# Announcements

- Homework 1 is due Thursday, 1/19, at noon
- There was a reading assignment due before lecture today

  Next week's homework will be available tomorrow

  Another reading assignment due Thursday
- You need access to Connect to do the homework: http://connect.mheducation.com/class/w17
- Course info, useful links, posted lectures: http://www.ucolick.org/~crockosi/AY2Rockosi2017
- iClickers and the REEF polling app:
  - Register a new iClicker free at www1.iclicker.com
  - Get the REEF polling app, set up an account and get a subscription (not free, but you don't need to purchase a clicker)

# Announcements

- Connect support: mhhe.com/support
- There is also help via phone and chat: do use that, they are there (and you paid them!) to help you.
- There is a "check my computer" link, that's the first place to go if you are having technical problems

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Astronomy - Explorations: An Introduction to Astronomy - Arny/Schneider, 8e, The Cycles of the Sky

Chapter 1 Introduction

1.1: the Celestial Sphere

1.2: the Seasons

1.3: the Moon

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# 1 The Cycles of the Sky

Stonehenge was built more than 4000 years ago in England. The huge stones are aligned to mark the seasonal rising and setting points of the Sun on the horizon.

Practice | Previous Highlight | Previous Section | Next Section | Next Highlight | A | A

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Constance Rockosi

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Astronomy - Explorations: An Introduction to Astronomy - Arny/Schneider, 8e, The Cycles of the Sky

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TRAINING & RESOURCES

SUPPORT

SYSTEM REQUIREMENTS

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# Training & Support for Students

TRAINING & RESOURCES
SUPPORT
SYSTEM REQUIREMENTS

## System Requirements

Connect works best with the following system requirements:

### Desktop

#### Operating systems:

- MS Windows 7
- MS Windows 8
- MS Windows 8.1
- MS Windows 10
- OSX 10.10 - Yosemite
- OSX 10.9 - Mavericks
- ChromeBook

#### Browsers:

- Chrome 40+
- Safari 7.x+
- Firefox 35+
- IE10+
- Windows Edge Browser

#### Plug-ins:

- Flash 11+
- Java SE6, SE7
- Quicktime 7.7+

### Tablets

(available for new versions of Connect *only*)

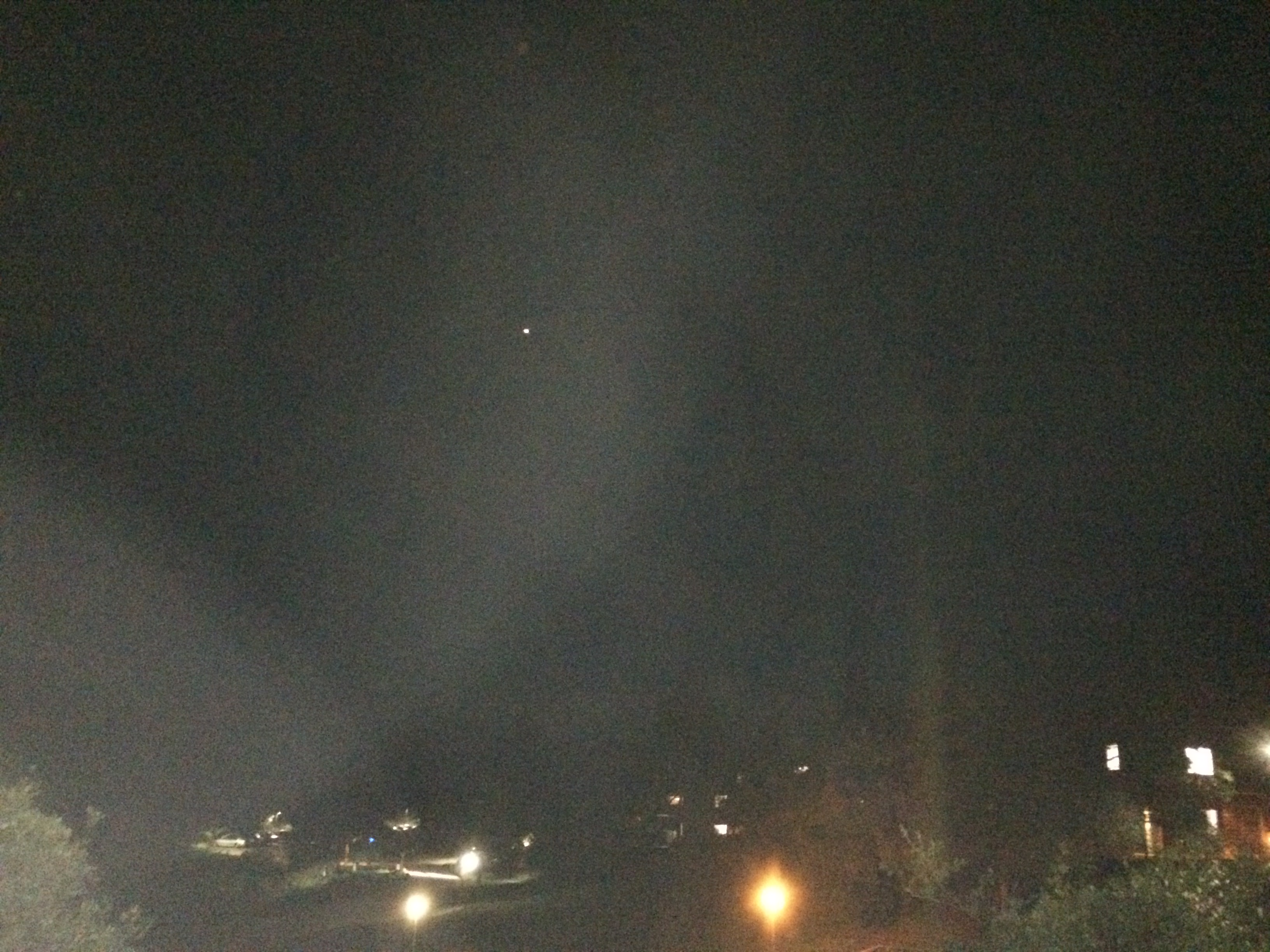
#### Operating systems:

- Android 4.4+ on 7", 8", 10" and 10.1" devices
- Android 5.X on 7", 8", 10" and 10.1" devices
- iOS 7.x on 8" and 10" devices
- iOS 8.X on 8" and 10" devices

#### Browsers:

- Chrome Mobile
- Mobile Safari

Does your device meet the requirements for Connect? Click here to check your device.



# iClicker (and polling app) Check

- “iClicker” will mean either a clicker or polling app, in case I forget on a slide

- Polling test question:

    A:  I brought my clicker today or I have the REEF polling app installed and registered

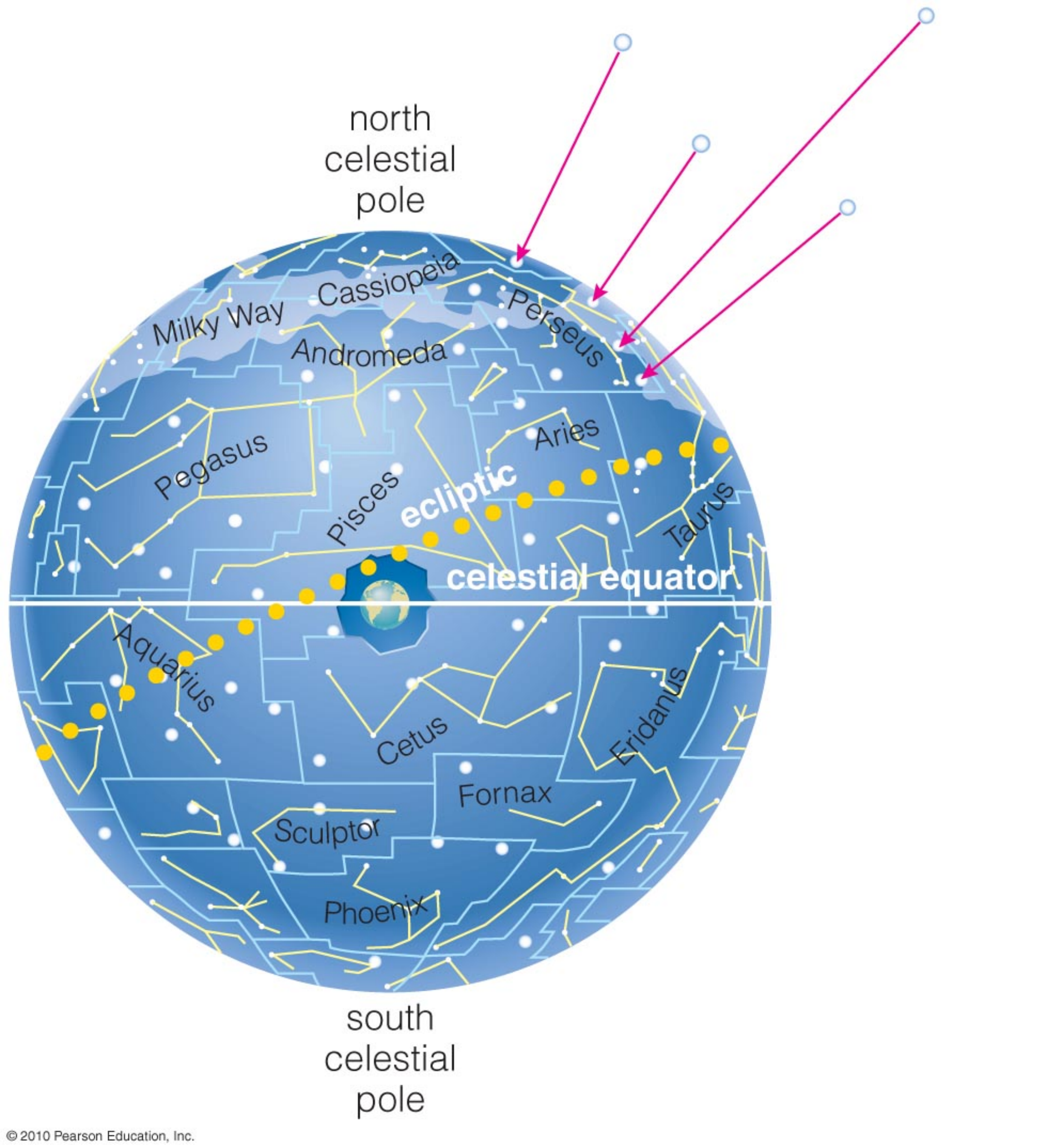
    B: Working on it!  I’ll have it done by the deadline this Thursday

# Learning the Size of Our Solar System

- All the stars rise and set in fixed patterns on the Celestial Sphere as the earth rotates
- We observe everything else (Sun, Moon, planets) as moving on the Celestial Sphere, too
- How do we interpret the separation of two objects on the Celestial Sphere?
- The big problem is distance

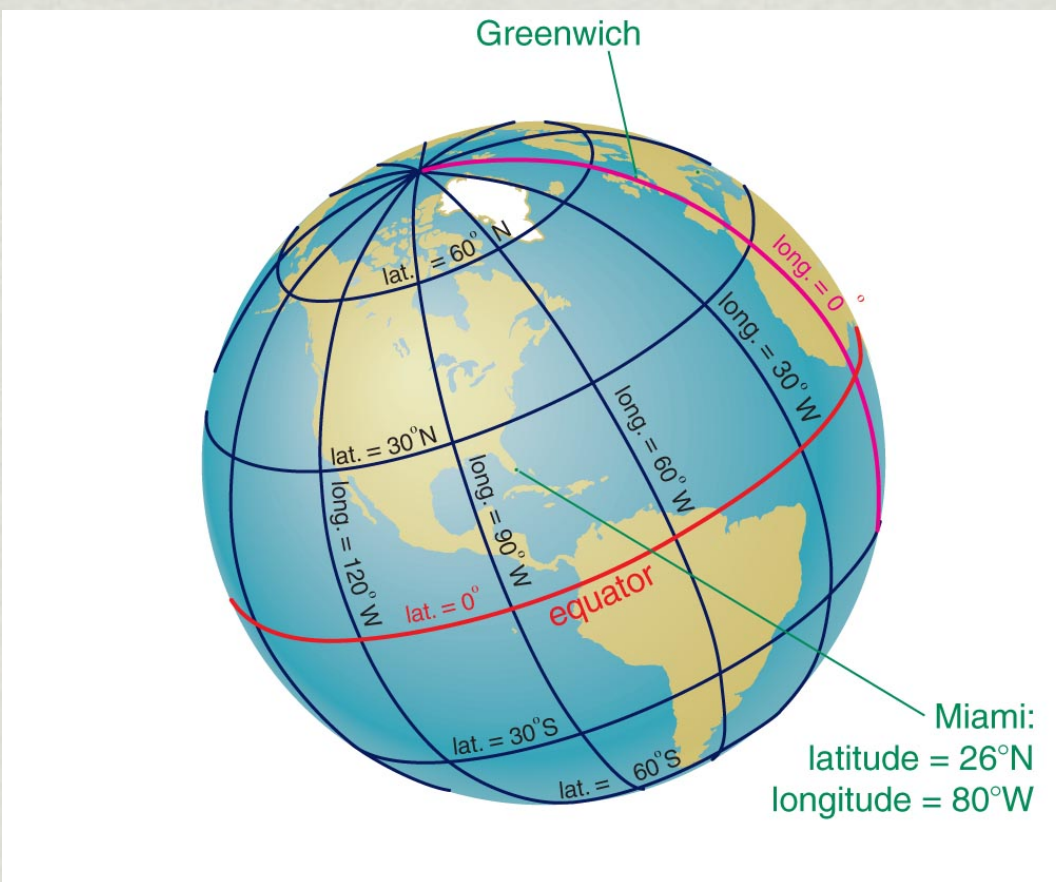
  Are bright stars really bright, or just close?

  Are faint stars faint because they are dim or far away?



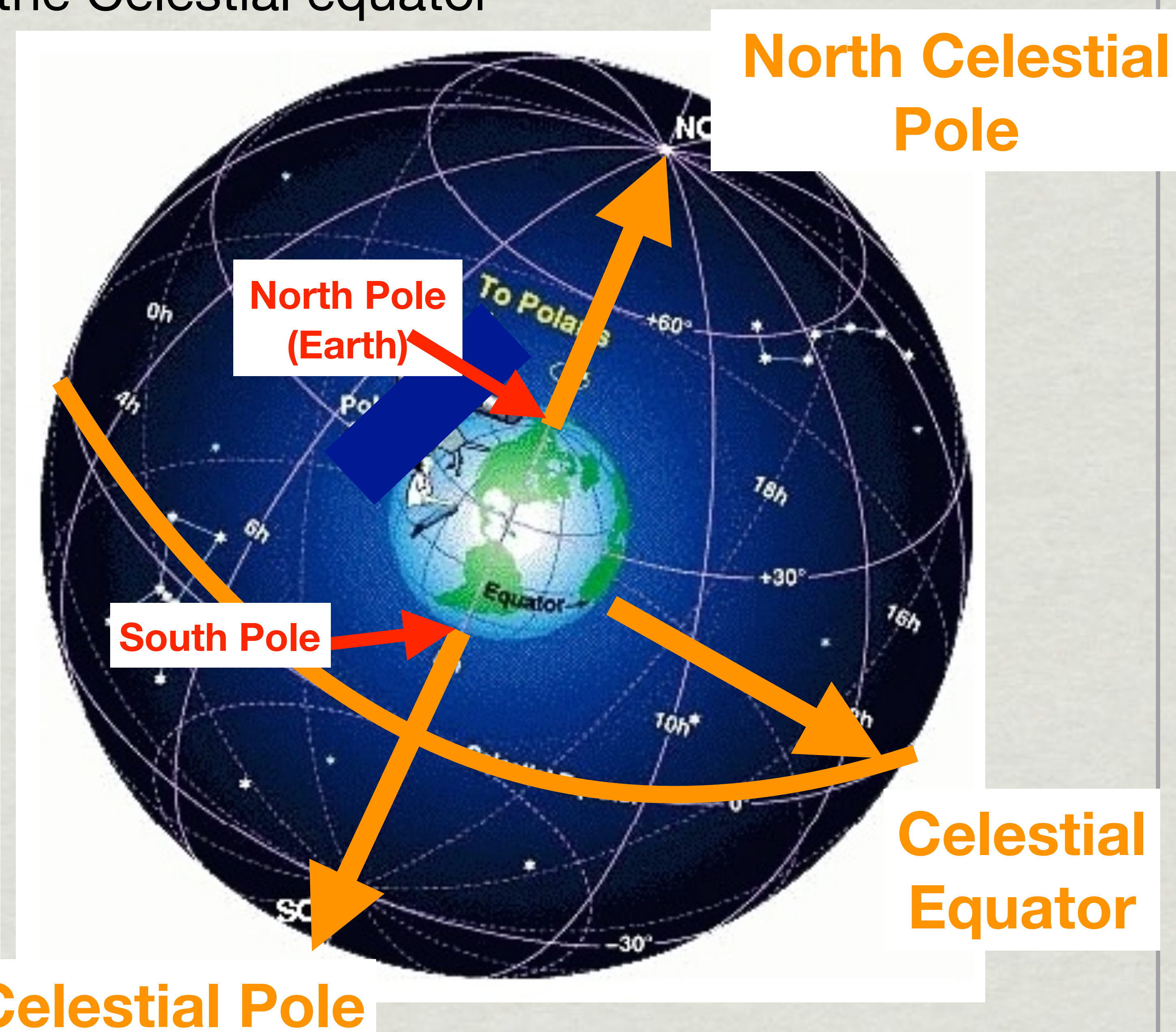
# Celestial Sphere and Angular Distance

- "Celestial Sphere": projection of latitude and longitude onto the sky
- North and South poles of Earth line up with the North and South Celestial Poles
- Equator of the Earth lines up with the Celestial equator



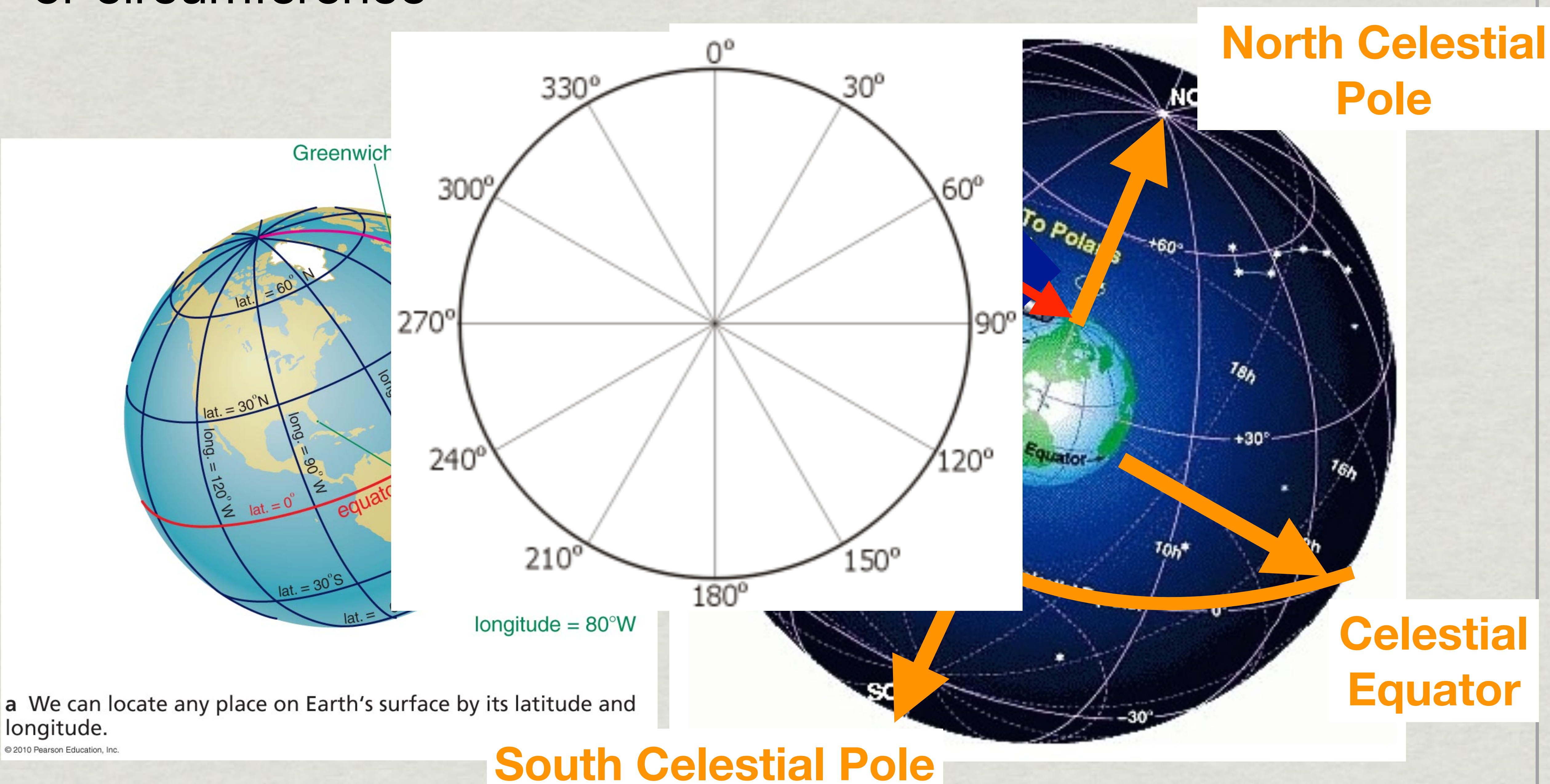

a We can locate any place on Earth's surface by its latitude and longitude.





