Time Systems

1 Time System

1.1 Facts

- The standard astronomical epoch = J2000.0 = JD2451545.0 = 2000 January 1, 12^h TT.
- The unit of time in the international system of units, the SI second, is defined as the fundamental unit of TAI.

1.2 Explanation

For the units to count time intervals, there are physical time like TAI and terrestial times like UA1 and GMST. The physical time defines a second by means of a well defined physics phenomena like atomic decay life time at the rest frame of atoms. The terrestial times are defined as angles of the earth rotation around its axis with respect to different terrestial objects, e.g. the Sun and stars. Descriptions here are based on Ref. [1]

Atomic and Dynamical times

- TAI (International Atomic Time) defines the unit SI second.
- TDT (Terrestial Dynamical Time) is the time passing at the center of gravity of the earth. Renamed to TT (Terrestial Time) in 1991.
- TDB (Barycentric Dynamical Time) is the time passing at the center of gravity of the slolar system.

One second in TAI and TT are practically the same and their origins are related as $TT = TAI + 32.184\text{sec}$.

Universal time

The universal time (UT) can be defined as the azimuth angle of the **meridian(眤)** at Greenwich from a straight line connecting the Sun and the center of the earth. The origin of the angle is the direction to the earth viewing from the Sun. The angle is expressed in hour:minuit:second. One complete rotation with respect to the Sun defines a day = 24 hours. The length of a day in time depends on year and season of the measurement. The origin of UT has therefore no absolute meaning in the time scales.

UT may be identified by a local measurement provided the latitude and longitude of the location is known. The value (UT0) is however depending on the location due to small fluctuation of the rotation axis of the earth. The value corrected for the location dependence is called **UT1**.

UTC (Coordinated Universal Time) counts time in the unit of SI second and tuned so that $|\Delta UT = UT1 - UTC| < 0.9$ sec. To do this, an integral number of seconds (leap seconds) are added to TAI at the last seconds of June and December. Thus $\Delta AT = TAI - UTC$ is always an integer seconds. Values of ΔAT in recent years are [2],
from 1996 01 Jul, UTC to 1997 01 Jul, UTC $\Delta AT = +30$ sec
from 1997 01 Jul, UTC to further notice $\Delta AT = +31$ sec

- No leap second will be introduced in UTC on 30 June 1998. [3]
- The Japanese standard time is given as $UTC + 9$hours.

Greenwich mean sidereal time (GMST)
Sidereal time is the rotation angle of the earth around its axis in a frame of reference fixed against the stars. The angle of the meridian of Greenwich is measured along the celestial equator to the direction of the earth rotation from the mean equinox.

GMST at 0h UT on a date JD in Julian date is given as

$$\text{GMST (sec)} = 2.411054841\times10^4 + 8.640184812866\times10^6 T_U + 0.093104 T_U^2 - 6.2\times10^{-6} T_U^3 \tag{1}$$

where

$$T_U = (JD - 2451545.0)/36525$$

Julian date (JD) is the number of solar days from an origin. JD of 1998/Jan/01 0h UT is 2450814.5 JD and 2000/Jan/01 12h UT = JD2451545.0.

To obtain a value of GMST (usually in hours) for a moment of time UT, first calculate GMST for 0h UT of the date. Add or subtract multiples of 24h as necessary. Add then to the result UT of the moment $\times$ <u>1.00273790935</u> if the moment is in the year 1998. The number multiplied to UT is the length of one mean solar day in the unit of mean sidereal day in the year 1998.

An example is shown here. See on page B7 in [1]. We calculate GMST for 1998/7/8 09:44:30 UT. First we find GMST(1998/7/8 0h UT) using Eq. (1). JD of the date at 0h is found from tables (1,2) that JD $= 2450814.5 + 181 + 7 = 2451002.5$. Eq. (eqn:GMST) gives

$$
\begin{aligned}
&\text{GMST(1998/7/8 0h UT)}\\
&= 2.411054841\times10^{4} - 1.283312871\times10^{5} + 2.05394\times10^{-5} - 2.0\times10^{-11}\\
&= -1.042207387\times10^{5}\ \text{seconds} = -28.95020519\ \text{hours}\\
&= 19:02:59.2613\ \text{(h:m:s)}
\end{aligned}
$$

