# Updated databank of backscattering Mueller matrices of cirrus clouds' ice crystals for lidar applications

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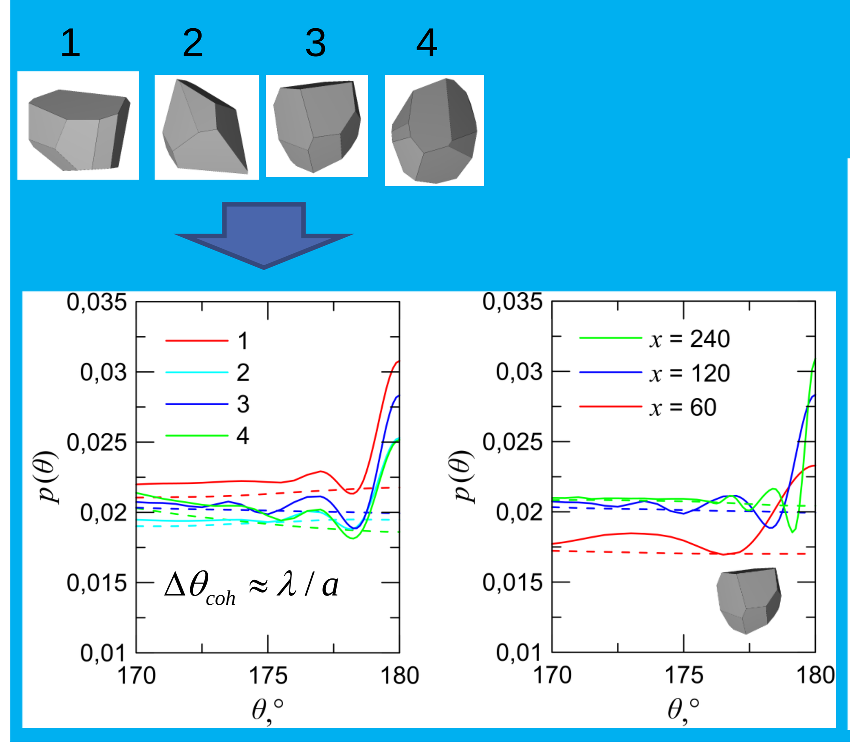
## Abstract

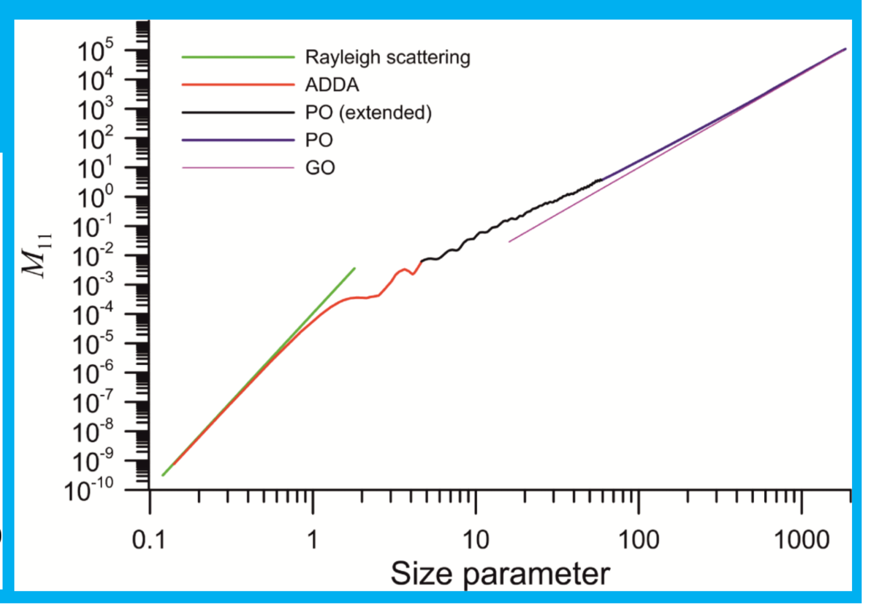
**Cirrus clouds are the object of active study in recent decades. Their influence on the processes of solar radiation transfer in the Earth's atmosphere, and, accordingly, on the planet's climate, has not been sufficiently studied yet. The main instrument for studying cirrus clouds are the active remote sensing tool: lidar. However, the interpretation of lidar data is a difficult problem for atmospheric optics. The main problem in the interpretation of lidar data is the absence of the complete solution to the direct problem of light scattering on the ice crystal particles of cirrus clouds. Nowadays, a large number of scientific teams have directed their efforts to solving this problem.**