# Celestial Sphere and Angular Distance

- Measure distances around a circle in angles,  units of degrees.
- There are 360 degrees in a circle, no matter its physical diameter or circumference




a We can locate any place on Earth's surface by its latitude and longitude.

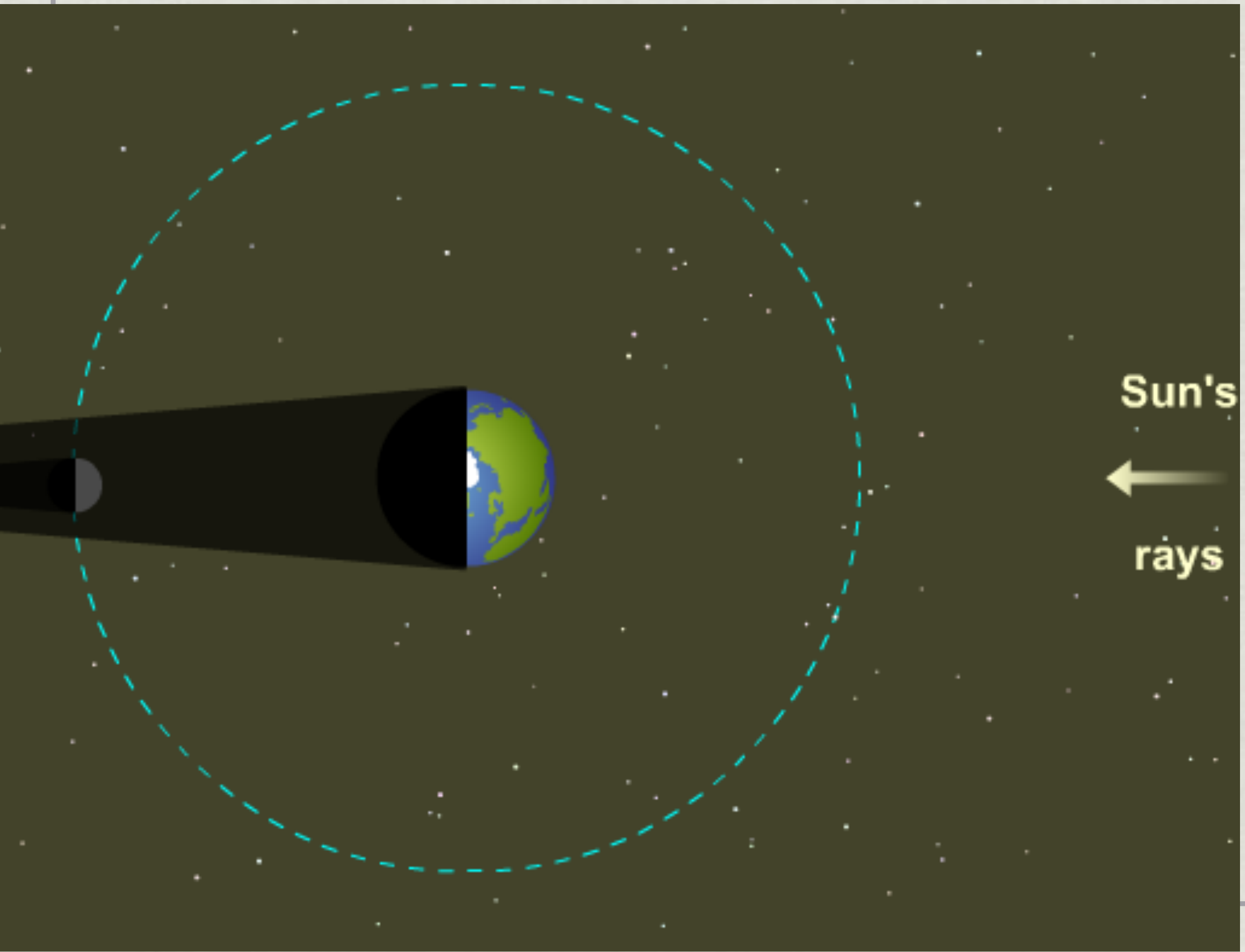
# Learning the Size of Our Solar System

Relative Measurements: sizes of the earth and moon

Lunar eclipse: moon passes through the shadow of the Earth

A reasonable guess: the diameter of Earth's shadow is about the same as the diameter of the Earth

So we can use the earth's diameter as a ruler!

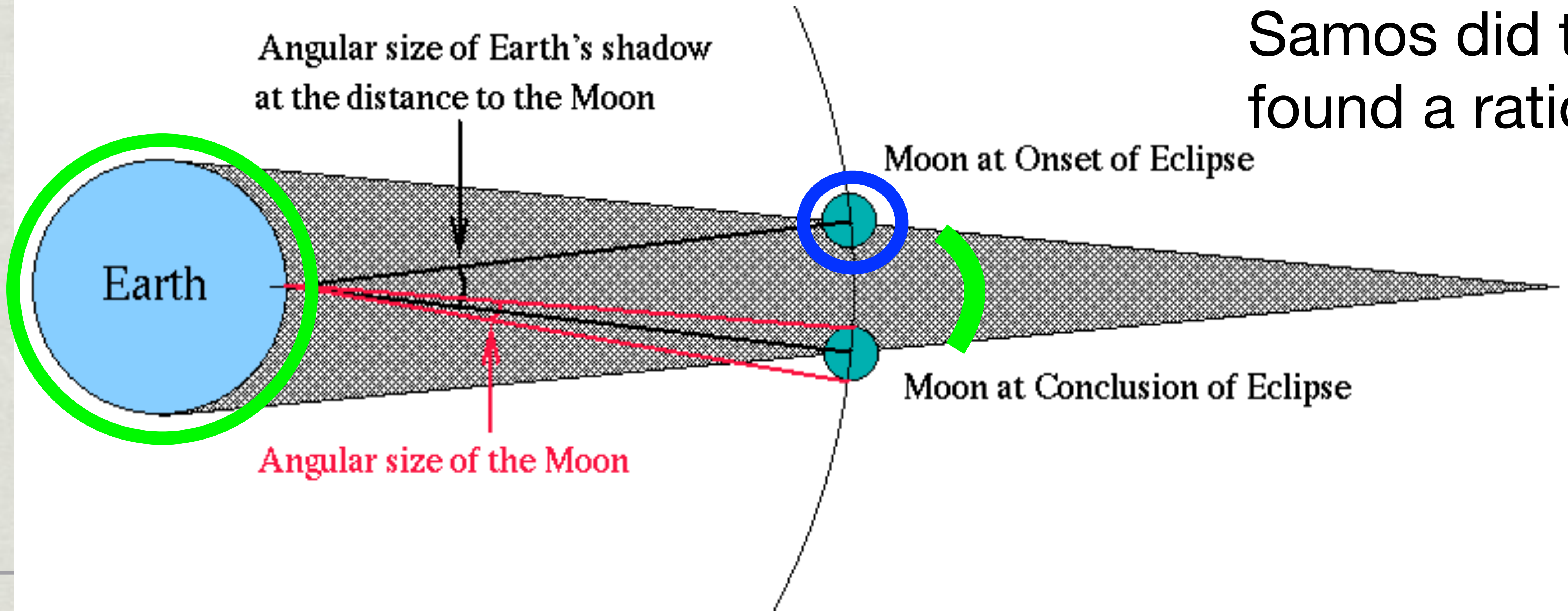



# Learning the Size of Our Solar System

Relative Measurements: sizes of the earth and moon

$$\frac{\text{Angle separation of moon before and after eclipse}}{\text{Angular size of moon}} = \frac{\text{Diameter of Earth}}{\text{Diameter of Moon}}$$

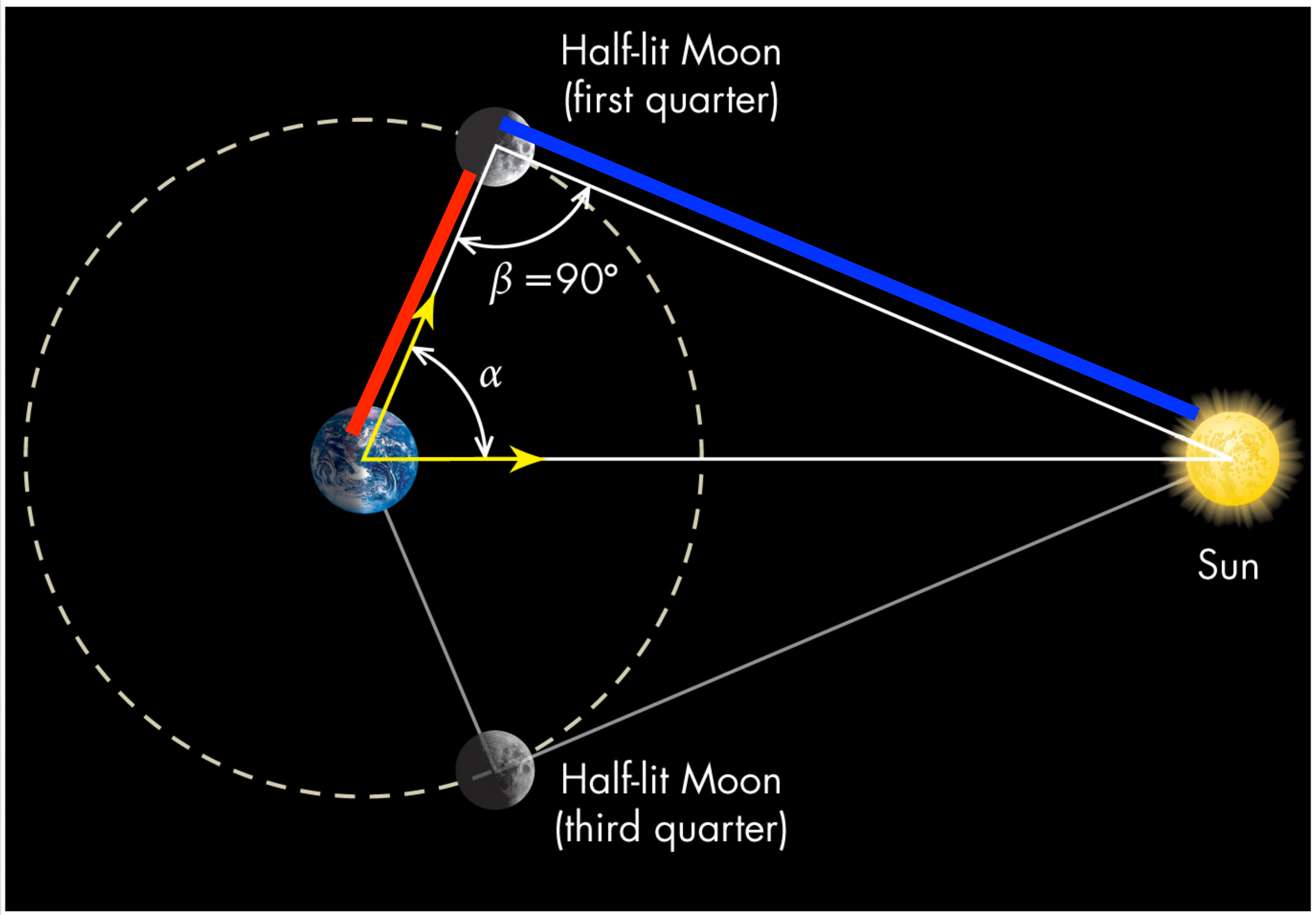
Aristarchus of Samos did this, found a ratio of 2.9



# Learning the Size of Our Solar System

## Relative Measurements: distance of the sun and moon






a: Aristotle (2010) *"On the Heavens and On Generatio*

Sun always illuminates one half of the moon.

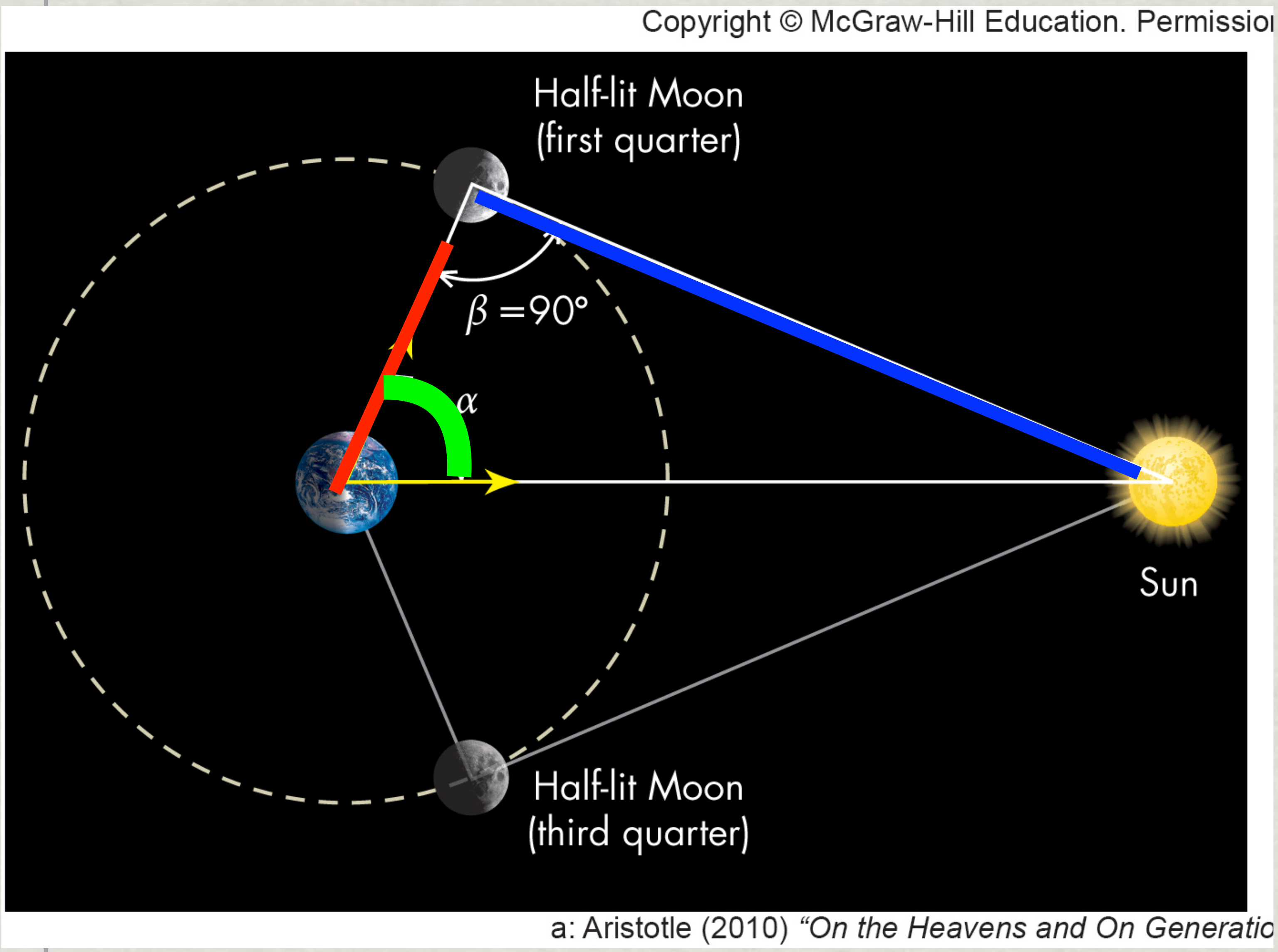
When we observe the moon to be half illuminated:

-> angle between our line of sight to the moon and the line of sight between the sun and moon is 90 degrees exactly

Aristarchus of Samos again

# Learning the Size of Our Solar System

Relative Measurements: distance of the sun and moon




Sun always illuminates one half of the moon.

