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ASTEROID PHASE CURVES FROM LOWELL OBSERVATORY PHOTOMETRIC DATABASE

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Abstract. We present results obtained from processing large photometric data base. We make use of low-precision (generally rounded to 0.1 mag) and low-accuracy (rms magnitude uncertainties of ±0.2 to 0.3 mag) data obtained from the Minor Planet Center and modified at Lowell Observatory. We explore first correlations between slope parameter(s) and albedo, and second distributions of slope parameter(s) in asteroid families and taxa.

1. Introduction

We start by fitting phase functions [1] to about half a million asteroids contained in the data base. We obtain absolute magnitude and slope parameter(s) for each of the fitted objects. The absolute magnitude for an asteroid is defined as the apparent V -band magnitude that the object would have if it were 1 AU from both the Sun and the observer and at zero solar phase angle (Sun-Target-Observer angle). Absolute magnitude relates directly to asteroid size and is useful in computing geometric and Bond albedo. Steepness of phase curve relates to physical properties of asteroid surface, such as for example porosity, packing density, roughness and grain size distribution. Steep phase curves are characteristic to bodies with exposed regolith. Flat phase curve can indicate for example dense atmosphere. Phase curve anomalies such as brightness excess of Venus could be useful indicators of atmospheric constitutes such as water, which is essential to life [2]. At small phase angles so-called opposition effect occurs [3]. Explanation of opposition effect is two fold: 1) shadowing effect related to rough surface; 2) coherent backscattering - constructive interference between two electromagnetic waves, propagating in the random medium in reversed paths. The width of opposition surge can indicate the compaction state of the regolith and the distribution of particle sizes. For modeling physical parameters it is important that data sets contain at least few points per degree at small phase angles, so that the opposition peak's hight and width can be unambiguously determined [4]. Phase curve parameters (absolute magnitude and slope parameter(s)) can be used to predict brightness of an object at given geometry and phase angle.

2. Phase functions

In the current study we made use of three phase functions: the H,G; H,G_1,G_2; and H,G_{12} phase function. The H,G phase function [5] was adopted by International Astronomical Union in 1985. The H,G phase function is based on trigonometric functions and is not valid for phase angles greater than 120°. The H,G_1,G_2 and H,G_{12} phase functions [1] are based on cubic splines and valid up to 150°. The H,G_1,G_2 phase function is designed to fit asteroid phase curves containing accurate observations, whereas the H,G_{12} phase function is applicable to asteroids that have sparse or low-accuracy photometric data. Therefore the H,G_{12} phase function is best fitted to our data. To produce phase curve fits, we perform least-squares fitting carried out in the flux-density domain, because it reduces the problem to a linear problem for the H,G_1,G_2 and H,G phase functions, the errors are symmetric about the fit and a greater weight is given to individual photons. For fitting H,G_{12} we make use of simplex non-linear regression [6]. To compute uncertainties in the photometric parameters, we make use of Monte-Carlo and Markov-chain Monte-Carlo techniques. Detailed description of fitting procedures can be found in [7]. In the current study we used the Asteroid Phase Curve Analyzer - an online java applet, which we also made publicly available at http://asteroid.astro.helsinki.fi/astphase/.

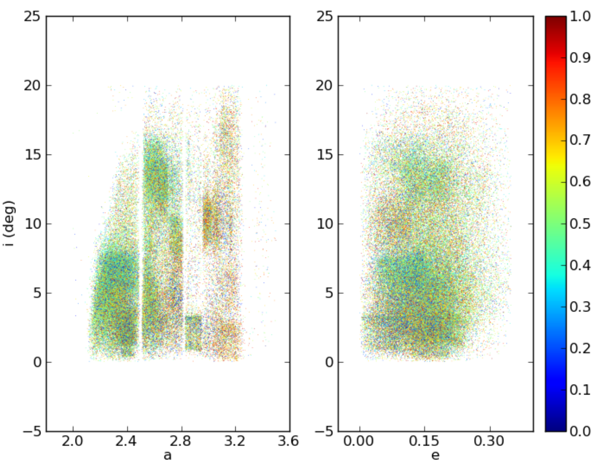

Figure 1. Distribution of osculating elements color coded with G_{12} value. Visible color clusters with similar G_{12} range correspond to asteroid families. The visible distinction in G_{12} values on both sides of the plot corresponds well with the distribution of S and C types asteroid in the belt.

