TUNABLE DIODE LASER SPECTROSCOPY (TDLS) BASED COMPLEX FOR THE AIRPLAN LABORATORY

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DLS LAB

ЦАО 1941

МФТИ SAPERE AUDE

Abstract

Federal Agency for Hydrometeorology of the Russian Federation creates the flying laboratory on the basis of the passenger airplane Yak-42D for geophysical monitoring of environment, including continuous aircraft vertical concentrations measurements of greenhouse gases in the troposphere. Within the frame of this project General Physics Institute of the Russian Academy of Science developed airborne TDLS based complex to measure altitude profiles of greenhouse gases (CO_2, CH_4, H_2O) and H_2O isotopes content.

TDLS complex contains 3 near IR diode lasers operating near 1.39, 1.6, and 1.65 mkm to measure H_2O, CO_2, and CH_4 respectively. The complex was integrated aboard in standard 19-inch rack. Air samples, taken from an aircraft pipeline were injected into the Chernin optical cell. Using inflow and pressure stabilization systems, laminar air flow in Chernin cell was achieved at rate of 80 liter/min and reduced pressure 50 mBar. Above mentioned parameters are enough to detect water vapor isotopes narrow absorption lines. Modulation-correlation technique was used to record absorption spectra and to process measurement of greenhouse gases concentration. Time of single measurement is about 30 milliseconds. Results obtained in real time are transfering to the airborne central computer. Sensitivity of TDLS measurements was estimated: 20-30 ppm for water, 3-4 ppm for CO_2, 20-25 ppb for CH_4.

Airplane - laboratory

Jak-42d	
Speed	730 km/h
Distance	4100 km
Altitude	9.6 km
Maximum take-off weight	57500 kg

Preliminary modeling of spectra (”Line by Line”)

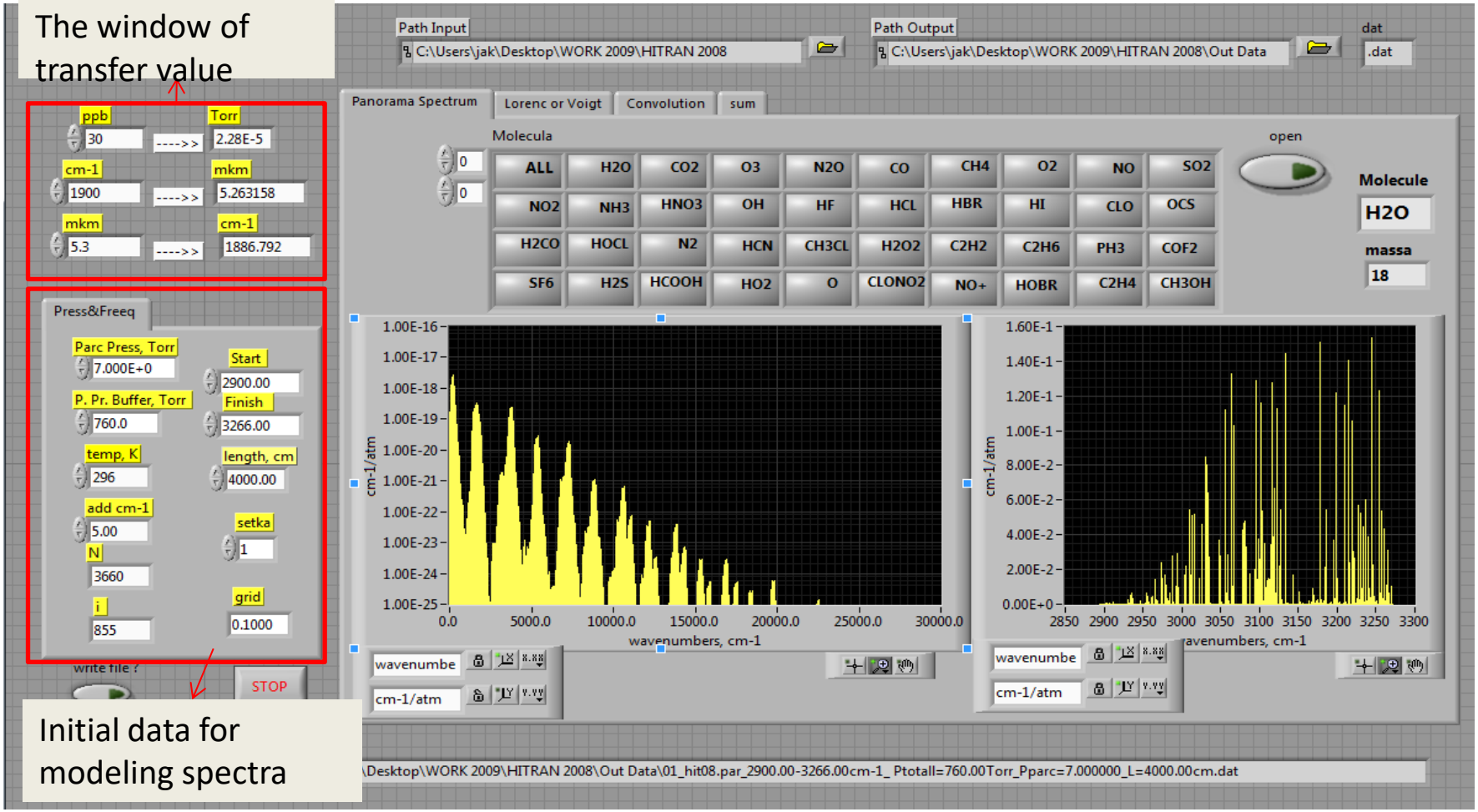
We made preliminary modeling of spectra to determine proper analytical lines in IR range. The main characteristics, that should have used the line:

1) Sufficient intensity
2) Lack of interference with the absorption bands of other gases.

