SAND2021-15738C

Laser-Absorption-Spectroscopy Measurements of Temperature, Pressure, and CO at 1 MHz in Post-Detonation Fireballs

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AIAA SciTech Forum 2022, July 14, 2021

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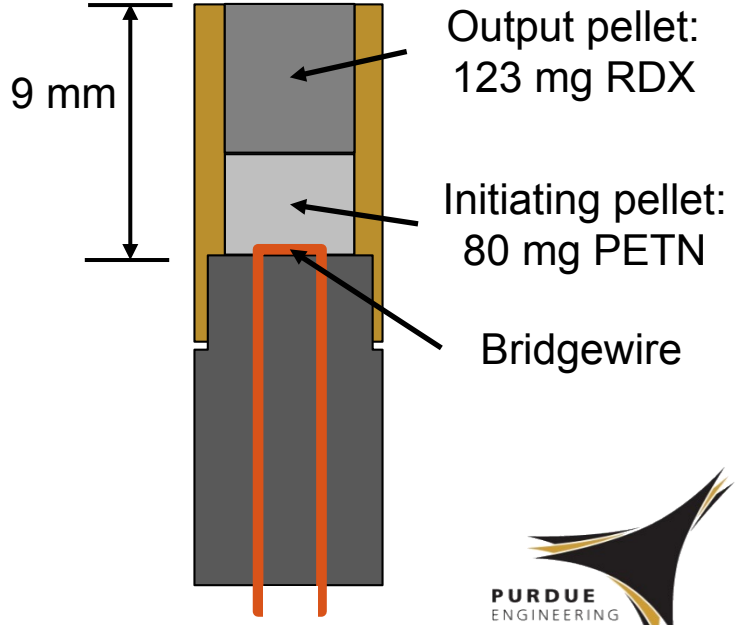
Research Motivation

- Validate advanced models describing post-detonation fireballs of energetic materials
  - Utilize lab-scale testing for simplicity and reduced cost
- RP-80 detonators widely applied in industrial and defense applications
  - Safe and repeatable detonation initiation
  - Testbed for diagnostic and model development



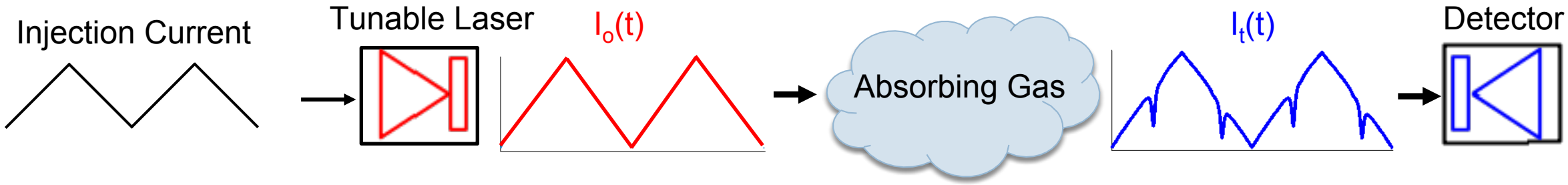
Project Goal: Perform measurements of T, P, CO at 1 MHz in post-detonation fireballs for evaluation of fireball models

Measurement Challenges:

- Short time scales (~1 μs)
- Elevated pressure
- Nonuniform distributions of T, P, species
- Optical losses (soot particles)

Fundamentals of Laser Absorption Spectroscopy

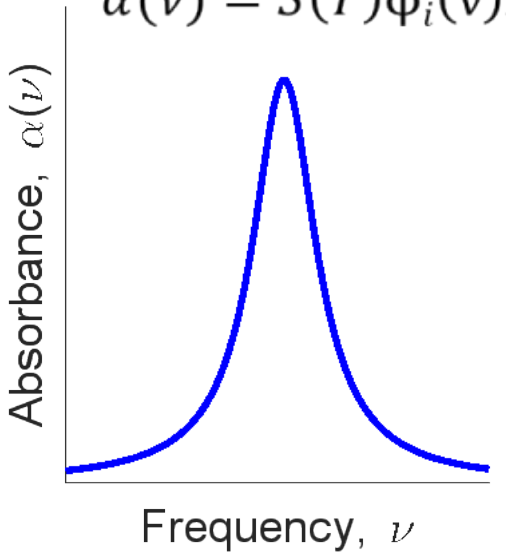
Technical approach: Utilize scanned-wavelength direct absorption spectroscopy



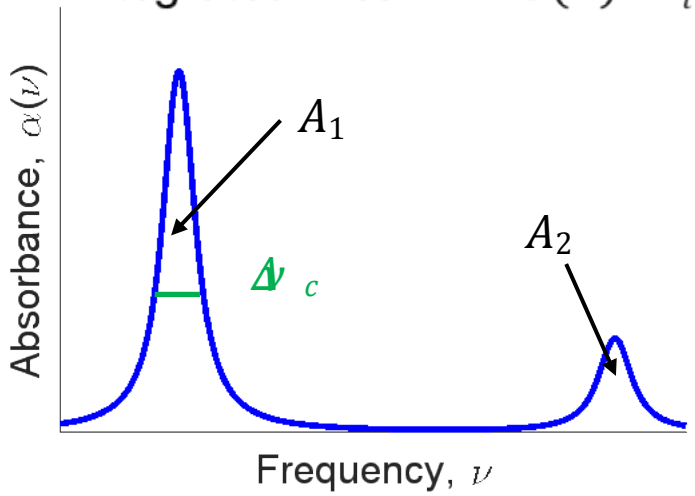
Spectral Absorbance: α(ν)

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

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



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



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

Measuring Gas Properties

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

$$\frac{A_1}{S_1(T)PL} = X_i$$ Absorbing Species (PX_i, X_iL)

