SOFA Astronomy Library

PREFACE

The routines described here comprise the SOFA astronomy library. Their general appearance and coding style conforms to conventions agreed by the SOFA Review Board, and their functions, names and algorithms have been ratified by the Board. Procedures for soliciting and agreeing additions to the library are still evolving.

PROGRAMMING LANGUAGES

The SOFA routines are available in two programming languages at present: Fortran 77 and ANSI C.

Except for a single obsolete Fortran routine, which has no C equivalent, there is a one-to-one relationship between the two language versions. The naming convention is such that a SOFA routine referred to generically as "EXAMPL" exists as a Fortran subprogram iau_EXAMPL and a C function iauExampl. The calls for the two versions are very similar, with the same arguments in the same order. In a few cases, the C equivalent of a Fortran SUBROUTINE subprogram uses a return value rather than an argument.

GENERAL PRINCIPLES

The principal function of the SOFA Astronomy Library is to provide definitive algorithms. A secondary function is to provide software suitable for convenient direct use by writers of astronomical applications.

The astronomy routines call on the SOFA vector/matrix library routines, which are separately listed.

The routines are designed to exploit the full floating-point accuracy of the machines on which they run, and not to rely on compiler optimizations. Within these constraints, the intention is that the code corresponds to the published formulation (if any).

Dates are always Julian Dates (except in calendar conversion routines) and are expressed as two double precision numbers which sum to the required value.

A distinction is made between routines that implement IAU-approved models and those that use those models to create other results. The former are referred to as "canonical models" in the preamble comments; the latter are described as "support routines".

Using the library requires knowledge of positional astronomy and time-scales. These topics are covered in "Explanatory Supplement to the Astronomical Almanac", P. Kenneth Seidelmann (ed.), University Science Books, 1992. Recent developments are documented in the journals, and references to the relevant papers are given in the SOFA code as required. The IERS Conventions are also an essential reference. The routines concerned with Earth attitude (precession-nutation etc.) are described in the SOFA document sofa_pn.pdf.

ROUTINES

Calendars

CAL2JD	Gregorian calendar to Julian Day number
EPB	Julian Date to Besselian Epoch
EPB2JD	Besselian Epoch to Julian Date
EPJ	Julian Date to Julian Epoch

EPJ2JD	Julian Epoch to Julian Date
JD2CAL	Julian Date to Gregorian year, month, day, fraction
JDCALF	Julian Date to Gregorian date for formatted output

Time scales

DAT	Delta(AT) (=TAI−UTC) for a given UTC date
DTDB	TDB−TT

Earth rotation angle and sidereal time

EE00	equation of the equinoxes, IAU 2000
EE00A	equation of the equinoxes, IAU 2000A
EE00B	equation of the equinoxes, IAU 2000B
EE06A	equation of the equinoxes, IAU 2006/2000A
EECT00	equation of the equinoxes complementary terms, IAU 2000
EQEQ94	equation of the equinoxes, IAU 1994
ERA00	Earth rotation angle, IAU 2000
GMST00	Greenwich mean sidereal time, IAU 2000
GMST06	Greenwich mean sidereal time, IAU 2006
GMST82	Greenwich mean sidereal time, IAU 1982
GST00A	Greenwich apparent sidereal time, IAU 2000A
GST00B	Greenwich apparent sidereal time, IAU 2000B
GST06	Greenwich apparent ST, IAU 2006, given NPB matrix
GST06A	Greenwich apparent sidereal time, IAU 2006/2000A
GST94	Greenwich apparent sidereal time, IAU 1994

Ephemerides (limited precision)

