MODELING NON-LOCAL PARALLEL ELECTRON HEAT TRANSPORT IN DIVERTOR PLASMAS

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Jean-Pierre Matte,
INRS-Énergie et Matériaux, Varennes, Québec

PROBLEM :

In divertor plasmas, heat and particles flow along $\vec{B}$.
Numerical simulations with fluid codes are used heavily.

Present fluid codes (e.g. UEDGE, B2) assume :

a) Maxwellian distributions
b) Classical (Spitzer-Härm) heat flow along field lines

This is dubious in steep temperature gradients.
(steep: m.f.p./L_T > 5×10^{-3} !!!)
ad hoc "flux limiters" often used $\Rightarrow$ uncertainty
Very steep T_e gradients exist near the neutralizer plate.
Especially in the detached plasmas.

PHYSICS

Why is mean free path/T_e scale-length > $5x10^{-3}$ steep ?
Heat flux is carried mostly by faster electrons,
with v=3-4 v_{th}. (mfp $\propto v^4$)
($v_{th} = \sqrt{(k_B T_e/m_e)}$)
These are not thermalized within the gradient;
They stream into the cold plasma.

$\Rightarrow$ **Surplus of faster electrons in colder plasma**

SO WHAT ?

Non-Maxwellian electron velocity distributions affect:

Heat flow:
Less than classical in hot plasma; pre-heat in cold.
(flux limiters limit the former,
but cannot represent this pre-heating)
Atomic physics rates:
Ionization and excitation depend on faster electrons,
Recombination and deexcitation on slower ones.
$\Rightarrow$ Continuum and line spectra are modified.
Analysis of Langmuir probe measurements.
Sheath potential ($\Rightarrow$ more sputtering).
Velocity-space instabilities, due to strong anisotropy.

PROPOSED SOLUTION

Full kinetic modeling in 2D **prohibitive** for routine work.

Feasable solution:
Use kinetic modeling in some representative cases
to develop and validate non-local correction formulas
for use in fluid codes.

NON-LOCAL HEAT FLOW FORMULAS

Used increasingly in fluid laser-plasma interaction simulations.
Heat flux NOT ONLY a function of local conditions and gradients
Depends on whole profile.
Convolution formulas express this.
Pioneered by Luciani and Mora (École Polytechnique), PRL 1983
Reviewed in : P. Mora and J.F. Luciani,
Laser and Particle Beams 12, 387 (1994).
Based on approximate solutions to Fokker-Planck equation.
General form:

$$q(x)=\beta(x)^{-1}\int_{-\infty}^{\infty} W(x,x')q_{SH}(x')dx'$$

Formulas differ in their kernel, *W(x,x')*.
q_{SH} *:* Classical (Spitzer Härm) heat flux.
$\beta(x)$*:* Normalizing factor.

Propose: Optimize this kernel for heat flow in divertor plasmas.
Also, develop analogous formulas for atomic rates.
(Will depend on x, x' and ratio χ/T_e).
Idem for sheath potential and probe signal.

THE "FPI" ELECTRON KINETIC CODE

Previous uses

Code developed for laser-plasma interaction.
(PRL 1982, 1984, 1987, 1992, 1994, 1998)

Was also used for high-power microwave heated plasmas.
(Phys. Fl. B, 1989, PRL 1994, PoP 1994)

And Tokamak edge plasmas
(Z. Abou-Assaleh ; Contr. Plasma Phys. 1990, 1992, 1994)
"Classical" problem: Attached plasma.
One end at fixed Te, and fixed density and (subsonic) flow ;
Other end: absorbing boundary, fairly high recycling.
(Based on previous fluid modeling by Neuhauser *et al*.).

THE "FPI" ELECTRON KINETIC CODE (cont'd)

The code is 1-D, planar geometry in $\vec{X}$.
2-D, cylindrical in $\vec{V}$. (azimutal symmetry assumed)
Angular dependence expanded in Legendre Polynomials.

Includes the following effects (may turn each on or off):

a) Transport term V_x df/dx
b) Electric field for quasi-neutrality (eE/m) df/dV_x
c) Classical Fokker-Planck collision term (e-e and e-i) .
d) Collisional absorption of laser or microwave beam.
e) Hydrodynamics: fluid model for ions.
f) Atomic physics with either:
  i) Prescribed transitions, which cool the plasma
  ii) Average ion model, fully coupled to the code
  iii) Package developed by Abou-Assaleh
    (ionisation and first excitation of atomic H)
  iv) Atomic physics package developed by Marchand
    (fairly detailed model for mid-Z atoms, e.g. C)
    (Phys. Fl. B 1990 and 1991 ; J. Comp. Phys. 1991)

(iii-iv) have not been used in a long time,
would need to be reactivated.

OUR PLAN

Use the planar 1-D electron kinetic code "FPI" .
Simulate several cases of flow along **B.**

Simulate same cases with fluid code in 1-D.
Implement and optimize convolution kernels for agreement.
(for heat flow AND atomic rates)
(+ sheath potential + probes signal)

Heat sources:

- Hot boundary (X-point) : usual 1-D model.
- Heat and particle source within simulation box (to account roughly for cross field diffusion)

Instabilities: Computed distribution functions may be post-processed for instability analysis. (Ion-acoustic and Weibel instabilities have been studied in the past)

POSSIBLE DIAGNOSTICS OF THIS PHYSICS

Non-Maxwellian energy distributions

Probes *
Spectroscopy (line and continuum) *
Thomson scattering

Anisotropy of velocity distributions

Directional probes *
Emission angular distribution
Polarization *

* These diagnostics have been simulated in the past, with “FPI”.