Lecture 28. Aerosol Lidar (4)
HSRL for Aerosol Measurements

- Review of single- and multi-channel aerosol lidars
- Principle of High Spectral Resolution Lidar (HSRL)
- HSRL instrumentation
- University of Wisconsin HSRL
- HSRL data example
- Comparison of aerosol lidar technique
- Summary

Review of Single- & Multi-Channel Methods

- Aerosols are measured by lidars through aerosol (Mie) scattering and molecular (Rayleigh) scattering. Usually, aerosol scattering results in a distinct peak or peaks, standing out of the background molecular scattering signal.

- Single-channel elastic scattering lidar: Klett method in deriving aerosol extinction, i.e., assuming the lidar ratio for aerosol (extinction coefficient to backscatter coefficient ratio). This is an unreliable method as this ratio can vary from 20 to 100 sr.

$$L_{aer}(R) = \frac{\alpha_{aer}(R)}{\beta_{aer}(R)}$$

- Multi-channel elastic (HSRL) or inelastic (Raman) lidar: providing more spectral information to derive aerosol characteristics more precisely. In this method, the Angstrom exponent that describes the wavelength dependence of the aerosol extinction coefficient has to be assumed. However, the aerosol results are insensitive to the Angstrom component value (unlike the lidar ratio).

$$\frac{\alpha_{aer}(\lambda_0)}{\alpha_{aer}(\lambda_{Ra})} = \left(\frac{\lambda_{Ra}}{\lambda_0}\right)^{a(R)}$$

Principle of HSRL

- A powerful aerosol lidar is the high-spectral-resolution lidar (HSRL) that utilizes high-spectral-resolution optical filters to resolve the Doppler-broadened molecular scattering spectrum and the aerosol signal.

