

Single-Ended, Fiber-Coupled, Diode-Laser Sensors for Characterizing Combustion Gases

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Goals and Motivation

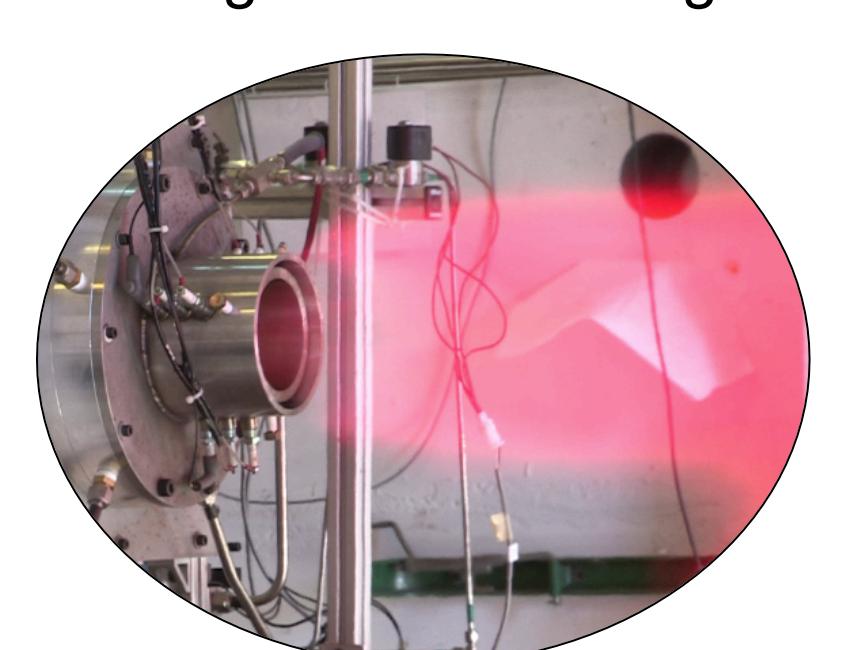
Goal

- Extend laser-absorption-spectroscopy (LAS) sensors for measurements of T, P, and X to a compact-, windowless-, single-ended-sensor package suitable for high-T environments

Motivation

- Many important combustion systems (e.g., RDEs, IC engines, gas turbines) have extremely limited optical access, thereby precluding or complicating the use of traditional LAS sensors which require an unobstructed line-of-sight

