Two-Beam Femtosecond Rotational CARS for One-Dimensional Thermometry in a Turbulent, Sooting Jet Flame

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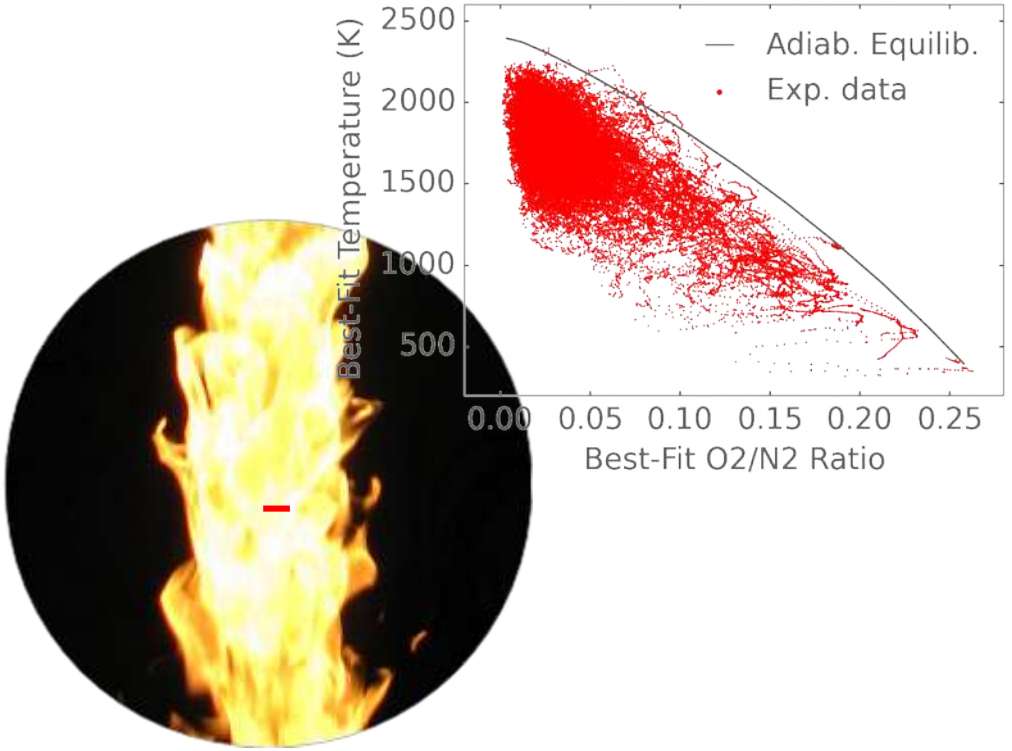

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Acknowledgments

- Research Team

  Dr. James Gord (AFRL)
  Dr. Paul Hsu (SE)
  Dr. Sean Kearney (Sandia NL)
  Dr. Sukesh Roy (SE)
  Mr. Ethan Legge (SE)

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  - Air Force Office of Scientific Research
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  - Air Force Research Laboratory

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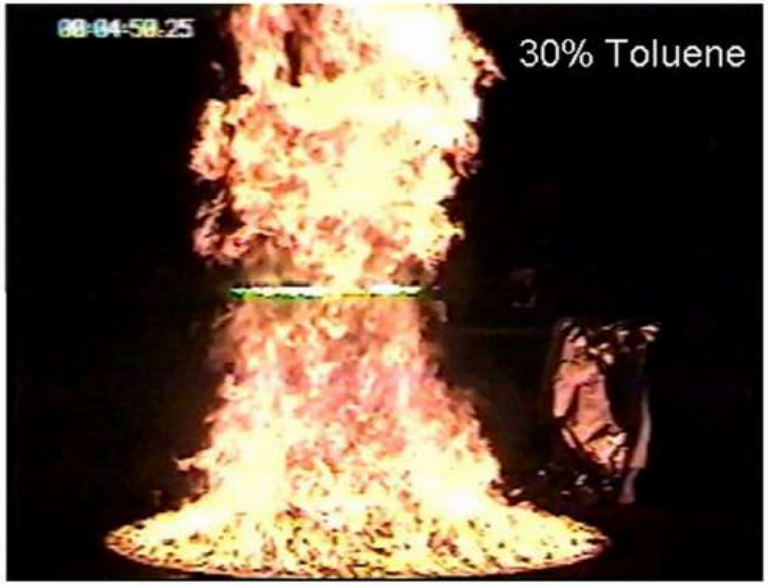
Motivation: Soot and Radiation

- Soot formation affects many engineering applications
  - Furnaces, boilers
  - Propulsion, power systems
- Soot is a primary player in radiation heat transfer
- Emissions, environment, health



S. Kearney, Combust. Flame, 2012

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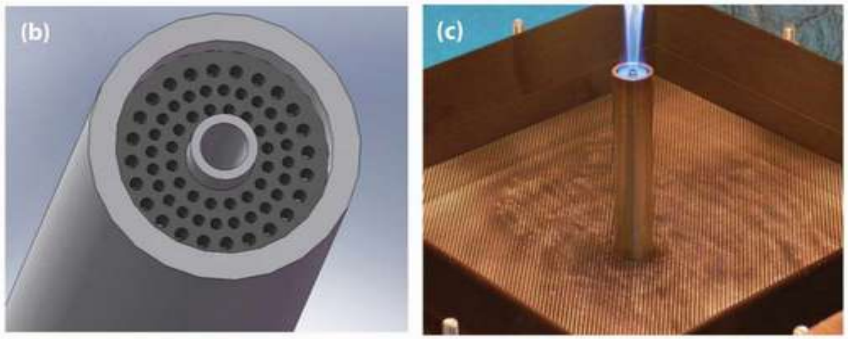
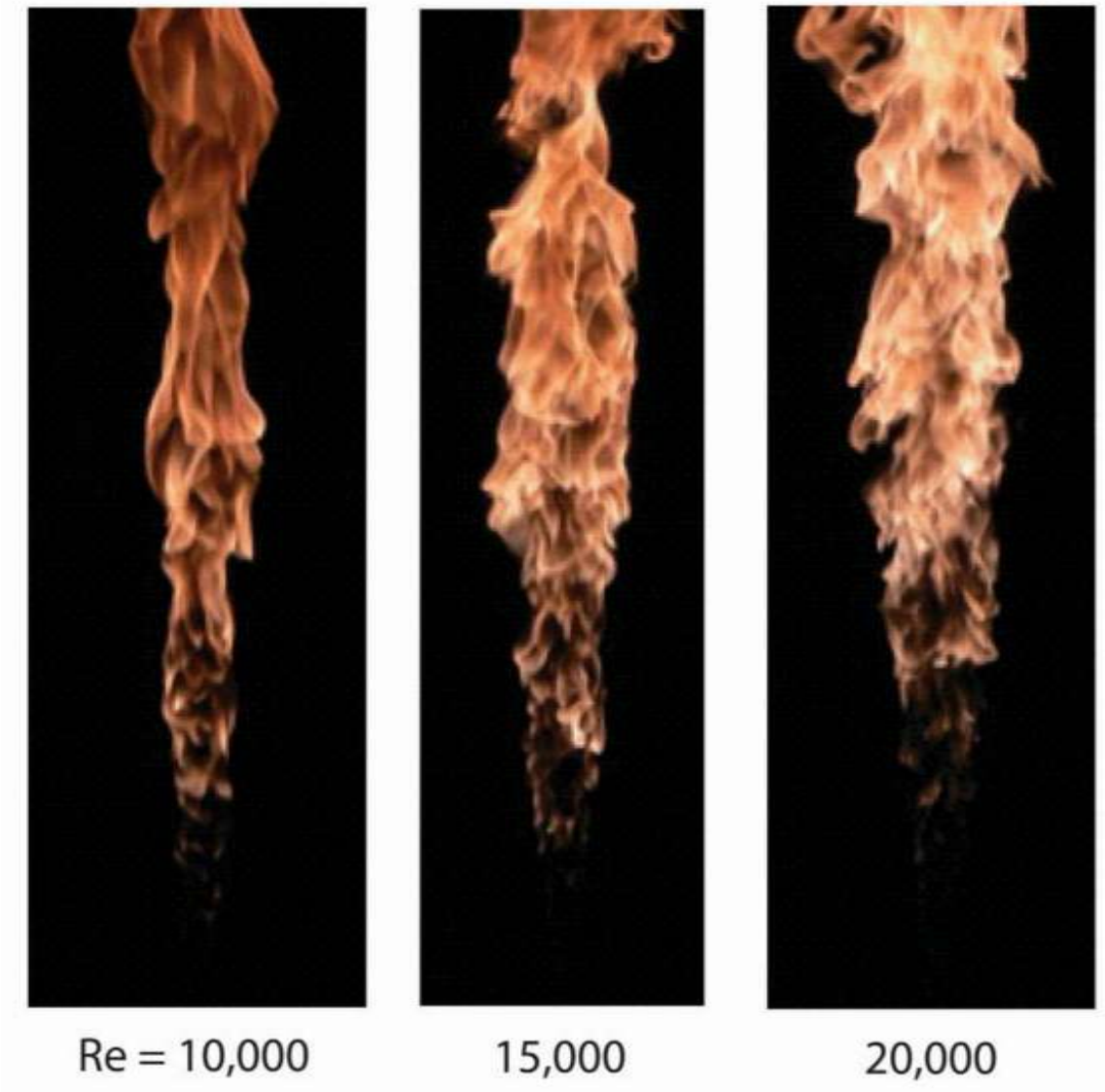
Introduction: Sooting Jet Flame

Canonical sooting flame (CRF Sandia, Shaddix)

- Soot formation, growth, and oxidation
- Turbulent
- **Radiation** models
- Relatively simple fuel



