# Planar Laser-Induced Fluorescence

## For the Detonation Facility at X Energy Laboratory

Presentation by: Camille Chihak, Michael Ross, Vince Tran

Sponsor: Xian Shi, Ph.D.

UCI Samueli School of Engineering

University of California, Irvine

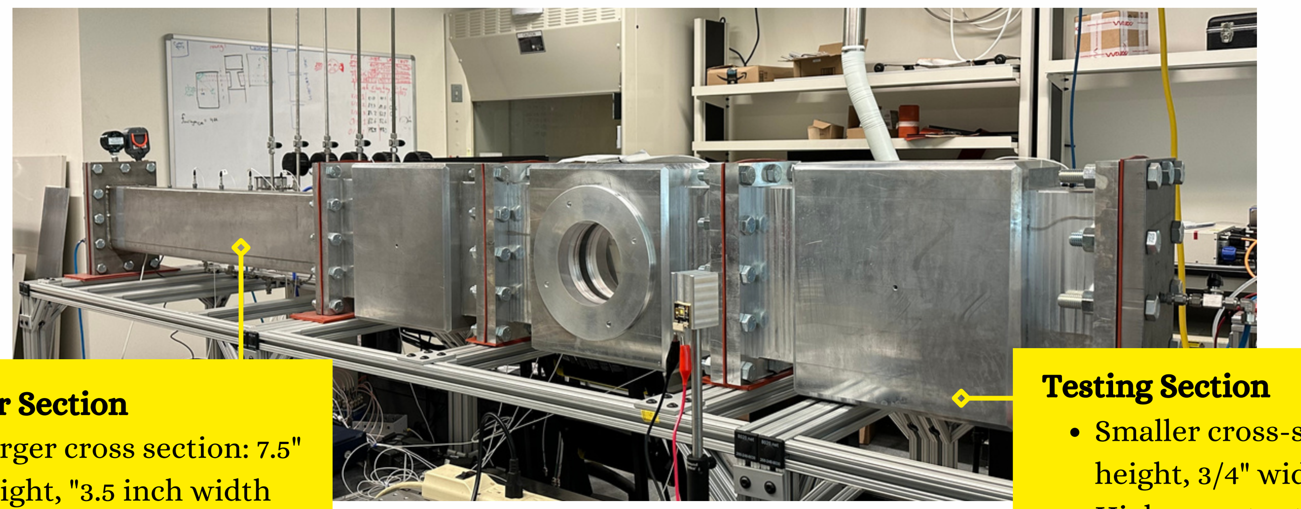
## What are Detonations?

- Detonations, as opposed to deflagrations, are combustions in which the reaction front is coupled with a shock wave, moving faster than the speed of sound
- Driving force behind explosions
- The current understanding of detonation theory was developed by David L. Chapman in 1899, and added to by Jacques Charles Émile Jouguet in 1905 [1]

## Why Research Detonations?

- Modern-day deflagration engines (rockets, jets, etc.) have a constant pressure across the combustion, whereas detonations have a theoretical gain in pressure across combustion, producing more work
- The drive to make air and space travel cleaner and more affordable has led to the proposal of many propulsion systems that use detonation
- Initiating and sustaining a continuously propagating detonation wave is difficult due to insufficient knowledge about detonations [2], which limits the ability of these proposed engines to be developed to meet the current aerospace field

## 1) Detonation Chamber



**Driver Section**

- Larger cross section: 7.5" height, "3.5 inch width
- Contains deflagration to detonation transition device to aid in initiating detonation

**Testing Section**

- Smaller cross-sectional area: 6" height, 3/4" width
- High aspect ratio allows detonations to be simplified as two-dimensional
- Contain an optical section for Schlieren and PLIF imaging