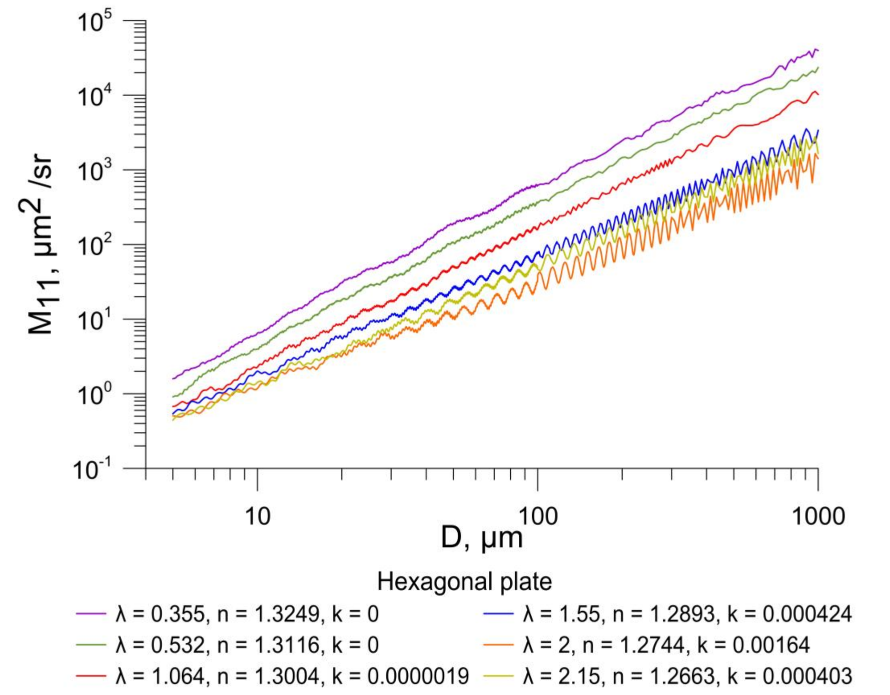
**This report presents a solution to the problem of light scattering for ice crystal particles typical for cirrus clouds: hexagonal plates and columns, droxtals, particles of arbitrary shape. The particle sizes varied from 10 up to 1000 µm. The calculation was carried out for six wavelengths: 0.355, 0.532, 1.064, 1.55, 2 and 2.15 µm. All calculations were carried out taking the effect of absorption into account. The refractive index corresponds to ice. The solution is presented as a databank of backscattering Mueller matrices. The obtained data bank is a significant update of the data bank of backscattering matrices available at the Institute of Atmospheric Optics SB RAS. The updated databank can improve the accuracy of the existing algorithms for interpreting lidar data from both ground-based and space-born lidars.**

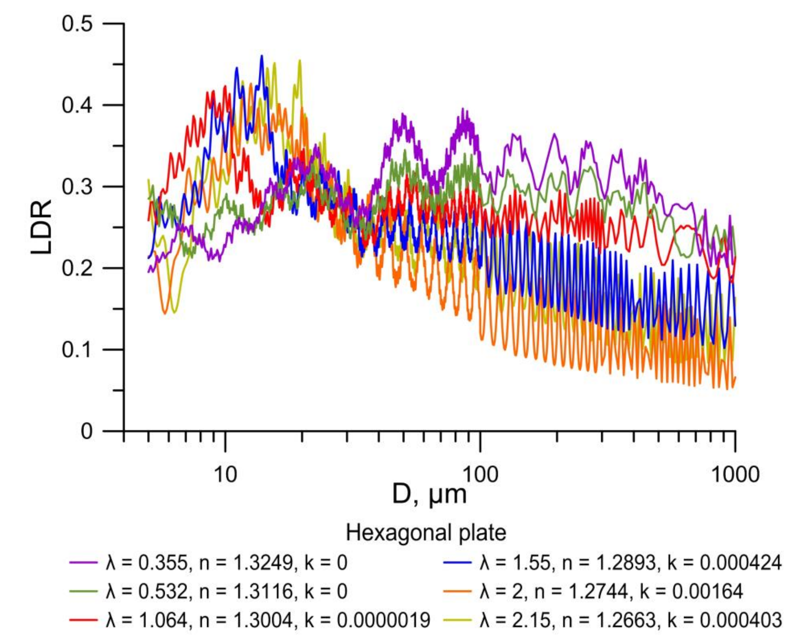
## The physical optics method (PO)

