Compact Multi-Channel Infrared Laser Absorption Spectrometer for Spacecraft Fire Safety Monitoring

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Jet Propulsion Laboratory

California Institute of Technology

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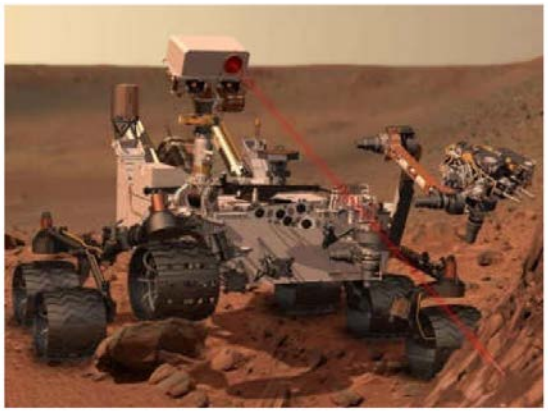
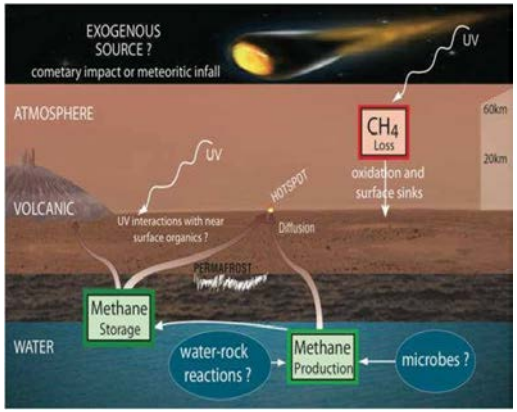
Applications for *in situ* trace gas detection within NASA

Planetary structure and evolution



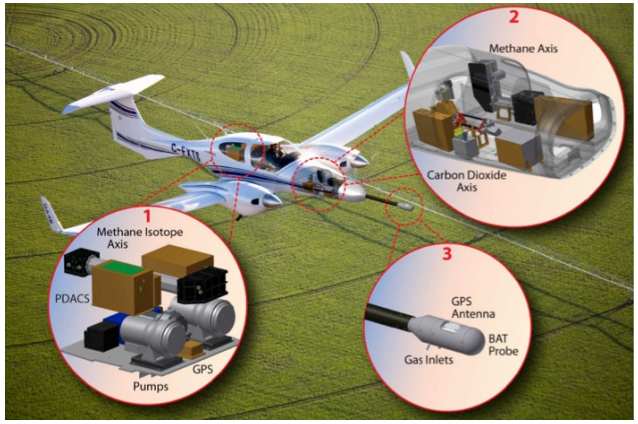


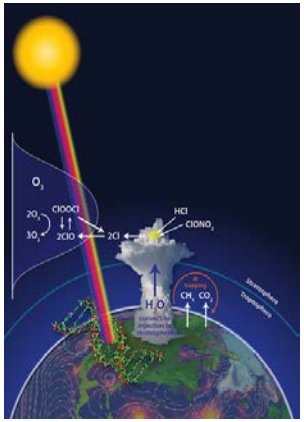
C. Webster, JPL

Manned spacecraft operations

NASA

Earth and climate sciences





J. Anderson, Harvard Univ.

Saffire: Spacecraft Fire Safety Demonstration

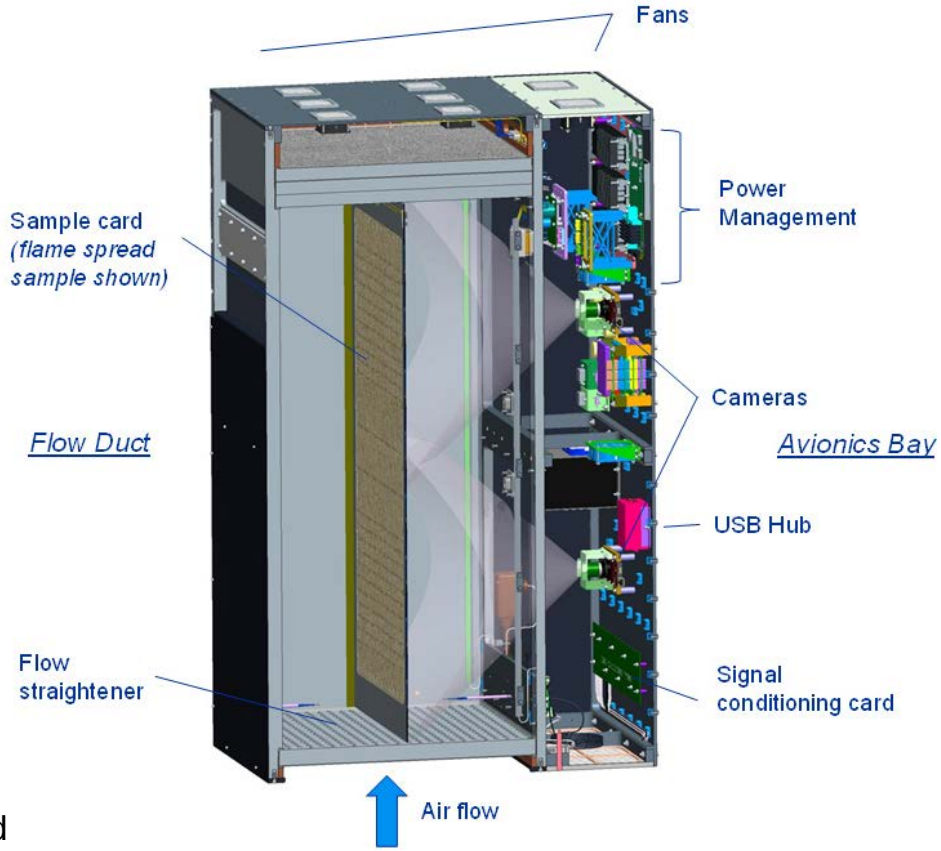
Investigators: David Urban and Gary Ruff, NASA GRC

Series of experiments designed to study combustion in a realistic spacecraft environment

Saffire I successfully completed inside a Cygnus resupply vehicle during a recent return trip from ISS

Saffire experiments IV, V, and VI will include a Far Field Diagnostics (FFD) module to study particulates, smoke abatement, and combustion product concentrations

