A Java Program Generating Barycentric Observer Velocities from JPL Ephemerides.

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This work presents a program which computes velocities of an Earth-bound observatory in the reference frame of the barycenter of the solar system. It feeds from ephemerides files of the Jet Propulsion Laboratory to extract the velocity of the geocenter, optionally with corrections from Earth rotation data of the International Earth Rotation Service, takes a datum (time and geodetic location) of the observer as parameters, and processes these data with the program library of the working group ‘Standards of Fundamental Astronomy’ of the International Astronomical Union.

The prospective application of the computed velocities is to subtract their projection onto a pointing direction from observed velocities in a step of data reduction of astrometric radial velocities.

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I. SIZE AND VELOCITY SCALES

From the perspective of the determination of spectrometric radial velocity measurements in Astronomy, red or blue shifts measure velocities in the observer’s rest frame [1]. The “known” component of the relative velocity between observer and star induced by the motion of the observer in the solar system is of no essential interest, so a first step of the data reduction is to remove the contributions of [2]

1. the Earth’s elliptic motion around the sun at approximately ±30 km/s,
2. a monthly rotation of ±12 m/s of the Earth around the barycenter of the Earth-Moon two-body system with a period of ≈ 27.3 days [3],
3. the daily rotation of the telescope with the Earth crust around the Earth axis, which is up to 400 m/s at the equator and proportional to the cosine of the telescope’s latitude,
4. small contributions from the Earth polar motion of the order of mm/s,
5. tiny contributions from the sea tides of the order of centimeters per day [4],
6. contributions of 230 km/s from the motion around the Galactic center and associated proper motions [5–7].

We present a Java program which summarizes the first four of these contributions.

II. PROCEDURAL STEPS

The aim of the program is to start from a convenient presentation of the datum of the observation, a time and a position on the Earth ellipsoid, and to superimpose the three rotations around the axes mentioned above to obtain a velocity in a (quasi) non-rotating frame in the solar-system barycenter.

The steps of the computation in our program are (for given Earth-based position and time)

1. Read the coordinates of the Earth-Moon barycenter from the ephemerides of the Jet Propulsion Laboratory (JPL). The positions are the original data expressed as expansion coefficients of Chebyshev Polynomials that have scaled time intervals as their arguments. The velocities are computed by using the standard formulas for derivatives of the Chebyshev Polynomials.

2. Read the coordinates of the Moon in the geocentric reference frame from the ephemerides.

3. Optionally read corrections to the models of the resolutions of the International Astronomical Union (IAU) concerning precession and nutation of the Earth axis (direction and lag) from Bulletin B files of the International Earth Rotation Service (IERS) [8, 9].

4. Convert the observer’s position to WGS84 coordinates [10–12] if it was specified as an observatory code of the Minor Planet Center (MPC).
Nutation or libration information stored in the ephemerides files is not used.

All subsequent steps delegate processing to the SOFA library [13], which embodies the transformation conventions of 2000 and 2006 [14] in an efficient interface:

1. Construct the elements of the precession-nutation matrix implementing the IAU 2006 model of precession and IAU 2000 A model of nutation given a Terrestrial Time (TT).
2. Extract the direction of the Celestial Intermediate Pole (CIP) from that matrix.
3. Move the CIP if the program can read corrections from the Bulletin B files of the IERS found on the local disks.
4. Fix the azimuths by computing the locator $s$ of the Celestial Intermediate Origin.
5. Obtain a value of UT1 by an intermediate transformation of TT to International Atomic Time (TAI) [15]. At that point accounting for leap seconds depends on having installed recent SOFA libraries which look them up in a hard-coded table of these events. If the time is too early to define UT1 because UTC was undefined then, the program assumes that TAI and UTC are the same value.
6. Compute the Earth Rotation Angle for that UT1.
7. Obtain the “locator” $s'$ of the Terrestrial Intermediate Origin (TIO) associated with TT.
8. In a call of a single function of the library
   (a) Construct the matrix that transforms between the Celestial Intermediate Reference System and the Geocentric Celestial Reference System (GCRS) (at J2000).
   (b) Compute the observer’s geocentric position and velocity.
   (c) Rotate these 6 values into the GCRS with the aforementioned matrix.
   (d) Obtain the observer’s coordinates in the barycenter, in the International Celestial Reference System (ICRS), by adding the velocities of Earth center and observer.
9. Convert the three velocity components to meters per second and print the results.

