# **29th Review of Atmospheric Transmission Models Meeting**

*13-14 June 2007*
*Museum of Our National Heritage*
*Lexington Massachusetts*

## ***Session 2: LIDAR***

*Invited Presentation ...*

**Chemical Species Measurements in the Atmosphere Using Lidar Techniques**

*Philbrick, C.R. (Slides & Paper)*

**White Light Lidar (WLL) Simulation and Measurements of Atmospheric Constituents**

*Brown, D.M., P.S. Edwards, Z. Liu and C.R. Philbrick (Slide Presentation)*

**Supercontinuum LIDAR Measurements of Atmospheric Constituents**

*Brown, D.M., P.S. Edwards, K. Shi, Z. Liu, and C.R. Philbrick (Paper)*

**Multistatic Lidar Measurements of Aerosol Multiple Scattering**

*Park, J.H., C.R. Philbrick and G. Roy*

*(Slides & Paper)*

# Multistatic LIDAR Measurements of Aerosol Multiple Scattering

June 13. 2007

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# Outline

- Introduction to Multiple Scattering
- Multiple Scattering Relationship

  - Depolarization

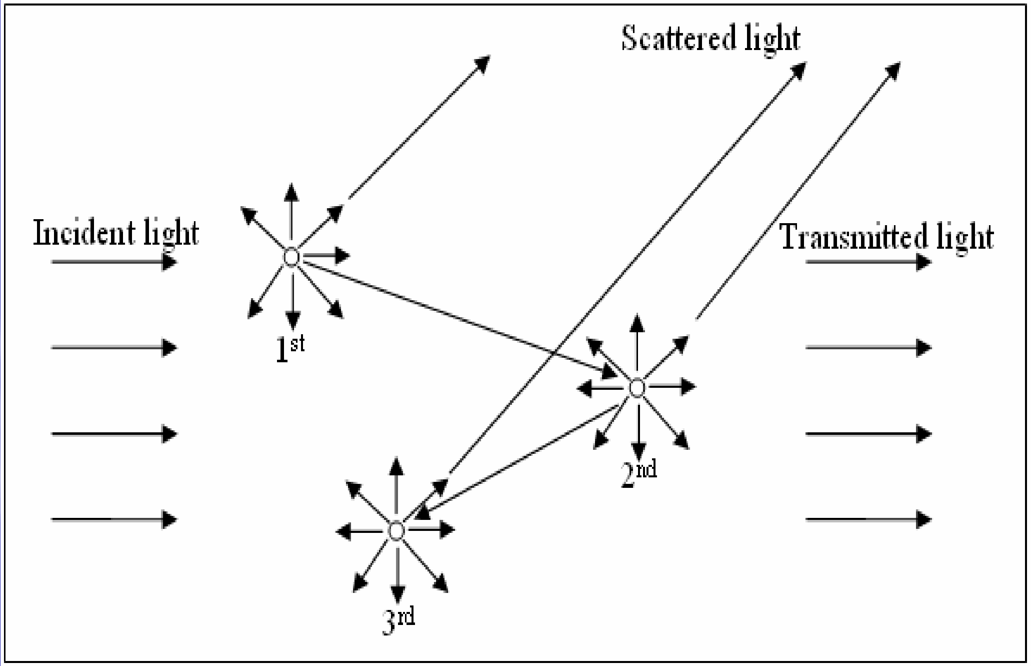
  - Radial Distribution of Scattered Radiation
- Multistatic Imaging Lidar

  - Lidar Geometry

  - Multistatic Lidar Theory
- Experimental Results
- Conclusions

# What is Multiple Scattering?

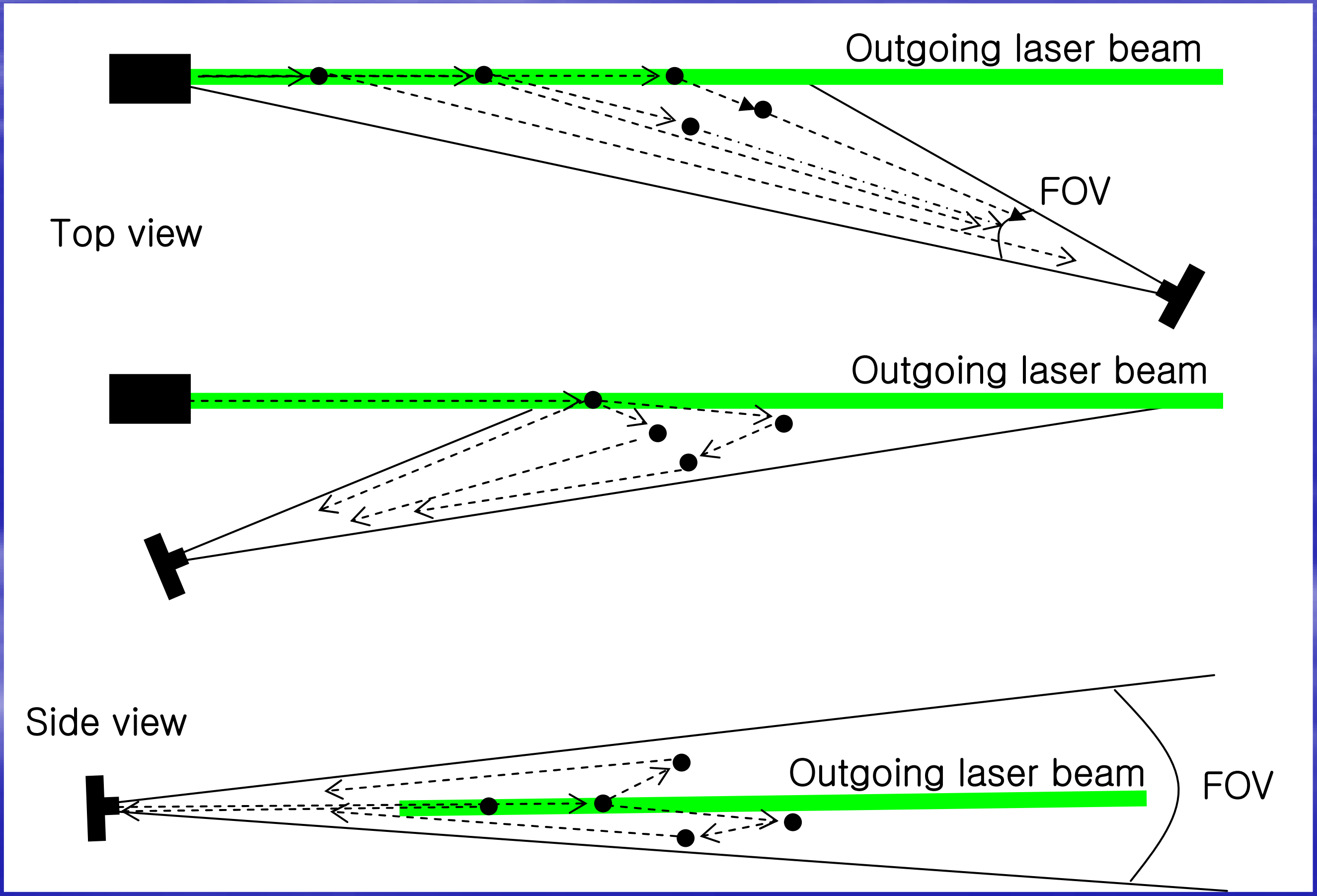
- **Multiple Scattering Process**
  - The first particle scatters the incident beam isotropically
    : Single scattering (or Independent scattering)
  - A portion of the scattered light reaches the 2nd particle which scatters isotropically again: 2nd order scattering
  - This phenomena will take place repeatedly: Multiple scattering




