IAGT Industrial Application of Gas Turbines

# IAGT 2015 SYMPOSIUM

www.iagtcommittee.com ——— Oct 19-21, 2015, Banff, Alberta

# Stack Emissions Monitoring Using Short Range Stand-Off Active Optical Sensing

A collaboration between TransCanada and INO

A R&D project for non-intrusive optical detection and quantification of natural gas pipeline compressor station exhaust stack emissions

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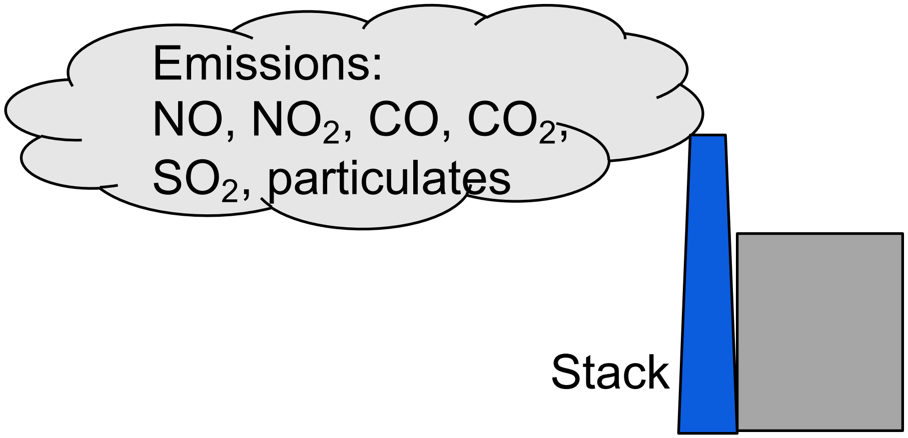
Presented at the 2015 Symposium on Industrial Application of Gas Turbines (IAGT)
Banff, Alberta, Canada - October 2015

# What?

- The emissions of interest are the amount of NOx (NO + $NO_2$ + $N_2O$) (tons per year), and somewhere down the line CO, $CO_2$ (and potentially $SO_2$) along with particulates (PM10 and PM2.5).



# Why stand-off monitoring?

- Be able to measure on most stacks, even the more remote ones and those without sampling ports.
- Monitor with minimal disturbance to operations.
- The R&D project seeks to show that some measurements can be done from a distance with optical techniques.
- The question is: Which optical technique or mix of techniques is the best?

# How?

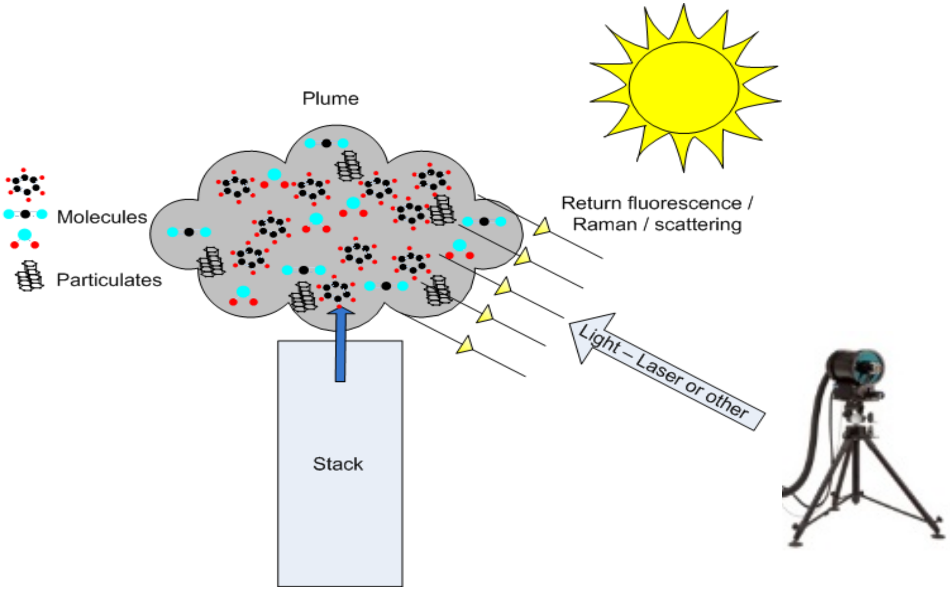
- As with many of the approaches using measurement ports to sample the exhaust:

**with optical techniques**

- But from a safe stand-off distance, without scaffolding or sampling ports
- While operations are ongoing
- ***Shining light on the exhaust plume, as close as possible to the exit***

