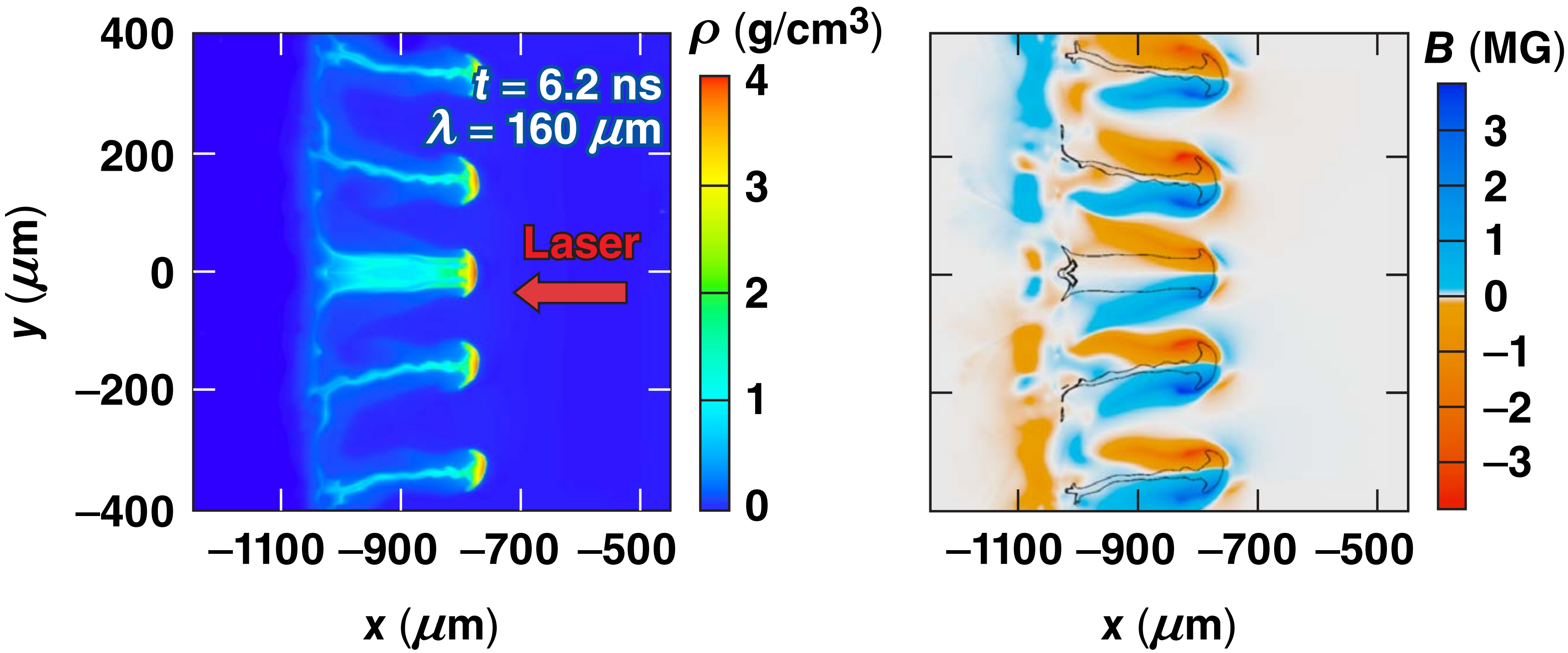
Effects of Self-Generated Magnetic Fields in Rayleigh–Taylor Unstable Laser-Irradiated Plastic Foils

Results of 2-D magnetohydrodynamic simulations



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Summary

Megagauss magnetic fields are predicted in Rayleigh–Taylor (RT) unstable, laser-accelerated plasma

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- The inferred fields were in good agreement with 2-D magnetohydrodynamic (MHD) simulations
- RT-generated magnetic fields are significantly subthermal ($\beta > 100$) and do not directly affect the plasma dynamics
- These fields moderately affect (reduce) the RT growth by altering electron-heat fluxes when the Hall parameter $\omega_e \tau_e > 0.1$

