Non-local Transport in the Strongly Magnetised Regime

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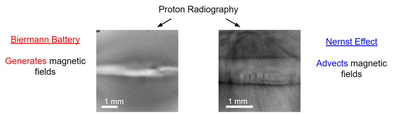
Accurately modelling transport is important

- Magnetic fields are of significant interest in a variety of physical contexts.
- Laser plasmas are characterised by short length scales.



Evolving the distribution function

f_0 equation:

$$\frac{\partial f_0}{\partial t} + \frac{v}{3}\nabla\cdot\mathbf{f}_1 + \frac{1}{3v^2}\frac{\partial}{\partial v}\left(v^2\mathbf{a}\cdot\mathbf{f}_1\right) = C_{e0}$$

($\mathbf{f}_1$ drives evolution of f_0)

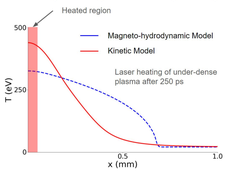
$\mathbf{f}_1$ equation:

$$\frac{\partial \mathbf{f}_1}{\partial t} + v\nabla f_0 + \mathbf{a}\frac{\partial f_0}{\partial v} + \boldsymbol{\omega}_L \times \mathbf{f}_1 = -\nu_{ei}\mathbf{f}_1 + \mathbf{C}_{e1}$$

(Gradients in f_0 cause growth of $\mathbf{f}_1$)

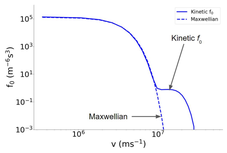
Breakdown of magneto-hydrodynamics (MHD)

- Fluid models which assume local thermodynamic equilibrium (LTE) do not capture non-local transport effects.
- Requires kinetic or extended fluid modelling.



Non-maxwellian distribution function

- Non-local transport causes the electron distribution function to evolve.
- Driven by growth of the anisotropic components of the distribution ($\mathbf{f}_1$).



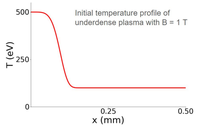
Extreme gradients in a magnetised plasma

- Temperature gradient in the plasma is extreme

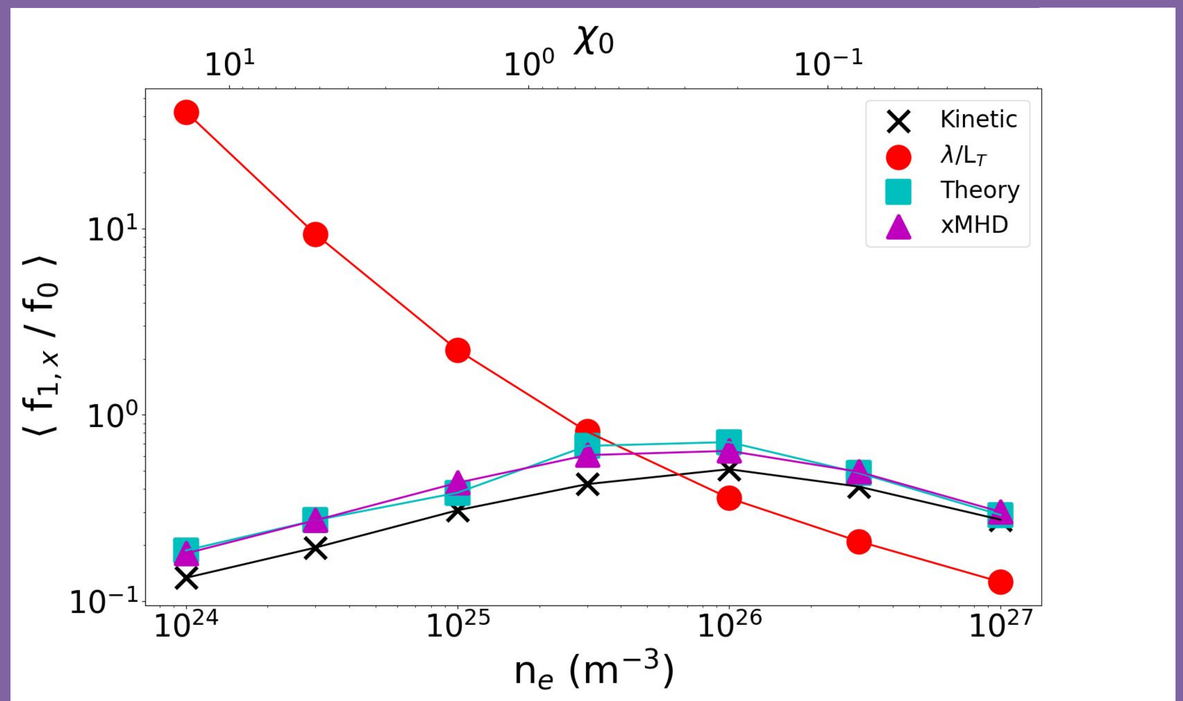
$$\frac{\lambda_T}{L_T} \simeq 1$$

- The plasma is strongly magnetised

$$\chi_T = \frac{\omega_g}{\omega_{ei}} \simeq 3$$



Magnetisation reduces non-local transport in the strongly magnetised regime ($\chi > 1$)



- Ratio $f_{1,x} / f_0$ characterises non-local transport.
- Knudsen number (λ / L_T) incorrectly predicts increase in non-local transport as collision rate decreases.
- Electrons are increasingly confined to their gyro-orbits as magnetisation increases.

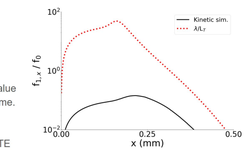
Predicting non-local growth with λ/L_T

- Non-locality parameter (~ Knudsen number)

$$\frac{f_{1,x}}{f_0} \propto \frac{\lambda}{L_T} \sim Kn$$

fails to estimate the true value of $f_{1,x}/f_0$ in magnetised regime.

- Suggests plasma is non-LTE when $f_{1,x}/f_0$ is actually small.



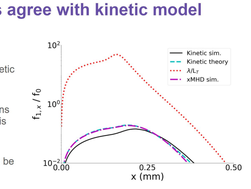
$f_{1,x}$ over f_0 from kinetic theory

$$\frac{f_{1,x}}{f_0} = -\frac{1}{1+\chi^2}\left[\frac{\lambda_{ei}}{l_f} + \frac{e\,\tau_{ei}}{m_e}\left(E_x - \frac{e\,B_z\,\tau_{ei}}{m_e}E_y\right)\frac{\partial_v f_0}{f_0}\right]$$

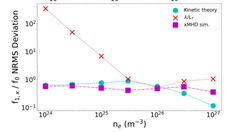
(Original term; Contribution from y-axis; Main effects of magnetisation; Restoring force)

MHD predictions agree with kinetic model

- We can obtain a more accurate ratio of $f_{1,x}/f_0$ by incorporating electromagnetic fields
- Distribution function remains Maxwellian provided $f_{1,x}/f_0$ is small.
- Magnetisation forces $f_{1,x}$ to be small.



Error in calculation of f_1/f_0



- λ / L_T incorrectly predicts increased non-local transport at low density.

Summary

- Growth in the $\mathbf{f}_1$ perturbation corresponds to increasing non-local transport.
  - Understanding its growth helps us understand how non-local transport emerges.
- The ratio $\mathbf{f}_1 / f_0$ can be obtained from local plasma parameters.
  - Provides a robust platform for studying the validity of MHD codes.
- Magnetisation restores LTE in plasmas that appear to be out of equilibrium.

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