OPENORB: OPEN-SOURCE ASTEROID-ORBIT-COMPUTATION SOFTWARE INCLUDING STATISTICAL ORBITAL RANGING. Mikael Granvik[1,2], Jenni Virtanen[1,3], and Karri Muinonen[1], [1]Observatory, University of Helsinki (P.O. Box 14, 00014 University of Helsinki, Finland), [2]Institute for Astronomy, University of Hawaii (2680 Woodlawn Drive, Honolulu, HI 96822, U.S.A., email: mikael.granvik@iki.fi), [3]Finnish Geodetic Institute (P.O. Box 15, 02431 Masala, Finland, email: jenni.virtanen@fgi.fi).

Introduction: We are making an open-source asteroid-orbit-computation software package called OpenOrb available upon request. OpenOrb will, at least initially, solely contain the statistical orbital ranging method (hereafter referred to as Ranging; [1] and [2], for a summary see also [3]). Ranging is used to solve the orbital inverse problem of computing non-Gaussian orbital-element probability density functions (p.d.f.s) based on input astrometry. Ranging is optimized for cases where the amount of astrometry is scarce or spans a relatively short timespan. Ranging-based methods have successfully been applied to a variety of different topics such as rigorous ephemeris prediction [4], orbital-element-distribution studies for transneptunian objects [5,6], the computation of invariant collision probabilities between NEOs and the Earth [7], detecting linkages between astrometric asteroid observations within an apparition [8] as well as between apparitions [9], and in the rigorous analysis of the impact of orbital arclength and/or astrometric uncertainty on the uncertainty of the resulting orbits [10,11]. In OpenOrb, tools for making ephemeris predictions and classification of objects (i.e., NEO-MBO-TNO) will be available.

Theory: In the Bayesian framework, the parameters to be estimated are treated as random variables and the complete solution to the inverse problem is contained in the parameters' posterior probability densities. The posterior distribution p_p is proportional to the a priori (p_{pr}) and the observational error (p_ϵ) p.d.f.s: $p_p(\boldsymbol{P}) \propto p_{pr}(\boldsymbol{P})\, p_\epsilon(\Delta\psi(\boldsymbol{P}))$, where $\boldsymbol{P}$ refers to the orbital elements and $\Delta\psi(\boldsymbol{P})$ stands for the observed minus computed (O-C) residuals. The a priori often used is Jeffreys' a priori which secures the invariance of the results. For example, the collision probability does not depend on the type of orbital elements used in the analysis.

Numerical Methods: Ranging maps the non-Gaussian orbital-element p.d.f. with a given number of sample orbits. Each sample orbit is computed using the following scheme: Two observations are chosen from the data set and a random deviate is added to all four coordinates to mimic observational noise. Next, a random topocentric distance is generated for the first observation date using a, typically, broad interval. The topocentric distance for the second observation date is generated from an interval relative to the topocentric distance on the first observation date. Since the location of the observatory with respect to the Sun is usually known, the four plane-of-sky coordinates and the two topocentric distances can be transformed into two heliocentric positions corresponding to the two observation dates. Using well-established methods in celestial mechanics, an orbit can be computed using the two heliocentric positions. The generated sample orbit is then used to compute ephemerides for the other observation dates. If the residuals are acceptable and the p.d.f. value is good enough with respect to the until-then best-fit orbit, the sample orbit is accepted. The inversion can be sped up by iteratively adjusting the intervals for the topocentric distance either by performing the simulation for a smaller number of sample orbits before performing the full-scale inversion [5] or by starting with only two observations and adding more observations step by step [8].

Software: The GPL-licensed OpenOrb package is written in Fortran90/95 using an object-oriented programming paradigm. The software is accompanied by documentation, but it is expected that the user is familiar with state-of-the-art orbit computation methods as well as with the Bayesian approach, e.g., through published literature such as the references given below. If the user intends to publish results obtained with OpenOrb, we would encourage the user to contact us in case of any doubt regarding the procedures or interpretation of the results.

References: [1] Virtanen J. et al. (2001) *Icarus, 155*, 1151–1154. [2] Muinonen et al. (2001) *CeMDA, 81*, 93–101. [3] Virtanen J. (2005) PhD thesis, Department of Astronomy, University of Helsinki. [4] Granvik M. et al. (2003) *EM&P, 92*, 73–78. [5] Virtanen J. et al. (2003) *Icarus, 161*, 419–430. [6] Virtanen J. et al. (2008) *The Solar System Beyond Neptune*, 25. [7] Virtanen J. and Muinonen K. (2006) *Icarus, 184*, 289–301. [8] Granvik M. and Muinonen K. (2005) *Icarus*, *179*, 109–127. [9] Granvik M. and Muinonen K. (2008) *Icarus*, in press. [10] Muinonen et al. (2006) *MNRAS, 368*, 809–818. [11] Virtanen J. et al. (2005) Proceedings of *The Three-Dimensional Universe with Gaia*, 325.

Additional Information: See also abstract entitled “New Method to Solve the Problem of Lost Asteroids.”