J. Zhang, R. Sci. Instrum., 2011



J. Zhang, R. Sci. Instrum., 2011

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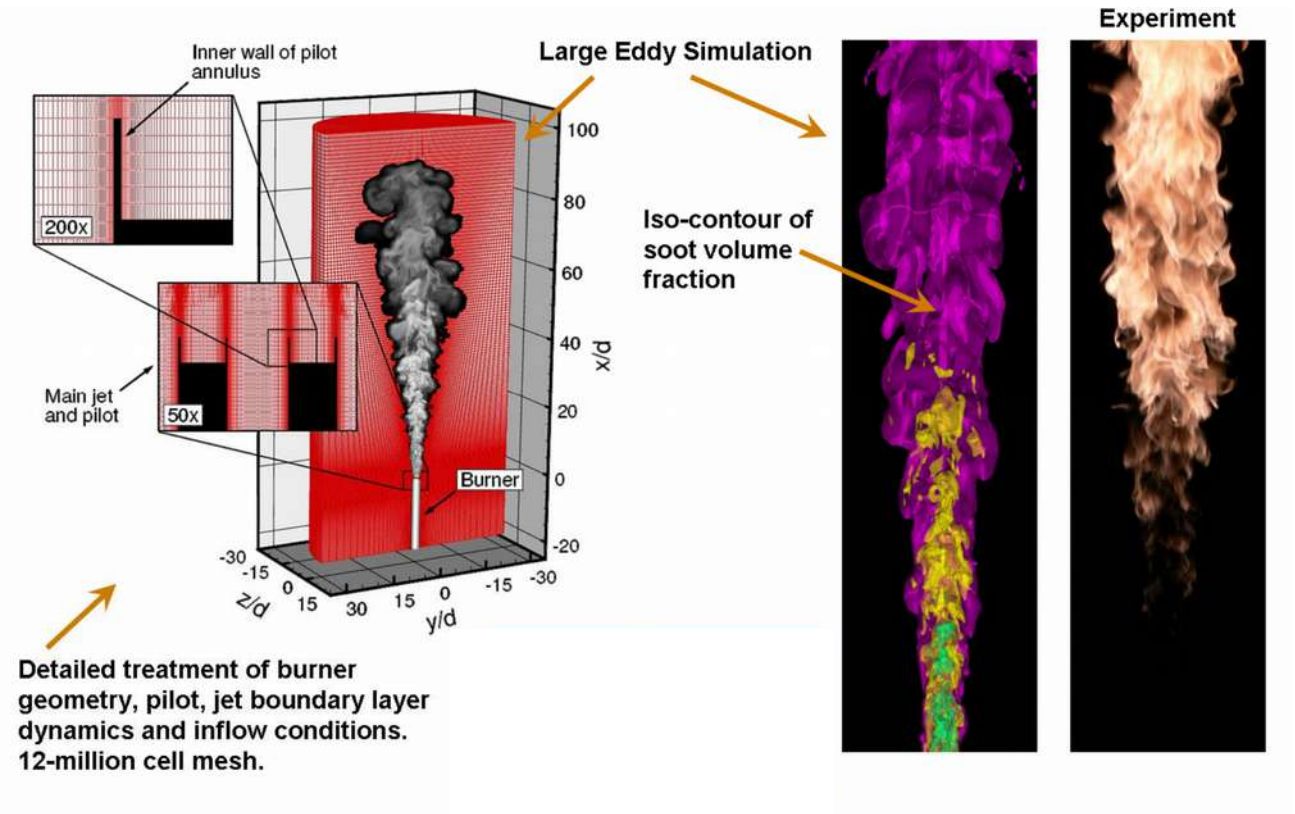
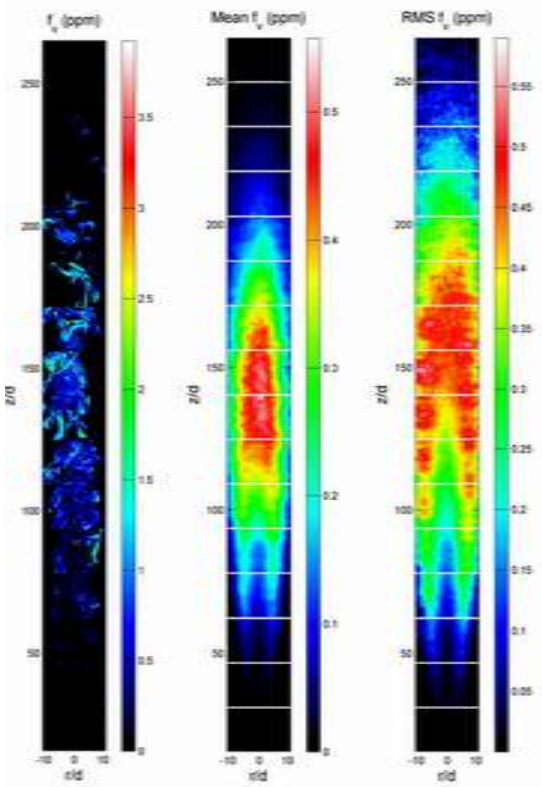
Introduction: Flame details

- Pilot: C_2H_4–air, 2% of Q
- Main jet: C_2H_4, 58 m/s
- Re_{jet} = 22 000
- Heat Release: 25 kW





C. Shaddix, Sandia Report, 2010

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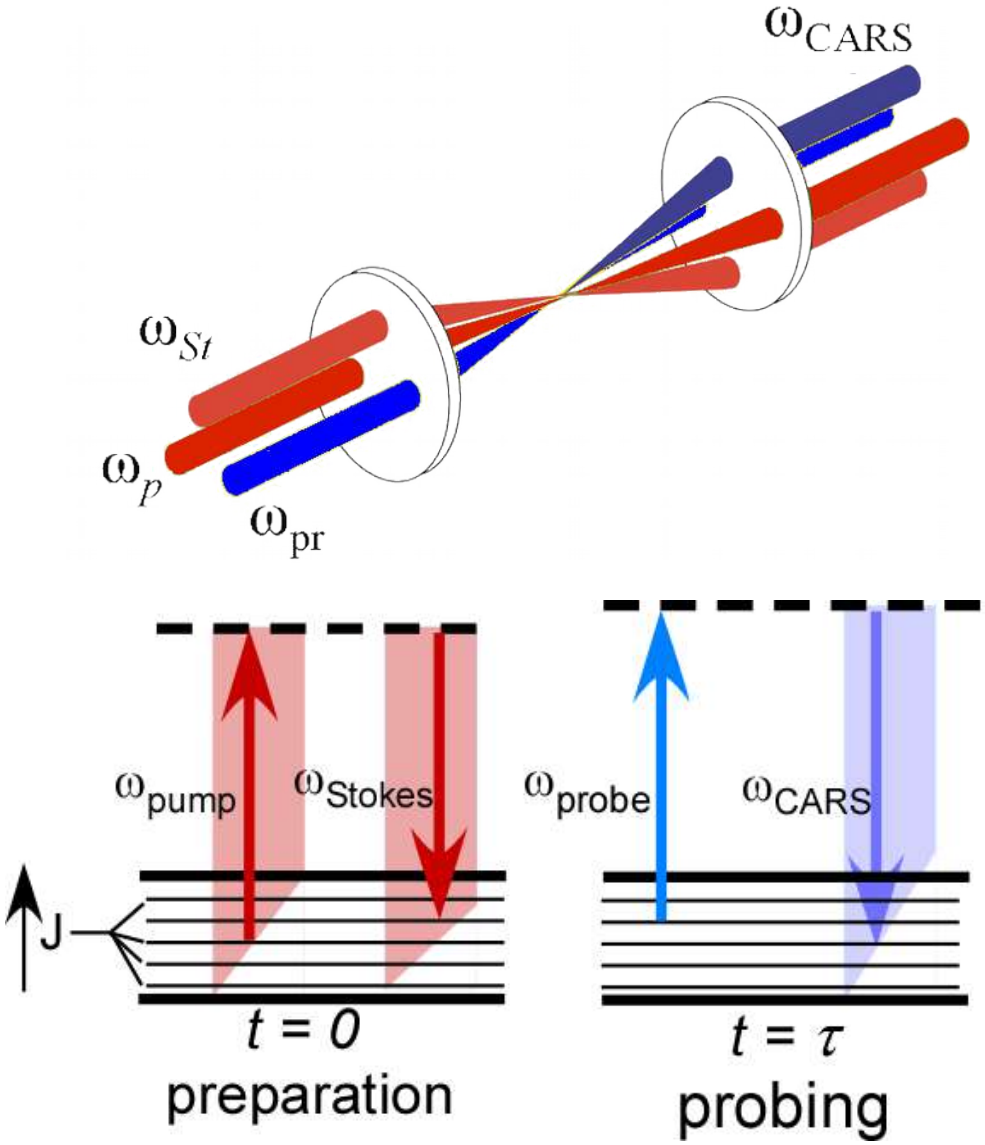
Introduction: Coherent anti-Stokes Raman Scattering

- CARS:
  - Noninvasive diagnostic
  - Excellent temperature accuracy and precision
  - Relative concentration measurements
- Ultrashort laser measurements
  - Temperature, pressure, concentration, velocity measurements in reacting flows
- Advantages of ultrashort pulses
  - 'Collision-free' measurements
  - High peak energies



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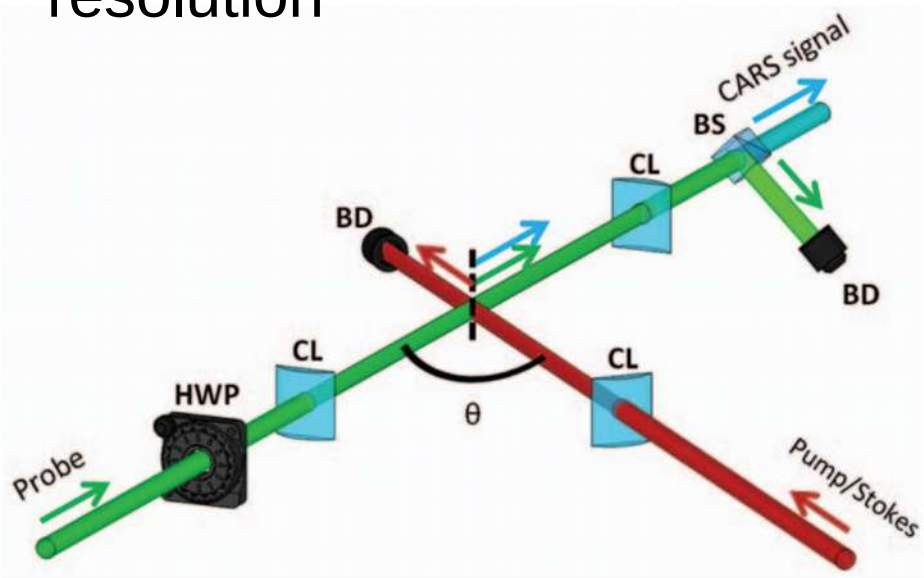
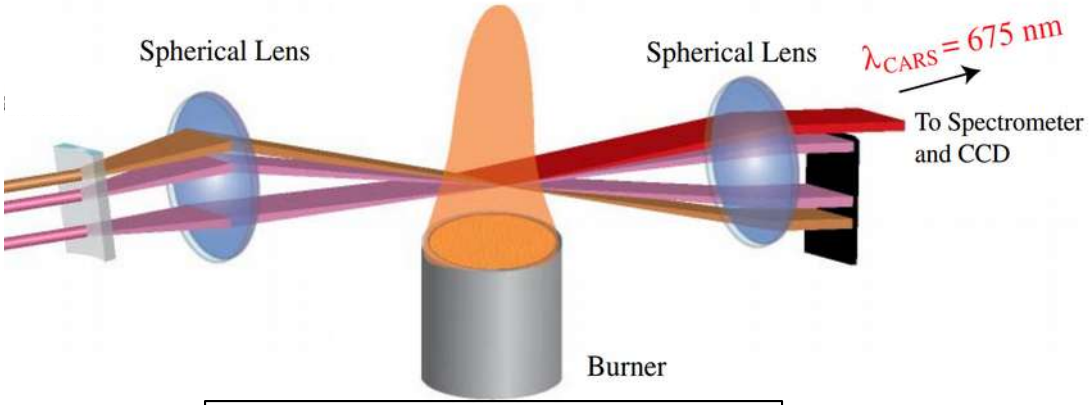
Introduction: 1D CARS Thermometry

