Announcements

- Homework is due on Thursday (1/25/2024) by 11am printed out and delivered in class
- If you know you will not be in class on Thursday then see me to make alternative arrangements to turn in the homework
- Remember help is available for the homework:

TA office hours (all in PAIS lobby):

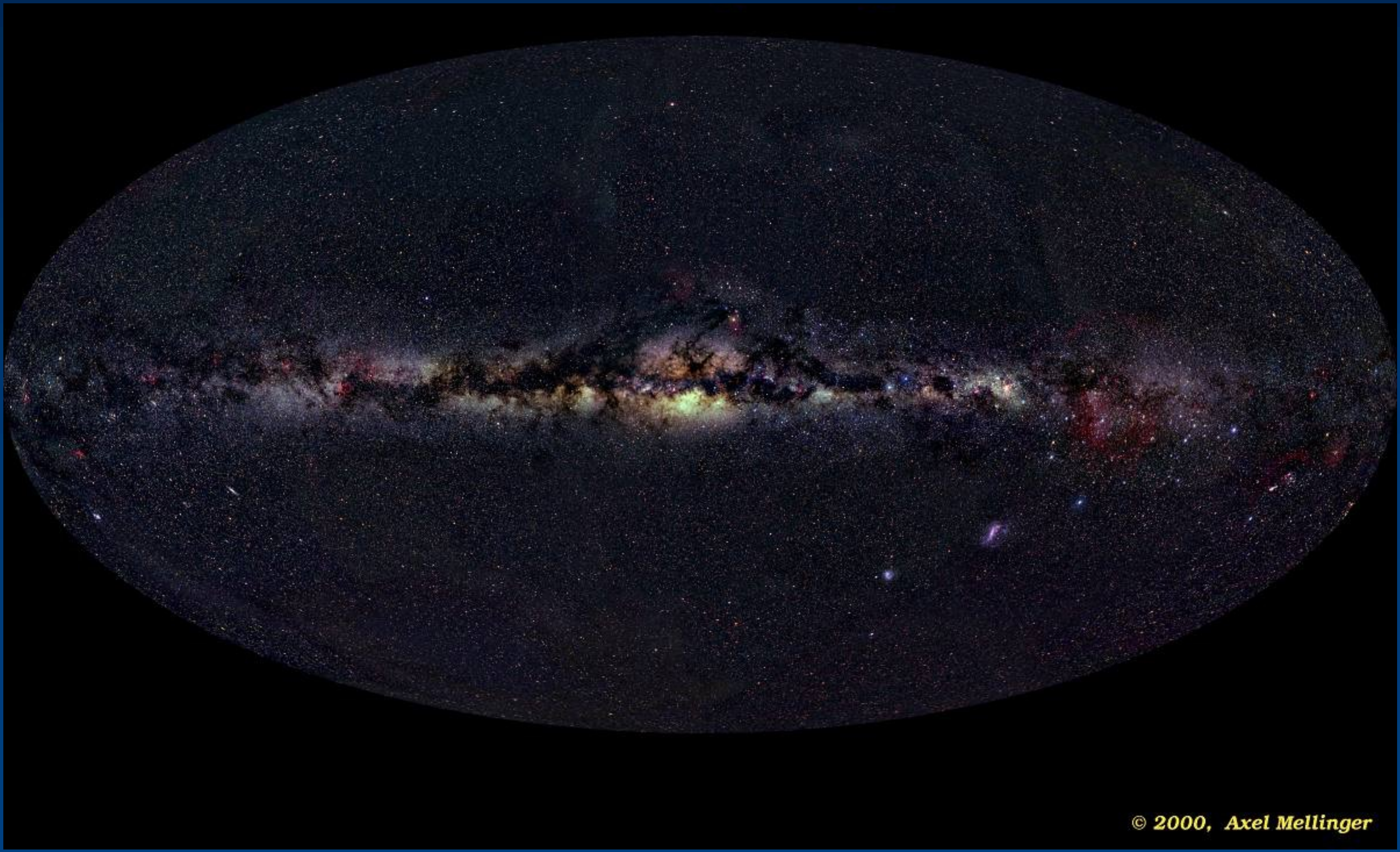
Wednesday 1-2pm : Dustin Edgeman

Wednesday 3-4pm : Evan David

Thursday 9:30-10:30am: Rachel Weller

- Nobel Prize Winner John Mather will be giving a public talk on JWST results Thursday (1/25) at 7pm in PAIS 1100

Celestial Navigation



Outline

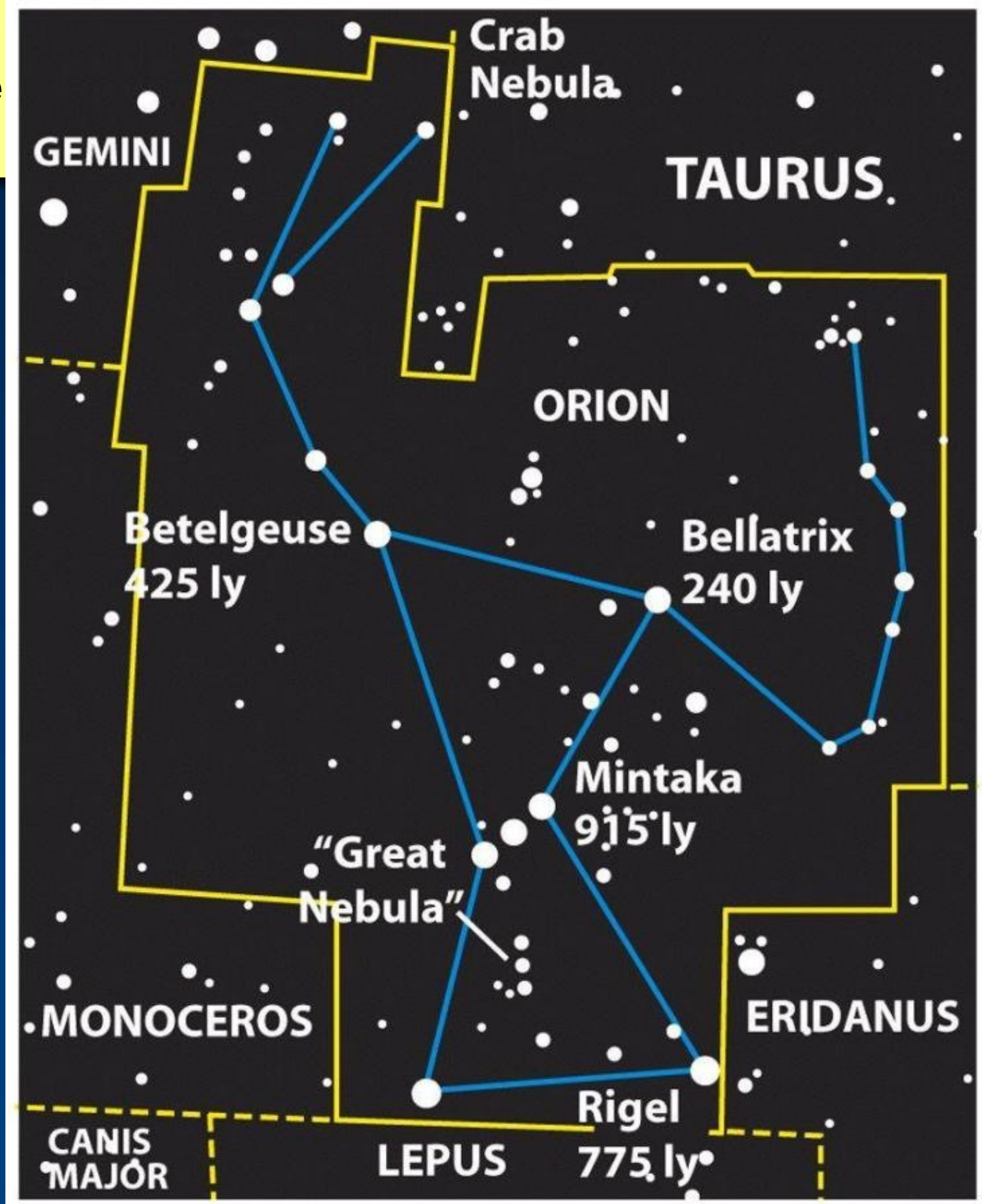
- Constellations
- Coordinate Systems
- Celestial Sphere
- Precession
- Seasons
- Apparent Motions of the Sun

What's Up?

- Stars: 88 Constellations, about 3000 stars visible (by eye) at any time
- Sun: Does it appear to move? On the same path from day to day?
- Moon: Does it always look the same?
- Planets: Do they stay put? Which ones can we see without a telescope?

On modern star charts, all stars are contained in some constellation on the sky – here is Orion:

88 constellations officially recognized by the International Astronomical Union (IAU).



But are the stars really all together in space?

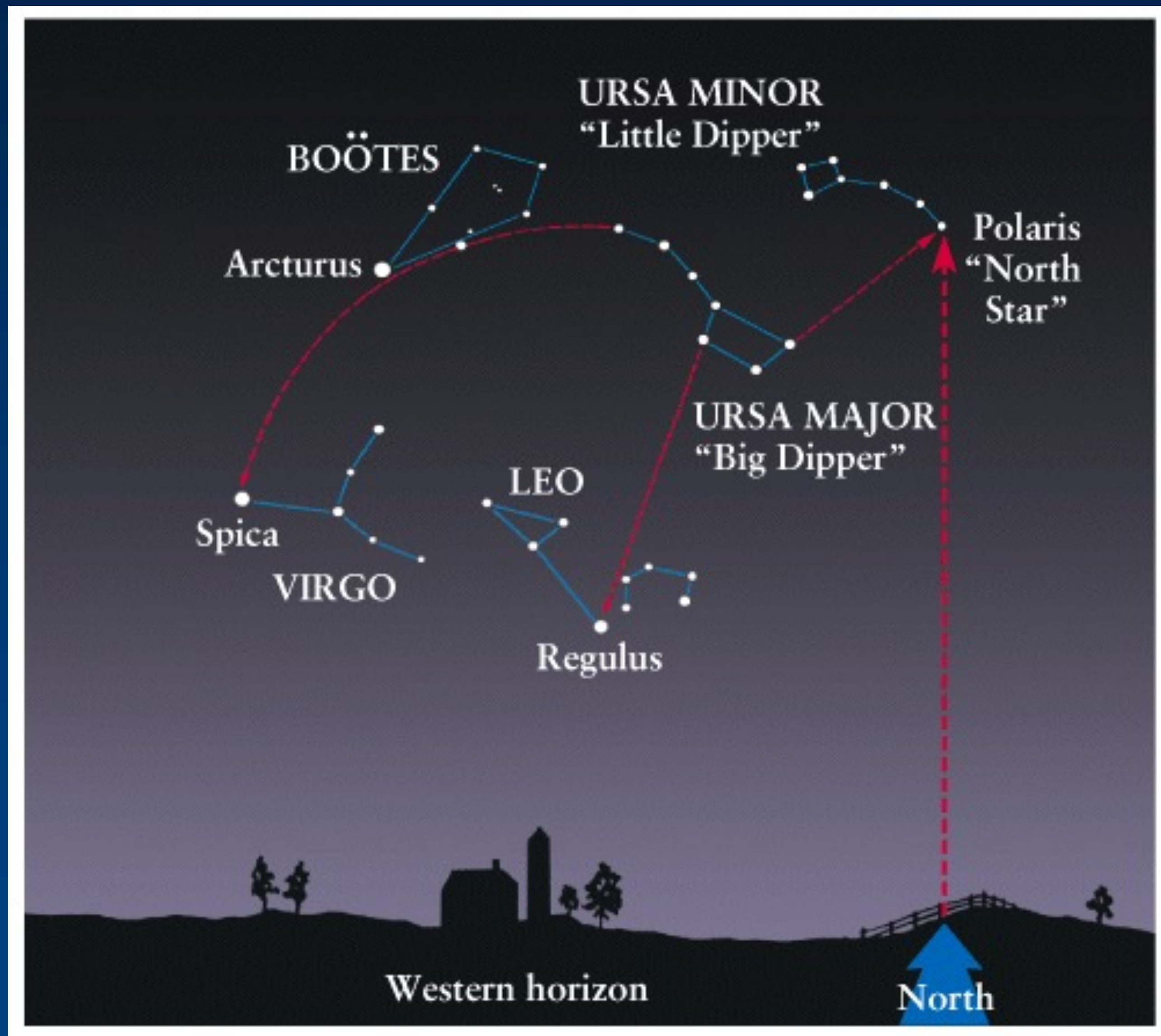
(Recall: light-year is the distance light travels in one year, or

9.46×10^{12} km, or 63,240 AU.

Speed of light is

3×10^5 km/s.)

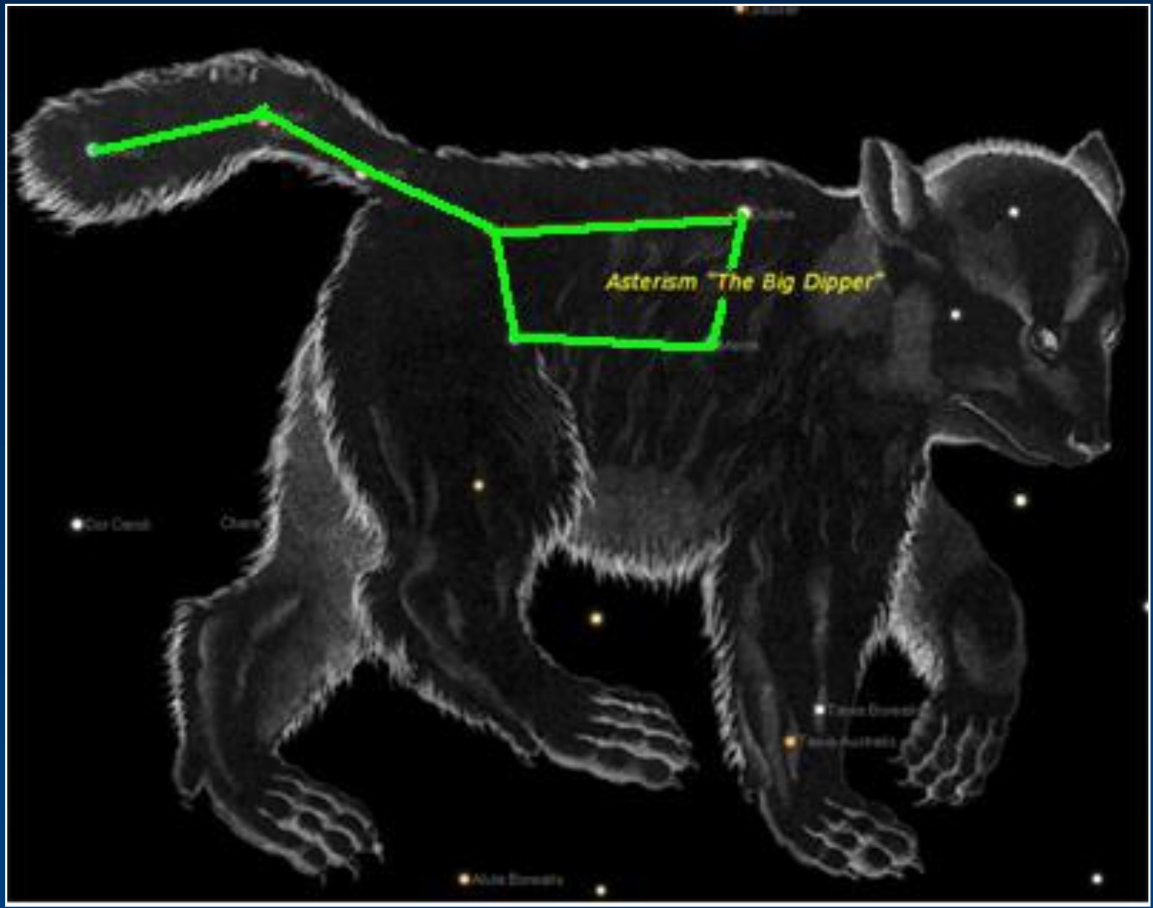
Star patterns can help you find your way around the sky or navigate at sea.



