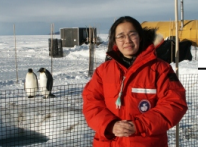
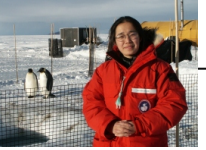


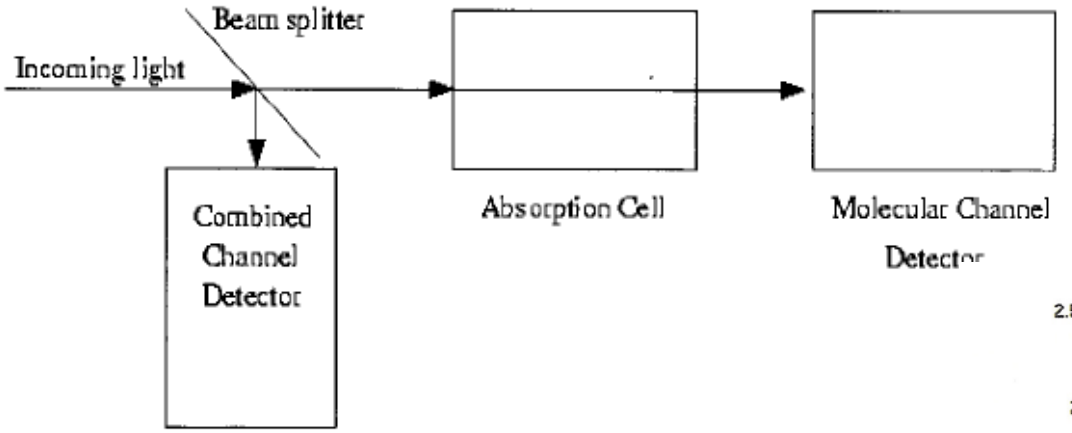
Lecture 34. Aerosol Lidar (3)

HSRL + Daytime Filter + PMT

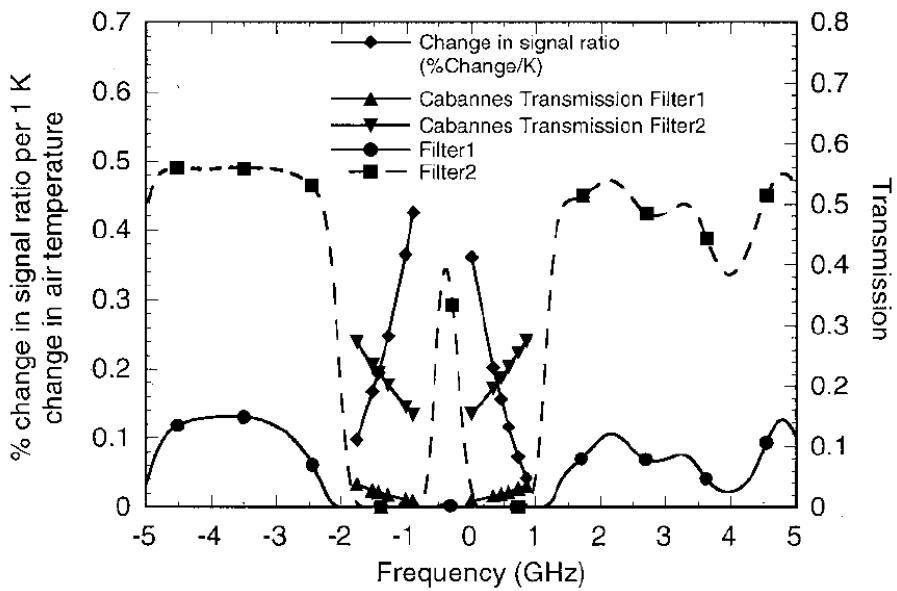
- University of Wisconsin HSRL example
- Comparison of aerosol lidar technique
- Summary
- Daytime filters (Faraday vs. FP etalon)
- PMT operation (analog vs. photon counting)



