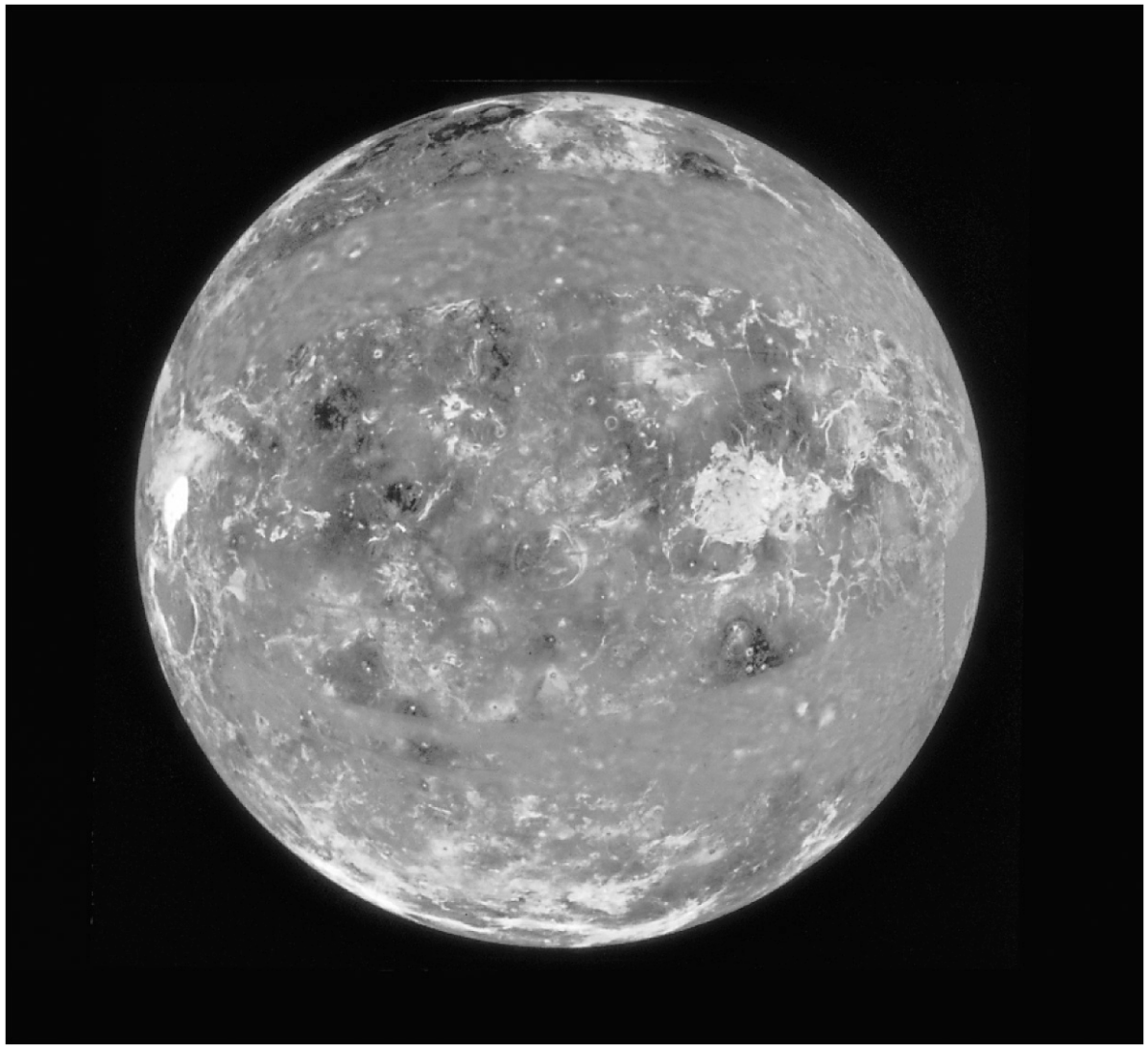
Introduction
Exploring the Heavens



Units of the Introduction

The “Obvious” View

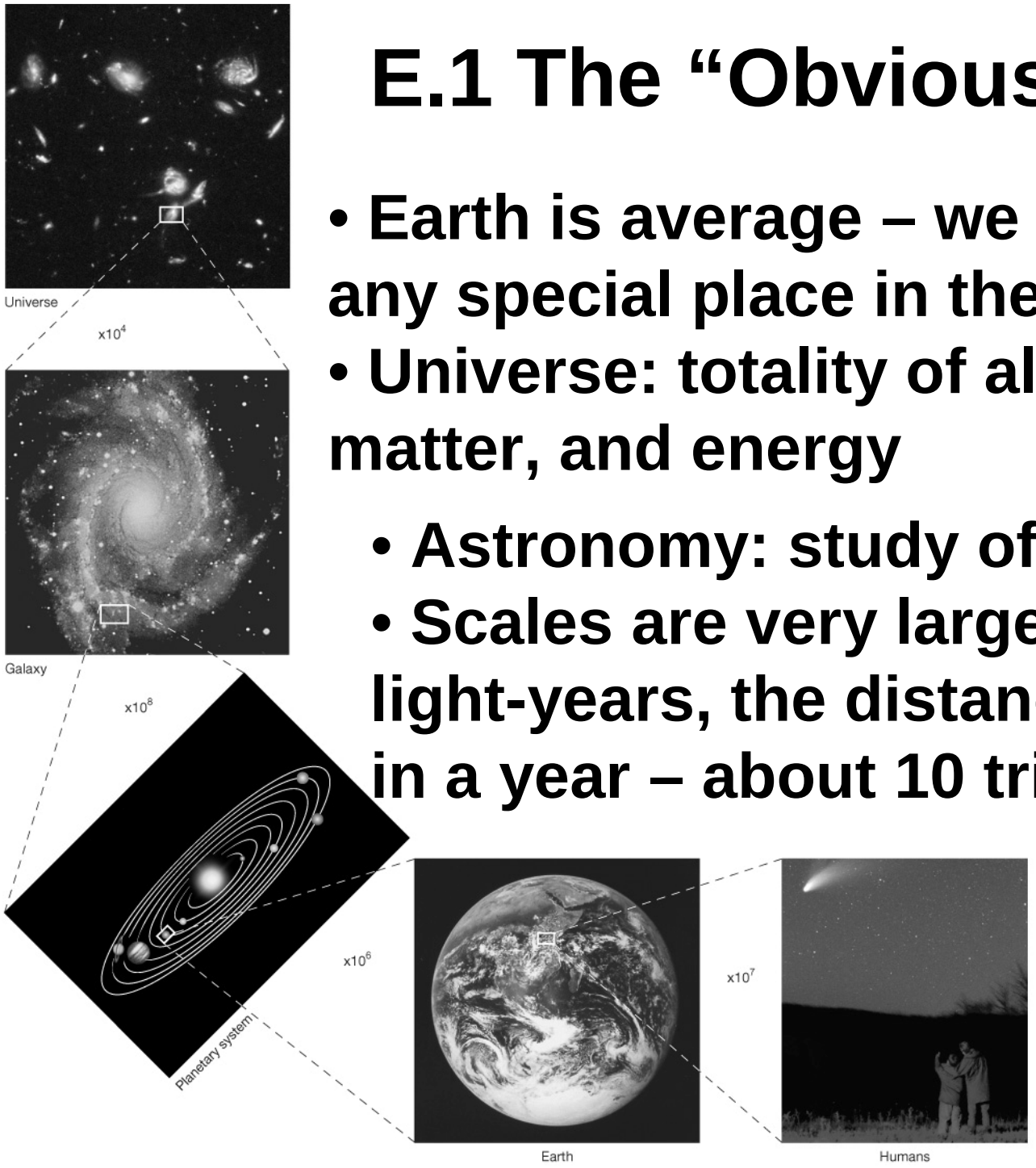
Earth’s Orbital Motion

The Motion of the Moon

The Measurement of Distance

Scientific Theory and the Scientific Method

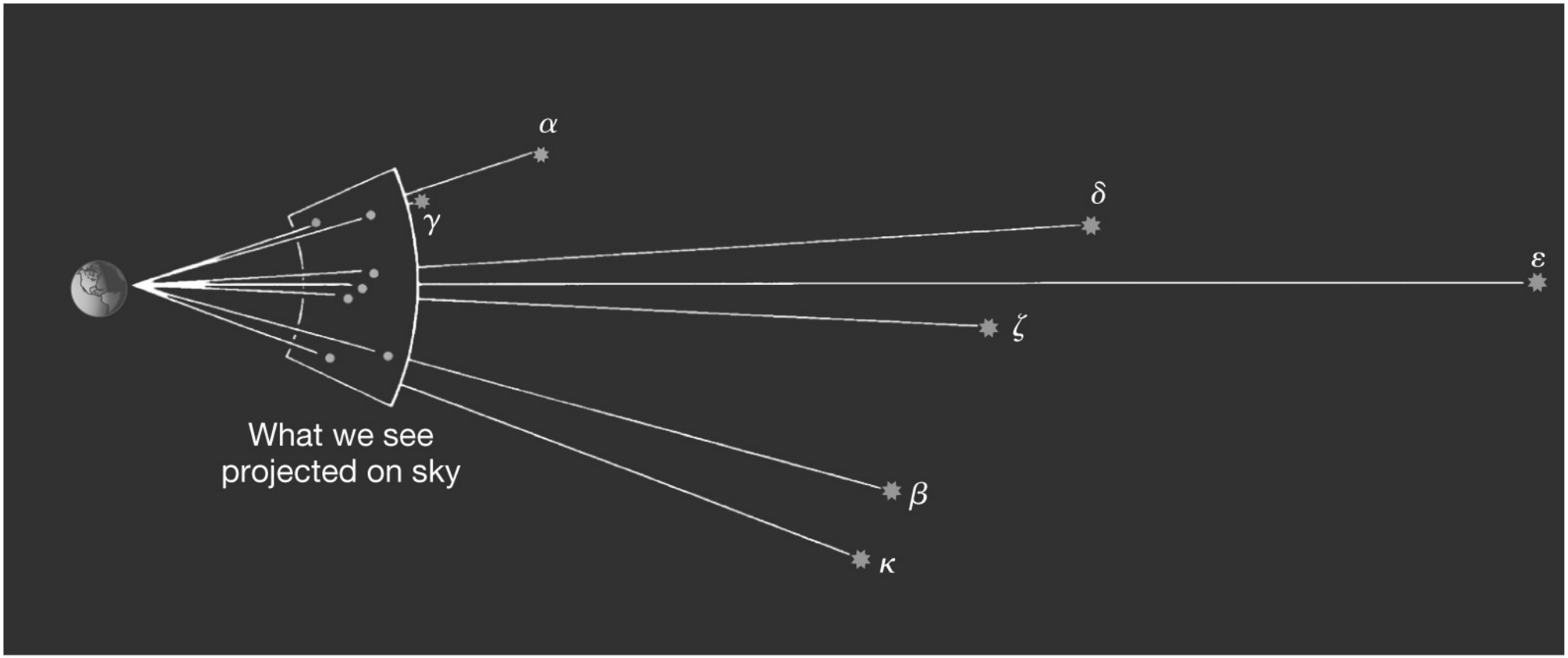
E.1 The “Obvious” View



- **Earth is average – we don’t occupy any special place in the universe**
- **Universe: totality of all space, time, matter, and energy**
  - **Astronomy: study of the universe**
  - **Scales are very large: measure in light-years, the distance light travels in a year – about 10 trillion miles**

E.1 The “Obvious” View

Stars that appear close in the sky may not actually be close in space:

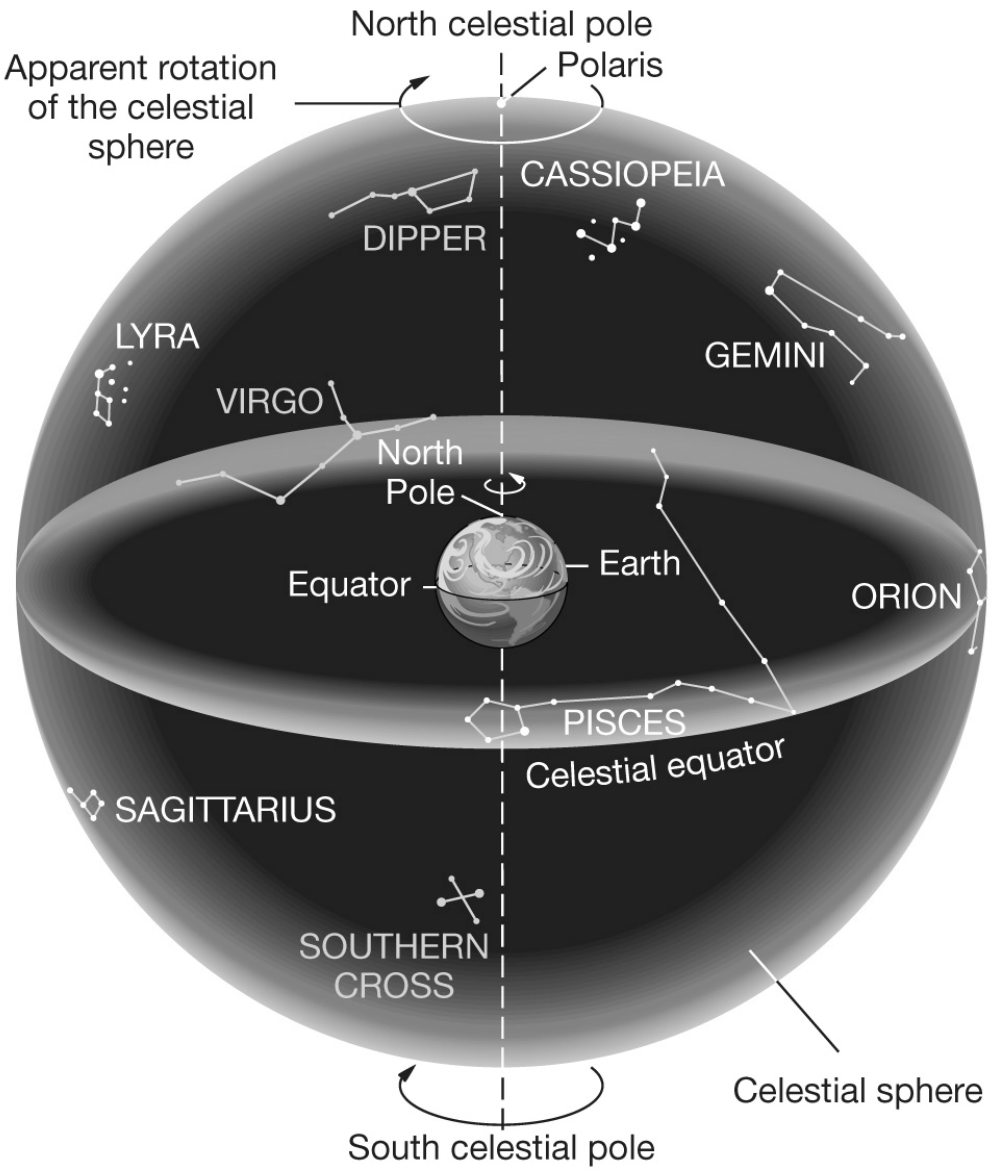


E.1 The “Obvious” View

The celestial sphere:

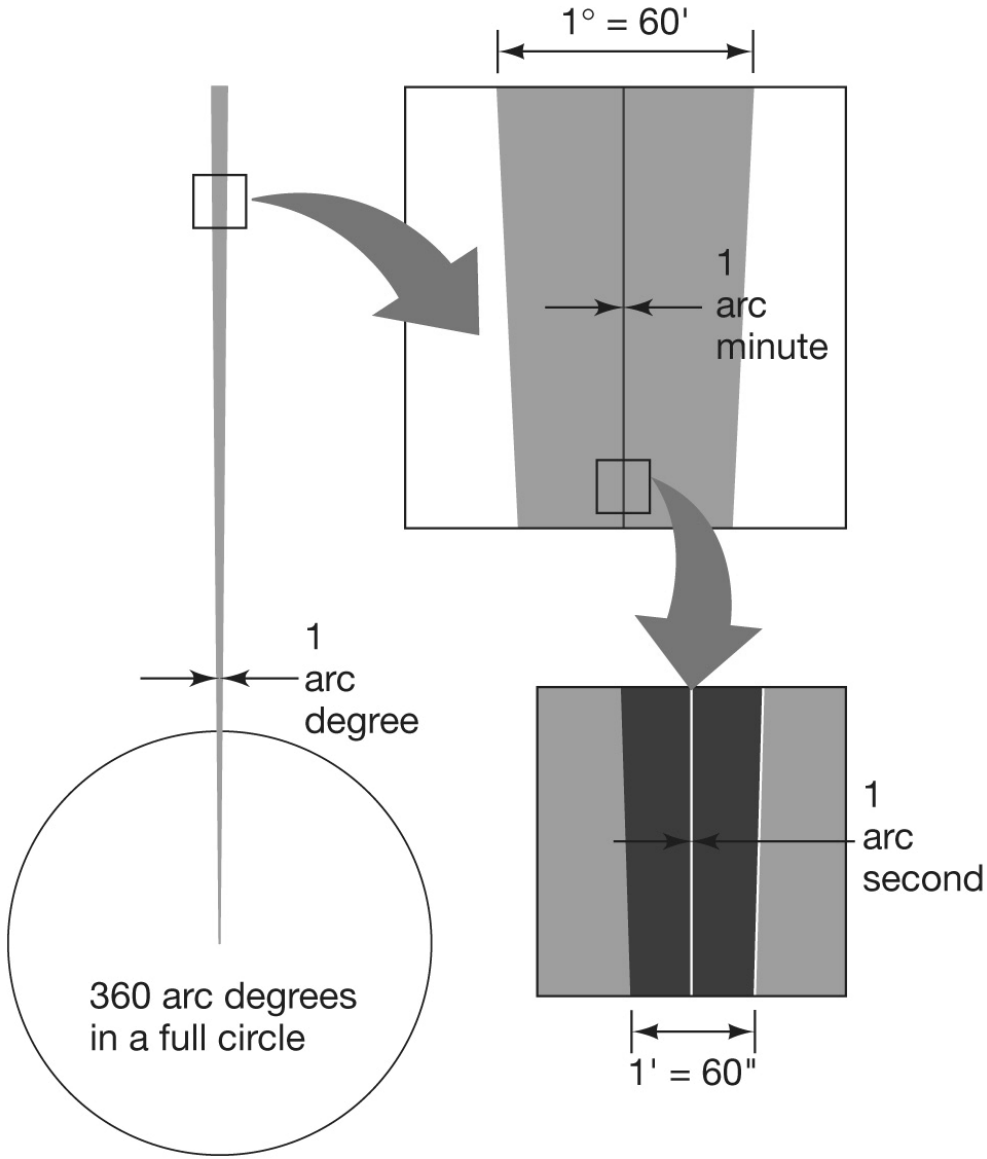
Stars *seem* to be on the inner surface of a sphere surrounding the Earth

They aren’t, but can use two-dimensional spherical coordinates (similar to latitude and longitude) to locate sky objects



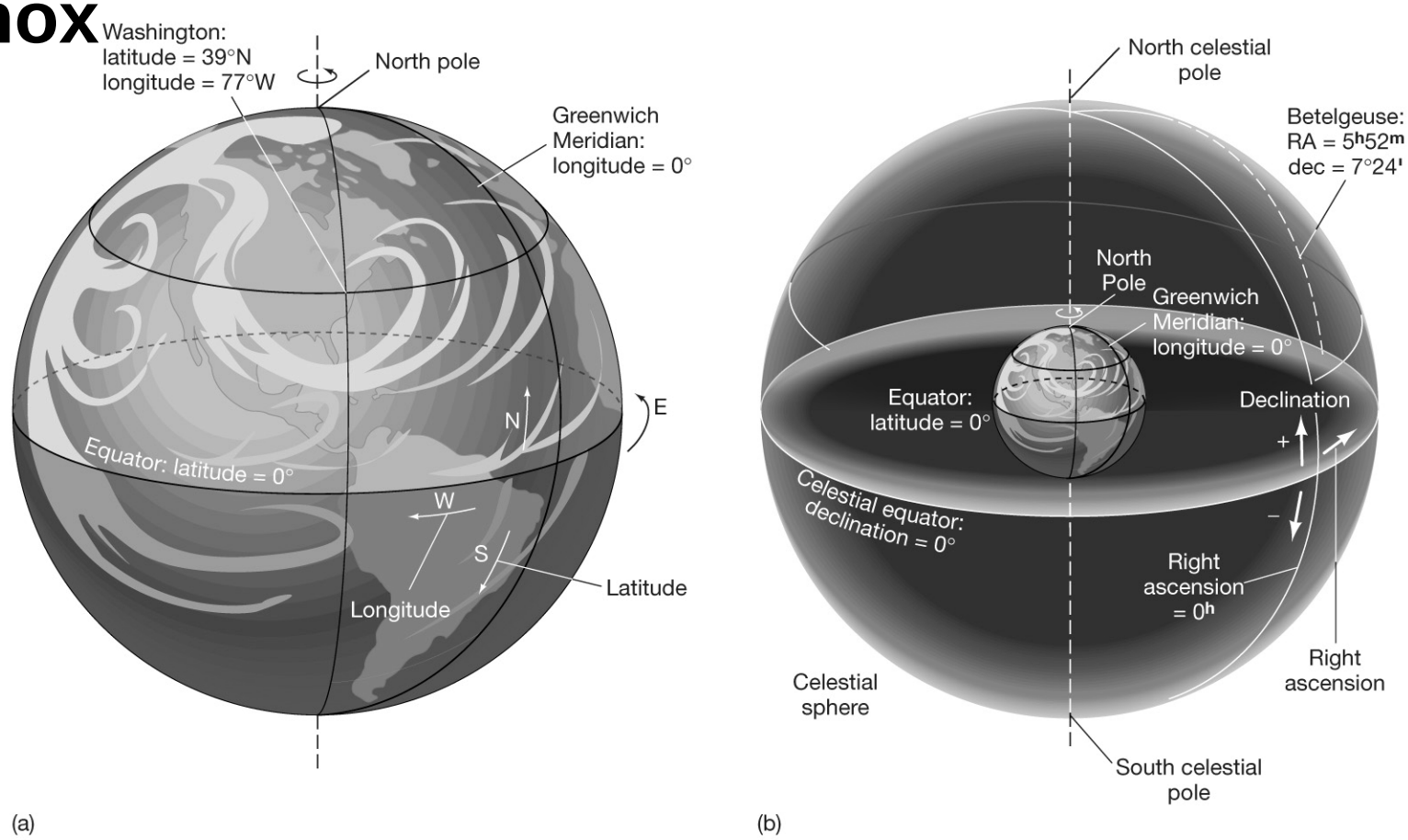
More Precisely E.1: Angular Measure

- **full circle contains 360° (degrees)**
- **each degree contains 60′ (arc-minutes)**
- **each arc-minute contains 60″ (arc-seconds)**
- **angular size of an object depends on actual size and distance away**



