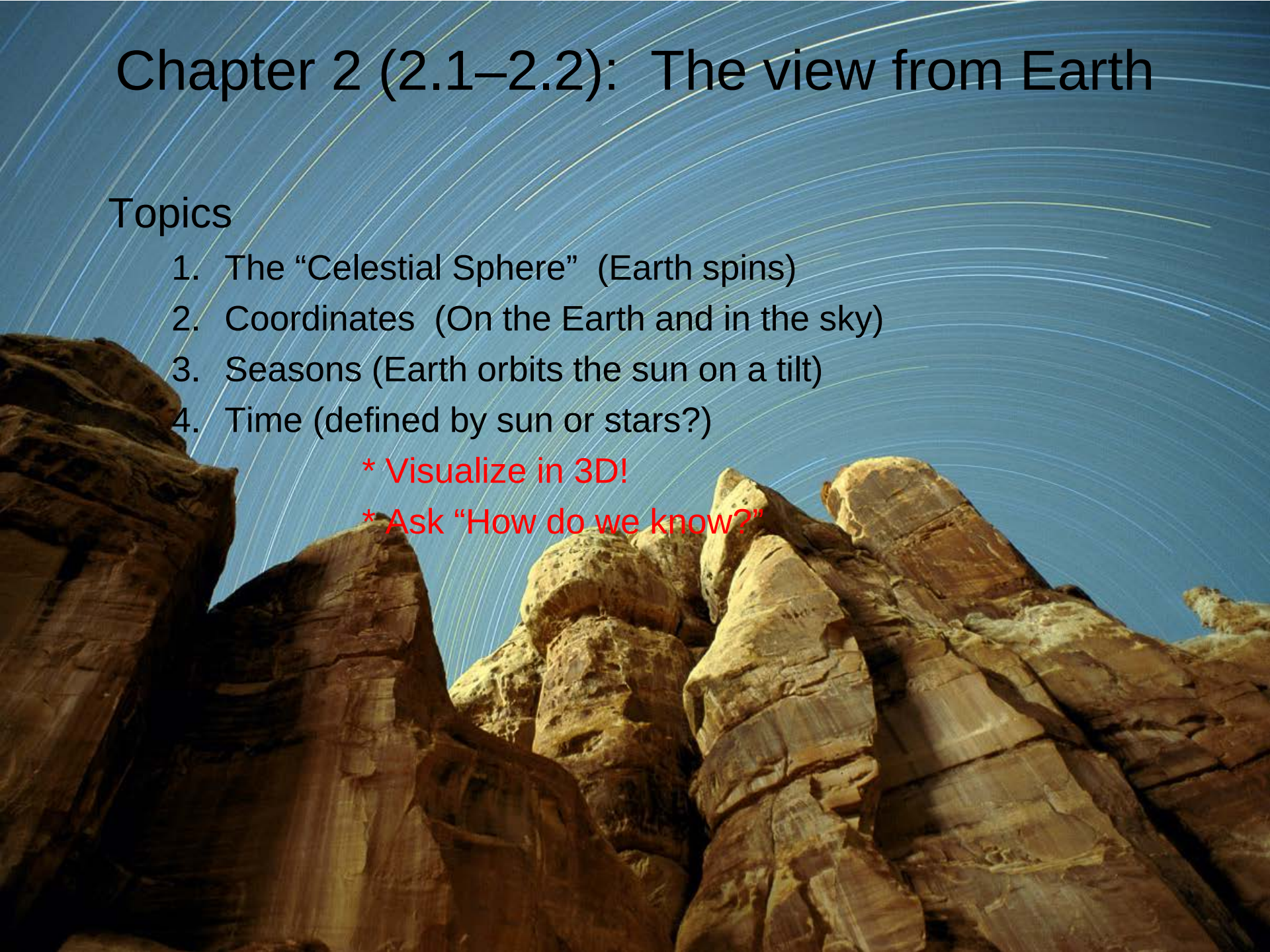
Chapter 2 (2.1–2.2): The view from Earth



Topics

1. The “Celestial Sphere” (Earth spins)
2. Coordinates (On the Earth and in the sky)
3. Seasons (Earth orbits the sun on a tilt)
4. Time (defined by sun or stars?)

* Visualize in 3D!
* Ask “How do we know?”

These four topics are all related to the motion of the Earth:

A. The Earth spins on its axis (once per day)

B. The Earth orbits the sun (axis tilted with respect to orbit)

C. The Sun orbits in the Milky Way

D. The Milky Way moves relative to the rest of the universe

These four distinct ways that Earth moves
are central to all four of today's/this week's topics.

1- The Celestial Sphere

A. The Earth spins on its axis (once per day)

Everything in the sky appears to rise and set once per rotation (i.e. once per day).

Star trails show this motion.

Everything (beyond the solar system) appears fixed on the sky.

(why?)

(what are constellations?)

Earth's spin causes the illusion of a "Celestial Sphere" surrounding the earth.

1- The Celestial Sphere

A. The Earth spins on its axis (once per day)

Everything in the sky appears to rise and set once per rotation (i.e. once per day)

Everything (beyond the solar system) appears fixed on the sky.

(why?)

(what are constellations?)

Constellations = fixed arrangements of stars that are NOT necessarily physically related.

Why Are You Taking This Class?

A. My friend told me the TA's are really cute
B. This was the only class that fit my schedule
C. I love astronomy
D. Me? I stumbled into the wrong classroom

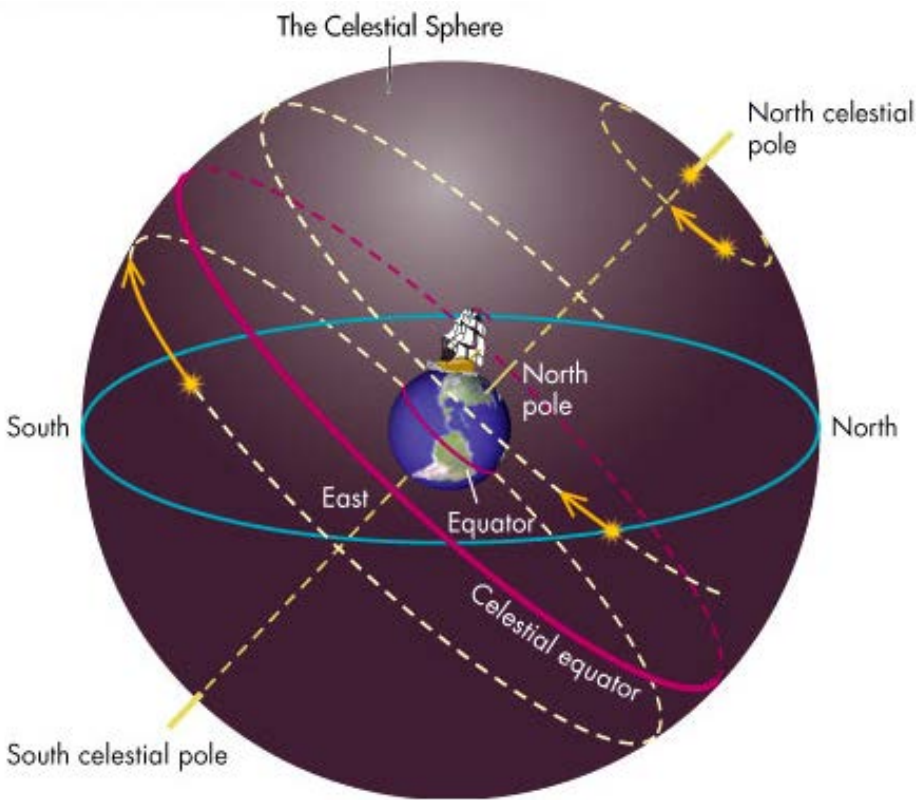
2- Coordinates (on the Celestial Sphere)

A. The Earth spins on its axis (once per day)

We can define a coordinate system as on Earth:

Absolute coordinates (unchanging):

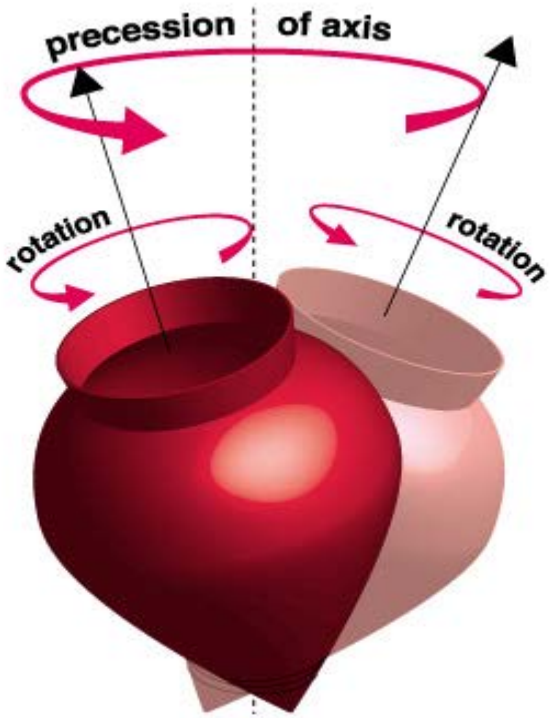
- North pole
- South pole
- Celestial equator

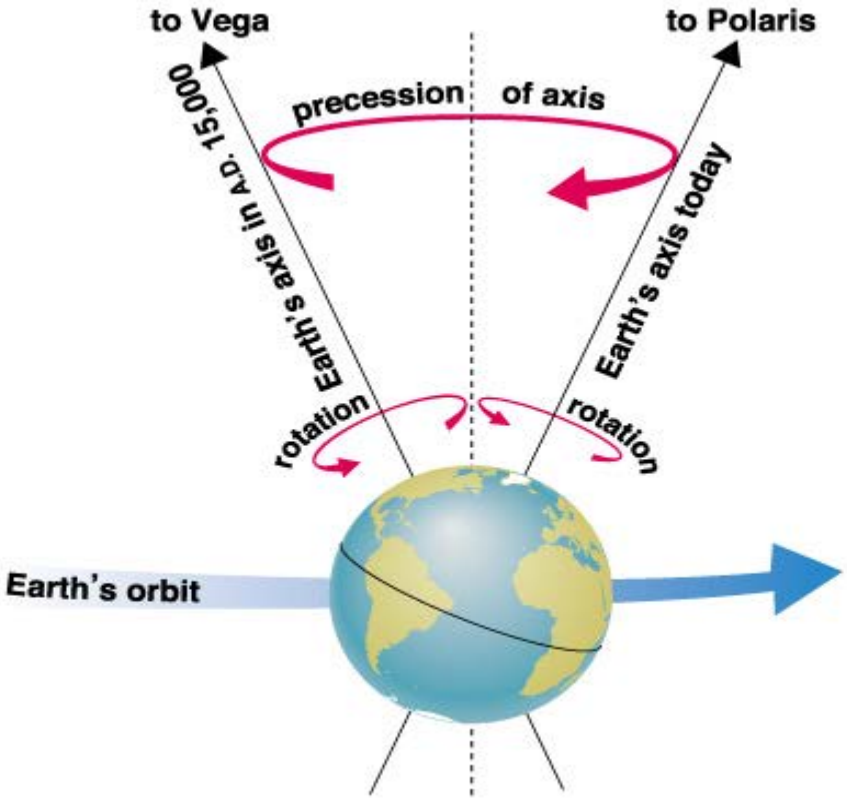


An aside:

The Earth's precesses (like a top) once per 26,000 yrs.

- The Celestial north pole moves in a circle over time.





2- Coordinates (on the Celestial Sphere)

A. The Earth spins on its axis (once per day)

We can define a coordinate system as on Earth:

NOT absolute (local to you).

- your zenith
- your horizon

Standing near the Earth's North pole

Standing near the Earth's equator

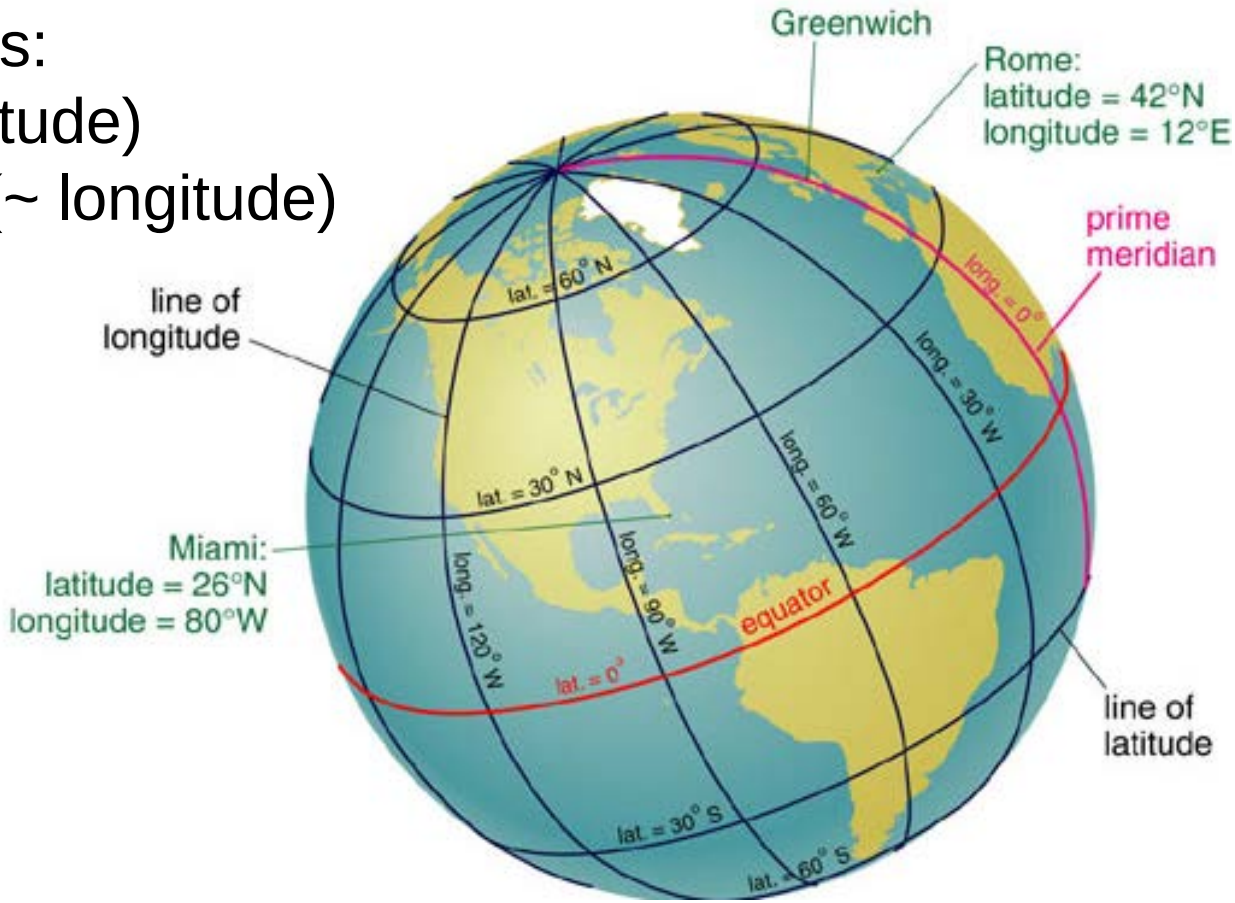
2- Coordinates (on the Celestial Sphere)

A. The Earth spins on its axis (once per day)

We can define a coordinate system as on Earth:

Absolute coordinates:

- Declination (~ latitude)
- Right Ascension (~ longitude)



2- Coordinates (on the Celestial Sphere)

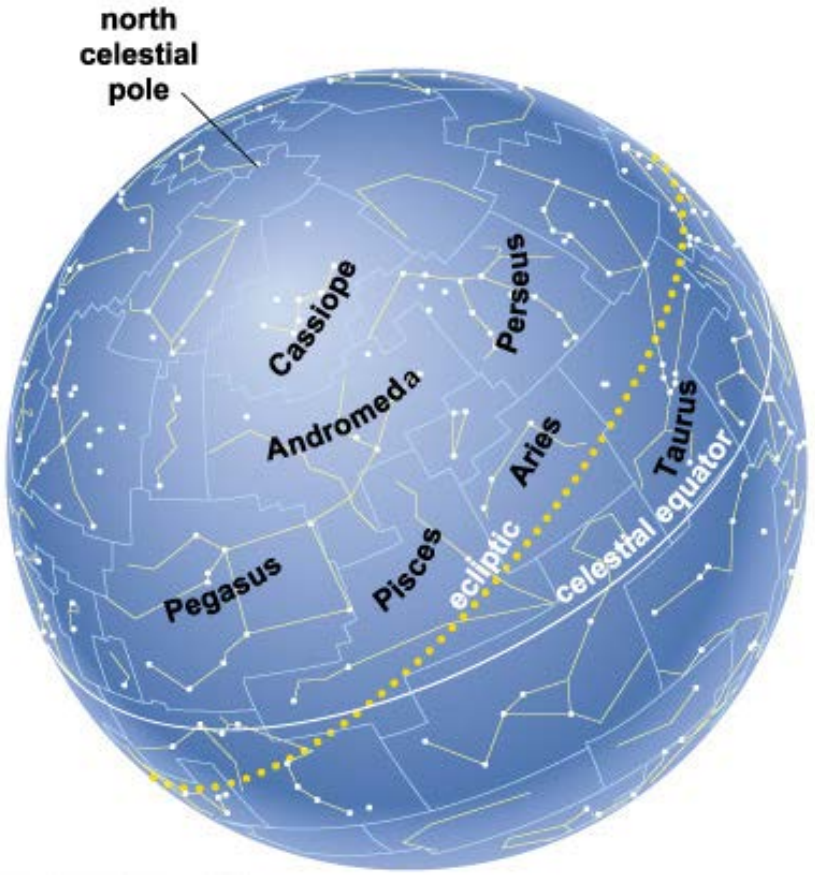
A. The Earth spins on its axis (once per day)

We can define a coordinate system as on Earth:

Absolute coordinates:
- Declination (~ latitude)
- Right Ascension (~ longitude)

Declination = –90 to 0 to 90
[pole – equator – pole]

Right Ascension = 0 – 360
[where is RA=0 ?]



2- Coordinates (on the Celestial Sphere)

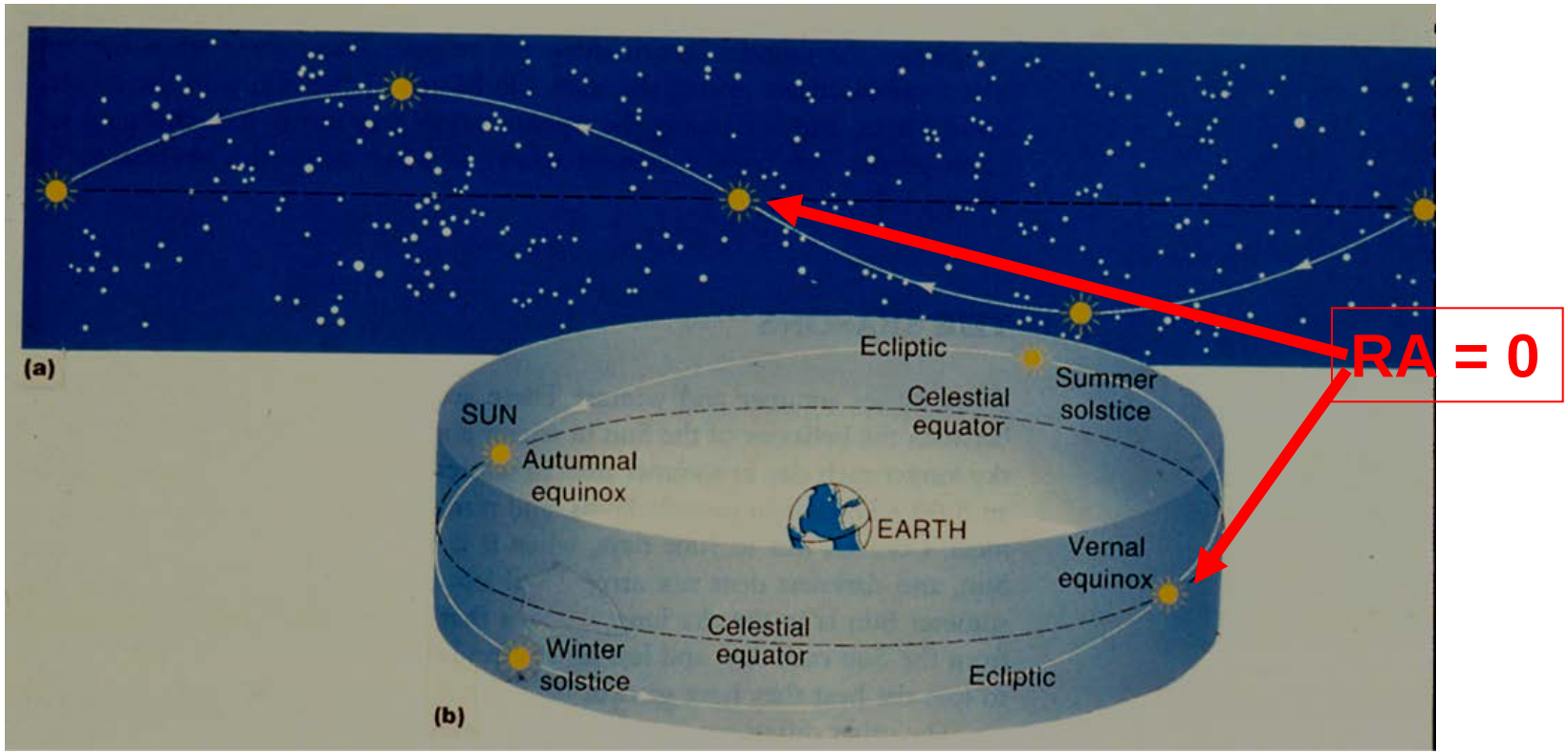
B. The Earth orbits the sun (once per year)

Half the sky is overhead during the day
… which half that is changes through the course of a year!

2- Coordinates (on the Celestial Sphere)

B. The Earth orbits the sun (once per year)

This makes a convenient way to define RA=0…

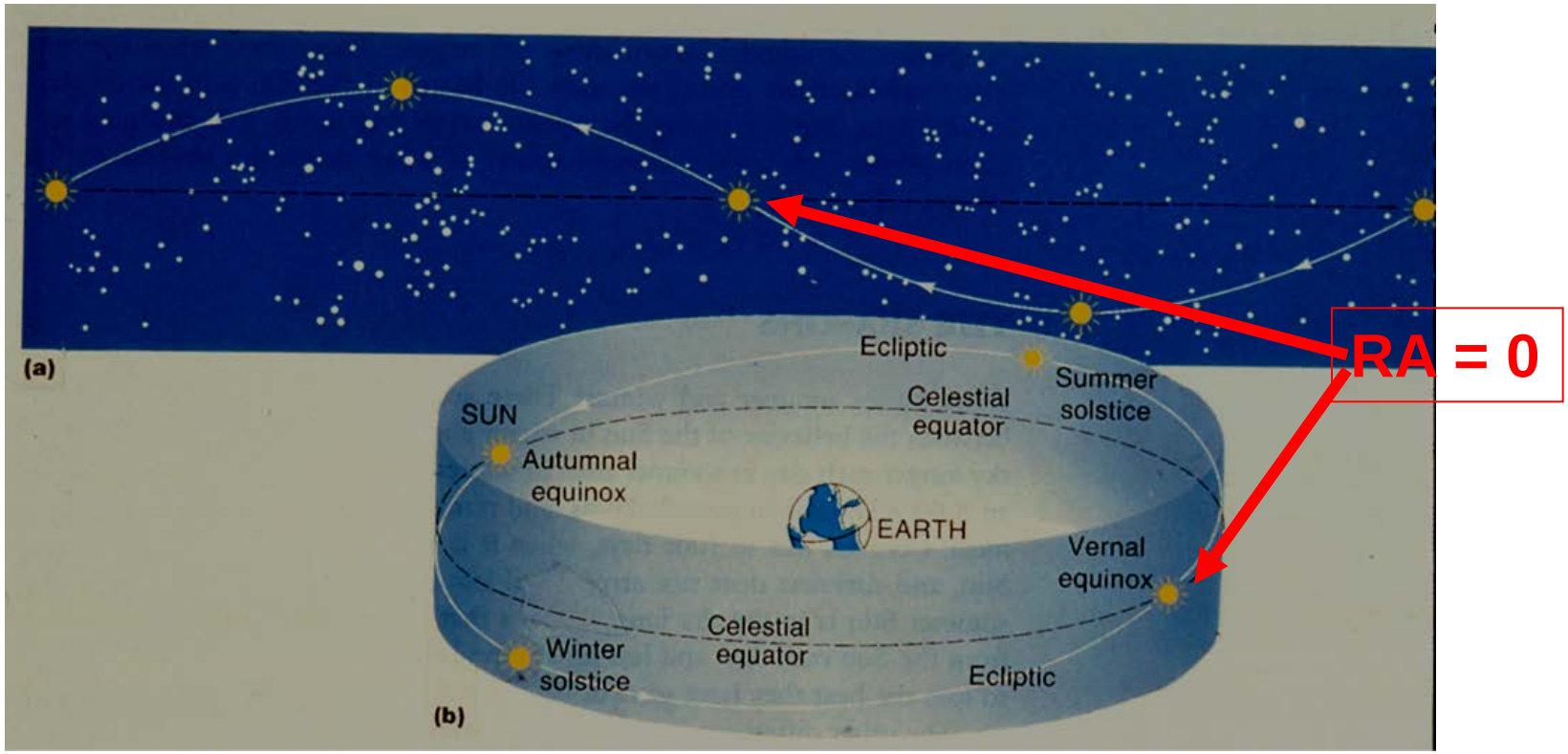


Ecliptic path = apparent path of sun through the stars.
Ecliptic plane = plane of the earth's motion (or the sun's apparent motion)

2- Coordinates (on the Celestial Sphere)

B. The Earth orbits the sun (once per year)

Let the sun mark the location of RA=0 deg on the Vernal equinox.

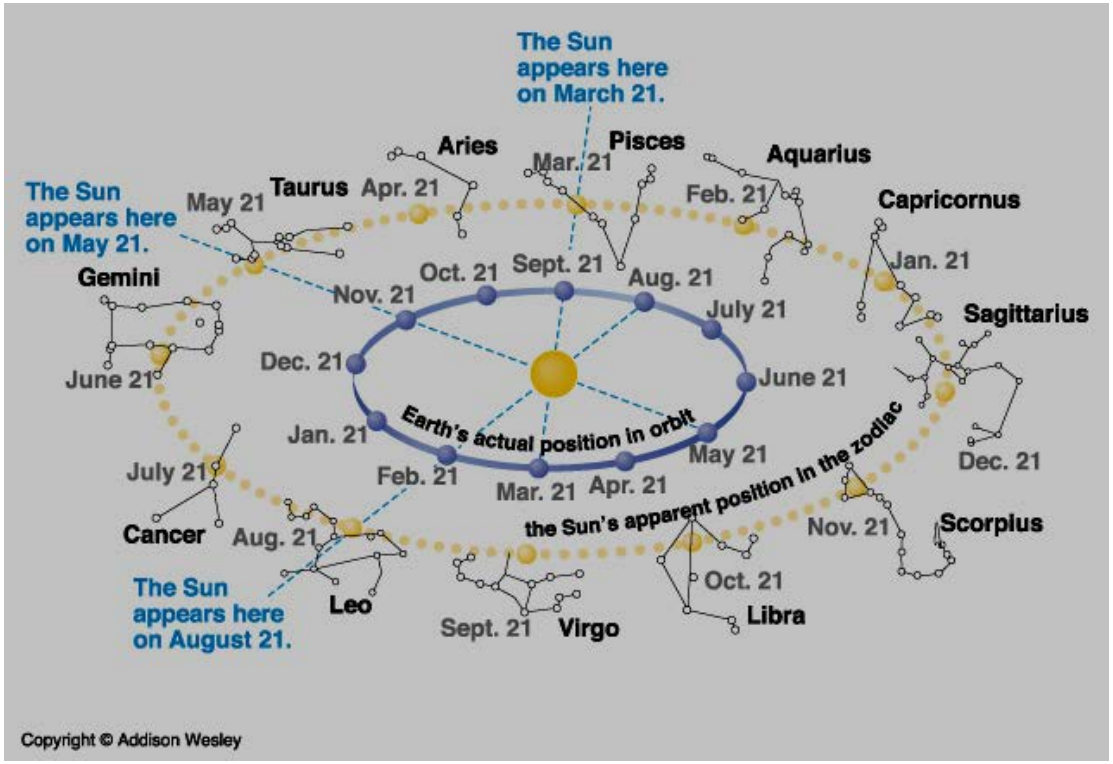


Stars at RA=0 can be seen in the fall.

2- Coordinates (on the Celestial Sphere)

B. The Earth orbits the sun (once per year)

Zodiac = constellations on the ecliptic plane

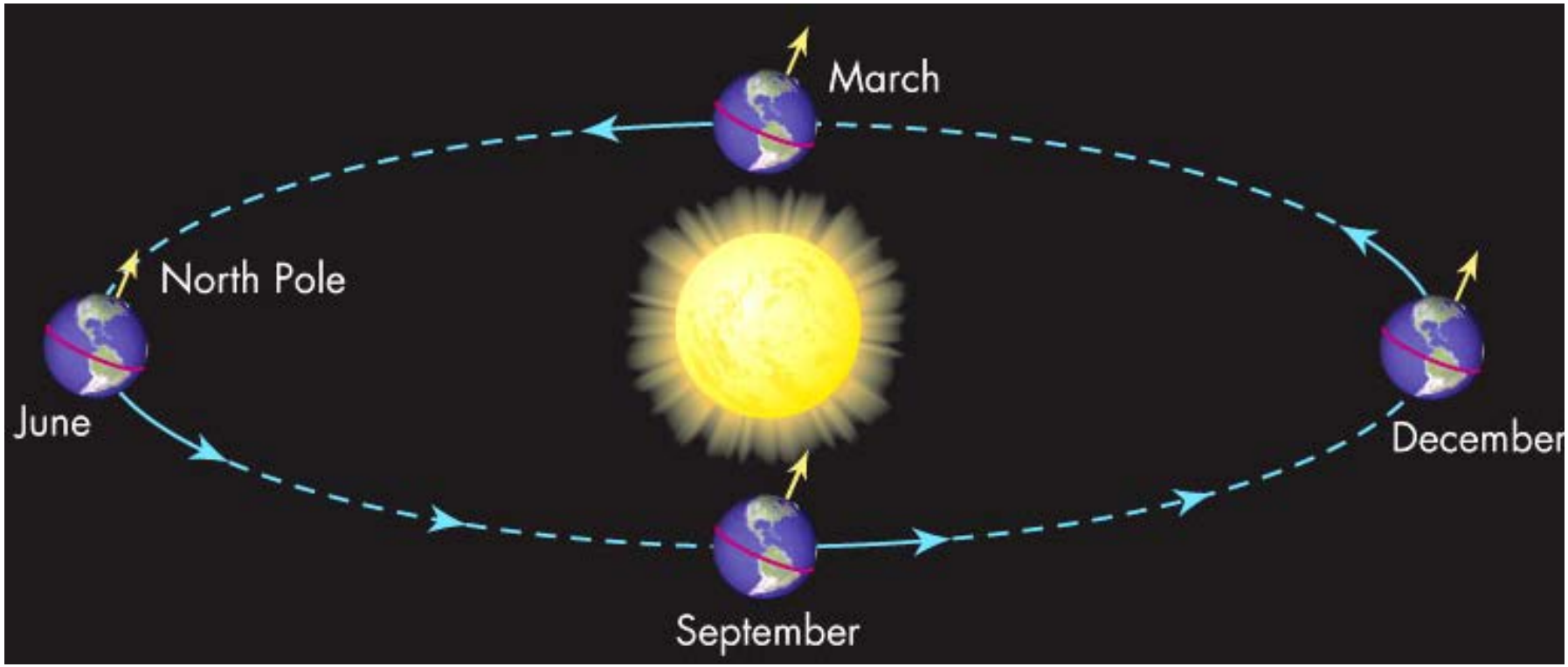


Defined in 100AD… constellations/dates are slightly off now. (Why?)

