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Vehicle Remote Sensing - Next Generation - Validation

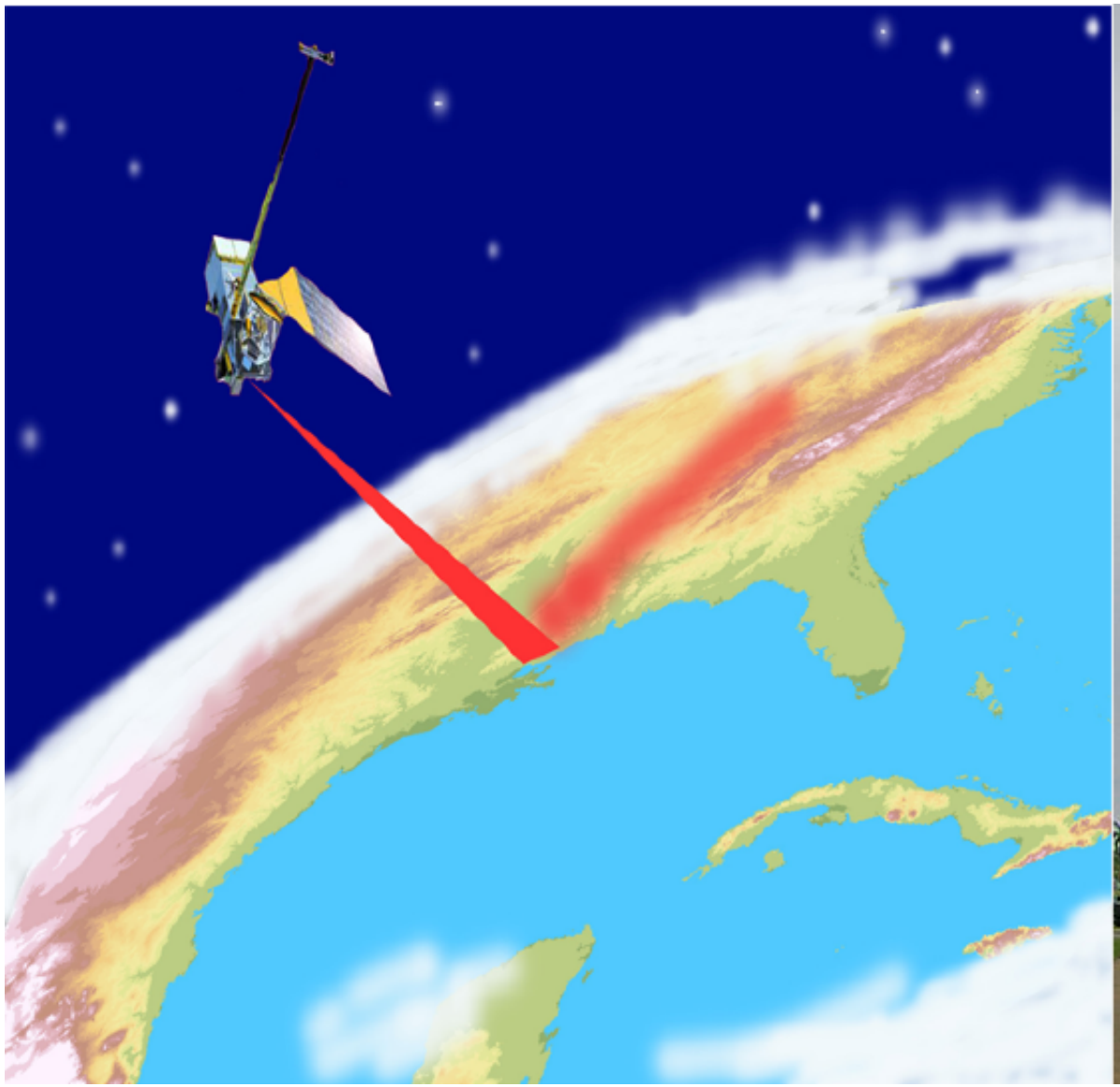
Portable Emissions Measurement Systems International Conference & Workshop

MARCH 17, 2016

More than half the cars in the United States have to have their emissions tested.

- People have to wait in long lines to have their emissions tested
- Cost vary from state to state
- Information is downloaded from the cars computer
- For older vehicles, tailpipe test and dynamometers are also used

A new, patented remote sensing system for vehicle exhaust, based on NASA satellite technology



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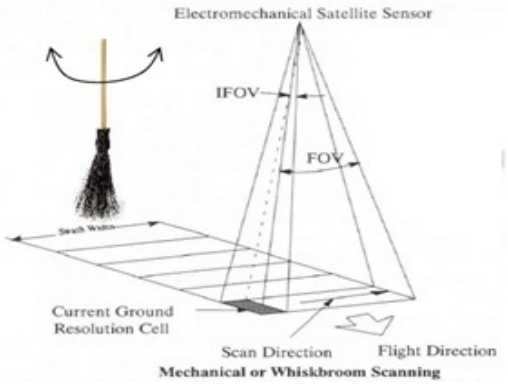
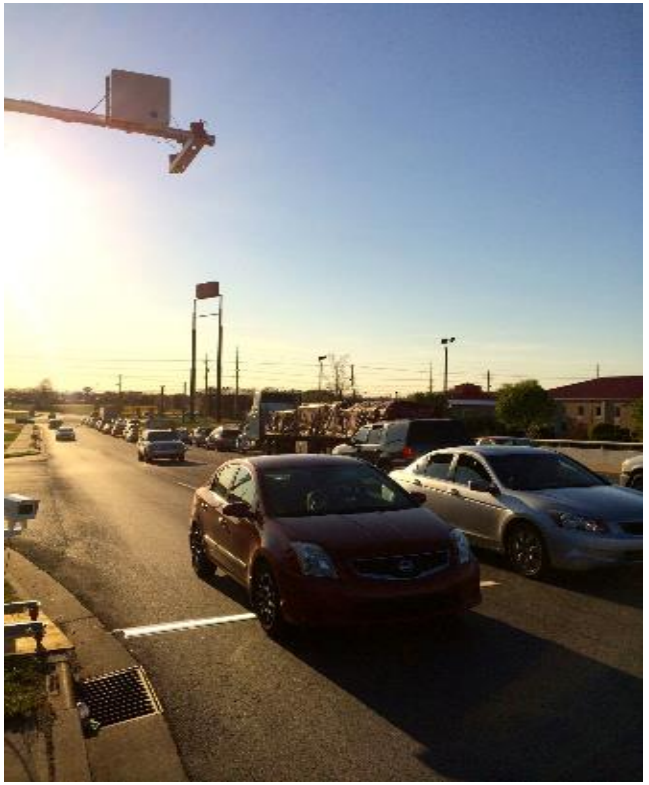
What is EDAR?

- "Emission Detection And Reporting"
- IR Laser based technology, Class 1 eye-safe, FDA approved & IEC 60825 certified
- Geometry – Whiskbroom scanning, where we look down on the plume.
- We have a 20,000 Hz sampling rate.
- Measures & Quantifies CO_2, CO, NO, NO_2, CH_4 and HC





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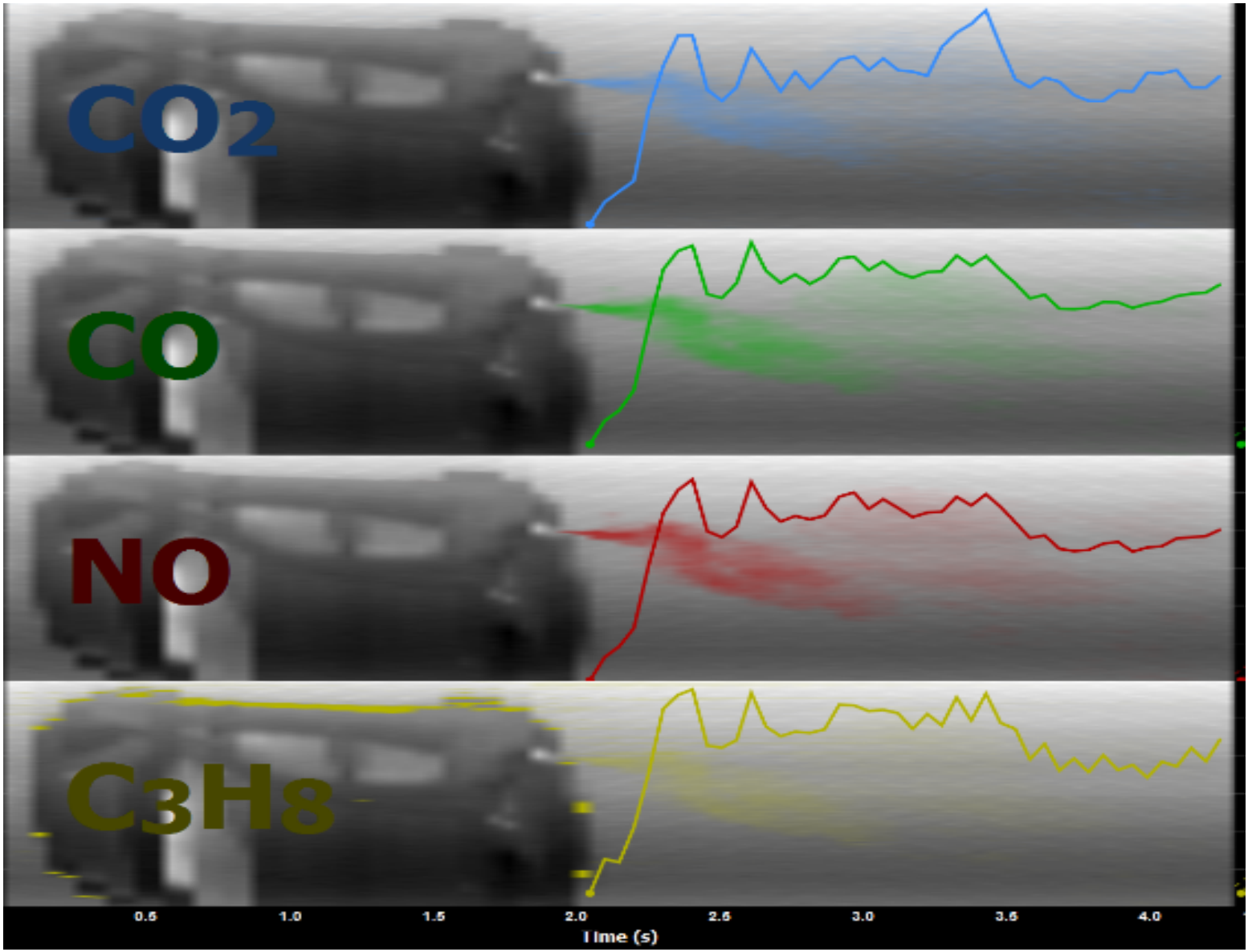
What EDAR sees