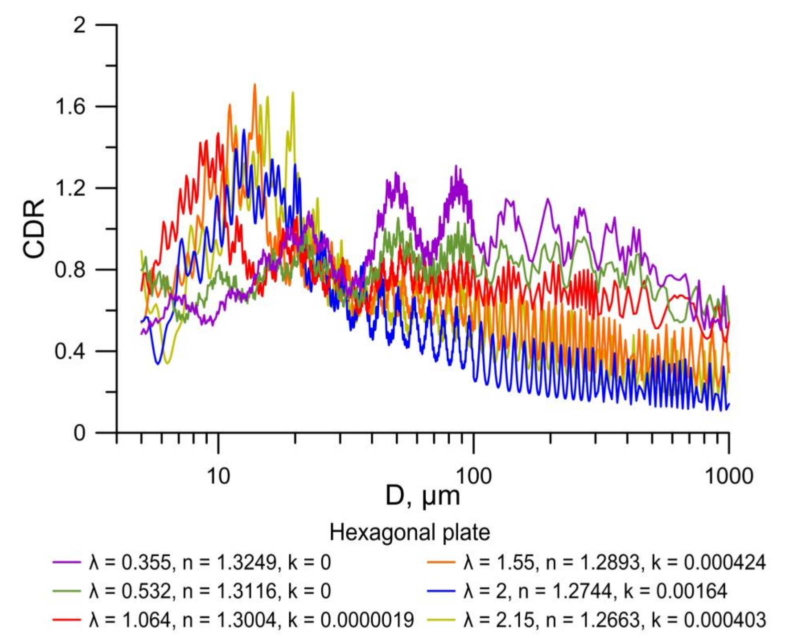
**Today the physical optics method as far as the PGOH (L.Bi) and IGOM (P.Yang) are the only suitable methods to solve the light scattering problem for ice crystal of cirrus clouds for lidar applications. This method can resolve the coherent backscattering peak (left figure below) – this is crucial for lidar signal interpretation. And it converges to the rigorous numerical method such as ADDA (right figure below)**



