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Trace HF Molecule Detection in Atmosphere Using Tunable Diode Lasers

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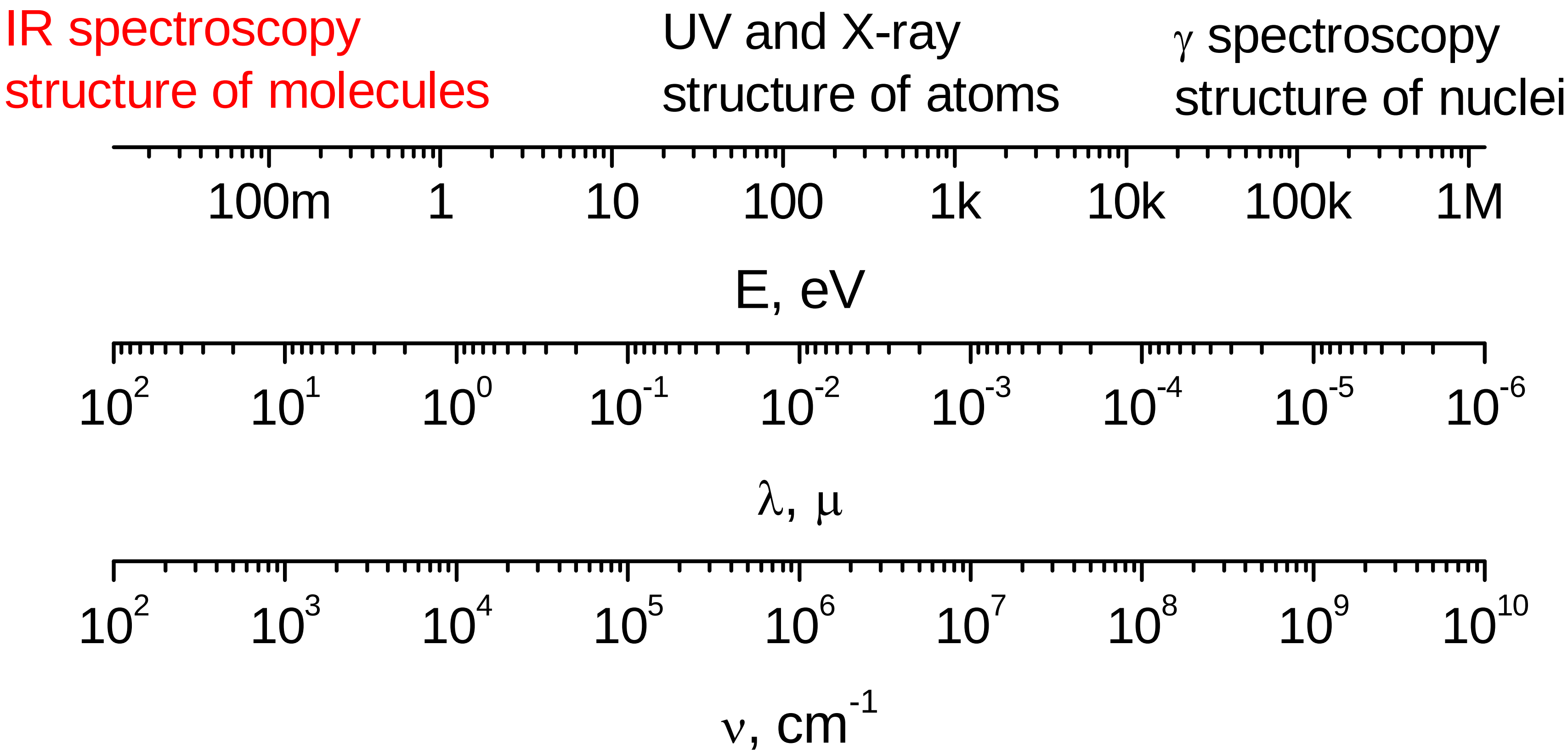
Abstract

The necessity of detection of trace HF concentrations may arise in order to check the leaks of UF_6 from the containers or technological processes, as well as to reveal the illegal activity in the manufacturing of 235-isotope enriched uranium. HF is a volatile compound and can be detected with high sensitivity by diode laser based device.