HSRL with Atomic and Molecular Absorption (Blocking) Filter



Atomic or molecular absorption block the aerosol scattering



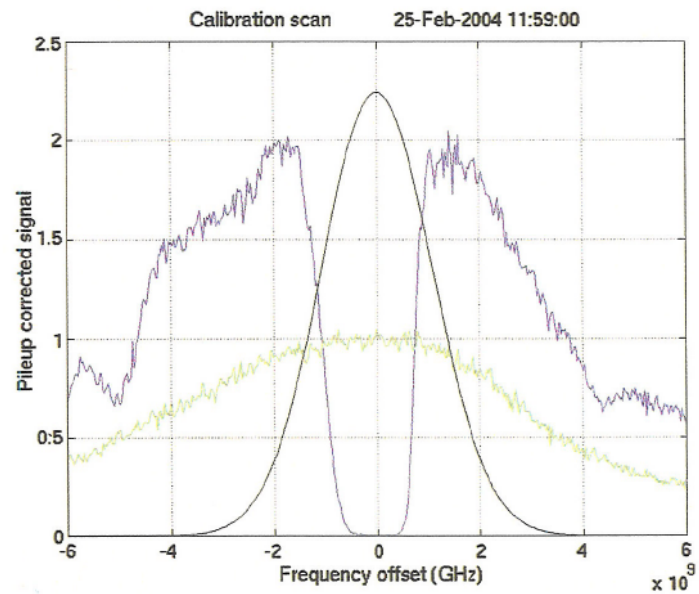
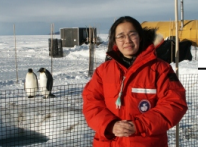
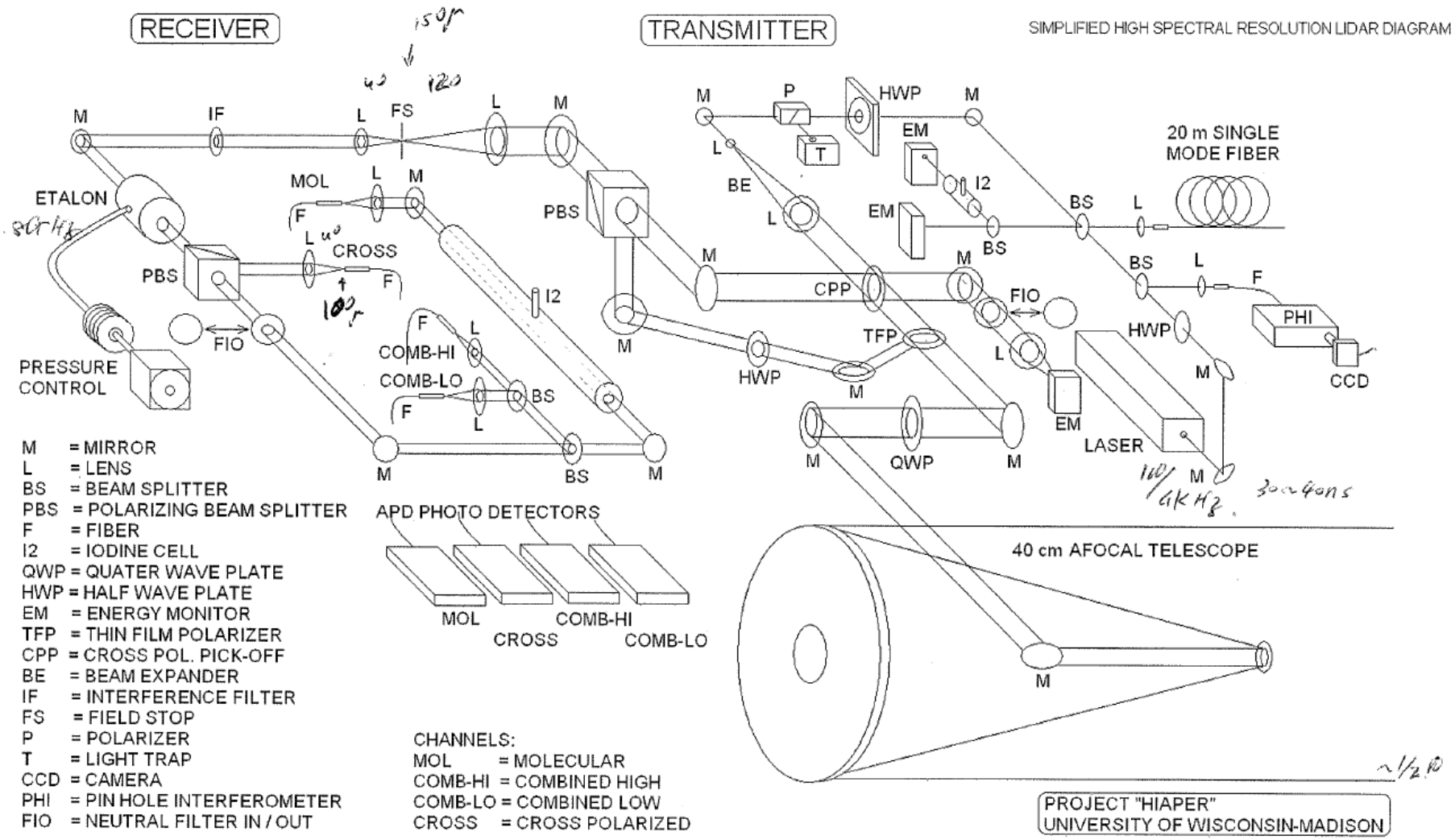