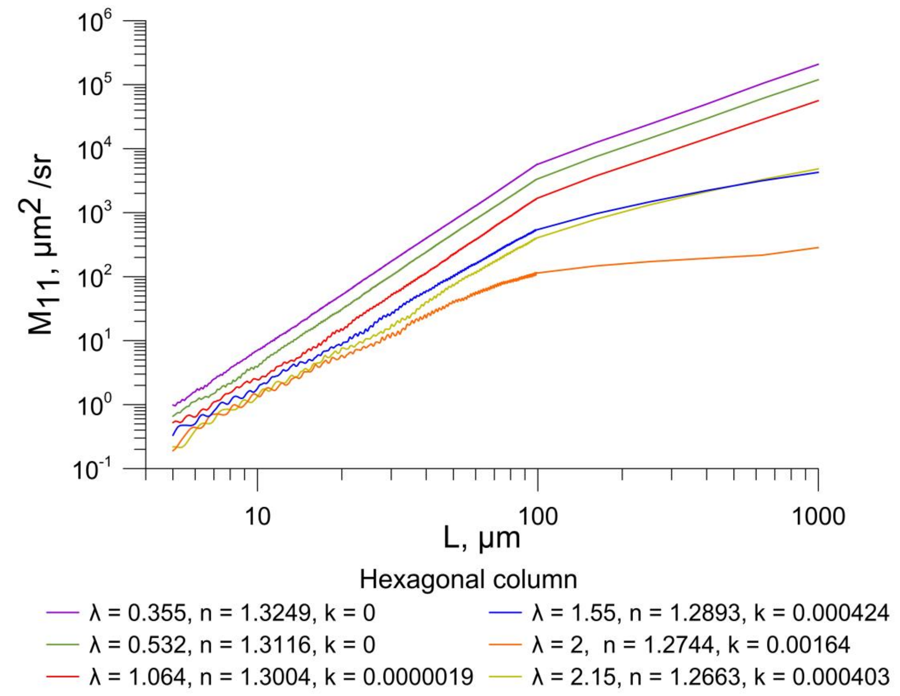



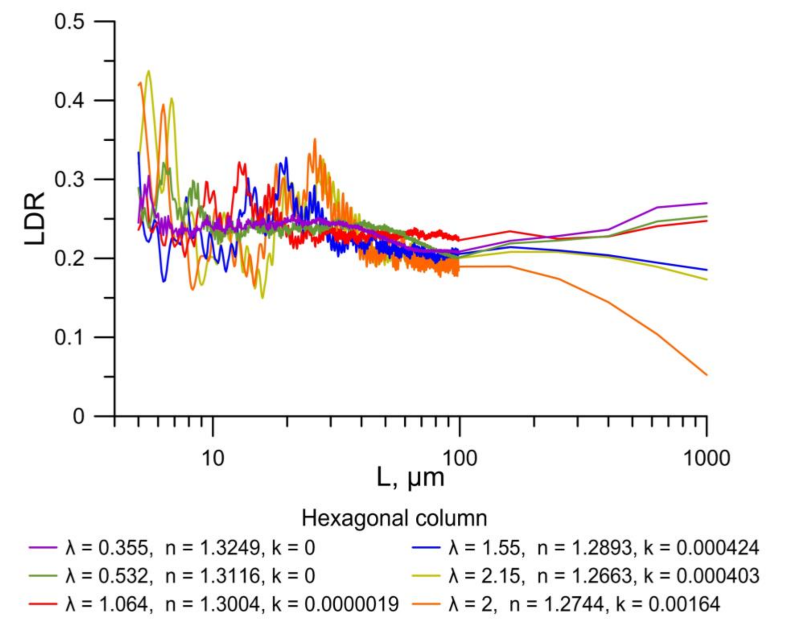



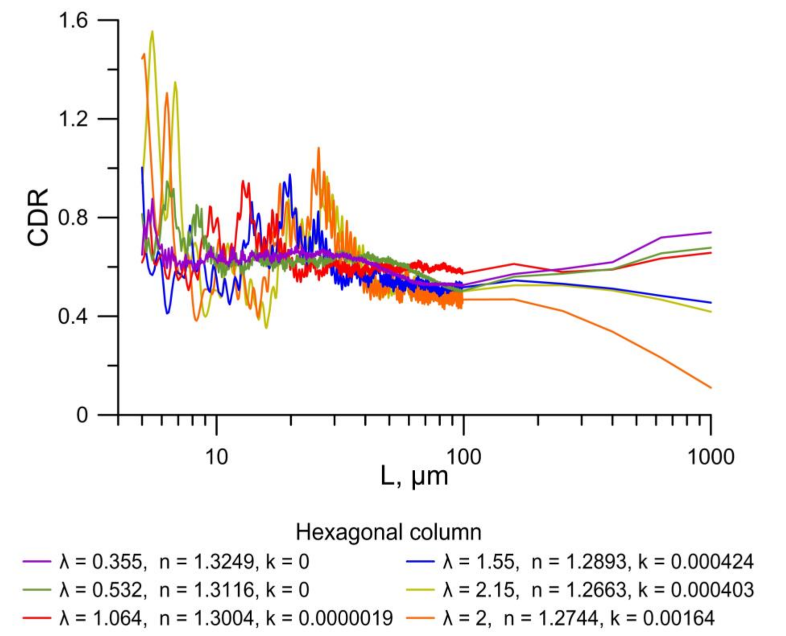



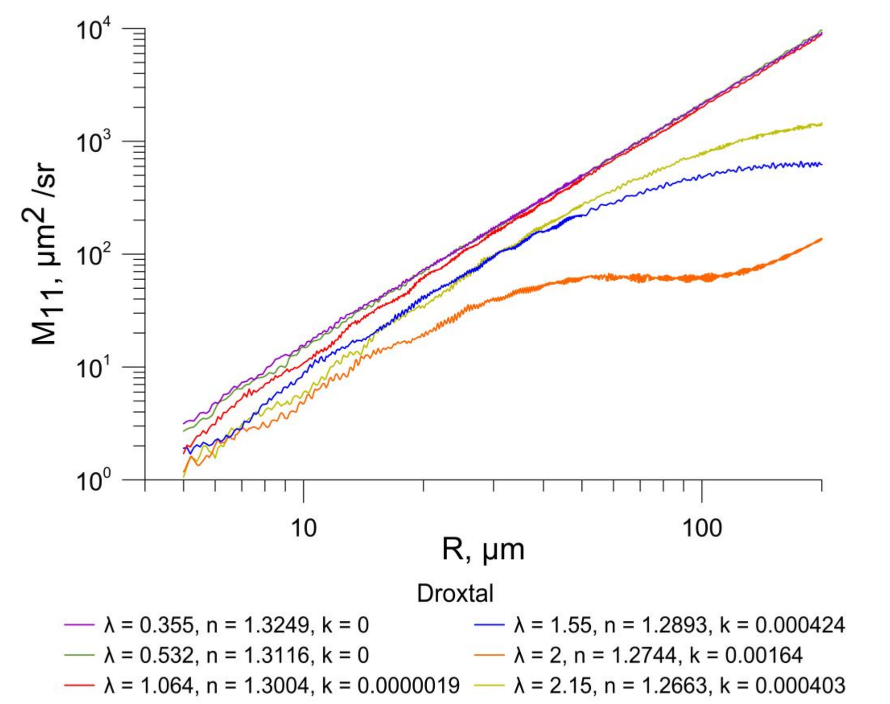

Figures 1-3 – First element of the Mueller matrix (left), linear depolarization ration (center) and circular depolarization ratio (right) for **perfect hexagonal ice plates** with size from 10 to 1000 µm. The height of the plates is $h$=2.02$D^{0.449}$. We can see the interference oscillations (high frequency) and waveguide effect low frequency oscillations. Waveguide effect presents only for the wavelength of 0.355, 0.532 and 1.064 (partly) where the absorption affect are weak.

