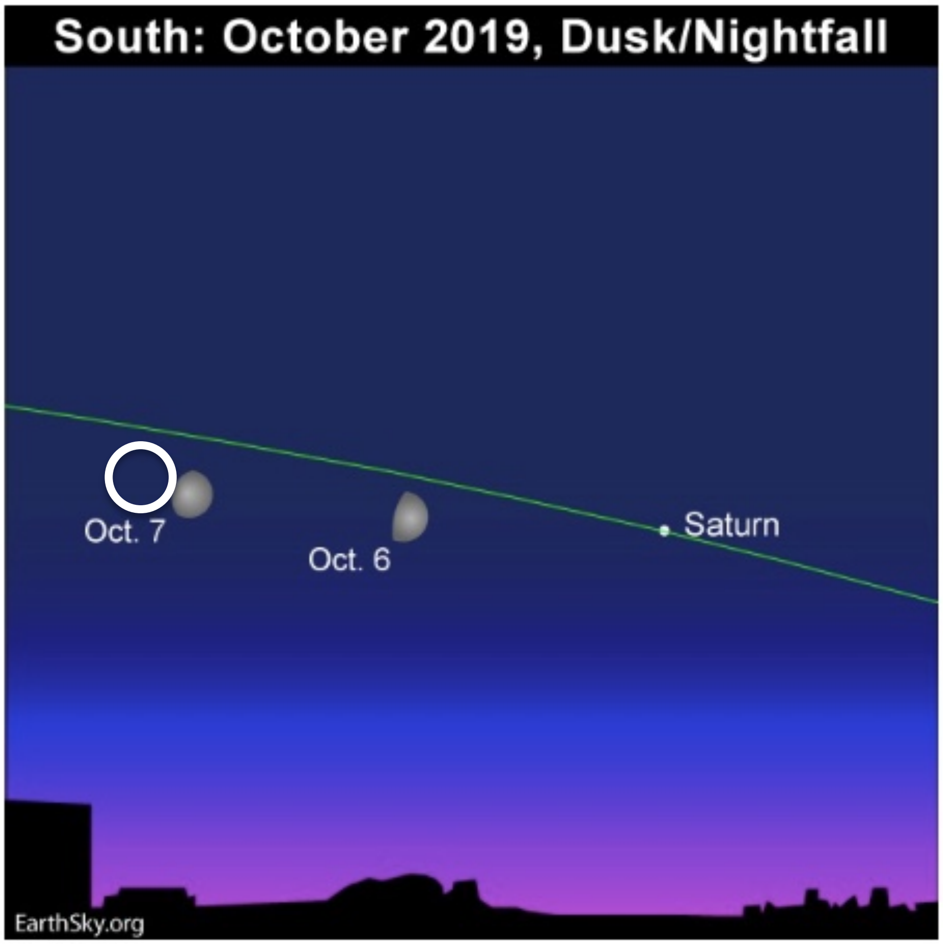
Astronomy 1 – Fall 2019



In the drawing –

- Where is the ecliptic?
- HW2 – problem 1 asks how it takes the moon to move 0.5 degrees.
- Which way will Saturn move?

Today on Astro-1

- How the scientific method solved the puzzle of retrograde motion.
- Newton's laws
- Newtonian gravity
  - Explains motions of planets
  - Creates tidal forces

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The Ancient Greeks were pretty good at astronomy. We'll see that they came up with a way to explain retrograde motion, but that the scientific method eventually showed their explanation was wrong.

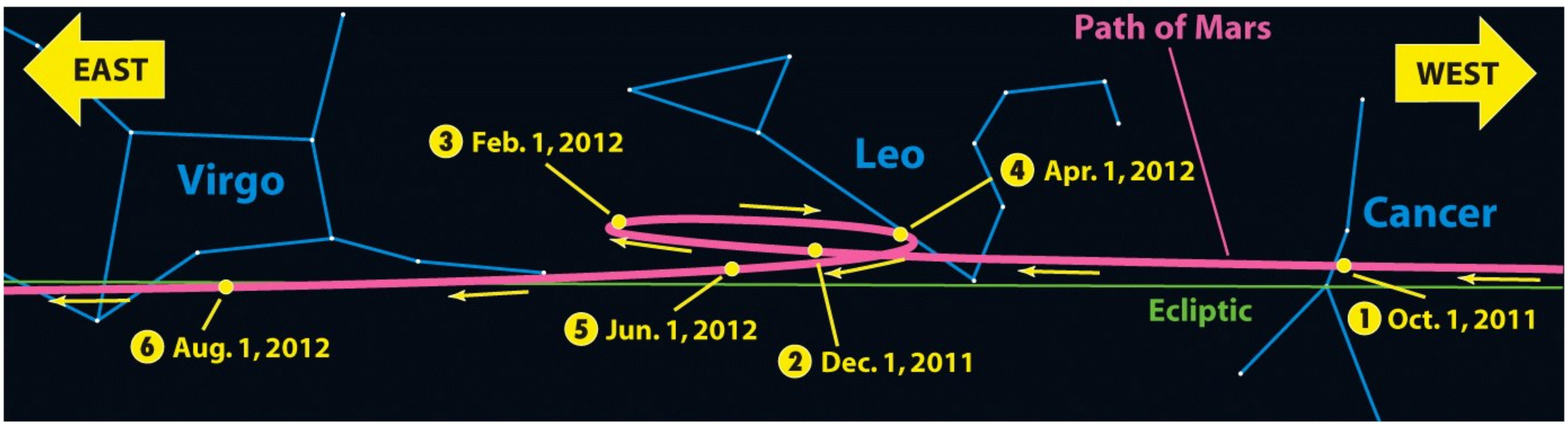

Figure 4-2
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Ancient Astronomers

- Knew the earth was round.
- Measured the diameter of the earth.
- Determined distances to the moon and sun.

PRETTY COOL HOW THEY USED GEOMETRY.
Read how in the textbook!

TABLE 3-3 Comparison of Ancient and Modern Astronomical Measurements

	Ancient (km)	Modern (km)
Earth's diameter	13,000	12,756
Moon's diameter	4,300	3,476
Sun's diameter	9×10^4	1.39×10^6
Earth-Moon distance	4×10^5	3.84×10^5
Earth-Sun distance	10^7	1.50×10^8

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Ancient Greek Notion of Planetary Motion

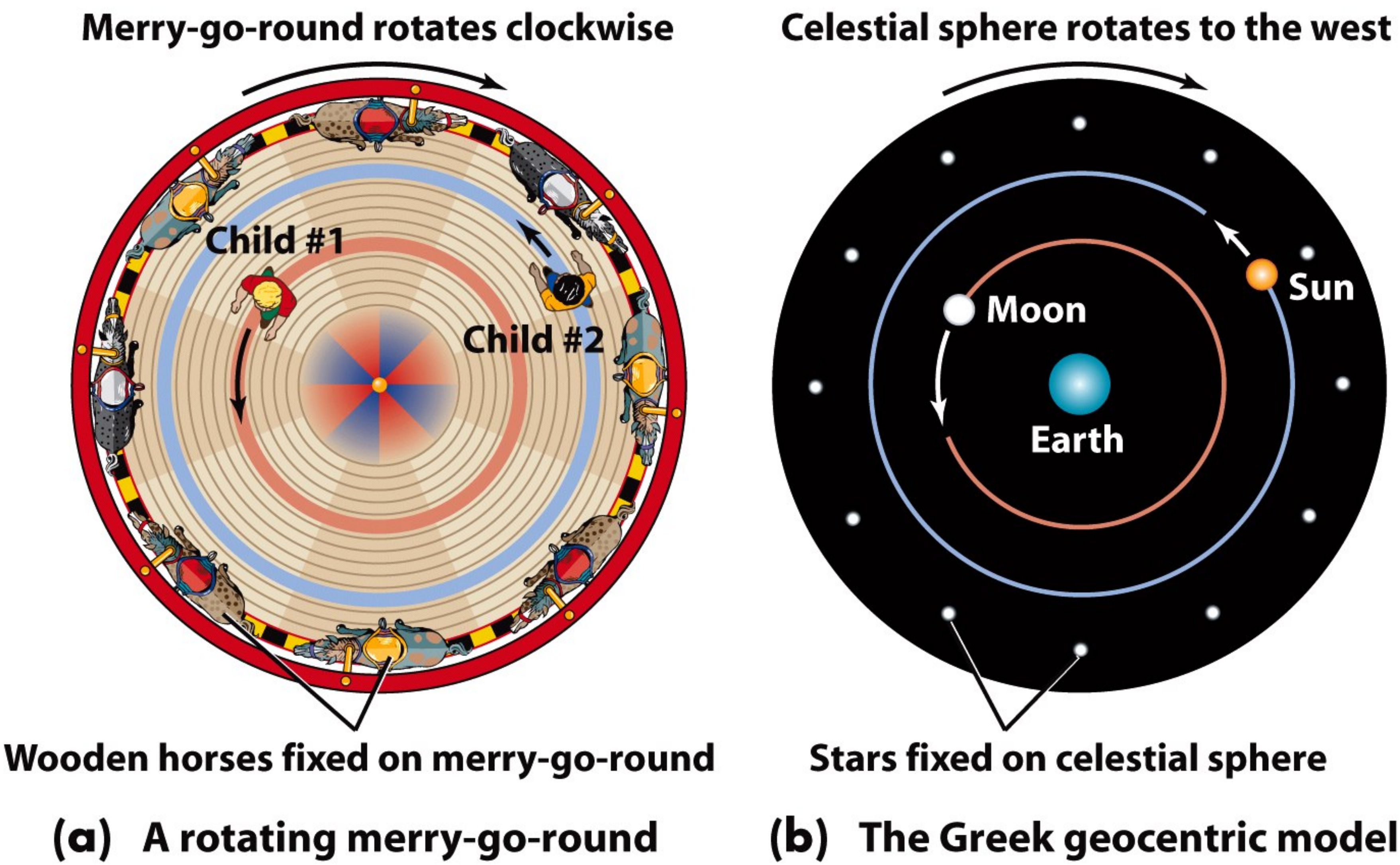

Figure 4-1
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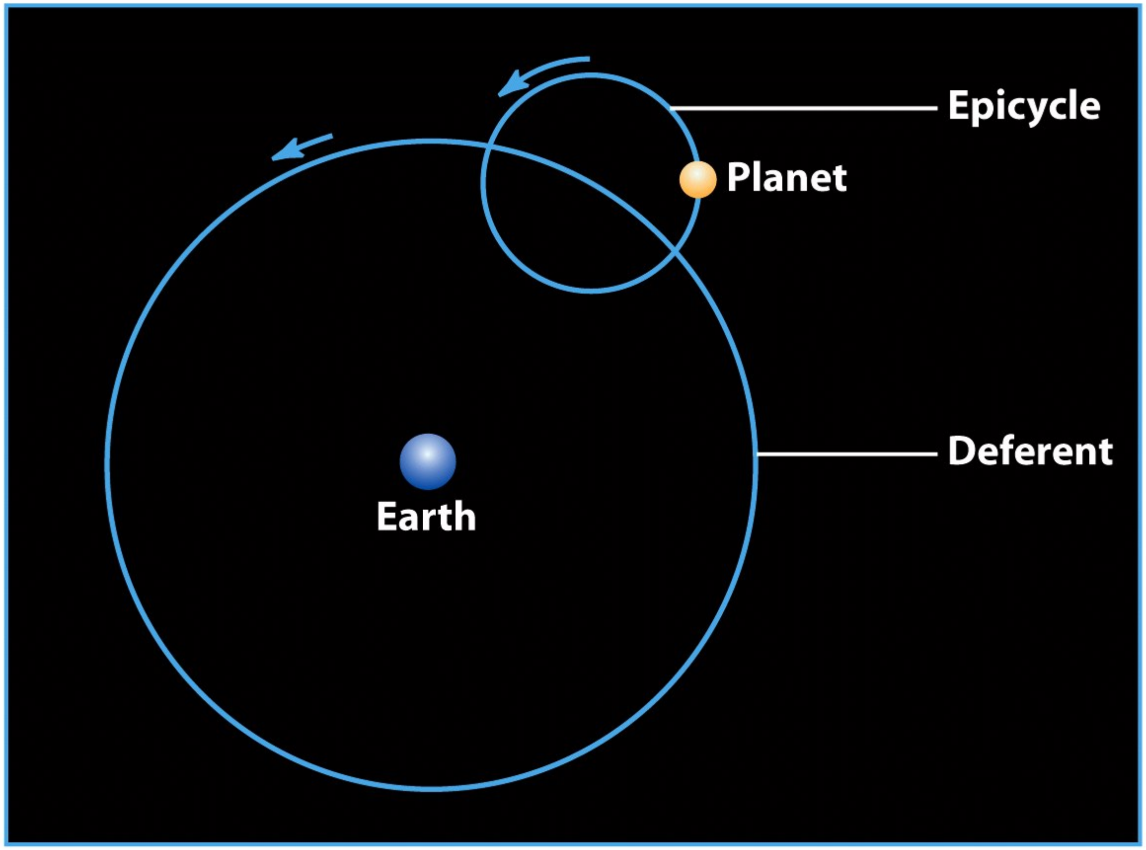
Geocentric Explanation of Retrograde Motion Requires Epicycles



Planetary motion modeled as a combination of circular motions

Figure 4-3a
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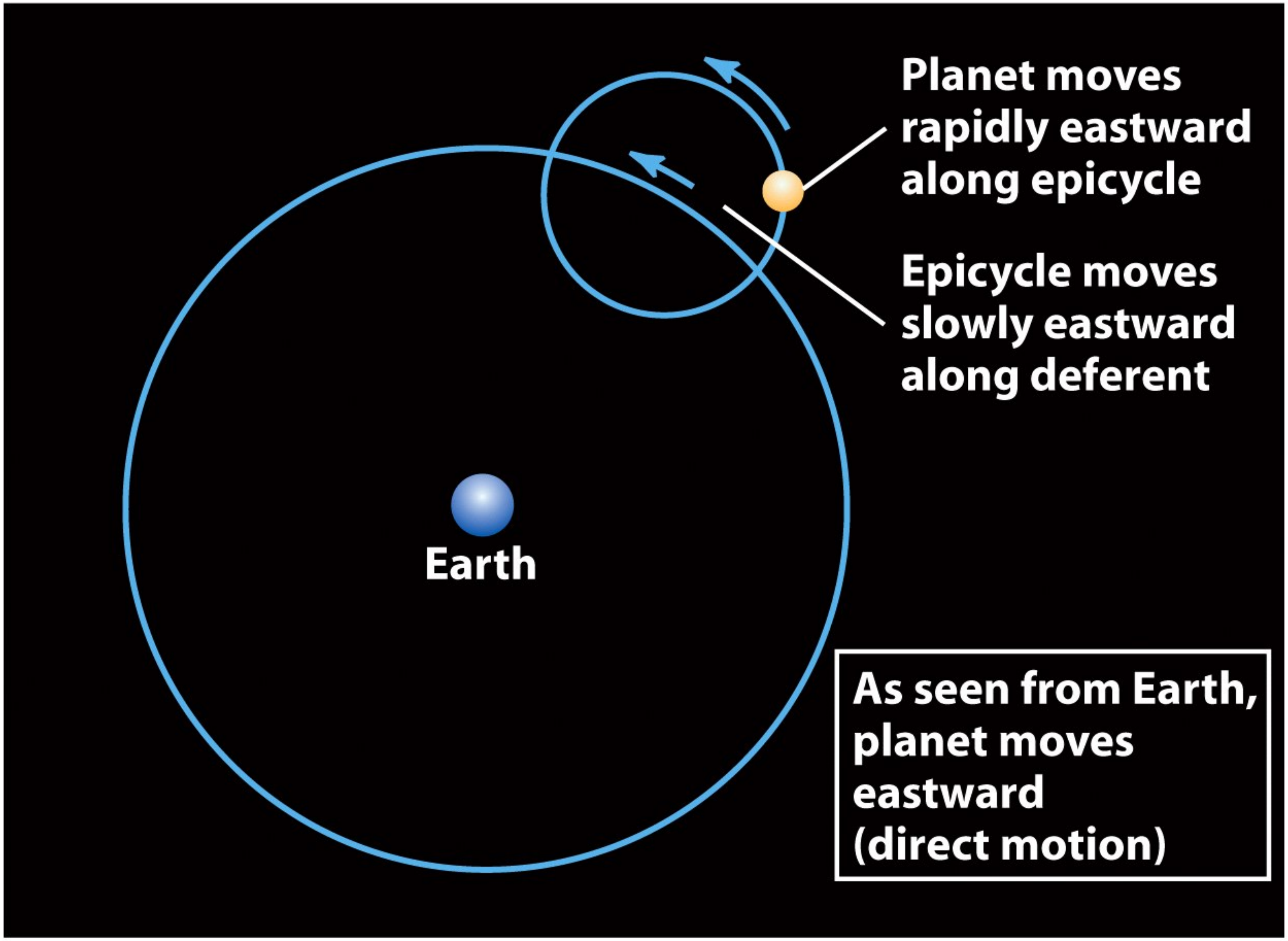

Modeling direct motion

Figure 4-3b
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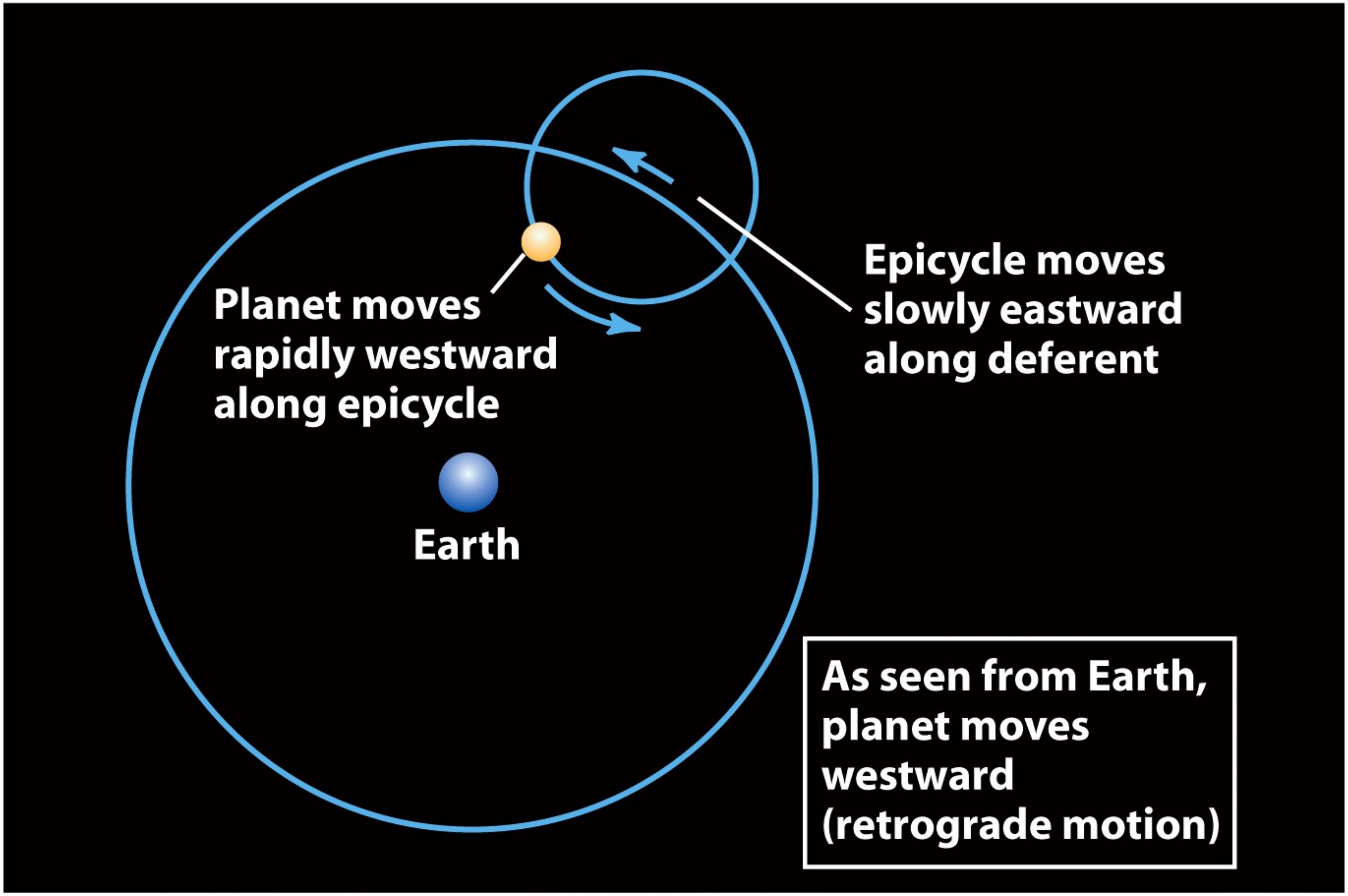

Modeling retrograde motion

Figure 4-3c
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Heliocentric Model for the Solar System

- Aristarchus suggested a heliocentric model in the 3^{rd} century BC, but it didn't catch on.