Note: angular distance between Polaris and Spica is about 100°, so this is a big chunk of the sky.

Consult the star charts in your book!

An asterism is a star pattern that is not classified as a constellation.



Why do we see different constellations at different times? Two reasons:

1. Over the night, "diurnal motion", due to the rotation of the Earth. Earth rotates from west to east, so sky appears to rotate from east to west. Stars rise and set.

Stars appear as trails due to diurnal motion. The trails are called diurnal circles.

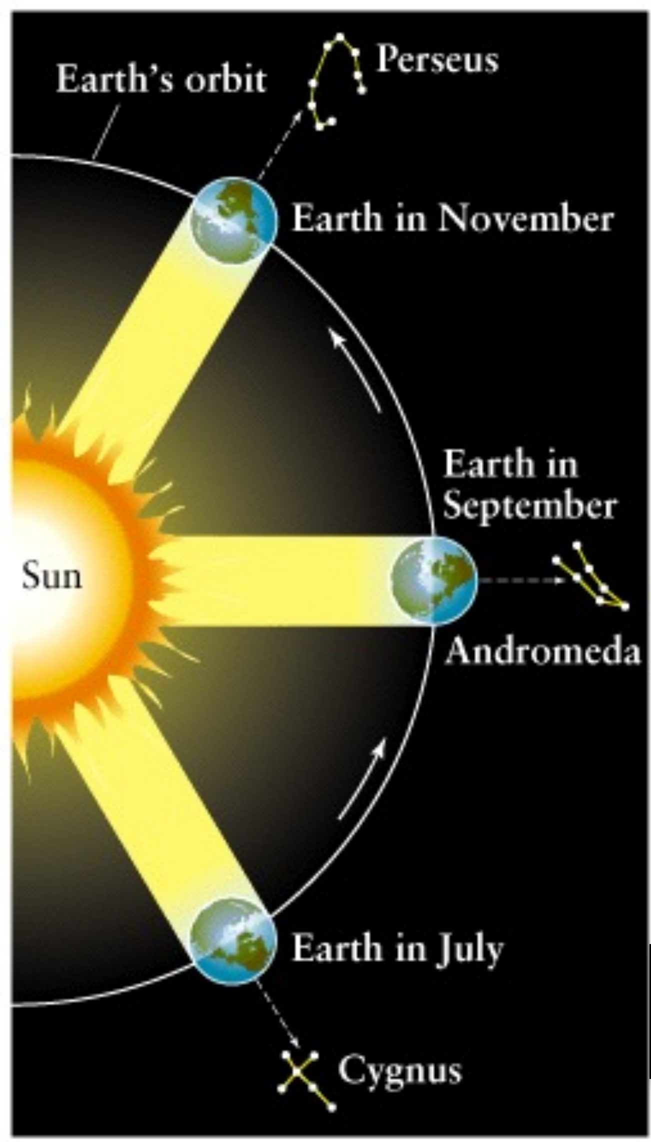
Circumpolar stars and constellations never rise or set.

In the northern sky, circles are centered on a point close to Polaris, the Pole Star.

2. Over the year, the nighttime side of Earth gradually turns toward different parts of the sky, so different constellations are visible during the course of the year.

These constellations are nearly overhead at midnight local time here for the months shown.

So why would it be tricky to try and observe Cygnus from Albuquerque in January or February?



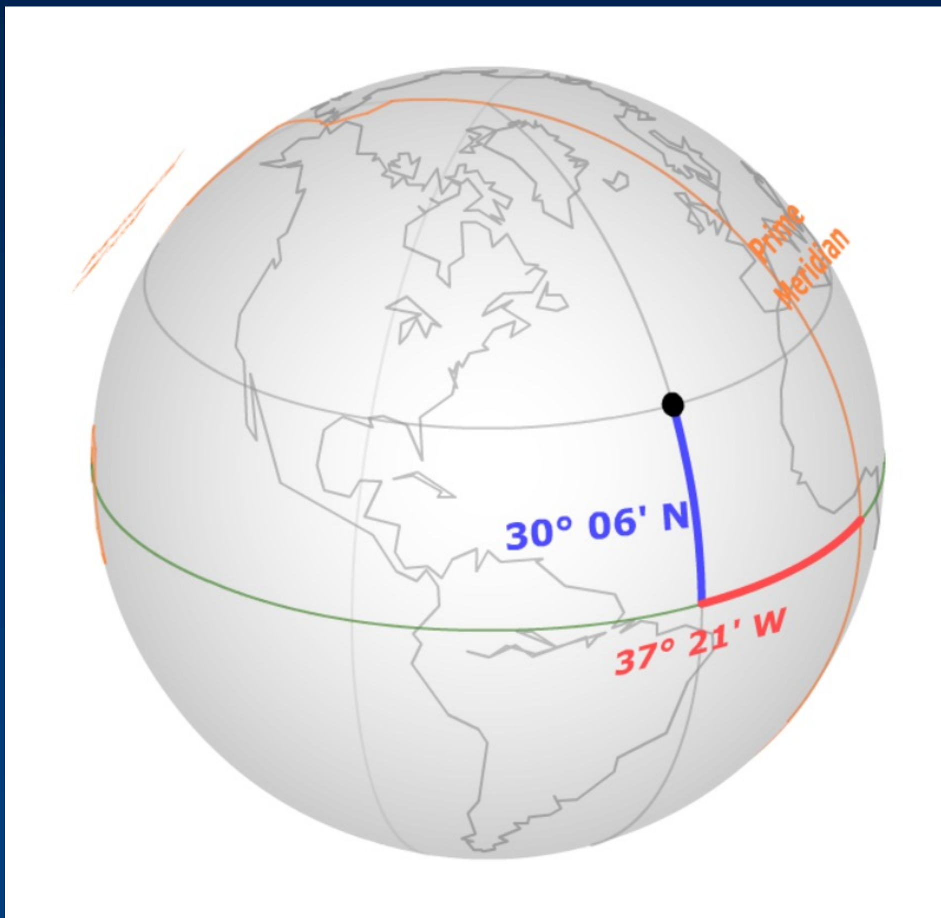
Note: this drawing is not to scale!!!

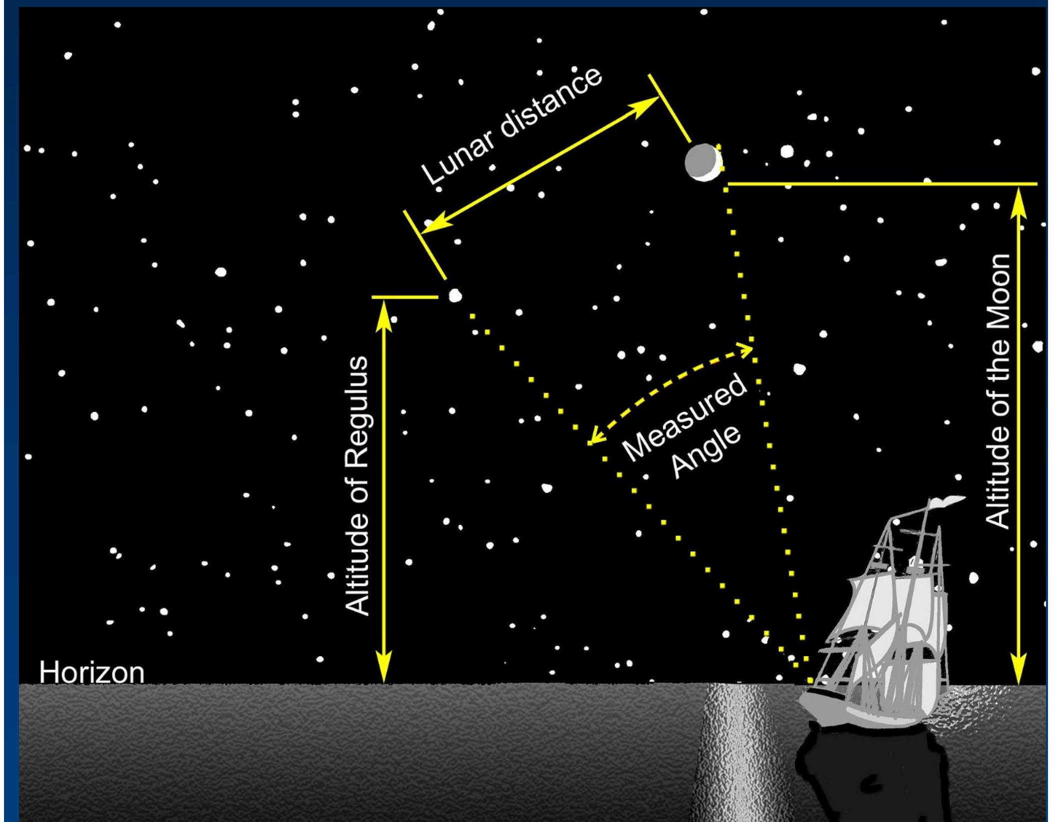
Astronomical Navigation

- Determining latitude is easy – just look at the Sun at transit, or famous stars at transit, or polaris.

- Longitude is hard, Longitude act of 1714 described prizes for determining longitude with accuracy better than 1 degree, or better than 0.5 degrees

Astronomical Navigation



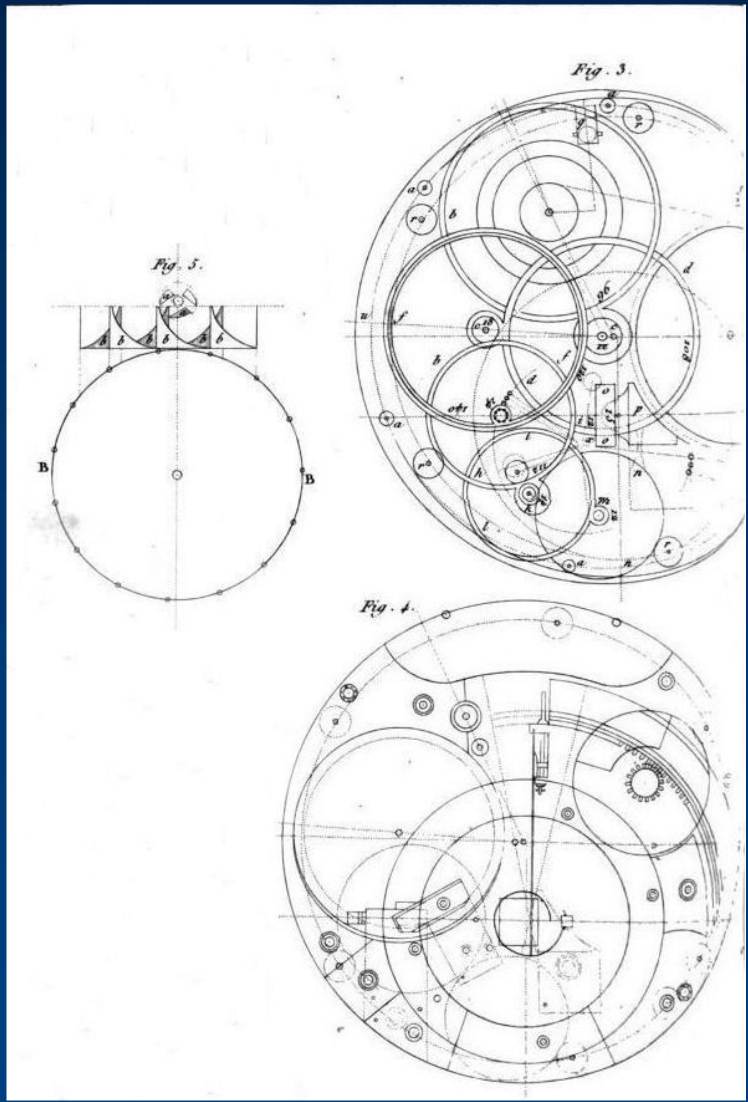


Local Time Time at Greenwich

Time Difference = Longitude

The Marine Chronometer

John Harrison claimed longitude prize in 1761 (finally paid in 1773)



What Time is it Anyway?

