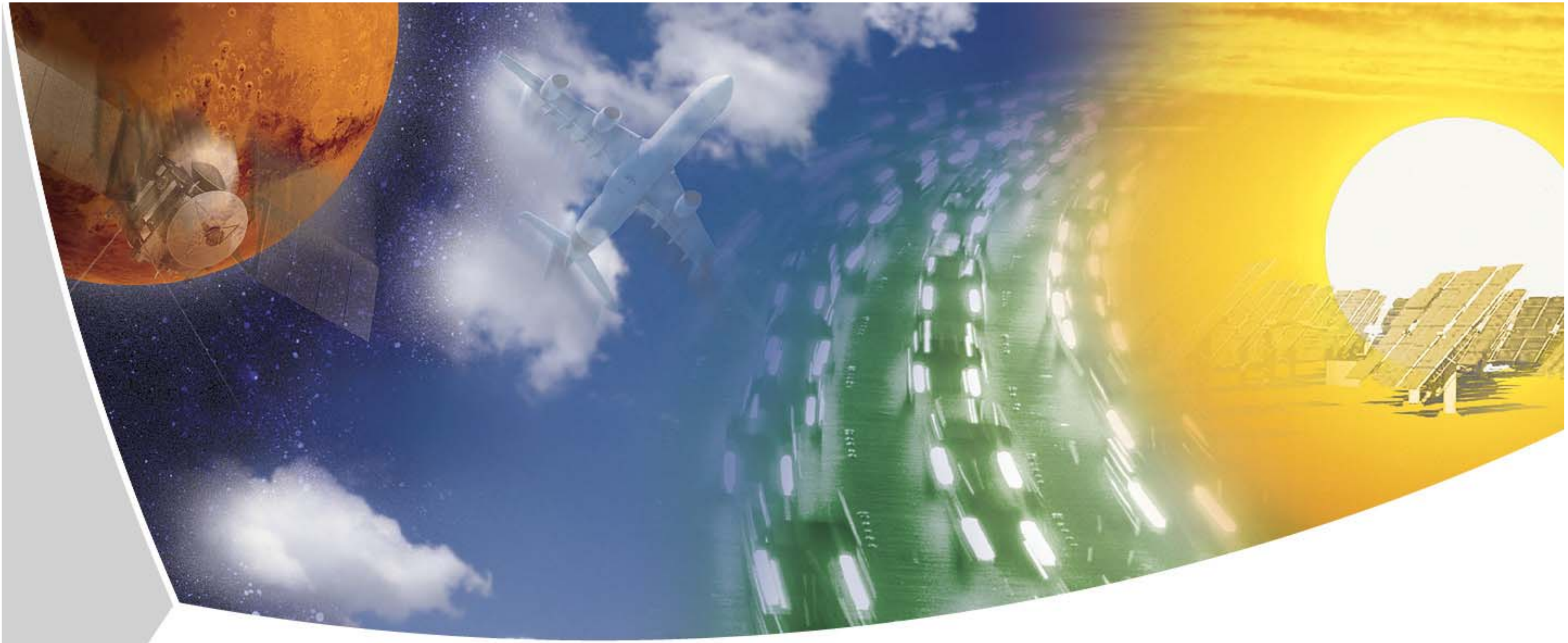


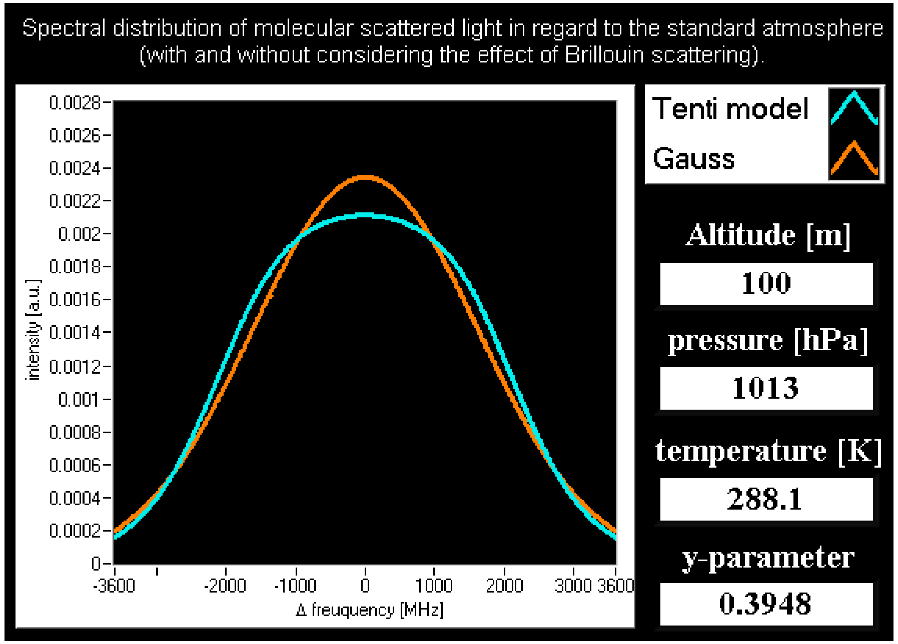
Rayleigh-Brillouin Scattering Experiment with Atmospheric Lidar from a Mountain Observatory

