



# Hydrogen Femtosecond Vibrational CARS Thermometry in Solid Propellant Flames

Daniel Richardson, Sean Kearney, Daniel Guildenbecher  
Sandia National Laboratories

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# Introduction

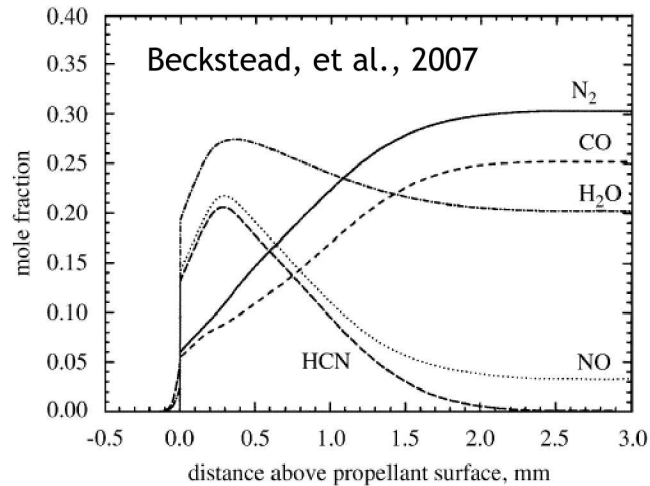
## Sandia Mission Space:

- DOE strategic systems safety
- Defense systems
- Homeland security
- Energy
- Large scale/challenging environments

