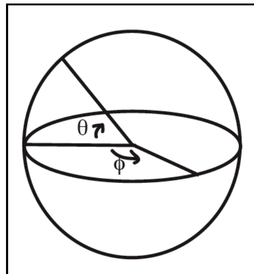
Coordinates and Time

Coordinates



Unit Sphere

Essentially all coordinate systems in astronomy are spherical coordinate systems. Consider a unit sphere.

One's location on the sphere is completely specified by the two angles, θ and φ , which can be converted into Cartesian coordinates by the standard transformations:

$$x= \sin \phi \cos \theta,\ \ y= \cos \phi \cos \theta,\ z=\sin \theta$$

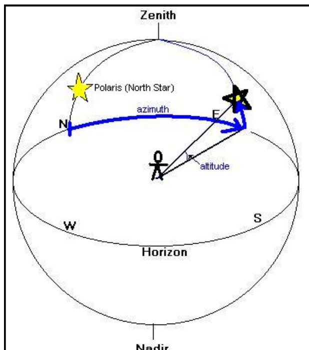
For any spherical coordinate system you also must define two *great circles* that define where the two angles equal zero.

Equator: great circle that defines $\theta=0$.
Prime meridian: great circle that defines $\phi=0$.

Note that the equator and prime meridian must be orthogonal, so given the equator the prime meridian can be defined by a single reference point on the sphere that is neither on the equator or at one of the poles.

Great circle: Any line on a sphere that is the intersection between the sphere and a plane passing through the center of the sphere.

Coordinates



Horizon Coordinates (altitude & azimuth)
Local coordinate system

Fundamental coordinates for telescopes.

Horizon coordinates are a local coordinate system, and perhaps the easiest to visualize. Imagine that you are standing outside.

The defining great circles are the horizon and the circle passing through *zenith* and the north pole.

Zenith: The point directly overhead.
Nadir: The point directly below.

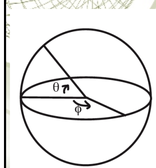
The two angles are:

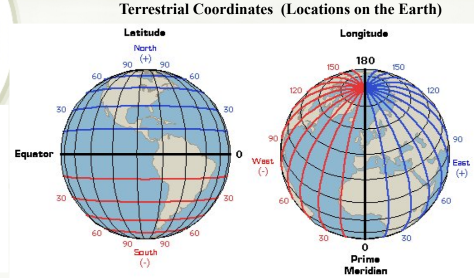
altitude (θ, commonly referred to as alt) -90° to 90°
*angle above horizon

azimuth (φ, commonly referred to as az) 0° to 360°, -180° to 180°
*Geographic definition, also commonly used in astronomy, is that azimuth is measured from the north point, increasing to the east. Note though that there is also an astronomical definition in which it is measured from the south point, increasing west. [So be careful]

Coordinates

Terrestrial Coordinates (Locations on the Earth)

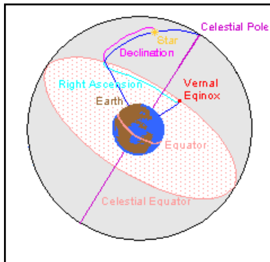




Angles: Latitude (θ) -90° to 90°
Longitude (φ) 0-180° W, 0-180° E **
Equator: Earth's equator
Prime Meridian Reference Point: Greenwich, UK.

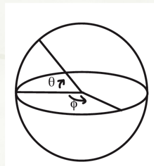
**This is the common usage. The International Astronomical Union defines longitude as going from -180° to 180°, with positive towards the east.

Globe image from www.lakelandsd.com/ tutorial/instructions.html



Coordinates

Equatorial Coordinates (Locations on Celestial Sphere)
Fundamental coordinates for observing

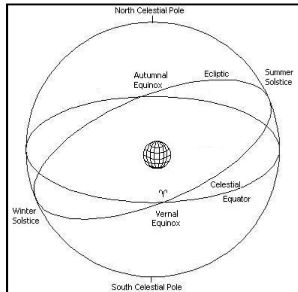


Angles:			
	Declination	(Dec, $\theta \rightarrow \delta$)	-90° to 90°
	Right Ascension	(RA, $\phi \rightarrow \alpha$)	0-360°, or 0-24 hours

Equator: Celestial equator = Earth's equator (extension of earth's equatorial plane to be precise)

Prime Meridian Reference Point: The point where the *ecliptic* crosses the celestial equator with the sun moving towards the summer solstice. [Direction of sun at the vernal equinox.]