Multiple scattering process involving first, second, and the third order scattering [After Liou, 2002]

# What is Multiple Scattering?

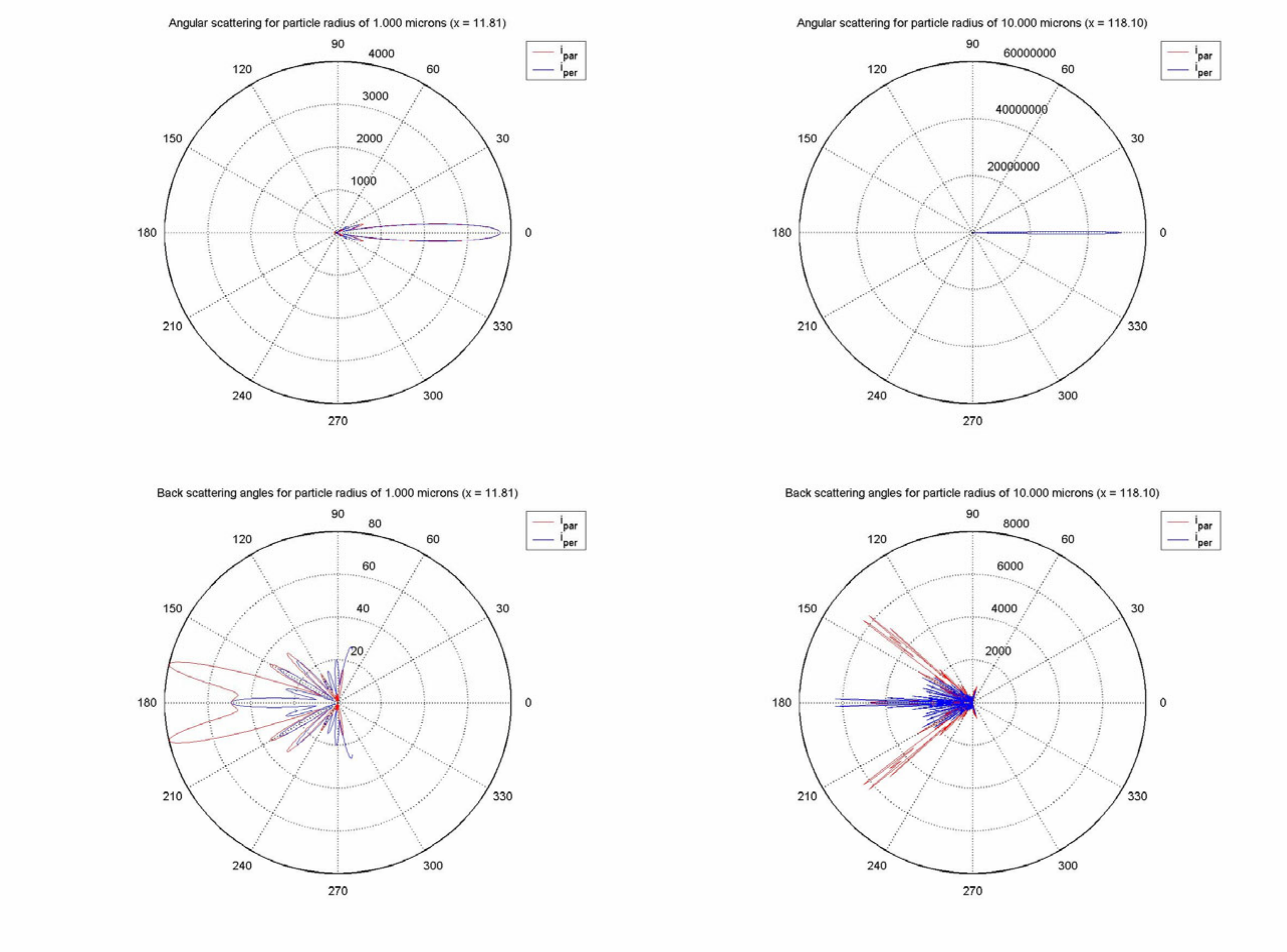
- Multiple Scattering Pattern into back and forward scattering regions




Multiple scattering within an optically thick medium

# What is Multiple Scattering?

- Scattering Phase Function



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# Multiple Scattering & Depolarization

- **Polarization Ratio, $\delta_p$**

$$\delta_p = \frac{I_{\parallel}(\theta)}{I_{\perp}(\theta)} = \frac{\int \left|S_2(r,\theta)\right|^2 y(r)dr + Molecular_{\parallel}}{\int \left|S_1(r,\theta)\right|^2 y(r)dr + Molecular_{\perp}}$$

