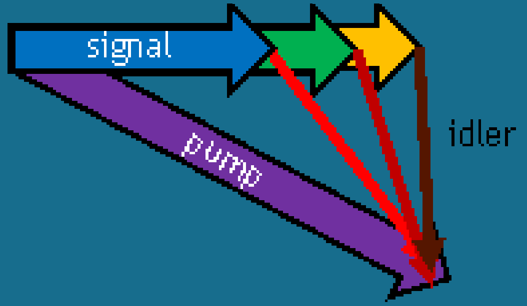
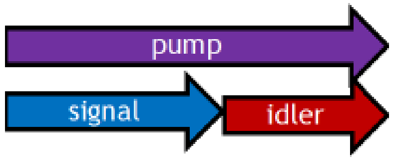
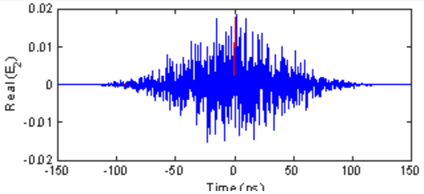
SAND2021-14875C

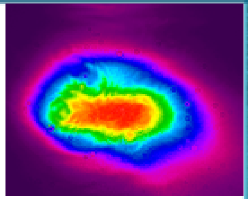
Sandia National Laboratories

Demonstration of a Burst-Mode-Pumped Noncolinear Optical Parametric Oscillator (NOPO) for Broadband CARS Diagnostics in Gases









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January 4th, 2022; AIAA-2022

AMT-09, Spectroscopic Techniques such as PLIF, CARS, LIBS, Raman Scattering, and Absorption Spectroscopy II

U.S. DEPARTMENT OF ENERGY NNSA

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Tunable burst-mode coherent anti-Stokes Raman Scattering (CARS)

Motivation: Develop a broadband tunable ns source for CARS thermometry measurements at 100 kHz data acquisition rate.

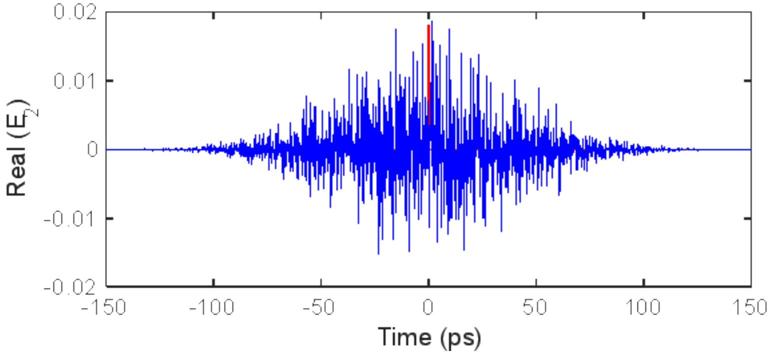
To achieve necessary speed we are using a burst-mode laser for which has pulse repetition rates up to several hundred kHz.

- ➢ But lacks tunability needed for CARS!

Time-Bandwidth Product

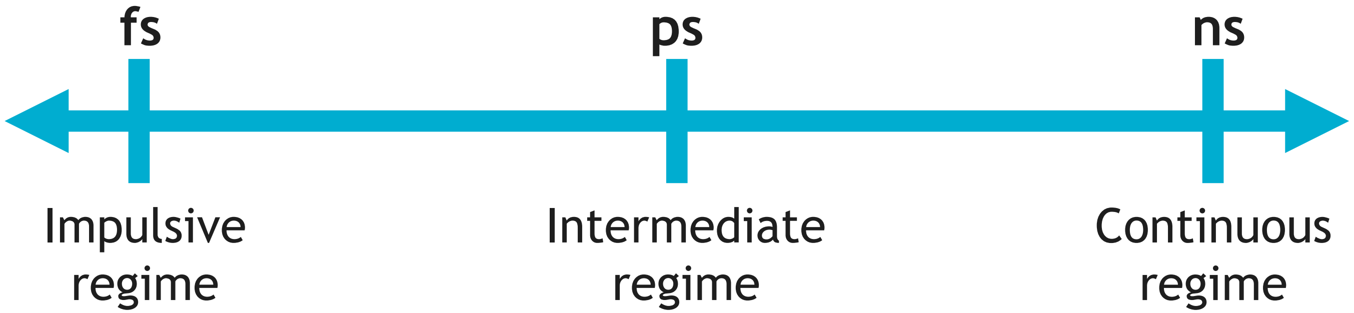
$$\Delta t\left[\mathrm{ps}\right]\Delta\omega\left[\mathrm{cm}^{-1}\right] \geq 14.67$$