- Nicolaus Copernicus (1473–1543) introduced the heliocentric (sun-centered) model of the solar system.

  - **Copernicus used the fact that Mars can sometimes be seen high in our sky at midnight to conclude that Earth came between the Sun and Mars.**

  - *De Revolutionibus* was published in 1543, but he had been circulating the ideas for 30 years.

- Revolutionized our understanding of our place in the universe.

Kepler's Laws

By analyzing Tycho Brahe's detailed records of planetary positions, Kepler (1571–1630) developed three general principles, called Kepler's laws, that describe how the planets move about the Sun.

1. Kepler was the first to realize that the orbits of the planets are ellipses and not circles.

2. He figured out how the speed of a planet must vary along its orbit

3. He determined how the size of the orbit affected the planet's speed.

Described the motions of the planets more accurately than any scheme before.

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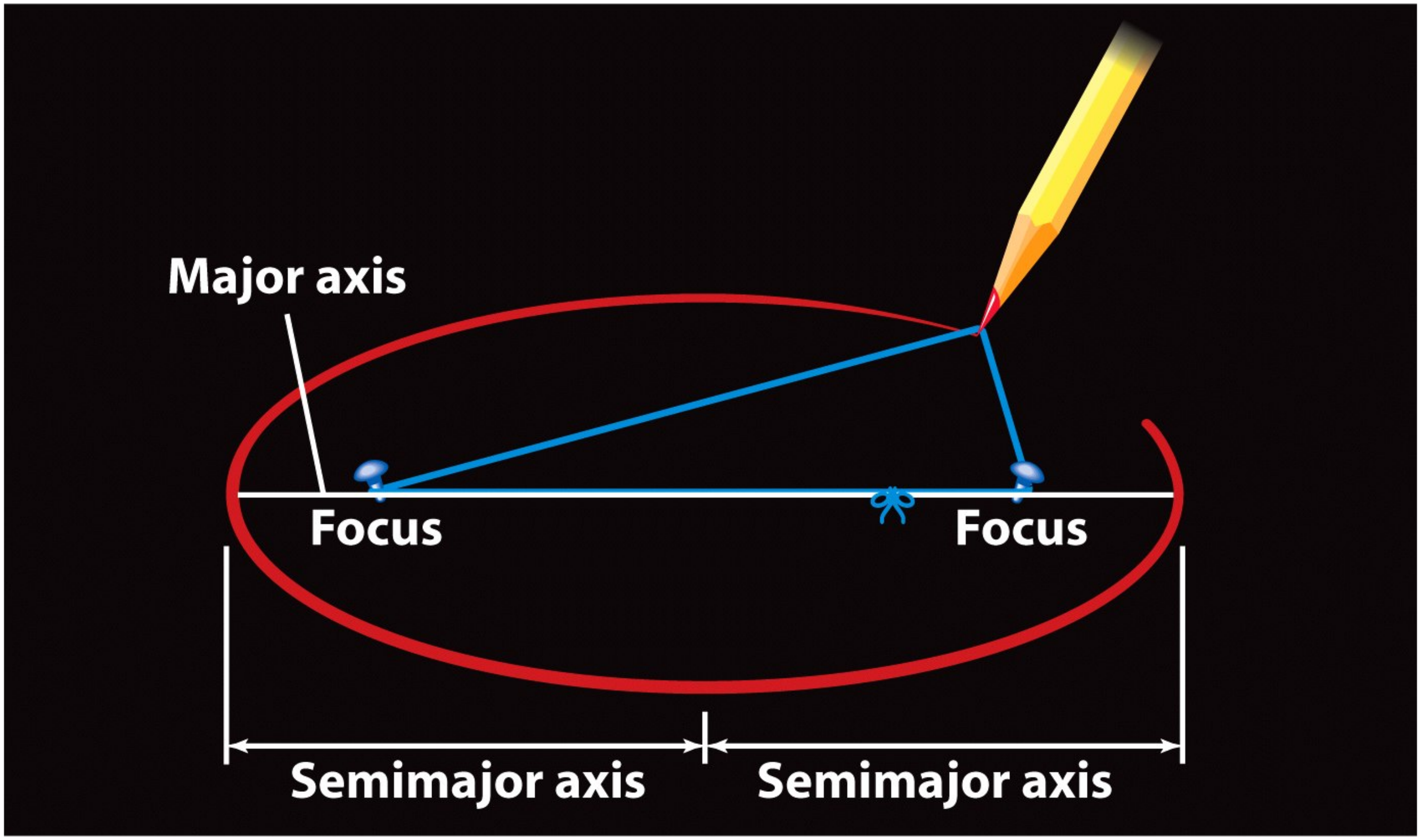

The geometry of an ellipse

Figure 4-10a
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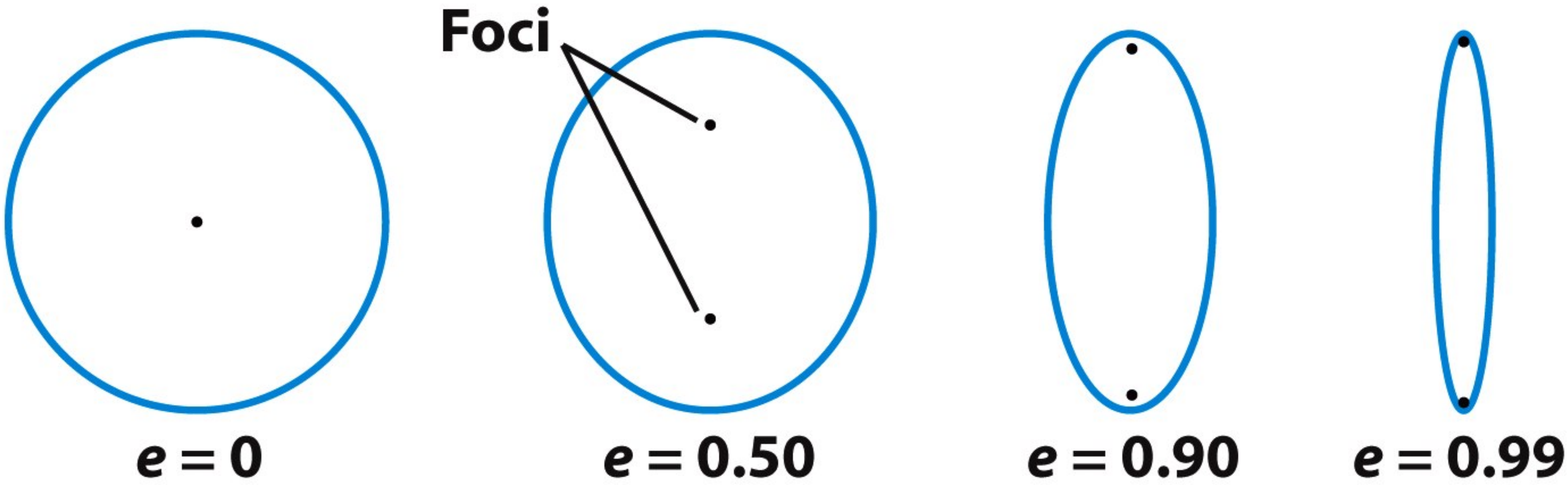

Ellipses with different eccentricities

Figure 4-10b
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Kepler's first law: The orbit of a planet about the Sun is an ellipse with the sun at one focus.

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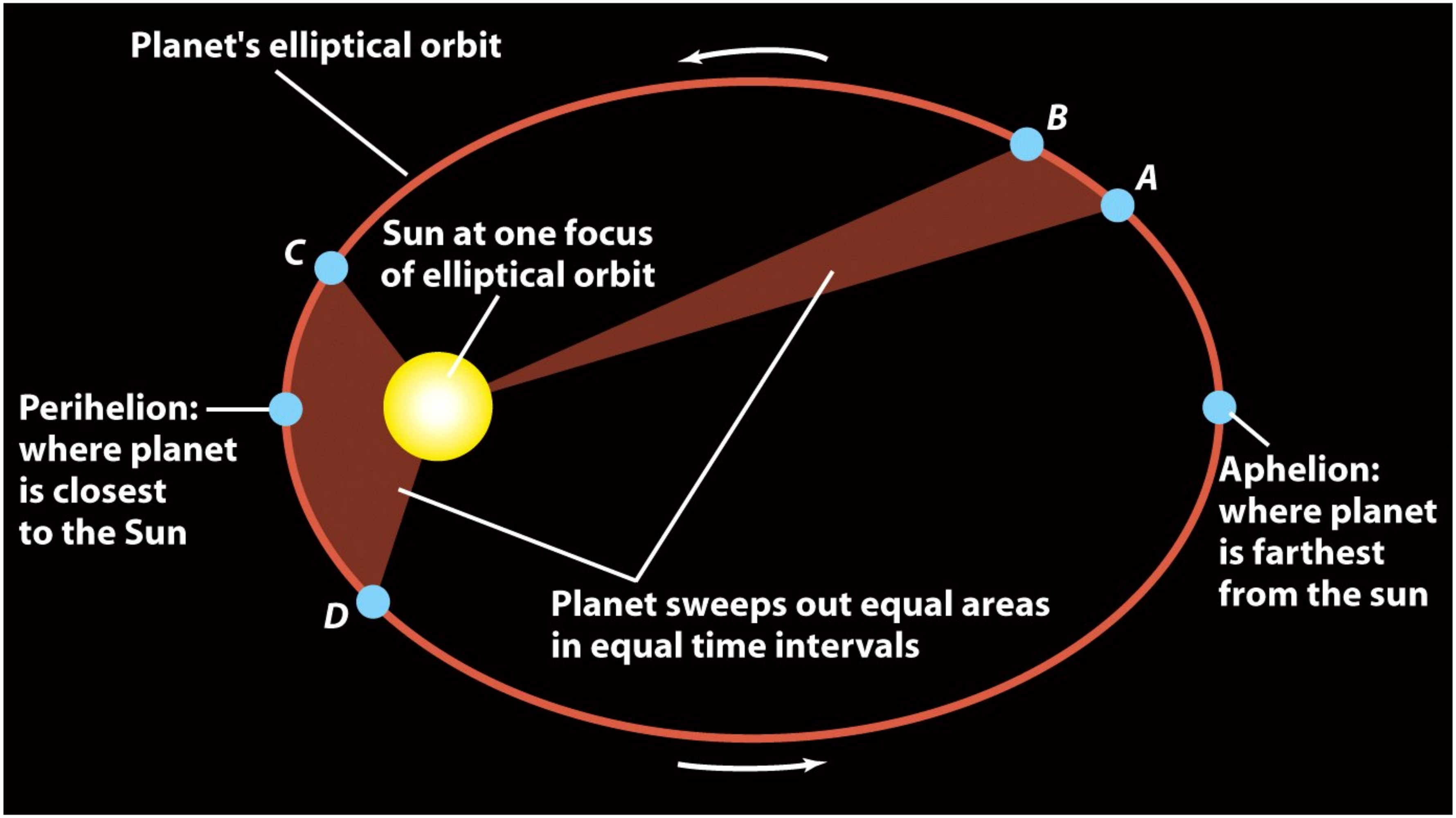

Figure 4-11
Universe, Eighth Edition

Kepler's second law: A line joining a planet and the Sun sweeps out equal areas in equal intervals of time.

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Table 4-3 A Demonstration of Kepler's Third Law ($P^2 = a^3$)

Planet	Sidereal period P (years)	Semimajor axis a (AU)	P^2	a^3
Mercury	0.24	0.39	0.06	0.06
Venus	0.61	0.72	0.37	0.37
Earth	1.00	1.00	1.00	1.00
Mars	1.88	1.52	3.53	3.51
Jupiter	11.86	5.20	140.7	140.6
Saturn	29.46	9.55	867.9	871.0
Uranus	84.10	19.19	7,072	7,067
Neptune	164.86	30.07	27,180	27,190

Kepler's third law states that $P^2 = a^3$ for each of the planets. The last two columns of this table demonstrate that this relationship holds true to a very high level of accuracy.

Table 4-3
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Heliocentric explanation of retrograde motion

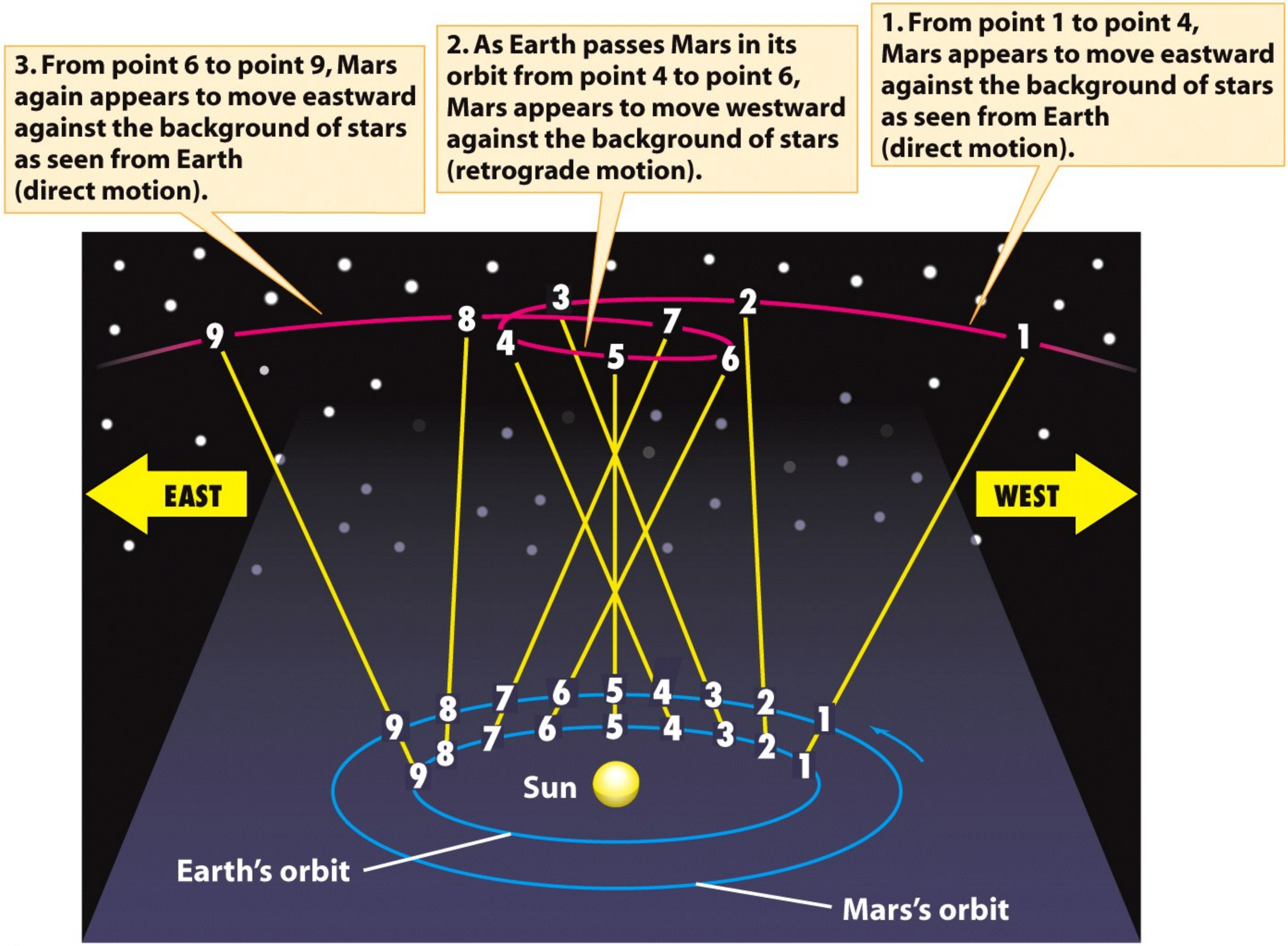

Figure 4-5
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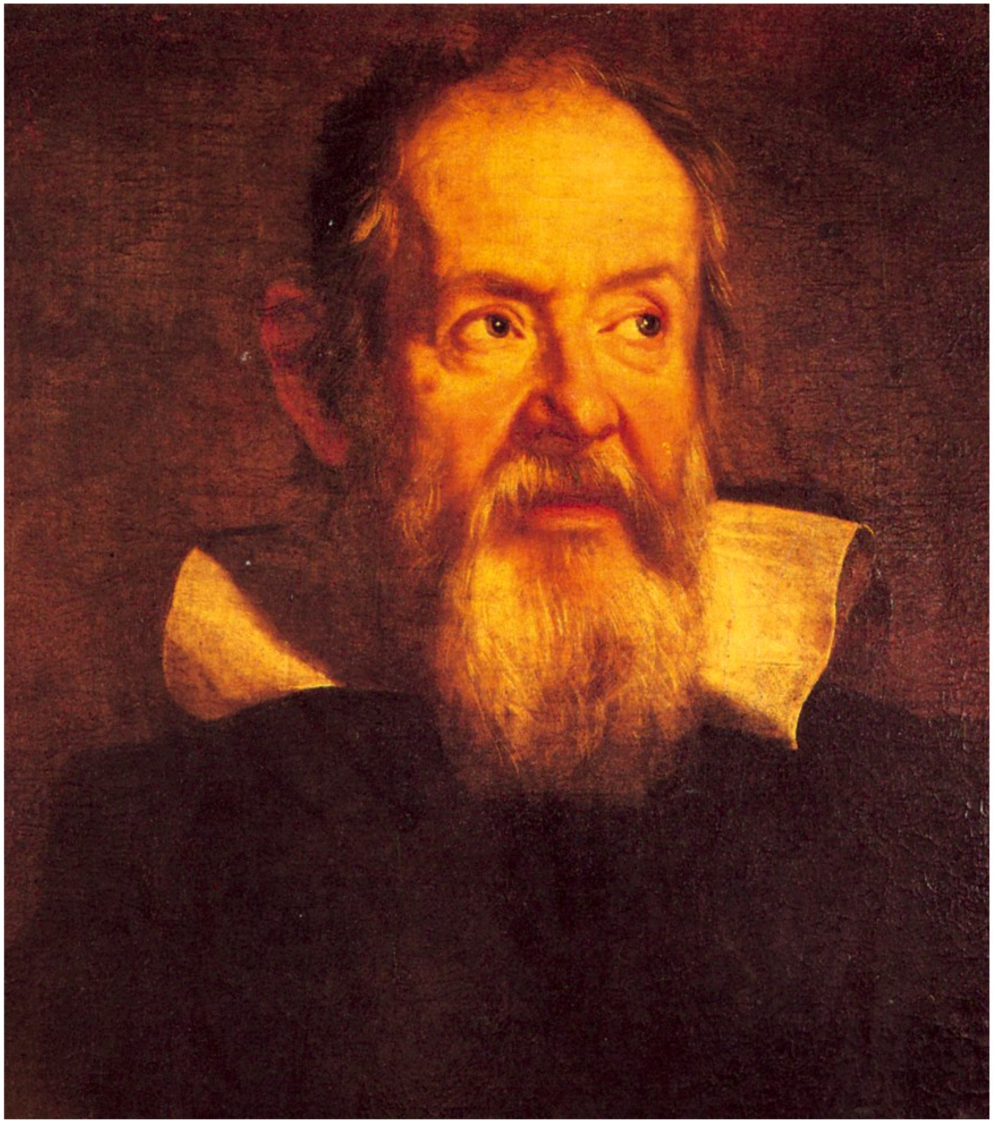

Figure 4-12
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Galileo Galilei (1564–1642)

Galileo was one of the first people to use a telescope to observe the heavens. He discovered craters on the Moon, sunspots on the Sun, the phases of Venus, and four moons orbiting Jupiter. His observations strongly suggested that the Earth orbits the Sun, not vice versa.

