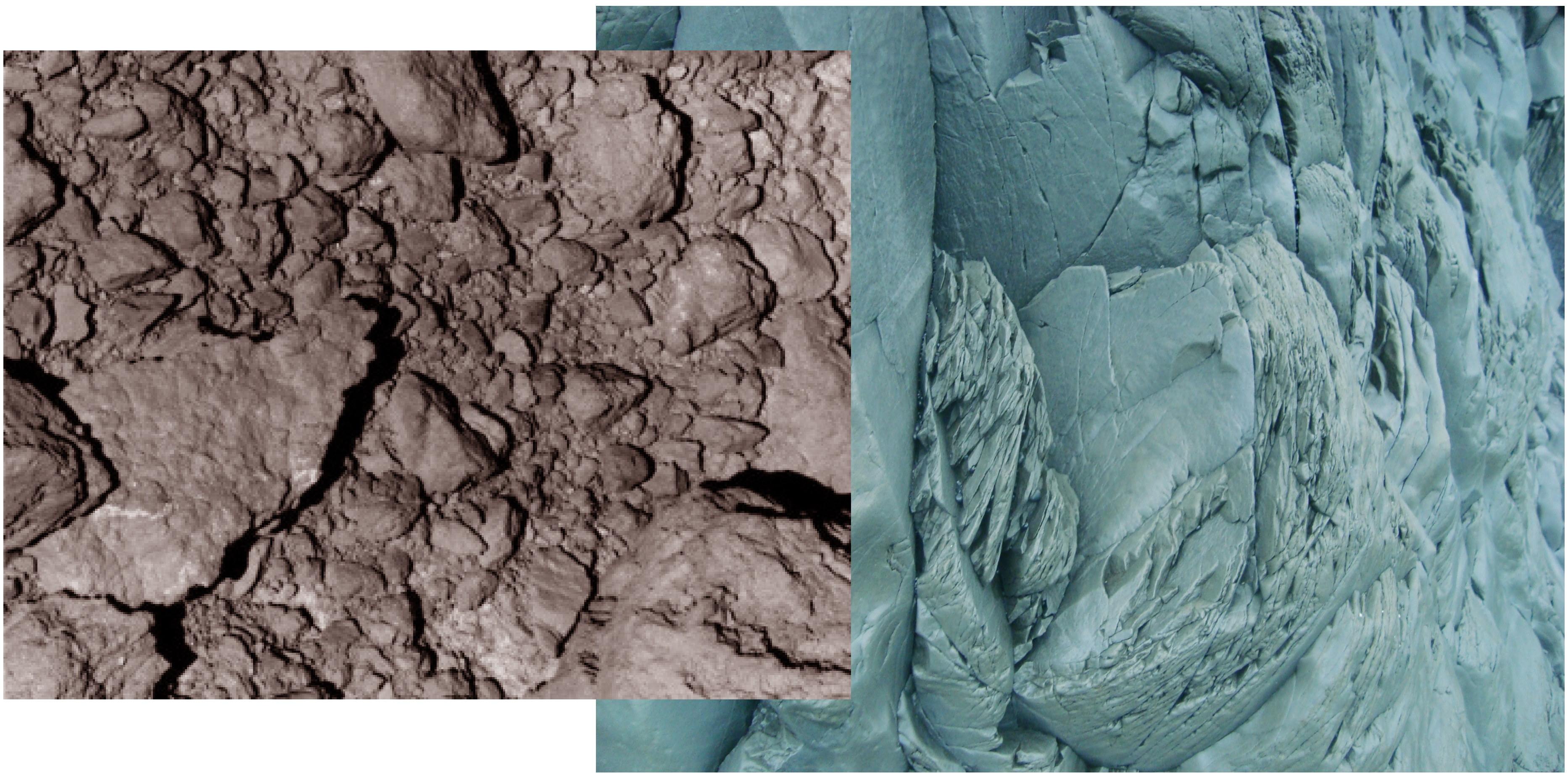
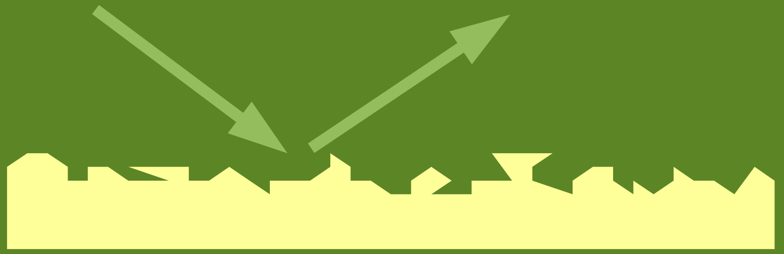
A Monte Carlo model for the reflection of polarized light on surfaces



D. Guirado, D. Stam & M. Smit

1st WG meeting, Warsaw, 7-10 May 2012

Why to model  ?

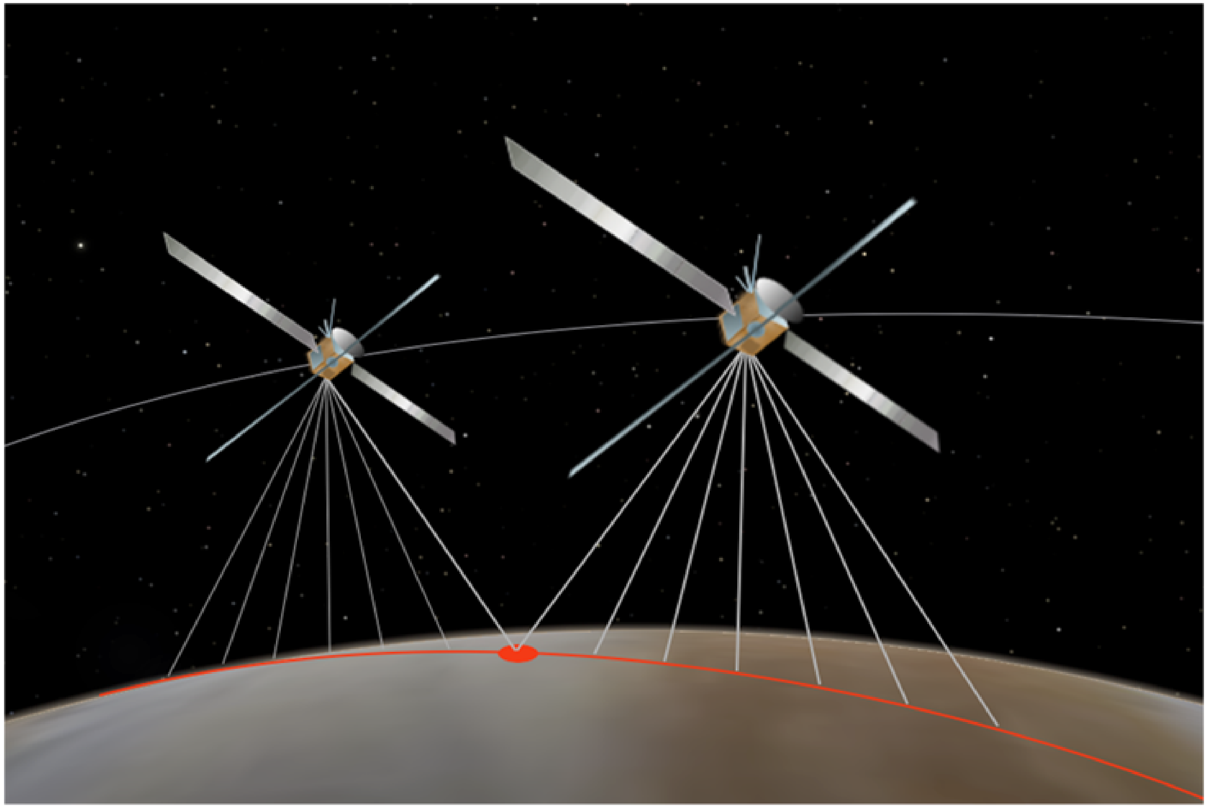
- To retrieve the properties of the surface (composition, fluffiness, stress, ...).
- To combine with atmospheric models.

roughness + inhomogeneous material + polarized incident light

Statement of the problem

To develop an exact model that accounts for the flux and the degree of linear polarization (DLP) observed in light scattered by rocky/icy planets and moons.

SPEX



- Spectropolarimeter.

•400Nm – 800nm, 20nm.