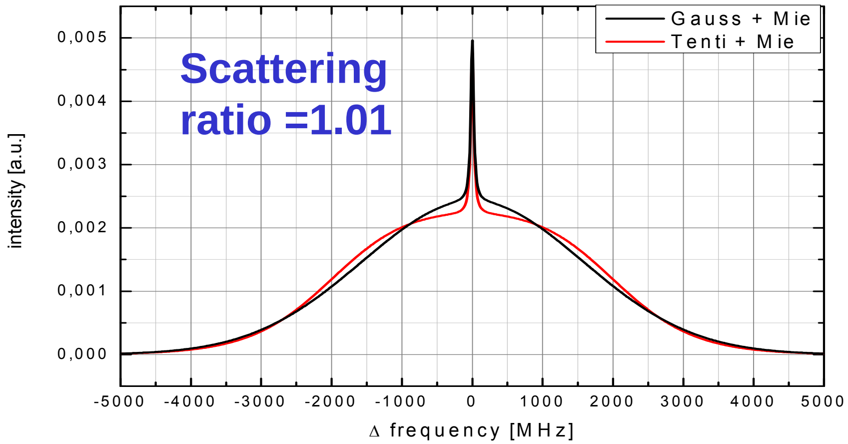
Oliver Reitebuch, Christian Lemmerz, Engelbert Nagel, Benjamin Witschas

Deutsches Zentrum
DLR für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Institut für Physik der Atmosphäre

Challenges for atmospheric lineshape measurements





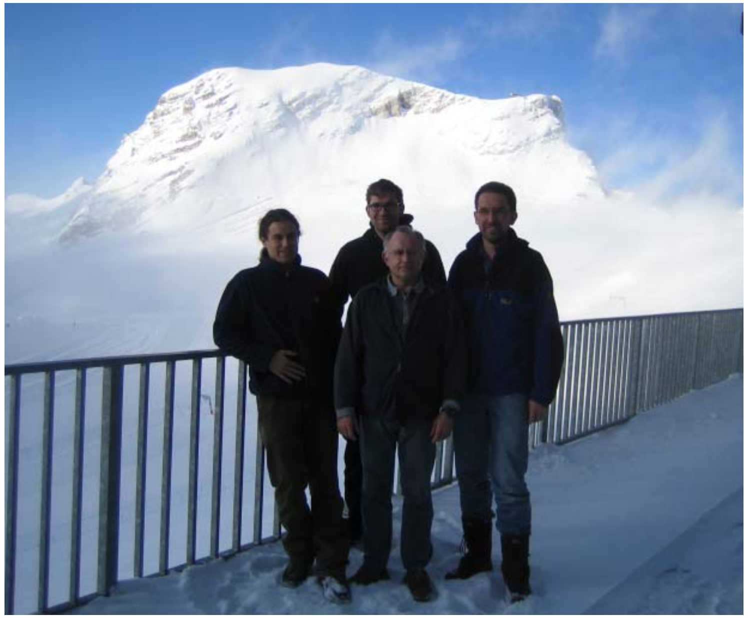
- Up to now no direct measurement of Cabannes lineshape in the atmosphere performed; only indirect via wind or temperature measurement
- Challenging measurement because
  - difference between Gaussian and actual lineshape is only a few % (up to 10% at ground) => requires to sample lineshape in the order of 100 points
  - width of line is in the order 4 GHz FWHM to 6 GHz (total) at 355 nm => sampling with 50 MHz or **21 fm = 21*10^{-15} m**
- Measured lineshape is convolution of atmospheric spectra and instrumental function
  => Instrumental function has to be known with high accuracy
  => analysis with forward model or deconvolution is challenging for noisy measurements
- Small bandwidth aerosol contribution "contaminates spectra" significantly, because contribution is convoluted with instrumental function

Where measuring the Brillouin effect in the atmosphere?

