

Single-shot Coherent Raman Multiplex Planar Imaging

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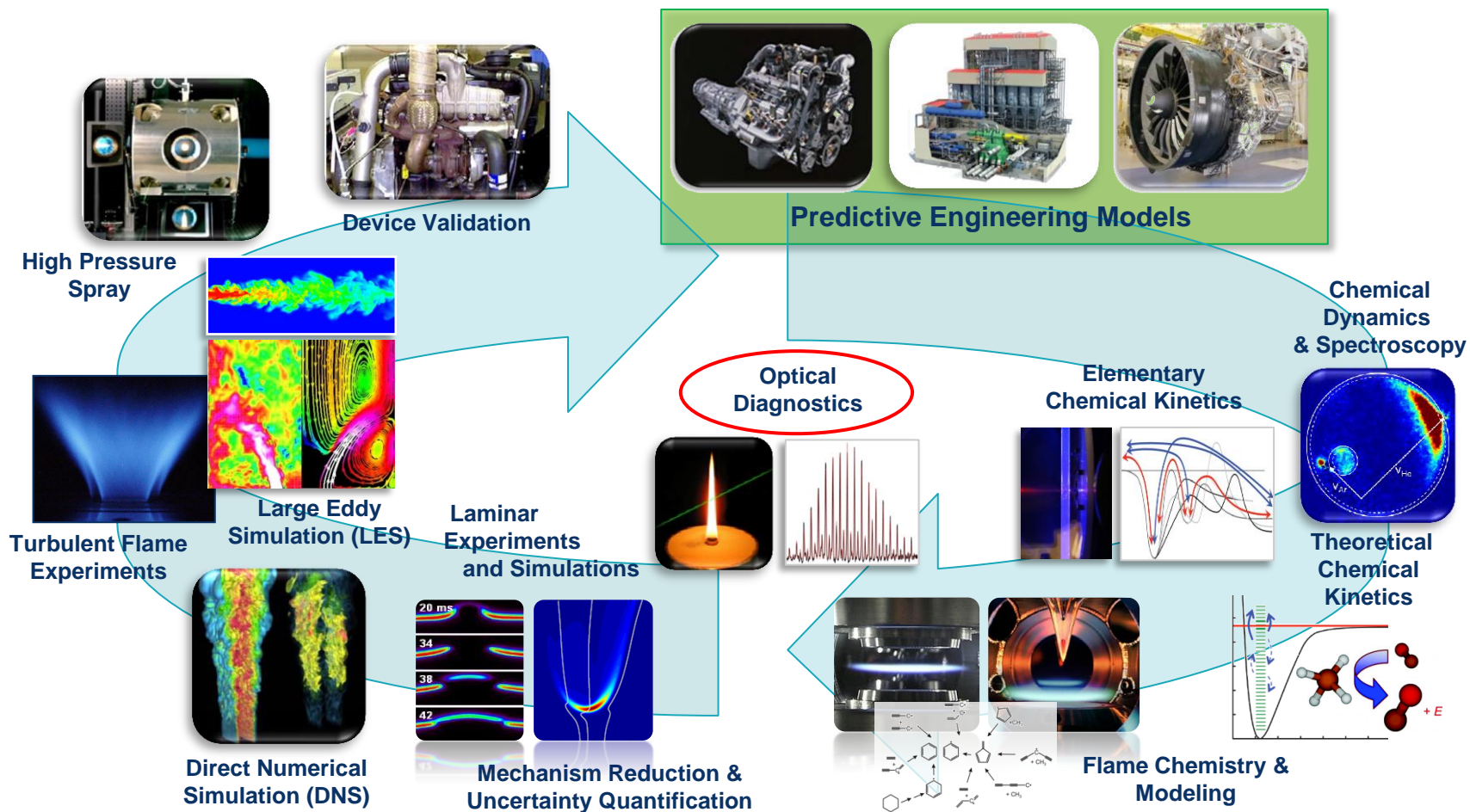
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Acknowledgement

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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

Scalar determination

Temperature

Flow Field

Mixture Fraction

Spatial Correlation

Planar Imaging Techniques

Crossed Plane Technique

Multiple Plane / 3D Analysis

Temporal Correlation

**Single-laser-shot
implementations**

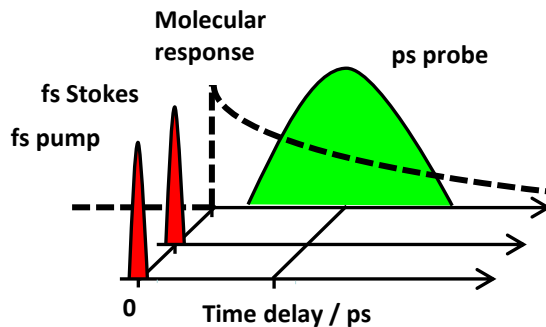
**Video rate imaging (μ s refresh
rate)**

Accuracy, Precision, Sensitivity

Resolution and “Field-of-View”

