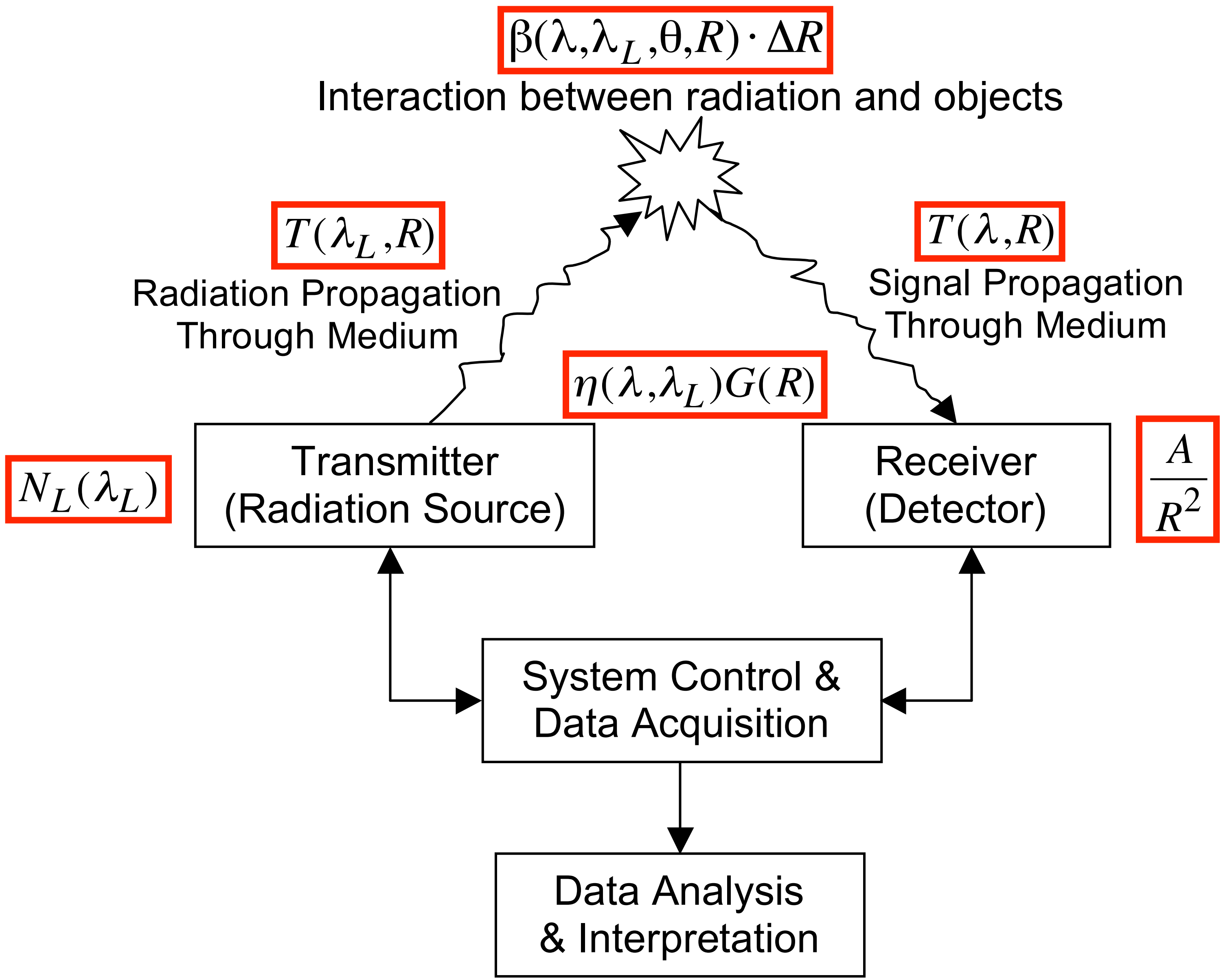
Lecture 11. Lidar Envelope Estimation and Classification

- Lidar Envelope Estimation
  -- Application of Lidar Equation
- Various Lidar Classifications
- Lidar Classification by Topics
  - Temperature lidar technologies
  - Wind lidar technologies
  - Constituent lidar technologies
  - Aerosol & cloud lidar technologies
  - Laser range finding and laser altimeter technologies
  - Target lidar technologies (Fluorescence, Raman, Brillouin)
- Summary

Lidar Envelope Estimation

- Lidar envelope estimation is to estimate the return photon counts from the entire (meteoric) metal layers using lidar equation and lidar/atomic/atmospheric parameters. It is useful to anticipate the expected signal levels for various lidar conditions.
- 1st, write down all fundamental constants used in lidar.
- 2nd, gather lidar, atomic/molecular & atmosphere parameters.
- 3rd, start with the laser source of transmitter and follow the lidar picture from transmitted photons, through atmosphere transmission, backscatter probability, collection probability, and receiver efficiency, to detected photon numbers.
- 4th, understand the physical process of light interaction with objects to calculate the backscatter probability.
- 5th, background estimate considering many factors (both atmosphere conditions and lidar parameters like filter, FOV, …)
- 6th, get the final results and verify them with reality.

