essentially differ. Let's mark, that the intensity of a scattered radiation decreases up to zero if $\mu \to 0$. It is a consequence of a selected model of scattering particles as thin sheets. In such model radiation scattered in a plane of a layer is absent.

### 3. Conclusion

This work regards the transfer of a radiation in a layer containing thin particles having an internal multilayer structure and oriented in a plane of a layer. For the description of a radiation propagation in such medium the equation of a radiative transfer with characteristics dependent on a direction of a radiation propagation and a taking into account mirror reflection on a surface of particles is used. The algorithm of a numerical solution of such equation based on a doubling method is developed. The numerical calculations of brightness factors of a scattered radiation are made.

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# Two New Applications of Large Scale DDA Simulations

Alfons Hoekstra, Martijn Frijlink, David de Kanter, and Peter Sloot

Section Computational Science, Faculty of Sciences, University of Amsterdam
Kruislaan 403, 1098 SJ Amsterdam, The Netherlands, 3120-5257543
alfons@wins.uva.nl, http://www.wins.uva.nl/research/pscs

## ABSTRACT

We present two applications of the DDA method. First, we calculate elastic light scattering from a sphere with a non-concentric spherical inclusion and compare DDA simulation with exact theory. In the second case we consider radiation pressure on a sphere and again compare DDA simulation with exact theory. In both cases the DDA simulations agree very well with theory.

## INTRODUCTION

The Discrete Dipole Approximation (DDA) is a well-known and much used method to simulate elastic light scattering from arbitrary shaped particles [1,2]. We have developed a highly efficient parallel fast DDA [3] capable of handling models containing as much as 10 million dipoles. This allows us to simulate scattering from particles with sizes far in the resonance regime (i.e. with dimensions a few times the wavelength of the incident light). Using DDA for such large particles still is a relatively unexplored field, and we feel that it is therefore necessary to keep testing the accuracy of DDA in new application regimes. We have for instance studied in detail the internal fields in VIEF models [4], which are closely related to DDA.

Our current interest in on scattering from biological cells, specifically Human White Blood Cells, and on radiation pressure on clusters of small spheres, as a model for dust. In this contribution we present two results of testing DDA for such applications. First, as a simplified model of a biological cell, we consider the case of scattering from a sphere with a non-concentric spherical inclusion, and compare DDA simulations with exact theory. In the second case we consider radiation pressure on a sphere, and again compare DDA simulation with exact theory.

## CASE I: A SPHERE WITH A NON-CONCENTRIC SPHERICAL INCLUSION

We consider the case of a sphere with a size parameter $x = 20.4$, i.e. with a diameter of 4.08 μm for the wavelength of incident light of 0.6283 μm. The sphere contains a second, non-concentric sphere with a size parameter of 0.7 times that of the outer sphere, i.e. $x_{inner} = 14.28$. The refractive index of the inner sphere is 1.05 and of the outer sphere is 1.02. The center of the outer sphere is on the origin of a co-ordinate system and we assume that the incoming plane is travelling in the positive $z$-direction. Furthermore, we assume that the center of the inner sphere is located on the $z$-axes, and $z_{inner}$ is the position of the center of the inner sphere. We have considered 9 different locations of the inner sphere. The DDA simulations were compared with exact theory [5]. We thank Gorden Videen for calculating the results for the exact theory. As a representative case we show the results for the scattering matrix for $z_{inner} = 0.62$ μm. The DDA simulations contained 884736 dipoles, and the diameter of the dipoles was $\lambda/14.7 = 0.043$ μm. Figure 1 shows the results for the matrix elements $S_{11}$, $S_{12}$, $S_{33}$, and $S_{34}$. These results are representative for the full range of cases that we tested. Usually, up to a scattering angle of 120° the agreement is very good, whereas in the back scattering directions the DDA results may have larger errors.

