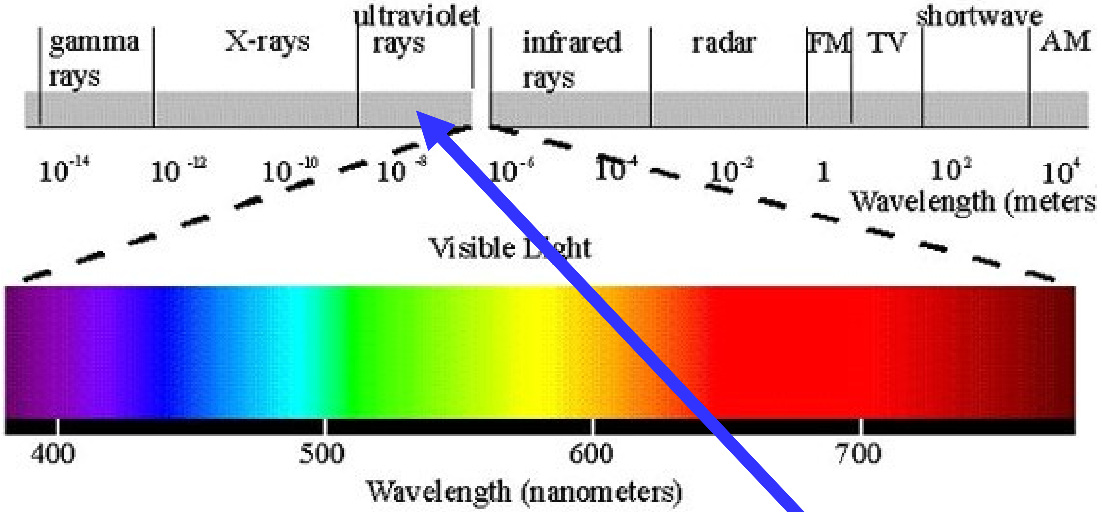
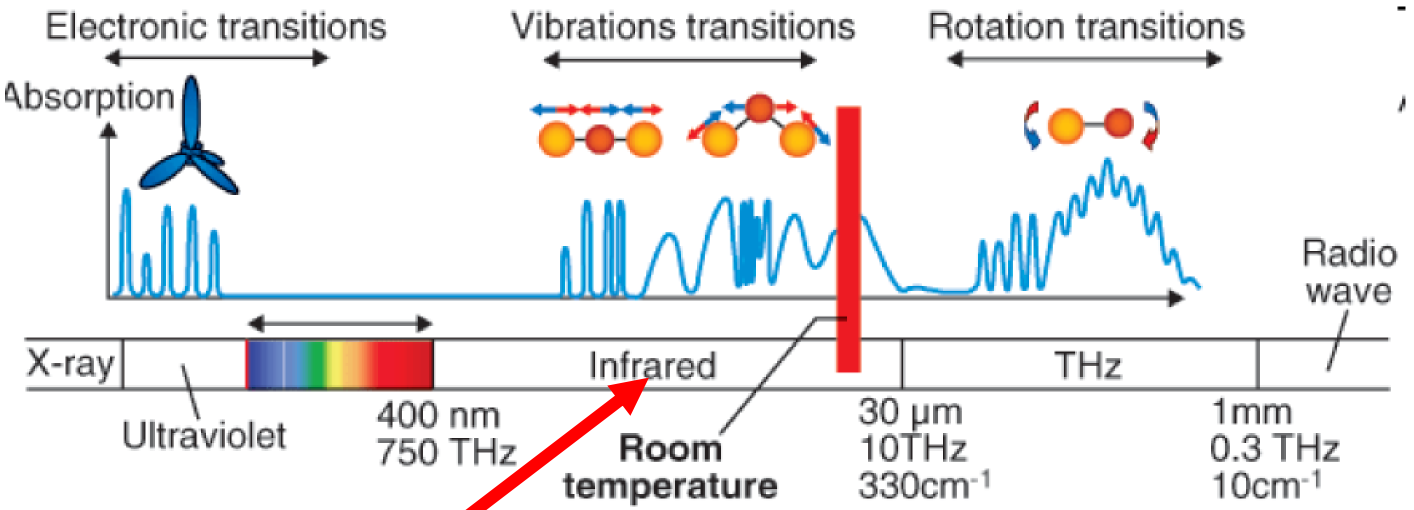
Dynamical temperature measurements for industrial applications

spectroscopy-based approach

Alexander Fateev, Senior Scientist
DTU Chemical Engineering, Denmark
alfa@kt.dtu.dk

1: Choice of spectral range:



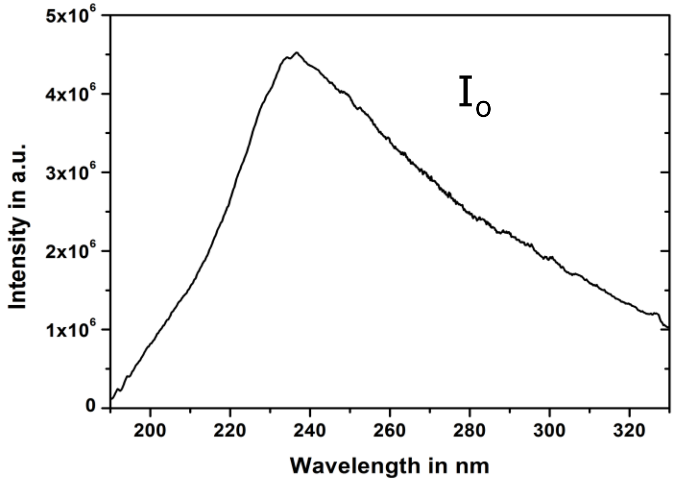


UV and IR

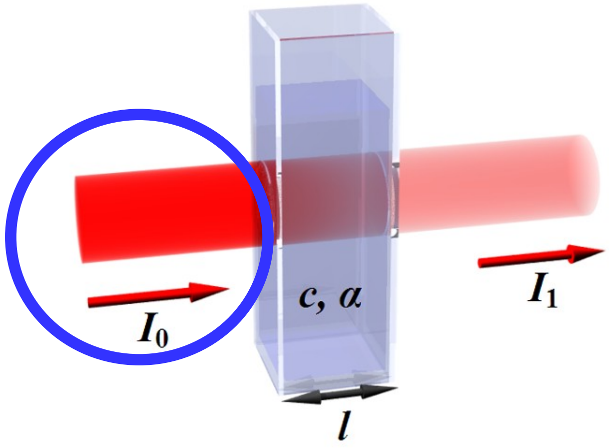
2: Choice of measurement approach:

Active or Passive

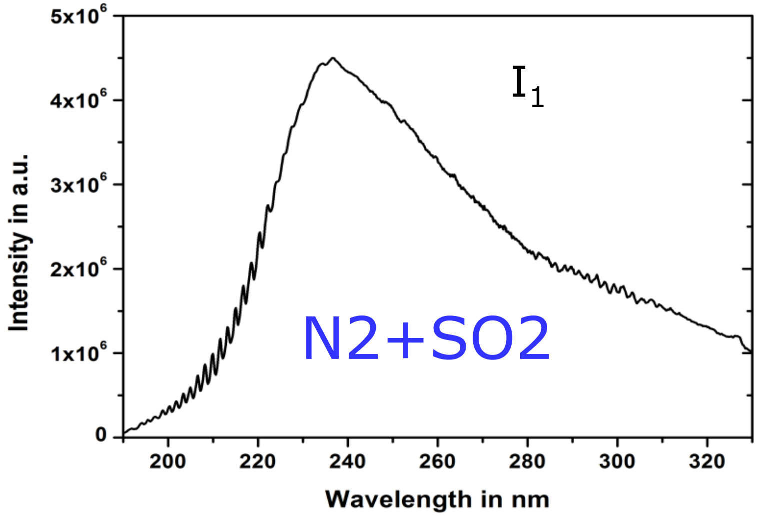
Spectrum w/o absorption

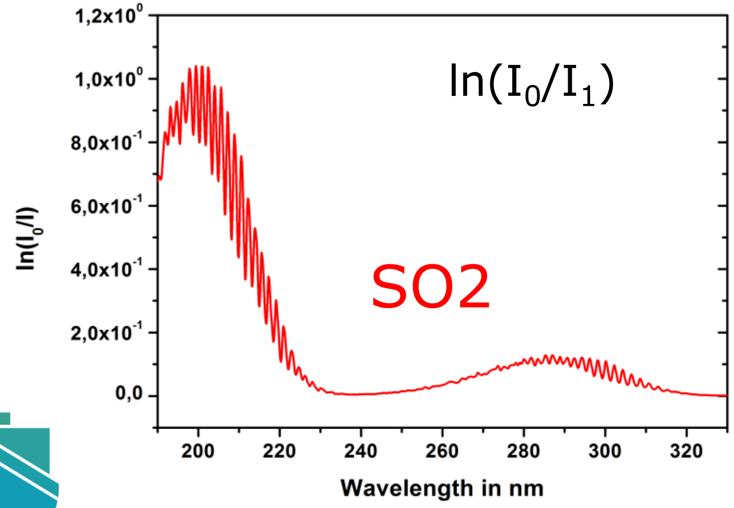


Lambert Beer Law



Spectrum with absorption





$$\frac{I_1}{I_0} = e^{-\alpha \cdot l} = e^{-\sigma \cdot N \cdot l}$$

$$\ln \frac{I_0}{I_1} = \sigma \cdot N \cdot l$$

σ: absorption cross-section (CS)
N: gas density

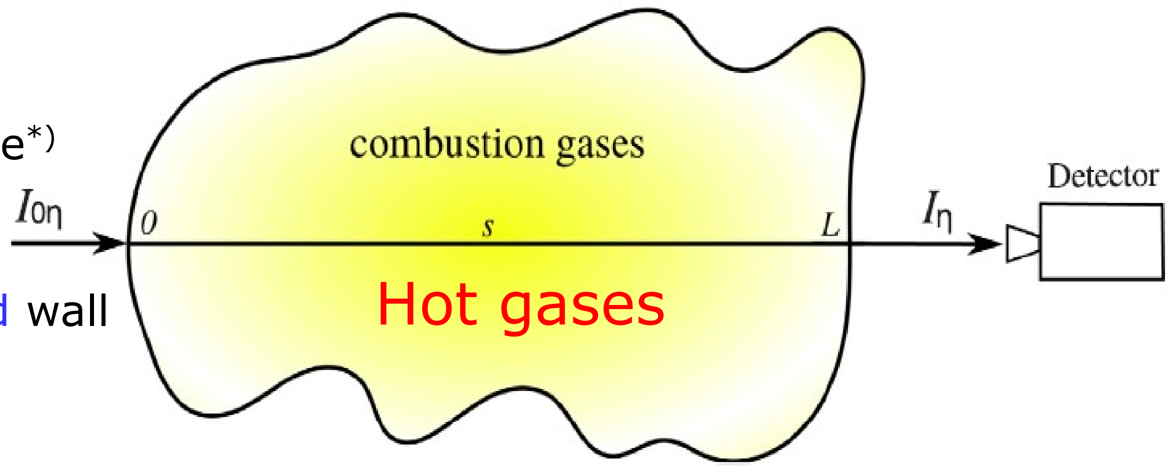
Need external light source!

Can be as Optical Gas Standard

Active approach: absorbance

(IR) source*)

*)hot or cold wall



Radiative Transfer in 1D uniform T case:

$$I_\eta(v) = L(v)\ \varepsilon(v)\ or$$

$$I_\eta(v) = L(v)\ (1 - \exp(-k(v)L)$$

- $L(v)$ is Planck's function
- $k(v)$ is an (molecular) absorption coefficient
- L dimention
- $\varepsilon(v)$ emissivity, if $\varepsilon(v) = 1$ then BB

No need for external light source!

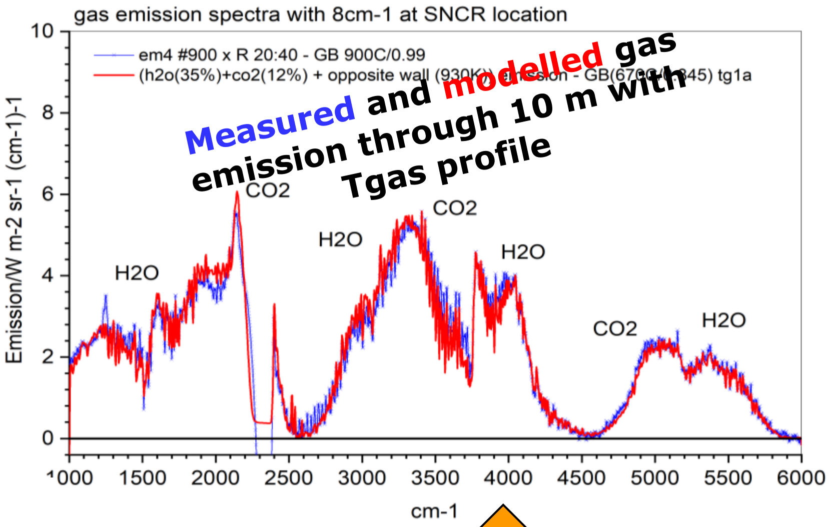
Medium = Source

<u>Need validation</u>

Passive approach: (IR) emission

Validation of HITEMP spectral database for IR spectra modelling (gas temperature retrievals)

International Journal of Thermophysics (2019) 40:99
https://doi.org/10.1007/s10765-019-2557-6

