LIQUID JET LASER LENSING:

Intensity enhancement by focusing at cylindrical liquid interfaces

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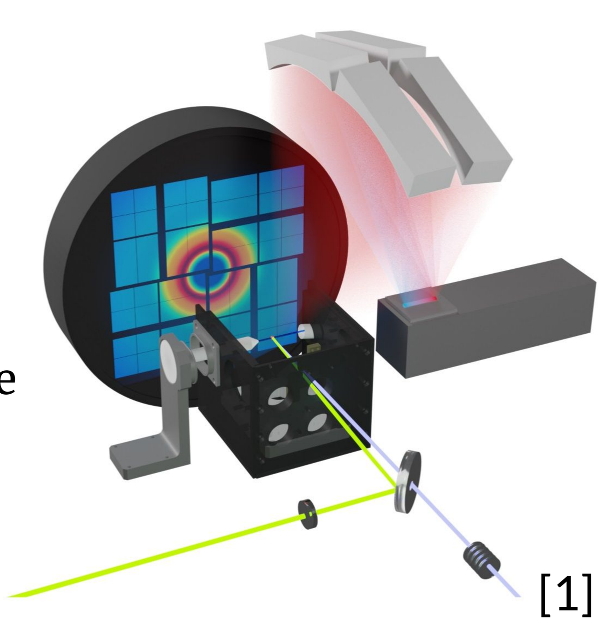
At LCLS, the liquid jet endstation (LJE) is used to study molecular dynamics in solution. The LJE can produce both cylindrical and flat jets; in experiments, cylindrical jets enhance beam intensity compared to flat jets. We created a linear optical model of cylindrical jet focusing, predicting intensity enhancement by a factor of ~2 compared to flat jets. Finally, we designed an experiment using the LJE to verify our simulated results.

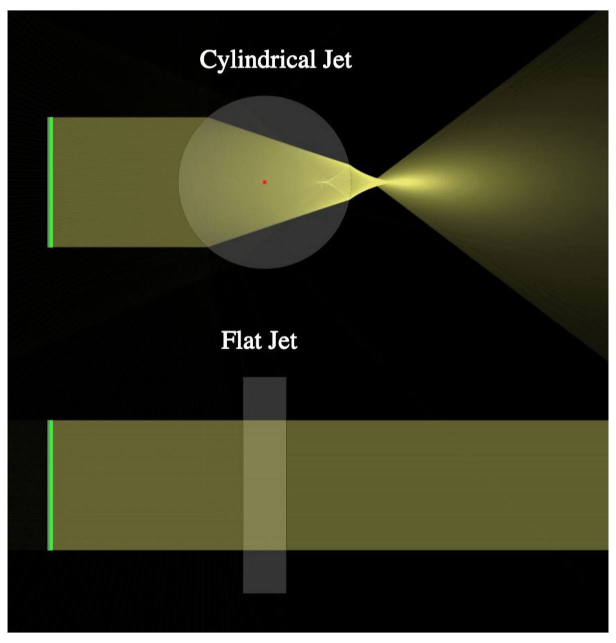
OVERVIEW: Liquid sample jets at XCS

The **liquid jet endstation (LJE)** at LCLS is used to study photochemistry and biochemistry in solution systems. The **pump-probe setup** uses an optical laser as the "pump" to excite the sample,



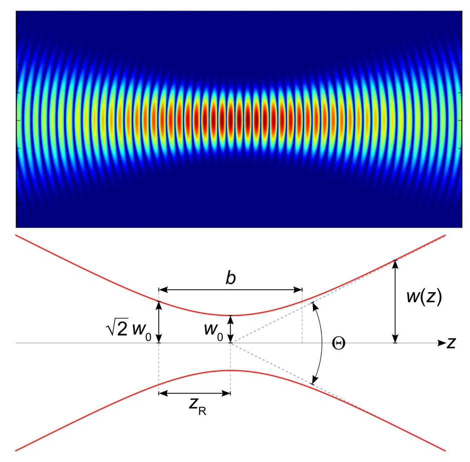
which is then probed by a hard x-ray pulse to resolve molecular dynamics at femtosecond scales. The LJE can produce both cylindrical jets (d = 20-500 µm) and sheet jets (10-80 µm) using fused silica nozzles. The x-ray (light blue) and optical (yellow) beams overlap within the sample jet; their relative phases are controlled by adjusting the position of the focusing lens (f = 750 mm).