Figure 1: Detonation Chamber

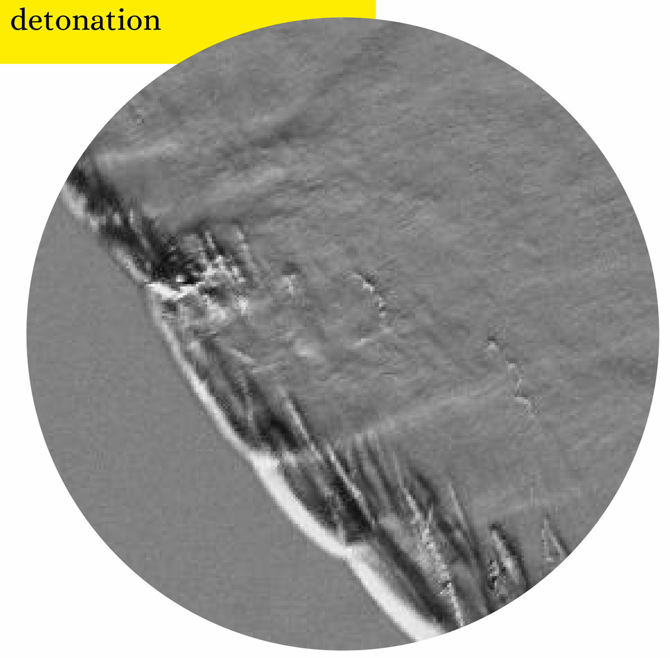


Figure 2: Schlieren Imaging from X Energy Lab

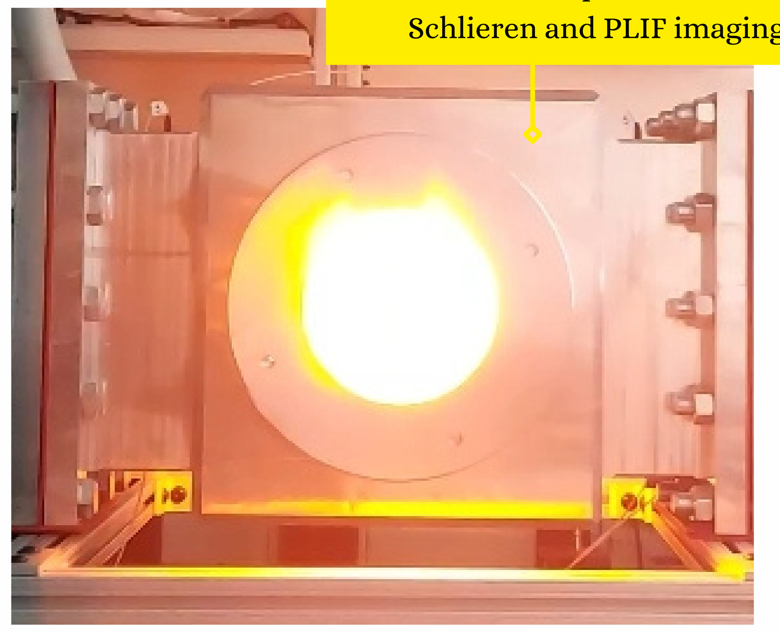
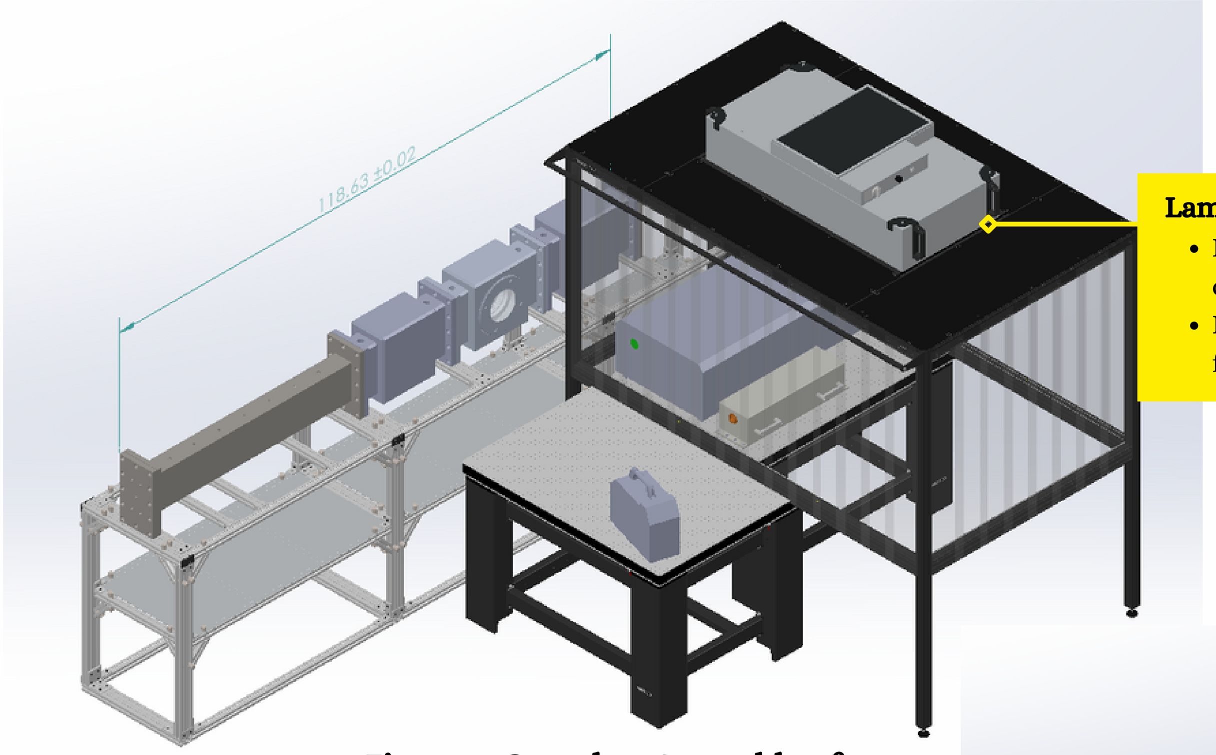