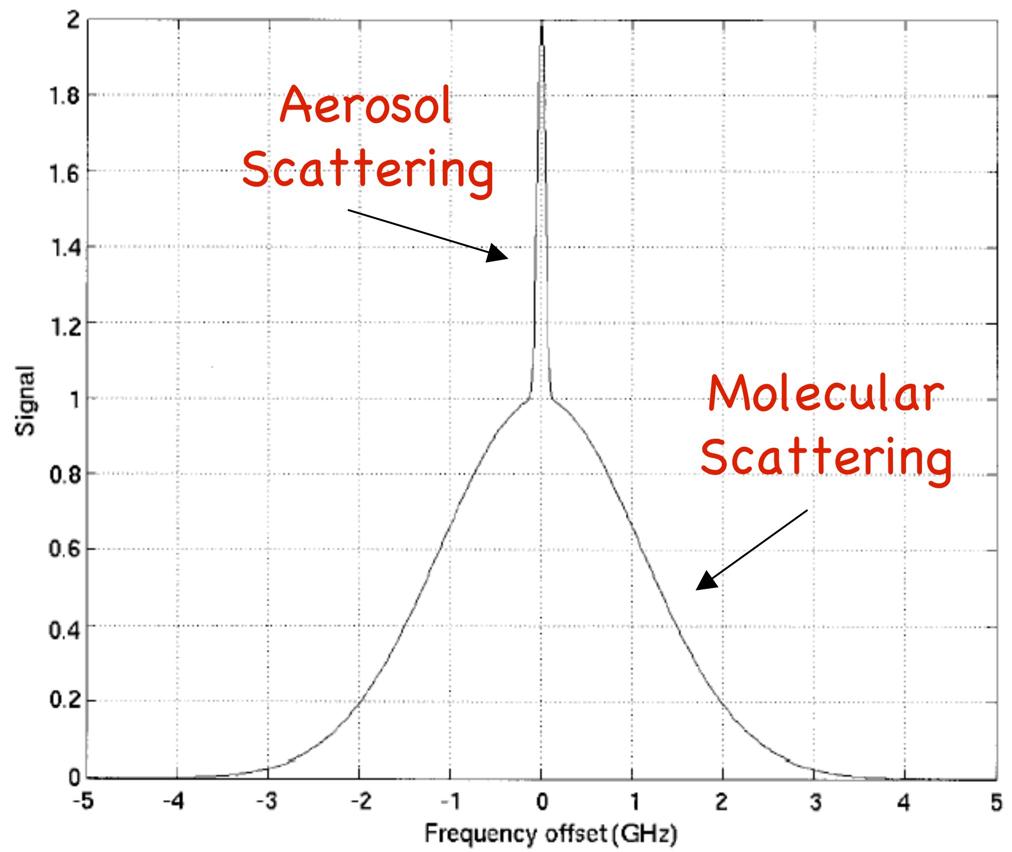


Fig. 5.1. Spectral profile of backscattering from a mixture of molecules and aerosols for a temperature of 300 K. The spectral width of the narrow aerosol return is normally determined by the line width of the transmitting laser.

HSRL: Scanning Fabry-Perot Interferometer

- The idea is to use a frequency-stabilized laser and a scanning Fabry-Perot interferometer to infer the combined particulate and molecular spectrum. This technique was pioneered by Fiocco et al. [1971].

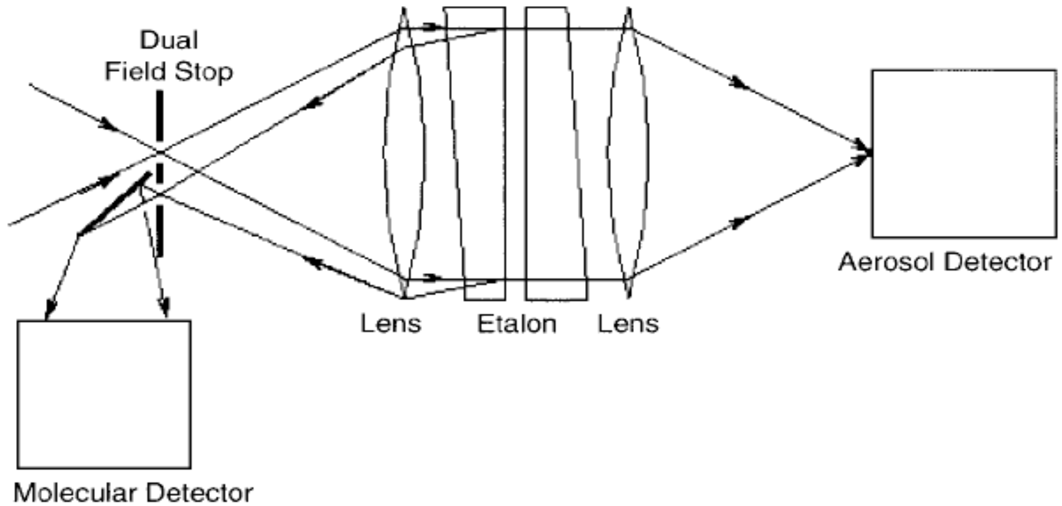
- The broadband molecular component of the measured spectrum can be fitted to predictions of a model molecular spectrum. The backscatter ratio can then be determined from the atmospheric density at the measurement altitude and the ratio of the areas under aerosol and molecular scattering curves.

- Disadvantages of scanning FPI (according to Dr. Edwin E. Eloranta)

(1) FPI filter is narrow so rejects most of the molecular scattering signals ⇨ low system efficiency and long measurement time.

(2) Spectral components are measured sequentially, allowing temporal variations of the atmospheric conditions to distort the spectrum.

HSRL: Fixed F-P Interferometer/Etalon



- System efficiency can be improved with nonscanning FPI. The FPI (etalon) is locked to the laser wavelength. Two detectors are employed: one for signal passing the FPI, and another for signal reflected from the FPI.
- Most of the aerosol scattering passes through the etalon transmission band with only a small fraction reflected. The Doppler-broadened molecular scattering is reflected outside the etalon transmission band and divided more equally between two channels.
- If the spectral transmission and reflection characteristics of the etalon are known, a model of the molecular spectrum can be used with an independently supplied atmospheric temperature profile to predict the transmission of the two channels for both aerosol and molecular signals. ⇨ for separating aerosol from molecular signals to derive aerosol information more precisely.