III. SOFTWARE

Our full source code of the software is in the ancillary directory anc and licensed under the LGPL; click on the details button of the arXiv web page and download the entire source package.

A. Compilation

1. SOFA

As mentioned above, the program absolutely rests on Harrison’s Java rendering of the IAU library [16]. There is a long and a short way to install the library:

- To compile the code yourself, move to https://github.com/Javastro/jsofa, click on download, obtain jsofa-master.zip, and unbundle the files with unzip jsofa-master.zip. Move (or link) the directory jsofa-master/src/main/java/org into the same directory as our source code; we have a directory structure with directories todir/de/mpg and todir/org/jastronomy for example, if todir (for example anc) is the top directory of the Java classes. Move into the top directory and create the file jsofa.jar with
cd todir
export JAVA_TOOL_OPTIONS=-Dfile.encoding=UTF8 javac -cp . org/jastronomy/jsofa/*.java jar cf jsofa.jar org or with our Makefile via
make jsofa.jar
if you have the standard tools of Unices.

- To obtain the compiled code right away, move to http://javastro.github.io/jsofa/, click on binary in the Download menu, and rename the file to jsofa.jar.

2. Local Source

To compile the source proposed here, call
cd todir
javac -cp . de/mpg/mpia/**/*.java jar cfm jderv.jar de/mpg/mpia/jderv/Manifest.txt \ de/**/**/*.class
or
make jderv.jar
in the top directory.

The backslash at the end of the line indicates that the call is a single command line in the operating system and broken down into many lines to fit into this manuscript’s printout.

For programmers it may be helpful generate a doc subdirectory with the documentation of the Application Program Interface (API) with
cd todir
B. Configuration

The program uses one mandatory database and two optional databases as described in the next three subsections.

1. JPL Ephemerides

The program needs the ASCII files of at least one version of the ephemerides of NASA's JPL covering the requested time of observation. It means at least one of the ASCII files with the wildcard name ascp*.* and its header file header.* (with the same and occasionally in newer versions a longer suffix with an underscore) must be copied to a local database directory on the local computer. We shall refer to this directory as jpldir further down. The files are obtained from https://ssd.jpl.nasa.gov/ftp/eph/planets/ascii/de4?? where the two question marks depend on which version is wished.

For standard contemporary use one downloads at least ascp1950.432 and header.432 into jpldir. This enables the computation of velocities in the years 1950 to 2050 via the option -E 432 in the main program (see Section III C 1).

Using DE202 and earlier is possible but erroneous, because these ephemerides did not use the coordinate system of the International Celestial Reference Frame (ICRF) which the transformations of the program are based on.

Each call of the programs (see below) reads the ASCII files; reading the binary files also provided by the JPL or creating intermediate binary files for speedier execution is not supported.

2. International Earth Rotation Service

The Earth Orientation Data can be obtained by starting from https://datacenter.iers.org/products/eop/bulletinb/format_2009/csv/ and downloading any number of the files in the Comma-Separated-Values (CSV) format into the ephemerides directory [8]. Rename the files consistently to bulletinb-???.csv by replacing the .txt suffix by the .csv suffix. Alternatively move to https://datacenter.iers.org/products/eop/long-term/ and download any set of the yearly files and rename these files to eopc04_14_IAU2000.*.csv.

If the date requested by our program is covered by more than one of the IERS files, the main program takes care to let entries marked as final take precedence over entries marked as predicted.

