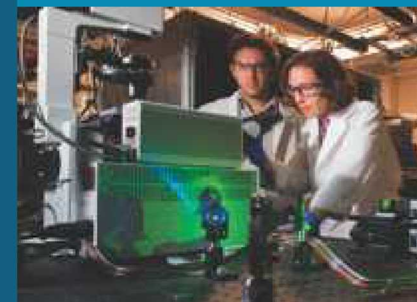
SAND2019-9436PE



Hydrogen Thermometry in Aluminized Propellant Burns

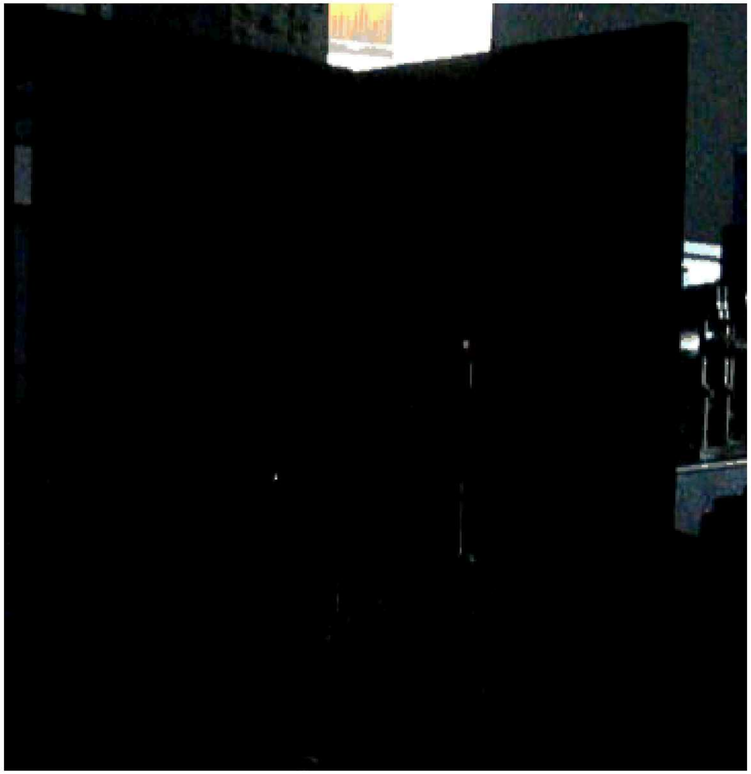
PRESENTED BY

Jonathan Retter, Daniel Richardson, Sean Kearney

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.

Why study aluminized propellant burns?

Safety: Abnormal Thermal Environments
- Propellant/launch safety
- Heat transfer (what T's are important?)



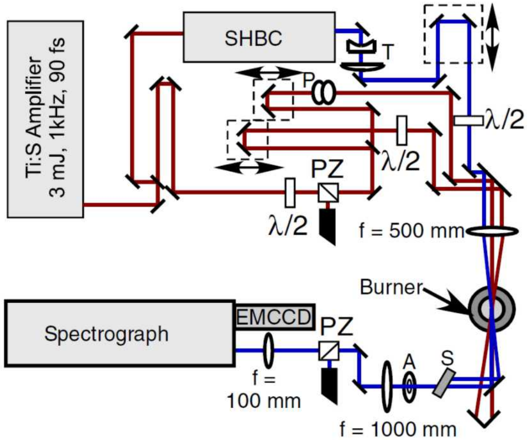
Challenging Research Environment
- High temperatures
- Bright emission
- Complex chemistry
- Multiphase plume

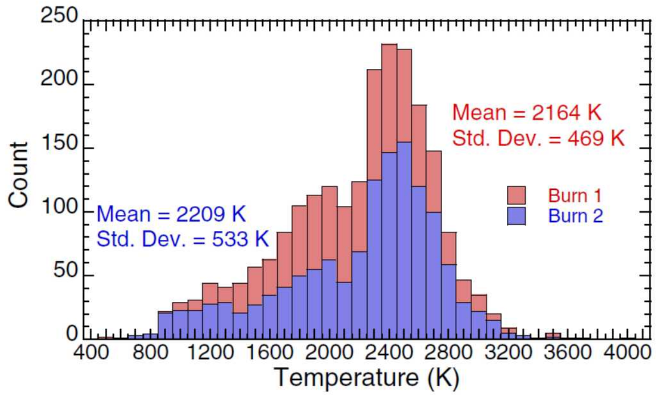
Encourages the use of laser diagnostics:
- Org. 1512 is a great place to start!

Previous work in our group:

Nitrogen/Oxygen pure-rotational CARS

- Correlations of rotational temperature and O2/N2 concentration

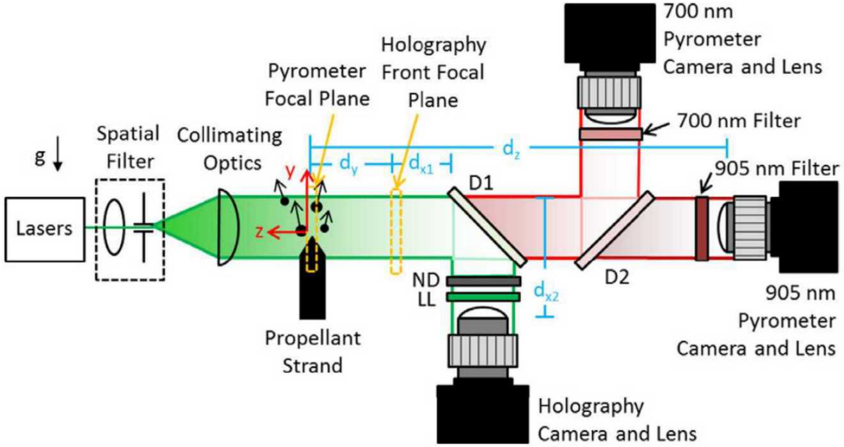


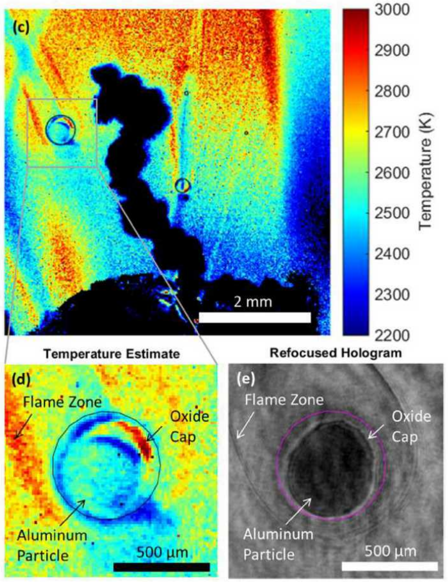


Kearney et al., *Applied Optics*, 2016

Simultaneous holography and pyrometry

- Particle size, velocity, and temperature





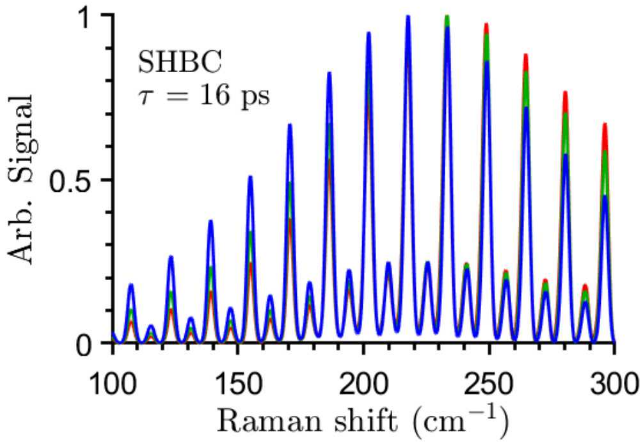
Chen et al., *Combustion and Flame*, 2017

Next step: improved thermometry

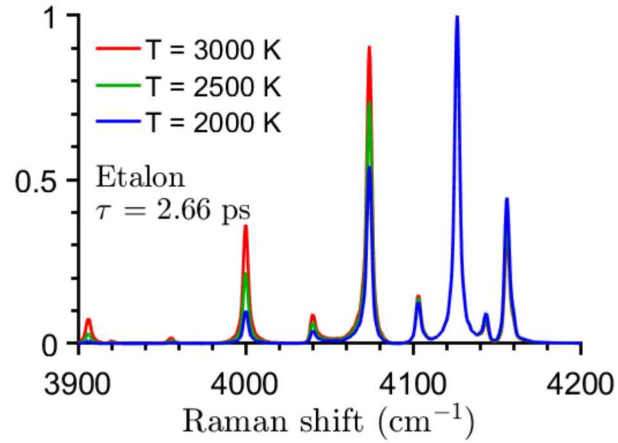
Switch to vibrational CARS

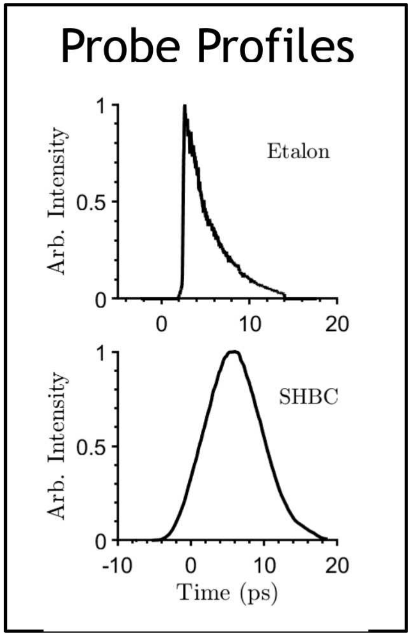
- Improved temperature sensitivity at high temperatures

N$_2$ S-branch (Δv = 0, ΔJ = +2)



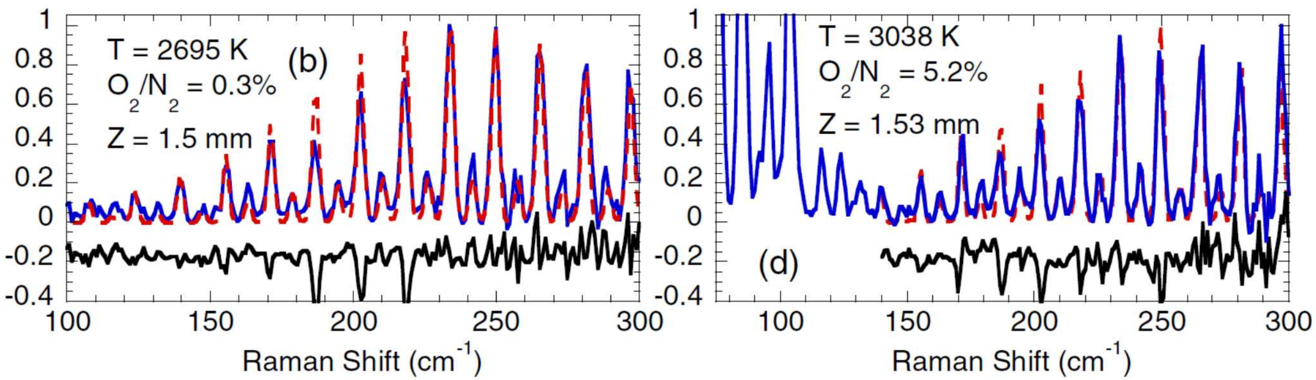
H$_2$ Q-branch (Δv = +1, ΔJ = 0)





Switch from inert gas to fuel detection

- Shouldn't be plagued by spatial averaging of cold, surrounding gas
- Ensuring measurements close to the burning surface