3- Seasons

B. The Earth orbits the sun (once per year) …on a tilt!

The Earth's spin-axis is tilted 23.5^{o}
relative to the plane of the orbit.☐

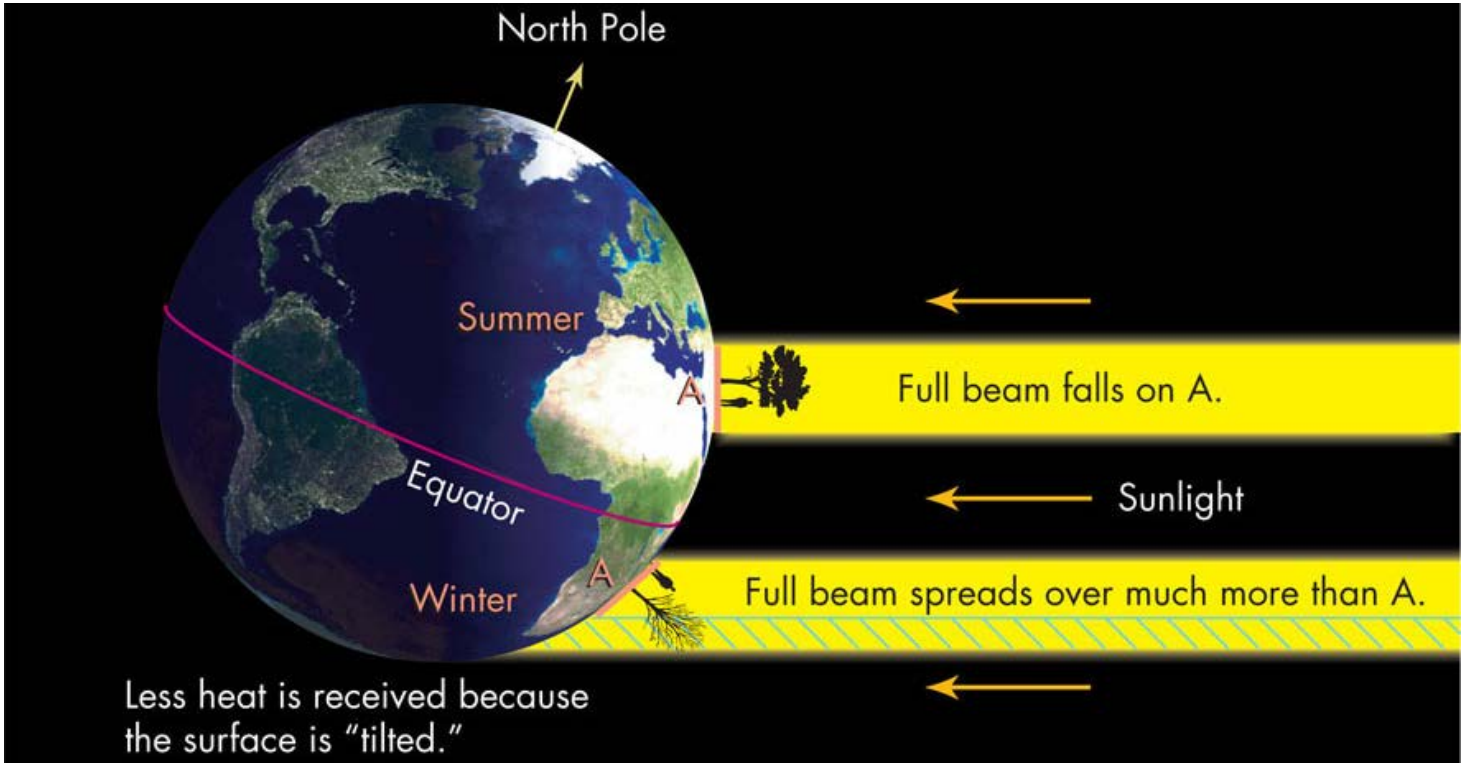


3- Seasons

B. The Earth orbits the sun (once per year) …on a tilt!

Heating depends on Energy per unit Area!

Experience confirms! (Sun feels hotter at 1pm than 5pm.
Shoulders/head gets sunburned first.)



3- Seasons

B. The Earth orbits the sun (once per year) …on a tilt!

Location of the sun at noon changes through the year

Photo taken every 10 days at noon. Records sun's highest point in sky through the year.

(Streaks are composite of photos taken every 2 minutes to show the sun ascending on 3 different days)

Which noontime location of the sun corresponds to:

- Summer Solstice?
- Winter Solstice?
- Spring equinox?
- Fall Equinox?

i>clicker quiz #1:

If I am standing at the north pole, which of the following is at the zenith?

A. The celestial equator
B. The moon
C. The nearby galaxy, M31
D. The north celestial pole
E. The Sun

Four i>clicker quizzes (#2–#5):

Santa Cruz is at about 36^{o} north Latitude and 122^{o} west longitude (about 8 hrs west of Greenwich, UK).

From here, can I see an object at the:

South Celestial Pole? A. Yes B. No
Celestial equator? A. Yes B. No
Moon? A. Yes B. No
North Celestial Pole? A. Yes B. No

4- TIME

A+B. The earth orbits and spins….which defines time?

which motion defines **time**?

Solar time: relative to sun

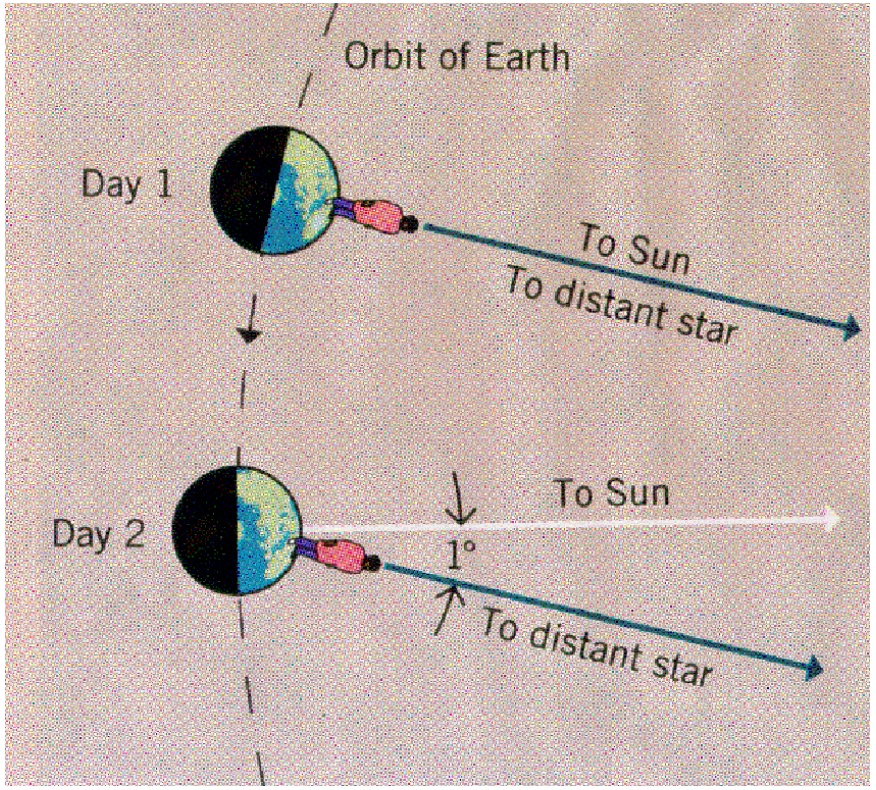
Solar day = 1 revolution

relative to the sun

Sidereal time: relative to stars

Sidereal day = 1 revolution

relative to the stars

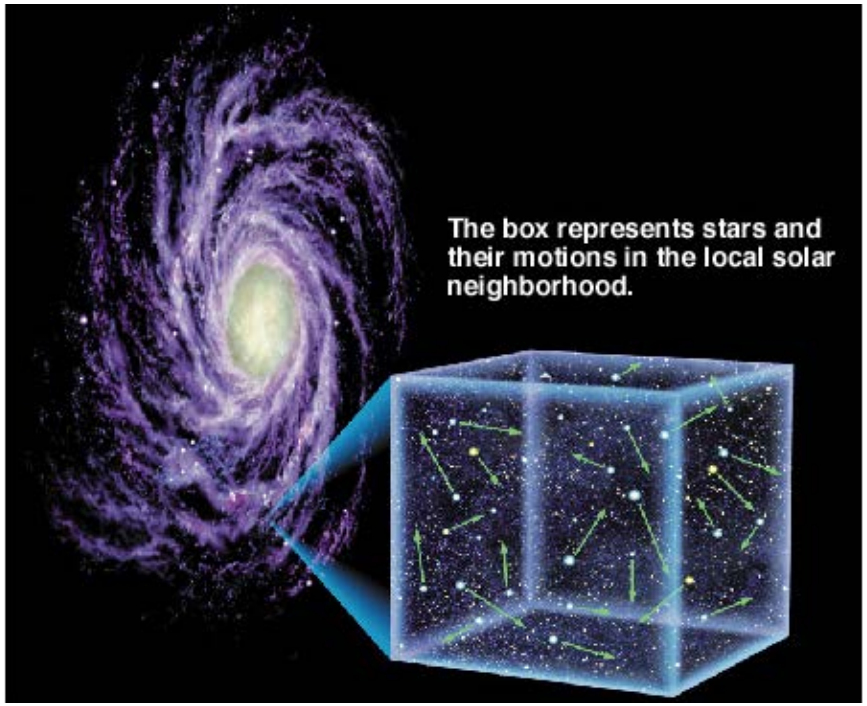


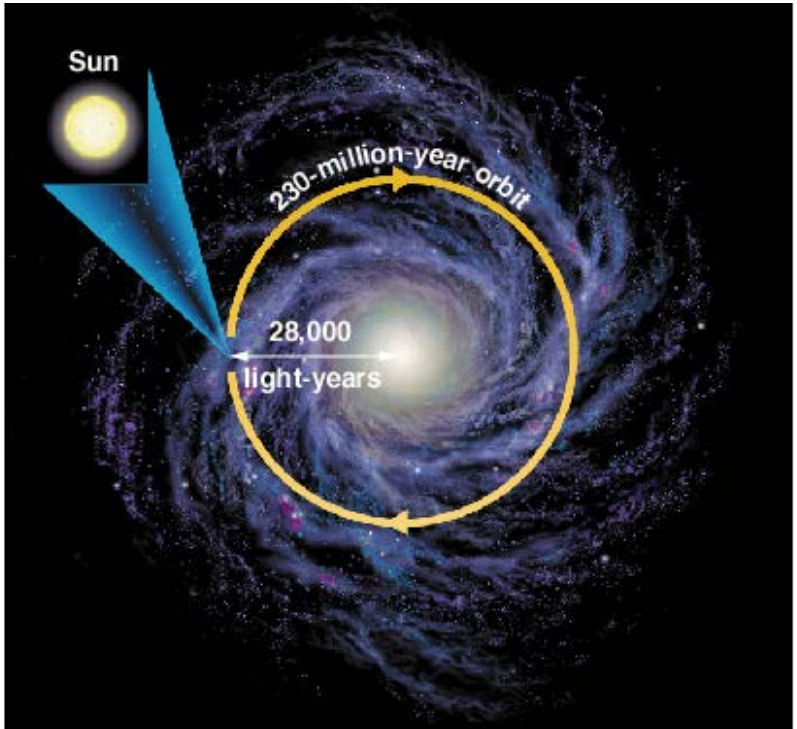
Two more ways we move through space…

3. The Sun orbits in the Milky Way

The sun (and nearby stars) orbit the center of the Milky Way once per 230,000,000 years.

How do we know? (motion of other stars in the Milky Way wrt the Sun; careful study of stellar positions over time)





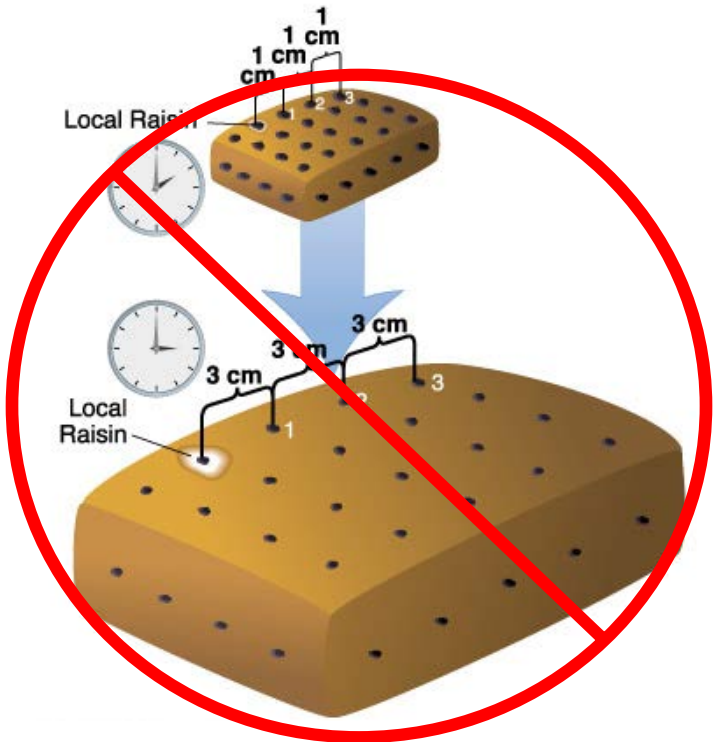
Two more ways we move through space…

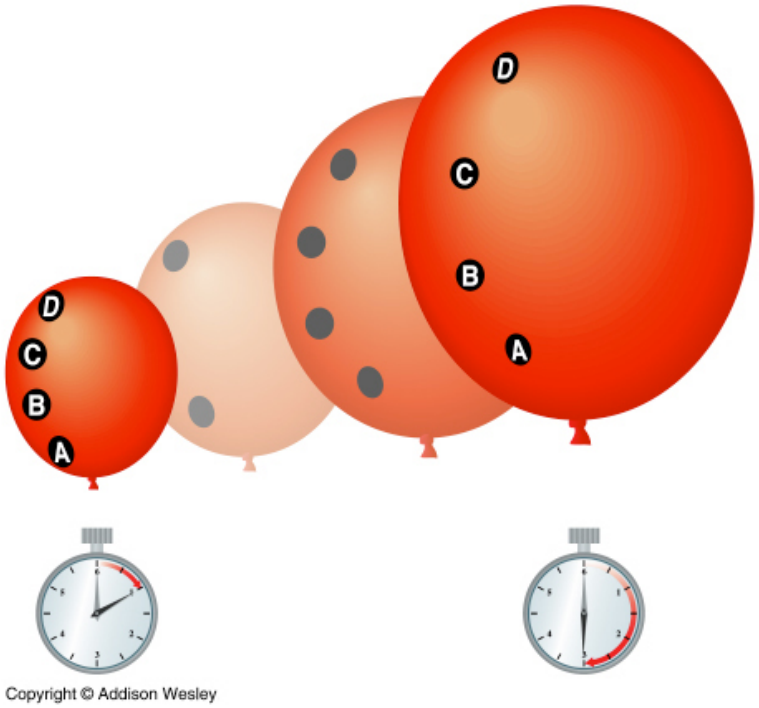
4. The Milky Way moves relative to the rest of the universe

Space itself is expanding (the space between things is increasing!)

No center. No edge.

Think of the surface of a balloon…only in 3D





Remember to ask: How do we know?

A. The Earth spins on its axis

… rather than the Sky spinning around the Earth?

First real proof that Earth spins:

1851, Foucault's pendulum

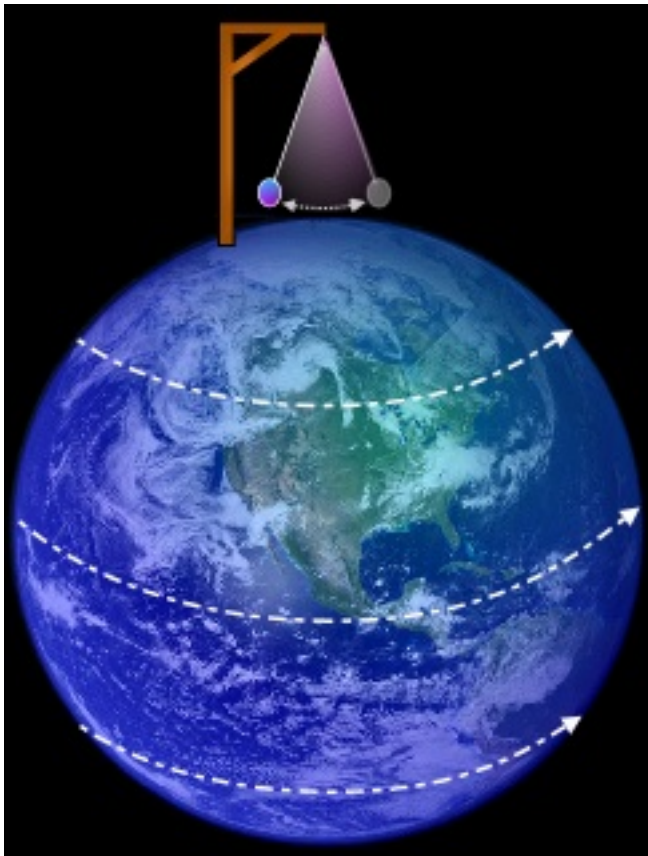
Imagine a pendulum at the North Pole.

The only force on it is gravity,

so it swings 1 plane forever.

The fact that it appears to spin

means the Earth moves under it!



Remember to ask: How do we know?

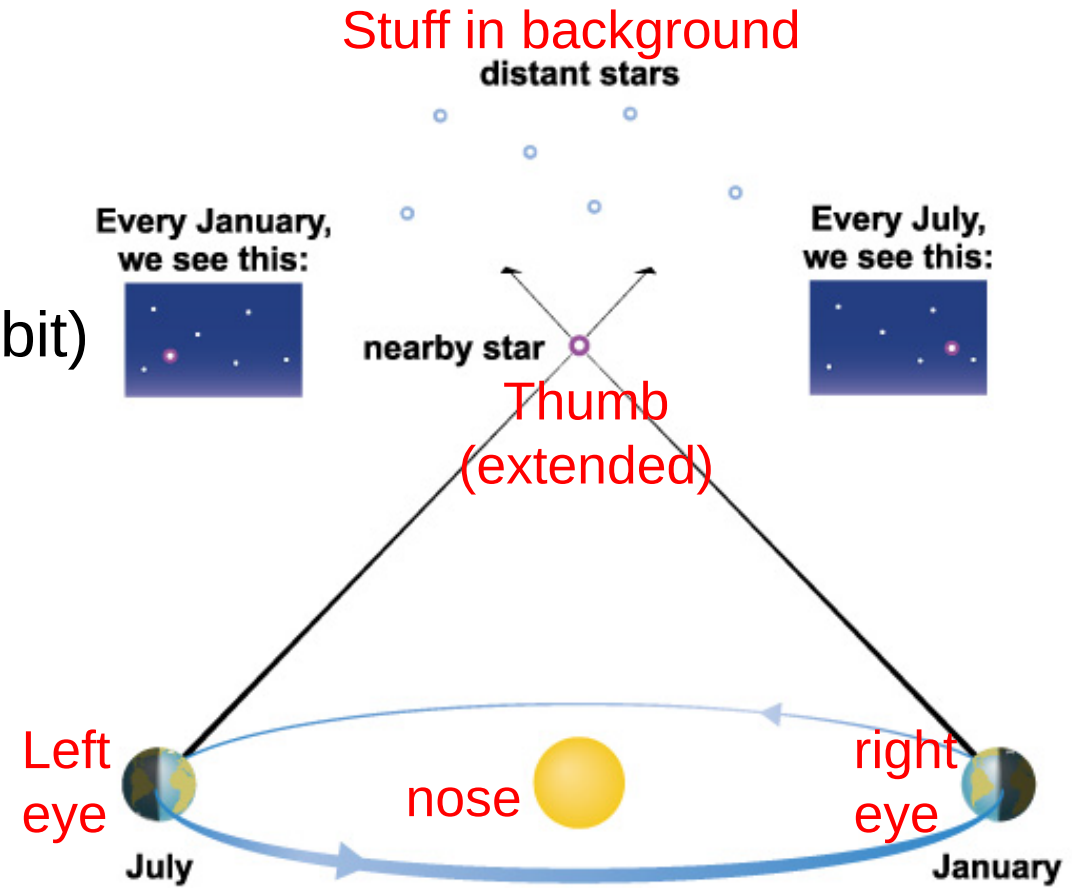
B. The Earth orbits the sun

… or does the Sun go around the Earth?

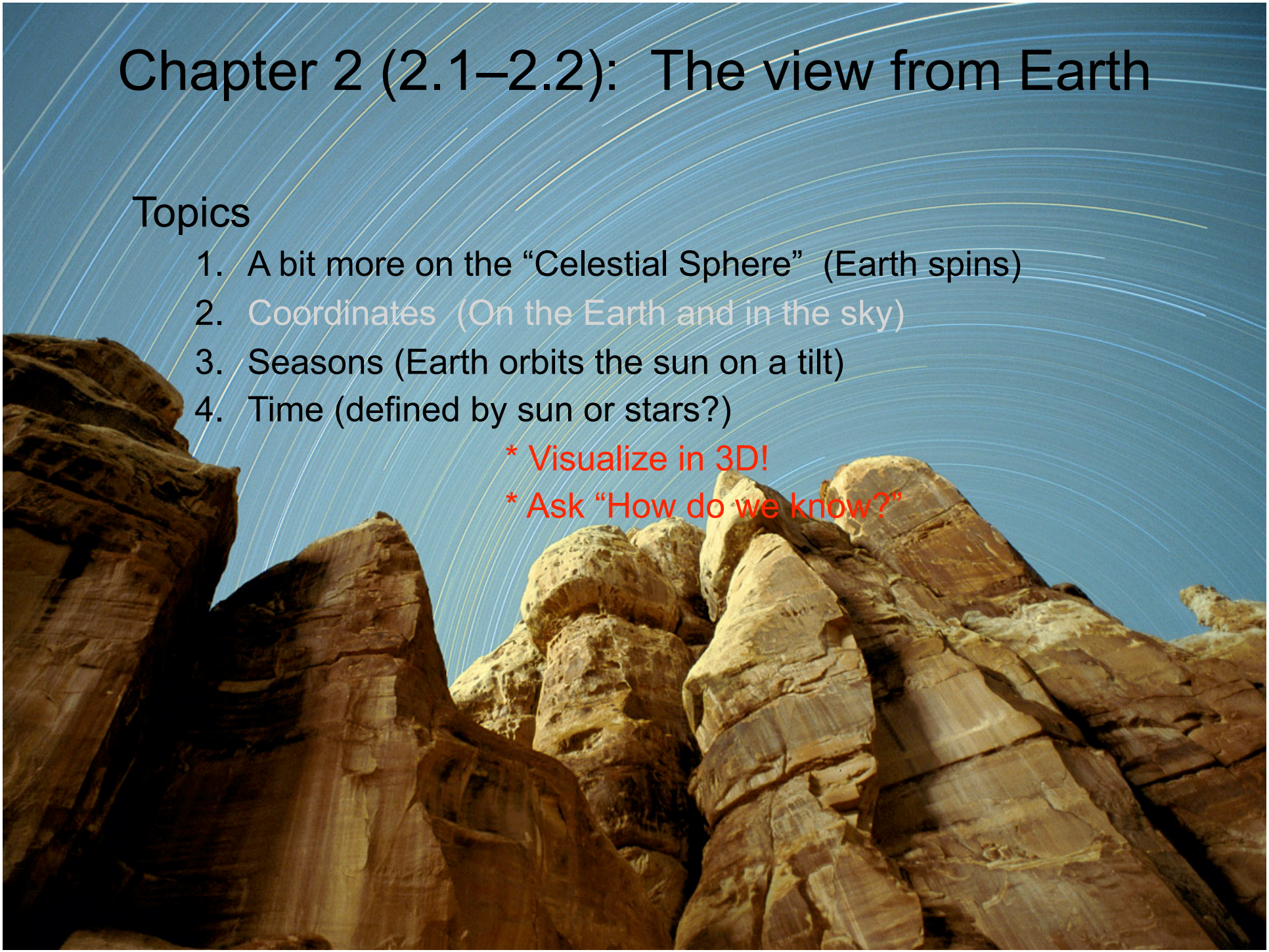
Stellar Parallax:

Earth (parallax+orbit) or
Sun (no parallax,only orbit)

(demo: wink. background still. thumb “moves.”)



Chapter 2 (2.1–2.2): The view from Earth



Topics

1. A bit more on the “Celestial Sphere” (Earth spins)
2. Coordinates (On the Earth and in the sky)
3. Seasons (Earth orbits the sun on a tilt)
4. Time (defined by sun or stars?)

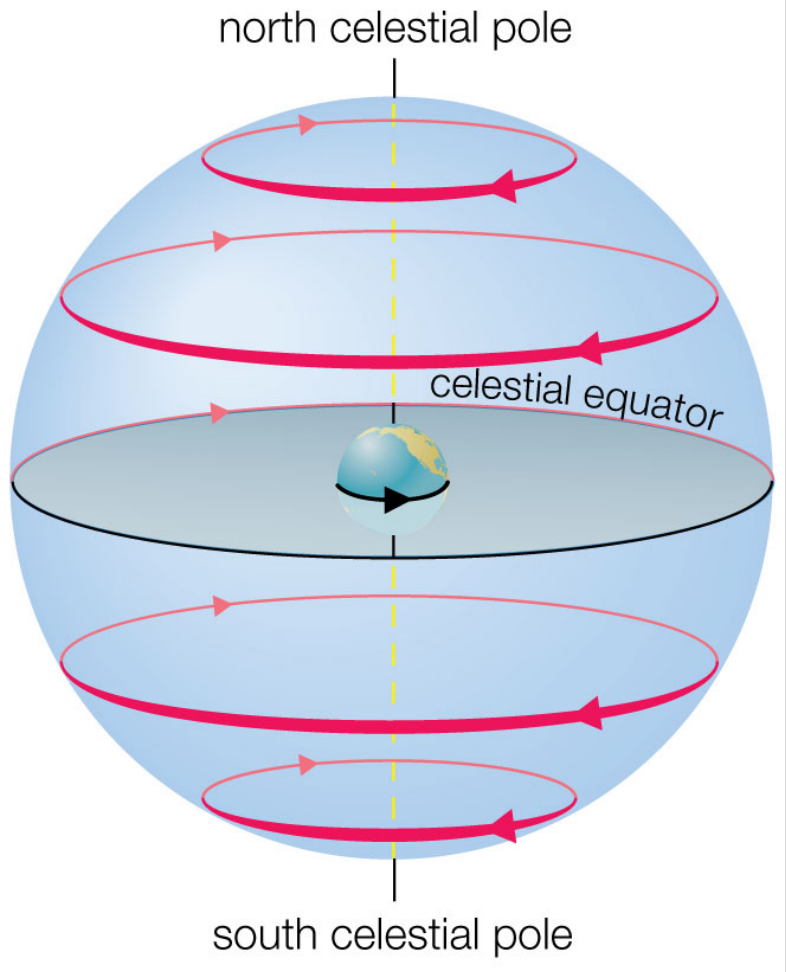
* Visualize in 3D!
* Ask “How do we know?”

Why do stars rise and set?

Earth rotates from west to east...

Celestial sphere appears to rotate from east to west

Objects in the sky appear to move from east to west



Each arrow represents the 24-hour motion of a star in the sky.

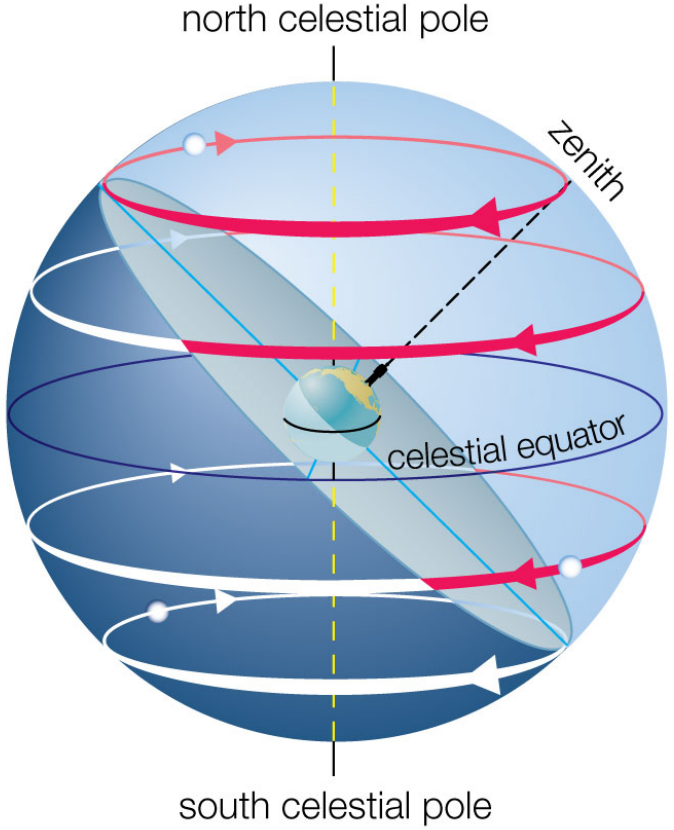
Why do stars rise and set?

The path of stars is more complicated in your local sky...

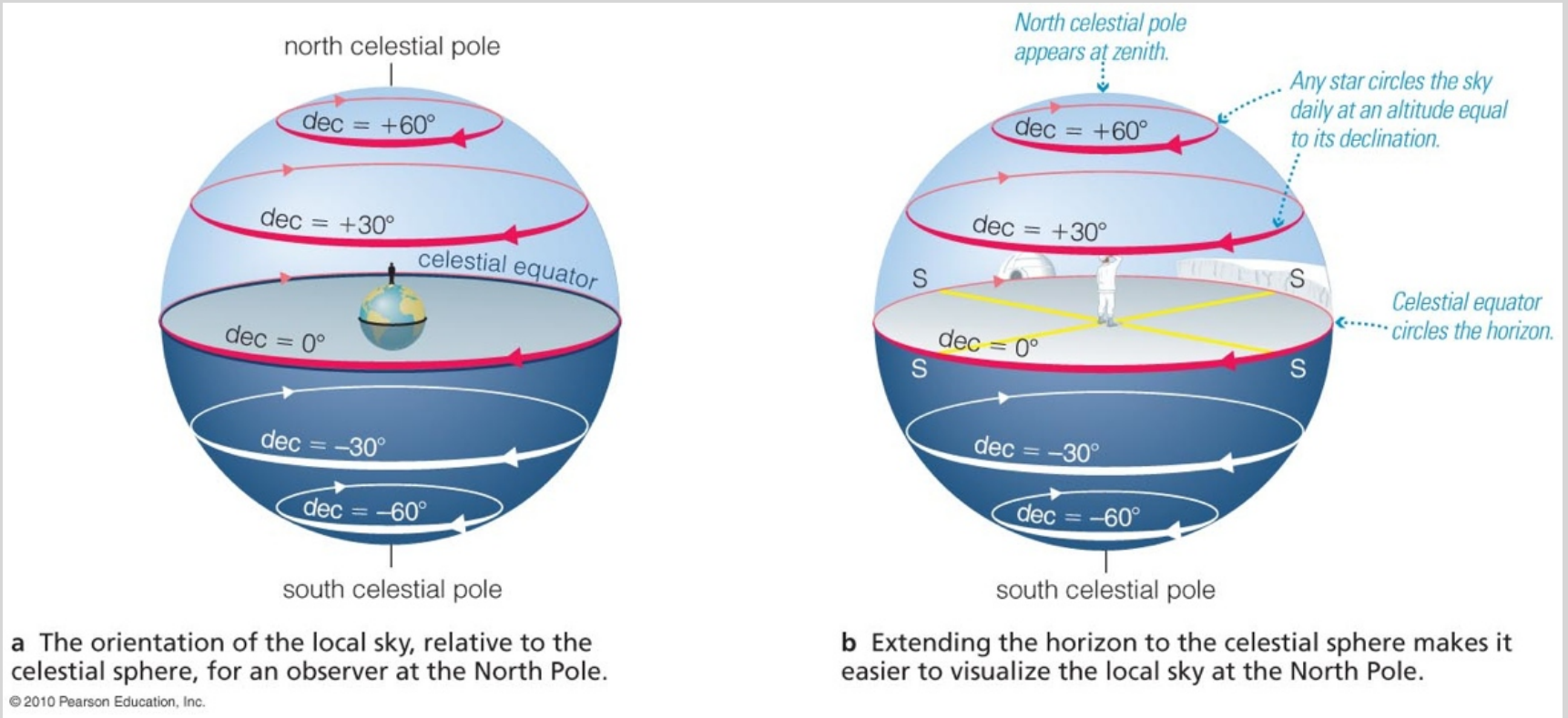
Some stars never rise or set (circumpolar stars)

Others never rise above the horizon

The rest rise in the east and set in the west



Your location determines what you can see in the sky.