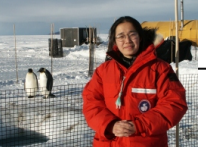
Fig. 5.5. Calibration scan showing the transmission of the molecular (blue) and combined (green) channels as a function of frequency. The Doppler broadened molecular spectrum for 300 K is also shown (black). Line 1109 of the iodine absorption spectrum (central notch) rejects most of the aerosol scattering 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.



University of Wisconsin HSRL on HIAPER



Courtesy of Dr. Edwin E. Eloranta, University of Wisconsin



Fiber Pinhole Interferometer (PHI) to measure relative frequency offset

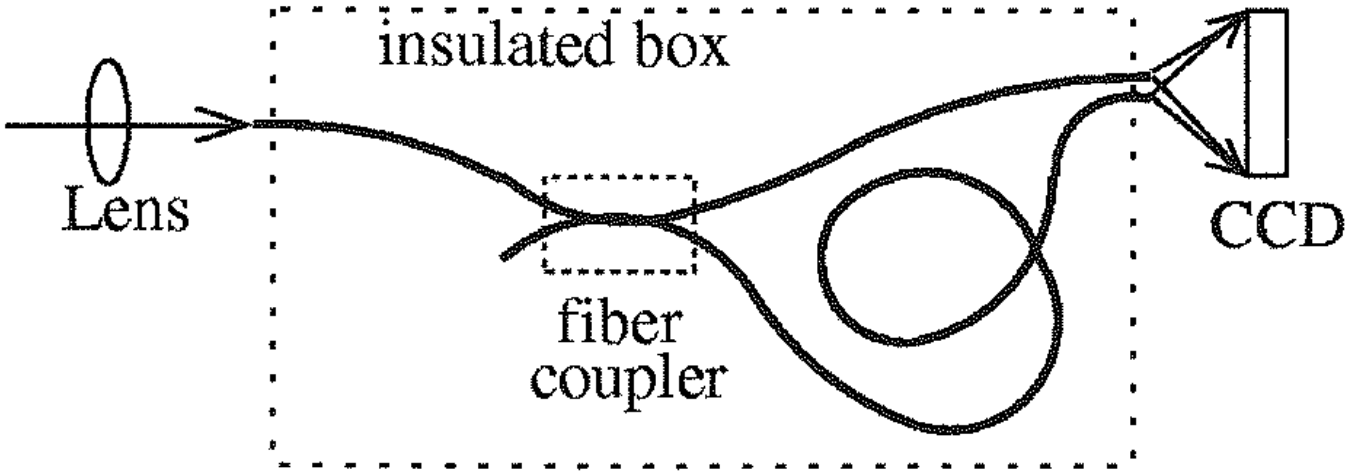
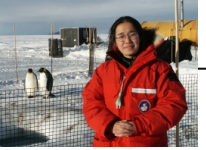


Figure 3--Fiber pinhole interferometer.

For the same optical path difference (OPD) setup, the spatial position of interference pattern will change with the incident laser frequency, so providing a measurement of relative frequency shift.

