Determining Asteroids' Poles and Dimensions

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ABSTRACT

Adaptive Optics (AO) imaging on a large aperture telescope can determine an asteroid's pole and dimensions in 1 or 2 nights on a single target, rather than the years of observations with typical lightcurve inversion techniques that only yield poles and axial ratios, not the true dimensions. Observations obtained at both Gemini N. and with Keck, using NGS AO, have determined the triaxial dimensions, shapes, and pole directions (spin vectors) for a number of smaller asteroids. The triaxial dimensions permit accurate determination of the body's volume so that densities can be calculated (such as when a satellite is present) to much greater precision than currently known.

INTRODUCTION

We have developed a method to determine the pole and triaxial dimensions of an asteroid in one or two nights from adaptive optics (AO) observations, and have successfully demonstrated this technique with natural guide star (NGS) AO observations of asteroids observed at the Lick 3m in 2004 and 2006 (Drummond and Christou 2008), as well as the large asteroids 511 Davida (Conrad et al 2007), 52 Europa (Conrad et al 2008 ;Merline et al, in prep), 2 Pallas (Drummond et al 2009; Carry et al 2009), 1 Ceres (Carry et al 2008) , and others with AO on Keck II. Fig 1 shows Davida from Conrad et al (2007), and from Drummond et al (2009) Fig 2 shows the the rotation of the smaller asteroid 129 Antigone.

The triaxial dimensions of the asteroids are determined by using the basic assumption that an asteroid can be modeled as a smooth featureless triaxial ellipsoid with diameters $a > b > c$ rotating about its short axis. As it rotates it projects a series of ellipses of apparent major axes α and minor axes β, where the long axis will make an angle γ with the line of nodes, the intersection of the asteroid's equatorial plane and the plane of the sky.

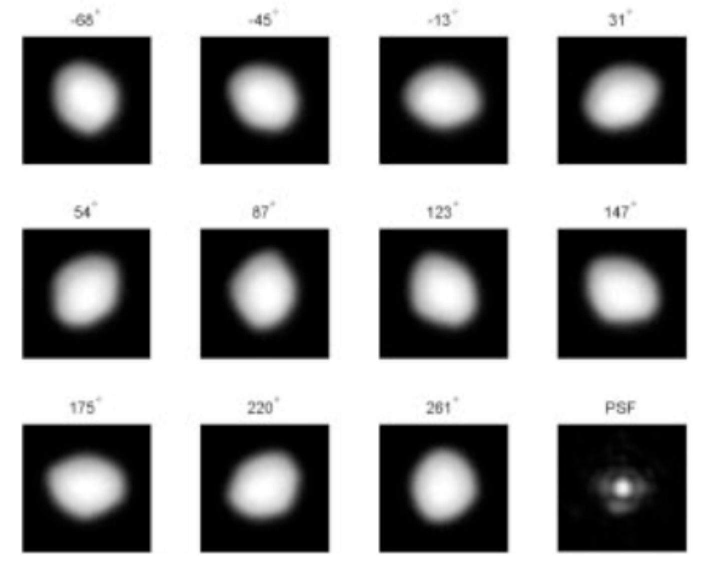

Fig. 1: K-band images of 511 Davida, December 27, 2002, with NGS AO on Keck 10m. Each image, 0.5" = 586 km on a side, is displayed with a squared stretch, which shows the edges well, but the Keck point spread function (PSF) from that night is shown at lower right with a square-root stretch to show the low-light-level structure.

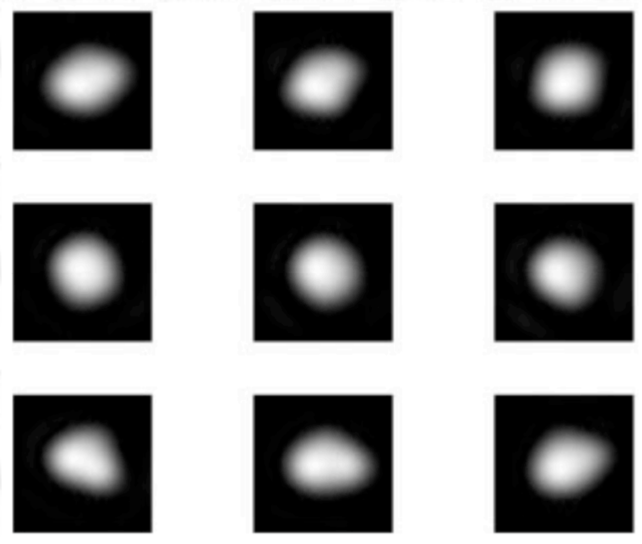

Fig. 2: Deconvolved images of 129 Antigone, August 16, 2006, with NGS AO on Keck 10 m. Each image is 0.2" = 253 km on a side. This is among the smallest main-belt asteroids possible to resolve with 8-10 m telescopes. Although Antigone may appear tantalizingly binary in some of the images, nothing in our reductions to triaxial ellipsoid diameters and pole supports this.

