CARGESE INTERNATIONAL SCHOOL 2009 - WATER VAPOUR IN THE CLIMATE SYSTEM

HAI: Hygrometer for Atmospheric Investigations

Airborne Laser Hygrometer for Stratospheric and Tropospheric Sensing

PCI

JÜLICH FORSCHUNGSZENTRUM

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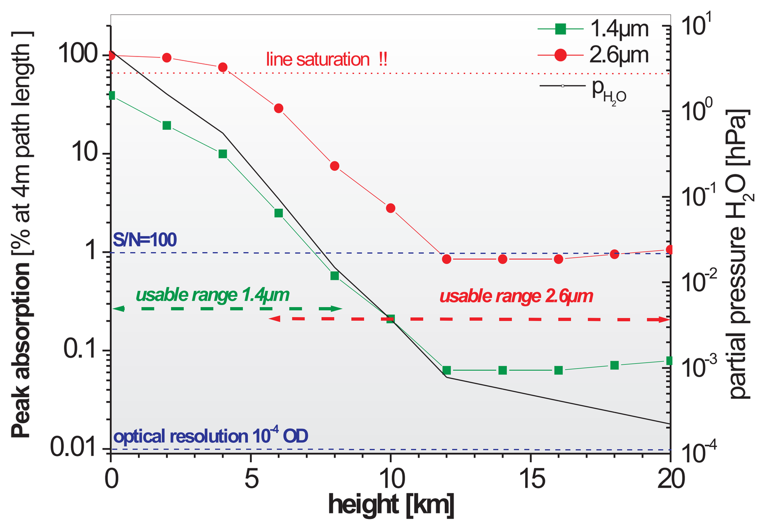
IMK-AAF

HAI: PERFORMANCE GOALS

Fast, open path H_2O-vapor and **Total-H_2O** sensor for **in-cloud** measurements

- ⇨ **Absolute** [H_2O], Self calibrating, high selectivity
- ⇨ **Small** (25cm base, 1”-2”optics),
- ⇨ **Light weight** (<20kg)
- ⇨ **Wide dynamic range** 2-10.000 ppm (40.000 long term)
- ⇨ **H_2O resolution** **100 ppb** (20 ppb)
- ⇨ **Time resolution** 1-**10Hz** (100Hz)
- ⇨ Press./temp. range 1000-100hPa 300-200K

⇨ **Simultaneous total water** measurement
⇨ Extractive sampling into small multipass cell inside



Path length selection
acc. to spectral simulations using
- P,T from US standard atmosphere
- [H_2O] TDL meas. in Kiruna

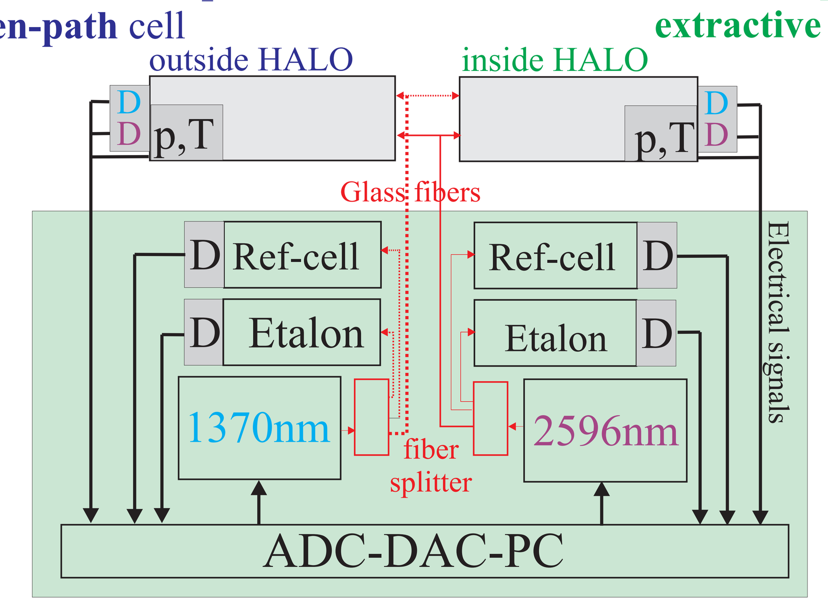
Assuming
- 10^{-4} OD opt. resolution S/N > 100 (ca 40ppb)

