Time Keeping in Astronomy

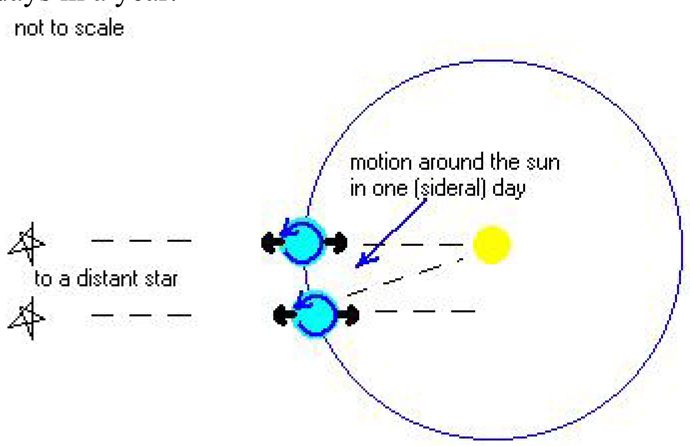
Sidereal and Solar Time

Rotation of the Earth

The basis of astronomical time is the rotation of the Earth on its axis. This causes objects to rise in the east, arc across the sky, *transiting* the *meridian*, and finally setting in the west (except for the special cases of the North and South Poles). One *Sidereal* day is one full rotation of the Earth relative to a fixed distant reference point such as a star (i.e. the time it will take a star to return to the meridian after on full rotation. This rotation of 360° takes 24 Sidereal hours for a rate of 15° per hour.

Solar Time

The orbital motion of the Earth around the Sun results in a difference between a solar day and a sidereal day. While rotating on its axis, the Earth is also revolving (orbiting) around the sun. One full (sidereal) rotation does not bring the sun back to the meridian. Since the Earth has moved about one degree in its orbit in one day, it must rotate one additional degree to bring the sun back to transit. This takes about four minutes. In other words, a sidereal day is shorter than a solar day (the difference is about 4 minutes of time). Thus, while there are approximately 365.25 solar days in one year, there are (approximately) 366.25 sidereal days in a year.

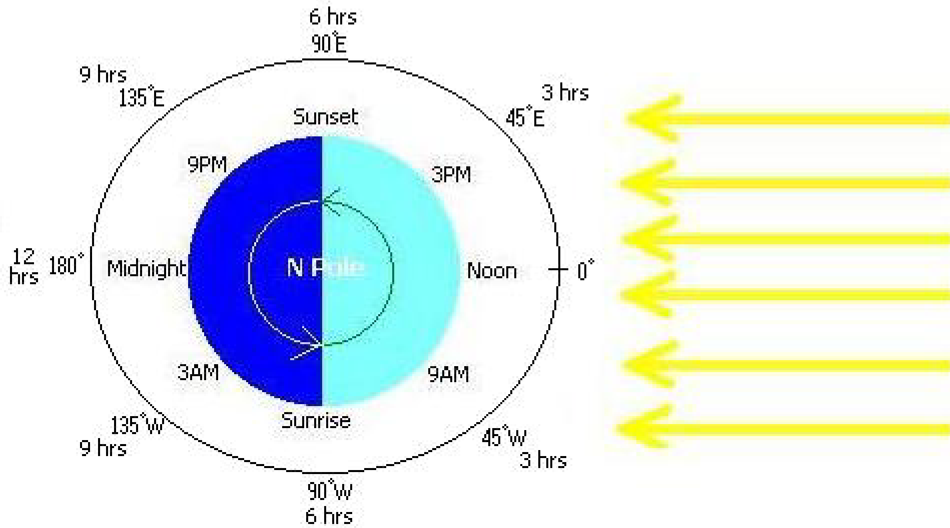


A Solar Day is the average time from Noon (when the sun is transiting the meridian) until the following noon. This rotation of 360° takes 24 Solar hours for a rate of 15° per hour.

