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Unification of Plasma Fluid and Kinetic Theory via Gaussian Radial Basis Functions[1]

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A fundamental macroscopic description of a magnetized plasma is the Vlasov equation supplemented by the nonlinear inverse-square force Fokker-Planck collision operator [Rosenbluth et al., Phys. Rev. 107, 1957]. The Vlasov part describes advection in a six-dimensional phase space whereas the collision operator contains friction and diffusion coefficients that are weighted velocity-space integrals of the particle distribution function. The Fokker-Planck collision operator is an integro-differential, nonlinear (bilinear) operator. Numerical discretization of the operator, in particular for collisions of unlike species, is extremely challenging. In this work, we describe a new approach to discretize the entire kinetic system based on an expansion in Gaussian Radial Basis functions (RBFs). This approach is particularly well-suited to treat the collision operator because the friction and diffusion coefficients can be analytically calculated. Although the RBF method is known to be a powerful scheme for the interpolation of scattered multidimensional data, Gaussian RBFs also have a deep physical interpretation in statistical mechanics and plasma physics as local thermodynamic equilibria. We outline the general theory, highlight the connection to plasma fluid theories, and also give 2D and 3D numerical solutions of the nonlinear Fokker-Planck equation. A broad spectrum of applications for the new method is anticipated in both astrophysical and laboratory plasmas. In particular, we believe that the RBF method may provide a new bridge between fluid and kinetic descriptions of magnetized plasma.

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