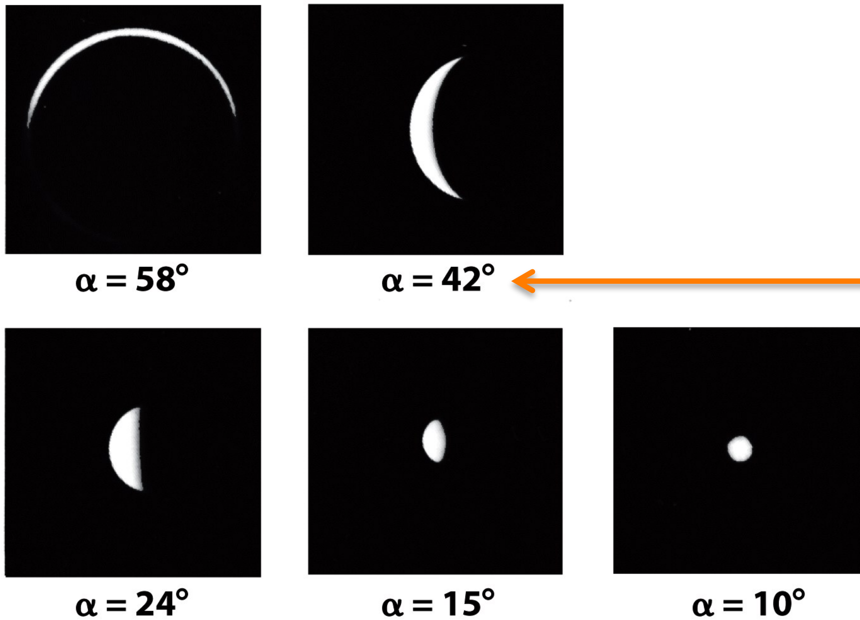

Figure 4-13
Universe, Eighth Edition

Numbers are angular size of Venus in arcsec, but mistakenly labeled as degrees in figure.

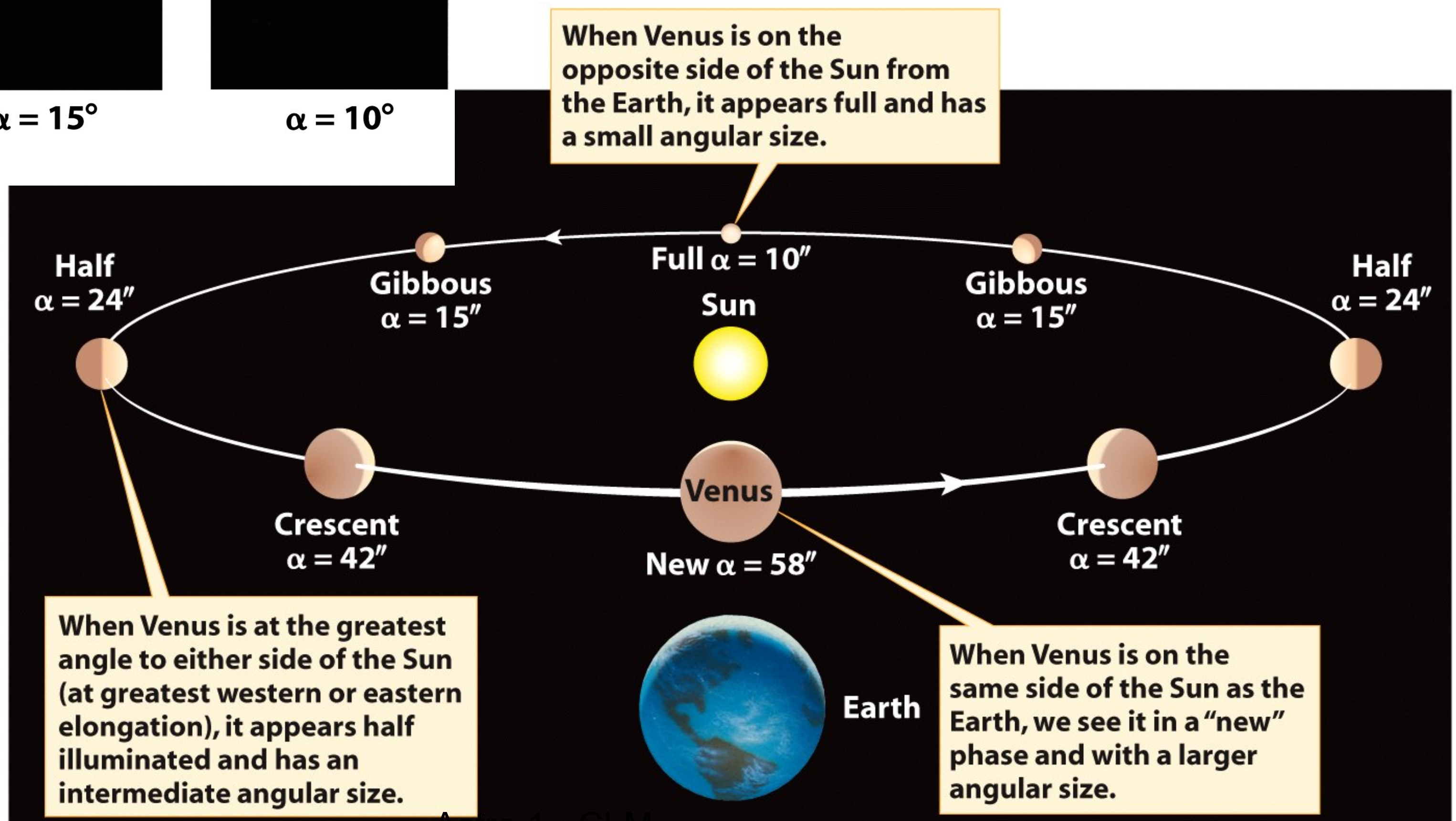

Figure 4-14
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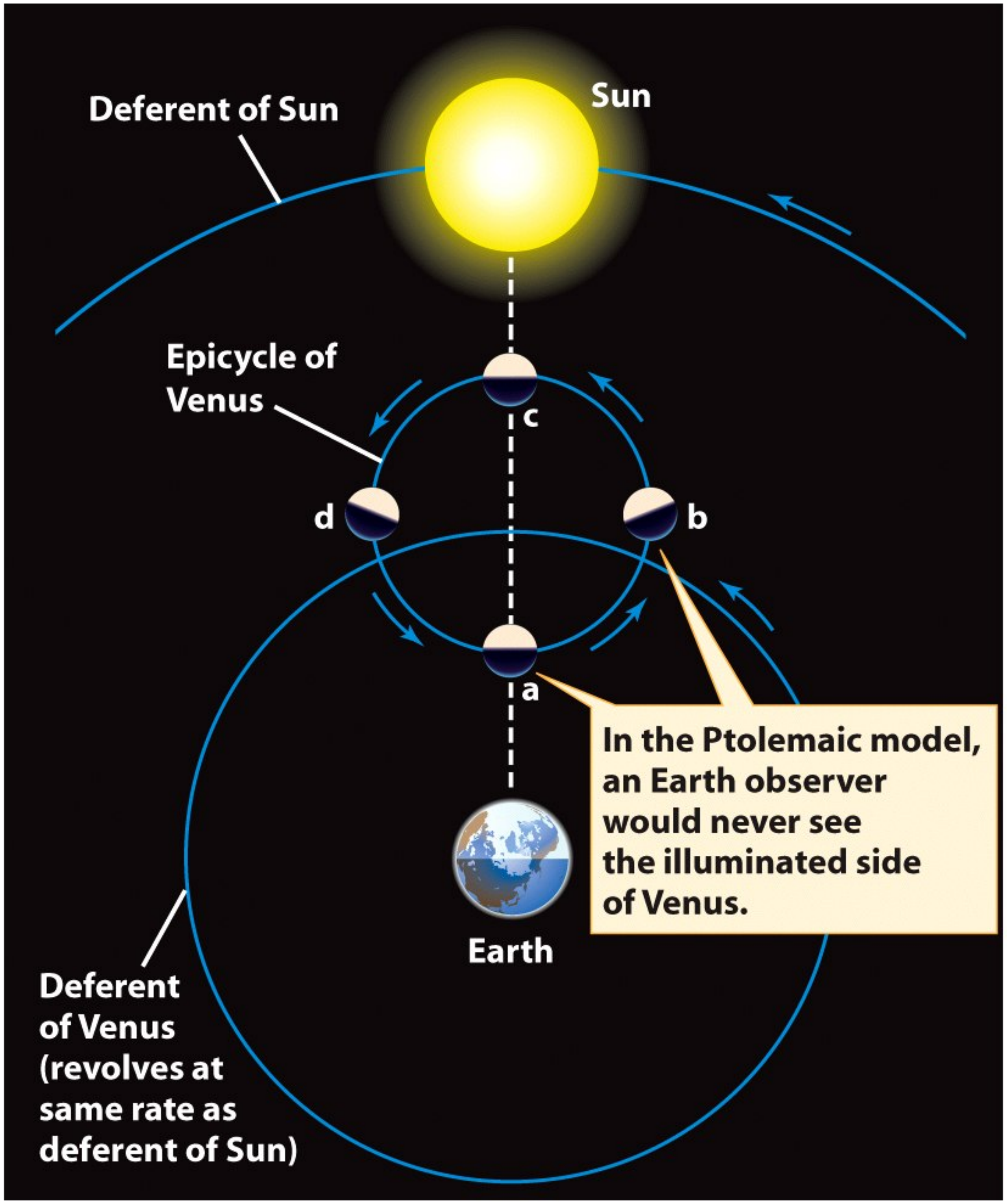

Figure 4-15
Universe, Eighth Edition

Galilean Satellites with a Small Telescope

Figure 4-16
Universe, Eighth Edition

- In 1610 Galileo discovered four "stars" that move back and forth across Jupiter from one night to the next.

- He concluded that these are four moons that orbit Jupiter, much as our Moon orbits the Earth.

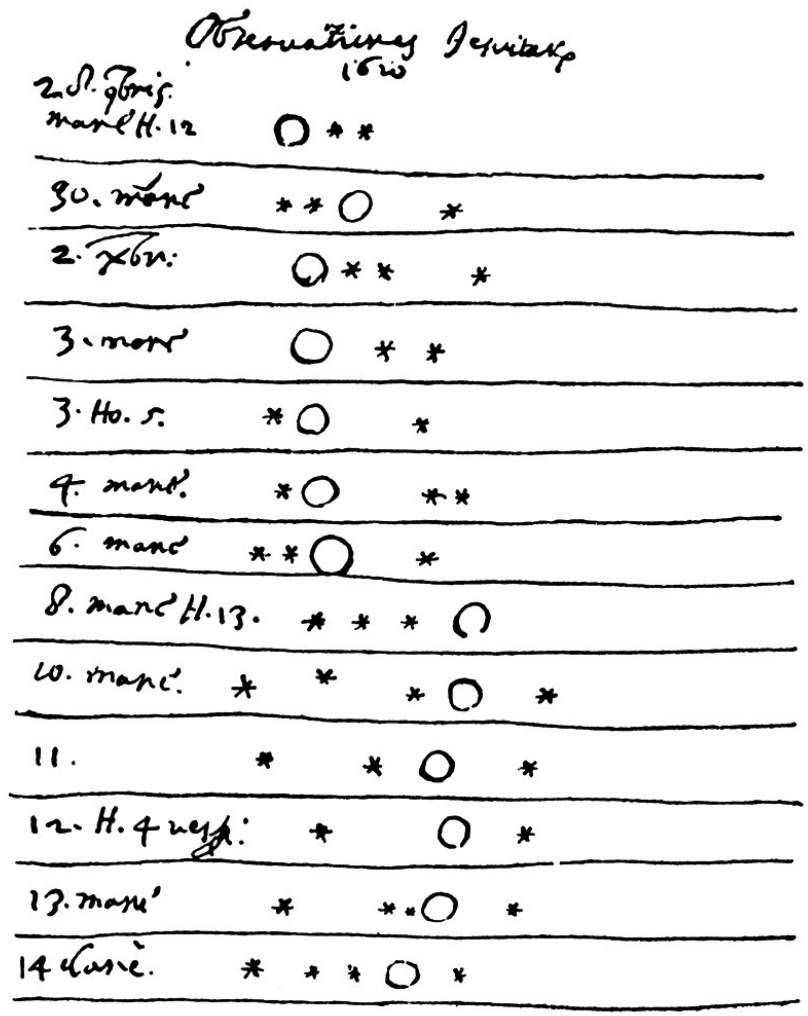

Figure 4-17
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Heliocentrism over Geocentrism

- Observations supporting heliocentric model
  - Phases of Venus
  - Stellar Parallax

- Observations against specific features of geocentric model
  - Moons of Jupiter
  - Sun spots
  - Moon spots

- Turned out to be a direct consequence of more fundamental physical laws of nature.

Newton's Laws of Motion Demonstrated

or

Physics is Fun!

Astro 1 - CLM

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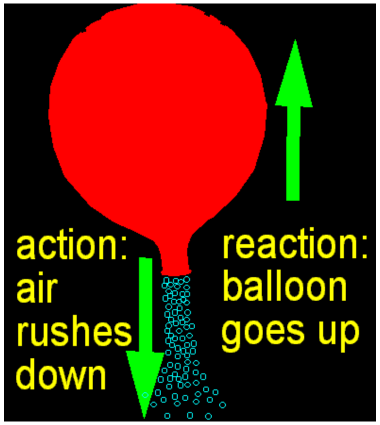
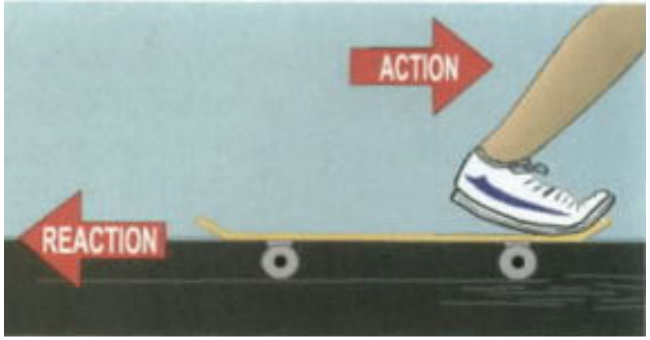
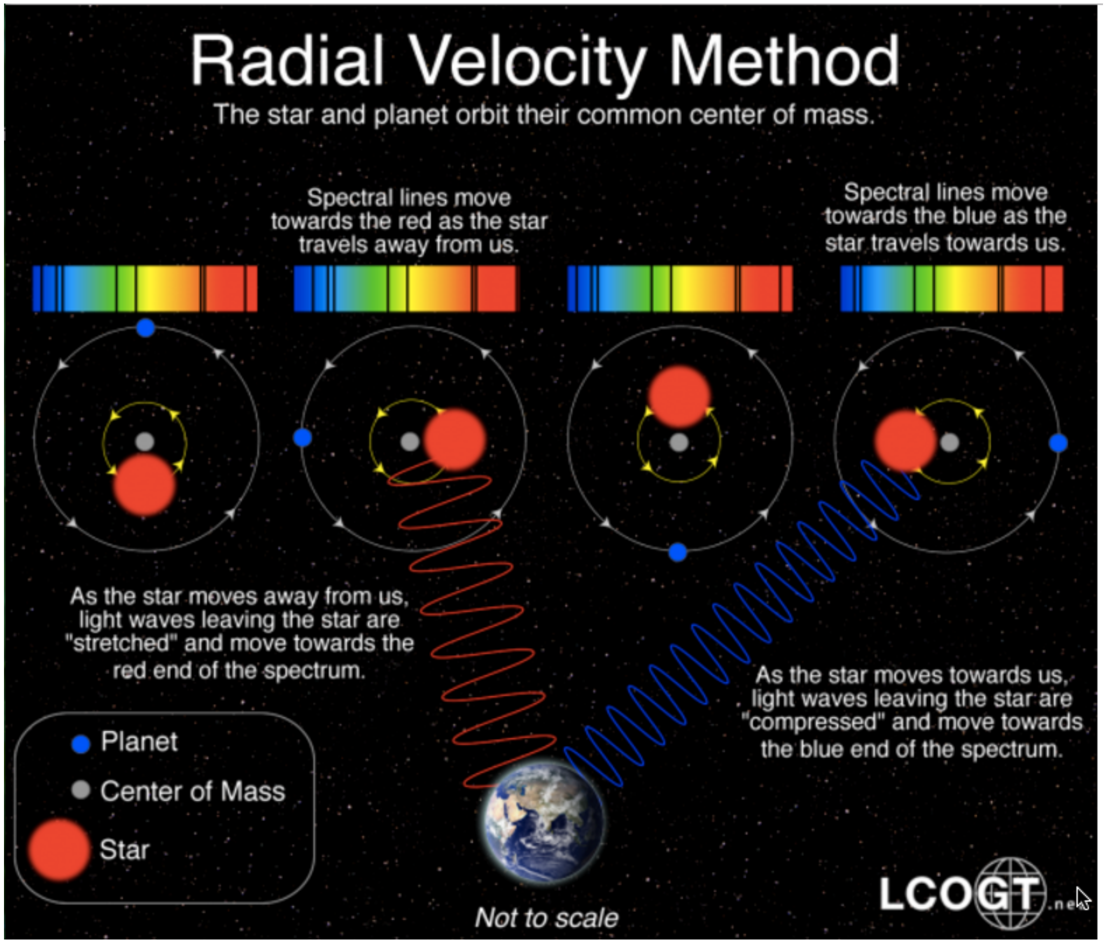
Newton's Third Law

Whenever one object exerts a force on a second object, the second object exerts and equal and opposite force on the first object.







