Absolute TDL Hygrometers for AIDA: Simultaneous Gas Phase and Total Water Measurements

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Outline:

- Role of water measurements in AIDA
- Water instruments available & set up at AIDA
- Calibration & intercomparison
- Typical performance
- Conclusions

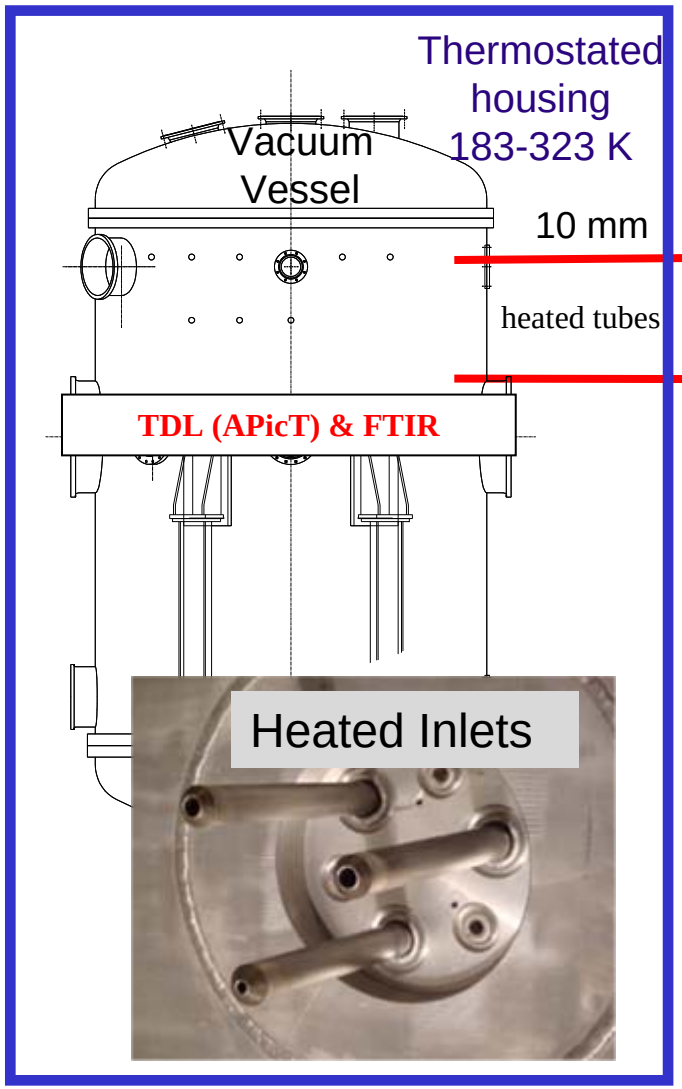
Role of water measurements in AIDA

- Determination of total water concentration (TW)
- Determination of water vapour concentration (WV)
- Determination of condensed water concentration (direct or as difference: TW - WV)
- Sufficient time resolution for dynamic experiments (1-10 s)
- Sufficient sensitivity for stratospheric experiments (< 1 ppm)
- Sufficient dynamic range for warm cloud experiments (1:500)

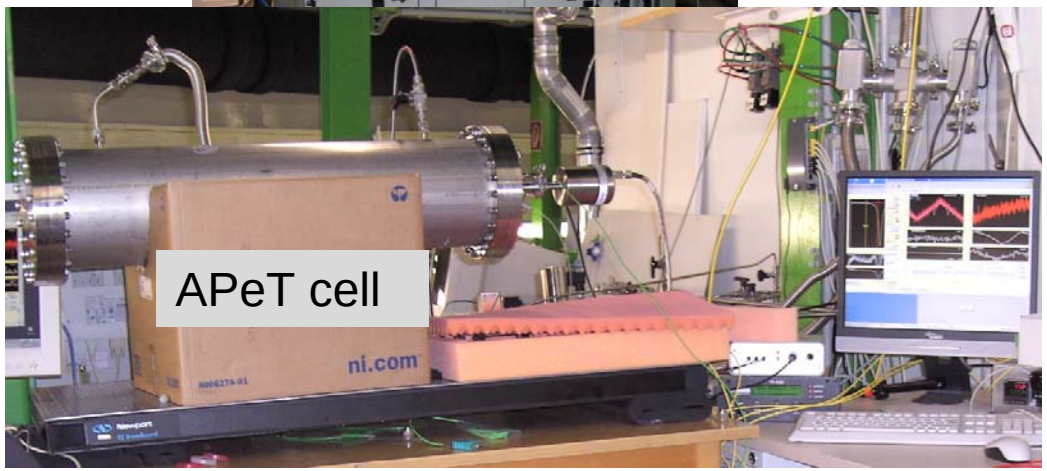
Water instruments available at AIDA

- **Sampling via heated stainless steel tubes (total water):**
  - **Dew point mirror (MBW 373LX)**
  - **Herriott cell with TDL absorption spectrometer (APeT)**[new]
- **Measurement of water vapour in situ:**
  - **White cell with TDL absorption spectrometer (APicT)**
- **Difference between total water and water vapour yields condensed water concentrations**
- **Measurement of condensed water in situ:**
  - **White cell with FTIR spectrometer (Bruker IFS66v)**

Location of AIDA water instruments

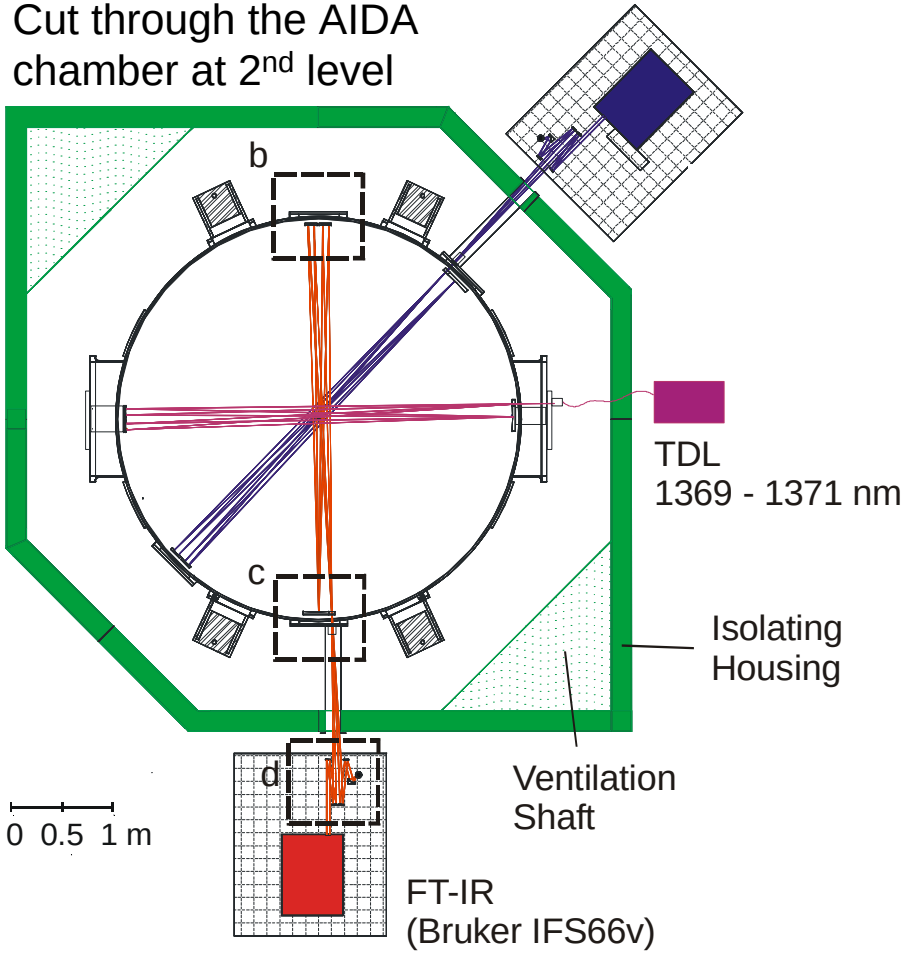


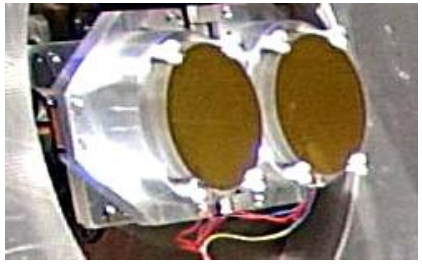
3. Level manifold	Flows [l/min]
MBW-373LX	0.3-1.0
TDL (APeT)	5-10