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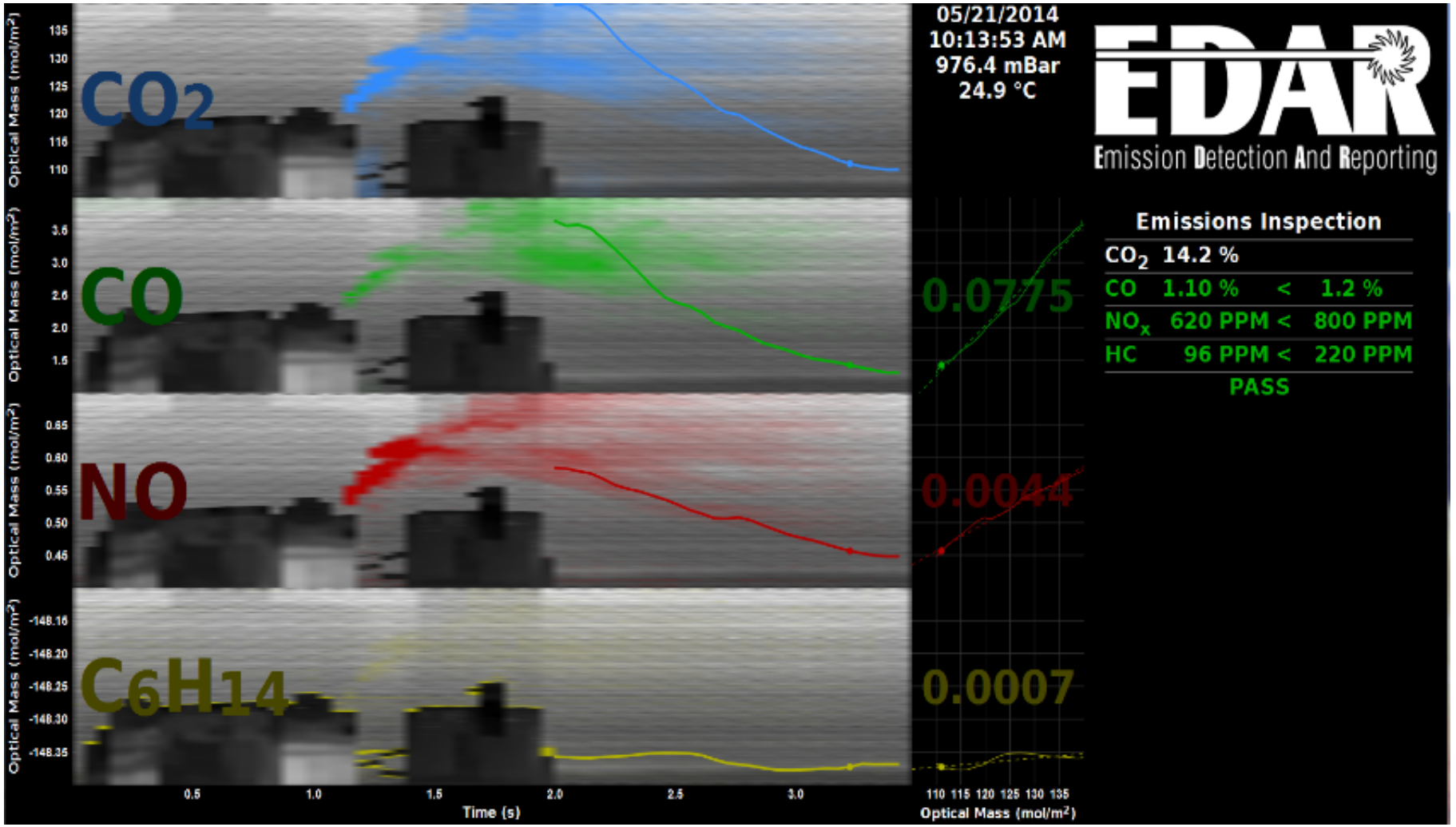
2-Dimensional Display View Truck and Semi-Trucks



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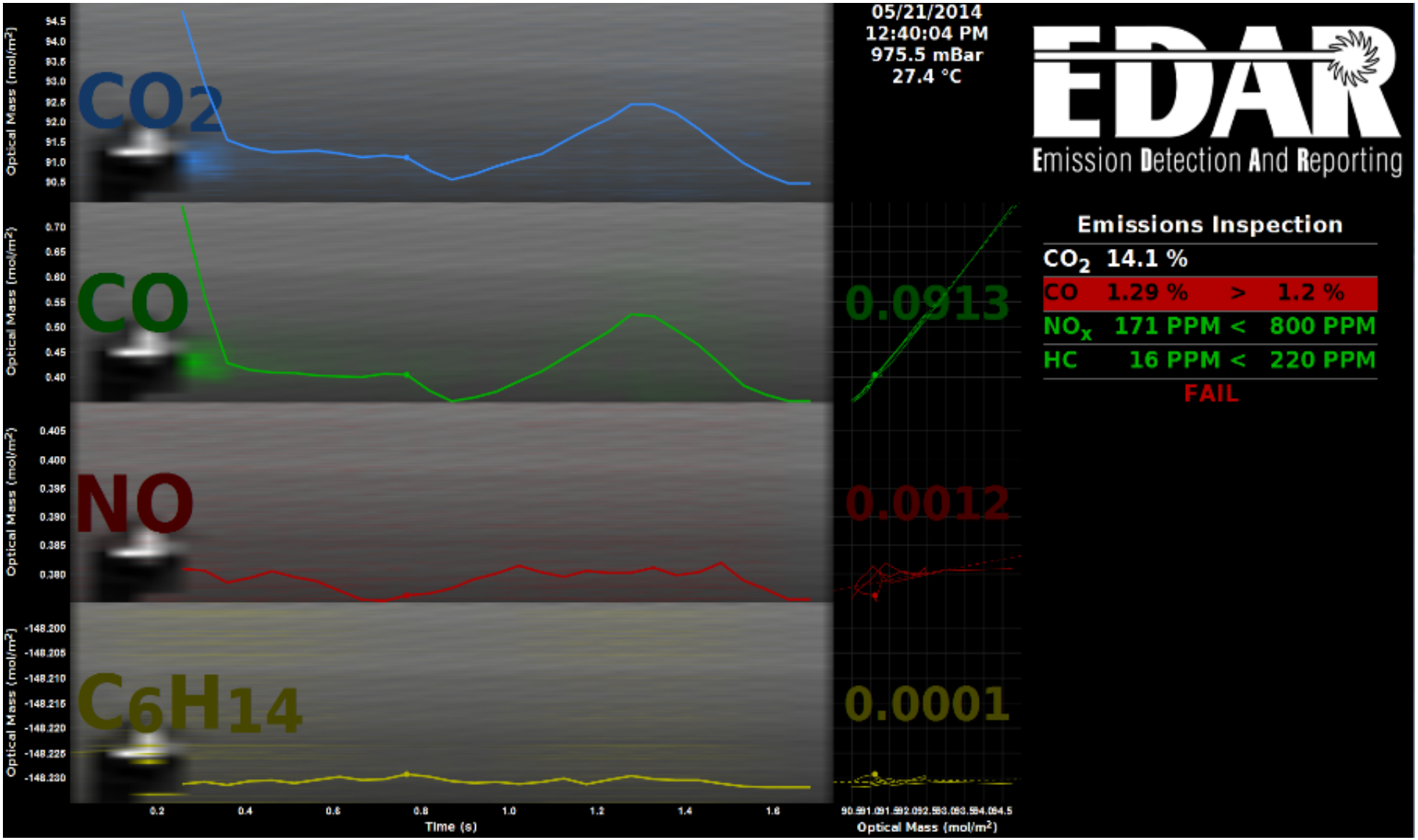
2-Dimensional Display View Motorcycles



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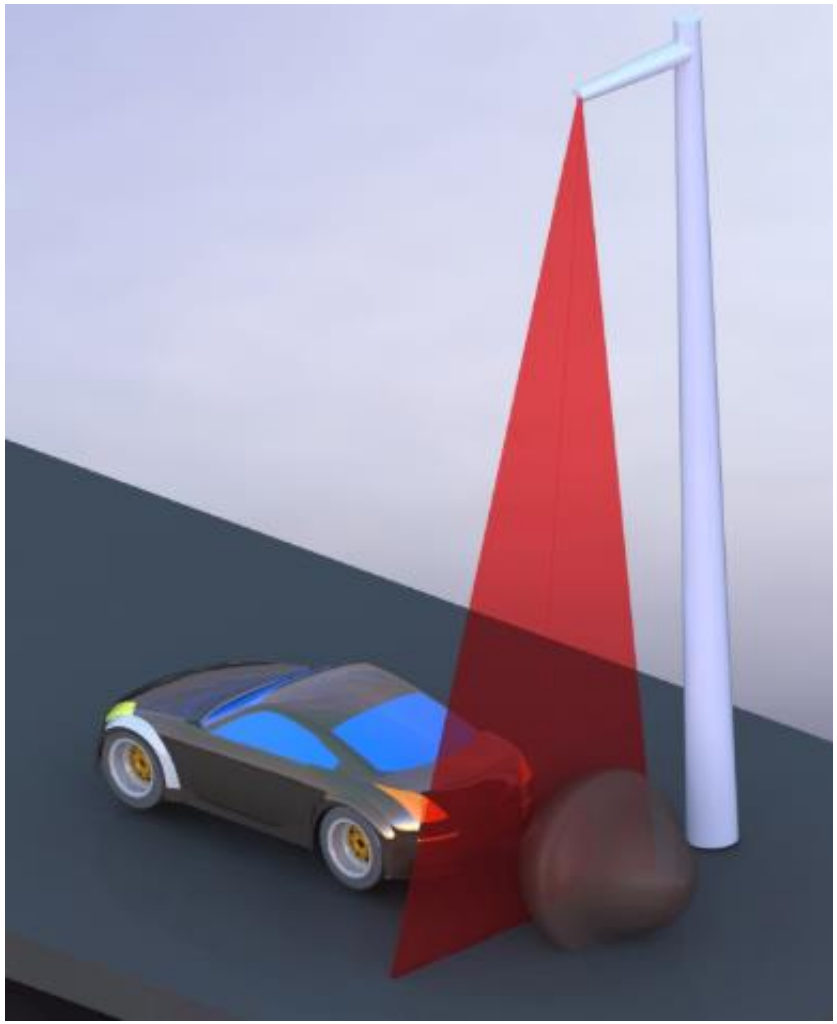
Improvements over existing remote sensing devices

Geometry:

- EDAR looks down the road allowing to see the entire plume
- EDAR technology allows remote sensing on multi-lane roads
- Virtually no drift. Allows for true unattended monitoring
- Sees Evaporative Emissions coming from different sources other than the tailpipe.



