Vectorial Complex Ray Model
from Geometrical Optics to Ray Theory of Wave

Kuan Fang REN[a], Claude ROZÉ[a], Yijia YUAN[b]

a. UMR 6614/CORIA, CNRS - Université et INSA de Rouen, Saint-Etienne du Rouvray, 76801, France
b. Shanghai Jiao Tong University - Paris Tech Elite Institute of Technology, 800 Dongchuan Road, Shanghai, 200240, China

email: fang.ren@coria.fr
http://www.coria.fr
Tél: (33)2 32 95 37 43
Fax: (33)2 32 95 37 94

Introduction

Many theoretical models and numerical methods have been developed for the prediction of scattering properties of light by particles. However, they are either valid for objects of very simple form or seriously limited in the size of the objects. The geometric optics, or ray model, is the unique candidate which can, in principle, be applied to large particles of any shape but their precision is not sufficient. By introducing the wave front curvature as an intrinsic property of the rays, Vectorial Complex Ray Model (VCRM) improves considerably the accessibility of ray model to complex shape particle and its precision. We present here this model, the Monte-Carlo Ray Tracing of Wave (MCRTW) as its variety and Ray Theory of Wave (RTW) as their extension.

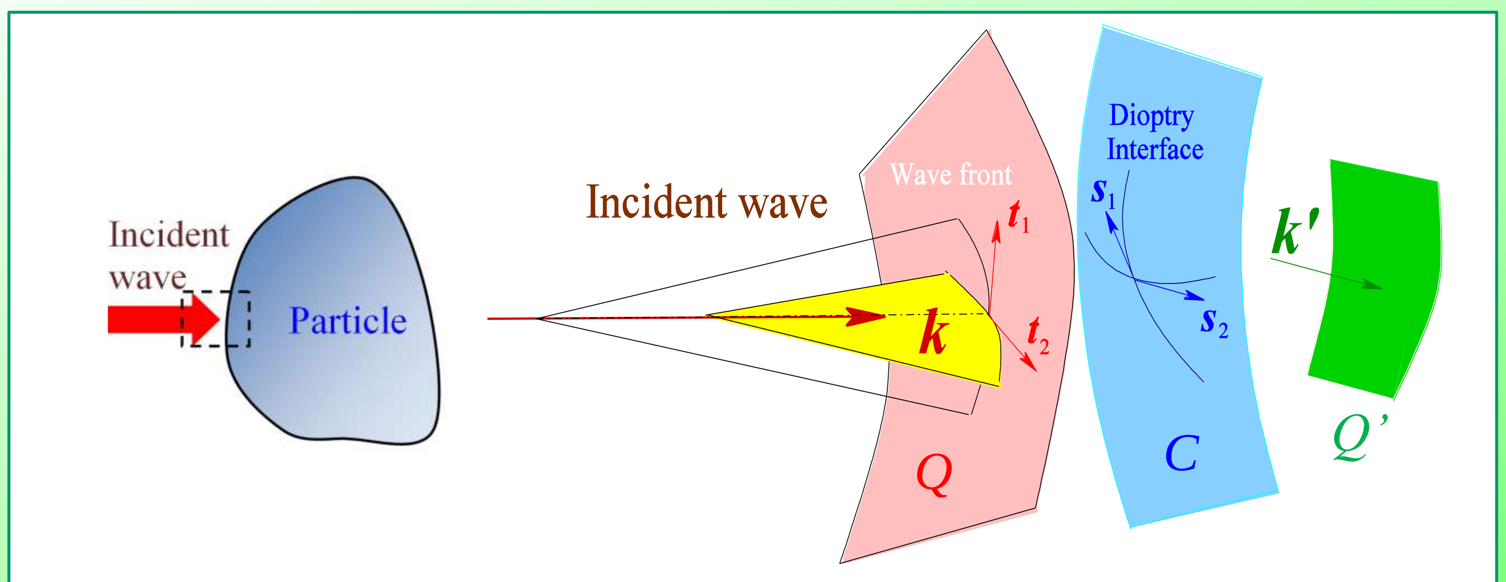
VCRM and wave front curvature equation

All waves are considered as bundles of rays which are characterized by the direction of propagation, the amplitude, the polarization, the phase and the ***curvature of the wave*** the rays present. The latter is a new property of the ray permitting to count easily the evolution of the amplitude when a wave is reflected or refracted by a curved diopter and the phase shift due to focal line. On the other hand, Snell law, Fresnel formulas and wave front equation are all expressed in wave vectors, so very suitable to deal with the scattering of arbitrarily shaped particles of smooth surface.

In the point view of the differential geometrics, the curvature of any smooth surface can be expressed with a 2×2 matrix. So the wave front curvatures of the incident wave, the refracted/reflected wave as well as the curvature of the dioptric surface at the vanity of the incident point can be described respectively with matrix Q, Q' and C. Their relation is given by the wave front equation [1,2]:

$$(\vec{k'}-\vec{k})\cdot\hat{n}C = k'\Theta'^T Q'\Theta' - k\Theta^T Q\Theta$$

where Θ and Θ' are the projection matrix between two surface basis. $\boldsymbol{k}$ and $\boldsymbol{k}'$ are the wave vectors of the incident and the refracted/reflected wave.



