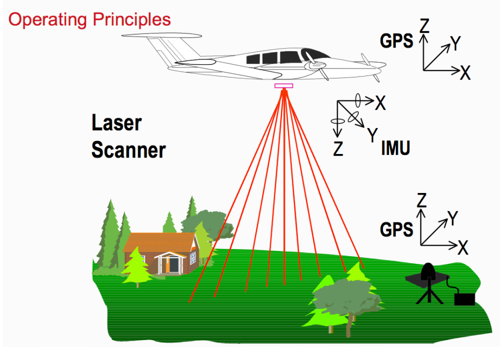
LIDAR
Light Detection and Ranging

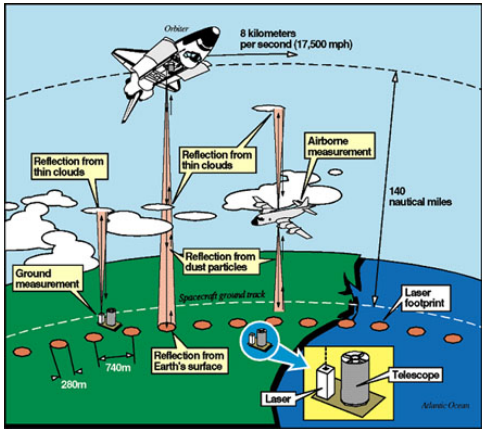
BASIC PRINCIPLE

- An active sensor emits a laser pulse or waveform in the target direction. The return reaches the sensor which measures the intensity and or time of flight/waveforms delay



LIDAR Scanners

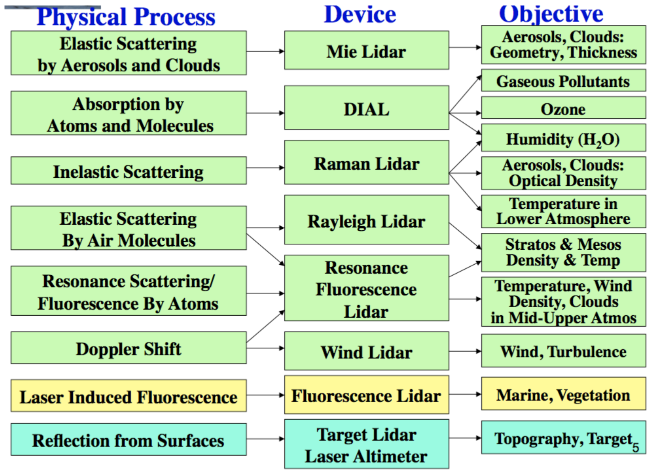
- Different uses of Lidar



Sensible Informations

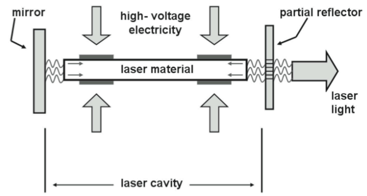
- Target distance (topographic LIDAR).
  - Measuring the time of flight.
- Chemical composition (DIAL: Differential Absorption Lidar).
  - Measuring the different absorption of pulses ad different wavelengths
- Target speed (Doppler Lidar).
  - Exploiting the doppler effect due to relative motion.
- And many other types/applications of Lidar...

Tipologie di Lidar



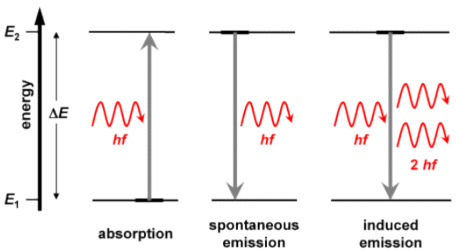
Physical principle: LASER

- LASER (Light Amplification by Stimulated Emission of Radiation)
  - A beam of light with very high coherence, almost perfectly monochromatic
  - Produced by means of stimulated coherent emission in a cavity
  - The beam exhibits a very high collimation



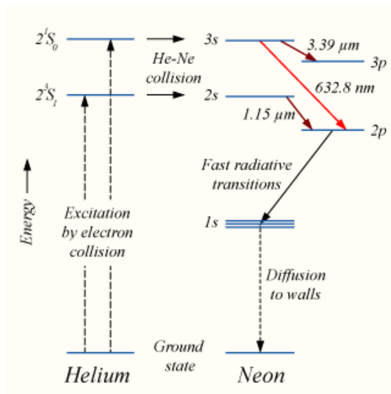
LASER

- Coherence by stimulated emission



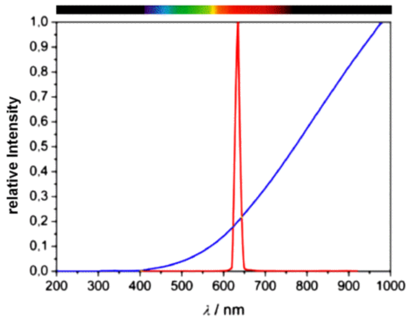
LASER

- Example: HeNe



LASER

- Example: HeNe

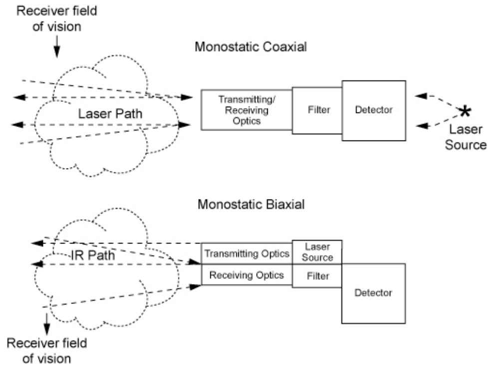


Red: HeNe laser light has a wavelength of 632,8 nm

Blue: halogen light

Monostatic vs Bistatic Lidar

- Monostatic:
  - Trasmitter and receiver are in the same location.
  - Two configurations: Coaxial and Biaxial

