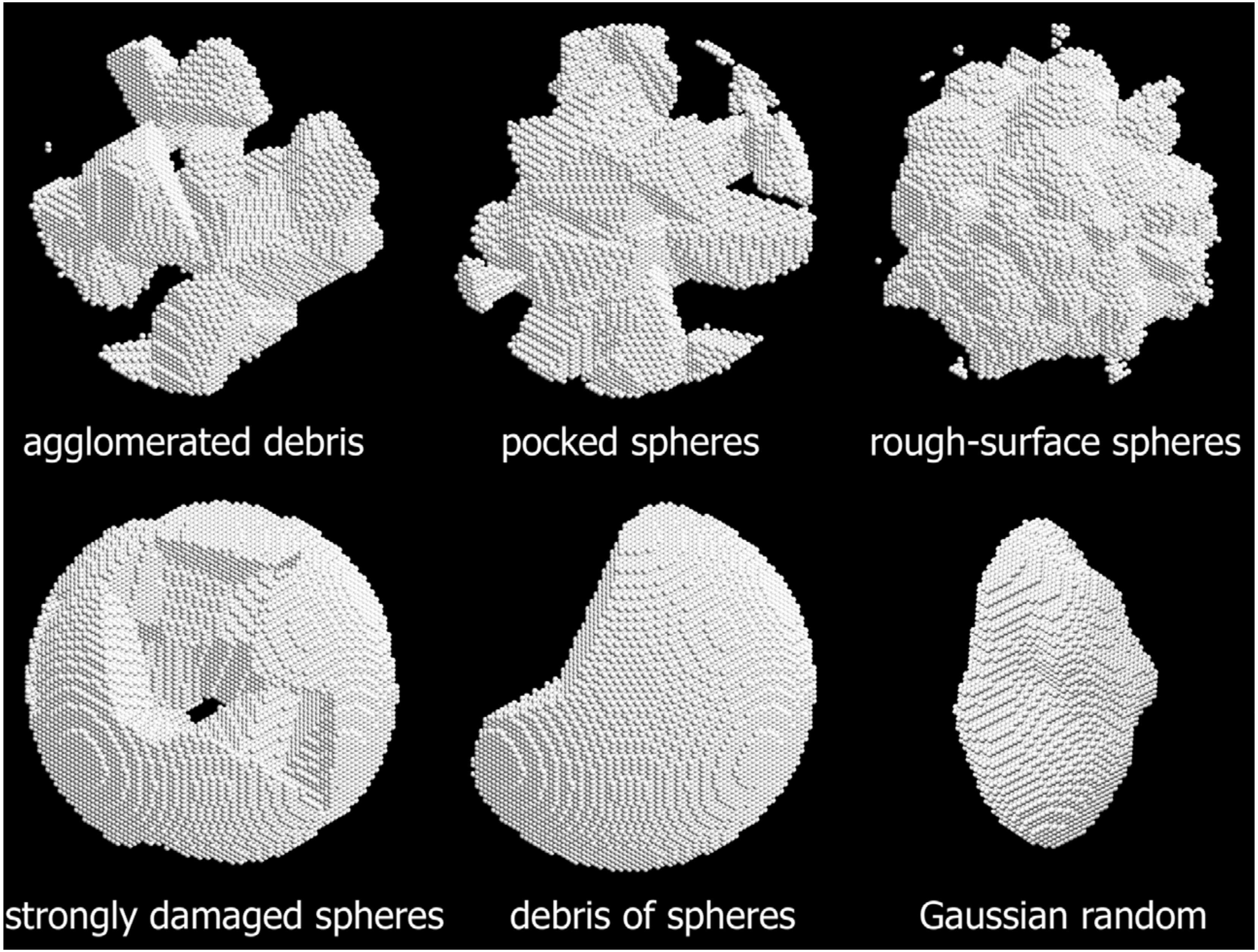
Interaction of light with cometary dust particles (3)

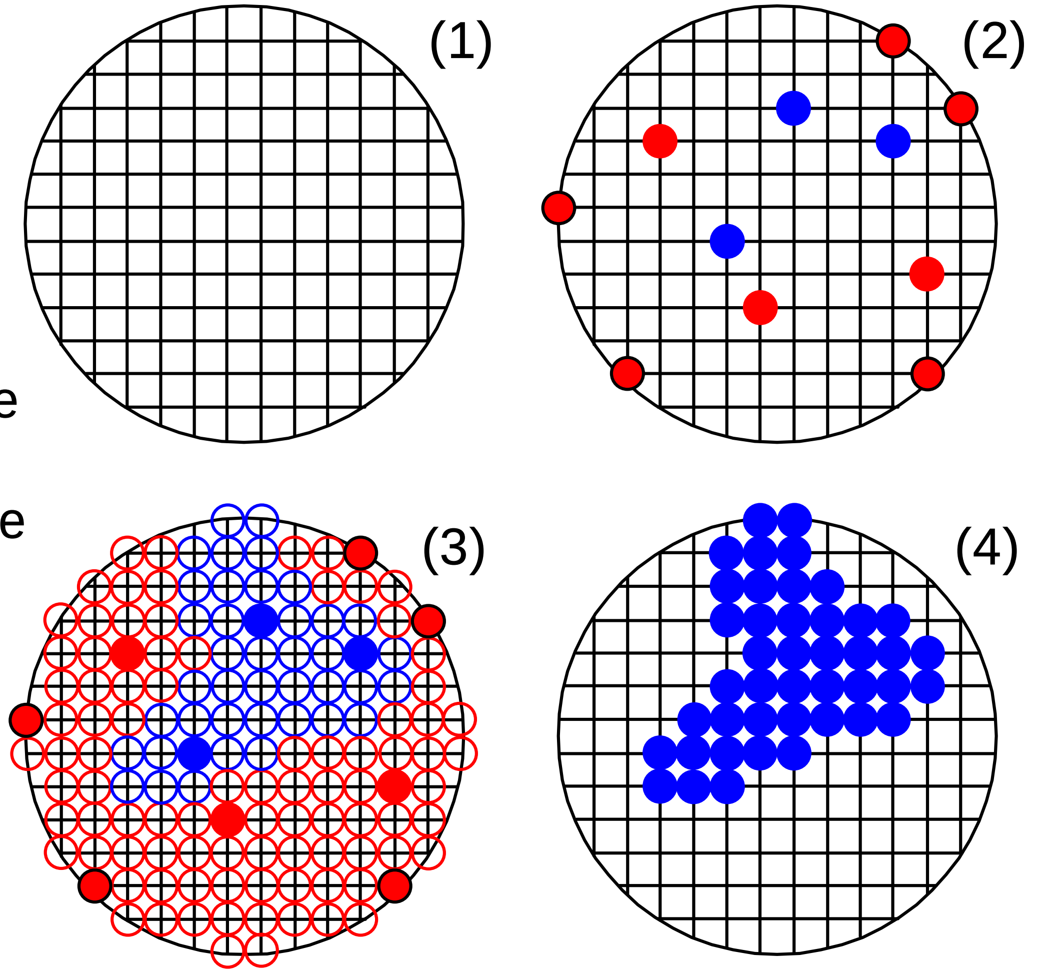
We consider six different types of irregularly shaped particles.



Five from six types of irregularly shaped particles have been generated with the same algorithm but at different parameters.

Formal parameters of model:

(1) surface seed cells for empty space
(2) depth of surface layer
(3) internal seed cells for empty space
(4) internal seed cells for a material

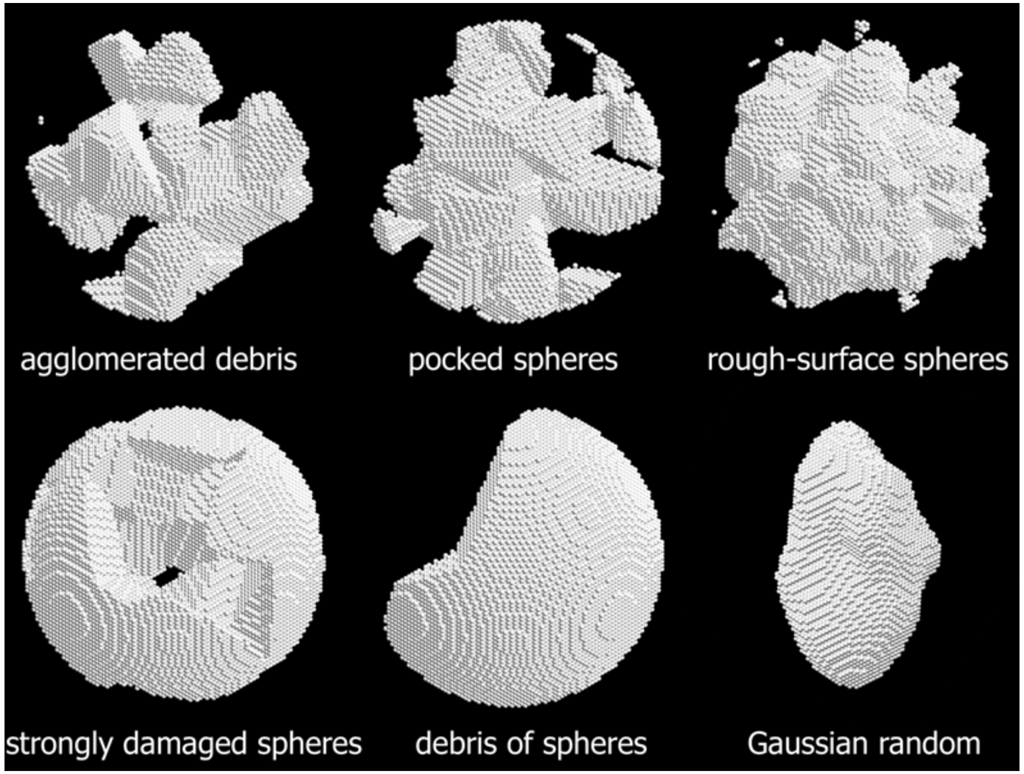


One can classify these particles as follows:

Fluffy structure: agglomerated debris and pocked spheres

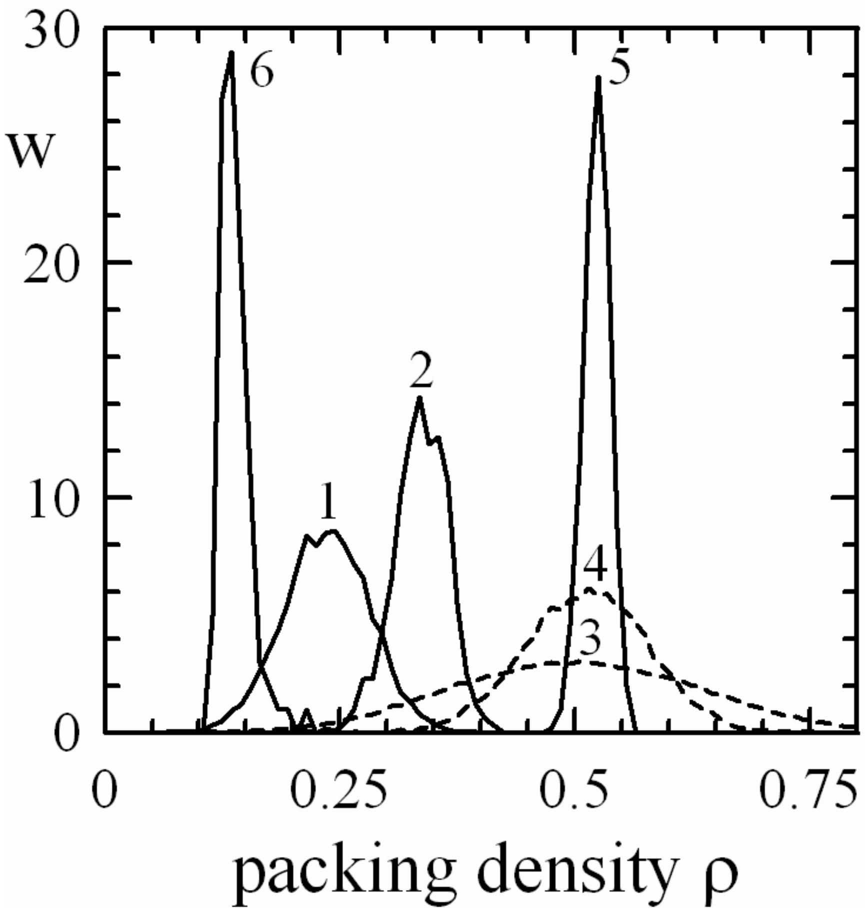
Moderate structure: strongly damaged spheres and debris of spheres

Compact structure: rough-surface spheres and Gaussian random particles



An important parameter characterizing the particles is the packing density ρ (ratio of the material volume to the total volume occupied by the particle). We define the later value as a volume of circumscribing sphere.

Distributions of the particles over packing density are as follows:



(1) agglomerated debris $\langle\rho\rangle=0.236$
(2) pocked spheres $\langle\rho\rangle=0.336$
(3) debris of spheres $\langle\rho\rangle=0.5$
(4) strongly damaged spheres $\langle\rho\rangle=0.512$
(5) rough-surface spheres $\langle\rho\rangle=0.523$
(6) random Gaussian particles $\langle\rho\rangle=0.139$

We will consider three refractive indices:

$m=1.313+0i$ (it can be attributed to water ice)

$m=1.6+0.0005i$ (it can be attributed to Mg-rich silicates)

$m=1.5+0.1i$ (it can be attributed to organic material)

Light-scattering properties of particle comparable with wavelength depend on the size parameter x:

$$x = 2\pi r/\lambda$$

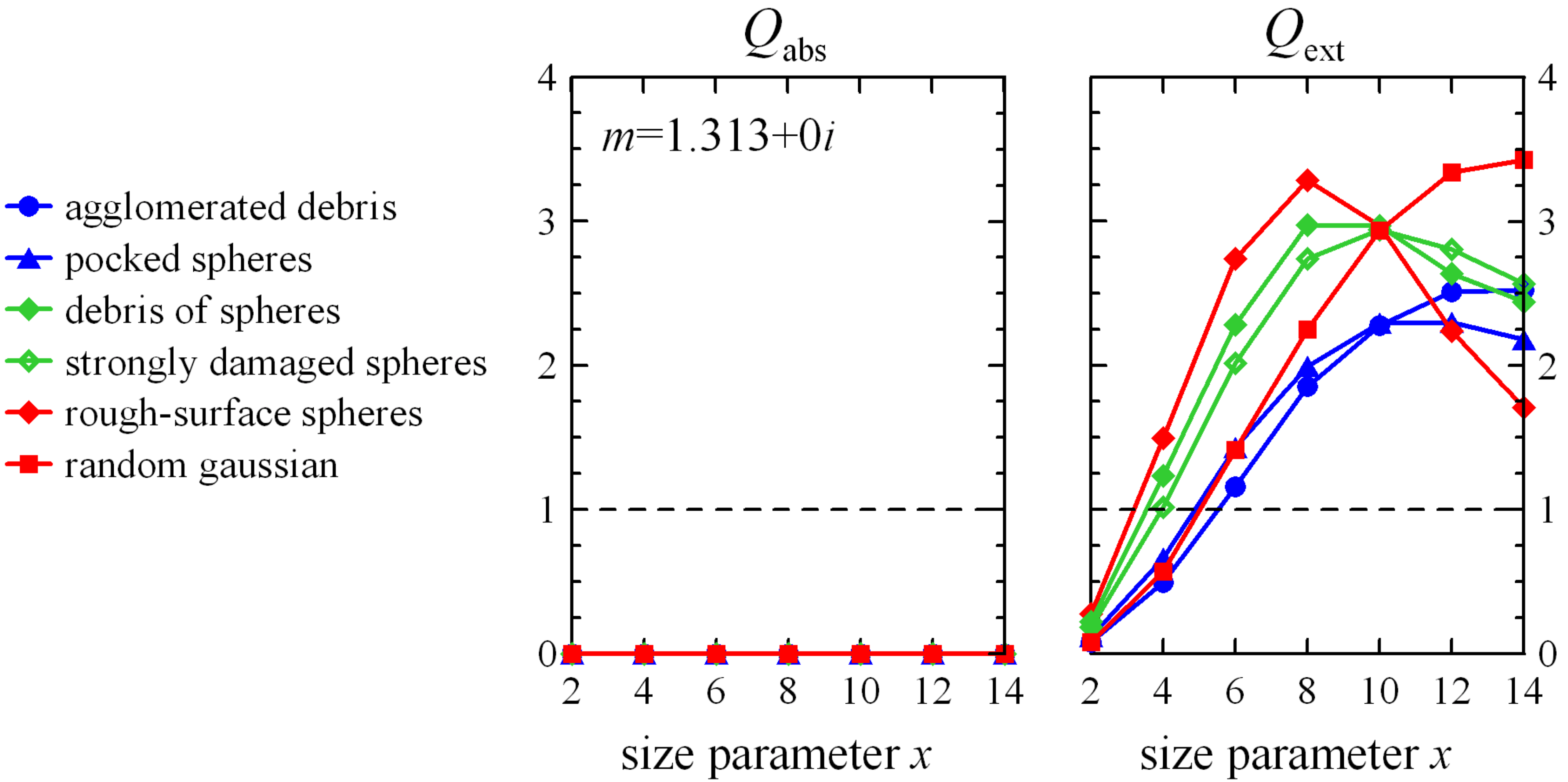
where r is radius of circumscribing sphere and λ – wavelength.

The following consequence of x will be considered:

2, 4, 6, 8, 10, 12, and 14

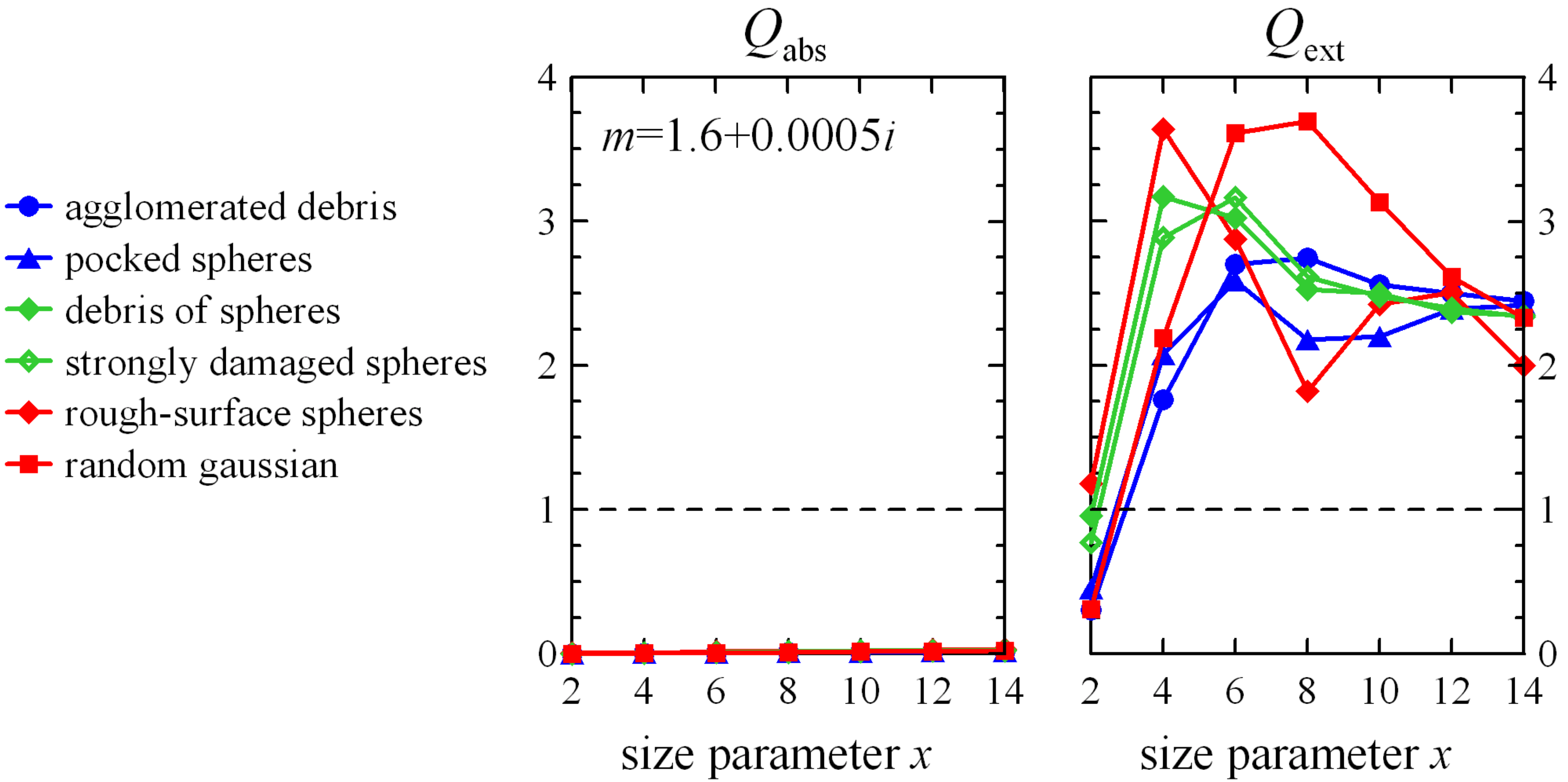
Efficiencies for absorption (left) and extinction (right).

Dash horizontal line shows the case when cross-sections for absorption and extinction are equal to geometric cross section.



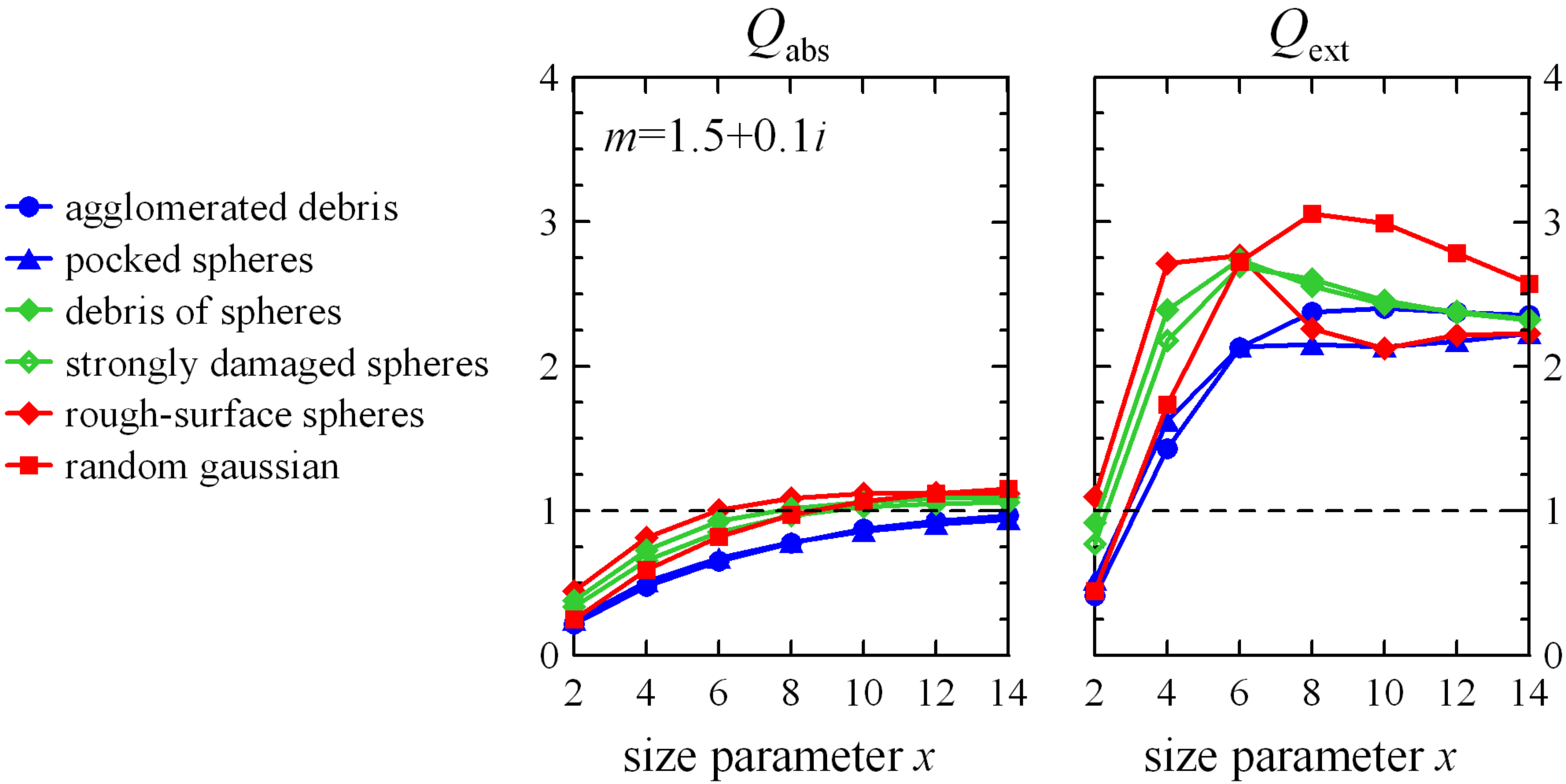
Efficiencies for absorption (left) and extinction (right).