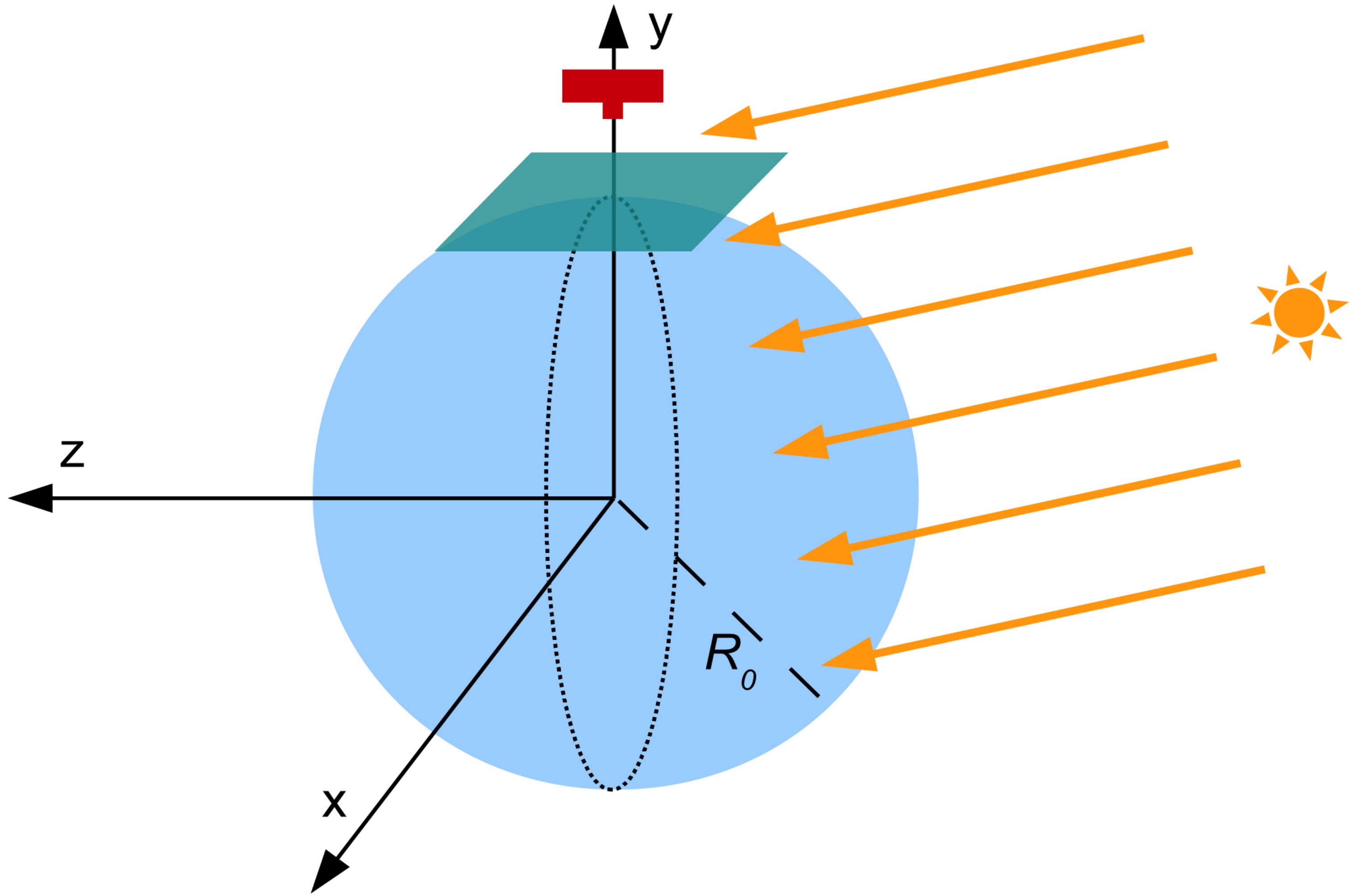
- Simultaneous measurement of flux and linear polarization.

•Orbital plane ⊥ sunlight.

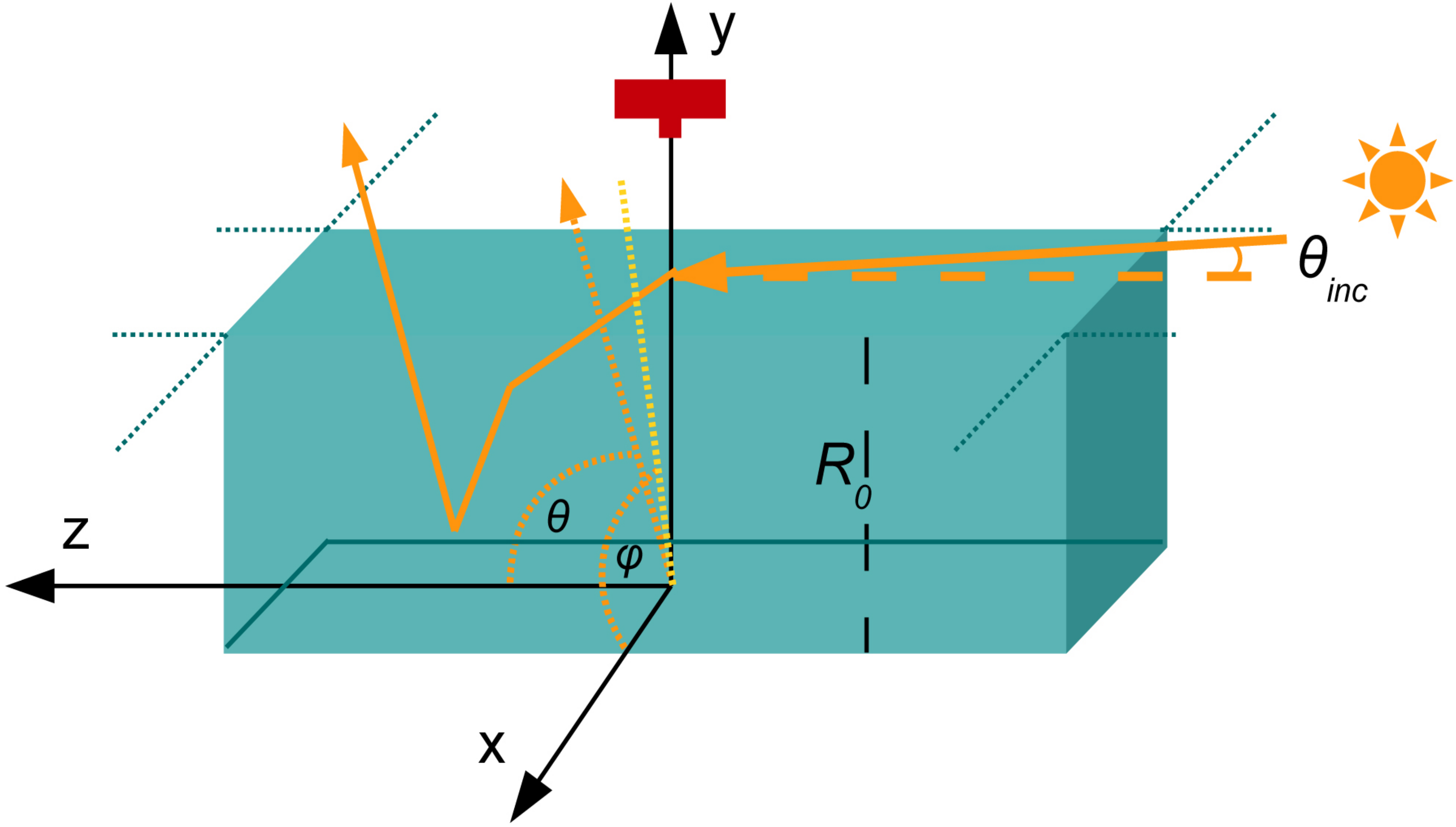
Approaches

Tecniques	**Advantages**	**Drawbacks**
Fresnel reflection	Quick and exact	For perfectly flat surfaces
Lambertian reflection	Quick and fast	Light systematically depolarized
Kirchoff approximation	Includes polarization	Smooth slopes
Adding-doubling	Includes polarization	Same scattering matrix for the whole medium, packing limit
Monte Carlo	Includes polarization and several kinds of scattering matrices	Packing limit, slow
T-matrix	Includes polarization, valid for densely packed media	Slow, just for aggregates of spheres
Discrete dipole approximation (DDA)	Any composition and packing in the medium	Very slow
Finite difference time domain (FDTD)	Exact solution	Very slow