These data contain essentially unpredictable corrections to the Earth Pole position. The files are optional; the main program assumes that corrections are zero if no values for a requested JD (day of observation) can be extracted from the files. This is the convenient interface definition for any client interface, because for most applications the values are too small to be of any relevance. The standard reasons for a failure to extract the values are

1. The files are not in the current working directory or the parameter provided by the -C option was wrong.
2. The files are present but not readable. Switching readability on and off (chmod a-r bulletinb-*.csv in Unices) is therefore a tool to study the impact of these corrections on the velocities.
3. The JD is outside the union of all days covered by the files on the local disk. Obviously this occurs if the date is in the future and the extrapolation by the IERS does not reach that far.
4. The files are not of the mandatory format with 23 fields separated by semicolons per line, because they have not been downloaded correctly.

3. MPC Observatory Codes

Observatory codes of the Minor Planet Center (MPC) are supported to simplify specifying the location of the observer on the Earth instead of specifying the three parameters in full detail for each call. That list should be obtained from https://www.minorplanetcenter.net/iau/lists/ObsCodes.html; do not grab the HTML version ObsCodesF.html. It must be moved into the same directory as the ephemerides and IERS files.

C. Use

1. Syntax Main Program

After compilation the main program is called as

    java -jar jder.jar [-E 4??] [-D juliandate] [-C jpldir] [-s samples] [-t timeIntvl] [-P ra dec] [-g long lat alt] [-g mpccode] [-v]

The brackets indicate optional arguments and are not to be keyed in. The vertical bar indicates that only one of the options must be used. All options and their arguments must be separated by white space.

The options are
• -E followed by a 3-digit number indicates the version of the JPL ephemeris to be used. If the option is missing a default is derived by searching for the environment variable PLEPHM. If this is the name (or full path name) of an existing and readable file on the computer, and if the file part starts with header., the default number is taken from the next three digits. If the lookup fails, a default of 432 is assumed.

• -D provides the time stamp of the first time. If the argument julian date contains the letter T, it must specify a UTC time stamp in the ISO 8601 format without time zone designator, YYYY-MM-DDTHH:mm:ss[.ss]. Note that the T, the two dashes and two colons, and the specification of the year by 4 digits and of the month, day, hours and minutes as 2 digits are mandatory in that format. Otherwise, if the argument is a simple number, the argument is interpreted as a Julian Date of the Terrestrial Time (TT) if larger than 2400000, or a Modified Julian Date of TT if smaller than 2400000.

If the option -D is not used, the time when the program is called is assumed.

• -C The argument of this option indicates the search directory for the ephemerides files, the optional bulletins B, and the optional ObCodes.html. If the option is used, all of these files must be in the same directory—with the aid of (symbolic) links if needed. The argument must point to a single directory. This specification may be a relative path name; the option -C .. for example tells the program to look into the parent of the current directory of the caller.

If the option is missing a default for the ephemerides directory is derived by searching for the environment variable PLEPHM. If this is the name (or full path name) of an existing and readable file or directory on the computer, the default string is taken from the directory portion. If the option -C is not used and this lookup via PLEPHM fails, the default is the current directory of the caller.

If the option is missing a default for the IERS directory is derived by searching for the environment variable iers_dir. If this is the name (or full path name) of an existing and readable directory on the computer, the directory name is taken from the environment variable. If the option is not used and this lookup via iers_dir fails, the default is to take the same directory as the ephemerides.

• -s Specifies the number of samples on the time axis. -s 1 means that the calculation is performed only once at the date clamped by the option -D. The option helps to run the program efficiently, because most of the computer time is spent converting the Ephemerides to a local binary representation, and this needs to be done only once if the range of julian dates is covered by a single JPL file. The default is 100.

• -t Specifies the time between the samples in seconds. The default is 60.

• -P Specifies a pointing direction by two angles, a right ascension and a declination. Both are floating point numbers: the right ascension in hours (modulo 24) and the declination in degrees in the range –90 to 90. They may also be submitted in the colon-separated HH:MM:SS.ss and ±DD:MM:SS.ss format.