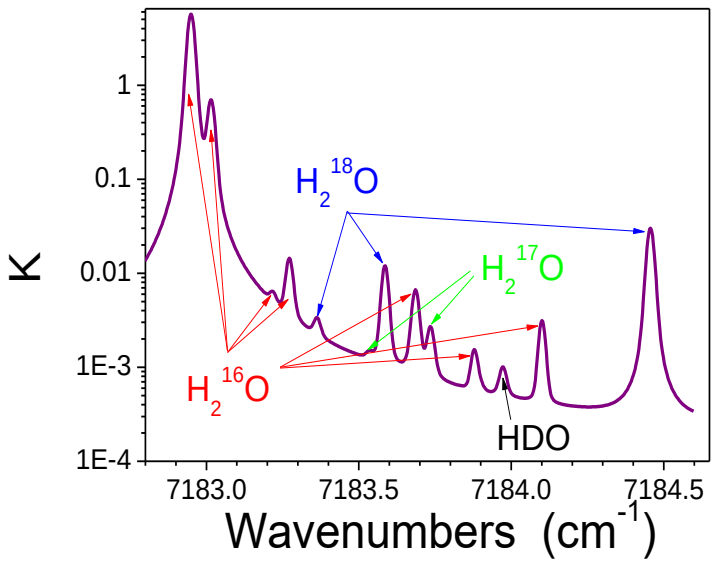
In our soft “Line-by-line” the user can select a molecule from the database HITRAN 2008. To establish the parameters of model spectra: the partial pressure of the gas of interest, the total pressure of the gas mixture, temperature, optical length, and the spectral range of interest. User can imagine the result as a function of the absorption or transmission, depending on the wave number or wavelength.

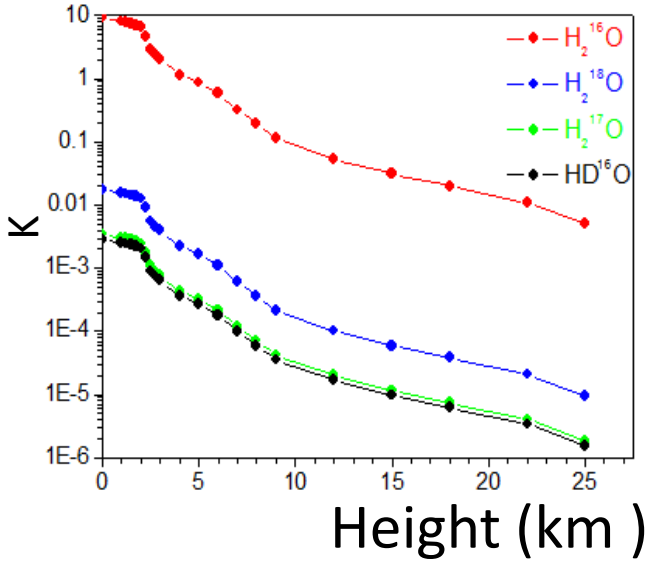
The program allow you to sum up to 4 different spectra, calculate the first and second derivatives of the absorption coefficient to find the optimal spectral bands perform convolution with the instrumental function of a certain width.

Main window of modeling soft (”Line by Line”)



Spectral range of H_2O channel





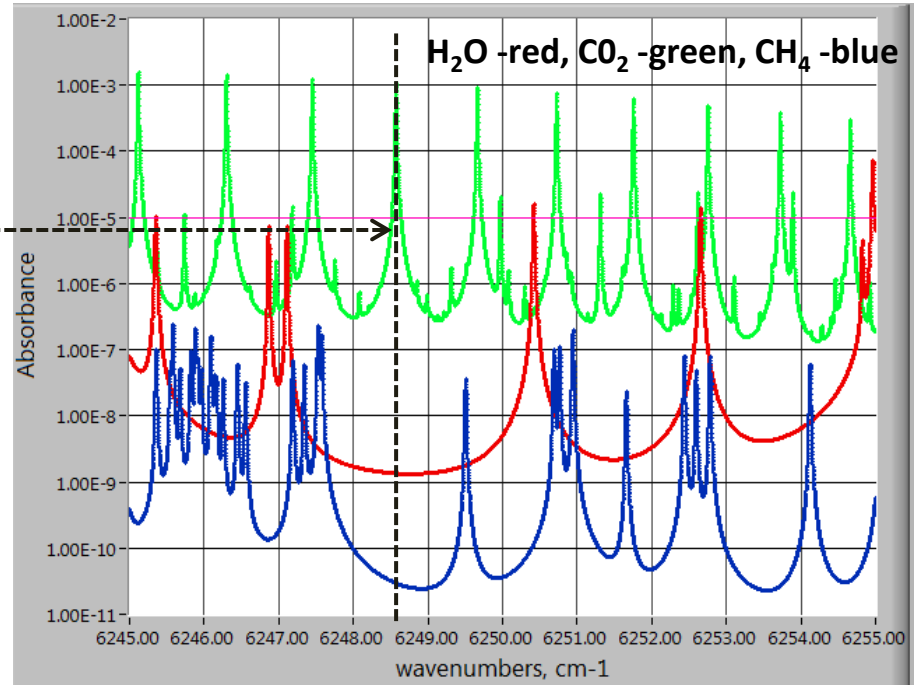
Parameters: L = 40 m, P = 100 mBar, T=23^{0}C, natural abundance.

