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

<table>
<thead>
<tr>
<th>Routine</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAL2JD</td>
<td>Gregorian calendar to Julian Day number</td>
</tr>
<tr>
<td>EPB</td>
<td>Julian Date to Besselian Epoch</td>
</tr>
<tr>
<td>EPB2JD</td>
<td>Besselian Epoch to Julian Date</td>
</tr>
<tr>
<td>EPJ</td>
<td>Julian Date to Julian Epoch</td>
</tr>
</tbody>
</table>
### Julian Epoch to Julian Date

- **EPJ2JD**  
  Julian Epoch to Julian Date

### Julian Date to Gregorian year, month, day, fraction

- **JD2CAL**  
  Julian Date to Gregorian year, month, day, fraction

### Julian Date to Gregorian date for formatted output

- **JDCALF**  
  Julian Date to Gregorian date for formatted output

### Time scales

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>D2DTF</td>
<td>format 2-part JD for output</td>
</tr>
<tr>
<td>DAT</td>
<td>Delta(AT) (=TAI-UTC) for a given UTC date</td>
</tr>
<tr>
<td>DTDB</td>
<td>TDB-TT</td>
</tr>
<tr>
<td>DTF2D</td>
<td>encode time and date fields into 2-part JD</td>
</tr>
<tr>
<td>TAIIT</td>
<td>TAI to TT</td>
</tr>
<tr>
<td>TAIUT1</td>
<td>TAI to UT1</td>
</tr>
<tr>
<td>TAIUTC</td>
<td>TAI to UTC</td>
</tr>
<tr>
<td>TCBTDB</td>
<td>TCB to TDB</td>
</tr>
<tr>
<td>TCGTT</td>
<td>TCG to TT</td>
</tr>
<tr>
<td>TDBTBC</td>
<td>TDB to TCB</td>
</tr>
<tr>
<td>TDBTT</td>
<td>TDB to TT</td>
</tr>
<tr>
<td>TTATAI</td>
<td>TT to TAI</td>
</tr>
<tr>
<td>TTATCG</td>
<td>TT to TCG</td>
</tr>
<tr>
<td>TTATDB</td>
<td>TT to TDB</td>
</tr>
<tr>
<td>TTATUT1</td>
<td>TT to UT1</td>
</tr>
<tr>
<td>UT1TAI</td>
<td>UT1 to TAI</td>
</tr>
<tr>
<td>UT1TT</td>
<td>UT1 to TT</td>
</tr>
<tr>
<td>UTCUTC</td>
<td>UTC to UT1</td>
</tr>
<tr>
<td>UTCTAI</td>
<td>UTC to TAI</td>
</tr>
<tr>
<td>UTCUT1</td>
<td>UTC to UT1</td>
</tr>
</tbody>
</table>

### Earth rotation angle and sidereal time

<table>
<thead>
<tr>
<th>Equation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE00</td>
<td>equation of the equinoxes, IAU 2000</td>
</tr>
<tr>
<td>EE00A</td>
<td>equation of the equinoxes, IAU 2000A</td>
</tr>
<tr>
<td>EE00B</td>
<td>equation of the equinoxes, IAU 2000B</td>
</tr>
<tr>
<td>EE06A</td>
<td>equation of the equinoxes, IAU 2006/2000A</td>
</tr>
<tr>
<td>EE06</td>
<td>equation of the equinoxes complementary terms, IAU 2000</td>
</tr>
<tr>
<td>EECT00</td>
<td>equation of the equinoxes, IAU 1994</td>
</tr>
<tr>
<td>ERA00</td>
<td>Earth rotation angle, IAU 2000</td>
</tr>
<tr>
<td>GMST00</td>
<td>Greenwich mean sidereal time, IAU 2000</td>
</tr>
<tr>
<td>GMST06</td>
<td>Greenwich mean sidereal time, IAU 2006</td>
</tr>
<tr>
<td>GMST82</td>
<td>Greenwich mean sidereal time, IAU 1982</td>
</tr>
<tr>
<td>GST00A</td>
<td>Greenwich apparent sidereal time, IAU 2000A</td>
</tr>
<tr>
<td>GST00B</td>
<td>Greenwich apparent sidereal time, IAU 2000B</td>
</tr>
<tr>
<td>GST06</td>
<td>Greenwich apparent ST, IAU 2006, given NPB matrix</td>
</tr>
<tr>
<td>GST06A</td>
<td>Greenwich apparent sidereal time, IAU 2006/2000A</td>
</tr>
<tr>
<td>GST94</td>
<td>Greenwich apparent sidereal time, IAU 1994</td>
</tr>
</tbody>
</table>