Angle > Time	360° per day	15° per hour	15' per minute	15" per second
Time > Angle	24 hours per 360	4 minutes per degree	4 seconds per arc minute	.067seconds per arc second

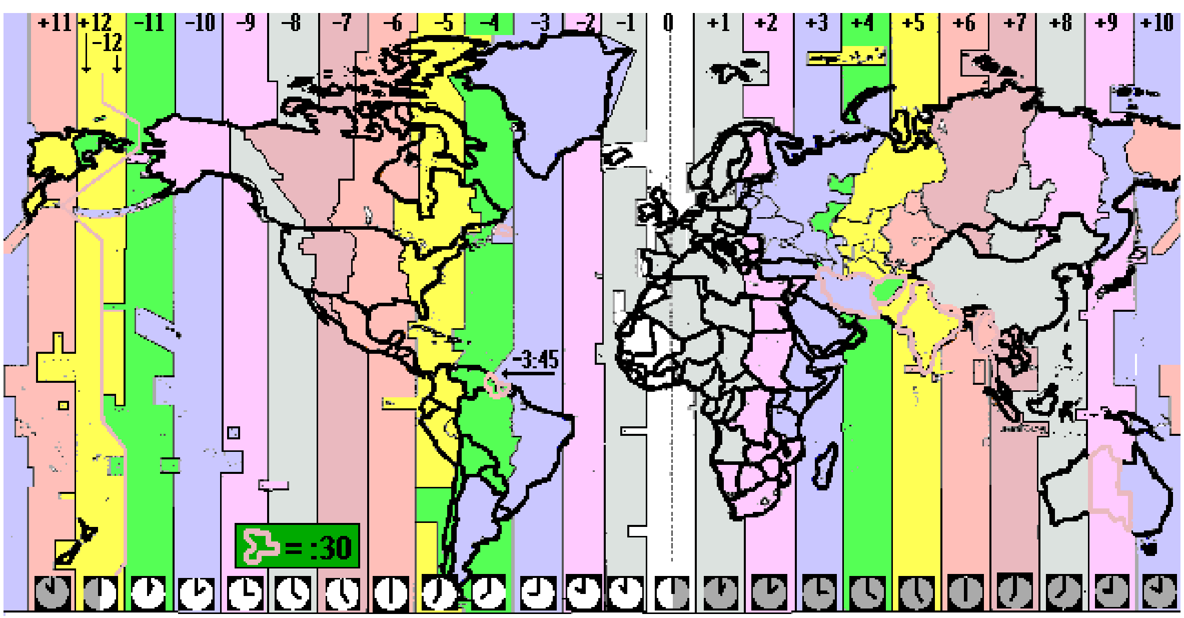
Solar time as kept on clocks is actually Mean Solar Time. The difference between time as indicated by observation of the actual motion of the sun and mean time will be discussed shortly.

UT or GMT



Mean Solar Time at the *Greenwich Meridian* (0° longitude) is called GMT (Greenwich Mean Time) or UT (Universal Time). Because the Earth is rotating towards the east, if the sun is crossing the meridian at Greenwich (*i.e.* noon) it will be before noon at locations to the west of Greenwich and after noon for locations east of Greenwich. Local Mean Solar Time (LMT) is given by $LMT = GMT + L$ where L is the longitude (note that this equation requires knowing the sign of the longitude and that east longitudes are positive). Note that LMT is not, in general, the same as the civil time (standard time) at a location since the civil time is the same for all locations in that zone and is the LMT for the zone's standard longitude.

Time Zones



Because most localities prefer to have their clock read 12:00 at local noon, the Earth has been divided up into time zones, typically about 15 longitude in width. Clock time for all locations within a zone is the LMT for the zone's standard longitude. The standard longitude is frequently (but not always) the central longitude within the zone. Time zones are political boundaries and thus are set by political considerations, not astronomical considerations.

[A useful world time zone clock]

Daylight Saving Time

Daylight Saving Time begins in the United States on the first Sunday in April and ends on the last Sunday in October. On the first Sunday in April, clocks are set ahead one hour at 2:00 a.m. local standard time, which becomes 3:00 a.m. local daylight time. On the last Sunday in October, clocks are set back one hour at 2:00 a.m. local daylight time. Arizona, Hawaii, parts of Indiana, Puerto Rico, the U.S. Virgin Islands, and American Samoa have chosen not to observe Daylight Saving Time. The mnemonic "Spring Forward, Fall Back" is frequently used to help remember the sign of the change.
According to Mining Co. Guide to Geography, DST is also observed in about 70 countries:
Other parts of the world observe Daylight Saving Time as well. While European nations have been taking advantage of the time change for decades, in 1996 the European Union (EU) standardized a EU-wide "summertime period." The EU version of Daylight Saving Time runs from the last Sunday in March through the last Sunday in October. During the summer, Russia's clocks are two hours ahead of standard time. During the winter, all 11 of the Russian time zones are an hour ahead of standard time. During the summer months, Russian clocks are advanced another hour ahead. With their high latitude, the two hours of Daylight Saving Time really helps to save daylight. In the southern hemisphere where summer comes in December, Daylight Saving Time is observed from October to March. Equatorial and tropical countries (lower latitudes) don't observe Daylight Saving Time since the daylight hours are similar during every season, so there's no advantage to moving clocks forward during the summer.
One useful reference can be found at http://aa.usno.navy.mil/faq/docs/daylight_time.html