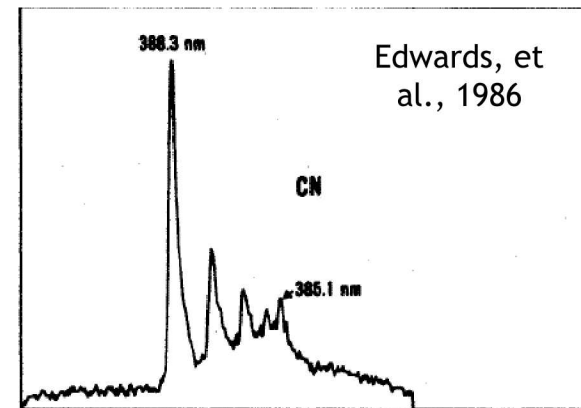


# Previous Research: Propellant Combustion

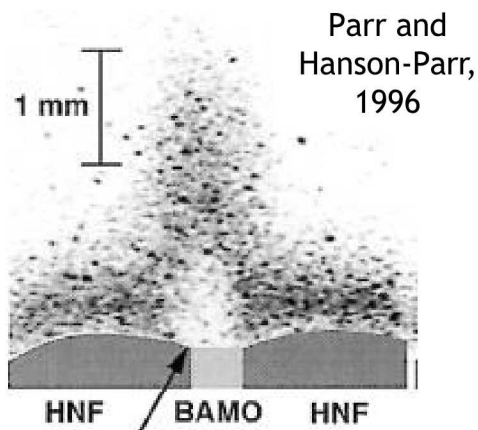
## Modeling Efforts



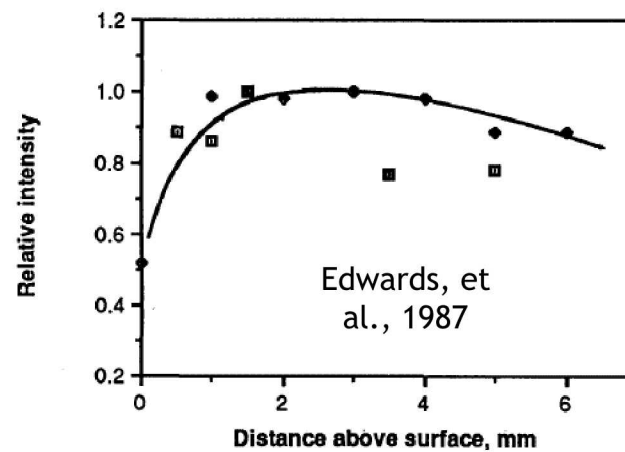
## Emission Spectroscopy



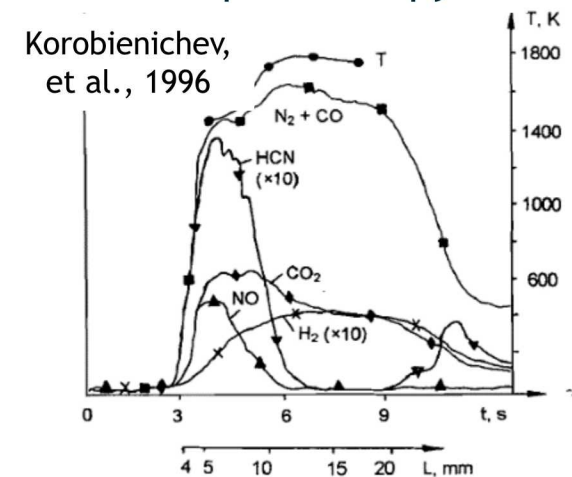