⇨ **4m path @2.6µm**

HAI: CONCEPT

High-resolution **direct absorption** spectroscopy
⇨ absolute [H_2O], line lock
New 2.6µm DFB-DL
⇨ 20x line strength ⇨ higher resolution, smaller size/weight
Dual-λ approach (2.6µm+1.4µm)
⇨ wide dynamic range ⇨ high accuracy ⇨ fail safe
Dual cell approach (open path cell + closed cell)
⇨ gas phase H_2O + total H_2O simultaneously
In-situ White Cell design with two laser paths
⇨ 150mm cell width with two 4,8m laser paths
Optical fiber coupling
⇨ robustness, accuracy (parasitic abs.), Handling, weight+size

GAS PHASE H_2O **open-path** cell — *TOTAL H_2O* **extractive** cell

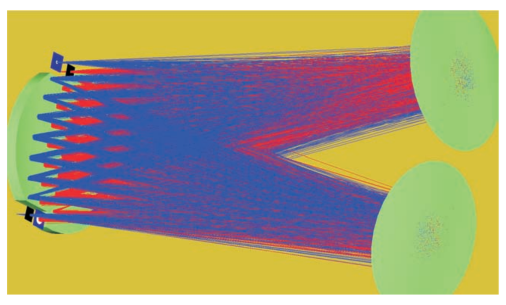


HAI: WORK PACKAGES

Spectroscopy (Laser characterization, precision line data validation / determination (AIDA, PTB), optimized line selection)
Optics development (Open-path+extractive multipass cells: ray tracing CFD optimization/ mechanics-temperature, fiber coupling optics 1.4µm+2.6µm)
Electronics and Software (PXI-System - function generators and multiple ADC cards, software for line locking, auto-reboot, remote control, real-time software support, characterization of the electrical components and compensation of phase and frequency shifts)
Aerodynamic simulation (CFD/FEM for p,T-variation+ air drag+mechanics, spectroscopic effects)
Instrument Validation (precision flow system, PTB national H_2O generator , climatic chamber FZJ+ FZK(AIDA); Comparison with other instruments (AQUAVIT))
Instrument certification and integration into HALO (EMV, EMC)
Demonstration Missions (ML-Cirrus, TACTS, POLSTRACC)

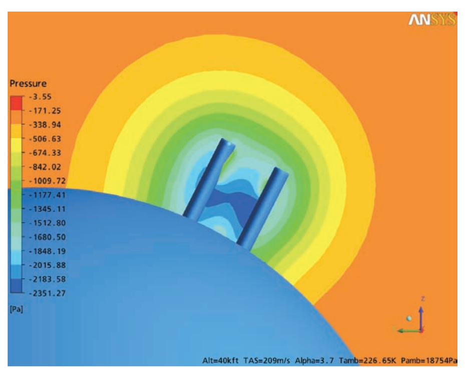
OPEN PATH CELL DESIGN

White Cell Simulation (PCI, FZJ)

