Atmospheric Lidar
1. Introduction

Lidar Tutorials

21st Coherent Laser Radar Conference

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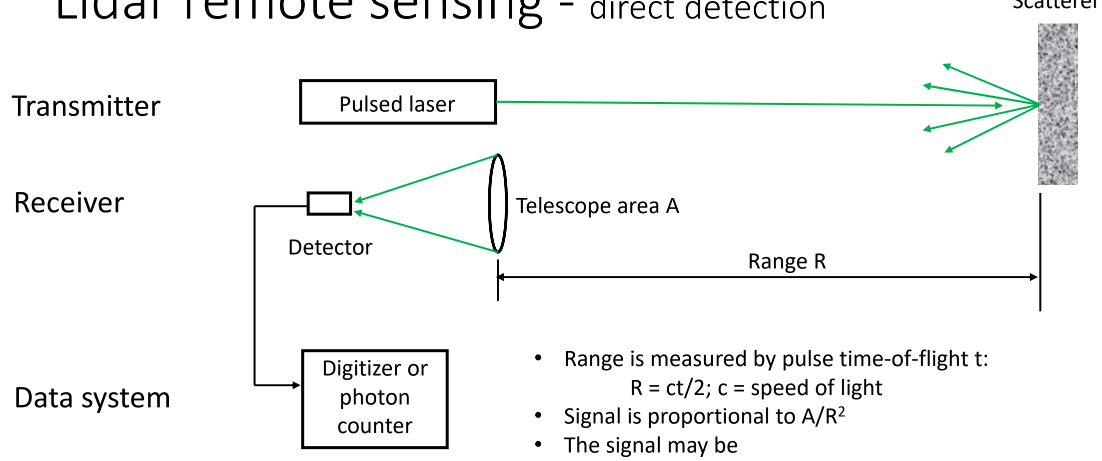
Lidar remote sensing - direct detection



- Range is measured by pulse time-of-flight t:
  R = ct/2; c = speed of light
- Signal is proportional to A/R^2
- The signal may be
  - range & reflectance (hard target lidar)
  - a waveform (atmosphere, ocean, forest)

G.G. Gimmestad graphic

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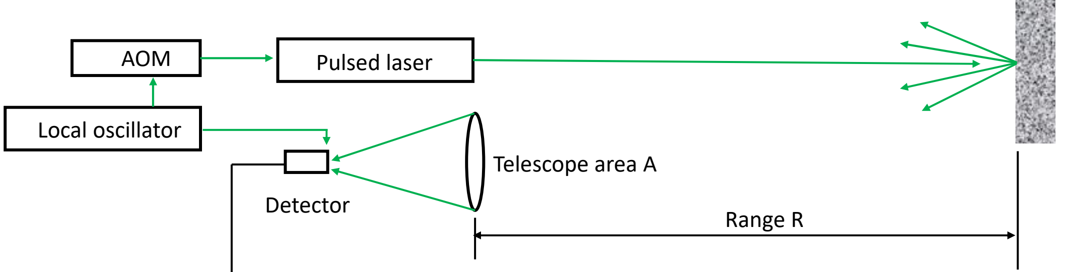
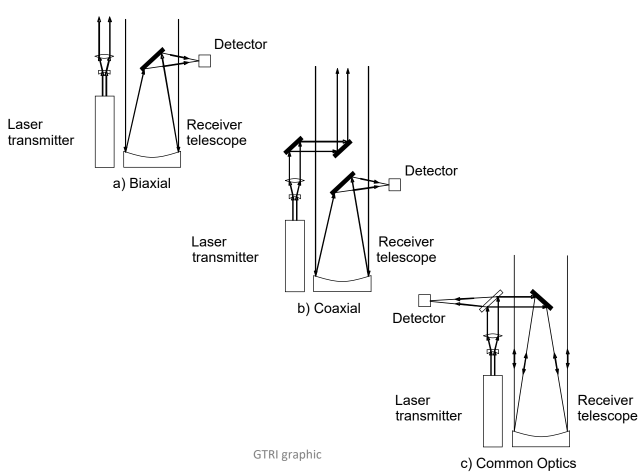
Lidar remote sensing - coherent detection



- An acousto-optical modulator shifts the laser frequency
- Two wavefronts are mixed on the detector
- The signal is at the difference frequency (RF)
    - The maximum signal-to-noise ratio is enabled
    - Immunity to background light is greatly improved
    - The lidar is sensitive to Doppler shifts!