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Laser based technology is far superior to NDIR

Other laser based gas monitors:

The Thermos Scientific™ IRIS 4800 Analyzer uses mid-infrared absorption spectroscopy for the precise and accurate measurement of ambient carbon monoxide (CO).

- Measures CO within 1 ppb precision
- Ultra low drift of less than 3 ppb per day
- Unique Difference Frequency Generation (DFG) Mid-IR laser absorption spectroscopy
- Exceeds World Meteorological-Organization (WMO) Global Air Watch (GAW) specifications
- Single-box solution with internal manifold and pump

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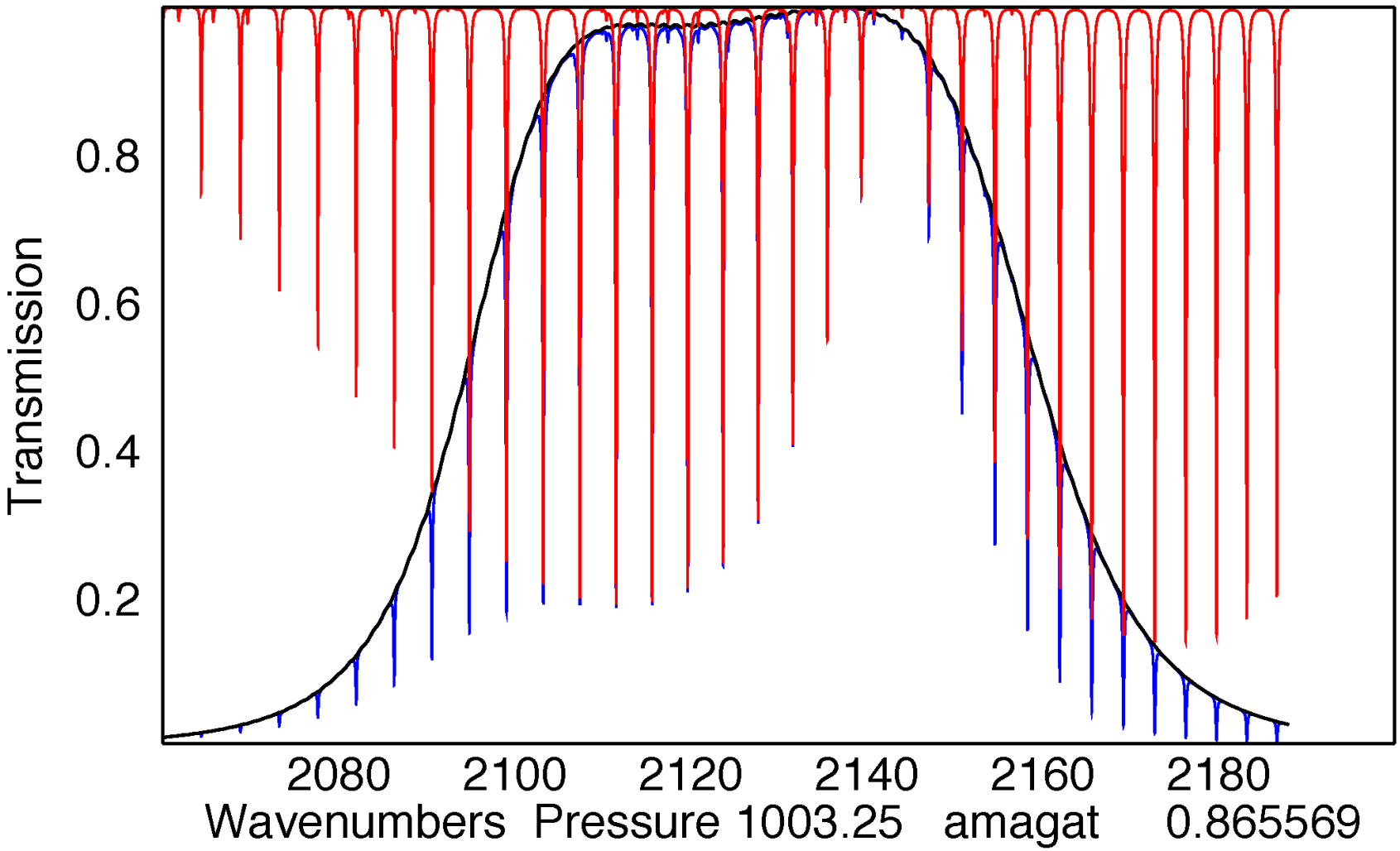
Resolution and Sensitivity of EDAR



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Key Differentiators

Technical	HEAT	NDIR
•Reading entire plume	Yes	No
•Periodic equipment calibration NOT req'd	Yes	No
•Single read validation per vehicle	Yes	No
•Sampling rate	20,000 HZ	100 HZ

Operational	HEAT	NDIR
•Unmanned system	Yes	No
•Multilane capable	Yes	No
•Operates 24/7	Yes	No
•Operates in rain	No	No
•Operates in windy conditions	</= 25 mph	?
•Vehicle speed range	0 to 55 mph	?
•Small footprint/single pole solution	Yes	No
•Same foot print for Heavy duty or light duty	Yes	No

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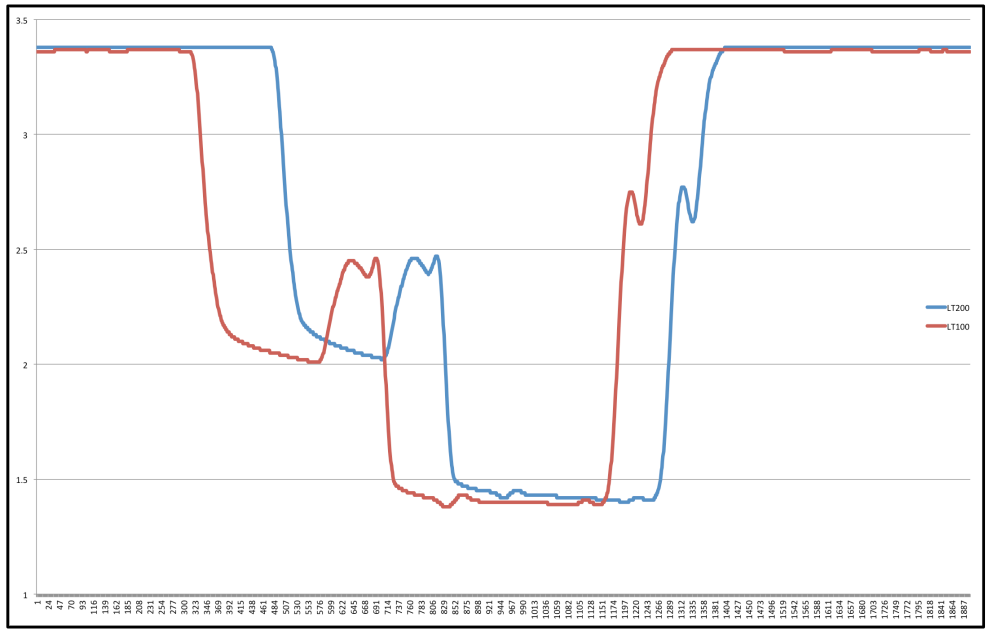
EDAR's Footprint, reads license plate, measure speed and acceleration

- Reflective tape is used on road to enhance reflectivity
- EDAR capture the license plate as well as two images of the passing car
- Speed and acceleration – through Vehicle profiles
- Vehicle profiles for vehicle typing

Snow plows can damage our reflective tape. Simple crosswalk paint is thick enough to protect protect our tape.



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Colorado Evaluation

ERG, EPA and CDPHE did a blind study on our system. They selected 4 different gas mixtures with CO2, CO, NO, CH4 and propane. We did not know the concentrations of these mixture until we gave ERG our results. We conducted this study along side the current Envirotest's remote sensing system.

They were looking for the accuracy, precision, limit of detection, and drift of the current EDAR instrument for measurement of exhaust CH4, non-methane hydrocarbon, CO, and NO on a moles emission per mole of CO2 basis as a function of vehicle speed.

	A	B	C	D
CH4 (ppmC)	209	103	51	24
C3H8 (ppmC3)	1300	398	115	32
CO (ppm)	20000	494	1500	30
NO (ppm)	502	377	151	41
CO2 (%)	13.9	14.9	14.9	14.9

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Colorado Evaluation

CDPHE RSD audit truck has the needed gas bottles and gas release controls as shown in Figure 1. The audit truck is equipped with a simulated tailpipe and gas release controls to allow release of bottle gas to simulate an exhaust plume while the vehicle is in motion. The truck is also equipped with a flow meter that can be used to set the flow rate of gas releases. The audit truck engine's exhaust is re-routed 10 feet to the driver's side in Figure 2.