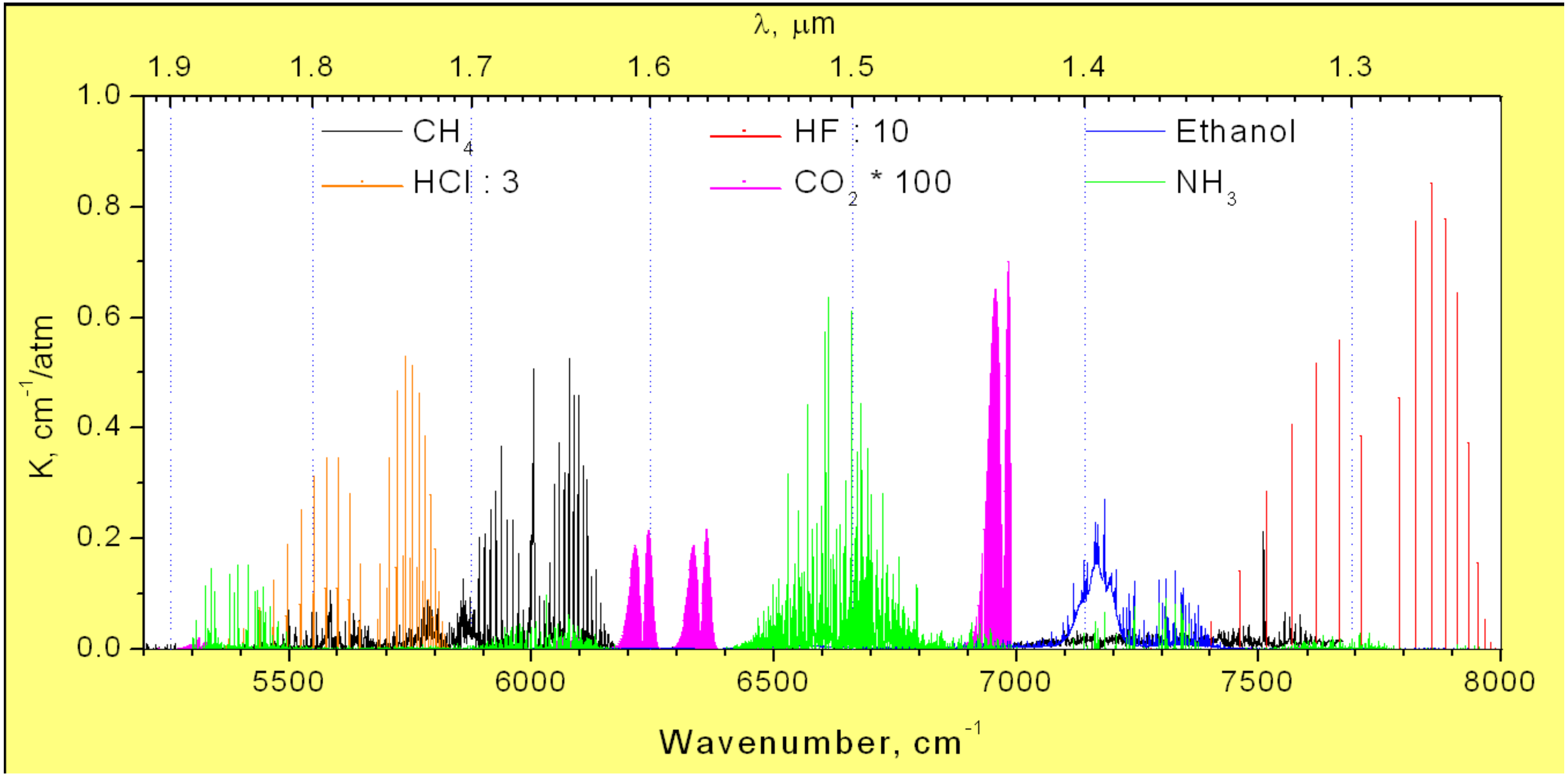
This report for the first time suggests a compact device prototype for rapid analysis of trace HF quantities in atmosphere with the use of near-infrared diode lasers (DL) and multi-pass cell.

The main destination of the sensor was the monitoring of HF content in the ambient air. The instrument prototype has been tested at the IAEA, Austria in 2006.

Spectral ranges

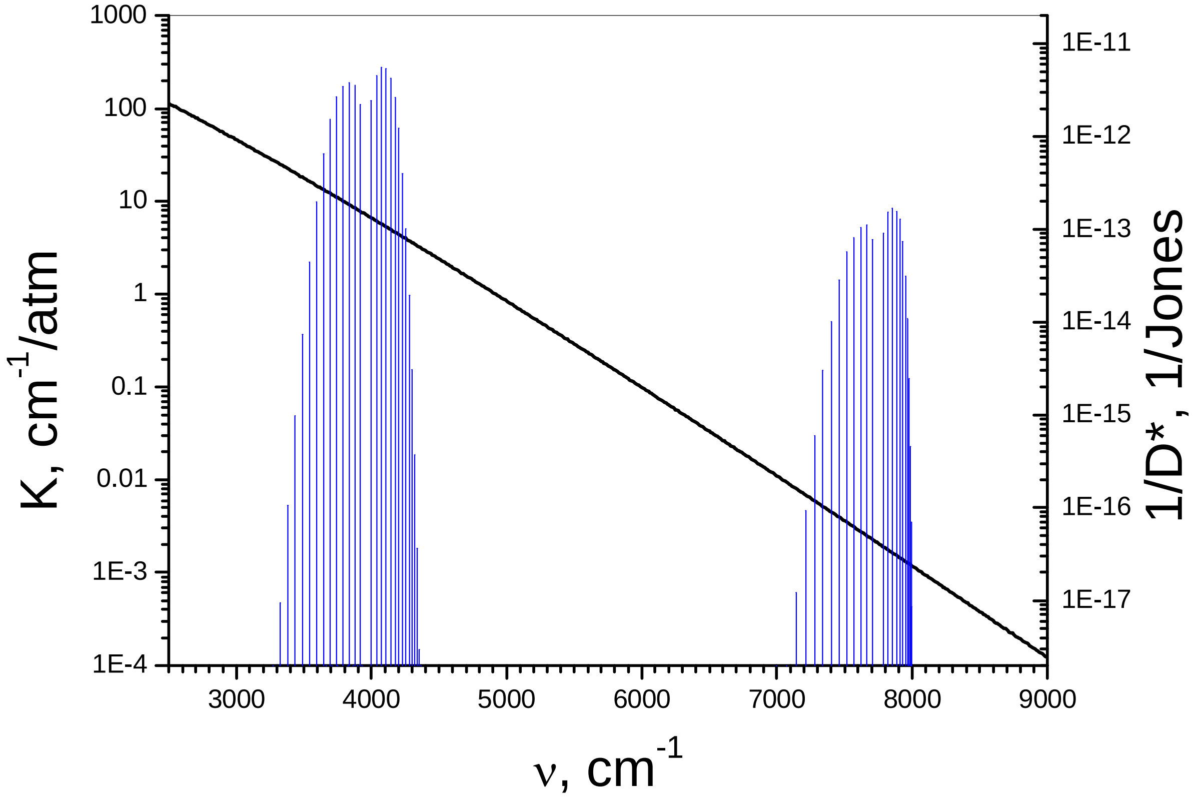


Spectra of several molecules in near Infrared spectral range



- Practically all molecules have absorption bands between 1 and 2 mm.
- Bands position are representative for such bonds as CH, OH, NH, FH, HCl etc.
- Using the same technique trace HF, HCL, and HTO can be detected.