Physical Picture of Lidar Equation



Envelope Estimate

(use parameters on page 28 of Lecture 4)

$$N_S(\lambda,R) = \left(\frac{P_L(\lambda)\Delta t}{hc/\lambda}\right)\left(\sigma_{eff}(\lambda,R)n_c(z)R_B(\lambda)\Delta R\right)\left(\frac{A}{4\pi R^2}\right)\left(T_a^2(\lambda,R)T_c^2(\lambda,R)\right)\left(\eta(\lambda)G(R)\right)+N_B$$

5.81×10^{17} 6×10^{-4} 4.94×10^{-12} 0.64 0.336

The scattering probability is given by: $P_{scattering} = \sigma_{eff} \times Kabdn = 6 \times 10^{-4}$

Transmitter efficiency $\eta_{transmitter} = (0.99)^5 = 0.95$
Receiver efficiency $\eta_{receiver} = 0.91 \times 0.9 \times 0.9 \times 0.8 \times 0.6 = 0.35$
Overall lidar efficiency $\eta = 0.336$

- The overall lidar return from the entire K layer is

$N_S = 5.81\times10^{17} \times 6\times10^{-4} \times 4.94\times10^{-12} \times 0.64 \times 0.35 =$ 370 counts/shot

- These returns originate from 5.8×10^{17} laser photons!!!

Envelope Estimate Procedure

$$N_L(\lambda_L) = \frac{P_L(\lambda_L)\Delta t}{hc/\lambda_L} = \frac{E_{pulse}}{hc/\lambda_L}$$

N_L = 5.81 x 10^{17}

$$N_{Trans} = N_L \cdot R_{Tmirror} \cdot T_{atmos}$$

N_{Trans} = 4.42 x 10^{17}

$$N_{Fluorescence} = N_{Trans} \cdot P_{scattering} = N_{Trans} \cdot \sigma_{eff} \cdot KAbdn$$

$N_{Fluorescene}$ = 2.65 x 10^{14}

$$N_{Sphere} = N_{Fluorescence} \cdot T_{atmos}$$

N_{Sphere} = 2.12 x 10^{14}

$$N_{Primary} = N_{Sphere} \cdot P_{collection} = N_{Sphere} \cdot \frac{A}{4\pi R^2}$$

N_{Sphere} = 1048.2

$$\eta_{receiver} = R_{primary} \cdot \eta_{fiber} \cdot T_{Rmirror} \cdot T_{IF} \cdot QE$$

$\eta_{receiver}$ = 35.38%

$$N_{S(K)} = N_{primary} \cdot \eta_{receiver}$$

$N_{S(K)}$ = 370.8

Comparison to reality: 50-175 count/shot

Lidar Classifications

There are several different classifications on lidars

e.g., based on the physical process;
(Mie, Rayleigh, Raman, DIAL, Res. Fluorescence, …)