24th ILRC proceeding [Razenkov et al., ILRC, 2008]



Laser Freq Locking with Brillouin Scattering

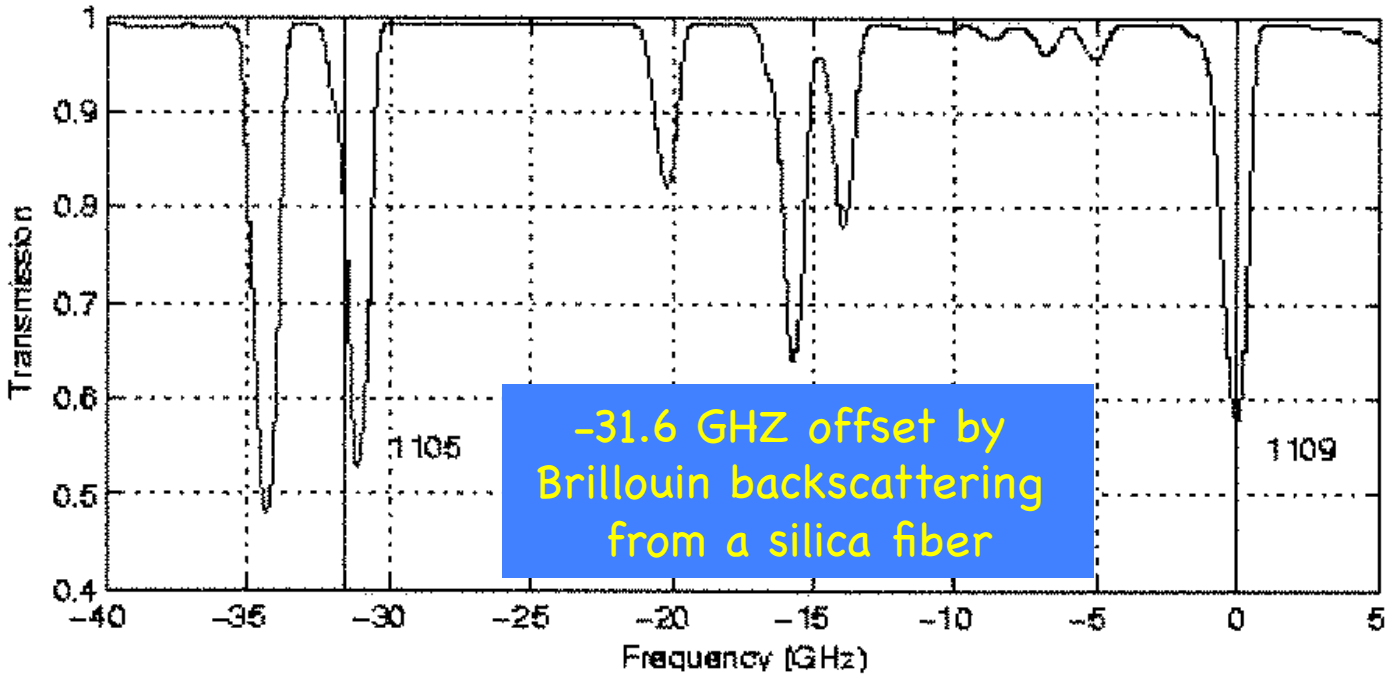
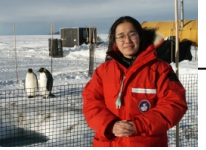
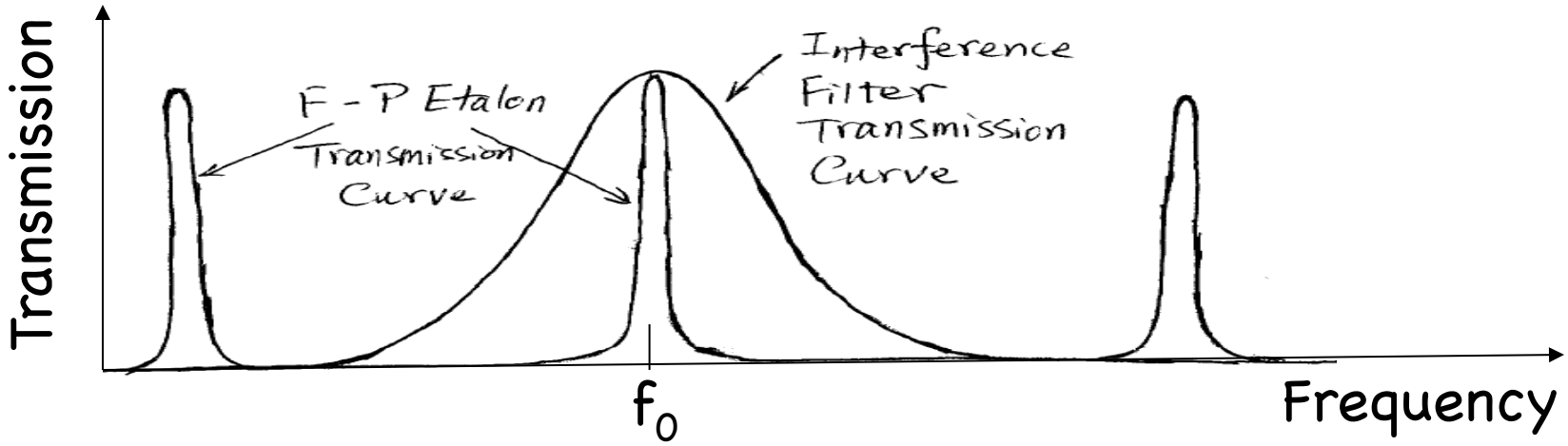


