Shaping Asteroids with Genetic Evolution (SAGE)

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Abstract

We created a genetic type of algorithm for modelling asteroid shape and spin parameters using disk-integrated photometry. The shapes are allowed to contain concavities. First tests of the resulting models against the ones from Adaptive Optics and stellar occultations are promising. The algorithm can model both single and binary objects. At present it uses the lightcurve data only.

1 Algorithm

We built a genetic algorithm named SAGE that basing on photometric data alone approximates asteroid shapes with the Gaussian spheres. The subroutines search for the sidereal period of rotation in the given, narrow range and the spin axis orientation on the whole celestial sphere. After that the algorithm lets the shape evolve and selects the shapes that are best adjusted to observations in terms of lightcurves they produce. Than, they evolve further and in finer details. For the first tests the scattering properties of the surface are described by a combination of Lommel-Seeliger and Lambert laws, similarly to the *lightcurve inversion* method [3].
The orientation of the obtained model for specific date is done in our Interactive Service for Asteroid Models, a web-based tool for comparing asteroid shape models obtained from different techniques [5].

2 Initial results

Even though the phase angles and thus shadowing by topographic features are never large for main-belt asteroids, their lightcurves occured to contain enough information for unique detection of large-scale concavities on their surfaces. Various starting shapes for one object inevitably drifted towards similar shape models thus firming the final solution.

Our test objects were large main belt-asteroids: (9) Metis, (21) Lutetia, and a binary (90) Antiope. They were chosen because very good quality data obtained using different techniques are available for them. For Metis they are adaptive optics images from two nearby epochs [4], and for Antiope the recent stellar occultation that gave dense and precise set of chords, revealing the silhouettes of its two components [6]. Lutetia is the best known of the three, as it was imaged by adaptive optics in multiple epochs, and then its shape model made on dataset combined with lighcurves, was confirmed by a fly-by images from Rosetta spacecraft [1]. For all of these objects rich photometric datasets exist, and they were the basis for our modelling.

(9) Metis

In Figure 1 there is a comparison of the W.M. Keck adaptive optics images for (9) Metis in two epochs separated by two hours compared to the convex *lightcurve inversion* model [4] plus our results based on the same photometric dataset as this model, in the same viewing and illumination geometries (at the bottom). Obtained solution for the north pole coordinates ($\lambda_p = 182°$, $\beta_p = +25°$) of Metis agrees well with the one determined previously ($\lambda_p = 181°$, $\beta_p = +23°$). The error of our spin pole determinations is of the order of a few degrees on the celestial sphere.

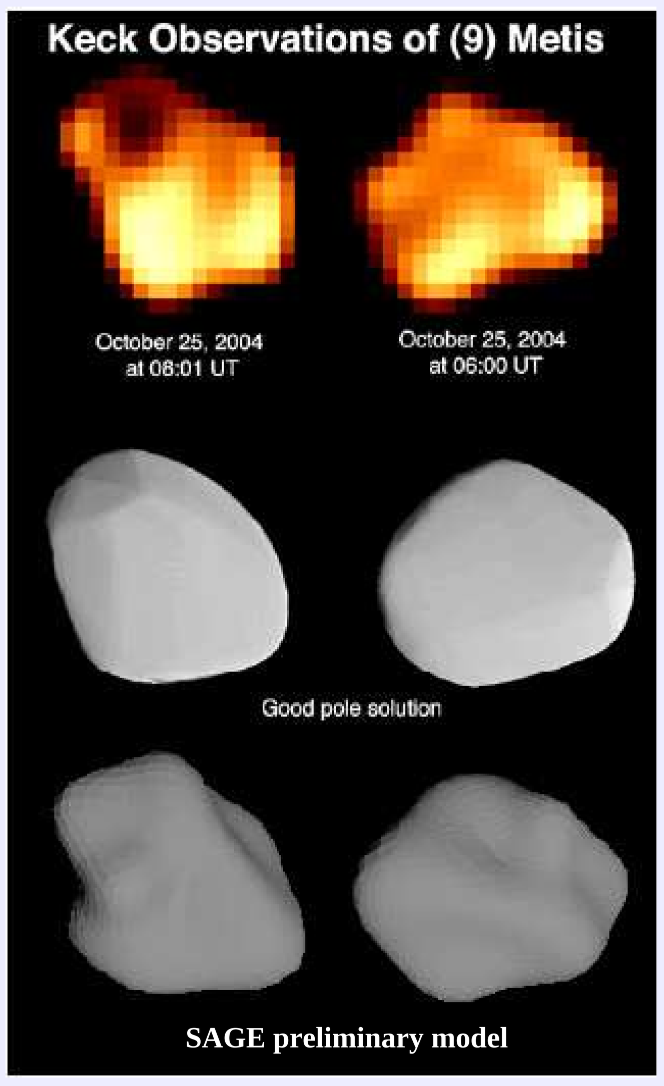

Figure 1: AO images of asteroid (9) Metis plus its inversion model [4] compared to the SAGE model displayed at the bottom.