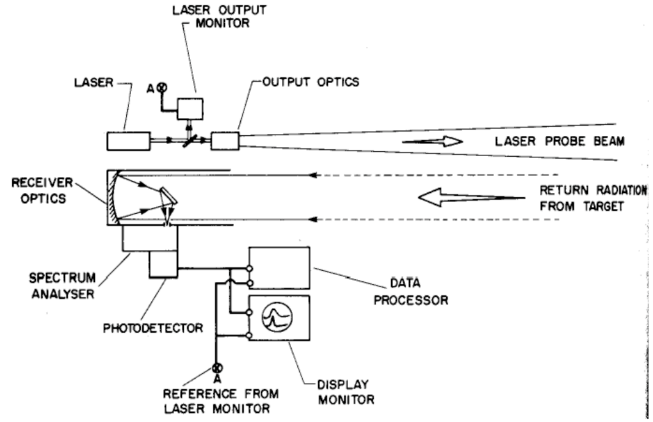


Monostatic Lidar

- Coaxial
  - In the coaxial arrangement, the axis of the laser beam is coincident with the axis of the receiver optics.
  - Therefore, the receiver can see the laser beam since the zero range bin. This can cause near-field backscattering which can saturate the photo-detector
  - In a coaxial system system this problem can be overcome by either gating of the photo-detector or use of a fast shutter or chopper to block the near-field scattering.
- Biaxial
  - Since in the biaxial arrangement the laser beam and the receiver axis are separated, the laser beam only enters the field of view of the receiver optics beyond some predetermined range.
  - This helps avoiding near-field backscattered radiation

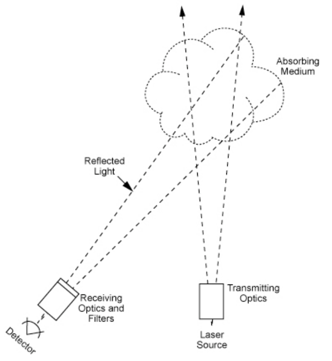
Monostatic Lidar

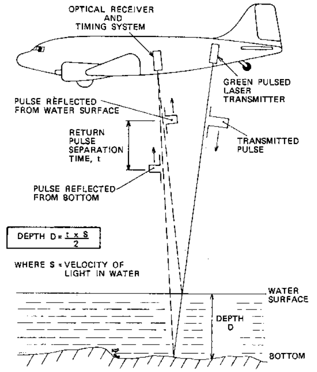
- Example of a complete system



Monostatic vs Bistatic Lidar

- Bistatic Lidar:
  - the transmitter and the receiver are not at the same location

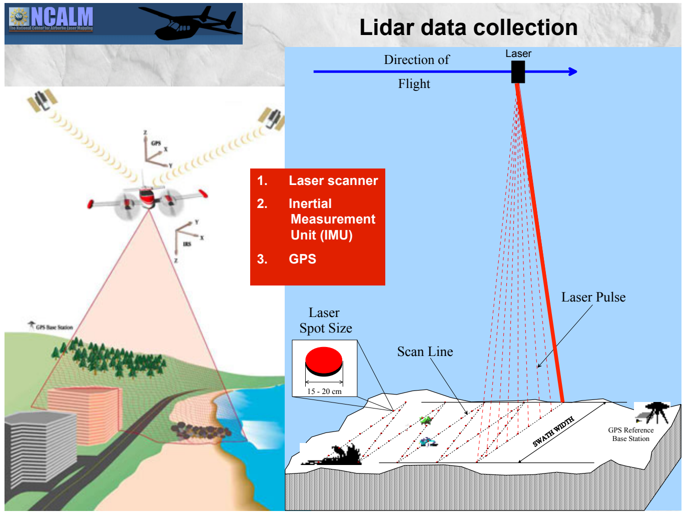




Pulsed and Continuous Waveforms

- Pulsed Systems (typically monostatic):
  - The device emits a sequence of laser pulses (up to 200.000 pulses per second) and it measures their time of flight
  - The time of flight can be measured with a precision up to 60ps, which is around 1 cm in range
- Continuous Waveforms (VW) systems (typically bistatic):
  - A waveform with sinusoidal envelope is emitted continuously and the phase difference between the emitted signal and the return signal is measured
  - Typically used as doppler LIDAR, in particular for wind profiling

