Measurements of circular depolarization of light scattered from single ice particles

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A novel small ice detector LISA was used to measure the circular depolarization ratio δ_C for light scattered from water droplets, just-frozen droplets and pristine ice crystals into near-backward direction. For hexagonal plates the values of δ_C were found to be very high compared to those for the columns and frozen droplets. For liquid droplets, the measured values of δ_C have shown a good agreement with the Mie calculations.

INTRODUCTION

Due to importance of ice phase for the radiative and microphysical properties of clouds, the in-situ characterization of single ice particles in clouds and in the laboratory has been receiving an increased attention in the past years. This characterization is often done optically, e.g., by detecting the light scattered by single particles or visualizing the ice crystals directly. The conventional light scattering methods do not provide the required information about the shape and orientation of ice crystals, and the imaging methods suffer from the resolution constraints and high detection limit. Therefore, some alternative approaches are necessary. The Leipzig Ice Scattering Apparatus (LISA) is a modification of the Small Ice Detector (SID3) [1] built by University of Hertfordshire to study the nucleation and growth of ice crystals in the Leipzig Aerosol and Cloud Interaction Simulator (LACIS) [2]. In October 2009 LISA took part in the experiment at the AIDA cloud chamber [3,4] at the Karlsruhe Institute of Technology within the framework of the Virtual Institute on Aerosol-Cloud Interaction (VI-ACI) of the Helmholtz Association. During this experiment, the ice formation on mineral dust and soot coated with secondary organic aerosol (SOA) was studied. The variability of growth processes in the AIDA chamber allowed measuring the scattering patterns and circular depolarization of light scattered by ice crystals of different shapes from almost spherical just-frozen droplets to pristine ice crystals like hexagonal plates or columns. Here we report some selected results of these measurements.

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EXPERIMENT

The optical layout of LISA is shown in Fig. 1. LISA is capable of capturing high-resolution two dimensional light-scattering patterns from single particles in an angular range of 9° to 25° in the near-forward direction with a gated intensified CCD camera (780 x 582 pixels). The size, shape, and orientation of the observed particles can be deduced by comparing recorded images with the scattering patterns calculated for particles of known shape and orientation [5] or measured with ice analog crystals [6]. As opposed to other SID3 instruments, LISA is also capable of measuring the circular depolarization ratio δ_C in near-backward direction (scattering angle from 166° to 172°). This is done by registering the cross-polarized components of backscattered light after sending it through a quarter wave plate (QWP), installed in front of a polarizing beam splitter cube (see Fig.1). In this way δ_C is defined as

$$\delta_C = \frac{I_s + V_s}{I_s - V_s},$$

where I_s and V_s are the first and the last components of the Stokes vector of the scattered light.

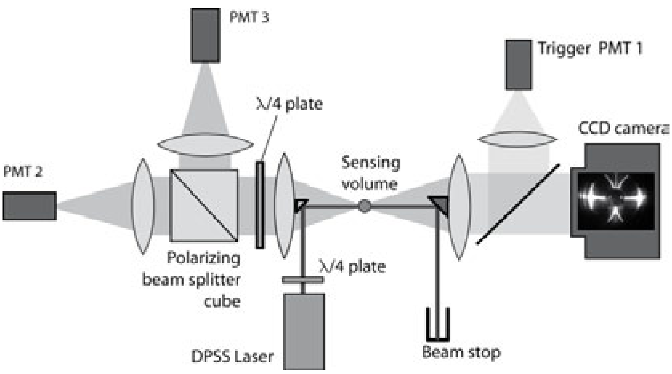

Figure 1. Schematic of LISA instrument (top view). Ice particles are crossing the sensing volume perpendicular to the drawing plane. The laser beam (λ = 532 nm) is circularly polarized to avoid polarization-dependent variations in the scattering patterns.

