A multi-species collisional operator for full-F global gyrokinetics codes: Numerical aspects and verification with the GYSELA code

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Core fusion plasmas are almost collisionless as the plasma density and temperature in the core of fusion devices are extremely small and high, respectively. Nevertheless, accounting for collisions remains essential for three main reasons. First, to a large extent, collisions govern the level of large scale flows – both the mean ion poloidal flow and turbulence-driven zonal flows – via the friction on trapped particles. Second, neoclassical transport can reveal dominant (or at least competitive) with respect to turbulent transport in certain regimes such as transport barriers, or for certain classes of particles such as heavy impurities like tungsten. Third, and more fundamentally, collisions ensure the relaxation of the distribution function towards a Maxwellian. In turn, they are critical for gyrokinetic simulations since they smooth out small scale structures in velocity space, contributing to numerical stability.

We report here on the numerical implementation of a new linearized multi-species collision operator in the full-f gyrokinetic code GYSELA [1]. It is based on the model operator developed by Estève *et al.* [2]. This new operator alleviates two important assumptions which were made previously. First, the operator now accounts for the velocity derivatives along the parallel *and* the transverse (new) directions. The adopted method makes use of projections on Laguerre polynomials. Second, the deflection and velocity relaxation frequencies are properly discriminated, so that the novel operator is valid for any multi-species collisions, regardless of their mass, charge and concentration. This operator does not include finite Larmor radius effects, although these corrections could be added if the resulting classical transport should be retained. An exact H-theorem is not available in the general case for this linearized operator [2]. However, a relaxation towards an isotropic Maxwellian, which is a part of the H-theorem, is expected.

The conservation properties of the new collision operator (particles, total momentum and energy) have been tested successfully. The relaxation towards an isotropic Maxwellian is always observed. In the case of small anisotropy, an isotropization rate in agreement with analytical prediction is found. Also, the exchange rates of parallel momentum and energy agree with theoretical predictions. To complete the verification of the collision operator, neoclassical transport can then be addressed when accounting for trajectories. In this framework, the collision operator has been successfully benchmarked against neoclassical theory (diffusion coefficient and ion poloidal flow) for the single species case in all three collisionality regimes. With two species, the diffusion coefficient, density peaking and thermal screening of a trace impurity agree with neoclassical predictions. Finally, collisional zonal flow damping, which is critical for turbulent transport, agrees with theoretical predictions [3].

References

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