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KNOSOS, a fast neoclassical code for three-dimensional magnetic configurations

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An accurate calculation of radial neoclassical transport is important for both tokamaks and stellarators. In tokamaks, deviations of the magnetic field from axisymmetry (caused, for example, by ripple due to the finite number of coils or by resonant magnetic perturbations) can result in significant neoclassical damping of the toroidal rotation [1]. In stellarators, their intrinsically three-dimensional configurations lead to specific neoclassical transport regimes (see e.g. [2, 3]) that produce radial energy transport comparable, and often larger, than its turbulent counterpart [4]. Although typically less demanding than gyrokinetic codes, the computational cost of neoclassical simulations is crucial for a thorough characterization of transport in three-dimensional configurations, especially at low plasma collisionalities.

In this work we present KNOSOS [5] (KiNetic Orbit-averaging SOlver for Stellarators), a freely-available [6] open-source code that provides a fast computation of low collisionality neoclassical transport in three-dimensional magnetic confinement devices by rigorously solving the radially local bounce-averaged drift kinetic equation coupled to the quasineutrality equation. Apart from its remarkable speed, KNOSOS includes physics often neglected in neoclassical codes, such as the effect of the component of the magnetic drift that is tangent to magnetic surfaces and the component of the electrostatic potential that varies on the magnetic surface, φ_1.

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In the first part of this contribution, by characterizing plasmas of several devices, we show that, where applicable, KNOSOS reproduces the results of standard neoclassical codes, as illustrated in figure 1, being orders of magnitude faster. The examples provided include the calculation of $\sqrt{\nu}$, which is compared to Doppler reflectometry measurements in the stellarator TJ-II [7]. This quantity, ν, can have a strong impact on the radial transport of highly-charged impurities in three-dimensional magnetic configurations [8]. Only recently did stellarator neoclassical codes start to calculate φ_1, and at a large computational cost. The fast calculation of the bounce averaged main ion distribution with KNOSOS opens the door to a fast evaluation of neoclassical impurity transport using recently-derived analytical expressions [9].

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In the second part of the contribution we illustrate how, by retaining the effect of the component of the magnetic drift that is tangent to magnetic surfaces, KNOSOS can describe the superbana-plateau transport regime of stellarators and non-axisymmetric tokamaks. An example is provided in figure 2. We also explain that KNOSOS keeps the dependence of the tangential magnetic drift on the magnetic shear, a relevant element for the calculation of the neoclassical toroidal viscosity in tokamaks with broken axisymmetry at low collisionalities [10]. We end by outlining several planned applications of KNOSOS for stellarators and tokamaks, including detailed validation activities in Wendelstein 7-X, LHD and ASDEX Upgrade, among others.

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