HUBBLE TAKES A LOOK AT PALLAS: SHAPE, SIZE AND SURFACE.

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Introduction: As Dawn's ion engine propels the spacecraft toward the asteroid belt, there is growing interest in the asteroids as planetary predecessors. Pallas is the third largest asteroid, similar in size to Vesta, and has an orbit similar to that of Ceres. Pallas is one of the three objects in the main belt that may be a proto-planet rather than a fragment or remnant of the early solar system.

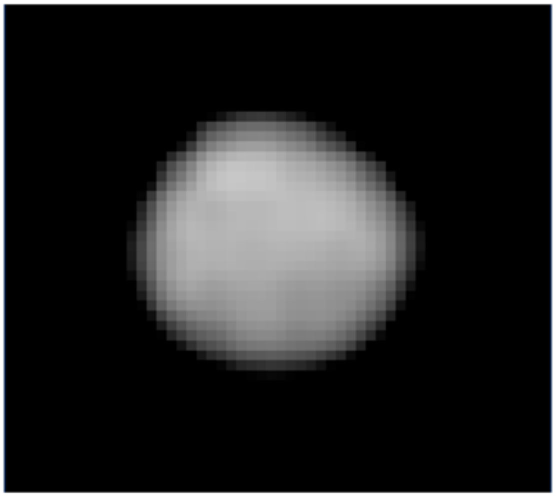


Figure 1: Pallas imaged by HST in 336nm UV filter.

Pallas is the least explored of the three major asteroids. Since several occultations in the mid-1980's were reported [3,5], Pallas' size and shape have been areas of contention. Without an accurate size determination, the asteroid's density--an important indicator of its internal structure--is also unconstrained. Historical size estimates are shown in Table 1. In addition, Pallas' pole position and sense of rotation have not been well determined. In September 2007 Pallas was observed with the Wide Field and Planetary Camera (WFPC2) camera on the Hubble Space Telescope. Images were taken in 5 filters from the UV to I in order to determine Pallas' surface properties, model its size and shape, and determine its rotational sense.

Observations: Images of Pallas were taken using the WFPC2 on HST. WFPC2 has an angular resolution of 0.045" resulting in ~70 km/pixel resolution in the final images. Observations were taken September 8, 2007 in five broad filters at 336nm (UV), 435nm (B), 555nm (V), 675nm (R), and 815nm (I). Deeper satellite search exposures were taken in V. No satellites have yet been detected, but this possibility will be further explored.

Table 1: Historical estimates of Pallas' size and the resulting density for each size. Densities were calculated assuming a mass of $1.7 \pm 0.3 \times 10^{-10}$ M_{sun}[6].

Author	Method	Size (radii)	Density
[3] Drummond & Cocke, 1989	Occultation & speckle interferom.	285±22 x 262.5 ± 4 x 241 ± 15 km	3092 kg/m^3
[5] Dunham et al, 2007	1983 Occultation	287 x 262 x 250.5 km, ±10 km	2954 kg/m^3
[4] Drummond et al, 2007	Keck IR	275±3 x 252.5±2 x 234±9 km	3444 kg/m^3
[2] Carry et al, 2007	Keck IR, ESO IR	276 x 256 x 248 km, ±10 km	3188 kg/m^3

Results: The most significant results from this study are the determinations of 1) Pallas' shape, 2) its implied density, and 3) its surface albedo variation.

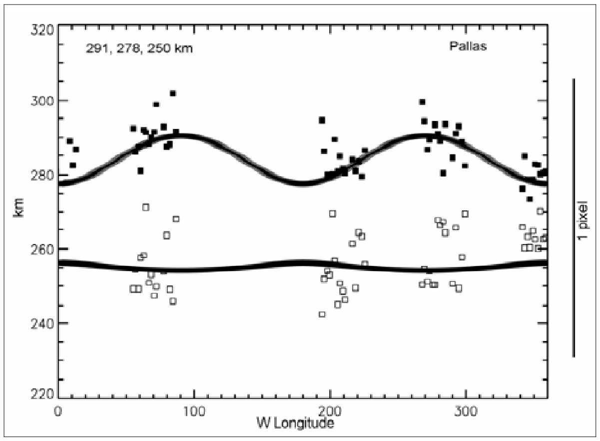
Shape and pole position. The asteroid's shape was modeled using the raw images to simultaneously solve for the edges of the limbs and the pole position. It is crucial to use raw data so as to not introduce any effects during processing. This method was first used by Thomas et al. (1998) to survey Io using Galileo images, and is described in detail in [7]. Figure 2 plots the lengths of the long and short axes as a function of rotation. The resulting size and pole position are:

$$291 \times 278 \times 250 \pm 9 \text{ km}; 2762 \text{ kg/m}^3$$
$$\text{RA}= 34, \text{Dec} =-11, \pm 10^{\circ}$$

The pole solution is in good agreement with the two most recent studies of Pallas with Keck [2&4]. The size determination, however, is larger than several of the previous estimates (Table 1). Our shape results are consistent with [5] to within uncertainties.