Topographic Laser Scanners



Airborne Topographic Laser Scanners

- The IMU and the GPS are fundamental
  - They allow to estimate with high precision the absolute position and speed of the airplane in any given moment
  - This is fundamental in order to have a high precision measurement
  - The sensor precision is in fact in the order of 15 cm, which means that if the airplane is not controlled with high precision the sensor resolution is useless

Raw Topographic LIDAR Data

- Raw LIDAR data consists of a list of (x,y,z) coordinates
  - A side result of LIDAR acquisition is the measure of the return intensity
  - Rarely used for quantitative analysis (too sensitive to unimportant external agents)

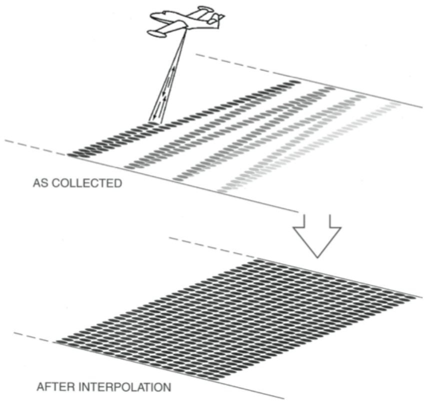
EASTING	NORTHING	ELEVATION	INTENSITY
1355800.01000000000	1127581.62999999000	561.84000000000	66
1355800.02000000000	1125511.54000000000	534.51000000000	56
1355800.02000000000	1125728.90999999000	546.26000000000	48
1355800.02000000000	1127122.34000000000	563.89000000000	70
1355800.03000000000	1126544.83000000000	564.99000000000	53
1355800.04000000000	1125108.12999999000	532.59000000000	21
1355800.04000000000	1125284.62000000000	534.08000000000	29
1355800.04000000000	1125836.62000000000	549.45000000000	36

LiDAR Data Characteristics

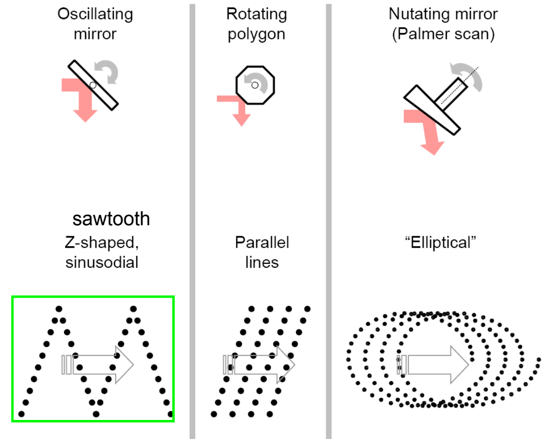
- Raw return data are XYZ points
- High spatial resolution
  - Laser footprint on ground ≤ 0.50 meters
  - Typical density is 0.5 to 20+ pulses/m^2
  - 2 to 3 returns/pulse in forest areas
  - Surface/canopy models typically 1 to 5m grid
- Large volume of data
  - 5,000 to 60,000+ pulses/hectare
  - 10 to100+ thousands of returns/hectare
  - 0.4 to 5.4+ MB/hectare

Topographic LIDAR

- Data samples and interpolation



Scanning Mechanisms



Most common pattern (Leica, Optech)

Figure modified from: Nikolaos 2006

Topographic LIDAR

- Typical characteristics

Table 11-2
Typical Sensor Characteristics

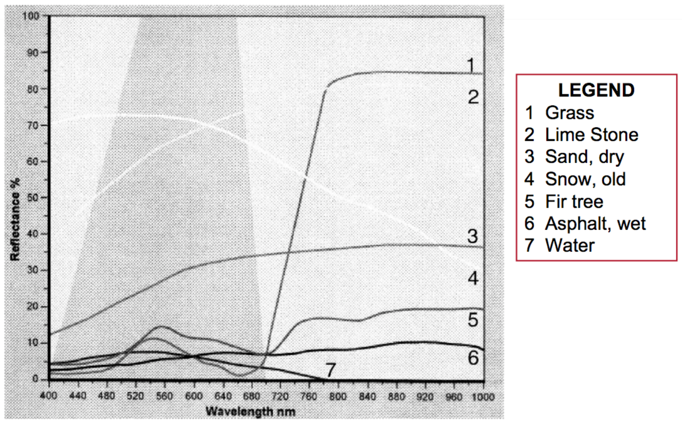
Parameter	Typical value(s)
Vertical accuracy (cm)	15
Horizontal accuracy (m)	0.2 - 1
Flying height (m)	200 – 6,000
Scan angle (deg)	1 – 75
Scan rate (Hz)	0 – 40
Beam divergence (mrads)	0.3 – 2
Pulse rate (KHz)	05 – 33
Footprint diameter (m) from 1,000 m	0.25 – 2
Spot density (m)	0.25 – 12

Traditional Photogrammetry vs. LiDAR

LiDAR	Photogrammetric
Day or night data acquisition	Day time collection only
Direct acquisition of 3D collection	Complicated and sometimes unreliable procedures
Vertical accuracy is better than planimetric*	Planimetric accuracy is better than vertical*
Point cloud difficult to derive semantic information; however, <u>intensity</u> values can be used to produce a visually rich image like product (example of an intensity image)	Rich in semantic information

