International Conference on Interstellar Dust, Molecules and Chemistry
IUCAA, Pune, November 22 – 25, 2011

Investigations on the forward scattering behavior of 543.5 nm, 594.5 nm and 632.8 nm light by a carbonaceous interstellar dust analogue using an original laboratory setup

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Outline of the presentation

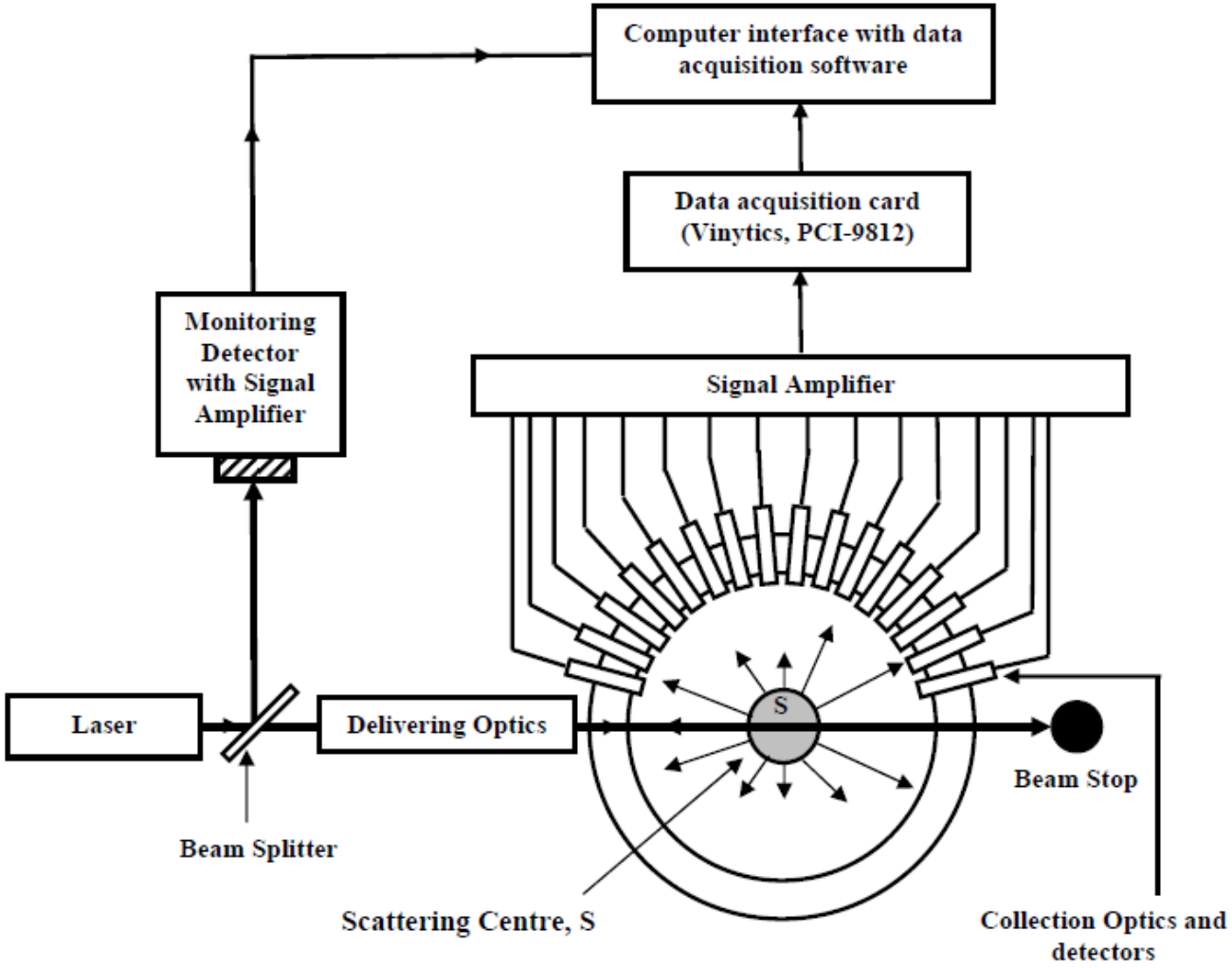
- Light Scattering Setup.
- Calibration.
- Experiments on carbonaceous interstellar dust analogue.

The Light Scattering Setup

Experimental setup for light scattering studies

- Laser source ($\lambda \approx 543.5$ nm, 594.5 nm and 632.8 nm)
- Controlled sample holders
- Spectroscopic arrangements
  - Polarizer
  - Analyzers
- Data acquisition systems
  - Photodetectors (Silicon photodiode BPW34)
  - Amplifier circuitry
  - Computer interface
- Associated instrumentation

Schematic Diagram of the Setup



*Ankur Gogoi, Lakhya J Borthakur, Amarjyouti Choudhury, George A Stanciu and **Gazi A Ahmed**. Detector array incorporated optical scattering instrument for nephelometric measurements on small particles. *Meas. Sci. Technol.* 20, 095901 (10pp), 2009.

A photograph of the light scattering setup. L: laser source; S: mechanical jack; N: nebulizer for spraying water droplets; T: turn table; A: detector array; P: aerosol nebulizer; R: external rack.

Mueller Matrix Formalism

The intensity and state of polarization of a beam of light can be completely described by Stokes vector I={*I*, *Q*, *U*, *V*}.
I is the total intensity,
Q is the difference between the polarization intensities at 0^0 and 90^0,
U is the difference between the polarization intensities at $+45^0$ and $-45^{0,}$
V is the difference between the left and right circular polarization intensities.

