Basic Equations and Computational Techniques

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(why me?)
Wide Range of Time Scales
Makes this a REALLY Hard Problem

- Current state-of-the-art is many $\tau_{corr} \sim 100$’s of $\mu s$ (for BOUT, a fluid code)
  - Sufficient for studying edge turbulence (and turbulence suppression)
  - Elucidation of the mechanisms for responsible for generation of shear-flow
- Often the pedestal continues to grow until it is terminated by an “ELM”
  - Fluid instability in which plasma sheds it surface layers (including edge pedestal)
  - Simulation of the ELM cycle dynamic range in time scales $\sim 10^6$
A kinetic edge code is required to model today’s tokamaks and for projections to ITER

- Fluid approximation requires:

\[
\ell_{mfp} \frac{T^2}{n} > \ell_c \sim 2\pi R
\]

or

\[
\text{orbit width} < \text{plasma scale length}
\]

- Not satisfied on DIII-D today
  Won’t be satisfied on ITER
- Need to move beyond fluid codes

- Describe each species with a kinetic distribution function,

\[
F^{(s)}(v_\parallel, v_\perp, r, \theta, \phi)
\]
Moving from core gyrokinetics to a kinetic edge code Presents new challenges

- A new ordering is required
  - $Q_b = \frac{Q}{L_B} \sim Q = \frac{Q}{Q} << I$
  - $Q_p = \frac{Q}{L_p} \sim I$

- Gyro-center Equations of motion
  - Valid for $Q_b << I$
  - Gyro-averaging to reduce phase space to 5 dimensions

- The essential complications:
  - Particle distribution on gyro orbit
  - Distortions of gyro orbit
  - These can be dealt with if ExB shearing rate is small compared to $Q_{ci}$

- Extensions to gyrokinetic formalism is required, and can be achieved with phase-space action/Lie perturbation techniques.

\[ \square_p \text{ from a DIII-D H-Mode Discharge} \]
Two Paths Forward
(to be pursued simultaneously)

• Continue development of 3-D fluid codes to model edge turbulence
  – Provide a reasonable model for C-Mod (where connection length and mean-free-path are about the same at the top of the pedestal)
  – C-Mod sees H-Mode transitions, ELMs, etc. similar to that is seen in less collisional tokamak edges.
  – Should include realistic geometry (separatrix, closed and open field lines)
  □ Near term understanding of H-Mode pedestal and ELM Cycle

• Begin development of Edge Kinetic Codes
  – Attention to advancing GK-formalism to a new regime
  – A Continuum Kinetic edge code being developed at LLNL under internal funding (see FP1.116, FP1.117, and FP1.118) for completion 10/06.
  – Interest in developing a PIC kinetic edge code?