ASTR 2401

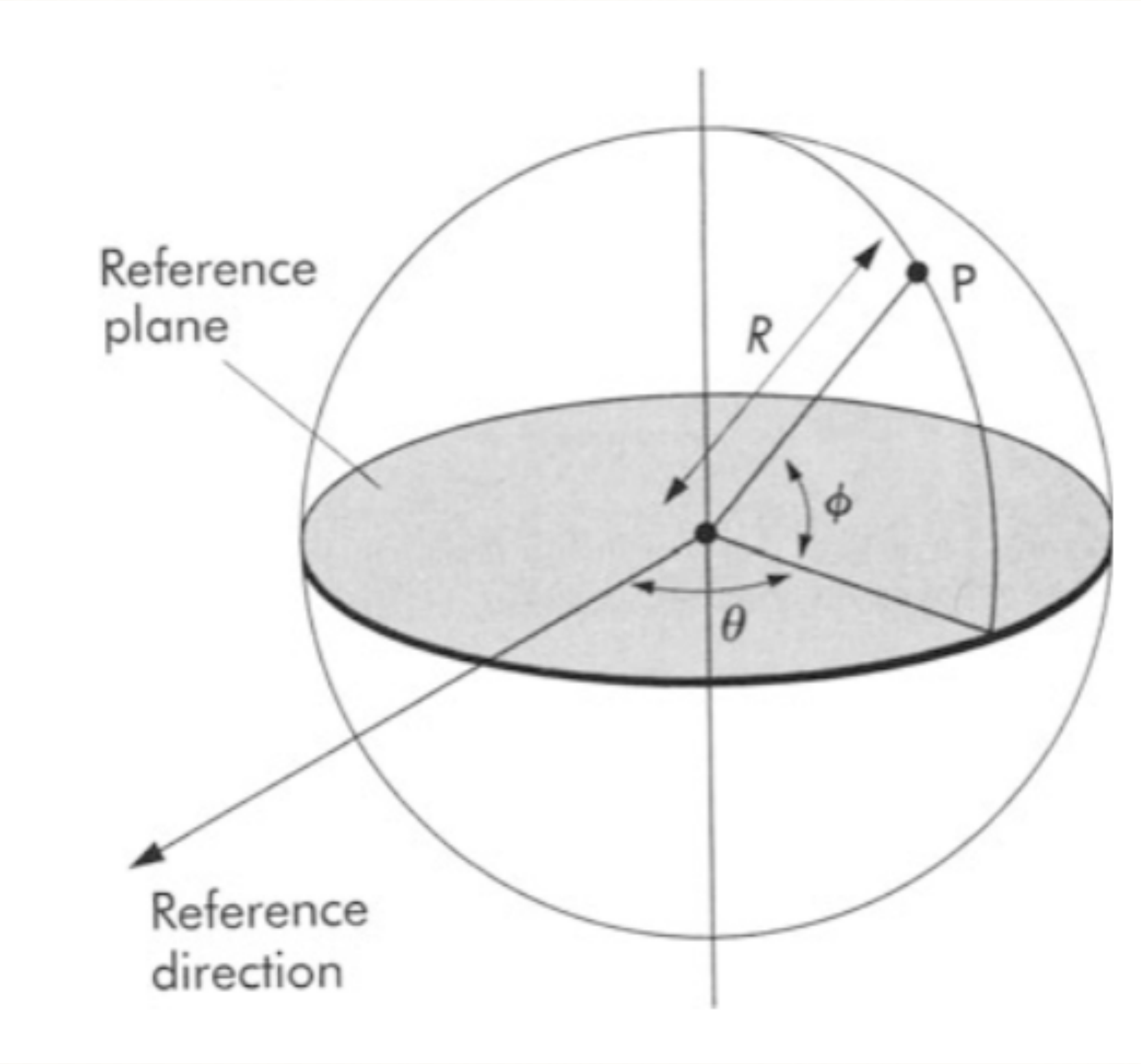
Astronomical Coordinates & Time

Observational Astronomy

Astronomical Coordinate systems are spherical polar coordinate systems.

- Points are defined by R, the radius of the sphere, the azimuthal angle θ with respect to a reference direction and polar angle ϕ with respect to a reference plane.

- Planes that pass through the center of the sphere define **a great circle.**

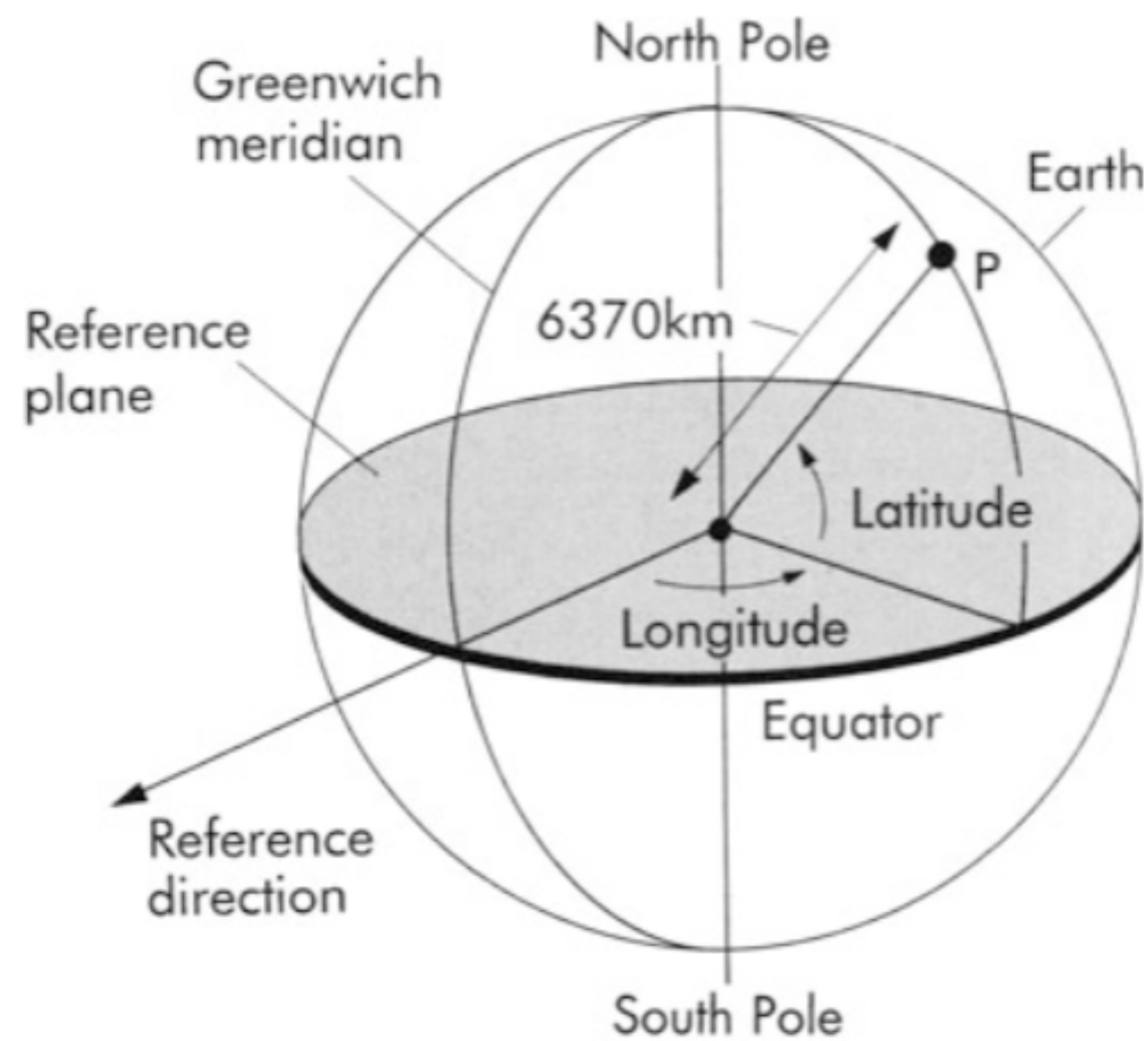


For example, latitude and longitude on the surface of the Earth are a spherical polar coordinate system.

Angles:
- Latitude (ϕ) -90° to 90°
- Longitude (θ) 0-180° W, 0-180° E

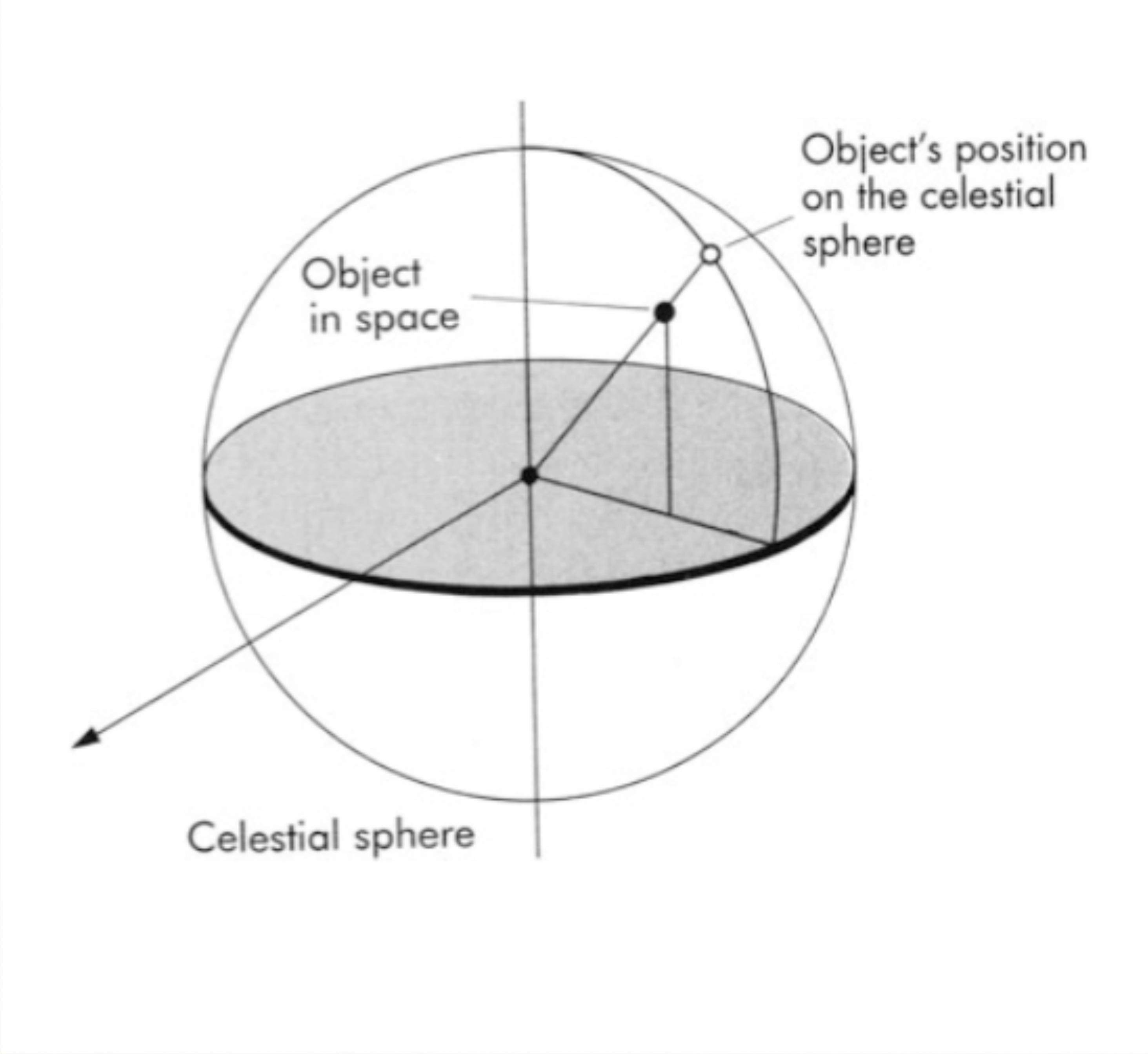
Equator:
- Earth's equator

Prime Meridian Reference Point:
- Prime Meridian (Greenwich)

