A parametric equilibrium distribution function for use in gyrokinetic simulations and modeling.

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Gyrokinetic theory in general and gyrokinetic simulations in particular make often use of an initial distribution function, usually indicated by $F_0$. Initial distribution function must represent a slowly evolving equilibrium, $F_{eq}$, for a perturbative approach. There are two conditions that $F_{eq}$ must satisfy in order to be considered an equilibrium one: it must depend only on the constants of motion (adiabatic invariants included) and the particles (or guiding centers) must remain confined for suitably long time. In this work we address the first condition.

We build a parametric form of $F_{eq}$ that depends only on constants of motion. Adopting the following guidelines to construct such a distribution function: it must have Boltzmann-like behavior $F_{eq} \propto \exp(-\mathcal{E}/T)$, the energy $\mathcal{E}$ must be expressed in terms of constants of motion, it must be mathematically tractable. For a given equilibrium magnetic field, commonly expressed by $B = \nabla \psi \times \nabla \phi + F(\psi)\nabla \phi$, we choose $P_\phi, w$ and $\lambda$ as the constants of motion; where we define $P_\phi = \psi + Fv_{\parallel}/\omega_c$ ($P_\phi$ corresponds to the toroidal angular momentum, conserved for an axisymmetric system), $w = v_{\parallel}^2/2 + \mu|B|$ and $\lambda = \mu/w$, conserved if the electric potential $A^0$ is negligible ($\mathcal{E} = mw + ZeA^0$), being $\mu$ the magnetic moment for unitary mass.

Given $F_{eq}$, we will show how this function can be modeled, with a proper choice of its parameters, to reproduce the most common distributions used in tokamak plasmas. For the thermal plasma, we obtain a distribution similar to a local Maxwellian in the Zero Orbit Width approximation, discussing the differences of the present method with the commonly used procedure [1] to replace $\psi$ with the constant $\psi_{\text{orb}} \sim P_\phi - mR_0/(Ze)\sigma\sqrt{2w(1 - \lambda B_0)}$ H(1/B_0 - $\lambda$), in $F_0$. For fusion $\alpha$ particles, $F_{eq}$ can also reproduce the Slowing Down (SD) distribution function. More generally, for supra-thermal particles, when external heatings are present, such as (N)NBI and ICRH, we will show strong similarities of the proposed model distribution function with the anisotropic SD and the biMaxwellian distributions.

This distribution function can be used to fit experimental profiles and it could provide a useful tool for experimental and numerical data analysis. It is possible to develop analytical computations for facilitating data interpretation in the light of theoretical models, such as the framework of the General Fishbone-Like Dispersion Relation [2]. Finally, the proposed model distribution function can be easily implemented in gyrokinetic codes, where it can be used to simulate plasma also in the presence of external heating sources, as recently demonstrated [3] for FAST [4] plasma conditions, using the HMGC code [5].