The Stokes vector describing the incident and the scattered light are connected by a 4×4 scattering matrix, S_{ij}, where *i*, *j* = 1 to 4, as given below

$$\begin{pmatrix} I_s \\ Q_s \\ U_s \\ V_s \end{pmatrix} = \frac{1}{k^2 r^2} \begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{pmatrix} \begin{pmatrix} I_i \\ Q_i \\ U_i \\ V_i \end{pmatrix}$$

Quantities measured in this work

- The measurements reported here are the volume scattering function $\beta(\theta)$ and the degree of linear polarization (or linear polarization ratio), $P(\theta)$.
- The volume scattering function $\beta(\theta)$ is determined by measuring the scattered light intensity as functions of scattering angle for unpolarized incident light.
- Moreover $\beta(\theta)$ is normalized to unity at 10º using the equation,

$$\beta_{norm} = \frac{\beta(\theta)}{\beta(10°)}$$

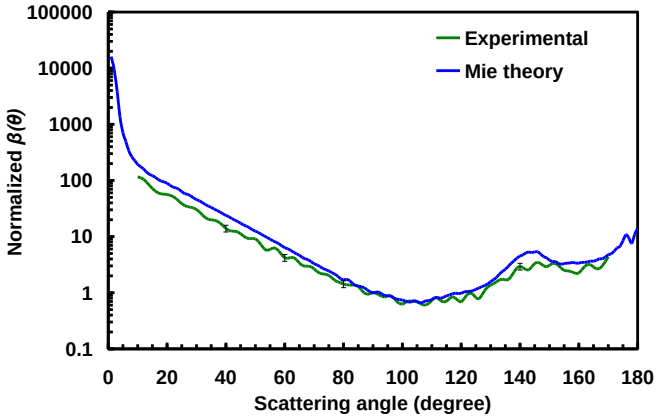
- For unpolarized incident light the degree of linear polarization is defined by the ratio, $-S_{12}/S_{11}$ and is given by,

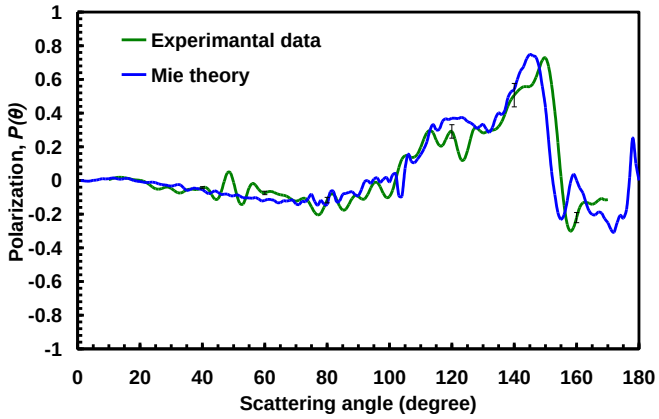
$$P(\theta) = -\frac{S_{12}(\theta)}{S_{11}(\theta)} = -\frac{\beta_{12}(\theta)}{\beta_{11}(\theta)} = \frac{I_{UV} - I_{UH}}{I_{UU}}$$

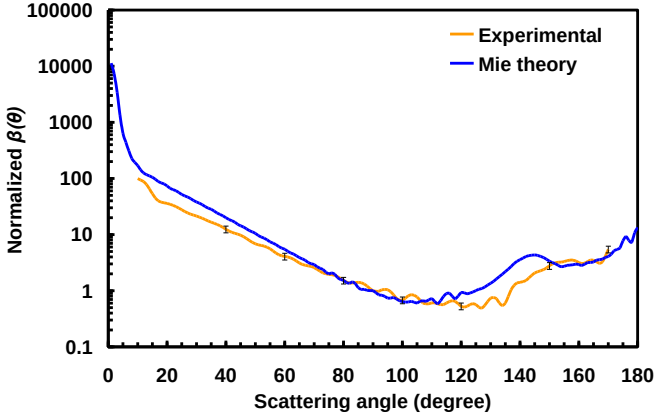
Calibration of the light scattering setup

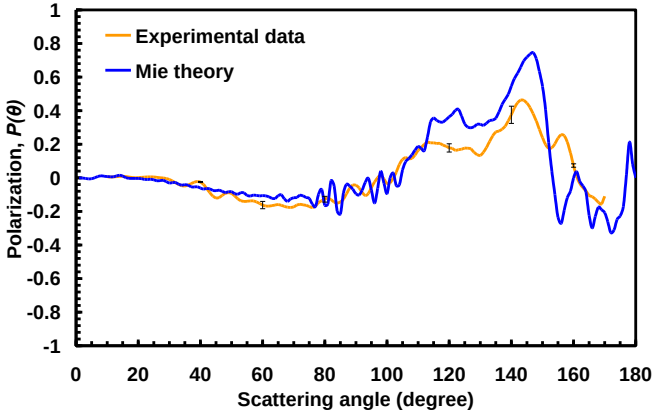
To calibrate the instrument extensive experiments on water droplets and polystyrene spheres suspended in double distilled water were performed with laser beams of wavelengths at 543.5 nm, 594.5 nm and 632.8 nm as incident light and the results obtained were compared with Mie calculations.

