Lecture 3. Quantum Physics & Lidar Principle Overview (Cont)

- Review lidar equation & lidar architecture
- An example lidar - K Doppler lidar
- Classification of lidar
- Quantum physics (1): quantum theory of light
- Summary

Review Lidar Equation & Architecture

(1) What is the lidar equation about? What's the idea behind the lidar equation? How to qualitatively to derive it?

(2) What's the basic architecture for a typical lidar? What's the basic function of each basic component?

(3) How do you determine altitude if a cw light or laser is used in the lidar? The derivation of the equation.

(4) How do you determine altitude if a short pulsed laser is used?

(5) Why can a laser altimeter determine altitude with a resolution/accuracy much higher than the width of the laser pulse?

Review Lidar Equation

Keep in mind the big picture of a lidar system –

Radiation source

Propagation in the medium

Interaction with the object

Signal again propagation in the medium

Photons are collected and detected

Can you derive a lidar equation by yourself?

Review Lidar Architecture

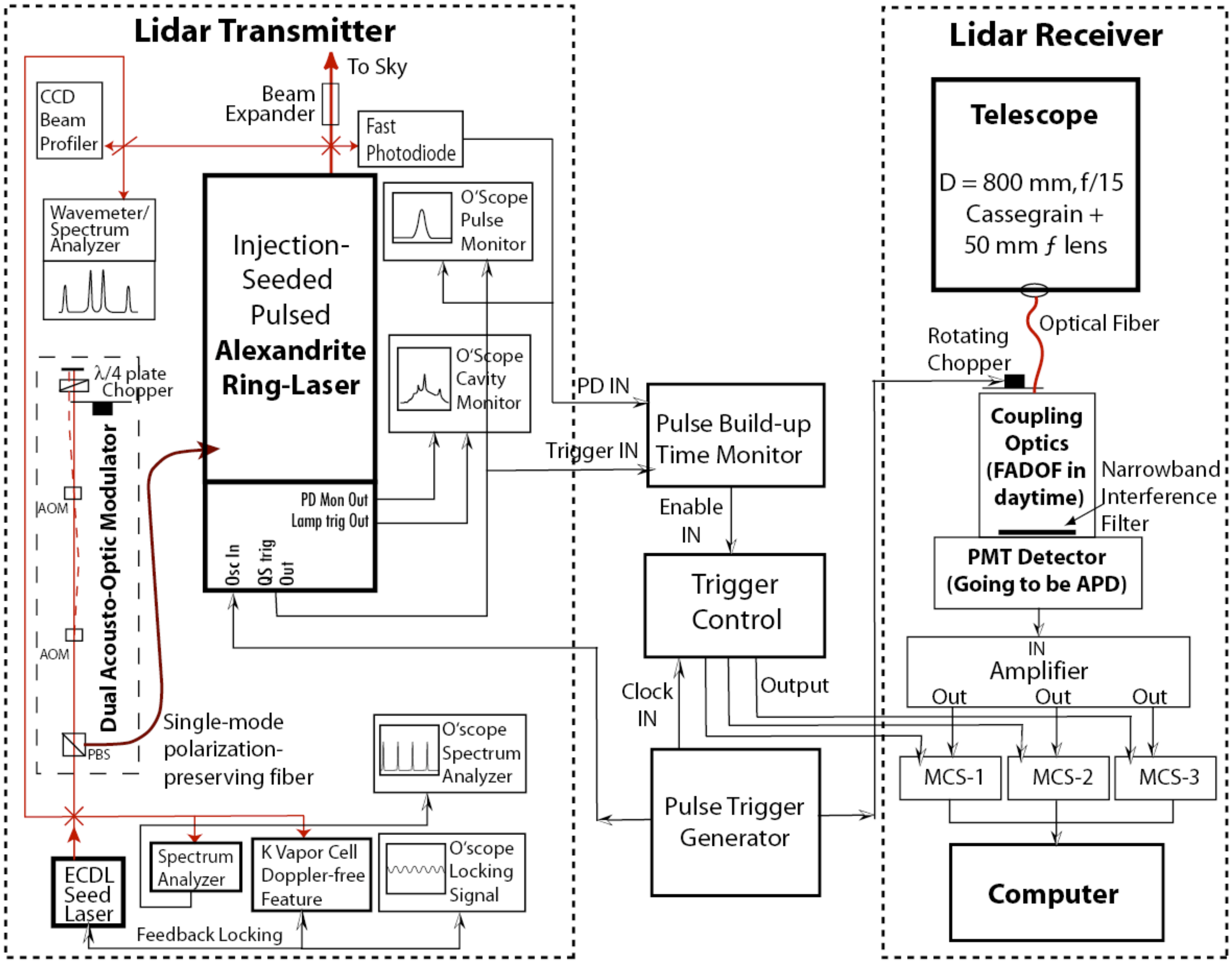
The basic components of a lidar system

The basic function for each component

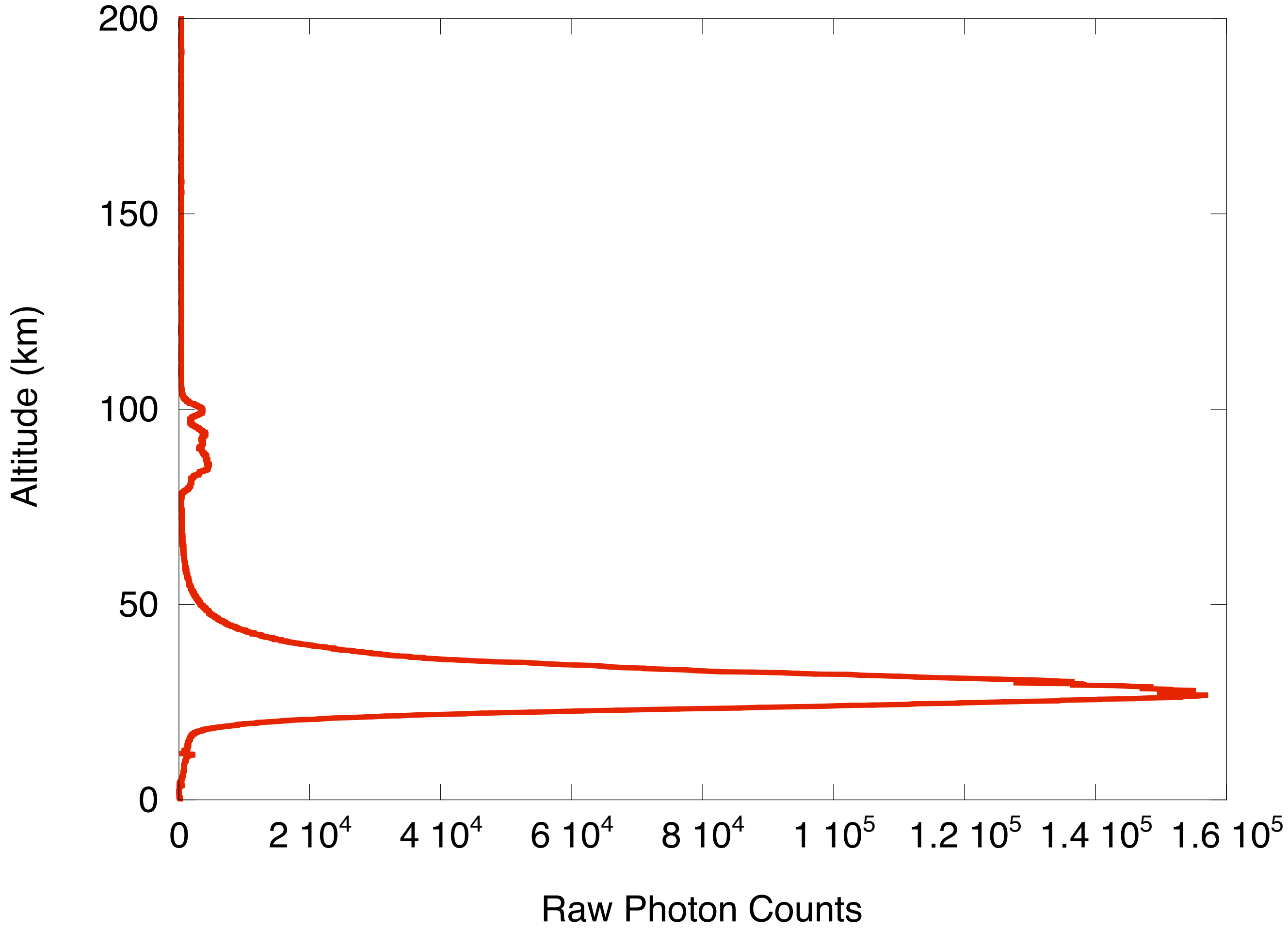
What kind of configurations can a lidar have?

How is altitude or range determined for different configuration?

