AISEM IX
Ferrara, **8-11 Febbraio 2004**

OPTOELECTRONIC SENSORS FOR AN INTEGRATED APPROACH TO ENVIRONMENTAL MONITORING

G.C. Righini, G. Cecchi, G. Nunzi Conti

Nello Carrara Institute of Applied Physics, CNR
Via Panciatichi 64, 50127 Firenze, Italy

G. Giusfredi

National Institute of Applied Optics, INOA,
Largo Fermi 6, 50125 Firenze, Italy

Environmental monitoring is certainly representing a social and economic priority, and a specific problem concerns areas with a high industrial density, that present a complex scenario, where fumes from vehicles and from heating systems combine with emissions due to the manufacturing plants.

Optoelectronic technologies may provide sensitive and/or innovative tools to monitor the different aspects of the atmospheric and water pollution in such areas: the demonstration of such a capability has been the aim of a project (**SERQUA: Se**nsori optoelettronici per il **r**ilevamento della **qua**lità dell'ambiente), based on a network of 16 partners, and funded by Regione Toscana and European Commission.

GOALS:

✓Measurement of dispersed Kyoto gas emissions from industrial and agricultural sources

✓- Remote sensing of toxins such as pathogens and chemical agents (e.g. anthrax)

BENEFITS:

✓- Support Kyoto accord

✓- Enhance security

✓- Improve quality of life

SOME NEEDS:

✓- Multidisciplinary collaborations (biology, chemistry, micrometeorology)

✓- Advanced sources and detectors, …**OPTOELECTRONICS**

Excerpt from a document of the ***Canadian Institute for Photonics Innovation***

www.ifac.cnr.it/serqua

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SERQUA Project

Proposer: *Istituto di Fisica Applicata Nello Carrara*

Coordinator: *Giancarlo C. Righini*

Participants:

ARPAT- Agenzia Reg. per la Protezione Ambientale della Toscana; Prato
CEO – Centro di Eccellenza Optronica, Soc. Consortile; Firenze
CII Pistoia - Centro di Impresa e Innovazione s.c.r.l.; Pistoia
CONSER - Consorzio Servizi del 1° Macrolotto Industriale di Prato sccrl;
El.En. - Electronic Engineering S.p.A.;
Eurobic Toscana Sud S.p.A.; Poggibonsi
Firenze Tecnologia, Azienda Spec. Camera di Commercio di Firenze;
Flyby S.r.l.; Livorno
Galileo Avionica S.p.A.; Campi Bisenzio
Idea I.S.E. s.n.c.; Prato
IDRA - Interventi di Riciclo Acque sccrl; Prato
INOA – Istituto Nazionale di Ottica Applicata; Firenze
Kayser Italia S.r.l.; Livorno
LENS, Laboratorio Europeo di Spettroscopie Non-lineari, Univ. di Firenze;
Dip. Ingegneria dell'Informazione, Università di Pisa.

4 Research Institutes & Universities, 2 Public Agencies, 7 Companies, 3 Consortia

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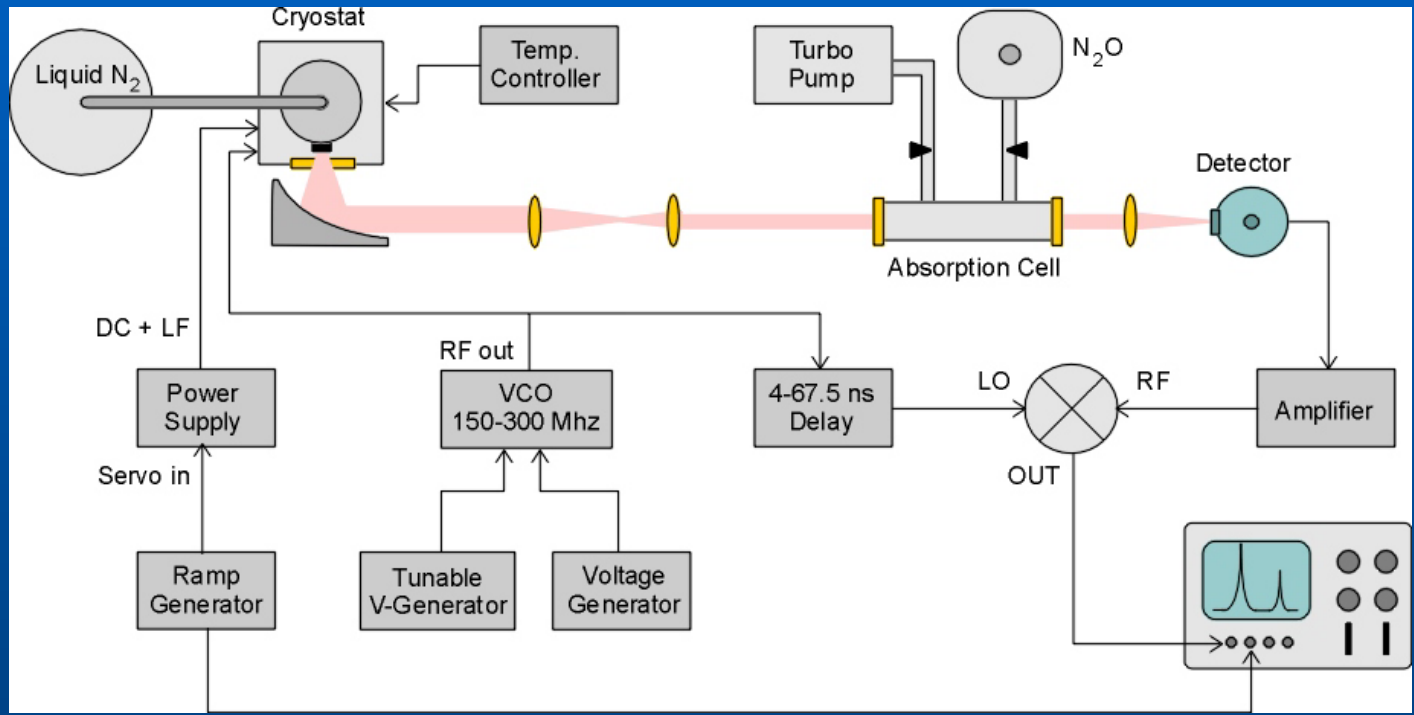
Main goals of the project:

- a prototype of spectroscopic sensor with quantum cascade laser (INOA, LENS)
- a prototype of microspherical sensor (IFAC)
- a prototype of an ATR sensor (IFAC, Galileo Avionica)
- a fiber optic miniaturized spectrophotometer (IFAC)

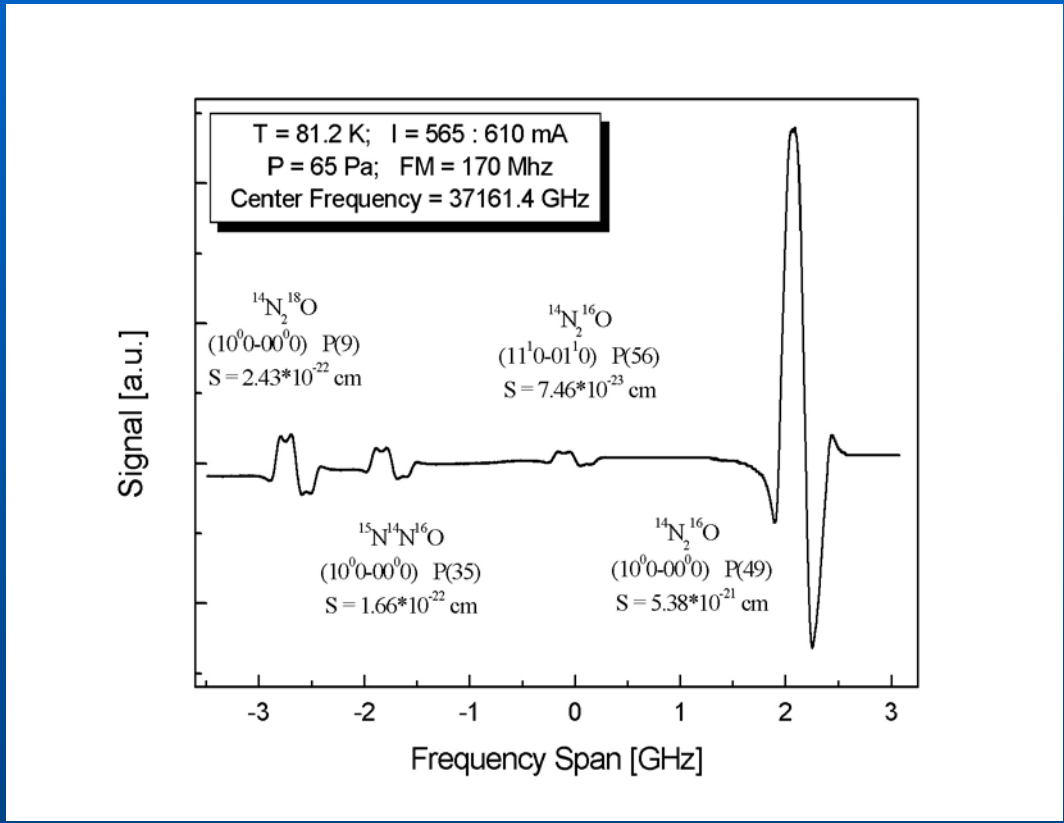
- **An integrated system of environmental monitoring**

(IFAC, INOA, El.En., Idea ISE, ….)

Spectroscopic sensor using a quantum cascade laser



The experimental setup for the monitoring of traces of gases in atmosphere uses a quantum cascade laser diode, that operates at –200 °C (inside a cryostat) and emits ~ 50 mW at the wavelength of 8.1 μm. In this spectral region the absorption lines of the molecules under analysis (e.g. CH_4, N_2O, NO_2) are almost two orders of magnitudes stronger than their harmonics, which are observed in the visible region.

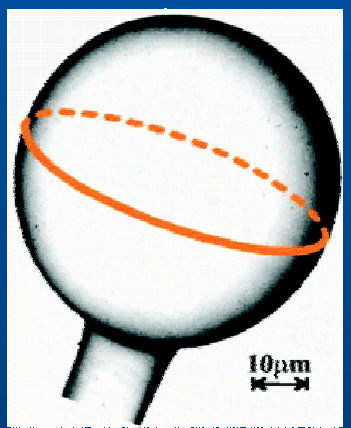


In the figure some absorption lines of the N_2O molecule are shown: one can notice the very good signal-to-noise ratio. The gas pressure in the measurement cell was 500 mTorr, the operating temperature of the laser was 81.20 K, and the electrical current was varied between 565 e 610 mA.