Dash horizontal line shows the case when cross-sections for absorption and extinction are equal to geometric cross section.

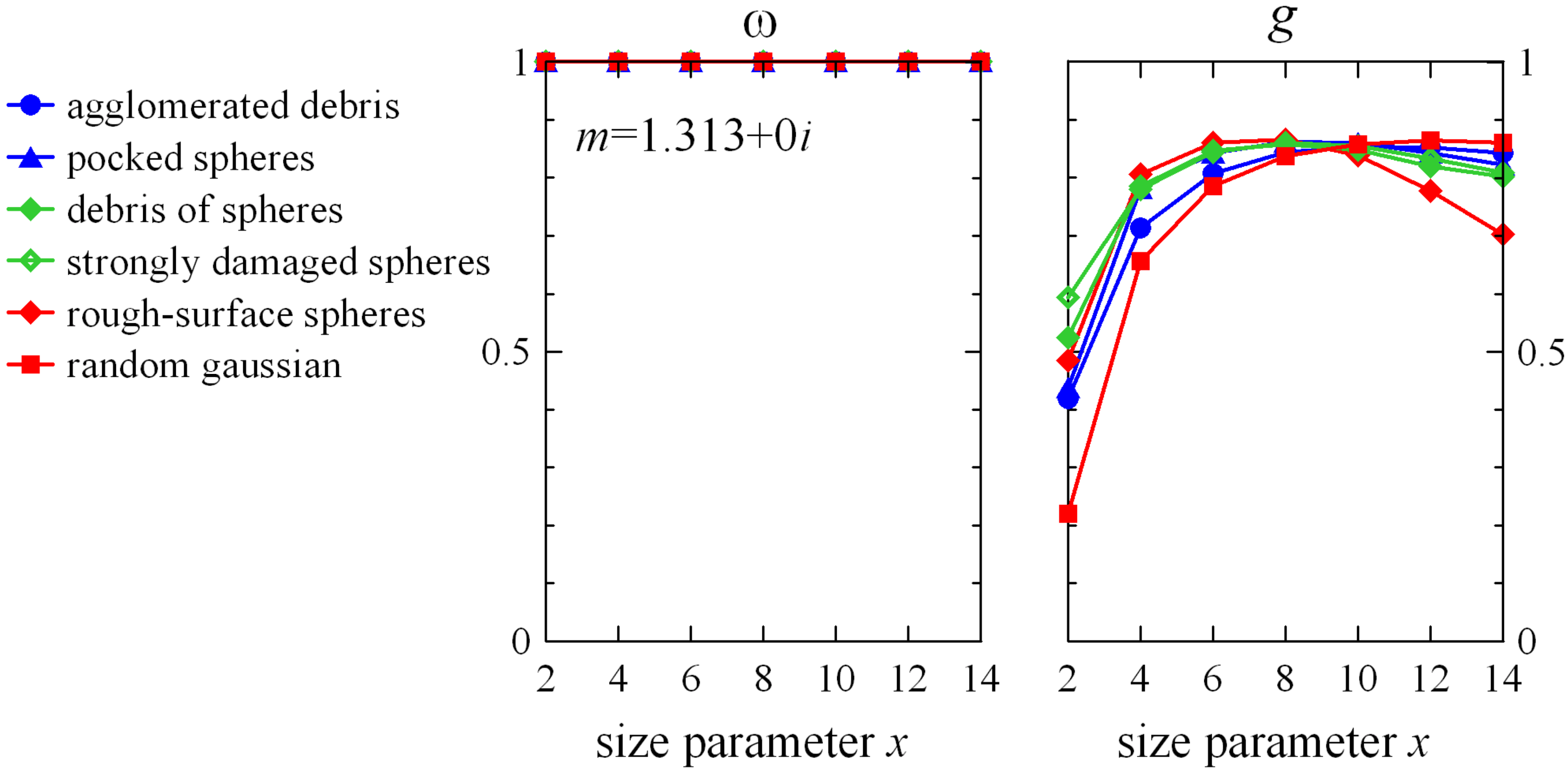


Efficiencies for absorption (left) and extinction (right).

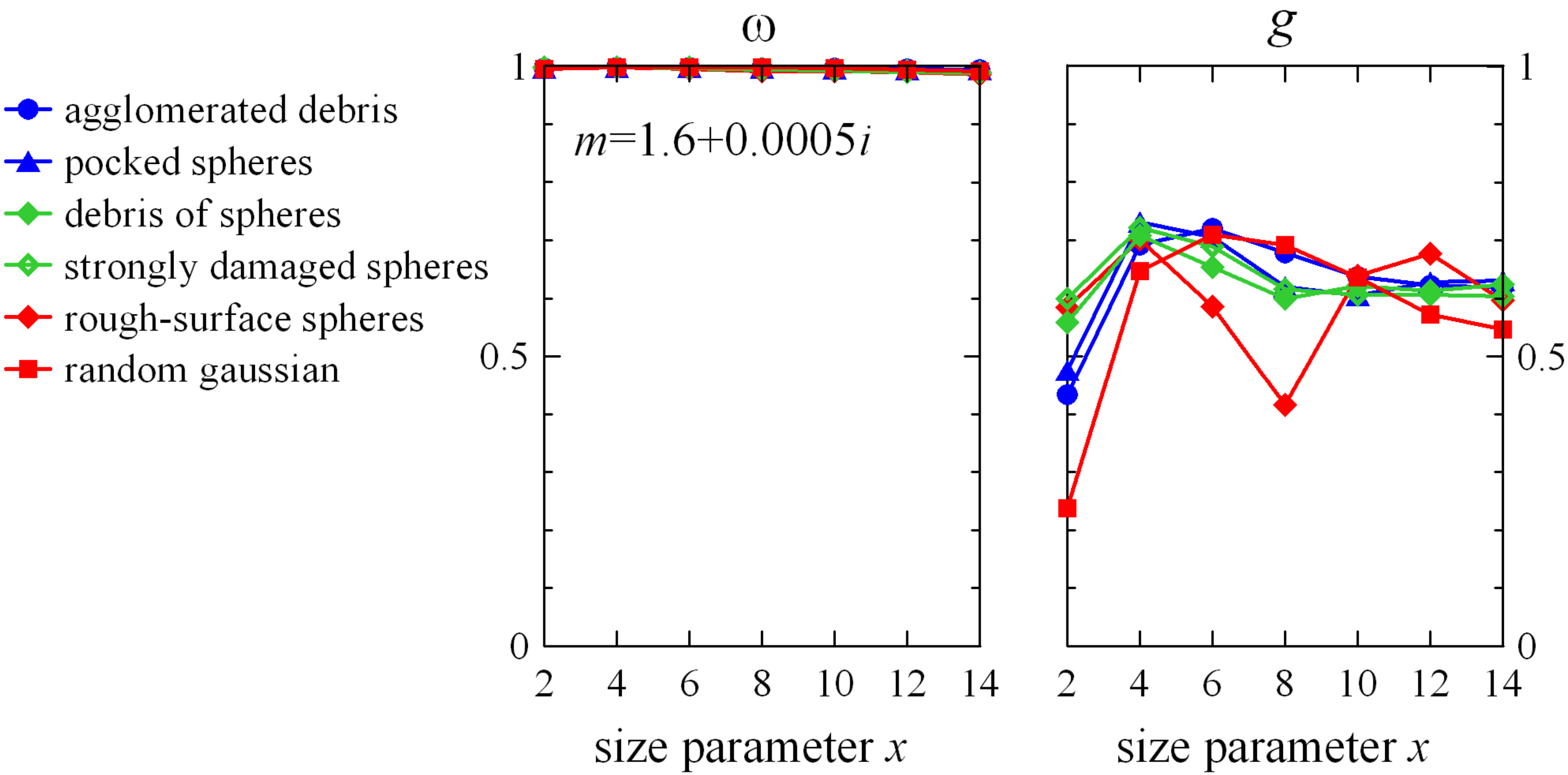
Dash horizontal line shows the case when cross-sections for absorption and extinction are equal to geometric cross section.



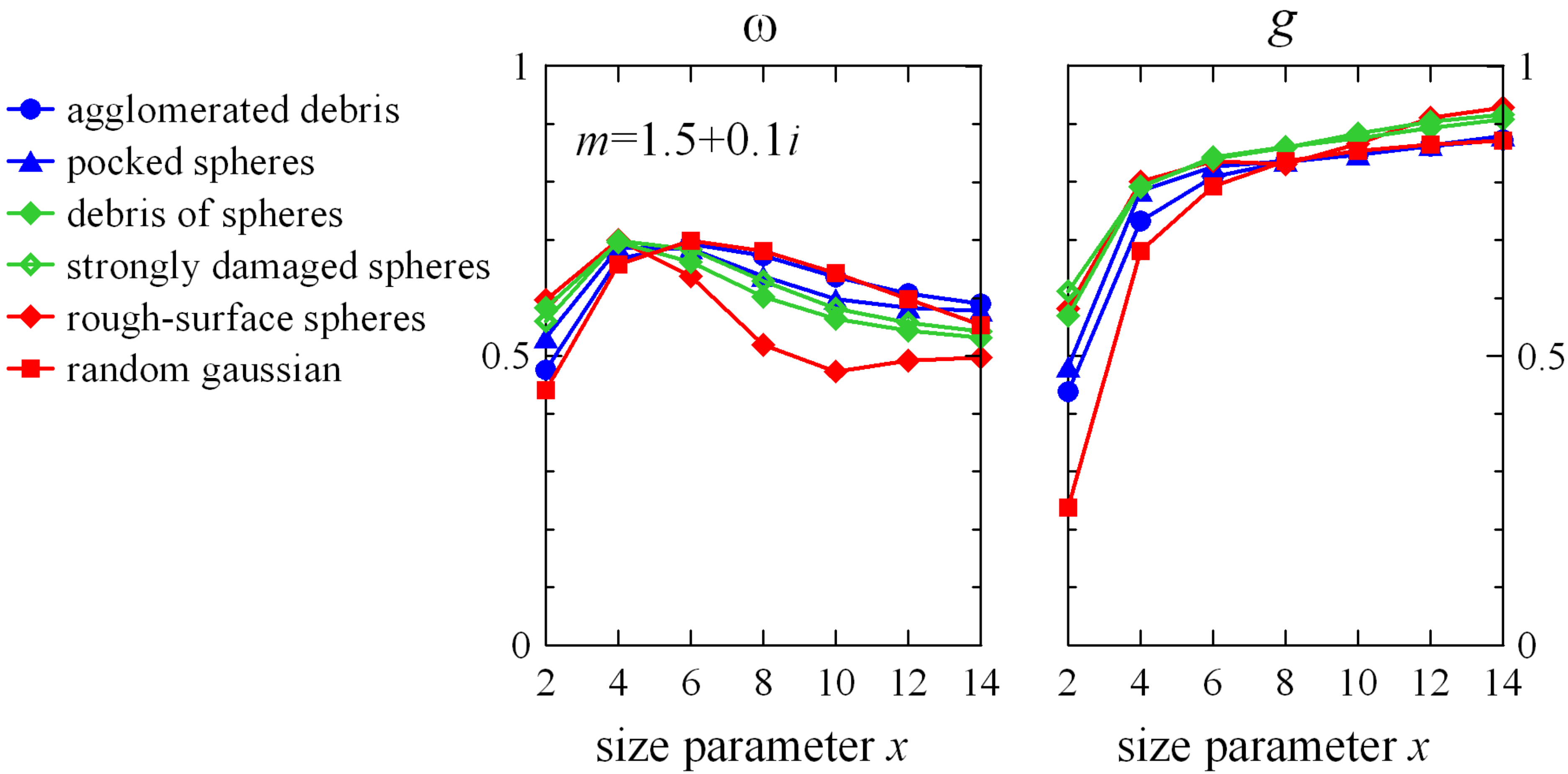
Albedo of single scattering ω (left) and asymmetry parameter *g* extinction (right).



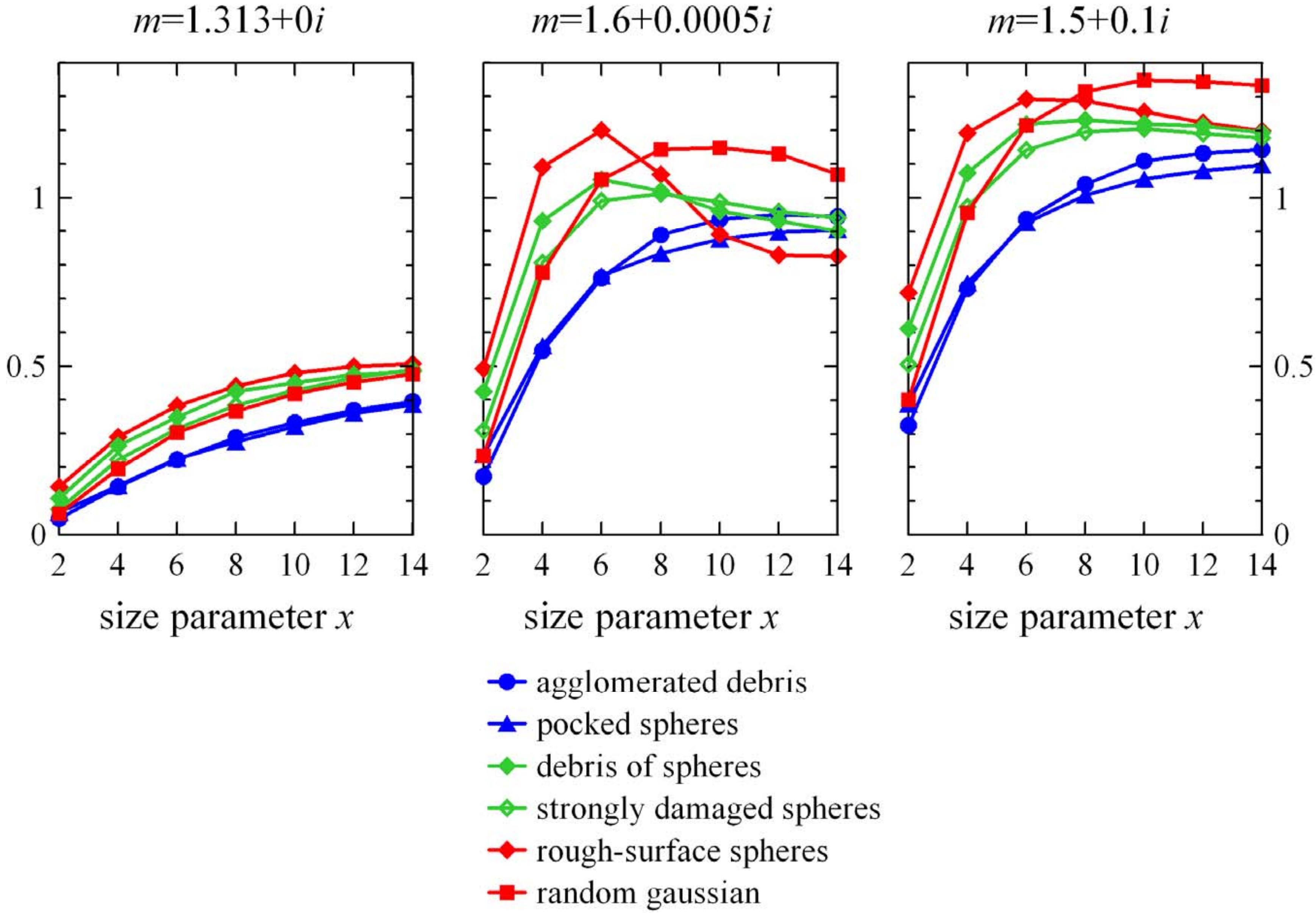
Albedo of single scattering ω (left) and asymmetry parameter *g* extinction (right).



Albedo of single scattering ω (left) and asymmetry parameter *g* extinction (right).

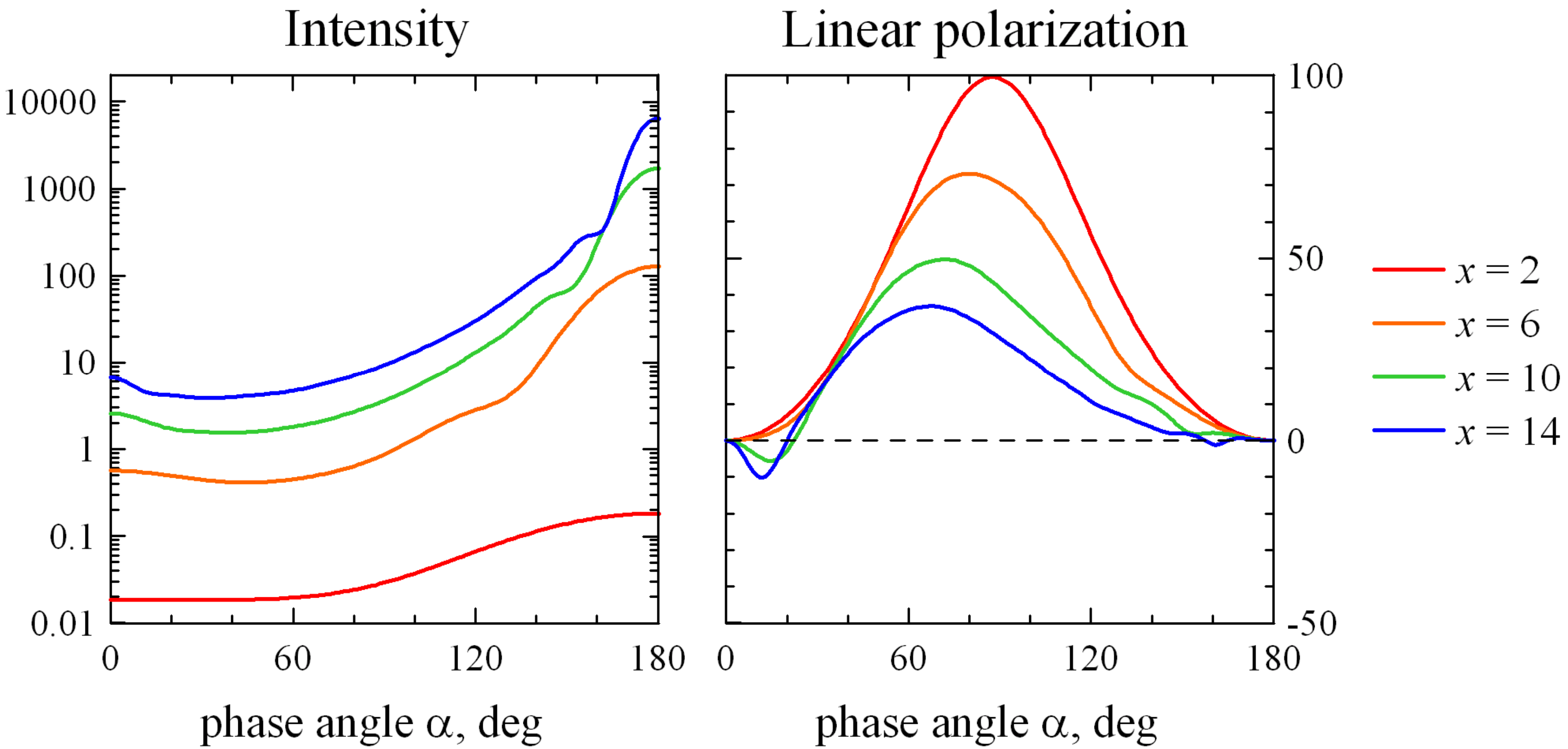


Efficiency for radiation pressure Q_{pr}.

