A High Spectral Resolution Lidar for Operation in the Arctic: A Progress Report

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The National Science Foundation has funded construction of a High Spectral Resolution Lidar (HSRL) for long-term unattended operation in the Arctic. The ARM site at Barrow, Alaska is a potential deployment site for the new HSRL. Our plan had been to complete construction during 2001, preform extensive system testing during the 2001-2002 winter and deploy the system during the summer of 2002. Unfortunately, this schedule has been delayed due to late delivery of major system components by vendors. We are still waiting for the complete set of computer cards for the photon counting system. A prototype timing and control card, and a prototype accumulator card was delivered in March of 2002. These are undergoing hardware testing and software integration is proceeding. We expect that delivery of the production cards very soon. This should allow us to begin comprehensive system testing this summer.

Thus far, we have assembled the optical system and generated a comprehensive optical model of the system with the Zemax optical design program. This model has allowed detailed assessment of design tolerances. Because the Arctic cloud bases are often at low altitudes, special effort has been placed on studies of the near range response of the lidar system and the proposed plan to calibrate this responses using the computer controlled focus control incorporated in the system. Initial tests of the this capability have been encouraging but precise verification awaits the installation of the data acquisition system so that the computer controlled alignment system can be activated.

This lidar shares one telescope between the transmitter and receiver. This design makes it much easier to maintain alignment between the transmitter and receiver beams. It is one of the major features enabling robust, untended operation. However, a potential for damaging or overloading detectors with stray light scattered from the transmitter beam was a major concern. Tests of the polarization transmit-receive switch show that this key component preforms properly and the scattered light levels are manageable.

HSRL CLOUD AND AEROSOL MEASUREMENTS:
- **Backscatter Cross Section Profiles**
- **Optical Depth Profiles**
- **Extinction Cross Section Profiles**
- **Cloud Water-Phase (depolarization)**
- **Backscatter Phase Function Profiles**
- **Cloud Boundaries**

HSRL PRINCIPLES

Taking advantage of the different spectral signatures associated with molecular and aerosol scattering, the HSRL measures two spectrally-separated signals to derive two lidar returns:

Aerosols: Aerosol-scattering lidar signal

$$P_a(r) = E_0 f(r) \frac{cA_r}{2r^2} \beta_a(r) \frac{\mathbf{P}(\pi, r)}{4\pi} \exp(-2\tau(r))$$

Measured

Molecules: Molecular-scattering lidar signal

$$P_m(r) = E_0 f(r) \frac{cA_r}{2r^2} \beta_m(r) \frac{3}{8\pi} \exp(-2\tau(r))$$

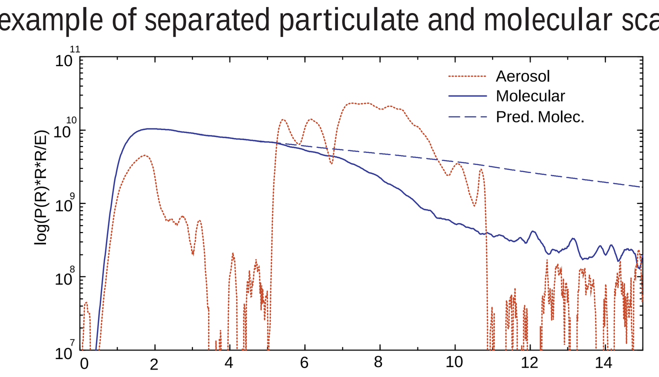
Calculated

System parameters
- E_0 = laser pulse energy, J
- c = speed of light, m s^{-1}
- A_r = collecting area of the receiver, m^2
- $f(r)$ = overlap factor

Optical depth:

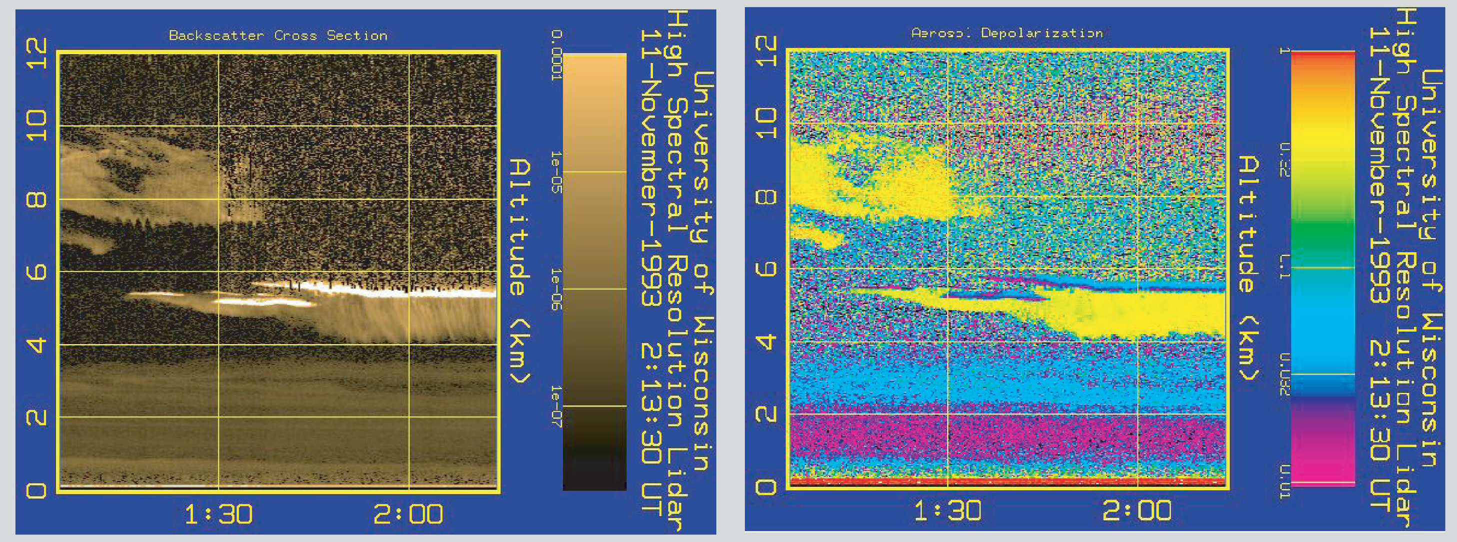
$$\tau(r) = \int_0^r \beta_e(r')dr'$$

An example of separated particulate and molecular scattering

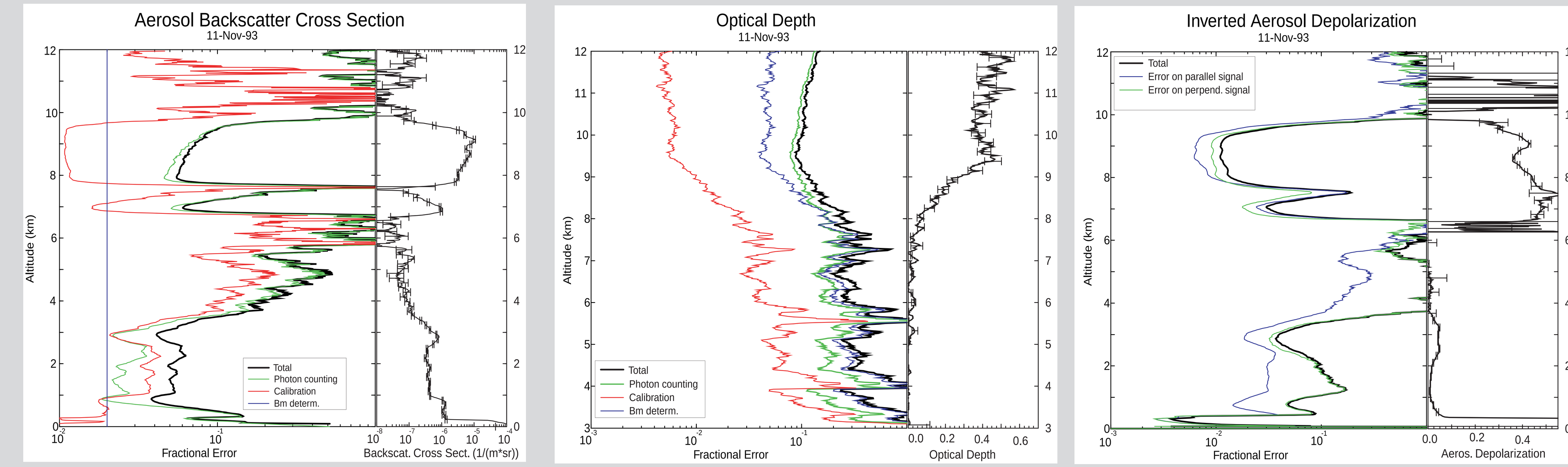


- **Molecular scattering cross section:** computed from Raleigh scattering theory and an externally supplied temperature profile.
- **Optical depth:** derived from the ratio of the received molecular signal to the predicted molecular signal.
- **Aerosol scattering cross section:** derived from the ratio of the observed aerosol-signal to the observed molecular-signal and scaled by the molecular-scattering cross-section.