The effect of using that option is that the three Cartesian components of the computed velocities are projected into that direction and that speed is printed in two additional columns in the output. The barycentric corrections of the star position are not taken into consideration [17, 18], assuming that the pointing also refers to J2000 coordinates, so the angle between the velocity vector and the star and therefore the dot product would not change by rotating both to the date of the observation.

• -g The three floating point arguments specify the observer’s position in the WGS84: the longitude in degrees in the range –180 to 180, the geographic latitude in degrees in the range –90 to 90, and the altitude relative to the ellipsoid in meters.

• +g This option followed by a 3-letter code of the Minor Planet Center (MPC) specifies the observer’s location on Earth (that is, in the ITRF). This is a lazy way to provide the same information as -g for the general positions by using the Obocode.html file as a lookup table.

If the options -g and +g are both used, +g takes precedence, so both options are effectively exclusive.

If neither -g nor +g is used, the positions of La Silla default [19].

There is one special flag: +g 500 triggers that any computations with respect to the observer’s motion with the Earth crust are skipped. The output reflects solely the velocity of the Earth center in the Solar System Barycenter read off the ephemerides.

Caution: some positions in the ObCodes.html are known only with 4 digits of precision, which may lead to obscure altitudes if transformed to the WGS84 system. In case of doubt run the program with -v to obtain the equivalent coordinates, or use the -g switch to provide coordinates to higher precision.

• -v This option increases the verbosity level and lets the program add values of intermediate variables
into the output stream. This additional information starts in lines with the hash (#). The option helps in particular to watch whether the IERS support data have actually been inserted into the evaluation or not; if not they are printed as zeros.

The program prints for each time stamp

1. the Julian Date (TT),
2. the three Cartesian components of the observer’s velocity in the coordinate system centered at the solar system barycenter,
3. the modulus of that barycentric velocity,
4. the projected velocity if the \-P option was used, (the dot product of the velocity and the unit vector into the pointing direction), followed by the modified value including aberration (light time effects) deduced by the radial and transverse components along the pointing direction [20],
5. the UTC time at the Julian Date in ISO format. This field is empty if the time lies earlier than the introduction of the Coordinated Time, which means, lies before a meaningful definition of leap seconds.

2. Minor Planet Equatorial Coordinates

A further program is included which transforms orbits of the Minor Planet Center to equatorial coordinates as observed from the Earth center at some spot in time.

The call is

```
java -jar jderv.jar de.mpg.mpia.jderv.MpcOrbFile E ?? -D julianate [-C jpldir] [-P ra dec coneas] [-m magni] [-a]
```

The brackets indicate optional arguments and are not to be keyed in. All options and their arguments must be separated by white space.

The options \-E and \-C have the same meaning as above and specify the JPL ephemerides to be read and a search directory. The search directory must contain the file MPCORB.DAT of the MPC, decompressed, as available from https://www.minorplanetcenter.net/data. This is the database of orbital parameters, names and magnitudes of all planets recognized by the MpcOrbFile program.

The option \-D has the same meaning as above, a time stamp of the observation in UTC or TT scales, with default the time when the program is run.

The option \-P followed by three arguments defines a region of interest in equatorial coordinates. The first and second argument are right ascension and declination in the same formats as described above, equivalent to a telescope pointing axis. The third argument is a maximum separation from that direction in arcseconds. Planets which are further away from that pointing direction than the maximum separation at the time of the observation are not printed. If the option is not used, there is no such filtering on positions, which means planets inhabiting the entire sky (even below the horizon) are considered.

The option \-m specifies a limiting magnitude. If the planet appears to be fainter than that magnitude at the time of observation, it is not printed. If the option is not used, the limit is set to 99th magnitude, which is essentially the same as none.

The option \-a indicates that all planets in the MPBORB.DAT file are to be considered, which are \approx 1.2 million in July 2022. If the option is not used, the preliminary assignments in the second part of the file (after a blank line, approximately half of the planets) are not considered.