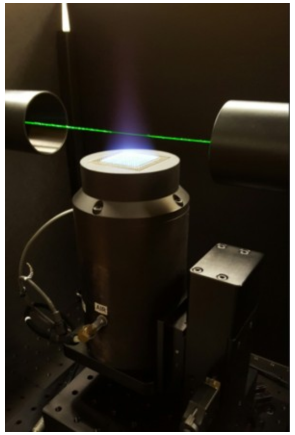


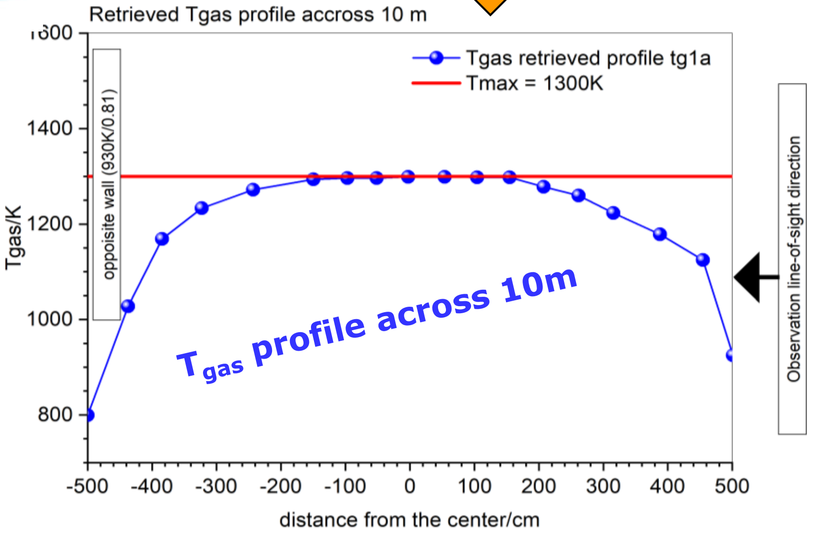
Validation of Emission Spectroscopy Gas Temperature Measurements Using a Standard Flame Traceable to the International Temperature Scale of 1990 (ITS-90)

Gavin Sutton[1] · Alexander Fateev[2] · Miguel A. Rodríguez-Conejo[3] · Juan Meléndez[3] · Guillermo Guarnizo[3]

Received: 30 November 2018 / Accepted: 9 October 2019

EMPRESS TEMPERATURE METROLOGY FOR PROCESS EFFICIENCY → EMPRESS 2 TEMPERATURE METROLOGY FOR PROCESS EFFICIENCY

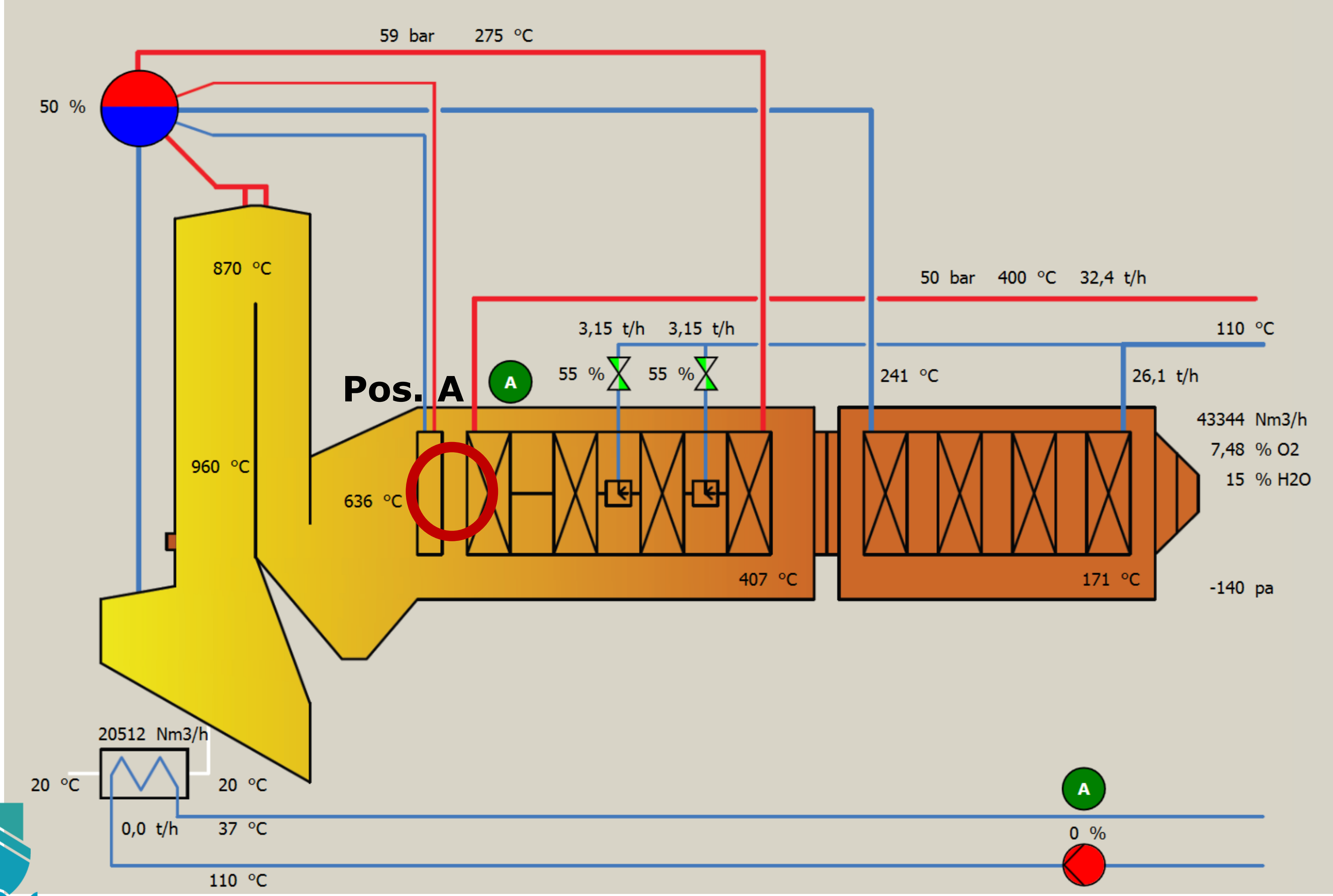




Passive approach: (IR) emission

Part A: Continuous In Situ Gas Temperature and Composition measurements in Hot Industrial Environments: Waste Incineration