**where $S_{1,2}$ are scattering matrices, y(r) is particle density distribution**

- **Sources of Depolarization**

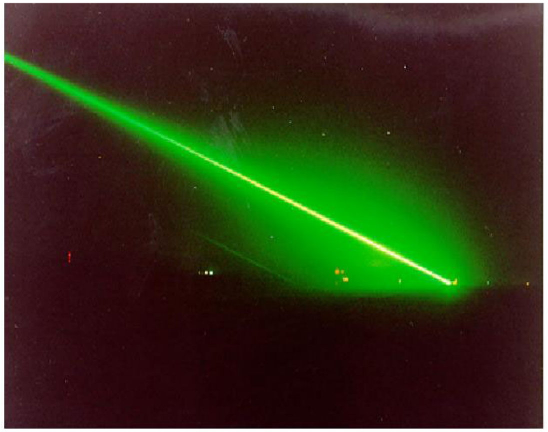
**- Anisotrophy of the polarizability of the molecules**

**- Nonsphericity of atmospheric particles**

**- Multiple scattering**

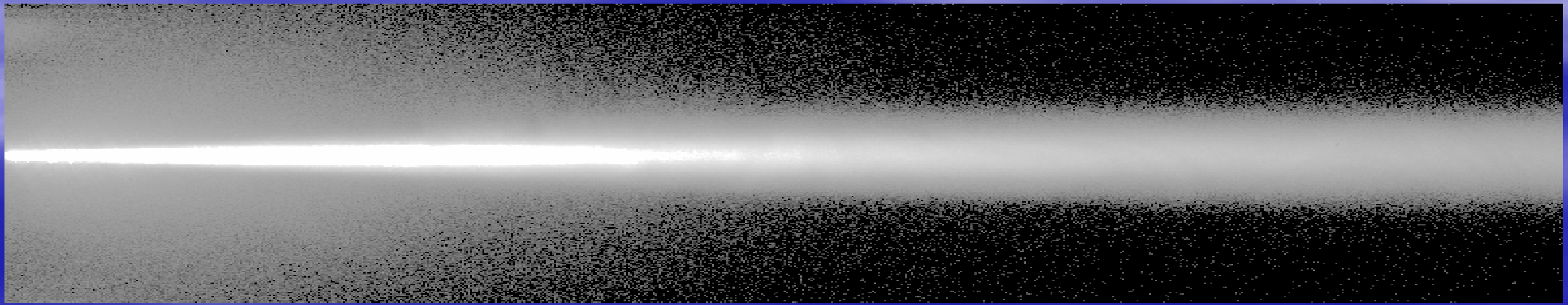
# Multiple Scattering & Radial Distribution

- Transmitted beam : Single scattering
- Wide aureole : Multiple scattering effect


From Target looking at Laser


Looking from Side


From Laser Looking at Target


CCD image of a CW Nd-VYO4 laser beam propagating in fog oil

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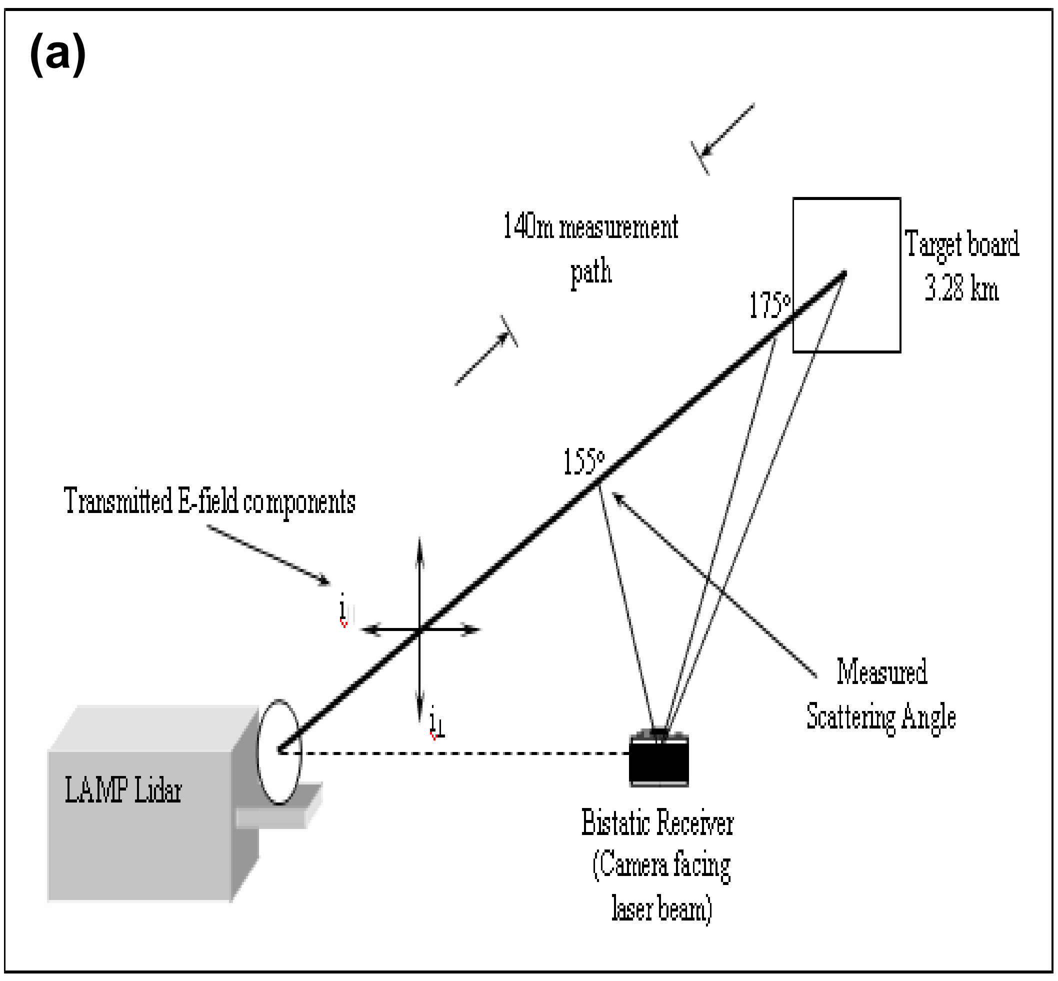
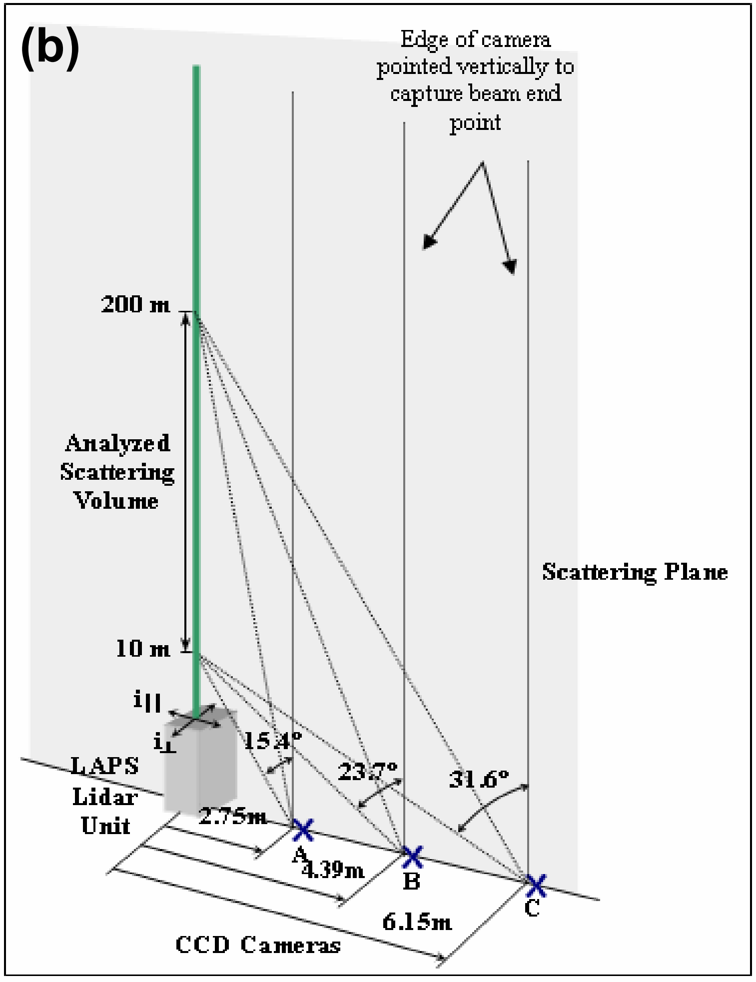
# Multistatic Imaging Lidar

