MASSES IN THE PLUTO SYSTEM.

D. J. Tholen[1], M. W. Buie[2] and W. M. Grundy[3], [1]Institute for Astronomy, University of Hawaii (2680 Woodlawn Drive, Honolulu, HI 96822, USA, tholen@ifa.hawaii.edu), [2]Southwest Research Institute (1050 Walnut St., Suite 300, Boulder, CO 80302, USA, buie@boulder.swri.edu), [3]Lowell Observatory (1400 W. Mars Hill Rd., Flagstaff, AZ 86001, USA, W.Grundy@lowell.edu).

Introduction: The presence of multiple bodies in the Pluto system allows their individual masses to be determined via the detection of departures from Keplerian motion due to their mutual gravitational perturbations. When coupled with sizes that will eventually be determined by either the stellar occultation method or the *New Horizons* spacecraft flyby in 2015, it will be possible to compute the densities of these bodies, which can be used to place constraints on the formation mechanism for the system.

Observations: The astrometry being used to solve for the masses has been extracted mostly from direct images obtained with the Hubble Space Telescope. For more details, see the companion abstract by Buie et al. A stellar occultation during which both Pluto and Charon occulted the same star has provided a additional, extremely accurate astrometric constraint [1]. We are also planning to eventually incorporate astrometry extracted from groundbased adaptive optics images, though it will be necessary to know each instrument's image scale to approximately one part in ten thousand to prevent systematic errors from crippling the solution. Lastly, the extensive set of mutual event photometric observations between 1985 and 1990 also carry considerable astrometric information on Charon relative to Pluto [2], and we are devising methods to incorporate this source of information.

Analysis: The N-body integrator of Everhart [3] along with chi-squared statistic minimization techniques are being used to find the position vector, velocity vector, and mass for each satellite, along with the mass of Pluto. The chi-squared hypersurface remains very complex, indicating that some of the solution parameters remain poorly constrained. It is necessary to start the solution at different points to see if the function minimization process converges to a local minimum. There are also plateaus in the hypersurface with very small gradients that can give the impression of convergence having been reached, but if allowed to run long enough, greater than one-sigma changes can accumulate. We are far from the ideal case of a single, well-defined parabolic minimum for which a solution could be found in short order.

The sizes of the perturbations obviously depend on the actual masses of the satellites, but for reasonable assumptions of density and albedo, one can expect to see departures from Keplerian motion on the order of tens of milliarcseconds. The best data have signal-to-noise ratios high enough to permit astrometry good to better than ten milliarcsec, though prediscovery observations tend to have very low signal-to-noise ratios and poorer astrometry. Note that variegation on Pluto alone can produce offsets of several milliarcseconds between the center of light and the center of body, which would correspond to the center of mass for a radially symmetric body, so it is necessary to deal with this issue in order to obtain believable results.

Results: Several four-body solutions for 22 free parameters were already in the advanced stages of computation when the discovery of a new satellite of Pluto was announced [4]. Rather than aborting these solutions, they were allowed to continue, with the understanding that they are valid only to the extent that the new satellite is massless. Assuming comparable albedo and density, the new satellite would have approximately 1/30 the mass of either Nix or Hydra. These four-body solutions incorporate astrometric data on Nix and Hydra spanning eight years, and on Charon spanning over two decades, which improves on our earlier result [5].

We have also started five-body solutions for 29 free parameters, but the available astrometric data for the newly discovered satellite are quite limited in both number and timespan. Current indications are that the mass of the new satellite is not usefully constrained by the available data.

The current solution values for the masses of the other four bodies in the Pluto system are, in units of $km^3\ sec^{-2}$:

Pluto	878.9
Charon	102.7
Nix	0.031
Hydra	0.057

References: [1] Sicardy B. et al. (2011) *Astron. J.* 141. [2] Tholen D. J. and Buie M. W. (1988) *Astron. J.* 96. [3] Everhart E. (1985) *Proc. IAU Colloq. 83*. [4] Showalter M. R. et al. (2011) CBET 2769. [5] Tholen D. J. et al. (2008) *Astron. J.* 135.