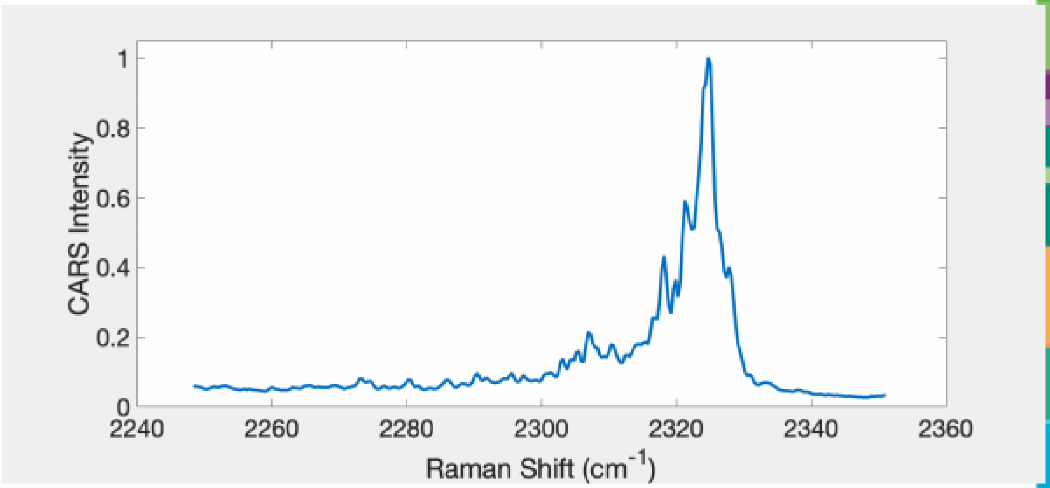
$$\Delta \quad = 150 \quad ^{-1} \approx 100$$



Recent development of ps-optical parametric generators (OPGs) has allowed for ps-CARS measurements in shock tubes!

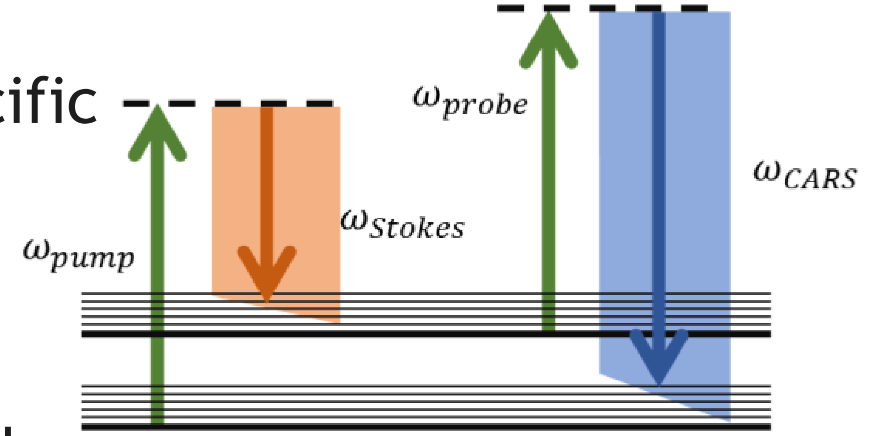
- ps-CARS spectra typically have much more noise due to the lack of averaging and the noise in the broadband pulses
  - 50-60 ps = 0.5-2 Raman lifetimes
  - 10 ns = hundreds of Raman lifetimes
- ps-CARS modeling uncertainties
  - Pulse width, pulse delays, pulse shapes are important factors



