ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Microsystems based Technologies for Air-Pollutant and Gas Detection

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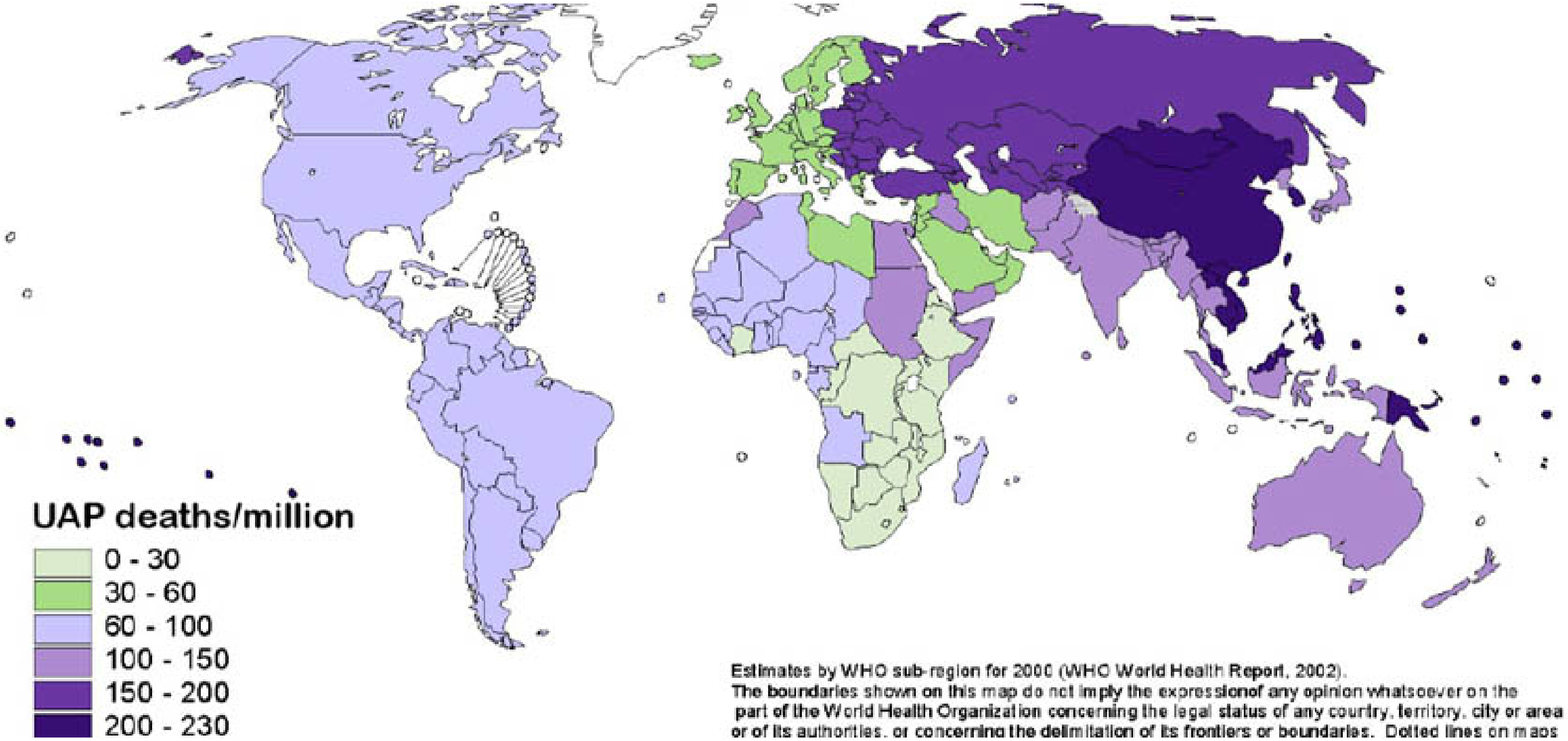
IMT - samlab

Outline

- Air pollution monitoring
  - Status, methods and what’s next
- Microsystems based analytical systems
  - Opportunities and challenges
- Some developments at EPFL-SAMLAB
  - Gas preconcentrators, micro-GCs, Micro FTIR gas analyser
- Conclusion

Air pollution

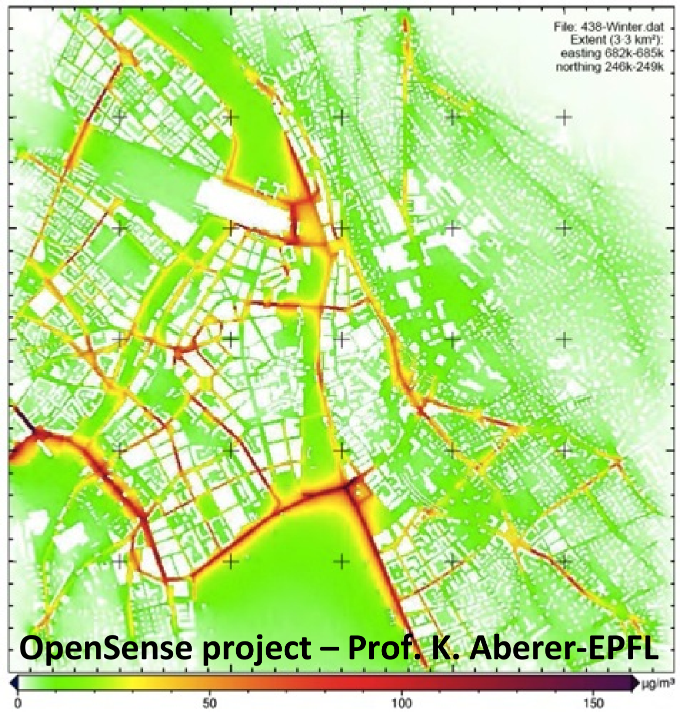
- Air pollution in urban areas is a global concern
  - affects quality of life and health
  - urban population is increasing



Deaths from Urban Air Pollution (courtesy CHUV)

Air pollution monitoring

- Air pollution is highly location-dependent
  - traffic chokepoints
  - urban canyons
  - industrial installations



➢ Precise location-dependent and real-time information on air pollution is needed

Official uses

- location of pollution sources
- incentives to reduce environmental footprint
- public health studies

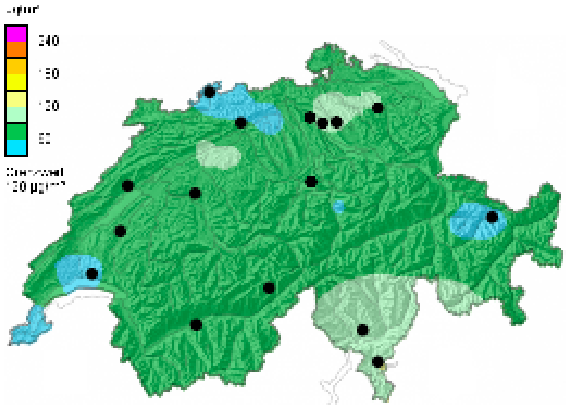
Citizen uses

- advice for outside activities
- assessment of long-term exposure
- pollution maps

Air pollution monitoring

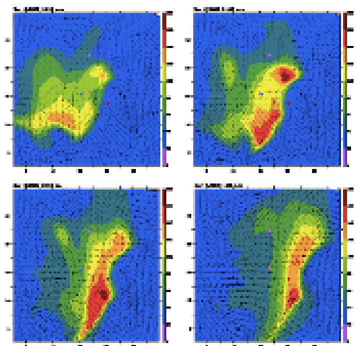
- Monitoring today

Stationary and expensive stations

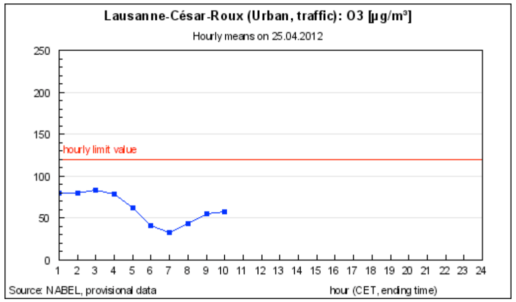


Sparse sensor network (Nabel)

Expensive mobile high fidelity equipment



Coarse models (mesoscale = 1km²)



Data difficult to integrate into applications (e.g. for correlating with other features like people's activities)

Air pollution monitoring

- **Sensing system**
  - With sufficient temporal and spatial resolution
  - With sufficient precision
  - At reasonable cost
- **Data analysis**
  - Interpolate air quality parameters from raw data
  - Ensure data quality
  - Reduce acquisition cost
- **User concerns**
  - Correlate with activity and mobility data
  - Consider privacy concerns
  - Provide individualized information
- **End-to-end system architecture**