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

Scanned-DA QCL Diagnostic for CO

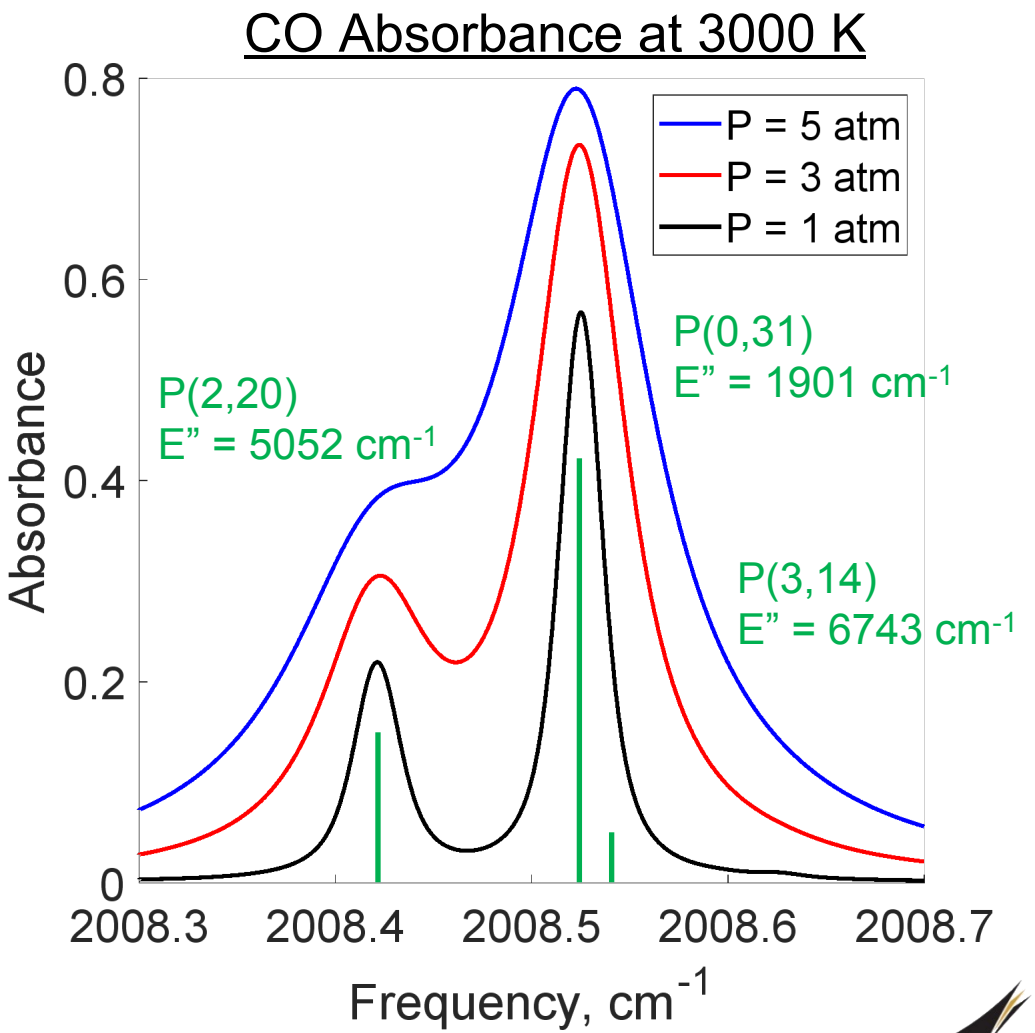
- CO transitions near 2008.5 cm^{-1}
  - High E'' → high temperature CO
- Scanned direct absorption at 1 MHz

- Spectral-fitting routine
  - Line parameters taken from HITEMP2010
  - Free parameters: T, P, P_{CO}
  - Improves robustness

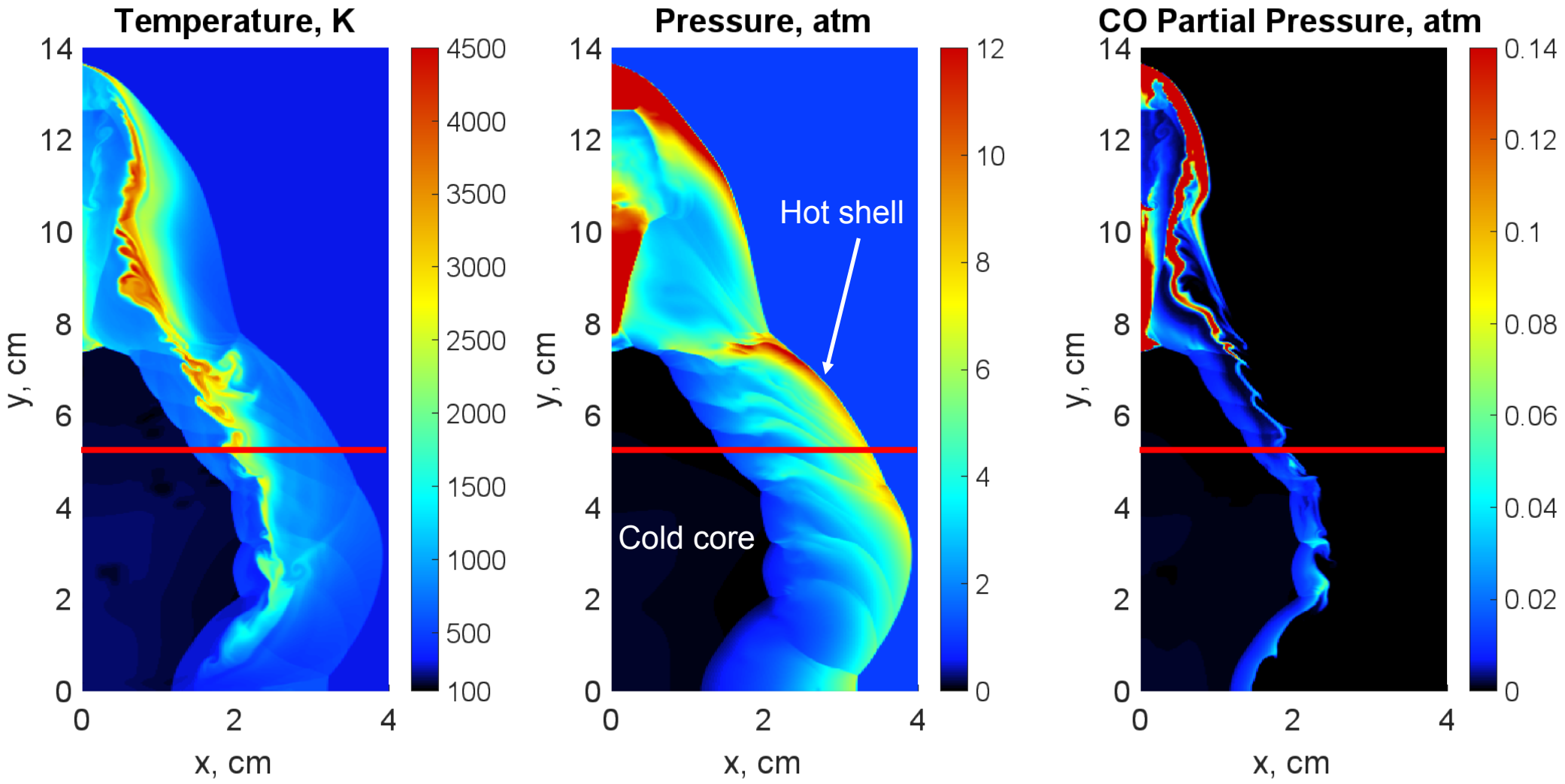
- Broadening model for pressure measurements