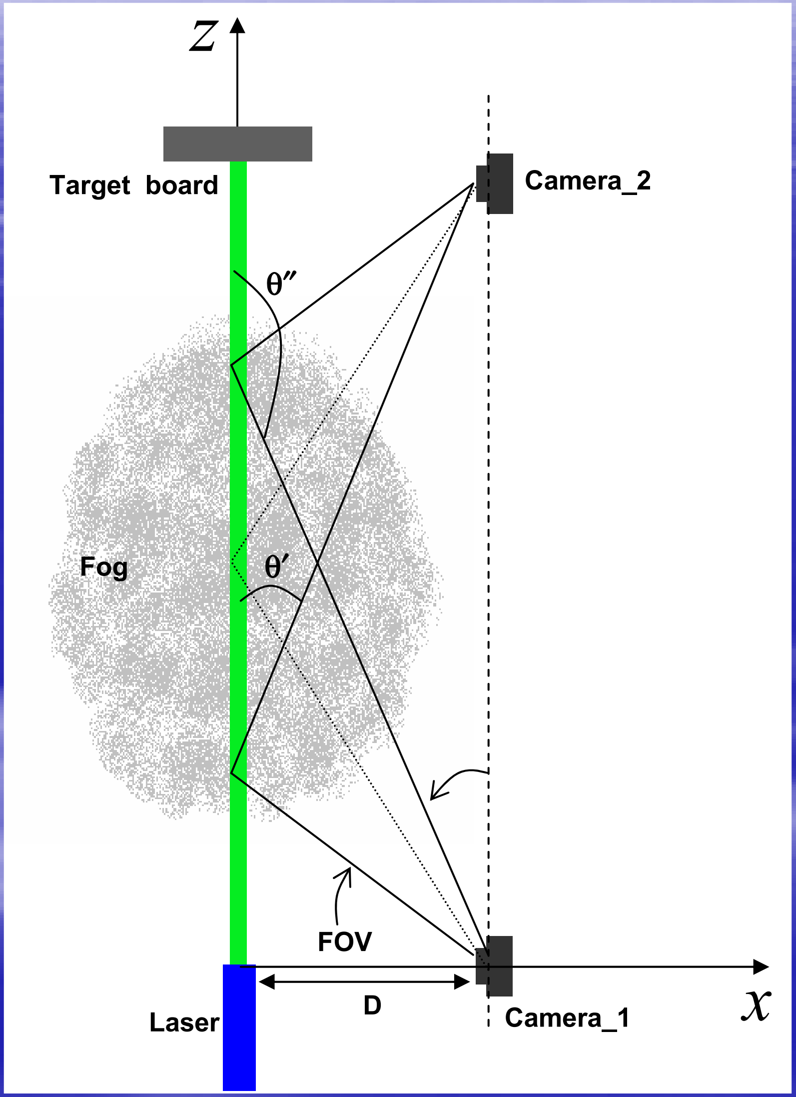



**Bistatic receiver [Stevens, 1996]**




**Multistatic receiver [Novitsky, 2002]**

# Multistatic Imaging Lidar (Cont.)

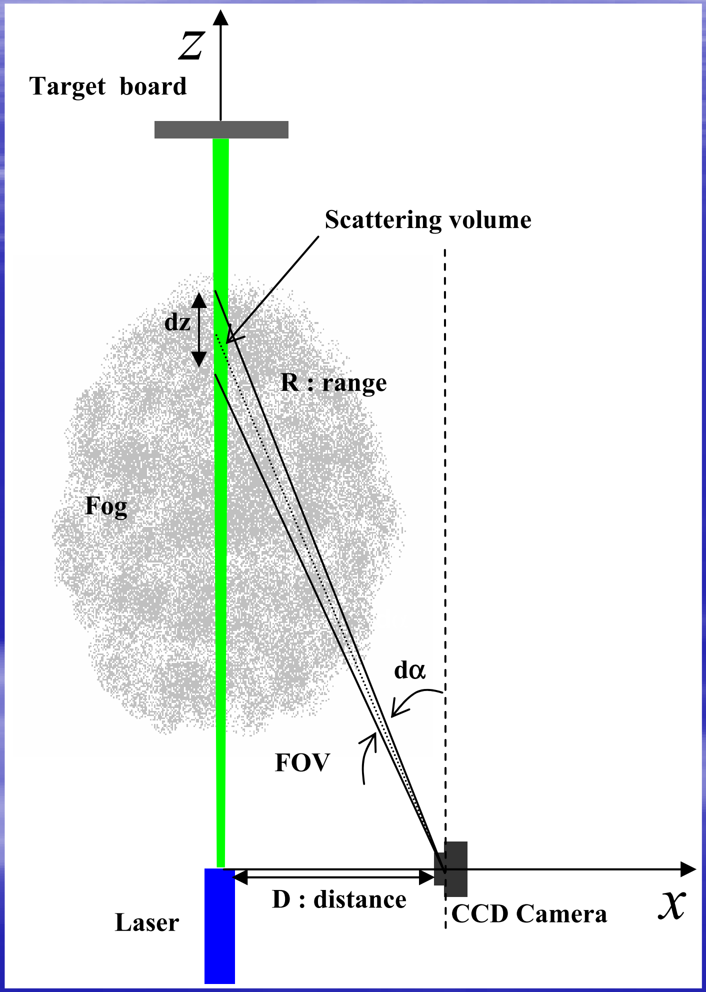



Configuration of a multistatic imaging lidar setup

**Multistatic Equiment Configuration**

- **Transmitter : CW Nd-VYO4**
  - Wavelength : 532 nm
  - Output power : 100 mW
  - Beam divergence : <0.2 mrad
- **Receiver**
  - Three 16-bit, thermoelectrically cooled CCD cameras (768×512)
  - FOV : 48°