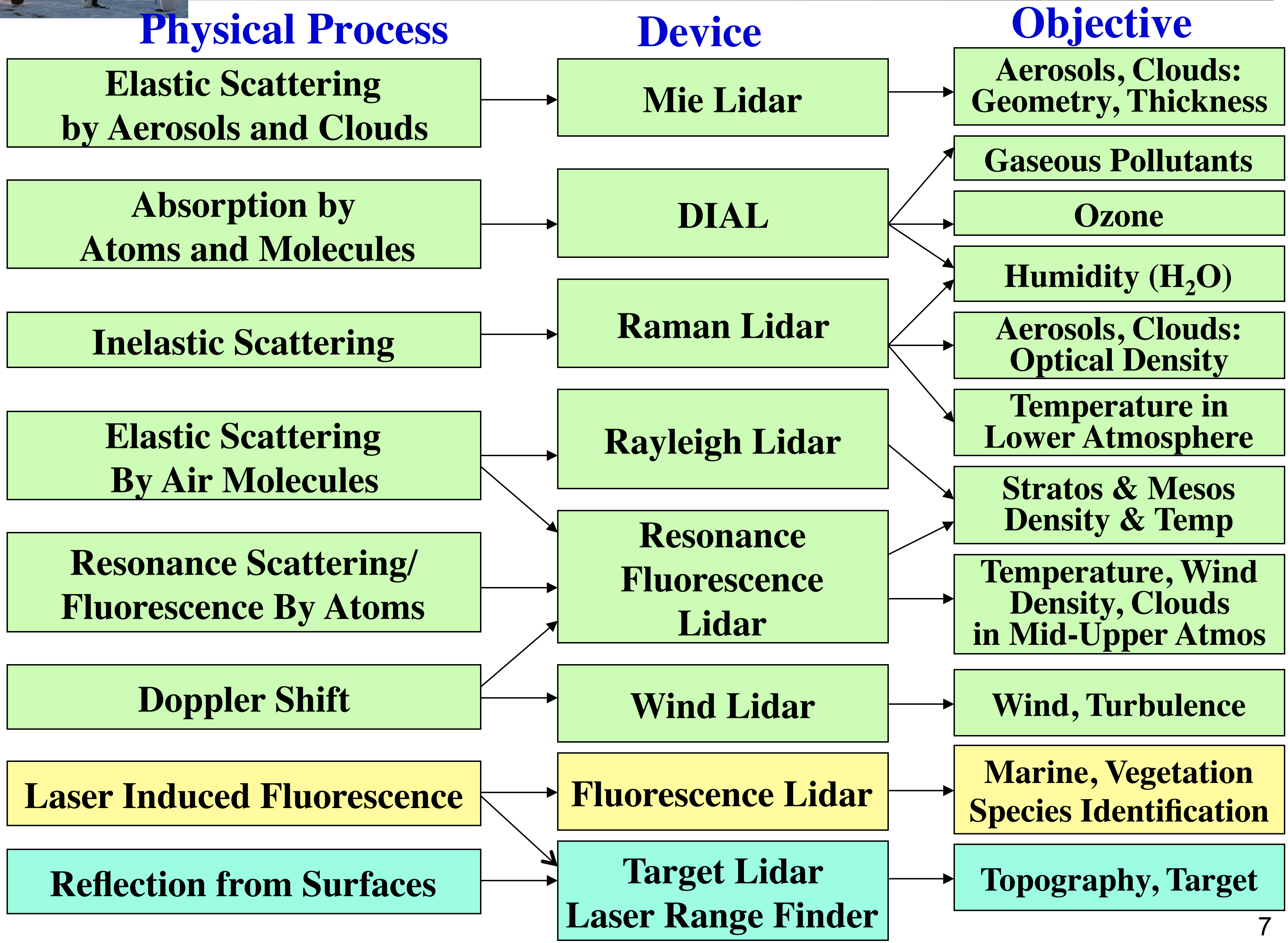
based on the platform;
(Groundbased, Airborne, Spaceborne, …)

based on the detection region;
(Atmosphere, Ocean, Solid Earth, Space, …)

based on the emphasis of signal type;
(Ranging, Scattering, …)

based on the topics to detect;
(Aerosol, Constituent, Temp, Wind, Target, …)

… …


Physical Process
Device
Objective
Elastic Scattering by Aerosols and Clouds
Mie Lidar
Aerosols, Clouds: Geometry, Thickness
Gaseous Pollutants
Absorption by Atoms and Molecules
DIAL
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
Laser Induced Fluorescence
Fluorescence Lidar
Marine, Vegetation Species Identification
Reflection from Surfaces
Target Lidar Laser Range Finder
Topography, Target

Classification on Platform

Spaceborne lidar

Satellite, Rocket
Space Shuttle.
Space Station

Airborne lidar

Jet, Propeller Airplanes
Unmanned Aerial Vehicle (UAV)
Kite, Balloonborne

Groundbased lidar

Stationary on the ground
Contanerized moving with truck

Shipborne lidar

Containerized onboard
Icebreakers, 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
Non-Gas-Phase 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

