

Spatially Resolved Species Measurements in a GO_2/GH_2 Propellant Rocket

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Statement of Problem

Local species concentration and temperature are among the most important parameters to characterize in a combustion system. However, the harsh environment in rocket chambers under hot-fire conditions limits the applicability of conventional probing methods for the acquisition of this information. Laser-based diagnostic methods show great promise for achieving this goal by providing instantaneous images of species concentrations and temperature.

Objective of Work

The objective of the current work is to develop a non-intrusive technique to experimentally determine the major species and temperature field in the combustion chamber of an uni-element rocket for a GO_2/GH_2 propellant combination.

Approach

The experiments were conducted at the Cryogenic Combustion Laboratory at Penn State University. The uni-element rocket chamber used is modular in design and is easily configured to provide optical access along the chamber length. A shear coaxial injector was used to introduce GO_2 and GH_2 into the combustion chamber. The nominal flow rates of GO_2 and GH_2 are 0.1 lb/s and 0.025 lb/s, respectively, resulting in an O/F ratio of four. The experiments were for a chamber pressure of 190 psia.

One-dimensional profiles of species concentrations and temperature were measured by using laser-induced spontaneous Raman spectroscopy. The Raman system consists of a flash pumped dye laser operating at 10 Hz and an intensified CCD camera. The dye laser has a typical pulse energy of 2 J at 511 nm and a pulse duration of 5 μs . The Raman emission was detected at a right angle to the laser beam. A narrow band interference filter was placed in front of the camera to selectively measure the number density of the species. For each rocket firing, 50 single-shot Raman images and 50 background images were captured. By using different optical filters, Raman images of oxygen, hydrogen, water and nitrogen (used for window cooling) were obtained. Measurements were conducted at 1, 2, and 5 inch downstream of the injector face. The ratio of the signal to background level for hydrogen and oxygen Raman images at 1 inch downstream is about 10. Further downstream, the background luminosity increases significantly. Thus, the species concentration can only be determined from averaged Raman images. The temperature profiles were calculated from averaged data of total species number density using the ideal gas law. Since the Raman signal is stronger in lower temperature regions, the averaged temperature generally underestimates the temperature in regions where temperature fluctuates highly.

Conclusions

Single-shot and averaged profiles of species concentration have been measured under combusting conditions. These results demonstrate that the laser-based technique can be effectively applied for in-situ measurements in a rocket chamber. Experiments with an improved detection system for obtaining images of instantaneous and simultaneous multi-species concentration and temperature are underway.

***SPATIALLY RESOLVED SPECIES
MEASUREMENTS IN A GO_2/GH_2
PROPELLANT ROCKET***

M. J. Foust, T. Ni and R. J. Santoro

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OVERVIEW

- **Demonstrate Application of Raman Spectroscopy**
- **Present Measurements Using 2 Techniques**
 - **Optical Bandpass Filters**
 - ⇒ **Good Light Collection for Obtaining Single Species**
 - ⇒ **Cannot Assess Flame Luminosity Contribution**
 - ⇒ **Simultaneous Species Measurements Require Multiple Detectors**
 - **Spectrometer**
 - ⇒ **Provides Simultaneous Species Measurements Using Single Detector**
 - ⇒ **Assessment of Flame Background**
 - ⇒ **Needs Wide Dynamic Range**
- **Summarize Raman Experiments**



MOTIVATION

- **Improved Fundamental Understanding of Combustion-Driven Flows**
- **Combusting Flowfield Measurements used for CFD Code Validation**
- **Performance Assessment for Candidate Gas/Gas Injectors in Reusable Launch Vehicle Program**

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APPROACH

- **Experiments in a Uni-Element Rocket**
- **Apply Laser-Based Diagnostic Techniques**
 - **Laser Doppler Velocimetry**
 - **Laser-Induced Fluorescence of OH**
 - **Laser Light Scattering from Tracer Particles**
 - ✓ **Laser-Induced Raman Spectroscopy**