Collaborators

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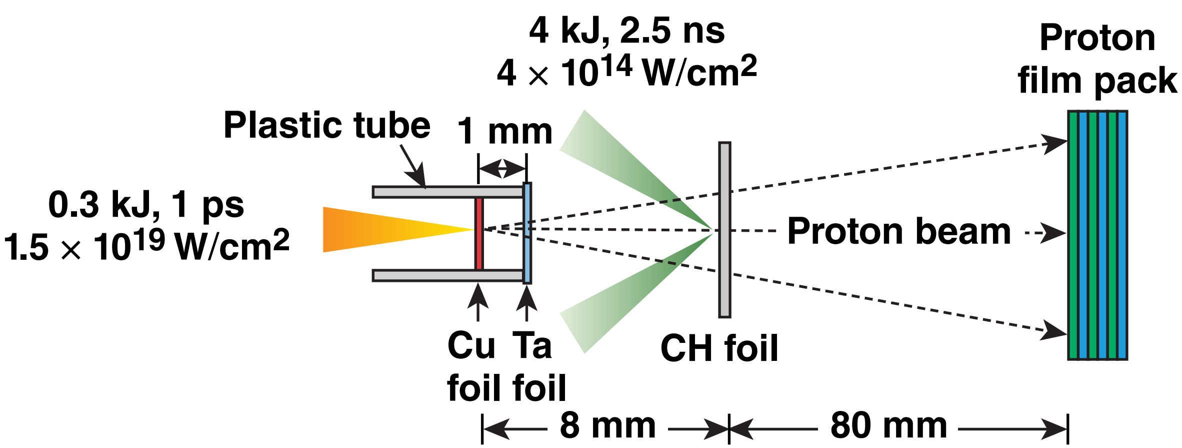
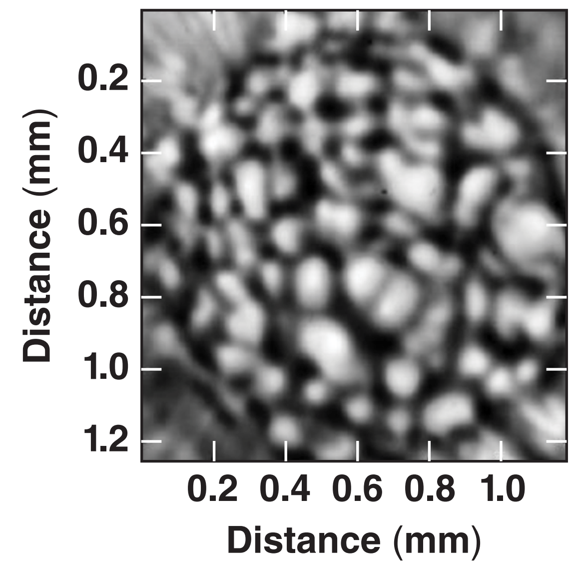
Proton radiography of RT unstable laser-accelerated foils was used to detect self-generated magnetic fields

OMEGA EP experimental setup*



Proton radiograph of RT unstable target



15-μm-thick CH foil
E_p = 13 MeV
t = 2.62 ns

- Magnetic fields up to ~2 MG were inferred
- Cellular magnetic structures are related to nonlinear RT bubble and spikes

*L. Gao *et al*., Phys. Rev. Lett. 110, 185003 (2013).

Self-generated magnetic fields in RT unstable plasma were studied using the Braginskii MHD model*

- The 2-D code *DRACO*** uses the induction equation with all Braginskii's terms

Flow convection, Source, Pinch, Nernst, Diffusion

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times \left(\vec{V} \times \vec{B}\right) + \frac{c}{e}\left[\nabla \times \frac{\nabla P_e}{n_e} - \nabla \times \frac{\left(\nabla \times \vec{B}\right) \times \vec{B}}{4\pi n_e} - \nabla \times \frac{\vec{R}_T + \vec{R}_u}{n_e}\right]$$