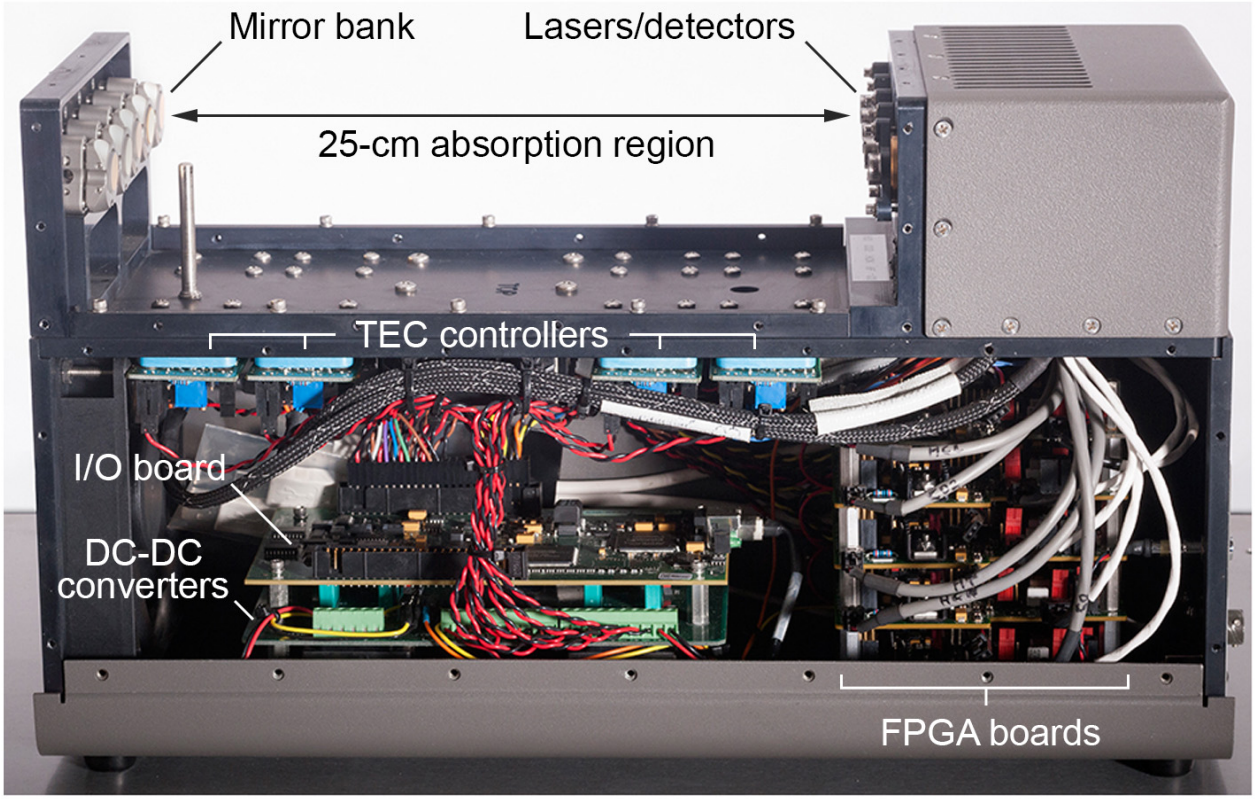
Saffire I Experiment Module



NASA Glenn Research Center

First-generation JPL Combustion Product Monitor (CPM)

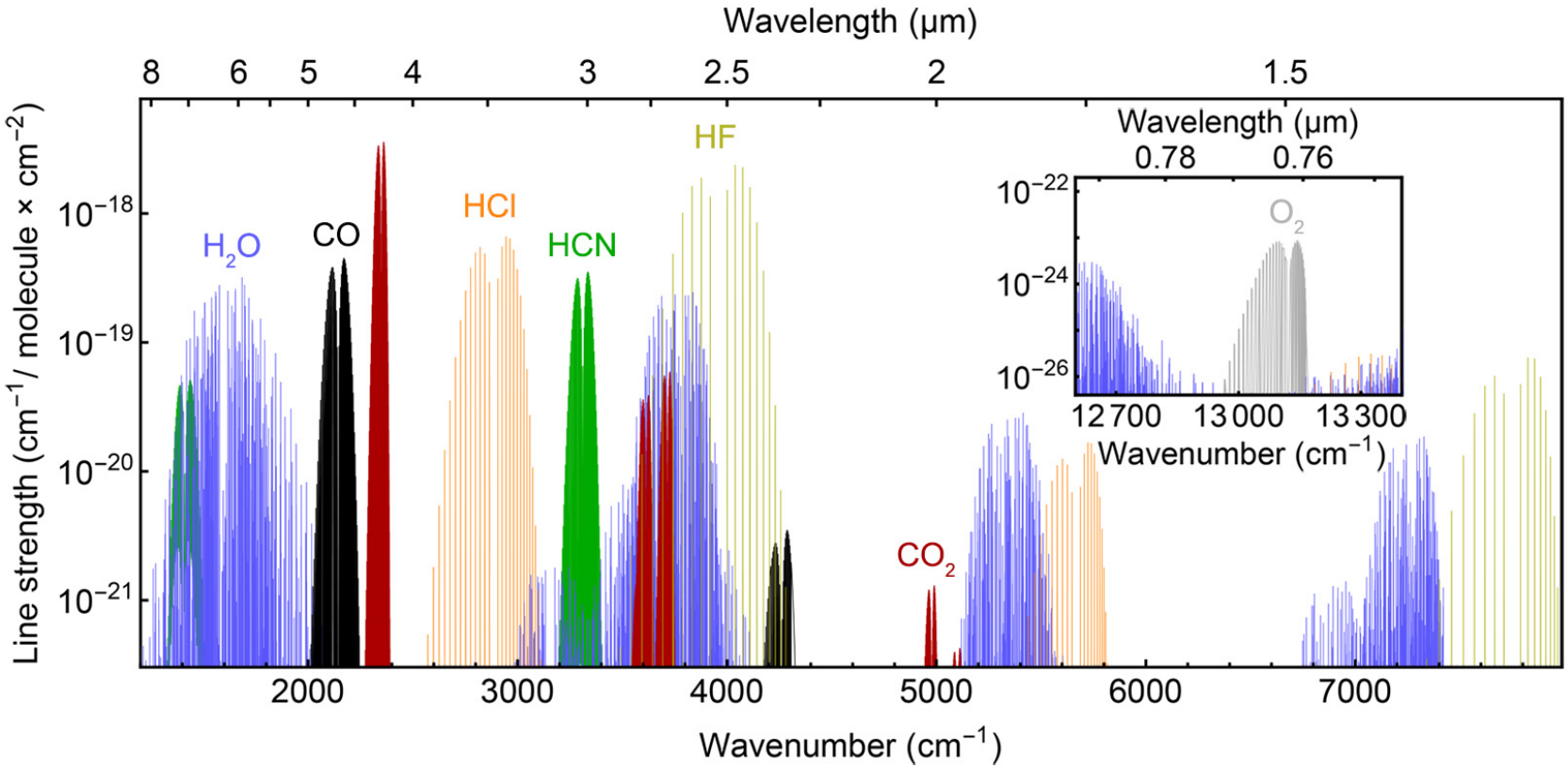
CPM tunable laser absorption spectrometer for monitoring CO, HCl, HCN, HF, and CO_2