Temperature lidar

Wind lidar

Constituent lidar

Aerosol/Cloud lidar

Laser Range Finding

Target lidar

… … … …

Topics to Be Covered

- Topics we will discuss in this class are

1. Temperature (structure from ground to thermosphere, diurnal/seasonal/interannual variations, etc.)

2. Wind (structure from ground to upper atmosphere, and its variations, etc.)

3. Constituents (O_3, CO_2, H_2O, NO_x, O_2, N_2^+, He, metal atoms like Na, Fe, K, Ca, pollution, etc)

4. Aerosols and clouds (distribution, extinction, composition, size, shape, and variations spatially and temporally)

5. Range finding and altimetry (accurate height & range determination)

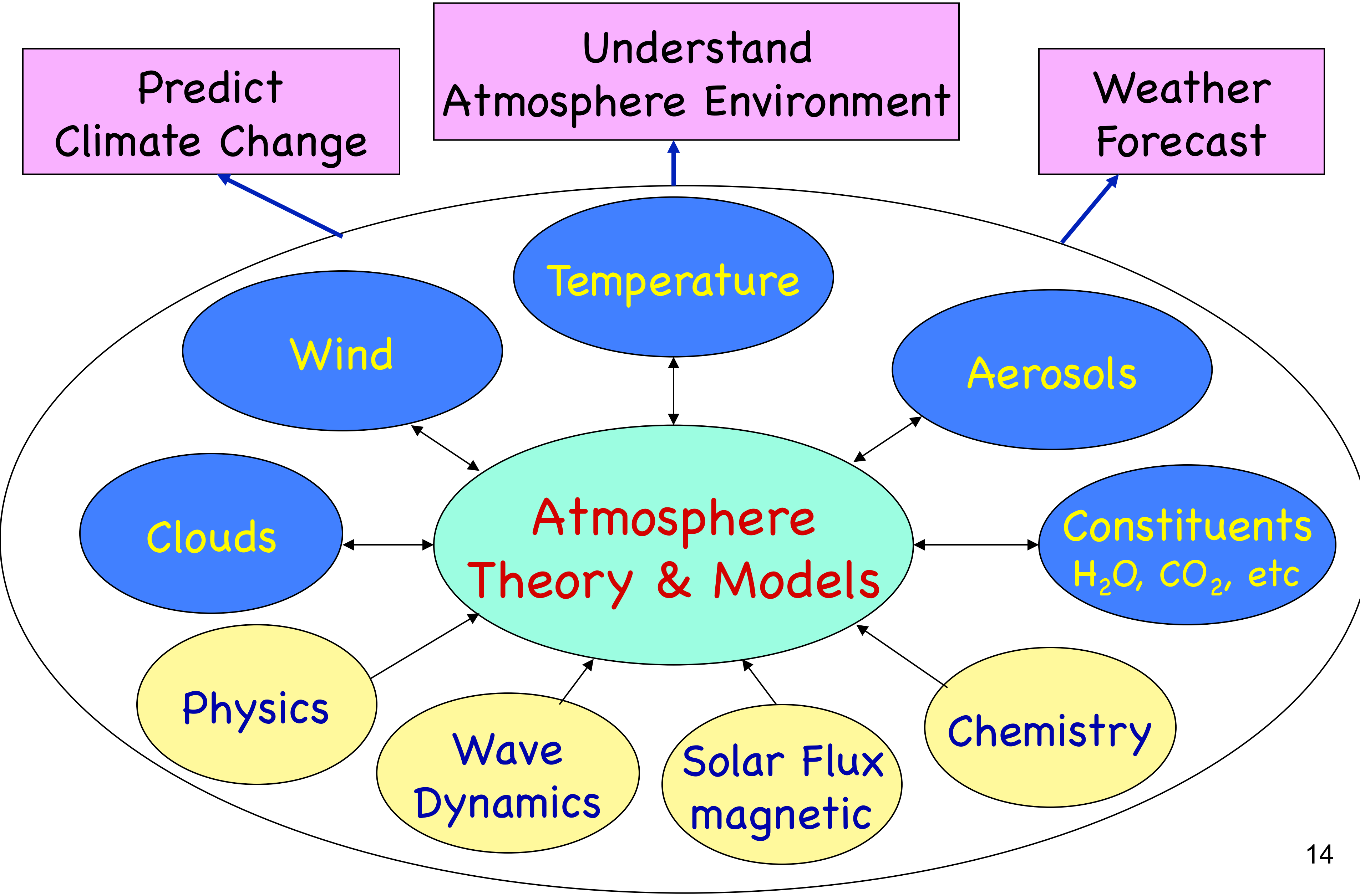
6. Target (species identification with fluorescence tech, temperature measurements in waterbody, etc.)

Why Going by Topics?