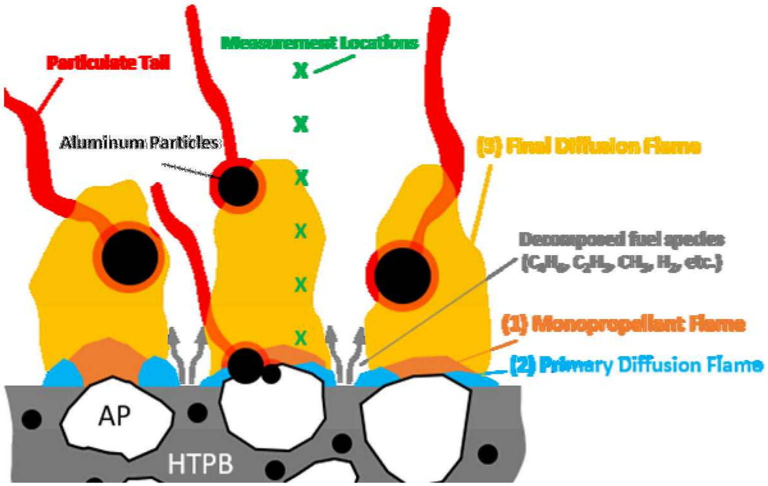


Kearney et al., *Applied Optics*, 2016

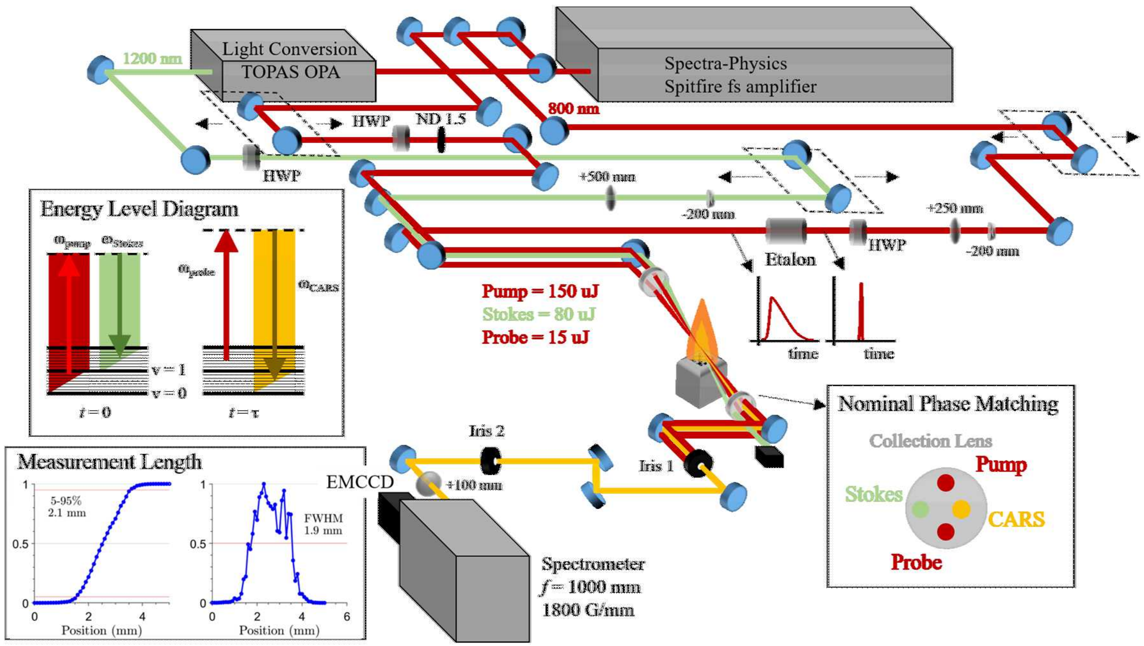
Experimental Setup

… but where is the H_2 from?

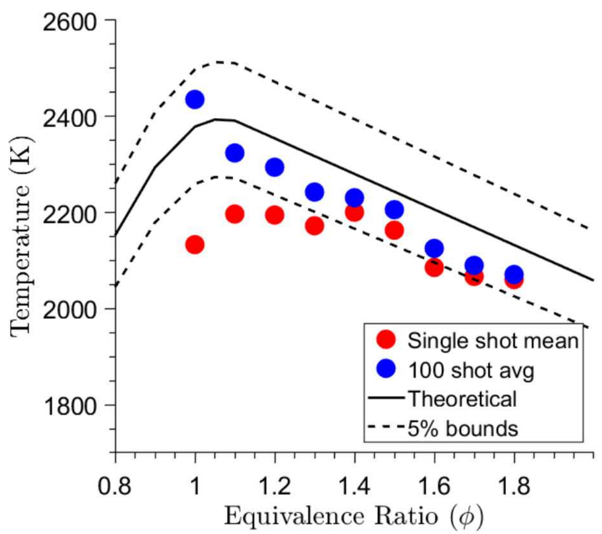
- Ammonium perchlorate oxidizer (AP, 70%)
  - NH_4ClO_4, decomposes to form ammonia and oxidizer species
    - Monopropellant flame
- Hydroxyl terminated polybutadiene binder (HTPB, 10%)
  - C_4H_6, bounded by OH, decomposes into hydrocarbon species and H_2
  - Decomposed hydrocarbons react with monopropellant products
    - Primary Diffusion Flame
- Aluminum (20%)
  - Melts at ~933 K, forms agglomerates on the burning surface



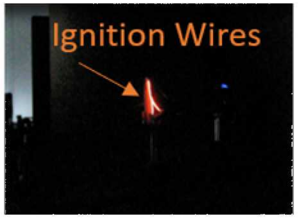
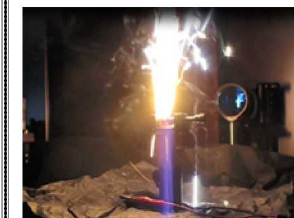
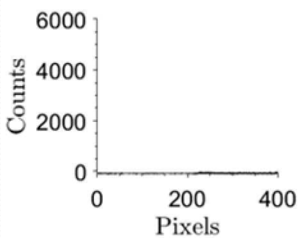
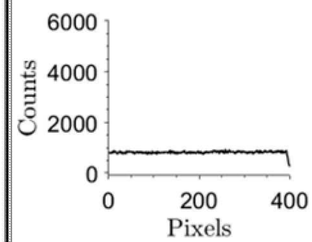
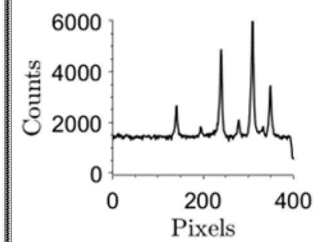
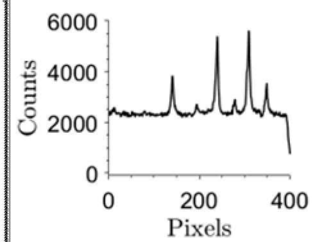
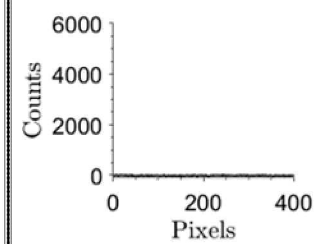
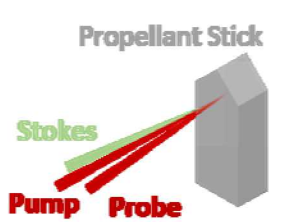
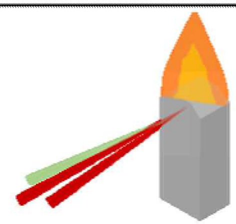
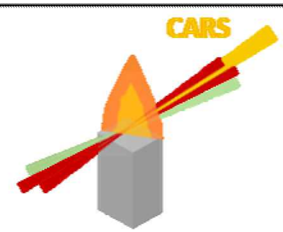
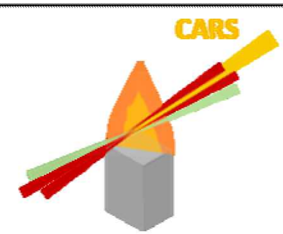
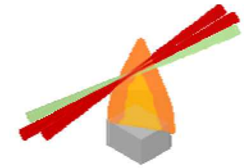
3-beam vibrational hydrogen CARS



S/N Sensitivity in a Hencken Burner:



Timeline of the burn

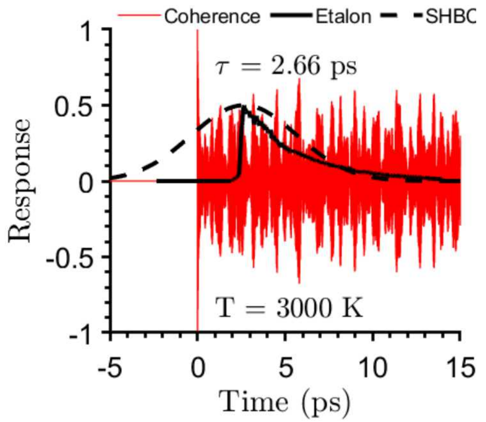
	Ignition	Background	Colder Gas	Main Dataset	Late Times
Picture					
Detector					
Cartoon					
Description	Beams are blocked by the propellant	Beams remain blocked, thus no resonant detection, but broadband emission	Beams now clear of propellant, probing colder hydrogen	Probing large quantities of higher temperature hydrogen	Probing product gases (no resonant detection)

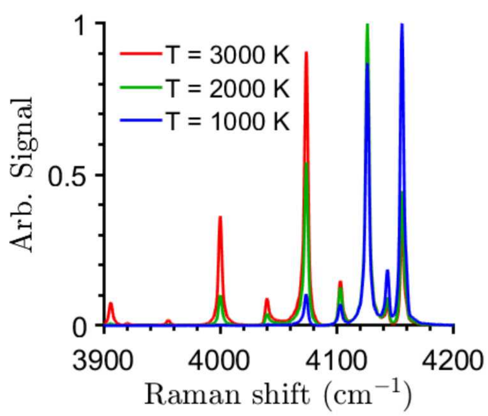
Spectral Fitting

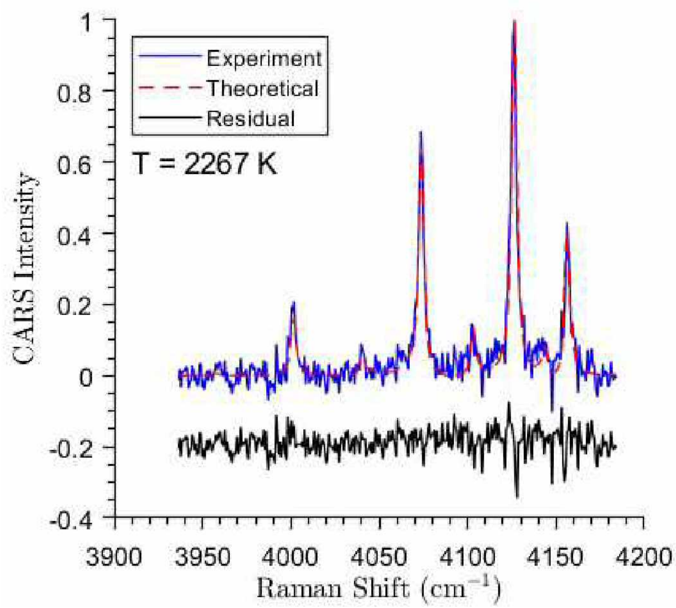
Generate synthetic libraries of the resonant response

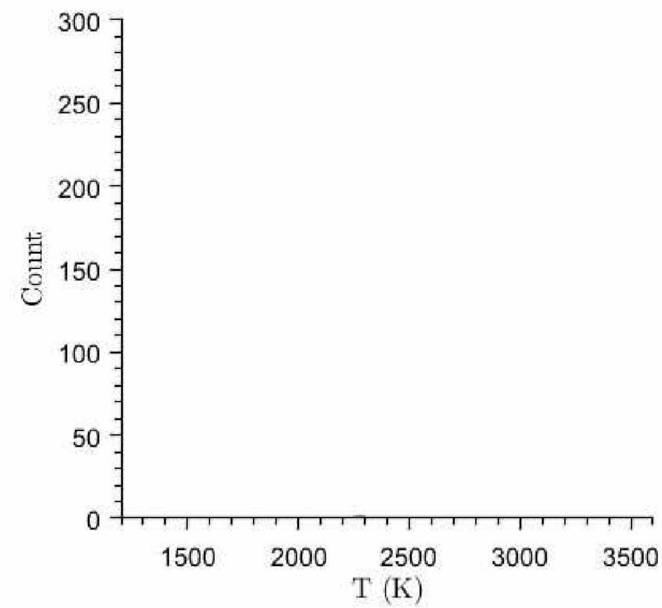
- Assume an impulsive preparation of the Raman coherence
- An etalon probe is very forgiving
  - Can ignore collisional and Doppler dephasing!