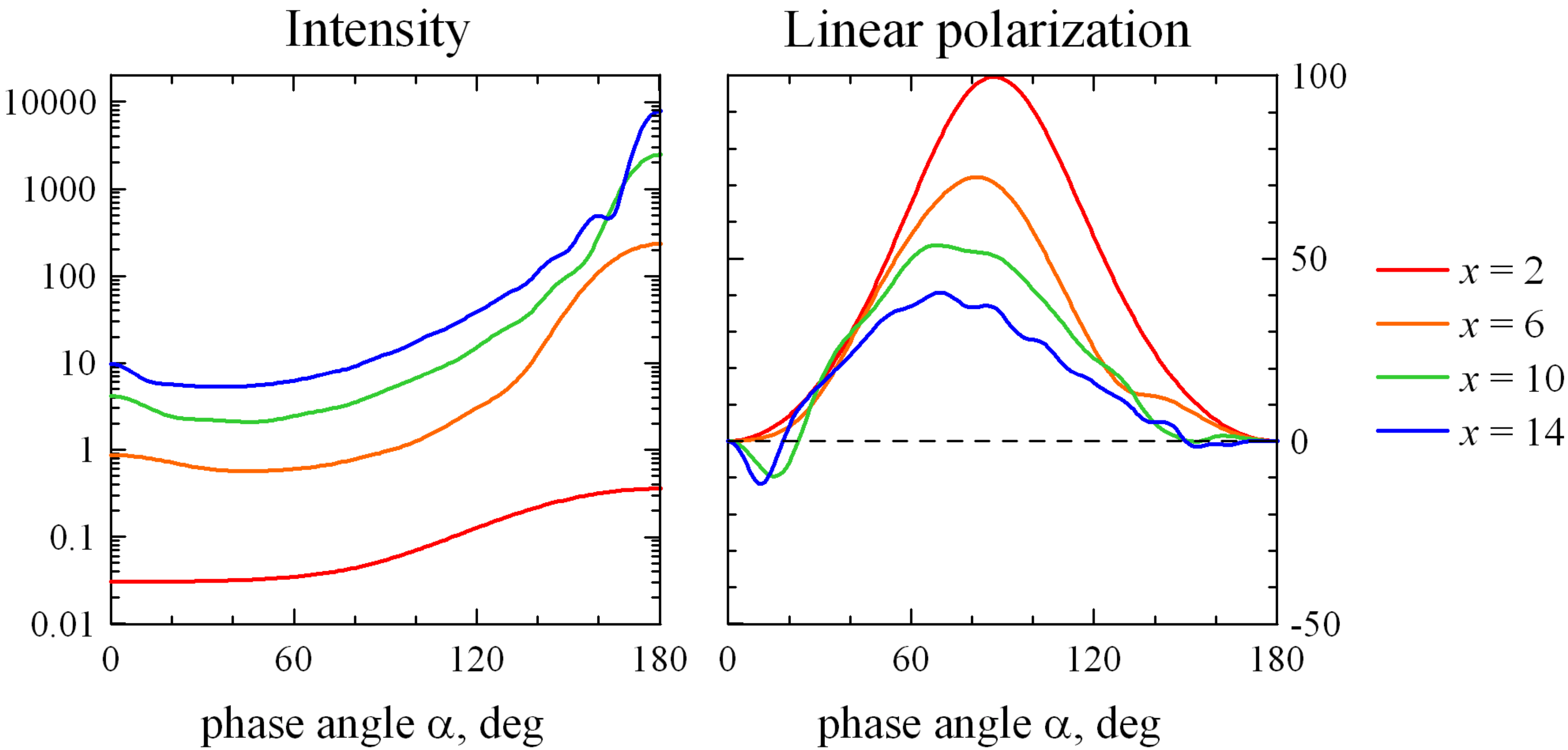


Angular profiles of intensity and degree of linear polarization for icy irregularly shaped particle (m=1.313+0i)

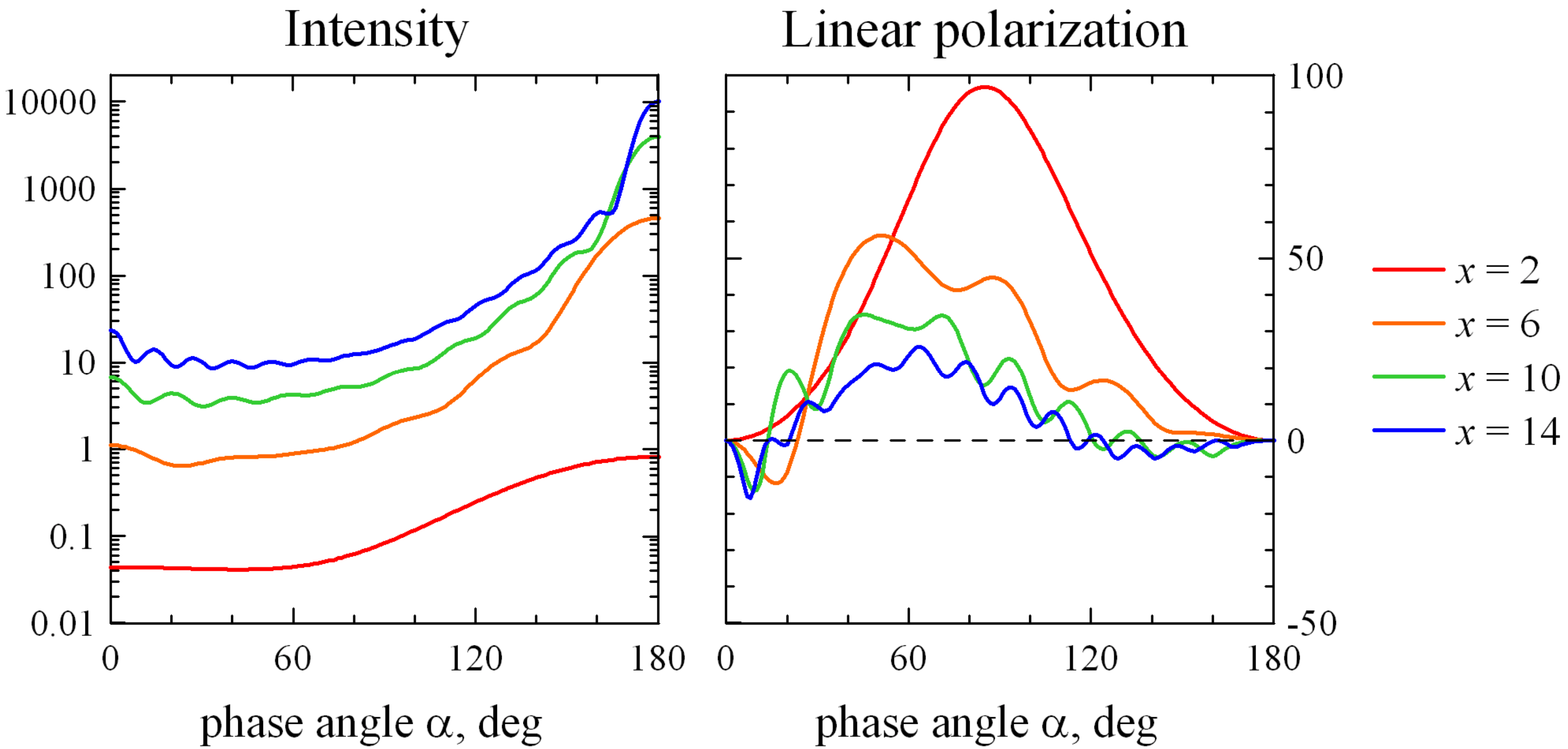
Angular profiles of intensity (left) and degree of linear polarization (right) for agglomerated debris particles at m=1.313+0i.



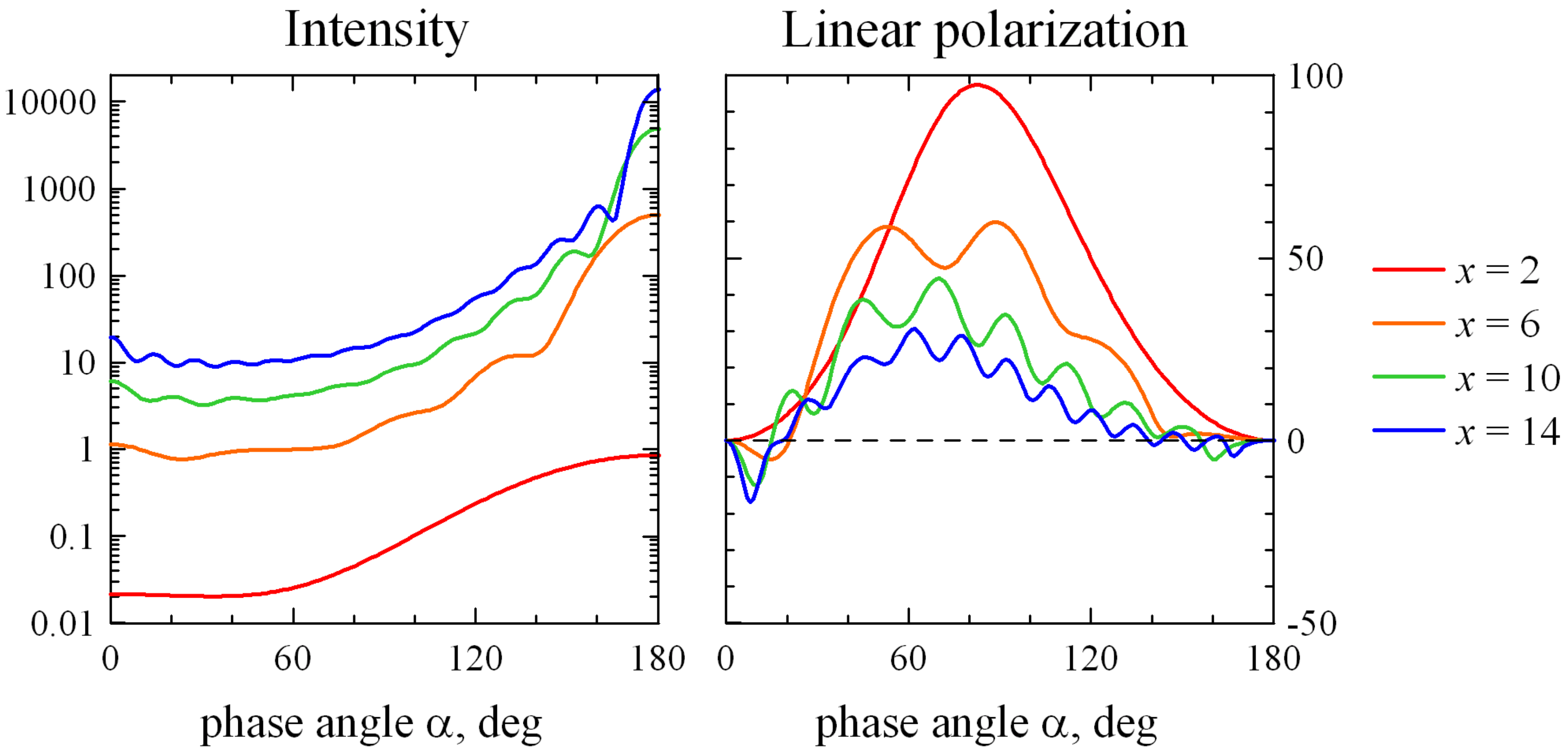
Angular profiles of intensity (left) and degree of linear polarization (right) for pocked spheres at m=1.313+0i.



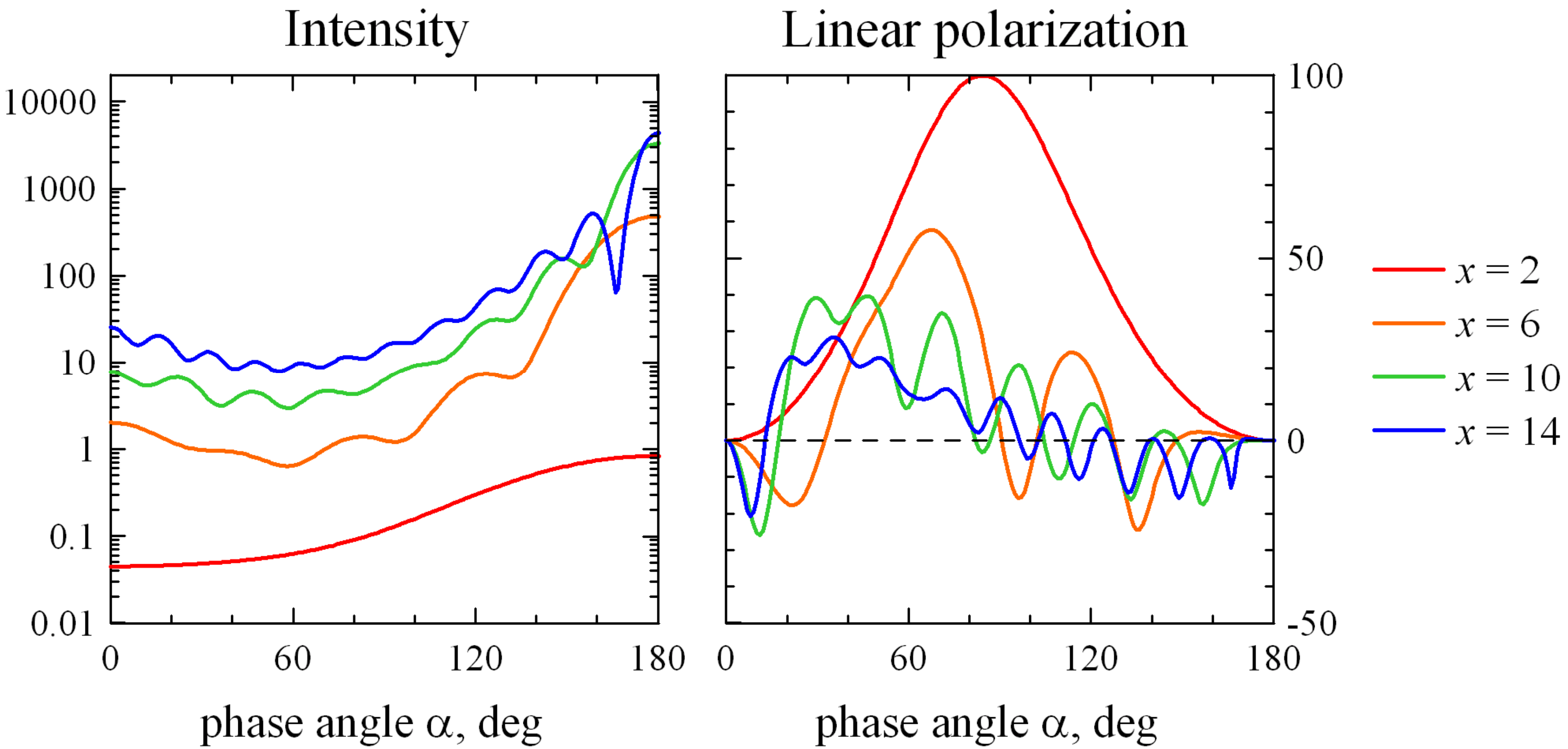
Angular profiles of intensity (left) and degree of linear polarization (right) for debris of spheres at m=1.313+0i.



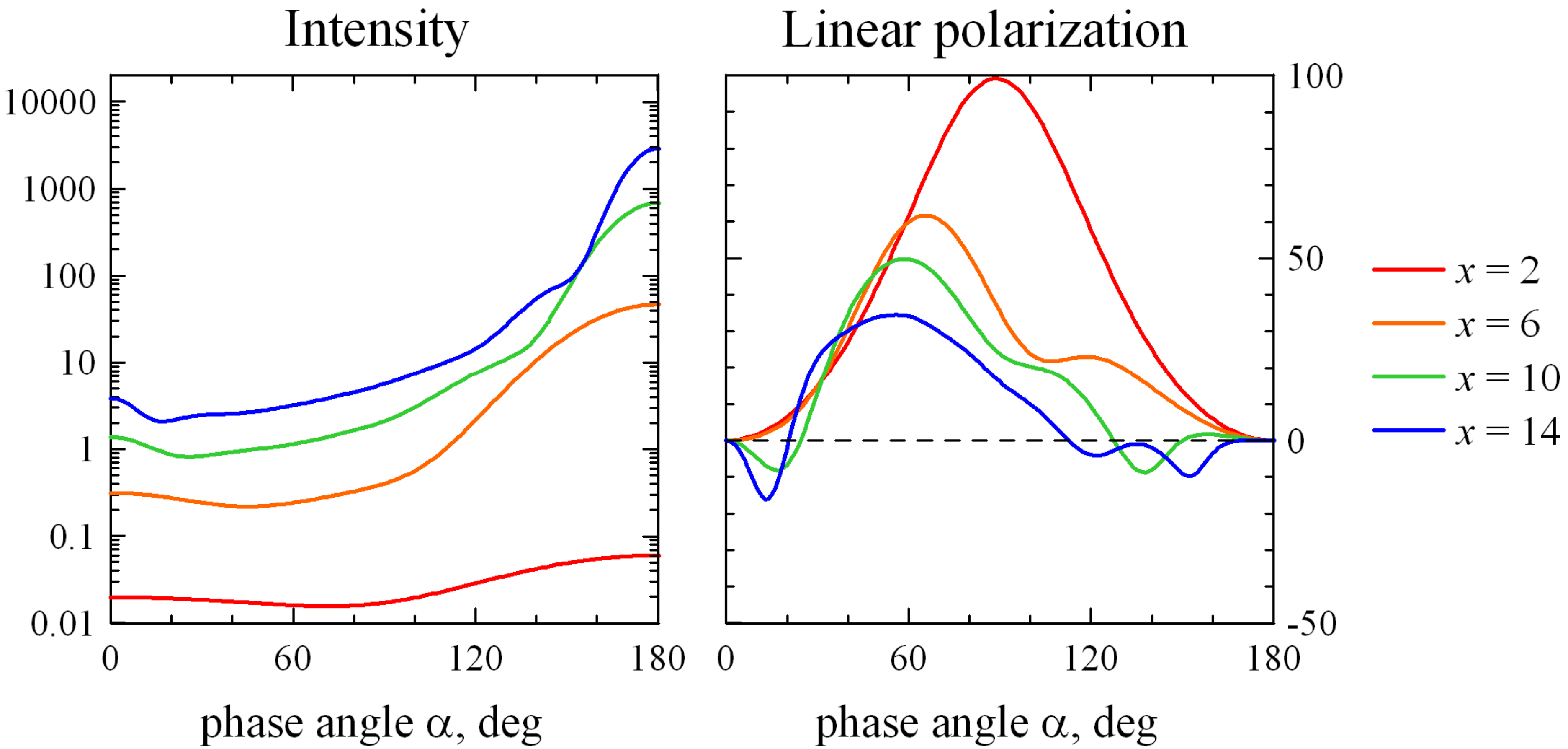
Angular profiles of intensity (left) and degree of linear polarization (right) for strongly damaged spheres at m=1.313+0i.



Angular profiles of intensity (left) and degree of linear polarization (right) for rough-surface spheres at m=1.313+0i.

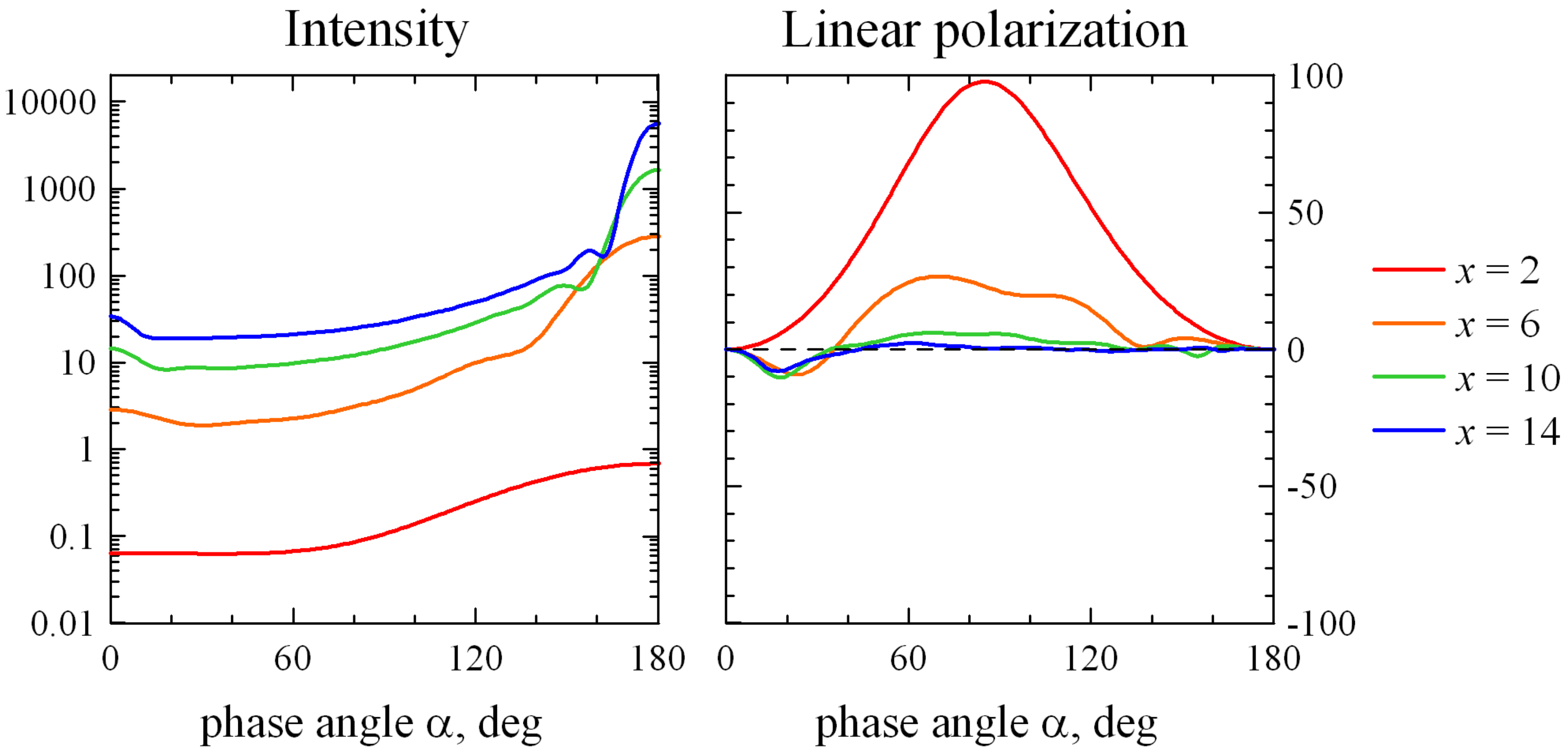


Angular profiles of intensity (left) and degree of linear polarization (right) for random Gaussian particles at m=1.313+0i.

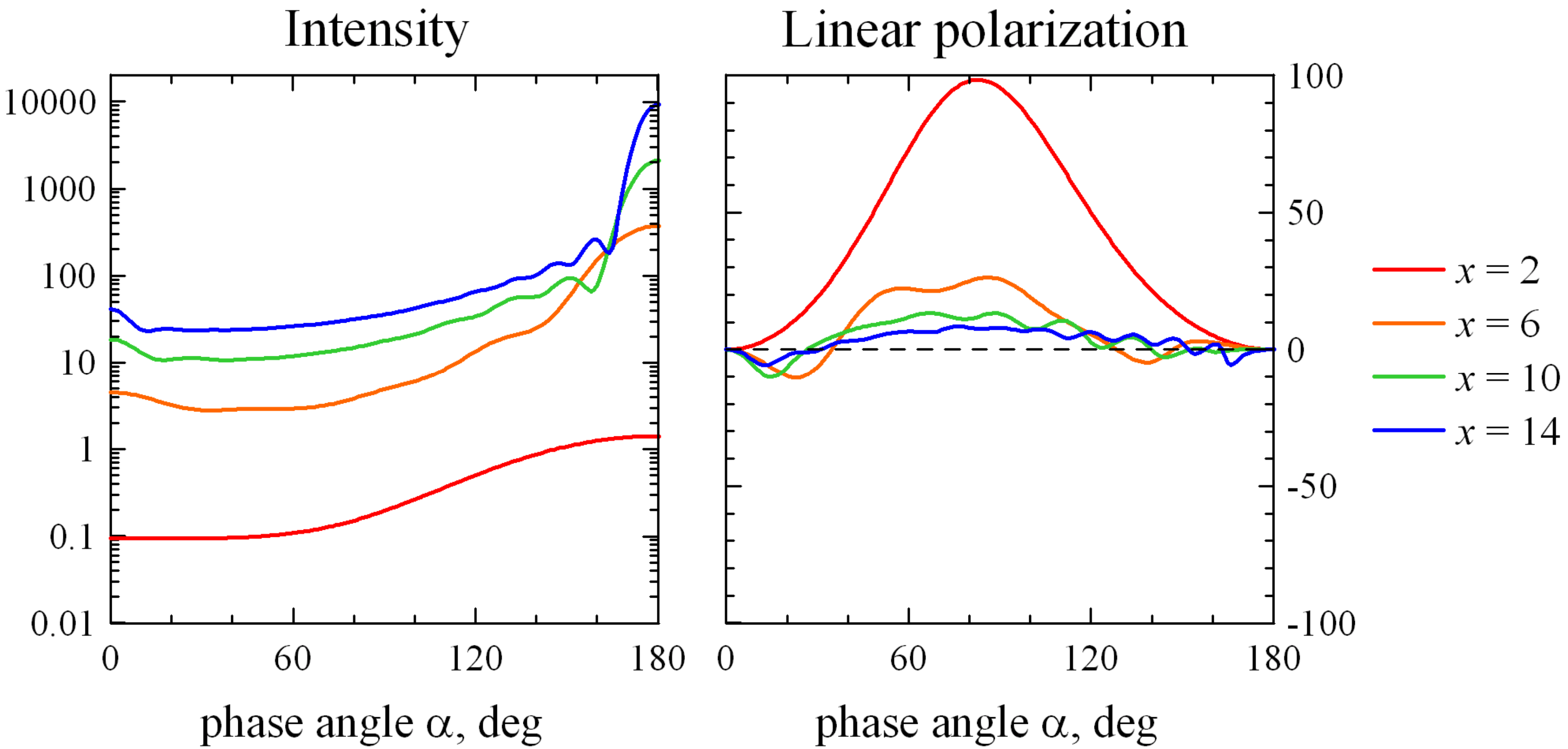


Angular profiles of intensity and degree of linear polarization for silicate irregularly shaped particle (m=1.6+0.0005i)

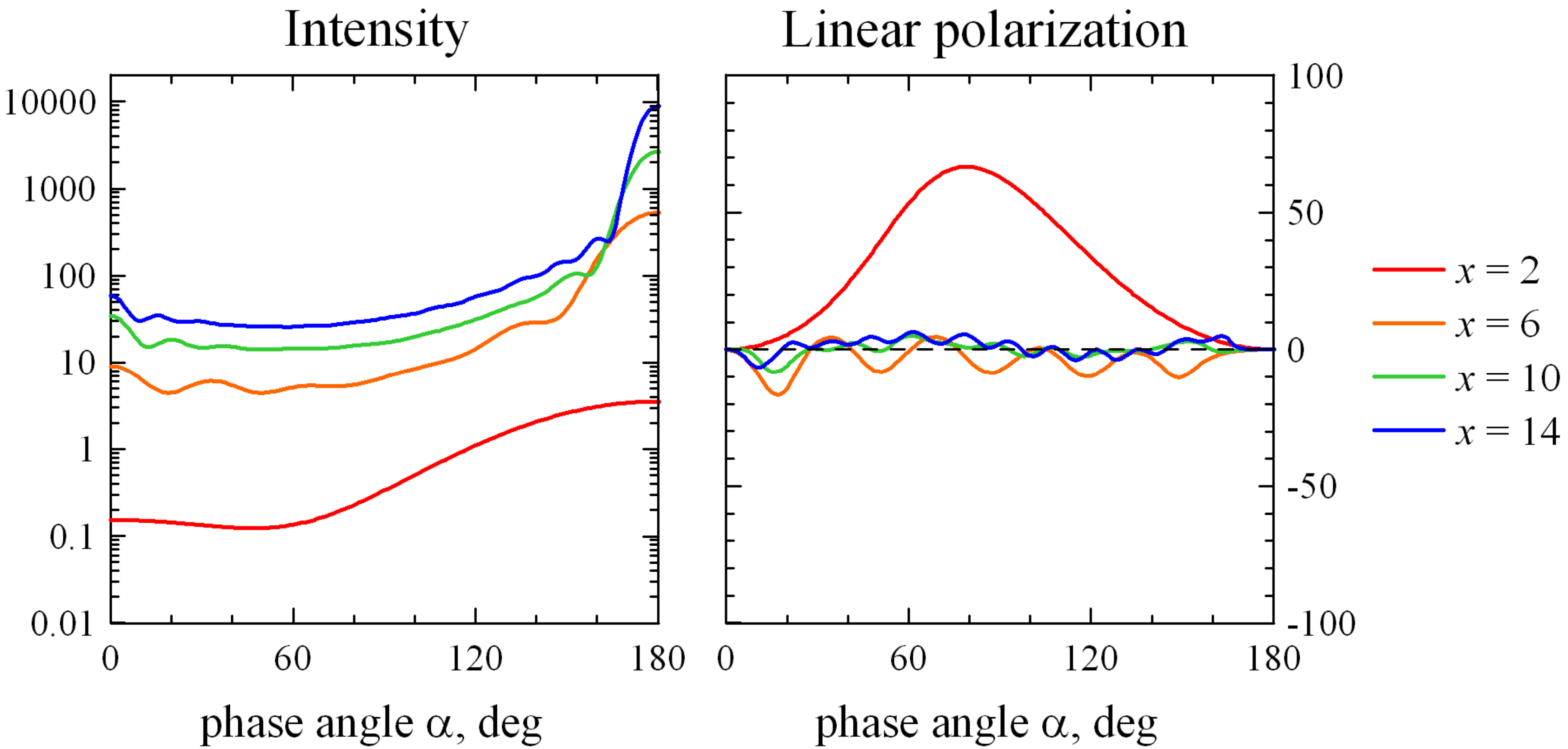
Angular profiles of intensity (left) and degree of linear polarization (right) for agglomerated debris particles at m=1.6+0.0005i.