NanoTera OpenSense

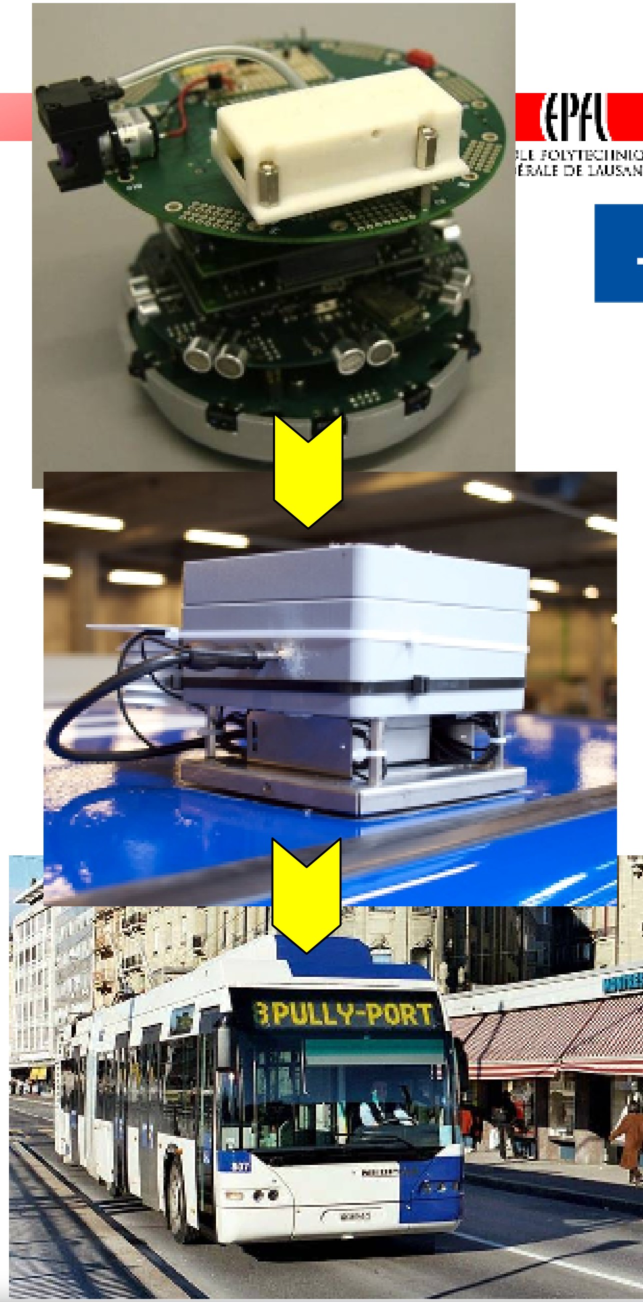
Coordinator Karl Aberer - EPFL

- Lausanne deployment

8 mobile stations

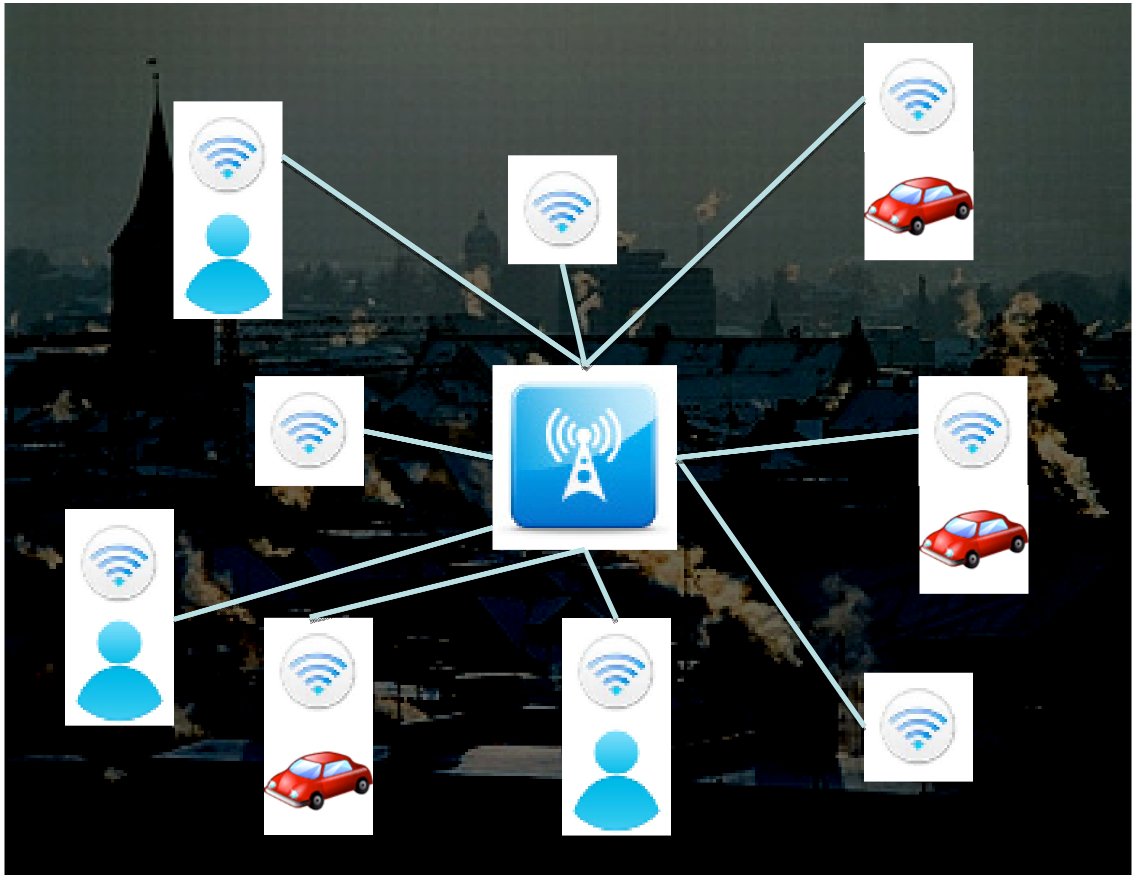
- NO_2, CO, CO_2, Humidity, Temperature
- Positioning module
- Communication: GSM

1 prototype station mounted on bus



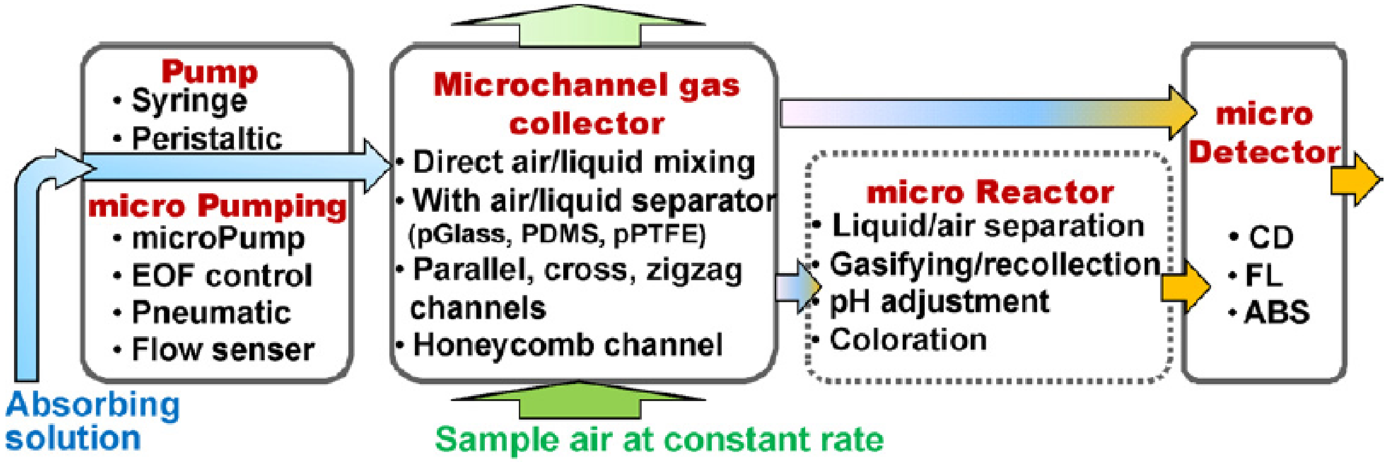
Opportunities

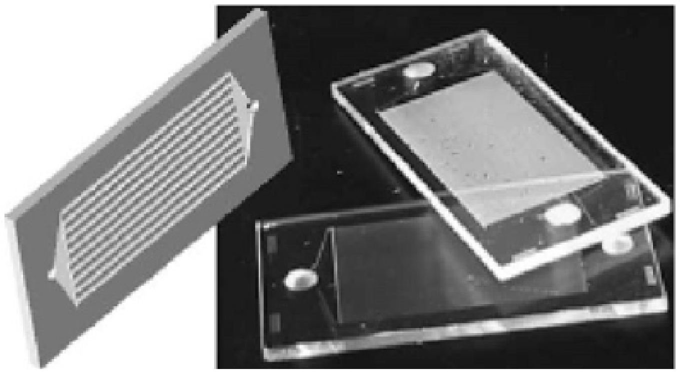
- ***Wireless communication and low cost sensors***: deploy larger numbers of stations
- ***Mobility***: deploy mobile stations to increase spatial coverage
- ***Communities***: citizens as data producers and information consumers