## CN PLIF



## OH LIF

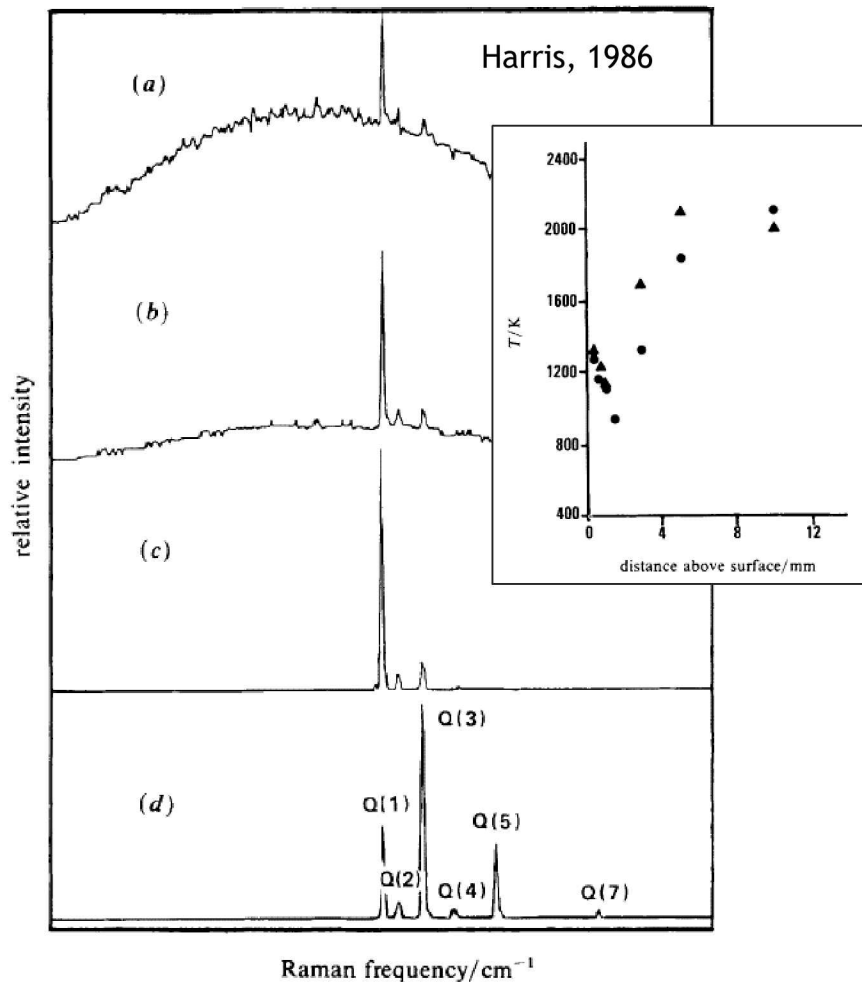


## Mass Spectroscopy

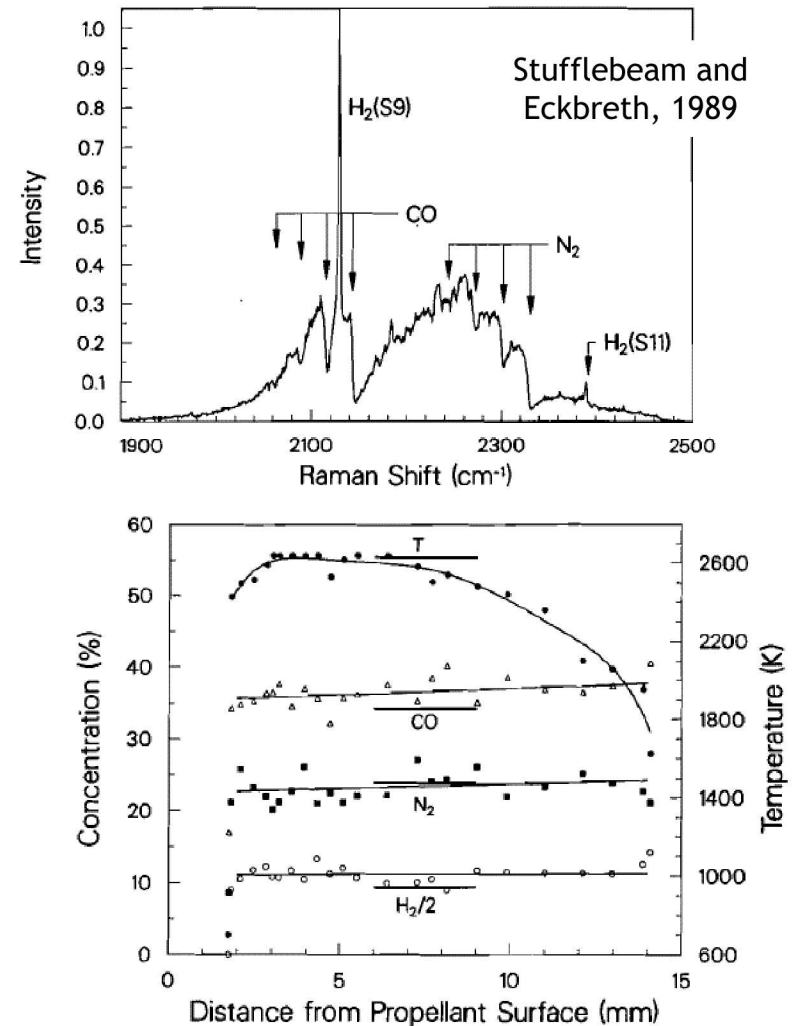


# Previous Research: Propellant Combustion

## H<sub>2</sub> ns CARS



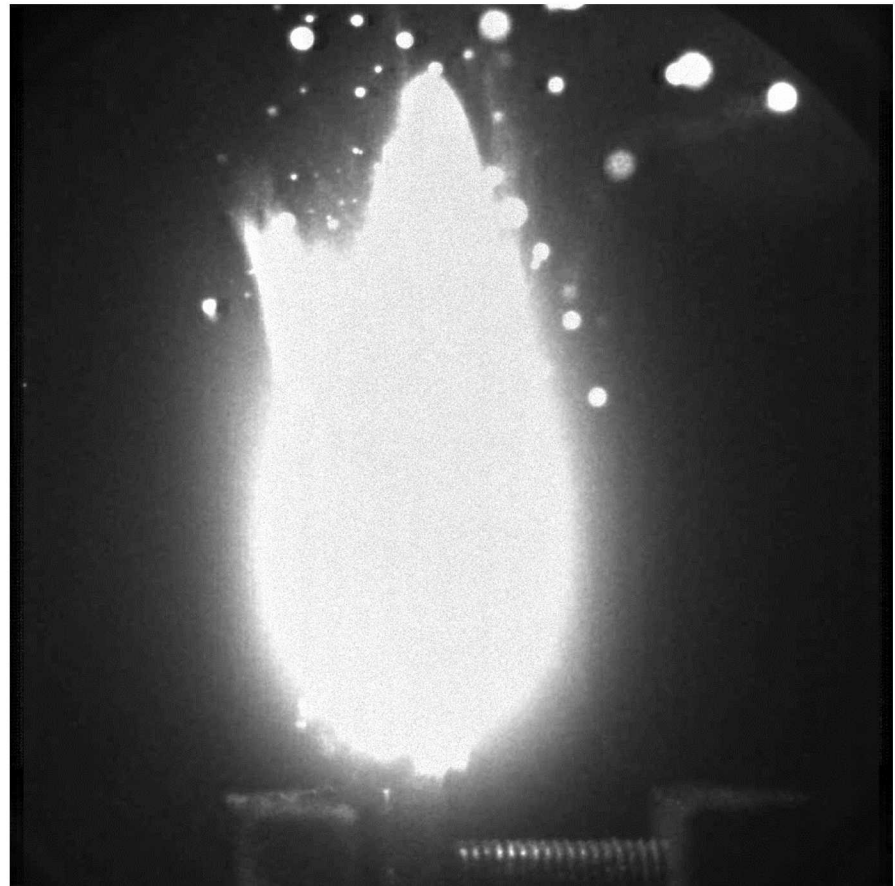
## Multi-Broadband ns CARS



# Metalized Propellant