### Ephemerides (limited precision)

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>EPV00</td>
<td>Earth position and velocity</td>
</tr>
<tr>
<td>PLAN94</td>
<td>major-planet position and velocity</td>
</tr>
</tbody>
</table>

### Precession, nutation, polar motion

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BI00</td>
<td>frame bias components, IAU 2000</td>
</tr>
<tr>
<td>BP00</td>
<td>frame bias and precession matrices, IAU 2000</td>
</tr>
<tr>
<td>BP06</td>
<td>frame bias and precession matrices, IAU 2006</td>
</tr>
<tr>
<td>BPN2XY</td>
<td>extract CIP X,Y coordinates from NPB matrix</td>
</tr>
<tr>
<td>C2I00A</td>
<td>celestial-to-intermediate matrix, IAU 2000A</td>
</tr>
<tr>
<td>C2I00B</td>
<td>celestial-to-intermediate matrix, IAU 2000B</td>
</tr>
<tr>
<td>C2I06A</td>
<td>celestial-to-intermediate matrix, IAU 2006/2000A</td>
</tr>
<tr>
<td>C2IBPN</td>
<td>celestial-to-intermediate matrix, given NPB matrix, IAU 2000</td>
</tr>
<tr>
<td>C2IXY</td>
<td>celestial-to-intermediate matrix, given X,Y, IAU 2000</td>
</tr>
<tr>
<td>C2IXYS</td>
<td>celestial-to-intermediate matrix, given X,Y and s</td>
</tr>
<tr>
<td>C2T00A</td>
<td>celestial-to-terrestrial matrix, IAU 2000A</td>
</tr>
<tr>
<td>C2T00B</td>
<td>celestial-to-terrestrial matrix, IAU 2000B</td>
</tr>
<tr>
<td>C2T06A</td>
<td>celestial-to-terrestrial matrix, IAU 2006/2000A</td>
</tr>
<tr>
<td>C2TCIO</td>
<td>form CIO-based celestial-to-terrestrial matrix</td>
</tr>
<tr>
<td>C2TQX</td>
<td>form equinox-based celestial-to-terrestrial matrix given nutation, IAU 2000</td>
</tr>
<tr>
<td>C2TPE</td>
<td>form equinox-based celestial-to-terrestrial matrix given nutation, IAU 2000</td>
</tr>
<tr>
<td>C2TXY</td>
<td>celestial-to-terrestrial matrix given CIP, IAU 2000</td>
</tr>
<tr>
<td>E06A</td>
<td>equation of the origins, IAU 2006/2000A</td>
</tr>
<tr>
<td>EORS</td>
<td>equation of the origins, given NPB matrix and s</td>
</tr>
<tr>
<td>FW2M</td>
<td>Fukushima-Williams angles to r-matrix</td>
</tr>
<tr>
<td>FW2XY</td>
<td>Fukushima-Williams angles to X,Y</td>
</tr>
</tbody>
</table>
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
OBL06   mean obliquity, IAU 2006
OBL80   mean obliquity, IAU 1980
PB06    zeta, z, theta precession angles, IAU 2006, including bias
PF06    bias-precession Fukushima-Williams angles, IAU 2006
PMA700  precession matrix (including frame bias), IAU 2000
PMA76   precession matrix, IAU 1976
PMN00A  classical NPB matrix, IAU 2000A
PMN00B  classical NPB matrix, IAU 2000B
PMN06A  classical NPB matrix, IAU 2006/2000A
PMN80   precession/nutation matrix, IAU 1976/1980
PNE06   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
S06B    the CIO locator s, IAU 2000B
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
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
HFK52   Hipparcos to FK5 assuming zero Hipparcos proper motion
STARM   proper motion between two epochs

