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KOALA: 3-D shape of asteroids from multi-data inversion

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Abstract

We describe our on-going observing program to determine the physical properties of asteroids from ground-based facilities. We combine disk-resolved images from adaptive optics, optical lightcurves, and stellar occultations to put tighter constraints on the spin, 3-D shape, and size of asteroids. We will discuss the relevance of the determination of physical properties to help understand the asteroid population (*e.g.*, density, composition, and non-gravitational forces). We will then briefly describe our multi-data inversion algorithm KOALA (Carry et al. 2010a, Kaasalainen 2011, see also Kaasalainen et al., same meeting), which allows the determination of certain physical properties of an asteroid from the combination of different techniques of observation. A comparison of results obtained with KOALA on asteroid (21) Lutetia, prior to the ESA Rosetta flyby, with the high spatial resolution images returned from that flyby, will then be presented, showing the high accuracy of KOALA inversion. Finally, we will describe our current development of the algorithm, and focus on examples of other asteroids currently being studied with KOALA.

1. Introduction

Knowledge of certain observable physical properties of small bodies (*e.g.*, size, spin, 3-D shape) have far-reaching implications in furthering our understanding of these objects, such as density, composition, internal structure, and the effects of non-gravitational forces. For instance, the distribution of spin axes of the larger asteroids (diameter larger than ∼100 km) on the celestial sphere is not expected to be isotropic. Numerical hydrocode simulations have predicted a slight excess in prograde rotators, due to the gas-pebble interaction in the protoplanetary disk (Johansen & Lacerda 2010). Similarly, the spin state of *small* asteroids (diameter of a few kilometers) is dominated by the non-gravitational YORP effect (Kaasalainen et al. 2007). Statistical knowledge of spin coordinates, how they are distributed within and among asteroid families of different ages, will provide strong constraints on the effectiveness of YORP.

Reconstruction of the 3-D shape (including the size) is required to estimate the volume of an asteroid, which in turn is used to derive its density, which is possibly the property most fundamental to our understanding of an asteroid (Britt et al. 2002). Observations of the surface of an asteroid, such as colours, spectra, or phase effects, can provide clues to the surface composition of the asteroid. This may or may not be related to the bulk composition of the body. Masses for asteroids can be determined from a spacecraft flyby, from the orbital motion of a natural moon, or even from the perturbations of asteroids on other bodies, such as Mars. In most cases, however, the uncertainty in the density is dominated by the uncertainty in the volume, rather than the uncertainty in the mass (Merline et al. 2002). Precise reconstruction of the 3-D shape is therefore of high importance for all asteroids for which a mass has been, or will be, estimated. From the accurate astrometry that will result from, for example, Gaia and PanSTARRS, about 150–200 mass estimates are expected in the near future (*e.g.*, Mouret et al. 2007).

2. KOALA

We have developped a multi-data inversion algorithm: Knitted Occultation, Adaptive-optics, and Lightcurve Analysis (KOALA), that makes simultaneous use of data from three distinct observation types to determine the physical properties of asteroids (Carry et al. 2010a, Kaasalainen 2011). KOALA takes advantage of the specificity of each observing mode: the direct measure of the apparent size and shape of asteroids on the plane of the sky provided by the timings of stellar occultations and disk-resolved images, and the in-direct constraints on its spin and 3-D shape given by its lightcurves.

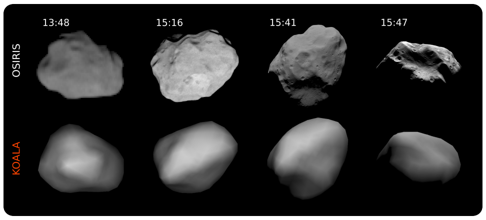

Figure 1: Comparison of four images of asteroid (21) Lutetia returned from the OSIRIS camera on-board Rosetta (Sierks et al. 2011) with predictions based on the KOALA shape model derived **before** the flyby by Carry et al. (2010b) and Drummond et al. (2010)

3. KOALA at (21) Lutetia

The accuracy of KOALA has been illustrated spectacularly during the flyby of asteroid (21) Lutetia by the ESA mission Rosetta on 2010 July 10 (see Fig. 1). The spin solution we had determined before the flyby (Carry et al. 2010b) was confirmed to be accurate within 2° (well inside the 5° uncertainty quoted for KOALA), and our dimensions estimates ($124\times101\times93$ km) are within 2 km of those ($126\times103\times95$ km) determined from the very high-spatial-resolution images returned by the OSIRIS camera on-board Rosetta (Sierks et al. 2011), again well within the uncertainties reported for each dimension using KOALA ($5\times4\times13$ km, see Drummond et al. 2010).

Owing to its high obliquity (96°, see Carry et al. 2010b, Sierks et al. 2011), Lutetia's spin axis is tilted such that its pole is nearly in its orbital plane. At the time of the Rosetta flyby, the southern hemisphere was in seasonal shadow, and observations at optical/NIR wavelengths were not possible below -40° latitude. The detailed shape model derived from flyby images using stereophotoclinometry therefore does not cover a large fraction of the asteroid's southern hemisphere, the southernmost portion of the shape model (Sierks et al. 2011), being being based on our ground-based data (Carry et al. 2010b) and the KOALA algorithm (Carry et al. 2010a, Kaasalainen 2011).

4. On-going research

Present implementation of KOALA allows the combined use of optical lightcurves (including sparse photometry), profiles from disk-resolved images, and chords from stellar occultations. We continue the development of KOALA toward the use of more data sets (*e.g.*, interferometry, thermal photometry) to increase the number of possible targets, and set better constraints on targets observable with different techniques. Using different wavelengths, in particular in the infrared thermal range, opens the possibility to derive additional physical properties, like albedo or thermal inertia. We also plan to incorporate additional safeguards in the inversion (that ensure that results are physically valid, and avoid the apparition of spurious topography). In particular, we plan to take into account the differing resolutions of different data sets to improve on detailed topography.

We will present the 3-D shape models of several asteroids determined with KOALA from our current analysis.

References

Britt, D. T., Yeomans, D. K., Housen, K. R., & Consolmagno, G. J. 2002, Asteroids III, 485

Carry, B., Dumas, C., Kaasalainen, M., et al. 2010a, Icarus, 205, 460

Carry, B., Kaasalainen, M., Leyrat, C., et al. 2010b, A&A, 523, A94

Drummond, J. D., Conrad, A., Merline, W. J., et al. 2010, A&A, 523, A93

Johansen, A. & Lacerda, P. 2010, MNRAS, 404, 475

Kaasalainen, M. 2011, IPI, 5, 37

Kaasalainen, M., Ďurech, J., Warner, B. D., Krugly, Y. N., & Gaftonyuk, N. M. 2007, Nature, 446, 420

Merline, W. J., Weidenschilling, S. J., Durda, D. D., et al. 2002, Asteroids III, 289

Mouret, S., Hestroffer, D., & Mignard, F. 2007, A&A, 472, 1017

Sierks, H., Lamy, P., Barbieri, C., et al. 2011, submitted to Science