HF absorption spectrum

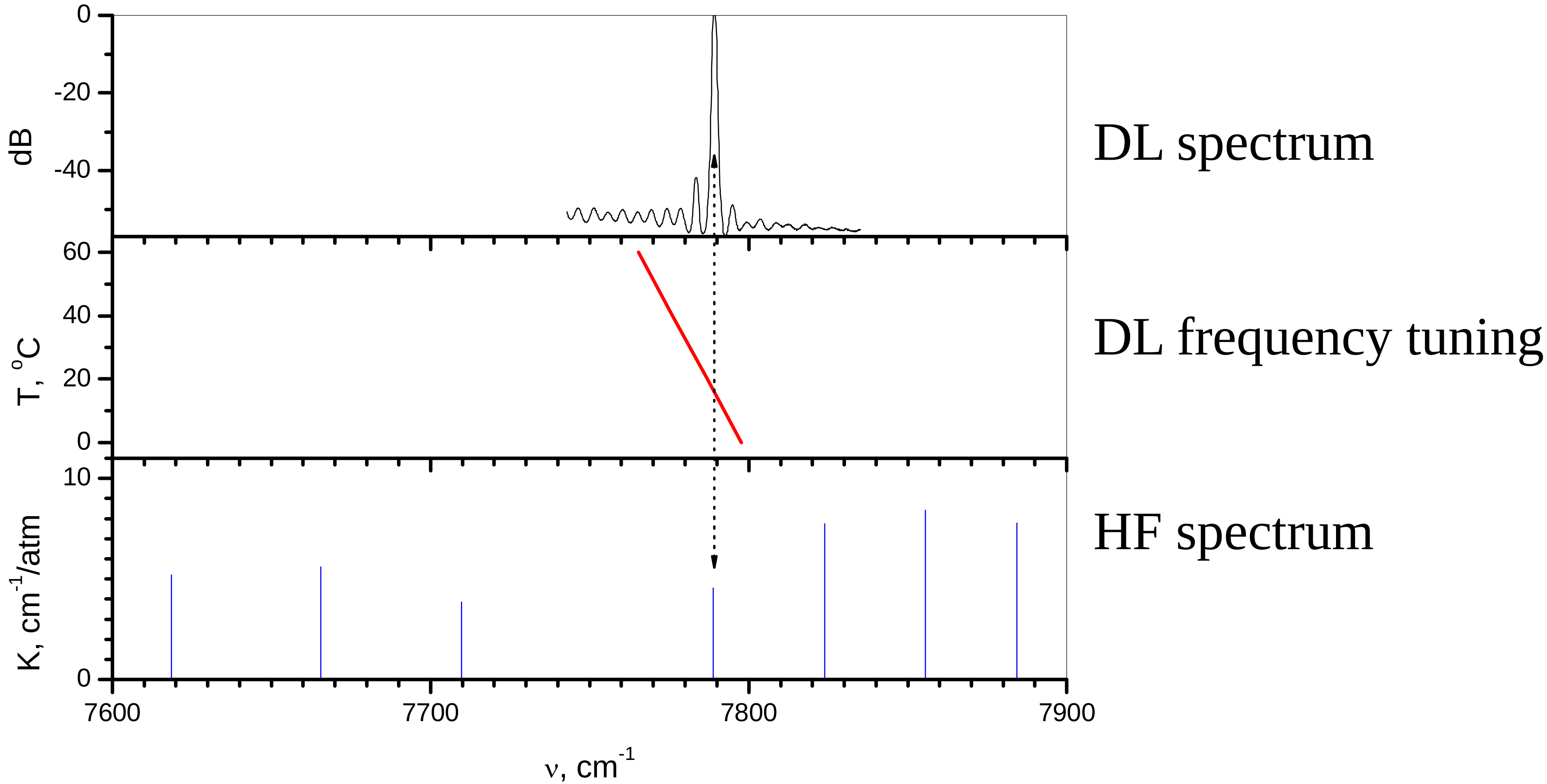


Spectrum of

HF absorption - K and noise of ideal photo-detector – D*

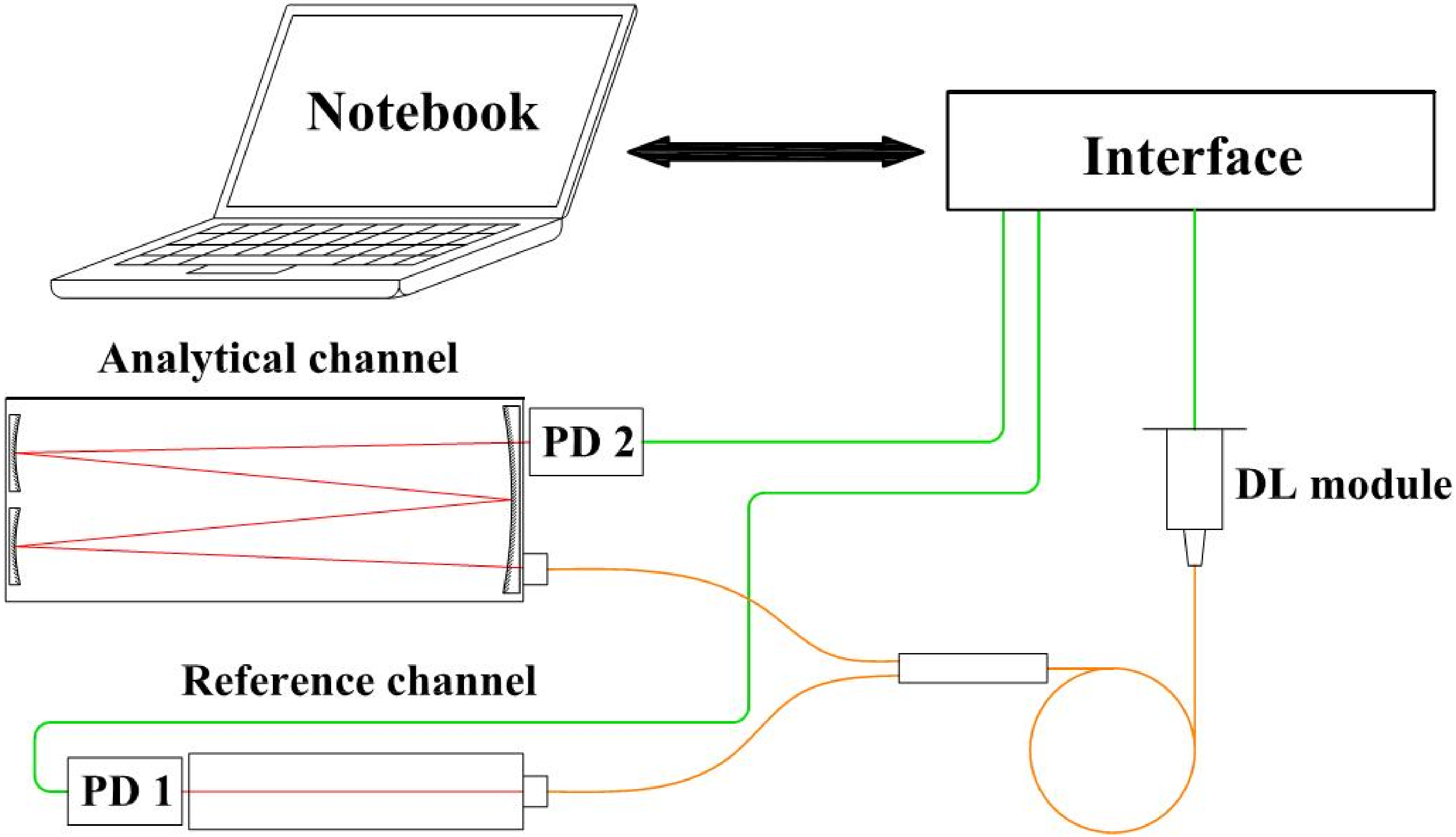
Near IR spectral range has better S/N ratio for trace HF detection

