National Aeronautics and Space Administration

Thermochemical structure of a hybrid rocket reaction layer based on laser absorption tomography

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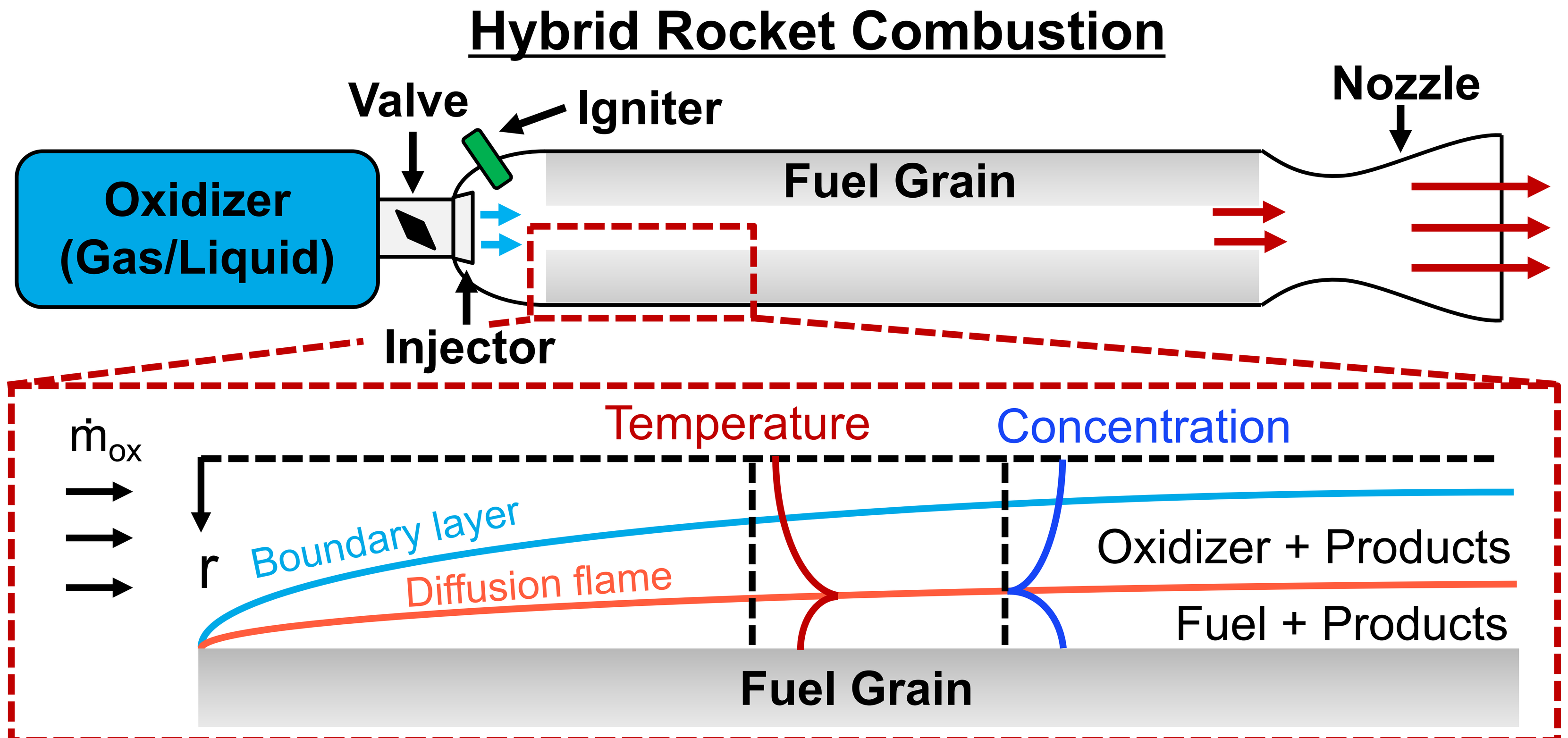
Program: SURP

Project Objectives

- Evaluate hybrid rocket combustion efficiency through quantitative, spatially-resolved thermochemistry measurements via laser absorption tomography
- Investigate the thermochemical structure of a hybrid rocket reaction layer to provide insights into hybrid combustion physics and overall motor design
- Develop quantitative metrics to describe the reaction layer progression and characterize loss mechanisms that result in suboptimal performance