Fixed FPI Advantages and Disadvantages

- Advantages:

(1) Errors due to temporal variations in the scattering media are suppressed because both signals are measured simultaneously.

(2) System efficiency is improved because the filter bandwidths are larger and both transmitted and reflected signals are detected.

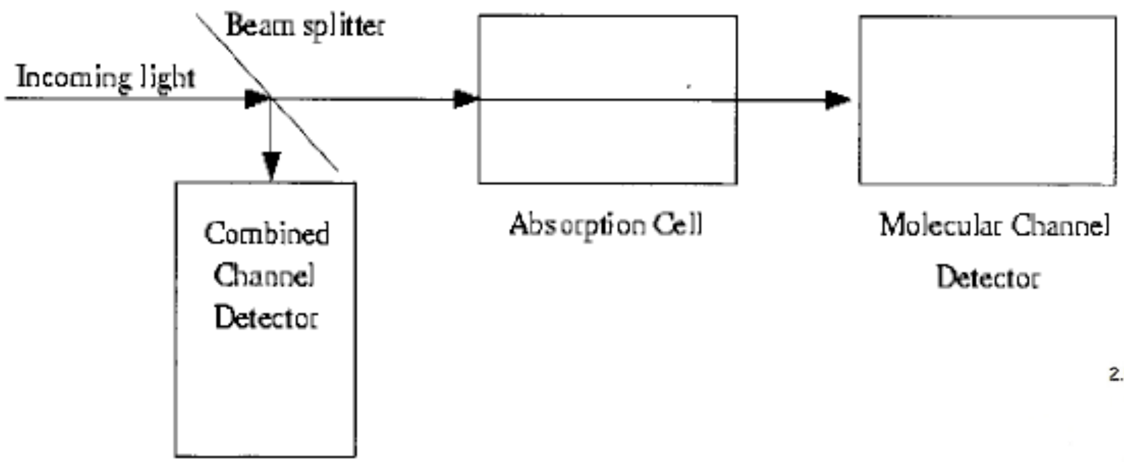
(3) The etalon can be tuned to any wavelength from UV to visible to IR.

- Disadvantages:

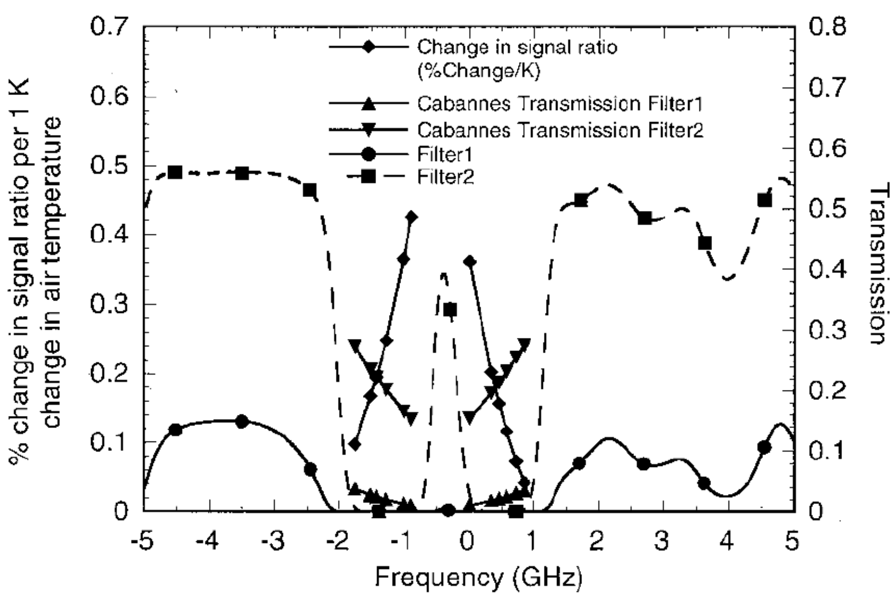
(1) The high-resolution etalons are sensitive to thermal and mechanical perturbations.

