OPTICAL MEASUREMENTS OF ICE CRYSTALS WITH SID3-LISA

FIRST RESULTS FROM **ACI'03** AND **FROST** EXPERIMENTS

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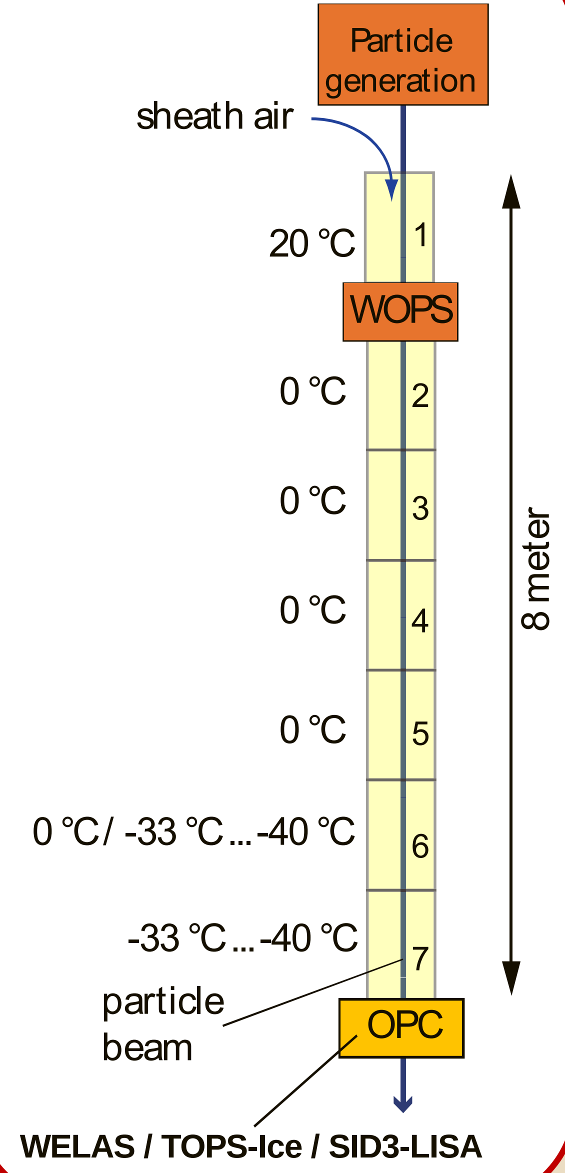
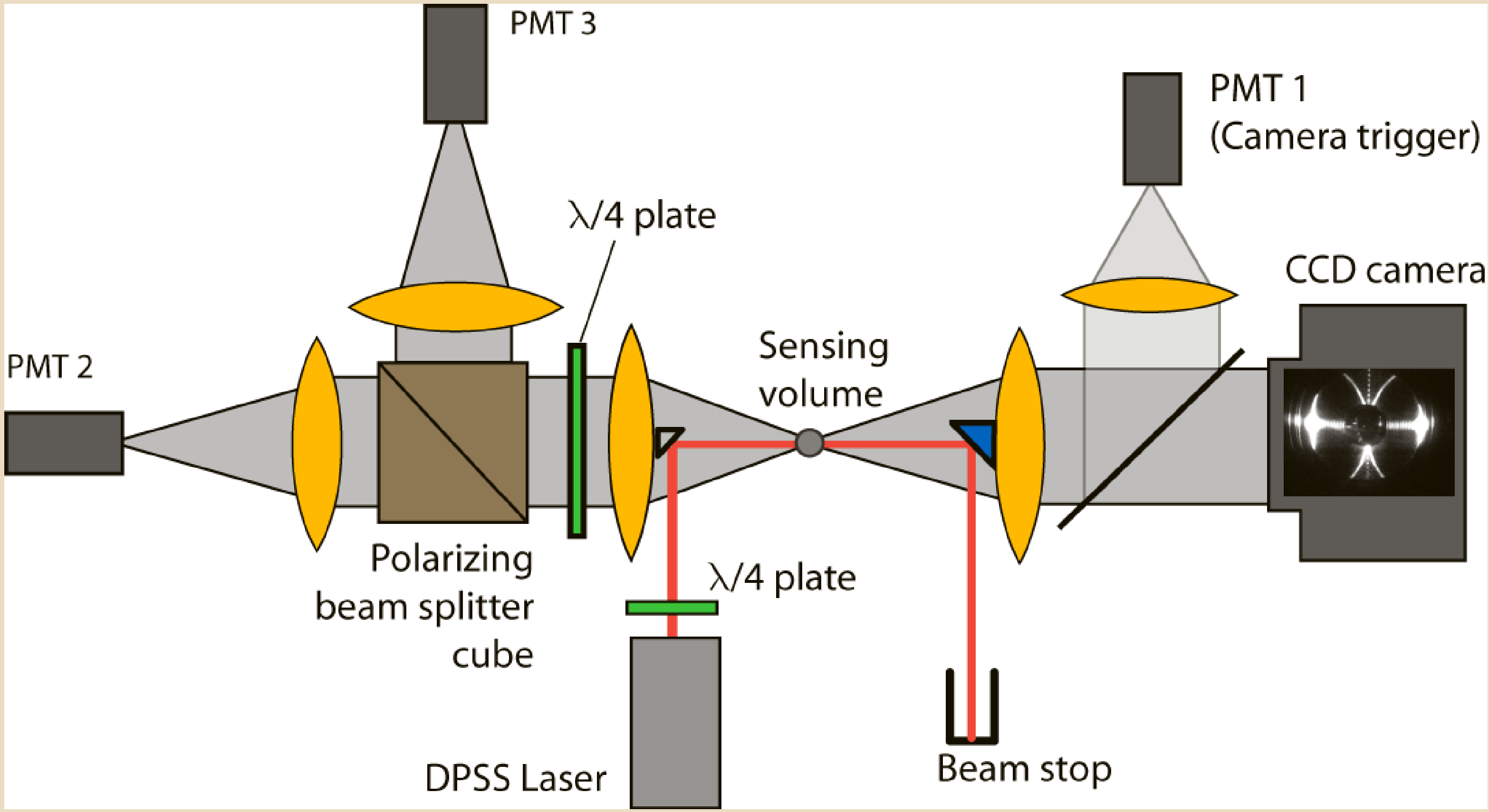
Why yet another OPC?

- Existing commercial instruments (e.g. WELAS) allow for particle size determination; it's OK if ice particles have time to grow (AIDA), but in LACIS it is not the case.
- Therefore, there is a need for reliable detection of ice particles in the presence of droplets and seed aerosol.
- Home-made instrument (TOPS-Ice) allow for ice detection based on ice crystal non-sphericity but delivers no shape information.
- Possibility to register 2D scattering patterns would permit crystal shape classification AND provide valuable data on optical properties of individual ice crystals (validation of scattering codes with respect to backscattering)