Figure 1. RSD Audit Truck Gas Bottle Stowage and Piping

Figure 2. RSD Audit Truck with Engine Exhaust 10-foot Side Extension

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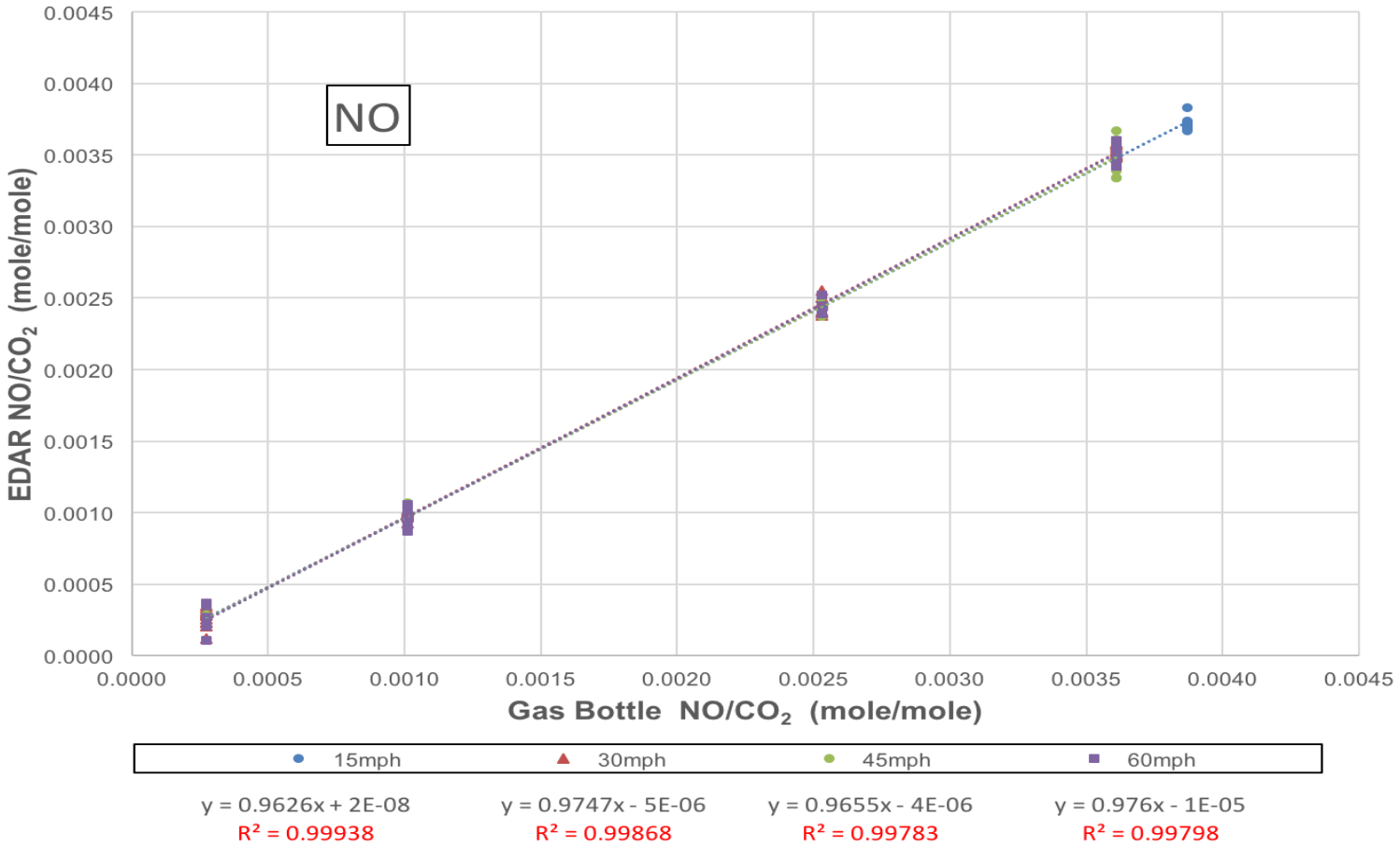
Colorado Evaluation

Comparison of EDAR-Measured and Bottle-Labeled NO at 4 Vehicle Speeds



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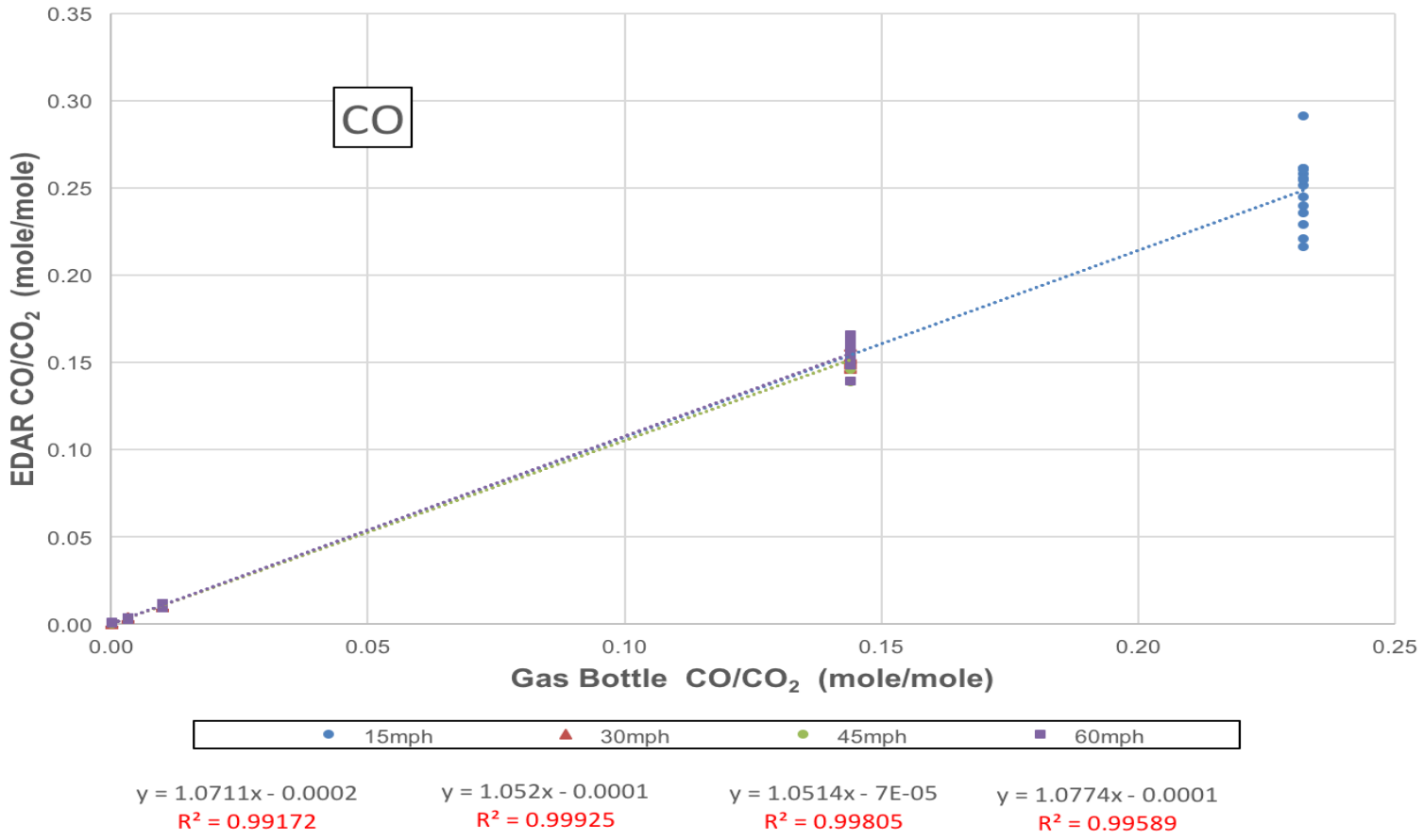
Colorado Evaluation

Comparison of EDAR-Measured and Bottle-Labeled CO at 4 Vehicle Speeds



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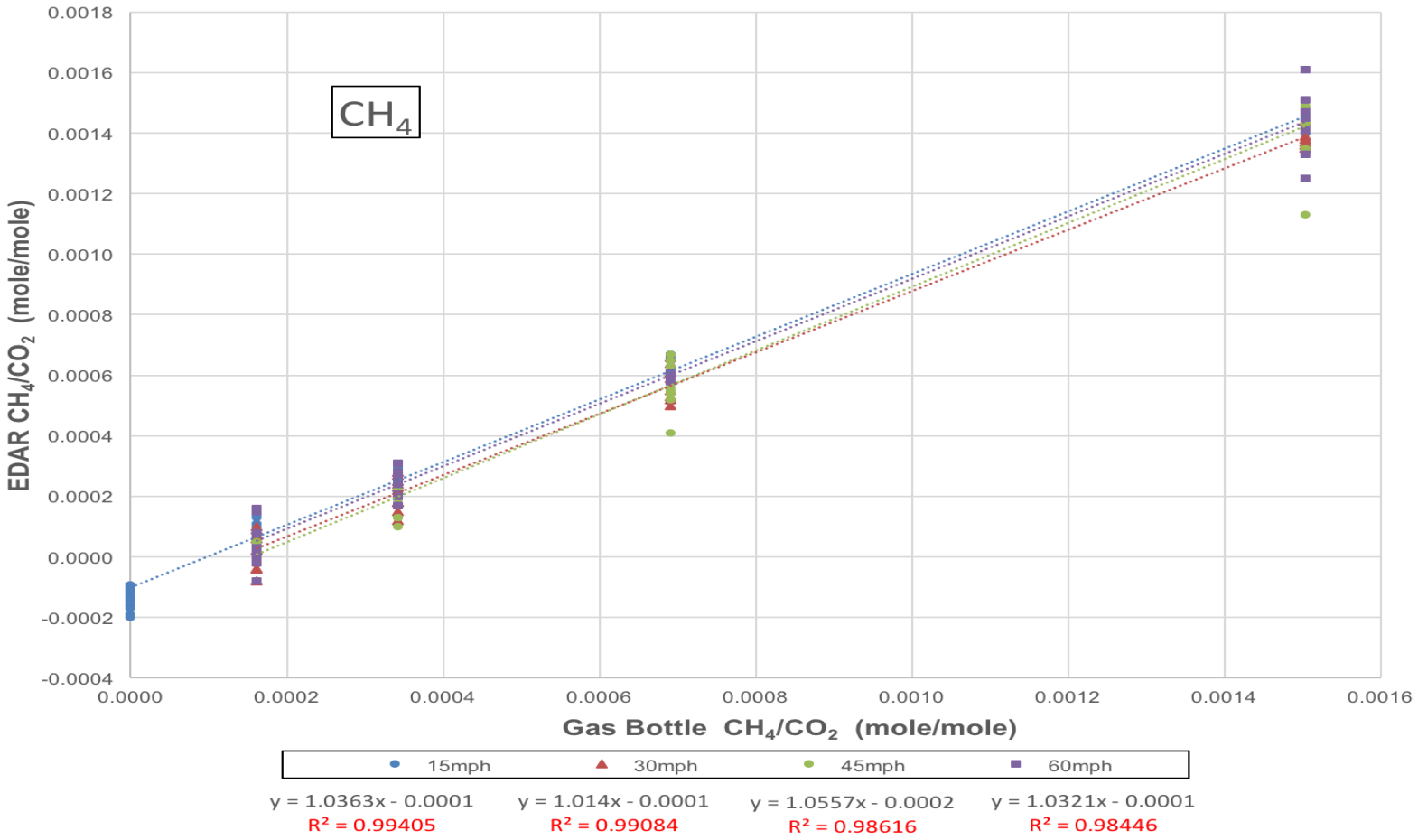
Colorado Evaluation