Five independent laser channels, each with a 50-cm two-pass optical path

Volume: 800 in^3, mass: 5 kg, max. power consumption @ 20 ºC: 20 W, operating pressure: 800 - 1200 mbar

Target combustion product absorption lines

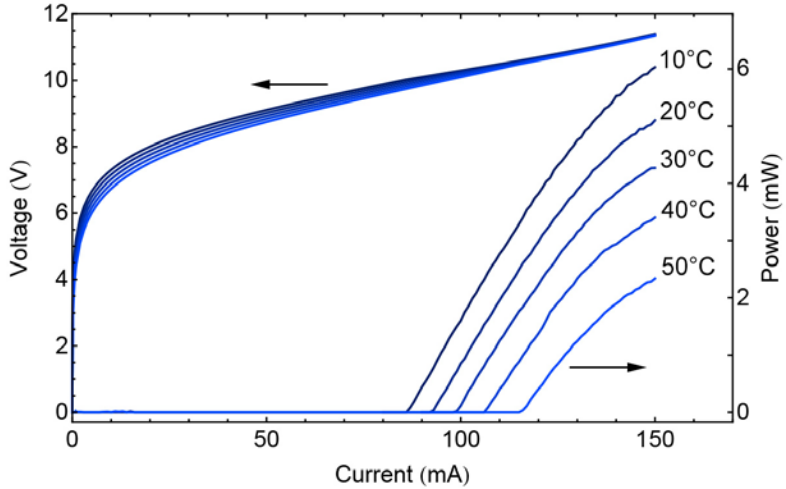


Strong fundamental rovibrational modes of target compounds occur in the mid-infrared regime

Absorption measurements require corresponding mid-infrared sources and detectors

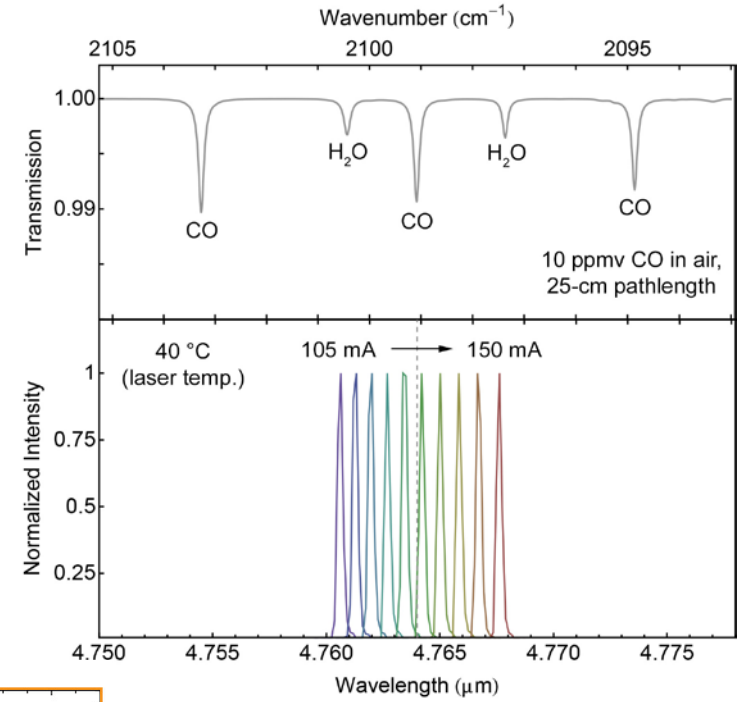
Laser wavelength modulation spectroscopy

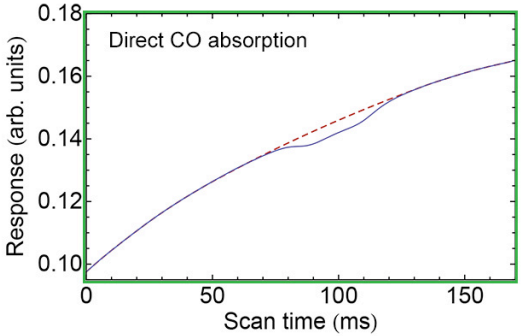
Laser light-current-voltage characteristics

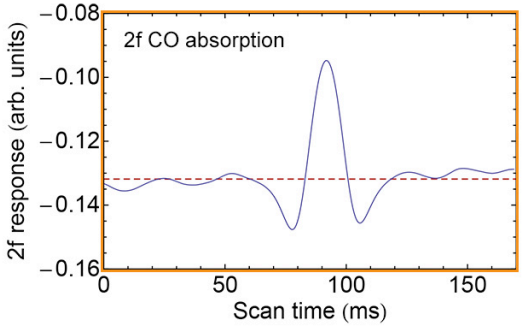


By sweeping current sourced to a single-mode laser, relative absorption is measured over a known pathlength

Current tuning of laser emission wavelength

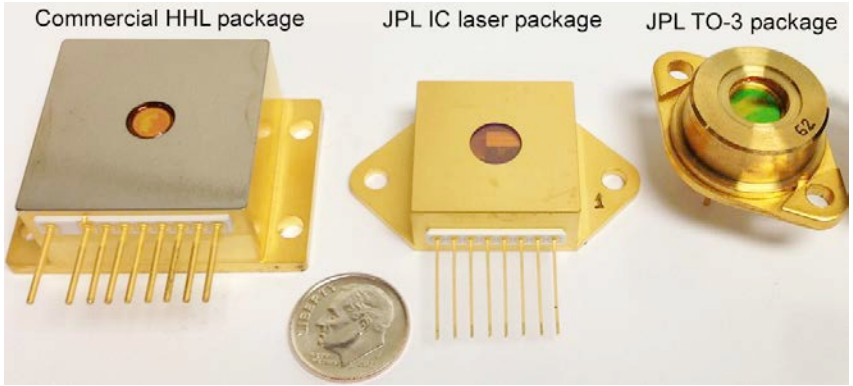






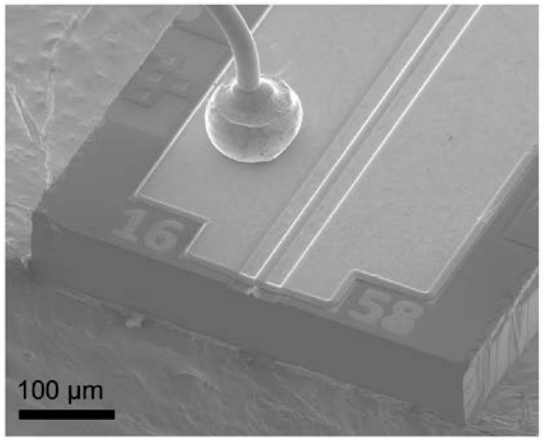
With additional small-amplitude modulation of the current, the demodulated spectral response can be measured with reduced noise