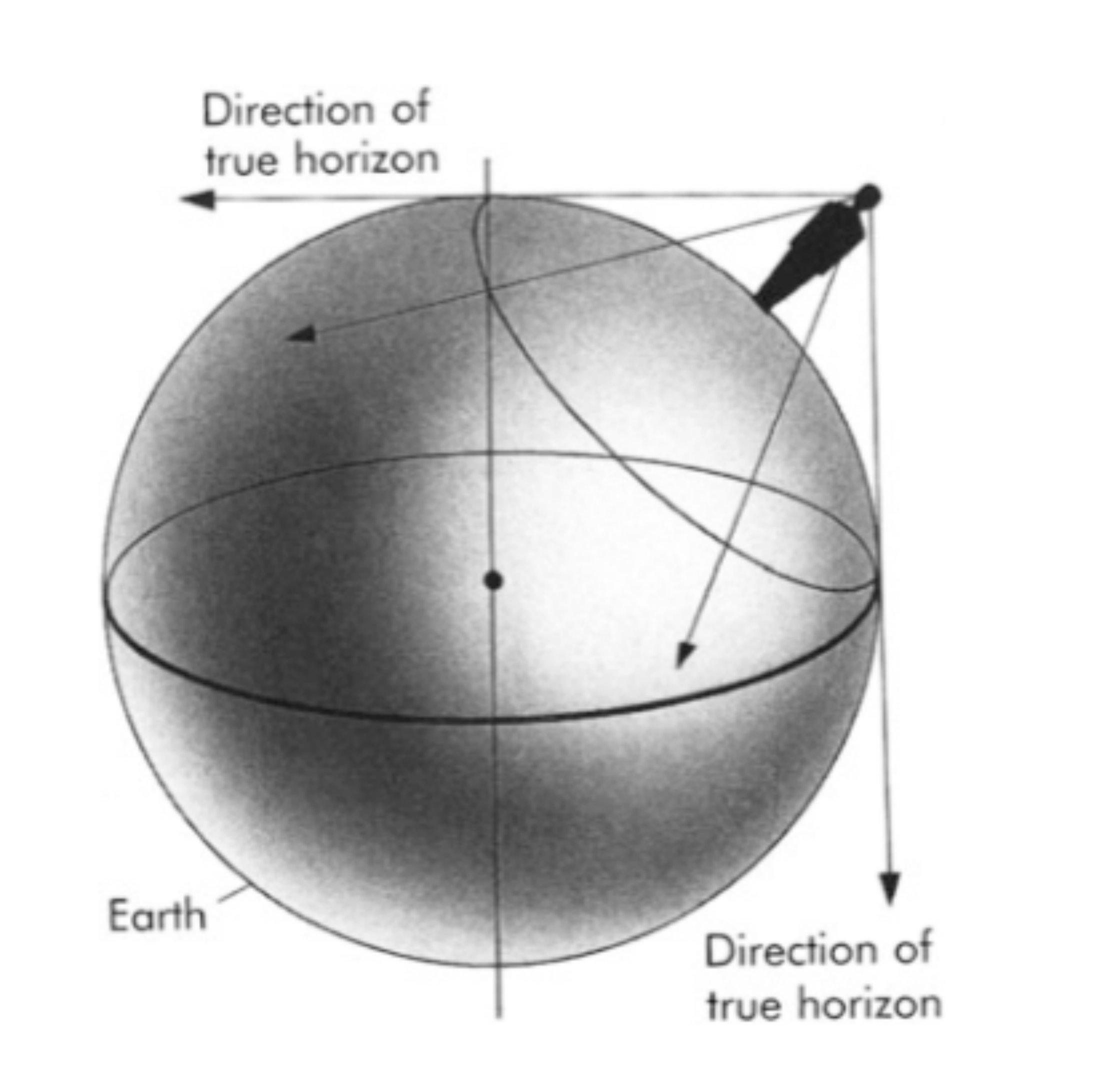


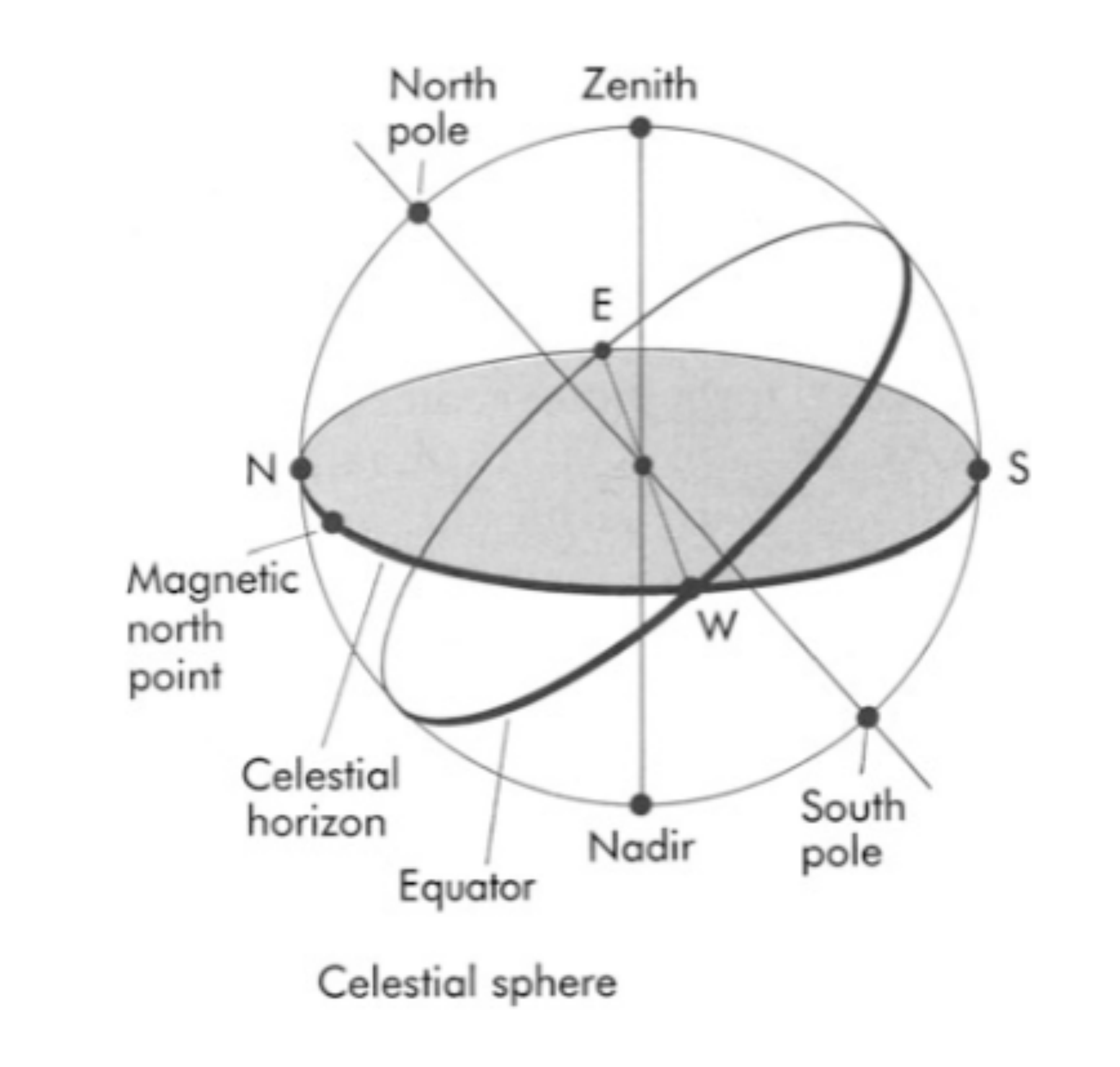
If we set R = infinity, then we can describe the position of any object in the sky with just two coordinates.

- This infinite sphere is called **The Celestial Sphere**.



The Earth blocks our view of ~half the celestial sphere, creating the **horizon**.