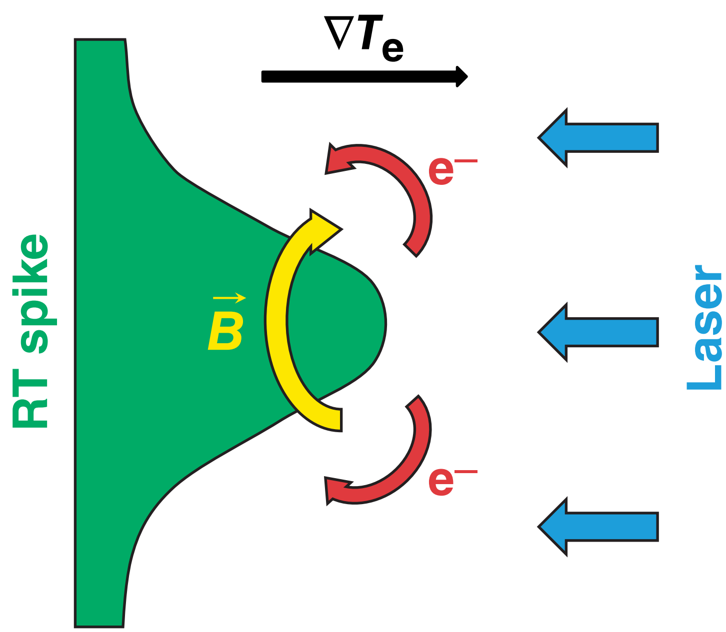
- National Ignition Facility (NIF) related conditions
  - $I = 6 \times 10^{14}$ W/cm^2
  - up to 20-ns pulse duration
  - 100-μm and thicker CH foils

- Main mechanisms
  - Biermann battery source
  - resistive dissipations
  - Nernst convection

*S. I. Braginskii, in *Reviews of Plasma Physics*, edited by Acad. M. A. Leontovich (Consultants Bureau, New York, 1965).
**P. B. Radha *et al*., Phys Plasmas 12, 032702 (2005).

Self-generated magnetic fields are sourced by thermoelectric currents developed near the tip of RT spikes

Magnetic fields produced by electron currents



The Biermann battery source*

$$\frac{\partial \vec{B}}{\partial t} \sim \nabla T_e \times \nabla n_e$$

*L. Biermann, Z. Naturforschg. 5a, 65 (1950).

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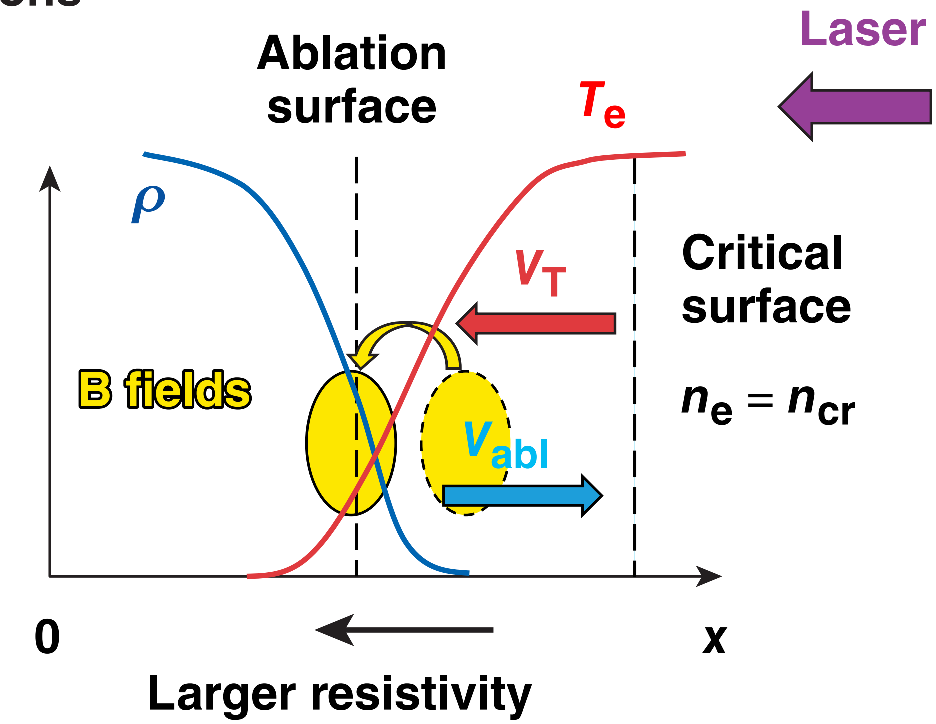
The Nernst convection dominates the convection flow and compresses magnetic fields toward the ablation surface