Curvatures of the wave fronts and the dioptric surface

Numerical results

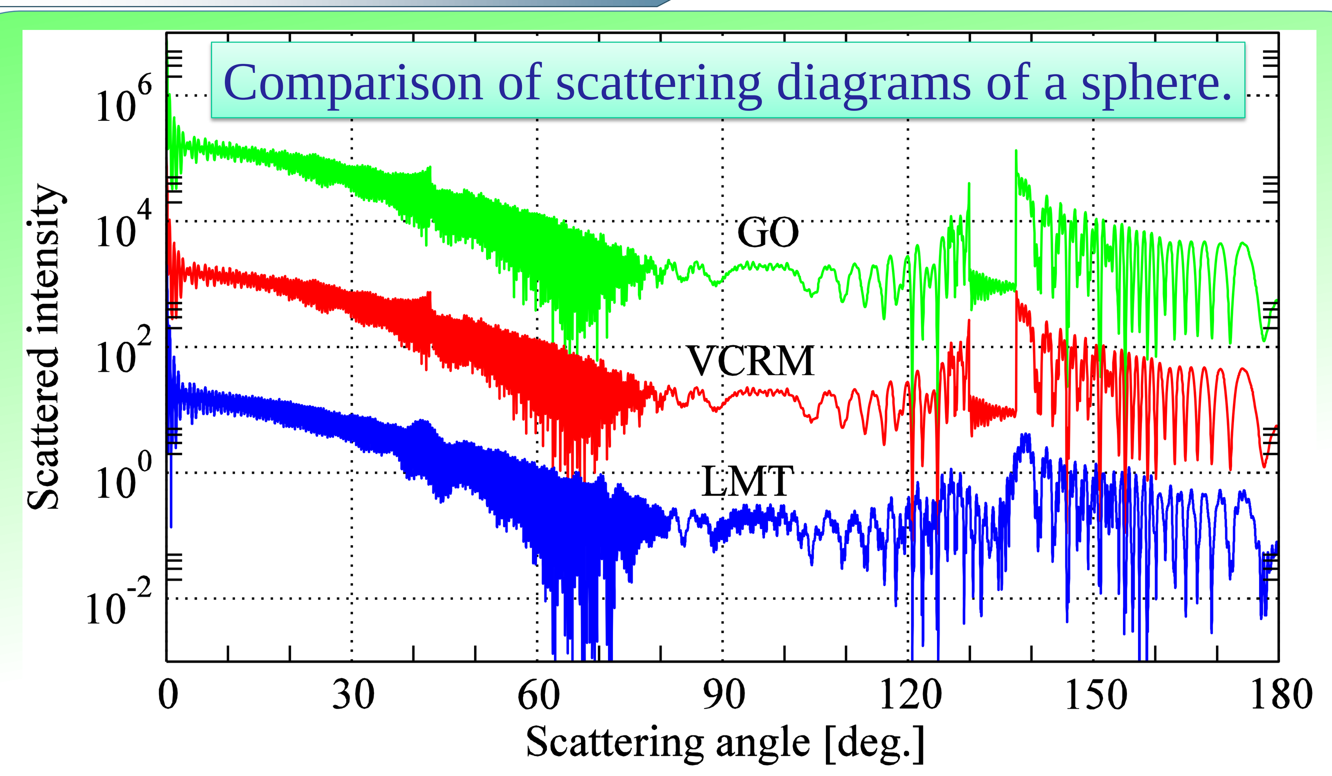


Fig. 1 Scattering diagrams calculated by LMT, GO and VCRM for a homogeneous sphere : refractive index m = 1.33, radius a = 50 µm, wavelength λ = 0.6328 µm.