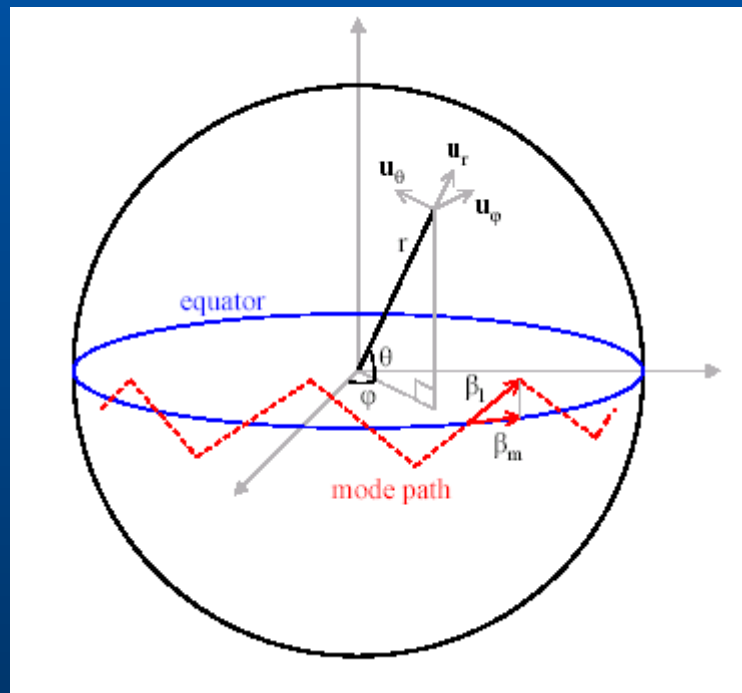
Microspherical sensor

The use of glass microspherical resonators (diameter between 30 and 150 μm) coupled with tapered fibers may allow the development of a very compact sensor with very high sensitivity both for gases and liquids.

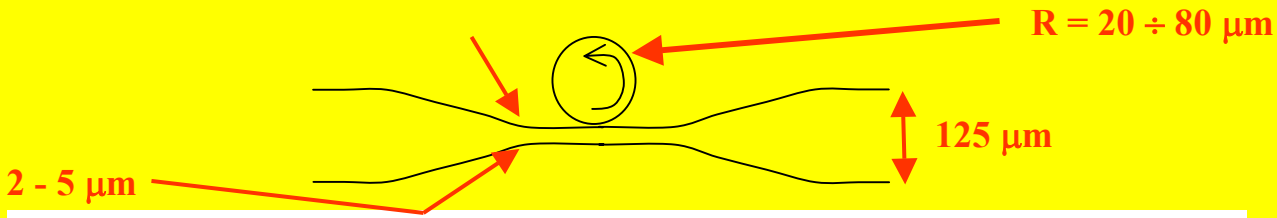
Spherical dielectric microresonators: "whispering gallery modes"



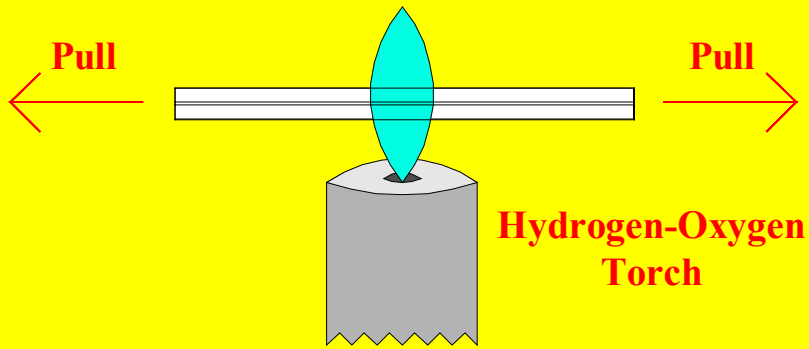
The quality factor $Q=\omega/d\omega$ of a microspherical resonator in pure silica reaches very high values, up to 10^{10}. When the light at a resonating frequency is attenuated by an external gas or liquid, the value of Q drops very rapidly, so that even very small quantities of chemical species may be detected.

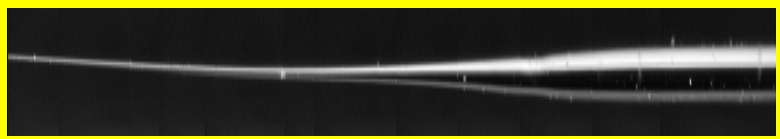


Light coupling into a microsphere occurs via a prism or a tapered fiber

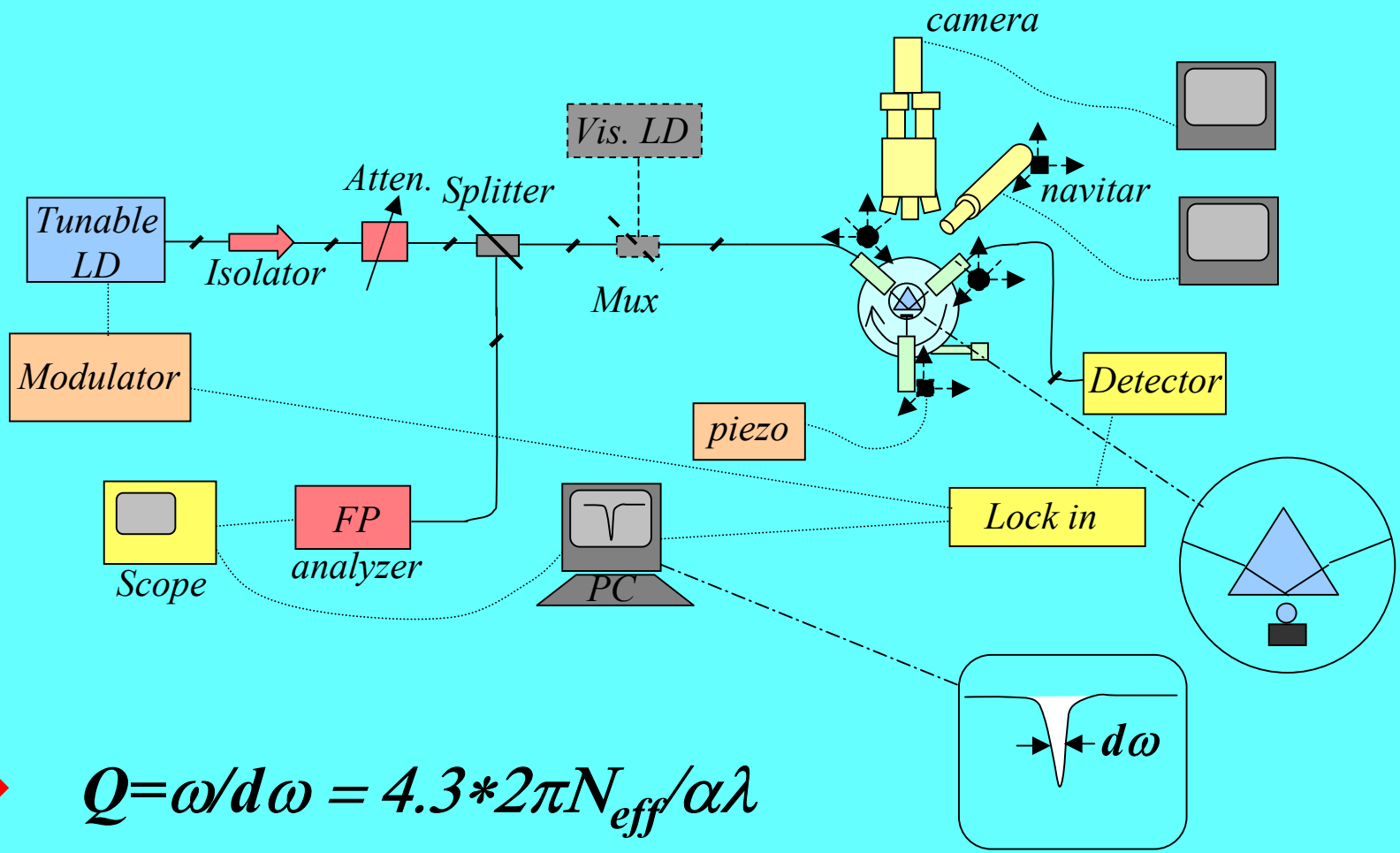


Coupling between a tapered fiber and a microsphere.





Experimental setup for the measurement of the quality factor Q



➔ $Q=\omega/d\omega = 4.3*2\pi N_{eff}/\alpha\lambda$

Remote and in-situ measurements of environmental parameters in an industrial area by using active and passive optoelectronic sensors

- Test areas:
  - 1° Macrolotto industriale, Prato
  - Water recycling plant at Baciacavallo, Prato.
- Sensors:
  - Lidar systems (elastic backscattering, and fluorescence spectroscopy)
  - DOAS sensors
  - TDL sensors
  - UV-VIS radiometers
  - *in situ* fiber-optic sensors

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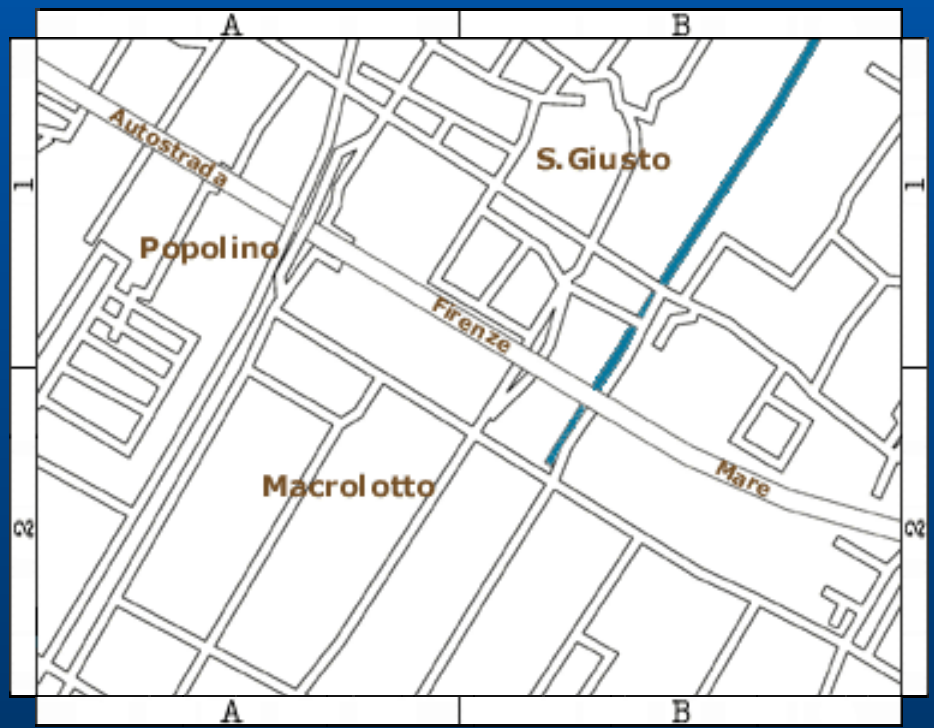
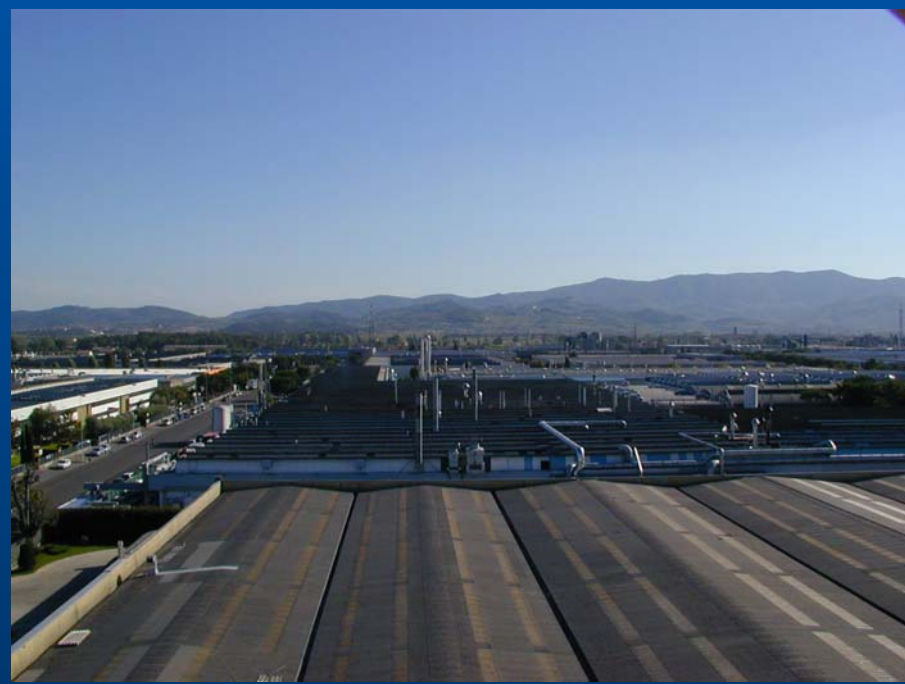
The selected test industrial area (Macrolotto 1, Prato) is close to Firenze: it includes more than 300 SMEs, mostly active in various phases of textile industry (weaving, washing and drying, dying, etc,).





