A New Optical Ice Particle Counter at LACIS: SHERLOCC

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Introduction

Clouds cover large areas of the Earth's surface throughout the year and thus play an important role in terms of climate, especially concerning the Earth's radiative energy budget. The radiative cloud properties themselves strongly depend on the fractions of ice crystals and cloud droplets, their size spectra, as well as ice crystal shapes and surface roughness. Hence, for quantifying cloud radiative properties, it is essential to know the absolute amounts of droplets and ice particles in a cloud, and in case of ice particles their respective surface roughness.

Detailed information on cloud composition can be provided by in-situ measurements using, e.g., optical particle counters. Although the optical instrumentations are already very advanced, measurements in the lower and sub-μm range are still problematic due to detection limit issues. Therefore, particle light scattering simulations focusing on the determination of the optimal scattering angle concerning the particle phase discrimination purposes were performed. Based on these simulations, a new optical ice particle counter called SHERLOCC (Single Hydrometeor Electromagnetic Response Logger for Optical Characterization and Counting) was developed similar to TOPS-Ice (Thermostabilized Optical Particle Spectrometer for the detection of Ice, Clauss et al. 2013). SHERLOCC is designed for laboratory measurements in combination with the laminar flow tube LACIS (Leipzig Aerosol Cloud Interaction Simulator, Stratmann et al., 2004). This setup aims at improving the water droplet and ice crystal discrimination in the lower micrometer range.

Particle Scattering Simulations

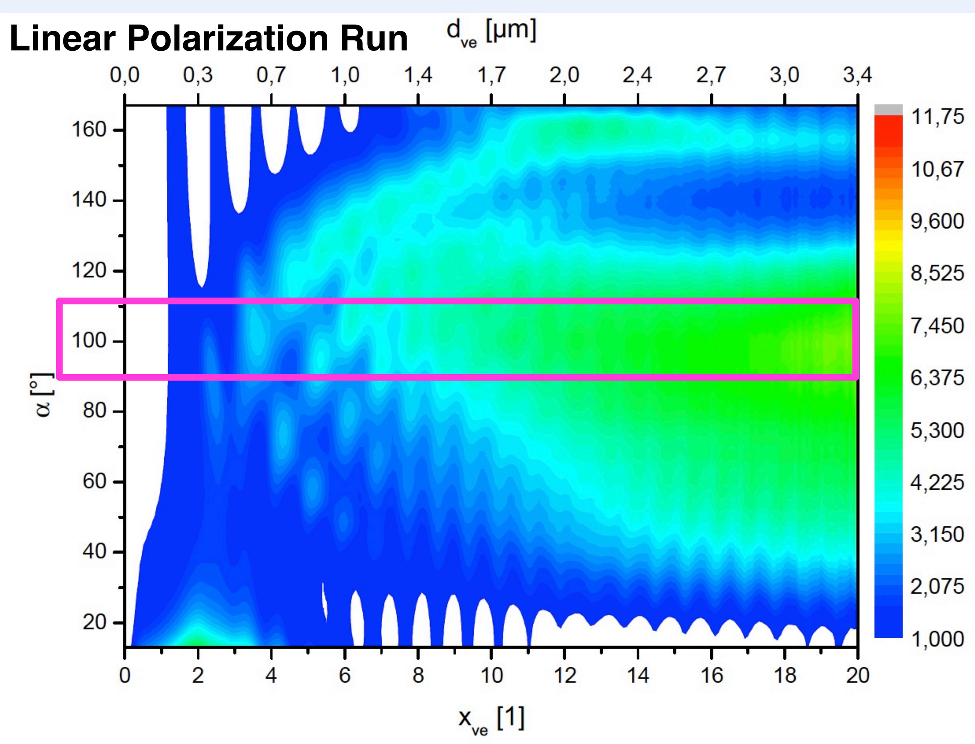

Fig. 1: Intensity ratios ($I_{0.77}/I_{1.00}$) in dependence of α and χ_{ve} (d_{ve}). Blue color: $I_{1.00} \approx I_{0.77}$; white color: $I_{1.00} > I_{0.77}$; other color: $I_{1.00} < I_{0.77}$ (good discrimination)

Settings:

- wavelength (λ): 532nm
  scattering angle (α): [13, 167]
  size range (χ_{ve}): [0.1, 20.0]
  aspect ratio (ε): [0.77 ,0.87, 1.00, 1.15, 1.30, 1.55, 2.00]
- Use of Lorenz-Mie theory for spheres (water droplets) and T-Matrix method for spheroids (ice crystals)
- „monodisperse" lognormal droplet size distribution with a 10% standard deviation
- Focus on geometrical shape only (refractive index: ice = water = 1.33)
- Use of the same volume equivalent diameter (d_{ve}) for comparison of spheres/ spheroids

Results for best phase discrimination:

- 100° scattering angle for linearly polarized incident light (Fig. 1+2)
- 142° scattering angle for circ. polarized incident light (Fig. 3)
- Circ. polarized light results in a higher sensitivity and better counting rate BUT it is limited to particles > 2.54μm.

→ use of linearly polarized light and a scattering angle of 100°

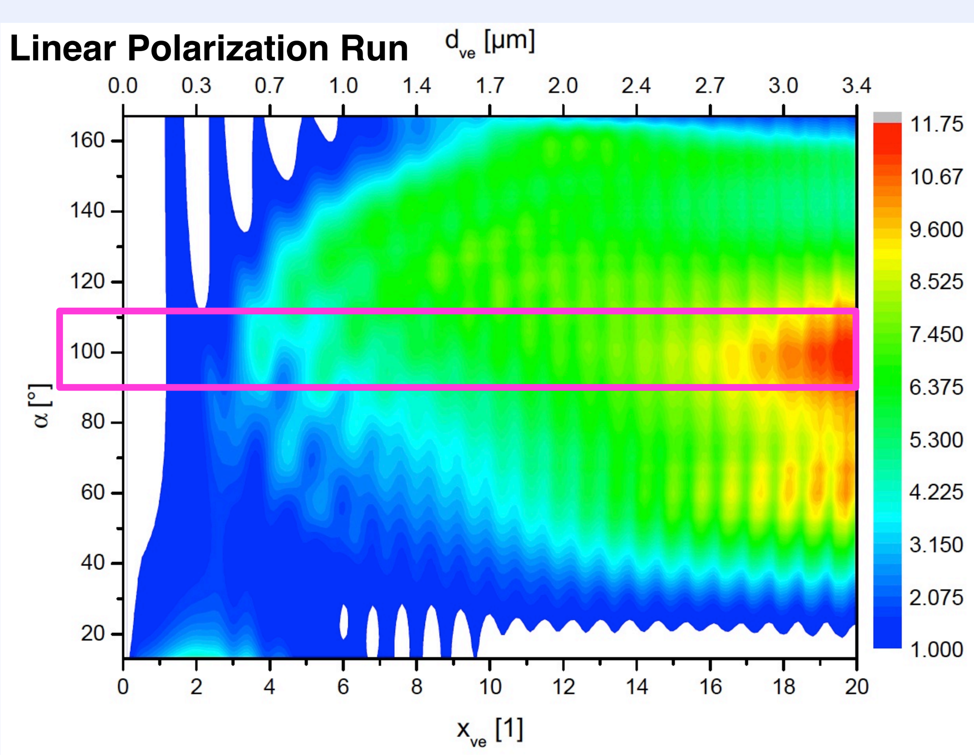

Fig. 2: Intensity ratios ($I_{1.30}/I_{1.00}$) in dependence of α and χ_{ve} (d_{ve}). Blue color: $I_{1.00} \approx I_{1.30}$; white color: $I_{1.00} > I_{1.30}$; other color: $I_{1.00} < I_{1.30}$ (good discrimination)

