Magnetic Reconnection and Plasma Dynamics in Two-Beam Laser–Solid Interactions

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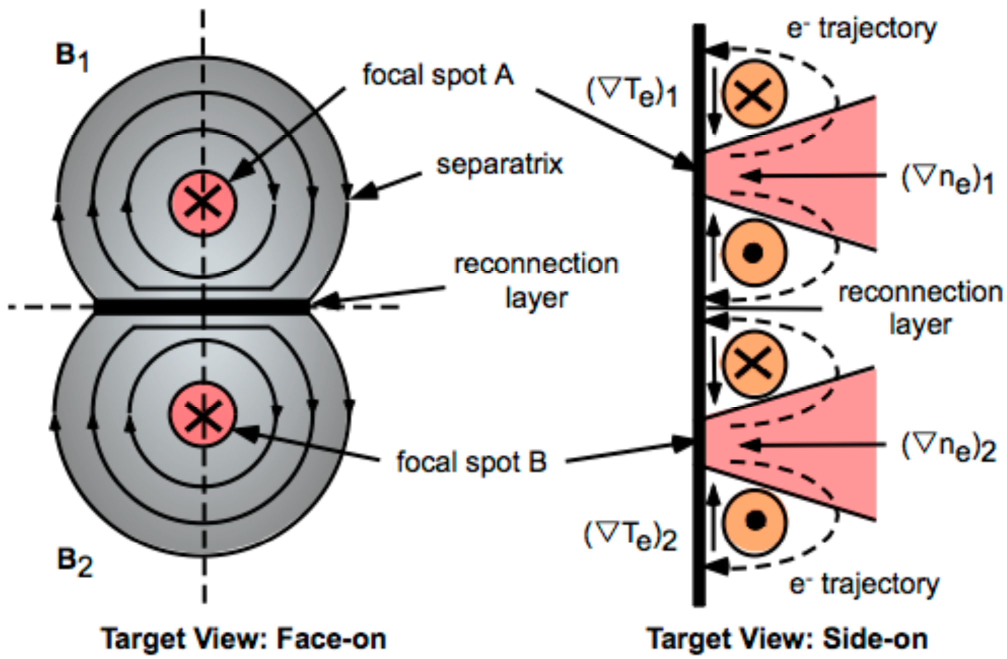

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48th Annual Meeting of the
American Physical Society
Division of Plasma Physics
Philadelphia, PA
30 October–3 November 2006

Summary

A magnetic-reconnection geometry has been studied using two closely focused laser beams (10^{15} W/cm^2, 1 ns)

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- The plasma dynamics created by two heater beams at the surface of a planar solid target (Al or Au) has been studied.
- Observations consistent with a magnetic reconnection have been made
  - the formation of a driven magnetic-reconnection field distribution
  - the interaction of 0.7- to 1.3-MG magnetic fields in a reconnection layer
  - collimated, high-velocity jet formation
  - high electron temperature (T_e = 1.7 keV) in the reconnection layer
- Reconnection rates predicted by the Sweet–Parker model of reconnection (assuming Spitzer resistivity) are too slow to explain these observations.

Collaborators

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Magnetic fields are generated by nonparallel electron-density and temperature gradients