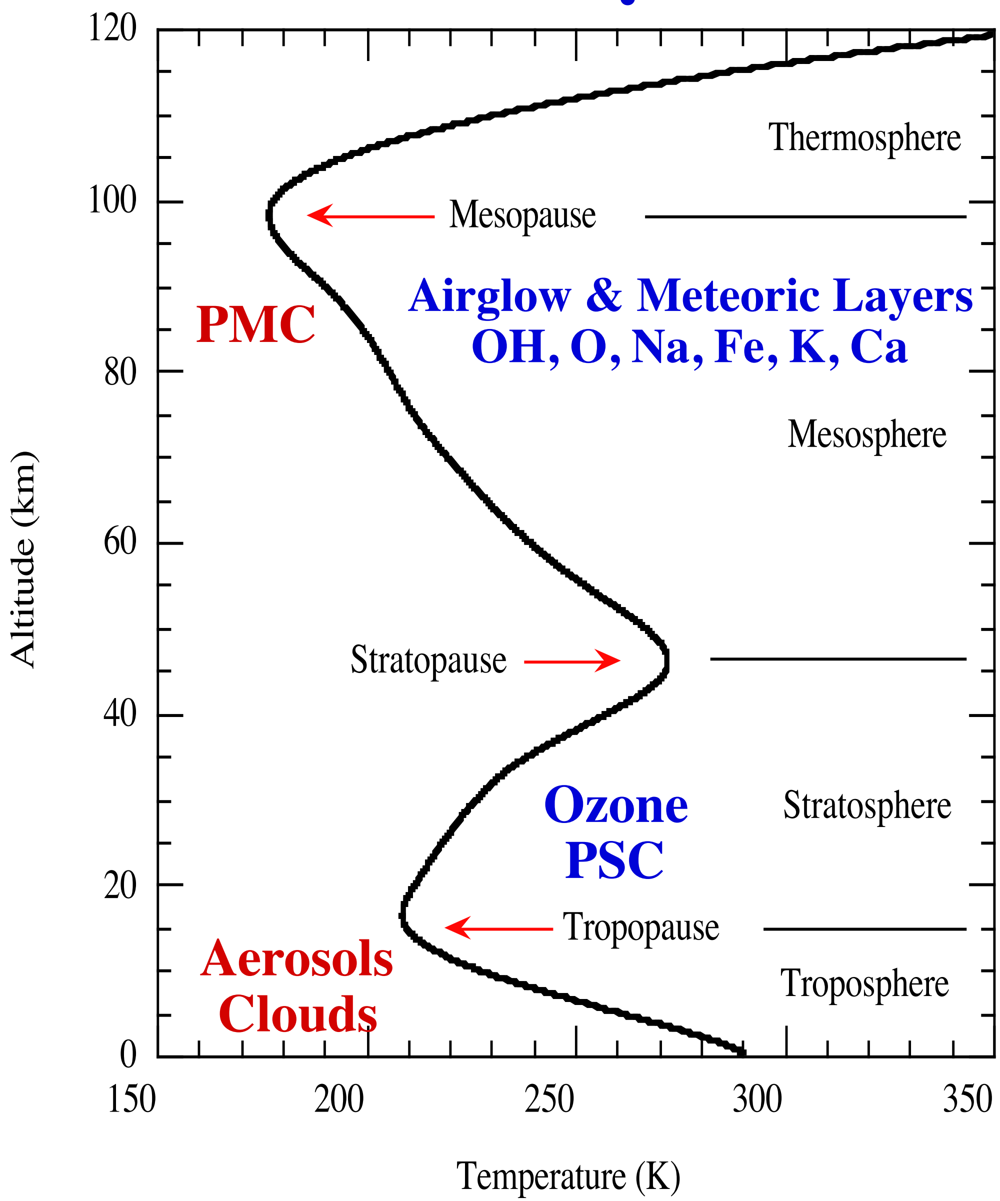
- To compare different lidar techniques that address the same topic, e.g., how many ways to measure temperature, and what is the essential point among these different lidars?
- To illustrate the strengths and limitations of each type of lidars, and give an insight of when and where to use what kind of lidars?
- To encourage students to explore new phenomena or effects to innovate novel lidars / methods.

- We choose 6 most interesting and hot topics in the atmosphere/space sciences, environmental research, and climate study. They have wide applications in environment, defense and industry.
- The lidar technologies used to address these six topics represent the key technology advancement in the past 20 years.
- There are also high potentials of future advancement in these aspects, so encouraging creative students to pursue technology innovation, development, implementation, as well as applying the existing and future technologies to conduct novel science and environmental research.