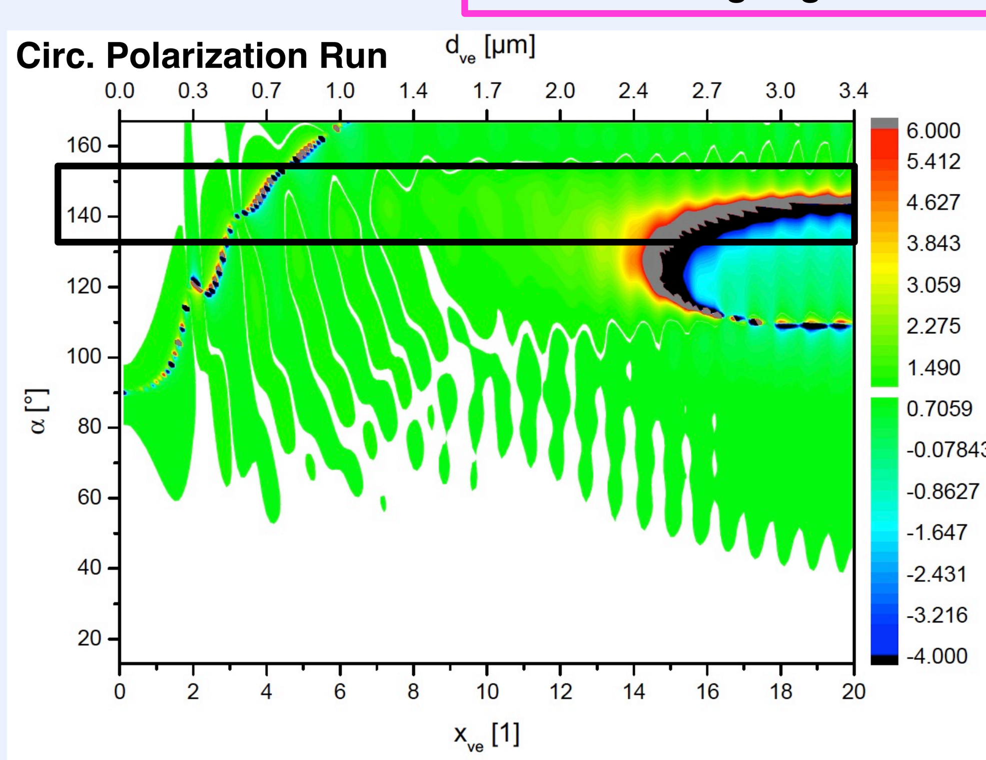

Fig. 3: Intensity ratios ($I_{1.30}/I_{1.00}$) in dependence of α and χ_{ve} (d_{ve}). Green color: $I_{1.00} \approx I_{1.30}$; white color: $I_{1.00} > I_{1.30}$; other color: $I_{1.00} < I_{1.30}$ (good discrimination)

