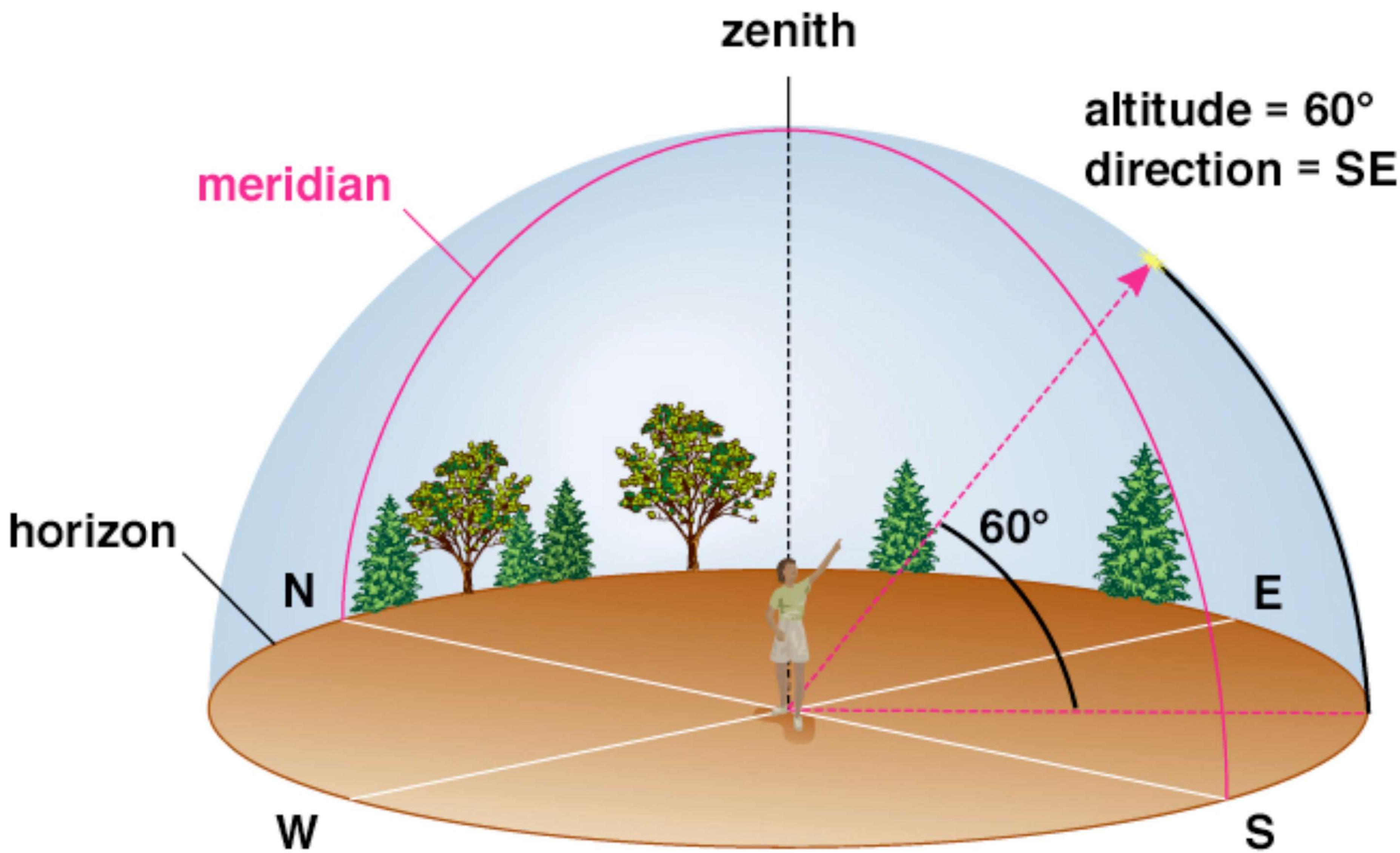
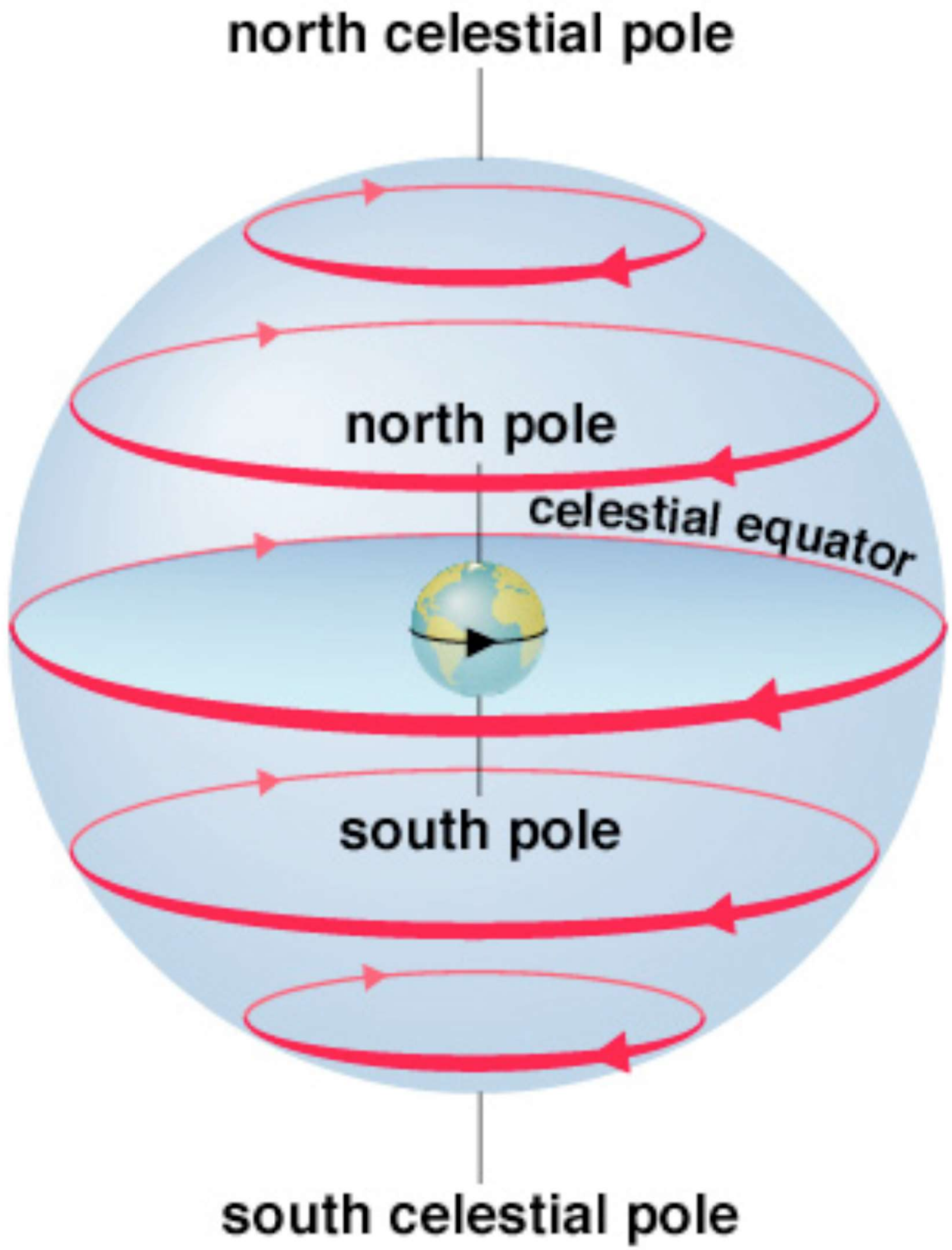
AST 3722

Lecture 2: Coordinates and Time

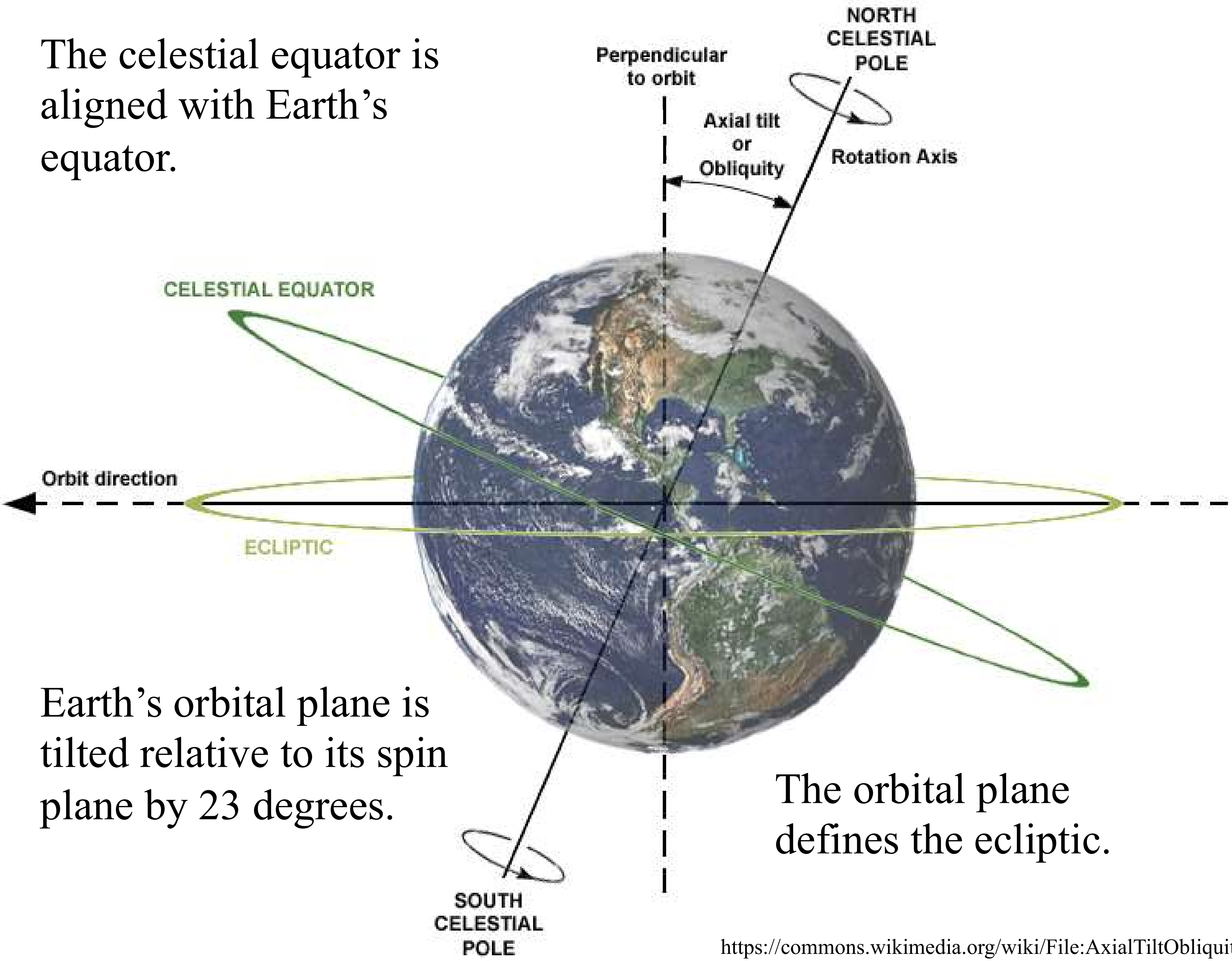

zenith
altitude = 60°
direction = SE
meridian
horizon
60°
N
E
W
S

Where are things on the sky?

- Stars & Galaxies: Celestial, rotation of Earth
- Planets & Sun: Ecliptic, orbit of Earth
- Our Galaxy: Galactic, orbit of the Sun


north celestial pole
north pole
celestial equator
south pole
south celestial pole

The celestial equator is aligned with Earth's equator.



Earth's orbital plane is tilted relative to its spin plane by 23 degrees.

The orbital plane defines the ecliptic.

https://commons.wikimedia.org/wiki/File:AxialTiltObliquity.png

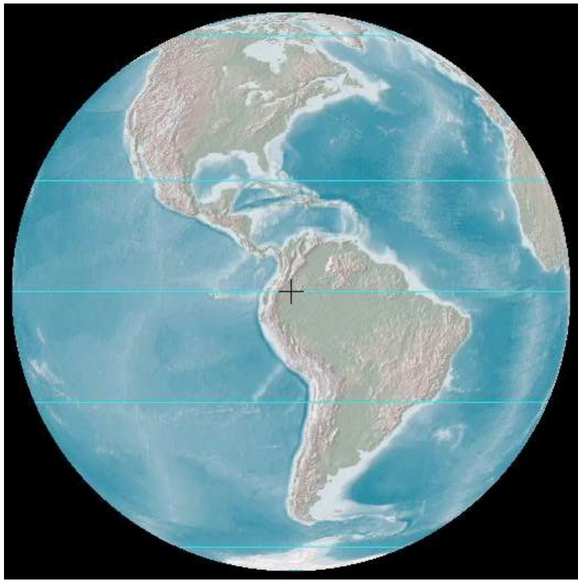
Why are our telescopes mounted at an angle?

- CTO’s telescopes are on *equatorial mounts*, which means they are tilted by the latitude of the observatory
- When mounted this way, they only have to rotate along one axis to track the sky
- Related to the lab exercise: What angle were the telescopes mounted at? What latitude are we at in Gainesville?

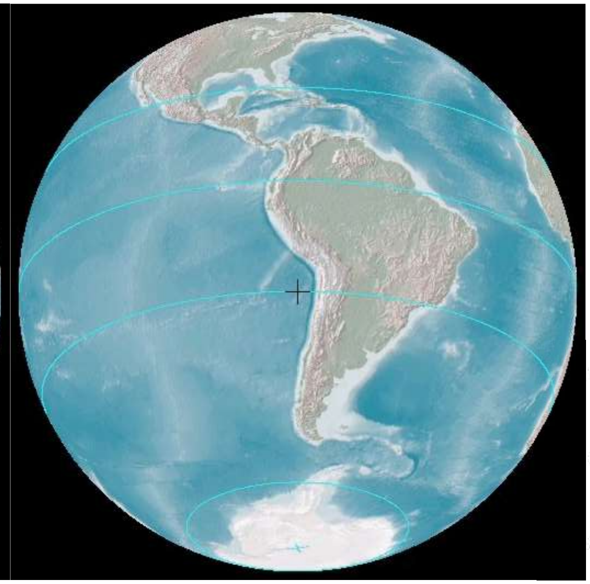
Where would you find the planets?