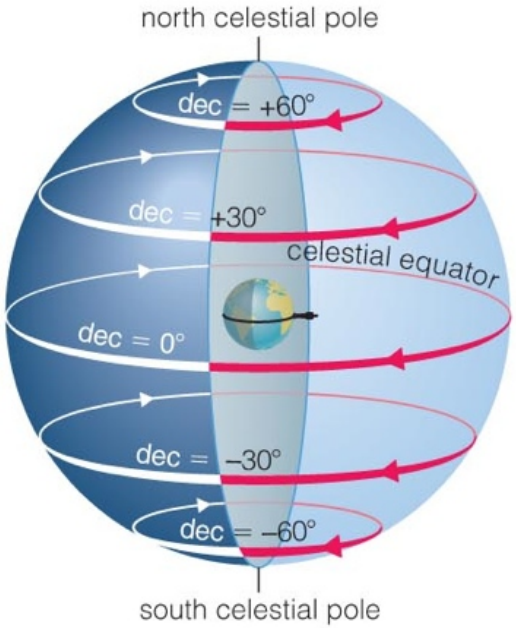
a The orientation of the local sky, relative to the celestial sphere, for an observer at the North Pole.

b Extending the horizon to the celestial sphere makes it easier to visualize the local sky at the North Pole.

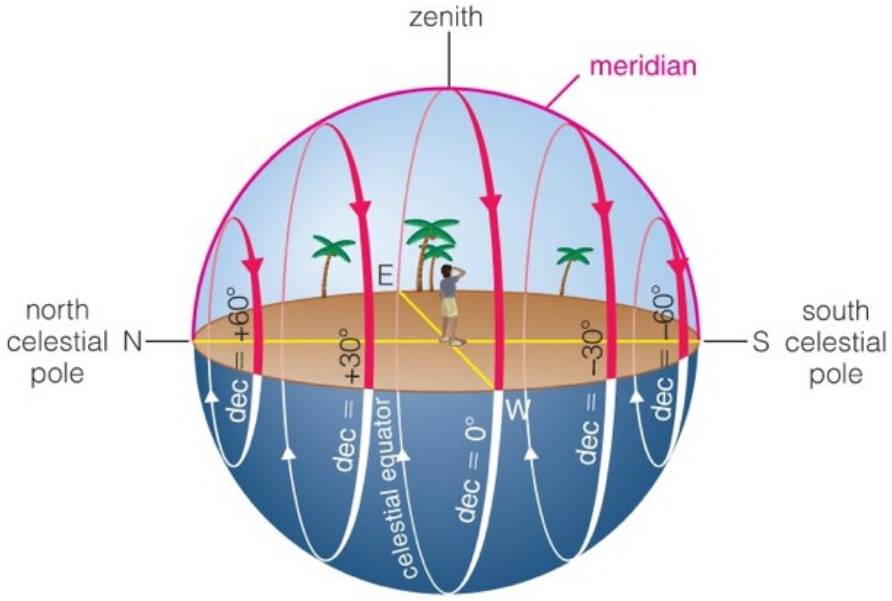
At the North Pole, stars go around in circles and never set.

What range of declinations are visible?

Your location determines what you can see in the sky.



a The orientation of the local sky, relative to the celestial sphere, for an observer at Earth's equator.

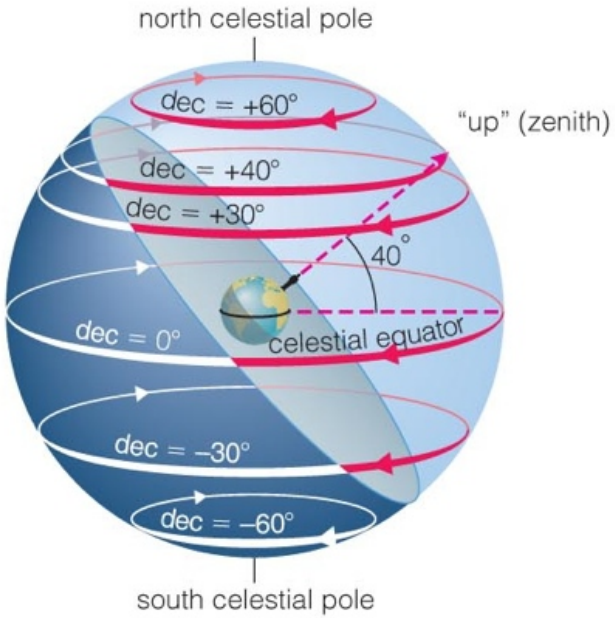


b Extending the horizon and rotating the diagram make it easier to visualize the local sky at the equator.

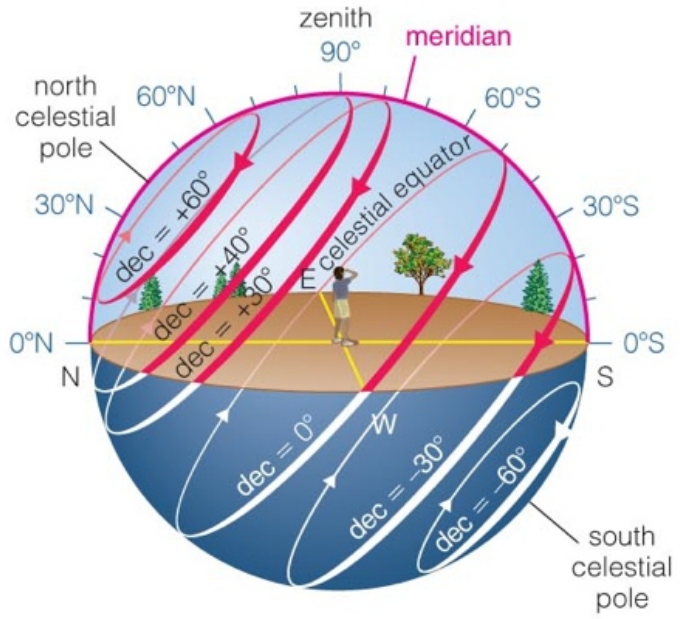
At the equator, all stars rise in the east and set in the west.

What range of declinations are visible?

Your location determines what you can see in the sky.



a The orientation of the local sky, relative to the celestial sphere, for an observer at latitude 40°N. Because latitude is the angle to Earth's equator, "up" points to the circle on the celestial sphere with declination +40°.



b Extending the horizon and rotating the diagram so the zenith is up make it easier to visualize the local sky. The blue scale along the meridian shows altitudes and directions in the local sky.

At 40 deg N, some stars never set, some never rise, the rest rise and set.

What range of declinations are visible?

“Clicker” question

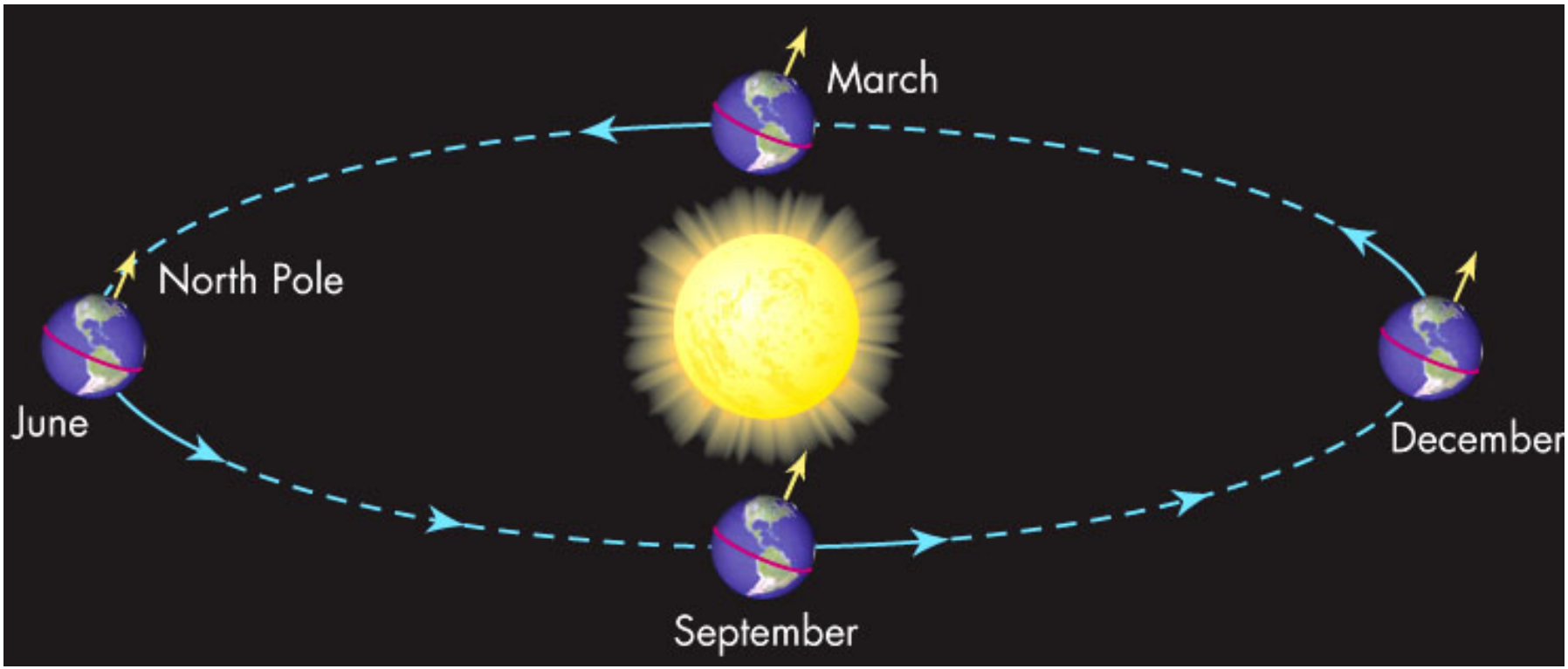
If I am standing at the north pole, which of the following is at the zenith?

A. The celestial equator
B. The moon
C. The nearby galaxy, M31
D. The north celestial pole
E. The Sun

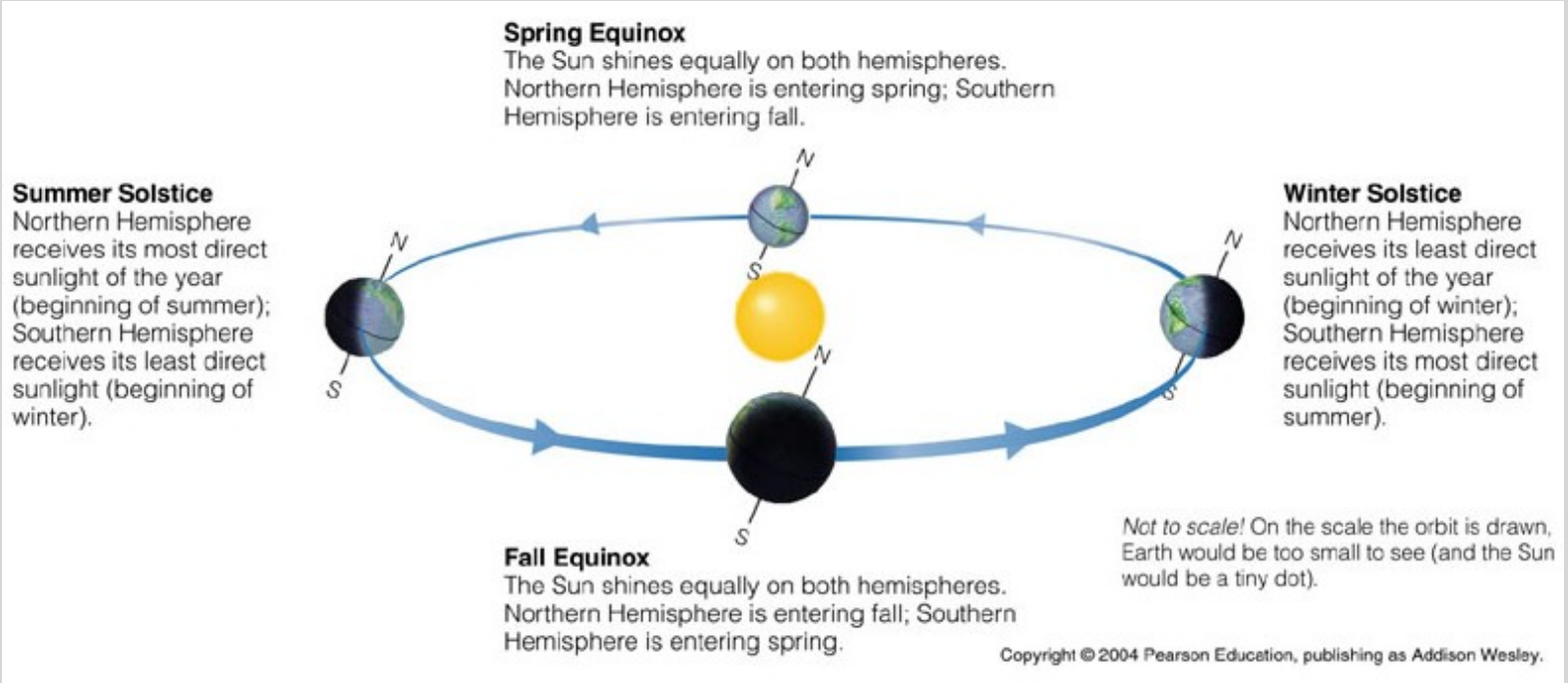
3- Seasons

B. The Earth orbits the sun (once per year) …on a tilt!

The Earth's spin-axis is tilted 23.5^{o}
relative to the plane of the orbit.



The seasons are caused by the tilt of the Earth's axis.



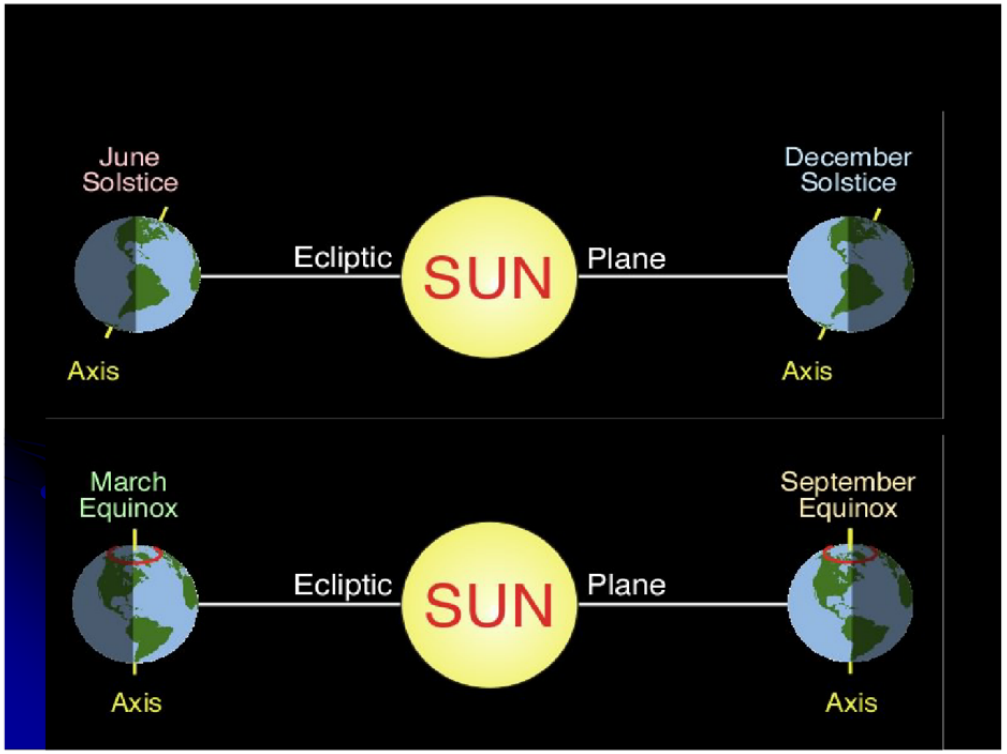
Earth's axis is tilted by 23.5° with respect to the ecliptic.

We mark the changing seasons with 4 specific moments in time.

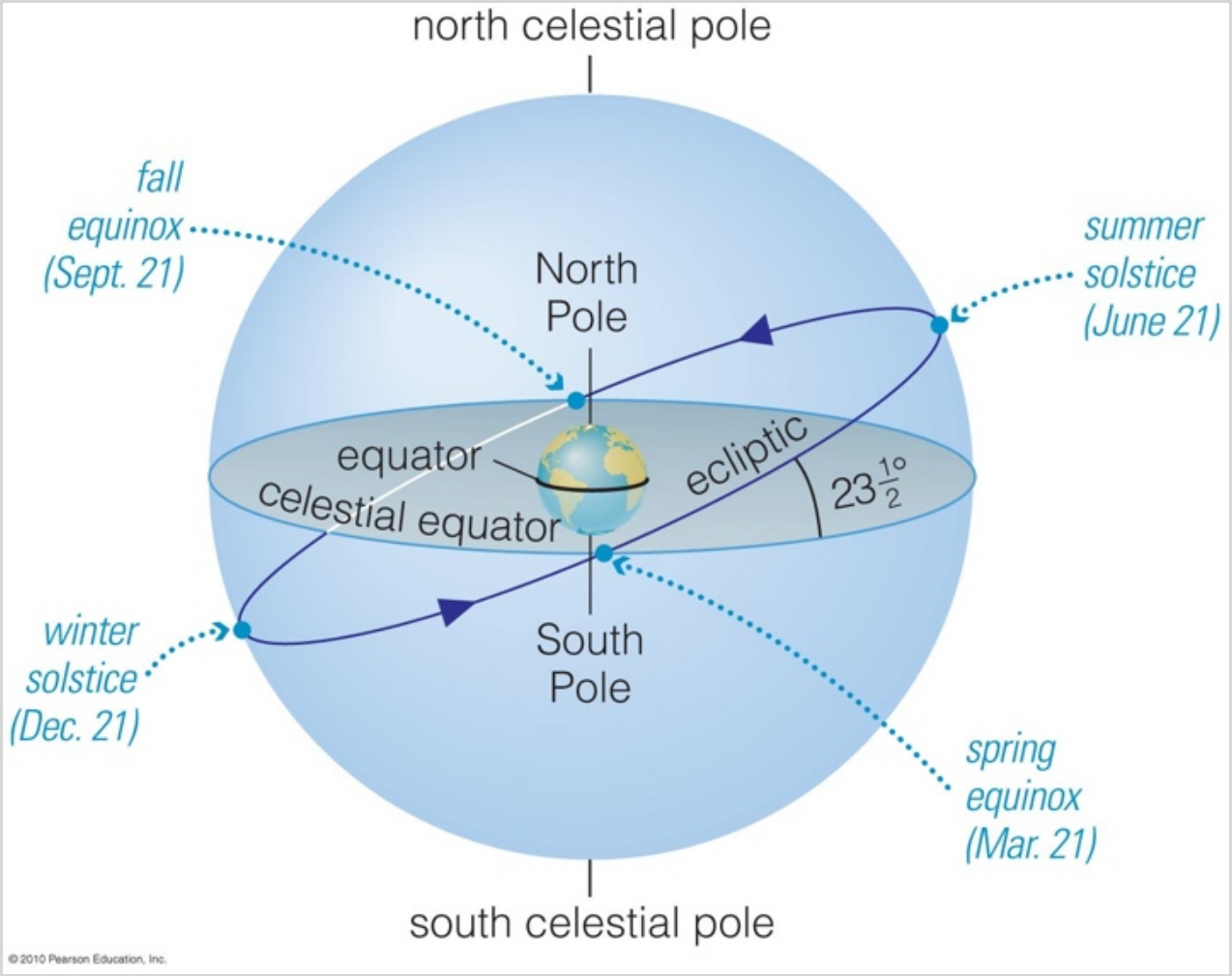
Spring equinox* (March 21)
Summer solstice (June 21)
Fall equinox (Sept 21)
Winter solstice (Dec 21)

Each day corresponds to the beginning of the season.

* = AKA "vernal equinox"



Solstices and equinoxes are both locations in space and moments in time.



The tilt causes opposite seasons in the northern and southern hemispheres.

Summer in N hemisphere

Winter in N hemisphere

Winter in S hemisphere

Summer in S hemisphere

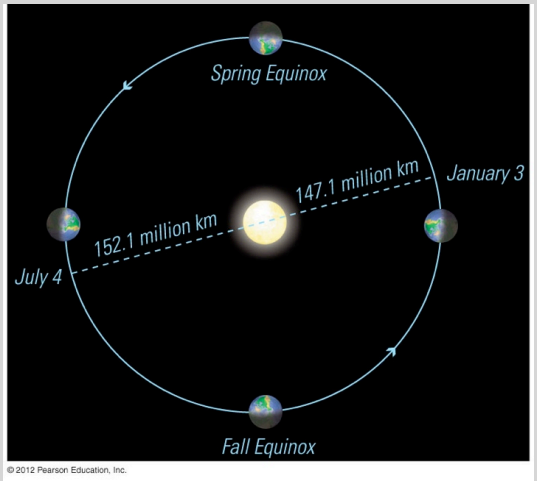
On which day does each begin?

The seasons are NOT due to Earth's distance from the Sun.

If distance were the reason, then the whole Earth would experience the same season at the same time.

While it's true that e.g., N hemisphere is tilted toward the Sun in summer, this little bit of distance has NO EFFECT on the seasons.

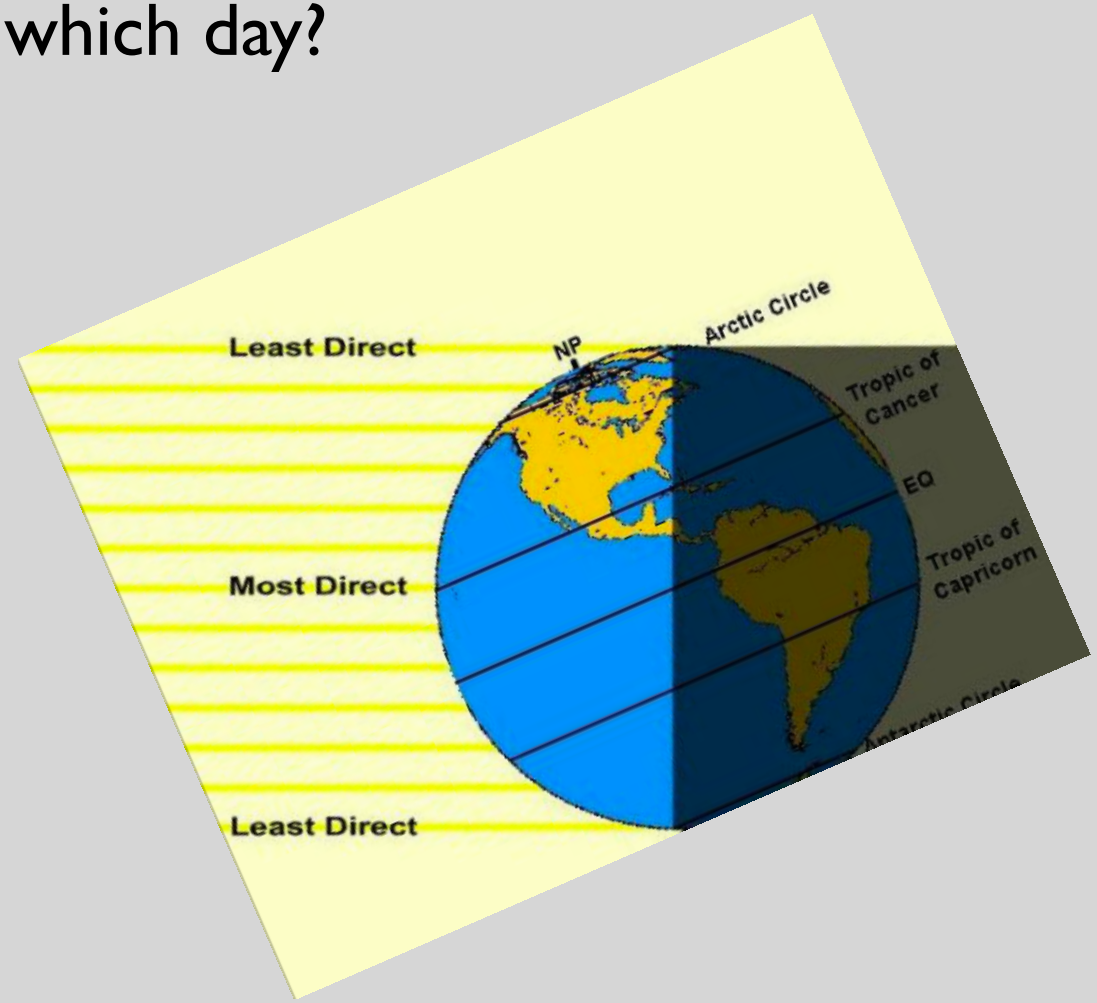
Why? Earth is tiny compared to its distance from the Sun. (A few thousand km closer to Sun is nothing since Earth is 150 million km away!)



"Clicker" Question

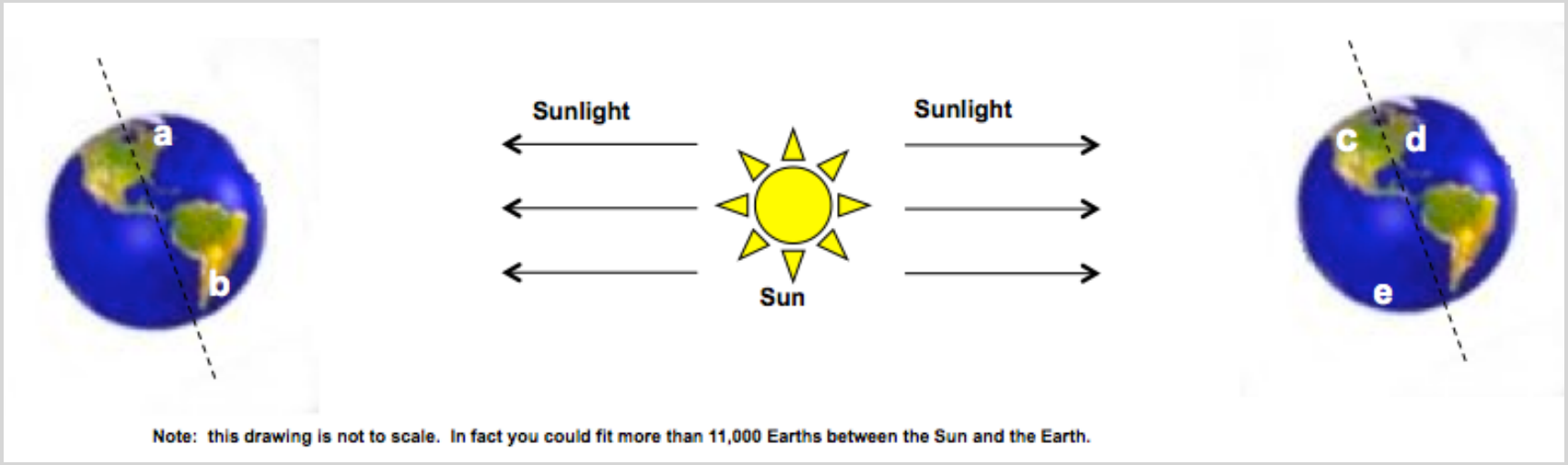
The image shows the Earth being hit by the Sun's rays on which day?

A. June 21
B. September 21
C. December 21
D. March 21



"Clicker" Question

Looking at the images below, which letter (a-e) best represents winter in the United States?

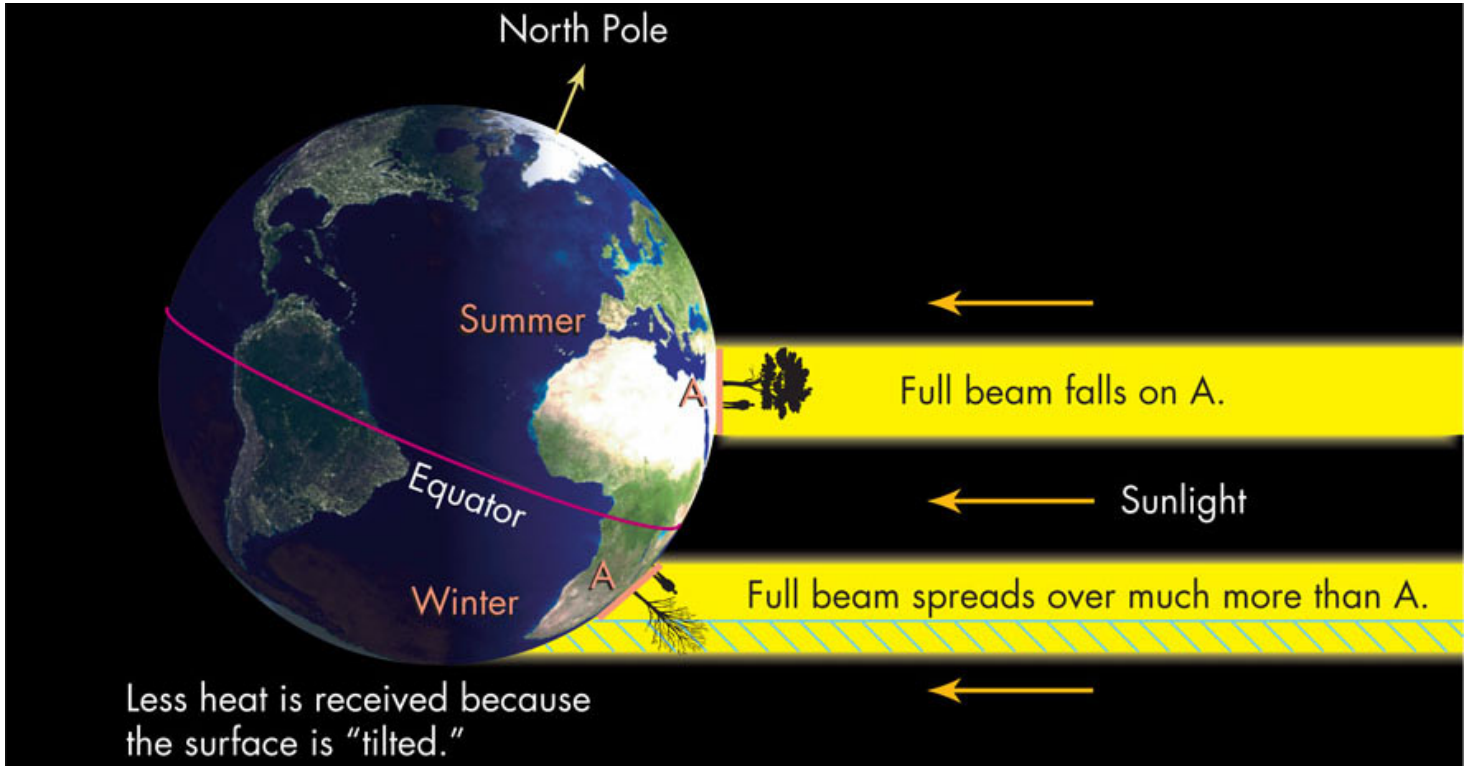


3- Seasons

B. The Earth orbits the sun (once per year) …on a tilt!

Heating depends on Energy per unit Area!