Particle Generation: LACIS

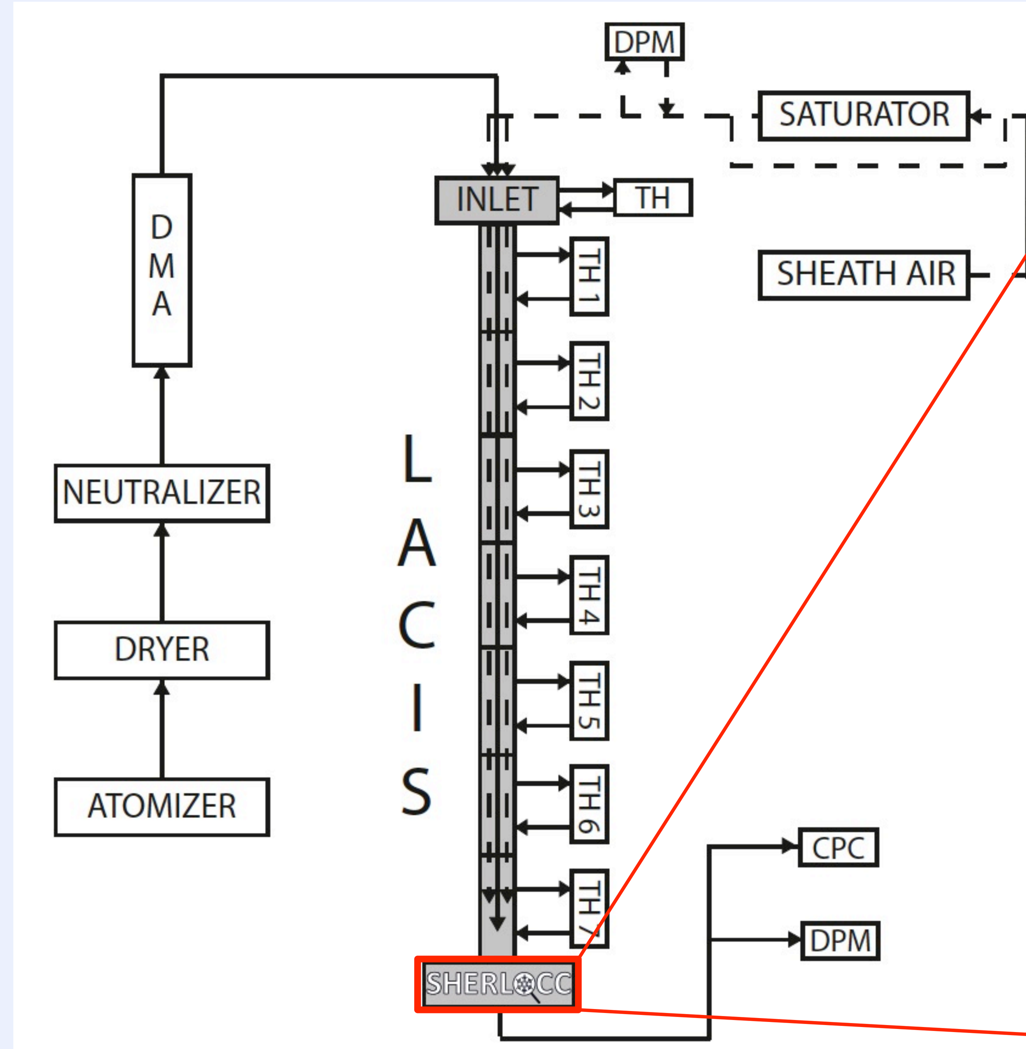

Fig. 4: Sketch of the particle generation, LACIS, and the optical detection system (modified from Hartmann et al., 2013).

- LACIS (7m length, 15mm Ø) is a laminar flow tube consisting of seven 1m sections and is connected with a particle generation system (Fig. 4).
- The particle generation system upstream of the LACIS tube produces dry quasi-monodisperse or polydisperse particles.
- The thermodynamic condition (temperature, relative humidity) inside the LACIS tube are separately controlled for each of the seven sections.
- Due to the adjusted thermodynamic conditions, liquid droplets and/or ice crystals can be formed in various sizes of the lower μm range.
- All particles generated by LACIS are directly fed into the optical detection system TOPS-Ice or SHERLOCC.