- Measurement at a mountain observatory, because
  - it is above aerosol-rich boundary layer especially during high pressure weather conditions in winter => no aerosol contamination
  - possibility of horizontal line-of-sight measurement over distances of 20-30 km => horizontal averaging possible

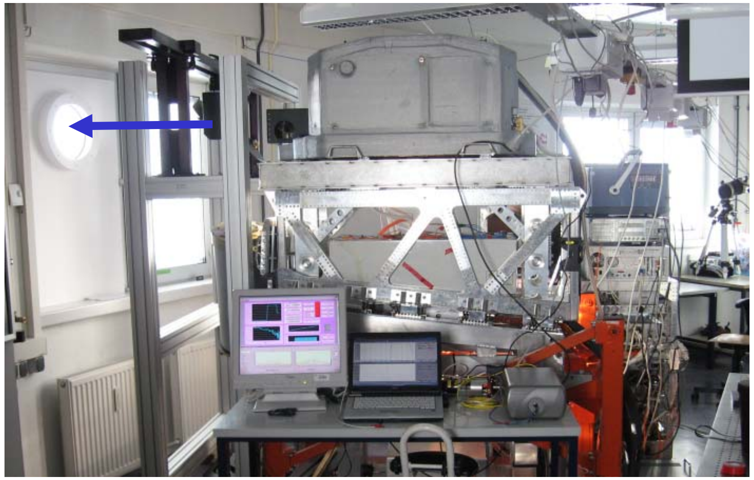
- Mountain observatory **Schneefernerhaus UFS** is at 2650 m ASL and 300 m below Zugspitze summit => ambient pressure from 705 hPa to 730 hPa during campaign, which should be large enough to see Brillouin effect

- Only small Aerosol scattering disturbances will occur → data of the German environmental agency (UBA) shows that the mean particle density on UFS is 500 p/cm^3 compared to 60000 p/cm^3 in the valley.



- Additional measurements from Microwave Radiometer of horizontal temperature profile and radiosondes from Innsbruck airport (30 km).

BRillouin Atmospheric INvestigation on Schneefernerhaus BRAINS 2009



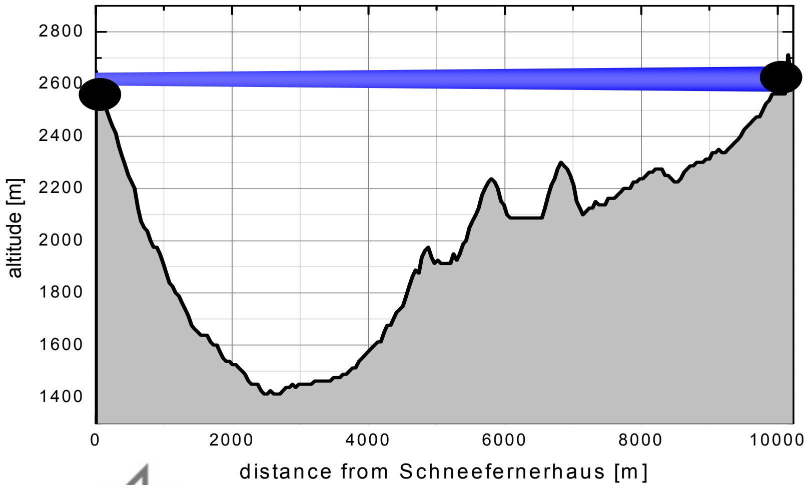
- Use ADM-Aeolus prototype lidar - the ALADIN airborne demonstrator A2D in horizontal pointing geometry with wavelength of 355 nm

- Use of molecular Rayleigh channel with Fabry-Perot interferometer to measure lineshape:
    - drawback is very broad instrument function of 1.7 GHz compared to atmospheric width of 4 GHz (FWHM) or filter function of laboratory setup at VU Amsterdam with 0.23 GHz

- Keep Fabry-Perot interferometer constant and change laser frequency in discrete steps over lineshape (calibration mode of ADM-Aeolus); monitor laser relative frequency with heterodyne unit and absolute frequency with wavemeter