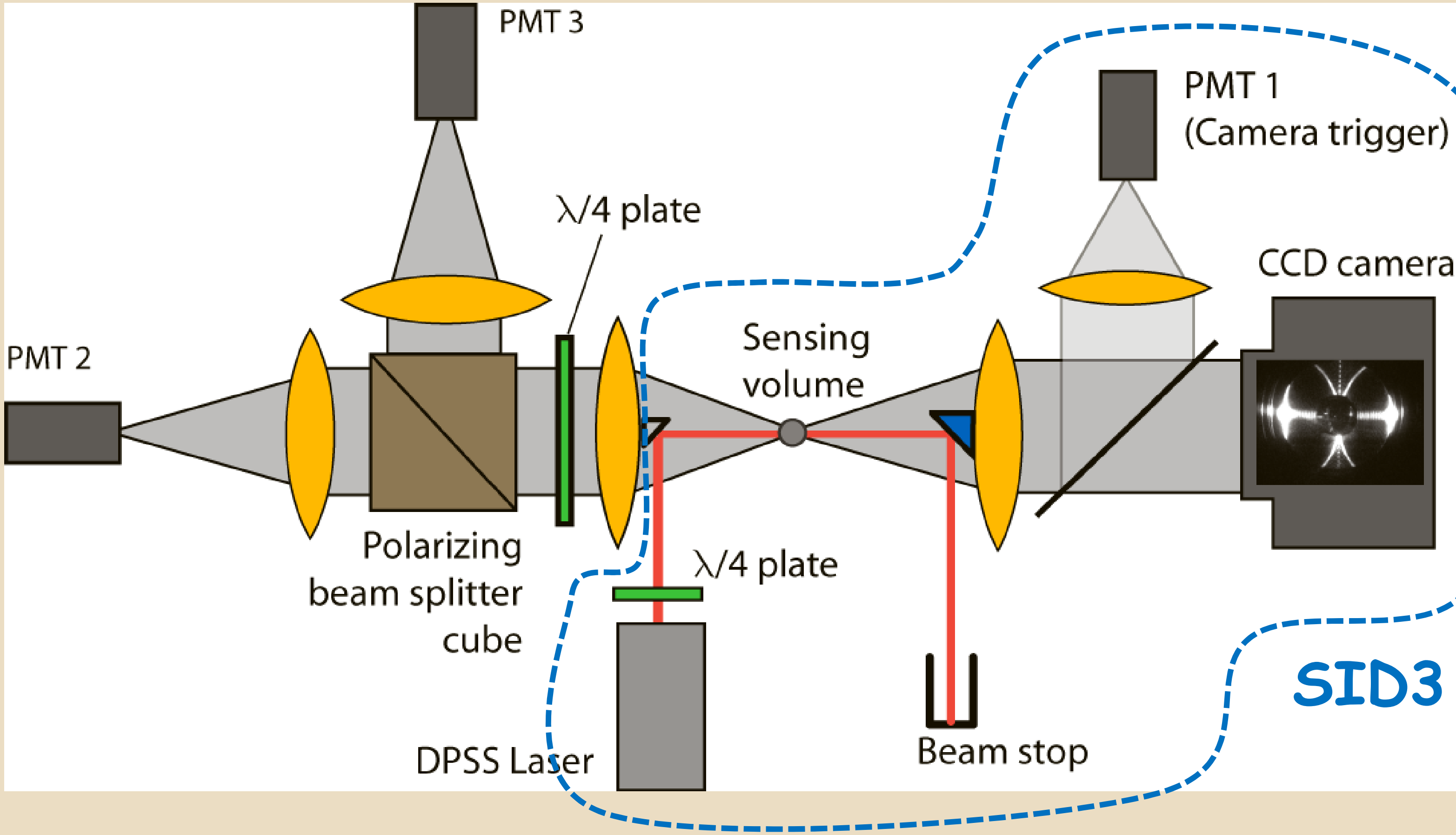


Optical Layout SID3-LISA

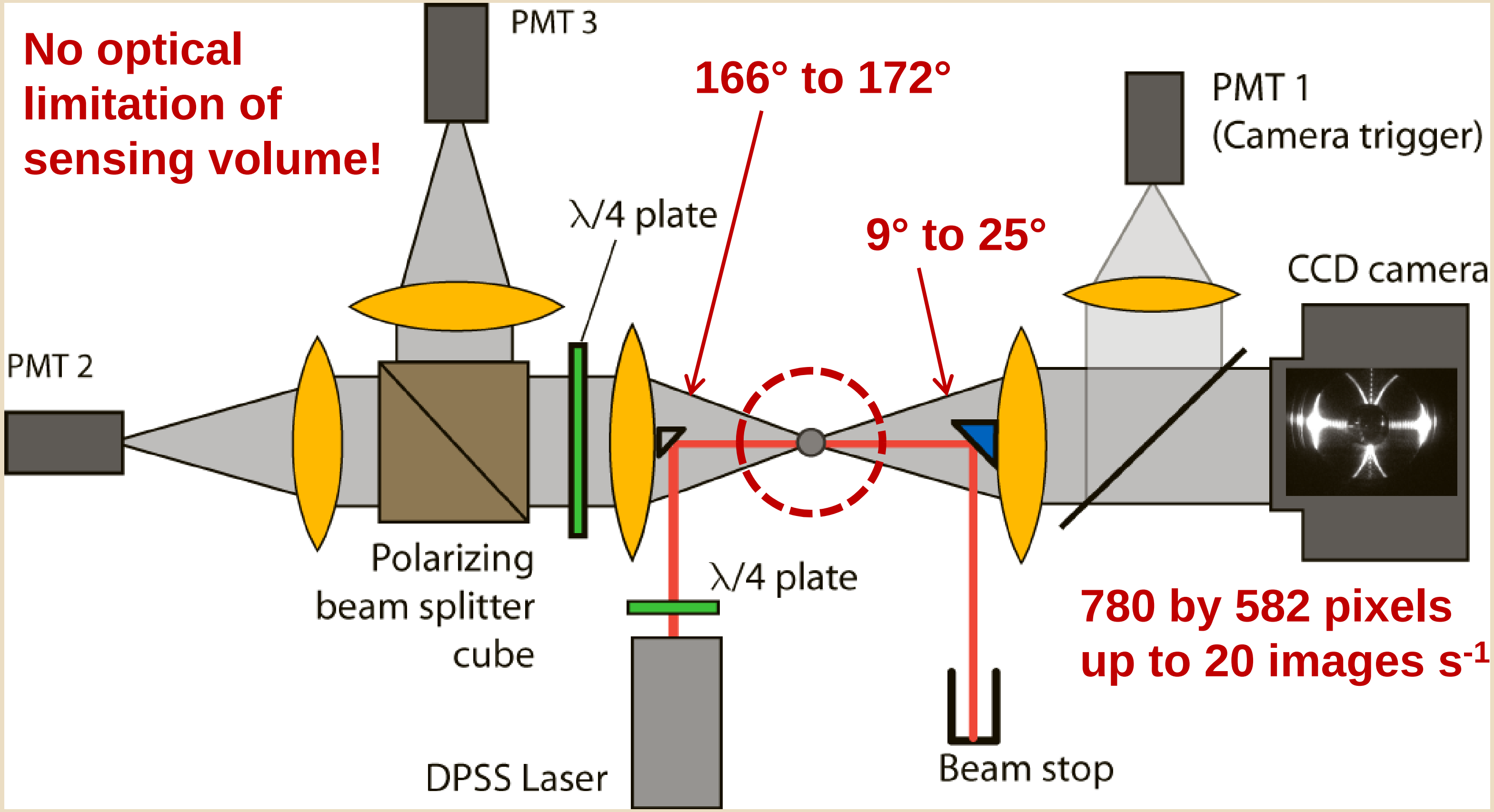
Small Ice Detector – **L**ACIS **I**ce **S**cattering **A**pparatus



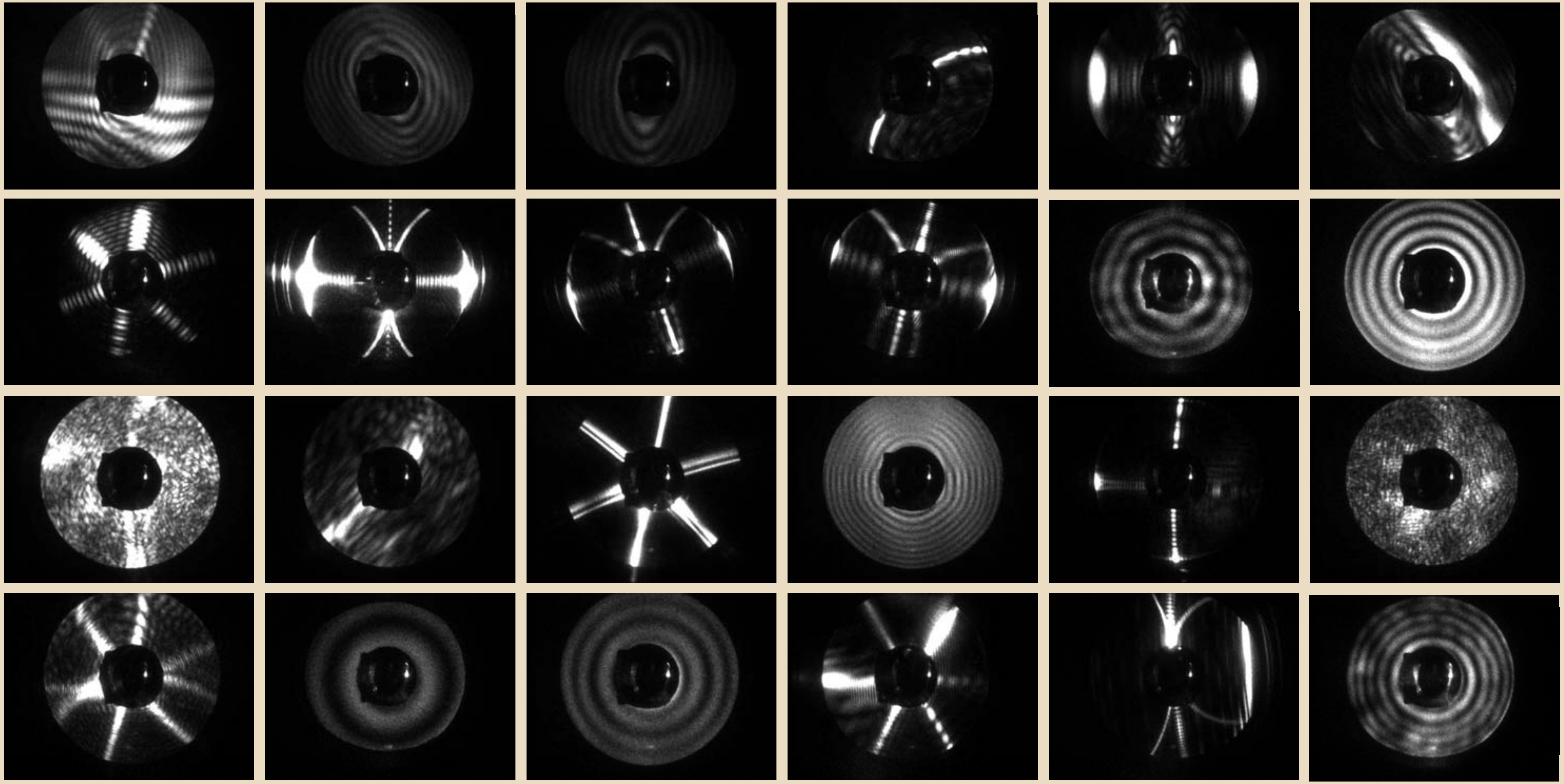
Optical Layout SID3-LISA



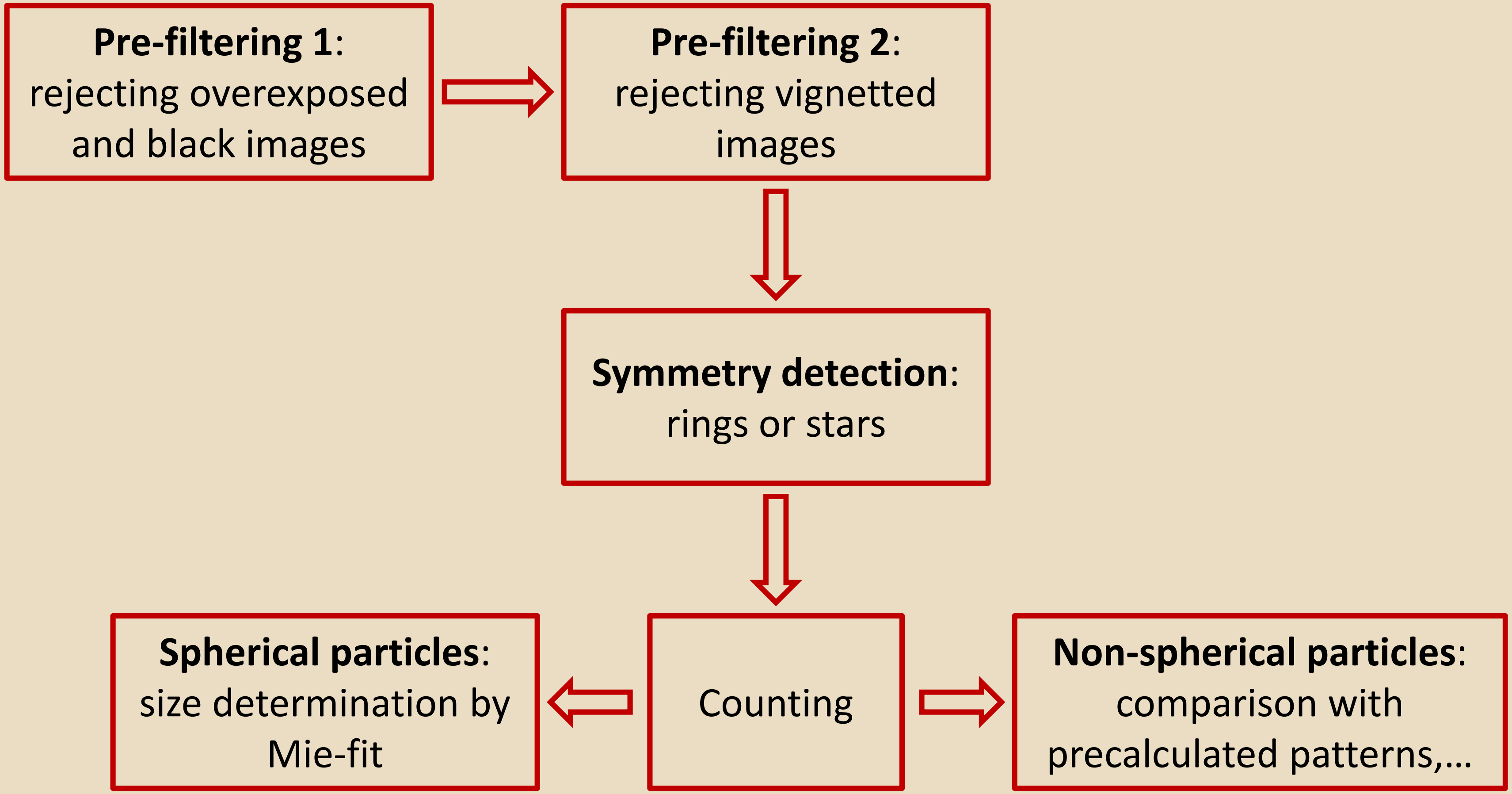
Optical Layout SID3-LISA



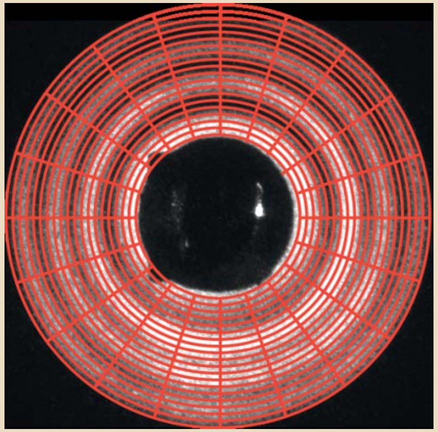
Part I: 2D scattering pattern analysis



What do we do with all this images???