1D CARS:

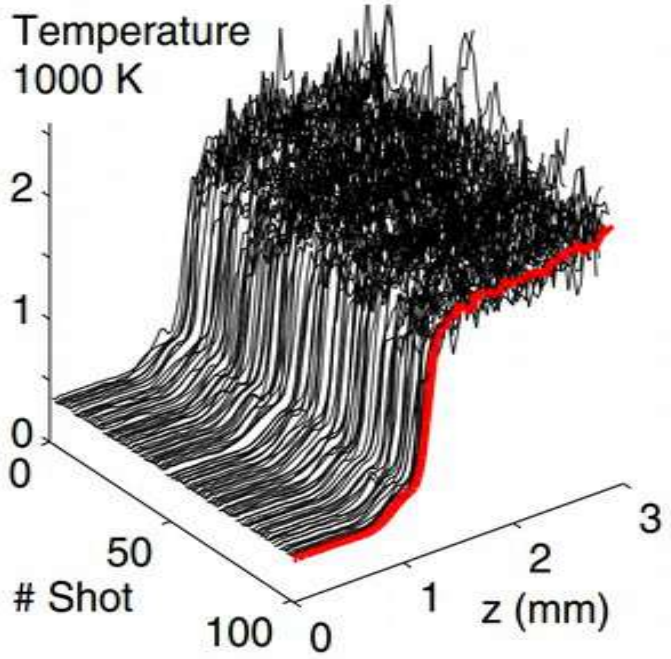
- Beams formed into sheets
- Phase matching
- Signal strength vs spatial resolution



A. Bohlin, J. Chem. Phys., 2013



W. Kulatilaka, Opt. Lett., 2011



A. Bohlin, PCI, 2015

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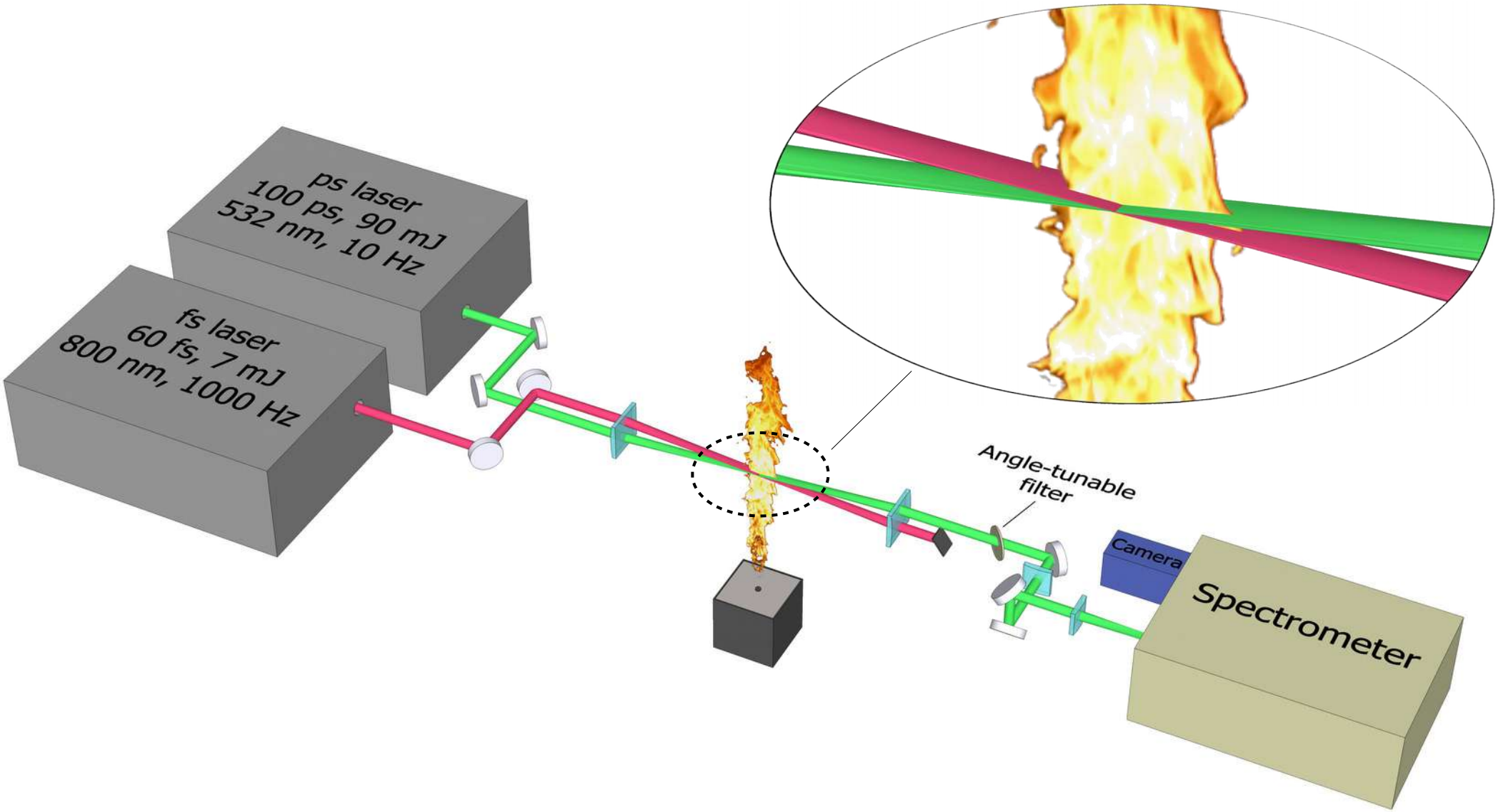
Experimental Setup:



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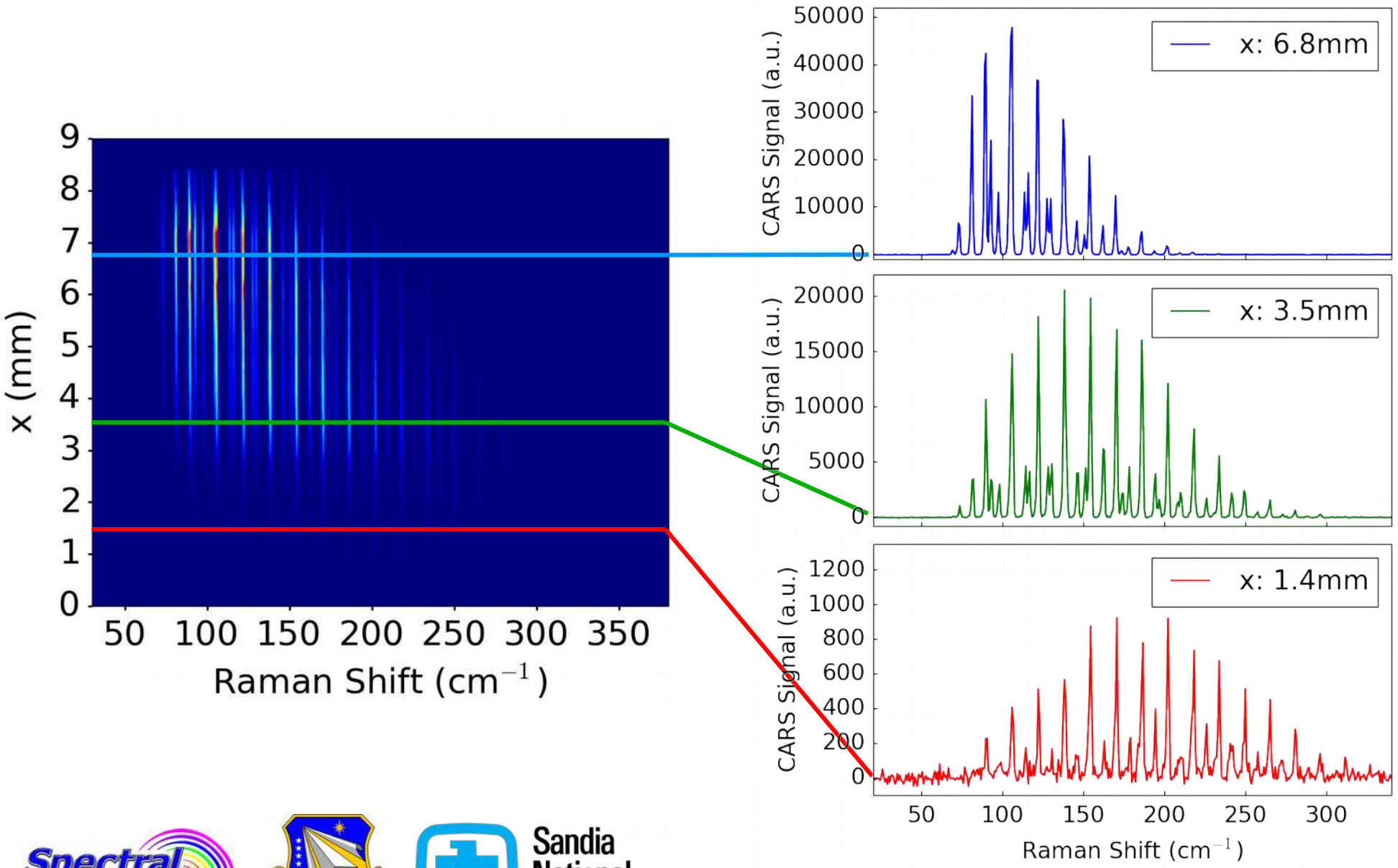
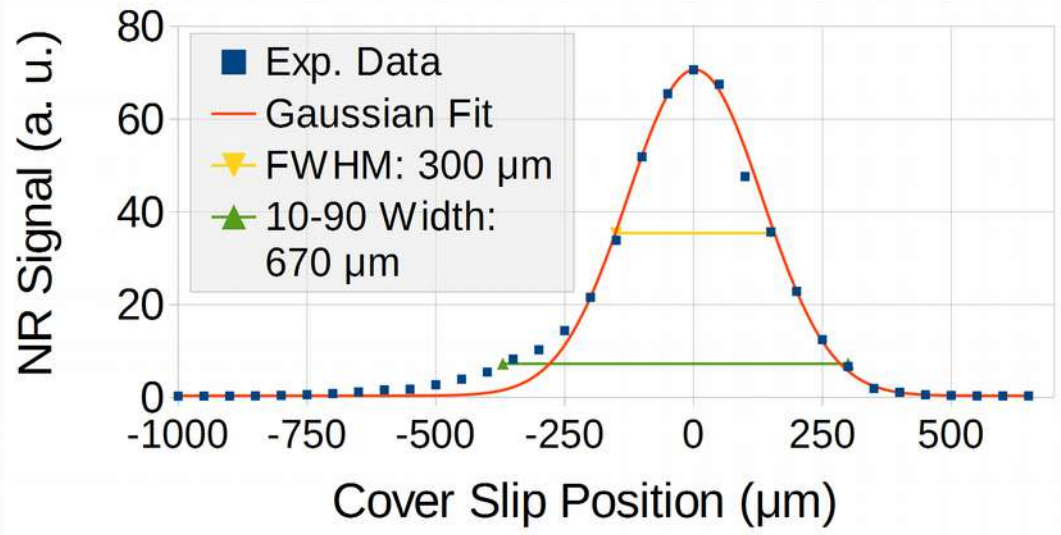
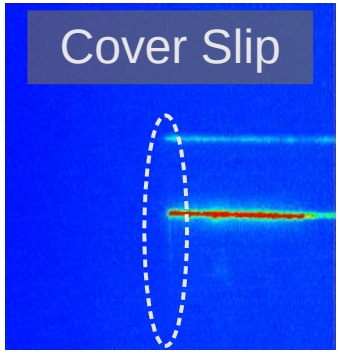
Results: Single-Laser-Shot 1D Thermometry