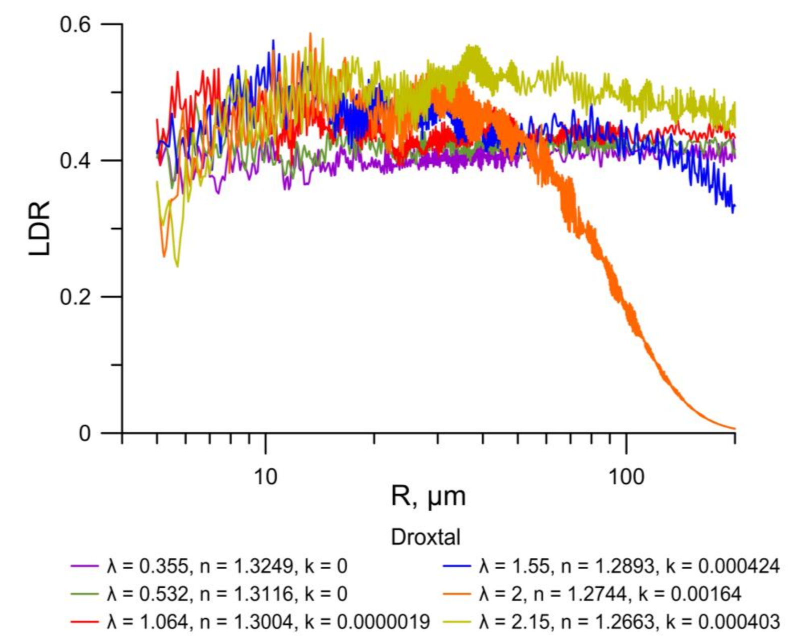


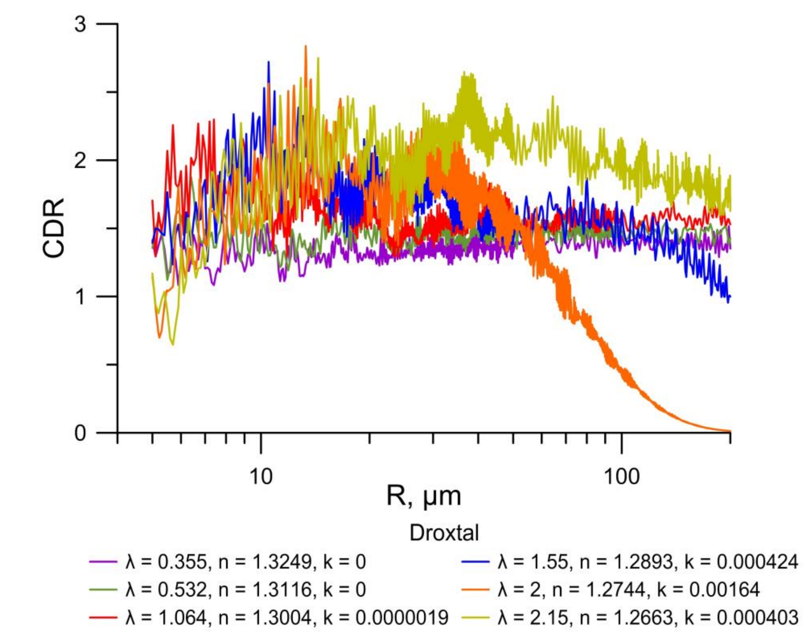



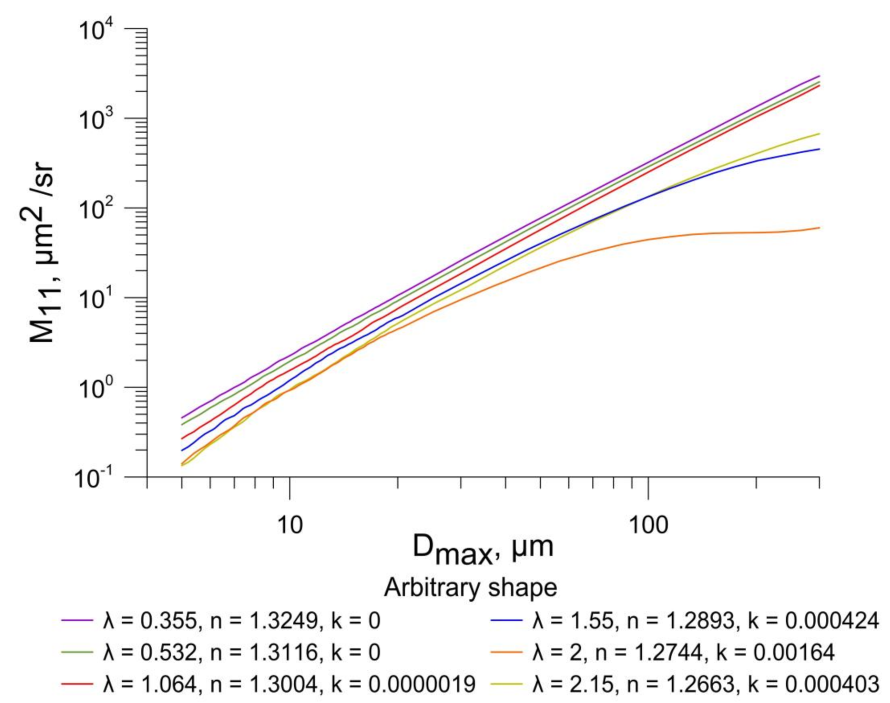

Figures 4-6 – First element of the Mueller matrix (left), linear depolarization ration (center) and circular depolarization ratio (right) for **perfect hexagonal ice columns** with size from 10 to 1000 µm. The diameter of the column is $D$=0.7$L$ for $L$<100 and $D$=0.69$L^{0.5}$ for $L$>100. There is no waveguide effect for columns and the interference oscillations are very weak. So we do not need to precisely calculate full range of the sizes for columns higher than 100 µm, only small vicinity of six basic sizes were calculated. Then averaged result for every vicinity were put into the databank.

