SAND2022-16768C

Near-MHz Temperature and H_2O Measurements in Large-Scale Post-Detonation Fireballs

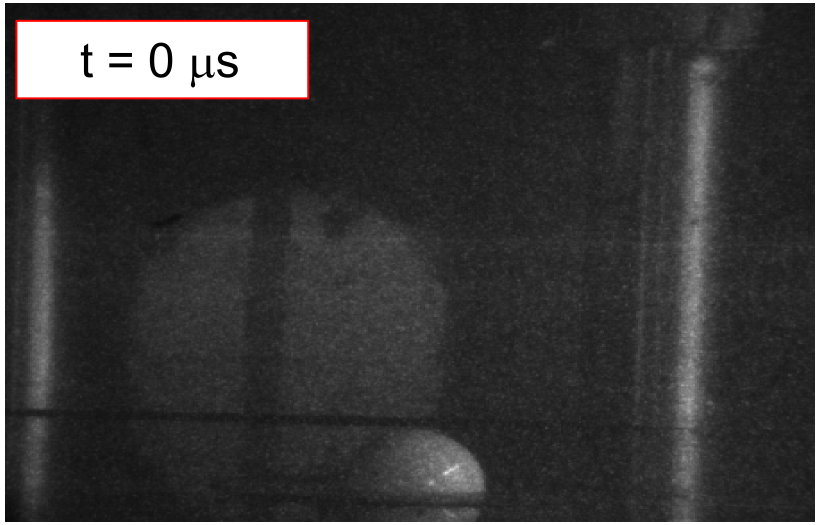
Charlie Schwartz[1], Josh Stiborek[2], Garrett Mathews[2,4], Austin Butler[3], Damon Chen[3], Prof. Nick Glumac[3], Dan Guildenbecher[5], Marc Welliver[5], and Prof. Christopher Goldenstein[2]

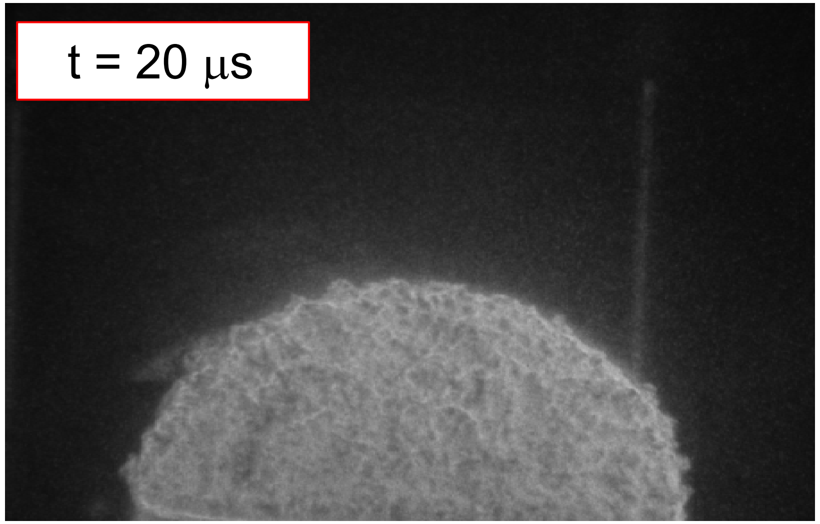
[1]School of Astronautics and Aeronautics, Purdue University, West Lafayette, IN 47906
[2]School of Mechanical Engineering, Purdue University, West Lafayette, IN 47906 || [3]Department of Mechanical Science and Engineering, UIUC, Champaign, IL 61801
[4]Paul M. Rady Mechanical Engineering, UC, Boulder, CO 80309 || [5]Sandia National Laboratories, Albuquerque, NM

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Overview

1. Goals and Motivation
2. Introduction to Laser Absorption Spectroscopy (LAS) Techniques
3. H_2O Line Selection
4. Sample Preparation
5. Experimental Setup
6. Results and Conclusion





Sandia LDRD Grand Challenge Project

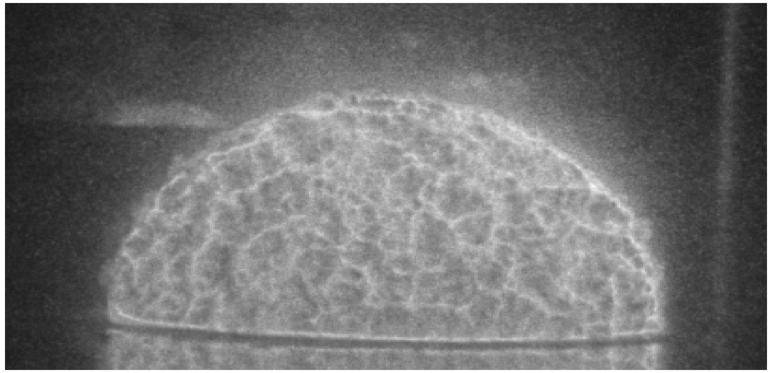
Motivation: Seeking improved understanding of optical radiation from post-detonation fireballs

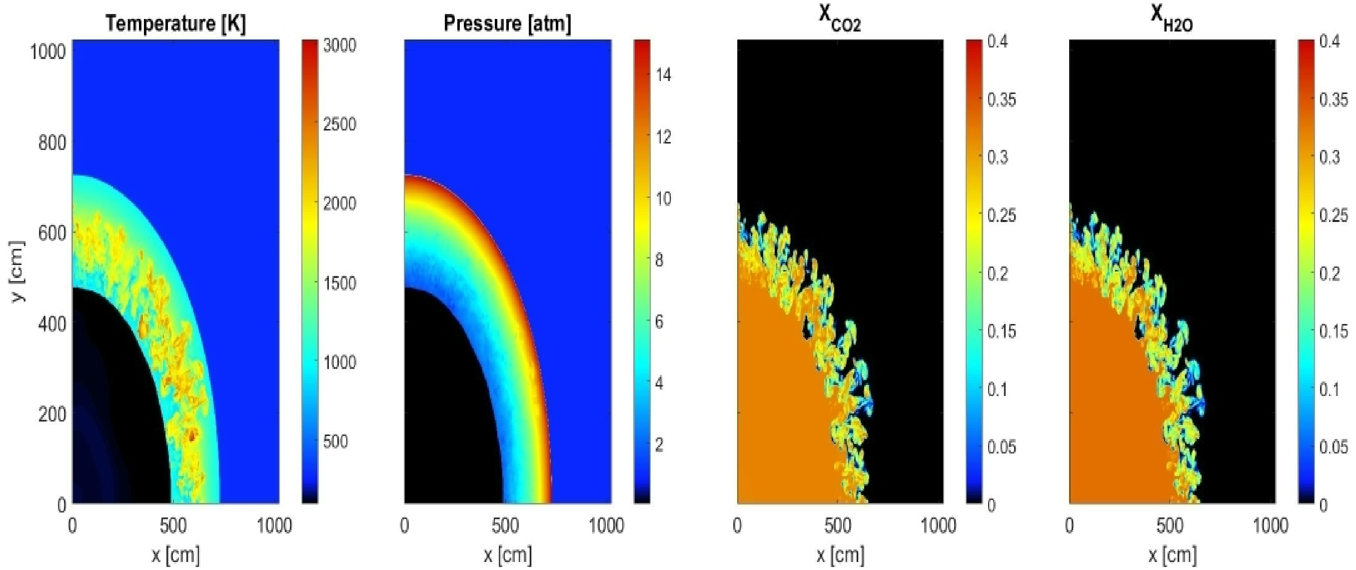
Project Goal: Advance tools to quantify and predict the internal dynamics of post-detonation fireballs, including the gas conditions (T, P, X) which are critical to optical emissions