# How? (cont.)

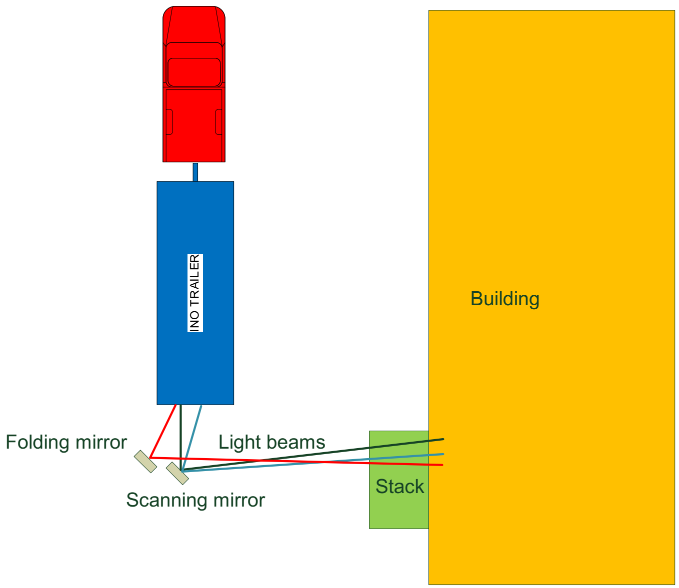
- Measuring light coming back from the exhaust through optical phenomena such as fluorescence, Raman or backscattering off molecules and particulates
- The end goal is a small and lightweight unit



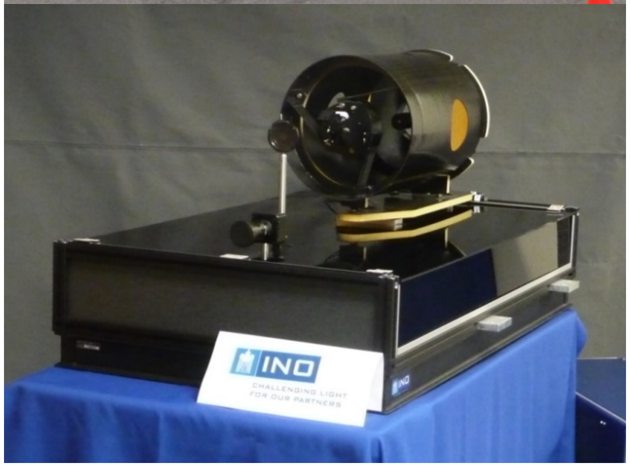
# Species Tunable Deep-UV LiDAR System

## Spatially Resolved Fluorescence, Raman and Absorption

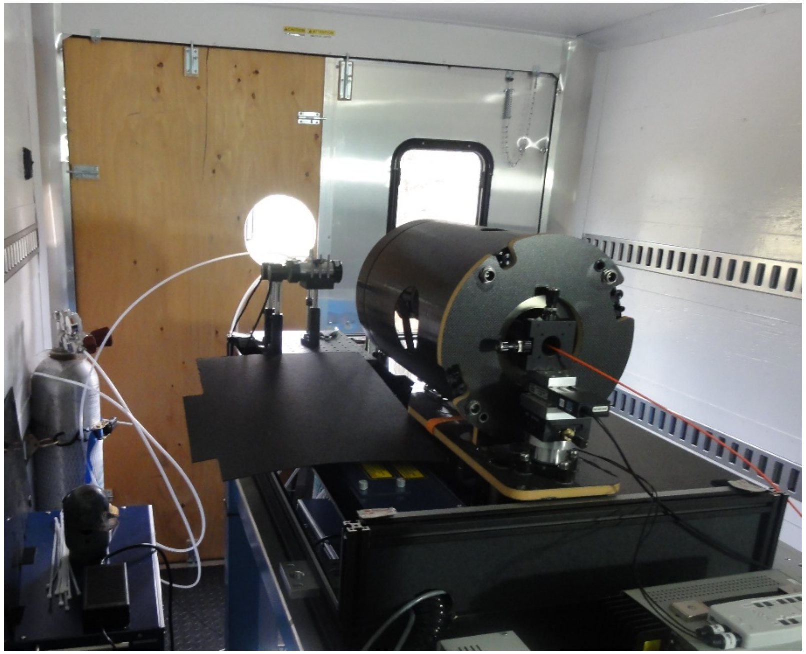
- Detection of specific molecules
- Multi-purpose systems







# Testing with mock-up stacks



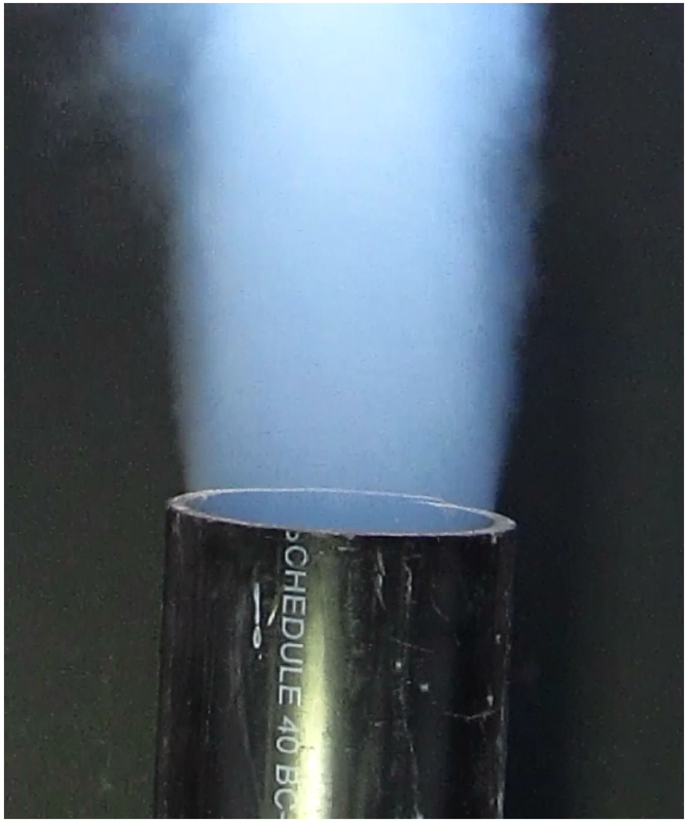
UV DiAL breadboard prototype in mobile laboratory