EPV00	Earth position and velocity
PLAN94	major−planet position and velocity

Precession, nutation, polar motion

BI00	frame bias components, IAU 2000
BP00	frame bias and precession matrices, IAU 2000
BP06	frame bias and precession matrices, IAU 2006
BPN2XY	extract CIP X,Y coordinates from NPB matrix
C2I00A	celestial−to−intermediate matrix, IAU 2000A
C2I00B	celestial−to−intermediate matrix, IAU 2000B
C2I06A	celestial−to−intermediate matrix, IAU 2006/2000A
C2IBPN	celestial−to−intermediate matrix, given NPB matrix, IAU 2000
C2IXY	celestial−to−intermediate matrix, given X,Y, IAU 2000
C2IXYS	celestial−to−intermediate matrix, given X,Y and s
C2T00A	celestial−to−terrestrial matrix, IAU 2000A
C2T00B	celestial−to−terrestrial matrix, IAU 2000B
C2T06A	celestial−to−terrestrial matrix, IAU 2006/2000A
C2TCIO	form CIO−based celestial−to−terrestrial matrix
C2TEQX	form equinox−based celestial−to−terrestrial matrix
C2TPE	celestial−to−terrestrial matrix given nutation, IAU 2000
C2TXY	celestial−to−terrestrial matrix given CIP, IAU 2000
EO06A	equation of the origins, IAU 2006/2000A
EORS	equation of the origins, given NPB matrix and s
FW2M	Fukushima−Williams angles to r−matrix
FW2XY	Fukushima−Williams angles to X,Y
NUM00A	nutation matrix, IAU 2000A
NUM00B	nutation matrix, IAU 2000B
NUM06A	nutation matrix, IAU 2006/2000A
NUMAT	form nutation matrix
NUT00A	nutation, IAU 2000A
NUT00B	nutation, IAU 2000B
NUT06A	nutation, IAU 2006/2000A
NUT80	nutation, IAU 1980
NUTM80	nutation matrix, IAU 1980
OBL06	mean obliquity, IAU 2006
OBL80	mean obliquity, IAU 1980
PB06	zeta,z,theta precession angles, IAU 2006, including bias
PFW06	bias−precession Fukushima−Williams angles, IAU 2006
PMAT00	precession matrix (including frame bias), IAU 2000
PMAT06	PB matrix, IAU 2006
PMAT76	precession matrix, IAU 1976
PN00	bias/precession/nutation results, IAU 2000
PN00A	bias/precession/nutation, IAU 2000A

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   PN00B     bias/precession/nutation, IAU 2000B
   PN06      bias/precession/nutation results, IAU 2006
   PN06A     bias/precession/nutation results, IAU 2006/2000A
   PNM00A    classical NPB matrix, IAU 2000A
   PNM00B    classical NPB matrix, IAU 2000B
   PNM06A    classical NPB matrix, IAU 2006/2000A
   PNM80     precession/nutation matrix, IAU 1976/1980
   P06E      precession angles, IAU 2006, equinox based
   POM00     polar motion matrix
   PR00      IAU 2000 precession adjustments
   PREC76    accumulated precession angles, IAU 1976
   S00       the CIO locator s, given X,Y, IAU 2000A
   S00A      the CIO locator s, IAU 2000A
   S00B      the CIO locator s, IAU 2000B
   S06       the CIO locator s, given X,Y, IAU 2006
   S06A      the CIO locator s, IAU 2006/2000A
   SP00      the TIO locator s', IERS 2003
   XY06      CIP, IAU 2006/2000A, from series
   XYS00A    CIP and s, IAU 2000A
   XYS00B    CIP and s, IAU 2000B
   XYS06A    CIP and s, IAU 2006/2000A

  Fundamental arguments for nutation etc.

   FAD03     mean elongation of the Moon from the Sun
   FAE03     mean longitude of Earth
   FAF03     mean argument of the latitude of the Moon
   FAJU03    mean longitude of Jupiter
   FAL03     mean anomaly of the Moon
   FALP03    mean anomaly of the Sun
   FAMA03    mean longitude of Mars
   FAME03    mean longitude of Mercury
   FANE03    mean longitude of Neptune
   FAOM03    mean longitude of the Moon's ascending node
   FAPA03    general accumulated precession in longitude
   FASA03    mean longitude of Saturn
   FAUR03    mean longitude of Uranus
   FAVE03    mean longitude of Venus

  Star space motion

   PVSTAR    space motion pv-vector to star catalog data
   STARPV    star catalog data to space motion pv-vector

  Star catalog conversions

   FK52H     transform FK5 star data into the Hipparcos system
   FK5HIP    FK5 to Hipparcos rotation and spin
   FK5HZ     FK5 to Hipparcos assuming zero Hipparcos proper motion
   H2FK5     transform Hipparcos star data into the FK5 system
   HFK5Z     Hipparcos to FK5 assuming zero Hipparcos proper motion
   STARPM    proper motion between two epochs