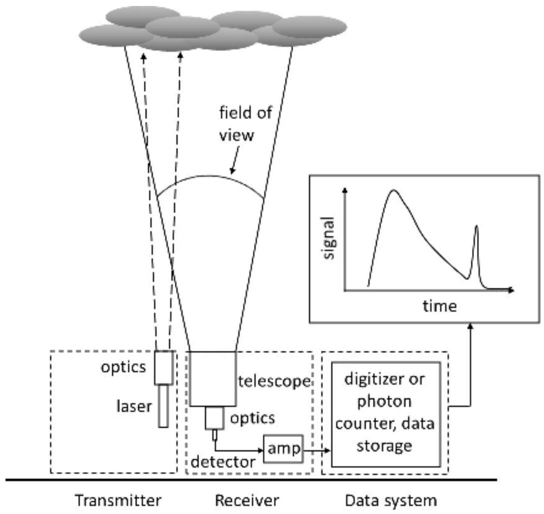
G.G. Gimmestad graphic

Lidar system configurations



GTRI graphic

The atmospheric lidar



G.G. Gimmestad graphic

Lidar signals are caused by *backscattering* of laser light.

Range $R = ct/2$ corresponds to 150 m/µs. The waveform occurs in < 1 ms.

System software provides control, data acquisition, data analysis, modelling, calibration, etc.

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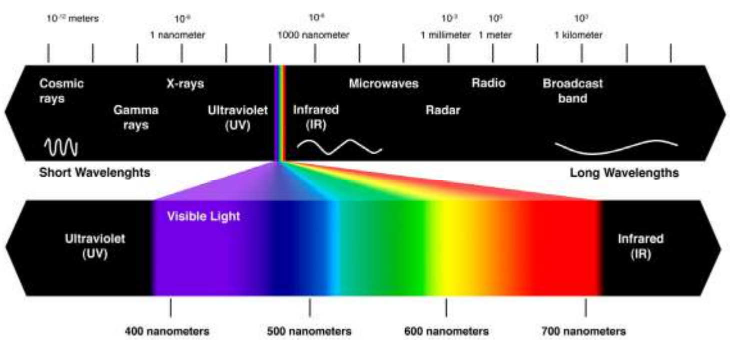
The electromagnetic spectrum



https://sites.google.com/site/mochebiologysite/online-textbook/light

- Lidar can operate wherever a laser is available and the atmosphere is transparent.
- The usual lidar wavelength range is 266 – 2200 nm, plus 3 – 5 µm and 10.6 µm.

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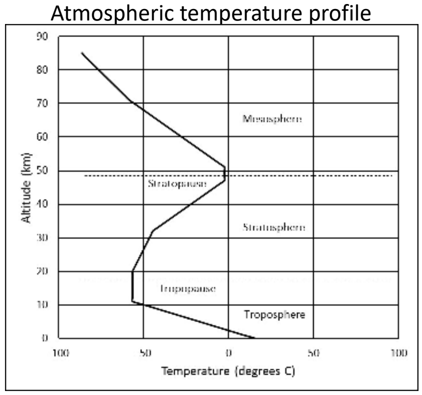
Atmospheric structure

- Earth's atmosphere is conventionally described as spherical shells defined by the temperature profile.
- From 0 – 100 km, the dry atmosphere has this composition:

N_2	78 %
O_2	21 %
Ar	1 %
CO_2	400 ppmv

- This is important because lidar data is often calibrated with the light backscattered by these gases.

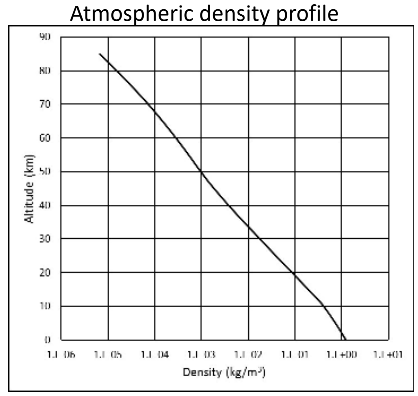
Atmospheric temperature profile



Inflection points in the profile determine the -sphere boundaries.