Atmospheric monitoring

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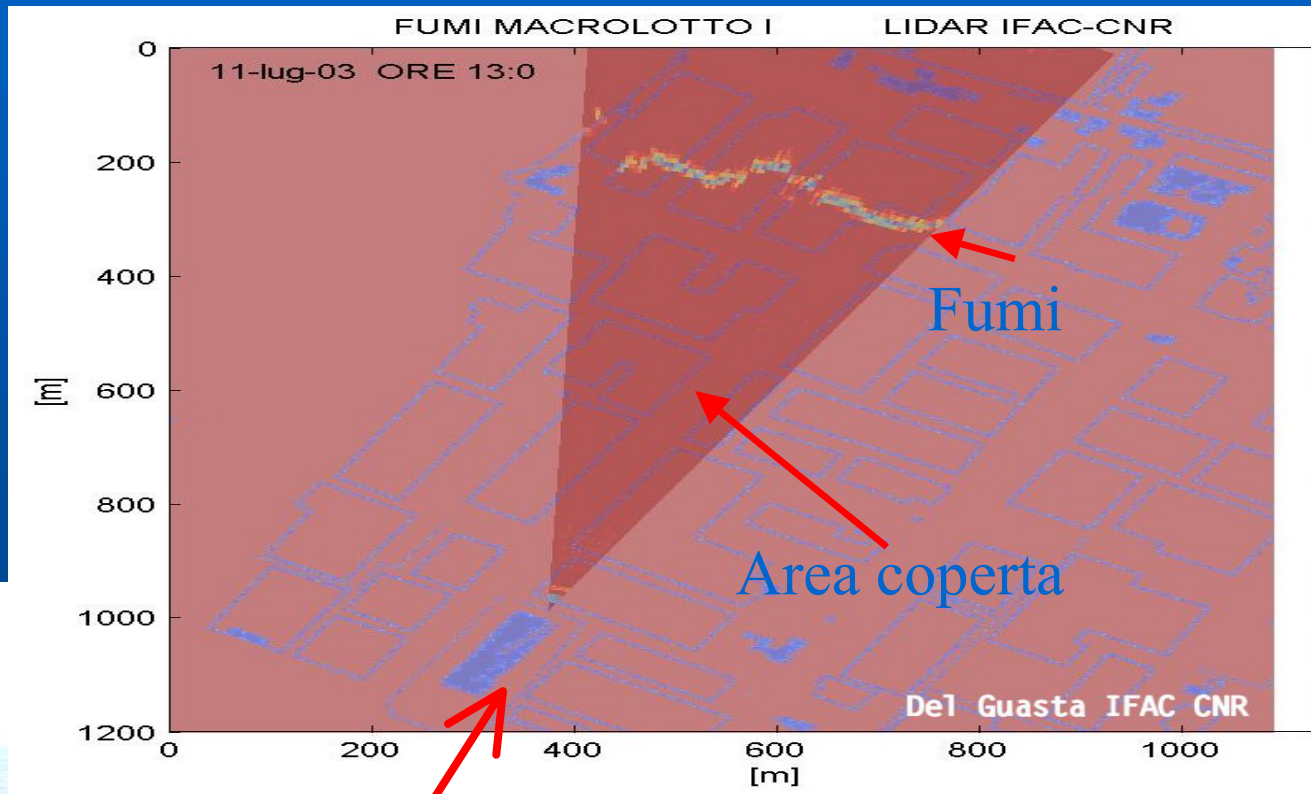
della QUalità
dell'Ambiente

Il LIDAR nel MACROLOTTO (m.delguasta@ifac.cnr.it)

One of the goals of the measurement campaign was to demonstrate the feasibility of a continuous monitoring and mapping (e.g. on a horizontal plane) the particulate emissions by using an elastic back-scattering LIDAR.



Characterization of solar radiation at ground level for atmospheric analysis and photobiological parameters

- Direct measures of global horizontal irradiance and of UV erythemic irradiance
- Indirect assessment of:
  - columnar quantity of ozone
  - atmospheric turbidity / aerosols
- Assessment of the photobiological effects due to the UV radiation reaching the ground

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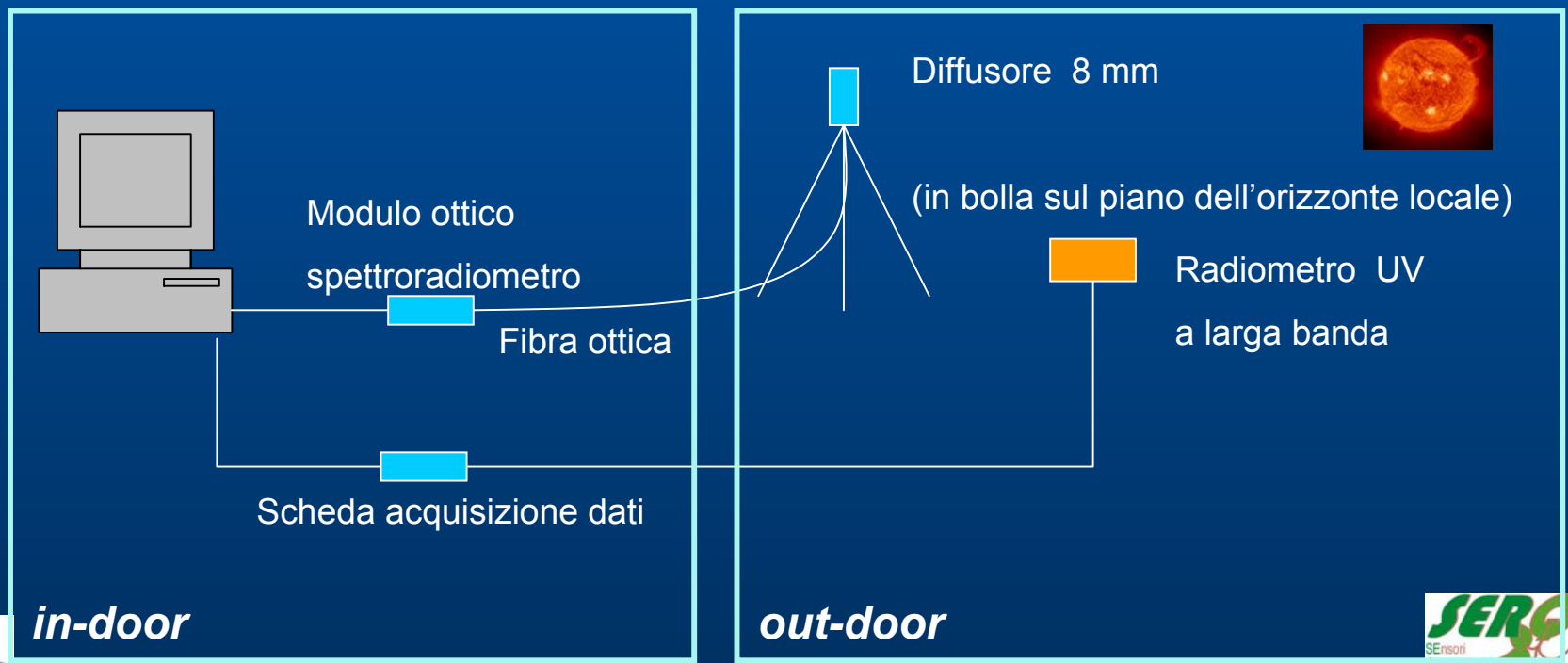
applied research solutions

Flyby

- **UV-VIS spectroradiometer in the 300-600 nm band**
- **Wideband (290 - 330 nm) radiometer**
- **Dedicated software (SpectrAir, EnvMon)**



