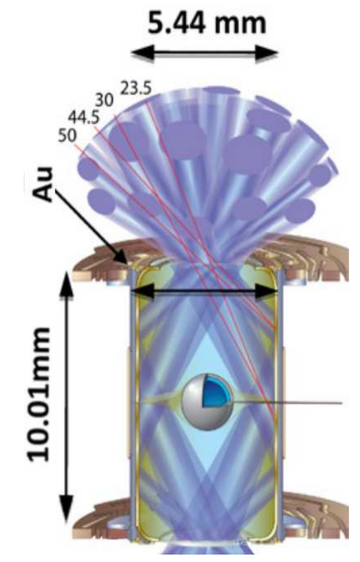
Nernst Effect in Magnetized Hohlraums

- A.S. Joglekar and A.G.R. Thomas Center for Ultrafast Optical Science, University of Michigan
- C. P. Ridgers University of York
- R. J. Kingham Imperial College

Background

Megagauss fields have been measured in hohlraums [1] using monoenergetic proton radiography as well as calculated using hydrocodes [2-4] but their effect on energetics and electron transport has not been considered. Additionally, the imposition of an external magnetic field to minimize energy loss to hot electrons and laser-plasma instabilities [5-7]. The transport of such magnetic fields is the topic of interest. To determine the applicable Ohm's Law, the static Vlasov Fokker Planck equation discarding second order effects, is considered [8,9]:

$$v\nabla f_0 - \frac{e\mathbf{E}}{m_e}\frac{\partial f_0}{\partial v} - \frac{e\mathbf{B}}{m_e}\times\mathbf{f}_1 = \nu_{ei}\mathbf{f}_1$$

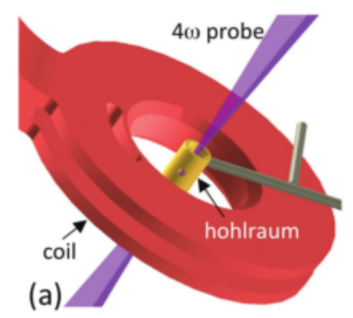


Classical Ohm's Law

$$\mathbf{E} = -\frac{\nabla n_e m_e\langle v^2\rangle}{3en_e\langle v^0\rangle} + \frac{n_e\langle \mathbf{v}v^2\rangle}{3n_e\langle v^0\rangle}\times\mathbf{B};\quad \nu_{ei}\propto v^0$$

$$\frac{\partial\mathbf{B}}{\partial t} = \frac{\nabla T_e\times\nabla n_e}{en_e} + \nabla\times\left(\mathbf{B}\times\frac{\mathbf{j}}{en_e}\right)$$

Semi-Collisional Ohm's Law)



$$\mathbf{E} = -\frac{\nabla n_e m_e\langle v^5\rangle}{6en_e\langle v^3\rangle} + \frac{n_e\langle \mathbf{v}v^5\rangle}{6n_e\langle v^3\rangle}\times\mathbf{B};\quad \nu_{ei}\propto v^{-3}$$

$$\frac{\partial\mathbf{B}}{\partial t} = \frac{\nabla(n_e\langle v^5\rangle)\times\nabla(n_e\langle v^3\rangle)}{6e(n_e\langle v^3\rangle)^2} + \nabla\times\left(\mathbf{B}\times\frac{\langle\mathbf{v}v^5\rangle}{en_e\langle v^3\rangle}\right)$$

Influence of hot electron population is magnified in field transport. In non-local systems [, this becomes important in order to model field dynamics accurately.

$$\mathbf{E} = \overline{\eta}\mathbf{j} + \frac{\nabla P_e}{en_e} + \frac{\mathbf{j}\times\mathbf{B}}{en_e} - \mathbf{U}\times\mathbf{B} - \mathbf{v}_N\times\mathbf{B} \qquad \mathbf{v}_N = \frac{\langle\mathbf{v}v^5\rangle}{en_e\langle v^3\rangle}\approx\frac{2\mathbf{q}_e}{5P_e}$$

Conclusions

Performed 2D Full-Scale kinetic modeling of thermal energy transport and magnetic field dynamics in plasma near hohlraum walls with an externally imposed 7.5T magnetic field over nanosecond time-scale.