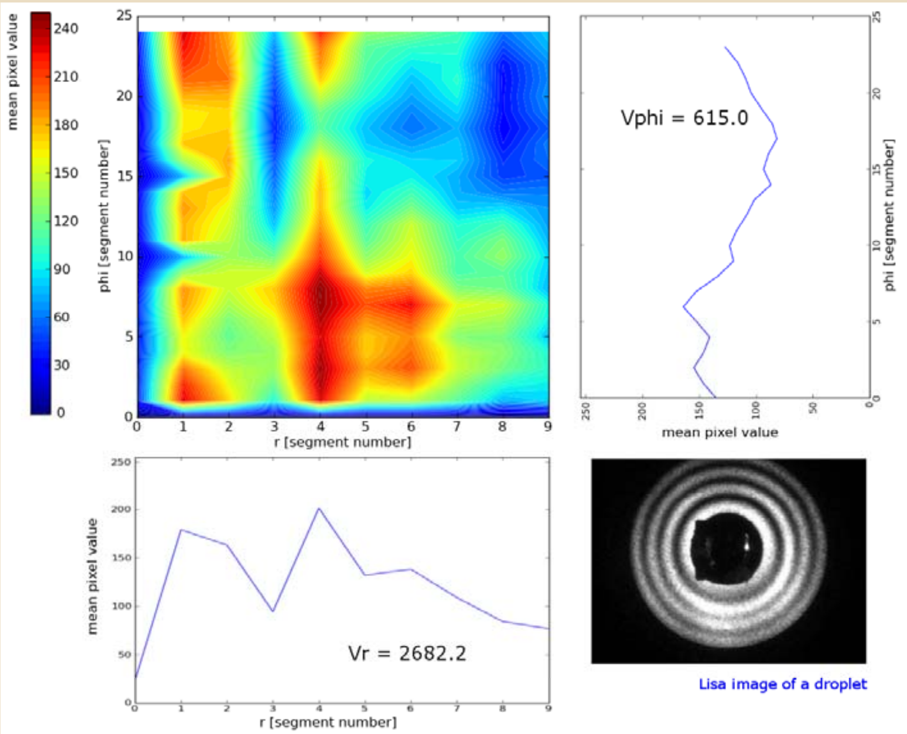


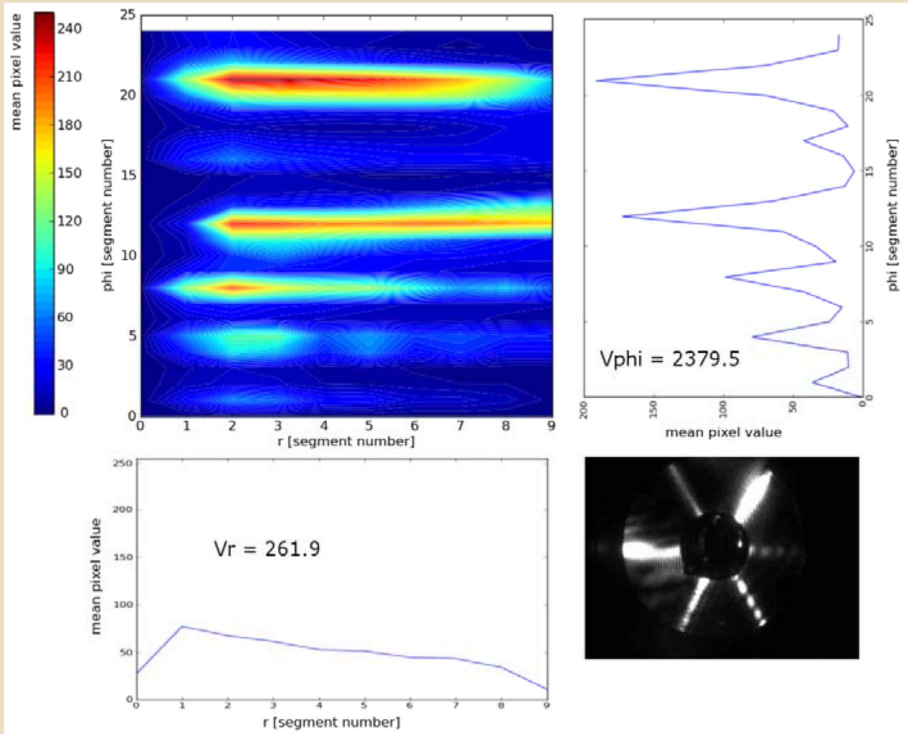
Symmetry type detection



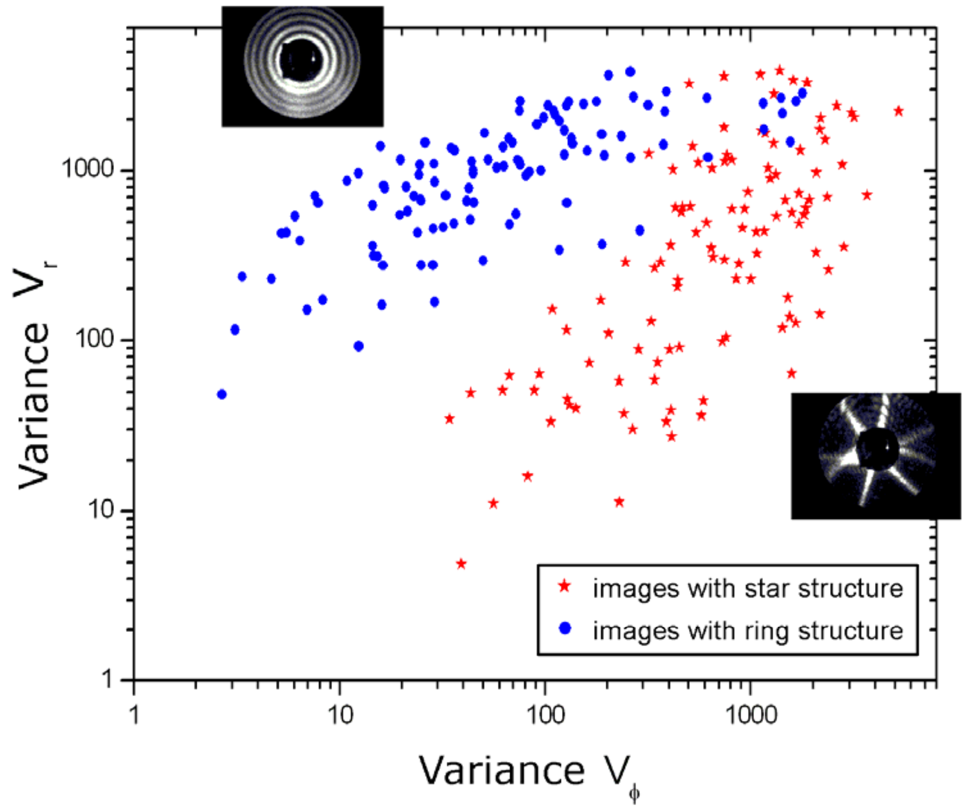
1. Divide image into segments
2. Define mean pixel value in every segment
3. Sum up pixel values along the radial and angular coordinates
4. Take the variance

Rings & stars


mean pixel value
phi [segment number]
r [segment number]
Vphi = 615.0
mean pixel value
Vr = 2682.2
Lisa image of a droplet

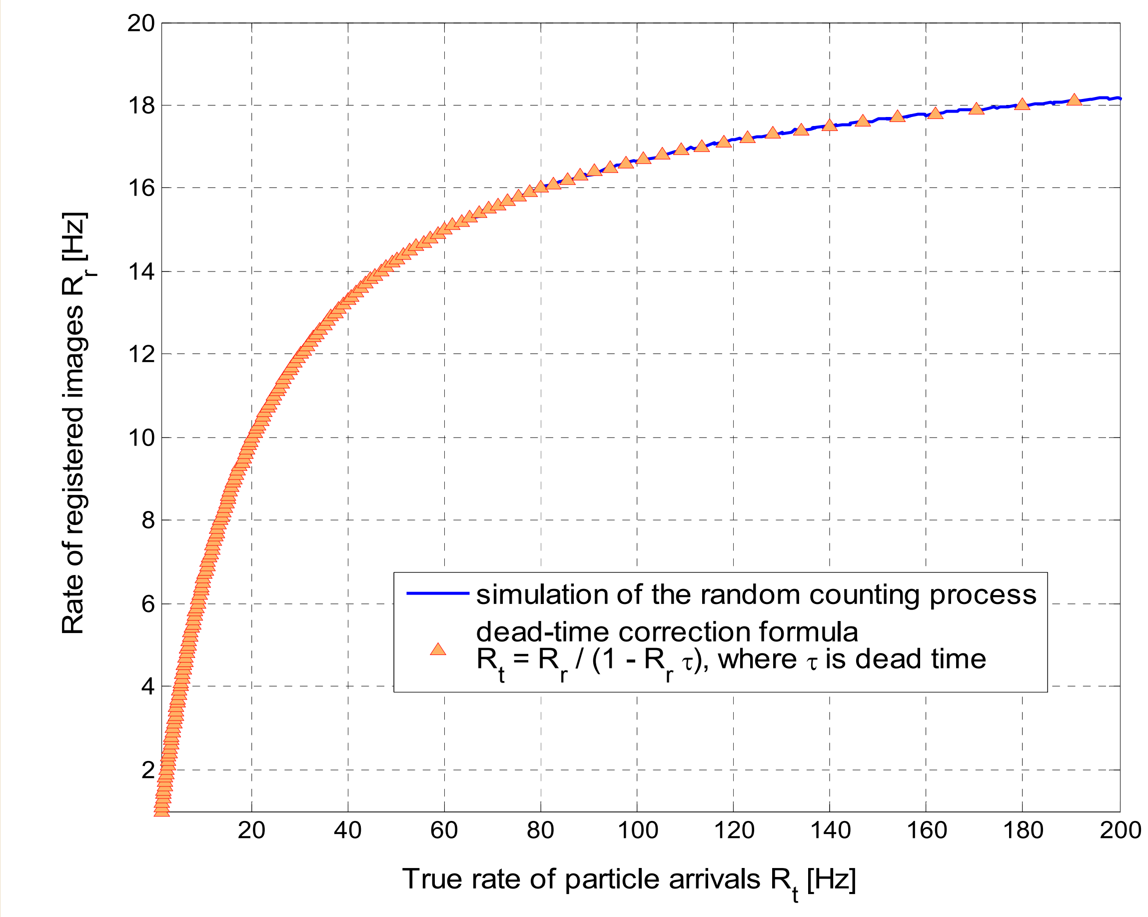

mean pixel value
phi [segment number]
r [segment number]
Vphi = 2379.5
mean pixel value
Vr = 261.9