Our Role: Acquire:
- T, P, CO, CO_2 at 1 MHz
- T & H_2O at ~ MHz rates

to evaluate fireball model accuracy

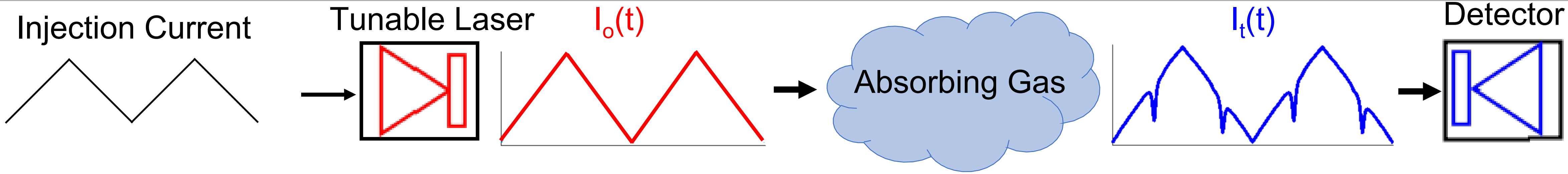
Fireball produced by 25 g hemispherical N5 charge. (courtesy UIUC)





Example CFD result for 1 g hemispherical change
Courtesy of Anthony Egeln and Prof. Ryan Houim: University of Florida

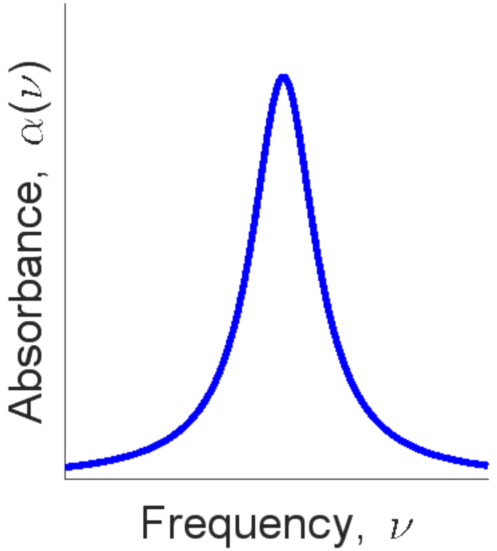
Fundamentals of LAS



Spectral Absorbance: α(v)

$$\alpha(\nu) = -\ln(I_t/I_0)$$

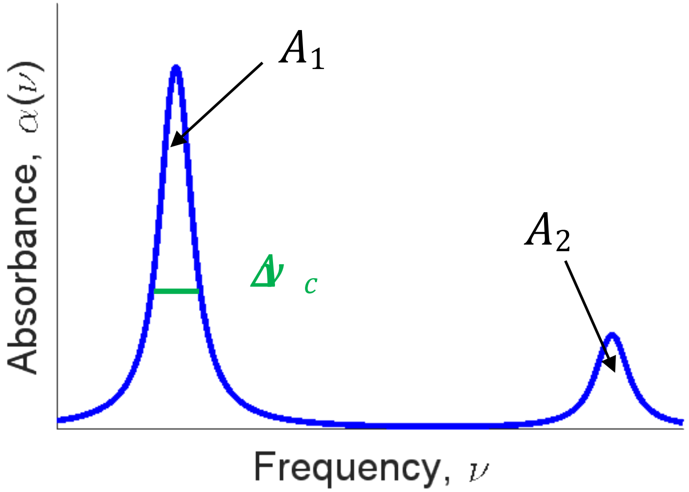
$$\alpha(\nu) = S(T)\phi_i(\nu)PX_iL$$



Measuring Gas Properties

Integrated Area: $A = S(T)PX_iL$

Lineshape: $\phi(\nu) = f(\Delta\nu_c, \Delta\nu_d, \nu)$



Collisional Width:

$$\Delta\nu_c = P\sum_A 2\gamma_{A-B}X_A$$

Pressure

Broadening coefficient

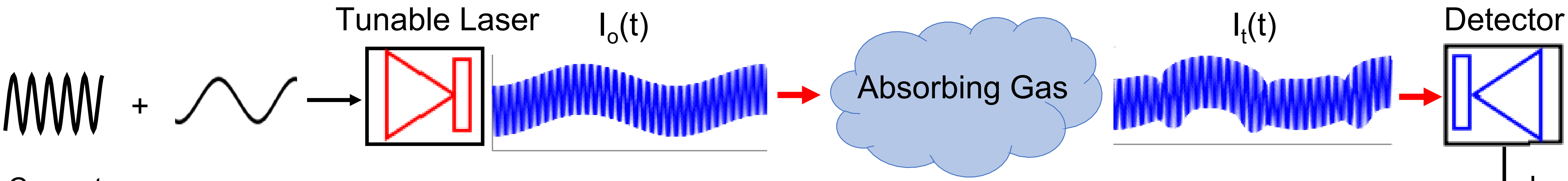
$$\frac{A_2}{A_1} = \frac{S_2(T)}{S_1(T)} = f(T)$$