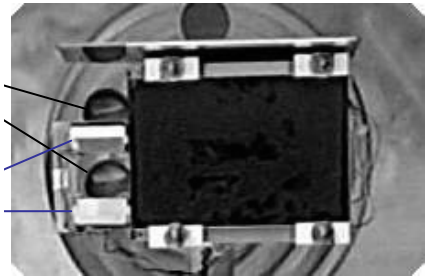


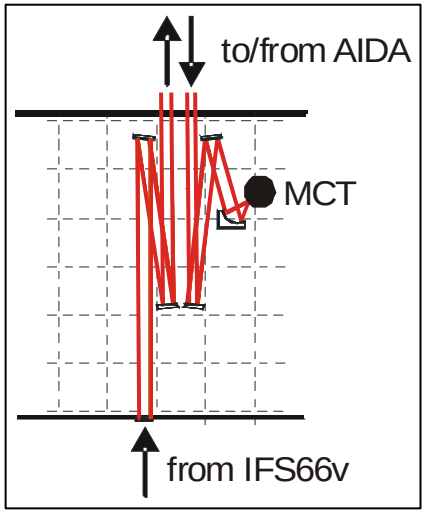
FTIR adaptation to AIDA

Cut through the AIDA chamber at 2nd level









FTIR adaptation to AIDA

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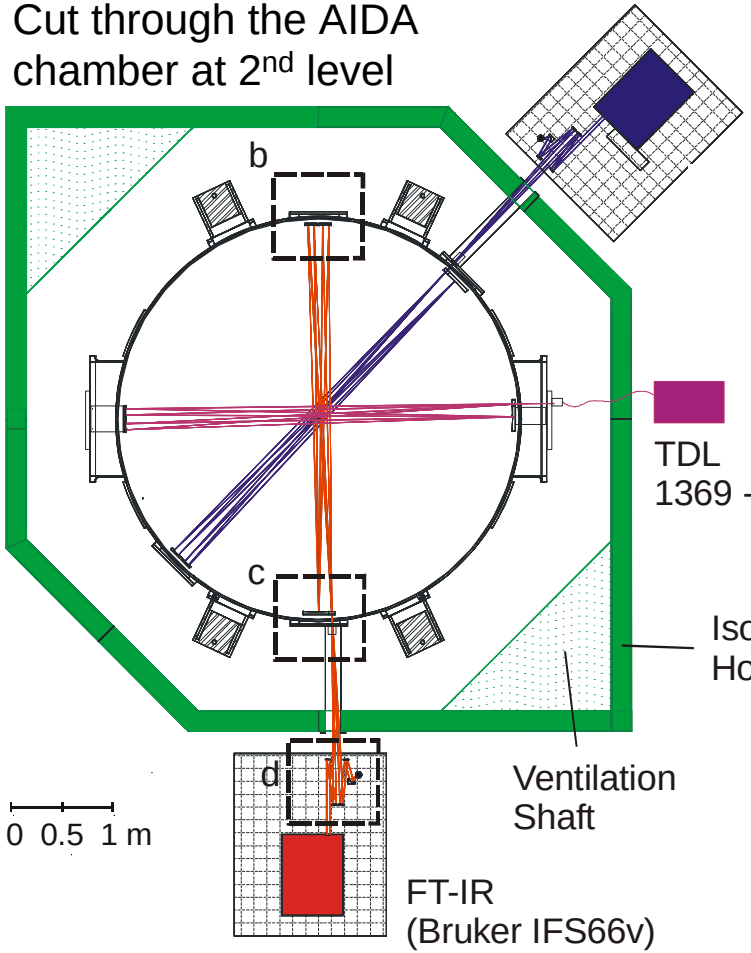
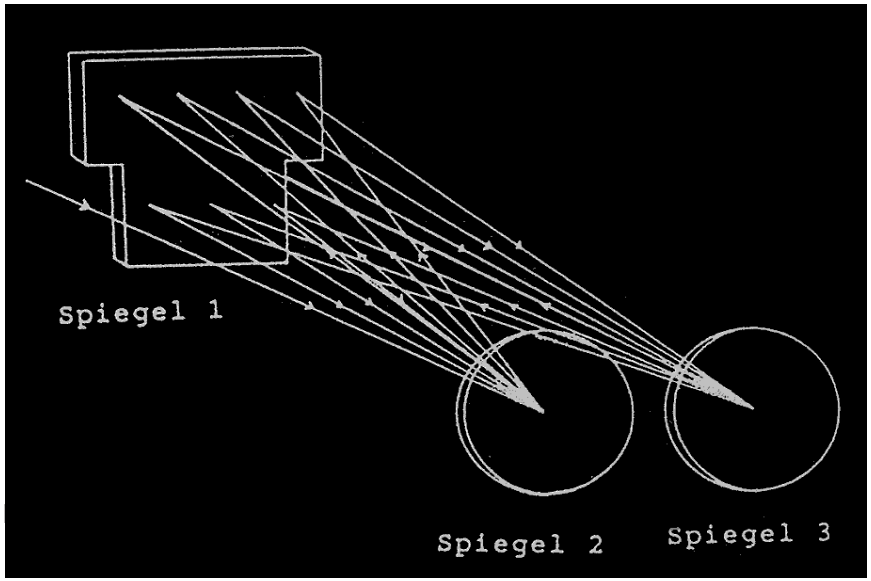
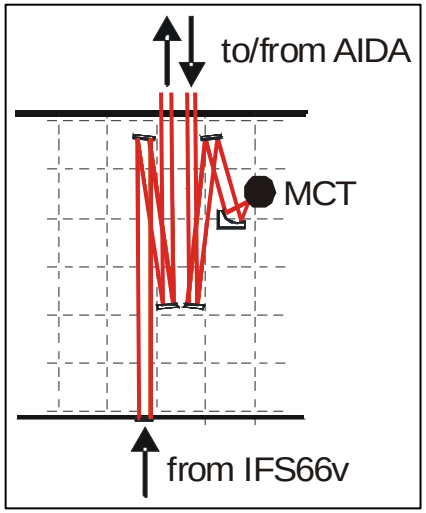
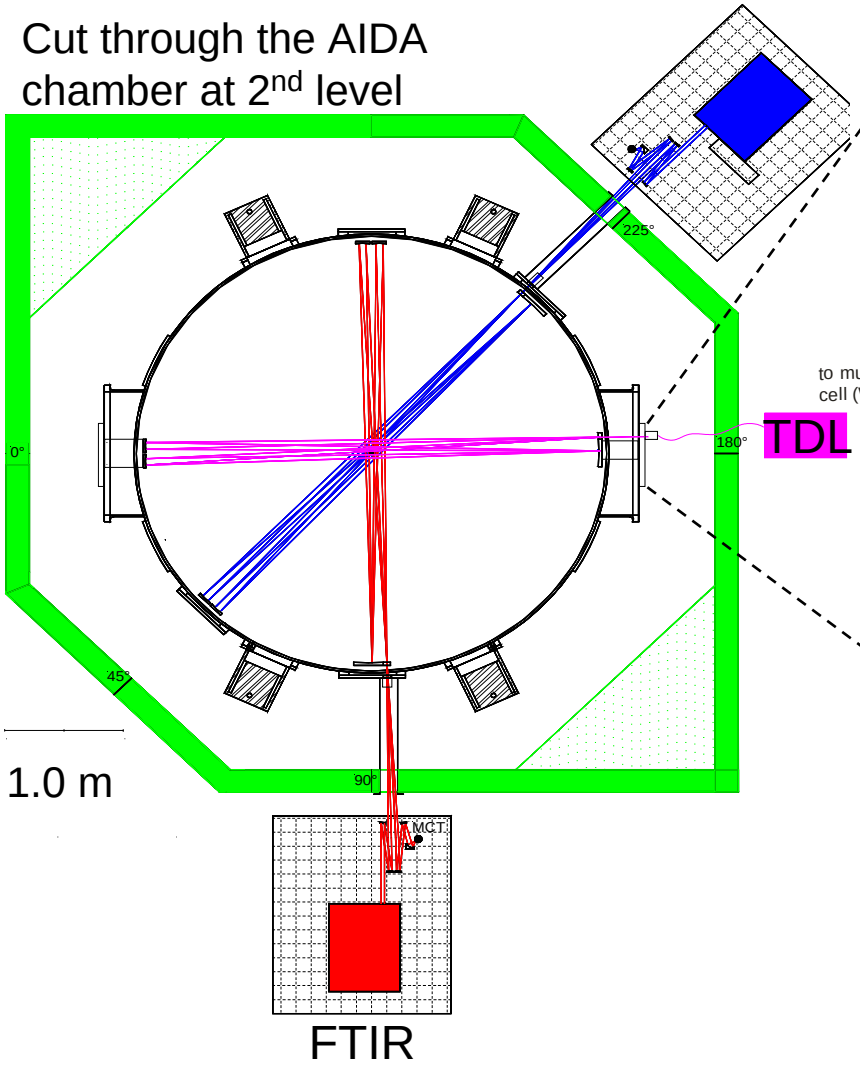




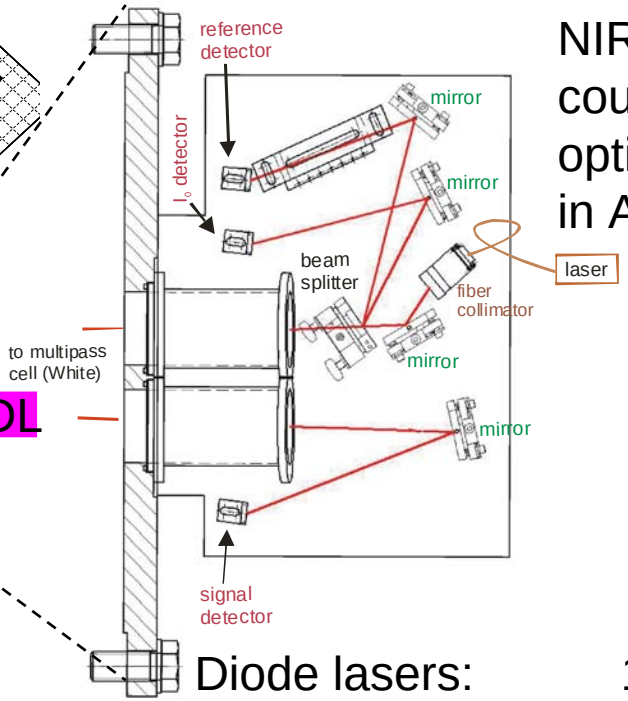


TDL (APicT) adaptation to AIDA

Cut through the AIDA chamber at 2nd level



TDL



NIR DFB lasers coupled with fibre optics to White cell in AIDA

Diode lasers:	1370 & 1392 nm
Tuning range:	~3 nm
Optical path length:	23 to 99 m
Scan frequency:	139.8 Hz
Time resolution:	1.5 s

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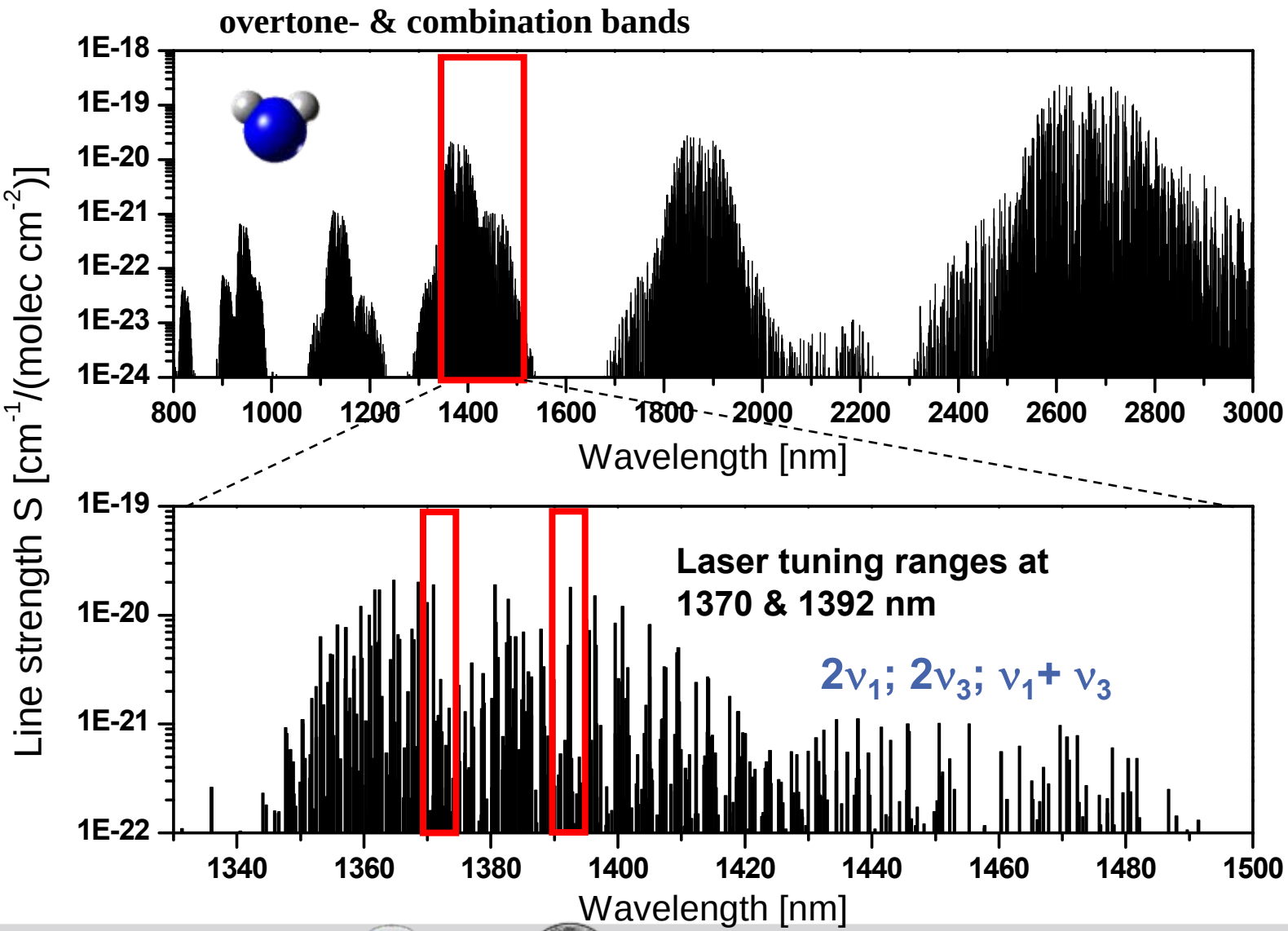
Ro-Vibrational Spectrum of Water Vapour