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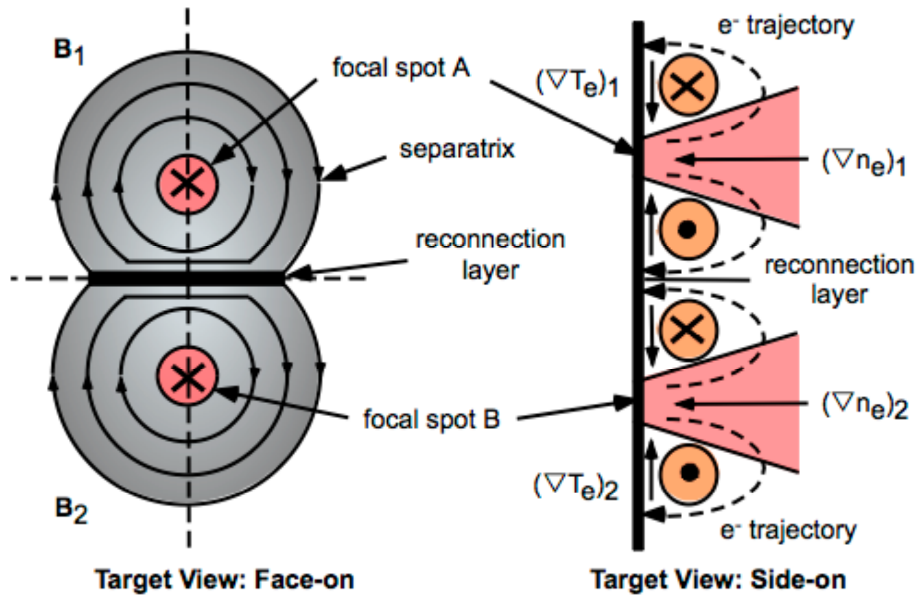
- **Laser-pulse characteristics: 1 ns, 10^{15} W/cm^2**



$$\partial_t \boldsymbol{B} = \nabla \times (\boldsymbol{\nu} + \boldsymbol{B}) + \left(k_B / n_e e\right) \nabla T_e \times \nabla n_e + \left(1/\mu_0\right) \nabla \times (\eta \nabla \times \boldsymbol{B})$$

The self-generated magnetic-field distribution is similar to the Sweet–Parker model of magnetic reconnection

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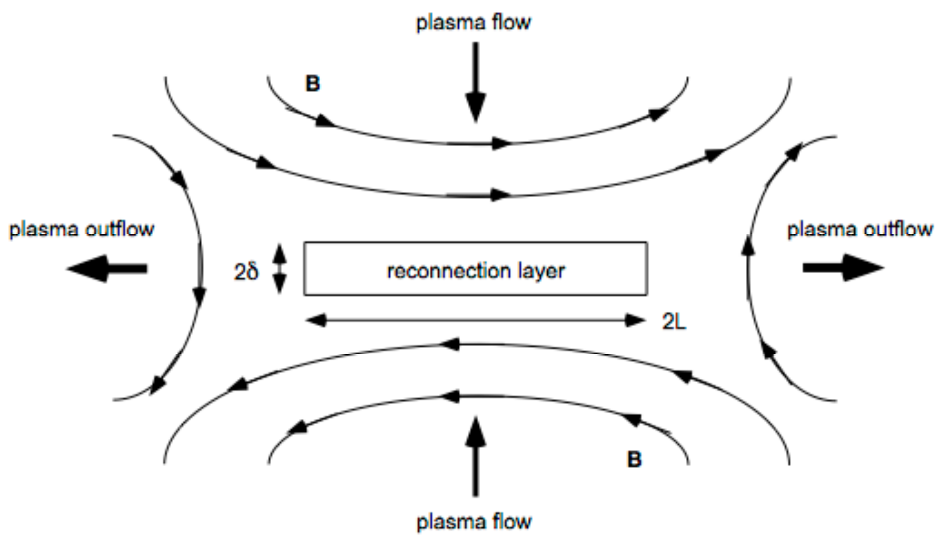

- **Magnetic Reynolds number:** $$\frac{1}{S^{1/2}} = \left(\frac{\eta}{\mu_0 L \nu_A}\right)^{1/2}$$
- **Reconnection time:** $$\tau_{sp} = \frac{L}{\nu_r} = \frac{L}{\nu_A S^{1/2}} = (\tau_A \tau_R)^{1/2} \approx 4 \text{ ns}$$

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Experimental setup:
The Vulcan Laser Facility

