



Figure 1: Relationship Between Celestial Coordinates

Star positions are published or catalogued using one of the mean $[\alpha, \delta]$ systems shown at the top. The “FK4” systems were used before about 1980 and are usually equinox B1950. The “FK5” system, equinox J2000, is now preferred. The figure relates a star’s mean $[\alpha, \delta]$ to the actual line-of-sight to the star. Note that for the conventional choices of equinox, namely B1950 or J2000, all of the precession and E-terms corrections are superfluous.

```

:          '''Polaris north polar distance (deg) 2096-2105''/')')
WRITE (*,'(4X,'Date'',7X,'NPD''/)'')
CALL sla_CLDJ(2096,1,1,DATE,J)
IDS=NINT(DATE)
CALL sla_CLDJ(2105,12,31,DATE,J)
IDE=NINT(DATE)
DO ID=IDS,IDE,10
  DATE=DBLE(ID)
  CALL sla_DJCAL(0,DATE,IY MDF,J)
  CALL sla_MAP(RM,DM,PR,PD,ODO,ODO,2000DO,DATE,RA,DA)
  WRITE (*,'(1X,I4,2I3.2,F9.5)') (IY MDF(I),I=1,3),(PIBY2-DA)/D2R
END DO

END

```

For cases where the transformation has to be repeated for different times or for more than one star, the straightforward `sla_MAP` approach is apt to be wasteful as both the Earth velocity and the precession/nutation matrix can be re-calculated relatively infrequently without ill effect. A more efficient method is to perform the target-independent calculations only when necessary, by calling `sla_MAPPA`, and then to use either `sla_MAPQKZ`, when only the $[\alpha, \delta]$ is known, or `sla_MAPQK`, when full catalogue positions, including proper motion, parallax and radial velocity, are available. How frequently to call `sla_MAPPA` depends on the accuracy objectives; once per night will deliver sub-arcsecond accuracy for example.

The routines `sla_AMP` and `sla_AMPQK` allow the reverse transformation, from apparent to mean place.

4.13 Apparent Place to Observed Place

The *observed place* of a source is its position as seen by a perfect theodolite at the location of the observer. Transformation of an apparent $[\alpha, \delta]$ to observed place involves the following effects:

- $[\alpha, \delta]$ to $[h, \delta]$.
- Diurnal aberration.
- $[h, \delta]$ to $[Az, El]$.
- Refraction.

The transformation from apparent $[\alpha, \delta]$ to apparent $[h, \delta]$ is made by allowing for *Earth rotation* through the *sidereal time*, θ :

$$h = \theta - \alpha$$

For this equation to work, α must be the apparent right ascension for the time of observation, and θ must be the *local apparent sidereal time*. The latter is obtained as follows:

1. from civil time obtain the coordinated universal time, UTC (more later on this);
2. add the UT1-UTC (typically a few tenths of a second) to give the UT;
3. from the UT compute the Greenwich mean sidereal time (using `sla_GMST`);

4. add the observer's (east) longitude, giving the local mean sidereal time;
5. add the equation of the equinoxes (using `sla_EQEQX`).

The *equation of the equinoxes* ($= \Delta\psi \cos \epsilon$ plus small terms) is the effect of nutation on the sidereal time. Its value is typically a second or less. It is interesting to note that if the object of the exercise is to transform a mean place all the way into an observed place (very often the case), then the equation of the equinoxes and the longitude component of nutation can both be omitted, removing a great deal of computation. However, SLALIB follows the normal convention and works *via* the apparent place.

Note that for very precise work the observer's longitude should be corrected for *polar motion*. There is no SLALIB routine for applying polar motion corrections to the observer's mean longitude and latitude, but the required formulae are straightforward and easy to implement. The corrections are always less than about 0".3, and are futile unless the position of the observer's telescope is known to better than a few metres.

Tables of observed and predicted UT1–UTC corrections and polar motion data are published every few weeks by the International Earth Rotation Service.

The transformation from apparent $[h, \delta]$ to *topocentric* $[h, \delta]$ consists of allowing for *diurnal aberration*. This effect, maximum amplitude 0".2, was described earlier. There is no specific SLALIB routine for computing the diurnal aberration, though the routines `sla_AOP` etc. include it, and the required velocity vector can be determined by calling `sla_GEOC`.