- A. The Galactic plane
- B. The Ecliptic plane
- C. The Celestial plane
- D. None of the above

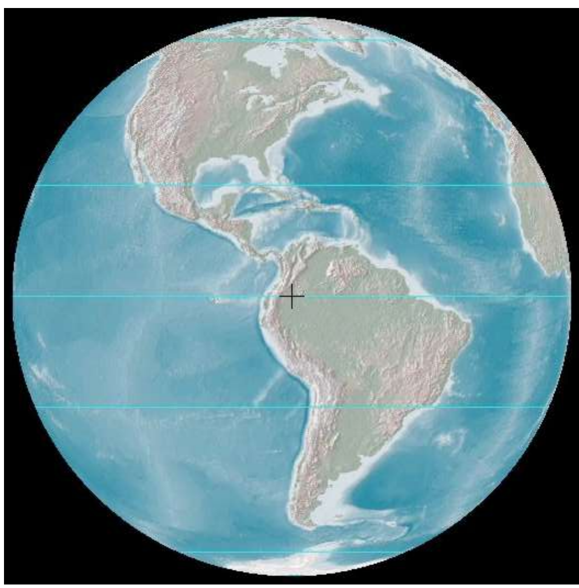
Equinoxes & Solar Elevation



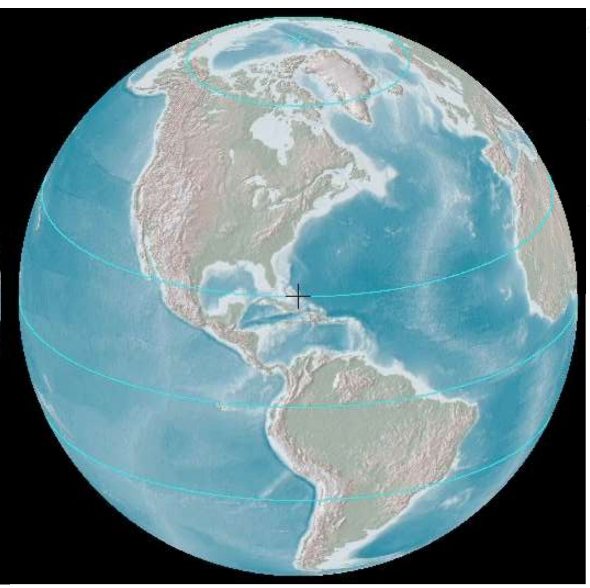
Autumnal Equinox



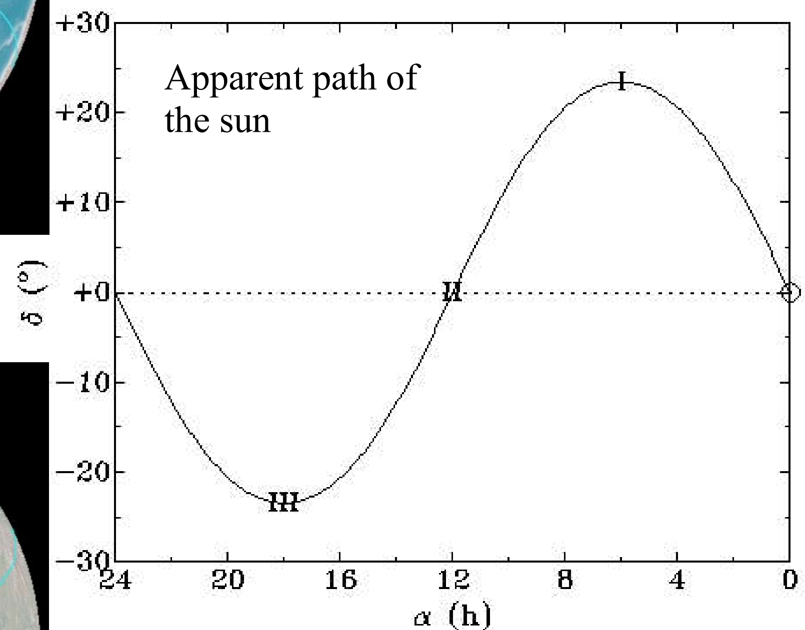
Winter Solstice (III)



Vernal Equinox (II)



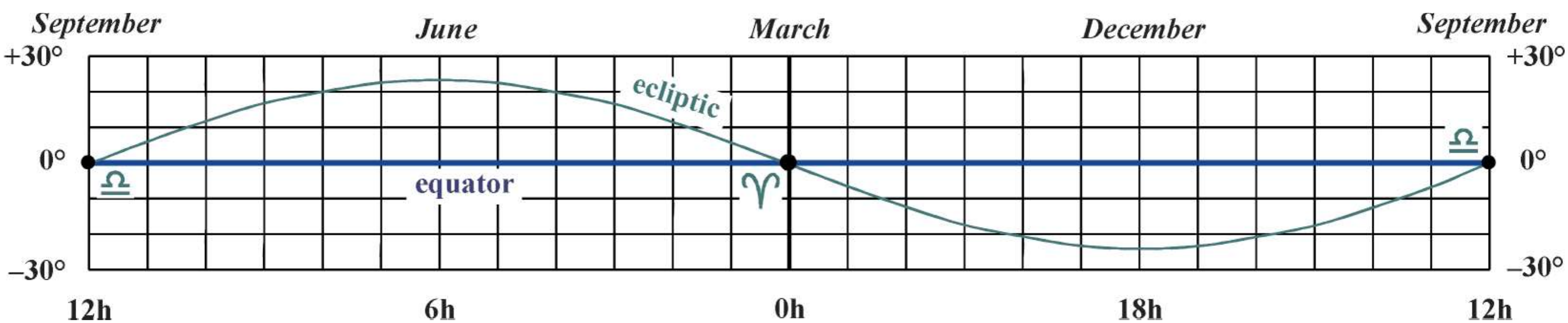
Summer Solstice (I)



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

Equinoxes & Solstices

Apparent path of the sun



Angles

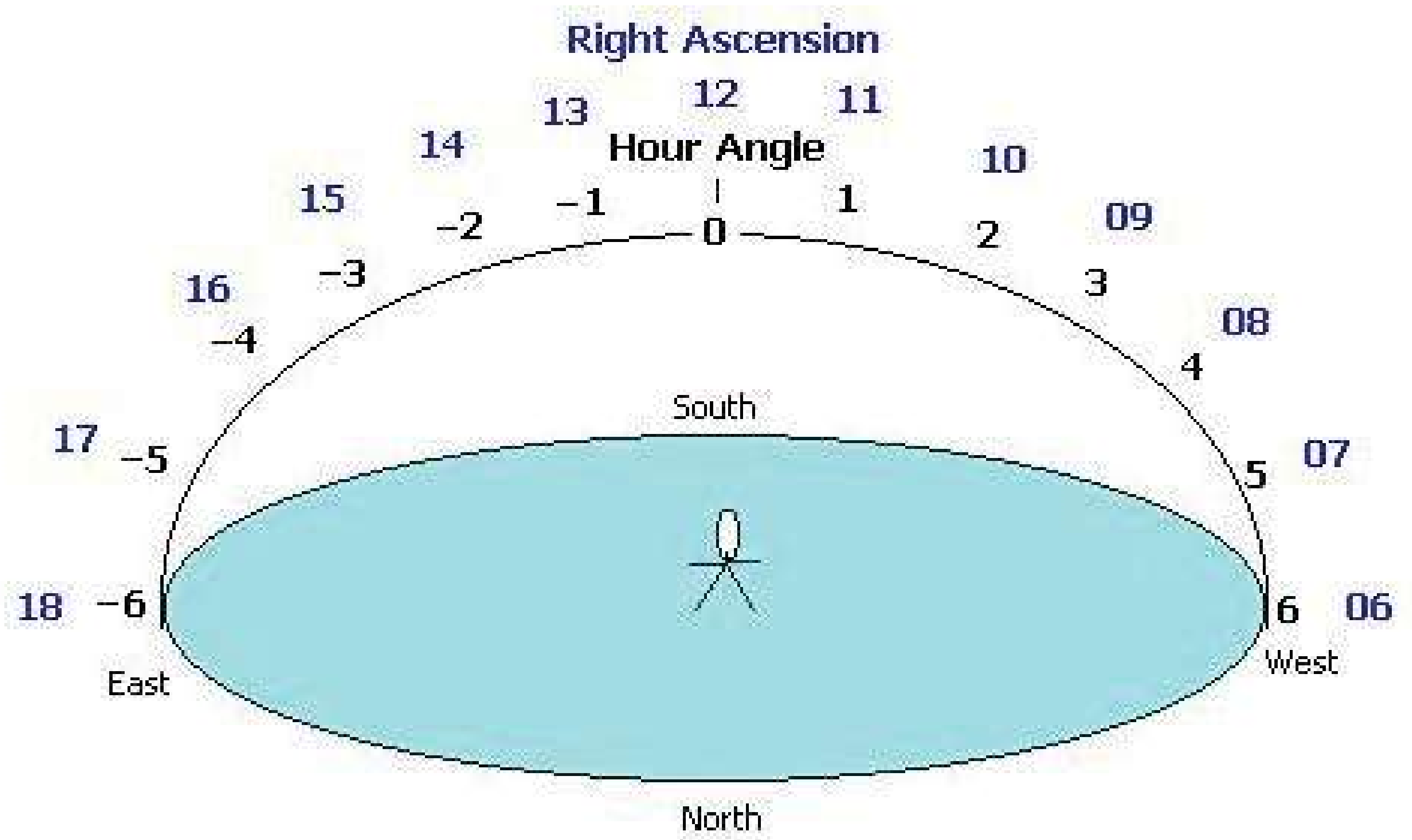
- Angles on the sky are measured in three systems:
- Degrees (°) / arcminutes (’) / arcseconds (”)
  - 1 / 60 / 3600
- Hours / minutes / seconds
  - 1 / 60 / 3600; 1 h = 15 deg; 1 min = 15 arcmin
- Radians
  - 360 deg = 2 pi radians = 24 h

Celestial Coordinates

- Celestial objects stay at (approximately) fixed coordinates
- Example: M31, Andromeda Galaxy
  00:42:44.3 +41:16:09
- Right Ascension (hms) / Declination (dms)
- hh:mm:ss dd:mm:ss
- Need to specify a *time* (e.g., J2000, B1950) – more details in a few slides

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

What is the hour angle of an object directly below you?

- A. 6h
- B. -6h
- C. 15h
- D. 12h
- E. 24h

What path does a star at +30° Declination trace (in Gainesville)?

- A. Rise on one side of the horizon, go overhead, set on the other
- B. Rise toward the north, go high in the sky, set toward the north
- C. Never rise nor set
- D. Rise in the north, go overhead, set in the south

How long does a celestial object with declination equal to your latitude stay above the horizon?

- A. 12h
- B. 6h
- C. 24h
- D. 18h

What path does a star at +75° Declination (15° from 90° North) trace (in Gainesville)?

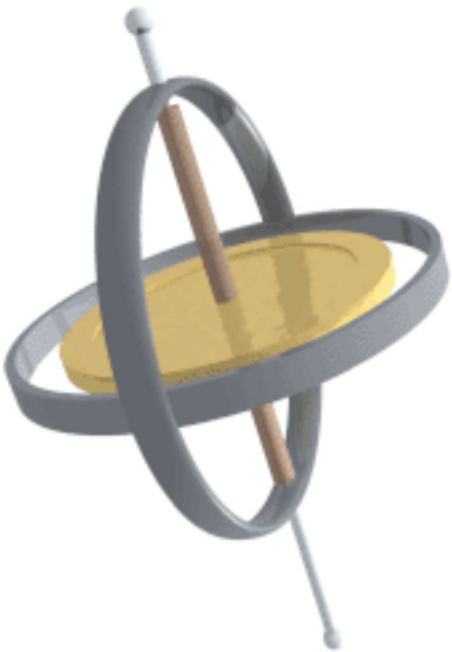
- A. Rise on one side of the horizon, go overhead, set on the other
- B. Rise toward the north, go high in the sky, set toward the north
- C. Never rise nor set
- D. Rise in the north, go overhead, set in the south

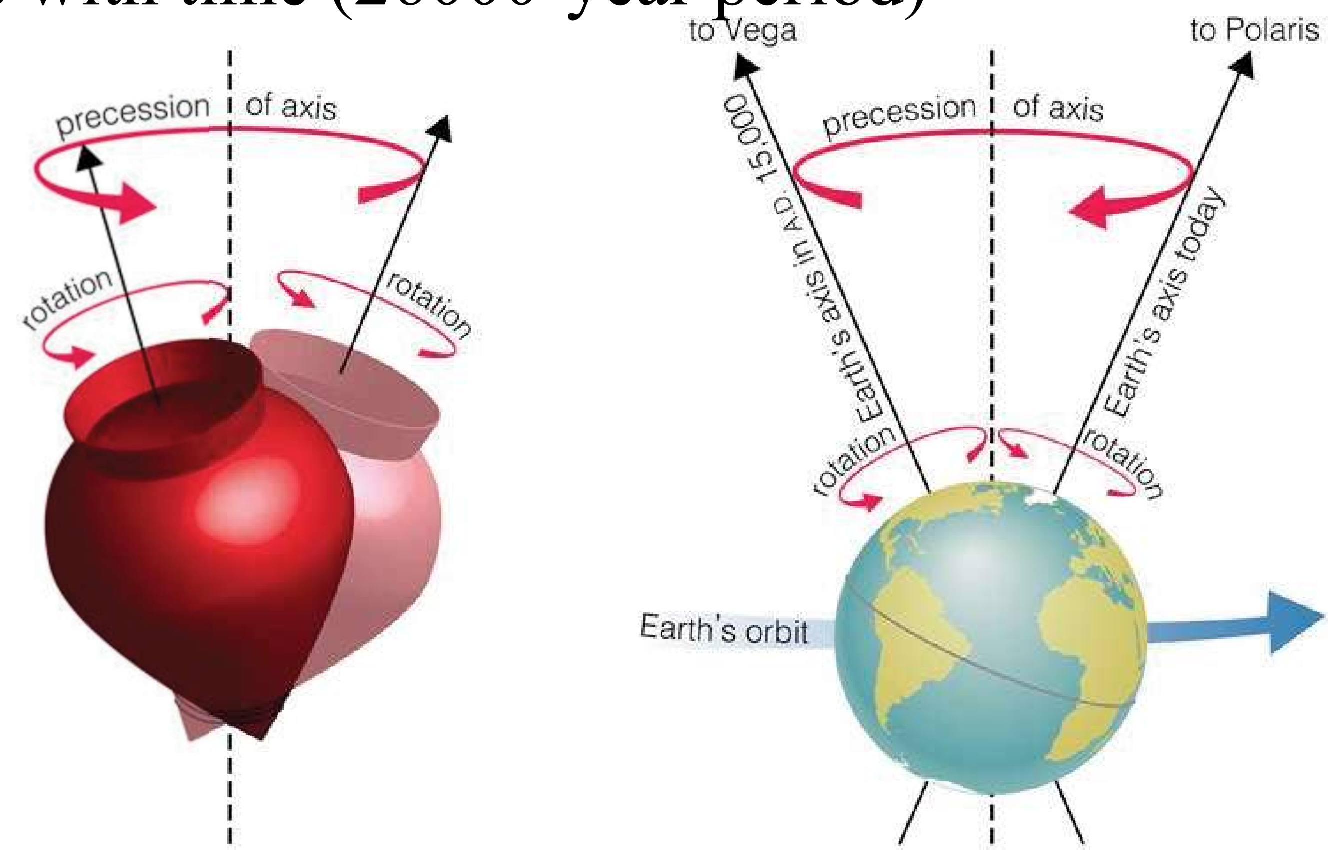
What is the longest period a celestial object can remain above the horizon?