Some rings are not quite rings, and some stars are not quite stars…

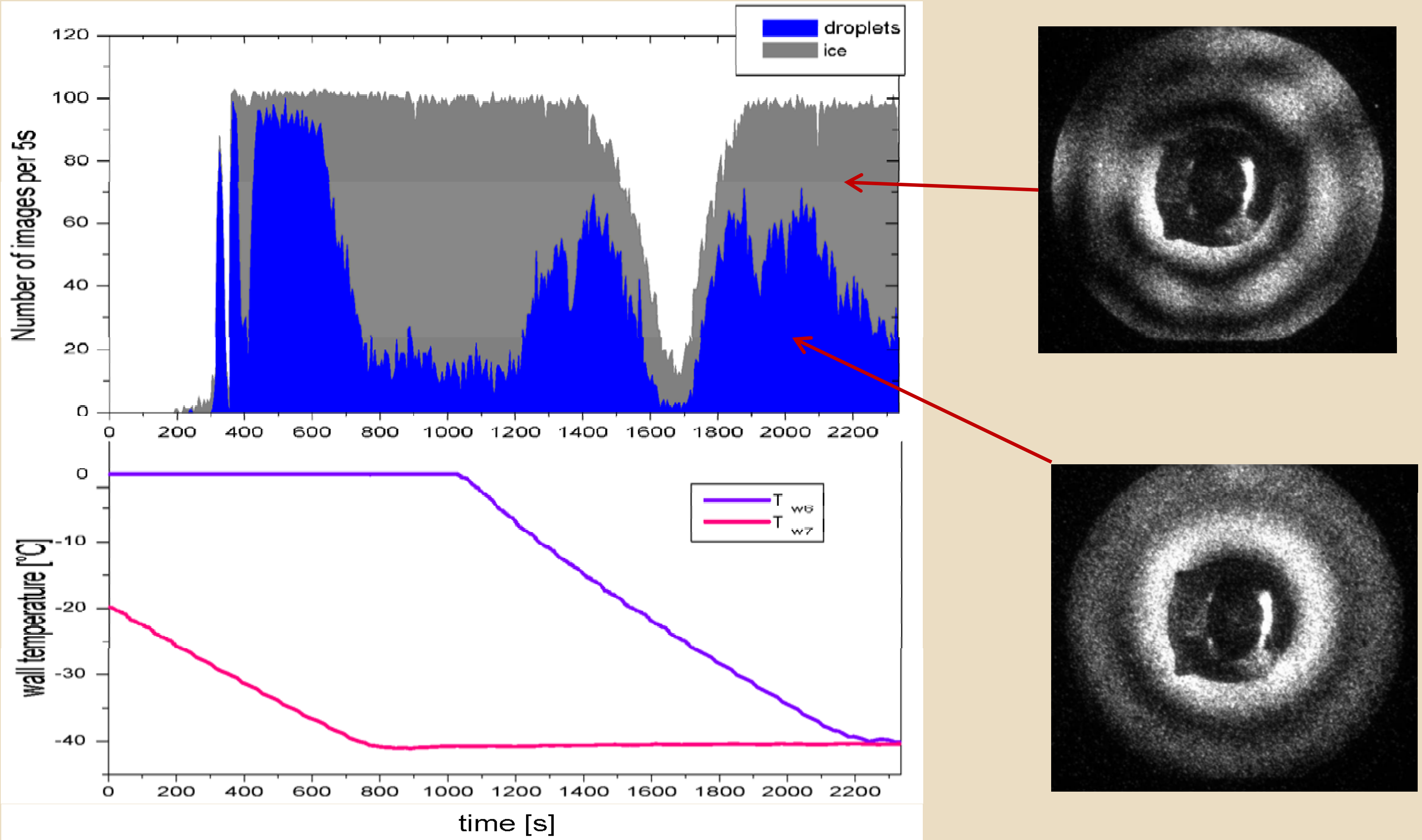


Counting the ice particles: results from FROST 2 experiment

- Image transfer rate is limited to 20 Hz
- Counting with correction is possible up to approx. 16 - 17 Hz

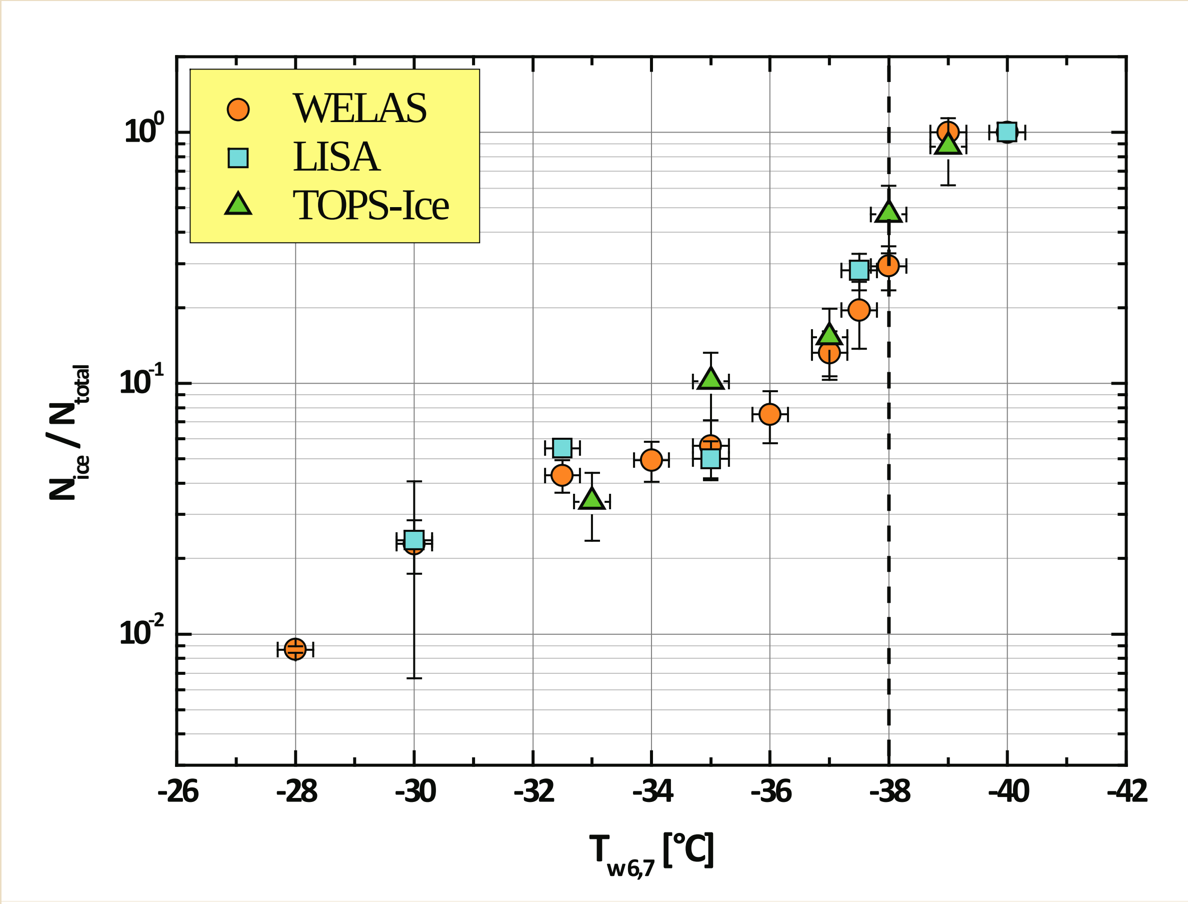


Time series of droplets / ice populations during the cooling cycle of LACIS



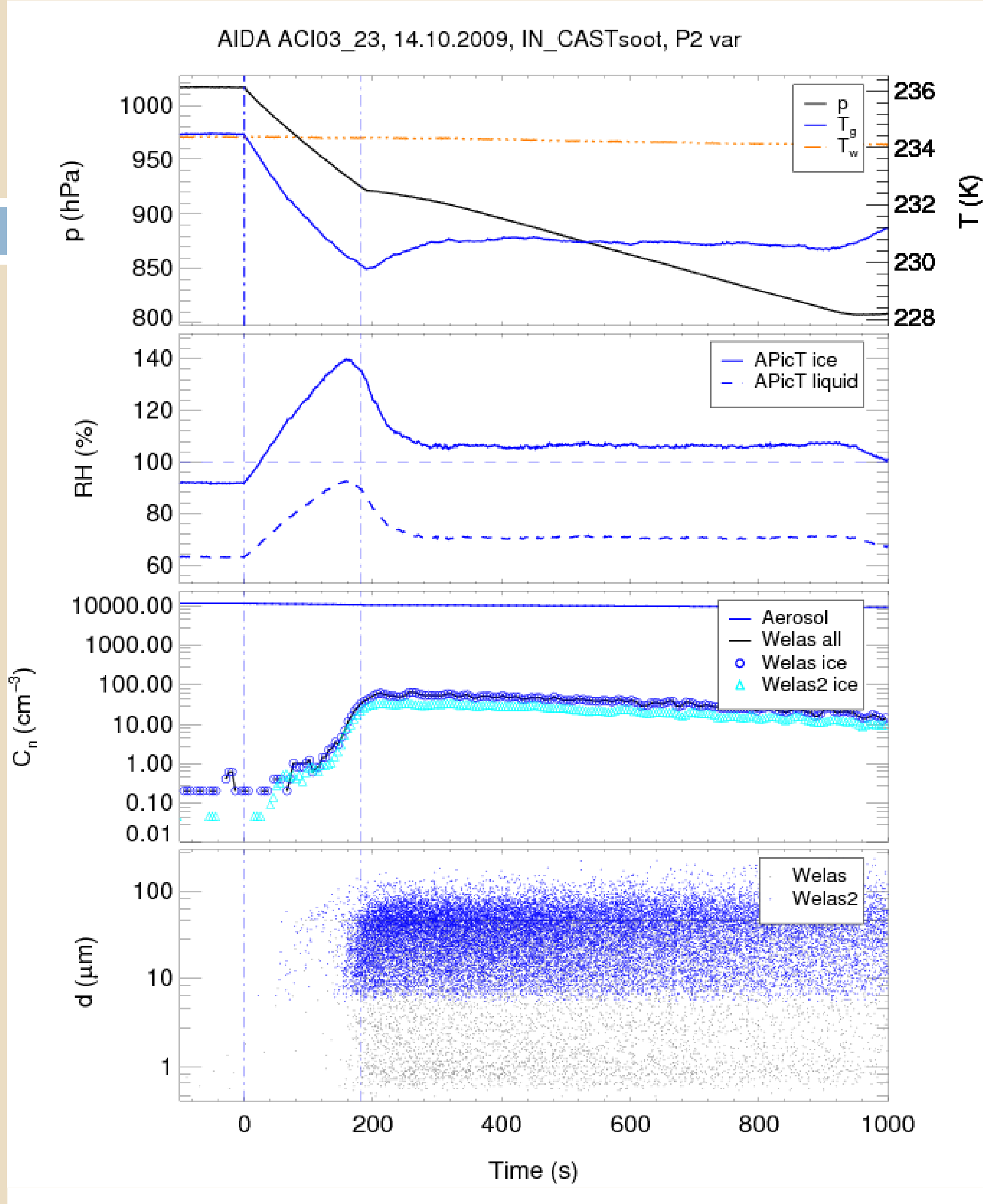
Counting the ice particles: results from FROST 2 experiment

