**Brief description of the database of light backscattering of cirrus clouds’ ice crystals, level 2**

**Note:** This database is based on “the database of light backscattering of cirrus clouds’ ice crystals, level 1”. The level 2 database is the same as the level 1 database but it contains the Mueller matrixes for the case of **randomly oriented crystals**.

(The level 1 database contains matrix of light scattering for particle that are averaged over only two Euler angles.)

[**1.General characteristics** 1](#_Toc146724824)

[**2.The parameters of the database** 5](#_Toc146724825)

[**3. General structure of the data bank** 11](#_Toc146724826)

[**4. Illustration of the database** 14](#_Toc146724827)

# **1.General characteristics**

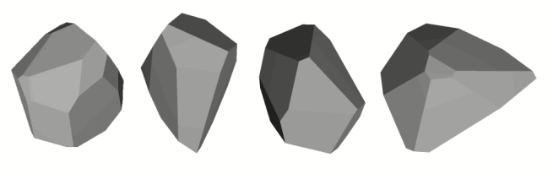
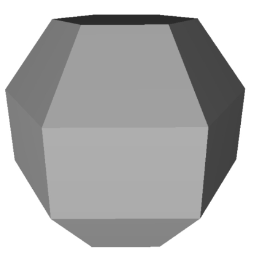
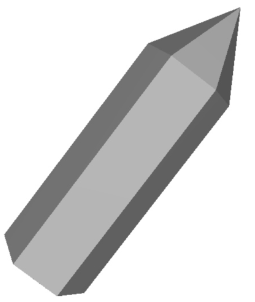
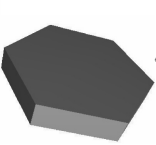
**1.1 The main wavelengths and the refractive indices of ice:**

* λ = 0.355 μm, n = 1.3249
* λ = 0.532 μm, n = 1.3116
* λ = 1.064 μm, n = 1.3004 + i·0.0000019
* λ = 2.15 μm, n = 1.2663 + i·0.000403
* λ = 2 μm, n = 1.2744 + i·0.00164
* λ = 1.55 μm, n = 1.2893 + i·0.000424

The additional wavelengths and the refractive indices:

* λ = 1.064 μm, n = 1.6 + i·0.002
* λ = 1.064 μm, n = 1.6
* λ = 0.532 μm, n = 1.48 +i·0.002
* λ = 0.532 μm, n = 1.48

**1.2 The particle’s shape.**



From left to right:

1. Hexagonal column
2. Hexagonal plate
3. Bullet
4. Droxtal
5. Arbitrary shape particle №1
6. Arbitrary shape particle №2
7. Arbitrary shape particle №3
8. Arbitrary shape particle №4

**1.3 Definition of the particle shapes.**

1) The hexagonal plate and column are defined by the diameter *D* and the length *L* according to: *A.H. Auer* and *D.L. Mitchell:*

[*Auer A.H., Veal D.L. The dimension of ice crystals in natural clouds // J. Atmos. Sci. 1970. V. 29. P. 311–317*.]  
[*Mitchell D.L., Arnott W.P. A model predicting the evolution of ice particle size spectra and radiative properties of cirrus clouds. Part II: Dependence of absorption and extinction on ice crystal morphology // J. Atmos. Sci. 1994. V. 51. P. 817–832*.]

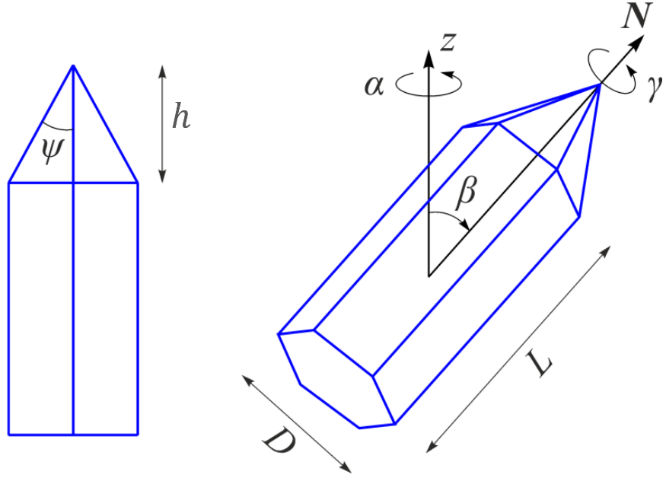
*For column:*

where ***L*** is the crystal height, ***D*** is the crystal width.

*For plate:*

*,* where ***L*** is the crystal height, ***D*** is the crystal width.

2) The bullet shape is defined by the diameter *D*, the length of a hexagonal part *L* and the angle of a tip *ψ=62°.*

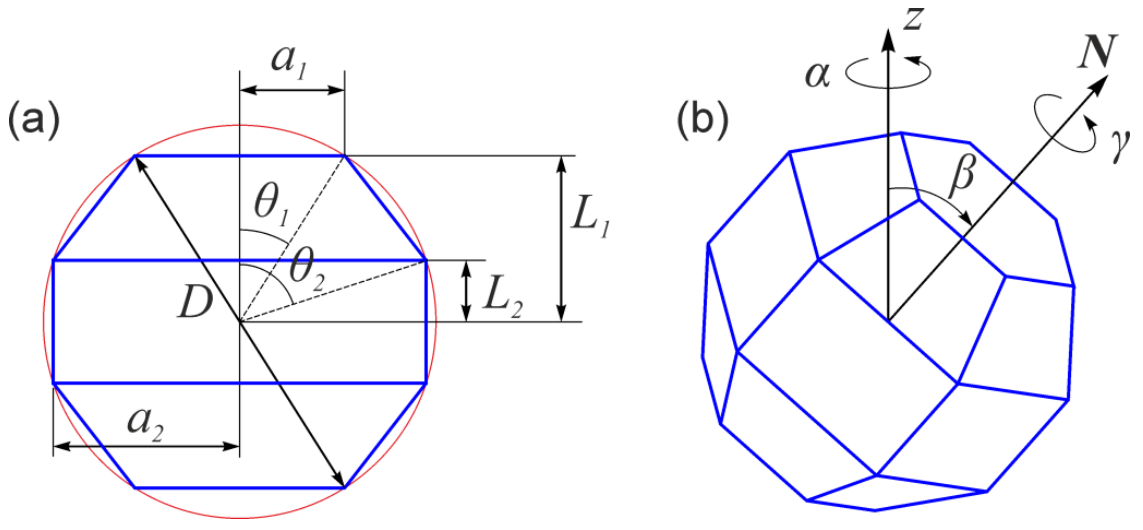


The size of bullets is defined similar to column, but a tip with a height of ***h*** is added to the hexagonal prism.