Ice crystals were nucleated and grown in the AIDA chamber as described in [3]. Under the varying conditions inside the chamber (temperature, pressure, and ice saturation) the evolution of the ice crystals' population was characterized with the help of in-situ optical instrumentation available at AIDA or by drawing a sample flow from the chamber [4]. In this experiment, LISA was operating alongside with several other ex-situ single-particle optical detectors (WELAS, PHIPS, SID3, NIXE-CAPS, CPI).

RESULTS AND DISCUSSION

With LISA, we were able to measure δ_C for several distinct classes of particles: liquid droplets, frozen droplets, hexagonal plates, and columns (Figs. 2 and 3). The shape and orientation of ice crystals was deduced from visual examination of scattering pattern and comparison with the exemplary patterns [5,6]. For water droplets, the diameter could be assessed by comparing the number of rings with Mie calculations. In all cases, the populations of several hundreds of particles were evaluated.

The distributions of δ_C for water drops were found to be in a good agreement with Mie calculations. However, the ice crystals originating from the heterogeneous freezing of droplets have shown a distinctly higher values of δ_C than expected for liquid droplets of almost the same size (Figs. 2b and 2c). Also the broadness of the distribution is evidently larger, which might be attributed to the variability of the slightly aspherical shape that droplets acquire when freezing.

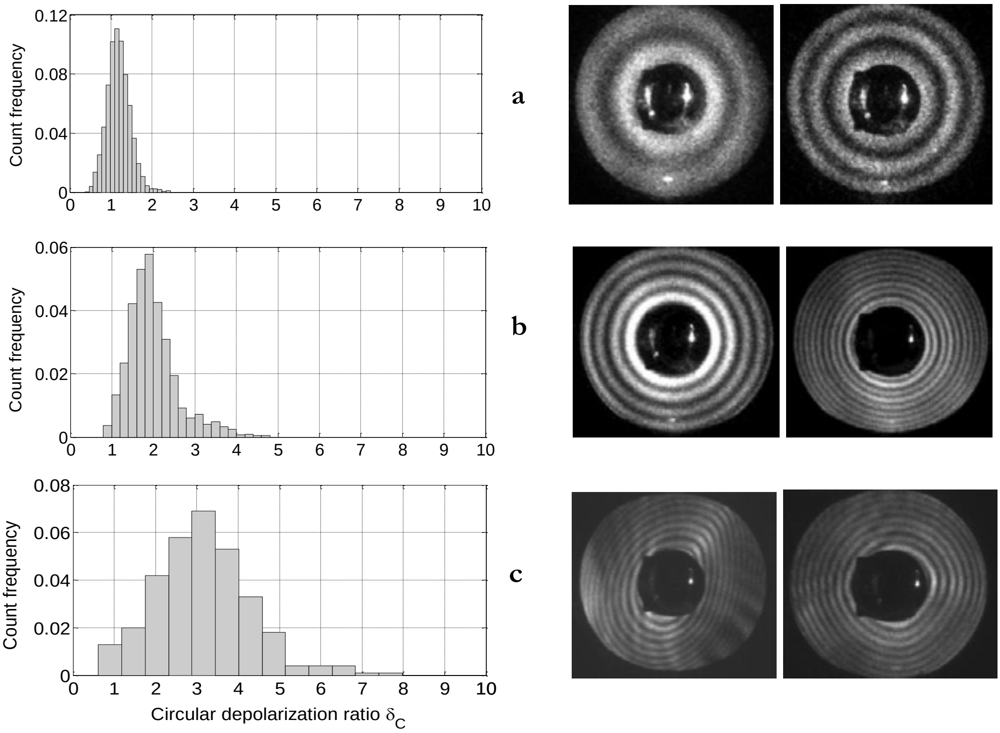

Figure 2. Scattering patterns (right) and histograms of δ_C (left) for liquid and frozen droplets. (a) liquid droplets with size from 3 μm to 15 μm; (b) liquid droplets with size from 10 μm to 26 μm; (c) just-frozen droplets, size in the range 15 μm – 27 μm.