JPL Combustion Product Monitor (CPM)

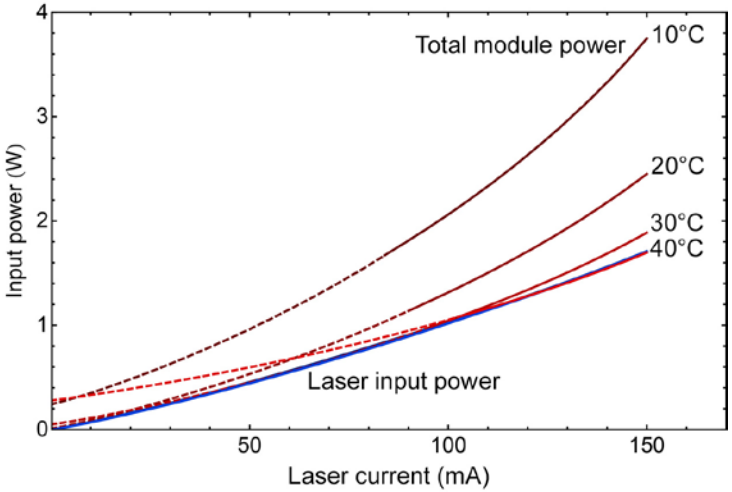


	Commercial QC laser (HHL package)	JPL QC laser (TO-3 package)
Voltage	10 – 12 V	10 – 12 V
Current	0.8 – 1.0 A	0.10 – 0.15 A
Operating temperature	10 – 30 ° C	20 – 50 ° C
Module power consumption	40 W typ.	1.8 W typ.
Emission wavelength	4.57 µm	4.76 µm
Module mass	120 g	25 g

Mounted quantum cascade (QC) laser die



Measured laser module power consumption



R.M. Briggs, et al., *Appl. Phys. Lett.* **105**, 14117 (2014)

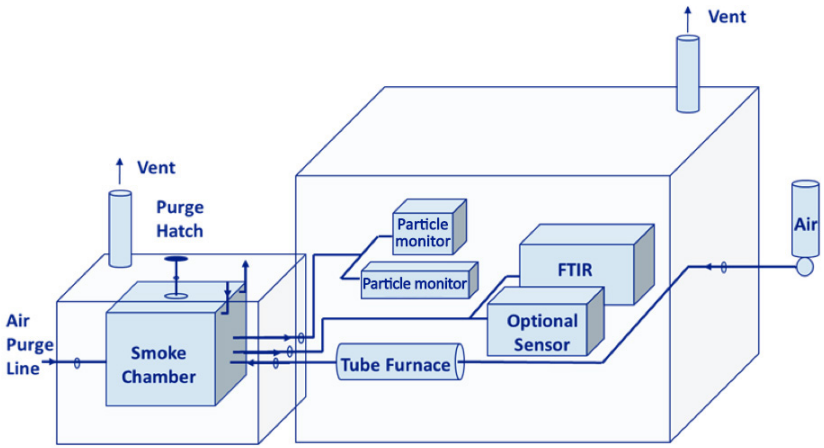
Original CPM performance targets

Compound	Spacecraft Maximum Allowable Concentration (ppmv)	CPM performance range (ppmv)	Wavelength (nm)	Absorption pathlength (cm)	Relative line-center absorption at minimum concentration*
CO	1 h: 425 24 h: 100 7 d: 55 30+ d: 15	1 - 1,000	4764.0	50	0.0020
HCl	1 h: 8 24 h: 4 7 d: 1 30+ d: 1	0.5 - 50	3572.8	50	0.0011
HCN	1 h: 5 24 h: 2.5 7d: 1 30+ d: 1	0.5 - 50	3001.5	50	0.0006
HF	1 h: 5 24 h: 2 7d: 1 30+ d: 1	0.5 - 50	2395.8	50	0.0027
CO_2	1 h: 20,000 24 h: 13,000 7 d: 7,000 30+ d: 7,000	300 - 30,000	2055.5	50	0.0006

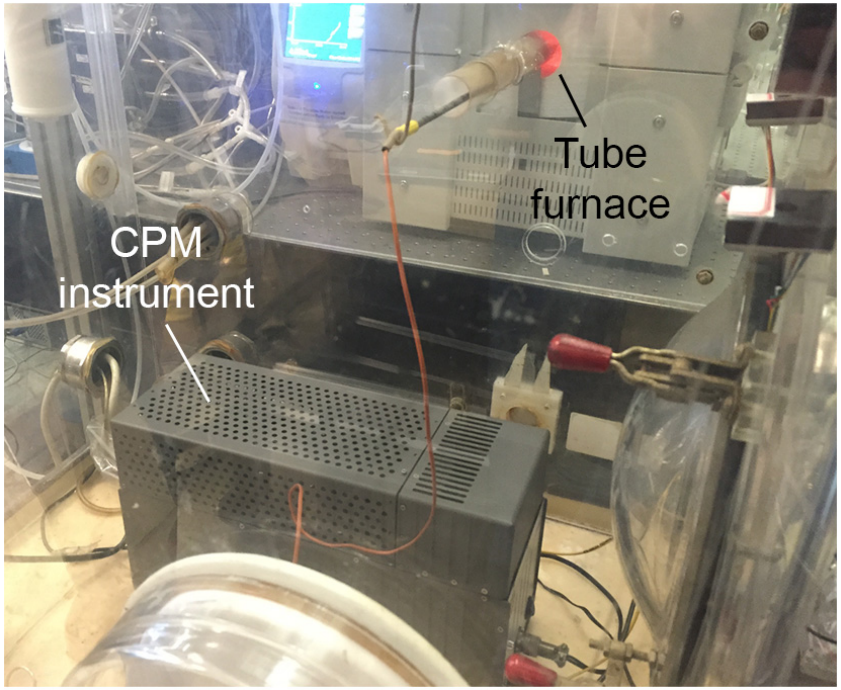
*Minimum resolvable line-center absorption ~10^{-4}

Initial CPM testing

Pyrolysis chamber at NASA GRC



CPM instrument testing with ambient flow cover



Samples heated in a tube furnace with 4.4 SLPM airflow and exhausted to a sealed smoked chamber

