MEASUREMENT OF WATER ISOTOPOMERS VIA TDLS IN THE VICINITY OF 1.392 μ

T. Kumanskaya, A. Nadezhdinskii, Ya. Ponurovskii,

Yu. Shapovalov, D. Stavrovskii, I. Vyazov

Natural Sciences Center of the A.M. Prokhorov

Moscow General Physics Institute, RAS
38 Vavilov street, 119991 Moscow,Russia
E-mail: jakov@nsc.gpi.ru

A. Babichev, G. Grigoriev, S. Malyugin, Sh. Nabiev, A. Ustinov

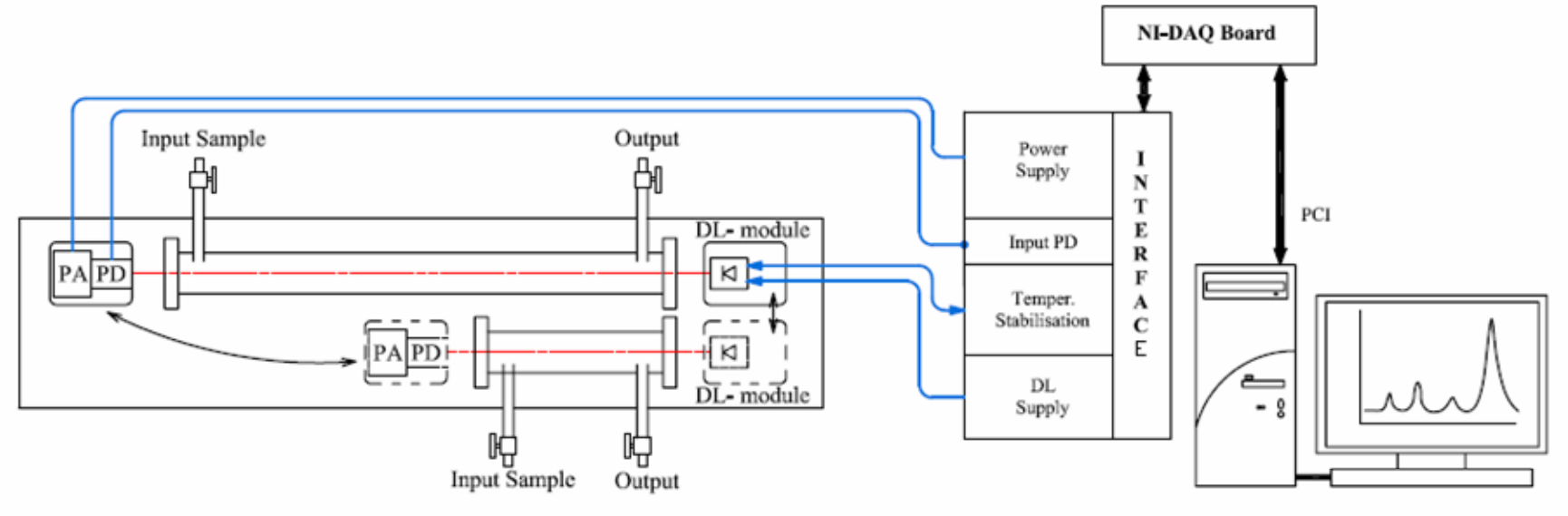
Russian Research Center "Kurchatov Institute"
1 Kurchatov sq., 123182 Moscow, Russia

Introduction

Production of oxygen isotopes with vacuum water rectification is an important sector of stable isotopes industry. The ^{18}O isotope (oxygen-18) is widely applicable in medicine, most of all, in positron-emission tomography (PET scanners) diagnostics and researches of various metabolism processes in live tissues. Mass-spectrometer measurements of water isotopomer composition are rather expensive and time-consuming; densitometry is a cheap and rapid method, but lacking the necessary accuracy. TDLS is a good alternative method [1]. This report suggests a prototype of the device intended for rapid analysis of water isotopomer composition with the use of near-infrared diode laser.