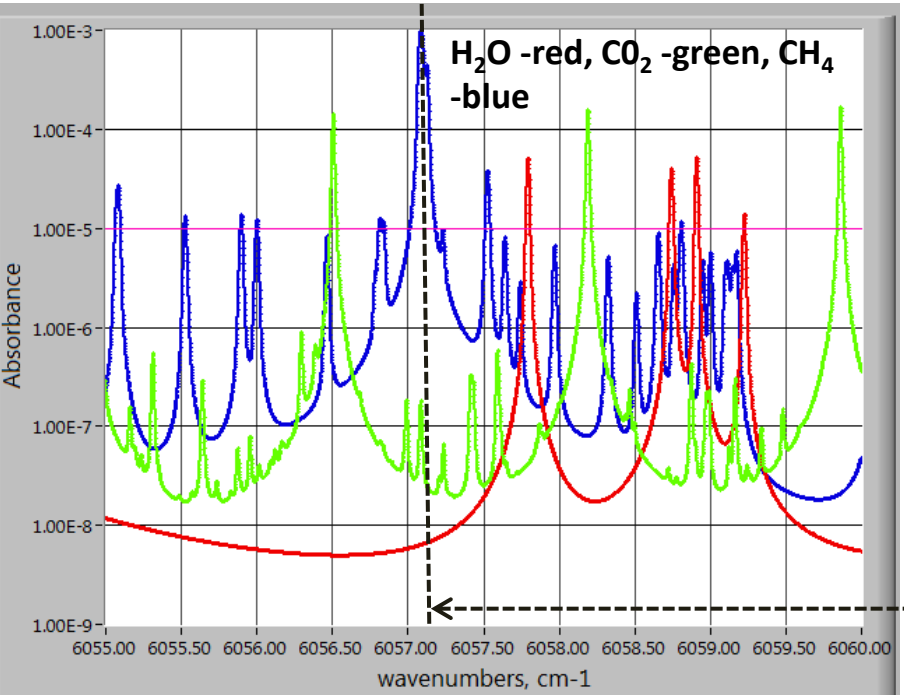
Molecule	Quantity
$H_2{}^{16}O$	0.997317
$H_2{}^{18}O$	1.99983E-03
$H_2{}^{17}O$	3.71884E-04
$HD^{16}O$	3.10693E-04
$HD^{18}O$	6.230E-07
$HD^{17}O$	1.158E-07
$D_2{}^{16}O$	2.41E-08

The dependence of the maximum absorption coefficient of the analytical of the height

Spectral ranges of CO_2 (1.60 mkm) and CH_4 (1.65 мкм) channels

Conditions of modeling:
L=40m, P=100mBar,C(CO_2)=365 ppm,
C(CH_4)=1.7 ppm, C(H_2O)=2500 ppm
Analytical CO_2 line : 6248.57 cm^{-1}





Conditions of modeling:
L=40m, P=100mBar,C(CO_2)=365 ppm,
C(CH_4)=1.7 ppm, C(H_2O)=2500 ppm
Analytical CH_4 line: 6057.08 cm^{-1}

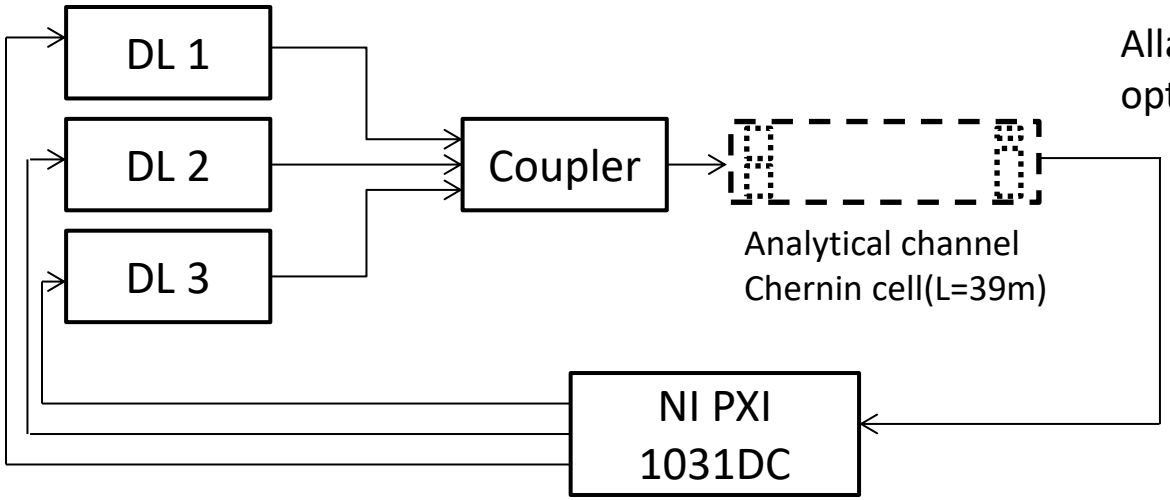
TDLS complex for airplane-laboratory in the telecommunication rack