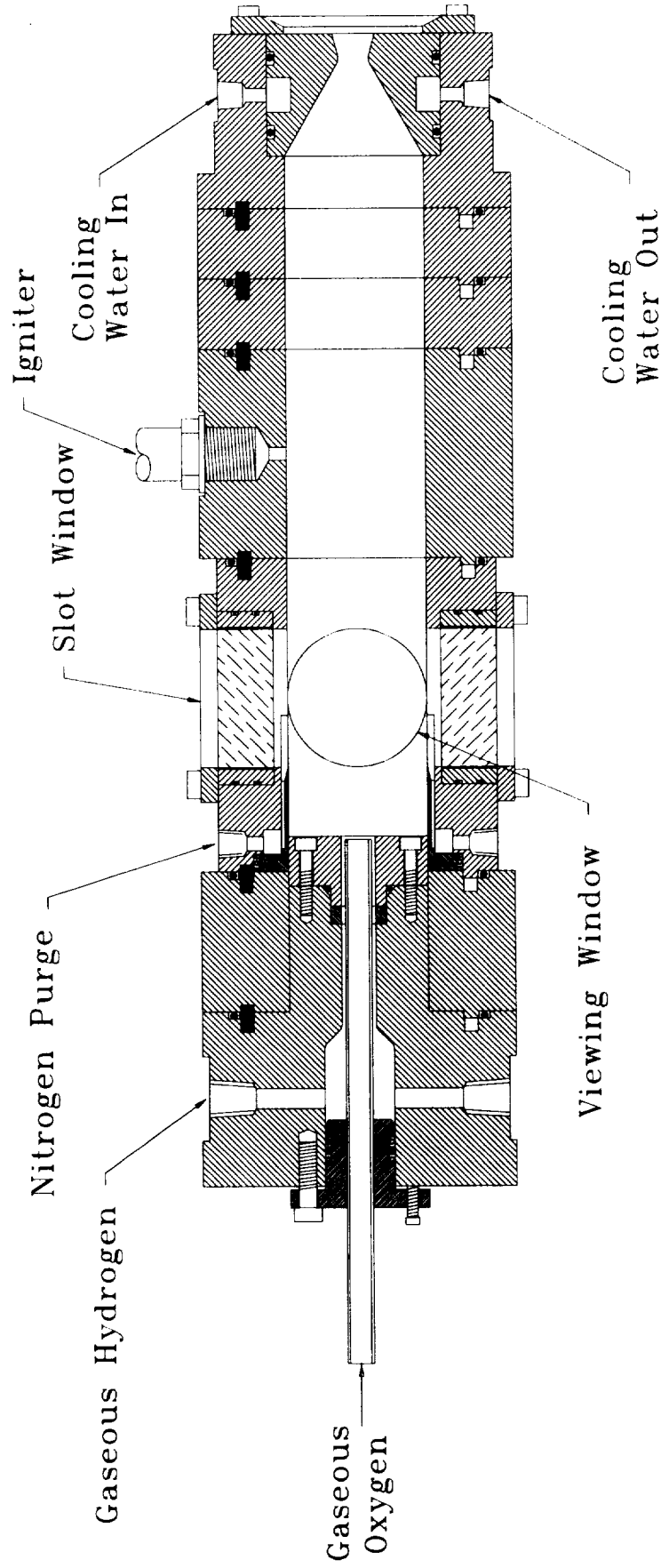
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OPTICALLY-ACCESSIBLE ROCKET CHAMBER



GO₂/GH₂ ROCKET TEST CONDITIONS

Shear Coaxial Injector

**GH₂ Mass Flow Rate
kg/s (lbfm/s) 0.010 (0.023)**

**GO₂ Mass Flow Rate
kg/s (lbfm/s) 0.042 (0.092)**

**GN₂ Mass Flow Rate
kg/s (lbfm/s) 0.010 (0.022)**

GO₂/GH₂ Mixture Ratio 4.0

**Chamber Pressure
MPa (psia) 1.29 (187)**

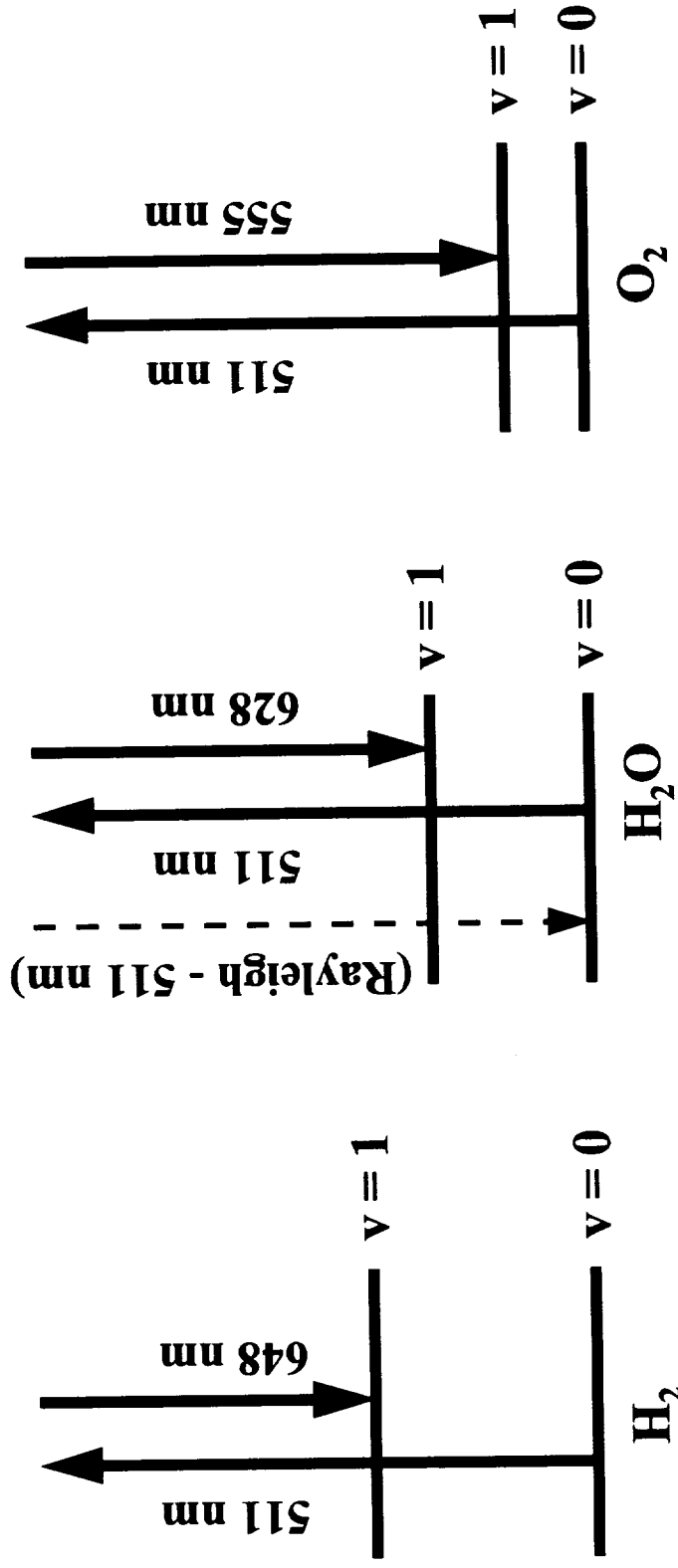
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RAMAN SPECTROSCOPY