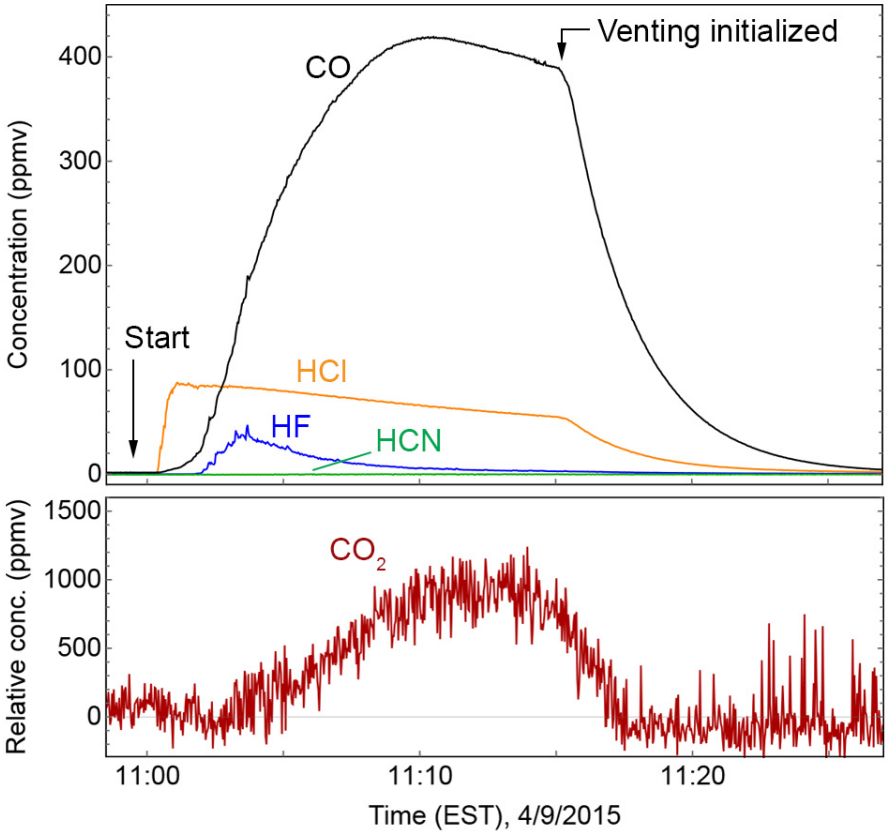
Furnace temperature ramped from 200 to 640 ° C over approx. 6 min prior to venting

CPM gas sampling rate of 1 Hz (5 sample average)

Compared against co-located electrochemical sensor with CO/CO_2/HCN sensitivity (Dräger)

Previous CPM testing results

CPM measured gas concentrations



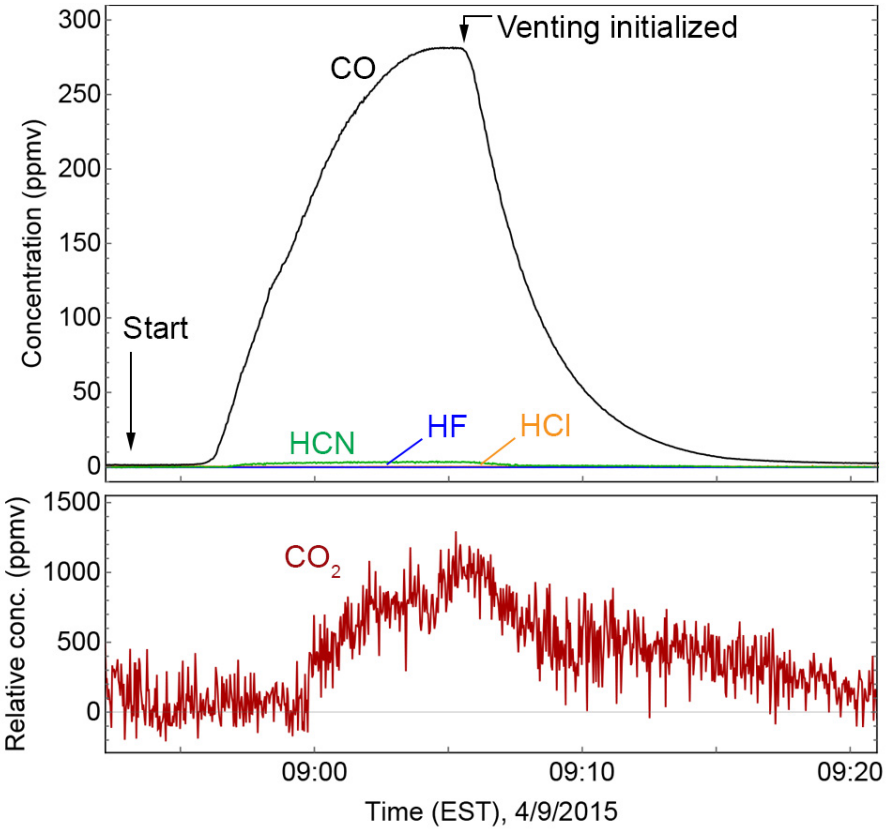
Fuel sample before and after pyrolysis

Mixture of Kapton film and electrical wire (M22759 and PVC-insulated), 1.46 g total pre-burn mass

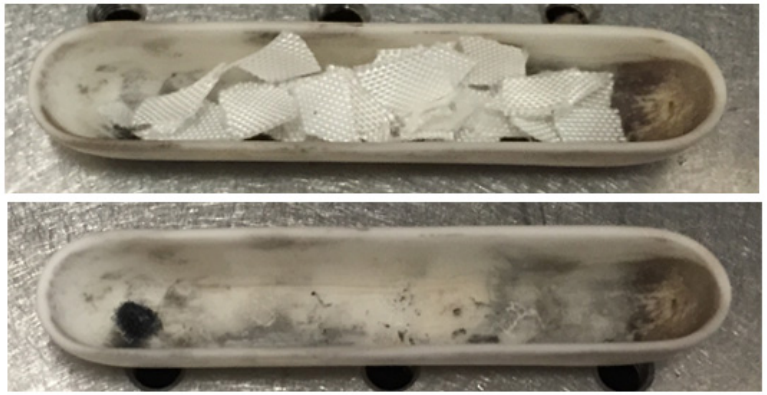
R.M. Briggs, et al., *Proc. of the 45th International Conference on Environmental Systems*, Bellevue, Washington, USA (2015)