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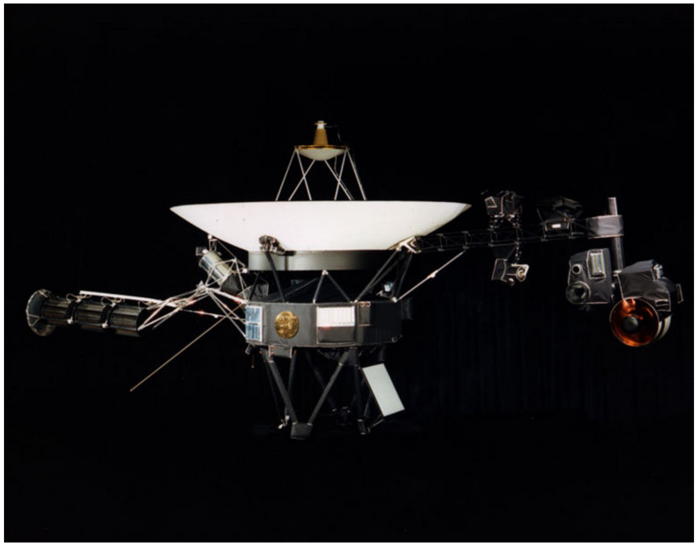
Newton's First Law (Inertia)

1. An object remains at rest or moves in a straight line at a constant speed unless acted upon by a net outside force.

Example: Voyager 1 -- launched in 1977, it is now on its way out of the solar system, forever traveling in a straight line (unless it encounters something).



Ball Rolling Along Curved Track iclicker Question

- What trajectory will the ball take when it rolls out of the loop?
  A. It will continue around the circle back to where it first touched the loop.
  B. It will continue on a curved path for a brief period, but its path will eventually straighten out.
  C. It will go around the loop two more times.
  D. It will roll along a straight line.
  E. Really, I have no idea. Let’s find out!

Newton's Second Law (acceleration)

F = ma

F = net outside force on a object

m = mass of object

a = acceleration of object

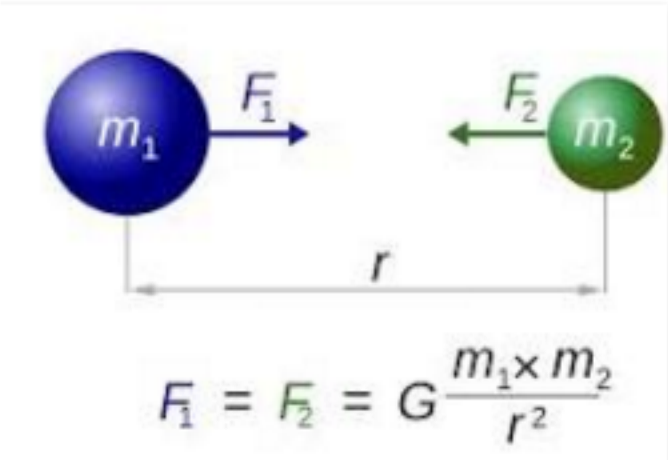
- If objects of different masses experience the same acceleration, the more massive object exerts the higher force upon impact.
- It requires more force to accelerate more massive objects.
- If you push two objects of different masses with the same force, the less massive object will accelerate more.

Newton’s Law of Gravity Demonstrated

The Law of Universal Gravitation

Two objects attract each other with a force that is directly proportional to the mass of each object and inversely proportional to the square of the distance between them.

$$F=Gm_1m_2/r^2$$



F = gravitational force between two objects

m_1 = mass of first object

m_2 = mass of second object

r = distance between objects

G = universal constant of gravitation

$G = 6.67 \times 10^{-11}$ newton•m^2/kg^2

Newton's Theory Explained Kepler's Third Law

$$P^2 = \left[\frac{4\pi^2}{G(m_1 + m_2)}\right]a^3$$

P = period of orbit, in seconds
m_1 = mass of first object, in kg
m_2 = mass of second object, in kg
a = semimajor axis of orbit, in meters
G = 6.67×10^{-11} newton•m^2/kg^2 (gravitational constant)

Note that Kepler's form is only valid for objects orbiting the sun. Newton's form can be applied to any two objects in the universe.

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The orbits of planets

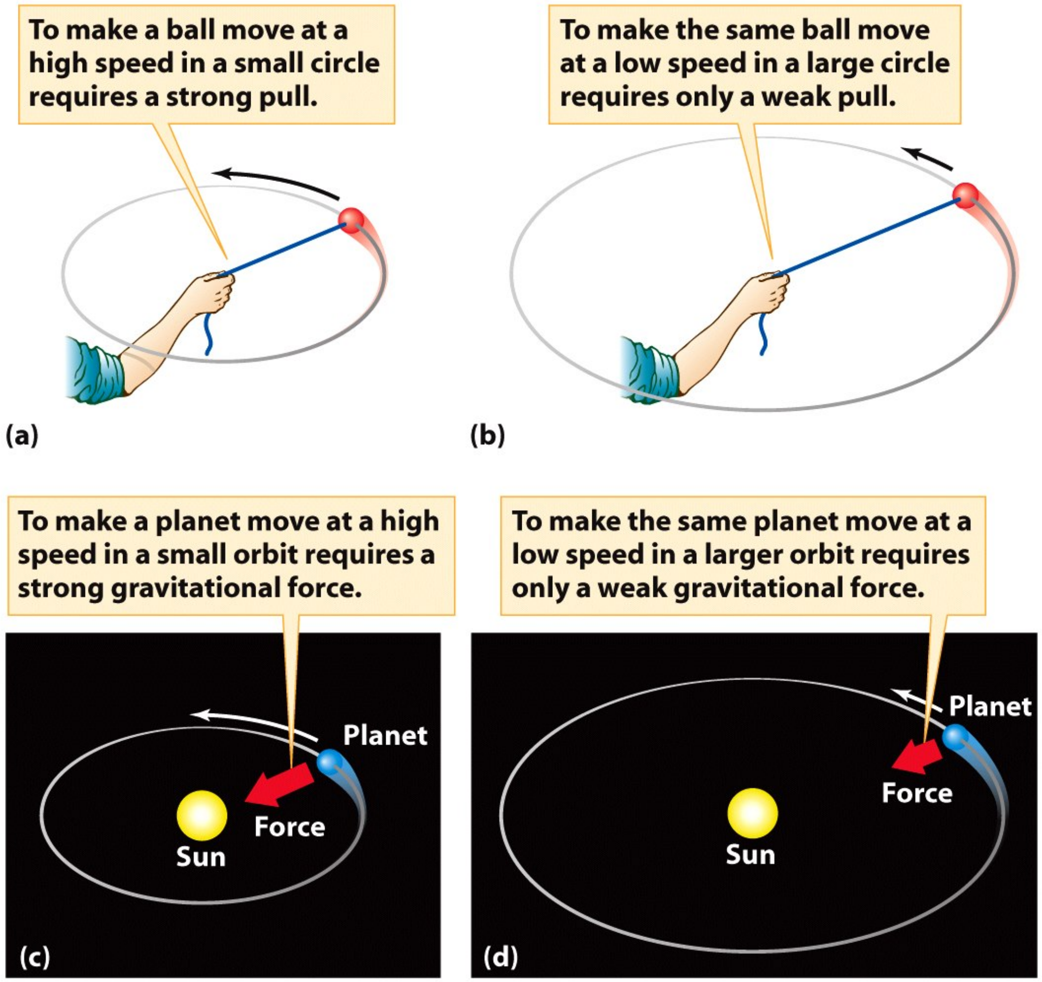

Figure 4-19
Universe, Eighth Edition

When a body moves in a circle, there must be a outside force acting on that body.

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Energy of Orbits

- Earth's gravity is making the ball fall, but the Earth's surface is falling away under the ball at the same rate.
- E – if you throw the ball at exactly the right speed, the ball's path will exactly match the curvature of the Earth's surface
- The greater the orbital energy, the greater the average orbital energy distance (semimajor axis a).

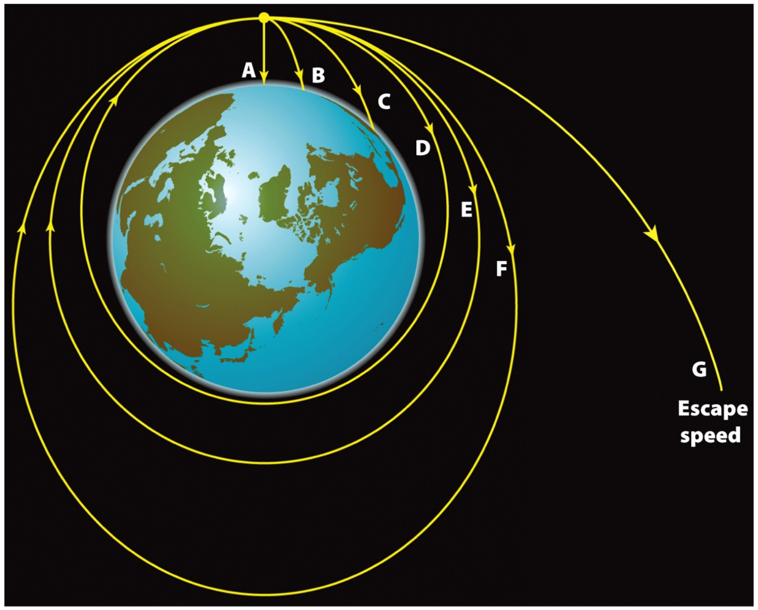

Figure 4-22
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Different Forms of Energy:
1. Kinetic Energy

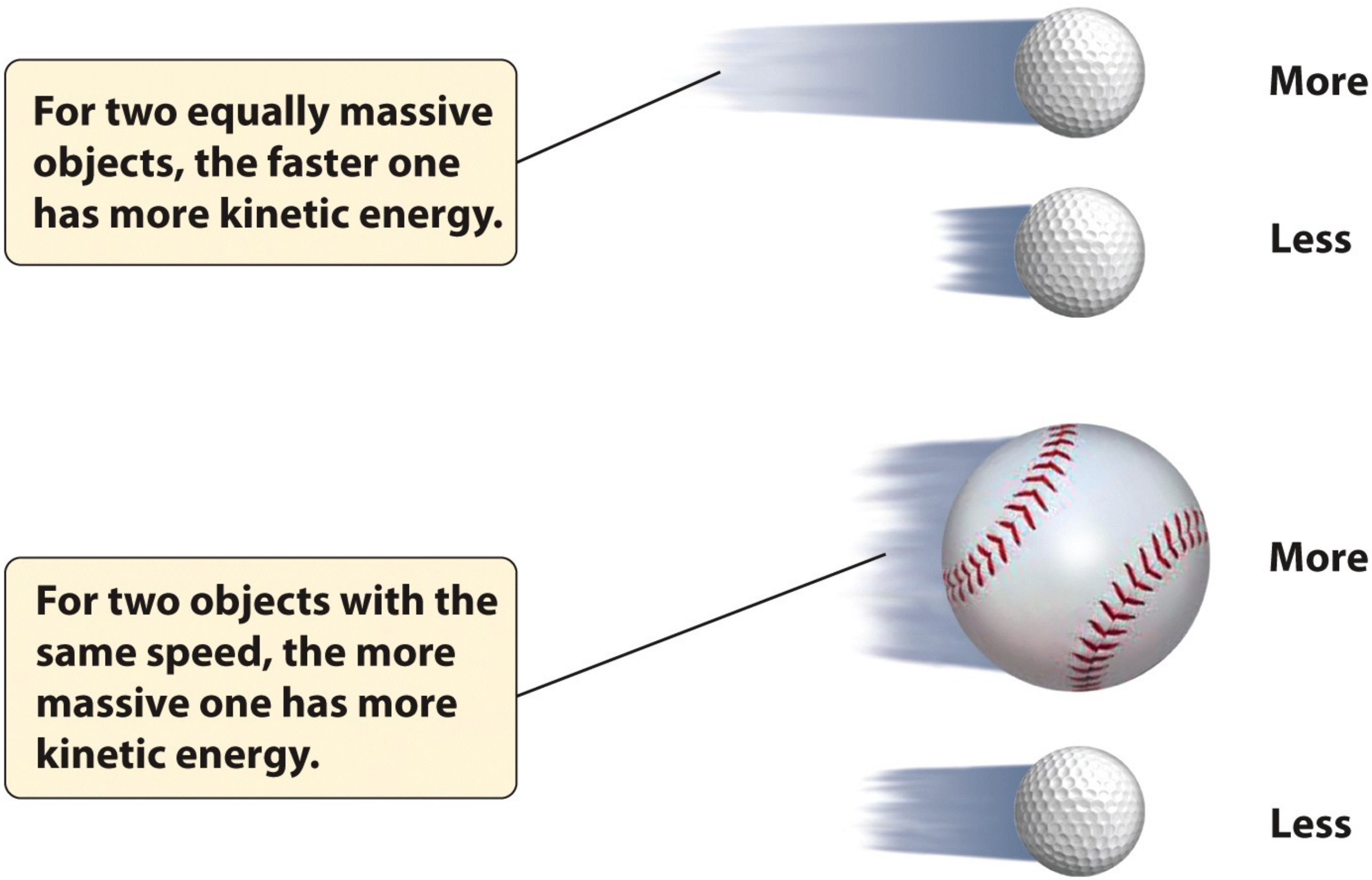

Figure 4-20
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Different Forms of Energy: 2. Potential Energy

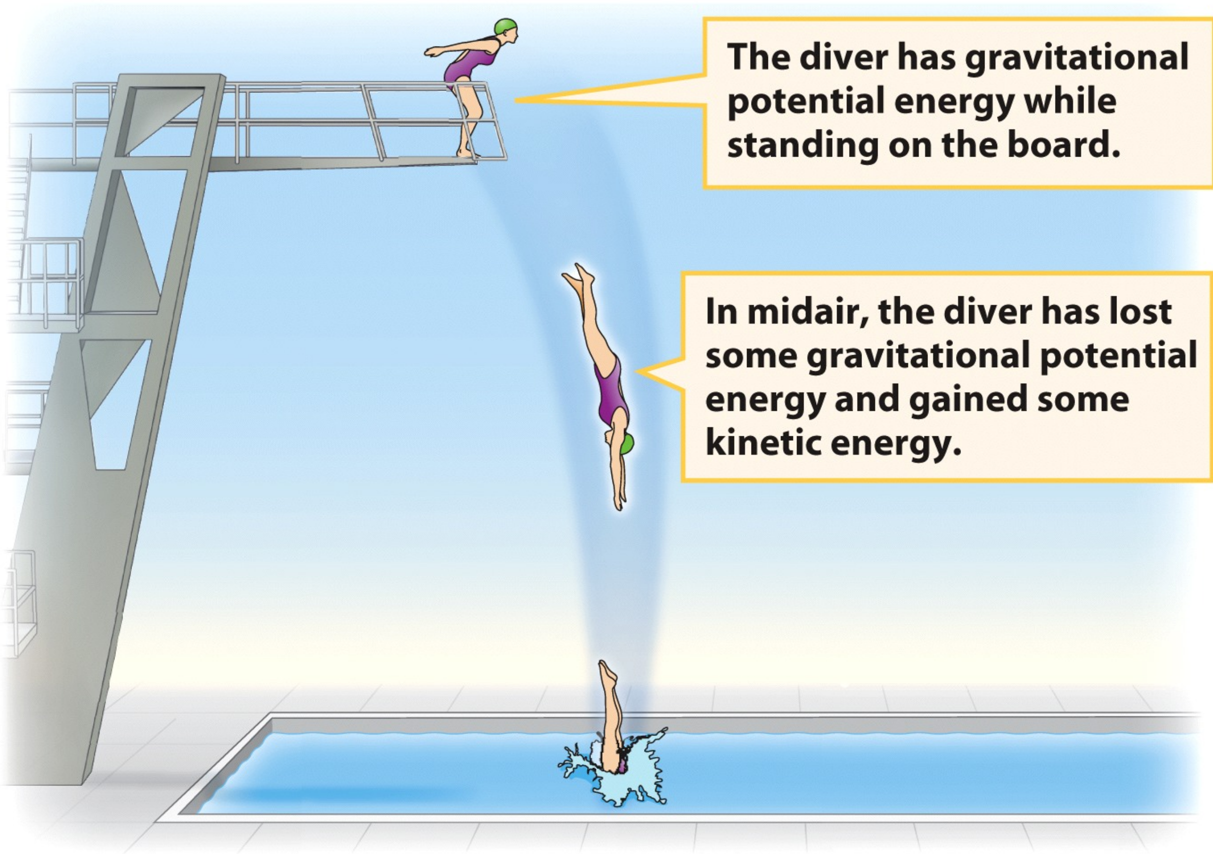

Figure 4-21
Universe, Tenth Edition

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The Total Energy is Conserved (not the individual types)

- The first American in space, Alan Shepard, did not orbit the Earth, because his Redstone rocket (a ballistic missile) was not powerful enough. John Glenn would later orbit Earth after being launched from an Atlas rocket.
- His total energy had a negative value!