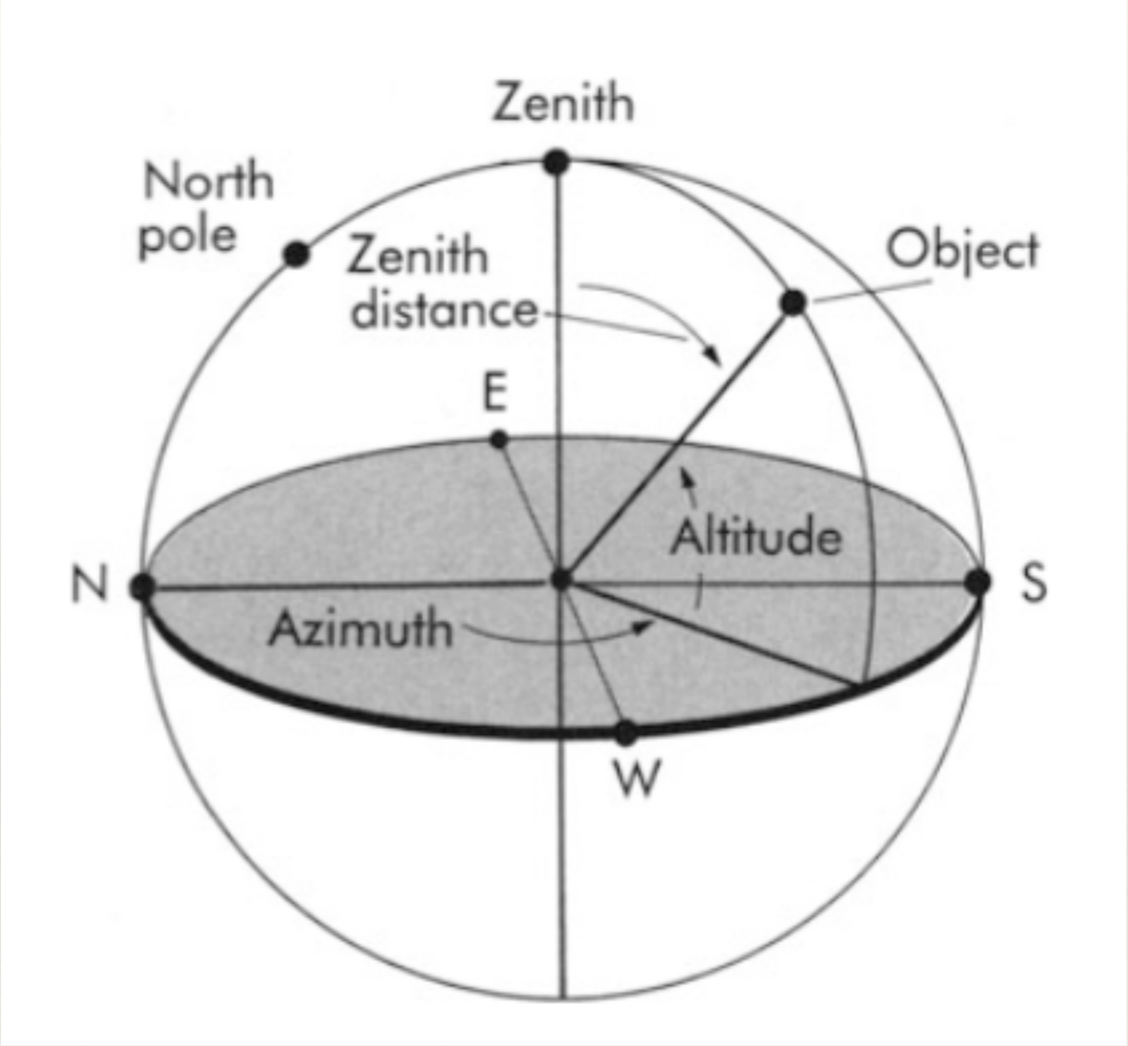
Zenith - the point directly overhead
Nadir - the point directly underneath you
Local Meridian - The great circle perpendicular to the horizon, that includes the Zenith and North Celestial Pole.

Horizontal coordinate system

Angles:
  Altitude ($\phi \rightarrow$alt)   0° to 90°
  Longitude ($\theta \rightarrow$az)   0-360° towards East
  (clockwise)

Equator:
  The local horizon (not a really a great circle)

Prime Meridian Reference Point:
  The Local Meridian



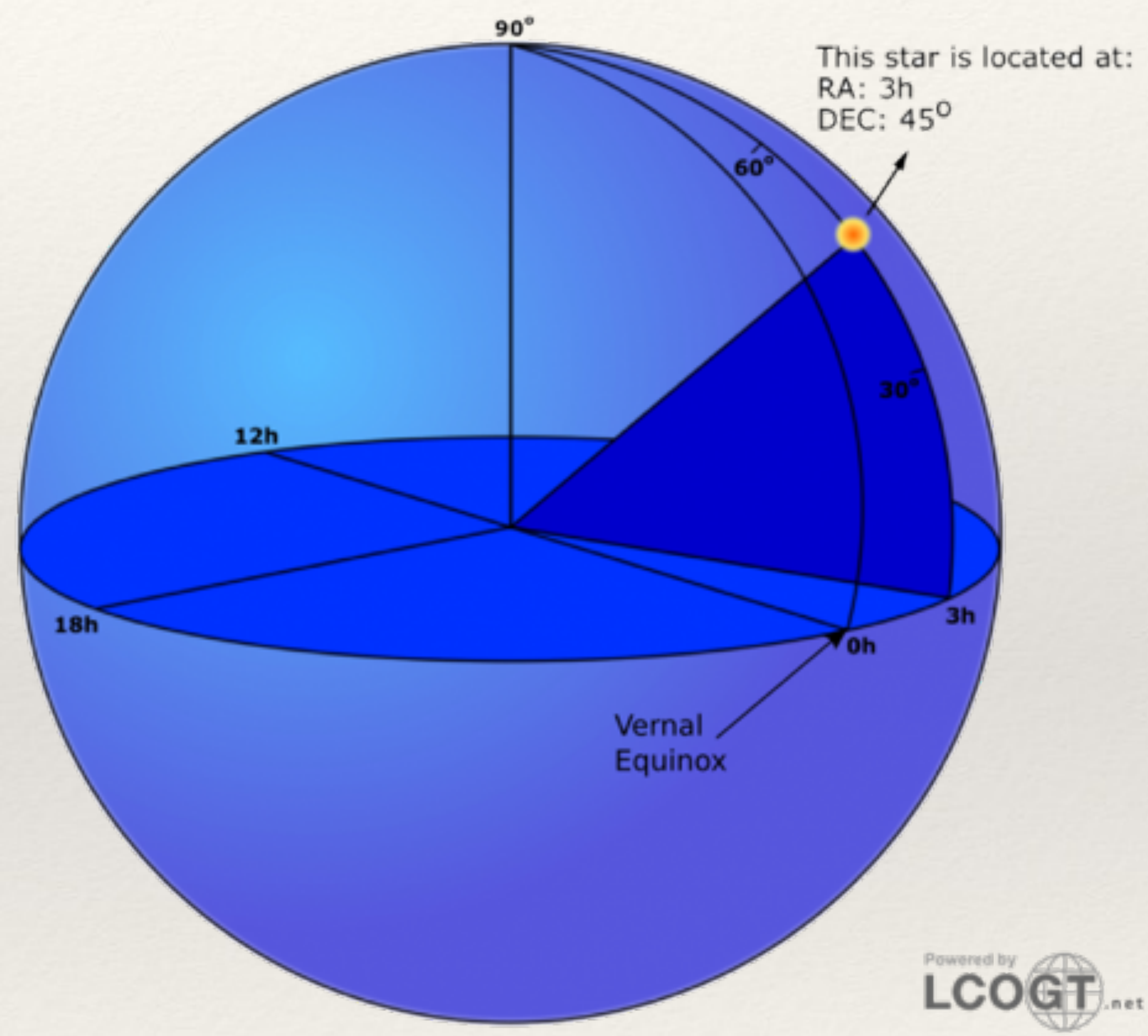
These are the fundamental coordinates for telescopes, so why not use only alt & az?

Equatorial Coordinates: RA and Dec

Angles:

Declination ($\phi \rightarrow \delta$) -90° to 90°

Right Accession ($\theta \rightarrow \alpha$) 0-360°, or 0 - 24 hours



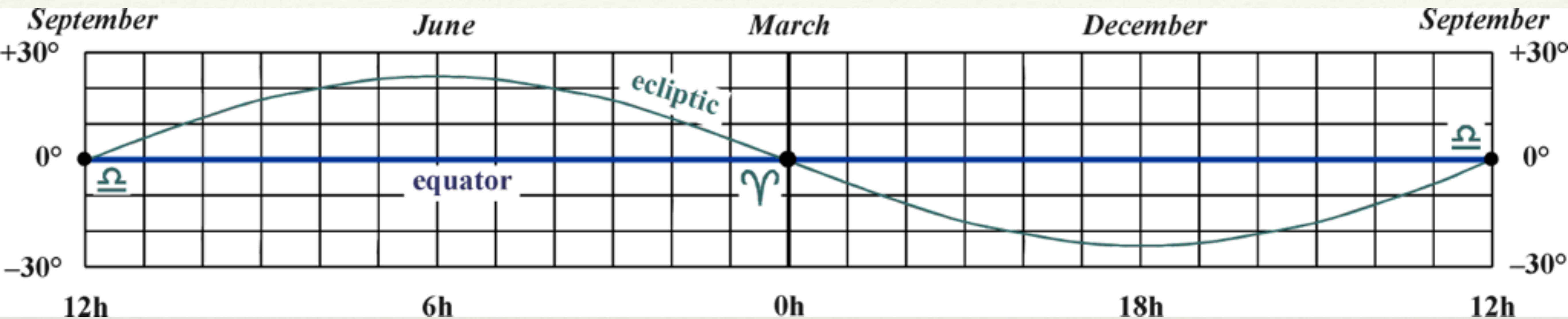
Equator:

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

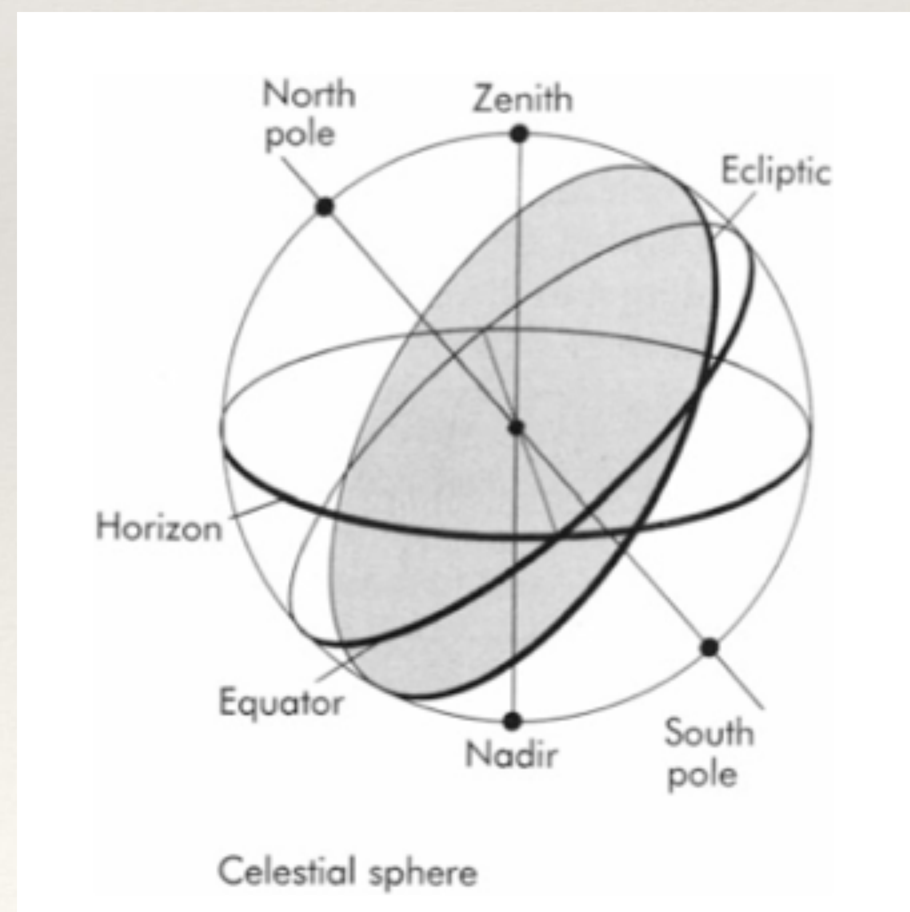
Prime Meridian Reference Point:

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

The ecliptic is the plane of Earth’s orbit around the Sun.



