Time in Astronomy

Lecture 03

Cristiano Guidorzi

Physics Department
University of Ferrara

Astrophysical Measurements

Outline

Outline

university of ferrara
600 YEARS OF LOOKING FORWARD.

Time and Day

In astronomy, time is the hour angle of a star (or a generic point in the celestial sphere).

The **day** is a unit of measurement of time and is the time interval between two successive (either lower or upper) culminations of a star.

If the reference star (point) is:

- the true Sun $\Rightarrow$ local true solar time
- the mean Sun $\Rightarrow$ local mean solar time
- vernal equinox $\gamma \Rightarrow$ local sidereal time

With solar times, the lower culminations are used.

Outline

1. Introduction
   - Time and Day
   - Sidereal Time
   - Solar Time
   - Universal Time

Sidereal Time

The *sidereal time* (ST) is the hour angle of the vernal equinox.

The *sidereal day* is the time between two successive culminations of the vernal equinox.
This is equivalent to the time it takes the Earth to accomplish a rotation around its axis.

Actually, the Earth rotation rate is slowly decreasing, so the length of the sidereal day is increasing. Precession of the ecliptic longitude of the vernal equinox also comes into play (50″/year).
Moreover, nutation causes more complicated wobbling. The *mean equinox* is the point where the vernal equinox would be in the absence of nutation.
There are two definitions of ST:

- *apparent ST*: determined by the true vernal equinox
- *mean ST*: determined by the mean vernal equinox

Equation of Equinoxes

The difference of the apparent and mean sidereal time is called *equation of equinoxes*

$$\Theta_{\mathrm{a}} - \Theta_{\mathrm{M}} = \Delta\psi \ \cos\varepsilon$$

where ε is the obliquity of the ecliptic (at obs time), $\Delta\psi$ the nutation in longitude.

It amounts to at most 1^{s} (to be taken into account in most precise calculations).

Tropical vs. Sidereal Year

Tropical Year

- Time interval it takes the Sun to move from one vernal equinox to the next (i.e. the R.A. of the Sun increases by exactly 24^{h}).
- Length: $365^{d}05^{h}48^{m}46^{s} = 365.2422$ d.

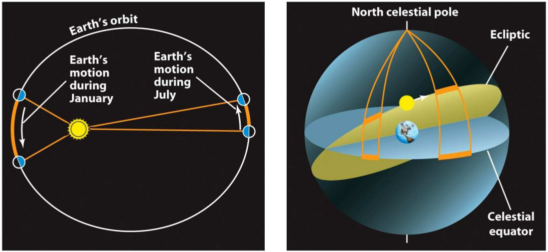
Sidereal Year

- Time interval it takes the Sun to make one revolution with respect to the celestial sphere.
- It differs from the tropical year because of the equinox precession.
- Length: $365^{d}06^{h}09^{m}13^{s} = 365.2564$ d.

Outline

Solar Time

The *Solar Time* is based on the daily motion of the Sun.
Unfortunately, it doesn't flow at a constant rate.



(a) A month's motion of the Earth along its orbit (b) A day's motion of the Sun along the ecliptic

Figure 2-22
Universe, Eighth Edition

- The Earth orbit is not exactly circular, but elliptical ($e = 0.0167$), so the Earth-Sun distance changes with time.
- The Sun moves along the ecliptic, so its R.A. cannot increase at a constant rate.

Mean Solar Time and Equation of Time

Mean Solar Time, T_M

- Based on the daily motion of the *mean* Sun.
- The mean Sun is fictitious and moves along the celestial equator with constant angular speed, making a complete revolution in one (tropical) year.
- $h(T)$: hour angle of the true Sun centre ($t = h(T) + 12^{\mathrm{h}}$, true solar time)
- $h(M)$: h. a. of the mean Sun centre ($t_{\mathrm{M}} = h(M) + 12^{\mathrm{h}}$, mean solar time)

Equation of Time

The difference between the hour angle of the true (T) and mean (M) Sun is called *Equation of Time*:

$$\varepsilon = h(T) - h(M) = t - t_M$$

Equation of Time

The local sidereal time, Θ, has the following property:

$$\Theta = h(X) + \alpha(X)$$

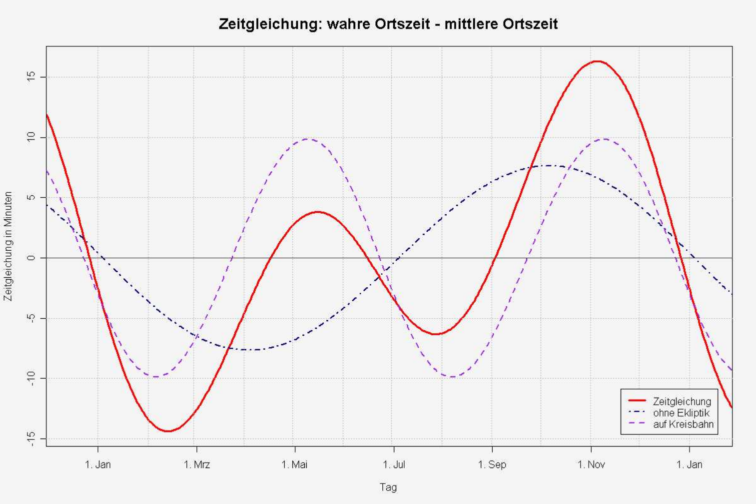
Taking the true (T) and the mean (M) Sun, this turns into:

$$\Theta = h(T) + \alpha(T) = h(M) + \alpha(M)$$

The equation of time can also be written as:

$$\varepsilon = \alpha(M) - \alpha(T)$$

Equation of Time



Sidereal vs. Synodic (Solar) Day

- P: orbital period of a planet around the Sun
- τ_*: sidereal rotation period of the planet (complete rotation wrt the stars)
- τ: synodic day (time interval between two successive Sun culminations)

After a year, sidereal and solar time will be again in phase.
The number of sidereal days in one year is one greater (smaller) than the number of solar days if the sense of the planet rotation is prograde (retrograde):

$$\frac{P}{\tau_*} - \frac{P}{\tau} = \pm 1 \quad \Rightarrow \quad \frac{1}{\tau} = \frac{1}{\tau_*} \pm \frac{1}{P}$$

For the Earth: $P = 365.2564$ d, $\tau = 1$ d, so that $\tau_* = 0.99727$ d, or $23^{\mathrm{h}}56^{\mathrm{m}}04^{\mathrm{s}}$.

Outline

Hour Angle and Observer Longitude

Both sidereal and solar times are *local*.

Let the Greenwich hour angle of a given object, X, be $h_G(X)$. For an observer at longitude λ (eastward), the corresponding local hour angle of the same object $h(X)$ is related to that of Greenwich as follows:

$$h(X) = h_G(X) + \lambda$$

The *Universal Time (UT)* is the hour angle of the mean Sun at the Greenwich meridian plus 12^h (Greenwich Mean Time):

$$\mathrm{UT} = \mathrm{GMT} = h_G(M) + 12^h$$

$\Rightarrow$ UT day change at the lower culmination of the mean Sun at the Greewich meridian.