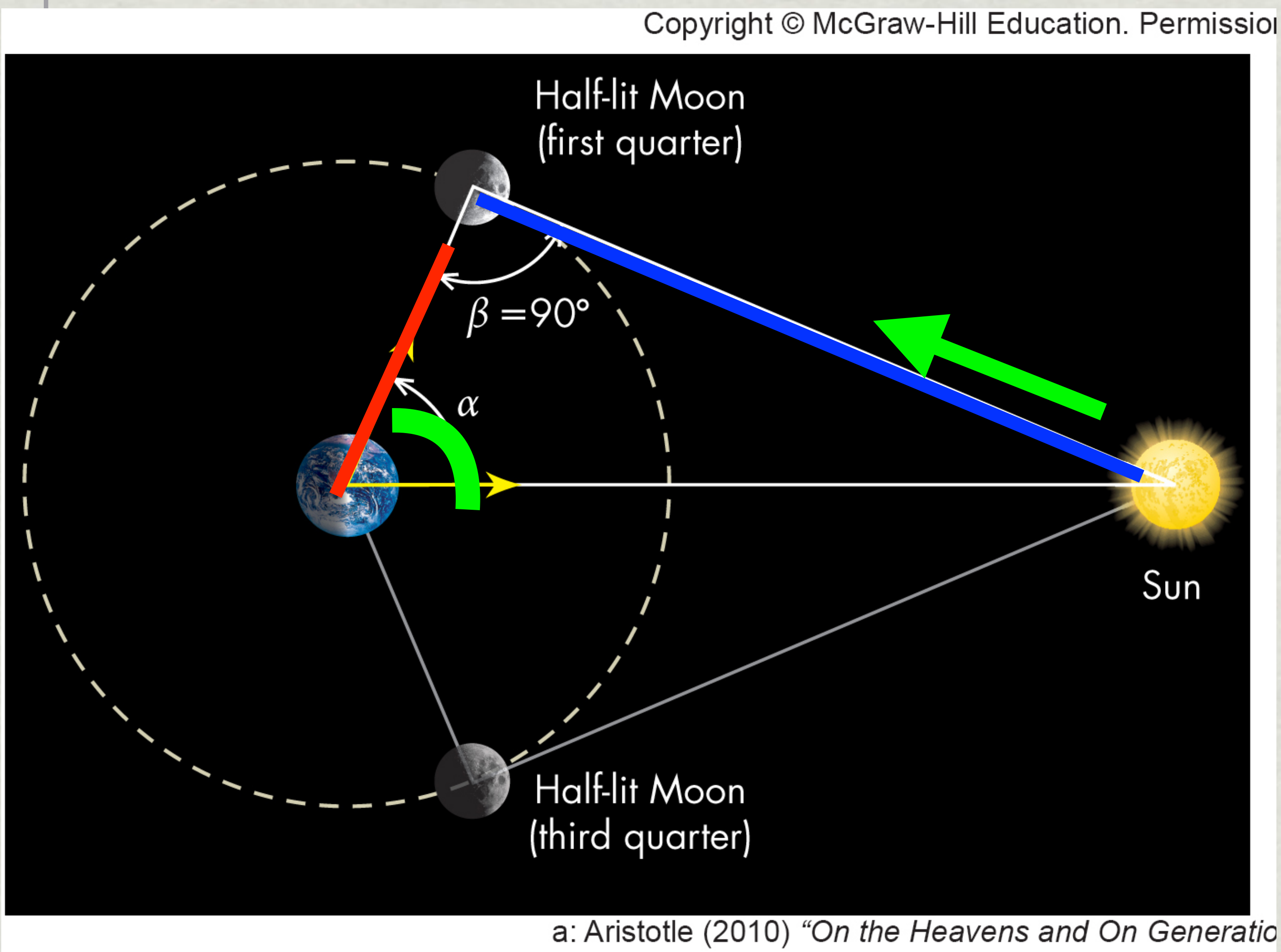
When we see the moon as half illuminated:

-> angle between our line of sight to the moon and the line of sight between the sun and moon is 90 degrees exactly

When we observe the moon to be half illuminated: the angle we measure between the moon and sun depends on the relative distances of the moon and sun.

# Learning the Size of Our Solar System

Relative Measurements: distance of the sun and moon

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# Learning the Size of Our Solar System

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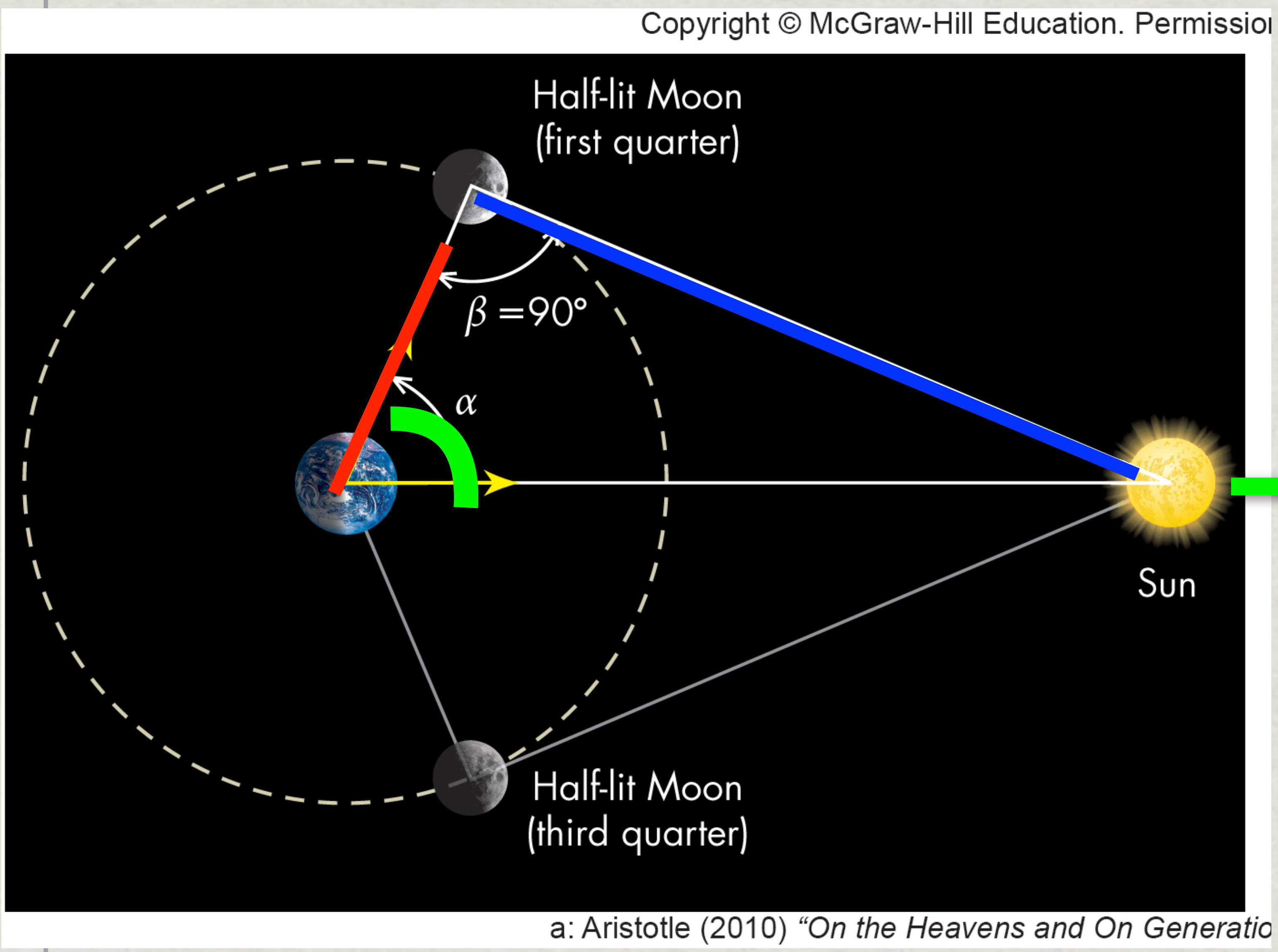


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When we see the moon as half illuminated:

-> angle between our line of sight to the moon and the line of sight between the sun and moon is 90 degrees exactly

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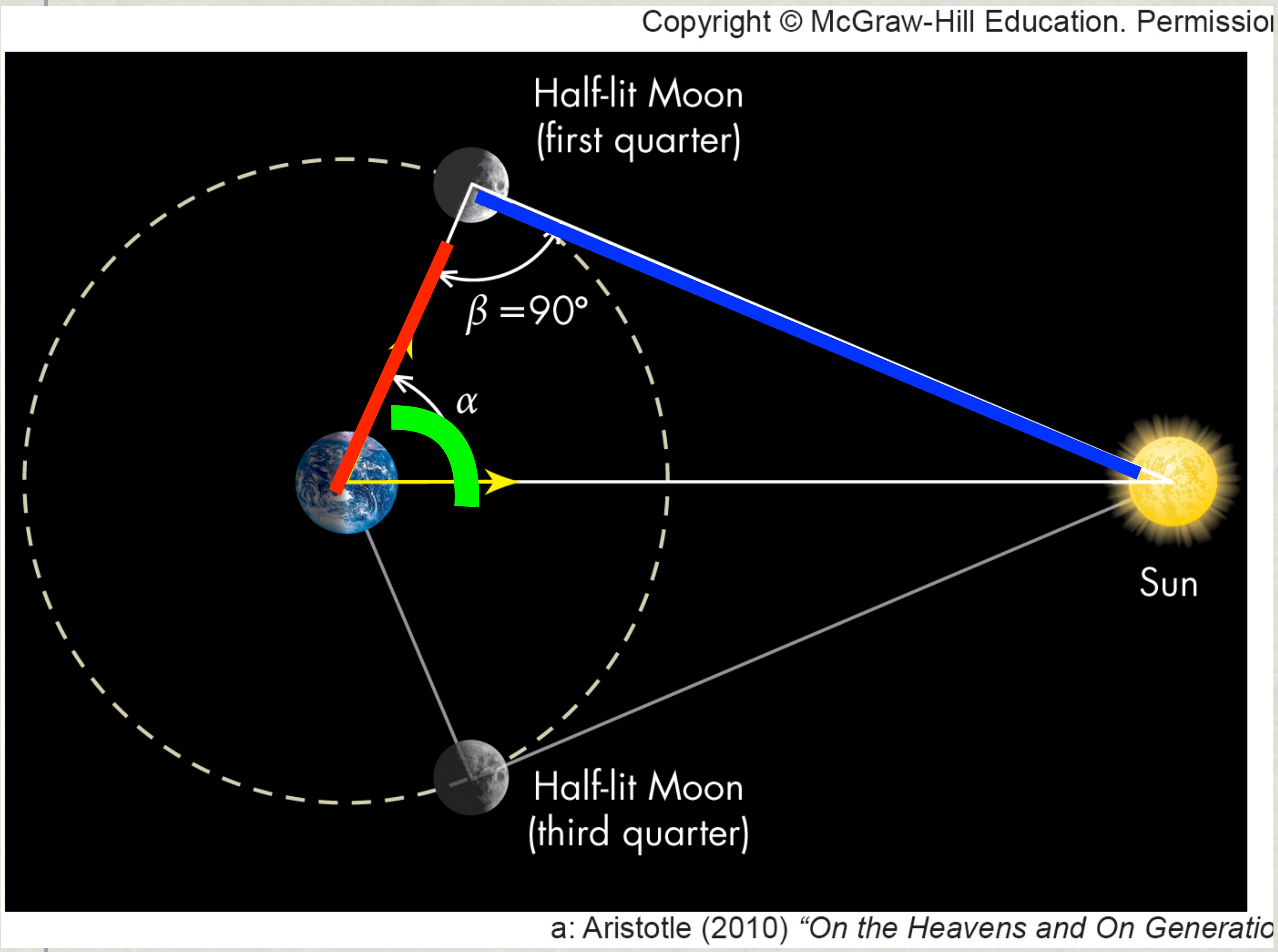
# Learning the Size of Our Solar System

Relative Measurements: distance of the sun and moon




Aristarchus used this, estimated that the sun is 20 times farther away from earth than the moon.

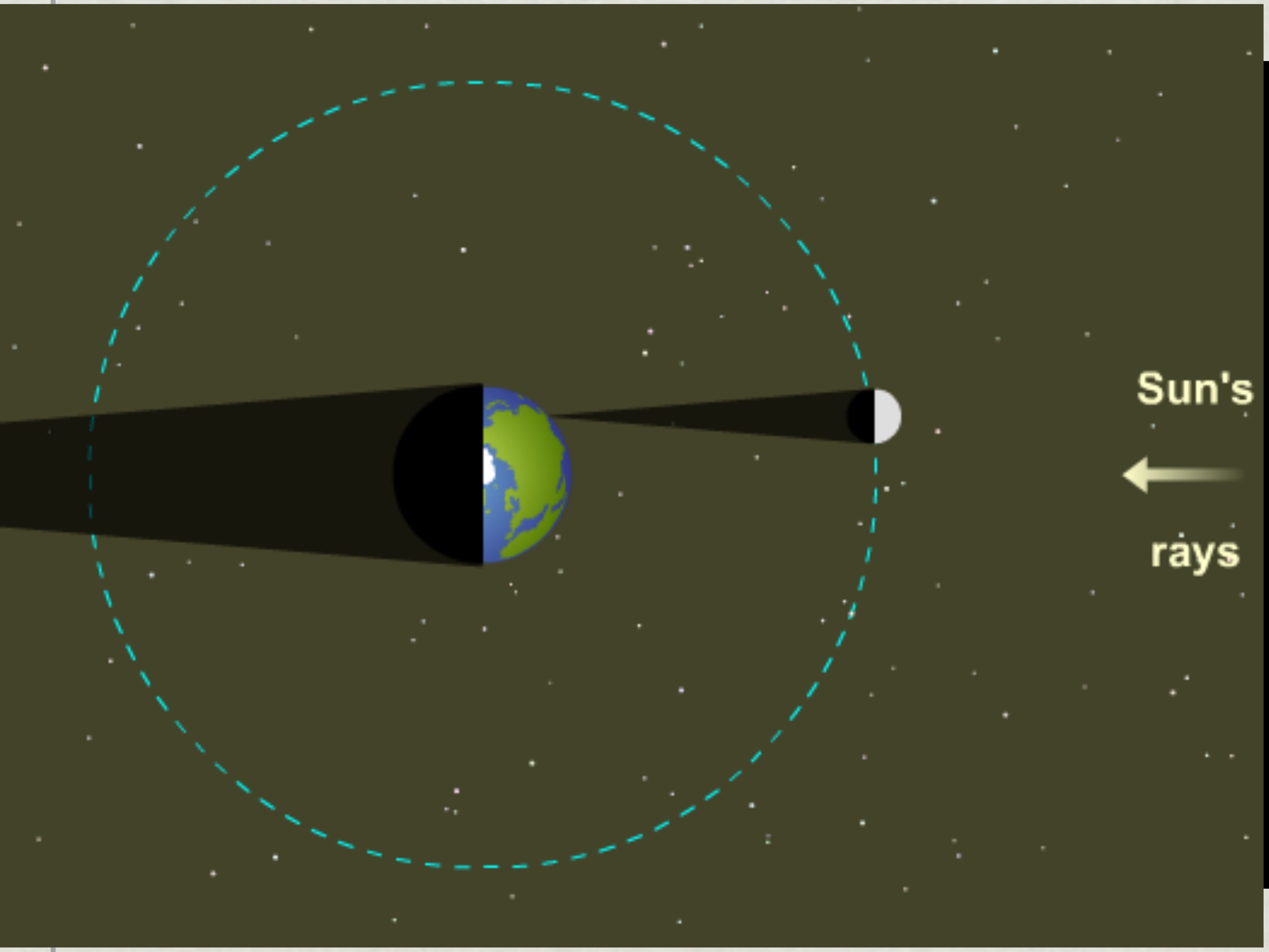
The true answer: the sun is 400x farther away than the moon.

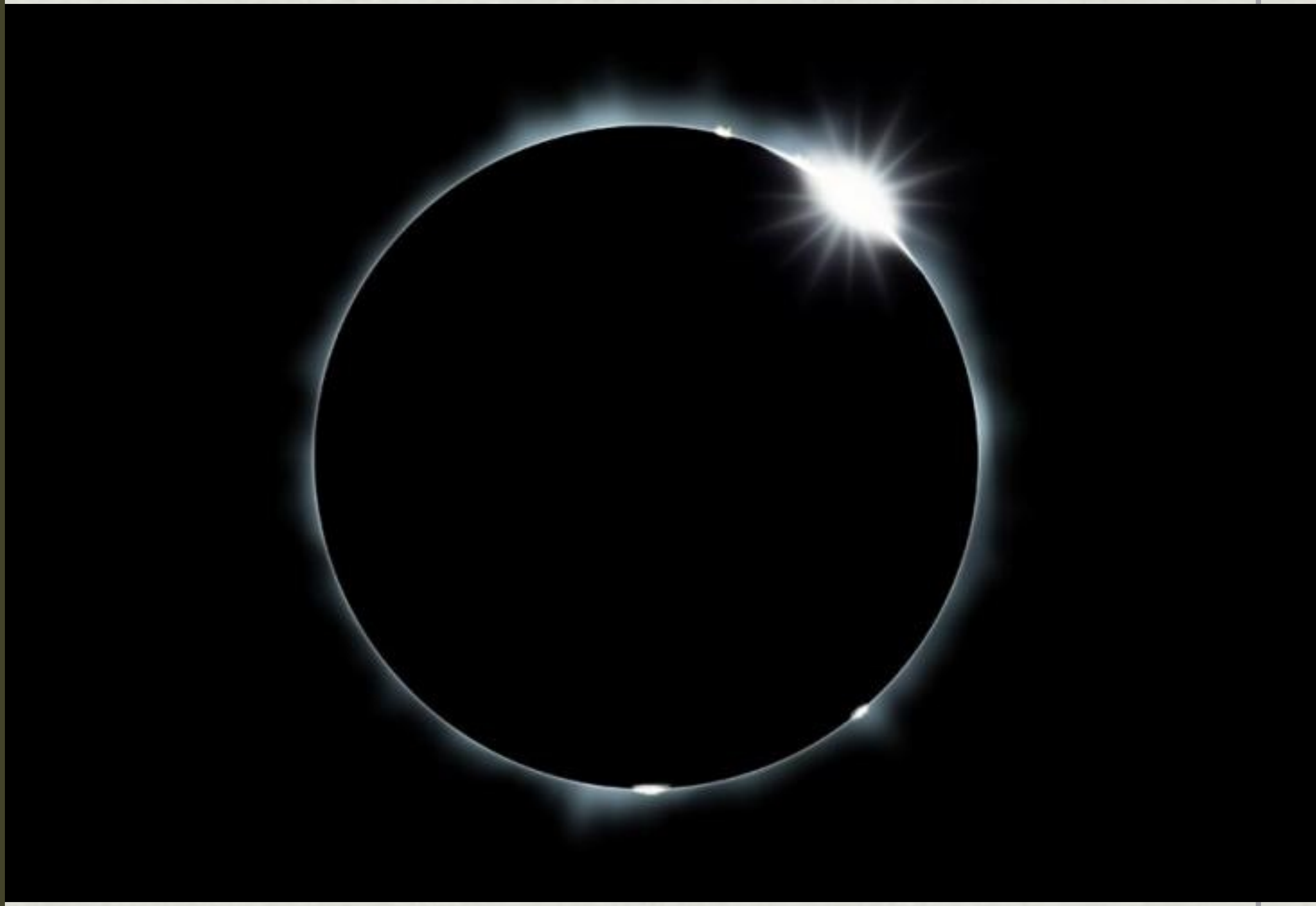
But even that factor of 20 changes how we think about the sun and moon being "on the Celestial Sphere"

# Learning the Size of Our Solar System

Relative Measurements: size of the sun and moon

Solar eclipse: tell us that the angular size of the sun and moon are similar.



# Learning the Size of Our Solar System

Relative Measurements: size of the sun and moon

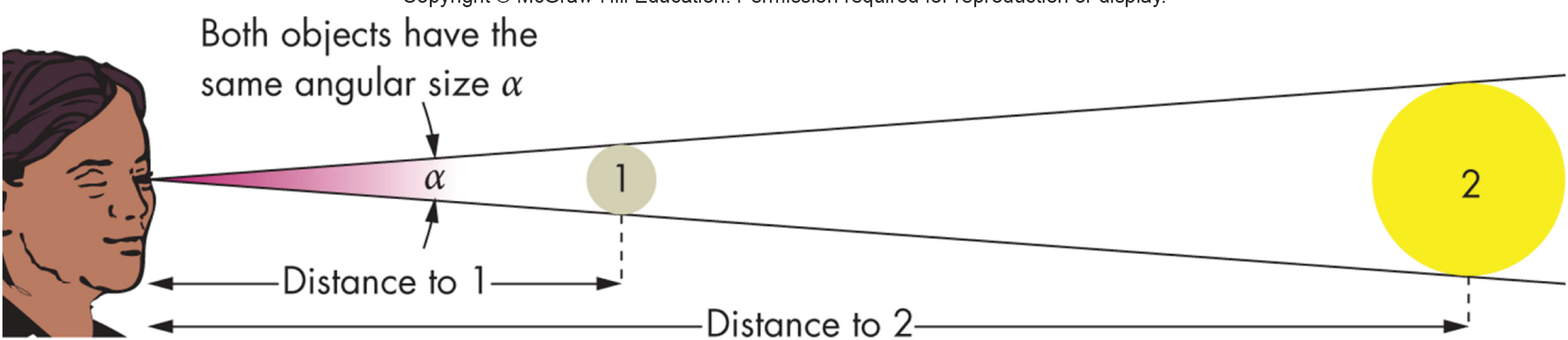
If we have the relative sizes of the moon and sun, we can also calculate their relative distances.

