The Study of Thermal Transport in Magnetized Laser-Produced Plasmas

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Introduction

- Experiments at the Omega Laser Facility are measuring the heat-wave propagation in plasmas where an external magnetic field is scaled up to 100 T
  - this new setup provides a platform for experimental testing of magnetohydrodynamic (MHD) and extended-MHD codes
  - initial studies of inhibited heat transport have been performed
  - collective Thomson scattering was used to spatially resolve the plasma conditions within a 2-mm-diam gas-jet plasma
  - at the highest magnetic field strengths of B $\approx$ 12 T, the magnetic-field pressure is significant compared to the plasma pressure $\left(\beta = \frac{2\mu_0 n k_B T}{B^2} \sim 10\right)$
  - this results in a quenching of heat transport perpendicular to the applied field, causing nearly a twofold increase in the local plasma temperature
  - classical thermal transport models break down when the magnetic field is turned off and the mean free path of the electrons is much larger than the temperature scale length

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Setup

- A 2-mm-diam gas-jet nozzle was positioned 1.3 mm below the midpoint of two magneto-inertial fusion electrical discharge system (MIFEDS) solenoid coils
- A 500-ps, 200 J, 3ω heater beam was directed along the axis of the coils, creating a 2-mm-long cylinder of nitrogen plasma; the plasma cylinder had a diameter of about 100 μm
  - laser intensity: 6.68 $\times$ 10^{15} W/cm^2
  - peak electric-field strength: 2.24 $\times$ 10^{11} V/m
- A 200-ps, 20-J, 4ω Thomson-scattering beam was turned on 100 ps after the heater beam; this beam was directed almost perpendicular to the plasma cylinder to probe the plasma conditions along the 100-μm diameter at target chamber center (TCC)
  - laser intensity: 1.67 $\times$ 10^{15} W/cm^2
  - peak electric-field strength: 1.12 $\times$ 10^{11} V/m
- The MIFEDS coils discharged ~10 kA of currents before the lasers fired; this created an on-axis magnetic-field strength close to 12 T prior to plasma formation
- Multiple shots were taken with and without the MIFEDS

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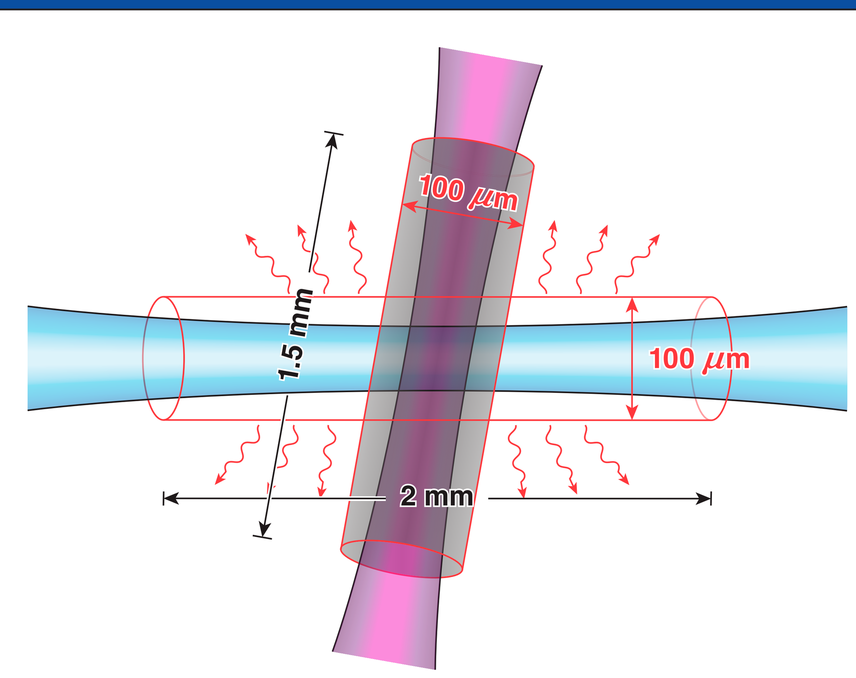
Heat Flow and Thomson Volume



