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LLNL Theory and Modeling highlights

B Dudson

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Disclaimer

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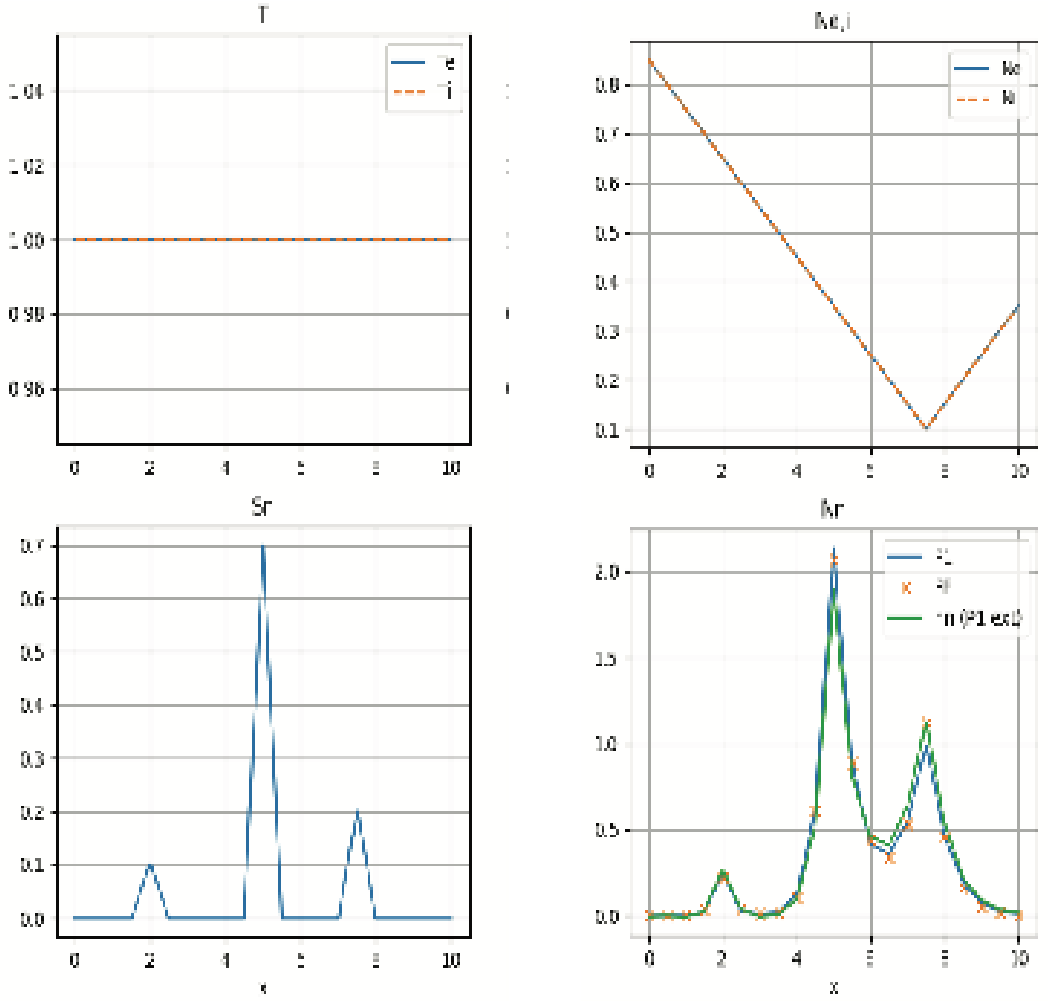
Machine Learning Approach to Modeling of Neutral Particle Transport in Plasmas

Impact: Accelerated Monte Carlo kinetic neutral models using AI/ML techniques while eliminating sampling noise.

- A Monte Carlo (MC) neutral code is used to construct a propagator (Green function) for the kinetic equation describing neutrals in plasmas
- For a set of plasma parameters, a large number of propagators are calculated for training of Neural Network (NN) model
- The Neural Network model provides fast and accurate calculation of neutral distribution function for given profiles of plasma and neutral source
- So far tested in 1D. Currently being generalized to higher dimensions

Supported by DOE FES AI/ML project MFE-FAST (SCW1924)
Performed by LLNL under contract DE-AC52-07NA27344

Umansky et al., submitted to CPP (2025)
Preprint: arXiv:2510.23088



Accelerating Kinetic Plasma Simulations with Advanced Implicit Methods

Accelerating high-fidelity simulations is essential to:

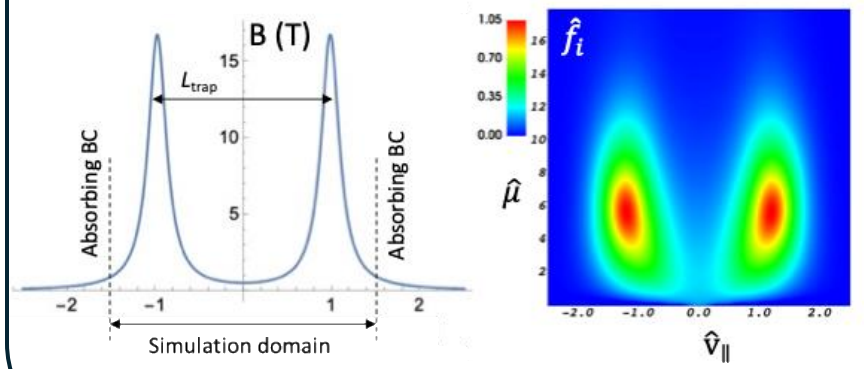
- Bridge the gap between detailed physics and reactor design
- Reduce the computational cost of high-fidelity training data
- Enable whole-device modeling and fully integrated fusion design