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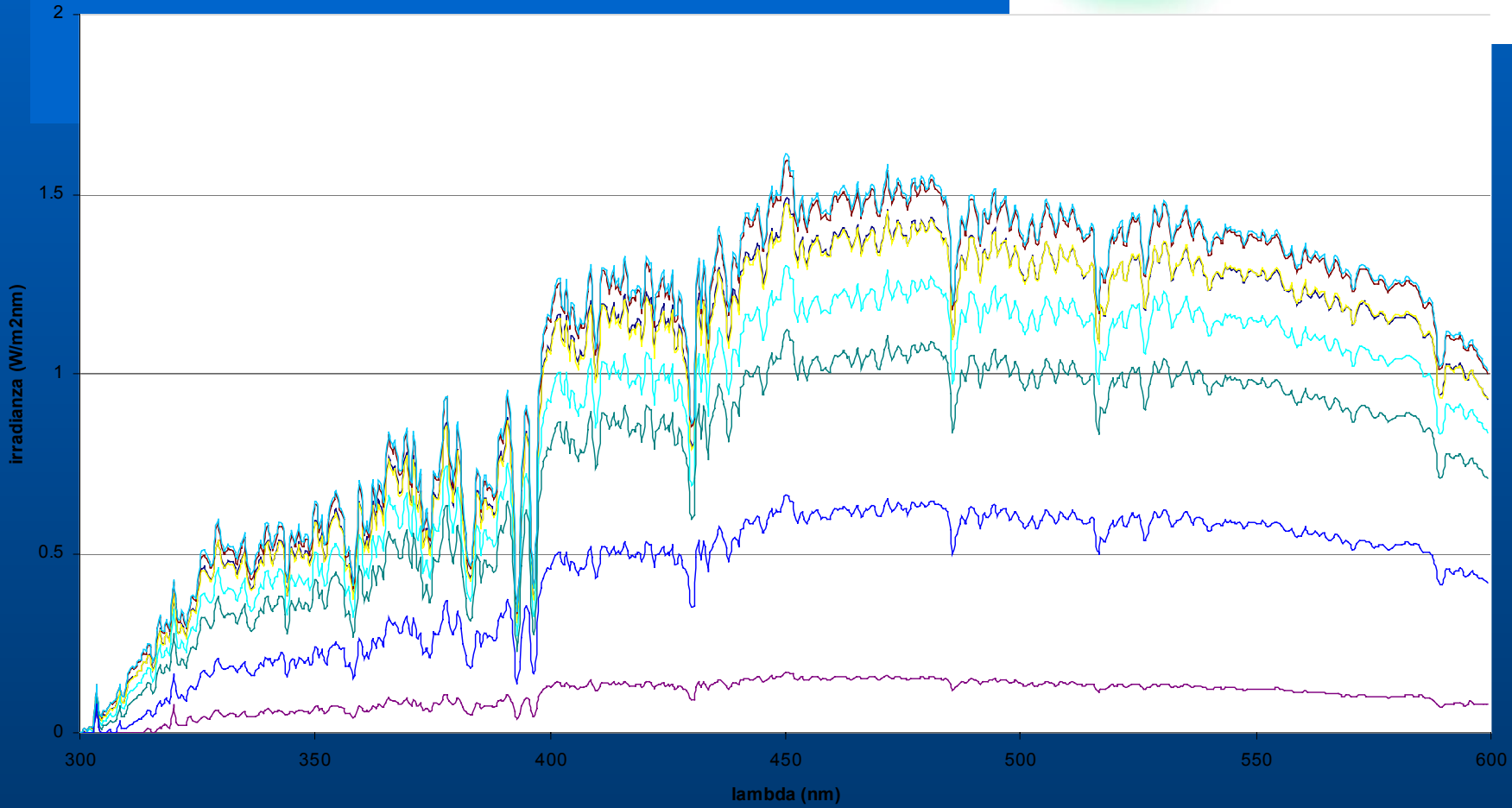
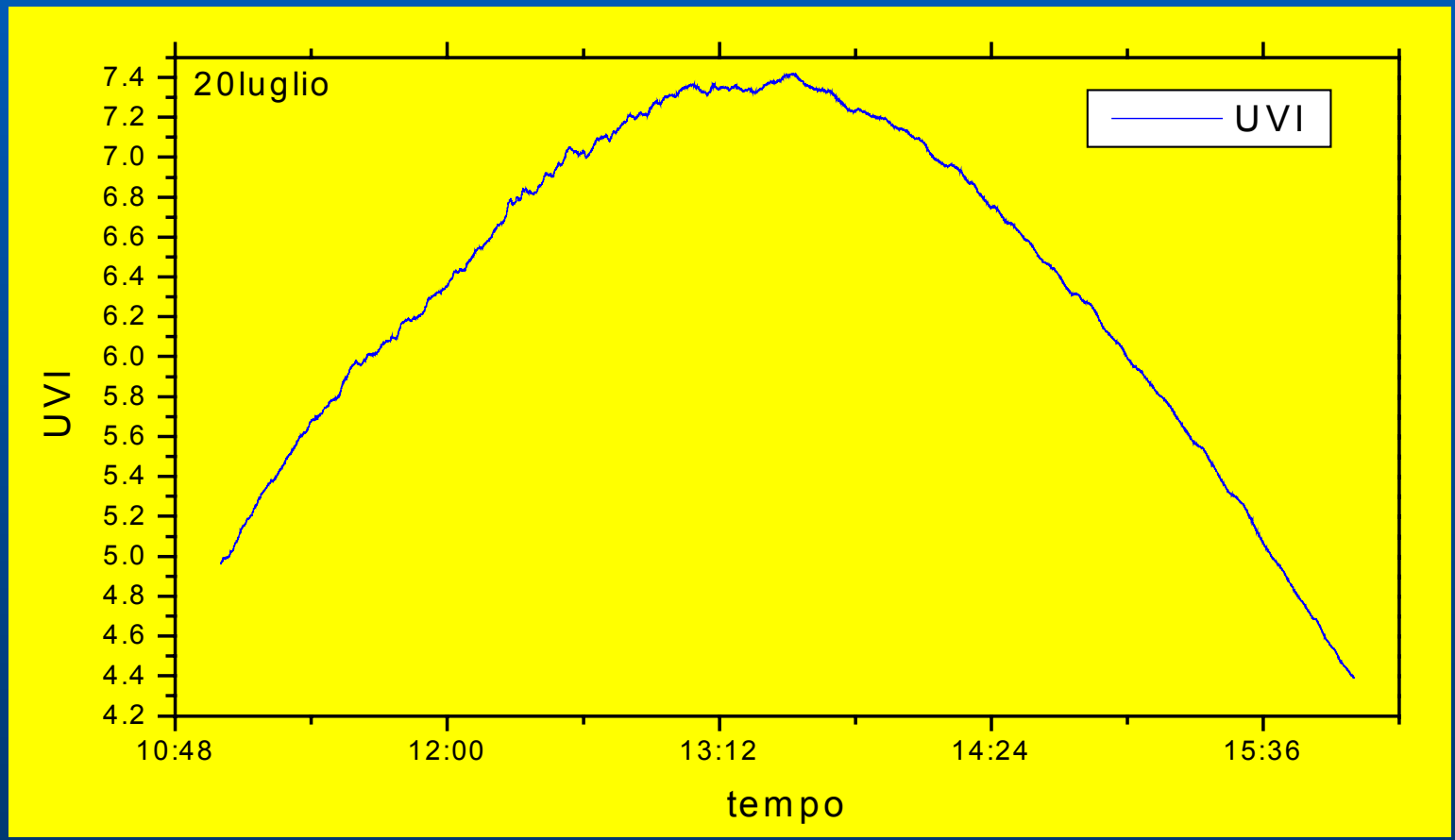
della QUalità
dell'Ambiente

Global horizontal spectral irradiance



data obtained at different day hours with clear sky (every 15 minutes; spectral resolution: 0.5 nm)

UV erythemic irradiance



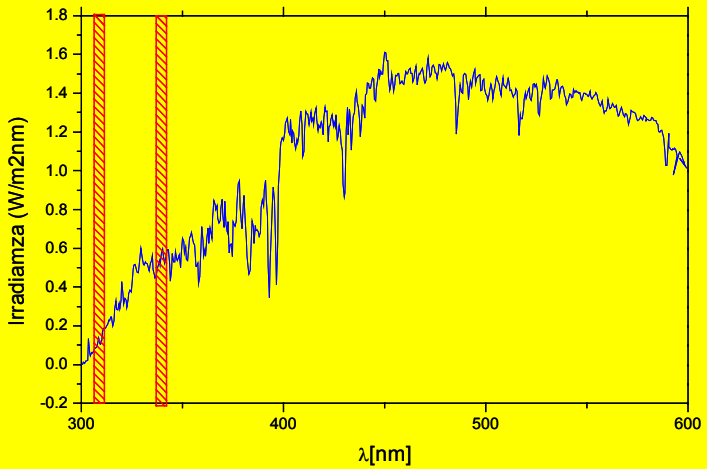
Time behaviour of the UV index in a clear sky day (measured every second)

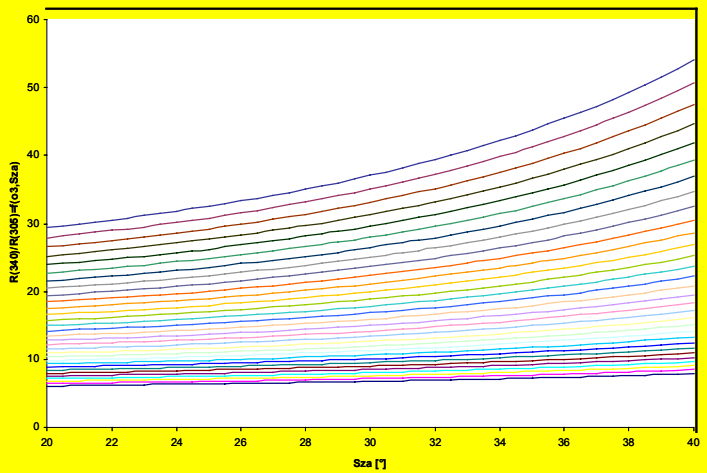
Atmospheric analysis

applied research solutions

Flyby

Columnar quantity of ozone is determined by the ratio between the values of global horizontal irradiance at 305nm and 340nm





A model of radiative transfer is used, that takes into account the absorption of radiation by the atmosphere.

Additional algorithms are being developed to determine aerosols concentrations and the optical thickness of the clouds.

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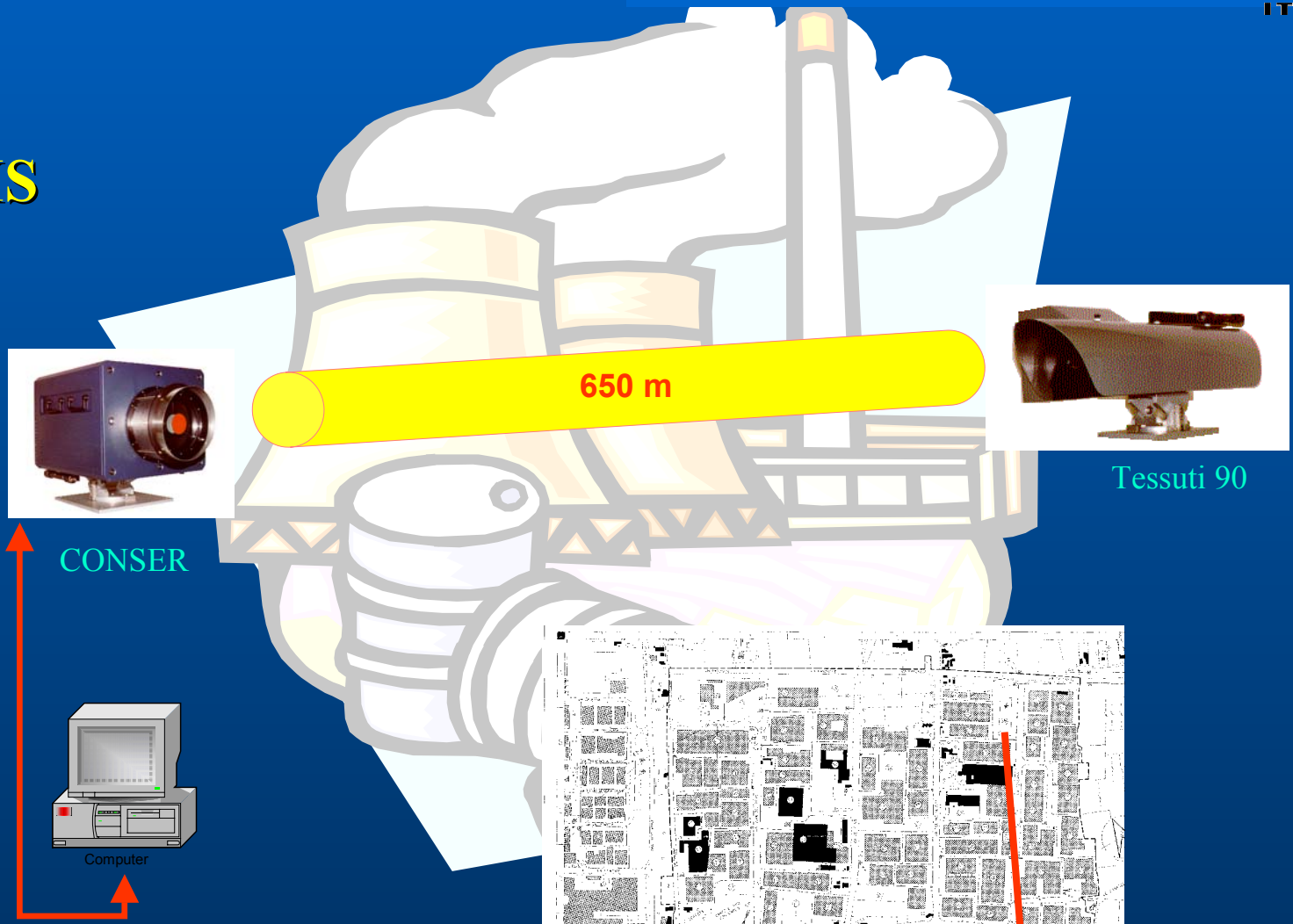
Differential Optical Absorption Spectroscopy:

positioning of the *SPOT*® instrument in the Macrolotto……

KAYSER ITALIA

UV-VIS



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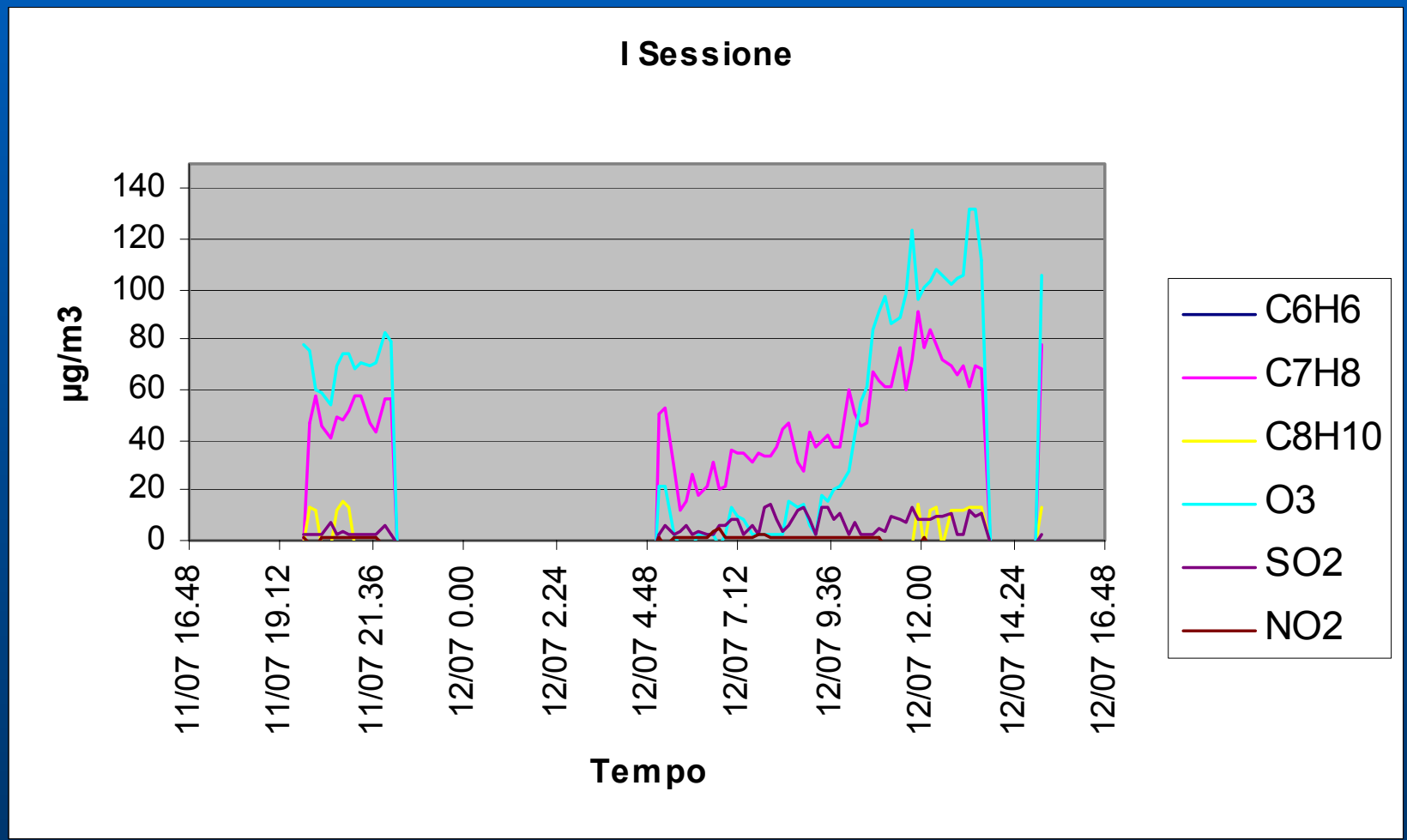
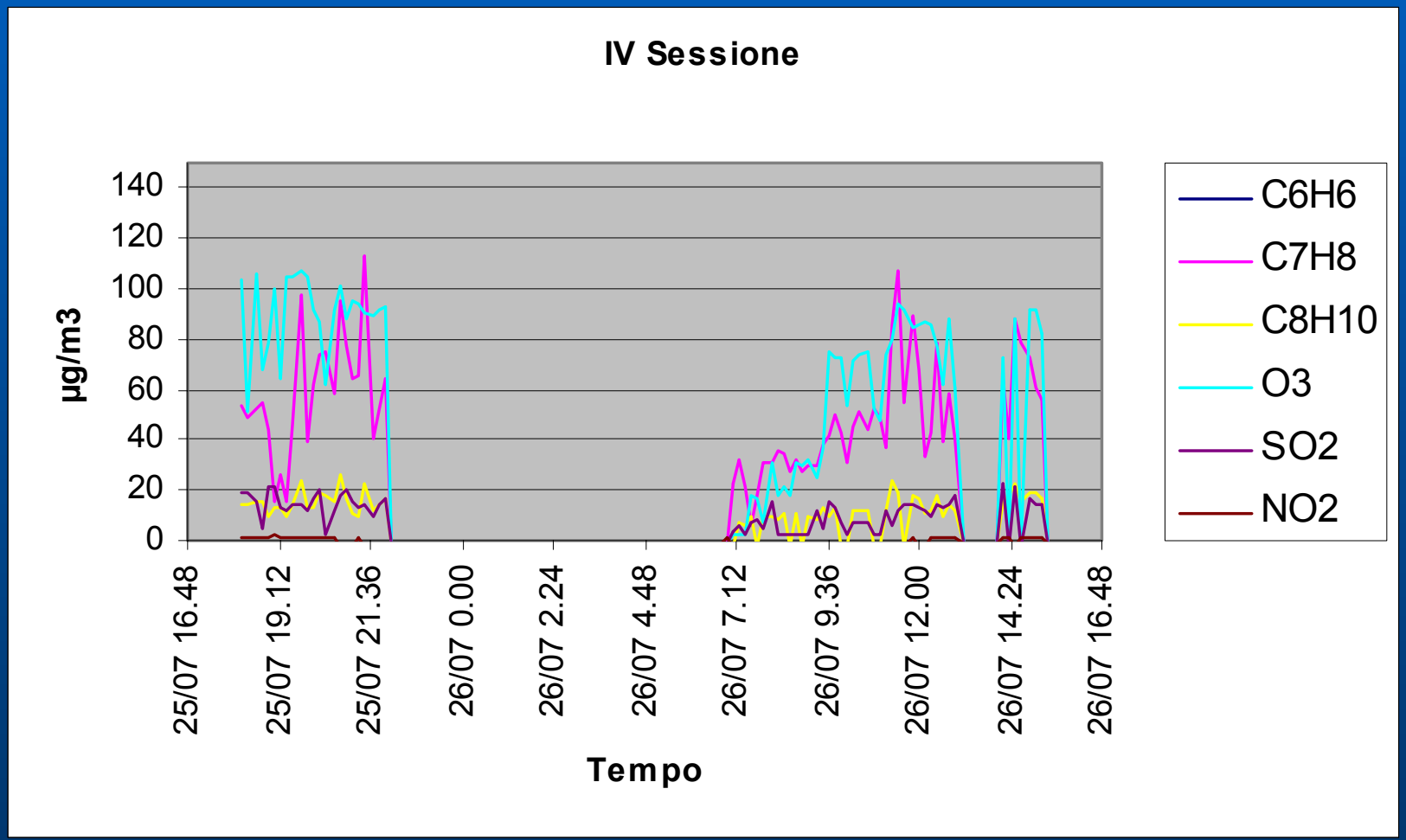
Benzene, Toluene, Xilene, Ozono, Biossido di zolfo, Biossido di azoto