Fit bandwidth-corrected experimental spectra via interpolation



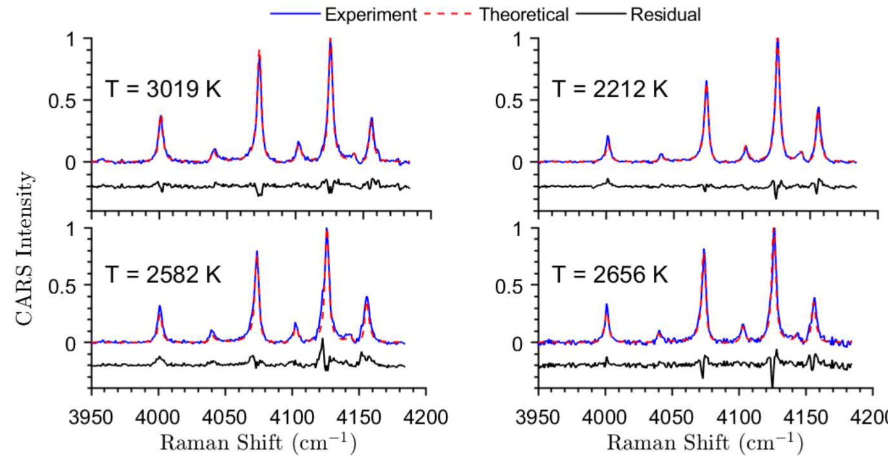


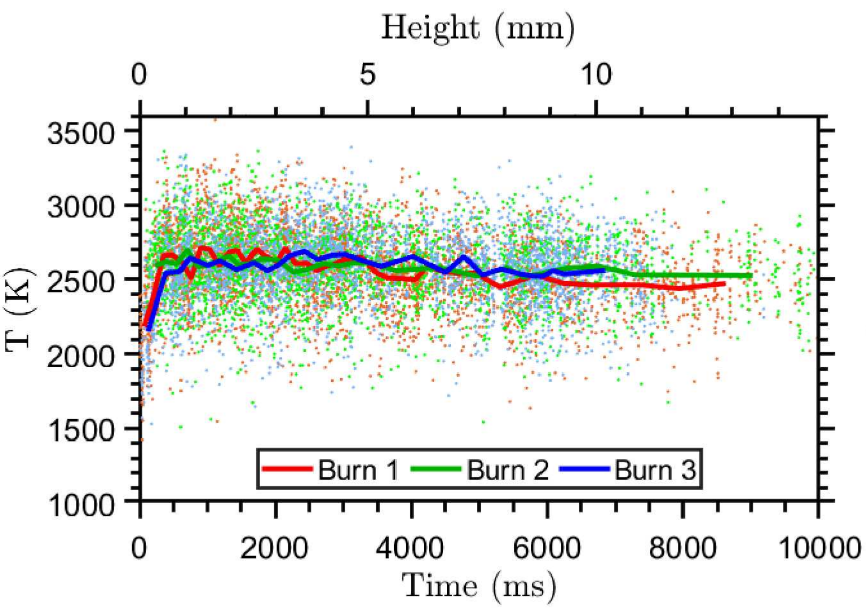


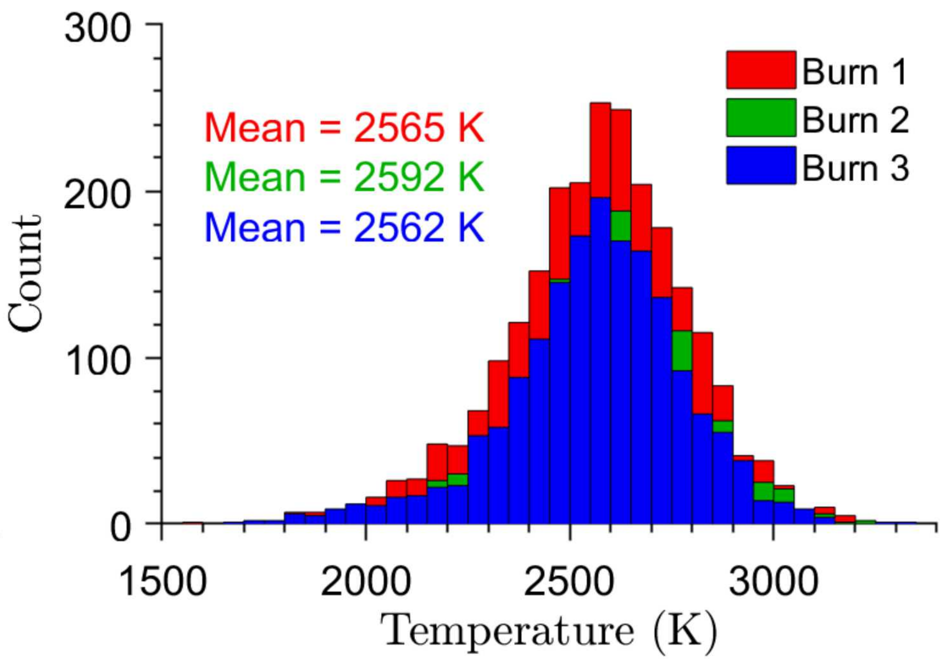


Results

3 Burns total
- Mean values within 30 K
- Temperature rise in the first 200 ms
- Otherwise constant temperature

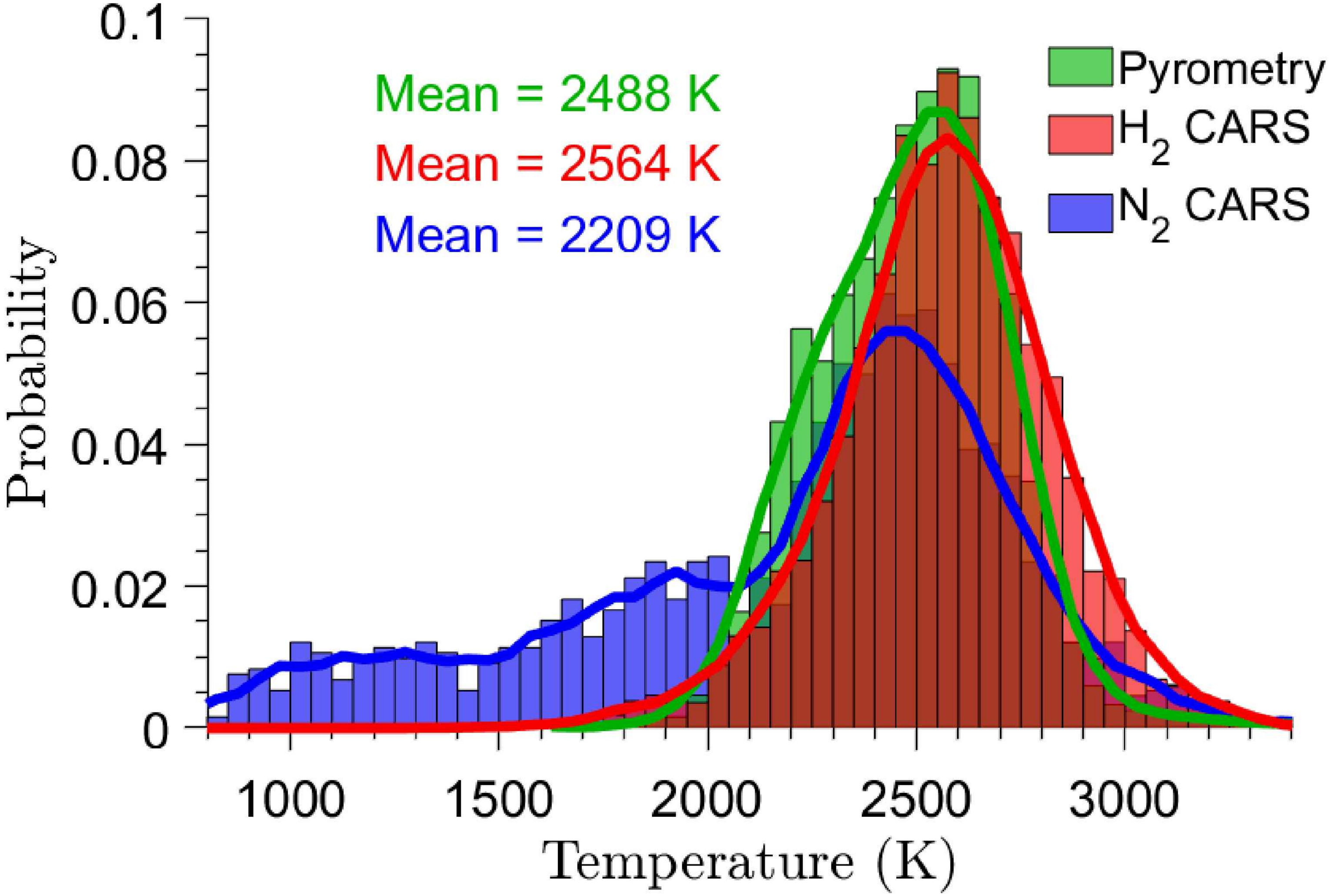




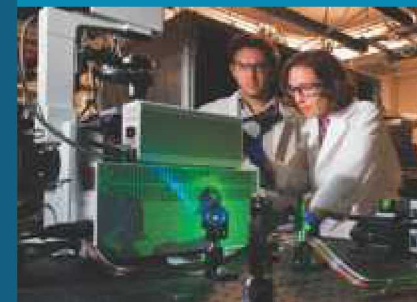


Comparison to previous work

Inert gas CARS, fuel CARS, and particle pyrometry



Diagnostic Development for High-Speed Flows



PRESENTED BY

Jonathan Retter, Daniel Richardson, Sean Kearney, and Steve Beresh

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.