Temperature →

$$\frac{A_1}{S_1(T)PL} = X_i$$

Mole Fraction (PX_i, X_iL)

Fundamentals of Scanned-WMS

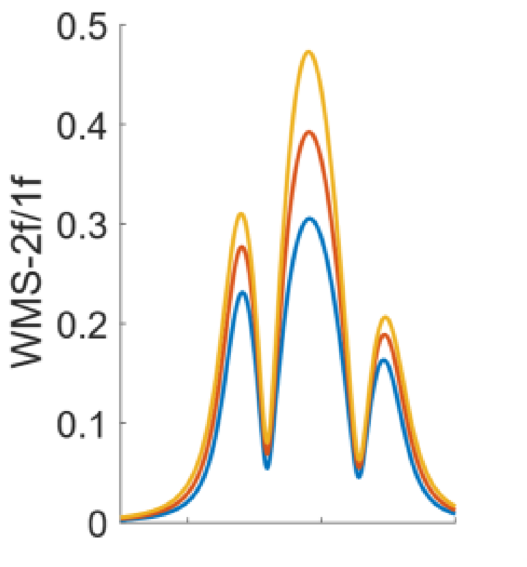


Current modulation @ f_m

Current scan @ $f_s << f_m$

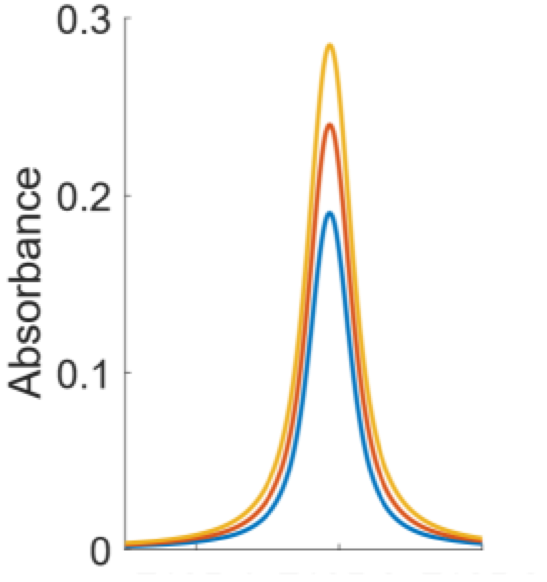
Lock-in @ $1f_m$ & $2f_m$

Measured WMS signals



WMS Models

Inferred Absorbance



Spectroscopic Models

$$\alpha(\nu) = \phi(\nu)S(T)PXL$$

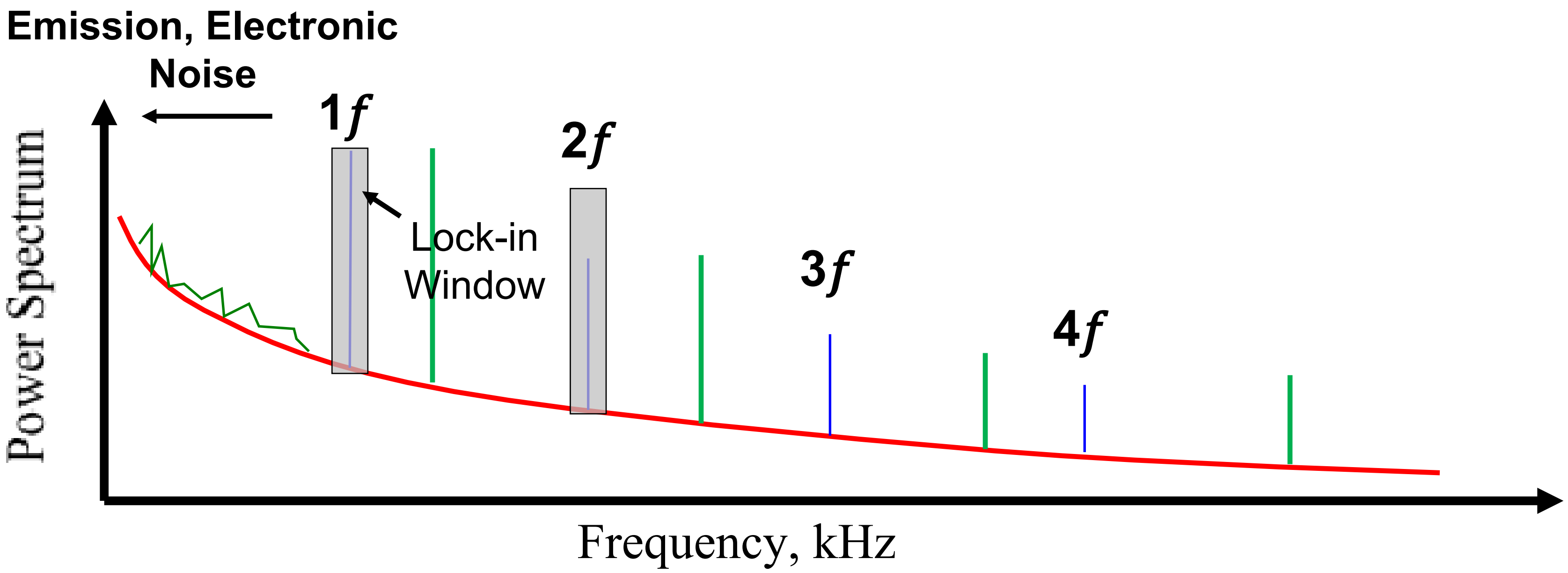
Gas Properties:

- Temperature
- Mole fraction

Benefits of Scanned-WMS

Benefits of scanned-wavelength-modulation spectroscopy:

1. Insensitive to non-absorbing transmission losses (i.e., particles in the flame)
2. Noise rejection outside of lock-in filter
3. Frequency multiplexing multiple lasers

