The University of Texas at Austin

CARS in an Inductively Coupled Plasma Torch, Part 1: High Temperature Nitrogen Thermometry

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Predictive Engineering & Computational Science

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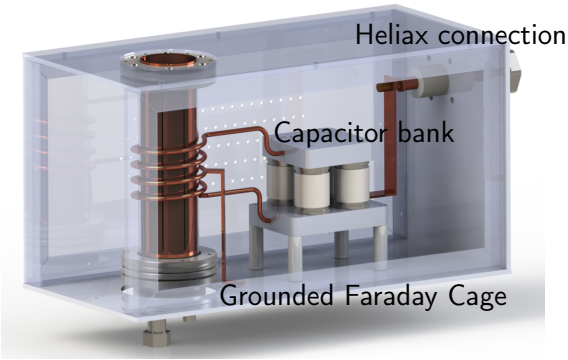
ICP Torch

Inductively coupled plasma torch produces bright air plasma plume, expect 5000-7000 K on centerline.

- Emission spectroscopy is line-of-sight averaged.
- Need enough signal and background rejection to perform spatially resolved measurements.
- Laser Induced Fluorescence → minor species
- Coherent Anti-Stokes Raman Scattering → major species[a].



[a] **gulhan2018characterization**.

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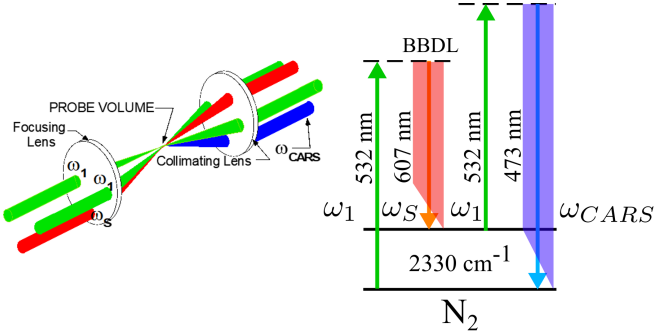
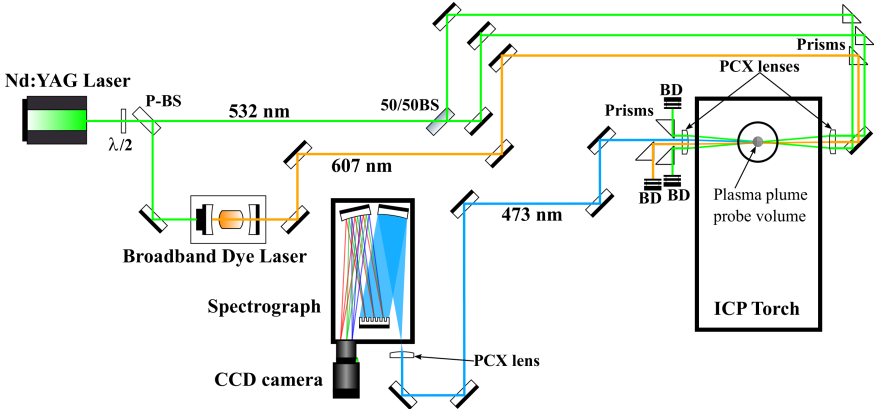
CARS-Setup



- Four-wave mixing process.
- $\lambda_{pump} = \lambda_{probe} \approx 532$ nm, degenerate pump waves.
- $\lambda_{Stokes} = 607$ nm with $\Delta\bar{\nu} = 140$ cm$^-$1 at FWHM.
- BOXCARS beam configuration.
- Measurement volume formed by pair of 500 or 300 mm lenses.
- Volume length: 1.3-5.4 mm (5-95% glass slide)
- Measuring rotational-vibrational equilibrium temperature.

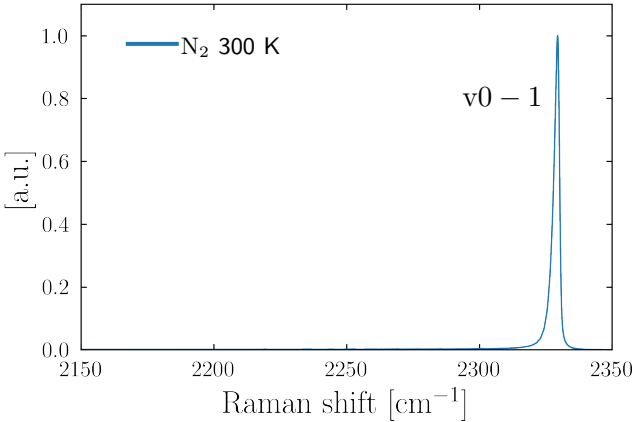
CARS-Setup

N_2 nanosecond CARS with a broadband dye laser: centered at 607 nm with 160 cm^{-1} FWHM, simultaneous excitation of full ro-vibrational spectrum.