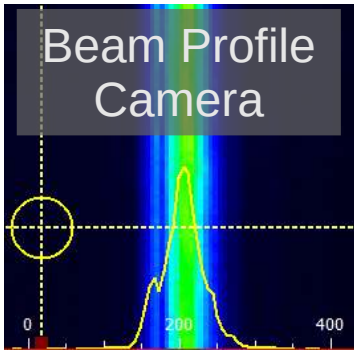


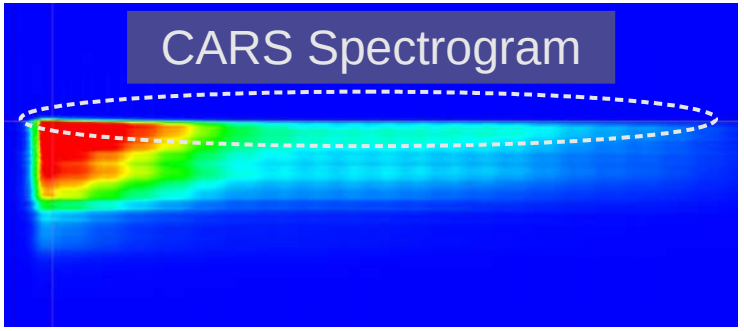
Results: Spatial Resolution

- Axial resolution:
  - Translate cover slip through probe volume
  - NR signal generated only when beams overlap in space and time
  - 500 µm
- Transverse resolution:
  - Images recorded with cover slip edge in field of view at two locations
  - Beam profile camera
  - 40 µm x 50 µm









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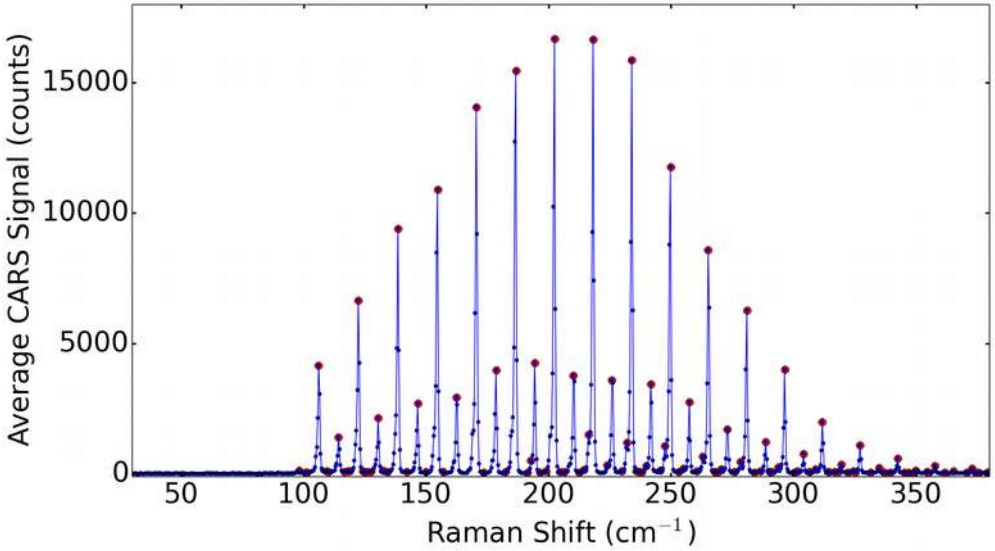
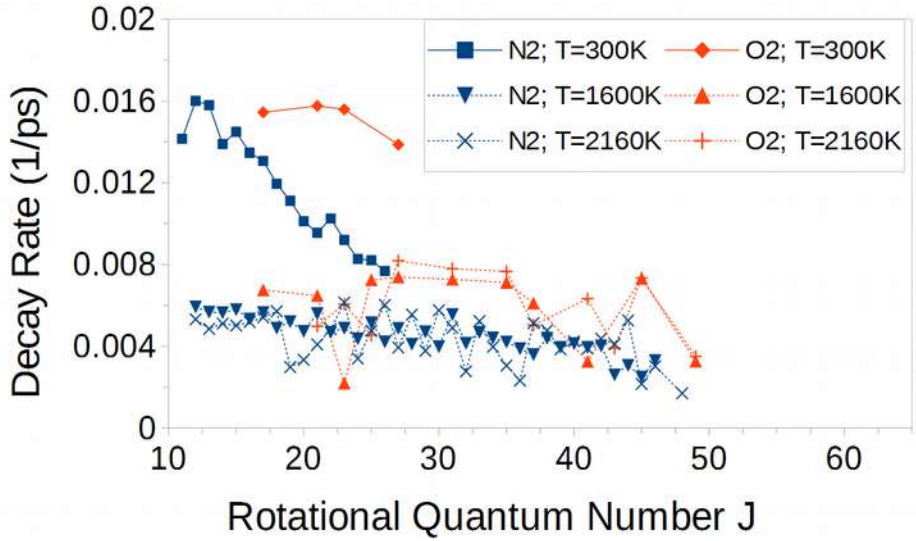
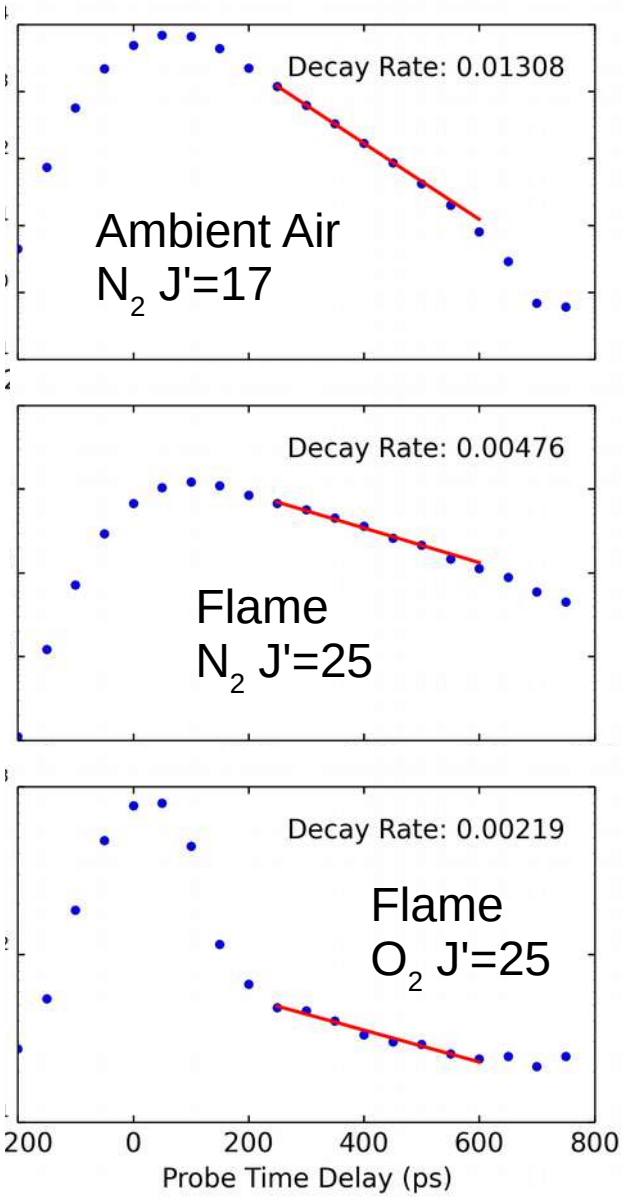
Results: Linewidth Measurements