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

→mixture based on RDX combustion

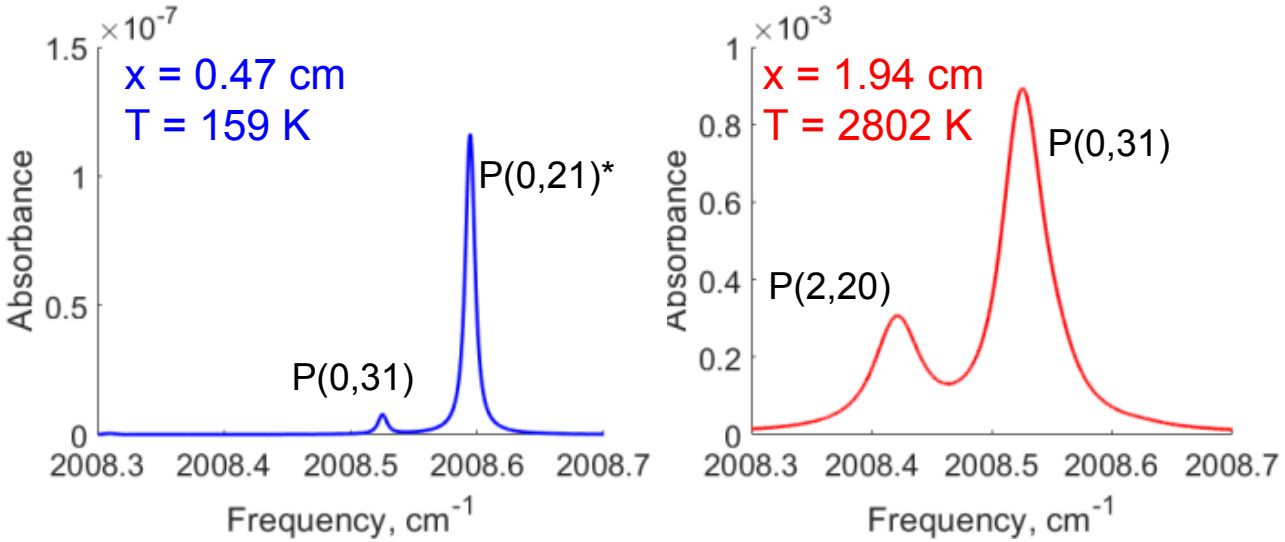


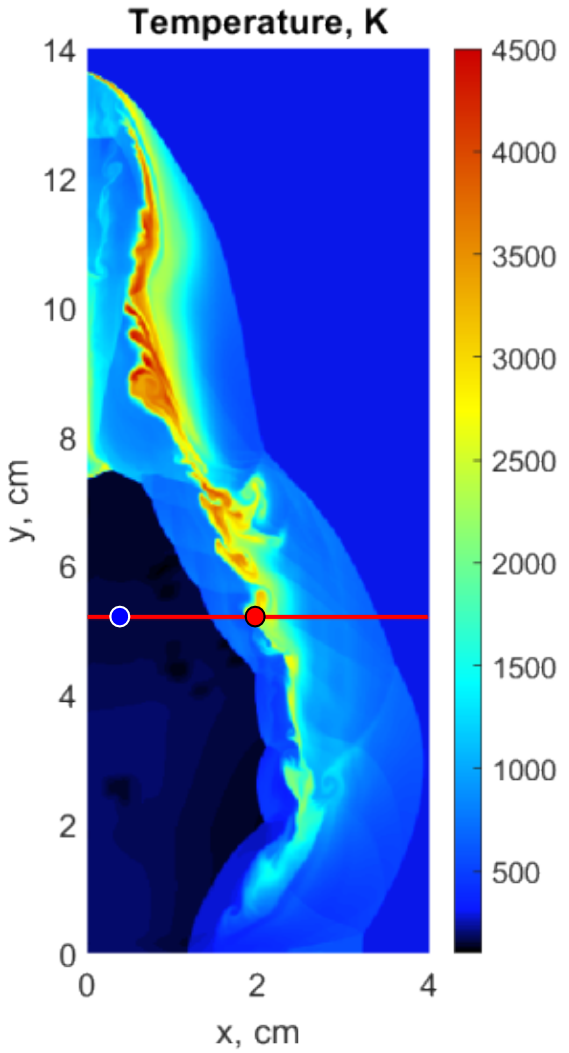
RP-80 Detonator Simulations

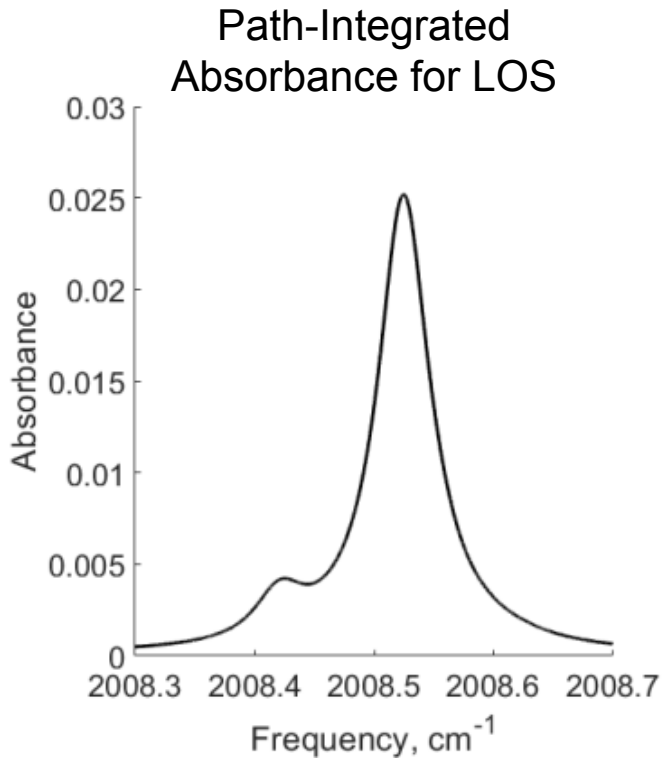


Highly nonuniform T, P, P_{CO} distributions along measurement LOS