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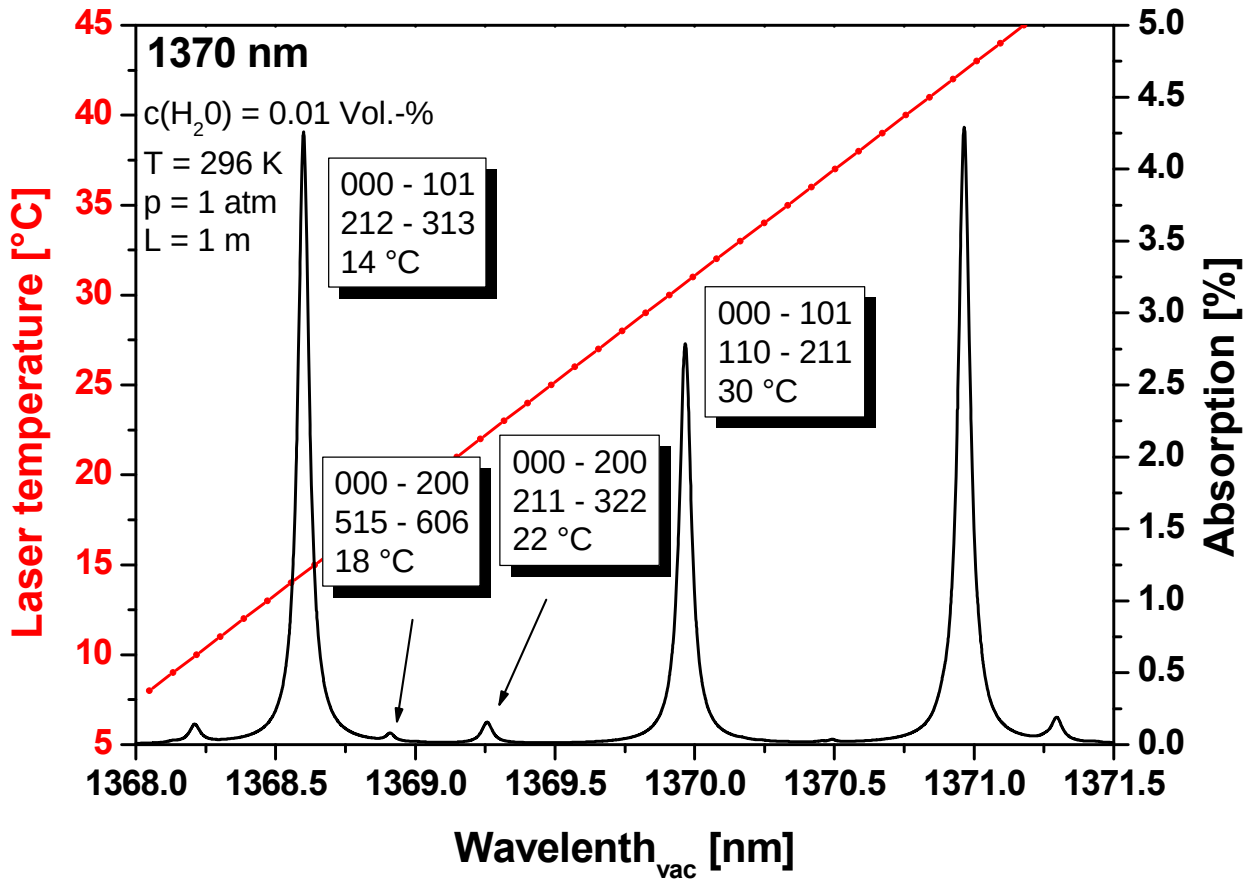
Thermal Laser Tuning Range



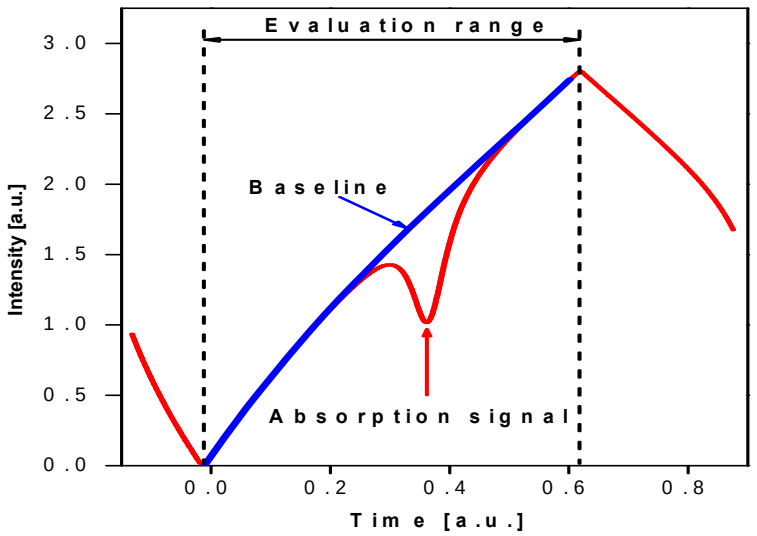
DFB-DL

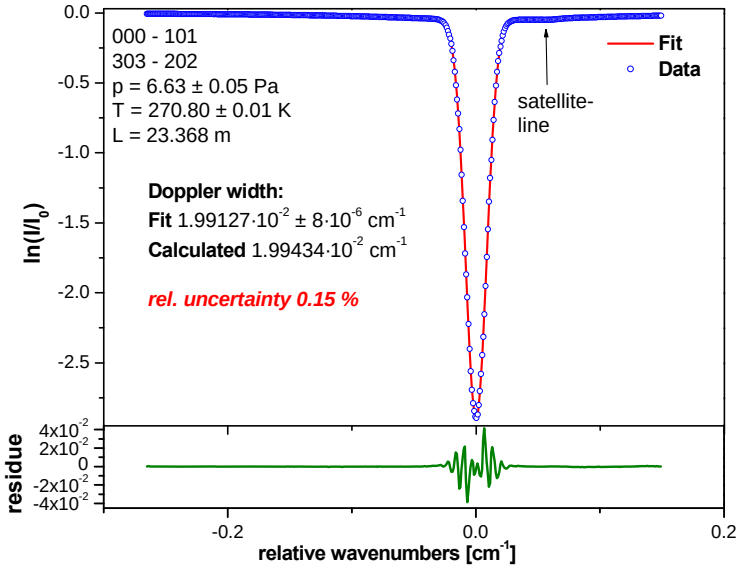
- Fiber coupled module
- 10 mW exF

Thermal tuning range

- ~ 3 nm
- 45 mA
- 8.5 x 10^{-2} nm/K

Direct TDL Absorption Spectroscopy





- Conversion from time domain into wavelength domain using diode laser tuning coefficients
- Voigt fit to the water line profile results directly the absorber density (n)
- No calibration required once the absorption line strength is known (S(T) e.g. from HITRAN database)
- Scattering e.g. by clouds reduces the transmitted light but not the line profile
- Simple treatment of pressure effects

$$n = -\frac{1}{S(T)\cdot L}\int \ln\left(\frac{I(\lambda,t)}{I_0(\lambda)}\right)\frac{\partial\lambda}{\partial t}\,\partial t$$

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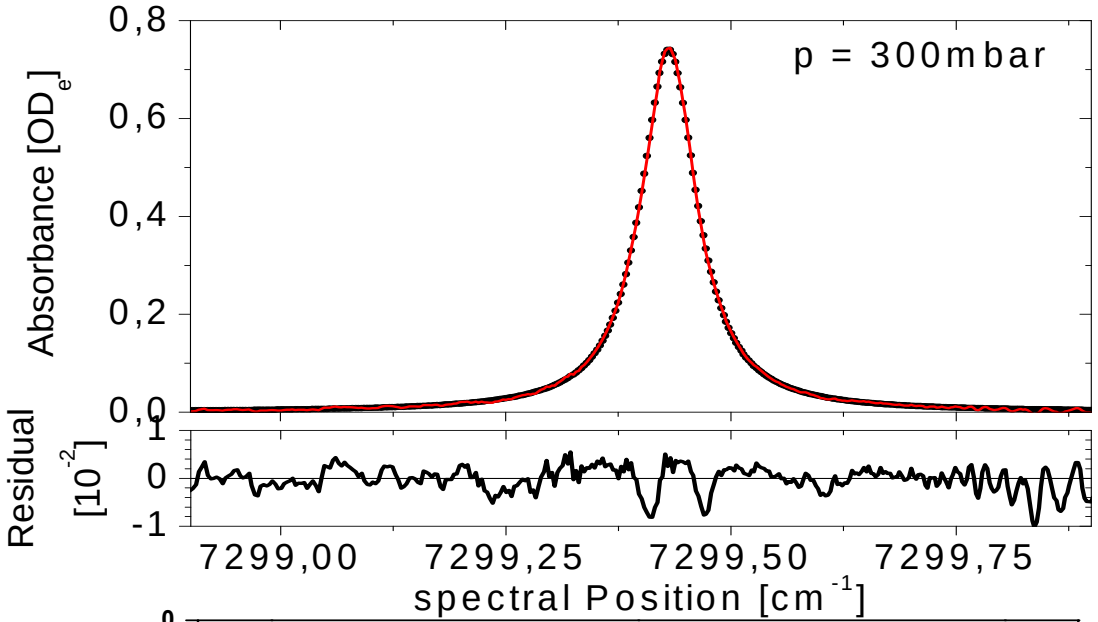
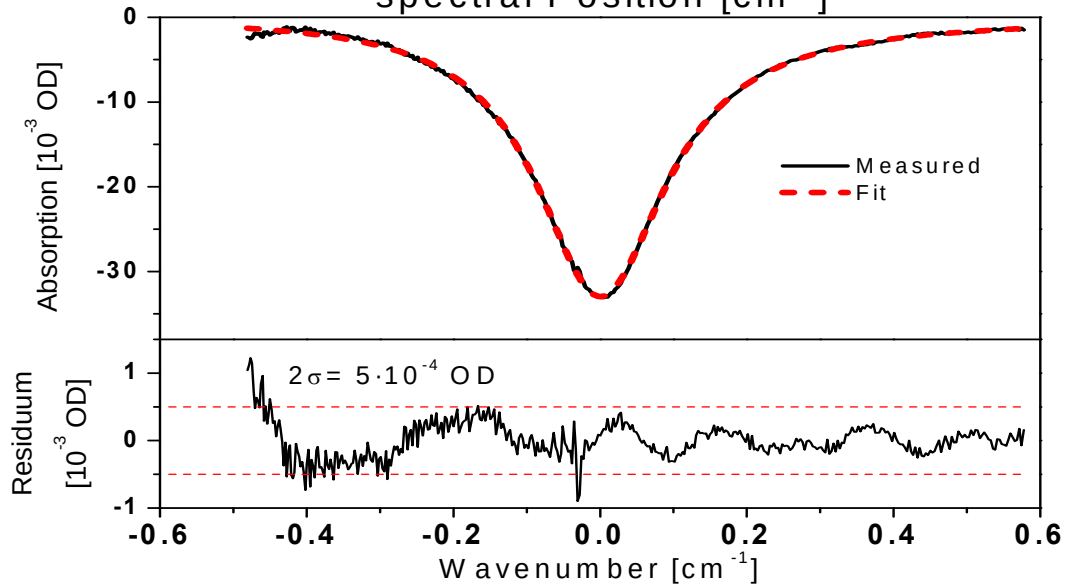
Typical Signals: APicT – in situ TDL

