Astronomical and Astrophysical Transactions (*AApTr*), 2016, Vol. 29, Issue 4, pp. 519–528,
ISSN 1055-6796, Photocopying permitted by license only, ©Cambridge Scientific Publishers

Physical simulation of asteroid and artificial Earth satellite surface optical properties

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Received 15 September, 2015

The article contains a review of photometric properties of Solar system minor bodies. It suggests that these bodies basically have a reddish hue, a low albedo, and sufficiently high phase coefficients.

The similar properties of minor bodies make them low-observable and are among the obstacles for optical detection and identification of asteroids and meteoroids dangerous for the Earth.

The author describes the physical simulation method which is used to compare the surfaces optical properties of asteroids and meteoroids, terrestrial rocks, and known meteorites. This method can be used to solve the problems of identifying dangerous astronomical bodies with similar surfaces.

Keywords: Solar system minor bodies, surfaces optical properties, physical simulation

1 Introduction

The photometric properties of the Solar system minor bodies have been by now studied in sufficient detail. The article contains an analysis of colour, albedo, and phase curve slope indices of various types that were investigated by a great number of famous experts in this field (Barucci et al. 1982; Belskaya et al. 2008; Binzel et al. 2004; Bus et al. 2002; Chapman et al. 1975; Lupishko et al. 2007; Rabinowitz 2006; Pravec et al. 2012; Shevchenko et al. 2012; Toth 2006).

The research suggests that these bodies basically have a reddish hue, a low albedo, and sufficiently high phase coefficients.

The similar properties of minor bodies make them low-observable and are among the obstacles for optical detection and identification of asteroids and meteoroids dangerous for the Earth.

To solve the problems of detecting, identifying, and defining optical properties it is found useful to simulate asteroid surface optical properties in laboratory conditions and compare the obtained data with observation results (I. Antipova-Karataeva, M.

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Barucci, R. Casacchia, M. Fulchignoni, R. Burchi; D. Deb, B. Hapke, N. Koshkin, J. Näränen, P. Oetking, Yu. Shkuratov).

The author has developed the routine of experiments in physical simulation of surfaces optical properties of asteroids, artificial satellites, their light curves and phase dependences (Murtazov 1990, 2000, 2013, 2014). He has developed an experimental test facility for physical simulation with the purpose of comparing asteroid and meteoroid surface photometric properties with the properties of terrestrial rocks and known meteorites.

The method implementation results can be used to solve the problems of light scattering by surfaces with various textures, as well as the problems of detecting and identifying dangerous astronomical bodies with similar surfaces.

2 Overview of asteroids photometric properties

Light scattering from natural atmosphereless astronomical body surfaces is far from perfect. It is influenced by mutual shading of surface particles, the tubular structure of regolith on the surfaces, etc. These effects increase the asteroid phase curve slopes.

Their scattering is diffuse, differs from that of Lambert's and is described by the Hapke and Lommel–Seeliger functions with regard to the porosity of such surfaces.

The surfaces of most natural debris have quite low albedos and colour indices which are normally characteristic of grey-brown and reddish bodies.

Illustratively, in Table 1 we show some data for asteroids of main types based on the Tholen classification (Lupishko et al. 2007).

These data show that the colour indices of the main types of asteroids belong to B–V = 0.69–0.86 with an accuracy to 0.03–0.09. Their albedos vary over quite a wide range from 0.06±0.02 for C asteroids to 0.48± 0.05 for E asteroids (the number of E asteroids is substantially less than that of C asteroids). The phase coefficients of all main type asteroids are fairly large from 0.024 to 0.043 with an accuracy to 0.002.

Moreover, Pravec et al. (2012) found that the mean geometric albedo of the Tholen/Bus/DeMeo C/G/B/F/P/D types asteroids 25–300 km in size is $a_v = 0.057$ with the standard deviation (dispersion) of the sample of 0.013 and the mean albedo of S/A/L types 0.6–200 km in size is 0.197 with the standard deviation of the sample of 0.051. The colour indices V–R for S/Q/A/C/D/T/X/Xc/Xe/V-class asteroids vary from 0.38 (C) to 0.567 (A) with the standard deviation 0.05-0.008.