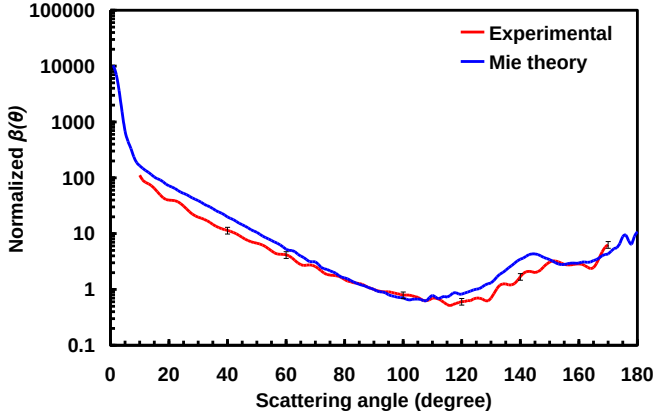
Experiment with water droplets

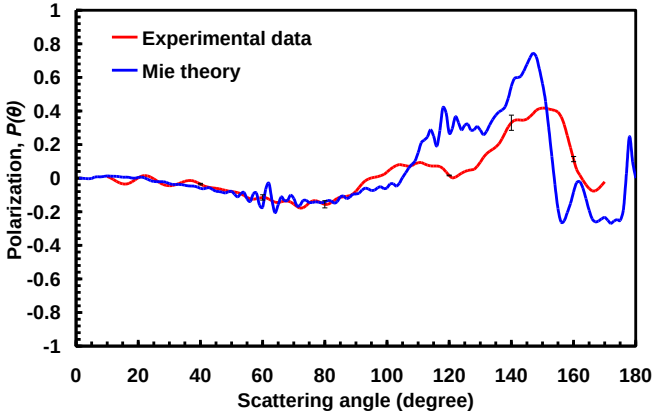






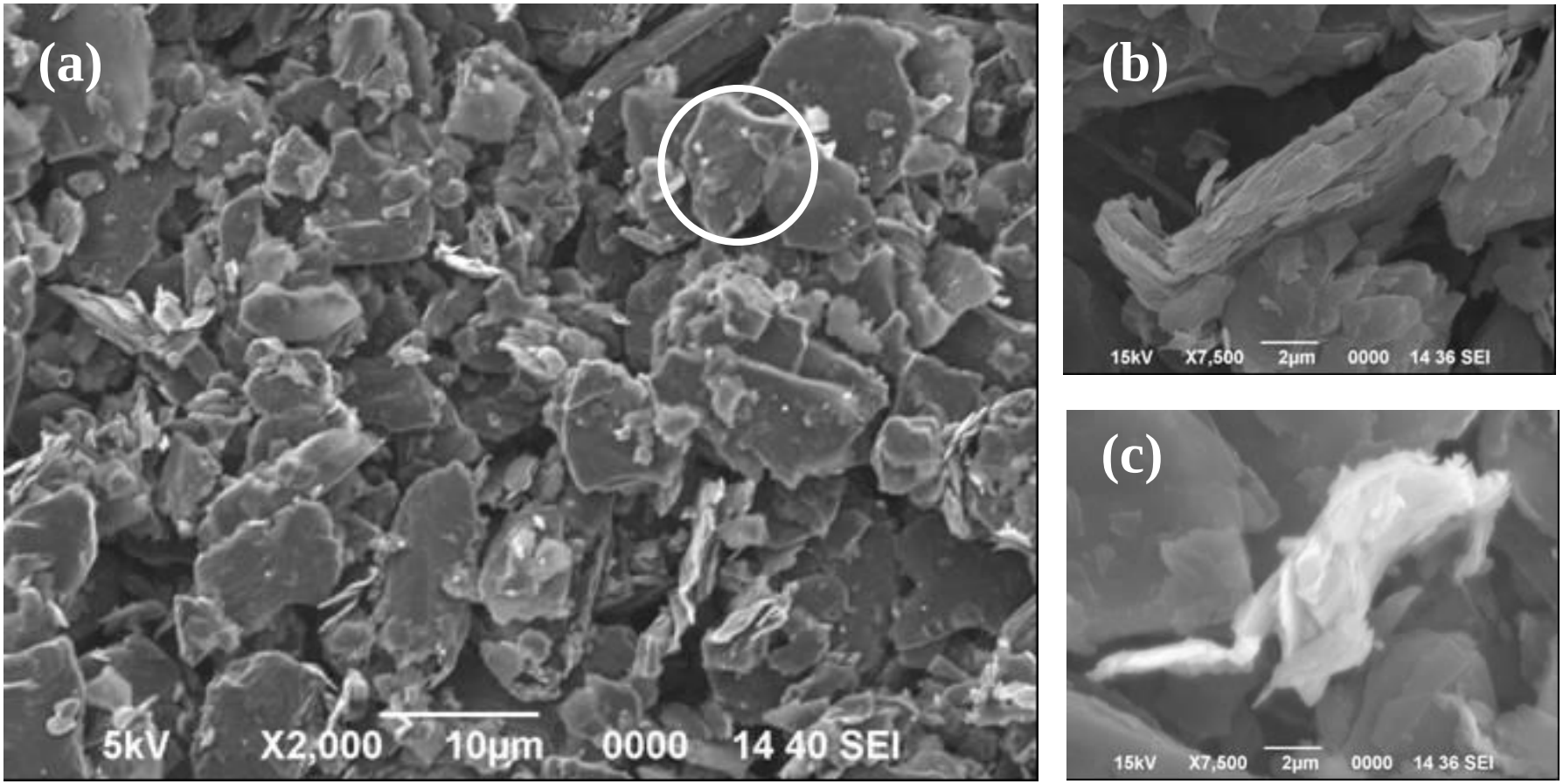




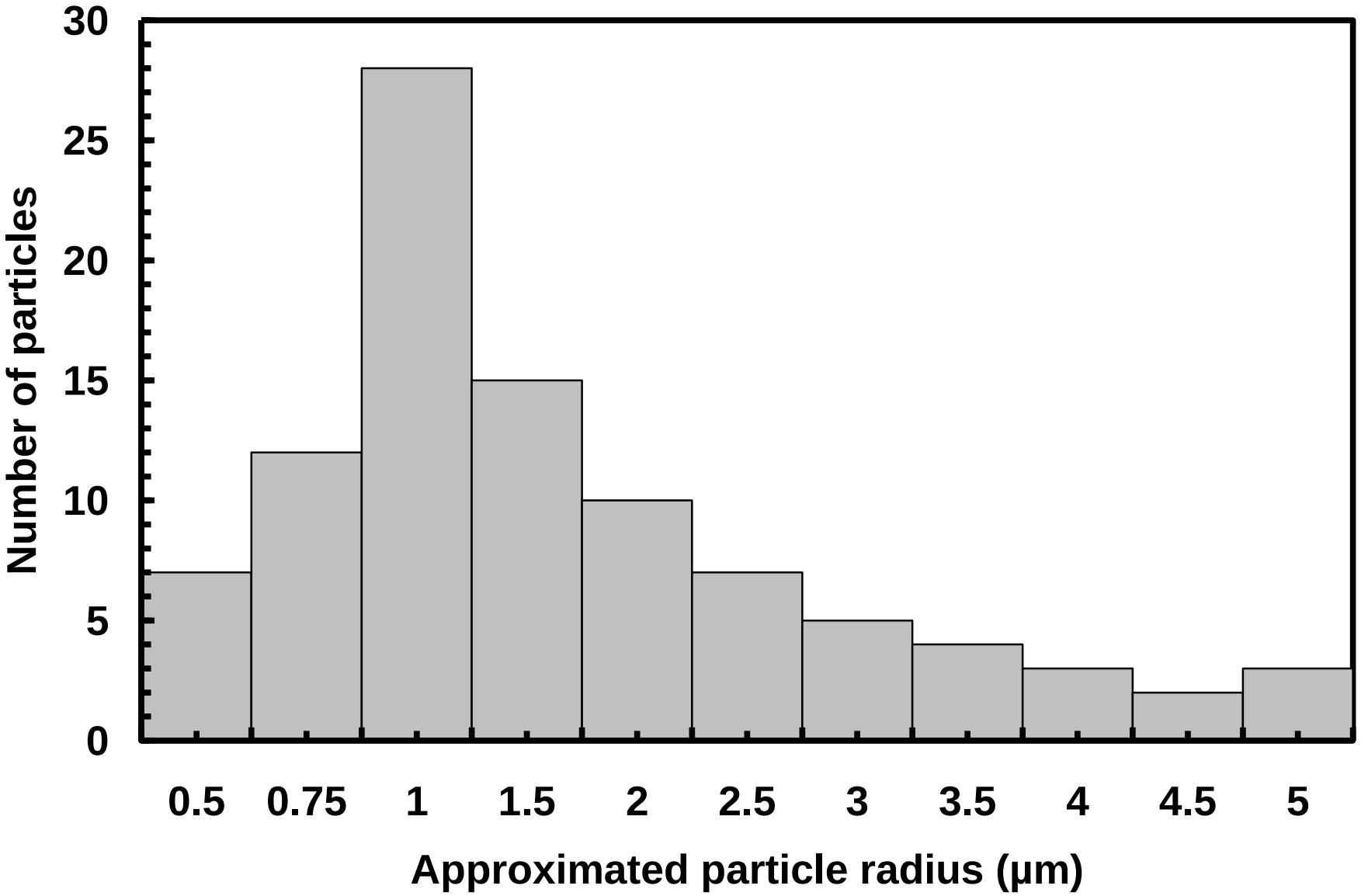


Measured volume scattering function, ***β(θ)*** and degree of linear polarization, ***P(θ)*** of water droplets are denoted by green, orange and red lines for 543.5 nm, 594.5 nm and 632.8 nm incident laser wavelengths respectively. The graph for Mie calculations is shown by solid blue line.