Image from www.science2life.org



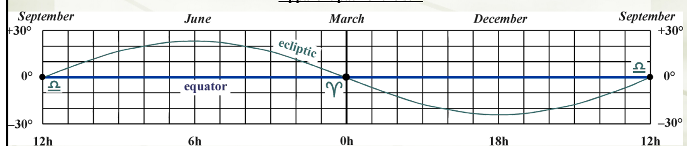
Coordinates

Equatorial Coordinates

Ecliptic: The apparent path of the Sun on the celestial sphere over the course of a year.

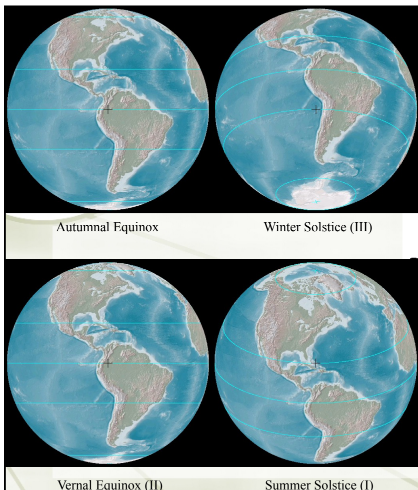
Ecliptic plane: The plane of the Earth's orbit, extended out to meet the celestial sphere.

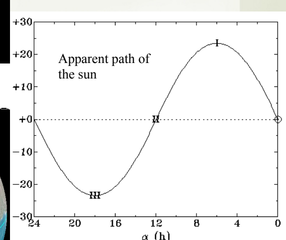
Apparent path of the sun



Images from http://star-www.st-and.ac.uk/~fv/webnotes/chapter9.htm

Coordinates





Images from **www.visualsunchart.com/.../ SolarDeclination/ and** http://www.astro.uu.nl/~strous/AA/en/antwoorden/hemel.html

Coordinates

Equatorial Coordinates

RA and Dec:

We noted on a previous slide that the standard convention for right ascension is to measure it in terms of hours rather than degrees. Just to be clear:

1 hour = 15 degrees
1 minute = 15 arcminutes
1 second = 15 arcseconds

You will normally see the coordinates given in the format of hours,minutes, and seconds for RA and degrees arcminutes, and arcseconds for declination. For example

$(\alpha,\delta) = (10h15m30.0s,+45d00m30s)$.
or $(\alpha,\delta) = (10:15:30.0,+45:00:30)$.

It is also common though for the coordinates to be given in decimal format with the RA in degrees, in which case the above would be:

$(\alpha,\delta) = (157.87500,+45.008333)$

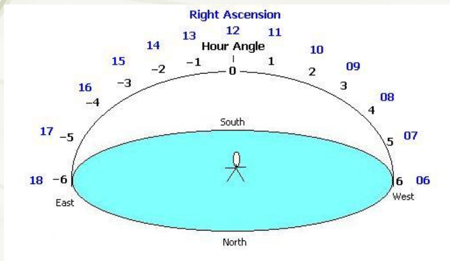
where these values come from:

$\alpha = 15 \times (10 + 15/60 + 30/3600)$
$\delta = 45 + 0/60 + 30/3600$

Coordinates

Equatorial Coordinates

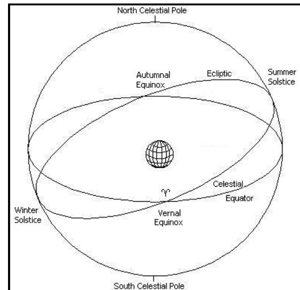
Hour Angle
The hour angle is defined as the distance in RA of an object from the local meridian.



It is defined as **the time since an object was directly overhead**. Negative values indicate that an object is in the east (still rising), while positive values indicate that the object has already passed zenith (setting).

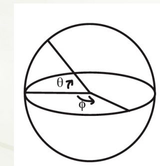
Images from John Oliver's web page

Coordinates



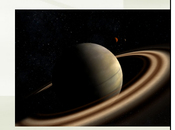
Ecliptic Coordinates

Besides equatorial, there are several other coordinate systems that are useful for various applications. Ecliptic coordinates are useful for observations of solar system objects. They are also useful if you want to pick a field that is *away* from solar system objects, in which case you may want to observe near the ecliptic poles.



One can convert between equatorial and ecliptic coordinates by a rotation of coordinate systems.