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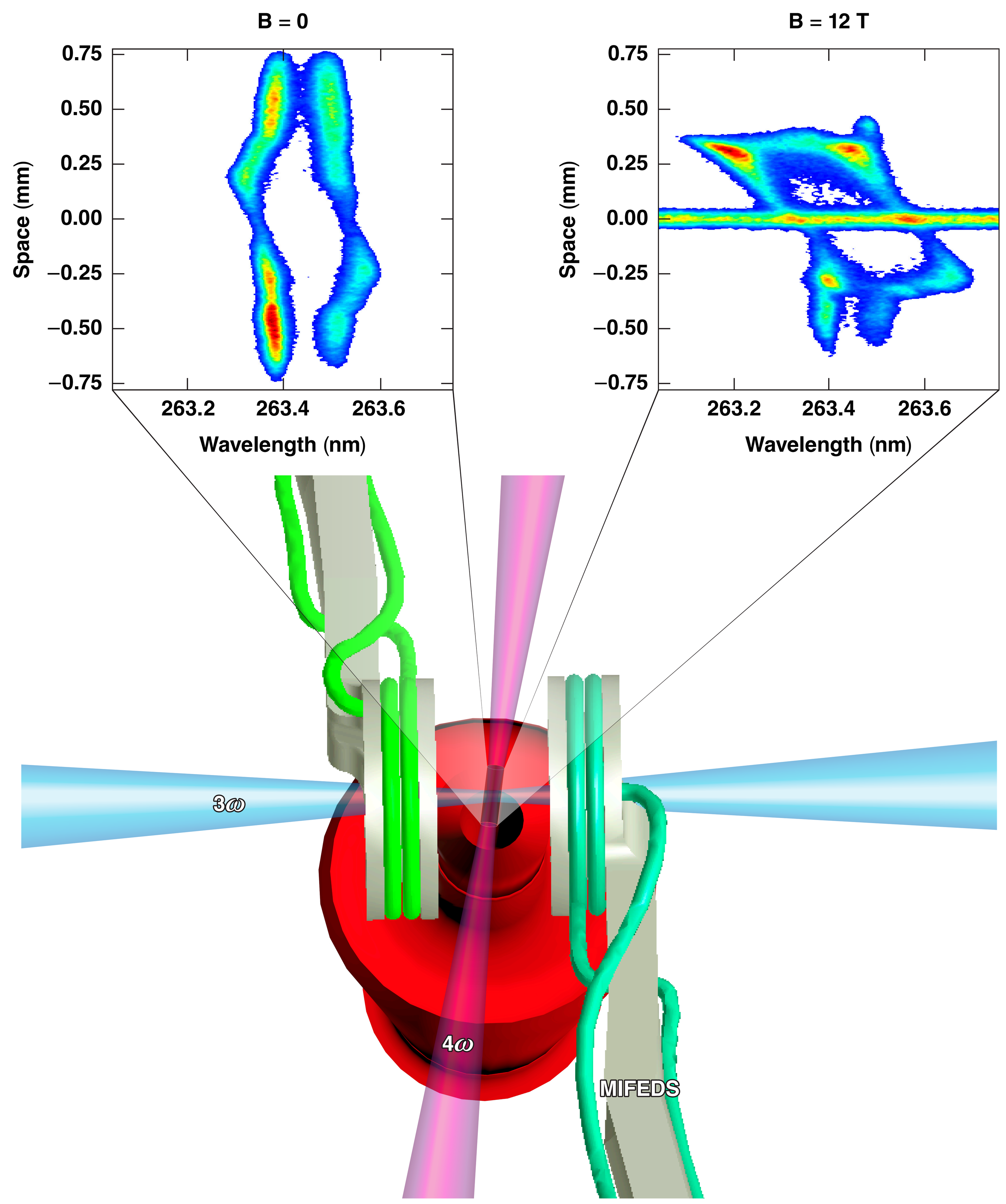
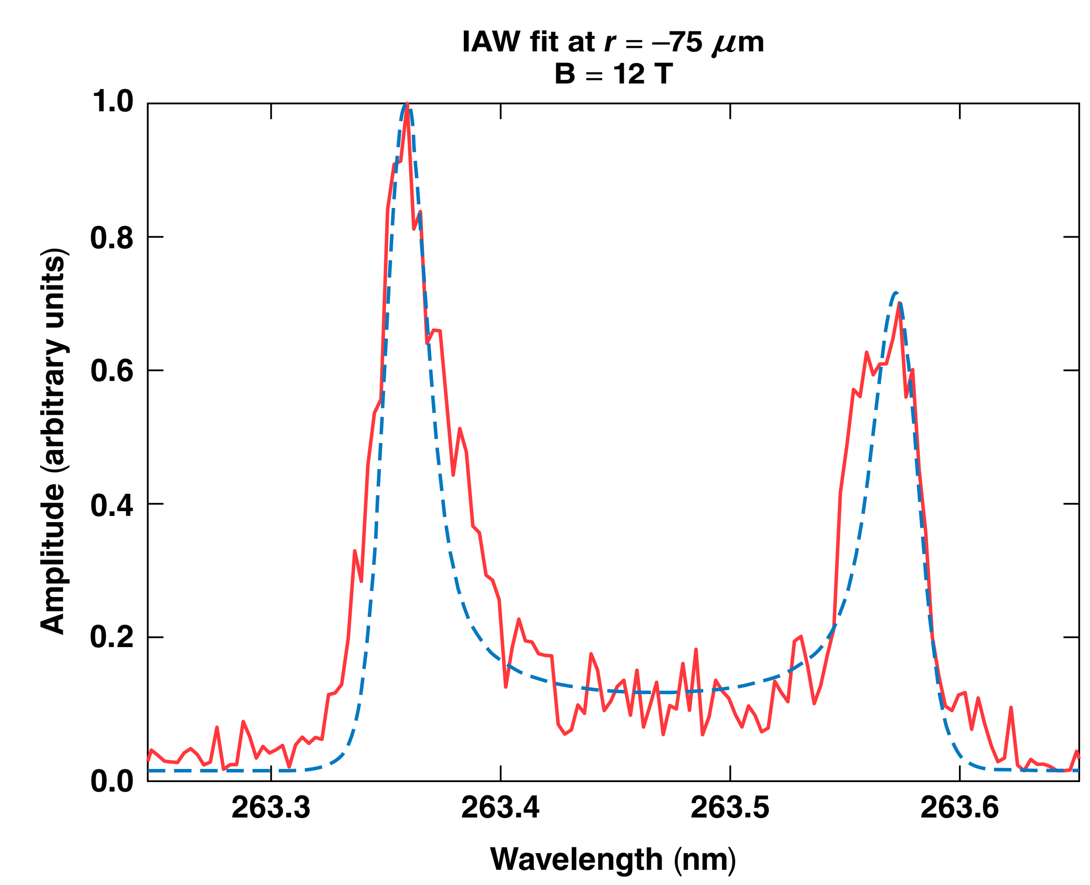
4ω Thomson-Scattering Images