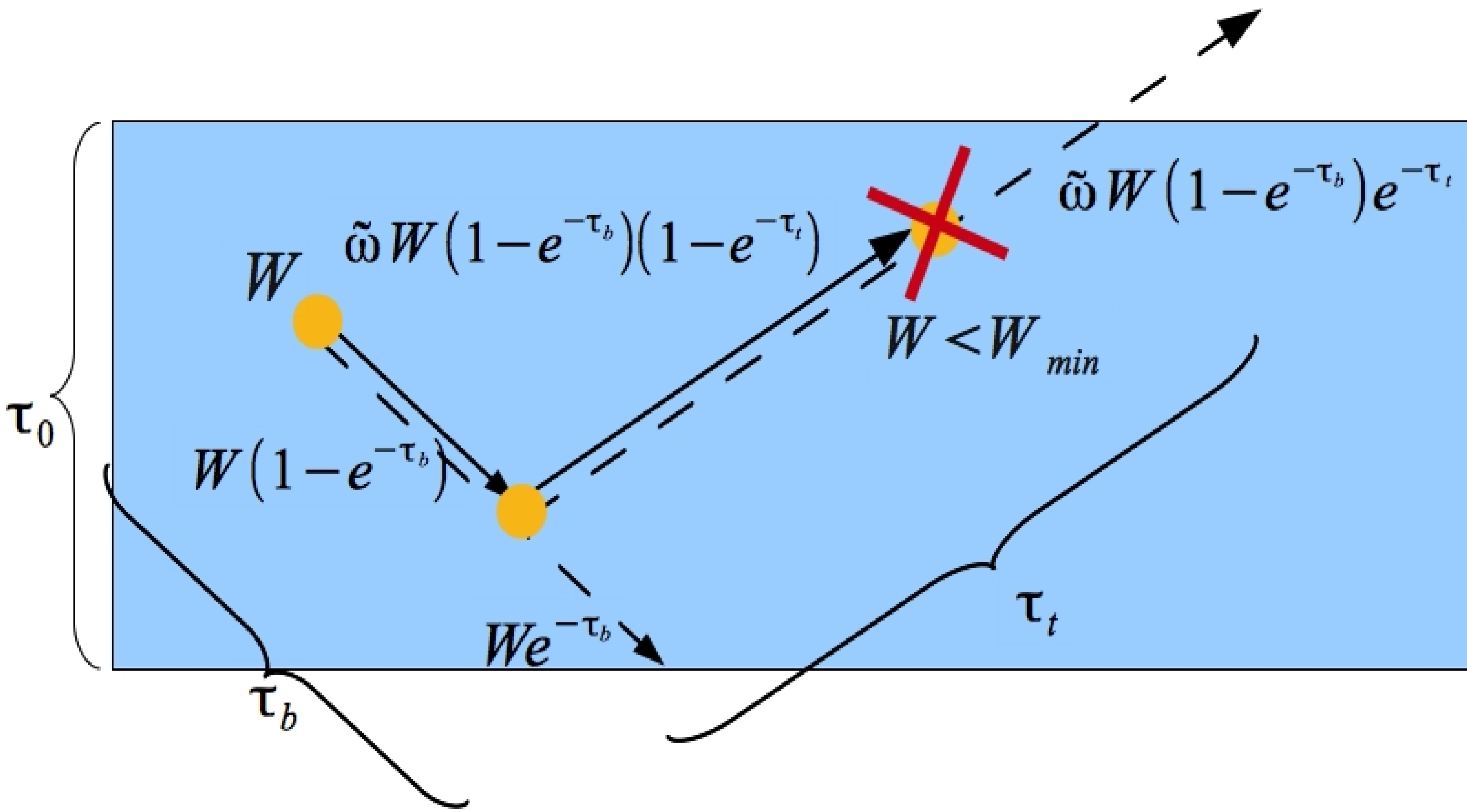
Description of the model I: global coordinate system



Description of the model II: local coordinate system



Description of the model III: path of a photon



Description of the model IV: interaction of a packet of photons with the grains

φ uniformly randomly obtained.

Choosing the scattering direction:
$p(\theta) \propto [F_{11}I_0 + F_{12}Q_0 + F_{13}U_0 + F_{14}V_0] \sin\theta.$

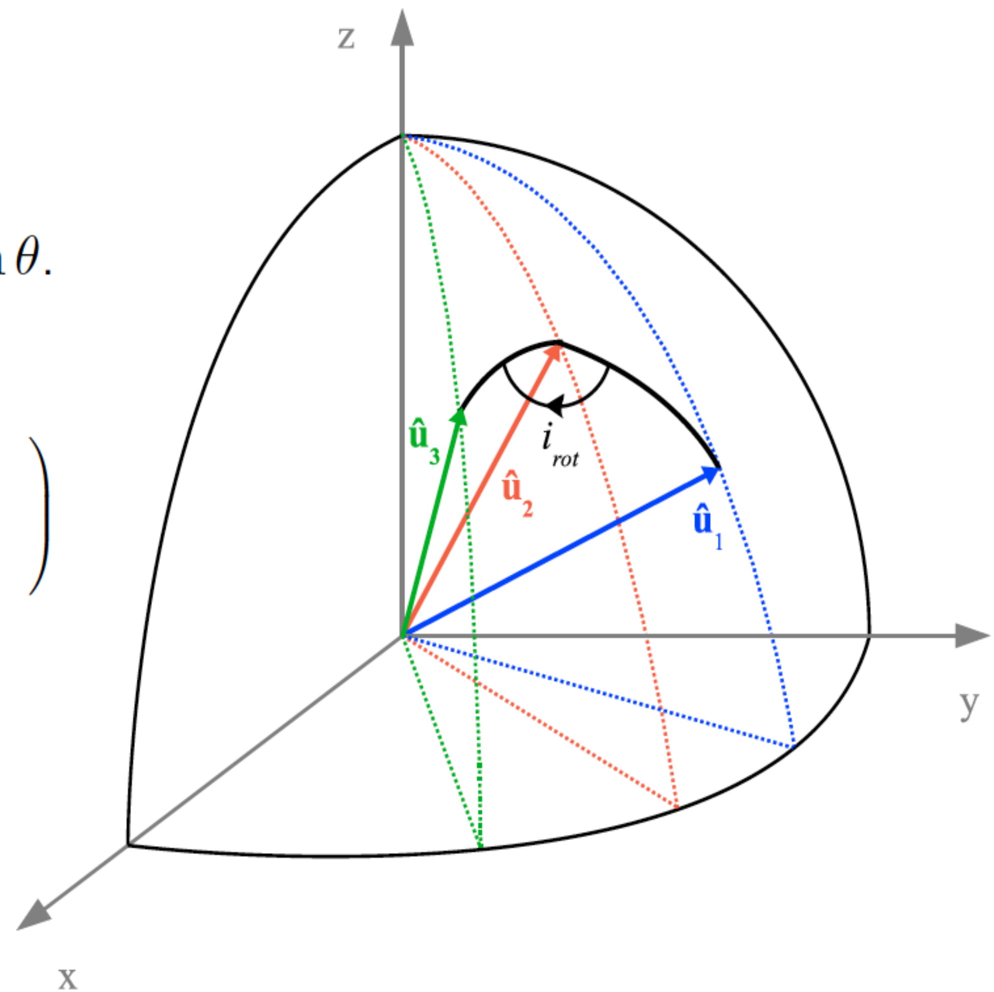
Change of the scattering plane.

$$\begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2i_{rot} & \sin 2i_{rot} & 0 \\ 0 & -\sin 2i_{rot} & \cos 2i_{rot} & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} I_0 \\ Q_0 \\ U_0 \\ V_0 \end{pmatrix}$$

.

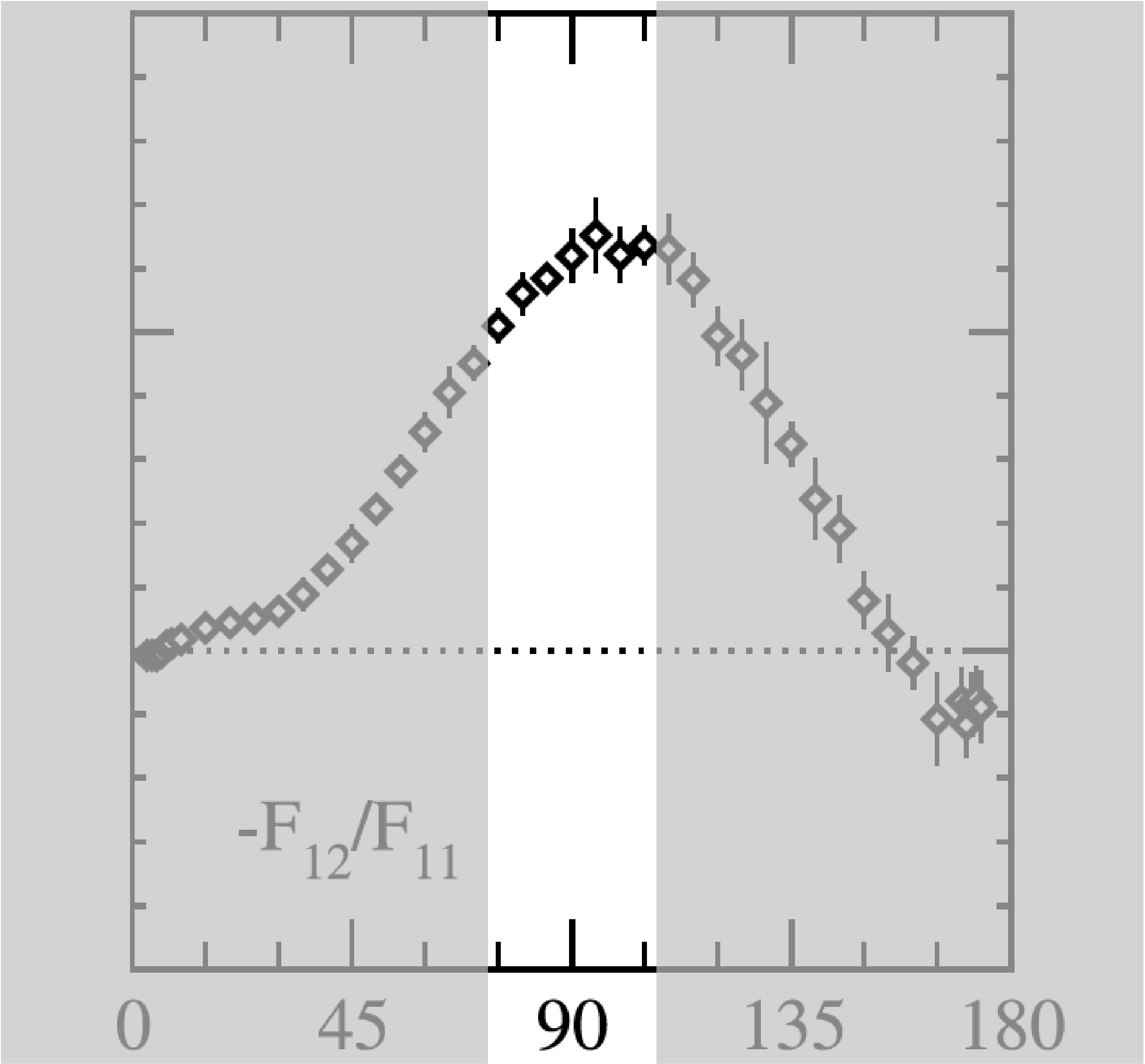
Multiplying by the scattering matrix.