Angles:	Ecliptic latitude	$(\theta \rightarrow \beta)$	-90° to 90°
	Ecliptic longitude	$(\phi \rightarrow \lambda)$	0-360°, or 0-24 hours

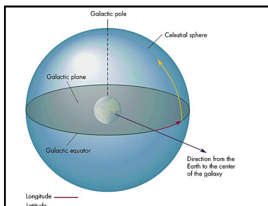


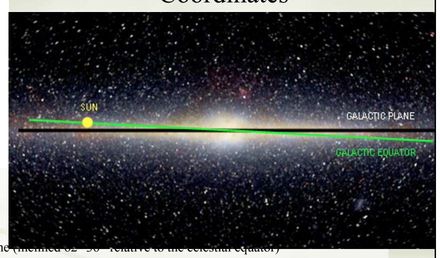
Equator: Ecliptic plane= Orbital plane of planets in solar system

Prime Meridian Reference Point: Vernal equinox (same as for equatorial)

Image from John Oliver's web page

Coordinates



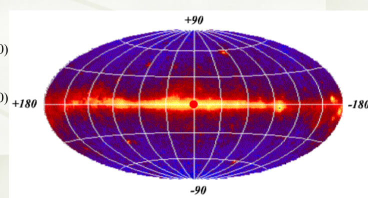


Angles: Galactic latitude
Galactic longitude

Equator: Galactic Plane
Prime Meridian Reference Point: Galactic Center

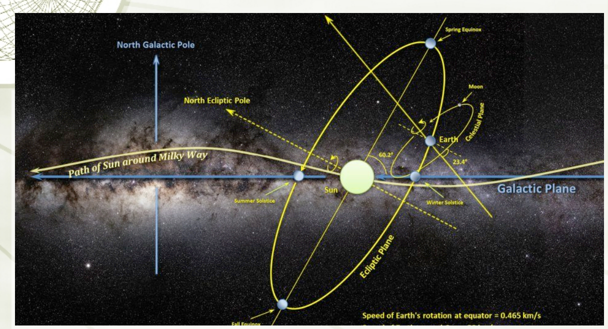
Location of galactic north pole:
RA,Dec = 12:51:24,+27:07:00 (J2000.0)

Location of galactic center:
RA,Dec = 17:45:36,-28:56:00 (J2000.0)

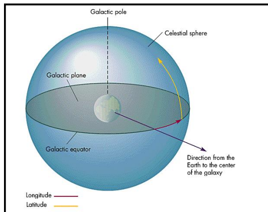


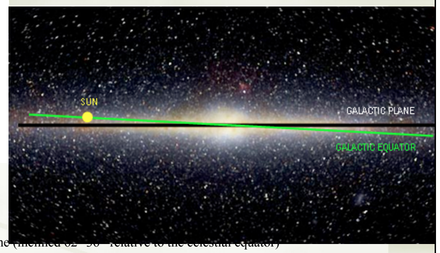
Images from www.mhhe.com/.../student/ chapter22/22f27.html and www.mhhe.com/.../student/ chapter22/22f27.html

Coordinate System Comparison



Coordinates



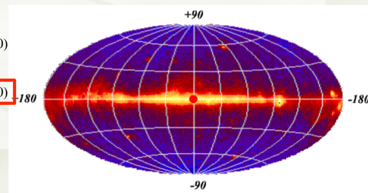


Angles: Galactic latitude
Galactic longitude

Equator: Galactic Plane (inclined 62° 36' relative to the celestial equator)
Prime Meridian Reference Point: Galactic Center

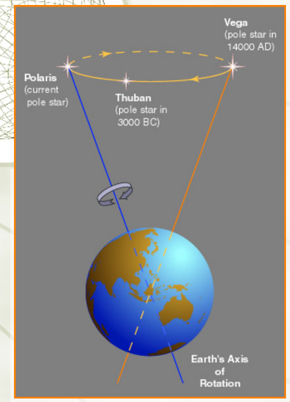
Location of galactic north pole:
RA,Dec = 12:51:24,+27:07:00 (J2000.0)

Location of galactic center:
RA,Dec = 17:45:36,-28:56:00 (J2000.0)



Images from www.mhhe.com/.../student/ chapter22/22f27.html
and www.mhhe.com/.../student/ chapter22/22f27.html

Coordinates



Precession

Now why on the last slide did I write (J2000.0) after the RA and Dec? What that notation means is that these are the coordinates at which you would find the galactic center on the first day of 2000. This is unfortunately necessary because *the equatorial coordinates of objects change with time*.