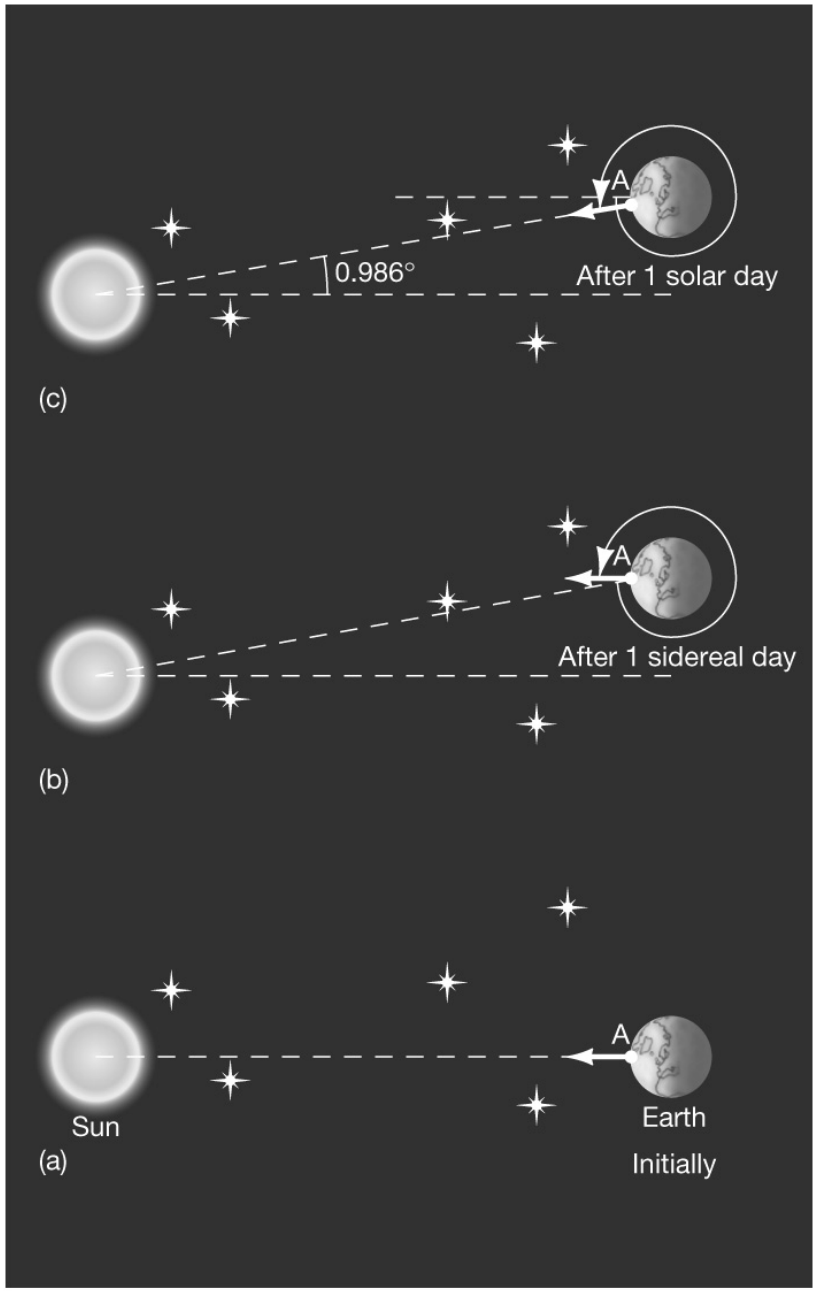
E.1 The “Obvious” View

- **Declination: degrees north or south of celestial equator**
- **Right ascension: measured in hours, minutes, and seconds eastward from position of Sun at vernal equinox**



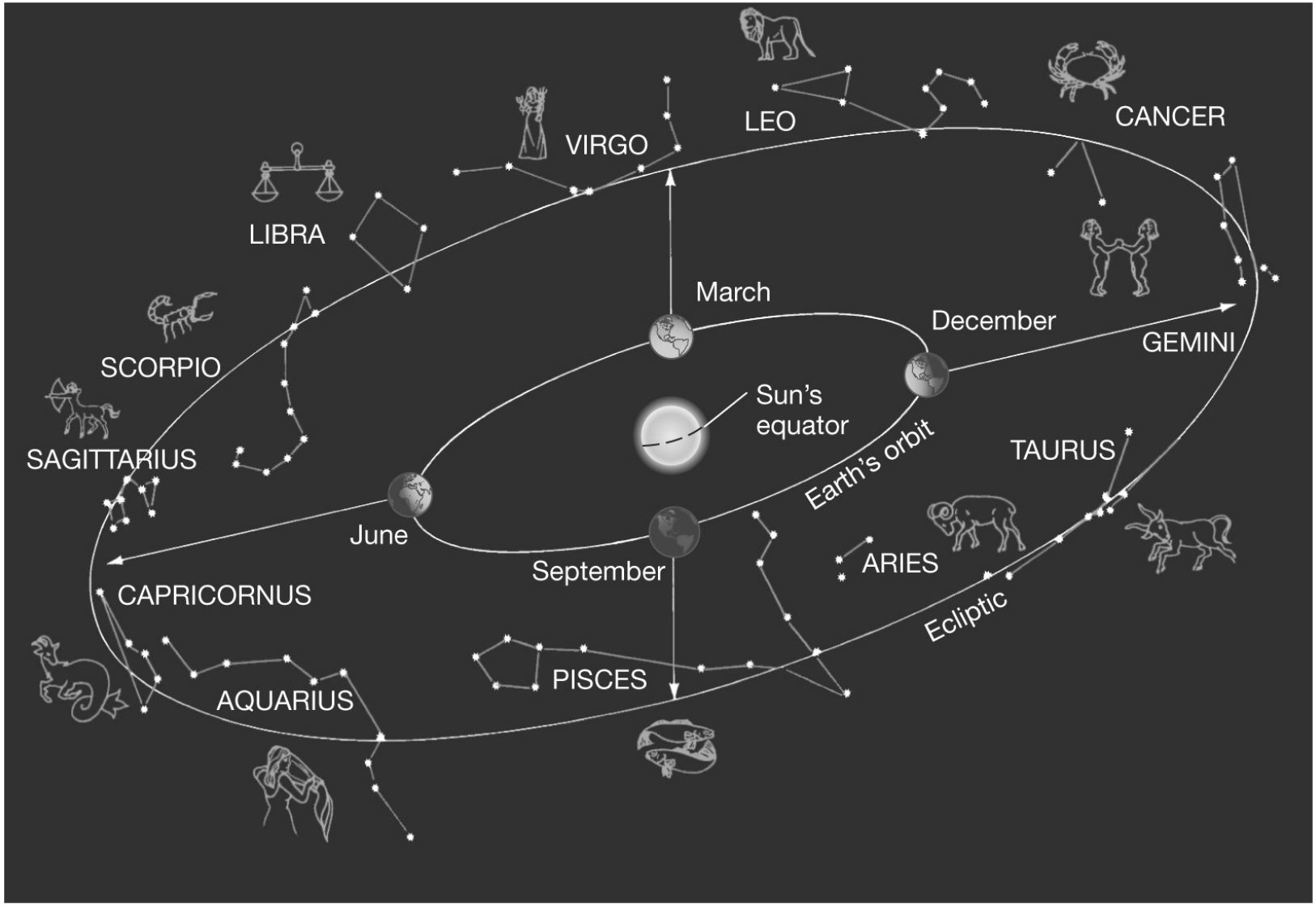
E.2 Earth's Orbital Motion

- **Daily cycle, noon to noon, is diurnal motion – solar day**
- **Stars aren't in quite the same place 24 hours later, though, due to Earth's rotation around Sun; when they are, one sidereal day has passed**



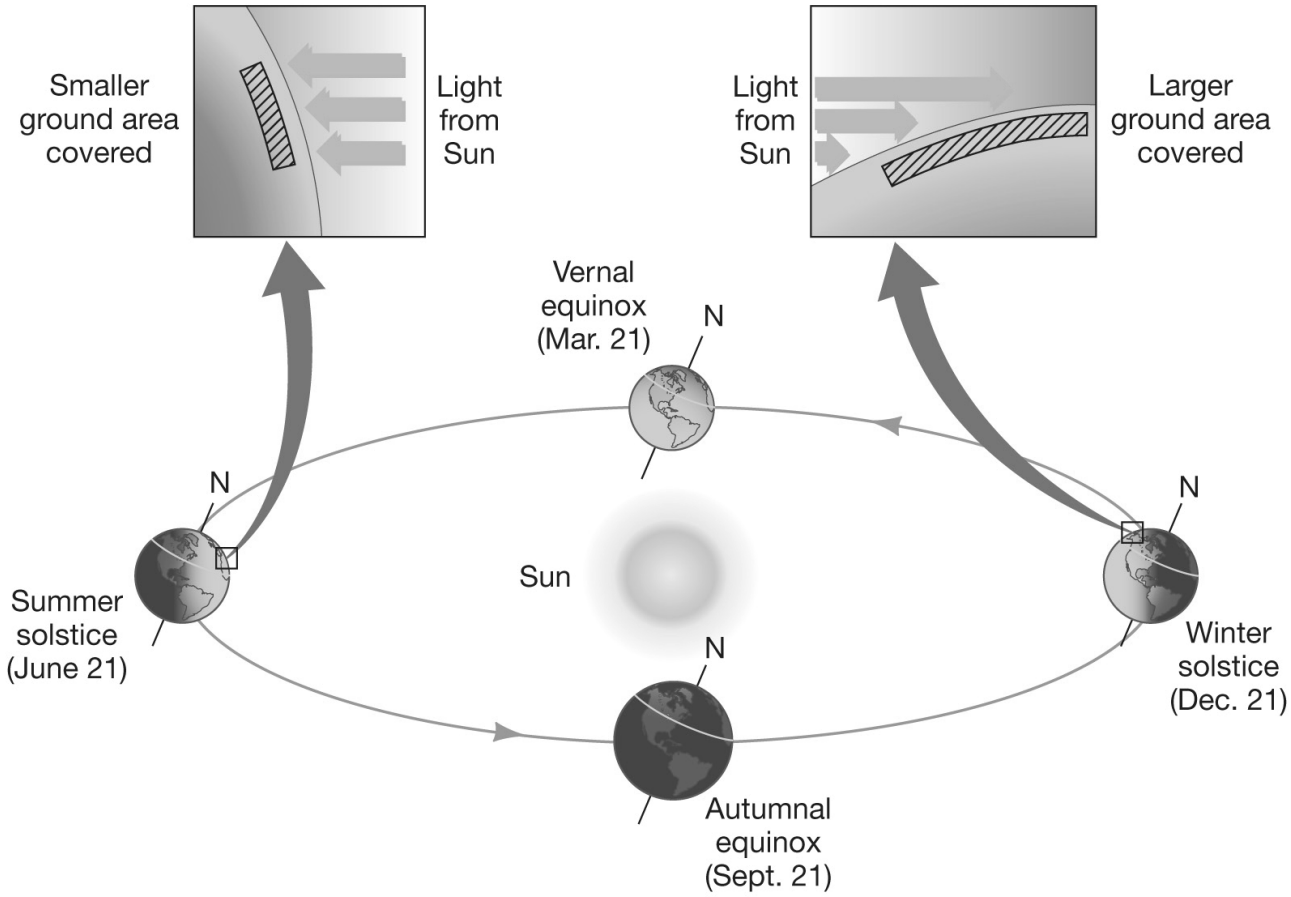
E.2 Earth's Orbital Motion

12 constellations Sun moves through during the year are called the zodiac; path is ecliptic