Observables, Atmosphere, and Processes

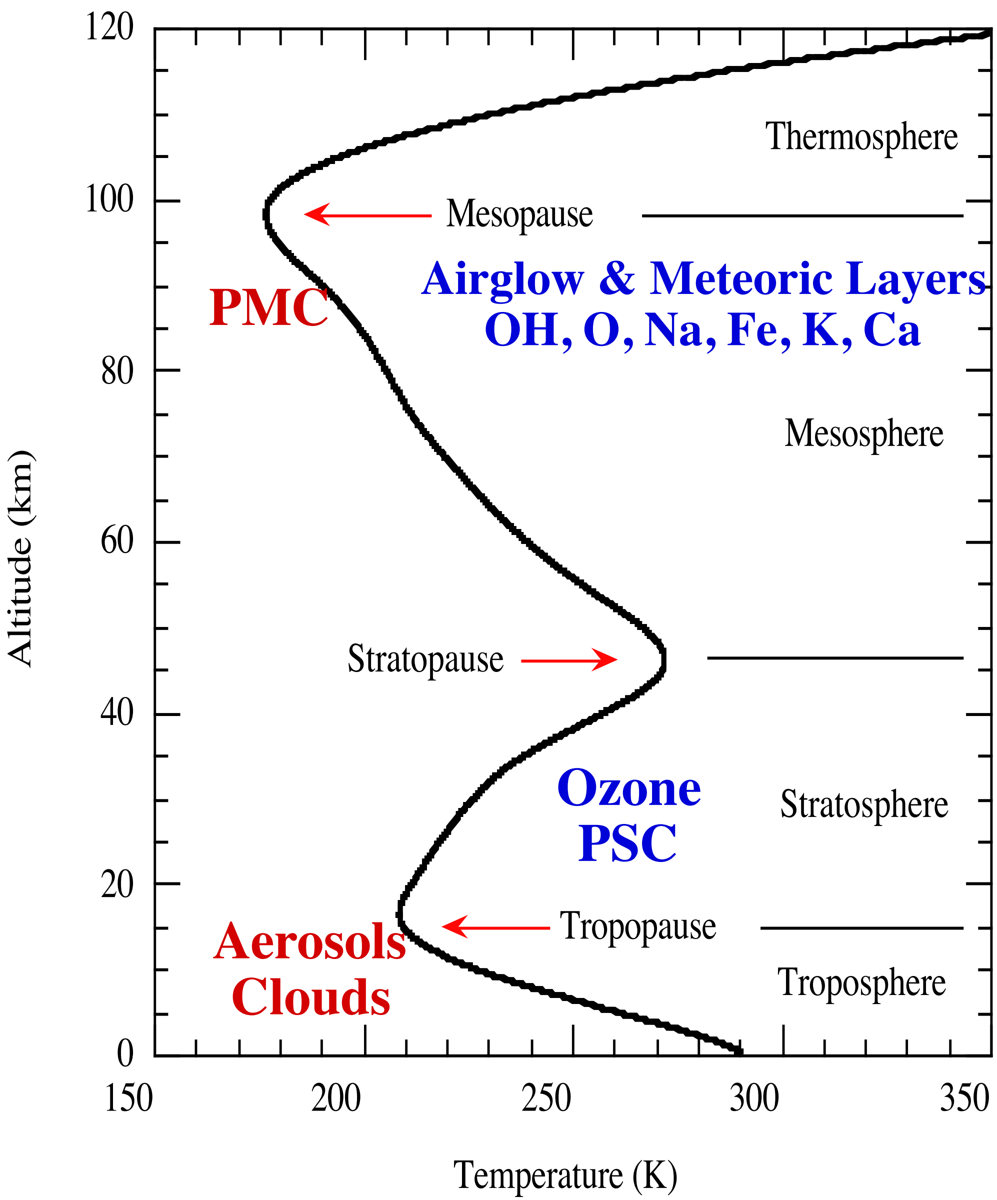


Temperature Lidars



- 75-120 km: resonance fluorescence Doppler technique (Na, K, Fe) & Boltzmann technique (Fe, OH, O_2)
- 30-90 km: Rayleigh integration technique & Rayleigh Doppler technique
- Below 30 km: scattering Doppler technique and Raman technique (Boltzmann and integration)
- Boundary layer: DIAL, HSRL, Rotational Raman