Electronic module

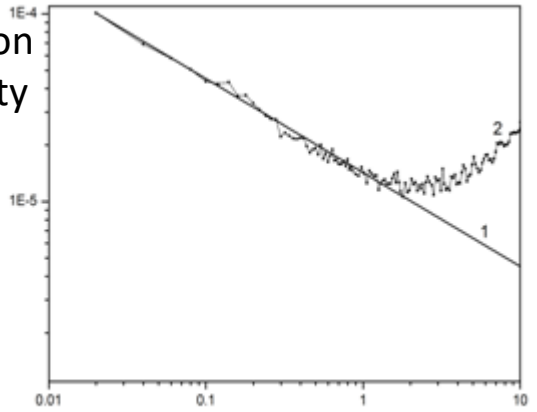
Cell module

TDLS complex for airplane-laboratory

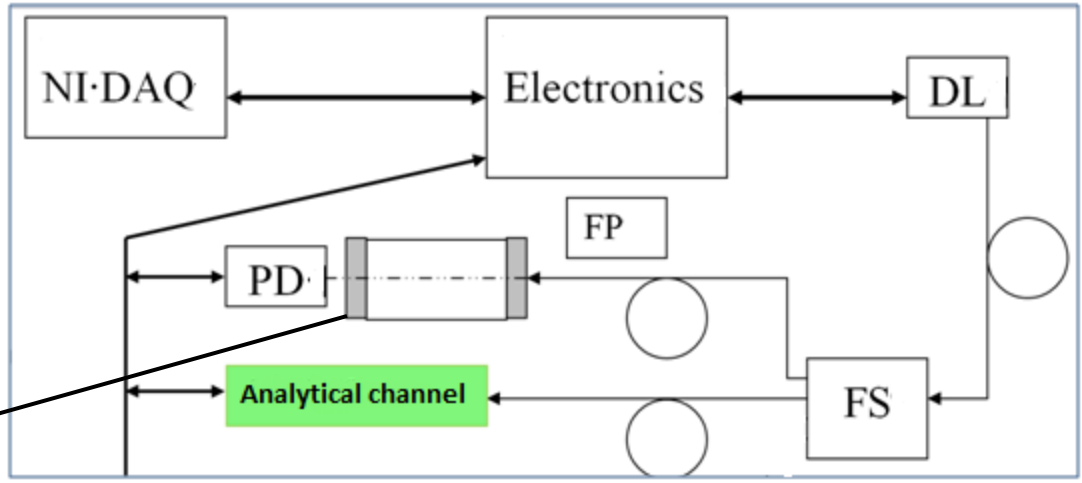
Structure diagram of spectrometer



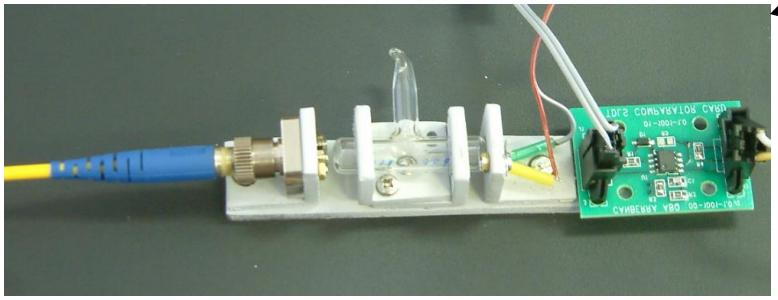
Allan deviation
optical density



Time, sec

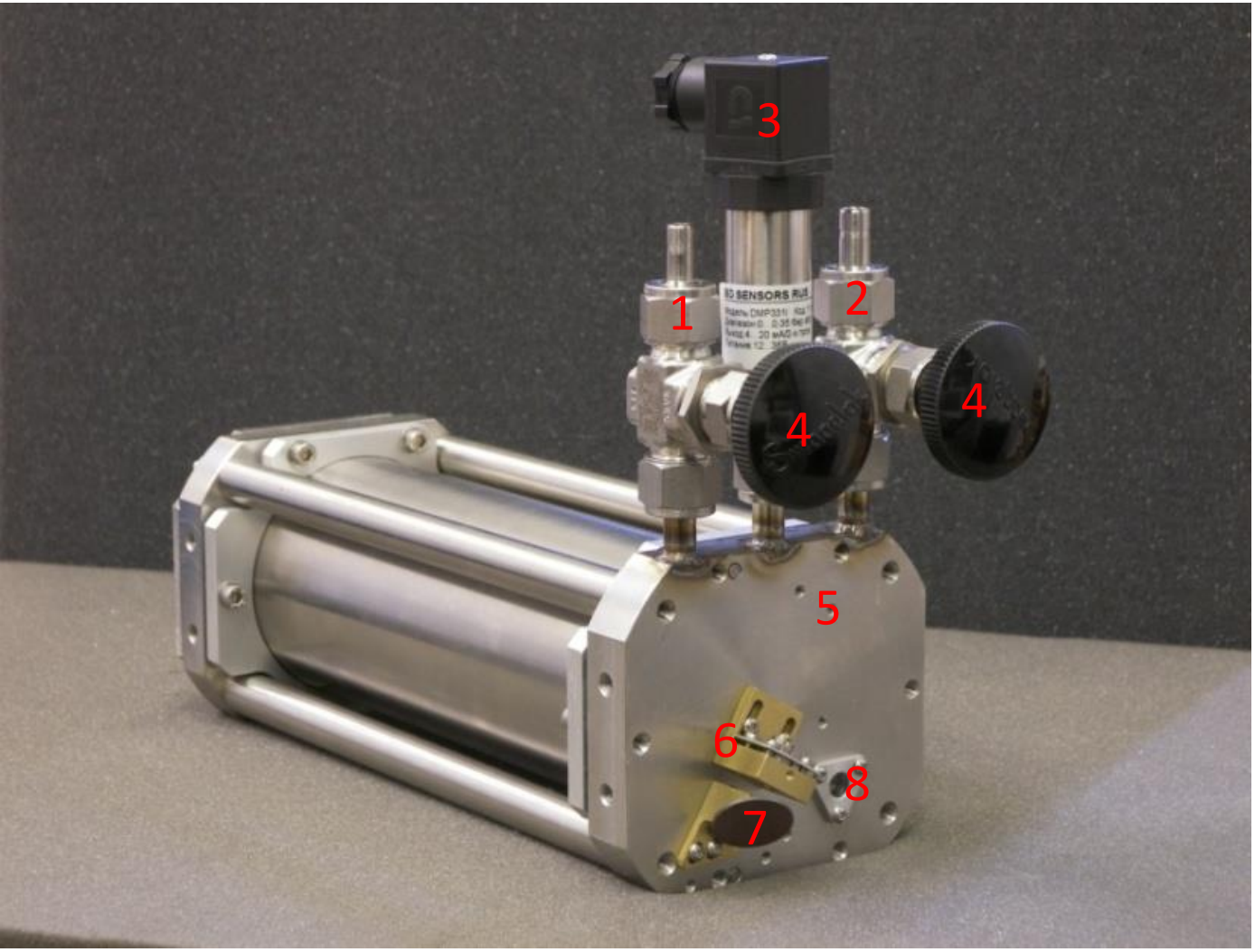


Reference channel with
photo detector and fiber



Block-scheme of one of