Waste Incineration Plant: predictive corrosion project



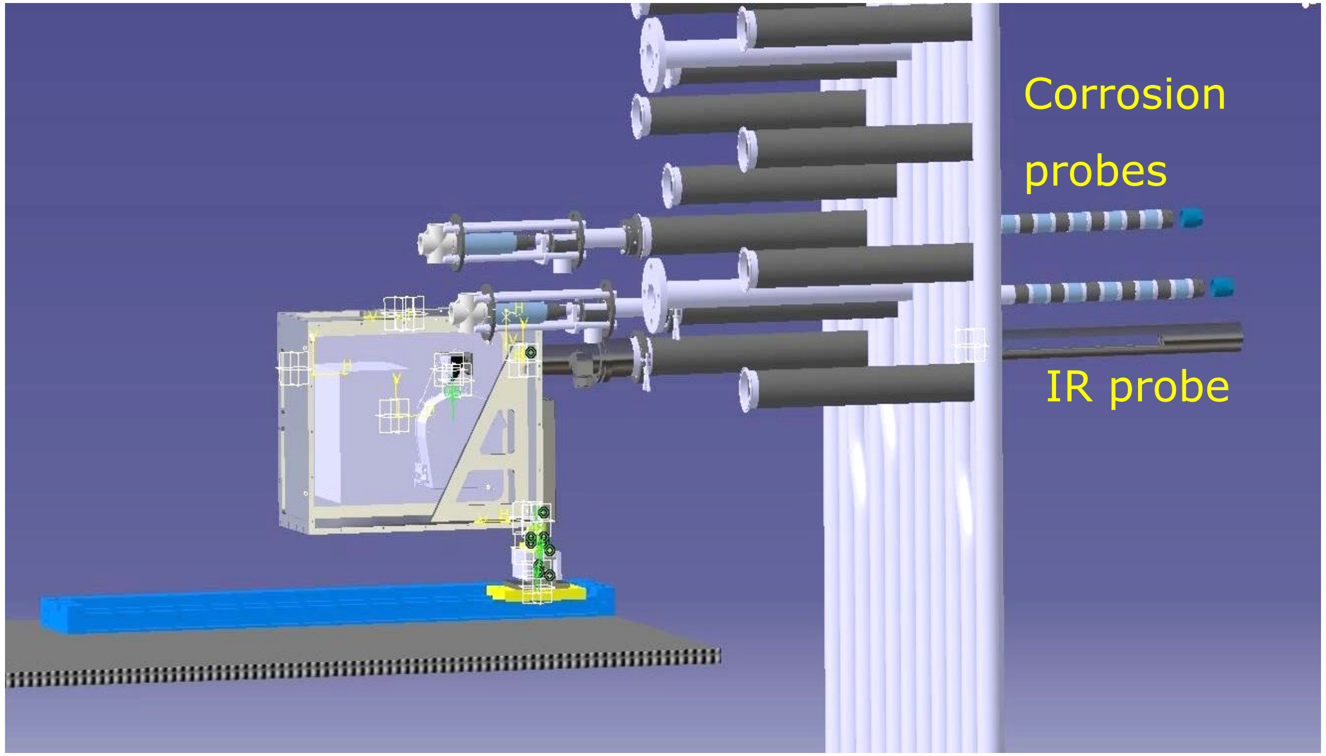
Pos. A:

- **after combustion chamber: in situ measurements with FTIR and UV probes**
- **Various corrosion probes**
- **24/7 gas temperature and gas composition**

In-situ measurements in hot and corrosive gas

- **FTIR (passive)** **and UV (active) probes** for **in-situ gas** measurements.
- Typically every 1 min data rate, 24/7.
- Probes are mounted on extraction system and can quickly be connected electrically to the control and data system.
- Direct measurement in hot gas (600-700^{o}C)

In-situ measurements in hot and corrosive gas

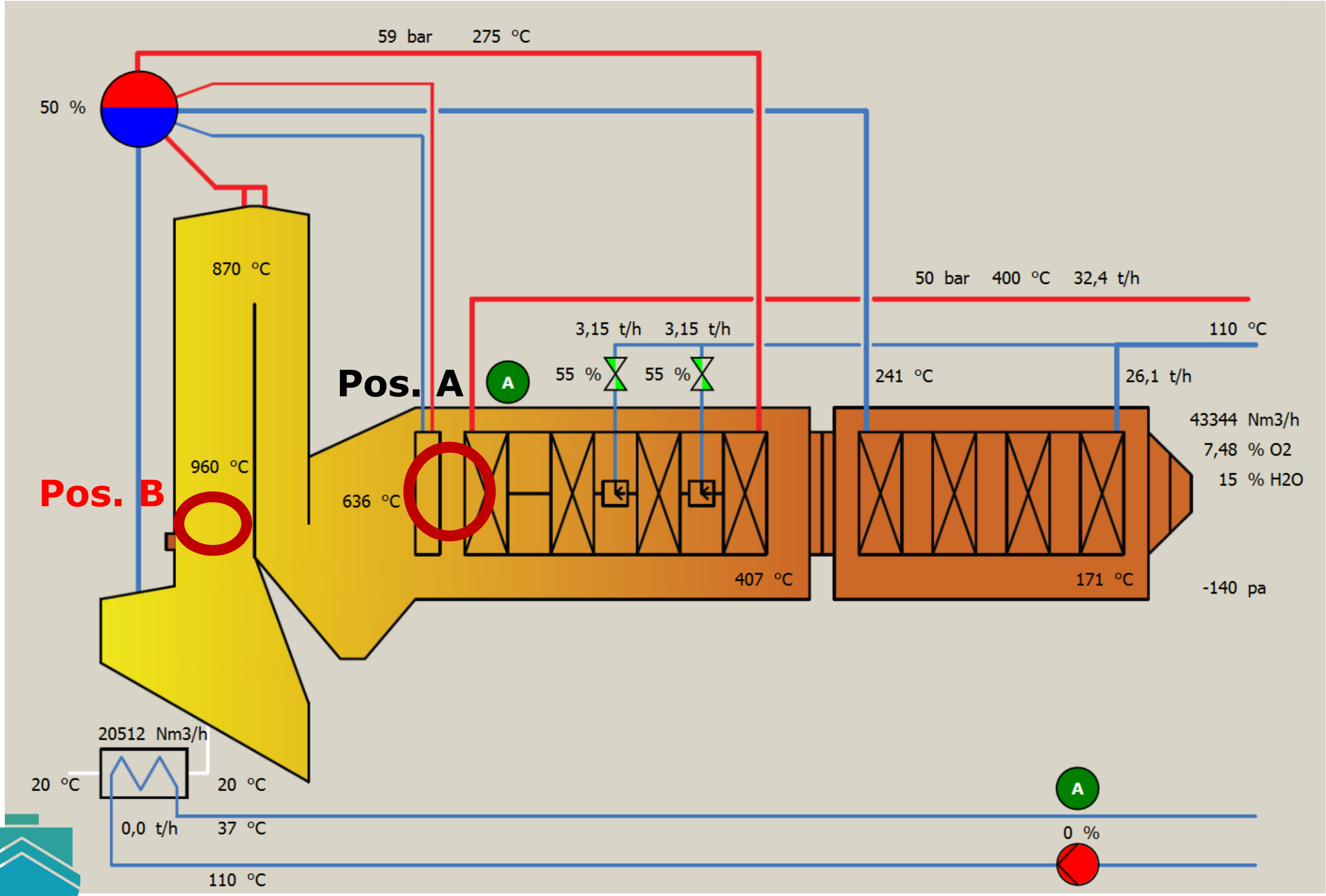


- Gas temperature is measured optically from the **thermal radiation** from the CO_2 band at 4.3 µm.
- Results have been verified by thermocouple measurements and suction pyrometer measurements.
- Pressure sensor used.