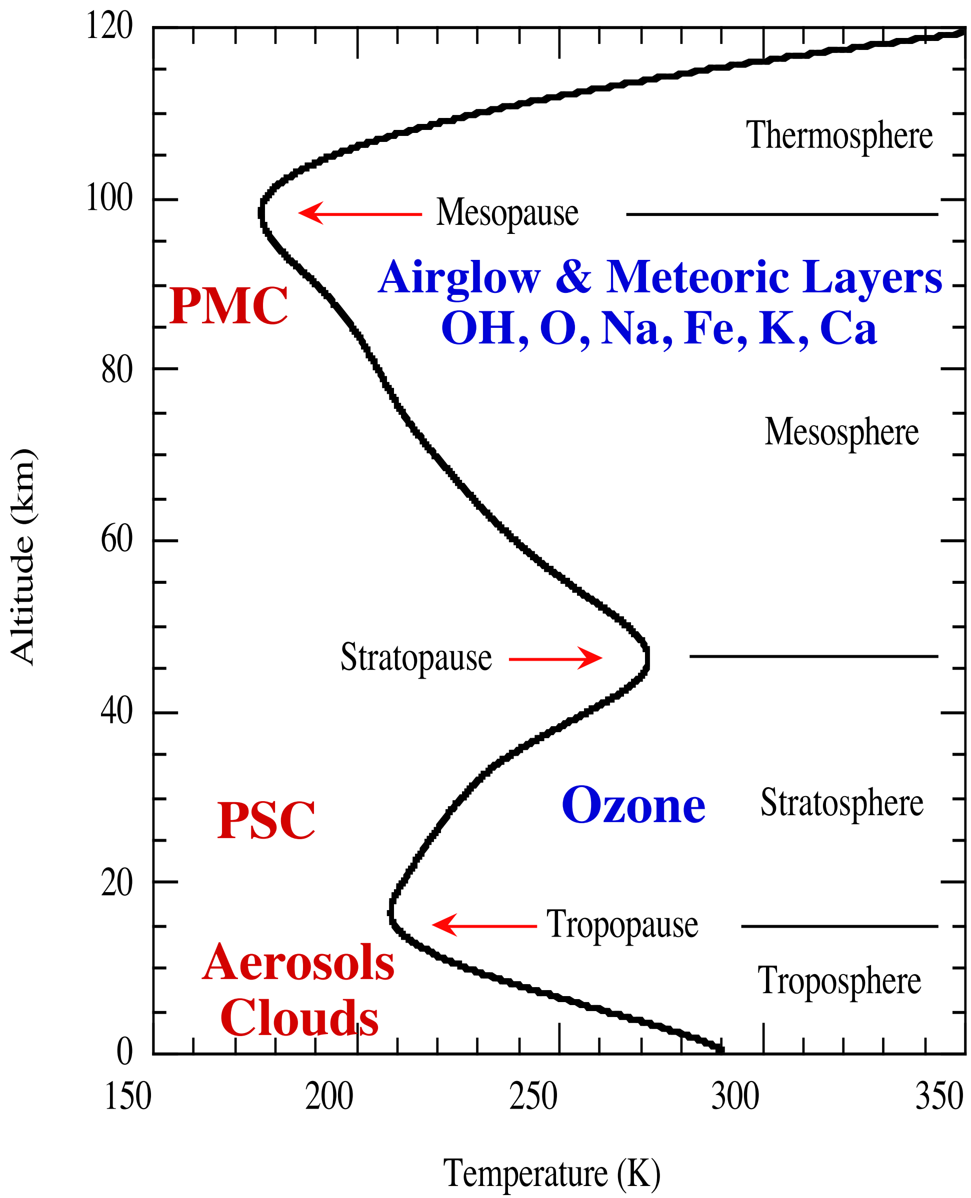
Wind Lidars vs. Altitude



- 75-120km: resonance fluorescence (Na, K, Fe) Doppler technique (DDL)
- FPI: Fabry-Perot Interferometer
- Below 60km: Rayleigh Doppler technique (DDL)
- Below 30 km: Direct Detection Doppler technique
- In troposphere:

Coherent Detection Doppler tech,
Direct Detection Doppler tech,
Direct motion Detection tech
(tracking aerosols, LDV, LTV)

Aerosol Lidar Comparison



- ❑ Aerosols in mesosphere (Mesospheric Clouds ~ 85 km): Rayleigh/Mie lidar, resonance fluorescence lidar (detuned)
- ❑ Aerosols in upper stratosphere (Polar Stratospheric Clouds ~ 20 km): Rayleigh/Mie lidar, resonance fluorescence lidar
- ❑ Aerosols in lower stratosphere and troposphere: Rayleigh/Mie elastic-scattering lidar, Raman scattering lidar, High-Spectral-Resolution Lidar (HSRL)

- ❑ In all altitude range, polarization & multi-wavelength detections help reveal aerosol microphysical properties

HSRL

- High-Spectral-Resolution-Lidar (HSRL) is to measure the molecule scattering separately from the aerosol scattering, utilizing the different spectral distribution of the Rayleigh and Mie scattering.

