Manual of the practical exercise „LIDAR“

LEIBNIZ-INSTITUT FÜR ATMOSPHÄREN PHYSIK IAP

LIDARs are an important type of instrument for atmospheric physics. Below is described how a lidar works. Most important physical processes (beside the emission of pulsed laser light) are the scattering and absorption of light by air molecules, aerosols and trace gases. In the experiment you will learn about the principle of lidar soundings as well as about selected processes of atmospheric physics. The experiment is near to our usual research or even part of it. If weather allows, you will perform a real sounding of the atmosphere and derive a density profile of the atmosphere.

How is the experiment organized?

We will provide you with some scientific publications and other material for preparation of your experiment (see below) that will take place at the IAP in Kühlungsborn. The experiment will last about half a day. In contrast to previous years the experiment now uses our daylight capable lidar, i.e. it is not limited to darkness. Lidar soundings are only possible during clear skies. Therefore it is not useful to fix a selected day some weeks in advance. The experiment will take place on short notice if your and my schedule allows and weather seems “cooperative”. It is recommended that you contact me as early as possible (for exchanging phone numbers or e-mail addresses). My contact info is given below. The transportation between Rostock and Kühlungsborn could be arranged by us if you have no car available.

What is a "lidar"?

- an important instrument for atmospheric research
- LIDAR means LIght Detection And Ranging
- How does it work? Light pulses are emitted into the atmosphere and partly backscattered. The intensity and time-of-flight (proportional to scattering height) is measured
- What is needed for a lidar?
  - a laser, emitting high-power pulses of light
  - a telescope to collect the backscattered photons
  - a sensitive detector to measure the intensity of the backscattered light, i.e. the number of photons
  - lots of electronics, ...
- What do we measure? Where, how and how much light is backscattered
- What do we learn from this? Several physical properties of the scattering medium, i.e. the atmosphere
- Selected advantages of a lidar?
  - high vertical resolution
  - coverage of the whole lower and middle atmosphere (0 - 110 km)
  - continuous series of soundings at a single location
  - cheaper than a satellite
  - etc. etc. ....

The experiment shall provide some insight into different lidar observation methods. You will learn in detail about the spectral filtering needed for daytime soundings and will work directly on the spectral transmission function of our detection system. The differences between elastic scattering (Rayleigh/Mie scattering) and inelastic scattering (vibrational Raman scattering) are examined. Differences between the observed density profile and an ideal exponential one can be used to give a rough estimation of atmospheric temperature.

The following information can be used for preparation:

- Exercise description on the IAP website (http://www.iap-kborn.de/index.php?id=517). There are some files for download:
    - A review paper of Kent, G. S., and R. W. H. Wright, A review of laser radar measurements of atmospheric properties, J. Atmos. Terr. Phys., 32(5), 917-943, doi:10.1016/0021-9169(70)90036-X, 1970 and
    - a PowerPoint presentation with several information regarding lidar
- Bob Sicas website on lidars (http://pcl.physics.uwo.ca/science/lidarintro/)
- The website of University of Wisconsin contains a description of the High Spectral Resolution Lidar (HSRL) (http://lidar.ssec.wisc.edu/papers/pp_thes/thes_4.htm). Please look in particular into section "Measurements" (excluding temperature measurements).
- A nice book on lidar is: C. Weitkamp: Lidar, Springer, 2005, ISBN 0387400753. In fact, it covers much more than the topics needed for the experiment.

The practical exercise is separated into the topics “Transmission function of the lidar detector” and “Density (temperature) observation by lidar”.

Fundamentals

Please inform yourself about the following topics:

- Layers of the neutral atmosphere (up to ~200 km). How are they determined?
- Light scattering by molecules (Rayleigh scattering) and aerosols.
- Principle of a Fabry-Perot etalon. How are finesse, free spectral range, and bandwidth of a single transmission peak determined?
- Barometric formula and the ideal gas law. Describe the decay of density with altitude in an isothermal atmosphere.