***Complementary characteristics suggest integration**

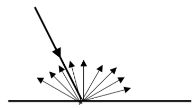
Reflectance of different surfaces



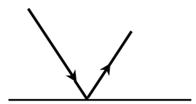
Reflectance

- Remind the main models of surfaces

Lambertian: they reflect in an isotropic way and thus there is always backscattering



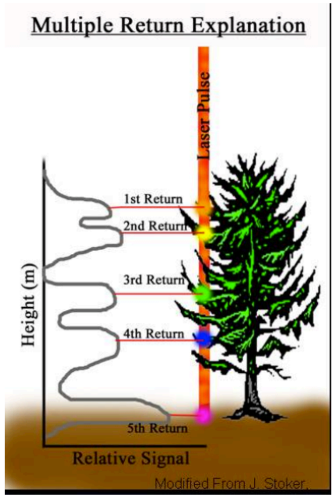
Perfectly reflective boundaries: they do not reflect in the incidence direction



- Weather conditions can change the nature of surfaces (ex.: wet surfaces can appear as smooth as mirrors)
- The type of surface impacts drastically on the measurable distances

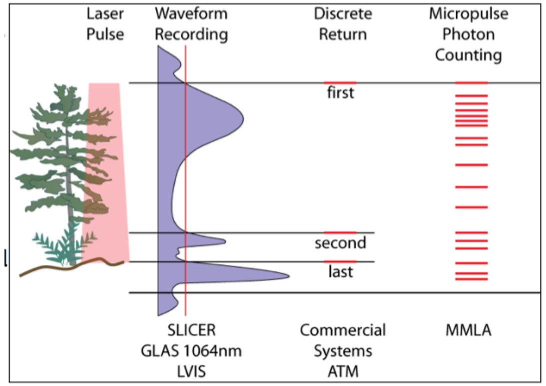
Multiple Returns

- Each emitted pulse can be sometimes reflected only partially by the an object and partially proceed further (photons!)
- This ways, different returns are measured for one single emitted pulse
- It is thus possible to extract information on the profile of complex structures such as trees. This is very useful in order to obtain a characterization of the type of trees in a wooded area



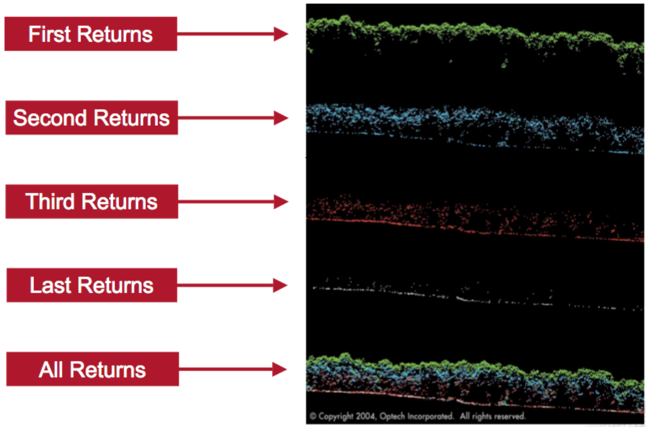
Measuring Returns

- Discrete return
  - – logs time when return
  - intensity exceeds threshold
  - – commercial airborne systems
- Waveform recording
  - – records entire return
  - intensity profile
  - – vegetation, atmospheric applications
- Photon counting
  - – digital recording of individual
  - photon returns
  - – low power requirements
  - – good cloud penetration
- Profiling or scanning – scan patterns