# Multistatic Imaging Lidar (Cont.)




## Multistatic Lidar Equation

$$P_r = P_t \frac{K A T_t T_r \beta(z,\theta)}{D} d\alpha$$

(Meki *et al.*, 1996)

$$dz = \frac{R^2}{D} d\alpha$$

$P_r$ : received power

$P_t$ : transmitted power

K : optical efficiency

A : collecting area of the receiver

$T_r$, $T_t$ : atmospheric transmittance

$\beta(z,\theta)$ : scattering coefficient

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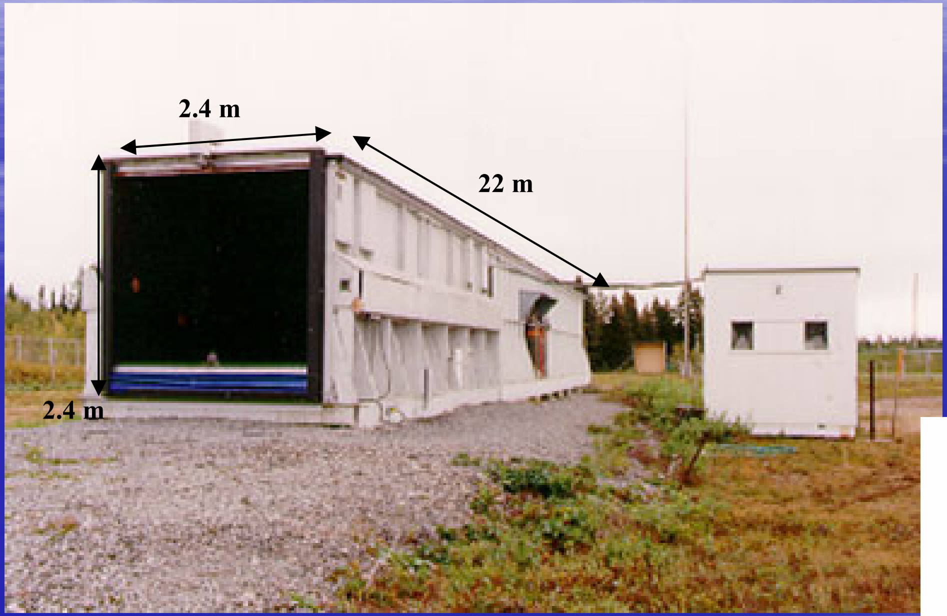
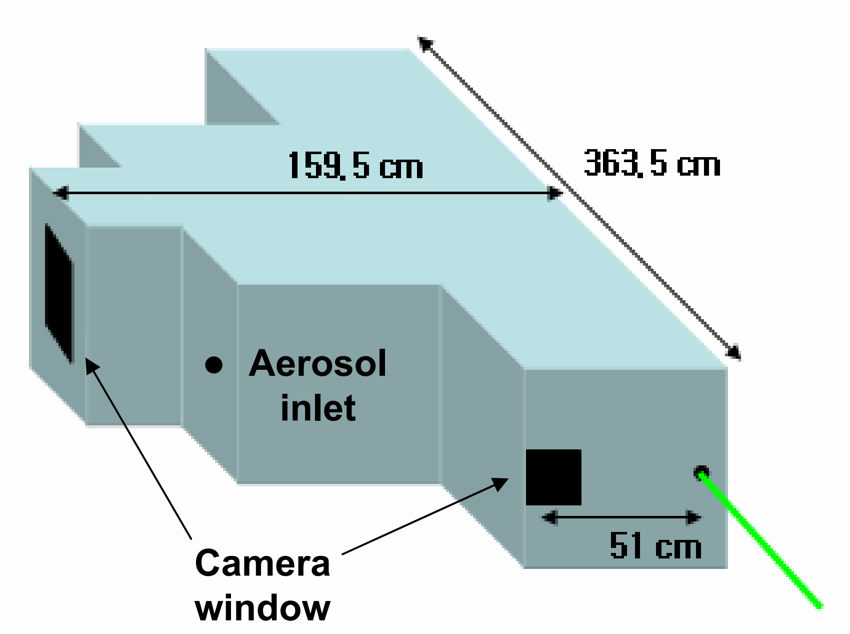
# Experimental Results