the electronic modules of
spectrometer

Chernin cell for analytical channel



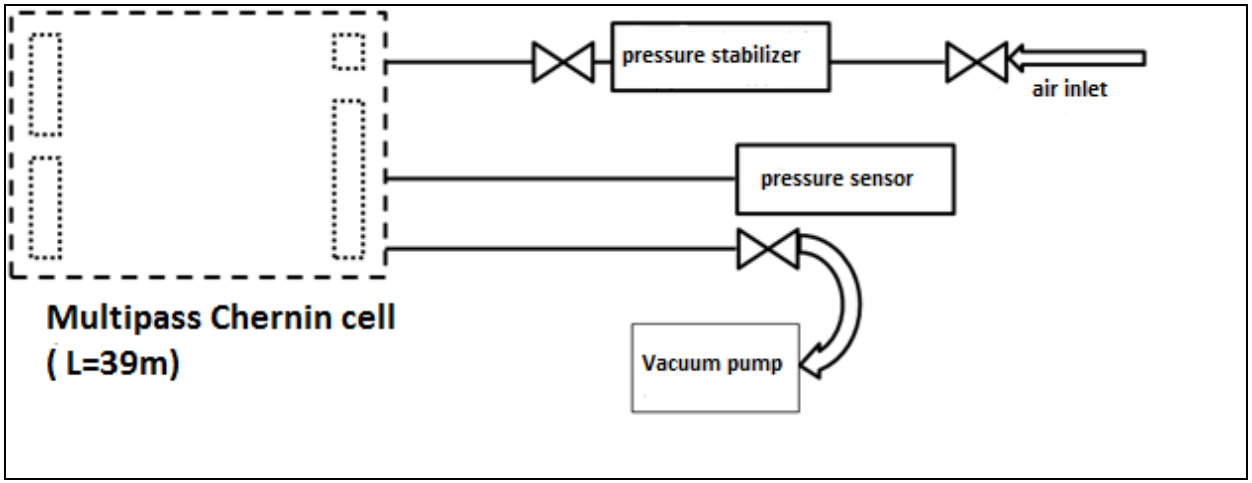
Distance between mirrors – 25 cm.

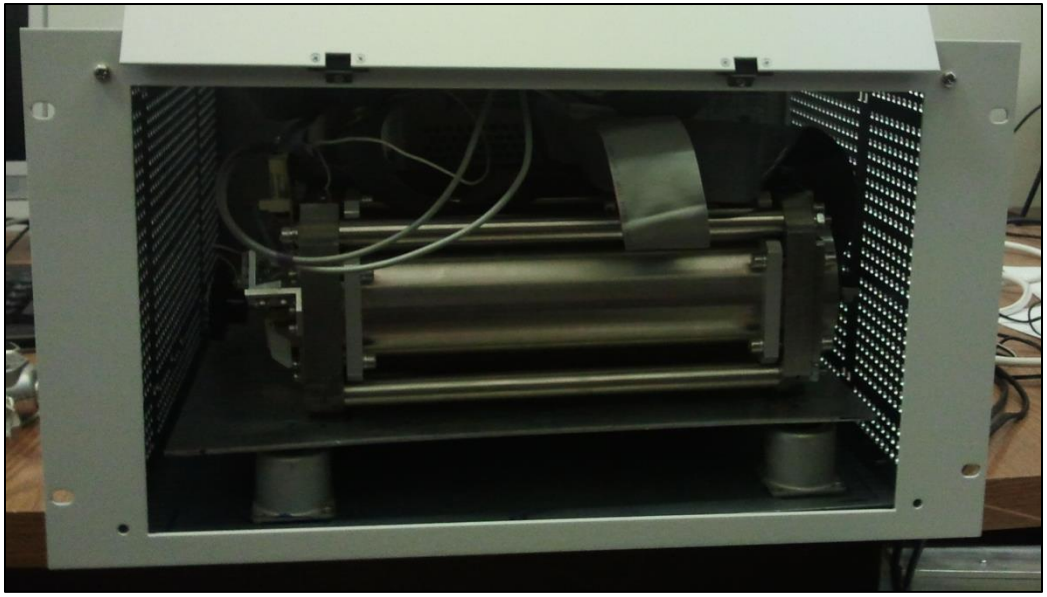
Number of passes N = 156.

Effective optical length L = 39 m.

1 – air flow in, 2 – air flow out, 3 – pressure sensor, 4 – valves, 5 - temperature sensor, 6 – fiber connector with collimator, 7 – DL in, 8 – DL out.