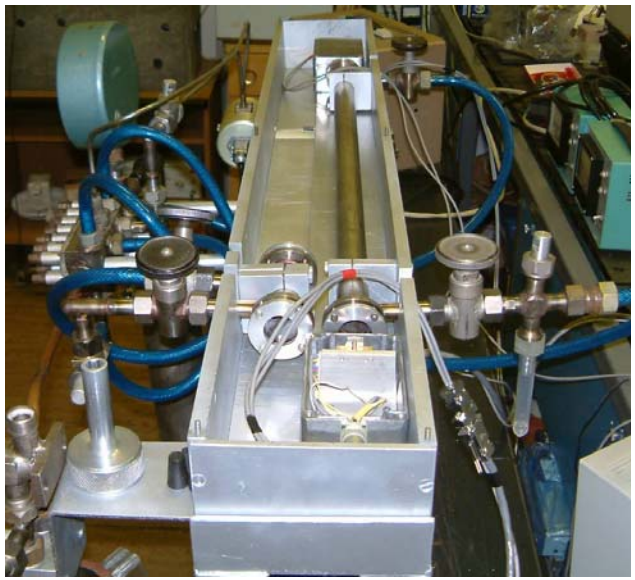
Samples of water vapor with various isotope contents were placed under pressure from 3 to 10 Torr in one of two cells with optical paths of 80 and 10 cm, depending on the task ("enrichment" or "depletion"). The 80-cm cell is intended for measuring the water isotope composition at low ^{18}O isotope content (from 0.01 to 1%). The other cell is used for measuring high ^{18}O isotope contents (0.5–100%). Absorption spectra of water vapor were detected with a NI DAQ I/O board. Software developed was based on LabVIEW. Isotopic ratio factors were calculated by use of integral cross section data of HITRAN-2004 [2]. The time interval of single measurement was ~ 0.2 s. The time of single probe development was much greater (up to 10 minutes). It depends mainly on pumping and filling process to reduce memory influence of previous sample. The results obtained in the interval of 0.5–98% ^{18}O concentration were compared with the results of mass spectrometry measurements. A good agreement was observed.

Experimental Setup

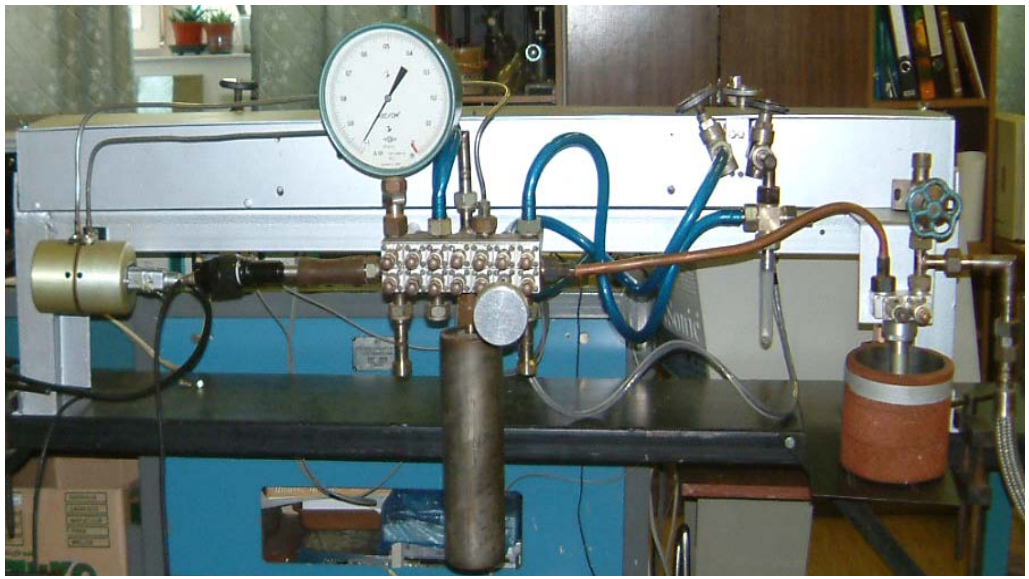


Distributed feedback (DFB) diode laser (DL) from Laser Components GmbH was used. The wavelength of lasing was in the vicinity of 1.392 μ. The DL was pumped with trapezoidal pulses of 0.5–1 ms duration and 1–2 kHz repetition rate. Frequency tuning of the DL radiation was produced in the frequency interval 7183.2–7185.0 cm^{-1}.