Ambient temperature mock-up exhaust stack and gas bottles

Propane burner used in the outdoors campaign

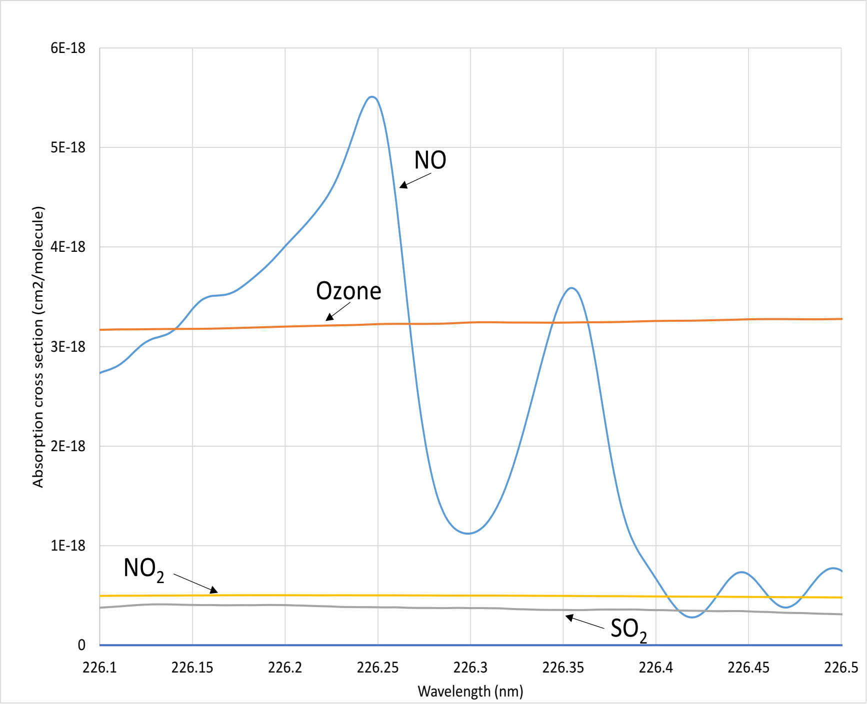
# Uniformity of stack gas output close to exit

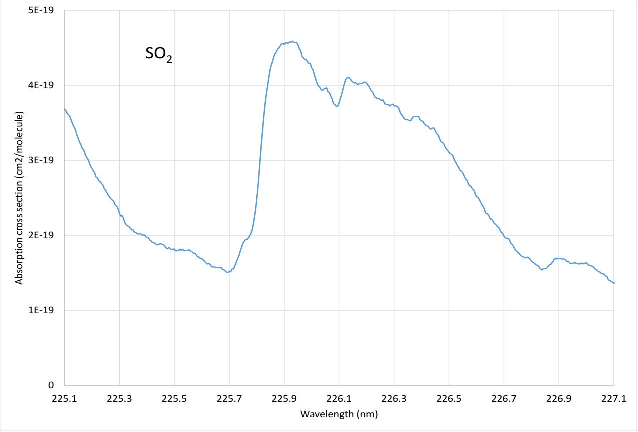
Fumes outputted from the mock-up stack at ~5 m/s

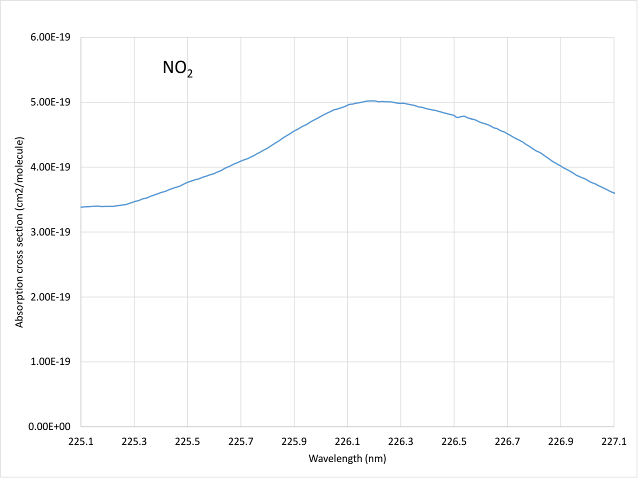


# UV – Differential Absorption

Laser light illuminates NO molecules – The laser emitter/receiver is “tuned” to NO -- NO absorbs the laser light – A unique signature