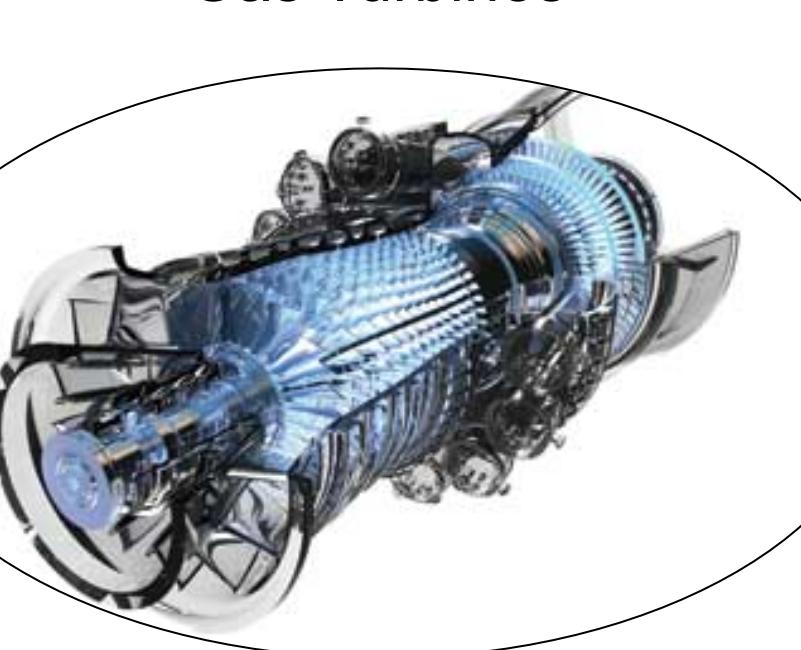
Rotating Detonation Engines



Internal Combustion Engines

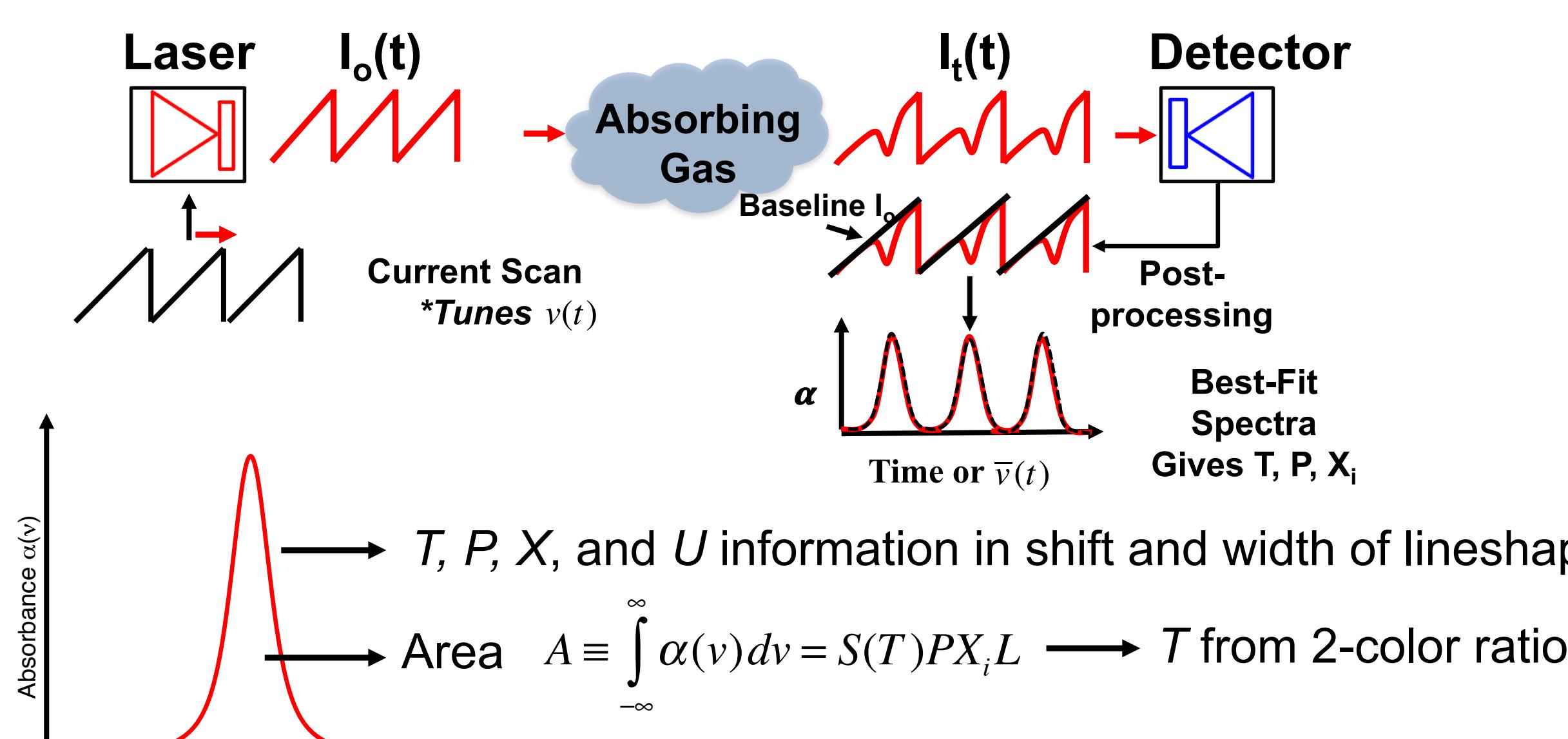


Gas Turbines

