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A new modelling method for non-convex shapes of asteroids based on photometric observations

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Abstract

We present the new SAGE algorithm (Shaping Asteroids with Genetic Evolution) able to derive 3-D non-convex shapes of asteroids and solving for their spin parameters using only disk-integrated photometry. A triangular mesh of 62 vertices is used as a seed during the parameters minimization, and the Catmull-Clark method is applied to generate bodies with higher resolution. The subroutines search for the sidereal period of rotation in a given range, and the spin axis orientation on the whole celestial sphere. A step-iterative algorithm is used to make the shape evolve under the minimization constrains between the synthetic generated photometry and the real observations. In order to generate the simulated lightcurves we propose the virtual frames algorithm. The algorithm simulates the pictures visible on hypothetical CCD frames and, using only elementary vector operations or quadratic algebraic equations, it takes into account all phase angle effects. Publicly available lightcurve data has been used to obtain a new non-convex model for (9) Metis and (433) Eros. The resulting body shapes are compared with the ones obtained using other observational techniques, such as adaptive optics and stellar occultations (for Metis) or the NEAR Shoemaker observations of Eros during its rendezvous.

1. Introduction

In spite of the growing number of adaptive optics observations and the spectacular results of the radar measurements, photometry still remains the principal source of information about the shape, rotational state and physical properties of asteroids. One possible approach is to study their lightcurves i.e. the brightness variation of the objects as they rotate about their axes. Multiple lightcurve observations from different apparitions provide information about sidereal spin period, axis orientation, sense of rotation, and body shape.

A complex method, called lightcurve inversion, was developed by Kaasalainen & Torppa (2001) and Kaasalainen, Torppa & Muinonen (2001). That method uses all data points (both relative and absolute photometry) and is able to derive a physical model with a large number of parameters (polyhedra with triangular surface facets or spherical harmonics) that accurately reproduce the photometric data. The resulting model is a convex representation of the asteroid shape. In Kaasalainen & Torppa (2001) some examples of non-convex shape models are investigated and their signs of nonconvexity seemed to appear only at observations with very large phase angles.

However, after studying some random model shapes we have found significant differences between the simulated photometry generated by the nonconvex shapes and their hulls, even for low phase angles. On the basis of this results, we studied the possibility of developing a modelling technique capable to derive nonconvex models of asteroids basing on their photometric measurements. Some of the results obtained so far are presented here.

2. Resulting models and comparison with observations

2.1 433 Eros

The obtained model of Eros (Fig.1) is successfully reproducing the lightcurves and is in a great visual agreement with the high resolution model based on the observations obtained during the NEAR Shoemaker rendezvous. The pole solution found is $\lambda = 16^\circ$ and $\beta = 11^\circ$ with an uncertainty of $\sigma = \pm 5^\circ$, while the asteroid rotational period found is P = 5.270255 $\pm$ 0.000001 hours. This result is in a good agreement with the ones obtained in previous modellings. The general shape is well represented, including the concavities. The model is suggesting the existance of two main parts, connected by a concavity in the middle of the asteroid. We have done a test comparing comprehensively the new presented shape model with the high-resolution. The average radii difference between both models is $\pm 0.67 km$ and the extremal differences are $+2km$ (region where our model is bigger) and $-3km$ (the opposite situation). The regions where the presented model is smaller are concentrated on the ends of the shape corresponding to the x axis, as the high-resolution shape model is slightly more elongated. On the other hand, another main difference lies in a boulder appearing on the northern pole region of the presented model. As the observations of 433 Eros were mainly obtained at high phase angle geometries, we cannot be sure if the scattering law used to generate the synthetic brightness is behaving well in these circumstances.

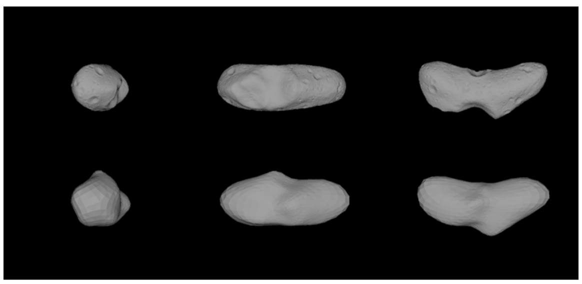

Figure 1: Fig.1. Comparison between Eros model based on the direct observations obtained with the NEAR Shoemaker NLR altimeter (Zuber et al. 2000) (top) and the shape model, based only on photometric observations, presented in this paper (down). The models are shown at equatorial viewing and illumination geometry, with rotational phases 90° apart (two pictures on the left), and the pole-on view on the right.

2.2 9 Metis

The presented model correctly reproduces the photometric observations of Metis. The pole solution found is $\lambda = 181°$ and $\beta = 22°$ with an uncertainty of $\sigma = \pm 5°$, almost identical to one of the convex solutions presented by Torppa et al. (2003) (available in the DAMIT database), while the asteroid rotational period found is P = 5.079178 $\pm$ 0.000001 hours, also in a total agreement with the convex model. The shape solution includes some global topography details. There is a large concavity on the southern pole region that is coincidental with the large planar area described on the convex model (Torppa et al. 2003), and a big boulder is present on the northern pole region, also in agreement with the bigger end of the convex model.

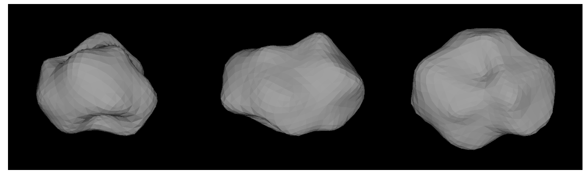

Figure 2: Fig.2. Three different spatial views of the presented non-convex model for 9 Metis (this paper) shown at equatorial viewing and illumination geometry, with rotational phases 90° apart (two pictures on the left), and the pole-on view at the right.

3. Conclusions

The SAGE inversion method is well describing the lightcurves for the two asteroids modelled, and their resulting 3-D model shapes are in a great agreement with other observations obtained with non-photometric techniques. It has been found that the average radii differences between the high-resolution model of Eros and the new model presented are smaller than 1 km, while the maximum radii error for the presented model of Metis is 4.9 km. The uncertainty of both shape models have been calculated to be close to 5

We have shown that the presented algorithm allows for an accurate description of the asteroid global topography, including its concavities. This might open a range of possibilities for the small bodies physical studies, e.g. a much better determination of asteroid densities or the study of non-gravitational effects.

Acknowledgements

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