Use similar triangles:

$$\frac{\text{Diameter of moon}}{\text{Distance to moon}} = \frac{\text{Diameter of sun}}{\text{Distance to sun}}$$

Rearrange: $$\frac{\text{Diameter of sun}}{\text{Diameter of moon}} = \frac{\text{Distance to sun}}{\text{Distance to moon}}$$





# Learning the Size of Our Solar System

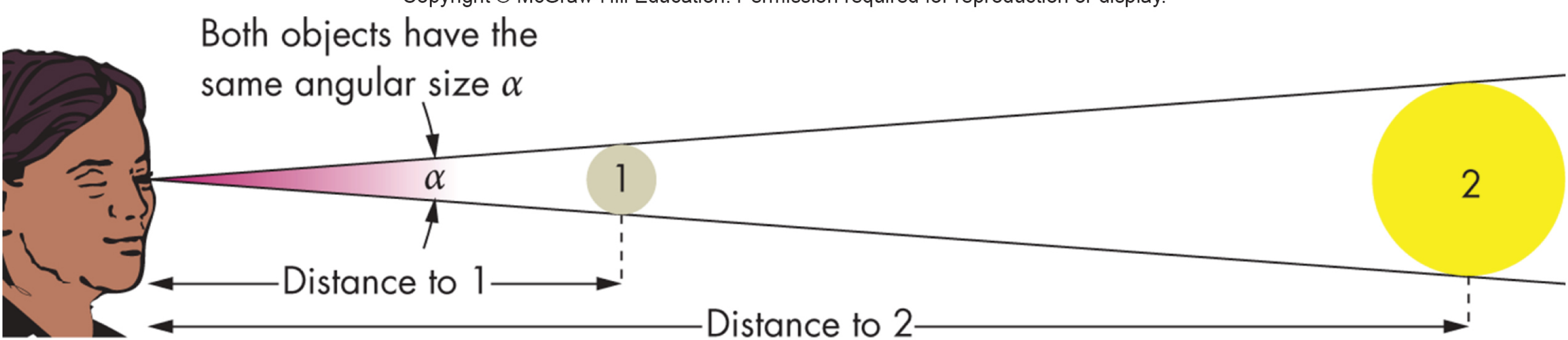
Relative Measurements: size of the sun and moon

From last slide: $\frac{\text{Diameter of Sun}}{\text{Diameter of Moon}} = \frac{\text{Distance to Sun}}{\text{Distance to Moon}}$

Remember: $\frac{\text{Distance Sun}}{\text{Distance to Moon}} = 20$ (Aristarchus of Samos, really 400)

So: $\frac{\text{Diameter of Sun}}{\text{Diameter of Moon}} = 20$





# Learning the Size of Our Solar System

Relative Measurements: size of the sun and moon

Similar triangles: $$\frac{\text{Diameter of Sun}}{\text{Diameter of Moon}} = \frac{\text{Distance to Sun}}{\text{Distance to Moon}}$$

Remember: $$\frac{\text{Diameter of Earth}}{\text{Diameter of Moon}} = 2.9$$

So: $$\frac{\text{Diameter of Moon}}{\text{Diameter of Earth}} = \frac{1}{2.9}$$

$$\frac{\text{Diameter of Moon}}{\text{Diameter of Earth}} \times \frac{\text{Diameter of Sun}}{\text{Diameter of Moon}} = \frac{\text{Diameter of Sun}}{\text{Diameter of Earth}}$$

Plug in numbers: 1/2.9 x 20 = 7

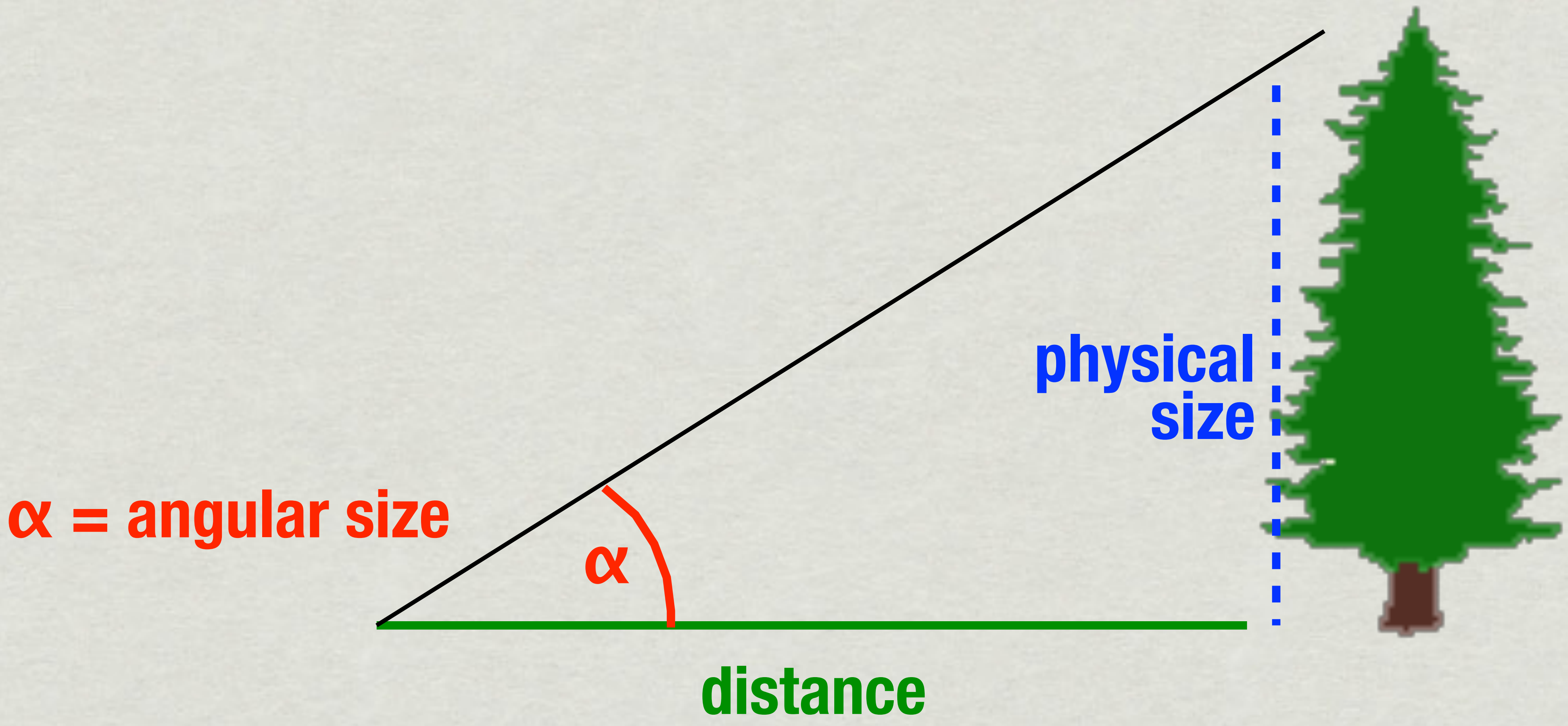
True answer: 100, but 7 is a long way from 1, ratio of angular sizes

# Distance and Angular Size

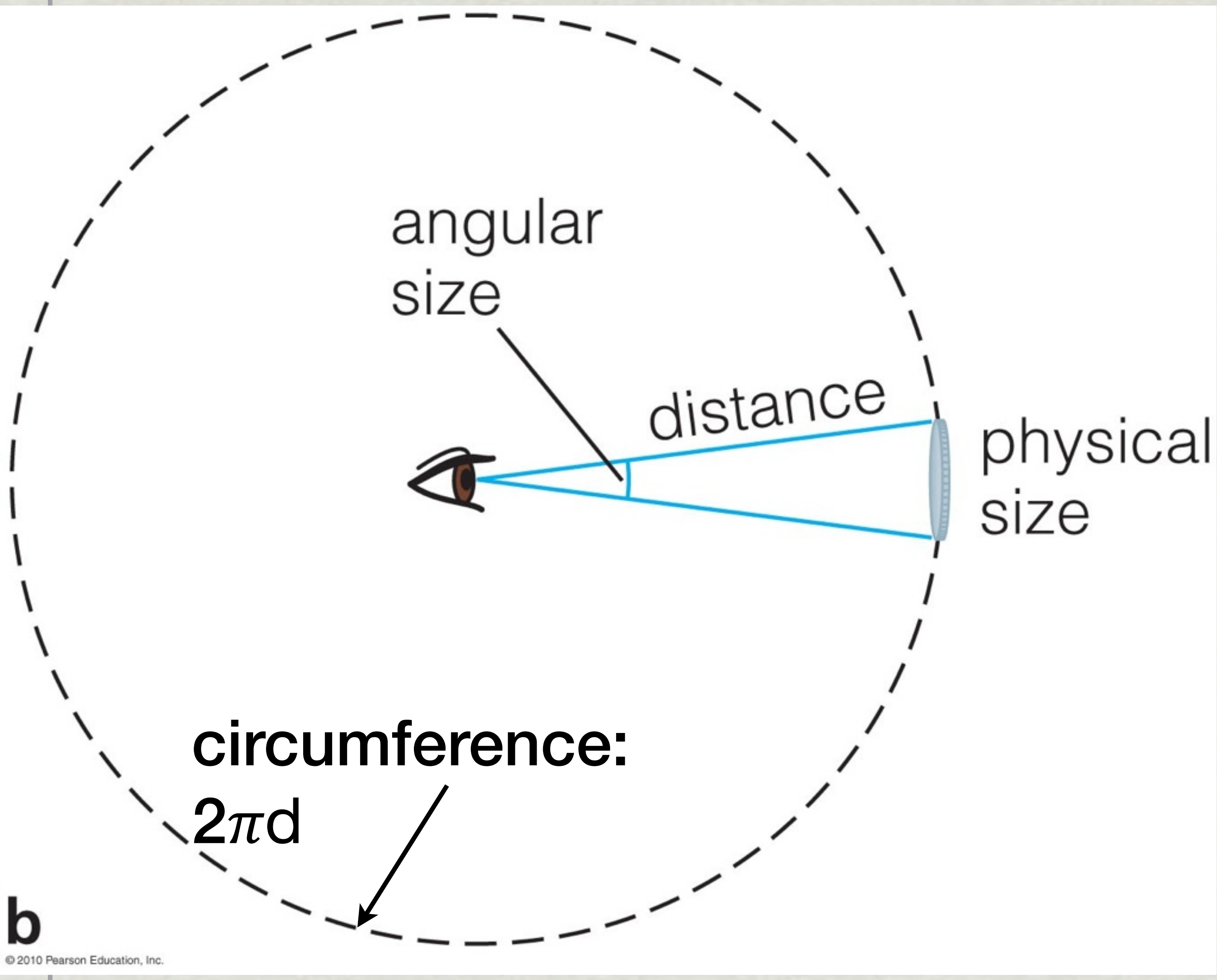
- If you know the true size of something, like a redwood

  - and you can measure its angular size

  -> then you can determine its distance



# Angular Size




A circle is always 360º

The physical size of the circle is the circumference: $2\pi d$

d is the distance from your eye to the object.

distance d is also the radius of the circle

ratio: $\frac{\text{angular size}}{360^\circ} = \frac{\text{physical size}}{\text{circumference}}$

This relation between angular and physical size works as long as the angle is small, < 25º
Compare: angular size of the moon is 0.5º

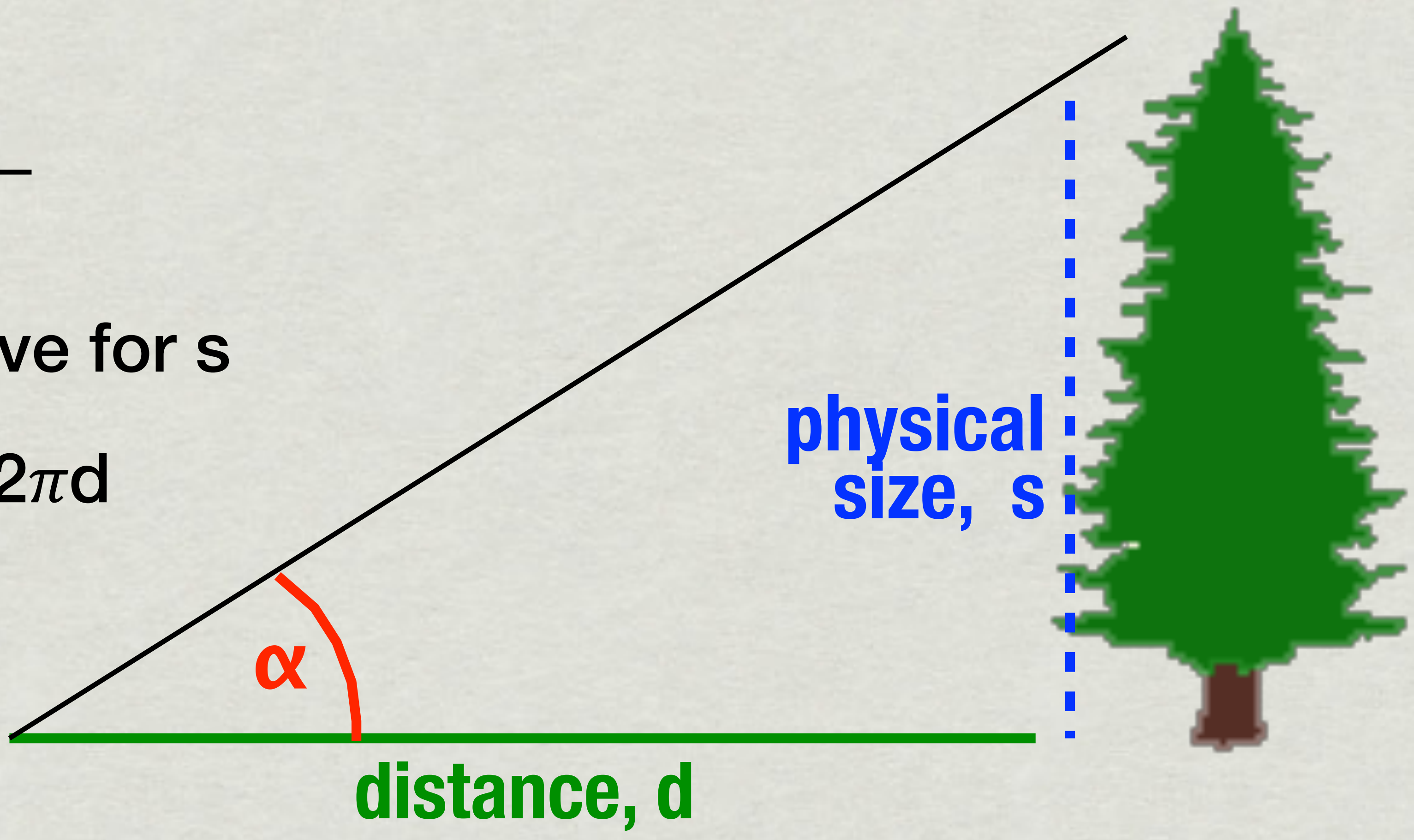
# Distance and Angular Size

- you can always measure the angular size α
- sometimes you know the distance, **d**
- then use angular size and distance to measure the physical size, **s**

$$\frac{\alpha}{360^\circ} = \frac{s}{2\pi d}$$

rearrange, solve for s

$$s = \frac{\alpha}{360^\circ} \times 2\pi d$$



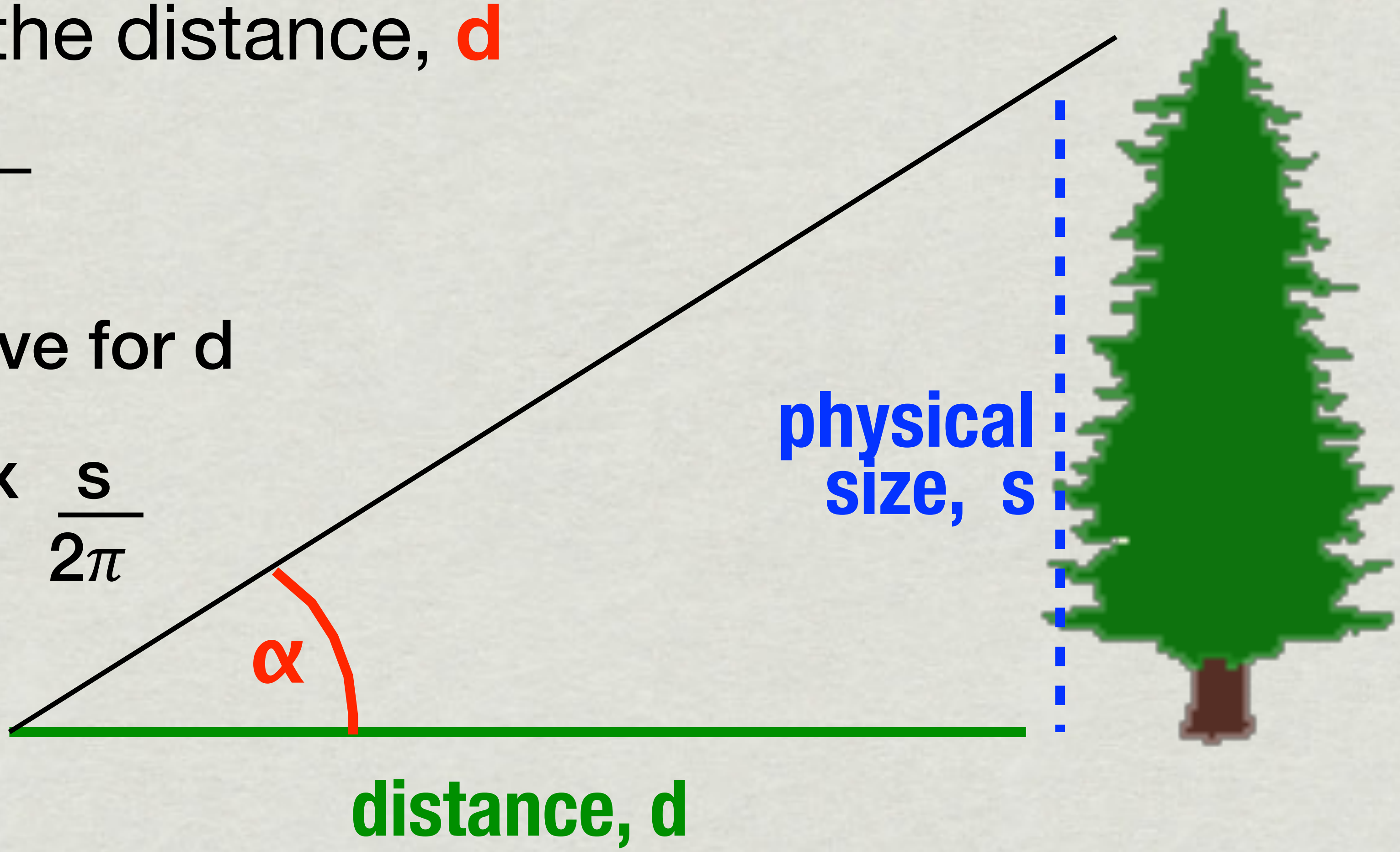
# Distance and Angular Size

- you can always measure the angular size α
- sometimes you know the physical size, **s**
- then use relation between angular size and physical size to measure the distance, **d**

$$\frac{\alpha}{360^\circ} = \frac{s}{2\pi d}$$

rearrange, solve for d

$$d = \frac{360^\circ}{\alpha} \times \frac{s}{2\pi}$$



# Distance and Angular Size

- This same geometric relation and clever observations allowed people to measure the size of the earth 2000 years ago