Hybrid Rocket Combustion



Combustion performance is typically characterized by c* efficiency:

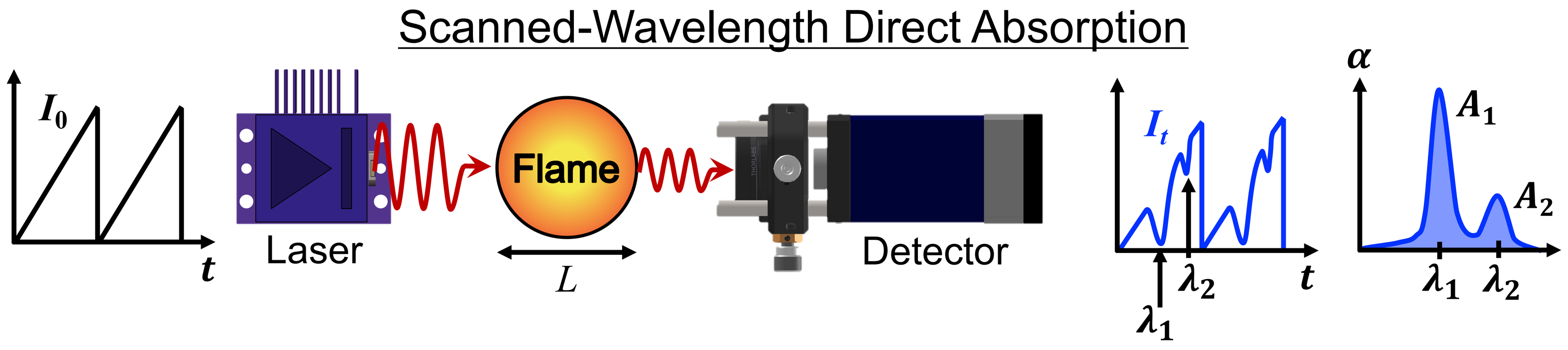
$$c^* = \frac{P_o A^*}{\dot{m}} = \sqrt{\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma+1}{\gamma-1}} \frac{\bar{R}T_o}{MW\gamma}}$$

Measure T and X_i for spatially-resolved information

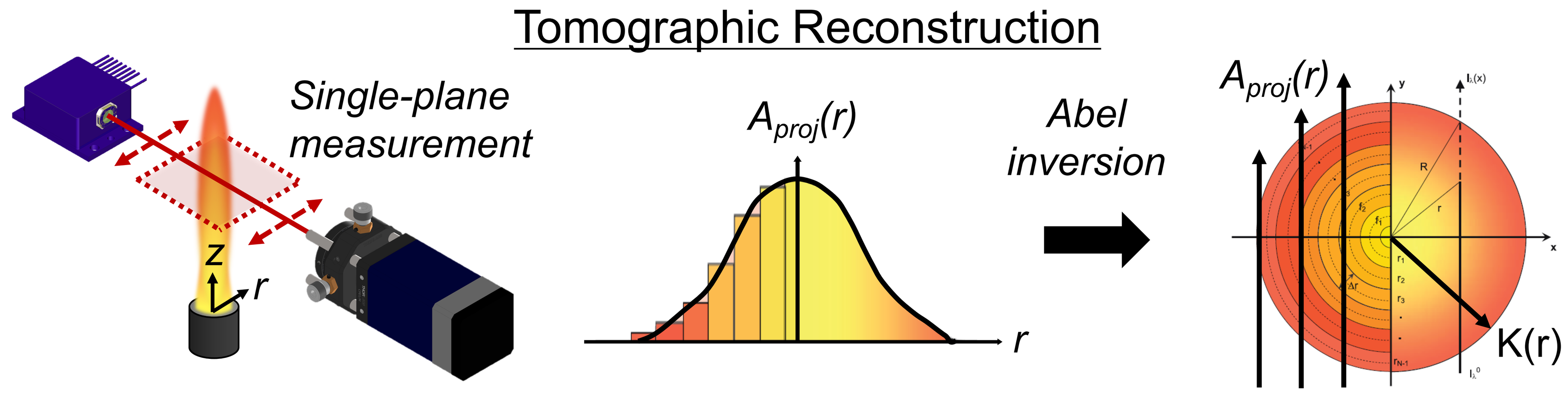
Laser Absorption Tomography

- Spectral absorbance of a molecule is related to thermophysical flow properties through the Beer-Lambert law
- Projected absorbance areas are obtained for single-plane measurements through a scanned-wavelength direction absorption technique
- Flow field symmetry enables Abel inversion, which relates projected absorbance areas to the thermochemical field distribution