PROBLEM



There is experimental evidence that a cylindrical jet results in enhancement of laser-induced signal compared to a flat jet under otherwise identical conditions. The cylindrical jet acts as a thick lens in the transverse dimension, focusing the laser to a smaller spot size and higher intensity compared to a flat jet.

SIMULATION MODEL



We model the pump laser as a Gaussian beam since most of its energy is concentrated in lower modes. The beam waist $w(z)$ and radius $R(z)$ are combined into the complex **q-value**:

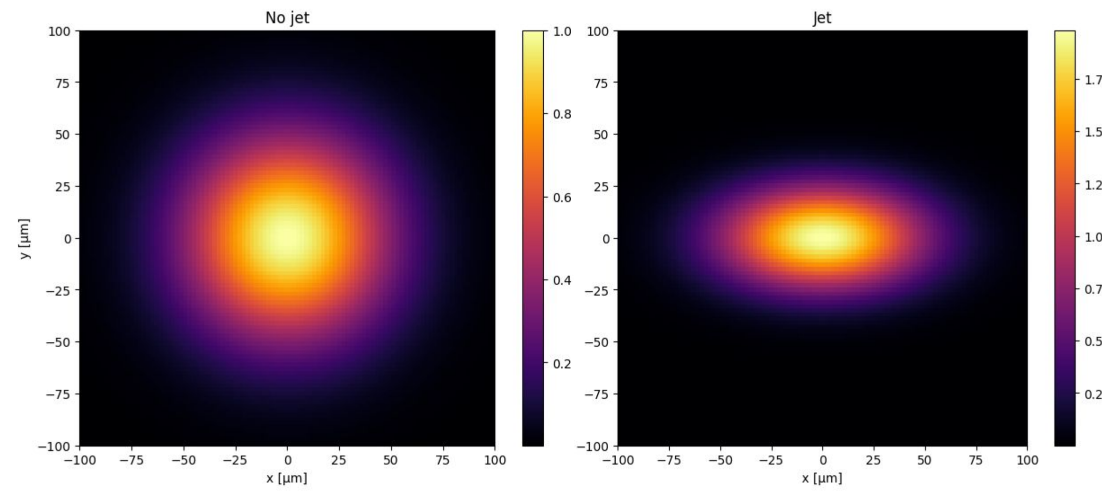
$$\frac{1}{q(z)} = \frac{1}{R(z)} - \frac{i\lambda}{\pi n(z) w^2(z)}$$

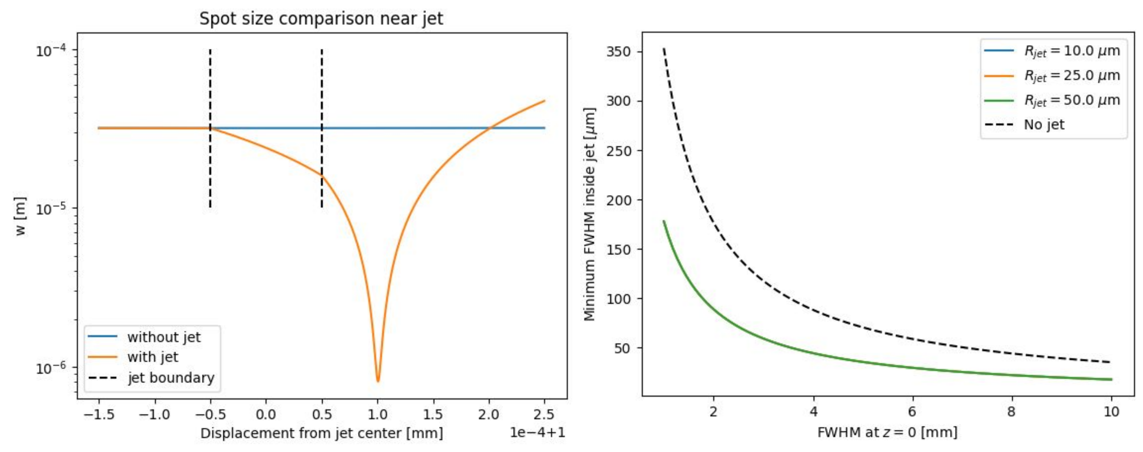
In paraxial ray optics, optical components and free space propagation are represented by ray transfer matrices $\mathbf{M} = \begin{pmatrix} A & B \\ C & D \end{pmatrix}$. As the Gaussian beam propagates through the optical system, its q-value evolves according to

$$q_2 = \frac{Aq_1 + B}{Cq_1 + D}$$

SIMULATION RESULTS

- Laser wavelength: λ = 800 nm (near-infrared)
- Input beam width: 1-10 mm
- Jet diameters: 20, 50, and 100 microns