The vernal equinox is also known as the “First Point of Aries.”



Equatorial Coordinates: RA and Dec

1 hour = 15 degrees (°)
1 minute = 15 arcminutes (ʻ)
1 second = 15 arcseconds (ʻʻ)

1 arcminute = 1/60°
1 arcsecond = 1/60′

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:

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

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:

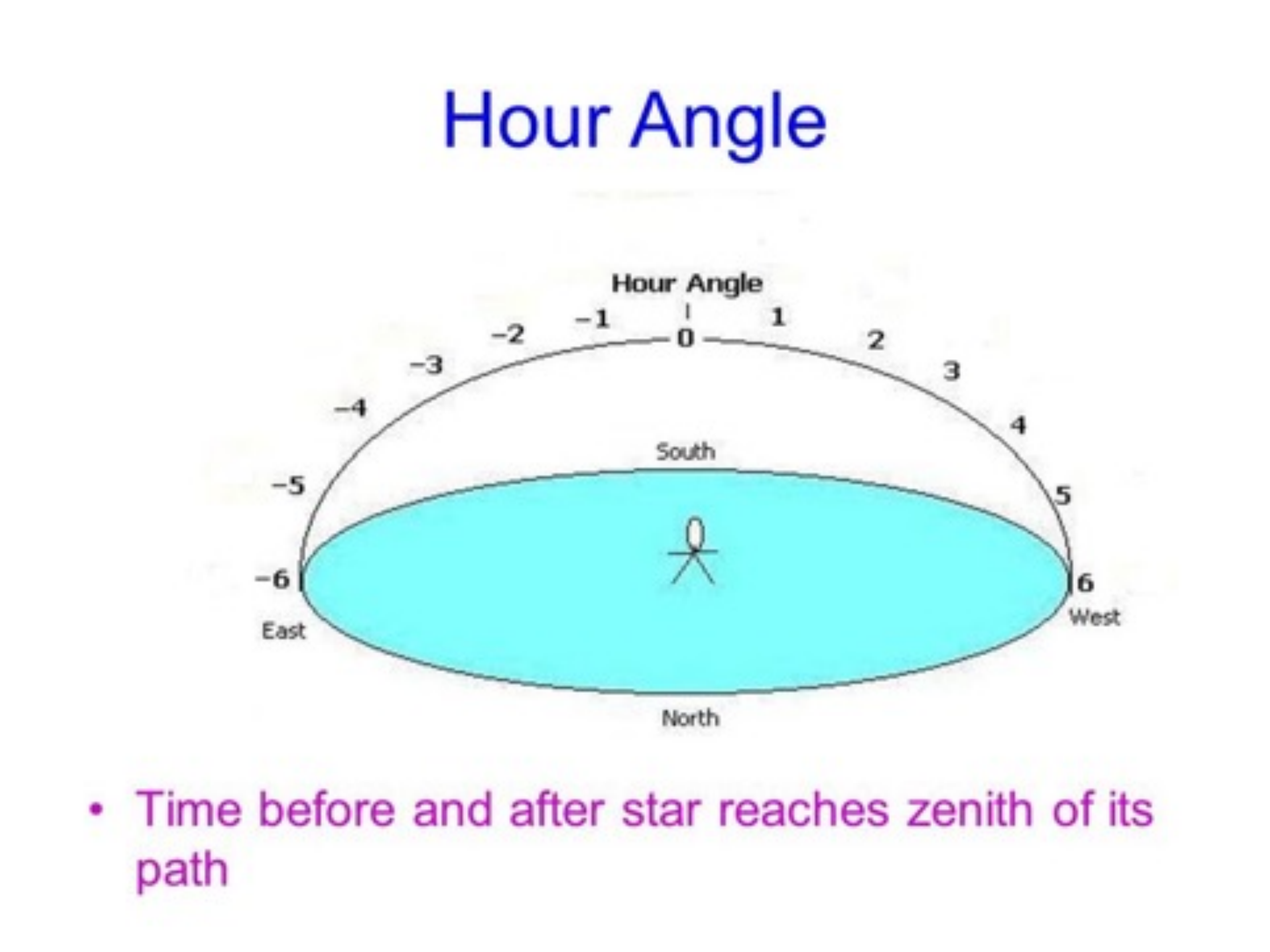
$\alpha = 15 \times (10 + 15/60 + 30/3600)$
$\delta = 45 + 0/60 + 30/3600$

Note: Sometimes you see RA in sexagesimal degrees too!

Hour Angle (HA)

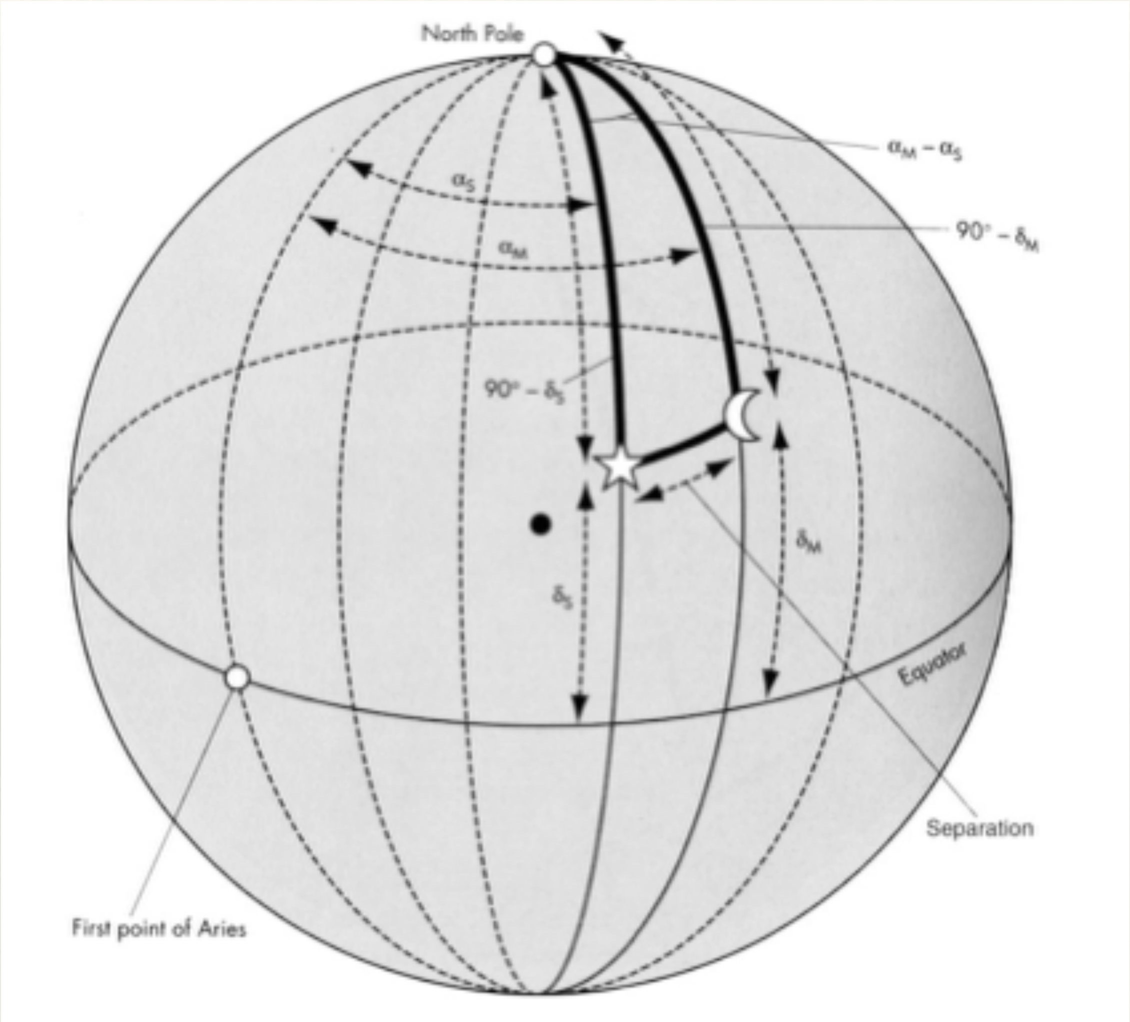
Hour Angle
The hour angle is defined as the distance in RA of an object from the local meridian.
Coordinates

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).



Equatorial Coordinates: RA and Dec

One last note of general relevance. It is often the case that you would like to know the angular separation between two objects that are close on the sky. Since we are on the surface of a sphere, this is not quite as simple as with Euclidean geometry.



Equatorial Coordinates: RA and Dec

Consider a circle through a sphere at constant declination. As you move to larger dec, the radius of this circle decreases, until at the poles the radius is zero.

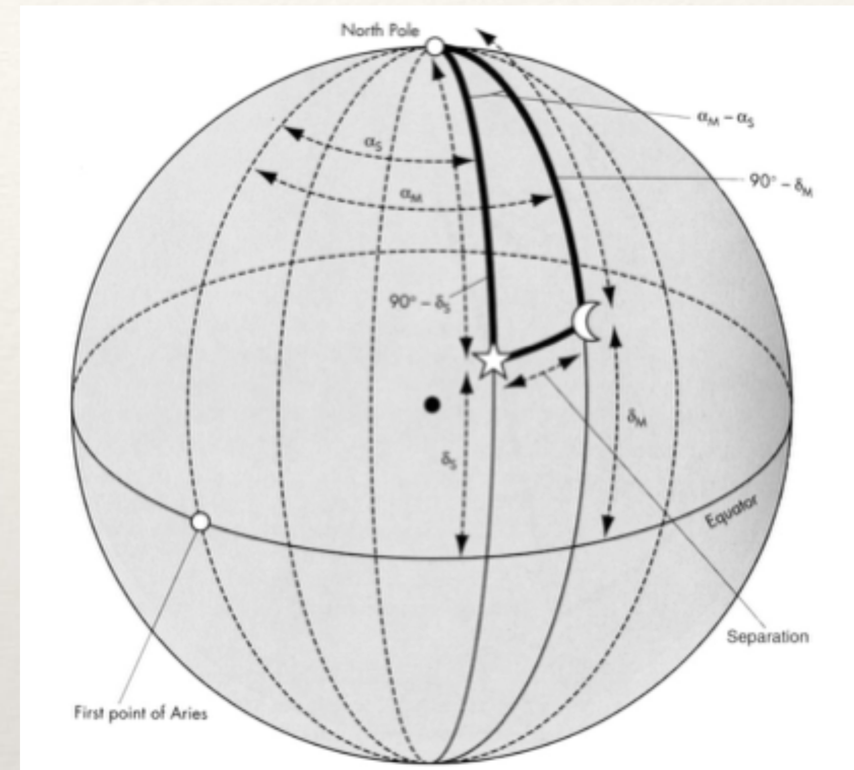
In other words, for a unit sphere the radius of the circle is $r = \cos\delta$.

