TEBC: A Multi-mission Time, Ephemeris, and Barycenter Correction Package

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Abstract.

TEBC is provided as a service to missions and observatories that all have to deal with issues of time and space.

Written in ANSI C, TEBC has five main components/tools to: perform conversions between various time scales (TT, TAI, ET, UTC, TDB); generate solar system ephemerides in FITS format; compute barycenter corrections; perform phase-binning of pulsar observations; calculate absolute phase for pulsars.

In addition, there is a related, though separate, C++ library that provides Time-related classes with an extensive repertoire of time transformation methods.

The TEBC package is based on a FITS-ified version of the JPL DE200 and DE405 solar system ephemerides and includes the code to convert the orginal JPL files to this format. It was originally written to provide a high-precision barycenter tool for the RXTE mission, but support for Chandra has been included, other missions can easily be added, and the functionality of the package has been extended.

1. Introduction

Several years ago, it was realized that the absolute timing accuracy of the Rossi X-ray Timing Explorer (RXTE)[1] exceeded the original specifications and requirements for the barycenter correction tools that were then in use in the High Energy Astrophysics community; it was not known anymore how accurate that code was. The only way to find out was to write new code in order to check the old.

The result is a new package that will perform time- and ephemeris-related functions such as barycenter corrections. It was decided to base the code directly on the JPL DE200 and DE405 ephemerides [2], using the Chebyshev polynomials, rather than the fourth order Taylor series used by the old code. In order to

[1] http://heasarc.gsfc.nasa.gov/docs/xte/abc/time.html

[2] http://ssd.jpl.nasa.gov/eph_info.html

achieve platform independence, these ephemerides were first converted to a FITS format. The package is written in ANSI C and it uses cfitsio [3].

2. Features

2.1. JPL Ephemerides in FITS

We have designed a simple but adequate (and complete) FITS format for the JPL solar and planetary ephemerides[4]. The objective was to acquire the conveniences of a FITS format while preserving all the information that is present in the original ephemeris files. The files consist of three binary table HDUs:

1. A simple two-column table containing all the constants (up to 200) that go with the ephemeris; the first column contains the names, the second the values of the constants. EXTNAME='DE1'.
2. The second table contains the names of the 13 solar system objects contained in the ephemeris, the number of coefficients and subintervals being used for each, and pointer information. EXTNAME='DE2'.
3. The last table contains the actual Chebyshev coefficients in a single column. Each row contains one vector with all coefficients for a particular time stamp. EXTNAME='DE3'.

The package provides a utility to create FITSified JPL ephemeris files from the original products for any time interval. Also included is a function library that contains a C version of the DPLEPH subroutine provided by JPL.

2.2. Time Conversions

TEBC recognizes and supports the following time scales[5]:
UTC, TAI, TT, TCG, TDB, TCB
Provided that all time-related keywords are properly provided in the header of the data files, time scale conversions will take place transparently. "Proper", in this context, means following the recommended conventions laid out in the appendix to the FITS Y2k DATE and TIME format agreement[6]. The basic time format is a *struct* that consists of a *long* and a *double* holding the integer and fractional part of time in MJD, and an *enumerator* holding the time scale. Shortcuts are provided to use elapsed seconds with respect to a certain epoch.

2.3. Supported Missions

The TEBC distribution contains support for RXTE and the Chandra X-ray Observatory (CXO), as well as the Geocenter. As far as I know, there are versions around that support USA and, possibly, XMM. Mission support is implemented by making the new mission known in bary.h and adding the necessary code to

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[3] http://heasarc.gsfc.nasa.gov/docs/software/fitsio/fitsio.html

[4] http://ssd.jpl.nasa.gov/eph_info.html

[5] http://legacy.gsfc.nasa.gov/docs/xte/abc/time_tutorial.html
http://tycho.usno.navy.mil/systime.html

[6] http://www.cv.nrao.edu/fits/documents/standards/year2000.txt

recognize the mission in `bary.c`. For barycenter corrections code needs to be added to `scorbit.c` to read the mission's orbit ephemeris files. This is the minimum required for supporting barycenter corrections. If one wants to be able to support clock corrections, that code needs to be added to `clock.c`. Support for *faseBin* requires added code in `phaseHist.c` to allow the package to understand some basics about the mission's data files.

