

# SOFA: AUTHORITATIVE TOOLS & STANDARD MODELS

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**ABSTRACT.** The International Astronomical Union’s Standards of Fundamental Astronomy (SOFA) service has the task of establishing and maintaining an accessible and authoritative set of algorithms and procedures that implement standard models used in fundamental astronomy. This poster highlights the current tools, in particular those that address *Times Scales and Calendars* and *Earth Attitude*, and previews the upcoming set of *Astrometry Tools*.

## 1. INTRODUCTION

SOFA is an IAU Division A Working Group that provides a library of building blocks of fundamental astronomy routines in Fortran and ANSI C. The SOFA library is authoritative, constructed with great care, practical, supported and accessible via its website at <http://www.iausofa.org>. Each month the website typically receives over 1500 unique visitors. At present there are 687 registered users and the latest edition (9a), released in July 2012, has been downloaded 4497 times. There are currently 59 canonical routines delivering IAU Standards, such as IAU 2006 precession, IAU 2000A nutation and other IAU Resolutions.

This poster highlights SOFA’s three “cookbooks” and the manual. The manual contains the terse descriptions consisting of detailed preamble comments in the individual routines as well as lists of the subroutine calls alphabetically and grouped into topics (e.g. time scales). The cookbooks on the other hand (see References) provide, for astronomers in particular, tutorial introduction into the topics. Short examples demonstrate how to call the routines to perform the types of conversions and transformations that may be needed in a particular application.

Note that the names of all Fortran routines have the form `iau.NAME` while for ANSI C the routine names are `iauName`. Here, for clarity, just `NAME` is used.

## 2. TOOLS FOR TIME SCALES AND CALENDARS

SOFA provides the standard routines for converting between civil and Julian dates and between Julian and Besselian epochs. Importantly SOFA includes conversion between time scales. In total there are 27 routines covering time scales and calendars.

SOFA recognizes seven time scales, namely TAI, UTC, UT1, TT, TCG, TDB and TCB. The strategy is to provide routines that link adjacent pairs of time scales (e.g. `UTCUT1` and `UTCTAI`). This is the simplest scheme that gives the user the most flexibility, needed because users provide the supplementary quantities such as  $\Delta T$  and  $UT1-UTC$ , which either cannot be predicted or for which there are model choices. The routines use SOFA’s two-argument Julian date convention, which enables rounding errors to be minimised. The routines `DTF2D` and `D2DTF` handle the conversion between civil date and time and Julian date (or, in the case of UTC, quasi-JD) and vice versa. In the case of UTC this deals with leap seconds, when it is correct to report 60.000 seconds. Importantly, the routines preserve precision by ensuring that the tiny differences are added to (or subtracted from) the smaller of the two date arguments.

## 3. TOOLS FOR EARTH ATTITUDE

SOFA’s Earth Attitude tools comprise 89, comprising not only the canonical routines that implement the various IAU standards and resolutions but also a variety of support routines. All these routines thus give the user the full scope of transformations to enable their application to achieve the results required easily and correctly. Table 1 lists some of the the most useful IAU 2006/2000A routines.

Quantities	Comments	SOFA Routine Names
$X, Y, s$	CIP & CIO locator	XYSO6A, XYO6, SO6
$\bar{\gamma}, \bar{\phi}, \bar{\psi}, \epsilon$	precession (Fukushima-Williams)	PFW06, FW2M
$\epsilon, \zeta, z, \theta$	precession (traditional)	P06E
$\Delta\psi, \Delta\epsilon$	nututation	NUT06A, NUT00A
ERA, EO	Earth rotation, equation of origins	ERA00, EO06A, EORS
GMST, GAST, EE	Greenwich sidereal time	GMST06, GST06A, EE06A
$\mathbf{M} = \mathbf{N P B}$	bias-precession-nutation	PN06A, PNM06A
$\mathbf{C} = \mathbf{C}(X + DX, Y + DY, s)$	Celestial to Intermediate	C2IXYS
$\mathbf{W} = \mathbf{R}_1(-y_p) \mathbf{R}_2(-x_p) \mathbf{R}_3(s')$	polar motion	POM00
$\mathbf{Q} = \mathbf{W R}_3(\text{GAST}) \mathbf{M}$	Celestial to Terrestrial (equinox)	C2TEQX
$\mathbf{Q} = \mathbf{W R}_3(\text{ERA}) \mathbf{C}$	Celestial to Terrestrial (CIO)	C2T06A, C2TCIO, C2TXY

Table 1: List of Earth orientation quantities and SOFA routine names. All routine names are preceded by `iau`.  $DX, DY, x_p, y_p$  (IERS) are supplied by the user. Use `TR` to calculate the inverse matrix.

#### 4. ASTROMETRY TOOLS

These routines deal with the chain of astrometric transformations linking star data from a catalog and the observed direction of the incoming radiation. The core routines convert between the barycentric and geocentric reference systems and thus deal with the effects of space motion, parallax, light-deflection and aberration, as well as refraction (approximate). These fundamental routines together with the others from the time and Earth orientation sections of SOFA provide a collection of routines that may be used to transform between any of the following: a star’s catalog position (ICRS), its astrometric position, its CIRS position, and its observed position (TIO position, ITRS position). This set of routines (32) will be made available in the next (10th) release.

*Acknowledgements.* The SOFA project is only possible due to the collaborative effort and hard work of the members of the Board, who with their institutes are listed in Table 2. Since the IAU General Assembly in 2012, Wen-Jing Jin of Shanghai Astronomical Observatory (an original Board member) retired and we welcome Jinling Li. George Hobbs (ATNF) stepped down to concentrate on other issues including Pulsar time scales, and we welcome Scott Ransom. The Board thank both Wen-Jing and George for their contributions.

Thanks are due to the Board for their oversight and in particular to Patrick Wallace, who in retirement continues to produce the source code, and Steven Bell who manages the website. Thanks are also due to the Institutes of Board members and to the United Kingdom Hydrographic Office for hosting the website.

John Bangert	United States Naval Observatory (retired)
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Brian Luzum	United States Naval Observatory (IERS)
Zinovy Malkin	Pulkovo Observatory, St Petersburg, Russia
Jeffrey Percival	University of Wisconsin, USA
Scott Ransom	National Radio Astronomy Observatory, USA
Patrick Wallace	RAL Space (retired), UK

Table 2: SOFA Board Members, their institute and country

#### 5. REFERENCES

SOFA Cookbooks downloadable from <http://www.iausofa.org/cookbooks.html>, including *SOFA Time Scales and Calendar Tools* (Fortran `sofa.ts.f.pdf` and ANSI C `sofa_ts.c.pdf` versions), *SOFA Tools for Earth Attitude* (`sofa.pn.pdf`).