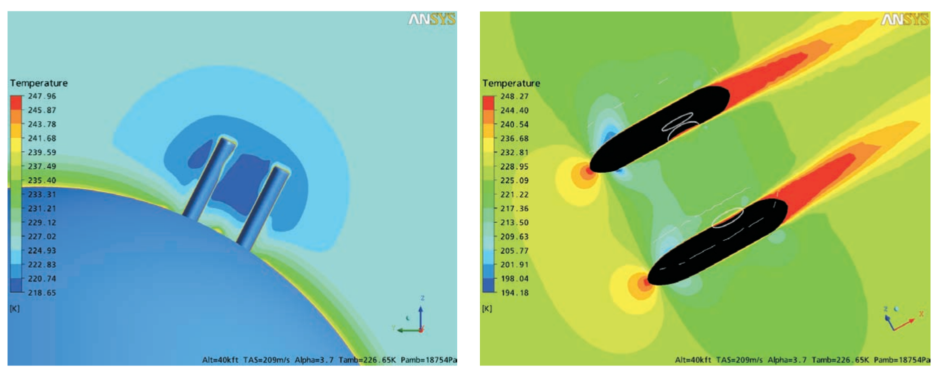


- Two Laser paths 1.4µm and 2,6µm for high dynamic measurements
- 4,8m absorption path for each laser
- Cell width 150mm
- Less optical components for minor optical fringes

CFD Analysis of the pylon structure (FZJ)

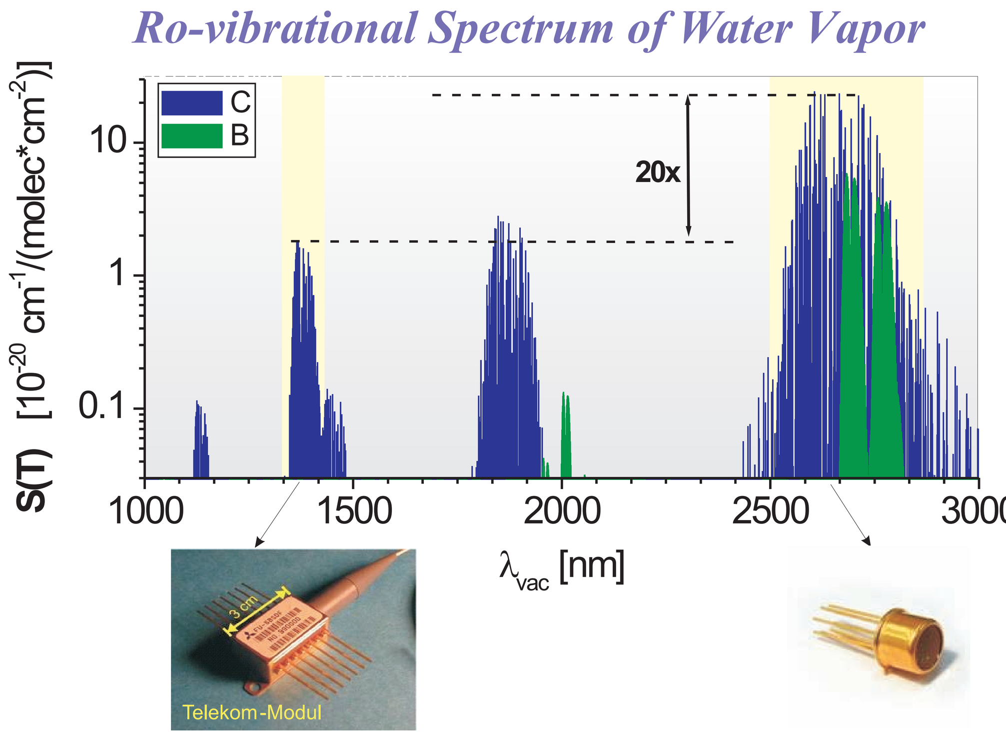


- Minimization of vorticity
- Measurement outside of the airplane boundary layer
- Relative pressure increase of only 30hPa
- Relative Temperature increase of only 2K
- Thin pylon boundary layer

