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Hybrid fs/ps CARS for Sooting and Metalized Flames

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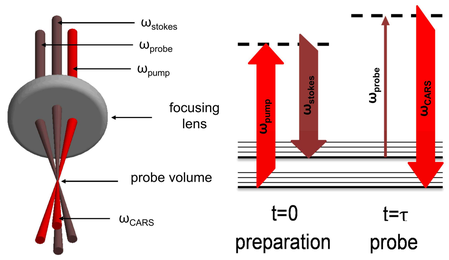
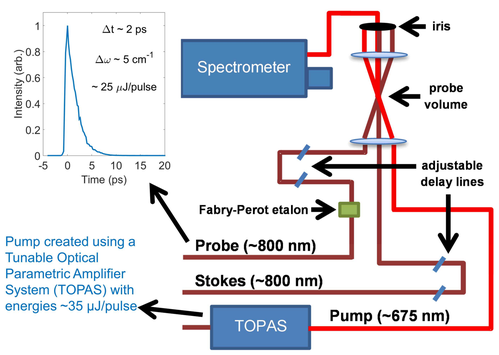
1. Hybrid fs/ps Vibrational CARS

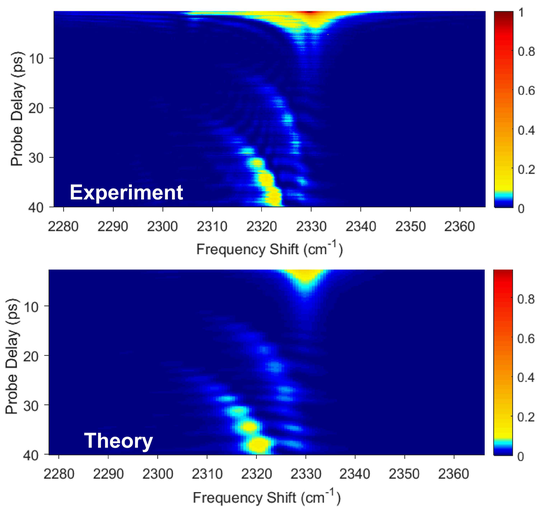


- Rotational coherence is prepared by a femtosecond and nearly Fourier transform-limited pump/Stokes pair
- Broad bandwidth and well-defined phase relationships provide efficient, low-noise Raman preparation
- A frequency narrow (~5 cm^{-1}) probe beam is introduced at delay, τ



Pump created using a Tunable Optical Parametric Amplifier System (TOPAS) with energies ~35 μJ/pulse

- Measurement validated in furnace heated air up to 1300 K
- Modeled and measured spectra compare favorably (probe delays of τ = 0.5 to 40 considered)



Time-dependence of fs/ps CARS spectra at 1300K

- Overall good agreement between the experiment and our vibrational CARS model
- Some difficulty mapping spectra into wavelength space (fewer wavelengths to match than with rotational CARS

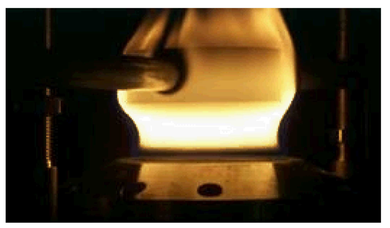
References:

Miller, Joseph D., Chloe E. Dedic, and Terrence R. Meyer. *Journal of Raman Spectroscopy* (2015).
Vestin, Fredrik, et al. *Proceedings of the Combustion Institute* 30.1 (2005): 1673-1680.

