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Extension and application of the gyrokinetic code GKV to space plasmas

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We have been developing a gyrokinetic simulation model for space plasmas by extending a nonlinear gyrokinetic code GKV [1], which has been widely used to study low-frequency turbulence and related phenomena in fusion plasmas. The first application of the extended code is the nonlinear evolution of magnetospheric plasmas coupled to the auroral ionosphere. The extension enables self-consistent calculations of auroral particle acceleration by electric fields parallel to the background magnetic field and the nonlinear growth of auroral structures.

Although a large class of space plasmas falls within the scope of gyrokinetic theory, several modifications to the basic framework used in fusion plasma simulation are necessary. First, the magnetic field configurations and boundary conditions are different. In a planetary magnetosphere, the primary component of the magnetic field is a dipole field, and the resulting strong magnetic mirror force may require modifications in numerical schemes. Moreover, in the case of the magnetosphere-ionosphere (M-I) coupling system, the coupling of two regions with significantly different plasma parameters must be incorporated. Second, the ordering assumptions behind the governing equations may require reconsideration. For instance, nonlinear parallel acceleration terms in the gyrokinetic equation, often ignored as higher order terms for fusion plasma simulations, can be comparable to conventional terms and play a crucial role in particle acceleration processes in space plasmas. Third, non-Maxwellian background distributions are much more common in space plasmas. Particularly, the so-called kappa distributions, which possess a high-energy tail, are observed in various space environments, including the auroral magnetosphere.

While the extension to introduce a dipole field will be discussed by Watanabe at the conference [2], we focus on the second and third aspects of the development: the introduction of the parallel nonlinear term and kappa distribution functions to the gyrokinetic model.

We first examine the impact of the parallel nonlinearity (PNL) using a Maxwellian as the background distribution. Figure 1 compares the differential energy flux spectra of precipitating electrons obtained by simulations of the M-I coupling system with and without PNL (top and bottom, respectively). The horizontal and vertical axes represent normalized time and energy level, respectively. For the case without PNL, the spectrum does not show any significant variation over time. On the other hand, the case with PNL exhibits a strong enhancement in both energy level and intensity after transitioning to the nonlinear phase (around time=10). This result indicates that PNL is essential for analyzing the auroral electron acceleration process.

Regarding the kappa distributions, we begin with examinations of the impact of superthermal electrons, represented by the kappa distribution tails, on the linear physics. Particularly, we investigate how these components affect the linear dispersion relation of dispersive Alfvén waves through the finite Larmor radius effects and Landau damping. We then integrate the extensions and perform nonlinear simulations with kappa distributions and parallel nonlinearity and compare the results with Maxwellian cases.

Along with the simulation results, we discuss how these modifications are implemented in the code. We also explore the potential applications of the code to a broader range of space plasmas, such as the radiation belts and solar wind, as well as possible feedback to fusion plasma studies.

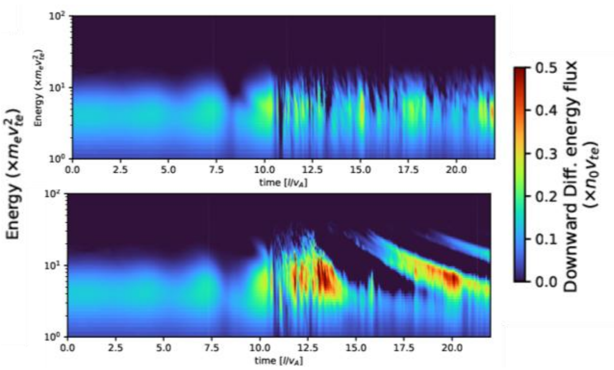

Figure 1: Comparison of the differential energy flux spectra of precipitating electrons with and without the parallel nonlinear term (top and bottom) obtained by nonlinear gyrokinetic simulations

References

[1] T.-H. Watanabe and H. Sugama, *Nucl. Fusion* **46**, 24-32 (2006).
[2] T.-H. Watanabe and K. Fujita, talk in this conference.