IAT: International Atomic Time

UTC: Coordinated Universal Time (IAT – 37 sec)

MDT: Mountain Daylight Time (UTC – 6 h)

LST: Local Sidereal Time

This class will end at:

19:15:00 UTC = 12:15:00 MST = 20:08:12 LST

The "Solar Day" and the "Sidereal Day"

Solar Day

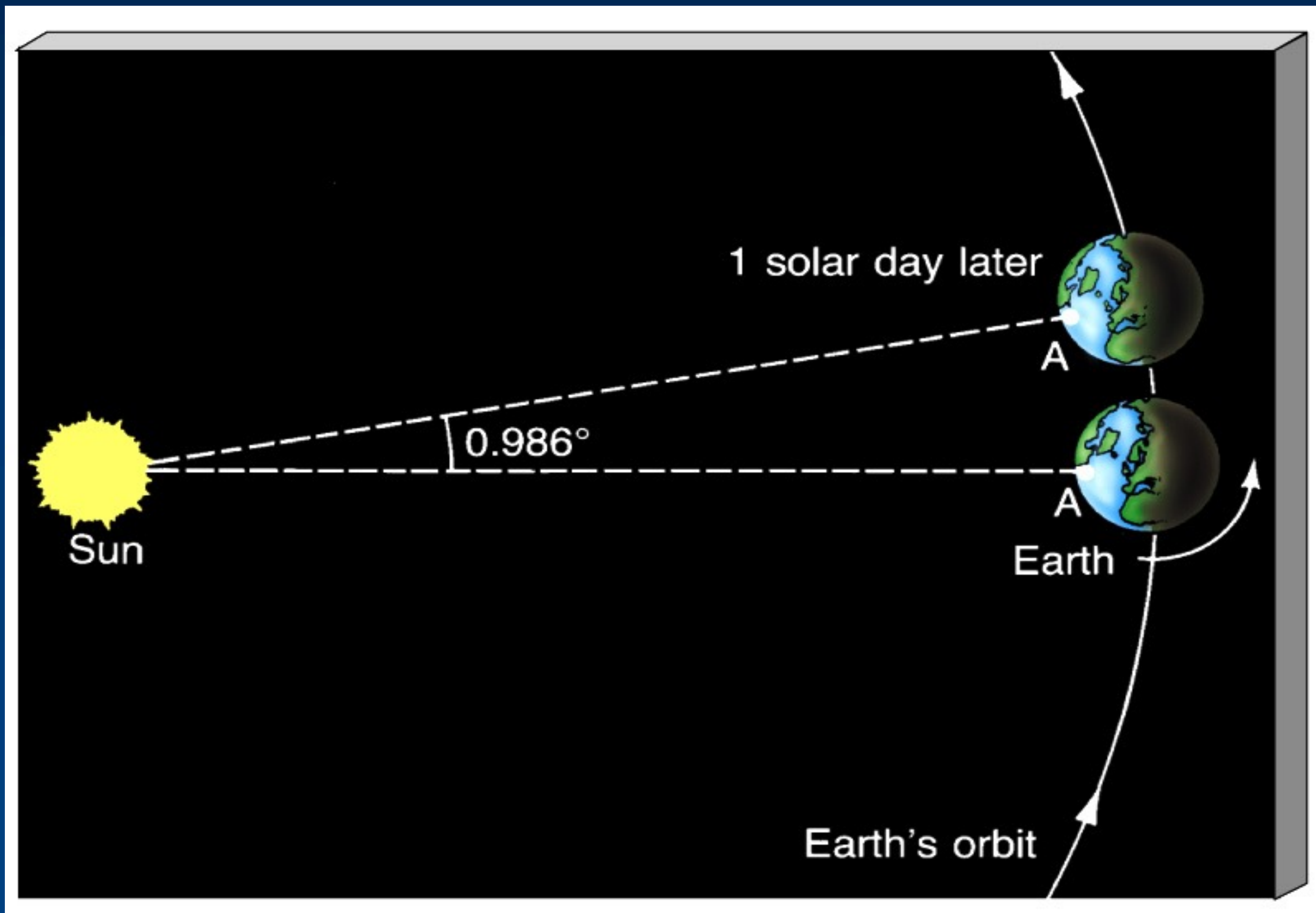
How long it takes for the Sun to return to the same position in the sky (24 hours).

Sidereal Day

How long it takes for the Earth to rotate 360^o on its axis.

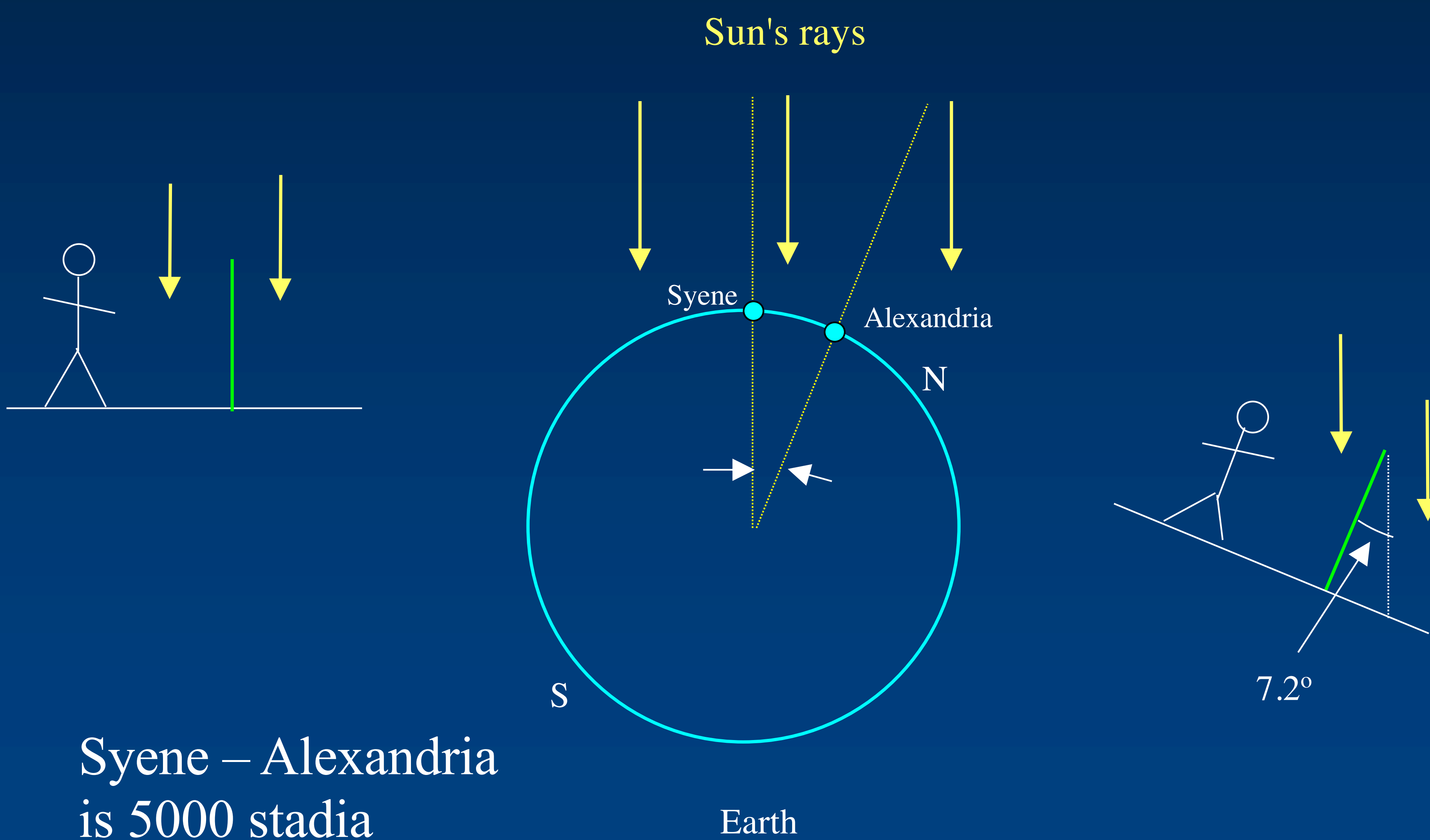
These are not the same!

One solar day later, the Earth has rotated slightly more than 360°
A solar day is longer than a sidereal day by 3.9 minutes
(24 hours vs. 23 hours 56 minutes 4.091 seconds)



Eratosthenes Determines the Size of the Earth in about 200 B.C.

Worksheet 2



Syene – Alexandria
is 5000 stadia

He knows the distance between the two cities is 5000 "stadia".

From geometry then,

$$\frac{7.2^o}{360^o} = \frac{5000 \text{ stadia}}{\text{Earth's circumference}}$$

=> circumference is 250,000 stadia, or 40,000 km.

So radius is:

$$\frac{40{,}000 \text{ km}}{2\pi} = 6366 \text{ km}$$

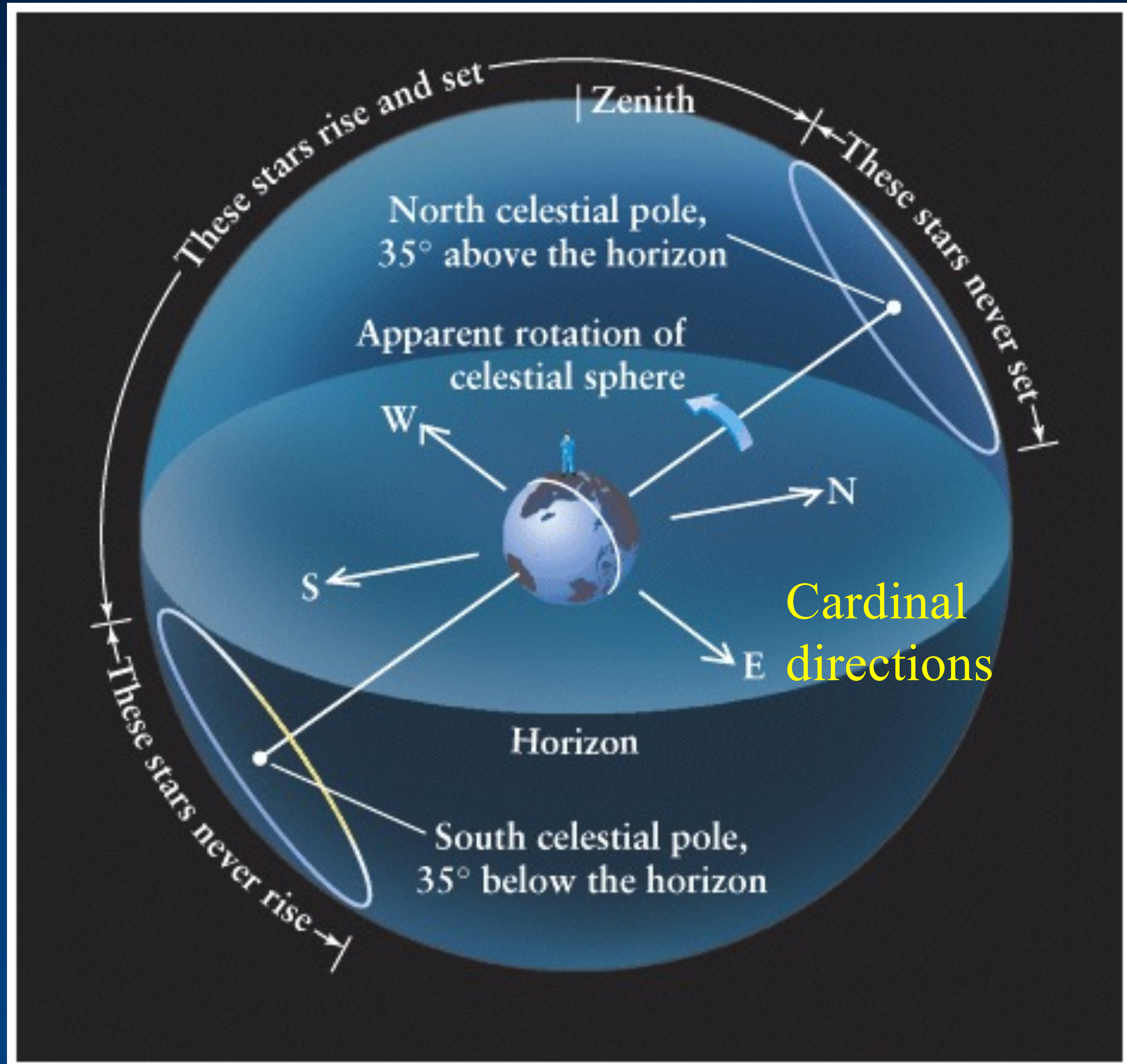
(very close to modern value, 6378 km!)

Astronomical coordinate systems

- Purpose: to locate astronomical objects on the sky
- The “sky” is a two-dimensional surface, a sphere above our heads. We use an angular coordinate system to locate objects on a sphere

The *zenith* is the point directly overhead (cf. nadir).

The view from our latitude:



The *horizon* delimits the portions of the sky we can and can't see at any given time.

The *meridian* is the north-south circle that passes through the zenith and both celestial poles.

Over the course of a night, the celestial sphere appears to rotate around us.

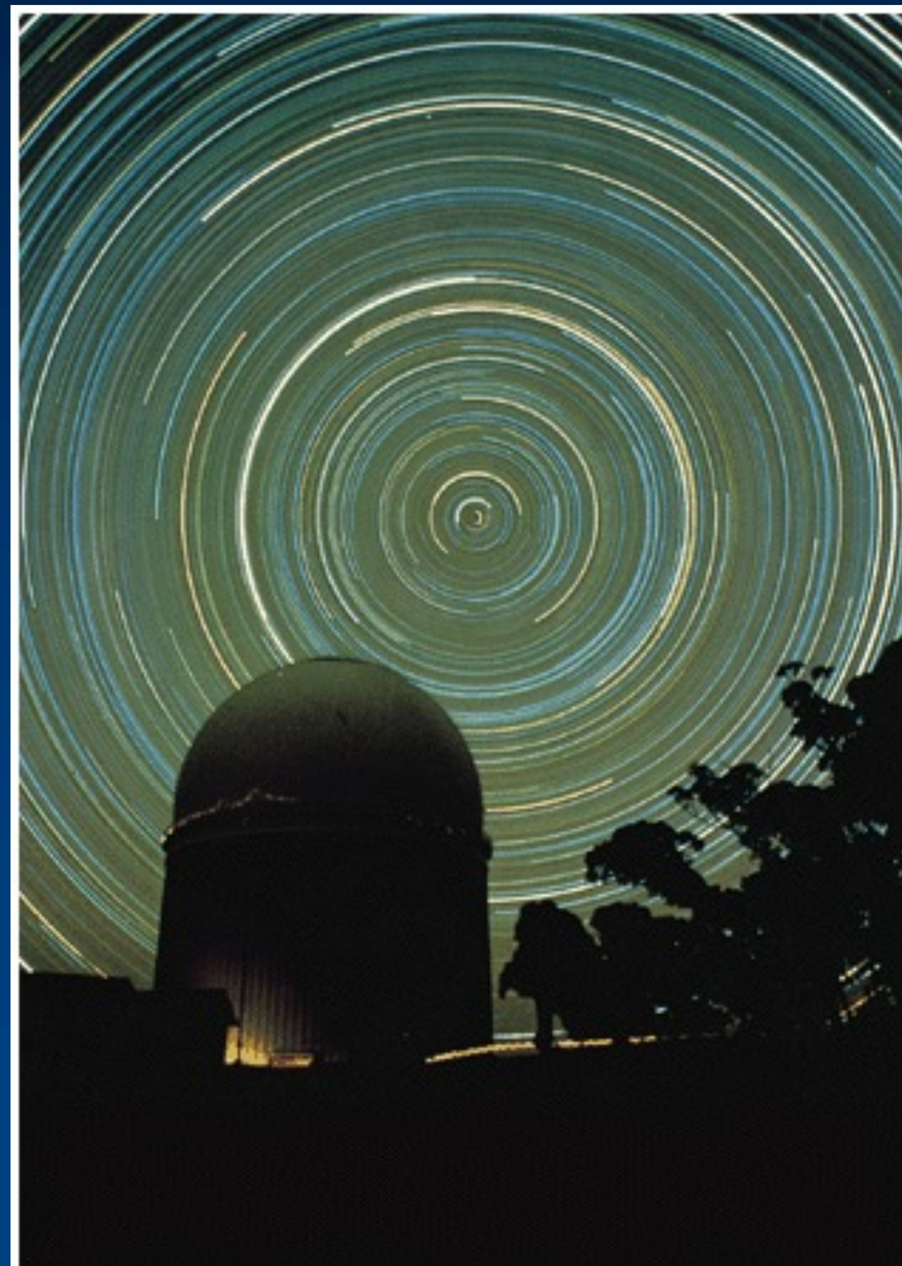
Question: what does A.M. mean? P.M.?