Absorbance Spectrum for Nonuniform LOS







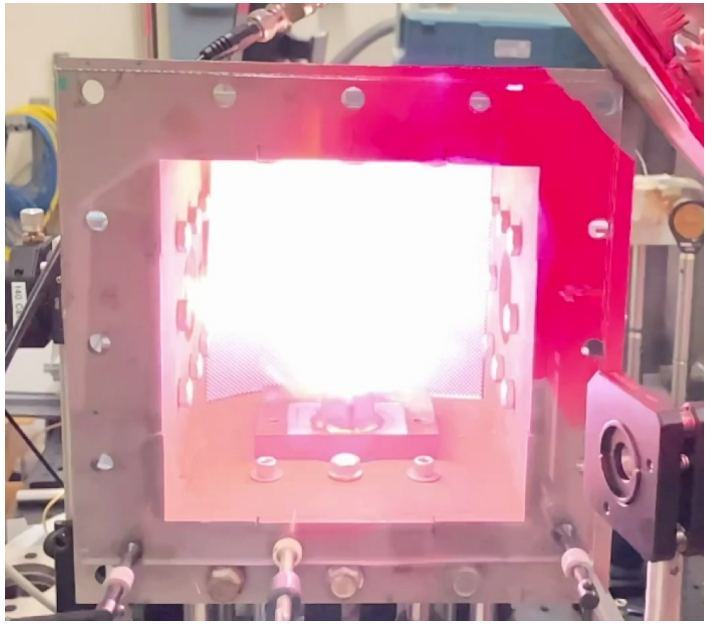
- Absorbance spectrum influenced by gas conditions along entire LOS:

$$\alpha = \int_0^L S(T_i) P_{CO,i} \phi_i(\nu, \Delta\nu_c, \Delta\nu_d) dl$$

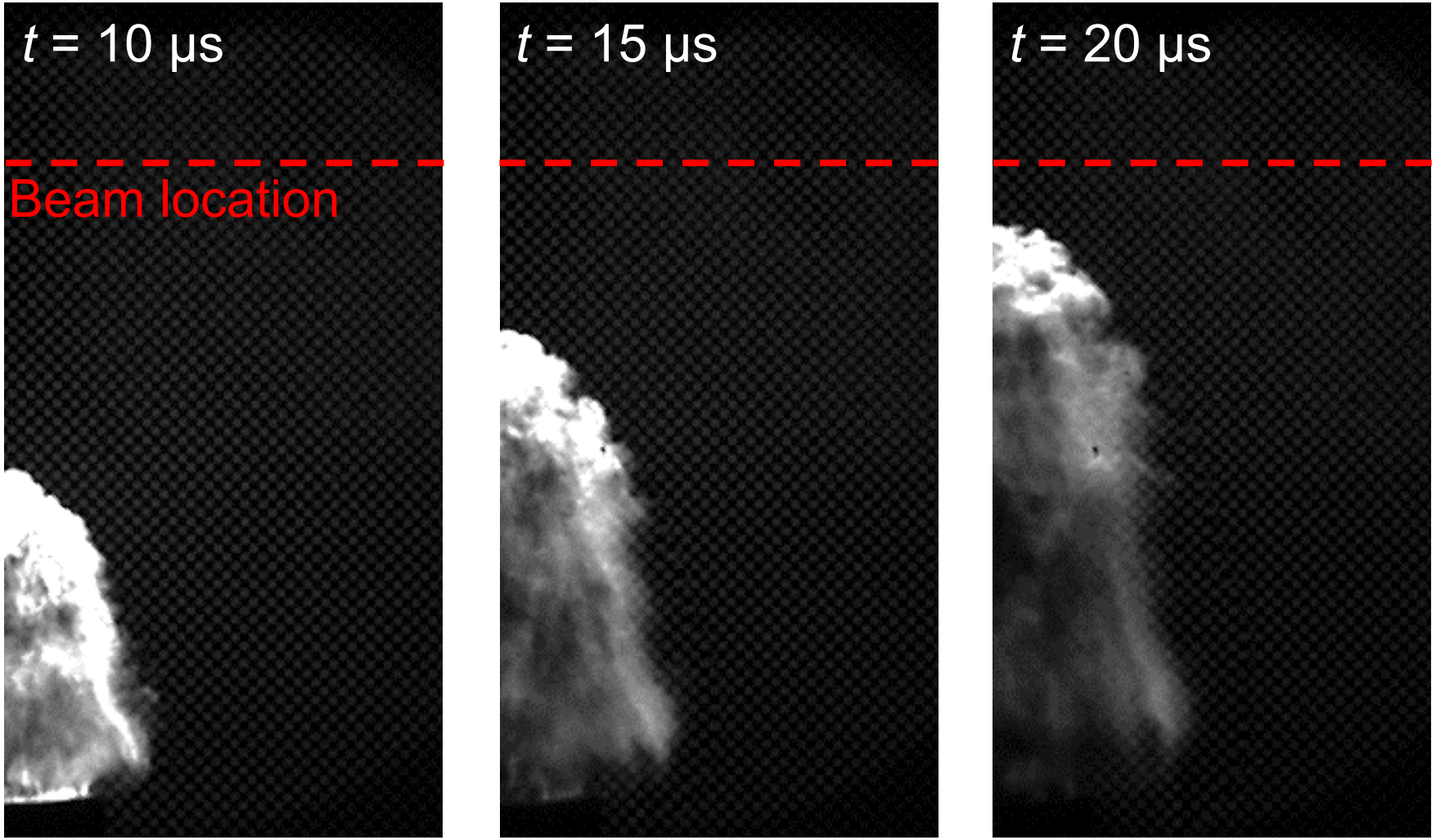
- Measurement biased toward regions with high temperature CO (high-E")

