

# Single-shot Coherent Raman Multiplex Planar Imaging

Alexis Bohlin and Christopher J. Kliewer

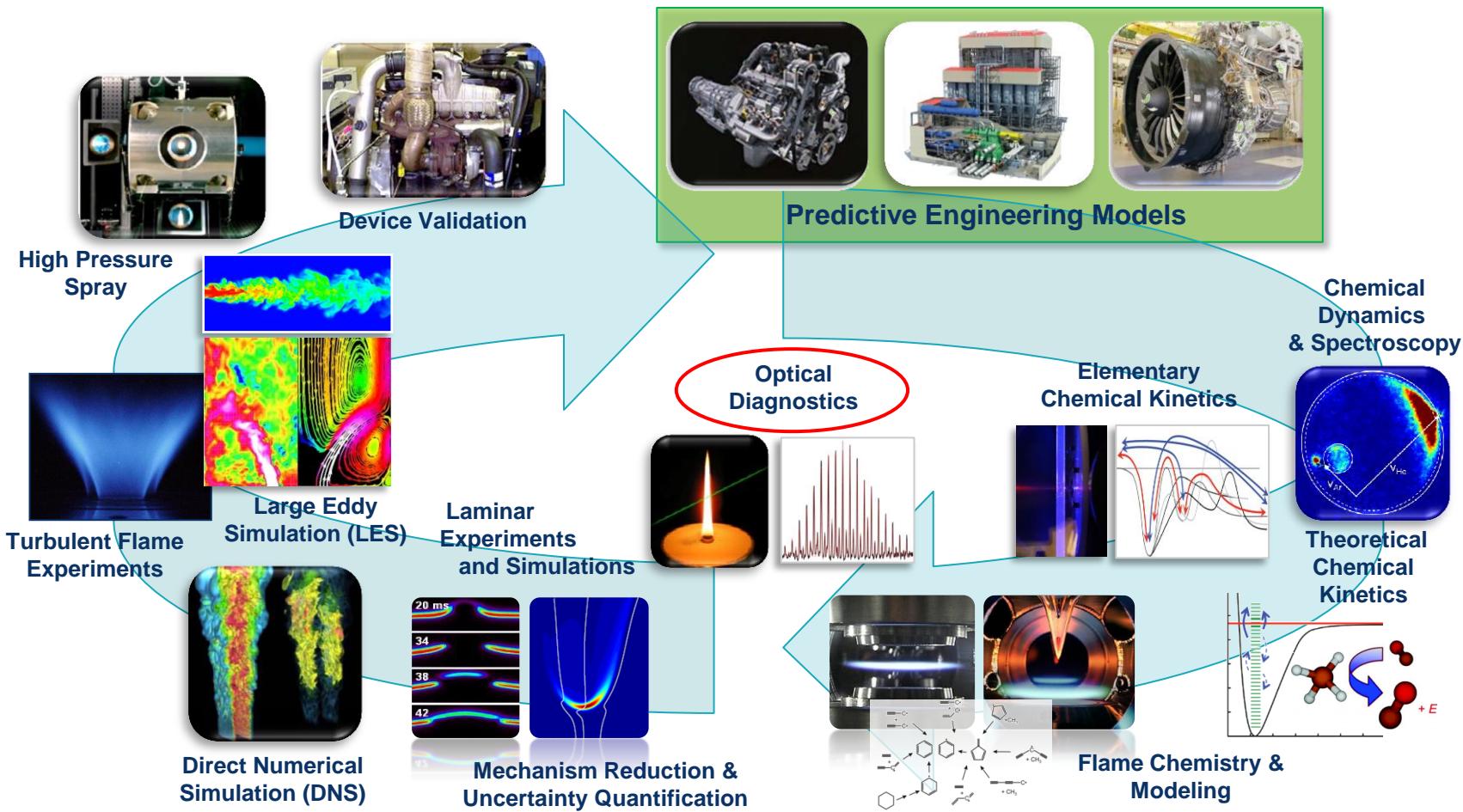
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## Acknowledgement

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# Basic science foundation for predictive combustion models



# Time-resolved optical diagnostics for combustion analysis

## Chemistry

Major species detection

Transient species

Particulate chemistry

Surface chemistry

## Spatial Correlation

Planar Imaging Techniques

Crossed Plane Technique

Multiple Plane / 3D Analysis

## Scalar determination

Temperature

Flow Field

Mixture Fraction

## Temporal Correlation

Single-laser-shot implementations

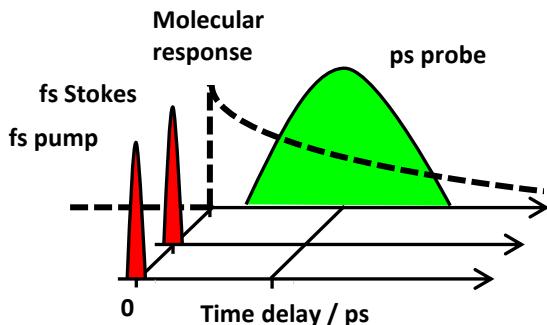
Video rate imaging ( $\mu$ s refresh rate)

Accuracy, Precision, Sensitivity

Resolution and “Field-of-View”