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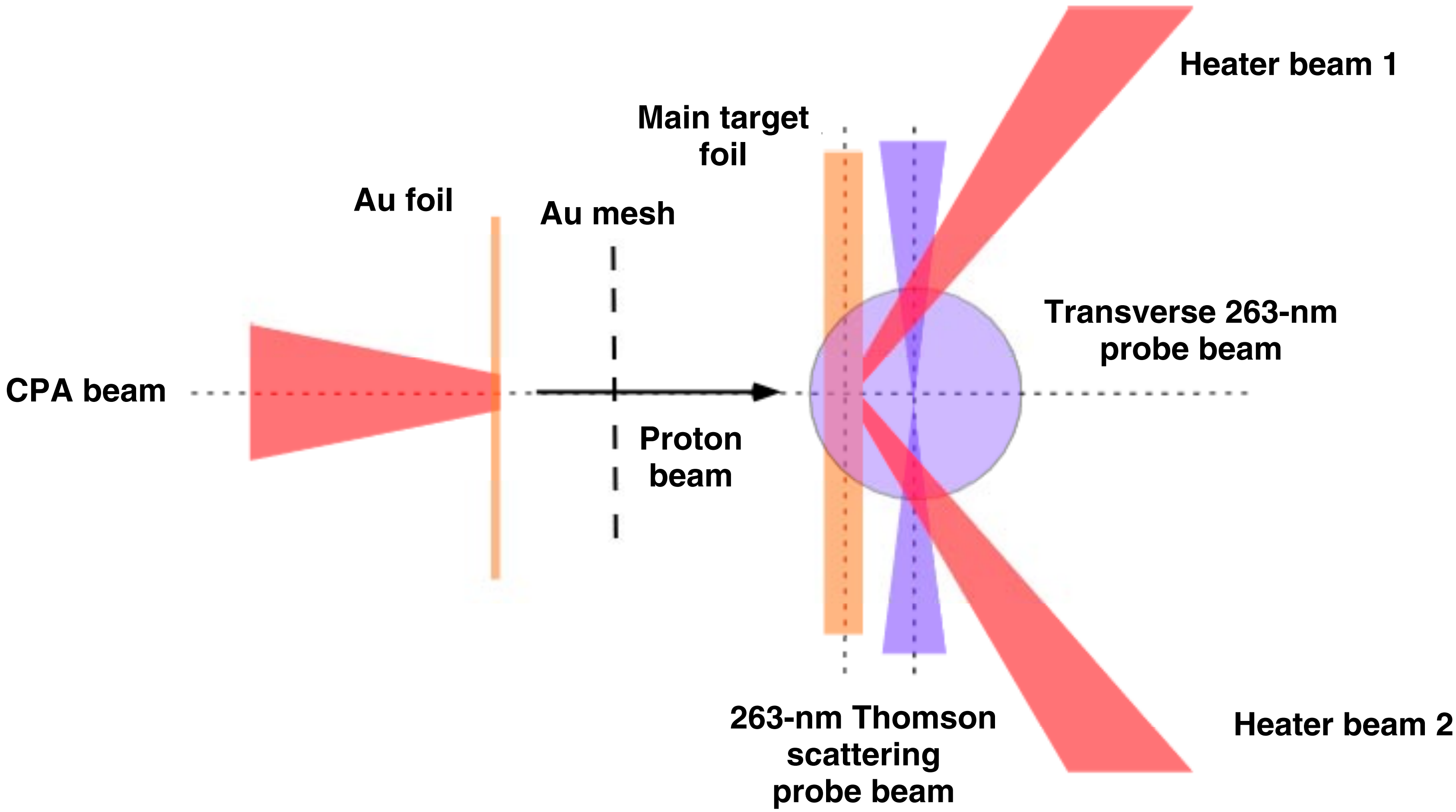

A single region of expanding plasma develops when the two heater beams are separated by approximately 200 μm