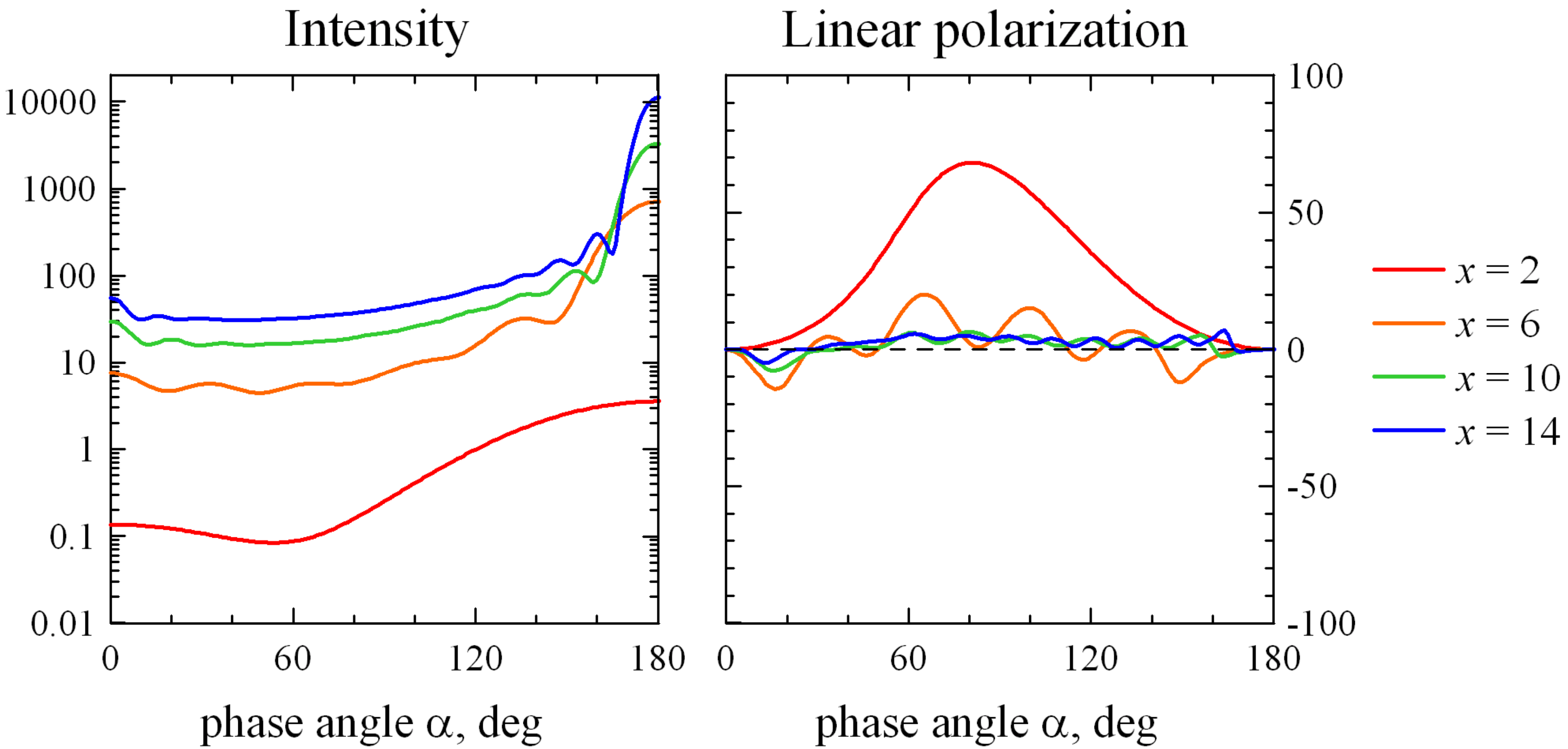
Angular profiles of intensity (left) and degree of linear polarization (right) for pocked spheres at m=1.6+0.0005i.



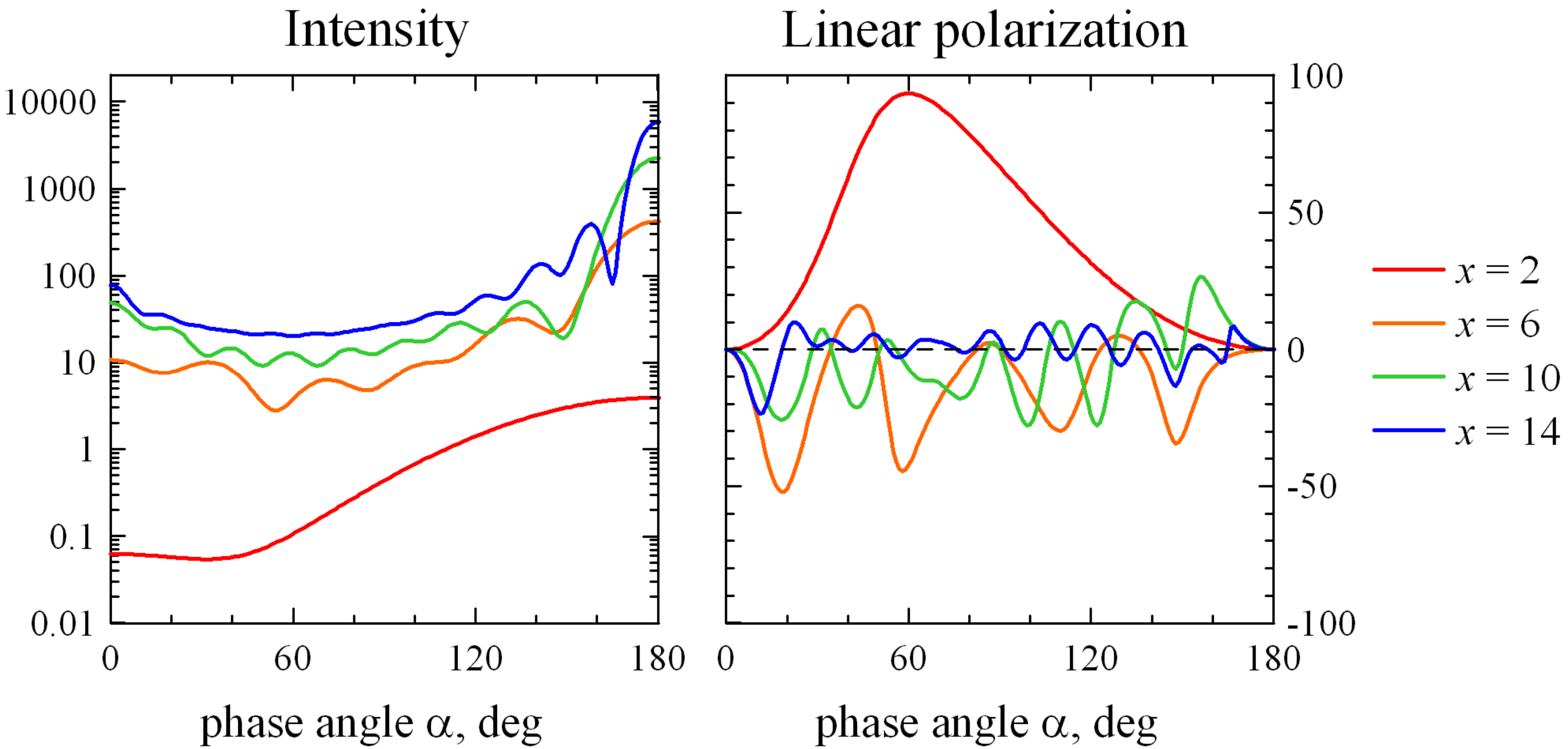
Angular profiles of intensity (left) and degree of linear polarization (right) for debris of spheres at m=1.6+0.0005i.



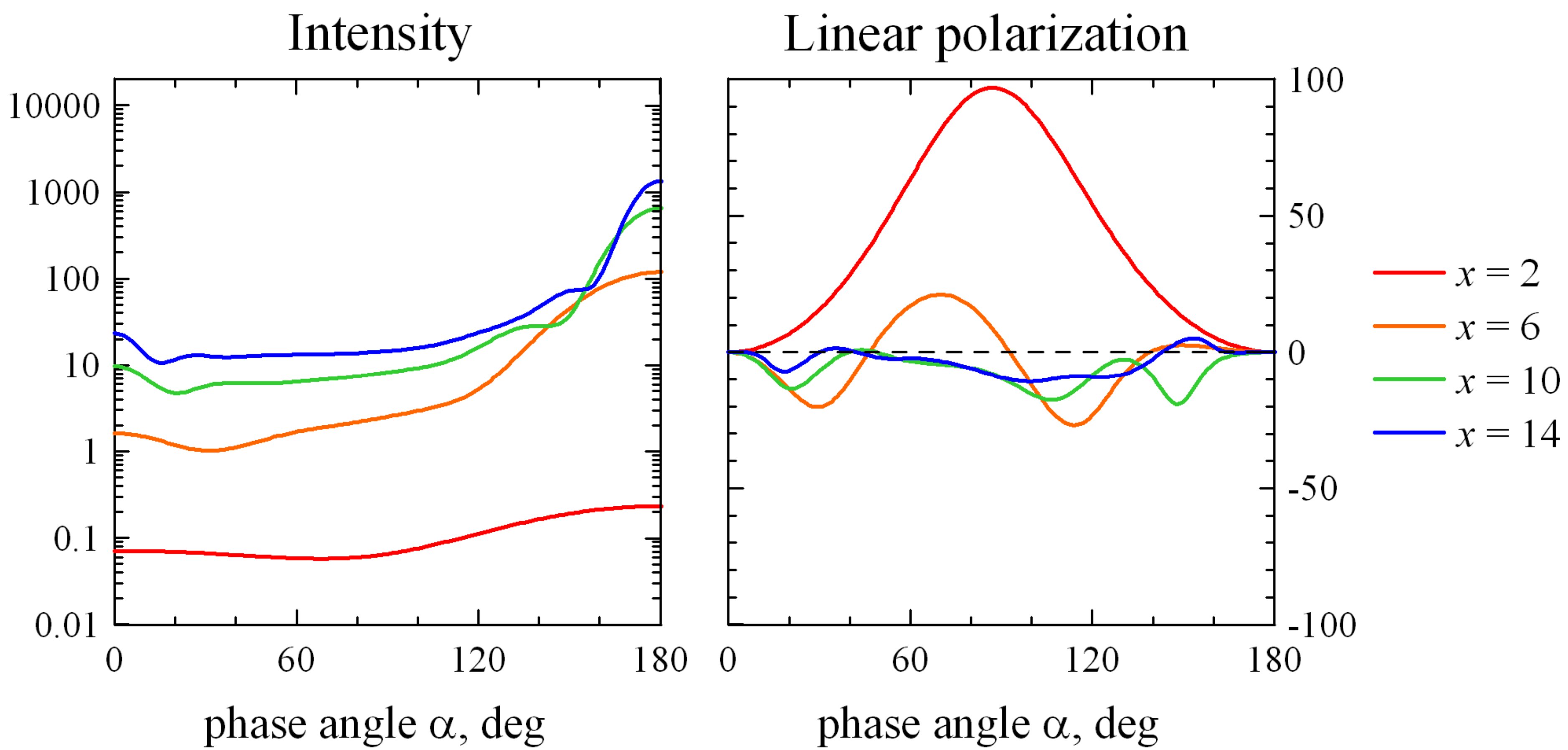
Angular profiles of intensity (left) and degree of linear polarization (right) for strongly damaged spheres at m=1.6+0.0005i.



Angular profiles of intensity (left) and degree of linear polarization (right) for rough-surface spheres at m=1.6+0.0005i.

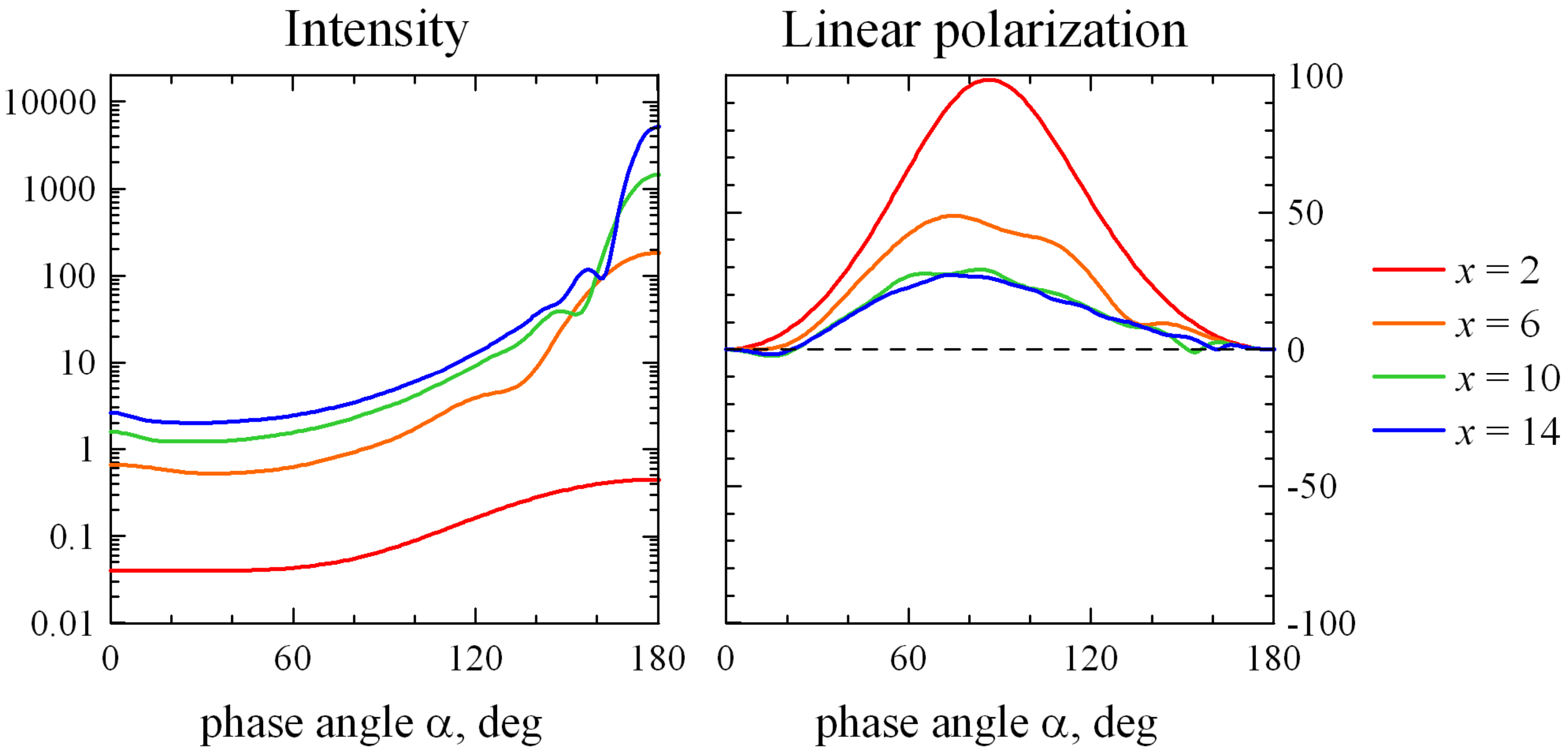


Angular profiles of intensity (left) and degree of linear polarization (right) for random Gaussian particles at m=1.6+0.0005i.

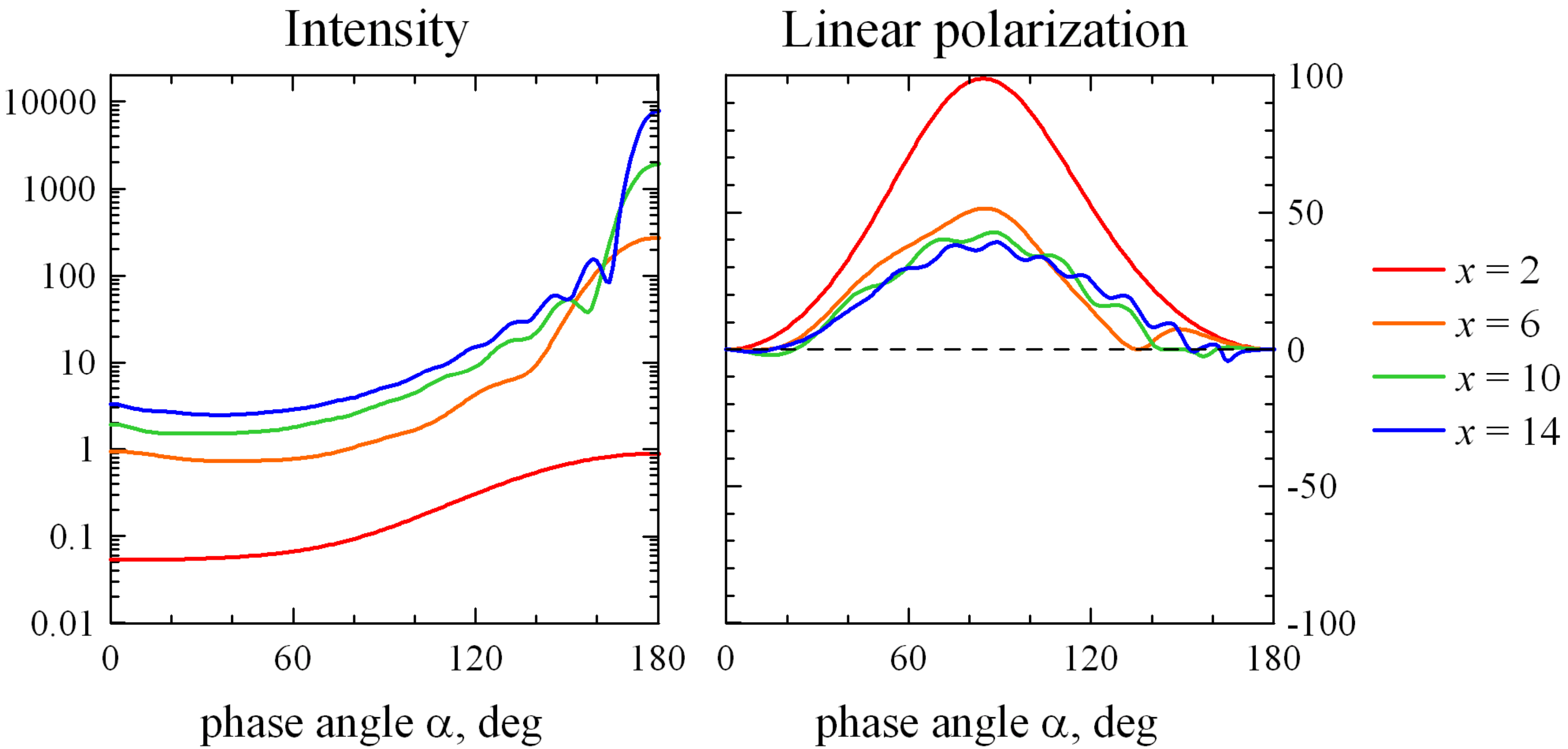


Angular profiles of intensity and degree of linear polarization for organic irregularly shaped particle (m=1.5+0.1i)

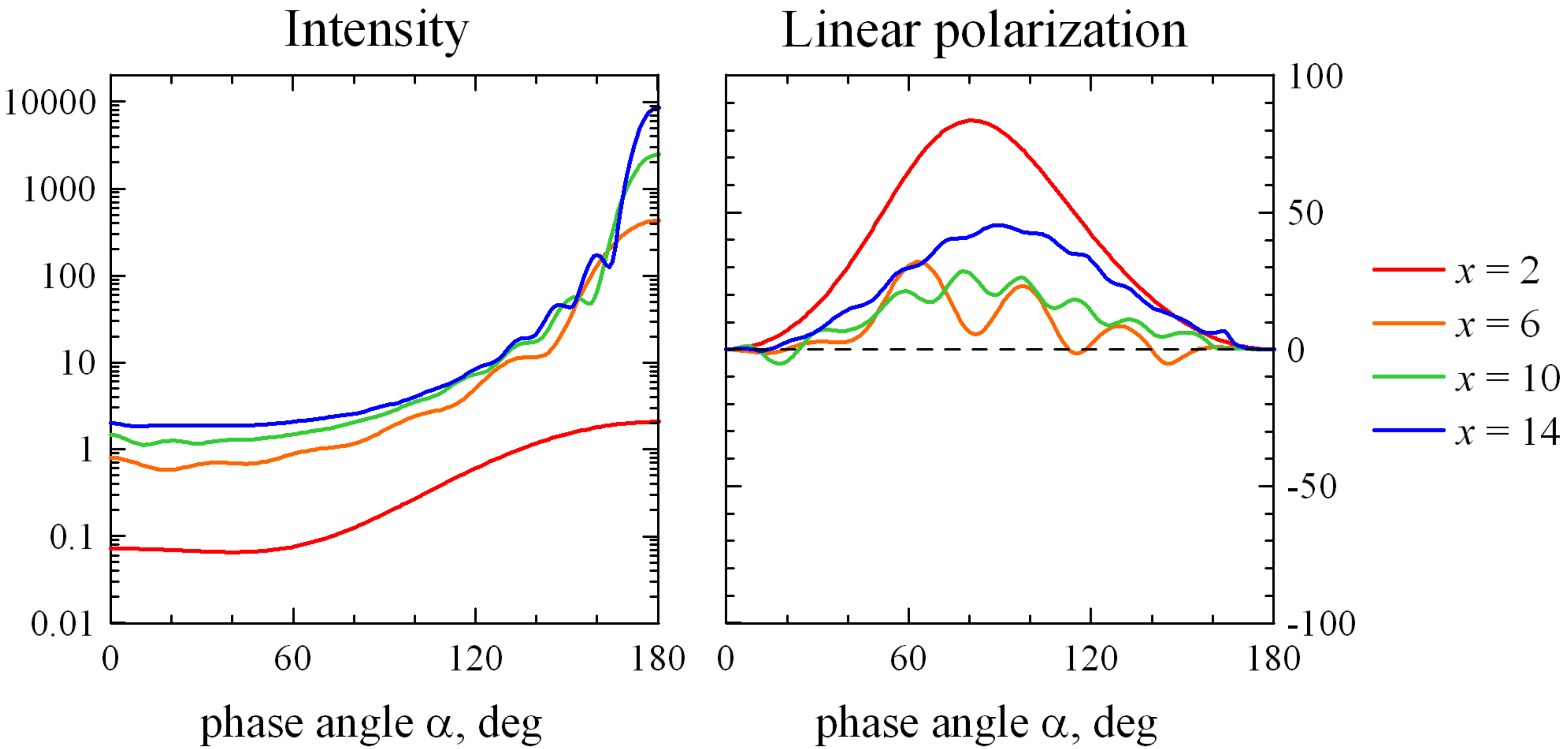
Angular profiles of intensity (left) and degree of linear polarization (right) for agglomerated debris particles at m=1.5+0.1i.