Combustion

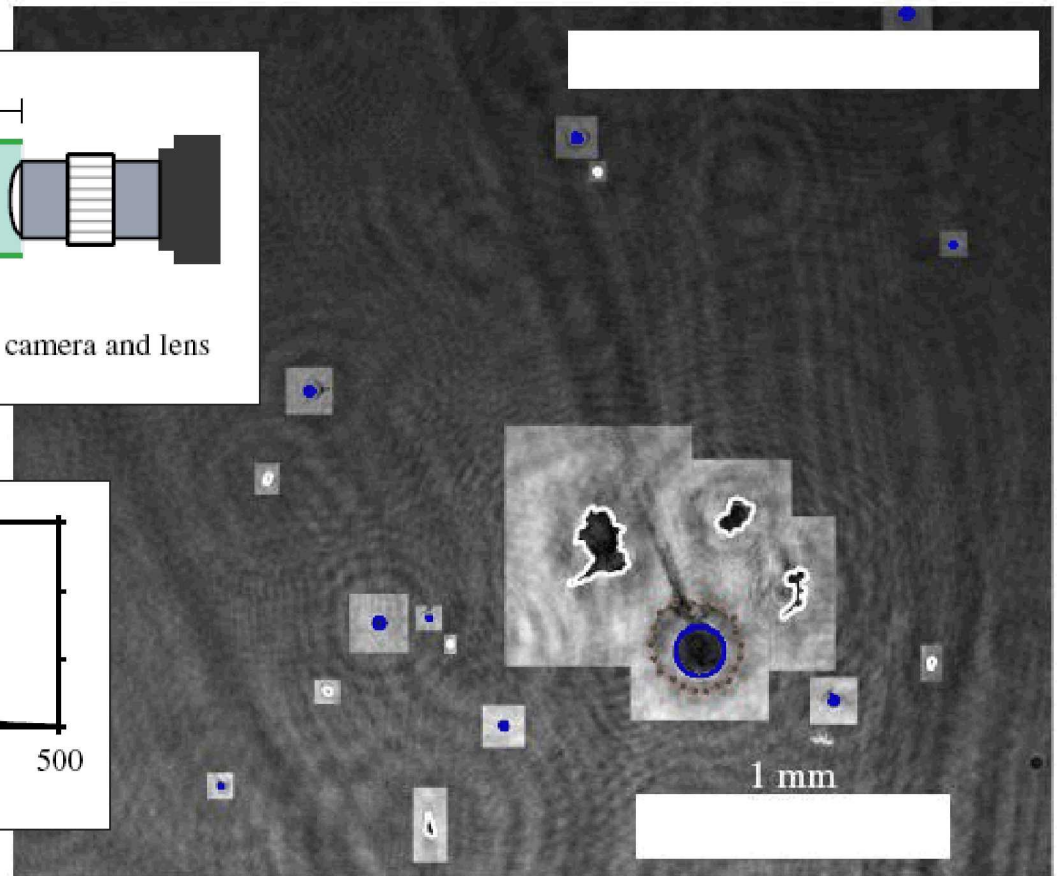
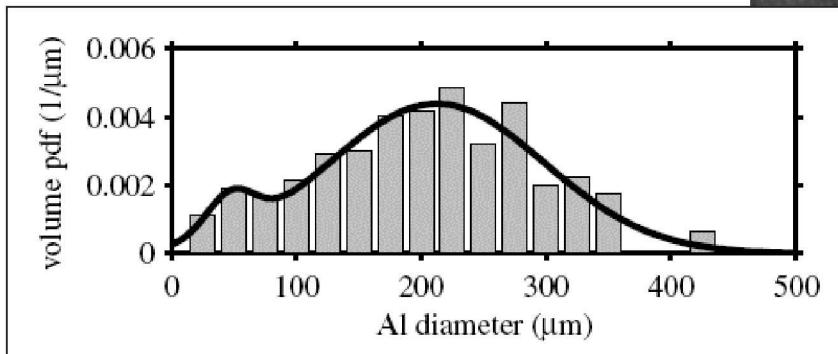
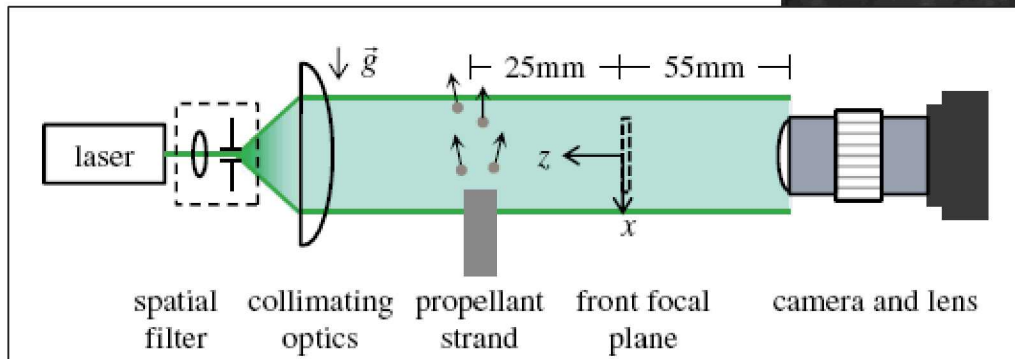
## Challenging Diagnostic Environment:

- Temperatures  $>3000$  K
- 10-300  $\mu\text{m}$  particles
- Bright flames
- Complex chemistry