$$\begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} \propto \begin{pmatrix} F_{11} & F_{12} & F_{13} & F_{14} \\ F_{21} & F_{22} & F_{23} & F_{24} \\ F_{31} & F_{32} & F_{33} & F_{34} \\ F_{41} & F_{42} & F_{43} & F_{44} \end{pmatrix} \begin{pmatrix} I_0 \\ Q_0 \\ U_0 \\ V_0 \end{pmatrix}$$



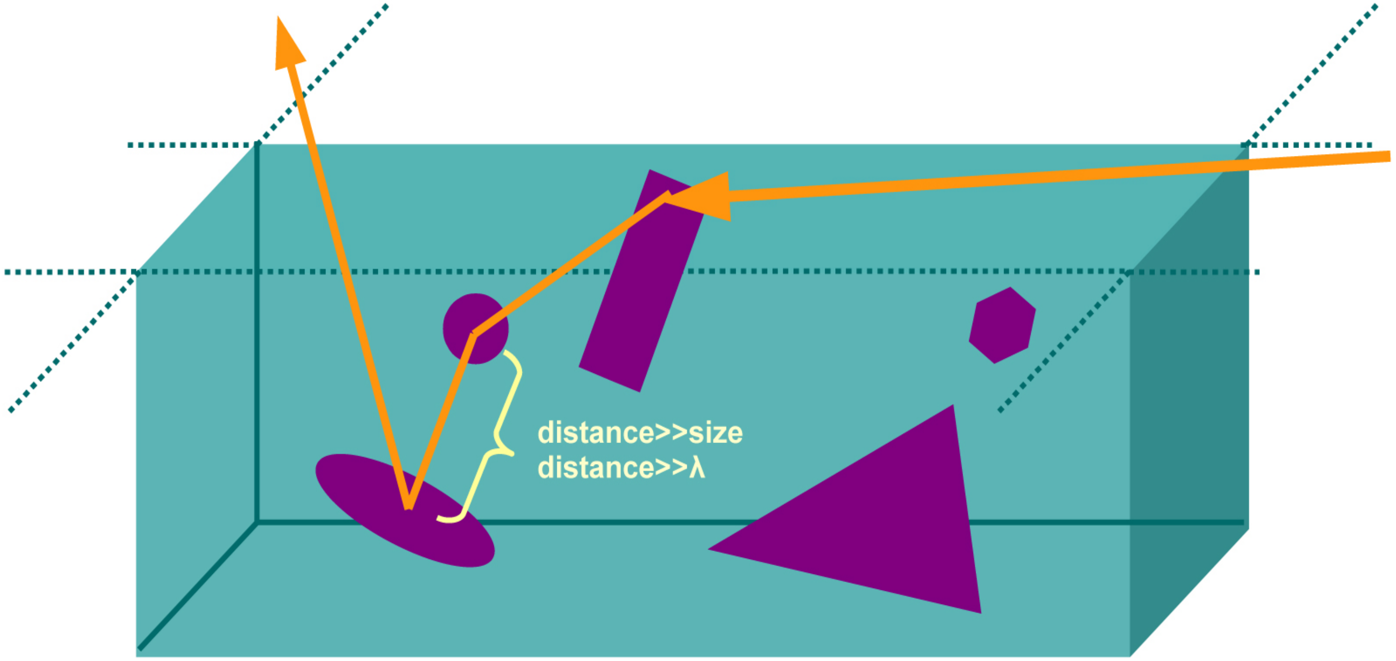
A different scattering matrix for each interaction!

Not interested in phase effects



Scattering angles (deg.)