Figure 1 presents a colour diagram for basic taxonomic types of asteroids (Lin et al., 2014) and a colour diagram of the Kuiper belt objects (Doressoundiram et al.,

Table 1 Optical parameters of main type asteroids (Lupishko et al. 2007).

Asteroid type	Visual albedo, a_v	B–V	V–I	Phase coeff., C
C	0.06±0.02	0.69±0.03	0.73±0.07	0.043±0.001
M	0.17±0.04	0.72±0.09	0.82±0.06	0.032±0.001
S	0.20±0.07	0.86±0.04	0.90±0.08	0.030±0.002
E	0.48±0.05	0.72±0.04	0.80±0.05	0.024±0.002

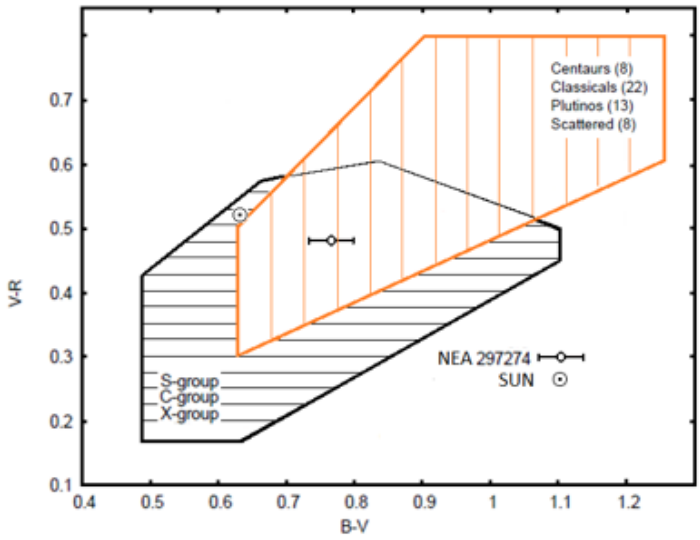


Figure 1 The color–color diagram of basic taxonomic types of asteroids (Lin et al. 2014) and Kuiper Belt asteroids (Doressoundiram et al. 2002) by comparison with location of the Sun and near-Earth asteroid 297174 1996 SK.

2002). The colour index B–V of basic type asteroids occupies the area 0.5–1.1, the index V–R – the area 0.15–0.6. NEA 297274 lies in the centre of the whole area on the line between S- and C-, X-classes. Kuiper belt objects, in general, are more reddish than the Main belt asteroids with colour indices B–V = 0.65–1.25 and V–R = 0.3–0.8.

The papers by Rabinowitz et al. (2006, 2007) contain the measurements of phase curves for distant Solar system objects, including 18 transneptunian objects (TNOs), and 7 Centaurs, and Plutoscale TNOs. The phase coefficients of asteroids belonging to the first two groups exceed 0.029±0.001 mag/deg.

But large TNOs (136199) Eris, (136472) 2005 FY9, and (136108) 2003 EL61 phase coefficients below 0.10 mag/deg are a salient feature of Plutoscale TNOs with neutral colors, high albedos, and icy surfaces.

Belskaya et al. (2008) describe phase coefficients measured for KBOs and Centaurs. Their values are restricted from 0.045 to 0.20 with an accuracy to 0.001–0.06. They noted that the values of phase coefficients depend on the phase-angle range used in the linear fitting. This is well illustrated by the phase coefficient of Varuna varying from 0.33 to 0.11 mag/deg.

The results of investigating the oppositional effect of the D-type Trojans 588 Achilles(Lagrangian point L4), 884 Priamus (Lagrangian point L5,) and 1143 Odysseus (Lagrangian point L4) are described by Shevchenko et al. (2012). Their color indices (the figures are presented in the order of asteroid numbers) are B–V = 0.70±0.03; 0.82±0.03; 0.74±0.03. The phase coefficients in different filters appeared to be similar, accurate to the measurement errors, and, consequently, equal (filter V values given as an example). The authors have not found any confident differences

between the phase slopes measured in B, V and R bands.

All three studied Trojans show linear magnitude phase dependences down to small phase angles of 0.1–0.2 arc degree. The linear phase coefficients are 0.045±0.001; 0.040±0.001; 0.044±0.001.

The above brief analysis makes it possible to conclude that the albedos of the most part of famous asteroids vary from 0.06 to 0.6, the colour indices B–V are restricted to 0.65–0.86, and the colour indices V–R to 0.38–0.567.