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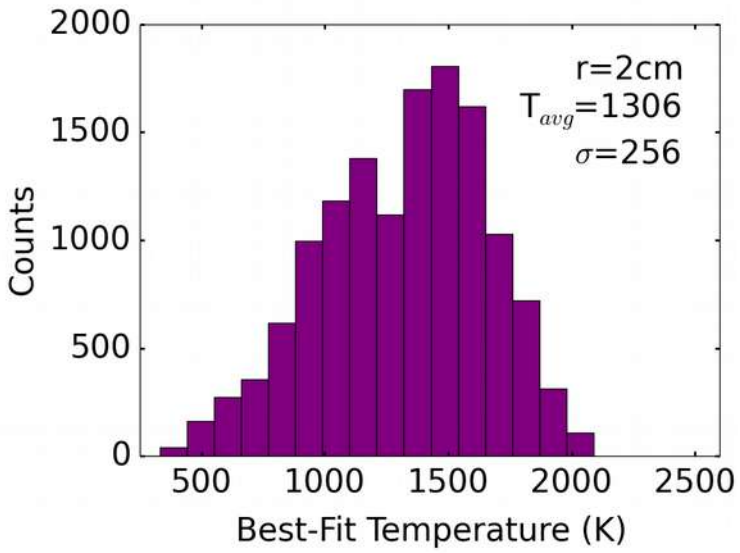
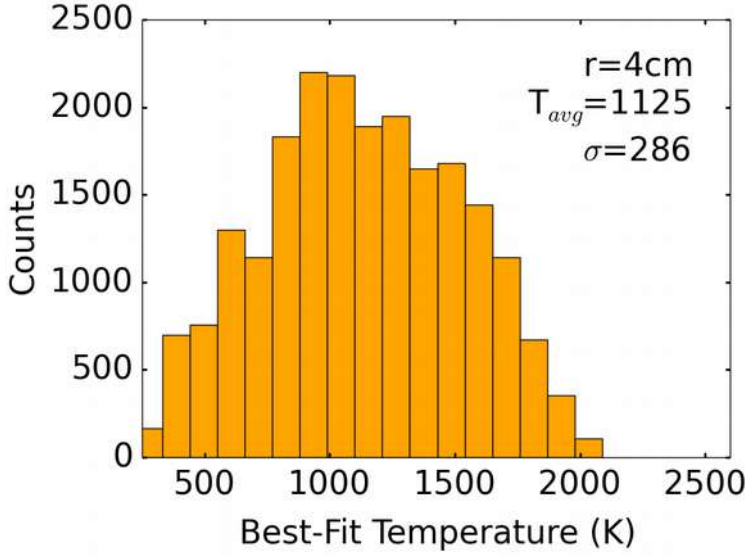
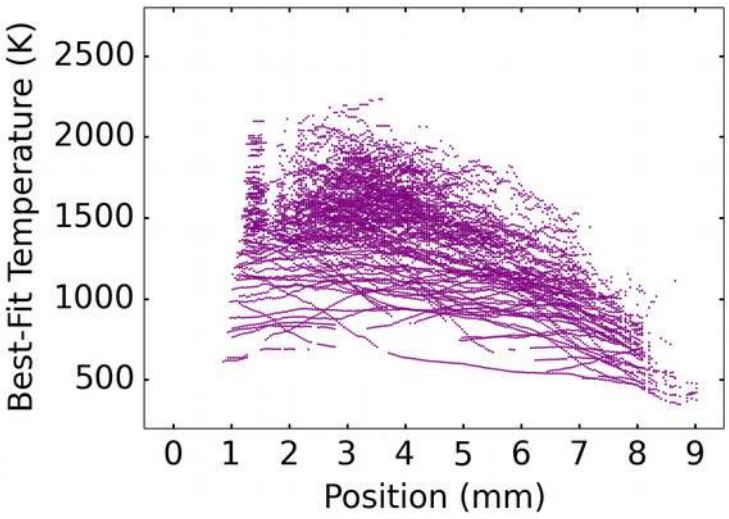
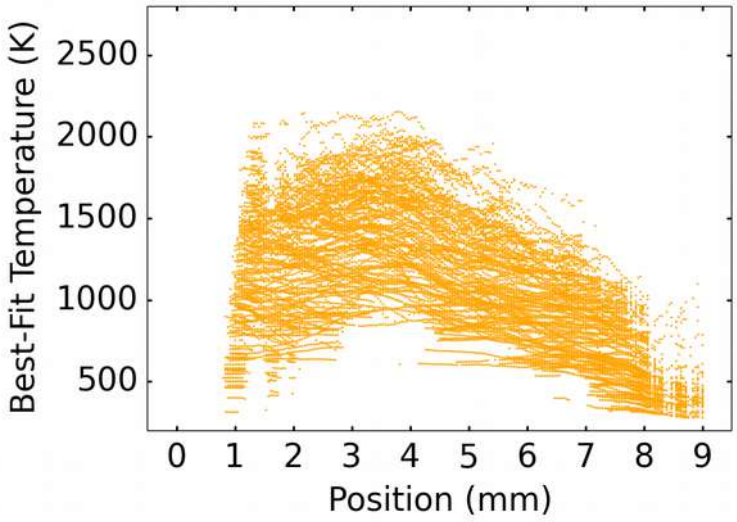
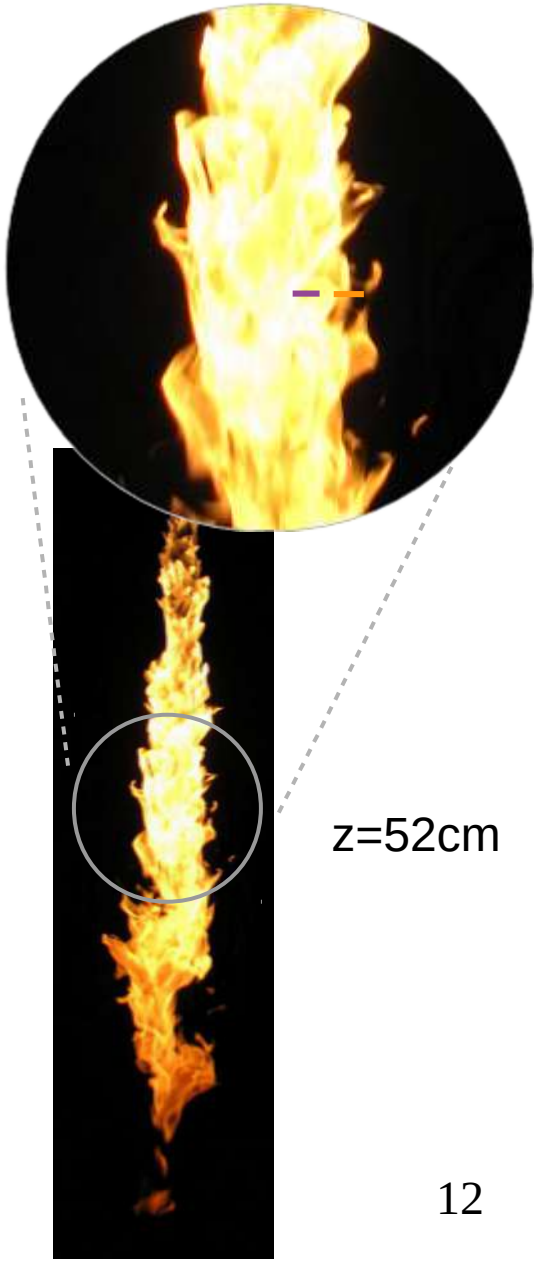
Results: Temperature Measurements











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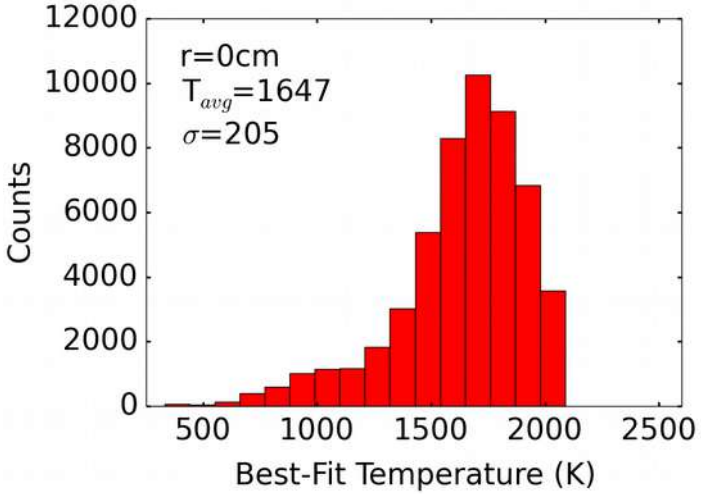
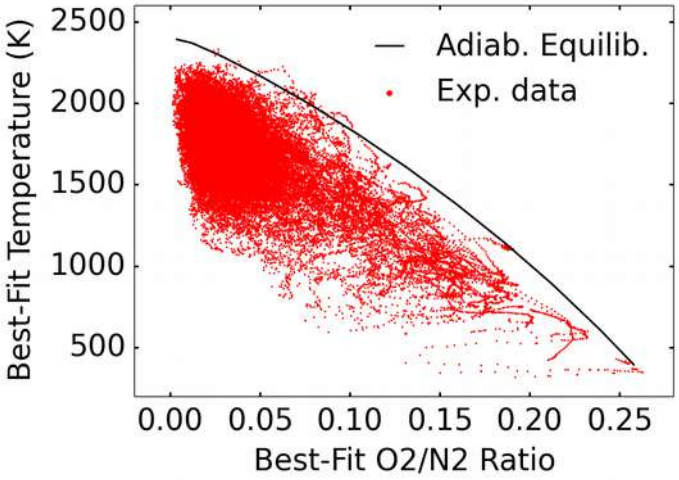
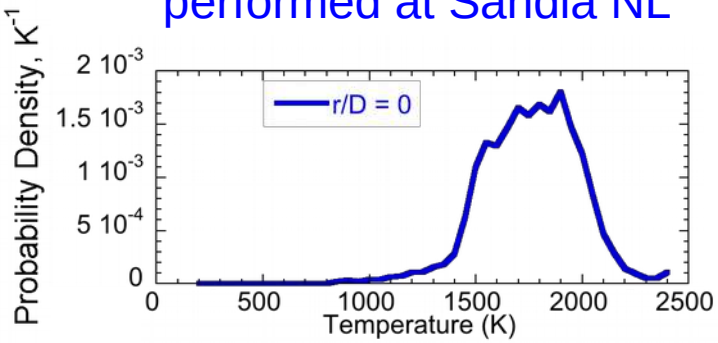
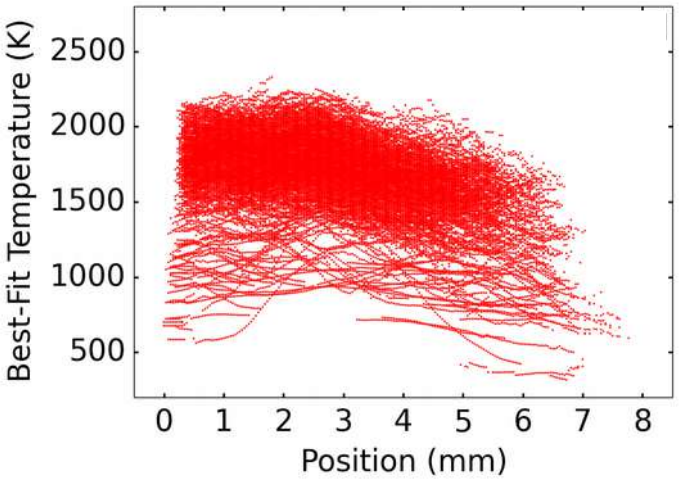
Results: Temperature Measurements