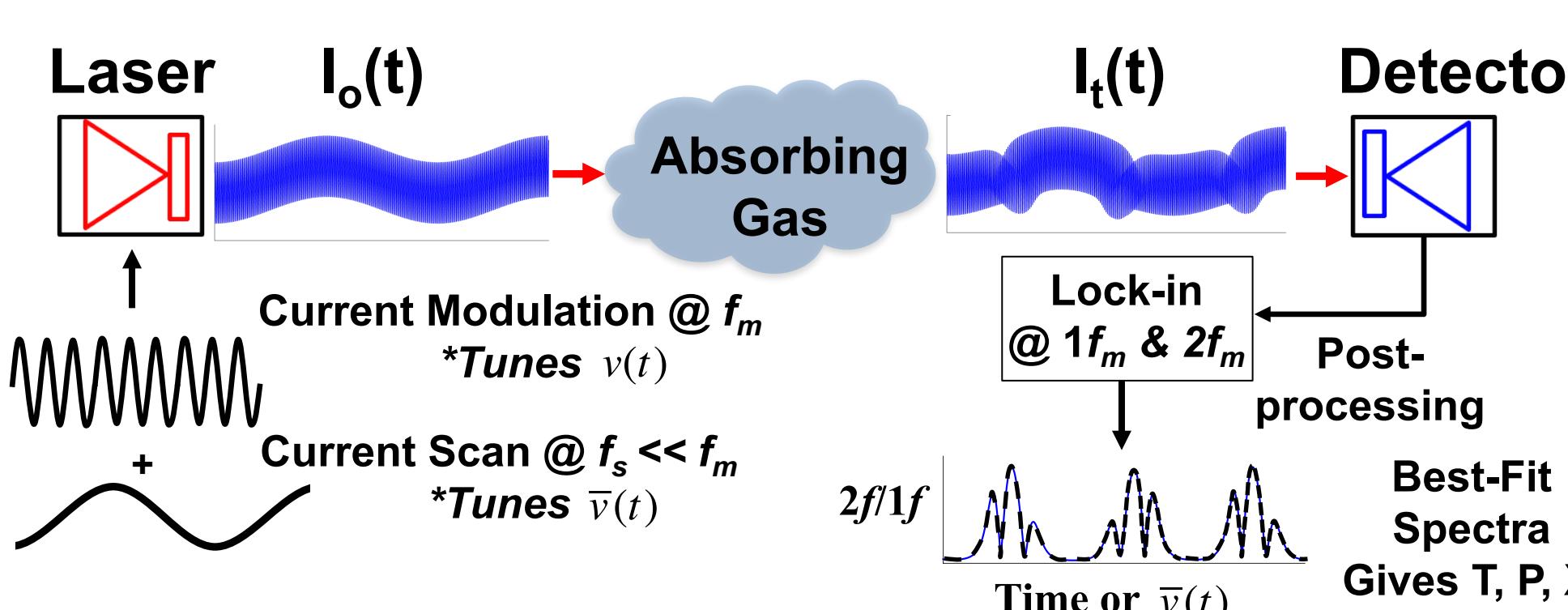


Laser-Absorption-Spectroscopy Techniques

Scanned-Wavelength Direct Absorption



Scanned-Wavelength-Modulation Spectroscopy (WMS)