Measurements on 11-12July 2004

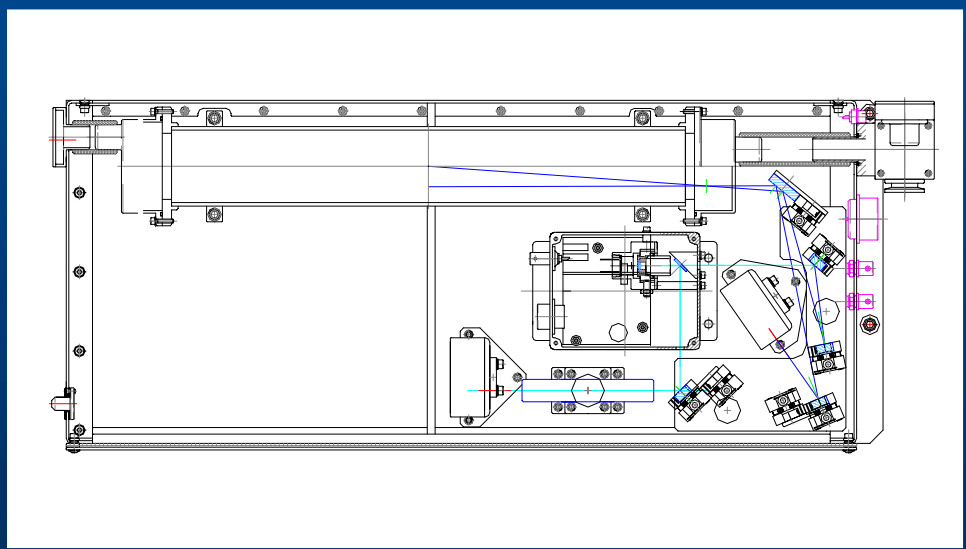


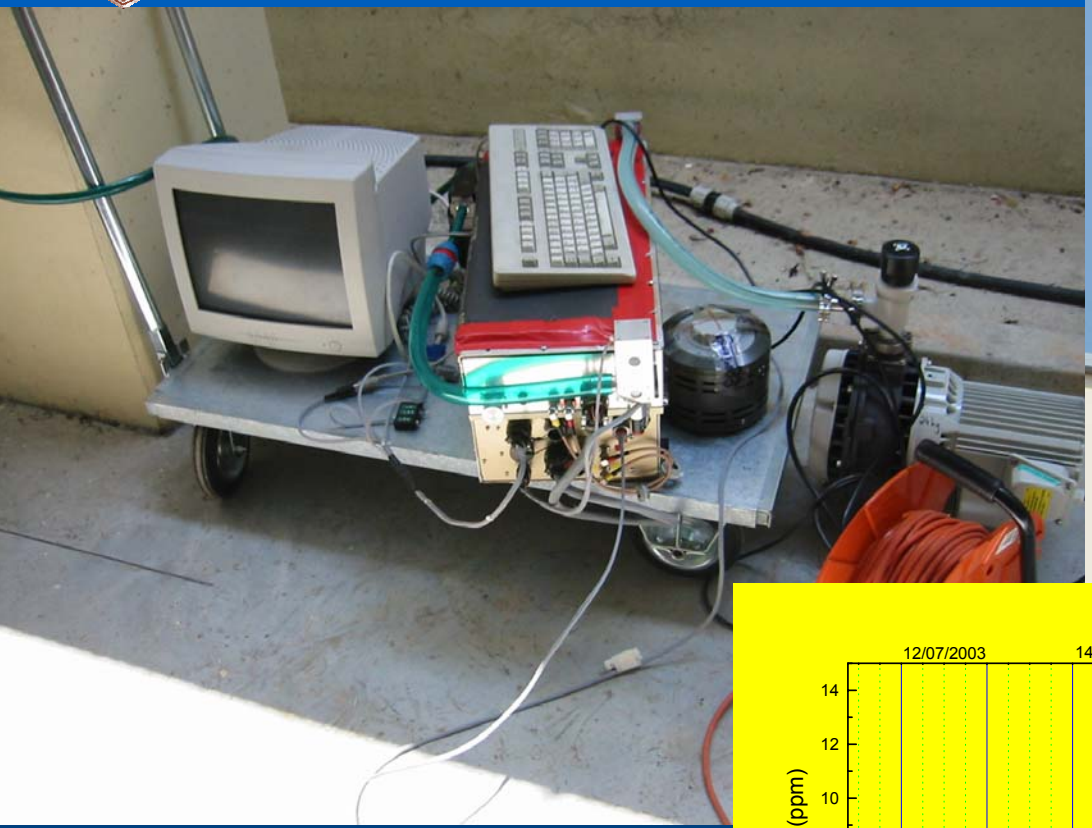
Measurements on 25-26July 2004

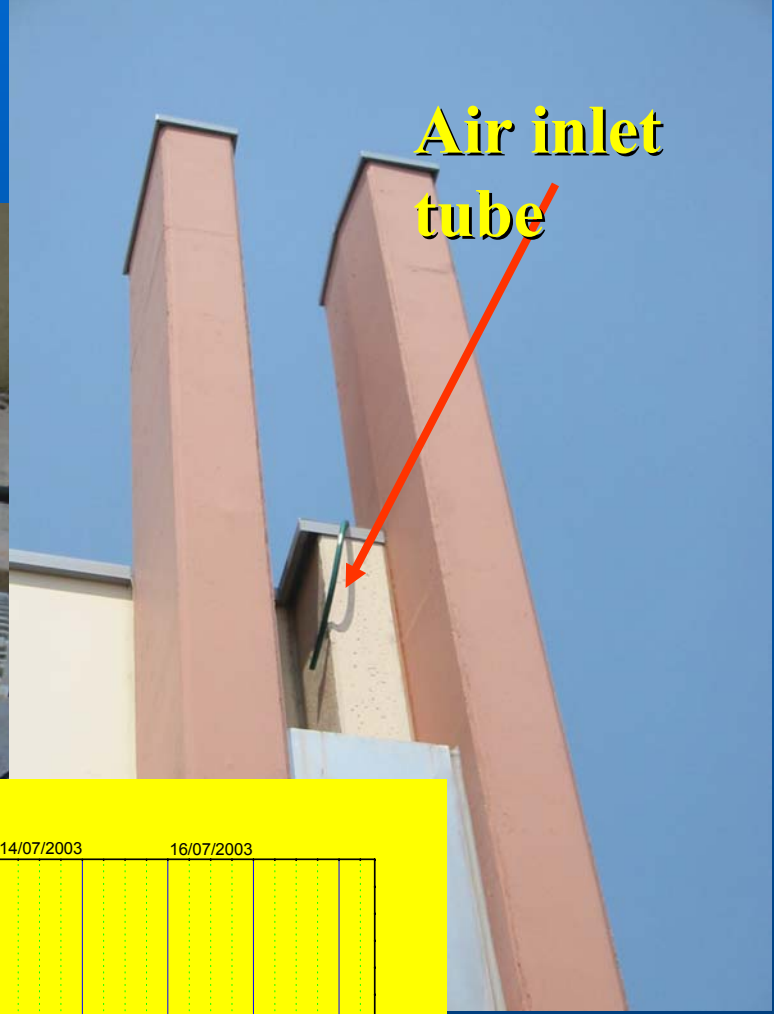


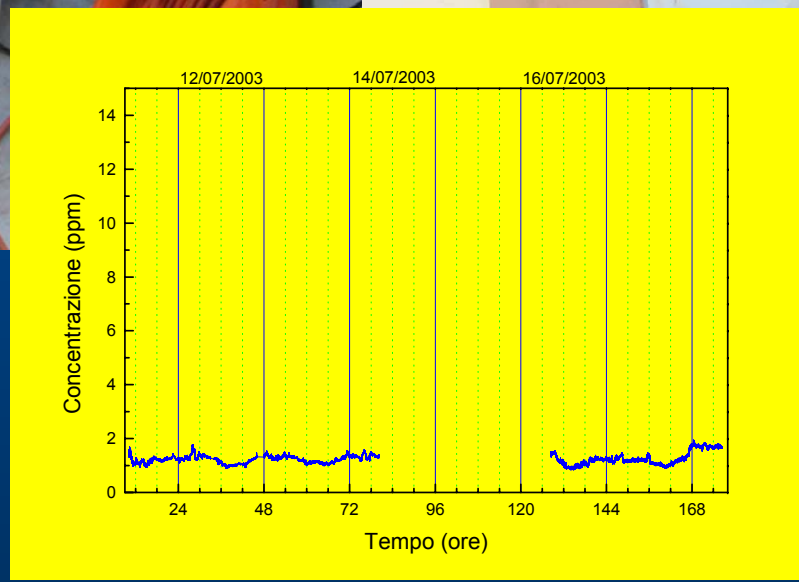
Measure of the CH_4 atmospheric concentration

CH_4 is usually present in the atmosphere at a concentration of about 2 ppm. It is due to natural phenomena (e.g. decomposition of biomaterials) and to human activities, including cars with methane-adapted engines. The sensor is a spectrophotometer with a tunable laser diode (TLD) source. Here, absorption at 1.65 μm is measured along a multipass cell, with equivalent length of 30 m.