Stokes Vibrational Shift



- Raman Signal Specific to Each Species
- Linearly Proportional to Species Number Density
- $1 / \lambda^4$ Wavelength Dependence

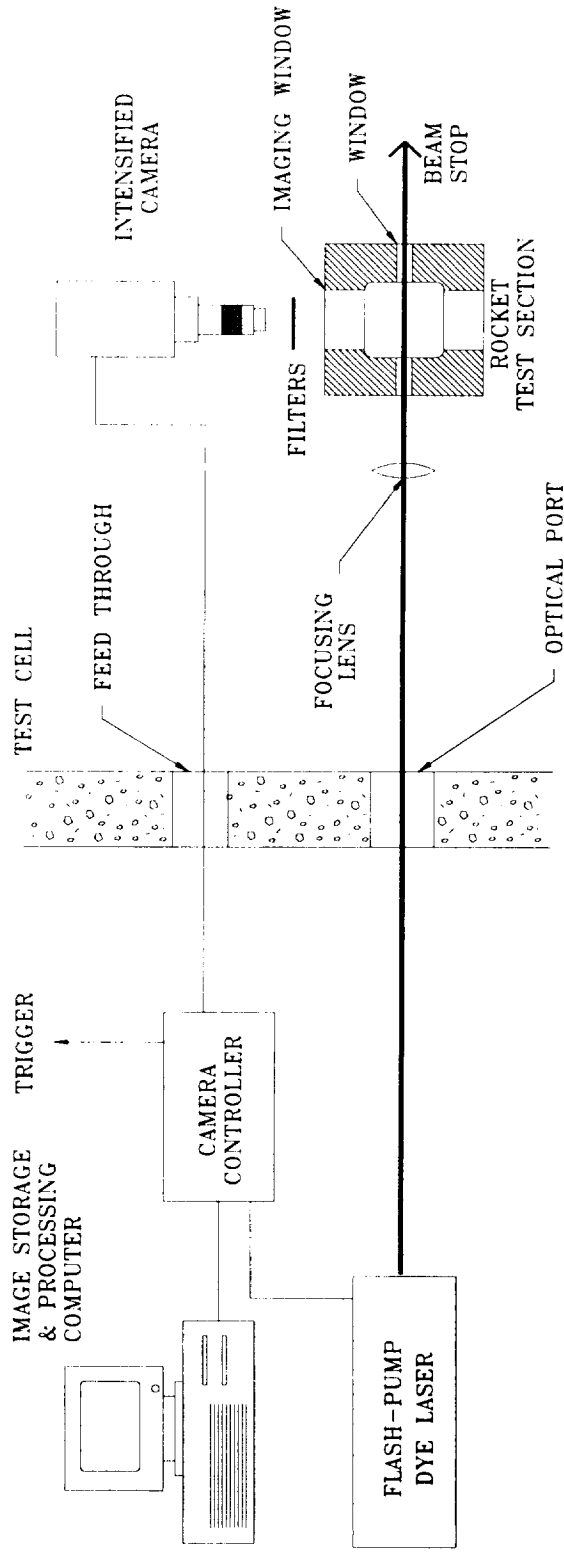
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EXPERIMENTAL SETUP

- Optimized System for Collecting Weak Raman Signal



SPECIES MEASUREMENTS IN GO₂/GH₂ Rocket

- **Obtained 35 Instantaneous Line Images Individually for Each Species (GO₂, GH₂, H₂O and GN₂ - Purge) During 4 sec. Rocket Firings**
- **Calibrated Measurements for Each Species Using Pure Gas Concentration**
- **Extracted Average Species Mole Fractions from 100 Images**