- Nernst effect: Convection of tangential magnetic fields by thermal electrons*

$$\frac{\partial B_y}{\partial t} = \frac{\partial}{\partial x}\left(V_T B_y\right),$$

$$V_T \propto -\frac{\partial T}{\partial x}$$

- $\vec{V}_T \cdot \vec{V}_{abl} < 0$ and $V_T \gg V_{abl}$ in the conduction zone

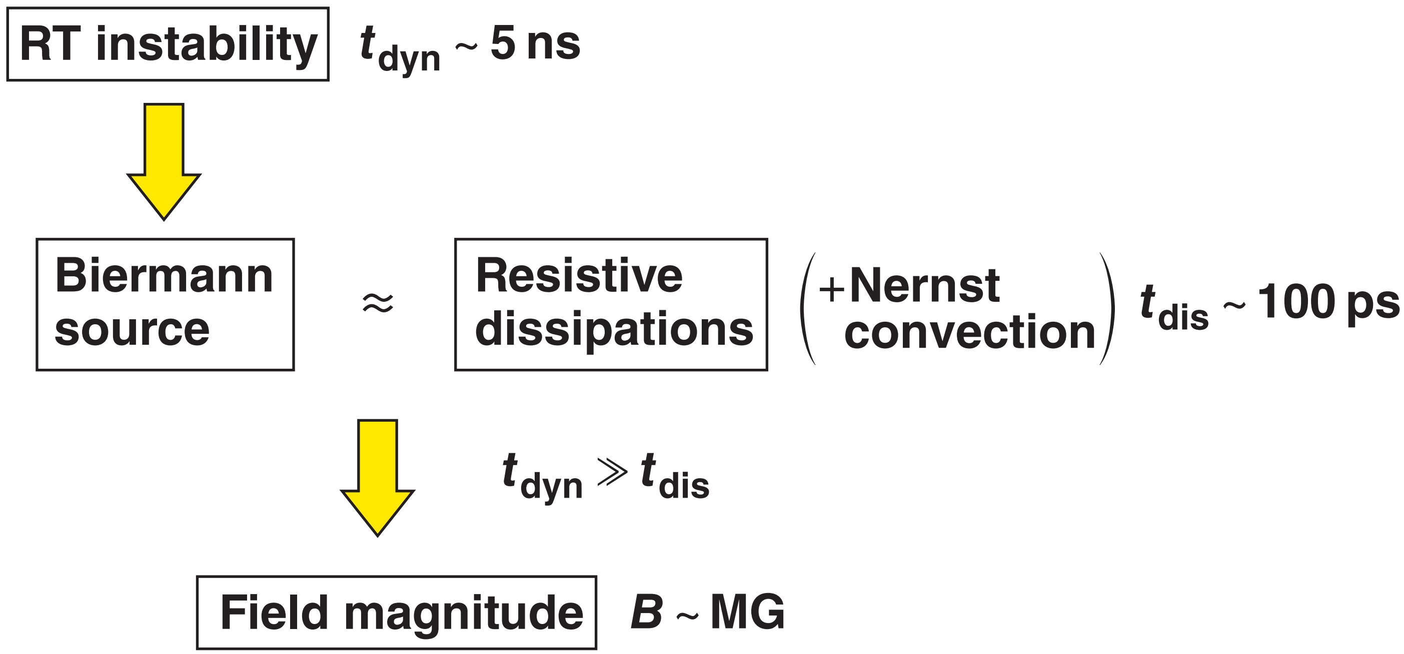


Nernst convection increases the dissipation rate of self-generated fields.

*A. Nishiguchi, T. Yabe, and M. G. Haines, Phys. Fluids 28, 3683 (1985).