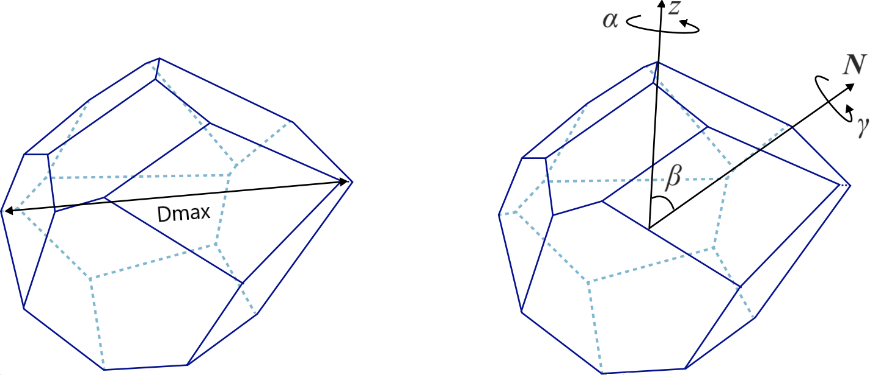
where ***L*** is the crystal height, ***D*** is the crystal width.

is the height of the tip on the bullet

3) The droxtal shape is defined by the diameter *D.* The two angles *θ*1 and *θ*2 are set as *θ*1 =32.35° and *θ*2 =71.81° [P. Yang et al., J. Quant. Spectrosc. Radiat. Transfer, 79–80, P. 1159–1169 (2003)]:



4) Arbitrary shape particle is specified by the maximum size (*D*max) between the vertices of the crystal. The coordinates of vertexes of the particle are given in a separate file, then the particles are simply scaled to the given *D*max.

****

**1.4 Averaging over particle orientation.**

In this database we assume that the particles have a random spatial orientation. The average Mueller matrix can be found as:

The orientation of the particle is specified by three Euler angles, where **α** defines rotation about the vertical direction, **β** is the angle between the vertical direction and the crystal main axis, **γ** describes rotation about the main axis; **D** is the particle size.

The averaging over the **α** angle can be done analytically, while averaging over the **β** and **γ** angles requires numerical integration. We choose the appoprient number of orientation for this numerical integration accordant to our estimation [*A. Konoshonkin, A. Borovoi, N. Kustova, H. Okamoto, H. Ishimoto, Y. Grynko, and J. Förstner, "Light scattering by ice crystals of cirrus clouds: From exact numerical methods to physical-optics approximation," Journal of Quantitative Spectroscopy and Radiative Transfer 195, 132–140 (2017).*]

This estimate requires the total number of orientations by angle **β** and angle **γ** as many as the angular step is twice less than

.

where *l*max is maximum edge length in a particle

On the basis of which the minimum step in the angles of orientation of the particle was chosen according to

,

**1.5 Basic relations**

A/4 is a particle cross section, A is the particle surface area.

is the lidar ratio

is the linear depolarization ratio

is the circular depolarization ratio

m14 = *M*14/*M*11…m44=*M*44/*M*11 are the normalized elements of the Muller matrix

The database consists of 16 elements, where the nonzero elements are: *M*11, *M*22, *M*33, *M*44. The value of the elements *M*14 and *M*41 is close to zero. The difference of the value of the elements *M*14 and *M*41 from the 0 for plates, columns, bullets and droxtals shows the inaccuracy (calculation error):

# **2.The parameters of the database**

**2.1. Hexagonal column (table 1)**



Table 1 – Continuation of Table 1.