Experience confirms! (Sun feels hotter at 1pm than 5pm.
Shoulders/head gets sunburned first.)

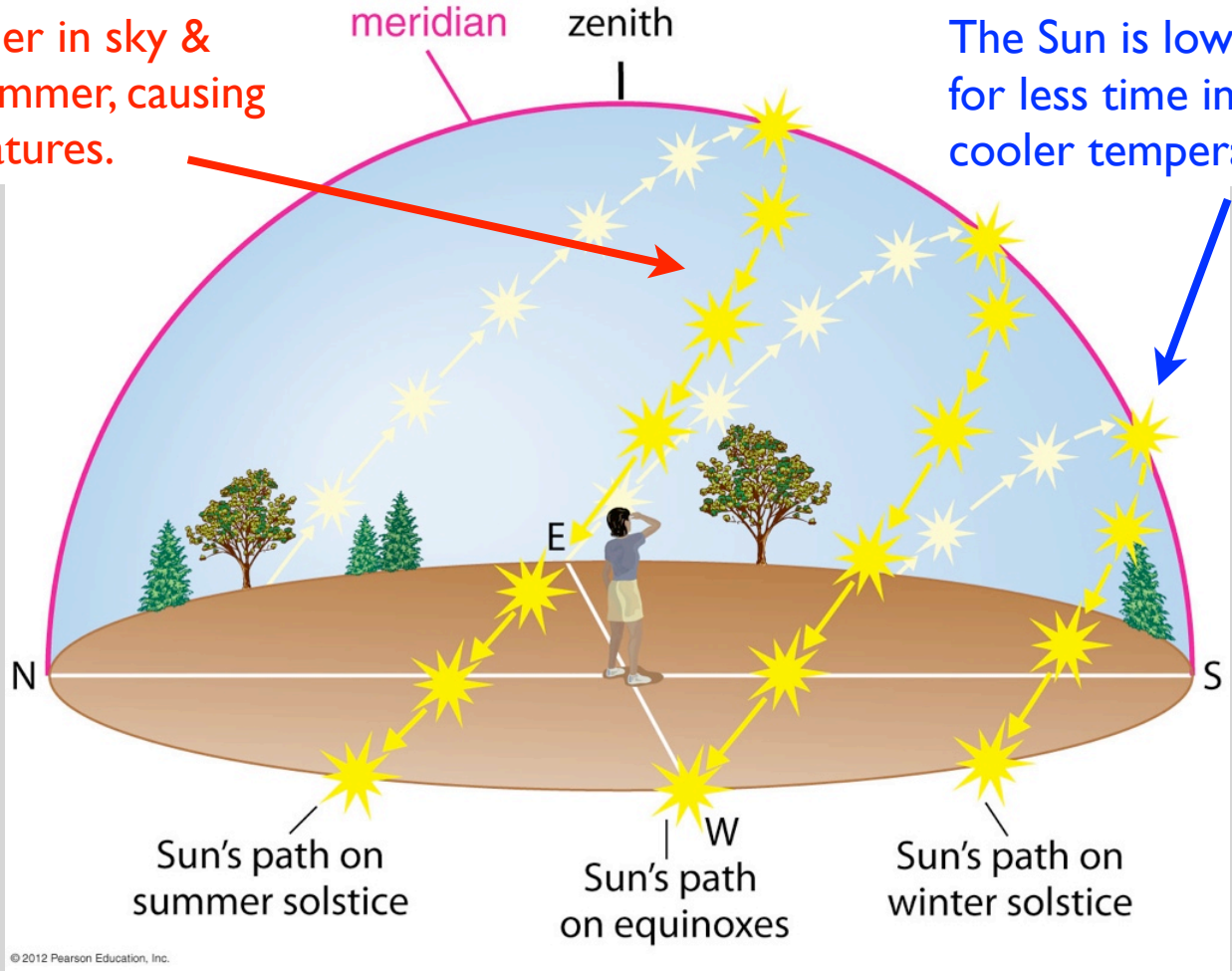


Why does the Earth's tilt cause the seasons?

1. It affects how long and how high the Sun is in the sky.

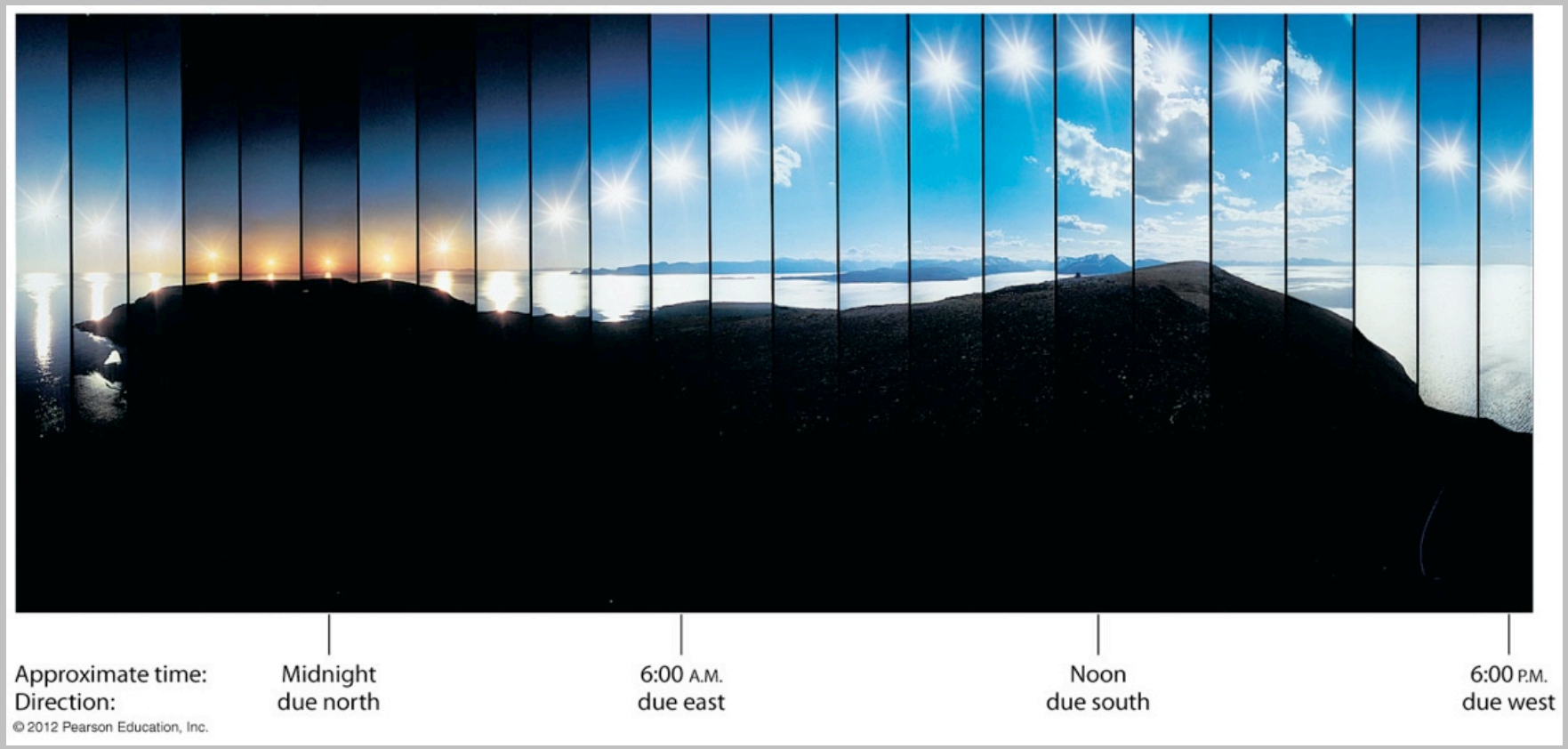
The Sun is higher in sky & up longer in summer, causing higher temperatures.

The Sun is lower in sky & up for less time in winter, causing cooler temperatures.



Both pictures are taken in the northern hemisphere. On which days?

The path of the Sun at the Arctic Circle on the summer solstice



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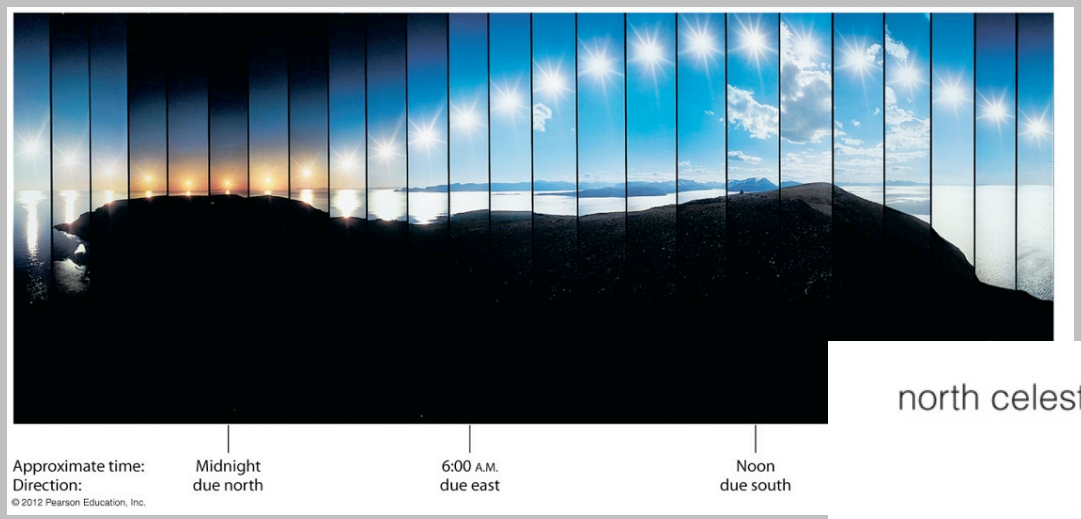
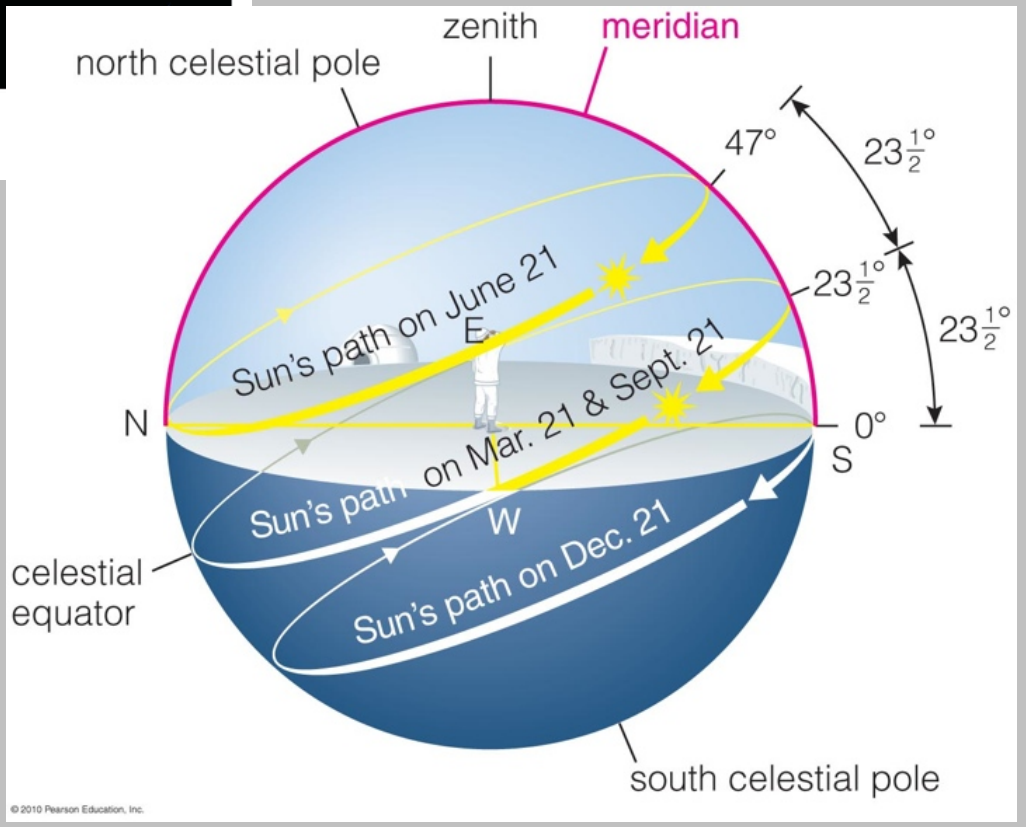
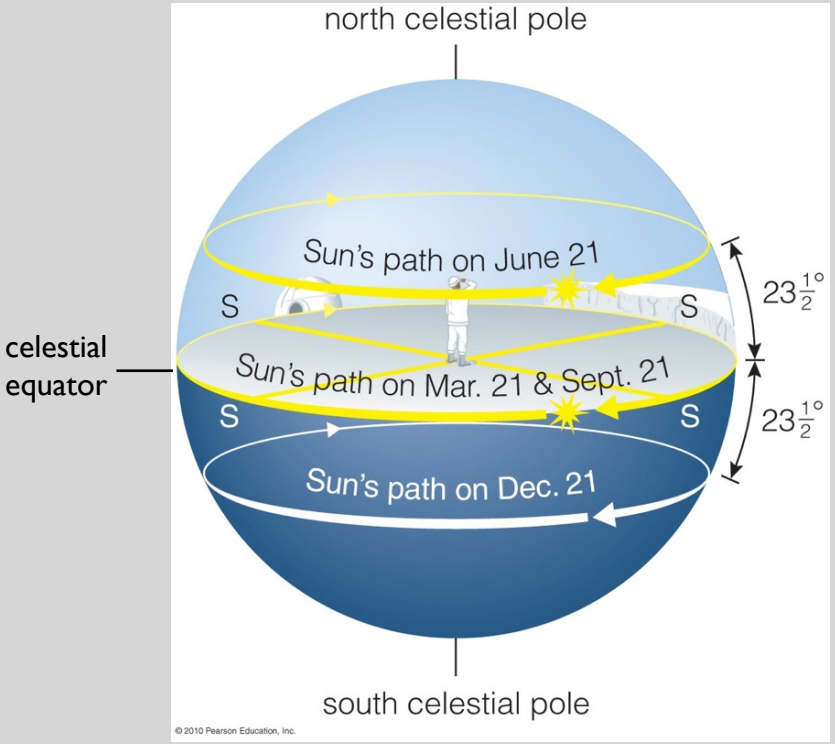
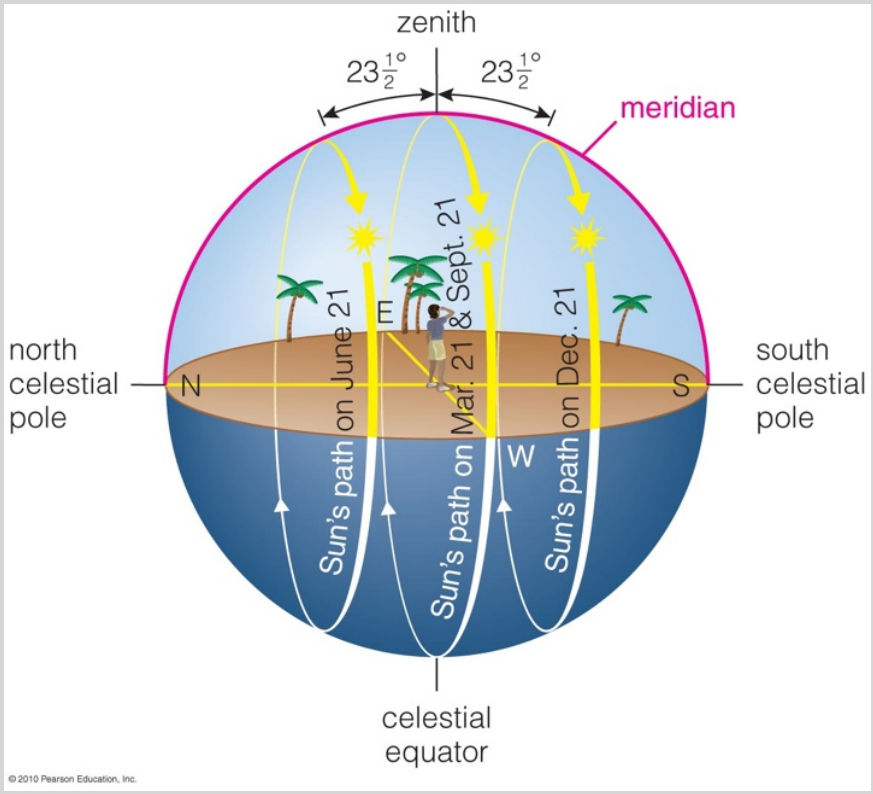




Latitude of Arctic Circle = 66.5 degrees N

The path of the Sun at various locations on Earth



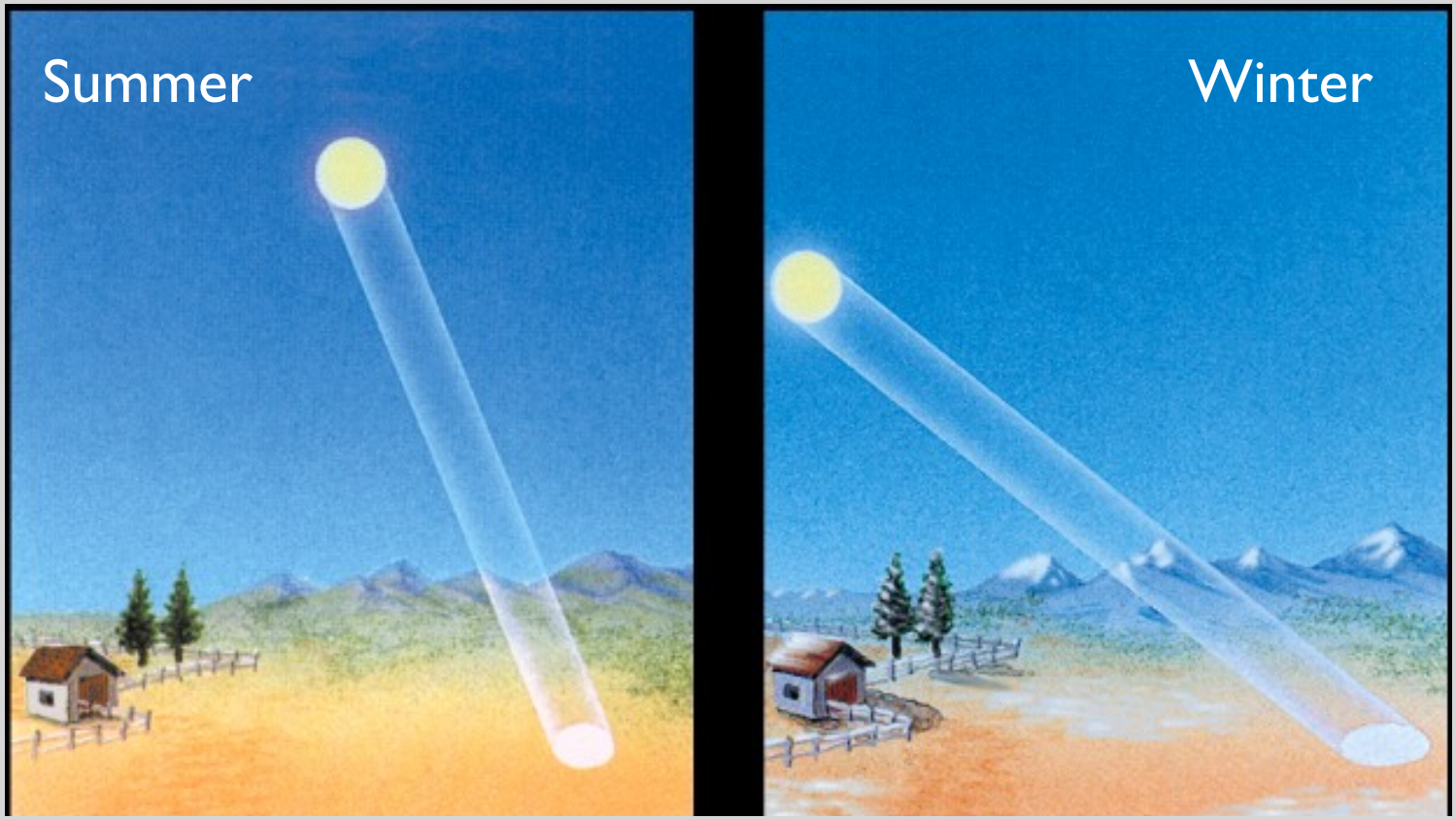


Over one year, what is the path of the Sun in the sky?

Why does the Earth's tilt cause the seasons?

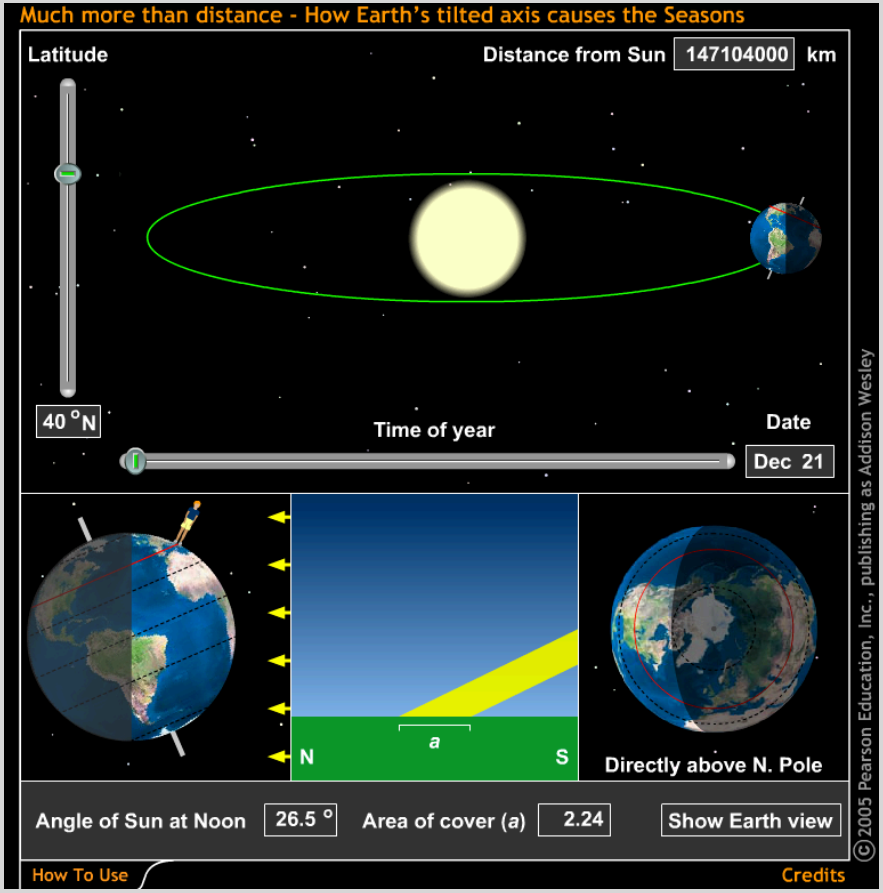
2. It affects how "concentrated" the sunlight we receive is.

The more concentrated the sunlight, the warmer it is.
The more spread out, the cooler it is.



Putting it all together...

Seasons simulation

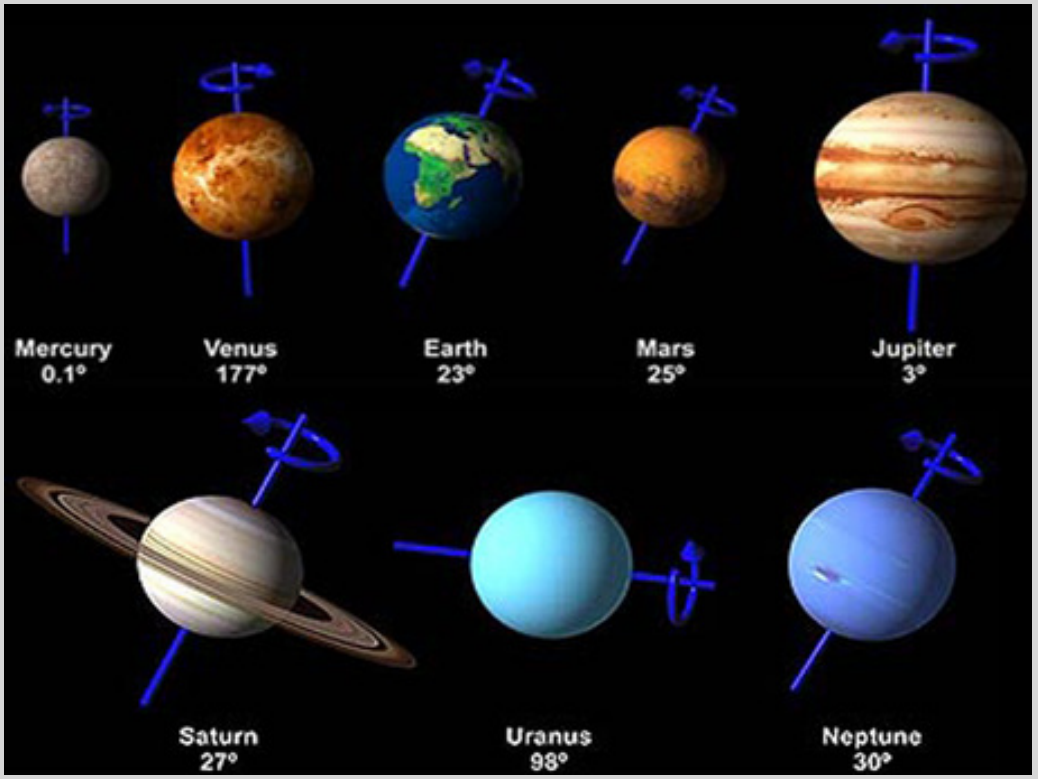


What about seasons on other planets?

Which planets would have more extreme seasons than Earth?

Similar seasons?

No seasons?



4- TIME

A+B. The earth orbits and spins….which defines time?

which motion defines **<u>time</u>**?