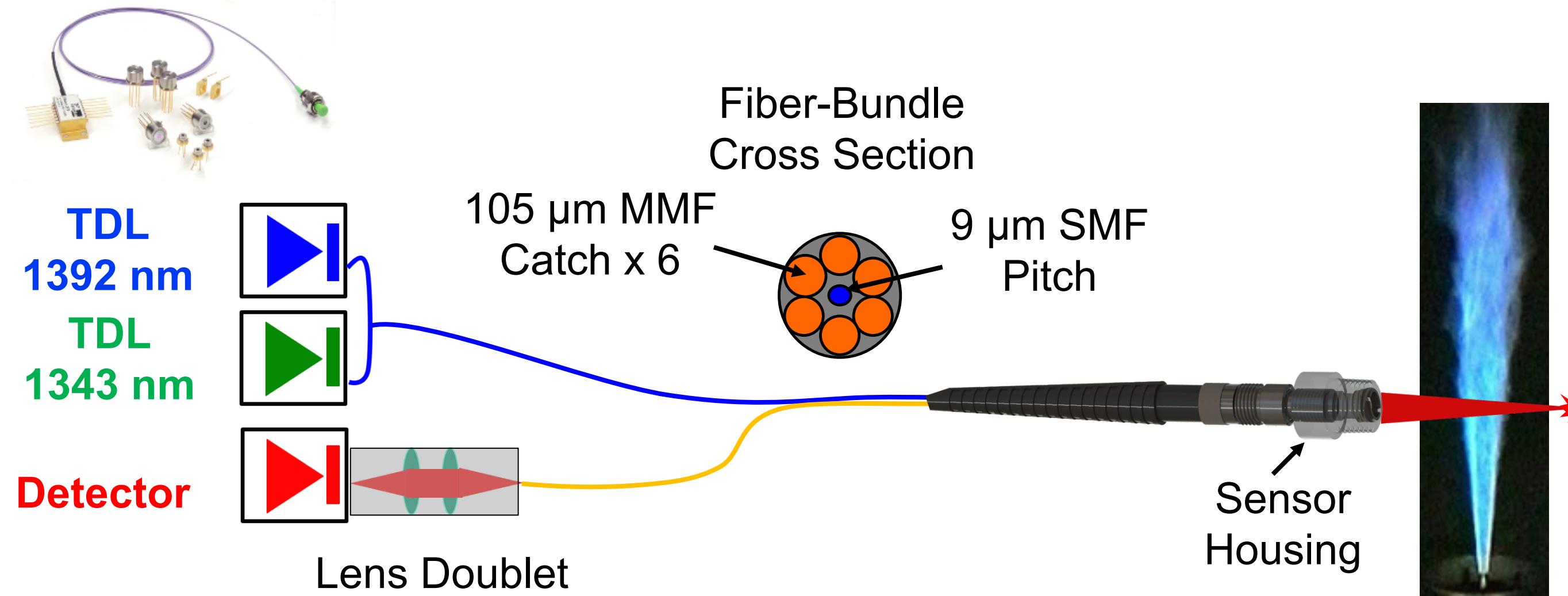


Advantages of WMS

- Independent of I_o & emission
- Well suited for environments with low optical throughput
- Well suited for high-P gases
- Noise rejection @ high-f
- Frequency multiplexing
- Applicable to most tunable lasers