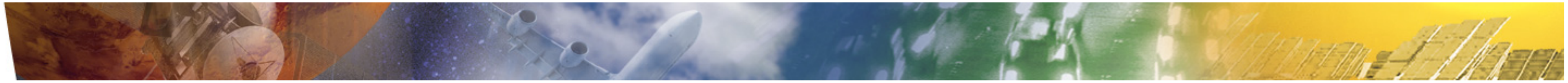
- Setup in laboratory together with H_2O-Differential Absorption Lidar DIAL of FZK/IMK (Trickl, Vogelmann) during a period of 6 weeks in January to March 2009
- More than 1000 kg of equipment was brought to the observatory by a cogwheel train

Horizontal LOS measurements of atmosphere and hard-target



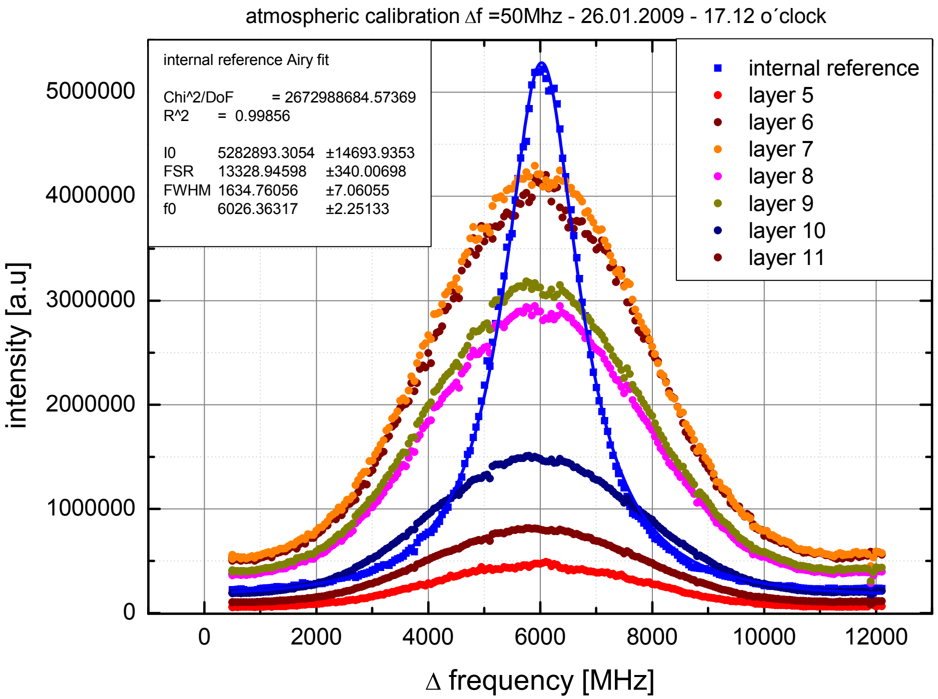
- Horizontal lidar measurements in nearly pure Rayleigh atmosphere are performed, and therefore averaging over all range gates is possible => increase SNR (assumption that p and T is constant is verified with MTP)

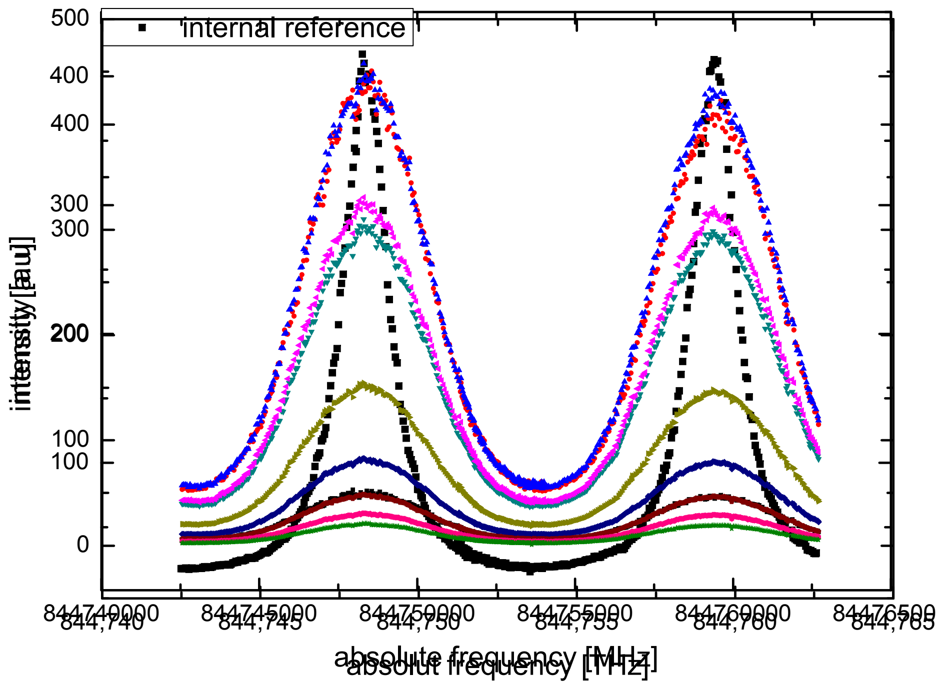
- Hard Target measurements are possible over a range of 10 km to verify the instrument function with a Mie-type signal in addition to the internal reference signal