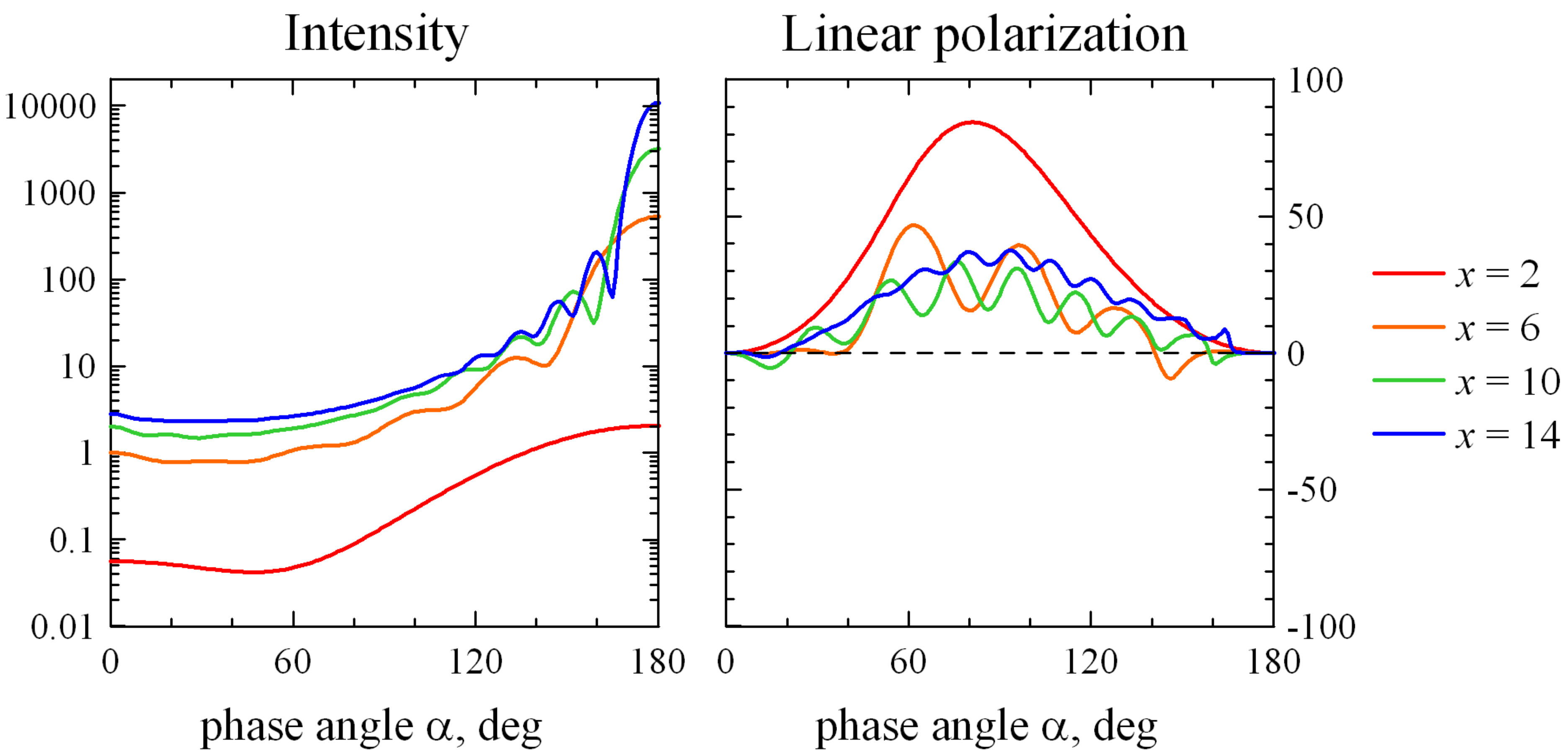
Angular profiles of intensity (left) and degree of linear polarization (right) for pocked spheres at m=1.5+0.1i.



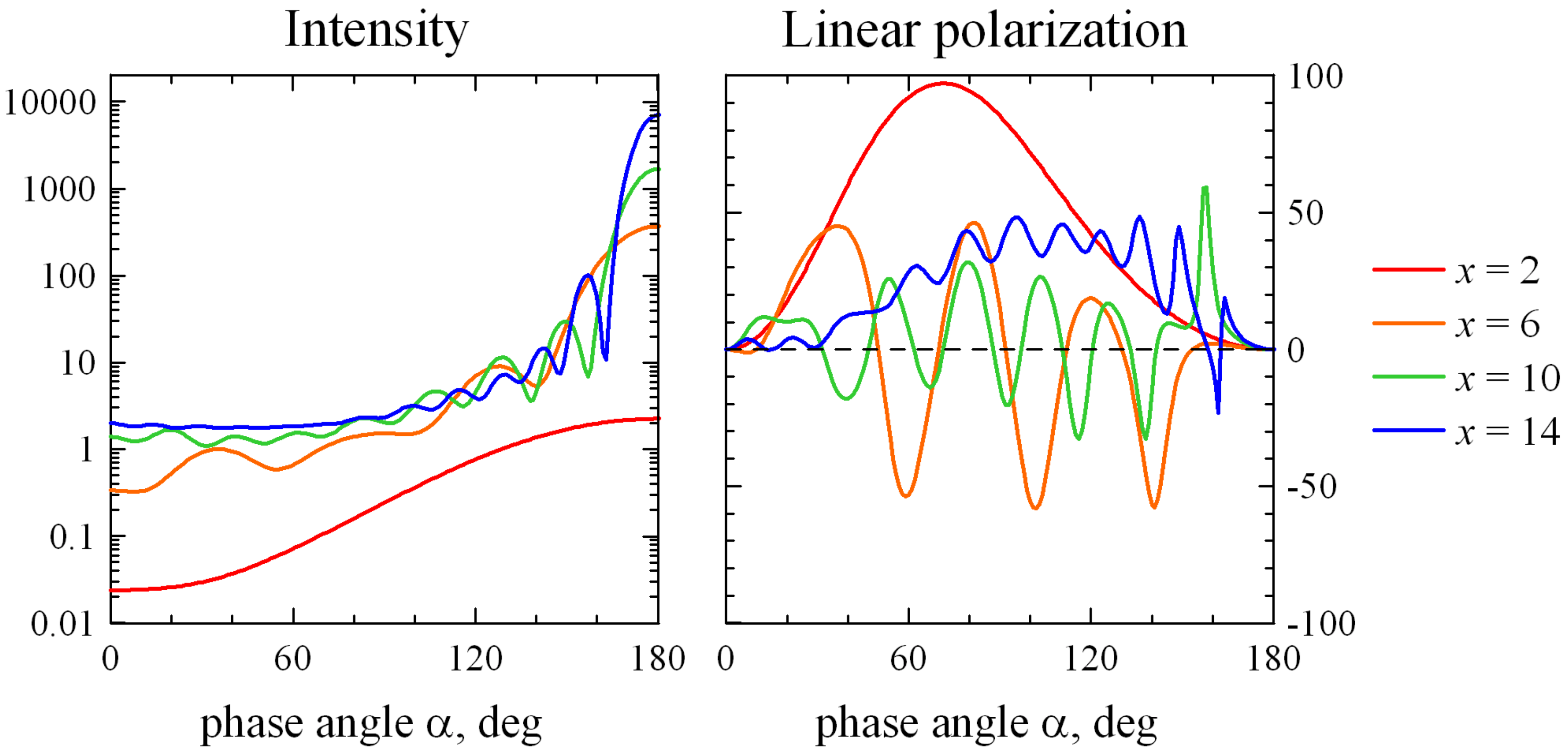
Angular profiles of intensity (left) and degree of linear polarization (right) for debris of spheres at m=1.5+0.1i.



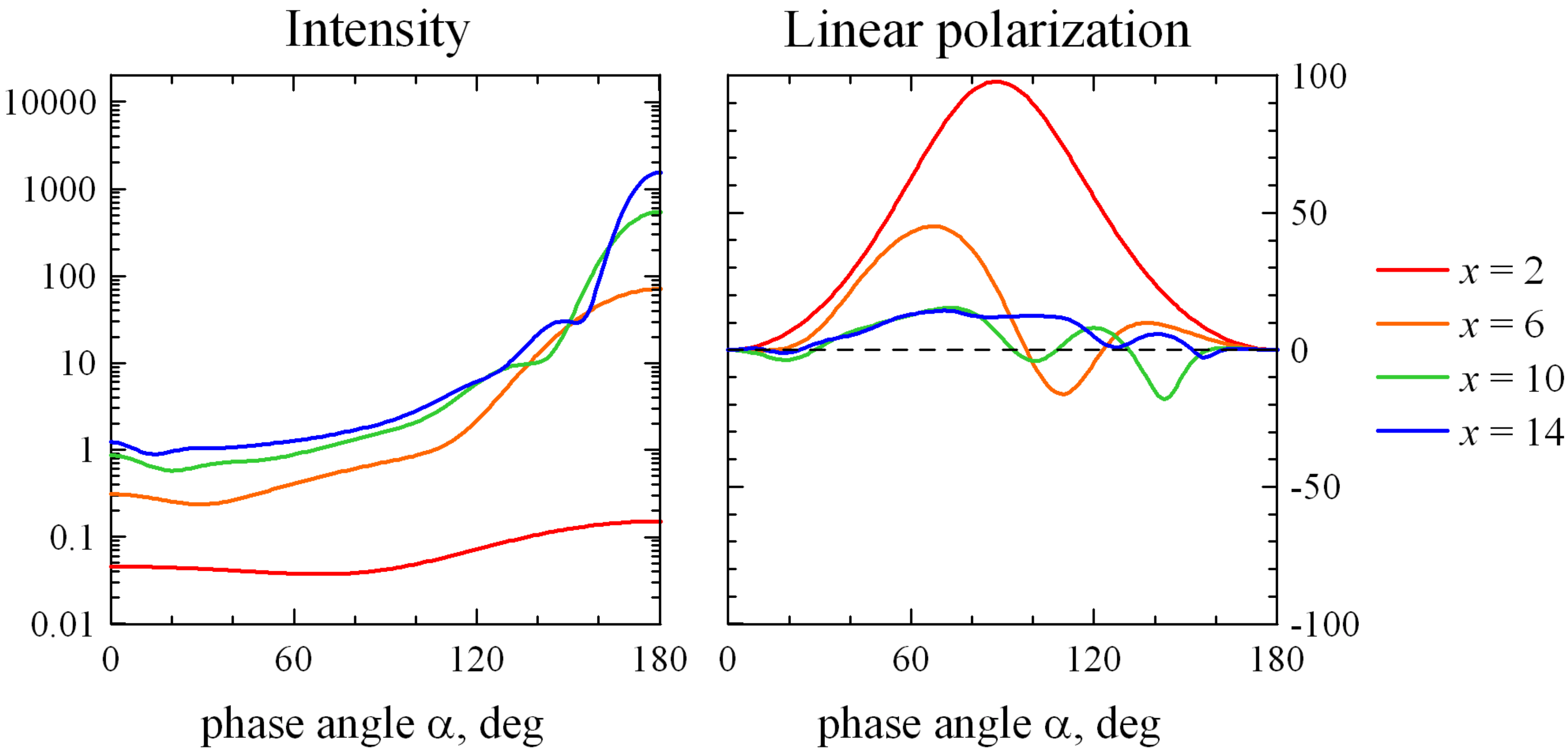
Angular profiles of intensity (left) and degree of linear polarization (right) for strongly damaged spheres at m=1.5+0.1i.



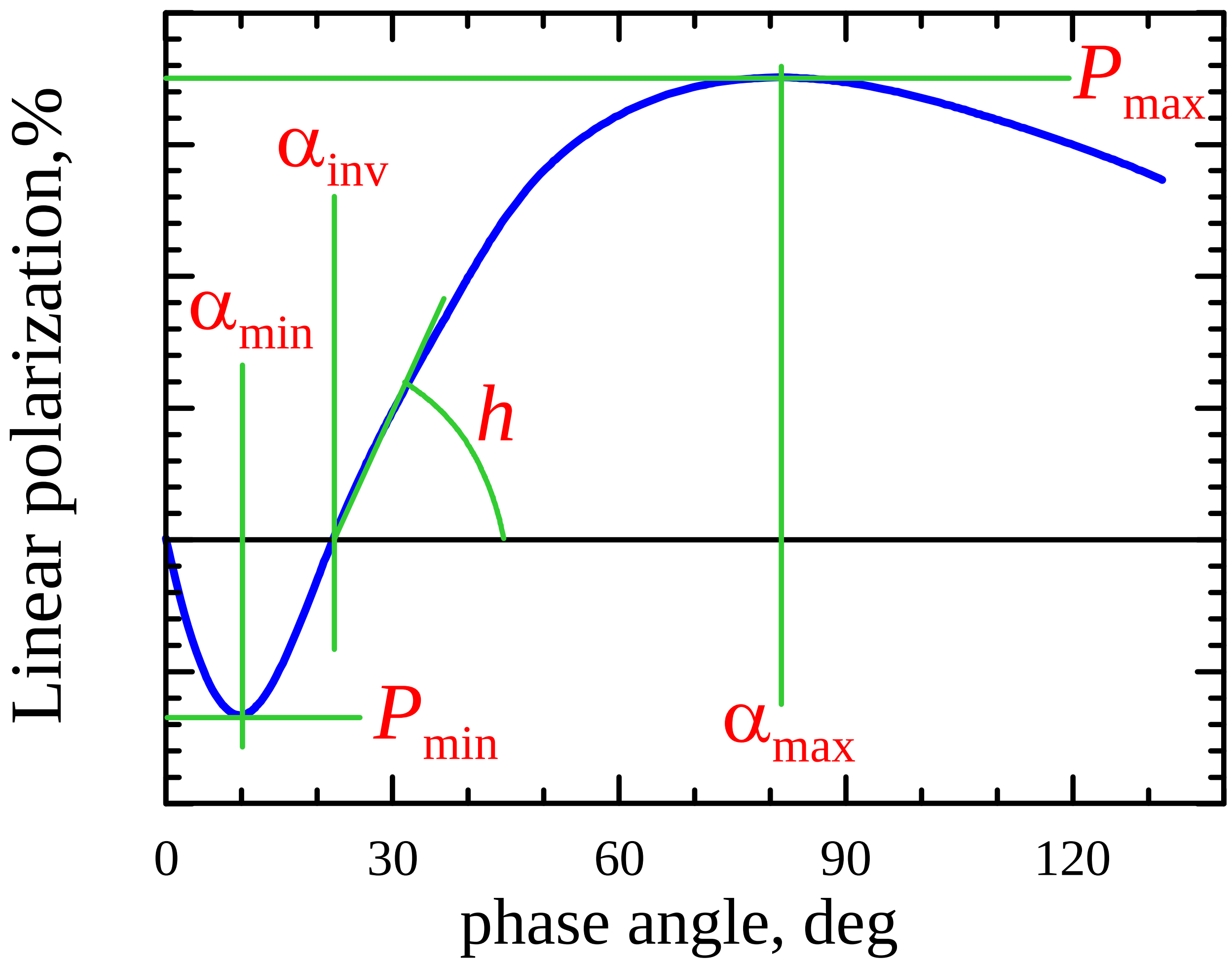
Angular profiles of intensity (left) and degree of linear polarization (right) for rough-surface spheres at m=1.5+0.1i.



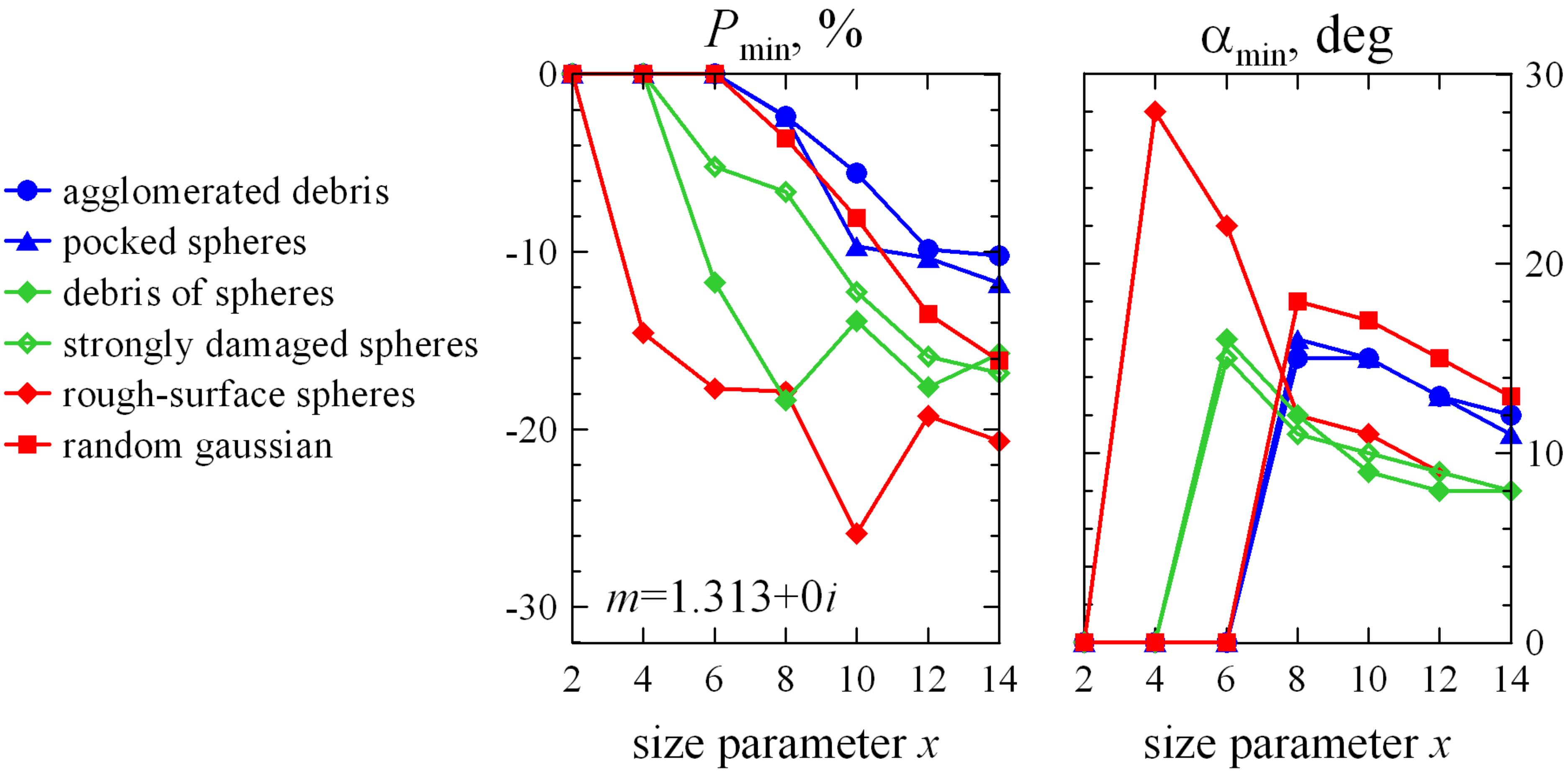
Angular profiles of intensity (left) and degree of linear polarization (right) for random Gaussian particles at m=1.5+0.1i.



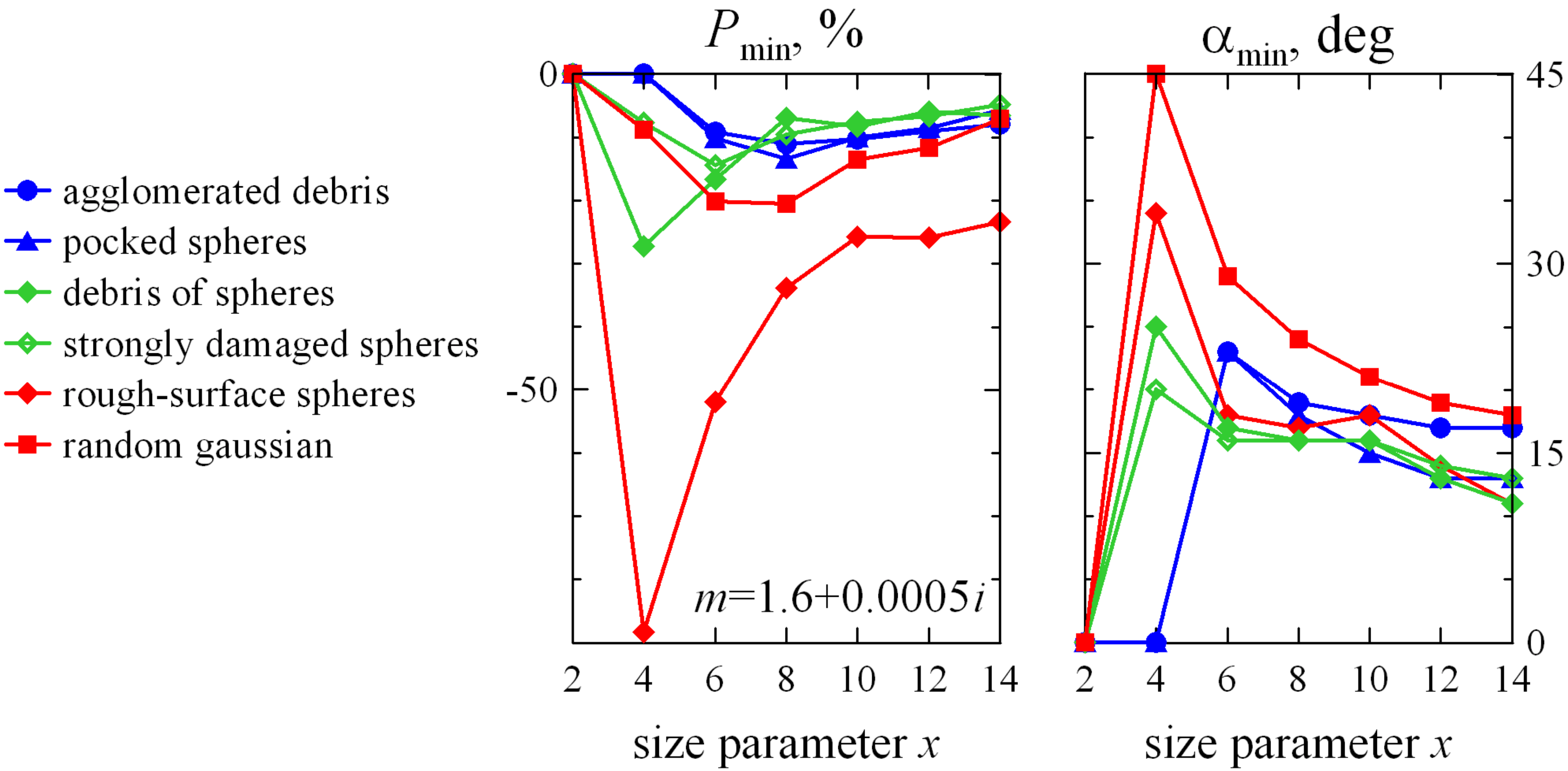
General profile of the degree of linear polarization for irregularly shaped particles with agglomerated structure consists of two quite stable features: negative polarization branch near small phase angles and positive polarization at intermediate phase angles.