Design of Single-Ended-LAS Sensor

Schematic of SE-LAS Sensor

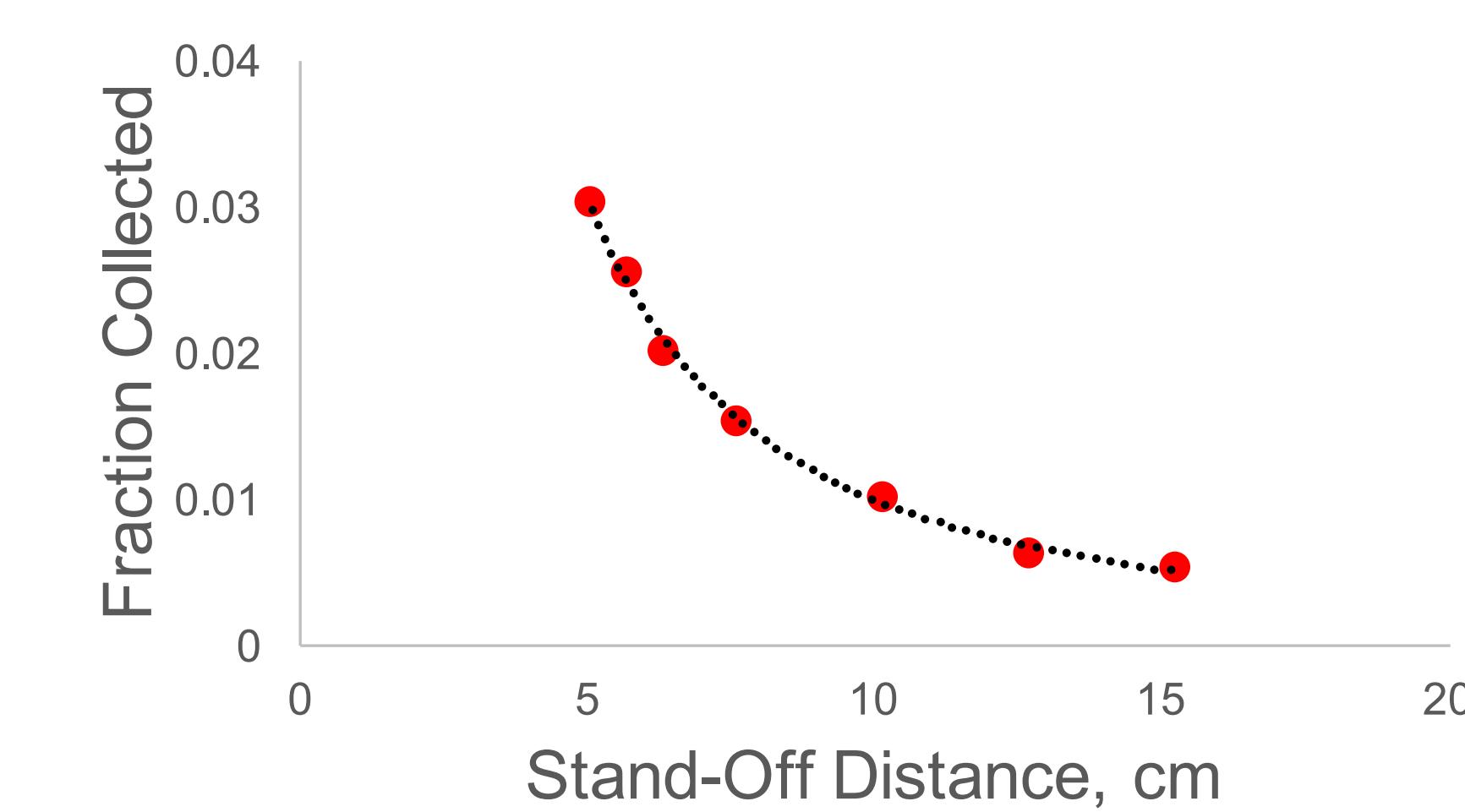


- TDLs near 1392 and 1343 nm used to measure T and H₂O via WMS-2f/1f
- TDLs frequency multiplexed via current-modulation at 160 and 200 kHz
- A fiber bundle is used to transmit and collect laser light backscattered off native surfaces
- WMS-2f/1f signals for each laser are extracted during post-processing via digital lock-in filters

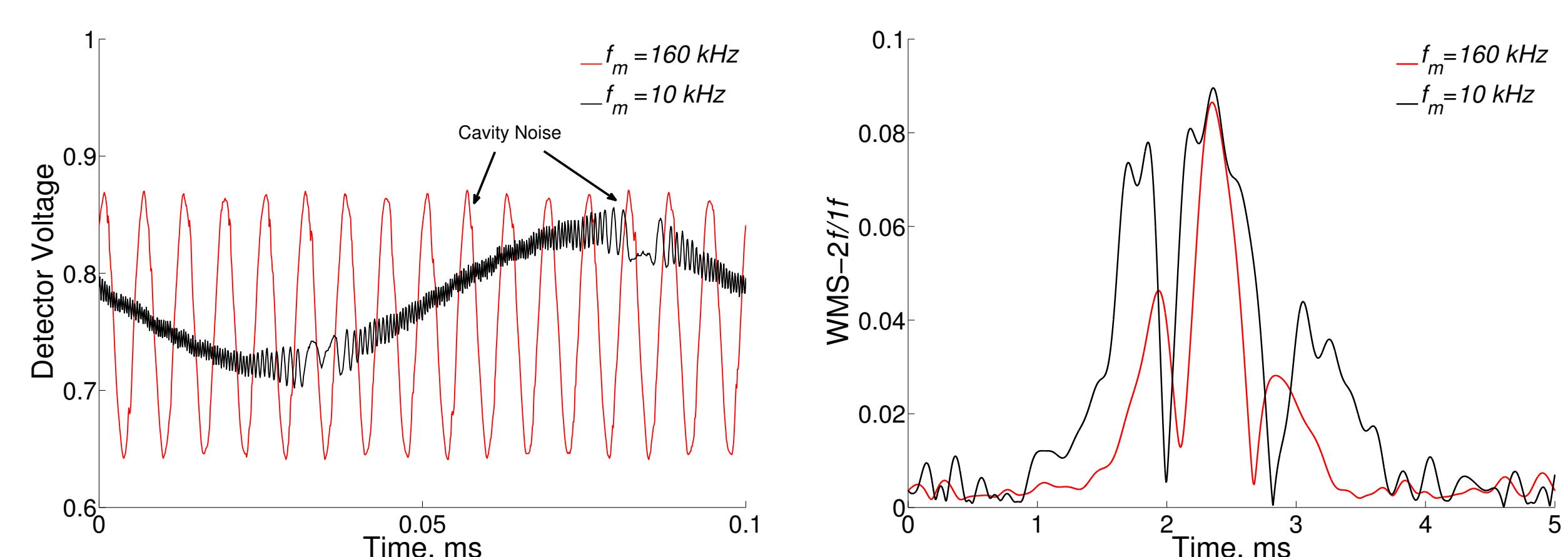
Design of Sensor Housing

- Sensor designed to provide measurements of T & H₂O in high-T environments *without requiring windows or optical alignment*
- Fiber bundle integrated within custom housing:
 - FC-PC to SMA adapter connects fiber to housing
 - Housing: SS with external 1/8" NPT threads
 - AR-coated, 6-mm diameter lens ($T_{melt} \sim 830$ K) to focus transmitted and backscattered light
 - Lens secured to housing with retaining ring