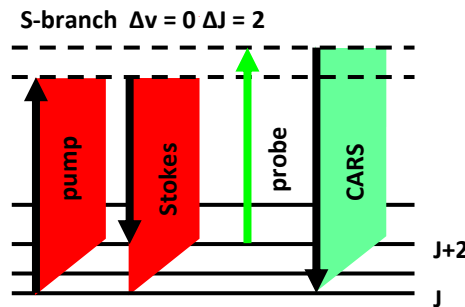
Hybrid femtosecond/picosecond CARS

Spectroscopy in the time-domain



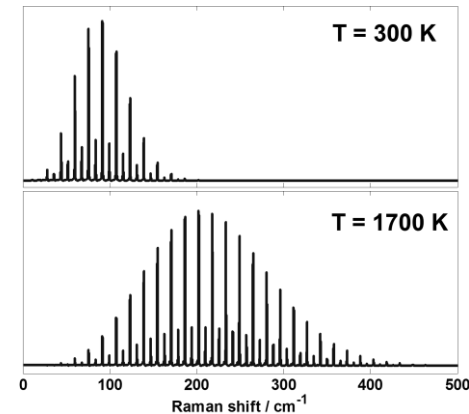
Time synchronized femtosecond (fs) and picosecond (ps) laser system.

Energy principle



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

N_2 spectra at two different temperatures

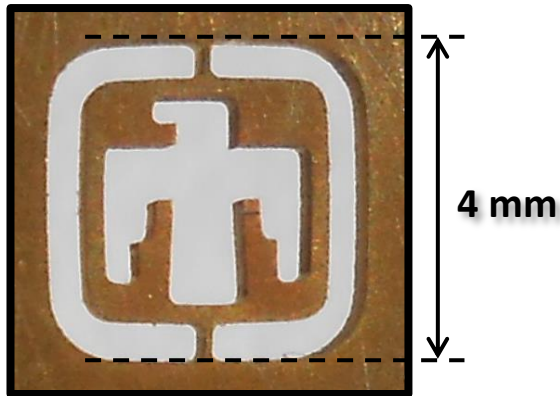


Advantages:

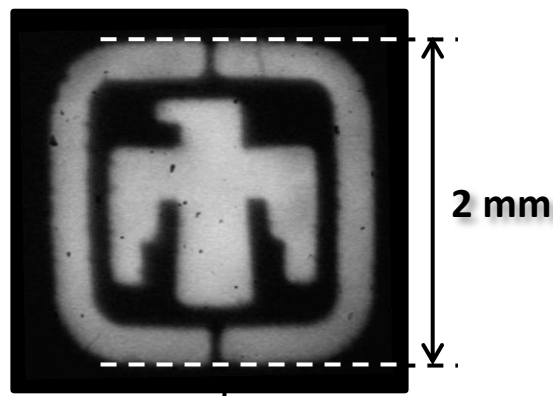
- Impulsive excitation creates highest possible signal levels.
- Collision-independent measurement possible (at certain conditions).
- Improved shot-to-shot precision.

Instantaneous Planar-Coherent Raman Spectroscopy

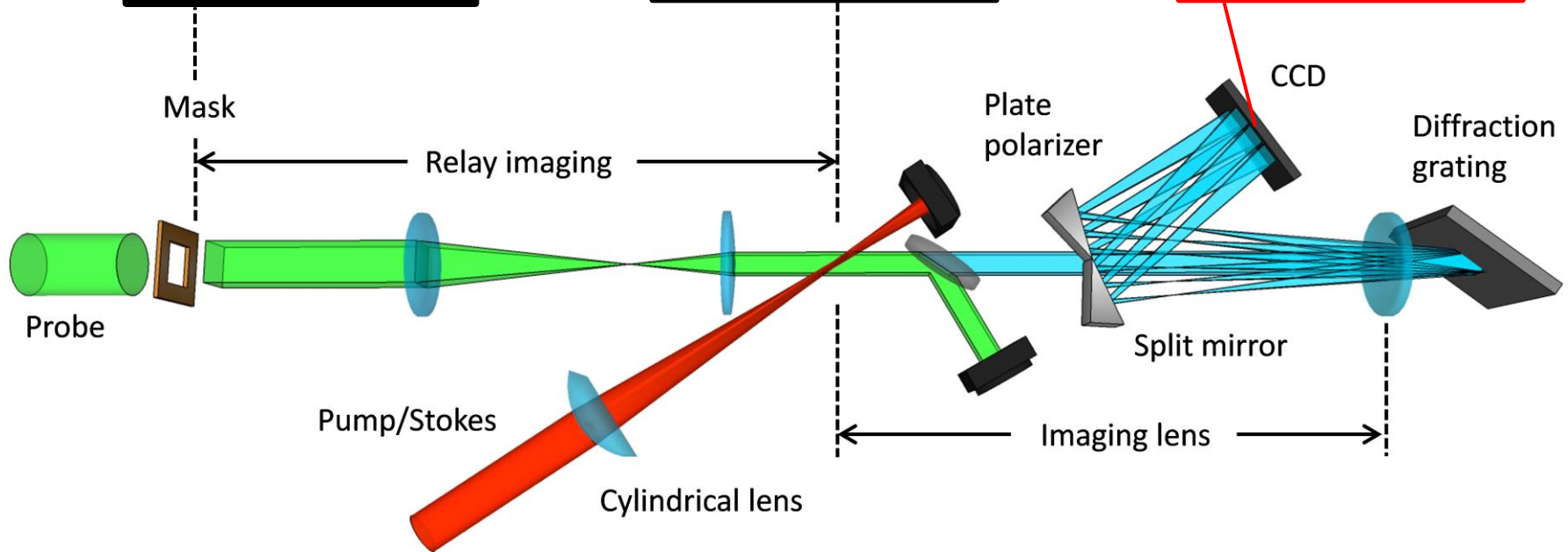
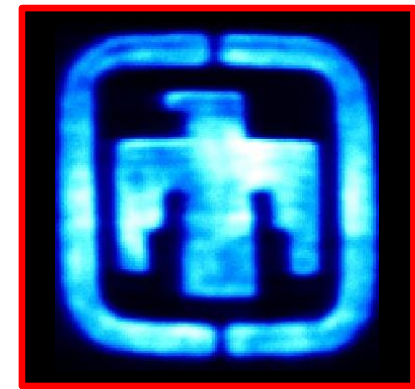
Spatial-filtering mask.