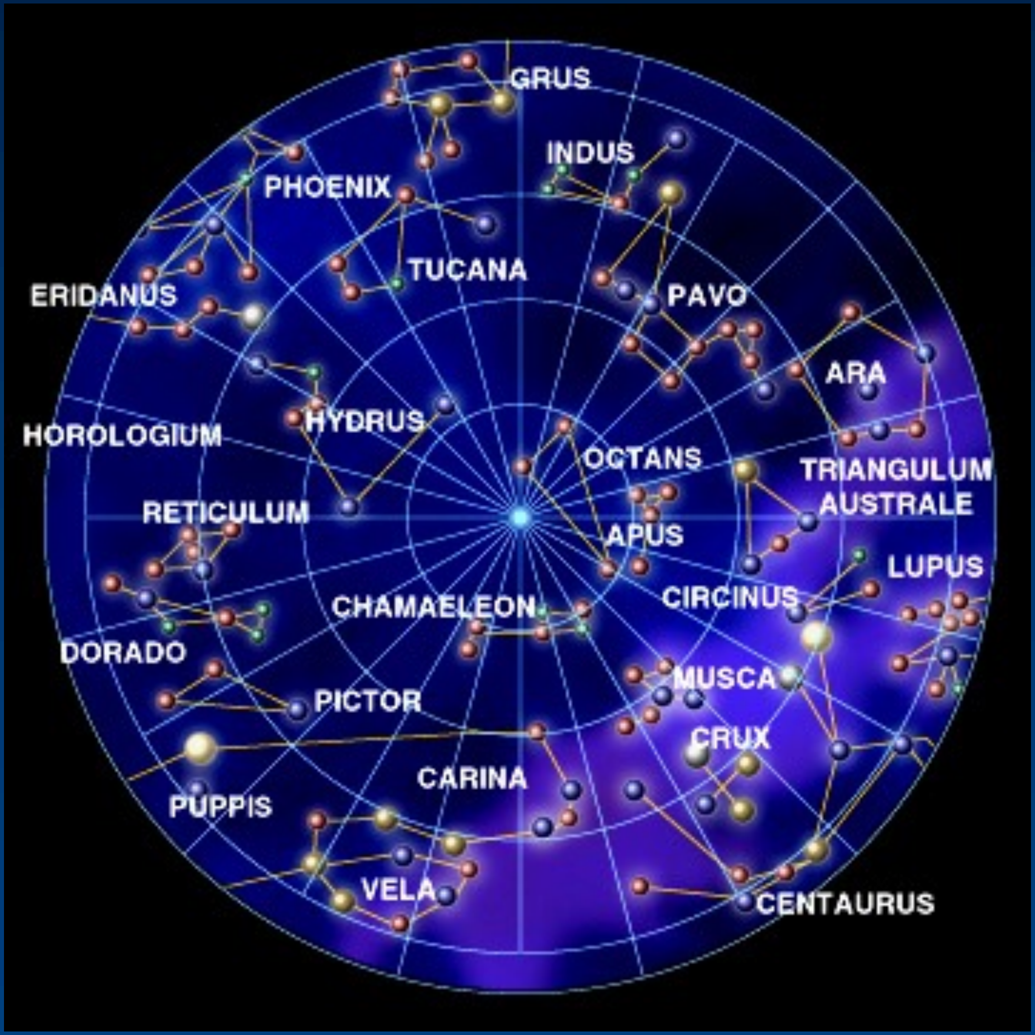
Circumpolar stars never set (or rise).

This picture is taken from Australia, at about -35° south latitude.

Can astronomers ever see Polaris from this observatory?

Is there a southern "pole star"?





(Note: you have to be at a latitude less than 30°N to see the Southern Cross)

Celestial Coordinates

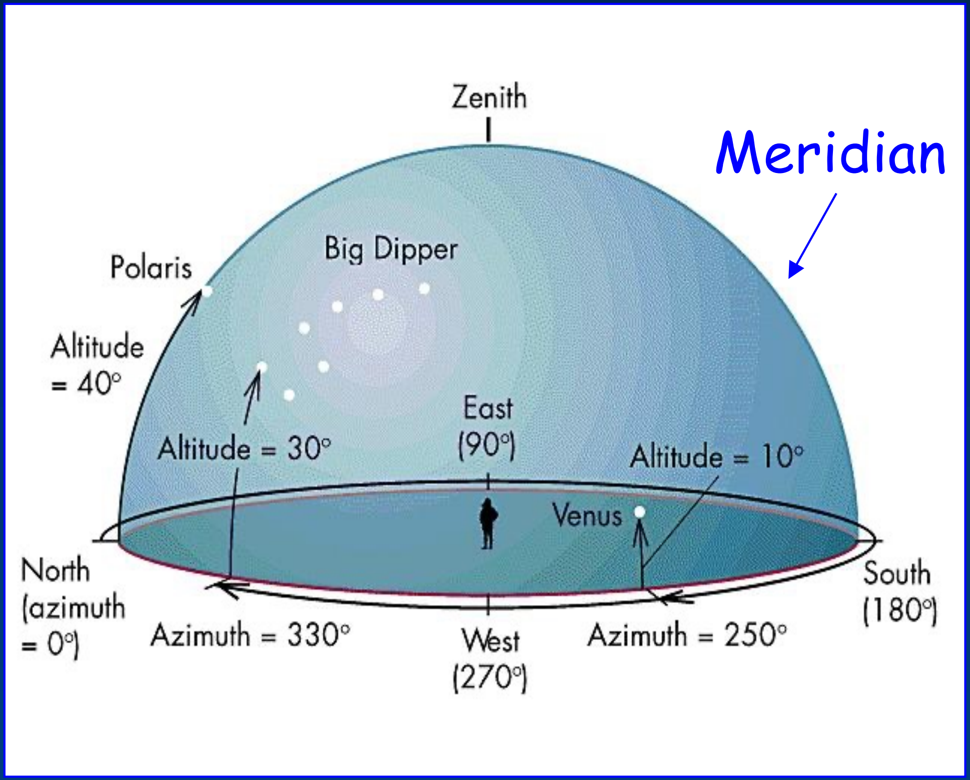
The imaginary Celestial Sphere is what astronomers use to define positions of objects in the sky.

Angular coordinates on the sphere tell us in what direction to look to see a particular star, or galaxy, etc.

Two coordinate systems worth mentioning

The Horizon Coordinate System

- Altitude
  - Angle above the horizon
  - 0-90º
  - The altitude of the north celestial pole equals the observer's latitude on Earth. Useful for navigation!
- Azimuth
  - Angle measured eastward along horizon, starting from the north
  - 0-360º



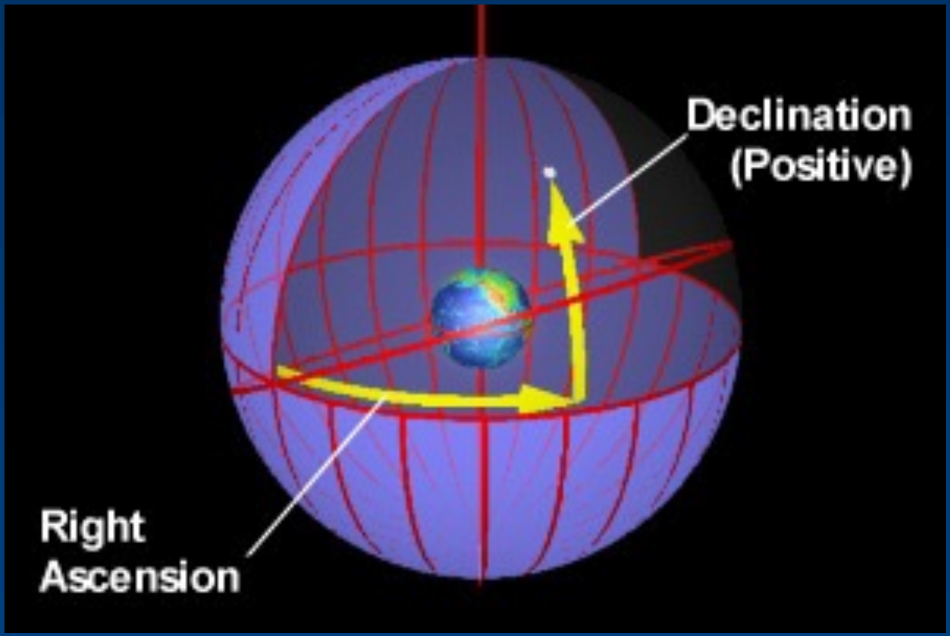
Pros and cons of the horizon system

- Pros
  - Easy to understand
- Cons
  - At different position on the Earth, the same object has different coordinates
  - At different times, the same object has different coordinates

The coordinates of an object change in the horizon system!

The Equatorial coordinate system

- A system in which the coordinates of stars and galaxies do NOT change for observers at different locations on Earth (well, almost…more later)
- The coordinates are called Right Ascension and Declination, and are analogous to longitude and latitude on Earth.

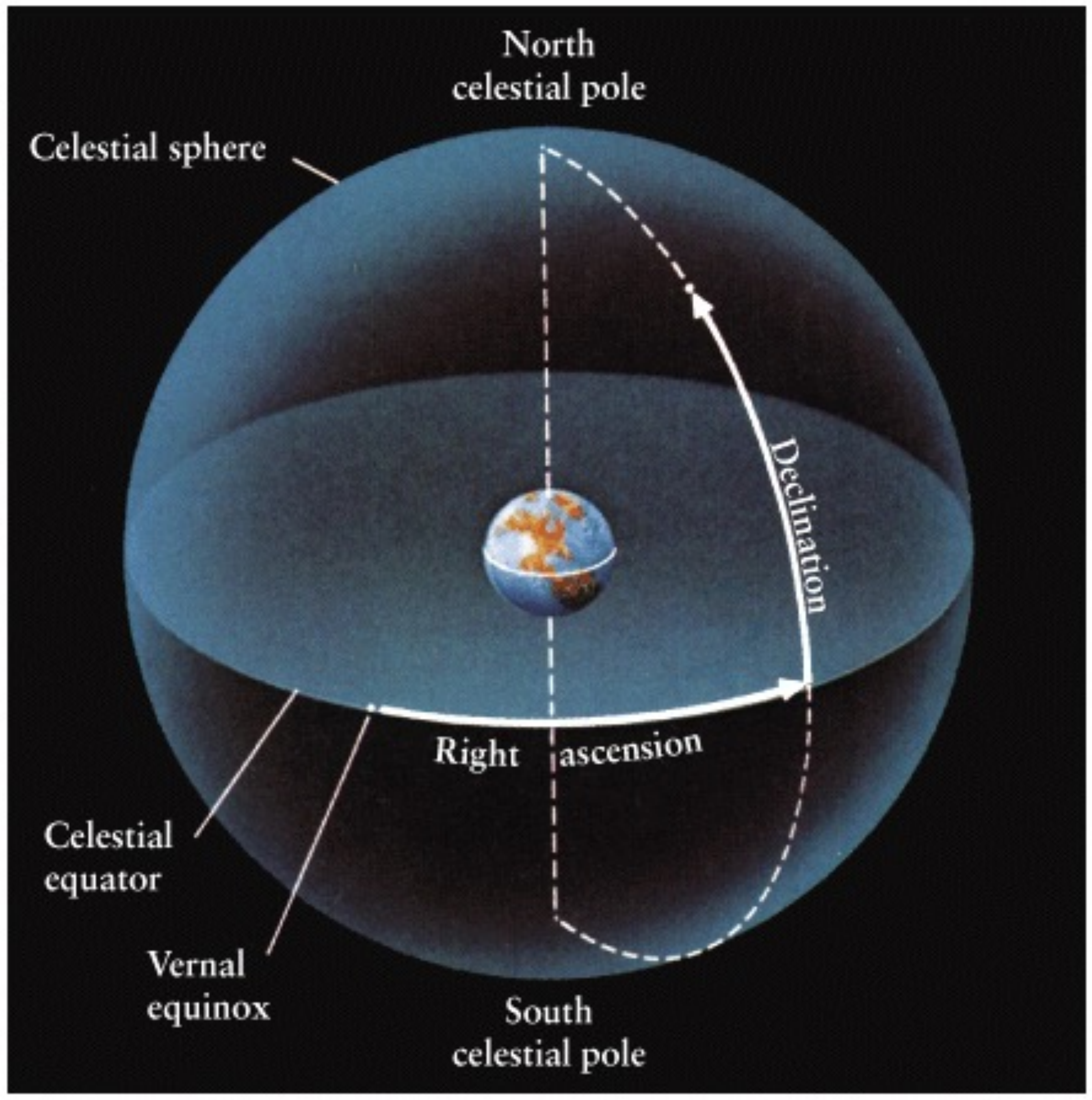


- The equatorial coordinate system is fixed to the celestial sphere.

Declination (Dec) is a set of imaginary lines parallel to the celestial equator.

Declination is the angular distance north or south of the celestial equator.