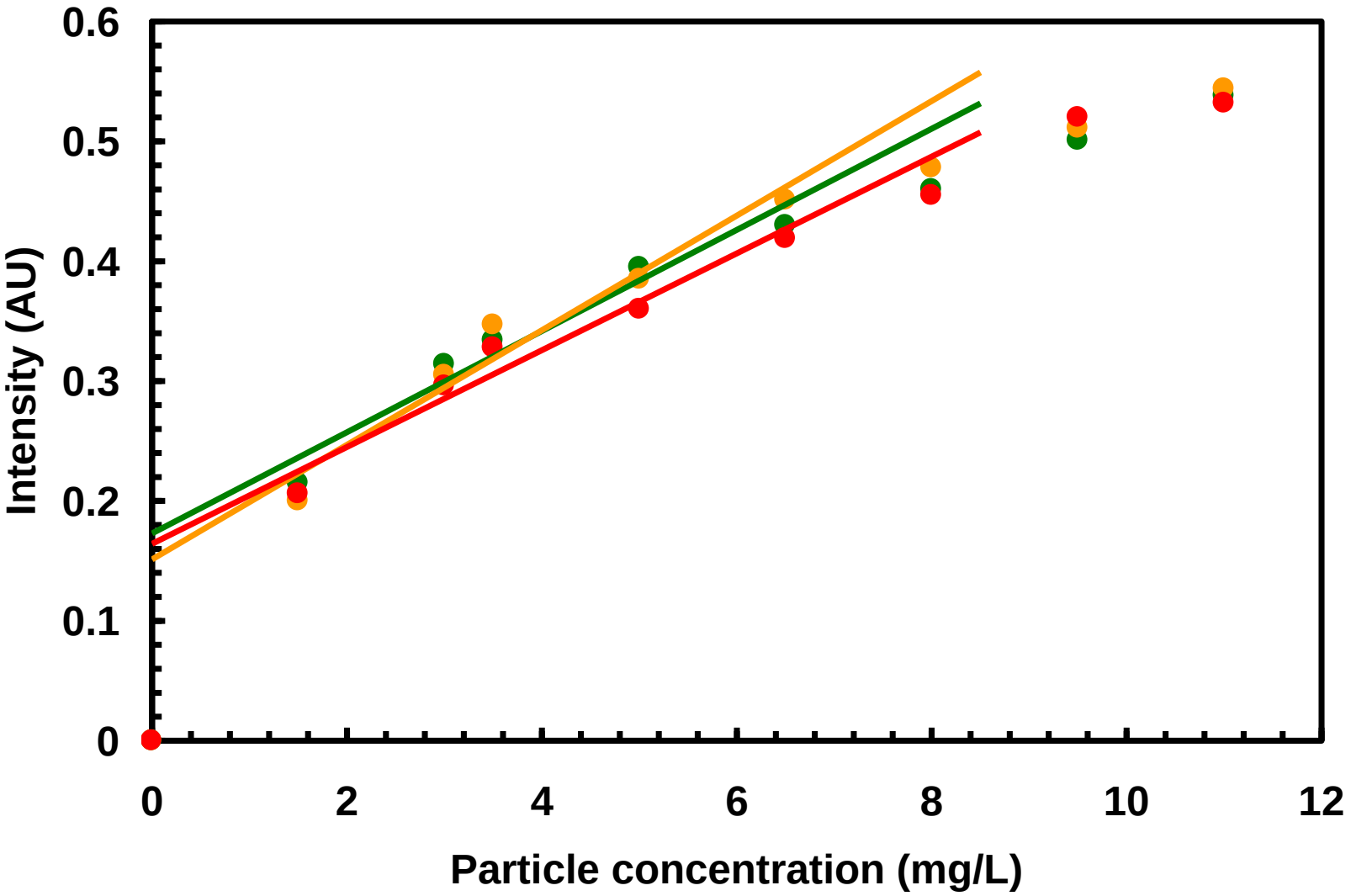
Experiments on carbonaceous interstellar dust analogue.



Scanning Electron Microscopy (SEM) images of nonspherical graphite particles. The white circle in (a) represents an approximated particle having equivalent radius of the circle. Side view of a graphite particle is shown in (b) whereas (c) shows another particle of highly irregular shape.