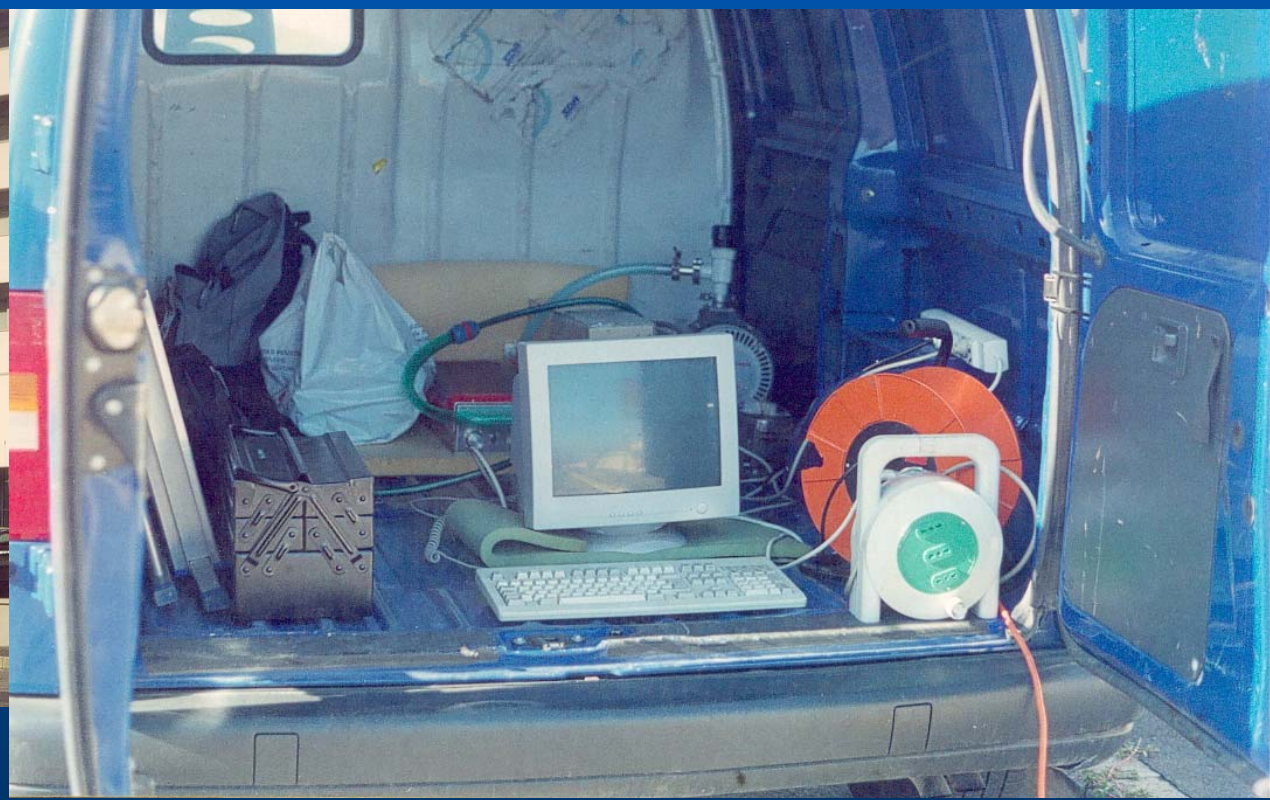




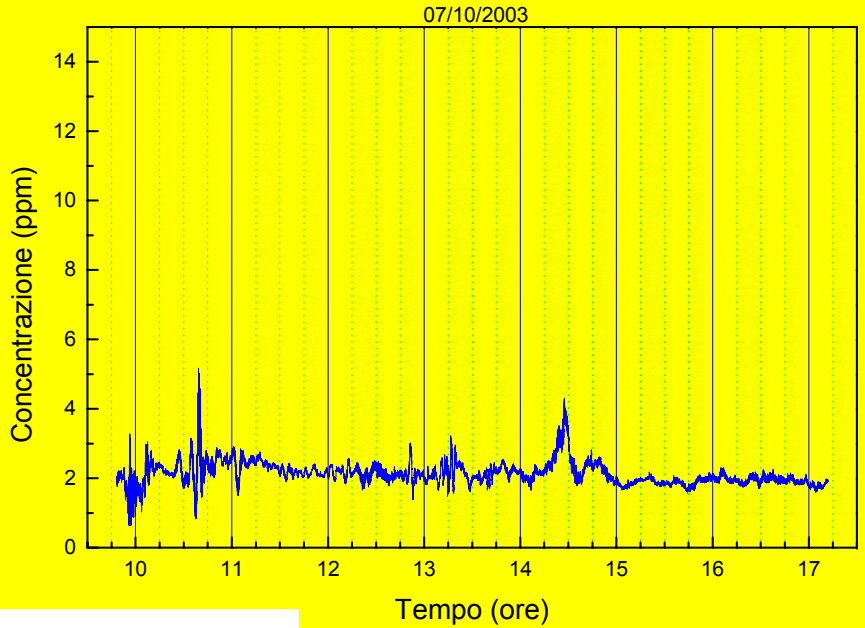

Air inlet
tube

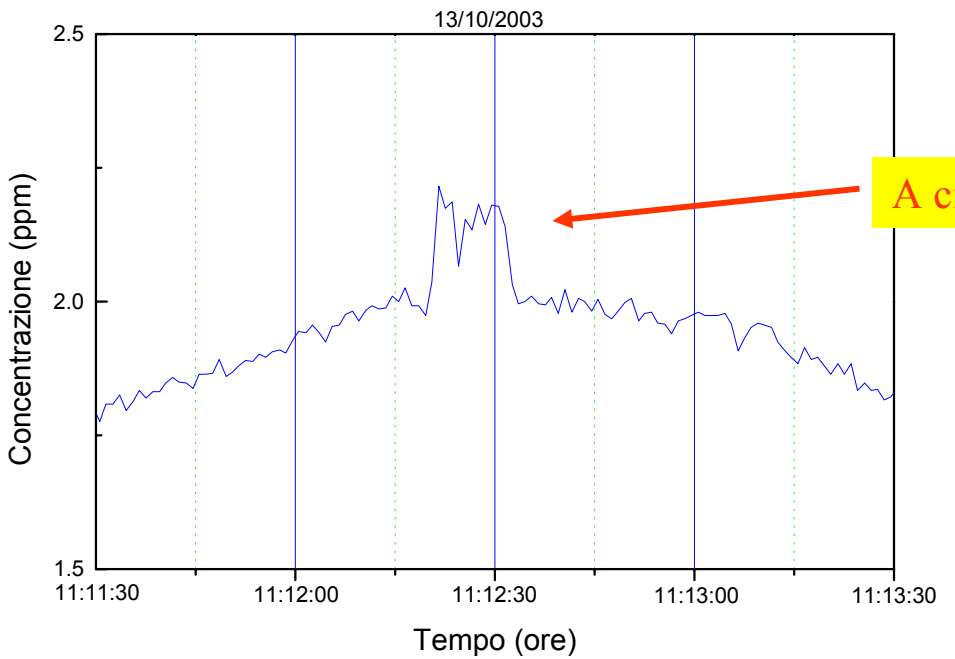

12/07/2003
14/07/2003
16/07/2003
Concentrazione (ppm)
0
2
4
6
8
10
12
14
24
48
72
96
120
144
168
Tempo (ore)

Installation on a van for measurements at street level



Examples of measured spectra





A city bus.(# 26)

Water monitoring

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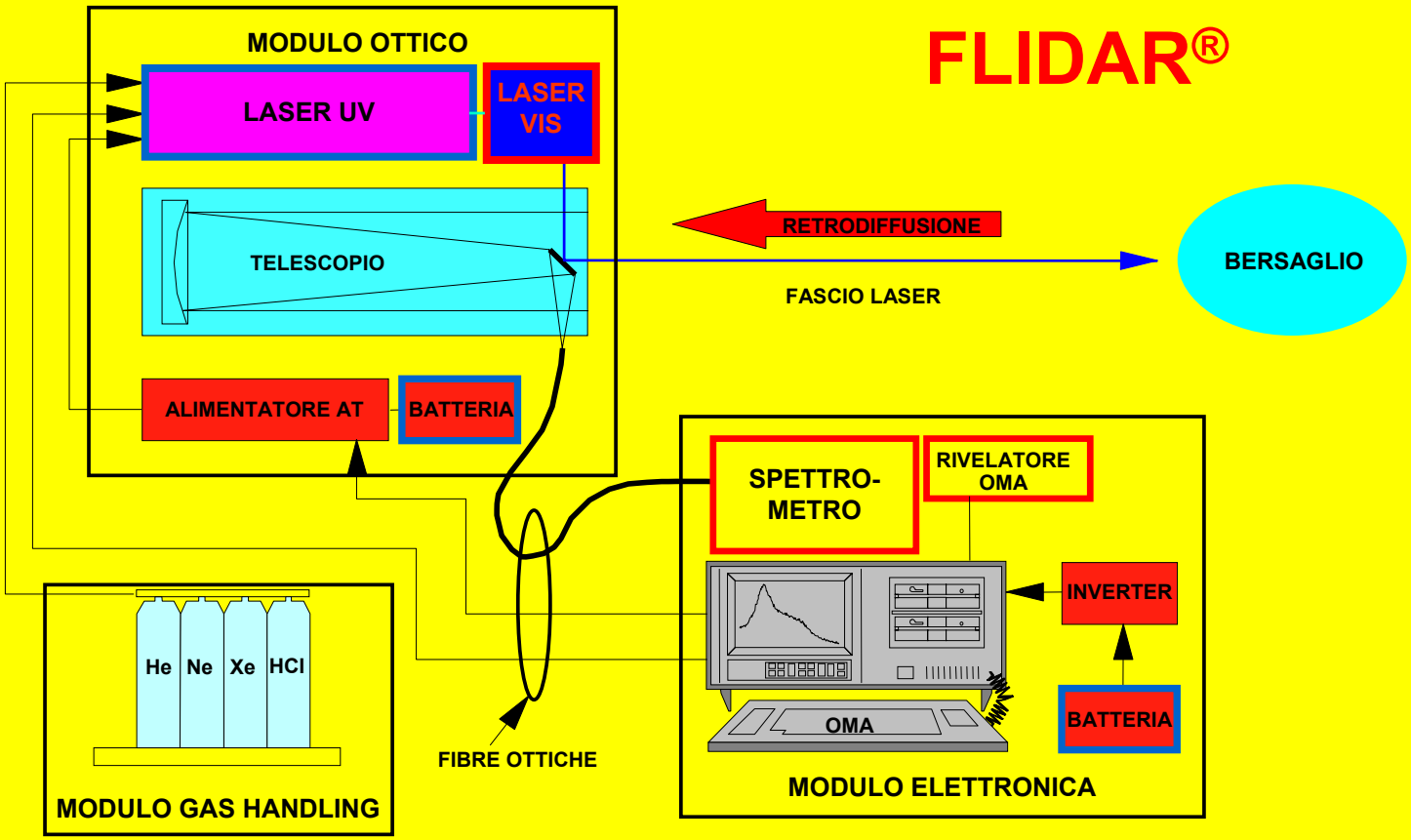
della QUalità
dell'Ambiente

FLUORESCENCE LIDAR

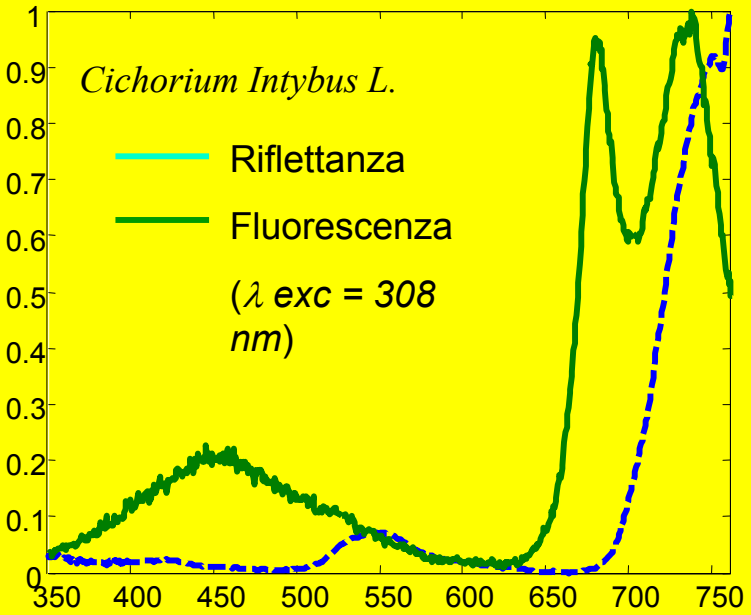


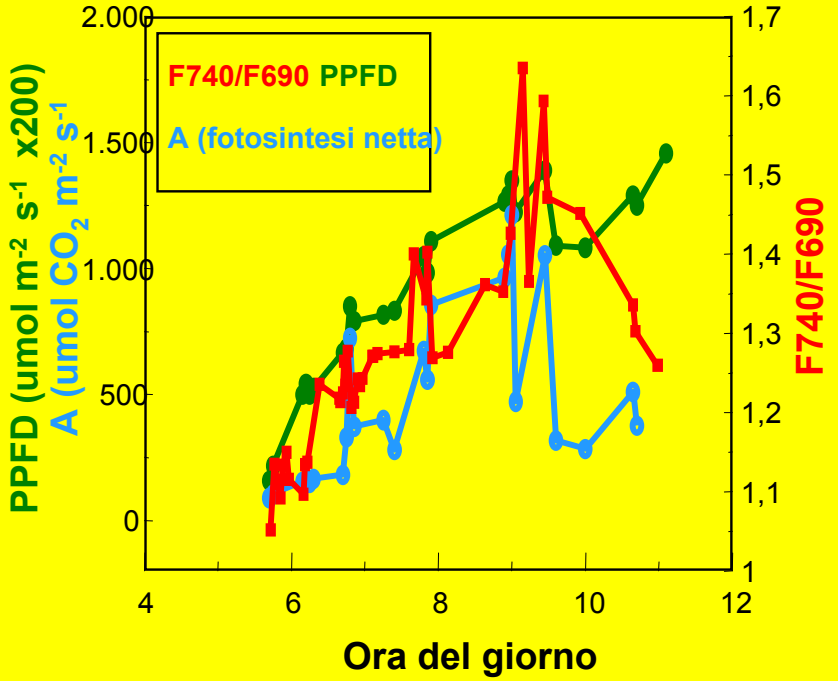
FLIDAR®

CHARACTERISTICS OF FLIDAR®-3

- ✓ Compact instrument, totally developed in-house (laser as well is patented)
- ✓ Battery operated
- ✓ High spectral resolution (up to 0.04 nm

Monitoring of vegetation





Fluorescence spectrum of vegetation shows two bands: one in the red (with peaks at 680 and 740 nm), due to chlorophyll, ed one in the blue. The analysis of the spectral profile is useful to detect a stress condition and to assess net photosynthesis.