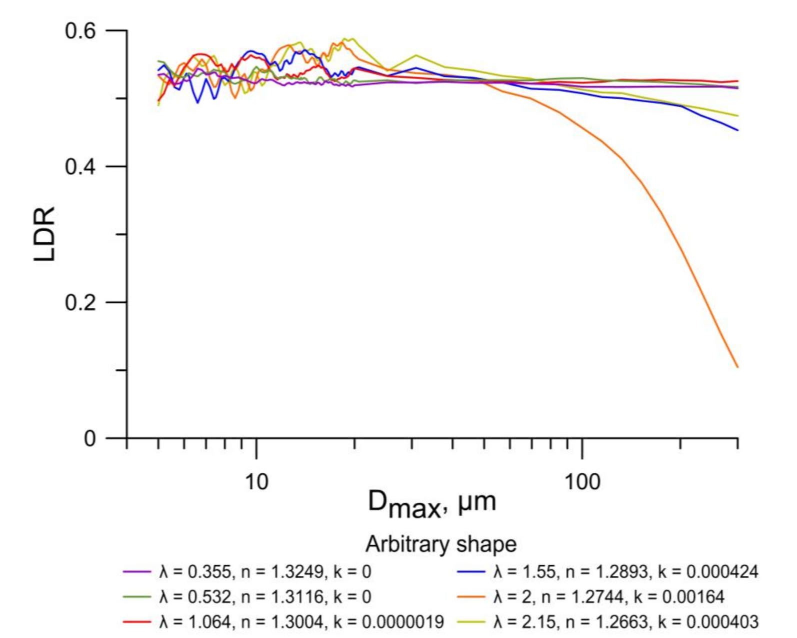


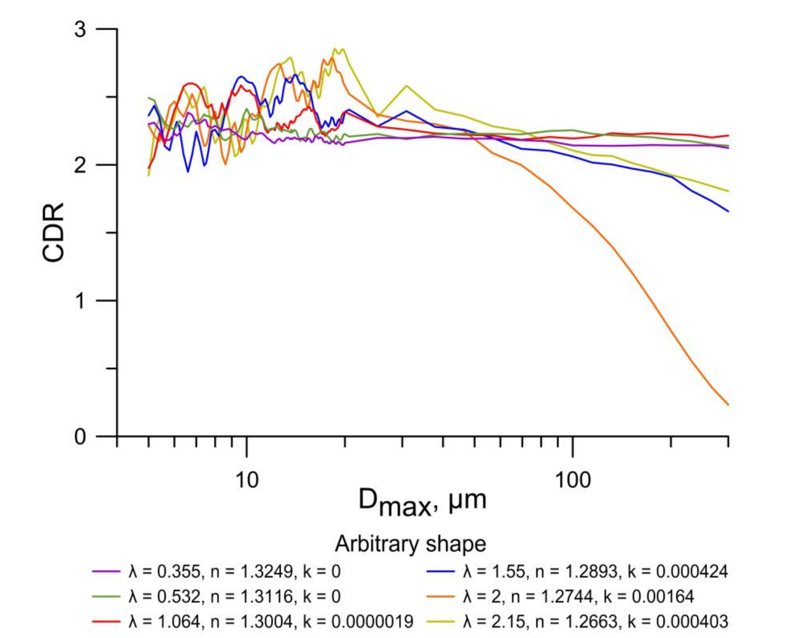




Figures 7-9 – First element of the Mueller matrix (left), linear depolarization ration (center) and circular depolarization ratio (right) for **ice droxtals** with diameter from 10 to 400 µm. There is no waveguide effect for droxtals but the interference oscillations are noticeable. Here we can see that the depolarization ratio at the 2 µm depends on the particle size due to the absorption effect. For the droxtal with radius of 200 µm the absorption is strong enough to completely absorb all the light came into the particle, so only external reflection with zero depolarization take place.




Figures 10-12 – First element of the Mueller matrix (left), linear depolarization ration (center) and circular depolarization ratio (right) for **ice particle of arbitrary shape** with diameter from 5 to 300 µm. There is no waveguide effect and the interference oscillations are very weak. So we do not need to precisely calculate full range of the sizes, only several basic sizes were calculated. Here we can also see that the depolarization ratio at the 2 µm depends on the particle size due to the absorption effect. But the absorption is weaker then for droxtals because the optical trajectories are shorter. Actually, even for the particle with size of 300 µm there are both external and internal parts of scattered light.