Approximated size distribution of the graphite particles

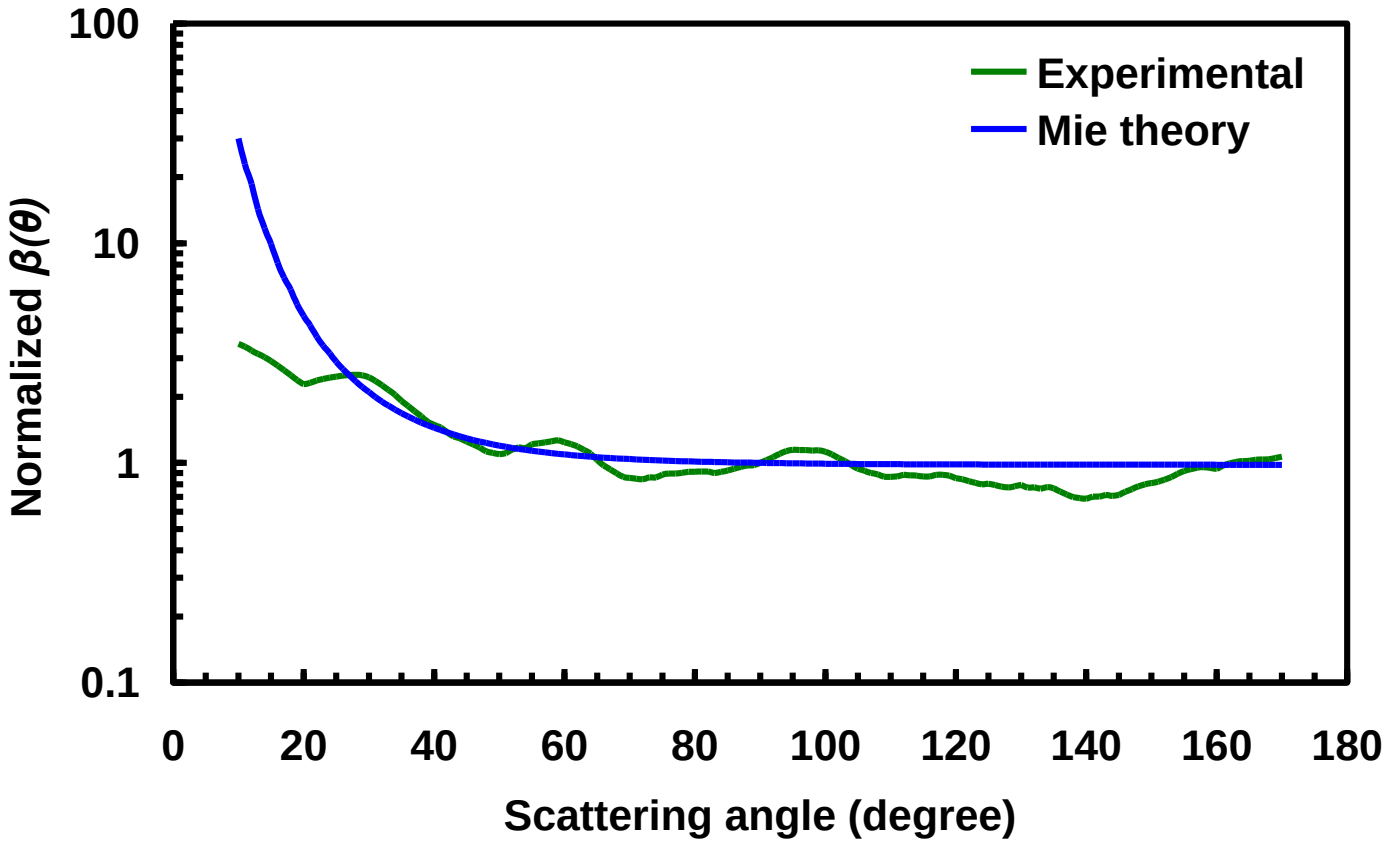


Graph for the scattered intensity light for unpolarized light versus concentration of graphite particles for a fixed position of the detector at 10^0. Results for 543.5 nm, 594.5 nm and 632.8 nm incident wavelengths are shown by green, orange and red circles respectively. The straight lines are fits to the initial linear regime.