We use a technique called parametric blind deconvolution (PBD) to estimate the size, shape, and orientation of an asteroid from the AO images. This method does not require a separate measurement of the PSF as it can be simply modeled by a Lorentzian (Drummond 1998; Drummond et al 1998). In the Fourier domain, the observed image can be modeled by the product of a Bessel function of the second kind of order 0, K_0, for the Lorentzian, and a Bessel function of the first kind of order 1, J_1, for the asteroid. A nonlinear least squares fit yields the asteroid's apparent major and minor axes dimensions and the position angle of the long axis, and the same quantities for the Lorentzian PSF. The triaxial ellipsoid shape of the asteroid as well as its rotational axis are then obtained by a least squares fit to the projected ellipses and the rotational period of the asteroids.

GEMINI OBSERVATIONS

AO imaging on an 8-10m class telescope at near infrared wavelengths can yield 2-4 resolution elements (main belt resolution is 70 km in the *K*-band at opposition) across the diameter of the brighter main-belt asteroids making them suitable candidates for NGS AO imaging. Observations of the asteroids 9 Metis, 532 Herculina, and 654 Zelinda were obtained on 8 and 9 December, 2008, at the Gemini North telescope, at 2.15 μm using Altair/NGS and NIRI. All asteroids were observed at several rotational phases with 12 images at each rotational phase.

Fig 3 shows the deconvolved images for 9 Metis, using the mean of the co-fitted PSFs from the PBD analysis for each rotational phase, alongside the predicted shapes from the lightcurve inversion models (Torppa et al 2003). Note the strong correspondence between the two techniques illustrating that similar information can be obtained in just only two nights worth of observing compared to lightcurves obtained over multiple oppositions.

The AO imaging also permits determination of the rotational pole from the triaxial ellipsoid model fit. Fig. 4 shows the two possible pole determinations (wedges over large circles) from the least squares fitting of the AO images compared with those determined by A. Kryszczyńska (Kryszczyńska et al. 2007) determined from light curve analysis (small circles). Note that there is overlap between the two techniques at only one of the AO/triaxial ellipsoid derived poles, which is also very close to the pole used with the lightcurve inversion models in Fig 3.

Table 1 gives the triaxial ellipsoid model fits to the AO images of the 3 asteroids obtained from the Gemini North observations over two nights. The c diameter carries a larger uncertainty for observations at sub-Earth latitudes (θ) closer to the pole. This uncertainty can be reduced with further AO observations obtained nearer to the equator at a future opposition. The asteroids' volume uncertainties will then also be reduced. Zelinda, for example, has a volume uncertainty of only 3%.

Table 1: Asteroid Shape Parameters

	Triaxial Ellipsoid Diameters			Latitude
Asteroid	a (km)	b (km)	c (km)	θ(°)
9 Metis	218 ± 3	175 ± 3	112 ± 47	+51
532 Herculina	245 ± 6	212 ± 4	192 ± 18	-39
654 Zelinda	133 ± 3	119 ± 2	116 ± 2	-16