(90) Antiope

Figure 2 displays the occultation sihouettes of (90) Antiope obtained on 19 July 2011 [6] compared to our model (right side) of both components at the same epoch and orientation as at the occultation (left). The lightcurves shown in Fig. 3 contain the comparison of the SAGE model lightcurves (lines) compared to observations (points). The fit is considerably better than in the previous works on this object, though the model is based on the same photometric dataset as in [2]. We confirmed the orbital pole and period solution obtained there: $\lambda_p = 200°$, $\beta_p = +40°$, $P_{orb} = 16.5051$ h, with our values: $\lambda_p = 200°$, $\beta_p = +45°$, $P = 16.50503$ h.

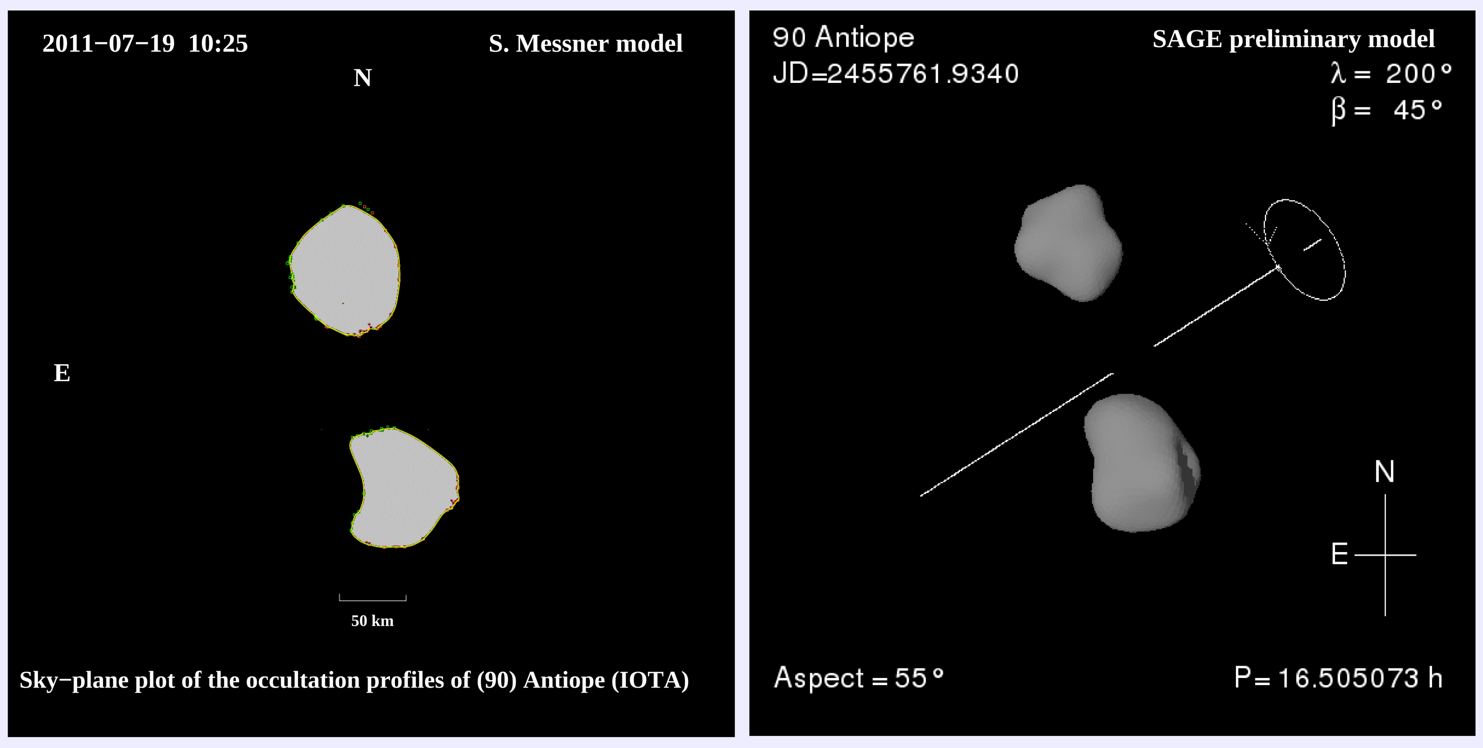

Figure 2: Occultation silhouettes of (90) Antiope (left) [6] compared to SAGE model of this binary (right).