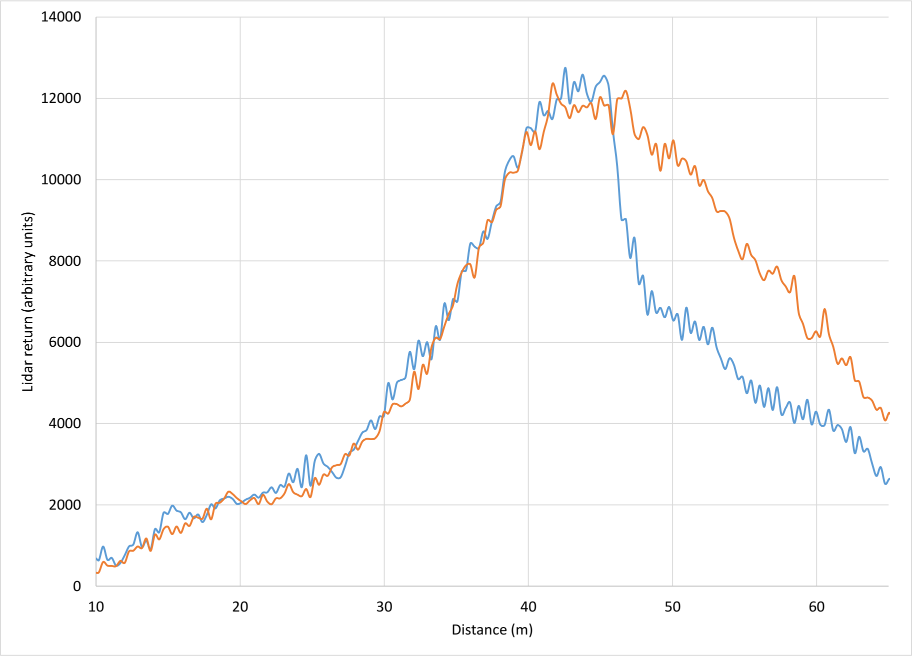




Absorption spectra of NO, ozone, oxygen, $NO_2$ and $SO_2$ around 226 nm

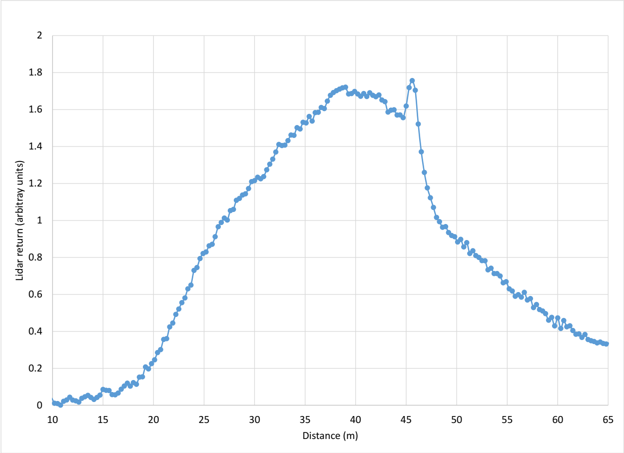
# UV – Differential Absorption LiDAR

- Differential decrease in backscatter signal strength with distance along the line of sight determines amount of NO in the atmospheric volume being sampled.
- Backscattering of laser light in the deep UV generates strong returns.
- The LiDAR system can be “tuned” to another molecule.
- The challenge is in designing user friendly systems

# UV – Differential Absorption LiDAR



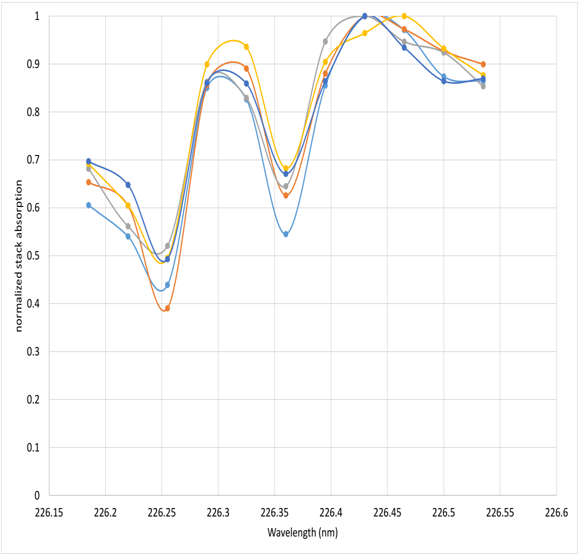

LiDAR return curves for NO in the mock-up exhaust stack without interfering fluorescence with and without absorption