  Obsolete

   C2TCEO    former name of C2TCIO


CALLS: FORTRAN VERSION

   CALL iau_BI00   ( DPSIBI, DEPSBI, DRA )
   CALL iau_BP00   ( DATE1, DATE2, RB, RP, RBP )
   CALL iau_BP06   ( DATE1, DATE2, RB, RP, RBP )
   CALL iau_BPN2XY ( RBPN, X, Y )
   CALL iau_C2I00A ( DATE1, DATE2, RC2I )
   CALL iau_C2I00B ( DATE1, DATE2, RC2I )
   CALL iau_C2I06A ( DATE1, DATE2, RC2I )
   CALL iau_C2IBPN ( DATE1, DATE2, RBPN, RC2I )
   CALL iau_C2IXY  ( DATE1, DATE2, X, Y, RC2I )
   CALL iau_C2IXYS ( X, Y, S, RC2I )
   CALL iau_C2T00A ( TTA, TTB, UTA, UTB, XP, YP, RC2T )
   CALL iau_C2T00B ( TTA, TTB, UTA, UTB, XP, YP, RC2T )
   CALL iau_C2T06A ( TTA, TTB, UTA, UTB, XP, YP, RC2T )
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      CALL iau_C2TCEO ( RC2I, ERA, RPOM, RC2T )
      CALL iau_C2TCIO ( RC2I, ERA, RPOM, RC2T )
      CALL iau_C2TEQX ( RBPN, GST, RPOM, RC2T )
      CALL iau_C2TPE  ( TTA, TTB, UTA, UTB, DPSI, DEPS, XP, YP, RC2T )
      CALL iau_C2TXY  ( TTA, TTB, UTA, UTB, X, Y, XP, YP, RC2T )
      CALL iau_CAL2JD ( IY, IM, ID, DJM0, DJM, J )
      CALL iau_DAT    ( IY, IM, ID, FD, DELTAT, J )
      D =  iau_DTDB   ( DATE1, DATE2, UT, ELONG, U, V )
      D =  iau_EE00   ( DATE1, DATE2, EPSA, DPSI )
      D =  iau_EE00A  ( DATE1, DATE2 )
      D =  iau_EE00B  ( DATE1, DATE2 )
      D =  iau_EE06A  ( DATE1, DATE2 )
      D =  iau_EECT00 ( DATE1, DATE2 )
      D =  iau_EO06A  ( DATE1, DATE2 )
      D =  iau_EORS   ( RNPB, S )
      D =  iau_EPB    ( DJ1, DJ2 )
      CALL iau_EPB2JD ( EPB, DJM0, DJM )
      D =  iau_EPJ    ( DJ1, DJ2 )
      CALL iau_EPJ2JD ( EPJ, DJM0, DJM )
      CALL iau_EPV00  ( DJ1, DJ2, PVH, PVB, J )
      D =  iau_EQEQ94 ( DATE1, DATE2 )
      D =  iau_ERA00  ( DJ1, DJ2 )
      D =  iau_FAD03  ( T )
      D =  iau_FAE03  ( T )
      D =  iau_FAF03  ( T )
      D =  iau_FAJU03 ( T )
      D =  iau_FAL03  ( T )
      D =  iau_FALP03 ( T )
      D =  iau_FAMA03 ( T )
      D =  iau_FAME03 ( T )
      D =  iau_FANE03 ( T )
      D =  iau_FAOM03 ( T )
      D =  iau_FAPA03 ( T )
      D =  iau_FASA03 ( T )
      D =  iau_FAUR03 ( T )
      D =  iau_FAVE03 ( T )
      CALL iau_FK52H  ( R5, D5, DR5, DD5, PX5, RV5,
     :                  RH, DH, DRH, DDH, PXH, RVH )
      CALL iau_FK5HIP ( R5H, S5H )
      CALL iau_FK5HZ  ( R5, D5, DATE1, DATE2, RH, DH )
      CALL iau_FW2M   ( GAMB, PHIB, PSI, EPS, R )
      CALL iau_FW2XY  ( GAMB, PHIB, PSI, EPS, X, Y )
      D =  iau_GMST00 ( UTA, UTB, TTA, TTB )
      D =  iau_GMST06 ( UTA, UTB, TTA, TTB )
      D =  iau_GMST82 ( UTA, UTB )
      D =  iau_GST00A ( UTA, UTB, TTA, TTB )
      D =  iau_GST00B ( UTA, UTB )
      D =  iau_GST06  ( UTA, UTB, TTA, TTB, RNPB )
      D =  iau_GST06A ( UTA, UTB, TTA, TTB )
      D =  iau_GST94  ( UTA, UTB )
      CALL iau_H2FK5  ( RH, DH, DRH, DDH, PXH, RVH,