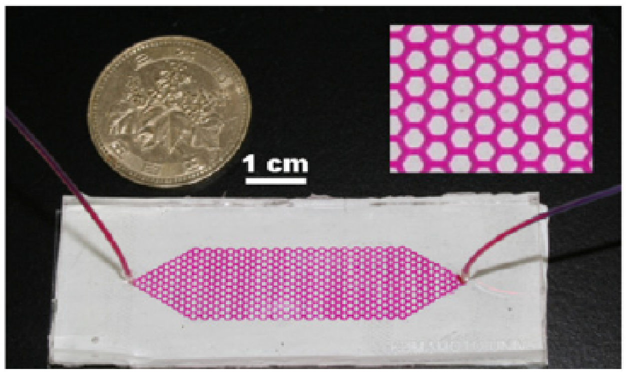


Microsystems based analytical instruments

- Water soluble gas and detection using wet chemistry



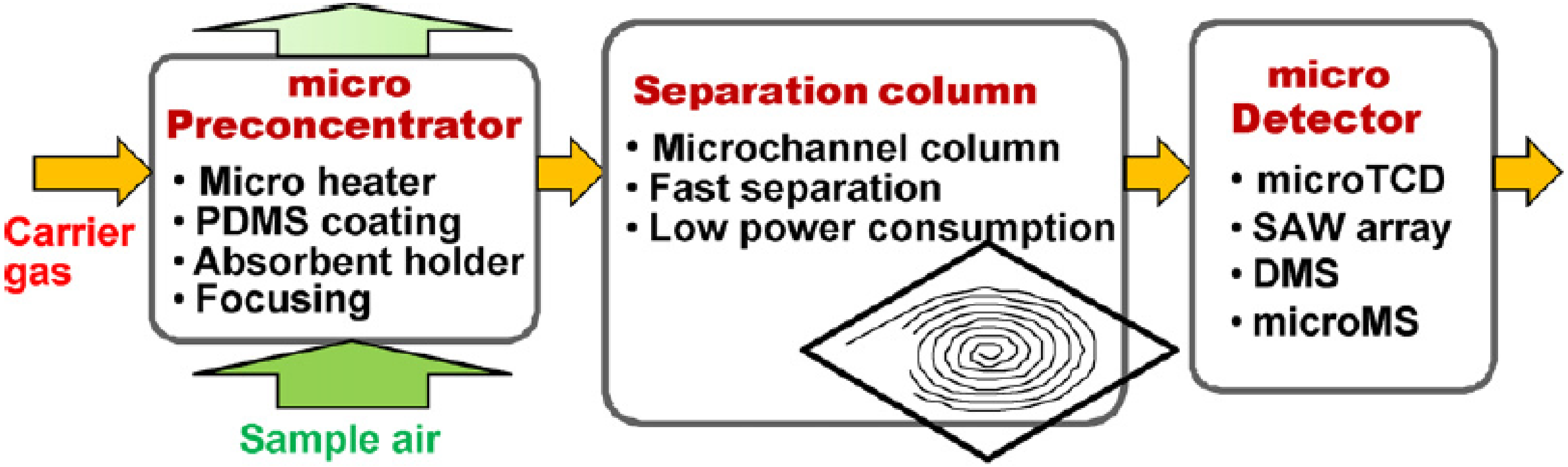


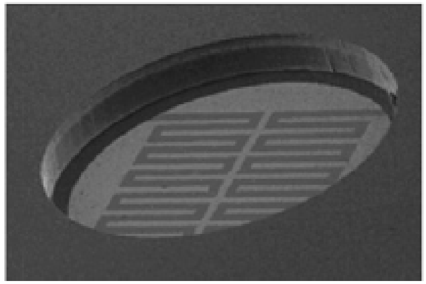


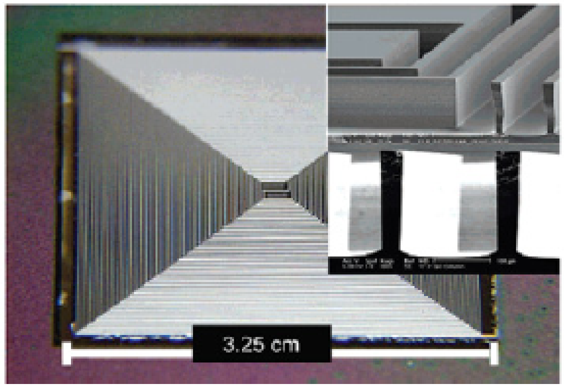
S.-I. Ohera, Analytica Chimica Acta 619 (2008) 143–156

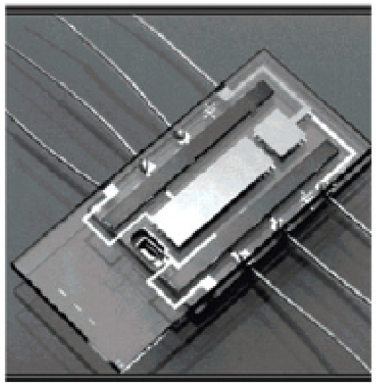
Microsystems based analytical instruments

- Gas phase detection system









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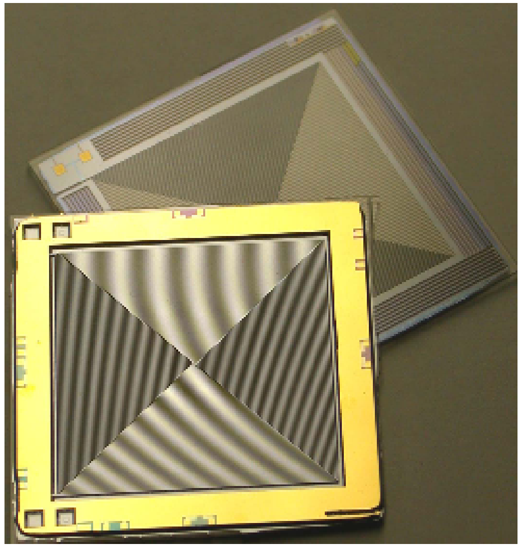
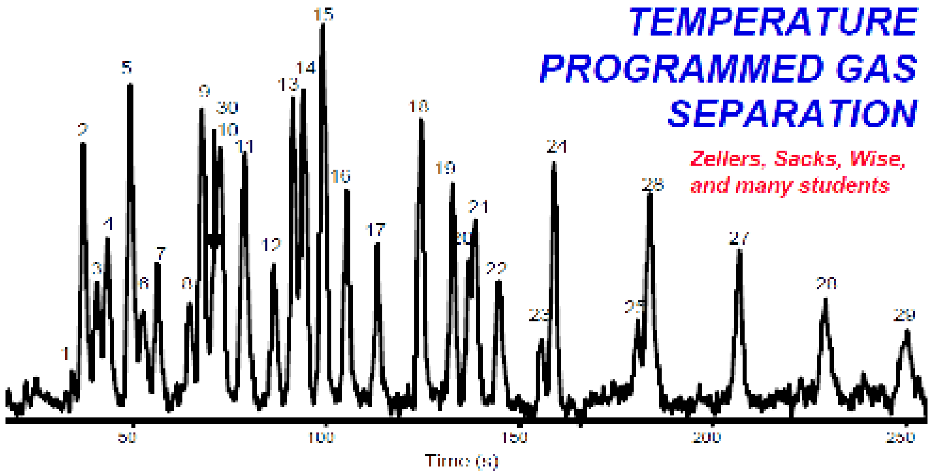
Microsystems based analytical instruments



WIMS µGC

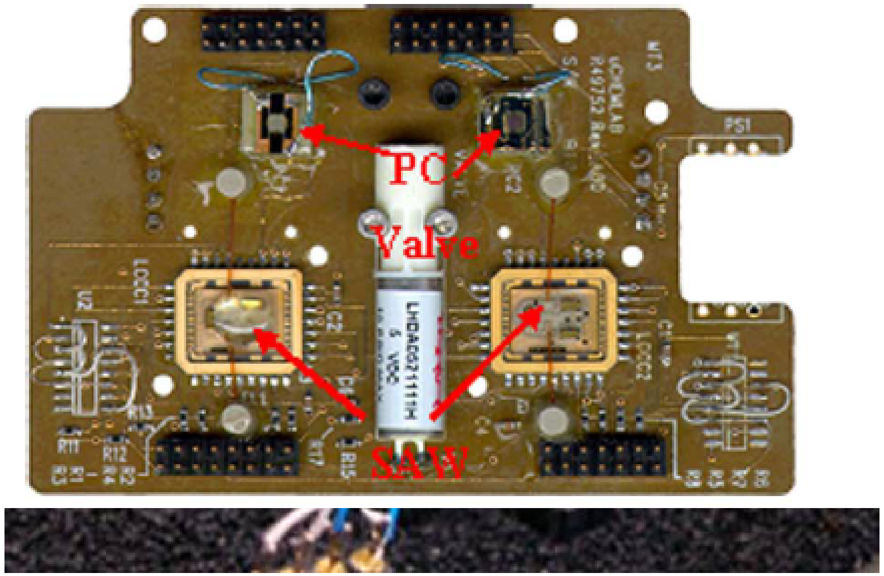


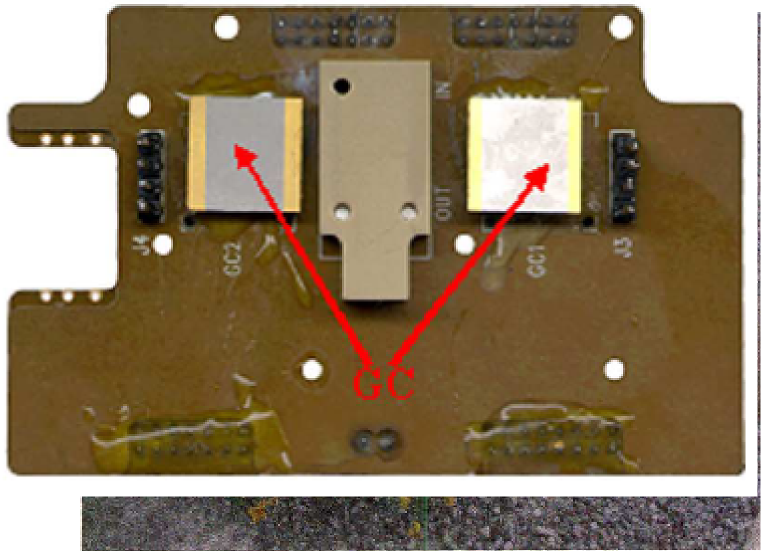
- Thirty air pollutants spanning three orders of magnitude in vapor pressure were separated in ***4.2min on a single 3m Si-glass column*** coated with polydimethylsiloxane and temperature programmed at 20°C/min.

- **Benefits**
  - Miniaturisation
  - Portabilty
  - High sensitivity (ppb to < ppb)
  - Selectivity
  - Cheaper ?

- **Status**
  - Performing individual components BUT
  - Not only microsystems components
  - Challenge: integration into a complete system