Instrument View

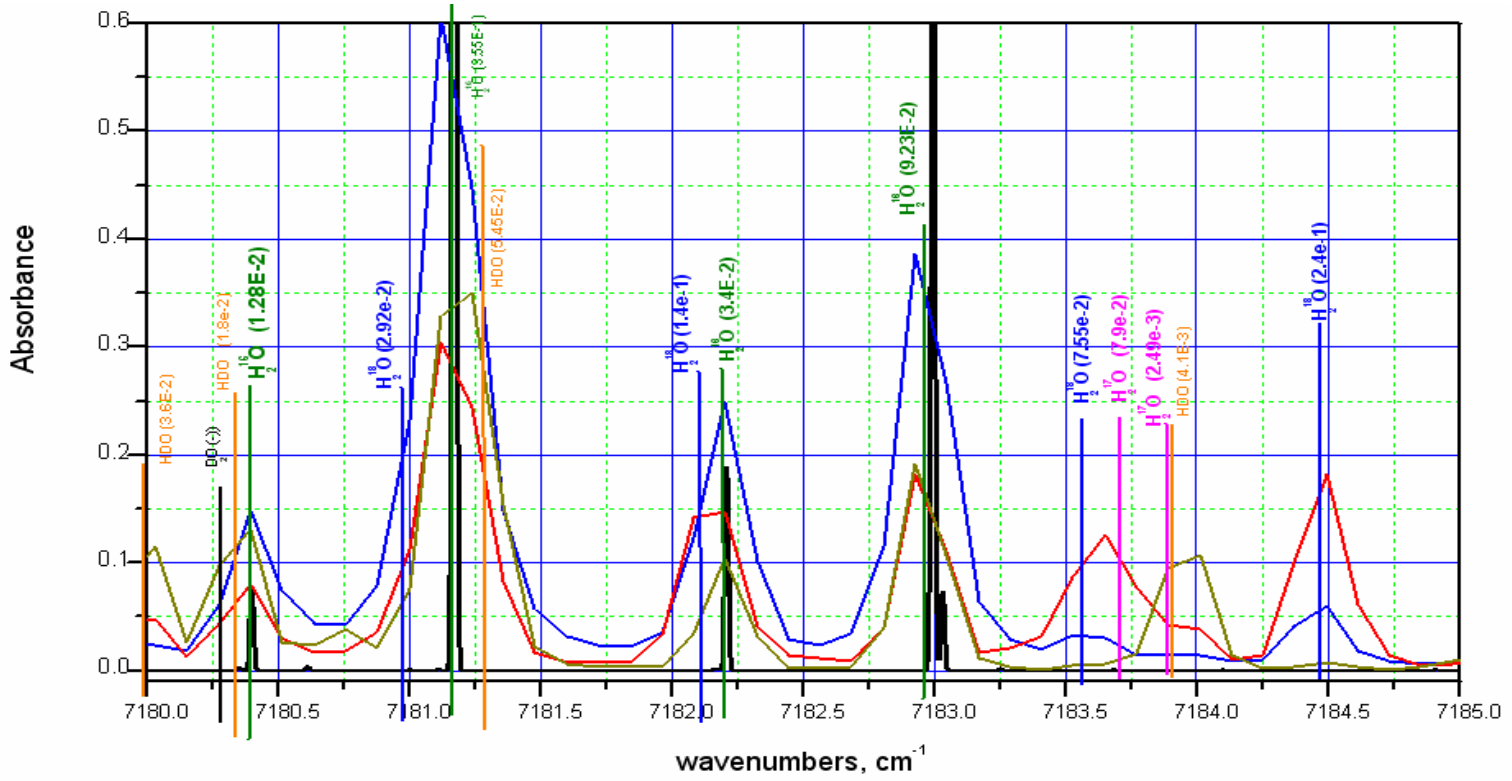


Optical section



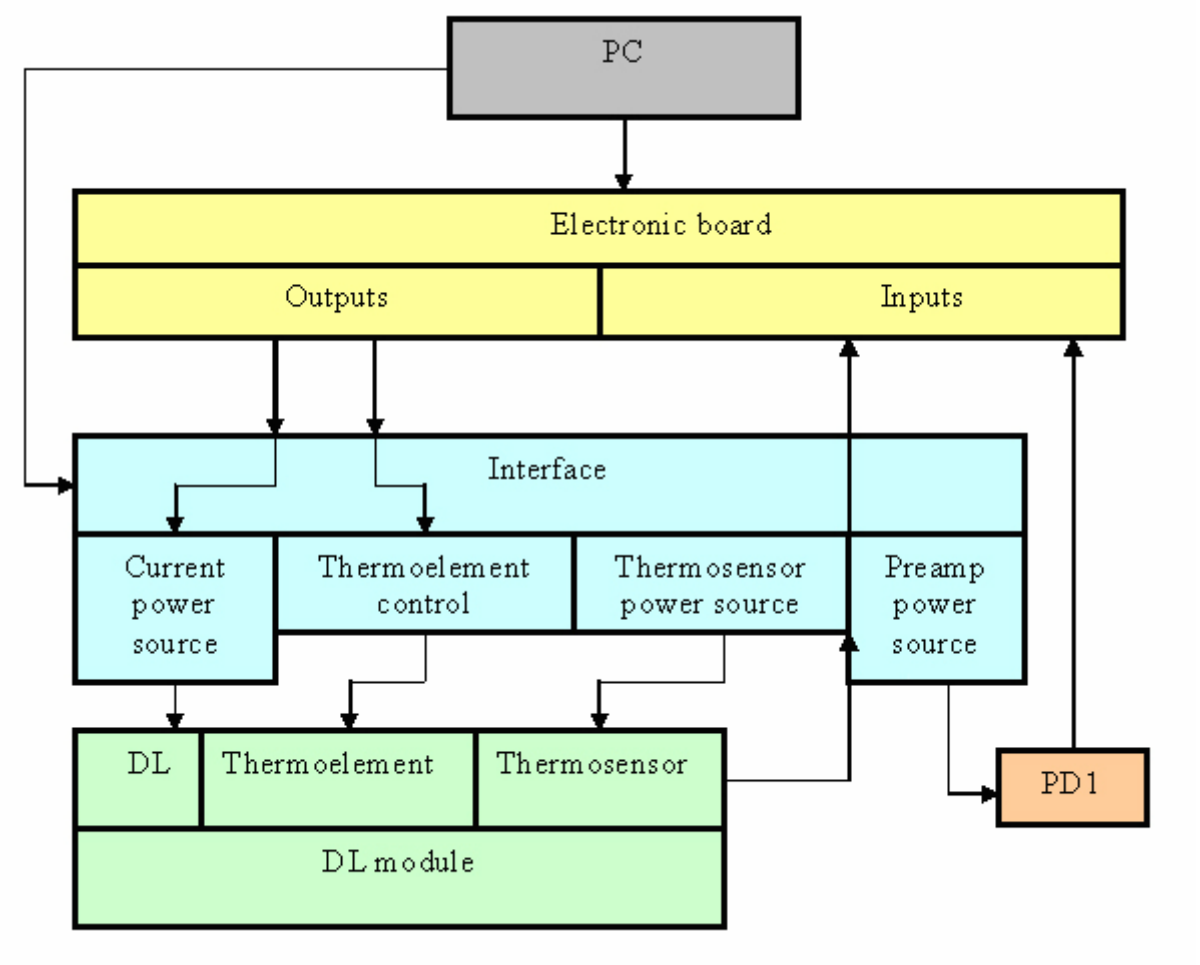
Sample feeding and pressure regulation

H_2O Fourier-spectroscopy over the range of 7180-7185 cm^{-1}

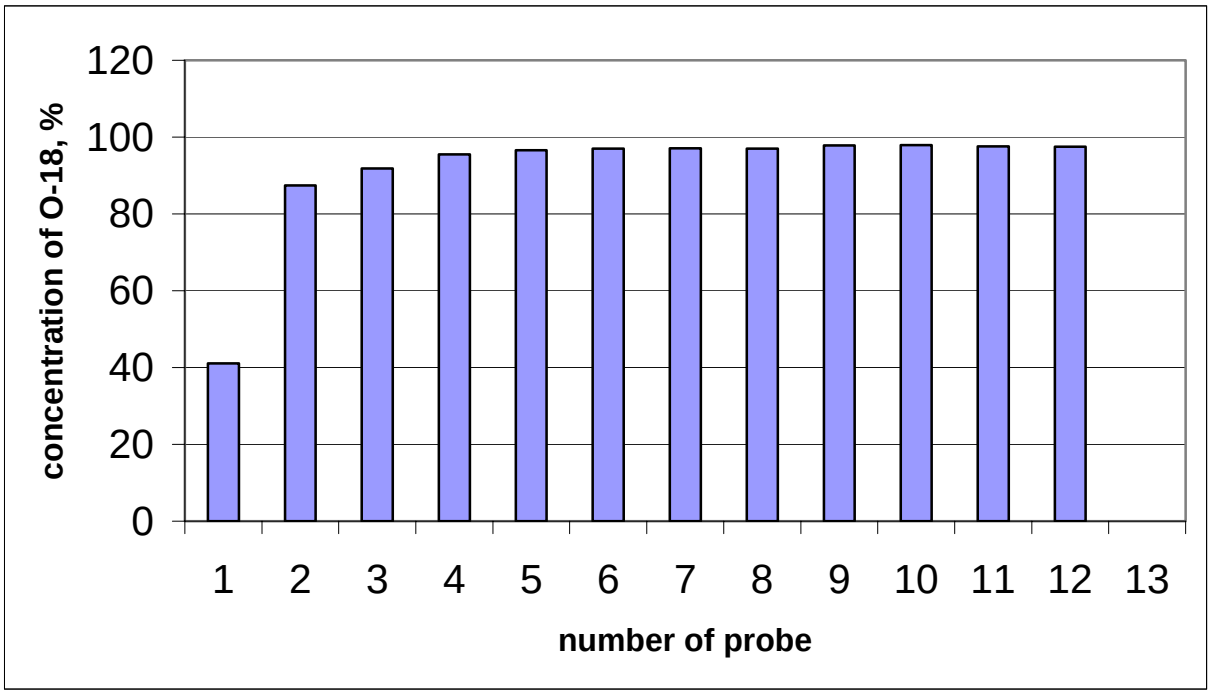


Absorption spectra of water vapor with different isotope contents as recorded with the Fourier-spectrometer with the 0.025 cm^{-1} spectral resolution. In brackets absorption line cross-sections (cm^{-2}/atm) are presented [1,2]. The frequency range of 7182.5-7185 cm^{-1} was chosen for simultaneous measurement of the following isotopomers: $H_2{}^{16}O$, $H_2{}^{17}O$, $H_2{}^{18}O$, $HD^{16}O$, $D_2{}^{16}O$.