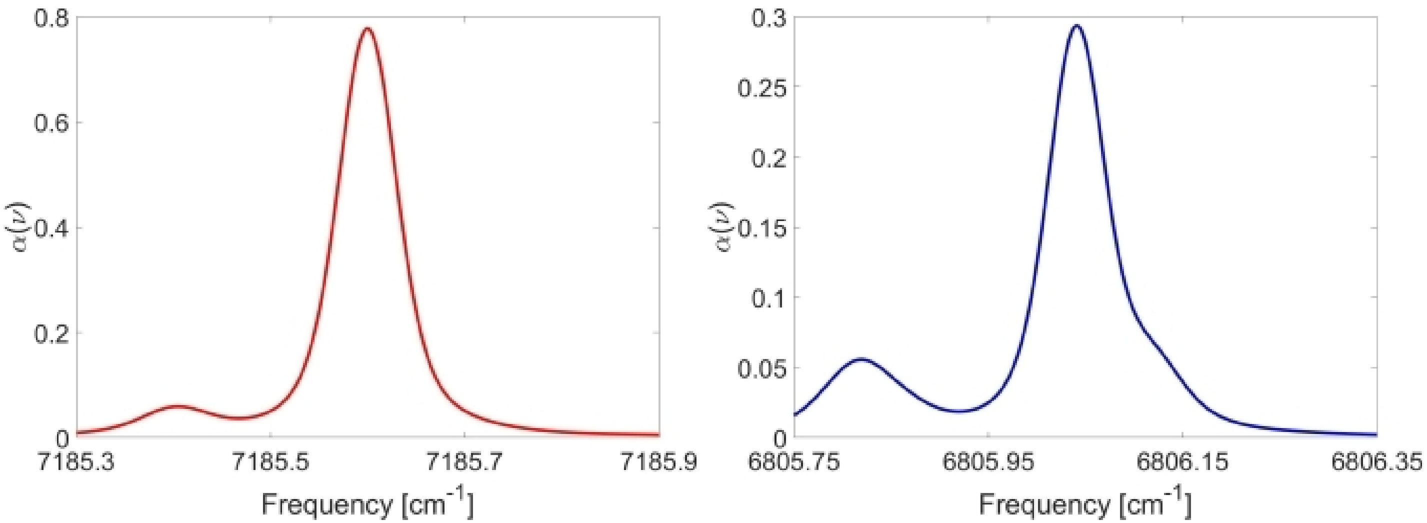


Line Selection

Parameters	Transition	
ν_0, cm^{-1}	7185.59	6806.03
$S(296K)$, cm^{-2}/atm	7.96×10^{-2}	6.40×10^{-7}
E'', cm^{-1}	1045.1	3291.2

Simulated Absorbance at 2000 K, 1 atm, 10% H_2O, and a pathlength of 10 cm

1392 nm | 1469 nm



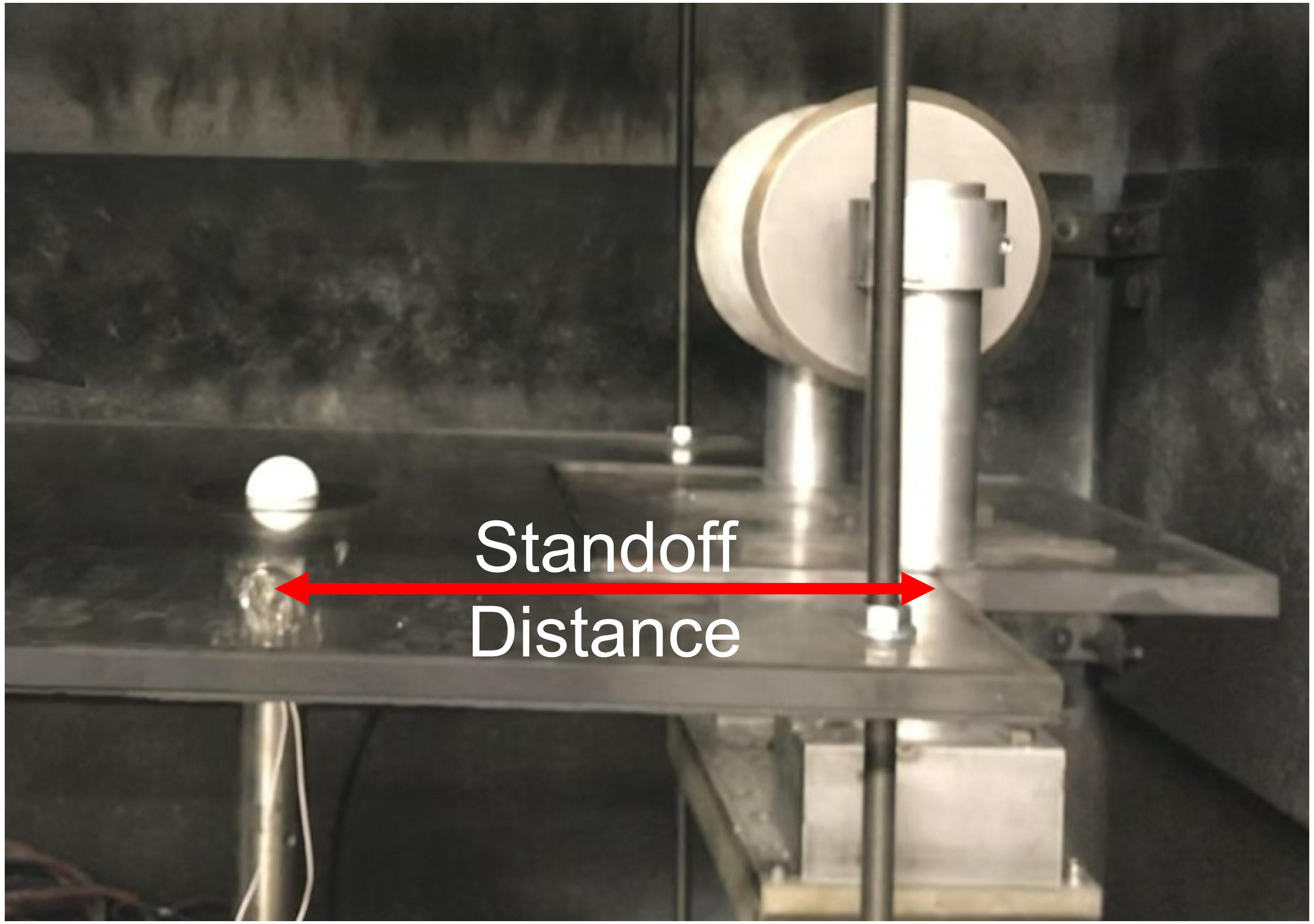
Line Selection Criteria

1. Good two-color temperature sensitivity at 1000-2500 K
2. Isolation from other absorption transitions
3. Detectable absorption levels in air and fireball gases