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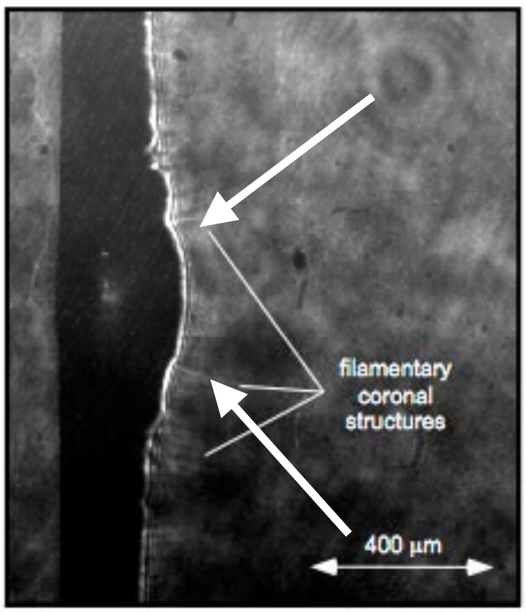
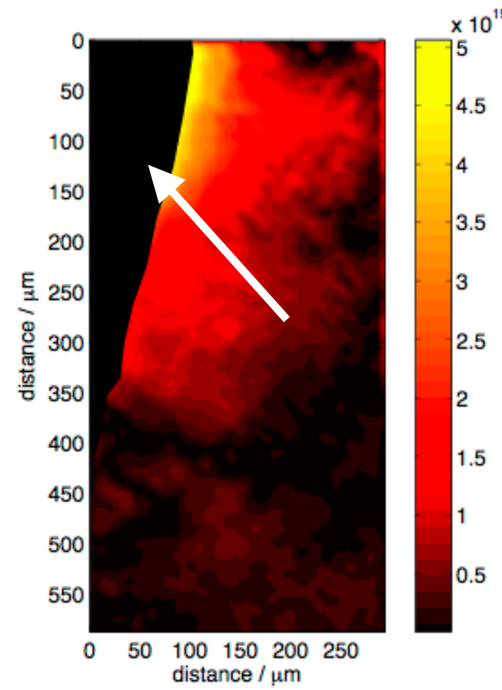
- Shadowgram
- $t = t_0 + 1.5$ ns



- Interferogram
- $t = t_0 + 1.5$ ns



- **Aluminum target foil**

Time-integrated x-ray pinhole imaging shows heating due to a plasma collision

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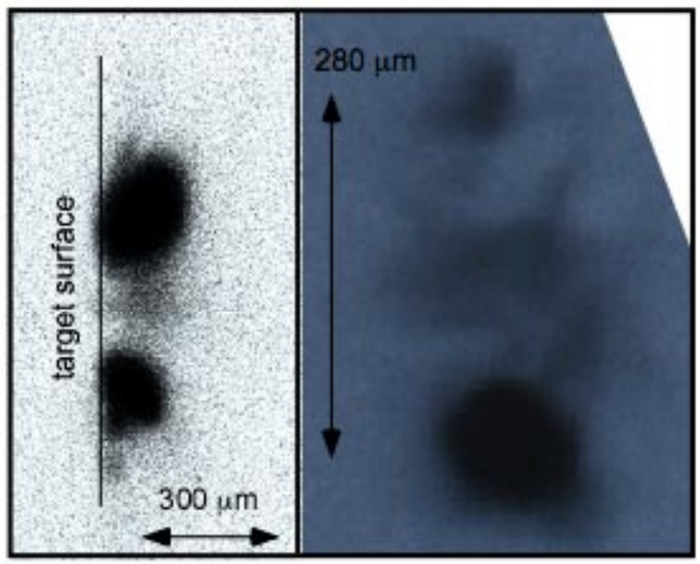
- X-ray pinhole images (time-integrated)
- Al target (1-keV emission)



- Conversion of streaming ion kinetic energy into ion thermal energy
- Electrons gain energy through election–ion equilibration