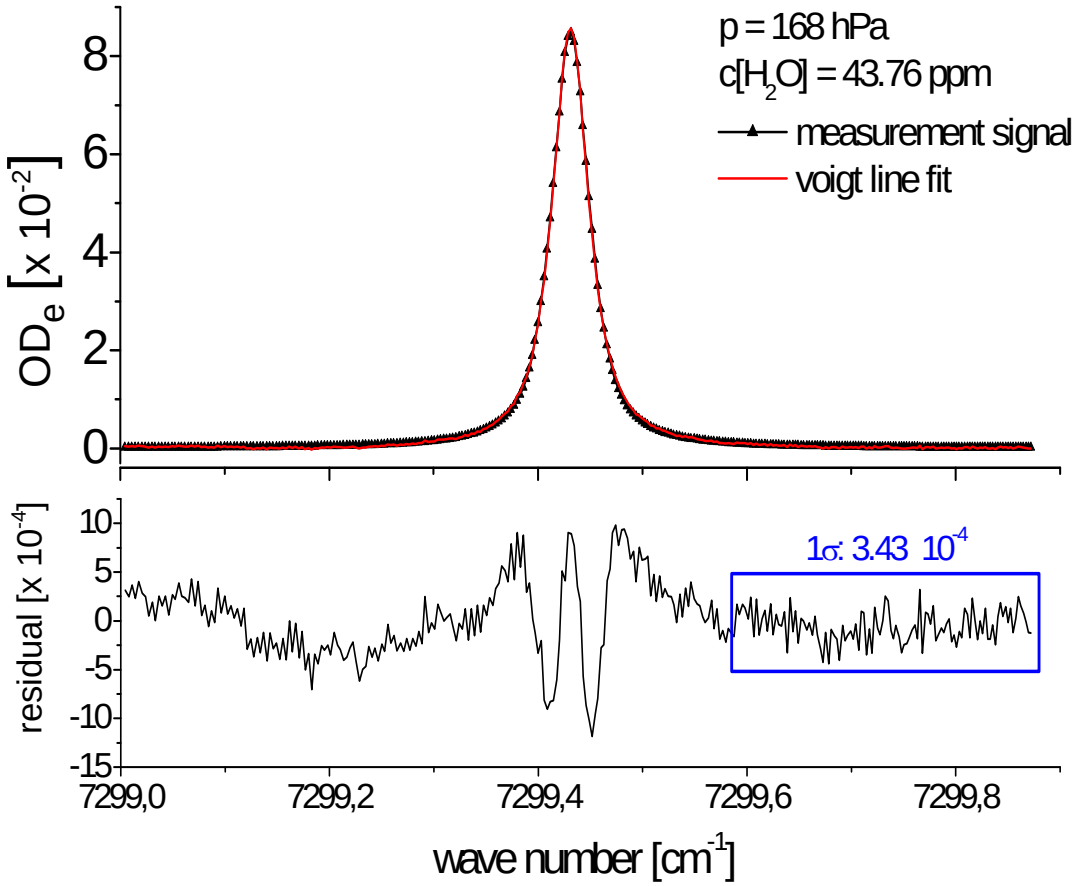


- 223 K, 300 hPa, 82m
- $[H_2O]$ =78 ppm
- S/N = 333
- δH_2O=150 ppb



- 203 K, 1000 hPa, 82m
- $[H_2O]$ = 1.48 ppm
- S/N = 124
- δH_2O=12 ppb
- $2 \cdot 10^{-4}$ OD (1σ)

Typical Signals: Extractive APeT-TDL



Extractive TDL = Total H_2O

- 168 hPa, 300 K, 30 m
- 8 % Absorption
- Voigt-Fit w/o calibration !

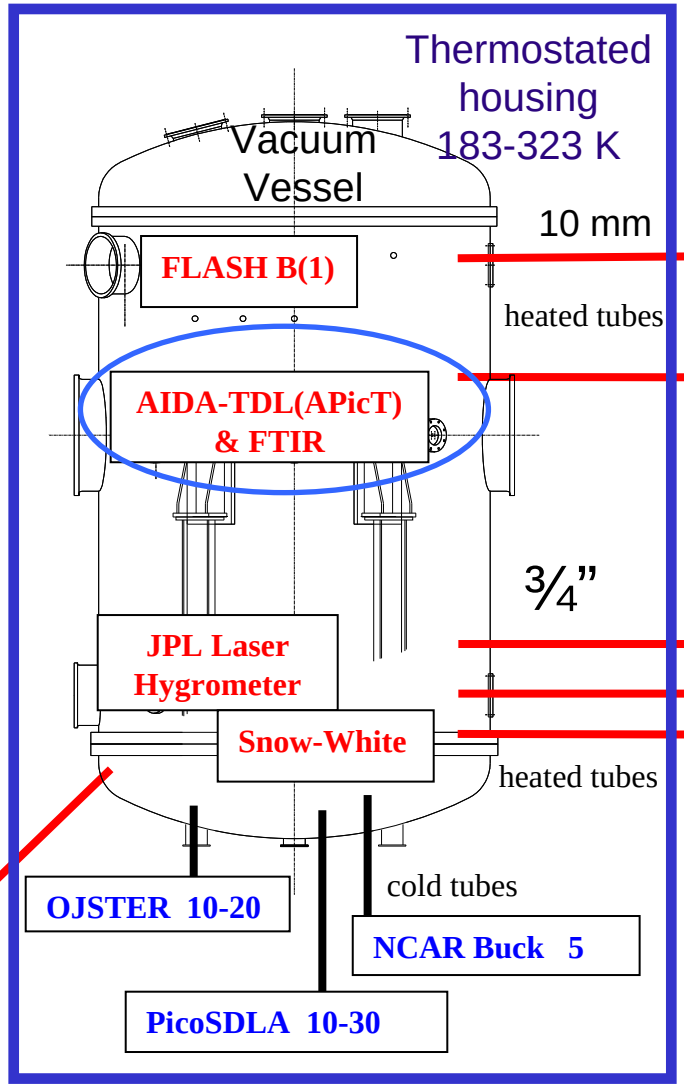
Resolution

- $3 \cdot 10^{-4}$ OD (1σ)
- 280 ppb H2O
- 154:1 S/N

AquaVIT intercomparison of water measurement instruments at AIDA (10/2007)

Karlsruhe Institute of Technology

Participation:
36 scientists
17 groups
11 countries
22 instruments
3 referees



3. Level manifold — Flows [l/min]

MBW-373LX (&DP30)	0.3-1.0
FISH (1)	1-5
Vaisala DM 500	1

2. Level manifold — Flows [l/min]

PADDY	*1-5*
AIDA-TDL(APeT)	5-10
CLH-TDL	2-8

1. Level manifold — Flows [l/min]

FISH (2)	1-5
FLASH B(2)	1-5
CFH	1-5
Harvard water vapour	25-50

3/4"

0. Level manifold(1) — Flows [l/min]

Met office hygrometer	*0.1-10*
Buck CR2 (CARIBIC)	*2*
Photoacoustic (CARIBIC)	*2*
Isotope TDLAS prototype	*2*

1/2"

0. Level manifold(2)

NCAR OPLH	5-10
HIAPER TDL	1-10
WaSul-Hygro	*0.6*

1/2"

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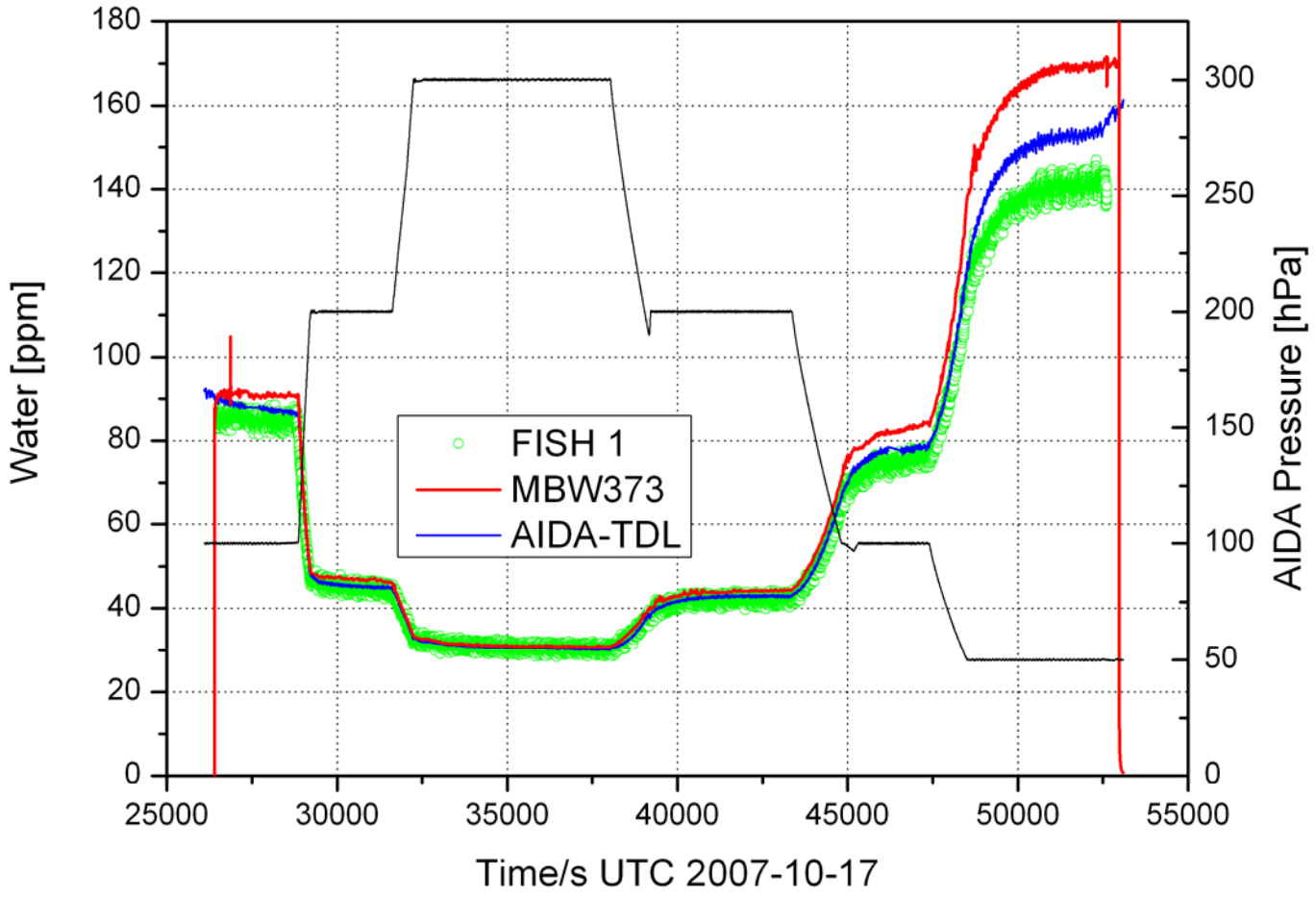
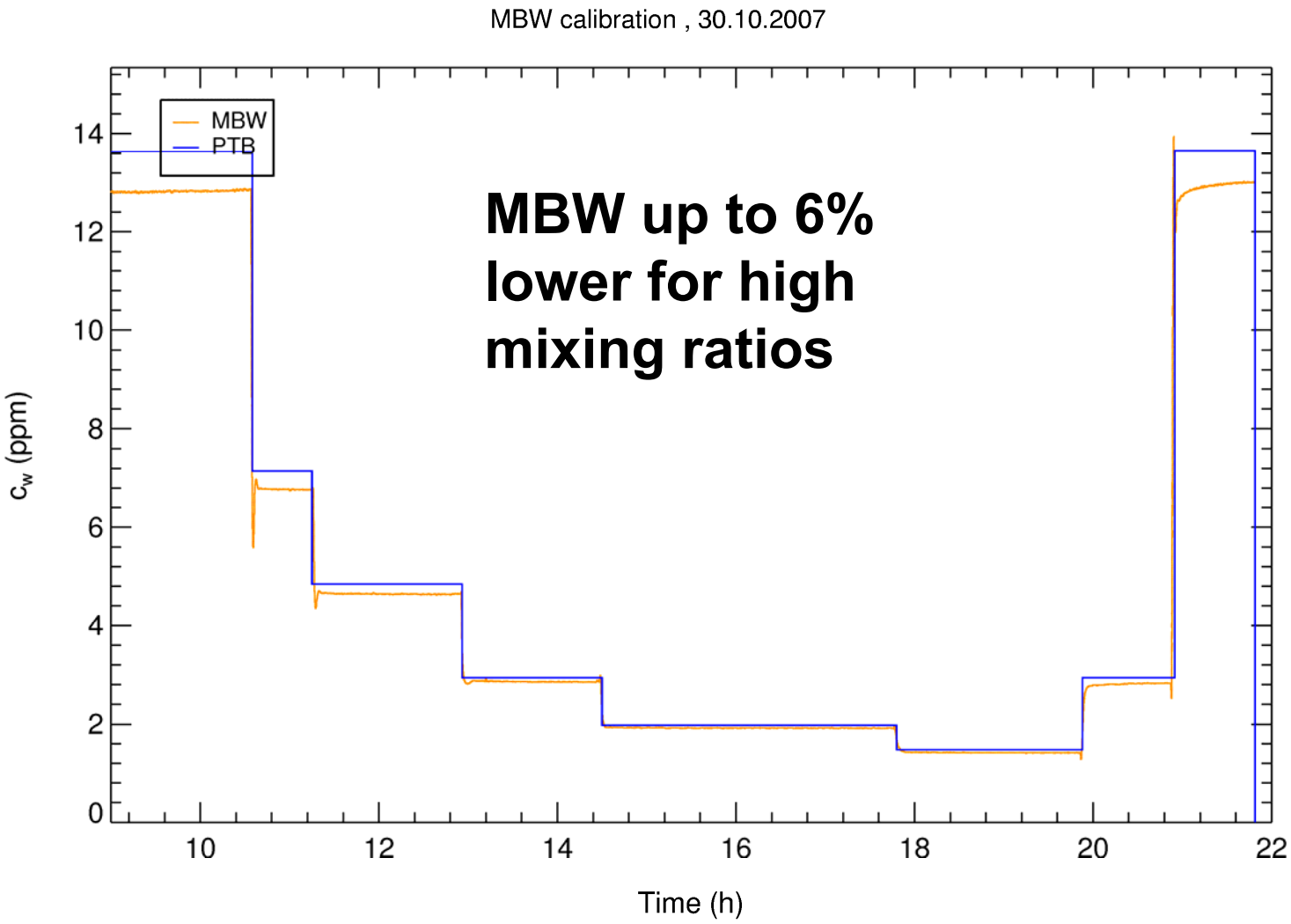
Intercomparison without aerosol