CARS

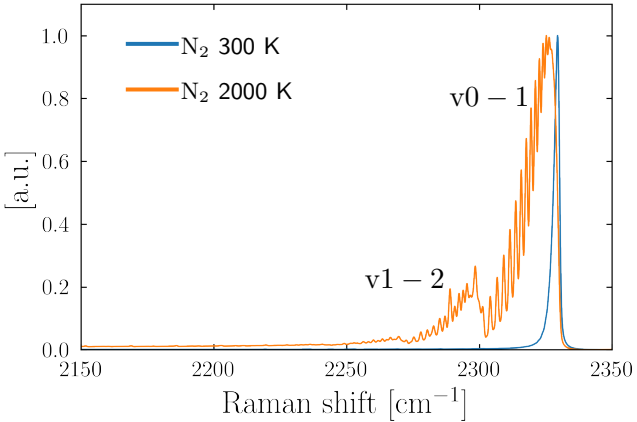
Spectral trends with Temperature



- Initially only $v = 0$ contributes.
- All particles in ground state.

CARS

Spectral trends with Temperature



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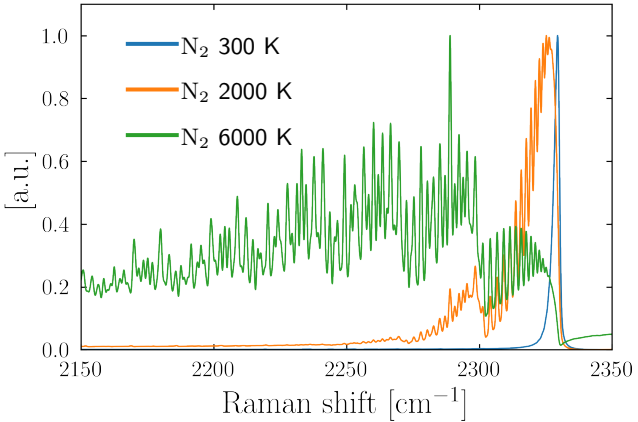
CARS

Spectral trends with Temperature

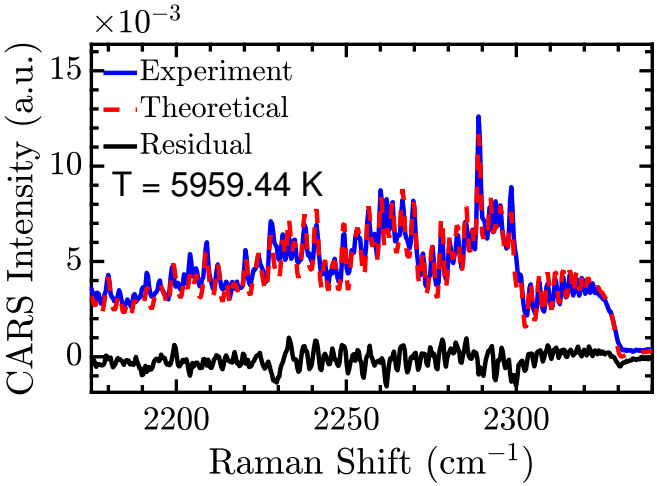


- Initially only $v = 0$ contributes.
- All particles in ground state.
- At combustion temperatures around 2000 K contributions from $v = 0 - 2$ discernible, $\Delta v = +1$.
- At plasma temperatures, significant contribution out to $v \sim 5$, $J \sim 100$.
- T increases $\Rightarrow$ number density and signal decreases.
- T increases $\Rightarrow$ signal partitioned amongst more Raman lines.

Example Spectra in Torch Plume - Average

10 kV DC anode voltage,
30 slpm air.

- PI-MAX 4 camera, rel. gain: 74.9.
- Pump beams: 13.0 mJ/pulse and 21.5 mJ/pulse, Stokes beam: 12.5 mJ/pulse.
- Average of **500 single shots** at 10 Hz.
- CARSFT: isolated lines and modified exponential gap model.