Defined to be 0° at the celestial equator, 90° at the north celestial pole, and -90° at the south celestial pole.



Right ascension (RA): imaginary lines that connect the celestial poles.

Right ascension is the angular distance eastward from the vernal equinox.

Vernal equinox is the point on the celestial equator the Sun crosses on its march north - the start of spring in the northern hemisphere (cp. Greenwich 0° longitude). More on this later.

- Declination (Dec) is measured in degrees, arcminutes, and arcseconds. 0° to +90° in north, and 0° to -90° in south. (Also can see N and S nomenclature)

- Right ascension (RA) is measured in units of time: hours, minutes, and seconds. Ranges 0h – 24h

- This stresses that the sky is rotating over us as time passes, making changes in the sky more meaningful to observers.

Example 1: The star Regulus has coordinates

$$RA = 10^h\ 08^m\ 22.2^s$$

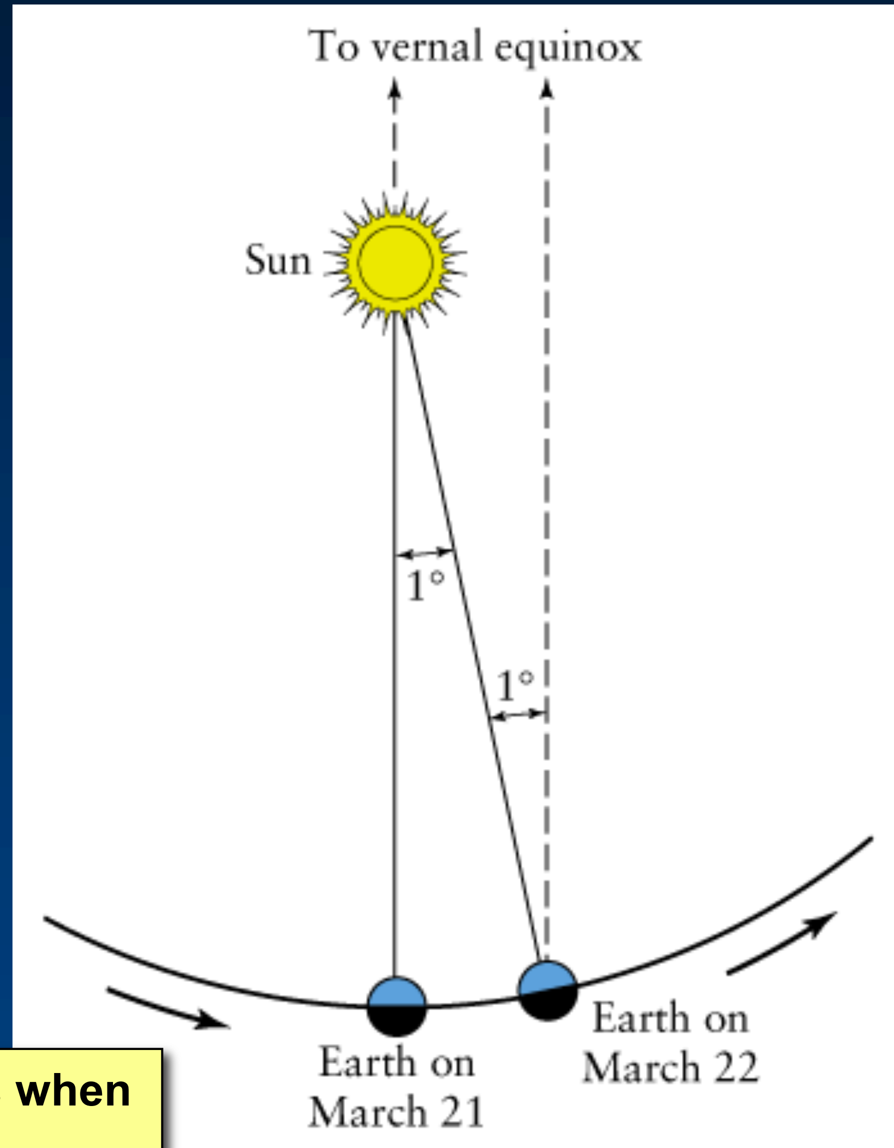
$$Dec = 11^\circ\ 58'\ 02''$$

Example 2: If a star with RA of 23^h is overhead at midnight, then a star with RA of 22^h would have been overhead an hour earlier.

Example 3: In Albuquerque, our zenith is at Dec=35° , and an RA that is always changing

Solar time and sidereal time are different because the Earth is not only rotating, but also revolving around the Sun.

The Earth turns 360° in one sidereal day, but must turn a bit more in a solar day because it's moved in its orbit a little while revolving.



The difference is about 3.9 minutes, in the sense that a solar day is 24 hours while a sidereal day is 23 hours, 56 minutes, 4.091 seconds.

Useful fact for observing: sidereal time zero is when vernal equinox crosses meridian. Happens at midday on March 21 or midnight on Sept 22. This is also time when an object with RA=0^h crosses meridian. So in general an object crosses the meridian when the sidereal time is equal to its RA. And sidereal time=solar time on midnight, Sept 22

Observatories use sidereal clocks!

- Caution: a star’s RA and Dec change slowly with time due to "precession" of the Earth.

- Celestial coordinates are exactly right for only one instant in time.

- Astronomers use "epochs", generally now 2000, to make sure everyone’s using the same reference frame! The coordinates given for Regulus are for epoch 2000.

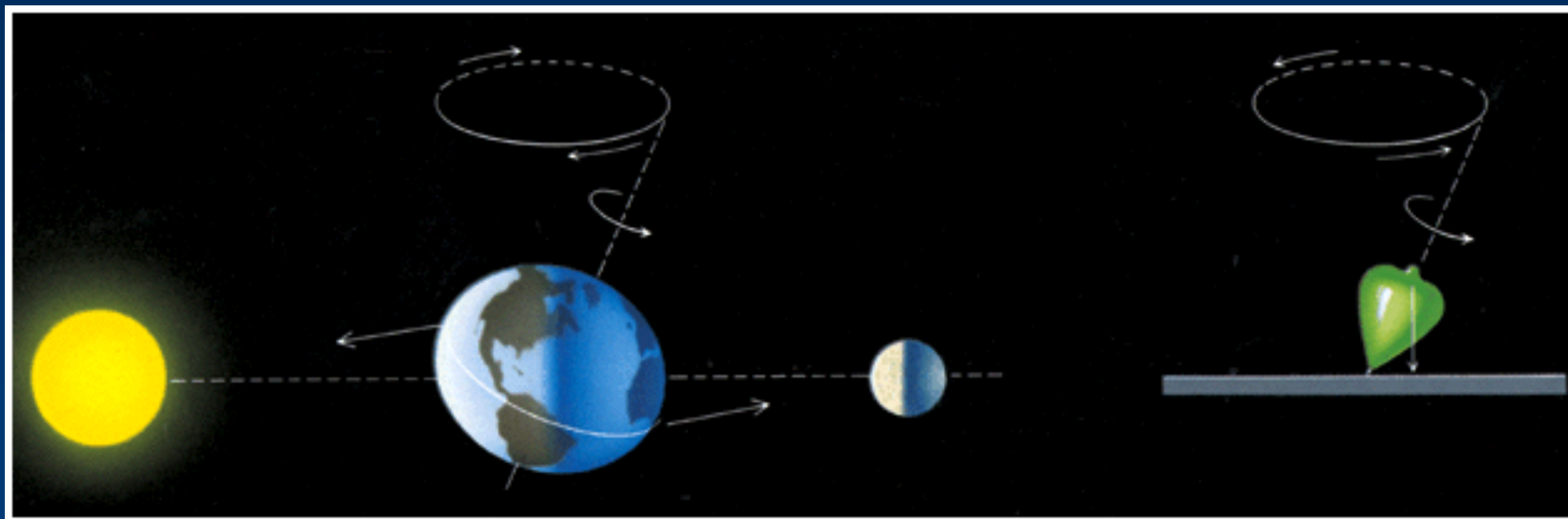
Precession

The direction where the Earth's poles point isn't always the same – the Earth is wobbling like a top.

Why? Due to the gravitational pull of the Sun and the Moon on the non-spherical Earth.

The Earth has an *equatorial bulge* – It is a little fatter across the equator than around the poles. (Diameter difference is 43 km out of 12,756 km)

The gravitational pull of Sun and Moon on Earth's equatorial bulge causes the poles to trace out a circle, like a spinning, wobbling top. This is "precession".



So the north celestial pole slowly traces out a circle among the northern constellations. It takes 26,000 years to trace out one circle.

Polaris won't always be our "pole star"! Most of the time we don't have one!

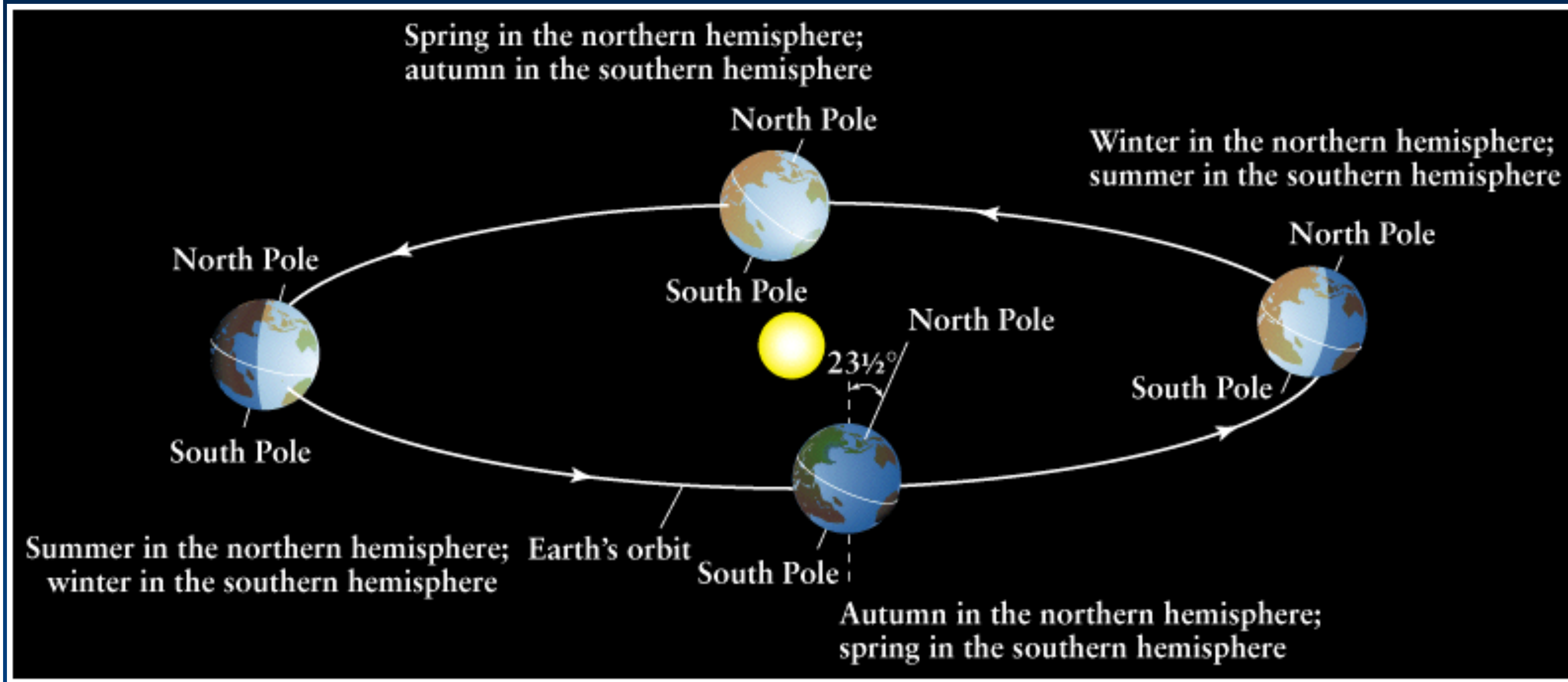
Thus RA and Dec coordinates, which are tied to the positions of the celestial poles and celestial equator, change slowly with time.

What causes the seasons?

- The Earth's axis of rotation is tilted with respect to the plane of the Earth's orbit around the Sun.

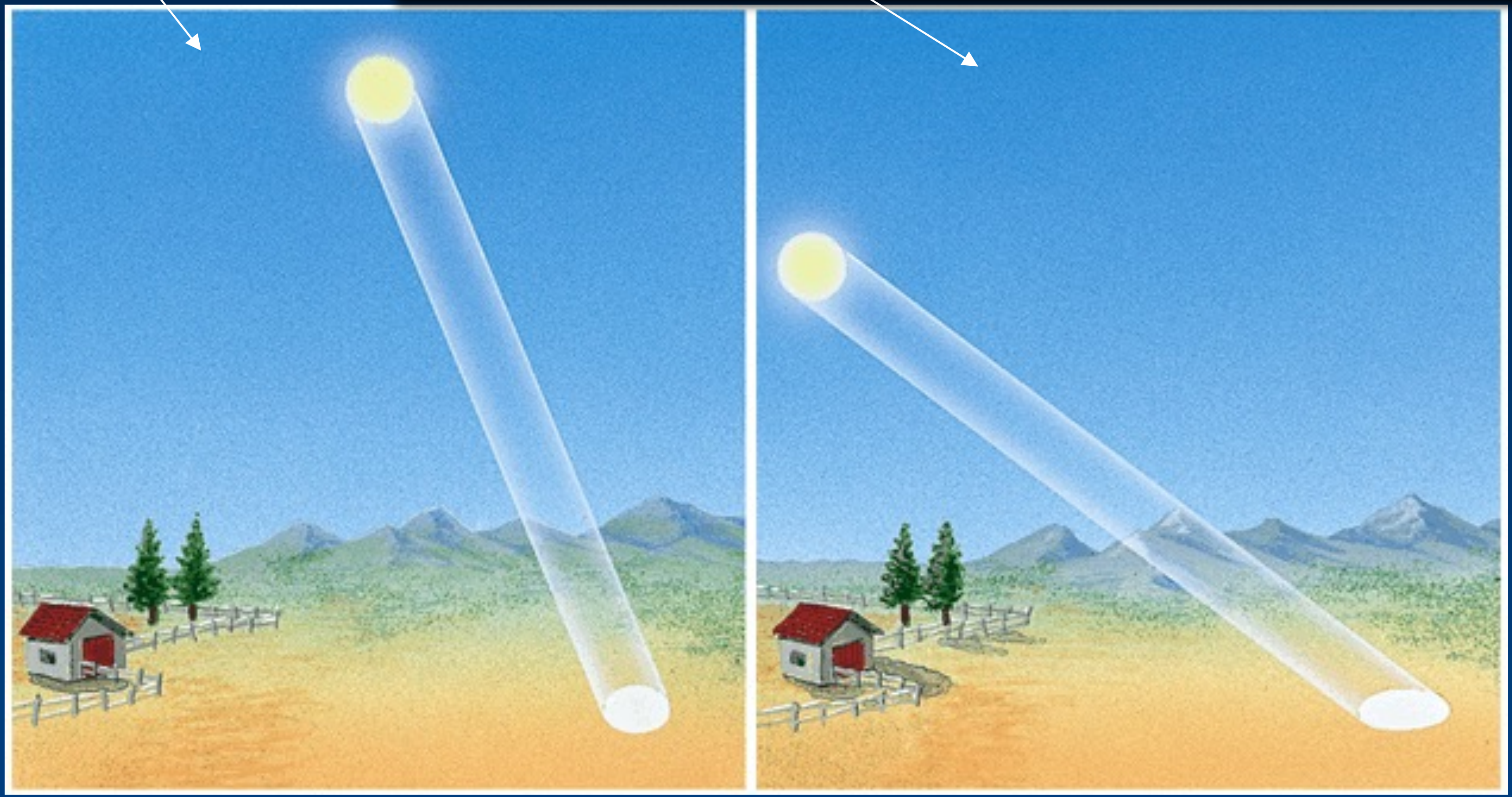
- Rotation axis inclined 23.5° away from the perpendicular to the orbital plane.