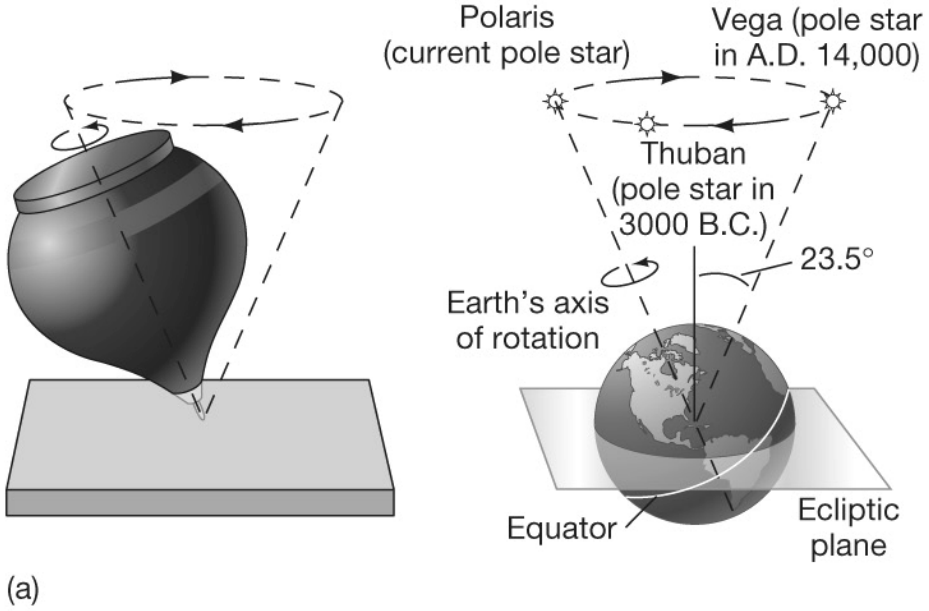
E.2 Earth's Orbital Motion

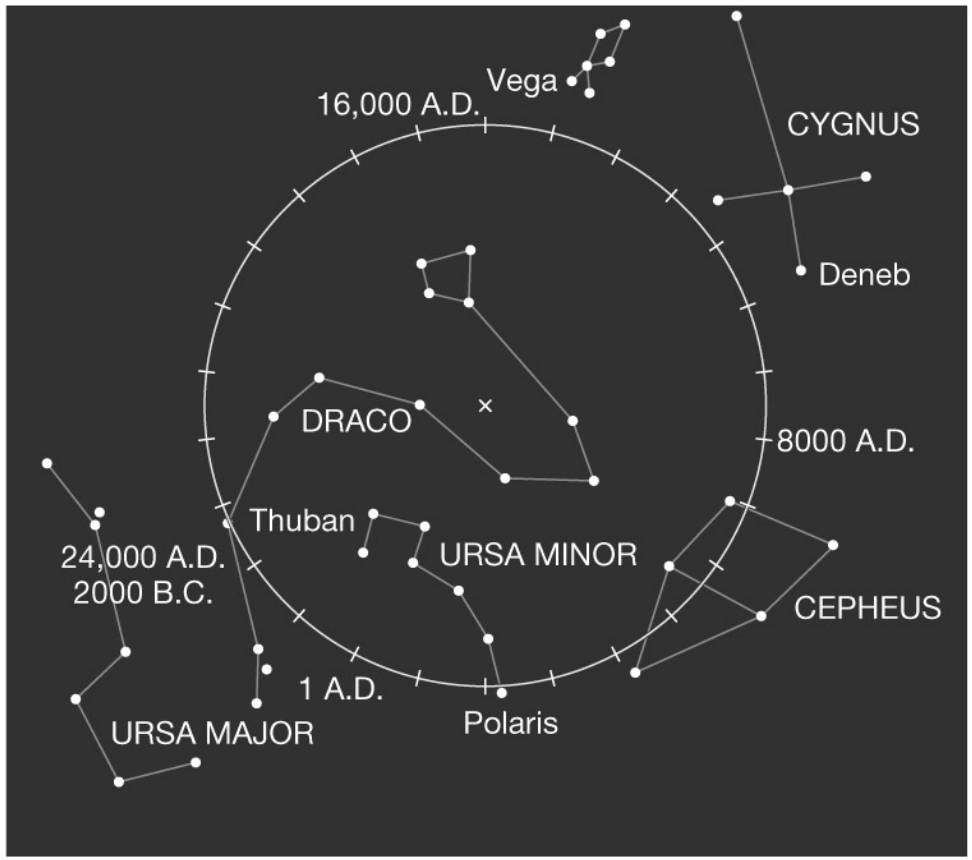
- **Ecliptic is plane of Earth's path around Sun; at 23.5° to celestial equator**
- **Northernmost point (above celestial equator) is summer solstice; southernmost is winter solstice; points where path cross celestial equator are vernal and autumnal equinoxes**
- **Combination of day length and sunlight angle gives seasons**
- **Time from one vernal equinox to next is tropical year**



E.2 Earth's Orbital Motion

Precession: rotation of Earth's axis itself; makes one complete circle in about 26,000 years



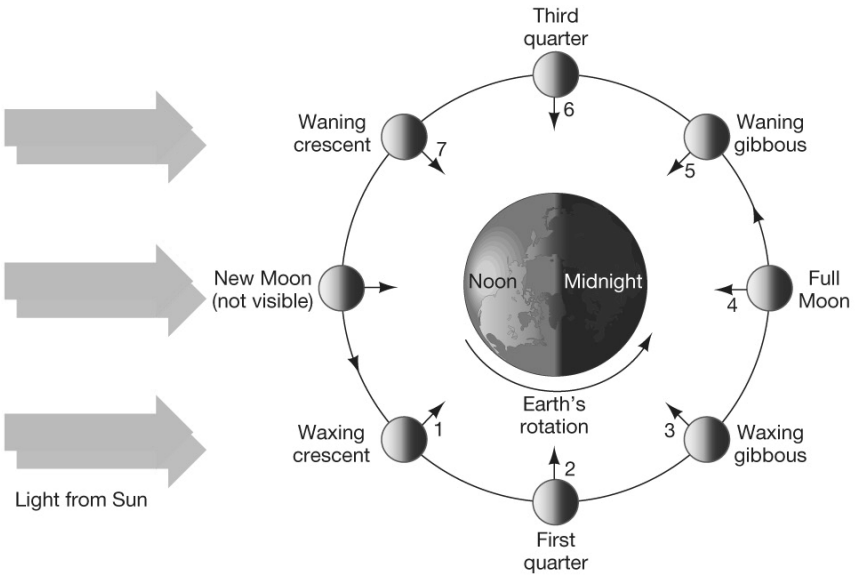


E.3 Motion of the Moon

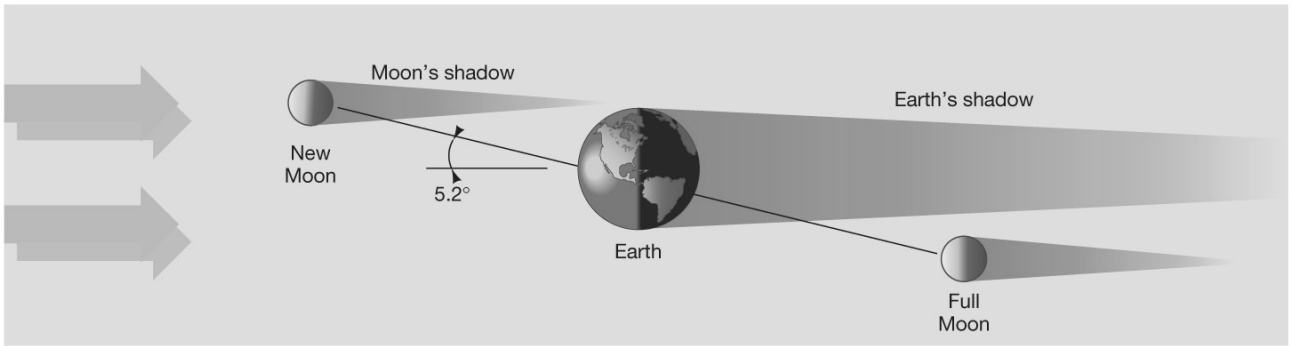
Moon takes about 29.5 days to go through whole cycle of phases – synodic month