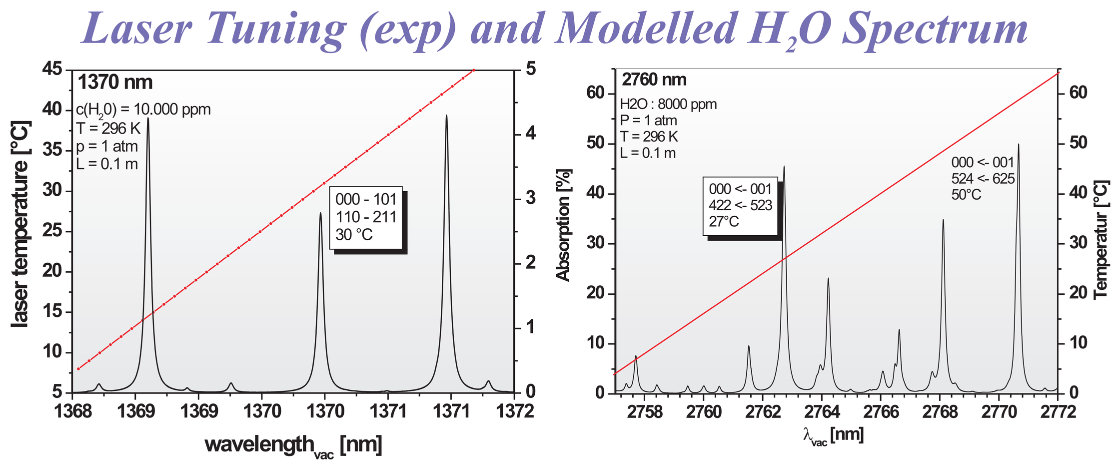


H_2O SPECTROSCOPY

Ro-vibrational Spectrum of Water Vapor



Laser Tuning (exp) and Modelled H_2O Spectrum

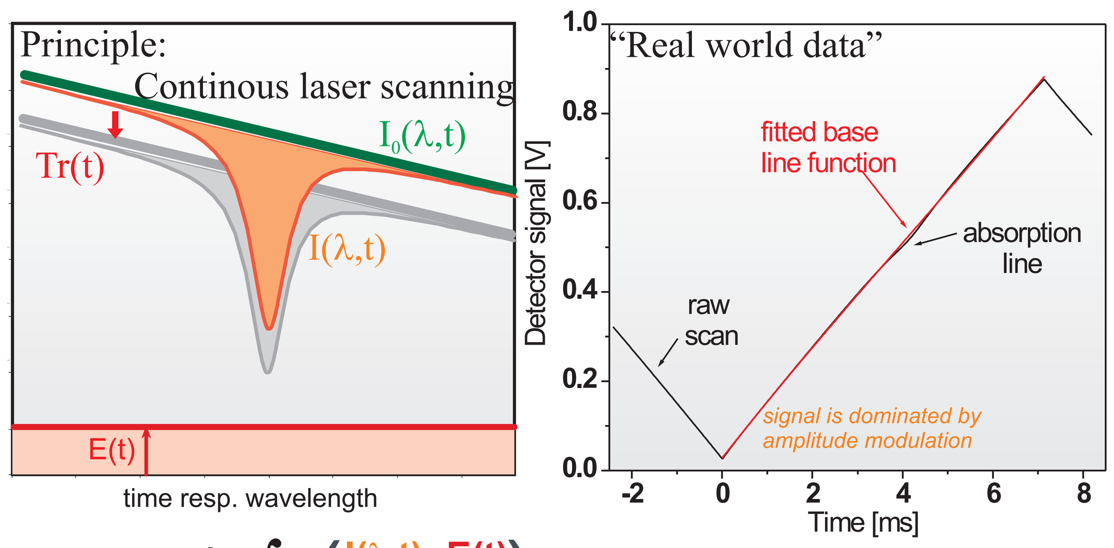


MEASUREMENT PRINCIPLE

Direct Absorption Spectroscopy

Lambert-Beer -Law

$$I(\lambda,t)= I_0(\lambda,t)\cdot Tr(t)\cdot \exp[-S(T)\cdot\phi_{line}\cdot N\cdot L]+ E(t)$$



$$\Rightarrow N = \frac{-1}{S(T)\cdot L}\int \ln\left(\frac{I(\lambda,t)-E(t)}{I_0(\lambda)\cdot Tr(t)}\right)\frac{\delta\lambda}{\delta t}\,dt \Rightarrow$$ **Absolute number densities** **Self calibrating**

- Laser characterisation
- Fitting process / Transm + emiss. Correction
- Absorption length measurement
- Line strength and temperature dependence

