Combined rotational Raman temperature lidar and water vapor DIAL for humidity, temperature, and particle measurements

Andreas Behrendt and Volker Wulfmeyer
University of Hohenheim

Contents

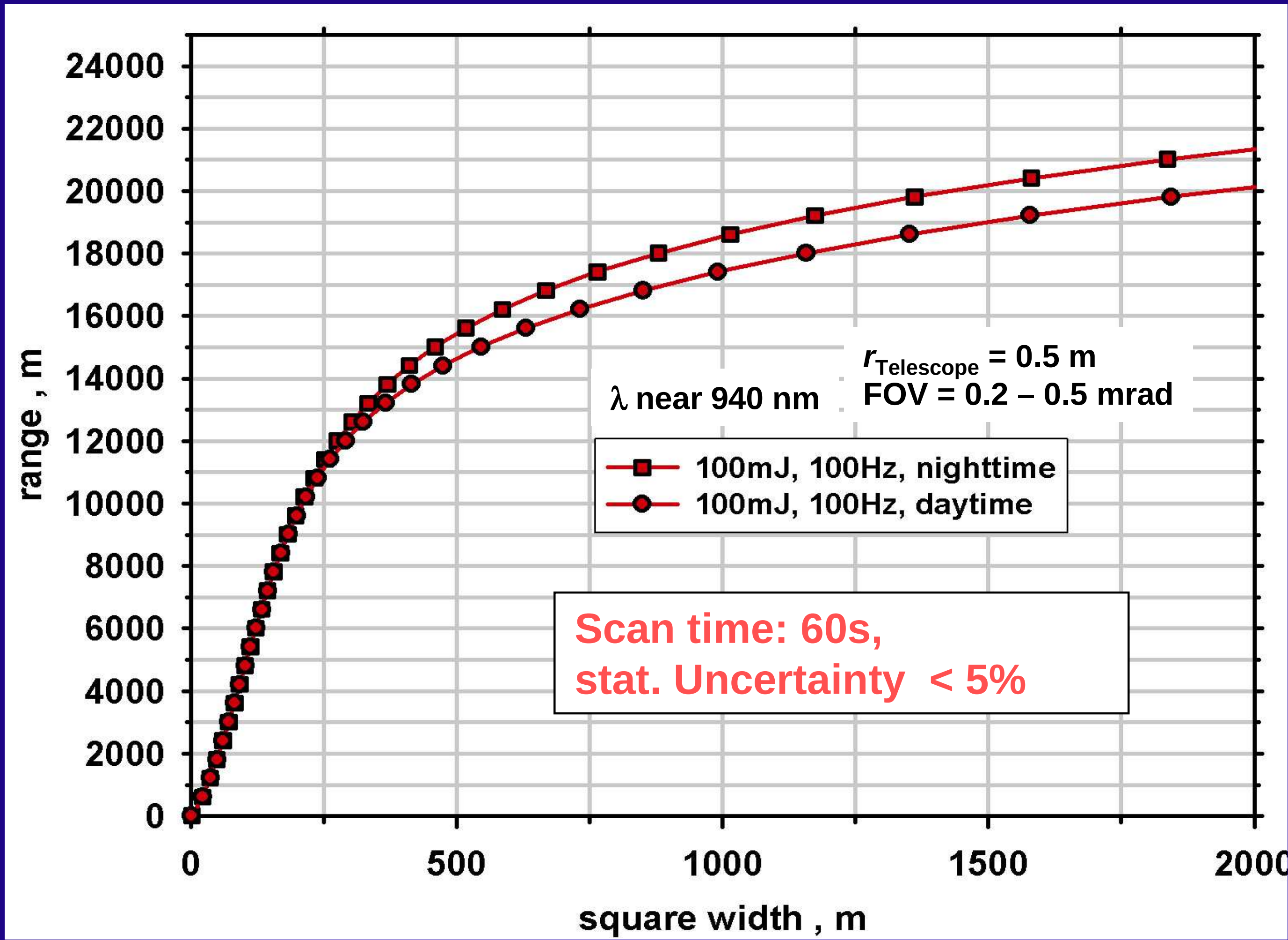
- Motivation
- Theory
- Concept
- Synergetic effects

Motivation

Simultaneous measurement of water vapor and temperature in planetary boundary layer and free troposphere with high resolution and accuracy