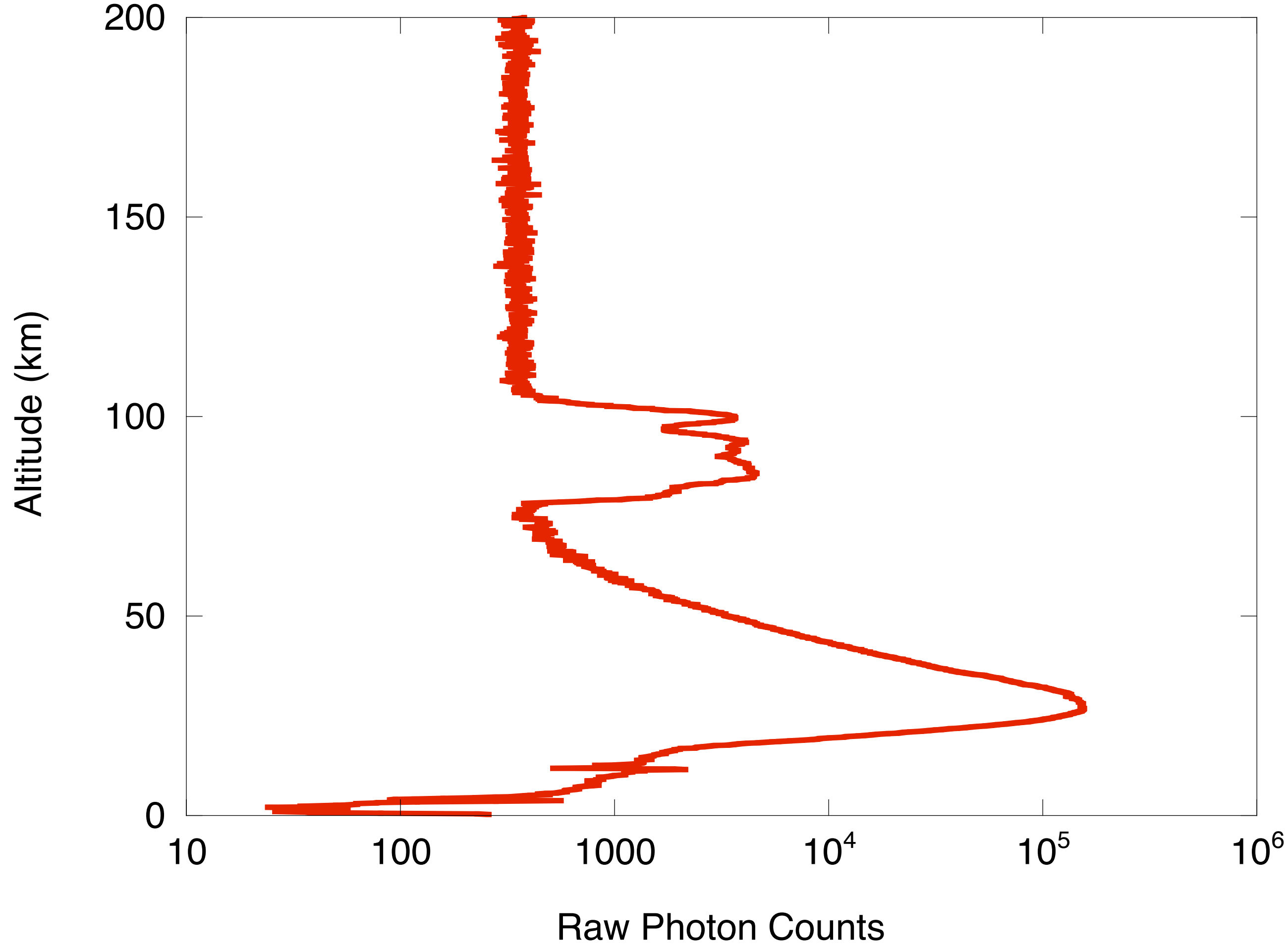
Example: K Doppler Lidar



Rawdata Profile of K Lidar



Rawdata Profile: Log Scale



Classifications of Lidar

There are several different classifications on lidars

e.g., based on the physical process;

(Mie, Rayleigh, Raman, Fluorescence, …)

based on the platform;

(Groundbased, Airborne, Spaceborne, …)

based on the detection region;

(Atmosphere, Ocean, Solid Target, …)

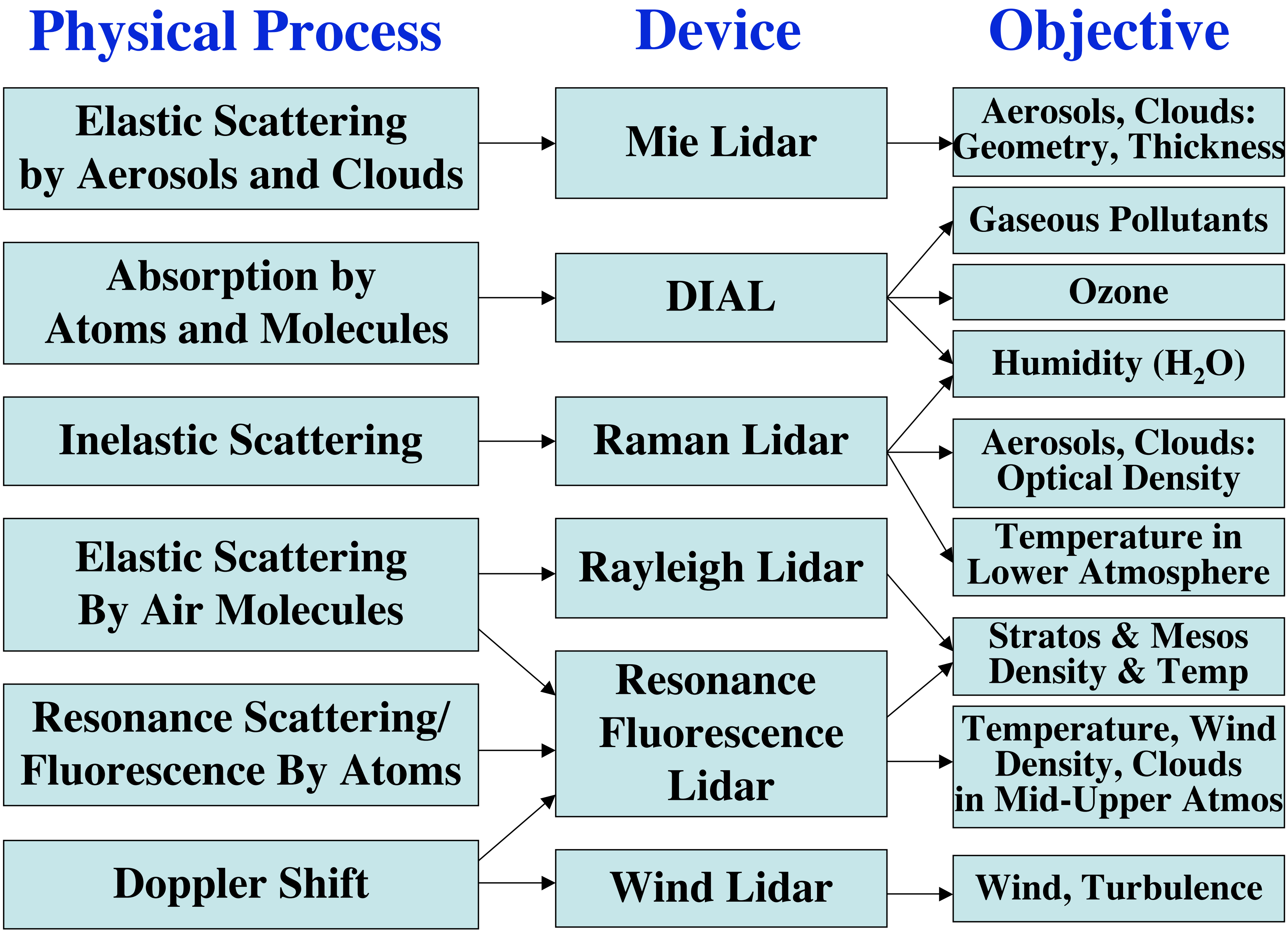
based on the emphasis of signal type;