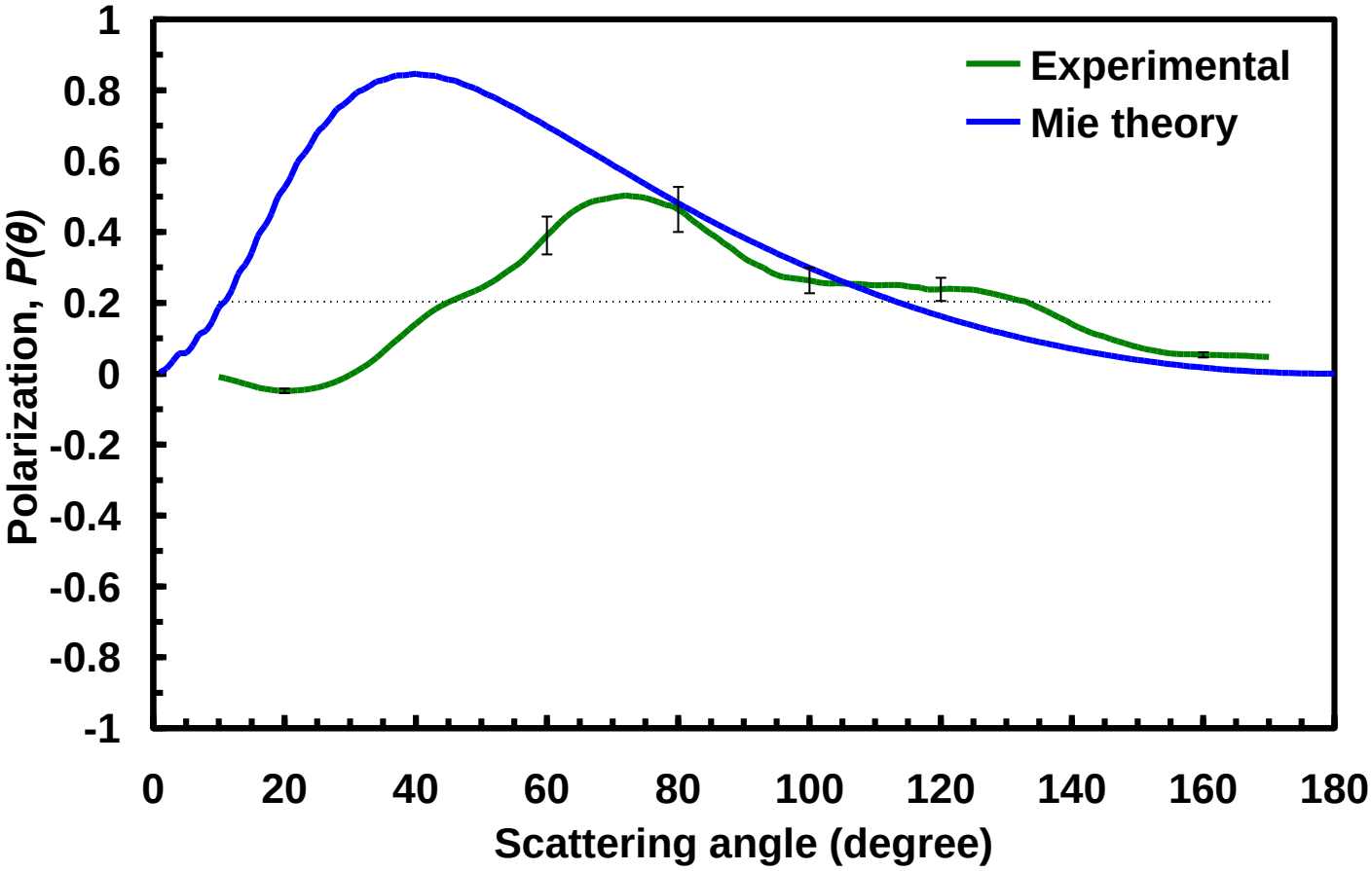
Estimated parameters

PARAMETERS	VALUE
Size distribution	Log normal
Modal radius (in μm)	1
Variance, σ^2	1
Minimum particle radius (in μm)	0.5
Maximum particle radius (in μm)	5
Incident light wavelengths in nanometers	543.5, 594.5 and 632.8
Environment refractive index	1.00 + i0.00000
Average refractive index of graphite at 543.5 nm	2.57+ i1.595