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Gravity Also Creates Tidal Forces

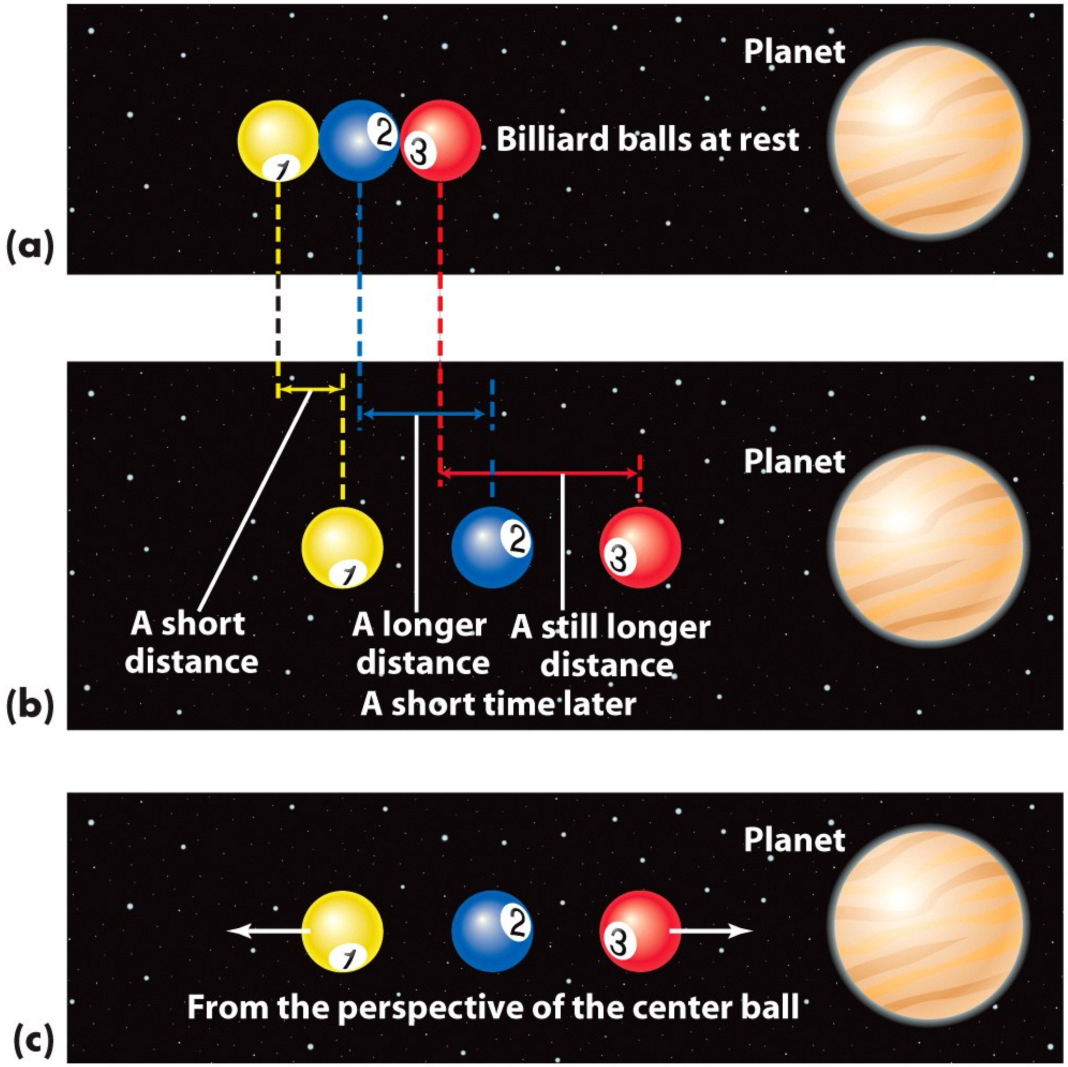
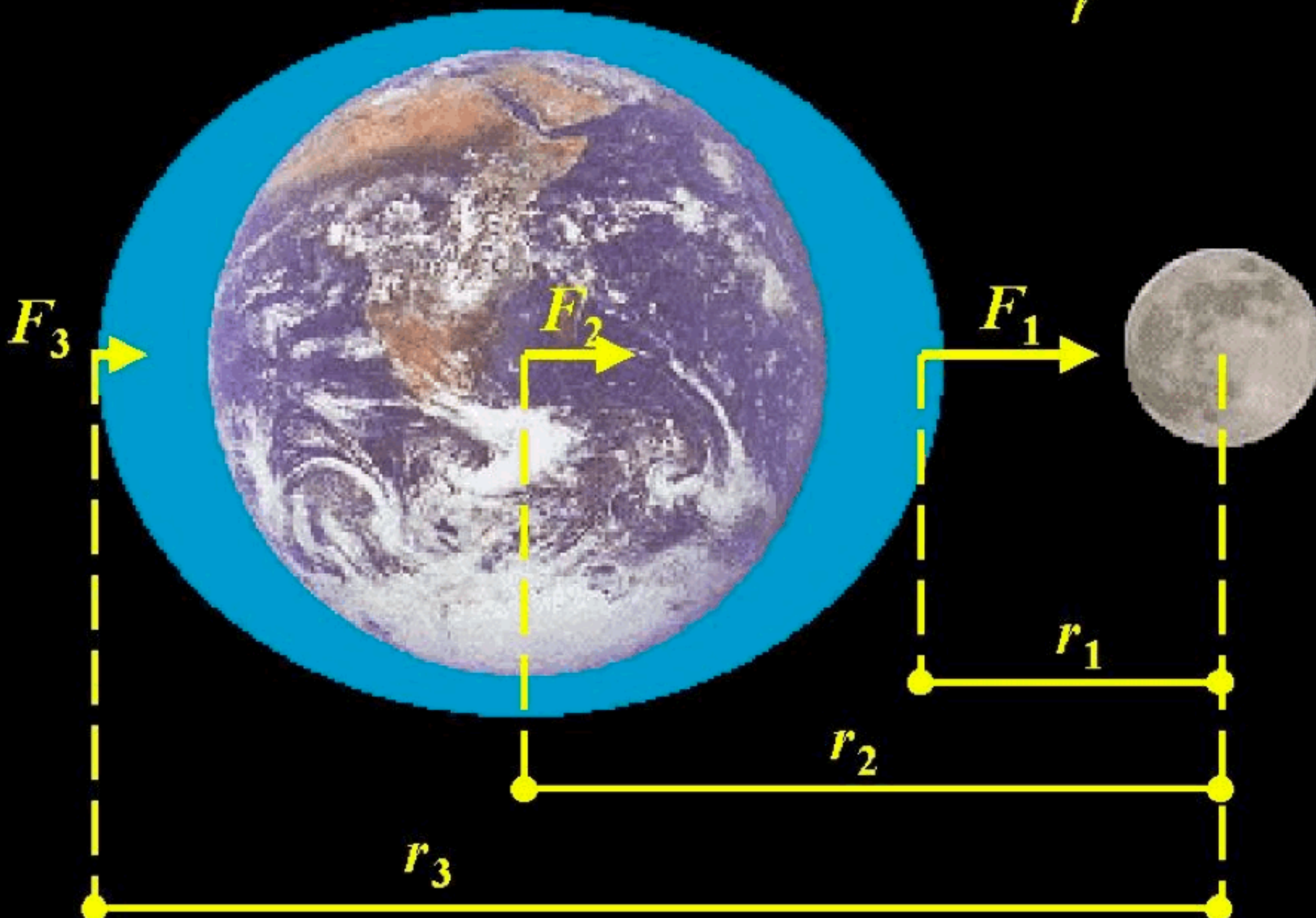


Figure 4-24
Universe, Eighth Edition

Tides are a difference in gravitational forces over a body of finite size.

$$F = \frac{G\, M_{moon}\, m}{r^2}$$



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High and Low Tides on Earth

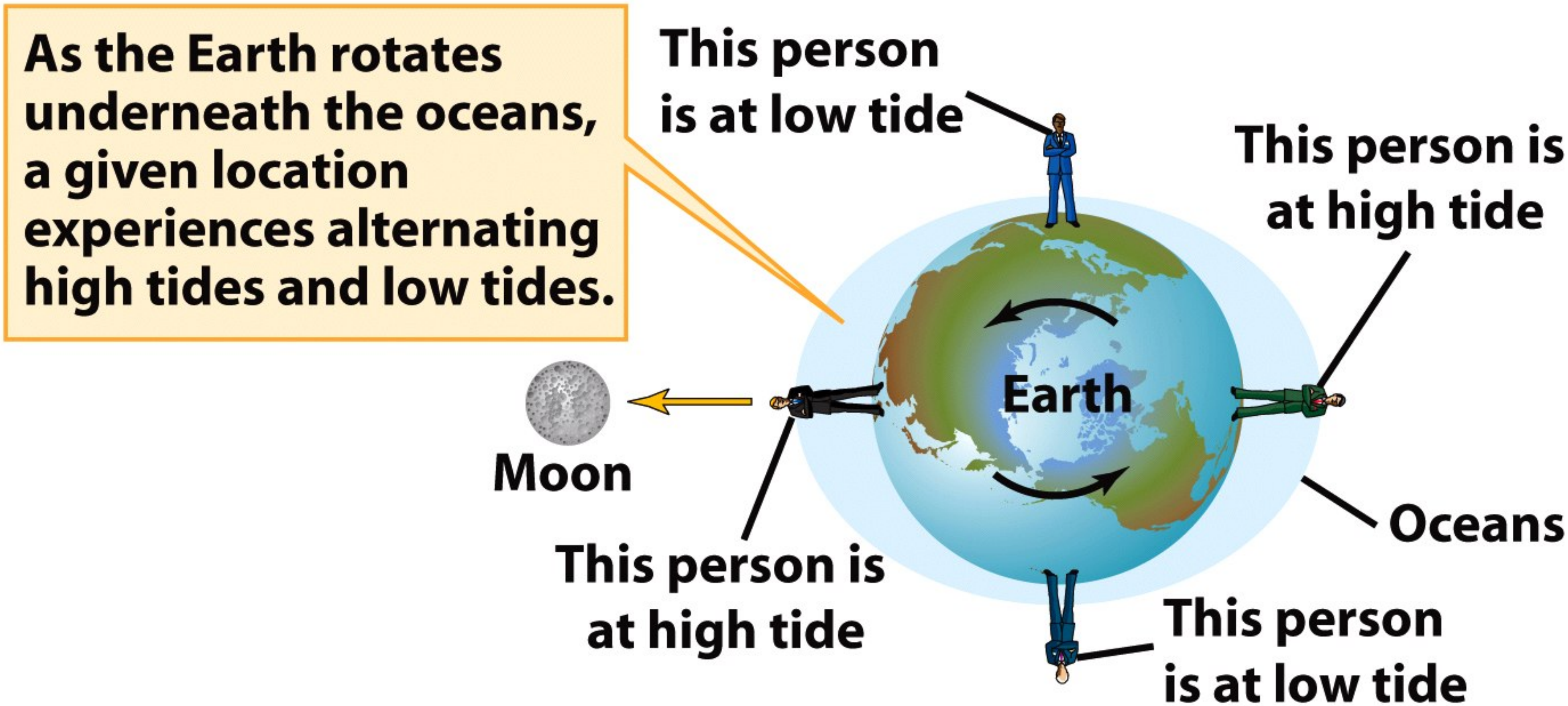

Figure 4-26a
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The Sun Contributes to Tides

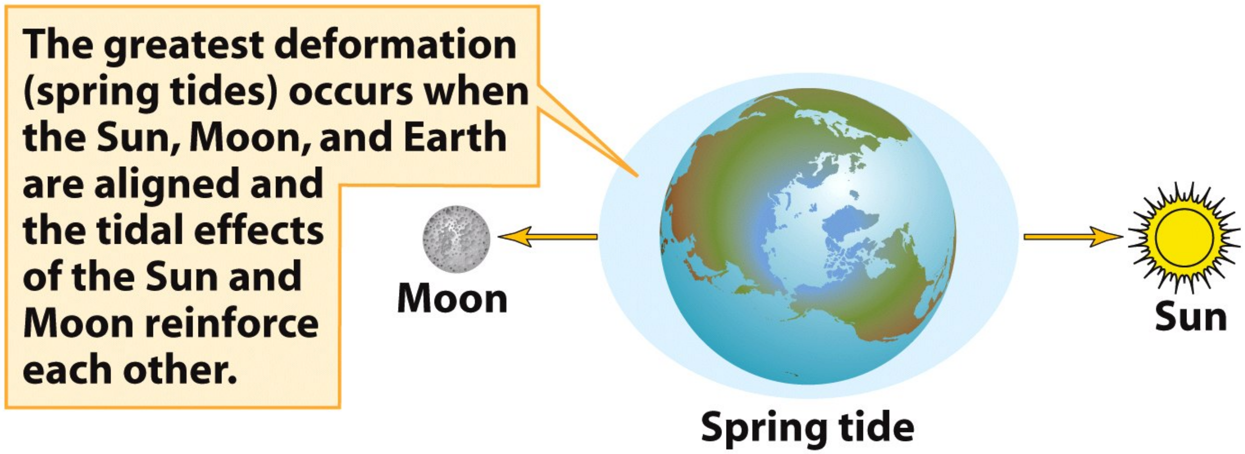

Figure 4-26b
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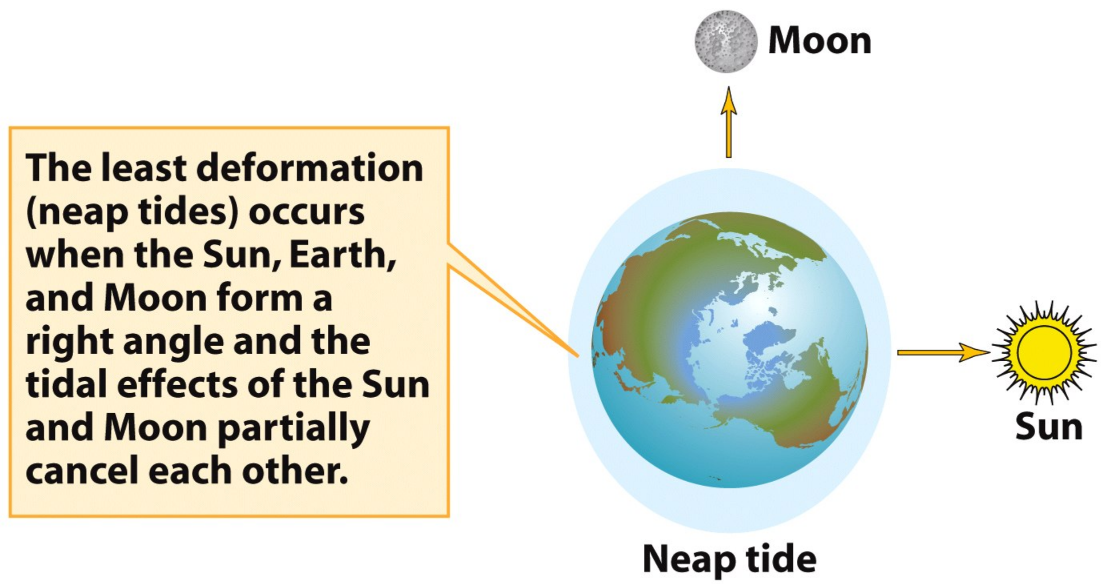

Figure 4-26c
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The Birth of New Scientific Theories

- Isaac Newton (1642–1727) explained Kepler's Laws as direct consequence of fundamental physical laws.
- Established that the laws of physics on earth extend up into the heavens,

Epitaph by Alexander Pope:
Nature and nature's laws lay hid in night;
God said "Let Newton be" and all was light.

Newton in a letter to Robert Hooke: "If I have seen further it is by standing on the shoulders of giants"

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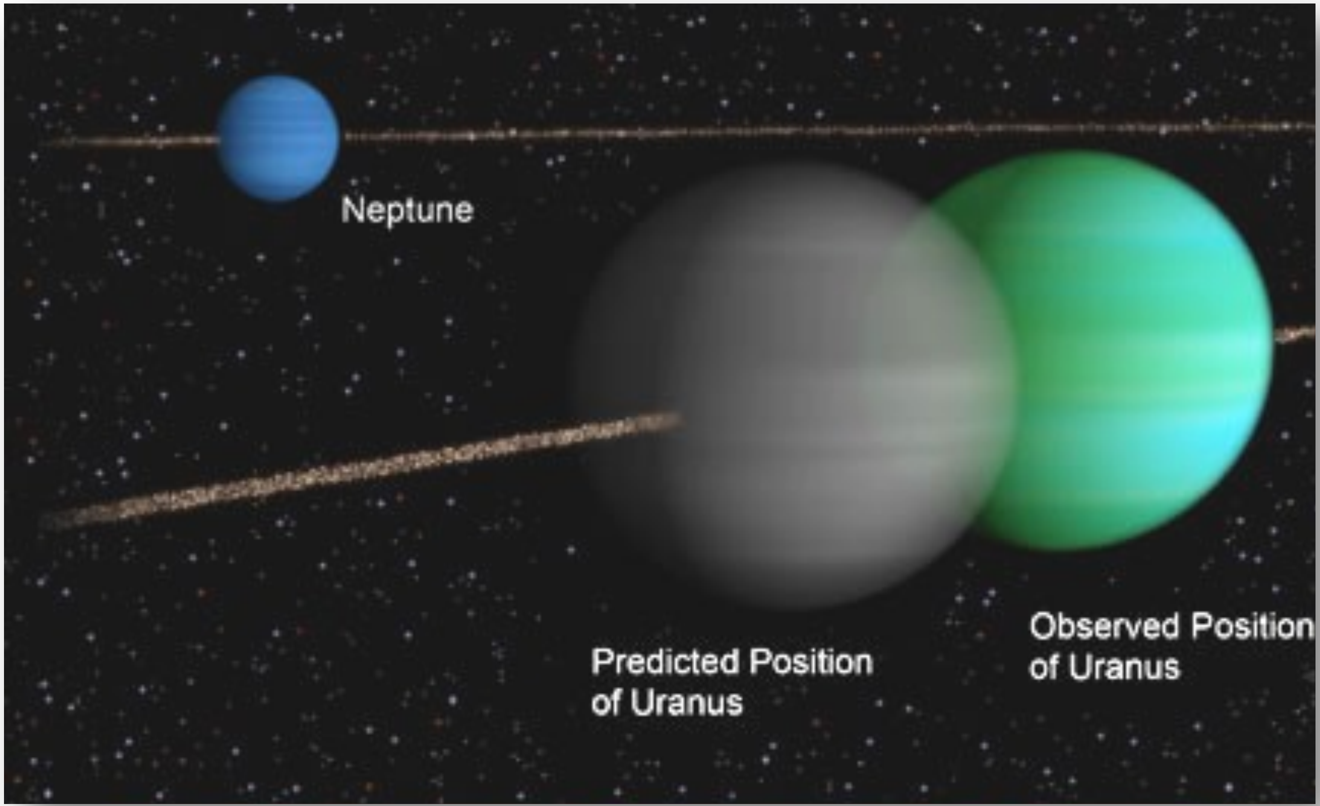
Newton'sTheories Were Used to Make Predictions



Le Verrier (1846)noticed Uranus was not in the right place. Predicted the existence of Neptune. Neptune was found where predicted to within one degree!

Iclicker Question

Which of the following statements is true according to Kepler's third law?