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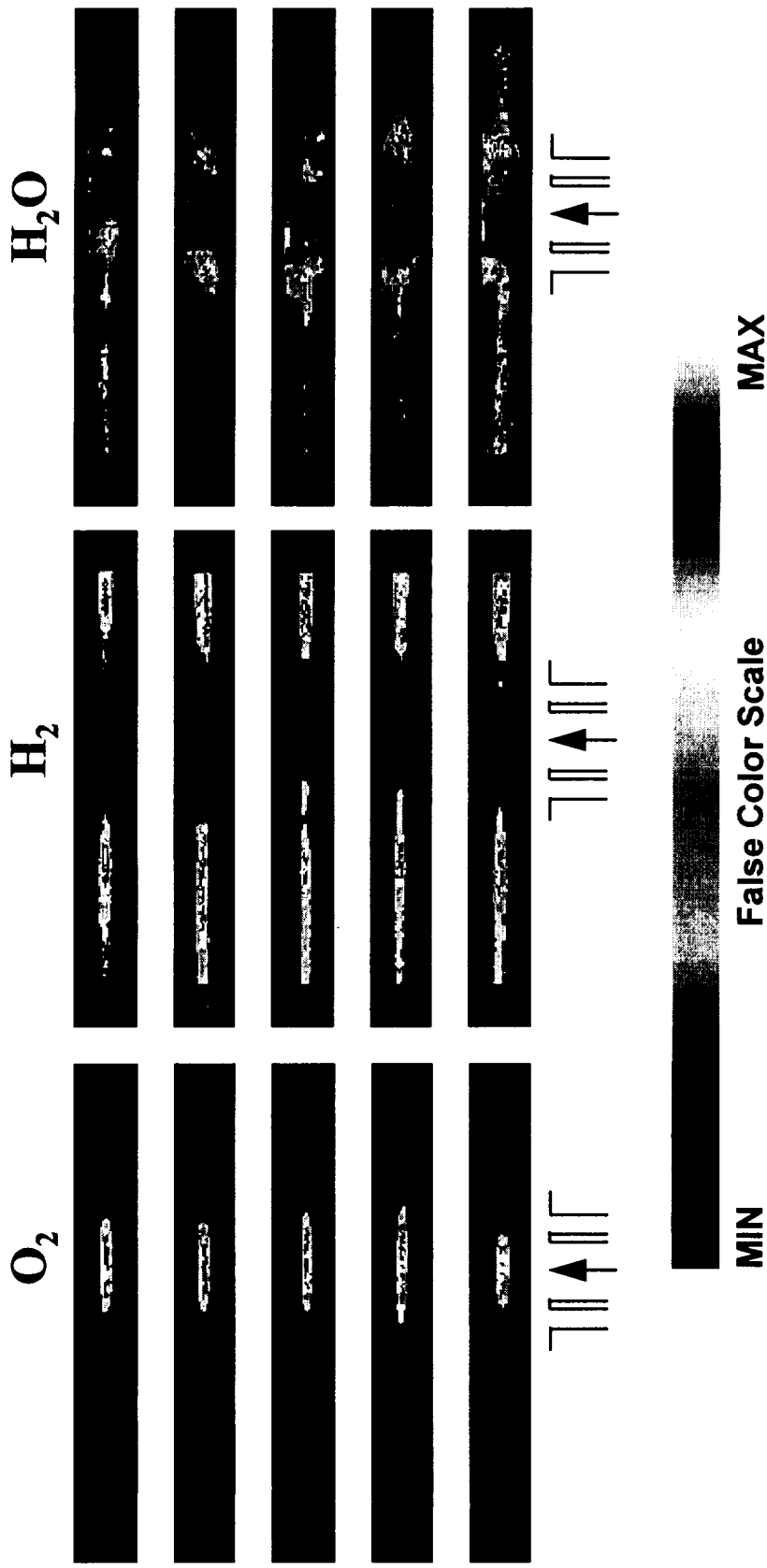


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INSTANTANEOUS RAMAN IMAGES

Shear Coaxial Injector

25.4 mm from Injector Face



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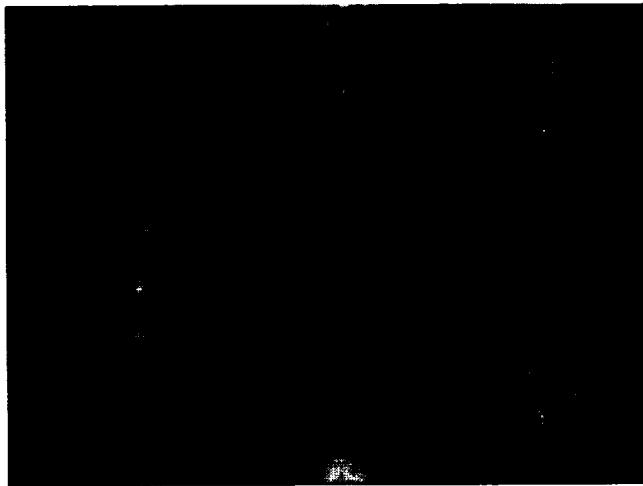
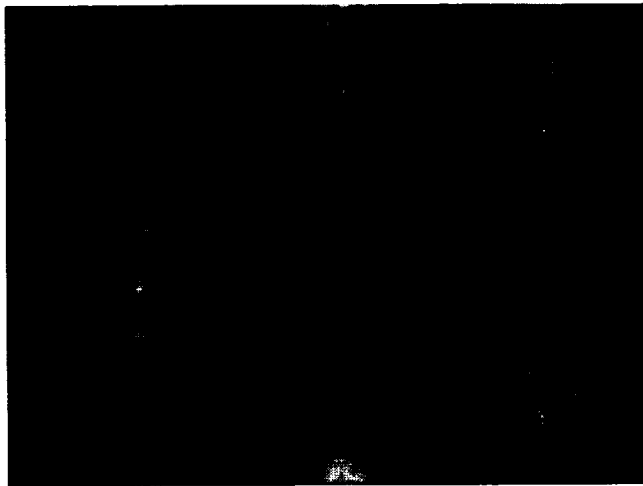
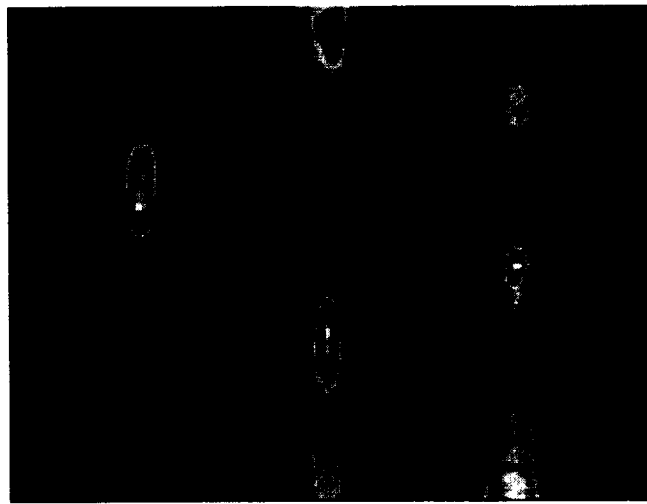
MEAN RAMAN IMAGES