- **Good agreement between FISH1, MBW 373LX, and AIDA-TDL for total pressures > 100 hPa**

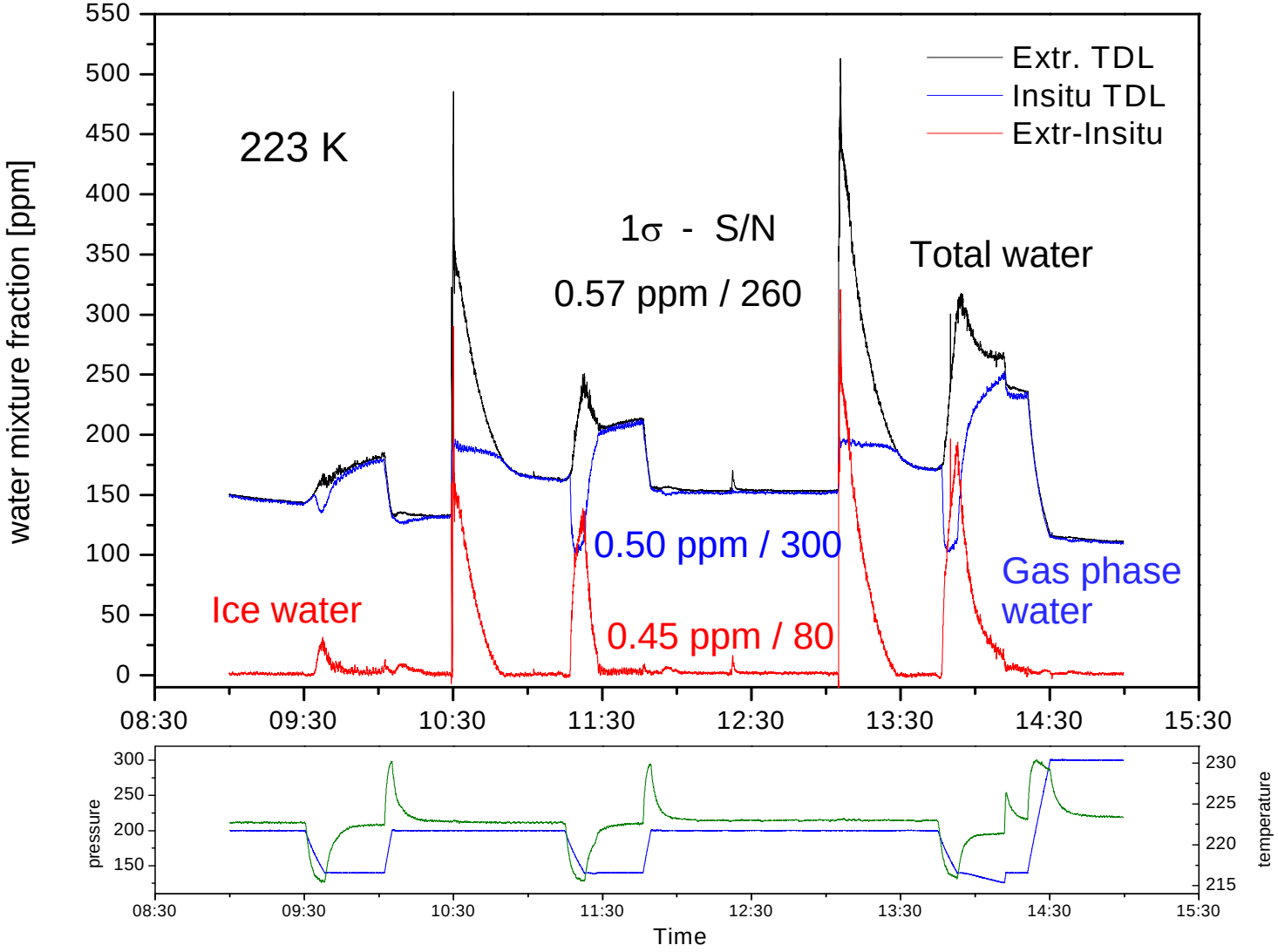


Calibration with PTB permeation source

AquaVIT

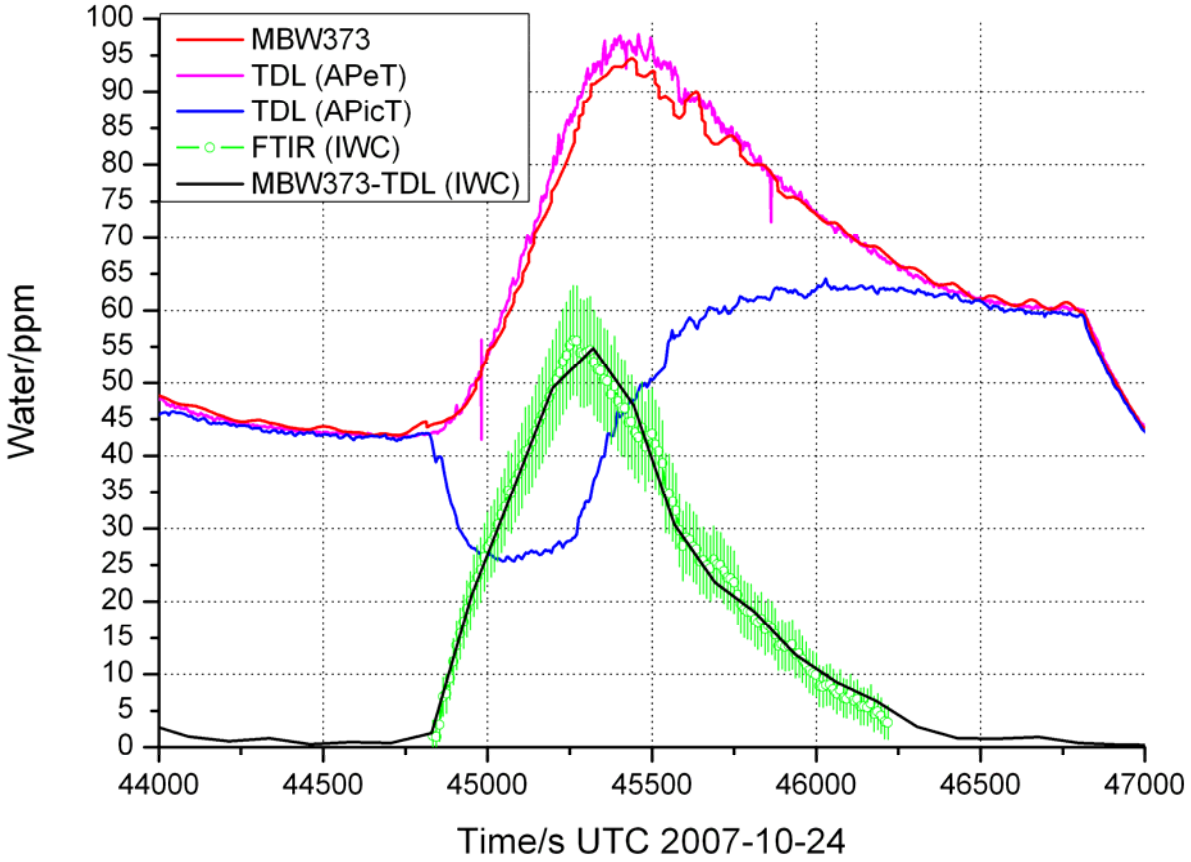


Gasphase, Total and Ice Water from both TDL



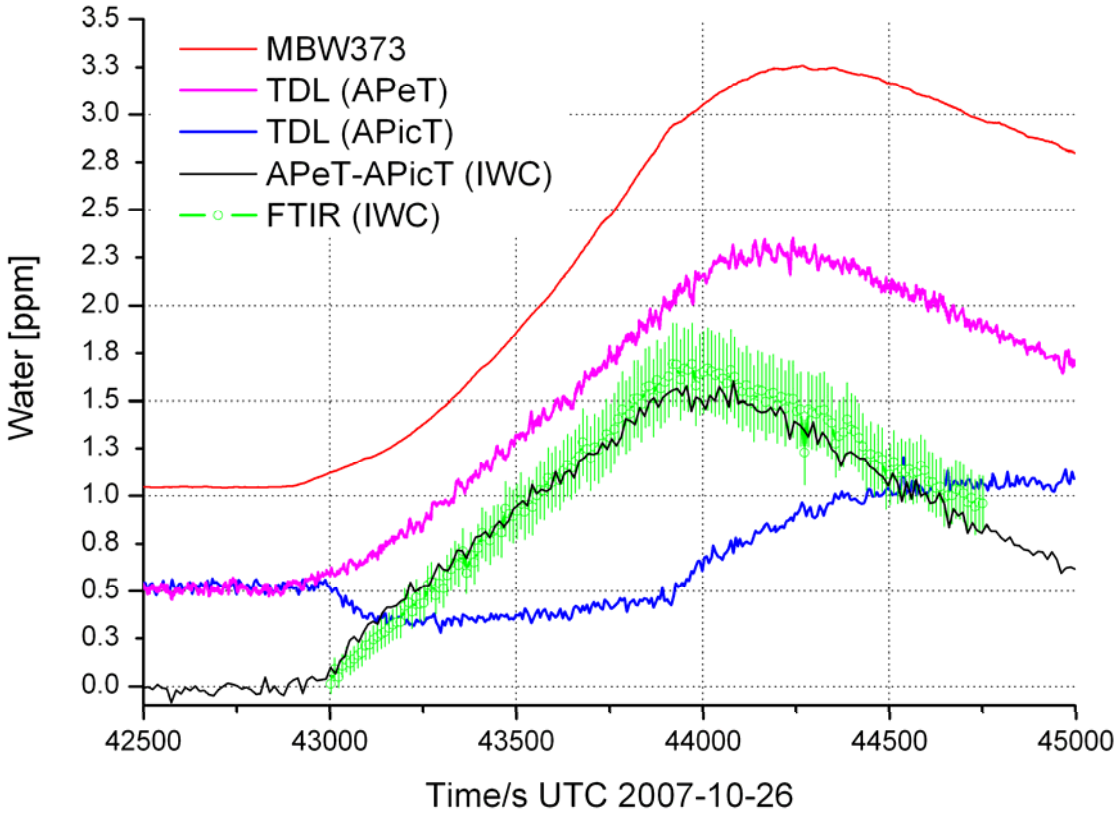
Intercomparison in dynamic experiments

- Good agreement between MBW373 and TDL (APicT and APeT)
- The ice water content calculated as MBW373 – in situ TDL water is in good agreement with values retrieved from in situ FTIR measurements



Intercomparison in dynamic experiments

- For a dynamic experiment at 185 K the MBW 373LX shows to high values and slow time response
- Ice water content (FTIR) is in good agreement with APeT - APicT



Performance of the MBW-373LX

- Good agreement in direct comparison with FISH and TDL.
- Difference of up to 6% compared to the permeation source (PTB) in a single intercomparison.
- For pressures ≤ 100 hPa systematically to high.
- For temperatures/mixing ratios < -80°C the dew point mirror MBW 373LX tends to show to high values and a slow time response.

Performance of in situ TDL (APicT) and extractive TDL (APeT)

- Good agreement in comparison with many state of the art instruments in formal intercomparison (AquaVIT)