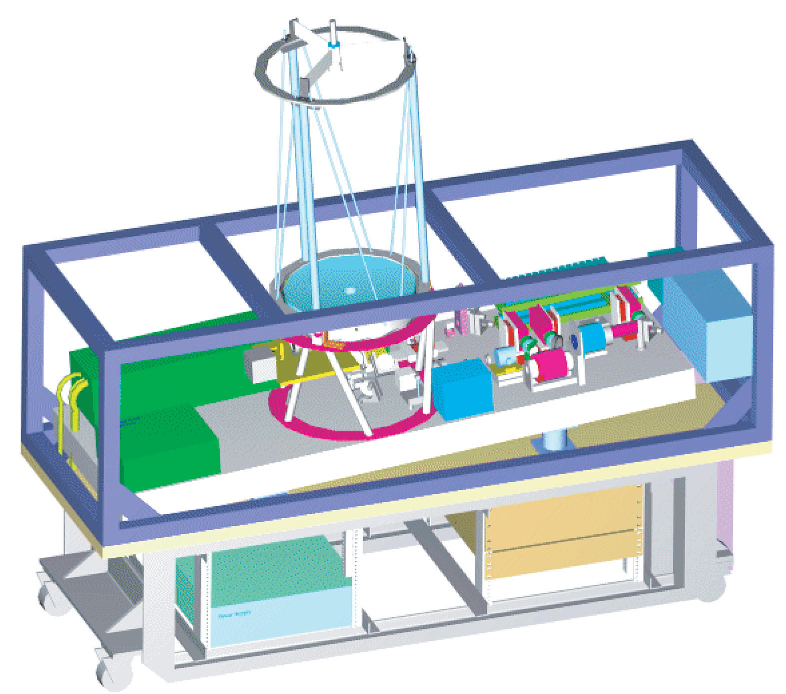
The HSRL Provides Calibrated Measurements with Known Error Bars--Data samples from the our previous system.



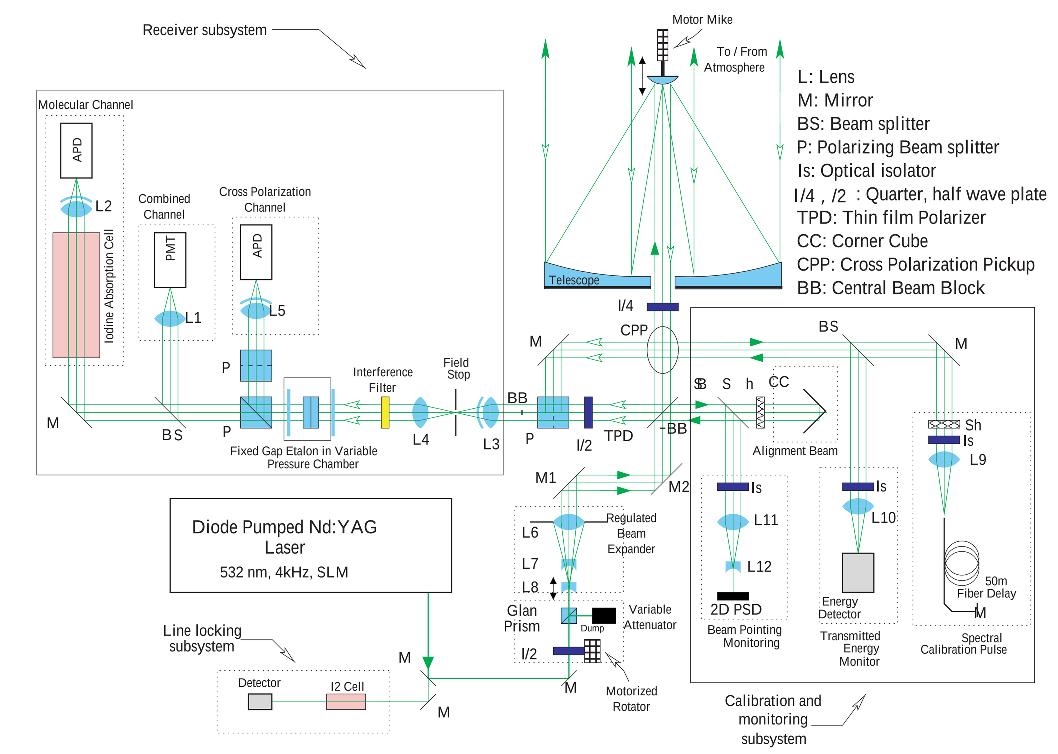
The HSRL provides calibrated measurements of aerosol backscatter cross-section, depolarization, and optical depth. Rigorous error bars can be computed for all quantities. Profiles and error estimates plotted on the right are derived from data obtained between 1:03 and 1;08 UT.