Why? The primary reason is the Earth's precession.
Precessional period: 26000 yrs
Yearly change: ~50'' (360 degrees / 26000 years)

There is also the Chandler wobble (433 day period), which is nutation, plus other small variations.

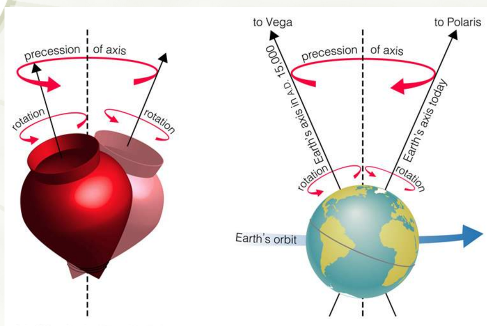
For this reason, when object coordinates are given they are always accompanied by the epoch (also called equinox) for which these coordinates are valid.

What this means in practice is that to observe an object you must start with the catalog values, which are given for a specific epoch (typically 1950.0 or 2000.0), and "precess" them to the current date. Typically this is done automatically by the telescope control software.

Images from www.physics.hku.hk/.../ lectures/chap03.html

Coordinates

Precession



Images from http://www.physast.uga.edu/~jss/1010/ch2/3fig2-19.jpg

Time

Rotation of the Earth

Knowing the time is just as important as good coordinates. Otherwise, you can't convert between RA,Dec and altitude,azimuth.

What shall we use as the basis for measuring time?

Time

Rotation of the Earth

Knowing the time is just as important as good coordinates. Otherwise, you can't convert between RA,Dec and altitude,azimuth.

The Earth's rotation is the basis of astronomical time, but the question arises – rotation relative to what?

Time

Rotation of the Earth

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The Earth's rotation is the basis of astronomical time, but the question arises – rotation relative to what?

Sidereal Time

Sidereal time is defined in terms of the Earth's rotation relative to the fixed stars.

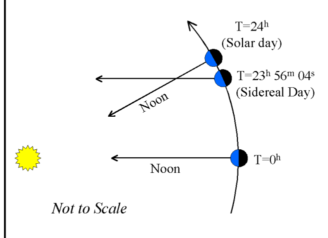
Sidereal day = the time for the earth to complete one rotation relative to a fixed star. In other words, a distant star transiting the meridian will return to the meridian after 1 sidereal day. The length of a sidereal day is 23 hours, 56 minutes.

Solar Time

Solar time is defined in terms of the Earth's rotation relative to the sun.

Mean solar day: The average time between noon one day and the next. More specifically, it is the length of time between solar transits of the local meridian. The length of a mean solar day is 24 hours.

Why are a sidereal day and mean solar day not the same length?



Time

Sidereal vs Solar Time

The sidereal day is shorter due to the orbital motion of the Earth around the sun. Specifically, the Earth moves in it's orbit roughly 1 degree per day (360°/365.25 days to be precise).

To reiterate the conversions from hours to degrees mentioned before:

1 day = 24 hours = 360 degrees
1 hour = 15 degrees (1 degree = 4 minutes)
1 minute = 15 arcmin (1 arcmin = 4 seconds)
1 second = 15 arcseconds (1 arcsec = 0.067 seconds)

Consequently, if the earth has moved one degree, then it takes an extra degree of rotation (4 minutes) for the sun to return to the meridian that if the Earth were stationary.

1 year = 365.25 solar days = 366.25 sidereal days

For astronomy, what we care about is sidereal.

Image from http://www-astronomy.mps.ohio-state.edu/~pogge/Ast161/Unit2/time.html

Time

…but of course everyone else cares about solar instead…

Solar Time

Mean Solar Time is the time of day based upon the mean solar day (i.e. 24 hours long). For mean solar time the sun is at zenith at noon.
Why is every solar day not exactly 24 hours long?

Greenwich Mean Time (GMT), or **Universal Time (UT)** is the mean solar time at the prime meridian. This serves as the reference for all local times.

Local Mean Solar Time (LMT) is given by LMT=GMT+L, where L is the longitude. By definition, the sun is at zenith at noon LMT. Note: beware of sign conventions for longitude. In the above equation east longitudes are positive.

You typically need to know the UT as well as the Local Sidereal Time, especially if the target is time variable.

Coordinates and Time

Announcements:

- Next Wednesday: Lab 1 @ CTO
- Trip to RHO moved to the following week.