Example Spectra in Torch Plume - Single Shot

10 kV DC anode voltage,
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- **Single shot.**
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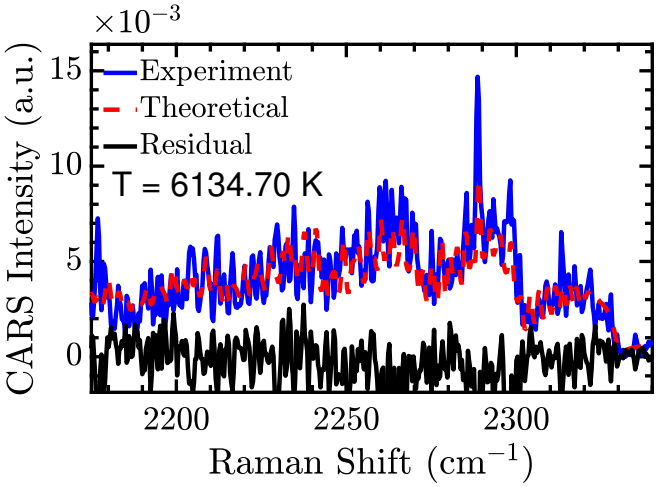
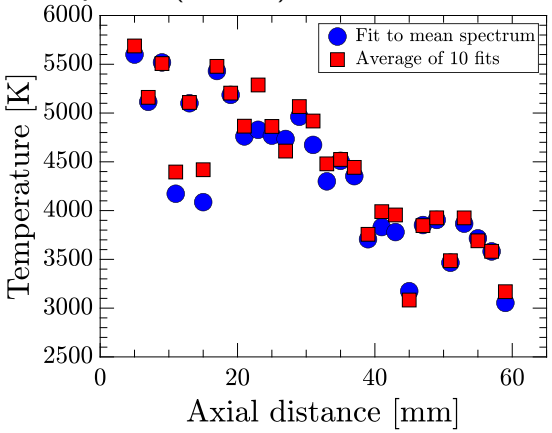


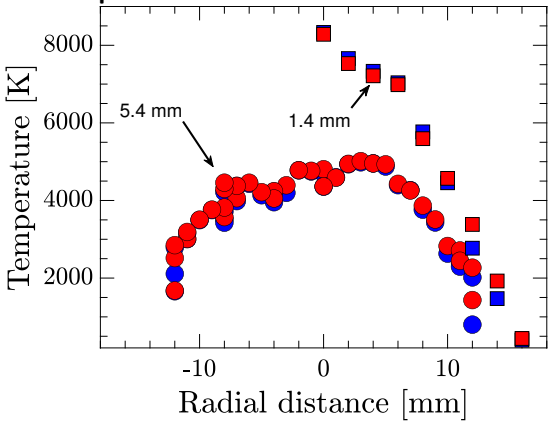
Temperature Profiles

Pump beams: 28.0 mJ/pulse and 32.0 mJ/pulse, Stokes beam: 19.0 mJ/pulse.

Axial profile (4.8 mm)