Optical Performance of SE-LAS Sensor



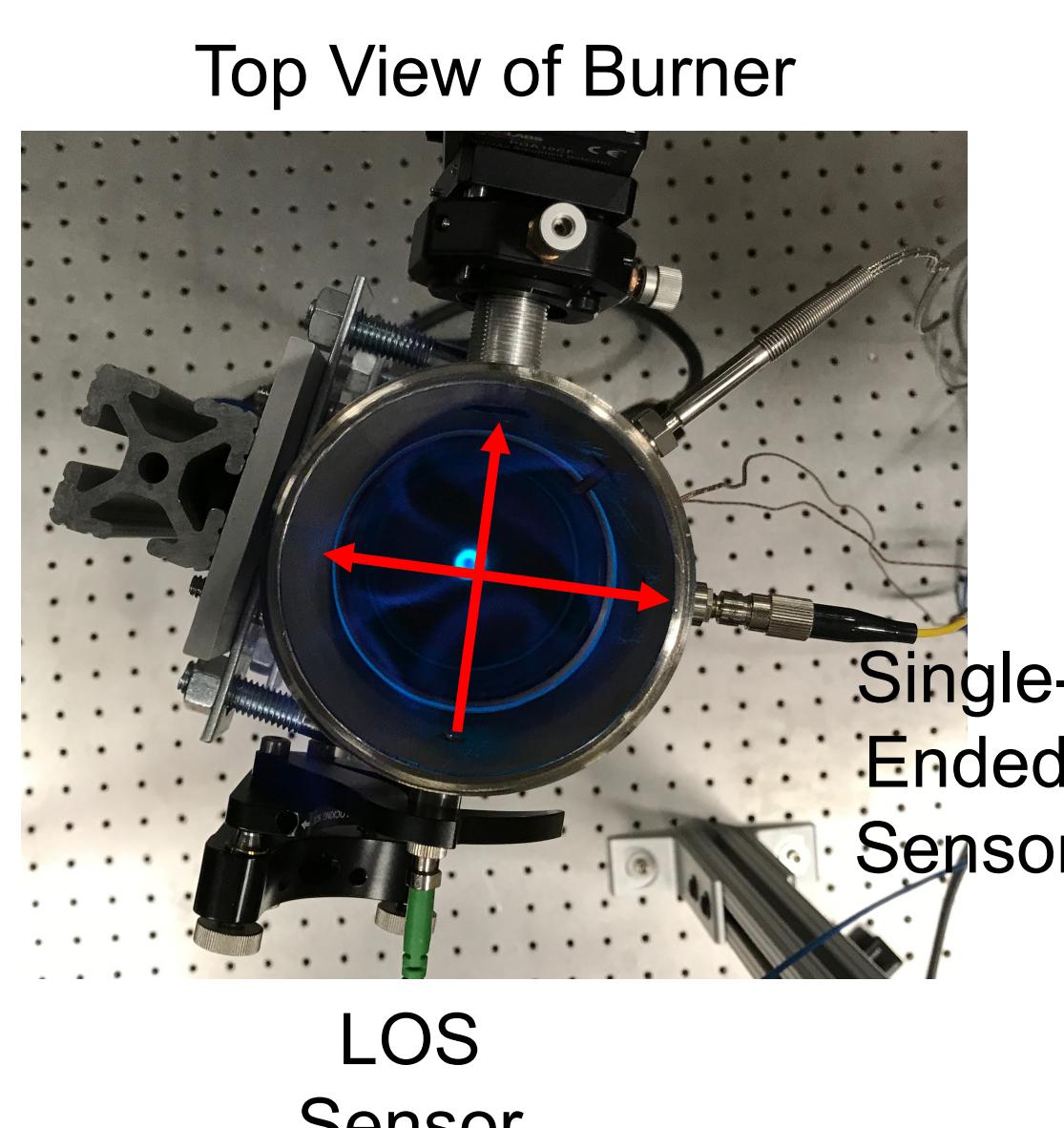
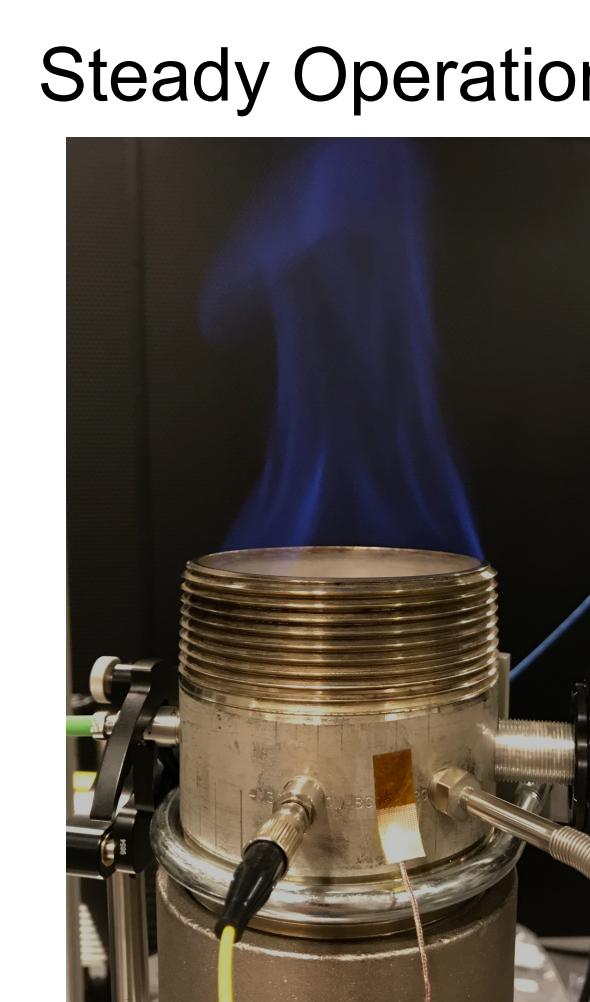
- Alignment-free sensor provides a collection efficiency of 3 to 0.5% at stand-off distances from 5 to 15 cm (results shown for unpolished aluminum surface)