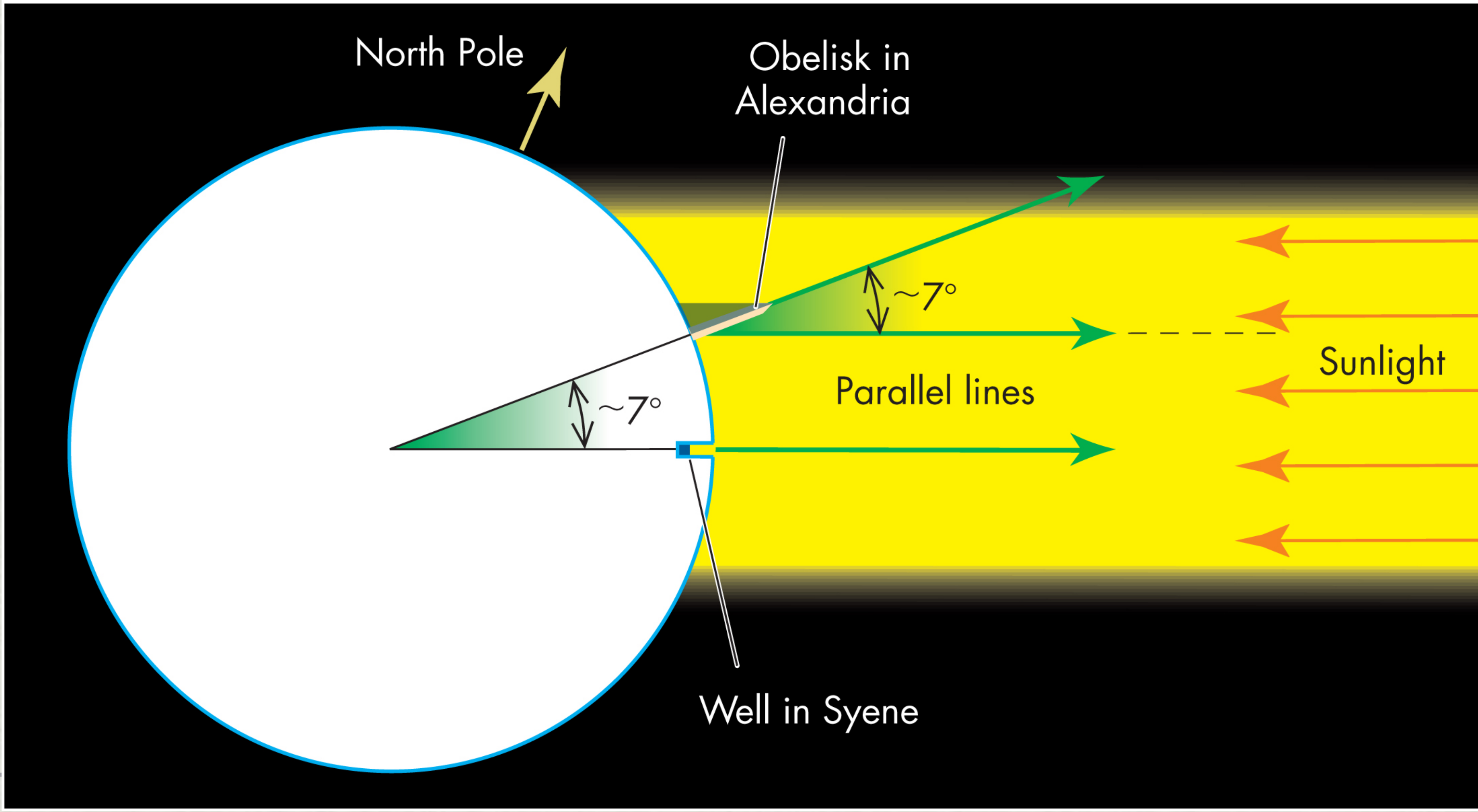
**Eratosthenes of Cyrene:**

**Observation: on a particular day of the year at noon, the sun is straight overhead (no shadows) of a well in Cyrene**

**Fact: the sun *can not* also be overhead in Alexandria, 925 km away**

**Assume: light from the sun is parallel, i.e., the sun is far away**





# Distance and Angular Size

Eratosthenes of Cyrene:

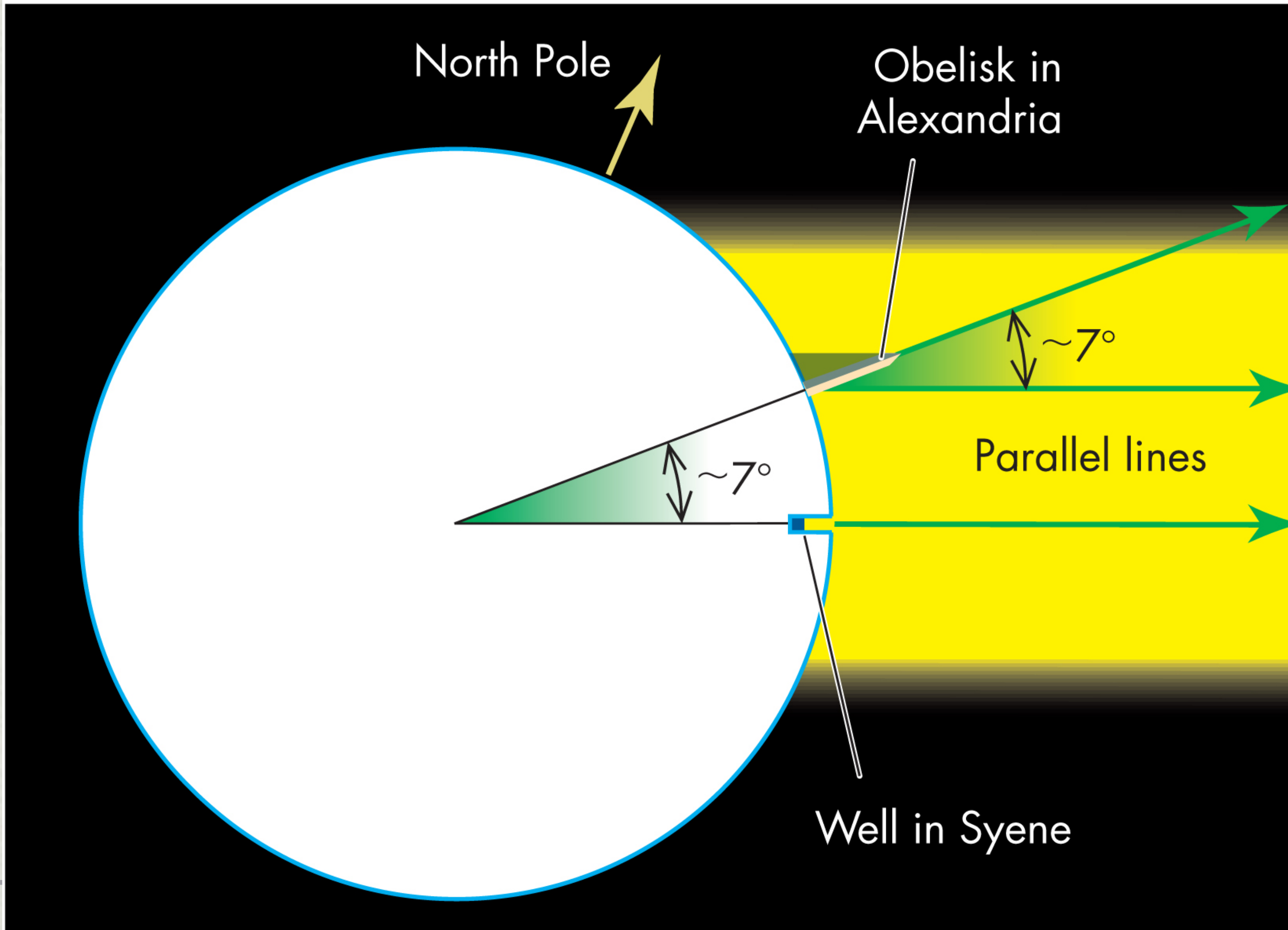
Observation: on a particular day of the year at noon, the sun is straight overhead (no shadows) of a well in Cyrene

Fact: the ***can not*** also be overhead in Alexandria, 925 km away

Angle A sunlight makes with a well in Alexandrea the same day it is straight overhead at Cyrene ?

Angle A:   7.2 degrees





# Distance and Angular Size

Eratosthenes of Cyrene:

Observation: on a particular day of the year at noon, the sun is straight overhead (no shadows) of a well in Cyrene

Fact: the ***can not*** also be overhead in Alexandria, 925 km away

Angle A: 7.2 degrees

$$\frac{A}{360^\circ} = \frac{\text{distance to Alexandria, } S}{\text{circumference of Earth, } C}$$

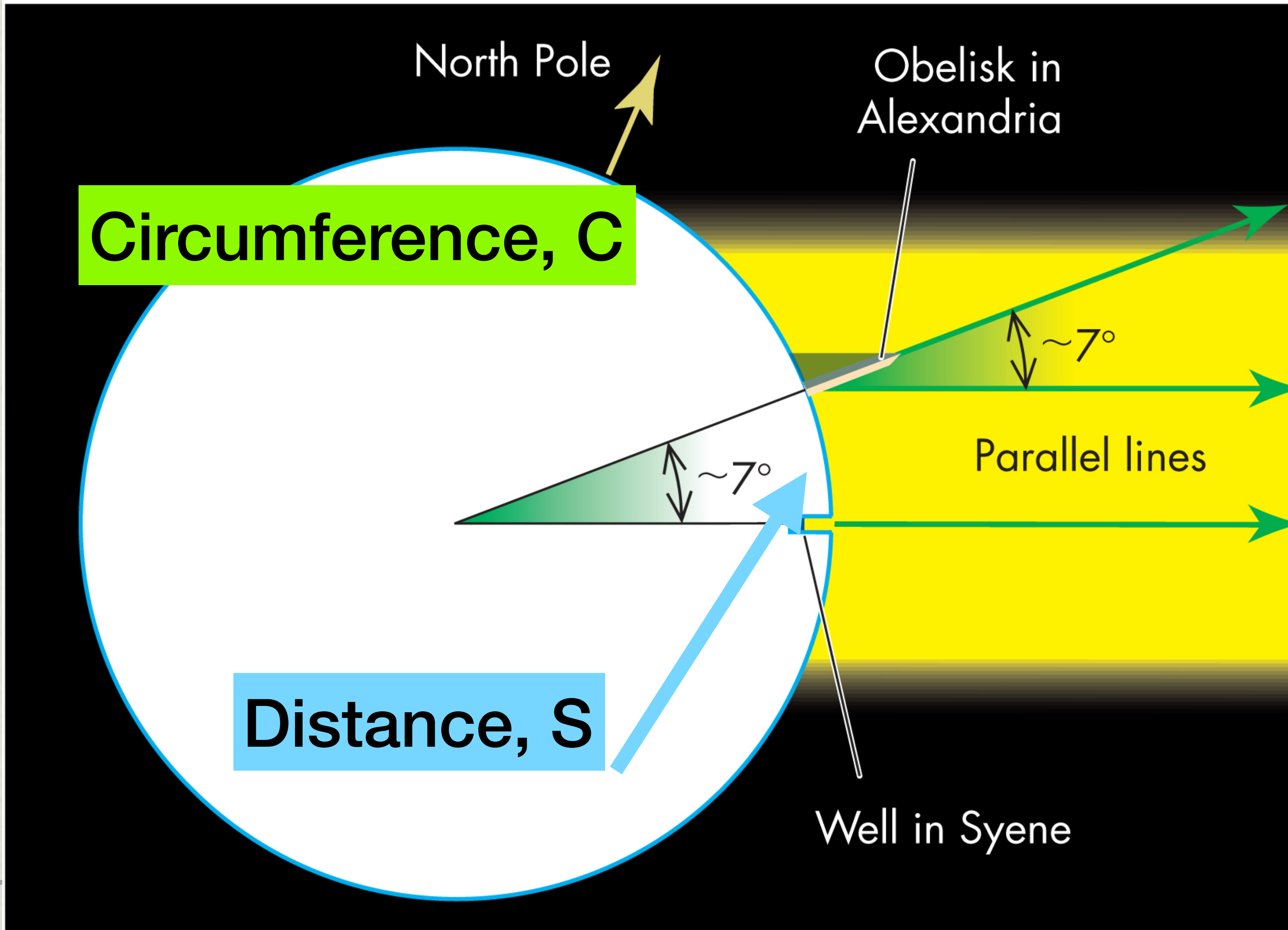
rearrange, solve for circumference:

$$C = \frac{360^\circ}{7.2^\circ} \times 925 \text{ km}$$

C = 46,250 km

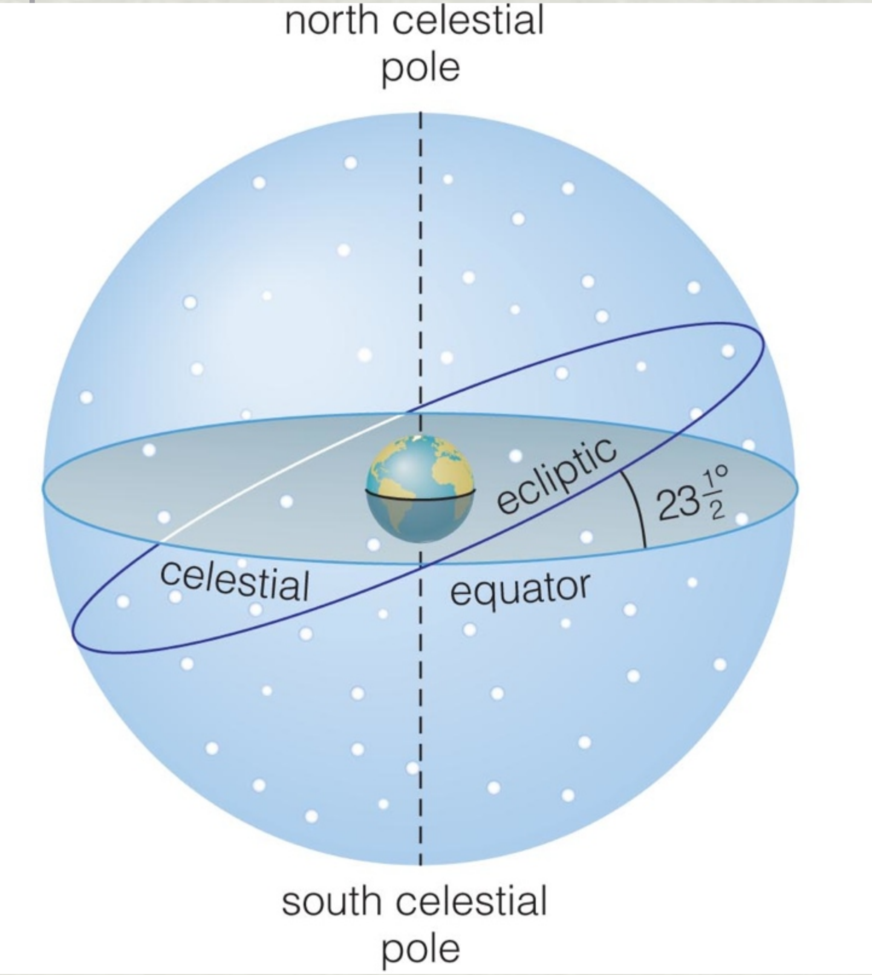
modern measurement: 40,070 km





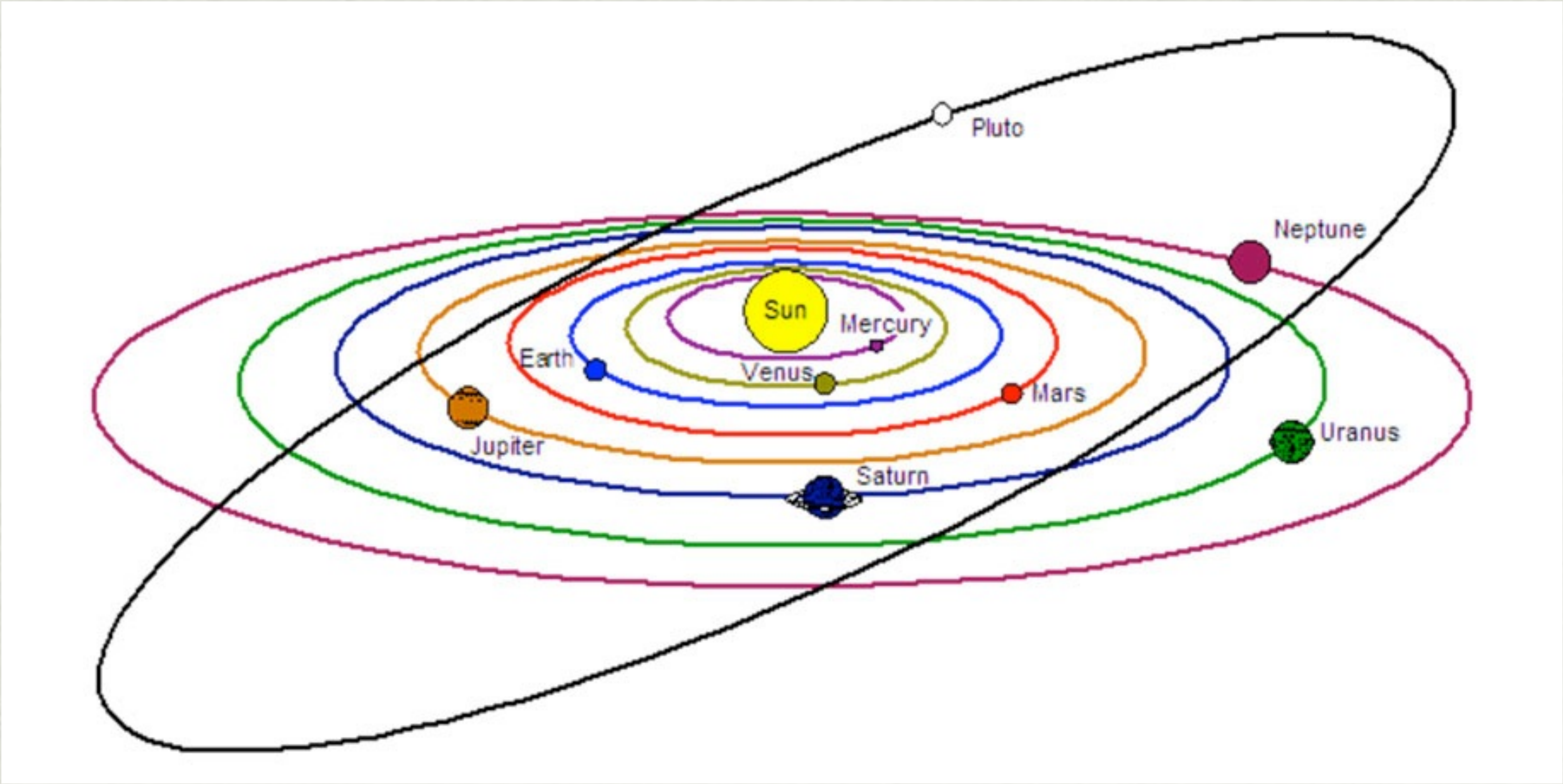
# Other Things in the Night Sky: Planets