Comparison of EDAR-Measured and Bottle-Labeled CH4 at 4 Vehicle Speeds



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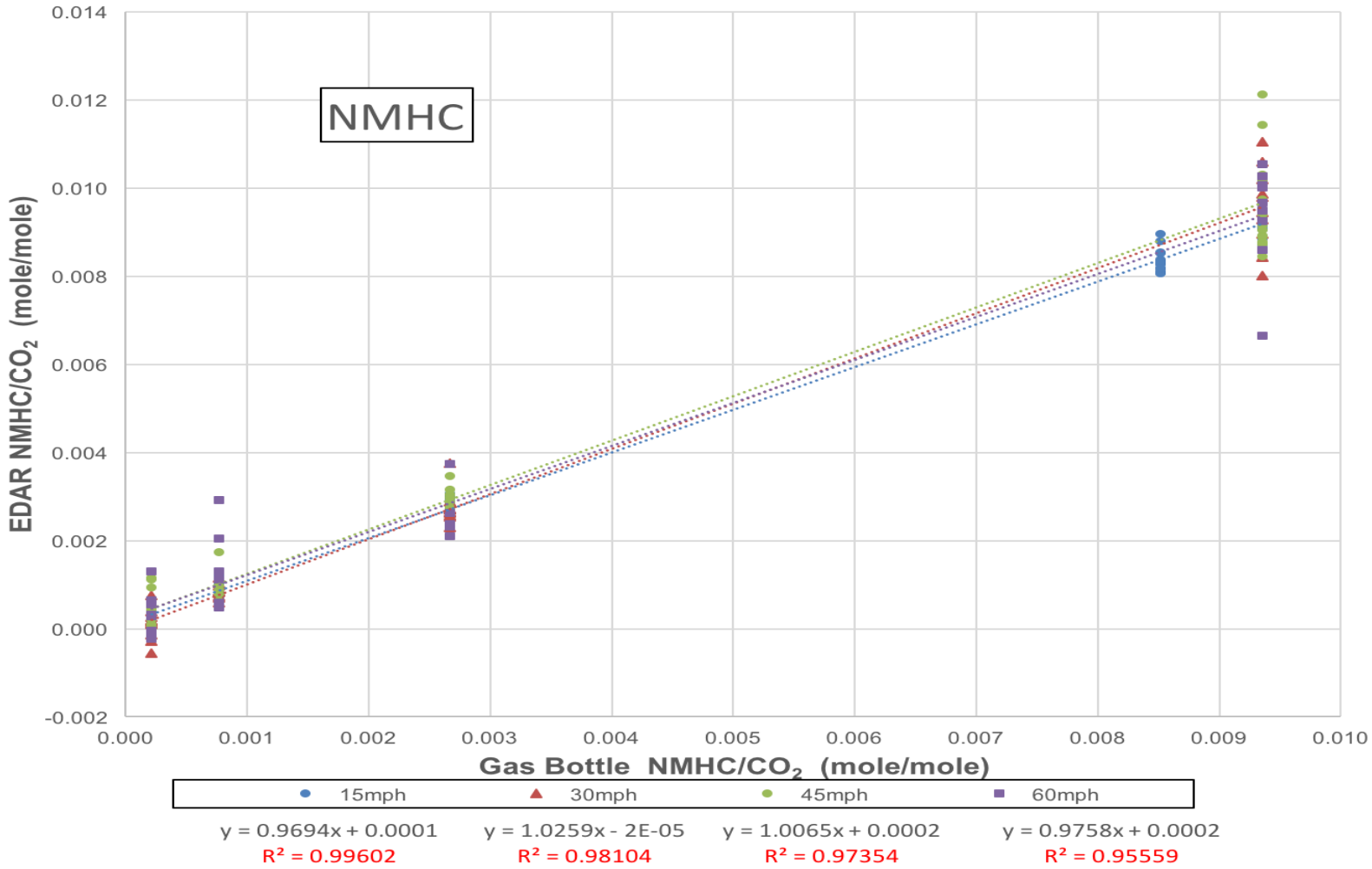
Colorado Evaluation

Comparison of EDAR-Measured and Bottle-Labeled NMHC at 4 Vehicle Speeds



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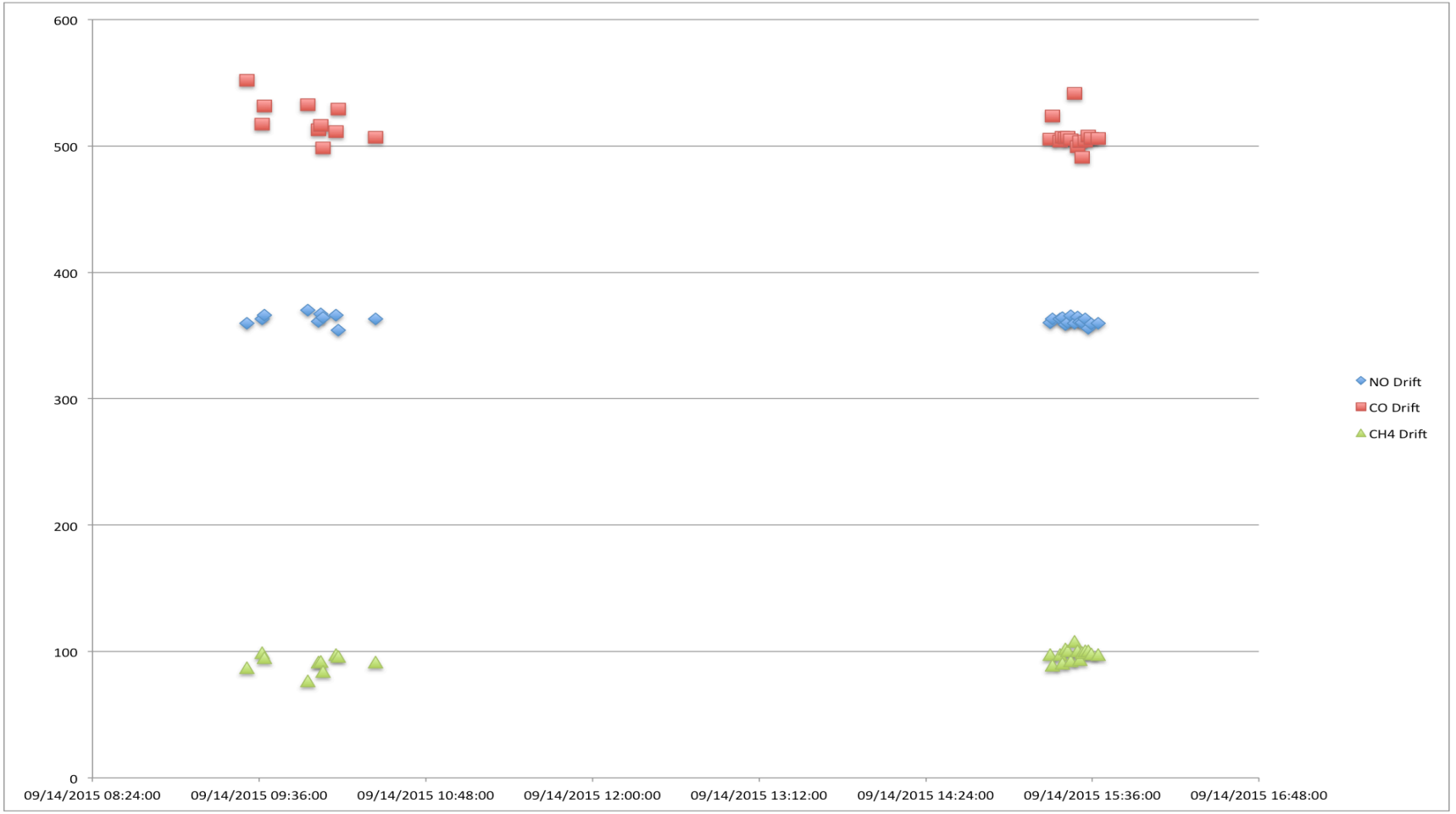
Drift

We started and ended the day with tank B. The results show virtually no drift.



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Colorado Evaluation

Comparison of EDAR-Measured and Bottle-Labeled NMHC at 4 Vehicle Speeds

Bottle Label	Bottle Value NO (ppm)	NO @ 15mph (ppm)	NO @ 30mph (ppm)	NO @ 45mph (ppm)	NO @ 60mph (ppm)
D	41	41 ± 3	39 ± 10	37 ± 4	38 ± 11
C	151	145 ± 4	146 ± 4	149 ± 6	146 ± 10
B	377	360 ± 2	365 ± 8	362 ± 7	365 ± 7
Q	500	480 ± 5			
A	502	488 ± 5	489 ± 5	484 ± 13	489 ± 8

Bottle Label	Bottle Value CO (ppm)	CO @ 15mph (ppm)	CO @ 30mph (ppm)	CO @ 45mph (ppm)	CO @ 60mph (ppm)
D	30	59 ± 57	52 ± 26	60 ± 28	63 ± 33
D*	30	32 ± 4	37 ± 8	36 ± 7	48 ± 6
B	494	509 ± 15	513 ± 16	497 ± 33	477 ± 64
C	1500	1532 ± 27	1507 ± 28	1536 ± 43	1554 ± 124
A	20000	21395 ± 575	21027 ± 507	21021 ± 747	21530 ± 1192
Q	30000	32116 ± 2517			

Bottle Label	Bottle Value CH4 (ppmC6)	CH4 @ 15mph (ppm)	CH4 @ 30mph (ppm)	CH4 @ 45mph (ppm)	CH4 @ 60mph (ppm)
Q	0	-18 ± 4			
D	24	13 ± 5	2 ± 9	3 ± 3	8 ± 13
C	51	42 ± 4	32 ± 8	27 ± 7	36 ± 7
B	103	96 ± 5	87 ± 8	85 ± 11	89 ± 2
A	209	200 ± 6	192 ± 5	198 ± 14	200 ± 14

Bottle Label	Bottle Value Eqvlnt. C6H14 (ppmC6)	NMHC @ 15mph (ppmC6)	NMHC @ 30mph (ppmC6)	NMHC @ 45mph (ppmC6)	NMHC @ 60mph (ppmC6)
D	16	15 ± 16	8 ± 26	35 ± 35	27 ± 35
C	58	57 ± 15	64 ± 12	72 ± 26	88 ± 66
B	199	210 ± 10	204 ± 29	224 ± 26	196 ± 48
Q	550	552 ± 26			
A	650	642 ± 33	664 ± 65	669 ± 70	652 ± 82