- A. 12h
- B. 6h
- C. 24h
- D. 18h

Coordinate Frames change

Precession is the motion of the tilt of Earth’s spin axis with time (26000-year period)





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

Celestial Coordinate Frames

- J2000: 12 noon (midday) on January 1, 2000
- J is for Julian, 1 year = 365.25 days

The currently-used standard epoch "J2000" is defined by international agreement to be equivalent to:

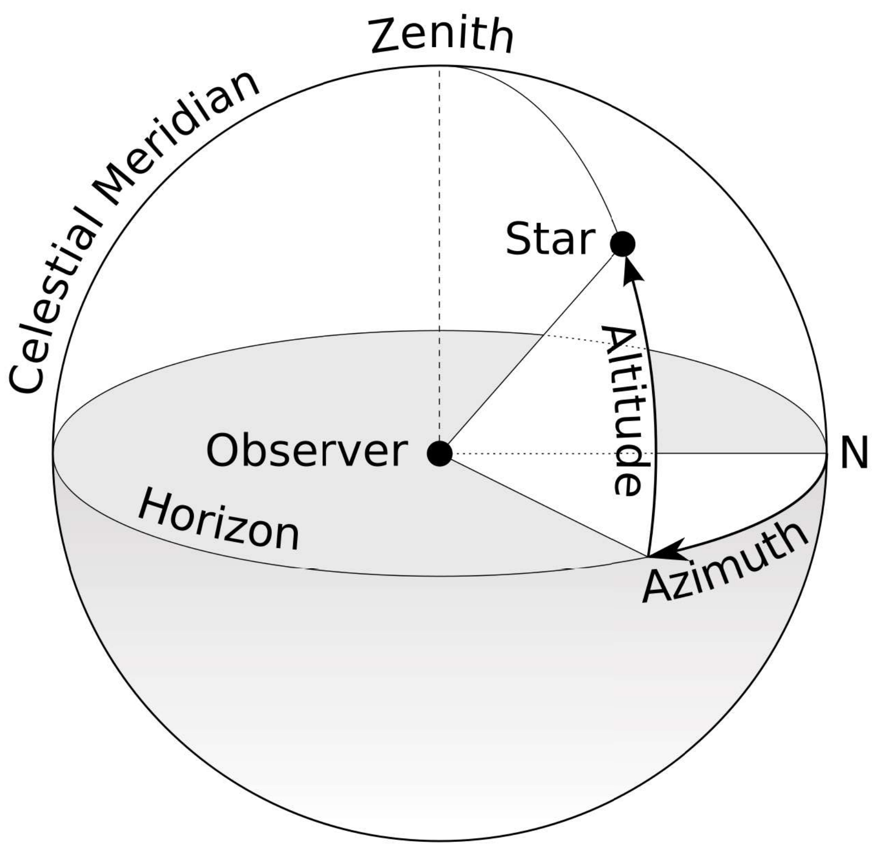
1. The Gregorian date January 1, 2000, at 12:00 TT (Terrestrial Time).
2. The Julian date 2451545.0 TT (Terrestrial Time).[12]
3. January 1, 2000, 11:59:27.816 TAI (International Atomic Time).[13]
4. January 1, 2000, 11:58:55.816 UTC (Coordinated Universal Time).[14]

- Julian day number 0 assigned to the day starting at noon on Monday, January 1, 4713 BC
- B1950 uses a different (Besselian) calendar;
  B = 1900.0 + (Julian date − 2415020.31352) / 365.242198781

What do you need to know about precession?

- Just know the concept
- Computer software is needed to convert coordinates from now (J2020.<whatever>) to “standard” coordinates (J2000), so you will learn to use that software

Altitude-Azimuth (Horizon) coordinates

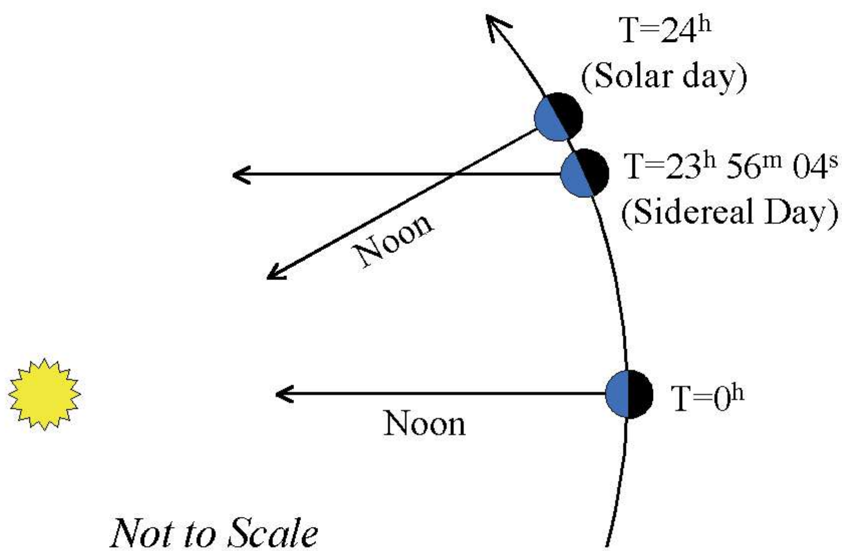


- Coordinates defined relative to the observer
- Azimuth: Degrees East of North (0-360)
- Altitude: Elevation above horizon. 0-90
- Used with Alt-Az telescopes

From Celestial to Horizon coordinates

- The celestial sphere moves (from our perspective) each night, but targets have fixed coordinates
- We need to convert from those fixed Celestial coordinates to local Horizon coordinates

Sidereal vs Solar time



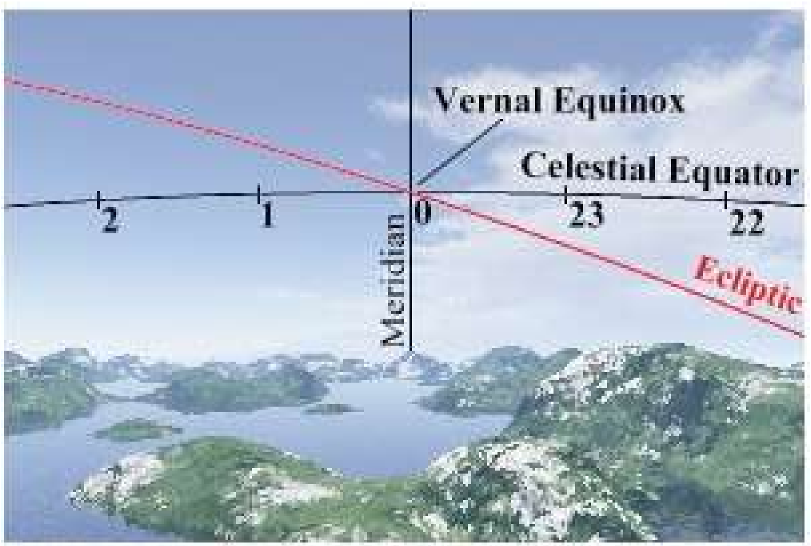
- The sun transits every 24 h, but the Celestial sphere transits every 23h56m

Sidereal Time

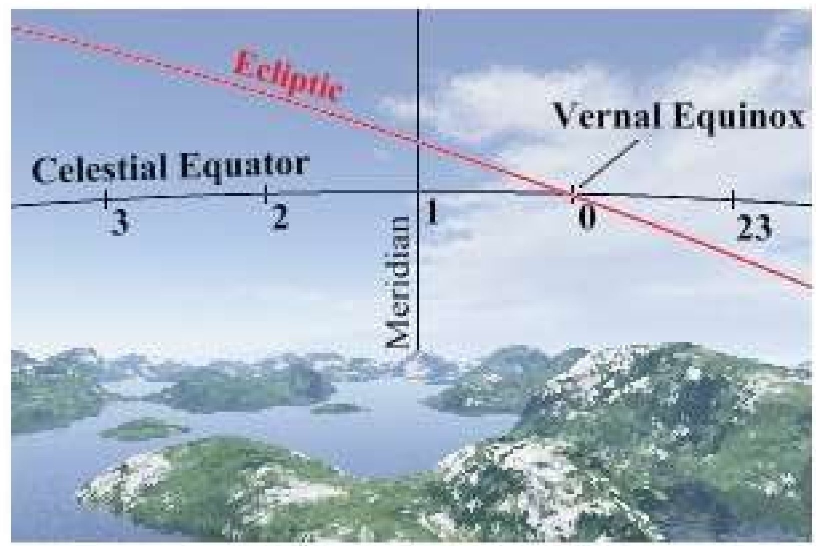
Sidereal time is kept relative to the stars instead of the sun

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.

Hour Angle (HA) is the number of hours before/after a source has reached zenith (HA = LST - RA)

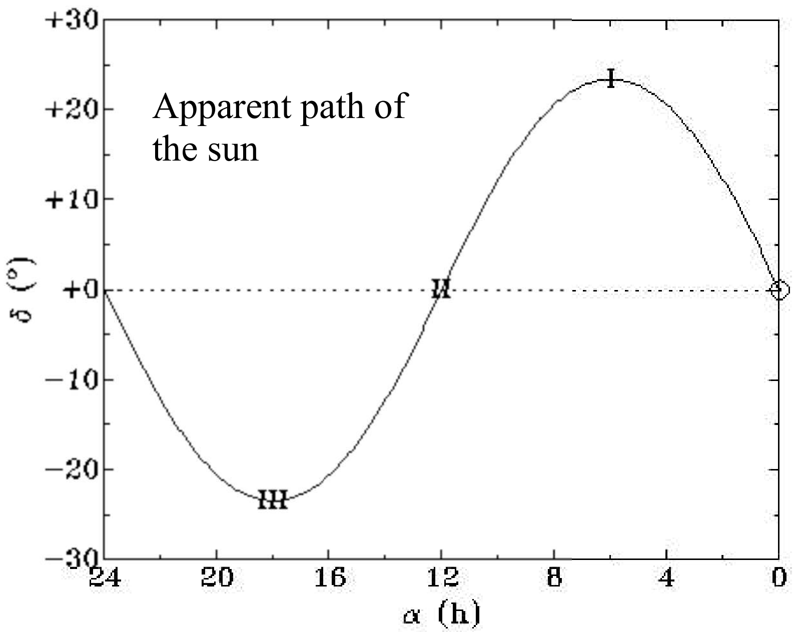


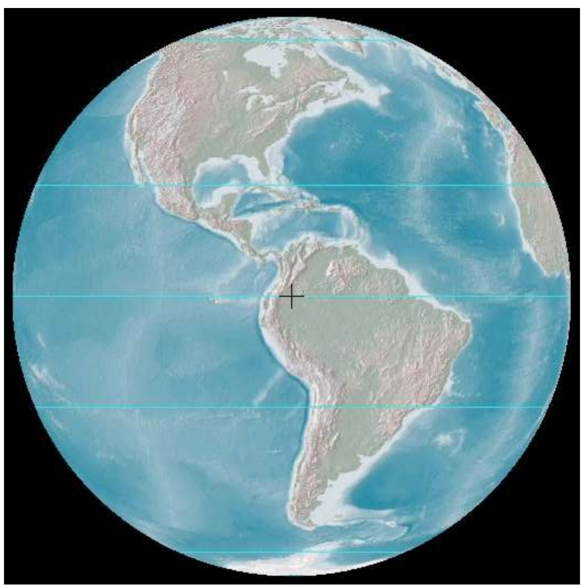
At the vernal equinox



One hour later: Higher RAs cross later

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



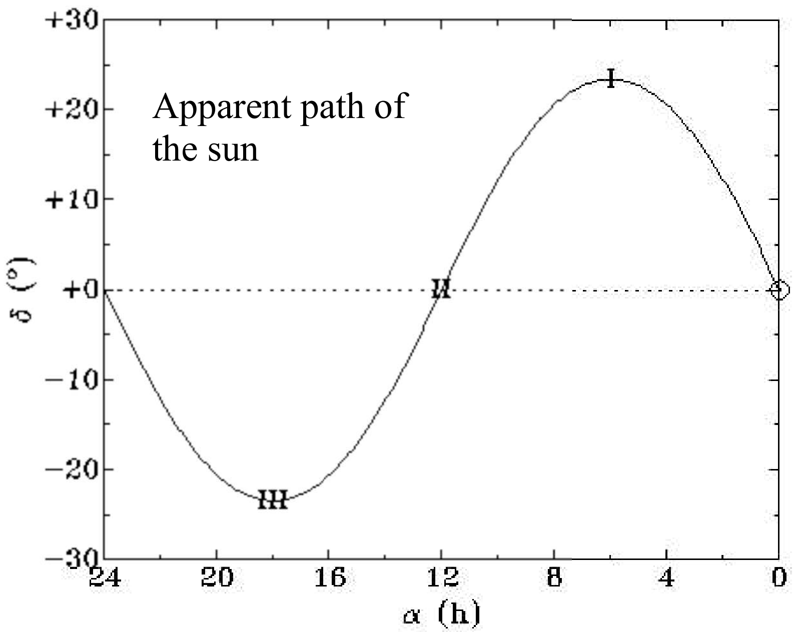


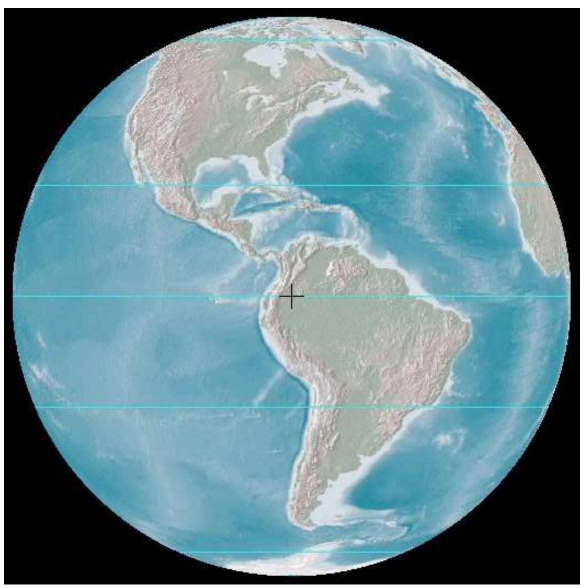
Vernal Equinox (II)

At the Vernal equinox, RA = 12h crosses overhead at midnight. At what time does RA = 15h pass overhead?