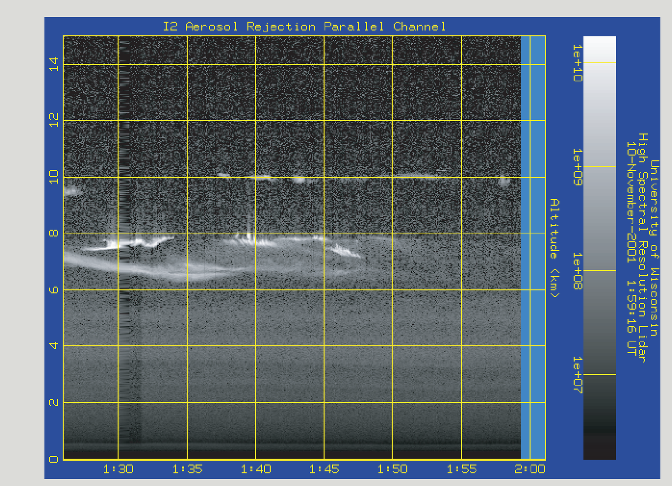
Profiles with error estimates are plotted in the right hand panels. Terms contributing to the errors are plotted in the left panels. Errors due to limitations in our knowledge of the molecular density profile are labeled "Bm determination", Errors due to calibration uncertainties are labeled "Calibration", and errors due to statistical fluctuations in the the number of photons counted are labeled as "Photon Counting".



A Perspective Drawing of the Arctic HSRL showing the 4-degree tilt of the telescope which is used to suppress specular reflections from oriented ice crystals.



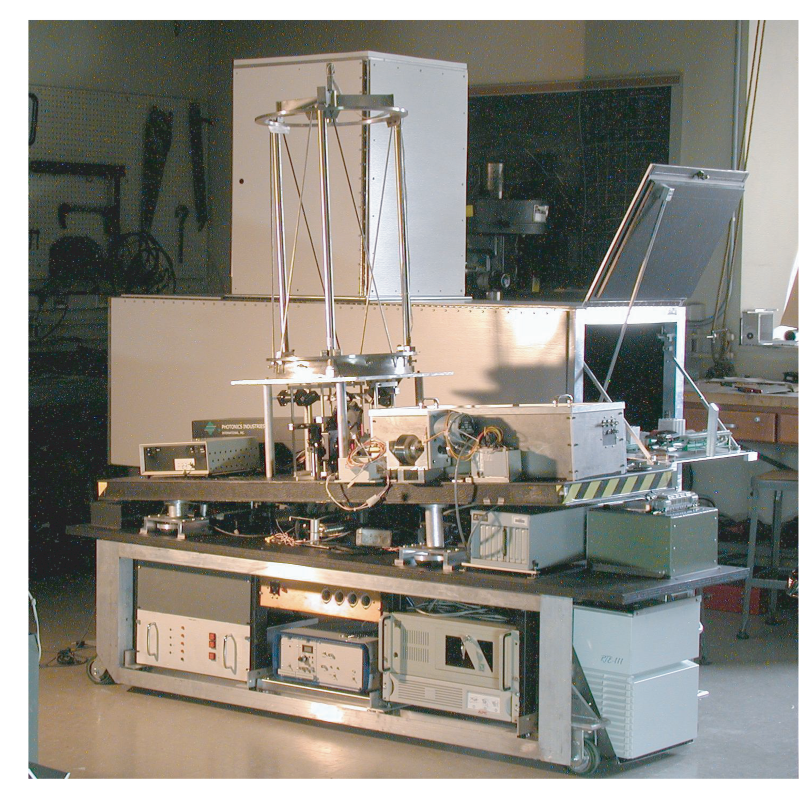
A Schematic showing the optical design of the new High Spectral Resolution Lidar



The first lidar cross section obtained with the new instrument.

The Arctic HSRL during first alignment and focusing tests which produced the lidar cross section displayed above. The system was mounted on a temporary table and the detectors wired to the our existing HSRL to allow data acquisition before the new data system was available. The system was operated as a standard lidar without the iodine filter for these tests.

The lidar mounted in it's temperature controlled housing



The lidar with the environmental housing removed

Key Design Features

- **Remote Operation:** Designed for continuous remote untended operation as an inter net appliance.
- **Transceiver Design:** Laser light goes through same optics for maximum stability of transmit and receive optical axis.
- **Passive TR switch:** Polarization is used to separate the transmitted laser pulse from the atmospheric returns.
- **Near Range Measurements:** Computer control of focus allows calibration of overlap function.
- **Stable Narrow Band Filter:** Fixed-gap Fabry-Perot etalon is pressure tuned by computer with bellows chamber.
- **Stable Iodine Notch Filter:** Precise temperature control provides stable spectral characteristics (line width and rejection).
- **High Efficiency Detector:** A Geiger mode avalanche photodiode (APD) provides high quantum efficiency in molecular channel.
- **Eye Safety:** The laser bream is spread over sufficient area to allow safe viewing of the output beam.

Arctic HSRL Specifications

Receiver:	
Aperture:	40 cm
Field of View:	0.075 mrad
Spectral bandpass:	8 pm
Detector quantum eff.	~40%
Transmitter:	
Average Power:	0.6 W
Spectral Width:	< 0.1 pm
Pulse Repetition Rate:	4 kHz

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