**2.2. Hexagonal plate (table 2)**



**2.3. Arbitrary shape particle (table 3)**

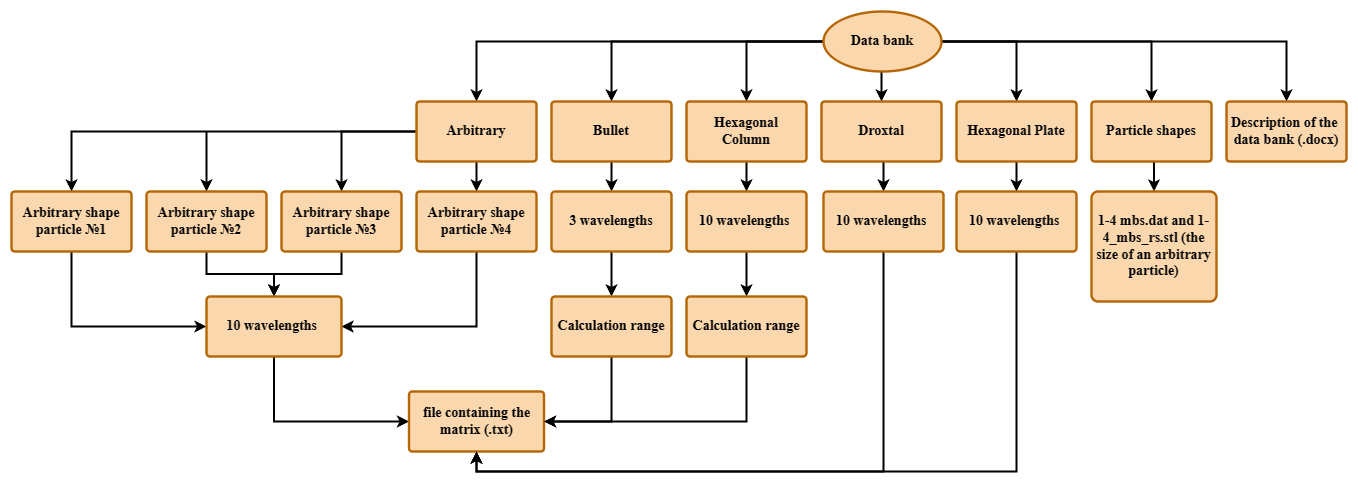


**2.4. Droxtal (table 4)**



**2.5. Bullet (table 5)**



**3. General structure of the data bank**

**3.1. File structure**

|  |  |
| --- | --- |
| **lmd** is the wavelength | **LDR** is the linear depolarization ratio |
| **n** is the real part of refractive index | **k** is the imaginary part of refractive index |
| **V** is the particle volume | **CS** is the cross section |
| ***M*11…*M*44** are the elements of the Muеller matrix | **m**14 ... **m**44 are the normalizedelements of the Muеller matrix (*M*14/*M*11…*M*44/*M*11) |
| **L** is the crystal height | **D** is the crystal width |
| **Dm, Dmax**  are the maximum particle sizes | **LR** is the lidar ratio |
| **CDR** is the circular depolarization |  |

**3.1.1 Hexagonal column**

• The final names of the subfolders include:

Wavelength (lmd), the real part of refractive index (n), the imaginary part of refractive index (k).

***Example***: lmd0.355\_n1.3249\_k0 means that the wavelength is 0.355, the real part of refractive index (n) is 1.3249, the imaginary part of refractive index (k) is 0.

• For hexagonal columns, the file names have the following format:

[Name of file]\_[Wavelength]\_[Real part of refractive index ]\_[Imaginary part of refractive index]\_[Calculation range in microns].

***Example***: "Column\_output\_lmd0.355\_n1.3249\_k0 (range 5-100 microns)" means that the file name “Column\_output”, the wavelength is 0.355, the real part of refractive index (n) is 1.3249, the imaginary part of refractive index (k) is 0, the calculation ranges 5 to 100 microns.

• Data files have the following structure:

[Column width D] [Column height L] [Dmax] [V] [CS] [LR] [LDR] [CDR] [M11] [M14] [M22] [M33] [M41] [M44] [m14] [m22] [m33] [m41] [m44]

***Example:***

HC

*For hexagonal column and bullet, the range from 100 to 1000 with nodal points (160, 250,400, 630 and 1000 microns) was calculated. This was necessary to speed up the calculations. The final result is located in a folder called "Averaged". The result for the nodal point was taken from averaging the range around the nodal point. The size range around the nodal point is also represented in folders named "Range 160 microns", "Range 250 microns", etc.*

**3.1.2 Hexagonal plates**

• The final names of the subfolders include:

Wavelength (lmd), the real part of refractive index (n), the imaginary part of refractive index (k).

***Example***: lmd0.355\_n1.3249\_k0 means that the wavelength is 0.355, the real part of refractive index (n) is 1.3249, the imaginary part of refractive index (k) is 0.

• For hexagonal plates, the file names have the following format:

[Name of file]\_[Wavelength]\_[Real part of refractive index ]\_[Imaginary part of refractive index]

***Example***: "Plate\_output\_lmd0.355\_n1.3249\_k0" means that the file name “Plate\_output”, the wavelength is 0.355, the real part of refractive index (n) is 1.3249, the imaginary part of refractive index (k) is 0.

• Data files have the following structure:

[Plate width D] [Plate height L] [Dmax] [V] [CS] [LR] [LDR] [CDR] [M11] [M14] [M22] [M33] [M41] [M44] [m14] [m22] [m33] [m41] [m44]

***Example:***

HP

**3.1.3 Arbitrary shape particle**

• The final names of the subfolders include:

Wavelength (lmd), the real part of refractive index (n), the imaginary part of refractive index (k).

***Example***: lmd0.355\_n1.3249\_k0 means that the wavelength is 0.355, the real part of refractive index (n) is 1.3249, the imaginary part of refractive index (k) is 0.

• For arbitrary shape particle, the file names have the following format:

[Name of file]\_[Wavelength]\_[Real part of refractive index ]\_[Imaginary part of refractive index].

***Example***: "Arbitrary1\_output\_lmd0.355\_n1.3249\_k0" means that the file name “Arbitrary1\_output”, the wavelength is 0.355, the real part of refractive index (n) is 1.3249, the imaginary part of refractive index (k) is 0.

• Data files have the following structure:

[Dmax] [V] [CS] [LR] [LDR] [CDR] [M11] [M14] [M22] [M33] [M41] [M44] [m14] [m22] [m33] [m41] [m44]

***Example:***

Arb1

• Similarly for particles 2, 3, 4

**3.1.4 Droxtals**

• The final names of the subfolders include:

Wavelength (lmd), the real part of refractive index (n), the imaginary part of refractive index (k).

***Example***: lmd0.355\_n1.3249\_k0 means that the wavelength is 0.355, the real part of refractive index (n) is 1.3249, the imaginary part of refractive index (k) is 0.

• For droxtal, the file names have the following format:

[Name of file]\_[Wavelength]\_[Real part of refractive index ]\_[Imaginary part of refractive index].

***Example***: "Droxtal\_output\_lmd0.355\_n1.3249\_k0" means that the file name “Droxtal\_output”, the wavelength is 0.355, the real part of refractive index (n) is 1.3249, the imaginary part of refractive index (k) is 0.

• Data files have the following structure:

[Dmax] [V] [CS] [LR] [LDR] [CDR] [M11] [M14] [M22] [M33] [M41] [M44] [m14] [m22] [m33] [m41] [m44]

***Example:***

Drox

**3.1.5 Bullet**

• The final names of the subfolders include:

Wavelength (lmd), the real part of refractive index (n), the imaginary part of refractive index (k).