Electrical Block-scheme

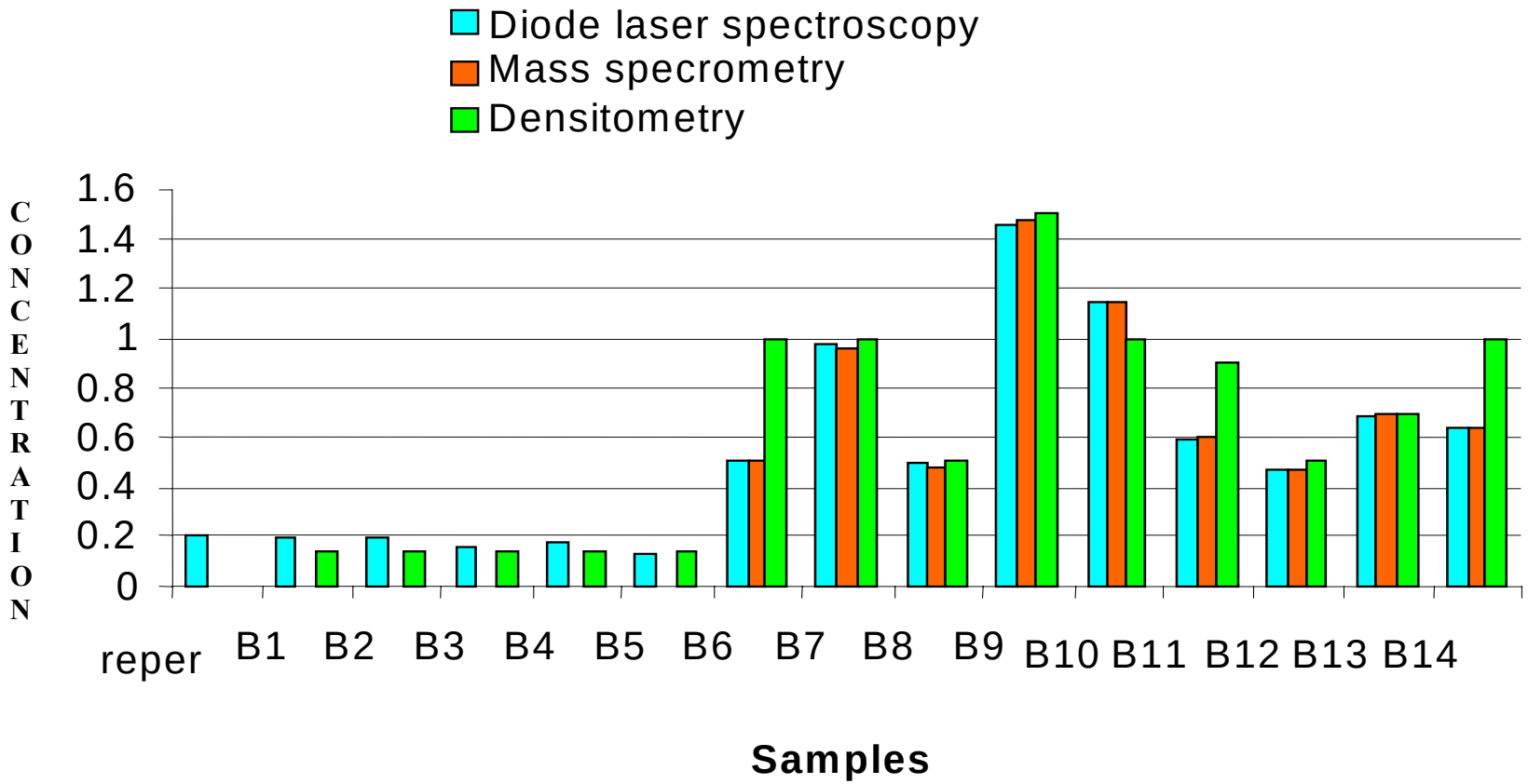


Effect of the previous probe content memory



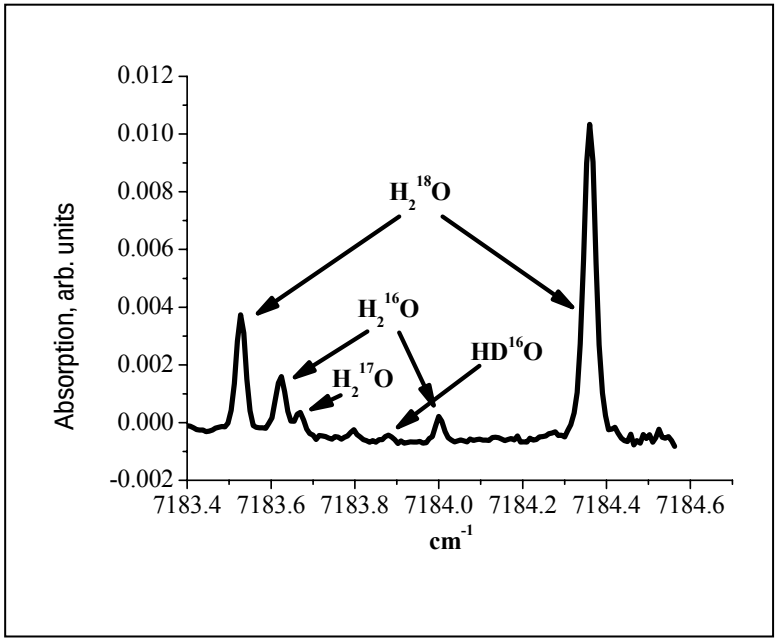
Measured concentration is 97.5 ±0.5 % (probes of #8-12)