Tunable Diode Laser Spectroscopy

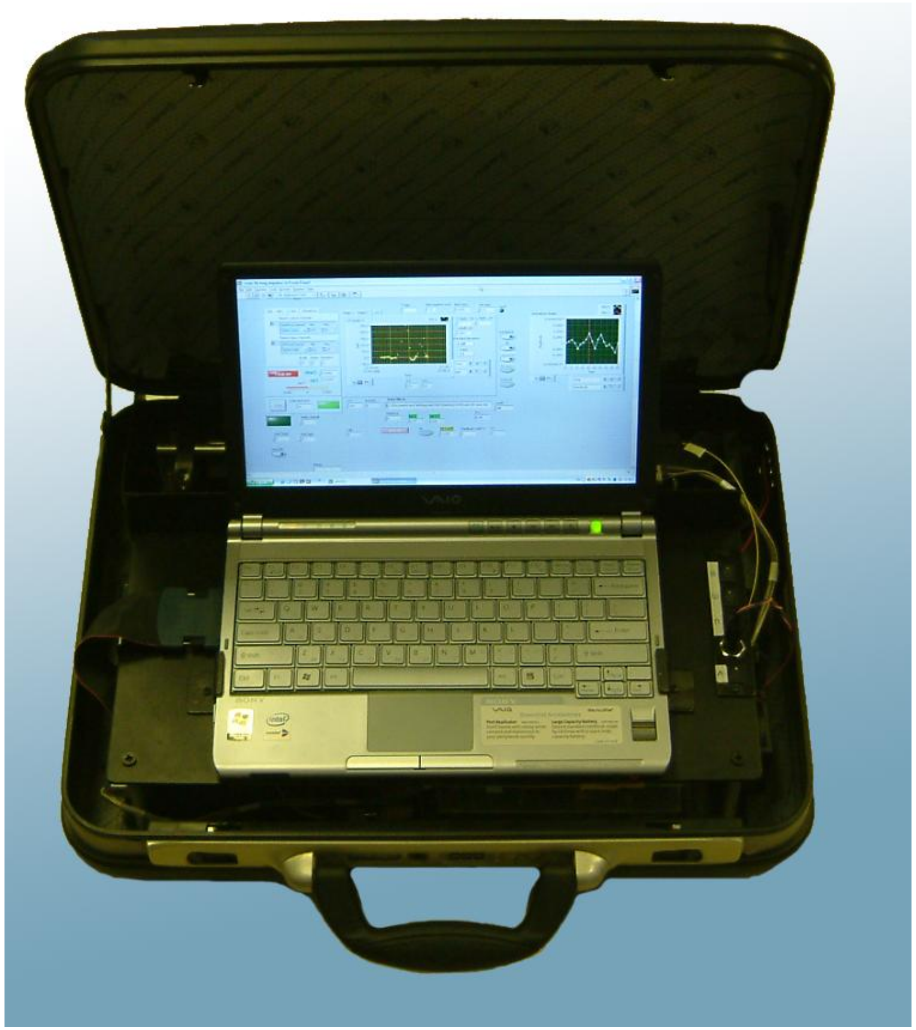


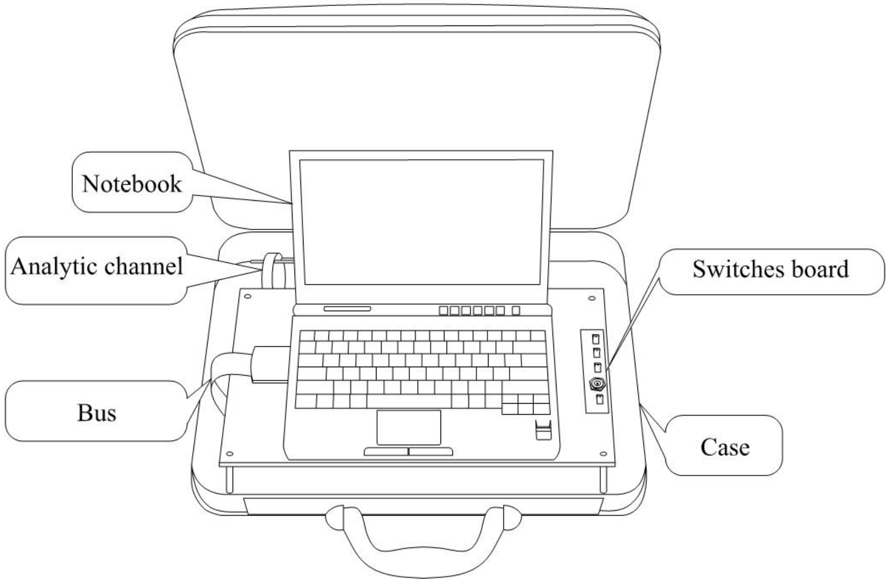
Selection of HF analytical line: 2-0, R0