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Evaporative Emissions Study

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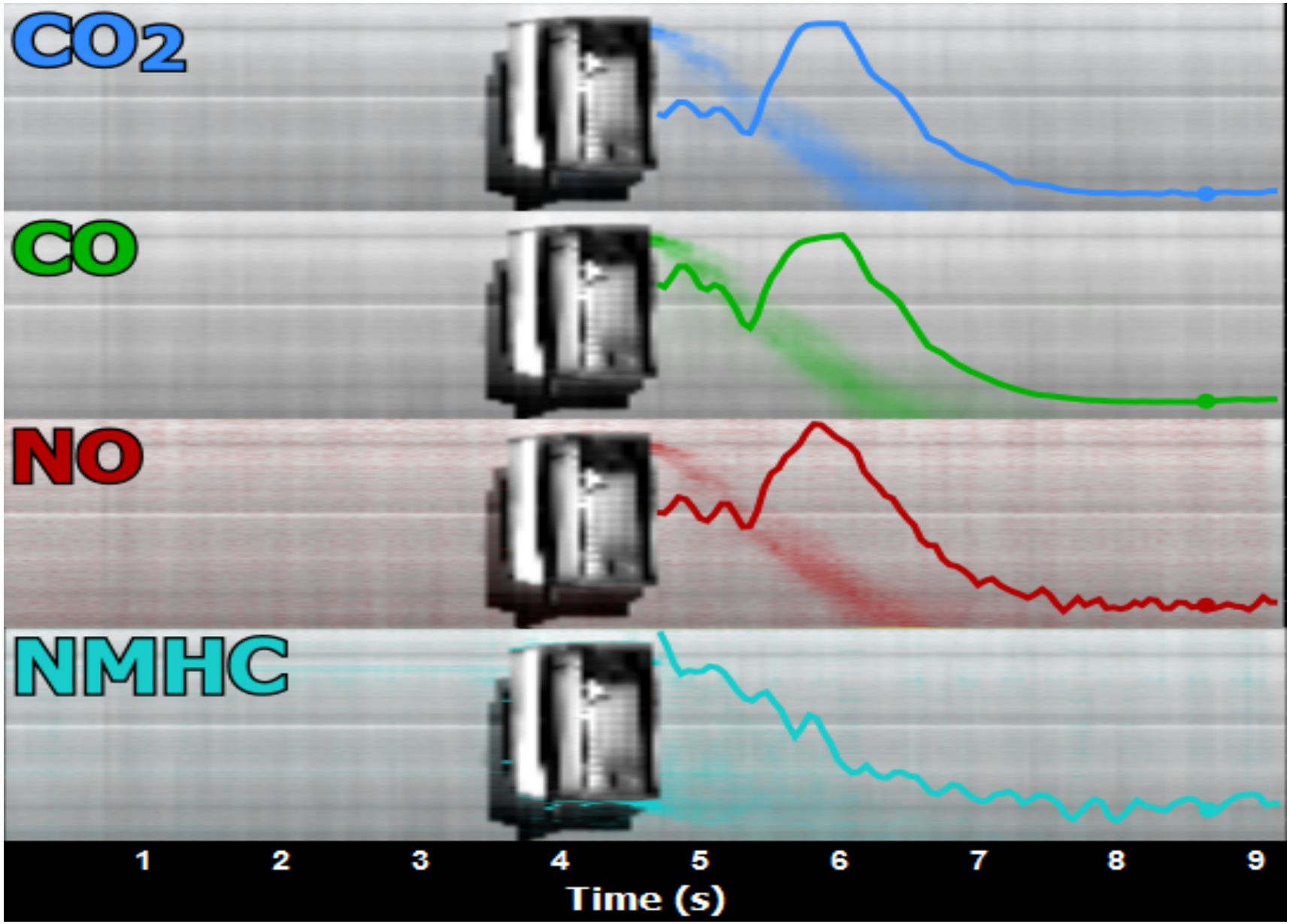
Evaporative Emissions Study



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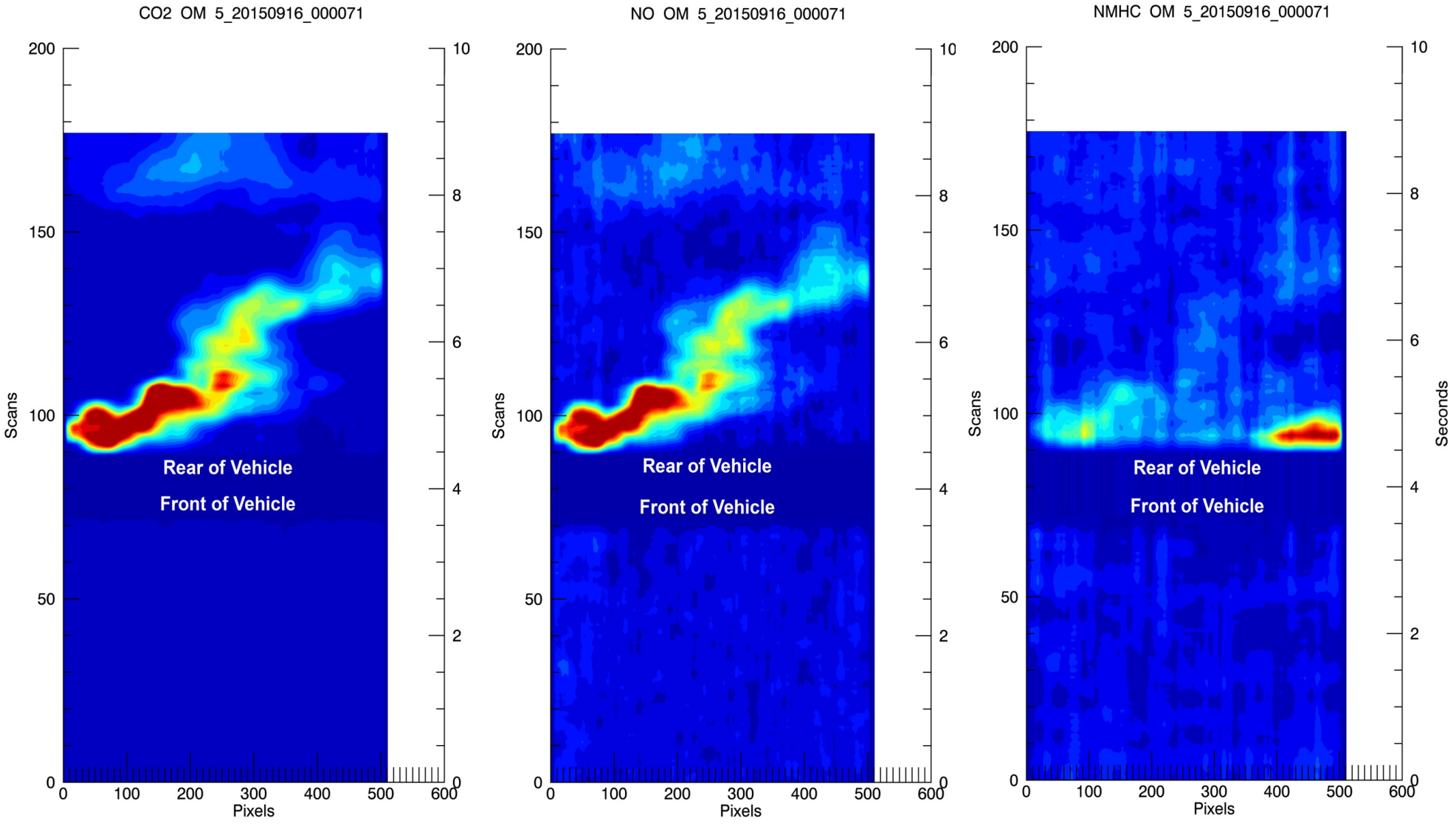
Evaporative Emissions Study



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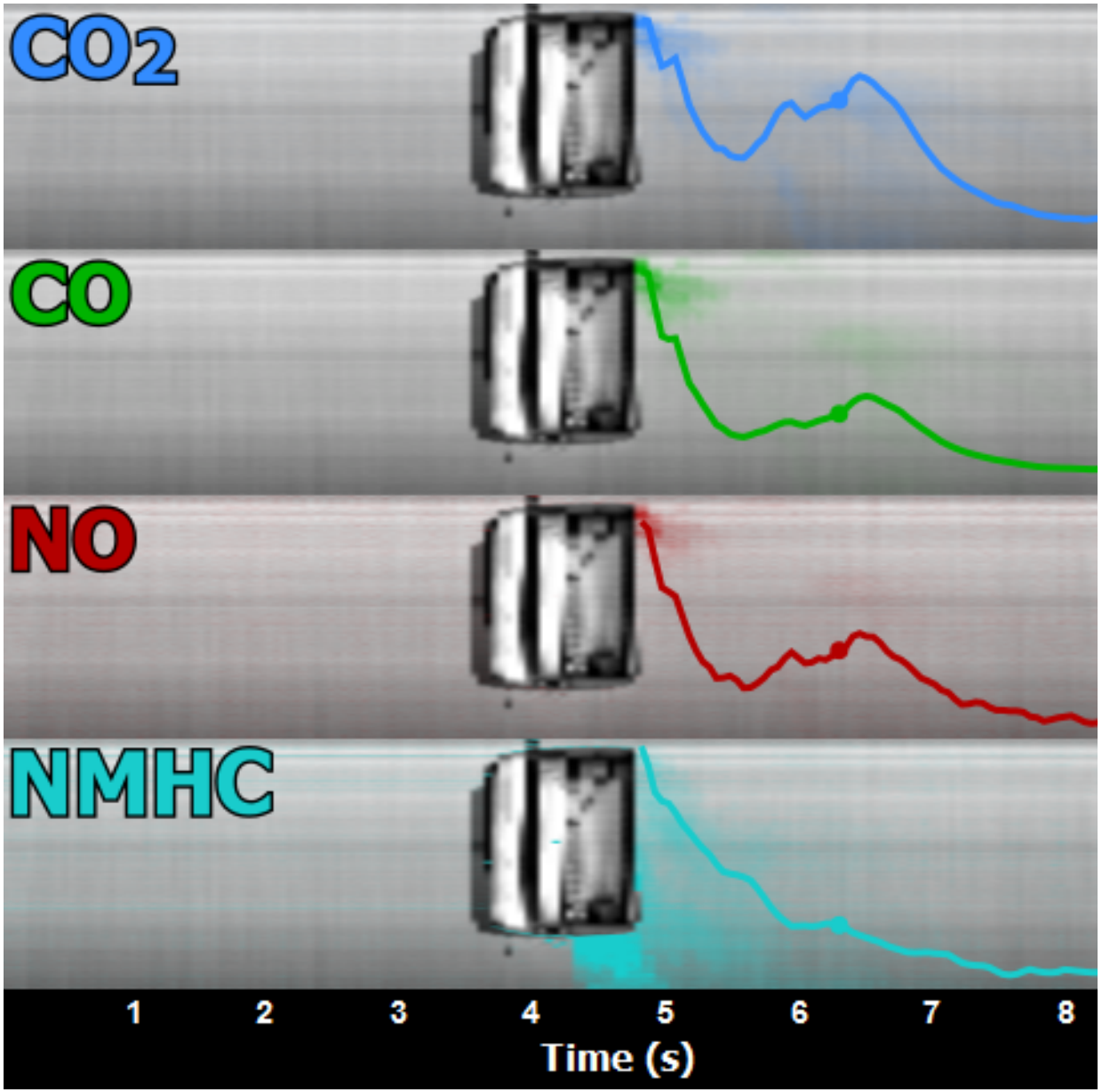
Evaporative Emissions Study

Knowing the location of the plume is a powerful tool. Not only can it detect Fugitive Emissions, but can spot interfering plumes.