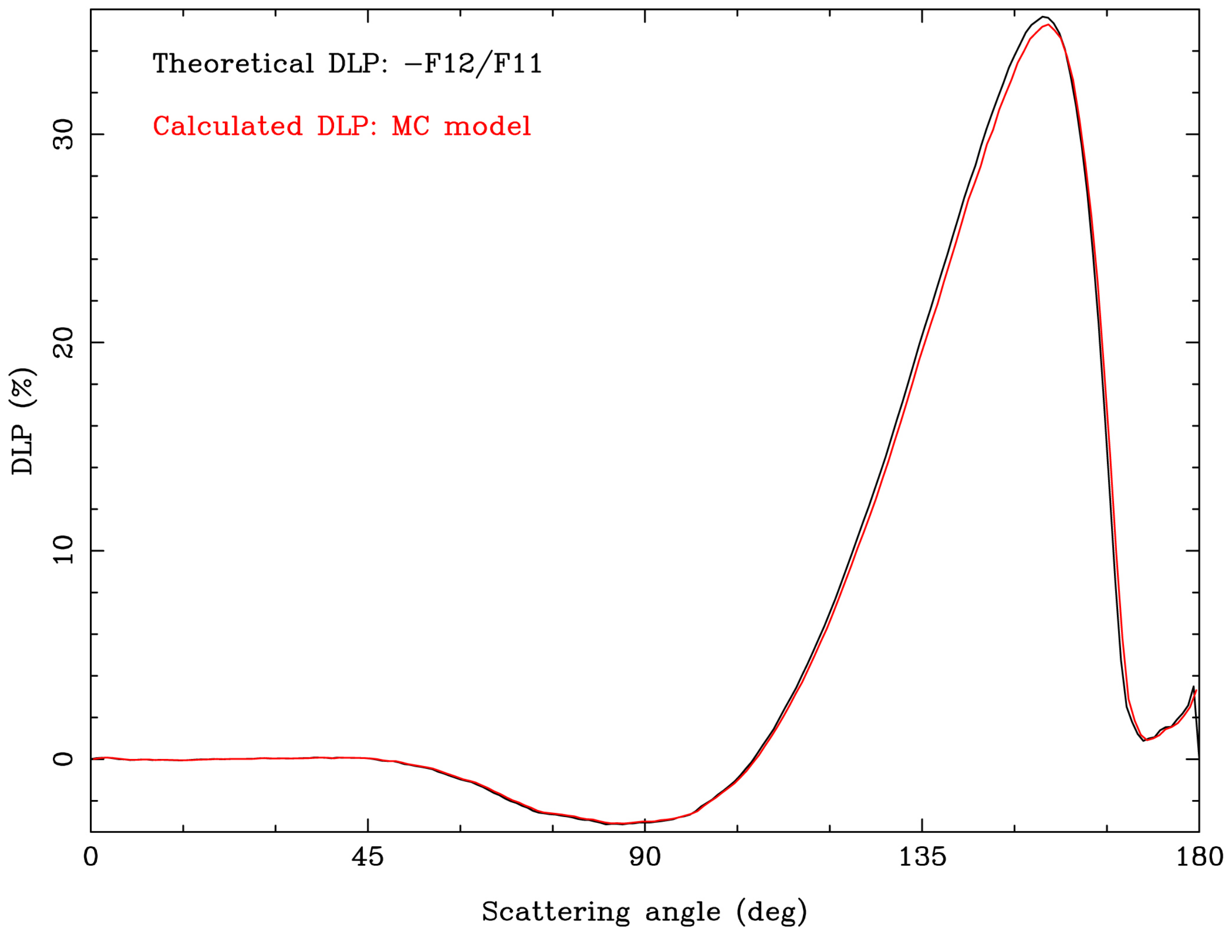
Pros and cons



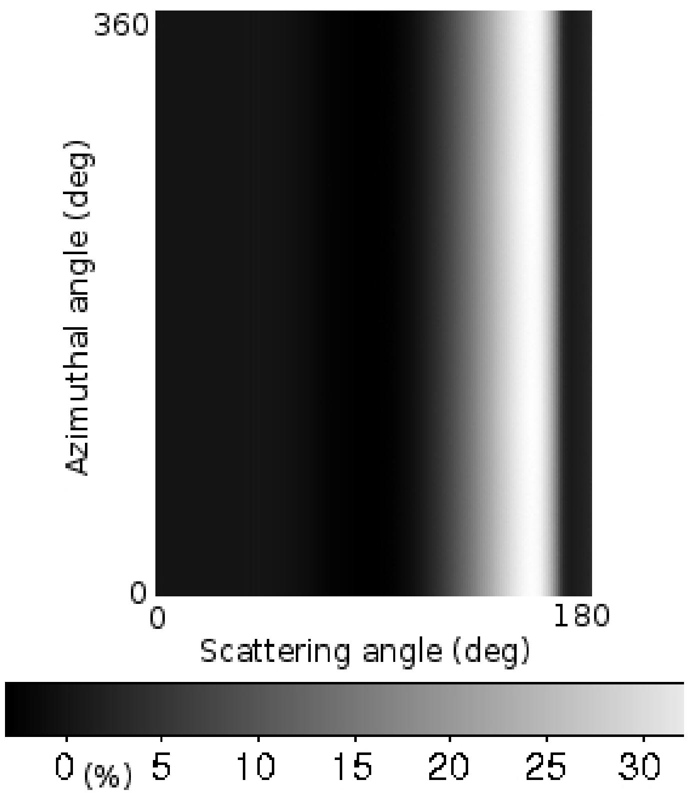
Pros
▪ Any size distribution of grains.
• Any refractive index of grains.
• Inhomogeneous material.

Cons
• Far field condition.
• Calculations are slow (t≈0.007NPHOTs with an Intel Core i7 at 2.7 GHz).

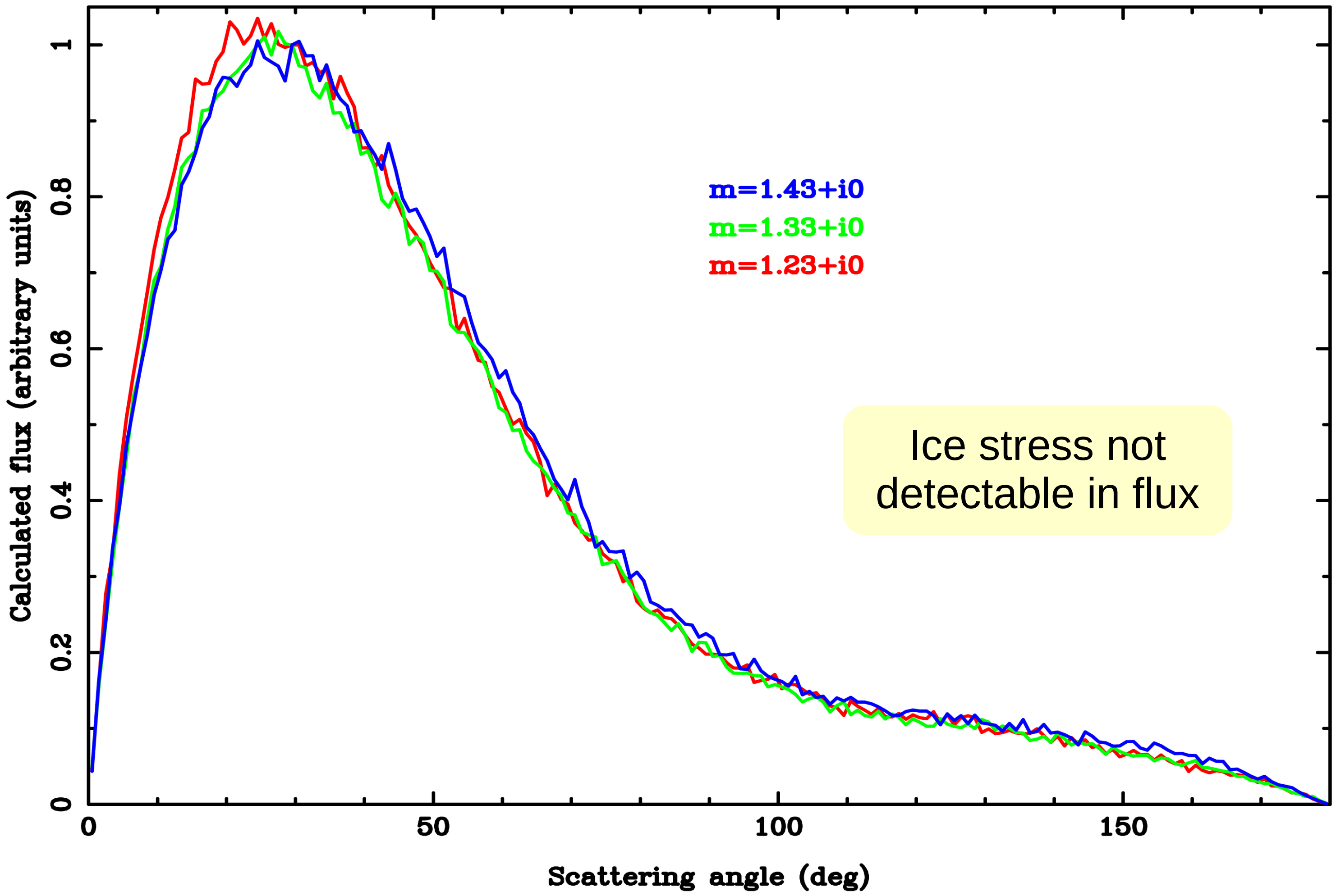
Checking the MC model



spheres
Power-law $\delta = 3.5$
$r \in [0.05, 20]\mu m$
10^8 packets of photons
$m = 1.6 + i0.001$
$\tau_N = 0.1$