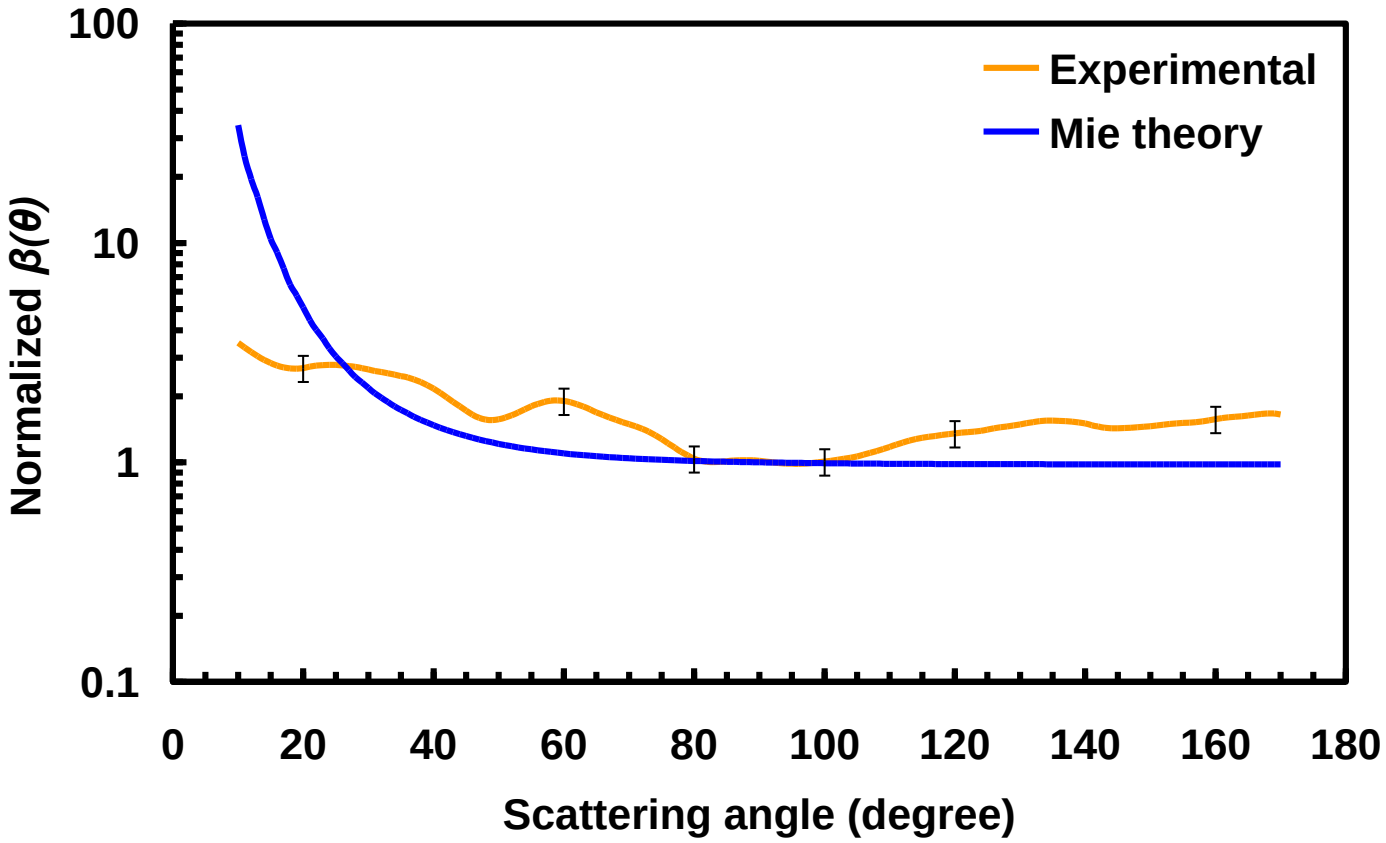
Results and analysis



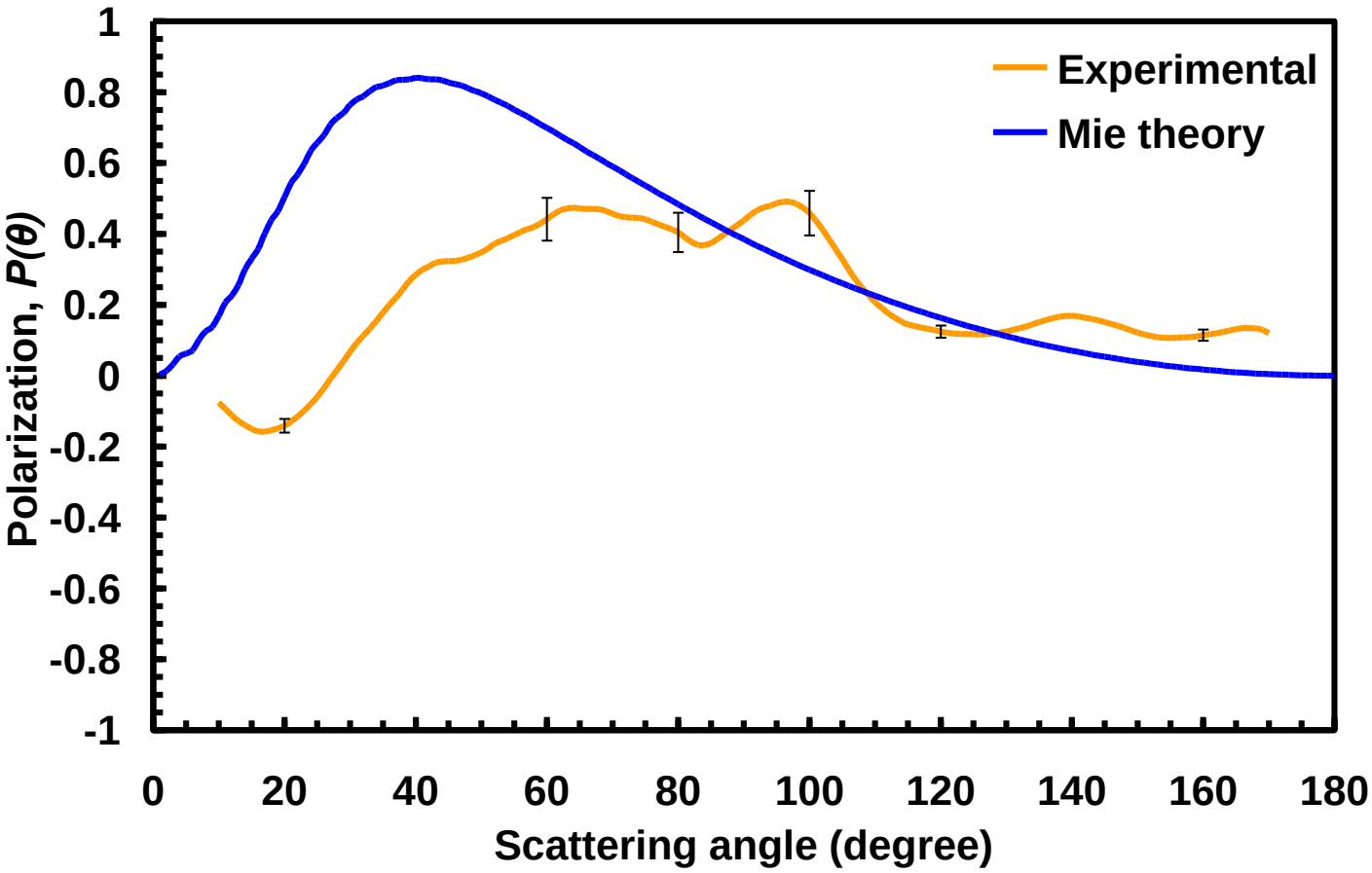
Measured volume scattering function, ***β(θ)*** of graphite particles at 543.5 nm incident wavelength is denoted by green circles. Theoretical curve generated using Mie theory is shown by solid blue line.



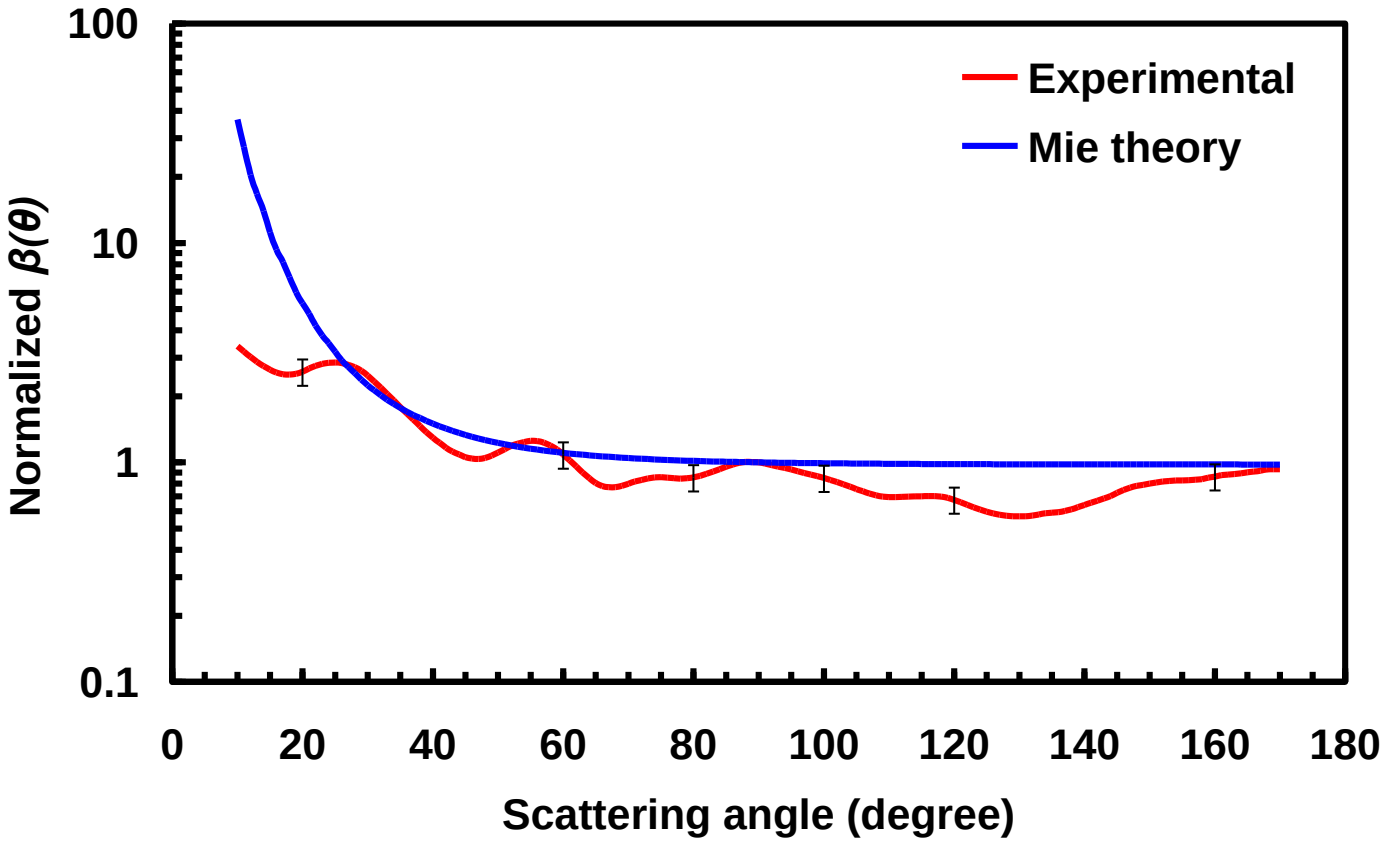
Measured degree of linear polarization, $\beta(\theta)$ of graphite particles at 543.5 nm incident wavelength is denoted by green circles. Theoretical curve generated using Mie theory is shown by solid blue line.