Solar time: relative to sun

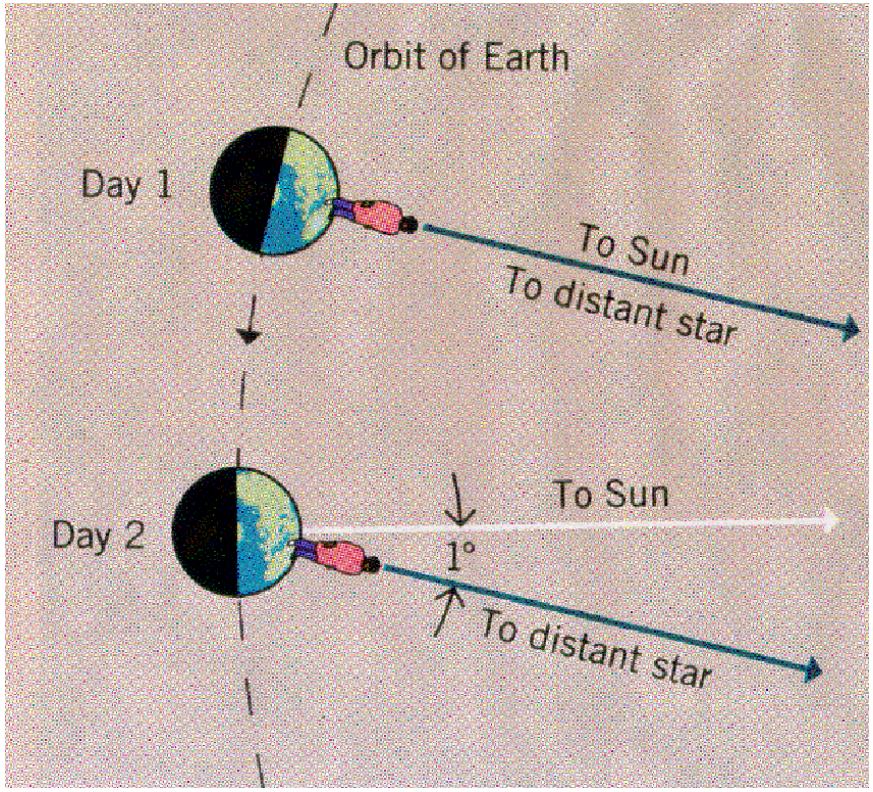
Solar day = 1 revolution

relative to the <u>sun</u>

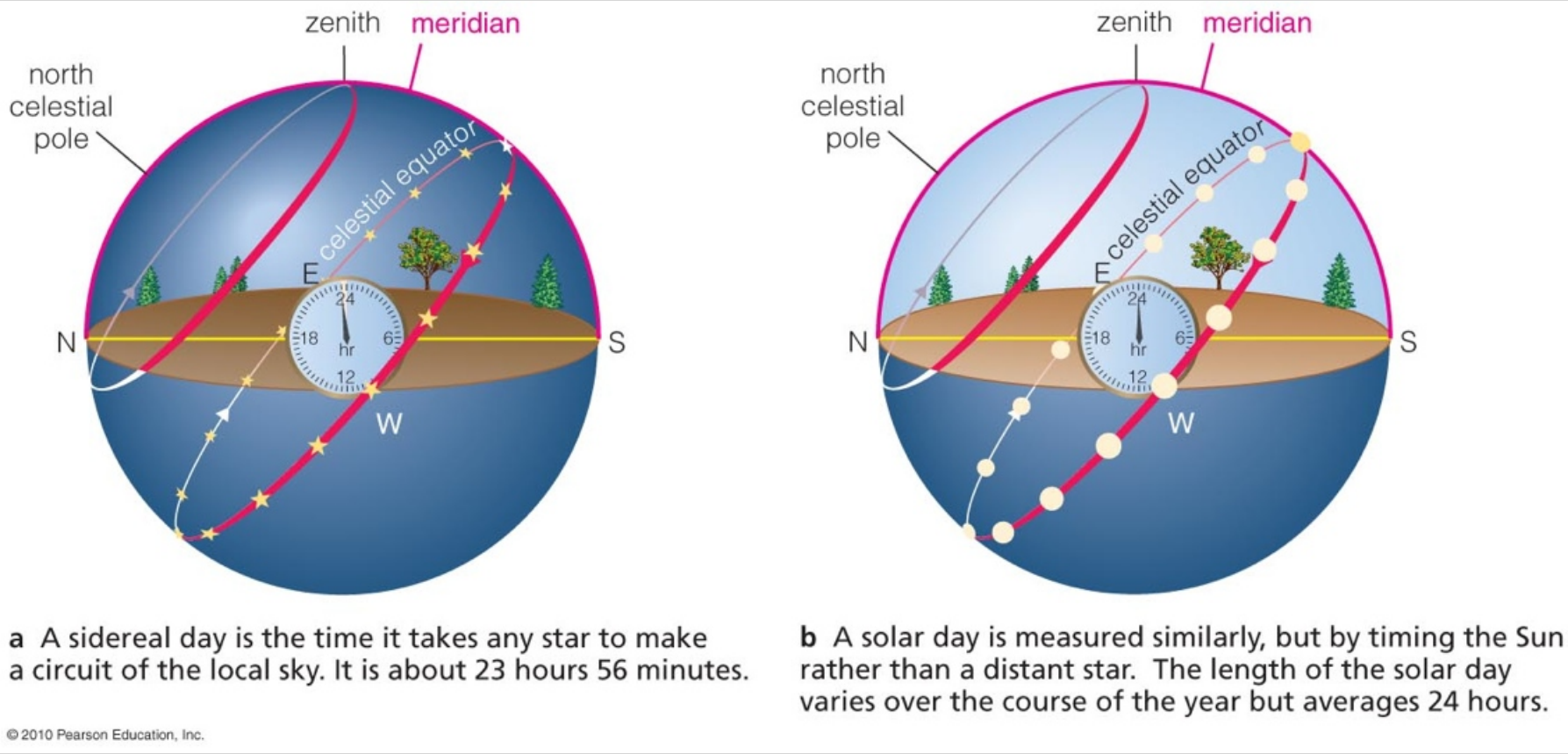
Sidereal time: relative to stars

Sidereal day = 1 revolution

relative to the <u>stars</u>



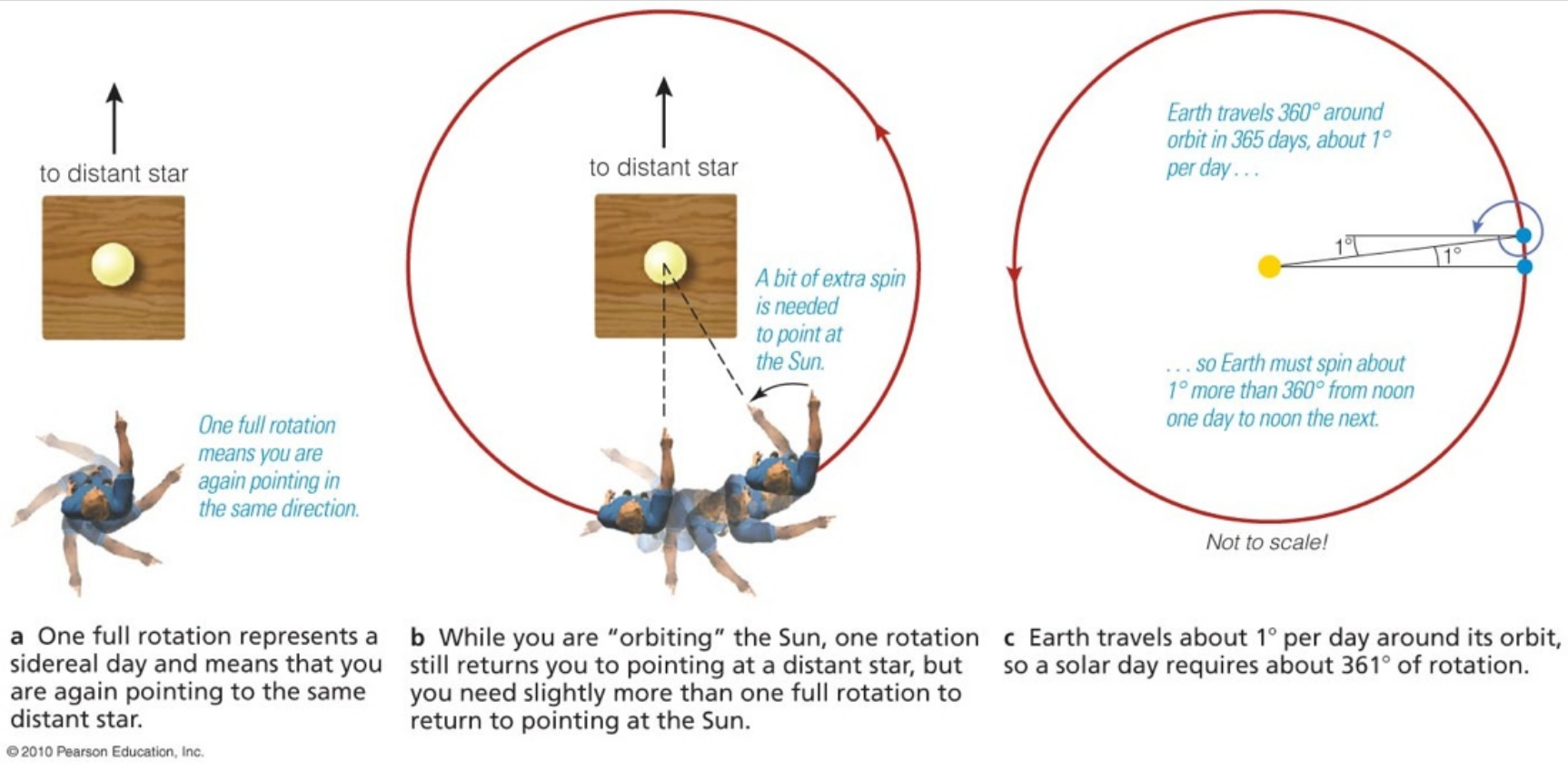
A sidereal day is 4 minutes shorter than a solar day.



a A sidereal day is the time it takes any star to make a circuit of the local sky. It is about 23 hours 56 minutes.

b A solar day is measured similarly, but by timing the Sun rather than a distant star. The length of the solar day varies over the course of the year but averages 24 hours.

The difference arises because Earth moves in its orbit.

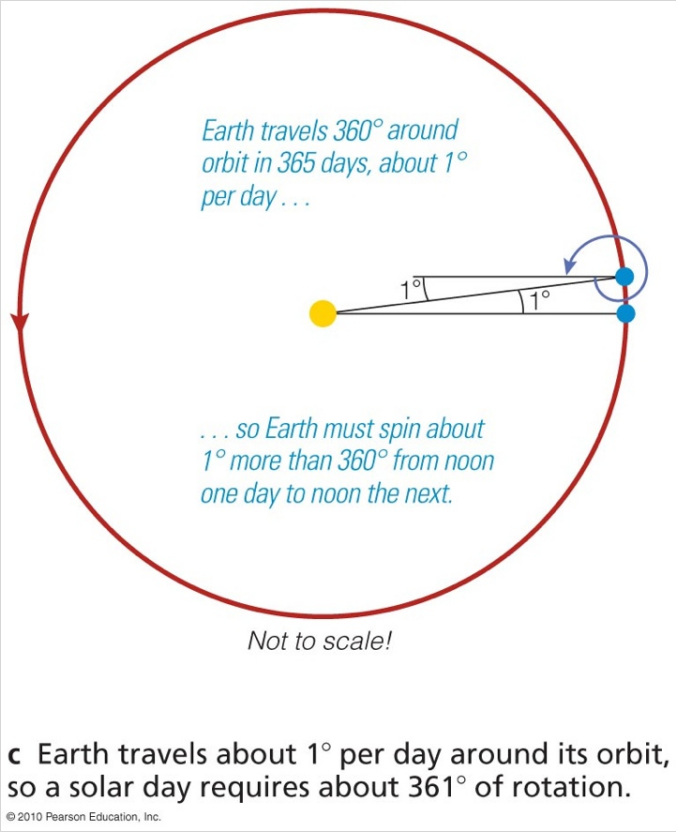


a One full rotation represents a sidereal day and means that you are again pointing to the same distant star.

b While you are "orbiting" the Sun, one rotation still returns you to pointing at a distant star, but you need slightly more than one full rotation to return to pointing at the Sun.

c Earth travels about 1° per day around its orbit, so a solar day requires about 361° of rotation.

It takes 4 minutes for the Earth to rotate 1 degree.



c Earth travels about 1° per day around its orbit, so a solar day requires about 361° of rotation.

How many minutes in a day?

$$24 \text{ hr} \times \frac{60 \text{ min}}{1 \text{ hr}} = 1440 \text{ min}$$

In one day the Earth rotates 360 degrees, so...

$$\frac{1440 \text{ min}}{360^\circ} = 4 \frac{\text{min}}{\text{deg}}$$

So a sidereal day is <u>4 minutes shorter than a solar day</u>.

How would the sidereal day change if...

...the Earth rotated twice as fast, but orbited the Sun at the same speed?

Two things to realize:

1. The Earth would travel through a smaller angle in one day (since it takes half the time to rotate once).
   - 0.5 degree instead of 1 degree

2. It takes a shorter amount of time for Earth to rotate through that extra 0.5 degree (since it rotates twice as fast).
   - 2 min/degree instead of 4 min/degree --> 1 min to rotate 0.5 degree

So a sidereal day would be 1 minute shorter than a solar day.

How would the sidereal day change if...

...the Earth rotated half as fast, but orbited the Sun at the same speed?

Take 2 minutes and try to come up with an answer. Then discuss with your neighbor.

A solar day would be 16 minutes longer than a sidereal day.

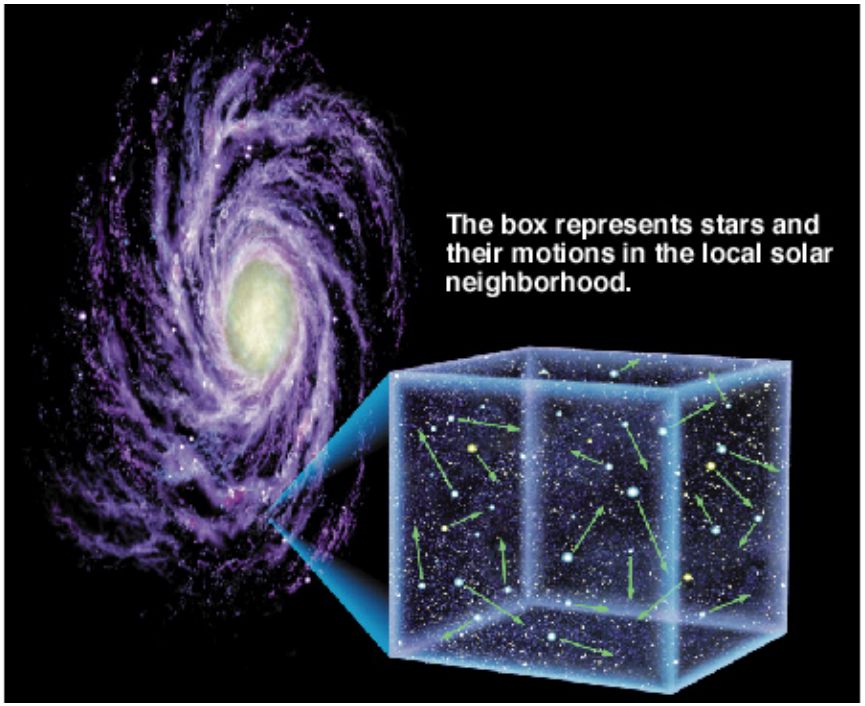
Or, equivalently, a sidereal day would be 16 minutes shorter than a solar day.

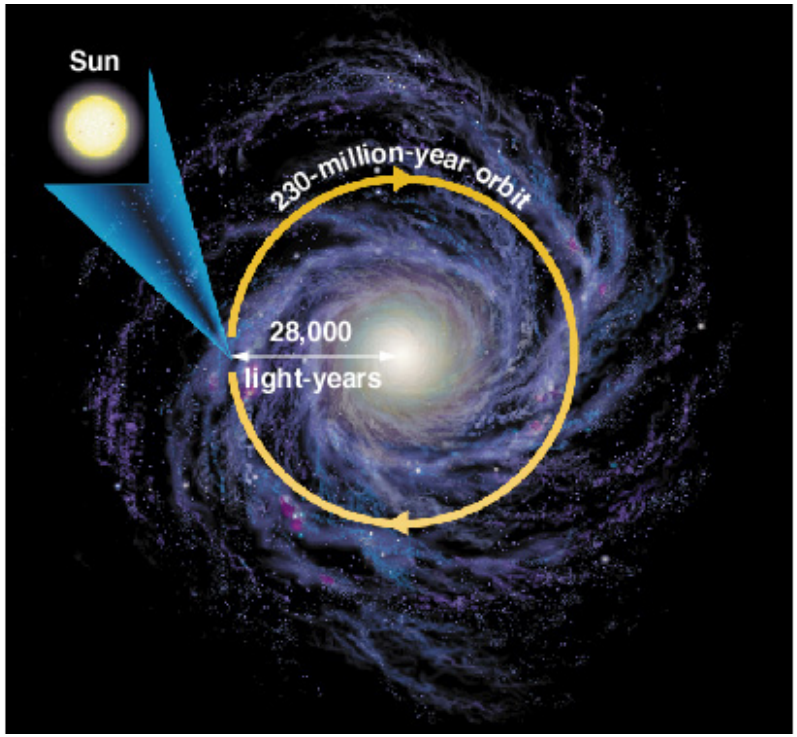
Two more ways we move through space…

3. The Sun orbits in the Milky Way

The sun (and nearby stars) orbit the center of the Milky Way once per 230,000,000 years.

How do we know? (motion of other stars in the Milky Way with respect to the Sun; careful study of stellar positions over time)



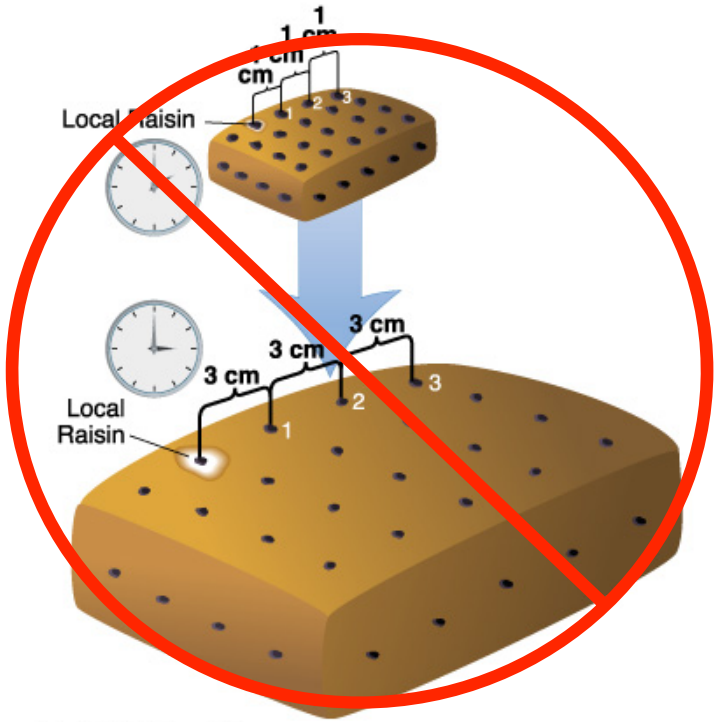


Two more ways we move through space…

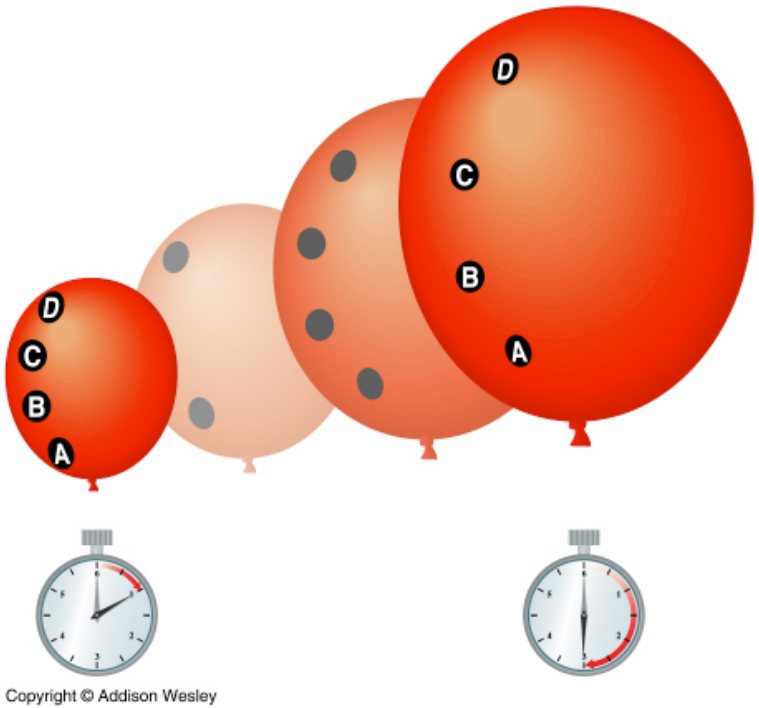
4. The Milky Way moves relative to the rest of the universe

Space itself is expanding (the space between things is increasing!)

No center. No edge.



Think of the surface of a balloon...only in 3D



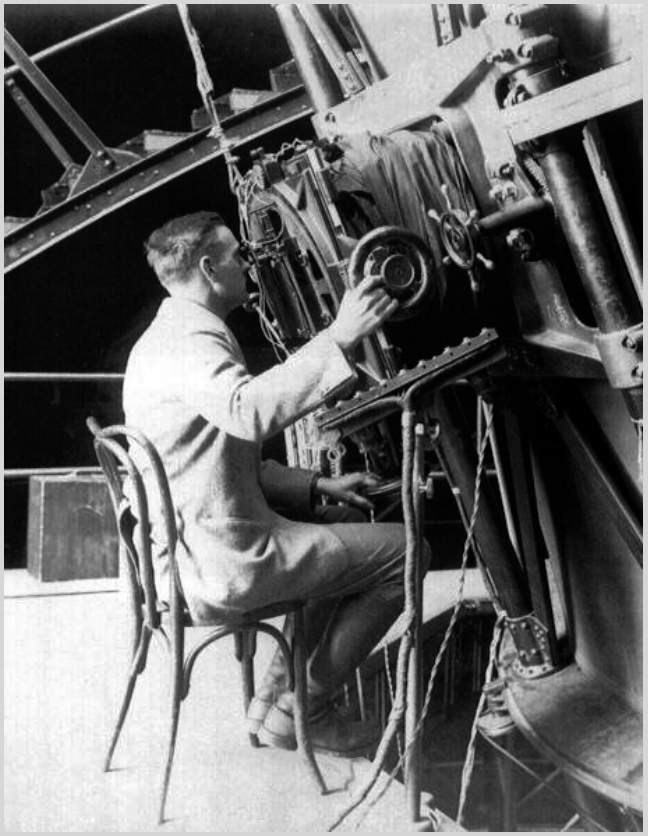
How do galaxies move within the universe?

Edwin Hubble's observations (1920s):

Outside the Local Group*, all galaxies are moving away from us.

The more distant the galaxy, the faster it appears to move away.

How to explain this?

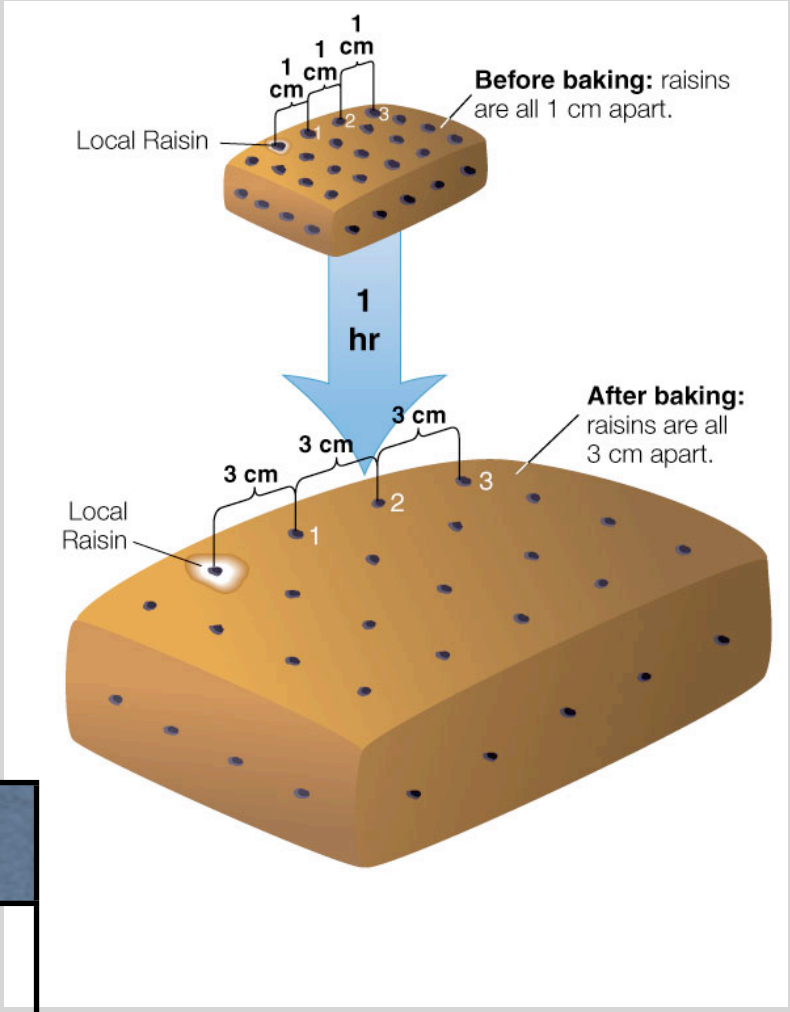


* = within a galaxy group, galaxies often are approaching each other

The raisin cake analogy...

Each raisin is a galaxy (or group of galaxies).

The cake batter represents the space between galaxies.



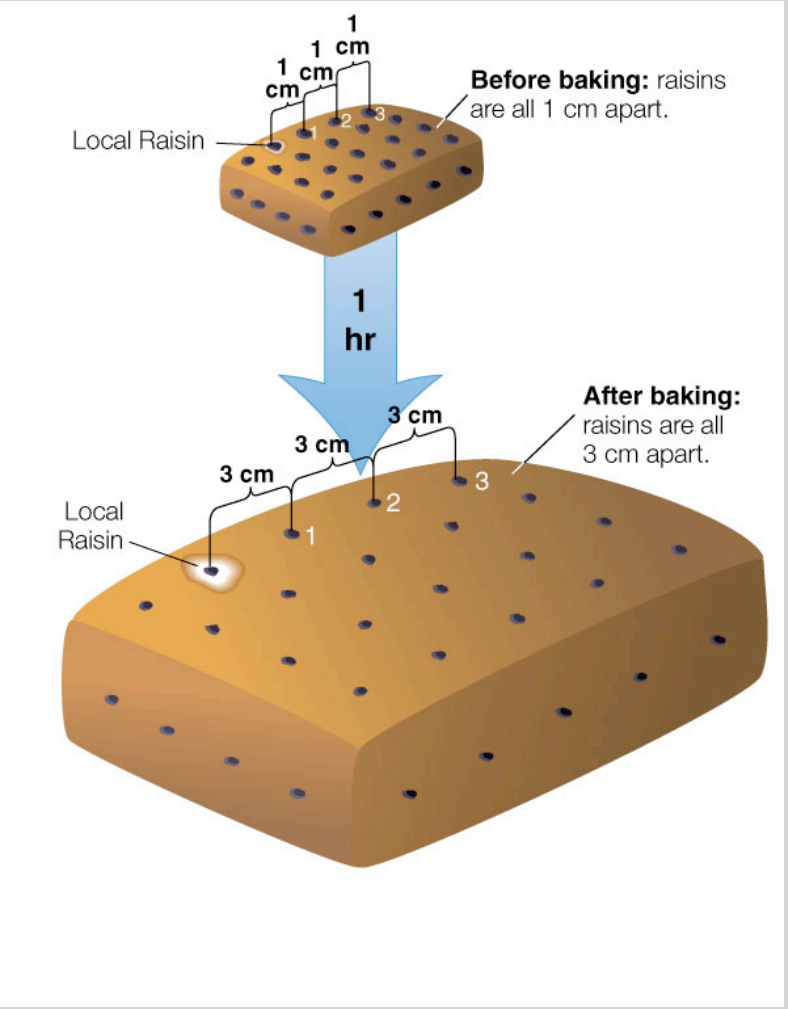
Raisin #	Distance before baking	Distance after baking	Speed
1	1 cm	3 cm	2 cm/hr
2	2 cm	?	?
3	3 cm	?	?

Raisin #	Distance before baking	Distance after baking	Speed
1	1 cm	3 cm	2 cm/hr
2	2 cm	6 cm	4 cm/hr
3	3 cm	9 cm	6 cm/hr

Conclusion: Hubble's observations are consistent with an expanding universe.

Unlike the cake, the actual universe has no center or edges.

NOTE: Each raisin does not expand as the cake expands!

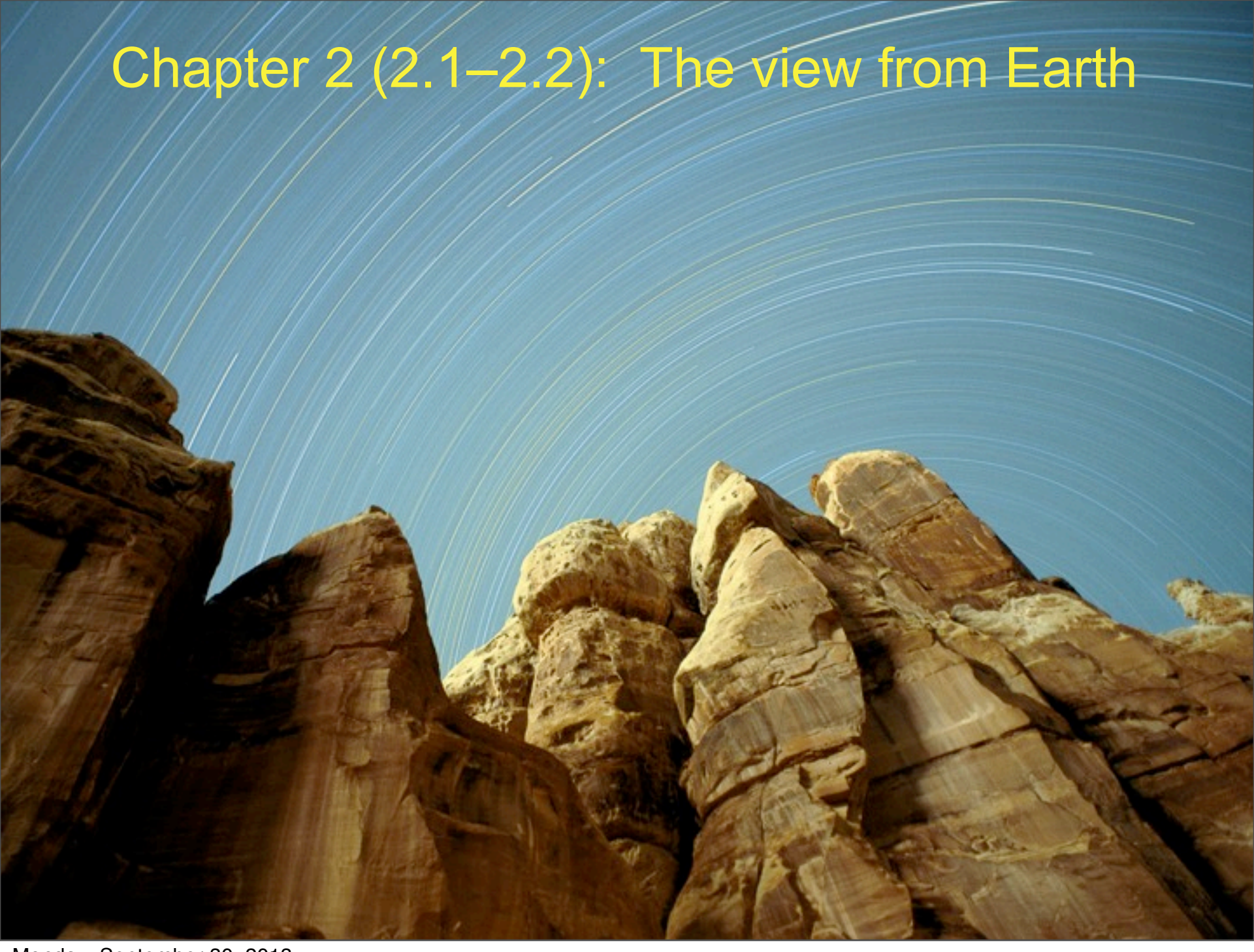


"Clicker" question

Which of the following are moving apart due to the expansion of the universe?