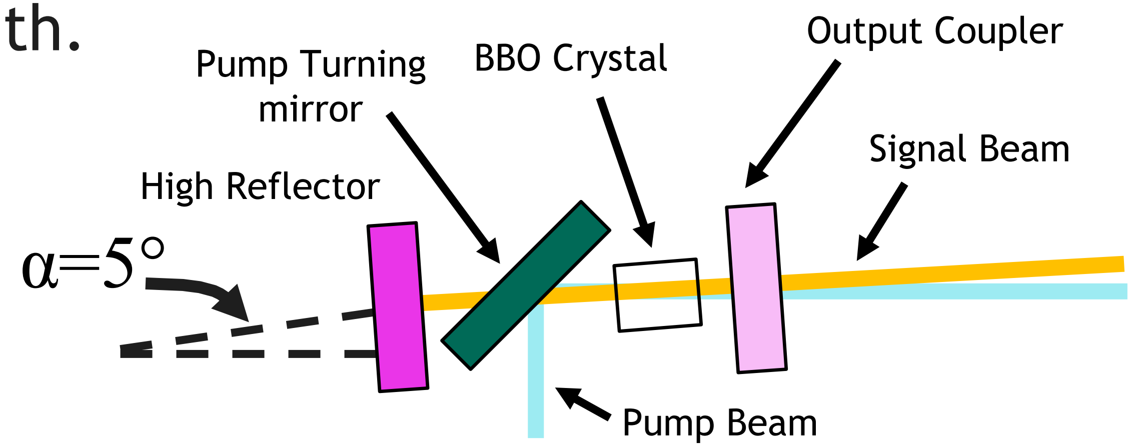


Non-collinear Optical Parametric Oscillator (NOPO)

- CARS measurements require a broadband, species specific wavelength.
  - ➢ **Generate broadband 607 nm for N_2 vibrational CARS.**

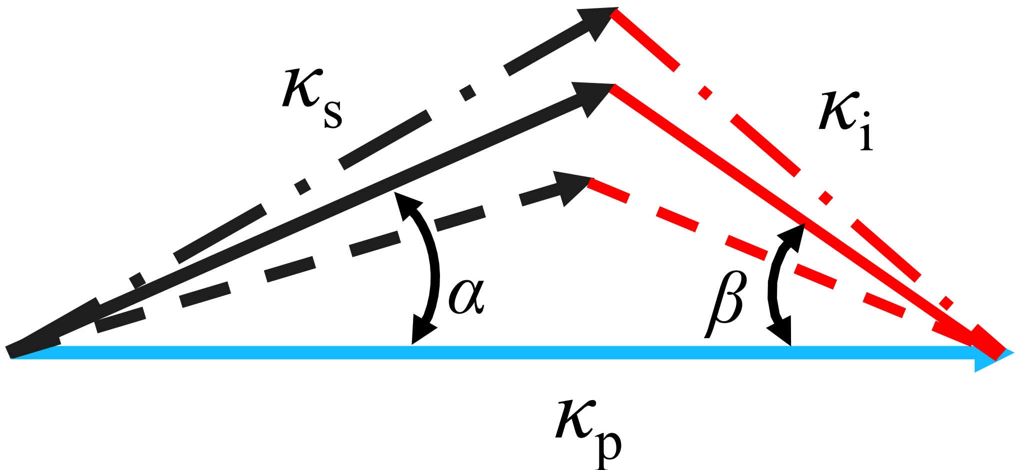


- OPO axis is tilted with respect to beam. Matching of group velocities in the NOPO allows to access for broad bandwidth.



Phase-matching diagram

Pump, k_p – 355 nm
Signal, k_s – 607 nm
Idler, k_i – 855 nm

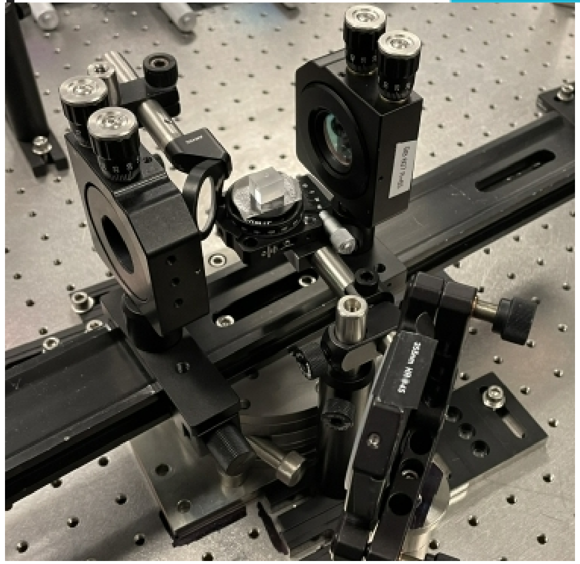


$$FWHM_{NOPO} = \frac{0.53\sqrt{\frac{\Gamma}{l_c}}}{c\left(\frac{1}{v_s} - \frac{1}{v_i}\right)}$$