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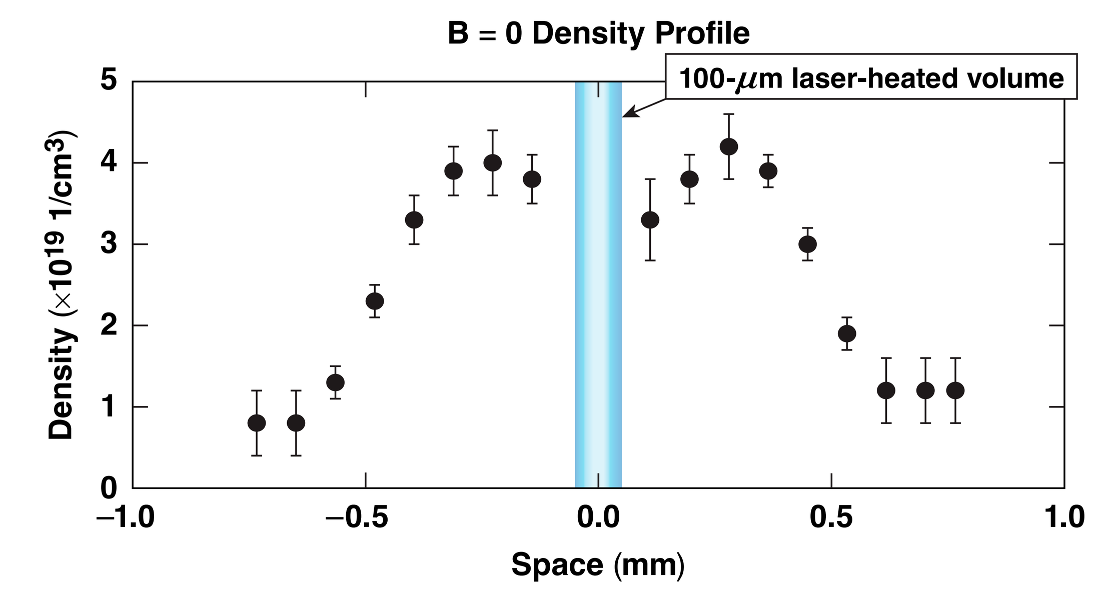