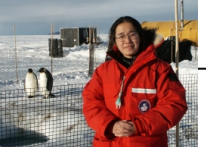
Figure 2--The iodine absorption spectrum. The lidar operates tuned to the center of line 1109. The transmission of Brillouin scattered light through the edge of line 1105 is used to lock the laser wavelength.

24th ILRC proceeding [Razenkov et al., ILRC, 2008]



Narrowband Daytime Spectral Filter: Single vs. Double Fabry-Perot Etalons





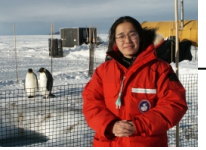
Daytime Spatial Filter: Small FOV vs. Beam Divergence

Small laser beam divergence
→ small receiver field of view (FOV)

-- A very effective way to reduce daytime background

Whether a small beam divergence thus small FOV can be used is mainly determined by two factors –

1) Will the atmosphere saturation be resulted? If yes, then we cannot use small divergence and FOV.
2) Is the laser spatial mode good enough (TEM00 mode) to achieve small beam divergence, enabling small FOV?



HSRL Measurement Results

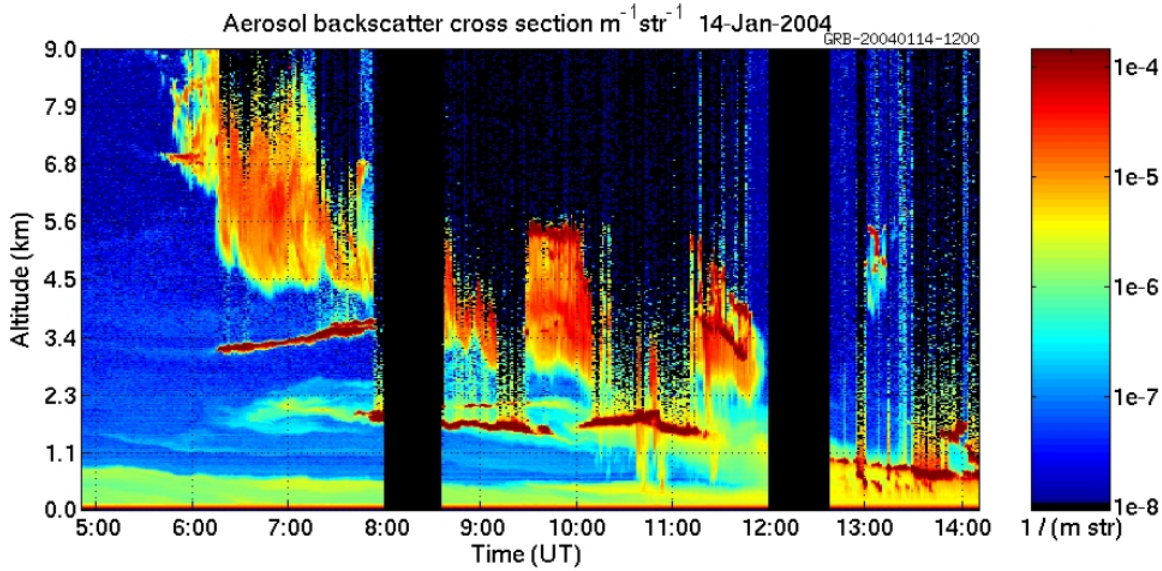


Figure 2: Calibrated backscatter cross section image derived using both HSRL data channels. This image is attenuation corrected and shadowing does not affect the measured cross section until signals are completely attenuated (black areas). Notice the greatly improved rendition of low density aerosol layers and of the upper layer of cirrus clouds.