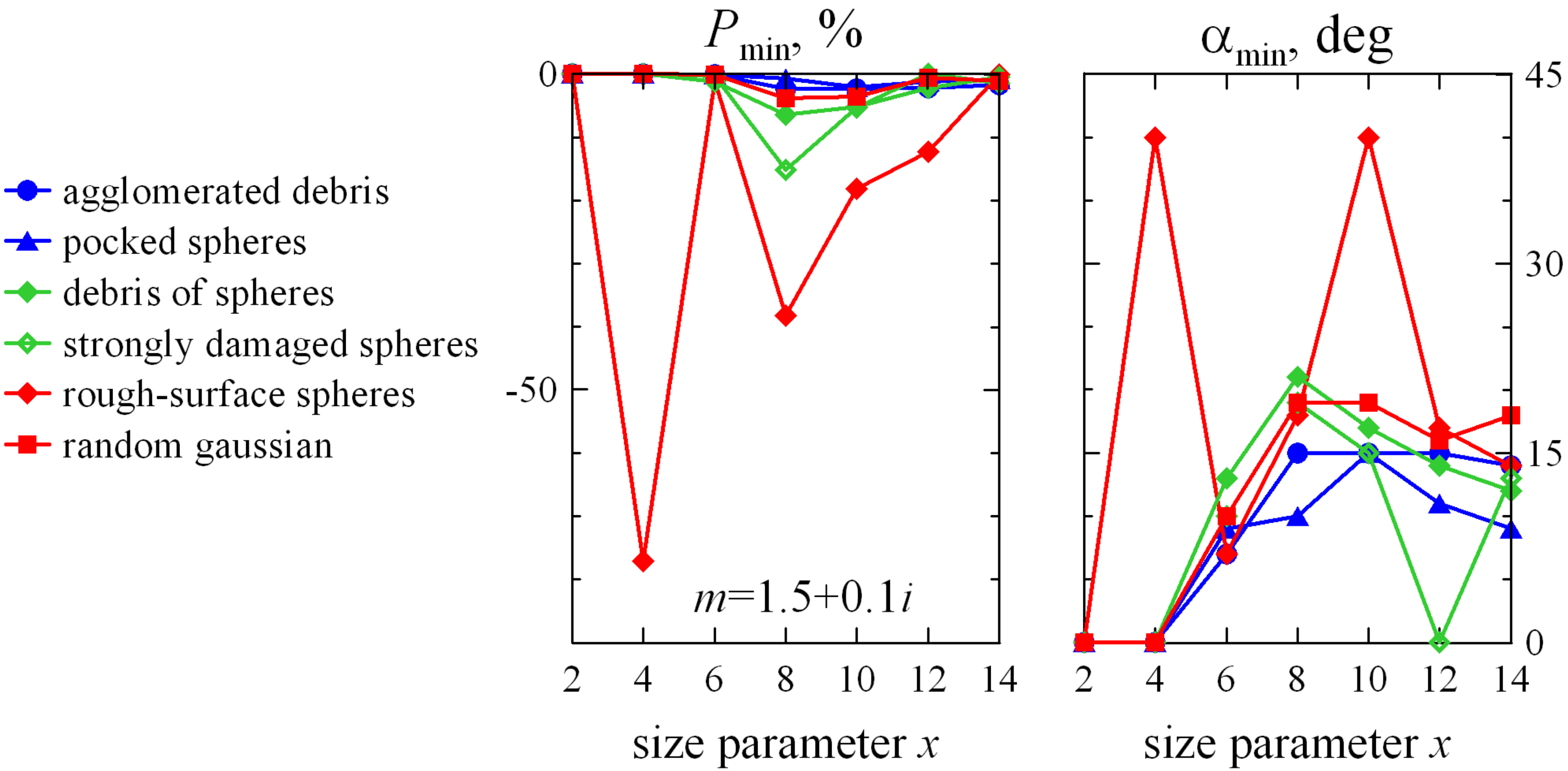
Parameters of the negative polarization branch P_{min} and α_{min} as function of size parameter x.



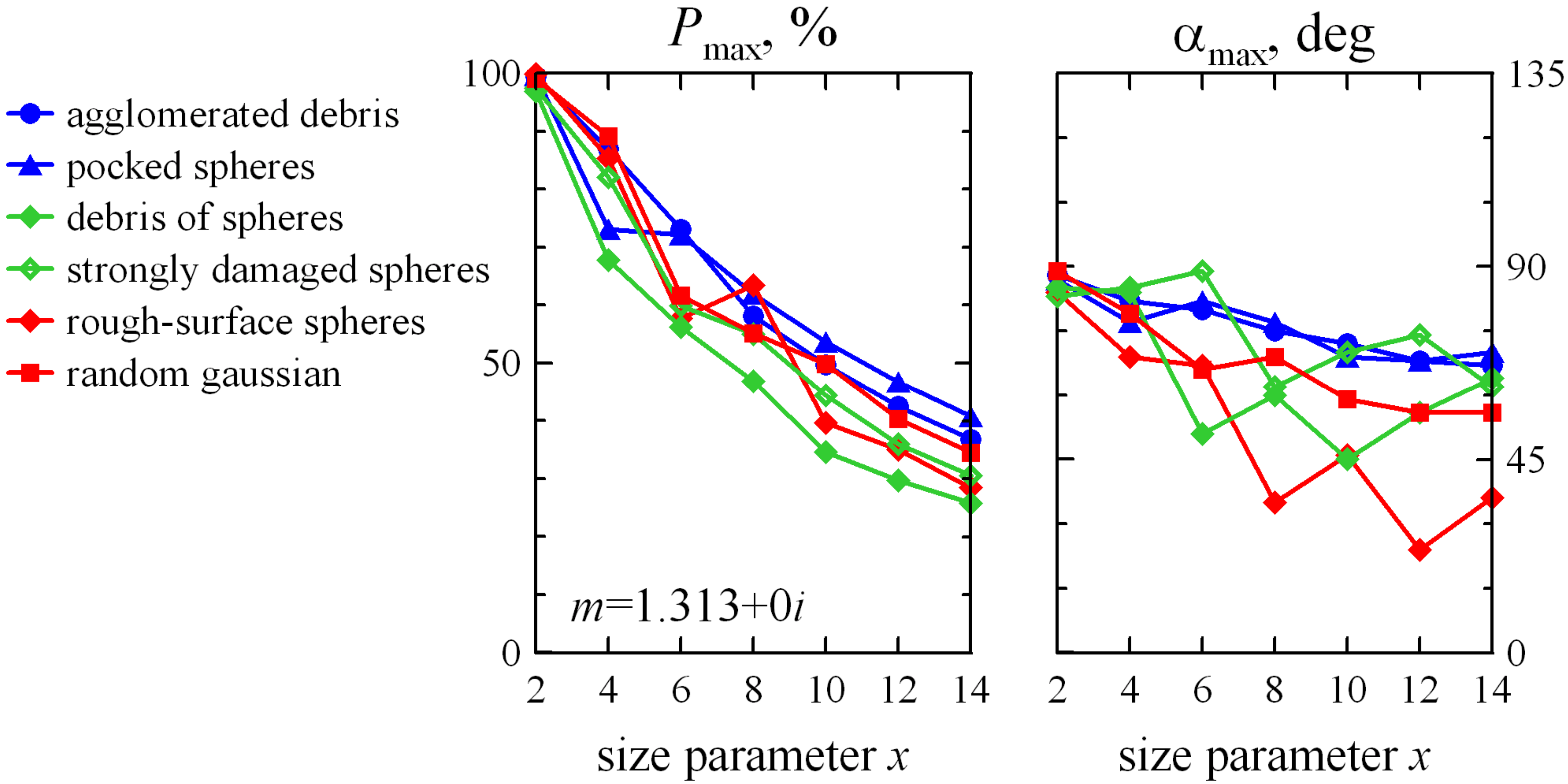
Parameters of the negative polarization branch P_{min} and α_{min} as function of size parameter x.



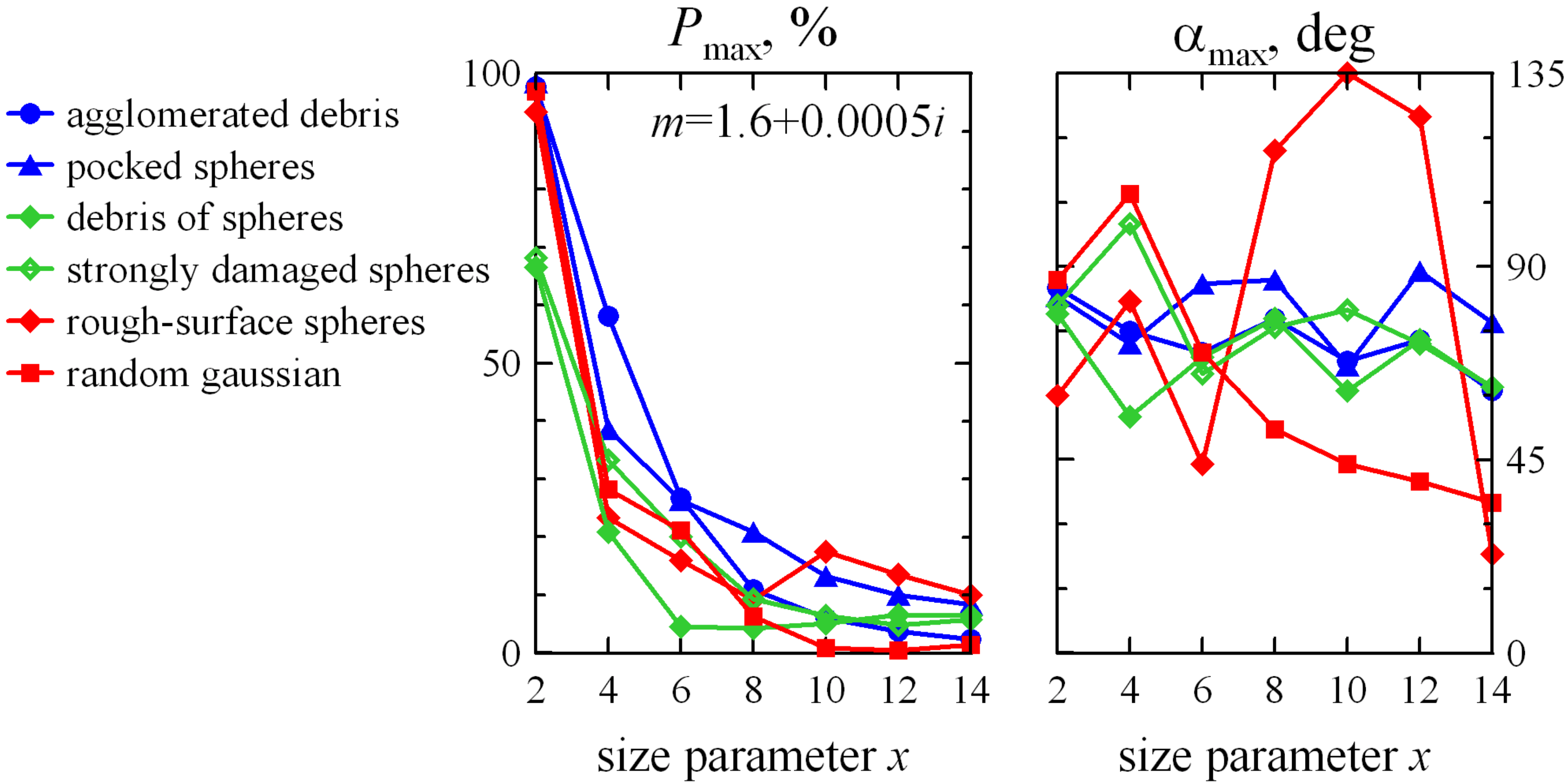
Parameters of the negative polarization branch P_{min} and α_{min} as function of size parameter x.



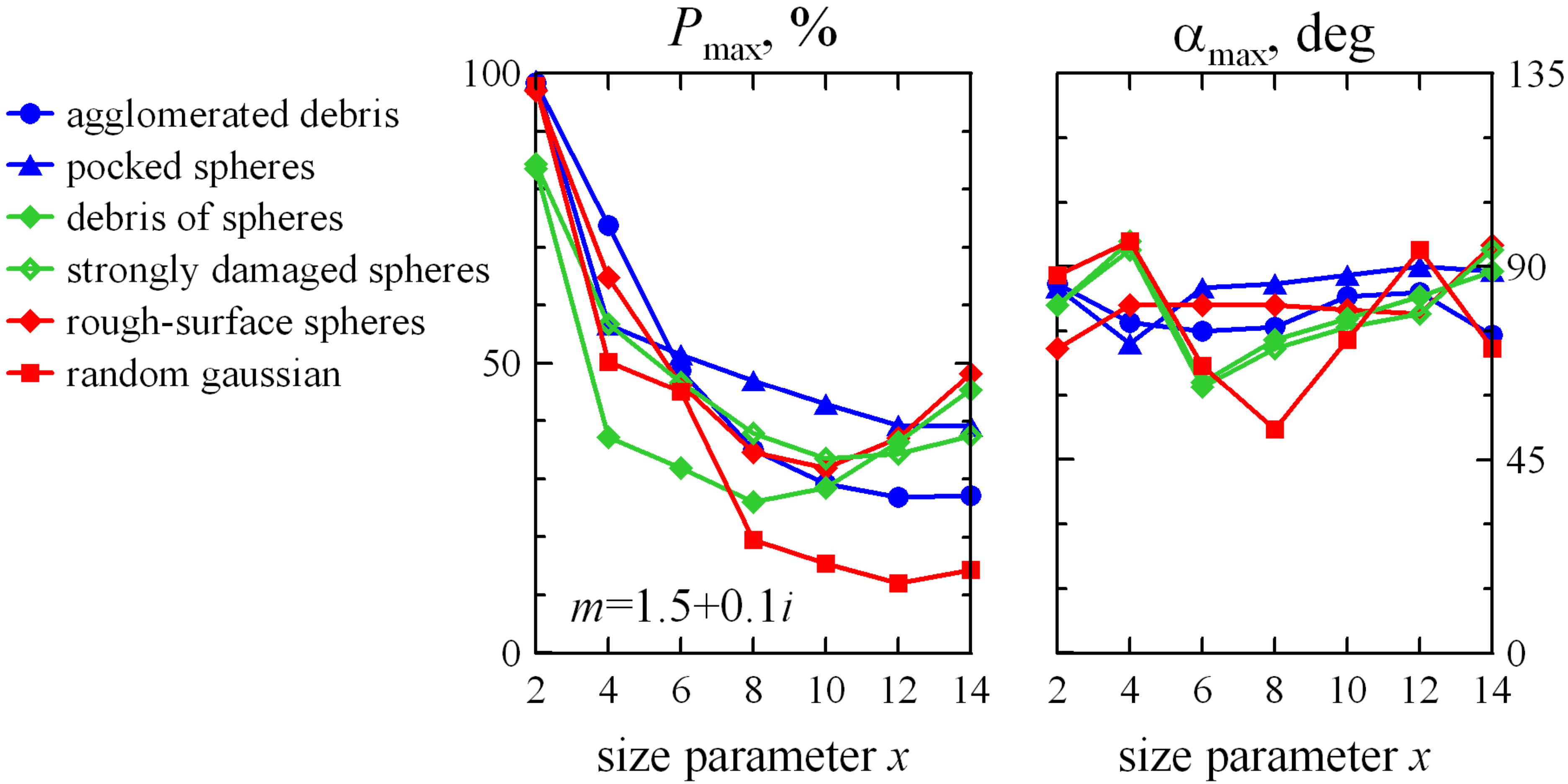
Parameters of the positive polarization branch P_{max} and α_{max} as function of size parameter x.



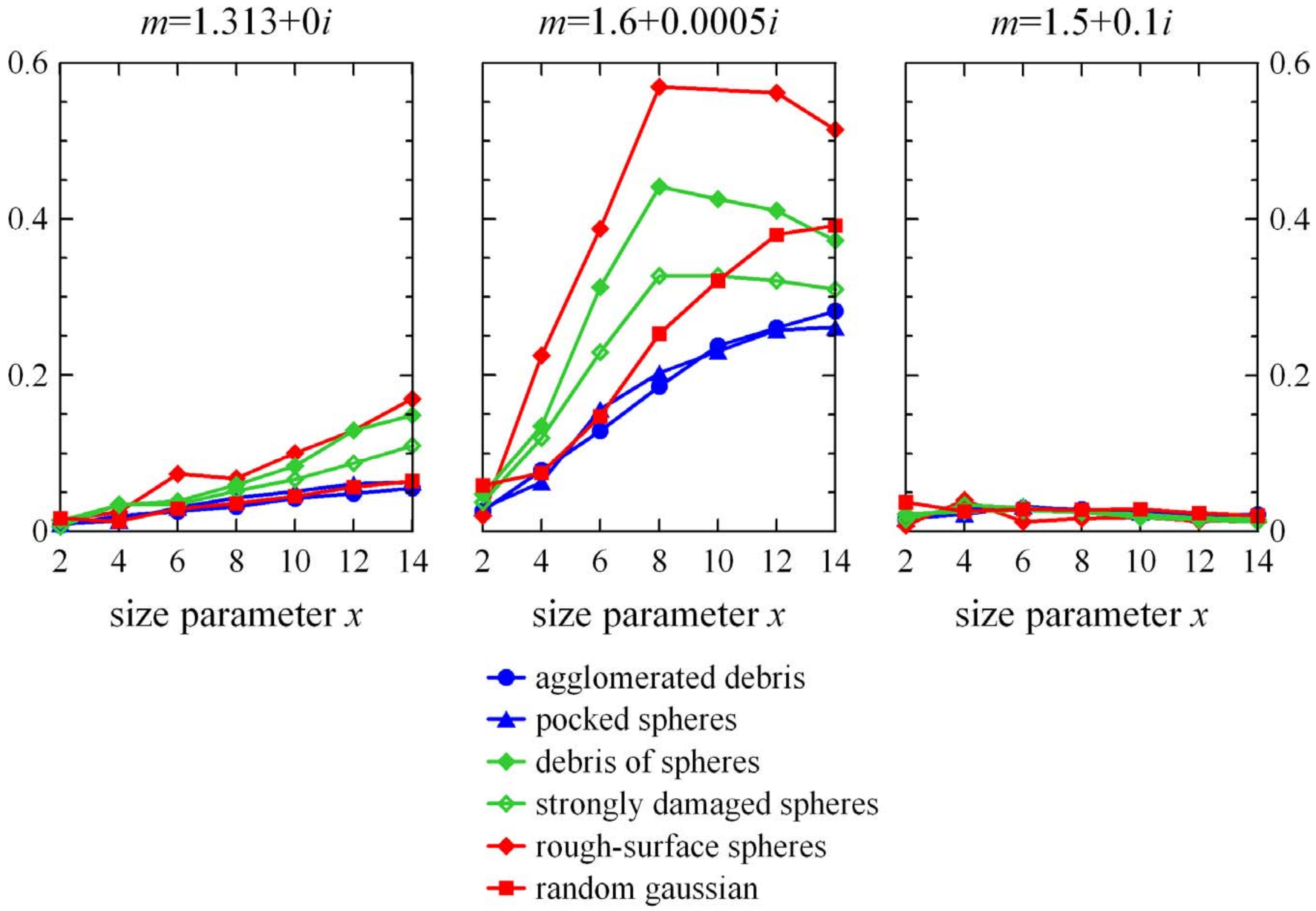
Parameters of the positive polarization branch P_{max} and α_{max} as function of size parameter x.



Parameters of the positive polarization branch P_{max} and α_{max} as function of size parameter x.

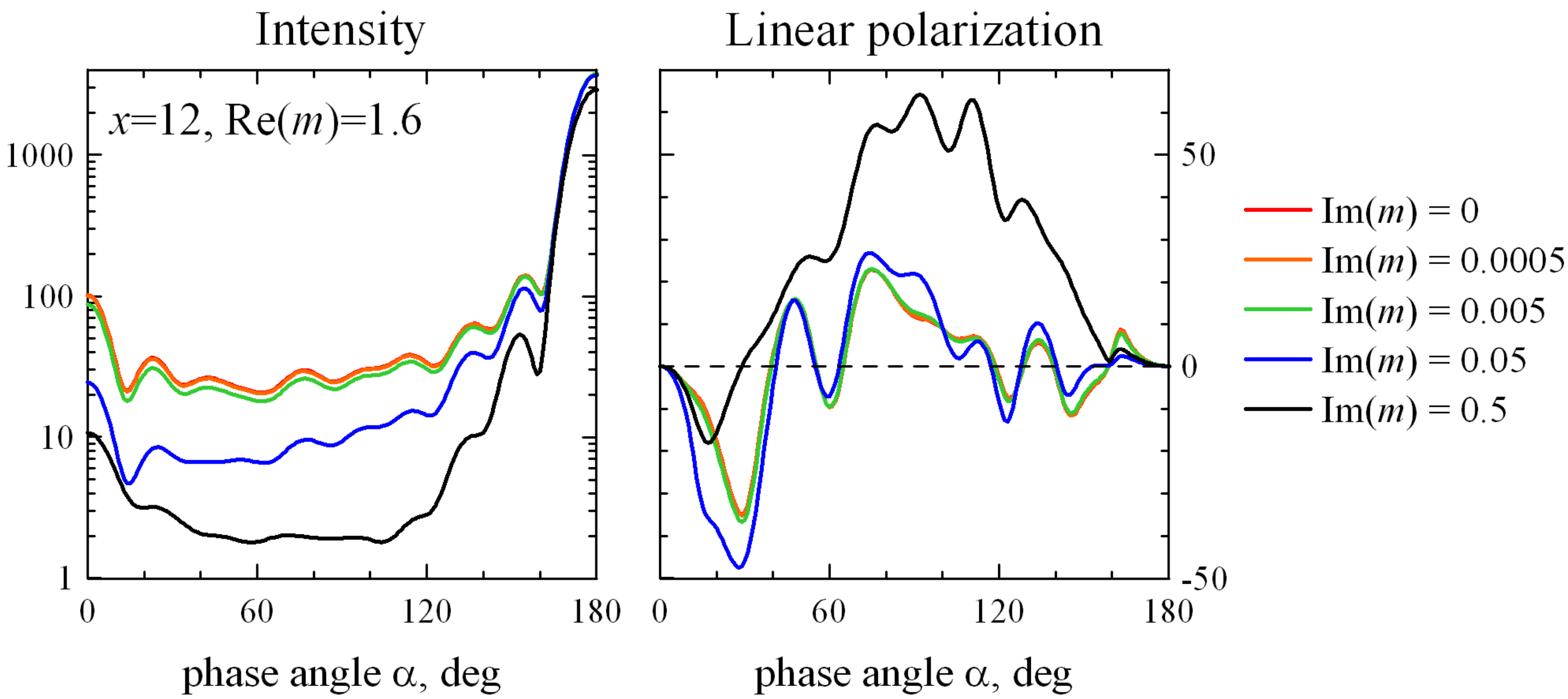


Geometric albedo A vs. size parameter x.