Probe beam at the crossing.

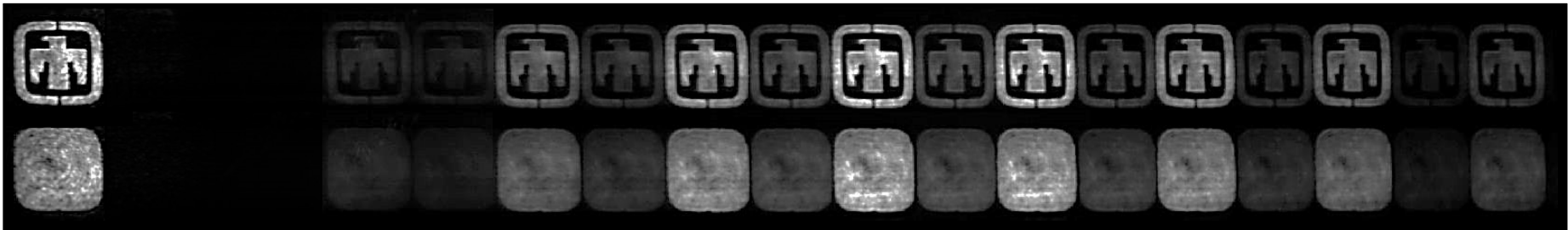


Single transition imaged through a grating.