Trace HF local concentration detector prototype block-scheme

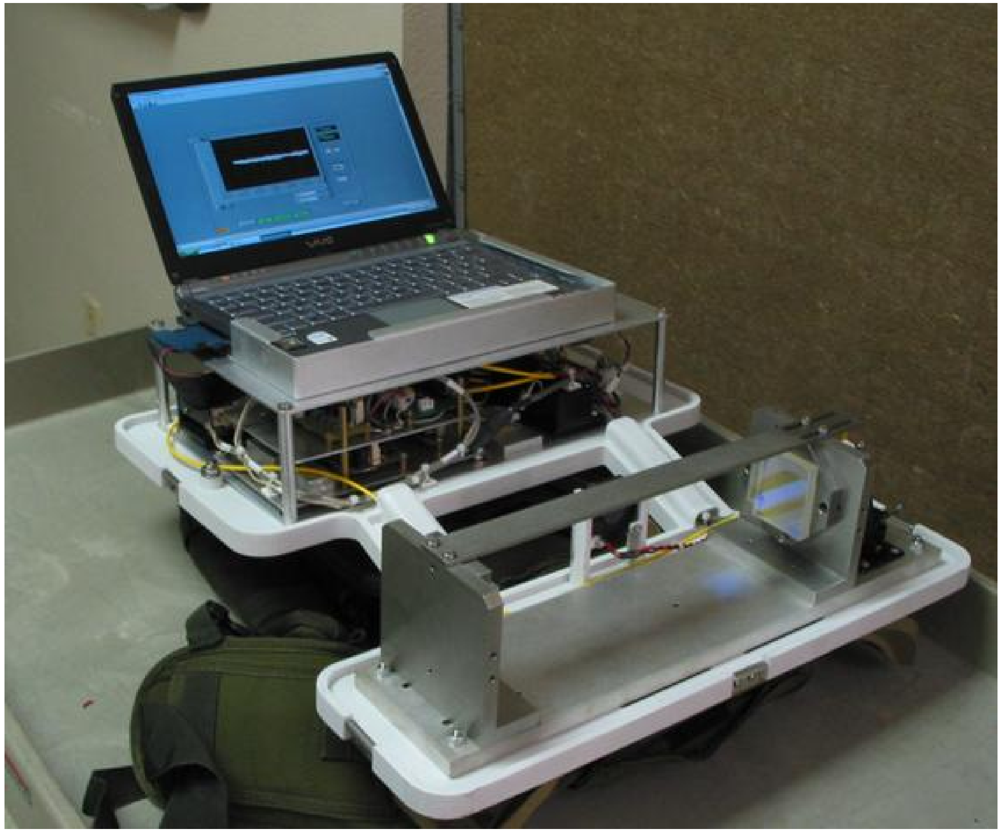


Trace HF local concentration detector prototype view (case version)



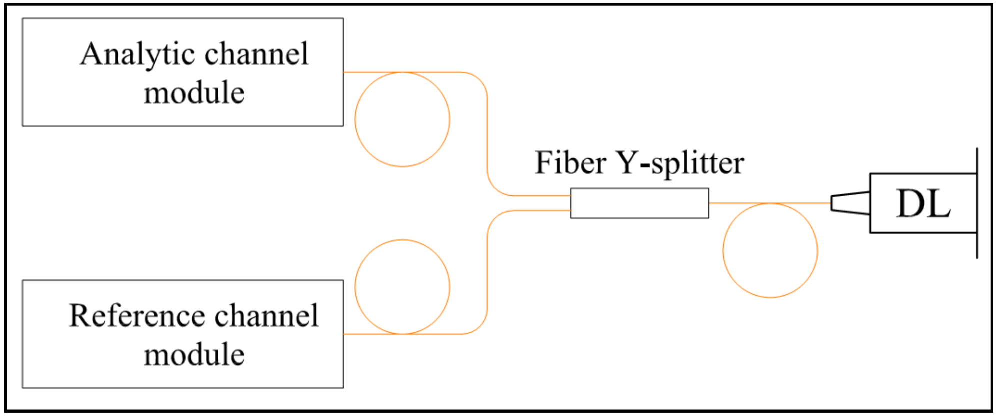


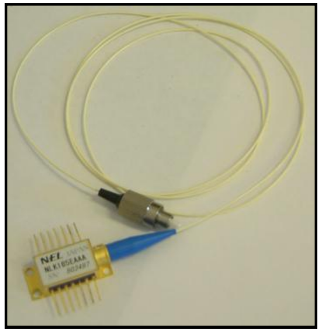
Trace HF local concentration detector prototype view (backpack version)



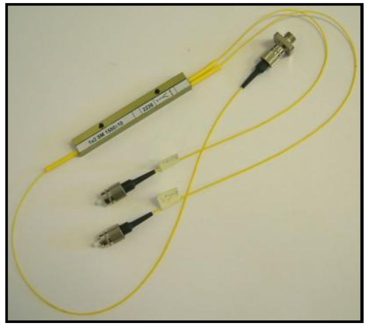
Backpack was developed by Canberra – Albuquerque.