Dependence of light-scattering properties on absorption

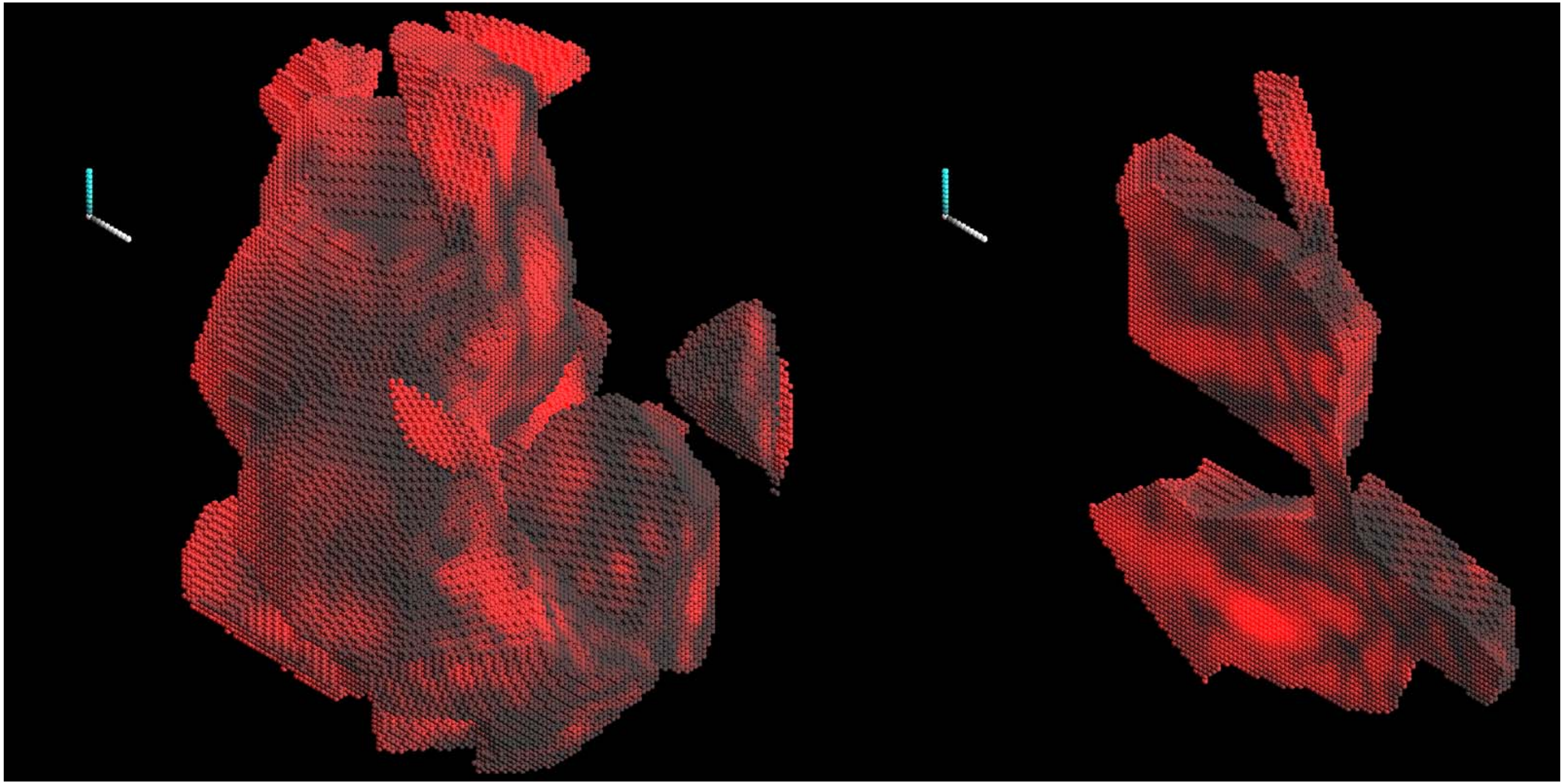
Sensitivity of angular profiles of intensity and degree of linear polarization to absorption.



For instance, refractive index m=1.6+0.02i corresponds to an extremely dark surface. However, in case of single particles, the effect is not too high.

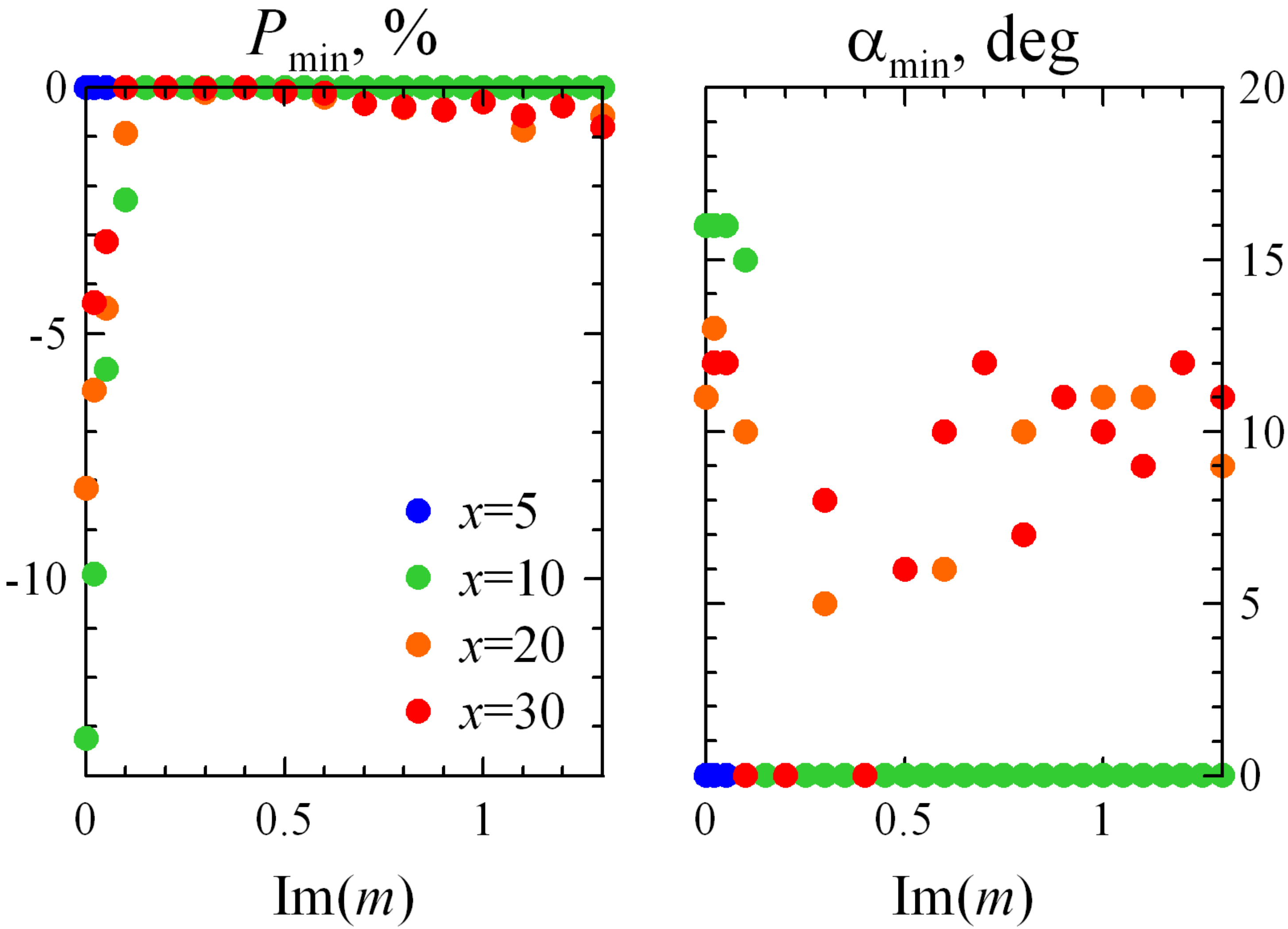
Transparency of particles consisting of highly absorbing material.

Below, it is the distribution of energy of the induced field through the given agglomerated debris particle at x=30 and m=1.5+0.05i. The redder color means the larger energy.



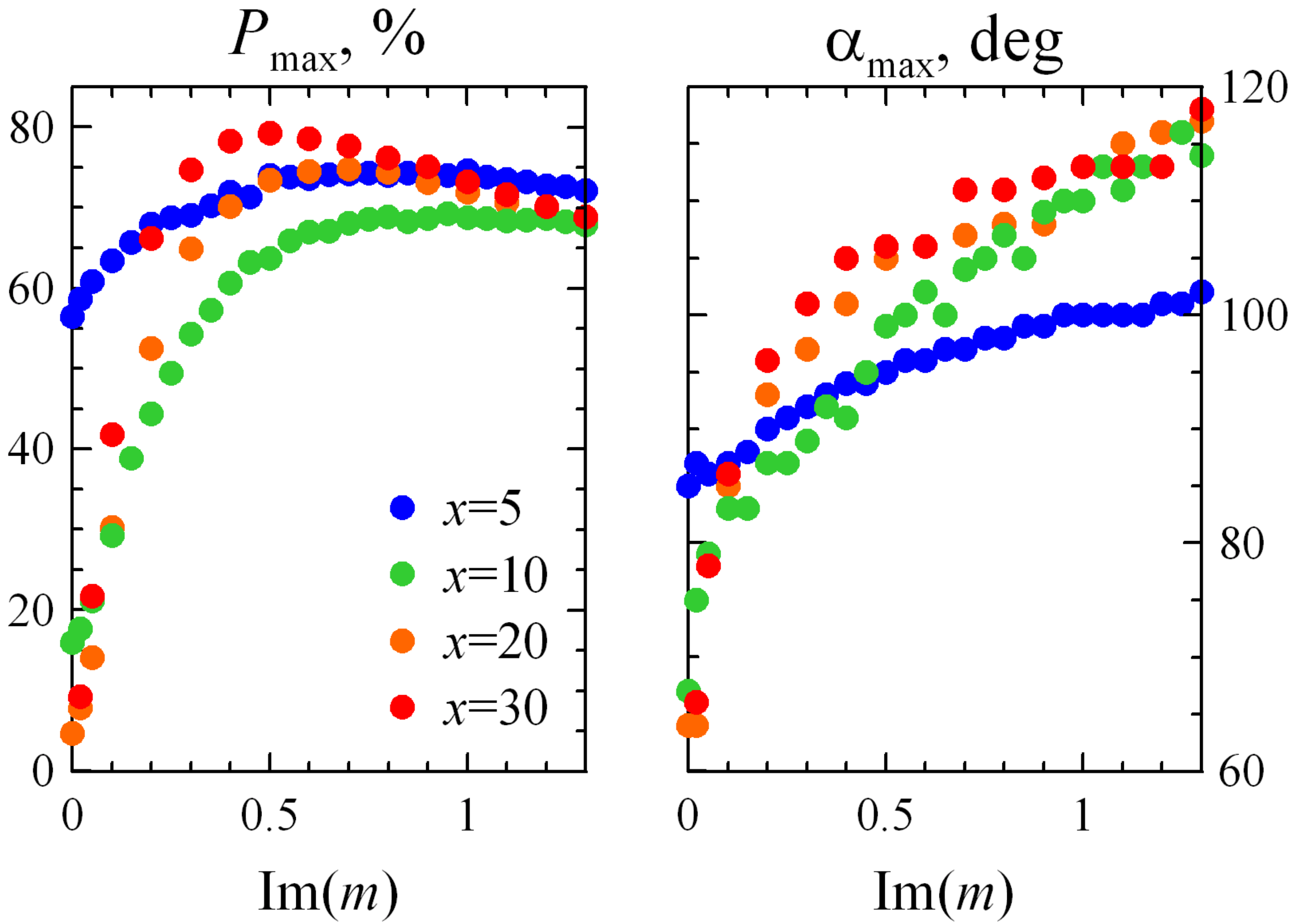
Dependence of parameters characterizing the negative polarization branch upon material absorption.

Agglomerated debris particles at Re(m)=1.5.



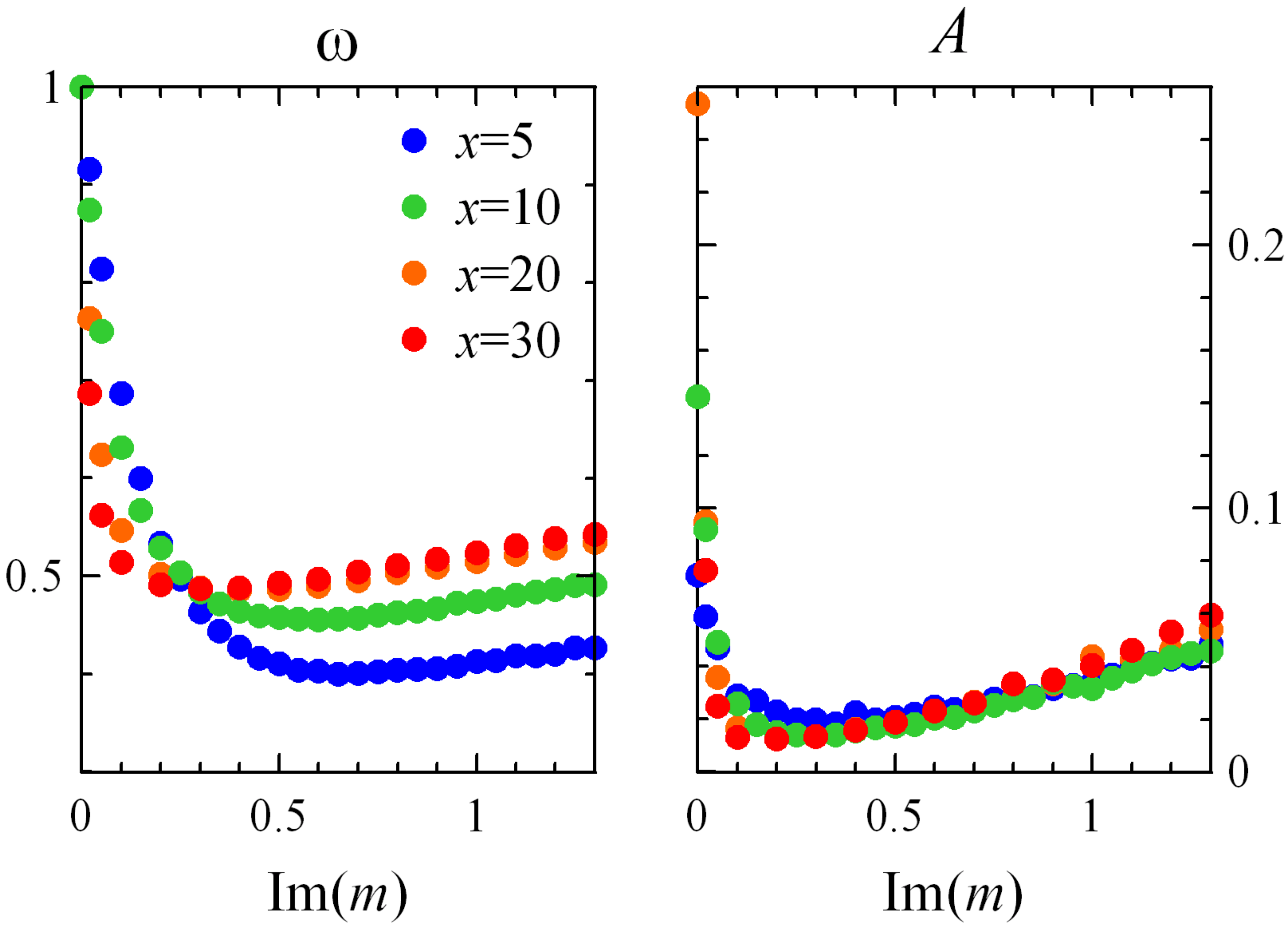
Dependence of parameters characterizing the positive polarization branch upon material absorption.

Agglomerated debris particles at Re(m)=1.5.



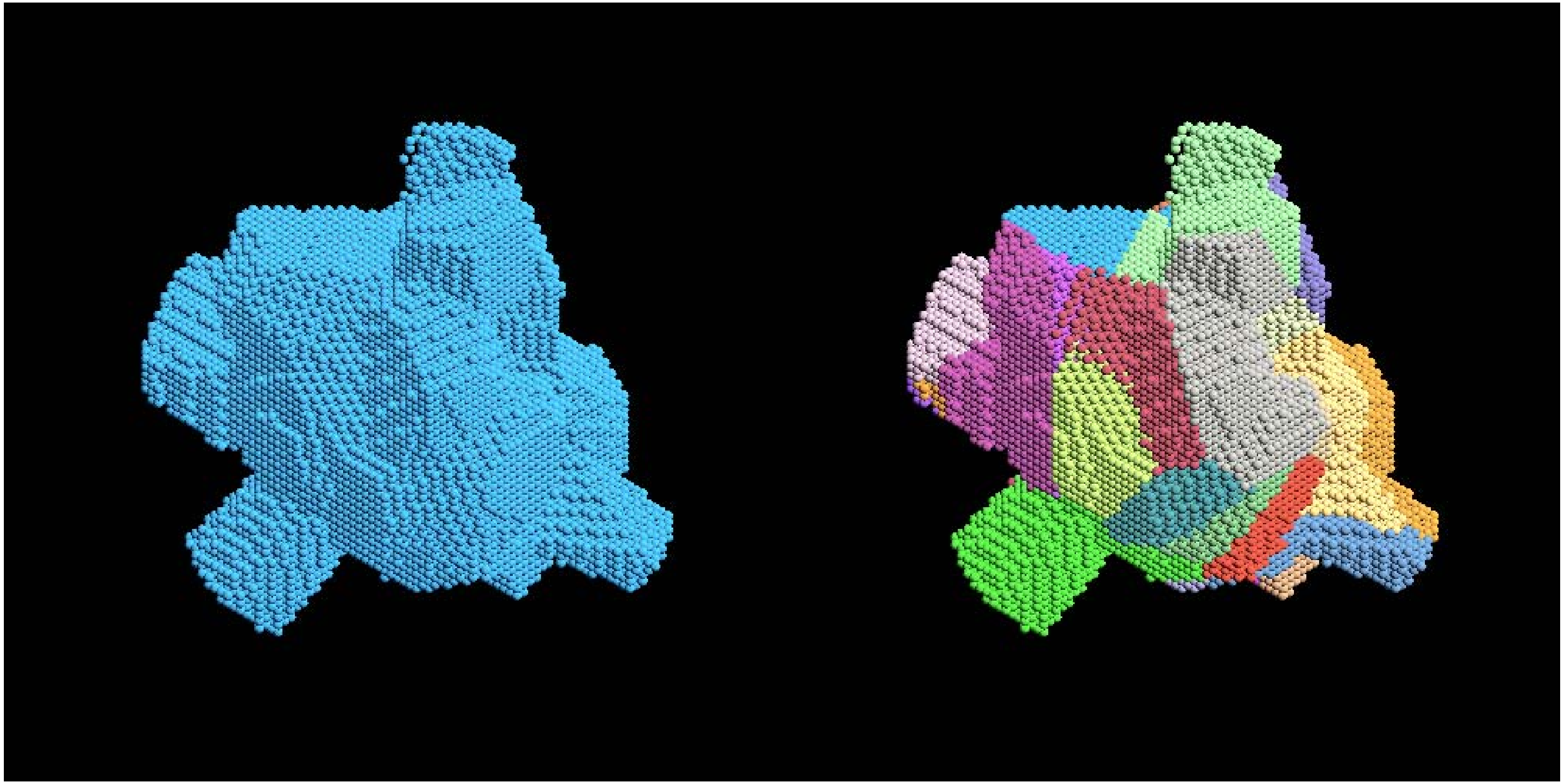
Dependence of single scattering albedo ω and geometric albedo A upon material absorption.

Agglomerated debris particles at Re(m)=1.5.



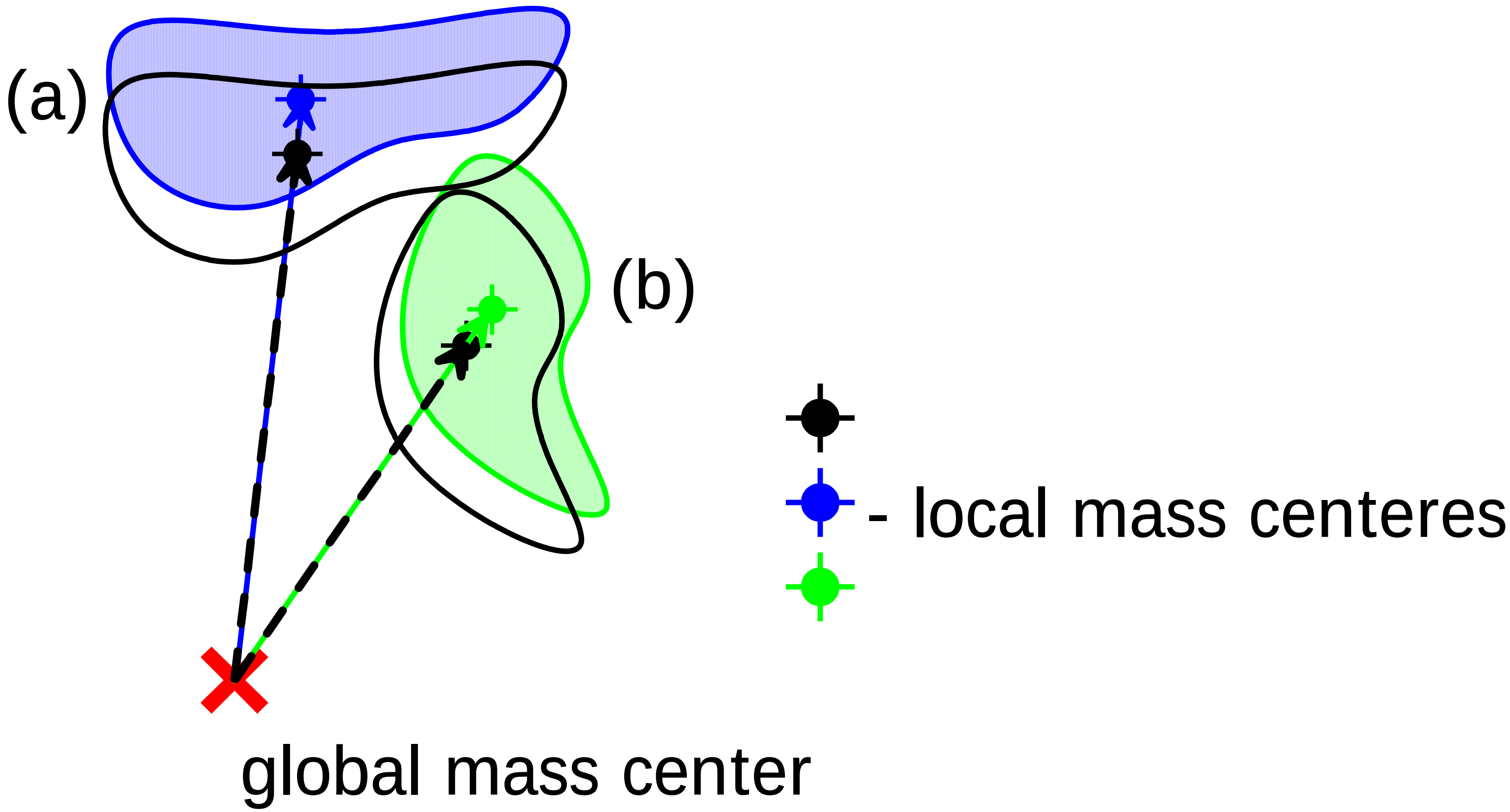
Dependence of light-scattering properties on packing density

We take one sample of agglomerated debris particles and divide it into 30 small random irregular fragments. Size parameter of whole particle x=12; whereas, size parameter of “average” fragment x=4.5. In terms of equivalent volume sphere, size parameters are x_{eq}=8.2 and x_{eq}=2.5, correspondingly.