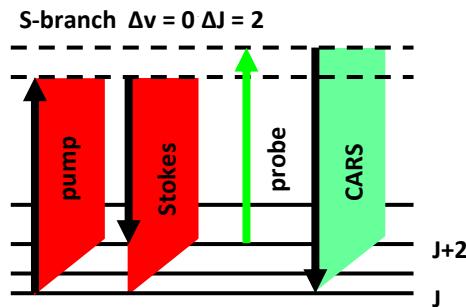
# Hybrid femtosecond/picosecond CARS

## Spectroscopy in the time-domain



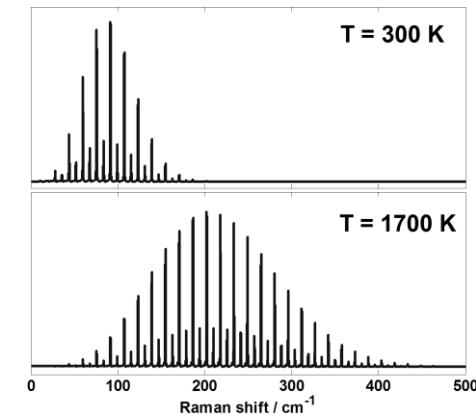
Time synchronized femtosecond (fs) and picosecond (ps) laser system.

## Energy principle



- 30 mJ / pulse @ 532 nm ( $\sim 90$  ps), 20 Hz
- 3 mJ / pulse @ 800 nm ( $\sim 45$  fs), 1 kHz

## $\text{N}_2$ spectra at two different temperatures

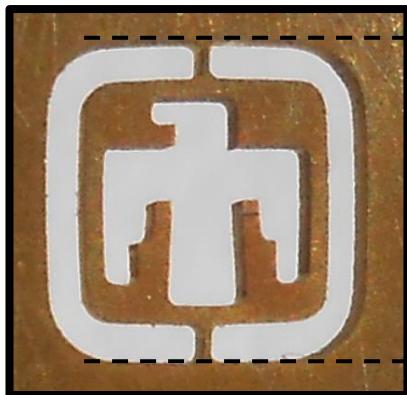


## Advantages:

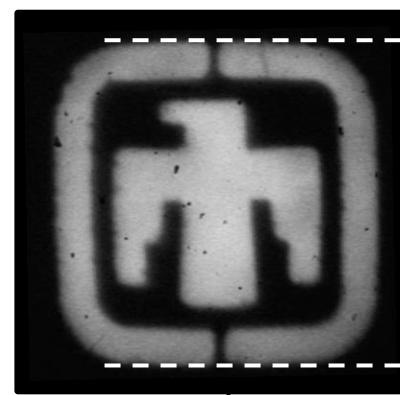
- Impulsive excitation creates highest possible signal levels.
- Collision-independent measurement possible (at certain conditions).
- Improved shot-to-shot precision.

# Instantaneous Planar-Coherent Raman Spectroscopy

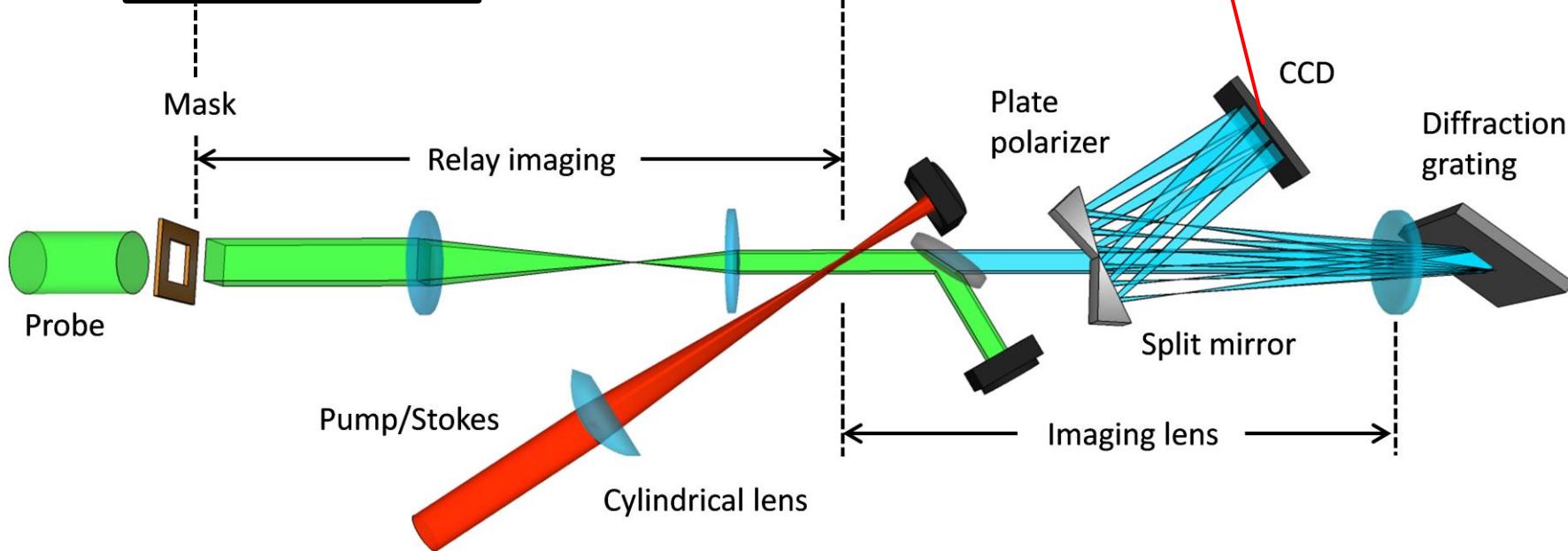
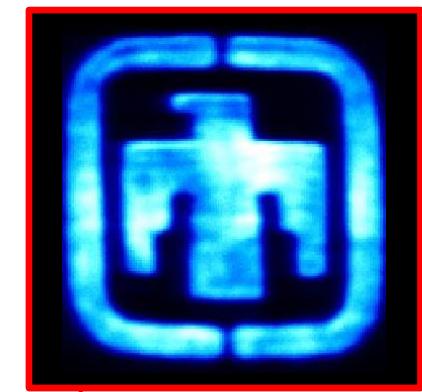
Spatial-filtering mask.