A Note on Longitude

Longitude can be measured to the east or the west from Greenwich. Many astronomical applications have taken longitude as increasing (positive) to the west. On the other hand, the IAU in 1982 defined longitude as positive measured east of Greenwich and negative measured to the west. It is therefore important to be certain of the convention used when supplying longitude to another. If possible, state longitude in the form "82.5° west" or "15° east". An interesting illustration of the possibility of errors can be found on the "Heavens Above" web pages where they plot the location of their subscribers. Note the pattern in central Asia which resembles a reversed map of the United States. Most of these points must have been entered erroneously as positive rather than negative longitudes. Using the IAU definition, $L = LMT - GMT$ where LMT is Local Mean Time and L is longitude measured in hours.

The Analemma and the Equation of Time

Sidereal Time

Sidereal time is time kept relative to the stars instead of relative to the sun. Thus sidereal time reflects the actual rotation of the Earth on its axis. A sidereal day is about 4 minutes shorter than a solar day. Local Sidereal Time (LST) is defined as the right ascension crossing the local meridian at a given instant. Greenwich Sidereal Time (GST or ST0) is the local sidereal time on the Greenwich meridian. In general LST = ST0 + L where L is the longitude (note that this equation requires knowing the sign of the longitude and that east longitudes are positive).

More about time

When we really want to get technical about time keeping many added details must be considered.

Precession

Because the Earth's mass is spherically symmetrical (i.e. the Earth bulges at the equator) the gravitational attraction of the Sun and the Moon (and to a much lesser degree, the planets) causes the Earth's axis to precess slowly like a top. The result is that the Vernal Equinox moves to the west at a rate of about 50 arc seconds per year (for a full revolution in about 26,000 years). The result is that though the "true" sidereal rotation of the Earth takes 86164.100 seconds, the rotation relative to the equinox (and hence relative to 0 hours RA) takes 86164.092 seconds.

UT1 (Universal Time)

Changes in the details of the distribution of the mass of the Earth (mostly due to the atmosphere) result in small changes in the location of the poles. Local mean time at Greenwich (GMT) is corrected for this and is called UT1.

Ephemeris Time (ET)

Between 1952 and 1984 calculations used to determine the orbital motions of the planets (and to plan the trajectories of spacecraft) used ET. This was based on the length of the year and was adjusted for a variety of factors totaling up to about one second per year which is added if needed on one of two dates a year ("leap second"; added June 30 and December 31).

Terrestrial Dynamical Time

The modern standard time is based on the SI (System International) second (s) which equals 9192631770 oscillations of a specified transition of Cs133. TDT is used for spacecraft navigational planning, solar system orbital motion studies etc.

UTC (Coordinated Universal Time)

UTC also uses the SI second but is offset twice a year (if necessary) to adjust it to UT1. Note: TDT is physics based time, UT1 is based on actual observation of the rotation rate of the Earth. UTC uses the standard second but is adjusted so it matches the Earth's rotation ("leap second"; added June 30 and December 31 if needed). A good source if UTC (and lots of useful information as well) is the US Naval Observatory.

Julian Day Number (JDN)

In order to allow calculation involving very long periods of time without worrying about "thirty days hath September ..." and leap year, etc. Astronomers use JDN. This is a running count of days since January 1, 4713 B.C., noon UT (i.e. the year -4712). This number is frequently referred to as JD (Julian Date or Julian Day) and some use JDN to refer to the integer day count and JD when including a fractional day (e.g. 2510000 is a JDN, 2510000.712345 is a JD). A modified Julian Date is also in use though I discourage it. MJD = JDN - 2400000.5 (so it starts at midnight rather than noon). Unfortunately, many astronomers drop the first two digits of JD resulting in a truncated JD that is indistinguishable from MJD. The 12 hour difference can (and has) caused problems in combining datasets. The USNO provides a nice web site that allows conversion of calendar dates to JD and vice versa.

JDN	JD	MJD	TJD	DoY
2452530	2452530.20345	52529.70345	52530.20345	255

Day of Year

Many accounting programs keep track of the individual days of the year with a running DoY count. Unfortunately, about 25 years ago, someone in the federal government started calling this DoY the "Julian Date". If your spreadsheet or statistical software offers you a "Julian Date" function it is almost certainly this non-astronomical JD.

The Time of Internet by Fabrizio Pollastri has a wealth of useful information about time and time keeping.

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