LLNL-TR-865889

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LLNL FESP Theory Highlights: June 2024

B. D. Dudson

June 21, 2024

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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Editor: Ben Dudson (Group Leader), on behalf of the LLNL Fusion Theory & Modeling group.

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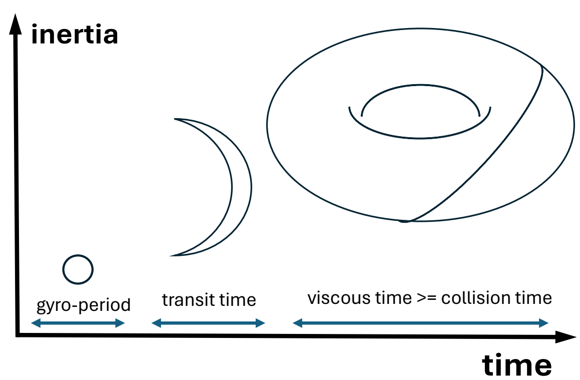
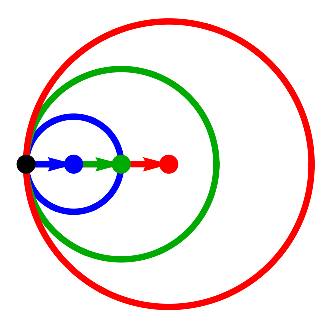
Invited presentations

Ilon Joseph, "Electric and Thermodynamic Polarization of Magnetically Confined Plasmas", invited talk at the 2024 International Sherwood Fusion Theory Conference, Missoula, MT May 6-8, 2024

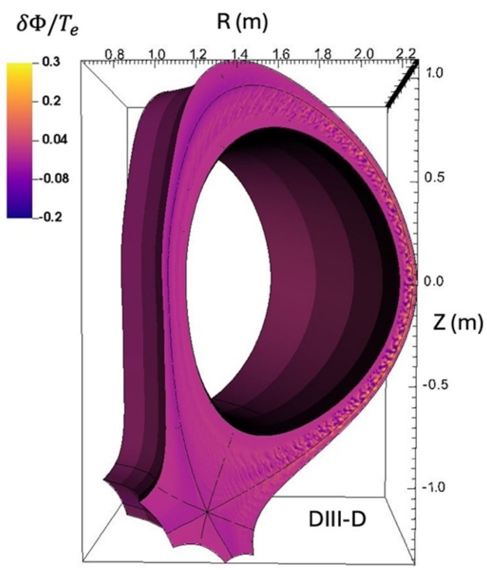
The polarization of charged particles in a strong magnetic field plays a central role in the adiabatic theory of magnetized plasmas. Both an electric field and other thermodynamic forces, such as pressure and temperature gradients, generate polarization and both effects are needed to determine the electric field self-consistently. Thermodynamic polarization arises due to the finite width of particle orbits, e.g. radial excursions from magnetic flux surfaces due to the gyro-motion, the parallel circulation and bouncing motion, as well as the toroidal drift motion. We derive an efficient framework for calculating both kinds of polarization effects at arbitrary collisionality to first order in amplitude and second order in gyroradius to scale length. In fact, the polarization response get stiffer as time evolves due to the fact that different nonlinear processes that determine the orbit widths become activated on different timescales.



In doing so, we resolve the diamagnetic polarization paradox: the pressure-driven diamagnetic polarization calculated using drift-reduced fluid theory and gyrokinetic theory differs by a factor of ½. The paradox is resolved by realizing that the difference is due to whether one compares the real space PDF to the PDF in action-angle coordinates or to the PDF in the limit of zero orbit width. Similar effects can be derived for the adiabatic bounce-kinetic polarization relevant on parallel transit timescales. For equilibrium timescales, collisions play an important role in changing the effective neoclassical polarization response, leading to a response that also depends on the thermal force and that scales as the square of the poloidal gyroradius to scale length.



Mikhail Dorf, "A semi-implicit gyrokinetic ion – fluid electron hybrid model for edge plasma simulations", invited talk at the 2024 PASC conference (minisymposium on High Performance Computing for Magnetic Fusion Applications), Zurich, Switzerland, June 3-5, 2024.