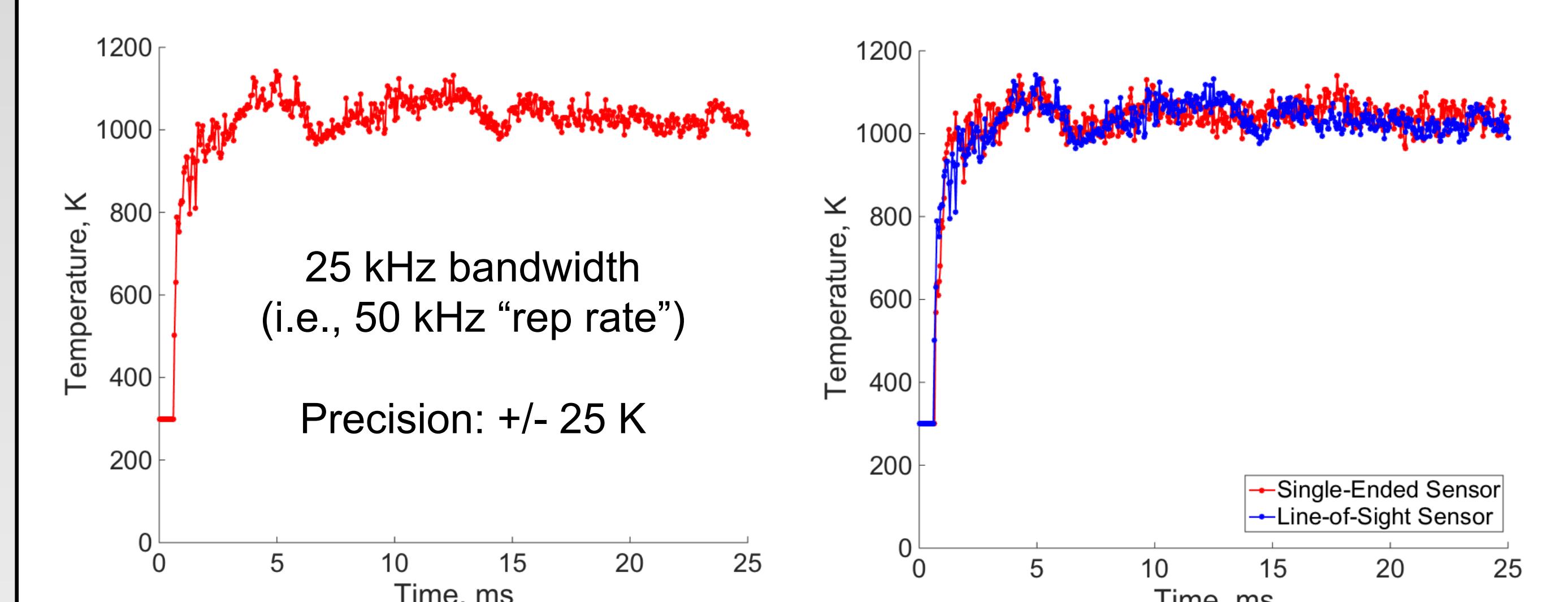
- Wavelength modulation is performed at frequencies of 160 and 200 kHz to reduce optical cavity noise and provide high-fidelity measurements of WMS-2f/1f spectra