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London – Birmingham UK

We did a recent study in Birmingham and London. We recorded NO_2 and PM.

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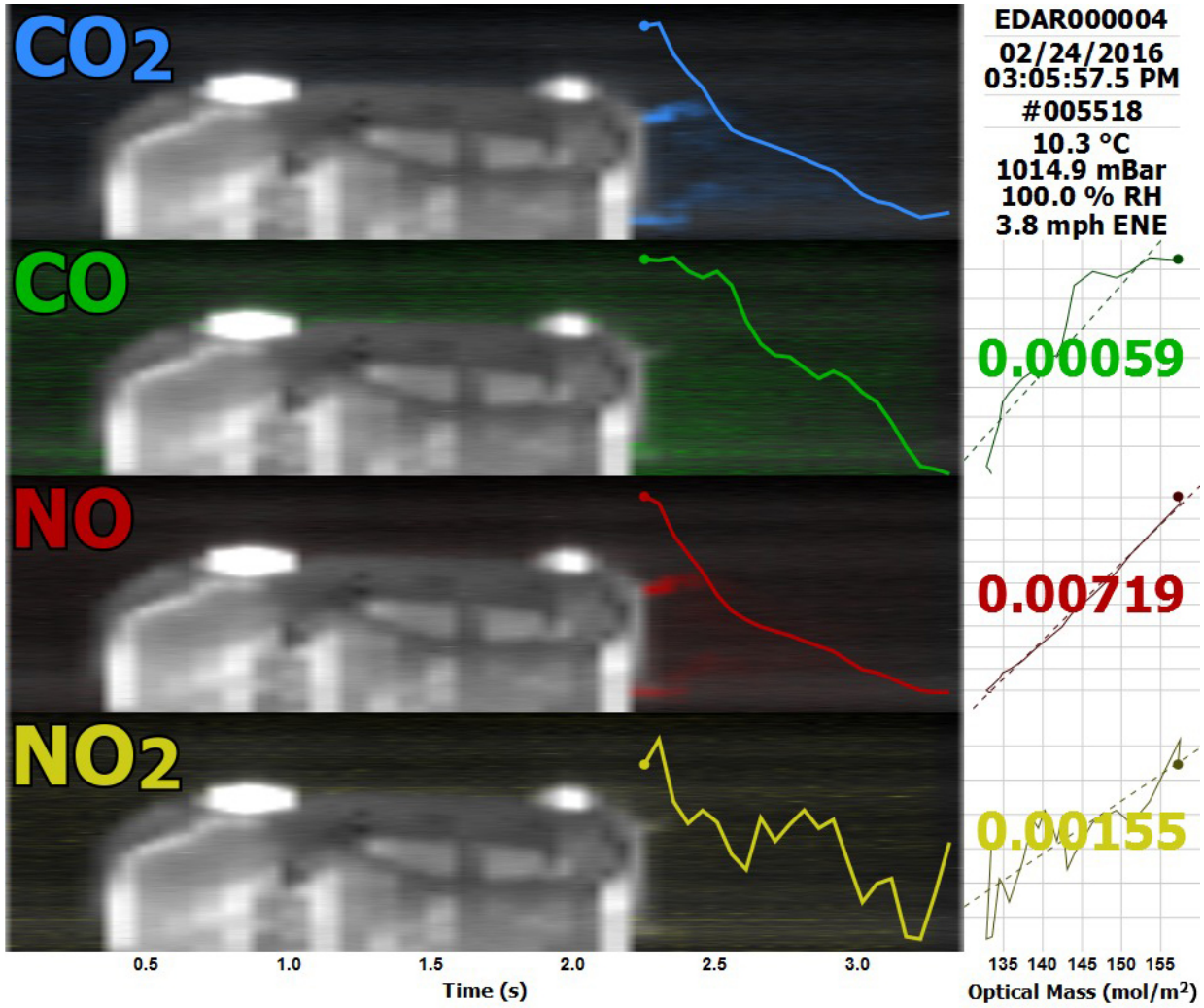
Nitrogen Dioxide

We can now measure NO_2. We can measure both NO and NO_2 at the same time.



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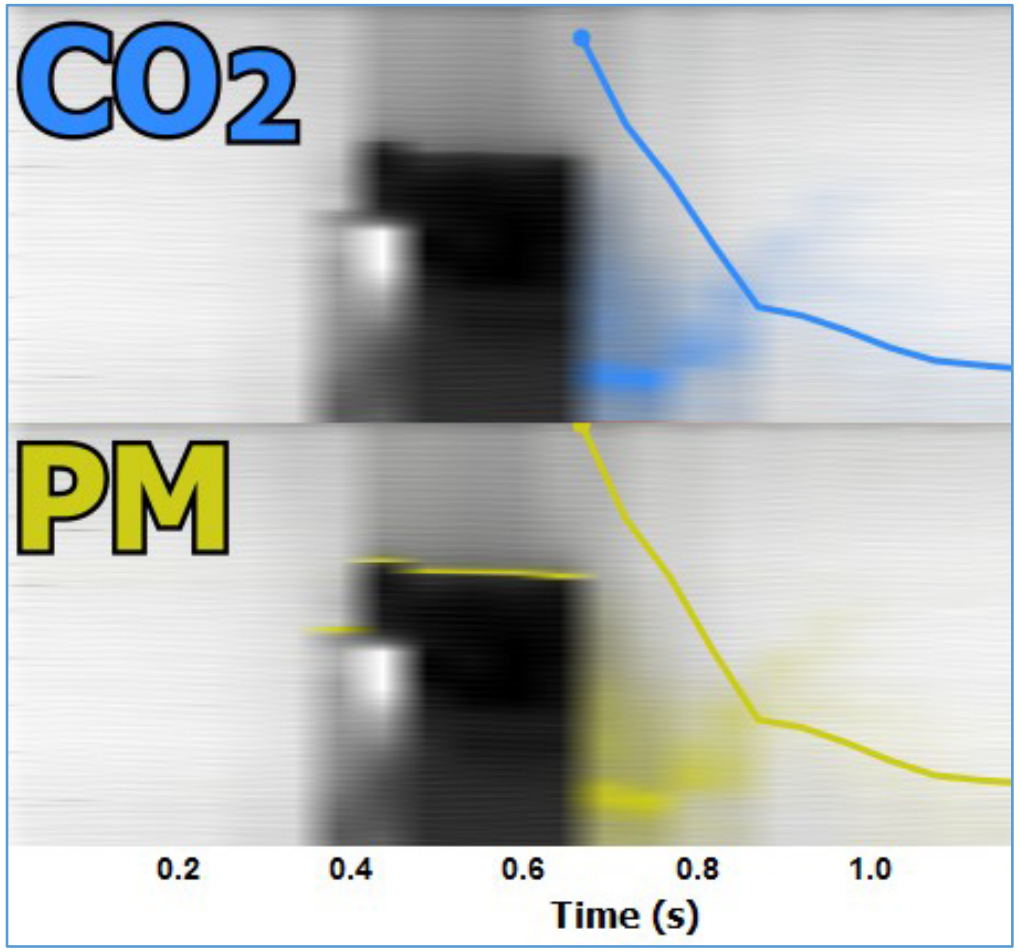
PM
Soot on the back windshield
PM/CO2 = 6.625 nanomole/mole



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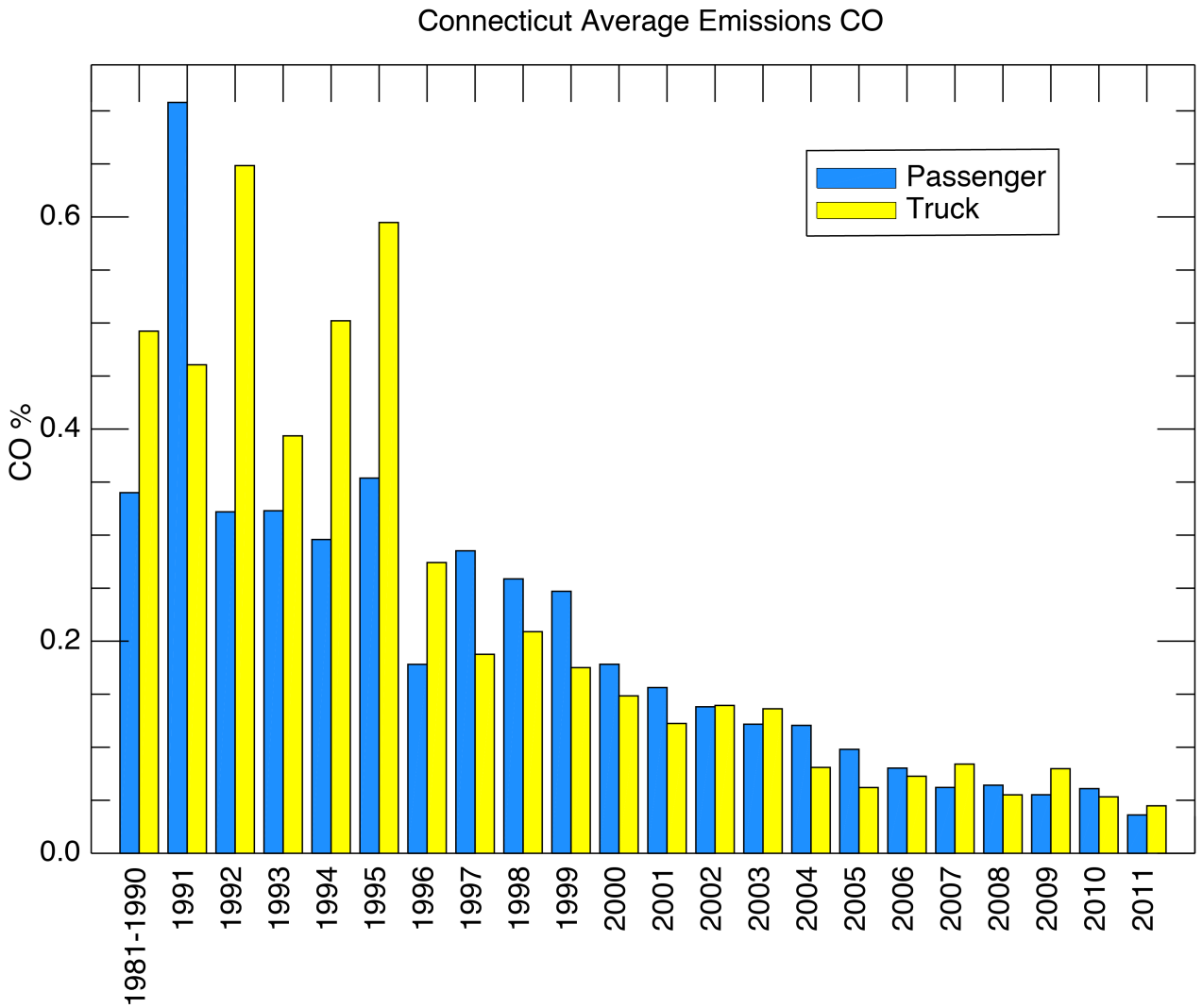
Connecticut Study
CO Results



