RECENT RESULTS FROM IMAGING ASTEROIDS WITH ADAPTIVE OPTICS A.R. Conrad[1], W.J. Merline[2], J.D. Drummond[3], B. Carry[5], C. Dumas[4], R.D. Campbell[1], R.W. Goodrich[1], C.R. Chapman[2], P.M. Tamblyn[2] [1]W.M. Keck Observatory, 65-1120 Mamalahoa Highway, Kamuela, HI, 96743, [2]Southwest Research Institute, 1050 Walnut Street, Suite 300, Boulder, CO 80302, [3]Starfire Optical Range, Directed Energy Directorate, Air Force Research Laboratory, Kirtland AFB, New Mexico 87117-5776, [4]ESO Very Large Telescope (VLT), European Southern Observatory, Alonso de Cordova 3107, Vitacura Casilla 19001, Santiago 19, Chile, [5]ESO and LESIA, Observatoire de Paris-Meudon, 5 place Jules Janssens, 92190 Meudon Cedex, France

Introduction: We report here some of our results from recent high-angular-resolution observations of asteroids using adaptive optics (AO) on large telescopes:

- Discovery of a small, close-in satellite of (41) Daphne and resulting density measurement [1,2,3]
- Shape, size, and surface properties of (2) Pallas [5,6,7]
- First-ever, resolved optical observations of a binary near-Earth asteroid [8]
- Observations of (21) Lutetia, target of an upcoming flyby of the Rosetta mission, to search for satellites and estimate the size, shape, and pole position
- Pushing AO to smaller asteroids
- Perspectives for extremely large telescopes (ELT) [12].

Context: 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 [13]. Of course, density is the single most critical observable having a bearing on bulk composition, porosity, and internal structure [13,14].

Satellite discovery and density of (41) Daphne: In 2008 March we discovered a small satellite to large C-type asteroid (41) Daphne (Fig. 1), using AO on Keck [1]. The system has the most extreme mass ratio (10^6) of any binary known [2]. Our analysis of the satellite orbit and Daphne's unusual shape (Fig. 1) (from the original Keck images, follow-up images with VLT, and past light-curve data), provide volume and mass estimates that lead to a density of Daphne near 2.0 g/cm^3 [3], somewhat high for a C-type. Using lightcurves in addition to AO has improved our volume estimate and produced a 3-D model of higher fidelity (Fig. 2).

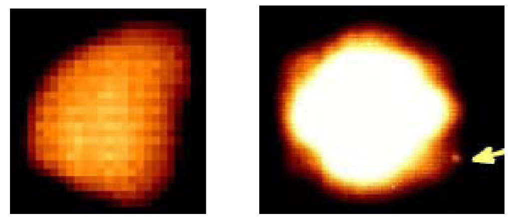

Figure 1. Representative image revealing Daphne's irregular shape (left) and discovery image of the satellite of (41) Daphne (right). Both images were obtained 2008 Mar 28 UT, using AO on Keck II.

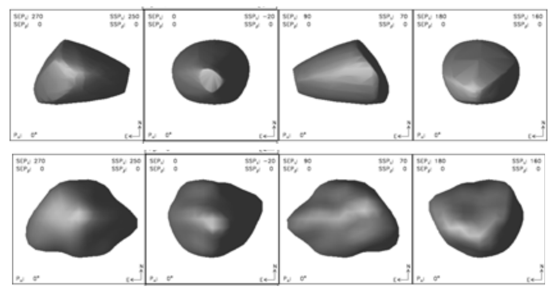

Figure 2. (41) Daphne shape models using lightcurves only (top) and lightcurves + AO (bottom).

Shape and surface properties of (2) Pallas: AO images from 7 epochs on Keck and VLT were combined with past lightcurve data to produce a triaxial fit (a=550±8 km, b=516±6 km, c=476±6 km), providing the best estimate of Pallas' short dimension, its density (3.4 ±0.6 g/cm^3), an albedo map (Fig. 3) and a two-fold improvement in the mean-diameter accuracy over the IRAS measurement [5,6]. In addition, an impact crater may have been detected [7].

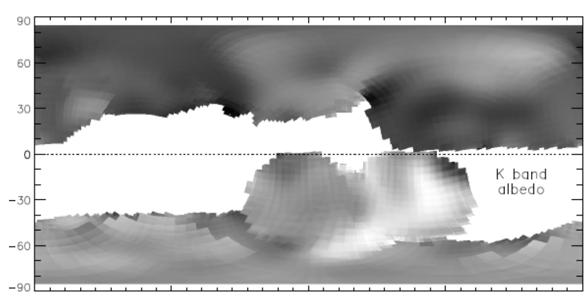

Figure 3. K-band albedo map of asteroid Pallas [6].