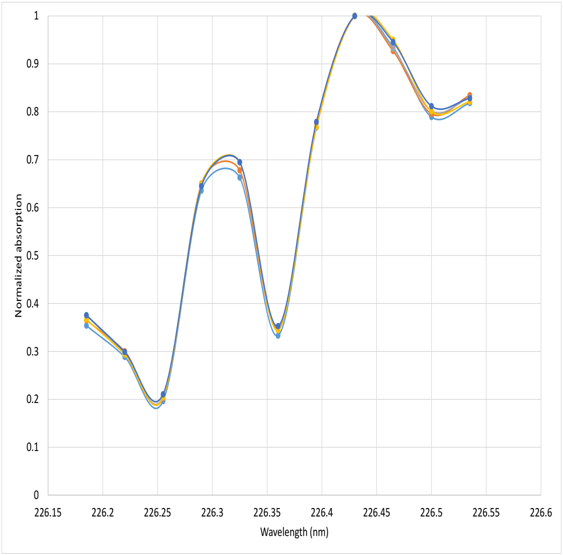

LiDAR return curve with distance. With fluorescence and absorption by NO

System spatial resolution ~ 1 m
Stack diameter : 0.1 m

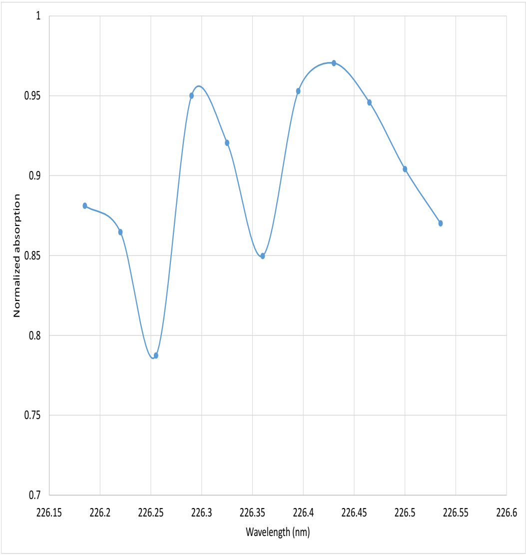
# UV – Differential Absorption LiDAR




Repeatability of exhaust stack transmission spectra of NO at 114 ppm-m (200 pulses per point)




Repeatability of reference cell spectra of NO




Average UV DiAL transmission spectrum of NO at ~24 ppm-m and 18.3 minutes measurement time

# UV – Differential Absorption LiDAR (cont.)

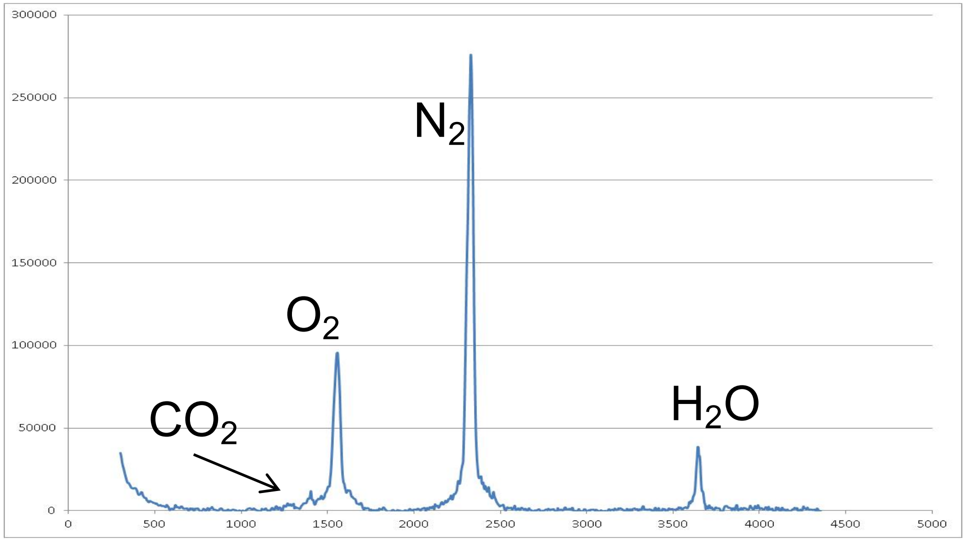
| | Expected (ppm-m) | Measured average (ppm-m) | Standard deviation |
|---|---|---|---|
| Concentration 1 | 116 | 111.5 | 15.4 |
| Concentration 2 | 52 | 40.4 | 3.5 |
| Concentration 3 | 23 | 20.3 | 3.8 |

Results from three sets of scans at different concentrations

# Non Resonant UV Enhanced Raman

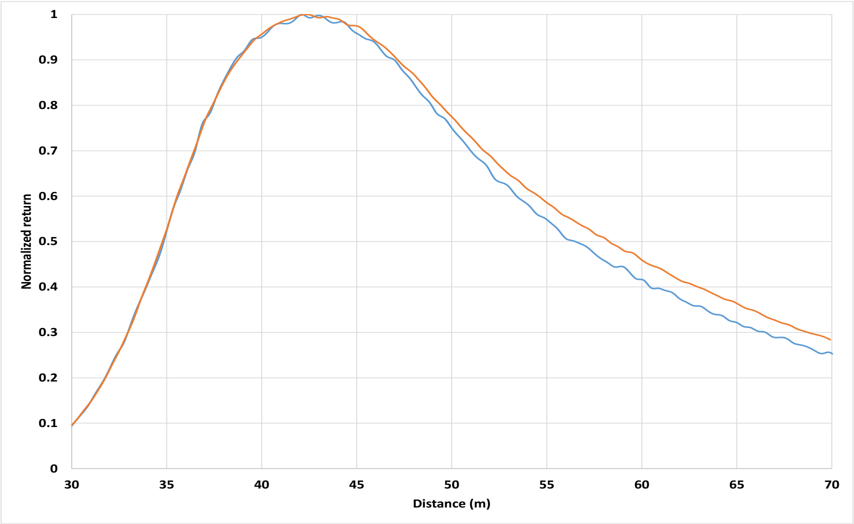
Any laser wavelength -- Molecules respond by emitting well defined spectral lines– A unique signature -- The receiver is “tuned” to a particular molecule

- Strength with respect to $N_2$ of the signal determines amount of molecules in the atmospheric volume being sampled
- Raman generates very weak returns for a given emitter strength
- The LiDAR system can be “tuned” to any high concentration molecule
- The challenge is in designing user friendly systems