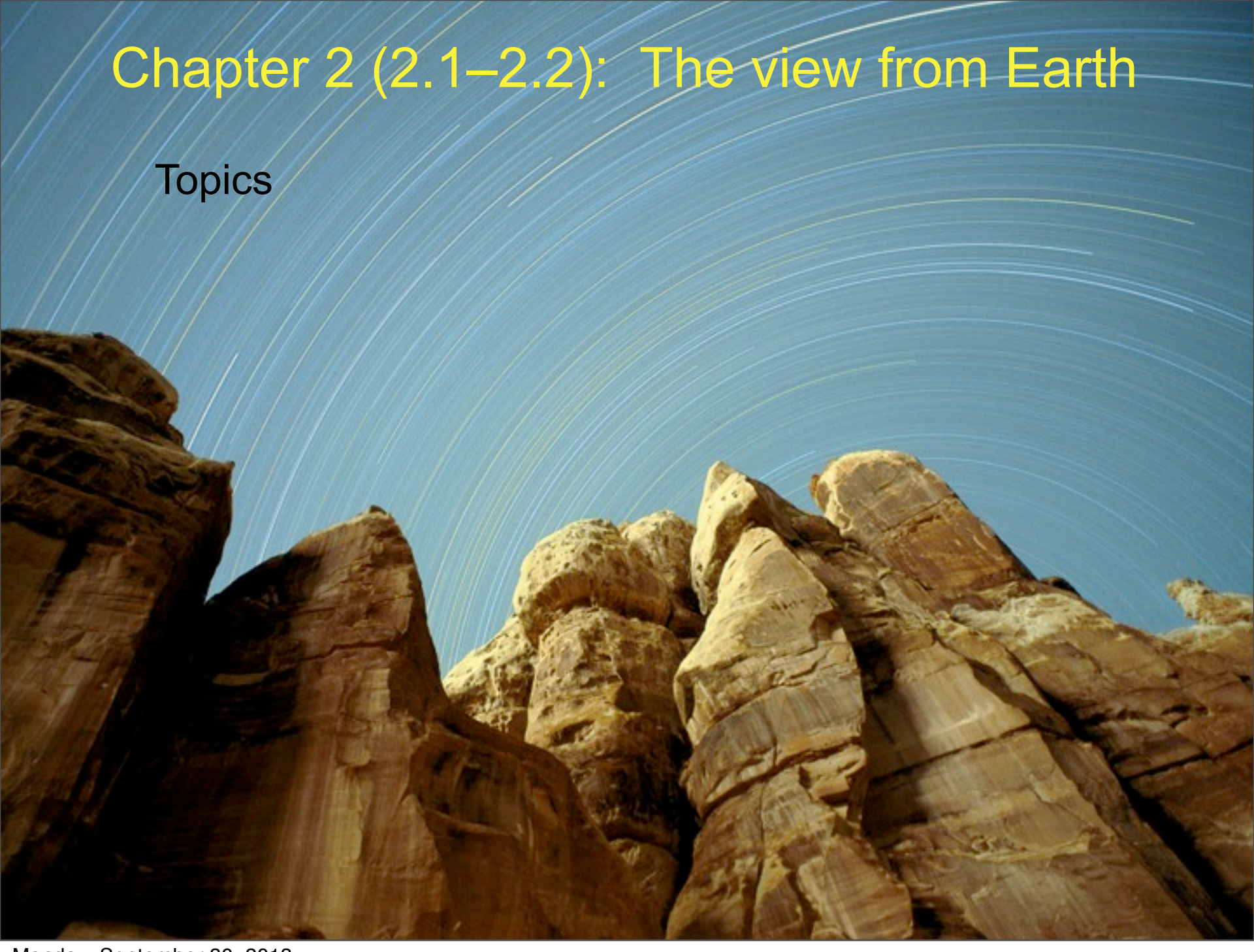
A. two hydrogen atoms in outer space
B. the Earth and the Sun
C. two stars in a galaxy
D. two widely separated galaxies
E. all of the above

Chapter 2 (2.1–2.2): The view from Earth



Chapter 2 (2.1–2.2): The view from Earth

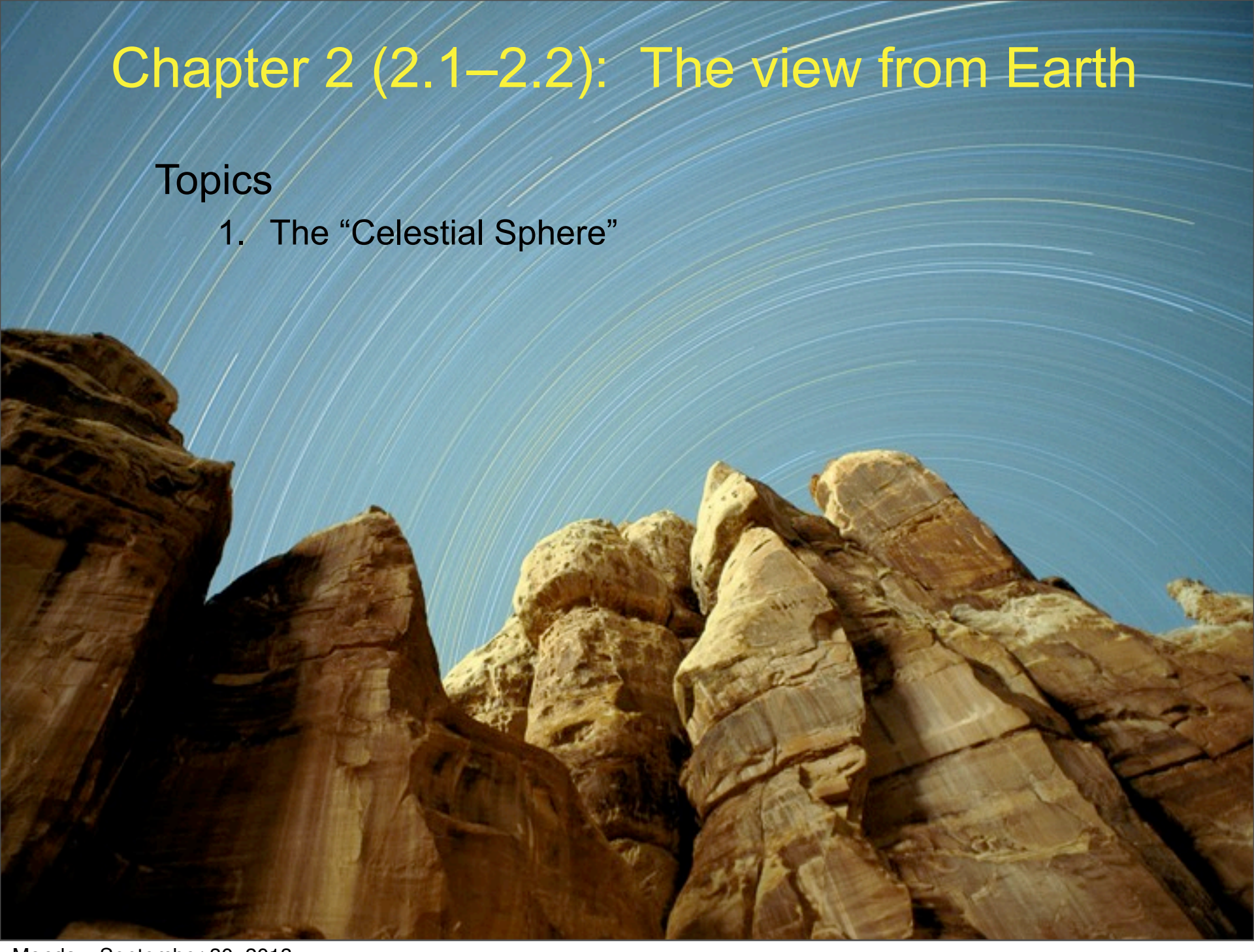
Topics



Chapter 2 (2.1–2.2): The view from Earth

Topics

1. The “Celestial Sphere”



Chapter 2 (2.1–2.2): The view from Earth

Topics

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2. Coordinates (On the Earth and in the sky)

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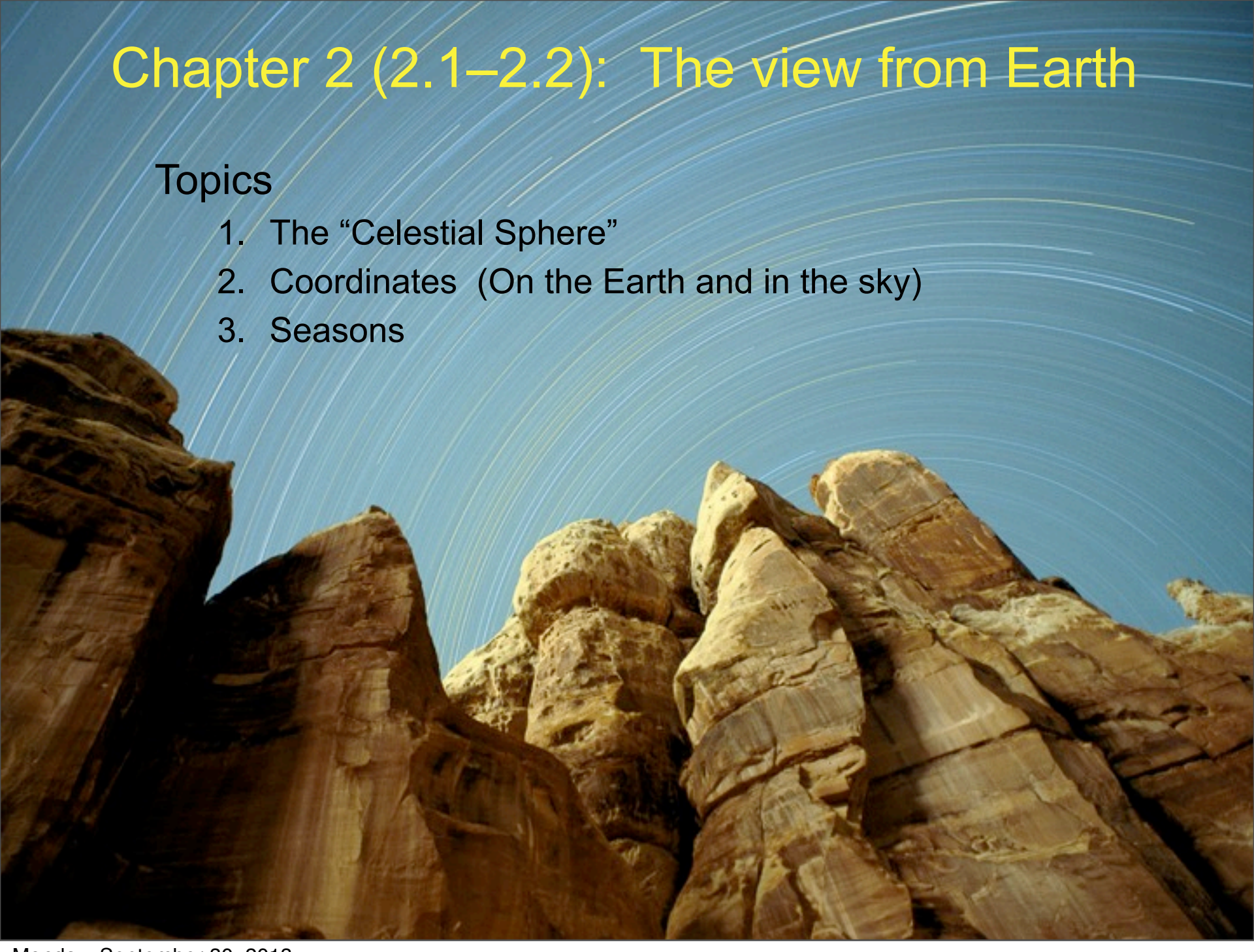
Topics

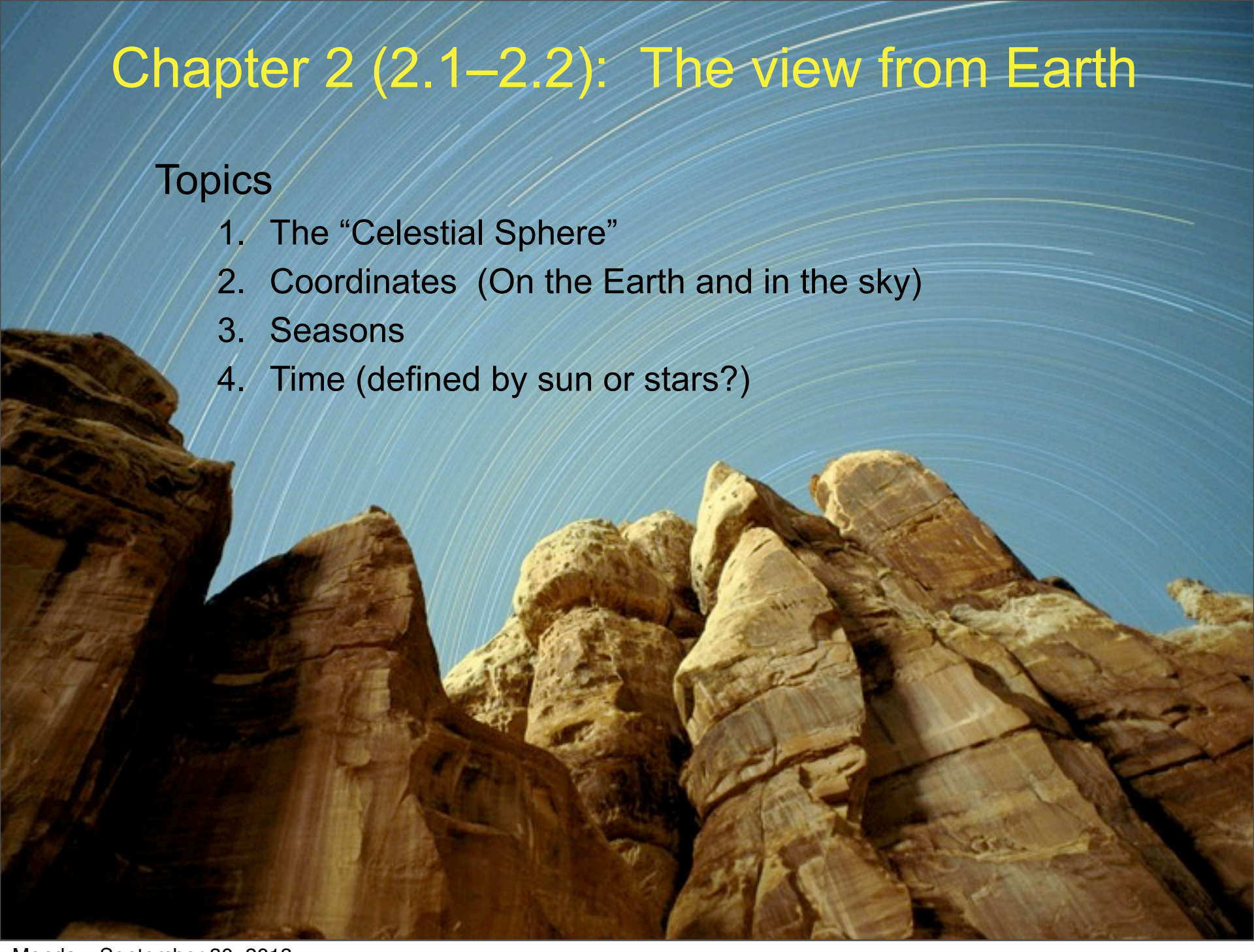
1. The “Celestial Sphere”
2. Coordinates (On the Earth and in the sky)
3. Seasons



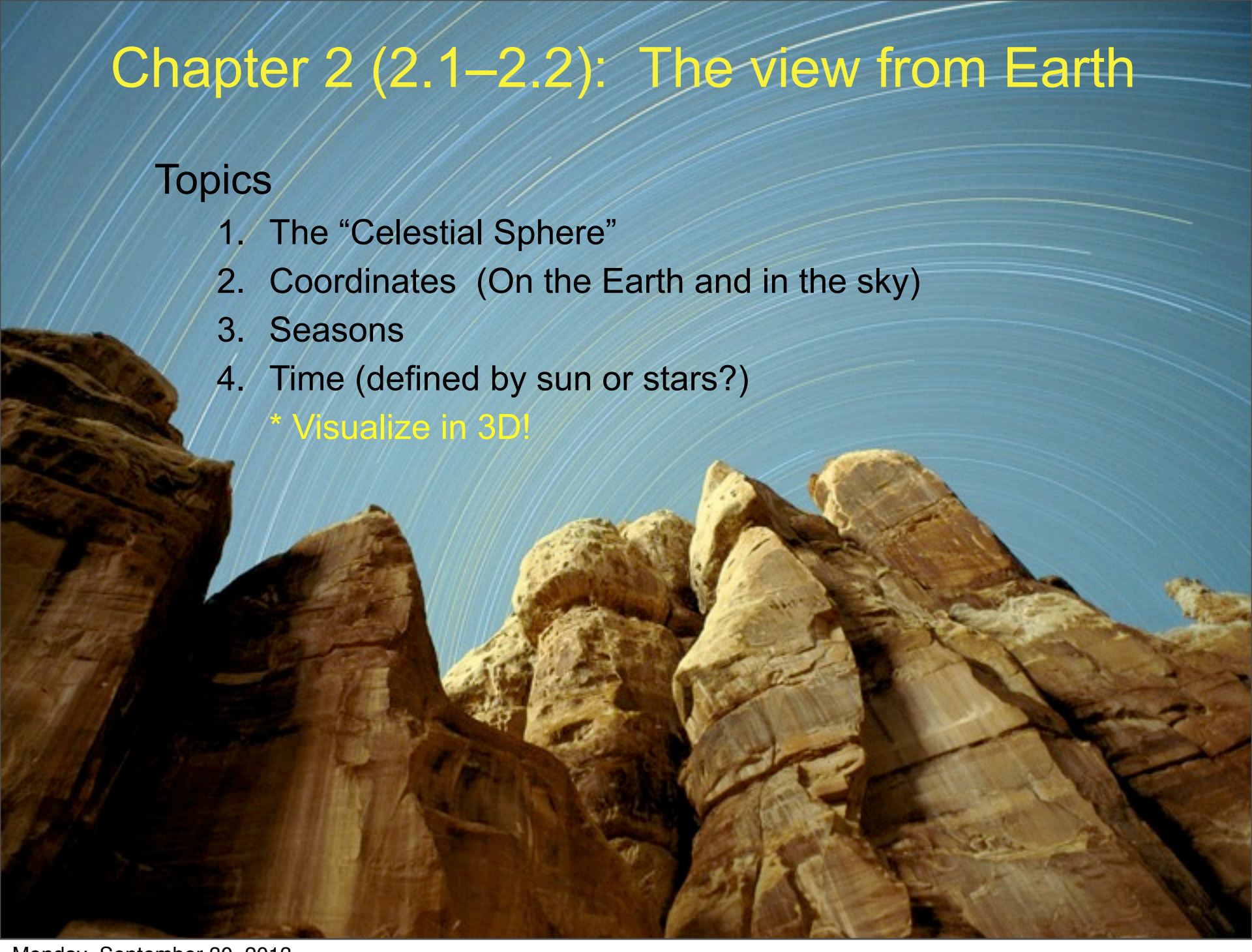
Chapter 2 (2.1–2.2): The view from Earth

Topics

1. The “Celestial Sphere”
2. Coordinates (On the Earth and in the sky)
3. Seasons
4. Time (defined by sun or stars?)



Chapter 2 (2.1–2.2): The view from Earth



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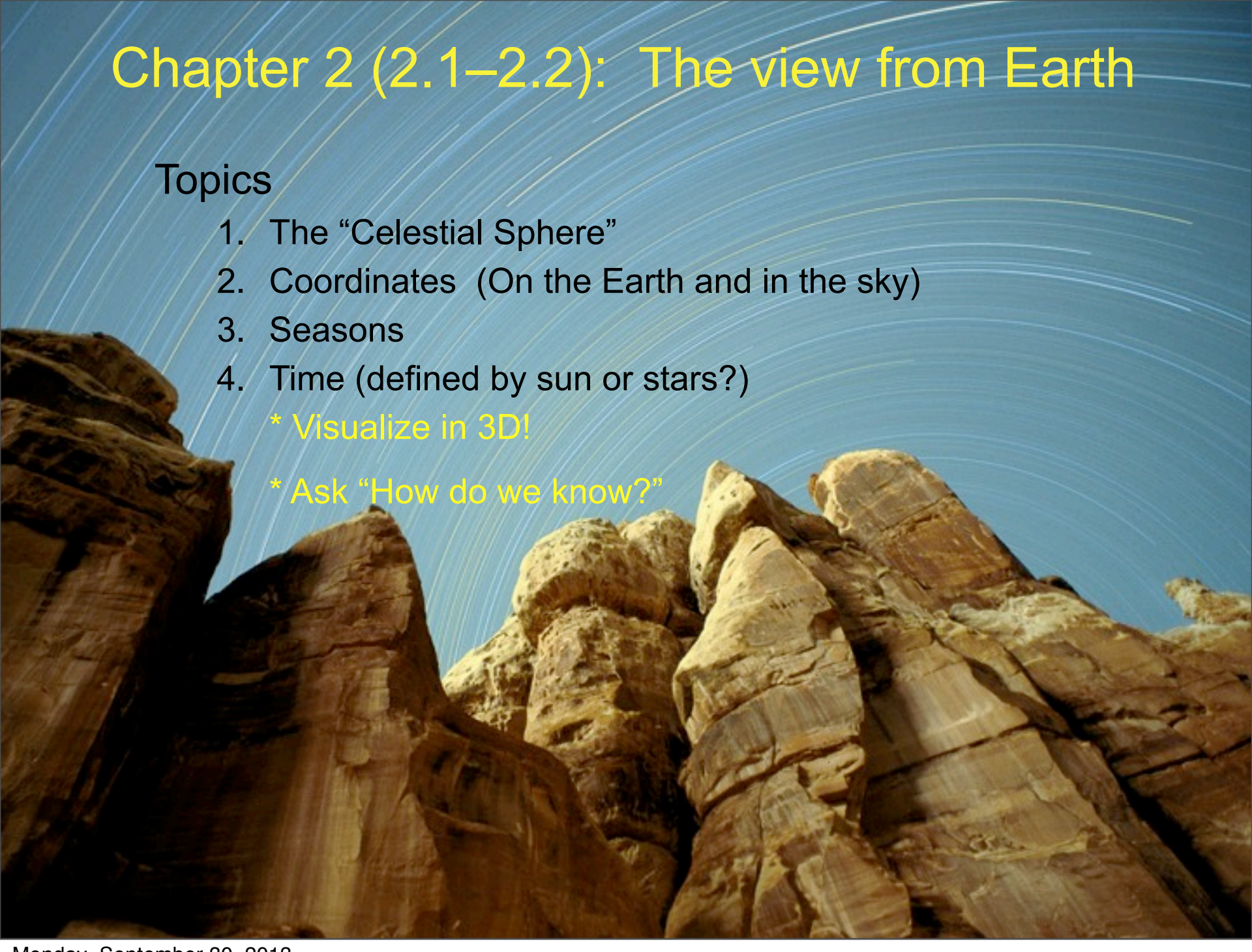
   * Visualize in 3D!

Chapter 2 (2.1–2.2): The view from Earth



Topics

1. The “Celestial Sphere”
2. Coordinates (On the Earth and in the sky)
3. Seasons
4. Time (defined by sun or stars?)

* Visualize in 3D!

* Ask “How do we know?”

Why Are You Taking This Class?

Why Are You Taking This Class?

A. My friend told me the instructor has an intriguing accent and sense of humor

B. This was the only class that fit my schedule

C. I love astronomy (but without all the math)

D. I'm in the wrong class (but at least I got to use this clicker thing)!

E. Cosmetology and astrology rock!

Motion of the Earth

The Earth moves in myriad (but not mysterious) ways:

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A. The Earth spins on its axis

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These four distinct modes of Earth's motion
are central to all four of today's/this week's topics.

1- The Celestial Sphere

A. The Earth spins on its axis (once per day)

Everything in the sky appears to rise and set once per rotation (i.e. once per day).

Appear fixed because most visible bodies are extremely far

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Everything (beyond the solar system) appears fixed on the sky to the naked eye.

(why?)

(what are constellations?)

Earth's spin causes the illusion of a "Celestial Sphere" surrounding the earth.

Appear fixed because most visible bodies are extremely far

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Everything in the sky appears to rise and set once per rotation (i.e. once per day)

Everything (beyond the solar system) appears fixed on the sky to the naked eye.

(why?)

(what are constellations?)

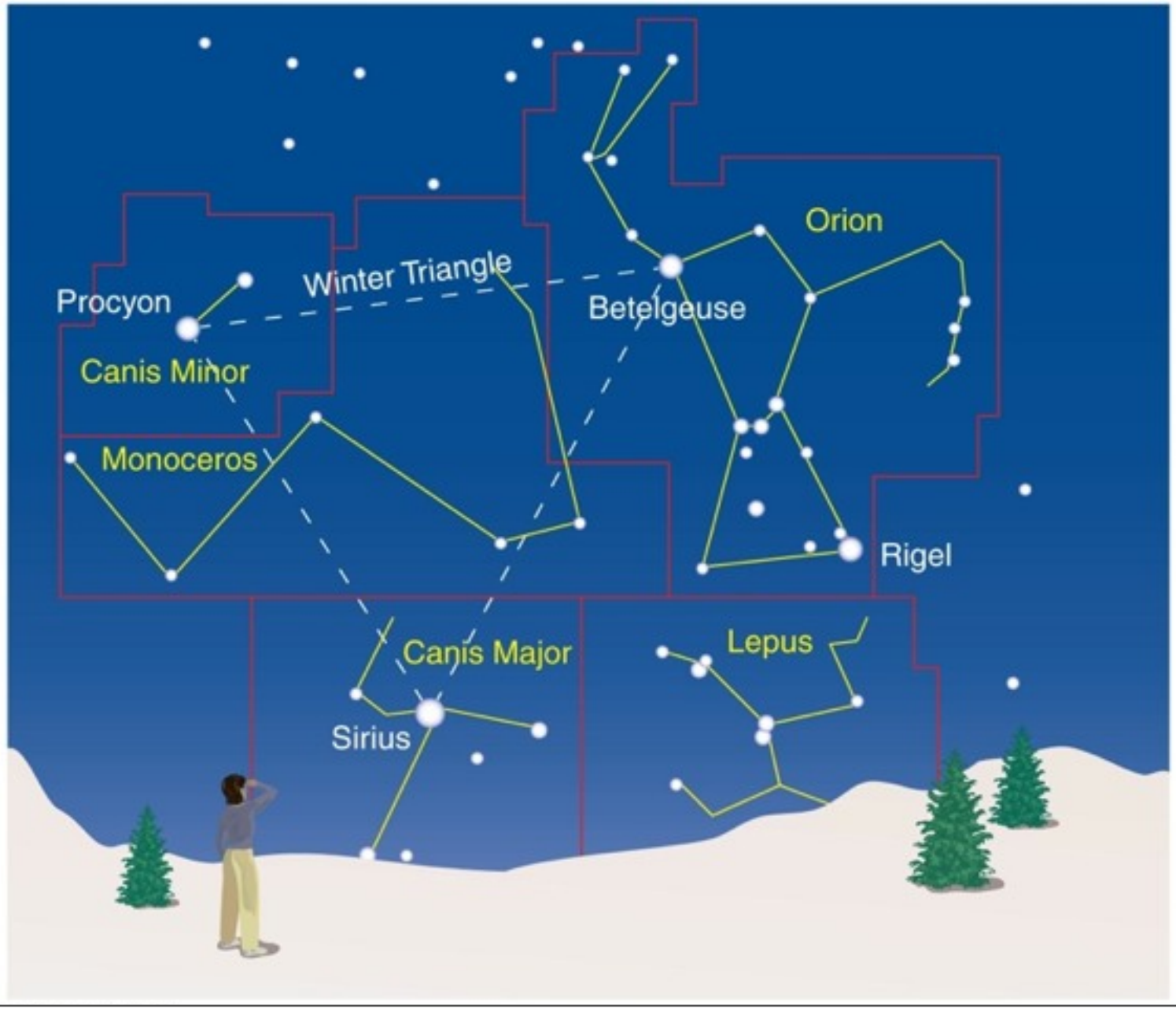
Constellations = fixed arrangements of stars that are NOT necessarily physically related.

Monday, September 30, 2013

There are 88 officially outlined constellations in the sky decided by IAU.
Allows quick location of objects rather than RA/Dec coordinates.

How do we know the earth is spinning and not the celestial sphere?
Foucault's pendulum. Coriolis force - fire a cannonball. North - South, deflects to the right (clockwise).

1- The Celestial Sphere



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The great nebula in Orion. Andromeda galaxy is in?

Remember to ask: How do we know?

A. The Earth spins on its axis

… rather than the Sky spinning around the Earth?

First real proof that Earth spins:

1851, Foucault's pendulum

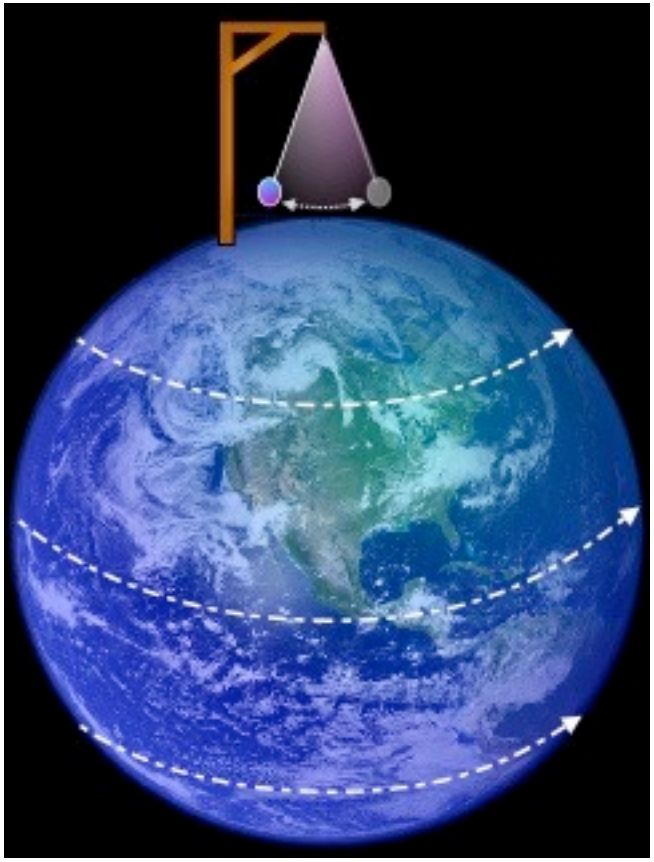
Imagine a pendulum at the North Pole.

The only force on it is gravity,

so it swings 1 plane forever.

The fact that it appears to spin

means the Earth moves under it!



Monday, September 30, 2013

Where would the pendulum not appear to spin and why?

burn the string and start the pendulum.

Then ask

So we just said that the earth is spinning. How do we know the celestial sphere isn't spinning?

2- Coordinates (on the Celestial Sphere)

A. The Earth spins on its axis (once per day)

We can define a coordinate system as on Earth:

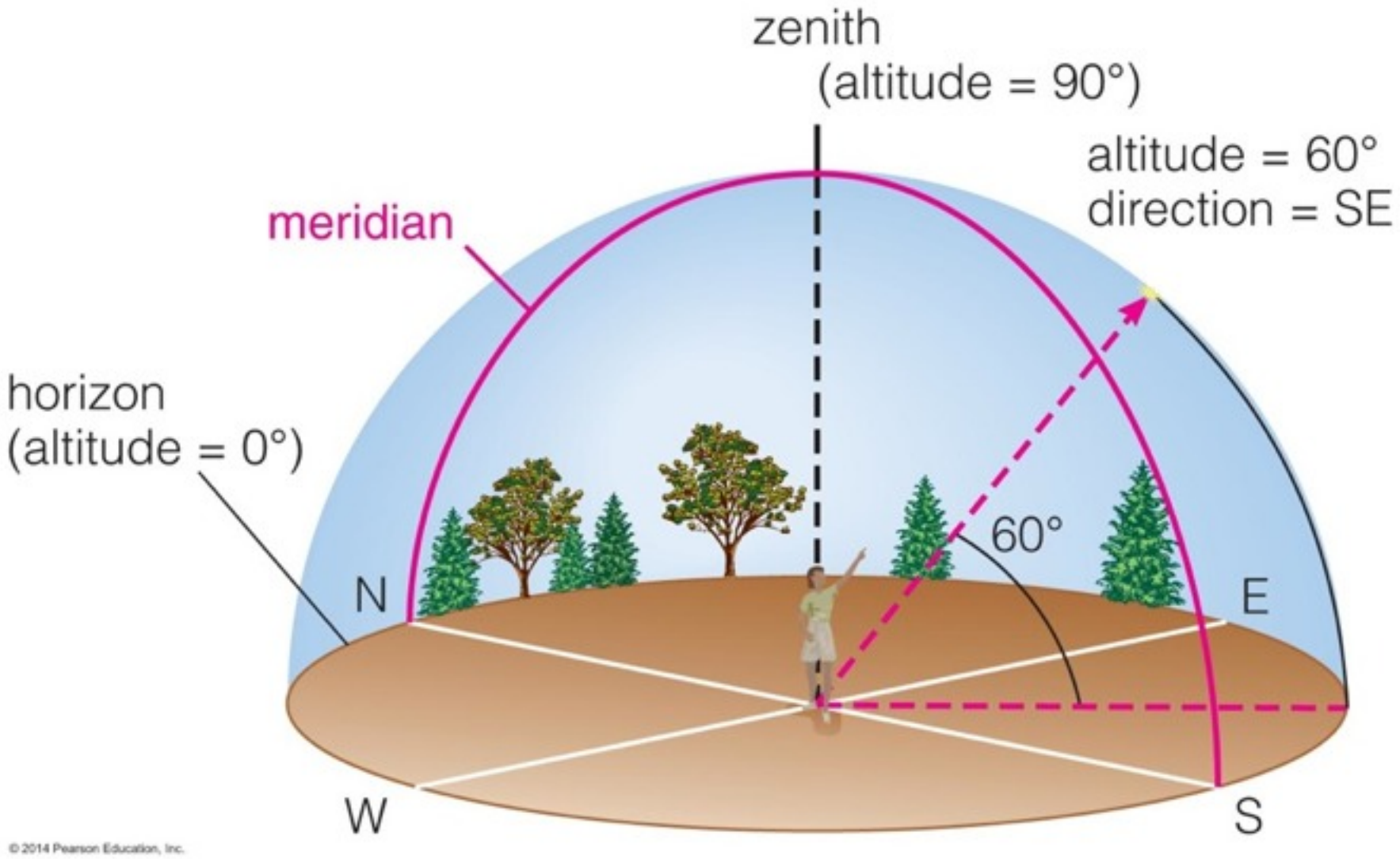
NOT absolute (local to you).