Structure diagram of spectrometer with external connections

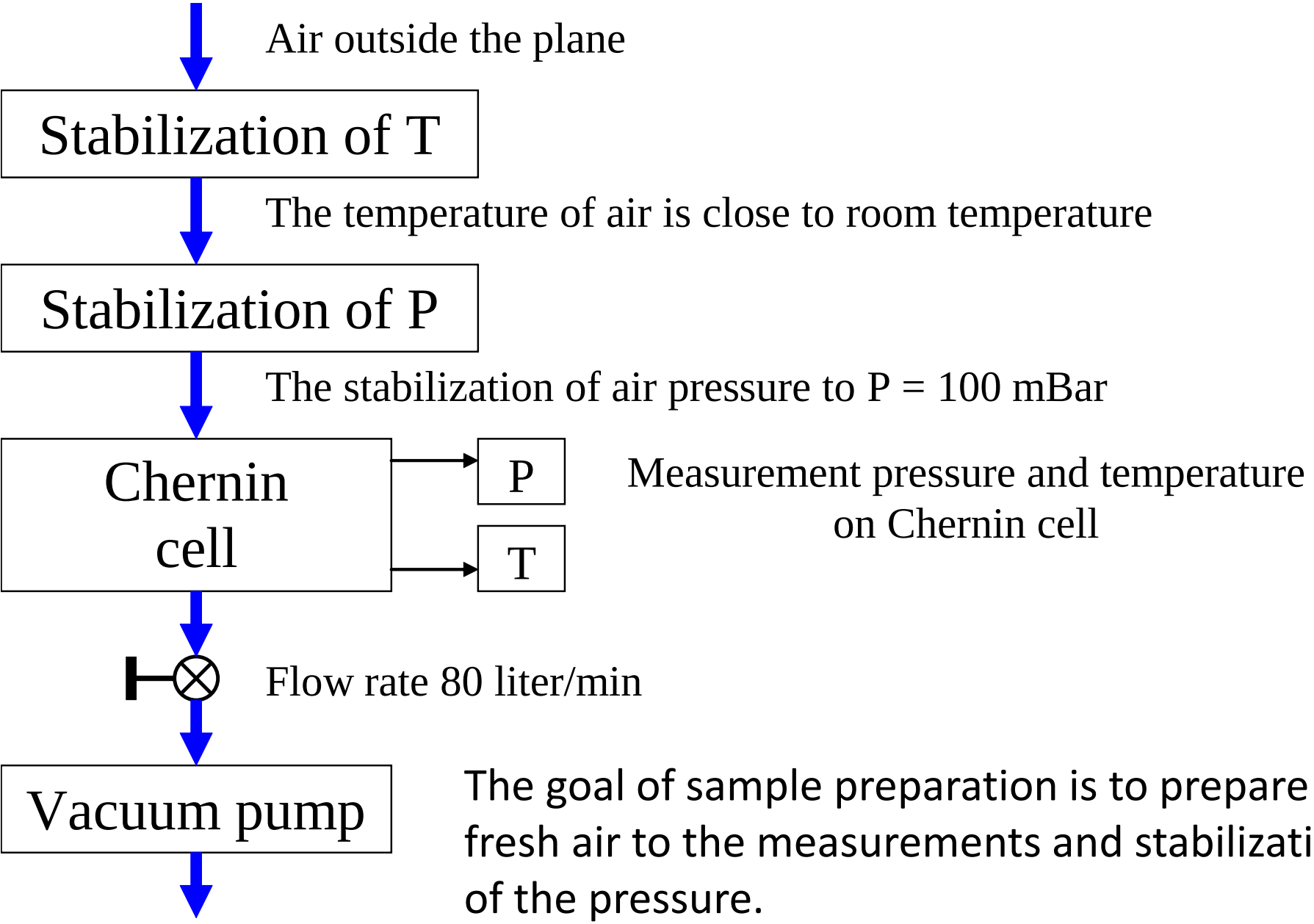




Cell module is mounted in the telecommunication rack at airplane dampers

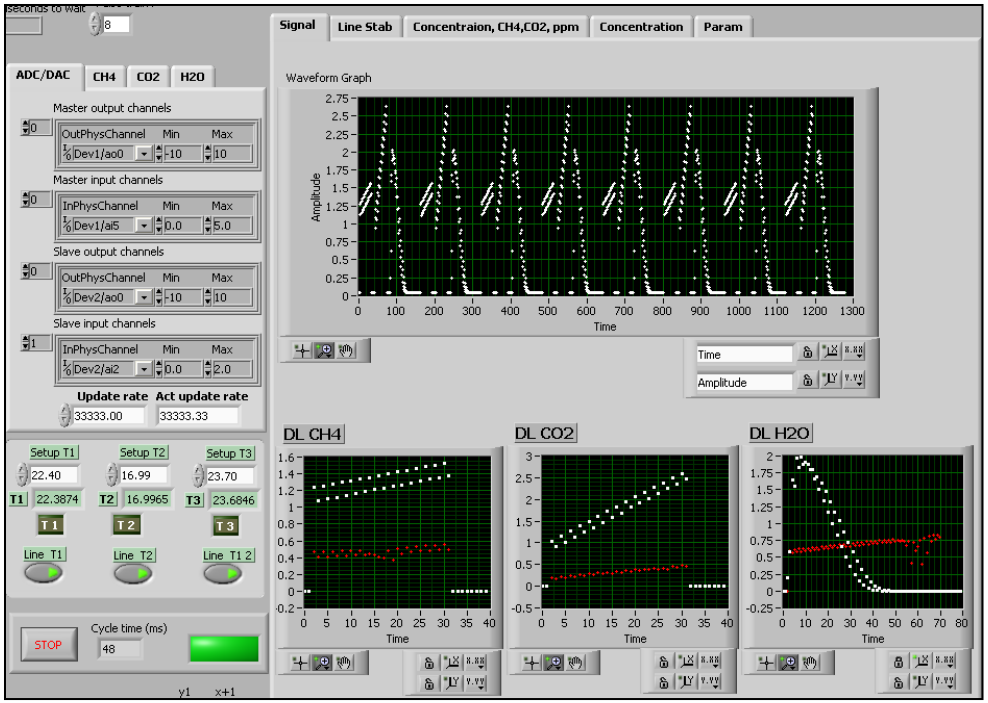
DL spectrometer with a vacuum pump

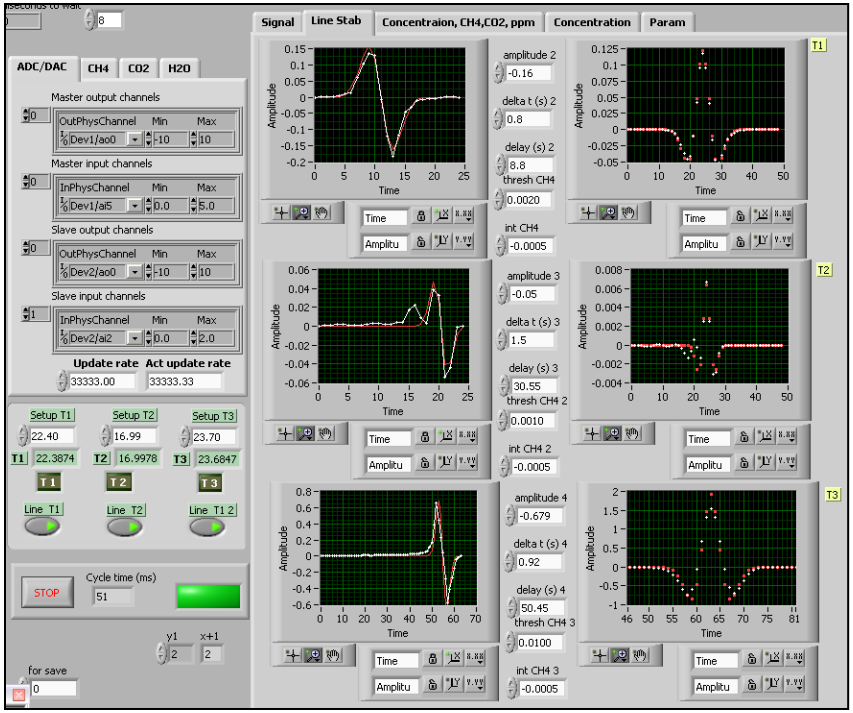
Sample preparation