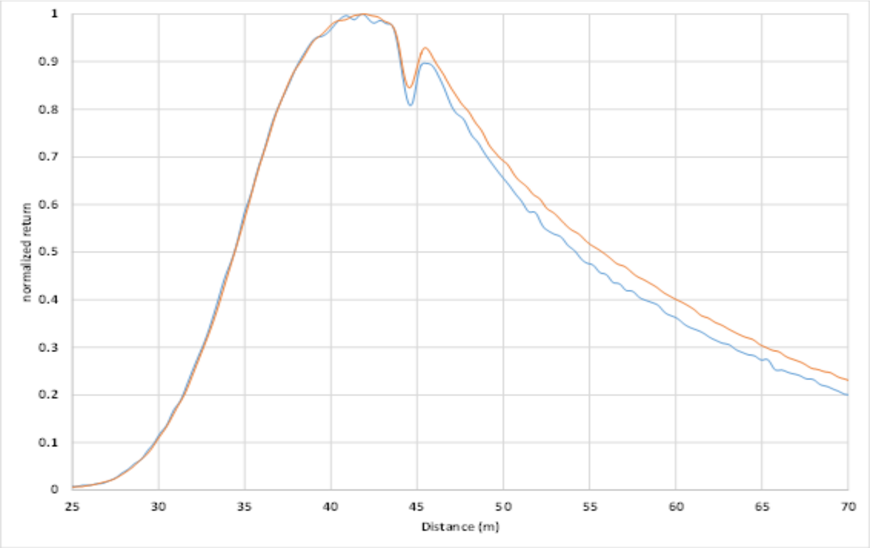



*Raman signatures*

# $O_2/N_2$ from Raman results on propane burner

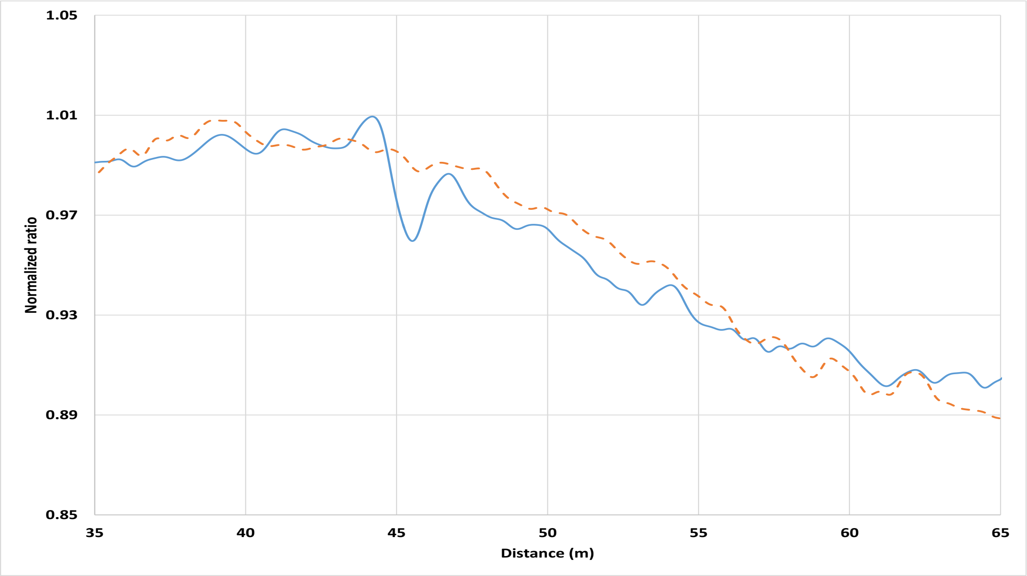



Raman LiDAR return curves of $N_2$ and $O_2$ without propane burner




LiDAR return curves of $O_2$ and $N_2$ with propane burner « ON »

# $O_2/N_2$ from Raman results on propane burner (cont.)




Raman intensity ratio of $O_2$ over $N_2$ with respect to distance

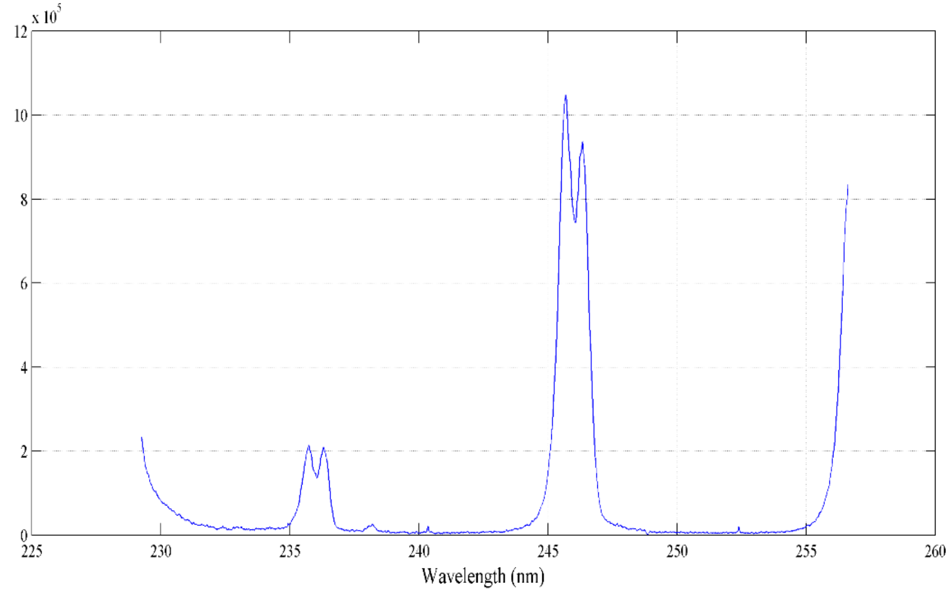
Spatial resolution ~ 1m
Stack diameter ~ 0.29 m
Drop in $O_2$ ~ 3 % ± 1.8 % (± 3σ)
Actual drop ~10%