***Example***: lmd0.355\_n1.3249\_k0 means that the wavelength is 0.355, the real part of refractive index (n) is 1.3249, the imaginary part of refractive index (k) is 0.

• For bullet, the file names have the following format:

[Name of file]\_[Wavelength]\_[Real part of refractive index ]\_[Imaginary part of refractive index]\_[Calculation range in microns].

***Example***: "Bullet\_output\_lmd0.355\_n1.3249\_k0 (range 10-100 microns)" means that the file name “Bullet\_output”, the wavelength is 0.355, the real part of refractive index (n) is 1.3249, the imaginary part of refractive index (k) is 0, the calculation ranges 10 to 100 microns.

• Data files have the following structure:

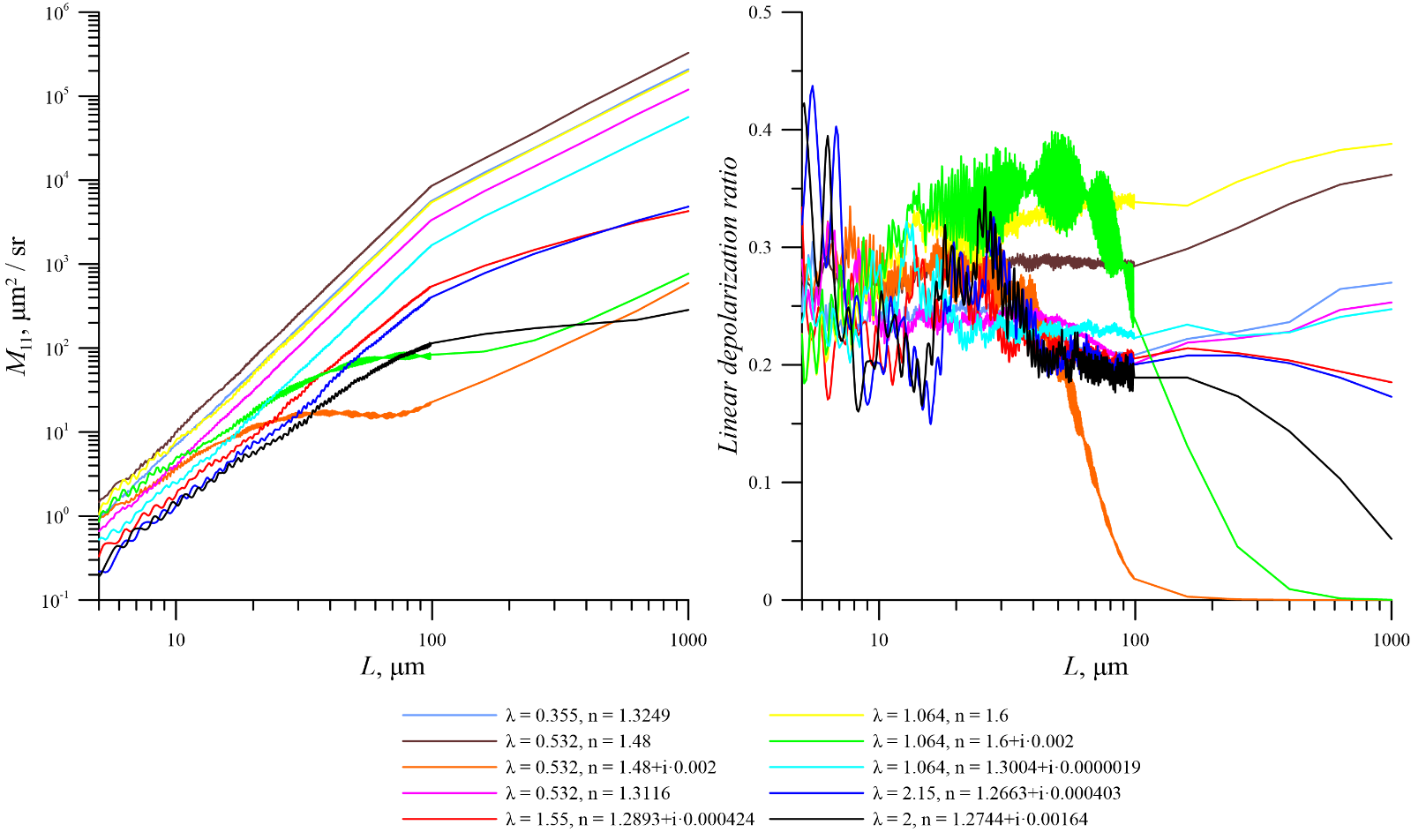
[Column width D] [Column height L] [h] [Dmax] [V] [CS] [LR] [LDR] [CDR] [M11] [M14] [M22] [M33] [M41] [M44] [m14] [m22] [m33] [m41] [m44]

***Example***:

Bull

*For column particles and bullet, the range from 100 to 1000 with nodal points (160, 250,400, 630 and 1000 microns) was calculated. This was necessary to speed up the calculations. The final result is located in a folder called "averaged". The result for the nodal point was taken from averaging the range around the nodal point. The size range around the nodal point is also represented in folders named "Range 160 microns", "Range 250 microns", etc.*