- ATD 300nm uncoated
- Immersion freezing of water droplets



ACI03 Exp. 23

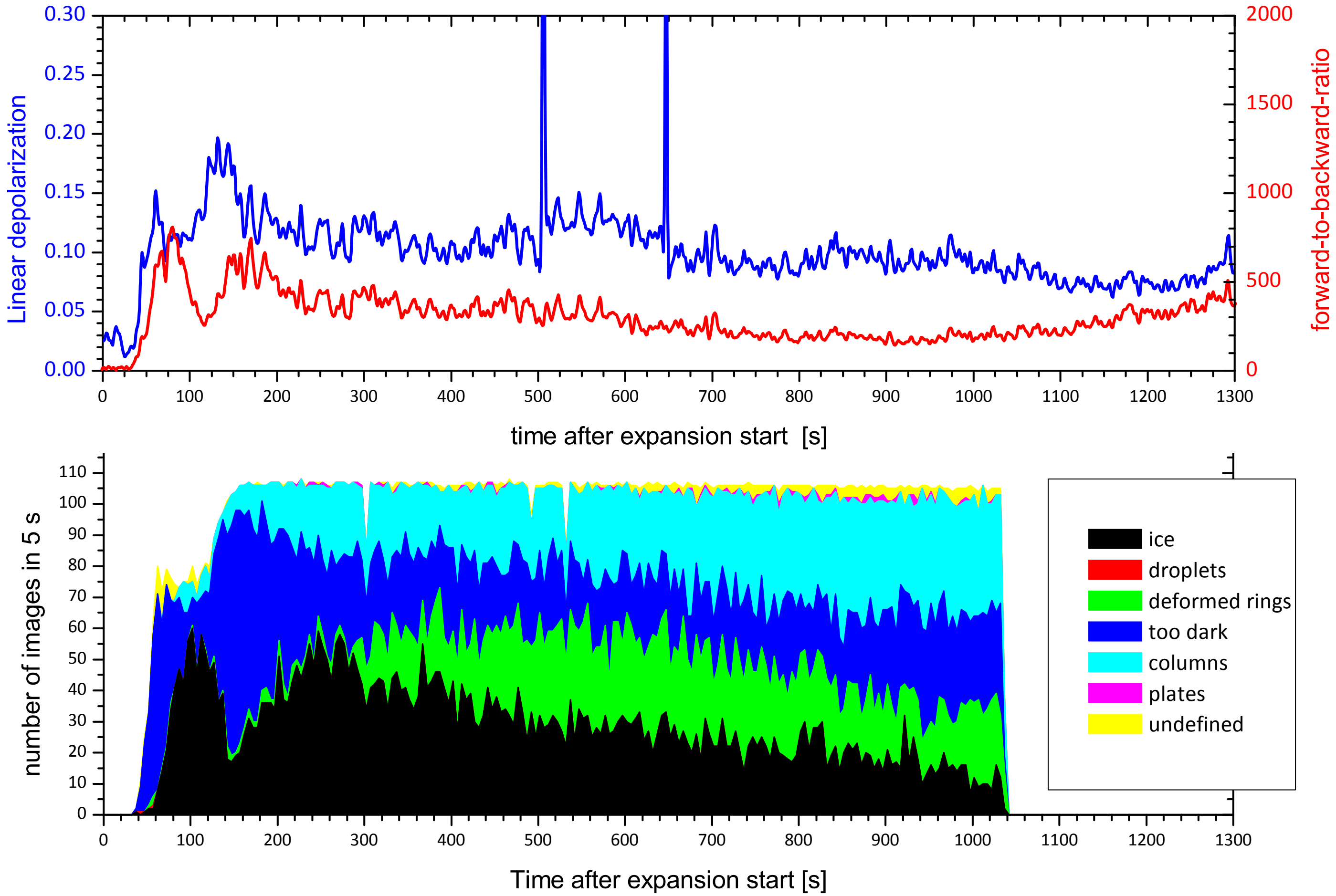
- CAST soot
- AIDA at -40°C
- No droplets



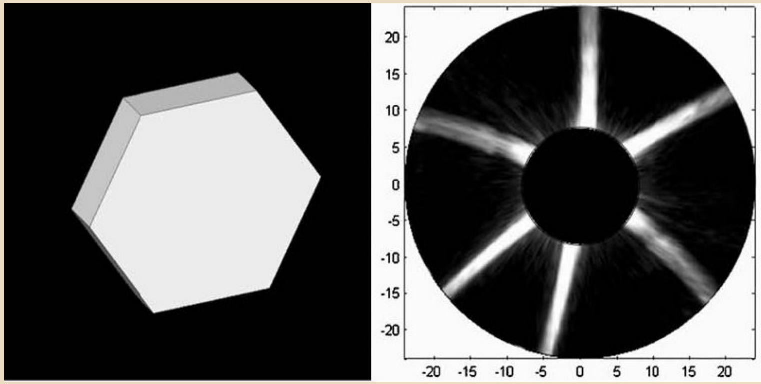
LISA vs. SIMONE: ACI03 - Exp. 23

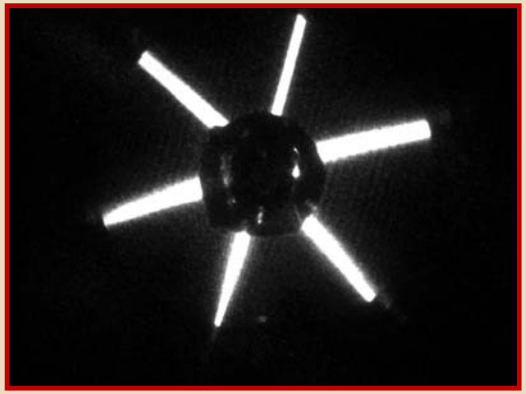
SIMONE

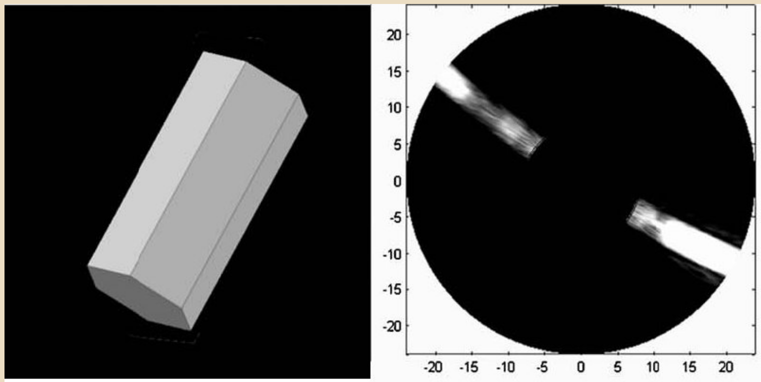
LISA

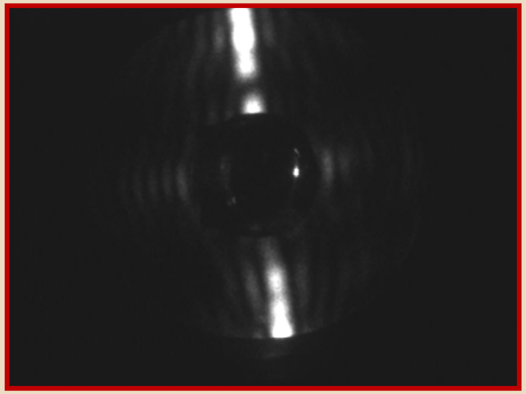


Non-spherical shapes: comparison with precalculated patterns?





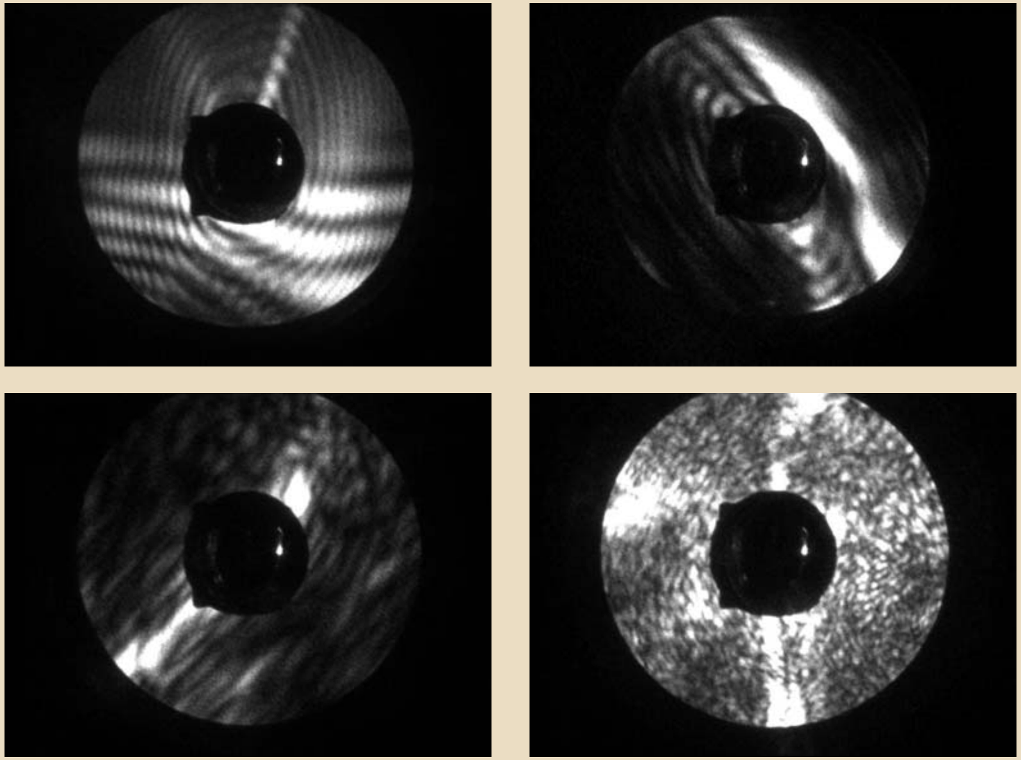




2D scattering patterns calculated with RTDF
(Kaye et al. Opt. Lett., 33(13), 2008.