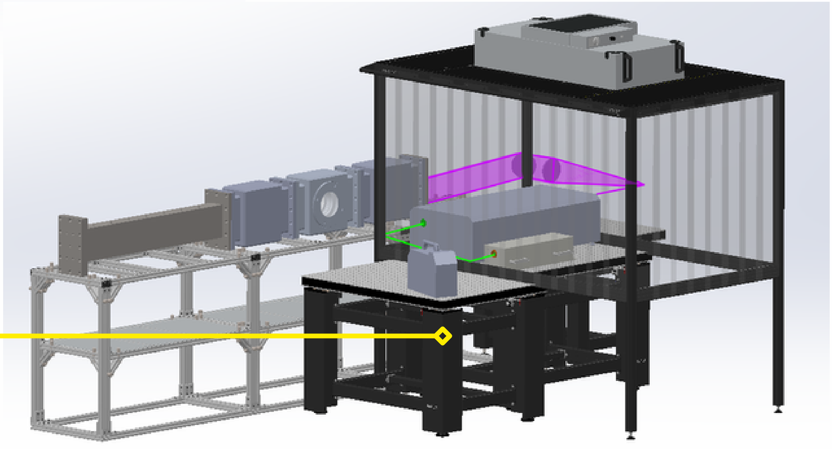
Figure 3: Hydrogen and Oxygen Mixture Detonation Through the Optical Window




**Laminar Flow Enclosure**

- Protects laser components from contamination and damage
- Provides full enclosure and filtration

Figure 4: Complete Assembly of Proposed OH PLIF System



**Green Path:** Beam from pump laser to OPO

**Purple Path:** Laser from OPO to chamber (includes conversion from beam to laser line)

Figure 5: Planned Laser Path with Sheet-Formation

## 2) OH PLIF Overview

- A long standing technique since the 1980s, Planar Laser-Induced Fluorescence (PLIF) has advanced significantly as an analysis tool for fluid dynamics
- PLIF will be employed at X Energy Lab to target minor combustion species, specifically OH, which may be used to analyze combustion completeness
- The process involves a plane of laser light passing through a flow field to excite the target species, which fluoresce when relaxing back to a lower energy state
- From captured images of the fluorescence, we will analyze the gradient of OH concentration to better understand transient combustion development
- The design of this system focuses on utilizing high frequency PLIF imaging to study high-speed detonation waves for combustion completeness of various fuel mixtures

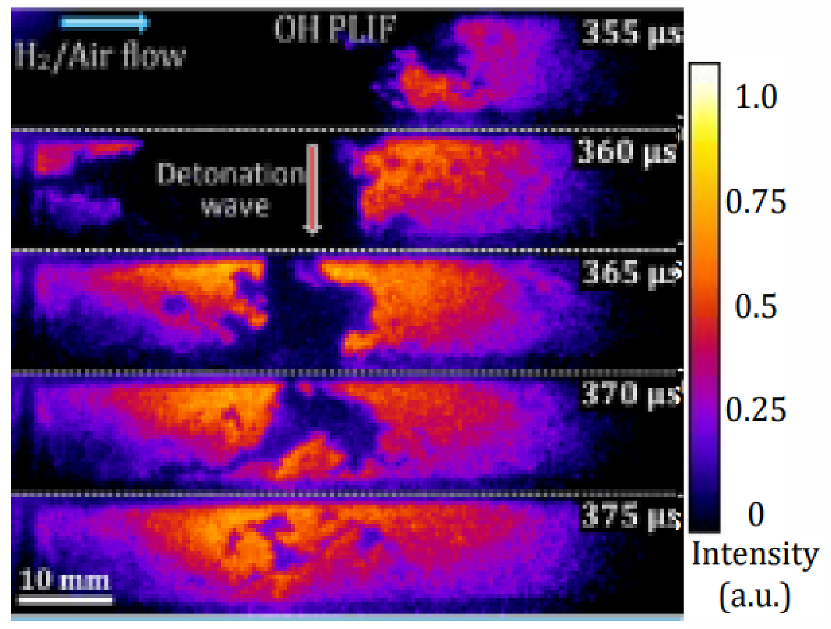



Figure 6: Post processed PLIF image [3]