Main optical components





Diode Laser

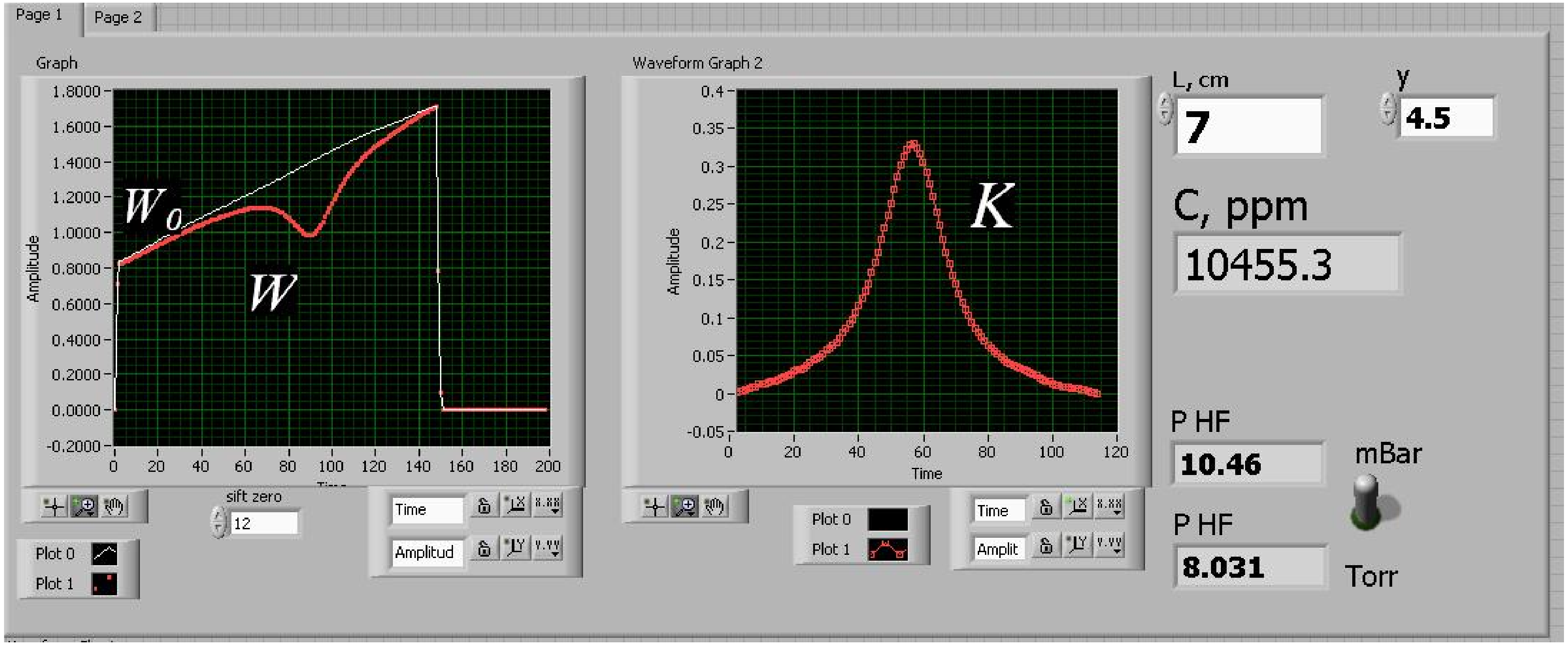


Fiber splitter

“Chernin” multi-pass analytical cell
(25 cm * 156 passes = 39 m)

Reference cell
L=7 cm,
P=7.2 Torr

HF absorption line shape in TDLS



Signal waveform in reference channel.

HF absorption line can be observed

HF absoption line shape in reference channel corresponding to L = 7 cm; P_{HF} = 10.46 mBar

HF concentration measurement

Bouguer law $W = W_0 \exp\left[-KCP_0L\right]$

Lorentz line $K(\nu) = \dfrac{S\Gamma}{\pi\left[(\nu - \nu_{line})^2 + \Gamma^2\right]}$

$$S = S_0 P_{HF}$$

$$\nu_l = \nu_0 + \delta_0 \left(P_0 - P_{HF}\right) + \delta_{HF} P_{HF}$$

$$\Gamma = \gamma_0 \left(P_0 - P_{HF}\right) + \gamma_{HF} P_{HF}$$

Absorption in line center

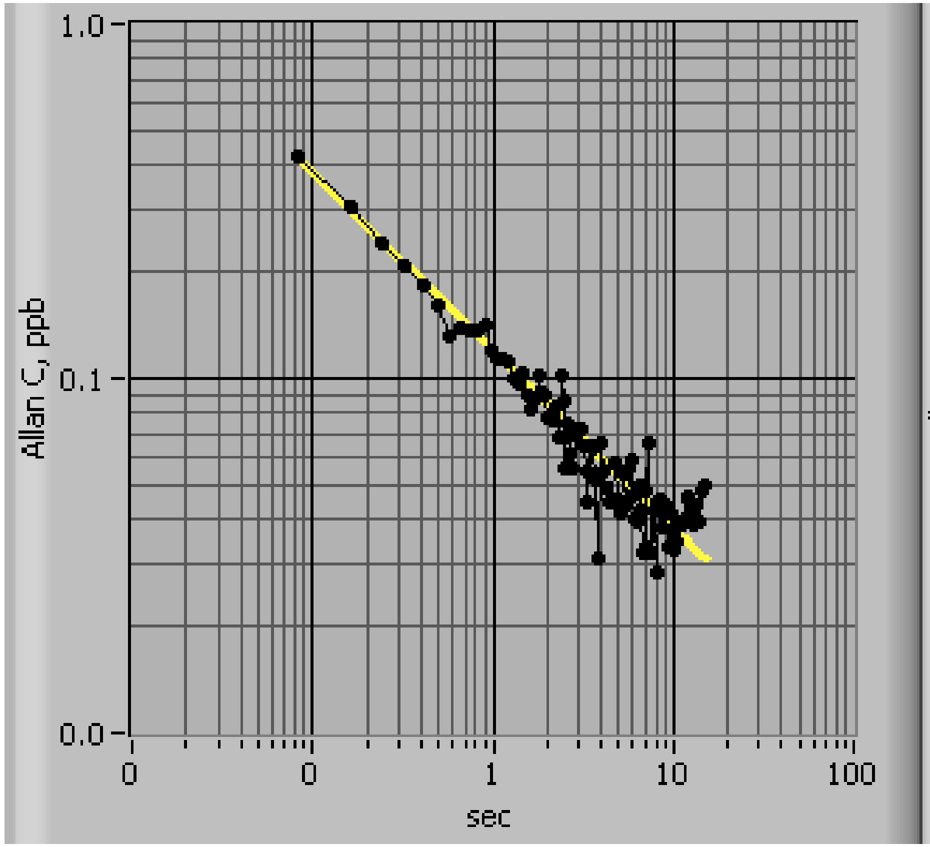
$$K(\nu_{line}) = \frac{S_0}{\pi\gamma_0} \frac{P_{HF}}{P_0} = \frac{S_0}{\pi\gamma_0} C_{HF}$$