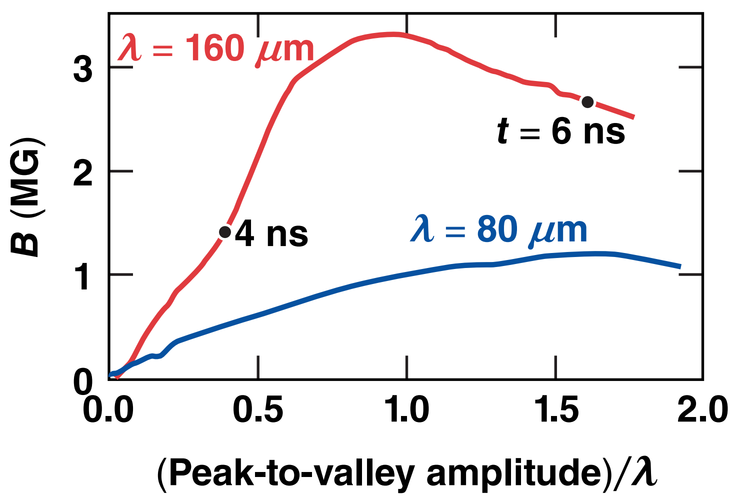
Resistive dissipations are efficient and determine the magnitude of self-generated magnetic fields

Main mechanisms diagram

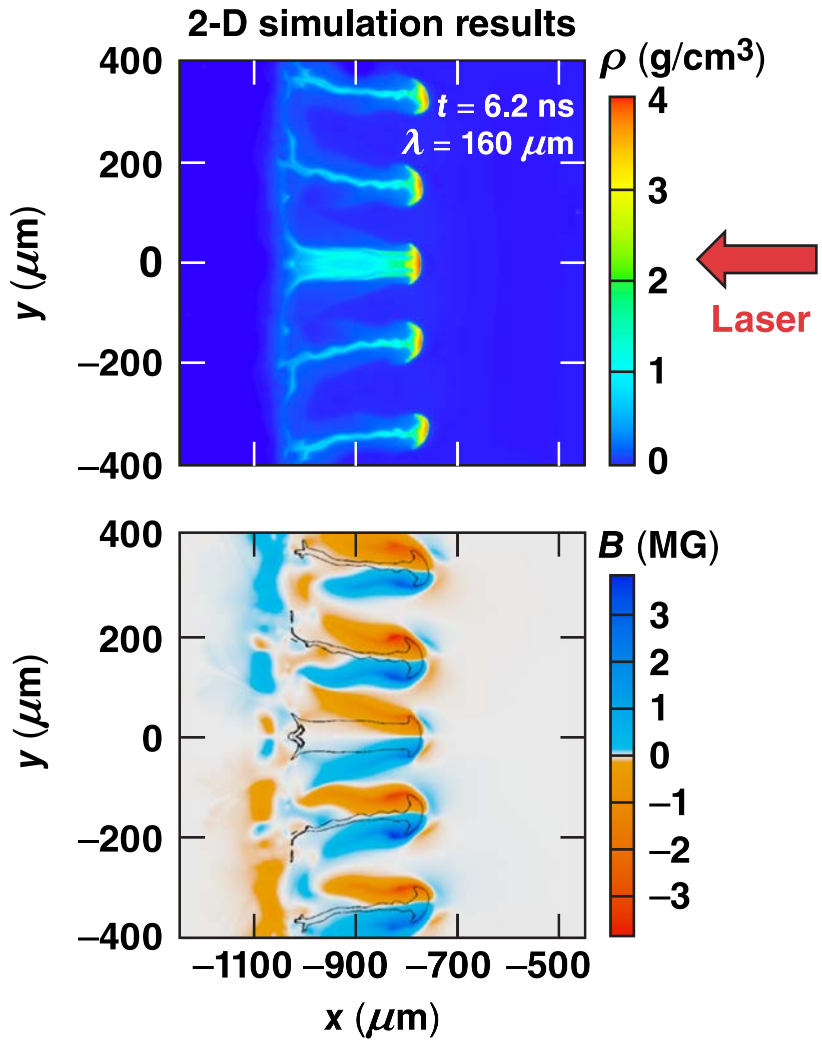


Saturation of self-generated magnetic fields is predicted at highly nonlinear RT stages