Shear Coaxial Injector

Z = 25.4 mm

Z = 50.8 mm

Z = 127 mm



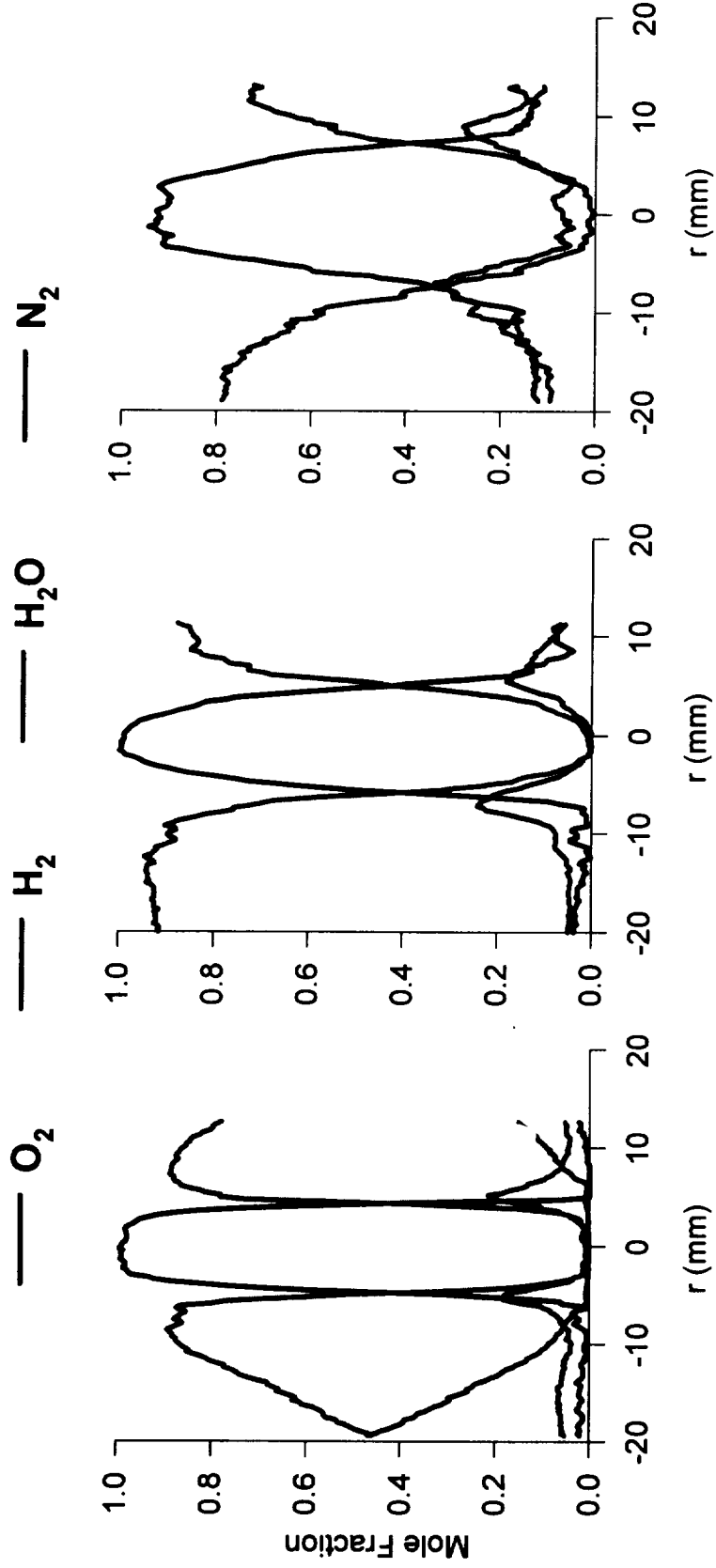
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SPECIES MEASUREMENTS