Probe beam at the crossing.

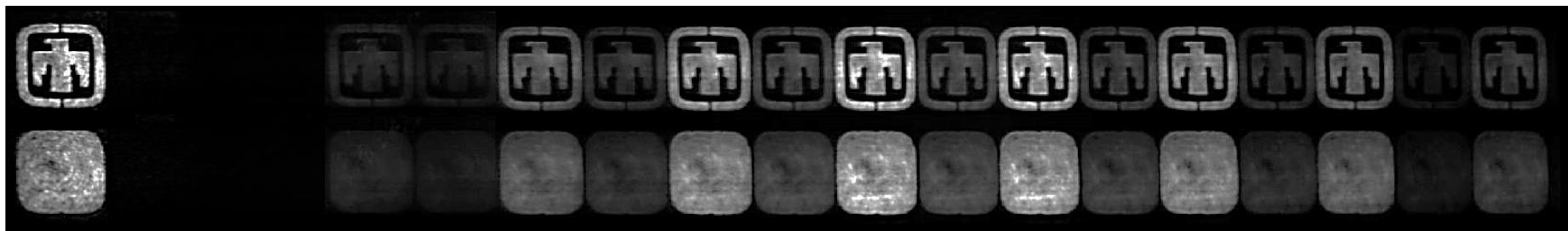


Single transition imaged through a grating.

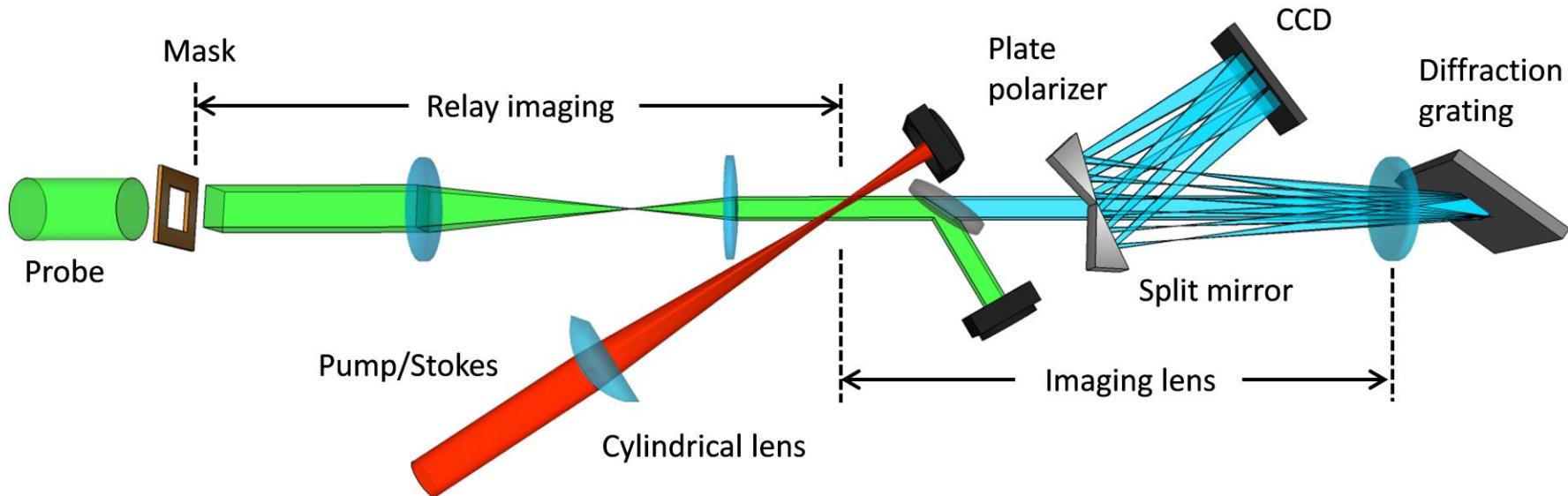


# Instantaneous Planar-Coherent Raman Spectroscopy

Rotational quantum number  $J = 4 \quad 5 \quad 6 \quad 7 \quad 8 \quad 9 \quad 10 \quad 11 \quad 12 \quad 13 \quad 14 \quad 15 \quad 16$