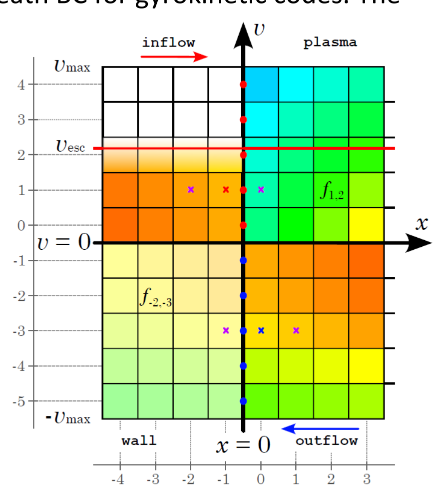


We report progress on the development and application of a hybrid gyrokinetic ion–fluid electron model for simulations of cross-separatrix plasma transport in the edge region of a divertor tokamak. The hybrid model includes ion-scale ion temperature gradient (ITG) and resistive drift and ballooning modes, as well as neoclassical ion physics and orbit loss effects. The model is implemented in the finite-volume gyrokinetic code COGENT, which employs a locally field-aligned coordinate system combined with mapped multi-block grid technology to handle strongly anisotropic edge plasma turbulence. Additionally, COGENT utilizes a flexible implicit-explicit (IMEX) time integration framework that handles the temporal multiscale nature of plasma transport. To that end, the 5D high-dimensional kinetic part of the system that involves ion parallel transients and diamagnetic drift time scales is treated explicitly. The 3D low-dimensional fluid part of the system that contains fast electron physics and Alfven-wave time scales is treated implicitly. The performance of the IMEX scheme is optimized by developing specialized preconditioners for the electrostatic and electromagnetic versions of the hybrid model. Verification results and simulations in realistic single-null geometries are presented.

Conference presentations

Vasily Geyko, Ilon Joseph, and Mikhail Dorf, "High order insulating sheath boundary condition for continuum finite volume codes", poster presentation at 26th International Conference on Plasma Surface Interaction, May 12-17, 2024

In this work, we derive the first high-order logical (insulating) sheath BC for gyrokinetic codes. The challenging disparity in spatial and temporal scales between the quasineutral bulk plasma and the fine-scale plasma sheath region can be resolved by using the logical sheath, which determines the boundary potential that reflects slow electrons to ensure the total current through the boundary is equal to zero. While the first order advection scheme is straightforward to implement, we find that it produces too much heating of the electrons to be used on ion time scales. Hence, we derived a new third order sheath BC, where the fluxes are determined self-consistently by the values of the probability distribution function (PDF) in the ghost cells. While this resolves the conservation issue for third and higher order



advection schemes, certain challenges remain. The presence of sharp interfaces of the electron PDF in the velocity space that are caused by the sheath BC lead to Gibbs oscillations and negative values of the PDF when employing higher-order advection schemes. Various strategies for mitigating this issue are being explored, including adding collisions and employing non-oscillatory advection schemes.

Menglong Zhao, Filippo Scotti, **Tom Rognlien**, Adam McLean, Galen Burke and Andreas Holm, '2D Analysis of Tokamak Divertor-plasma Detachment-bifurcation with Operational Parameters and Geometry', poster presentation at 26th International Conference on Plasma Surface Interaction, May 12-17, 2024

This work studied the conditions for the existence of a detachment cliff using UEDGE with an extended parameter range by varying particle and thermal diffusivities, power input and leg length. The simulation results shows that a more pronounced detachment cliff tends to occur with higher power input regardless of diffusivities and leg length. Time-dependent simulations of a detachment cliff dynamics indicates that when the rapid decrease of the outer target Te starts (Te cliff), the outer strike point Mach number (Mosp) start decreasing and the radiation above the X-point start increasing rapidly, as shown in Fig. 5. However, the increase of radiation is very fast and only lasts ~ 0.3-0.5 ms, whereas the decrease of Te and Mosp last ~ 2-3 ms and ~ 1 ms, respectively, indicating that the radiation front moving across the separatrix seems to be the trigger for the Te cliff behavior. This requires further support from DIII-D experimental observations. These results have been summarized and submitted to the journal Nuclear Materials and Energy.