= group velocity of signal beam

= group velocity of idler beam

Experimental Set-up for 40 kHz CARS system

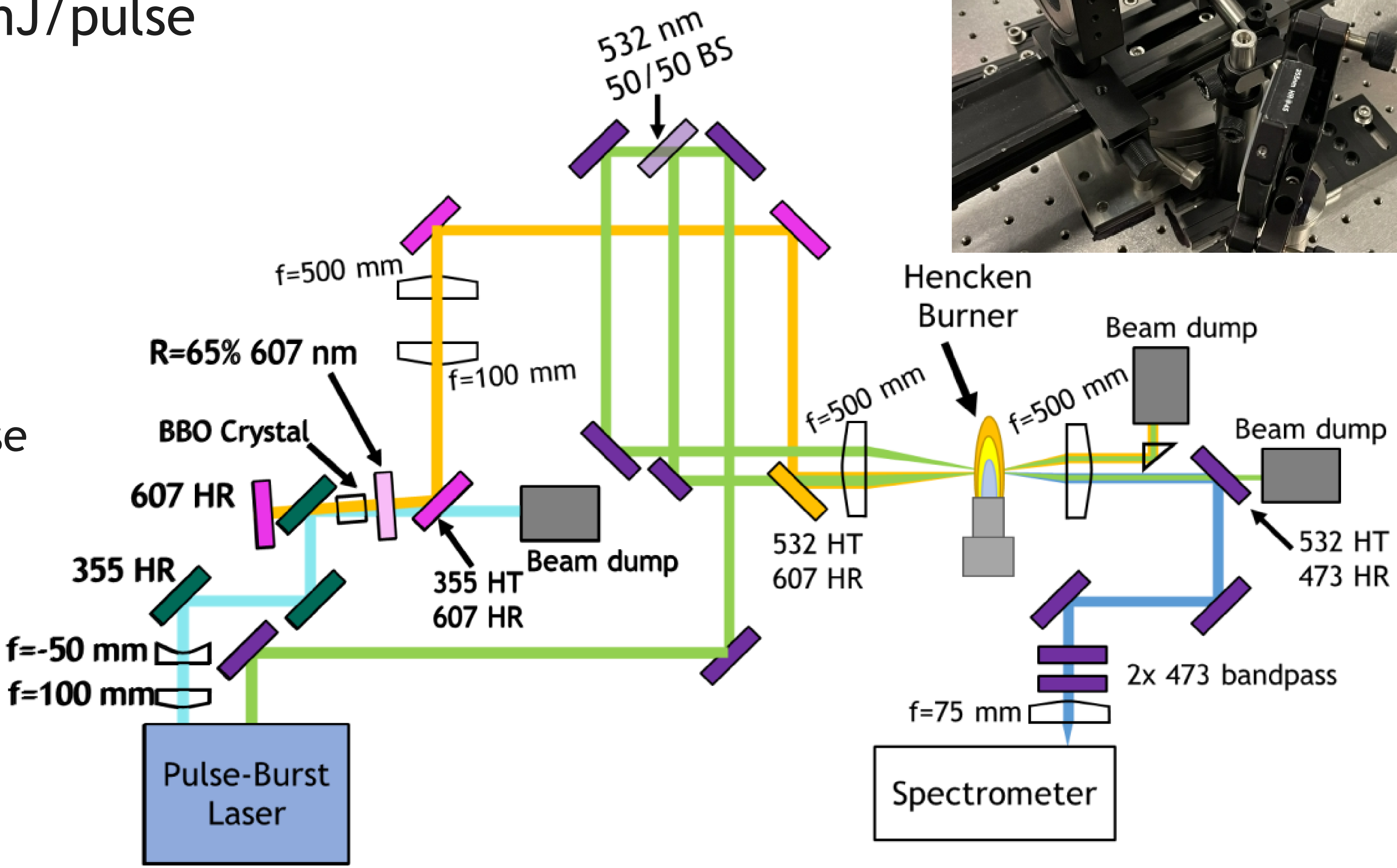


Pulse Burst Laser/NOPO:

- 1.5 ms burst @ 40 kHz for 45 pulses
- 355 nm pump beam: 50 mJ/pulse
- 9 cm cavity length
- Cavity tilt angle of 5°

BOXCARS set-up

- Pump/probe beam: 40 mJ/pulse
- 0.5m spectrometer with PI ProEM EMCCD for 40 kHz

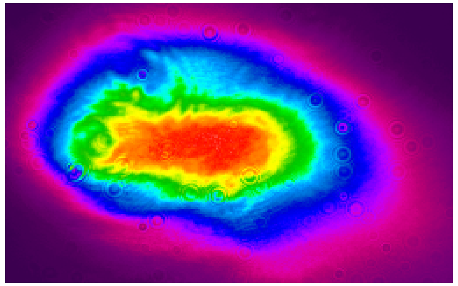


NOPO performance at 40 kHz

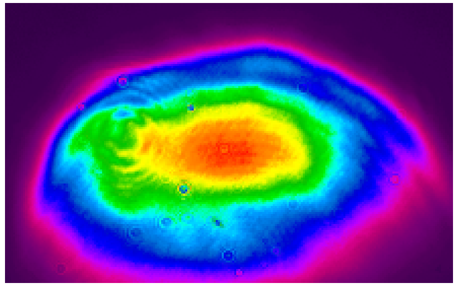
OPO Characteristics

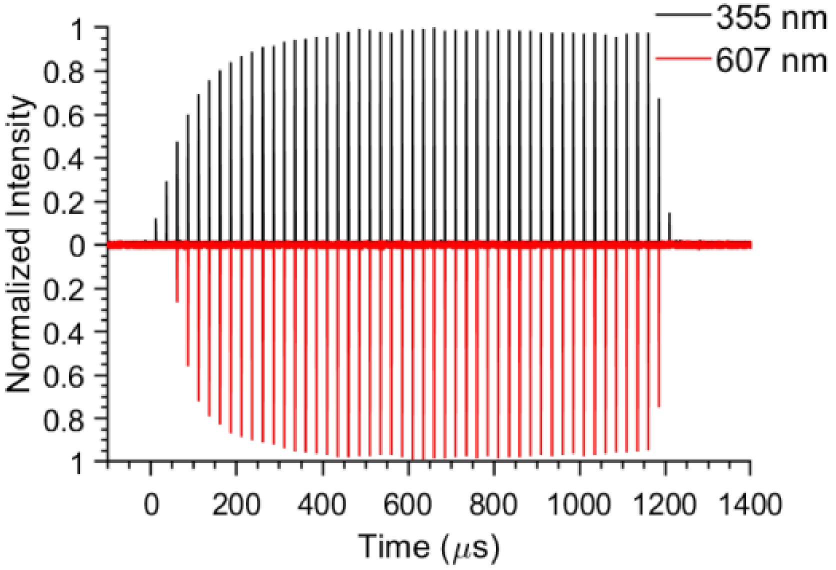
- 5 mJ/pulse for 10% efficiency
- Excellent shot-to-shot reproducibility
- Good beam quality output

Near field:



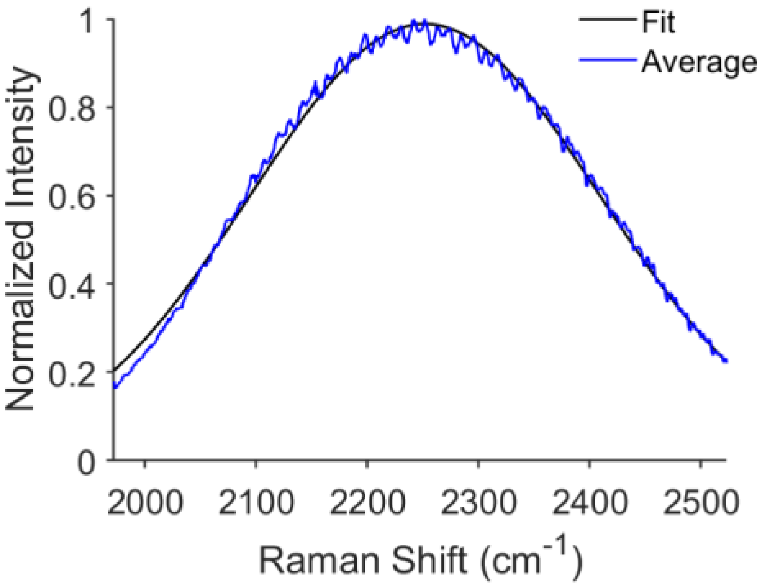
Far field:





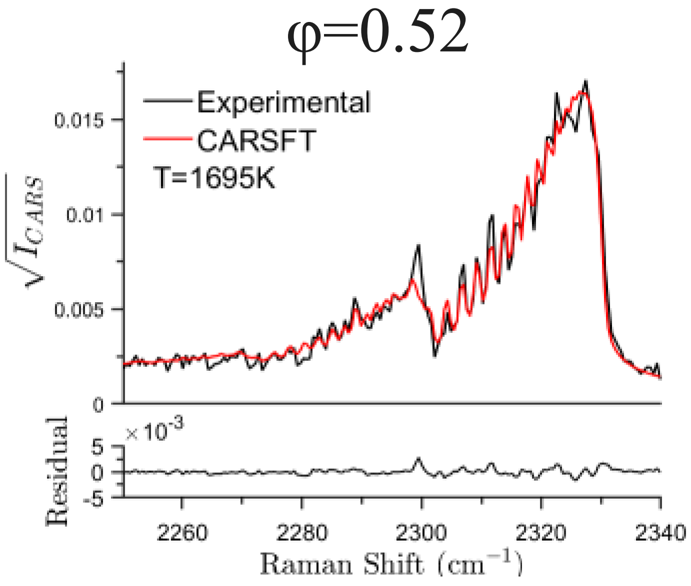
Nonresonant background (NRB) in Argon

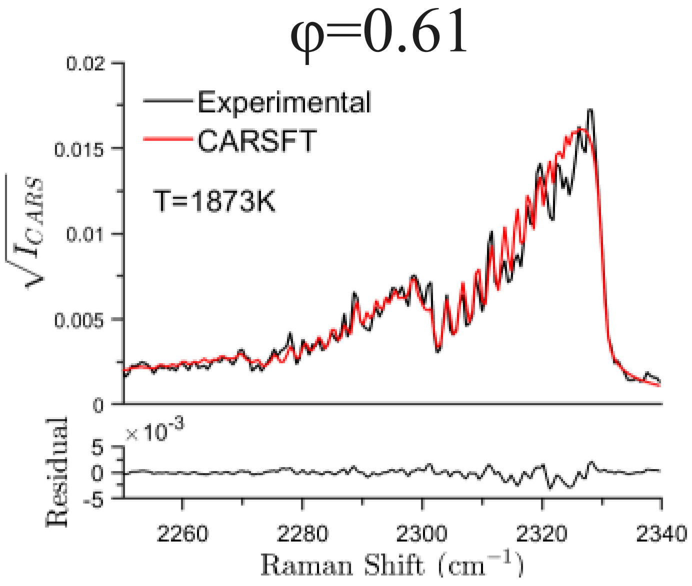
- Coupled 370 cm^{-1} of bandwidth
- Central wavelength jitter of 30 cm^{-1}
- Bandwidth variation of 18 cm^{-1}