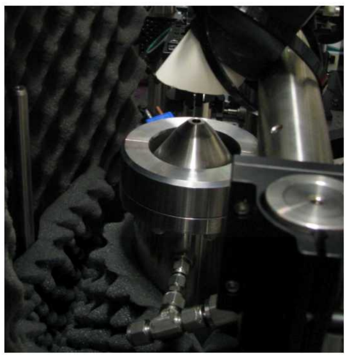
Benchtop testing → HWT

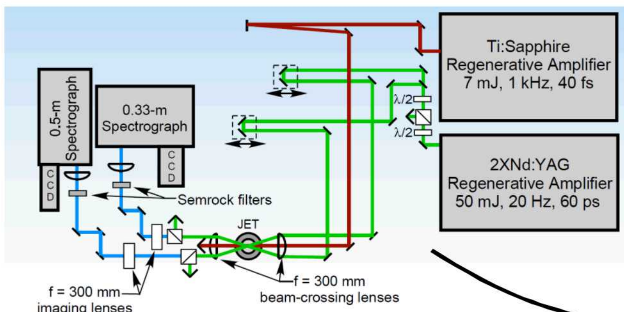
Significant Diagnostic Challenges

- Low density, high velocity environment with limited optical access

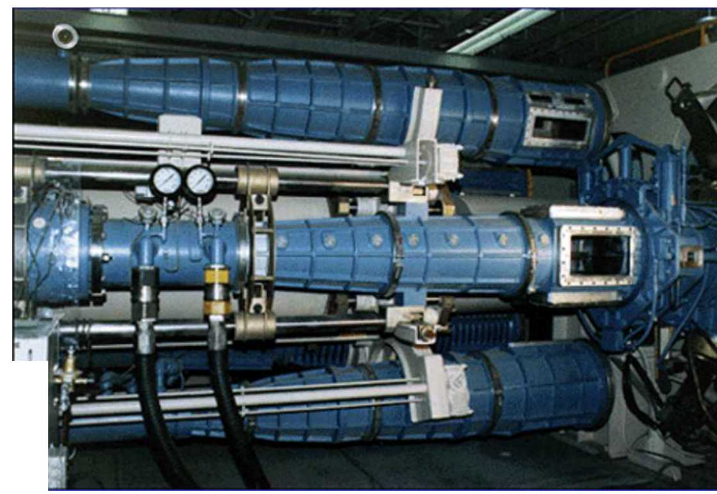
Off-Body Temperature and Pressure Measurements

- Dual-probe hybrid fs/ps CARS instrument



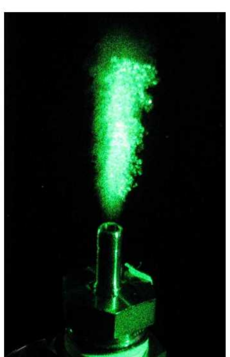


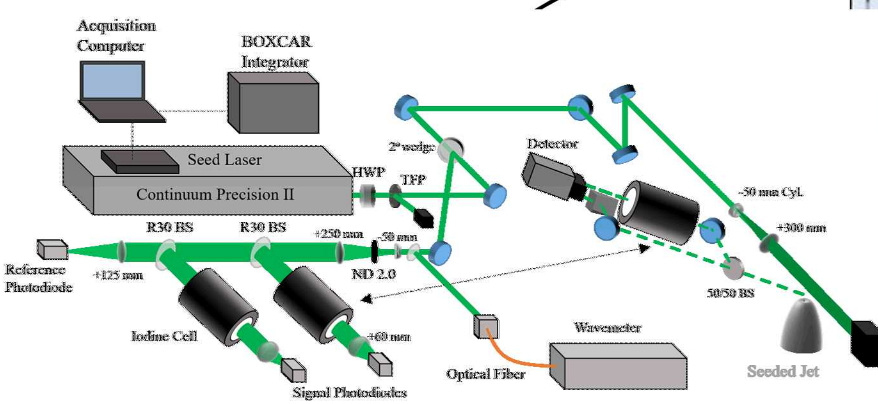
Hypersonic Wind Tunnel (HWT)



Robust velocity measurements

- FLEET or <u>CC-DGV</u>

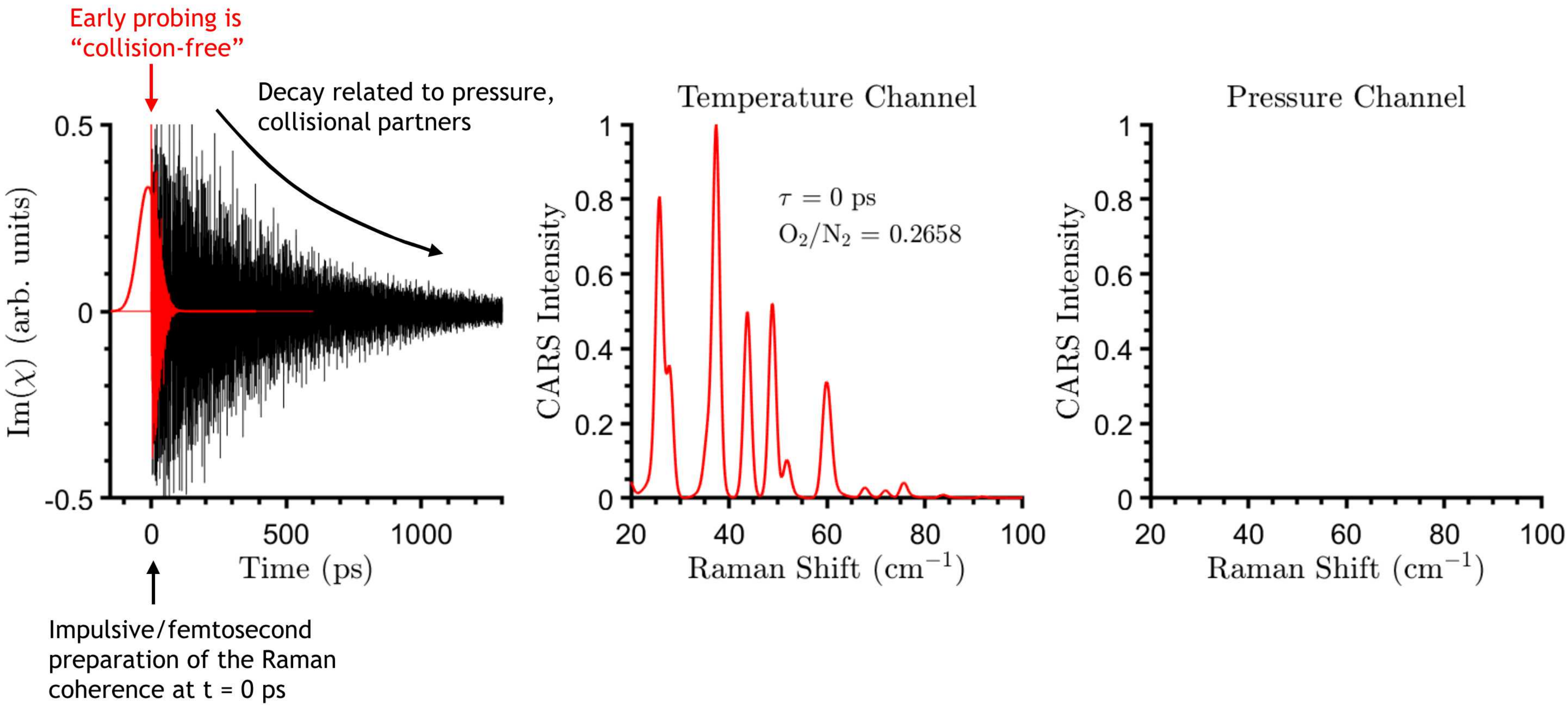




Temperature-Pressure CARS

Dual-probe technique

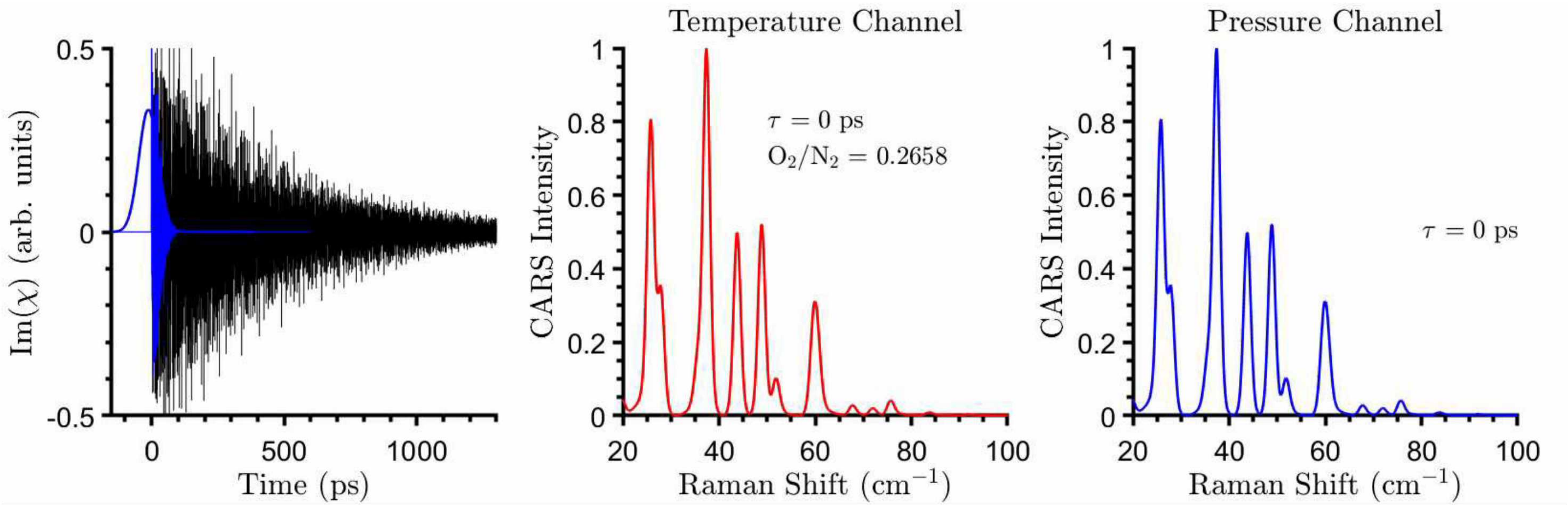
- Early, "collision-free" channel → temperature measurement
- Late, "collisionally-dephased" channel → pressure measurement