Radial Profiles of Species Mole Fractions



$Z = 25.4$ mm

$Z = 50.8$ mm

$Z = 127$ mm

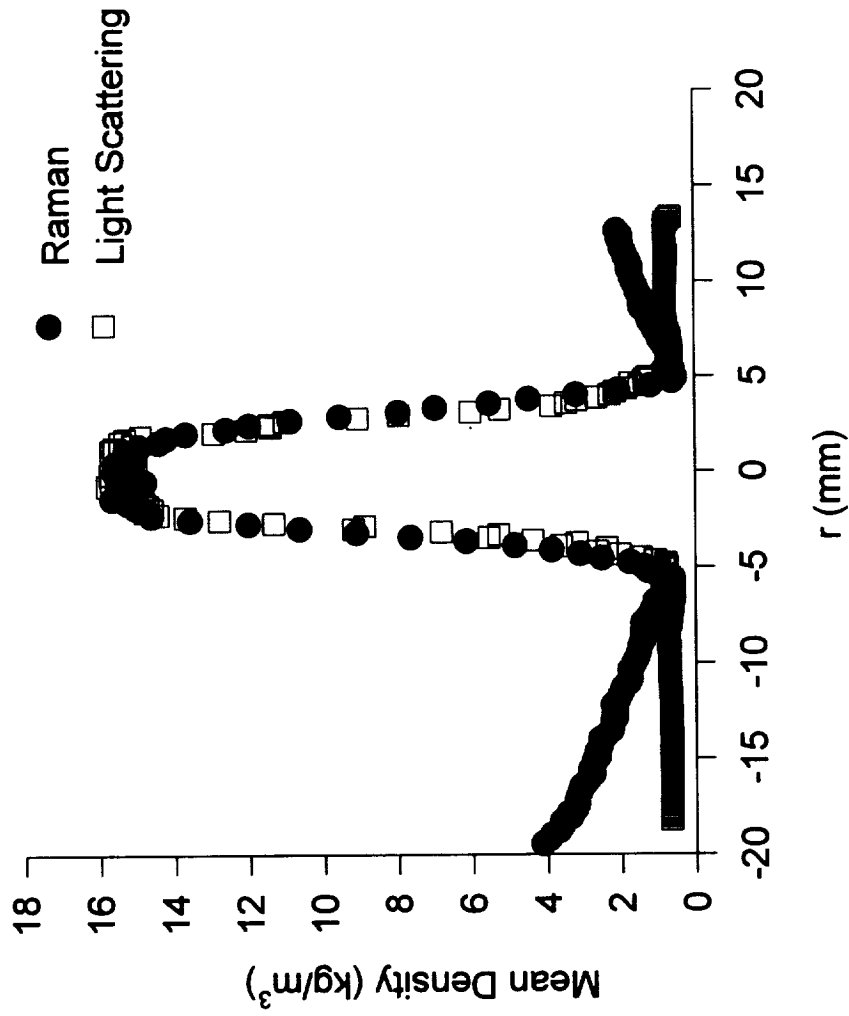
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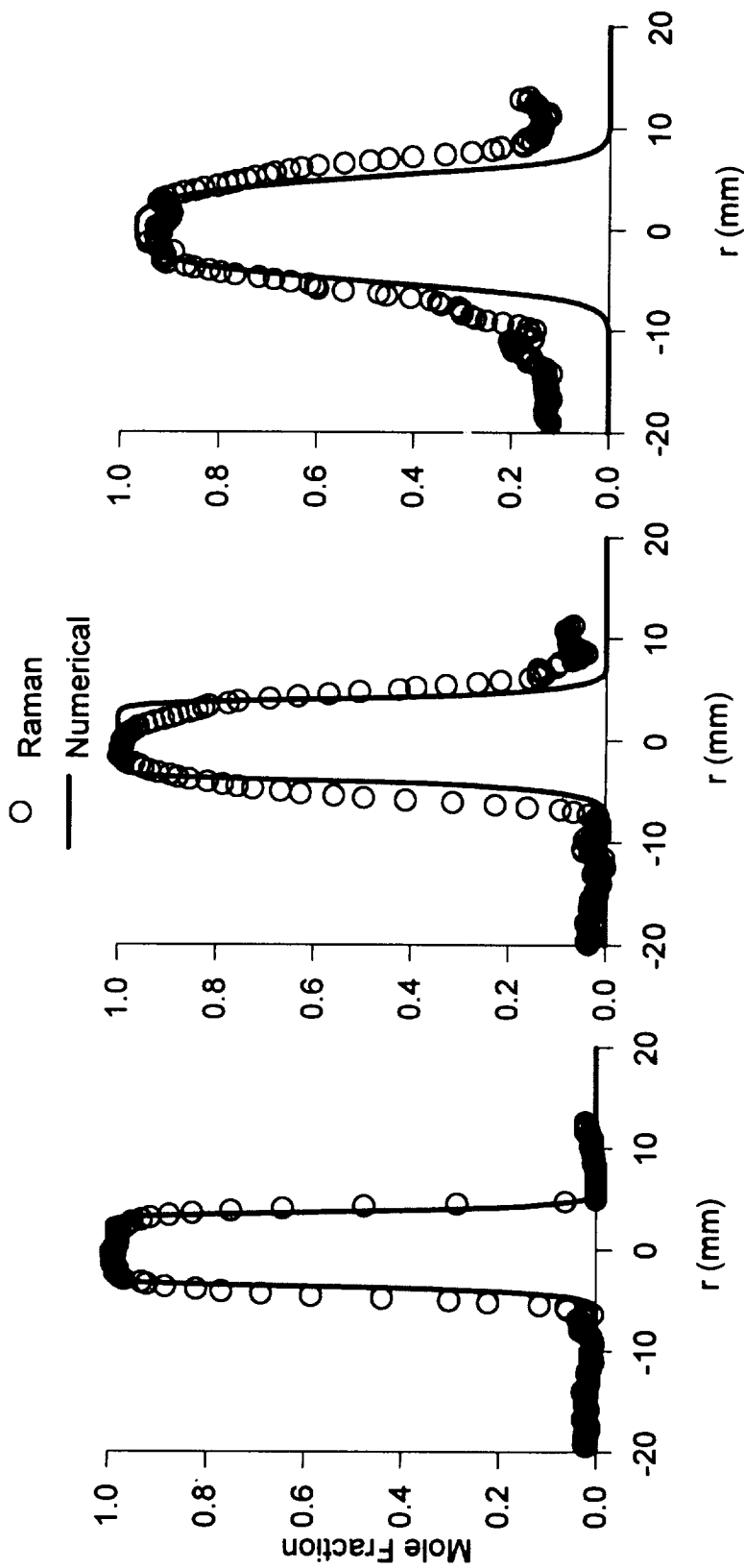
EXPERIMENTAL MEASUREMENTS