18.3 minutes (8000 laser pulses)

# UV-Fluorescence (Resonant) System

The laser is "tuned" to NO -- NO responds by emitting a well defined unique spectral signature -- The receiver is "tuned" to NO

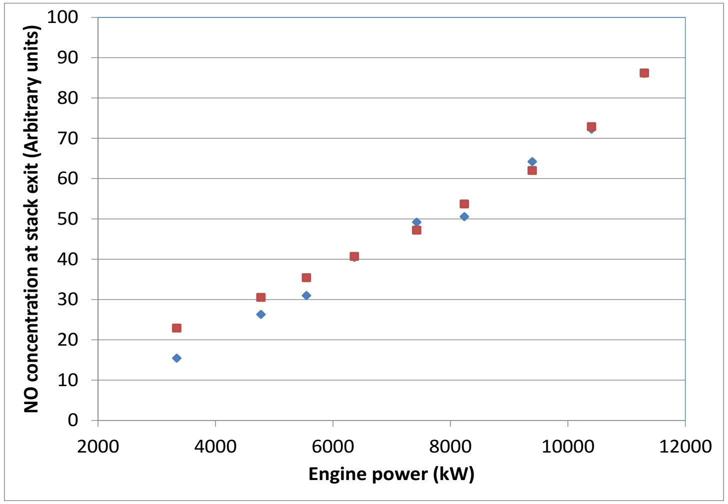
- Signal strength determines amount of NO in the atmospheric volume being sampled
- Fluorescence generates strong returns from NO for a given emitter strength
- The LiDAR system can be "tuned" to another fluorescing molecule
- The challenge is in calibrating the measurement and in designing user friendly systems




*NO fluorescence signature*
*Excitation at 226 nm (~13 mW)*

In *field trials,* Fluorescence has been proven very sensitive for the detection of NO

# UV-Fluorescence field results




Calibrated fluorescence measurements
(100s per point and 5 m resolution)

$$n = -\frac{1}{\epsilon_\lambda}\left\{\frac{1}{L} ln\left(1 - \frac{1}{\emptyset}\frac{I_f}{I_0}\frac{O_0}{O_f}\right) + \sigma_{ext}\right\}$$

Practically → need absorption to get $\phi$ → So why measure fluorescence if absorption is measured?

# Referee measurements in field campaign

- Measurements done by independent stack tester
- NOx – Chemiluminescence
- Results somewhat similar for fluorescence (wet)
  - ➢ Discrepancy at lower concentrations
- For Raman → $O_2$, $CO_2$ and $H_2O$
- INO → Uncalibrated measurements
- Not enough SNR in INO measurements for comparing to stack tester results
  - ➢ System needs optimization

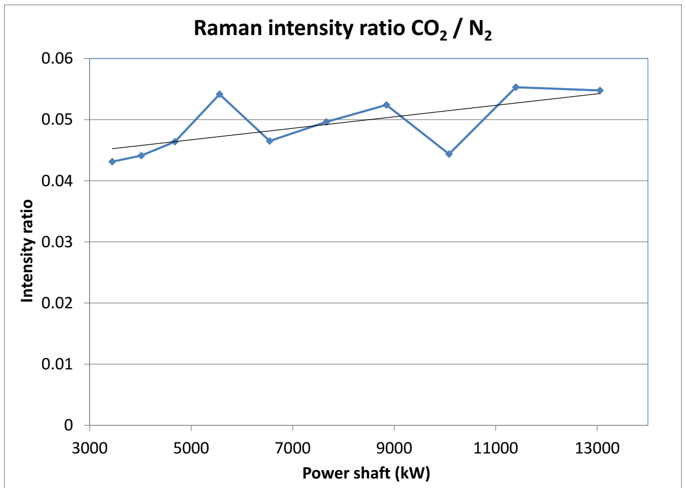
# Referee measurements in field campaign (cont.)