Corrosion probes: in-situ measurements

Large amount of fly ash on the probes after only **6 days in operation.**

Waste Incineration Plant: Independent B-measurements



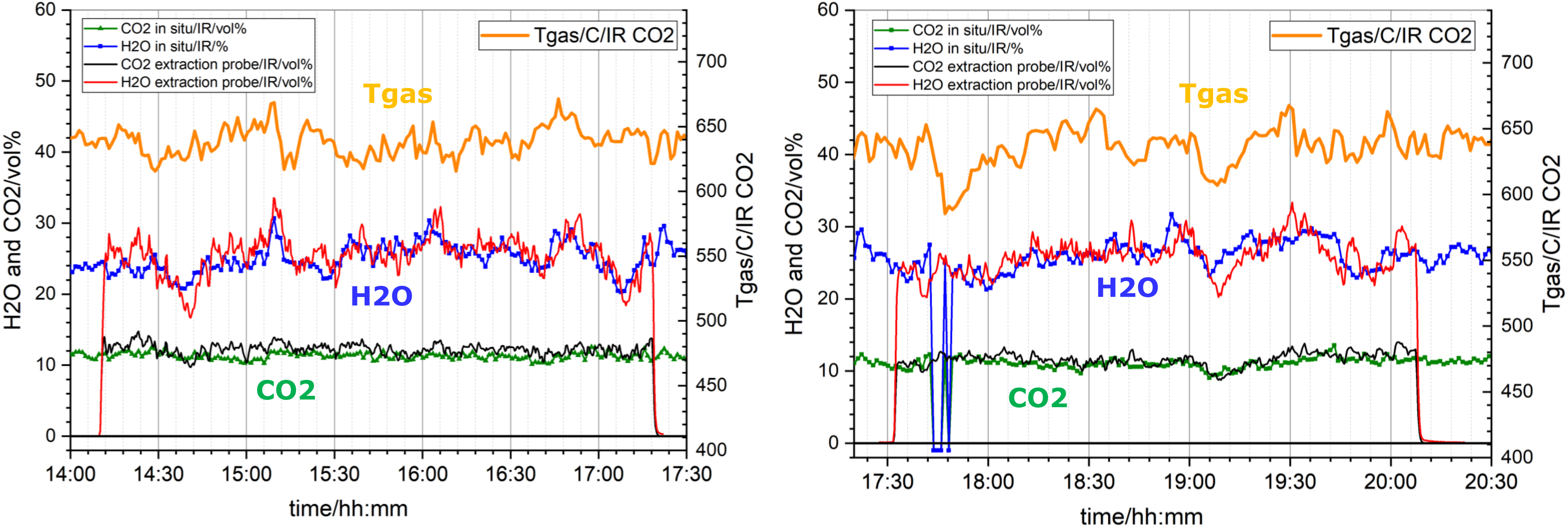
Pos. A:

- after combustion chamber: in situ measurements with FTIR and UV probes
- Various corrosion probes
- 24/7 gas temperature and gas composition

Pos. B:

- above grate, before SNCR: gas sampling with heated probe. point measurement in gas
- **Independent parallel measurement campaign**

