ASTEROID SHAPE DETERMINATION: A COMPARISON OF AO IMAGING WITH LIGHTCURVE INVERSION

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Summary: We present imaging data on 3 larger asteroids, taken with adaptive optics (AO) on large telescopes, with high spatial and rotational resolution. The resulting shapes can be compared with previous shape models derived from inversion of lightcurve data, and the agreement is generally good.

Introduction: The physical and statistical study of asteroids requires accurate knowledge of their shape, size, and pole position. Improved size permits improved estimates of albedo, in turn allowing better interpretation of surface composition. In those cases where we have an estimate of the mass, e.g. from the presence of a satellite, uncertainty in an asteroid's volume is the overwhelming uncertainty in attempts to derive its density [1]. Of course, density is the single most critical observable having a bearing on bulk composition, porosity, and internal structure [1,2].

Traditionally, asteroid size has been expressed as dimensions of a best-fit triaxial ellipsoid [3]. For a rapidly increasing number of asteroids, however, shape models are becoming available. Spacecraft visits have yielded high-fidelity shape models for only 5 asteroids. Radar imaging [5,6] can deliver spectacular shape models but is very range sensitive and suffers certain ambiguities in interpretation. Lightcurve inversion [7,8] has produced shape models for a large number of asteroids but cannot directly measure size and requires data collected over many years.

Direct, accurate, measurements of asteroid shapes, sizes, and poles are now possible for larger asteroids, which can be well resolved using AO on large ground-based telescopes. Approximate sizes of many asteroids can now be determined from single AO snapshots [1,4]. By extending to AO the methods that were developed by Drummond et al. [e.g., see 3] for speckle interferometry, we can now determine shapes, sizes, and poles for asteroids within one or two nights that are typically much improved from those obtained by indirect methods [9,12].

We continue to evaluate and improve our observational and analysis techniques to achieve the best possible size and shape information in the shortest time. We utilize the world's largest telescopes (Keck, Gemini, VLT) and can acquire quality data down to angular sizes of ~0.08". Consequently ~100 asteroids are accessible for this type of analysis. We have shown that it is even possible to formulate a complete shape model from a single-rotation data set. Additional observations taken later in time can give powerful leverage to reduce uncertainties [12]. We can identify and rotationally confirm large shape features, such as the two facets and the promontory identified on Davida [9]. Further this can lead to geological interpretations such as the identification of giant craters, giving insight into impact history [9]. Here we extend efforts by our group and others [10,11] to validate earlier shape models produced with lightcurve techniques.

Comparison Method: To produce the lightcurve inversion models shown here, we used the web site "Asteroid Models from Light Curve Inversions"[1], which is maintained by J. Durech and compiles the work of M. Kaasalainen and colleagues. The vertex and connection data, transferred from the site, were used to define a triangular mesh that we then converted into solid model representations via two methods. First we used IDL/ION® to produce an interactive model for our preliminary discussion. The majority of the rendering work, and all of the depictions shown below, were produced using a Matlab® code. The light source, used to render shadows and spectral highlights, was positioned at the Sun direction for each epoch. The orientation of the model was determined using the formula given on the lightcurve web site.

In each case, we compared the AO images to a model orientation for that epoch and, in addition, we chose another display that was 180 deg offset in rotational phase, which in the case of a symmetric triaxial ellipsoid would be indistinguishable. We use this merely as a demonstration or verification of the degree of symmetry of the asteroid. As expected, we see that comparison between the lightcurve model and the AO images is more straightforward when there is more asymmetry.

511 Davida: Figure 1 compares our Keck AO observations of 511 Davida with the lightcurve model. Agreement can be seen in many epochs for one depiction, while for the other, offset by 180 deg, a weaker correlation exists. A promontory (labeled 'A') is clearly visible in both direct imaging and lightcurve epochs 6 through 9. While the same promontory is evident in all views of the lightcurve model, it is not evident in the remaining imaging views. A discrep-

[1] http://astro.troja.mff.cuni.cz/~projects/asteroids3D/

ancy in pole or detailed shape relative to our imaging is likely responsible. We believe that this promontory rotates out of view behind the limb [9], and may therefore be somewhat shallower than predicted by the lightcurve model.