The algorithm of the program is as follows: The JPL Ephemerides are used to locate the Earth-Moon barycenter and the relative position Moon-to-Earth and to superimpose them to yield the position of the Earth in the Solar System Barycenter as described in Section II. Furthermore the position of the sun is subtracted and the result is a heliocentric position vector of the center of the Earth.

The MPCORB.DAT file is scanned entirely but chopping off of the unconfirmed later planets (unless the \-a was used).

The following steps are performed for each planet in the order of appearance in the MPCORB.DAT:

The anomaly \(M\) of the planet is moved forward from its ephemerides time to the observation time linearly with the mean angular motion \(n\). Kepler’s equation is solved to derive the angle \(E\) [21, (8.31)(9.18)]. The inclination, major semiaxis and node-perihelion angles yield its three Cartesian coordinates in the ecliptic plane [21, (8.32)(8.35)(9.19),(9.21)]. These coordinates are tilted into the equatorial plane (of the epoch J2000) to produce heliocentric coordinates of the planet. The vector from the Earth to the Planet is computed by subtraction of the Earth center.

The light delay is derived by dividing the distance Earth-to-Planet by the light velocity, and the Planet shifted back by that time along its orbit—solving once again the Kepler equation. This is not done to full self-consistency but only once, in tangential order so to speak.

The position vector from the Earth to that light-delay-adjusted planet position is expressed in the usual right-ascension and declination angles; if that direction falls outside the cone defined with the \-P option the planet is discarded.

The apparent magnitude is computed from the \(H\) and slope-\(G\) parameters via the product of distances to Sun and Earth and mutual inclination angle [22, (10.38)(10.42)]. If the magnitude is fainter than the limit set by \-m the planet is discarded. At that step planets with a blank field for \(H\) are also considered too faint and discarded.

The program prints for each planet in the MPCORB.DAT file admitted by the filtering with the \-m, \-P and \-a op-
tions, separated by commas:

- the MPC designation,
- the right ascension in degrees,
- the declination in degrees,
- the apparent visual magnitude,
- the light time distance between Earth and planet in seconds,
- the right ascension in the hour-minute-seconds format,
- the declination in the degrees-arcminutes-arcseconds format,
- the long form of the designation, which contains the unpacked designation in parenthesis and often the assigned names of the planet.

Note that this calculation never enters a stage where the Earth attitude is needed at times other than the J2000 epoch. That reference frame is never left. The intent is to remain comparable with the modern catalogs' standard; right ascension and declination are not processed to “apparent” positions including precession-nutation, aberration or atmospheric refraction effects.

The use case of the program is to provide a warning for any minor planet that may appear as an unexpected intruder in observations which look primarily at sidereal targets. Complementary to the planet-hunters approach to find the position of the planet at a given time, this program acts like a reverse lookup to sift for known planets given position and time.

It is recommended to compare these positions with the positions computed by https://www.minorplanetcenter.net under menu Observers and Ephemerides Service. This web page offers in addition to take into account small parallaxes induced by the finite distance of the observer to the Earth center.

The program described here is convenient because one does not need to know the planets in advance which may happen to appear in some field of view of the telescope at some particular time. Its disadvantage is that 7 major planets need to be handled by other means. (The Earth is obviously not a candidate; Pluto is included in MPCORB.DAT.)

To sort the output according to declination one could for example eliminate the commas and sort numerically by the 3rd field in the style of: j

| sed 's/,/ /g' | sort -k 3g. The alternative is to import the output in a spread sheet program like oocalc using the comma as separator and to sort inside that program.

3. Syntax Bulletin B Checker

A test program that scans the Bulletin B files downloaded to the local disk is called as

```
java -jar jderv.jar de.mpg.mpia.jderv.BulletinB [-C jpldir]
```

The meaning of the -C option is the same as above: it defines the search directory for files of the form bulletinb-*.csv if that directory is not the working directory of the caller. This test program takes a time stamp 90 days backwards from the time of the call, and prints for 100 days from then on the associated data found in the files. The output shows the Modified Julian Date (MJD), the x and y components of the CIP offset, the dX and dY offsets describing polar motion, and the time shift UT1−UTC. The MJD is printed in units of days. The first four values are converted to radians, so they differ from the data of the bulletins which are in milli-arcseconds. The time lag is in units of seconds.