ACI03, Exp. 29, LISA

But what do we do with irregular patterns?

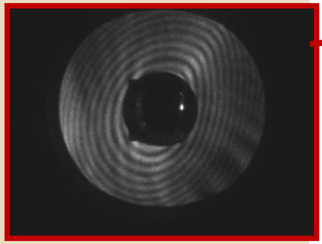


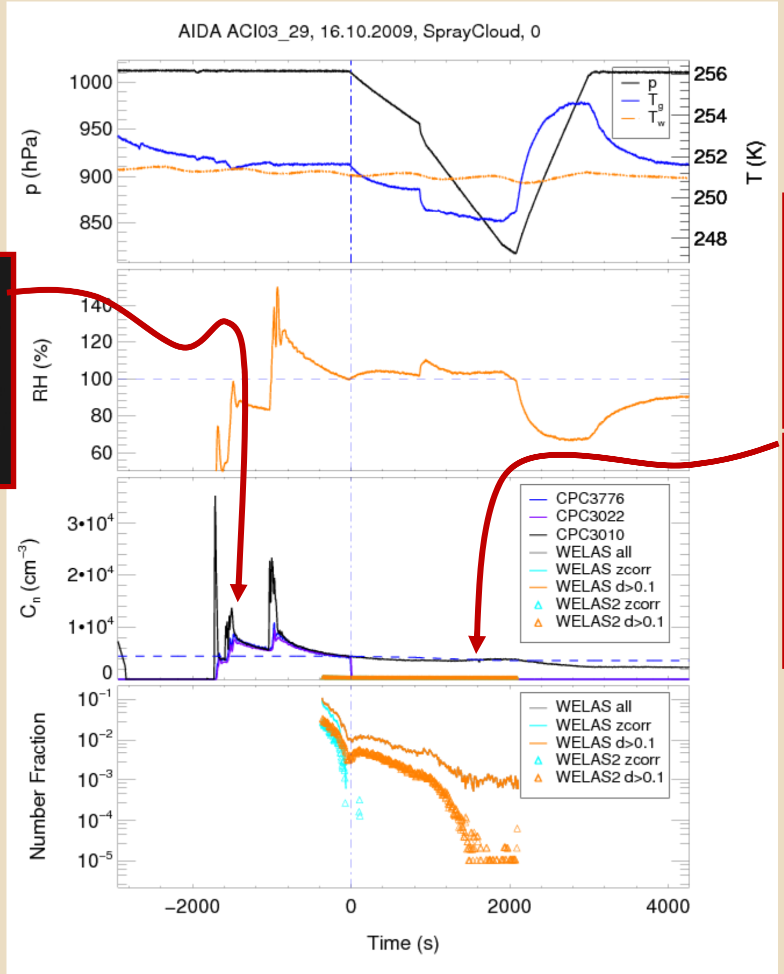
Possible approaches:

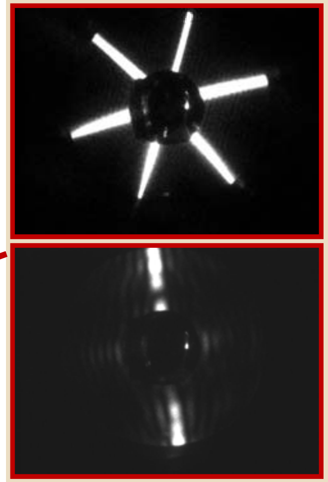
- Measurements with ice analogs
- Calculations of scattering patterns for irregular crystal shapes
- Combined measurements with PHIPS / CPI / …?
- ………………. ???

Part II: Circular Depolarization analysis

- ACI03 Exp 29 (spraying water into AIDA at -22°C)







How we define the circular depolarization:

Stokes vector
of incident light

$$S_0 = \begin{bmatrix} I_0 \\ Q_0 \\ U_0 \\ V_0 \end{bmatrix}$$

Stokes vector
of scattered light

$$S_s = \begin{bmatrix} I_s \\ Q_s \\ U_s \\ V_s \end{bmatrix}$$

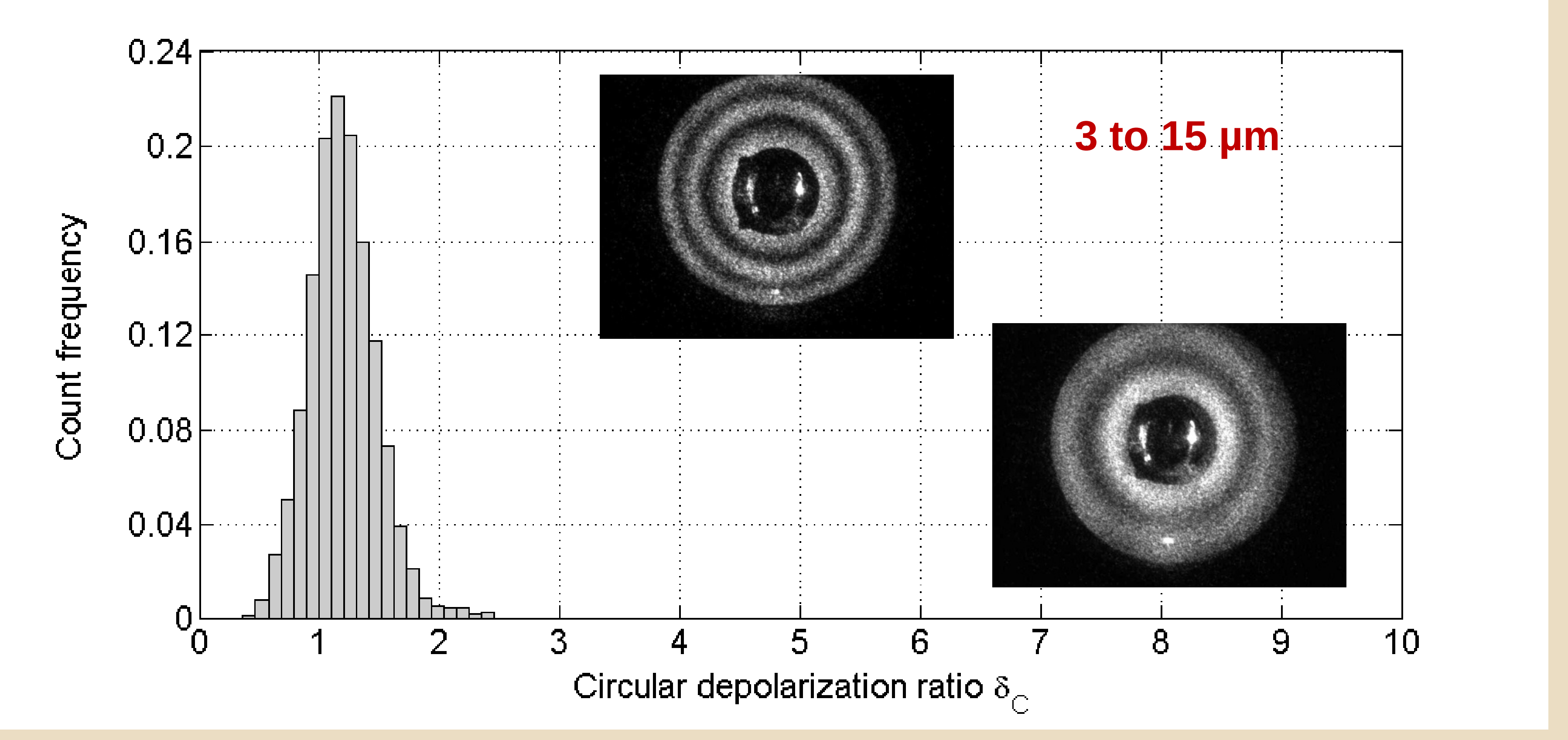
Stokes vector
of light scattered by the particle and passed through a QWP

$$S_s^{QWP} = \begin{bmatrix} I'_s \\ Q'_s \\ U'_s \\ V'_s \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} I_s \\ Q_s \\ U_s \\ V_s \end{bmatrix} = \begin{bmatrix} I_s \\ -V_s \\ U_s \\ Q_s \end{bmatrix}$$

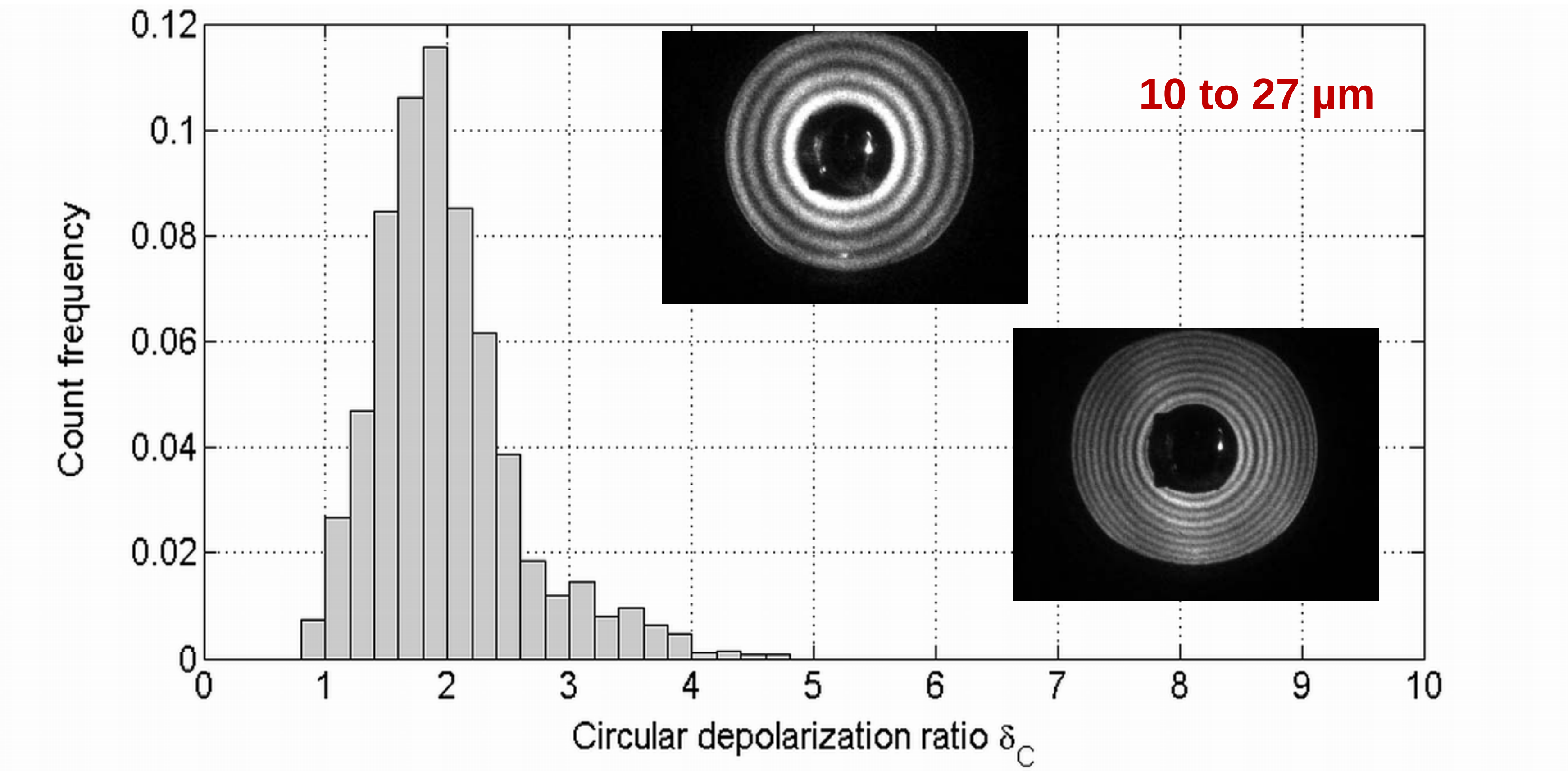
Linear depolarization of light passed through a QWP
(directly measured by LISA)