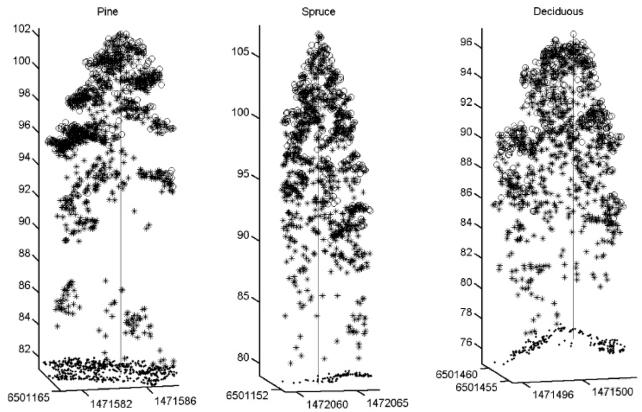
Multiple Returns

- Combining multiple returns

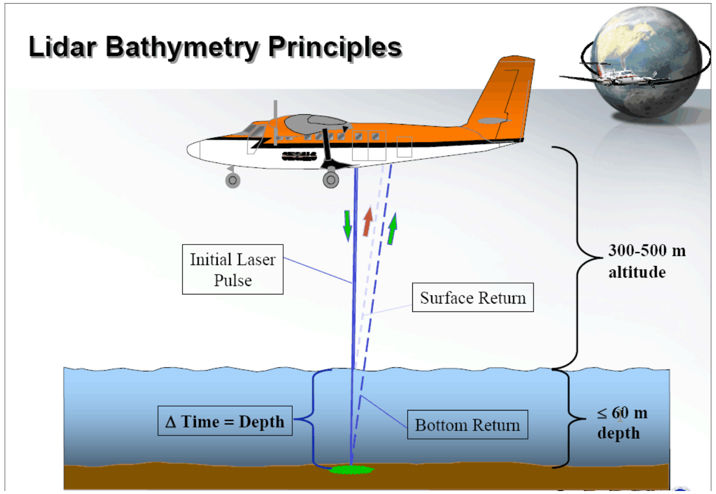


Multiple Returns

- Forestry application



Bathymetry



Atmosphere Lidar

- The first application of lidar was the detection of atmospheric aerosols and density. Basically, it is to know whether there are aerosols/density in the regions and how much. However, the composition of atmosphere cannot be told, because only the scattering intensity was detected but nothing about the spectra.
- An important advance in lidar was the recognition that the spectra of the detected radiation contained highly specific information related to the species, which could be used to determine the composition of the object region.
- Furthermore, the utilization of Doppler effect and Boltzmann distribution lead to more sophisticated spectral analysis for wind and temperature measurements.

Atmosphere Lidar

- Usually with bistatic lidar
- Usually with waveform lidar
- Usually doppler lidar

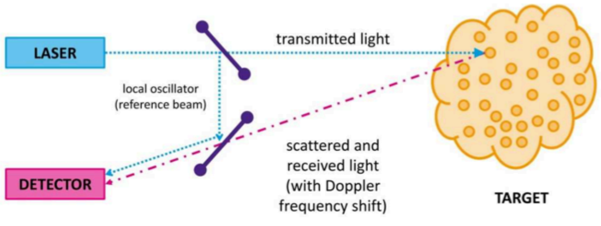


Figure 1: Generic bistatic lidar system. A small fraction of the transmitted light is tapped off by a beamsplitter to form a reference beam. This is superimposed at a second beamsplitter with the weak return scattered from moving particles. The detector picks up the resulting beat signal; this undergoes spectral analysis to determine particle velocity.

Scan Patterns

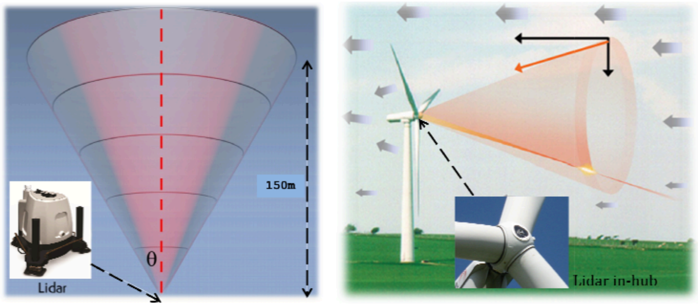
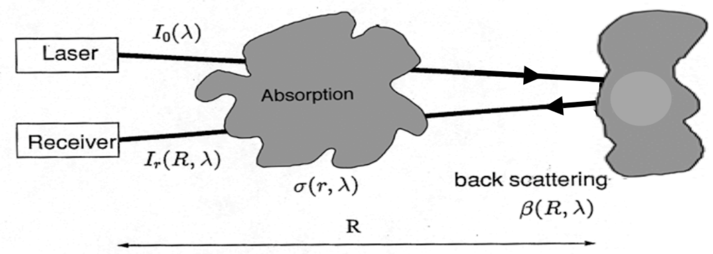


Figure 2: Conical scan pattern as used for lidar wind profiling. Left: ground based, vertical scanning. The cone half-angle (θ) is typically of order 30 degrees. The lidar can operate successfully even when part of its scan is obscured, e.g. by an adjacent met mast. In order to build up a wind profile, the lidar operates in a repeating sequence during which all the heights are interrogated in series. Right: one of several turbine mounted configurations, where the lidar is near horizontal and scans around a horizontal axis, usually pointing into the wind.

The LIDAR equation



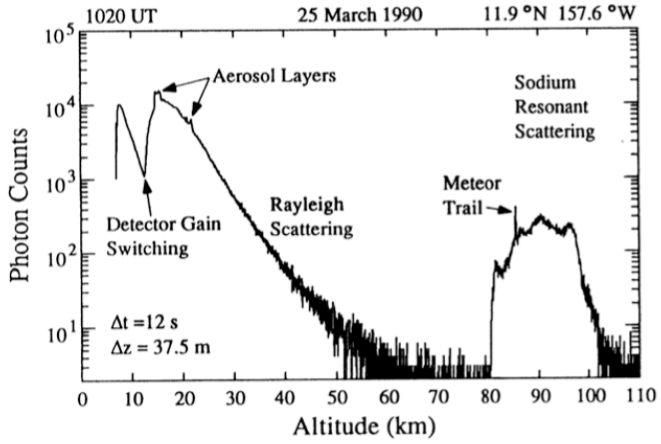
Lidar equation:

$$I_r(R,\lambda) = I_0 \eta \frac{A}{4\pi R^2} \beta(R,\lambda) \exp\left(-2\int_0^R \sigma(r,\lambda)dr\right)$$