4. Examples

```
java -jar jderv.jar
```

prints the velocities for an observer on La Silla based on the DE432 ephemerides (in the current working directory) for the next 100 minutes in one minute intervals.

```
export PLEPHEM=/usr/local/share/jpl/header.430_229
export iers_dir=$HOME/DATA/IERS
java -jar jderv.jar -s 1
```

prints the velocities for an observer on La Silla based on the DE430 ephemerides in the /usr/local/.. directory and on the IERS bulletins in the indicated subdirectory of the home directory observing now.

```
java -jar jderv.jar -s 1800 -t 2
```

prints the velocities for an observer on La Silla based on the DE432 ephemerides for the next hour in 2 second intervals.

```
java -jar jderv.jar -s 1800 -t 2 +g 500
```

prints the velocities of the Earth center based on the DE432 ephemerides for the next hour in 2 second intervals.

```
java -jar jderv.jar -E 430 -s 30 -t 43200000 +g 000
```

prints the velocities of the Greenwich observer based on the DE432 ephemerides for the next minute in 2 second intervals.

Another test is to compute the Earth barycentric velocities in the years between 1945 and 1999 once every 500 days with

```
java -jar jderv.jar -C jpldir
-D 2431500.5 -s 41 -t 43200000 +g 500
```
The velocity’s moduli differ by less than 0.3 m/s for all years from Stumpff’s Table VII [23]. The three Cartesian components, however, differ individually by typically 200 m/s. To uncover this discrepancy, we derive a mean obliquity of the ecliptic near the middle of the period, that is 1972 and $T = -0.28$ centuries off the J2000 reference, from [24, Eq. (10)]

$$\epsilon_A \approx 84028.206305 + 0.3624445T - 0.000040397T^2$$

$$-110 \times 10^{-9}T^3 \text{arcsec},$$

$$\epsilon_A \approx 0.4073797 \text{rad}. \quad (1)$$

In addition we advance the ascending node at a pace of [24, Eq. (10)]

$$p_A \approx 8134.017132 + 5043.0520035T - 0.007107337T^2$$

$$-271 \times 10^{-9}T^3 \text{arcsec},$$

$$\overline{\text{over a period of 50 years}}, \quad T = 0.5, \quad \text{by } \Delta p_A \approx 0.01222 \text{rad.} \quad (2)$$

Performing the rotation (precession) with that angle in that ecliptic plane — rotation around $x$ by $\epsilon_A$, rotation around $z$ by $\Delta p_A$ and counter-rotation around $x$ by $-\epsilon_A$ — reduces the differences in the velocities’ Cartesian coordinates to values of $1.3 \text{m/s}$ or less. Within that precision the calculation of the program is compatible with Stumpff’s models.

App. A: JPL Reader

1. **Change Log**

   1. Much of the configuration of the classes that read individual versions of the ephemerides has been moved into the virtual base class. In particular all the individual astrometric constants are gathered from the ASCII header files; this avoids typographic errors converting these into numbers in the Java code of the derived classes that occasionally appear in JDEread 1.4. Also the storage needs are calculated from the number of Chebychev coefficients read from the header files.

   2. In consequence the `header.4??` file associated with the desired ephemeris version must now be present while the client program reads the main part of the ephemeris.

   3. In consequence the derived classes contain much less code. Adding readers for additional (forthcoming) editions of the ephemerides is reduced to gathering the file names of the ephemerides and their time spans in the derived classes.

   4. Base classes to read hitherto unsupported ephemerides versions have been added on that basis.

   5. The API has been changed such that the principal positions that are returned are measured in kilometers and the associated velocities in kilometers per day. It is left to the client to divide through the astronomical unit to get the old units.