(2) At a given spectral resolution, the product of the etalon diameter and the angular acceptance of an etalon is limited. As a result, large telescopes require large and expensive etalons.

HSRL: Atomic and Molecular Absorption (Blocking) Filter



Atomic or molecular absorption block the aerosol scattering



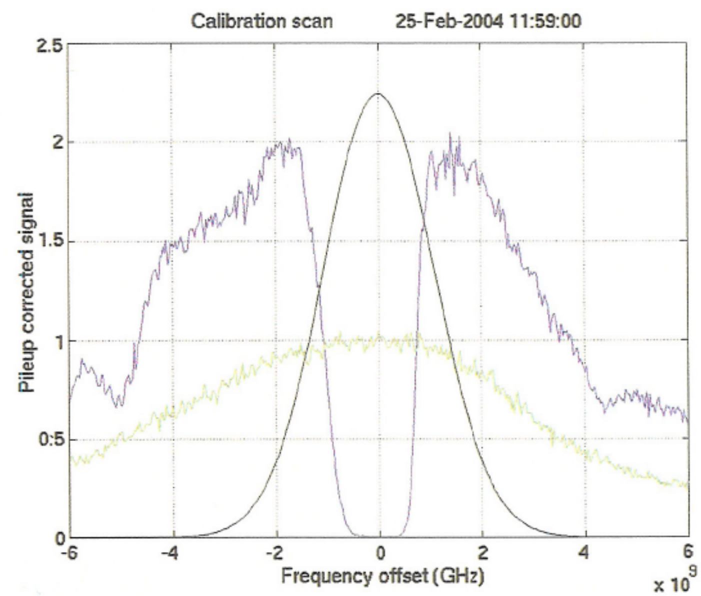


Fig. 5.5. Calibration scan showing the transmission of the molecular (blue) and combined (green) channels as a function of frequency. The Doppler broadened molecular spectrum for 300 K is also shown (black). Line 1109 of the iodine absorption spectrum (central notch) rejects most of the aerosol scattering and the central portion of the molecular scattering while passing the wings of the molecular line. The spectral transmission of the combined channel is determined by the pre-filter etalon.

Atomic and Molecular Absorption Filter: Advantages and Disadvantages

- Advantages:

(1) The atomic/molecular vapor version HSRL replace the temperature-sensitive and mechanical-sensitive Fabry-Perot etalon with a robust and stable atomic/molecular absorption filter.

(2) It also provides much larger acceptance angle, overcoming the FPI limitation.

- Disadvantages:

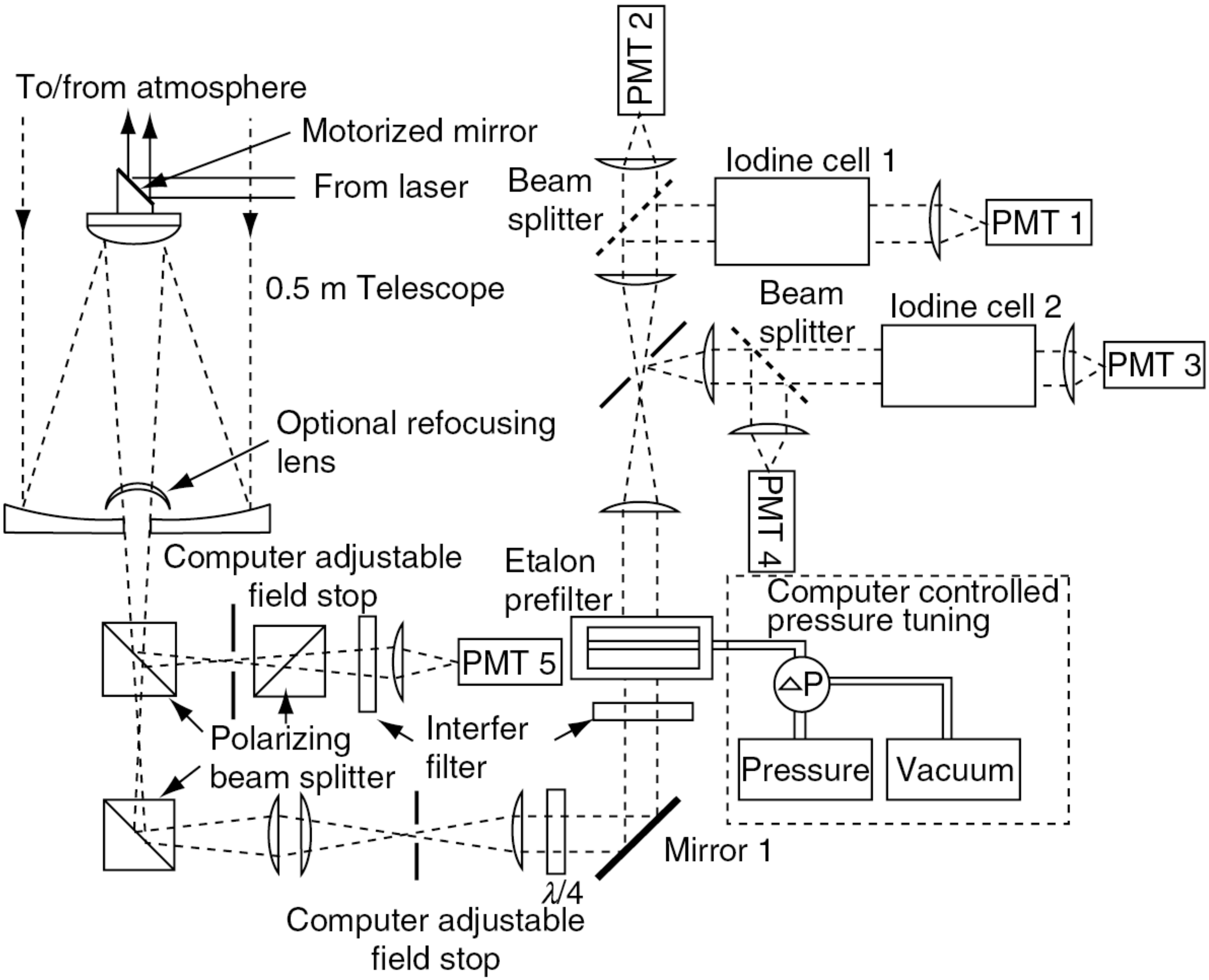
(1) The atomic/molecular absorption filters only work at certain wavelengths, limiting the application of available lasers.

(2) The Ba vapor cell needs high operating temperature.