As a result, while the angular separation in declination is simply:
$\Delta\delta = \delta 1 - \delta 2$

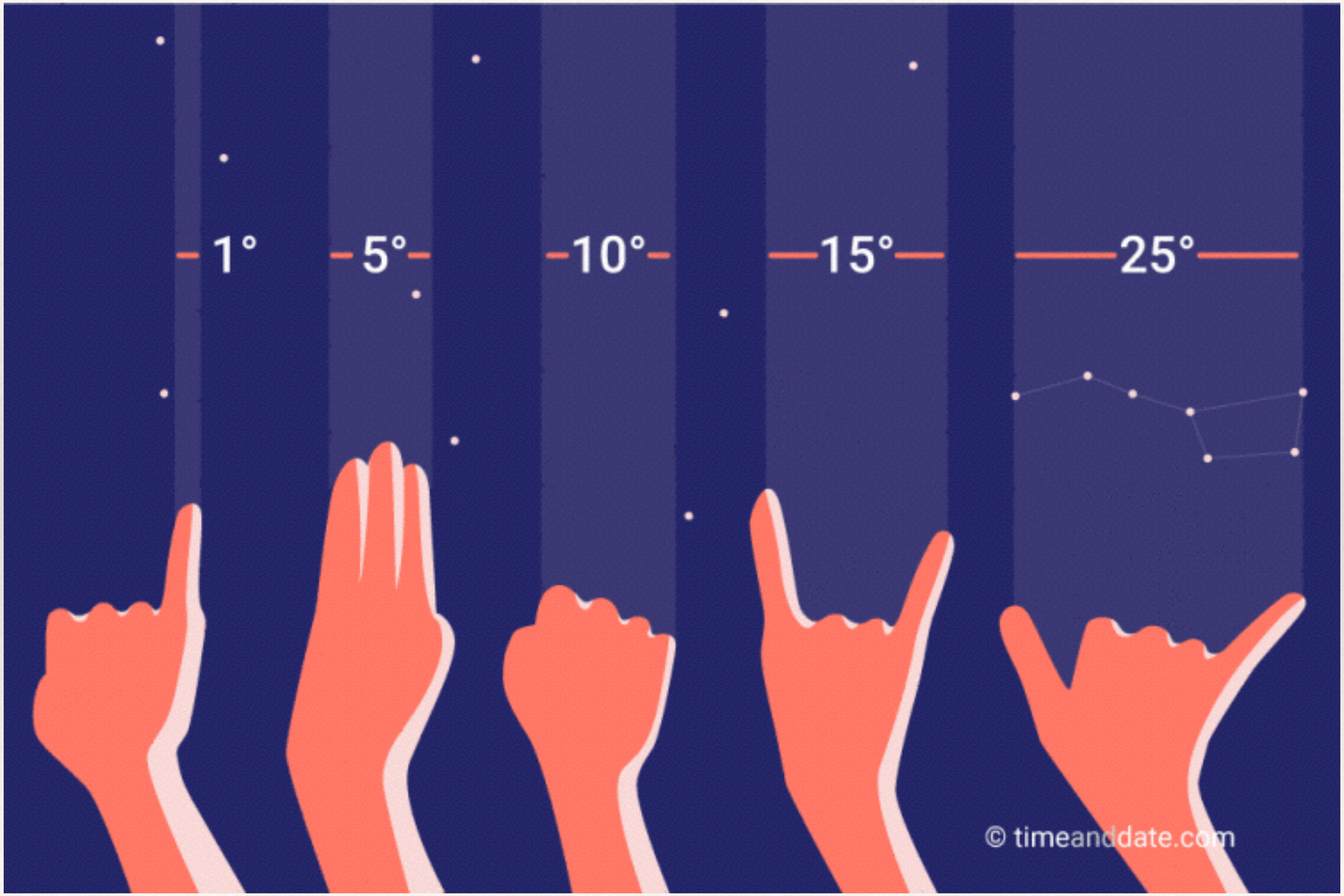
for RA you have to take account this shrinking of the circle:
angular separation in RA = $\Delta\alpha \cos\delta$

For two closely separated objects (or more specifically two objects at **similar dec**), this means that

$$\Delta\theta \approx [(\Delta\delta)^2 + (\Delta\alpha \cos\delta)^2]^{1/2}$$



Old Astronomer Trick: You can estimate angles on the sky with your fingers on a out-stretched arm.

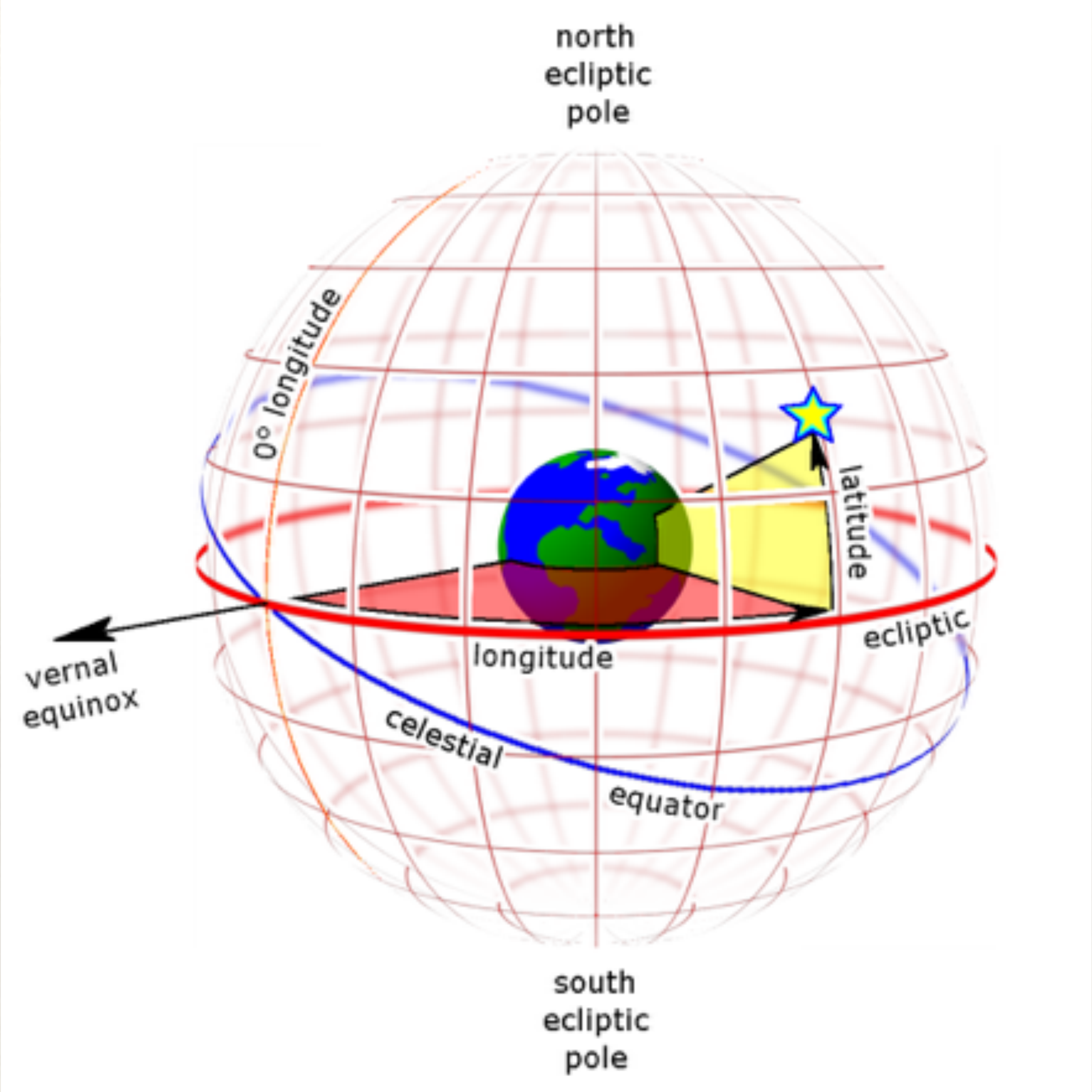


Ecliptic Coordinates

Angles:
  Ecliptic latitude (θ→β) -90° to 90°
  Ecliptic longitude (ϕ→λ) 0-360°, or 0-24 hours