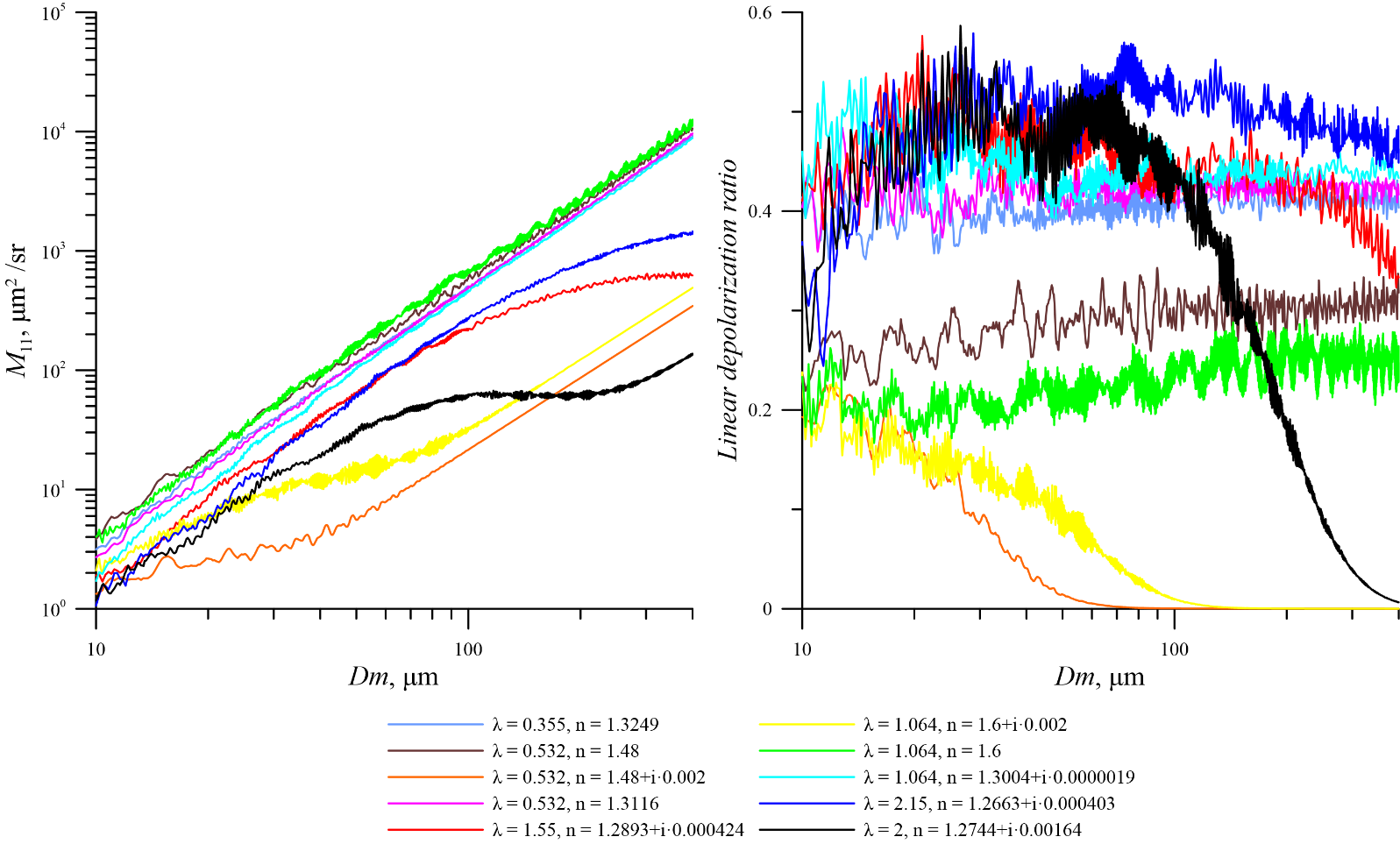
# **4. Illustration of the database**



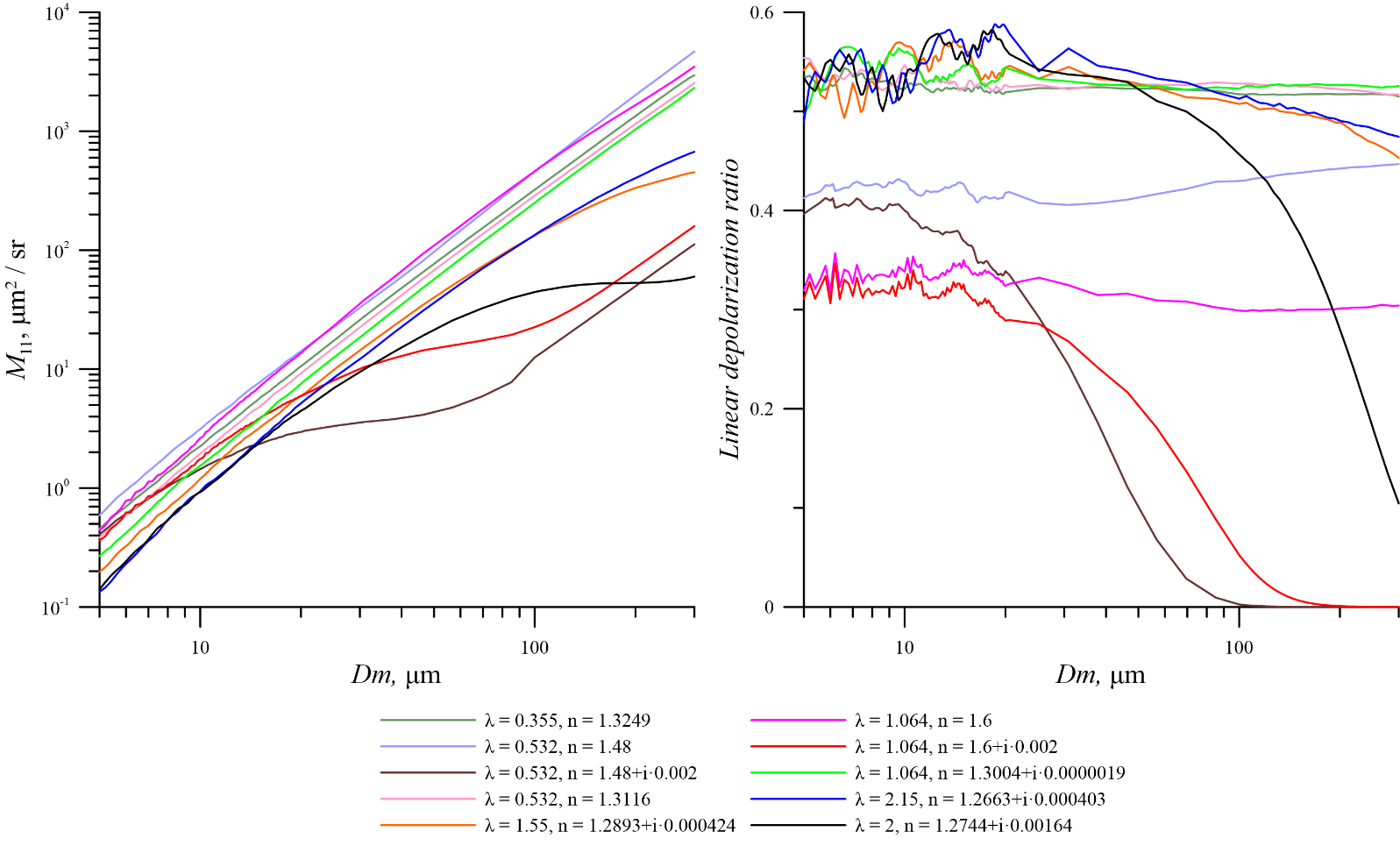
The dependence of the *M*11 element of the backscattering matrix and the linear depolarization ratio (*LDR*) on the length of the hexagonal column