- $I = 6 \times 10^{14}$ W/cm^2
- 100-μm-thick CH foil
- $t_{RT} \gg t_{mag} \sim 100$ ps $\Rightarrow$ Quasi-steady magnetic field



- Resistive dissipations limit the fields at small wavelength perturbations



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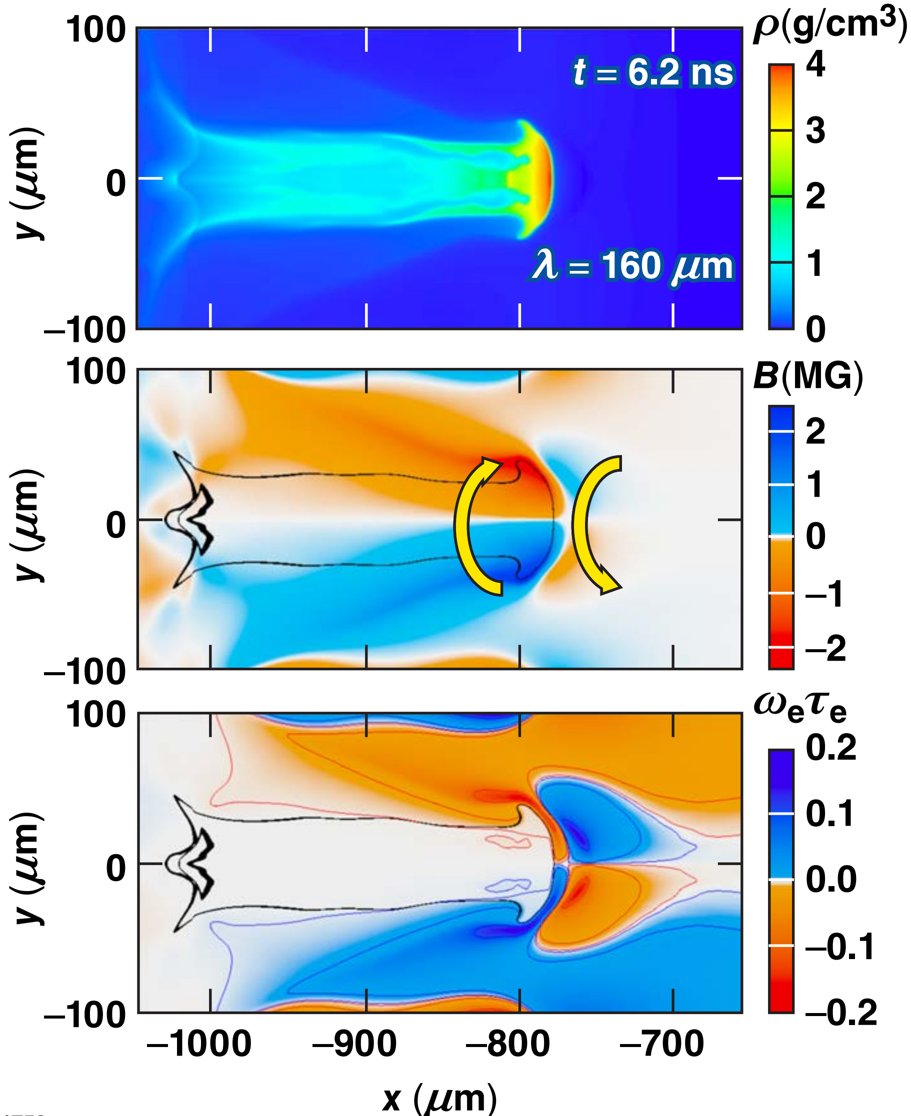
Simulations predict complicated plasma flows resulting in sandwiched magnetic fields



- Self-generated fields are significantly subthermal, $\beta_{min} \sim 100$
- $\omega_e \tau_e > 0.1$ is achieved for long-wavelength perturbations ($\lambda > 100\ \mu m$) and at highly nonlinear stages