Equator:
  Ecliptic plane

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

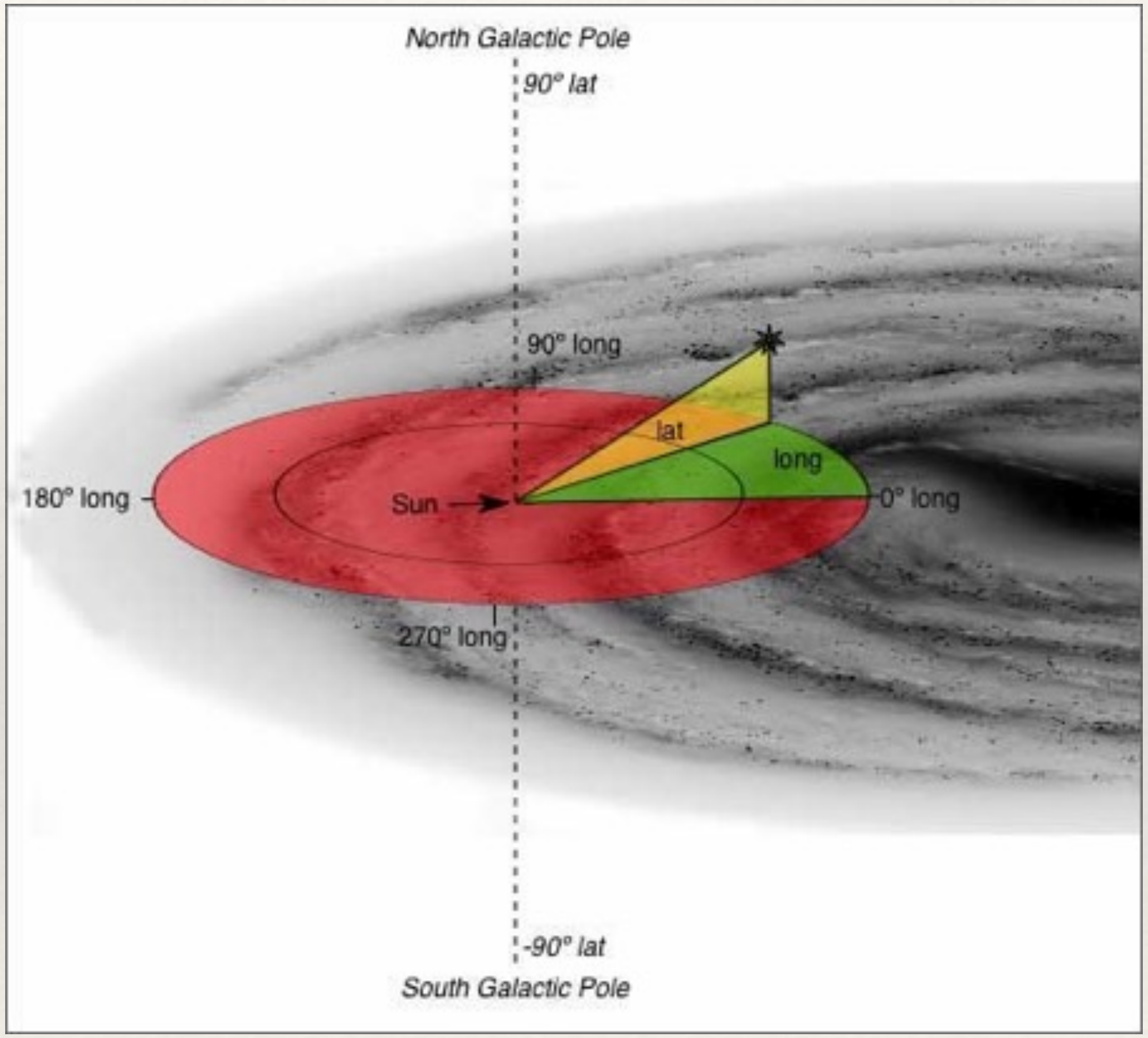


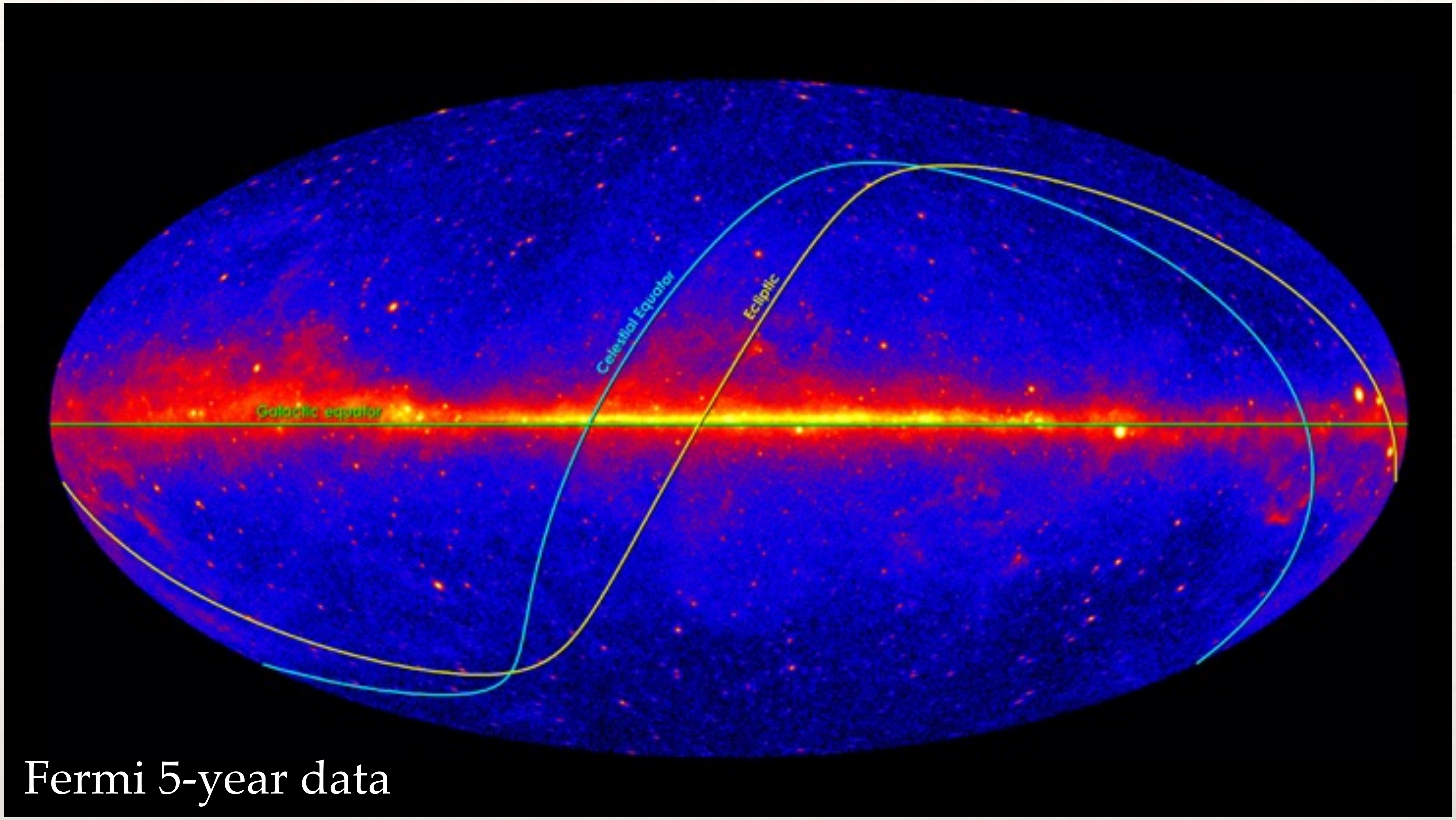
Galactic Coordinates

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

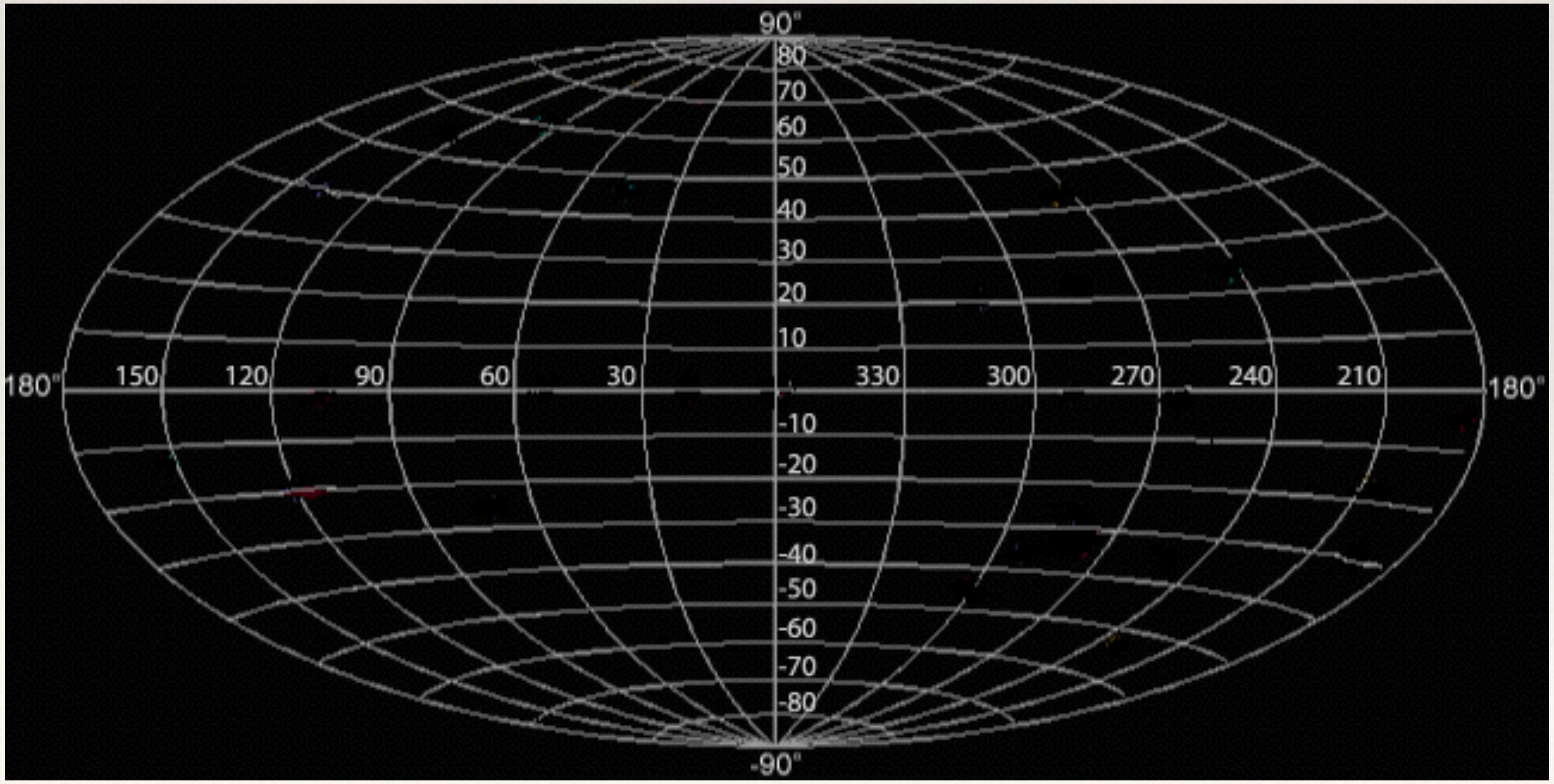
Equator:
Galactic Plane
(inclined 62° 36′ relative to the celestial equator)
Prime Meridian Reference Point:
Galactic Center

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)