     :                  R5, D5, DR5, DD5, PX5, RV5 )
      CALL iau_HFK5Z  ( RH, DH, DATE1, DATE2, R5, D5, DR5, DD5 )
      CALL iau_JD2CAL ( DJ1, DJ2, IY, IM, ID, FD, J )
      CALL iau_JDCALF ( NDP, DJ1, DJ2, IYMDF, J )
      CALL iau_NUM00A ( DATE1, DATE2, RMATN )
      CALL iau_NUM00B ( DATE1, DATE2, RMATN )
      CALL iau_NUM06A ( DATE1, DATE2, RMATN )
      CALL iau_NUMAT  ( EPSA, DPSI, DEPS, RMATN )
      CALL iau_NUT00A ( DATE1, DATE2, DPSI, DEPS )
      CALL iau_NUT00B ( DATE1, DATE2, DPSI, DEPS )
      CALL iau_NUT06A ( DATE1, DATE2, DPSI, DEPS )
      CALL iau_NUT80  ( DATE1, DATE2, DPSI, DEPS )
      CALL iau_NUTM80 ( DATE1, DATE2, RMATN )
      D =  iau_OBL06  ( DATE1, DATE2 )
      D =  iau_OBL80  ( DATE1, DATE2 )
      CALL iau_PB06   ( DATE1, DATE2, BZETA, BZ, BTHETA )
      CALL iau_PFW06  ( DATE1, DATE2, GAMB, PHIB, PSIB, EPSA )
      CALL iau_PLAN94 ( DATE1, DATE2, NP, PV, J )
      CALL iau_PMAT00 ( DATE1, DATE2, RBP )
      CALL iau_PMAT06 ( DATE1, DATE2, RBP )
      CALL iau_PMAT76 ( DATE1, DATE2, RMATP )
      CALL iau_PN00   ( DATE1, DATE2, DPSI, DEPS,
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   :                 EPSA, RB, RP, RBP, RN, RBPN )
    CALL iau_PN00A  ( DATE1, DATE2,
   :                 DPSI, DEPS, EPSA, RB, RP, RBP, RN, RBPN )
    CALL iau_PN00B  ( DATE1, DATE2,
   :                 DPSI, DEPS, EPSA, RB, RP, RBP, RN, RBPN )
    CALL iau_PN06   ( DATE1, DATE2, DPSI, DEPS,
   :                 EPSA, RB, RP, RBP, RN, RBPN )
    CALL iau_PN06A  ( DATE1, DATE2,
                      DPSI, DEPS, RB, RP, RBP, RN, RBPN )
    CALL iau_PNM00A ( DATE1, DATE2, RBPN )
    CALL iau_PNM00B ( DATE1, DATE2, RBPN )
    CALL iau_PNM06A ( DATE1, DATE2, RNPB )
    CALL iau_PNM80  ( DATE1, DATE2, RMATPN )
    CALL iau_P06E   ( DATE1, DATE2,
   :                 EPS0, PSIA, OMA, BPA, BQA, PIA, BPIA,
   :                 EPSA, CHIA, ZA, ZETAA, THETAA, PA, GAM, PHI, PSI )
    CALL iau_POM00  ( XP, YP, SP, RPOM )
    CALL iau_PR00   ( DATE1, DATE2, DPSIPR, DEPSPR )
    CALL iau_PREC76 ( EP01, EP02, EP11, EP12, ZETA, Z, THETA )
    CALL iau_PVSTAR ( PV, RA, DEC, PMR, PMD, PX, RV, J )
    D =  iau_S00    ( DATE1, DATE2, X, Y )
    D =  iau_S00A   ( DATE1, DATE2 )
    D =  iau_S00B   ( DATE1, DATE2 )
    D =  iau_S06    ( DATE1, DATE2, X, Y )
    D =  iau_S06A   ( DATE1, DATE2 )
    D =  iau_SP00   ( DATE1, DATE2 )
    CALL iau_STARPM ( RA1, DEC1, PMR1, PMD1, PX1, RV1,
   :                 EP1A, EP1B, EP2A, EP2B,
   :                 RA2, DEC2, PMR2, PMD2, PX2, RV2, J )
    CALL iau_STARPV ( RA, DEC, PMR, PMD, PX, RV, PV, J )
    CALL iau_XYS06  ( DATE1, DATE2, X, Y )
    CALL iau_XYS00A ( DATE1, DATE2, X, Y, S )
    CALL iau_XYS00B ( DATE1, DATE2, X, Y, S )
    CALL iau_XYS06A ( DATE1, DATE2, X, Y, S )