- Uncertainty ≥5% mainly due to uncertainty in absolute water line strength (HITRAN)
- Time resolution: 1.5 s,
- Sensitivity up to 30 ppb (100 ppb, APeT)
- Dynamic range sufficient for warm cloud experiments except for very dense clouds (1:500 to 1:4000)
- Good agreement of APeT - APicT with ice water content from FTIR analysis

➢ **Absolute water vapour, total water, and condensed water concentrations without calibration**

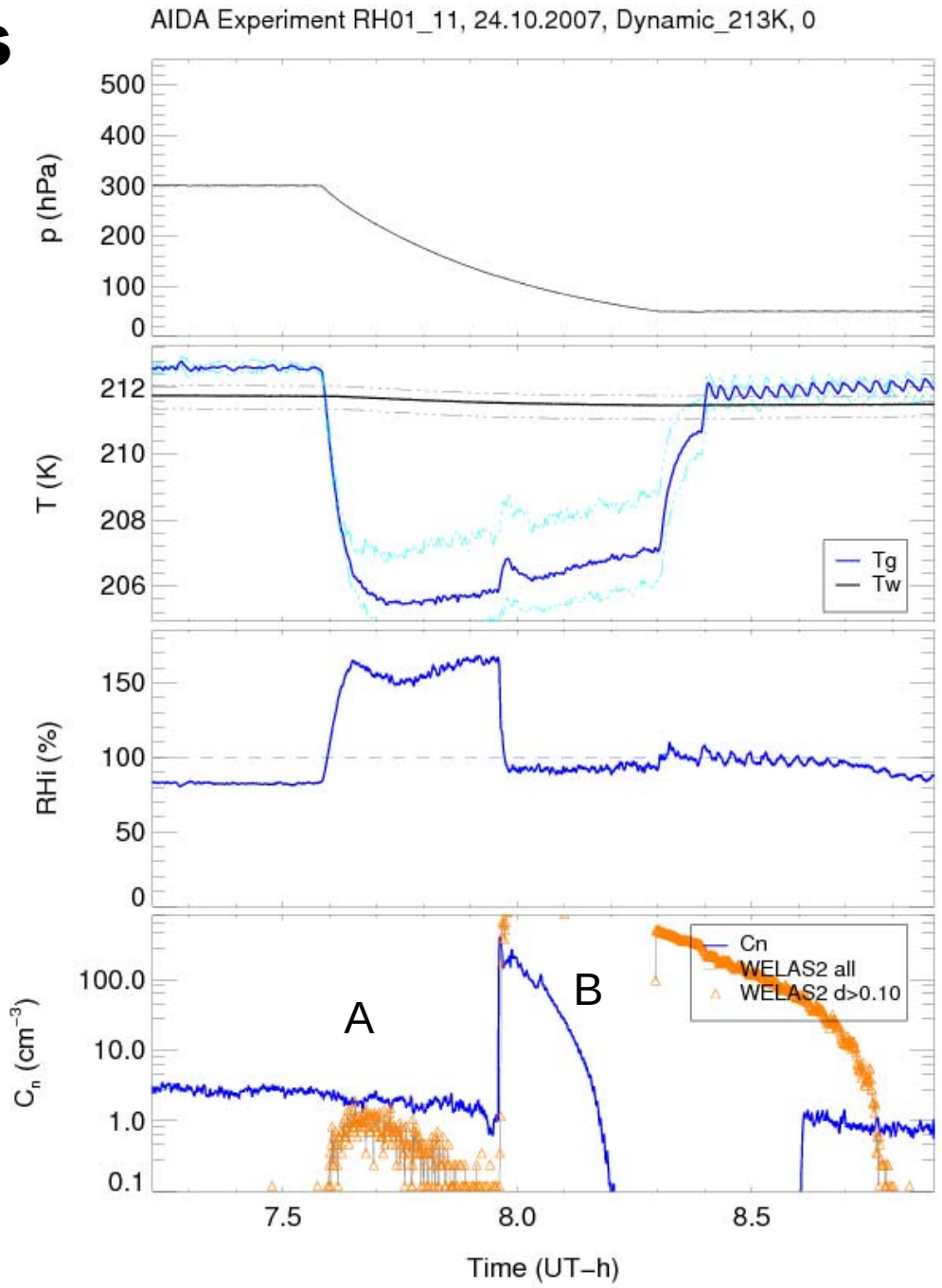
Conclusions

- Set of fast and sensitive water measurement instruments at AIDA
  - Total water (Dew point & TDL)
  - Water vapour (TDL)
  - Condensed water content (FTIR & Difference method)
- Instruments are validated with national standards and by intercomparison with many other instruments
  - PTB permeation source
  - AquaVIT formal intercomparison
  - Spectroscopic data for water in the literature
- Together with well established temperature measurements this is a good basis to determine relative humidities

Dynamic Experiments

A)
Relative humidity
in thin
ice cloud ≈ 160%

B)
Relative humidity
in thick
ice cloud ≈ 100%



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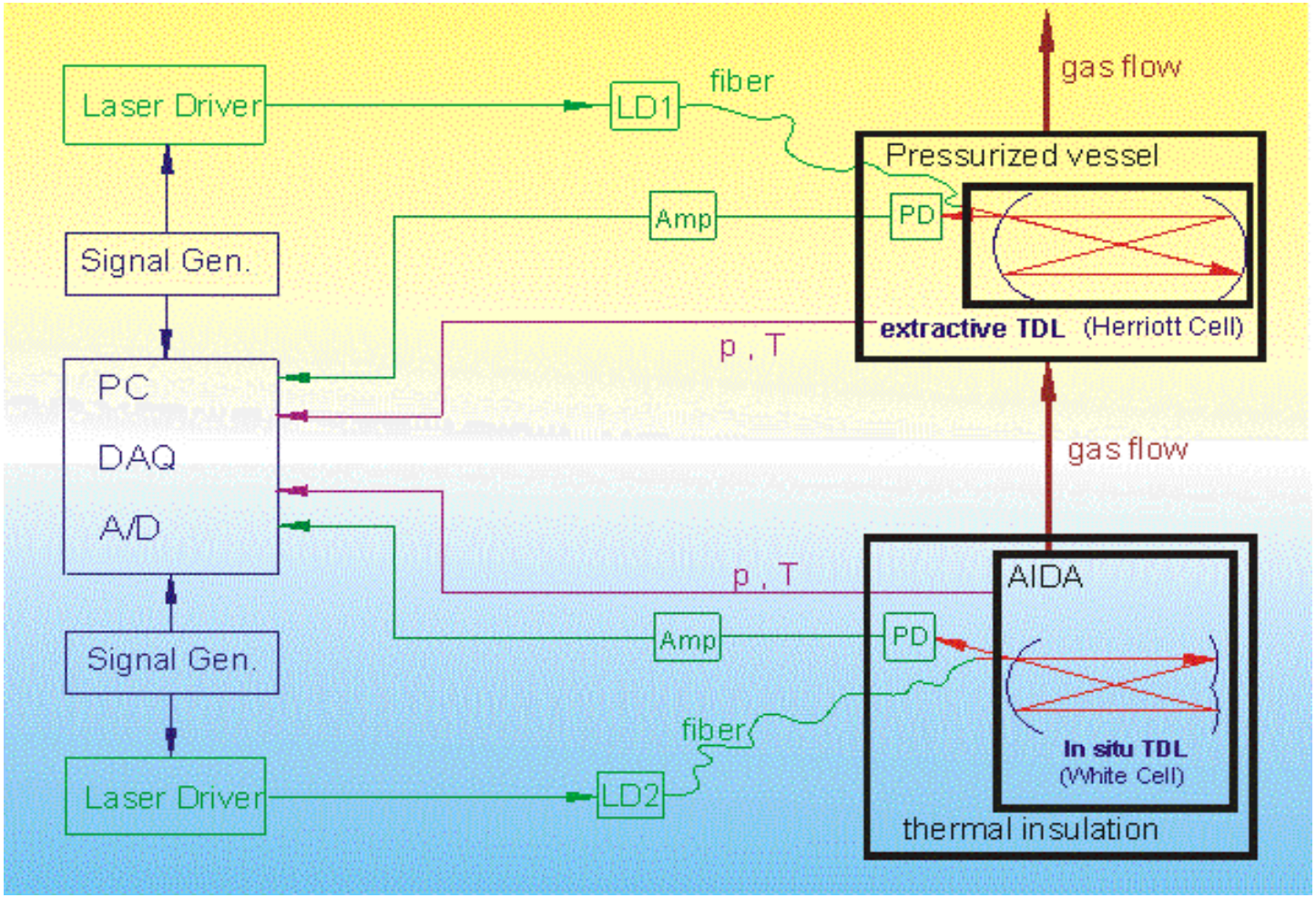
In situ and extractive TDL Setup