A. 1500 (3 PM)
B. 0900 (9 AM)
C. 0300 (3 AM)
D. 2100 (9 PM)

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



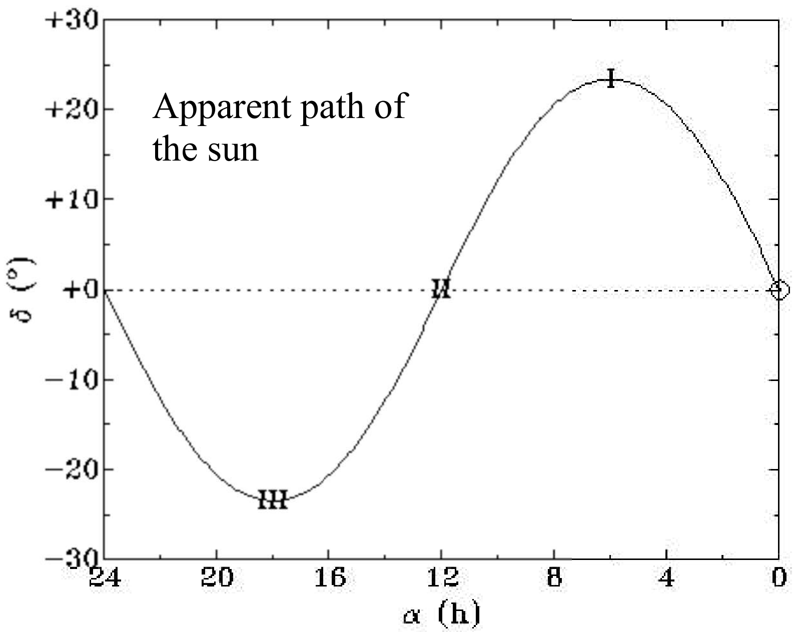


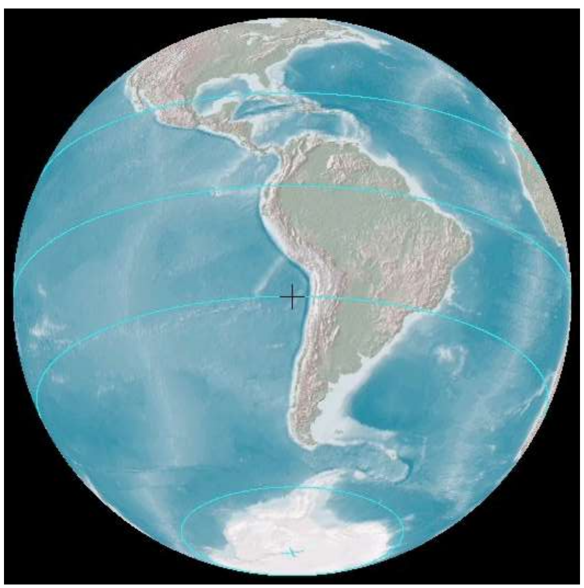
Vernal Equinox (II)

At the Vernal equinox, RA = 12h crosses overhead at midnight. At what time does RA = 9h pass overhead?

A. 1500 (3 PM)
B. 0900 (9 AM)
C. 0300 (3 AM)
D. 2100 (9 PM)

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



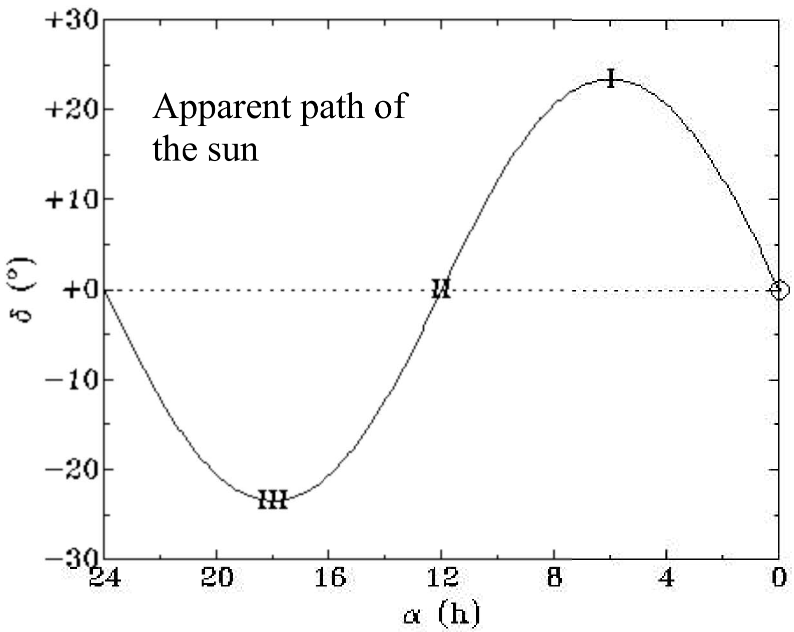


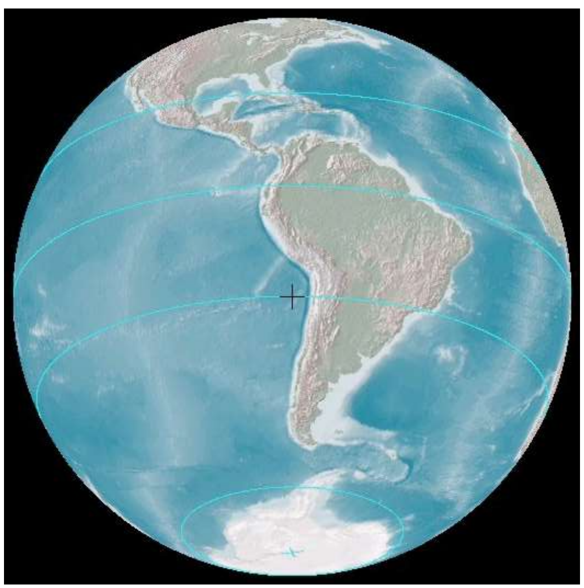
Winter Solstice (III)

At the Winter Solstice, RA = 6h crosses overhead at midnight. At what time does RA = 9h pass overhead?

A. 1500 (3 PM)
B. 0900 (9 AM)
C. 0300 (3 AM)
D. 2100 (9 PM)

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





Winter Solstice (III)

The constellation of Orion is at about 5h RA. At approximately (within an hour) what time does it pass overhead on the Winter Solstice?

A. 0000 (Midnight)
B. 0600 (6 AM)
C. 1200 (Noon)
D. 1800 (6 PM)

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

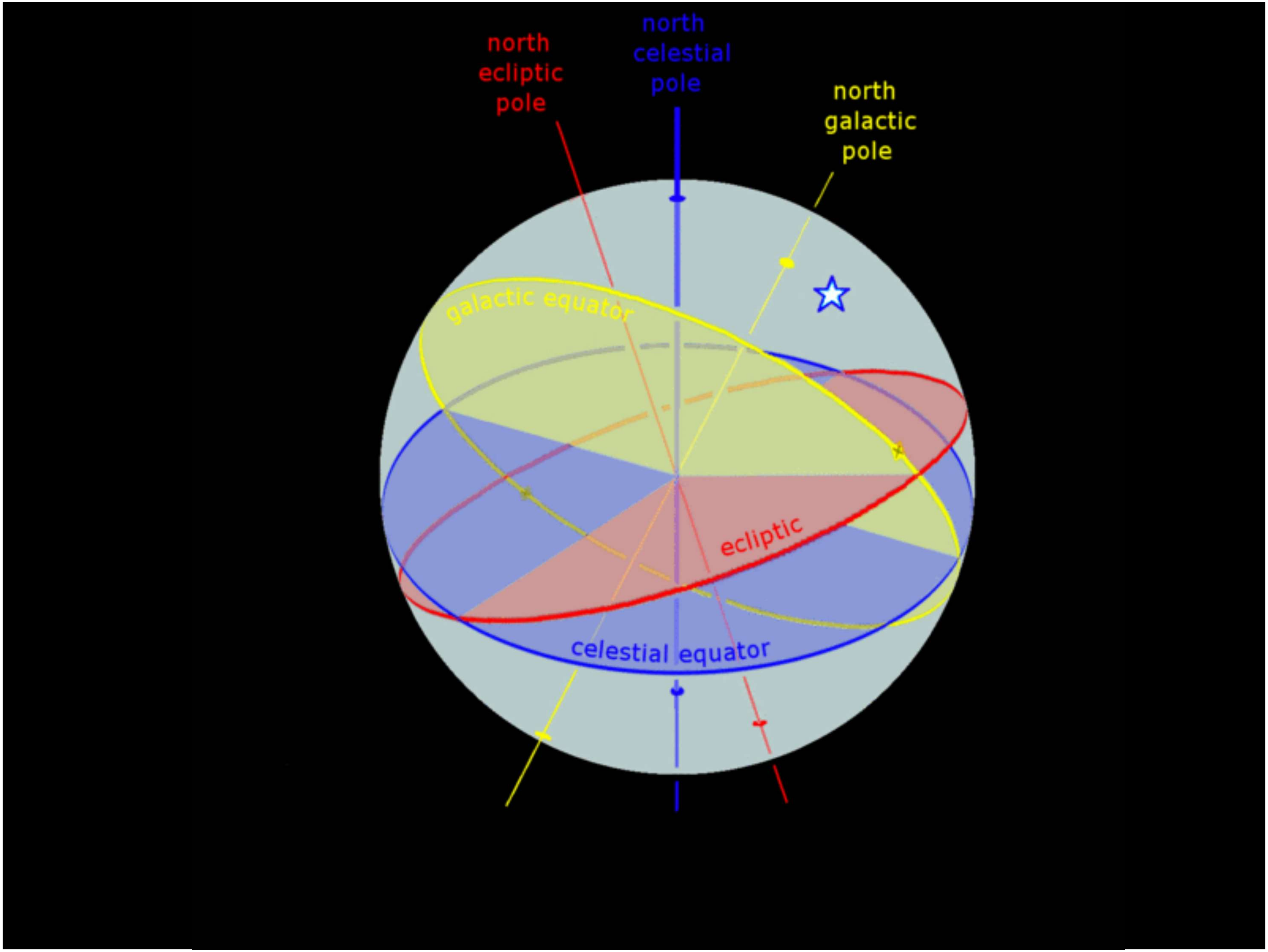
During what season is the constellation Cygnus (RA=20h) overhead at midnight?

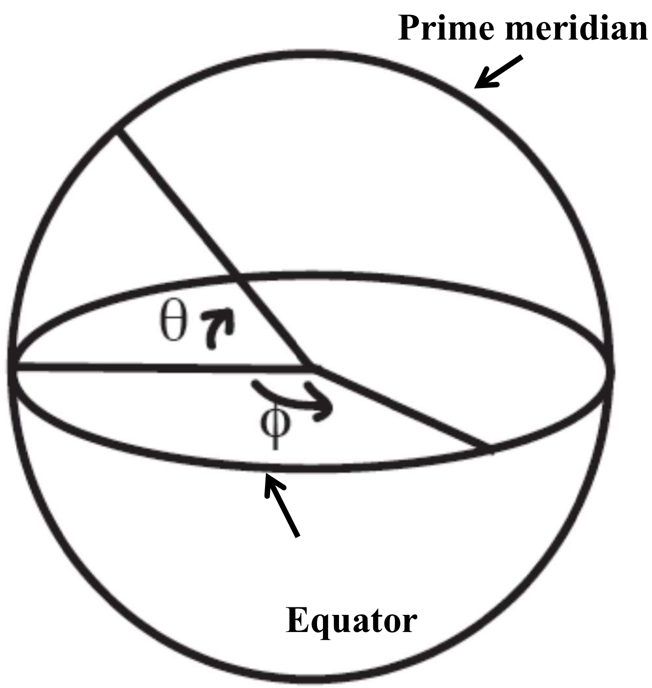
- A. Spring
- B. Summer
- C. Fall
- D. Winter
- E. Always
- F. Never

How do we use this information in practice?

- Software tools!
- astropy
- astroplan
- astroquery

Beyond this point are reference notes


north
ecliptic
pole
north
celestial
pole
north
galactic
pole
galactic equator
ecliptic
celestial equator



Coordinates

Unit Sphere

Essentially all coordinate systems in astronomy are spherical coordinate systems.

One's location on the sphere is completely specified by the two angles, θ [-90,90] and ϕ [0,360], which can be converted into Cartesian coordinates:
$x = \sin\phi \cos\theta$, $y = \cos\phi \cos\theta$, $z = \sin\theta$

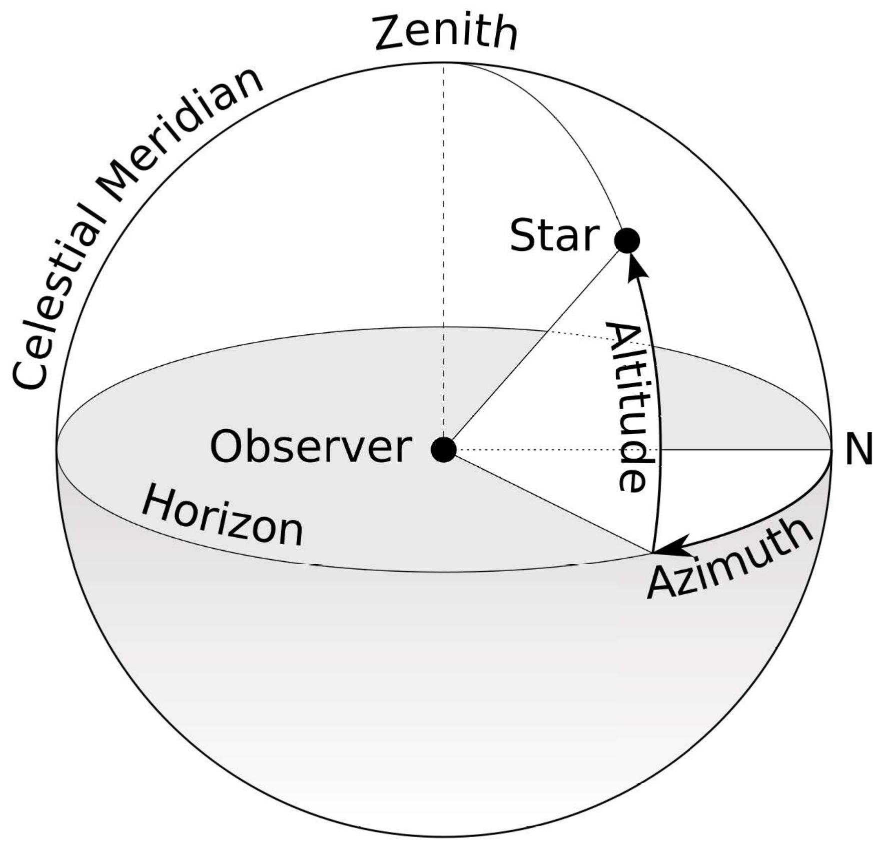
For any spherical coordinate system you also must define two *great circles* that define where the two angles equal zero.