Time

…but of course everyone else cares about solar instead…

Solar Time

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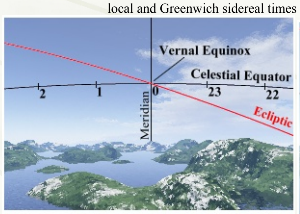
Time

Sidereal Time

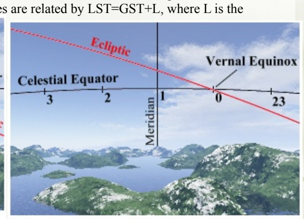
Sidereal time is kept relative to the stars instead of the sun. Thus sidereal time reflects the actual rotation of the Earth on its axis. A sidereal day is 23h56m long.

Local Sidereal Time (LST) is defined as the RA crossing the local meridian at a given instant. Since the RA is defined to be 0 hours at the vernal equinox, the LST is also 0 when the vernal equinox is on the observer's local meridian.

Greenwich Sidereal Time (GST) is the local sideral time at the prime meridian. The local and Greenwich sidereal times are related by LST=GST+L, where L is the



Observer's horizon, looking south
At the vernal equinox



Observer's horizon, looking south
One hour later

Images from **www.polaris.iastate.edu/.../ Unit4/unit4_sub2.htm**

Time

The complexities of "normal" time

Civil time (what we use every day, also known as **Standard Time**) is based upon the 24 hour mean solar day, *but is different from LMT because of the use of time zones.*

Time Zones

While everyone would probably like to have their clocks read noon when the sun is overhead, there are also some obvious practical difficulties with having time change continuously with location. For this reason, standard time is divided up into 24 time zones, each approximately 1 hr (15 degrees) in width…with a lot of quirkiness due to politics.

The point here to keep in mind is that standard (civil) time is ***not*** generally the same as LMT.

Time

Time Zones

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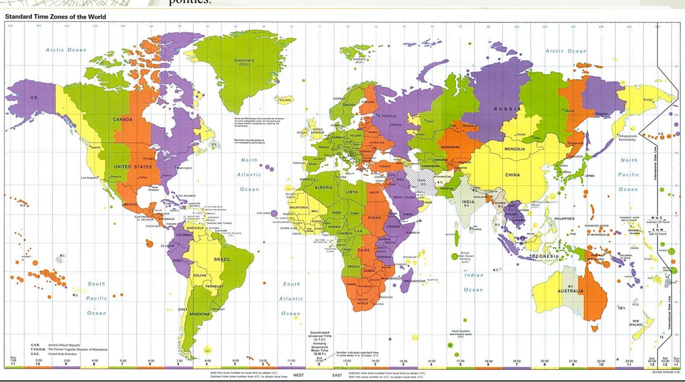

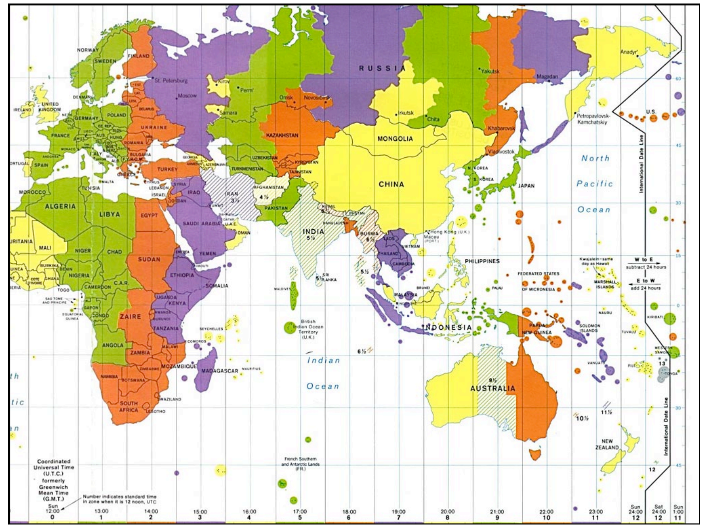

Time

Daylight Savings Time

Adding a bit of extra confusion, many locations observe some form of daylight savings time.

- In the U.S. the time changes occur on the second Sunday of March (spring forward) and the first Sunday of November (fall back) at 2am local time.
- In the EU, it runs from the last Sunday of March to the last Sunday of October.
- In the US, Arizona, Hawaii, Puerto Rico, the U.S. Virgin Islands, and American Samoa don't observe daylight savings time.

2017: DST is: March 12 to November 5 in US
March 26 to October 29 in Europe

Most nations in the tropics do not observe daylight savings time.