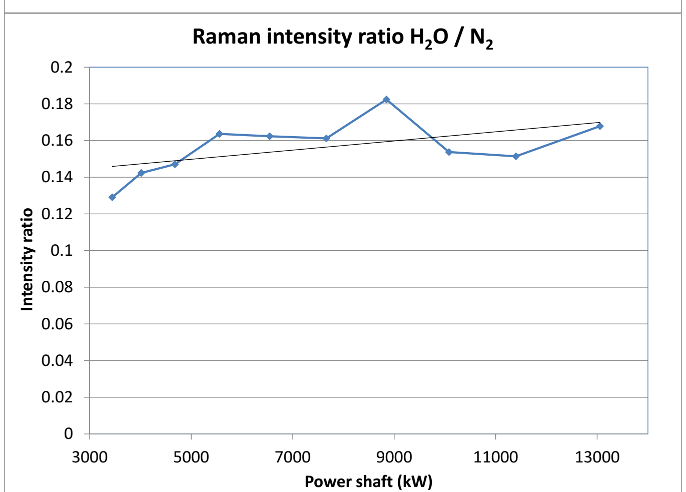
| | $H_2O$ | $O_2$ | $CO_2$ |
|---|---|---|---|
| Stack tester | 1.14 | 0.88 | 1.45 |
| INO | 1.2 | 0.99 | 1.19 |

Rise or fall factor during ramp-up

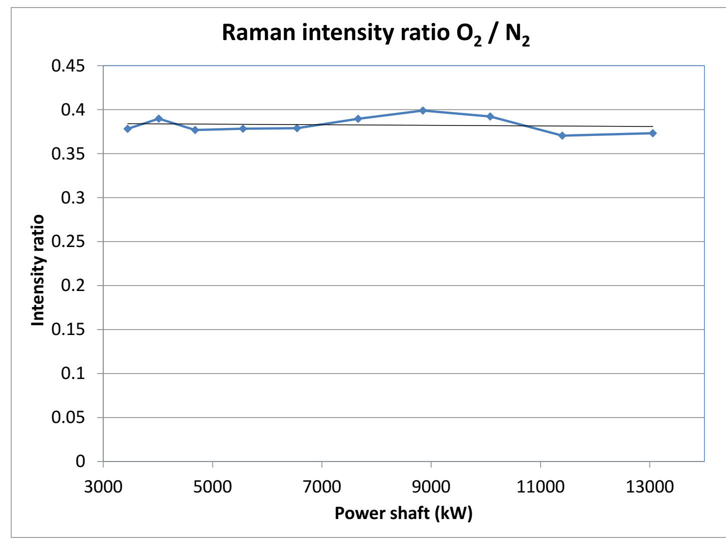
But spatial resolution too low
→ Effect of ambient air

# Results from Raman field measurements




Uncalibrated measurements
Excitation at 355 nm ~ 275 mW
Resolution ~ 5 m
200 s/point



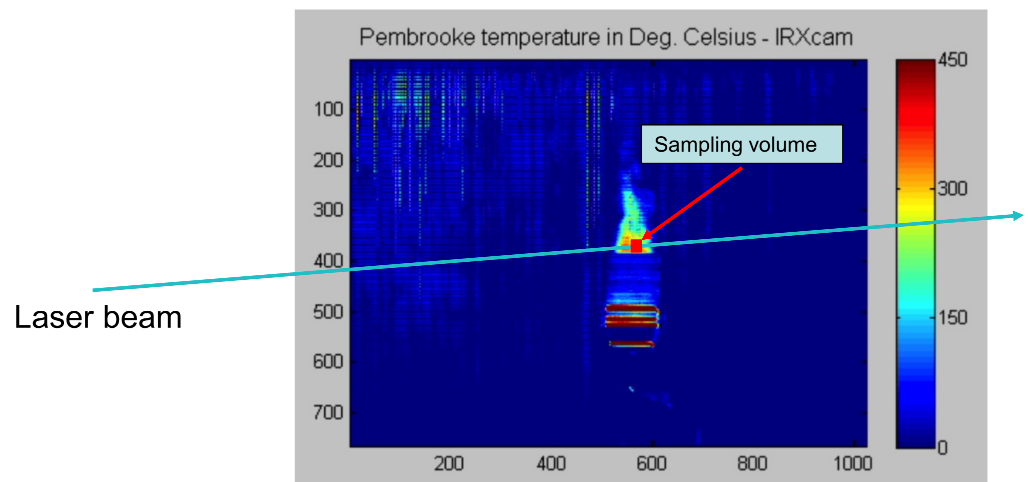

The idea was to show that it was possible to measure Raman returns from the exhaust plume

# What needs to be tackled?

- Our approaches remotely "interrogate" only a specific volume of space (the stack plume in this case)
- This is equivalent to sampling → But sampling is in the "wrong" place relative to the promulgated methods
- Requirement in promulgated methods is to measure at least one half diameter upstream of exhaust orifice
  - Velocity and concentration are to be measured in a plane verified as uniform ***inside*** the stack
- Is the flow laminar at the exit/outside stack? On how long a distance? What type of gradients are there?
  - What happens on very windy days?
- Volumetric flow rate must be measured; How? **Remotely**?
  - In promulgated methods; corrected gas velocity x stack cross-sectional area

# What needs to be tackled?

- Some form of scanning across the exhaust will probably be required to ascertain concentration uniformity across plume or measure size of exhaust plume in measurement plane



# Conclusions

- It is possible to detect molecules in exhaust stack plumes from a standoff distance of more than 40 m
- Using deep UV resonant absorption or fluorescence or both for NO
- It is possible to detect high concentration molecules by UV enhanced Raman
    - $CO_2$, $O_2$ and $H_2O$
- Open path sampling
- Long measurement times enhance sensitivity
- Resolutions down to 0.1 m are feasible with reduced sensitivity

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