Equator: great circle that defines θ=0.
Prime meridian: great circle that defines ϕ=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

<u>Fundamental coordinates for telescopes.</u>

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:

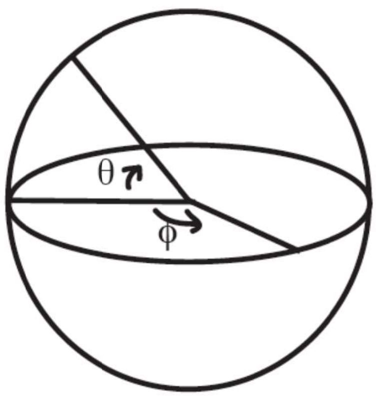
altitude	(θ, commonly referred to as alt) *angle above horizon	-90° to 90°
azimuth	(ϕ, commonly referred to as az)	0° to 360°, -180° to 180°

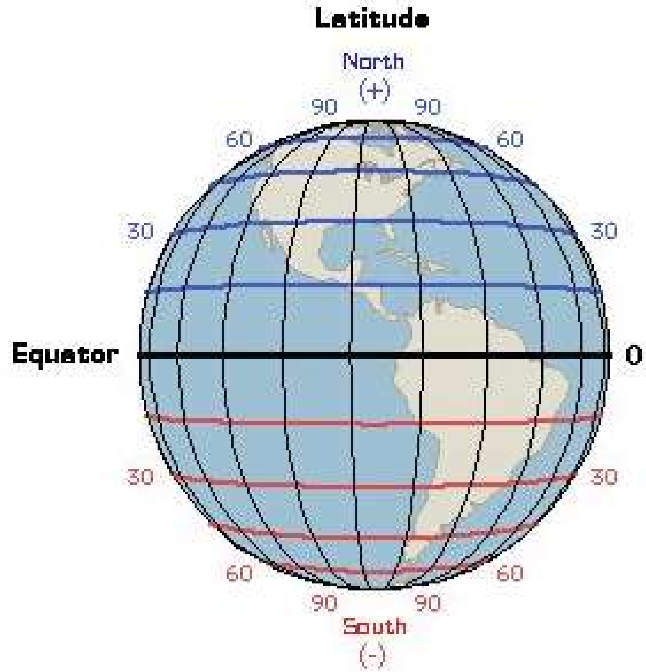
*Geographic definition, also commonly used in astronomy, is that azimuth is measured from the north point, increasing to the east. Note though that there is also an astronomical definition in which it is measured from the south point, increasing west. [So be careful]

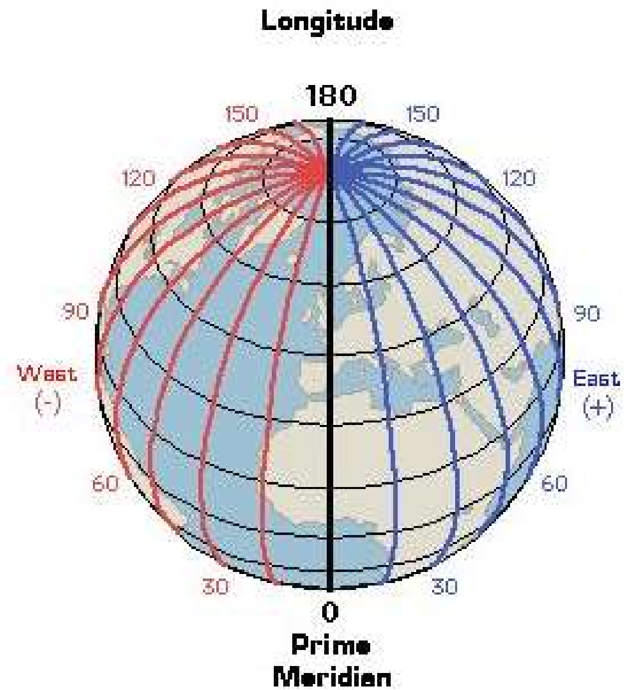
https://commons.wikimedia.org/wiki/File:Azimuth-Altitude_schematic.svg

Coordinates

Terrestrial Coordinates (Locations on the Earth)







Angles: **Latitude** **(θ)** -90° to 90°

Longitude **(ϕ)** 0-180° W, 0-180° E **

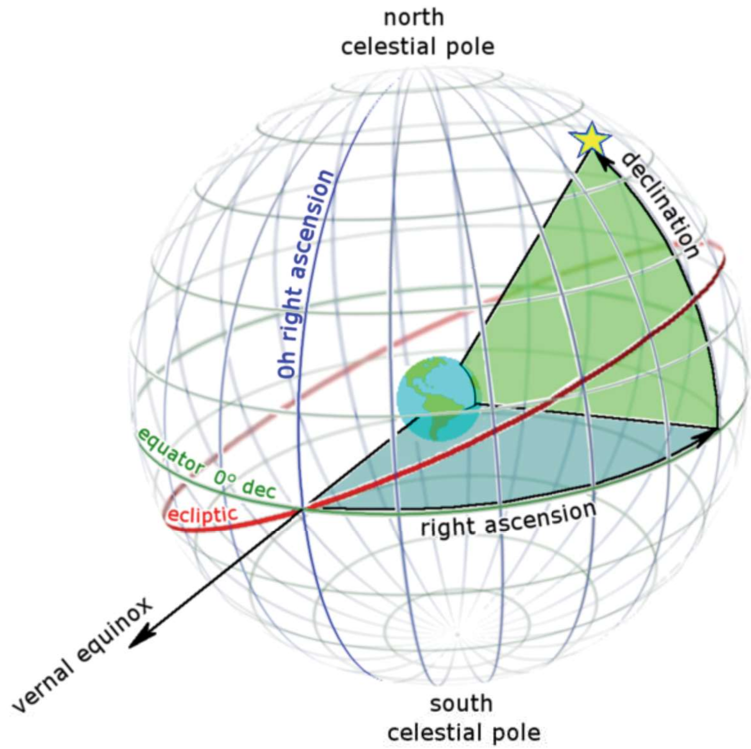
Equator: Earth's equator

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.

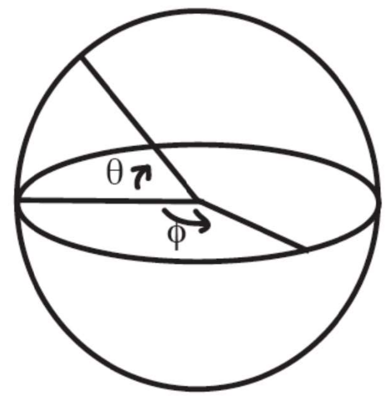
Gainesville coordinates: 29.6516° N, 82.3248° W

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

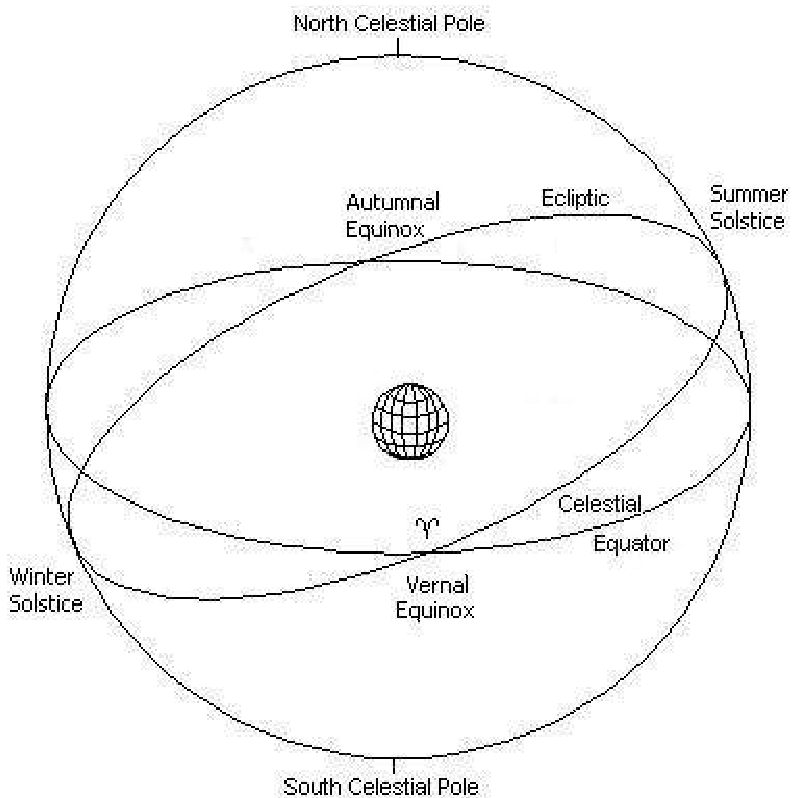
Equator: Celestial equator = Earth’s equator (extension of earth’s equatorial plane to be precise)

Prime Meridian Reference Point: Vernal equinox (the sun is at RA=0 on March 21)

https://en.wikipedia.org/wiki/File:Ra_and_dec_on_celestial_sphere.png

Coordinates

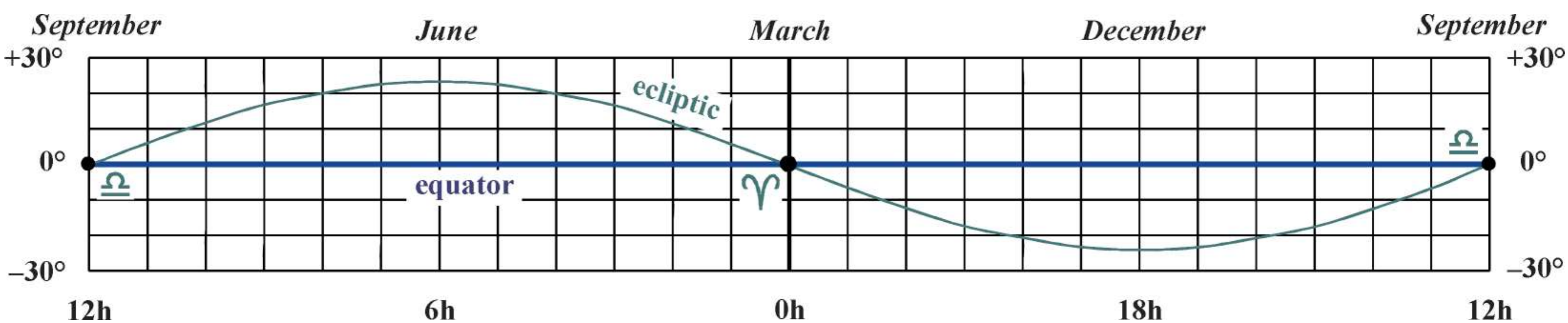
Equatorial Coordinates



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

Equatorial Coordinates

RA and Dec:

Right Ascension is measured in hours (usually), Declination is measured in degrees

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 (sexagesimal, "hmsdms"). For example:

(α,δ) = (10h15m30.0s,+45d00m30s).

or (α,δ) = (10:15:30.0,+45:00:30).

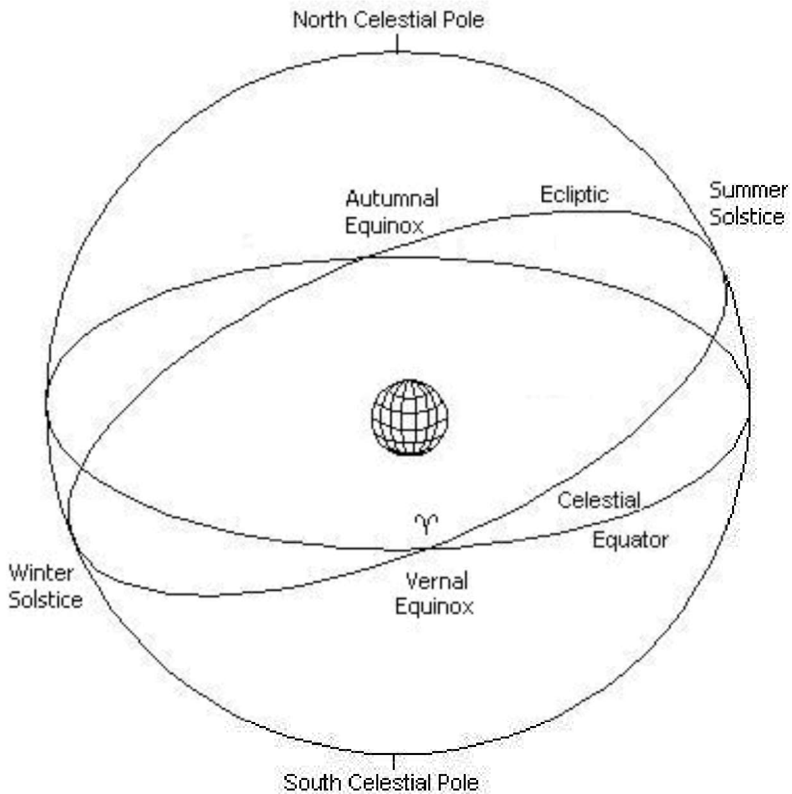
It is also common though for the coordinates to be given in decimal format with the RA in degrees, in which case the above would be:

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

where these values come from:

$\boldsymbol{\alpha = 15 \times (10 + 15/60 + 30/3600)}$

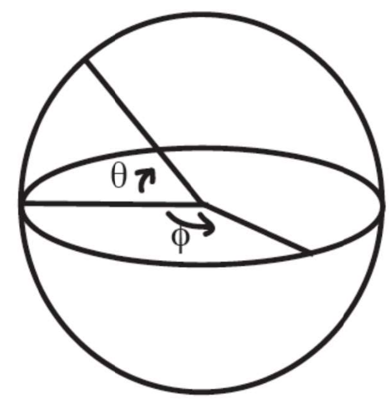
$\delta = 45 + 0/60 + 30/3600$



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 eclipitic poles.



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

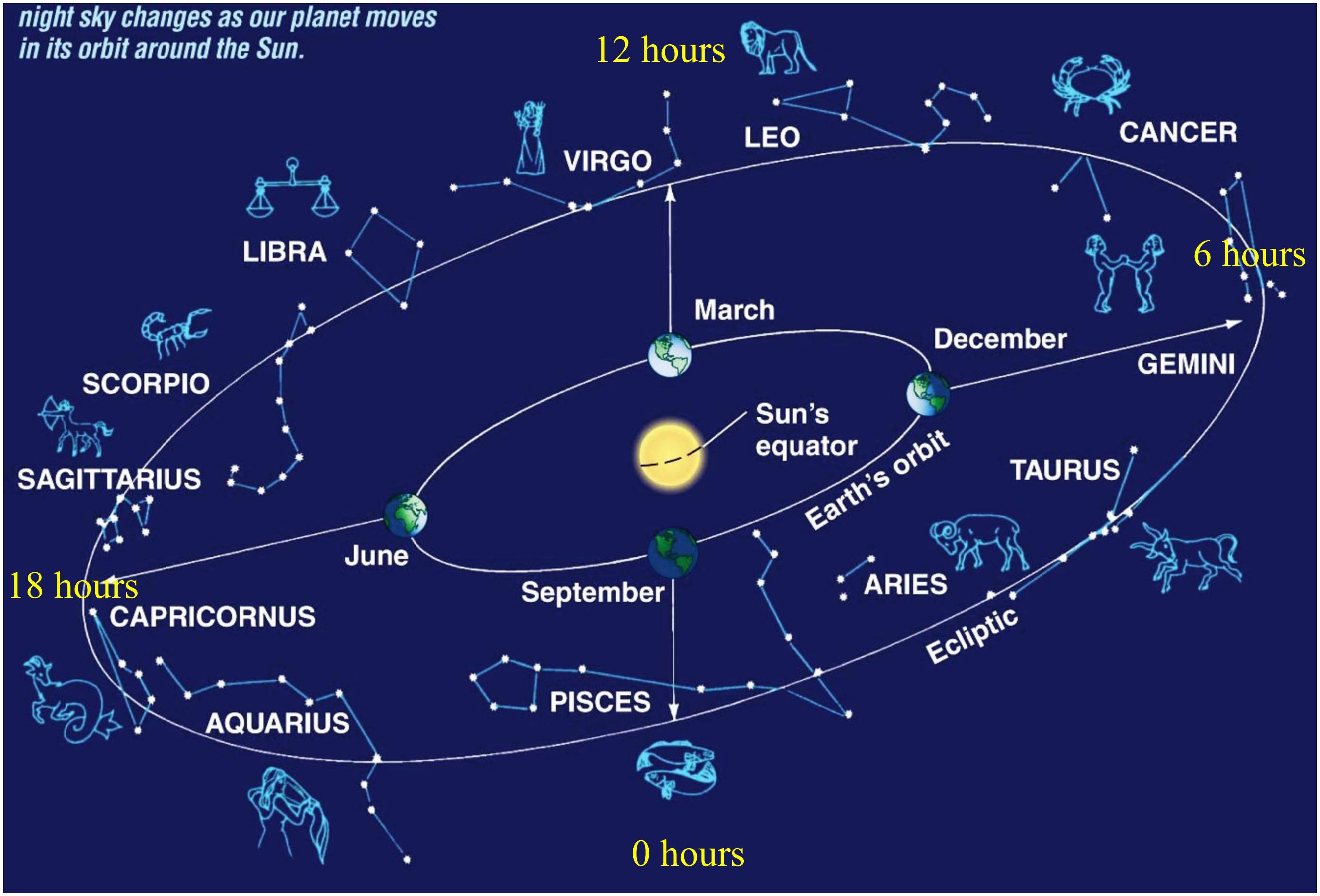
Angles:	**Ecliptic latitude**	($\theta \rightarrow \beta$)	-90° to 90°
	Ecliptic longitude	($\phi \rightarrow \lambda$)	0-360°, or 0-24 hours