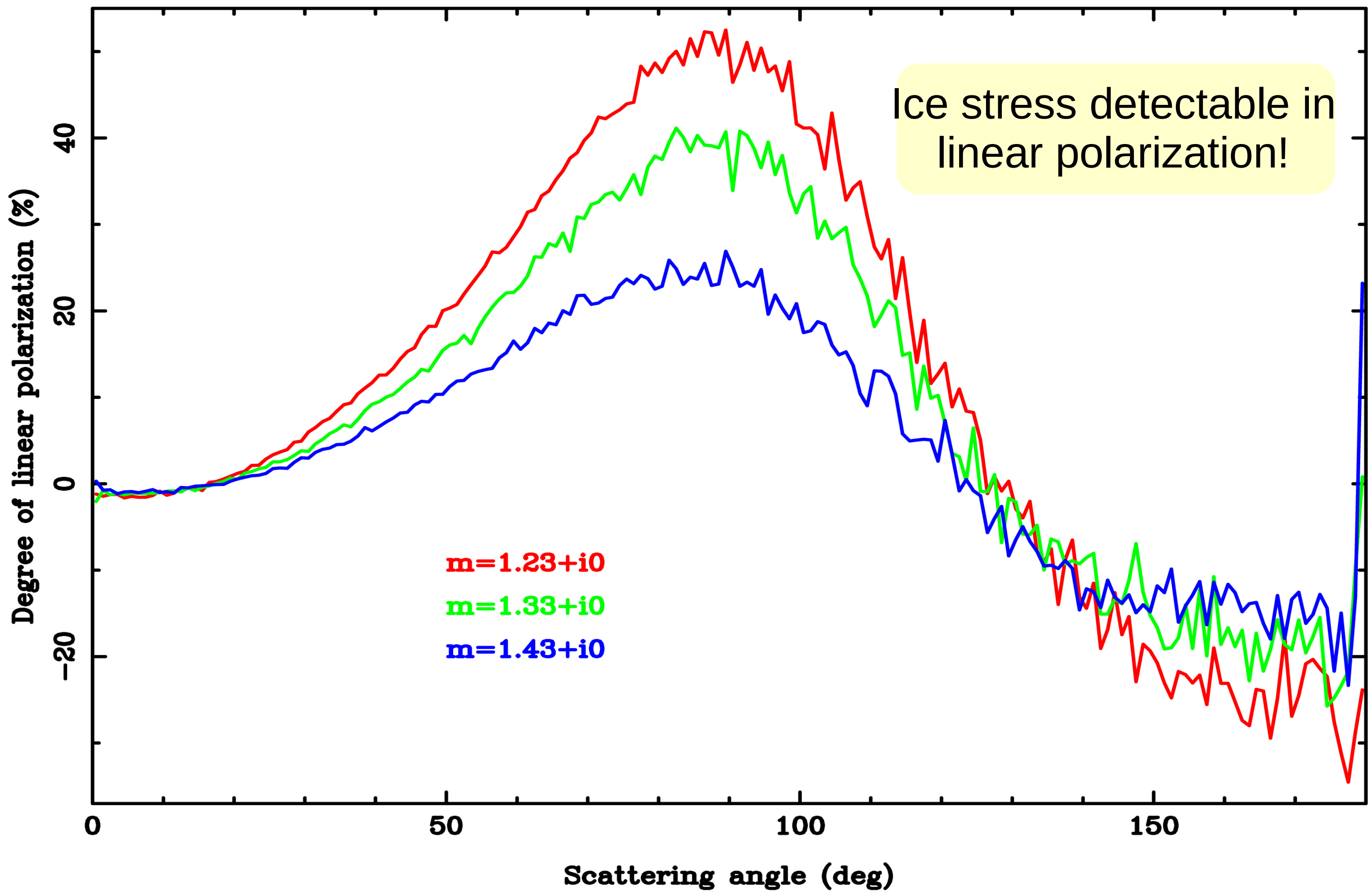
Ice stress in flux



Ice stress not detectable in flux

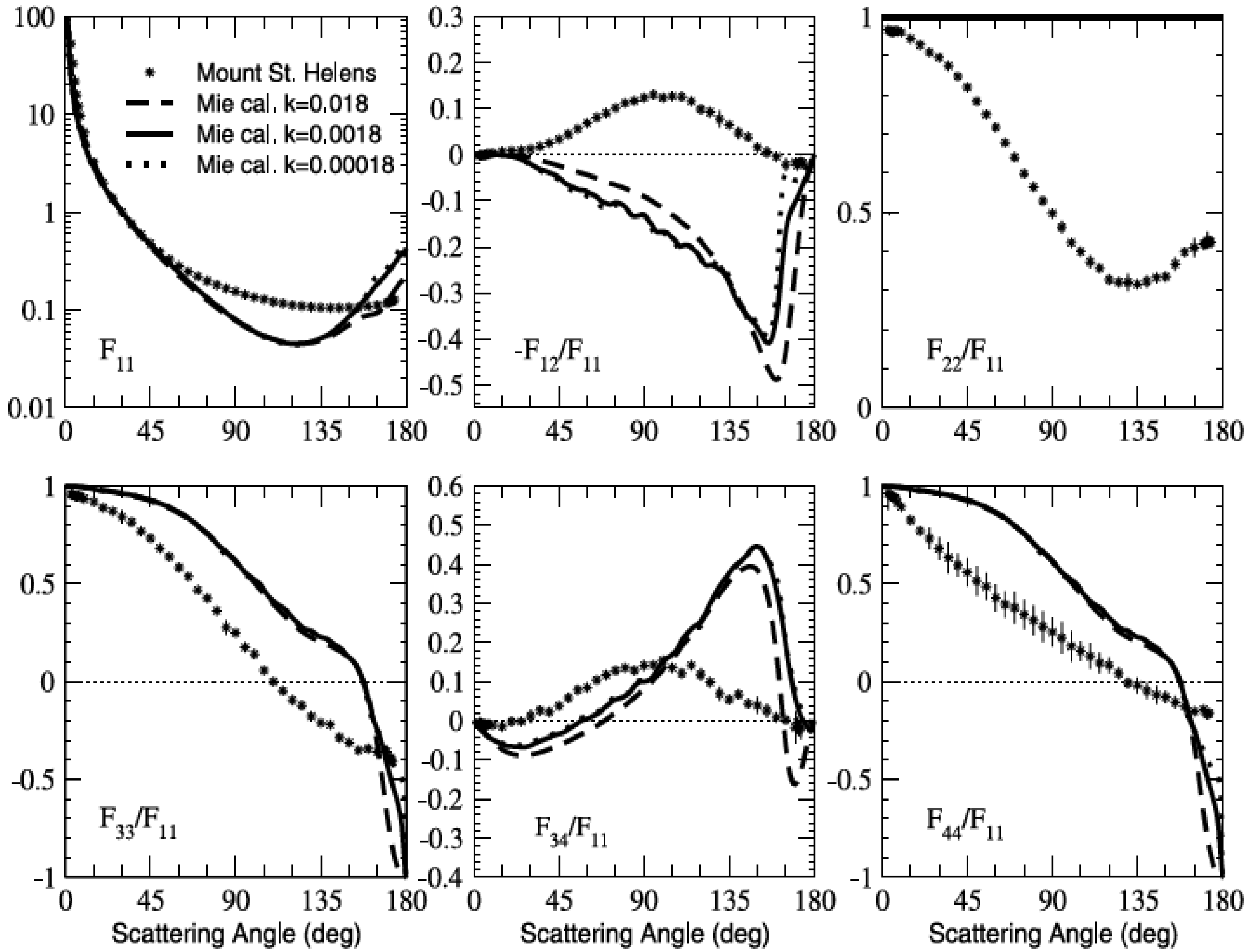
Spheres, power-law with an index of 3 in the range [0.1, 10000] microns, η=0.1%, λ= 400 nm, 10^8 photons, almost horizontal incidence.

Ice stress in linear polarization



Spheres, power-law with an index of 3 in the range [0.1, 10000] microns, η=0.1%, λ= 400 nm, 10^8 photons, almost horizontal incidence.

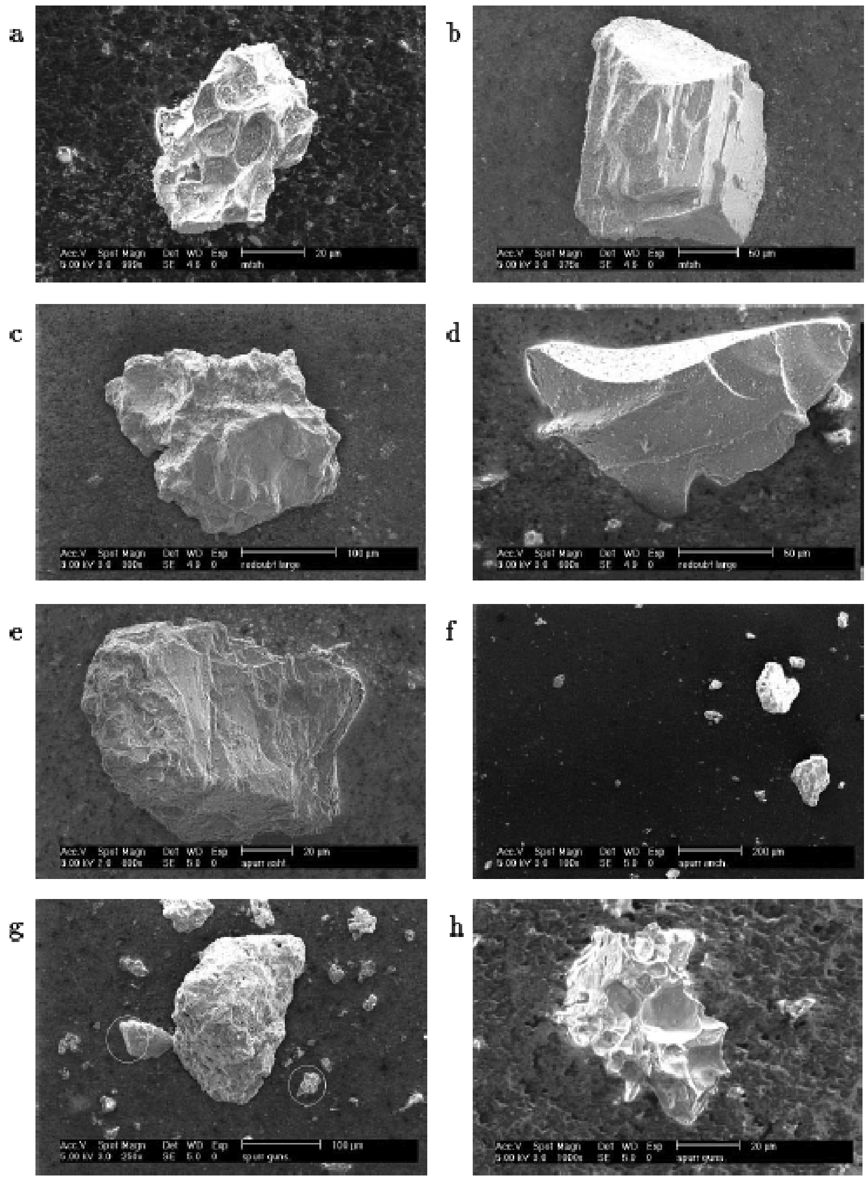
Using non-spherical grains



Muñoz et al., JGR, 2004.

Spheres with the same size distribution as the sample, λ= 632. nm, Re(m)=1.5, Im(m)=k.