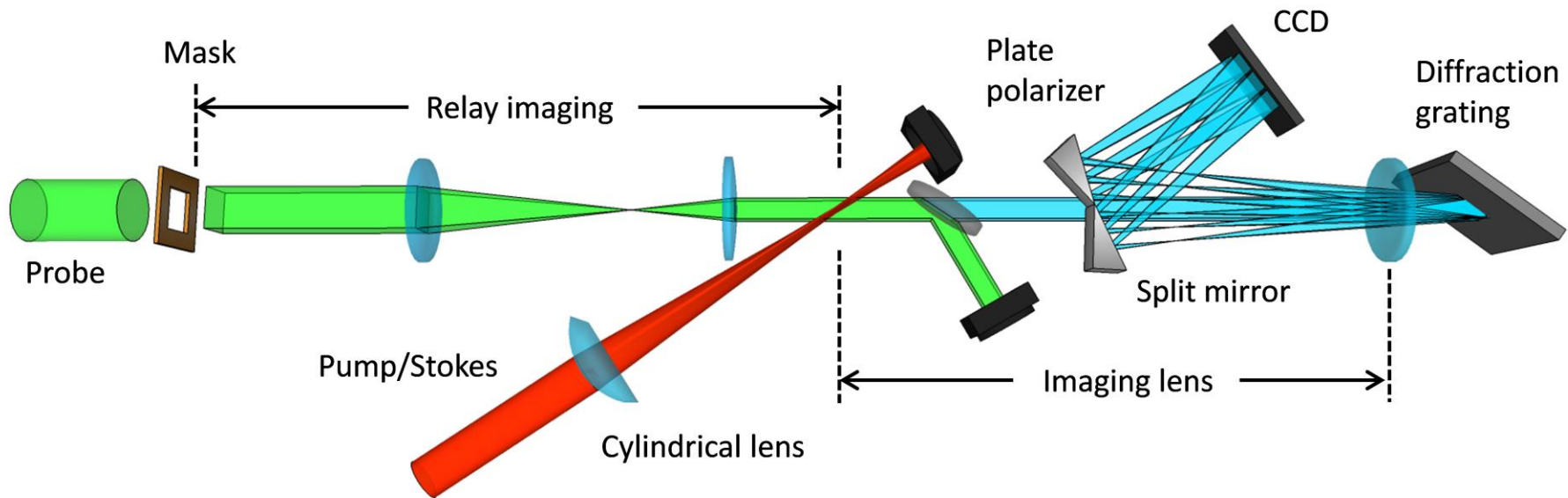


Instantaneous Planar-Coherent Raman Spectroscopy

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



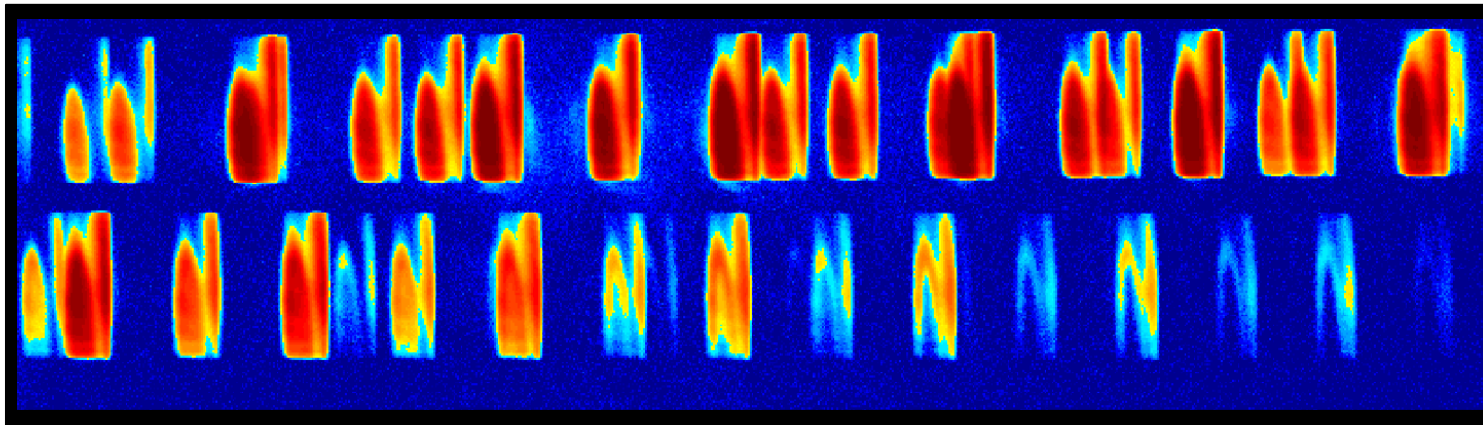
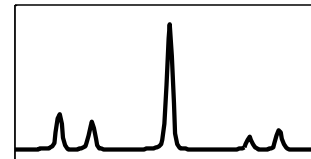
120 X 125 pixels = 15000 spatially correlated spectra in a single laser shot.



2D-mapping of temperature and species in flames

- Detecting #25 N_2 and #14 O_2 S-branch transitions with small spectral interference.

N_2 S(14) @ 123.18 cm^{-1}



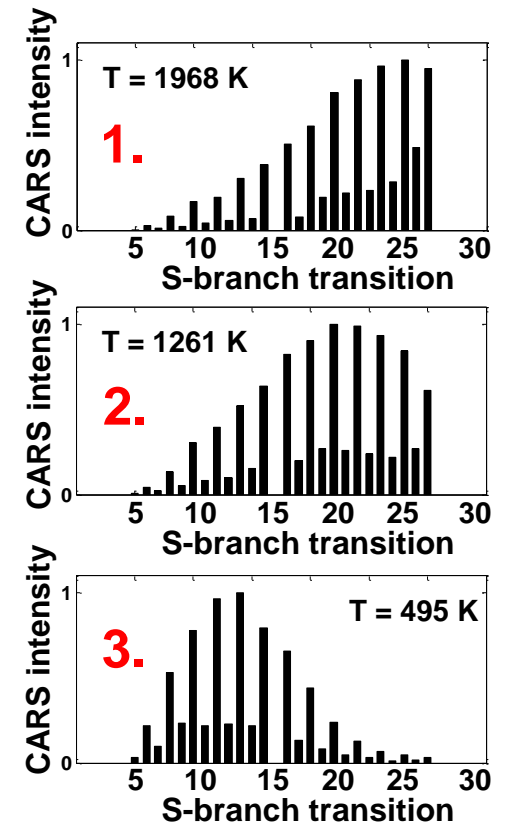
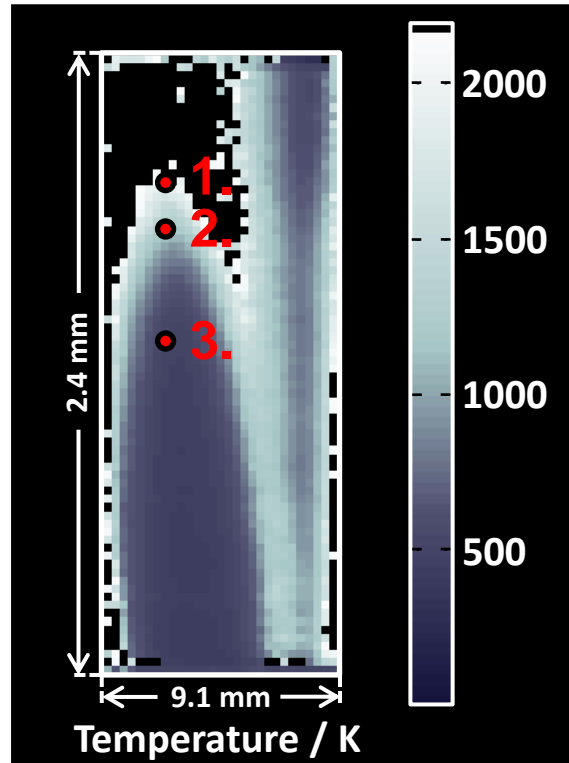
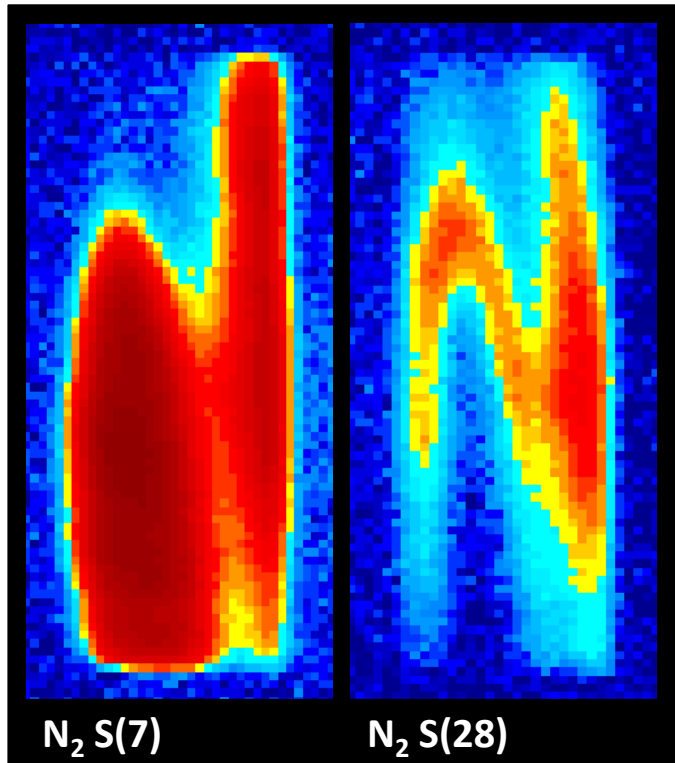
100 accumulated shots