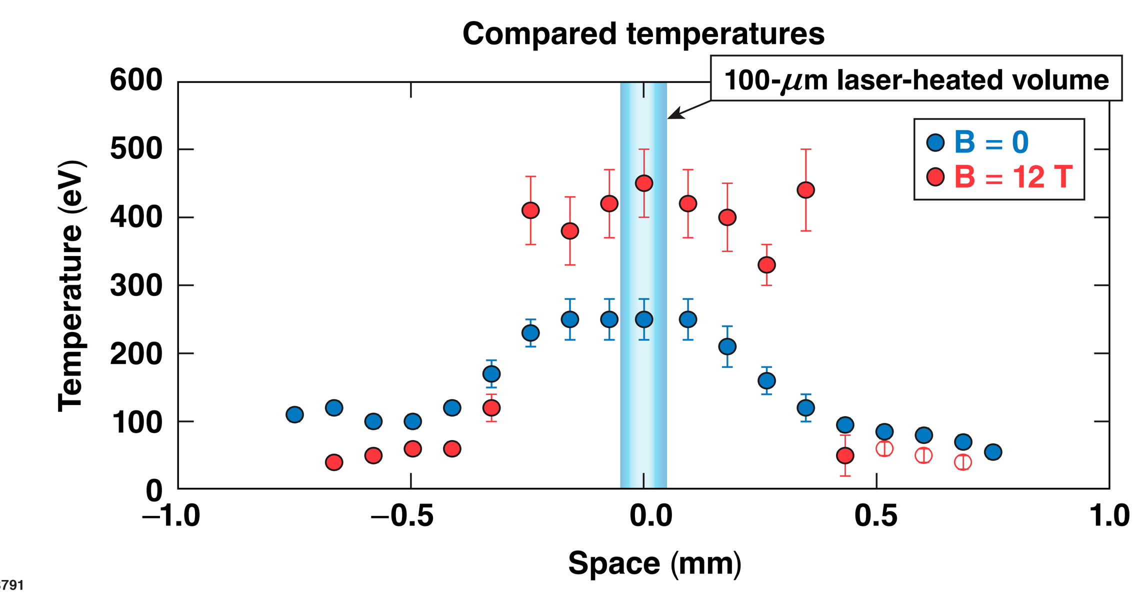

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Results

- Electron-plasma wave features from 4ω Thomson scattering showed a characteristic dip in the density profile across the 100-μm center of the plasma without an external magnetic field
- Temperature measurements from the ion-acoustic waves show an average temperature of 250 eV without an external B field
- The temperature was amplified to over 400 eV when the MIFEDS provided a 12-T magnetic field, thereby inhibiting heat transport, causing strong local heating
- Estimates of β are between 11 and 25 due to variation in the density and temperature profiles
- β was 16.8 to 22.4 on axis during the analyzed MIFEDS shot

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Future work

- Shots planned on the OMEGA laser for 2020 will demonstrate stronger magnetic fields (100 T), leading to much greater magnetic pressures ($\beta \le 1$)
- Proton radiography will be implemented to take accurate measurements of the magnetic field and Nernst velocity

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This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856, the University of Rochester, and the New York State Energy Research and Development Authority.