Microsystems based analytical instruments



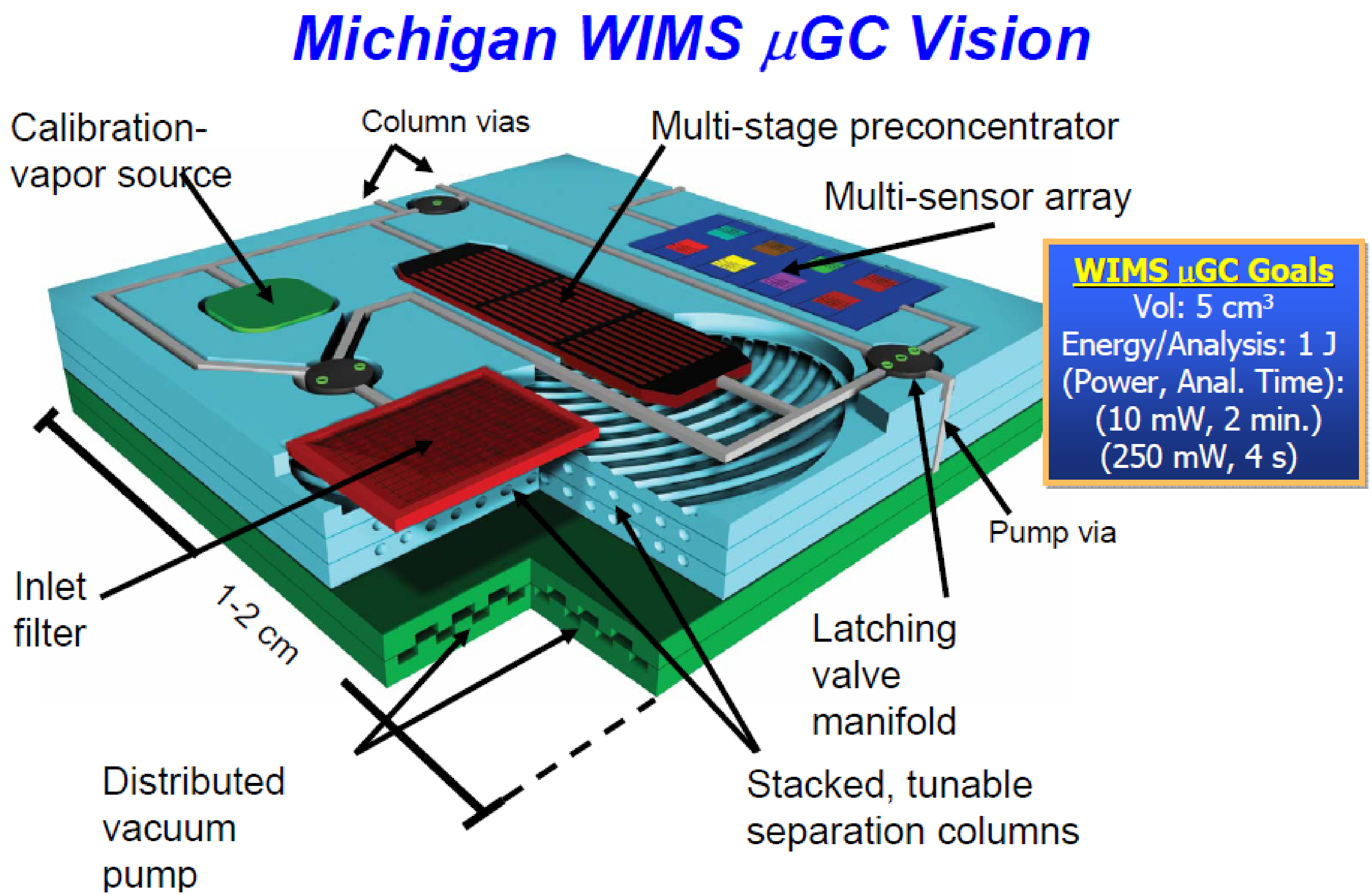


Sandia National Lab

Gas-phase MicroChemLab

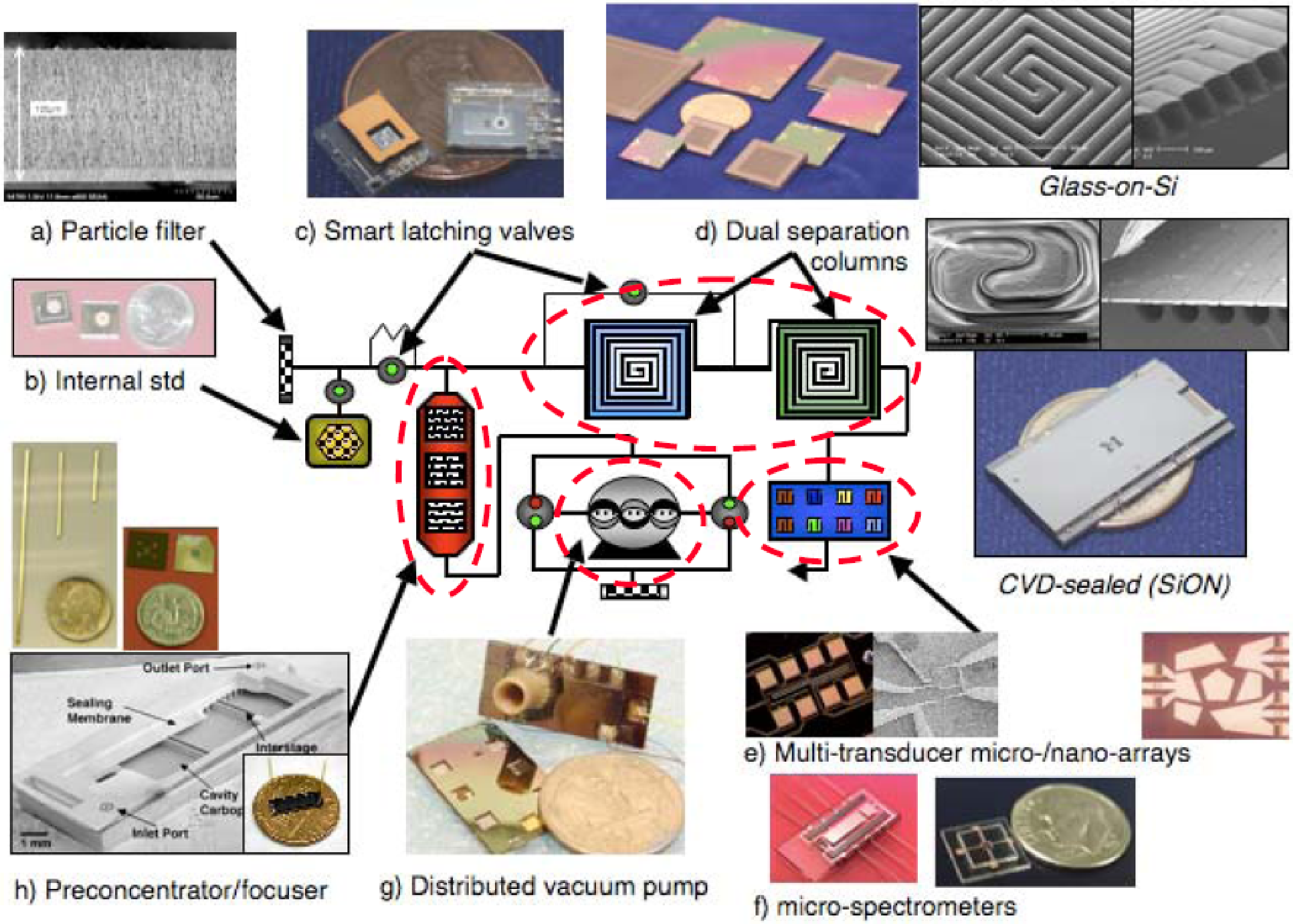
- **Status**
  - Performing individual components BUT
  - Not only microsystems components
  - Challenge: integration into a complete system

Microsystems based analytical instruments



University of Michigan, WIMS μGC

Microsystems based analytical instruments



University of Michigan, WIMS µGC

Microsystems based analytical instruments

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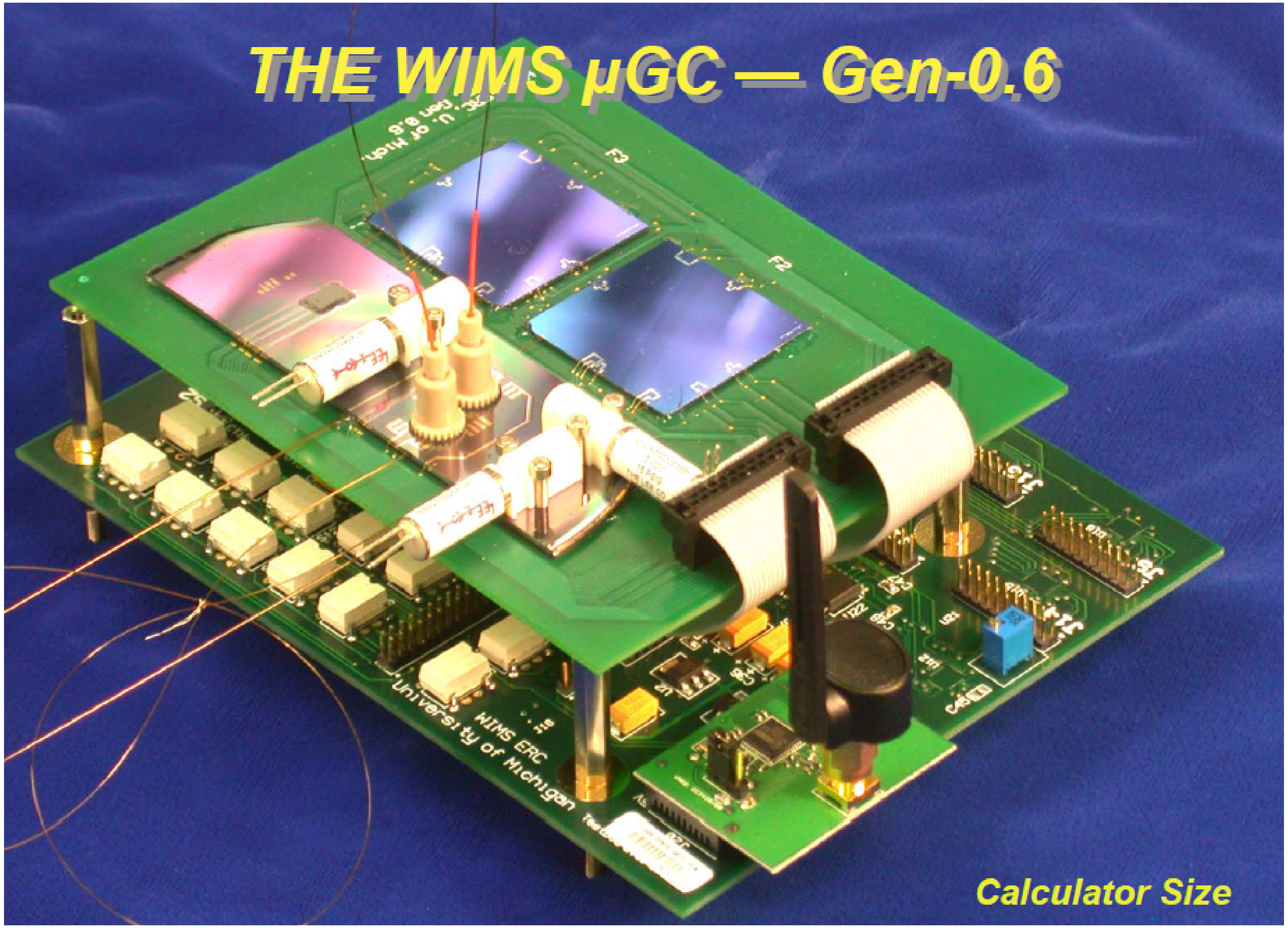
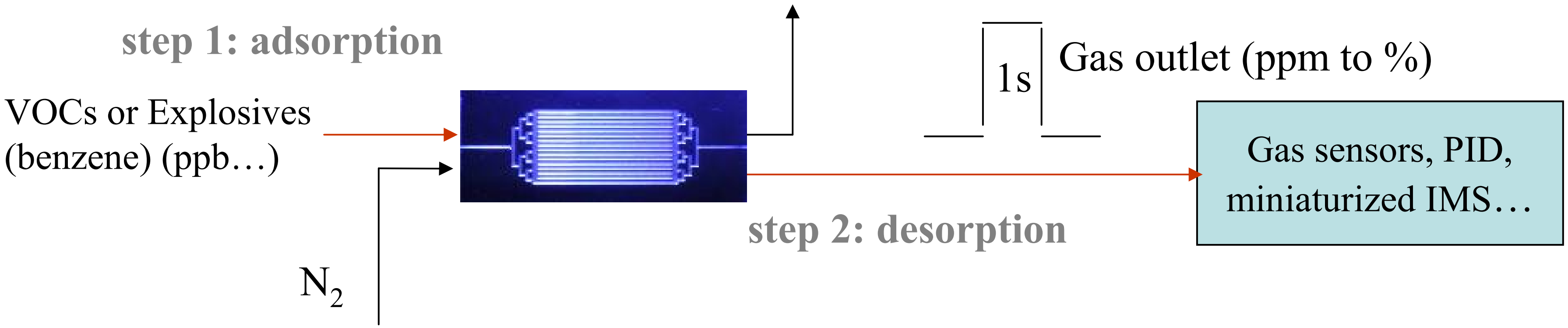