(Ranging, Scattering, …)

based on the topics to detect;

(Aerosol, Density, Temperature, Wind, …)

… …


Physical Process
Device
Objective
Elastic Scattering by Aerosols and Clouds
Mie Lidar
Aerosols, Clouds: Geometry, Thickness
Absorption by Atoms and Molecules
DIAL
Gaseous Pollutants
Ozone
Humidity (H_2O)
Inelastic Scattering
Raman Lidar
Aerosols, Clouds: Optical Density
Temperature in Lower Atmosphere
Elastic Scattering By Air Molecules
Rayleigh Lidar
Stratos & Mesos Density & Temp
Resonance Scattering/ Fluorescence By Atoms
Resonance Fluorescence Lidar
Temperature, Wind Density, Clouds in Mid-Upper Atmos
Doppler Shift
Wind Lidar
Wind, Turbulence

Comparison of Scatterings

Elastic scattering: no wavelength change

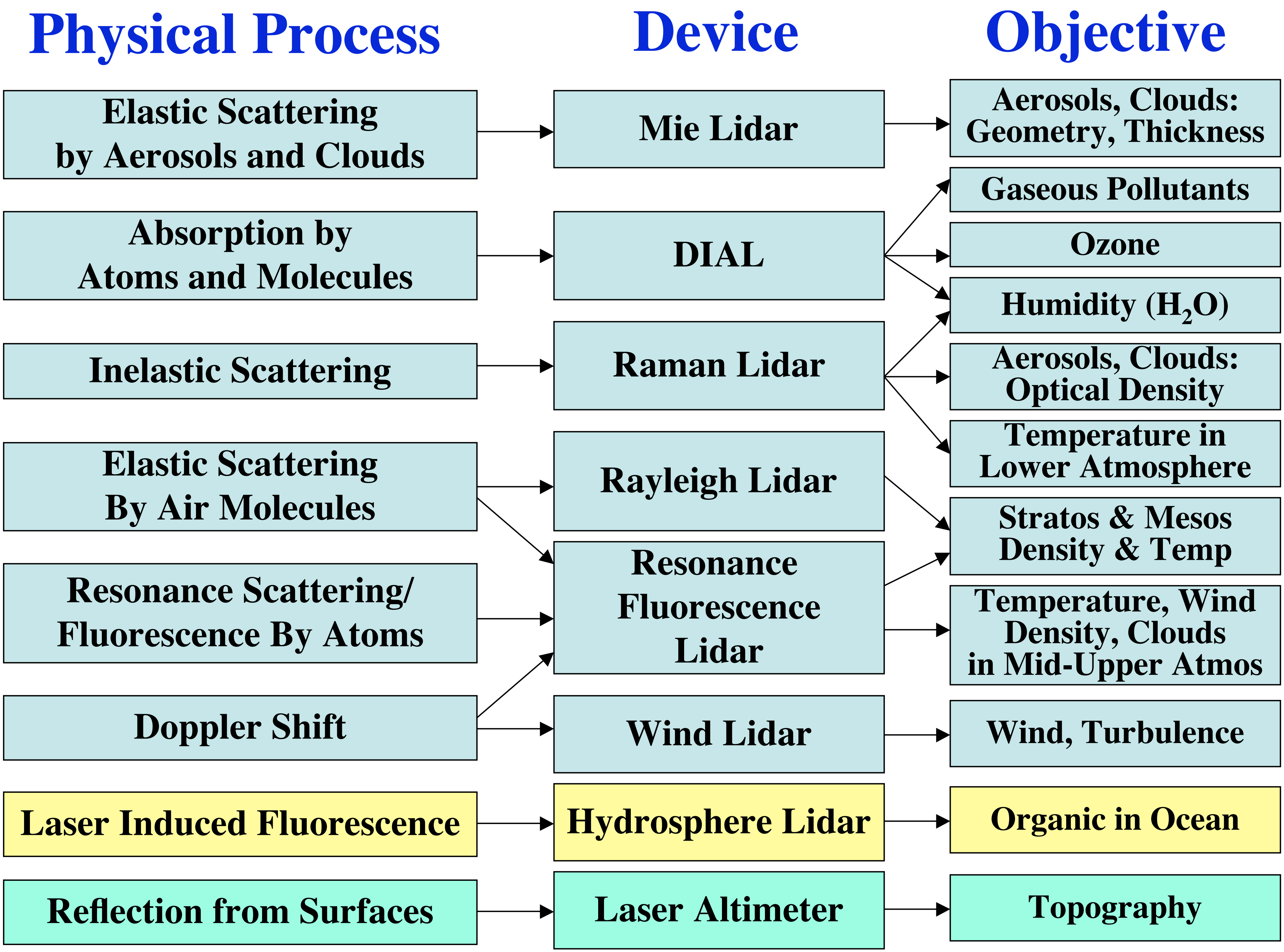
Mie scattering: elastic scattering by aerosols