Previous CPM testing results

CPM measured gas concentrations



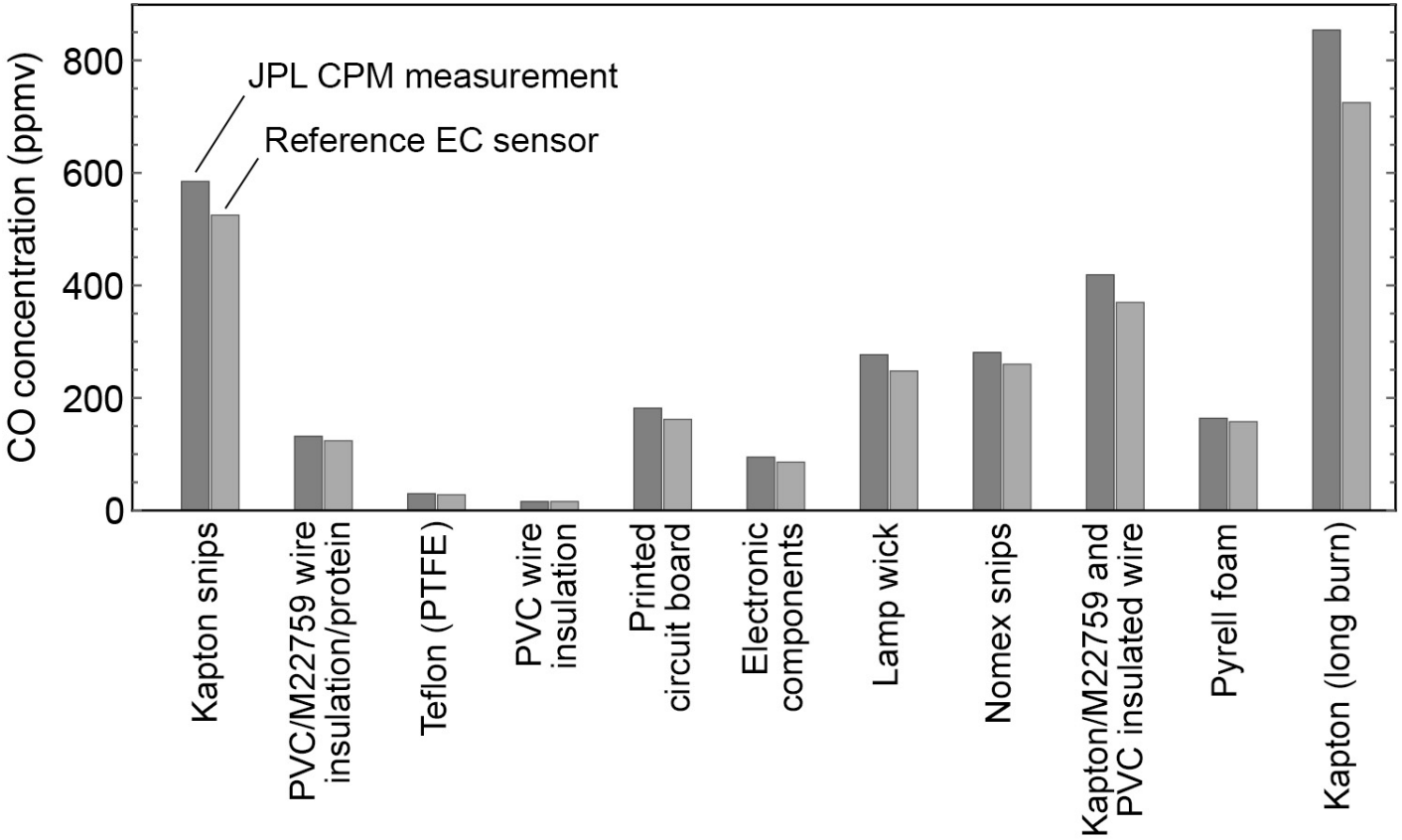
Fuel sample before and after pyrolysis



Nomex snips, 0.25 g pre-burn mass

R.M. Briggs, et al., *Proc. of the 45th International Conference on Environmental Systems*, Bellevue, Washington, USA (2015)

Previous CPM testing results

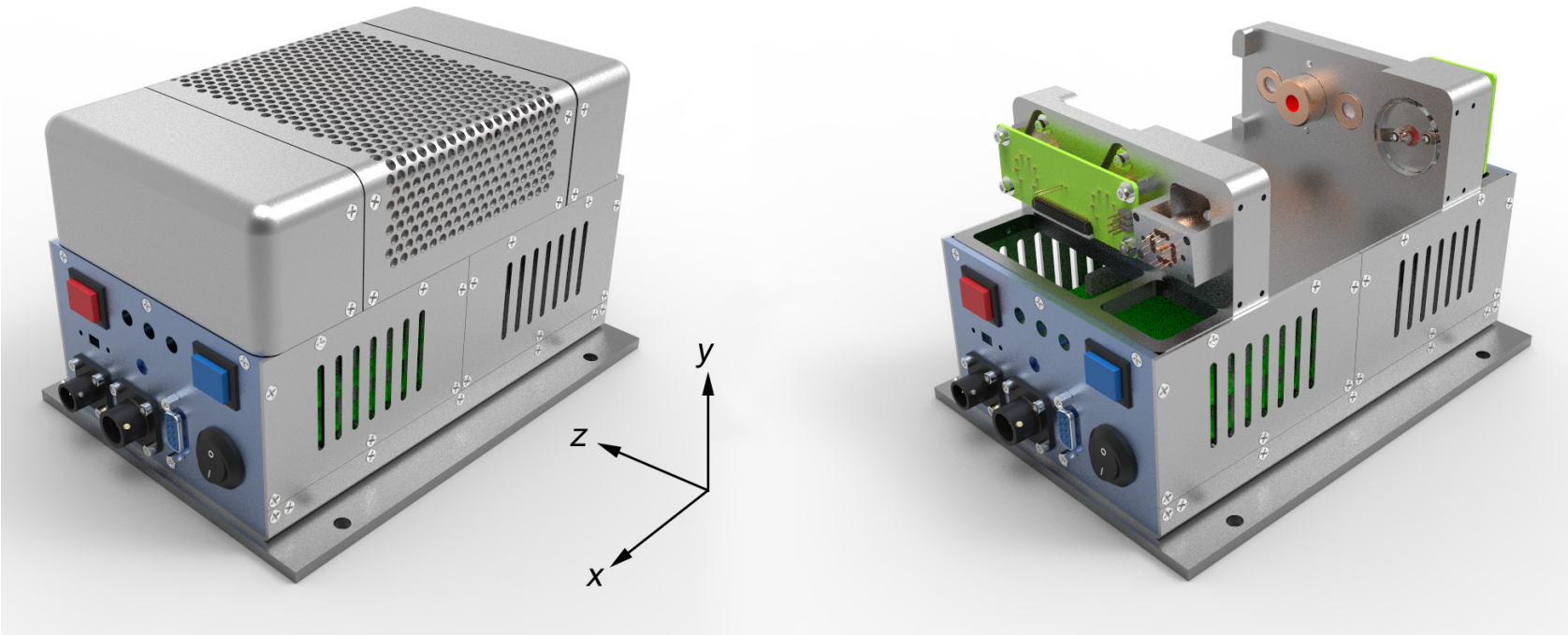


Excellent agreement for maximum CO level compared with Dräger reference sensor (within 20%)

R.M. Briggs, et al., *Proc. of the 45th International Conference on Environmental Systems*, Bellevue, Washington, USA (2015)