A book chapter
"High Spectral Resolution Lidar"
by Dr. Edwin E. Eloranta
University of Wisconsin

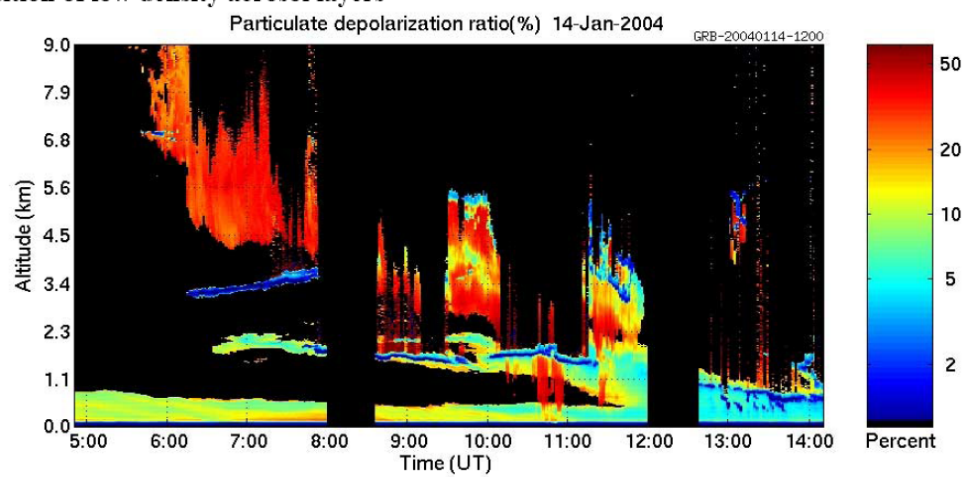
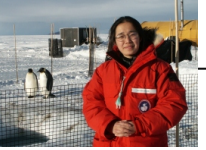


Figure 3: Circular depolarization ratio (note: log scale) for all points with particulate to molecular backscatter ratio >0.2. Water clouds (blue) are easily distinguished from ice clouds (red).



Challenging Questions

- How about if we have multiple wavelengths of elastic scattering lidar channels, e.g., 1064, 532 and 355 nm simultaneously? Can we derive the aerosols' extinction and backscatter coefficient better than single elastic scattering channel?

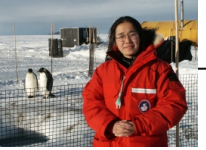
$$S(R,\lambda_1) = P(R,\lambda_1)R^2 = E_0\eta_L\left[\beta_{aer}(R,\lambda_1)+\beta_{mol}(R,\lambda_1)\right]\exp\left[-2\int_o^R\left[\alpha_{aer}(r,\lambda_1)+\alpha_{mol}(r,\lambda_1)\right]dr\right]$$

$$S(R,\lambda_2) = P(R,\lambda_2)R^2 = E_0\eta_L\left[\beta_{aer}(R,\lambda_2)+\beta_{mol}(R,\lambda_2)\right]\exp\left[-2\int_o^R\left[\alpha_{aer}(r,\lambda_2)+\alpha_{mol}(r,\lambda_2)\right]dr\right]$$