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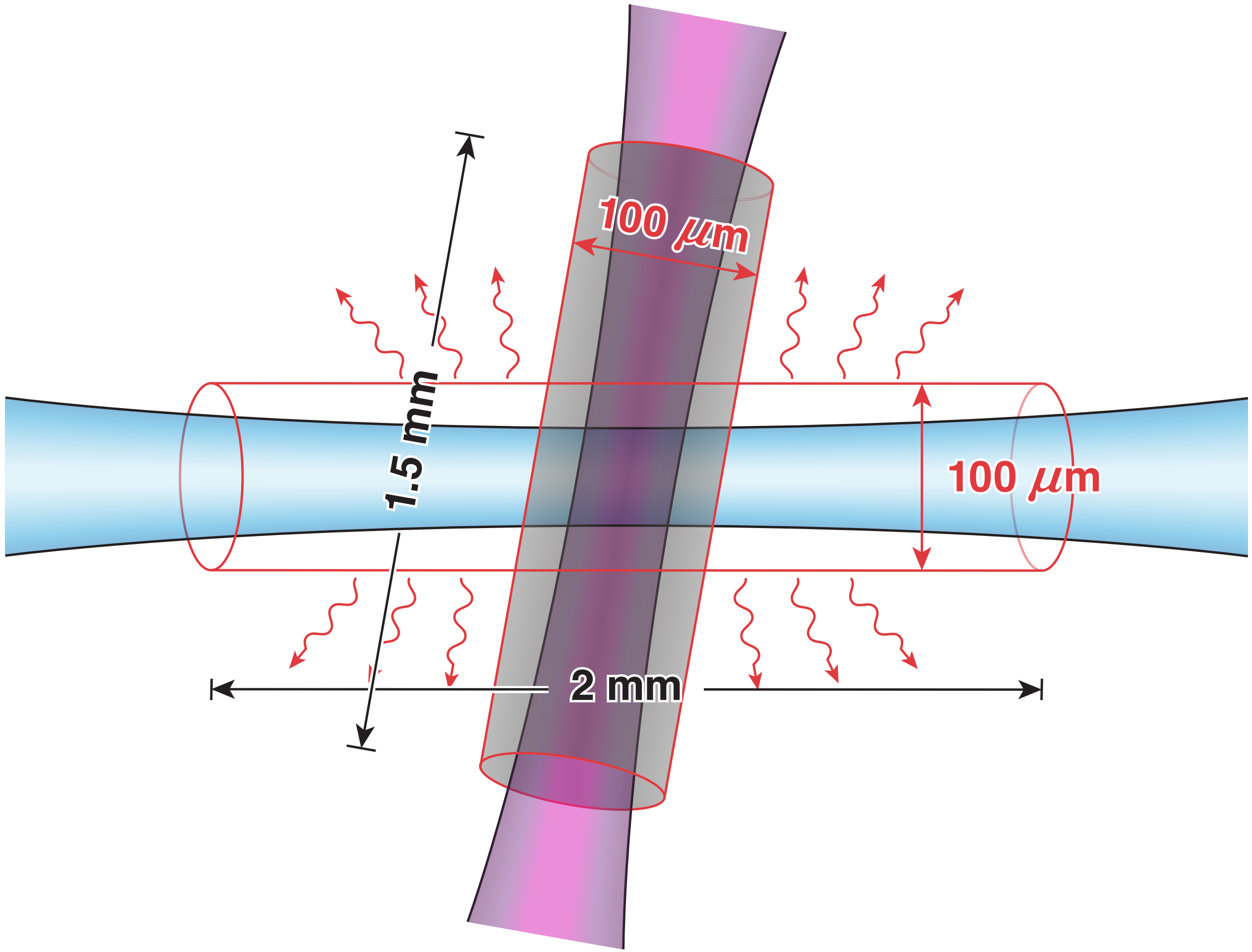