The goal of sample preparation is to prepare fresh air to the measurements and stabilization of the pressure.

Program interface of DL spectrometer

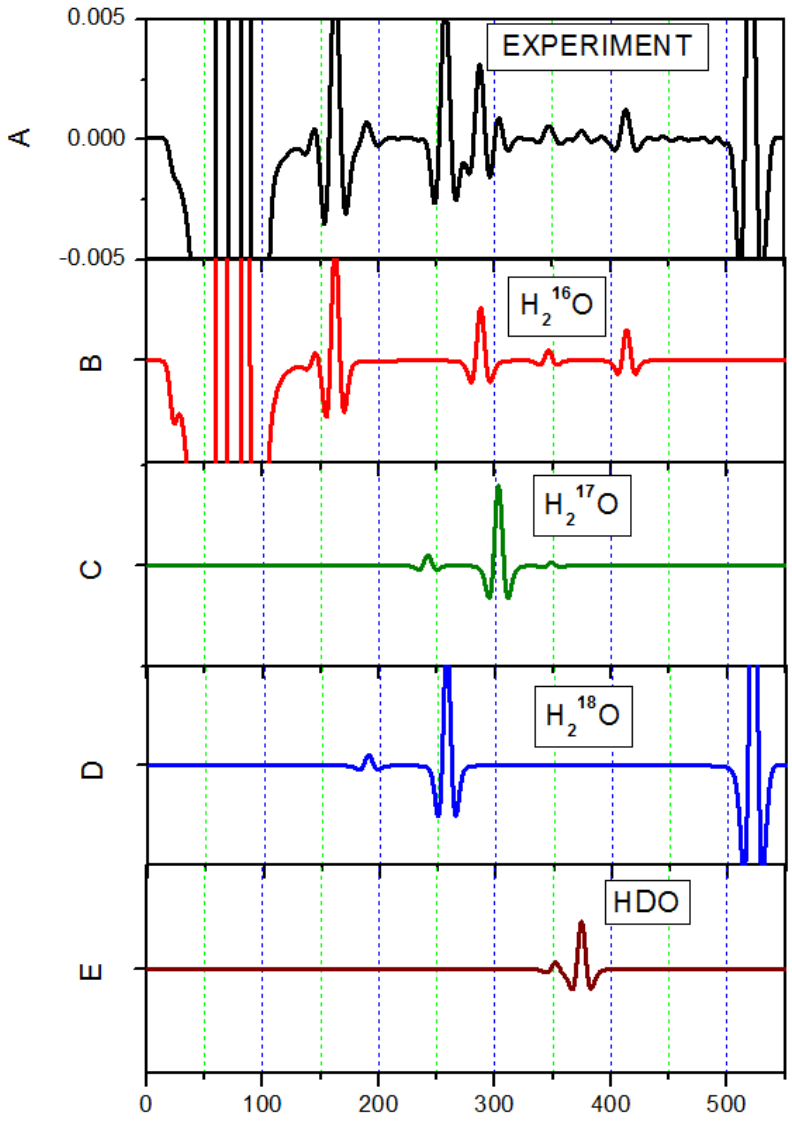




$$C_{xy}(t) = X(t) \otimes Y(t) = \int_{-\infty}^{\infty} X(t)\,Y(t+\tau)\,d\tau \Rightarrow C_{xy} = \alpha \cdot C_{xx} + P \Rightarrow C = \frac{\alpha \cdot P_R \cdot L_R}{P_A \cdot L_A} \cdot 10^6, [ppm]$$