Experimental Setup

RP-80 Detonation



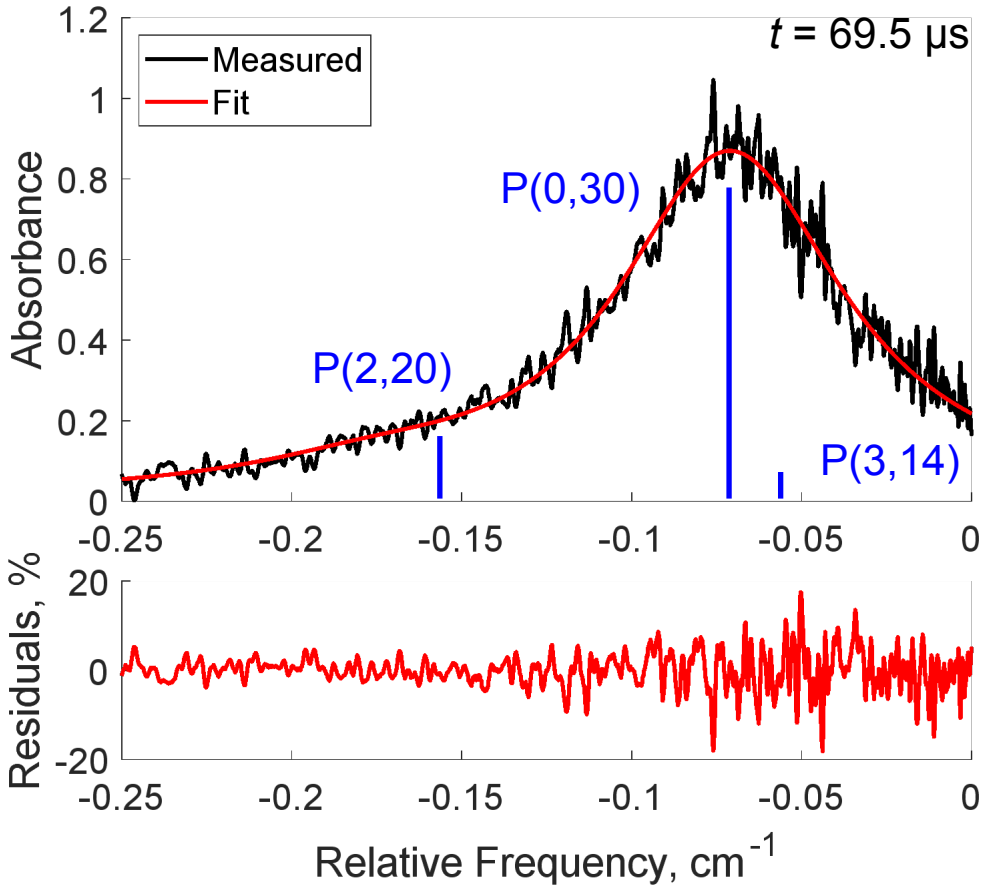
Imaging Results



- t = 0 defined by first light (measured with camera)
- Post-detonation fireball has relatively thin, luminous outer shell

Results - Single Spectrum and Best Fit

- Measured absorbance spectra often well-characterized by model for uniform LOS absorbance spectrum
  - Quantities give single T, P, P_{CO} effectively describing the measured spectrum
- Flat residuals indicate model can accurately describe measurement