- The measurements are optimized for flame thermometry and detecting $[N_2]/[O_2]$, i.e. narrower mask, ~2100 spectra collected simultaneously, 2D-field of 2 x 7.5 mm.

Laminar premixed
~ $\Phi=1$, CH_4 /air flame



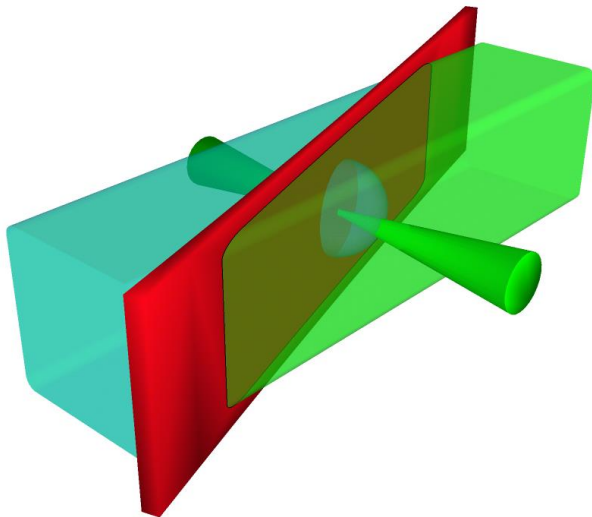
2D-mapping of temperature and species in flames



A. Bohlin, C.J. Kliwer, *J. Phys. Chem. Lett.* 5, 1243 (2014).

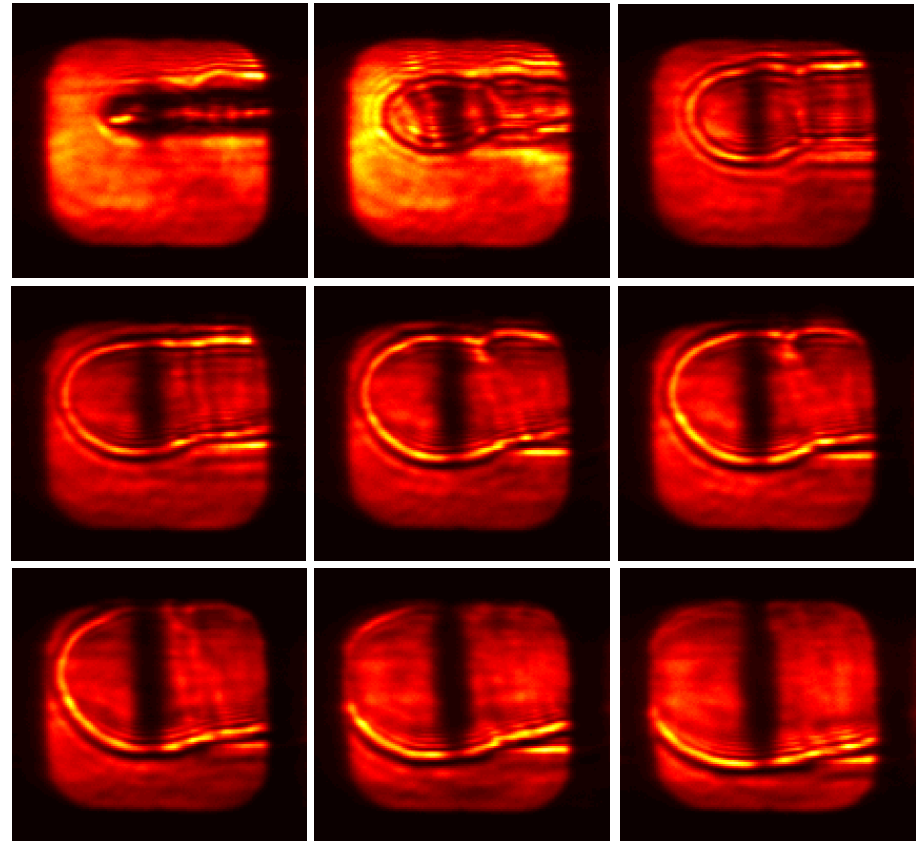
Preliminary low temperature application in intense laser pulse induced plasma