Rayleigh scattering: elastic scattering by molecules

Inelastic scattering: apparent wavelength change

Raman scattering

Resonance fluorescence: real transitions between energy levels (instead of virtual transition)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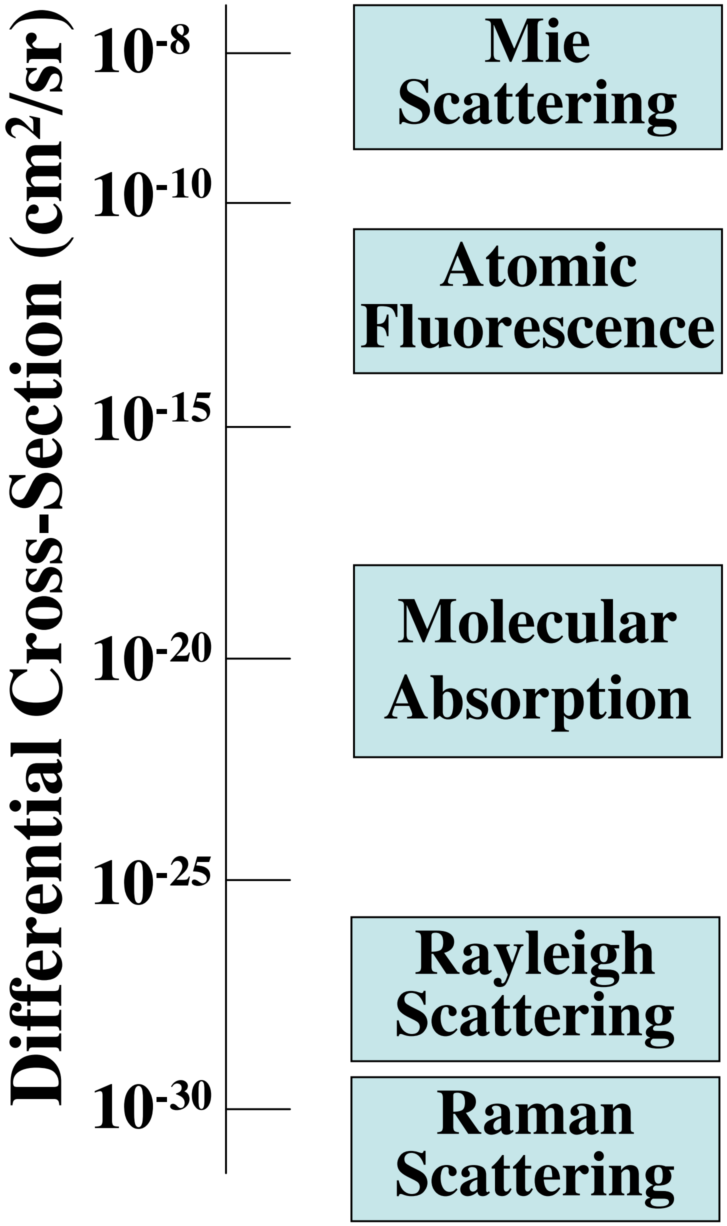
Rayleigh Lidar
Stratos & Mesos Density & Temp
Resonance Scattering/ Fluorescence By Atoms
Resonance Fluorescence Lidar
Temperature, Wind Density, Clouds in Mid-Upper Atmos
Doppler Shift
Wind Lidar
Wind, Turbulence
Laser Induced Fluorescence
Hydrosphere Lidar
Organic in Ocean
Reflection from Surfaces
Laser Altimeter
Topography

Comparison of Scattering



$$\beta(\lambda, \lambda_L, z) = \sum_i \left[\frac{\mathrm{d}\sigma_i(\lambda_L)}{\mathrm{d}\Omega} n_i(z) p_i(\lambda) \right]$$