The next stage is the major coordinate rotation from local equatorial coordinates $[h, \delta]$ into horizon coordinates. The SLALIB routines `sla_E2H` etc. can be used for this. For high-precision applications the mean geodetic latitude should be corrected for polar motion.

The final correction is for atmospheric refraction. This effect, which depends on local meteorological conditions and the effective colour of the source/detector combination, increases the observed elevation of the source by a significant effect even at moderate zenith distances, and near the horizon by over 0".5. The amount of refraction can be computed by calling the SLALIB routine `sla_REFRO`; however, this requires as input the observed zenith distance, which is what we are trying to predict. For high precision it is therefore necessary to iterate, using the topocentric zenith distance as the initial estimate of the observed zenith distance.

The full refraction calculation is onerous, and for zenith distances of less than 70° the following model can be used instead:

$$\zeta_{vac} \approx \zeta_{obs} + A \tan \zeta_{obs} + B \tan^3 \zeta_{obs}$$

where ζ_{vac} is the topocentric zenith distance (i.e. *in vacuo*), ζ_{obs} is the observed zenith distance (i.e. affected by refraction), and A and B are constants (which can be obtained by calling `sla_REFRO`). At sea level, A and B are about 60" and $-0".06$ respectively. Like the full refraction model, this formulation works in the wrong direction for our purposes, predicting the *in vacuo* (topocentric) zenith distance given the refracted (observed) zenith distance, rather than *vice versa*. The obvious approach of interchanging ζ_{vac} and ζ_{obs} and reversing the signs, though approximately correct, gives avoidable errors which are just significant in some applications; for example about 0".2 at 70° zenith distance. A much better result can easily be obtained, by using one Newton-Raphson iteration as follows:

$$\zeta_{obs} \approx \zeta_{vac} - \frac{A \tan \zeta_{vac} + B \tan^3 \zeta_{vac}}{1 + (A + 3B \tan^2 \zeta_{vac}) \sec^2 \zeta_{vac}}$$

The effect of refraction can be applied to an unrefracted zenith distance by calling `sla_REFZ` or to an unrefracted $[x, y, z]$ by calling `sla_REFV`. Over most of the sky these two routines deliver almost identical results, but beyond $\zeta = 83^\circ$ `sla_REFV` becomes unacceptably inaccurate while `sla_REFZ` remains usable. (However `sla_REFV` is significantly faster, which may be important in some applications.) SLALIB also provides a routine for computing the airmass, the function `sla_AIRMAS`.

The complete apparent place to observed place transformation can be carried out by calling `sla_AOP`. For improved efficiency in cases of more than one star or a sequence of times, the target-independent calculations can be done once by calling `sla_AOPPA`, the time can be updated by calling `sla_AOPPAT`, and `sla_AOPQK` can then be used to perform the apparent-to-observed transformation. The reverse transformation is available through `sla_OAP` and `sla_OAPQK`. (*n.b.* These routines use accurate but computationally-expensive refraction algorithms for zenith distances beyond about 76° . For many purposes, in-line code tailored to the accuracy requirements of the application will be preferable, for example ignoring UT1–UTC, omitting diurnal aberration and using `sla_REFZ` to apply the refraction.)

4.14 Timescales

SLALIB provides for conversion between several timescales, and involves use of one or two others. The full list is as follows:

- TAI: International Atomic Time
- UTC: Coordinated Universal Time
- UT: Universal Time
- GMST: Greenwich Mean Sidereal Time
- LAST: Local Apparent Sidereal Time
- TT: Terrestrial Time
- TDB: Barycentric Dynamical Time.

Three obsolete timescales should be mentioned here to avoid confusion.

- GMT: Greenwich Mean Time – can mean either UTC or UT1.
- ET: Ephemeris Time – more or less the same as either TT or TDB.
- TDT: Terrestrial Dynamical Time – former name of TT.

4.14.1 Atomic Time: TAI

International Atomic Time TAI is a laboratory timescale. Its unit is the SI second, which is defined in terms of a defined number of wavelengths of the radiation produced by a certain electronic transition in the caesium 133 atom. It is realized through a changing population of high-precision atomic clocks held at standards institutes in various countries. There is an elaborate process of continuous intercomparison, leading to a weighted average of all the clocks involved.