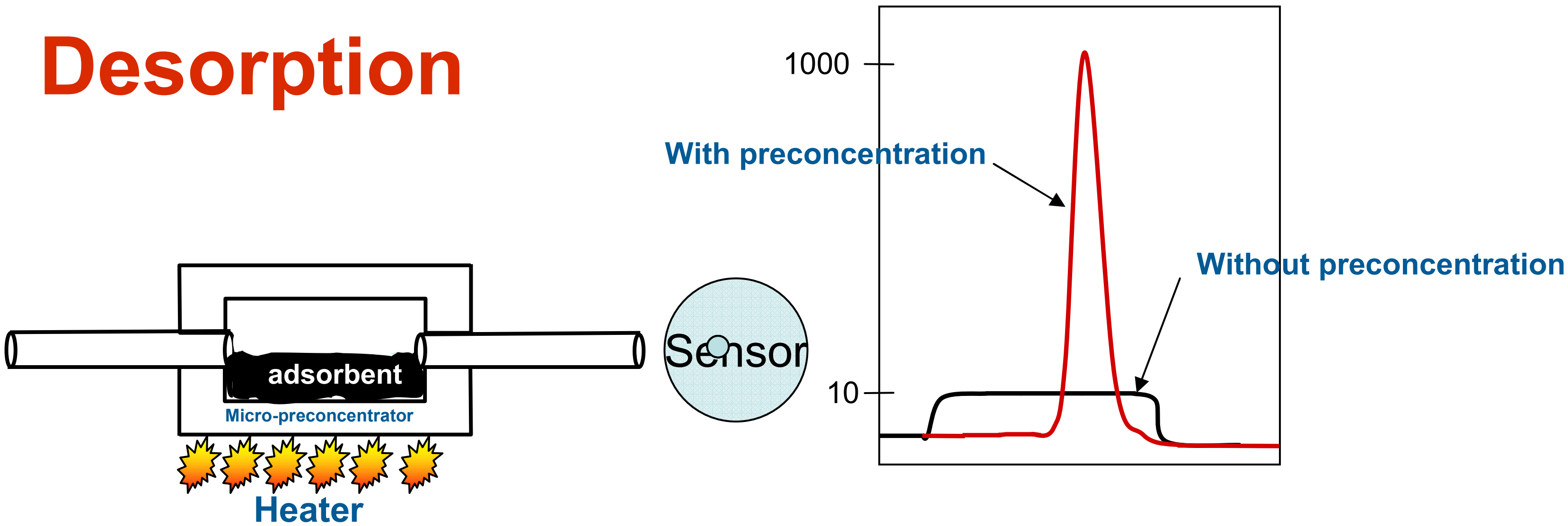
University of Michigan, WIMS μGC

Micro gas preconcentrator

- Principle of operation



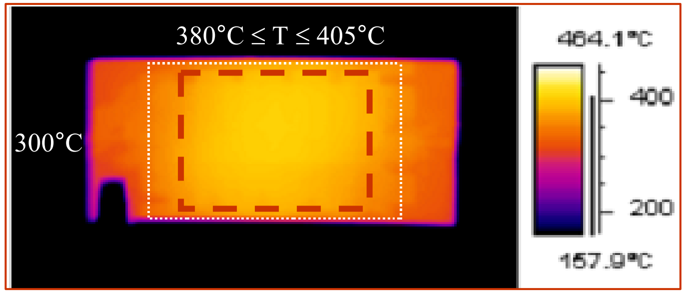
Desorption

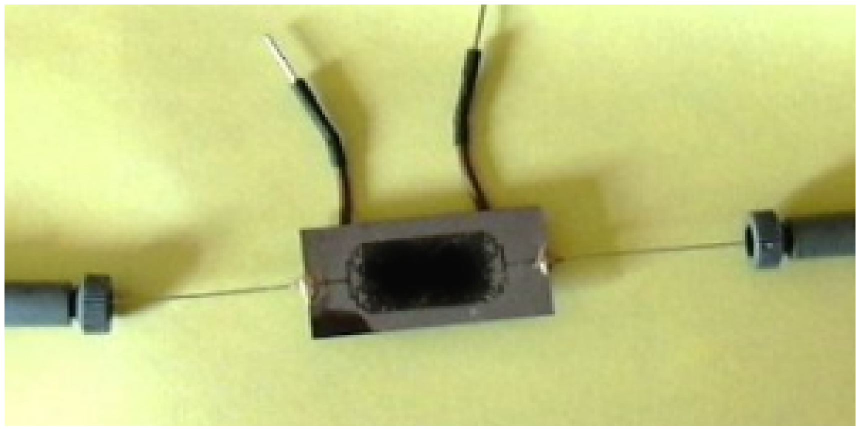


Micro gas preconcentrator

Ecole Nationale Supérieure des Mines SAINT-ETIENNE

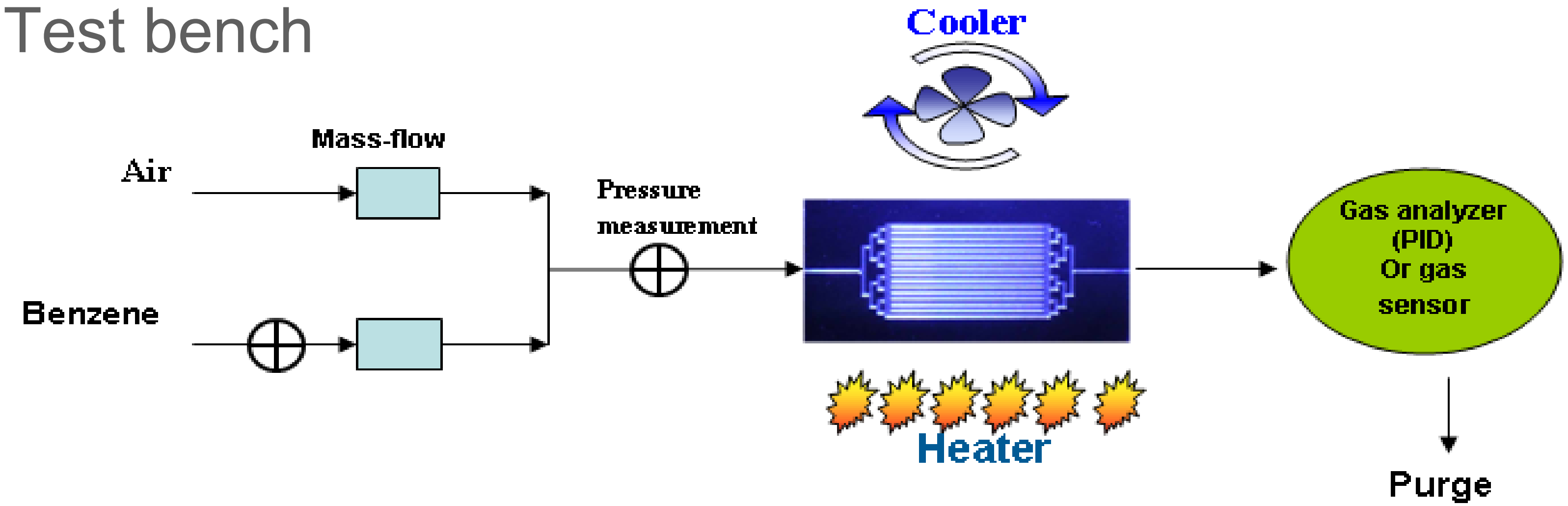
- Silicon micro-channels filled with a gas adsorbent
- Metallic fluidic capillaries (ϕ int = 250 µm) fixed with a glass frit
- Platinum heater screen printed on the back side
  - Can reach 300 to 400°C within few seconds

