Online optical measurements in hot gas flow

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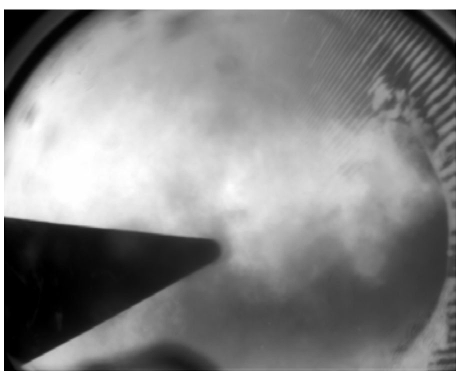
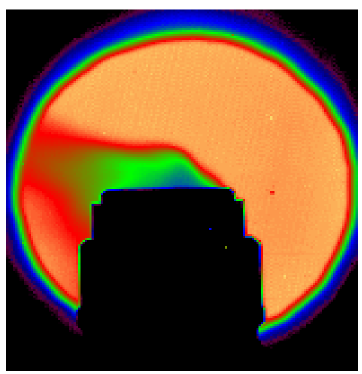
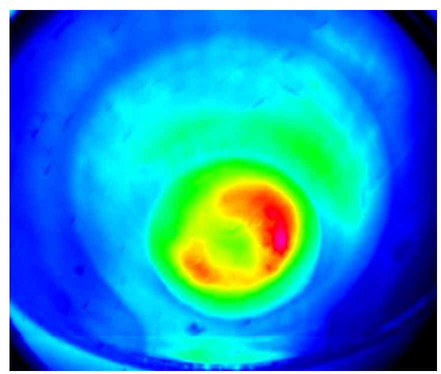


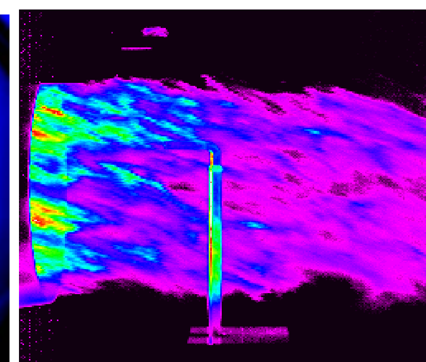
Large scale flame



Leak valve bottle



Ship engine



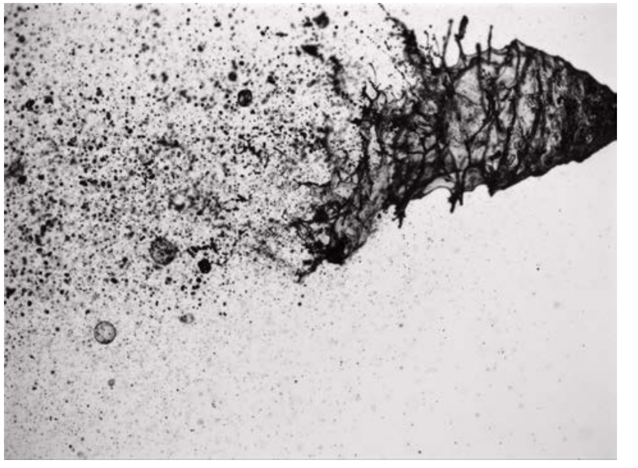
Exhaust air craft engine

Optical measurements at DTU KT

Laboratory & Full scale

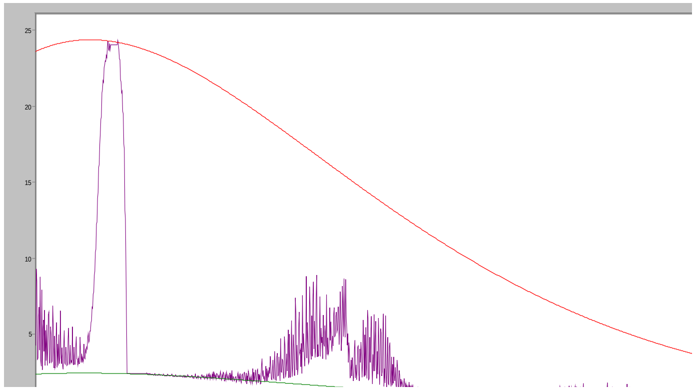
- Gas temperature
- Gas composition
- Gas velocity and mixing
- Particle concentration and size
- Thermal heat exchange, spectral emissivity
- Fuel properties, burning value
- Imaging

- Your application?



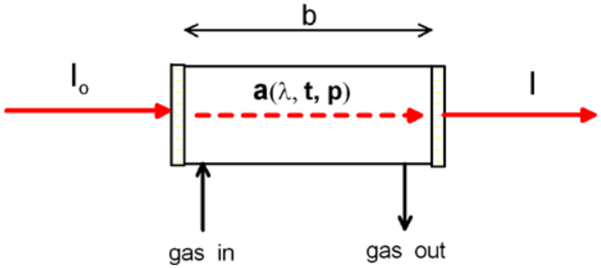
Optical measurement principles

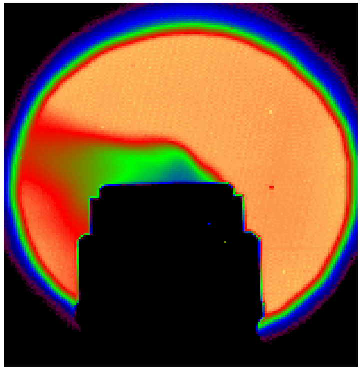
- **Passive measurement**
  (no active light source, one port)



- **Absorption measurement**
  (light source, two ports)

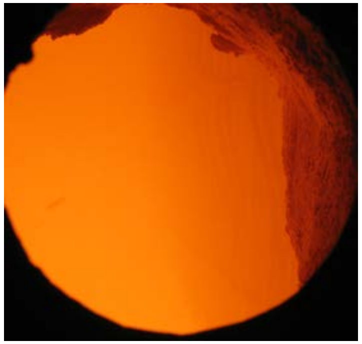
$$I = I_o e^{-abc}$$



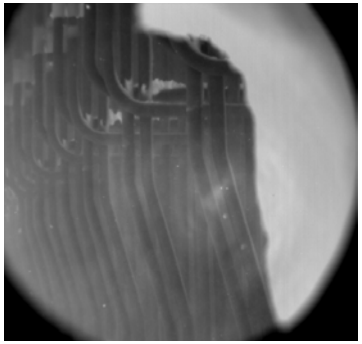


- **Spectral range 120 nm – 250 µm**

UV: NO, SO_2, KCl, OH, tar, ..
IR: H_2O, CO, CO_2, C_xH_y, HCl, SO_3,..



VIS



IR

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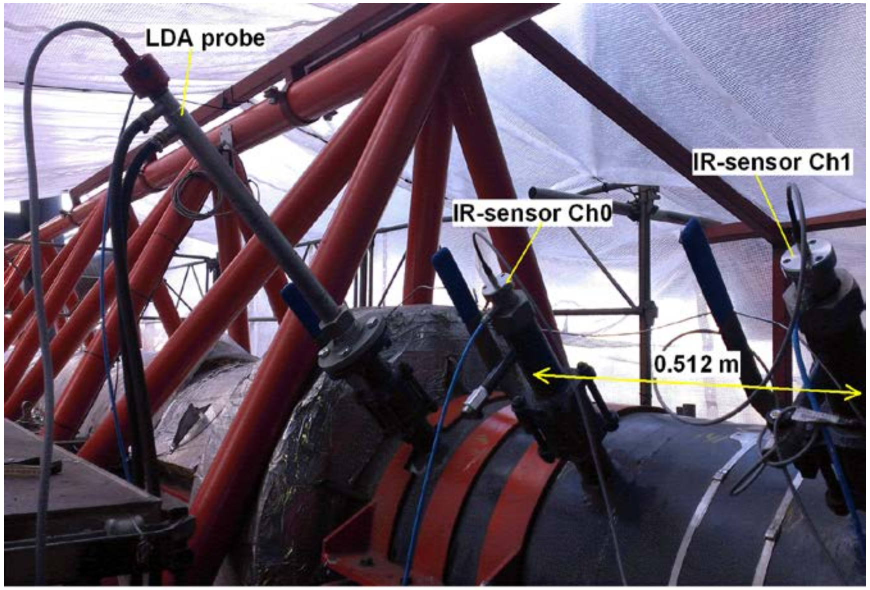
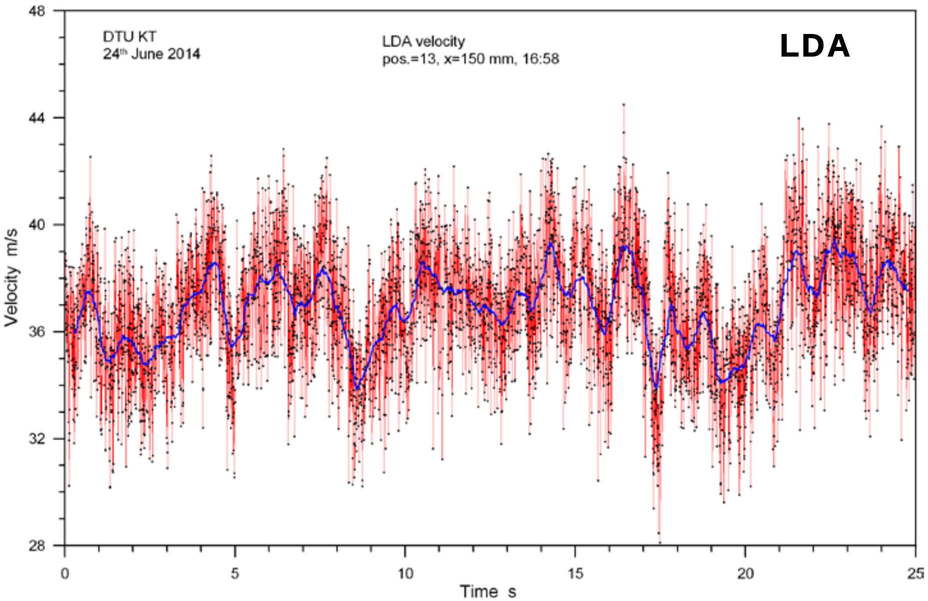
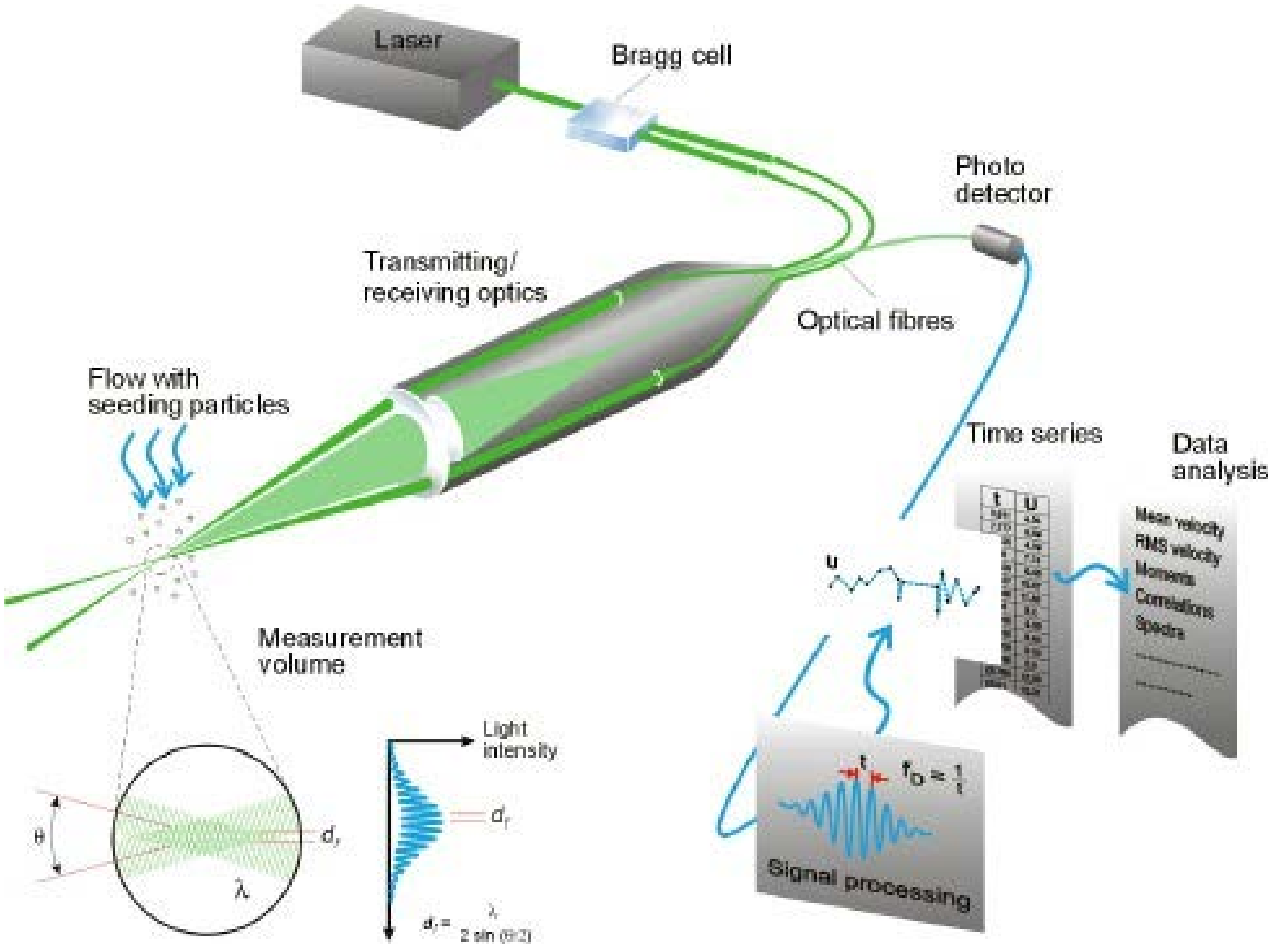
Optical measurements