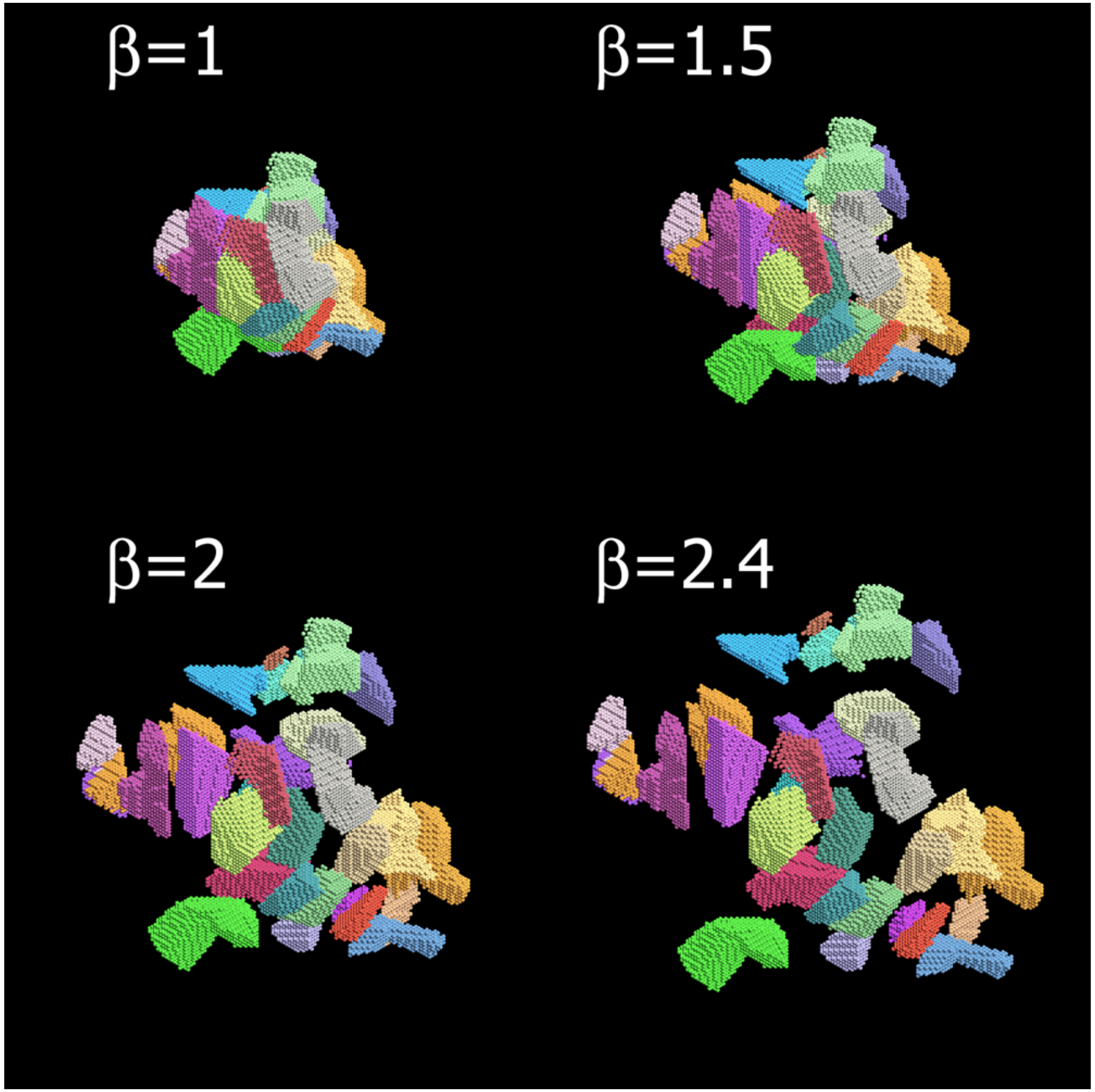


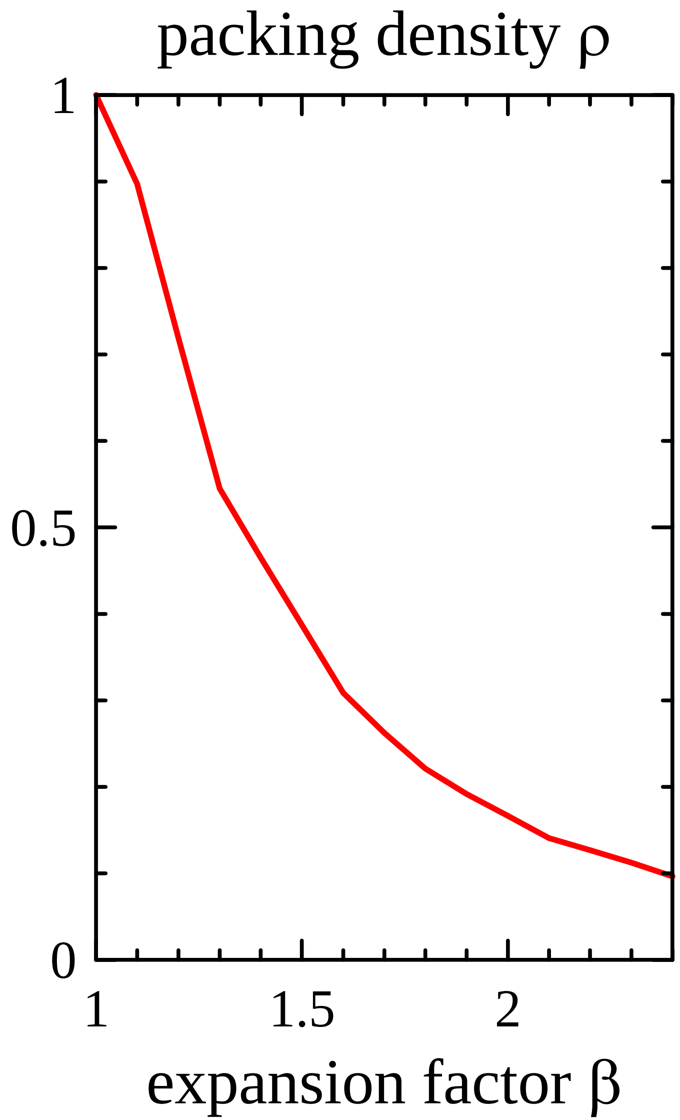
The particle divided into fragments is being exploded with the following algorithm:

new distance = $\beta \times$ old distance

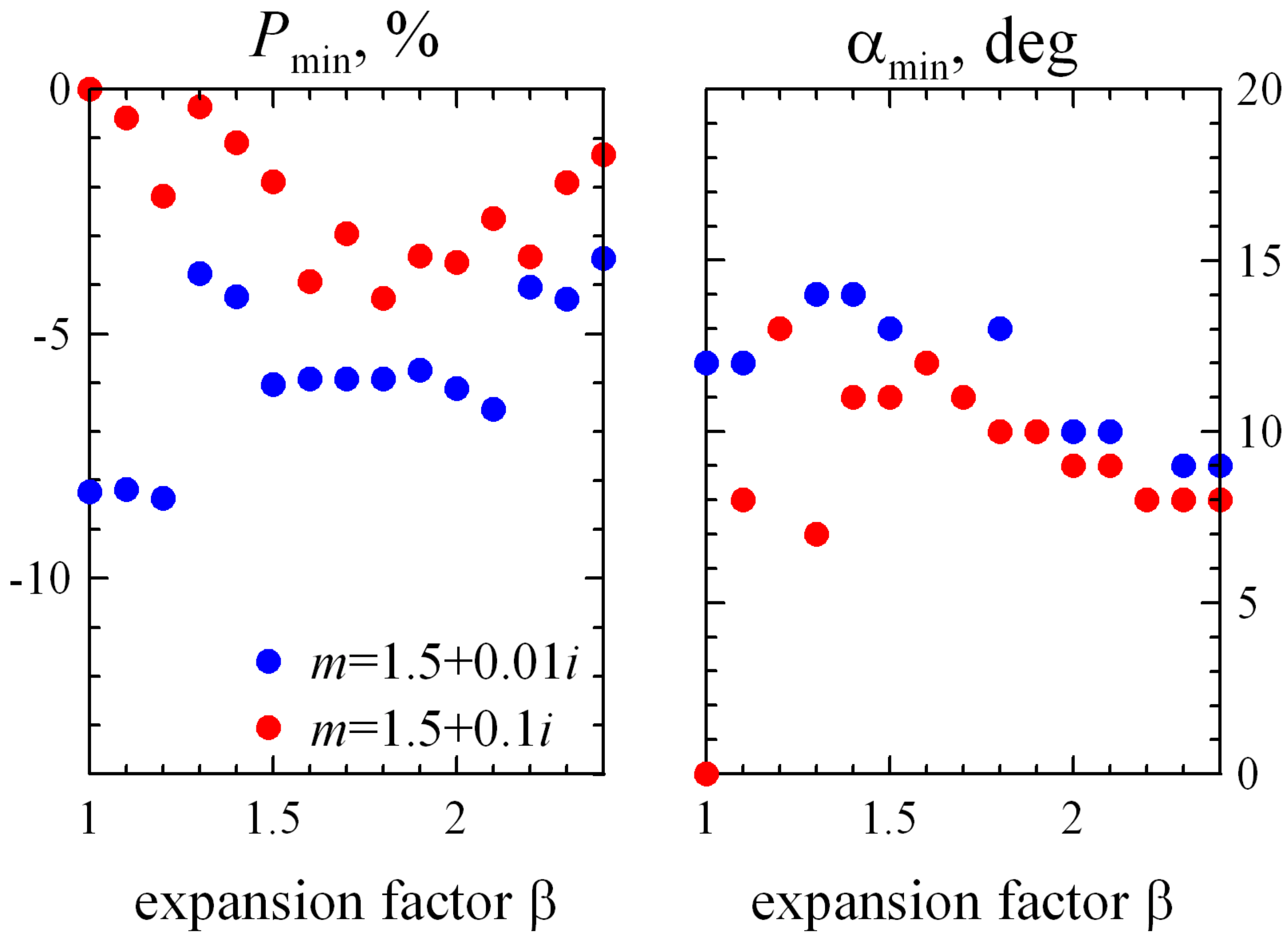


Expansion factor β is varied from 1 (the most compact case) through 2.4.



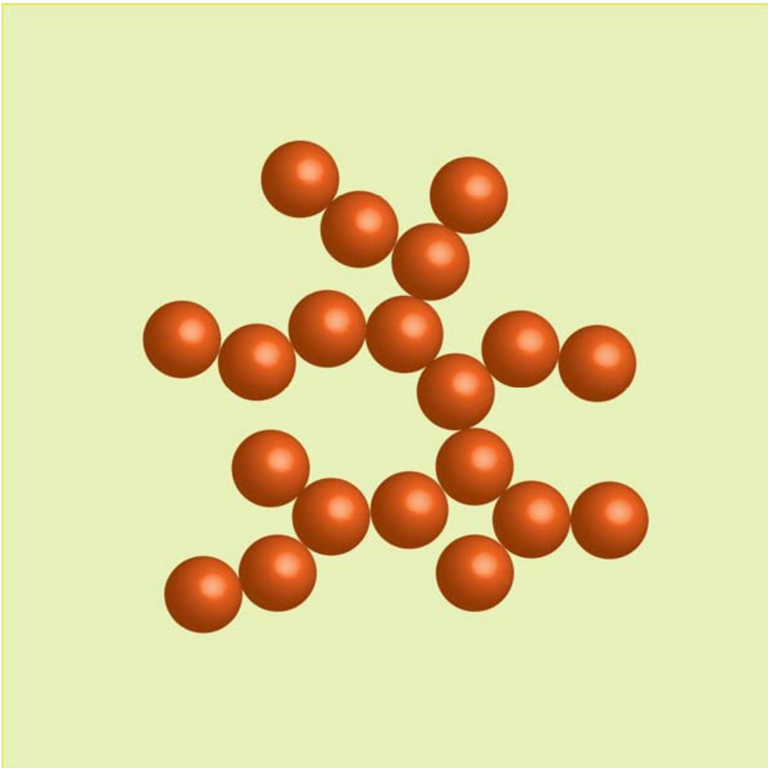


Dependence of parameters characterizing the negative polarization branch upon expansion factor β.

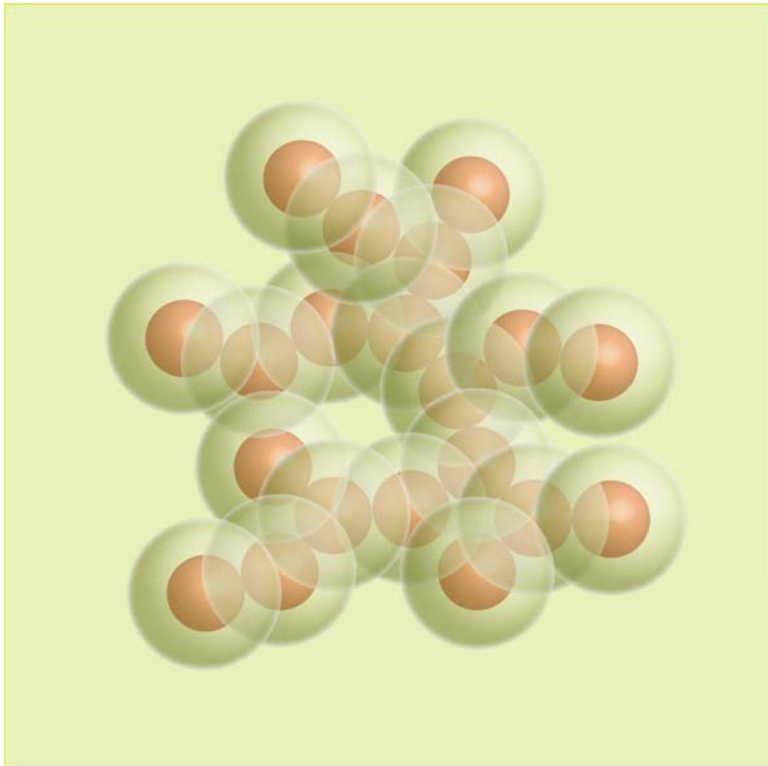


Amplitude of the negative polarization remains relatively high up to significant degree of expansion ($\beta > 2$). Taking into account that the negative polarization is produced by multiple scattering among fragments, it is an unexpected behavior. It can be explained by high efficiency for the scattering:

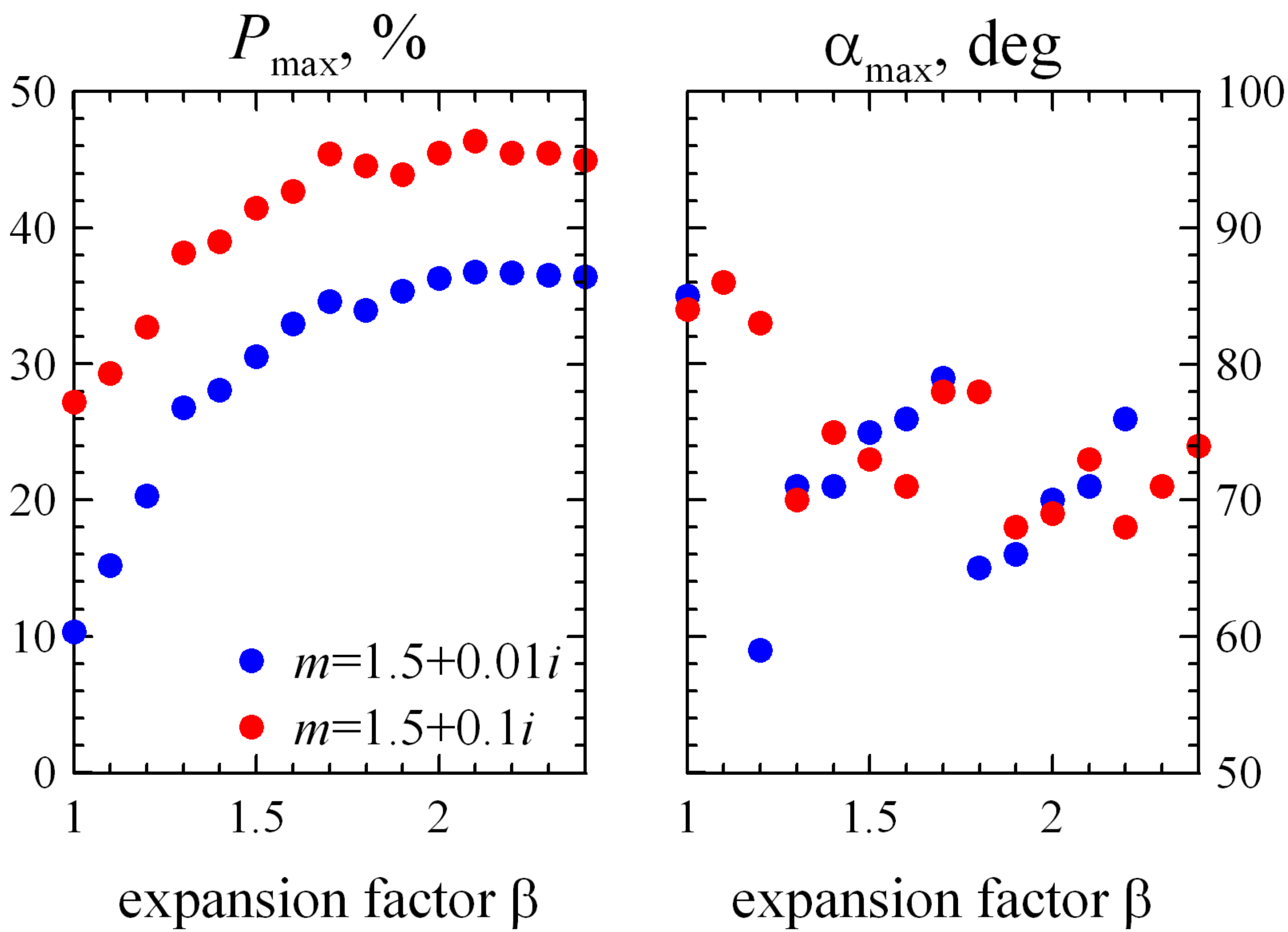
aggregate



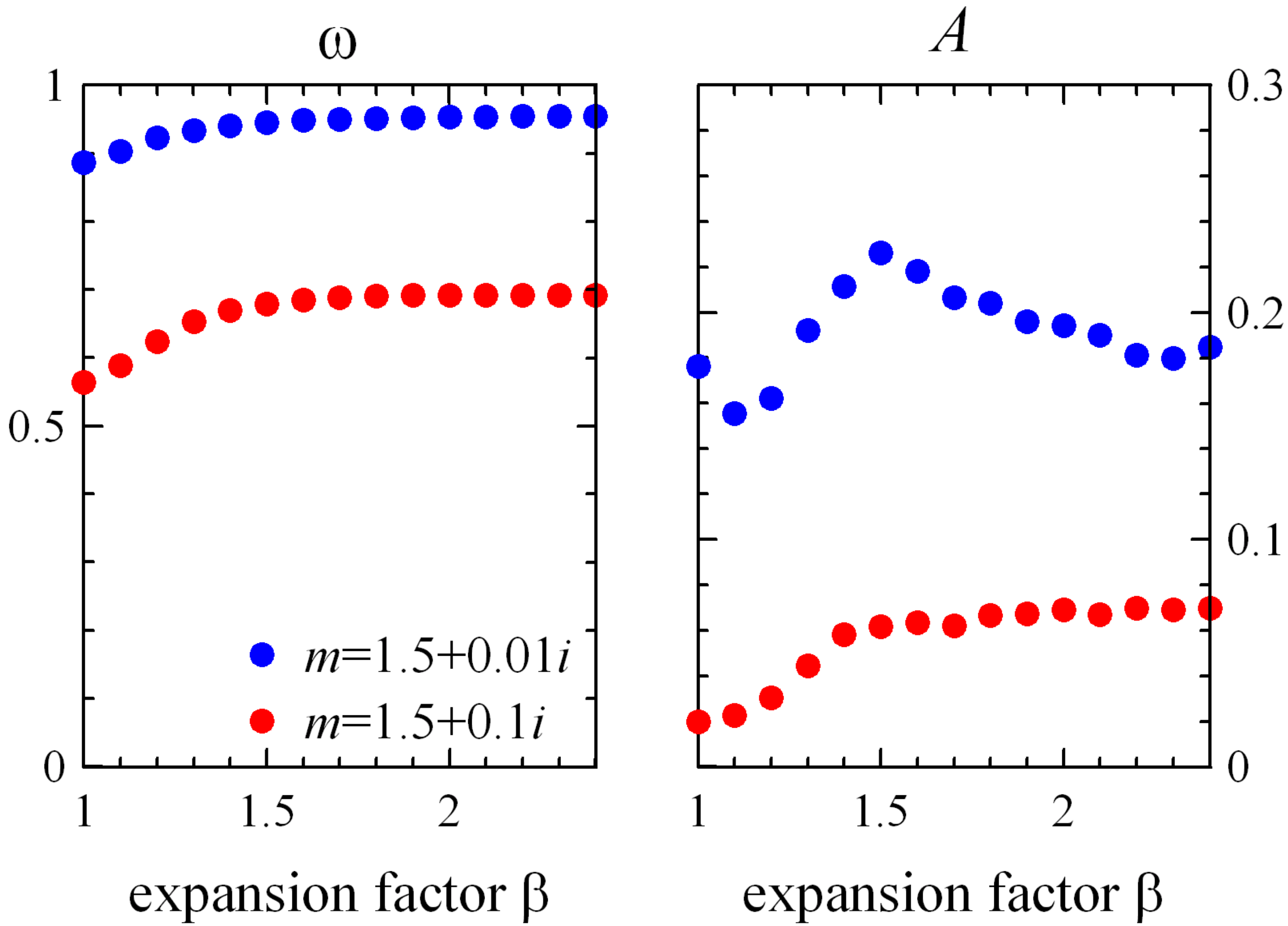
when interacting with light



Dependence of parameters characterizing the positive polarization branch upon expansion factor β.



Dependence of single scattering albedo ω and geometric albedo A upon expansion factor β.



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(1) Zubko E., Shkuratov Yu., Kiselev N., Videen G.. “DDA simulations of light scattering by small irregular particles with various structure,” J. Quant. Spectr. Rad. Trans., **101**, 416–434 (2006).

(2) Zubko E., Muinonen K., Shkuratov Yu.G., Videen G., Nousiainen T.. “Scattering of light by roughened Gaussian random particles,” J. Quant. Spectr. Rad. Trans., **106**, 604–615 (2007).

(3) Zubko E., Shkuratov Yu., Mishchenko M., Videen G.. “Light scattering in a finite multi-particle system,” J. Quant. Spectr. Rad. Trans., **109**, 2195–2206 (2008).

(4) Zubko E., Kimura H., Shkuratov Yu., Muinonen K., Yamamoto T., Okamoto H., Videen G.. “Effect of absorption on light scattering by agglomerated debris particles,” J. Quant. Spectr. Rad. Trans., **110**, 1741–1749 (2009).