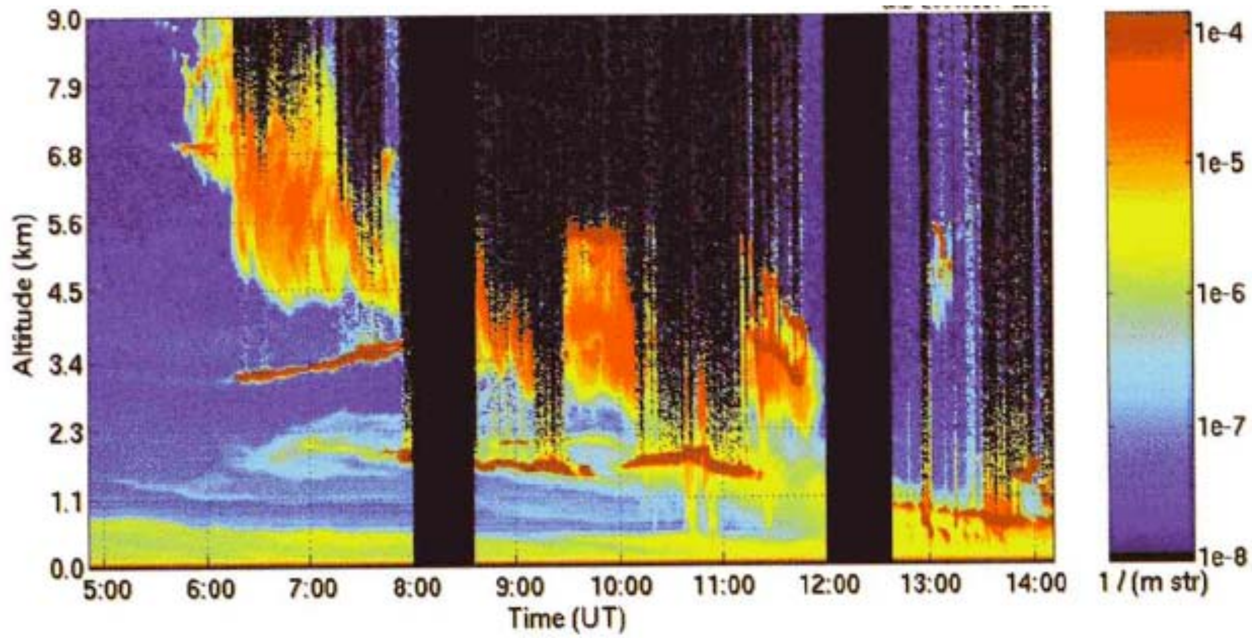
- Now (I_2) iodine-vapor-cell-based HSRL has become robust and suitable for long-term deployment.

- Other atomic vapor cell like Na, K, Ba can also work for particular wavelengths and situations.

University of Wisconsin HSRL



HSRL Results



Aerosol Backscatter Coefficient ($m^{-1}sr^{-1}$)