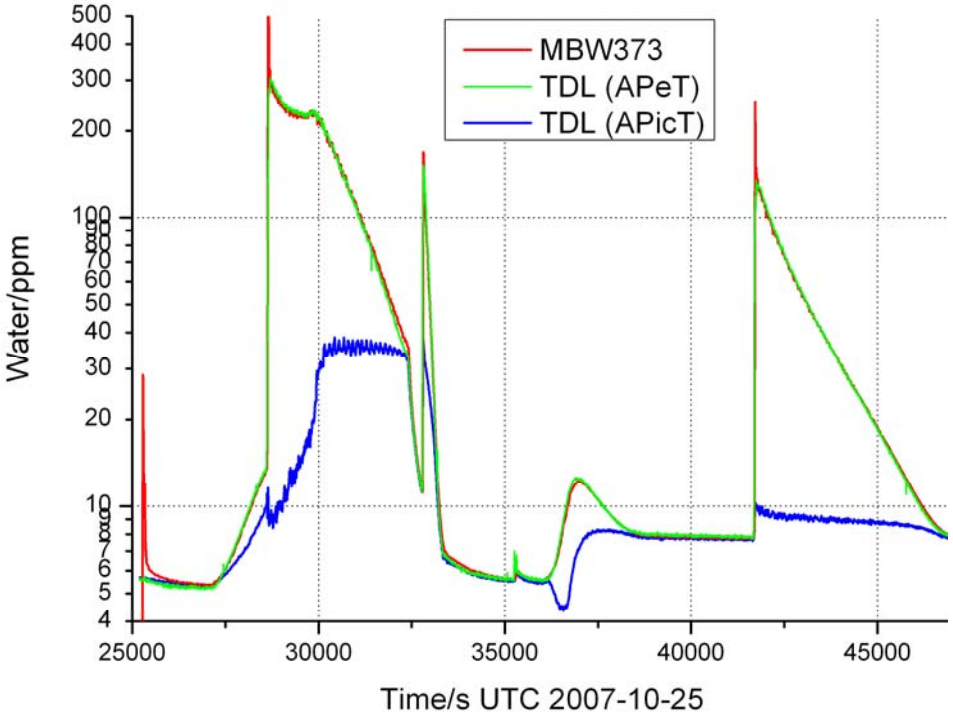
Extractive TDLAS ⇒ **Total Water**

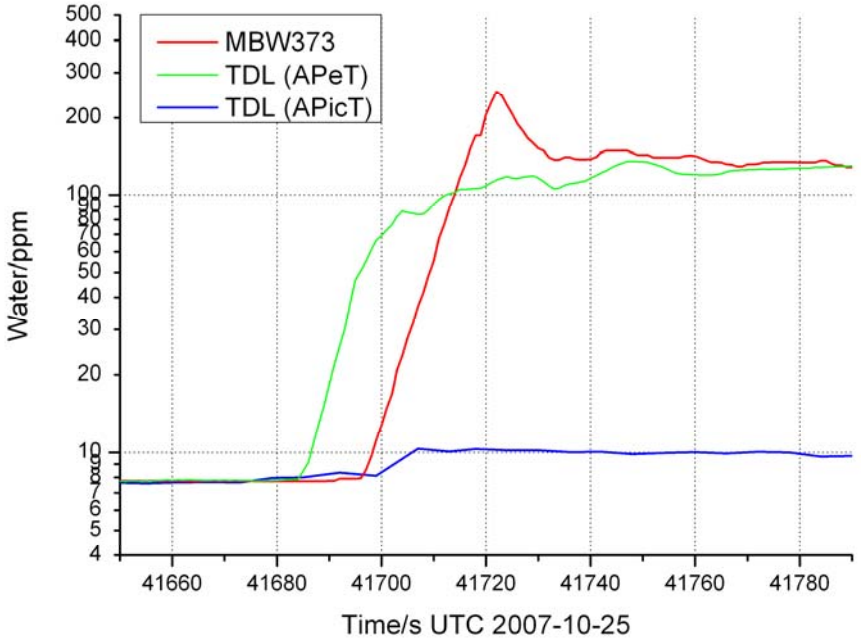


In situ TDLAS ⇒ **Gas Phase Water – In-cloud**

Intercomparison in dynamic experiments

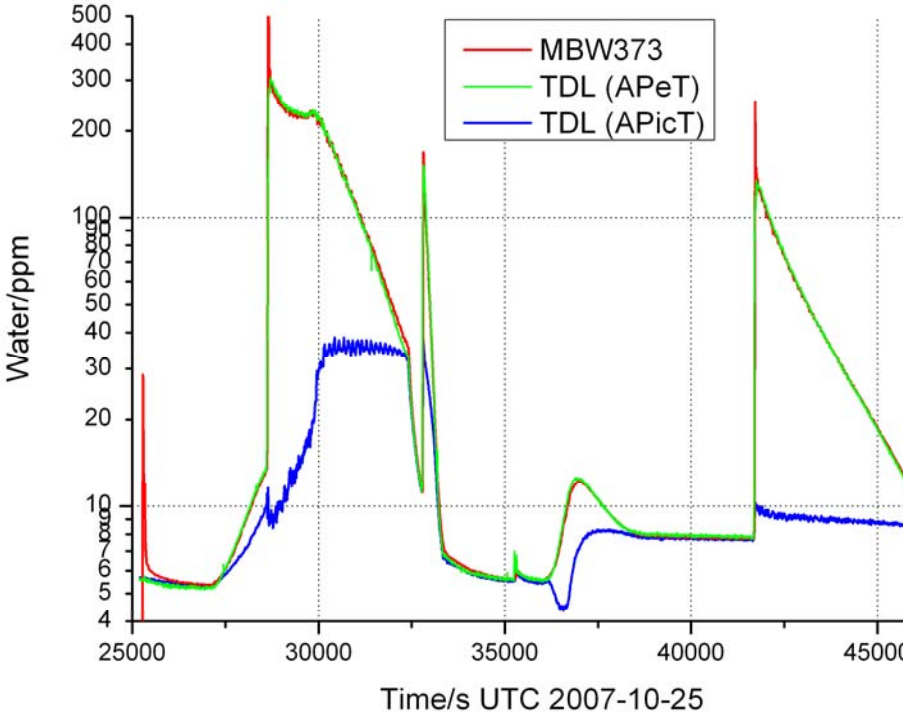
- Good agreement between MBW373 and TDL (APicT and APeT) except
- The ice water content calculated as MBW373 – in situ TDL water is in good agreement with values retrieved from in situ FTIR measurements

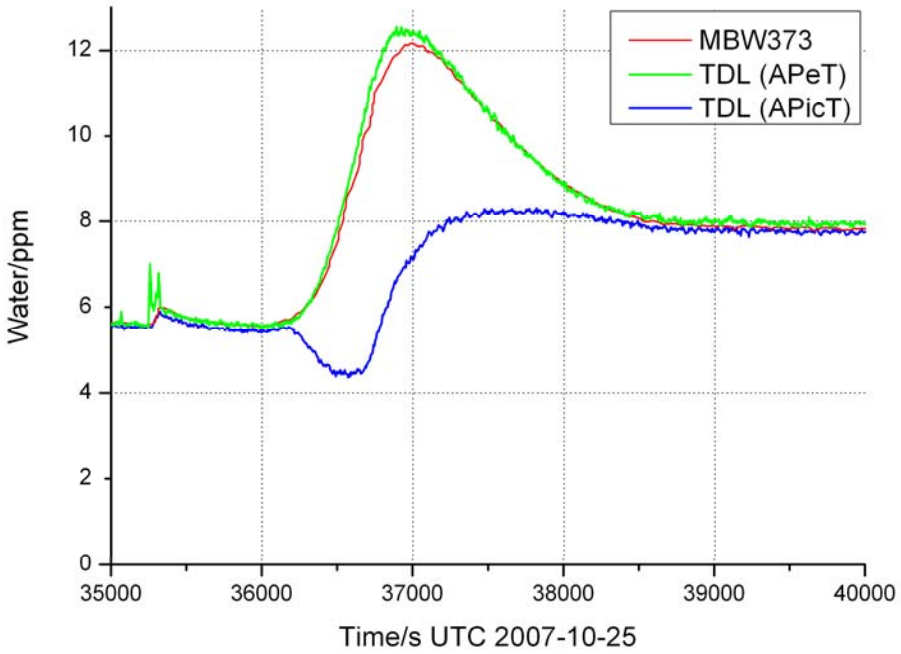




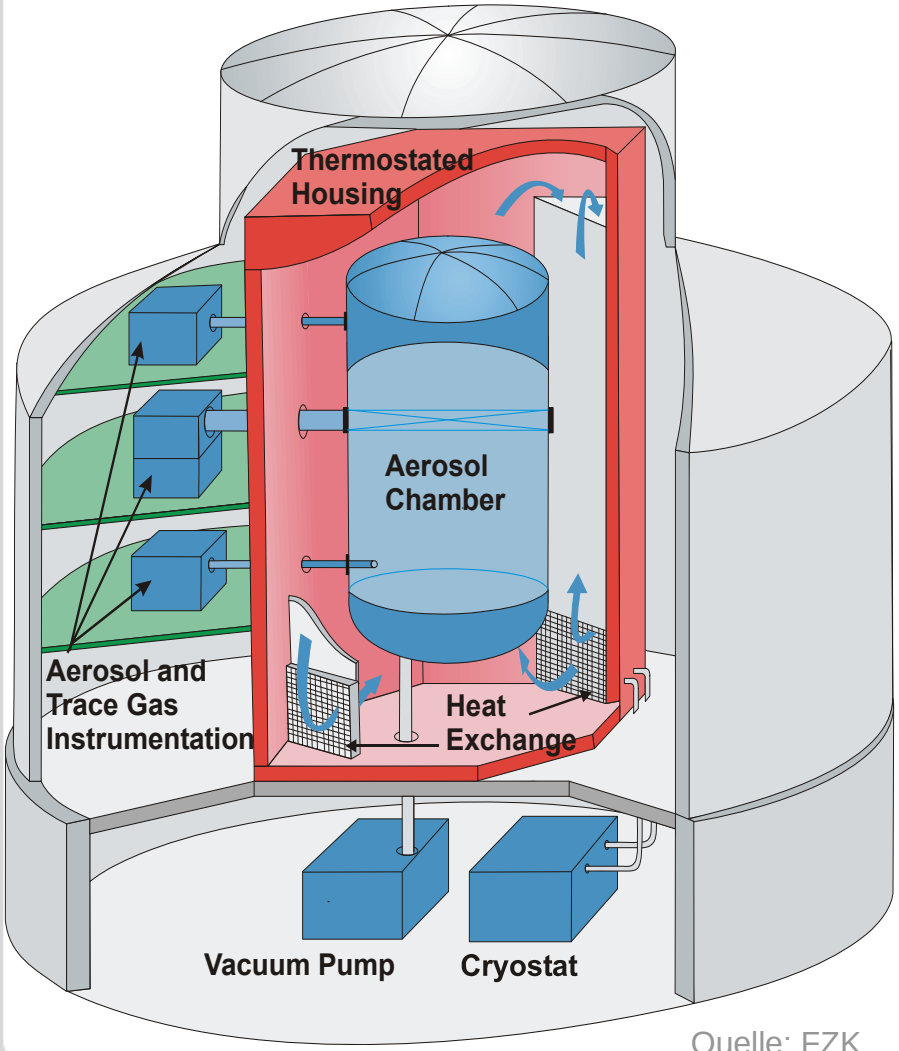
MBW-373LX in dynamic experiments

- Good agreement between MBW373 and TDL (APicT and APeT) except for the last dynamic experiment at 185 K
- The ice water content calculated as MBW373 – in situ TDL water is in good agreement with values retrieved from in situ FTIR measurements