# 6 Metalized Propellant Combustion

## Particle Size Measurements via DIH



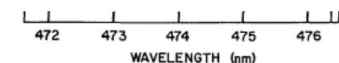
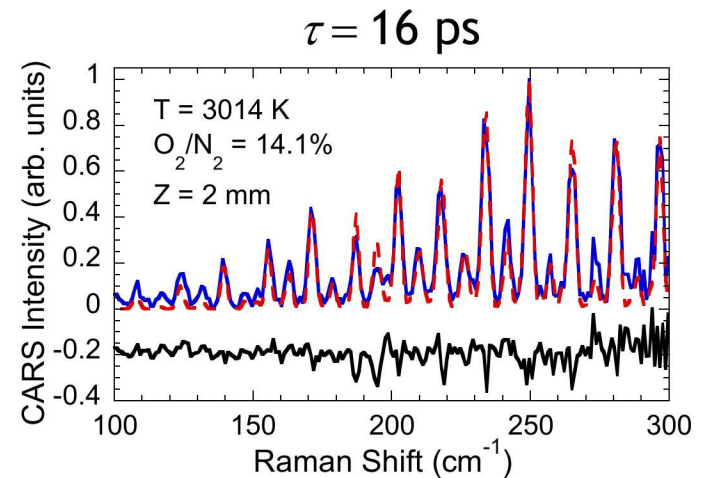
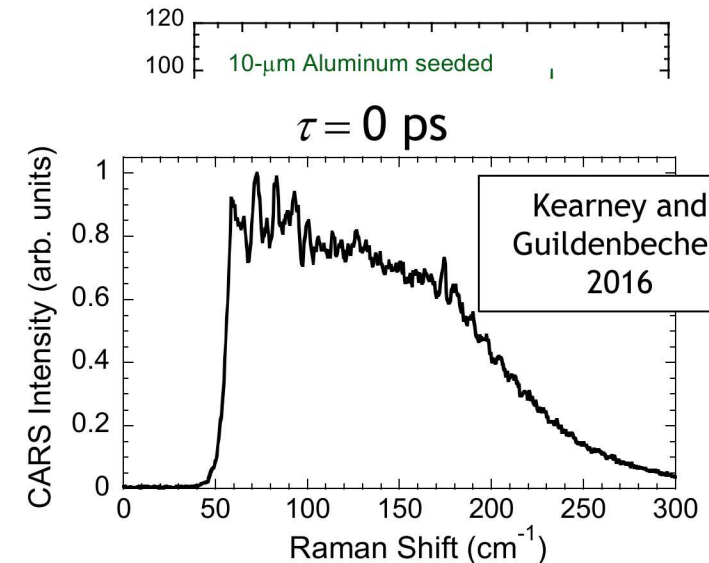
# Metalized Propellant Combustion

## Metalized Propellant is Challenging!

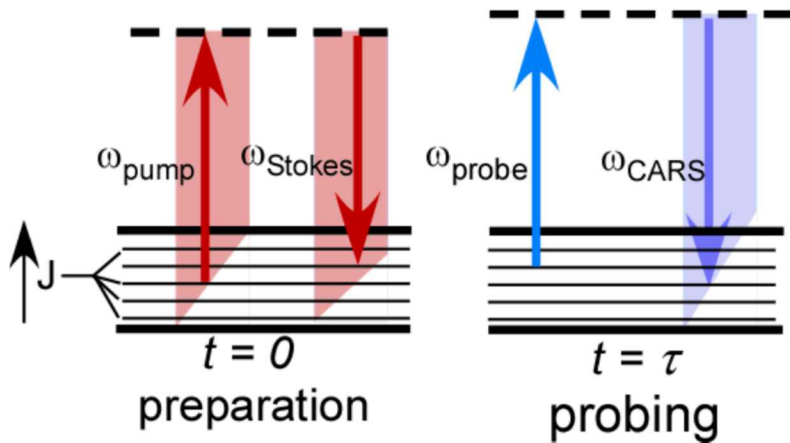
- ns CARS measurements did not work
  - Metal particle induced breakdown
  - High nonresonant background levels
  - Similar to breakdown in coal combustion!

## Advantages of fs/ps CARS

- fs/ps Pulse energies much less than with ns lasers
  - Less chance of breakdown
- Nonresonant background decays quickly after pump pulse
  - Avoid nonresonant background via probe time delays