Comparison of different measurement methods

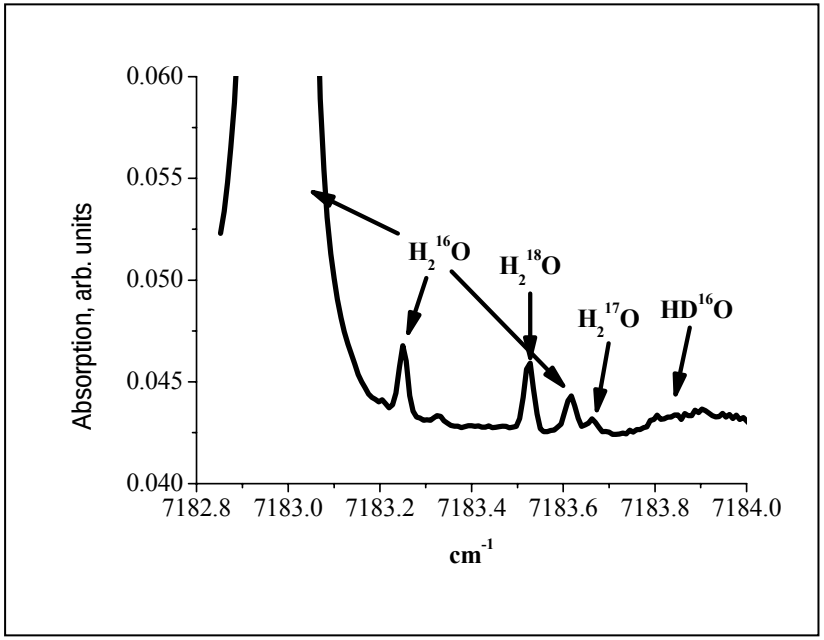


Two spectral regions of DL operation

Measurements of isotope composition with the natural isotope content and high enrichment in ^{18}O (up to 99%) require a broad dynamic range (more than 4 orders) of measuring the absorption coefficients of different water isotopomers. That's why two spectral regions of DL operation have been chosen: for "depletion" (0.05-0.5 % of ^{18}O content) and for "enrichment" with ^{18}O (0.5-99.9%).



"depletion"



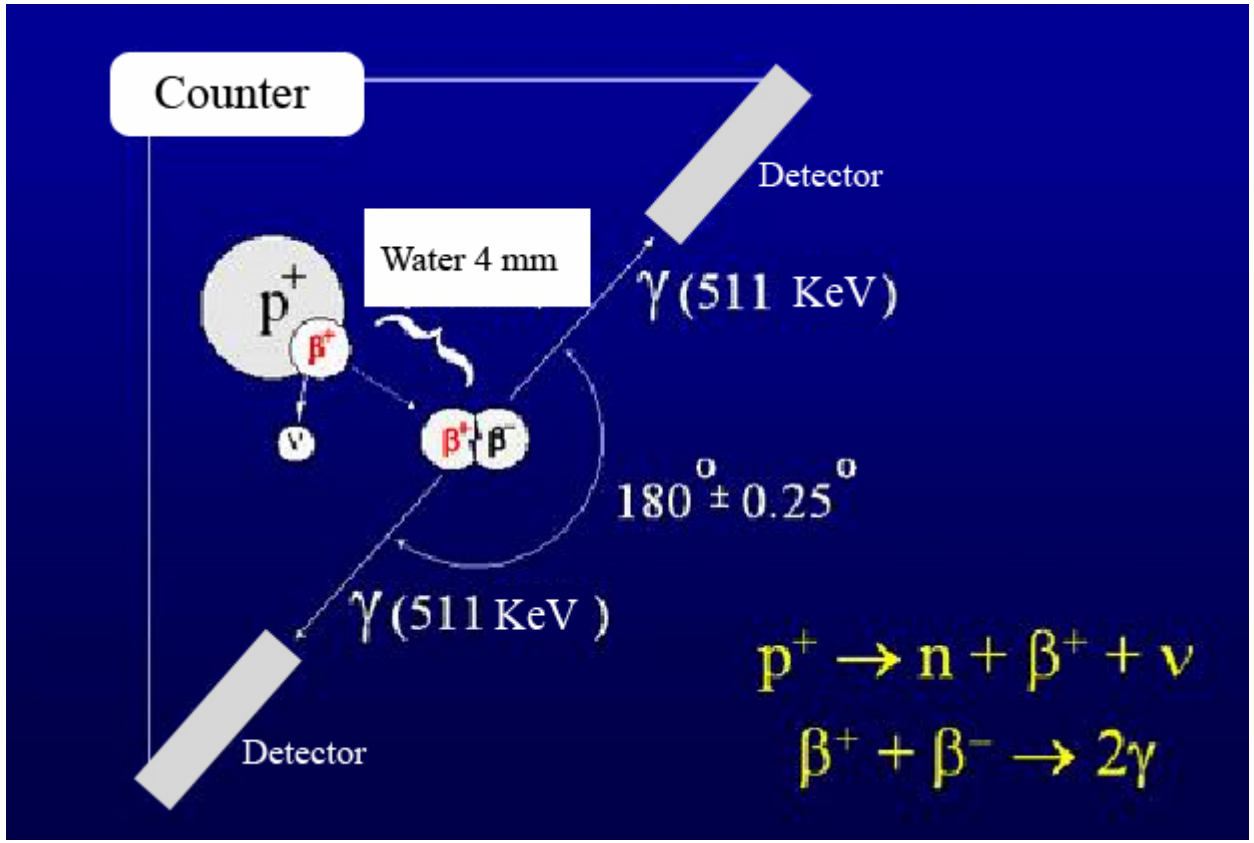
"enrichment"