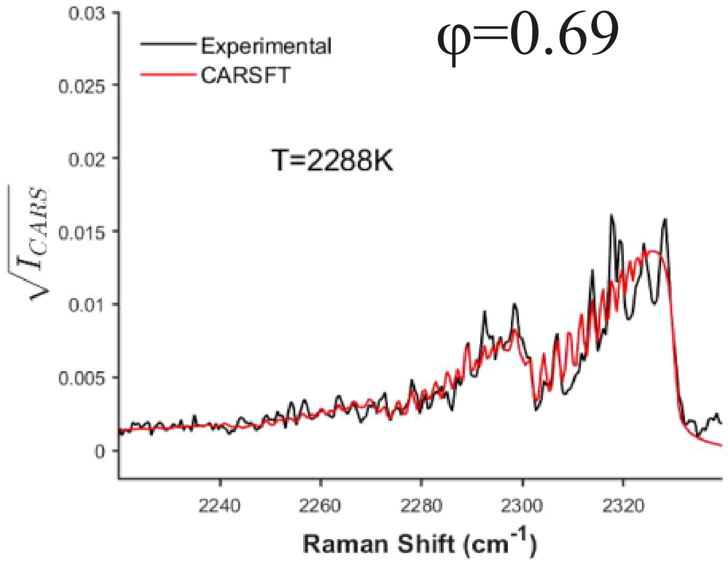


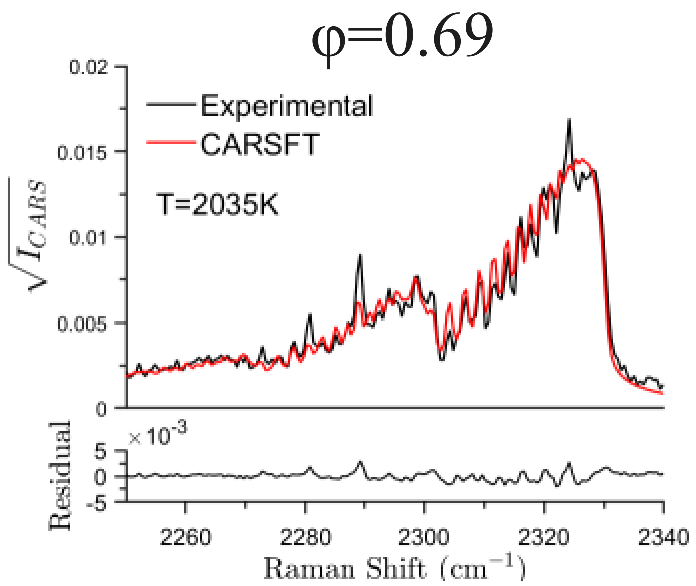
Single-shot CARS from the Hencken burner

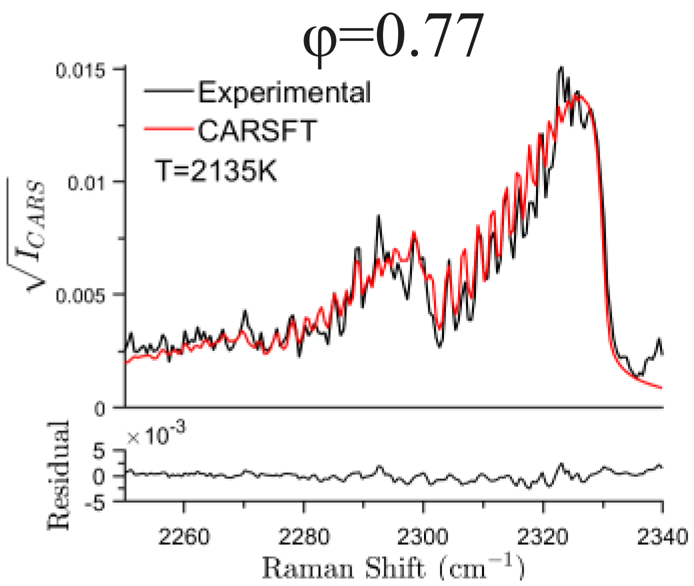
- ➢Single-shot data have been taken for T=1700-2200 K (φ=0.52-0.86).
- ➢Used burst-averaged nonresonant background.
- ➢ Temperature inferred by library fit using CARSFT.