# N<sub>2</sub> Rotational fs/ps CARS



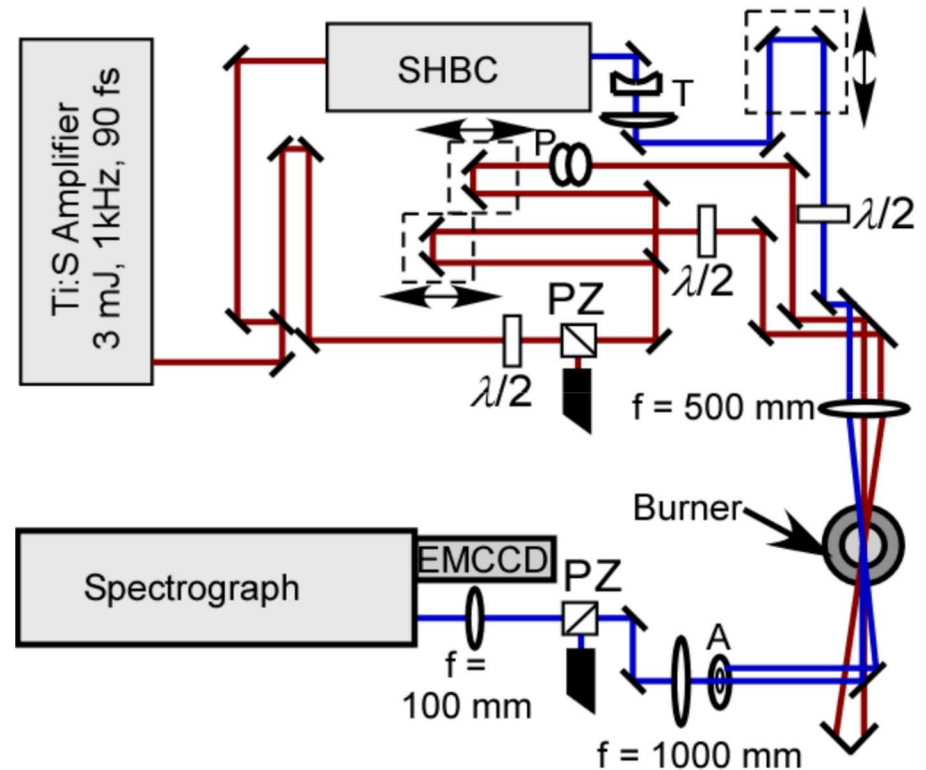
## Second harmonic bandwidth compressor:

- 800-nm fs pulses to 400-nm ps pulses
- Split input, apply equal and opposite chirp, then sum-frequency-mixing
- 35-50% efficient
- 400-nm bandwidth < 3.5 cm<sup>-1</sup>

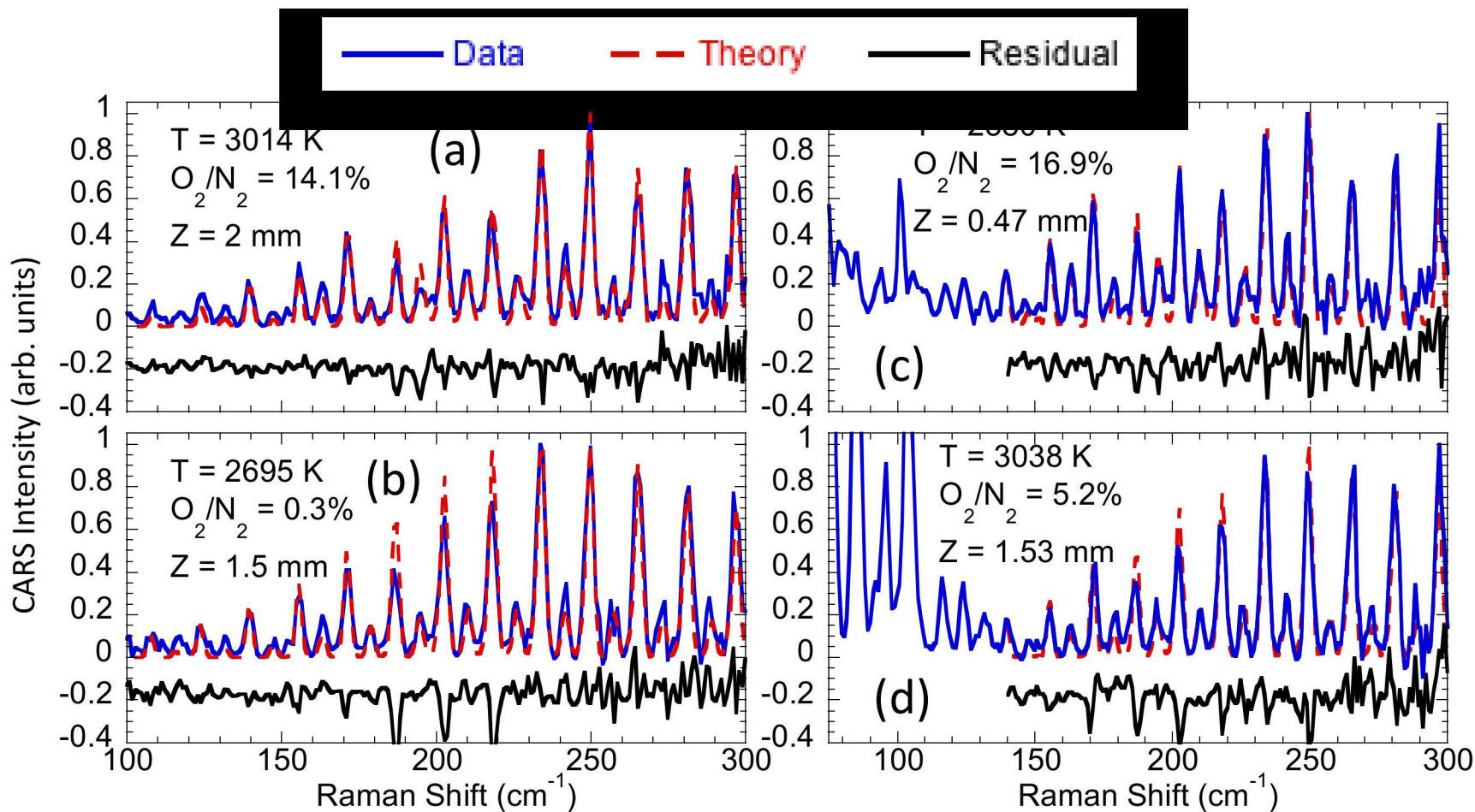
$$E_{\text{CARS}}(t - \tau) = E_{\text{probe}}(t - \tau) \times \chi(t)$$