$$\delta_L^{QWP} = \frac{PMT_2}{PMT_3} = \frac{I'_s - Q'_s}{I'_s + Q'_s} = \boxed{\frac{I_s + V_s}{I_s - V_s} = \delta_C}$$

Depolarization on droplets: “small” droplets

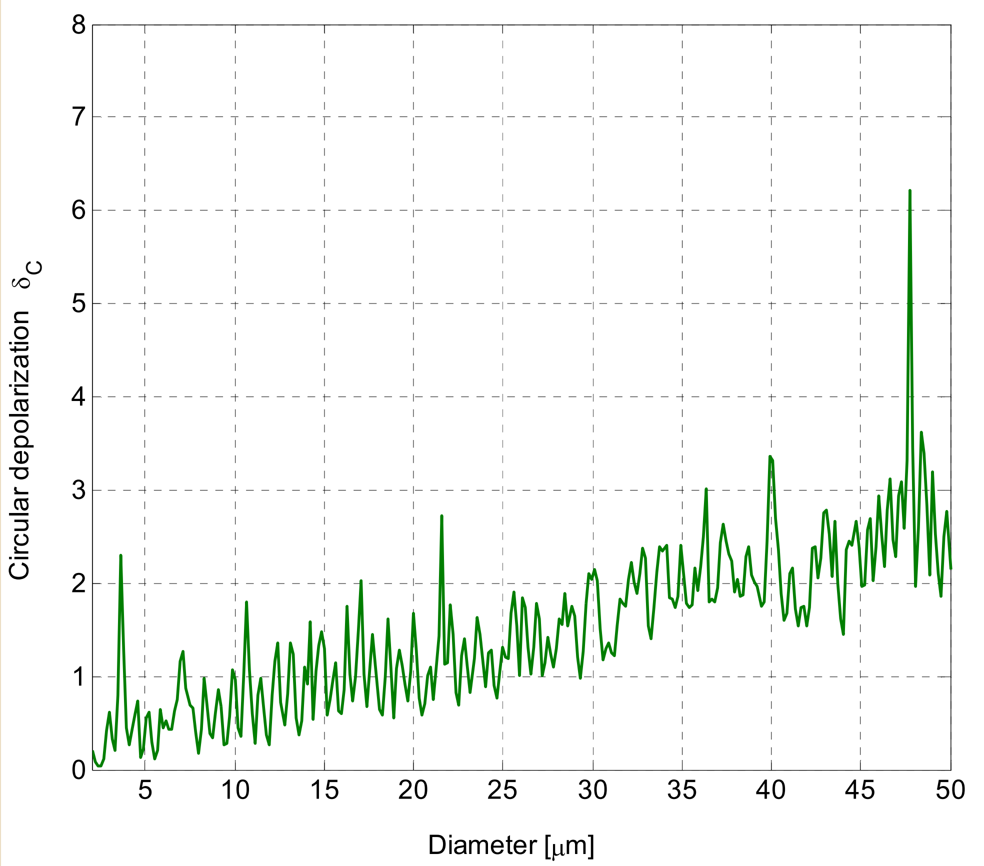


Depolarization on droplets: “large” droplets



ACI03 exp 29

δ_C calculated for backscattering geometry in LISA for water droplets:

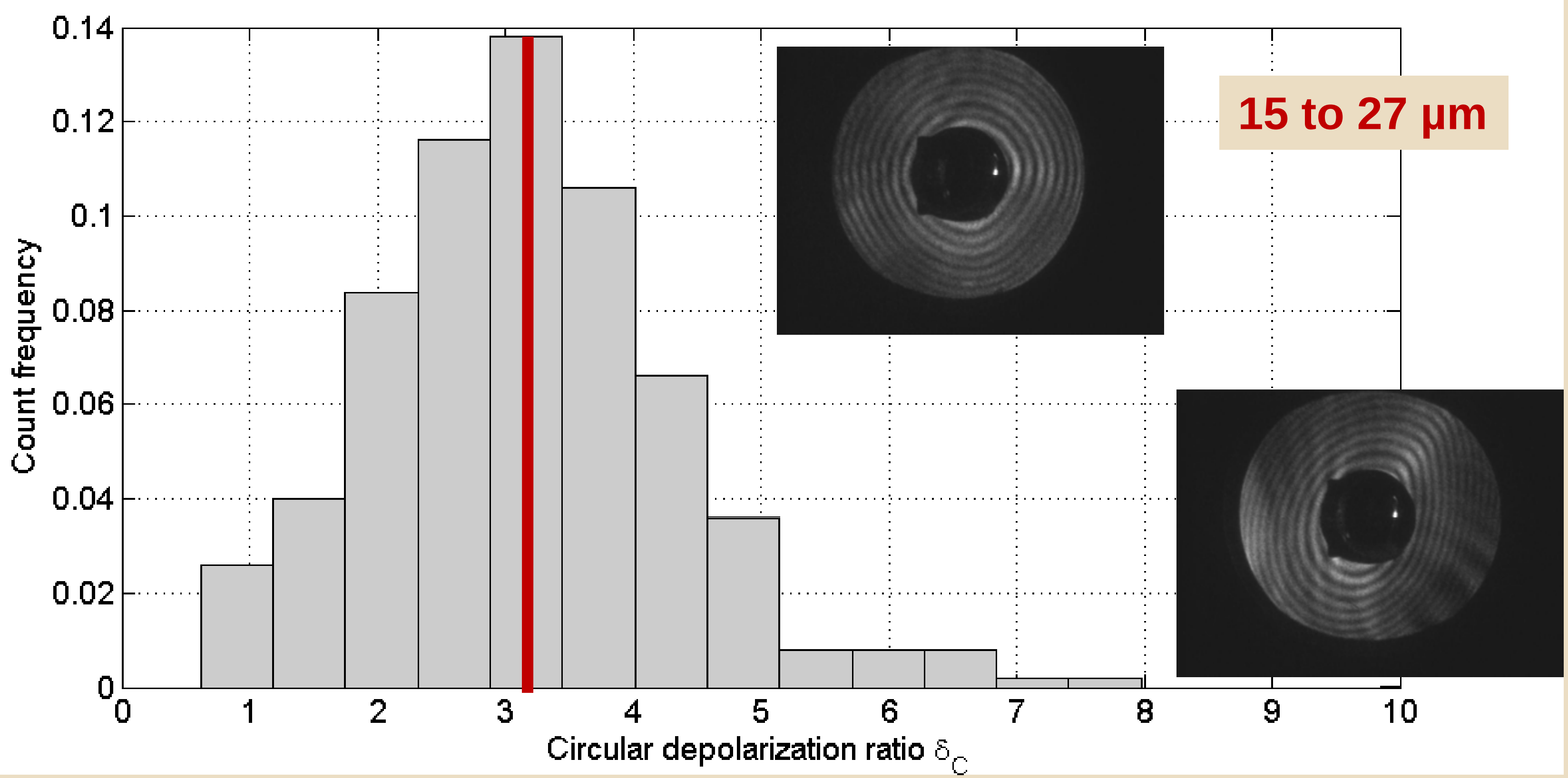


Calculations with Mie theory:

scattering into angle range 166° to 172°

λ = 532.8 nm

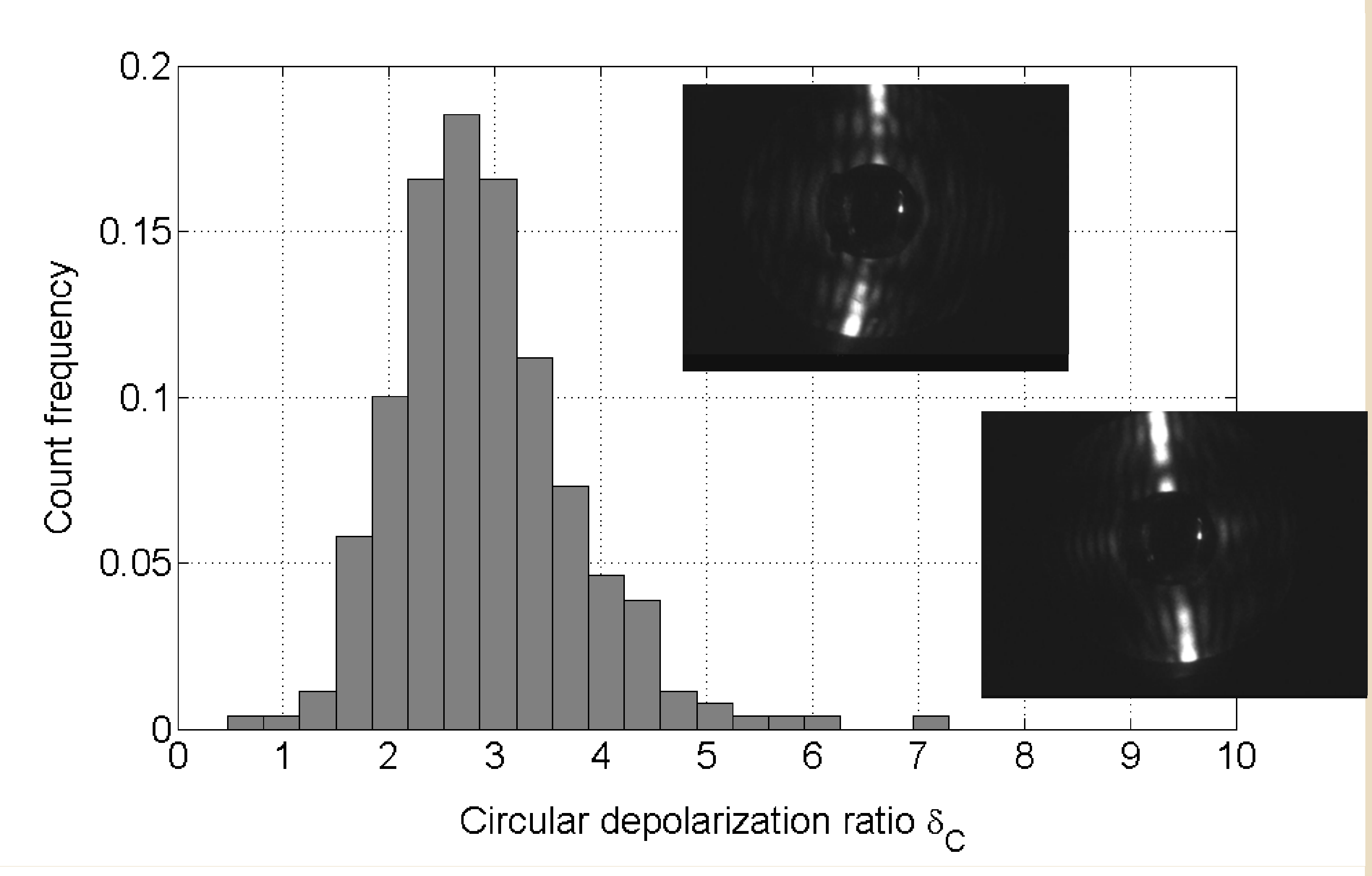
Depolarization on “frozen droplets”