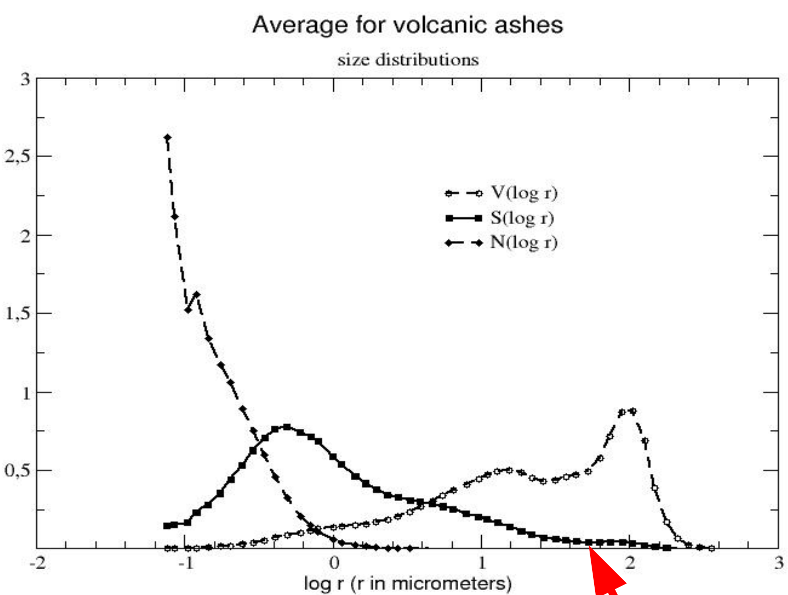
Average of ashes of 7 volcanoes



Muñoz et al.,
JGR, 2004.

(a and b) Mount St. Helens, (c and d) Redoubt A, (e) Spurr Ashton, (f) Spurr Anchorage, and (g and h) Spurr Gunsight. Also Redoubt B and Stop.

www.iaa.es/scattering



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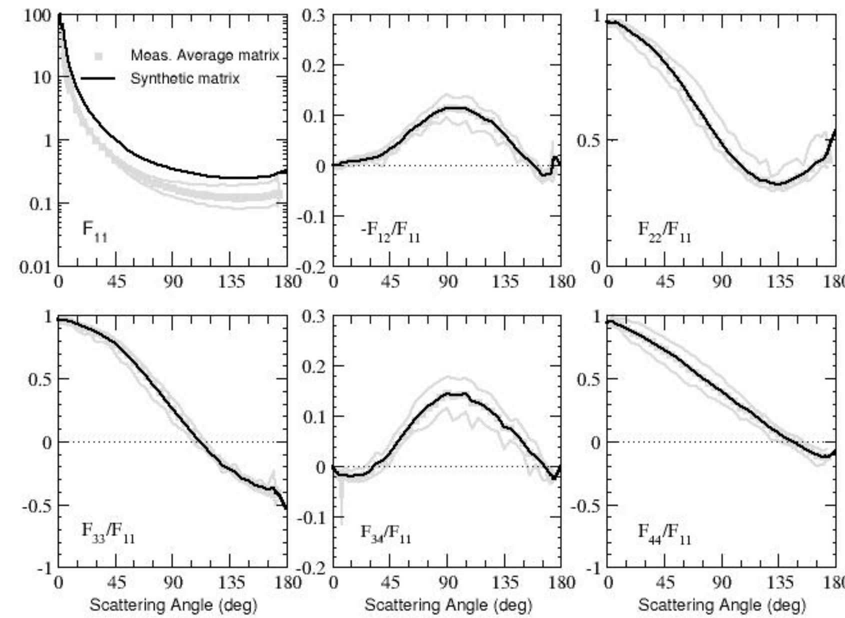
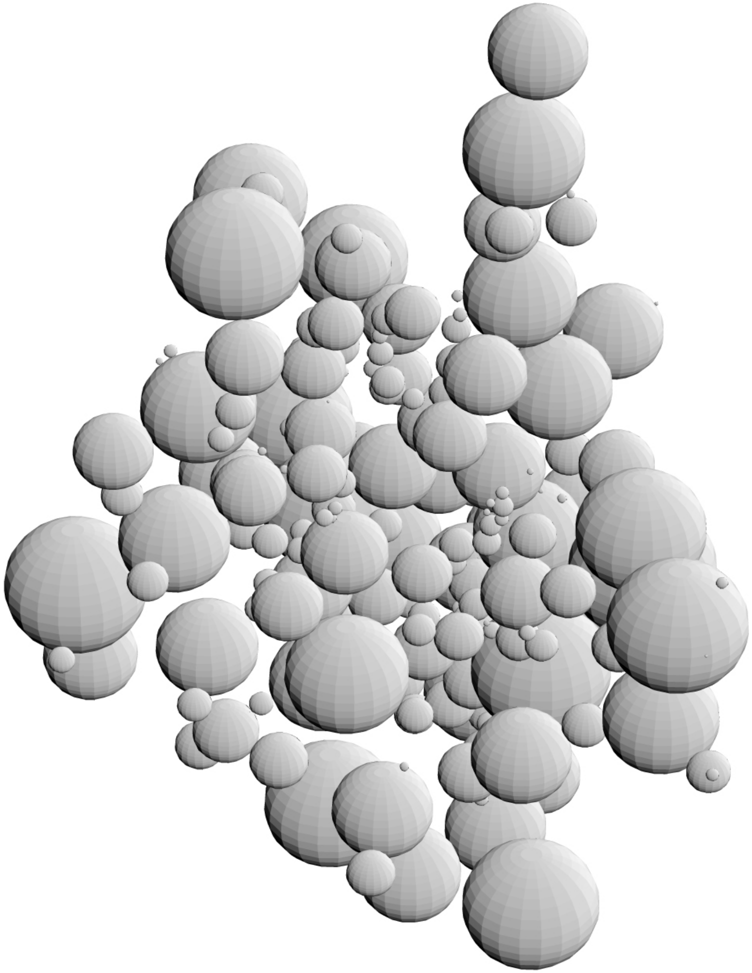


particle size	average of laser diffraction measurements r_{eff} between 3 and 14 micrometer
particle shape	irregular
refractive index	estimated to be in the range: 1.48-1.7 - i0.02-0.00001
color	various
scattering matrix	Synthetic Average Volcanic Scattering Matrix from 0-180 degrees scattering angle

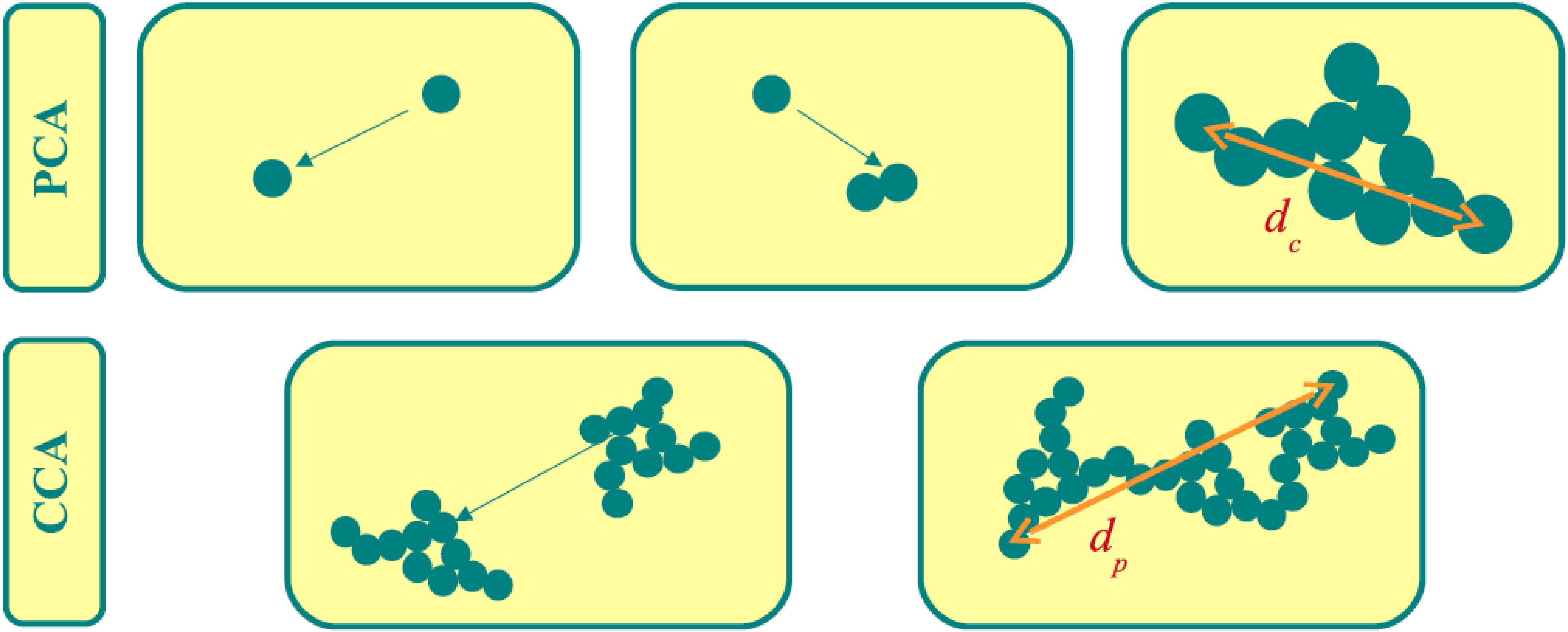
Other method: T-matrix

T – matrix method + superposition method + parallelization (Mackowski 2011)