Measurement geometry



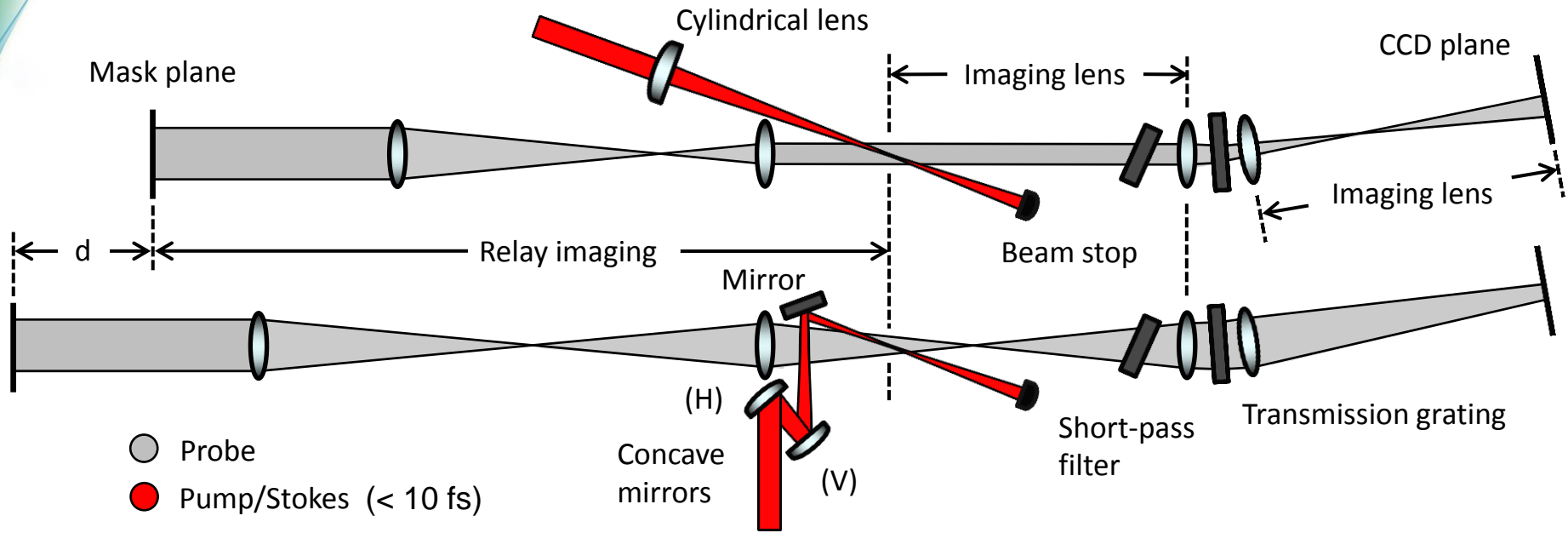
Laser pulse
→

Plasma – CARS delay, 15ns – 175ns



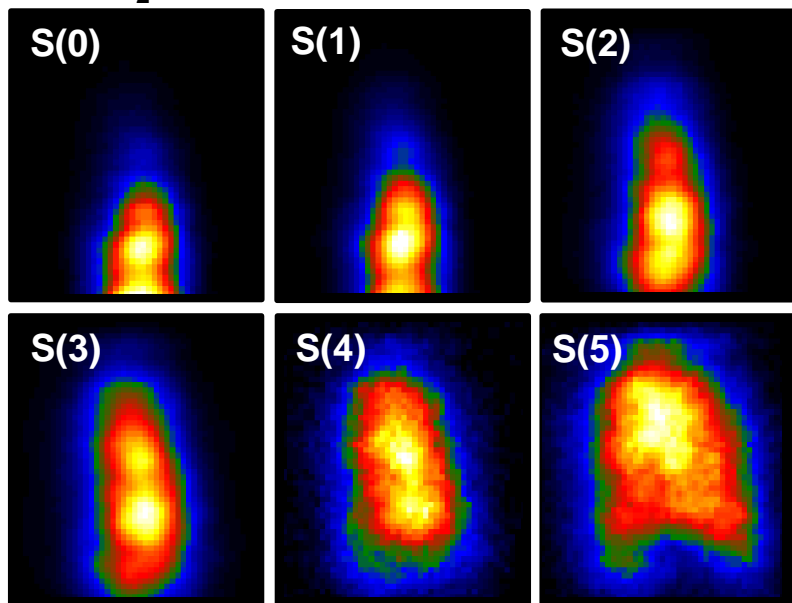
- Time-resolved measurements studying the propagation of the plasma induced shock wave.
- Observed rotational heating.

