CHART: TRANSFORMATION FROM ICRS TO OBSERVED PLACES OF STARS

The aim is to highlight the CIO and Equinox based approaches and to specify in what order to apply the usual corrections (annual aberration, precession-nutation etc.) when predicting apparent star directions for a ground-based observer. In typical cases the BCRS to GCRS portion of the method, using existing annual aberration and light deflection formulations, is accurate to a small fraction of a milliarcsecond. However, the omission of light deflection by the planets could in extreme cases cause errors approaching 20 milliarcseconds and there are various other missing terms at the sub-milliarcsecond level.

For very precise reductions it is necessary to use a fully GR-based approach: for more details, see IERS Conventions 2003 (Chapter 11), Klioner 2003, or Kaplan 1998. Note also that the transformation from the ITRS to observed place set out in the chart would require more complicated steps in the GR framework to achieve microarcsecond accuracy. Similarly, in demanding interferometer applications such as VLBI the geometry of the baselines requires a fully relativistic treatment.

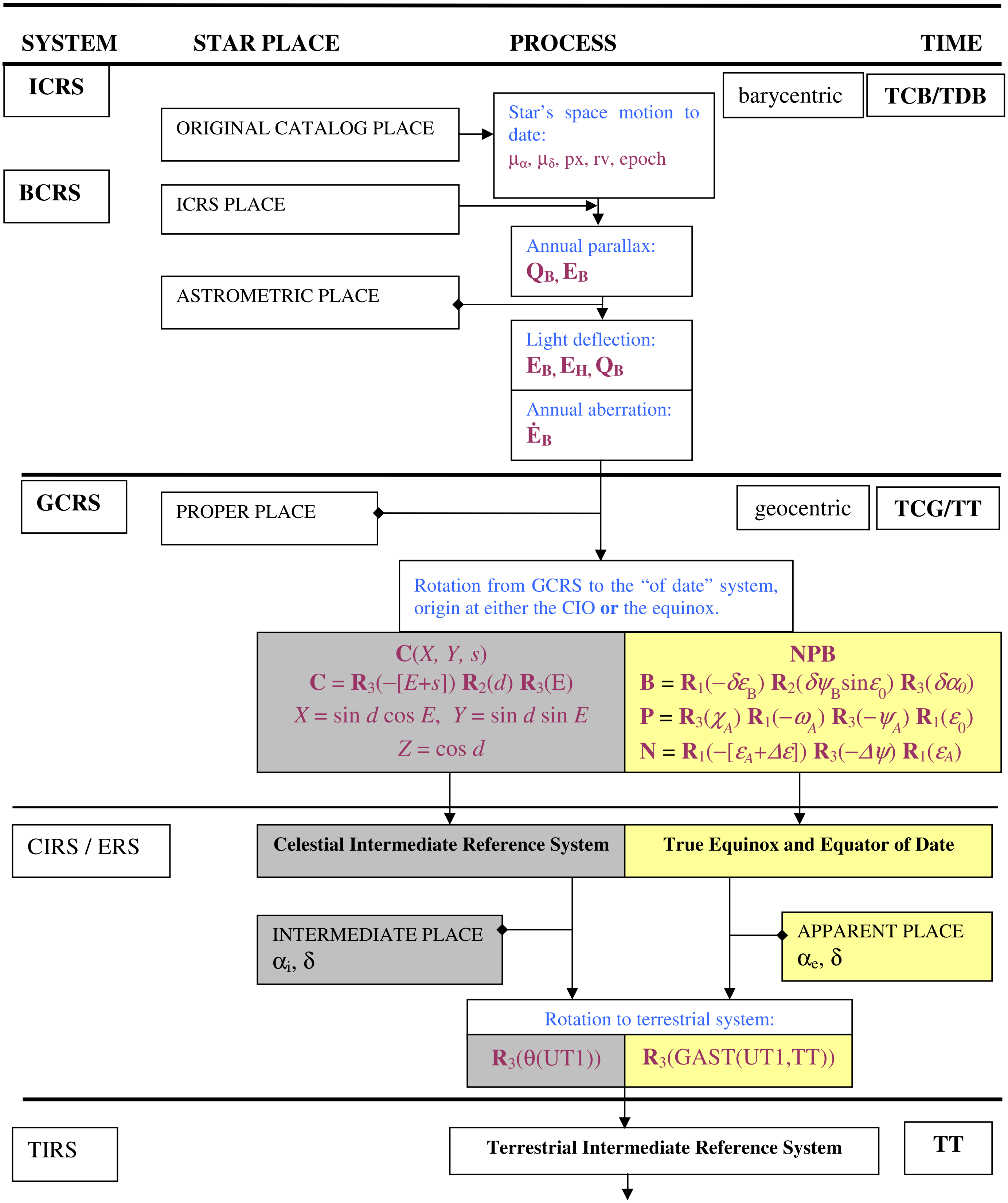
The chart summarizes the system, and the elements that are associated with that system, i.e. the name for the positions (place), the processes/corrections, the origin to which the coordinates are referred, and the time scale to use. In particular the blue type in the box in the "Process" column is the operation/correction to be applied, and the purple type indicates the quantities required for that process. CIO and equinox based processes are indicated using grey and yellow shading, respectively.