- your zenith
- your horizon

Standing nearer the Earth's equator

Standing near the Earth's North pole

2- Coordinates (on the Celestial Sphere)



Monday, September 30, 2013

Horizon is boundary
Meridian - N to S thru zenith.
Azimuth - along horizon

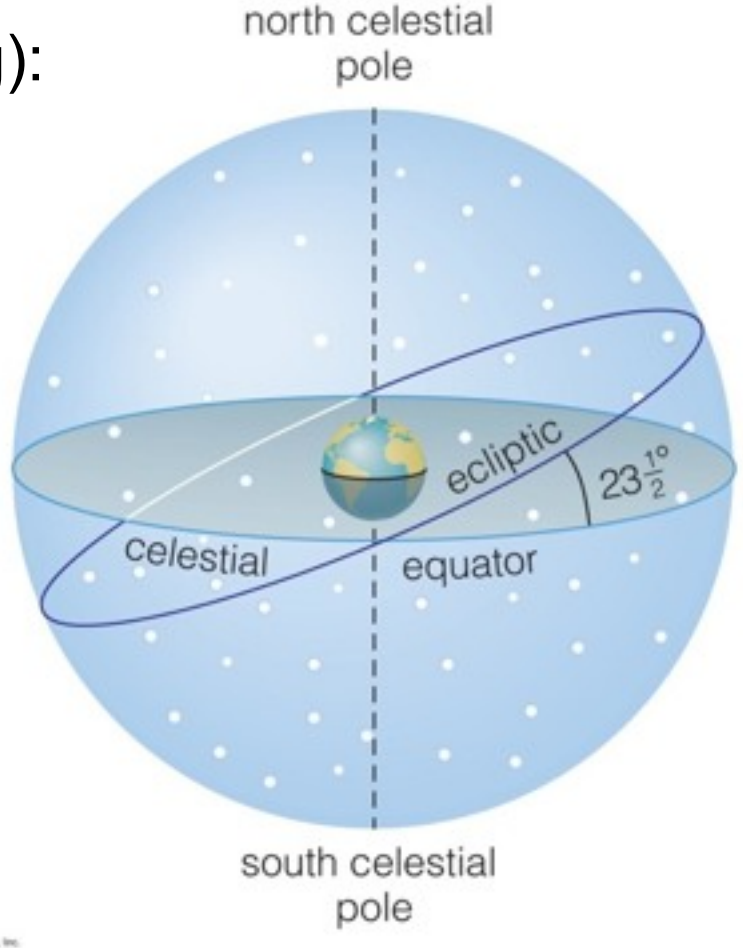
2- Coordinates (on the Celestial Sphere)

A. The Earth spins on its axis (once per day)

We can define a coordinate system as on Earth:

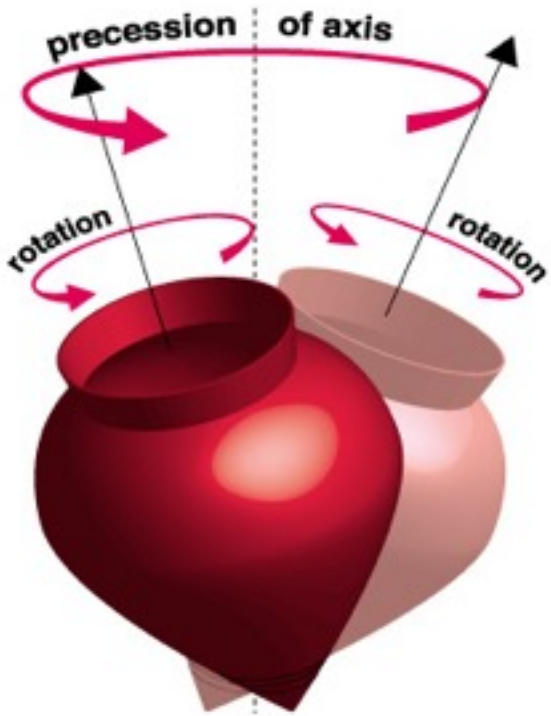
Absolute coordinates (unchanging):

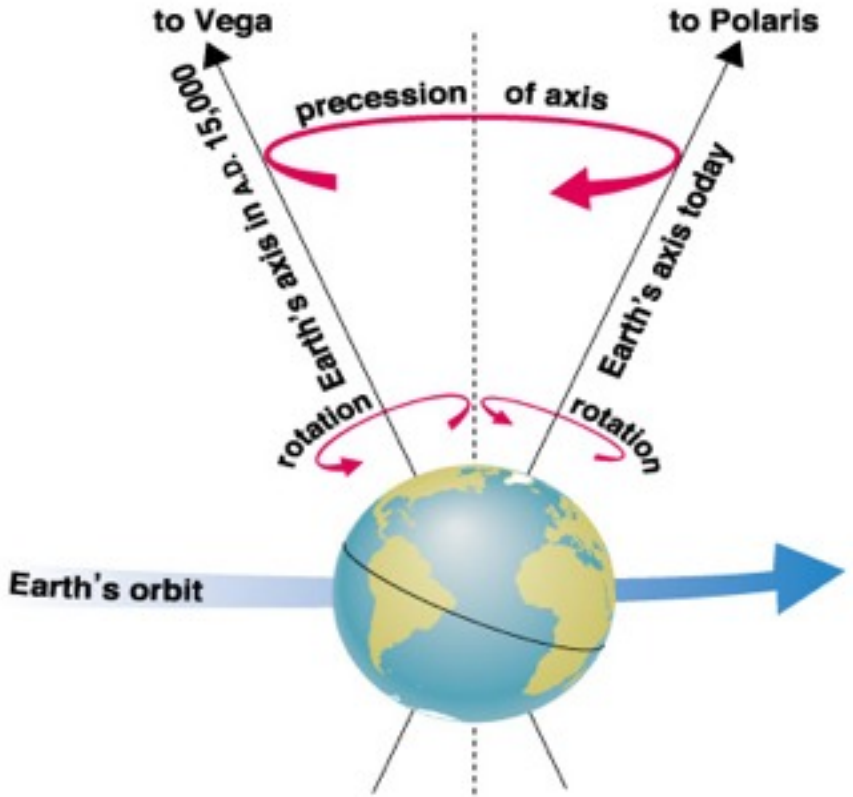
- North pole
- South pole
- Celestial equator



An aside:

The Earth's precesses (like a top) once per 26,000 yrs.
The Celestial north pole moves in a circle over time.





The North star is now Polaris, used to be Thuban (pyramids are aligned to it) in 3000 BC, will be some star in Cepheus by 3000 AD

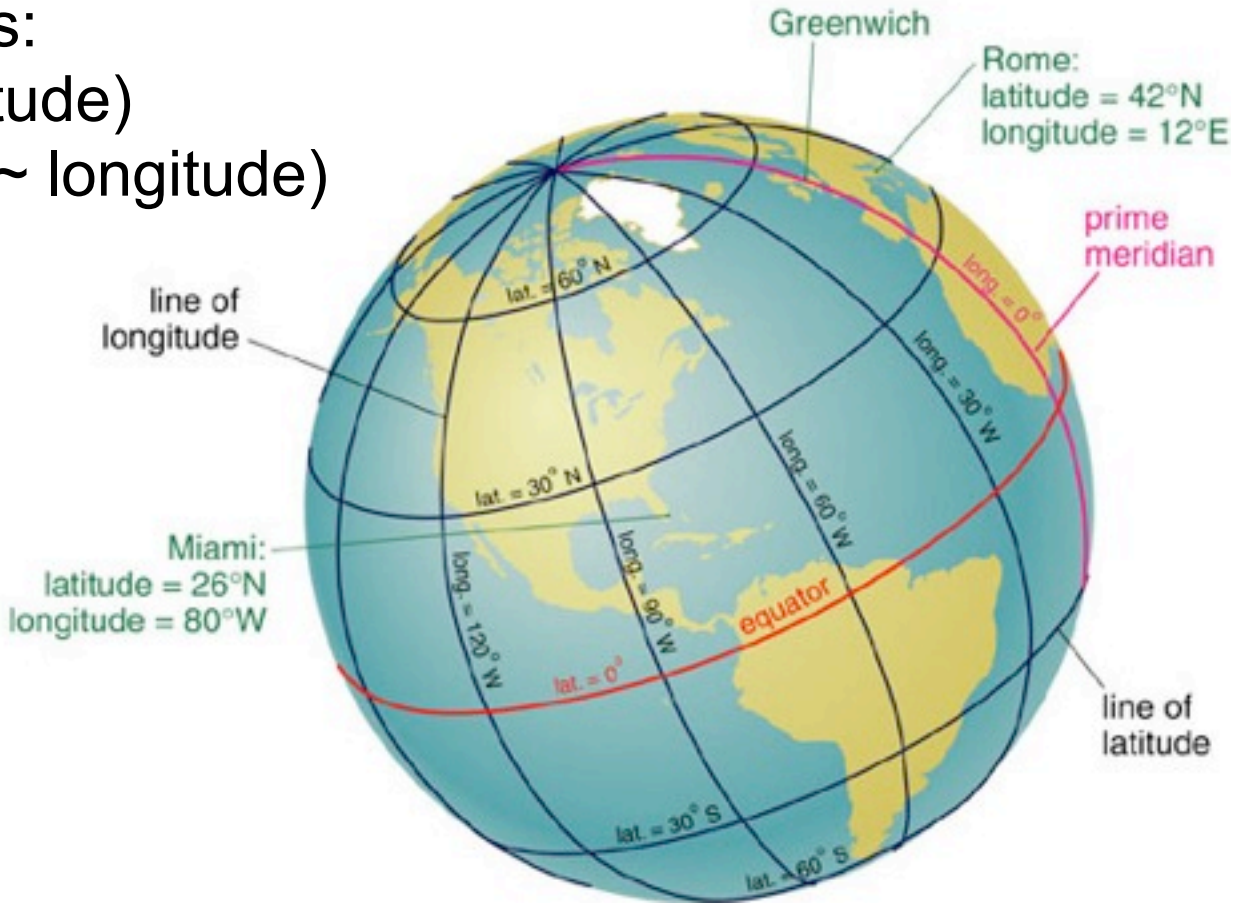
2- Coordinates (on the Celestial Sphere)

A. The Earth spins on its axis (once per day)

We can define a coordinate system as on Earth:

Absolute coordinates:

- Declination (~ latitude)
- Right Ascension (~ longitude)



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- Declination (~ latitude)
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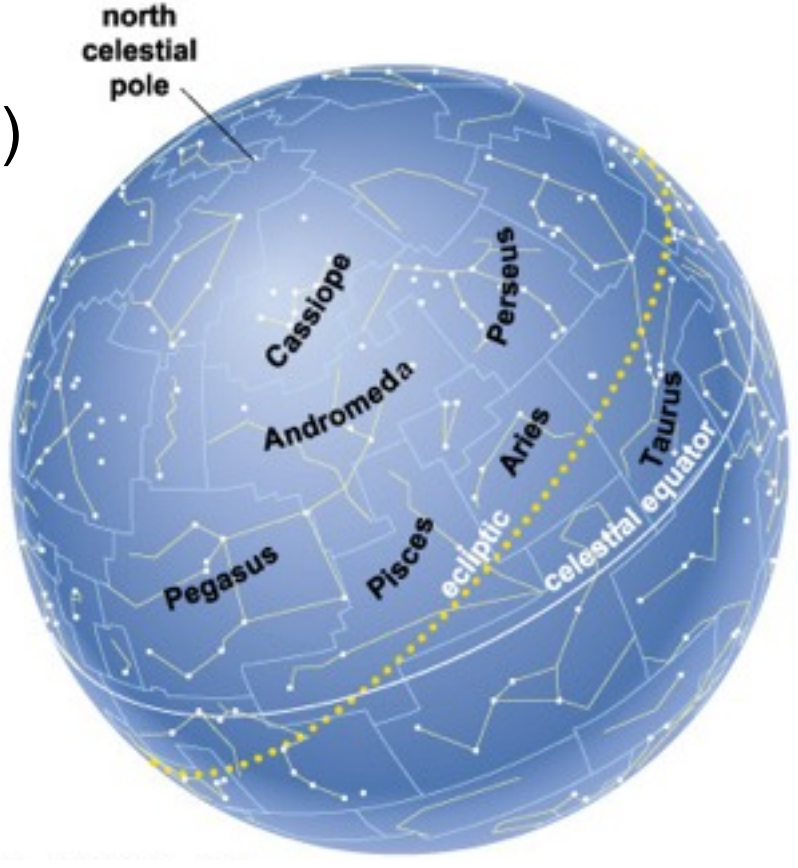
Declination = –90 to 0 to 90
[pole – equator – pole]

Right Ascension = 0 – 360



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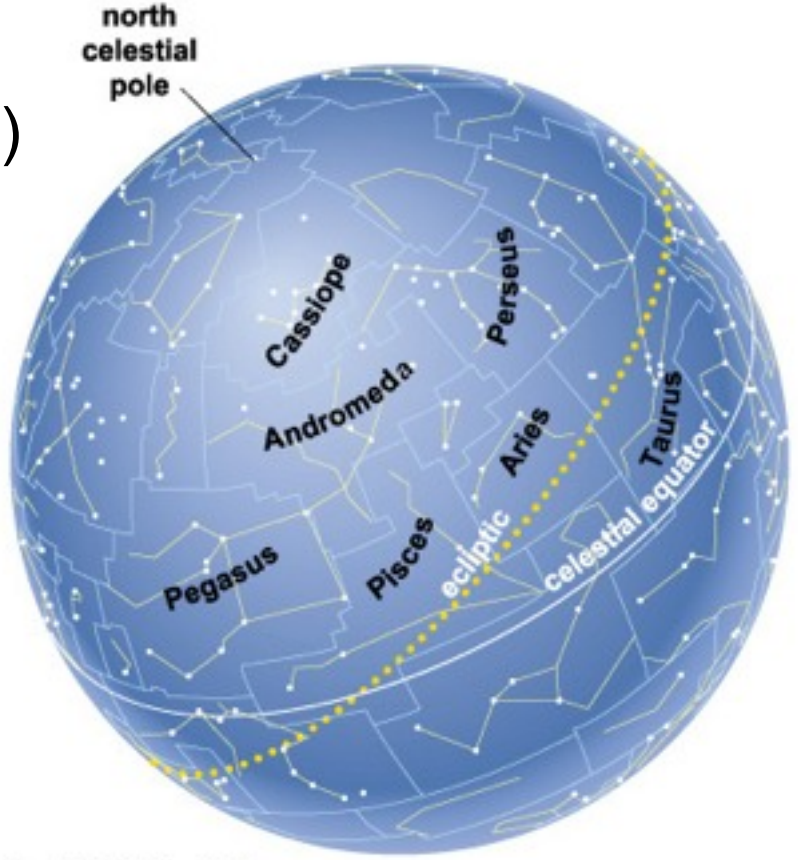
[pole – equator – pole]

Right Ascension = 0 – 360
[where is RA=0 ?]



2- Coordinates (on the Celestial Sphere)

B. The Earth orbits the sun (once per year)

Half the sky is overhead during the day
… which half that is changes through the course of a year!

Monday, September 30, 2013

What's "a sign" that tells you the sky overhead is different?
Earth goes 360 degrees in 365 days - 1 deg/day

2- Coordinates (on the Celestial Sphere)

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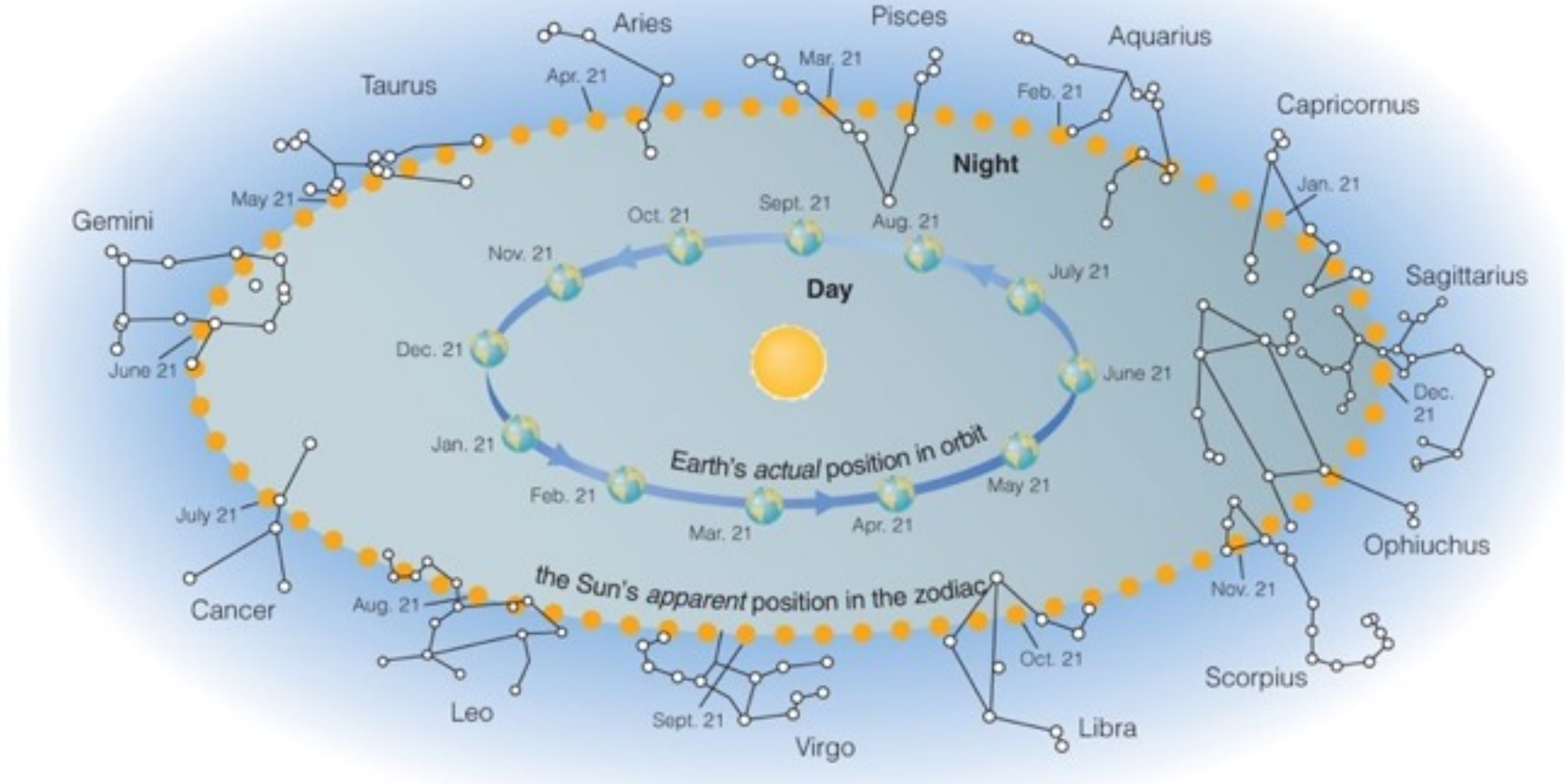

Monday, September 30, 2013

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Remember to ask: How do we know?

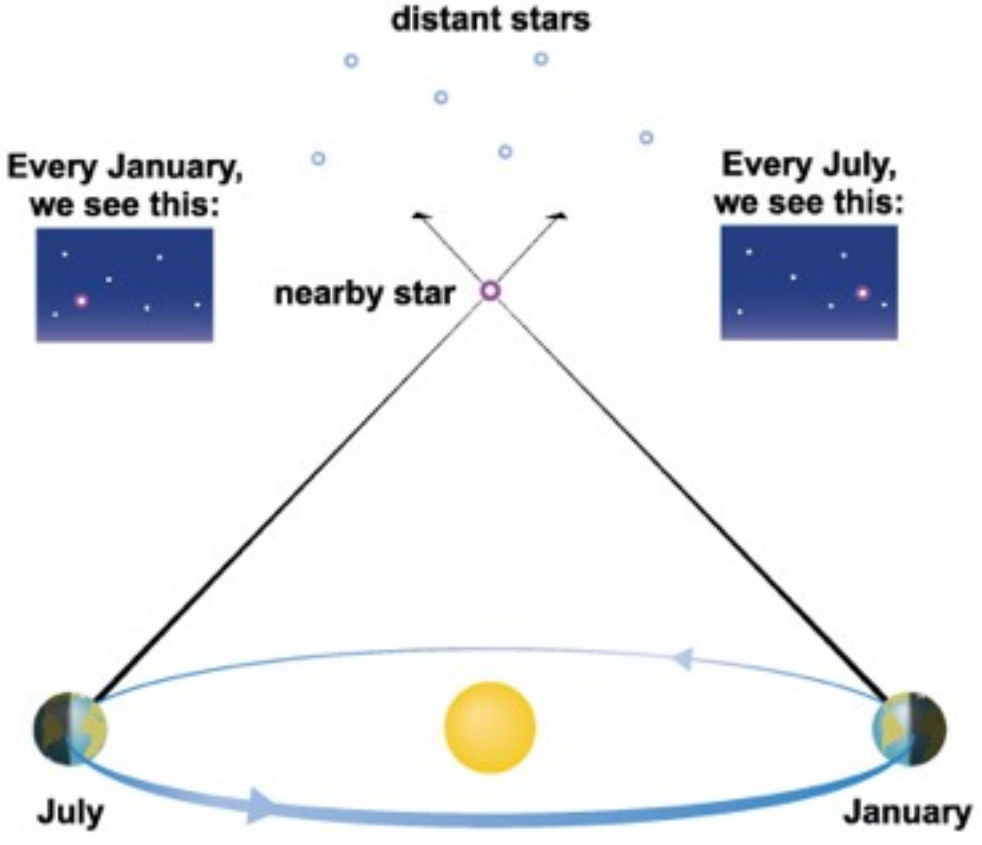
B. The Earth orbits the sun

… or does the Sun go around the Earth?

Stuff in background

Stellar Parallax:

Earth (parallax+orbit) or
Sun (no parallax,only orbit)



retrograde motion of Mars, phases of Venus, moons of Jupiter

Remember to ask: How do we know?

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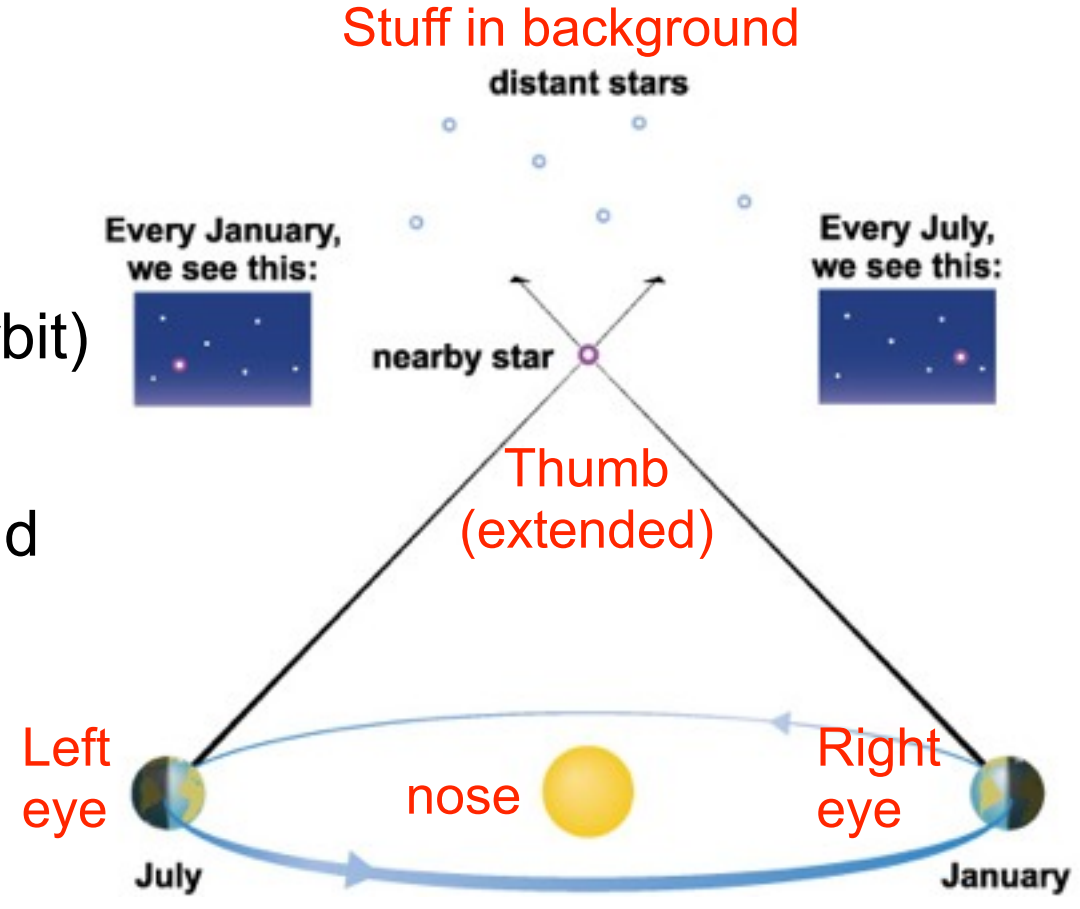
Sun (no parallax,only orbit)

(demo: wink. background still. thumb “moves.”)

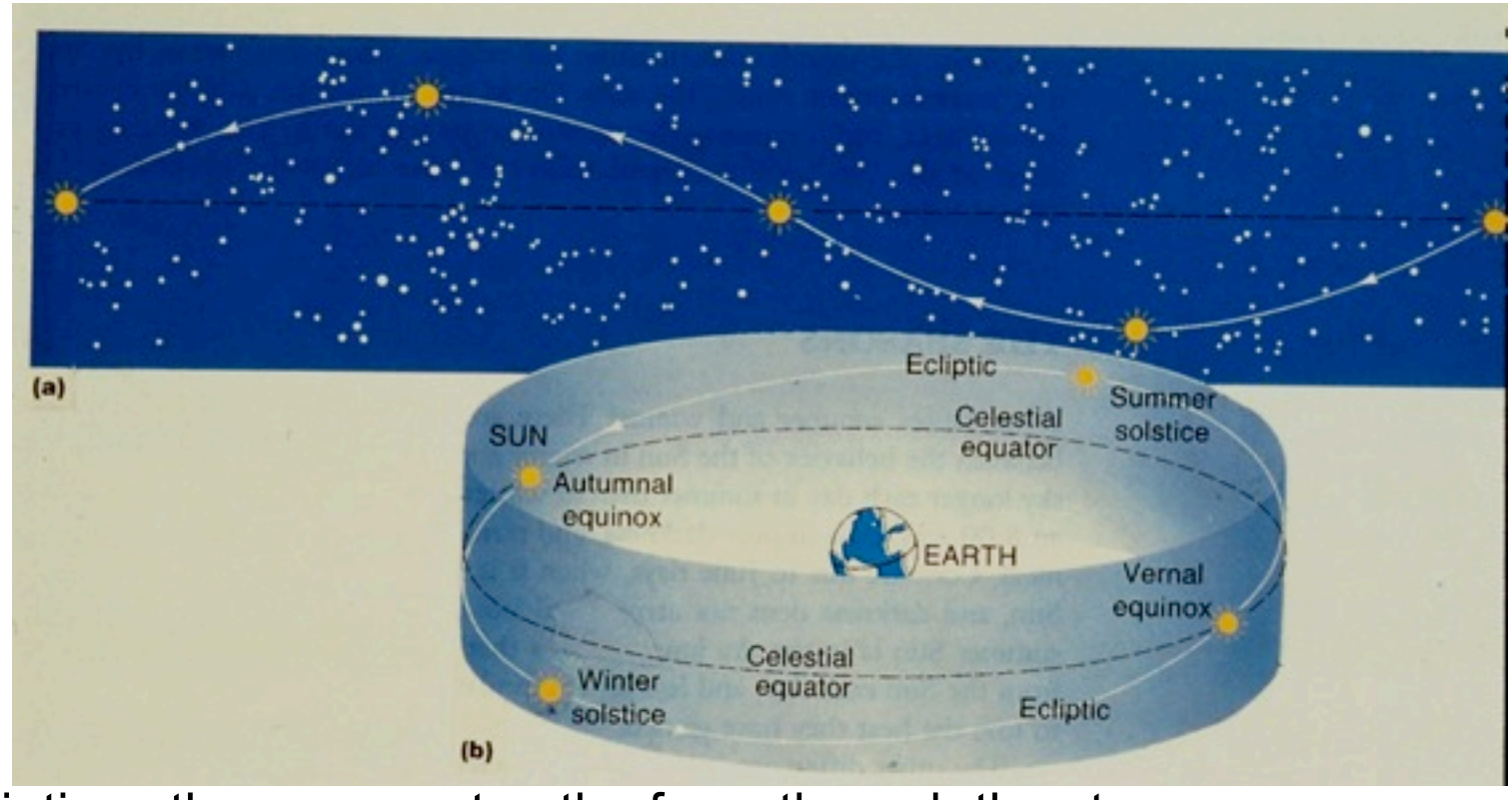


retrograde motion of Mars, phases of Venus, moons of Jupiter

2- Coordinates (on the Celestial Sphere)

B. The Earth orbits the sun (once per year)

This makes a convenient way to define RA=0…

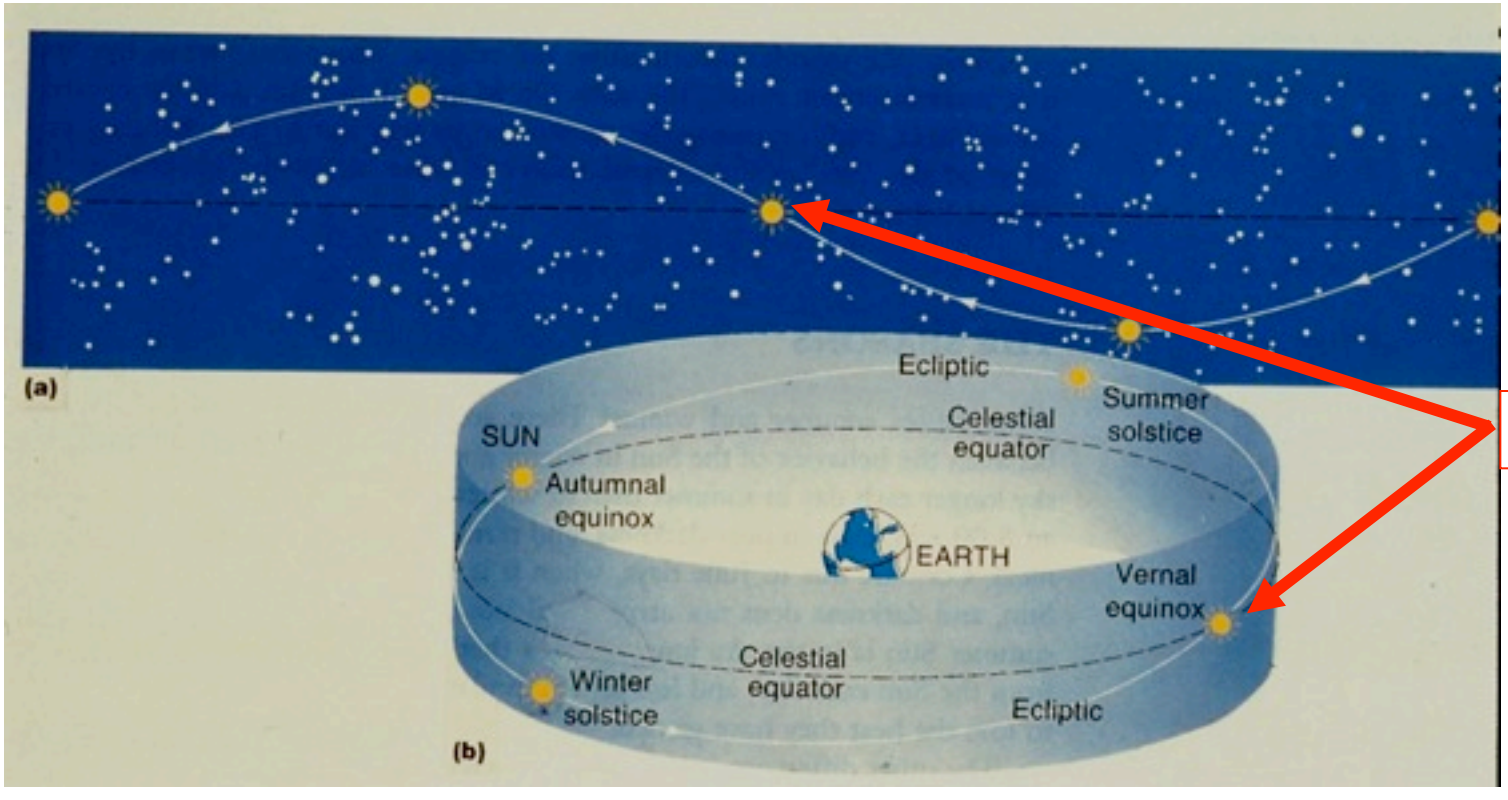


Ecliptic path = apparent path of sun through the stars.
Ecliptic plane = plane of the earth's motion (or the sun's apparent motion)

2- Coordinates (on the Celestial Sphere)

B. The Earth orbits the sun (once per year)

Let the sun mark the location of RA=0 deg on the Vernal equinox.



