THE ASTEROID MASS DETERMINATION PROJECT AT THE U.S. NAVAL OBSERVATORY

JAMES L. HILTON
U.S. Naval Observatory, 3450 Massachusetts Ave. NW, Washington, DC 20392, USA
and
RONALD C. STONE
U.S. Naval Observatory Flagstaff Station, P.O. Box 1149, Flagstaff, AZ 86002, USA

Asteroid masses are the largest source of unmodeled forces in current planetary ephemerides research. Williams (1984) showed that the asteroids produce km size perturbations in the position of Mars. However, the masses of only three asteroids are known to better than 10%, and only six other asteroid masses have been determined at all.

Detecting the mass of an asteroid is difficult because the observed quantity is the change in the mean motion of a second, perturbed asteroid. Asteroid masses are small, so the change in the mean motion is typically on the order of 0."015 yr^{-1}. Thus, excellent orbit determinations are needed both before and after the perturbing encounter. This requires high precision observations over as many oppositions as possible.

Hilton (1997) determined the mass of 15 Eunomia to within 25% by detecting perturbations of 1313 Berna. The greatest source of uncertainty in determining the mass of Eunomia was the very poor coverage and accuracy of pre-encounter observations. Hilton (1998) has determined the masses of 1 Ceres, 2 Pallas and 4 Vesta, all based on mutual interactions. The uncertainties in the masses are 1% for Ceres, 3% for Pallas, and 7% for Vesta. The masses of Ceres and Pallas are the best so far, and the mass for Vesta corroborates previous determinations of its mass.

Thirty-six encounters have been chosen from (Hilton *et al.*, 1996) as being the best candidates for asteroid mass determinations. These 40 encounters can determine masses of 13 asteroids. The most important asteroids for observation are: (1) 3946 Shor can give the mass of 10 Hygiea, the fourth largest asteroid. The current uncertainty in the mass of Hygiea is 50%. (2) 263 Dresda can give the mass of 16 Psyche, the largest of the M-type asteroids. (3) 827 Wolfiana is perturbed by 19 Fortuna. (4) 2296 Kugultinov can give the mass of 24 Themis. The oppositions in 1998 and 1999 are particularly important to improve the pre-encounter orbit. (5) 2873 Binzel can significantly improve on the mass of Vesta. Other potential targets for mass determination are: 45 Eugenia, 52 Europa, 65 Cybele, 324 Bamberga, 511 Davida, and 704 Interamnia. Improving the masses of 1 Ceres and 15 Eunomia is also likely.

As previously discussed, accurate positions are needed before and after the mutual encounter of two asteroids. Most of the existing positions for asteroids have uncertainties of 0."5 or larger and contain systematic errors on the order of

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a few tenths of an arcsecond inherited from the reference frame or star catalog used in making the reductions. Starting in 1984 observations taken with either the Carlsberg Automatic Meridian Circle (Helmer and Morrison, 1985) or the Flagstaff Astrometric Scanning Transit Telescope (FASTT) (Stone, 1997) have reduced the errors in these positions to ±0."1 to ±0."2 in each coordinate.

Even better observations are now possible using a large format CCD detector and on-chip differential reductions using ACT Reference catalog reference stars (Urban et al., 1998). An observing program using this technique has been started with the FASTT telescope. Positional accuracies of ±0."06 (s.e.) are routinely obtained. Systematic errors in these observations are believed to be less than ±0."02. The FASTT observing program includes high-accuracy observations of all the asteroids involved in the 40 encounters. These data will be necessary to provide new and improved asteroid masses during the next few years. Other observatories will soon be starting similar astrometric programs.

Thus, determinations of accurate masses for several asteroids are planned over the next several years. More information, including the list of target asteroids, is available at `http://aa.usno.navy.mil/hilton/`.

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