- Fast measurements
- Non-intrusive measurement
- Insight into process
- Work successfully in lab and full scale
- High-end and low cost instruments
- More accurate measurements
- No calibration using modern methods and database
- Remote measurements
- Work in LT gasifiers (tar, high dust load)
- Many parameters at the same time
- Wide range of applications





LDA FLOW MEASUREMENTS



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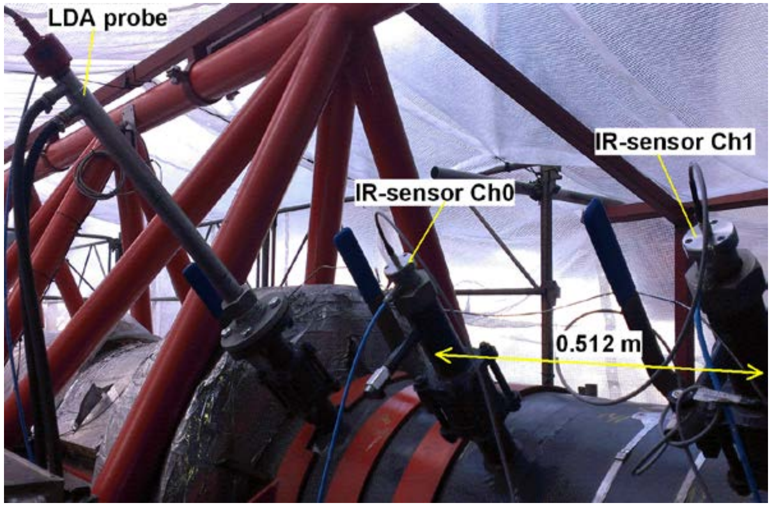
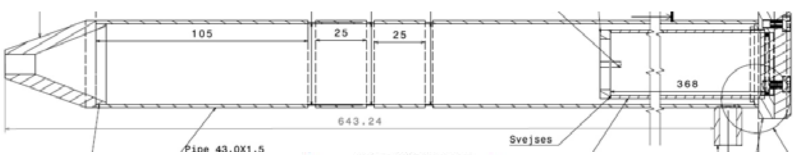
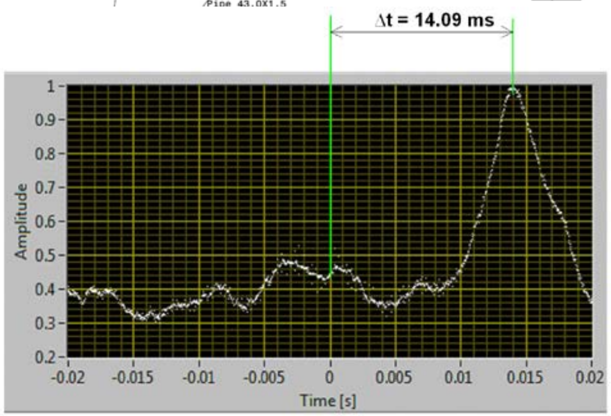
Flow measurement Pyroneer (LT)

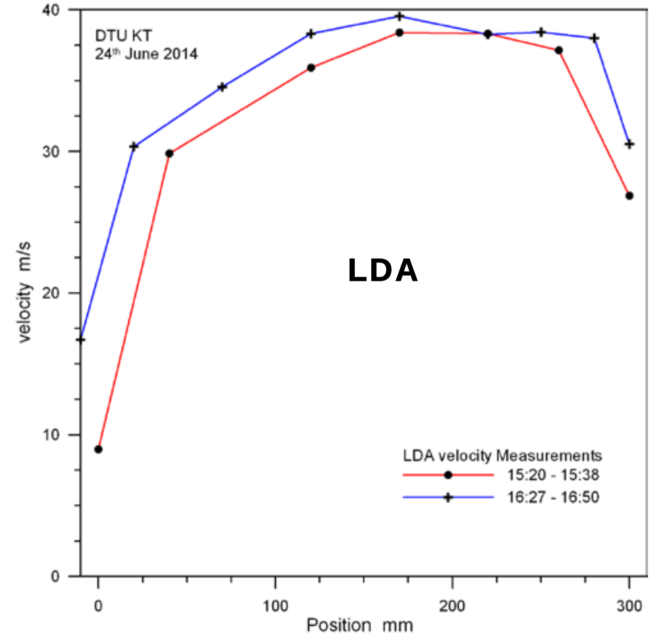


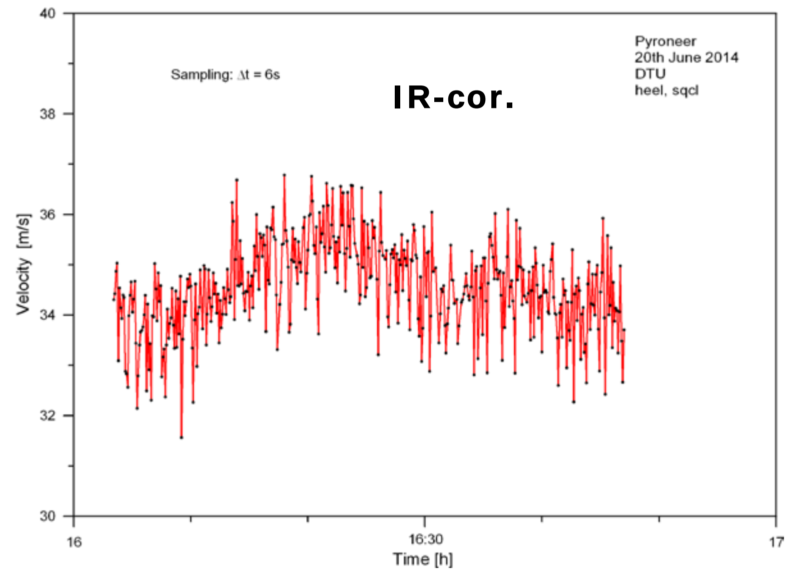




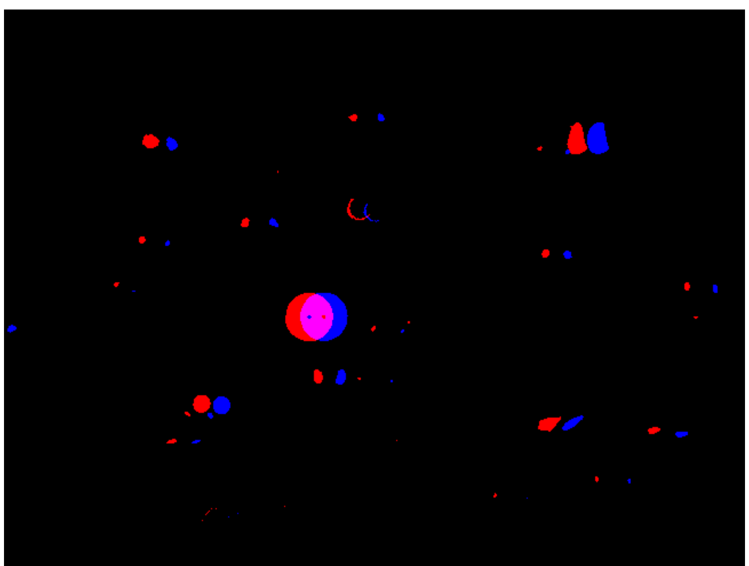
$V = \Delta X/\Delta t$
$= 0.512\ m/0.01409\ s$
$= 36.3\ m/s$

IR-cor.

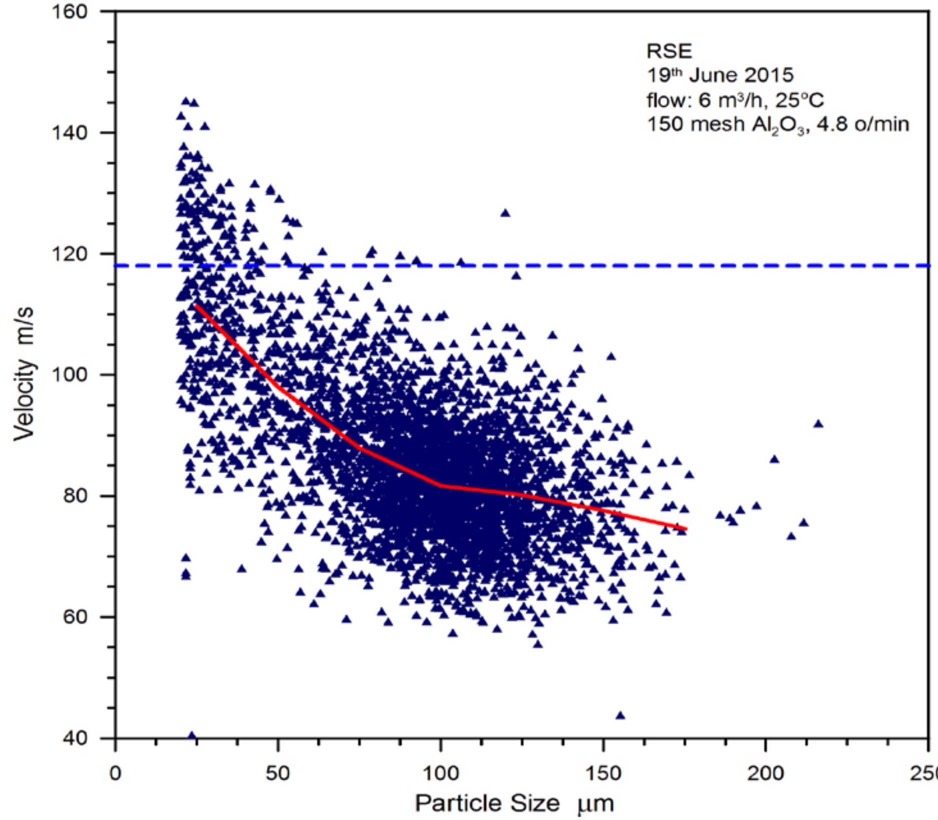




Particle size and velocity



Double 70 ns pulsed LED, Δt = 1 μs



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Sprays, droplet size and velocity

Giovanni: oil spray

Morten Søe: spray

Coating: erosion

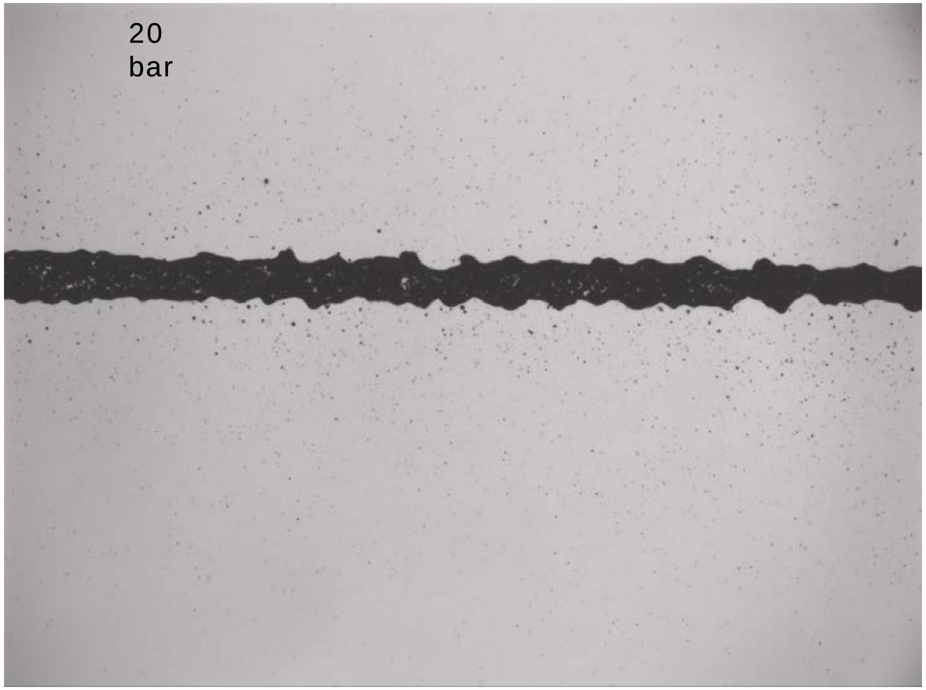
Velocity principles:

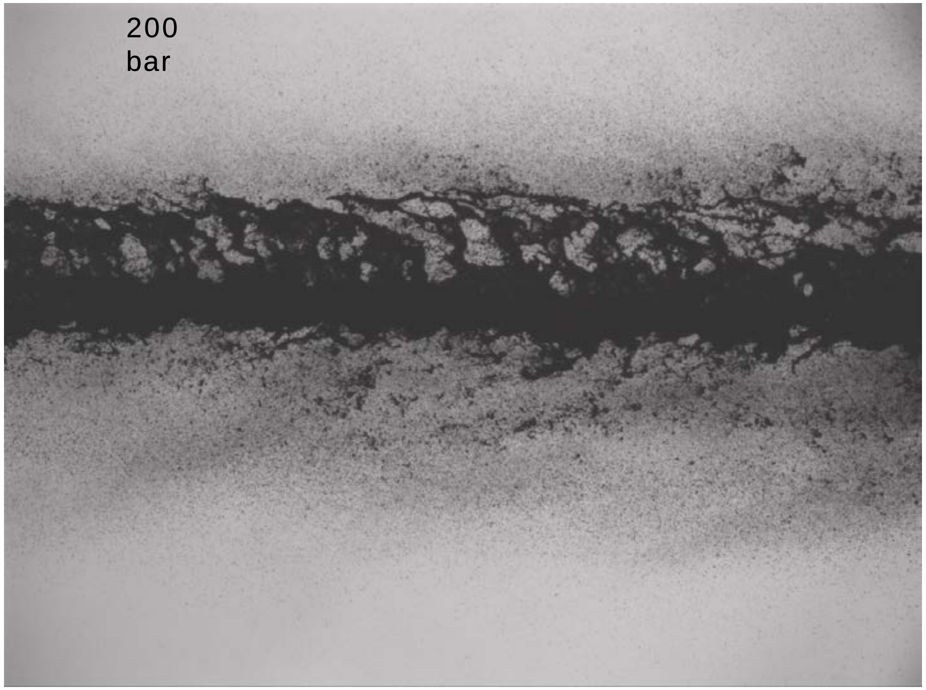
Imaging (dual pulse, high speed)

Laser (LDA)

Correlation

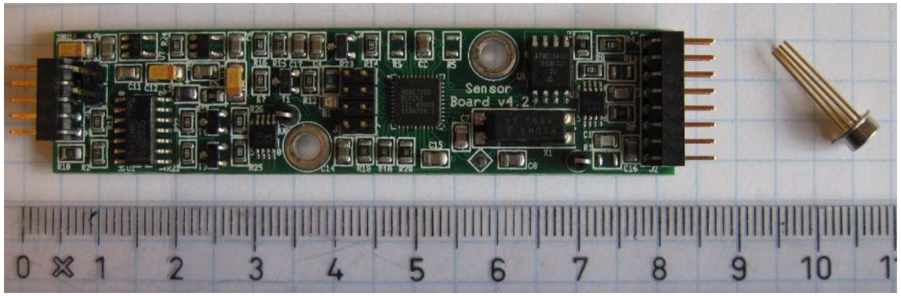
Water jet 48 mm from nozzle

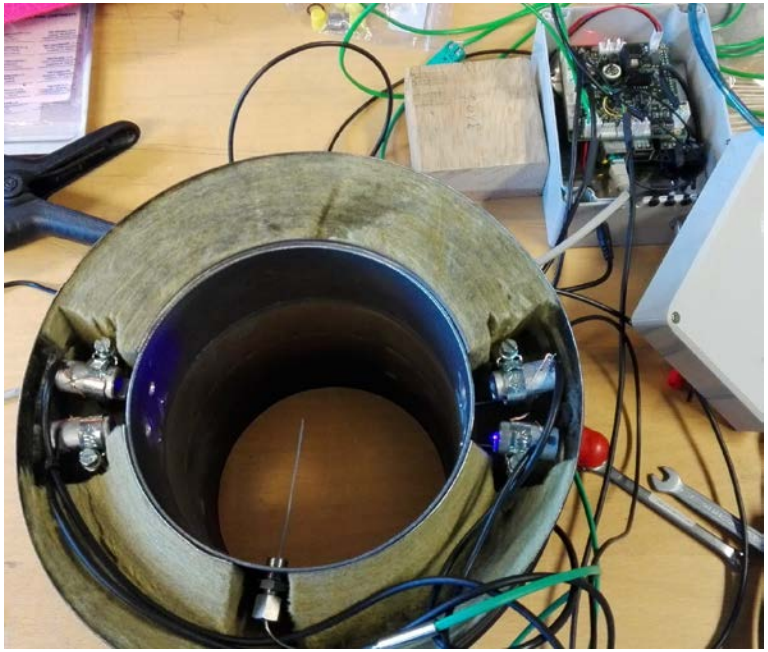




Simple optical sensors

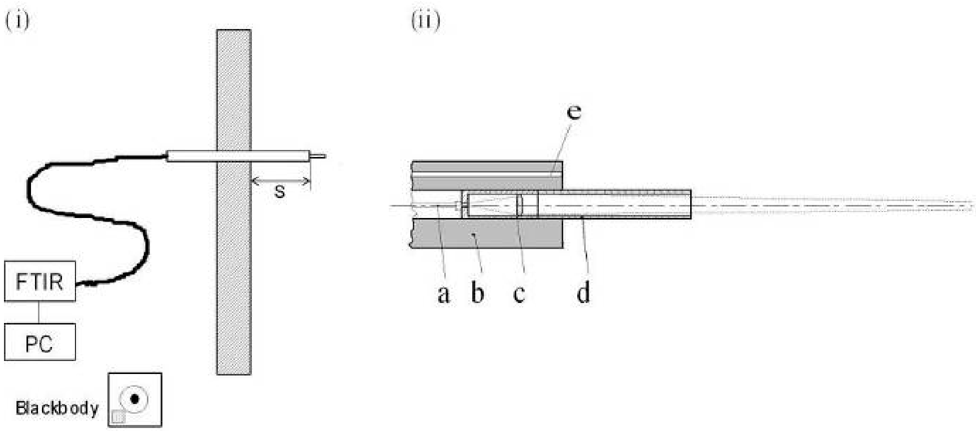
- Monitor parameters of interest
- Improving process
- New opportunities

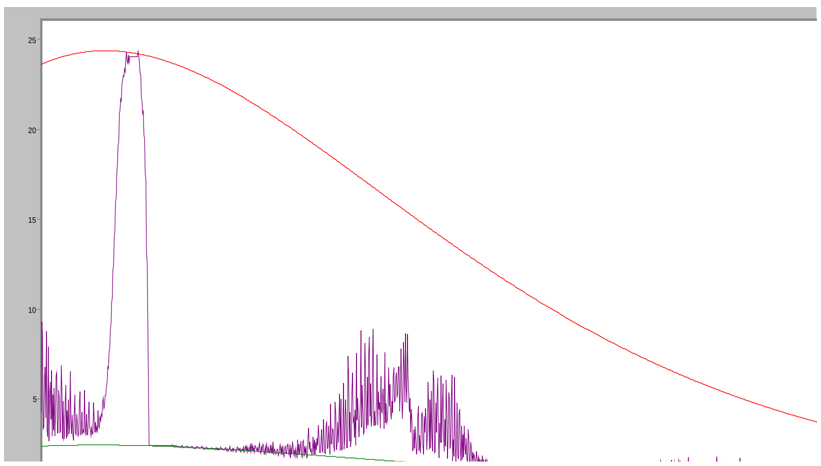




- Fast response
- Innovation
- Output 4 – 20 mA
- Store data in data base

Gas temperature

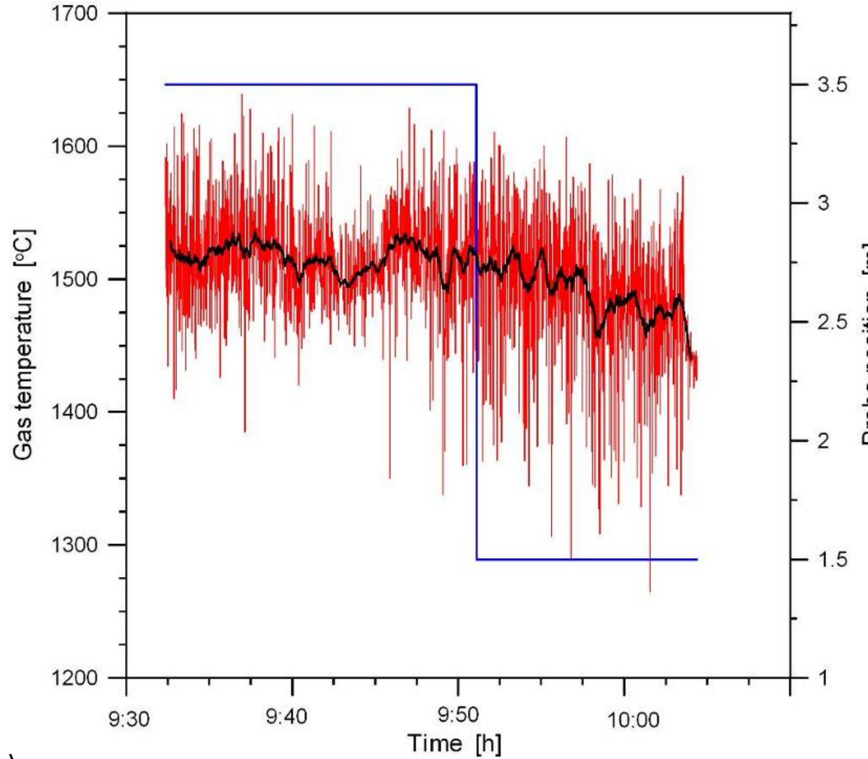




Burner region.