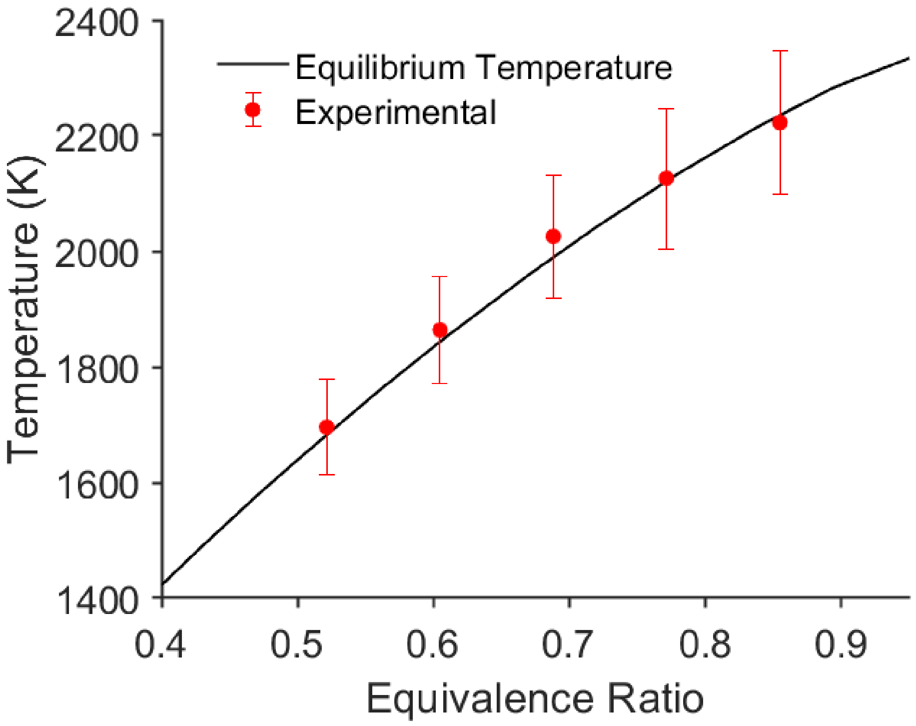






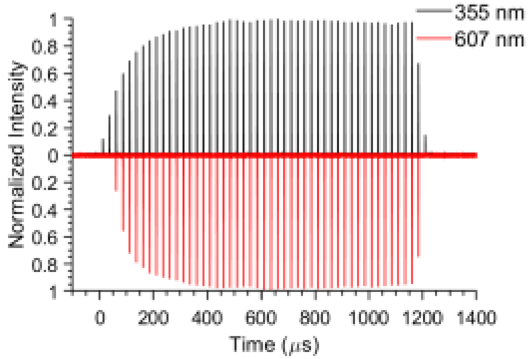
Temperature vs. Equivalence ratio

- 10 bursts of ~45 pulses/bursts were taken for each equivalence ratio.
- Comparison to adiabatic equilibrium temperatures show excellent agreement with single-shot CARS temperature.
- Lowest uncertainty of 4.9%
- Highest uncertainty of 5.7%



Eq. Ratio	T_{mean}	T_{std}	Precision (%)
0.52	1695.8	82.6	4.9
0.61	1863.7	91.7	4.9
0.69	2025.7	106.3	5.2
0.77	2125.9	121.22	5.7
0.86	2222.7	124.1	5.6

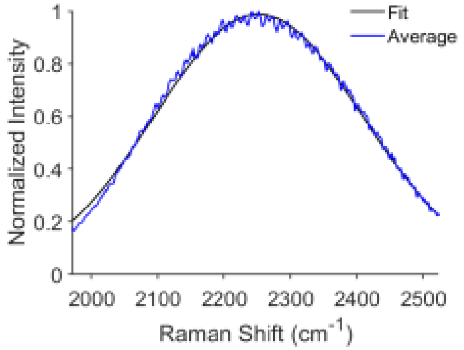
Summary and Conclusion

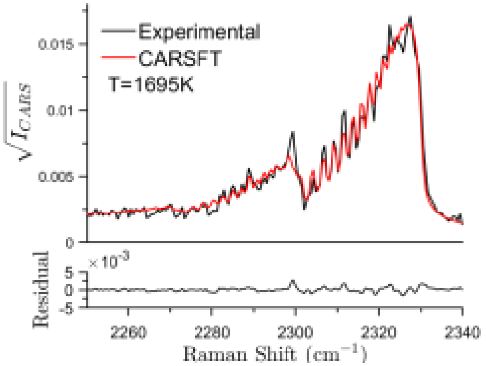


✓ Demonstration of broadband NOPO output at 40 kHz with FWHM ~ 370 cm^{-1}.

✓Good shot-to-shot reproducibility with a 10% conversion efficiency.

✓ Single-shot CARS measurements were taken in a near-adiabatic hydrogen flame with temperatures of T=1700-2200 K (φ=0.52-0.86).





✓ Measurement precision of ~5% for all equivalence ratios.

Future work:

➢ Add an optical parametric amplifier (OPA) stage to boost Stokes pulse energy to 20 mJ/pulse.

➢ Increase pulse repetition rate to 100 kHz for longer bursts.

➢ Perform single-shot measurements in a shock tube or shock tunnel up to 5000 K and several bars.

Acknowledgements

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