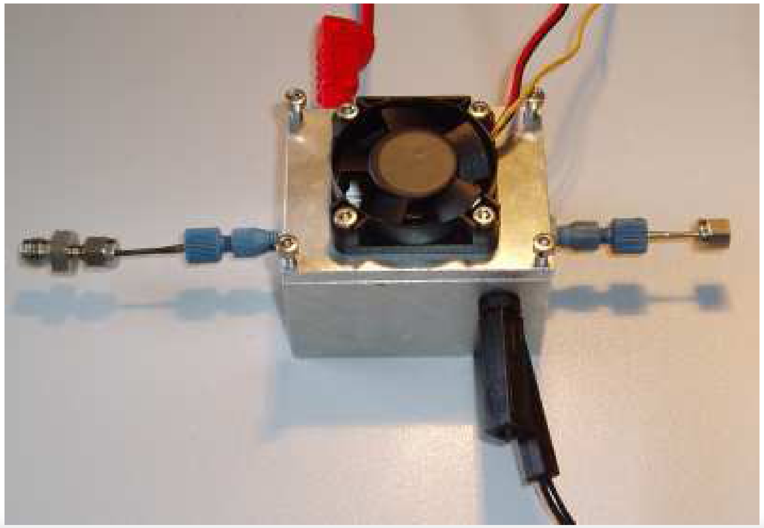


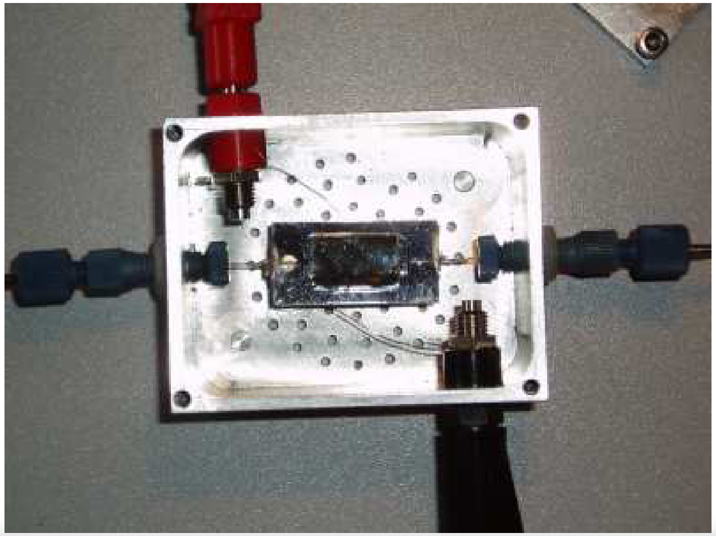


Micro gas preconcentrator

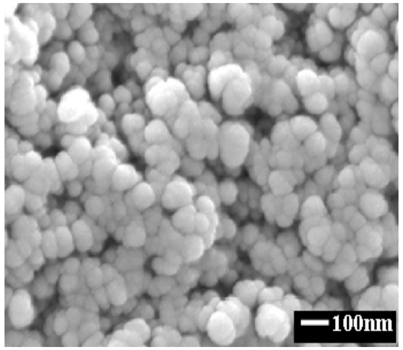
- Test bench



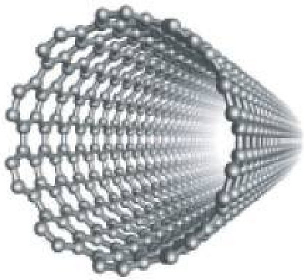




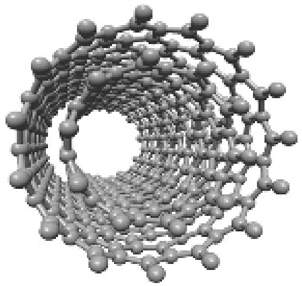
Micro gas preconcentrator



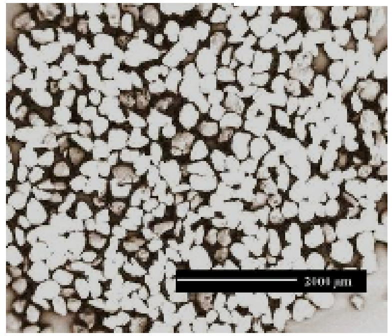
Carbon nanopowder



SWCNT

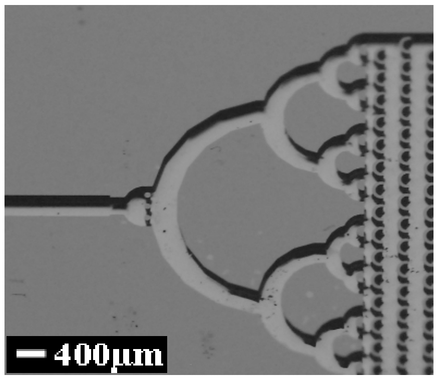


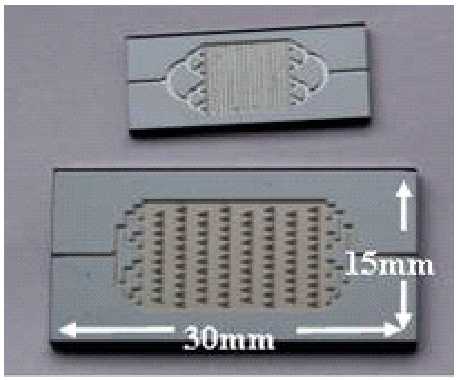
MWCNT

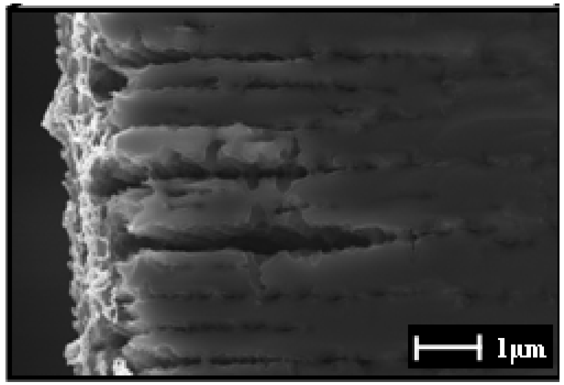


Polymer Tenax TA.

- Absorbent choice based on specific surface and affinity to gases
- Deposition method chosen according to particles size
- Test under exposure to benzene, xylene, nitrobenzene



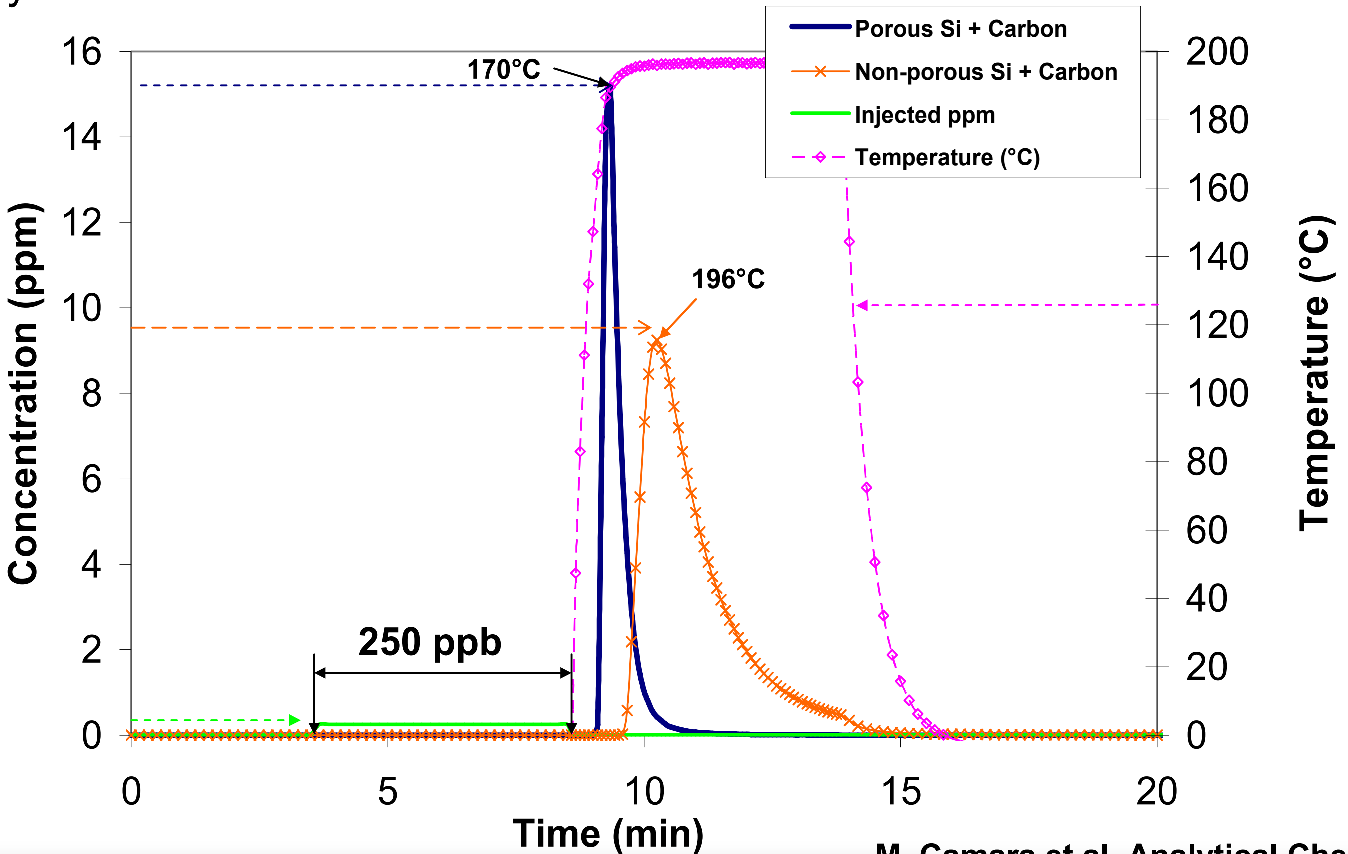




Porous Si: Micro and Macro

Micro gas preconcentrator

- Standard vs. Porous silicon
  - Flow absorption: 10 L/h, desorption: 2 L/h
  - Temperature ramp: 160°C/min
  - Cycle time: 10 min