Sampling of the atmospheric lineshape and instrument function

- Atmospheric signal and internal reference for filter transmission is sampled with 240 frequency steps with Δf =50 MHz (21 fm) over a frequency range of 12 GHz (5.1 pm)
- 630 laser pulse returns with 60 mJ/pulse accumulated for every frequency step
- Some measurements were performed over 20 GHz with Δf = 50 MHz



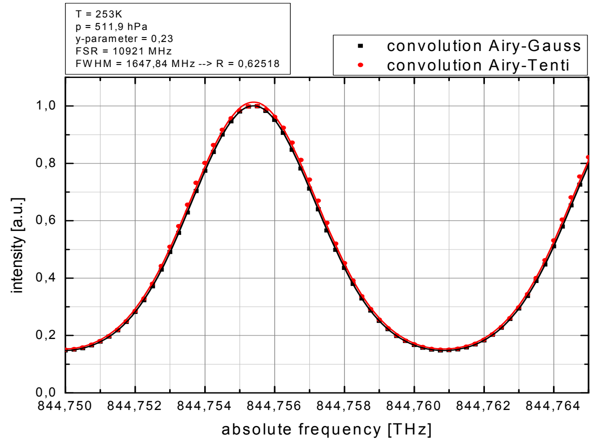


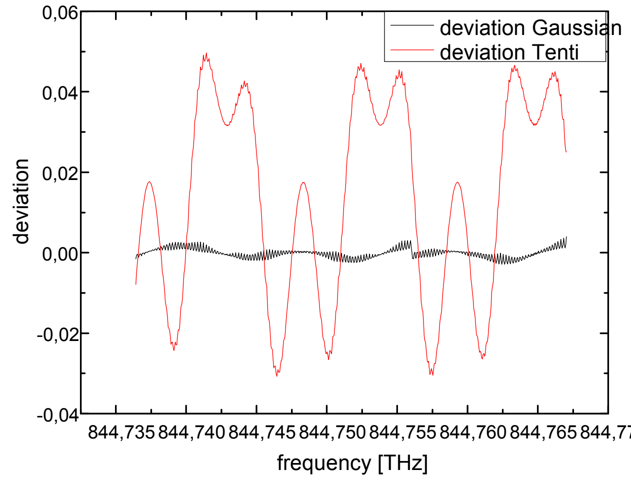
How to compare measurements with models?

Ongoing PhD thesis by Benjamin Witschas to develop method and analyse measurements from BRAINS