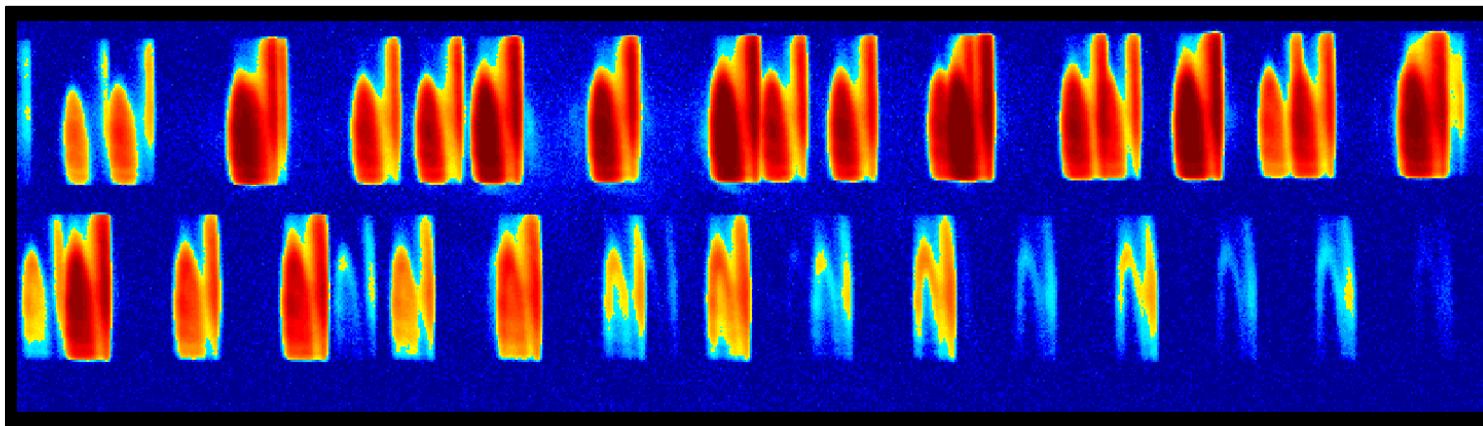


120 X 125 pixels = 15000 spatially correlated spectra in a single laser shot.



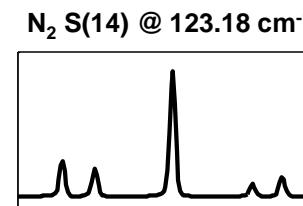
# 2D-mapping of temperature and species in flames

- Detecting #25 N<sub>2</sub> and #14 O<sub>2</sub> S-branch transitions with small spectral interference.



100 accumulated shots

Laminar premixed  
 $\sim\Phi=1$ , CH<sub>4</sub>/air flame

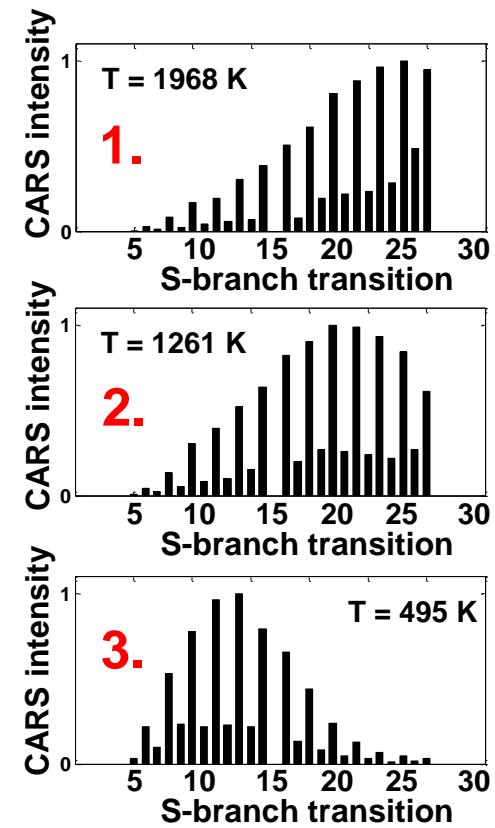
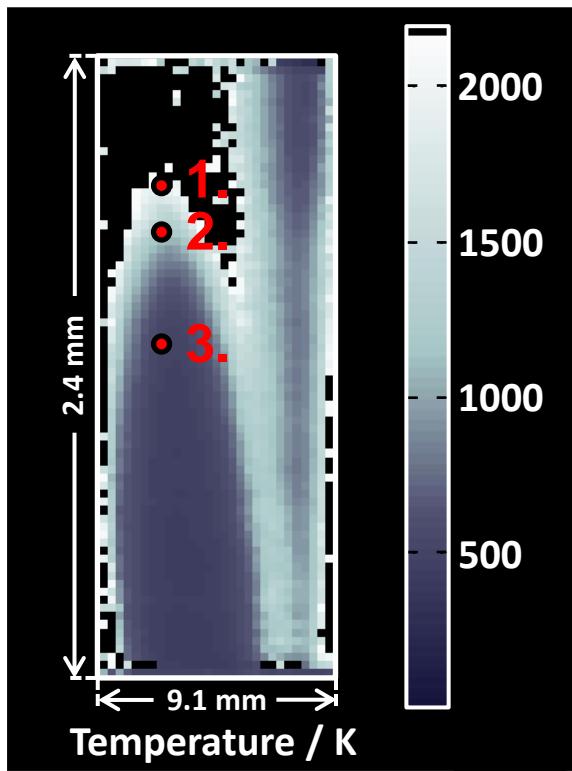
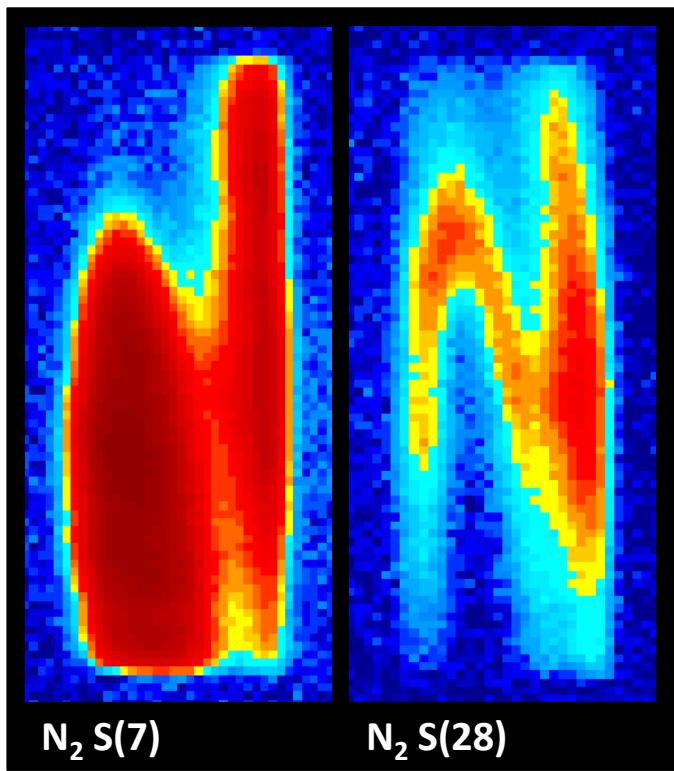