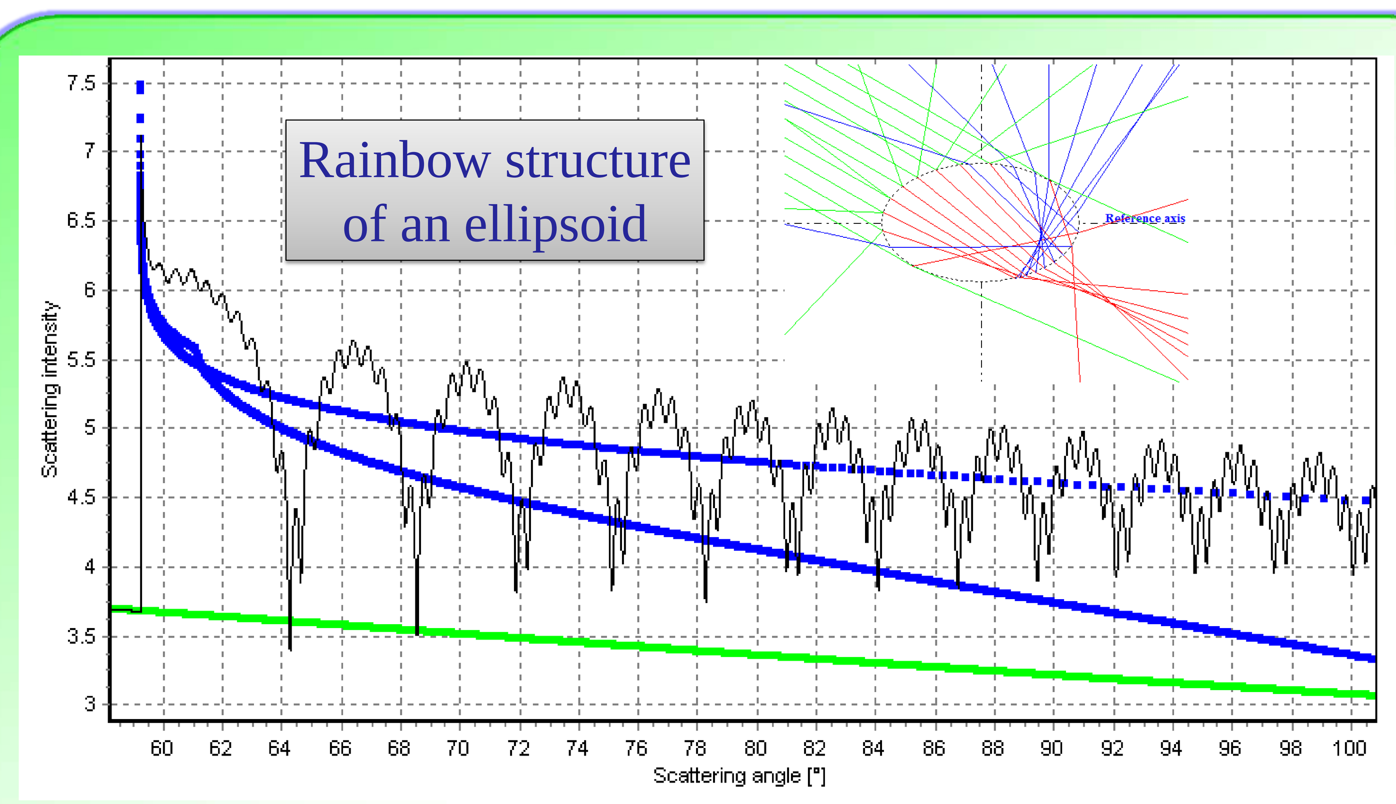


Fig. 2 Rainbow-like structure calculated with the software VCRMEll2D for an ellipsoid of water droplet: m=1.33, a=30 µm, b=40 µm, c=50 µm, incident angle 30° with long axis .