Red: snap-shot,

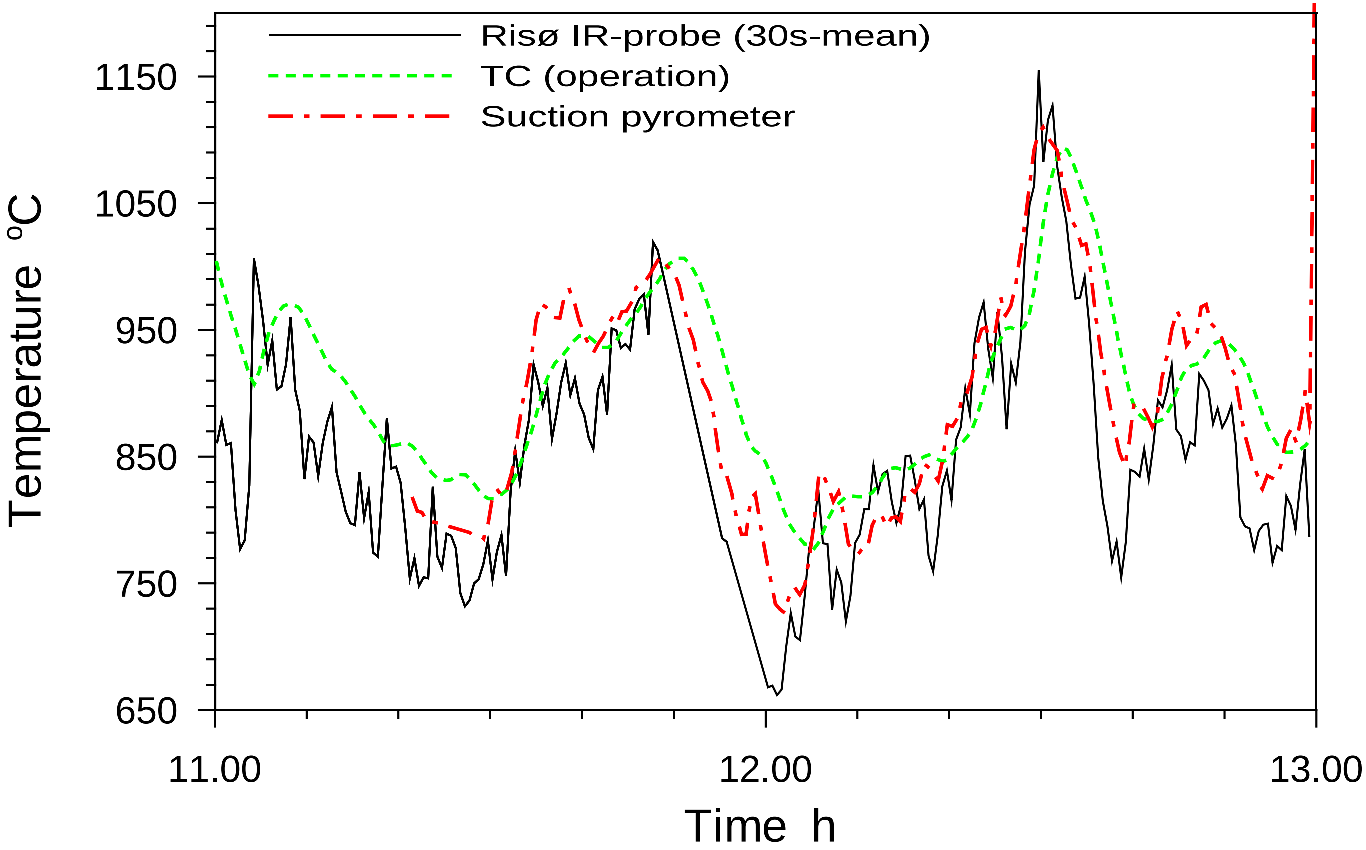
Black: running average over 40 s



Methods: Suction pyrometers (TC), FTIR (intensity), UV (shape features)

TIME CONSTANT GAS TEMPERATURE

Practical boiler measurements



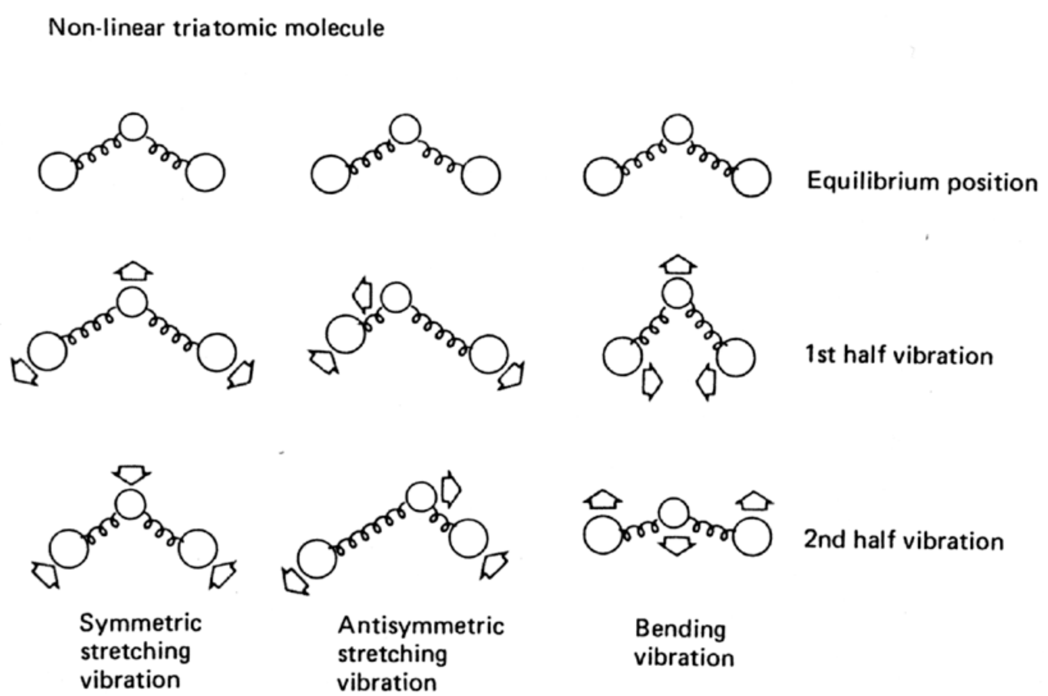
Measurement of flue gas temperature with IR-thermometer, thermocouple (TC) and suction pyrometer. Approx. 5 minutes delay on TC measurement.

IR Gas Measurement

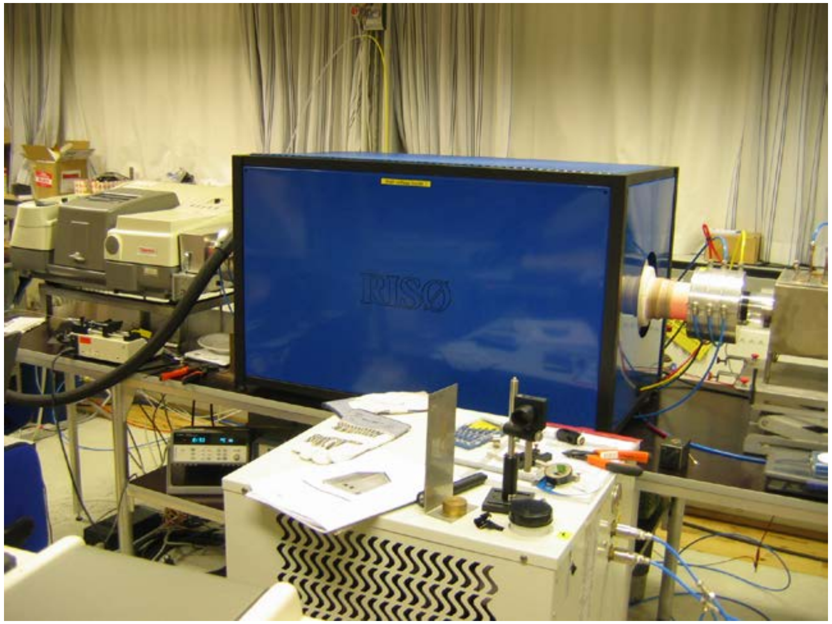
A gas has an unique finger print

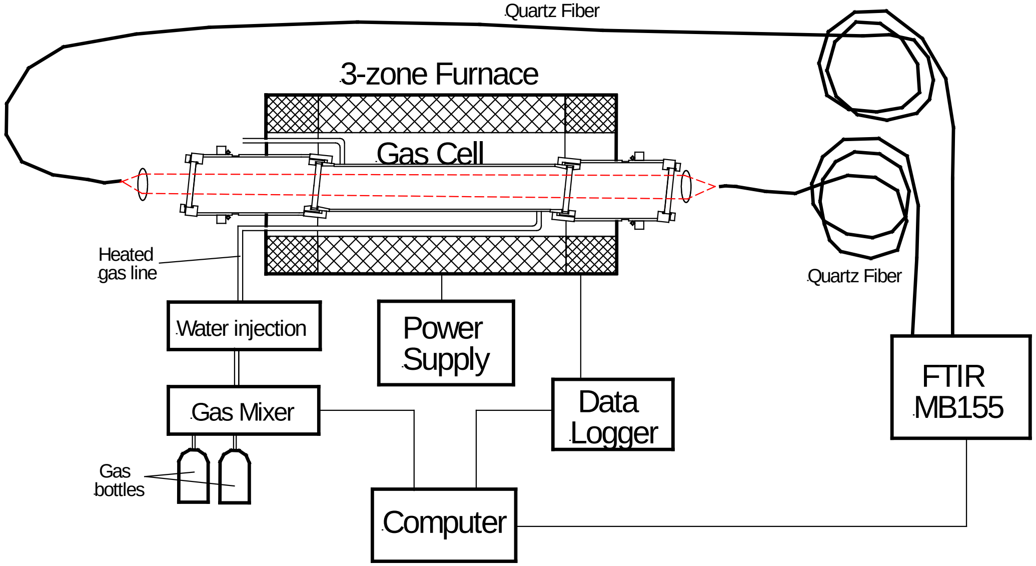
Dipole: H_2O, CO, CO_2, CH_4, HCl, …

No IR spectrum: N_2, O_2, H_2, …



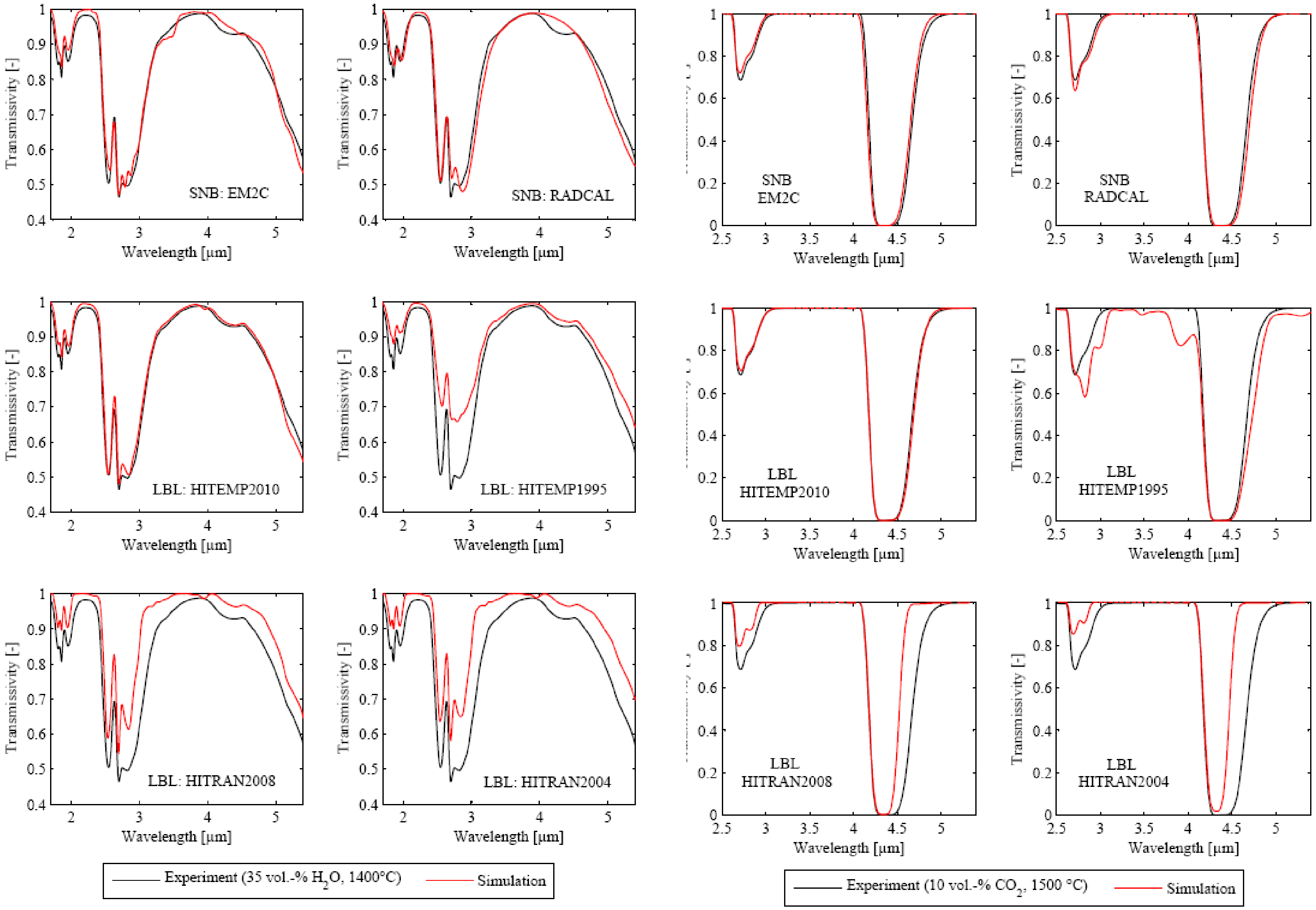
Hot Gas Cell Facilities at DTU





Temperature range: 23 ° C – 1600 ° C
Pressure range: 0 – 200 bar
UV, VIS, IR, FAR,…