Scanned-Wavelength Direct Absorption



Tomographic Reconstruction



Beer-Lambert law

$$\alpha = -\ln\left(\frac{I_t}{I_0}\right)_v = \int_0^{L(r)} S(T(r))X_i(r)P\varphi_v \mathrm{d}l$$

$$\int_{-\infty}^{\infty} \alpha\, dv = A(r) = \int_0^{L(r)} S(T(r))X_i(r)P\mathrm{d}l$$

$$= \int_0^{L(r)} K(r)\mathrm{d}l$$

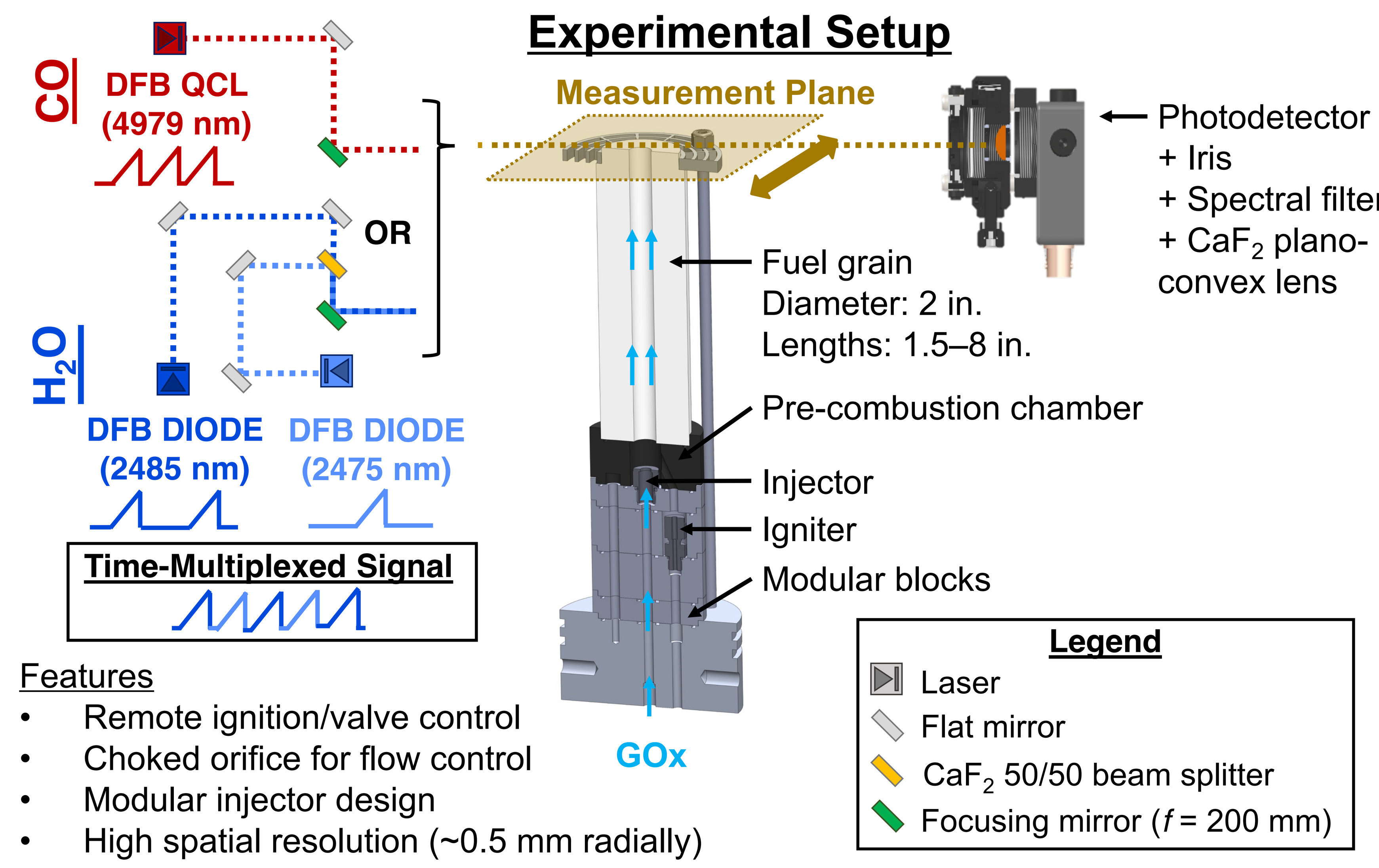
Temperature

$$\frac{K_2(r)}{K_1(r)} = \frac{S_2(T(r))}{S_1(T(r))} = f(\boldsymbol{T(r)})$$

Mole Fraction

$$X_i(r) = \frac{K_1(r)}{S_1(\boldsymbol{T(r)})P} = \frac{K_2(r)}{S_2(\boldsymbol{T(r)})P}$$