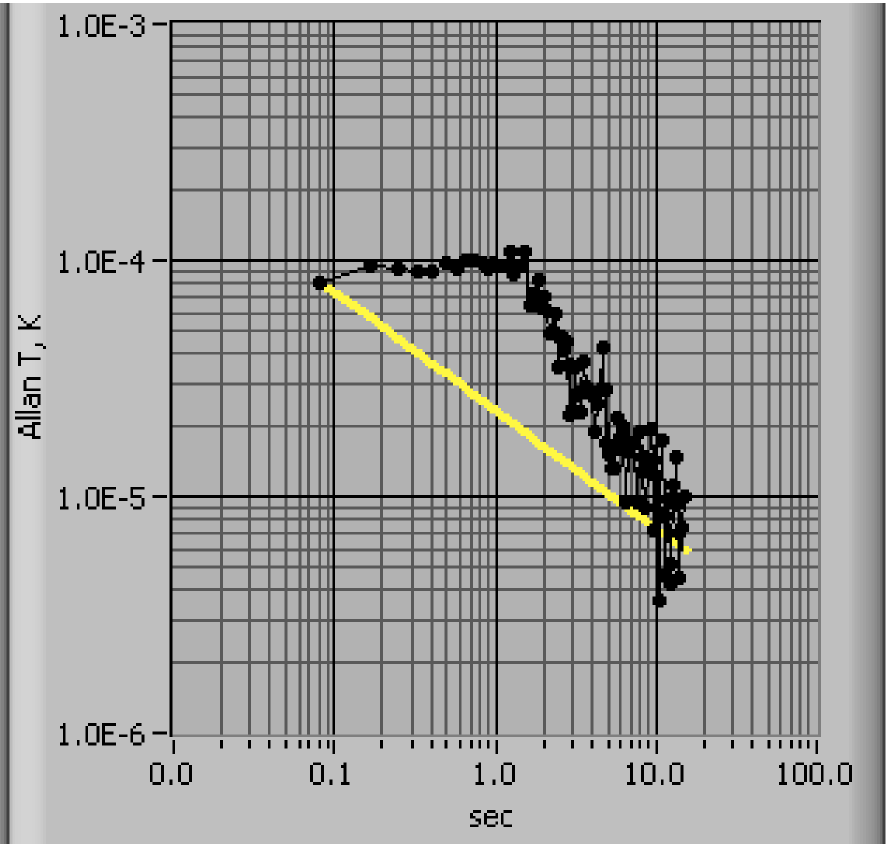
$$\frac{S_0}{\pi\gamma_0} = [4.5 \pm 0.6] cm^{-1}$$

When transmission spectrum is measured, HF concentration can be obtained straightforward

$$C_{HF} = \frac{\pi\gamma_0}{S_0 L} \ln\left[\frac{W_0(\nu_{line})}{W(\nu_{line})}\right]$$