Sudden jet formation occurs for larger laser-spot separations of around 400 μm

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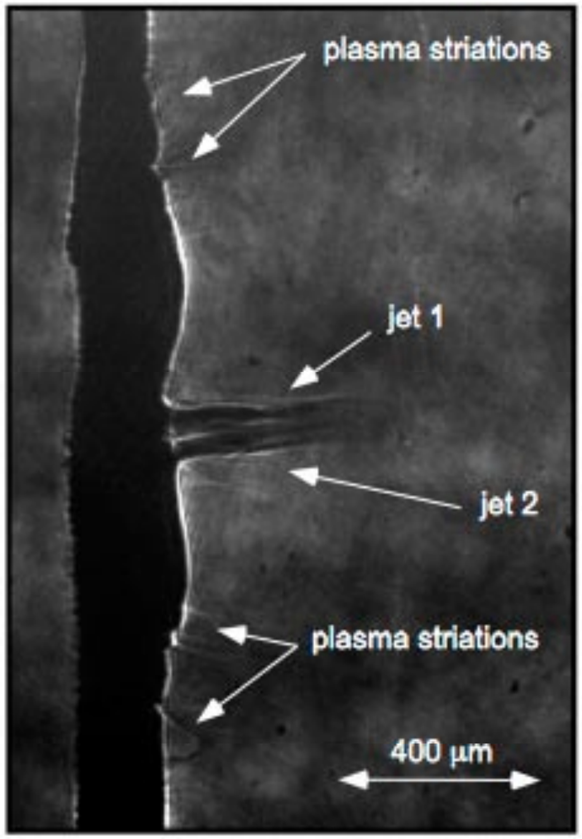

- **Aluminum target foil**
- **$t = t_0 + 1.5$ ns**

- **Jet formation occurs at an angle to the target surface**

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Jet formation occurs at an angle to the target surface

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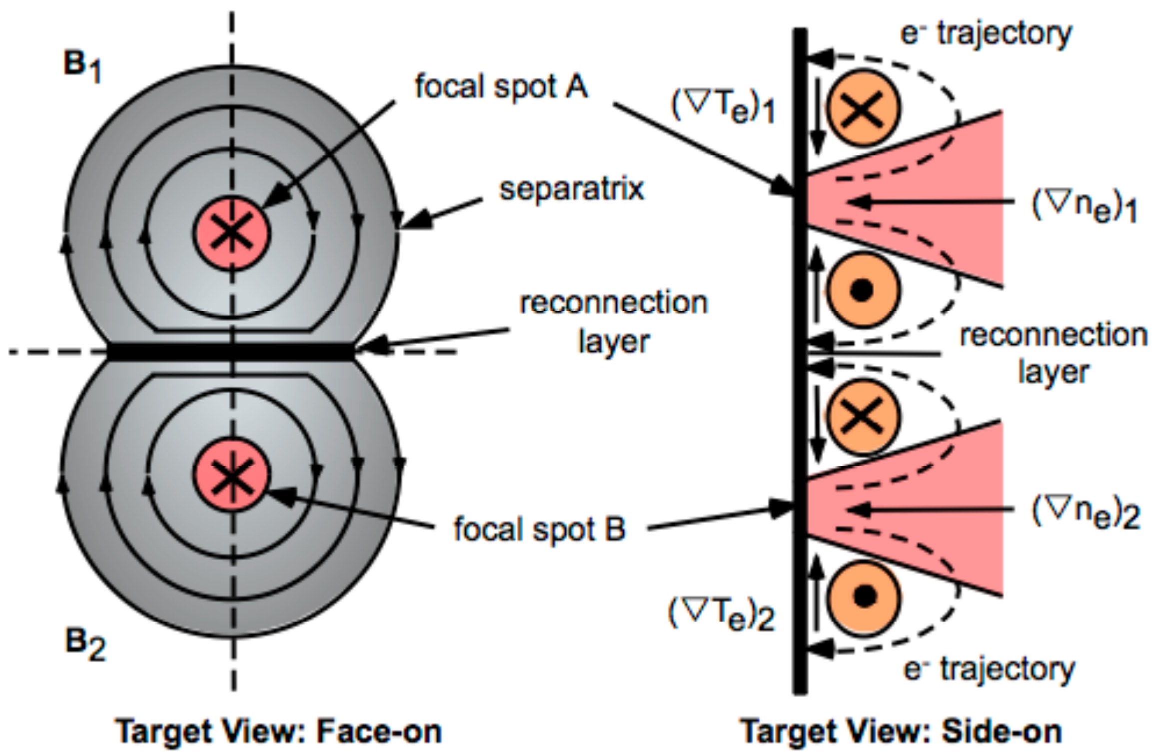

Greater jet collimation is observed in gold target interactions consistent with radiative-cooling effects