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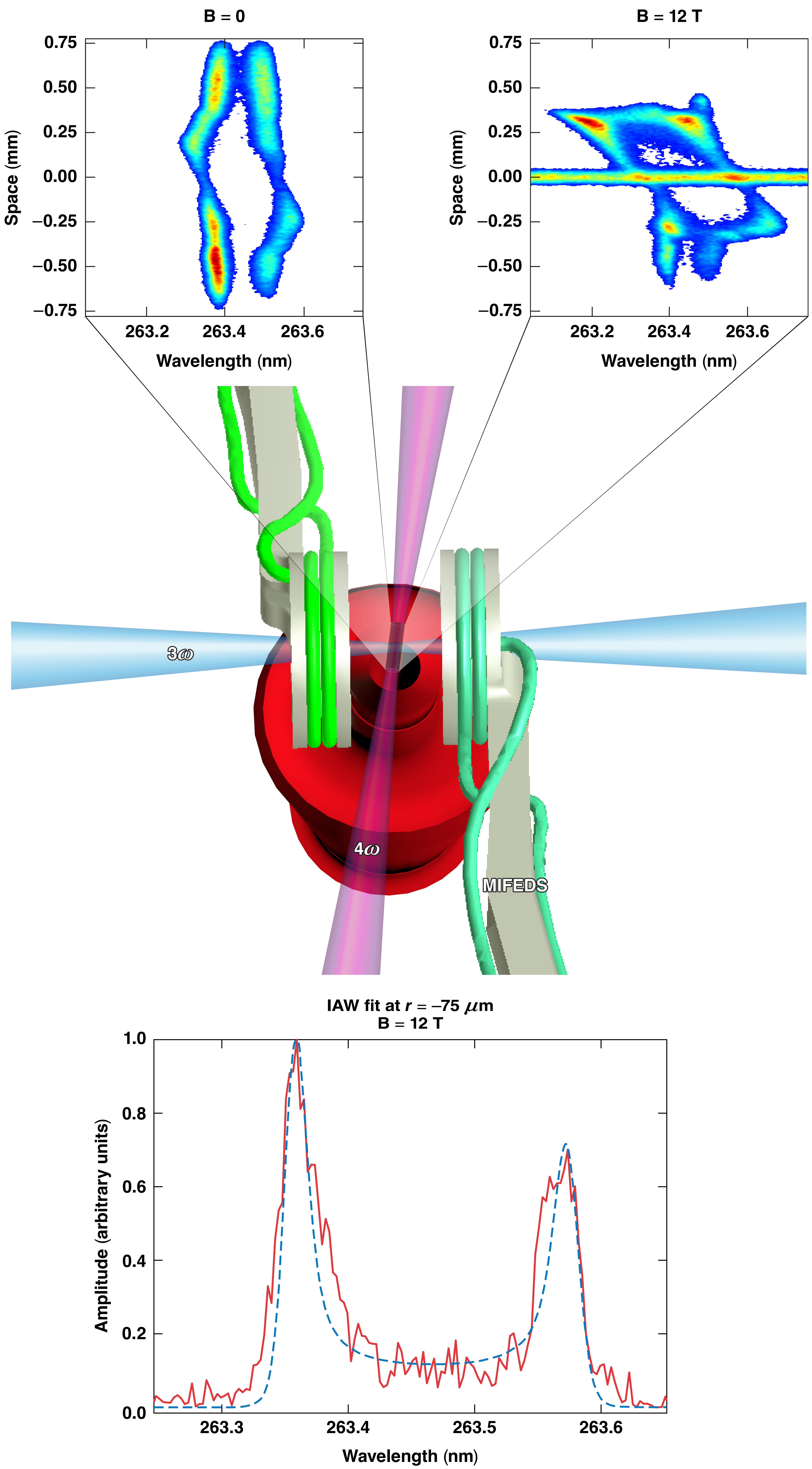
4ω Thomson-Scattering Images