C:\Users\vyz89\OneDrive\Рабочий стол\Банк даных 2023 (Рабочий)\рисунки\Plate.tif

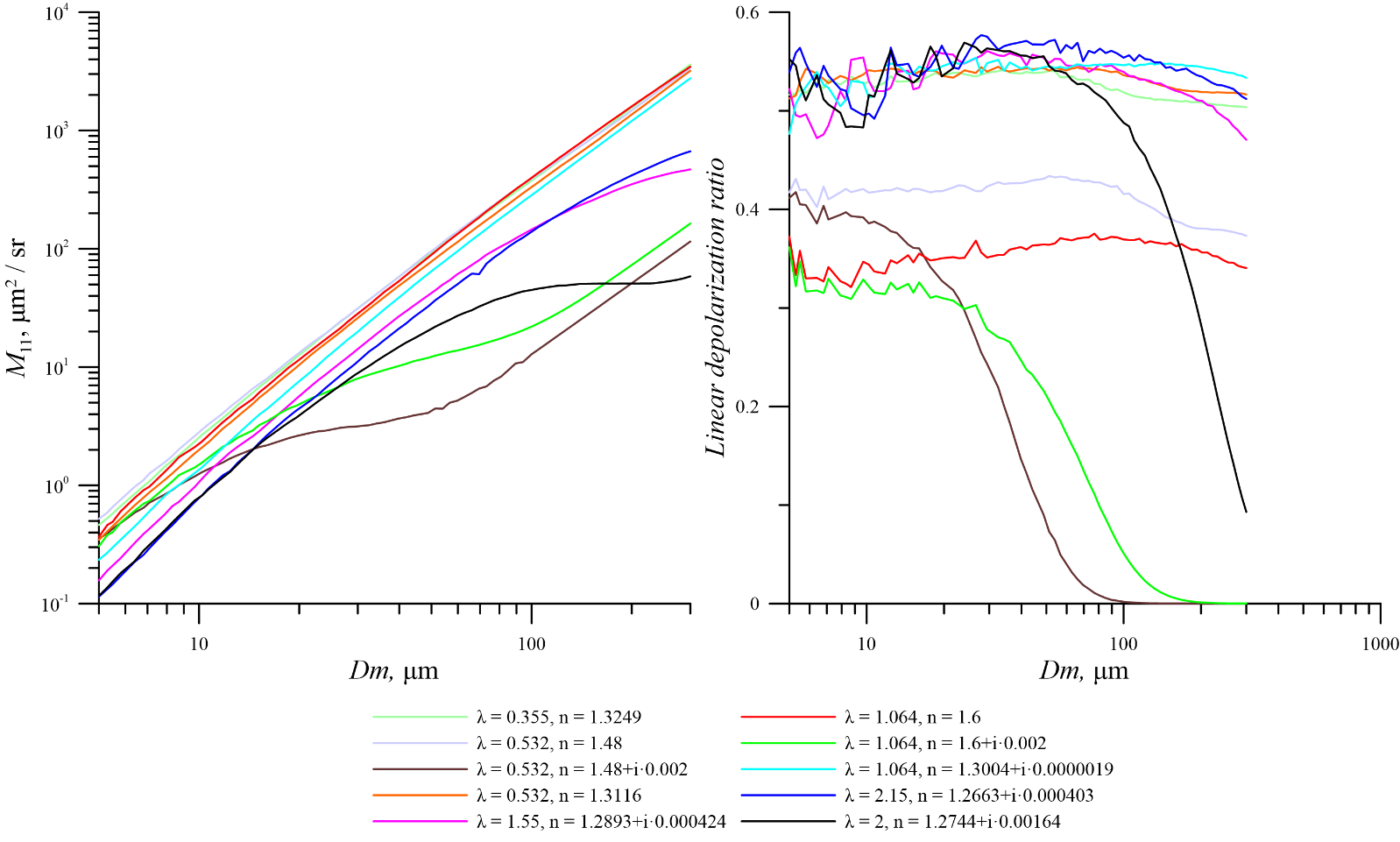
The dependence of the *M*11 element of the backscattering matrix and the linear depolarization ratio (*LDR*) on the width of the hexagonal plate