Validation of CO_2 and H_2O Radiative Properties



Paper: International Journal of Greenhouse Gas Control, Jan. 17, 2011

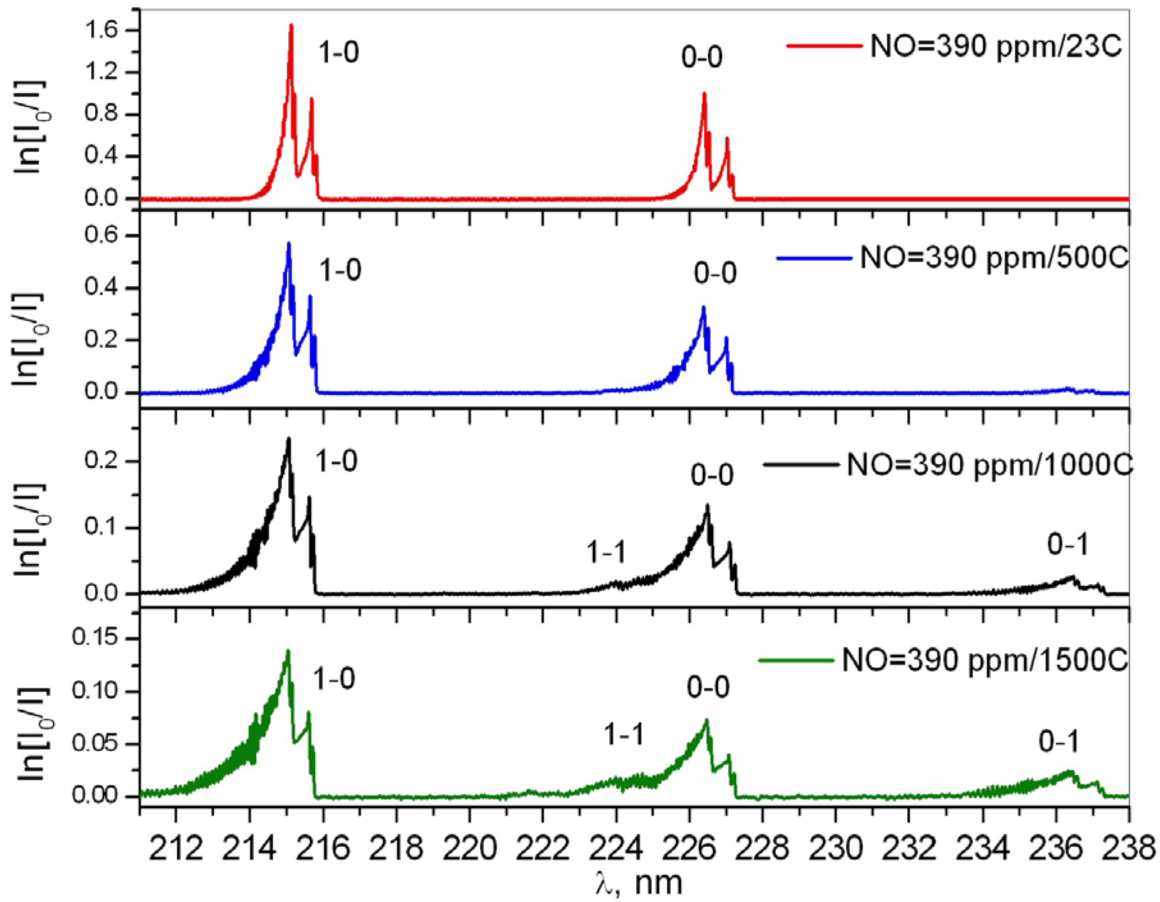
UV NO detection

λ=215 nm absorption band: $DT=DT_{rot}$ ±50°C

Ideal Gas Law:

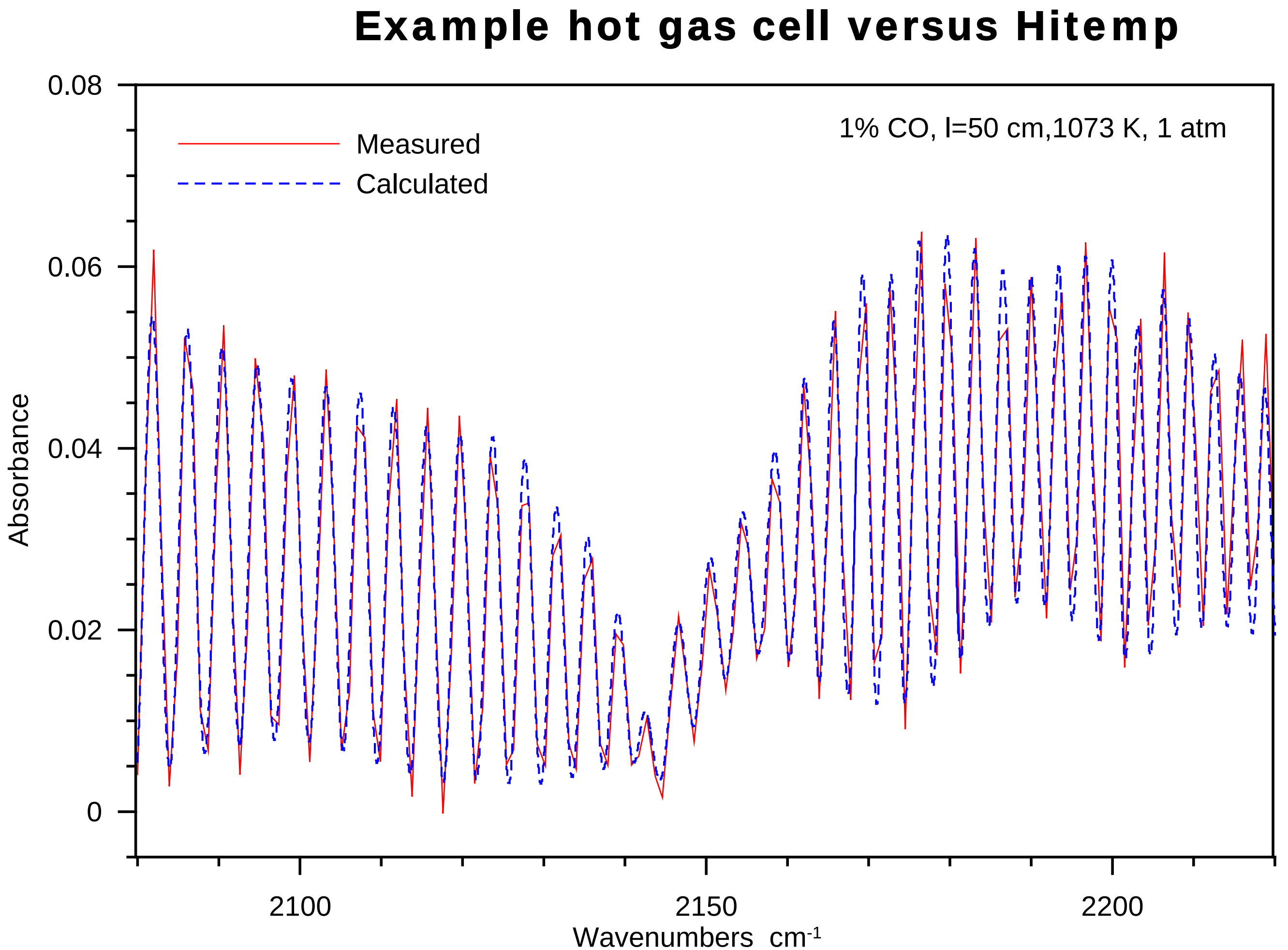
1773K/296K =6.0

but signal drop by approx. a factor 10 due to broadering of gas bands.



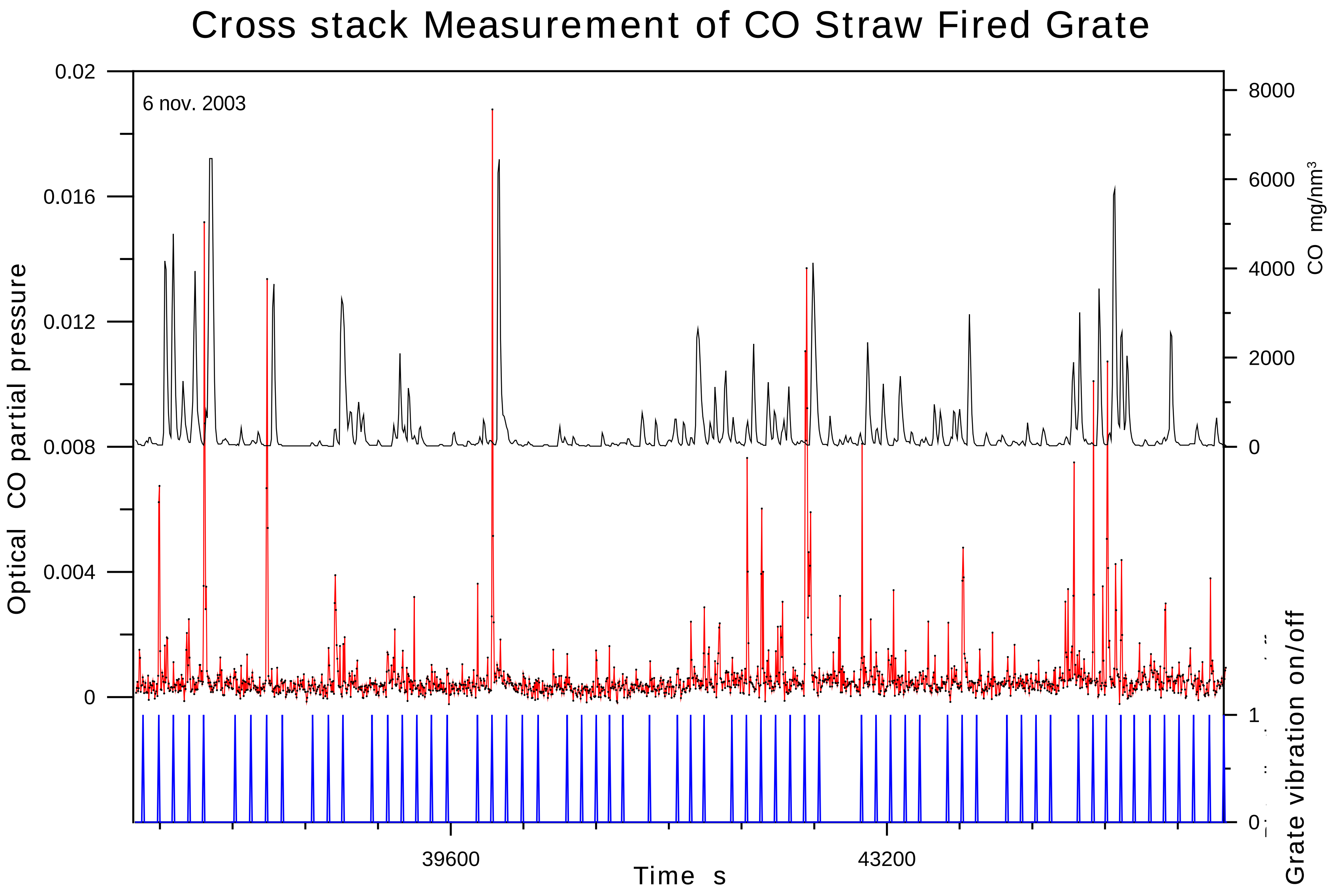
Paper: *In-situ Gas temperature measurements by UV-absorption spectroscopy*