Phases are due to different amounts of sunlit portion being visible from Earth

Time to make full 360° around Earth, sidereal month, is about 2 days shorter



(a) Top-down view

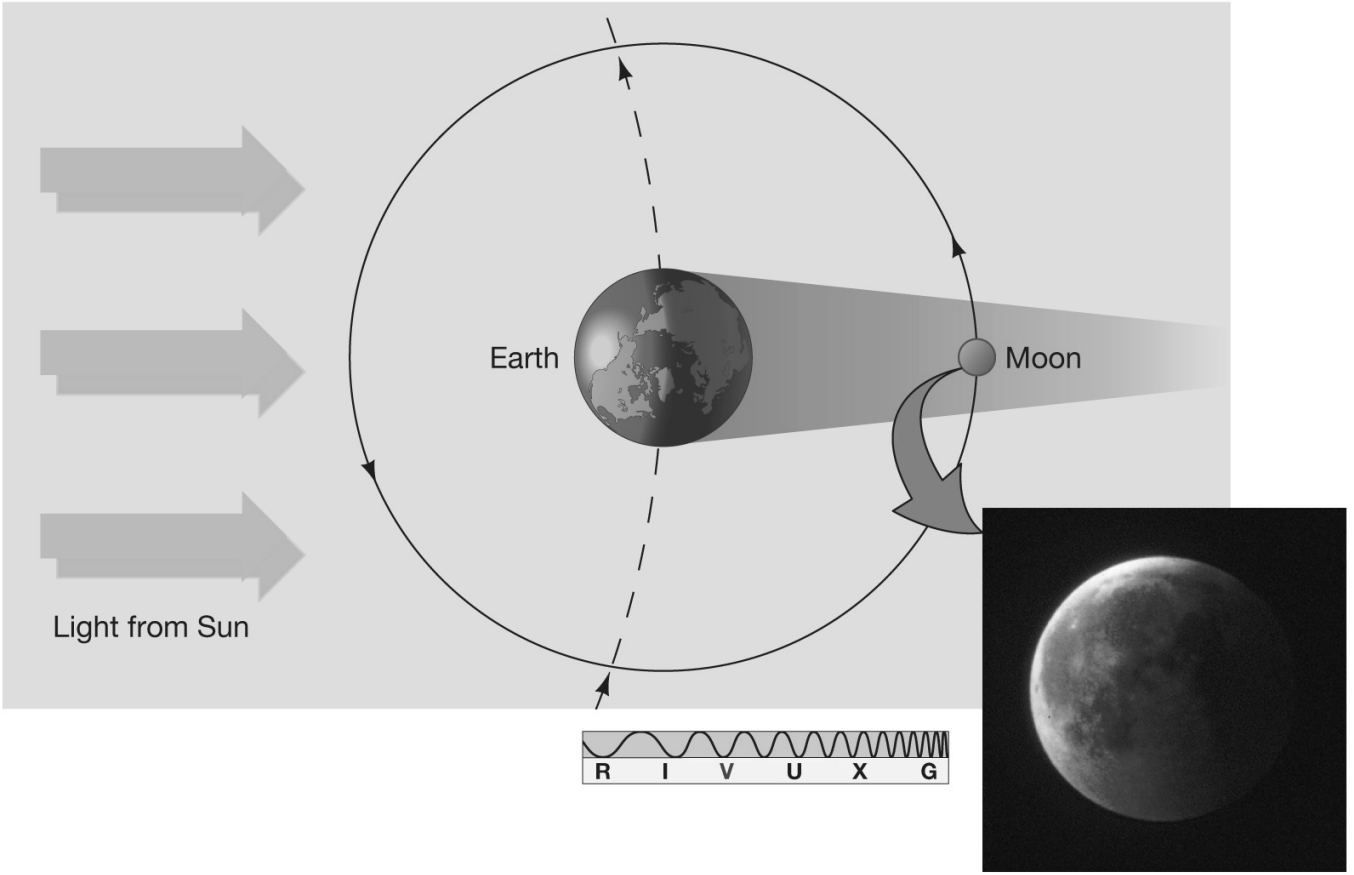


(b) Side view

E.3 Motion of the Moon

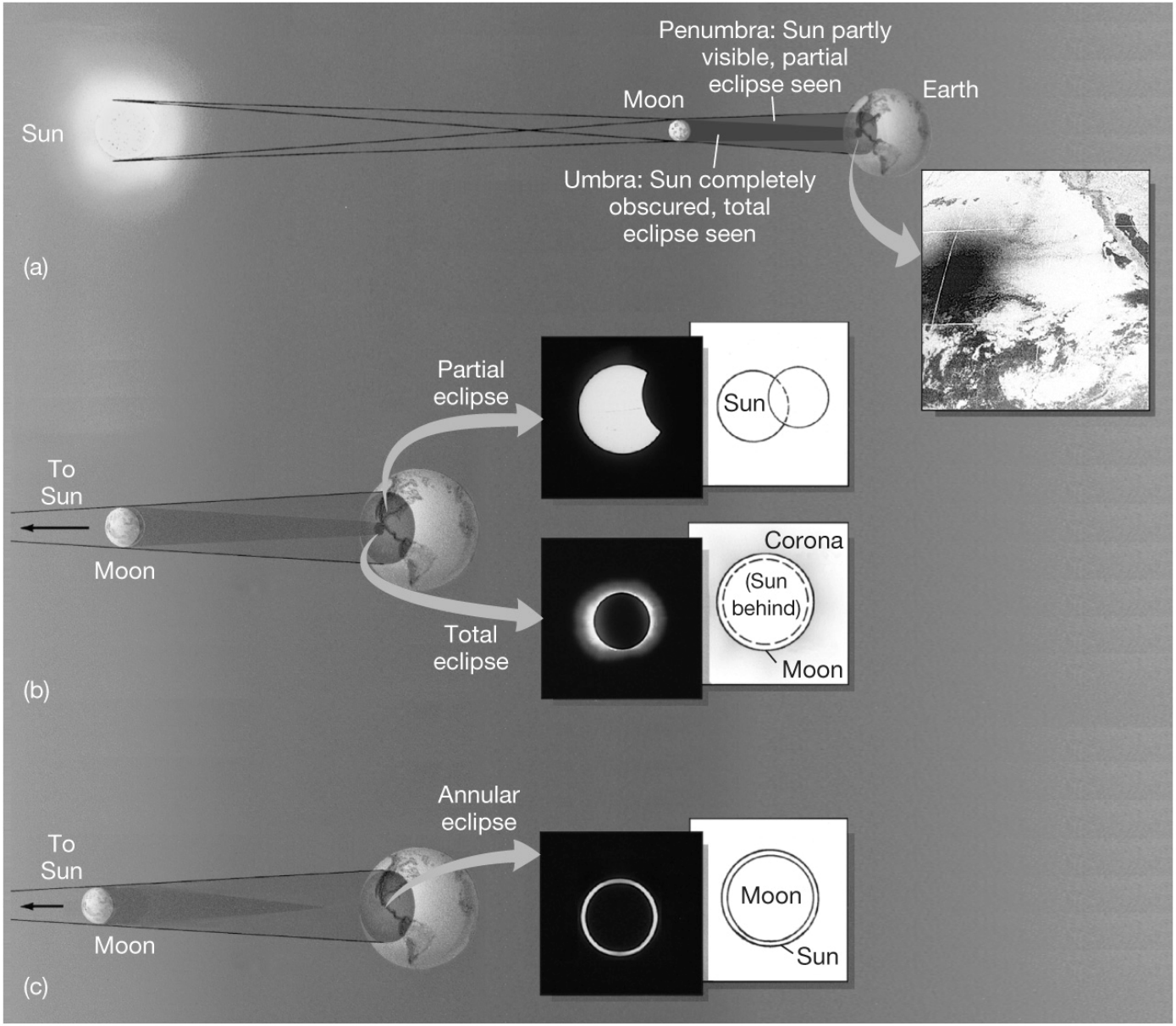
Lunar eclipse:

- **Earth is between Moon and Sun**
- **partial when only part of Moon is in shadow**
- **total when it all is**



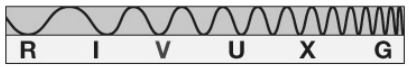
E.3 Motion of the Moon

Solar eclipse: Moon is between Earth and Sun



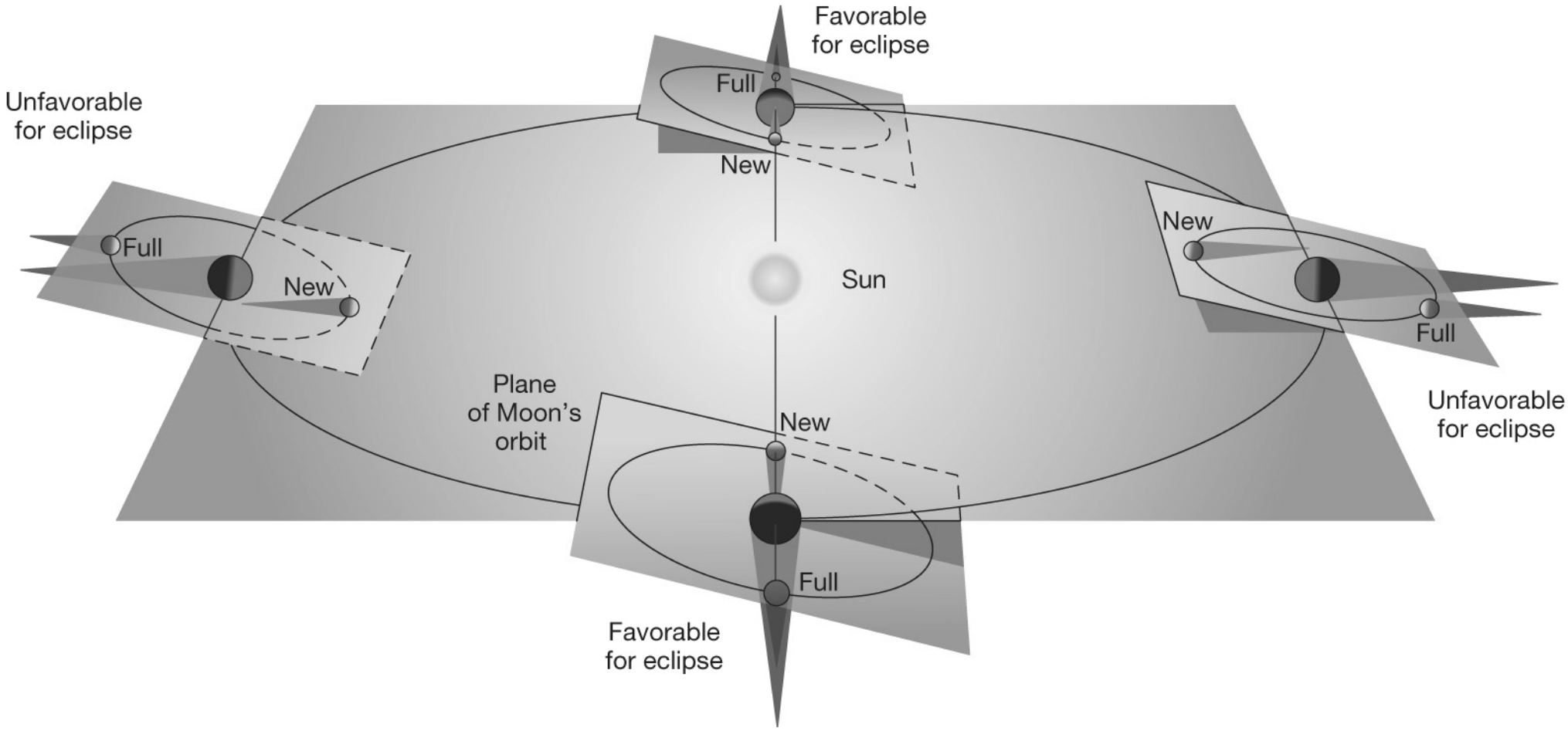
E.3 Motion of the Moon

Solar eclipse is partial when only part of Sun is blocked, total when it all is, and annular when Moon is too far from Earth for total



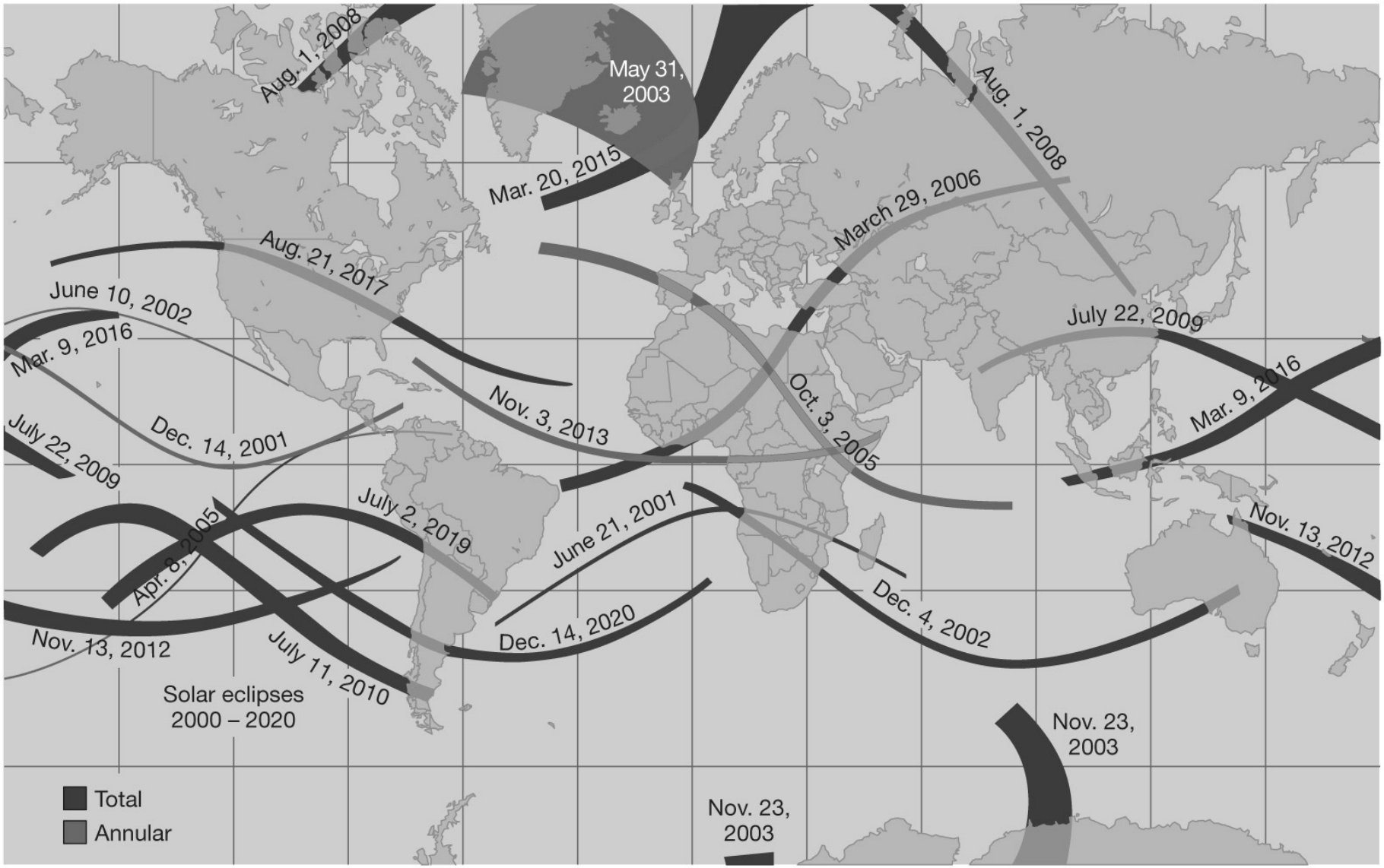
E.3 Motion of the Moon

Eclipses don’t occur every month because Earth’s and Moon’s orbits are not in the same plane