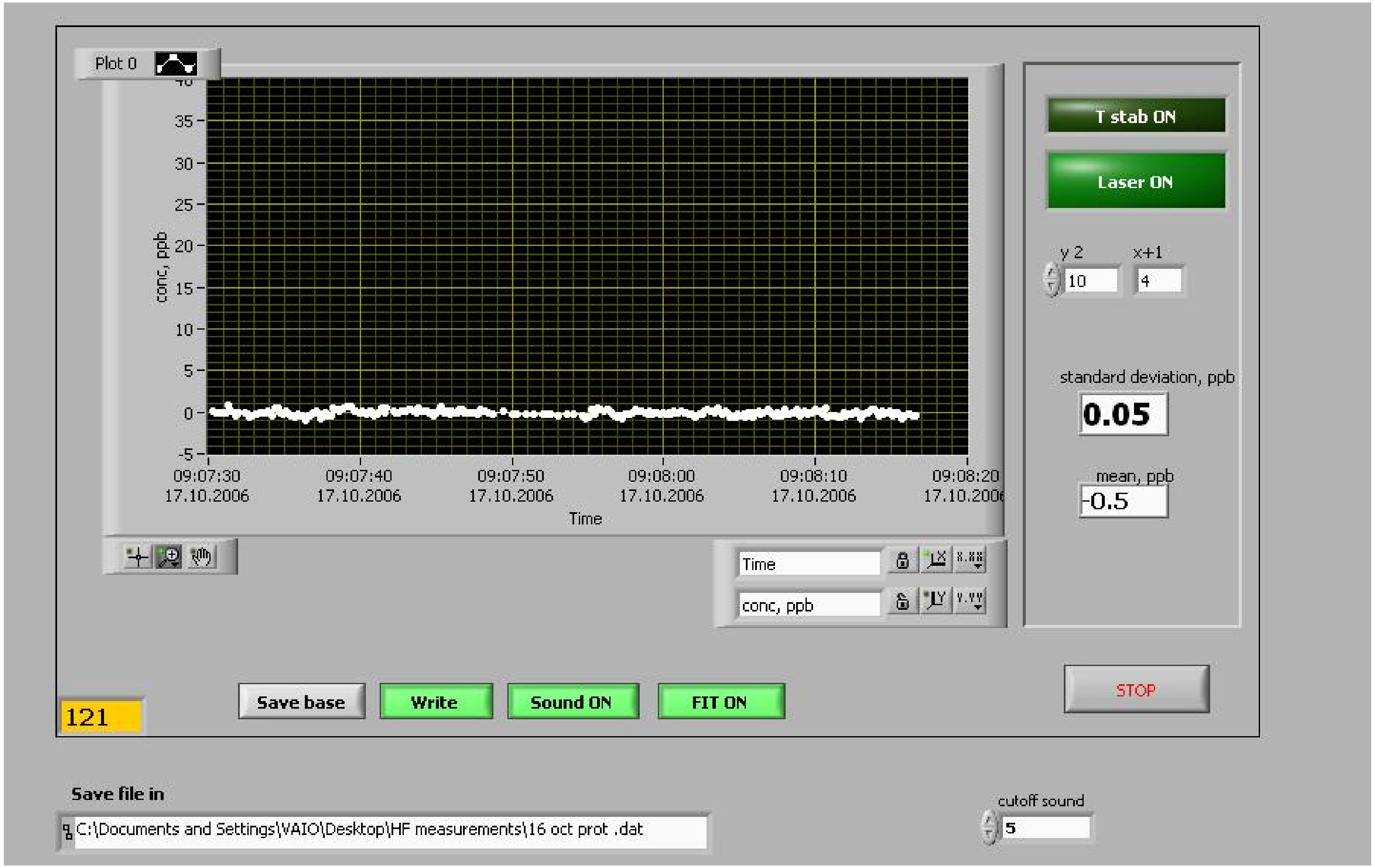
Allan plots





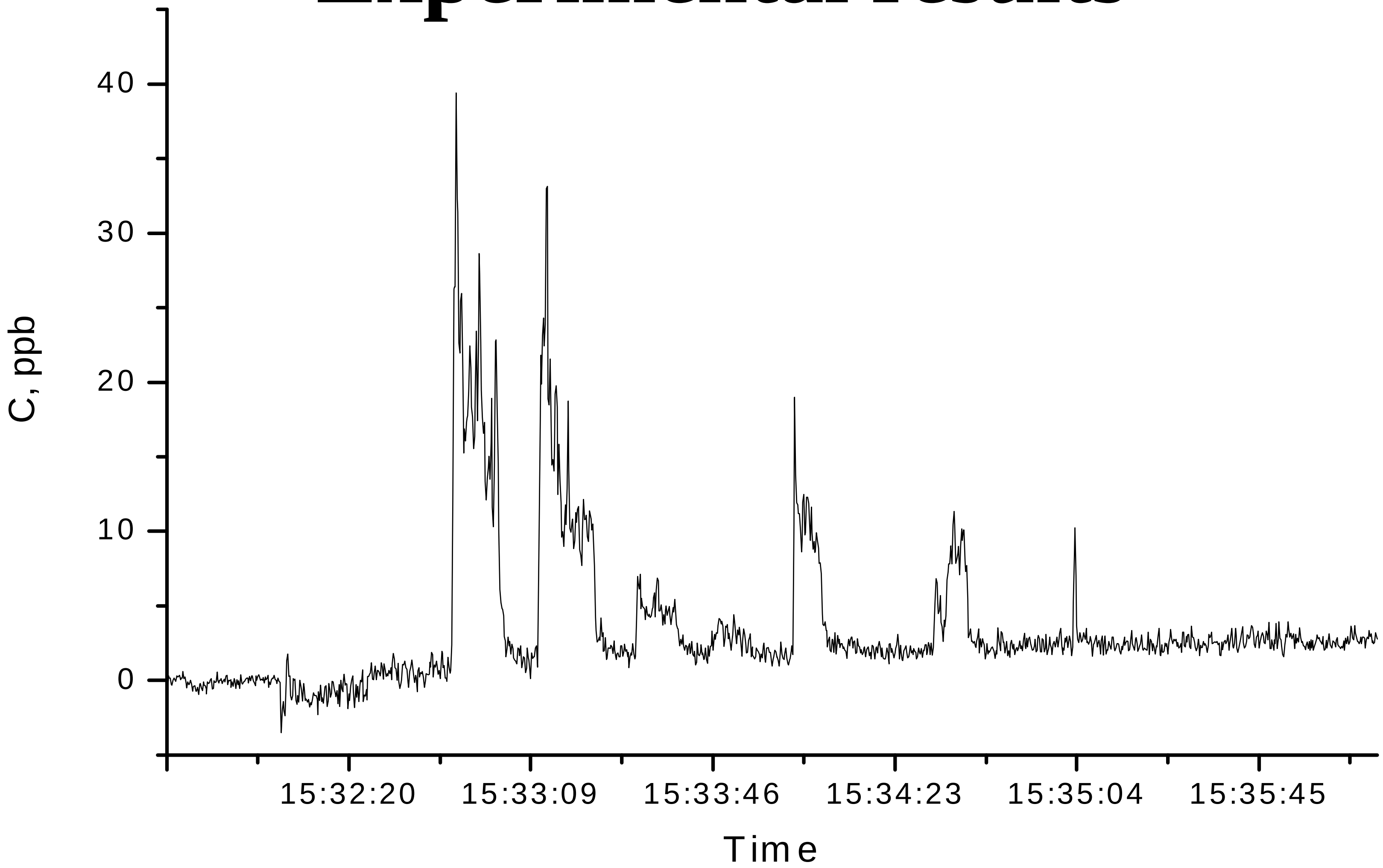
Allan plot of concentration C and temperature T

Program interface



"Zero level" HF vapor monitoring

Experimental results



Measurement results of HF vapor above different HF water solution (Vienna, December 2006).