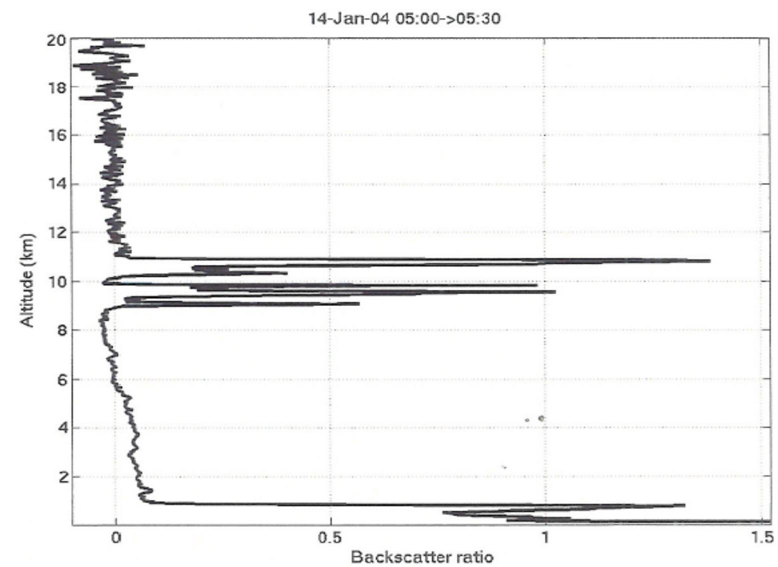
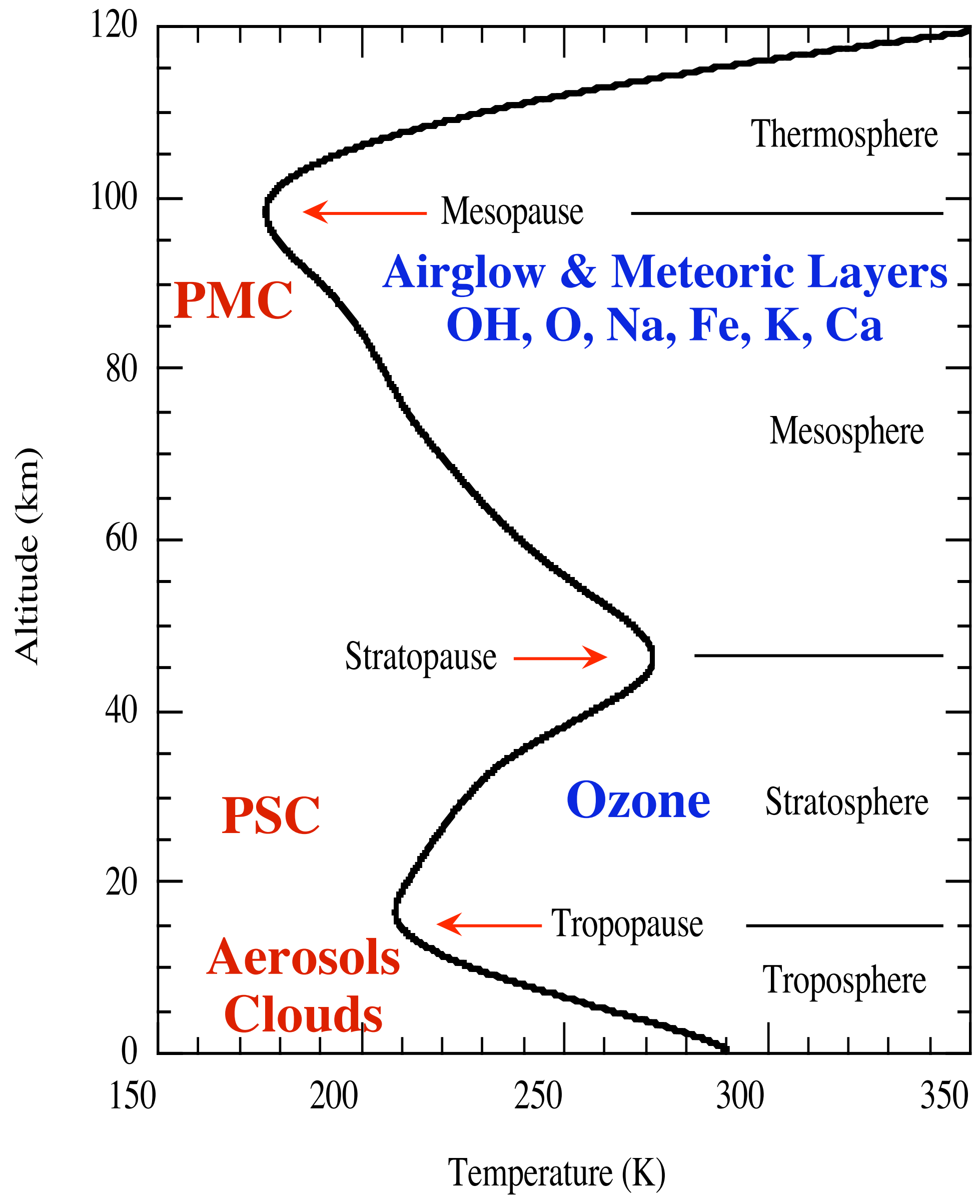


Fig. 5.9. Scattering ratio profile measured between 5:00 and 5:30 UTC on 14 January 2004.

Aerosol Lidar Technique 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

Summary

- Aerosol is an important topic in atmospheric science and environmental research.
- Aerosol can be measured by hot lidar technologies, mainly the elastic scattering lidar (Mie and Rayleigh lidars) and the inelastic scattering lidar (Raman lidar).
- Precise aerosol measurements require good spectrum measurements to distinguish aerosol from molecular signals.
- High Spectral Resolution Lidar, especially the ones based on iodine or atomic absorption filters, promises very bright future.
- Polarization detection and multi-wavelength detection can help identify aerosol shape, size, distribution, and number density.