A PUBLIC–DOMAIN ASTEROID ORBIT DATABASE

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Abstract. We are constructing a database of J2000.0 osculating elements for all asteroids that have reasonably calculable orbits, and to make it publicly accessible via anonymous ftp. The database will be a very dynamic one; it will change on a quasi–daily basis as new observations and orbits become available. At present, an incomplete version of the database is online. In this paper, we present and discuss sample records of asteroid orbital data as they might appear in more mature form.

1. PURPOSE OF THE DATABASE

Conventionally, asteroid orbits resulting from four or more observations are calculated by means of least–squares differential correction of a preliminary orbit. Planetary perturbations are taken into account when : (1) observations from more than one apparition are available; (2) observations from a single apparition span a long arc; (3) a single–apparition asteroid has been observed near Earth. These are some of the precepts adopted by the Minor Planet Center in preparing the *Minor Planet Circulars* (*MPCs*), the prime source of information on asteroid orbits. We largely agree with that approach.

Our recent work on asteroid orbital errors (Muinonen and Bowell 1993a, 1993b; Muinonen *et al.* 1994) has made it clear to us that the orbits in our public–domain database could usefully contain information, in addition to that published in the *MPCs*, such as error parameters and more complete documentation of perturbation schemes. Accordingly, we plan to construct an asteroid orbital element database that will contain much more information than is customary.

2. CONTENT OF THE DATABASE

Our principal file of osculating elements will be called `astorb.dat`. In Table I we present partial sample records for two asteroids, one the very well–observed

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TABLE I
Sample Orbital Database Records for Two Asteroids

(263) Dresda	1991 RT_2	number–name/designation
331.37020559	34.82453961	M, deg (1)
161.45751209	82.40590120	ω, deg (1)
216.82169458	229.55741997	Ω, deg (1)
1.30831575	4.30946682	i, deg (1)
0.0793944410	0.1958489932	e (1)
2.8860918975	2.2386595195	a, AU (1)
19940217.0	19910921.0	epoch of osculation, TDT (yyyymmdd.d) (1)
87.98 91	15 30	arc, years or days; number of observations (2)
19050731 19930724	19910909 19911009	dates of first, last observations (2)
1.03 1.01	0.68 0.57	rms (O–C) residuals in α, δ, arcsec (2)
E. Bowell	E. Bowell	Orbit computer/ *MPC* or *EMP* reference (3)
10.40 0.15	16.0 0.15	H, mag, G (4)
		covariance matrix, rad (5)
0 0 0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0 0 0	integer–coded information (6)
M–N,1,2,4		perturbation scheme (7)
DE200		planetary ephemeris and masses(8)
2.0D9 9.2D9 7.3D9		asteroid inverse solar masses (8)
19880704 19931124	19910122 19930207	dates of record entry and last amendment (9)

(multi–apparition) main–belt asteroid (263) Dresda, the other the single–apparition asteroid 1991 RT_2. We comment on the items in each asteroid's record :

(1) J2000.0 elements are given to higher precision than is customary, even though their accuracy may be much less. This allows accurate representation of the observations and computation of residuals. Normally, the epoch of osculation for integrated orbits is the nearest 100–day Julian Date (e.g., 1993 November 11, 1994 February 17) to the current date; for 2–body orbits it is the 20–day Julian Date nearest the midtime of the orbital arc. Customized files in which, for example, the epoch of osculation is not the aforementioned, will be available on request.

(2) For a multi–apparition orbit (meaning that the asteroid passed through solar conjunction in longitude at least once between the first and last observations), the orbital arc is given in years. The number of observations is that used in the orbit computation.

(3) Orbit computers' names are given, except where reference is made to the *Minor Planet Circular* or *Ephemerides of Minor Planets* in which the orbit was published.

(4) Absolute magnitudes H and slope parameters G for numbered asteroids are

those adopted by IAU Commission 20. G defaults to 0.15 unless photometric observations suggest otherwise.

(5) Orbital element covariance matrices (not shown) contain twenty–one nonredundant elements of a 36–element matrix in M, ω, Ω, i, e, and a. They are only calculable for sufficiently well–observed asteroids. In general, at least five good–quality observations are required to yield a meaningful covariance matrix. For poor–quality (single–apparition) orbits, we will include other error parameters (to be decided) based on the results given in Muinonen *et al.* (1994). With the publication of new observations, it will usually be possible to update the covariance matrix without recomputing an orbit.

(6) We invite suggestions for the content of these important integer identifiers (there could be more than the nine integers indicated). Uses we have in mind at present (and in no particular order) are :

  (a) Orbit based on uncertain linkage(s).
  (b) Orbit includes radar observations (number given).
  (c) Orbit includes the effects of general relativity.
  (d) The asteroid is a planet–crosser, according to Shoemaker *et al.*'s (1979) definition. The parameter could also indicate crossing with respect to other planets' orbits and/or the presence of one or more protective resonances.
  (e) Family membership.
  (f) Observed in one or more of the major surveys (P–L, T–1, T–2, T–3, UCAS).
  (g) Orbit status flag, indicating, for example, an orbit in need of updating or one that does not result from all the available accurate observations.
  (h) Orbit contains fixed elements. In the case of poor or indeterminate orbits, it is customary to fix one or more elements (typically e, a, q, or i) at "reasonable" values.
  (i) Observations needed. This is our version of the Minor Planet Center's "critical list". It will be based on criteria deriving from the error analysis.