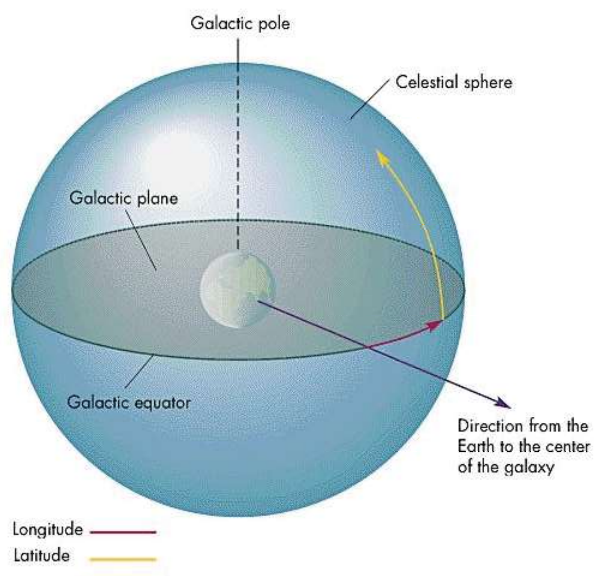
Equator: Ecliptic plane= Orbital plane of planets in solar system

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

Image from John Oliver' s web page

Constellations at Different Seasons





Coordinates

Galactic Coordinates

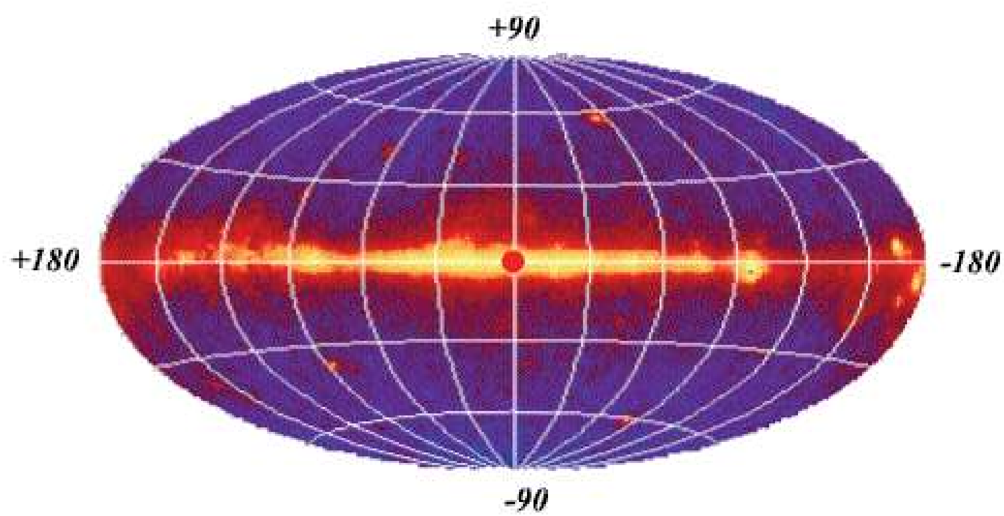
Galactic coordinates are another widely used coordinate system. The idea of galactic coordinates is to provide a reference frame based upon the galactic plane rather than solar system.

Angles:	**Galactic latitude**	(***b***)	-90° to 90°
	Galactic longitude	(***l***)	0-360°, or 0-24 hours

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

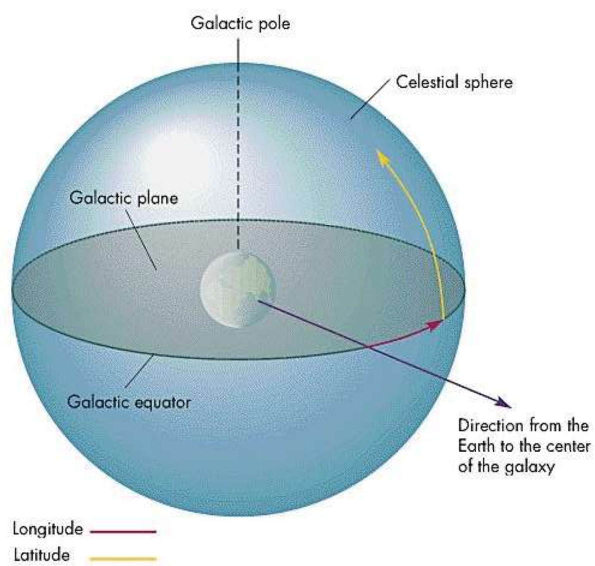
Location of galactic north pole:
RA,Dec = 12:51:24,+27:07:00 (J2000.0)

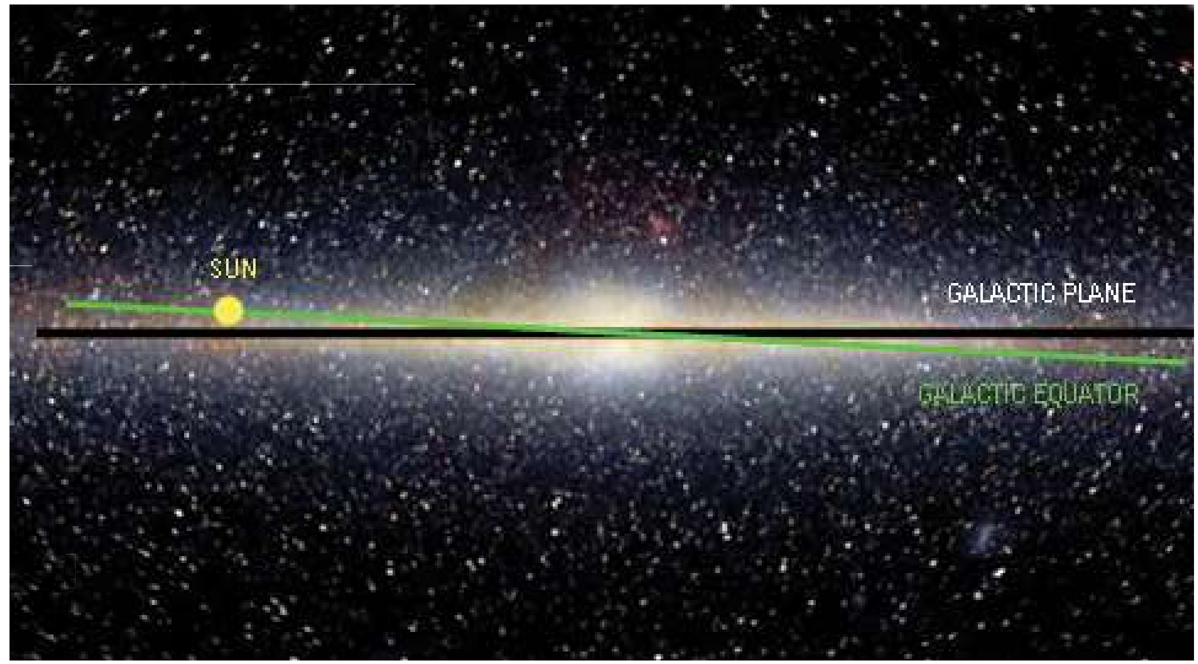
Location of galactic center:
RA,Dec = 17:45:36,-28:56:00 (J2000.0)



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

Coordinates



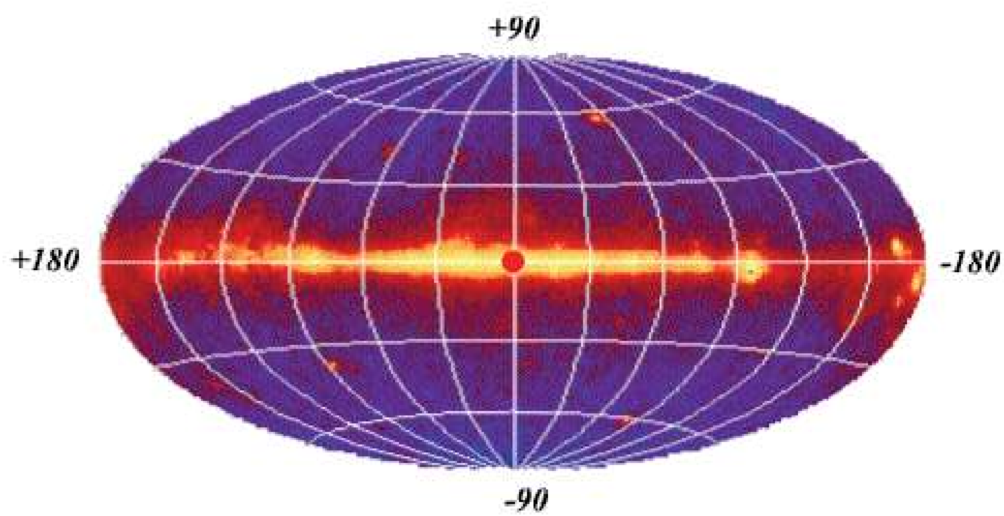


Angles: **Galactic latitude**
Galactic longitude

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

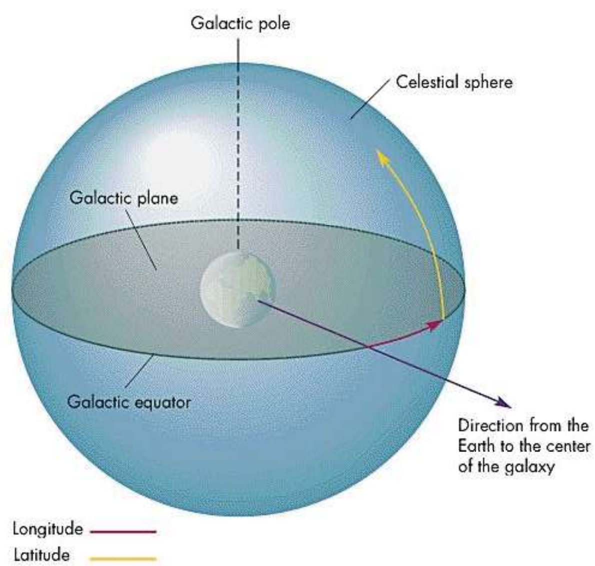
Location of galactic north pole:
RA,Dec = 12:51:24,+27:07:00 (J2000.0)

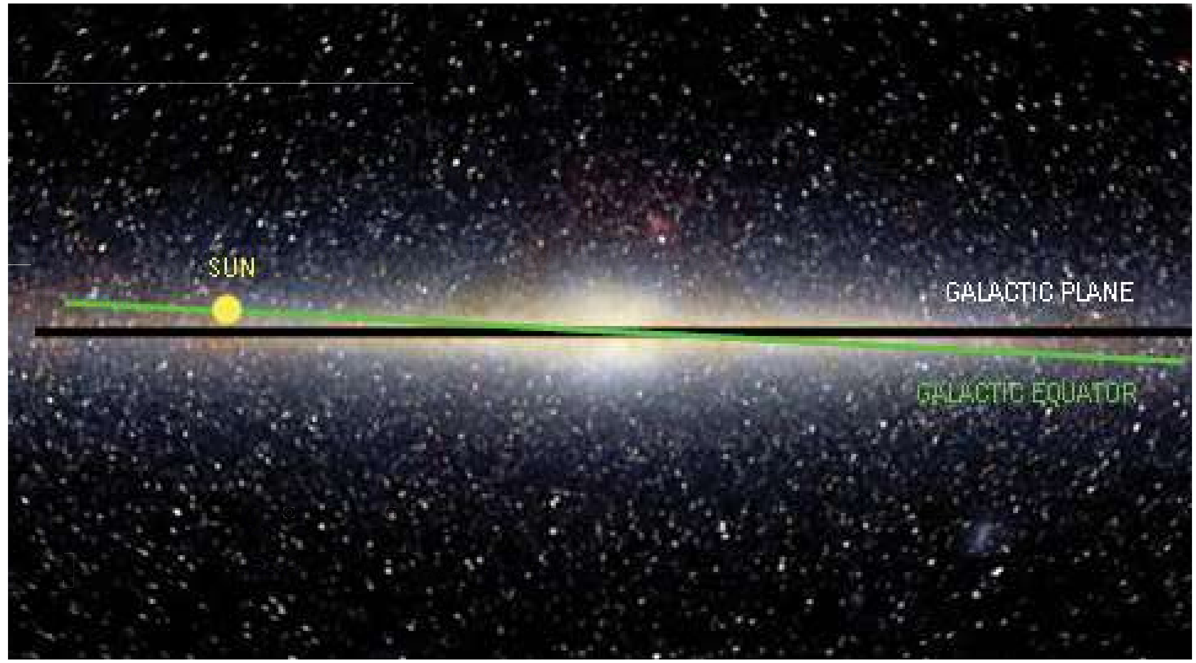
Location of galactic center:
RA,Dec = 17:45:36,-28:56:00 (J2000.0)