7.5 mm  
2 mm

- The measurements are optimized for flame thermometry and detecting [N<sub>2</sub>]/[O<sub>2</sub>], i.e. narrower mask, ~2100 spectra collected simultaneously, 2D-field of 2 x 7.5 mm.

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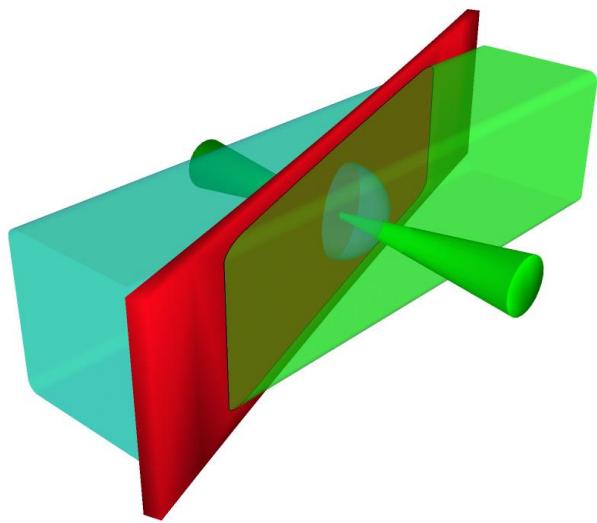
# 2D-mapping of temperature and species in flames



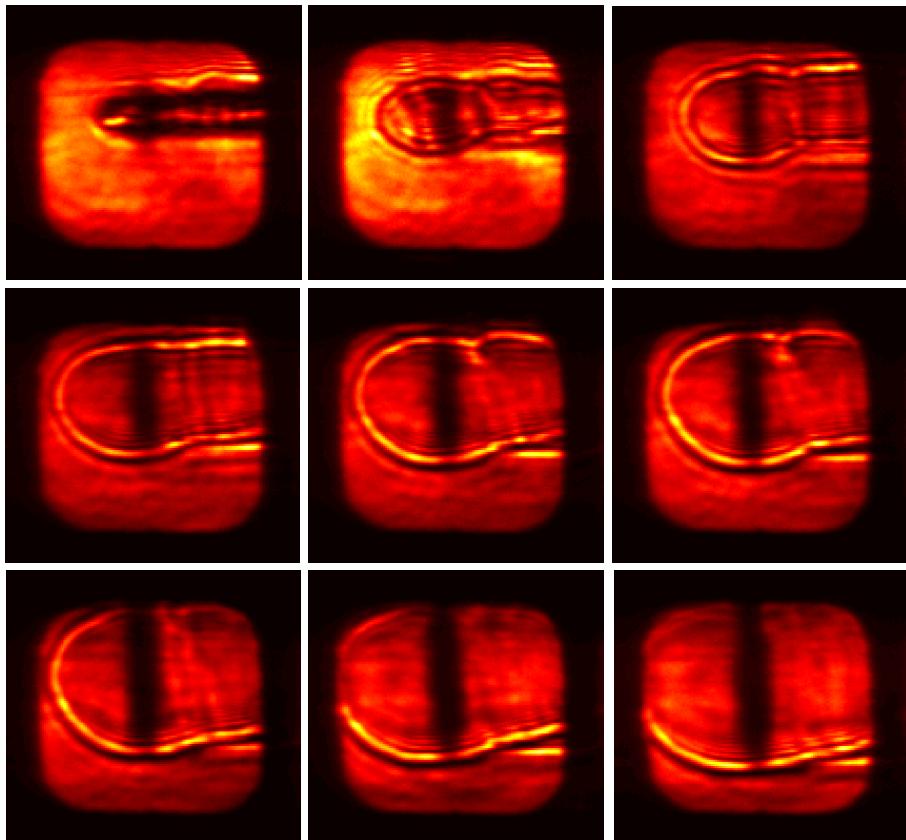
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# Preliminary low temperature application in intense laser pulse induced plasma