M. Camara et al. Analytical Chemical Acta, 2010

Micro gas preconcentrator

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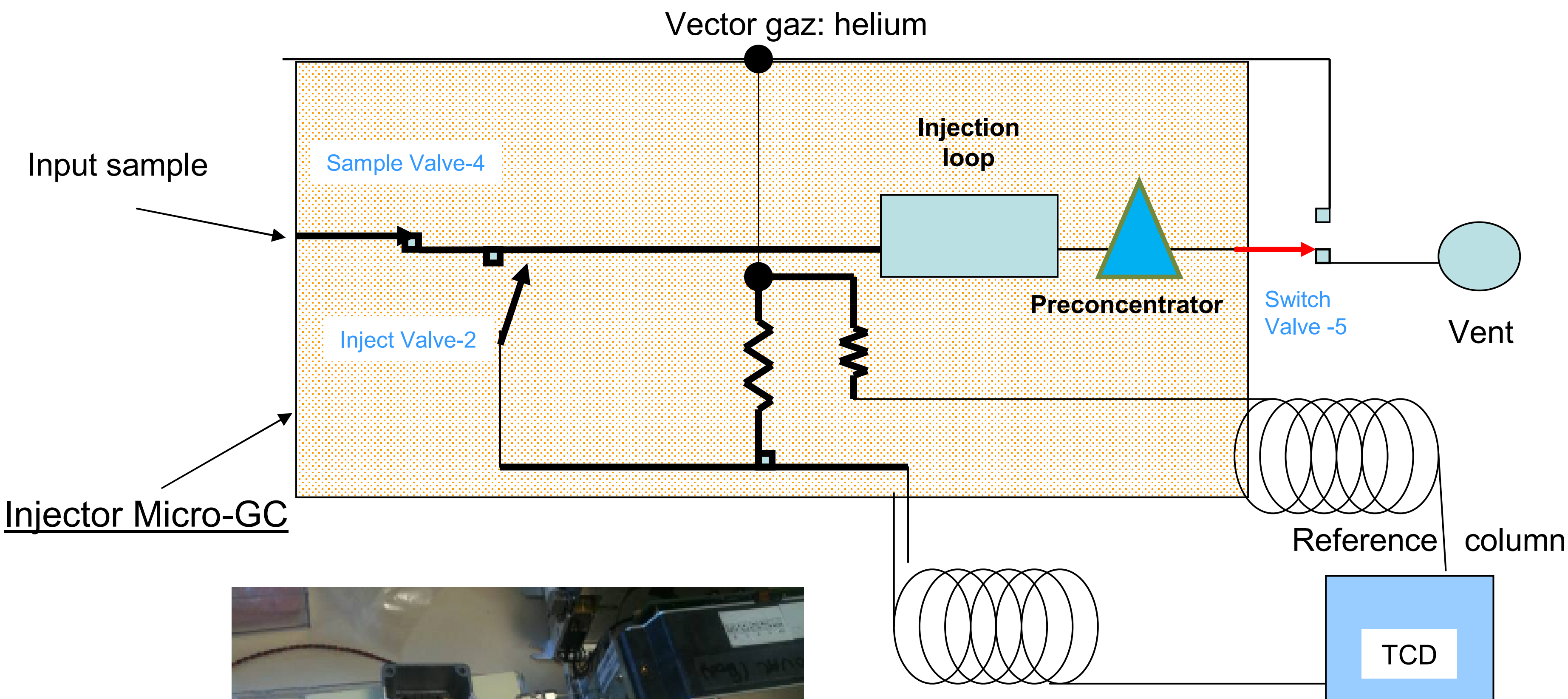
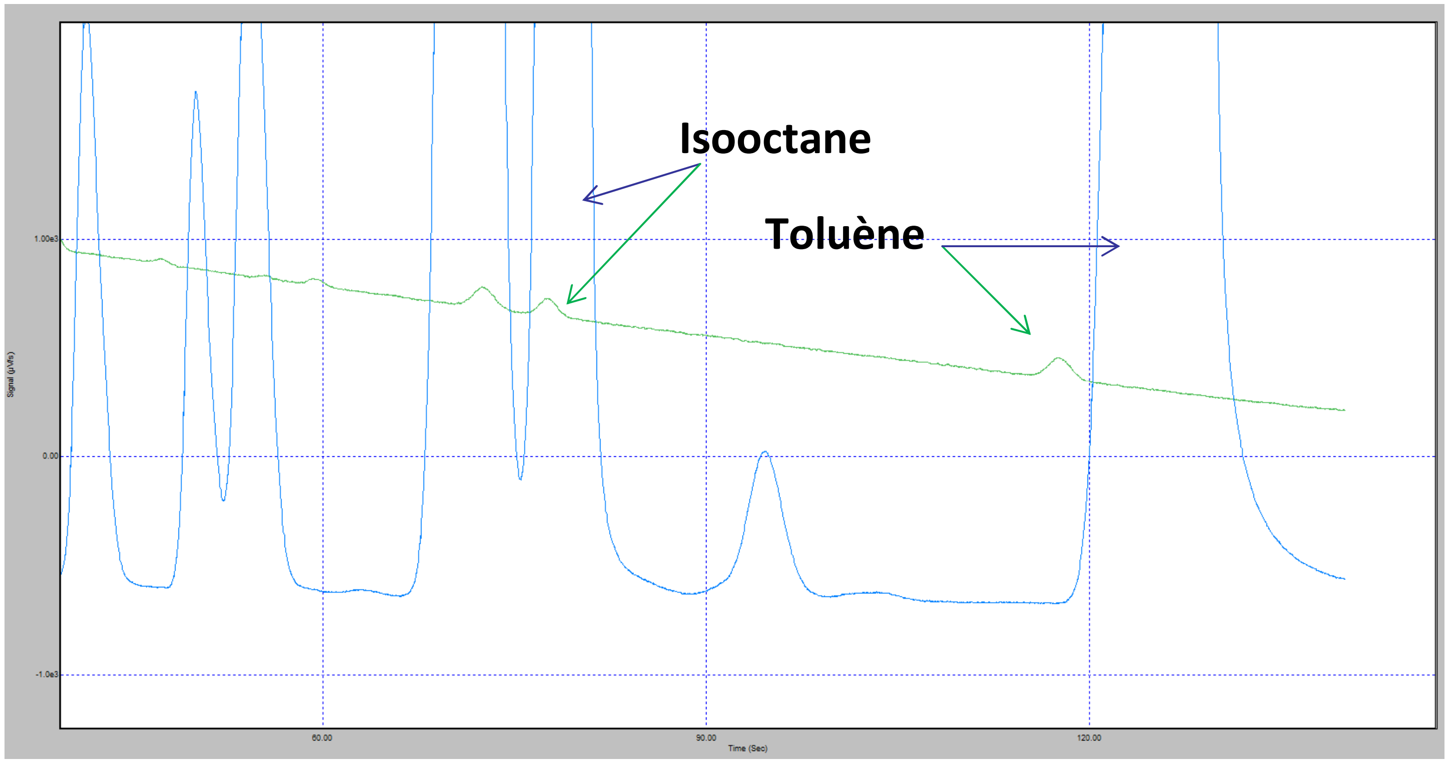
Schematic of the injector μGC with preconcentrator



Micro gas preconcentrator

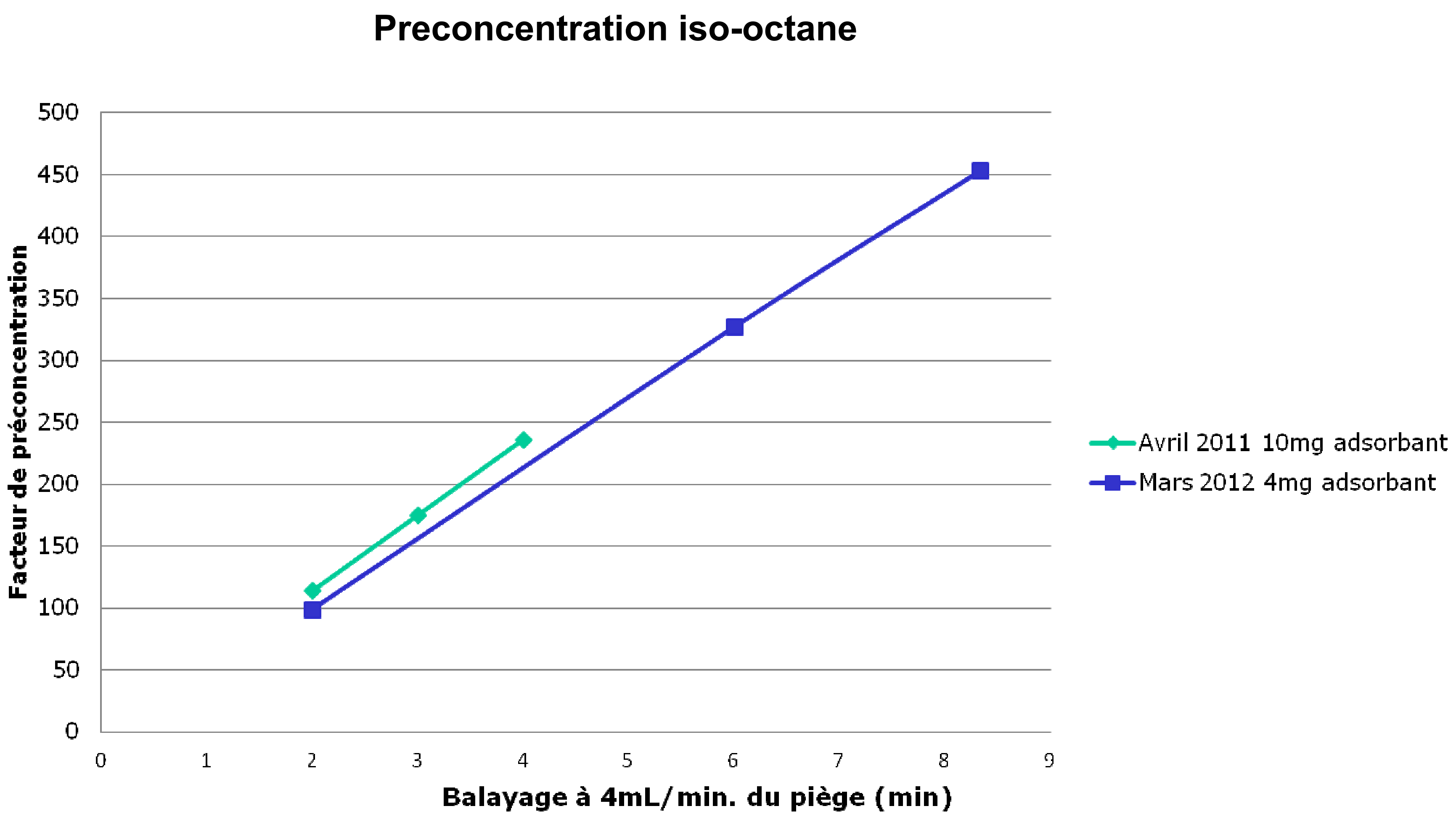
Comparison for same sample
Micro-GC alone and Micro-GC with preconcentrator

Response



Time

Micro gas preconcentrator



Micro gas preconcentrator

- Choice of absorbent and substrate depending on the target gas

Adsorbents \ Gas	Benzene	Xylene	Nitrobenzene
Carbone / Si	+++	++	
Carbone / Si macroporous	+++	+++	+ ?
SWCNTs / Si	++	+	
SWCNTs / Si macroporous	+++	++	
Tenax TA / Si	++	++	++
Si microporous	+	++	+++ ?

