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4D Fokker-Planck calculations of neoclassical effects in tokamak pedestals and stellarators[1]

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In this work, techniques are discussed for efficiently solving time-independent 4D (2 space + 2 velocity) linear drift-kinetic equations with Fokker-Planck collisions, illustrating several applications in stellarators and tokamaks. Conventional calculations of neoclassical flows, current, and fluxes can become inadequate in the tokamak pedestal if strong gradients violate the thin-orbit-width ordering, yet accurate calculation of these quantities is important for understanding edge stability and confinement. We have therefore developed a new radially global continuum neoclassical code PERFECT [1] which allows some radial scale lengths to be as small as the poloidal ion gyroradius. Using this tool, we demonstrate the first precise verification of recent analytic theory that accounts for finite orbit width effects in the limit of large aspect ratio [2]. The main-ion and impurity flows predicted by the finite-orbit-width calculations can have significantly different magnitude and poloidal variation compared to conventional (local) calculations. PERFECT solves 4D drift-kinetic equations for each species, using a preconditioned Krylov-space algorithm to accelerate solution of the time-independent problem. A related new code SFINCS implements these same algorithms but with a toroidal angle in place of the radial coordinate, enabling radially local calculations for stellarators and rippled tokamaks [3]. For W7-X and LHD scenarios, we use SFINCS to compare the common incompressible-$E \times B$ drift-kinetic equation to more accurate drift-kinetic equations. For radial electric fields below roughly 1/3 of the resonant value, the different kinetic equations lead to similar predictions for the fluxes and flows, whereas the results can differ significantly for larger electric fields. In SFINCS calculations for expected W7-X conditions, the various kinetic models predict similar levels of bootstrap current, improving confidence in past predictions for this quantity that strongly impacts the W7-X divertor.

[1] Landreman et al, PPCF 56, 045005 (2014).
[2] Catto et al, PPCF 55, 045009 (2013).
[3] Landreman et al, Phys Plasmas 21, 042503 (2014).

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