Measurement geometry

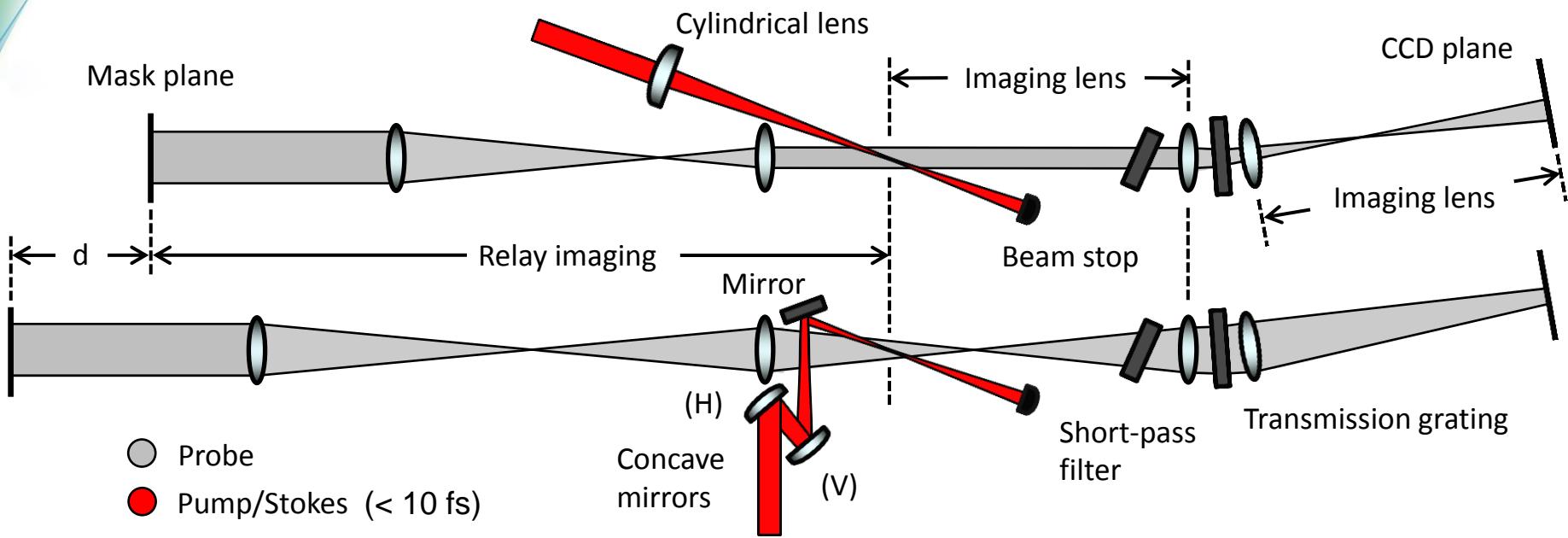


Plasma – CARS delay, 15ns – 175ns



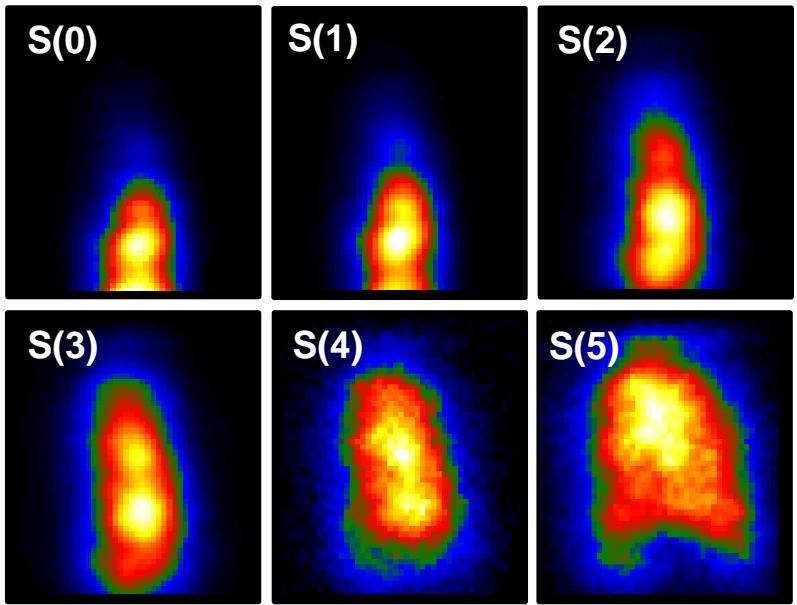
- Time-resolved measurements studying the propagation of the plasma induced shock wave.
- Observed rotational heating.

# Two-beam 2D Ultrabroadband CARS

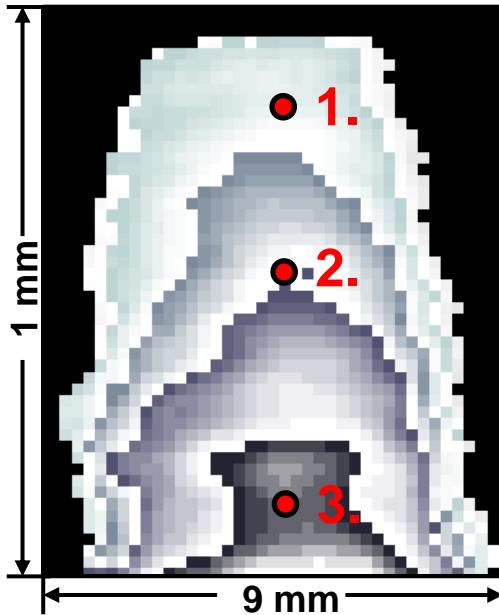


- Enables imaging of most all fundamental Raman modes.
- Astigmatic focus to increase the irradiance of the Pump/Stokes beam.
- Expanded beam through detection optics -> only spectral filter required for probe suppression.