2.4. Required Files

The time conversions require the file `tai-utc.dat`, containing leap second information, that is distributed by IERS[7]. Processing of RXTE data requires the file `tdc.dat`[8] that contains the coefficients for the RXTE fine clock corrections (achieving absolute time accuracy to 5 μs). The files `JPLEPH.200` and `JPLEPH.405` (and `JPLEPH`, the default) are included in the package but may also be made independently; the included ephemeris files cover the years 1950-2050. The files `psrtime.dat` and `psrbin.dat` are required for *faseBin* and *baryFase*; these contain pulsar timing ephemerides and may be obtained from the Princeton Pulsar group[9], though specialized versions are available from, e.g., ATNF[10] and Jodrell Bank[11].

3. TEBC Tools

3.1. bineph2fits

This is a utility that converts JPL ephemeris files to FITS format.

3.2. axBary

axBary is the barycenter correction tool. It searches for the principal HDU in a FITS file to determine the conversion parameters (in case not all headers are completely populated) and then corrects the HDUs.

axBary tries to determine whether DE200 or DE405 should be used, but the user can override this decision. Similarly, the user can provide the RA and Dec to be used. It also applies the best clock correction available if needed, provided it is defined for the mission; the decision is based on the value of `TIERABSO`. *axBary* is provided as a function to allow it to be easily incorporated in a wrapper that provides the desired look and feel; a simple command line wrapper is included in TEBC.

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[7] ftp://maia.usno.navy.mil/ser7/tai-utc.dat

[8] ftp://heasarc.gsfc.nasa.gov/xte/calib_data/clock/tdc.dat

[9] http://pulsar.princeton.edu/ftpdocs/gro/

[10] http://www.atnf.csiro.au/research/pulsar/psr/archive/

[11] http://www.jb.man.ac.uk/ pulsar/crab.html
ftp://ftp.jb.man.ac.uk/pub/psr/crab/all.gro

3.3. baryFase

This is a utility that returns the absolute phase, based on the timing ephemeris in `psrtime.dat` and `psrbin.dat`, for a pulsar, a time, a time scale, and a mission specified by the user. An appropriate orbit ephemeris file needs to be provided.

3.4. faseBin

faseBin combines all the elements of the previous two tools: taking event or binned data with spectral information, it bins the spectra into a specified number of absolute phase bins on the basis of a timing ephemeris in `psrtime.dat` and `psrbin.dat`. That timing ephemeris may include up to quintic (fourth period derivative) terms. Effectively, it creates a two-dimensional image with axes phase and energy to facilitate phase-resolved spectral analysis. The format of the resulting FITS file is Type II PHA, as defined by the HEASARC FITS Working Group[12]. Auxiliary tools allow the user to manipulate these images: add images; subtract baseline spectra (the "unpulsed component"); collapse along the spectral axis to obtain pulse profiles and phase-resolved hardness ratios; collapse along the phase axis to obtain phase-averaged spectra.

4. XTime

The C++ class library *XTime* contains three classes, XTime, XTimeRange, and XTRList, that support an extensive suite of time transformations and manipulations. It is in use at the RXTE SOF and the CXC. It supports time scales UTC, TAI, and TT, as well as Mission Elapsed Time (MET). Supported formats for the latter include seconds, hexadecimal seconds, and elapsed day:hh:mm:ss. Formats for the "proper" time scales include JD, MJD, FITS, calendar, and year-and-day-number.

Two command line tools for quick conversions using the library, *axTime* and *axTime3*, are included.

5. Download

TEBC:
ftp://cda.harvard.edu/pub/arcftp/bary/TEBC.tar
XTime:
ftp://cda.harvard.edu/pub/arcftp/bary/XTime.tar

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[12] http://heasarc.gsfc.nasa.gov/docs/heasarc/ofwg/ofwg_intro.html
http://heasarc.gsfc.nasa.gov/docs/heasarc/ofwg/docs/spectra/ogip_92_007/ogip_92_007.html