Rayleigh

$$\frac{d\sigma}{d\Omega} = \sigma_R \propto \frac{1}{\lambda^4}$$

Resonance Fluorescence

$$\frac{d\sigma}{d\Omega} = \frac{\sigma_{eff}}{4\pi} = \frac{\int_{-\infty}^{+\infty} \sigma_{abs}(\nu, \nu_0) \cdot g_L(\nu, \nu_L)\, \mathrm{d}\nu}{4\pi}$$

Platform Classification

Spaceborne lidar	Satellite, Space Shuttle. Space Station
Airborne lidar	Jet, Propeller Airplanes Unmanned Aerial Vehicle (UAV) Kite
Groundbased lidar	Stationary Contanerized moved with truck
Shipborne lidar	Icebreaker, Ships
Submarine lidar	Submarine

Detection Regions

Atmosphere lidar	Various types From various platforms
Hydrosphere lidar	Various types From various platforms
Solid Earth lidar	Airborne or Spaceborne Laser altimeter
Solid Target lidar	Various type With or without Imaging function

Emphasis on Signal Type

Scattering Lidar → Besides time delay, more interested in signal strength, spectra, etc

Ranging/Profiling Lidar → Mainly concern Time delay between transmission and reception

Various Topics

Aerosol/Cloud lidar

Constituent lidar

Temperature lidar

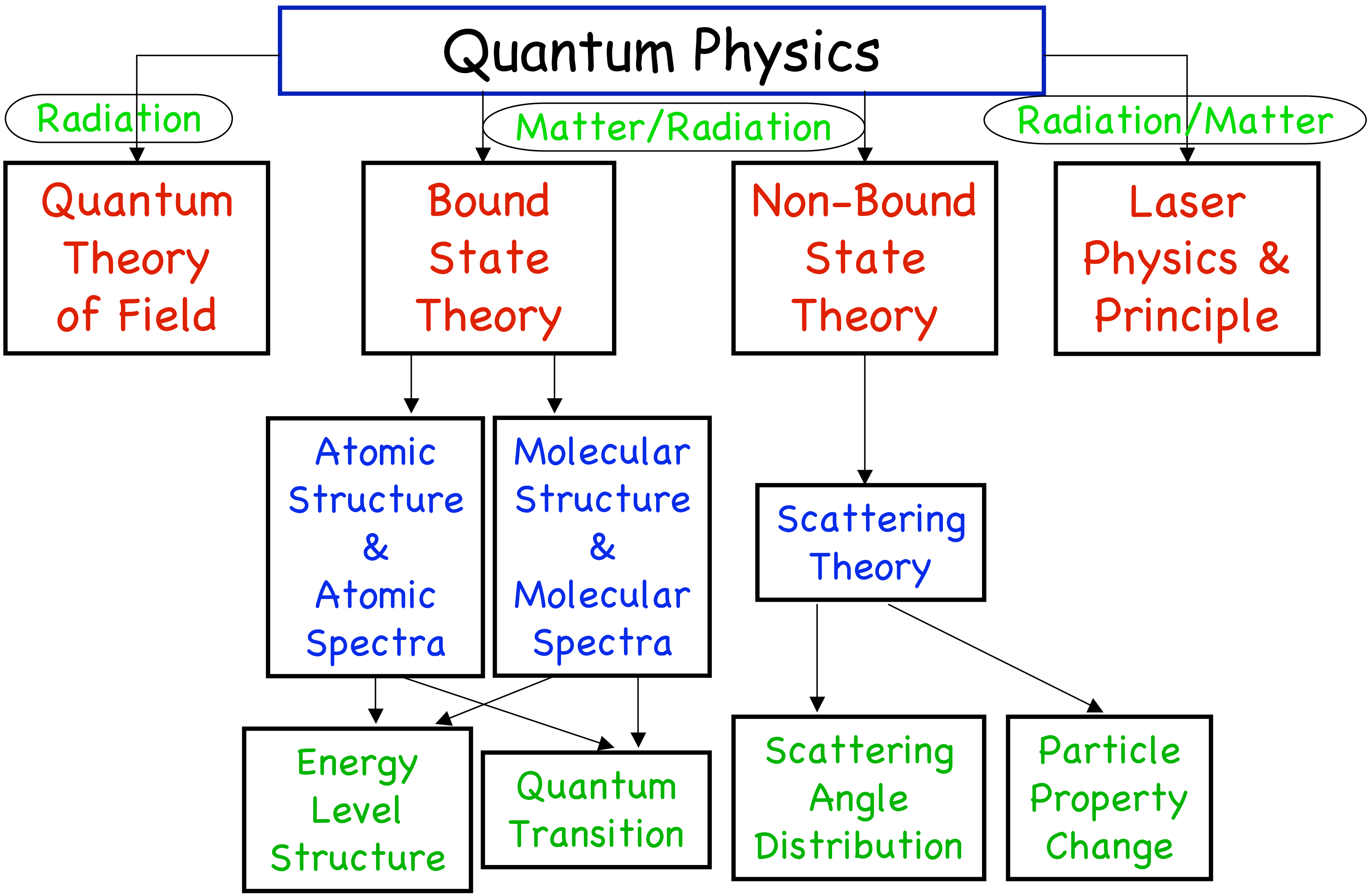
Wind lidar

Topography lidar

Fish lidar

… … … …

Lectures on Quantum Physics



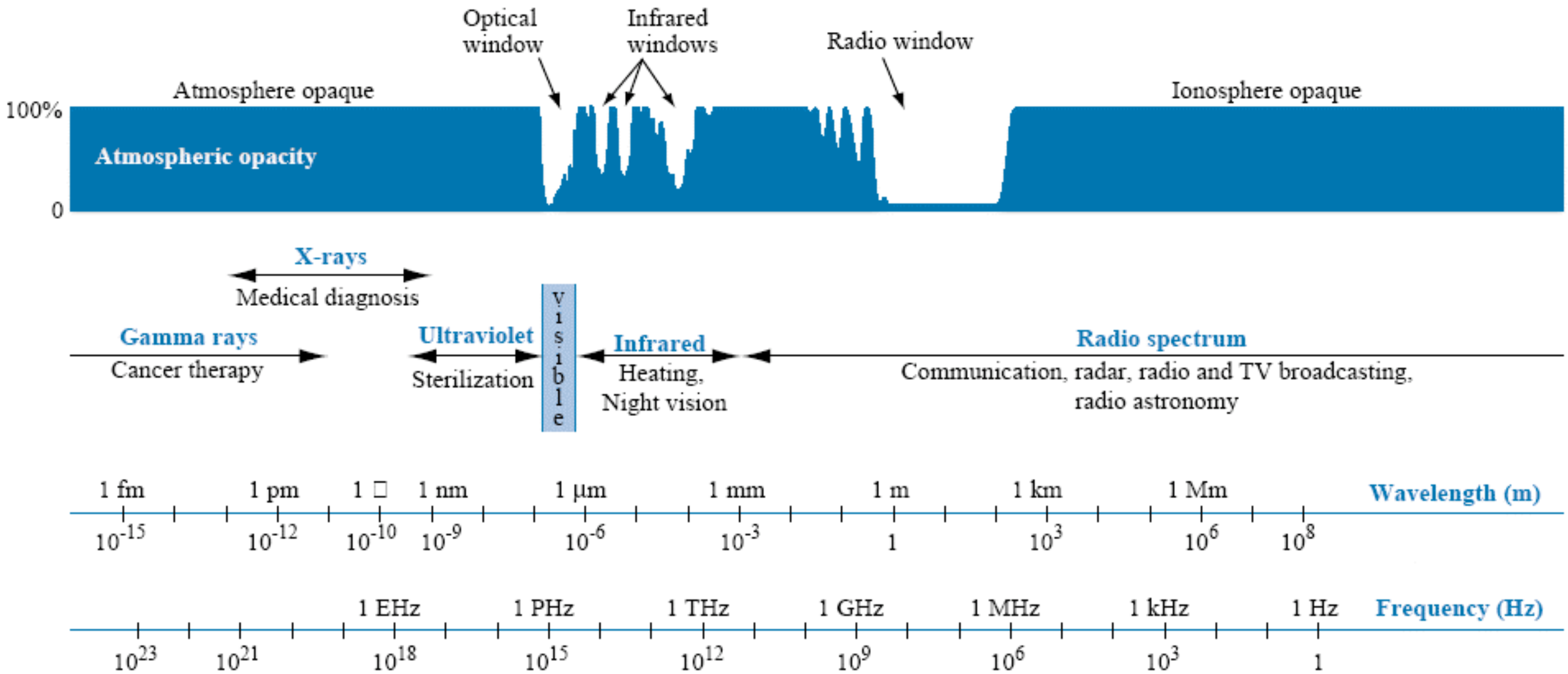
What is light: wave or particle?

Light is electromagnetic waves at optical frequency - light wave!

Light is photon streams with quantized energy and momentum.

How do we choose what to use?

