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A solver for energetic particles transport in constants of motion space with collision and phase space zonal structures in tokamak plasmas

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Recently, a general theoretical framework for the transport of Phase Space Zonal Structures (PSZS) has been developed \cite{zonca2015,falessi2019}. PSZS are the long-lived toroidal symmetric ($n = 0$) structures that define the nonlinear equilibrium in the presence of fluctuations such as Alfv\'enic instabilities. In order to include sources and sinks and collisional slowing down processes, a new solver, ATEP-3D was implemented to describe the evolution of the EP distribution in the 3D Constants of Motion (COM) space. It is fully embedded in ITER IMAS framework and combined with the LIGKA/HAGIS codes \cite{LIGKA,HAGIS}. The new development is motivated by the need to use the COM (toroidal canonical momentum P_ζ, energy E, and magnetic moment μ) representation in the PSZS transport model.
The Fokker-Planck collision operator represented in the 3D COM space is derived and implemented in the HAGIS code giving orbit-averaged neoclassical transport coefficients.
For solving the PSZS equation including collisions, a finite volume method and the implicit scheme are adopted in the ATEP-3D code for optimized numerical properties. Open boundary conditions that allow the flux to pass through the boundaries without affecting the interior solution are implemented. ATEP-3D allows the analysis of the particle and power balance with sources and sinks in the presence of EP transport induced by Alfv\'enic fluctuations to evaluate the EP confinement properties. The first benchmarks and applications of this new reduced EP transport model in different parameter regimes are presented.

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