The exception is apparently the Main belt A-type asteroid 1562 Gondolatsch with the colour index B–$V = 1.04$ and the visual albedo $a_v = 0.25$ (Lagerkvist et al. 1998).

For reference: comet nuclei based on the overview data from Toth (2006) are on average more red than asteroids. The values B–V for them are within 0.65–1.25.

The near-Earth asteroids have on an average a higher albedo than the bulk of the Main belt asteroids.

The phase coefficients of the main type asteroids vary from 0.024 to 0.20 mag/deg excluding probably phase coefficients of icy surface asteroids.

It may be noted that the Trojans phase coefficients are on average larger than those of the Main belt asteroids, and those of Centaurs larger than those of the Trojans.

Separate from these are ice bodies with a high albedo and a very small phase coefficient.

Thus, the bulk of the minor bodies of the Solar system have sufficiently low albedos, reddish-brown colour, and a reasonably high phase coefficient. In the context of the detection of near-Earth asteroids and dangerous meteoroids, similar features and minor dimensions make these bodies low observable. They are difficult to detect. Moreover, high phase coefficients drop the brightness of minor bodies in case of wide phase angles and also decrease the probability of their detection.

3 Physical simulation of the Solar system minor bodies optical properties

To solve the problems of defining the expected brightness of the dangerous minor planets, the peculiarities of light scattering by the rough surfaces of these bodies, it is useful to simulate the optical properties of asteroids in laboratory conditions and compare the simulation data with observation results.

Similar studies were and are presently performed by various authors (Antipova-Karataeva et al. 1976; Barucci et al. 1982; Bugaenko et al. 1971; Deb et al. 2011; Hapke 1963; Koshkin 1988; Mattews 1971; Murtazov 1990, 2000, 2013, 2014; Näränen et al. 2004; Oetking 1966; Shkuratov et al. 2008).

The author of this article (Murtazov, 1983–2013) has developed the routine of experiments in physical simulation of surfaces optical properties of asteroids and artificial satellites. It includes requirements for the equipment used for the experiments; the methods of measuring spectral brightness of different surfaces; the methods of simulating asteroid and artificial satellite photometric observations.

1. Requirements for simulation, associated with observation conditions:

• finiteness of the Solar disc radius seen from an object (0.0093 radian at 1 a.u.);

• parallel beams falling onto a planet's surface due to sufficient remoteness of the Sun;

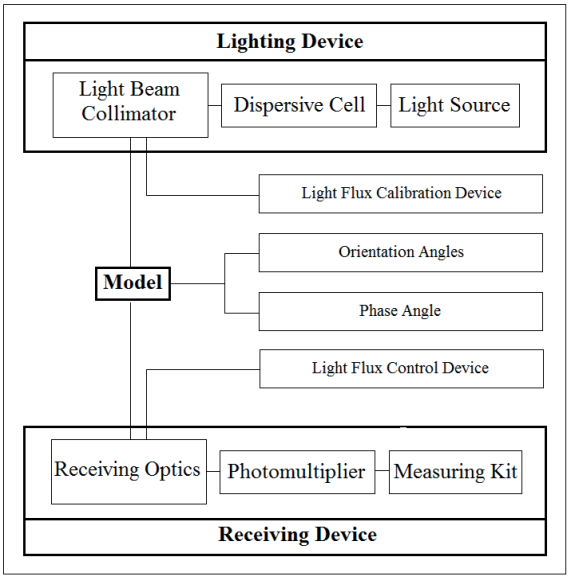


Figure 2 Flowchart of the installation for simulating surface optical properties of astronomical bodies.

• the maximum of radiation illuminating an object falls on within the yellow-green area of the spectrum with $\lambda = 475$ nm and is observed at $\lambda = 555$ nm from the Earths surface;

• the image of any astronomical object is dotty. In case of a closely adjacent and large object (e.g. ISS) it is important that the whole object could be held by the photometers field diaphragm.