CALLS: C VERSION

       iauBi00   ( &dpsibi, &depsbi, &dra );
       iauBp00   ( date1, date2, rb, rp, rbp );
       iauBp06   ( date1, date2, rb, rp, rbp );
       iauBpn2xy ( rbpn, &x, &y );
       iauC2i00a ( date1, date2, rc2i );
       iauC2i00b ( date1, date2, rc2i );
       iauC2i06a ( date1, date2, rc2i );
       iauC2ibpn ( date1, date2, rbpn, rc2i );
       iauC2ixy  ( date1, date2, x, y, rc2i );
       iauC2ixys ( x, y, s, rc2i );
       iauC2t00a ( tta, ttb, uta, utb, xp, yp, rc2t );
       iauC2t00b ( tta, ttb, uta, utb, xp, yp, rc2t );
       iauC2t06a ( tta, ttb, uta, utb, xp, yp, rc2t );
       iauC2tcio ( rc2i, era, rpom, rc2t );
       iauC2teqx ( rbpn, gst, rpom, rc2t );
       iauC2tpe  ( tta, ttb, uta, utb, dpsi, deps, xp, yp, rc2t );
       iauC2txy  ( tta, ttb, uta, utb, x, y, xp, yp, rc2t );
    i = iauCal2jd ( iy, im, id, &djm0, &djm );
    i = iauDat    ( iy, im, id, fd, &deltat );
    d = iauDtdb   ( date1, date2, ut, elong, u, v );
    d = iauEe00   ( date1, date2, epsa, dpsi );
    d = iauEe00a  ( date1, date2 );
    d = iauEe00b  ( date1, date2 );
    d = iauEe06   ( date1, date2 );
    d = iauEect00 ( date1, date2 );
    d = iauEo06   ( date1, date2 );
    d = iauEors   ( rnpb, s );
    d = iauEpb    ( dj1, dj2 );
        iauEpb2jd ( epb, &djm0, &djm );
    d = iauEpj    ( dj1, dj2 );
        iauEpj2jd ( epj, &djm0, &djm );
    i = iauEpv00  ( dj1, dj2, pvh, pvb );
    d = iauEqeq94 ( date1, date2 );
    d = iauEra00  ( dj1, dj2 );
    d = iauFad03  ( t );
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d = iauFae03  ( t );
d = iauFaf03  ( t );
d = iauFaju03 ( t );
d = iauFal03  ( t );
d = iauFalp03 ( t );
d = iauFama03 ( t );
d = iauFame03 ( t );
d = iauFane03 ( t );
d = iauFaom03 ( t );
d = iauFapa03 ( t );
d = iauFasa03 ( t );
d = iauFaur03 ( t );
d = iauFave03 ( t );
    iauFk52h  ( r5, d5, dr5, dd5, px5, rv5,
                &rh, &dh, &drh, &ddh, &pxh, &rvh );
    iauFk5hip ( r5h, s5h );
    iauFk5hz  ( r5, d5, date1, date2, &rh, &dh );
    iauFw2m   ( gamb, phib, psi, eps, r );
    iauFw2xy  ( gamb, phib, psi, eps, &x, &y );
d = iauGmst00 ( uta, utb, tta, ttb );
d = iauGmst06 ( uta, utb, tta, ttb );
d = iauGmst82 ( uta, utb );
d = iauGst00a ( uta, utb, tta, ttb );
d = iauGst00b ( uta, utb );
d = iauGst06  ( uta, utb, tta, ttb, rnpb );
d = iauGst06a ( uta, utb, tta, ttb );
d = iauGst94  ( uta, utb );
    iauH2fk5  ( rh, dh, drh, ddh, pxh, rvh,
                &r5, &d5, &dr5, &dd5, &px5, &rv5 );
    iauHfk5z  ( rh, dh, date1, date2,