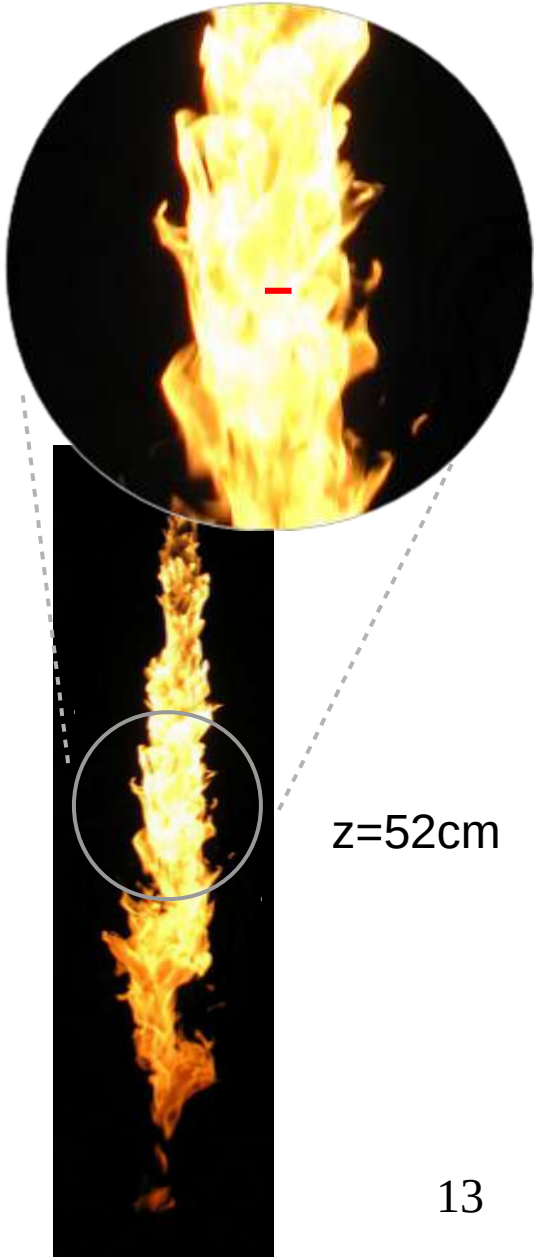




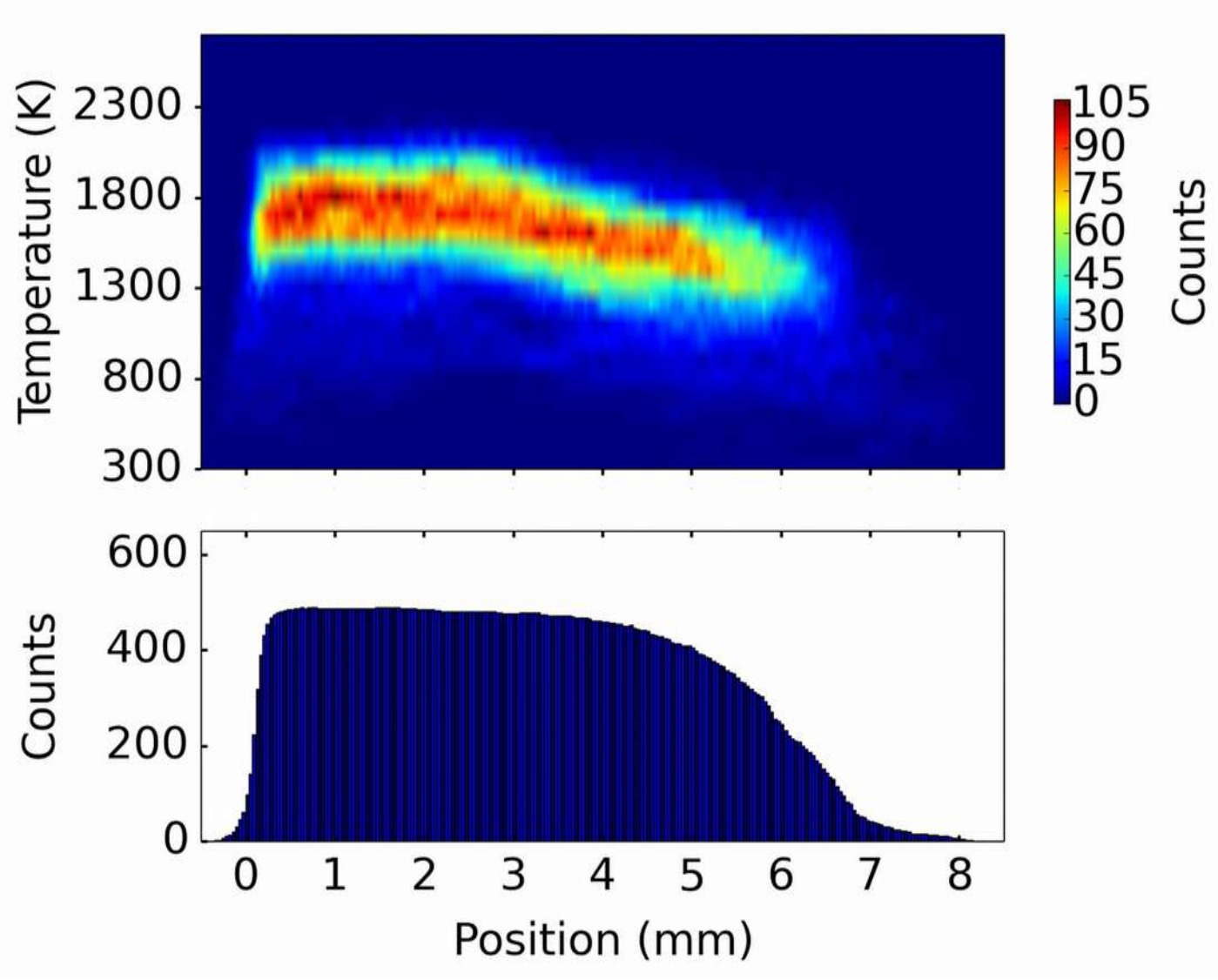
Point RCARS measurements performed at Sandia NL