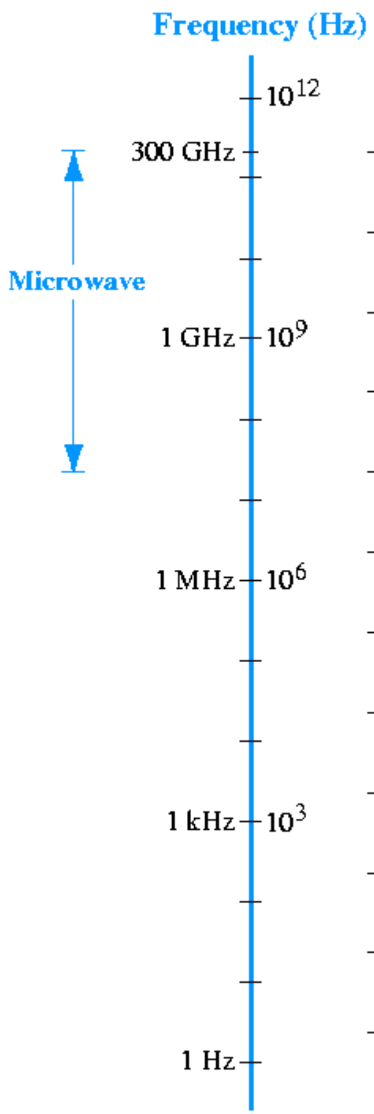
Light as Electromagnetic Waves



Spectrum of electromagnetic waves

Visible wavelength is 400-700 nm, corresponding to 10^{14} Hz

Electromagnetic Waves used in Radar



Band	Applications
Extremely High Frequency EHF (30 - 300 GHz)	Radar, advanced communication systems, remote sensing, radio astronomy
Super High Frequency SHF (3 - 30 GHz)	Radar, satellite communication systems, aircraft navigation, radio astronomy, remote sensing
Ultra High Frequency UHF (300 MHz - 3 GHz)	TV broadcasting, radar, radio astronomy, microwave ovens, cellular telephone
Very High Frequency VHF (30 - 300 MHz)	TV and FM broadcasting, mobile radio communication, air traffic control
High Frequency HF (3 - 30 MHz)	Short wave broadcasting
Medium Frequency MF (300 kHz - 3 MHz)	AM broadcasting
Low Frequency LF (30 - 300 kHz)	Radio beacons, weather broadcast stations for air navigation
Very Low Frequency VLF (3 - 30 kHz)	Navigation and position location
Ultra Low Frequency ULF (300 Hz - 3 kHz)	Audio signals on telephone
Super Low Frequency SLF (30 - 300 Hz)	Ionospheric sensing, electric power distribution, submarine communication
Extremely Low Frequency ELF (3 - 30 Hz)	Detection of buried metal objects
$f < 3$ Hz	Magnetotelluric sensing of the earth's structure

Figure 1-16

Light compose of Photons

- Plank's quantization to explain blackbody radiation

$$\rho(\nu) = \frac{8\pi\nu^2}{c^3} \cdot \frac{h\nu}{e^{h\nu/kT} - 1}$$

$\rho(\nu)$ is the radiant energy density within a cavity in thermal equilibrium at temperature T
K is the Boltzmann constant = 1.381×10^{-23} J/K
ν is frequency, and c is the speed of light
h is the famous Plank constant = 6.626×10^{-34} Js

Plank found that the energy of an atomic oscillator in the walls of a blackbody needed to be quantized to integer numbers of $h\nu$ in order to describe the observed curve.

Photon: Quanta of Light

The quantized nature of electromagnetic field: the energy and momentum are not continuous, but are integer values of minimum quanta - the photons.

The particle-properties and wave-properties of light are connected by the following relationship

Photon energy $$E = h\nu$$

Photon momentum $$P = h/\lambda$$

ν is the light frequency and λ is the light wavelength

Light: Wave-Particle Duality

- Experimental proof of wave nature of light:
  - Young's double-split interference
  - Light diffraction
- Experimental proof of particle nature of light:
  - Blackbody radiation
  - Photo-electric effect
  - Compton scattering
  - Lamb-shift in H atom

Young's Experiment

Each photo interferes with itself.

Matter Particle's Diffraction

Matter wave - de Broglie wave: electron and other matter particles all possess a dual (wave-particle) nature.

Dual Nature of Matter and Radiation Wave-Particle Duality

- Essential particle nature is that energy and momentum are quantized.
- Essential wave nature is that the wave function represents the probability of single particle in certain state. The wave function obeys wave behavior and can have wave interference.
- The statistical character of the wave function can connect the particle nature with the wave nature.

Dual Nature of Matter and Radiation
Wave-Particle Duality

- The wave-particle duality is universal to all radiations (like light) and matter (like all particles).

- The association of particles with waves is applicable to all matter. All kind of particles are associated with waves in this way and conversely all wave motion is associated with particles.

- All particles can be made to exhibit interference effects and all wave motion has its energy in the form of quanta.

Summary

- LIDAR actually started with CW searchlight using geometry to determine altitude. The invention of lasers pushed lidar to a whole new level - modern laser remote sensing. The time-of-flight of a short pulse is used to precisely determine range and altitude.

- Basic lidar architecture includes transmitter, receiver and data acquisition/control system. Each has special functions. The determination of range is further discussed.

- Lidar equation relates the received photons (power) to the transmitted photons (power), properties of scatters, medium transmissions, and system efficiencies. It is the basic equation governing the lidar field.

- Classifications of lidars can have different categories.

Homework for quantum theory of light

1. The light intensity for sunlight arriving at the top of Earth's atmosphere (1.5×10^{11}m from the Sun) is about 1.4kW/m^2.
   (a) Compute the average radiation pressure exerted on a metal reflector facing the Sun.
   (b) Approximate the average radiation pressure at the surface of the Sun whose diameter is 1.4×10^9m.

2. A pulsed laser (532 nm) runs at a repetition rate of 50 Hz. Each single pulse energy is 300 mJ.
   (a) During 10 minutes operation time, how many photons are shot out?
   (b) How much is the total momentum of photons sent out?
   (c) The beam divergence is 1-mrad, and hits on a reflector mirror 100m away from the laser (assuming 100% reflectivity). How much radiation pressure does the laser beam exert on the mirror?

3. Compute the de Broglie wavelength for an electron traveling at 1000 m/s. Then assess to show the wave nature of an electron, what kind of dimension slit do you need?