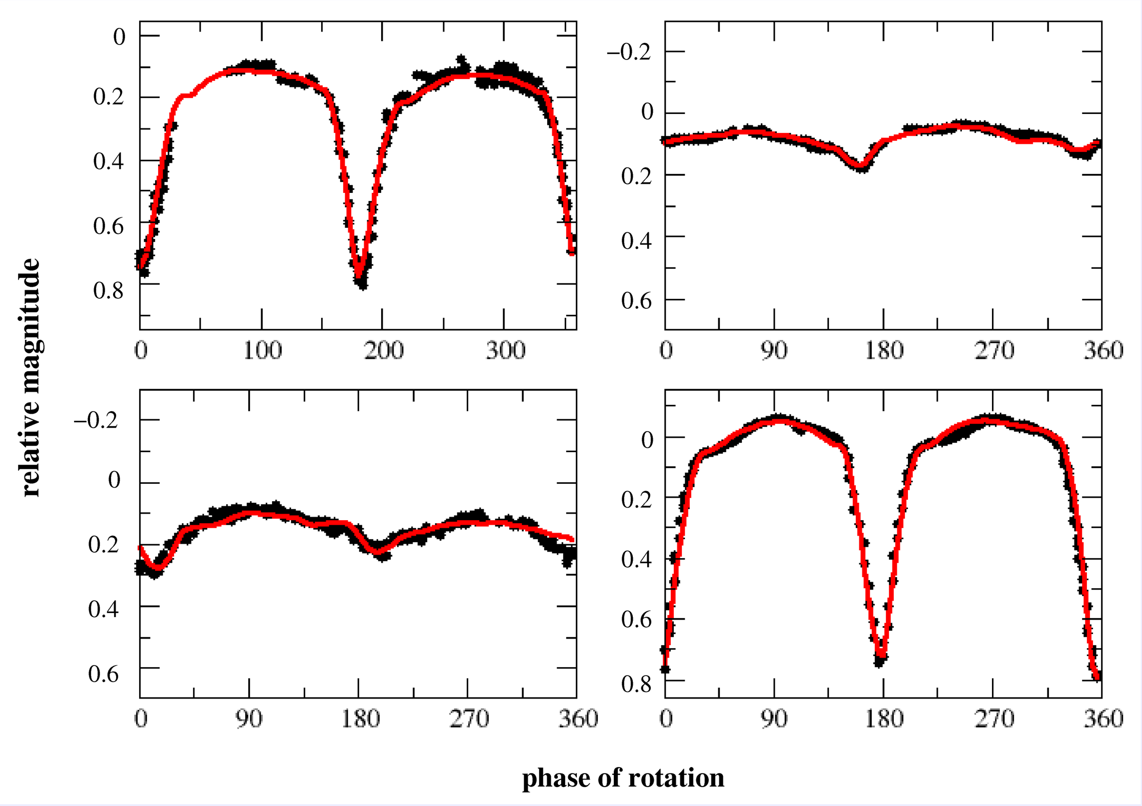

Figure 3: Example lightcurve fits given by the SAGE model of Antiope (lines) against observations (points).

(21) Lutetia

For (21) Lutetia we show our preliminary model in Fig. 4, where it is compared to Rosetta images, and KOALA inversion model on combined dataset of lightcurves and adaptive optics images [1]. Although SAGE model is based on lightcurves only, it reproduces main irregularities and concavities of this asteroid. The spin solution ($\lambda_p = 52°$, $\beta_p = -5°$, $P = 8.168272$ h) is very close to one given in the above-mentioned work ($\lambda_p = 52°$, $\beta_p = -6°$, $P = 8.168270$ h). Currently, we are working on applying various scattering laws and more detailed shape modelling, to improve the algorithm.