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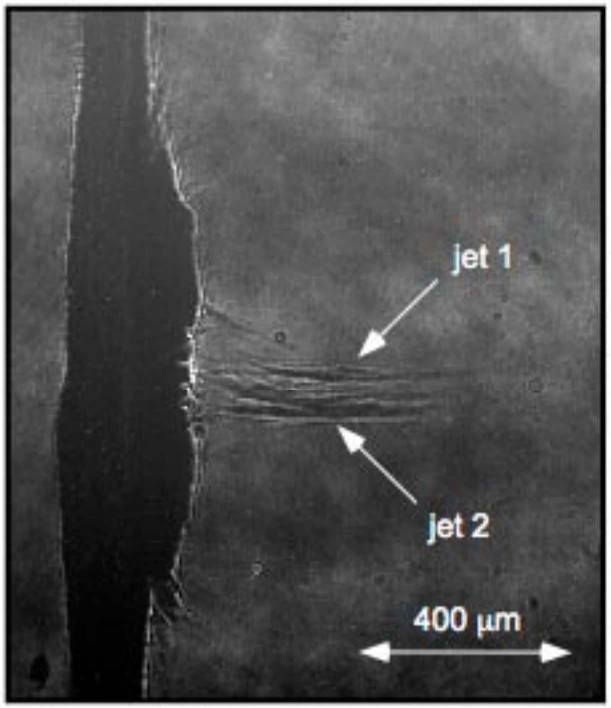
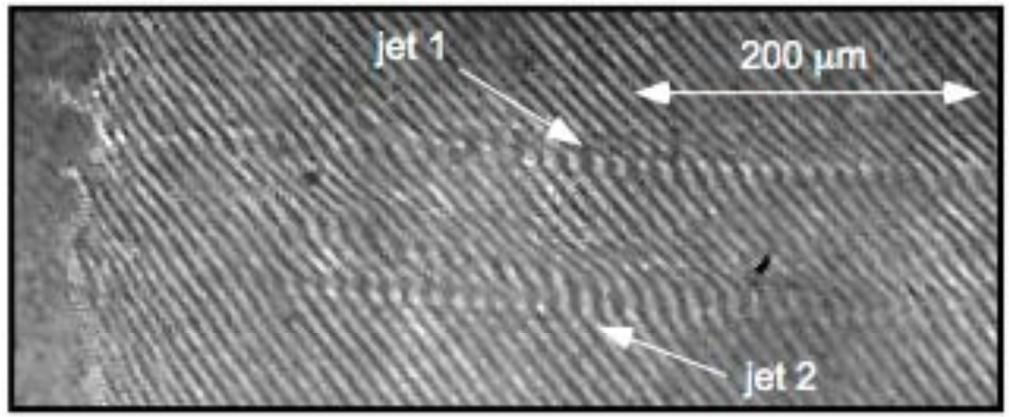
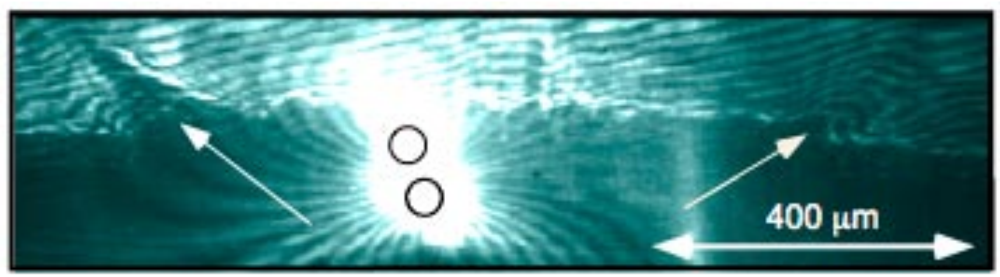
$t = t_0 + 2.5$ ns



$t = t_0 + 0.7$ ns





Gold target foil

Interacting MG-level azimuthal magnetic fields are measured with proton deflectometry