In-situ measurements: Tgas, H_2O and CO_2

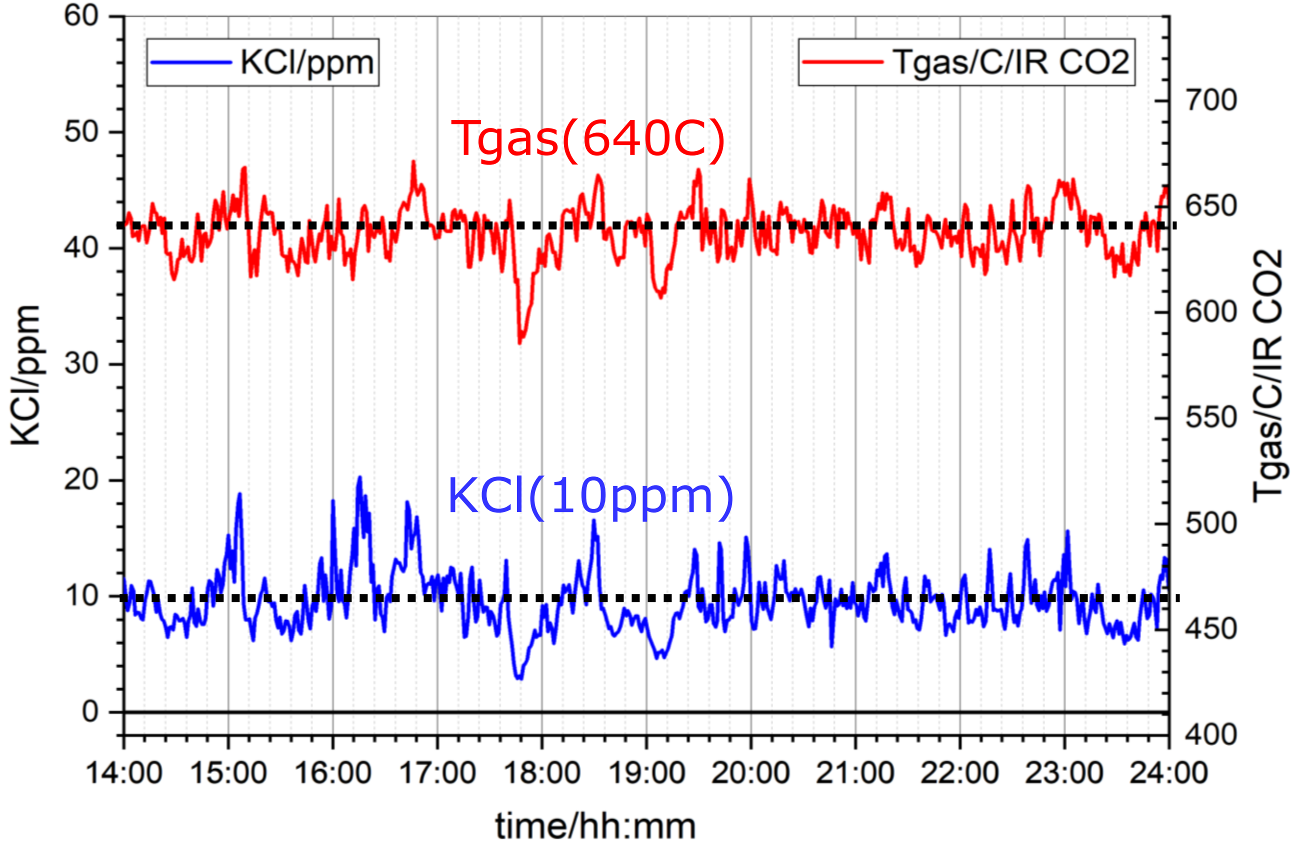


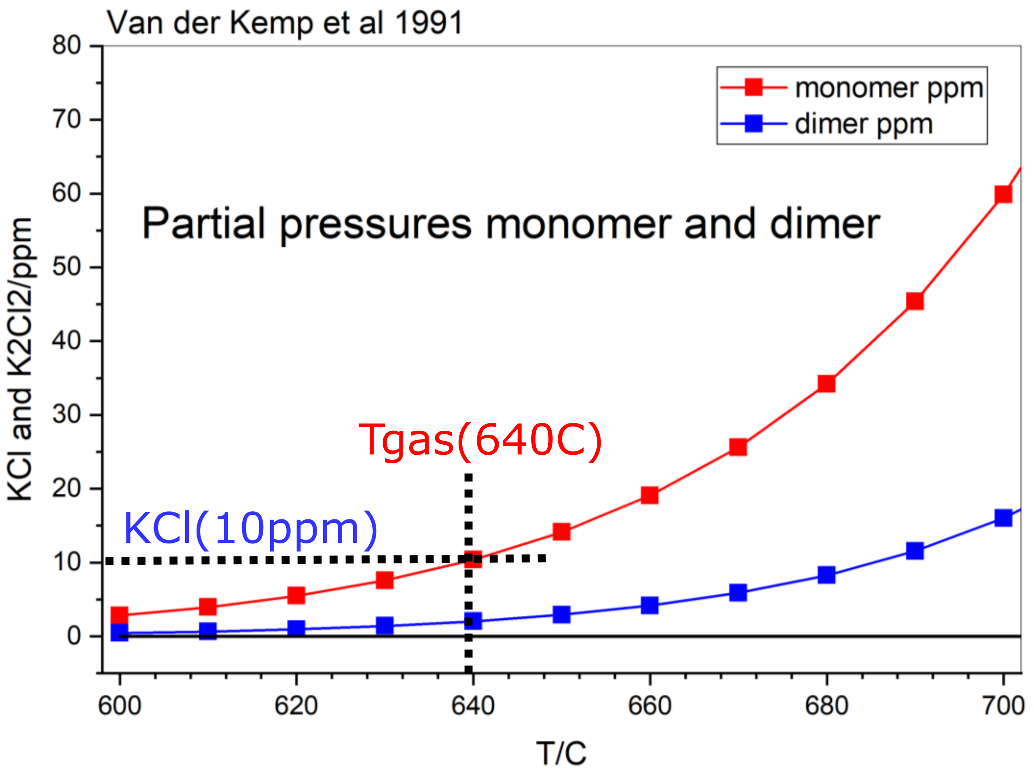
Pos. A (after combustion chamber, in-situ): olive (CO_2), blue (H_2O)

Pos. B (above grate, gas extraction): red (H_2O), black (CO_2)

Similar values & patterns for two different methods at different time slots

In-situ measurements: KCl and Tgas correlations

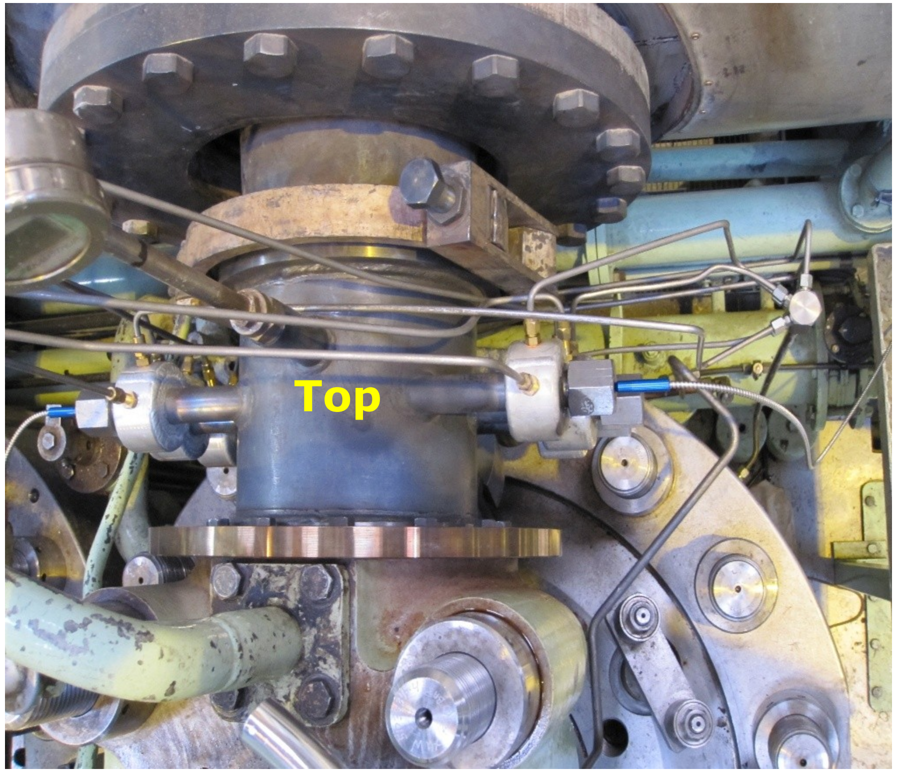


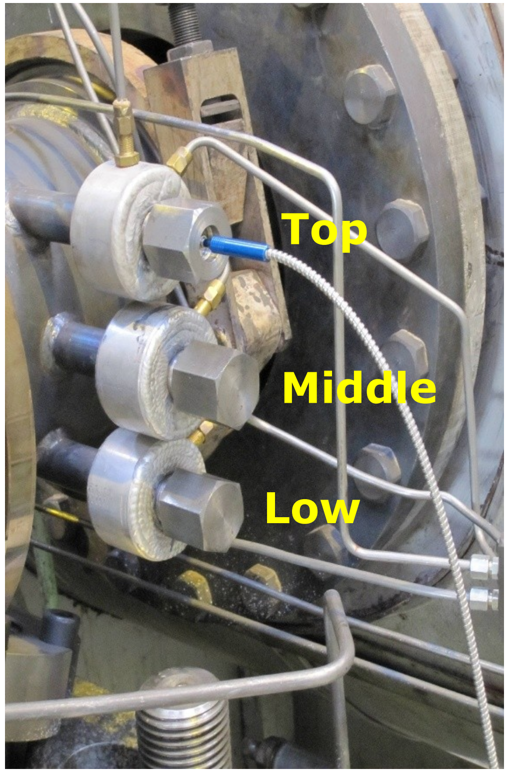


KCl (UV) concentration correlates with Tgas variations

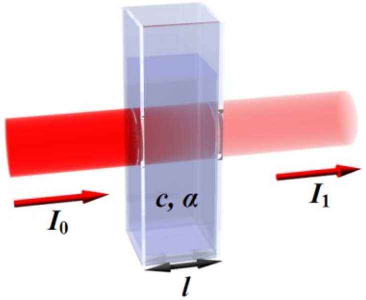
Part B: In Situ Gas Temperature and Composition Measurements: Marine Engine