A. The smaller the orbit, the longer it takes for the planet to complete one revolution
B. The smaller the radius of a planet the more rapidly it rotates on its axis
C. The larger the orbit the longer it takes for the planet to complete one revolution
D. The time to complete one revolution of its orbit depends on the size or radius of the planet

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Iclicker Question

The most significant observation Galileo made through his home-built telescope that convinced him that the planets revolved around the Sun was

A. The appearance of the Milky Way as a mass of individual stars
B. The discovery of rings around the planet Saturn
C. The appearance of mountains and craters on the Moon
D. That the appearance of Venus followed a cycle of phases, from crescent through quarter and gibbous phases to full phase

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Most Important Things to Know

- In the modern Heliocentric model, the planets go around the sun (Copernican model)
  - What pieces of evidence show that the Geocentric model is false?
  - How did the Geocentric model explain retrograde motion of the planets?
- Kepler's Laws
  1. The orbits of planets are ellipses
  2. A planet's speed varies along the orbit
  3. The period of the orbit is related to the size of the orbit
- Newton's Laws of Motion
  1. Inertia
  2. Relation between force and acceleration
  3. Action/Reaction
- Newton's Law of gravity (orbits, tides, inertial vs. gravitational mass)

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Skateboard Experiment iclicker Question

- When the skateboarders push off, who will accelerate more?
  - A. Their accelerations are equal
  - B. The more massive person
  - C. The less massive person.
  - D. Neither person will move
  - E. It is impossible to predict with certainty.

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Skateboard Experiment icliker Question

- When the less massive person pulls on the rope what will happen?
  A. Both people move inwards toward the center of mass.
  B. The less massive person is pulled towards the more massive person.
  C. The more massive person is pulled towards the less massive person.
  D. The distance between the skateboarders increases due to Newton's third law..
  E. Neither person will move

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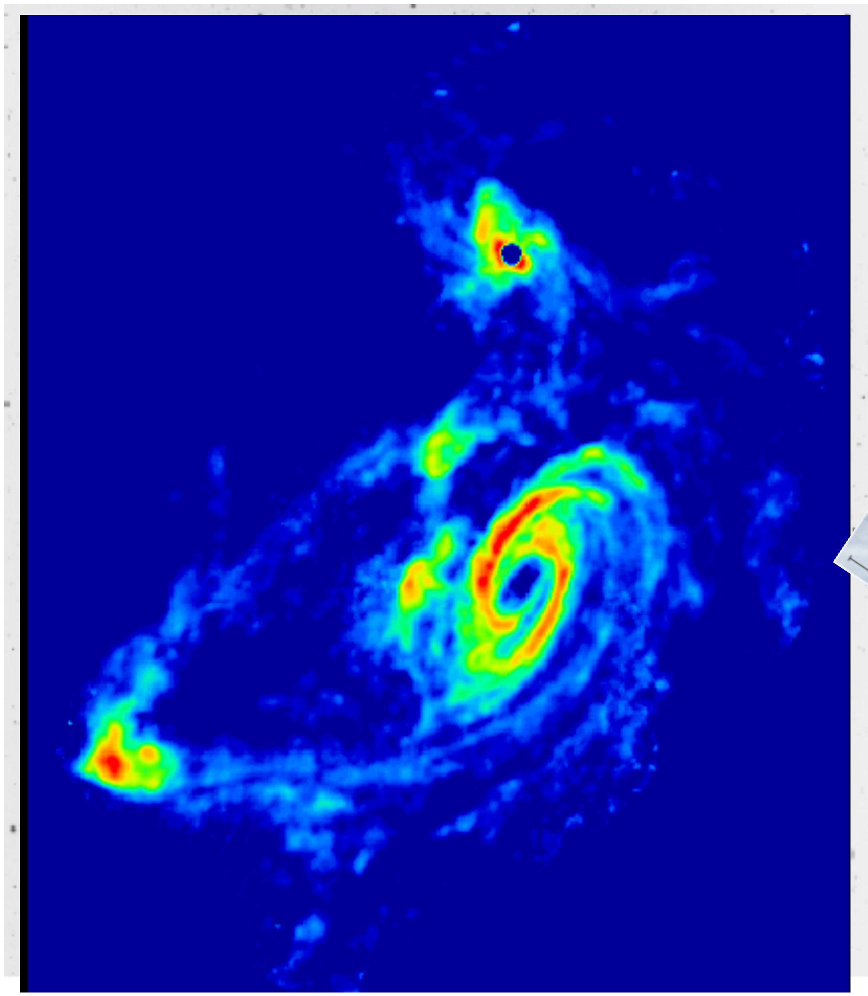
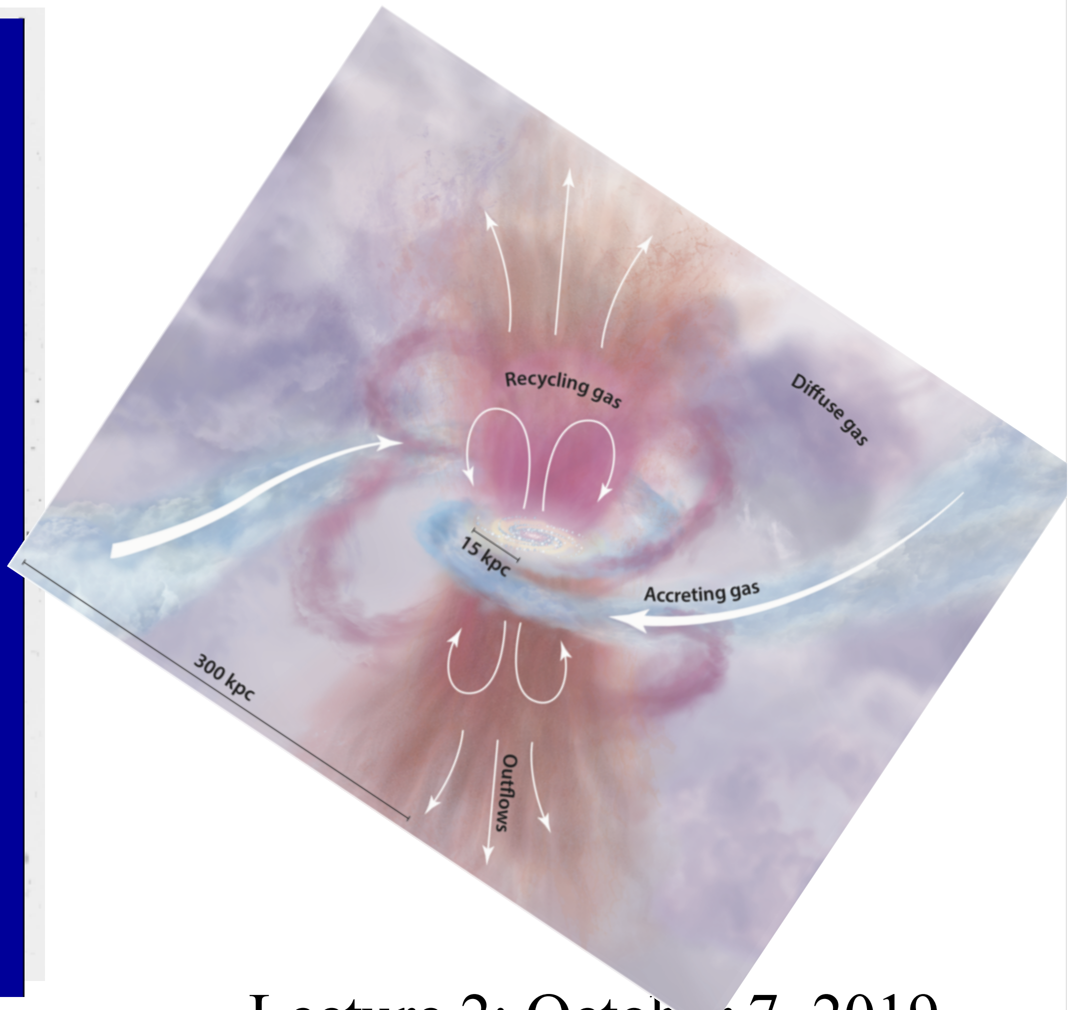
Astronomy News (not on exam)

The Galactic Ecosystem





Lecture 2; October 7, 2019

Discussion Sections

Difference between weight and mass

- Mass describes how much matter is in an object (measured in kg)
- Weight is a force (F=ma)that describes how gravity affects a mass (measured in Newtons: $1\ N = 1\ kg\ m/s^2$)
- *100 kg on the surface of the Earth weighs 980 N*

Example: If the Earth were the same mass, but twice the radius, what would a 100 kg person weigh?

$F = G m_e m_p / r^2$

$m_e = 5.97 \times 10^{24}$ kg and $m_p = 100$ kg

$r = 2 \times$ radius of Earth $= 2 \times 6.38 \times 10^6$ m $= 1.28 \times 10^7$ m

F = 245 Newtons = ¼ 980 Newtons

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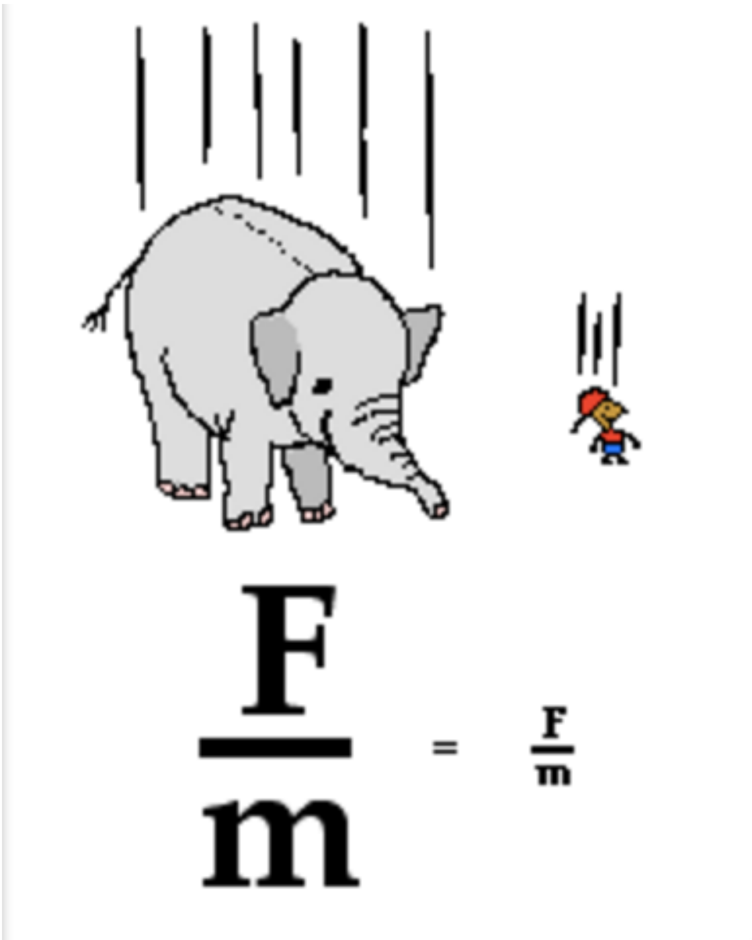
The fall of bodies in a gravitational field does not depend on their mass



Gravitational Force:

$$F=GM_Em/r^2$$

Causes an accleration:

$$a = GM_E/(r_E)^2$$

Move to galaxies lecture …

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Tidal Forces between Galaxies

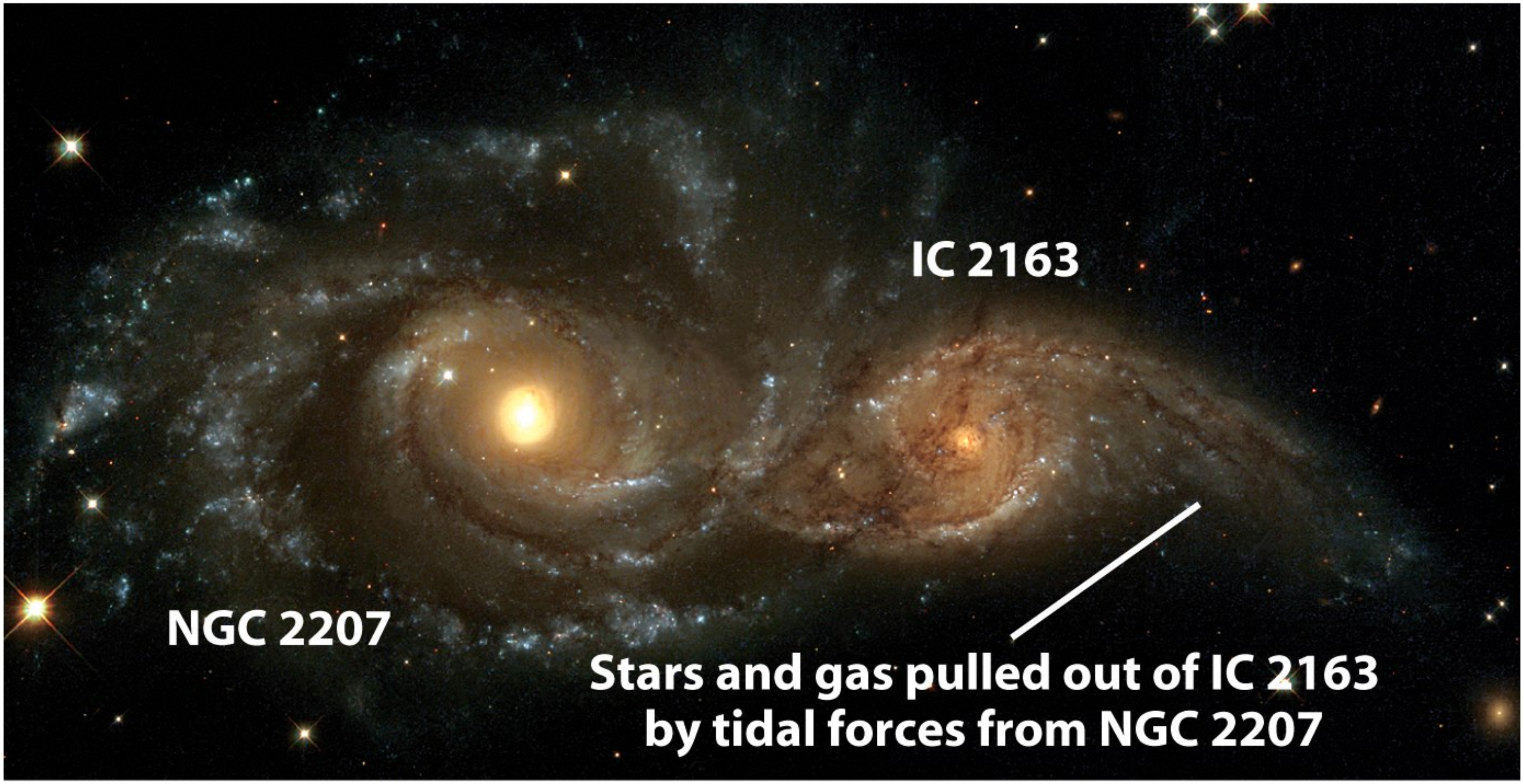

Figure 4-27
Universe, Eighth Edition

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Tidal Forces between Galaxies

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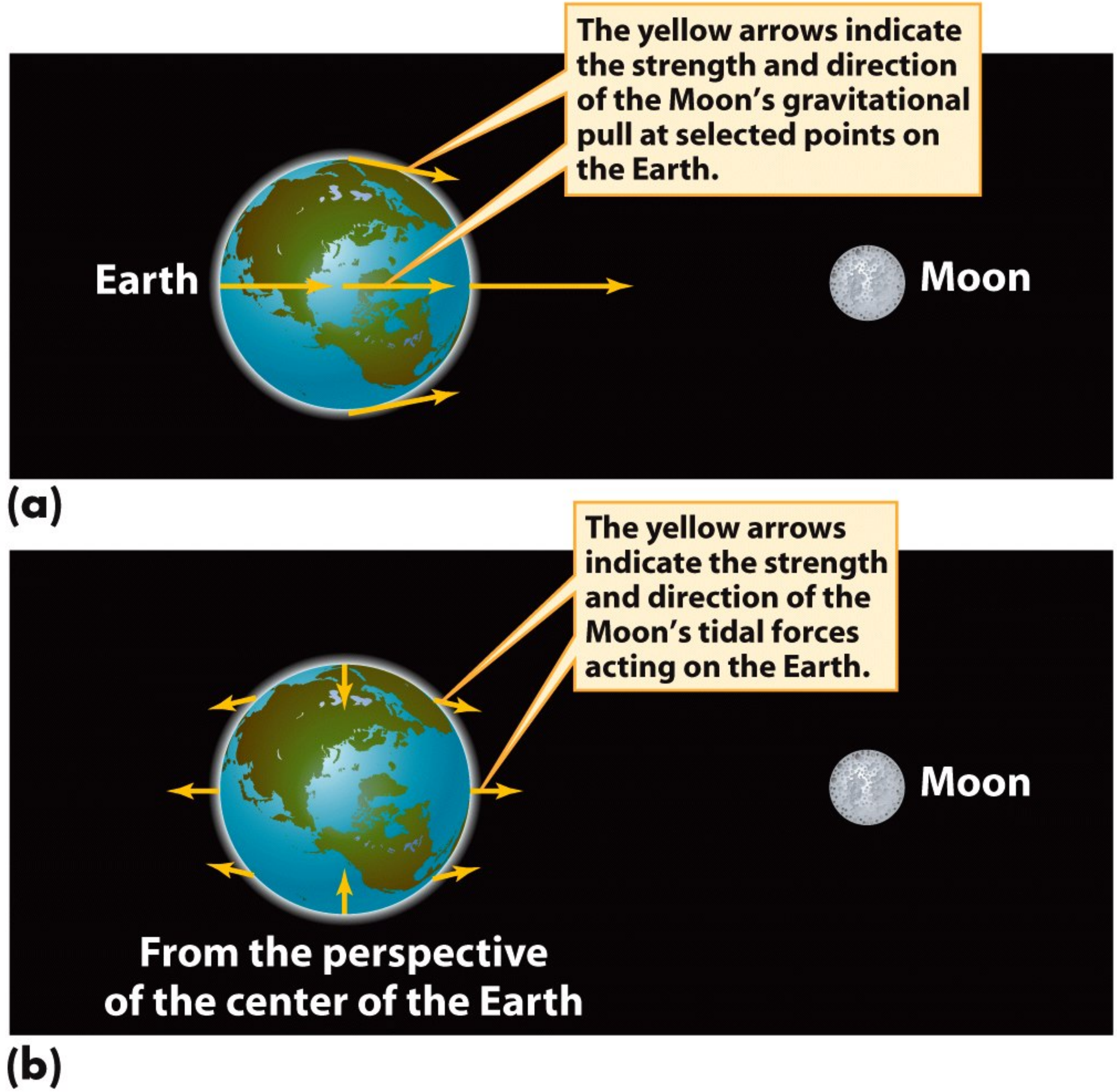