- Aerosol Chambers at DRDC and PSU



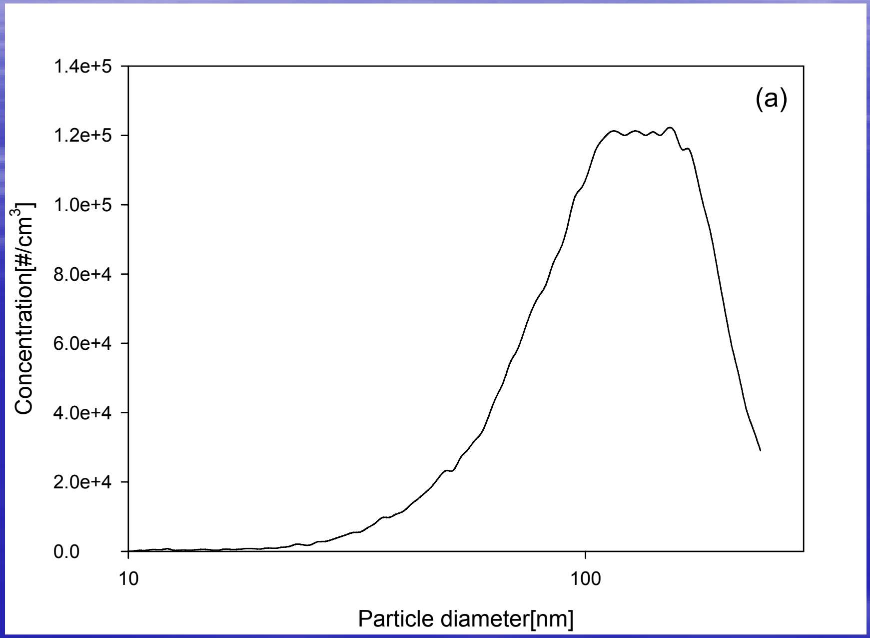

Aerosol chamber at DRDC

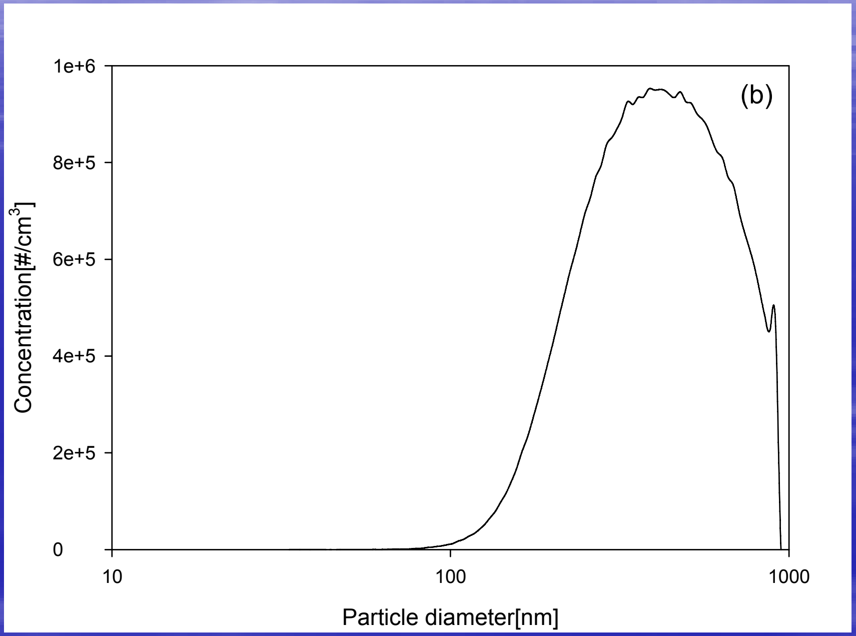



Aerosol chamber at PSU

# Experimental Results (Cont.)

- **Size Distribution of Fog Oil measured by SMPS**



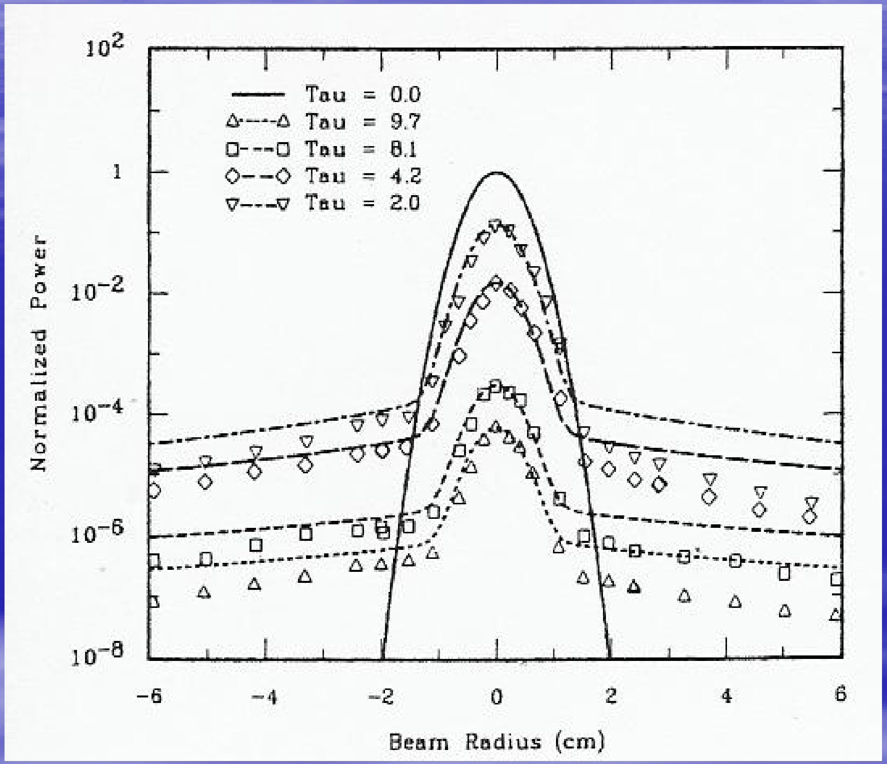



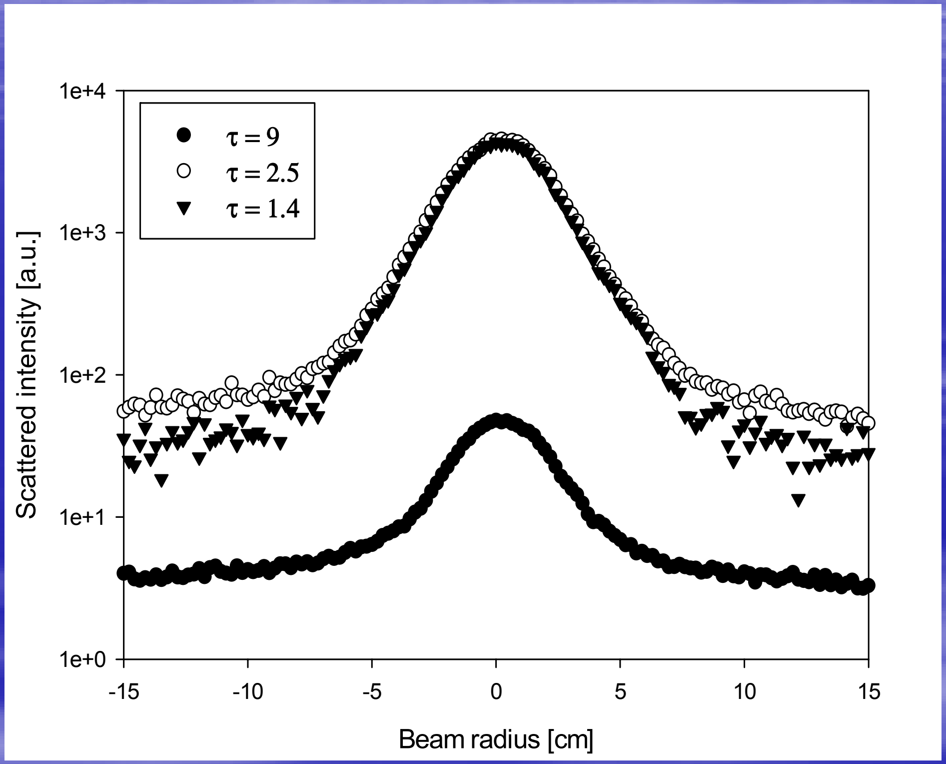

| Parameter | Fog oil (a) | Fog oil (b) |
|---|---|---|
| Median diameter[nm] | 117.6 | 450 |
| Geo. St. Dev | 1.71 | 1.71 |
| Total Conc.[#/cm$^3$] | $6.03 \times 10^4$ | $1.09 \times 10^6$ |

Parameters of the best fit log-normal size distribution of (a) MDG Super Max 5000 fog oil generator at DRDC (b) TDA-5A aerosol generator at PSU