AIDA in situ TDL-Hygrometer



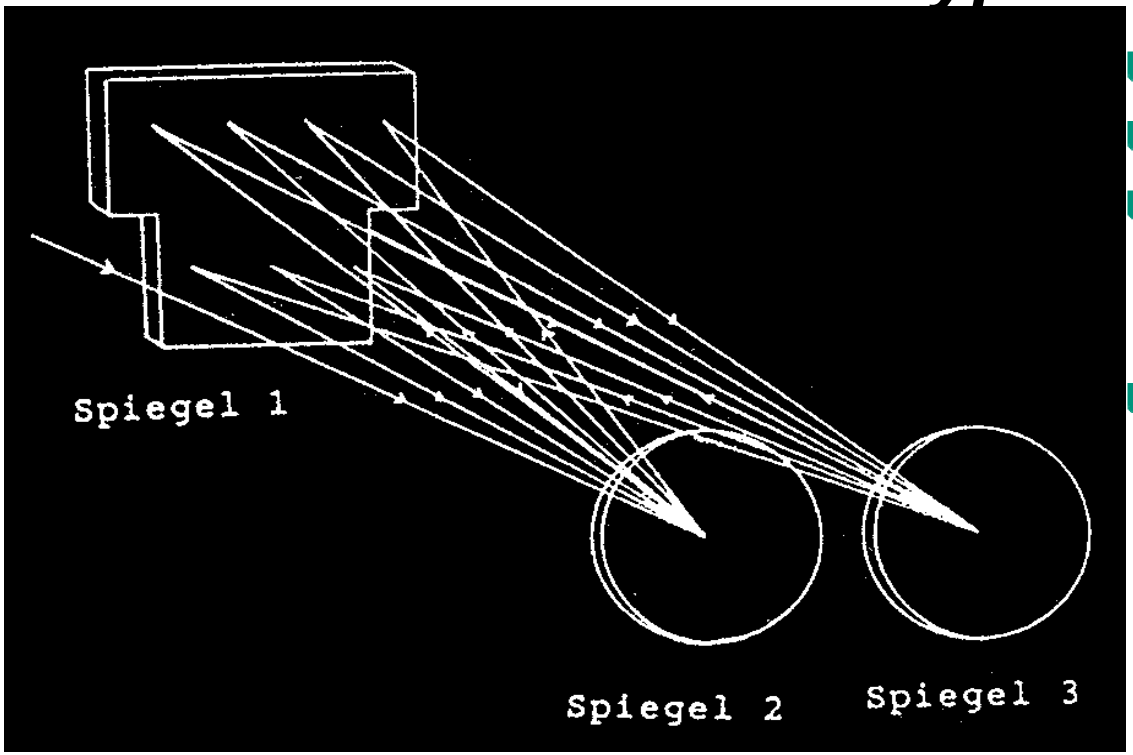
Quelle: FZK

- fiber coupled
  - NIR-DFB Laser
- sampling-free
  - open path White cell
  - measures within clouds
  - corrects for scattering losses
- calibration-free
  - Direct TDLAS
- ppb resolution
  - 10 - 30ppb @ 100m, 1bar
- fast response
  - Δt=1.5s , scan 140Hz

Technisches Messen 72, 1, 23-30 (2005),
J. Geophys. Res. 110, D11210, (2005)

High Sensitivity ➡Long Path Optics

Multi-Path-Cell: White-Type



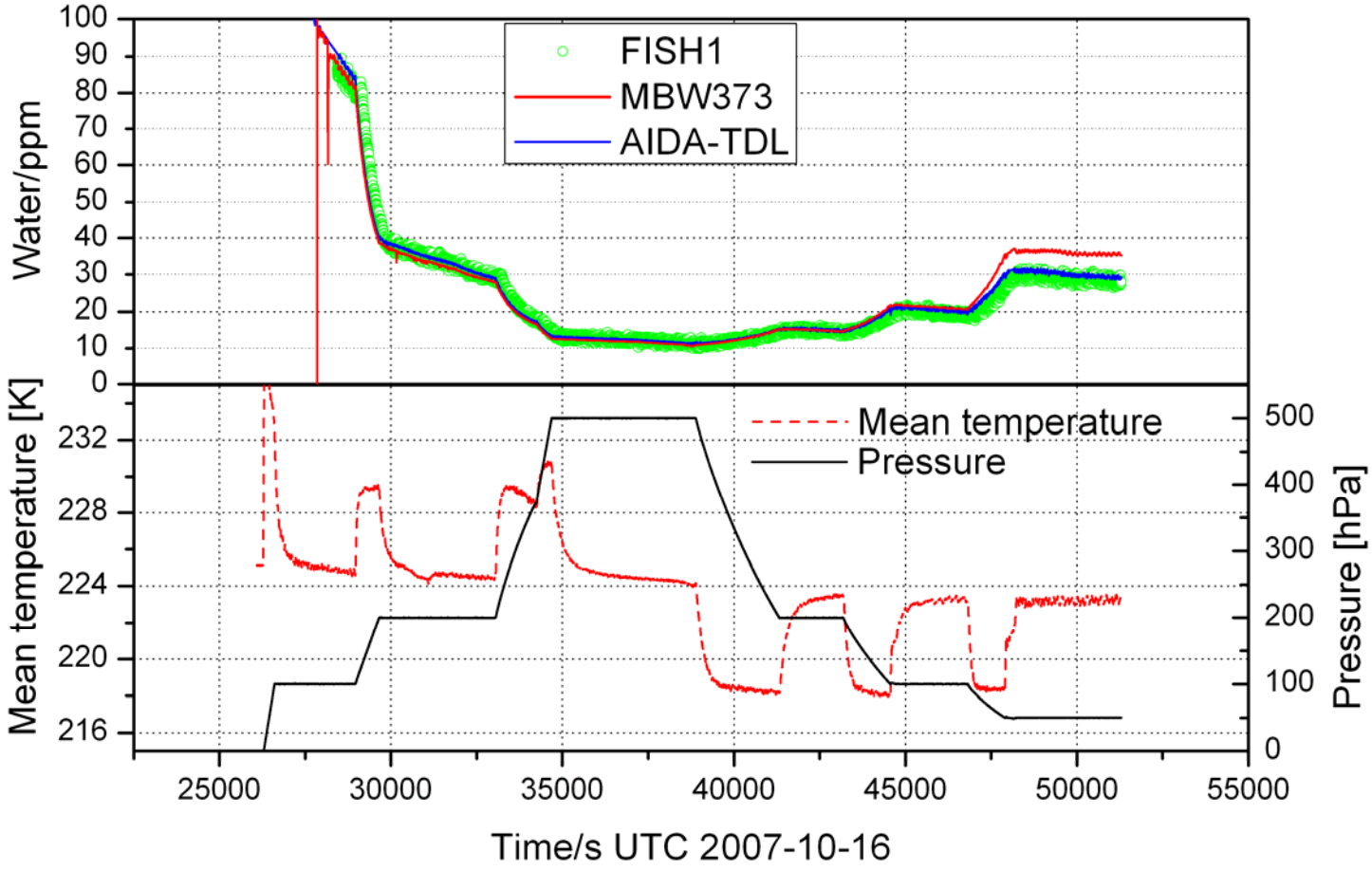
- 3-Mirror concept
- Constant base length
- Mirror tilt
  - Modifies Abs.-path
  - (4n+2)·base length
- Spatially separated entrance and exit spots

AIDA-Cell

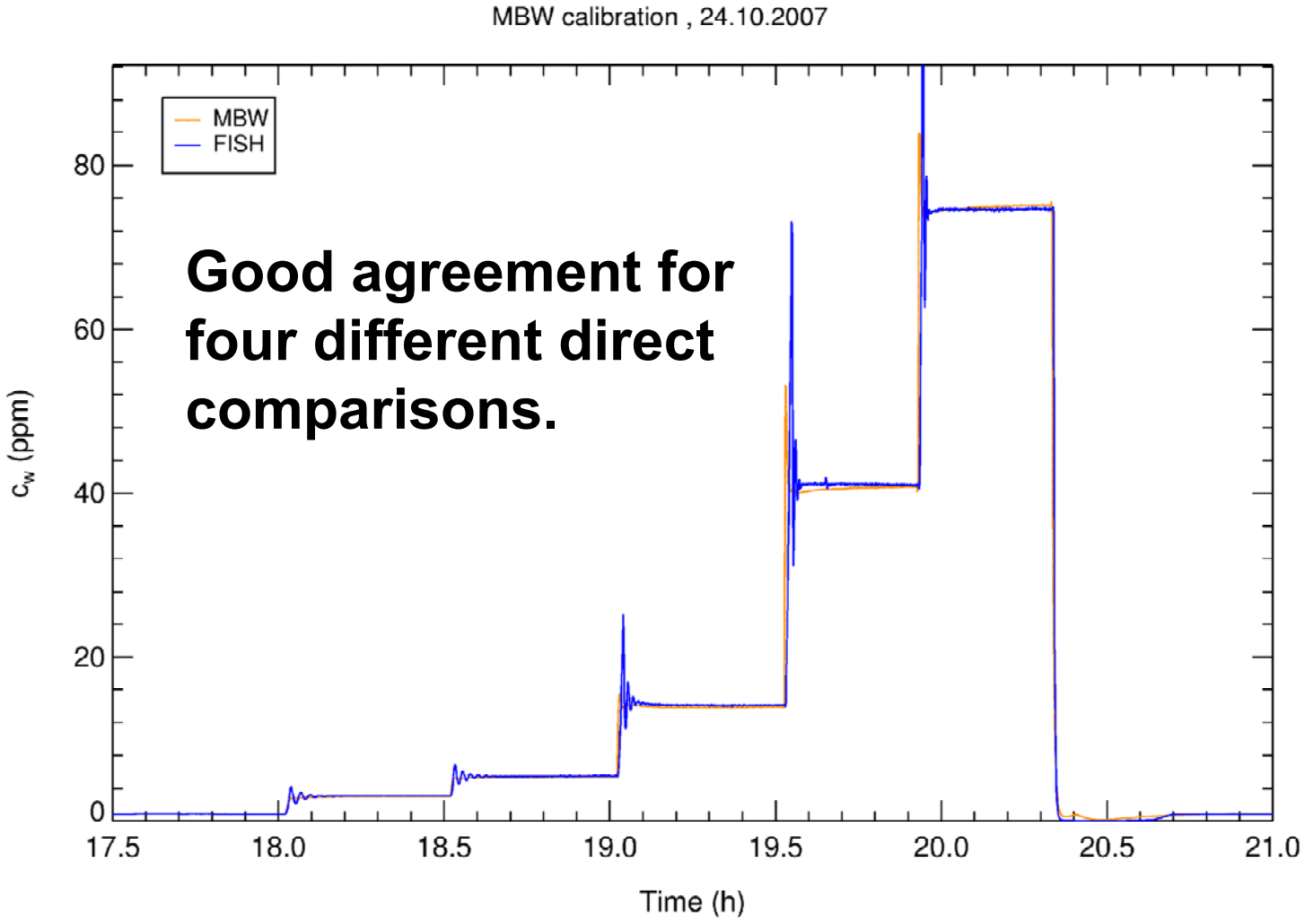
- Permanent setup
- Motorized alingment
- base length 3.74m
- L : 15-254m (22 round trips, 82.28 m)

Intercomparison

- **Good agreement between FISH1, MBW 373LX and AIDA-TDL for total pressures > 100 hPa**



Intercomparison of MBW 373LX with FISH



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