(7) The rather unwieldy string for (263) Dresda is meant to indicate that all the planets except Pluto are included in the calculation of perturbations, that the Earth and Moon are treated as separate bodies, and that the effects of asteroids (1) Ceres, (2) Pallas, and (4) Vesta—but no other asteroid—are included. Since there are a limited number of perturbation schemes used in practice, all this information (and that of other schemes) could be condensed to a single parameter. (It is to be hoped that orbit computers will move toward adopting a standardized method of orbit computation.) However, we do plan to allow for the gravitational effects of additional selected asteroids, whenever close asteroid–asteroid encounters are identified. No perturbation scheme is given for the orbit of 1991 RT_2 because that orbit is a 2–body one. In general, it is our view that the selection of orbits for which perturbed elements can usefully be calculated should be based on a threshold value (to be decided) of one or more error metrics (see below and Muinonen and Bowell 1993a). A rule of thumb, applicable to main–belt asteroids, is that some single–lunation orbits, most two–lunation orbits, and almost all longer–arc orbits should be integrated. Such orbits often lead to the identification of images on search or archive plates, whereas 2–body

TABLE II
Orbital Error Parameters for 1991 RT_2

Least–Squares Orbit (J2000.0)		
Epoch	=	1991 9 21.0 TDT = 2448520.50 JDT
Perihelion passage T	=	1991 5 25.65133072 ±0.18370150 d
Mean anomaly M	=	34.82453961 ±0.03582387 deg
Argument of perihelion ω	=	82.40590120 ±0.05129419 deg
Longitude of ascending node Ω	=	229.55741997 ±0.03034063 deg
Inclination i	=	4.30946682 ±0.00464656 deg
Eccentricity e	=	0.1958489932 ±0.0002624519
Semimajor axis a	=	2.2386595195 ±0.0007856229 AU
Mean motion n	=	0.2942537489 ±0.0001548957 deg/d
Period P	=	3.3495793586 ±0.0017632244 y
Energy	=	−0.2169652124 ±0.0000761406 (deg AU/d)^2
Angular momentum	=	1.4461224662 ±0.0002712855 deg AU^2/d
Semiminor axis b	=	2.1953057876 ±0.0007887974 AU
Perihelion distance q	=	1.8002203066 ±0.0008975046 AU
Aphelion distance Q	=	2.6770987325 ±0.0010662278AU
Heliocentric Equatorial Rectangular Coordinates (J2000.0)		
Position X	=	1.9098854236 ±0.0009740748 AU
Position Y	=	0.0395827014 ±0.0000831233 AU
Position Z	=	0.1318170525 ±0.0001578007 AU
Velocity $\dot{X}$	=	2.0712419890 ±0.0057775864 km/s
Velocity $\dot{Y}$	=	21.4207118167 ±0.0062698051 km/s
Velocity $\dot{Z}$	=	8.1956900467 ±0.0044504393 km/s

orbits may not. For near–Earth or other planet–approaching asteroids, we prefer to calculate perturbed orbits for all but the shortest arcs.

(8) We are currently using the DE200 planetary ephemeris supplied by the Jet Propulsion Laboratory. Planetary masses are defined as part of this and other such ephemerides. However, the mass of Ceres that we have adopted is slightly different from that used in computing the DE200 ephemeris.

(9) Two dates indicate when a record was first entered into the database and when the record was last amended, respectively. The latter will point the user to an auxiliary file (`astorb.log`) in which changes to the main database, including the identity of deleted records, may be traced. Thus, for example, it will be a simple matter to identify all changes during the last month.

It is possible to recover uncertainties in the orbital elements using the methods given in detail in Muinonen and Bowell (1993a). In Table II, we list some of these uncertainties. The overall quality of the orbit can be assessed using various metrics (not listed). One particular application is assessing the suitability of an orbit for proper–element calculation using the so–called incomplete *sleak* metric (Muinonen *et al.* 1994) The covariance matrix itself may be used to compute the 1–σ sky–plane uncertainty as a function of time. Also, by performing statistical tests on the distributions of the sky–plane (O–C) residuals in right ascension and declination, it is usually possible to decide which observations should be omitted to provide an improved orbit. We hope to make software available to users of the orbit database so they can perform the aforementioned calculations and tests themselves.

At present, we are only able to make publicly available a subset of the asteroid orbital data (minus error analyses), although we have already constructed a pilot version of the complete database, containing 22,735 orbits (records) of which 11,147 are integrated and the remainder 2–body. A number of tasks remain to be completed before we start on the full database. As of January 1994, we have developed software for orbit computation and differential correction (including general relativity), and subroutines for Bayesian error analysis. We will shortly combine the aforementioned software into a single mainline, and then develop a method of automatic orbit determination suitable for the analysis of the majority of the orbits to be calculated. Adding the treatment of radar observations and assessing the effects of close asteroid–asteroid encounters (other than those involving Ceres, Pallas, and Vesta) will follow. We anticipate constructing most of the database during 1994. Interested readers are invited to use `anonymous ftp` at the `internet` address `lowell.edu` (absolute address `192.103.11.2`). The password is your usual login name; then type `cd pub` and use `ls -lt astorb.*` to look for files `astorb.dat`, `astorb.log`, and `astorb.txt`, the last of which contains information on the current content of the database.

We invite potential users of the osculating element database to discuss its proposed content and to make suggestions for improvement.

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