Sample Preparation

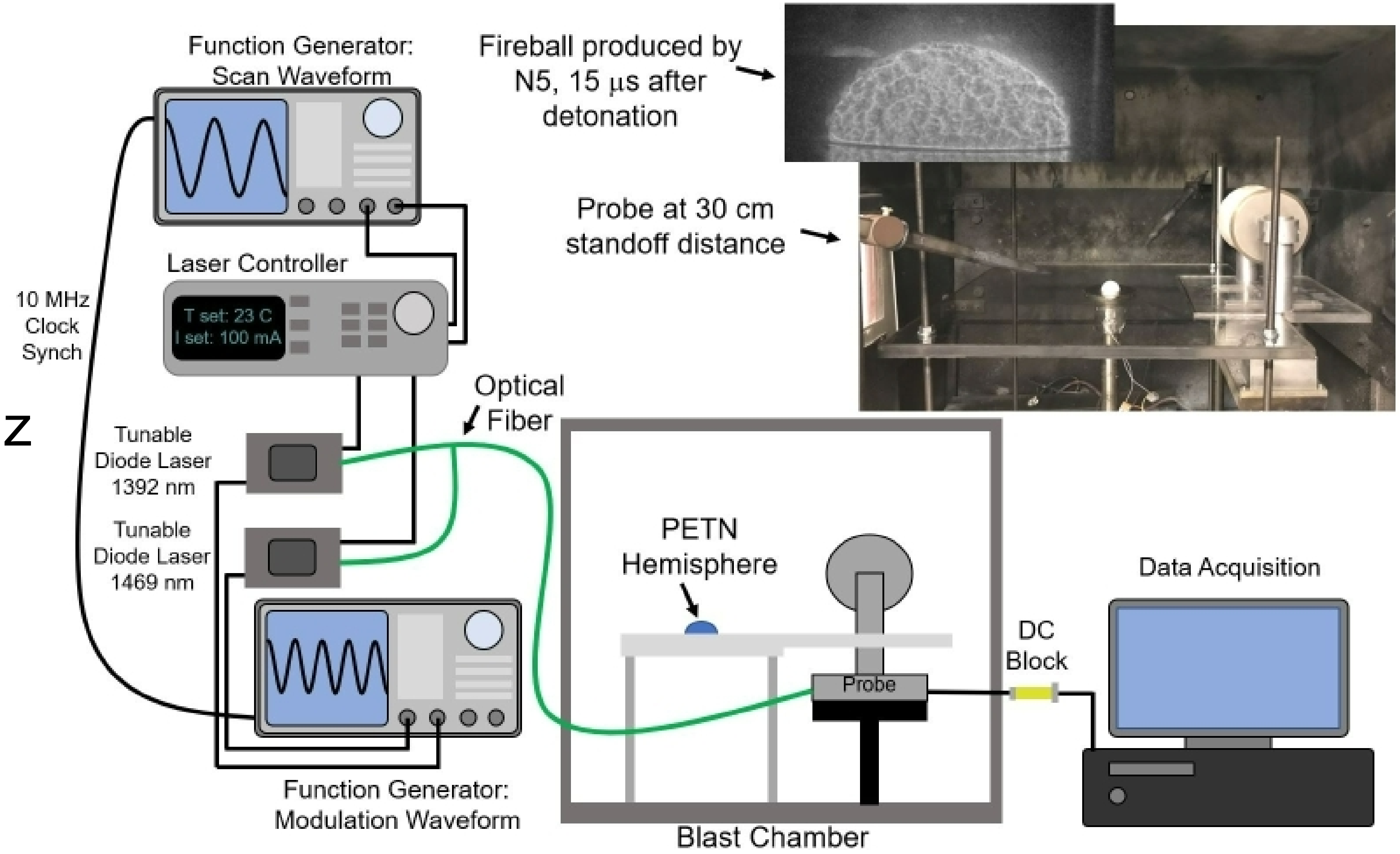
- 25 g of explosive powder was pressed into a hemispherical die with a diameter of 1.5”