The first line in the above eqations shows that the third and fourth terms are negligible for the most purposes. From the second to third line, we have added 48h to get a regular expression for time (angle). The next step is to add the part of time passed from 0h UT to 09:44:30 UT. The sidereal time passed during this time span is

$$09:44:30\ \text{UT} = 9.7417\ \text{hours UT} = 9.7683\ \text{sidereal hours}$$

We thus obtain,

$$\text{GMST(1998/7/8 09:44:30 UT)} = 4.8181\text{hours} = 04:49:05\ .$$

2 Coordinate System

The earth rotations

The earth is revolving around the Sun. This defines the ecliptic ()circle around the earth. The ecliptic circle is a circle centered at the center of the earth and is on the plane of the revolution. The earth is rotating around its axis. The axis defines the direction north. The polar angle of the axis with respect to the normal direction to the revolution plane is called obliquity of the ecliptic () and given by = 2326' 21".488. A plane parpendicular to the earth rotation axis defines the celestial equator(). The angle between the celestial equator and the ecliptic is the obliquity of the ecliptic. The direction of the revolution and the rotation are the same in a sense that vectors of the revolution and rotation axes direct into the same hemisphare. When one views the Sun-earth system from the north side of the celestial sphere, the earth is revolving anti-clockwise around the Sun and it rotates anti-clockwise around its axis. One of two points where the ecliptic and the celestial equator crosses is the vernal equinox(). A line from the Sun to the earth goes through this point on the equinox.

表 1: Julian day number on January 1st of a year at 0h UT.

year	JD
1996	2450083.5
1997	2450449.5
1998	2450814.5
1999	2451179.5
2000	2451544.5
2001	2451910.5
2002	2452275.5
2003	2452640.5

表 2: Number of days in a month and that to the end of a month from the begining of a normal year.

month		
1	31	31
2	28	59
3	31	90
4	30	120
5	31	151
6	30	181
7	31	212
8	31	243
9	30	273
10	31	304
11	30	334
12	31	365

- **ephemerides**:
- **geocentric**: with reference to the center of the Earth.
- **topocentric**: with reference to a point on the surface of the earth.
- **zenith (), geocentric**: the point on the celestial sphere which the line from the center of the Earth through the observer crosses.
- **hour circle**: a great circle on the celestial sphere that passes through the celestial (north and south) poles and is therefore perpendicular to the celestial equator.
- **right ascension (RA)**: angular distance on the celestial sphere measured eastward along the celestial equator from the equinox to the hour circle passing through the celestial object.
- **declination**: angular distance on the celestial sphere north or south of the celestial equator. It is measured along the hour circle passing through the celestial object.
- **meridian**: a great circle passing through the celestial poles and through the zenith of the location on the surface of the Earth.
- **hour angle**: angular distance on the celestial sphere measured eastward along the celestial equator from the hour circle of the object to the meridian.
- **latitude, celestial**: angular distance on the celestial sphere measured north or south of the ecliptic along the great circle passing through the poles of the ecliptic and the celestial object.
- **latitude, terrestial**: angular distance on the Earth measured north or south of the equator along the meridian of the location.
- **longitude, celestial**: angular distance on the celestial sphere measured eastward along the ecliptic from the dynamical equinox to the great circle passing through the poles of the ecliptic and the celestial object.
- **longitude, terrestial**: angular distance measured along the Earth's equator from the Greenwich meridian to the meridian of a location.

3 Moon

Low precision formulae for geocentric coordinates of the Moon
The time argument T_U is defined as

$$T_U = (JD - 2451545.0)/36525$$

The universal time UT should be included in JD as a fraction of a day, namely, JD = JD(0h UT) + UT/24.

参考文献

[1] "The Astronomical Almanac, 2000", U.S. Government printing office, Washington, "The Astronomical Almanac, 1998", U.S. Government printing office, Washington.

[2] http://image.gsfc.nasa.gov/poetry/activity/earthr4.html

[3] ftp://maia.usno.navy.mil/ser7/ser7.dat