QUALITA' DELLE ACQUE
Progetto SERQUA

Acque reflue (A1)

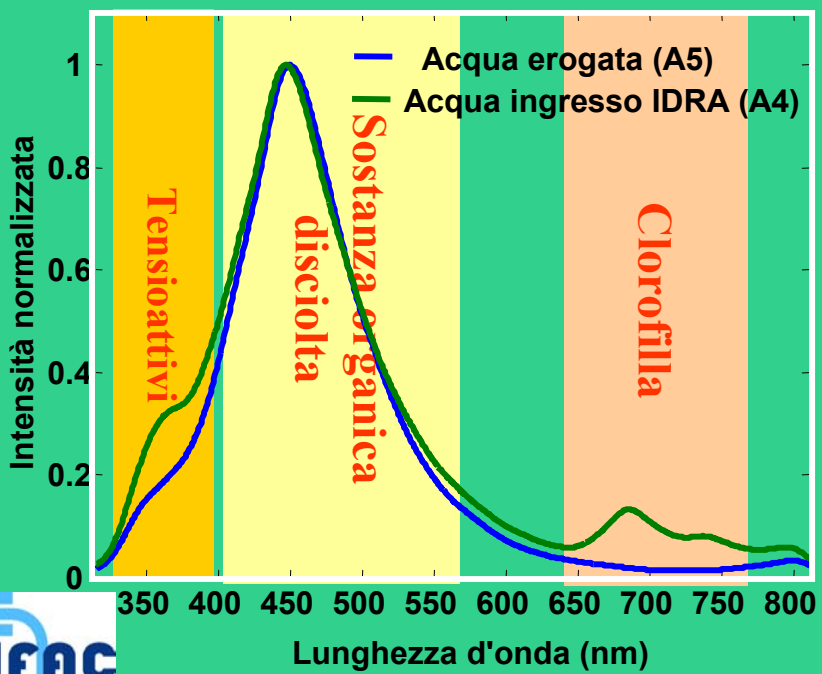
Impianto depurazione Stadio 1 → (A2) → Impianto depurazione Ossidazione → (A3) → Impianto Ozono → (A4) → Impianto Riciclo IDRA

Acqua erogata (A5)

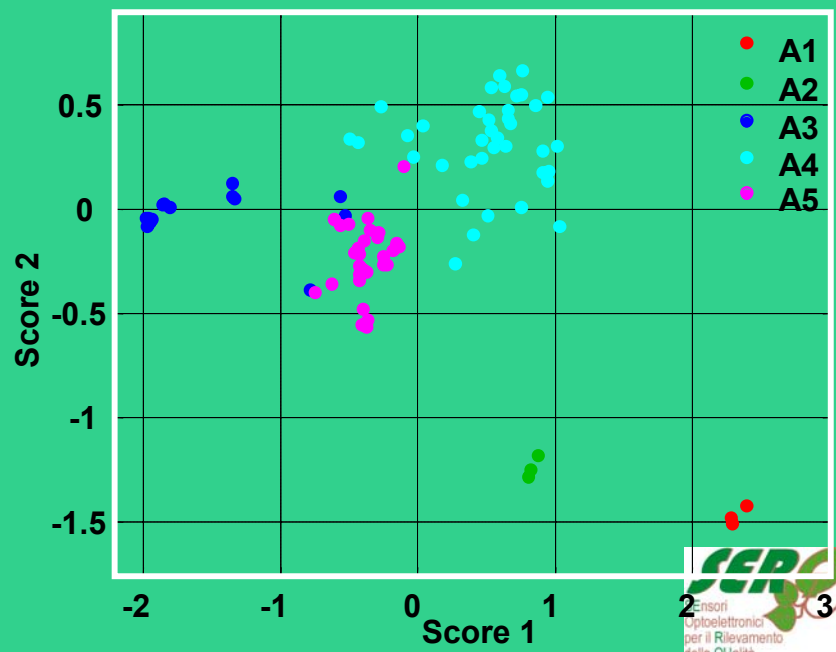
IDL Baciacavallo

IDRA

Confronto spettri
Impianto Riciclo IDRA



Classificazione acque
Principal Component Analysis



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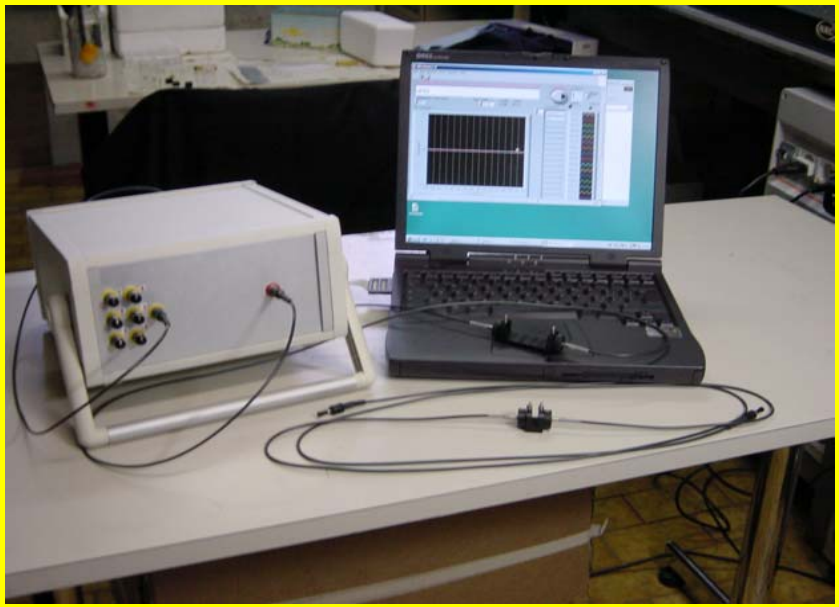
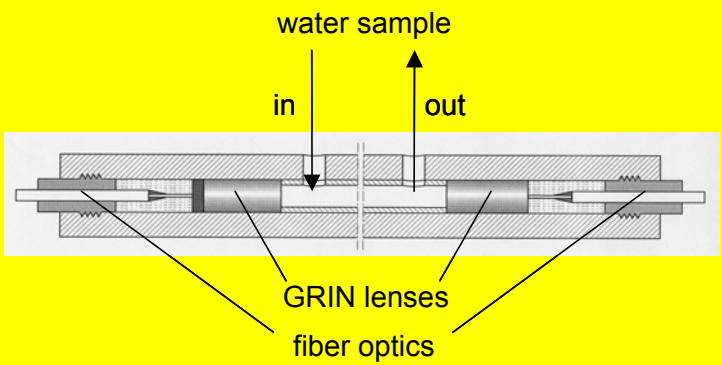
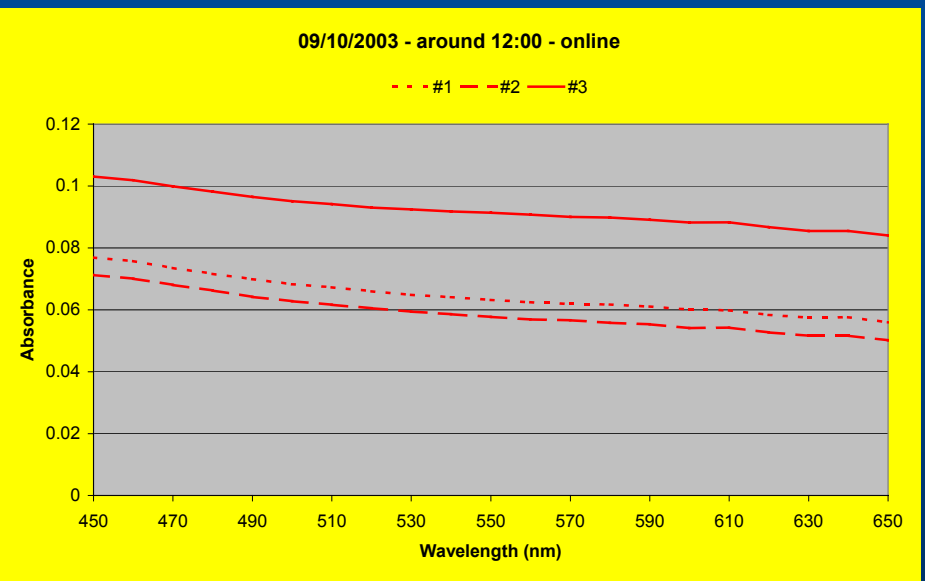
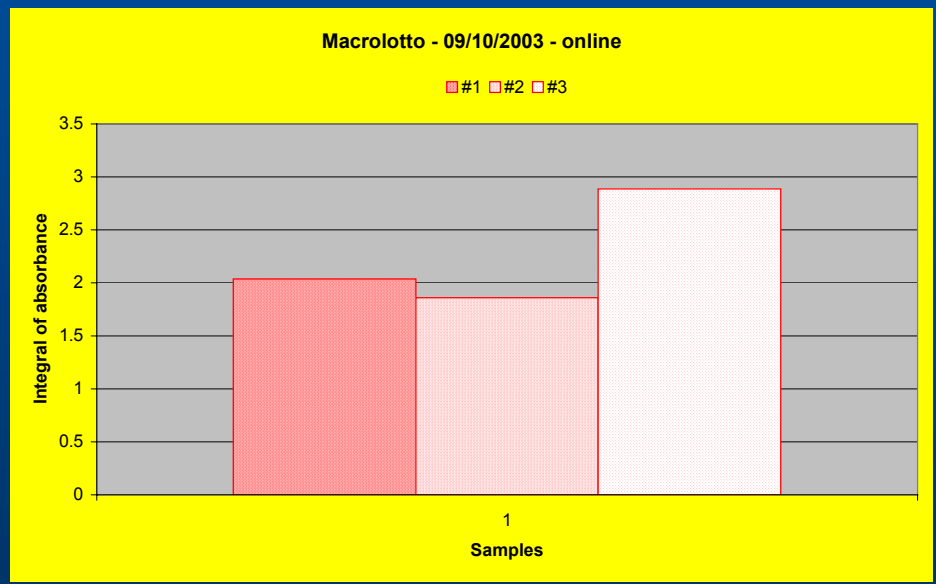
Water analysis in the recycling plant has been made also by doing color monitoring by a fiber-optic spectrophotometer






09/10/2003 - around 12:00 - online
#1
#2
#3
0.12
0.1
0.08
0.06
0.04
0.02
0
Absorbance
450
470
490
510
530
550
570
590
610
630
650
Wavelength (nm)


Macrolotto - 09/10/2003 - online
#1
#2
#3
3.5
3
2.5
2
1.5
1
0.5
0
Integral of absorbance
1
Samples

CONCLUSIONS

A few innovative optoelectronic sensors are being developed.

The combination of different optoelectronic sensors has allowed a detailed analysis of many environmental parameters in a high-industrial-density area.

Data processing and data fusion are still in progress, and we expect we will be able to give a comprehensive description of the environmental quality and of the possible correlations between pollution and industrial activities.

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ACKNOWLEDGEMENTS

The financial support by Regione Toscana and the friendly and fructuous collaboration of all the people from different Institutions and Companies involved in SERQUA project are gratefully acknowledged.