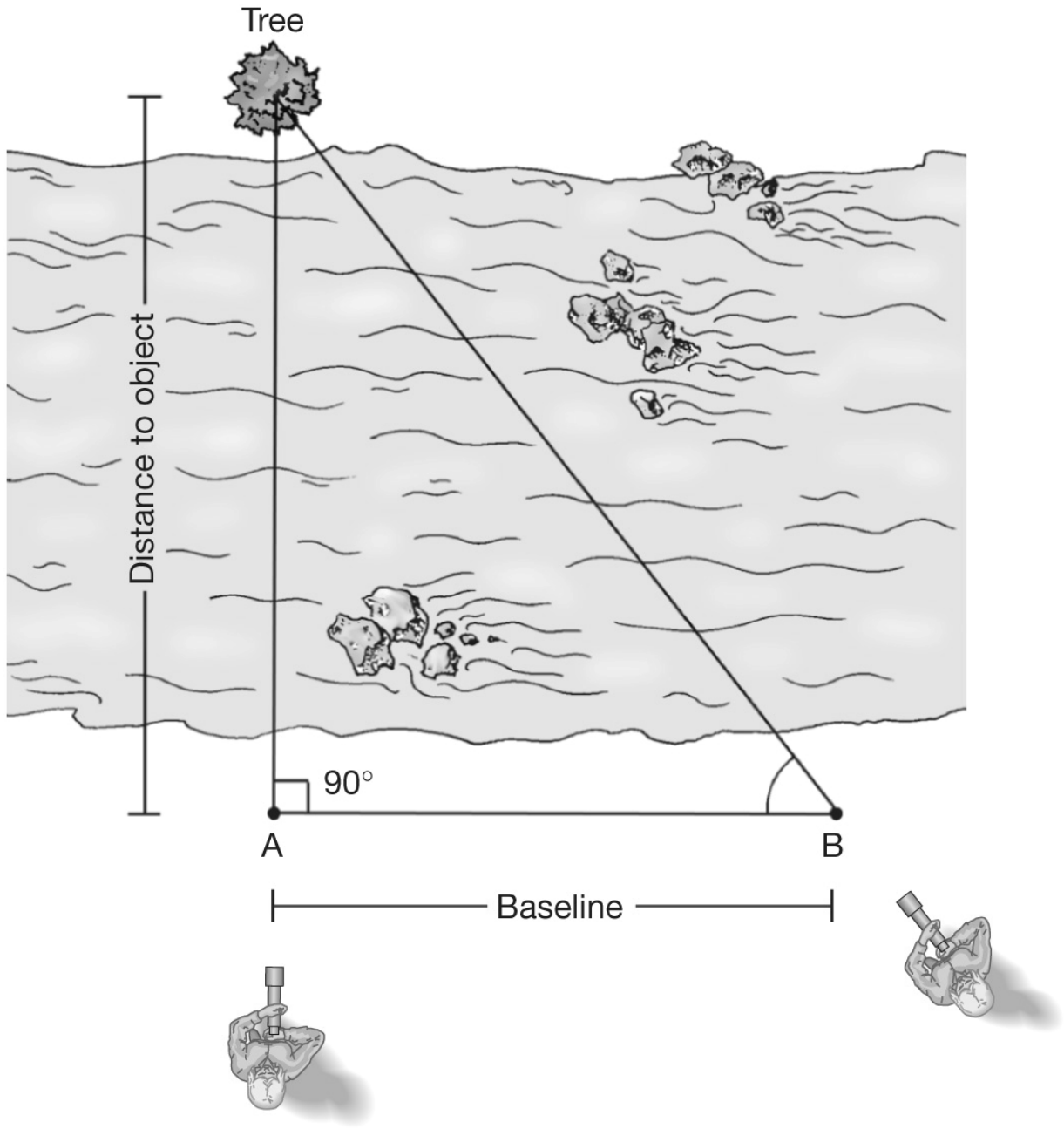
E.3 Motion of the Moon

Eclipse tracks, 2000 - 2020



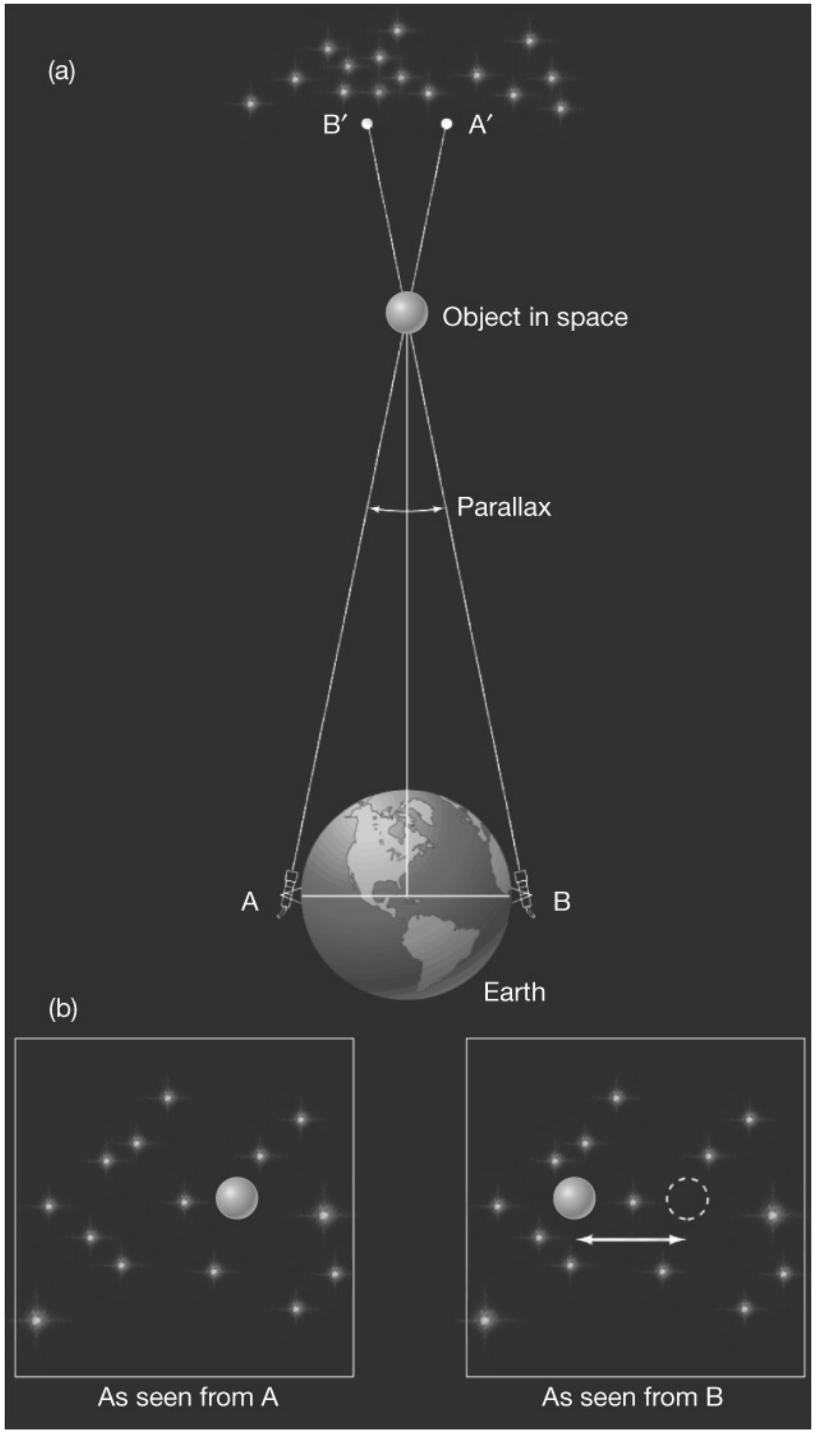
E.4 The Measurement of Distance

Triangulation: measure baseline and angles, can calculate distance



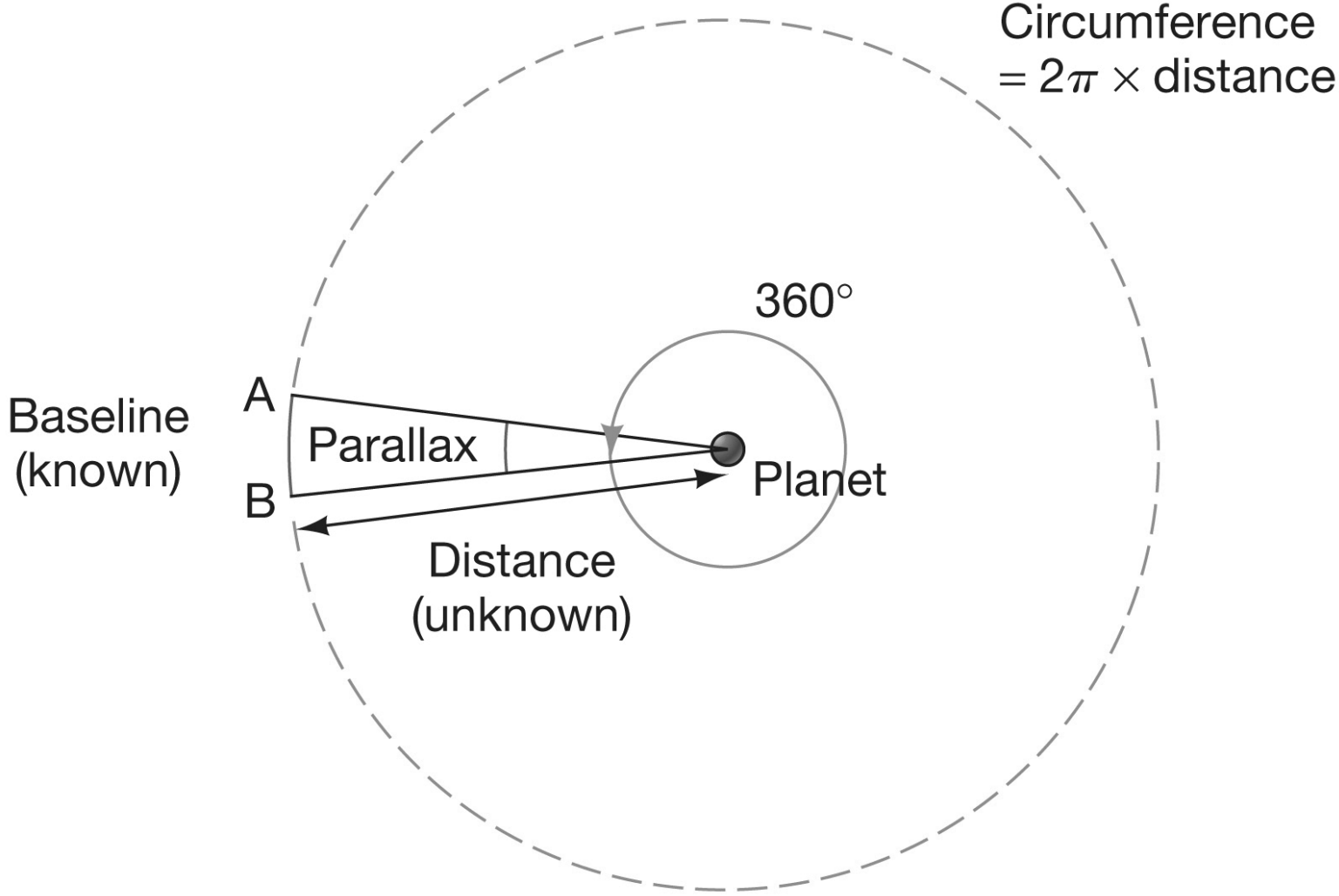
E.4 The Measurement of Distance

Parallax: similar to triangulation, but look at apparent motion of object against distant background from two vantage points