Best-fit conditions

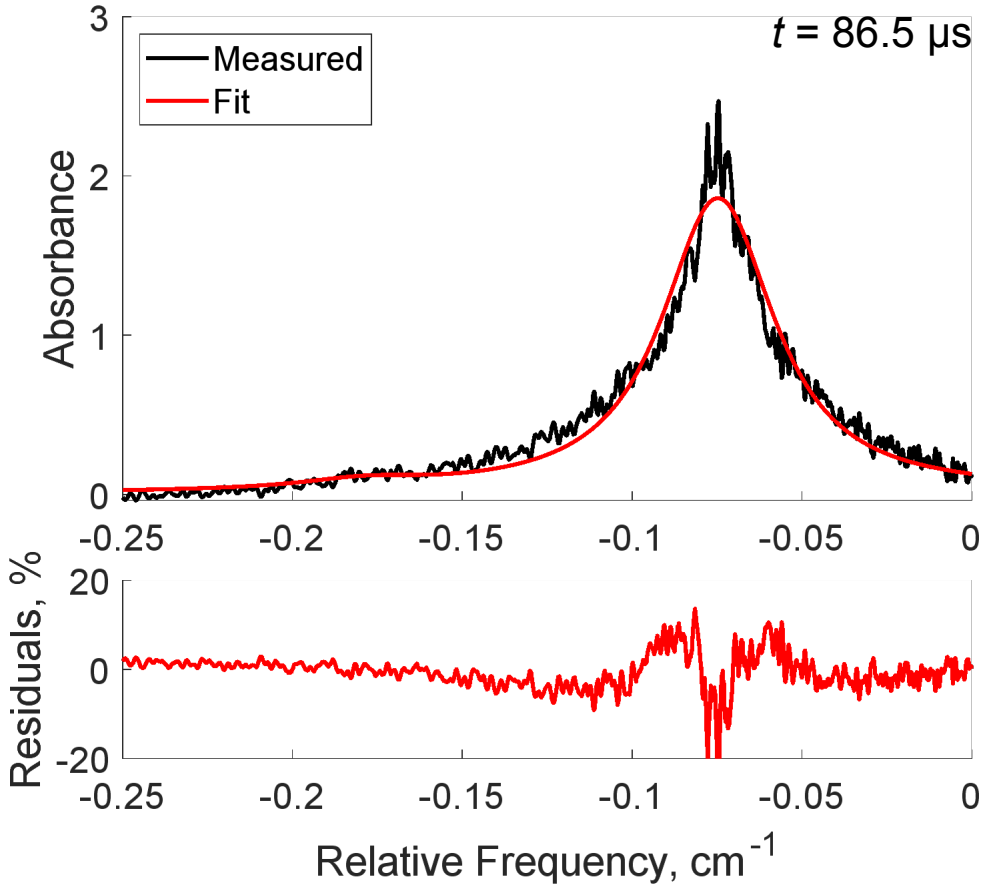
T = 1360 K

P = 1.63 atm

$P_{CO}L$ = 0.315 atm-cm

Results - Single Spectrum Fit

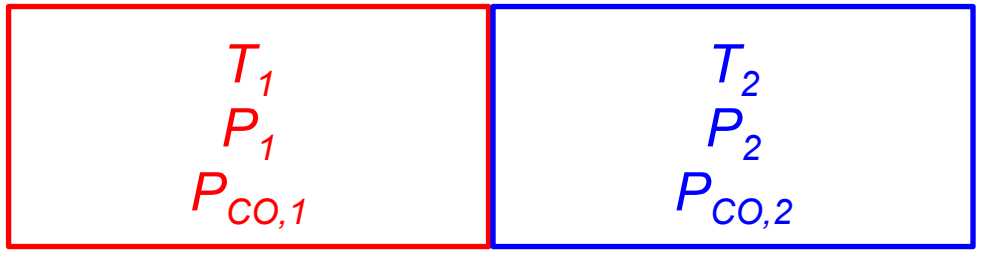
- Some measured spectra are not described well by uniform-LOS model
  - Narrow peak
  - Wide base
  - Indicates nonuniform pressure distribution
- Structure in residuals indicates model cannot simulate measured spectrum
- Nonuniform spectra measured from 82-107 μs



Simulating Spectra with Nonuniform LOS

Dual-zone model:

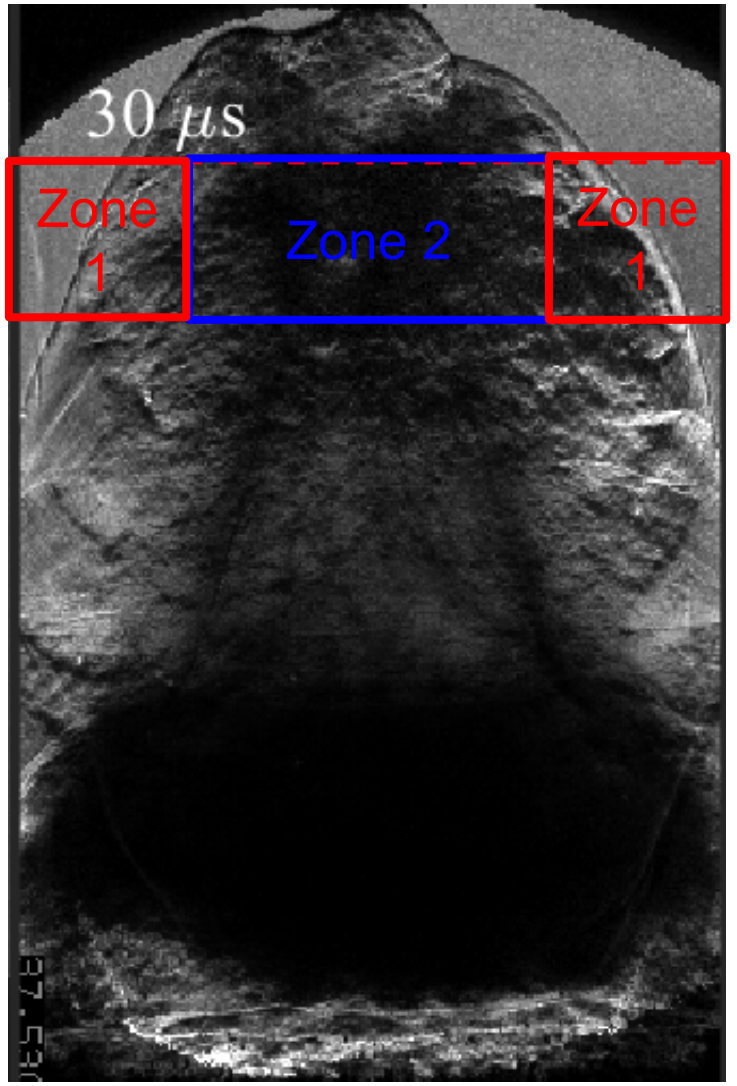
- LOS modeled as consisting of two homogeneous zones



- Set of free parameters for each zone:

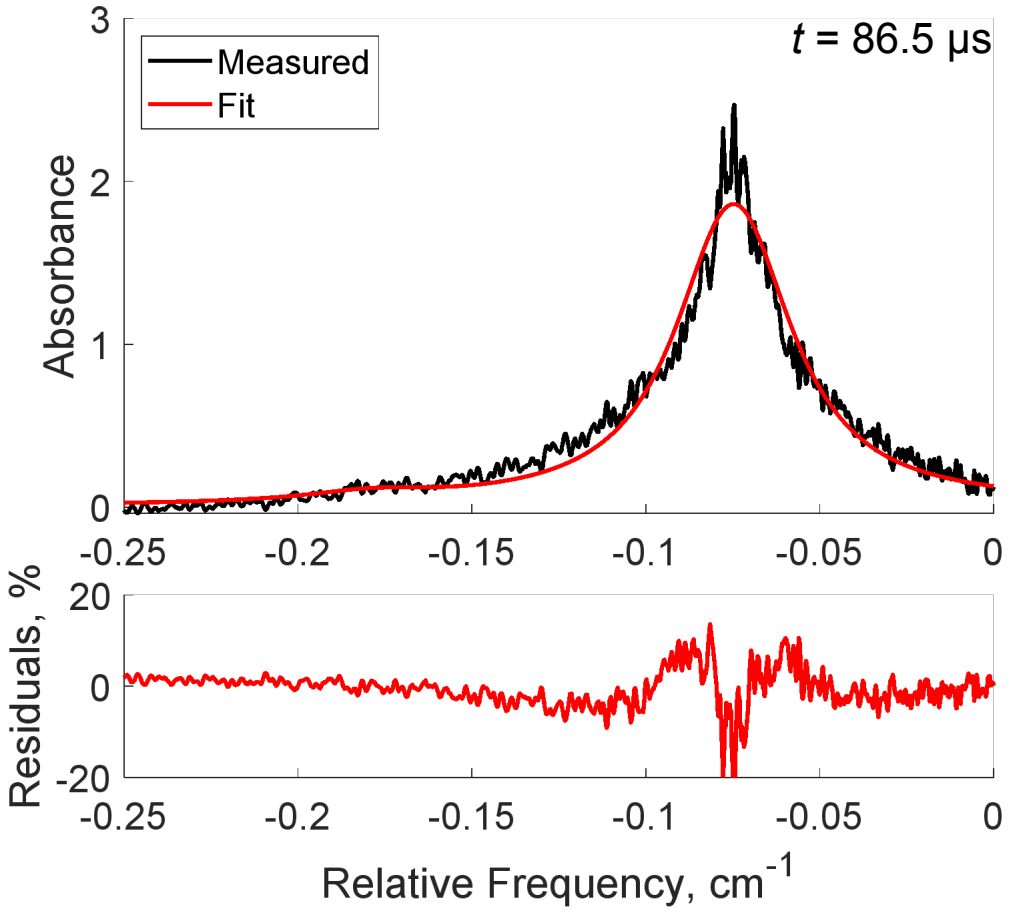
$$\alpha_{total} = \alpha_1(T_1, P_1, P_{CO,1}, \nu) + \alpha_2(T_2, P_2, P_{CO,2}, \nu)$$