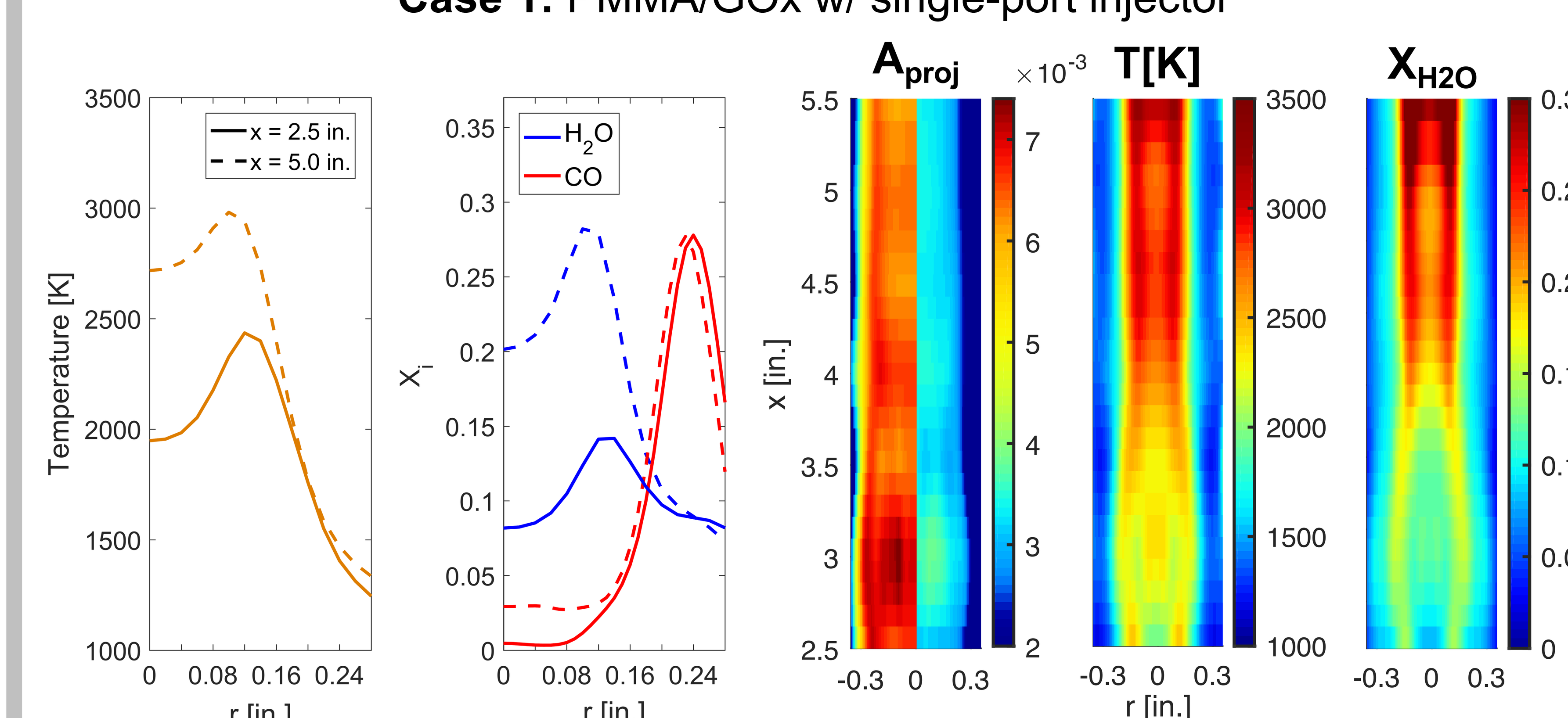
Experimental Setup

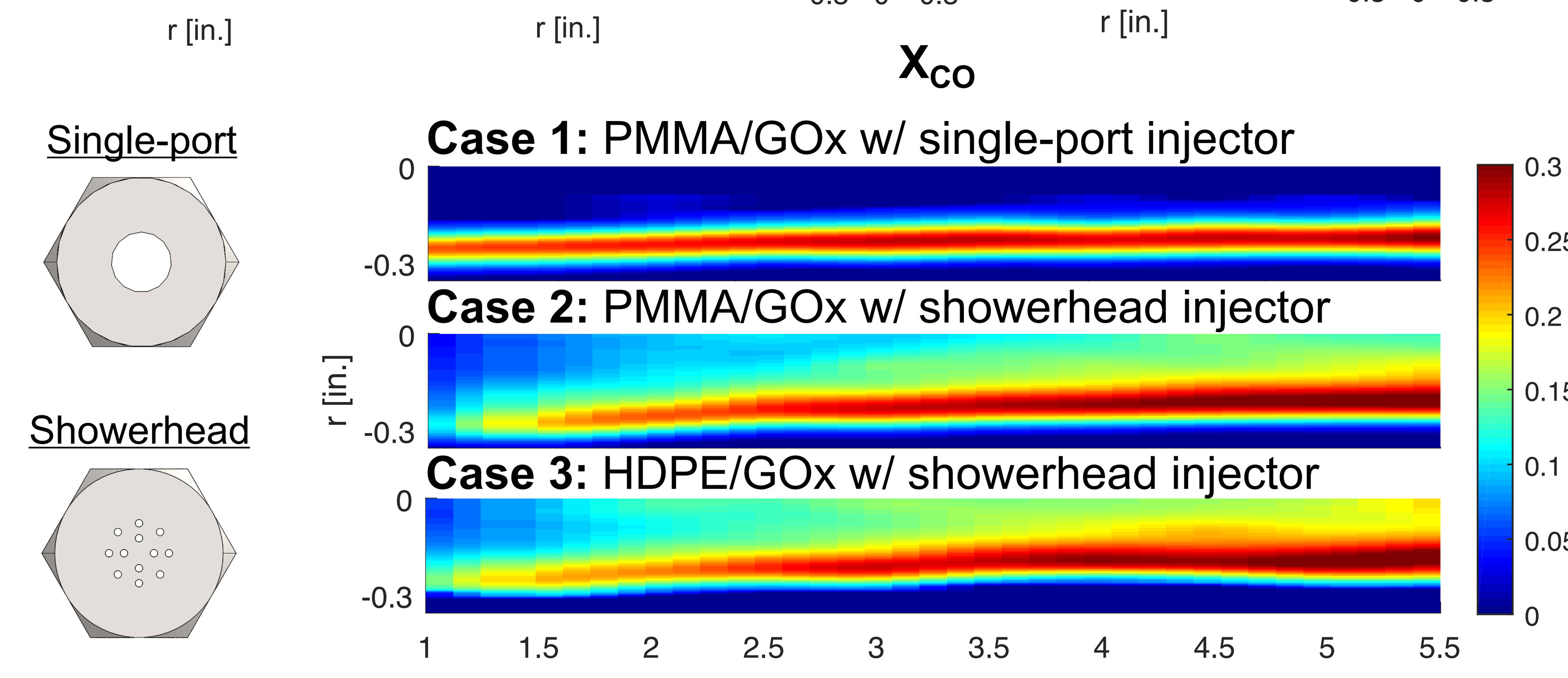


Features
- Remote ignition/valve control
- Choked orifice for flow control
- Modular injector design
- High spatial resolution (~0.5 mm radially)

Results

Case 1: PMMA/GOx w/ single-port injector





Benefits to NASA-JPL

- Developed a granular method to evaluate and improve hybrid rocket performance through spatially-resolved temperature/species measurements
- Thermochemistry provides a basis for characterizing performance impacts of different motor designs under consideration for interplanetary SmallSats and a Mars Ascent Vehicle
- Resulting thermochemical data are useful for anchoring reacting thermo-fluids models of heterogeneous combustion

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