The rays/photons in MCRTW[3] possess also the 5 properties of the rays in VCRM.

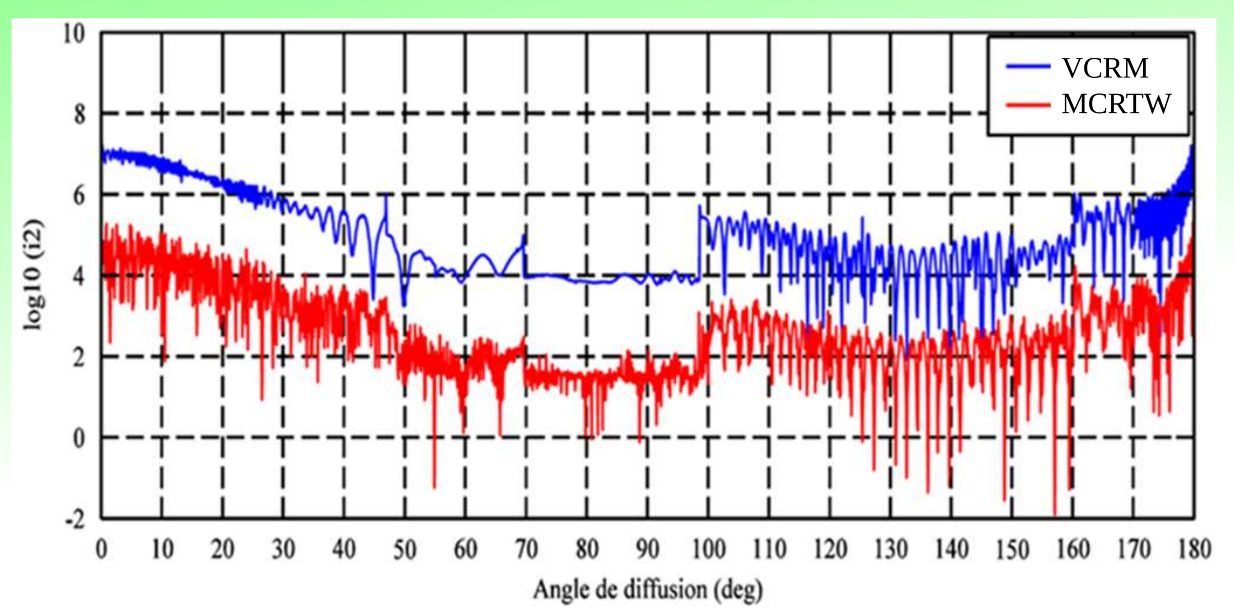
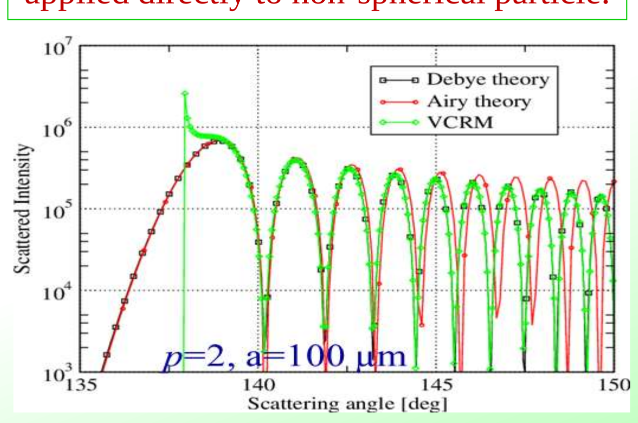
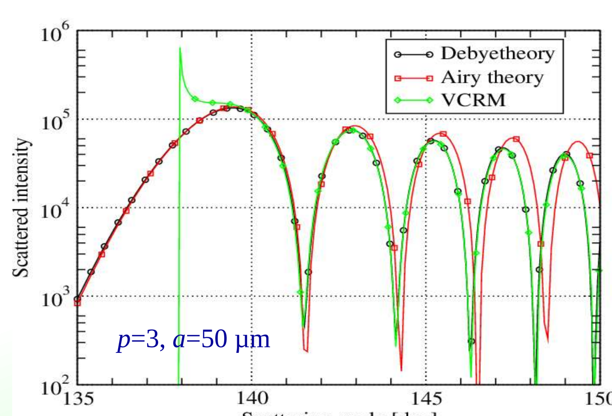


