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A multi-species collision operator for gyrokinetic codes

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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. It is based on the model operator developed by Estève *et al.* [1]. 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 to keep good parallel scalability – despite μ is no longer an adiabatic invariant – 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. So far, this operator does not include finite Larmor radius effects, although these corrections could be added if the resulting classical transport should be retained.

The conservation properties of the new collision operator (particles, total momentum and energy) have been tested successfully. The relaxation towards a Maxwellian, which is a part of the H-theorem, is recovered. Also, the exchange rates of parallel momentum and energy agree with theoretical predictions. Neoclassical transport can then be addressed when accounting for trajectories. In this framework, the collision operator has been successfully benchmarked against neoclassical theory in banana and plateau regimes. The Pfirsch-Schlüter regime is under investigation. The Zonal Flow damping will also be compared with predictions made by Hinton and Rosenbluth [2].

Finally, neoclassical benchmarks with two species will be shown, with particular focus on the thermal screening factor, which is expected to play a critical role in preventing core plasma pollution by heavy impurities. As part of future work, comparison with other collision operators will be performed in the frame of the Enabling Research project "TNT" (Turbulent & Neoclassical Transport).

References

[1] D. Estève, X. Garbet, Y. Sarazin et al., "A multi-species collisional operator for full-f gyrokinetics", Physics of Plasmas 22 (2015) 122506; D. Estève, Y. Sarazin, X. Garbet et al., "Self-consistent gyrokinetic modeling of neoclassical and turbulent impurity transport", to appear in Nuclear Fusion (2017)

[2] F. L. Hinton and M. N. Rosenbluth, "Dynamics of axisymmetric ExB and poloidal flows in tokamaks", Plasma Phys. Control. Fusion 41 (1999) A653