BOUT++ simulations reveal the dynamics of filamentary eruptions of hot plasma from the edge and heat flux footprints on divertor targets in a DIII-D experiment.

LLNL FESP Theory and Modeling Program Overview

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Overarching Goals

- **Our mission:** To advance the understanding and predictability of MFE plasmas

- **We pursue knowledge and innovation, with a focus in two main task areas**
  - **Edge Physics:** turbulence, transport, and divertor physics
  - **Integrated Modeling:** predictive & whole device modeling, timescale bridging

- **We also engage in emerging areas of broad interest**
  - Effective use of advanced computer architectures
  - Quantum information science, machine learning

- **We emphasize connections to experiments**
  - Planning, analysis, and modeling
  - DIII-D, NSTX-U, MAST, EAST, KSTAR, ...
  - Studies toward future machines: ITER, CFETR, SPARC/ARC, possible new U.S. device

![UEDGE electron temperature (Te) prediction for the DIII-D tokamak.](image)
We employ a range of advanced codes and analytic theory

**Edge Physics:** Recent FESAC and community reports emphasize the importance of predicting and mitigating heat flux and impurity erosion of divertor and first wall.

- **BOUT++** is both a code and a flexible framework, capable of employing a broad range of fluid models for tokamak plasma simulation in 2D and 3D, including simulation of ELM activity and edge plasma turbulence. *(Many of our collaborations with Chinese institutions center on BOUT++.)*

- **UEDGE** can perform 2D edge and divertor transport calculations, including coupled plasma, neutral, sheath and radiation physics, in flux surface-aligned geometry. Uniquely, it offers iteration to a steady-state w/o laborious time-stepping.

- **COGENT** (part of the ESL collaboration) is the only code in the world capable of continuum kinetic simulations in tokamak geometry, in 4D and 5D.

**Integrated Modeling:** Integrated models are important for machine design, operating scenario development, and experimental modeling.

- **CORSICA** offers a unique interactive environment for modeling design and operation, including studies of equilibrium configurations, startup, and stability. *(L. LoDestro has presented well-attended tutorials on CORSICA in China.)*
Major Research Projects

DOE / FES

- Toroidal Theory and Integrated Modeling (Friedman)
- Experimental Modeling with UEDGE (EMU) initiative (multi-institutional collab.)
- Fusion technology, reactor design, & PFC modeling (Rognlien, Umansky)
- International Collaboration project using BOUT++ (Holcomb, Xu)
- Edge Simulation Lab (w/ GA’s P. Snyder): COGENT code (Dorf, Ghosh)
- DOE/FES SciDAC’s:
  - Dimits: RF Actuators
  - Dorf: Adv. Tokamak Modeling
  - Joseph: Plasma-Surface Interactions
  - LoDestro: Multiscale Gyrokin.
  - Xu: Tokamak Disruption Simulation
- Exascale Computing Program (via CASC): timescale bridging (LoDestro)
- “Quantum Leap for FES”: quantum computing for fusion (Joseph)

LLNL LDRD

- Scalable and accurate simulation of magnetized edge plasmas using CASC’s Modular Finite Element Method (MFEM) library (Joseph)
- A novel way to mitigate surface damage in tokamaks (Campanell)