Density. Using our new shape estimate gives a density for Pallas of 2762 kg/m^3. This density is significantly lower than that of Vesta at 3478 kg/m^3, which is thought to have an iron core and is largely thermally altered. The density we derive is similar to that of uncondensed CM meteorite material at 2710 kg/m^3. It may however be difficult to reconcile this source with current understanding of how large asteroids thermally evolve. Given Pallas' mass and size, it seems probable

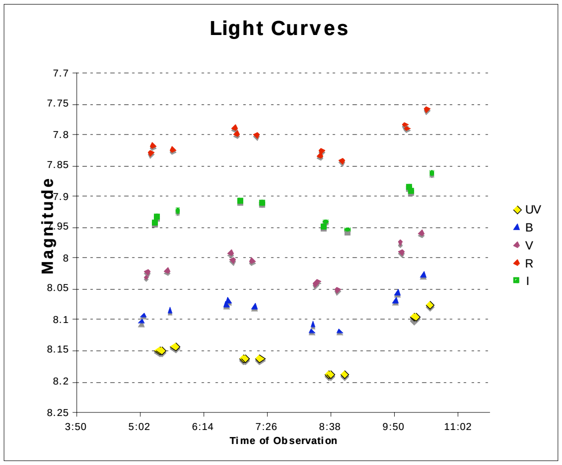
Figure 2: Dimensions of Pallas' long and short axes as a function of rotation.



that Pallas, like Vesta and Ceres, has undergone at least some degree of thermal alteration and partial differen-tiation. It is also important to understand how Pallas then relates to Ceres, assuming that both asteroids formed near their current locations and thus from potentially the same reservoir. Ceres has a density of 2077 kg/m^3 which, from its shape and mass, is proposed to be due to a large fraction of water ice beneath its surface. For Pallas to be a mixture of ice and rock, ~20-25% ice would be expected. Significant macroporosity is likely an insufficient explanation as Pallas may be too large to be highly porous [1]. Assuming a density of 3300 kg/m^3 for the rocky portion of the asteroid, a porosity of ~17% would be required to explain Pallas' density, and ~20% if the rocky fraction is the density of Vesta. Whether or not any of these interior structures is consistent with an asteroid body that survived the chaos of solar system formation has yet to be determined. Ultimately, interior models of Pallas from its shape and mass should be used to determine the nature of Pallas' low density.

Surface variation. The raw data showed evidence for pixel-to-pixel variation. But, the challenge of using WFPC2 to observe Pallas is that the asteroid is relatively dark with an albedo of 0.12, and during this opposition was close to the size of the telescope's point spread function. Image deconvolution was used to enhance the edges and any surface or albedo features on the body of the asteroid. The Maximum Entropy Method (MEM) deconvolved images that were strongest in the shorter UV and B wavelengths. The best image is shown in Figure 1. Photometry of the calibrated but unprocessed images was used to create rotational light curves in each of the five filters, shown in Figure 3. Light curves plot surface brightness over the course of an object's rotation, and their shapes can be used to find rotational periods as well as to map brightness and albedo spatial variation. With a light curve amplitude of ~0.1 and an a/b axes ratio of 1.04, only 0.04 magnitude amplitude can be derived from shape. The amplitude due to albedo variation is therefore expected to be ~0.06 magnitudes, or ~6% total variation. For Pallas, the shapes of the lightcurves are similar in each of the B, V, R and I filters, but the UV light curve departs from this trend, perhaps suggesting features near 285 degrees and near 75 degrees W longitude. From inspecting the images frame-by-frame and considering the body's shape, the progression of features is consistent with a prograde sense of rotation.

Figure 3: Light curves of Pallas in 5 filters.



Conclusions: Pallas is one of three large asteroids that stand apart as protoplanets. Using HST's WFPC2 camera, we have measured Pallas' size, shape, and physical properties. From five-band imaging there is evidence for albedo variation at the few-percent level. They are also consistent with a prograde sense of rotation. The shape measured of 291 x 278 x 250 km implies a bulk density of 2762 kg/m^3, which should drive a discussion of its internal structure. Pallas is the third piece of the puzzle in understanding the evolution of planetary bodies early in the solar system, and the roles that size and distance from the sun play in this process.

References: [1] Britt, D. T. et al (2002), in *Asteroids III*, University of Arizona Press, 485-500. [2] Carry, B. et al. (2007) *AAS-DPS Meeting*. [3] Drummond, J. D. & Cocke, W. J. (1989) *Icarus, 78*, 323-329. [4] Drummond, J. D., personal communication. [5] Dunham et al. (1990) *Astronomical Journal* 99, 1636-1652. [6] Goffin, B. (2001) *Astronomy & Astrophysics* 365, 627-630. [7] Thomas, P. C. et al. (1998) *Icarus, 135*, 175-180.

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