Comparison Measurement and Model

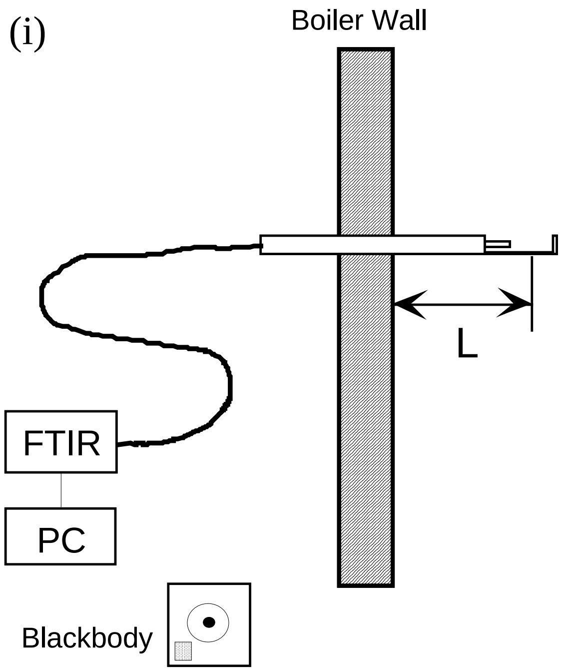


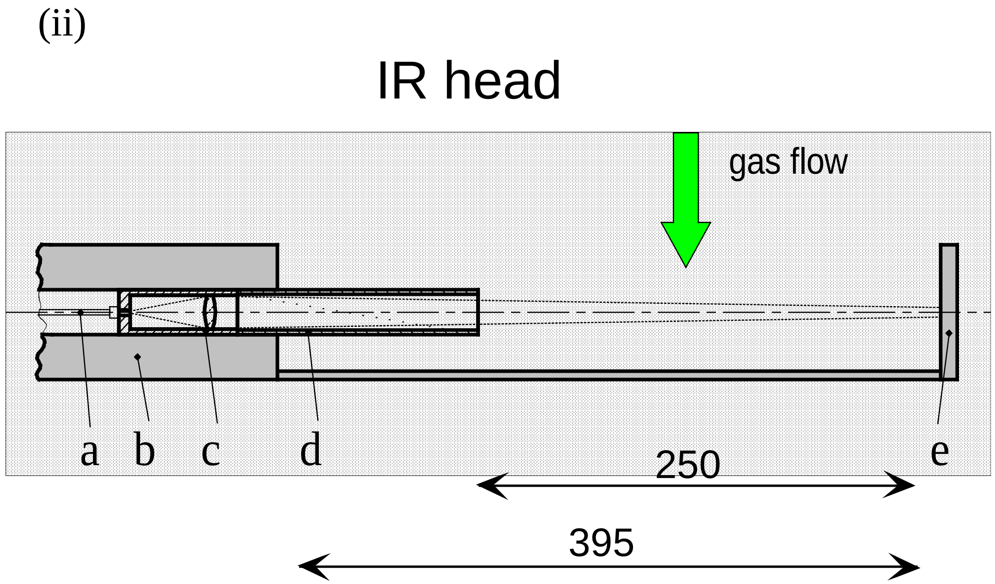
CALIBRATION FREE GAS CONCENTRATION MEASUREMENT

CO Concentration

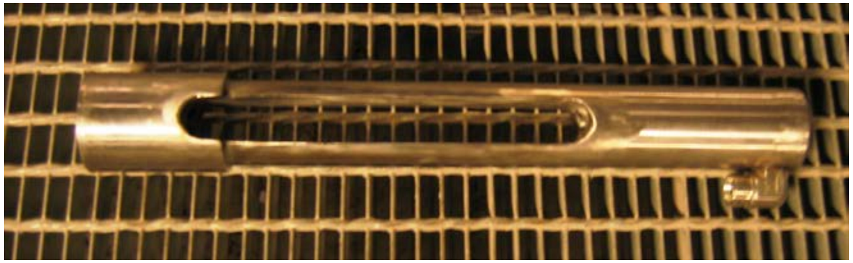


FTIR and UV Spectroscopy - probes



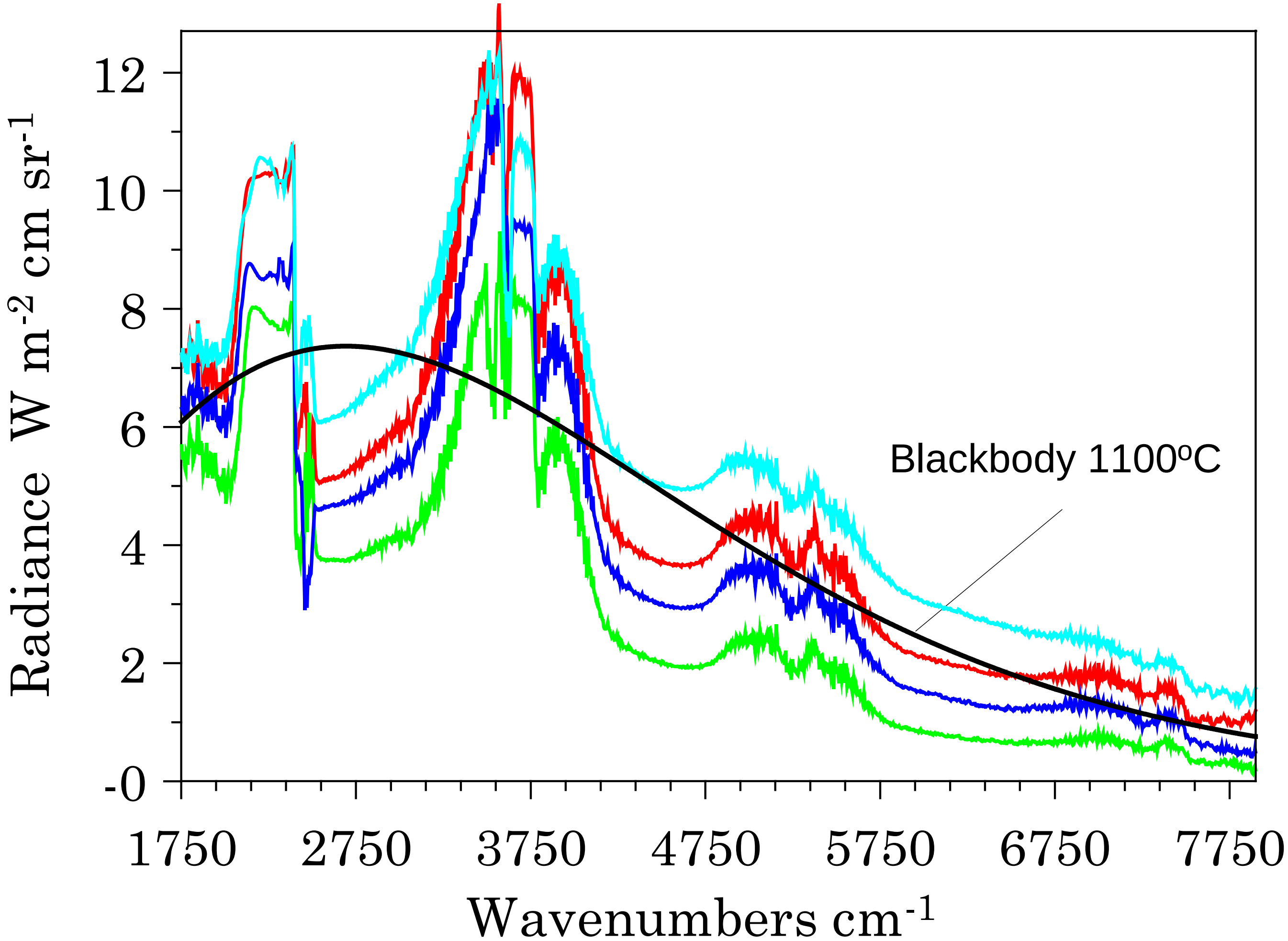


UV head



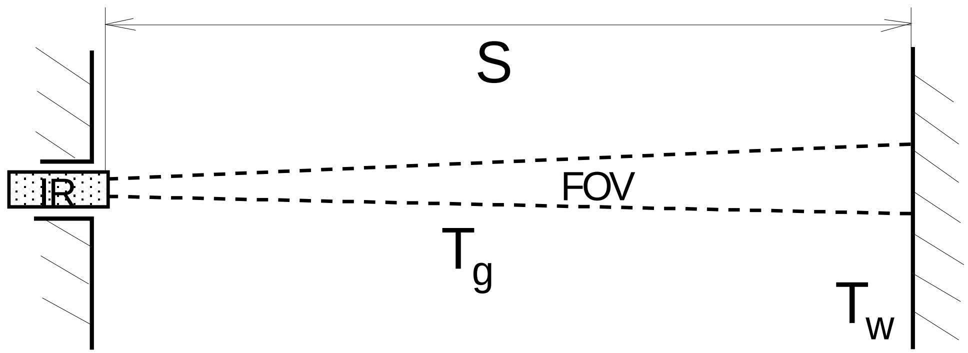
Snap-shot spectra

Straw fired boiler



Incoming radiation: 160-242 kW/m^2 (±1 sigma)

Theory – Principles On-line Gas Analysis

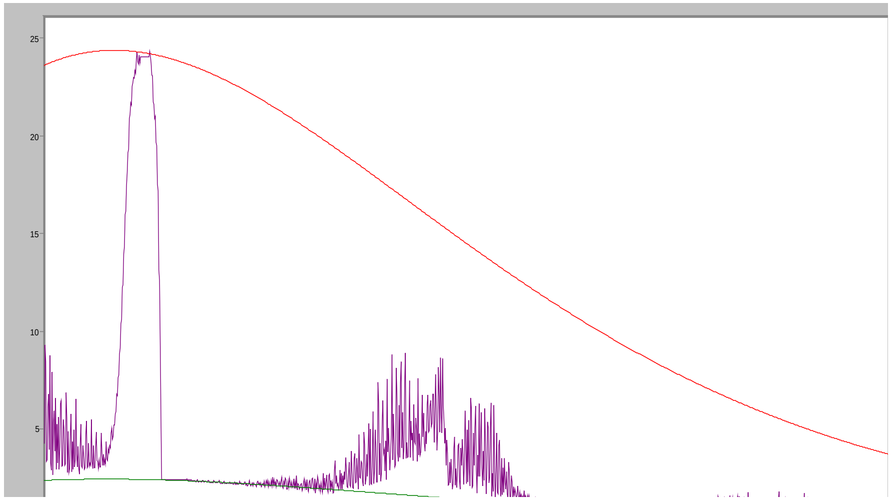


$$(1)\qquad L_m(\lambda) = \varepsilon(\lambda, T_{g,c_i})\, L(\lambda, T_g) + \tau(\lambda, T_{g,c_i})\, L(\lambda, T_w)$$

$$(2a)\quad \varepsilon(\lambda, T_{g,c_i}) = \alpha(\lambda, T_{g,c_i}), \qquad (2b)\quad \tilde{\nu} = \frac{1}{\lambda}$$

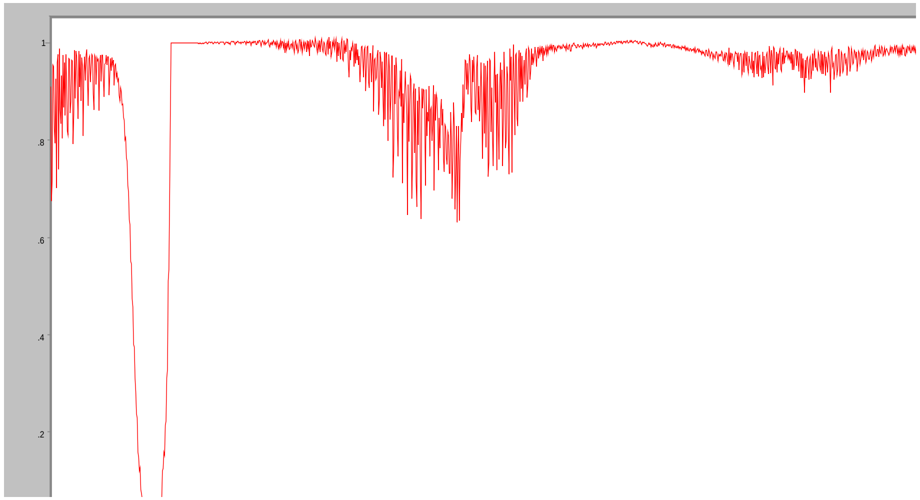
$$(3)\qquad \alpha(\lambda, T_g) = \frac{L_m(\lambda) - L(\lambda, T_w)}{L(\lambda, T_g) - L(\lambda, T_w)}$$