Fermi 5-year data

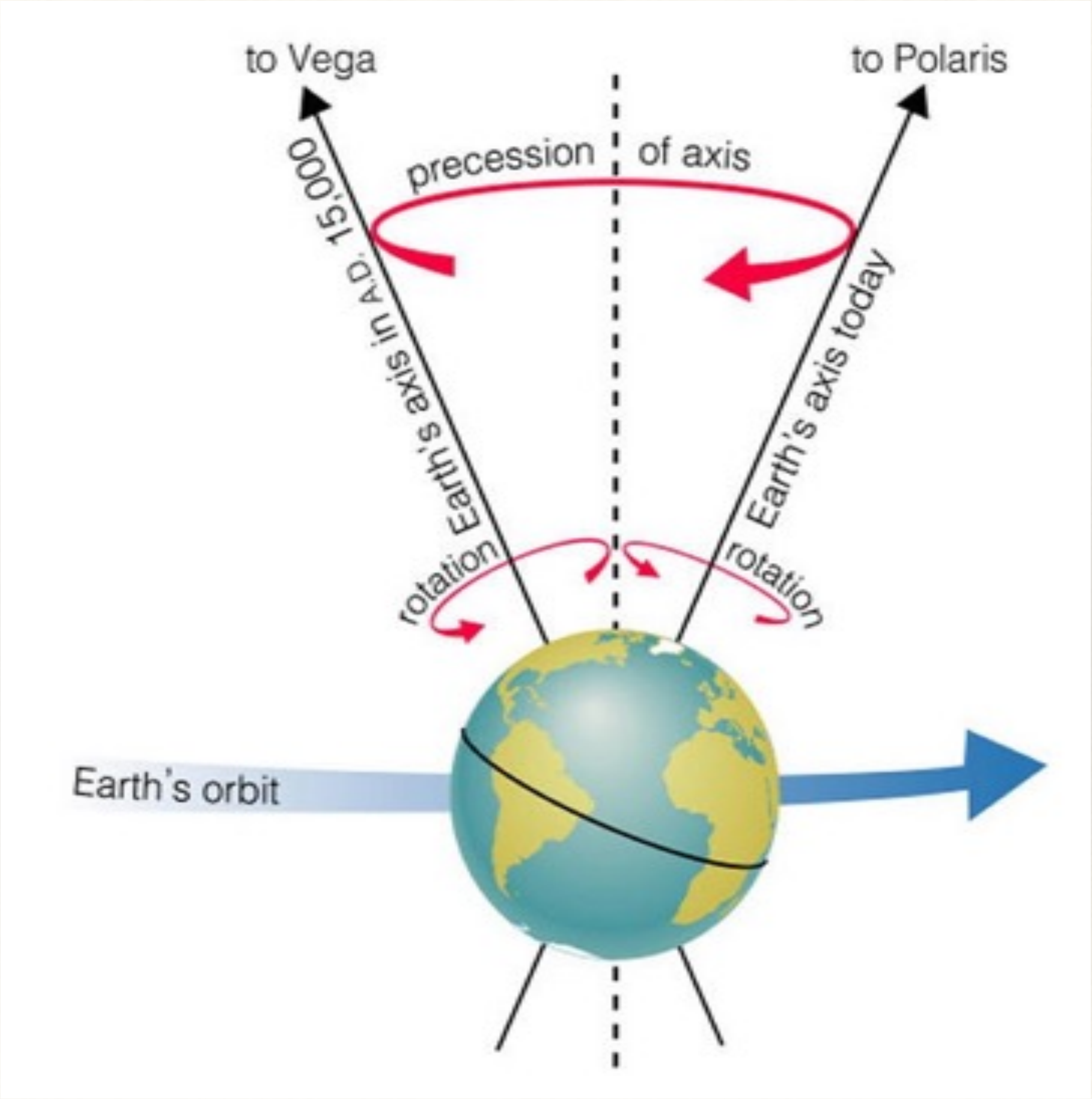


Wait, what does J2000.0 mean?

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)**

Precession

- The equatorial coordinates of objects change with time.
- 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

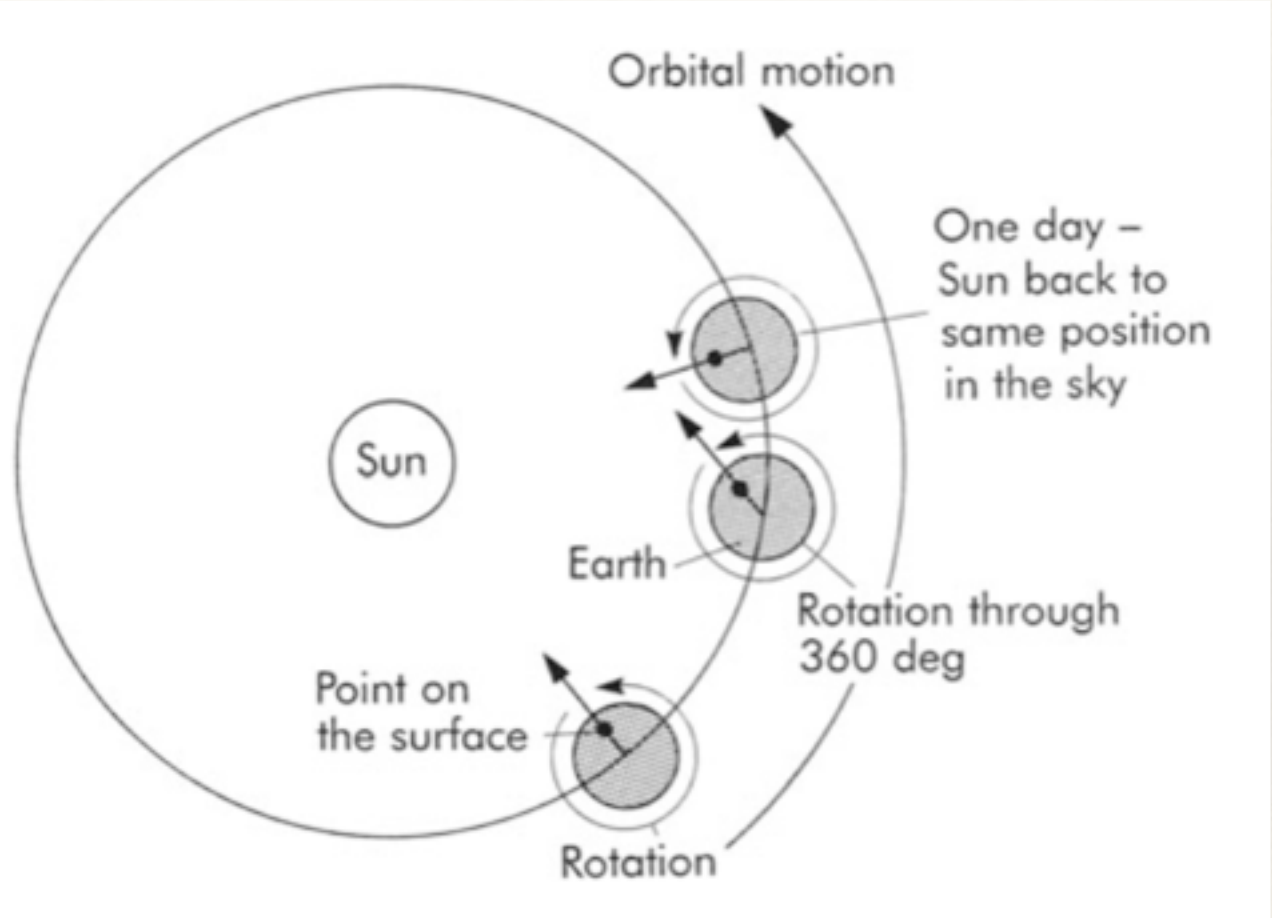


Time

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

Sidereal Time

- The sidereal day is the true rotation period with respect to the vernal equinox
- 23 hours, 56 minutes, 4.0916 seconds
- The local sidereal time (LST), is HA of the vernal equinox
- **LST = the current RA of the local meridian**



Solar Time

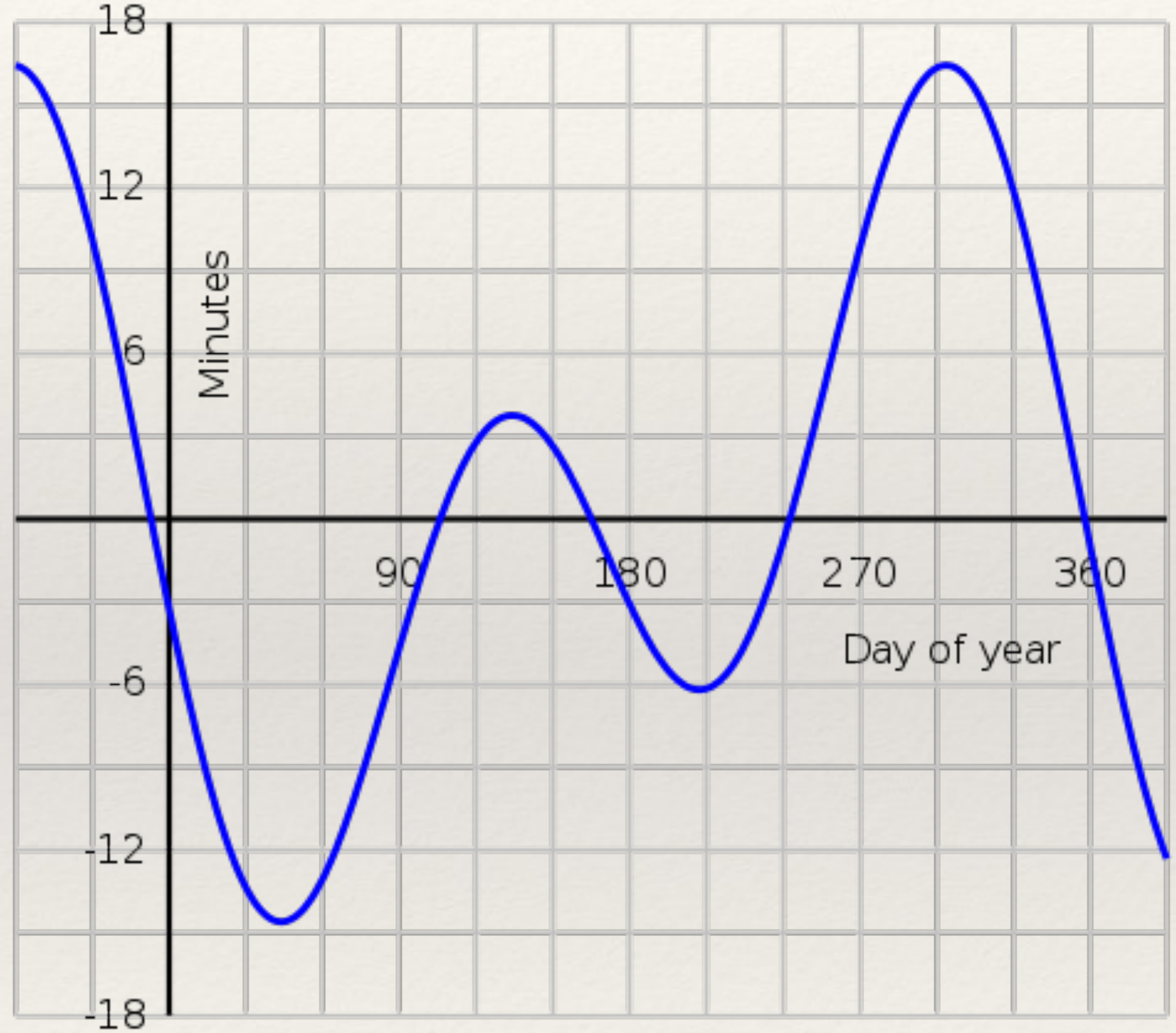
Mean Solar Time is the time of day based upon the mean solar day (i.e. 24 hours long). For mean solar time the sun is at zenith at noon.