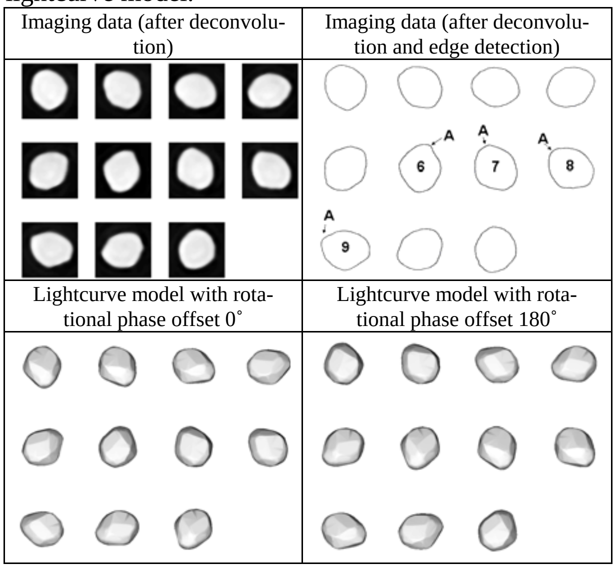

Figure 1. Four depictions of Davida at the eleven epochs acquired with Keck AO on December 27, 2001 [9]. The top panels show the AO data: upper left deconvolved (Mistral[2] [13]) and upper right produced by applying a discrete differential operator (Sobel) to the deconvolution. The lower panels show lightcurve models for these same epochs with 0˚ and 180˚ phase offsets. The 'A' promontory [9] is indicated in epochs 6,7,8, & 9.

52 Europa: Figure 2 compares our Keck AO observations of 52 Europa with the lightcurve model. The two results agree broadly in that no striking edge features (like Promontory A on Davida) are visible in either depiction. Indeed, we confirmed that no edge features detectable with AO can be rotationally confirmed and 52 Europa is therefore an excellent candidate for designation as a standard tri-axial-ellipsoid asteroid (STEA)[3] [12]. Unlike Davida, when we artificially rotate the asteroid 180 degrees, the agreement between the imaging and the model are similar. This indicates that the asteroid is a relatively smooth ellipsoid.

15 Eunomia: Figure 3 compares our Keck AO observations of 15 Eunomia with the lightcurve model. These preliminary results reveal a shape that broadly agrees with the lightcurve model. Like Davida, Eunomia shows shape irregularities that are visible in the unprocessed, non-deconvolved data shown here. Determining edges that can be rotationally confirmed and then compared to the lightcurve model awaits deconvolution and edge detection.

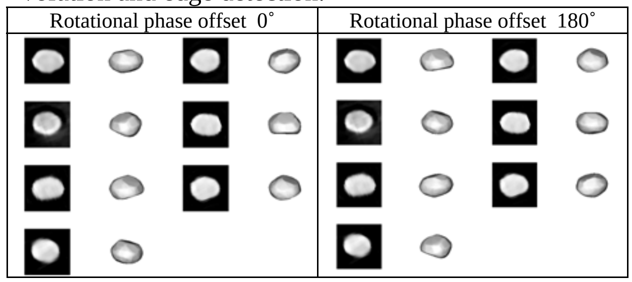

Figure 2. Two depictions of 52 Europa for the 7 epochs observed with Keck AO on January 20, 2005. The same direct imaging data (black background) is shown in both panels.

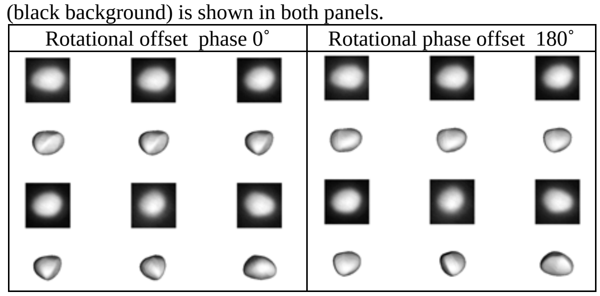

Figure 3. AO observations of 15 Eunomia (black background) compared with lightcurve models. The imaging data, collected on December 15, 2007, at 6 epochs, has not yet been deconvolved.

Conclusion: With our AO/lightcurve comparison of 511 Davida, we have shown that it is possible to confirm the accuracy of both techniques by comparing the edges detected from direct AO images with lightcurve shape models reconstructed to render views for the same times as the observations. For roughly symmetric asteroids like 52 Europa, the comparison confirms that no striking edge features exist. As we add more examples (like 15 Eunomia) to this population of asteroids that have shape information from both techniques, we will learn more about the asteroid shapes as well as the potential and limitations of the techniques.

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[2] MISTRAL: COPYRIGHT © Conan, Mugnier, Fusco – ONERA 1998-2000

[3] Part of our program is to define standard asteroids that can be used by a variety of observers for radiometry, AO imaging, and spectroscopy, much as standard stars are used in astronomy.