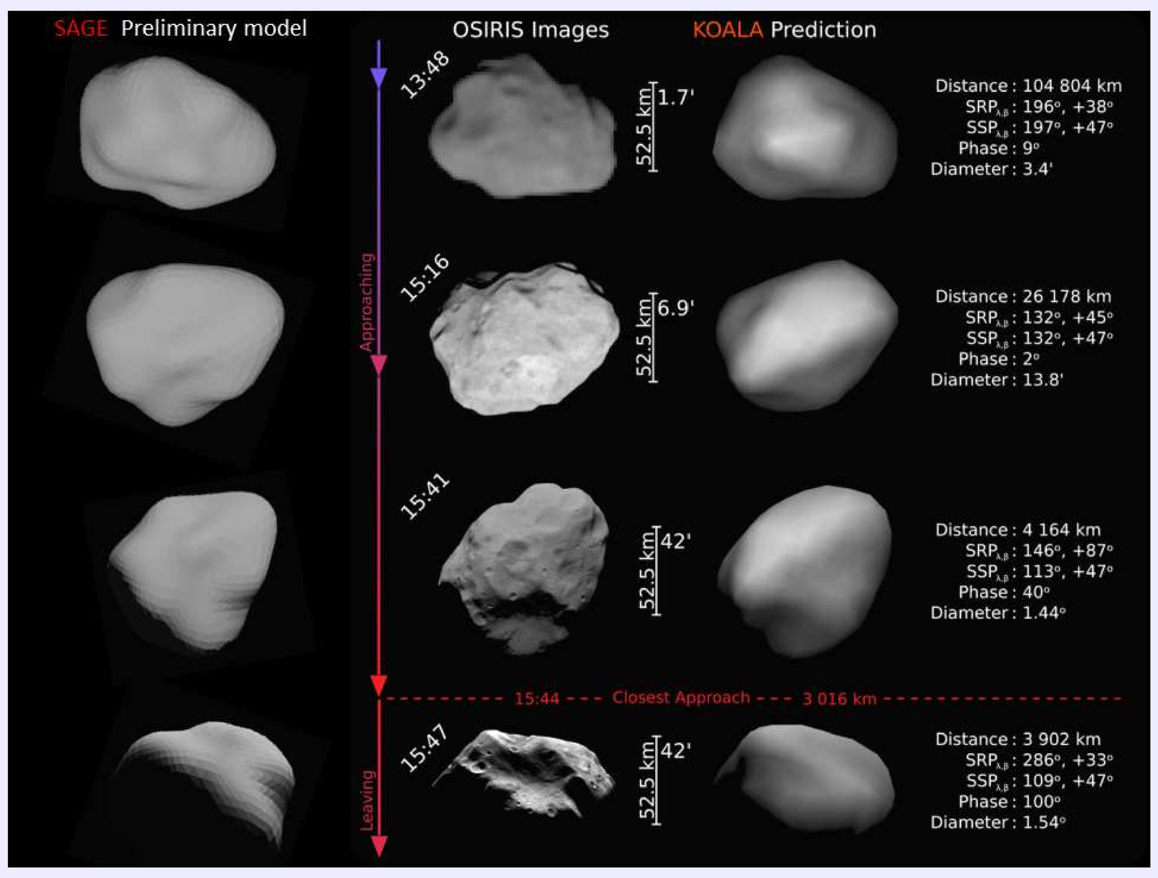

Figure 4: Our SAGE model of (21) Lutetia compared to its Rosetta fly-by images and pre-flyby KOALA model [1].

3 Conclusions and future plans

Possible applications of SAGE algorithm are wide: from evaluating asteroid spin and shape models independently from the *lightcurve inversion* method; to obtaining new asteroid models with concavities for better density estimates, where mass values are available.
Now working on lightcurve data only, the code already proved its robustness, so its planned development to process data from various other techniques (stellar occultations, thermal infrared, adaptive optics or radar ranging), will make it a versatile tool for multi-technique asteroid modelling. This in the future can result in a large dataset of asteroid models where possibly widest span of information sources are contained in one, concise model to yield asteroid diameters, albedoes, thermal properties, detailed shape and density estimates.

[1] Carry, B., Kaasalainen, M., Leyrat, C. et al. *Astron. Astrophys*, Vol. 523, A94, 2010

[2] Descamps, P., Marchis F., Michałowski, T., et al. *Icarus*, Vol. 203, p. 102, 2009

[3] Kaasalainen, M., Torrpa, J., & Muinonen, K., *Icarus*, Vol. 153, p. 37, 2001

[4] Marchis, F., et al., *Icarus*, Vol. 185, p. 39, 2006

[5] Marciniak, A., Bartczak, P., Santana T., et al. "Photometry and models of selected main belt asteroids IX. Introducing Interactive Service for Asteroid Models (ISAM)", *Astron. Astrophys*, submitted

[6] http://www.asteroidoccultation.com/observations/NA/