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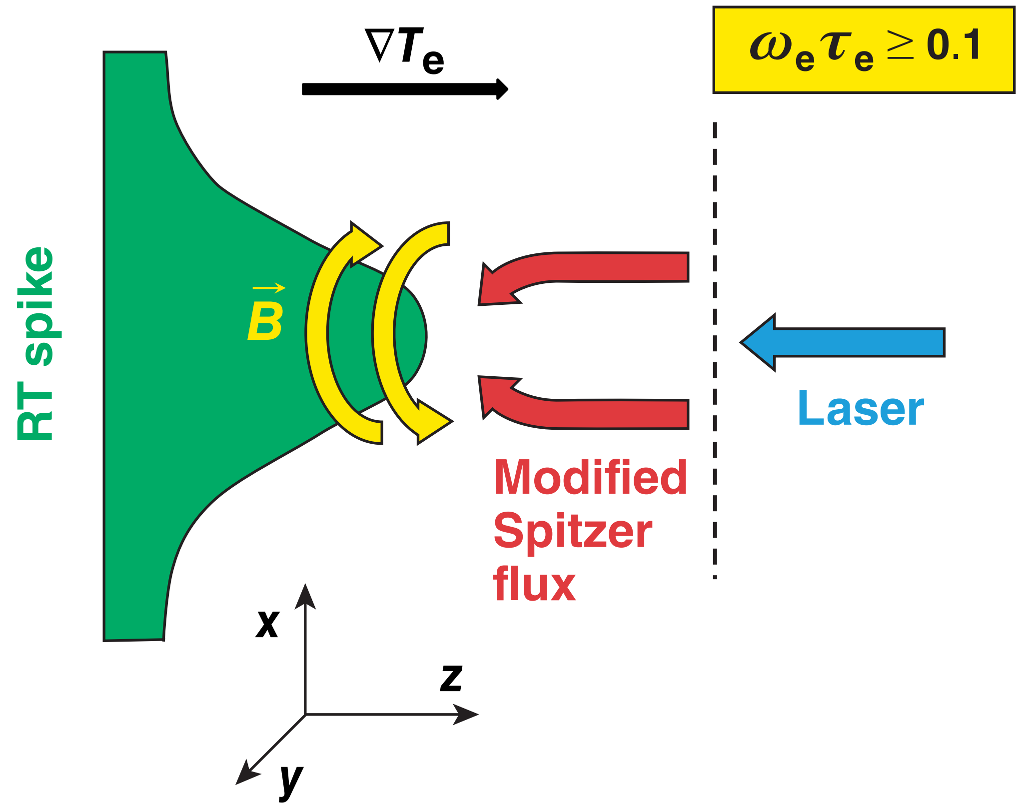
The sandwiched fields focus the heat flux toward the tip of the RT spike



$$T_e = T_e(z), \quad \vec{B} = (0, B_y, 0)$$

Spitzer flux

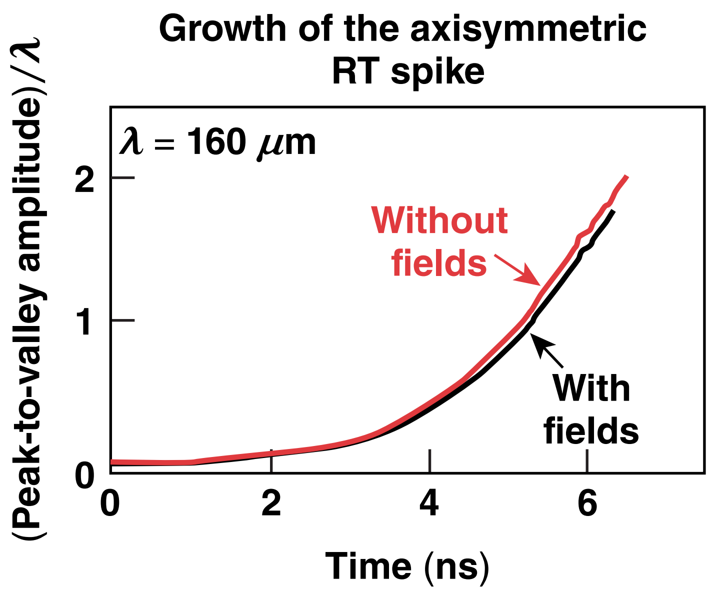
$$\left(\vec{q}_T^{\,e}\right)_z = -k_\perp^e \frac{\partial T_e}{\partial z}, \quad k_\perp^e = k_\perp^e\left(B_y\right)$$