- The planets also rise and set each night as the earth rotates
- Like the sun, we see them move along the ecliptic on the Celestial Sphere




# Solar System, brief census

- The planets, in order from closest to farthest from the sun:




Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
dwarf planets:
Pluto, Eris

These five were known and observed by ancient cultures

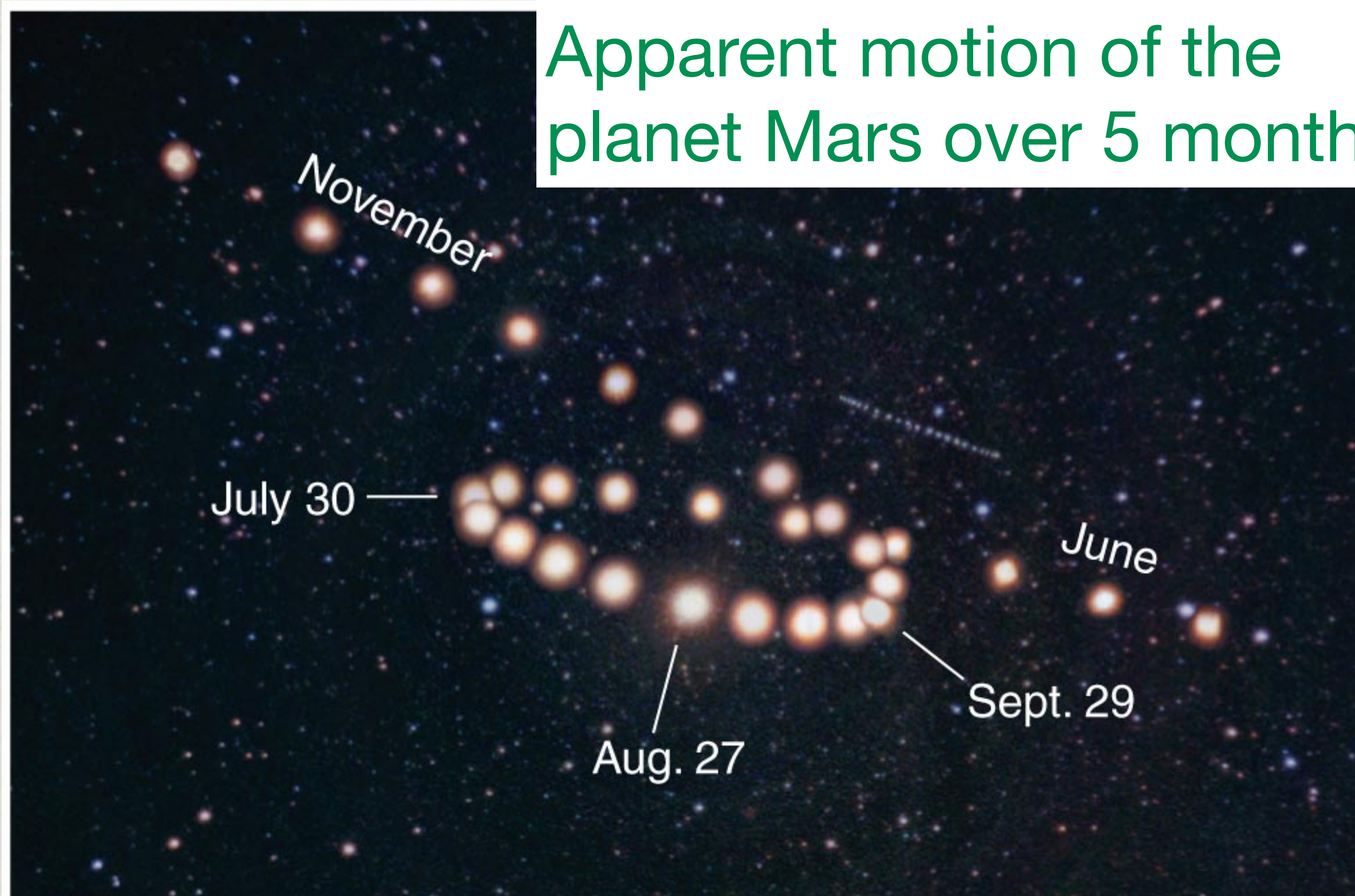
# Other Things in the Night Sky: Planets

- Unlike the sun:

– Planets take much more or much less time than a year to circle the Celestial Sphere on the ecliptic

- Planets appear to speed up or slow down as the move through the ecliptic. Some even go backwards!

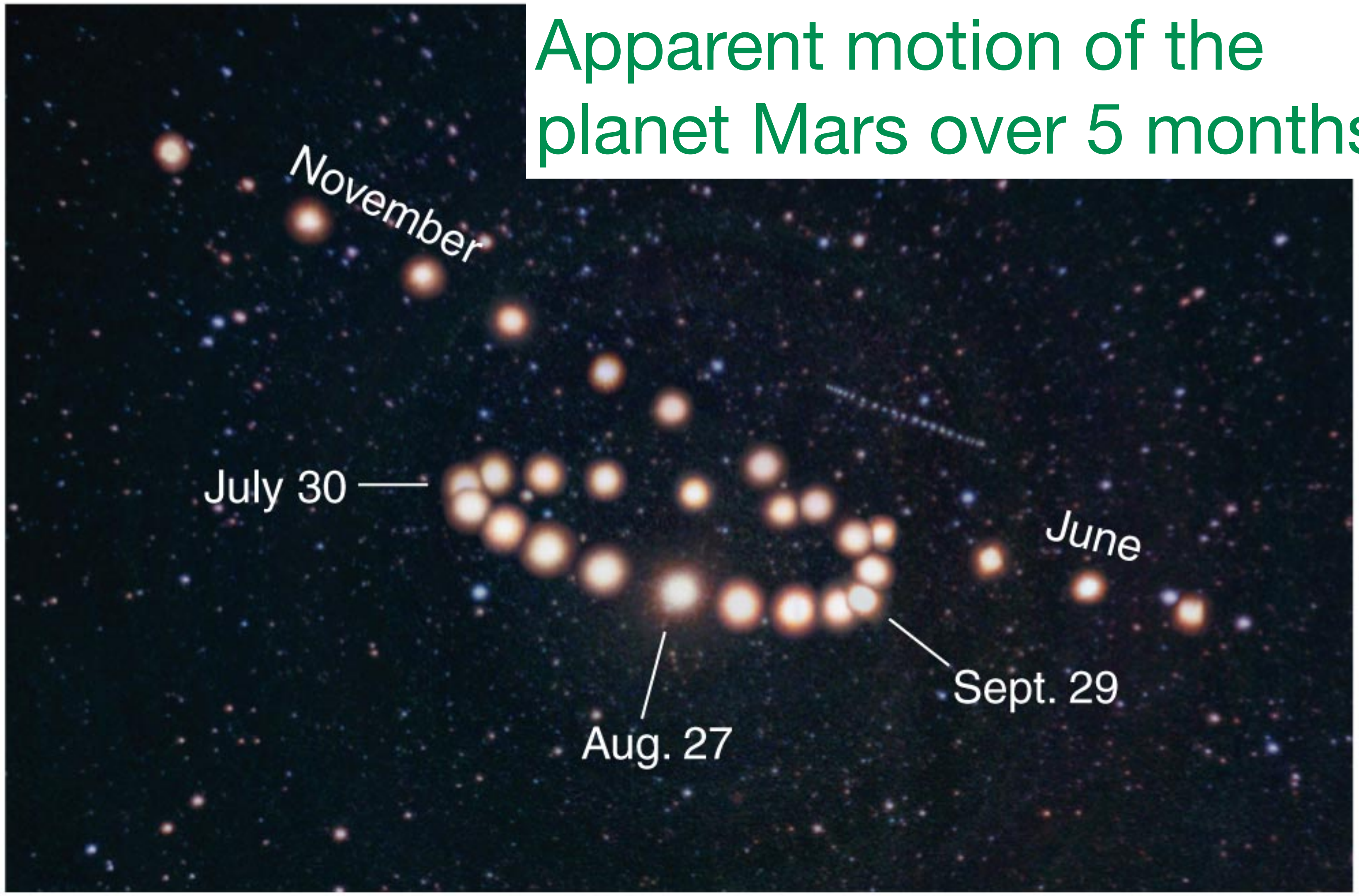
Apparent motion of the planet Mars over 5 months



# Other Things in the Night Sky: Planets

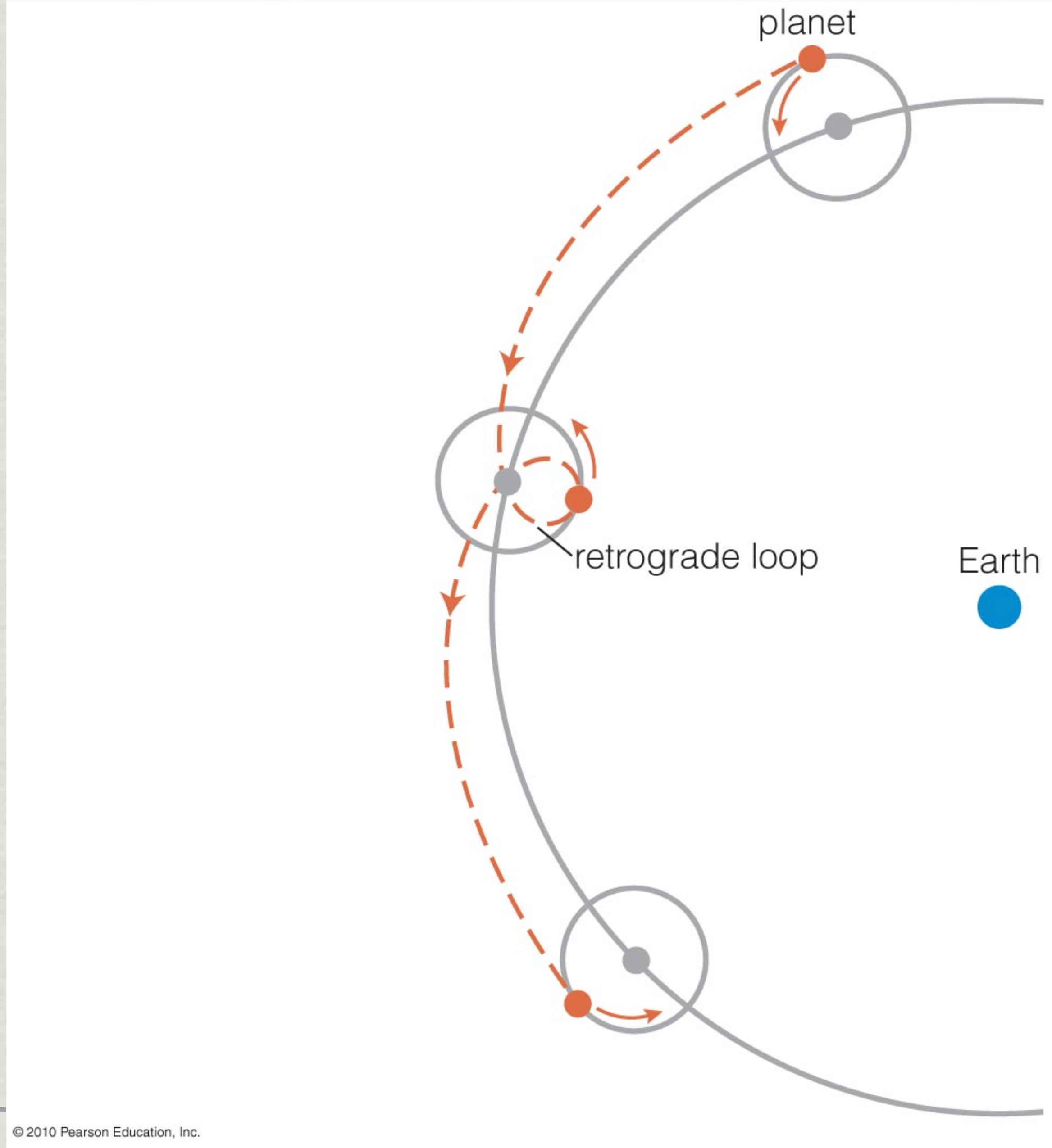
- This apparent backwards (retrograde) motion is extremely difficult to explain in a model of the solar system with the earth in the center

- Explaining the apparent backwards motion of the planets in the sky was a major reason to adopt our modern model of the solar system

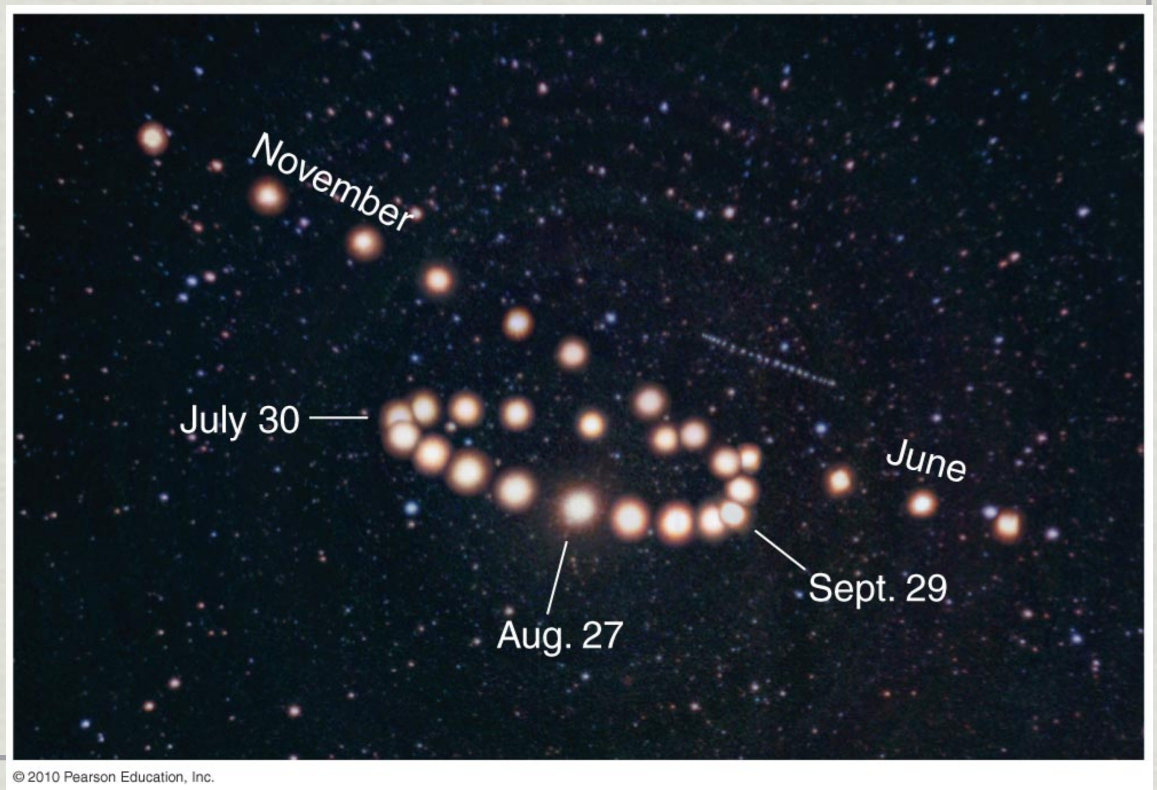



Apparent motion of the planet Mars over 5 months

- Geocentric (earth-centered) models explained the retrograde orbit of Mars with epicycles: simultaneous motion on multiple circles



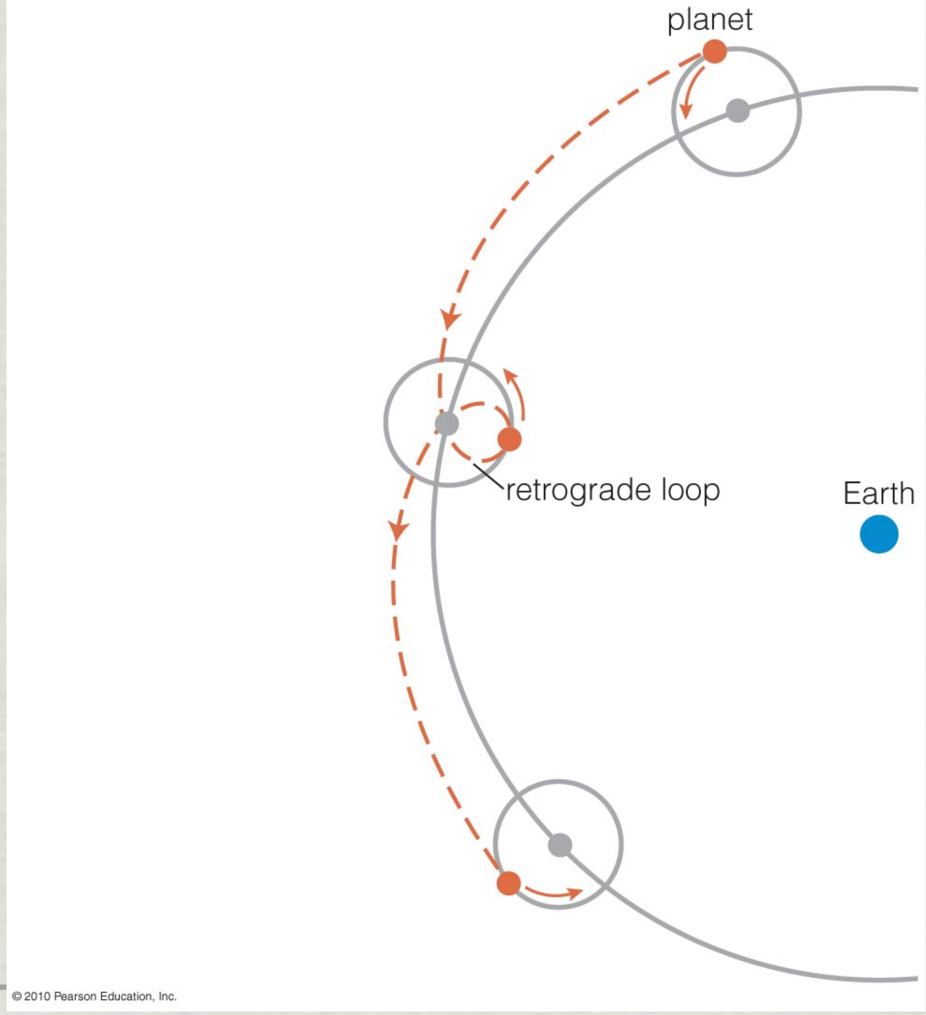

Comprehensive version of this model of the solar system was created by Ptolemy around 100 AD ("Ptolemaic System")



- Epicycles can explain retrograde motion

  BUT:

  - does not explain why Venus and Mercury have phases
  - does a TERRIBLE job of predicting the future locations of planets
  - very complicated and contrived, and got worse as it tried to predict better data (more epicycles)



- Progress:  Nicholas Copernicus 1473 - 1543 AD

  proposed that the planets orbit the sun, heliocentric model

  - simpler explanation for retrograde motion
  - BUT he kept the circles, so predictions for future locations of the planets were still TERRIBLE
  - The printing press was invented in 1440, so Copernicus was able to publish his ideas.
    - Lots of people liked the simplicity, but the bad predictions were still a problem

History of science calls the change from geocentric to heliocentric model the "Copernican Revolution"  but Copernicus was just the start