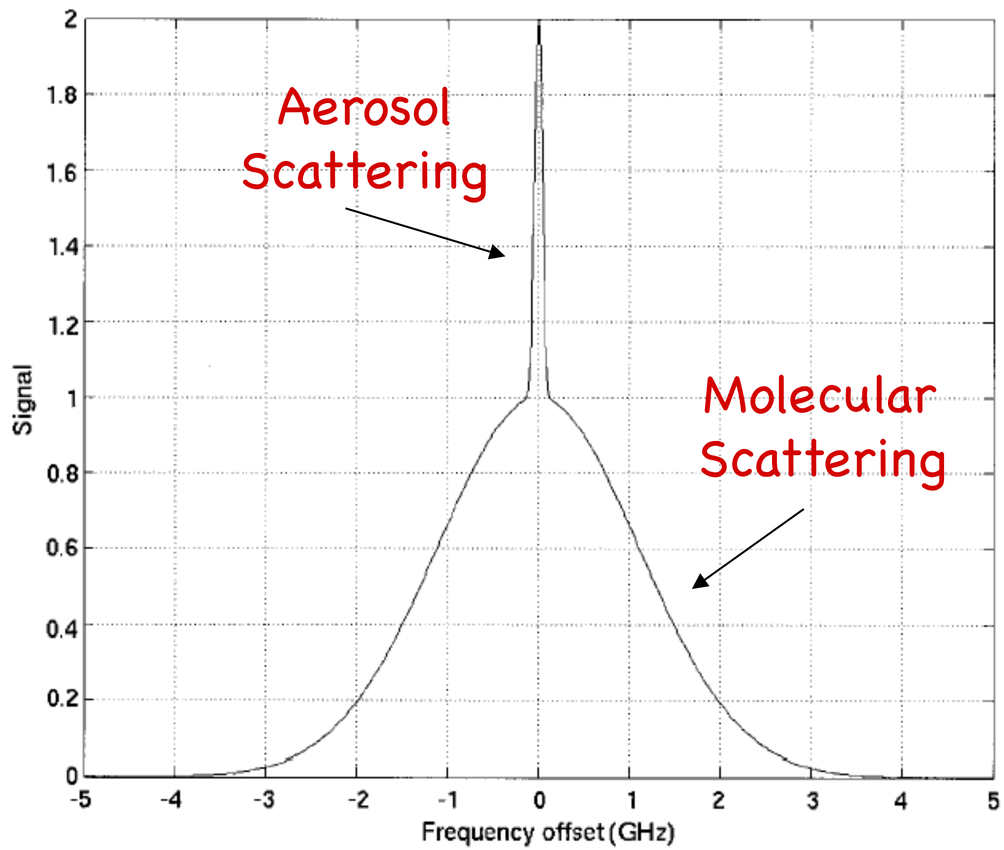
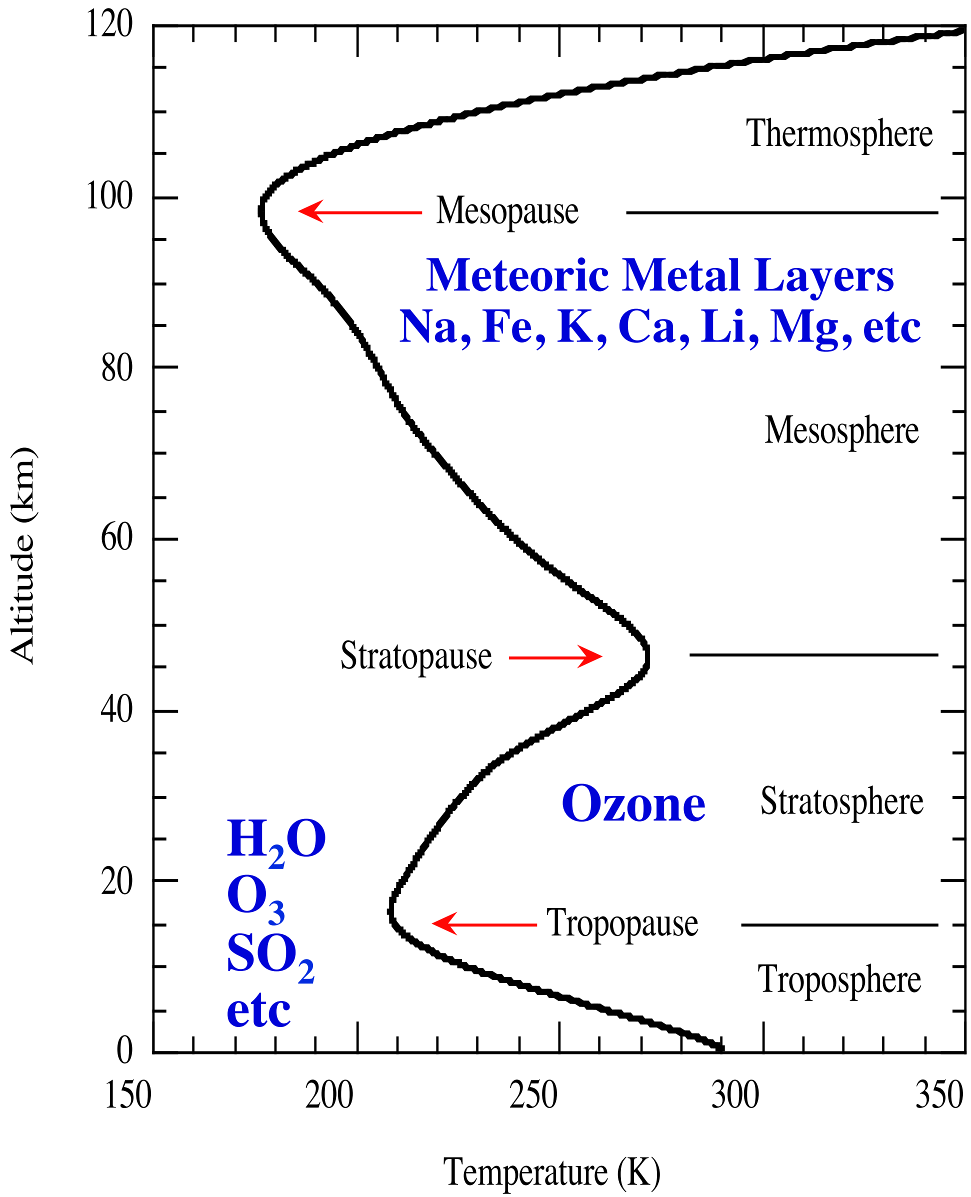


Fig. 5.1. Spectral profile of backscattering from a mixture of molecules and aerosols for a temperature of 300 K. The spectral width of the narrow aerosol return is normally determined by the line width of the transmitting laser.

Constituent Lidars



- He and N_2^+ in thermosphere: resonance fluorescence lidar
- O in thermosphere: resonance fluorescence lidar or DIAL from space
- Metal atoms in 75-120km: resonance fluorescence lidar (broadband or narrowband transmitter)
- Molecular species in lower stratosphere & troposphere: Differential absorption lidar (DIAL), Raman scattering lidar, Raman DIAL, RVR Raman DIAL, Multiwavelength DIAL
- Laser-induced-fluorescence

- The key is to use spectroscopic detection for distinguish species.

Summary

- Lidar envelope estimation is a good application of lidar equation. Start with the lidar picture and then follow the photon paths to estimate the return signals.

- Six major topics are chosen for reviewing lidar measurement principles and technologies: temperature, wind, constituent, aerosol, altimetry and target.

- For each topic, various technologies will be compared to reveal the key ideas behind the lidar technologies.

- Real lidar data for some of the topics will be given for students to perform data inversion, i.e., from raw photon counts to meaningful physical parameters.

- Data inversion principles and procedures will be explained along the way.