- Sample Density:
  - 1.689 g/cc for PETN
  - 1.807 g/cc for N5

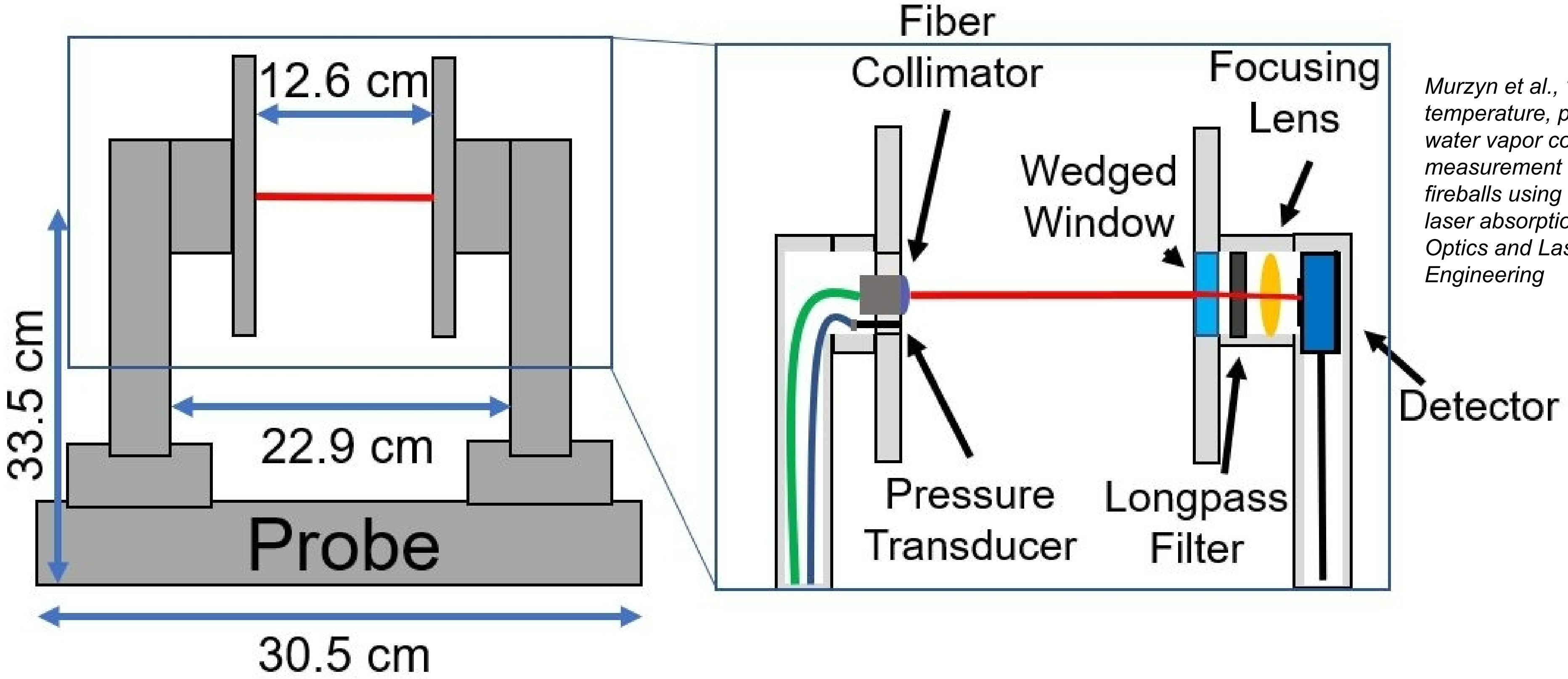


Experimental Setup

- Peak-picking scanned-WMS performed to measure temperature and H_2O at 500 kHz
- Used fiber coupled TDLs emitting near 1392 and 1469 nm
- TDLs were scanned at 500 kHz and modulated at 35.5 or 45 MHz
- Detector sampled at 3 GS/s
- Laser light directed into an optical probe inside blast chamber



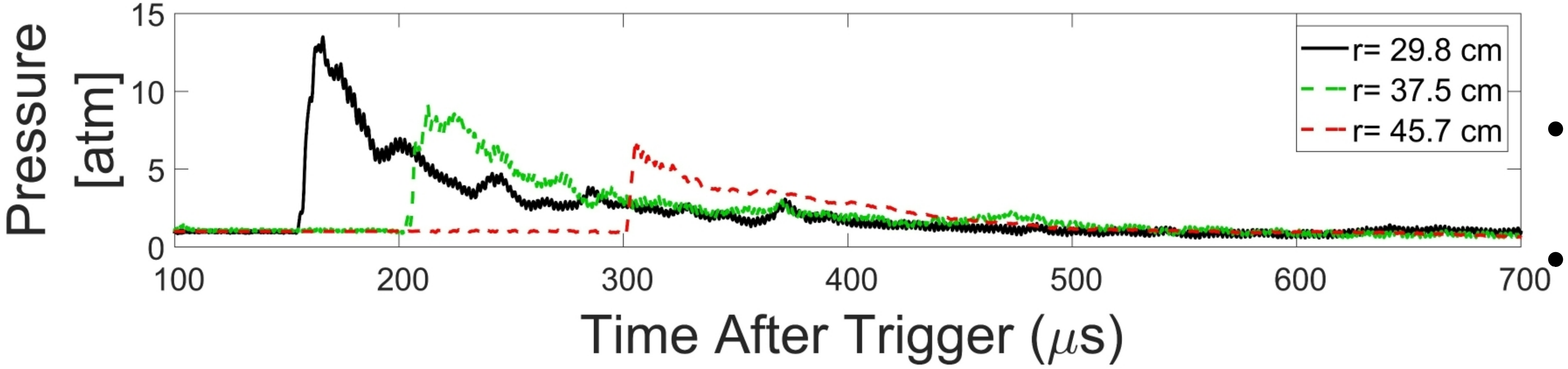
Optical Probe



Murzyn et al., "High speed temperature, pressure, and water vapor concentration measurement in explosive fireballs using tunable diode laser absorption spectroscopy", Optics and Lasers in Engineering

- Pitch side contained a pressure transducer and an optical fiber connected to a collimator
  - Used to pitch laser light across a test gas
- Catch side contained a 1350 nm cutoff longpass filter to reduce emission and a f = 25 mm focusing lens to focus beam onto a 150 MHz bandwidth detector

PETN Results



100 200 300 400 500 600 700

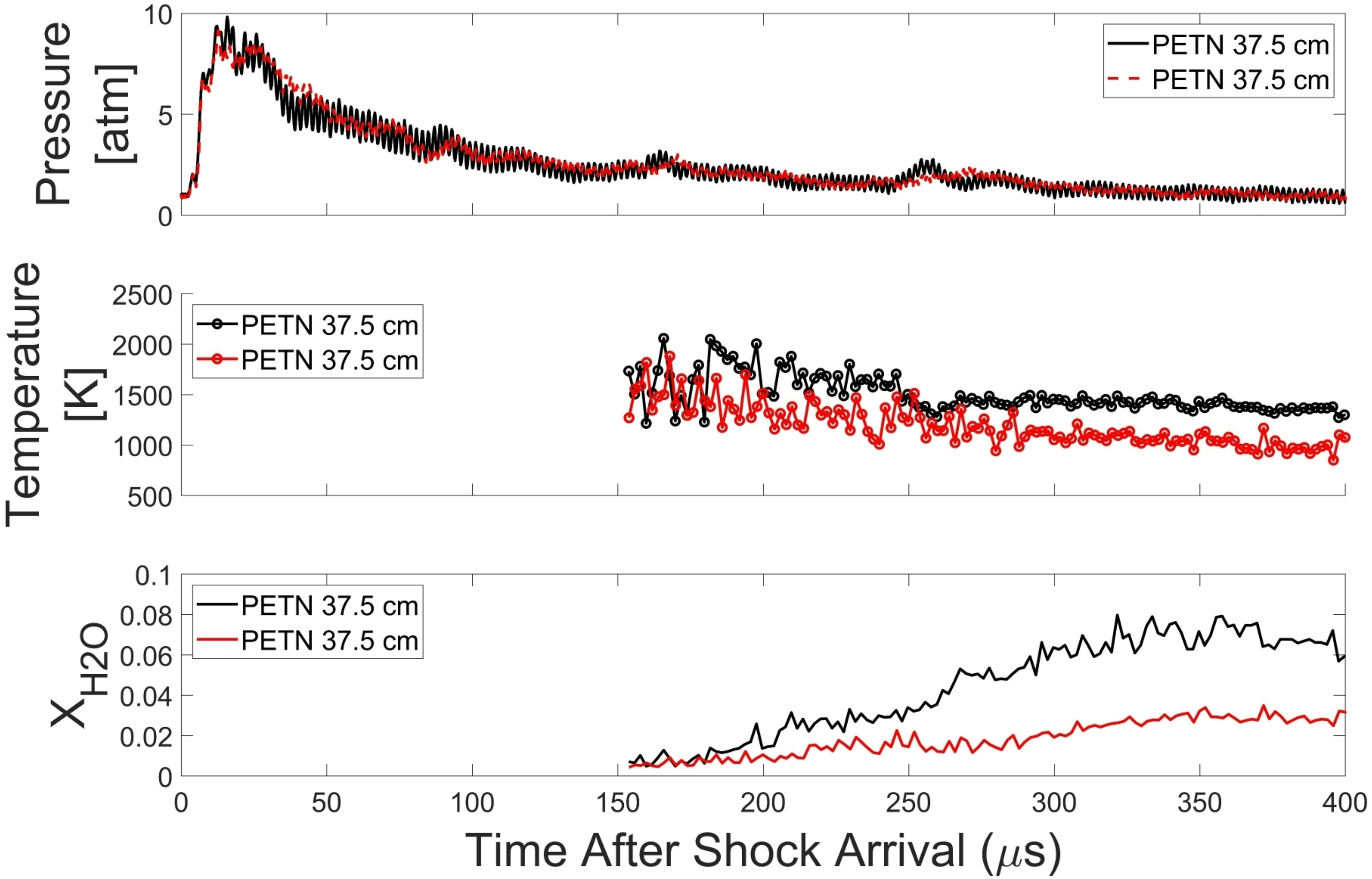
Time After Trigger (μs)