- Tycho Brahe (1546 - 1601)
- Better data: very accurate positions of the planets over many years.
- Impossible to ignore the problems with Ptolemaic system:
  - Convinced that the heliocentric model is correct
  - Could not reconcile circular orbits for planets with the data

- Johannes Kepler (1571-1630)
  - Tycho’s assistant
  - Believed the data, tried to explain it
  - Found that ellipses worked better than circles to describe the motions of planets

# Predict!

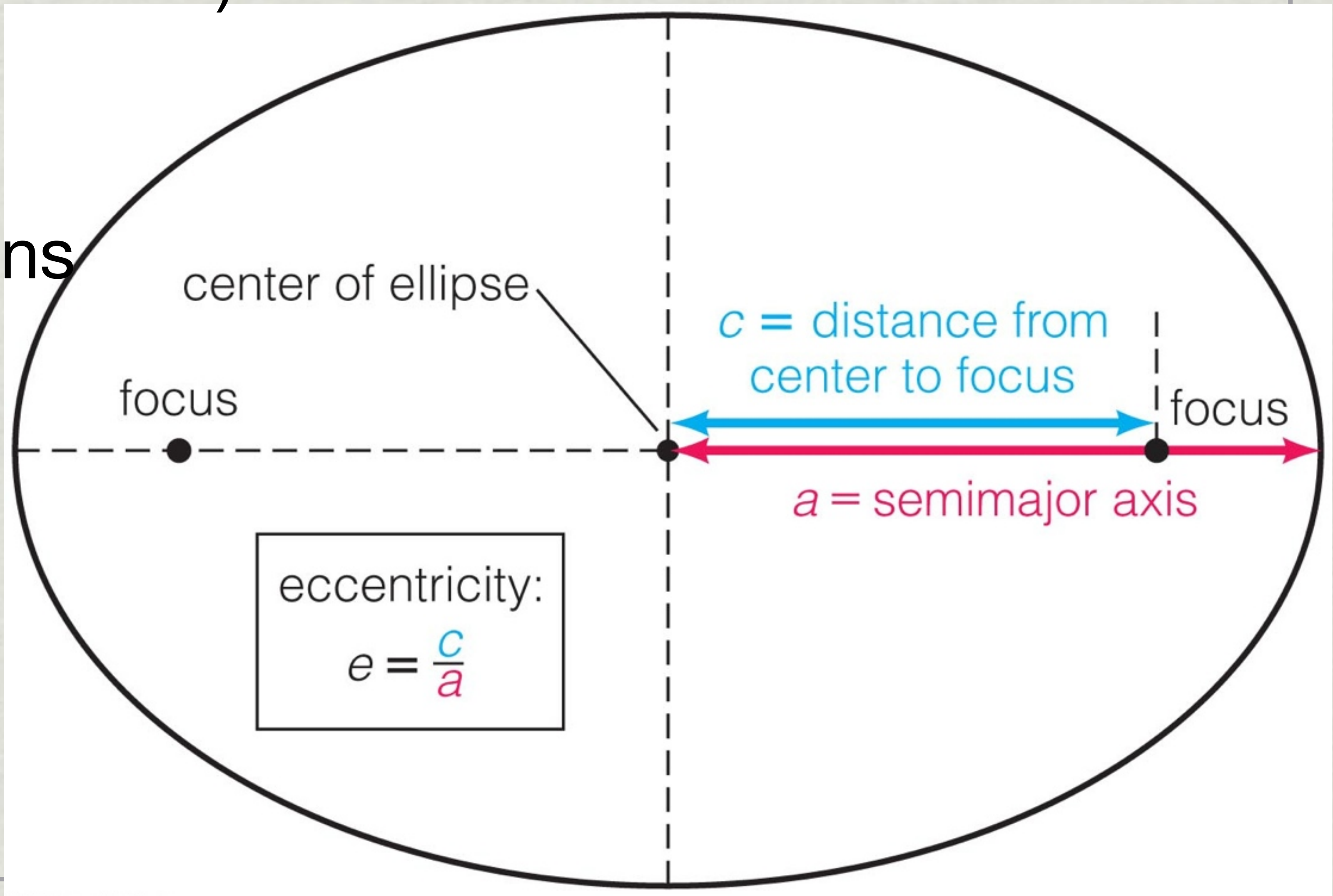
- Kepler's model:

Heliocentric: the earth and all the planets orbit the sun

The orbits of the planets are ellipses (This is Kepler's 1st Law)

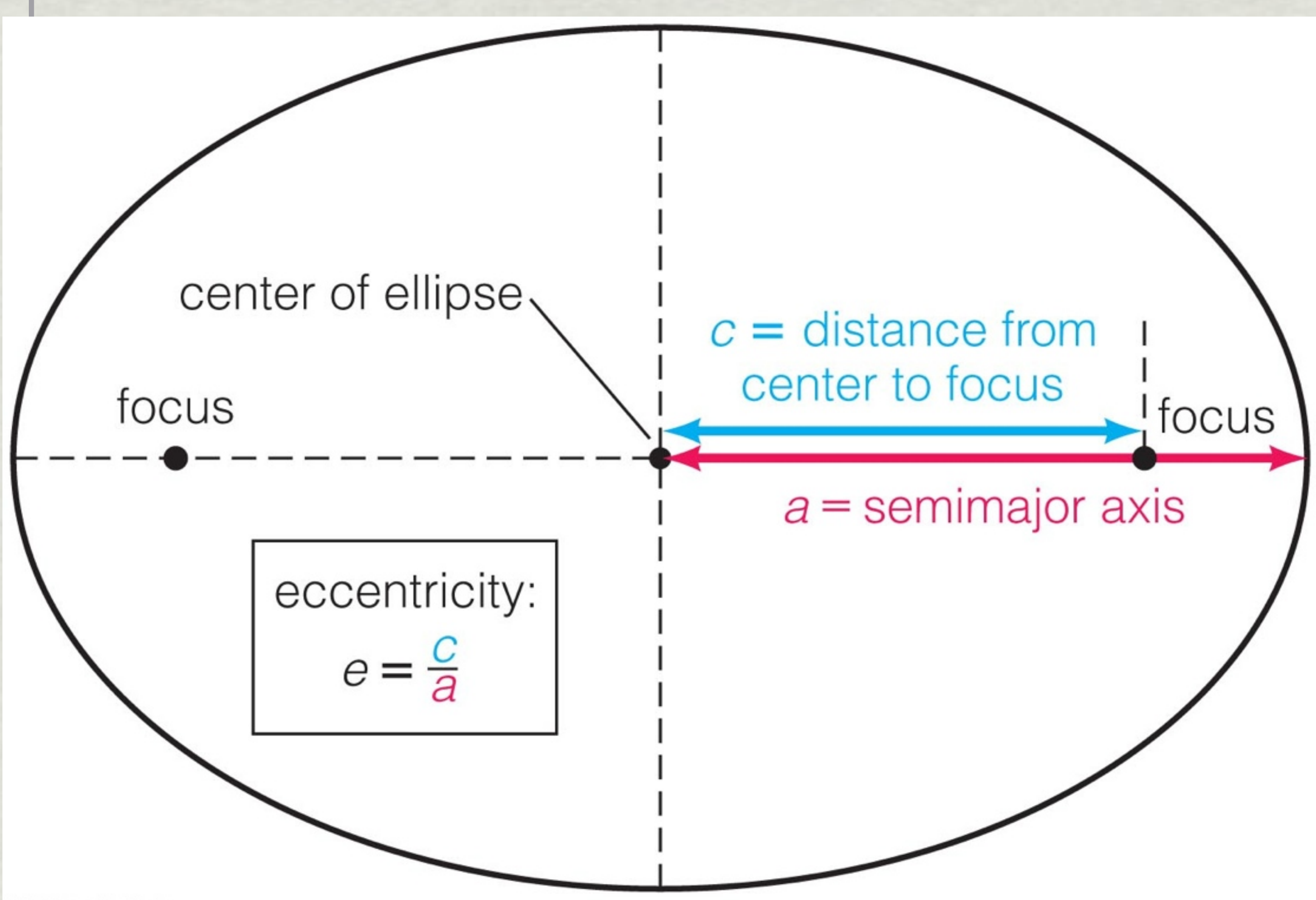
Excellent fit to the data

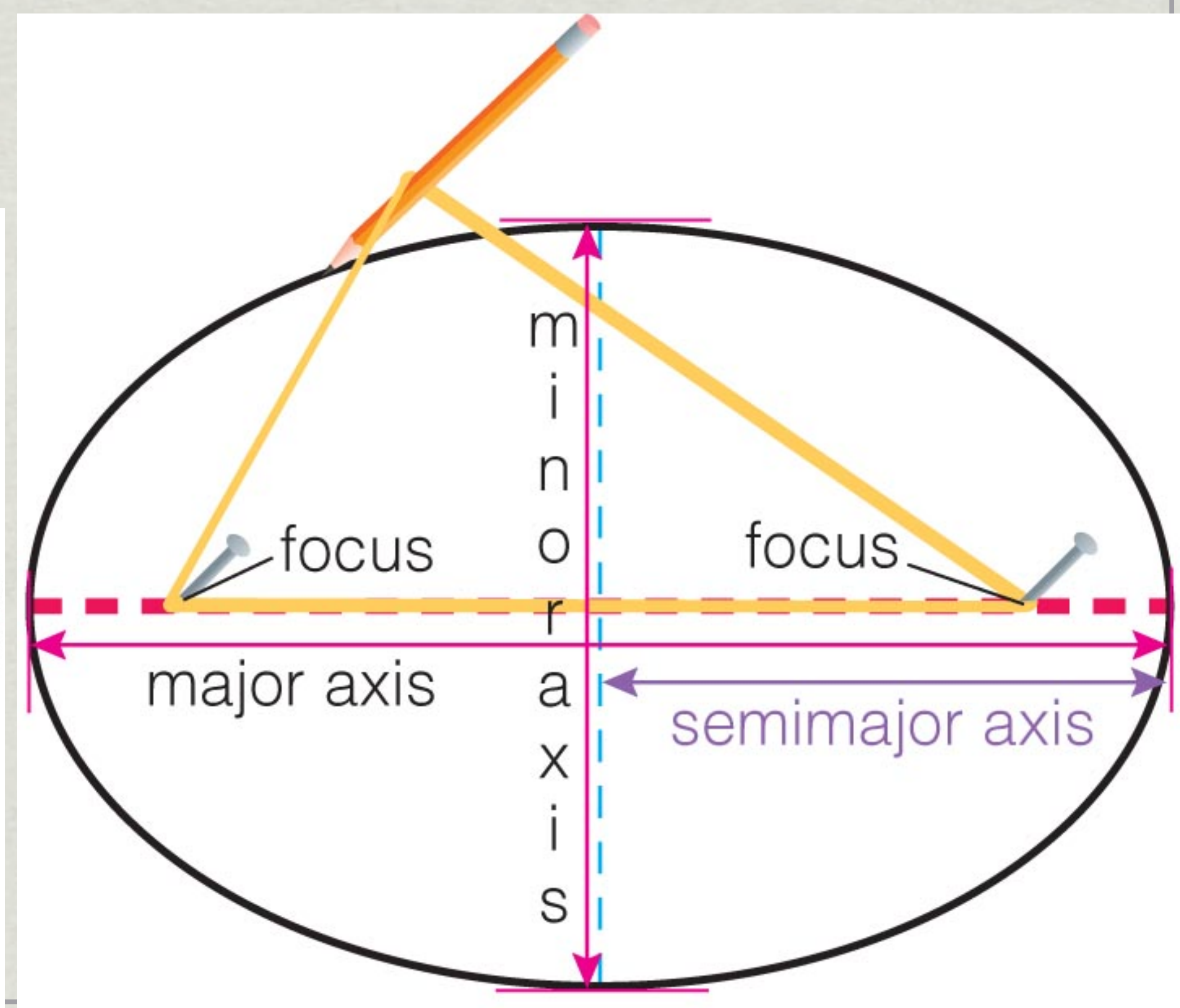
Makes accurate predictions for the locations of the planets, including the apparent backwards motion



# about ellipses

- An ellipse is defined by a center, eccentricity and semi-major axis
- It can also be defined as the curve for which the sum of the distances from the foci is constant

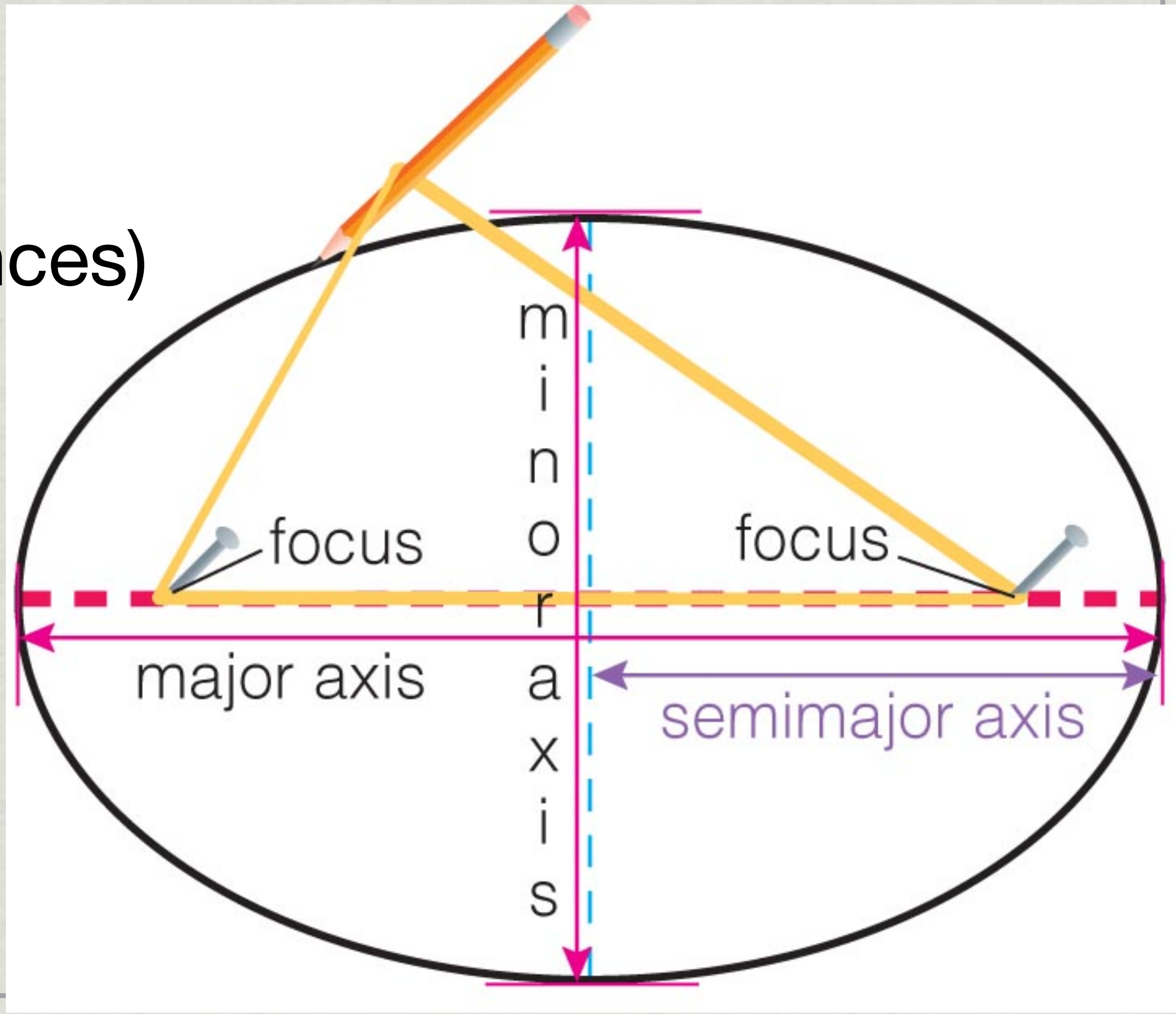


# about ellipses

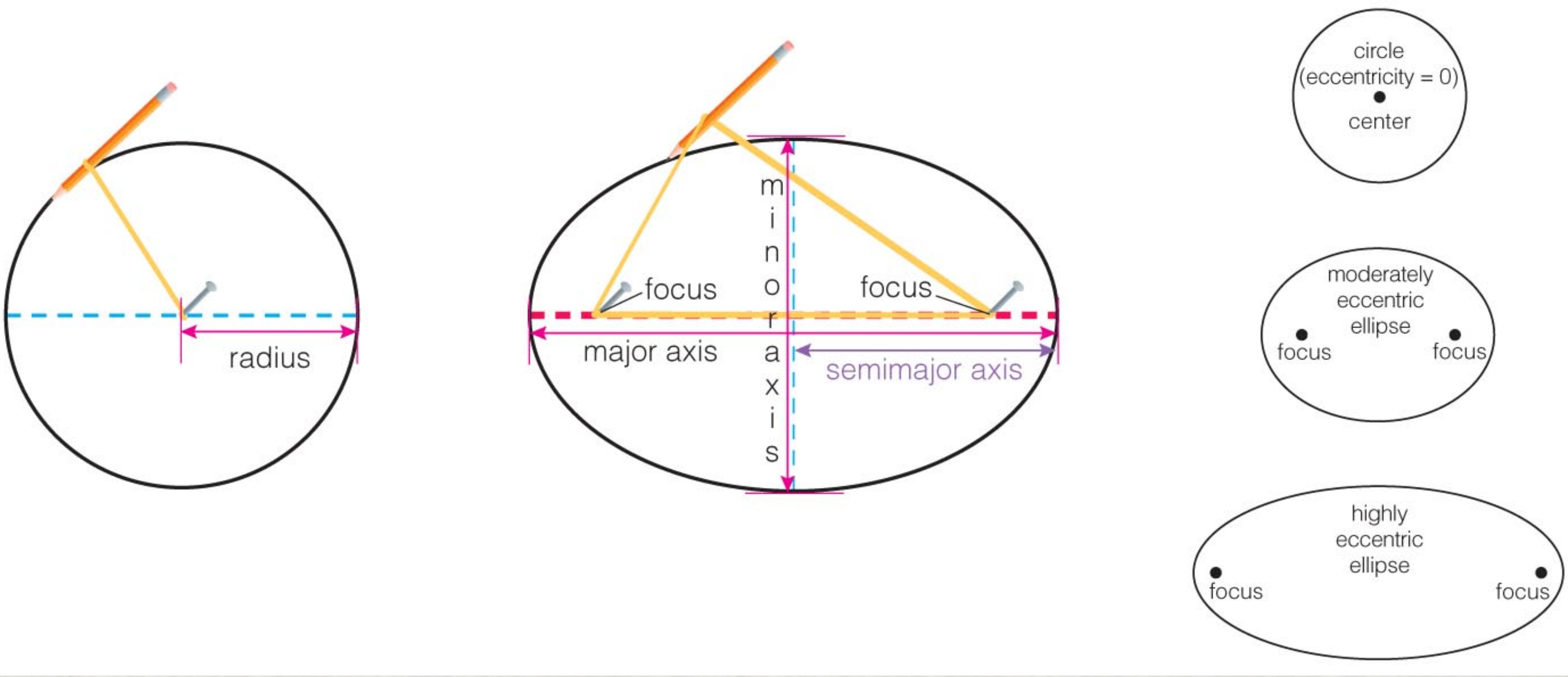
- An ellipse is defined by a center, eccentricity and semi-major axis
- It can also be defined as the curve for which the sum of the distances from the foci is constant

To make an ellipse, you need:
- String (constant sum of distances)
- 2 tacks (the foci)
- A pencil to draw the curve