## CASE II: RADIATION PRESSURE ON A SPHERE

We are interested in calculating radiation pressure on clusters of small spheres. We are not just interested in the overall radiation pressure on the entire cluster, but also in the radiation forces on each small sphere in the cluster. Draine showed how to include radiation pressure calculation into DDA [6]. Here we follow Draine's method to calculate the asymmetry parameter $g$ by integrating over the full solid angle, using a Romberg integration routine. The same approach was also taken by Kimura and Mann [7]. We have calculated radiation pressure using DDA for spheres up to size parameters of 20, and in a range of refractive indices. In all cases the accuracy of the radiation pressure is in the same order of magnitude as in the extinction coefficient, i.e. a few percents. Detailed results will be provided during the presentation.

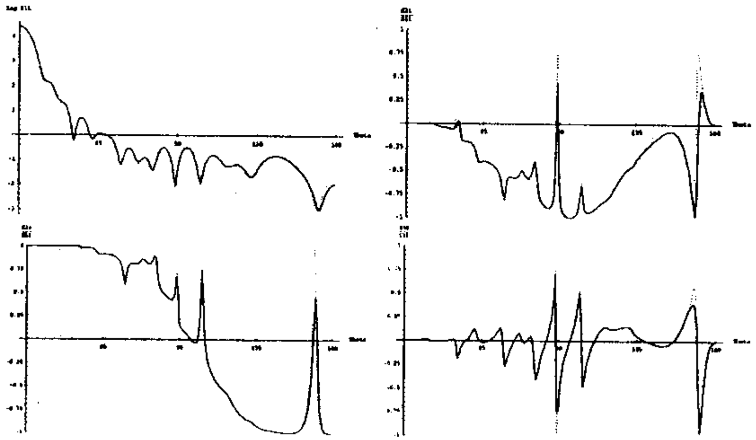

Figure 1 : DDA simulations (solid lines) and exact theory (dashed lines) for a sphere with a spherical inclusion; for details, see main text.

## CONCLUSIONS

We have presented two more tests of large scale DDA simulations. As in previous cases, the DDA seems to be able to simulate light scattering with accuracy of a few percent, even for models containing in the order of 1 million dipoles.

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# LIGHT SCATTERING BY RANDOMLY ORIENTED SPHEROIDS: THE EFFECT OF COATING

Arturo Quirantes Sierra, Ángel V. Delgado Mora
Department of Applied Physics, Faculty of Sciences
University of Granada (SPAIN)
aquiran@goliat.ugr.es

In order to calculate light scattering properties of nonspherical particles, several theoretical methods have been developed. One of the most efficient techniques is the Extended Boundary Condition Method (EBCM), devised by Waterman[1] and refined by other authors. It is especially suitable for axisymmetric particles. Analytical angle-averaging[2] allows for calculations of LS properties in an ensemble of randomly oriented particles, with practical applications for particle sizing in systems ranging from noctilucent clouds to colloidal particles.

However, few applications of the EBCM (or T-matrix) method have been carried out for heterogeneous particles. Although an EBCM formulation[3,4] exists since 1974 that allows for the study of nonspherical, multicoated particles, the number of practical uses on real particle systems has been small. Convergence problems of the T-matrix approach on highly nonspherical and/or absorbing particles, along with heavy CPU requirements, combine to make the EBCM method unsuitable for calculations in such cases.

As the T-matrix method has been successfully used in many different applications, it would be useful to implement and test its extension to coated, nonspherical particle systems. Light scattering calculations on coated spherical particles using the Aden-Kerker[5] theory show differences with respect to the homogeneous-sphere Mie[6] theory, in particular for large particles or thin coatings. It would thus not be surprising that a similar behavior be found on nonspherical scatterers.

In the present work, light scattering data are shown for ensembles of randomly oriented, coated spheroidal particles. The size and shape of the whole particle are here described by three parameters: the dimensionless size parameter $kr_{eq}$ ($r_{eq}$ being the radius of the equivolume sphere, and $k$ the wavenumber in the surrounding medium), the eccentricity or axial ratio $\gamma=a/b$ (where $b$ is the revolution axis; for prolate spheroids, $\gamma<1$) and the complex refractive index $m$. Core size is given by the dimensionless core/particle ratio $q$. It is assumed that both the core and the whole particle have the same axial ratio.