In situ gas temperature and NO measurements on two strokes marine diesel engine

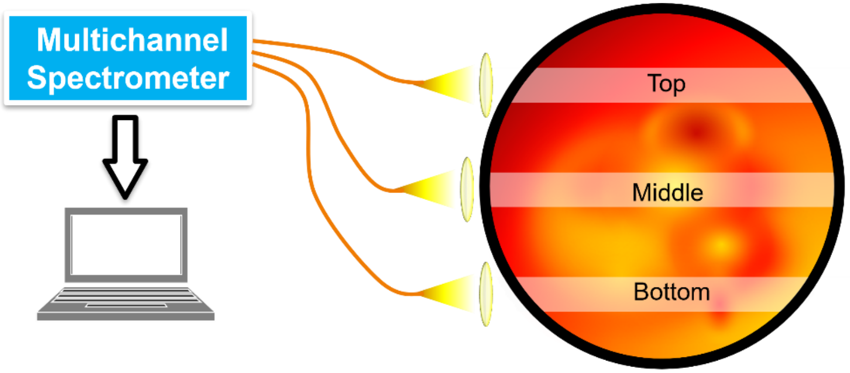




Active: UV absorbance (NO, 226 nm)

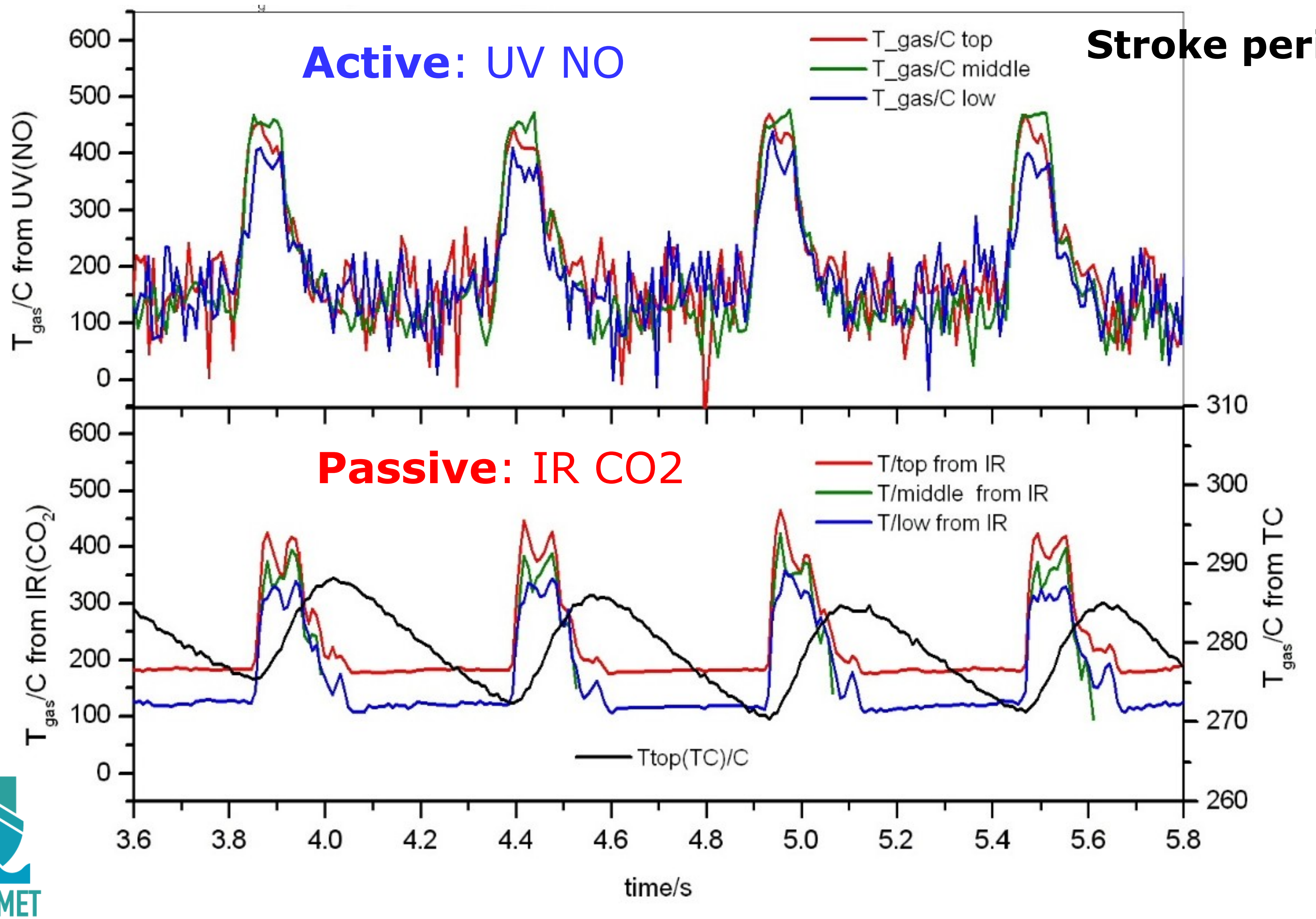


Passive: IR radiation (CO2, 4.3 μm)



Exhaust duct of a cylinder
(cross-section)

In situ Tgas from NO (UV) and CO_2 (IR)