- External 10 T magnetic field results in thermal energy confinement at hohlraum wall.
- Heat flow into the hohlraum wall results in nearly 2.5x increase in magnetic field
- **The magnetic field is transported towards the hohlraum axis by the Nernst effect on a MUCH faster time-scale than due to frozen-in-flux.**
- **Non-local contribution to the Nernst effect results in a nearly 2x augmentation of the magnetic field transport rate.**
- **Self-consistent calculations with kinetic modeling allows to overcome classical transport approximations.**

References & Acknowledgements

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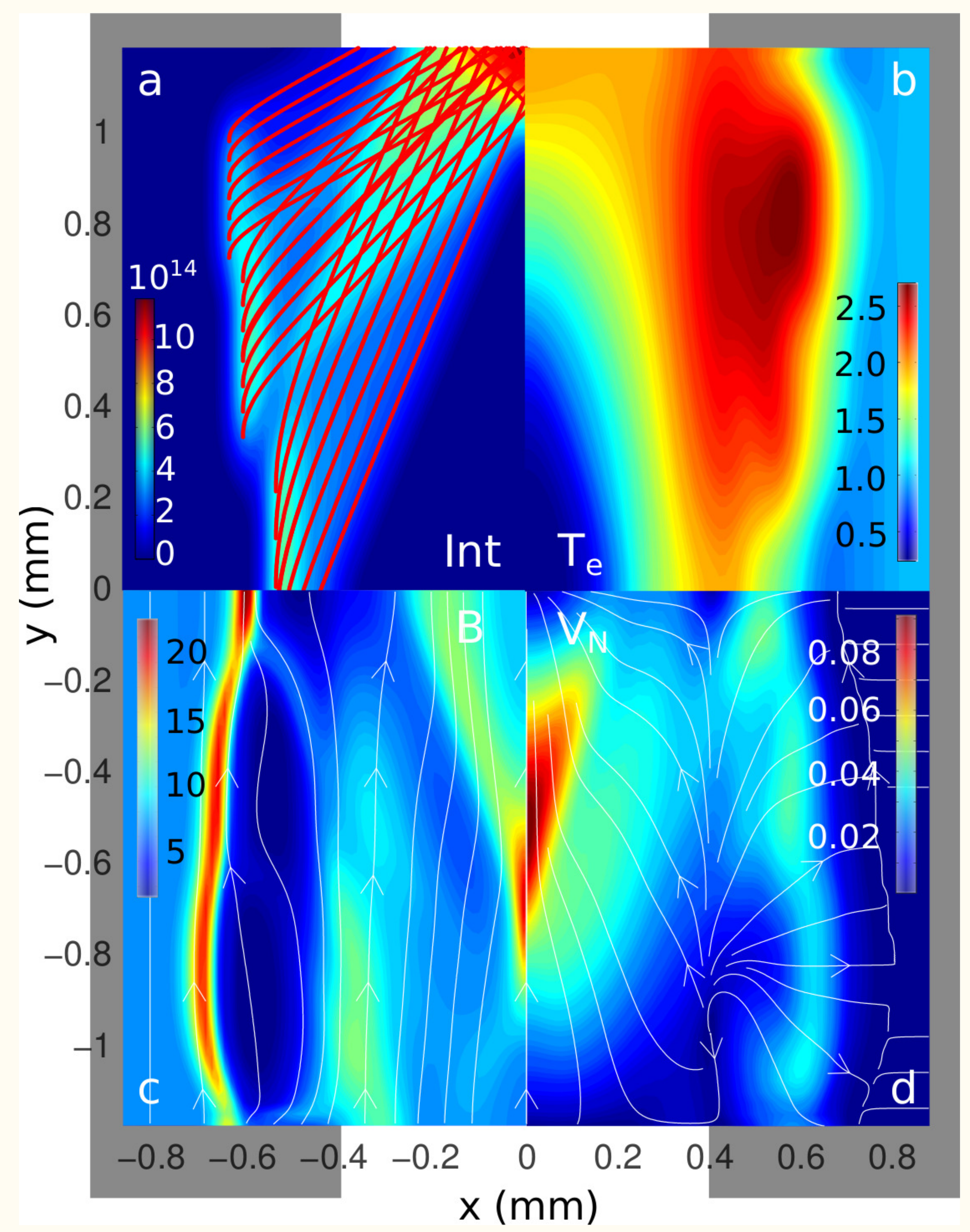
Abstract

2D Vlasov-Fokker-Planck-Maxwell modelling of electron plasma in a Omega-scale hohlraum is performed to explain the dynamic and complex interplay between thermal transport and externally imposed O(10) T magnetic fields that occurs. Externally imposed magnetic fields are transported away due to strong, non-local heat flows unless the magnetic field strength is > 60 T. These fields compress in the walls to strengths > 1 MG due to the heat flow. More importantly, the magnetic field also piles up on the hohlraum axis over time-scales faster than that predicted by common MHD processes such as diffusion or frozen-in-flow.