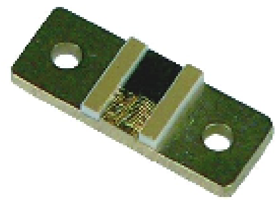
- **Carbone/Si macroporous ideal for the absorption of VOCs**
- **SWCNTs/Si macroporeux appropriate for VOCs having high vapor pressure**
- **Tenax/Si interesting for the low desorption temperature of VOCs**
- **Si microporous of high interest for VOCs with low vapor pressure**
- **Tenax and SWCNTs exhibit low affinity to water**

IR gas detection

Mid-IR spectroscopy involves IR source, gas cell, detectors

Gas detection by probing the rotational-vibrational transitions of molecules caused by the absorption of IR light

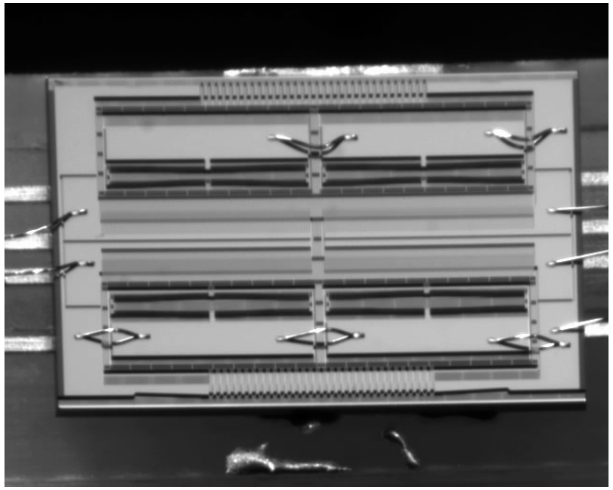
- Convential DFB laser diodes operating in the NIR
  - Transitions on higher electronic states with a low absorption probability
- Quantum cascade lasers (MIR)
  - Transitions on electronic ground states with a high probability

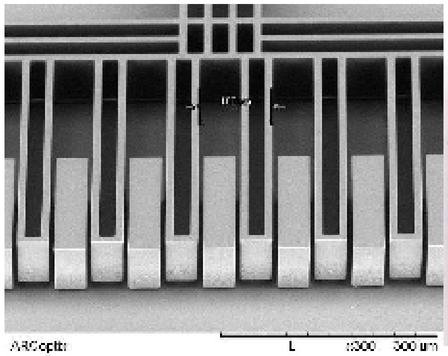


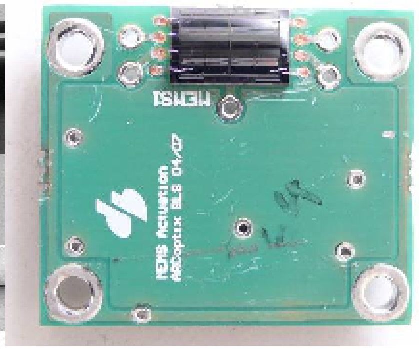
Mid-IR spectroscopy is an important gas detection technology which combines high sensitivity, fast response time, high reliability

Micro FTIR gas analyser

- Large wavelength range : 380 – 2600/4500 nm
- High resolution of 8 cm^{-1}
- Hundreds of measurements per second
- Active laser position control
- Baseline stability < 1%
- Low noise detection
- Low power consumption



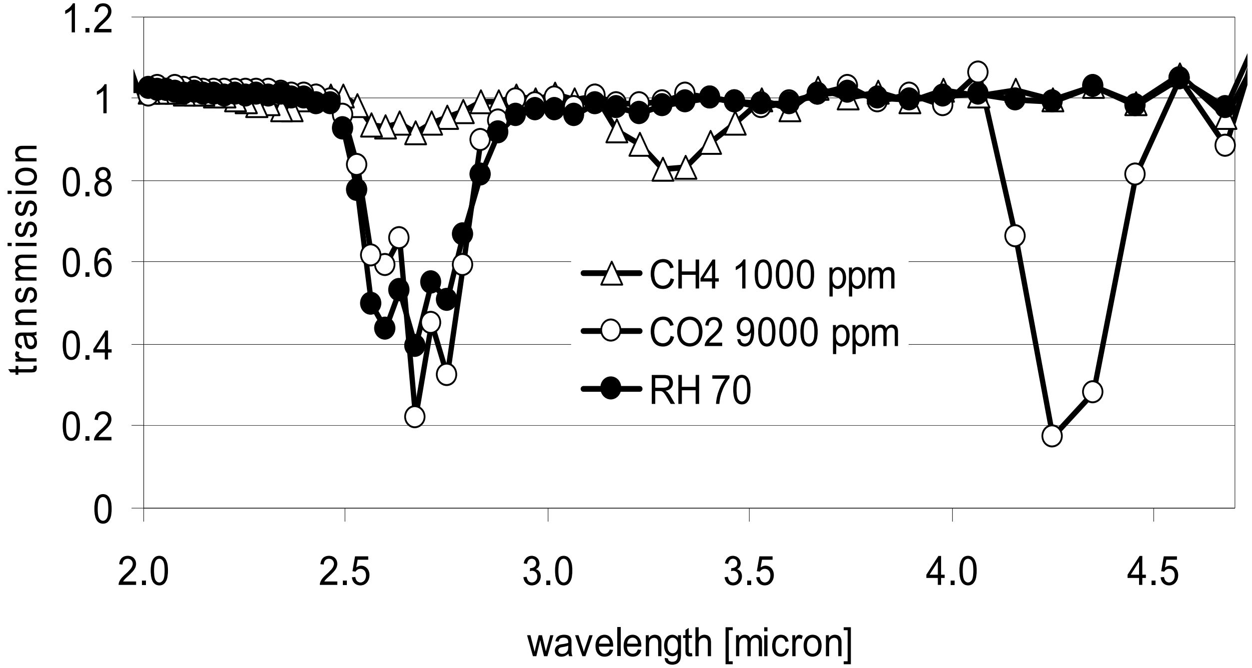




2nd generation

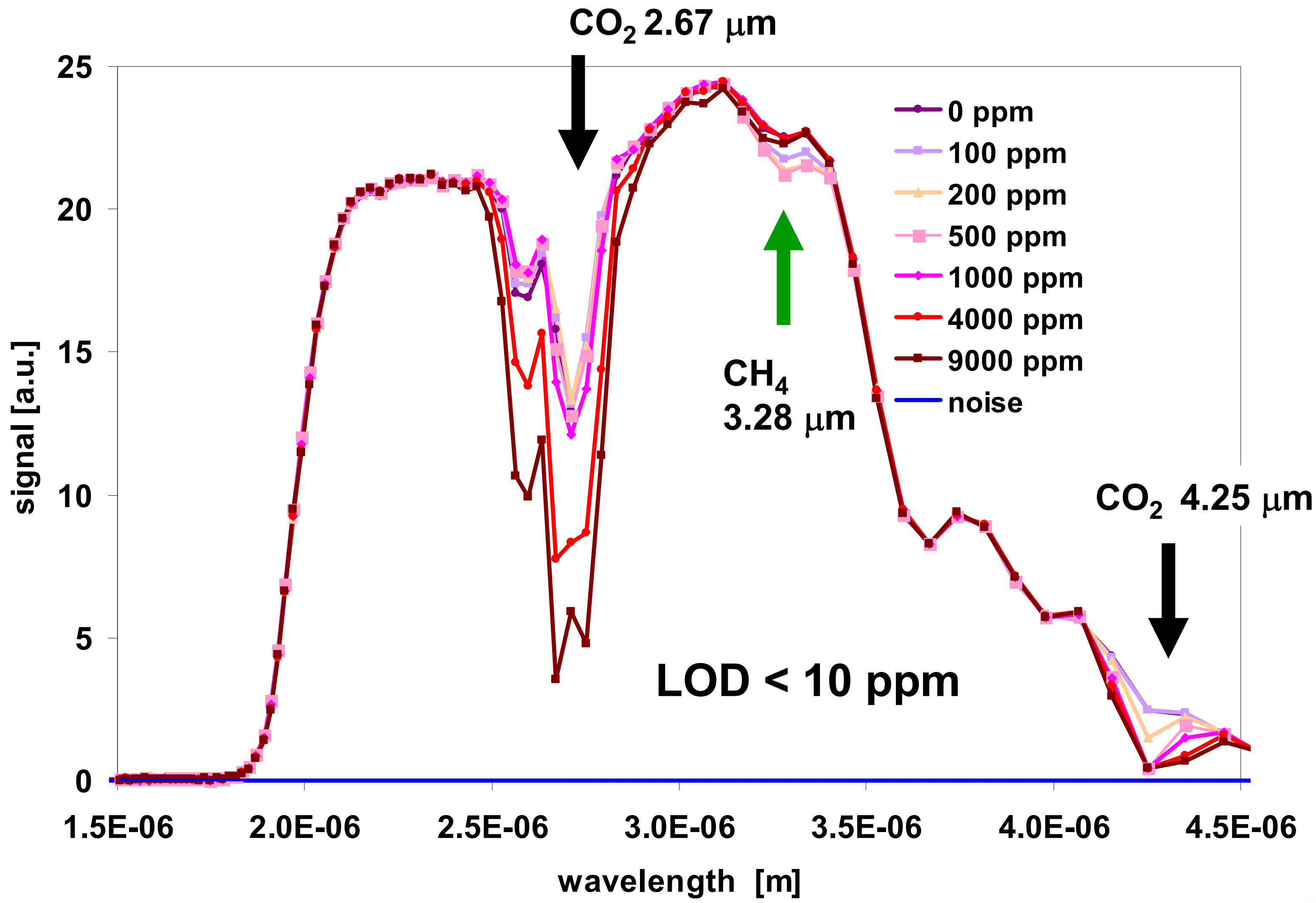
Micro FTIR gas analyser

	Carbon dioxide CO_2	Methane CH_4	Water vapor H_2O
Absorption - strengths	**2.67 µm - 1**		**2.6 – 2.8 µm**
		3.28 µm	
	4.25 µm - 10		



SNR	Time s
50	0.0025
200	0.5
>1000	**5**

Micro FTIR gas analyser



Micro FTIR gas analyser

3rd generation

ARCoptix
Switzerland

- Extended MIR Wavelength range:
  - 2-6 µm / 1500- 5000 cm^{-1} with currently used detector (VIGO PVI-2TE-5)
  - up to 10 µm (1000 cm^{-1}) is possible thanks to hollow-core IR optical fibers
  - OPD of up to 1.8 mm, corresponding to a theoretical resolution of 6 cm^{-1}

Conclusion

- **MEMS based micro-analytical instruments (w/wo gas sensors) have surely a strong potential in distributed environmental monitoring applications such as in air pollutants detection**
  - They present some advantages compared to the use of chemical sensors arrays alone
  - They could be deployed as air quality monitoring stations or mobile monitoring solutions

BUT

!!! Applicative systems design and production need to evolve according to the standards in the field of environmental monitoring in a commercially viable way

Acknowledgements

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- Dr. Toralf Scharf, EPFL, and ArcOPTIX, CH
- Udo Weimar and Nicolae Barsan, Univ. Tübingen, DE

Processing:

- CSEM Division C clean room facility
- Center for Microfabrication: CMI-EPFL

Funding: GOSPEL EU Network of Excellence, FP6