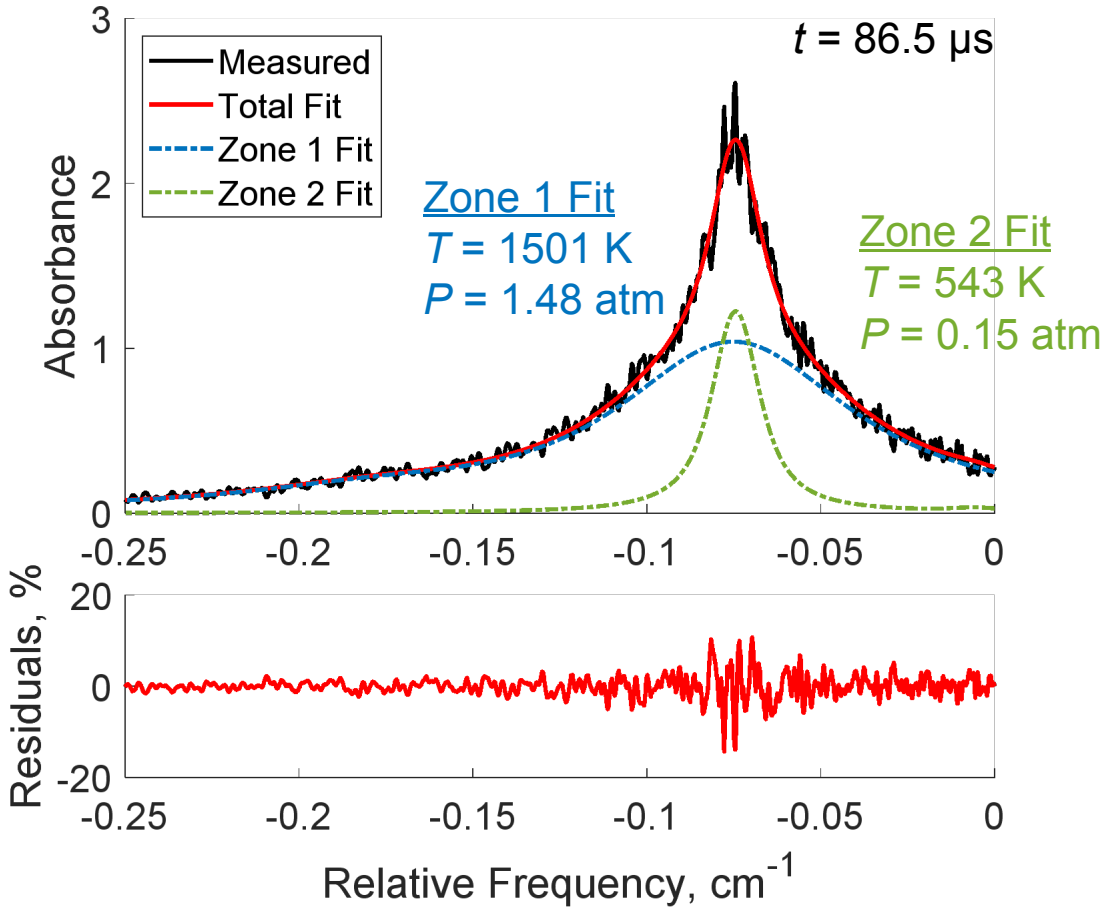
- Dual-zone model required from 82-107 μs



Guildenbecher et al. (2020)