# Experimental Results (Cont.)

- **Cross-sectional Distribution of Multiply Scattered Beam**



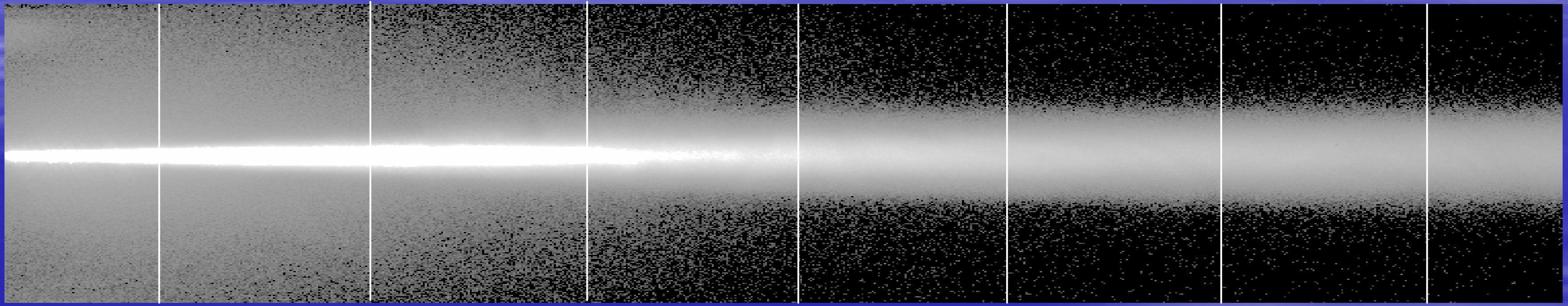



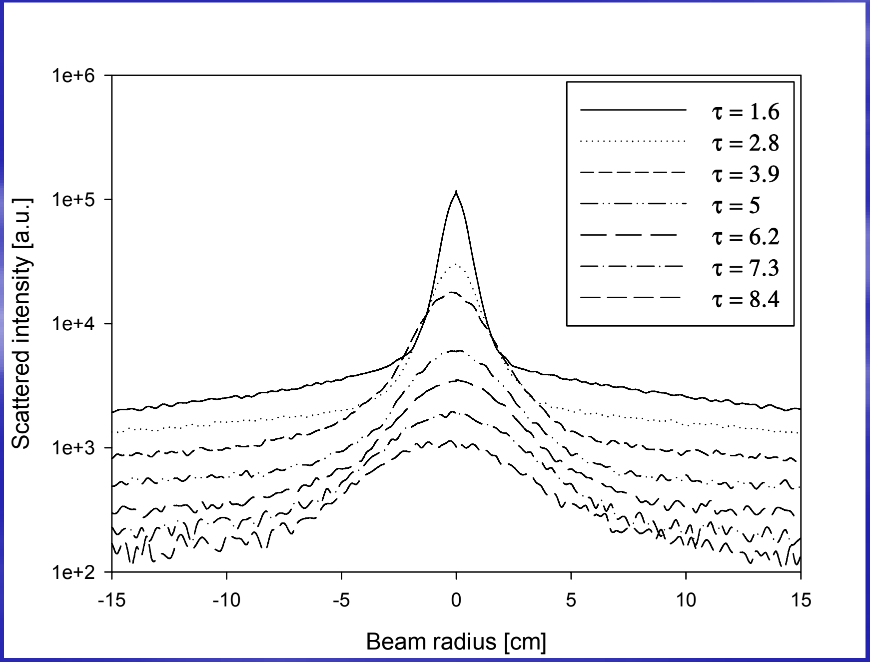

**Bissonnette's model and measurements (Bissonnette, 1995)**

**Multistatic lidar data using fog oil (b)**

# Experimental Results (Cont.)

- **Cross-sectional Distribution of Multiply Scattered Beam**





# Experimental Results (Cont.)

- Cross-sectional Distribution of Multiply Scattered Beam

  - Depending on number density

  - Transmitted beam : Gaussian shape (single scattering)

    Beer-Lambert's law

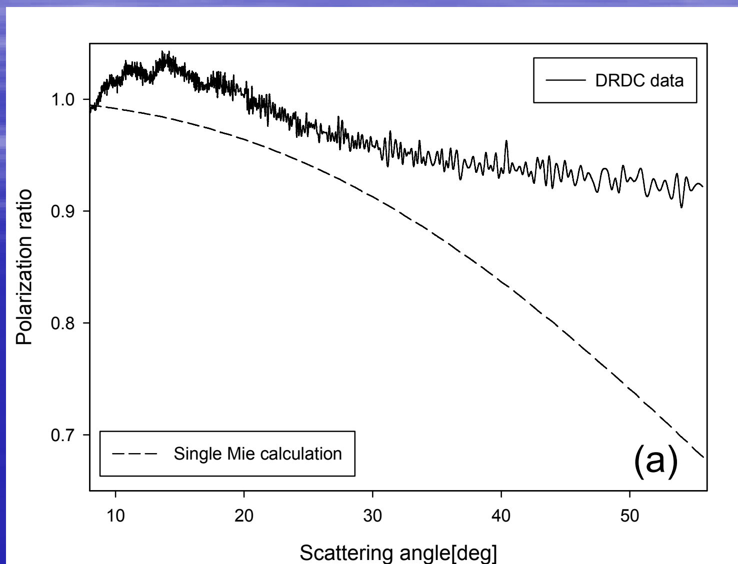
  - Aureole : Multiple scattering

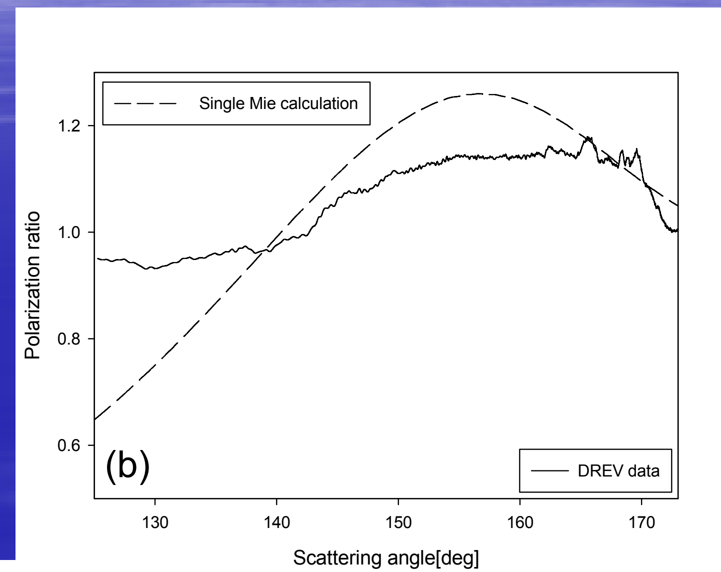
    Intensity increase with optical depth

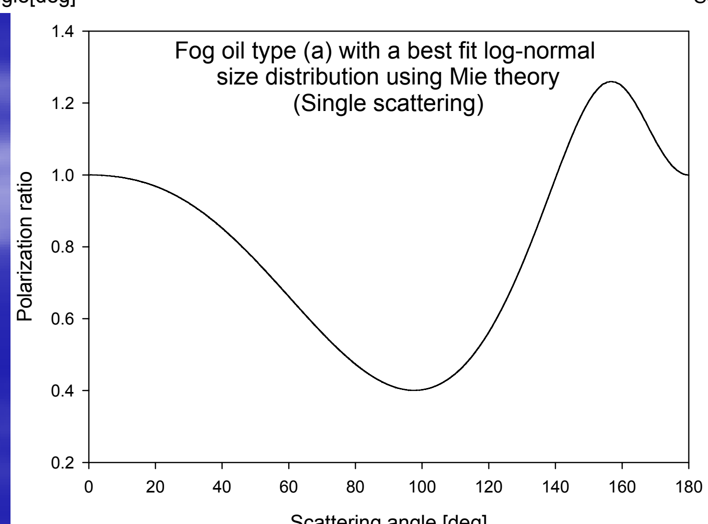
    Diffusion process

# Experimental Results (Cont.)

- Polarization Ratio




**Polarization ratio at**

**(a) forward region**

**(b) backward region**

**using fog oil (a)**

# Conclusions

## Multiple Scattering · · · · · · · ·

- must be considered in an optically thick medium
- effects can be recognized by measurement of polarization ratio and radial distribution of scattered radiation
- depends strongly on number density of aerosols
- depolarizes radiation at angles between 40° and 140°

# References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Thank you for your Attention!!

Questions?