G.G. Gimmestad graphic

Atmospheric density profile



Air density decreases by 10^{-6} going from the surface to 100 km!

G.G. Gimmestad graphic

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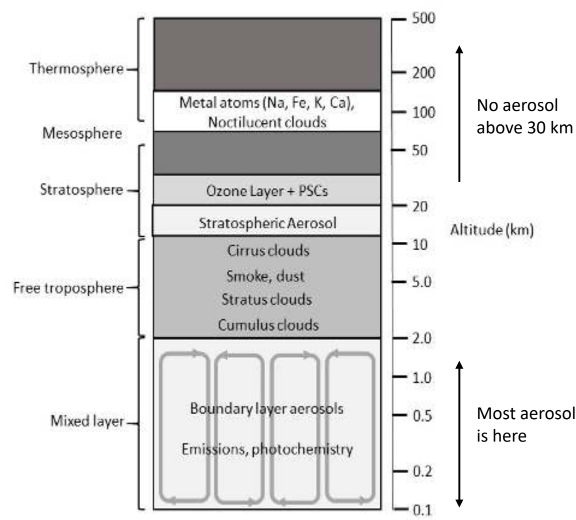
The lidar point of view

The atmosphere is full of interesting stuff at all altitudes from the ground up into the thermosphere!

- Boundary layer aerosols, ozone, PM, other pollutants
- Clouds, smoke & dust, greenhouse gases
- Water vapor
- Stratospheric aerosol
- Stratospheric ozone
- Polar stratospheric clouds
- Metal atoms

And wind measurements at all altitudes are valuable!

So are weather variables (temperature & pressure).



GTRI graphic

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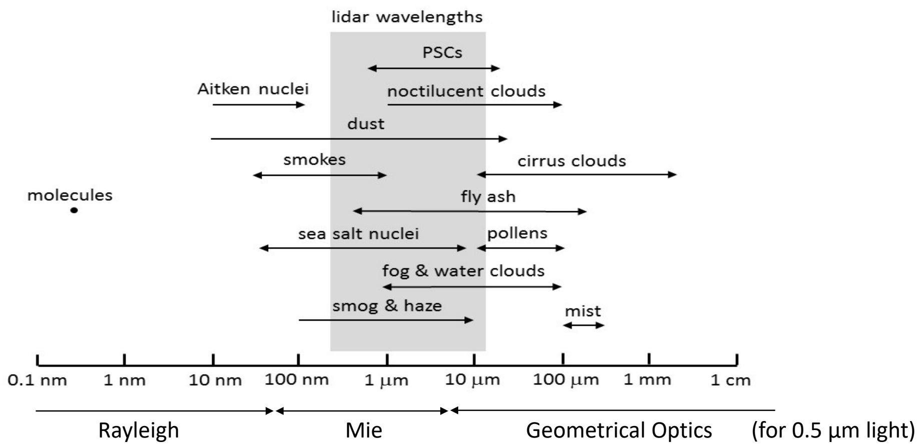
Sizes of atmospheric particles + molecules

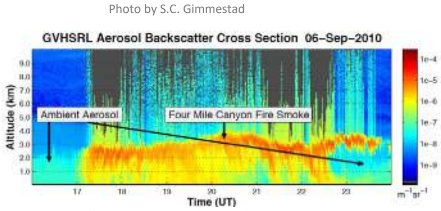


Adapted from R.M. Measures *Laser Remote Sensing* (1984)

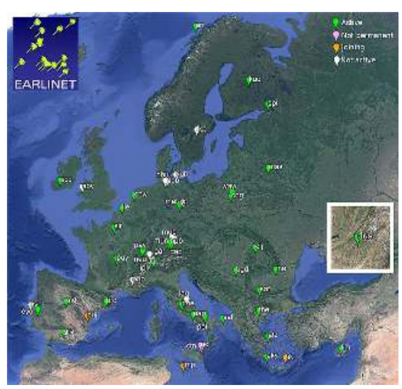
Profiling aerosol extinction coefficients

Two lidar techniques provide quantitative aerosol profiles: High Spectral Resolution Lidar (HSRL), and Raman lidar.