   6. A default search path for ephemerides is recognized by scanning an optional environment variable PLEPHM.

   7. All indices of array data have been converted from the 1-based FORTRAN scheme to the 0-based C/C++/Java scheme. The 6-vectors of positions and velocity have been transformed into $2 \times 3$ arrays.

   8. Reading the Chebyshev coefficients is much more based on converting strings to double with the standard Java libraries than on parsing mantissa and exponents separately on a term-by-term basis.

2. **Standalone Uses**

   a. **Unit Test**

   The test program that compares positions and velocities with the JPL reference values is still available. First download all ephemerides for one type in the time range to be checked, the associated header file `header.4??`, and the reference data `testpo.4??` into the directory chosen to keep the data base files. Then call the test program with

   ```java -cp jderv.jar de.mpg.mpia.jdread.MainTest \ -E 4?? -C jpldir```

   where the number following the option `-E` is the ephemerides version to be tested, and where the directory name after the option `-C` is the directory with the ephemerides files. If `-E` is missing the program will assume 432, and if `-C` is missing the program will assume the current working directory.

   For DE441 also note that the currently distributed data in the JPL directories start with file `ascm13000.441` at ephemerides dates $\approx -3.027 \times 10^6$ which is insufficient coverage of the `testpo.441` which requires back to $\approx -3.099 \times 10^6$. The coverage in the data files is up to $7.93 \times 10^6$ in file `ascp16000.441` which is also insufficient to run the tests which require data up to $8.00 \times 10^6$. So to run the test successfully the lines 9–2400 and all lines from 362402 on in `testpo.441` need to be deleted to succeed.
b. All-Planets One-Time Snapshot

The program that gathers positions and velocities for all tabulated planets at a snapshot in time is called as

```
java -cp jderv.jar de.mpg.mpia.jderead.Main -E "file" -C jpldir -D jdate
```

where the three options specify available ephemerides version, directory of the ephemerides files, and a Julian Date as a floating point number. If the option -D is not used, a value of 2440400.5 is assumed, i.e., the reference value in [21, Tab. 8.2].

The output shows for each planet the three Cartesian coordinates of the position in astronomical units (AU), and the three Cartesian coordinates of the velocity in units of AU per day. The conversion factor for kilometers per AU is taken from the parameter AU of the header.4 of the ephemeris; it is not a constant.

The enumeration is 1 for Mercury, 2 for Venus, 3 for the Earth-Moon Barycenter, 4 for Mars, 5 for Jupiter, 6 for Saturn, 7 for Uranus, 8 for Neptun, 9 for Pluto, 10 for the Moon (relative to the Earth center), and 11 for the Sun. Some ephemerides have additional data that are shown without scaling to AU.

Appendix B: MPC Position Checker

There is a debugging program wired into the parser of the MPC positions list which can be called as

```
java -cp de.mpg.mpia.jderv.Jder.MpcObscod
```

where the argument is the full path name of the ASCII file with the stations list. This translates all positions from geocentric to geodetic coordinates and prints for each station the observatory code, the longitude (in degrees), the geodetic latitude (WGS84, in degrees), the altitude relative to the ellipsoid (in meters) and the description. Large negative (deep sea) altitudes or altitudes beyond the few thousand meters of Himalaya summits indicate that the quality of the entry is dubious and that these stations ought not be used with the +g flag of the main program.

An equivalent interactive transformation is implemented in

https://dc.zah.uni-heidelberg.de/obscode/q/query/form

The program also converts WGS84 positions into geocentric coordinates of the MPC via option -r (meaning “reverse”):

```
java -cp de.mpg.mpia.jderv.MpcObscod -jar jderv.jar
```

The final three numbers in this call are the longitude in degrees, the geodetic latitude in degrees, and the altitude above the ellipsoid in meters. This can be used to patch inaccurate ObsCodes.html files, or to attach new codes to the ObsCodes.html file for future use with the +g option. A MPC line for the Zugspitze at the German-Austrian border could for example be created with

```
java -cp de.mpg.mpia.jderv.MpcObscod -jar jderv.jar -r 10.9848606 47.4208929 2965
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