Advanced implicit methods implemented in COGENT accelerate collisional transport simulations

- Employ a modern multigrid (AIR) solver to precondition advection
- Utilize operator splitting for multiphysics preconditioning
- Successful application to fusion systems include
  - 2500x speed-up for parallel transport in the WHAM mirror
  - 10x speed-up for axisymmetric transport in the LTX tokamak

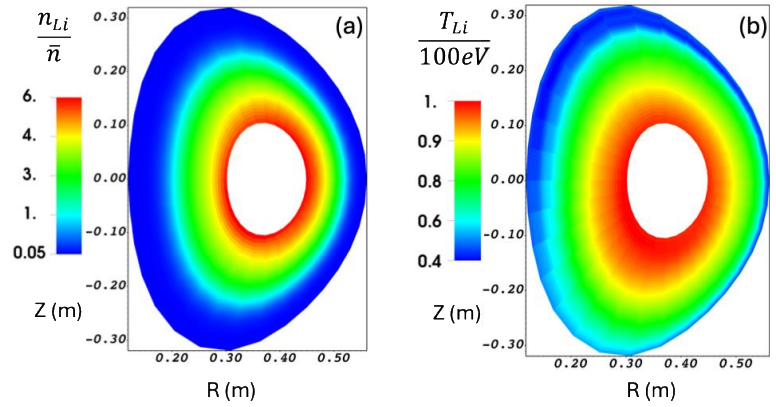
Supported by the DOE FES Base Theory Program (SCW0229)
Performed by LLNL under contract DE-AC52-07NA27344

x2500 speed-up in simulations of parallel kinetic ion transport in mirrors



Dorf er al, Phys. Plasmas 32, 103903 (2025)

x10 speed-up in kinetic transport modeling of a tokamak core region



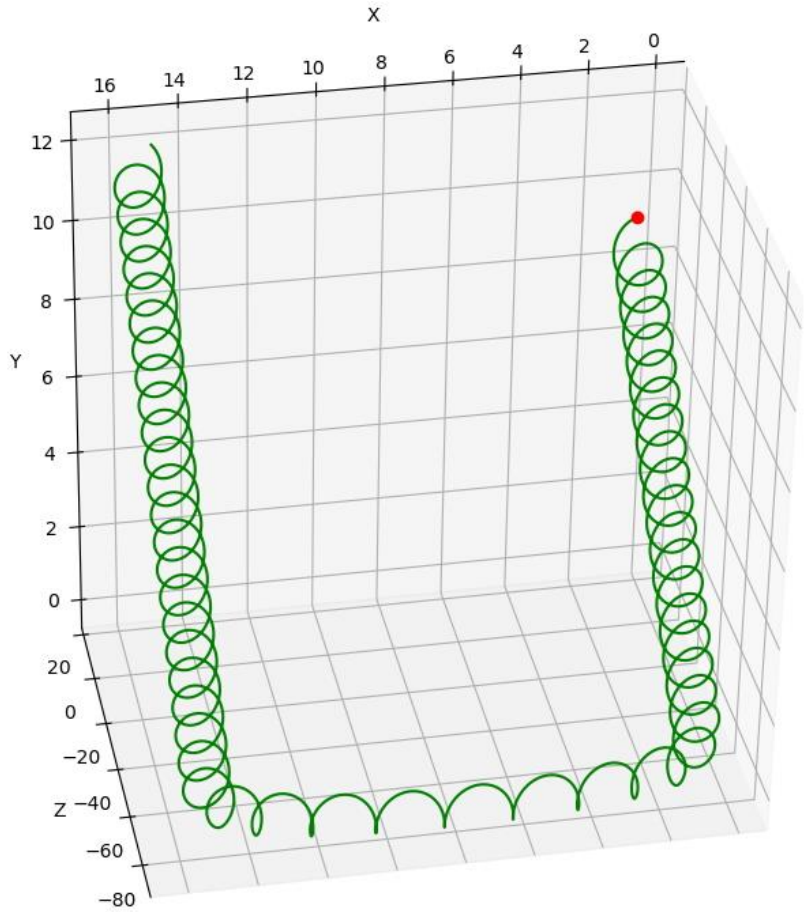
Dorf et al, Phys. Plasmas 32, 083904 (2025)

Analysis of Electron Trajectories in Magnetized Plasma Sheaths

Impact: A new mechanism contributing to cross-field electron transport in the Scrape-Off Layer (SOL) of magnetized plasmas.

M.V. Umansky and S.I. Krasheninnikov, *Phys. Plasmas* 32, 103508 (2025)

- Electron trajectories are analyzed in plasma sheath region, for B field at shallow angle w/respect to material surface
- For thin sheath, $\lambda_D/\rho_e \ll 1$, electron follows a sequence of bouncing on the surface before full reflection
- This leads to violation of electron magnetic moment conservation, which opens a channel of anomalous radial transport for electrons in plasma devices



Supported by DOE FES Base Theory Program (SCW0229).
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