100 200 300 400 500 600 700

Time After Trigger (μs)

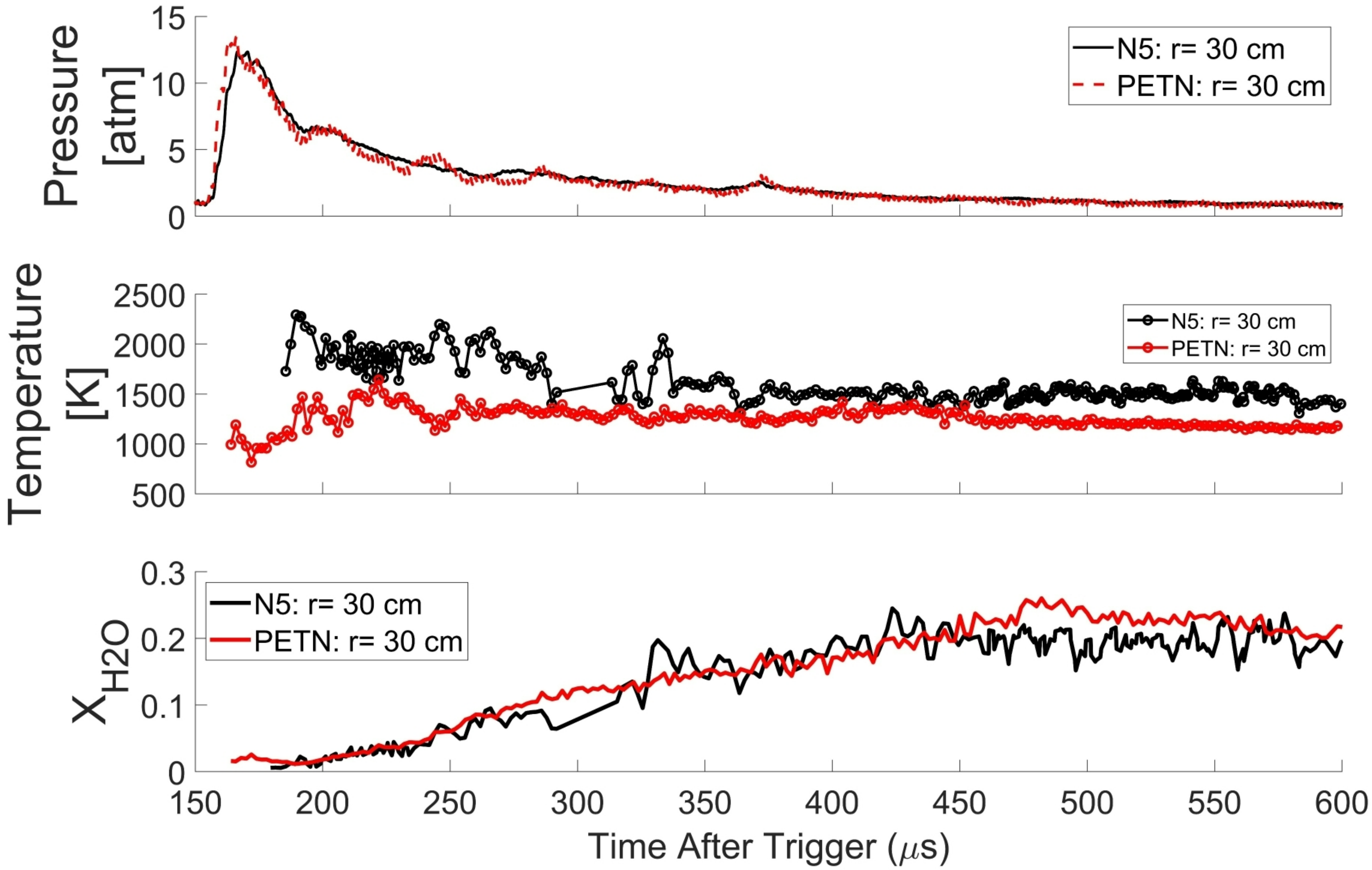
- Peak pressure decreases
- Temperature starts below 1300 K
  - 1st measurements in shock-heated air
- H_2O mole fraction increase
  - Due to fireball arrival
- X_{H2O} increase between 37.5 and 45 cm is small compared to 30 cm

PETN Shot-to-Shot Variability at r=37.5 cm



- Pressure trace is nearly identical for both cases
- Similar temperature initially, but results diverge at longer times
- Higher temperature corresponds to larger H_2O mole fraction increase