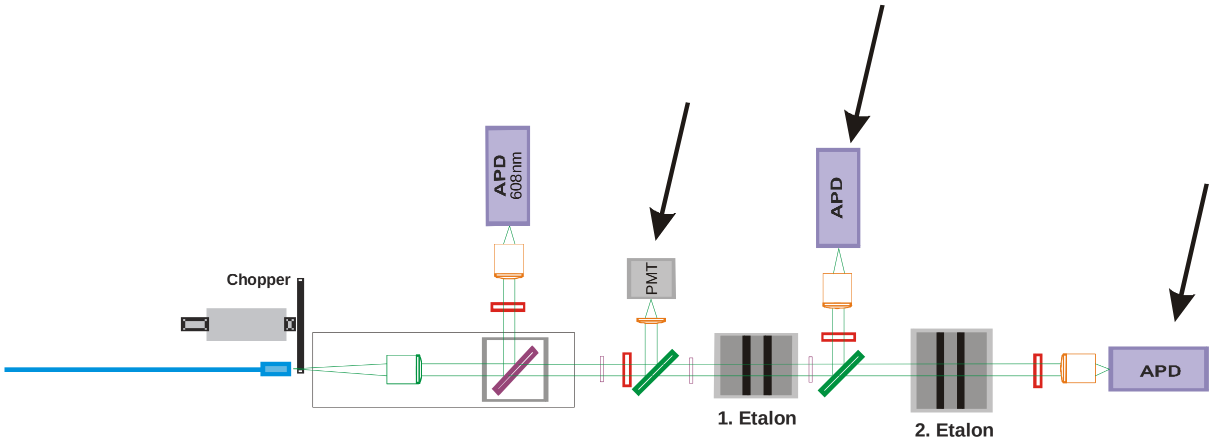
The experiment

1. *Transmission function of the lidar detector*

The Nd:YAG laser of the Rayleigh-Mie-Raman lidar (RMR lidar) is seeded by an external cw laser. The seedlaser is normally locked to an iodine resonance line and determines the wavelength of the Nd:YAG laser. The seedlaser can be tuned by a piezo-coupled resonator (fast, small wavelength range) and by the temperature of the laser crystal (slow, wide wavelength range). For normal lidar operation the wavelength is kept constant and the lidar detector is adjusted to the wavelength of the laser. Especially the Fabry-Perot etalons (FPE) of the lidar detector need to be fixed to the laser as they have only about 4 pm FWHM (~4 GHz at 532 nm). Compared to this, the spectral width of the backscattered photons is near 2.5 nm due to temperature-dependent Doppler broadening.

In the exercise the spectral width of the two FPE shall be determined. For this the temperature of the laser crystal is changed by software. The laser changes between modes every few picometers. The mode hop is connected with a strong change in emitted wavelength that may disturb the measurement of the FPE transmission curve. As a first step a range of wavelengths (temperatures) without mode hopping is selected. The temperature is changed continuously, and the transmission of the etalons and an independent wavelength measurement are watched. Note the temperature (wavelength) when the mode changes. After selecting the wavelength (i.e. temperature) range, the temperature is changed stepwise to measure the transmission curve (see below). 15 – 20 different wavelengths shall be examined.

The backscattered signal is detected by three sensors, one before the first FPE, one in between, one behind the second FPE (see arrows in Figure below). For the exercise, only the channel behind the second FPE is used, while the other might be additionally used for transmission control. The data acquisition is done by our standard software after integration of 1000 laser pulses (~30 s). One profile shall be acquired for a single wavelength value. The particular temperature, wavelength and file number must by noted for later evaluation.



For the protocol plot the signal intensity at a selected height against the laser wavelengths. Mind removing the solar background before plotting the data. The background can be determined by averaging the signal between e.g. 130 and 150 km altitude. After that, several height channels (195 m width each) could be added to improve the signal-noise-ratio. Fit an Airy function to the data, with the FWHM as free parameter.

Note: The observed relation between wavelength and signal is not a pure Airy function, but a combined Airy function of the two etalons convolved with the Gaussian shape profile of the Doppler broadened backscatter. If the exercise is done under lab conditions (bad weather), the detected light is emitted directly by the seedlaser and is not Doppler-broadened. In this case, no convolution has to be acknowledged.

2. Atmospheric density and temperature

The density profile of the atmosphere is determined by the barometric formula. For an isothermal atmosphere a pure exponential decay of density would be observed. In a non-isothermal atmosphere density and temperature are related by the ideal gas law under the assumption of hydrostatic equilibrium. The Rayleigh backscatter signal is proportional to the air density, i.e. the whole backscatter profile is proportional to the density profile of the atmosphere. For a rough estimation of the temperature gradient, the backscatter profile can be compared with an exponential function. (The most practicable way to do this is by plotting the logarithm of the backscatter signal against altitude or by plotting the signal on a log scale and the altitude on a linear scale.)

Plot the backscatter profile derived at the centre of the FPE transmission as described above. Mind subtracting the background as first step. Describe the altitude dependence of the temperature gradient and derive the altitude where the gradient changes strongest. Take the statistical noise into account. If necessary smooth the data. Take into account that with a linear running average the data has to be logarithmised beforehand.

Addendum: General hint for the calculations and the protocol

Background and noise are not the same, even if they are sometimes mixed up! Background count rate is formed from the detected photons from the sun, moon, streetlights etc. that have no temporal correlation with the laser pulse, i.e. that are constant with altitude. Noise is the statistical variation of the signal (count rate) due to some probabilities below 100%: A photon is scattered under some arbitrary angle and it may hit the telescope mirror (and is detected) or it may hit the wall beside the telescope (and is not detected). The interference filters have less than 100 % transmission (some photons are rejected even if they have the correct wavelength) and the detectors have less than 100 % quantum efficiency (some photons do produce a voltage signal and some do not – a question of probability). At the end detecting a photon or not is a statistical process. With our lidars the Poisson statistic is applicable where the statistical noise can be calculated from the square root of the count rate. Also the background signal contains some noise. If it would not, the background could be exactly determined and extrapolated for the altitude where also lidar backscatter is detected. In reality, some noise remains after background subtraction, which is limiting the overall signal quality.

The raw data will be provided electronically.

Good luck!

In case of questions, please contact Michael Gerding (gerding@iap-kborn.de),

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