Next-generation JPL Combustion Product Monitor (CPM2)

Tunable laser absorption spectrometer for monitoring CO, HCl, HCN, HF, CO_2, and O_2



Six independent laser channels: four with a 10-cm single-pass optical path, and a two-channel Herriott cell

Volume: 184 in^3 (8.0x4.9x4.7 in), mass: 2.25 kg (with 0.5 kg batteries), power consumption @ 20 ºC: <10 W

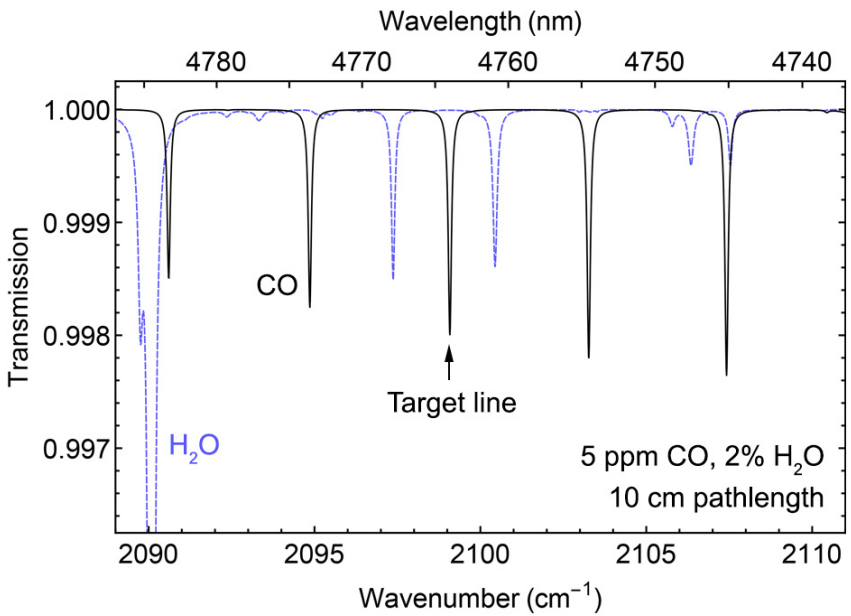
CPM2 performance targets

Compound	Spacecraft Maximum Allowable Concentration (ppmv)	CPM performance range (ppmv)	Wavelength (nm)	Absorption pathlength (cm)	Relative line-center absorption at minimum concentration*
CO	1 h: 425 24 h: 100 7 d: 55 30+ d: 15	5 - 1,000	4764.0	10	0.0020
HCl	1 h: 8 24 h: 4 7 d: 1 30+ d: 1	2 - 50	3572.8	10	0.0009
HCN	1 h: 5 24 h: 2.5 7d: 1 30+ d: 1	2 - 50	3001.5	10	0.0005
HF	1 h: 5 24 h: 2 7d: 1 30+ d: 1	2 - 50	2395.8	10	0.0023
CO_2	1 h: 20,000 24 h: 13,000 7 d: 7,000 30+ d: 7,000	>100	2003.5	170	0.0023
O_2	--	15 – 50%	760.9	170	0.0337

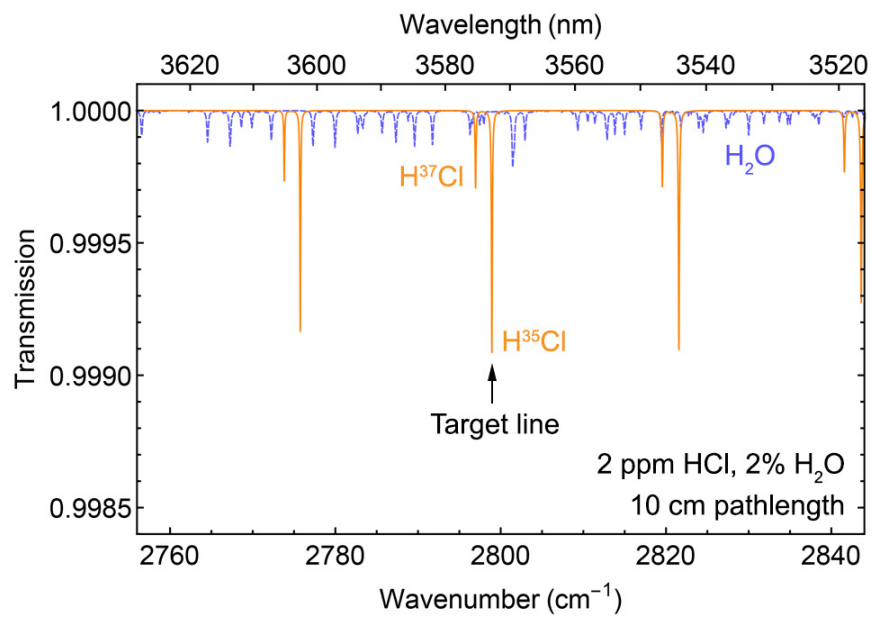
*Minimum resolvable line-center absorption ~10^{-4}