Results

Experimental Setup for Measurements in Burner

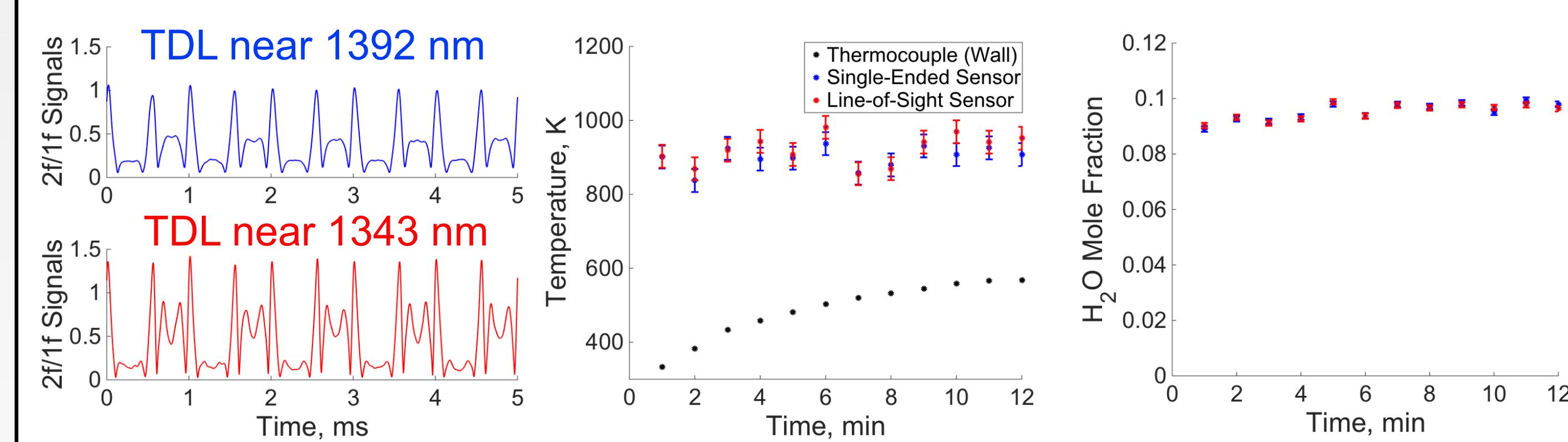


Temperature Measurements Behind Ignition Blast



- SE-LAS sensor provides temperature measurements at 50 kHz with accuracy and precision equal to LOS sensor despite losing 99% of incident laser light

Temperature & H₂O Measurements During Quasi-Steady Burner Operation



- SE-LAS sensor provides high-fidelity measurements of scanned-WMS-2f/1f spectra, temperature, and H₂O mole fraction
- Accuracy and precision of SE-LAS sensor validated against LOS sensor at wall (i.e., sensor housing) temperatures up to 575 K
- No degradation in sensor performance was observed over 12 minute fired test

Acknowledgements

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- Additional details regarding this work can be found in: C.S. Goldenstein, G.C. Mathews, and Y. Zhou, Single-ended infrared laser-absorption sensing of gas properties, in: OSA Advanced Photonics Congress, New Orleans, LA, (2017) <https://doi.org/10.1364/SENSORS.2017.SeM3E.1>