Figure 4-25
Universe, Eighth Edition

Astro 1 - CLM

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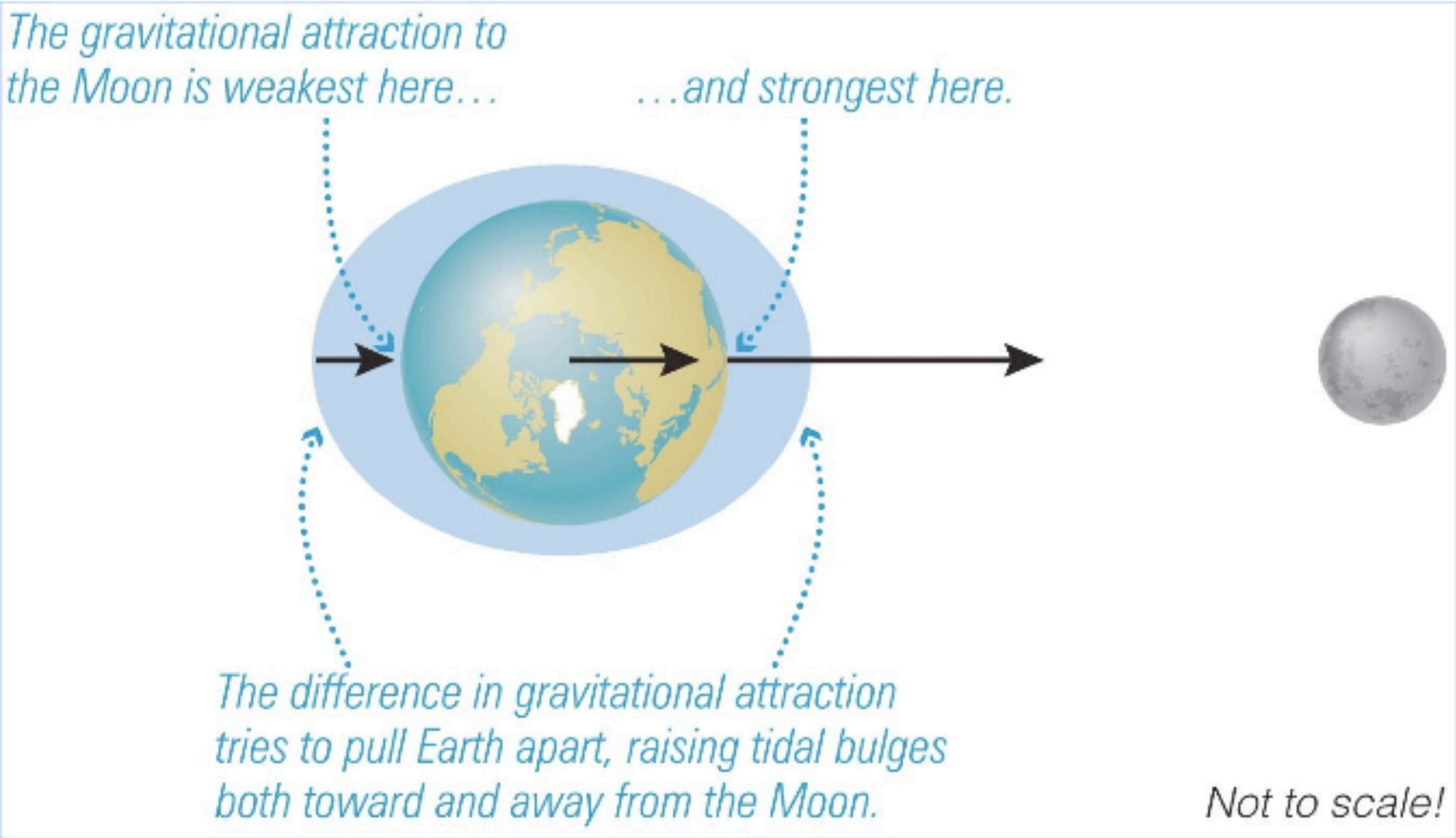

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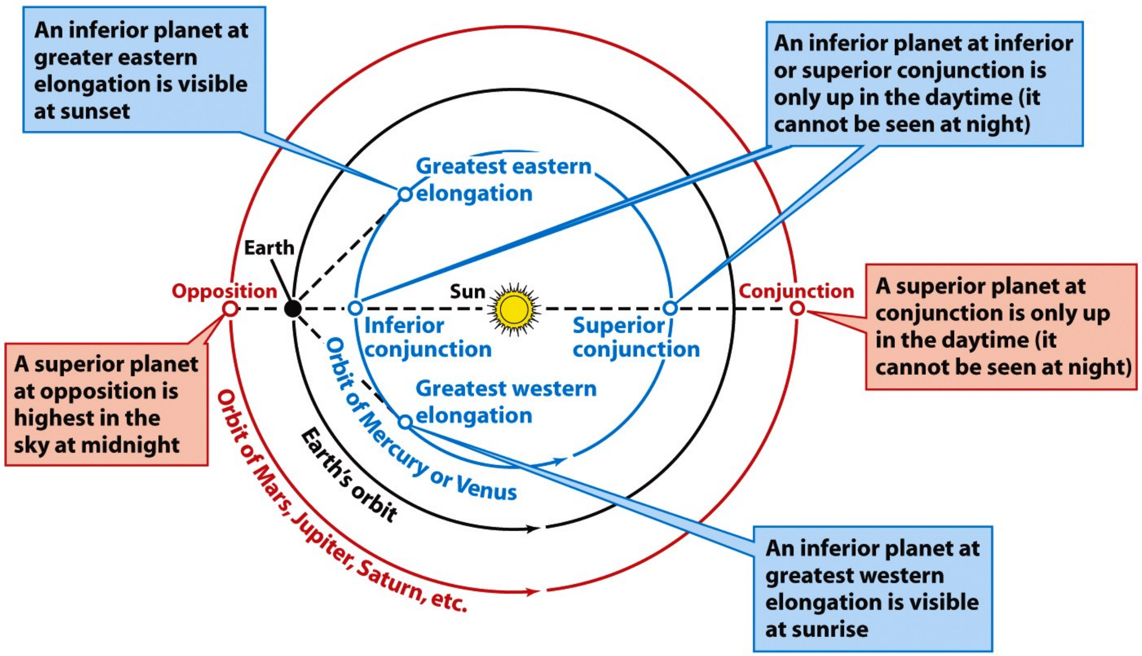

Figure 4-6
Universe, Eighth Edition

Question: You see a very bright planet at midnight (you know it is a planet, because planets don't twinkle like stars do). Is it Venus?

Answer: Venus can never be farther than 45° from the sun. Since there are 360° in the sky, and it rotates in 24h, the celestial sphere rotates at 360°/24h=15°/hr. If Venus is at greatest eastern elongation, it will set 45°/(15°/hr) = 3hr after sunset. So it can't be seen at midnight.

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Eratosthenes' s determined the diameter of the Earth around 200 B.C.!

Distance from Alexandria to Syene was said to be about 5000 stades, so Earth' s circumference was computed to be 50 × 5000 = 250,000 stades

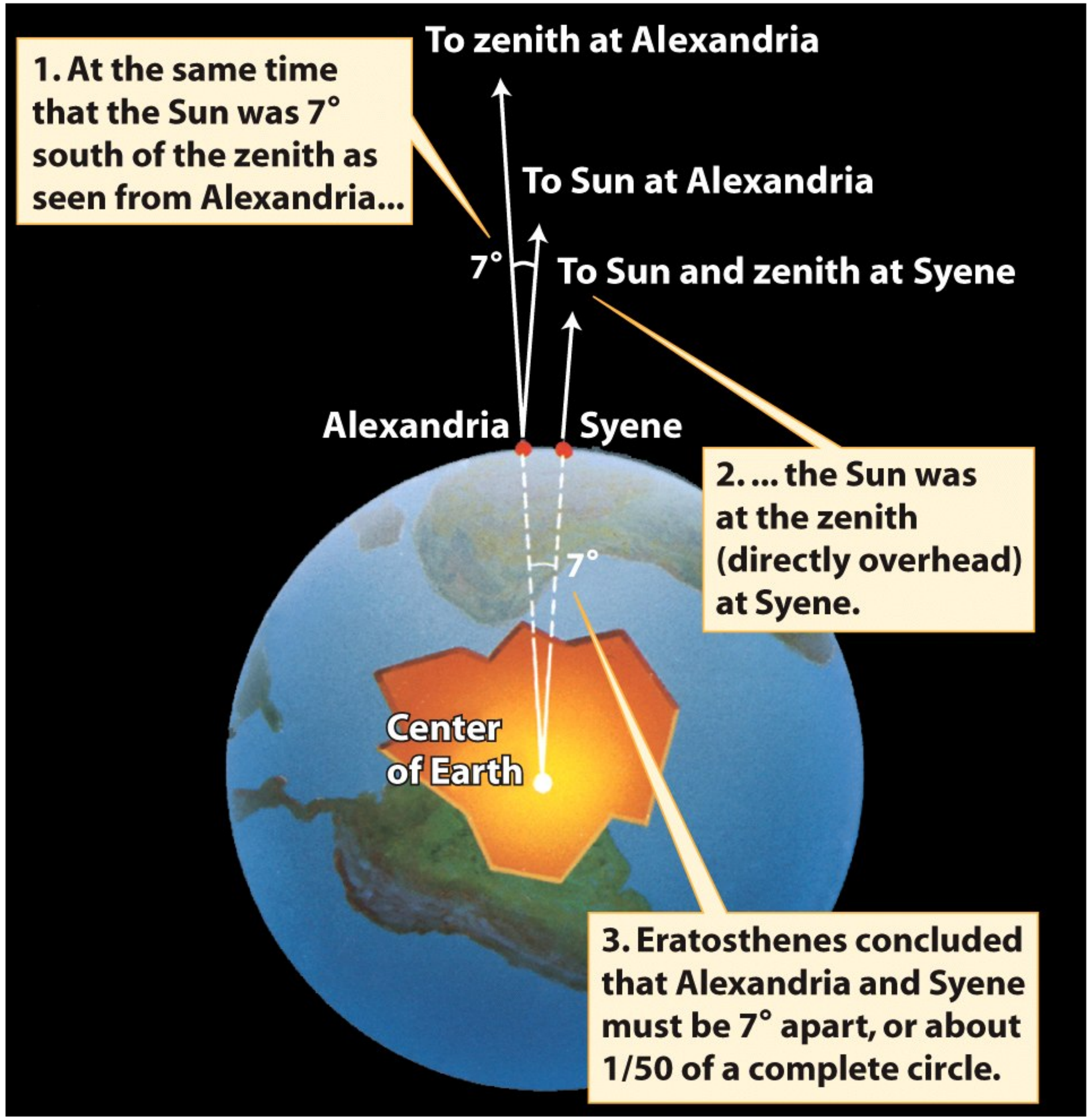

Figure 3-14
Universe, Eighth Edition

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Aristarchus determined distances to sun and moon, and determined sizes of moon and sun relative to Earth around 280 B.C.! He got the answer wrong because of poor measurements, but had the right technique.

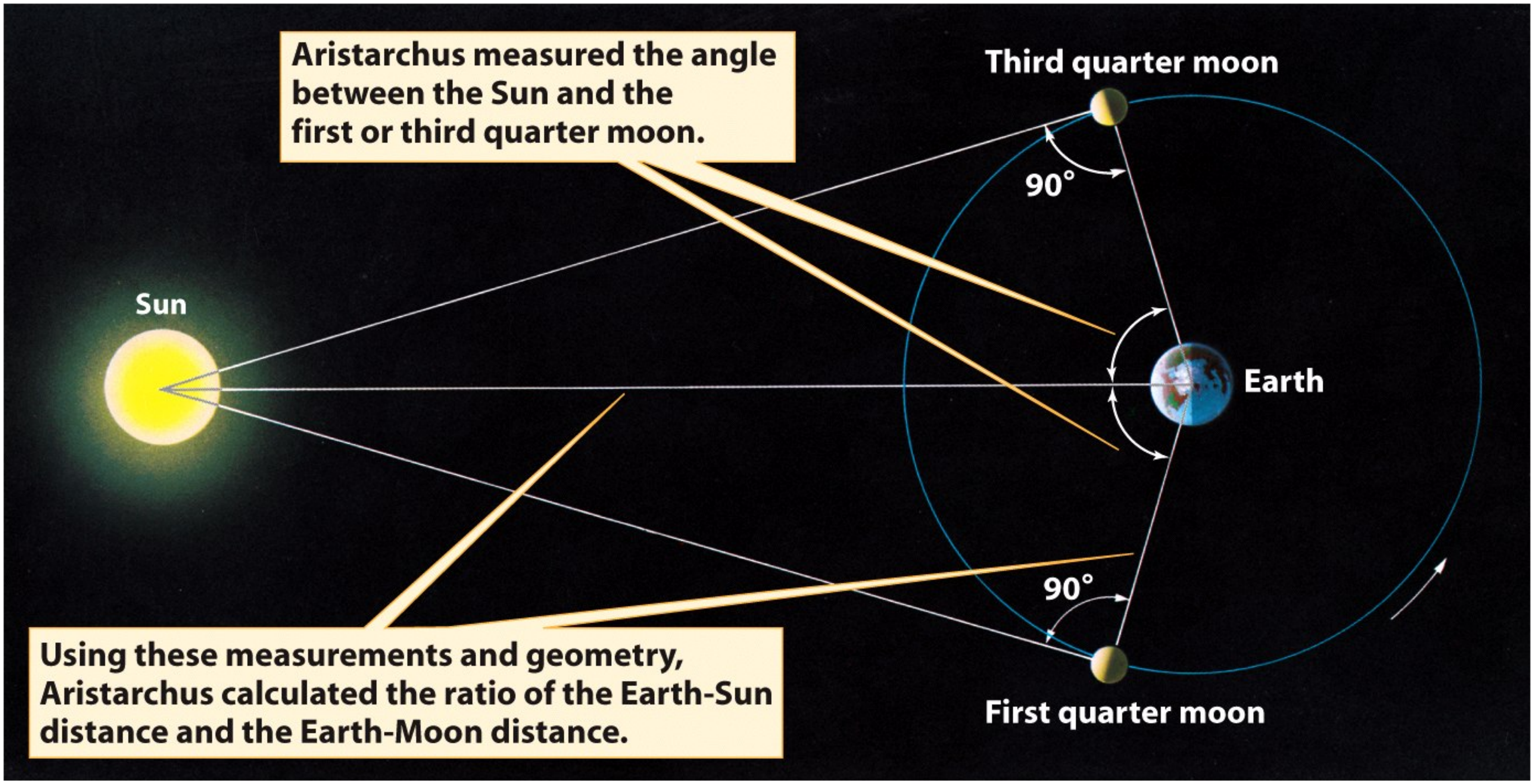

Figure 3-15
Universe, Eighth Edition

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But sometimes the motion of planets is "retrograde"
Can't explain this with simple "perfect" circular motion of the planets

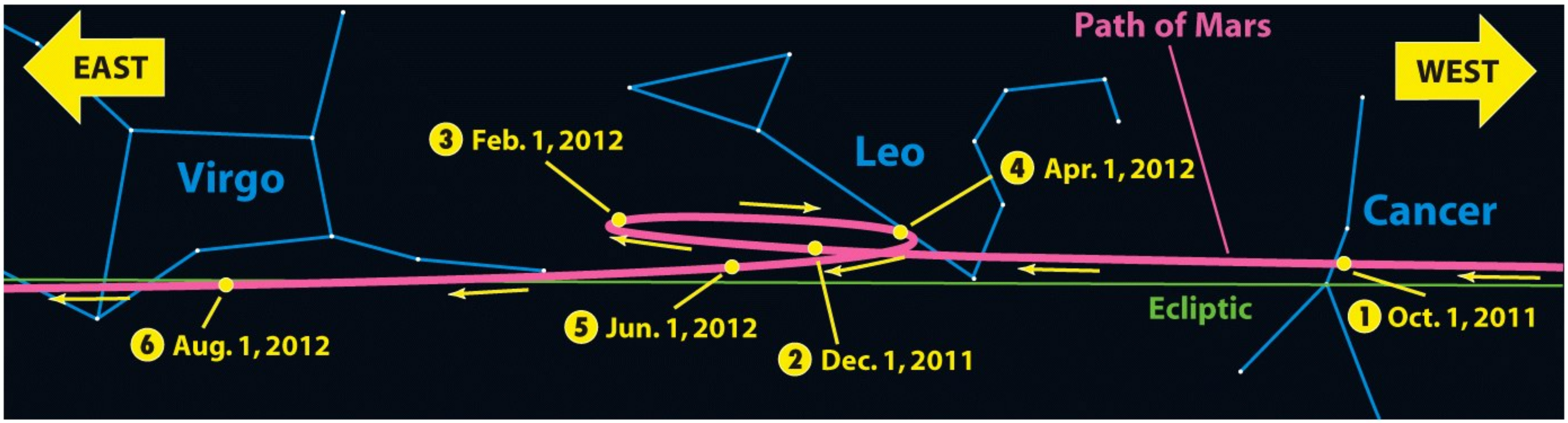

Figure 4-2
Universe, Eighth Edition

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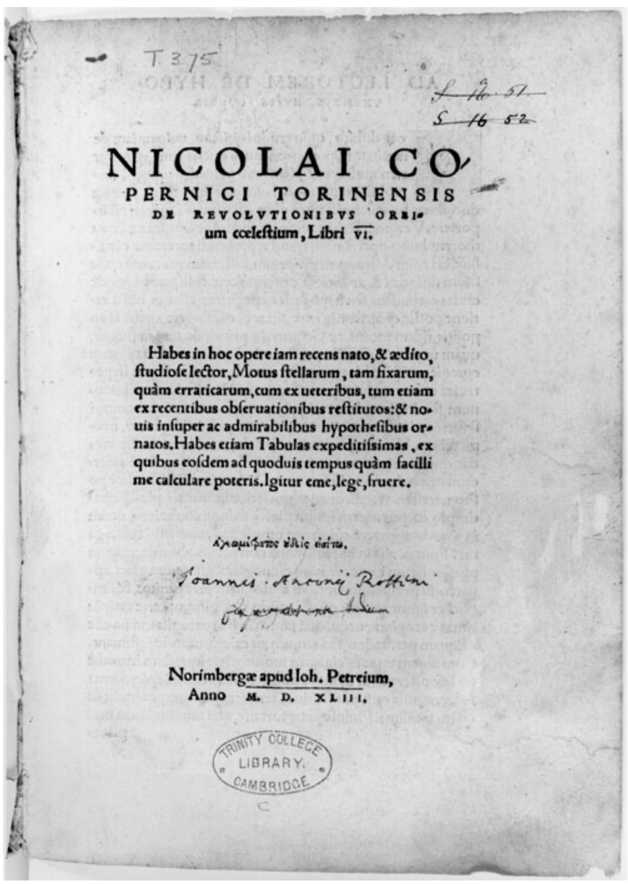
Copernican Revolution

De Revolutionibus was published in 1543, but he had been circulating the ideas for 30 years.


NICOLAI CO
PERNICI TORINENSIS
DE REVOLVTIONIBVS ORBI-
um cœleſtium, Libri VI.