2. Surface spectral brightness measuring technique:

$$\begin{cases} d\Phi = b(\lambda) \sin \phi_N d\omega dS, \\ d\Phi_0 = b_0(\lambda) \sin \phi_N d\omega dS, \end{cases} \tag{1}$$

where Φ and Φ_0 are light fluxes from the studied and standard surfaces; $b(\lambda)$ and $b_0(\lambda)$ are their geometric spectral albedos; ϕ_N, the receivers latitude in the surface-related spherical system; ω, the solid angle; S, the visible illuminated surface area.

3. The technique of simulating a light flux scattered by an astronomical body model, e.g. an artificial satellite, i.e. the simulation of photometric observations real conditions

$$d\Phi(\lambda) = \Sigma_{i=1}^{N} b_i(\lambda) dS_i \sin \phi_N d\omega, \tag{2}$$

when all the i-th element parameters of a satellites structure are summed up.

Figure 2 shows a flowchart of the installation for experiments in simulating surface photometric properties of atmosphereless bodies in the Solar system and artificial Earth satellites (Kuryshev et al. 1985). It includes:

• a lighting device making a parallel monochromatic beam (consists of a glow-lamp bulb and an 1:10 astronomical refractor for integral photometry or a monochromator

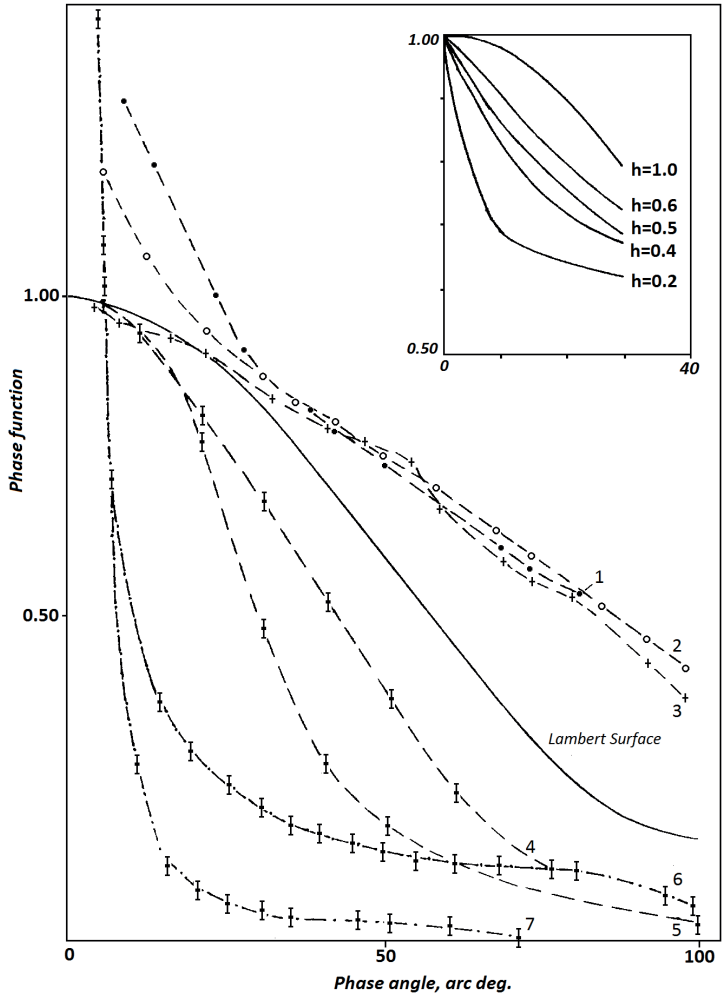


Figure 3 Phase curves of some space debris surface coating materials as compared to phase curves of ideal scatterers (solid line) and lunar surface insert (Hapke and van Hoen, 1963): 1–3 glass fabrics, 4–5 asteroid-like surfaces, 6–7 solar panels.

for spectral measurements);

• a receiver (a photoamplifier-based astronomical electrophotometer or a CCD-camera);

• suspension with the satellite or asteroid model;

• supplementary equipment: measuring apparatus, control sensors of supply voltages and light fluxes stability.

Below are some results of the physical simulation experiments implementation.