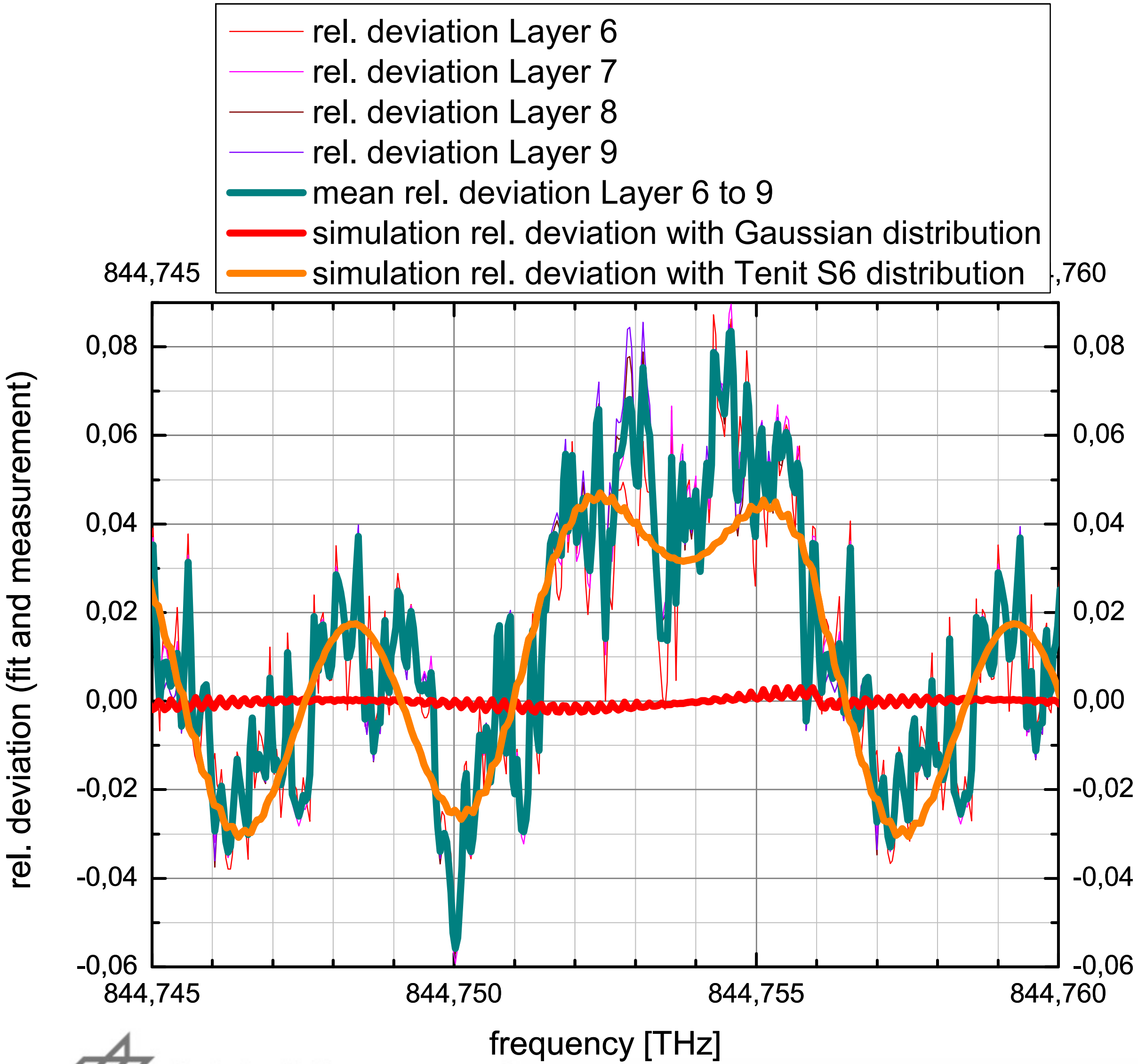
1) Develop accurate instrument function I(f) of the Fabry-Perot Interferometer => relevant for ADM-Aeolus
2) Atmospheric lineshape can be best modelled by Tenti S6: But this is an iterative algorithm, not a function, which can be analytically convoluted with instrument function in order to fit to measurements
3) Calculate expected difference between convolution of instrument function I(f) with Gaussian lineshape G(f)*I(f) and lineshape from Tenti S6 T(f)*I(f) => "fingerprint" of Brillouin scattering
4) Calculate difference between measured lineshape M(f) and Gaussian G(f)*I(f)
5) Compare expected difference (3) or "fingerprint" with measured difference (4)

→ **The deviation between Gaussian model and Tenti simulation is up to 5 % and has a characteristic "fingerprint".**





Is fingerprint of Rayleigh-Brillouin scattering measured?



- The deviations from measurement to Gaussian assumption and simulation with the Tenti S6 model to Gaussian assumption have the same characteristics.

→ The Tenti model describes molecular scattered light (from gas in the kinetic regime) quiet well.

→ We have measured the effect of Brillouin scattering in the atmosphere the first time!

Summary

- For the first time the lineshape from Rayleigh-Brillouin scattering was measured with high spectral resolution in the atmosphere
- Method to compare deviations of measurements from Gaussian lineshape and expected from Tenti S6 model was developed including convolution with instrument function
- Measurements confirm that the atmospheric lineshape deviates from a Gaussian as expected
- Lineshape and deviations can be modelled with Tenti S6
- As an important secondary result an accurate description of the instrument function of the sequential Fabry-Perot interferometer for ADM-Aeolus was obtained:
    - pure Airy-function is not sufficient to describe filter transmission
    - refinement of the model was performed including plate defects similar to an approach by McGill et al. (1997)

Next STEPS

- More than 50 spectral scans have been performed => analysis of spectra for different conditions, e.g. influence of Mie-scattering

Excellent location for meetings