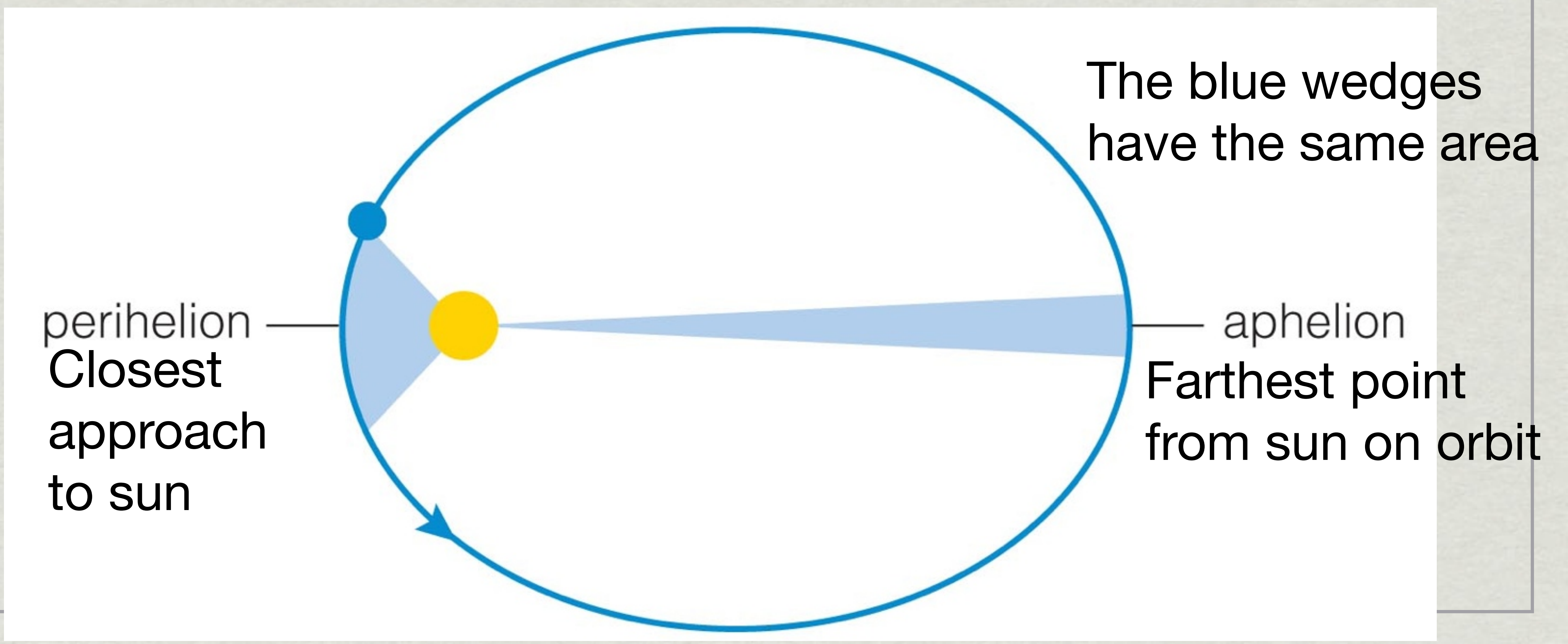
# about ellipses

- Eccentricity describes how much an ellipse deviates from a circle.
- If e=0, no eccentricity. The curve is a circle.
- Kepler's 1st Law: The orbits of the planets are ellipses, with the Sun at one Focus



# Kepler's Laws

- Kepler's Second Law:  A planet moving along its orbit sweeps out equal area in equal time

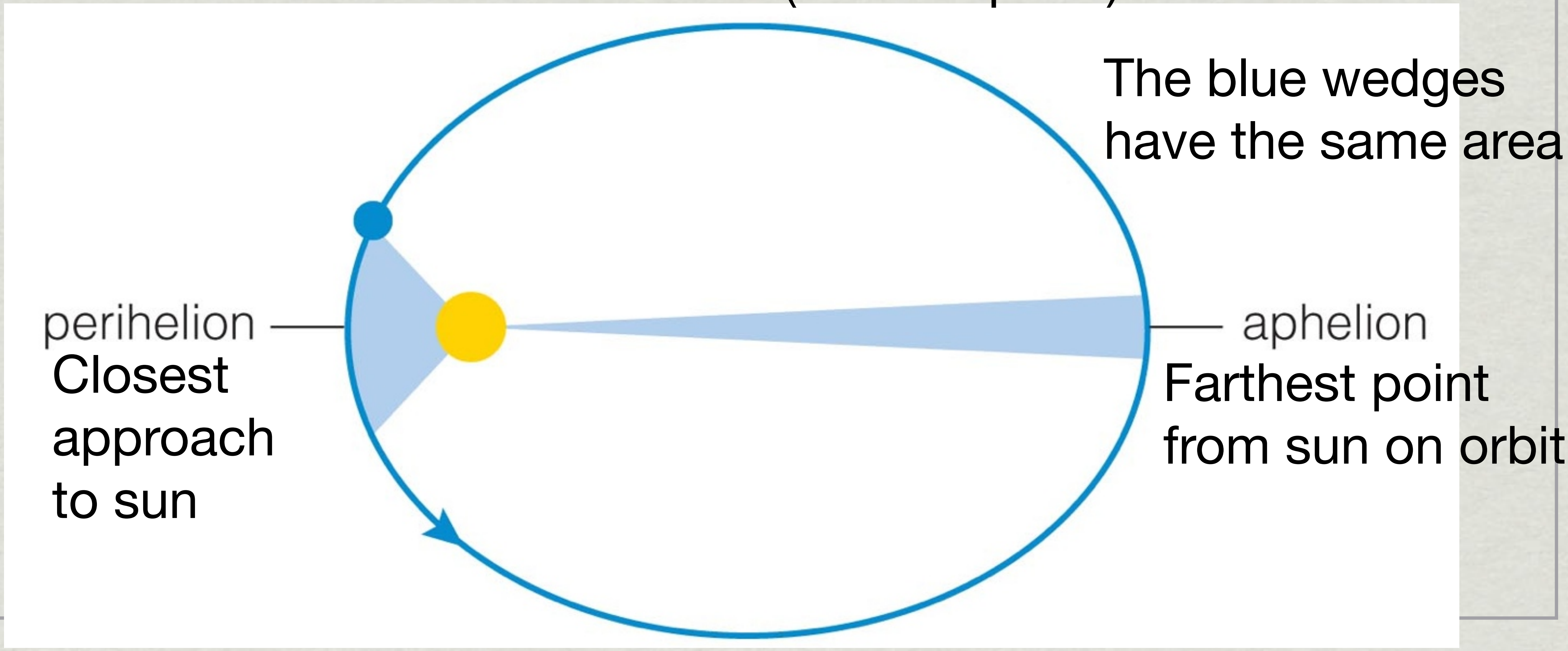


# Kepler's Laws

- Kepler's Second Law:  A planet moving along its orbit sweeps out equal area in equal time
- iClicker question: where on its orbit does a does a planet have the fastest speed?

A: Aphelion (Farthest point)

B: Perihelion (Closest point)



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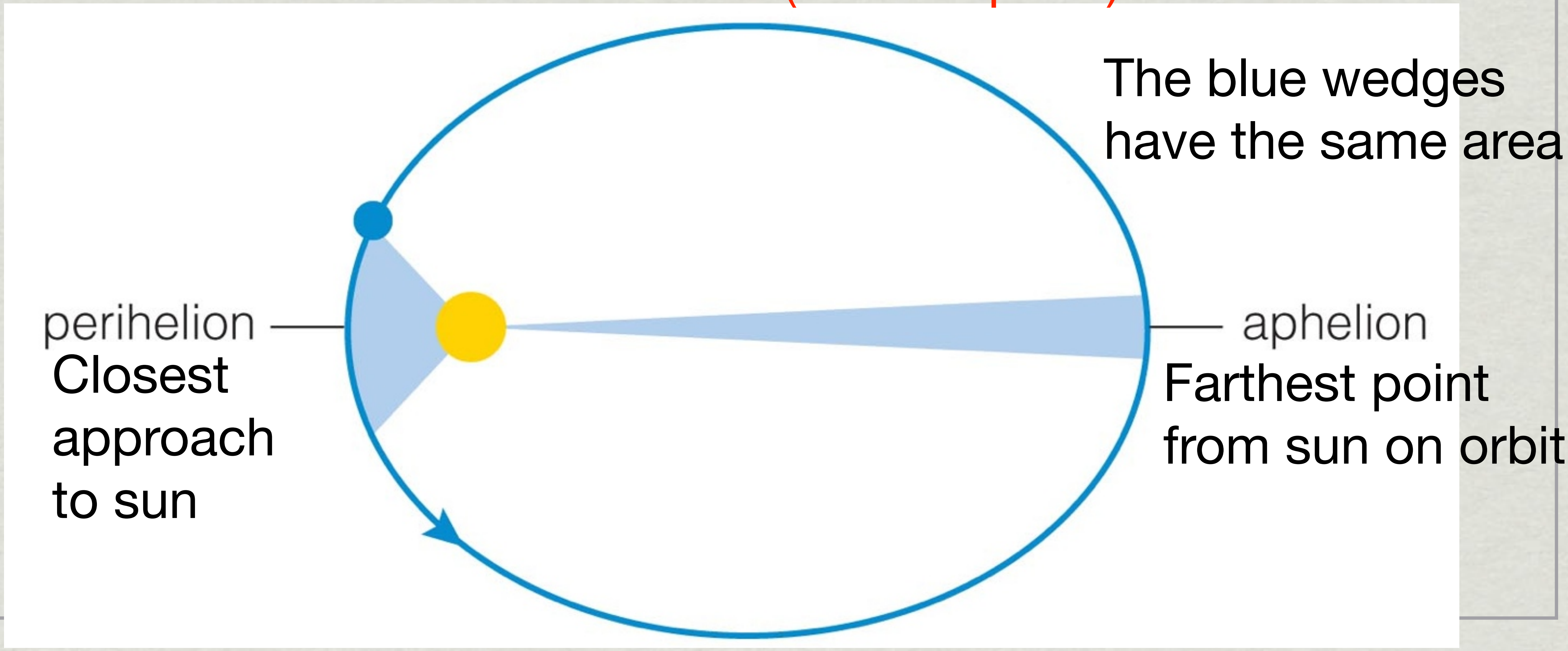

# Kepler's Laws

- Kepler's third law: The ratio of

  (average distance from the sun, **A**)$^3$ to (orbital period, **P**)$^2$

$$\frac{A^3}{P^2}$$

  is constant (the same) for all the planets

- Units:
  - Period: years
  - Distance from the sun: AU
    - remember, 1 AU is the distance from the Earth to the Sun
- OK, it's constant. But what is it?

# Kepler's Laws

- Kepler's third law: $\dfrac{A^3}{P^2}$ is constant for all the planets

For the earth: $\dfrac{(1\ \text{AU})^3}{(1\ \text{year})^2} = 1\dfrac{(\text{AU})^3}{(\text{year})^2}$

- Convenient units!

If $\dfrac{A^3}{P^2} = 1$ for the earth, then $A^3 = P^2$

- Kepler's 3rd Law says this is true for all planets
- So in our solar system, $P^2 = A^3$ for everything in orbit around the sun, when using units of AU and years.

# Kepler's Laws

- Kepler's third law: $\frac{A^3}{P^2} = 1 \frac{(AU)^3}{(year)^2}$ for all the planets
- Example:

  For a planet at a distance of 2 AU from the sun, what is the period of its orbit?

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  Step 1: $\frac{A^3}{P^2} = \frac{(2\ AU)^3}{P^2} = \frac{(8\ AU^3)}{P^2}$

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  Step 2:
  Apply Kepler's
  3rd Law

  $\frac{(8\ AU^3)}{P^2} = 1 \frac{(AU)^3}{(year)^2}$

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Step 3: Rearrange: $P^2 = \frac{(8\ AU^3)}{(1\ AU^3/1\ year^2)}$

# Kepler's Laws

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Step 2: Apply Kepler's 3rd Law $\frac{(8\ AU^3)}{P^2} = 1 \frac{(AU)^3}{(year)^2}$

Step 3: Rearrange: $\frac{P^2 = (8\ AU^3)}{(1\ AU^3/1\ year^2)}$ …and group the units, cancel where you can

Step 4: Solve: $P^2 = (8\ yr)^2$ $P = \sqrt{(8\ yr)^2} = 2.8$ years

# Kepler's Laws

- Kepler's third law: $\dfrac{A^3}{P^2}$ is constant for all the planets

For the earth: $\dfrac{(1\ AU)^3}{(1\ year)^2} = 1\ \dfrac{(AU)^3}{(year)^2}$

$\dfrac{A^3}{P^2} = 1\ \dfrac{(AU)^3}{(year)^2}$ for everything in orbit around the sun

- In our solar system, $P^2 = A^3$ for everything in orbit around the sun, when using units of AU and years.

A similar law, but not exactly the same, works in other star systems, too.

But in units of (Earth) years and AU, the ratio $\dfrac{A^3}{P^2}$ is not 1, it is some other number.

# Evidence for the Heliocentric Model

- A major objection to the Heliocentric model was the difficulty of parallax observations
- What is parallax and why does it matter?

  Hold out your thumb

  Look past it to something in the “background”

  Close one eye.  Look at where your thumb is relative to the background object.  Open.

  Close the other eye. Look at where your thumb is relative to the background object.  Open.

  The background object doesn’t move, but the nearby object (your thumb) does.   Nearby to what?

# Evidence for the Heliocentric Model

- A major objection to the Heliocentric model was the difficulty of parallax observations
- What is parallax and why does it matter?

    Hold out your thumb

    Line it up with something far away in the “background”, like me

    Close one eye.  Look at where your thumb is relative to the background object.  Open.

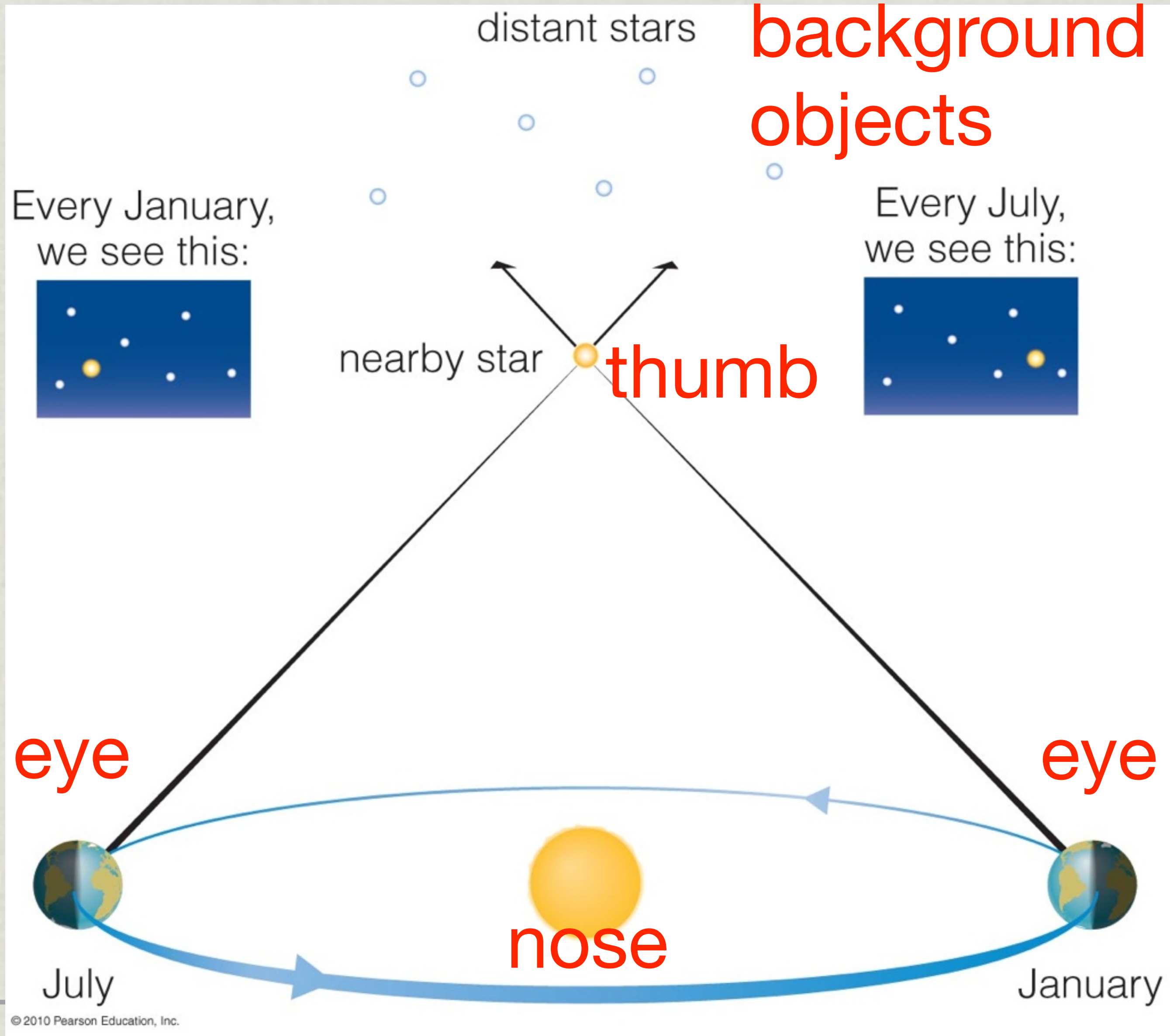
    Close the other eye. Look at where your thumb is relative to the background object.  Open.

    The background object doesn’t move, but the nearby object (your thumb) does.   Nearby to what? Your eyes, which are set apart on your face

# Evidence for the Heliocentric Model

- A major objection to the Heliocentric model was the difficulty of parallax observations
- If the earth moves, we expect to see the parallax effect in the observations of nearby stars

This was difficult to show because stars, even nearby ones, are much farther away than Ptolemy, Tycho and others realized.



# Evidence for the Heliocentric Model

- First stellar parallax measured in 1838, 200 years after Kepler's laws made their good predictions and the Heliocentric model were adopted
- How was the model adopted without this important observation?

Tycho's data and Kepler's laws: Heliocentric model and Kepler's ellipses made best predictions for future observations of the planets.

Ptolemaic model was increasingly cumbersome. Heliocentric model explained all the data on planets most simply.

Galileo Galilei: More experiments and new data.

# Evidence for the Heliocentric Model

- Galileo Galilei (1564-1642)
- Experiments: moving objects continue moving unless acted on by a force.

    Everything on the earth moves with it as it rotates on its axis and orbits the sun.

    So the idea that the earth moves was no longer crazy.

# Evidence for the Heliocentric Model

- Galileo Galilei (1564-1642)
- Observations:  Galileo made the telescope a useful tool
  - Telescopes gather more light than our eyes.
  - We can see fainter objects using a telescope
- Galileo found that Jupiter has moons that orbit Jupiter, just like earth has a moon that orbits earth
  - The Earth is not anything special, so it doesn't need to be in the center of anything
- Galileo also saw that "empty" sky and the fuzzy Milky Way are really full of stars
  - Stars might be farther away than everyone thought, so their parallax might be really tiny

# Evidence for the Heliocentric Model

- This is what we mean by “A Theory.”
  - Not that it is true: someone may get new data tomorrow that proves a theory to be incomplete
  - A theory makes predictions that can be tested, and has done so successfully for many tests
  - A theory explains all the available data in a way that makes sense given how we understand the world, i.e., a “rational” explanation