To investigate the orientation dependence of δ_C for columns, we have divided the evaluated column-like ice crystals into two populations: one, with the main axis oriented exactly perpendicular to the illuminating laser beam (no curvature of the main feature on the scattering pattern can be established, Fig. 3a), and second, with the main axis tilted with respect to the exact perpendicular plane (the main bright feature on the scattering pattern clearly curved, see Fig. 3b). No significant difference of the δ_C values have been found for these two populations.

The highest values of δ_C were observed for the hexagonal plates with the main facet oriented perpendicular to the laser beam. In this case only scattering patterns showing straight rays of the six-pointed "star" were hand-selected for the evaluation (see Fig. 3c). The size assessment of the pristine ice crystals from the scattering patterns was not possible. To achieve this, and also to get a better understanding of the circular depolarization results, a model calculations of scattering by single ice crystals in a fixed orientation will be necessary. That we are going to address in the near future.

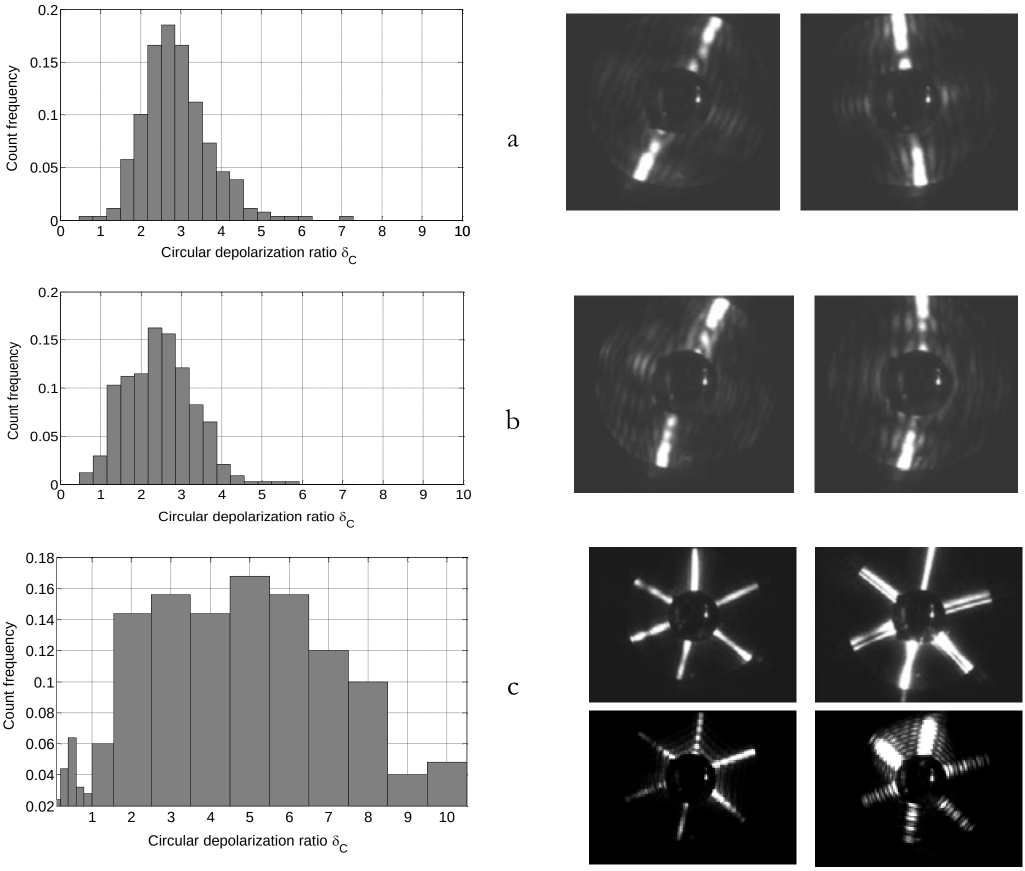

Figure 3. Scattering patterns (right) and histograms of δ_C (left) for pristine ice crystals. (a) columns oriented perpendicular to the laser beam; (b) columns tilted with respect to the laser beam; (c) hexagonal plates oriented perpendicular to the laser beam.

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