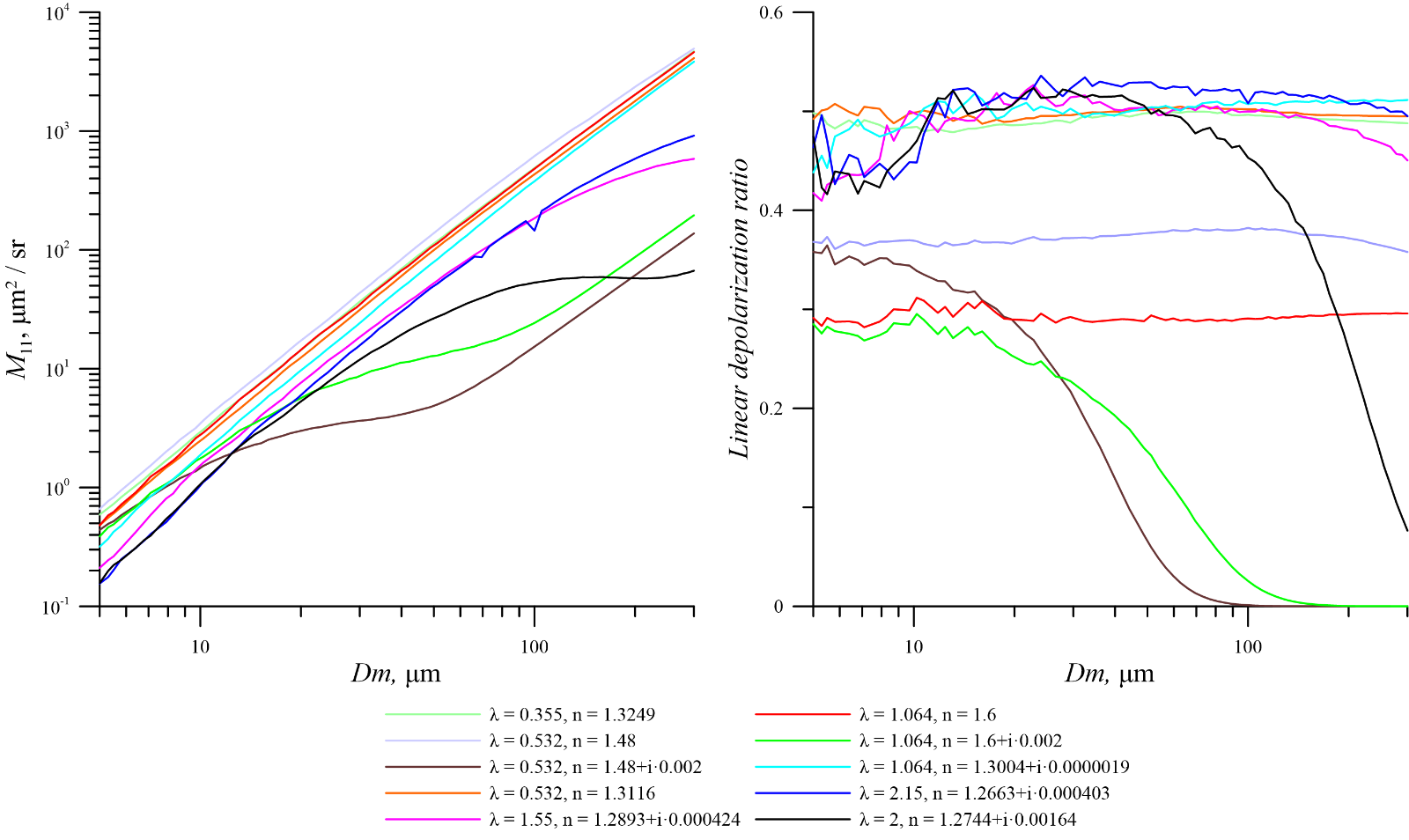
Dependence of the *M*11 element of the backscattering matrix and the linear depolarization ratio (*LDR*) on the Dmax of the droxtal



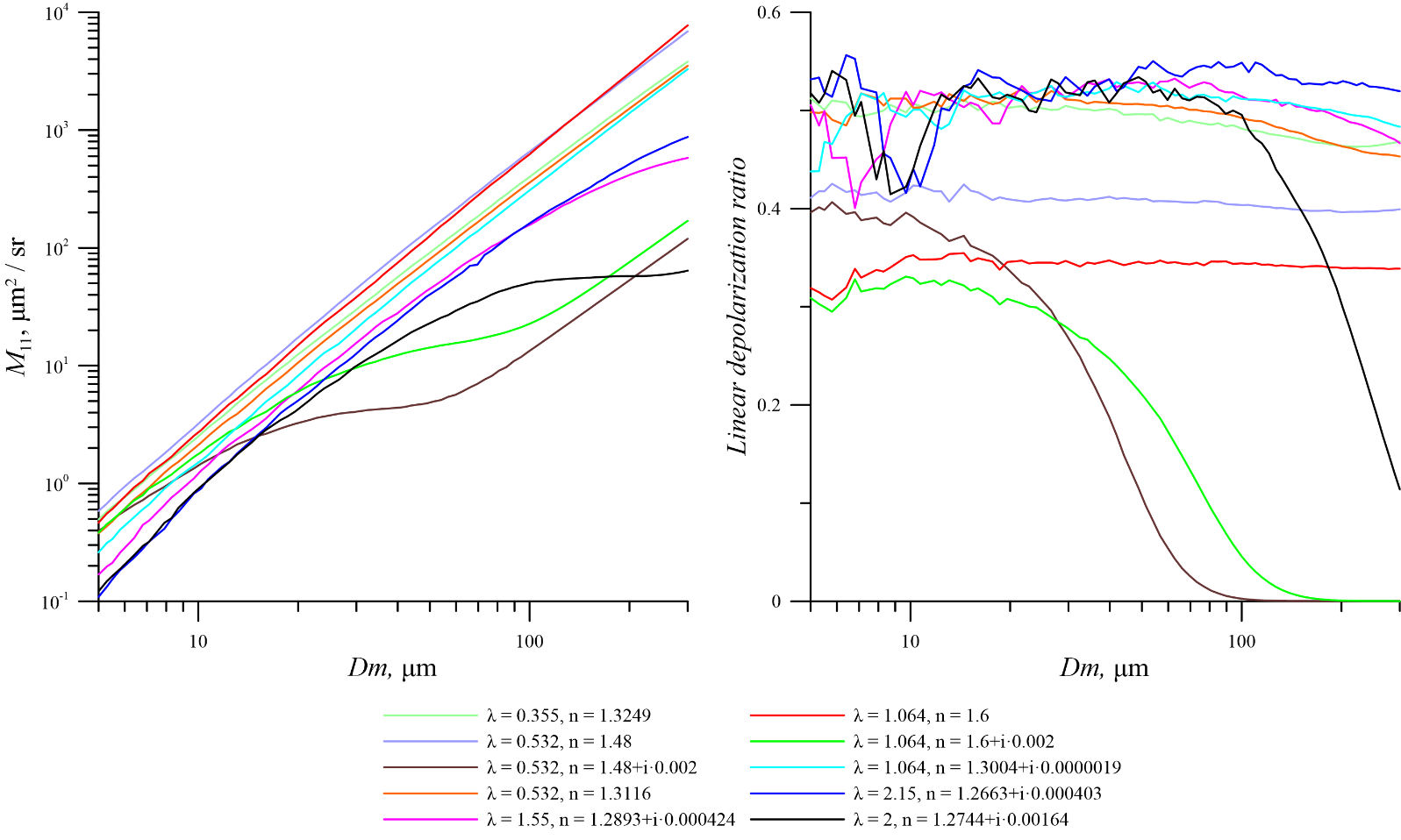
Dependence of the *M*11 element of the backscattering matrix and the linear depolarization ratio (*LDR*) on the Dmax of an arbitrary shape particle № 1