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

Coordinates



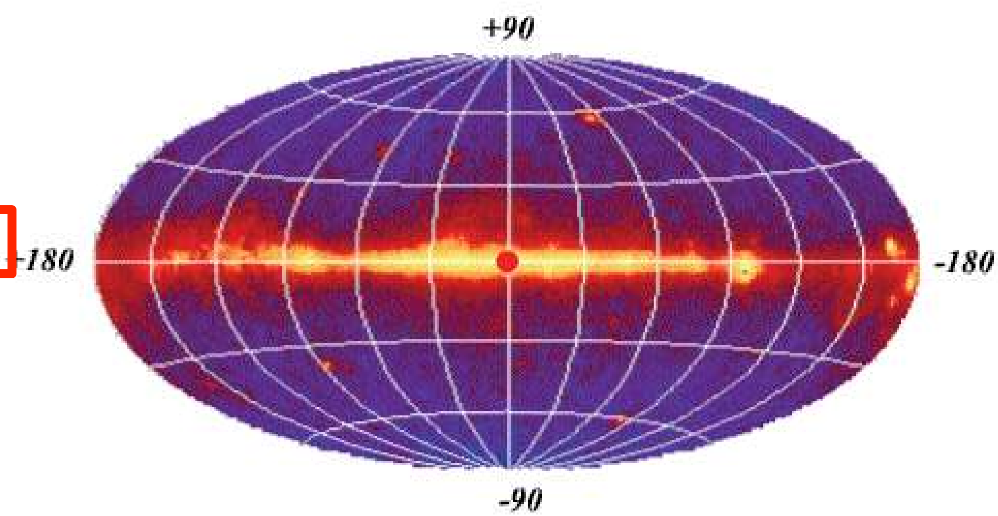


Angles: **Galactic latitude**
Galactic longitude

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

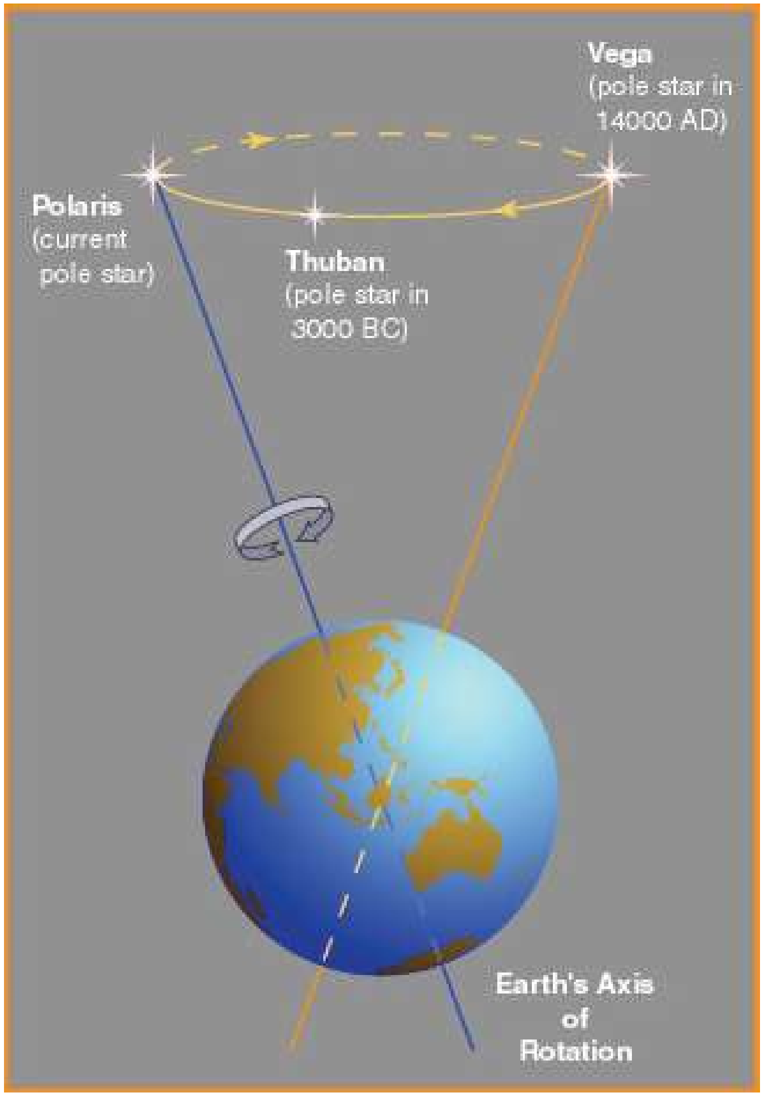
Location of galactic north pole:
RA,Dec = 12:51:24,+27:07:00 (J2000.0)

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.

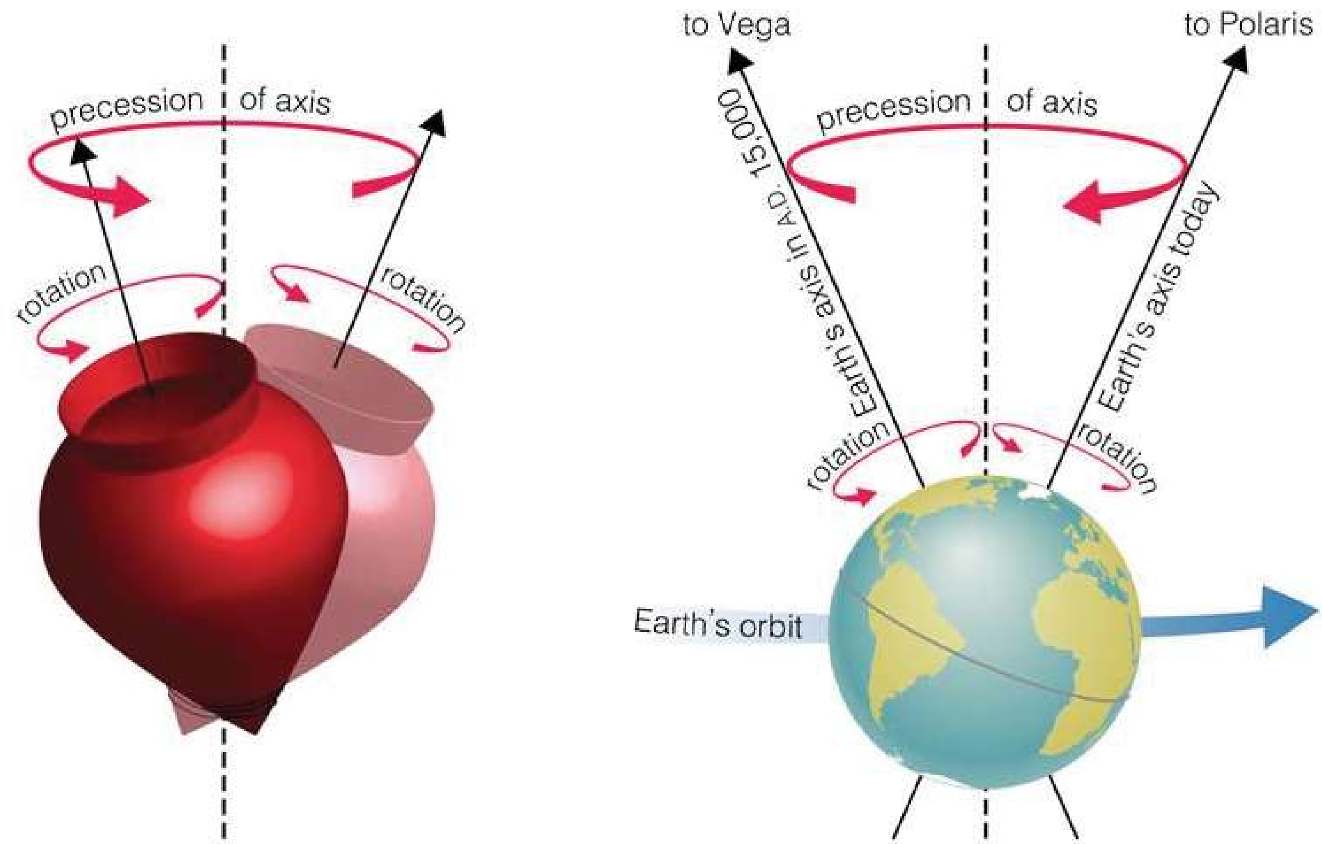
For this reason, when object coordinates are given they are always accompanied by the **epoch** (also called **equinox**) for which these coordinates are valid.

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

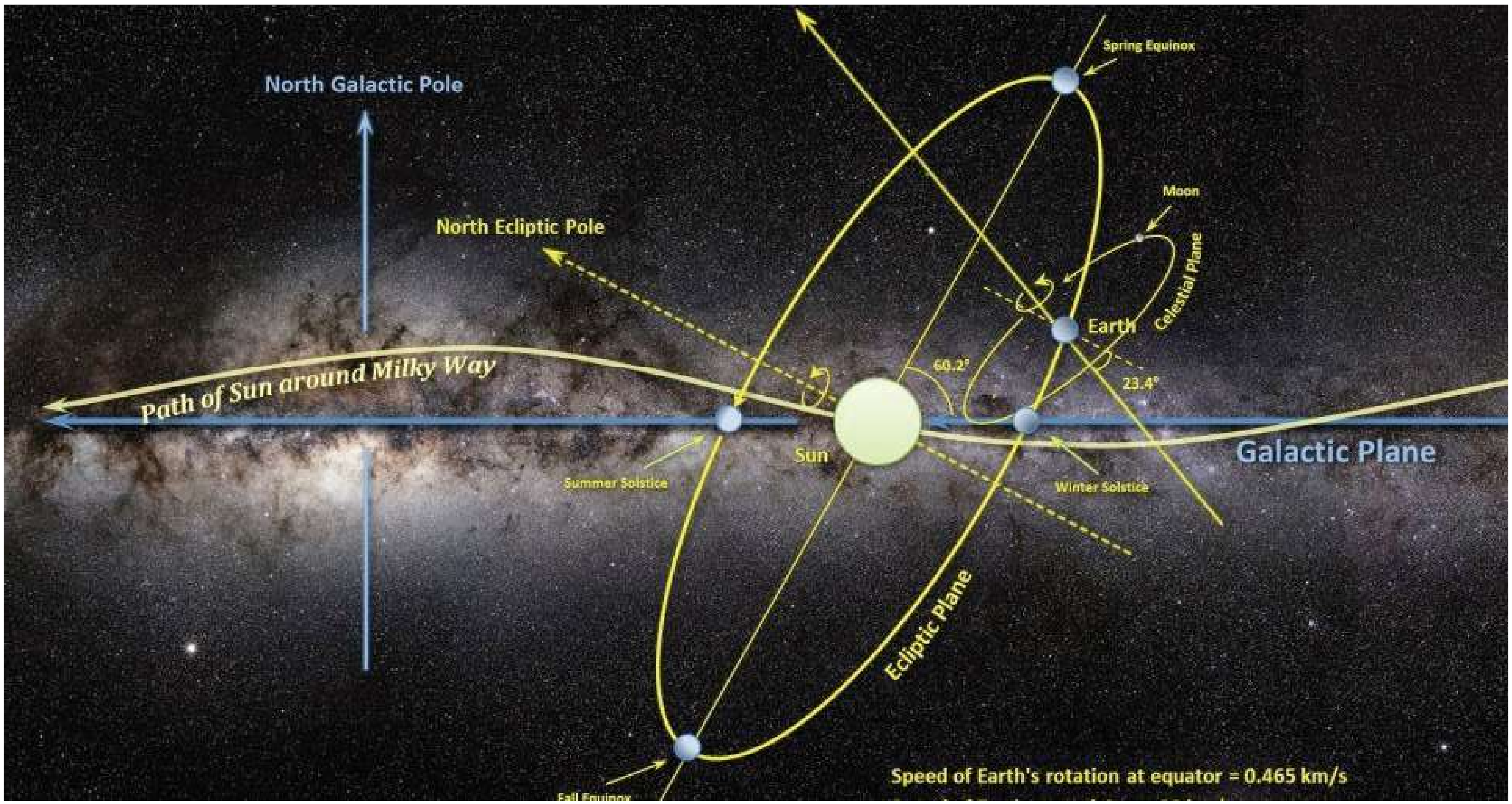
Coordinates

Precession



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

Coordinate System Comparison



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

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?

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.

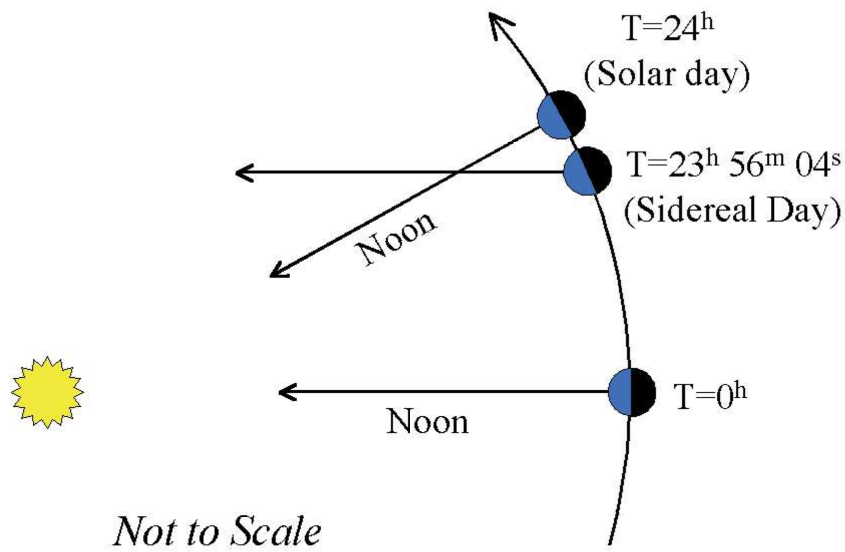
Solar Time

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.

Gainesville coordinates: 29.6516° N, 82.3248° W or 5.488 hr W

Time

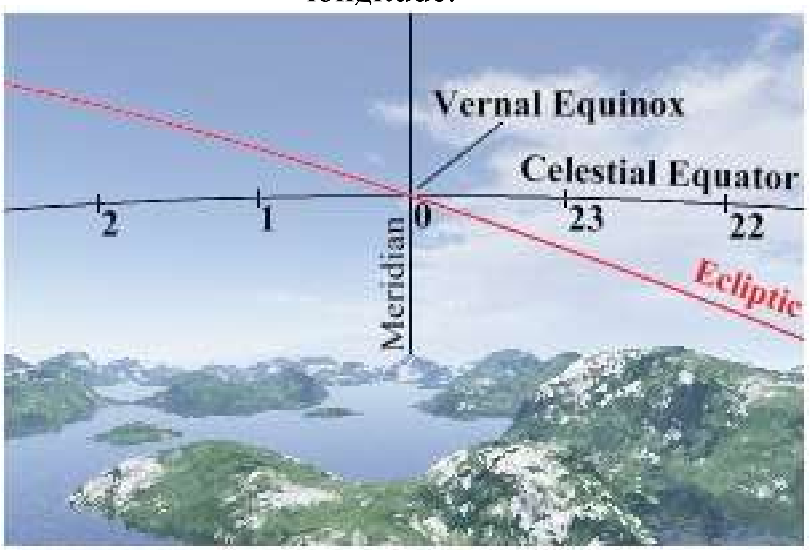
Sidereal Time

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.