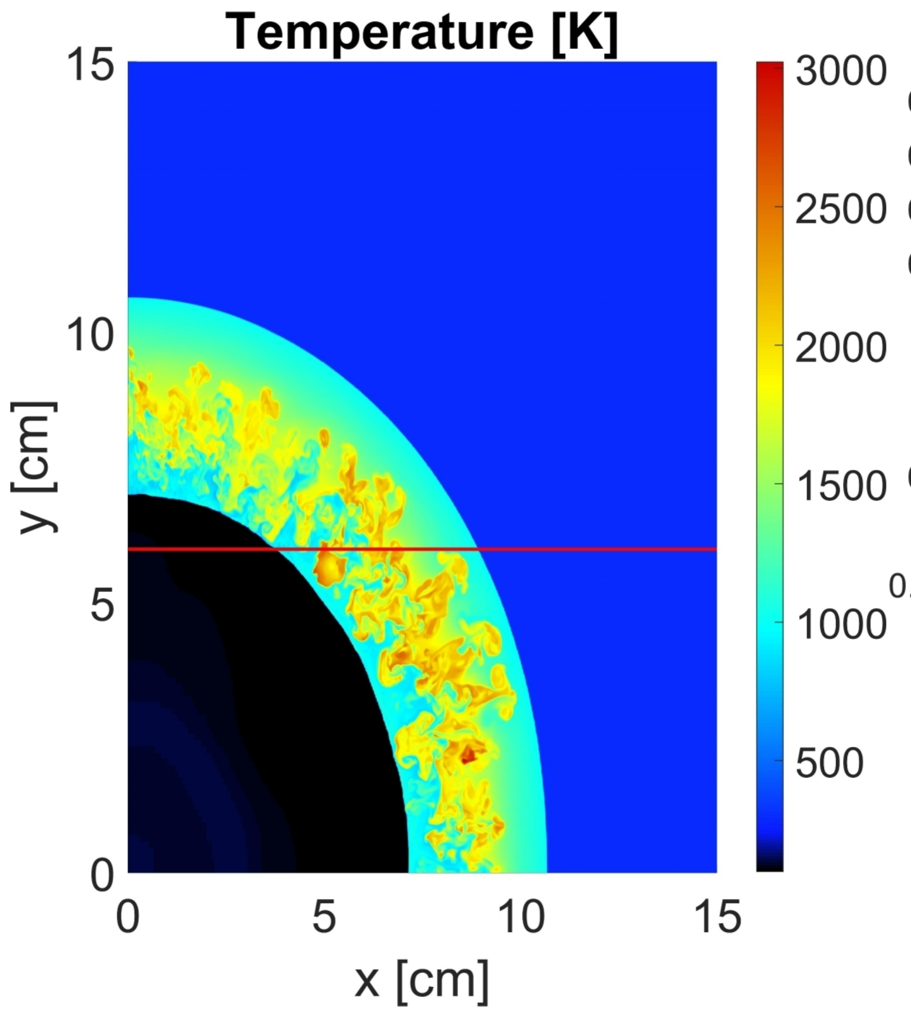
Comparing PETN & N5: 30 cm



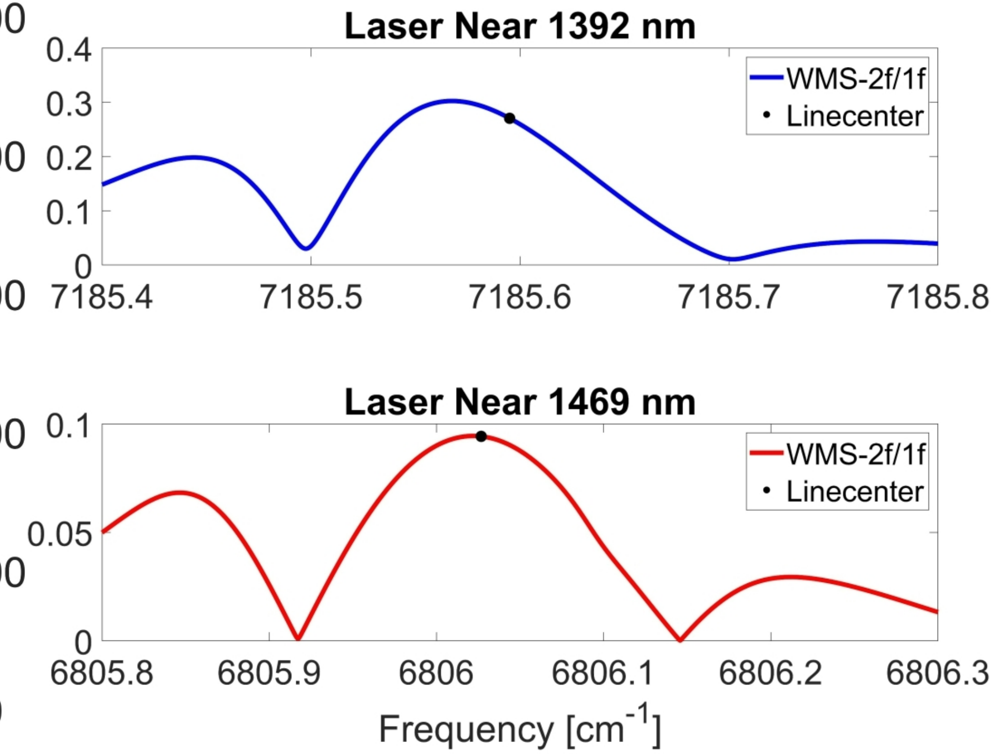
- Pressure trace is similar for both explosives
- Temperature of N5 fireball is hotter at this distance
- H_2O mole fraction for the two explosives is similar throughout the test

Future Work: Evaluation of CFD Models

1. Simulation data:
   - T, P, X_{CO}, X_{CO2}, X_{H2O}, X_{OH}, X_{NO}
2. Simulate WMS-2*f*/1*f* signal for both lasers
3. Determine the peak of the simulated WMS-2*f*/1*f* signals
4. Use peak values to determine a simulated temperature, and X_{H2O}



Simulated LOS WMS-2*f*/1*f* Signals



Results:
T = 1857 K
X_{H2O} = 0.13

Conclusion

- A two-color TDLAS sensor providing measurements of temperature and H_2O at 500 kHz in shock-heated air and fireballs of 25 g charges was successfully developed and deployed at UIUC
- Diagnostic used scanned-WMS-2f/1f to facilitate two-color measurements at 500 kHz and improve SNR
- Measurements of temperature and H_2O were taken at multiple standoff distances for fireballs of PETN and N5
- Future work will compare these experimental results with synthetic measurements obtained from CFD models

Acknowledgments

- **Dr. Garrett Mathews at UC-Boulder (previously at Purdue University)**

- **Sandia National Laboratories**

- This work was supported by the Laboratory Directed Research and Development (LDRD) program at Sandia National Laboratories, which is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. This presentation describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.