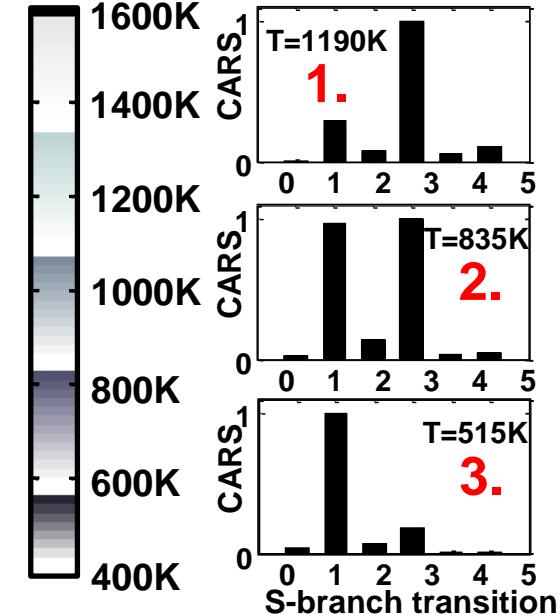
a  $\text{H}_2$  S-branch  $354 \text{ cm}^{-1} - 1447 \text{ cm}^{-1}$



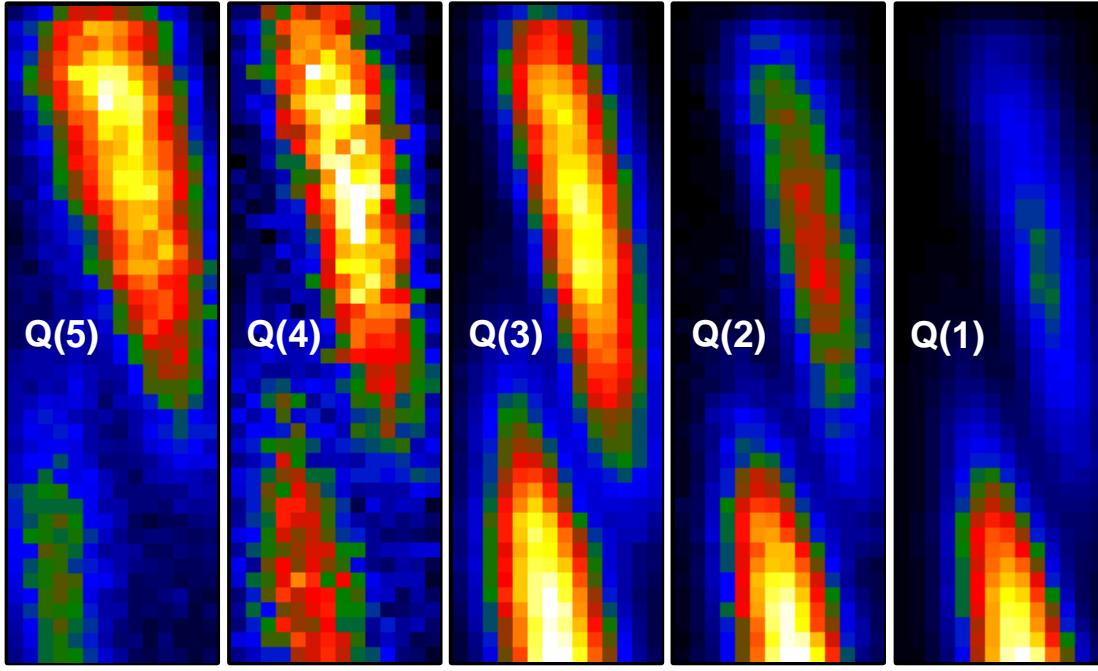
b



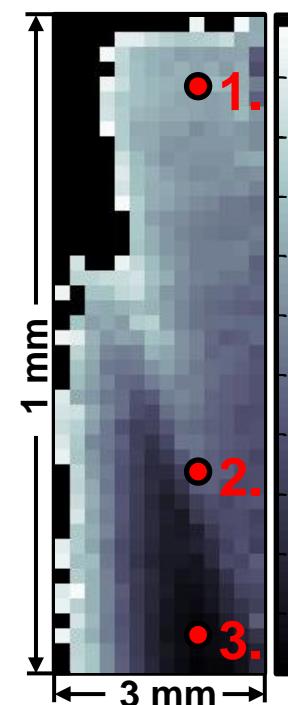
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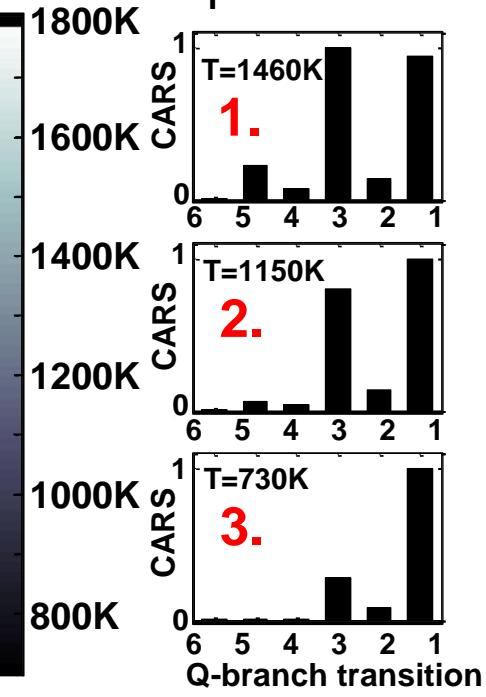
d  $\text{H}_2$  Q-branch  $4037 \text{ cm}^{-1} - 4155 \text{ cm}^{-1}$