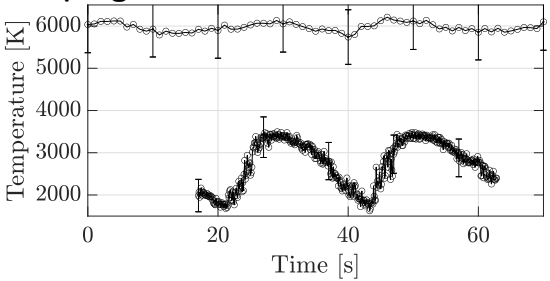


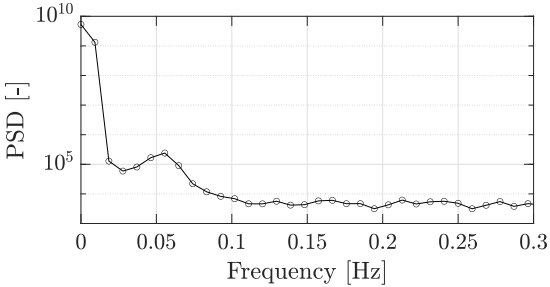
Radial profile



Sources of Error

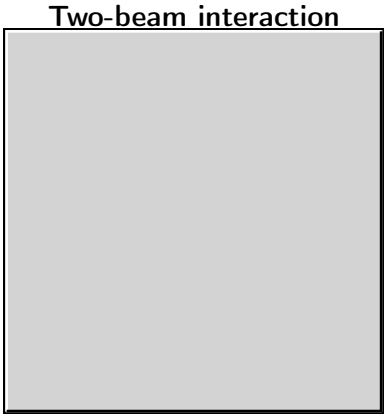
Sampling error





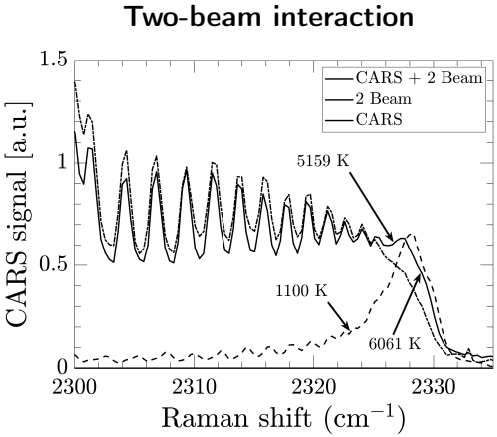
- Periodic temperature variation on centerline around $\pm 4\%$.
- Much larger variation closer to edge.
- Distinct peak at 0.05 Hz $\rightarrow$ origin currently unclear.
- Causes sampling error in short data sets.

Sources of Error



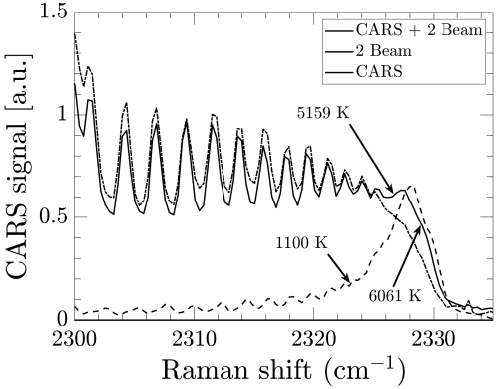
1.27 mm steps along beam direction.

Sources of Error

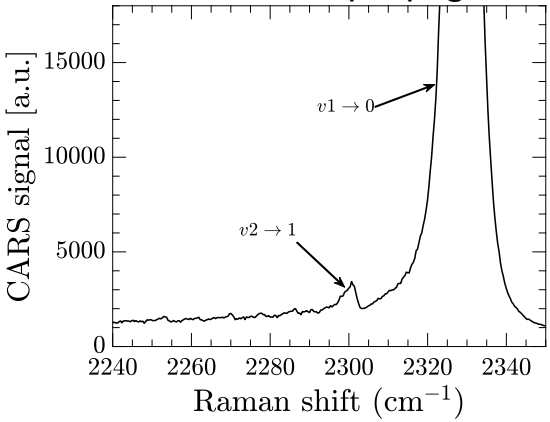


Sources of Error

Two-beam interaction



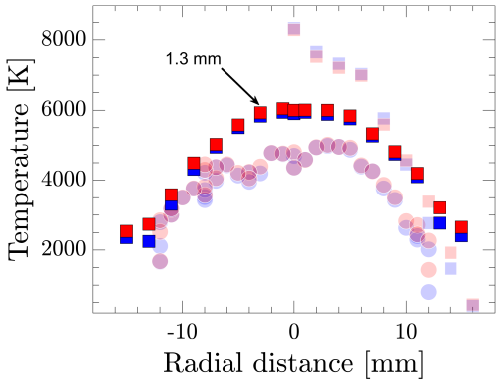
Stimulated Raman pumping



Radial Profile After Mitigation of Error Sources

- Pump beams: 13.0 mJ/pulse and 21.5 mJ/pulse, Stokes beam: 12.5 mJ/pulse.
- Telescope ahead of amplifier cell in dye laser.
- Spatial masking of Stokes beam fringe region.
- 300 mm lenses.
- 500 single shot measurements.

Radial profile



Conclusion

Results

- Demonstrated N_2 multiplex CARS in an air plasma at very high temperatures.
- Successful average and single shot CARS N_2 measurements in ~ 6000 K environment close to thermal equilibrium.
- Identified and mitigated multiple sources of uncertainty: sampling error, two-beam interaction, stimulated Raman pumping.
- General guidelines to test for two-beam interaction and stimulated Raman pumping.

Future Plans

- Spatial filter on Stokes and/or CARS signal beam.
- Uncertainties due to fitting non-resonant background and temperature simultaneously.
- Multi-species measurements and measurements near interfaces: see companion paper/presentation coming next![a]

[a] Sean Kearney et al. "CARS in an Inductively Coupled Plasma Torch, Part 2: Temperature and Carbon-Monoxide Measurements in the Reaction Layer of a Graphite Ablator"

Acknowledgments

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Thank you for your attention!
Questions?

References I