Temperature-Pressure CARS

Dual-probe technique

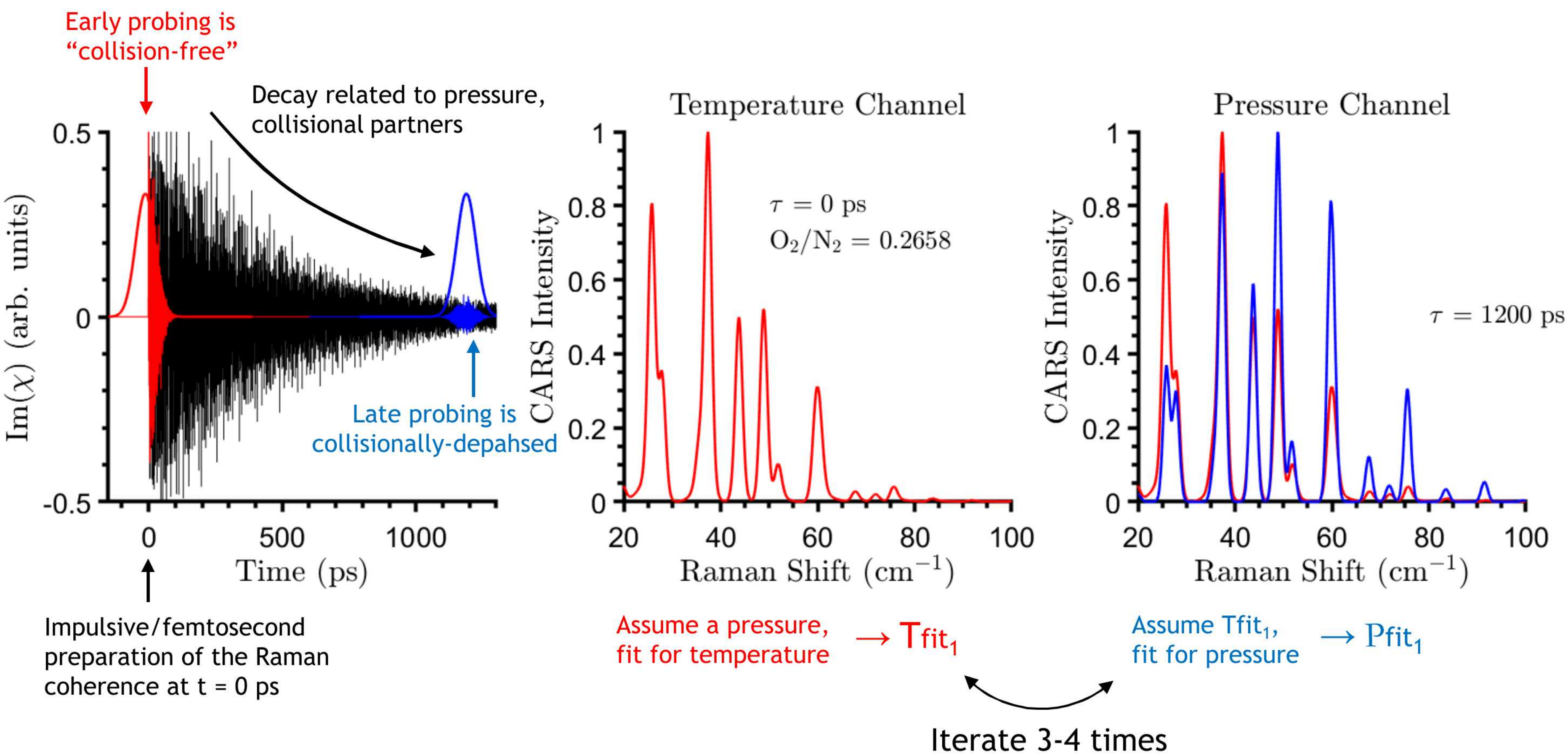
- Early, "collision-free" channel → temperature measurement
- Late, "collisionally-dephased" channel → pressure measurement



Temperature-Pressure CARS

Dual-probe technique

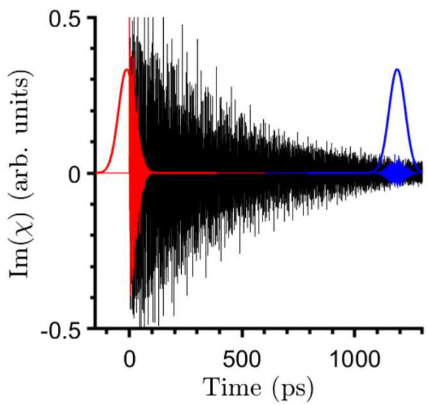
- Early, "collision-free" channel → temperature measurement
- Late, "collisionally-dephased" channel → pressure measurement

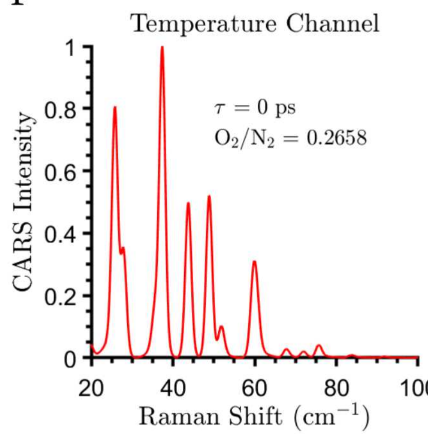


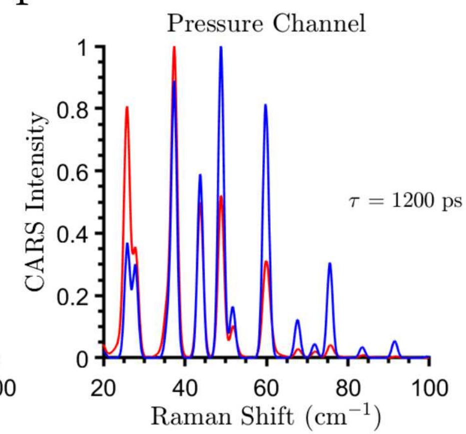
Temperature-Pressure CARS

Dual-probe technique

- Early, "collision-free" channel → temperature measurement
- Late, "collisionally-dephased" channel → pressure measurement

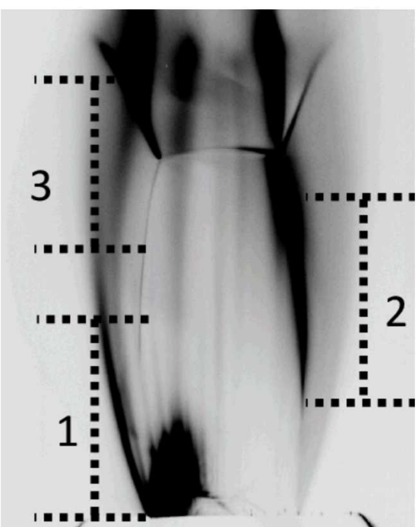


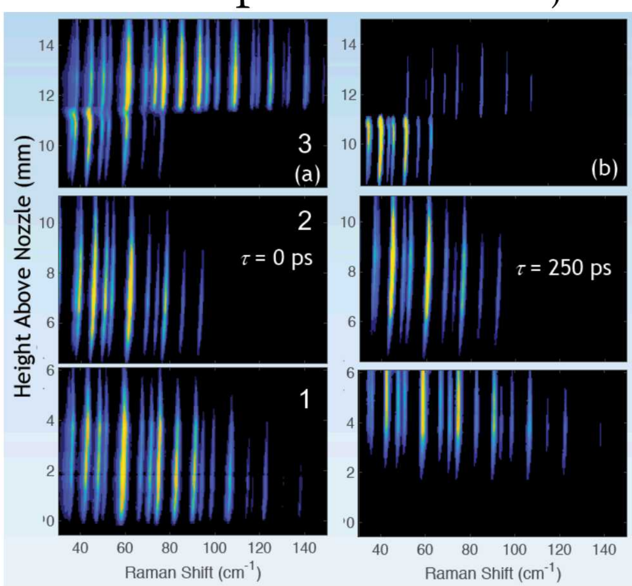


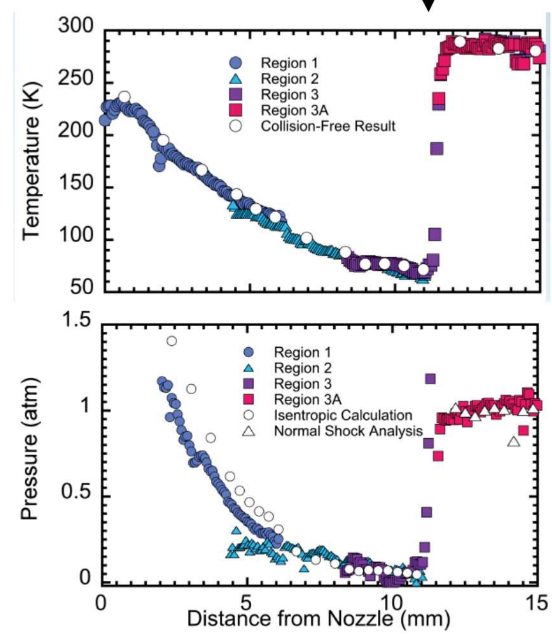


Additional thanks to:
Paul Danehy
Chloe Dedic

Demonstration in an underexpanded sonic jet



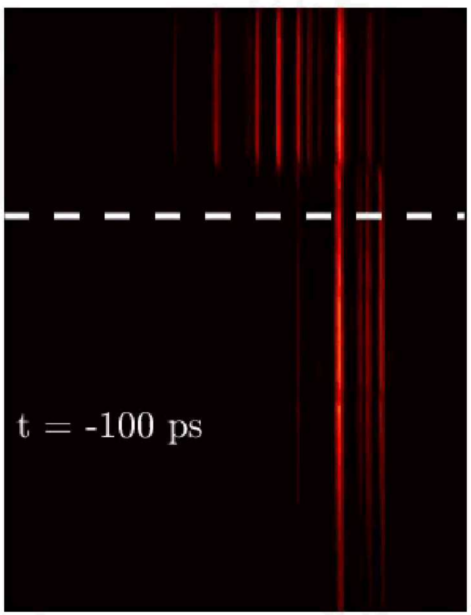


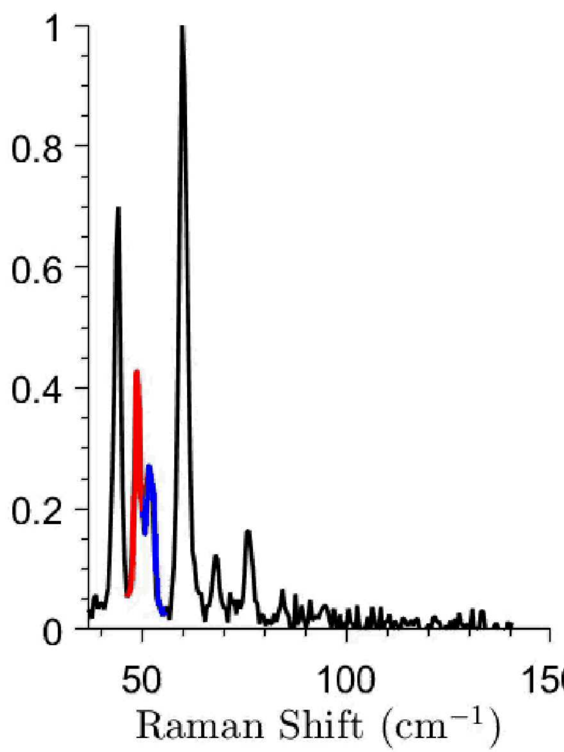


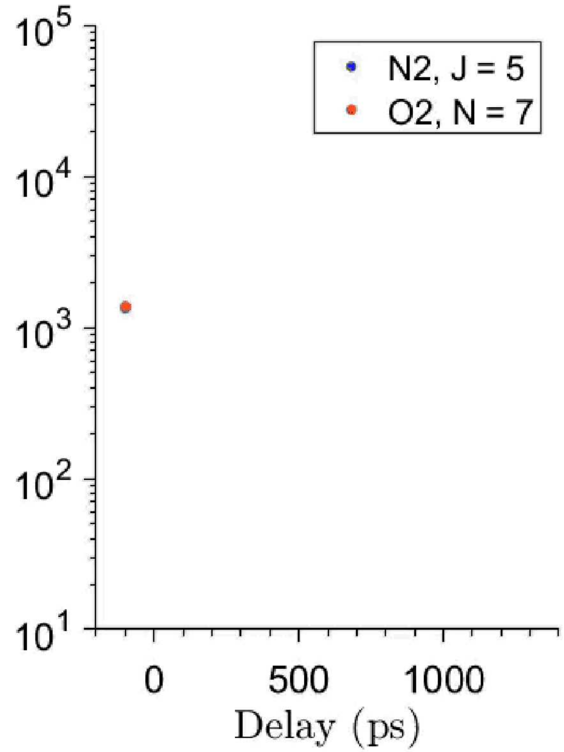
Temperature-Pressure CARS

Collisional Model must be correct for an accurate P measurement

- Examine "isolated" rotational lines of N_2 and O_2
  - Singlet ground state of $N_2 = {}^1\Sigma_g^+$ (electron spin S = 0)
  - Triplet ground state of $O_2 = {}^3\Sigma_g^-$ (electron spin S = 1)
  - Total angular momentum quantum number, J, is related to the rotational angular momentum, N, by $J = (\ldots, N\text{-}S, N, N+S, \ldots)$, and pure rotational Raman is $\Delta N = +2$, thus
  - **For N_2, $J = N \rightarrow$ 1 transition for each "J" level**
  - **For O_2, $J = (N\text{-}1, N, N+1) \rightarrow$ 6 transitions for each "N" level**