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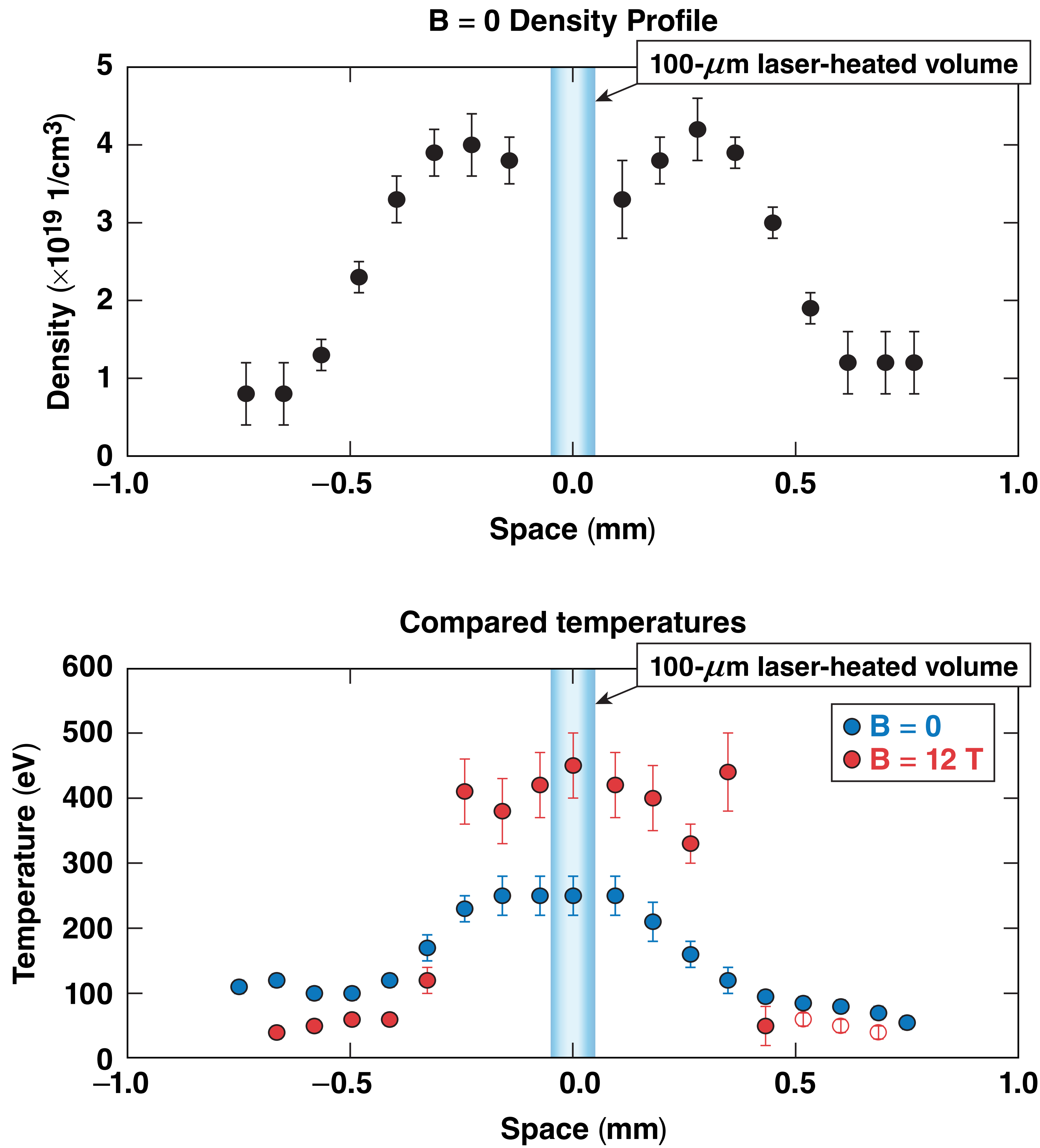

B = 0 Density Profile
100-μm laser-heated volume
Density (×10^19 1/cm^3)
5
4
3
2
1
0
–1.0
–0.5
0.0
0.5
1.0
Space (mm)
Compared temperatures
100-μm laser-heated volume
B = 0
B = 12 T
Temperature (eV)
600
500
400
300
200
100
0
–1.0
–0.5
0.0
0.5
1.0
Space (mm)

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