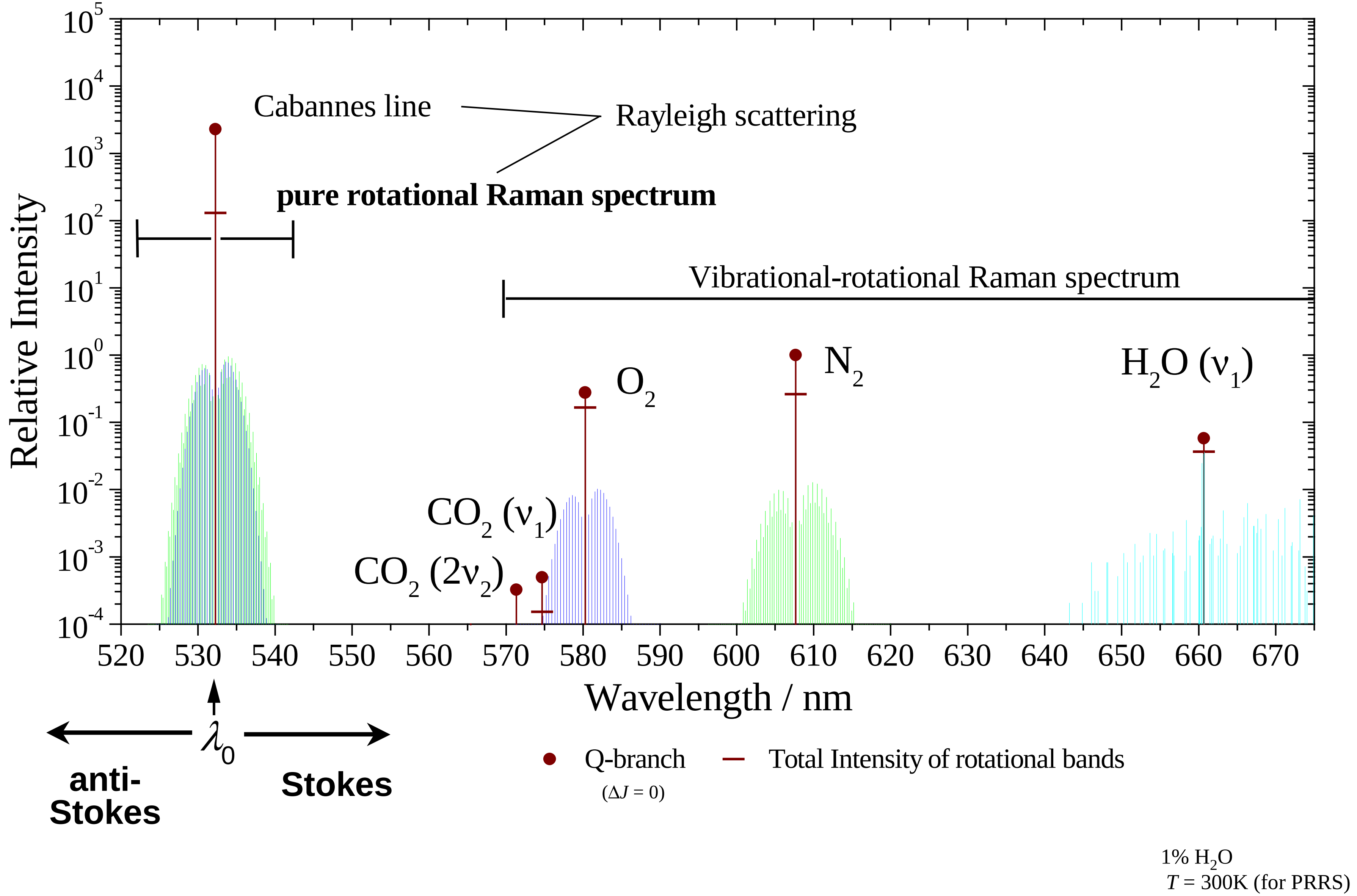
-> RH, CAPE, CIN

Groundbased scanning H_2O DIAL

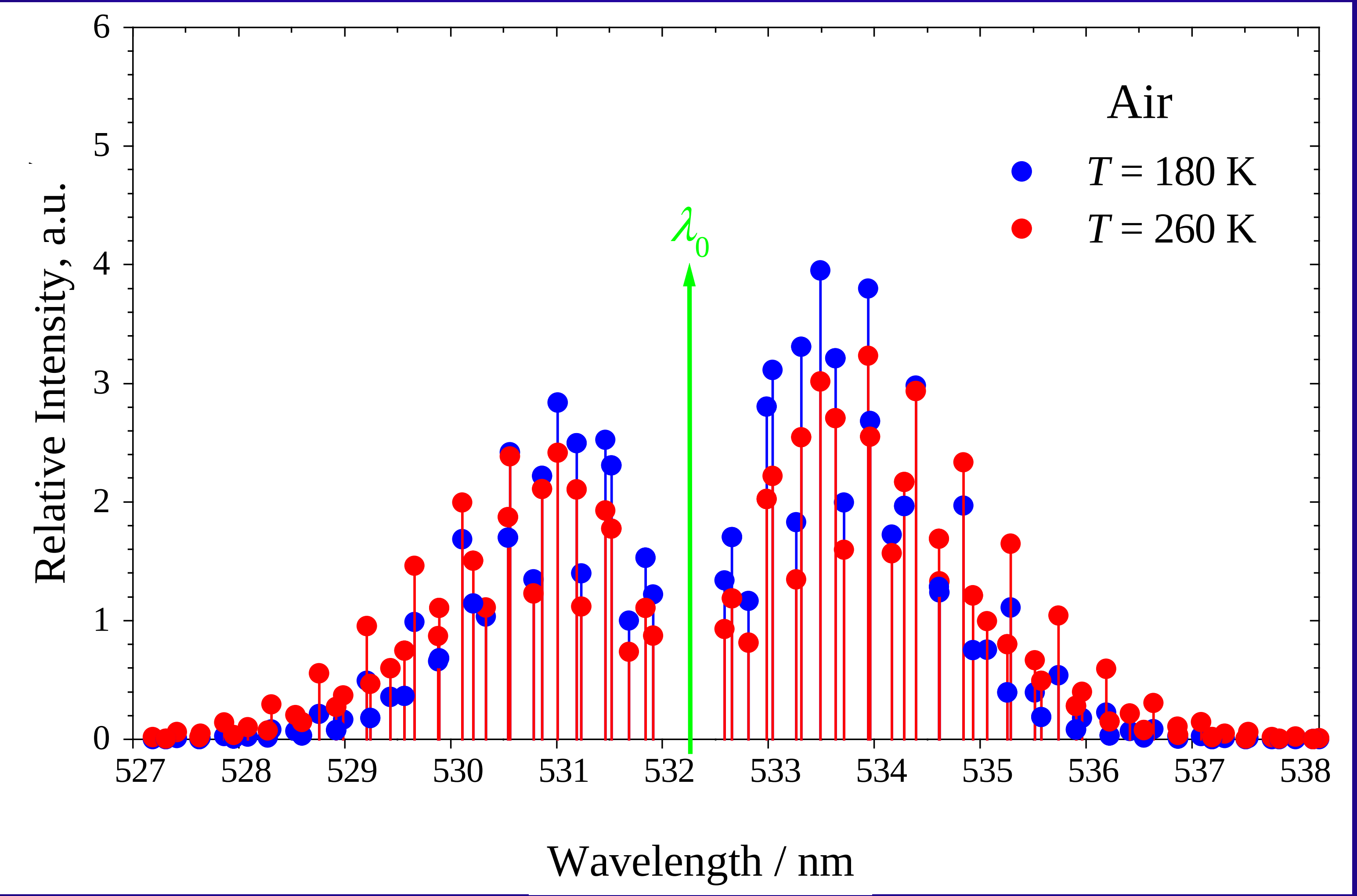


Wulfmeyer and Walther, Appl. Opt. 2001

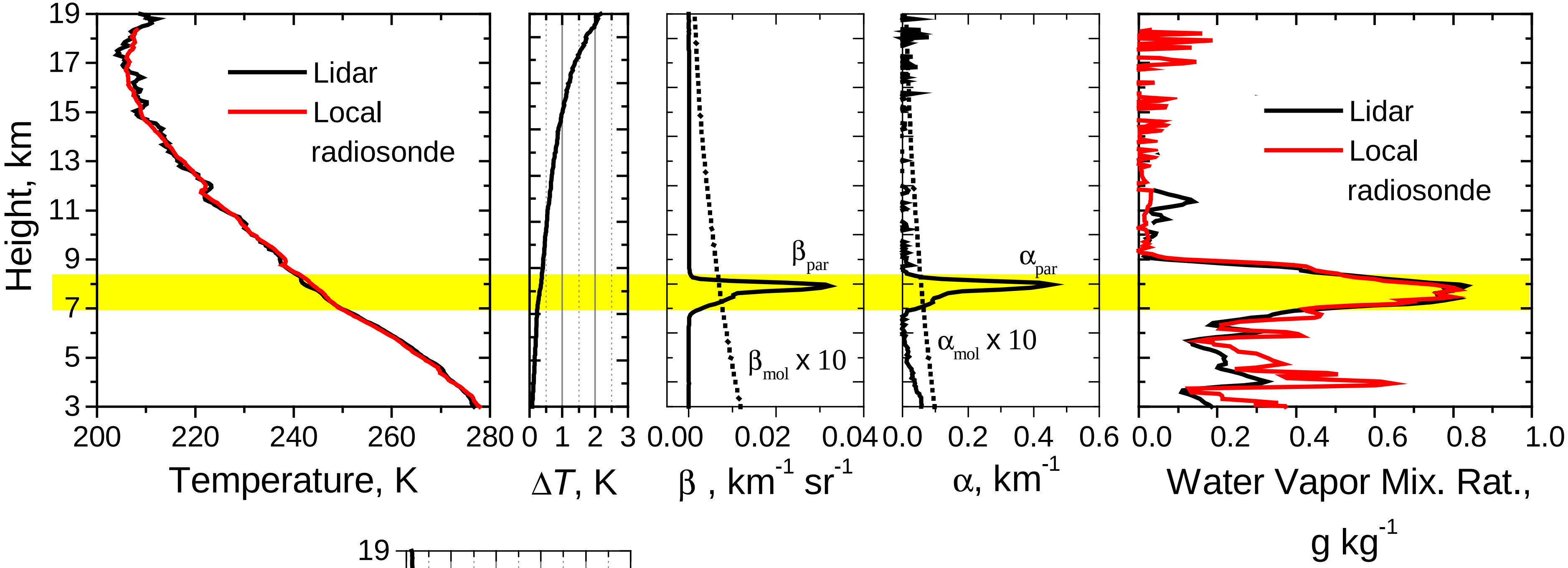
Atmospheric Backscatter Signals

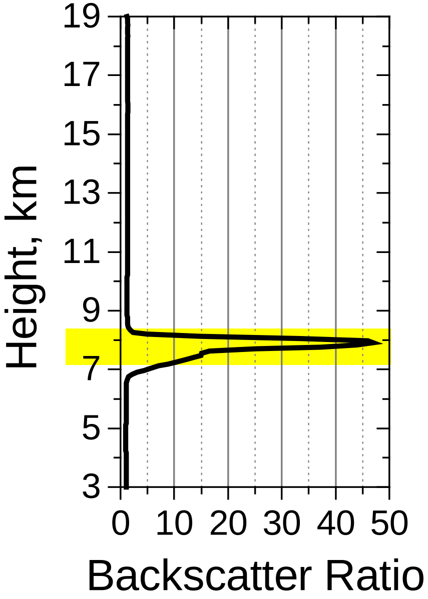