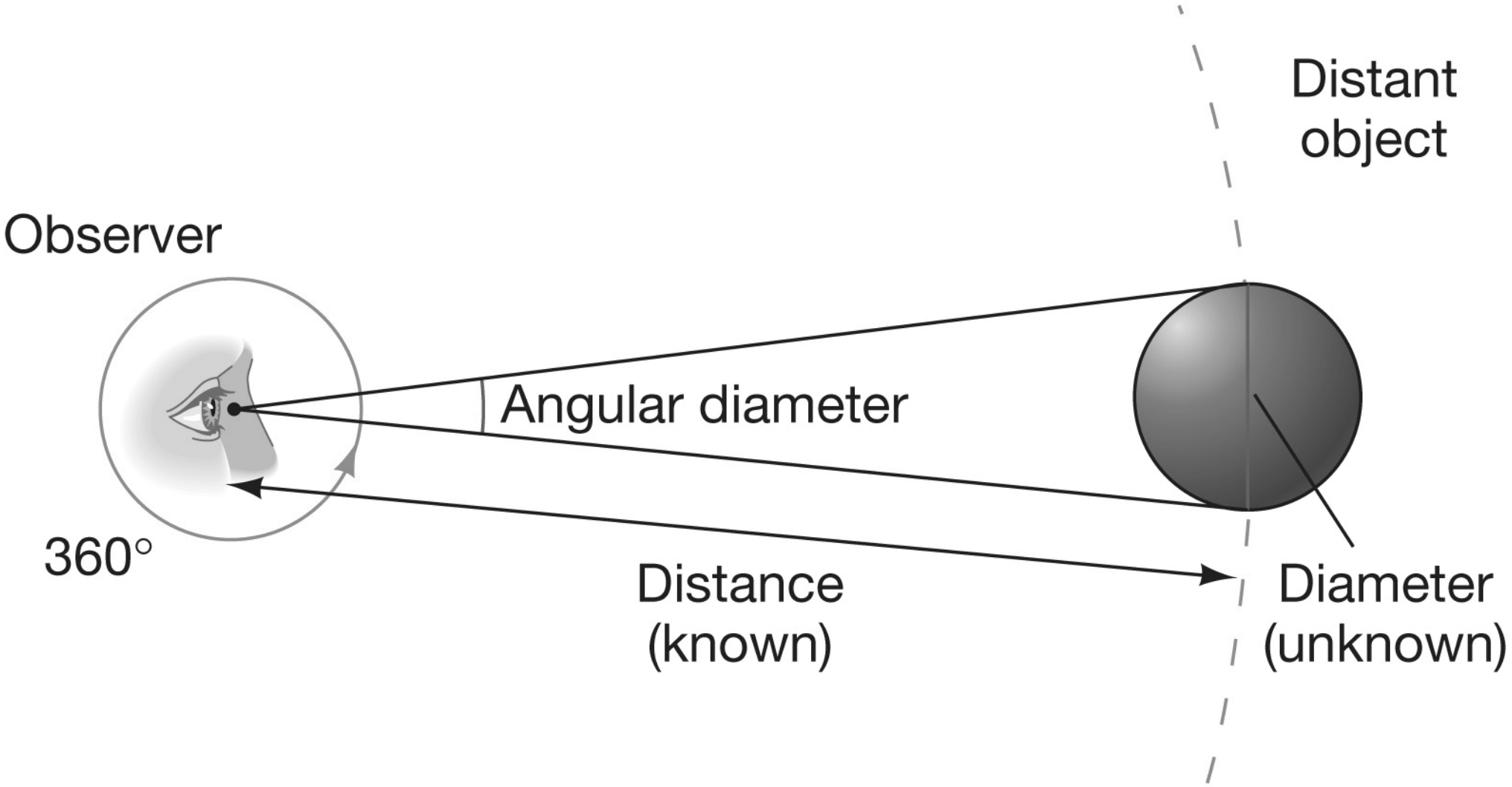
More Precisely E-2
Measuring Distances with Geometry

Converting baselines and parallaxes into distances:



More Precisely E-2
Measuring Distances with Geometry

Converting angular diameter and distance into size:



E.5 Scientific Theory and the Scientific Method

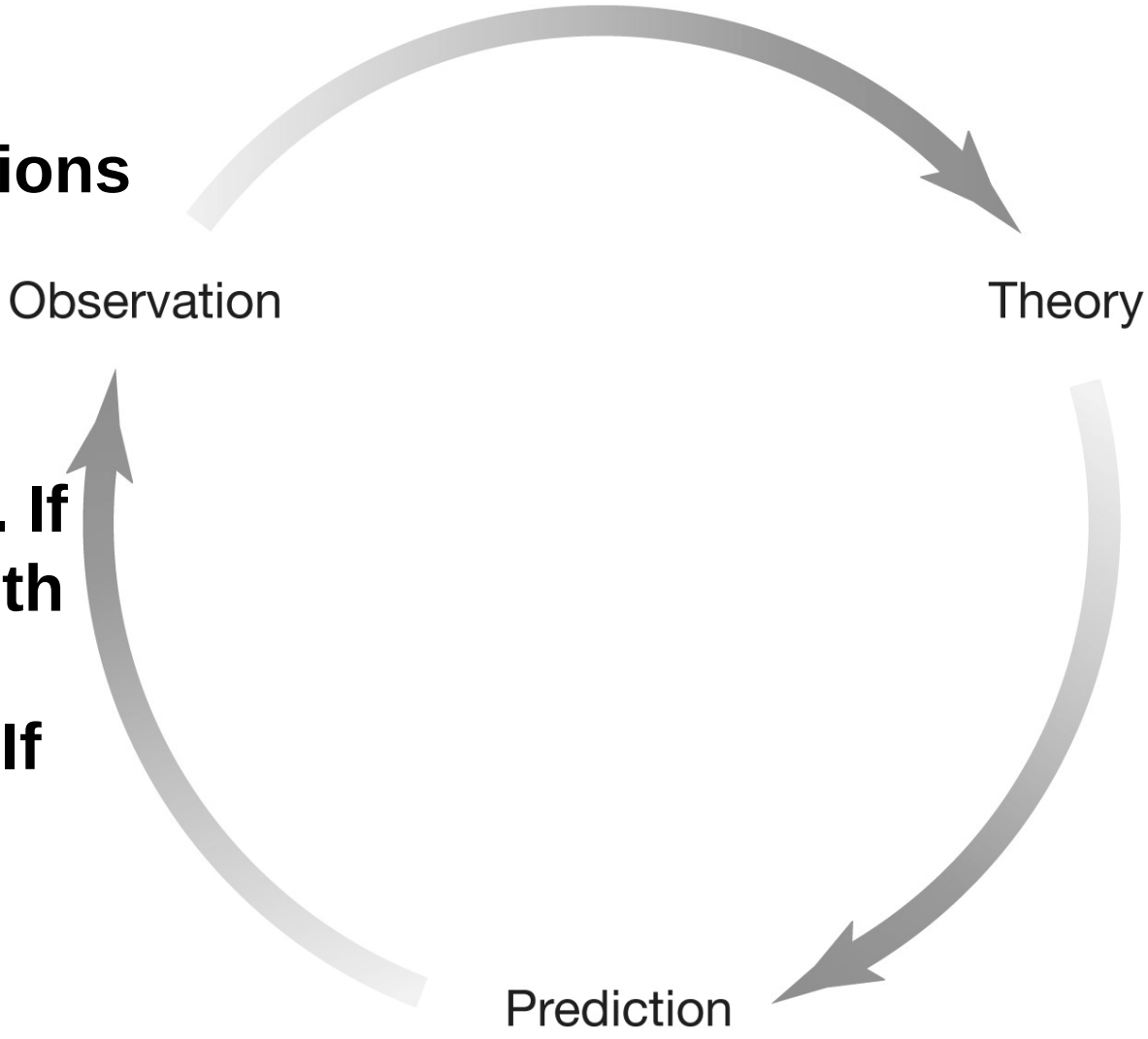
Scientific theories:

- **must be testable**
- **must be continually tested**
- **should be simple**
- **should be elegant**

Scientific theories can be proven wrong, but they can never be proven right with 100% certainty

E.5 Scientific Theory and the Scientific Method

- **Observation** leads to theory explaining it
- **Theory** leads to predictions consistent with previous observations
- **Predictions** of new phenomena are observed. If the observations agree with the prediction, more predictions can be made. If not, a new theory can be made.



Summary of the Introduction

- **Astronomy: study of the universe**
- **Stars can be imagined to be on inside of celestial sphere; useful for describing location**
- **Plane of Earth's orbit around Sun is ecliptic; at 23.5° to celestial equator**
- **Angle of Earth's axis causes seasons**
- **Moon shines by reflected light, has phases**
- **Solar day ≠ sidereal day, due to Earth's rotation around Sun**

Summary of the Introduction

- **Synodic month ≠ sidereal month, also due to Earth's rotation around Sun**
- **Tropical year ≠ sidereal year, due to precession of Earth's axis**
- **Distances can be measured through triangulation and parallax**
- **Eclipses of Sun and Moon occur due to alignment; only occur occasionally as orbits are not in same plane**
- **Scientific method: observation, theory, prediction, observation, …**

Chapter 1

The Copernican Revolution

Units of Chapter 1

The Motions of the Planets

The Birth of Modern Astronomy

The Laws of Planetary Motion

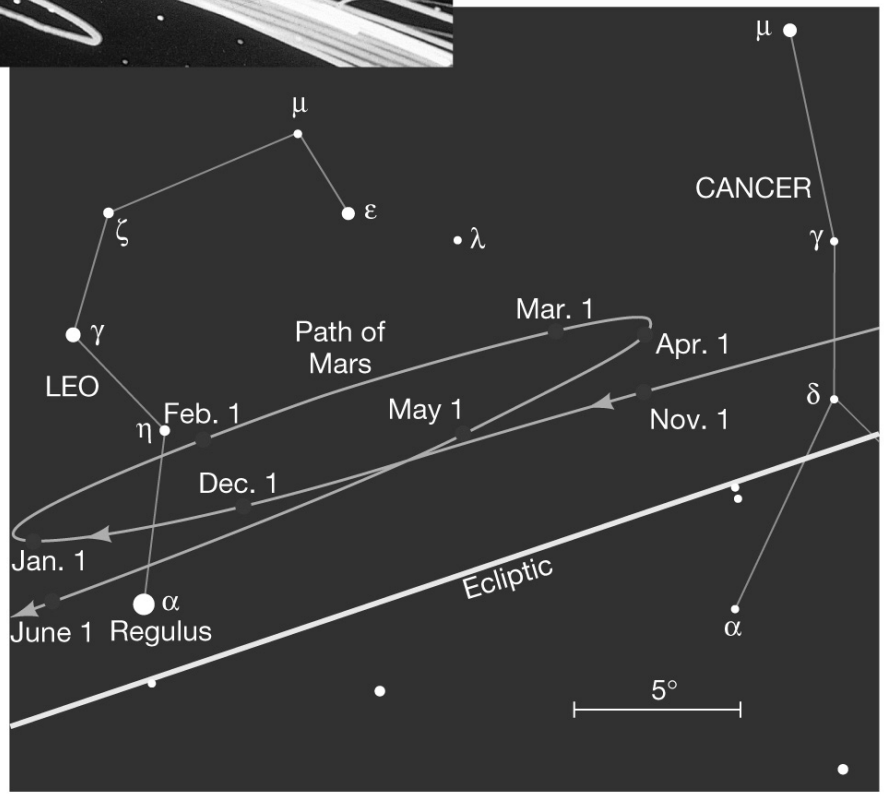
Newton’s Laws

1.1 The Motions of the Planets

Sun, Moon, and stars all have simple movements in the sky, consistent with an earth-centered system