Two-beam 2D Ultrabroadband CARS

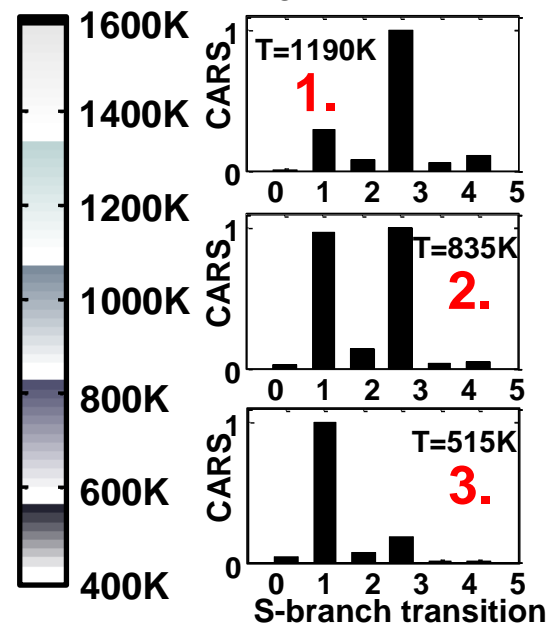
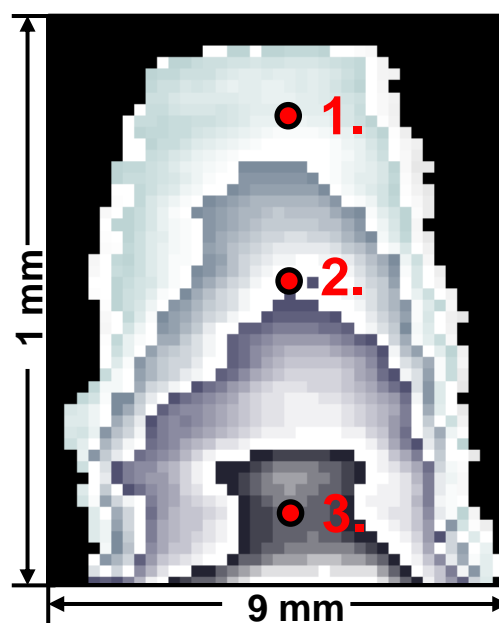


- Enables imaging of most all fundamental Raman modes.
- Astigmatic focus to increase the irradiance of the Pump/Stokes beam.
- Expanded beam through detection optics -> only spectral filter required for probe suppression.

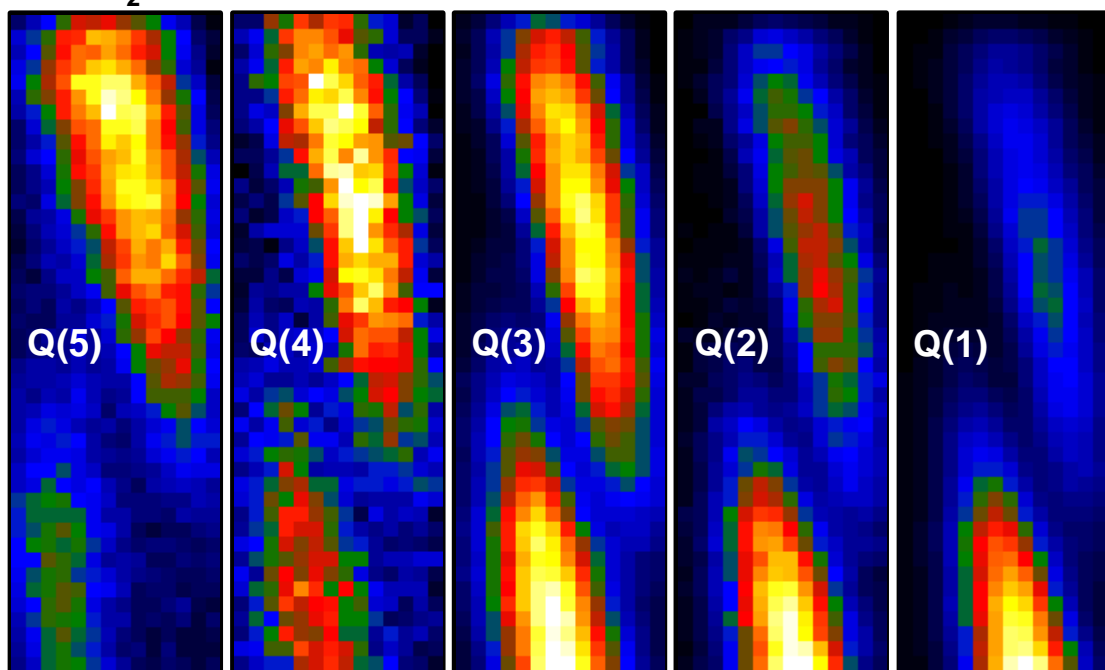
a H_2 S-branch $354\text{ cm}^{-1} - 1447\text{ cm}^{-1}$



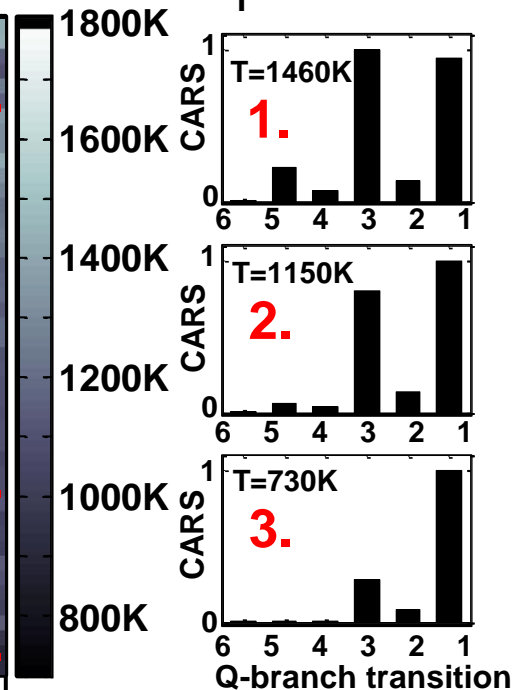
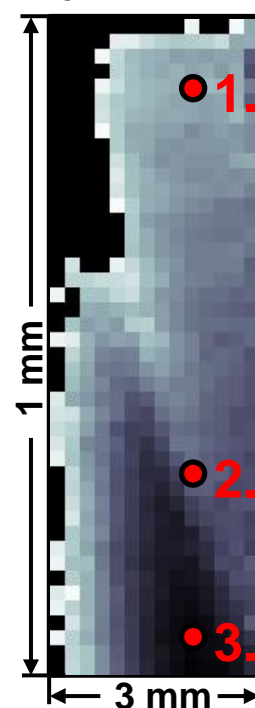
b