Fig. 4 Comparisons of the scattering patterns of a spheroidal droplet (m=1.33, a=b=25 µm, c=50 µm, λ = 0.6328 µm) calculated by VCRM and MCRTW.

Toward the Ray Theory of wave

VCRM can predict much better Airy structure than the Airy theory and can be applied directly to non-spherical particle.





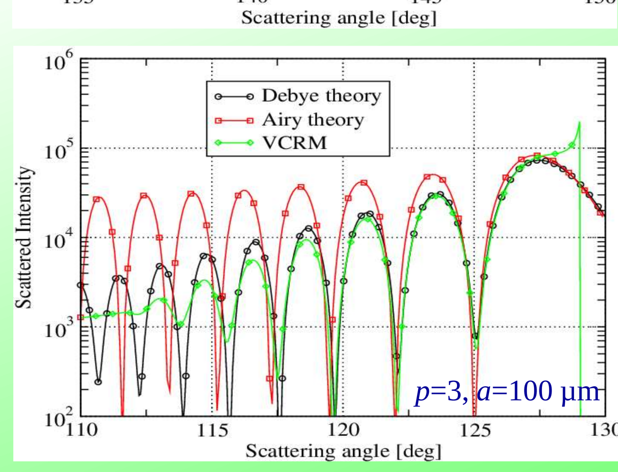


Fig. 3 Comparison of Airy structure calculated with the three methods.

Acknowledgement:

This work has been also partially supported by substantial computation facilities from CRIHAN (Centre de Ressources Informatiques de Haute-Normandie) and the French National Research Agency (ANR) grant ANR-13-BS09-0008-01

References:

[1]. K. F. Ren, F. Onofri, C. Rozé and T. Girasole, "Vectorial complex ray model and application to two-dimensional scattering of plane wave by a spheroidal particle", *Opt. Lett.* 36(3): 370-372, 2011.
[2]. K. F. Ren, C. Rozé and T. Girasole, "Scattering and transversal divergence of an ellipsoidal particle by using Vectorial Complex Ray Model", *J. Quant. Spectrosc. Radiat. Transfer* 113:2419–2423, 2012.
[3]. Y.Yuan, Diffusion de la lumière par un objet irrégulier pour l'application à l'imagerie des sprays, PhD thesis of Rouen University, France, 29 March 2012.
[4]. K. F. Ren, Software ***VCRMEll2D*** - Vectorial Complex Ray Model for 2-dimension scattering of an ellipsoidal particle», referenced 24/03/2014 under n°IDDN.FR.001.130023.000.R.P.2014.000.30000.