3. Results

We applied the three phase functions to a large corpus of asteroid photometric data. We make use of the Lowell Observatory orbital data file maintained by EB and LHW. As of December 2010 it contained data for about 536,000 asteroids. The orbital data are used in combination with photometric data from the Minor Planet Center (MPC). Most of the photometric data are of low precision (generally rounded to 0.1 mag) and low accuracy (rms magnitude uncertainties of $\pm$ 0.2 to 0.3 are typical). Detailed description of the data set and photometric reduction procedure can be found in [7]. The majority of the data used in this study are very noisy, and the H,G_1,G_2 (designed for dense, accurate data) phase function fits often lead to large uncertainties in the H,G_1,G_2 parameters, lack of convergence or non-physical solutions. The H,G_{12} phase function better fits noisy data. The majority of the H,G_{12} fits lead to uncertainty $|\sigma_H| < 0.05$ and $|\sigma_{G_{12}}| < 0.25$. Most of the numbered asteroid have observations well distributed with phase angle. Unnumbered asteroids generally have fewer observations. Therefore, numbered asteroids usually lead to better-constrained photometric parameters.

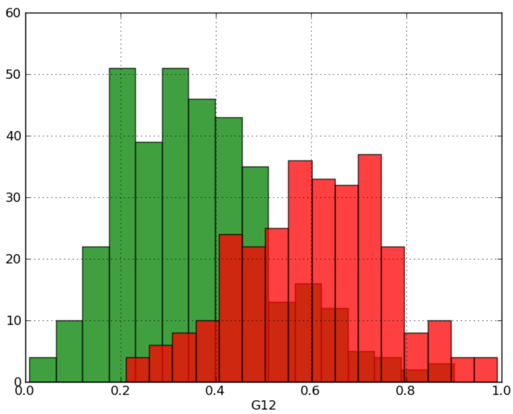

Figure 2. G_{12} histograms for 285 C (green) and 356 S (red) type asteroids. Diversity in composition and surface properties leads to diversity in phase curves of asteroids within the same taxonomic classification. To increase sample size asteroids of combined classes were treated as asteroids of a single class (for example, asteroids of type CG were combined with those of the predominant type C).

We fitted [7] asteroid families assuming that they can be fitted with the same G_1,G_2 values and individual Hs. We found that the slope parameters G_1 and G_2 correlate well with median albedo of asteroid families. Correlation between G_1 and albedo is -0.75 and correlation between G_2 and albedo is 0.80. Similar correlation was noticed also for G_1 and G_2 derived for asteroid groups having the same taxa. Because H,G_1,G_2 phase function usually results in low accuracy in photometric parameters for this noisy data set, we chose to fit individual asteroids with the H,G_{12} phase function. Figure 1 shows distribution of osculation elements, color-coded with G_{12} values. Even though distributions of G_{12} values in families can sometimes be quite broad, asteroids in family clusters [7] stand out, and tend to have similar G_{12}s. Distinctive distributions of G_{12} values within families are best visible in the proper elements phase space [7]. Dots of other colors mixed into families relate to asteroid with different G_{12} range and could relate to interlopers or to asteroid originating from differentiated parent body. The variable colored family members in this plot correlate well with families in the SDSS color-color plot [8]. Asteroids having similar taxa also tend to group around certain range of G_{12} values. Figure 2 presents G_{12} histograms for C and S asteroid taxa. The means of those histograms are clearly different. S taxon has a mean of 0.61 and standard deviation of 0.15. C taxon has a mean of 0.36 and standard deviation of 0.16. We conclude that those results could be useful in both taxonomic and family asteroid classification.

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