Mean Density Comparisons @ 25.4 mm from Injector Face



GO₂/GH₂ ROCKET

Oxygen Mole Fraction Comparisons



$Z = 25.4$ mm

$Z = 50.8$ mm

$Z = 127$ mm

- Computation Predicts Faster Combustion Rates

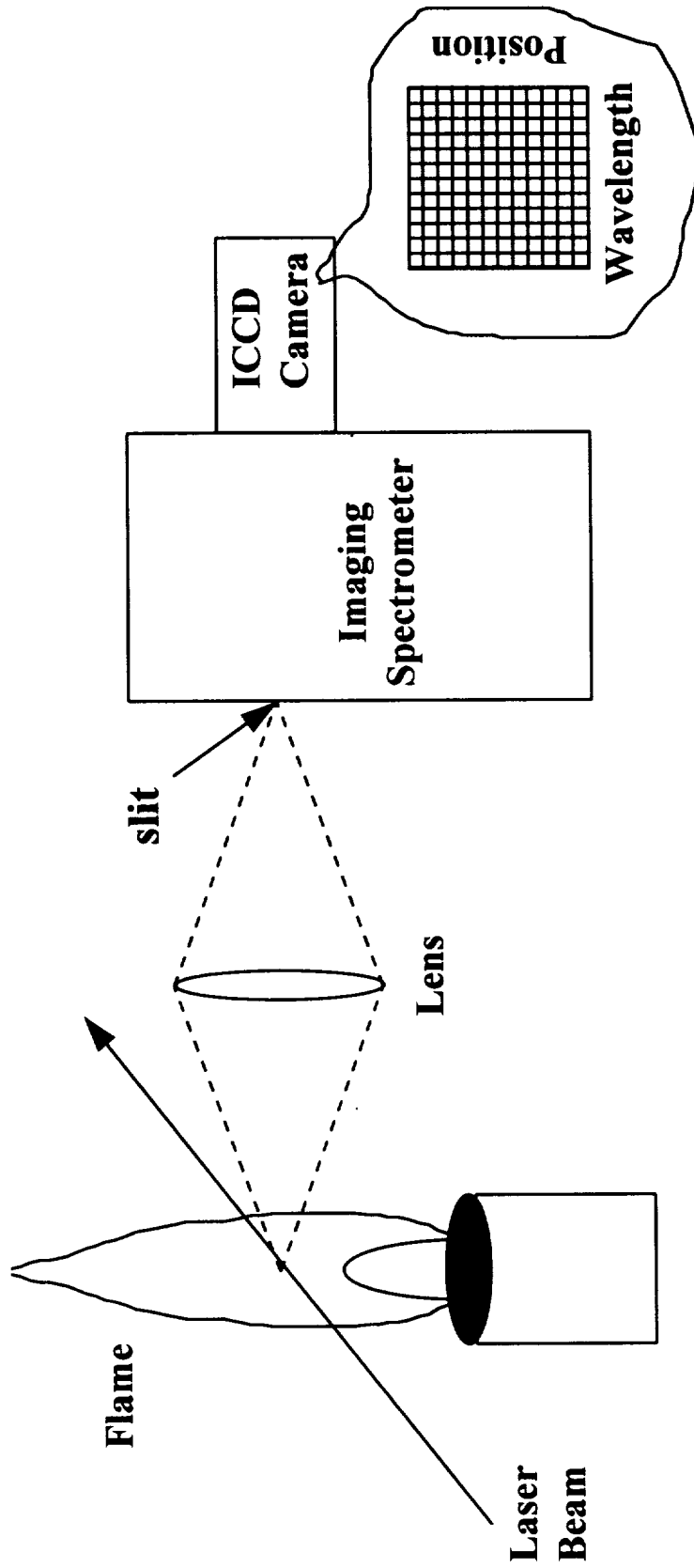
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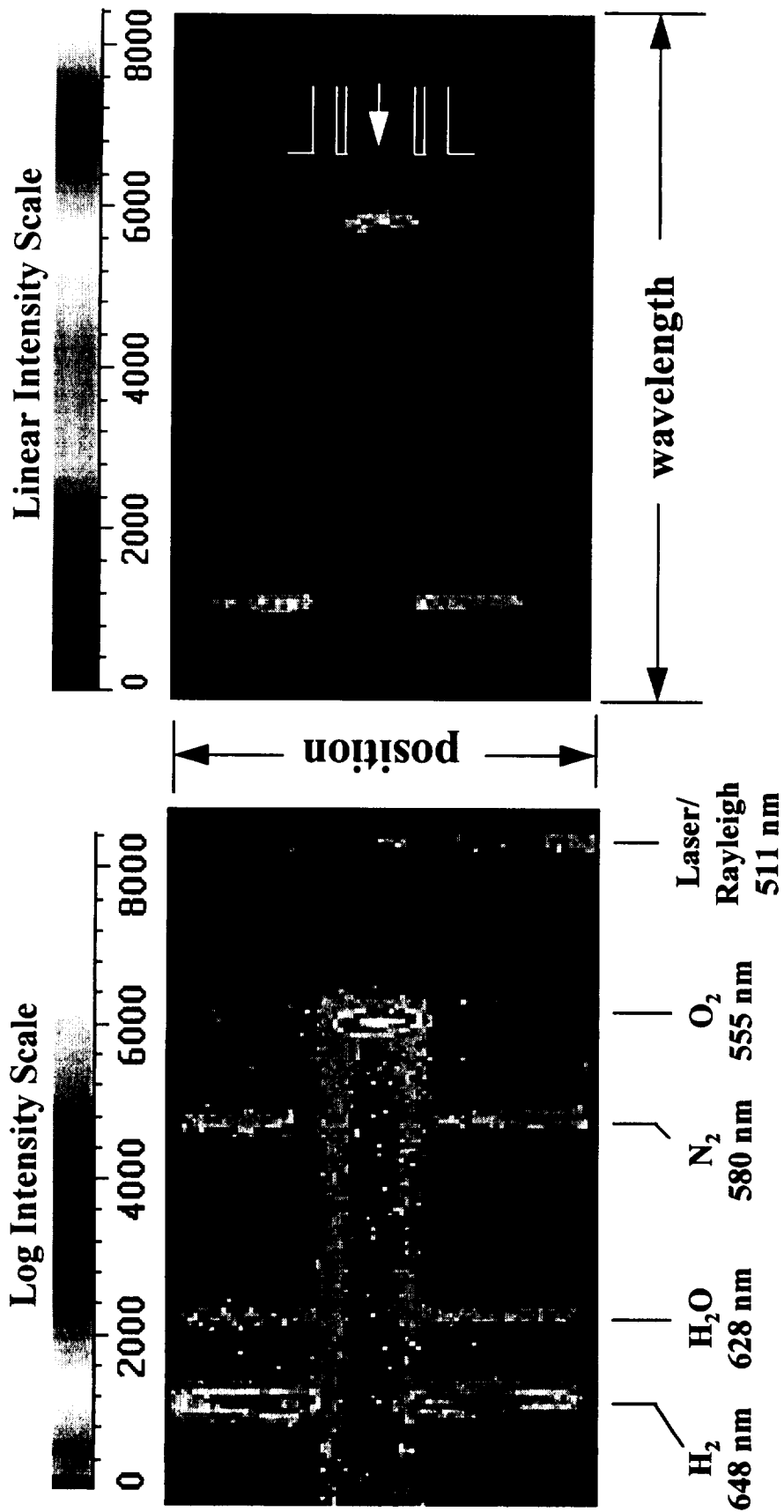
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SINGLE-SHOT MULTI-SPECIES DETECTION

(Recent Development)



SIMULTANEOUS SPECIES MEASUREMENTS 25.4 mm from Injector Face



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SUMMARY/CONCLUSIONS

- **2 Techniques for Raman Species Detection**
 - **Optical Bandpass Filters**
 - ⇒ **Single-Shot Measurements for a Single Species**
 - ⇒ **Spatially Resolved Average Species Mole Fractions**
 - ⇒ **Feasible in Relatively Low Flame Background**
 - **Spectrometer**
 - ⇒ **Single-Shot Multiple Species Measurements**
 - ⇒ **Possible Method for Subtracting Flame Background Luminosity**

- **Shear Coaxial Injector Exhibits Poor Mixing**
 - **GO₂ Core Region Extends Beyond Mid-Chamber**
 - **H₂O Mole Fraction Levels Low**



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