density by (a) conventional 1D parallel and 1D radial theory and (b) new 2D formulation. JET #82722 t=7.5 seconds case [1]

References

[1] Angioni, et.al. Nucl. Fusion 54 (2014) 083028
[2] Helander, Physics of Plasmas 5 (1998) 3999