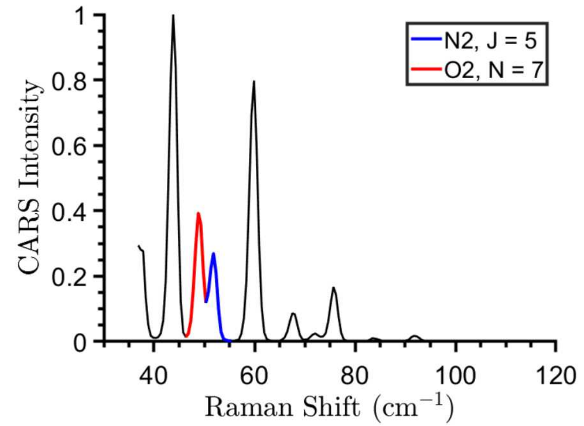




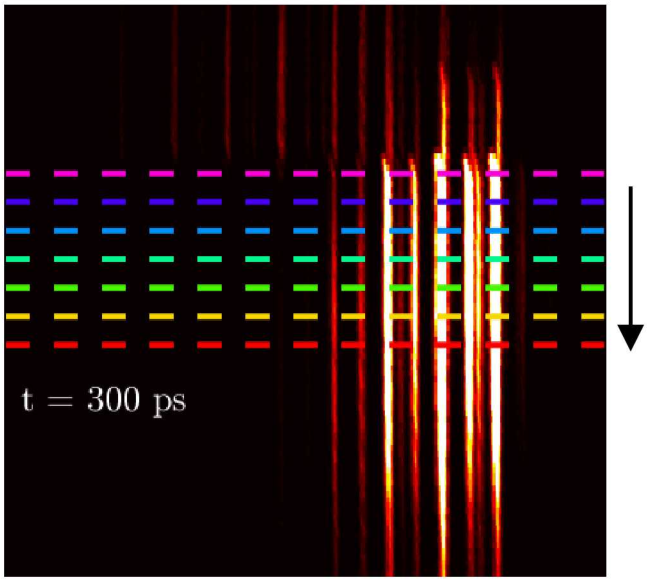


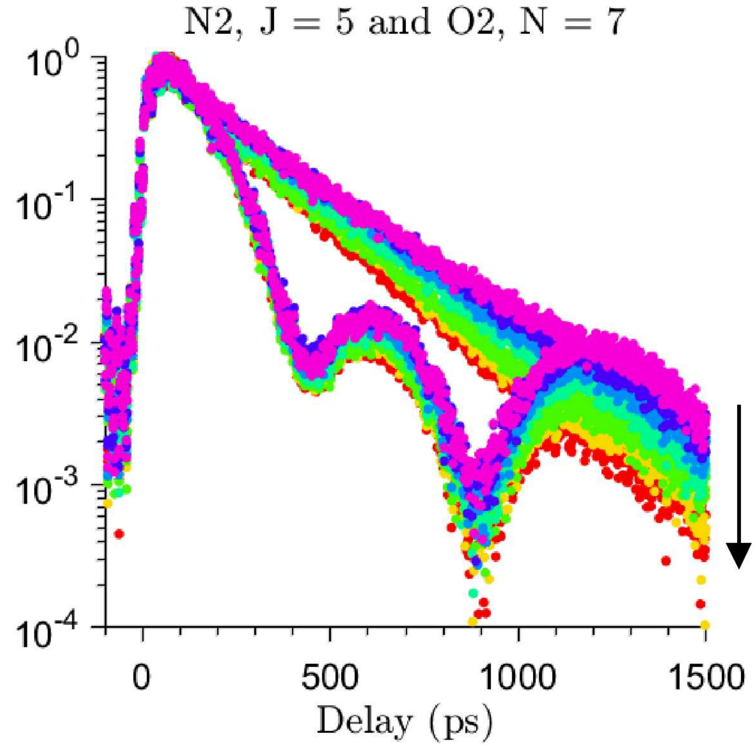
Temperature-Pressure CARS

Relative decay of the Raman lines gives us the pressure



Relative decays of O2 and N2 as a function of position on the chip (simultaneously a function of T and P):

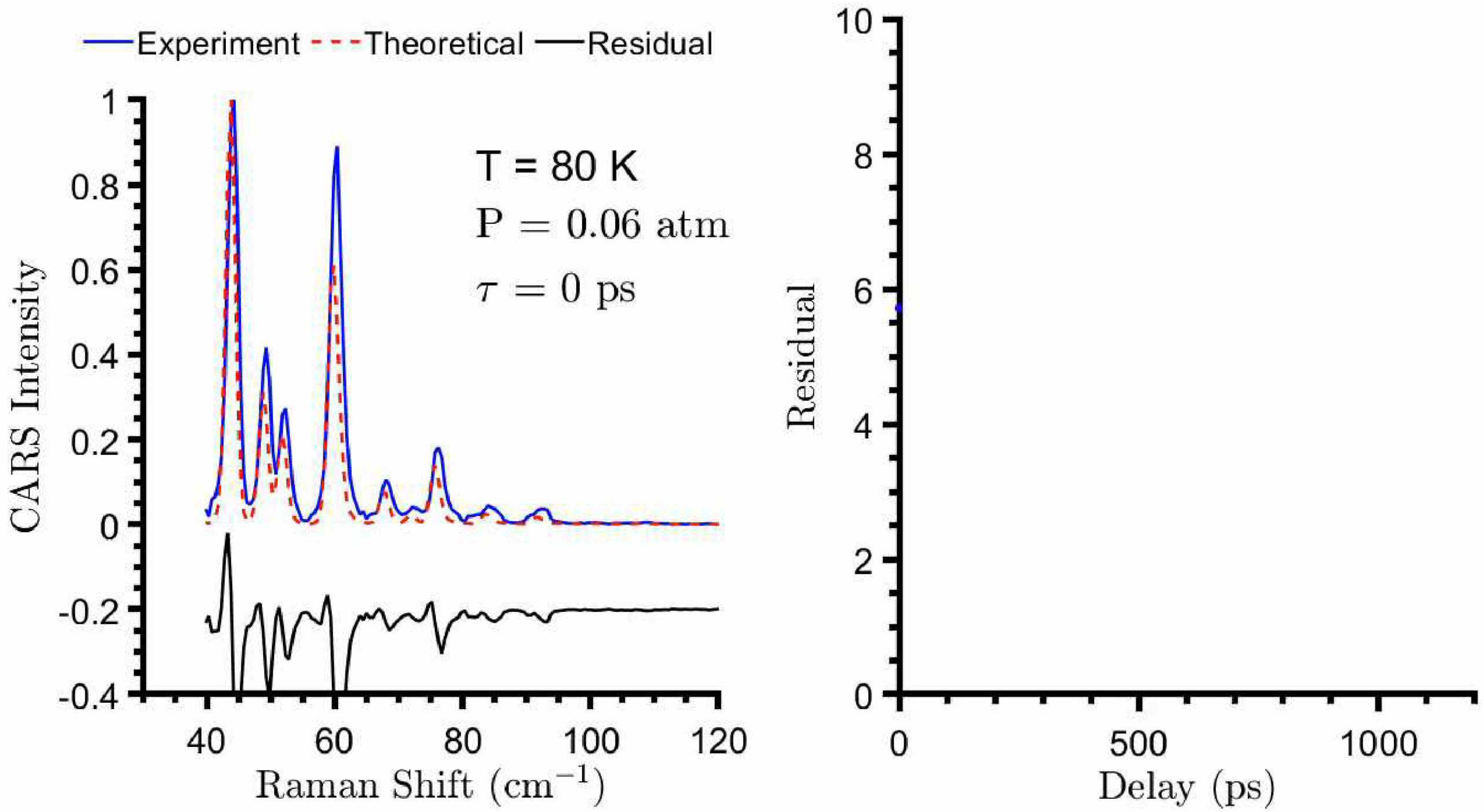




Faster decay, higher the pressure

Temperature-Pressure CARS

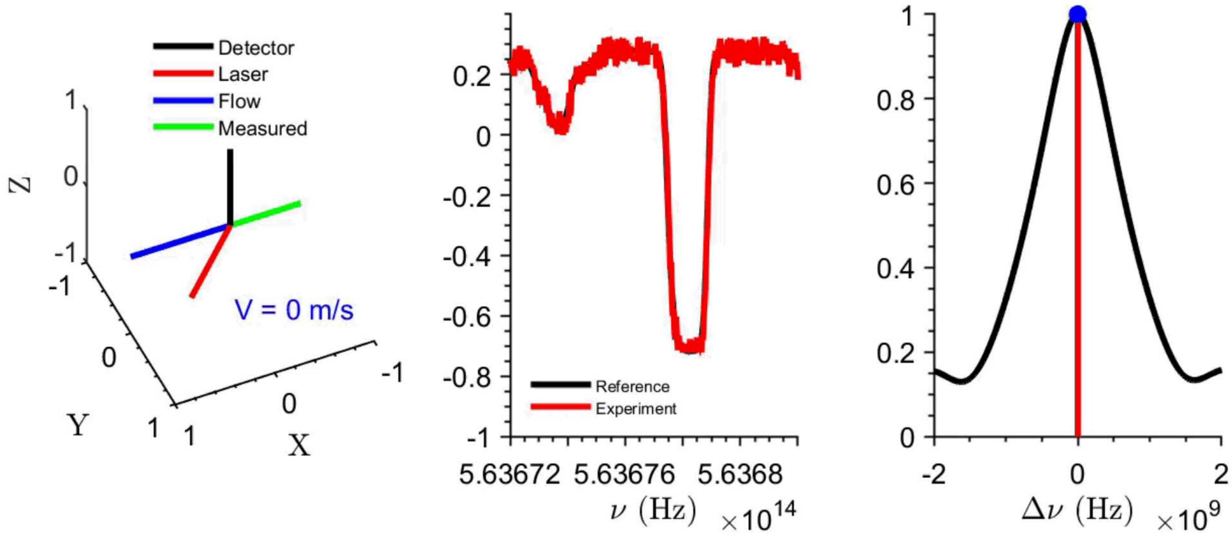
Comparison of our collisional model to real data:



CC-DGV

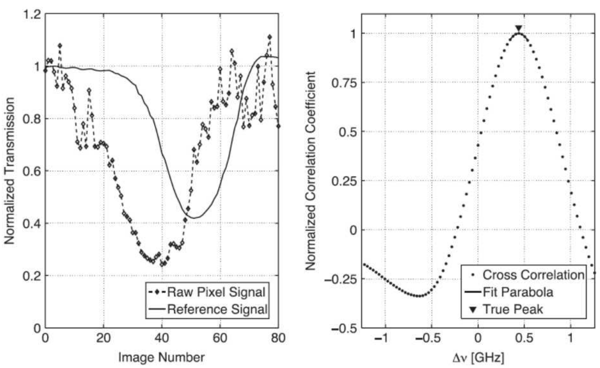
Cross-Correlation Doppler Global Velocimetry. Main Idea:

- More robust version of traditional DGV



Not a new idea:

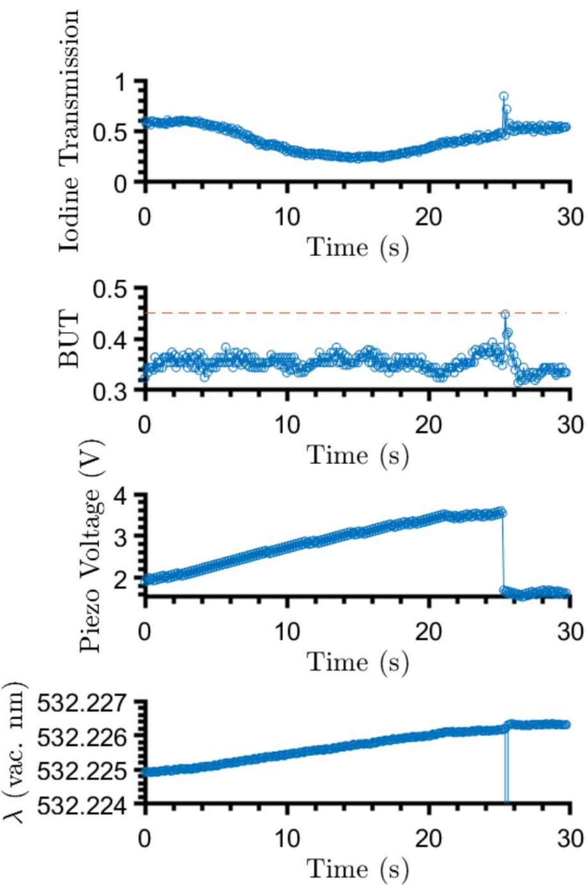
- **Scan every 2-4 minutes**



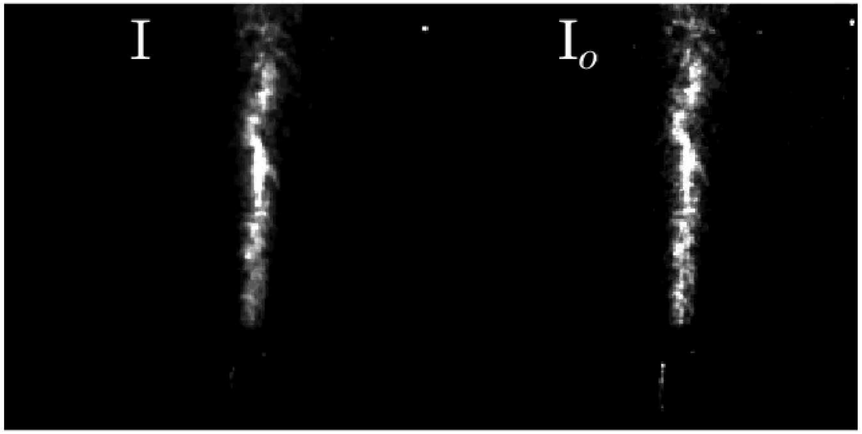
Cadel et al., "Cross-correlation Doppler global velocimetry (CC-DGV)", Optics and Lasers, 2015

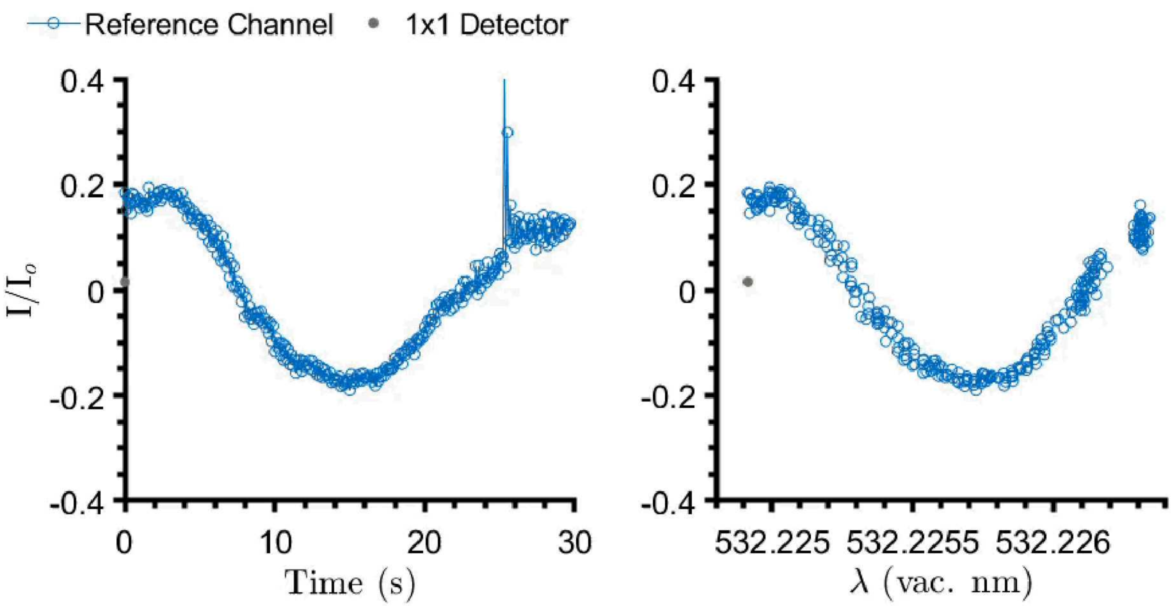
CC-DGV

Our attempt at scanning at 10 Hz:



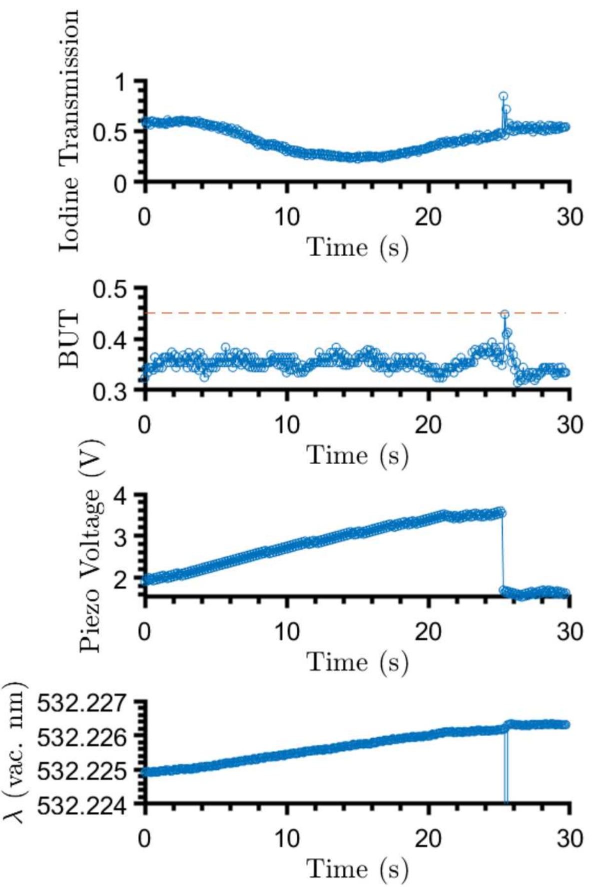
Single pixel, raw data:



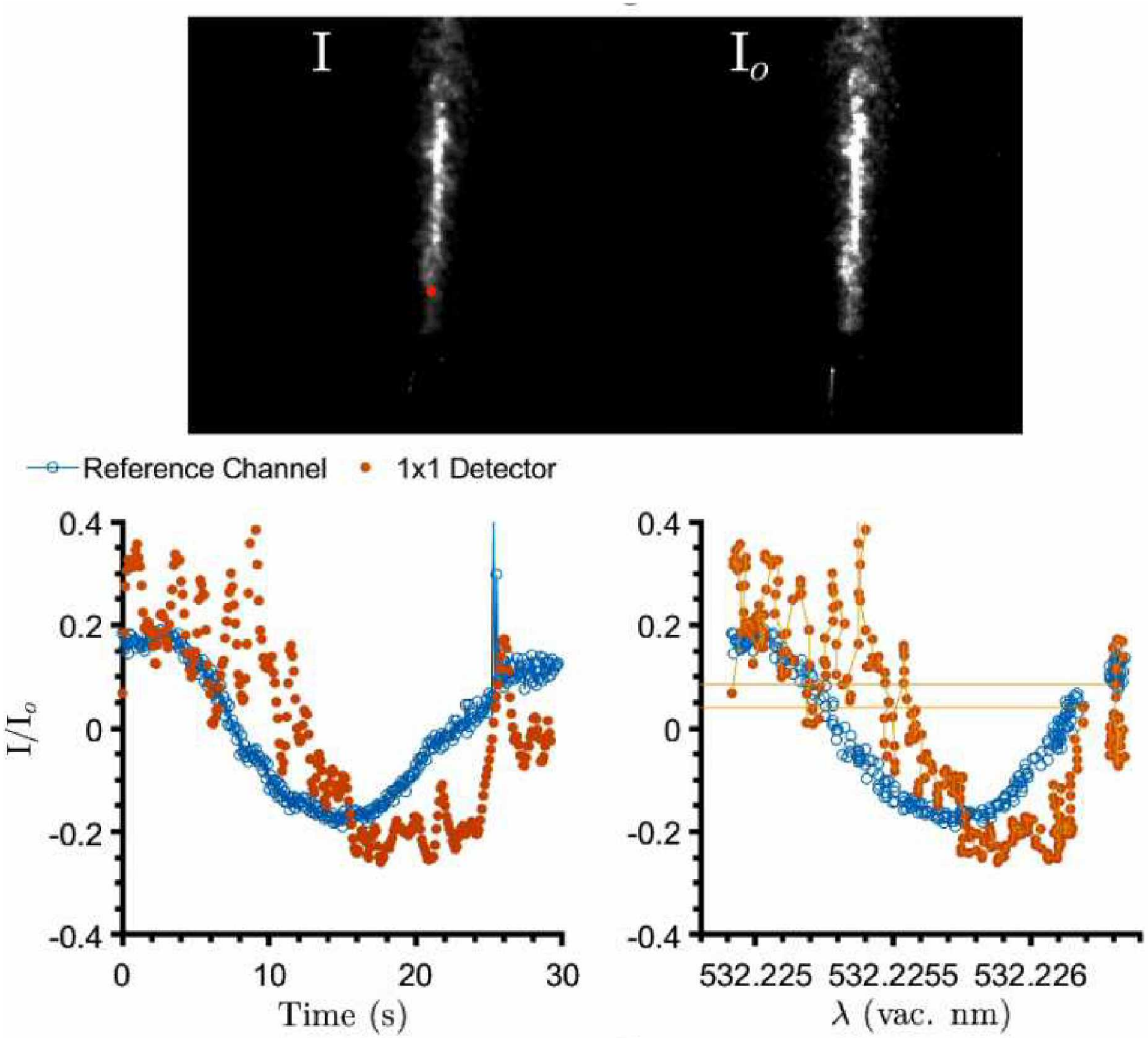


CC-DGV

Our attempt at scanning at 10 Hz:

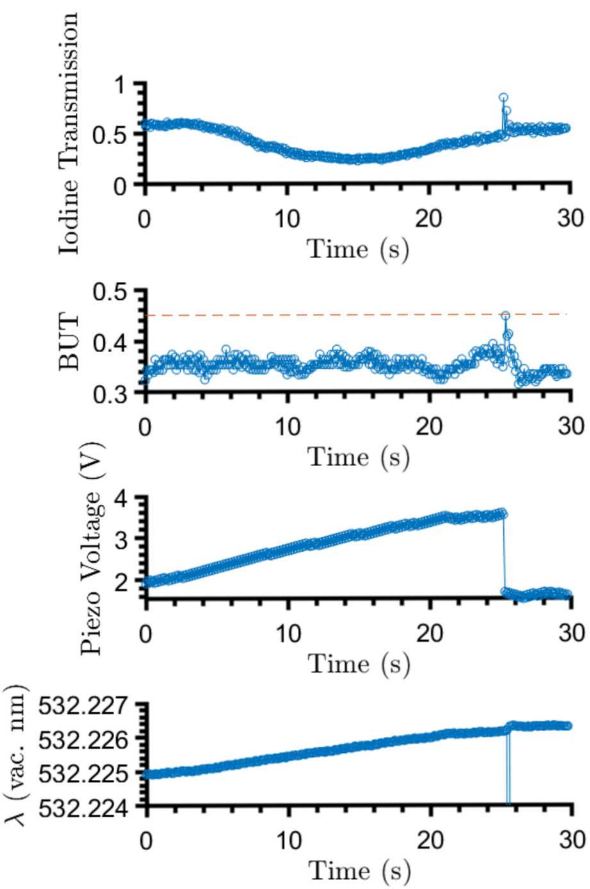


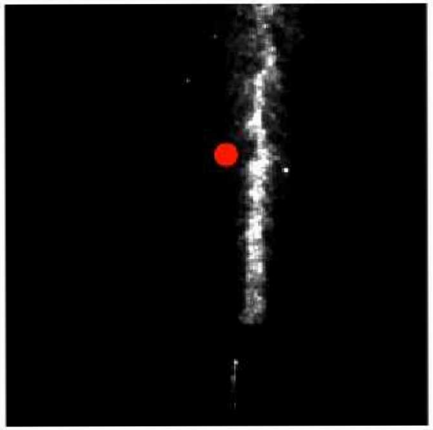
Single pixel, smoothed data:

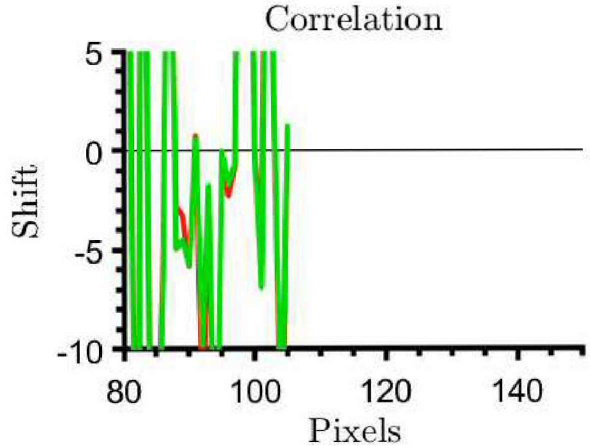


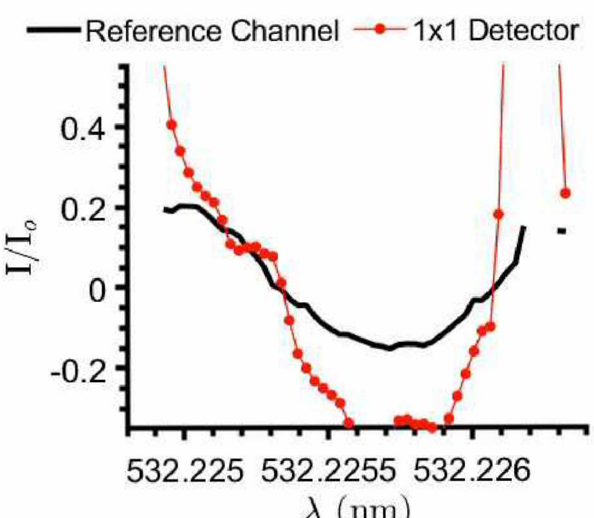
CC-DGV

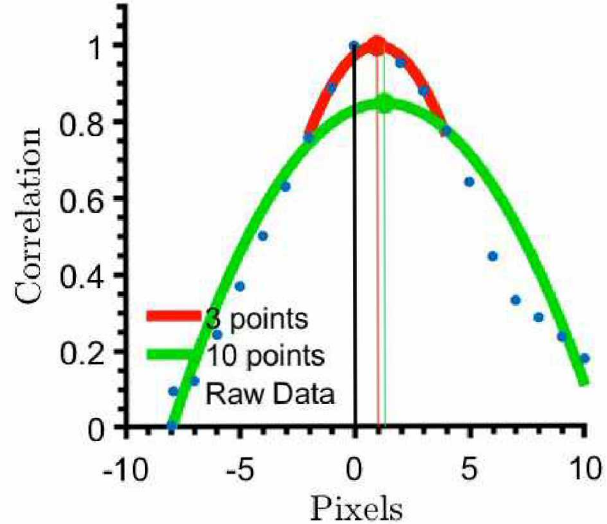
View the correlations for different points in the jet:





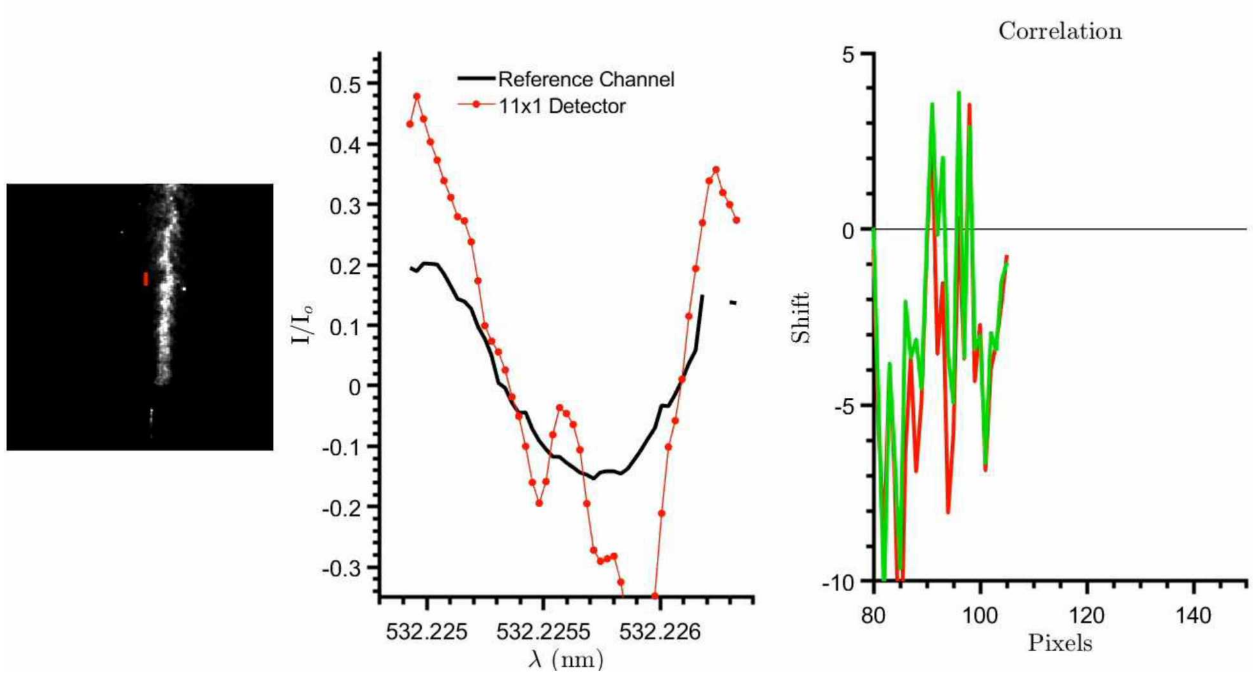




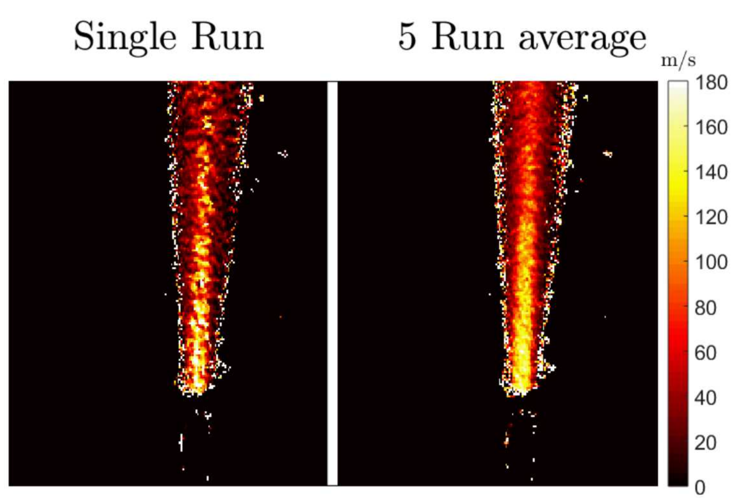


CC-DGV

Now average some pixels to improve the S/N:

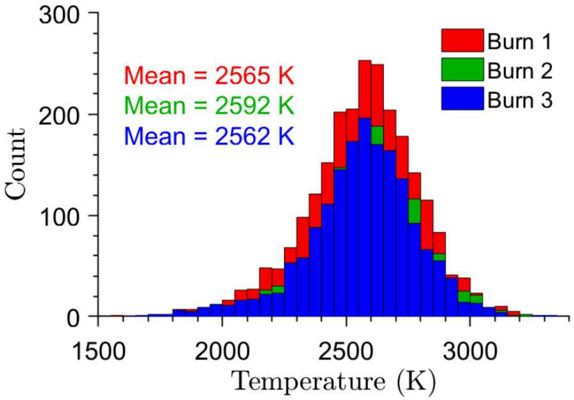


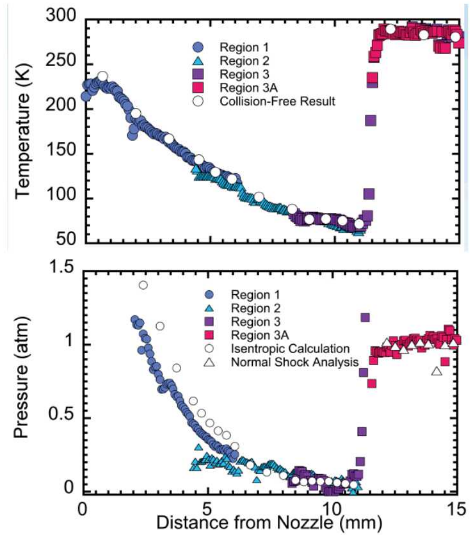
Shift related back to velocity:

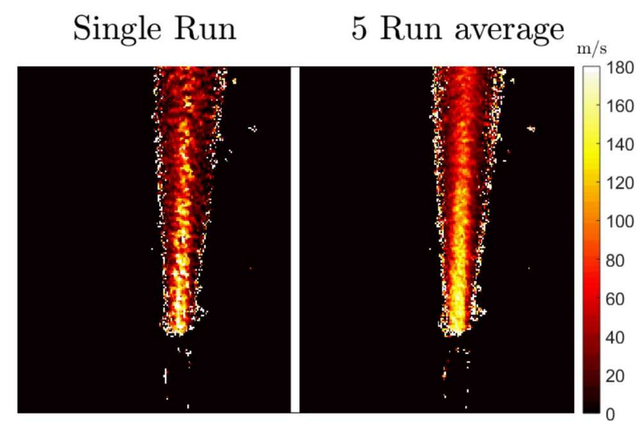


Concluding Thoughts

Diagnostic development → Improved measurements → Improved physical understand







This presentation describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the presentation do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

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. SAND ######

Thank you! Questions?