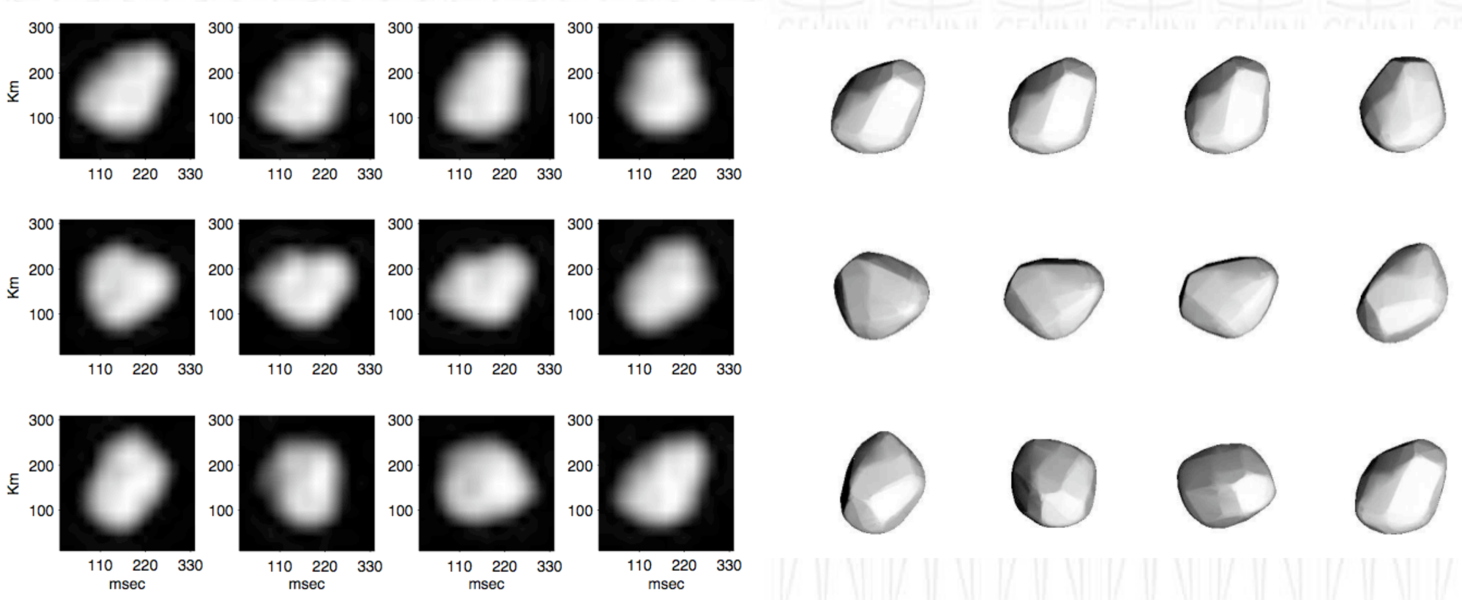

Fig. 3: Linearly deconvolved images of 9 Metis from the December 2008 Gemini data (left) compared with lightcurve inversion model projected forward from November 2, 1949 (right). Note the strong similarity in shape between the two approaches. (Each image is the average of 12 individual observations at that rotational phase.)

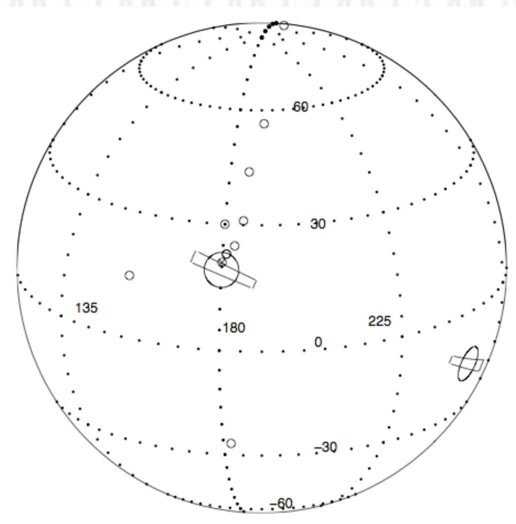

Fig. 4: Rotational poles (wedges on large circles) on the Ecliptic globe, from Gemini observations. The wedges and large circles have the same area, corresponding to the uncertainty for the pole locations, but the wedges show the actual distribution of the uncertainty region. The Gemini pole near the center overlaps with one of the lightcurve poles (small circles) yielding an unambiguous pole position.

REFERENCES

Carry, B., Dumas, C., Fulchignoni, M., Merline, W. J., Berthier, J., Hestroffer, D., Fusco, T., Tamblyn, P. 2008. Near-infrared mapping and physical properties of the dwarf-planet Ceres. Astronomy and Astrophysics 478, 235-244.

Carry, B, Dumas, C., Kassalainen, M., Berthier, J., Merline, W.J., Erard, S., Conrad, A., Drummond, J.D., Hestroffer, D., Fulchignoni, M., Fusco, T. 2009. Physical Properties of 2 Pallas. Icarus, in press.

Conrad, A. R., and 10 colleagues 2007. Direct measurement of the size, shape, and pole of 511 Davida with Keck AO in a single night. Icarus 191, 616-627.

Conrad, A.R., Merline, W.J., Drummond, J.D., Carry, B., Dumas, C., Tamblyn, P.M., Chapman, C.R., Campbell, R.D., Goodrich, R.W. 2008. Properties of 4 Asteroids from Keck Adaptive Optics, ACM 2008, 1405,,8326

Drummond, J.D. 1998. Adaptive optics Lorentzian point spread function. SPIE 3353, 1030-1037.

Drummond, J. D., Fugate, R.Q., Christou, J.C. and E.K. Hege 1998. Full adaptive optics images of asteroids Ceres and Vesta; Rotational poles and triaxial ellipsoid dimensions. Icarus 132, 80-99.

Drummond, J. D. and Christou, J. C. 2008. Triaxial ellipsoid dimensions and rotational poles of seven asteroids from Lick Observatory adaptive optics images, and of Ceres. Icarus, 197, 480-496.

Drummond, J. , Christou, J. , and Nelson, J. 2009. Triaxial ellipsoid dimensions and poles of asteroids from AO observations at the Keck-II telescope. Icarus, in press.

Kryszczyńska, A., La Spina, A., Paolicchi, P., Harris, A.W., Breiter, S., Pravec, P. 2007. New findings on asteroid spin-vector distributions. Icarus 192, 223-237.

Torppa, J., Kaasalainen, M., Michalowski, T., Kwiatkowski, T., Kryszczyńska A., Denchev, P., Kowalski, R. 2003. Shapes and rotational properties of thirty asteroids from photometric data. Icarus 164, 346-383.