Rotational Raman Spectrum of Air



λ_0 = 532 nm, 4 signals: Elastic, RR1, RR2, H2O VR





λ= 532 nm
P = 30 W (600 mJ, 50 Hz)
$r_{Telescope}$ = 0.5 m
FOV = 1.5 mrad

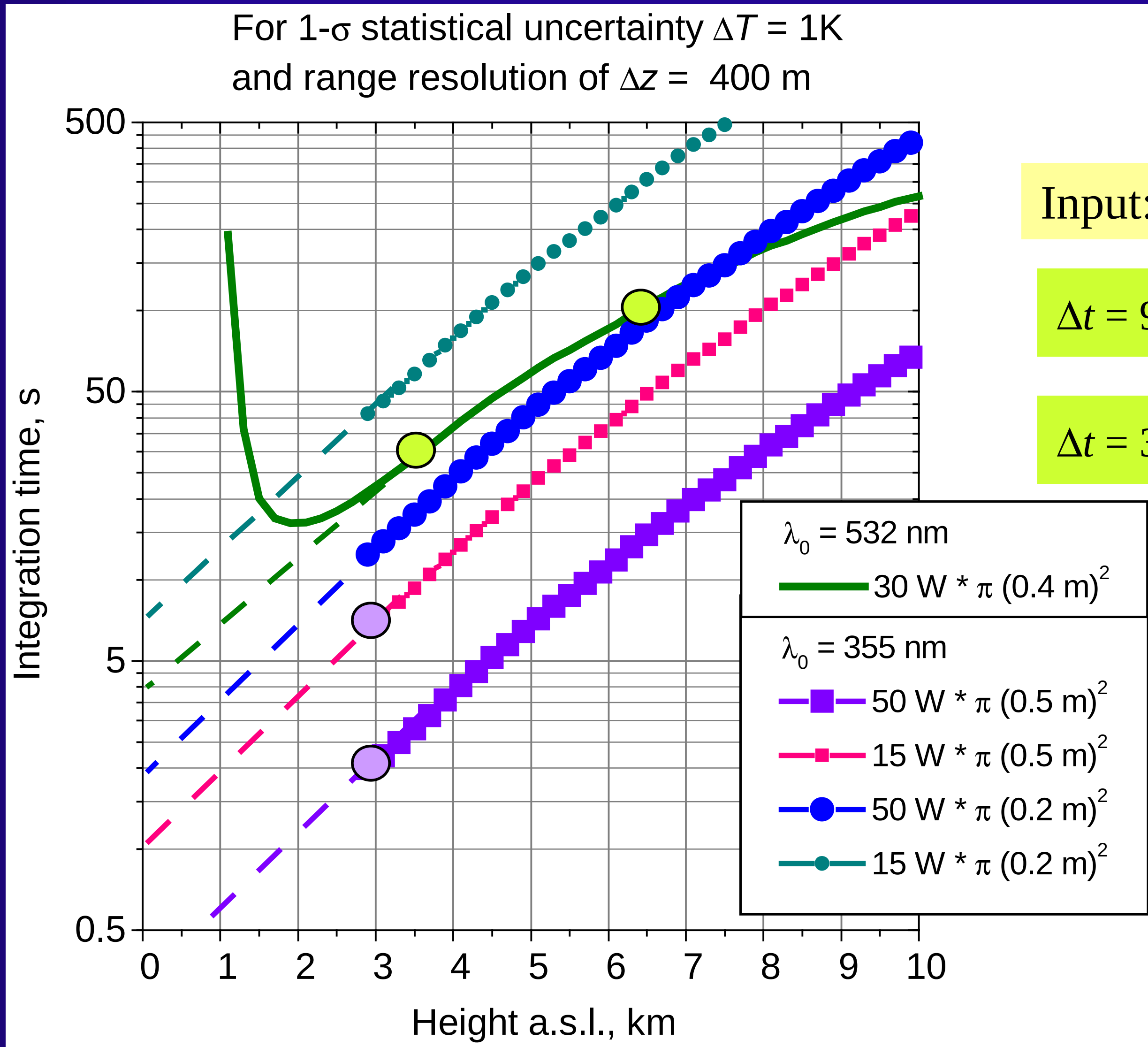
Δt = 30 minutes,
Δz = 360 m

***T* measurements with highest resolution**
No systematic errors even in thin clouds

A. Behrendt, T. Nakamura, T. Tsuda, Appl. Opt., 2004

Ground-based RR Lidar, vertical profiling

Input: Experimental data of RASC Raman Lidar



Input: RASC Lidar

Δt = 90 s, z = 6.5 km

Δt = 30 s, z = 3.5 km

Future UV Lidar:

Δt = 2 - 7 s, z = 3 km

Theory H_2O DIAL

The water vapor concentration can be found in

$$\ln\left(\frac{\tau_{WV}^2(\nu_{off},z_2)}{\tau_{WV}^2(\nu_{on},z_2)}\right)-\ln\left(\frac{\tau_{WV}^2(\nu_{off},z_1)}{\tau_{WV}^2(\nu_{on},z_1)}\right)=2\int_{z_1}^{z_2}N_{WV}(r)\sigma_{WV}(r)dr\cong 2\,N_{WV,eff}\;\sigma_{WV,eff}\;\Delta z$$

but it also shows up in the correction terms!