$$\chi = \sum_J W_J \exp(i \omega_J t)$$

$$W_J = X \gamma^2 b_{JJ'} (N_{J'} - N_J)$$



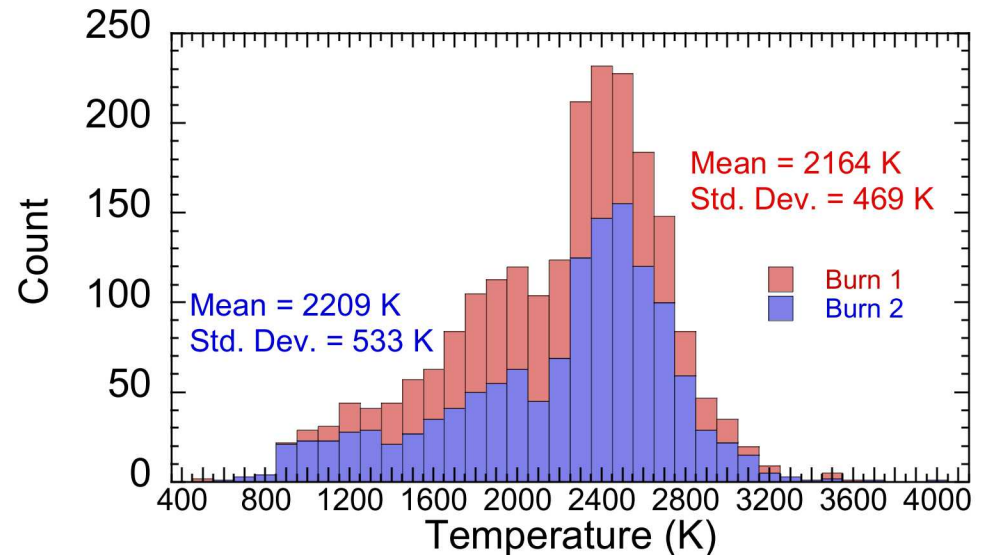
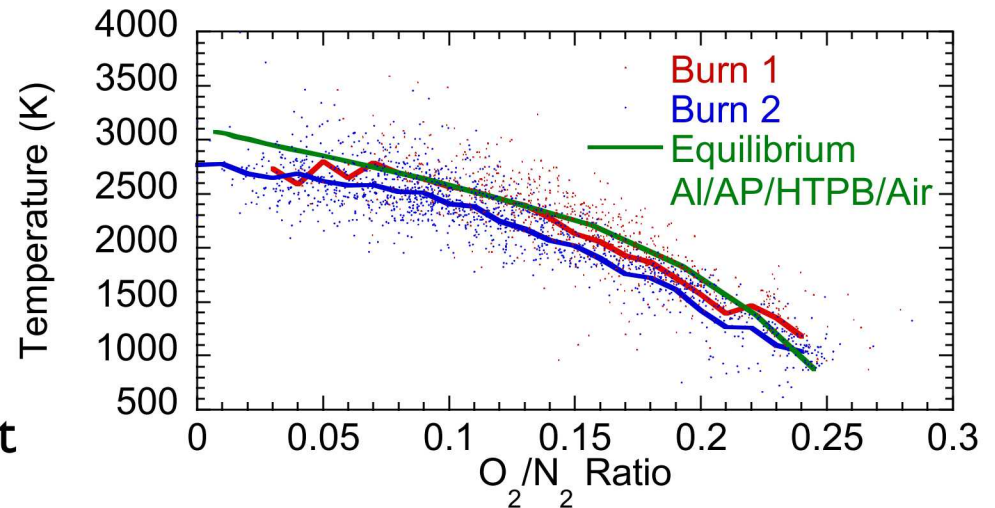
# 9 Results: N<sub>2</sub> Rotational fs/ps CARS



# N<sub>2</sub> Rotational fs/ps CARS

## Results

- CARS measurements performed within 3 mm of propellant surface
- No breakdown, nonresonant background or loss of resonant Raman signal
- Spectra dominated by N<sub>2</sub> and O<sub>2</sub> contributions
  - Cl<sub>2</sub>; HCl; NO; NO<sub>2</sub> also present
- Temperature and N<sub>2</sub>/O<sub>2</sub> ratio close to adiabatic equilibrium