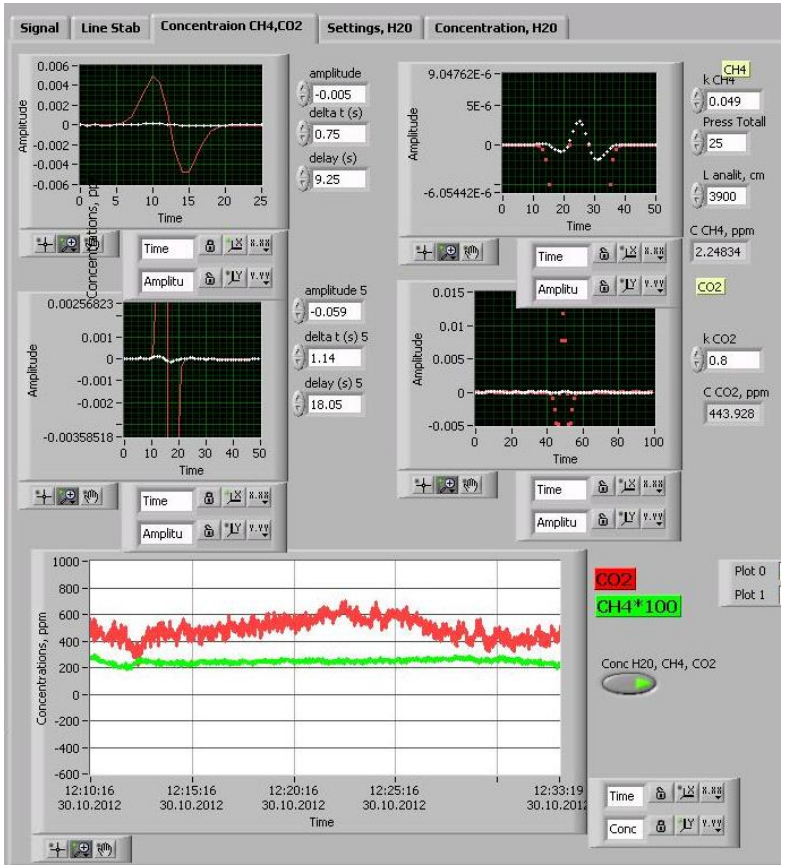
The autocorrelation (Cxx) channel of the frame signal (X (t)) and correlation (Cxy) of the analytical signal channel (Y (t)) of the frame (X (t))

H_2O channel interface

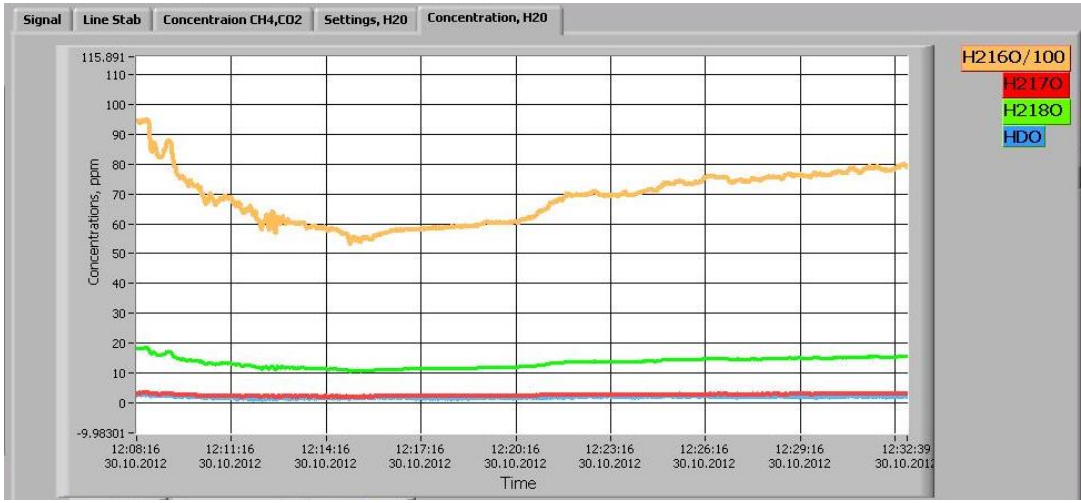


- Linearization recorded water signal using Fabry-Perrot interferometer ($D^* = 0.04933\ cm^{-1}$))
- Execution operations A, B and C (like CH_4 and CO_2) with recorded water signal. Calculation function C_{XY} using G-filter.
- Synthesis 4 basis functions of a isotopomers: ($H_2{}^{16}O$, $H_2{}^{17}O$, $H_2{}^{18}O$, H DO) using Hitran database . **Model Parameters: Length 39 m, (like multipath cell), Totall pressure 40 mBar, (air flow through cell), 1% concentration $H_2{}^{16}O$.** String of synthesis: Absorption spectrum >> Derivative >> C_{XXi} functions by use G-filter.
- Linear regression C_{XY} with respect to C_{XXi} determination concentration isotopomers of a water vapor .

First results



Window to measure the concentrations of methane and carbon dioxide



Window to measure the concentrations of isotopomers of water vapor

Conclusions

1. ***A prototype of DL spectrometer for airplane-laboratory was developed.***
2. ***Analytical spectral range for H_2O ,CO_2,CH_4 channels was selected.***
3. ***Analytical lines parameters were investigated and calibrated.***
4. ***Algorithms and software to measure concentration gases was developed.***
5. ***Lab tests were performed.***