EPSC Abstracts
Vol. 8, EPSC2013-908, 2013
European Planetary Science Congress 2013


# Photometric Modeling of Asteroids 2867-Steins and 21-Lutetia Surfaces and Grain Size Estimate using Hapke's Bidirectional Reflectance

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## Abstract

We present a photometric method for the interpretation of the reflectance properties of atmosphereless bodies such as asteroids and comets nuclei. The method is self-consistent, easily reusable for any space mission target and independent of the shape model of the object. We investigated the reflectance dependence on the phase angle, interpreted in terms of the Hapke theory of bidirectional reflectance. We then present a method for the estimate of the grain size of the regolith on the surfaces of the asteroids. We applied the method to the two Main Belt asteroids 2867-Steins and 21-Lutetia observed from the OSIRIS camera onboard Rosetta spacecraft on 5 September 2008 and on 10 July 2010 respectively.

## 1. Introduction

Recently more and more space missions are dedicated to small bodies of the Solar System, as asteroids and comets, samples of the primordial planetesimals that accreted in the original solar nebula. The space missions allow to observe those bodies from a much wider range of illumination geometries than it's possible from ground-based observations. This in turn allows a detailed study of the reflectance properties of those bodies and of the material they are formed of.

The ESA mission Rosetta was launched on March 2, 2004 directed to its final target, the comet 67P/Churyumov–Gerasimenko, that it will reach on August 2014. During the long trek towards the comet, the spacecraft performed two successful fly–bys with the Main Belt asteroids 2867-Steins, about 6 km wide, and 21-Lutetia, about 100 km wide. During those fly–bys the OSIRIS camera (Optical Spectroscopic and Infrared Imaging System) onboard Rosetta was deeply operating and obtained high resolution images of the two surfaces from a minimum distance of about 800 km for Steins and of about 3200 km for Lutetia in a spectral range extending from near UV to near IR. The geometry of Steins fly-by was such that the angle between the light source and the observer, as seen by the target, called phase angle, was about 38° in the approaching phase, decreased down to 0° at the opposition and increased again up to 141° during the departure phase. Rosetta approached instead Lutetia with a phase angle of about 10°, it reached the opposition and then the phase angle rapidly increased up to 157° in the departure phase. For both asteroids it was then possible to observe and study the most part of the light curve.

## 2. Method

For the photometric analysis we use a limb determination to isolate the asteroid region from the background in order to avoid spurious light such as straylight, ghosts and cosmic rays, which are present in the observations.

We measure the reflectance of the asteroid, that is the fraction of the total incident light scattered by the surface, which depends on the geometry of illumination and observation but also on the physical and chemical characteristics of the surface material.

We then investigate the reflectance as function of the phase angle, which is called phase curve, in all available filters of the camera, from near UV (245nm) up to near IR (1 μm).

The phase curve is then interpreted in terms of the Hapke bidirectional reflectance theory [3] that solve the inverse scattering problem from a planetary surface, modeling the integrated phase curve with a five-parameter function. An iterative Levenberg-Marquardt least-squares fit [4],[5] of the observed curve is then used to obtain the numerical parameters that describe the curve. Those parameters are strongly connected with the fundamental optical properties of the surface regolith particles forming the surface layer covering the asteroid and

responsible for the light scattering. The parameters depend on many physical characteristics such as their chemical composition, their size, the pattern in which they scatter the light, their opacity, their shape and many others. Therefore modeling the phase curve may give important information on the material covering the surface of the asteroids.
Moreover, using those parameters additional information can be retrieved if a chemical composition is assumed, for example derived by spectroscopic observations and other physical considerations. Approximate and exact solutions of the light scattering problem by isolate particles can be found using respectively Hapke theories and Mie theory [2] for spherical particles. Those solutions provide direct relations between one of the Hapke's parameters and the diameter of the particles. Comparing the value obtained from the phase curve modeling, with the theoretical relationships, we infer a gross estimate of the grain size range forming the regolith.

# 3. Results

Steins regolith surface seems to be made of large, highly scattering iron-poor opaque silicate particles. The macroscopic roughness, probably influenced by the global irregular shape, appears fairly high, comparable with radar measurements of other E-type asteroids [1]. Assuming an enstatite composition, we estimated a grain size in the range 30–130 μm and we noticed a correlation between grain size and wavelength, suggesting the existence of a grain size distribution, as expected for realistic particulate material. The same photometric analysis for Lutetia phase curve is under development and the results are foreseen soon.

# 4. Conclusions

The results allow us to conclude that the modeling of the phase curve with Hapke's theory is very useful in investigating the reflectance behavior of small atmosphereless bodies, catching the physics of the scattering problem and giving a good description of the most important properties of the surface scattering regolith layer, and making comparison with asteroids easier and immediate. Moreover, comparison with more accurate calculations [6] taking into consideration the shape of the body, shows that our simplified method is robust and reliable for a preliminary shape-independent analysis of the reflectance properties of small bodies.

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