	Standard Time	*Jan 1*	*March 15*	*June 1*
Florida	UTC-5	UTC-5	UTC-4	UTC-4
London	UTC-0	UTC-0	UTC-0	UTC-1

For obvious reasons, daylight savings time is not used in astronomy.

Images from http://www.emarkay.com/win98se/windowstimezone.html

Time

Other Time Conventions

Julian Day (JD)

If you're dealing with observations over an extended time baseline (months, years, centuries), it is useful to have an means of keeping track without worry about leap years, days the month, changes in calendar systems in medieval times, etc. Julian days were introduced for this purpose. Julian days are a running count of days since noon UT, January 1, 4713 B.C. (The Modified Date is computed in the same way starting on November 17, 1858)

There's a calculator on the USNO web page (http://aa.usno.navy.mil/data/docs/JulianDate.php)

Examples: 2pm, January 12, 2006 JD 2453748.20833
2pm, January 12, 1000BC JD 1356185.20833

Beware, a number of non-astronomical software programs now use a "Julian Date", which is not generally the same as the astronomical Julian Date.

Greenwich Mean Sidereal Time can be calculated given the Julian Date:

The formula GMST (in hours) = 18.697374558 + 24.06570982441908 (JD – 241545.0)

is a good approximation, with a loss in precision of 0.1 seconds per century.

Time

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Examples: 2pm, January 12, 2006 JD 2453748.20833
2pm, January 12, 1000BC JD 1356185.20833

Modified Julian Day (MJD)

Julian dates are rather long, so MJD = JD - 2,400,000.5 (i.e. it starts on Nov 17, 1858)

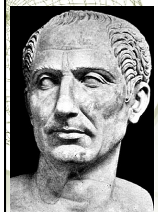
Terresterial Dynamical Time (TDT) and International Atomic Time (IAT)

The modern standard time is based upon the SI second, which is defined in terms of the oscillations for a particular transition of ^{133}Cs rather than astronomical measures. One second = 9192631770 oscillations. IAT is effectively the atomic equivalent of UT, based upon atomic clocks instead of mean solar time in Greenwich. TDT is additionally accounts for the gradual slowing of the Earth' s rotation. TDT =UT+ δT, where δT is an empirical correction that accounts for this slowing. TDT is used for spacecraft navigational planning and solar system motion studies among other things. The advantage is that TDT is independent of the slow increase in the Earth' s rotational period. (~a 2ms change since 1900, Birney et al.)

Coordinated Universal Time (UTC)

UTC uses the SI second but is offset twice a year to adjust to UT (which is based upon the Earth' s rotation). These adjustments are leap seconds that are added June 30 and December 31 when necessary.

Time



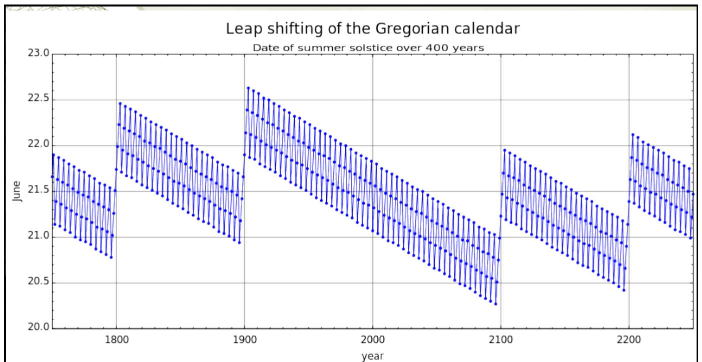
An Aside on Calendars

Julian Calendar (not to be confused with Julian Date)

- Introduced in 46 BC
- 12 months, 365 days, with a leap year every 4 years
- 365.25 days per year is just inaccurate enough that by 1500's the vernal equinox was on March 11 rather than March 21, which led to Gregorian Calendar

Gregorian Calendar

- Current calendar
- Intended to correct the drift of the equinox
  - Established on October 4, 1582. Pope Gregory XIII declared that the next day would be October 15, 1582, so there is an 11 day gap in 1582. In other parts of the world (England, Germany, …) the switch to the Gregorian calendar occurred centuries later.
- Introduced the rule that leap years do not occur if the year is divisible by 100 (i.e. 1900), unless the year is also divisible by 400 (i.e. 2000). Thus, the next time we skip a leap year will be 2100.
- Error of 1 day every ~7700 years rather than 1 day every 128 years



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