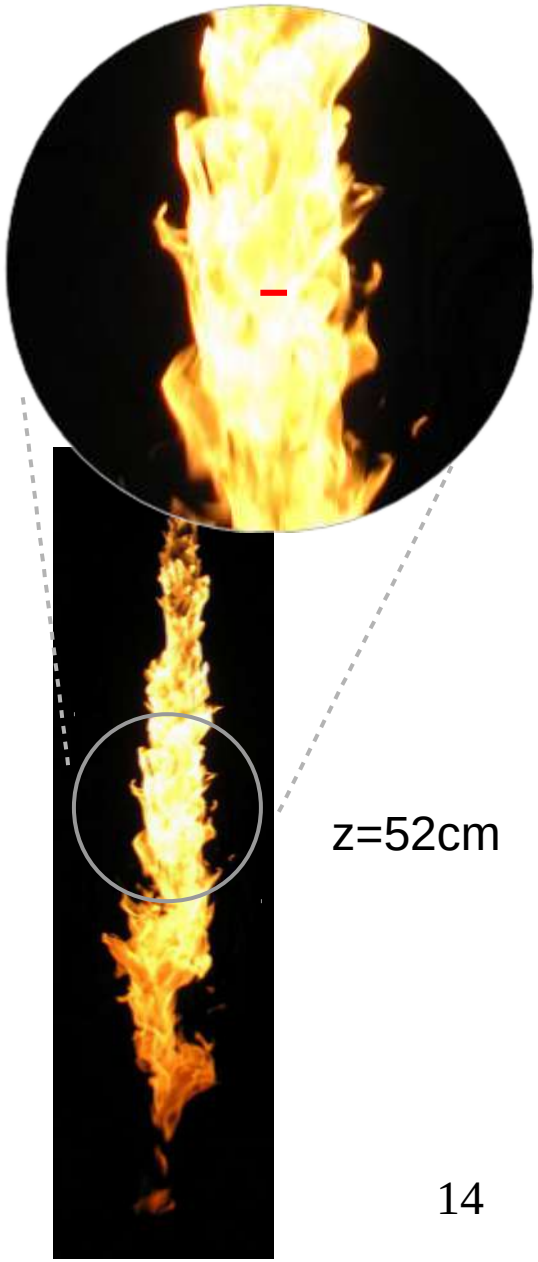






Results: Temperature Measurements





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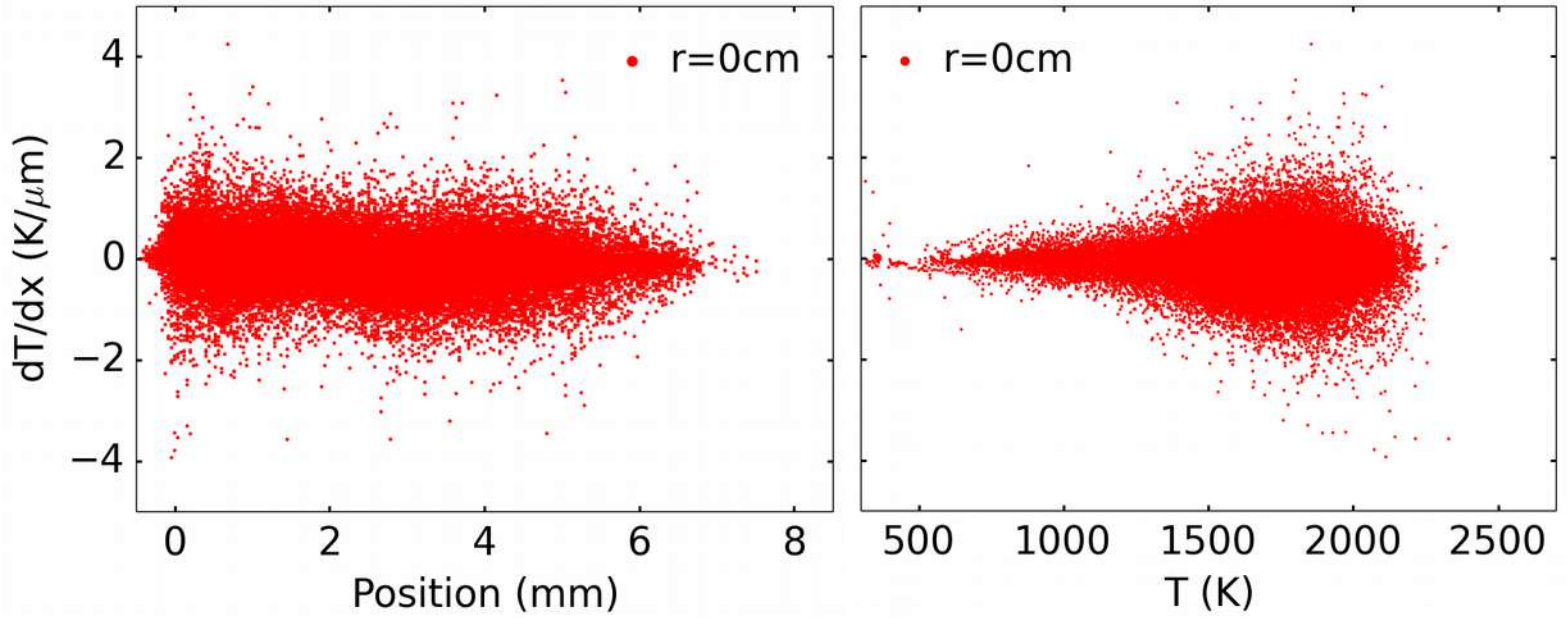
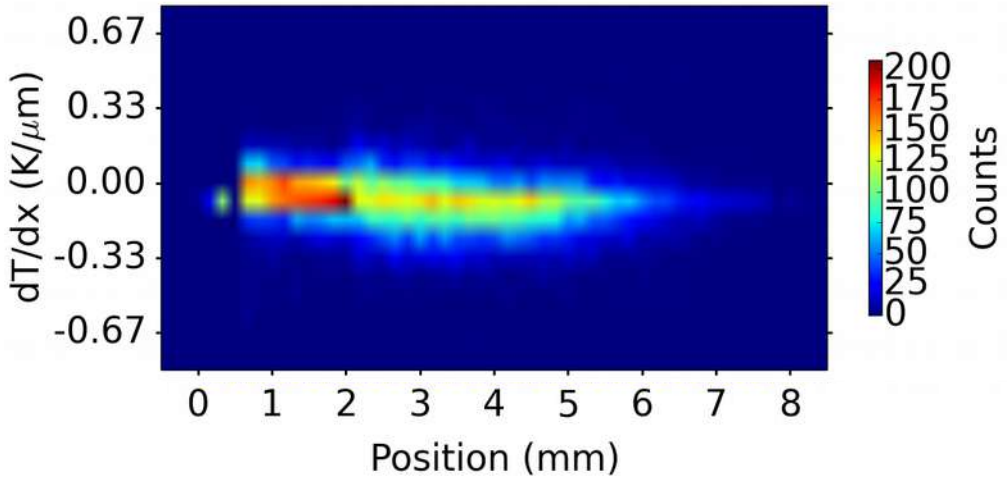
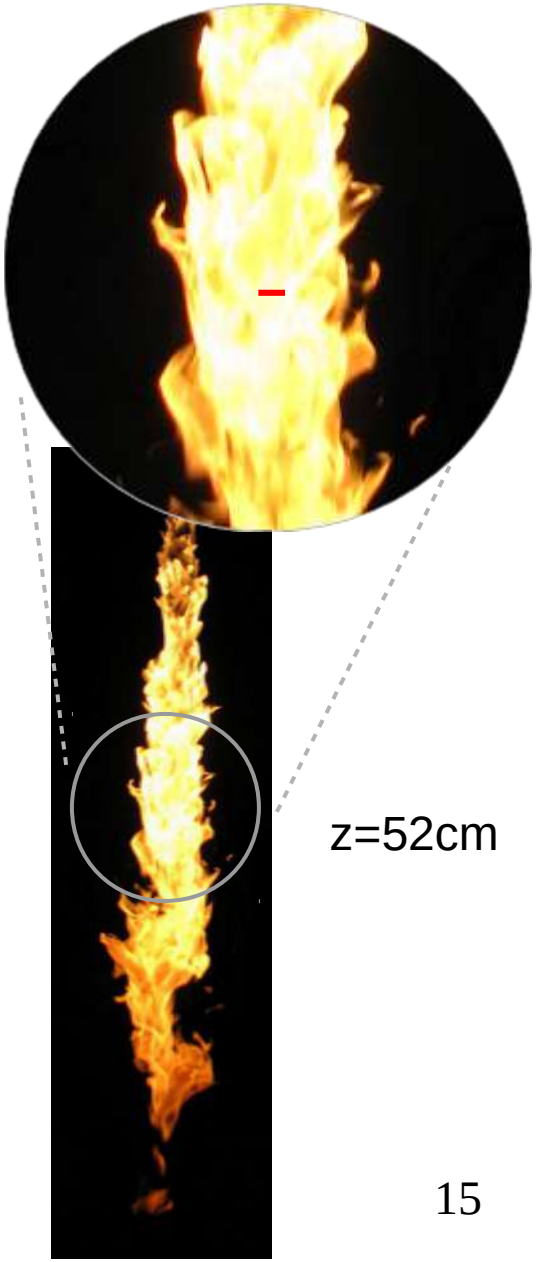
Results: Temperature Gradients







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Results: Combine with LII measurements

Radiative Transfer Equation (RTE)

$$\frac{d\overline{I_\lambda}}{ds} = \overline{\mu_\lambda I_{\lambda,b}(T)} - \overline{\mu_\lambda}\,\overline{I_\lambda}$$

emission — absorption

$I_{\lambda,b}(T)$ = blackbody at temperature, T

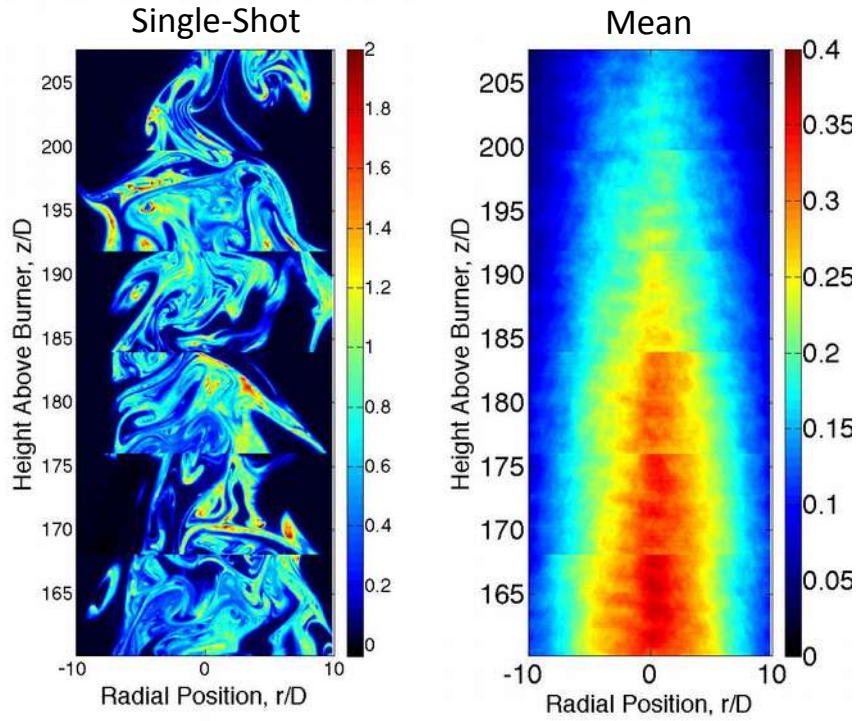
$\mu_\lambda = \frac{f_v}{\lambda} g(n,k)$ = soot absorption coeff.

Direct validation of RTE and heat-transfer models require

- Temperature and soot measurements
- Time- and space-resolved

Laser-Induced Incandescence

- 1064-nm, ns laser excitation
- Rapid heating of soot particles
- Emission captured with ICCD



LII measurements from S. Kearney, Sandia NL

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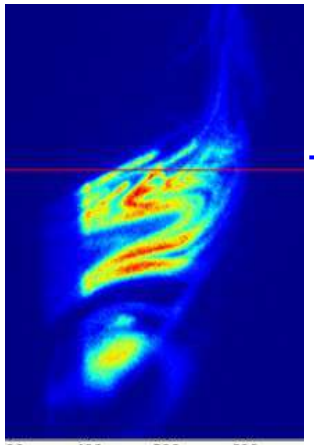