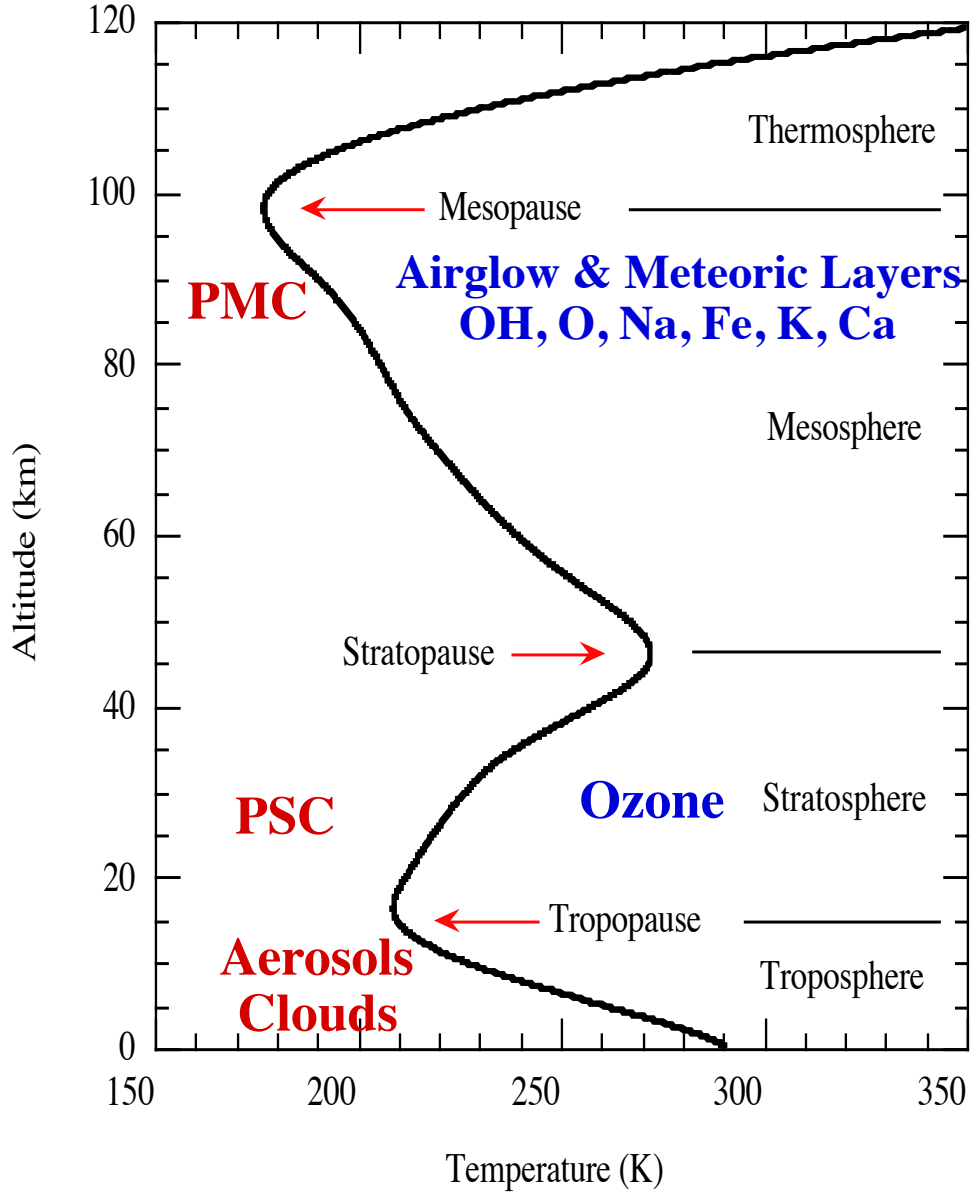
$$S(R,\lambda_3) = P(R,\lambda_3)R^2 = E_0\eta_L\left[\beta_{aer}(R,\lambda_3)+\beta_{mol}(R,\lambda_3)\right]\exp\left[-2\int_o^R\left[\alpha_{aer}(r,\lambda_3)+\alpha_{mol}(r,\lambda_3)\right]dr\right]$$

$$\frac{\alpha_{aer2}}{\alpha_{aer1}} = \left(\frac{\lambda_1}{\lambda_2}\right)^a \qquad \frac{\beta_{aer2}}{\beta_{aer1}} = \left(\frac{\lambda_1}{\lambda_2}\right)^b$$

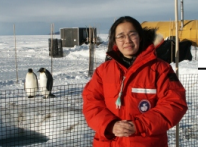
References: Our textbook Chapter 3 on aerosol lidars; two short book chapters at our class website: AerosolLidarChap.pdf and HSRL.pdf



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 20-30 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. It can be measured/monitored by hot lidar technologies.
- Single-channel elastic-scattering lidar can beautifully detect PMC and PSC backscatter, and monitor the occurrence, height, vertical structure, etc. However, it is unreliable to derive aerosol extinction.
- Multi-channel lidars like Raman lidar and HSRL provide addition information by adding Raman channel or separating molecular scattering from aerosol scattering. Both can measure aerosol backscatter and extinction nicely. HSRL is more desirable when longer range detection is needed as Rayleigh scattering is much stronger than Raman scattering.
- 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.
- Multi-wavelength and polarization detection can help identify aerosol shape, size, distribution, and number density.
- Aerosol study is growing, and awaiting for more smart lidar ideas.