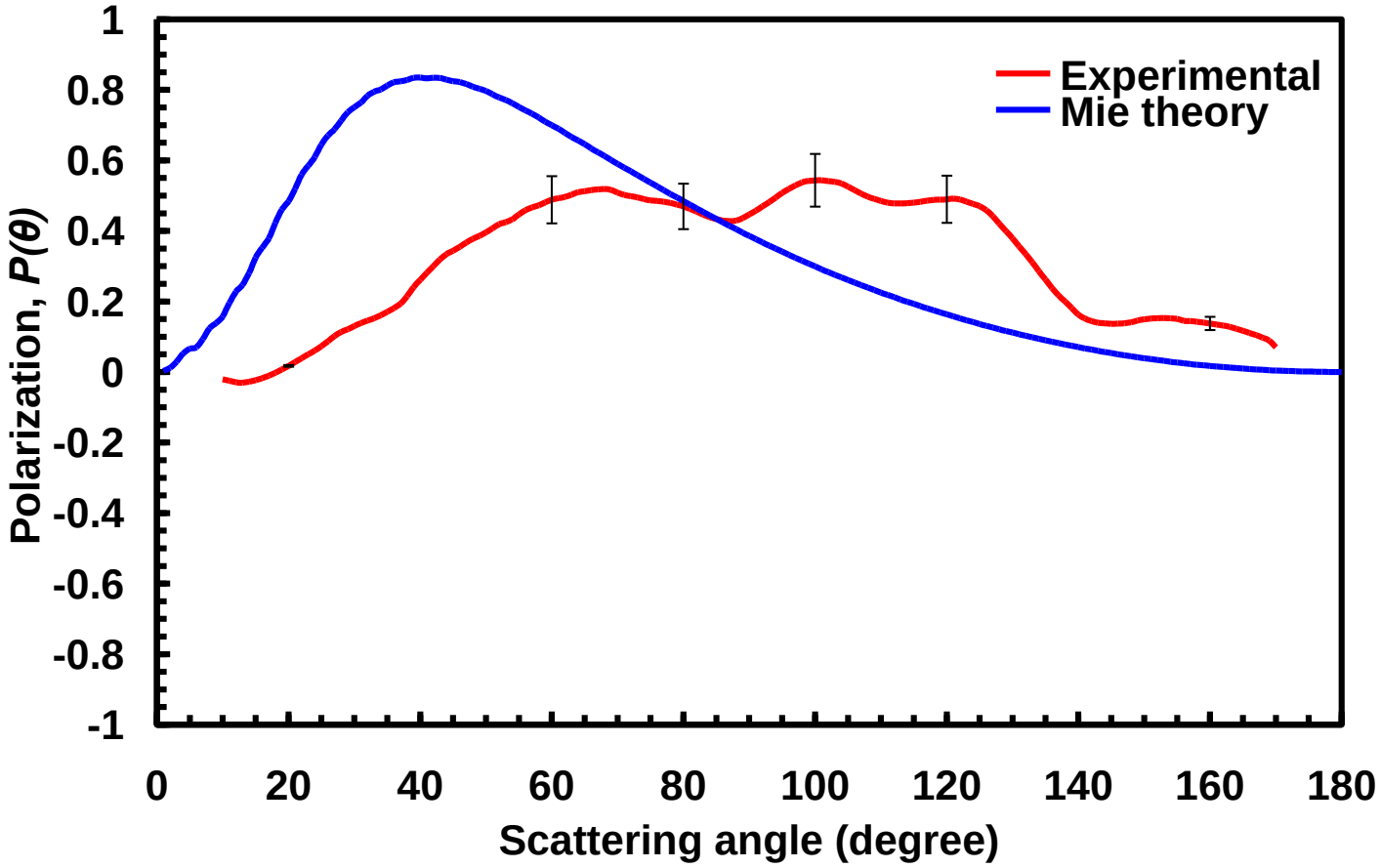
Measured volume scattering function, ***β(θ)*** of graphite particles at 594.5 nm incident wavelength is denoted by green circles. Theoretical curve generated using Mie theory is shown by solid blue line.



Measured degree of linear polarization, $\beta(\theta)$ of graphite particles at 594.5 nm incident wavelength is denoted by green circles. Theoretical curve generated using Mie theory is shown by solid blue line.



Measured volume scattering function, ***β(θ)*** of graphite particles at 632.8 nm incident wavelength. Theoretical curve generated using Mie theory is shown by solid blue line.



Measured degree of linear polarization, $\beta(\theta)$ of graphite particles at 632.8 nm incident wavelength. Theoretical curve generated using Mie theory is shown by solid blue line.

Results

- It has been observed that the volume scattering function, $\beta(\theta)$ is less intense at the small angles (forward direction) at all the three incident wavelengths as compared to the higher angles (backscattering direction).
- The decrease of scattered intensity in the forward direction may be attributed to absorption of the incident radiation significantly by the graphite grains having very high value of imaginary refractive index.
- The measured degree of linear polarization, $P(\theta)$ for graphite aggregates showed typical bell shaped behavior with the associated negative branch at small phase angles. The polarization was found to be positive for the remaining phase angles.
- At 632.8 nm laser wavelength highest positive polarization of 0.54 (equivalent percent of polarization ~54%) was observed. The measured lowest negative polarization was 0.16 (equivalent percent of polarization ~16%) and it was obtained at 543.5 nm incident wavelength.
- In our measurements, at the scattering angle of 170^0 we found the values of polarization to be 0.11, 0.07 and 0.04 at 543.5 nm, 594.5 nm and 632.8 nm laser wavelengths respectively.

Conclusion

- Here we report the design and fabrication of a light weight and miniaturized light scattering instrument which uses an array of 16 Si detectors.
- The use of low power lasers and Si photodetector has made the setup sensitive, compact and energy efficient.
- The current light scattering theories are still inadequate to be effectively applied to the scattering patterns from nonspherical structures such as graphite flakes
- It is necessary to understand the morphology of the structure to a greater extent and modify the existing theories to correlate the experimental results.

References

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Thank You