β → reflectance or backscattering coefficient (Rayleigh, Mie, Raman, fluorescence)
σ → extinction coefficient (absorption, scattering)

Atmosphere Lidar

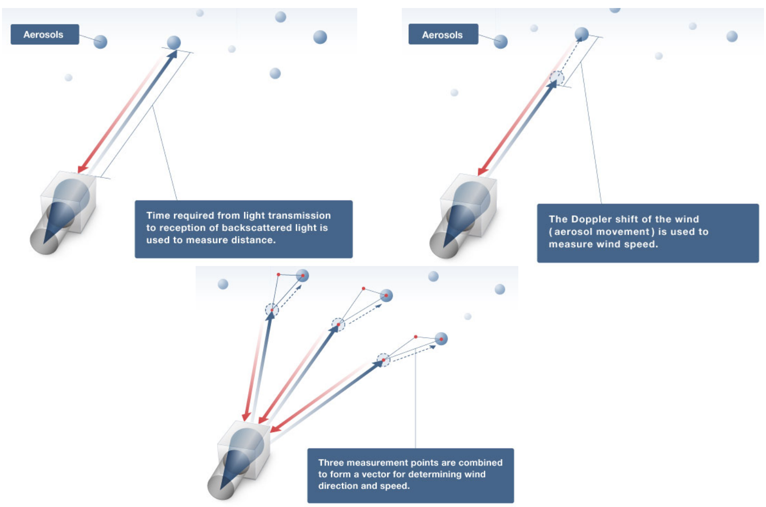
- Typical Atmosphere Lidar Profile



Doppler Lidar

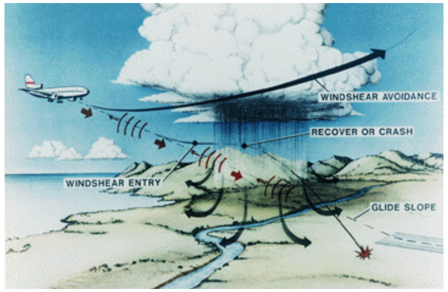
- It exploits the doppler effect to estimate the speed of the target
- Used for example for estimating the wind speed
  - A laser waveform is emitted in the direction of interest
  - Small particles, aerosol etc., reflect part of the laser signal
  - The receiver determines speed of the particle due to the doppler effect
  - Combining with time of flight, intensity of reflected beam and angle information it can give extremely precise information on the profile of wind speed

Doppler Lidar



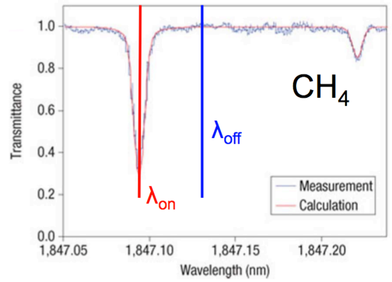
Doppler Lidar

- Other applications



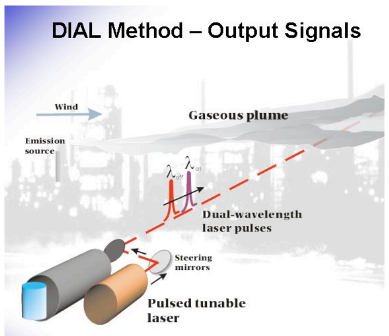
Differential Absorption Lidar

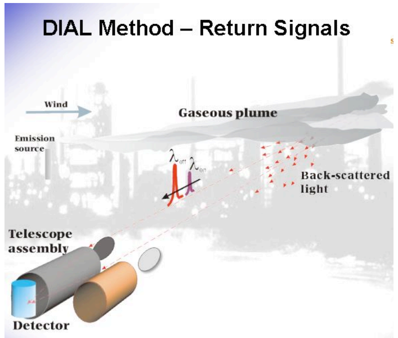
- Used to detect the level of concentration of substances
- It is based on the absorption properties of the substances to study
- Two pulses with different frequencies are used, one at the absorption frequency, the other at a different frequency



Differential Absorption Lidar

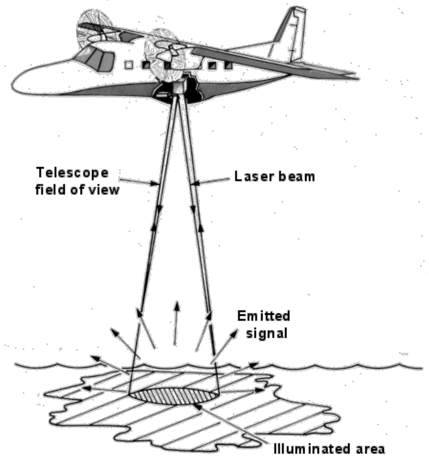
- The two pulses go through a region of interest and are reflected by a background obstacle
- By measuring the different intensities of the two returned pulses we deduce the absorption and thus the concentration of the substance





Fluorescence Lidar

- The laser pulse hits a target inducing a fluorescence reaction
- The energy of the incident pulse is absorbed by the target
- Later on, the target emits radiation at a different wavelength