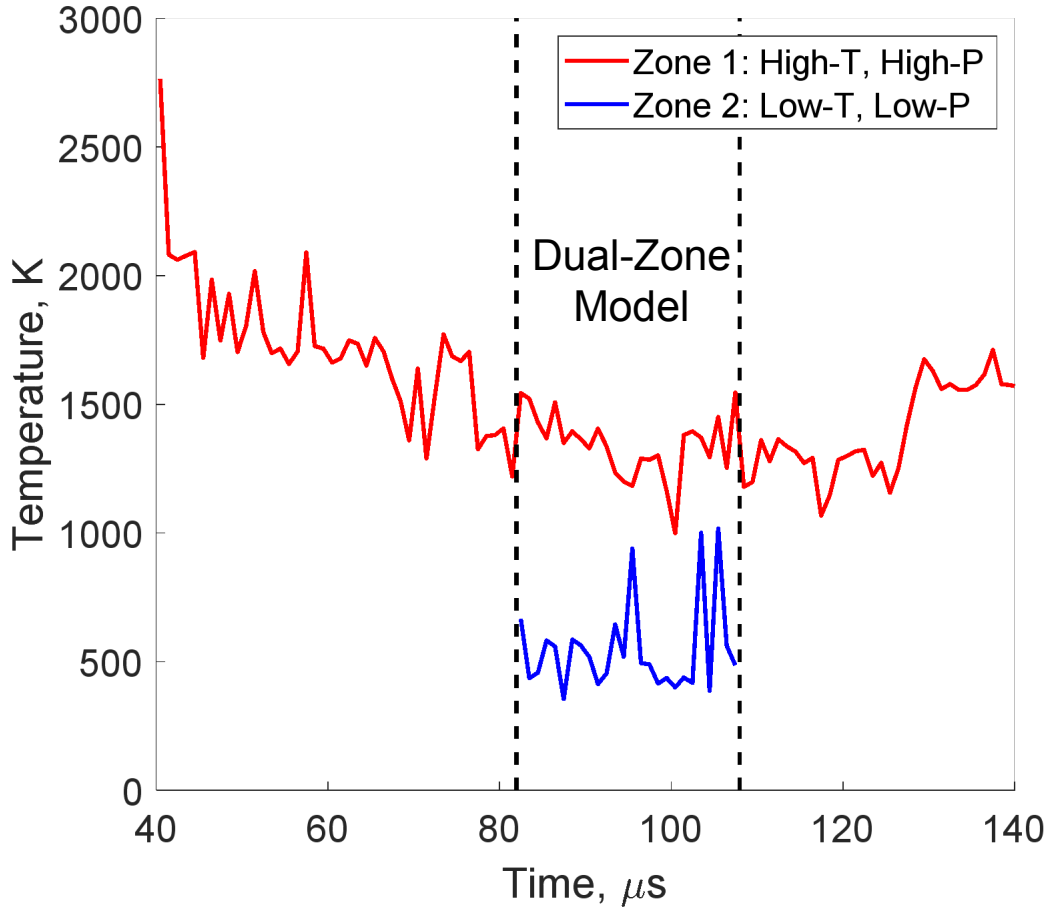
Results – Dual Zone Model

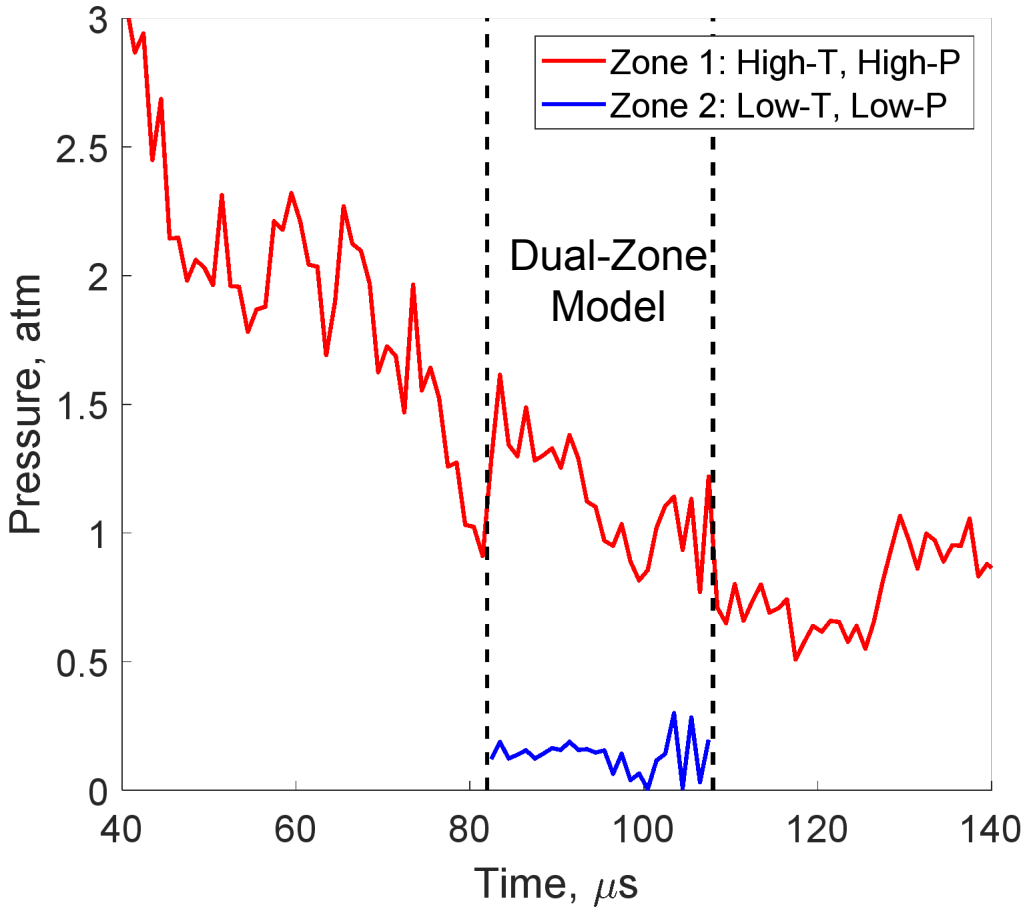




- Pressure variations encode absorbance information along nonuniform LOS
- Dual-zone model used to extract measurements in multiple regions of fireball

Temperature and Pressure – 91 mm beam height





- Nonuniform spectra measured from 82-107 μs (low pressure gases at LOS)
- Dual-zone model enables continuous measurements in high-T, high-P zone

Conclusions

- Scanned-DA QCL diagnostic applied to measure T, P, $P_{CO}L$ at 1 MHz
  - First LAS measurements in post-detonation fireballs > 30 kHz
  - First spectroscopic measurements of pressure and CO in post-detonation fireballs
- Highly nonuniform absorbance spectra recorded 82 -107 μs after detonator initiation
  - Hypothesized to be pocket of cold, low-pressure gas passing LOS
- Dual-zone absorption model used to measure multiple T and P values
  - First time pressure variations along LOS have been leveraged to acquire multi -zone LAS measurements of T, P, and species

Acknowledgements

- Funding Agencies
  - Sandia National Laboratories
    - Laboratory Directed Research and Development program
  - National Science Foundation
    - Graduate Research Fellowship Program

- Additional Support:
  - University of Florida
    - Professor Ryan Houim
    - Anthony Egeln

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Questions?

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