

Nonlocal Magneto-Hydrodynamic Model and Its Applications to Laser Plasmas

Serious Numerics for Serious Physics

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- Introduction to Nonlocal Magneto-Hydrodynamic model (Nonlocal-MHD)
 - Radiation-Hydrodynamics
 - Nonlocal electron transport

Boltzmann transport equation

$$\frac{\partial \mathbf{f}}{\partial t} + \mathbf{v} \cdot \nabla_{\mathbf{x}} \mathbf{f} + \frac{q_e}{m_e} \left(\mathbf{E} + \frac{\mathbf{v}}{c} \times \mathbf{B} \right) \cdot \nabla_{\mathbf{v}} \mathbf{f} = \sigma \nabla_{\mathbf{v}} \cdot \int \frac{|\mathbf{v} - \mathbf{v}'|^2 \mathbf{l} - (\mathbf{v} - \mathbf{v}') \otimes \mathbf{v} - \mathbf{v}'}{|\mathbf{v} - \mathbf{v}'|^3} (\nabla_{\mathbf{v}} \mathbf{f}(\mathbf{v}) f(\mathbf{v}') - \mathbf{f}(\mathbf{v}) \nabla_{\mathbf{v}} f(\mathbf{v}')) d\mathbf{v}'$$

Fluid equations in Lagrangian frame

$$\begin{aligned}\frac{d\rho}{dt} &= -\rho \nabla_{\mathbf{x}} \cdot \mathbf{U} \\ \rho \frac{d\mathbf{U}}{dt} &= \nabla_{\mathbf{x}} \cdot \sigma \\ \rho \frac{d\varepsilon}{dt} &= \sigma : \nabla_{\mathbf{x}} \mathbf{U} - \nabla_{\mathbf{x}} \cdot (\mathbf{q}_e + \mathbf{q}_R)\end{aligned}$$

Microscopic closure

$$\begin{aligned}\sigma &= -\rho \int (\mathbf{v} - \mathbf{U}) \otimes (\mathbf{v} - \mathbf{U}) \mathbf{f} d\mathbf{v}^3 \approx -\mathbf{l} p + \tilde{\sigma}(\nabla \mathbf{U}) \\ \mathbf{q}_e &= \frac{\rho}{2} \int |\mathbf{v} - \mathbf{U}|^2 (\mathbf{v} - \mathbf{U}) \mathbf{f} d\mathbf{v}^3 \approx \frac{\rho}{2} \int_{4\pi} \mathbf{n} \int_0^\infty |\mathbf{v}|^5 \mathbf{f} d|\mathbf{v}| d\mathbf{n} \approx -\kappa(T^{2.5}) \nabla T \\ \mathbf{q}_R &= \int_{4\pi} \mathbf{n} \int_\nu I_\nu^p d\nu d\mathbf{n} \approx - \int_\nu \frac{c}{\chi_\nu} \nabla(f_\nu E_\nu) d\nu\end{aligned}$$

Nonlocal electron transport & Maxwell equations

AWBS electron transport equation

$$\mathbf{v} \cdot \nabla_{\mathbf{x}} f + (\mathbf{E} + \mathbf{v} \times \mathbf{B}) \cdot \nabla_{\mathbf{v}} f = v \frac{\nu_e}{2} \frac{\partial}{\partial v} (f - f_{MB}(T_e)) + \left(\nu_{ei} + \frac{\nu_e}{2} \right) (f_0 - f)$$

$$\frac{\partial f}{\partial t} + \mathbf{v} \cdot \nabla_{\mathbf{x}} f + (\mathbf{E} + \mathbf{v} \times \mathbf{B}) \cdot \nabla_{\mathbf{v}} f = v \frac{\nu_e}{2} \frac{\partial}{\partial v} \left(F(f_0) f_0 + D(f_0) \frac{\partial f_0}{\partial v} \right) + \nu_{ei} (f_0 - f)$$

Generalized Ohm's law vs. nonlocal Ohm's law

$$\begin{aligned} \mathbf{E} &= (\mathbf{R}_T - \nabla p_e) + \frac{\mathbf{j}}{\sigma} + \mathbf{j} \times \mathbf{B} \\ \mathbf{E} \int v \frac{\partial f_0}{\partial v} v^2 dv &= \int v^2 \nabla f_0 v^2 dv + \int v \nu_{ei} \mathbf{f}_1 v^2 dv + \int v \mathbf{f}_1 \times \mathbf{B} v^2 dv \end{aligned} \quad (1)$$

$$\nabla \times \mathbf{E} = -\frac{1}{c} \frac{\partial \mathbf{B}}{\partial t} \quad (\text{life of magnetic field } \mathbf{B} \text{ in fluid frame})$$

$$\nabla \times \mathbf{B} = \frac{4\pi}{c} \mathbf{j} \quad (\text{quasi-neutrality } \nabla \cdot \mathbf{j} = 0)$$

$$\mathbf{j} = C(\mathbf{E}, f) \quad (\text{from nonlocal electron transport model (1)})$$

Nonlocal-MHD \iff aiming HIGH



Height 250 m, overhang 40 m, Visera, Riglos, Spain.

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