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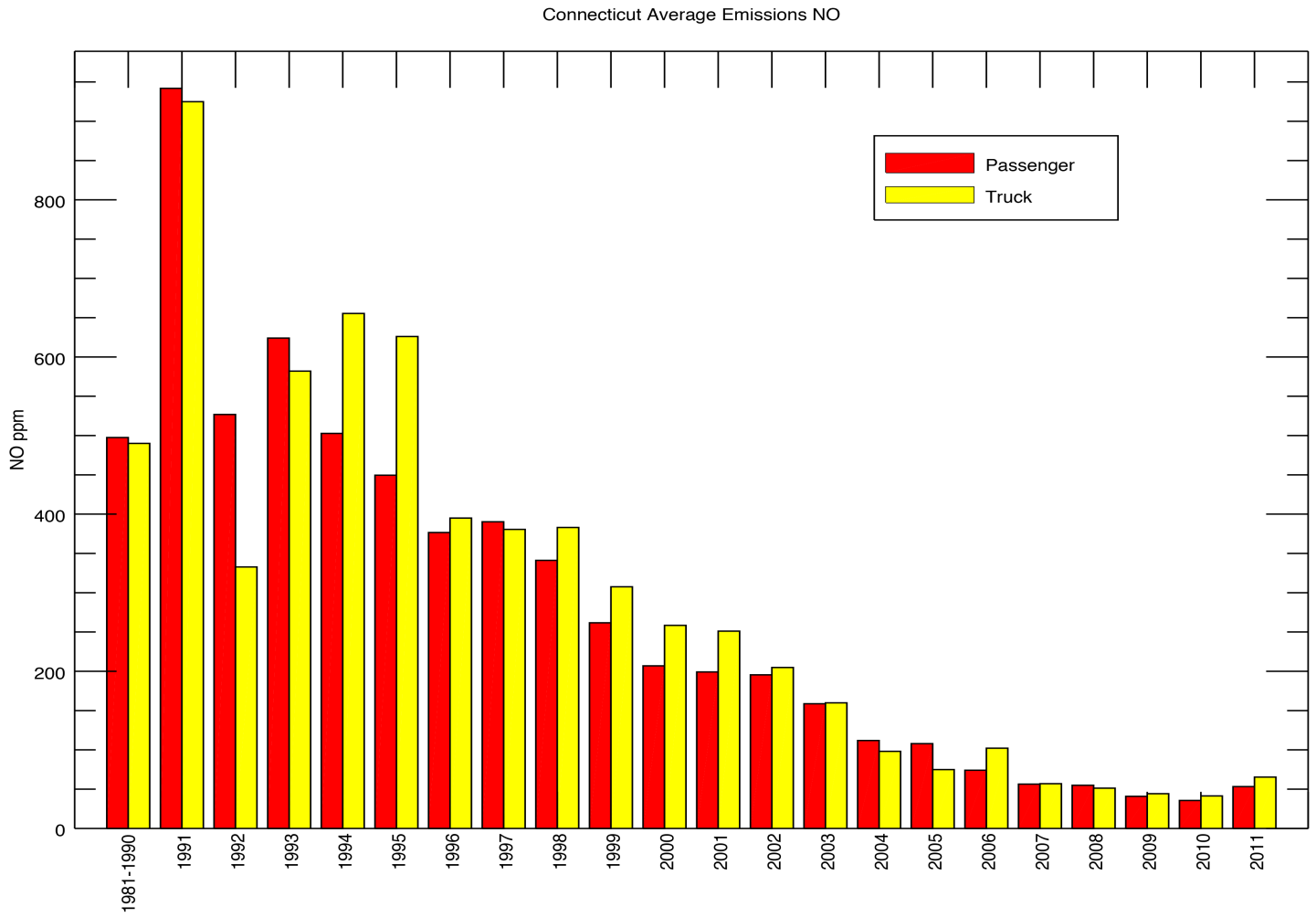
Connecticut Study
Nitric Oxide Results



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Gas & Oil Industry Foot Print

- **EDAR** can be equipped with a large aperture scan head.
- Instead of scanning back and forth, it can create a **cone shaped** pattern around a wellhead.
- **Methane gas** crossing the boundary of the cone can be **detected** and **quantified** using the same techniques as in car exhaust **remote sensing**.

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Gas & Oil Industry: Approaches

Limitations of Existing Technology

- Infrared cameras cannot see or measure gas if it is the same temperature as the surroundings.
- Passive FTIR systems need the plume to be at relatively high temperatures and they cannot image the plume.
- SOS FTIR systems depend on the Sun's position to measure column amounts, but they cannot use the most sensitive methane absorption features because ambient amounts remove the Sun's light at those wavelengths.

EDAR Approaches

- **EDAR** can scan up and down and side to side in order to do fence line monitoring
- **EDAR** can be equipped with an LEL (Lower Explosive Limit) meter in the boxes and can go into immediate shut down if necessary.
- **EDAR** can be attached to existing infrastructures inside a refinery for instance. It can then sweep out a "tent" of laser light. Any fugitive emissions from underneath the "tent" could then be quantified.

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Summary

The Benefits of having EDAR as your Remote Sensing Device:

- No Calibrations/Unmanned
- Multi-lane deployment
- High sensitivity and accuracy
- Small foot print/stealthy
- Operates 24/7

The Results are:

- Capture High Emitters that avoid garage testing
- Helps eliminates fraud
- Vehicle emission data collected in a natural driving environment
- Eliminates time requirement and frustration for consumers

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Acknowledgments

ERG:

- Sandeep Kishan
- Tim DeFries

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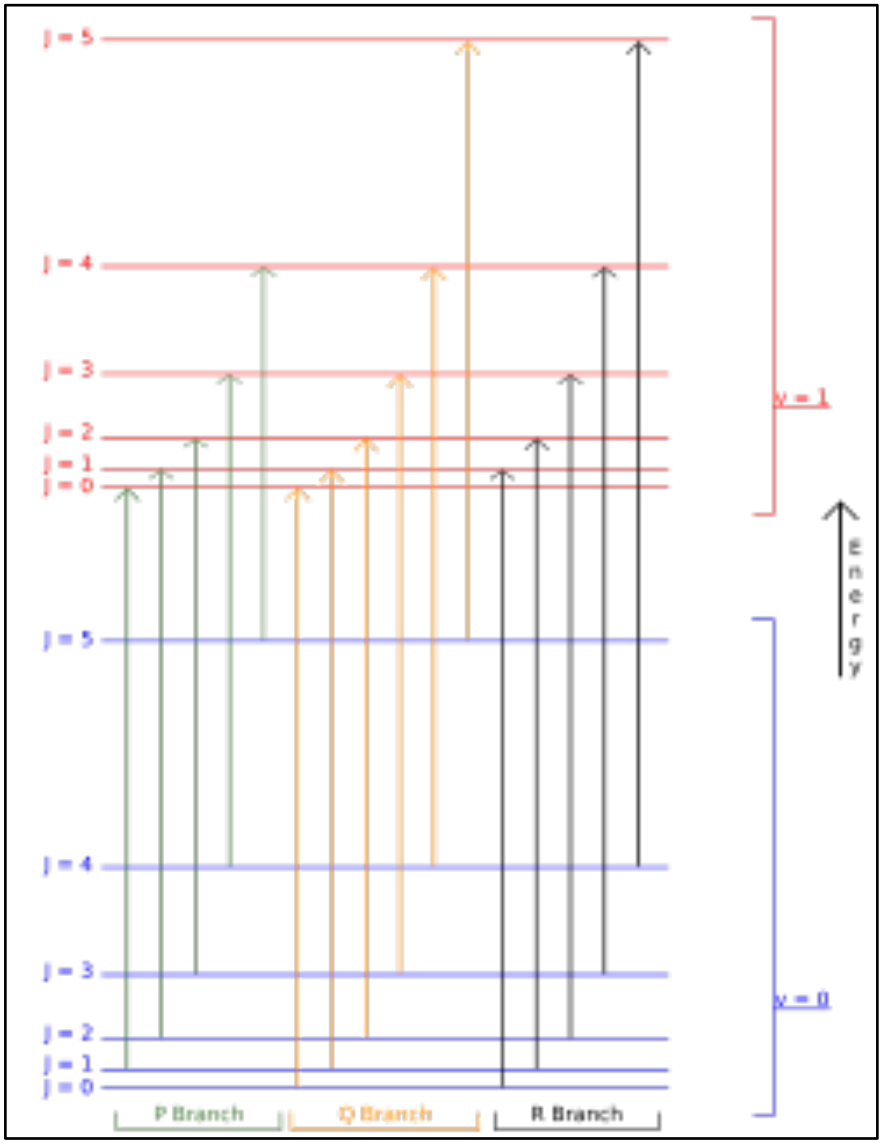
- Carl Fulper
- Connie Hart
- Jim Warila

CDPHE:

- Jim Sidebottom
- Jim Kemper



This is the foundation of our measurements, ro-vibrational quantum mechanics.

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Thank you for your attention

Questions?