Habes in hoc opere iam recens nato, & ædito, ſtudioſe lector, Motus ſtellarum, tam fixarum, quàm erraticarum, cum ex ueteribus, tum etiam ex recentibus obſeruationibus reſtitutos: & nouis inſuper ac admirabilibus hypotheſibus ornatos. Habes etiam Tabulas expeditiſsimas, ex quibus eoſdem ad quoduis tempus quàm facilli me calculare poteris. Igitur eme, lege, fruere.

Ἀγεωμέτρητος οὐδεὶς εἰσίτω.

Norimbergæ apud Ioh. Petreium,
Anno M. D. XLIII.

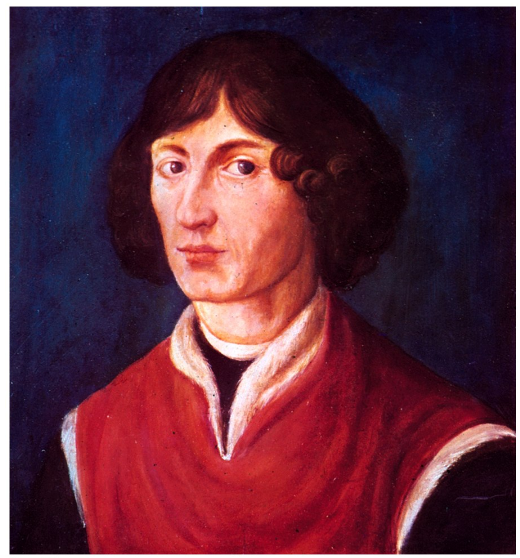


Figure 4-4
Universe, Eighth Edition
© 2008 W. H. Freeman and Company

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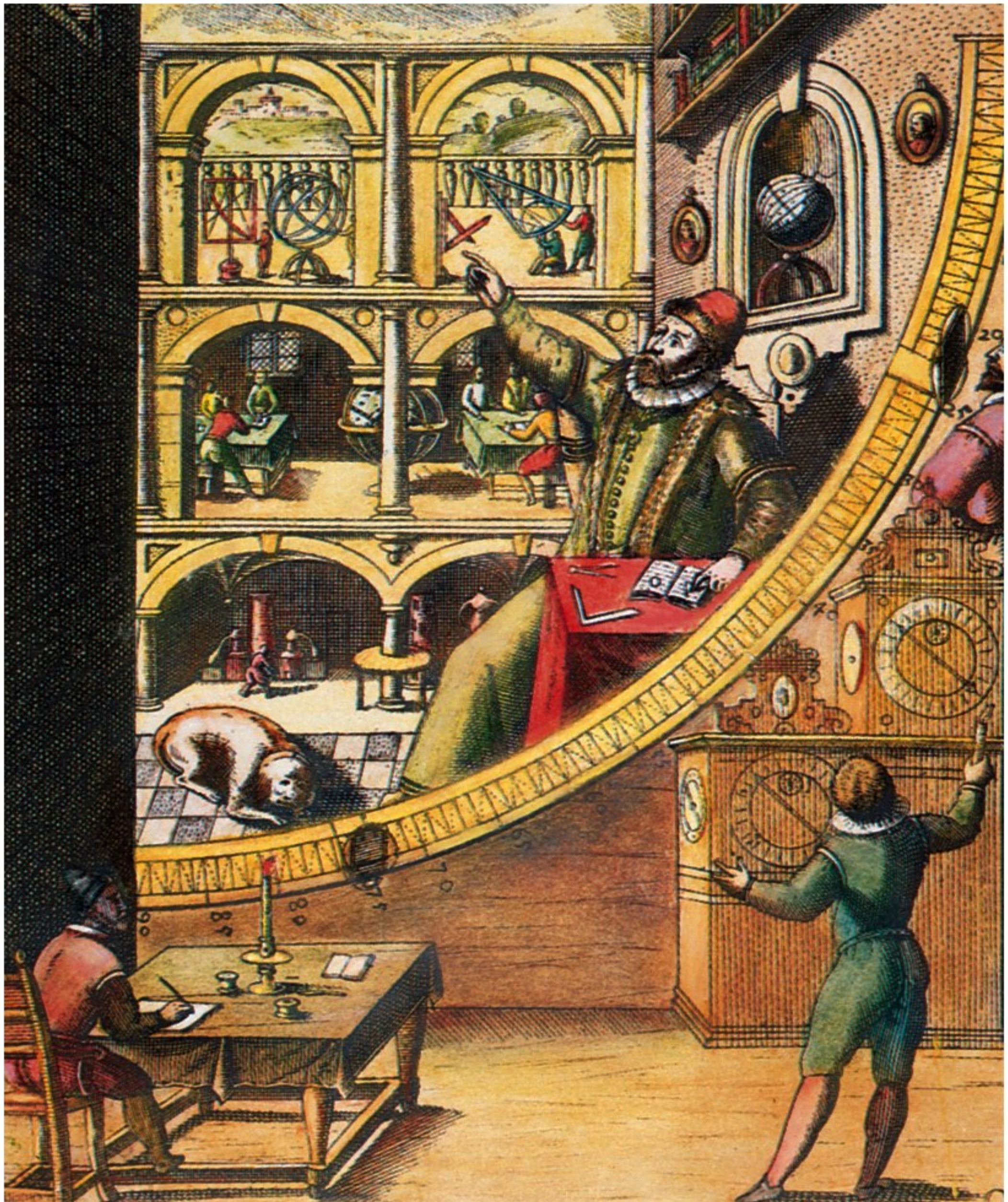

Figure 4-8
Universe, Eighth Edition

Tycho Brahe (1546–1601)
Here shown at Uraniborg, one of the two observatories that he built under the patronage of Frederik II of Denmark (though the telescope had not yet been invented). Kepler later used Tycho' s exquisite measurements.

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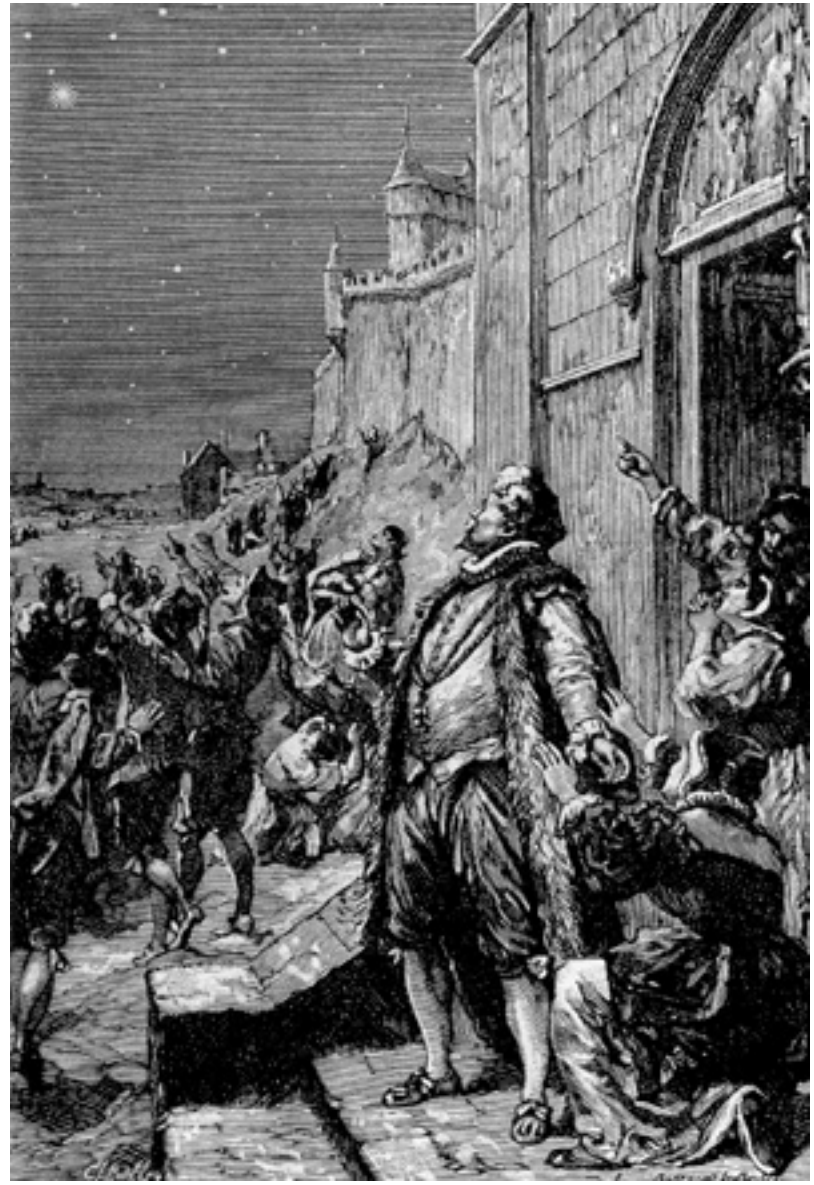
From Tycho's Stella Nova



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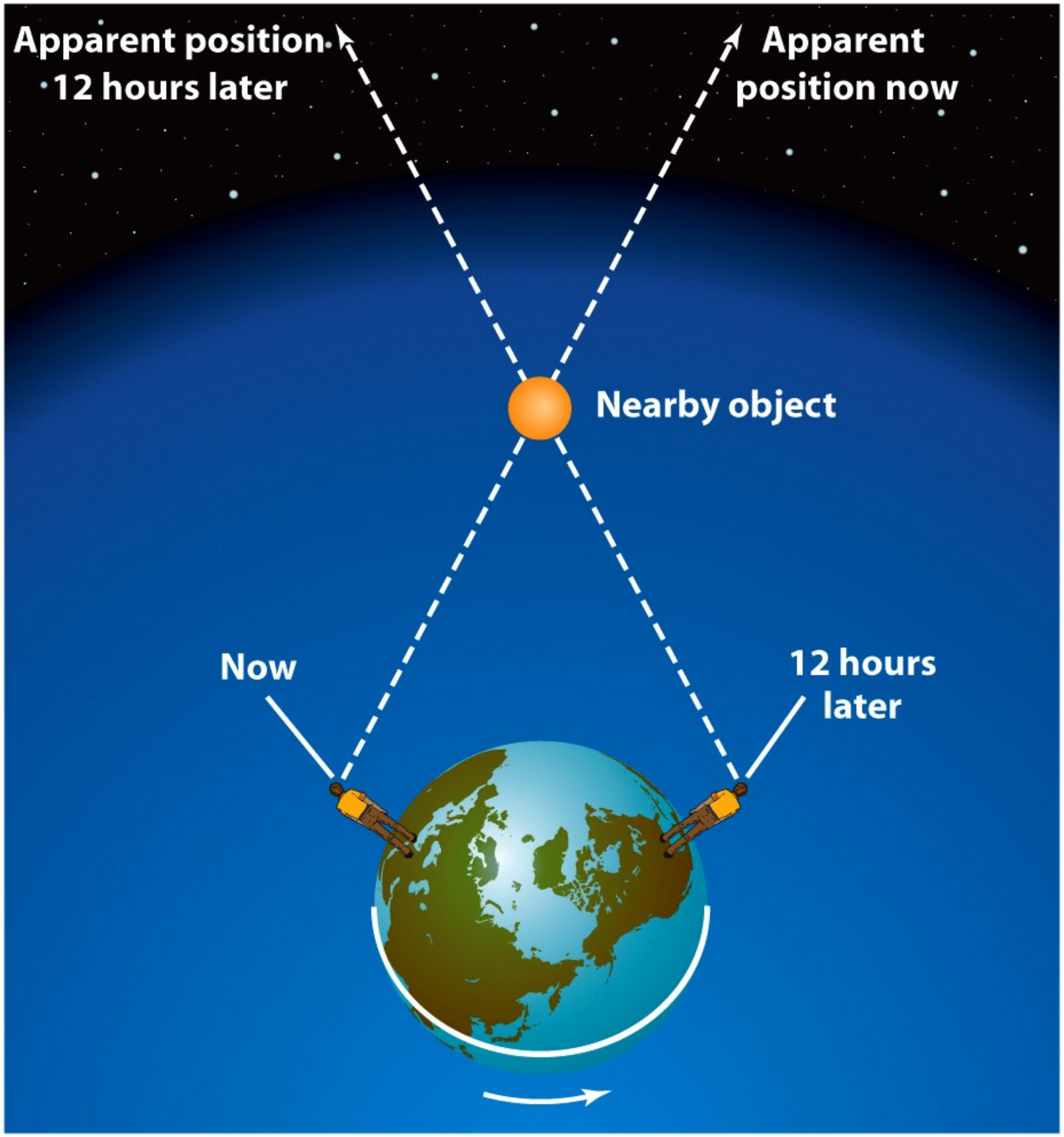

Figure 4-7
Universe, Eighth Edition

Parallax: Tycho Brahe argued that if an object is near the Earth, an observer would have to look in different directions to see that object over the course of a night and its position relative to the background stars would change. Tycho failed to measure such changes for a supernova in 1572 and a comet in 1577, and concluded that these objects were far from the Earth.

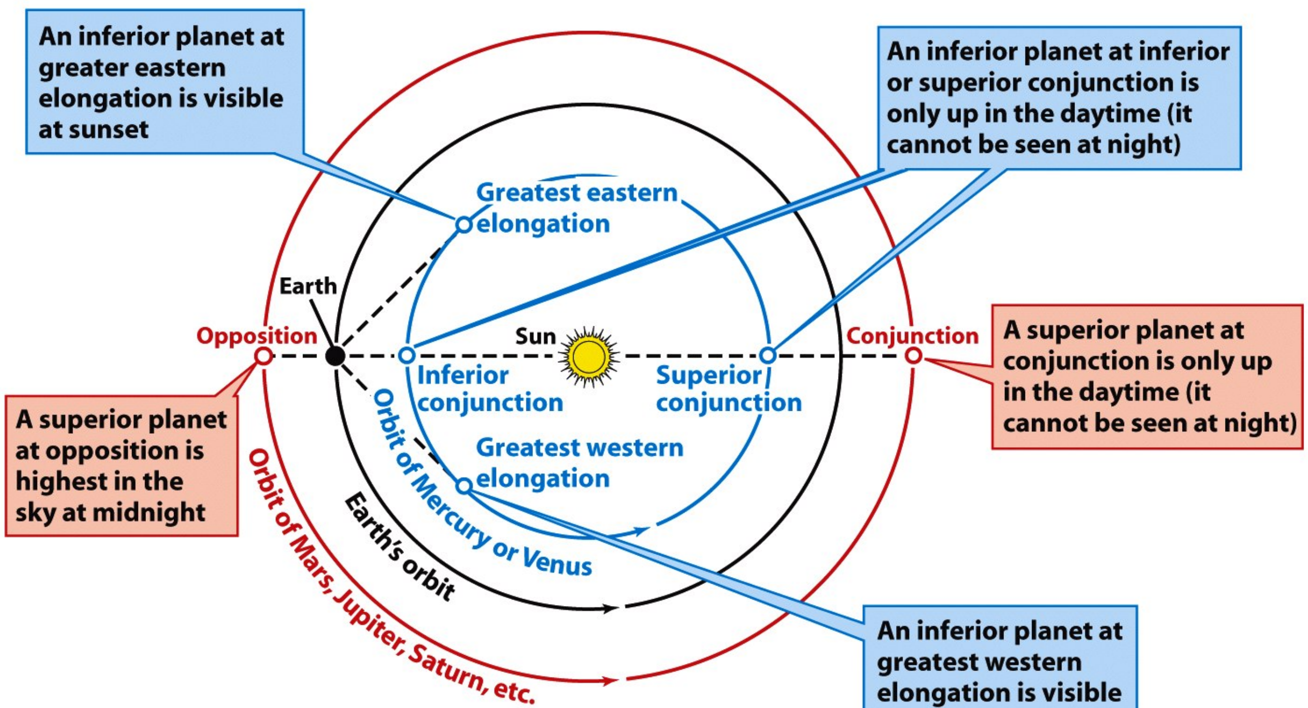

Figure 4-6
Universe, Eighth Edition

Maximum greatest elongation for Venus is 45°, and for Mercury 28°, so they can never be farther than that from the sun.

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Figure 4-9
Universe, Eighth Edition

Johannes Kepler (1571–1630)

By analyzing Tycho Brahe's detailed records of planetary positions, Kepler developed three general principles, called Kepler's laws, that describe how the planets move about the Sun. Kepler was the first to realize that the orbits of the planets are ellipses and not circles.

Level Air Track Experiment iclicker Question

- What will happen to the cart when the professor turns the air off?
  A. Car will stop suddenly.
  B. Car will slowly come to a stop.
  C. Car will slowly speed up.
  D. Car will rapidly speed up.
  E. Car will continue to move at a constant speed along the track.

Waiter's Dilemma iclicker Question

- What will happen to the dinner if the waiter pulls out the tablecloth?
  A. Everything will spill because an outside force is applied.
  B. If the tablecloth is removed very quickly, the force of friction will not last long enough to accelerate the table setting to a significant velocity.
  C. Nothing. Gravity keeps the objects on the table regardless of the speed of the pull.
  D. Nothing, objects at rest stay at rest in the absence of an outside force.
  E. Both B & D.

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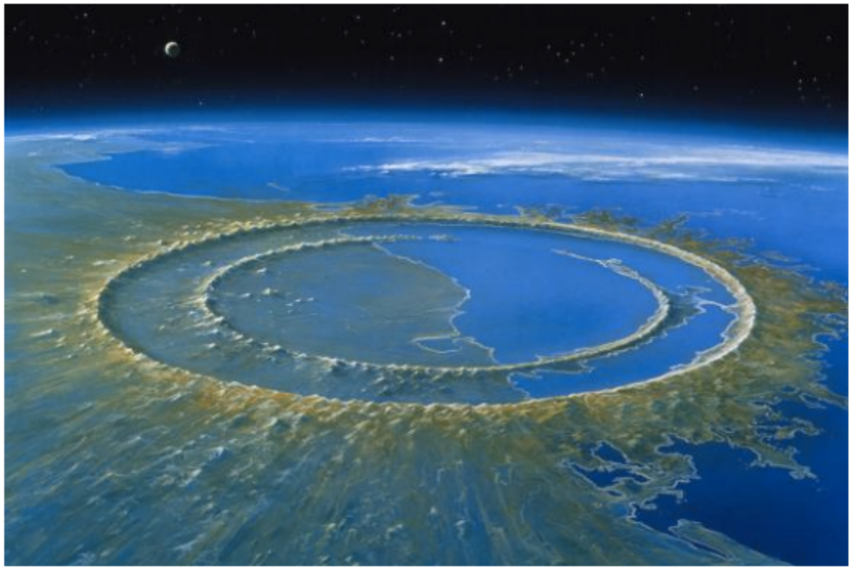
Example: Newton's 2nd Law



An illustration of the Chicxulub impact crater in the Yucatán Peninsula.

ILLUSTRATION BY DETLEV VAN RAVENSWAAY, SCIENCE SOURCE

Chicxulub crater:
180 km across
66 Myr old

Waber crater:
11 m across
~200 yr old