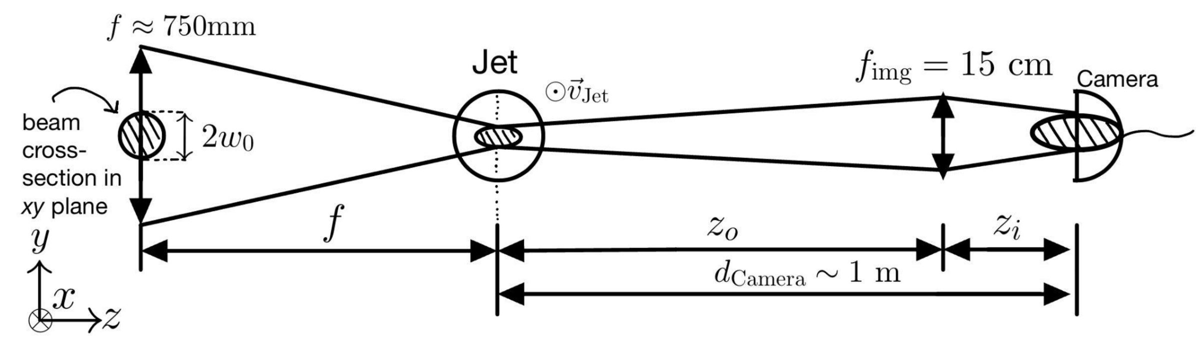




Key conclusions

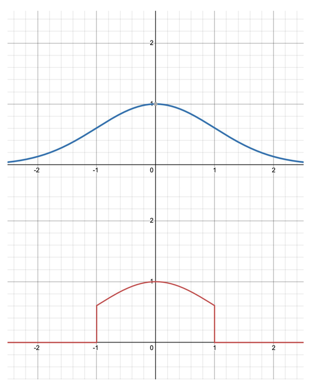
- Surfaces of **cylindrical jets lead to focusing**
- **Intensity enhancement** is on the order of **2x**
- Focusing is **independent of jet diameter**

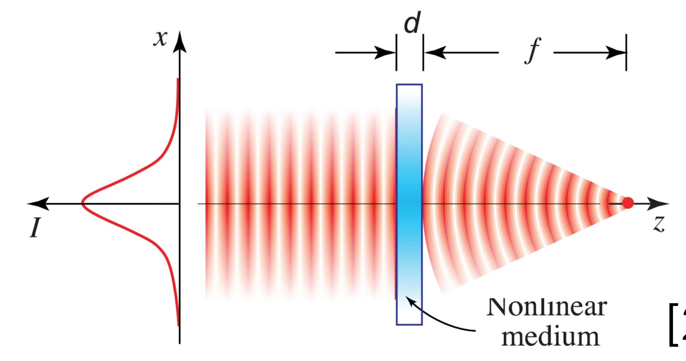
PROPOSED TESTS



We will use an imaging lens (f = 15 cm) to image the center of the jet onto a camera, with a magnification of $M \approx 5$. This will enable us to measure the elliptical spot both with and without a liquid jet and compare the measured area of ellipse to the simulated area.

DISCREPANCIES AND FUTURE WORK





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Windowed Gaussian beam

In the LJE, the beam passes through a circular aperture, removing the 'tail' of the Gaussian intensity profile. We may consider more sophisticated beam models (e.g., Laguerre-Gauss modes) to improve simulation accuracy.

Self-focusing

At high optical intensity, transparent media can exhibit a nonlinear index of refraction:

$$n(I) = n_0 + n_2 I$$

We may model some self-focusing effects by discretizing the volume within the jet into thin lenses.

IMPACT

At LCLS, liquid sample delivery systems have been used in the XCS, CXI, RIXS, XPP, and MFX hutches. Understanding how jet shape affects optical intensity will improve experimental design and enable more accurate reporting of intensity data in experiments.

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