$$\ln\frac{S_{off}(z_2)}{S_{on}(z_2)}-\ln\frac{S_{off}(z_1)}{S_{on}(z_1)}=\ln\left(\frac{\tau_{WV}^2(\nu_{off},z_2)}{\tau_{WV}^2(\nu_{on},z_2)}\right)-\ln\left(\frac{\tau_{WV}^2(\nu_{off},z_1)}{\tau_{WV}^2(\nu_{on},z_1)}\right)$$

$$+\ln\left[\frac{\beta_{par}(z_2)+\dfrac{\beta_{mol}(z_2)\int_{\nu=0}^{\infty}b(\nu-\nu_{off})\tau_{WV}(\nu,z_2)d\nu}{\tau_{WV}(\nu_{off},z_2)}}{\beta_{par}(z_2)+\dfrac{\beta_{mol}(z_2)\int_{\nu=0}^{\infty}b(\nu-\nu_{on})\tau_{WV}(\nu,z_2)d\nu}{\tau_{WV}(\nu_{on},z_2)}}\right]-\ln\left[\frac{\beta_{par}(z_1)+\dfrac{\beta_{mol}(z_1)\int_{\nu=0}^{\infty}b(\nu-\nu_{off})\tau_{WV}(\nu,z_1)d\nu}{\tau_{WV}(\nu_{off},z_1)}}{\beta_{par}(z_1)+\dfrac{\beta_{mol}(z_1)\int_{\nu=0}^{\infty}b(\nu-\nu_{on})\tau_{WV}(\nu,z_1)d\nu}{\tau_{WV}(\nu_{on},z_1)}}\right]$$

H_2O DIAL

"Simulation results show that great care has to be taken in the analysis of H_2O DIAL measurements when **layers with high aerosol concentration, clouds, or strong temperature inversion** exist."

(Ansmann, AO 1985)

To correct for errors caused the Rayleigh-Doppler effect, information on the aerosol backscattering properties is necessary.

These can be retrieved from the off-line signal.
For this retrieval **Rayleigh scattering coefficients, aerosol extinction/backscatter ratio, and the aerosol backscatter coefficient** at a calibration range have to be known. (Klett-algorithm)

(Ansmann & Boesenberg, AO 1987)

Concept

Idea: Correction of Rayleigh-Doppler effect by use of rotational Raman signal measured in the UV.

Scheme:

1) Measurement of $\alpha_{par,IR}$, $\beta_{par,IR}$ with lower resolution
$\alpha_{par,UV}$, $\beta_{par,UV}$ with high resolution

2) Radiative properties of atmospheric particles constant in time scale of minutes (concentration of particles not necessarily constant)

$\frac{\alpha_{par,IR}}{\alpha_{par,UV}}$ = constant $\frac{\beta_{par,IR}}{\beta_{par,UV}}$ = constant $\alpha_{par,UV}$, $\beta_{par,UV}$ $\Rightarrow$ $\alpha'_{par,IR}$ and $\beta'_{par,IR}$ with high resolution

3) Use measured $\alpha'_{par,IR}$, $\beta'_{par,IR}$, T to correct for Rayleigh-Doppler effect

Possible scheme

Synergy

IR elastic
- $S_{IR,on}$
- $S_{IR,off}$

IR rotational Raman *T*-independent
- $S_{IR,RR}$

q

$\beta_{par,IR}$ low resolution

$\alpha_{par,IR}$ low resolution

$\dfrac{\alpha_{par,IR}}{\beta_{par,IR}}$

UV elastic
- S_{UV}

UV rotational Raman *T*-dependent
- $S_{UV,RR1}$
- $S_{UV,RR2}$

$S_{UV,RR}$ *T*-independent

$\beta_{par,UV}$ high resolution

$\alpha_{par,UV}$ high resolution

T

$\dfrac{\beta_{par,IR}}{\beta_{par,UV}}$

$\dfrac{\alpha_{par,IR}}{\alpha_{par,UV}}$

$\dfrac{\alpha_{par,UV}}{\beta_{par,UV}}$

Synergy:

q'

$\beta'_{par,IR}$ high resolution

RH
CAPE
CIN
...

Behrendt and Wulfmeyer, SPIE 2003.