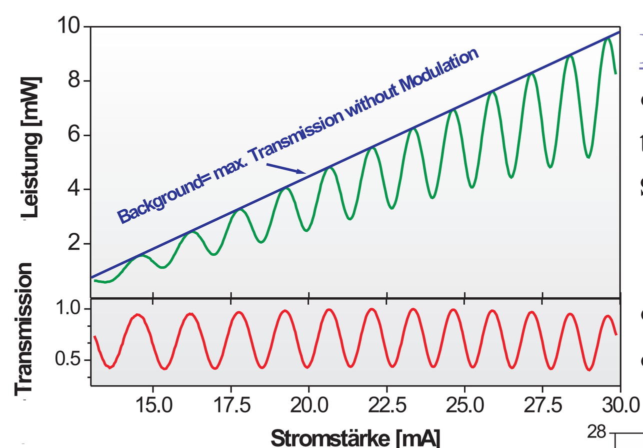
(Hitran or exp.)

Mixture fraction via ideal gas law

$$c_{H_2O} = \frac{p_{H_2O}}{p} = \frac{n\cdot k\cdot T}{p}$$

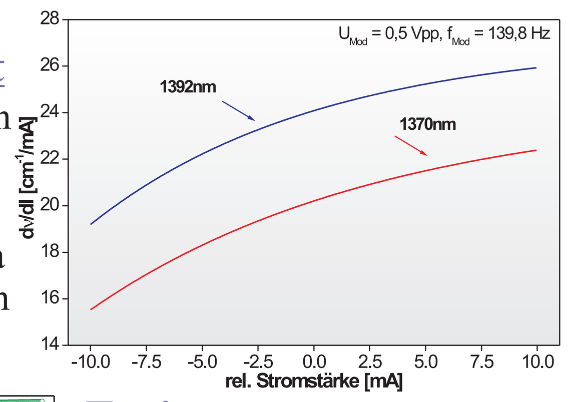
← Temperature
← Pressure → Pressure broad. coefficient γ^0 → Line width

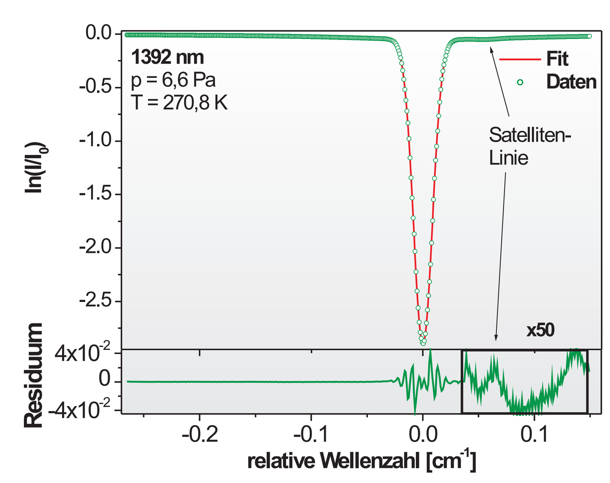
PRECISE LASER CHARACTERIZATION



Determination of ν(t)
- spectral integration requires **transfer** of the signal from **time space** to frequency space $\frac{\partial\nu}{\partial t} \Leftrightarrow \frac{\partial\nu}{\partial I_{Op.}}$
- use 10cm air spaced etalon
- advanced fitting procedure

Temporal behavior of dν/dt
- needed for abolute concentration
- nonlinear behavior
- sensitive to working conditions
- without: line width and line area depends strongly on scan position