Photo by S.C. Gimmestad



https://www.eol.ucar.edu/content/hsrl-data-examples



https://www.tropos.de/en/research/projects-infrastructures-technology/coordinated-observations-and-networks/earlinet/

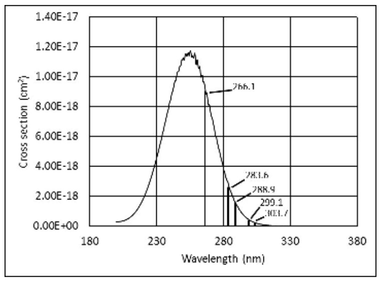
Twenty-nine of the 33 stations in the European Aerosol Lidar Network (EARLINET) use detection channels for Raman scattering to retrieve aerosol extinction profiles.

Water vapor and trace gas lidars

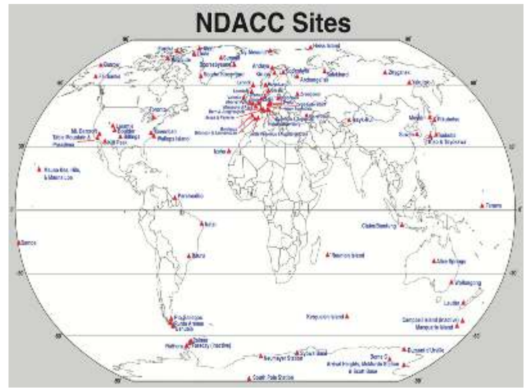
Georgia Tech H_2O Raman lidar

GTRI photo

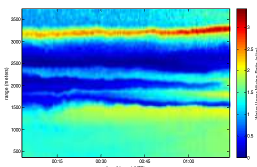
Ozone UV absorption spectrum



G.G. Gimmestad graphic



Time-height plot of water vapor mixing ratio



GTRI graphic

The Network for the Detection of Atmospheric Composition Change (NDACC) is worldwide, with 30 lidar stations.

https://www.esrl.noaa.gov/gmd/publications/annual_meetings/2012/slides/32-120405-A.pdf

Weather parameters – winds, temperature

- Wind measurements are based on the Doppler shift.
- Wind lidars use both coherent and incoherent detection.

Leosphere Windcube Lidar

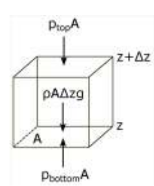
https://www.leosphere.com/products/scanning-wincube/

- Rayleigh lidar signals are proportional to air density above the aerosols (>30 km).
- Using the Ideal Gas Law and hydrostatic equilibrium, the temperature profile T(h) can be obtained.
- In the troposphere, temperature is measured with rotational Raman lidars.

Photo by Leda Sox

$PV = nRT$

$p_{bottom}A - p_{top}A = \rho A \Delta z g$



https://www.e-education.psu.edu/meteo300/node/7

Lidars in space

LITE on Space Shuttle 1994

https://www.nasa.gov/centers/langley/news/factsheets/LITE.html

GLAS on ICESat 2003

Courtesy of Ball Aerospace

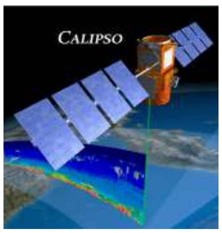
ADM Aeolus 2018

https://www.esa.int/Our_Activities/Operations/Aeolus_operations

MERLIN 2024

https://merlin.cnes.fr/en/MERLIN/index.htm

CALIOP on CALIPSO 2006



https://www.nasa.gov/mission_pages/calipso/mission/mission-objectives_prt.htm

CATS on ISS 2015

https://www.nasa.gov/mission_pages/station/research/experiments/cats_on_iss_print.jpg

ATLID on EarthCARE 2023

https://earth.esa.int/web/guest/missions/esa-future-missions/earthcare

Atmospheric lidar capabilities & applications

- Profiling Capabilities
  - H_2O and trace gases
  - Clouds and aerosols
  - Winds
  - Temperature
- Applications
  - Earth's energy balance
  - Ozone layer recovery
  - Air quality
  - Meteorology
  - Aviation safety

D.W. Roberts photo

Atmospheric lidar engineering challenges

1. A basic lidar has one signal but several unknowns.
2. The signal often has a huge dynamic range.
3. You must have sufficient SNR for the intended measurement.
4. You must avoid distortions (optical or electronic) in the lidar data.
5. Mechanical stability is always required.
6. Precision spectral control is often required.
7. Background light is often a limiting factor.
8. You must avoid causing optical damage with the laser.