Geodetic/geocentric
EFORM     a,f for a nominated Earth reference ellipsoid
GC2GD     geocentric to geodetic for a nominated ellipsoid
GC2GDE    geocentric to geodetic given ellipsoid a,f
GD2GCE    geodetic to geocentric given ellipsoid a,f

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 )
CALL iau_C2TCEO ( RC2I, ERA, RPOM, RC2T )
CALL iau_C2TCIO ( RC2I, ERA, RPOM, RC2T )
CALL iau_C2TEQX ( RC2I, ERA, RPOM, RC2T )
CALL iau_CAL2JD ( IY, IM, ID, DJM0, DJM, J )
CALL iau_D2DTF ( SCALE, NDP, D1, D2, IY, IM, ID, IHMSF, J )
CALL iau_DAT ( IY, IM, ID, FD, DELTAT, J )
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 )
CALL iau_EFORM ( N, A, F, J )
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_FA03 ( T )
D = iau_FAU03 ( T )
D = iau_FAL03 ( T )
D = iau_FALP03 ( T )
D = iau_FAMA03 ( T )
D = iau_FANE03 ( T )
D = iau_FAOM03 ( T )
D = iau_FAPA03 ( T )
D = iau_FAFA03 ( T )
D = iau_FAS03 ( T )
D = iau_FASS03 ( T )
D = iau_FAV03 ( T )
D = iau_FFA03 ( T )
D = iau_FFA03 ( T )
D = iau_FFAU03 ( T )
D = iau_FGK0 ( T )
D = iau_FGK52H ( R5, D5, DR5, DD5, PX5, RV5, RH, DH, DRH, DDH, PXH, RVH )
CALL iau_FK5HIP ( RSH, S5H )
CALL iau_FK55HZ ( R5, D5, DATE1, DATE2, RH, DH )
CALL iau_FW2M ( GAMB, PHIB, PSI, EPS, R )
CALL iau_FW2XY ( GAMB, PHIB, PSI, EPS, X, Y )
CALL iau_GC2GD ( N, XYZ, ELONG, PHI, HEIGHT, J )
CALL iau_GC2GDE ( A, F, XYZ, ELONG, PHI, HEIGHT, J )
CALL iau_GD2GC  ( N, ELONG, PHI, HEIGHT, XYZ, J )
CALL iau_GD2GCE ( A, F, ELONG, PHI, HEIGHT, XYZ, J )
D = iau_GMST00 ( UTA, UTB, TTA, TTB )
D = iau_GMST06 ( UTA, UTB, TTA, TTB )
D = iau_GST00A ( UTA, UTB, TTA, TTB )
D = iau_GST00B ( UTA, UTB )
D = iau_GST06  ( UTA, UTB, TTA, TTB )
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 )
CALL iau_HFK5Z  ( RH, DH, DATE1, DATE2, R5, D5, DR5, DD5 )
CALL iau_JD2CAL ( DJ1, DJ2, IY, IM, ID, 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_NUM06B ( DATE1, DATE2, RMATN )
CALL iau_OBL06  ( DATE1, DATE2 )
D = iau_OBL80 ( DATE1, DATE2 )
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, RPM )
CALL iau_PR00   ( DATE1, DATE2, DPSIPR, DEPSPR )
CALL iau_PVEC76 ( EPS1, EPS2, EPS1, EPS2, 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_S06B   ( 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_TAITT ( TAI1, TAI2, TT1, TT2, J )
CALL iau_TAIUTC ( TAI1, TAI2, UTC1, UTC2, J )
CALL iau_TCBTDB ( TCB1, TCB2, TDB1, TDB2, J )
CALL iau_TCDT  ( TCG1, TCG2, TT1, TT2, J )
CALL iau_TCDT80 ( TDB1, TDB2, TCB1, TCB2, J )
CALL iau_TDTB  ( TDB1, TDB2, DTR, TT1, TT2, J )
CALL iau_TTTAI ( TT1, TT2, TAI1, TAI2, J )
CALL iau_TTTCG ( TT1, TT2, TCG1, TCG2, J )
CALL iau_TTTDB  ( TT1, TT2, DTR, TDB1, TDB2, J )
CALL iau_TTU1T1 ( TT1, TT2, DT, UT11, UT12, J )
CALL iau_UT1TAI ( UT11, UT12, TAI1, TAI2, J )
CALL iau_UT1TTT ( UT1, UT11, DT, TT1, TT2, J )
CALL iau_UT1UTC ( UT11, UT12, DUT, UTC1, UTC2, J )
CALL iau_UTCTAI ( UTC1, UTC2, DTA, TAI1, TAI2, J )
CALL iau_UTCTUT1 ( UTC1, UTC2, DUT, UT11, UT12, J )
CALL iau_XY06 ( 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