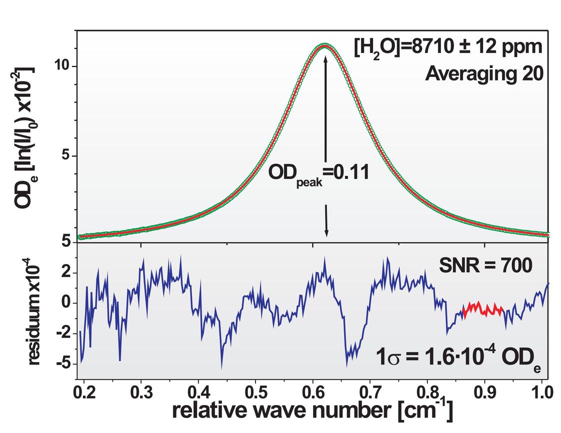
Tuning test:
Exp. Doppler width

Calculated: $1.994\cdot10^{-2}$
Fit: $1.991\cdot10^{-2}$

⇒ 0.15% deviation
⇒ precise determinat. of dν/dt
dν/dt reproducability ≤ 0.5%

PREVIOUS RESULTS

Latest results with the 1.37µm DFB-DL

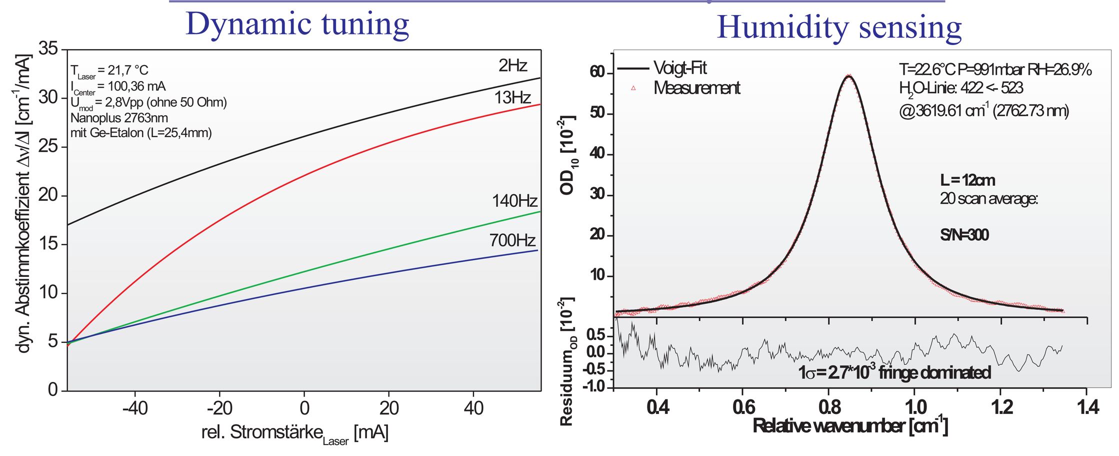


Optical resolution:
Path length L=15cm
Median from 20 absorption profiles
⇨ Time resolution: 0,9 Hz
⇨ 1,6·10-4 ODe S/N = 700
⇨ Δc = 12 ppm
⇨ 1,9 ppm·m·Hz-0,5

Spectrometer stability:
450 ppb·m·Hz^0,5 (H2O)

First results with the new 2.6µm DFB-DL

Dynamic tuning — Humidity sensing



Future potential: Direct Abs.-2f multiplexing / optical temperature and pressure measurement / extended basis instrumentation / more species

CONCLUSION

The HAI spectrometer will allow fast, calibration-free, in-situ and extractive water vapour detection. This affords to measure gas phase water vapour and total water (gas phase + liquid + ice crystals). Due to the use of fast micro processors and the developement of new, faster algorithms it will be possible to quantify the water vapour concentration rapidly with 10 to 100Hz. With an airplane velocity of 250m/s follows a spatial resolution about 25 to 2.5m is possible. By developing the new 2.6µm laser optics and fiber coupling to make the 2.6µm water absorption band accessible, HAI will use the 20 times more sensitive absorption lines, so that it will be possible to reach better limits of detection.

OUTLOOK

To provide exact analysis of the water concentration it is important to do exact charaterizations of the used lasers, optical- and electronical components. Furthermore the optical components have to be mounted very stable without transfering vibrations caused by the airplane to provide high and constant laser power inside the measurement cells. The development of faster data-aquisition and transfer hardware will enable higher spatial resolution. By using direct absorption / 2f multiplexing the detection limit would be improved further.