10–4 Simulation Technology for Long-Time-Scale Analyses of Fusion Plasmas

— Progress Toward Multi-Time-Scale Analyses —

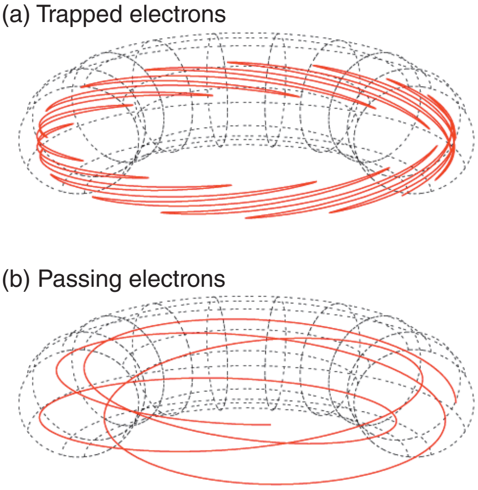

Fig.10-8 Electron orbits in fusion plasmas
(a) Trapped electrons are distributed in the outer torus region with weak magnetic fields and exhibit slow precession drifts (~100 kHz), which excite plasma turbulence by a resonant interaction. (b) Passing electrons show fast passing motion in torus plasmas (~6 Mhz), generating high-frequency noise.

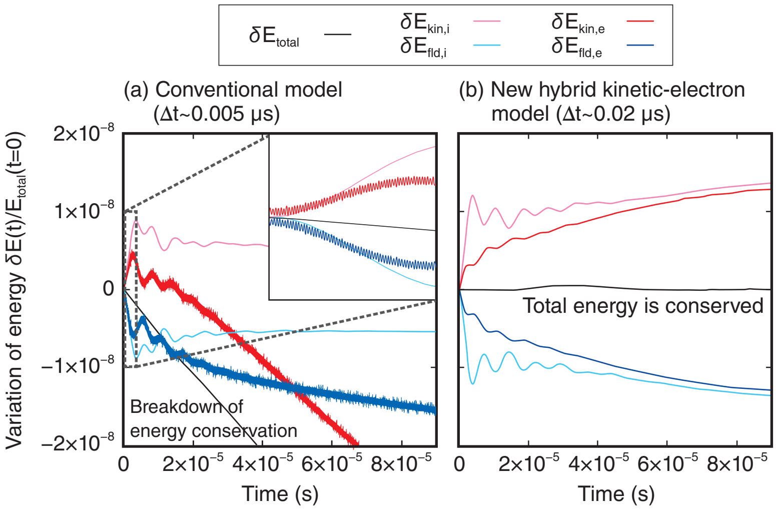

Fig.10-9 Energy conservation in decaying turbulence simulations
The time evolutions of the kinetic ($\delta E_{kin,i}$,$\delta E_{kin,e}$) and field ($\delta E_{fld,i}$,$\delta E_{fld,e}$) energies of ions and electrons as well as the total energy (δE_{total}) in decaying turbulence simulations, where given initial turbulent fields decay. (a) In the conventional model for computing passing electrons (Δt~0.005 μs), the accumulation of errors in the electron energy owing to high-frequency noise violates energy conservation, whereas (b) in the new hybrid kinetic-electron model (Δt~0.02 μs), the time-step width is extended (lower computational cost) and the accuracy of energy conservation is improved by eliminating high-frequency noise.

Long-time-scale simulations of electron turbulence are essential for estimating turbulent transport of fuel particles and energy, which dictates the performance of fusion reactors. However, such a simulation is difficult because of fast electron motion. We have resolved this issue by developing a new electron model.

Fusion plasmas involve multi-time-scale phenomena such as gyro motion of charged particles along confinement magnetic fields (electron~140 GHz, ion~40 MHz), passing motion of charged particles in torus plasmas (electron~6 MHz, ion~100 kHz), slow precession drifts of trapped electrons (~100 kHz), plasma turbulence (~100 kHz), collisions between charged particles (~1 kHz), and a time scale of temperature-profile variations (~1 s). The development of a first-principles model that analytically approximates gyro motion with higher frequency than plasma turbulence as well as advances in modern supercomputers have enabled simulations of ion turbulence covering time scales from those of plasma turbulence to those of temperature-profile variations. However, long-time-scale simulations of electron turbulence have been limited because the passing motion of electrons is two orders of magnitudes faster than plasma turbulence, and energy conservation cannot be maintained in the simulations.

To resolve this issue, we have developed a new electron model based on the properties of electron motion in fusion plasmas. Depending on the velocity, electron orbits are classified into trapped electrons, which are distributed in the outer torus region with weak magnetic fields and exhibit slow precessional drifts, and passing electrons, which exhibit fast passing motion in torus plasmas (Fig.10-8). The plasma turbulence is mainly excited by a resonant interaction with the former, while the latter generates high-frequency non-physical numerical noise. To enable low-cost and high-accuracy simulations by avoiding the high-frequency noise, in computing turbulent fields, the responses of passing electrons are approximated by an analytic solution for low-frequency fluctuations. Conversely, computation of collisions also requires strict treatments for passing electrons; thus, the same first-principles model is applied to both trapped and passing electrons. Such a hybrid electron model, in which different passing electron models are switched depending on physical processes, satisfies the reduction of computational cost and the improvement of energy conservation (Fig.10-9) and enables long-time-scale simulations of electron turbulence.

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Reference

Idomura, Y., A New Hybrid Kinetic Electron Model for Full-*f* Gyrokinetic Simulations, Journal of Computational Physics, vol.313, 2016, p.511-531.