iauB00 ( &dpsibi, &depsbi, &dra );
iauBp00 ( datel, date2, rb, rp, rbp );
iauBp06 ( datel, date2, rb, rp, rbp );
iauBpn2xy ( rbpn, &x, &y );
iauC2i00a ( datel, date2, rc2i );
iauC2i00b ( datel, date2, rc2i );
iauC2i06a ( datel, date2, rc2i );
iauC2ibpn ( datel, date2, rbpn, rc2i );
iauC2ixy ( datel, 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, gast, rpom, rc2t );
iauC2tpe ( tta, ttb, uta, utb, dps, epsi, dpsi, xp, yp, rc2t );
i = iauCal12jd ( iy, im, id, &djm0, &djm );
i = iauD2dtf ( scale, ndp, d1, d2, &iy, &im, &id, ihmsf );
i = iauDat ( iy, im, id, fd, &deltat );
d = iauD2dtf2 ( scale, iy, im, id, ihr, imn, sec, &d1, &d2 );
d = iauDtr ( datel, date2, epsa, dpsi );
d = iauEe00 ( datel, date2 );
d = iauEe00a ( datel, date2 );
d = iauEe00b ( datel, date2 );
d = iauEe06 ( datel, date2 );
d = iauEect00 ( datel, date2 );
i = iauEform ( n, &a, &f );
d = iauEo06 ( datel, date2 );
d = iauEors ( rnpb, s );
d = iauEpb ( dj1, dj2 );
iauEpp2jd ( epb, &djm0, &djm );
d = iauEpj ( dj1, dj2 );
iauEpj2jd ( epj, &djm0, &djm );
i = iauEvp00 ( dj1, dj2, pvh, pvh );
d = iauEvq6 ( datel, date2 );
d = iauEra00 ( dj1, dj2 );
d = iauFad03 ( t );
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d = iauFadd03 ( t );
d = iauFaalp03 ( t );
d = iauFama03 ( t );
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d = iauFama03 ( t );

iauFk52h ( r5, d5, dr5, dd5, px5, rv5, &rh, &dh, &dhh, &pxh, &rvh );
iauFk5hip ( r5h, s5h );
iauFk5hz ( r5, d5, datel, date2, &rh, &dh );
iauFw2m ( gamb, phib, psi, eps, r );
iauFw2xy ( gamb, phib, psi, eps, &x, &y );
i = iauTdbtt ( tdb1, tdb2, dtr, &tt1, &tt2 );
i = iauTttai ( ttl, tt2, &tai1, &tai2 );
i = iauTttcg ( ttl, tt2, &tcg1, &tcg2 );
i = iauTttdb ( ttl, tt2, dtr, &tdb1, &tdb2 );
i = iauTtut ( ttl, tt2, dt, &ut11, &ut12 );
i = iauUt1ttai ( ut11, ut12, &tai1, &tai2 );
i = iauUt1tt ( ut11, ut12, dt, &tt1, &tt2 );
i = iauUt1utc ( ut11, ut12, dut, &utc1, &utc2 );
i = iauUtctai ( utc1, utc2, dt, &tai1, &tai2 );
i = iauUtct ( utc1, utc2, dut, &ut11, &ut12 );
iauXy06 ( date1, date2, &x, &y );
iauXys00a ( date1, date2, &x, &y, &s );
iauXys00b ( date1, date2, &x, &y, &s );
iauXys06a ( date1, date2, &x, &y, &s );