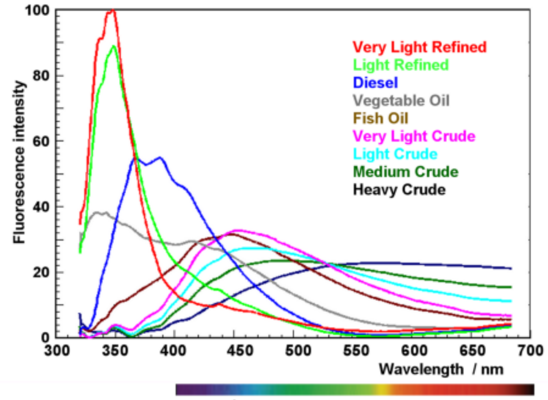
Fluorescence Lidar

- Application example: detection of oil spill
  - Oil belongs to the substances which absorb light and re-emit part of it as fluorescence.
  - The degree of absorbance (and thus fluorescence) is strong in the ultraviolet and decreases monotonically with increasing wavelengths in the visible range (blue, green yellow, red).
  - Pulse lasers are utilised with emission wavelengths in the ultraviolett at about 250 to 350 nm.

Fluorescence Lidar: oil spill

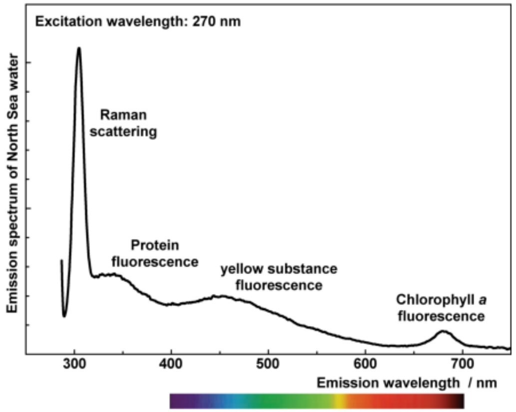
- Oil fluorescence

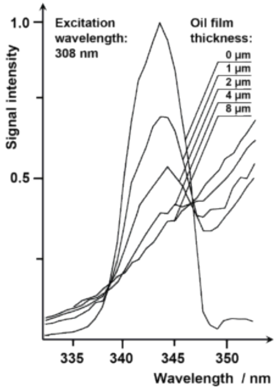
• Fluorescence spectra upon irradiation with UV light at 308 nm wavelength (curve normalised to the same total fluorescence intensity)
• The absolute fluorescence intensity of heavy oils is much weaker than that of light oils and could not be visualised on the graph without normalisation.



Fluorescence Lidar: oil spill

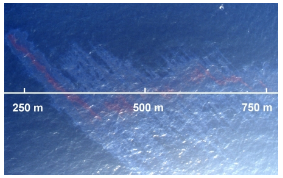
- Water emission

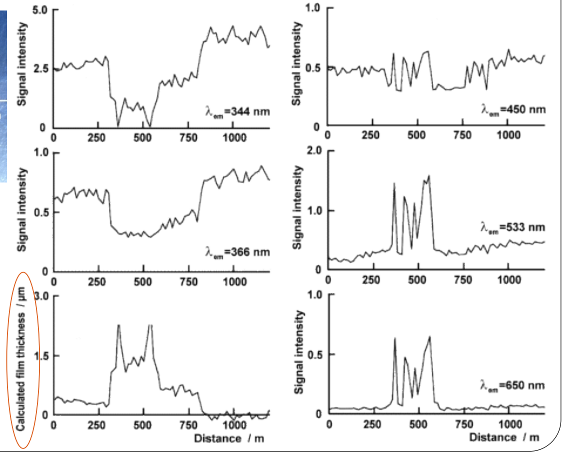




Fluorescence Lidar: oil spill

- Thickness estimation



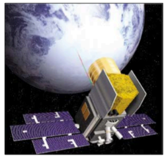


NASA Missions

Mars Orbiter Laser Altimeter (MOLA)

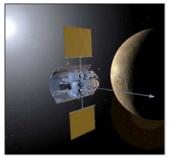
Mars 1997 - 2002

ICESat Geoscience Laser Altimeter System (GLAS)



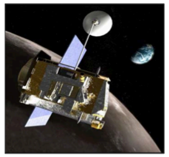
Earth 2003 - 2010

MESSENGER Laser Altimeter (MLA)



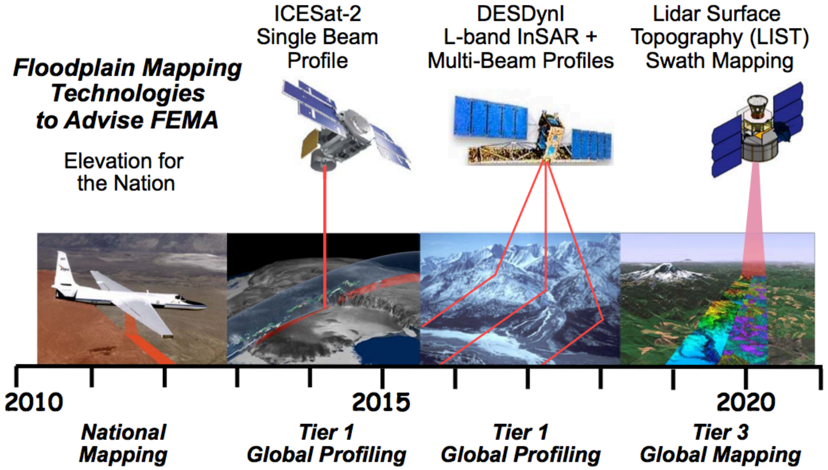
Mercury 2008 - 2013

Lunar Reconnaissance Orbiter Laser Altimeter (LOLA)