=> This causes solar illumination and number of daylight hours to vary at any location throughout the year.


Spring in the northern hemisphere;
autumn in the southern hemisphere
North Pole
Winter in the northern hemisphere;
summer in the southern hemisphere
North Pole
North Pole
South Pole
North Pole
23½°
South Pole
South Pole
Summer in the northern hemisphere;
winter in the southern hemisphere
Earth's orbit
South Pole
Autumn in the northern hemisphere;
spring in the southern hemisphere

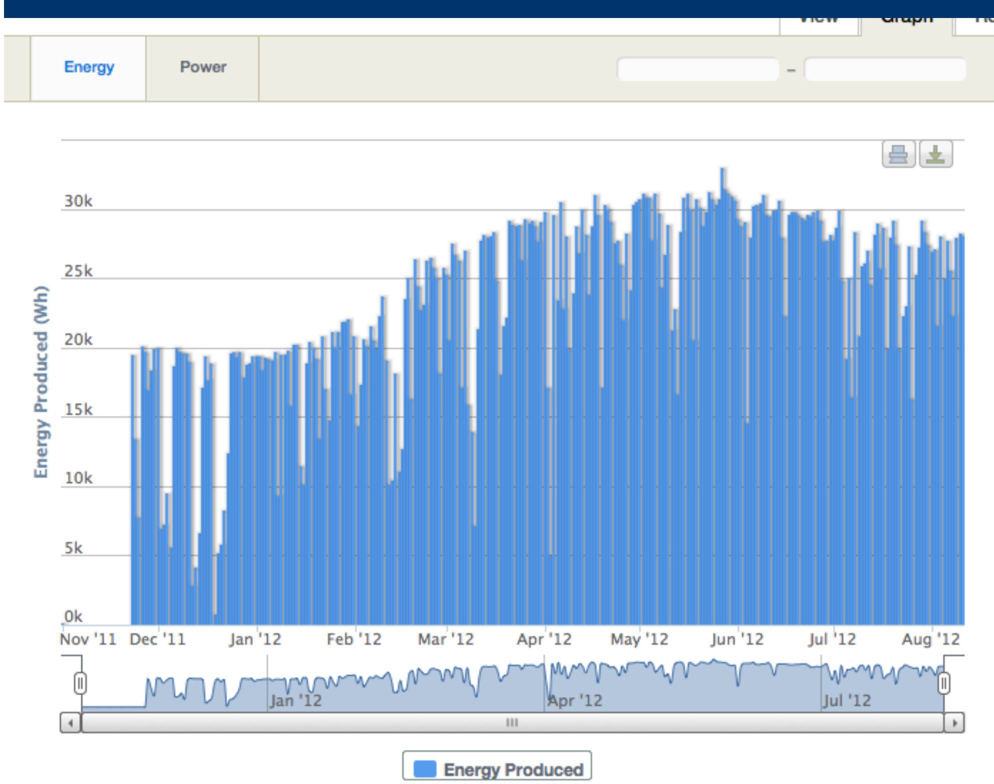
When the Sun is higher in the sky (summer), energy is concentrated, and ground heats up.

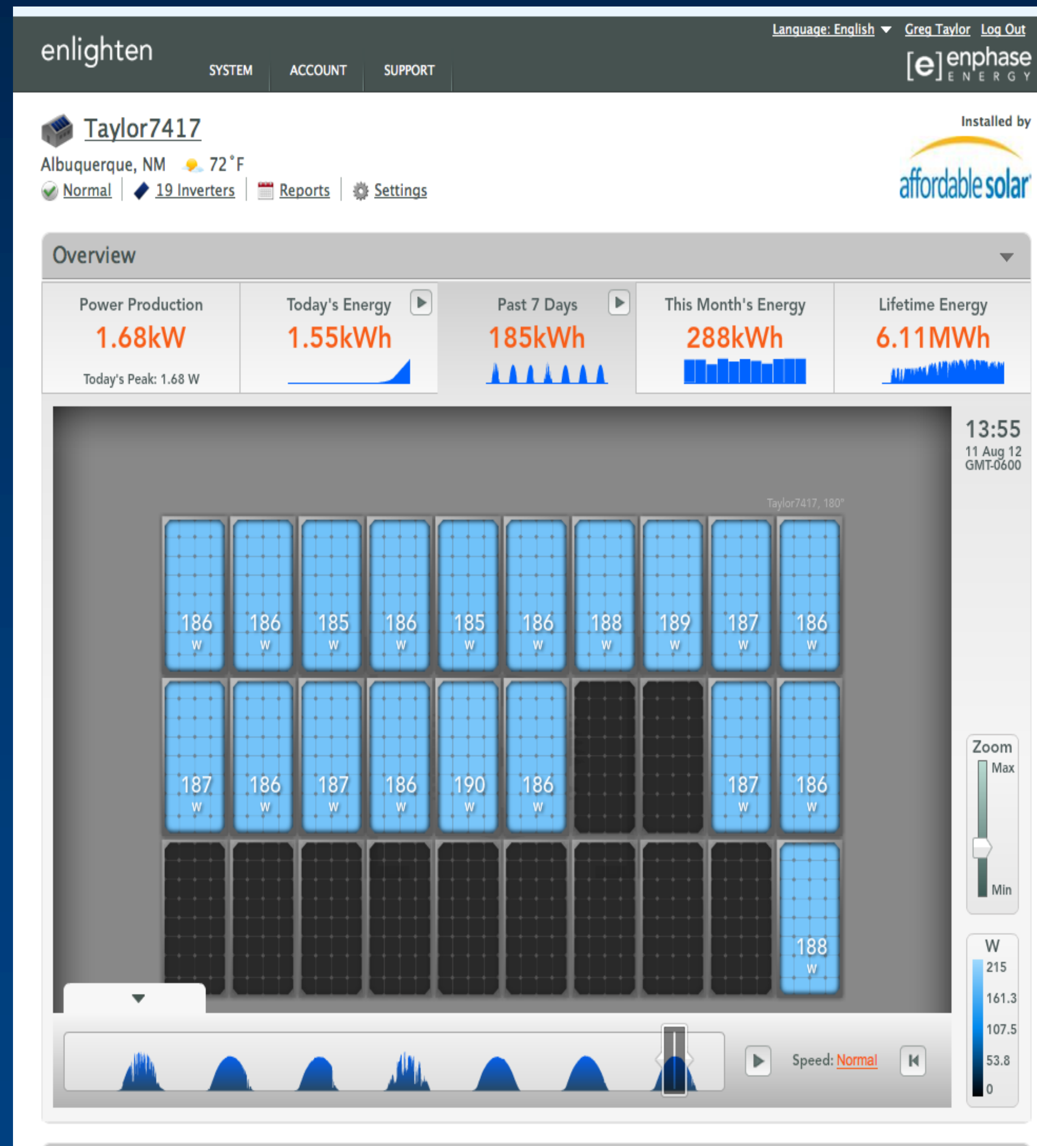
When the Sun is lower (winter), its energy is more diffuse, and ground stays cooler.



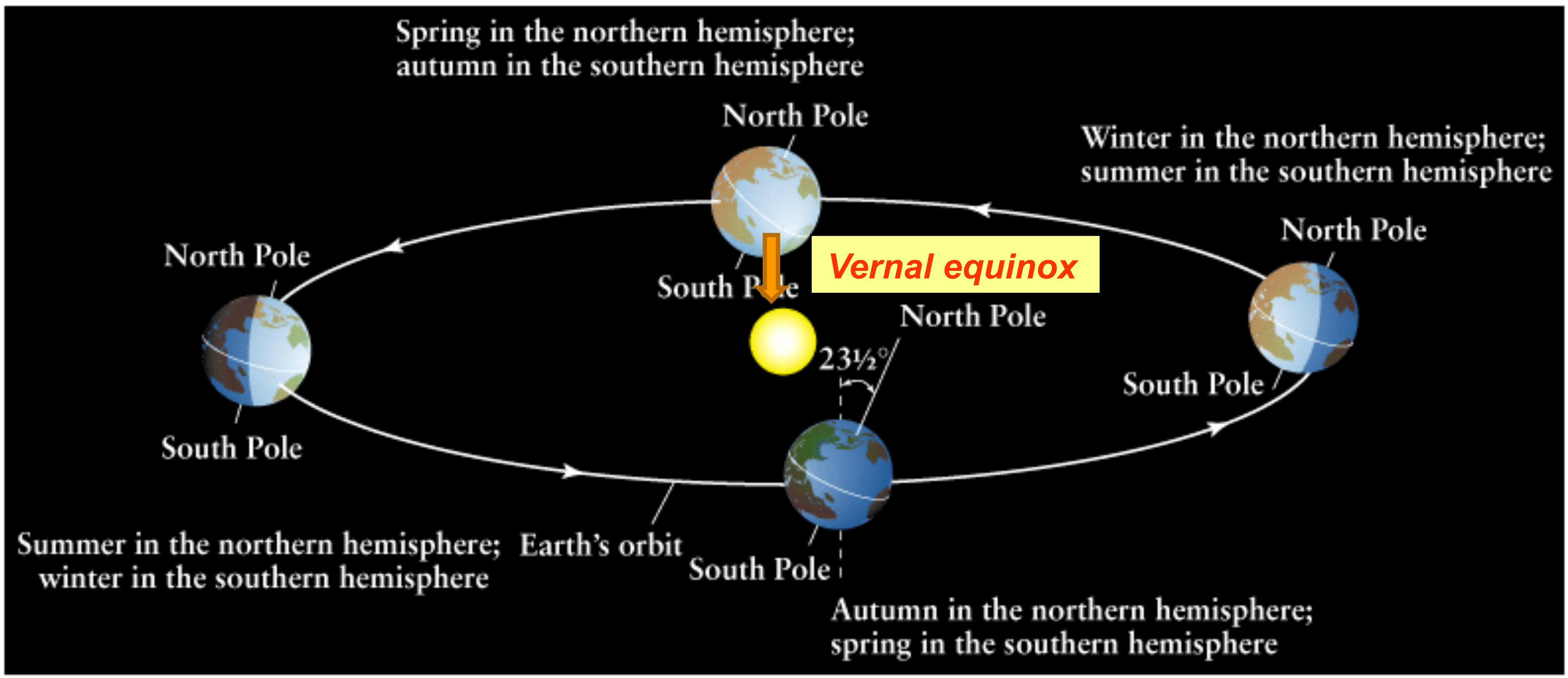
Also, there are more hours of daylight in the summer, making it hotter.

My Solar Energy production is best around May 25





Vernal equinox **is the point on the celestial equator the Sun crosses on its march north - the start of spring in the northern hemisphere .**



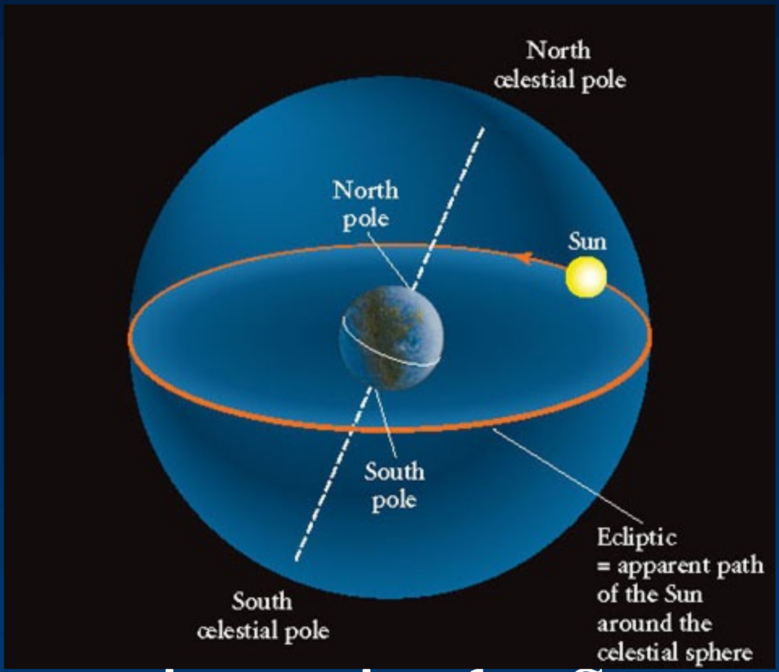
Erroneous explanation of seasons

- Some think seasons are caused by the Earth being closer or farther away from the Sun.