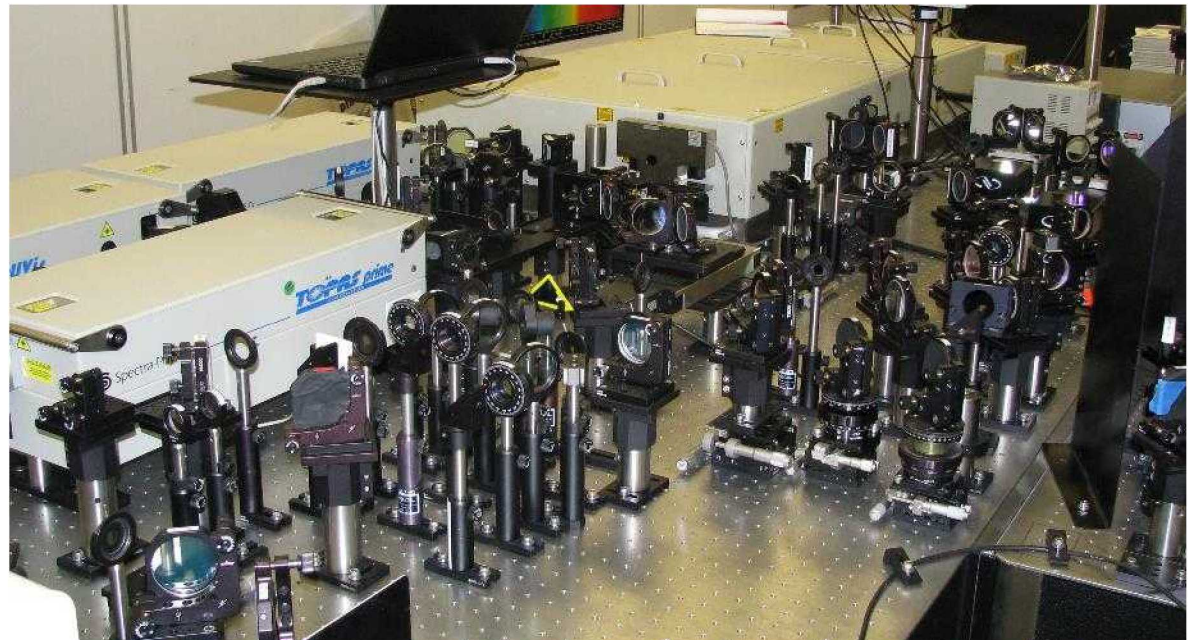
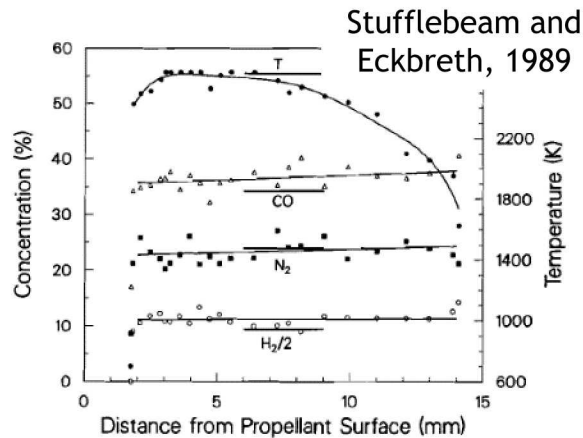
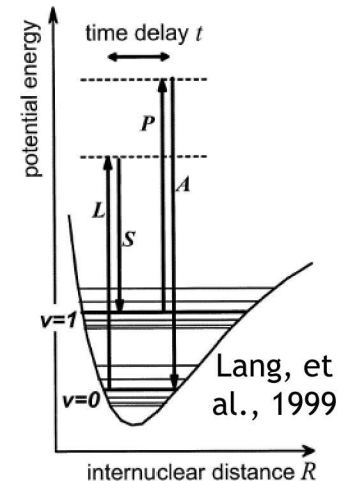
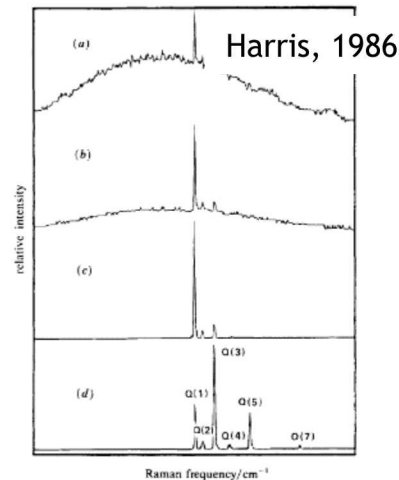


# Future Work: H<sub>2</sub> Vibrational fs/ps CARS

## Future Improvements

- Switch to vibrational CARS for better temperature sensitivity
- Tunable vibrational excitation to H<sub>2</sub>, CO, or other species
- Reduce probe volume size

## H<sub>2</sub> ns CARS



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