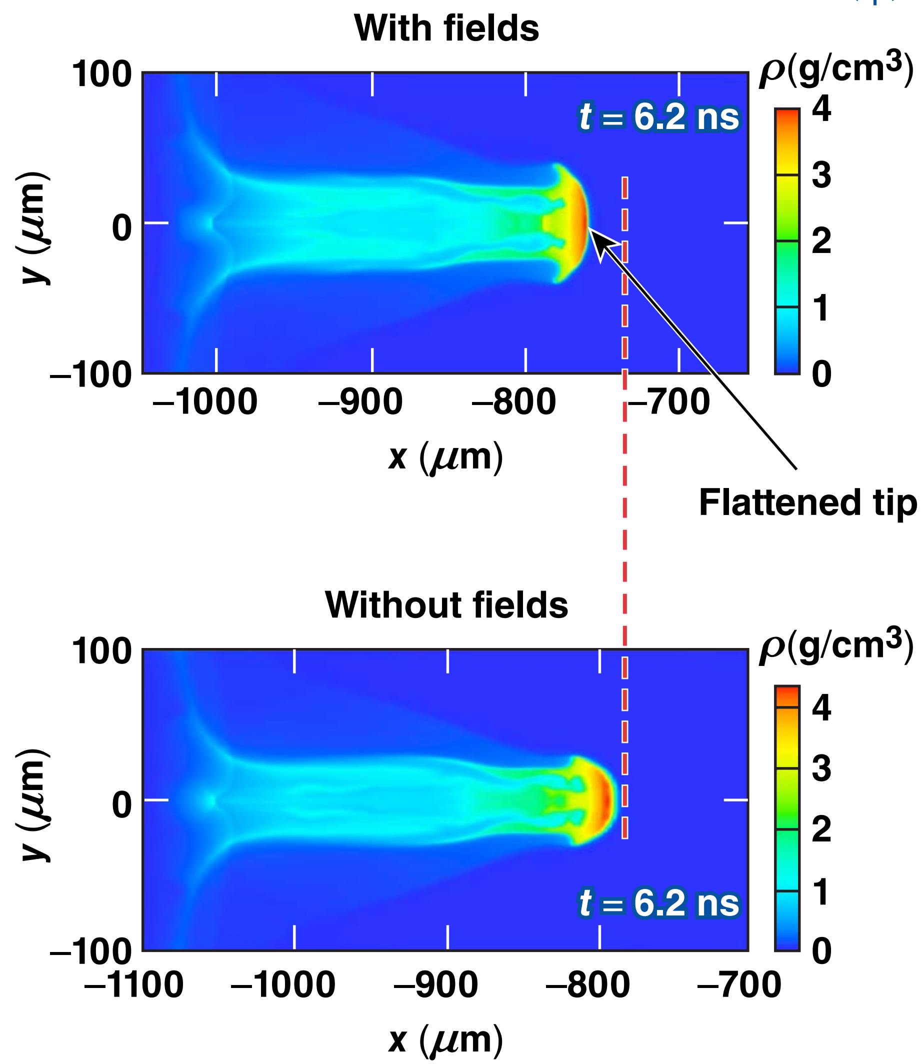
Cross-gradient flux

$$\left(\vec{q}_T^{\,e}\right)_x = -k_\wedge^e \frac{\partial T_e}{\partial z}, \quad k_\wedge^e \propto B_y$$

- The ablation pressure near the tip increases
- Heat entering the RT bubble decreases

Self-generated magnetic fields moderately reduce the RT growth





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Summary/Conclusions

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