IR Gas Analysis

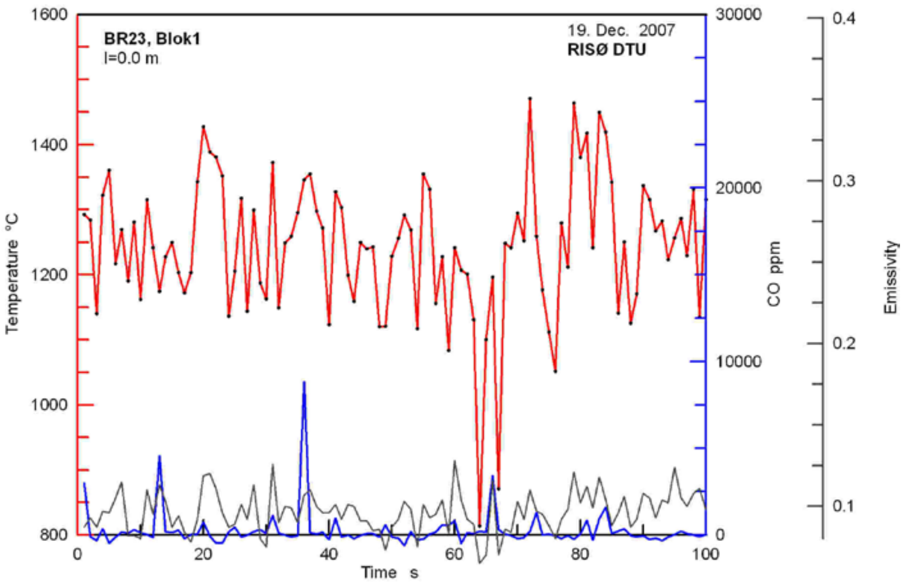


<u>Emission spectrum</u>:
GB: 816.9ºC, ε=0.106
Blackbody curve at 836.0ºC

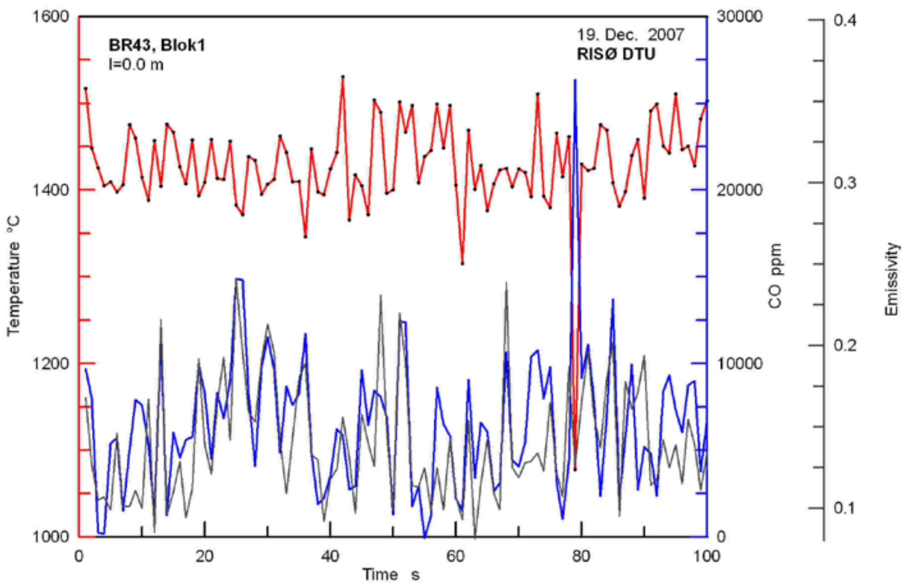
<u>Transmittance spectrum</u>
CO_2, H_2O, CO, C_xH_y, …



Ex.1: FTIR Fiber Optic Flame Measurements

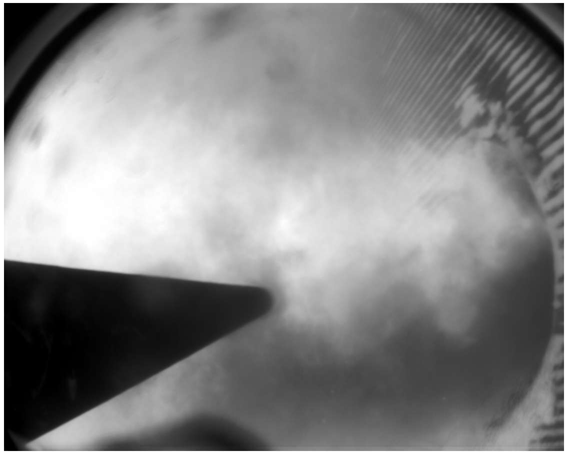


Measurements close to wall

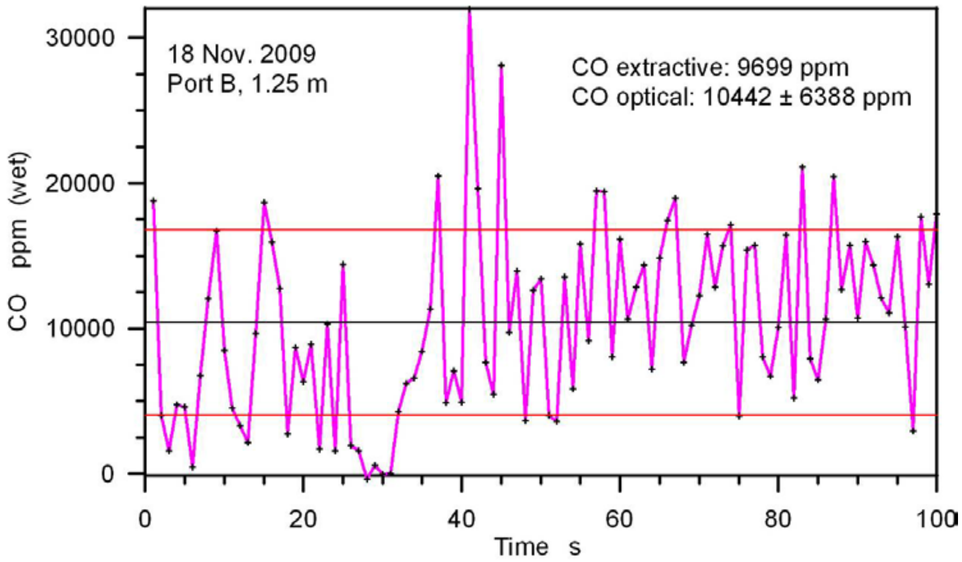


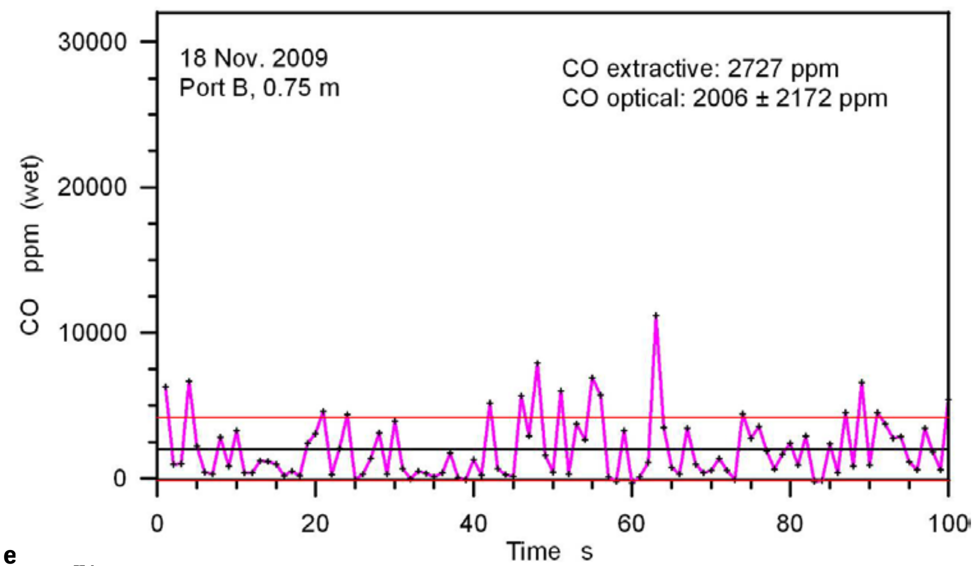
Measurements in Flame

CO follow particle concentration and typical in an on/off mode (poor mixing)



Optical versus Extractive



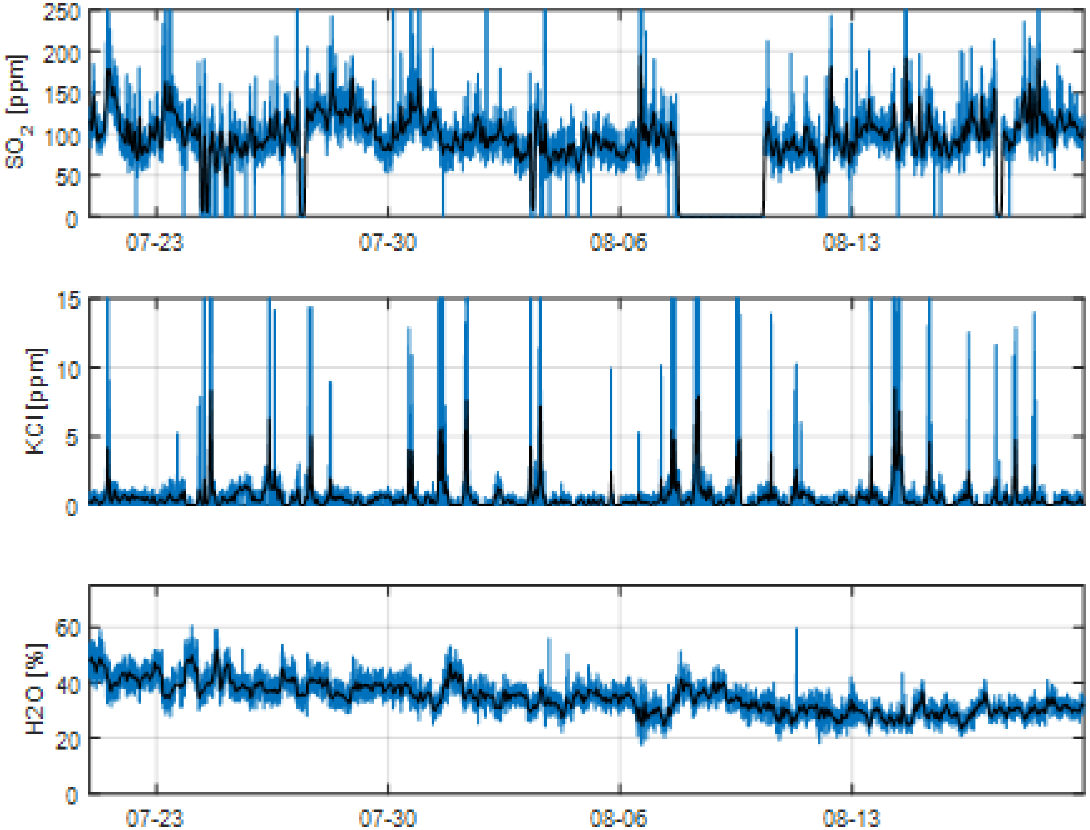


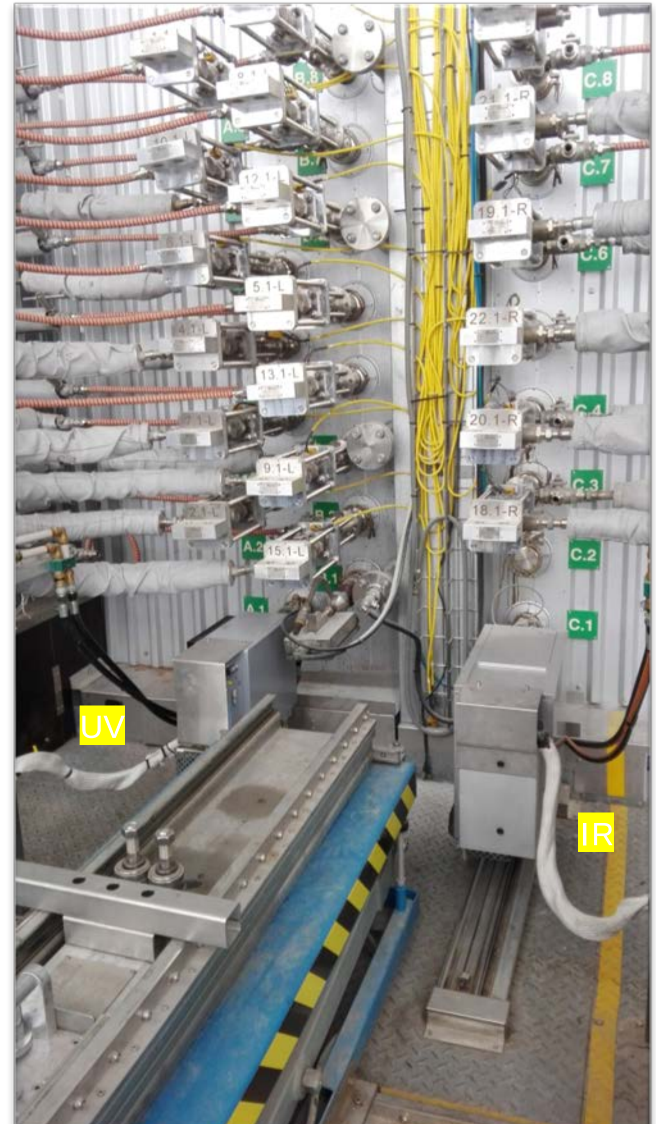
On-line corrosive Monitoring System

- FTIR: CO, CO_2, H_2O, HCl, ...
- UV: SO_2, metals, KCl, ...