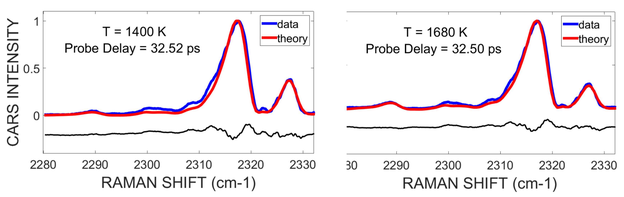
2. Applications of Hybrid fs/ps Vibrational CARS in Sooting Flames

Initial Tests in Sooting McKenna Burner Stabilized Flames

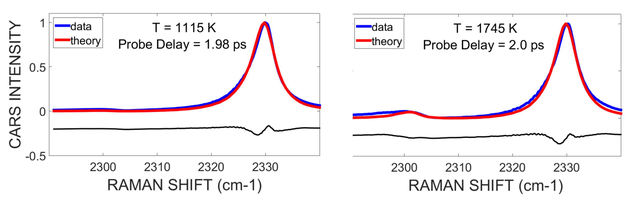
- Validated accuracy of signals averaged over 200 laser shots
- Performed in McKenna Burner with stabilization plate 21mm above burner surface
- Measurement volume height above burner surface varied at Φ = 2.1
- Equivalence Ratio varied (.5 < Φ < 3.0) at ~8.5 mm above burner surface
- Temperatures Ranged ~1200 K – 1700 K



McKenna Burner Stabilized Flame
From liiscience.org



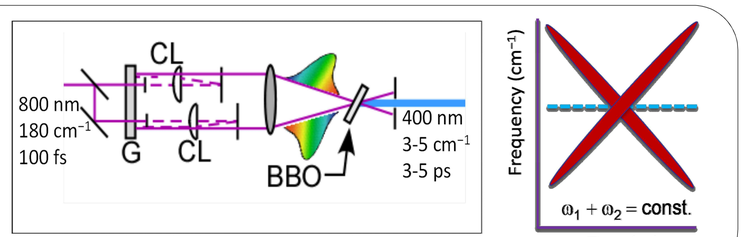
Sample vCARS Spectra at τ = 32.5 ps



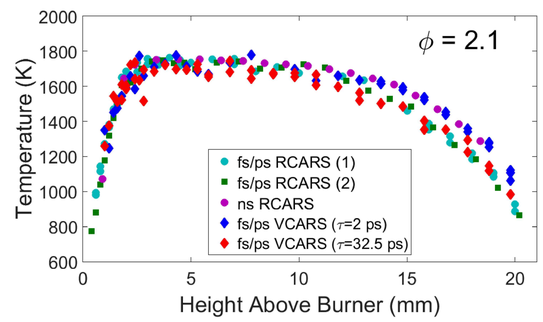
Sample vCARS Spectra at τ = 2.0 ps

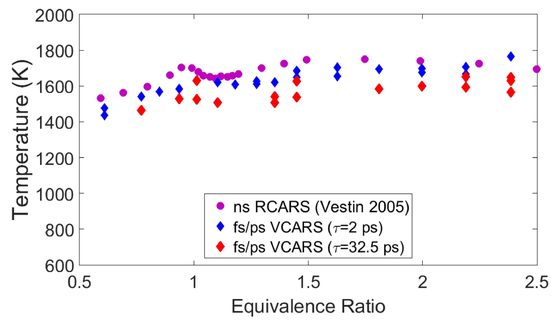
Future Work:

- Integrate SHBC into vCARS setup
- Increased probe energies will allow for measurements in sootier environments
- Measure gas-phase temperatures in solid rocket propellant burns (see below)



Second Harmonic Bandwidth Compression (SHBC)

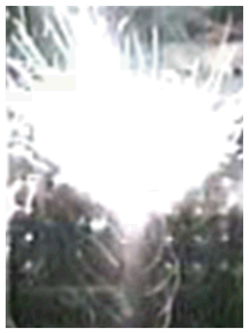




Comparison of CARS Measurements in McKenna Flames

- Overall initial data shows good agreement with previous measurements
- Data taken with a probe delay of 2 ps shows promise, particularly due to its higher signal levels (and SNR)