Frozen droplets or evaporating crystals?

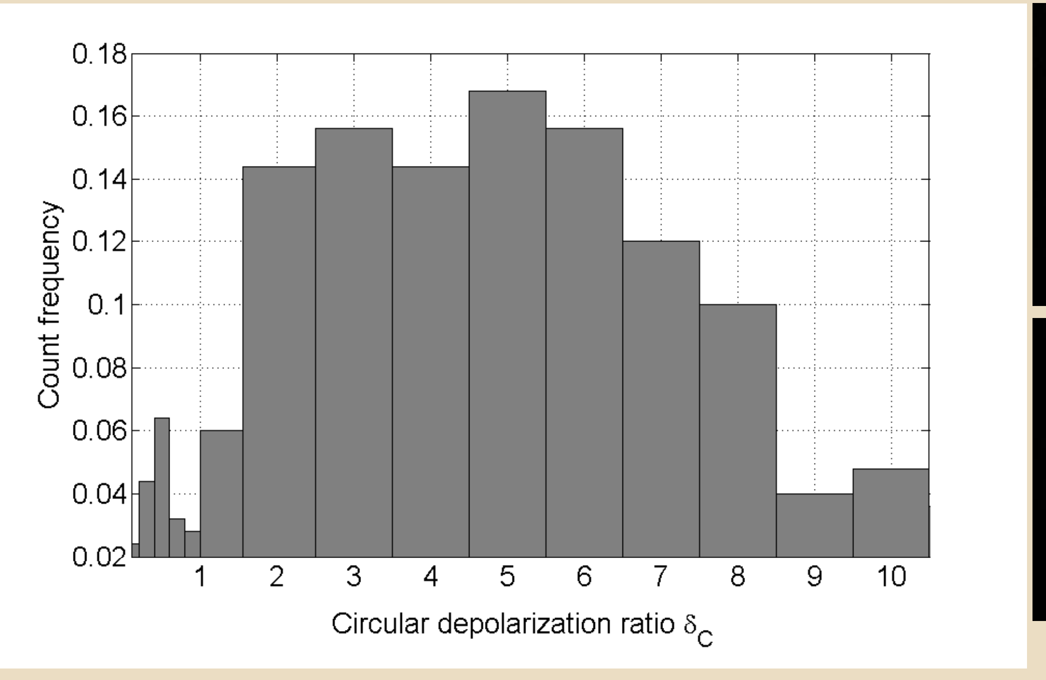
ACI03 exp 29

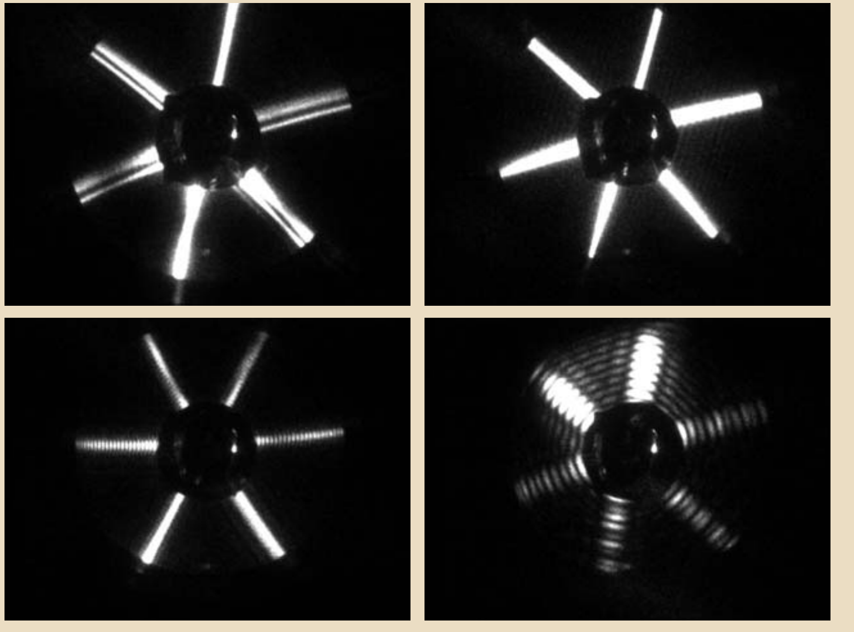
Depolarization on ice columns



ACI03 exp 29

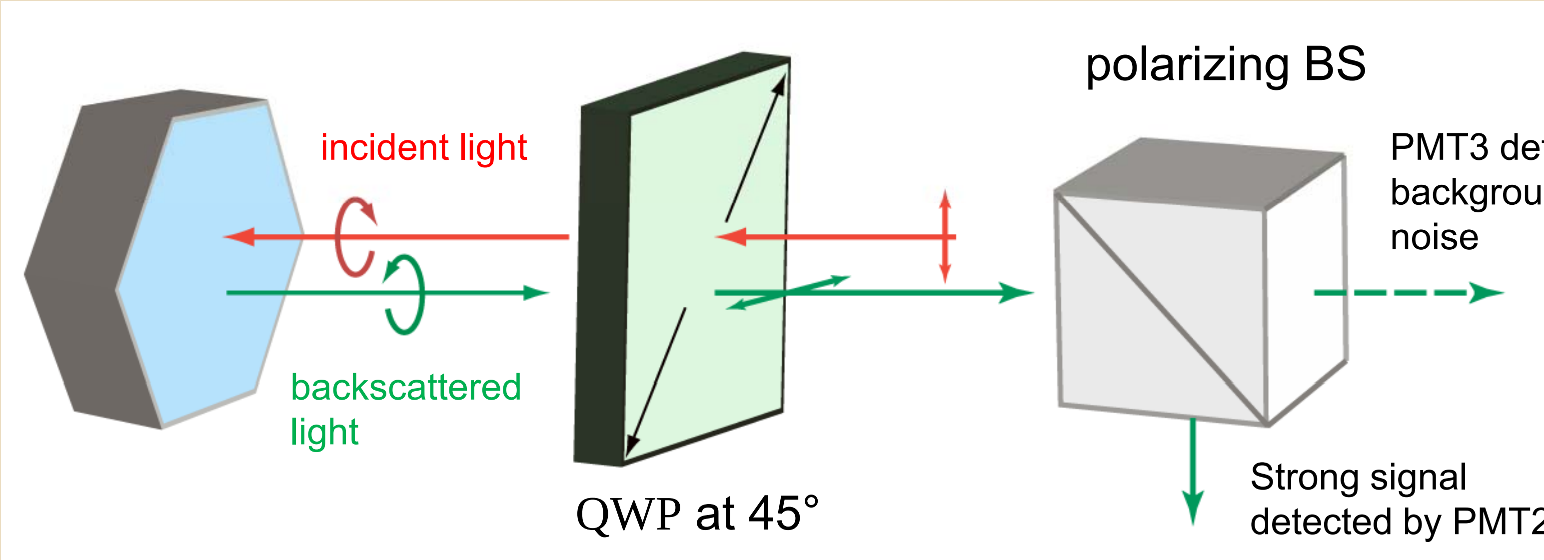
Depolarization on hexagonal plates





ACI03 exp 29

Understanding the high values of δ_c for hexagonal plates:



$$\begin{bmatrix}1\\-1\\0\\0\end{bmatrix}=\begin{bmatrix}1&0&0&0\\0&0&0&-1\\0&0&1&0\\0&1&0&0\end{bmatrix}\times\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&-1&0\\0&0&0&-1\end{bmatrix}\times\begin{bmatrix}1&0&0&0\\0&0&0&1\\0&0&1&0\\0&-1&0&0\end{bmatrix}\times\begin{bmatrix}1\\1\\0\\0\end{bmatrix}$$

S_{scatt} — Quarter-wave plate at 45° — **Ideal reflector** — Quarter-wave plate at -45° — S_0

The ratio of PMT2 to PMT3 is finite

So what we already can do with LISA?

- 2D scattering patterns
  - size measurements of spherical particles above 2 µm (by fitting the number of rings) if refraction index is known
  - determination of fraction of ice particles in the presence of droplets, if the total rate of image acquisition is below 20 sec^{-1}
  - ice shape determination, if the relationships (theoretical or empirical) between shape, orientation and 2D scattering pattern are known (hex plates, columns and "frozen drops")
  - Rapid classification of ice crystal shapes for several types of habits
- Backscattering
  - Measuring of circular depolarization for ice crystals of known shape and orientation
  - Providing additional parameter for statistical classification of the detected particles

Future work

- 2D scattering patterns
  - Further development of automatic image classification (improving preprocession, etc.)
  - Adding automatic size evaluation for spherical particles
  - Retrieval of complex shapes from 2D scattering patterns (collaboration with HU)
  - Statistical evaluation of all experiments from FROST and ACI-03
  - Comparison with data from SID3-AIDA
- Backscattering
  - Improving accuracy of the measurements (noise correction)
  - Comparing measured δ_C for crystals with known shape and orientation with scattering codes (collaboration with HU – RTDF)
  - Statistical evaluation of data collected during FROST and ACI03 experiments