The following symbols, which are used only in the Chart and are defined below.

Symbol	**Meaning**
μ_α, μ_δ, px, rv	Proper motions in right ascension & declination, stellar parallax and radial velocity, respectively.
$\mathbf{Q_B}$	Barycentric position of the object, evaluated at the required TDB instant.
$\mathbf{E_B}$, $\mathbf{\dot{E}_B}$	Barycentric position and velocity of the Earth, at the required TDB instant.
$\mathbf{E_H}$	Heliocentric position of the Earth, evaluated at the required TDB instant.
π	equatorial horizontal parallax of the object.
ϕ, ϕ', λ	Latitude, geodetic and geocentric, and longitude respectively.
ρ	geocentric distance of the object.
$\mathbf{R}_1, \mathbf{R}_2, \mathbf{R}_3$	represent the standard rotation matrices about the x, y and z axes, respectively. Where

$$\mathbf{R}_1 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\mu & \sin\mu \\ 0 & -\sin\mu & \cos\mu \end{pmatrix}, \quad \mathbf{R}_2 = \begin{pmatrix} \cos\mu & 0 & -\sin\mu \\ 0 & 1 & 0 \\ \sin\mu & 0 & \cos\mu \end{pmatrix}, \quad \mathbf{R}_3 = \begin{pmatrix} \cos\mu & \sin\mu & 0 \\ -\sin\mu & \cos\mu & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

and μ is the angle of rotation.


SYSTEM
STAR PLACE
PROCESS
TIME
ICRS
BCRS
ORIGINAL CATALOG PLACE
ICRS PLACE
ASTROMETRIC PLACE
Star's space motion to date:
μ_α, μ_δ, px, rv, epoch
barycentric
TCB/TDB
Annual parallax:
$\mathbf{Q_B}$, $\mathbf{E_B}$
Light deflection:
$\mathbf{E_B}$, $\mathbf{E_H}$, $\mathbf{Q_B}$
Annual aberration:
$\dot{\mathbf{E}}_\mathbf{B}$
GCRS
PROPER PLACE
geocentric
TCG/TT
Rotation from GCRS to the "of date" system, origin at either the CIO **or** the equinox.
$\mathbf{C}(X, Y, s)$
$\mathbf{C} = \mathbf{R}_3(-[E+s])\,\mathbf{R}_2(d)\,\mathbf{R}_3(E)$
$X = \sin d \cos E,\quad Y = \sin d \sin E$
$Z = \cos d$
NPB
$\mathbf{B} = \mathbf{R}_1(-\delta\varepsilon_B)\,\mathbf{R}_2(\delta\psi_B \sin\varepsilon_0)\,\mathbf{R}_3(\delta\alpha_0)$
$\mathbf{P} = \mathbf{R}_3(\chi_A)\,\mathbf{R}_1(-\omega_A)\,\mathbf{R}_3(-\psi_A)\,\mathbf{R}_1(\varepsilon_0)$
$\mathbf{N} = \mathbf{R}_1(-[\varepsilon_A+\Delta\varepsilon])\,\mathbf{R}_3(-\Delta\psi)\,\mathbf{R}_1(\varepsilon_A)$
CIRS / ERS
Celestial Intermediate Reference System
True Equinox and Equator of Date
INTERMEDIATE PLACE
α_i, δ
APPARENT PLACE
α_e, δ
Rotation to terrestrial system:
$\mathbf{R}_3(\theta(\mathrm{UT1}))$
$\mathbf{R}_3(\mathrm{GAST}(\mathrm{UT1,TT}))$
TIRS
Terrestrial Intermediate Reference System
TT

continued …

continued …

SYSTEM **PLACE** **PROCESS** **TIME**

TIRS

Terrestrial Intermediate Reference System

geocentric

TT

Rotation to the ITRS origin:
$\mathbf{R}_3(s')$

Rotation for polar motion:
$\mathbf{R}_2(-x_\mathrm{p})\ \mathbf{R}_1(-y_\mathrm{p})$

ITRS

International Terrestrial Reference System

geocentric

TT

Rotation to local meridian:
$\mathbf{R}_3(\lambda)$

The following diurnal transformations are provided for specific use and are generally not used at the μas level.

Diurnal parallax:
$\phi', \lambda, \rho, \pi$

Diurnal aberration:
ϕ', λ, ρ

TOPOCENTRIC PLACE

topocentric

TT

Rotation to horizon:
$\mathbf{R}_2(-\phi)$

Refraction:
pressure, temperature, relative humidity, model atmosphere, frequency

OBSERVED PLACE