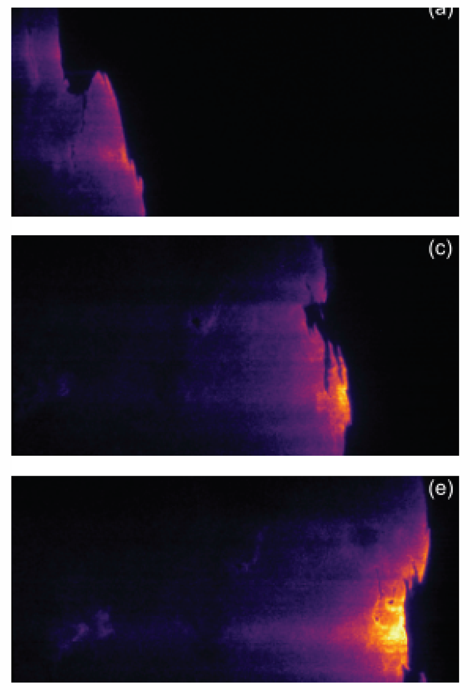


Figure 7: Directly captured PLIF image [4]

## 3) Laser Selection

- We want to take ~10 developing photos of OH concentration throughout detonation wave propagation
  - Minimum repetition rate of 100 kHz for lasers
- The chosen Nd:YAG burst-mode laser, Spectral Energies QuasiModo, provides a minimum repetition rate of 100 kHz and produces a wavelength of 532nm
- The Spectral Energies Optical Parametric Oscillator (OPO) allows tuning to a wavelength of 283.2nm to excite the desired Q1(7) excitation line

## 4) Optical System

- Camera operates at up to 2.1 million frames per second (fps) with a minimum requirement of 100,000 fps
- Optical component selection focuses on sheet formation utilizing a diverging plano-concave lens and collimating plano-convex lens

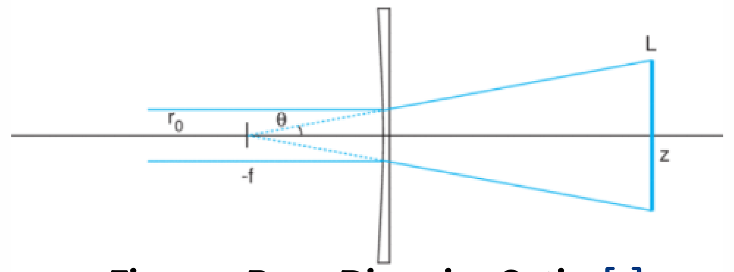


Figure 8: Beam Diverging Optics [5]

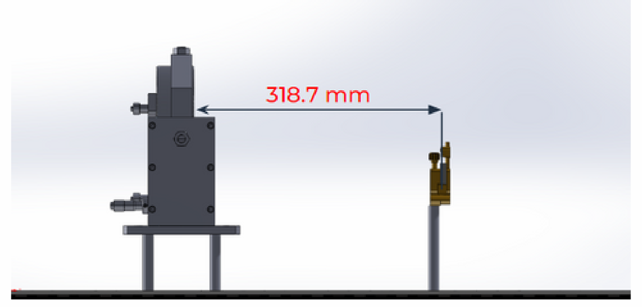



Figure 9: Proposed Sheet-Forming Optics

## 5) MATLAB Calculations

- Utilizes pressure and temperature inputs to calculate relative fluorescence intensity (normalized to 1.4 bar)
- Calculates energy concentration given laser power and optical parameters

### Output Display

```
Energy per unit area of the 0.070686 cm^2 beam is 28.2942 mJ/cm^2
Energy per unit area at the 4.572 cm^2 window is 0.43745 mJ/cm^2
Total relative intensity at 2 Bar and 1500 Kelvin is 0.72288
```

*Published with MATLAB® R2023a*

## 6) Future Goals

- Integrate the PLIF system alongside an existing Schlieren imaging setup
- Capture and analyze the relation between intensity and OH-concentration from PLIF along with simultaneous Schlieren images

## References

[1] Róbert, N. (2012).
[2] Lu, F. K., & Braun, E. M. (2014).
[3] Webb, A., Crabtree, C., Athmanathan, V., Meyer, T., Kearney, S., Slipchenko, M. (2024). DOI: 10.1364/OL.510334
[4] Frederick, M., Strelau, R., Geiji, R., Slabaugh, C. (2024). DOI: 10.2514/6.2024-1031
[5] “Beam Shaping with Cylindrical Lenses.” Newport Corporation. Retrieved February 27, 2024, from https://www.newport.com/n/beam-shaping-with-cylindrical-lenses