Through kinetic modeling, we show that non-locality strongly affects heat-flow and the Nernst velocity. Non-local effects augment the Nernst velocity by a factor of 2 for O(10 T) fields contributing significantly to the fast and significant transport of the magnetic field.

Modeling Results



Ray Trace + Laser Intensity (W/cm^2) - Top Left: Ray tracing is peformed to accurately calculate laser propagation through hohlraum culminating in an intensity map.

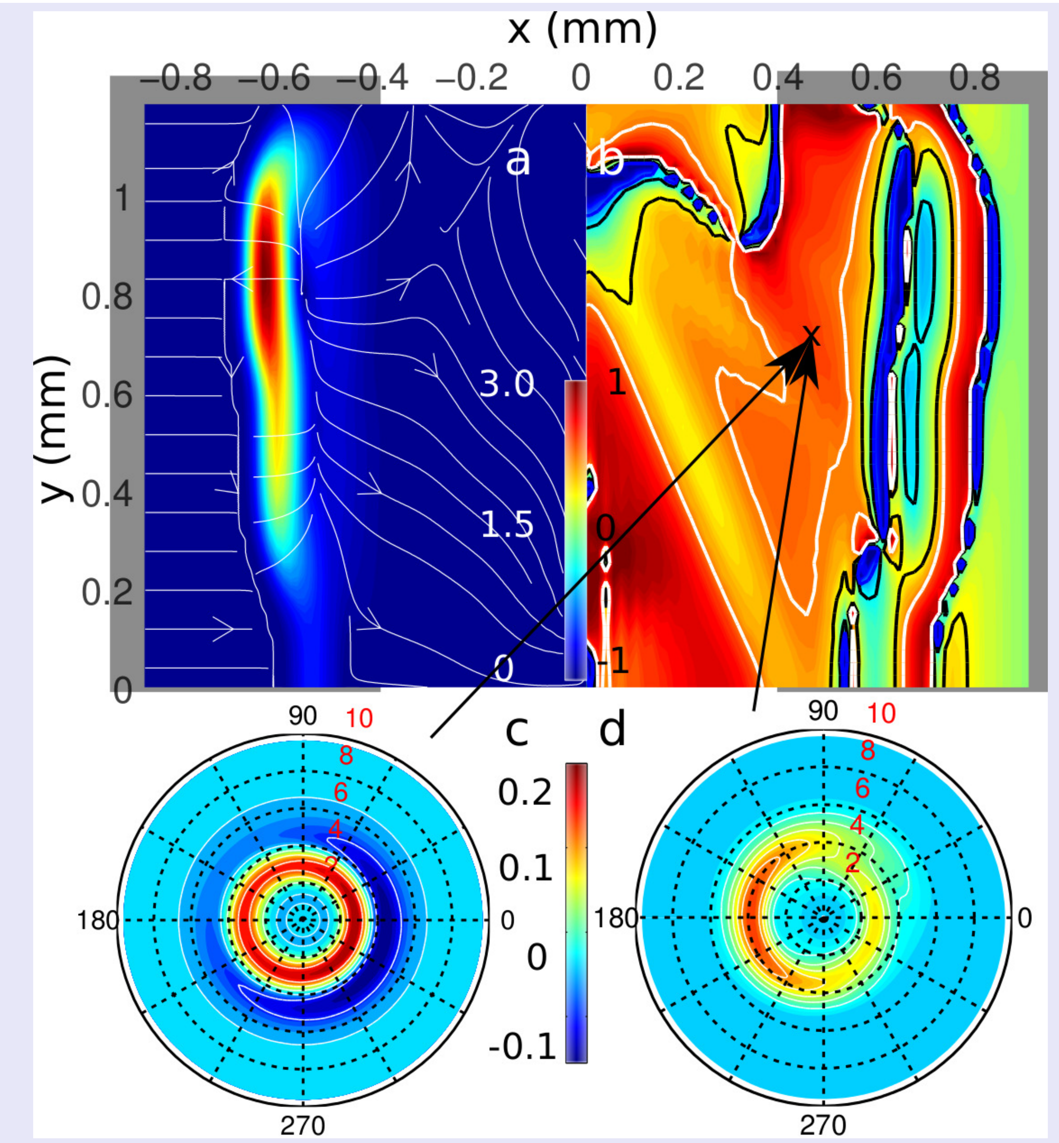
Temperature (keV) - Top Right: The intensity map is used as a heating profile and results in heating of the electron plasma