NEA 1991 VH: In 2008 August, we acquired the first-ever optical imaging (Fig. 4) of any binary near-Earth asteroid [8]. The asteroid, (35107) 1991 VH, was first suspected as a binary by Pravec et al. [9]. We observed a separation and size ratio consistent with that work and that of recent radar observations by Margot et al. [10]. The observered physical separation (3 km) and angular separation (0.08 arcsec) are the smallest separations ever observed for a binary asteroid with AO. This new capability is largely complementary to radar.

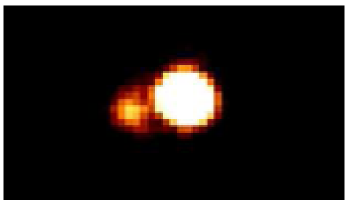

Figure 4. K-band image of near-Earth Asteroid (35107) 1991 VH taken with Keck AO on 2008 Aug 9 UT. Separation of the objects was only 3 km.

21 Lutetia: We performed extensive AO imaging of (21) Lutetia during its 2008 Dec opposition (Fig. 5). Our goals were to determine size, shape, and pole position, as well as search for satellites. We placed special emphasis on this object as part of our collaborative work with the Rosetta team. This was effectively the last opportunity to acquire data that might influence the plan for the Rosetta flyby in July 2010.

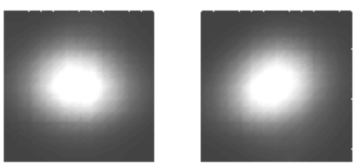

Figure 5. Two snapshots of (21) Lutetia taken with AO on Gemini North. The asteroid here is only 0.09 arcsec in diameter. Yet, its oblong shape is apparent. The observed rotation is consistent with the Lutetia's known spin period.

Pushing AO to smaller asteroids: We have demonstrated that by using AO imaging, we can determine the pole and dimensions of an asteroid in 1 or 2 nights [11], rather than the years of observations with typical lightcurve inversion techniques that only yield poles and axial ratios, not true dimensions. However, until recently we have applied our techniques only to larger asteroids --- those subtending 200+ milliarcsecond (i.e., 4 or 5 resolution elements at K-band when observed from an 8 or 10 meter telescope, respectively). At Gemini North in 2008 December, we observed 10 asteroids, specifically testing our technique on asteroids as small as 90 milliarcsec in angular size. For (9) Metis, (10) Hygeia, (21) Lutetia, (27) Euterpe, and (532) Herculina, we obtained good rotational coverage, and for (654) Zelinda and (704) Interamnia, partial rotational coverage. We also obtained a few snapshots of (29) Amphitrite, (43) Aridane, and (192) Nausikaa, which can be tied later to full rotational coverage on these objects to improve our pole and size/shape solutions. For all objects, we made a thorough search for satellites. No satellites have been detected in our initial quick-look analysis.

Perspectives for ELT: During September 2008 we reported to attendees of the *Workshop on Future Ground Based Solar System Research: Synergies with Space Probes and Space Telescope* (Elba 2008), for eventual consideration by the designers of the next generation of ("extremely") large telescopes (ELT), perspectives relevant to AO imaging of asteroids and other solar system objects [12]. These included ground-up support for differential tracking modes and the detector read-out modes required for time critical solar system events.

Acknowledgements: We acknowledge and thank M. Kaasalainen, J. Torppa, T. Michalowski et al., for making all of their shape model results publicly available on their web site. Some of the data presented herein were obtained at the W.M. Keck Observatory, which is operated as a scientific partnership among the Cal Tech, Univ. California and NASA. Keck Observatory was made possible by the generous financial support of the W.M. Keck Foundation. We also acknowledge Gemini Observatory for telescope time awarded under US/NOAO allocation as well time awarded from ESO's Very Large Telescope facility. Work was supported by the NASA PAST and OPR research programs and the NSF Planetary Astronomy program.

References: [1] Conrad, A.R. et al. (2008) *IAUC* **8930** [2] Merline, W.J. et al. (2008) *LPICo* ***1405***, 8370. [3] Conrad, A.R. et al. (2008) *DPS* **40**, 2812C. [4] Thomas, P. et al. (2004) *Icarus* **107**, 23. [5] Drummond, J.D. et al. (2009) *Icarus, submitted.* [6] Carry, B. et al. (2009) *Icarus, submitted*. [7] Carry, B. et al. (2008) *LPICo* ***1405***, 8303. [8] Merline, W.J. et al. (2008) *IAUC* **8977**. [9] Pravec, P. et al. (1997) *IAUC* **6607**. [10] Margot, J.L. et al. (2008) *DPS* **40**, 2506. [11] Conrad, A.R. et al. (2007) *Icarus* **191**, 616. [12] Conrad, A.R. et al. (2009) *EMP, submitted.* [13] Merline, W.J. et al. (2002) *Asteroids III*, 289. [14] Britt, D.T. et al. (2006) *LPSC* **37**, 2214.