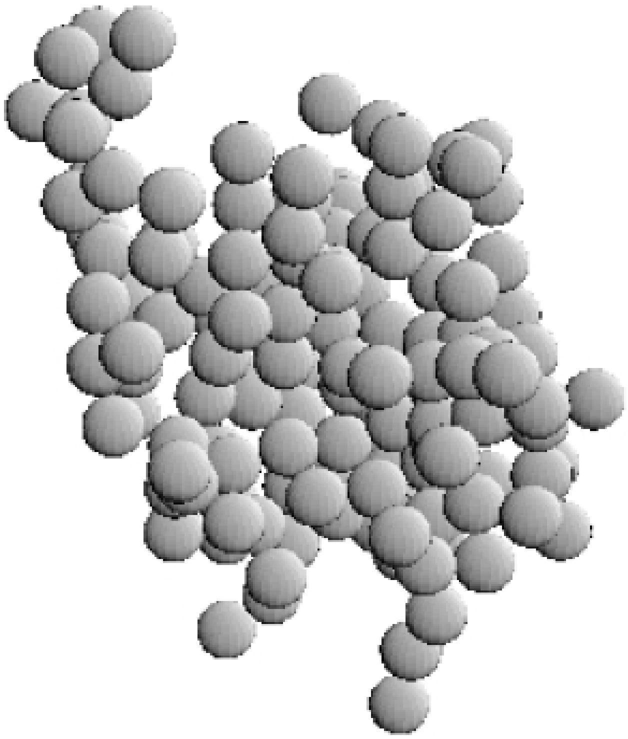


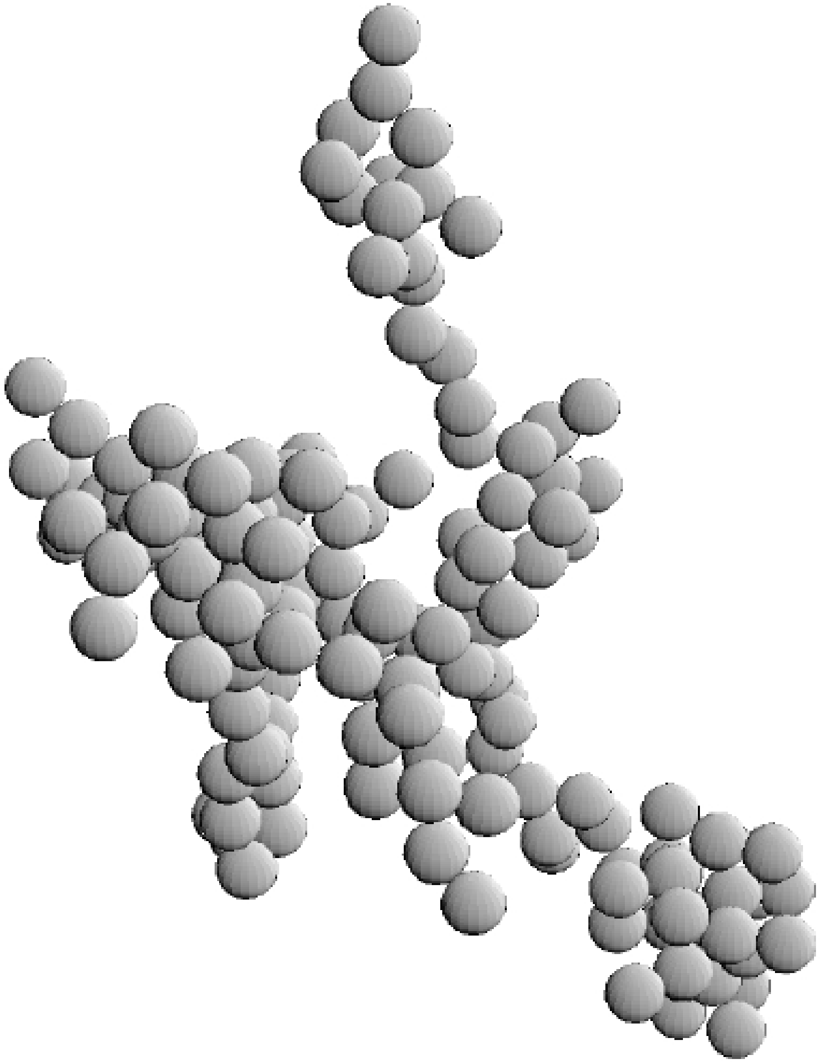
No packing limit!

Building the aggregates



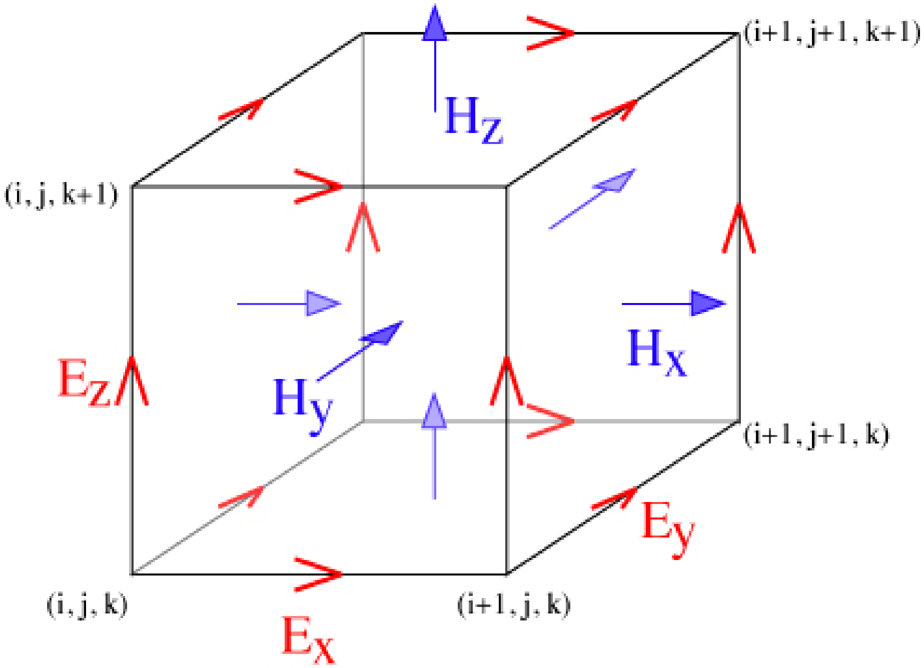
Aggregates

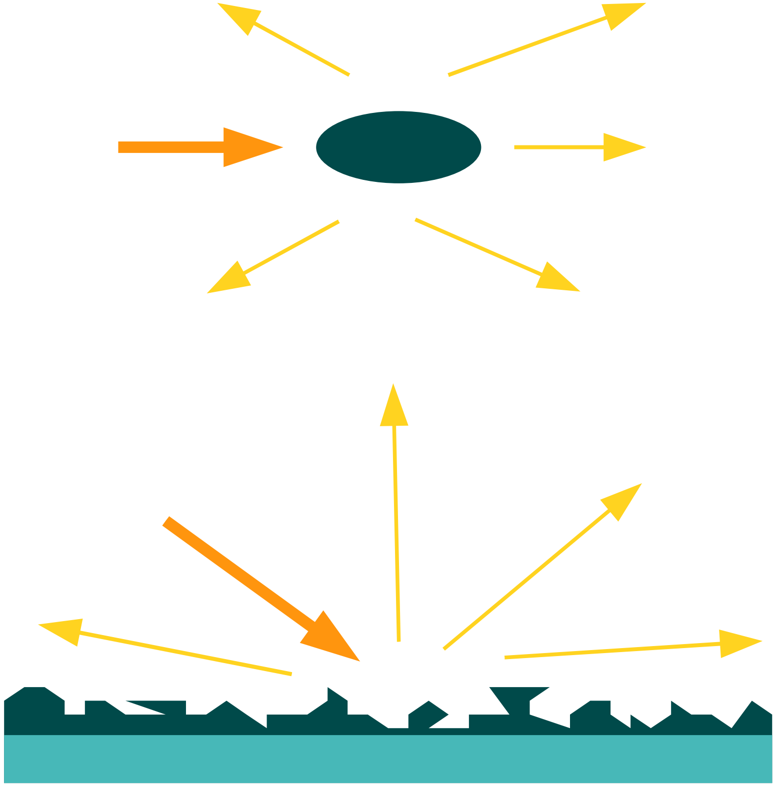




Other method: Finite difference time domain (FDTD)

Numerical solution of the Maxwell equations.





Promising!

Conclusions

1. A MC model for the reflection of light in any state of polarization on a surface has been developed. A constrain exists on the packing density.

2. Slight changes of the refractive index of the surface material can be detected by this model in the maximum of the DLP, at 90 deg. scattering angle.

3. T-matrix can be used to model compact surfaces, though it's quite slow.

4. FDTD is very promising as an accurate and fast method.