3. Toward Total Heat Flux Measurements in Aluminized Solid Rocket Propellant Burns

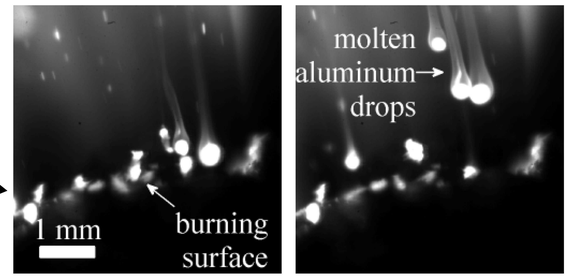


Extremely hostile environment for diagnostics

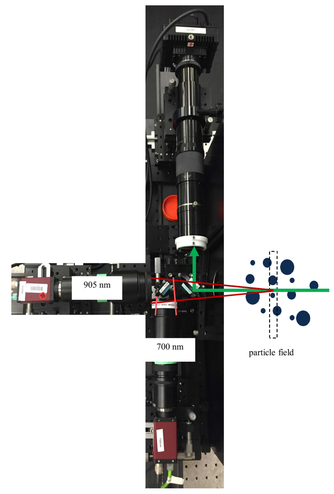
- Very high temperatures – fluctuations over 3,000K
- Dense field of large molten metal particles (diameters ~10-100mm)

Goal is Total Heat Flux Measurements

- Gas-phase temperature (fs/ps CARS)
- Particle temperature (two-color pyrometry)
- Particle size distribution (Digital Inline Holography – DIH)
- Particle velocity distribution (high-speed Digital Inline Holography – DIH)



High-speed Imaging of Propellant Burn

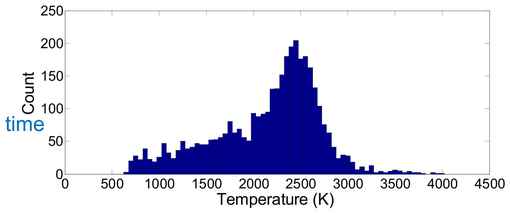


Two-Color Pyrometry Experiment in Development

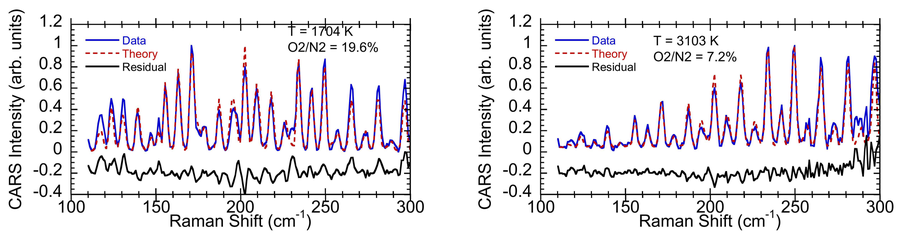
Proof-of-concept using existing rotational CARS instrument in aluminized solid rocket propellants

- >20,000 Spectra used for temperature measurements
- Generated gas-phase temperature pdf over ~12 sec burn time
- Rotational CARS not generally used at such high temperatures (median ~ 2300 K)

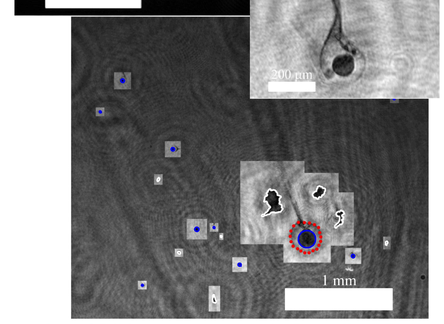
Switch to vibrational CARS for future experiments



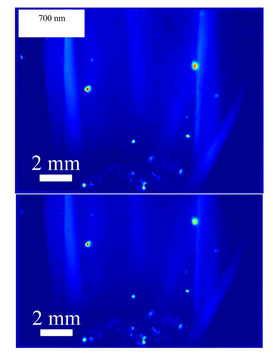
Gas-phase Temperature Distribution (rCARS)



Sample rotational CARS spectra taken in Propellant Burns



Examples of DIH measurements in Propellant Burns



Uncalibrated Pyrometry Results

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