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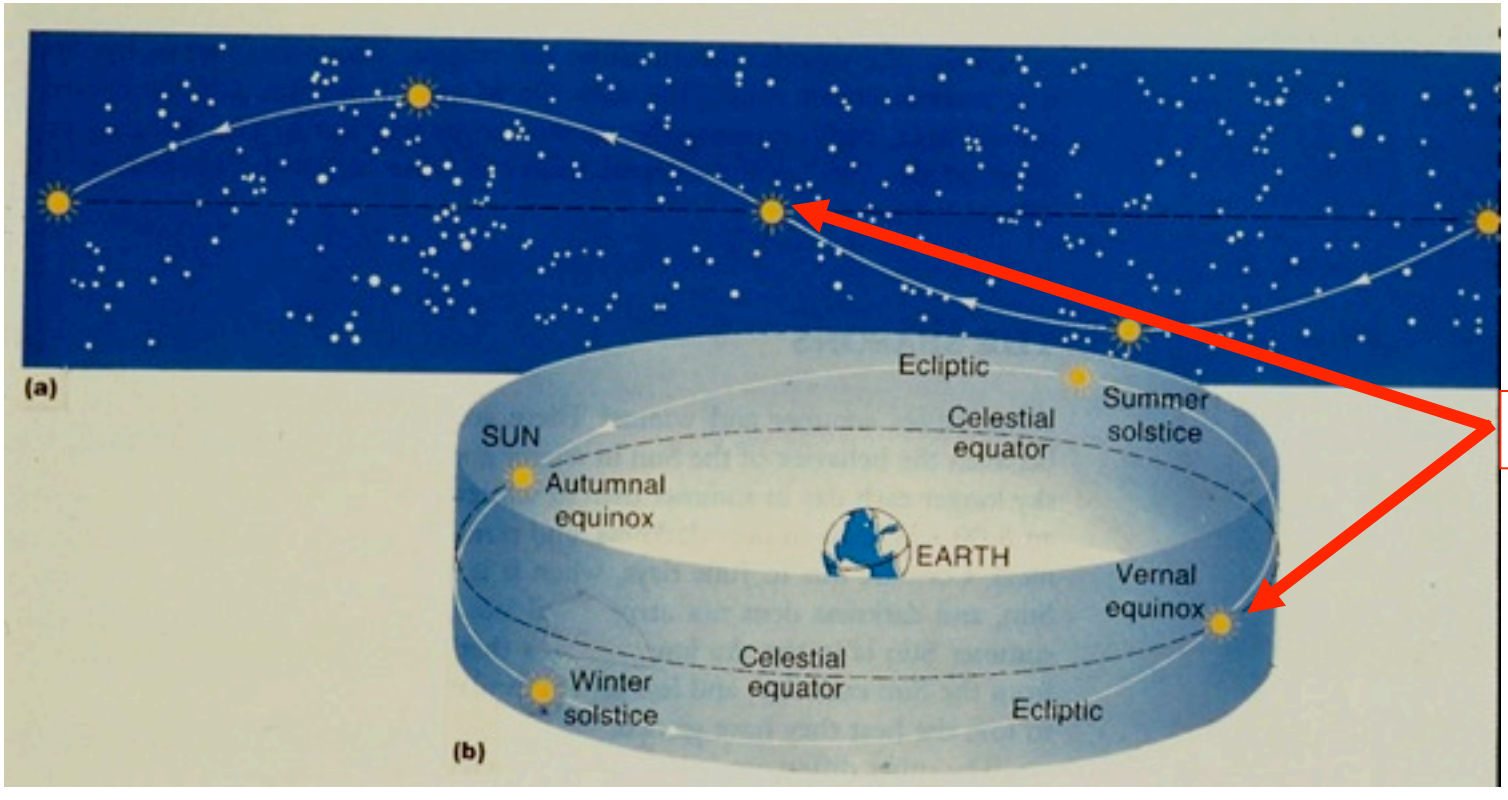
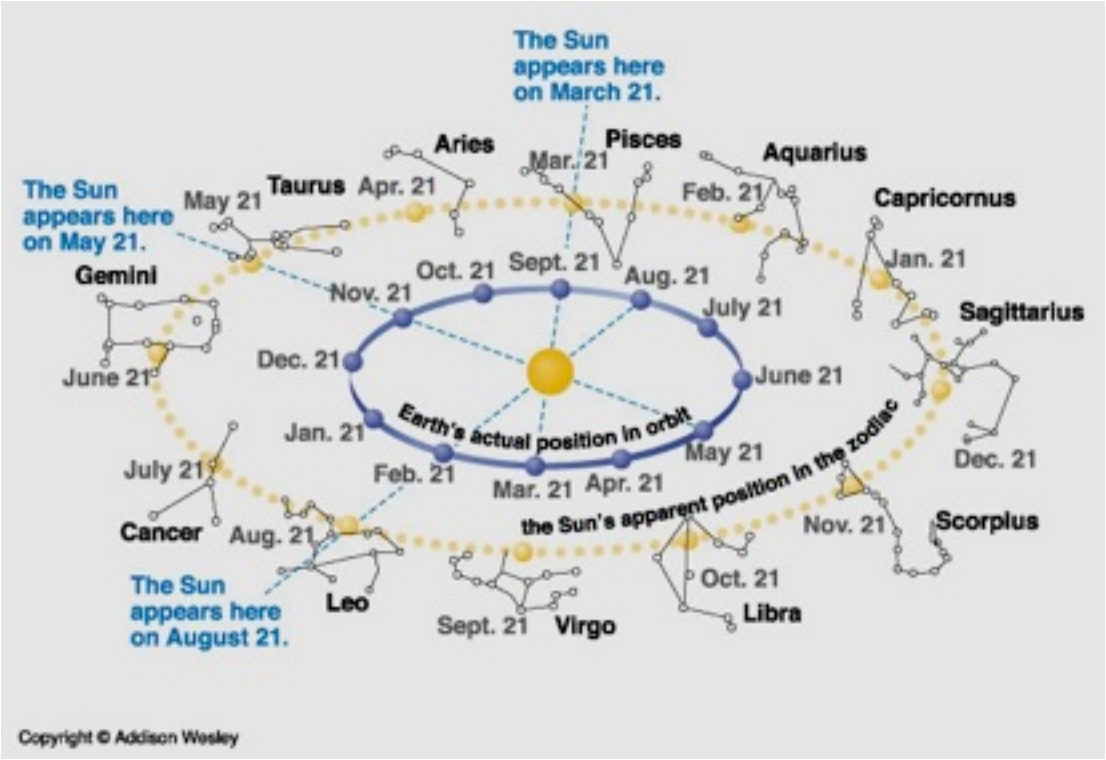


Stars at RA=0 can be seen in the fall.

2- Coordinates (on the Celestial Sphere)

B. The Earth orbits the sun (once per year)

Zodiac = constellations on the ecliptic plane



Defined in 100AD… constellations/dates are slightly off now. (Why?)

Monday, September 30, 2013

Why are signs slightly off?

Stars are so far away that the motion around sun has no effect on our position relative to the stars, so it's not that.

We spin, stars rise and set…

How has Earth's orientation changed relative to the stars?

What causes the seasons on Earth?

A. The Earth's atmosphere expands and contracts, heating and cooling as it does

B. The Earth is nearer the Sun in winter and further in the summer

C. The tilt of the Earth's axis causes differential heating in the northern and southern hemispheres

D. Differences in CO_2 levels at various times of the year causes a varying greenhouse effect

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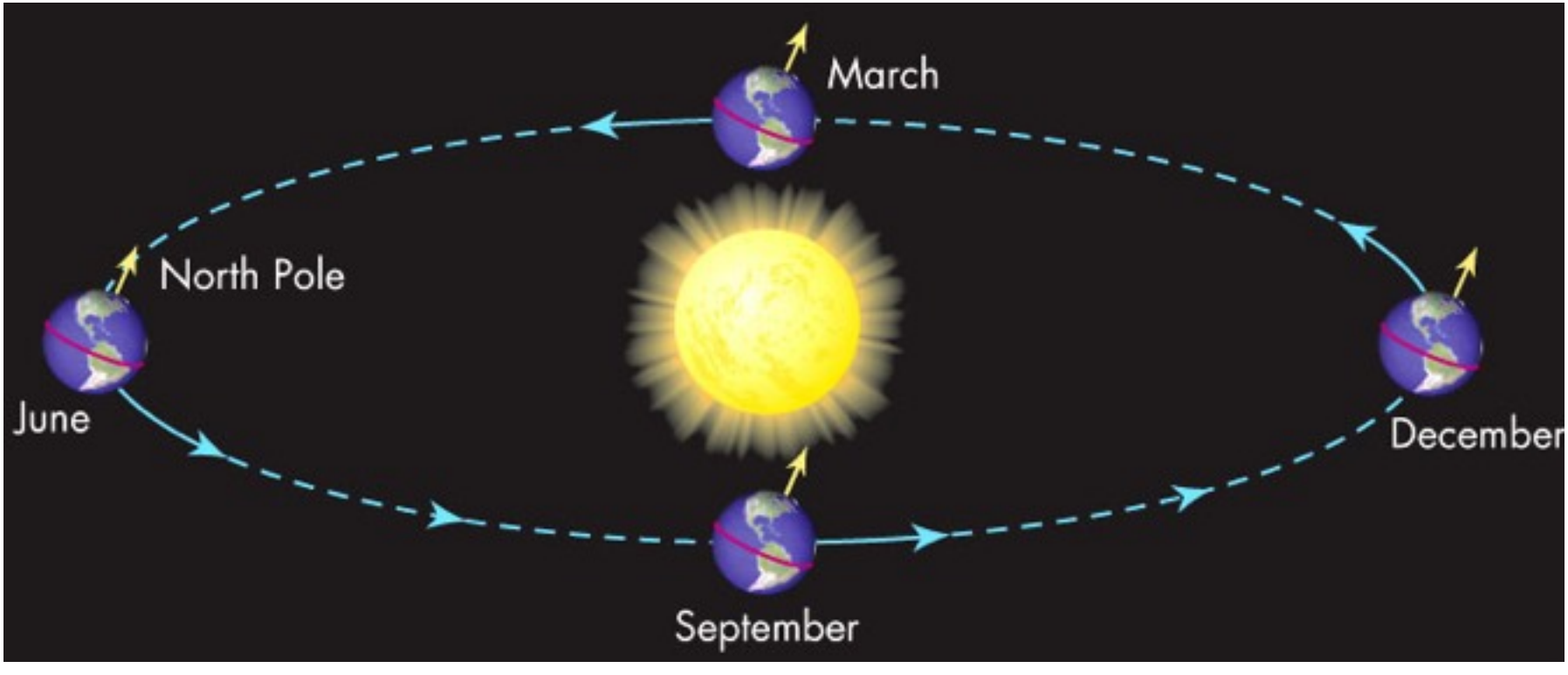
Monday, September 30, 2013

Earth is actually closest to Sun in January.

3- Seasons

B. The Earth orbits the sun (once per year) …on a tilt!

The Earth's spin-axis is tilted 23.5^{o}
relative to the plane of the orbit.

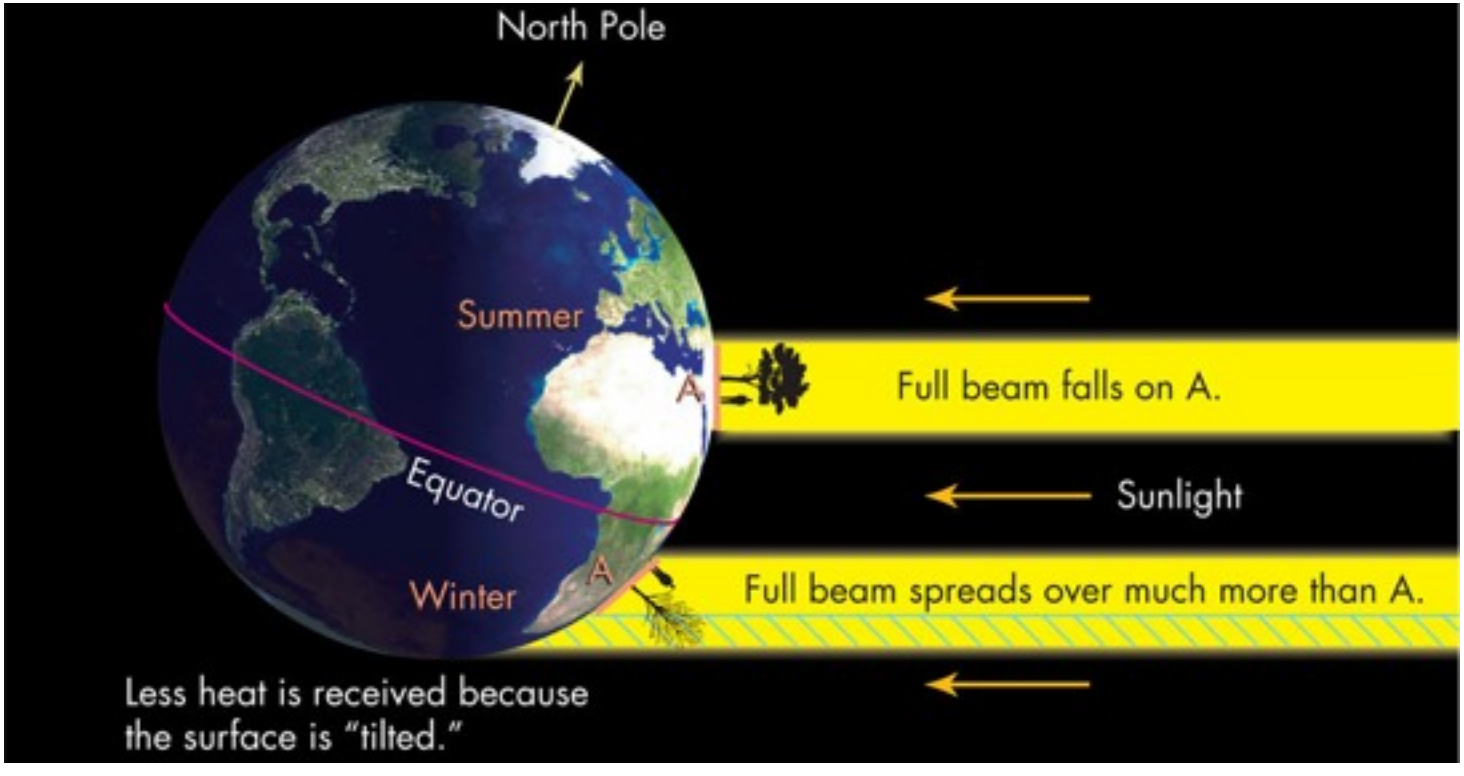


3- Seasons

B. The Earth orbits the sun (once per year) …on a tilt!

Heating depends on Energy per unit Area!

Experience confirms! (Sun feels hotter at 1pm than 5pm.
Shoulders/head gets sunburned first.)



3- Seasons

B. The Earth orbits the sun (once per year) …on a tilt!

Location of the sun at noon changes through the year

Photo taken every 10 days at noon. Records sun's highest point in sky through the year.

(Streaks are composite of photos taken every 2 minutes to show the sun ascending on 3 different days)

Which noontime location of the sun corresponds to:

- Summer Solstice?
- Winter Solstice?
- Spring equinox?
- Fall Equinox?

Monday, September 30, 2013

Called an analemma

Why is winter lobe longer than summer lobe?

- Analemma shows discrepancy between apparent and mean

4- TIME

A+B. The earth orbits and spins….which defines time?

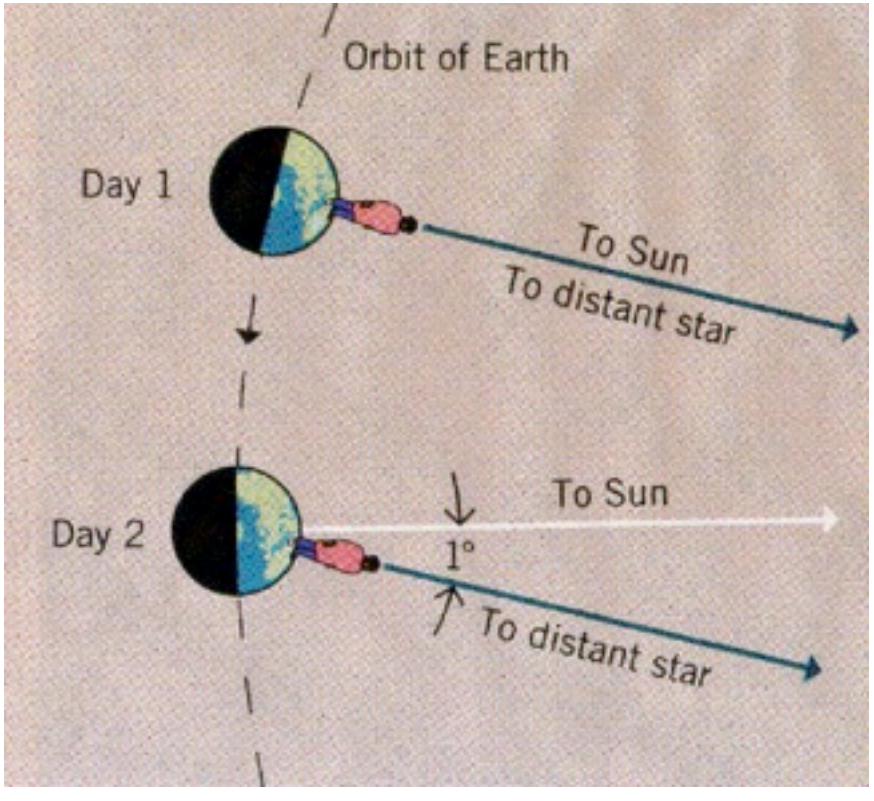
which motion defines **time**?

Solar time: relative to sun

Solar day = 1 revolution relative to the sun

Sidereal time: relative to stars

Sidereal day = 1 revolution relative to the stars



Monday, September 30, 2013

Do the spin dance – turn and move – solar vs. sidereal day

Two more ways we move through space…

3. The Sun orbits in the Milky Way

The sun (and nearby stars) orbit the center of the Milky Way once per 230,000,000 years.

How do we know? (motion of other stars in the Milky Way w.r.t. the Sun; careful study of stellar positions over time)

Chimp/human last common ancestor ~10 million years ago

Lifetime of earth – 4 by, so ~16 orbits

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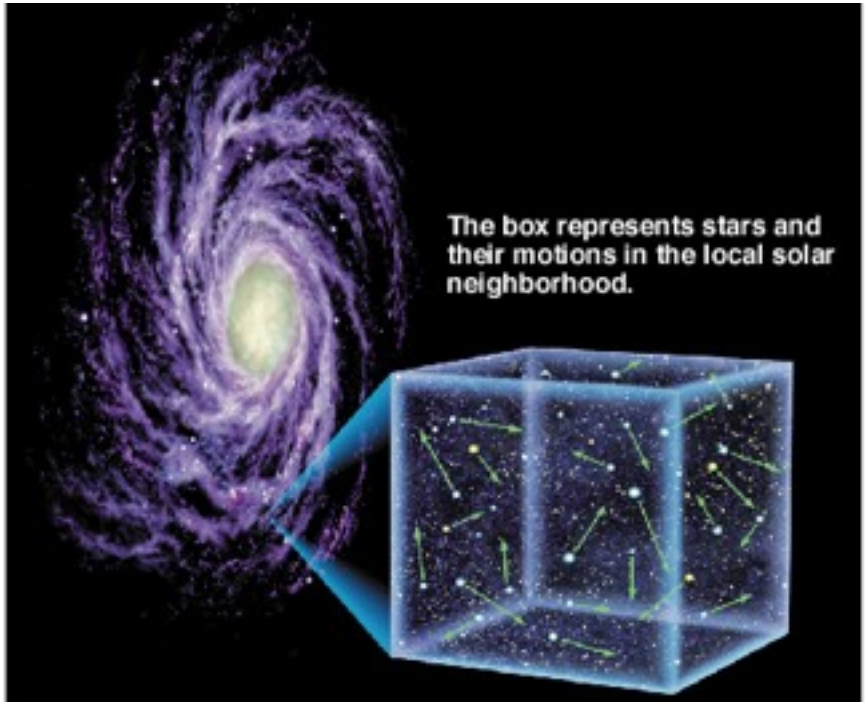

Monday, September 30, 2013

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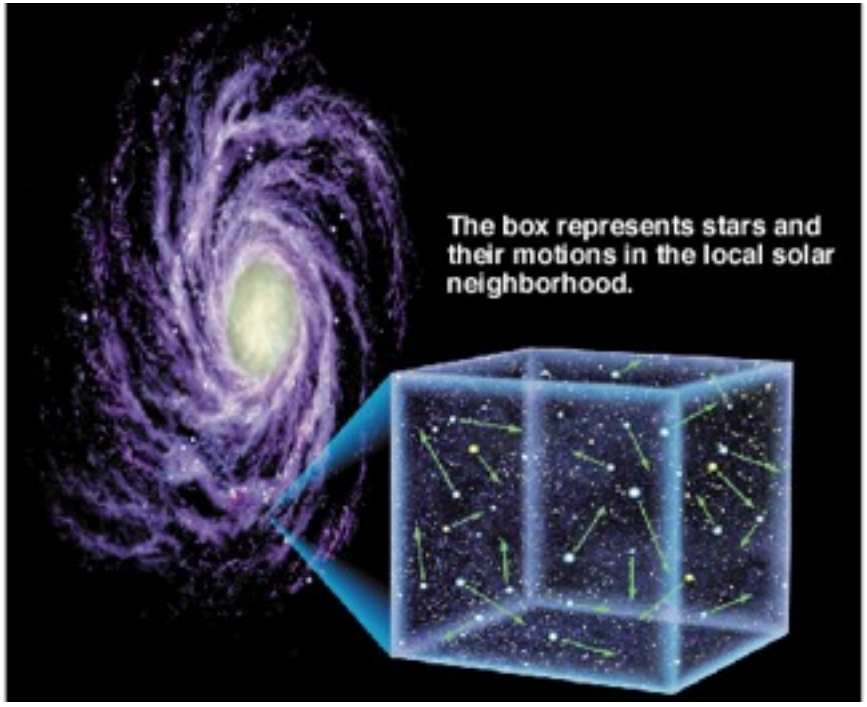

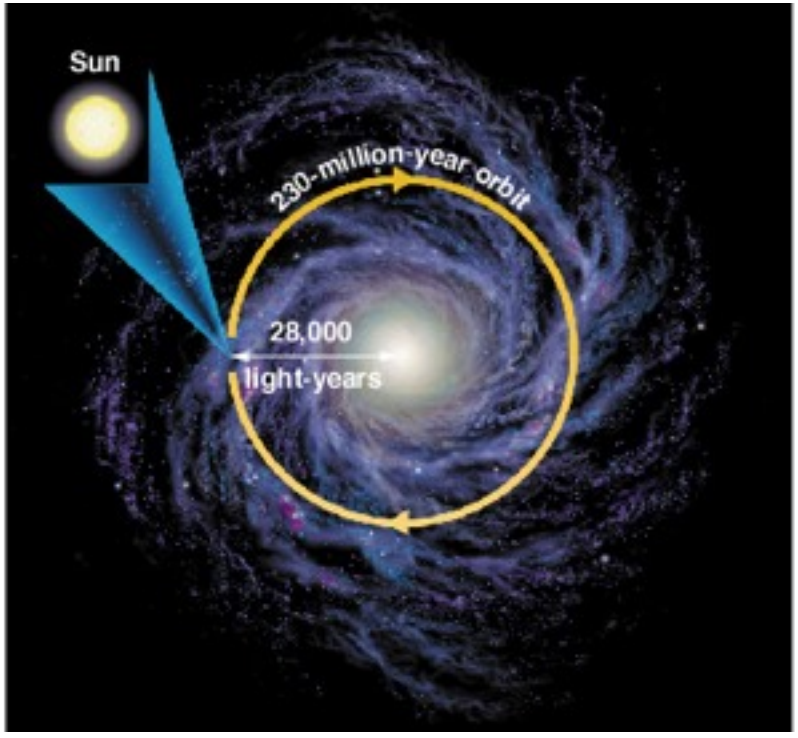

Monday, September 30, 2013

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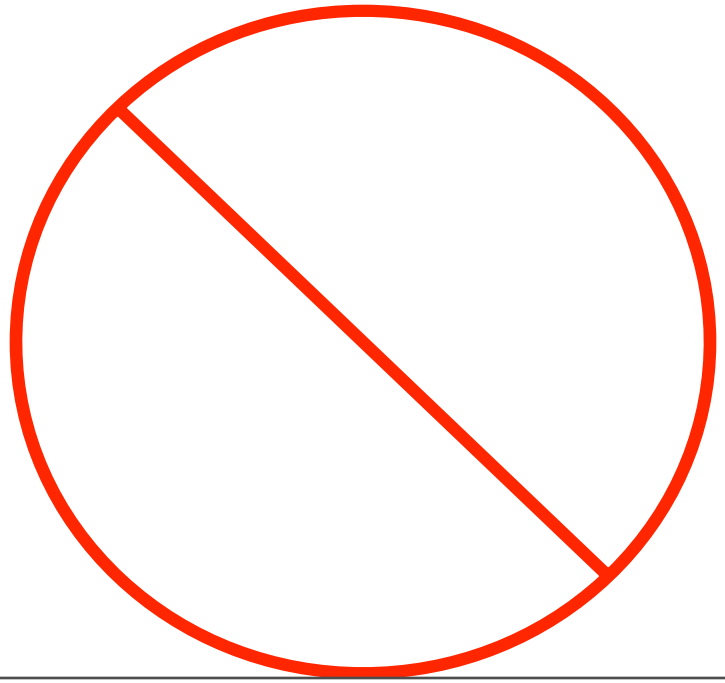
Two more ways we move through space…

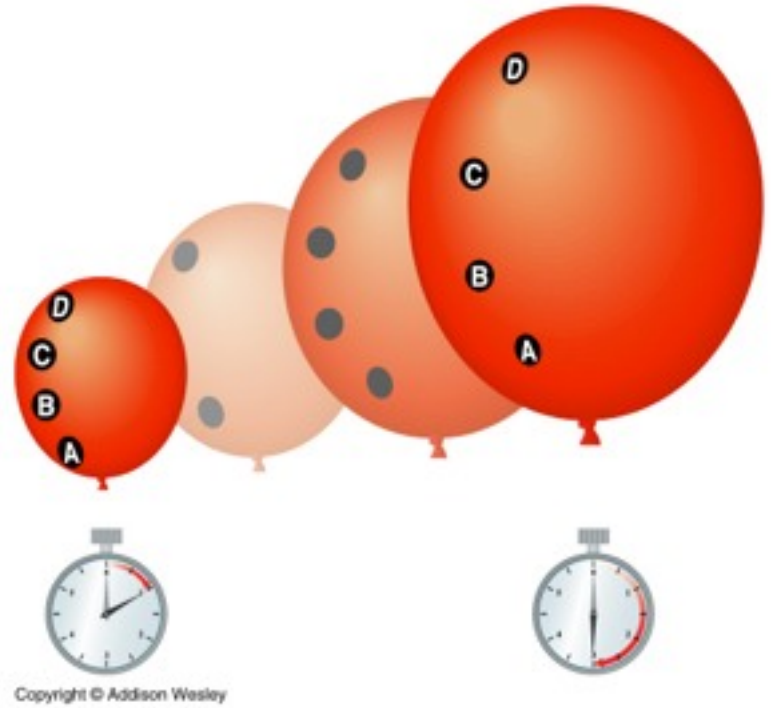
4. The Milky Way moves relative to the rest of the universe

Space itself is expanding (the space between things is increasing!)

No center. No edge.

Think of the surface of a balloon…only in 3D





Monday, September 30, 2013

Space expanding

Local motion – M31 and MW on collision course, Local Group moving towards Virgo cluster (M87) – all of which moving to

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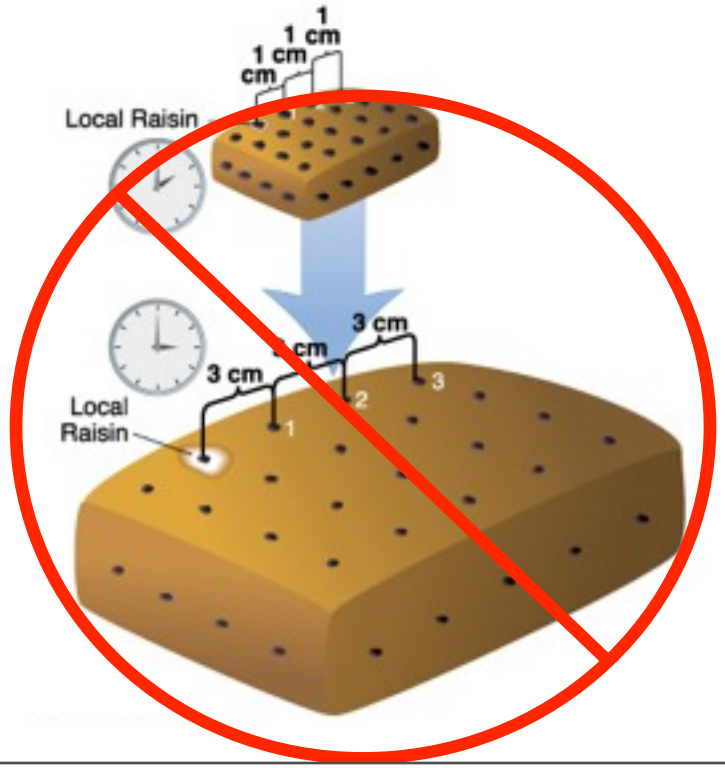

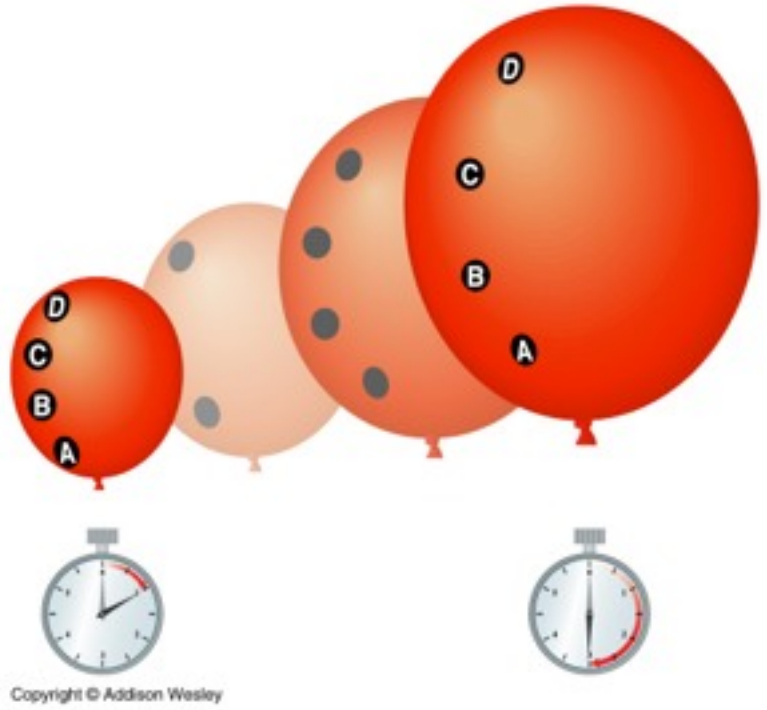

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