KNOSOS, a fast neoclassical code for optimization of magnetic geometries

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Good confinement of the bulk plasma and fusion-generated alpha particles are two basic design properties of a fusion reactor. First, small radial energy fluxes are necessary for the plasma to achieve fusion-relevant conditions. In turn, fusion-born alpha particles are expected to contribute to heat the plasma, which requires their confinement time to be sufficiently long.

In stellarators, neoclassical processes are a major concern with respect to bulk and energetic ion confinement. In a generic three-dimensional device, trapped particles move back and forth along the field lines with a non-zero average radial drift. This, in combination with collisions, gives place to a variety of stellarator-specific neoclassical transport regimes of which the most relevant ones for low-collisionality bulk plasma transport are the $1/\nu$, $\sqrt{\nu}$ [1] and superbanana-plateau regimes [2]. The same processes and regimes can be observed in tokamaks with broken symmetry [3]. In most fusion-revelant cases, bulk ions are typically in the $\sqrt{\nu}$ regime, and the superbanana orbits are the mechanism behind prompt energetic ion losses. Stellarator optimization is the numerical procedure by which the magnetic configuration is tailored to meet several design criteria, and neoclassical transport of bulk and energetic ions are two of them. The effective ripple, a figure of merit for the level of transport in the $1/\nu$ regime, is usually addressed; the loss fraction of energetic ions is targeted by means of simplified proxies.

In this talk, we present the recently developed code KNOSOS (KiNetic Orbit-averaging SOlver for Stellarators), a freely-available open-source code that provides a fast computation of low collisionality neoclassical transport in three-dimensional magnetic confinement devices [4] by rigorously solving the radially local bounce-averaged drift kinetic equation coupled to the quasineutrality equation. In the first part of the talk, we show that KNOSOS reproduces the results of the standard neoclassical code DKES and can be orders of magnitude faster. For this reason, KNOSOS can provide new figures of merit for stellarator optimization for bulk neoclassical transport that could not be considered before, such as the level of transport in the $\sqrt{\nu}$ regime and the superbana-plateau regime. The latter can be described because the component of the magnetic drift tangent to flux surfaces is rigorously included in the equations.

In the second part of the talk, we go one step further and show that, by also keeping the radial component of the magnetic drift in the particle orbits, the resulting radially global bounce-averaged drift-kinetic equation can be employed to accurately describe the neoclassical transport of energetic ions in stellarators. This is demonstrated by comparing the solutions of this equation against guiding-center and full-orbit simulations using the code ASCOT. The bounce average reduces the dimensionality of the equation and could lead to potentially faster calculations, that would be specially suited for stellarator optimization and parameter scans.

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