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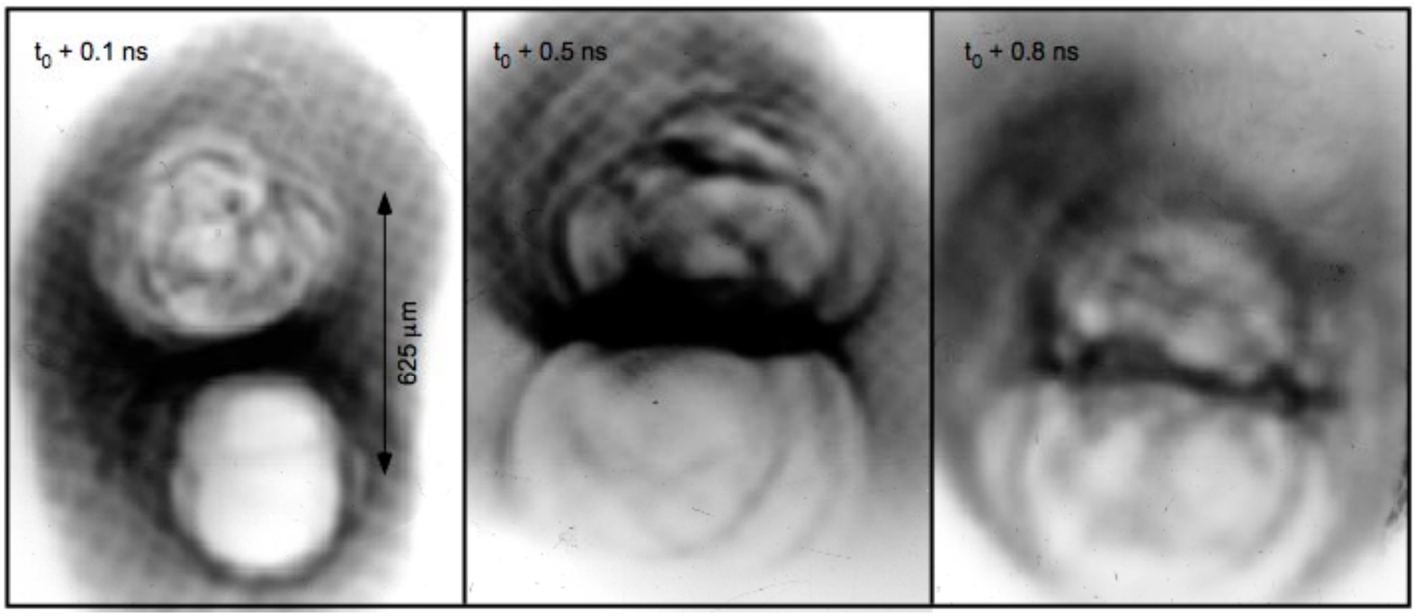
$t = t_0 + 0.1$ ns $\quad t = t_0 + 0.5$ ns $\quad t = t_0 + 0.8$ ns



- **0.7- to 1.3-MG magnetic fields**
- **Stressed magnetic-field lines**

More detail: JO2.00009 Willingale

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Thomson scattering (TS) measurements show kilo-electron-volt electron temperatures in the aluminum interaction layer

