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Development of discontinuous Galerkin gyrokinetic code for whole tokamak

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A newly developed gyrokinetic code for the whole tokamak domain simulation is presented. In this code, DG (discontinuous Galerkin) method and the unstructured triangular mesh are adopted for the discretization of plasma distribution functions.

To verify the robustness of the developed scheme, several conservation benchmarks are performed. With a proper choice for the basis functions and the grid size, good conservation properties for mass, canonical toroidal angular momentum and energy are demonstrated. Also, it is shown that the DG method provides a lot of flexibility for basis functions, which can be useful to resolve small scale structures in the phase space with less numerical cost. Due to numerical benefits of the DG method, favorable scalability is demonstrated as shown in Fig. 1.

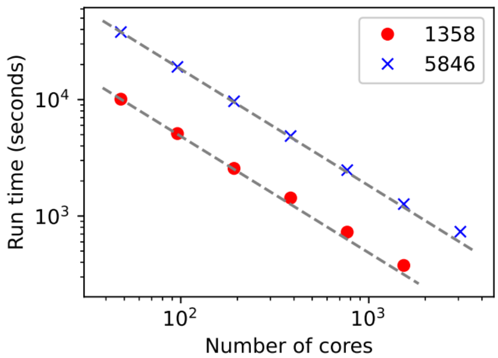

Fig. 1. Strong scaling: [red : 1358 grid case, blue : 5846 grid case]

To address collisional physics, Dougherty model and the typical test particle collision model are implemented and tested. [1-3] Although the Dougherty model has many desirable aspects such as self-adjointness, it has drawbacks for high energy particle simulations due to the lack of velocity dependence in the model collision frequency. On the other hand, the typical test particle collision model is better than Dougherty model for describing the pitch-angle scattering, but it is not trivial to implement field particle collision parts for the DG scheme since spatially varying information for density and temperature is needed to construct the background Maxwellian distribution functions. To investigate the difference between Dougherty and test particle collision model, equilibration tests for anisotropic temperature distribution are performed as shown in Fig. 2. In the tests, the Maxwellian function with $T_\perp = 1.3 \times T_\parallel$ is used as an initial condition. As time increases, both of $T_\perp$ and $T_\parallel$ converge to a same value by collisional processes. In Fig. 2., the test particle collision case shows a similar time scale for the equilibration with the analytic formula, while Dougherty case shows much faster equilibration. This is consistent to the prediction from that smaller collision frequency for fast moving particles is not accounted in the Dougherty model.

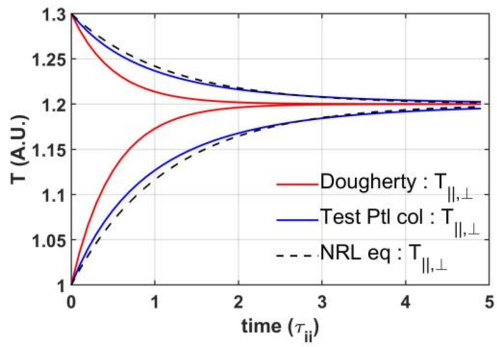

Fig. 2. Equilibration tests for anisotropic temperature distribution.

Even though the linear collision model is known to provide satisfactory results for the core plasma, nonlinear collision operators are desirable for edge and SOL since the distribution function can be highly non-Maxwellan at those regions. The Landau model is more straightforward to implement and beneficial to achieve good numerical conservation properties, but its numerical costs increase as $O(N^2)$. On the other hand, Rosenbluth potential method [4], which is adopted in this work, is numerically cheaper, but it is not trivial to guarantee the numerical conservation. In this work, the conservation issue is circumvented by imposing conservation conditions into the potential FEM solver directly.

Although most of works presented in this presentation are based on toroidally symmetric distribution functions, field-line following grids for toroidal variation are under development to describe anomalous turbulent transports. Unlike particle-in-cell approaches, field-line following grids are non-trivial issues for Eulerian approaches such as FDM or DG methods. Since major difficulties arise at the non-conformal boundaries in the toroidal direction, Gaussian quadratures for arbitrary polygon shapes will be used to describe particle flux across those boundaries.

In addition to the modules presented in this work, the efficient field-aligned Maxwell equation solver is important for turbulent physics simulations. Both of C^0 and C^1 basis are being tested and the related numerical issues will be reported in the near future.

References

[1] J.P. Dougherty, Phys. Fluids **7**, 1788 (1964).
[2] M. Francisquez *et al*., Nucl. Fusion **60**, 096021 (2020).
[3] H. Sugama *et al*., Phys. Plasmas **16**, 112503 (2009).
[4] M.N. Rosenbluth *et al*., Phys. Rev. **107,** 1–6 (1957).