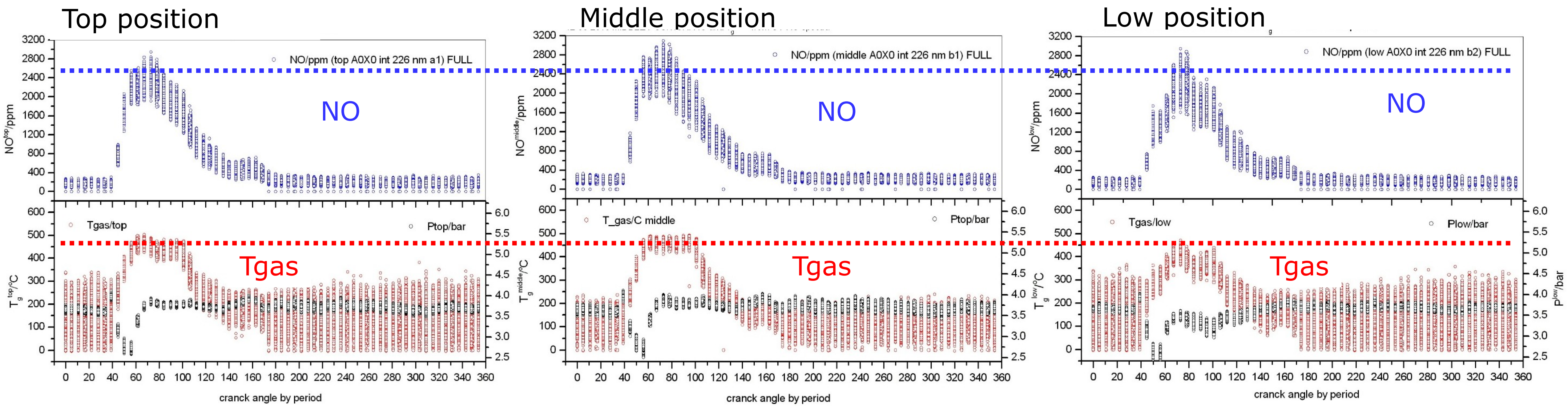


Stroke period=0.5376 s/1.9 Hz

- ❑ Correlations between Tgas*) from fast in situ UV(NO), IR(CO_2) optical
- ❑ Slow thermocouple measurements after cylinder
- ❑ Dilution by scavenge air

*) UV/IR measurements were not performed at the same time

In situ Tgas and NO from NO (UV): crank angle

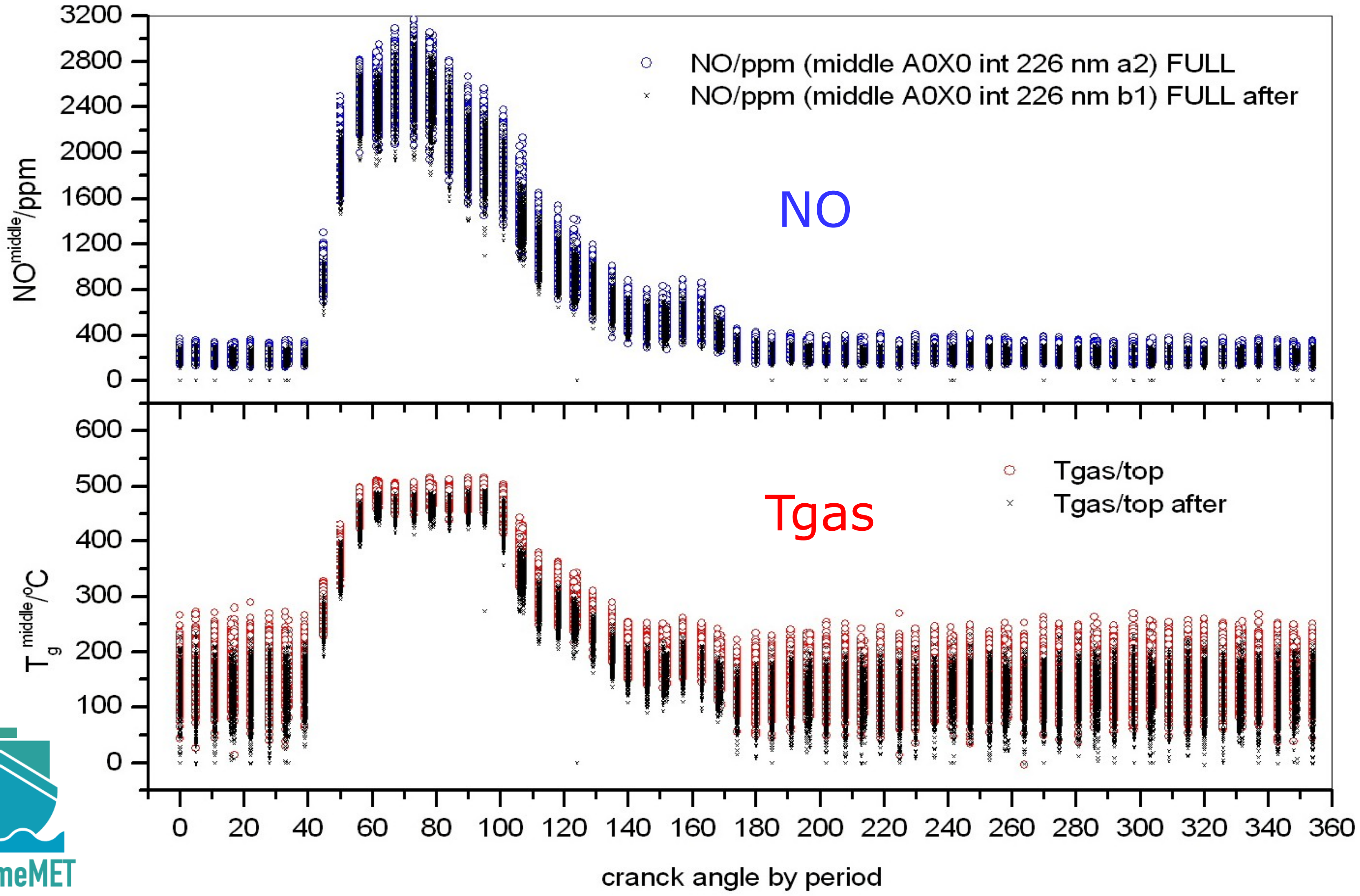


- ❑ Pressure and Temperature give NO mol fraction
- ❑ Temperature from NO(226nm) band structure
- ❑ Pressure from external (fast) p-sensor
- ❑ Quite uniform flow patterns (similar Tgas and NO distributions)

MaritimeMET

In situ Tgas and NO from NO (UV): repeatability

Middle position **BEFORE (a2)** and **AFTER (b1)** engine stop



- Two subsequent stop-go engine runs
- Small variations in NO and Tgas from run-to-run engine operation

Summary:

- Spectroscopy is a right choice for in situ gas T-measurements (and gas composition)
- Active or passive measurements with high time-resolution are possible
- Passive approach is best suitable for gas temperature profiles retrievals (gas slabs with T-gradients)
- Active approach is best suitable for an "effective" gas temperature measurements
- Molecules such as e.g. CO_2, H_2O and NO can serve as temperature sensors
- MaritimeMET: p-measurements (in addition to T-) with spectroscopy-based approaches are under development

Acknowledgements:

PCMS project 64018-0016 funded by ForskEL/EUDP

HERCULES-B project SCP7-GA-217878 funded under EU 7th Framework Program "Sustainable Surface Transport"

These projects have received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

The project 23IND09 MaritimeMET has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

Thank you for your attention

Alexander Fateev, Senior Scientist
DTU Chemical Engineering, Denmark
alfa@kt.dtu.dk

MaritimeMET