# A practical model for computing the BRDF of real world materials

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## Introduction

Physically correct modeling of BRDF must take into account of the subsurface volumetric light transport. Most of the accurate numerical solution methods (ex: Monte Carlo, Discrete Ordinate Methods (DOM)) for volumetric light transport compute radiance field for the whole volume, and are expensive. As BRDF ultimately relates only the outgoing radiation field at the boundary to the incident radiation, radiation field computed for the bulk of the material does not provide any useful information and hence the effort involved in computing them can be considered as wasteful. So for efficient BRDF computation any method that allows us to compute the radiance field only at the boundary would be a preferable choice. The search for such a method led us to the Ambartsumian's method [1, 2]. This method models the exiting light field from the surface of a semi-infinite material layer in the form of integral equations, and hence allows us to model the BRDF from such surfaces as a set of integral equations.

## Ambartsumian's Integral Equation

$$\begin{aligned} R^m(\eta,\eta_o) &= \frac{\alpha}{4(\eta+\eta_o)} p^m(-\eta,\eta_o) \\ &+ \frac{\alpha\eta_o}{2(\eta+\eta_o)} \int_0^1 p^m(\eta,\eta')R^m(\eta',\eta_o)\mathrm{d}\eta' \\ &+ \frac{\alpha\eta}{2(\eta+\eta_o)} \int_0^1 p^m(\eta',\eta_o)R^m(\eta,\eta')\mathrm{d}\eta' \\ &+ \frac{\alpha\eta\eta_o}{\eta+\eta_o} \int_0^1 R^m(\eta,\eta')\mathrm{d}\eta' \int_0^1 p^m(\eta',-\eta'')R^m(\eta'',\eta_o)\mathrm{d}\eta'' \end{aligned} \quad (1)$$

Here the $R^m$ and $p^m$ represent the $m^{th}$ order Fourier expansion coefficients of the reflectance function and the phase function respectively. $\alpha$ is the single scattering albedo. $\eta$ stands for the cosine value of the scattering zenith angle, and $\eta_o$ for the cosine value of the incident light beam. Given single scattering albedo and the Fourier coefficients of the phase function of the subsurface material, these integral equations can be numerically solved to compute the coefficients for the BRDF and in turn to compute the reconstructed BRDF.

## Implementation

The algorithm has three major steps:

(1) Computing single scattering albedo $\alpha$ and Fourier expansion coefficients of the phase function $p^m$ using Lorenz-Mie theory.

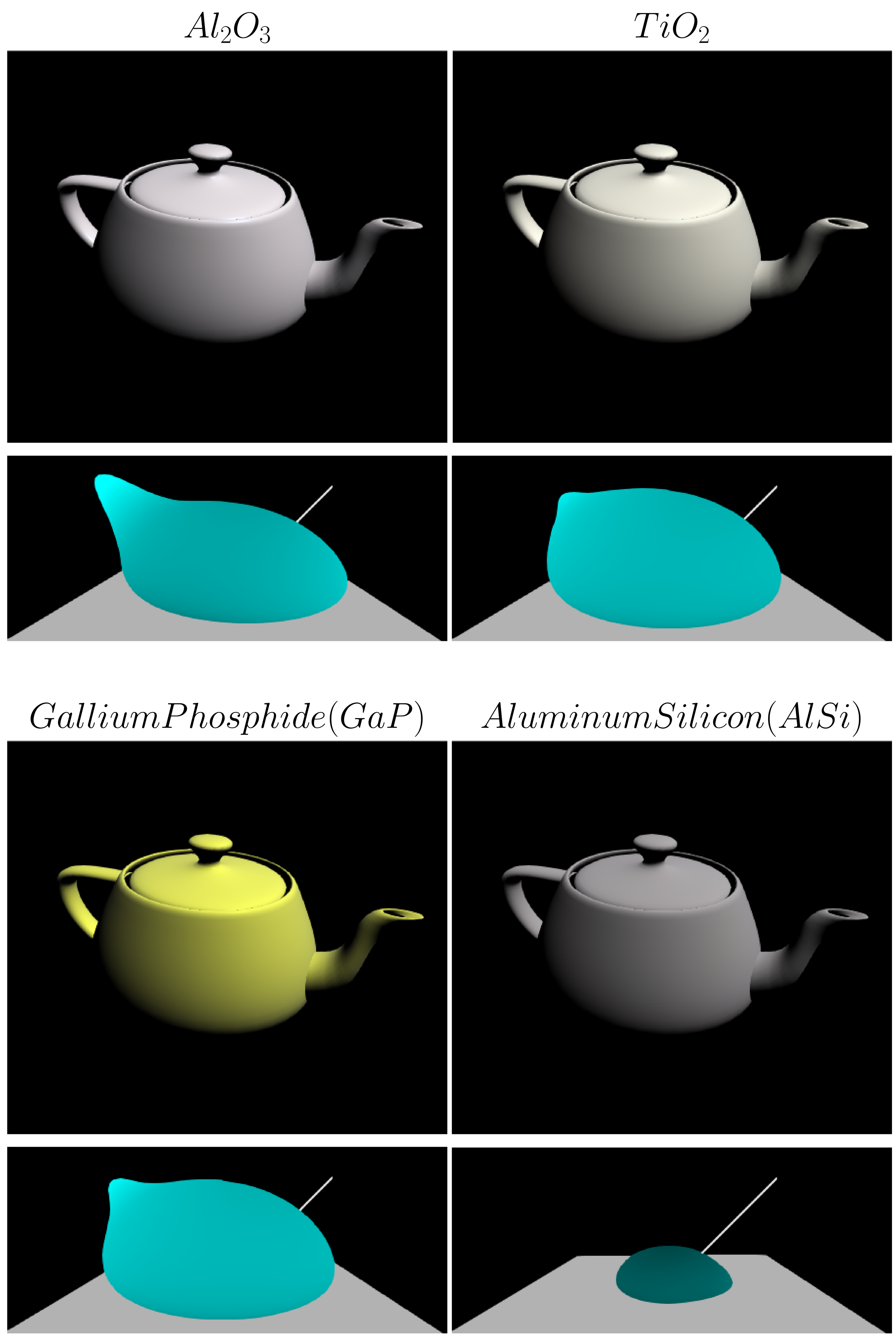
(2) Solving $R^m$ iteratively using equation 1.

(3) Reconstructing BRDF from its Fourier expansion coefficients.

The algorithm was implemented using C++ and OpenCL on an Intel i-3960X processor and a NVIDIA GTX 580 graphics card. We computed the BRDF table for 31 wavelengths (from 400nm to 700nm) and stored it as texture buffer.

## Results

The following shows the Uath teapot rendered using different materials. The lobe shows the BRDF in wavelength $480nm$ with $36.8^o$ incident light direction.




## References

[1] Mishchenko, M. I., Dlugach, J. M., Yanovitskij, E. G., and Zakharova, N. T. 1999. Bidirectional reflectance of flat, optically thick particulate layers: an efficient radiative transfer solution and applications to snow and soil surfaces. *J. Quant. Spectrosc. Radiat. Transfer 63*, 2-6, 409 – 432.

[2] Sobolev, V. V. 1975. *Light Scattering in Planetary Atmospheres.* Pergamon Press.

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