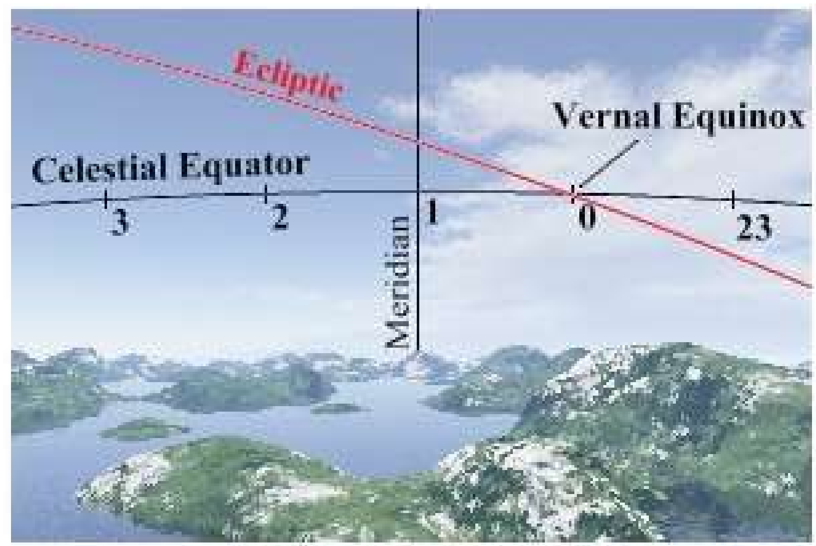
Local Sidereal Time (LST) is defined as **the RA crossing the local meridian at a given instant.** Since the RA is defined to be 0 hours at the vernal equinox, the LST is also 0 when the vernal equinox is on the observer's local meridian.

HA=LST-RA

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 longitude.



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.

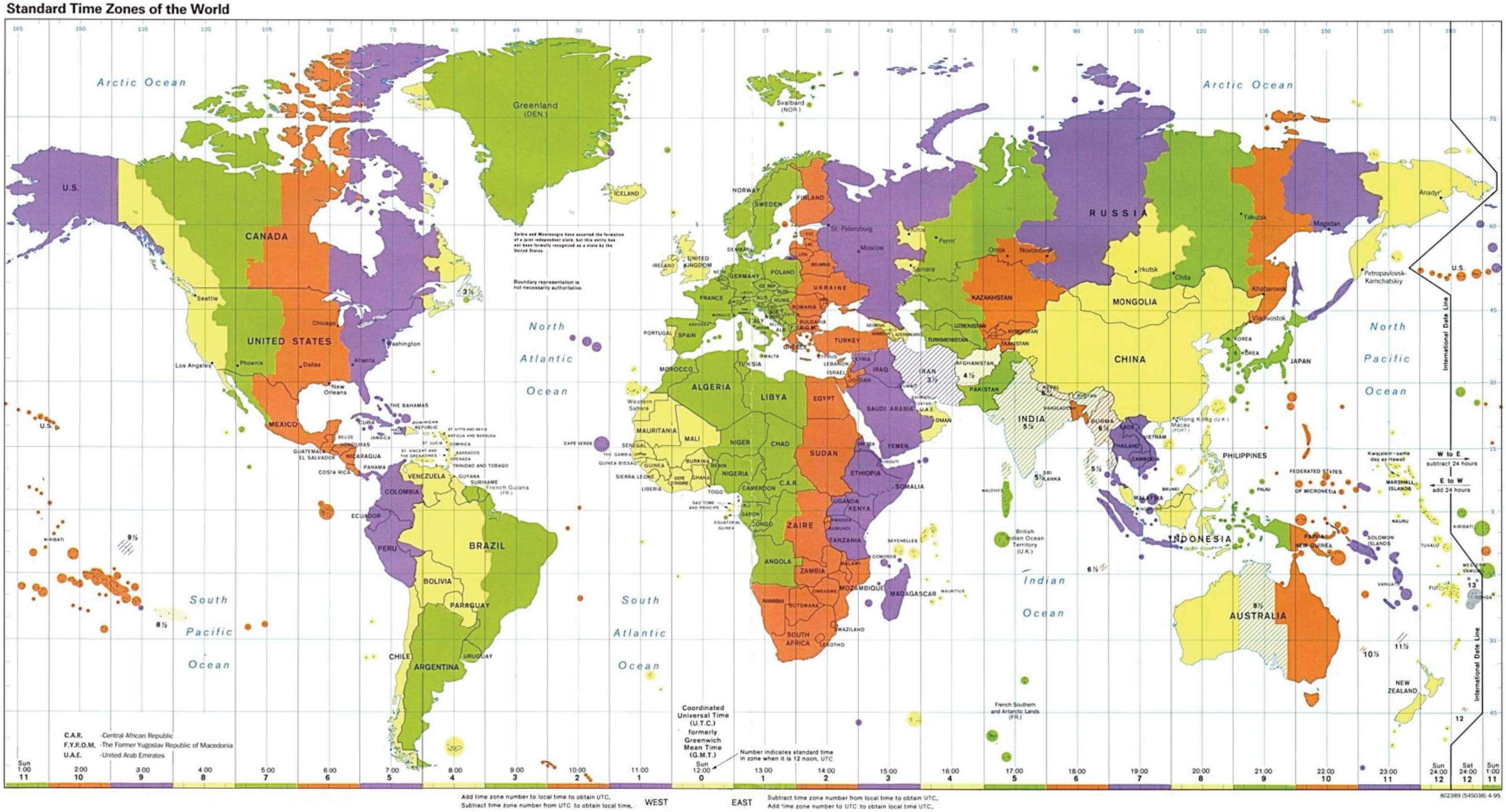
The point here to keep in mind is that standard (civil) time is ***not*** generally the same as LMT.

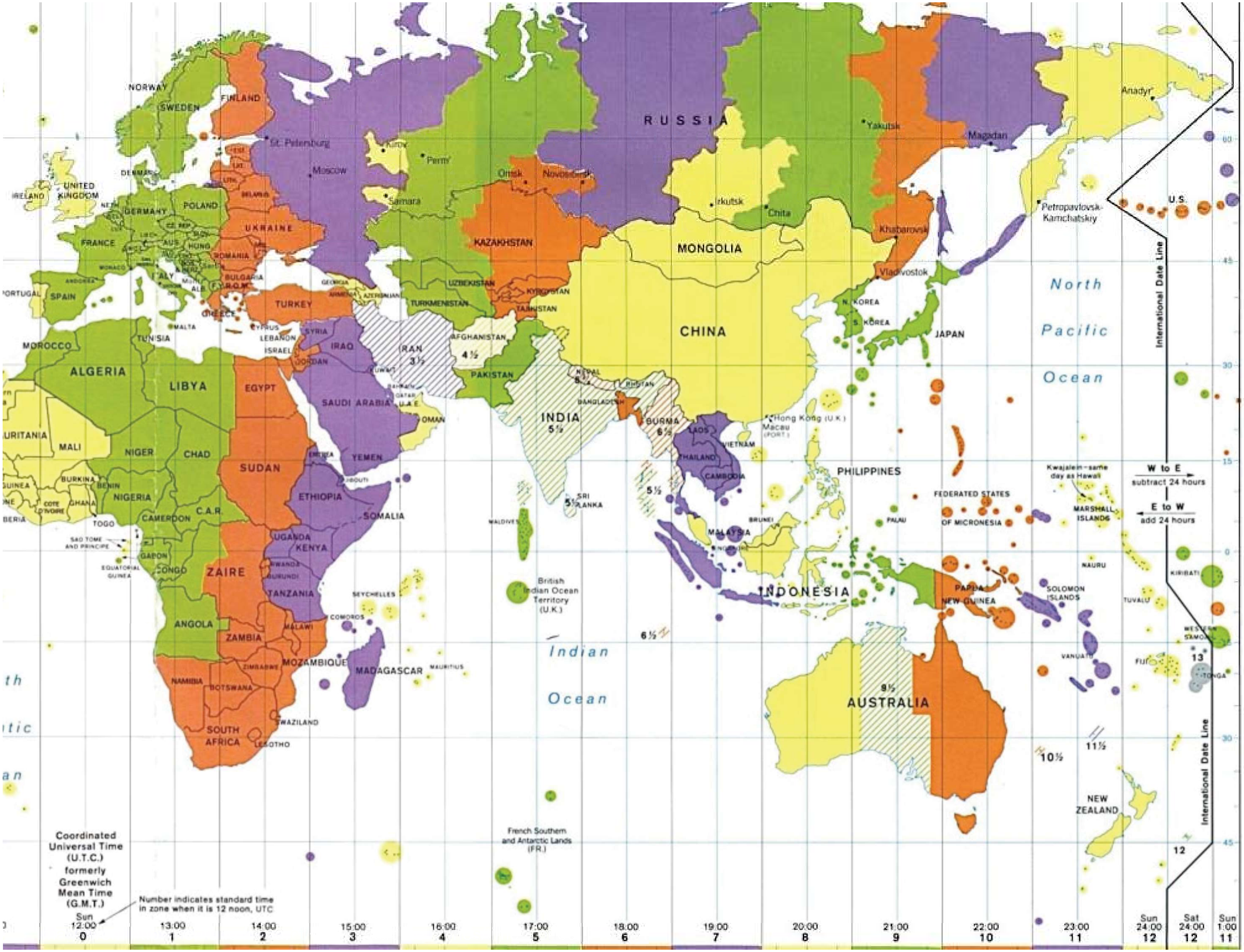
Time

Time Zones

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.

Standard Time Zones of the World





RUSSIA
CHINA
MONGOLIA
INDIA 5½
AUSTRALIA 9½
INDONESIA
PHILIPPINES
JAPAN
KAZAKHSTAN
IRAN 3½
AFGHANISTAN 4½
PAKISTAN
BURMA 6½
SRI LANKA 5½
North Pacific Ocean
Indian Ocean
International Date Line
W to E subtract 24 hours
E to W add 24 hours
Kwajalein—same day as Hawaii
NEW ZEALAND
11½
10½
British Indian Ocean Territory (U.K.)
French Southern and Antarctic Lands (FR.)
Coordinated Universal Time (U.T.C.) formerly Greenwich Mean Time (G.M.T.)
Number indicates standard time in zone when it is 12 noon, UTC
Sun 12:00 0
13:00 1
14:00 2
15:00 3
16:00 4
17:00 5
18:00 6
19:00 7
20:00 8
21:00 9
22:00 10
23:00 11
Sun 24:00 12
Sat 24:00 12
Sun 1:00 11

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 (https://ui.adsabs.harvard.edu/abs/2019AAS...23413102S/abstract has links)

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 – 2451545.0)

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

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 (https://ui.adsabs.harvard.edu/abs/2019AAS...23413102S/abstract)

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**)

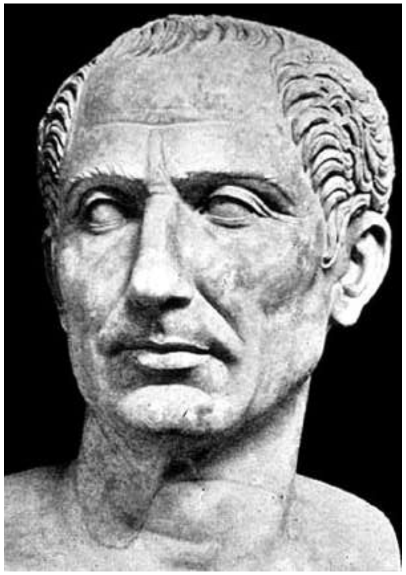
Terresterial Dynamical Time (TDT) and International Atomic Time (IAT)

The modern standard time is based upon the Standard International (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 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

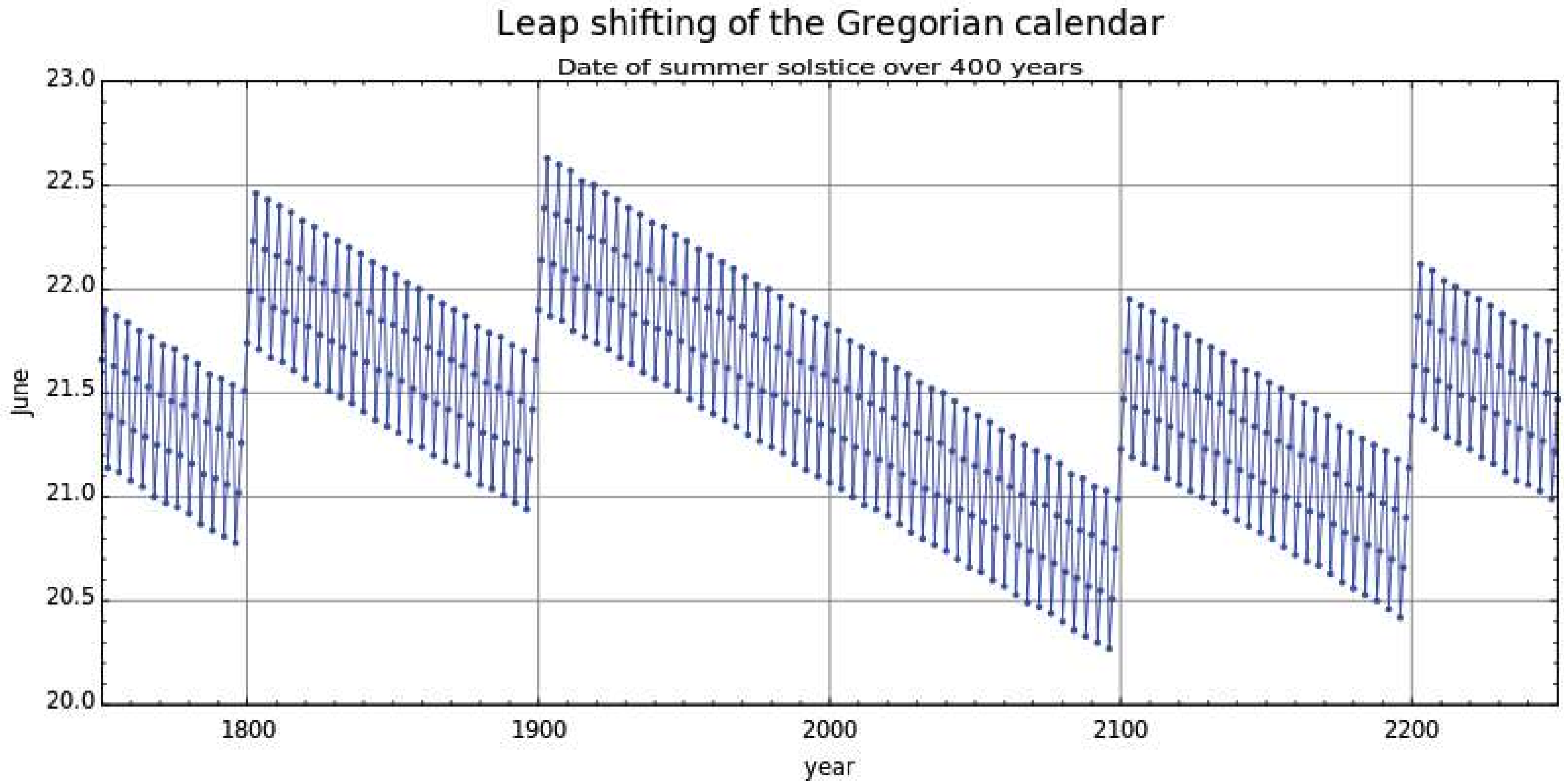
Julian Calendar (not to be confused with Julian Date)

- 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

The average (mean) year length = 365.2422222 days

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



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.