NEW

LONG TERM MEASUREMENTS for years





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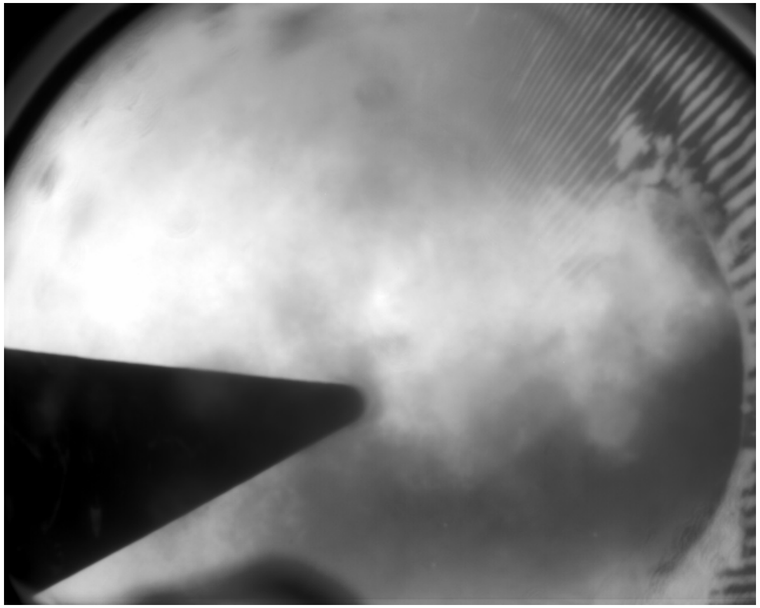
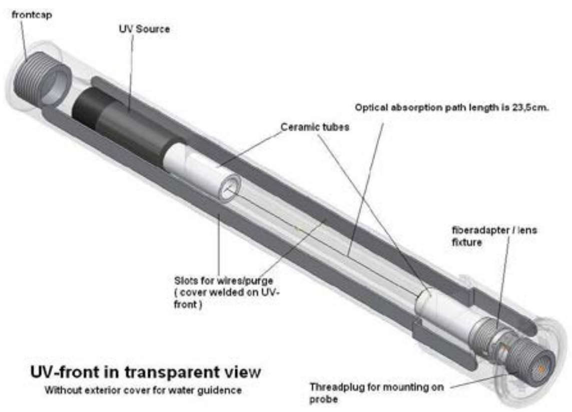
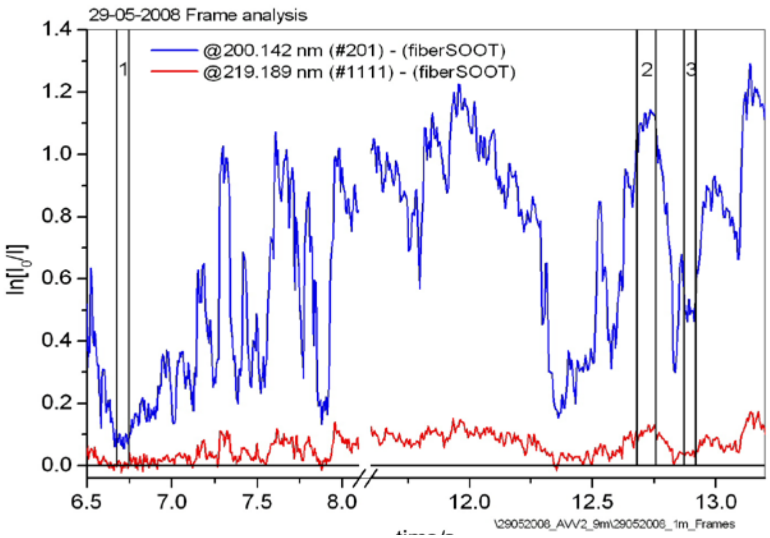
Corrosive and dust loaded hot gas

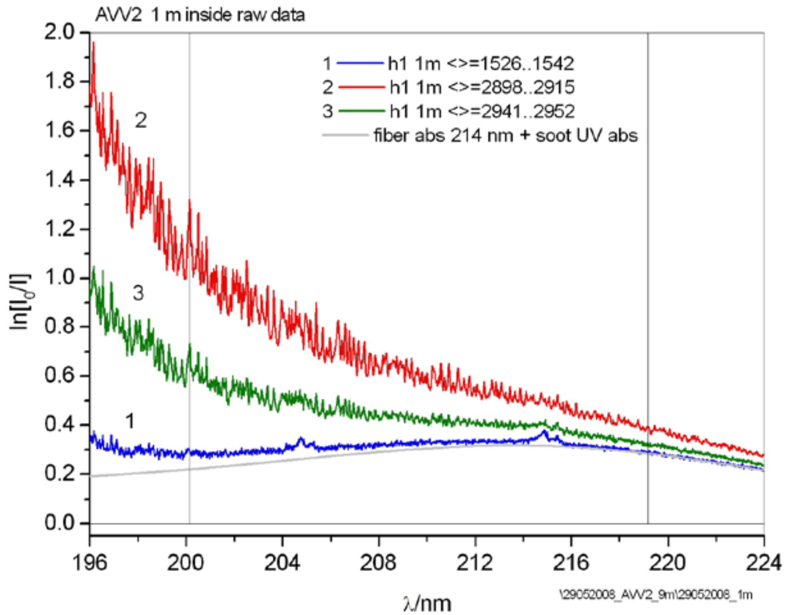
NO problems?



UV SPECTROSCOPY



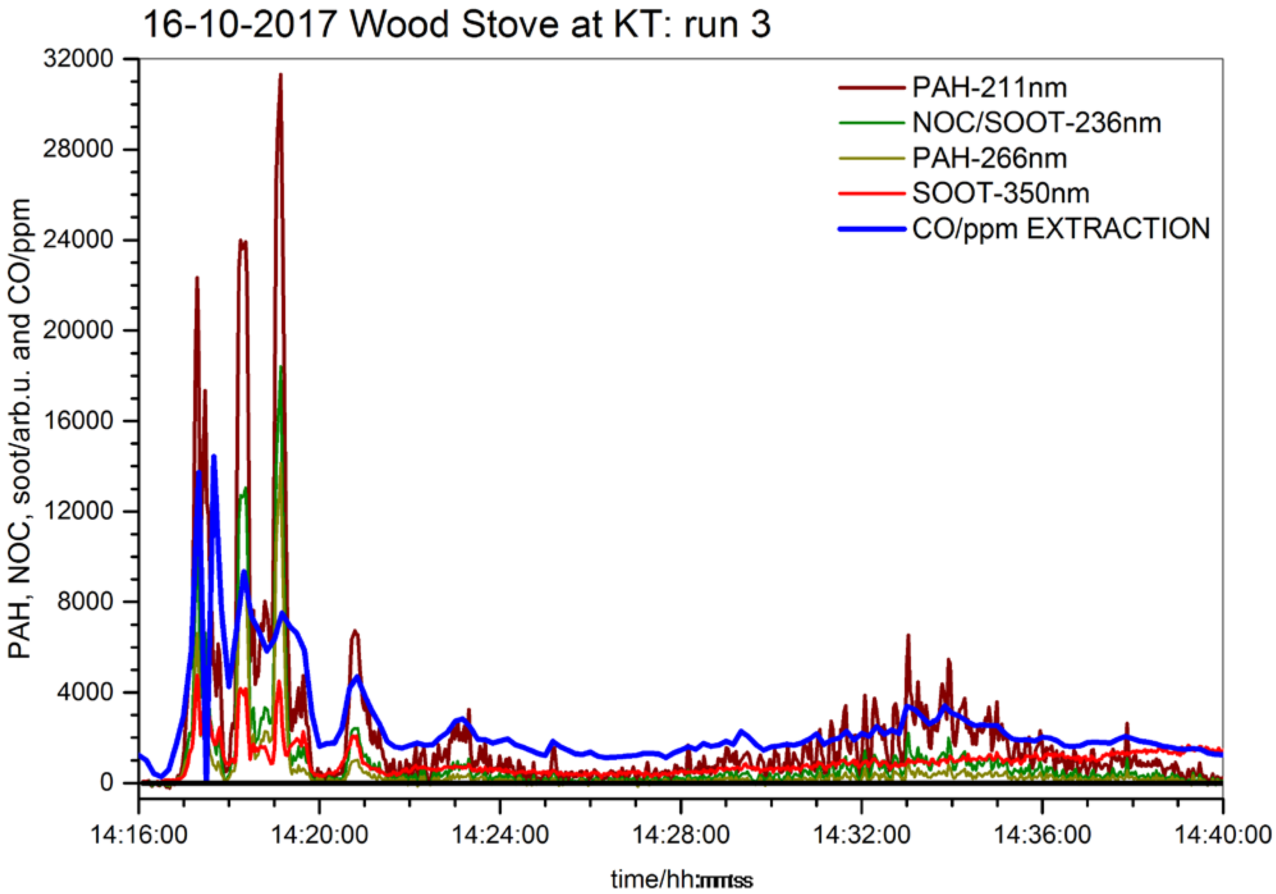




Low cost soot and tar sensor

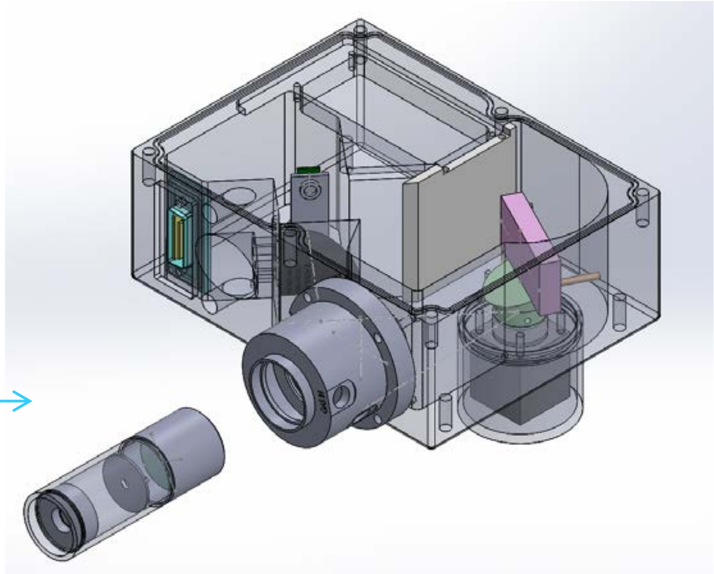
Patented principle: fast signal of soot and tar for regulation

HWAM wood stove

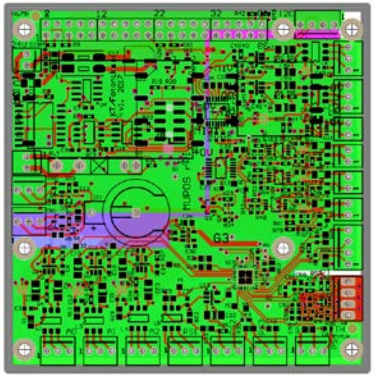


Instruments and sensors

- Natural gas burning value



- Soot and tar monitor (patent)

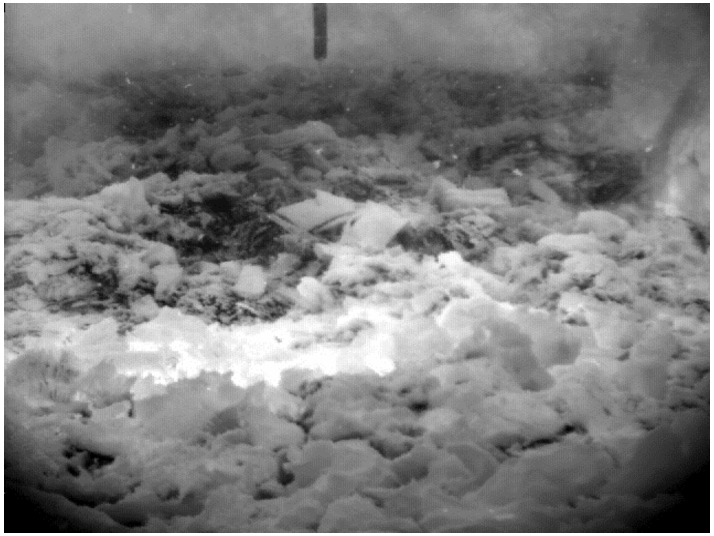


Raspberry Pi (30 EUR) + DTU board

Summary

- Optical measurements powerful tool
- Wide range of parameters can be measured
  (welcome to contact me about specific topics)
- Mobile instrumentation for large scale
- Good performance
- Deep insight into process and physics
- Work in corrosive, hot and difficult applications
  (like gasifiers)
- 30 years experience in the field at DTU

- DTU is open for cooperation



Questions?

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