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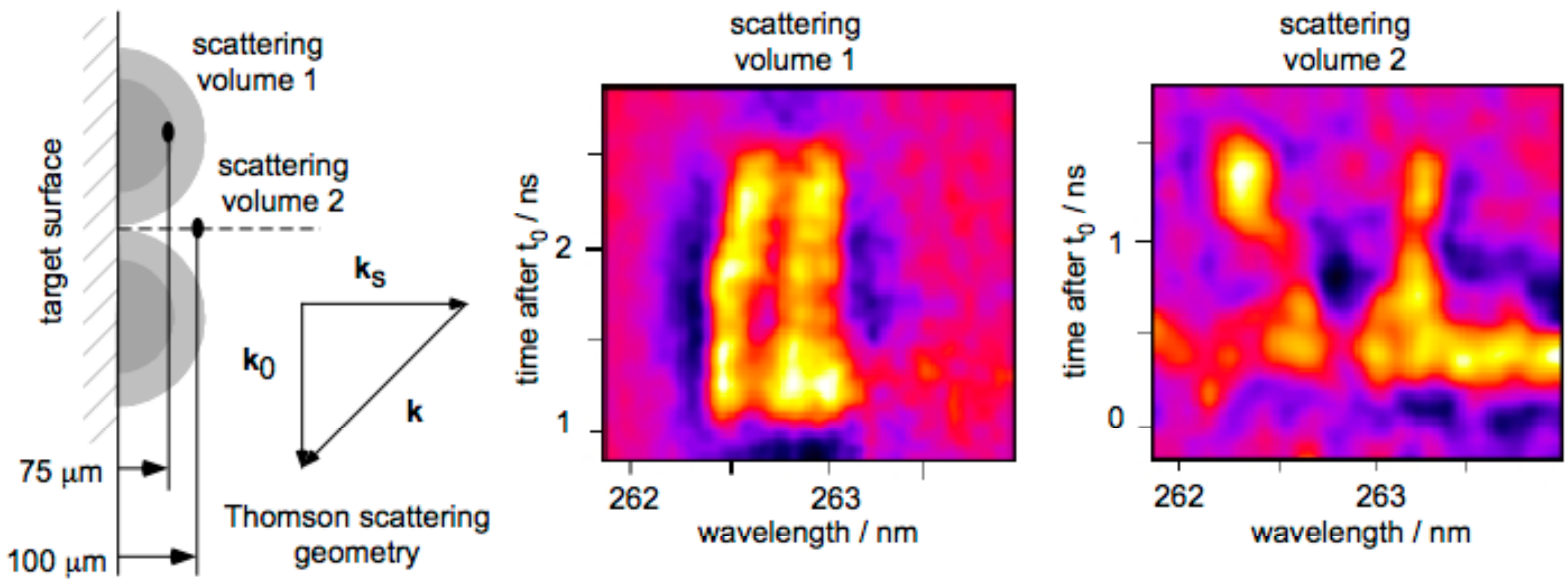

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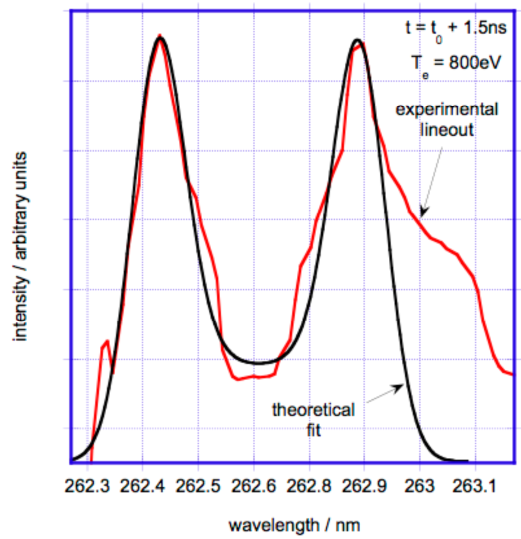
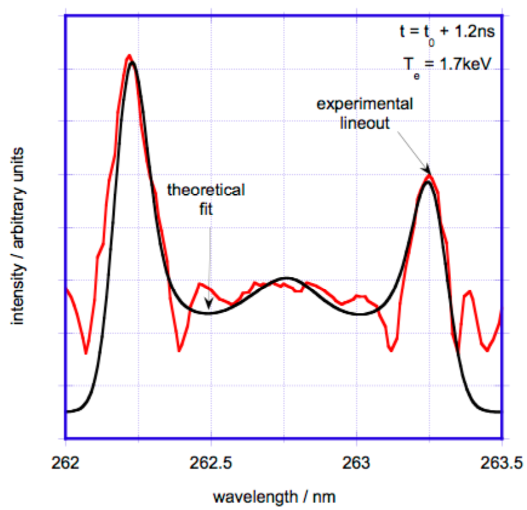


- Scattering volume 1: plume
- T_e = 800 eV at $t = t_0$ + 1.5 ns

- **Cooling due to hydrodynamic expansion**



- Scattering volume 2: interaction region
- T_e = 1700 eV at $t = t_0$ + 1.2 ns

- **Assumes an ion-distribution function represented by the sum of two Maxwellians shifted by the beam flow velocity**

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