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.

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

The Equation of Time plotted over a year.



Astronomer’s Headache

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 local solar time 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.

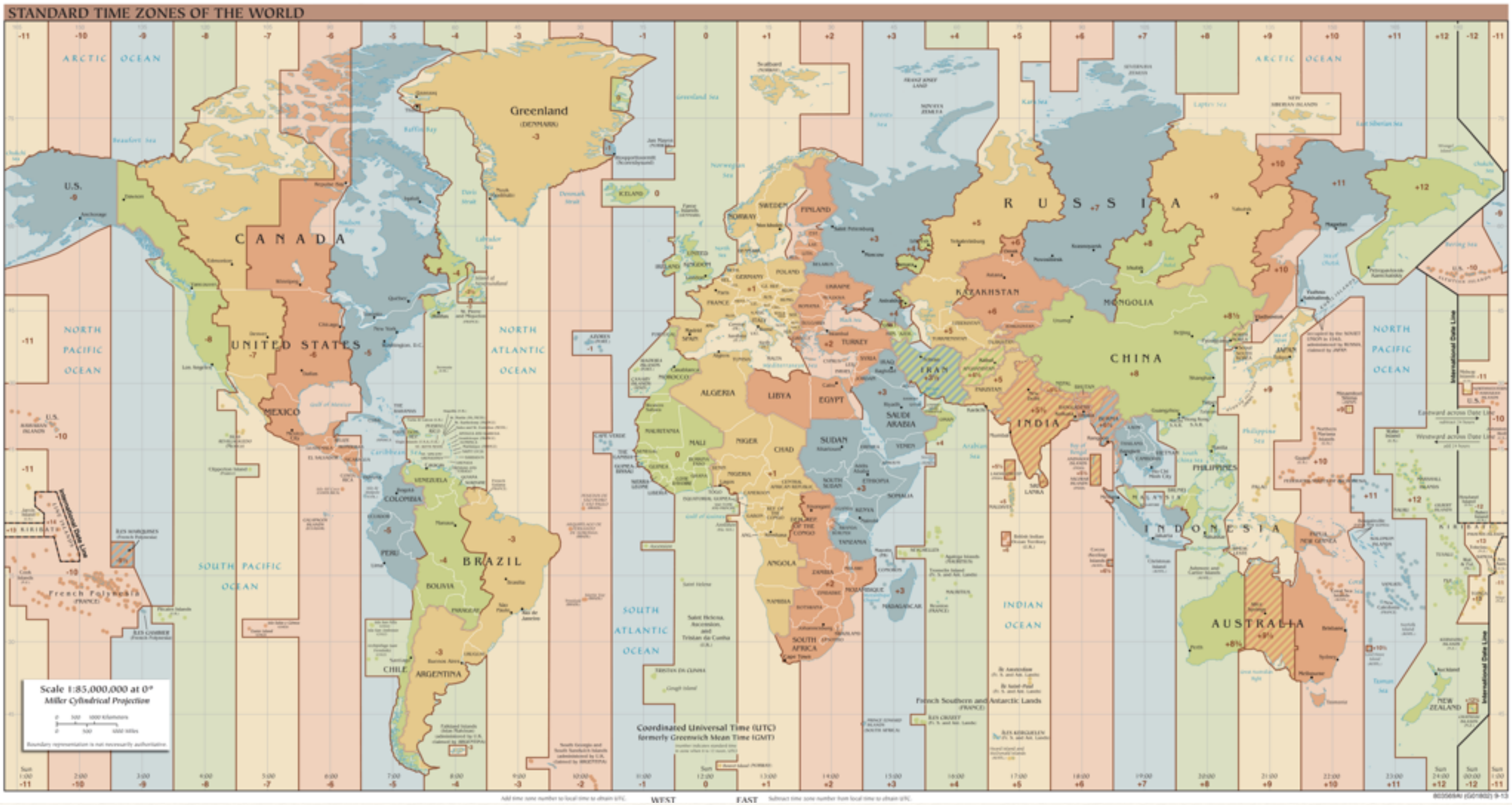
The point here to keep in mind is that standard (civil) time is not generally the same as local solar time.

Daylight Saving Time (DST)
Adding a bit of extra confusion, many locations observe some form of daylight saving time.

- In the U.S. the time changes occur on the second Sunday in 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 DST.

DST dates for this school year: Sunday, November 6, 2016 and Sunday, March 12, 2017

Time Zones



STANDARD TIME ZONES OF THE WORLD
ARCTIC OCEAN
Greenland
(DENMARK)
CANADA
UNITED STATES
MEXICO
BRAZIL
ARGENTINA
CHILE
RUSSIA
CHINA
INDIA
MONGOLIA
KAZAKHSTAN
IRAN
ALGERIA
LIBYA
EGYPT
SUDAN
SAUDI ARABIA
INDONESIA
AUSTRALIA
NEW ZEALAND
NORTH PACIFIC OCEAN
NORTH ATLANTIC OCEAN
SOUTH PACIFIC OCEAN
SOUTH ATLANTIC OCEAN
INDIAN OCEAN
French Polynesia
Coordinated Universal Time (UTC)
formerly Greenwich Mean Time (GMT)
Scale 1:85,000,000 at 0°
Miller Cylindrical Projection
International Date Line
WEST
EAST

Julian Days

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.

Examples:

```
2pm, January 12, 2006   JD 2453748.20833
2pm, January 12, 1000BC JD 1356185.20833
12am, August 28, 2016   JD 2457630.500000
```

Name		Epoch	Calculation
Julian Date	(JD)	12h Jan 1, 4713 BC	
Reduced JD	(RJD)	12h Nov 16, 1858	JD - 2400000
Modified	(MJD)	0h Nov 17, 1858	JD - 2400000.5

Julian Days (Date)

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Name	Epoch	Calculation
Julian Date (JD)	12h Jan 1, 4713 BC	
Reduced JD (RJD)	12h Nov 16, 1858	JD - 2400000
Modified (MJD)	0h Nov 17, 1858	JD - 2400000.5

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

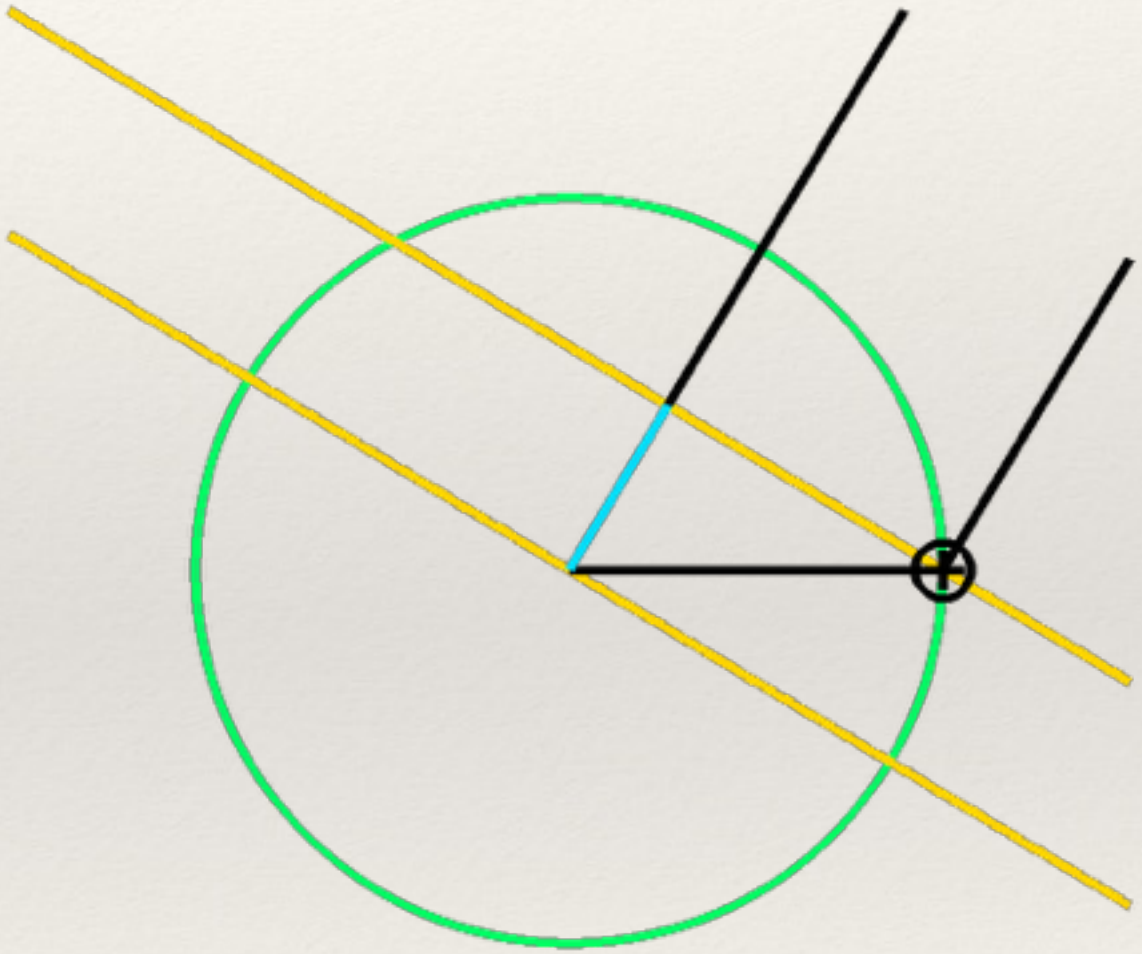
Heliocentric Julian Date

When need high temporal precision in your timing, you have to account for the light travel time across Earth's orbit (pulsar timing, for example).

It is convenient to use the frame of reference of hypothetical observer on the Sun, thus **Heliocentric Julian Date (HJD)**.

The conversion is complex, so it is best left to computers.

Also it has now been replaced.



Barycentric Julian Date

The Sun is not stationary, it orbits around the barycenter of the Solar System.

In 1991, **Barycentric Julian Date (BJD)** replaces HJD as the standard reference.

BJD and HJD can vary but up ± 4s.