Nernst Flow - Bottom Right: The strong heat flows result in Nernst flow into the wall as well as into the center of the hohlraum

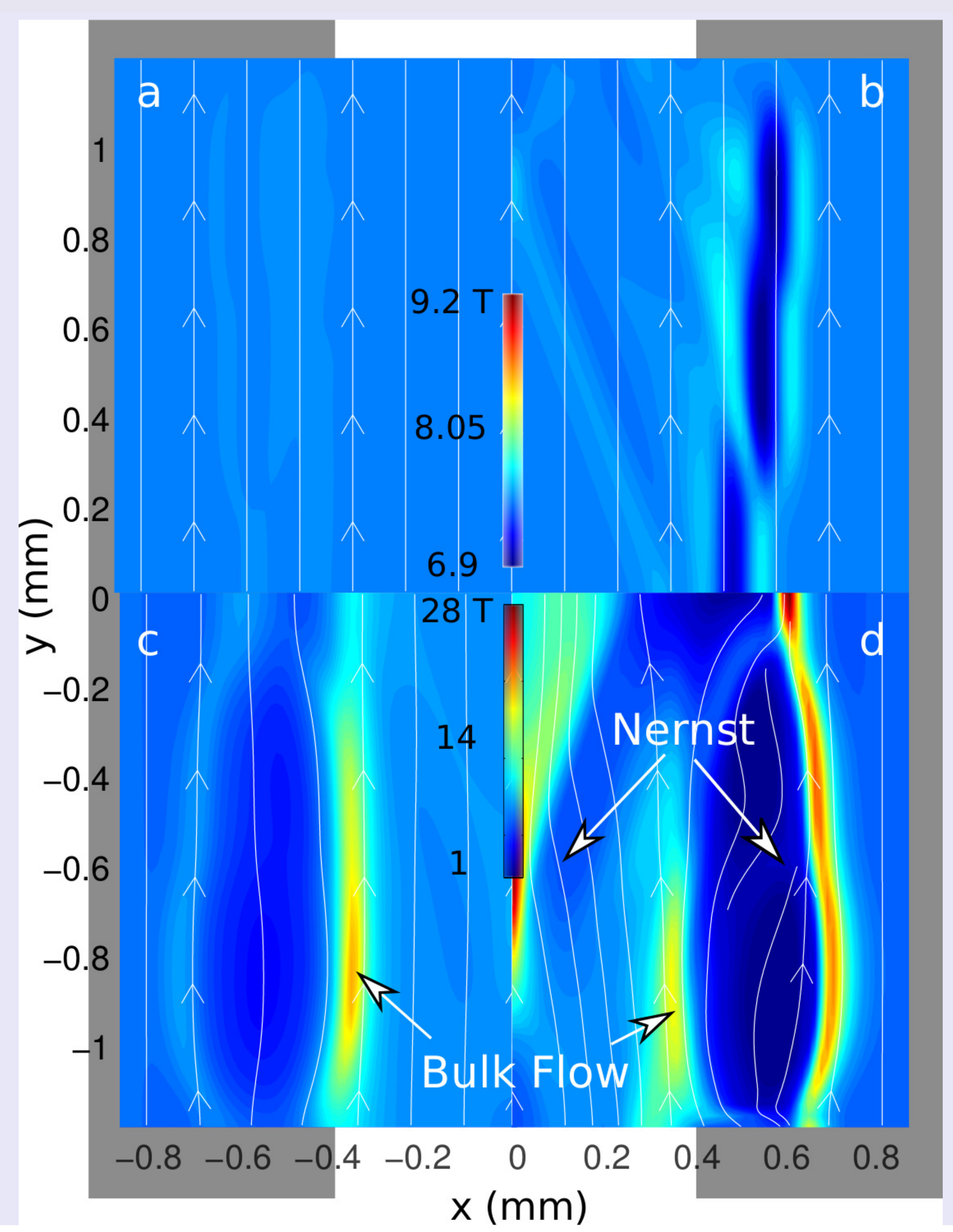
Magnetic Field - Bottom Left: The Nernst flow results in magnetic field compression into the wall as well as magnetic field pile-up in along the hohlraum axis.