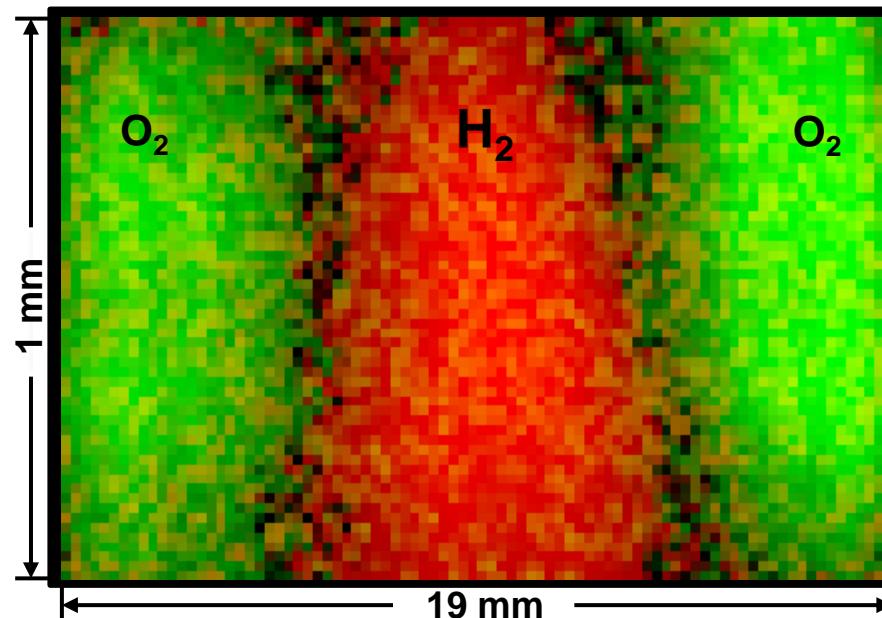
e



f



# Two-beam 2D Ultrabroadband CARS



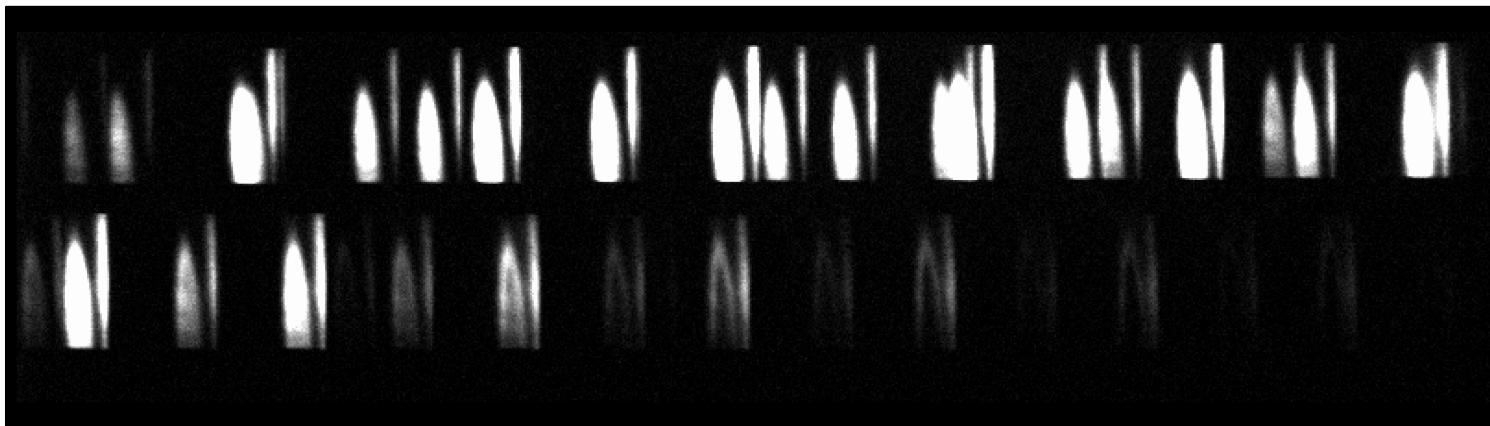
- Direct CARS imaging of fuel / oxidizer – mixture fraction.
- Thermometry directly on reactant molecules.
- Accomplishes the goal of all dual pump CARS setups in a single apparatus.

# Recent advances for gas-phase CARS

- Two-beam phase matching scheme for simplified signal generation.
  - Significantly improved spatial resolution.
  - Automatically overlapped pump/Stokes fields, temporally and spatially, makes the technique more robust and higher pulse energy available.
- Two-dimensional (2D) measurement capability.
  - Diagnostic imaging of temperature and species will significantly increase to the information provided for rigorous comparison between numerical simulation and experiments for model validation.
- Ultrabroadband planar-coherent Raman imaging.
  - Unique instantaneous and spatially correlated assessment which enables multiplexed studies in transient dynamical systems in a 2D field.
  - Enables wideband chemically selective mapping of molecular partition functions.

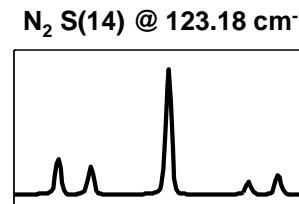
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- Detecting #25 N<sub>2</sub> and #14 O<sub>2</sub> S-branch transitions with small spectral interference.



Single shot raw data collected @ ~5 Hz

Laminar premixed  
~Φ=1, CH<sub>4</sub>/air flame



- The measurements are optimized for flame thermometry and detecting [N<sub>2</sub>]/[O<sub>2</sub>], i.e. narrower mask, ~2100 spectra collected simultaneously, 2D-field of 2 x 7.5 mm.

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