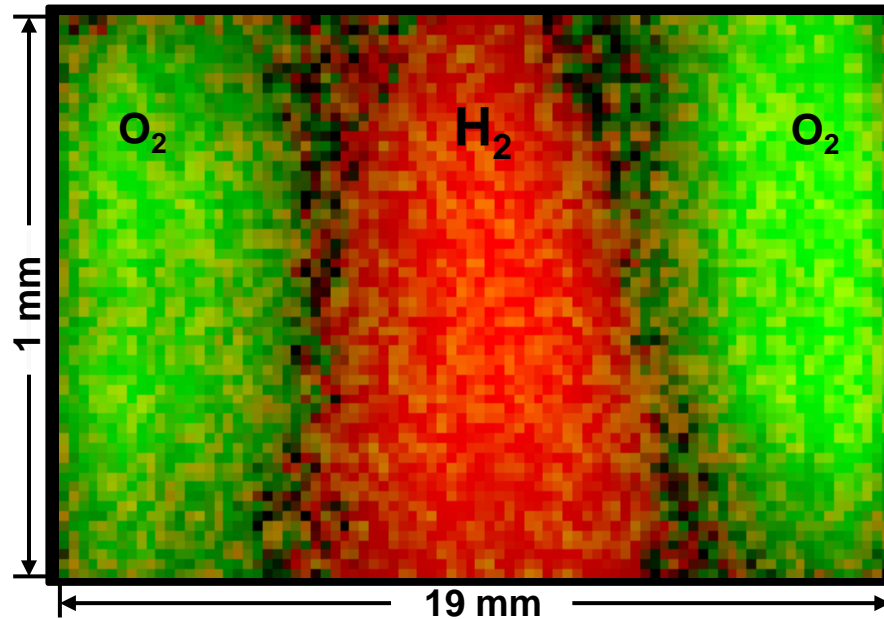
d H_2 Q-branch $4037\text{ cm}^{-1} - 4155\text{ cm}^{-1}$



e



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.



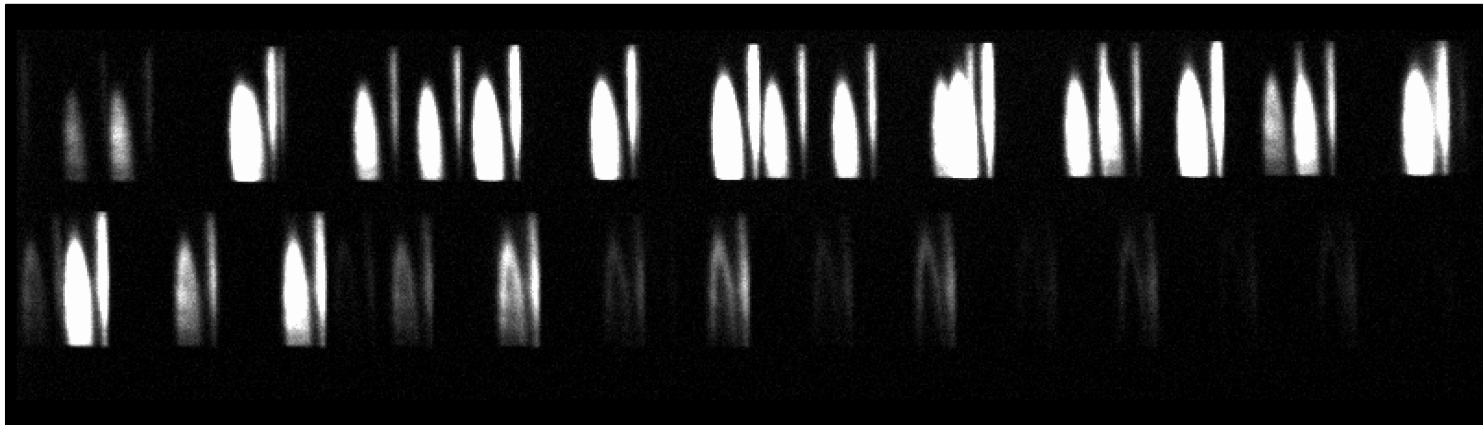
Recent advances for gas-phase CARS

- 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.

2D-mapping of temperature and species in flames

- Detecting #25 N_2 and #14 O_2 S-branch transitions with small spectral interference.

N_2 S(14) @ 123.18 cm^{-1}



Single shot raw data collected @ ~5 Hz

- The measurements are optimized for flame thermometry and detecting $[N_2]/[O_2]$, i.e. narrower mask, ~2100 spectra collected simultaneously, 2D-field of 2 x 7.5 mm.



A. Bohlin, C.J. Kliwer, *J. Phys. Chem. Lett.* 5, 1243 (2014).