- Not true, because:
  - When it is summer in the northern hemisphere, there is winter in the southern
  - The Earth's orbit is almost a circle
  - The Earth is closest to the Sun in January

More on Sun's apparent motion as seen from Earth

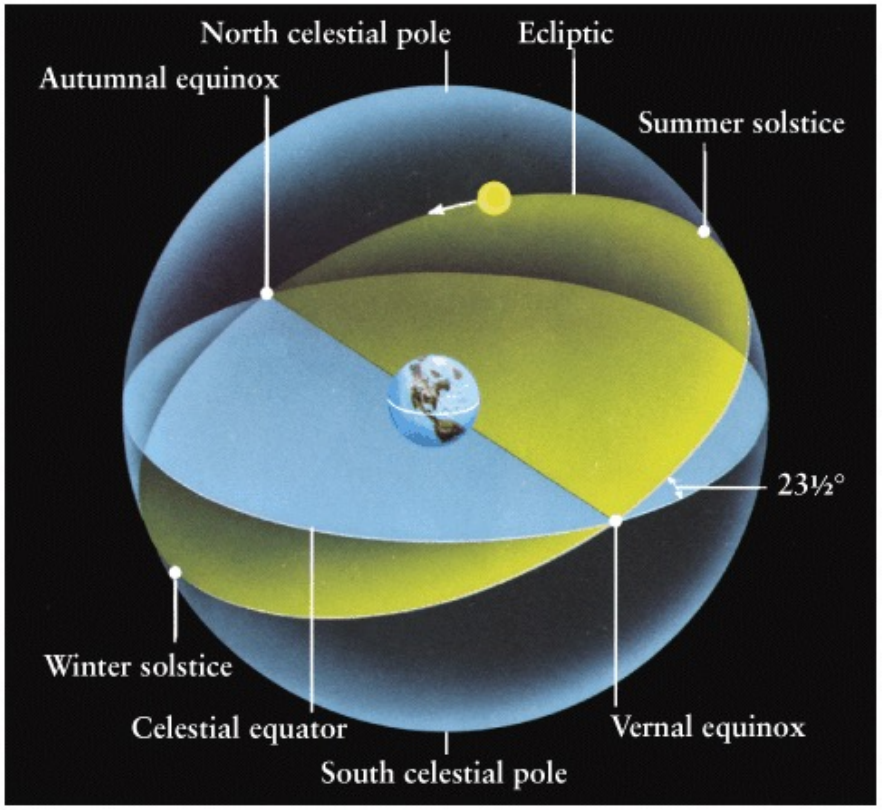
The Ecliptic



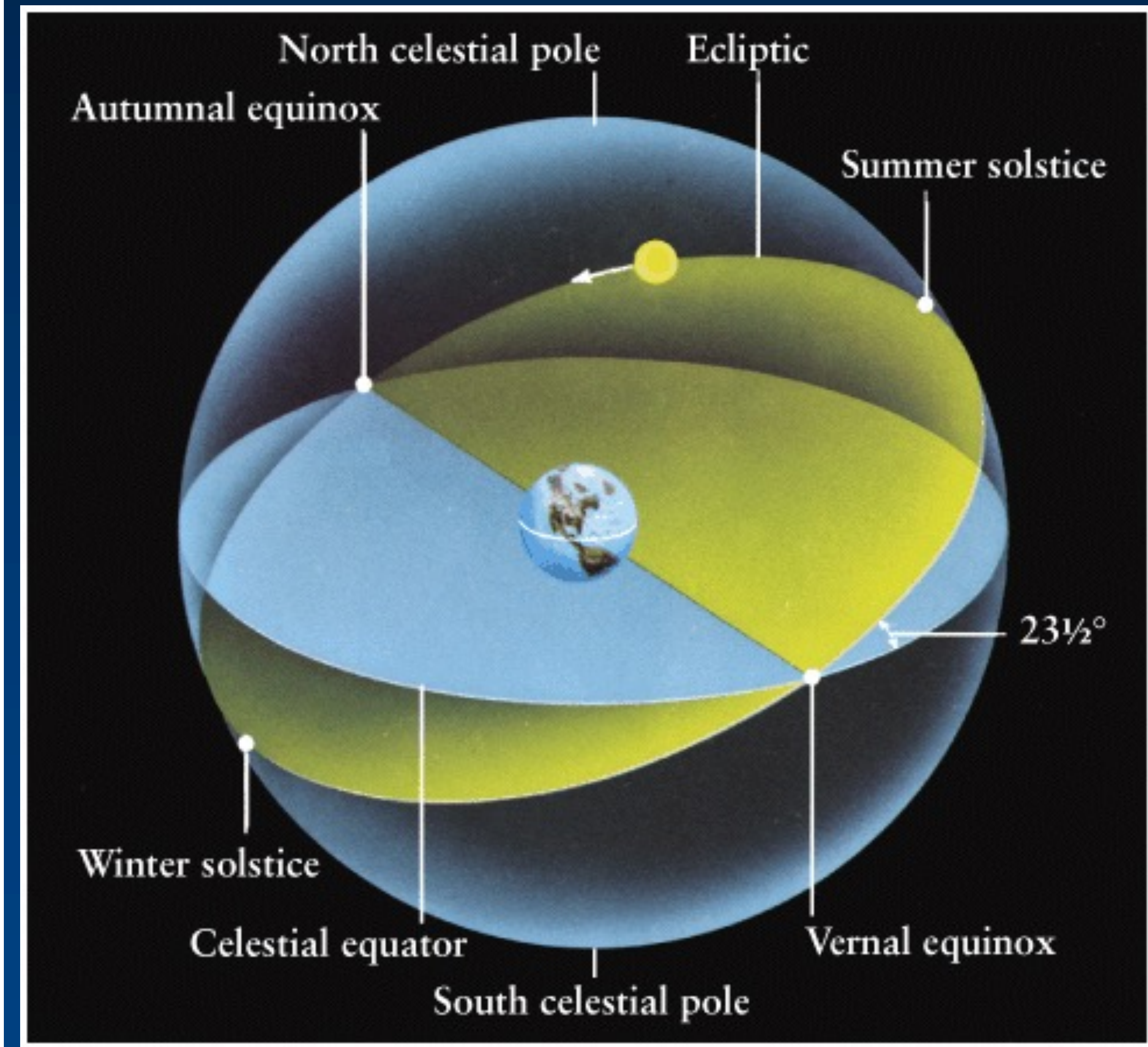
- Because of the tilt of the Earth's rotation axis, the Sun seems to travel on a path on the celestial sphere, the "ecliptic", which is tilted 23.5° with respect to the celestial equator.
- It appears to us that the Sun travels around the Celestial Sphere once a year. A parallax effect: as we orbit Sun, it is projected against different stars. After 1 year, it returns to same position relative to the stars (ecliptic sim)

Equinoxes

- The 2 intersections of the celestial equator and the ecliptic are called the equinoxes. (*Equinoctis = equal nights*)
- Day and night are 12 hours long when the Sun passes through these points



Solstices and Equinoxes



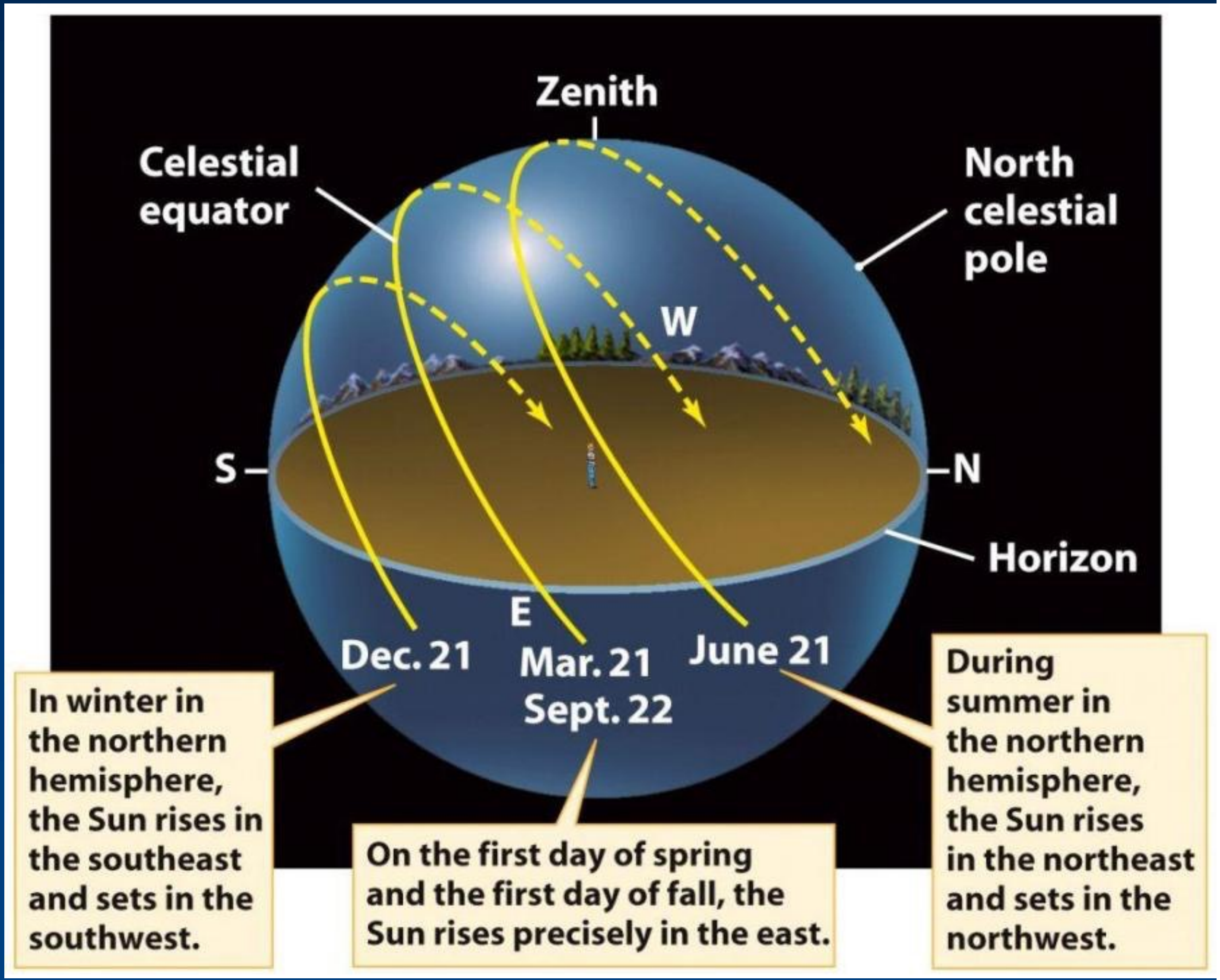
In March, the Sun moves northward across the celestial equator - at the vernal equinox (recall this defines 0^h RA).

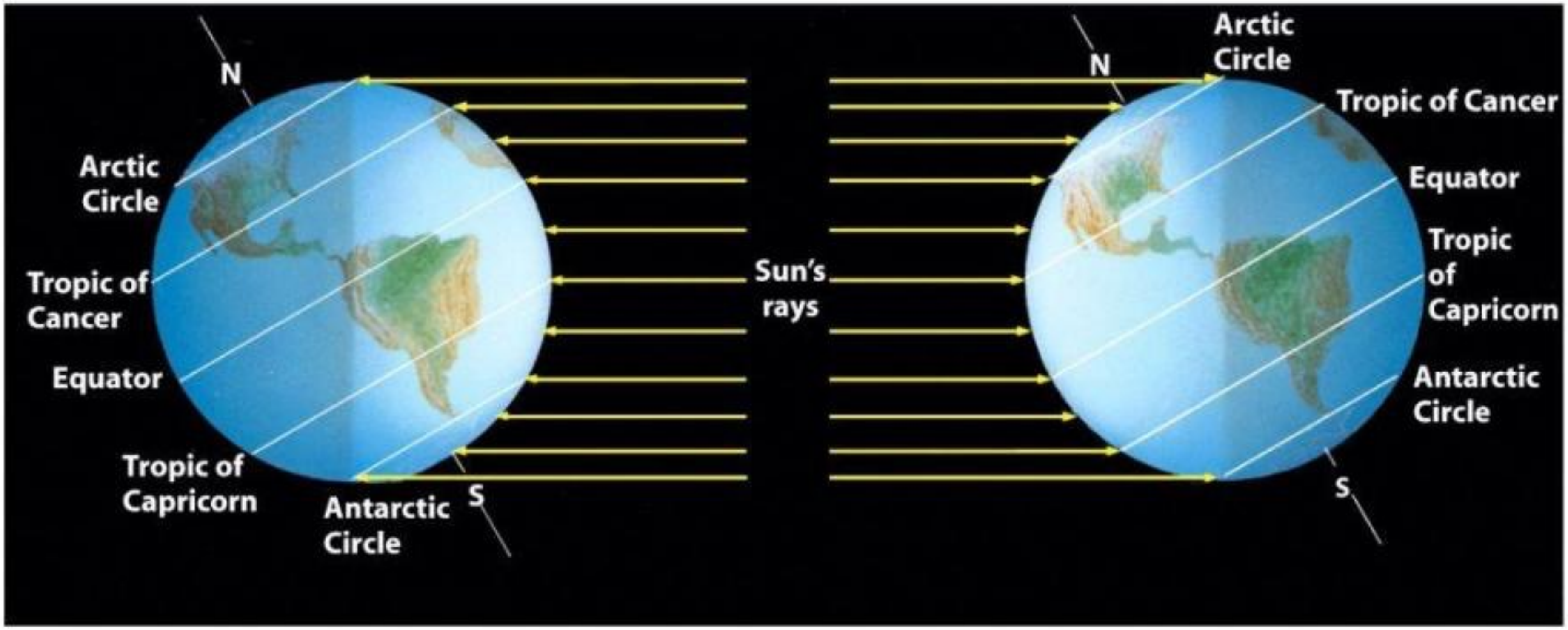
In September, the Sun moves southward across the celestial equator - at the autumnal equinox.

The summer and winter solstices occur at the northernmost and southernmost points of the ecliptic.