Absorption line calculations

CO channel



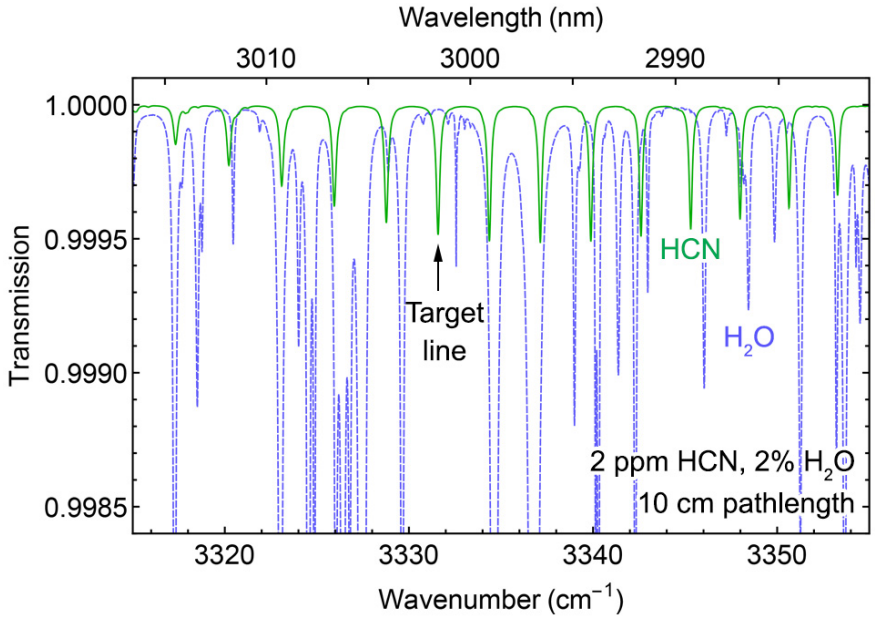
HCl channel



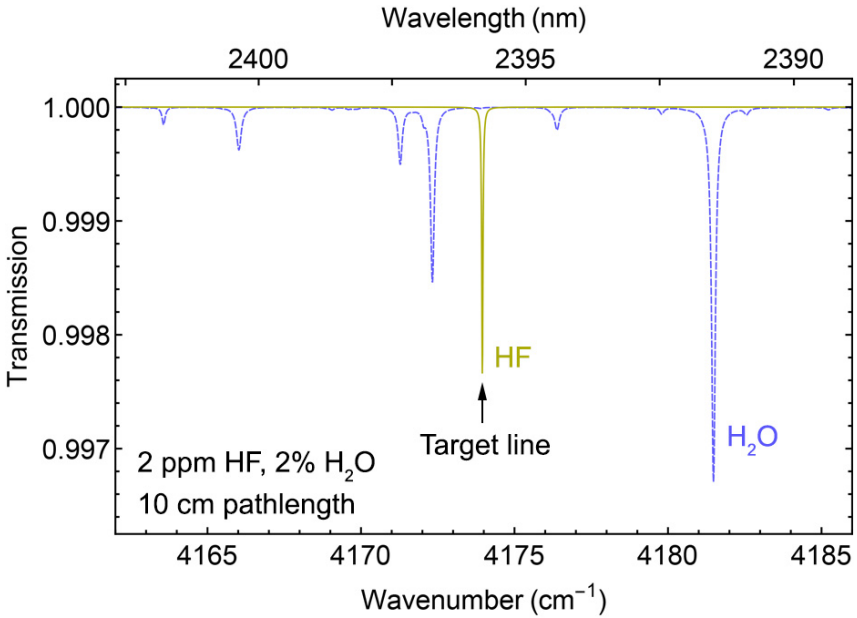
Calculated transmission spectra at minimum detection limit with 100% humidity near 25 ºC at 1 atm

Absorption line calculations

HCN channel

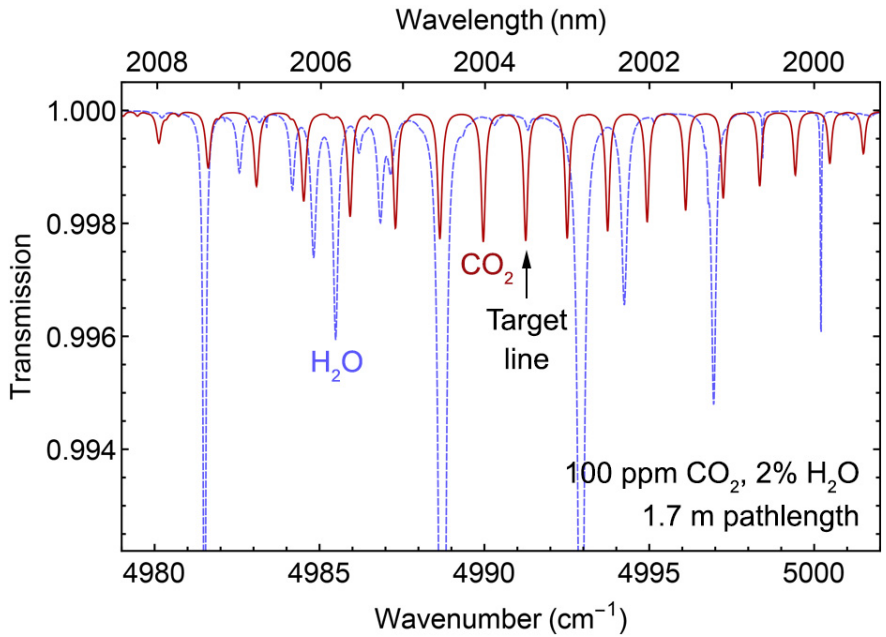


HF channel

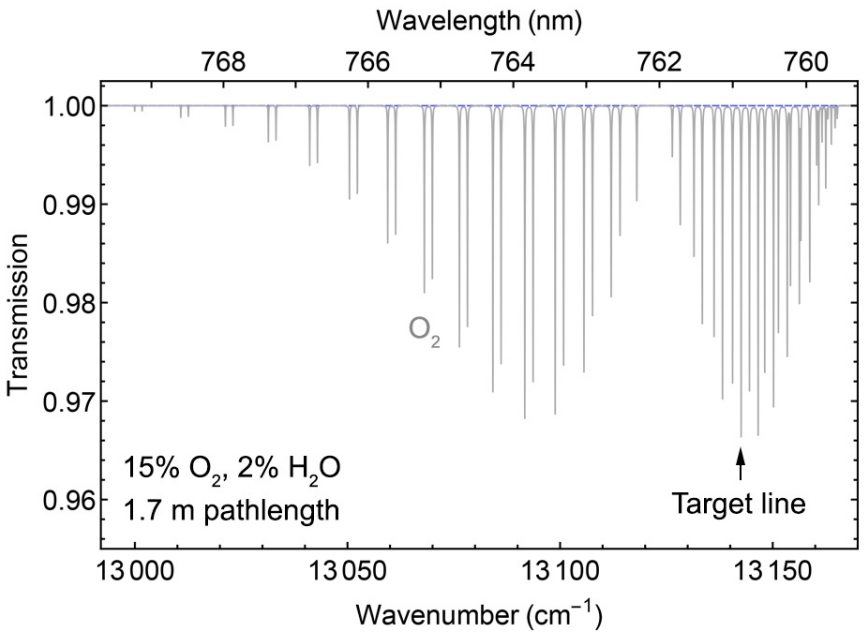


Absorption line calculations

CO_2 channel



O_2 channel



Summary

Conclusions:

Previously demonstrated a five-channel laser spectrometer to simultaneously and unambiguously detect CO, HCN, HF, HCl, and CO_2 with fast response and long-term calibration stability

Completed initial pyrolysis tests to measure emissions from combustible spacecraft materials

Designed and built a next generation instrument with an additional O_2 channel, less than a quarter of the volume, less than half the mass, and capability for multi-day battery-powered operation

Future work:

Testing and qualification of the CPM2 instrument is scheduled at NASA GRC starting in August

Pending instrument selection, three flight versions of the CPM instrument will be built for Saffire missions IV, V, and VI

Demonstration of a laser spectrometer for combustion product monitoring in a spacecraft environment will lay the ground work for implementation aboard ISS and/or Orion

Acknowledgments

Gary Ruff, NASA GRC – Saffire technical lead

Marit Meyer, **Gordon Berger**, **Michael Kulis**, NASA GRC and **Paul Mudgett**, NASA JSC – testing support

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Murray Darrach, **Benny Toomarian**, and **Dave Eisenman,** JPL – program management