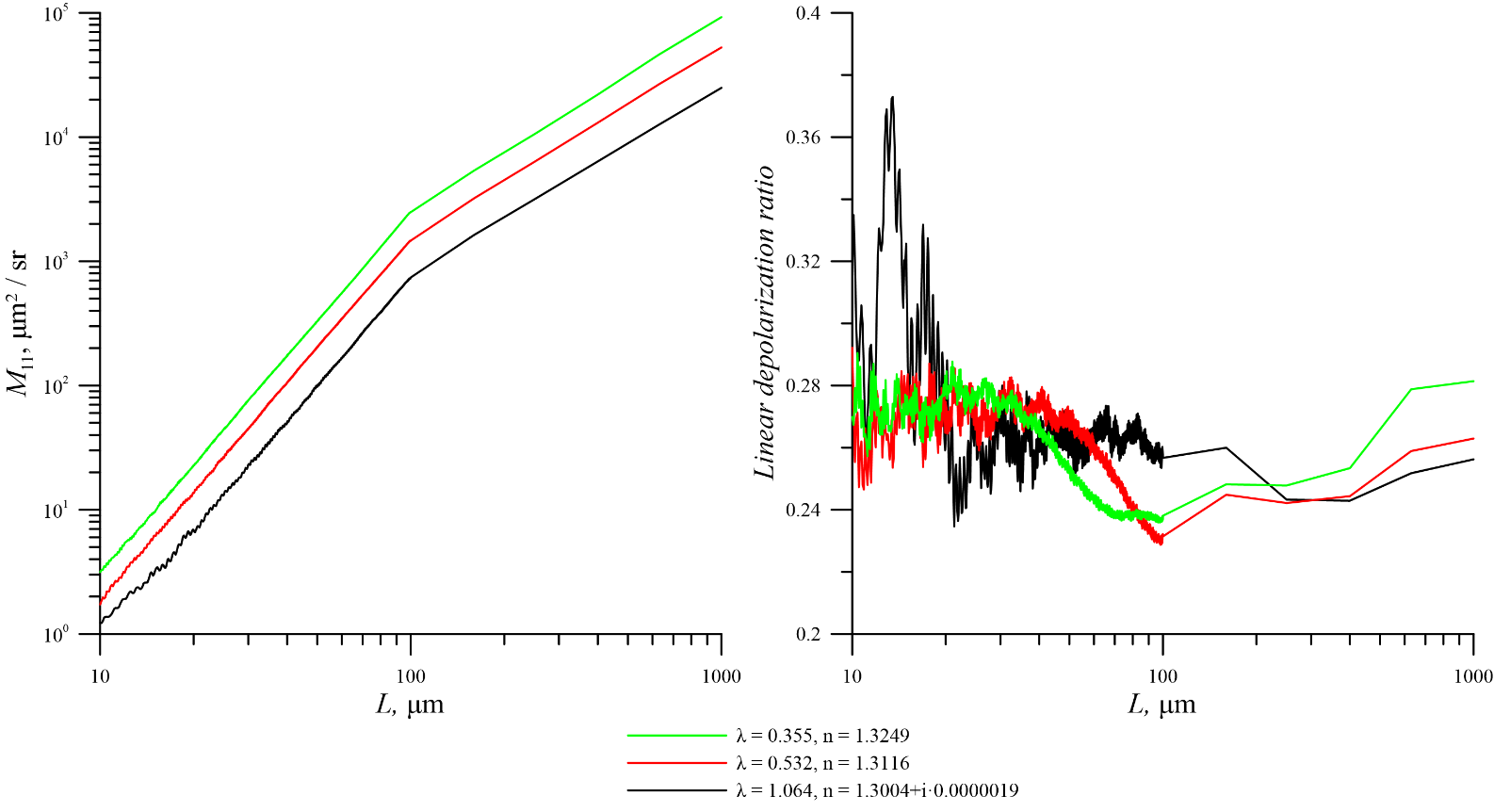
Dependence of the *M*11 element of the backscattering matrix and the linear depolarization ratio (*LDR*) on the Dmax of an arbitrary shape particle № 2



Dependence of the *M*11 element of the backscattering matrix and the linear depolarization ratio (*LDR*) on the Dmax of an arbitrary shape particle № 3



Dependence of the *M*11 element of the backscattering matrix and the linear depolarization ratio (*LDR*) on the Dmax of an arbitrary shape particle № 4

****

The dependence of the *M*11 element of the backscattering matrix and the linear depolarization ratio (*LDR*) on the length of the bullet