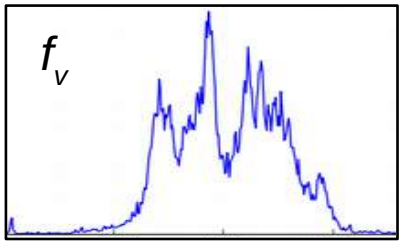

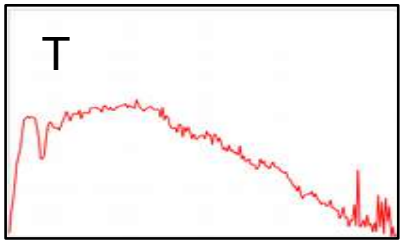

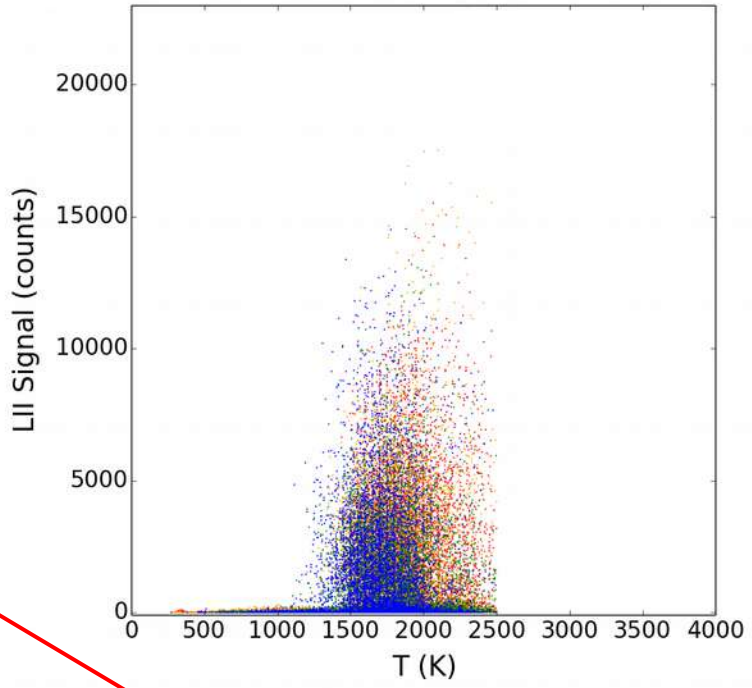

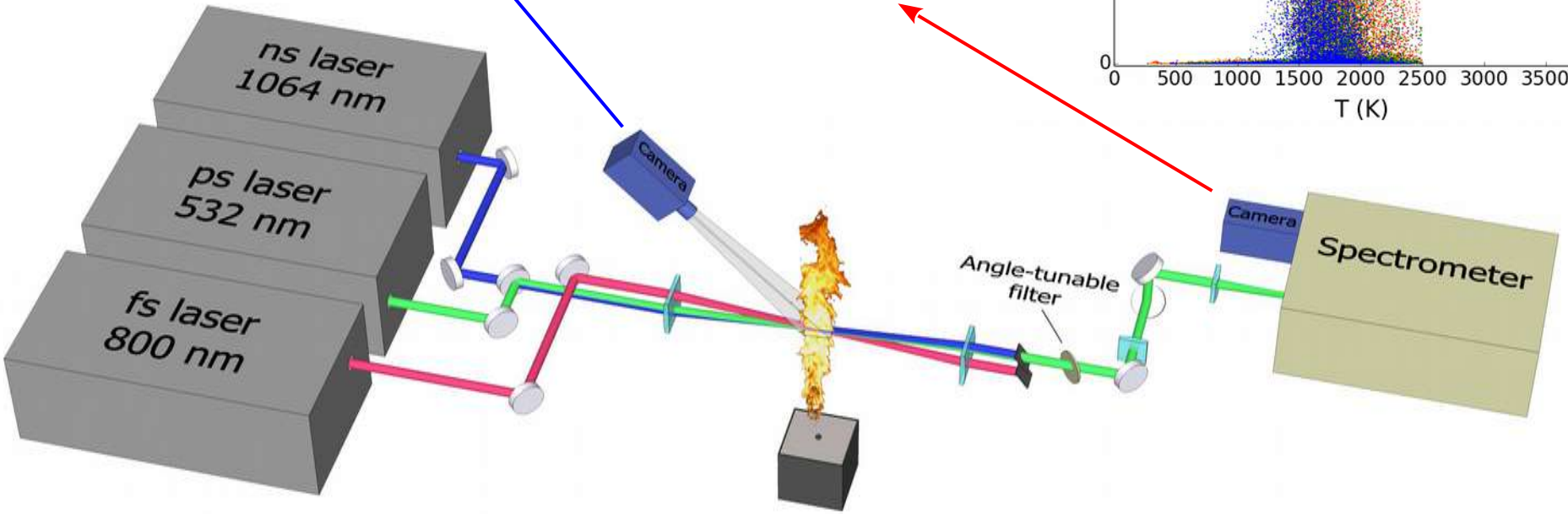

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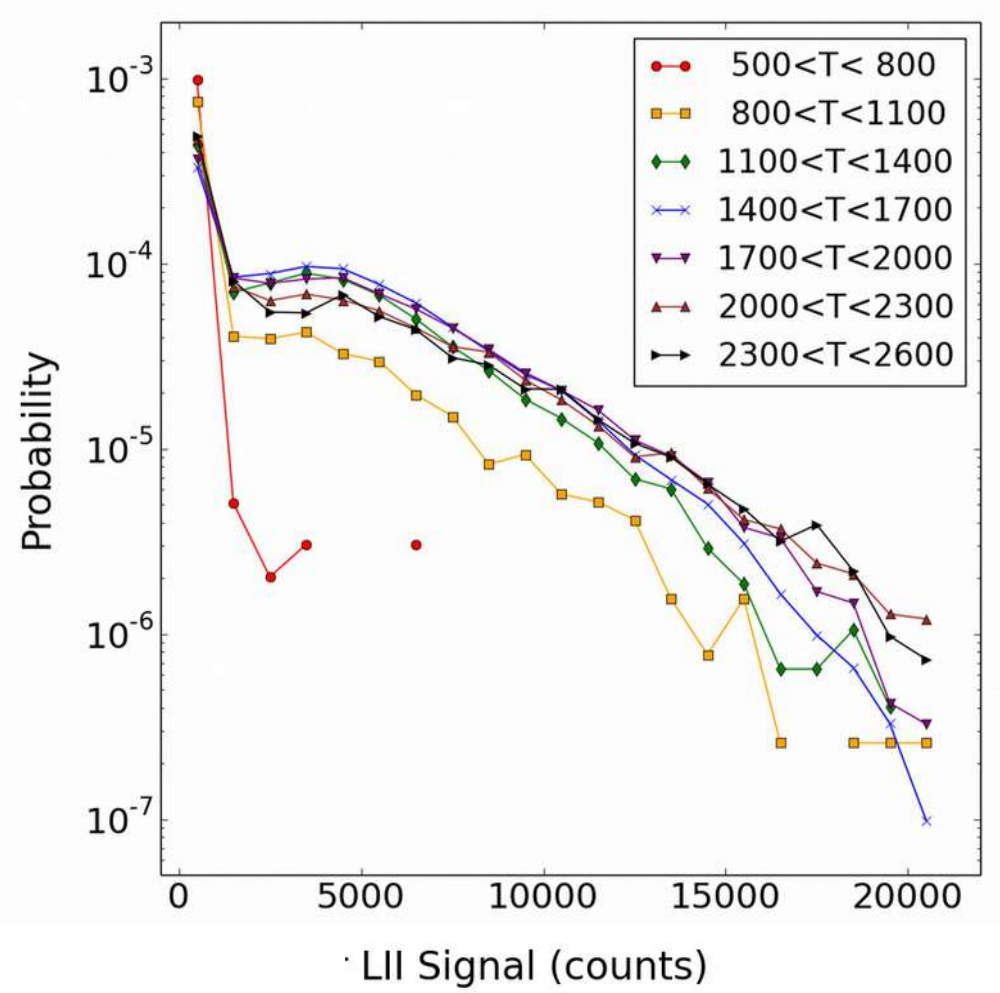
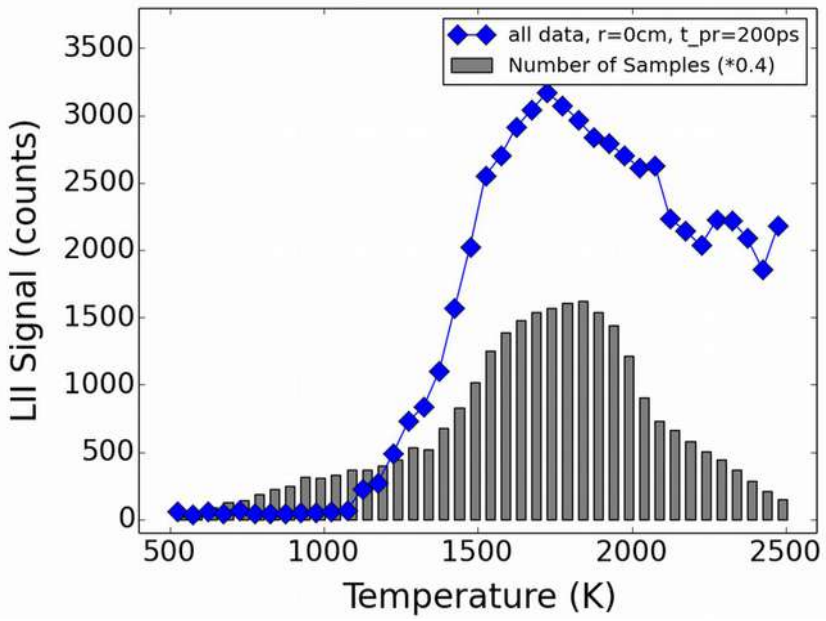
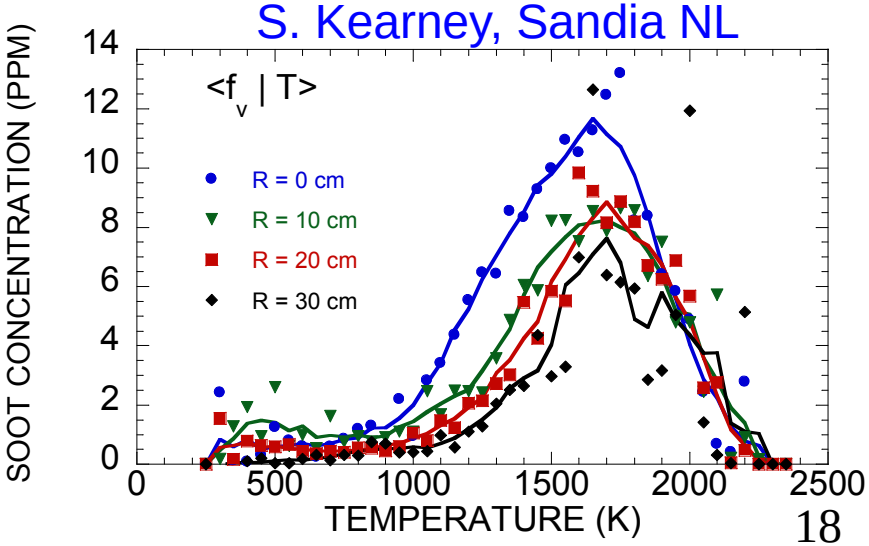
Results: Combine with LII measurements





Point data from
S. Kearney, Sandia NL



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Conclusions:

- Sooting, turbulent jet flame studied
- 1-dimensional measurements of:
  - temperature
  - relative O_2/N_2 concentration
- Rotational, two-beam fs/ps CARS
  - Probe volume size: 500 x 40 x 50 μm
  - Single-laser-shot T, O_2–N_2 ratio
  - 5-mm measurement line (125 spatially correlated temperatures)
- Temperature gradient analysis

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Future Work:

- Improve stability and SNR of measurements
- Combine with simultaneous LII measurements for joint statistical analysis
- Characterize soot inception, growth and oxidation regions of flame
- Compare to previous point temperature and LII data

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