                &r5, &d5, &dr5, &dd5 );
i = iauJd2cal ( dj1, dj2, &iy, &im, &id, &fd );
i = iauJdcalf ( ndp, dj1, dj2, iymdf );
    iauNum00a ( date1, date2, rmatn );
    iauNum00b ( date1, date2, rmatn );
    iauNum06a ( date1, date2, rmatn );
    iauNumat  ( epsa, dpsi, deps, rmatn );
    iauNut00a ( date1, date2, &dpsi, &deps );
    iauNut00b ( date1, date2, &dpsi, &deps );
    iauNut06a ( date1, date2, &dpsi, &deps );
    iauNut80  ( date1, date2, &dpsi, &deps );
    iauNutm80 ( date1, date2, rmatn );
d = iauObl06  ( date1, date2 );
d = iauObl80  ( date1, date2 );
    iauPb06   ( date1, date2, &bzeta, &bz, &btheta );
    iauPfw06  ( date1, date2, &gamb, &phib, &psib, &epsa );
i = iauPlan94 ( date1, date2, np, pv );
    iauPmat00 ( date1, date2, rbp );
    iauPmat06 ( date1, date2, rbp );
    iauPmat76 ( date1, date2, rmatp );
    iauPn00   ( date1, date2, dpsi, deps,
                &epsa, rb, rp, rbp, rn, rbpn );
    iauPn00a  ( date1, date2,
                &dpsi, &deps, &epsa, rb, rp, rbp, rn, rbpn );
    iauPn00b  ( date1, date2,
                &dpsi, &deps, &epsa, rb, rp, rbp, rn, rbpn );
    iauPn06   ( date1, date2, dpsi, deps,
                &epsa, rb, rp, rbp, rn, rbpn );
    iauPn06a  ( date1, date2,
                &dpsi, &deps, &epsa, rb, rp, rbp, rn, rbpn );
    iauPnm00a ( date1, date2, rbpn );
    iauPnm00b ( date1, date2, rbpn );
    iauPnm06a ( date1, date2, rnpb );
    iauPnm80  ( date1, date2, rmatpn );
    iauP06e   ( date1, date2,
                &eps0, &psia, &oma, &bpa, &bqa, &pia, &bpia,
                &epsa, &chia, &za, &zetaa, &thetaa, &pa,
                &gam, &phi, &psi );
    iauPom00  ( xp, yp, sp, rpom );
    iauPr00   ( date1, date2, &dpsipr, &depspr );
    iauPrec76 ( ep01, ep02, ep11, ep12, &zeta, &z, &theta );
i = iauPvstar ( pv, &ra, &dec, &pmr, &pmd, &px, &rv );
d = iauS00    ( date1, date2, x, y );
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d = iauS00a   ( date1, date2 );
d = iauS00b   ( date1, date2 );
d = iauS06    ( date1, date2, x, y );
d = iauS06a   ( date1, date2 );
d = iauSp00   ( date1, date2 );
i = iauStarpm ( ra1, dec1, pmr1, pmd1, px1, rv1,
                ep1a, ep1b, ep2a, ep2b,
                &ra2, &dec2, &pmr2, &pmd2, &px2, &rv2 );
i = iauStarpv ( ra, dec, pmr, pmd, px, rv, pv );
    iauXys06  ( date1, date2, &x, &y );
    iauXys00a ( date1, date2, &x, &y, &s );
    iauXys00b ( date1, date2, &x, &y, &s );
    iauXys06a ( date1, date2, &x, &y, &s );
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