Absorption spectra of water vapor with natural isotope content as recorded with the DL-spectrometer

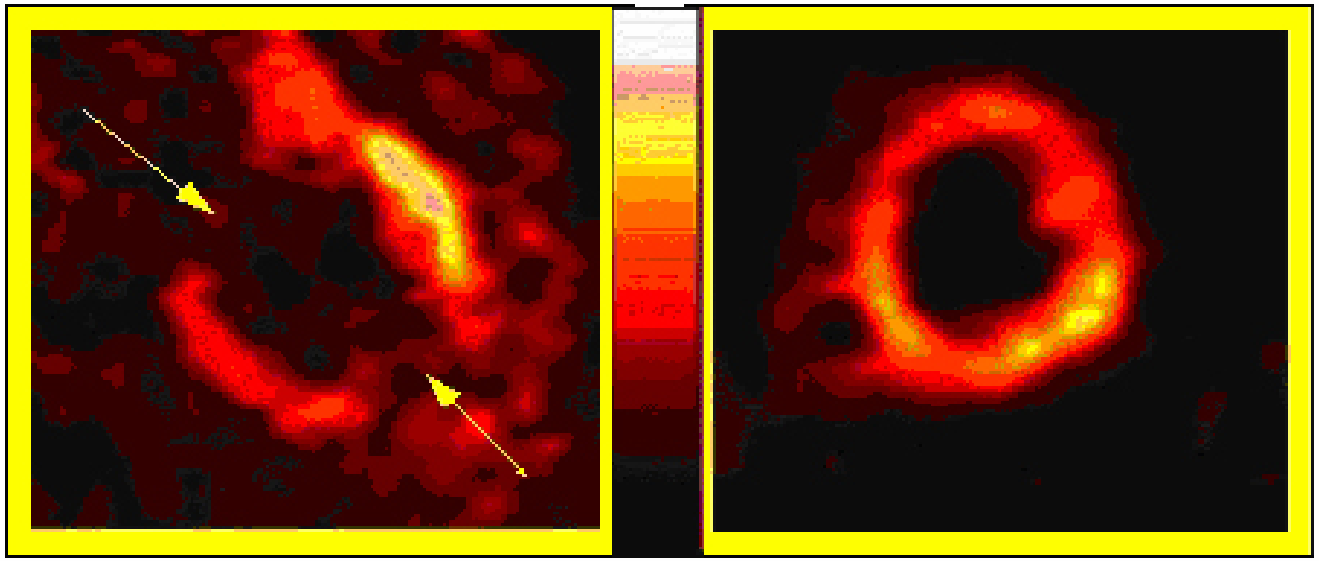
Positron Emission Tomography (PET)