Particle Detection: SHERLOCC

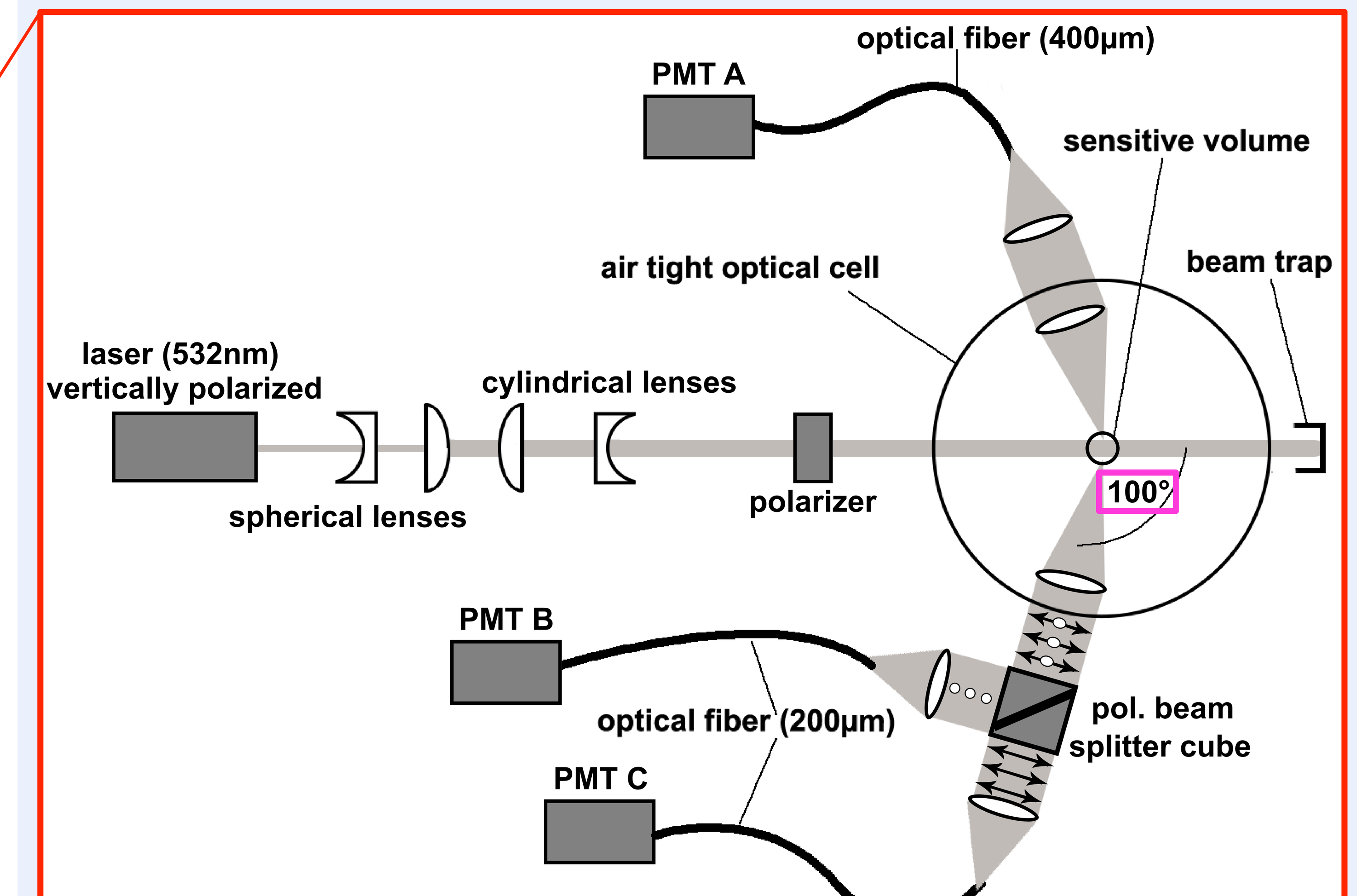

Fig. 5: Sketch of SHERLOCC (top view).

- SHERLOCC (Fig. 5) is based on TOPS-Ice (Clauss et al., 2013).
- The key modification in SHERLOCC is the change of the detected scattering angle from 42.5° to 100° based on particle scattering simulations.
- SHERLOCC is designed to detect the number concentration, size (PMT A) and phase of the particles (PMT B/C) in the lower μm range.
- This setup uses a vertically polarized 200mW laser at 532nm to measure single ice particles inside the sensitive volume.
- The change in polarization detected by PMT C is used for the discrimination between liquid droplets and ice crystals.
- The lower detection limit of TOPS-Ice was ~1μm for mixed phase and pure ice clouds, and ~0.5μm for liquid clouds. Due to the modification of the scattering angle in SHERLOCC, the detection limit is supposed to decrease even further.

Results and Outlook

- Based on particle scattering simulations it was found that a scattering angle of 100° is best for phase discrimination when using linearly polarized light.
- Circularly polarized light in combination with an scattering angle of 142° result in an even higher sensitivity concerning the particle phase but it is restricted to particles > 2.54μm.
- Based on these results, a new optical particle counter called SHERLOCC was developed.
- A detailed comparison of SHERLOCC and TOPS-Ice based on measurements using illite, kaolinite, Snomax®, ATD and/or biological particles as CCN/IN is planned.

Abbreviations

ATD – Arizona Test Dust; **CCN** – Cloud Condensation Nuclei; **CPC** – Condensation Particle Counter; **DMA** – Differential Mobility Analyzer; **DPM** – Dew Point hygroMeter; **IN** – Ice Nuclei; **PMT** – PhotoMultiplier Tube; **SHERLOCC** – Single Hydrometeor Electromagnetic Response Logger for Characterization and Counting; **TH** – Thermostat; **TOPS-Ice** – Thermostabilized Optical Particle Spectrometer for the detection of Ice

Acknowledgements

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