Heat Flow - Top Left: The heat flow shows strong heat flow towards the wall but also shows signs of heat flow towards the center of the hohlraum where the temperature gradient does not extend.

$1 - q_{classical}/q_{code}$ Measure of non-locality - Top Right: The regions within the black contours are <50% deviations from classical transport. The regions within the white contours, however, are regions where non-locality is dominant.



Distribution function distortions: Kinetic modeling shows how laser heating (bottom left) and non-local heat flow (bottom right) can distort a distribution function and alter heat flow.

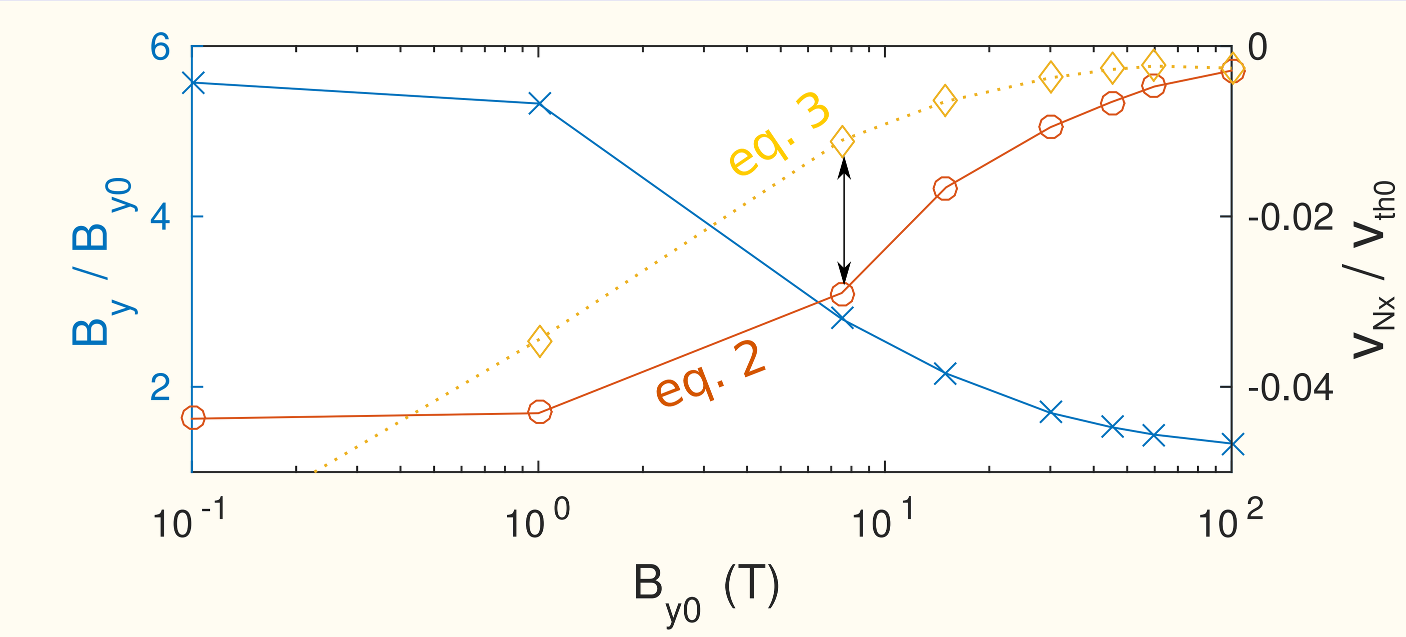


Left frames: "Frozen-in-flux" only

Right frames: Full Ohm's Law

Top frames - 100 ps: The magnetic field is relatively unperturbed early in time when only considering "frozen-in-flux" as the transport mechanism.

Bottom frames - 500 ps: This effect is clear later in time, where there is significant evacuation of the field from the laser heated region due to the Nernst effect. While the result of magnetic field transport from the bulk flow



As magnetic field strength is increased, Nernst flow is mitigated and magnetic field transport diminishes.

The difference between the two calculations of the Nernst velocity, one from the code, the other from the diffusive approximation of the heat flow, is explained by non-locality. **The non-local heat flow augments the Nernst transport of the magnetic field by up to a factor of 2.**