Figure 3 presents phase curves of natural rough surfaces, the shading effects of which are quite significant, versus Lamberts surface phase curves and glass fiber

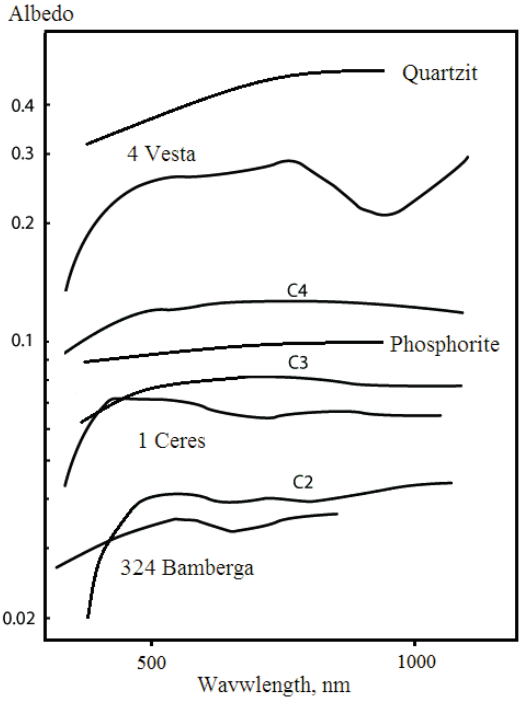


Figure 4 Spectral geometric albedo of some asteroids as compared to chondrites, carbonaceous C2–C4, and Earths minerals, phosphorite and quartzite.

phase curves. The phase curve of a painted plain diffuse surface coincides with the Lambertian one. By comparison, the insert shows Hapke curves for the lunar surface with different porosity parameters.

Figure 4 shows the reflectance spectra of some asteroids and chondrites carbonaceous C2–C4 according to the data of Chapman (1975) and preliminary spectra of quartzite and phosphorite samples which we achieved during the experiments in simulating astronomical object spectral properties.

Figure 5 shows (a) the satellite's integral light curve, (b) the model's spectrum during the specular flash, and (c), the spectrum's diffuse component where $\Delta\theta$=60^o.

The light curve of this model has attributes typical of geostationary satellite light curves in general, i.e., the specular flash central peak's asymmetry which is associated with the shadow effects and the model's orientation, as well as the brightness of the diffuse component after the flash which approaches to that of Lambertian for this portion of the curve. The diffuse component spectrum, (c), has nearly the same spectrum of the TiO white paint (in this instance the contribution of the solar cell's diffuse component is fairly small). The flash spectrum, (b), is as pronounced as the spectrum of silicon solar panels (Murtazov 1990, 2000). This maximum in the shortwave region of the spectrum helps to identify both.

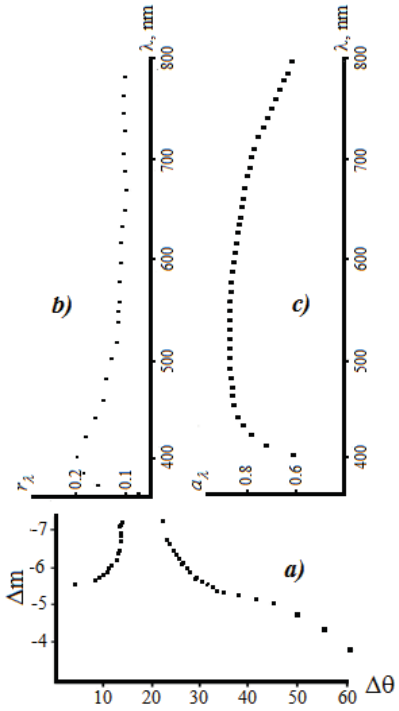


Figure 5 (a) Satellite's model integral light curve; (b) the model's spectrum during the specular flash; (c) the spectrum's diffuse component where phase angle $\Delta\theta = 60°$.

4 Conclusion

The experiments in simulating optical properties of astronomical bodies under the conditions corresponding to the geometrical conditions of their observations have demonstrated manifold possibilities of the technique that we have developed.

Based on this technique, it appeared possible to solve the direct problem of photometric measuring space objects of different origin. Spectral indicatrices were kernels of integral equations by means of which the reverse problem of space object photometric measures was solved; they also helped to decrease the equations redundance.

The physical simulation method makes it possible to perform a comparative analysis between asteroid surface properties, including those of dangerous ones, and the optical properties of meteorites and terrestrial rocks, in order to solve both fundamental problems of the Solar system bodies origin, and applied problems, related to the detection of space objects dangerous for the Earth.

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