$$^{18}O + p \rightarrow {}^{18}F + n$$

$$^{18}F \rightarrow {}^{18}O + \beta^{+} + \nu$$



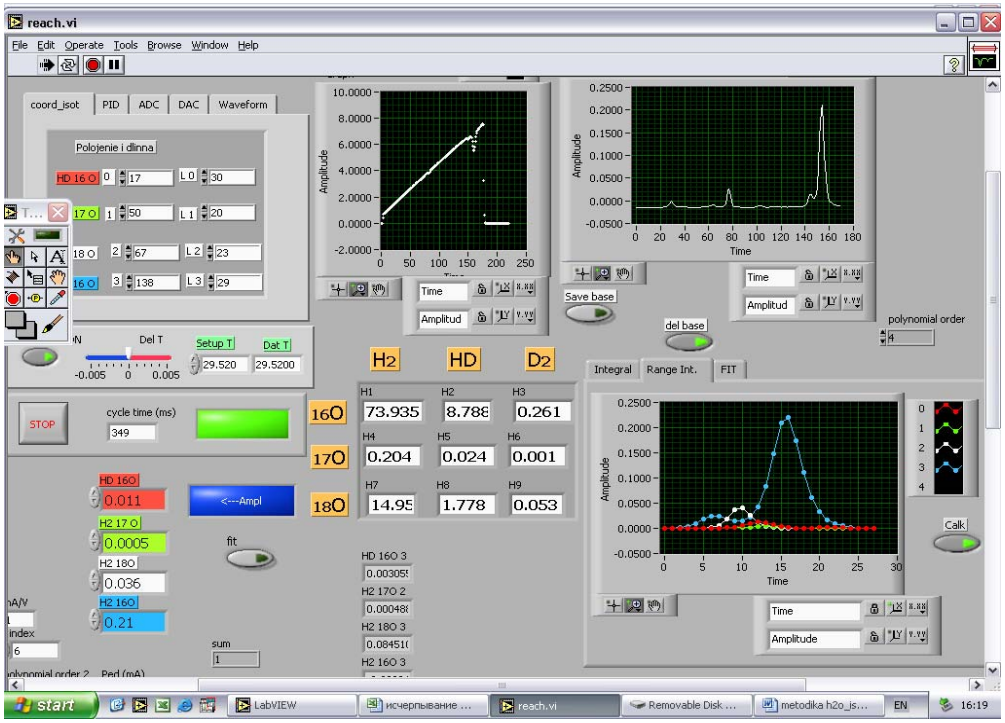
Example of PET application

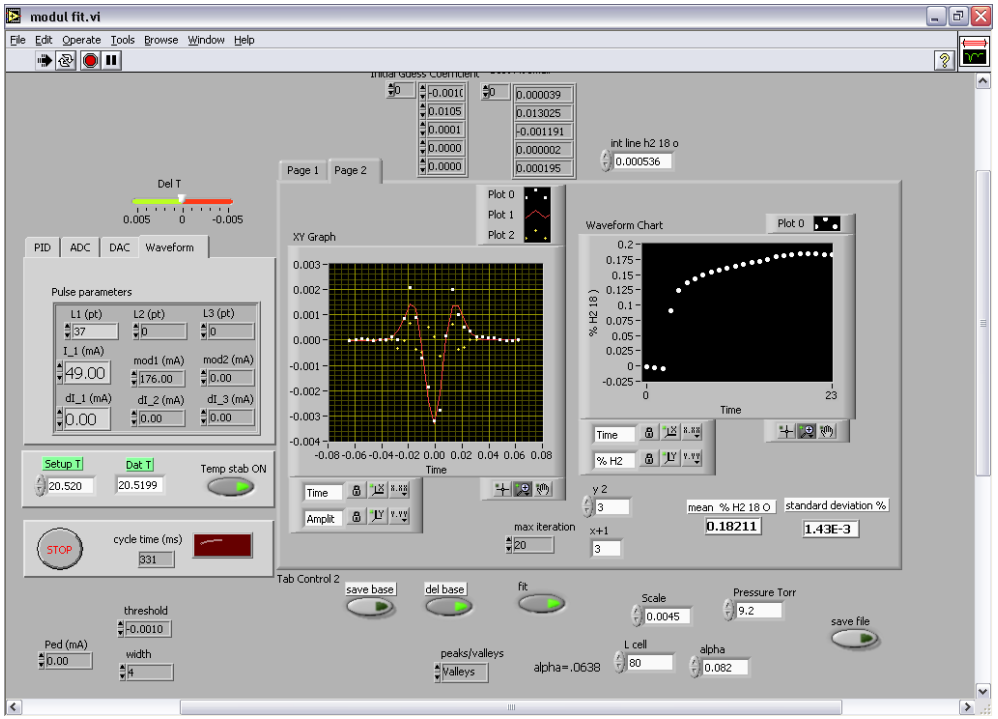


Human heart after infarction

The heart of healthy patient

Interface





“enrichment”

“depletion”

Graphic interfaces of the application in the LabVIEW environment

Conclusion

A pilot DL-spectrometer for rapid measurements of water isotope composition ($H_2{}^{16}O$, $H_2{}^{17}O$, $H_2{}^{18}O$, $HD^{16}O$, $D_2{}^{16}O$) with the use of a DL (λ=1.39 μm) was designed and investigated. The time of one sample development does not exceed of 15 minutes. The range of measured concentration of O-18 is 0.01…100%. The apparatus and procedures developed are used for routine measurements to control water isotopomers separation process at Kurchatov Institute.

References:

1. E. R. T. Kerstel et al. *Spectrochemica Acta Part A 58* (2002) 2389-2396.
2. L. S. Rothman et al, The HITRAN molecular spectroscopic database, *JQSRT*, vol. **82**, numbers 1–4, 15 November–15 December (2003). http://cfa-www.harvard.edu/hitran/
3. R. A. Toth, *Appl. Opt. 33* (1994) 4851–4867; *Appl. Opt. 33* (1994) 4868–4879; *J. Mol. Spectrosc. 186* (1997) 66–89.