Apparent path of the Sun over the <u>day</u> at different times of <u>year</u>

Sun’s motion demonstrator



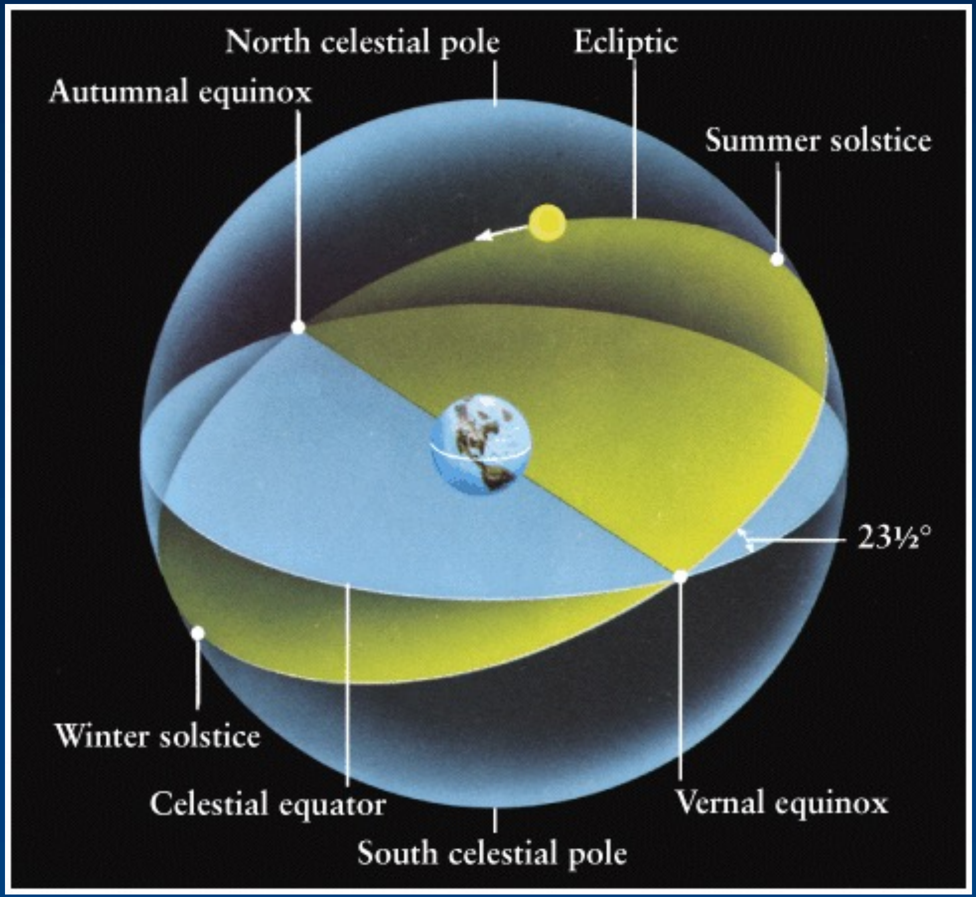


(a) Earth at winter solstice (b) Earth at summer solstice

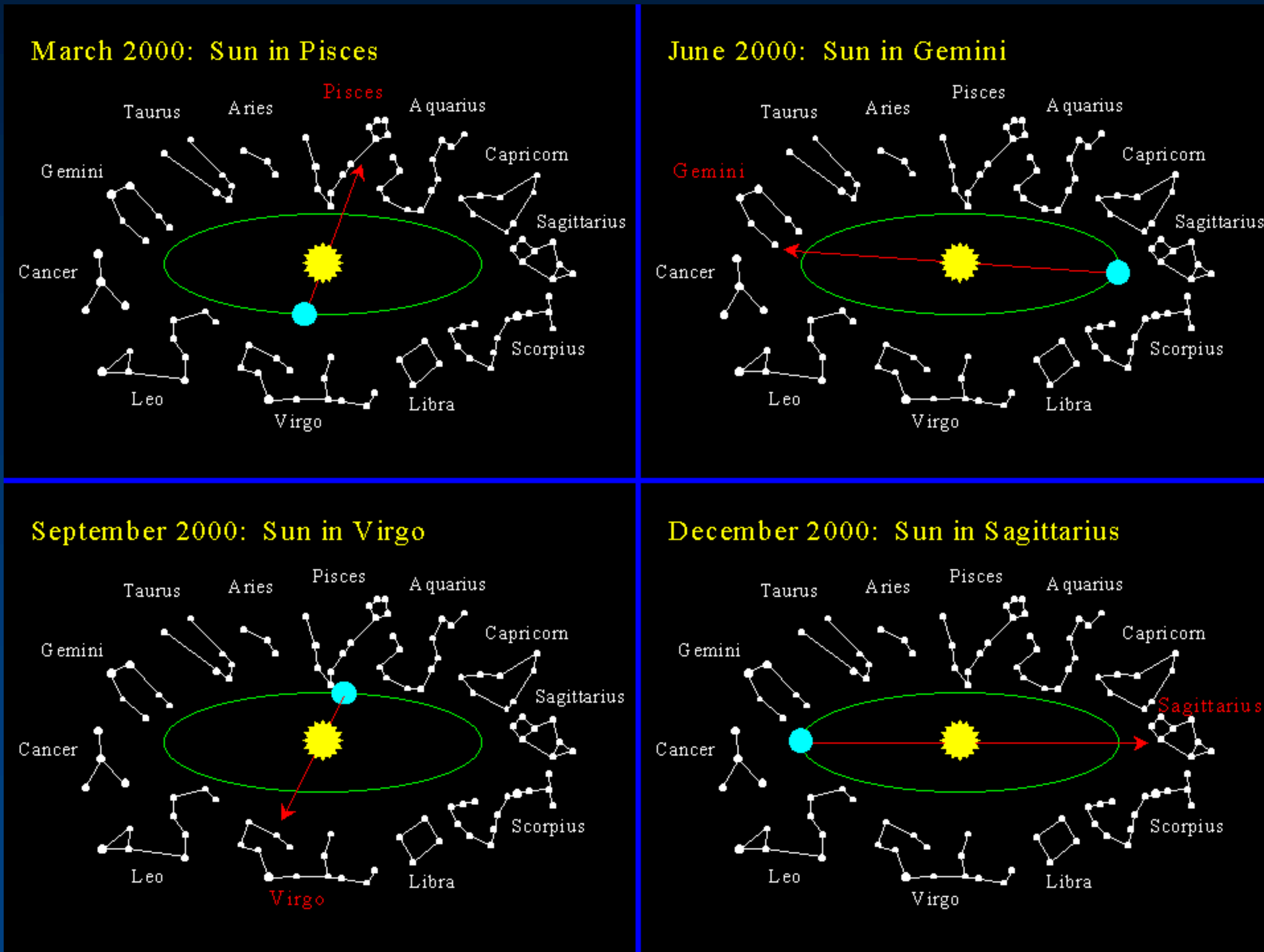
Change in length of day for people at high latitudes is quite dramatic! Above Arctic Circle, Sun never sets for some days in summer.

The Zodiac

- As the Sun moves along the Ecliptic it passes through 12 constellations known as the *Zodiac*



- Ecliptic (Zodiac) simulator



March 2000: Sun in Pisces
Pisces
Taurus
Aries
Aquarius
Capricorn
Gemini
Sagittarius
Cancer
Scorpius
Leo
Libra
Virgo
June 2000: Sun in Gemini
Taurus
Aries
Pisces
Aquarius
Capricorn
Gemini
Sagittarius
Cancer
Scorpius
Leo
Libra
Virgo
September 2000: Sun in Virgo
Taurus
Aries
Pisces
Aquarius
Capricorn
Gemini
Sagittarius
Cancer
Scorpius
Leo
Libra
Virgo
December 2000: Sun in Sagittarius
Taurus
Aries
Pisces
Aquarius
Capricorn
Gemini
Sagittarius
Cancer
Scorpius
Leo
Libra
Virgo

Distance and Brightness

Distance to Deneb 3230 light-years
Distance to Vega 25 light-years
Distance to Altair 168 light-years

But they appear almost as bright - Deneb must be superluminous.

Aside: A closer look

- You are not required to know the following details for the exams… but hopefully you will appreciate what's involved in the relation between horizontal and equatorial coordinates.

- Problem: I've got the RA and Dec coordinates for my favorite object, but where is it really on the sky tonight?

The easy way

- Find a close constellation that you can easily recognize.
- Estimate the offset in degrees from your favorite source.
- Use the telescope dial (or your hands and fingers) to locate your source on the sky when you have identified the constellation.

The accurate way

P = North Pole

Z = zenith

X = location of object

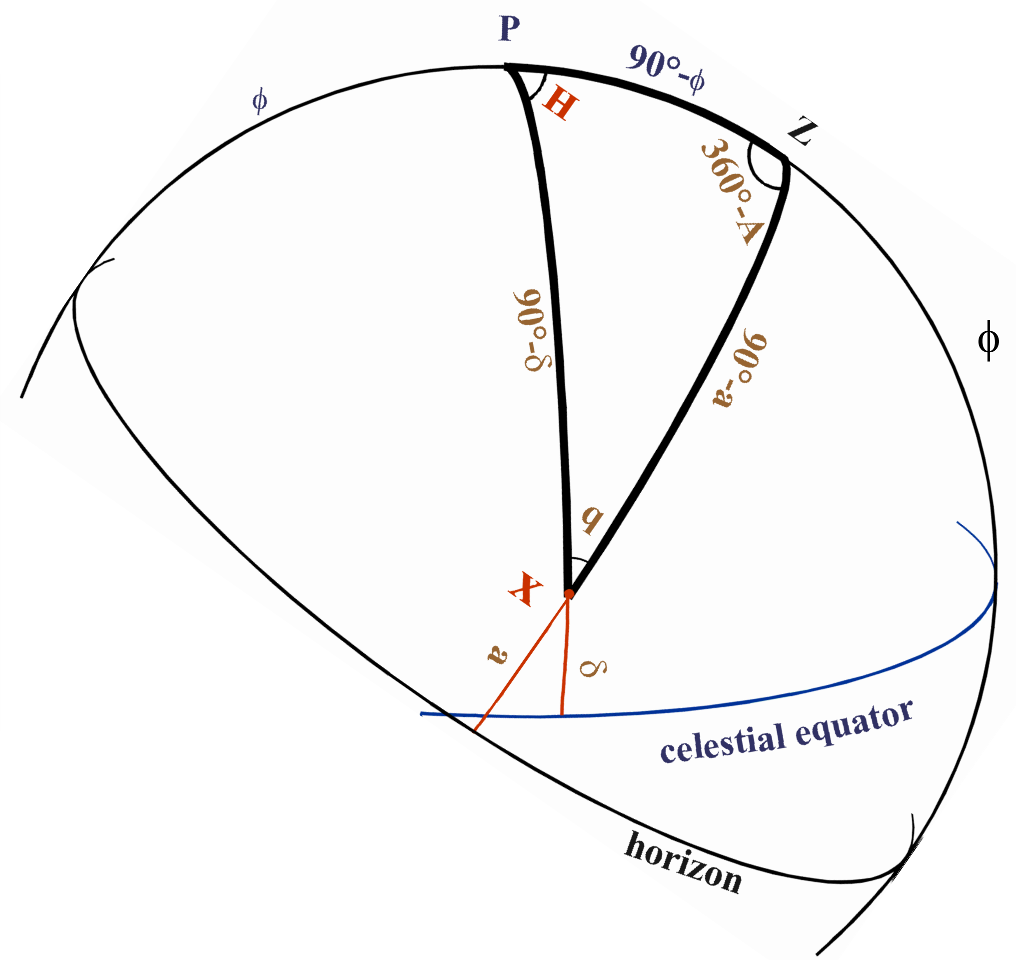
α = RA

δ = Dec

A = azimuth

a = altitude

ϕ = observer's latitude



Given α, we have H = RA of meridian-RA of object, convert H to degrees (multiply by 15).

Now we want azimuth A and altitude a.

The cosine rule:

$$\cos(90^\circ\text{-}a) = \cos(90^\circ\text{-}\delta)\cos(90^\circ\text{-}\phi) + \sin(90^\circ\text{-}\delta)\sin(90^\circ\text{-}\phi)\cos(H)$$

which simplifies to:

$$\sin(a) = \sin(\delta)\sin(\phi) + \cos(\delta)\cos(\phi)\cos(H)$$

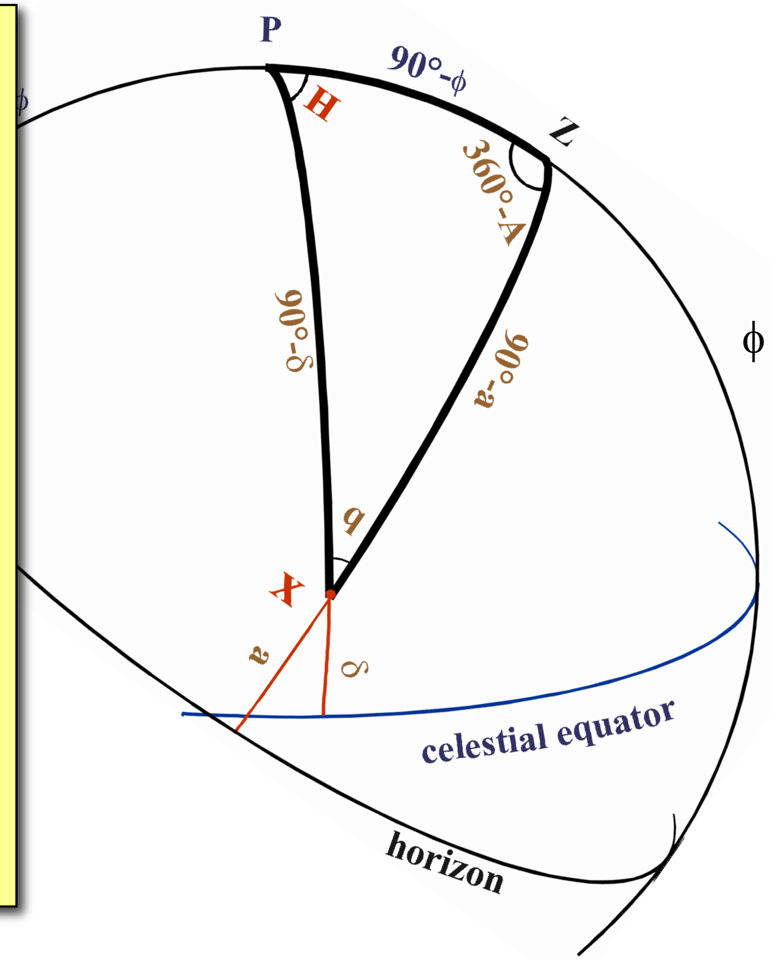
The sine rule:

$$\sin(360^\circ\text{-}A)/\sin(90^\circ\text{-}\delta) = \sin(H)/\sin(90^\circ\text{-}a)$$

which simplifies to:

$$-\sin(A)/\cos(\delta) = \sin(H)/\cos(a)$$

$$\sin(A) = -\sin(H)\cos(\delta)/\cos(a)$$



Recommendations

- Use a computer software program, either something that comes with your telescope or something separate
- DEMO stellarium
- Use the Astronomical Almanac, or similar