An improved hybrid electron model for global gyrokinetic simulations using the ORB5 PIC code

E. Lanti, S. Brunner, N. Ohana, A. Scheinberg, and L. Villard

Swiss Plasma Center, École Polytechnique Fédérale de Lausanne, Switzerland

Gyrokinetic simulations are extensively used as a tool to describe various phenomena in magnetically confined plasmas. Among others, turbulent transport induced by drift-wave type instabilities such as Ion Temperature Gradient (ITG), Trapped Electron Mode (TEM) and Electron Temperature Gradient (ETG) plays a central role in fusion research. While the ITG mode in first approximations can be modeled using a reduced adiabatic electron model, the TEM and ETG modes require a kinetic description.

The global delta-f PIC code ORB5 [1] currently implements three electron models: in the first, all the electrons are treated adiabatically, in the second they are all treated as kinetic and finally, in the so-called hybrid model the trapped electrons are treated as kinetic while the passing ones are considered to have an adiabatic response. Although the hybrid model is very useful to simulate electron driven modes such as the TEM at a lower numerical cost as compared to the fully kinetic electron model, in its standard form it does not ensure the ambipolarity condition and toroidal angular momentum conservation, which is clearly problematic for long nonlinear simulations.

Recently, an improved hybrid electron model was proposed [2] to solve the ambipolarity problem while avoiding the electrostatic limit of the shear Alfvén mode (so-called ω_H mode) that constrains the time step to small enough values so as to resolve this high frequency mode. This new model treats the trapped electrons as kinetic but separates the passing contribution into a zonal contribution that is treated kinetically and a non-zonal contribution that has an adiabatic response. Finally, all the zonal modes with a poloidal mode number $m \neq 0$ are filtered out. Although this model clearly satisfies the ambipolarity condition, it affects the GAM frequency, which is problematic, for example for comparisons with the experiment [3].

In this work, we propose a further improved hybrid electron model based on [2]. This version considers the zonal contribution of the passing electrons as kinetic but contrarily to the reference, it also includes the zonal modes with $m \neq 0$ as an adiabatic response. In addition to verifying the ambipolarity condition, it affects less the GAM frequency. Zonal flows damping (Rosenbluth-Hinton) tests are used to validate the linear regime of this improved hybrid electron model and comparison with other models and theory will be shown to assess the GAM properties. Nonlinear simulations confirm the ambipolarity condition and show a richer physics that will be discussed. In particular, the zonal flow dynamics is affected by the proximity of mode rational surfaces.

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References

[1] S. Jolliet, et al., Comput. Phys. Commun. 177, 409 (2007); T.M. Tran, et al., Varenna (1999)
[2] Y. Idomura, Journal of Computational Physics 313 (2016), 511-531
[3] C. A. de Meijeire, et al., Plasma Phys. Control. Fusion 56, 072001 (2014)