Moon 2010 - 2014

NASA Missions



NASA Lite mission

- LITE (Lidar In-space Technology Experiment) is a three-wavelength backscatter lidar developed by NASA to fly on the Space Shuttle
- LITE flew on Discovery in September 1994 as part of the STS-64 mission

Table 4 LITE Mission Parameters

mission, vehicle	STS-64, Discovery
launch	22:22 GMT, September 9, 1994
mission duration	11 days
orbital altitude	260/240 km
orbital inclination	57°
orbital period	89.6 min
orbital velocity	7.4 km/s
nominal viewing angle	5° off-nadir
vertical resolution	15 m
horizontal resolution	740 m

NASA Lite mission

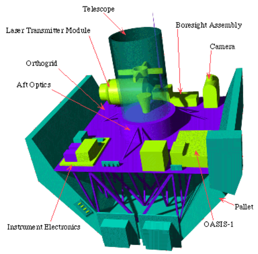
- Gof the mission
  - validate key lidar technologies for spaceborne applications
  - explore the applications of space lidar
  - gain operational experience to benefit the development of future systems on free-flying satellite platforms.

LITE Science Objectives

Tropospheric Aerosols	Stratospheric Aerosols	Clouds	Surface Reflectance
aerosol scattering ratio and wavelength dependence	aerosol scattering ratio and wavelength dependence	vertical distribution, multilayer structure	albedo
PBL height and structure	averaged integrated backscatter	fractional cloud cover	multiangle backscatter (+/- 30 degrees)
PBL optical depth	Stratospheric density and temperature	optical depth	

NASA Lite Mission

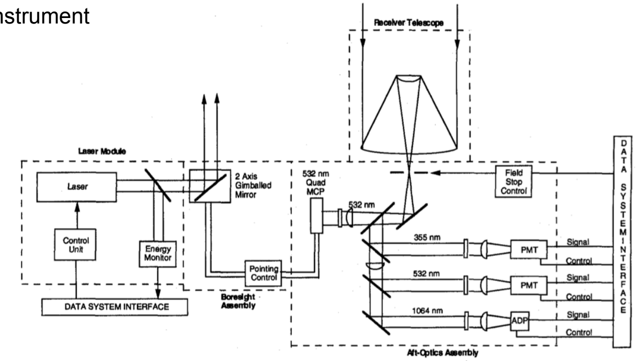
- Instrument



- Three harmonically related wavelengths
  - 1064 nm (infrared)
  - 532 nm (visible green)
  - 355 nm (ultraviolet).
- The two-laser system provides redundancy in case one laser fails.
- Only one laser operates at a time.

NASA Lite Mission

- Instrument



- A one meter telescope collects laser light scattered from the atmosphere, and brings it to focus in the aft optics.
- The return signal is separated into its three color components. The 532 nm and 355 nm detectors are photomultiplier tubes, while the 1064 nm detector is a silicon avalanche photodiode.

NASA Lite Mission

- Data are available on the web-site

SELECT AN ORBIT

355 nm 532 nm 1064 nm

5 5 5	6 6 6	13 13 13
14 14 14	15 15 15	22 22 22
23 23 23	24 24 24	27 27 27
28 28 28	32 32 32	33 33 33
34 34 34	35 35 35	45 45 45
47 47 47	48 48 48	50 50 50
53 53 53	54 54 54	55 55 55
60 60 60	66 66 66	71 71 71
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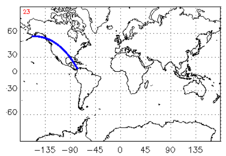
105 105 105	113 113 113	115 115 115
116 116 116	117 117 117	118 118 118
119 119 119	122 122 122	123 123 123
124 124 124	125 125 125	127 127 127
128 128 128	129 129 129	131 131 131
133 133 133	134 134 134	135 135 135
136 136 136	137 137 137	141 141 141
145 145 145	146 146 146	147 147 147
148 148 148	149 149 149	150 150 150



Measurement Locations for LITE - Orbit 23

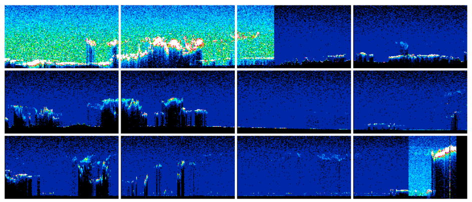


Image Description

Image		GMT	MET	Latitude	Longitude
1	Start	254/07:34:13.9	001/09:11:19.0	57.36	-157.42
	End	254/07:35:53.8	001/09:12:58.9	56.96	-145.60