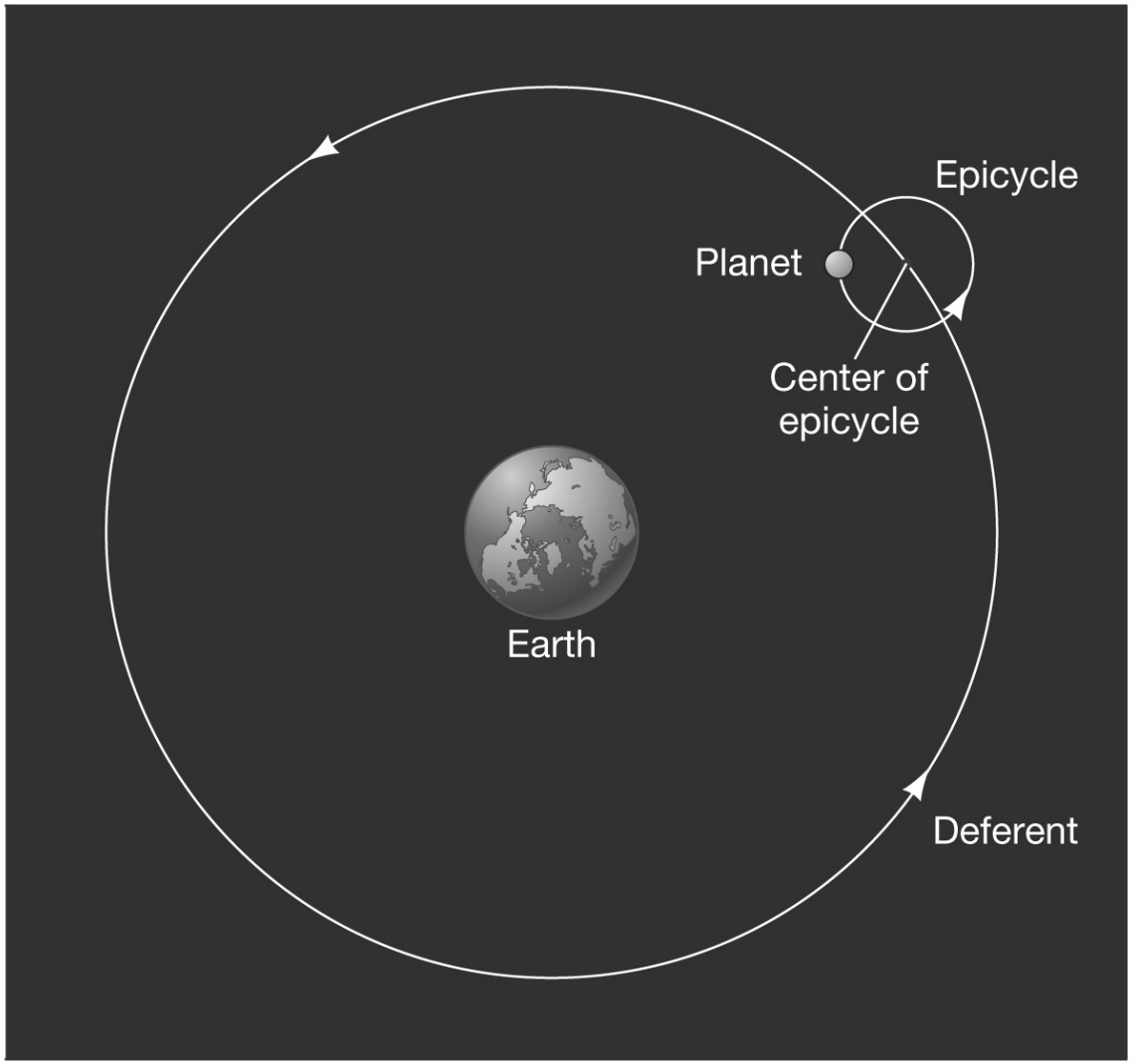
Planets:

- **move with respect to fixed stars**
- **change in brightness**
- **change speed**
- **have retrograde motion**
- **are difficult to describe in earth-centered system**



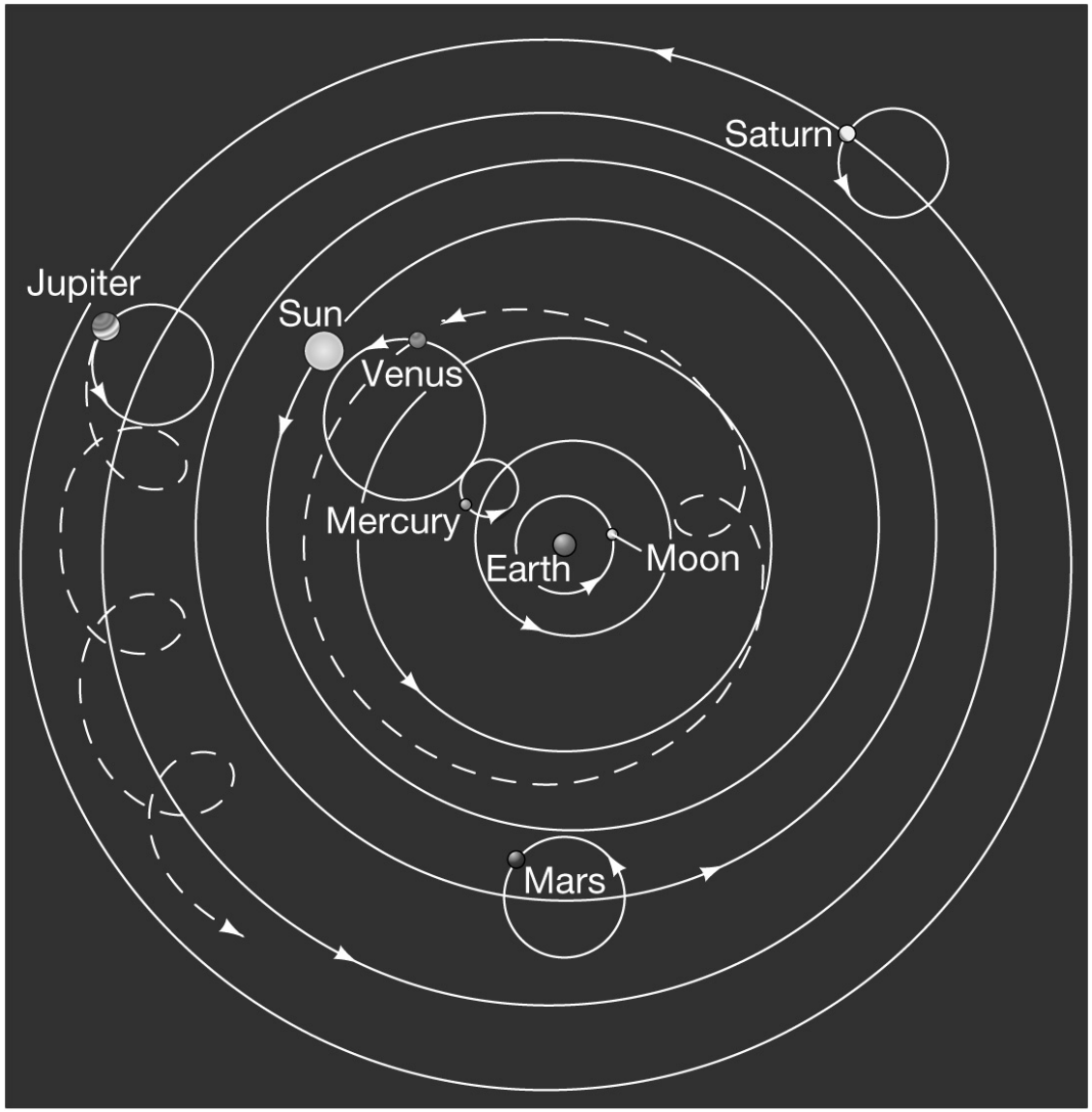
1.1 The Motions of the Planets

A basic geocentric model, showing an epicycle (used to explain planetary motions):



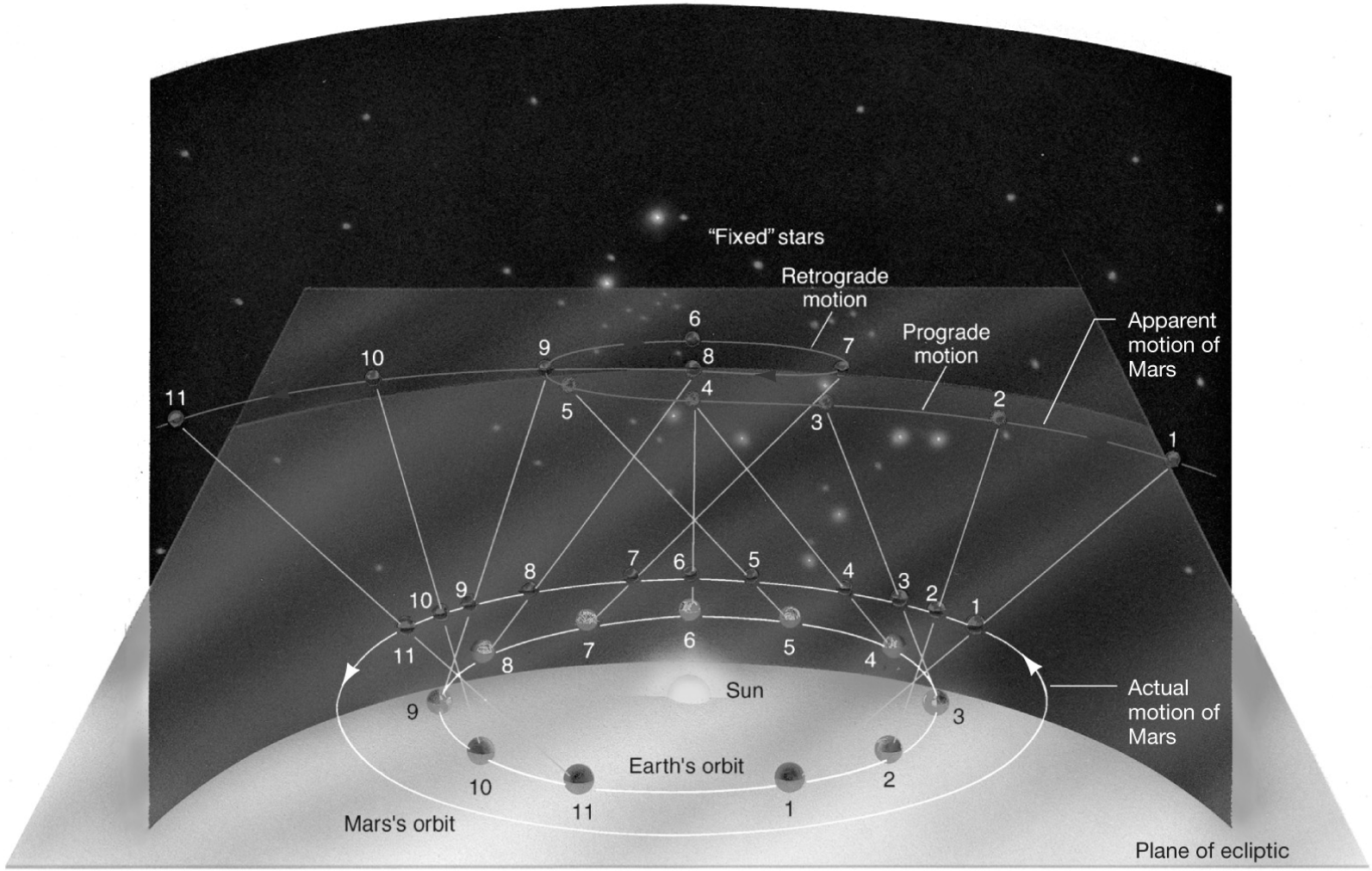
1.1 The Motions of the Planets

Lots of epicycles were needed to accurately track planetary motions, especially retrograde motions. This is Ptolemy's model:



1.1 The Motions of the Planets

A heliocentric (sun-centered) model of the solar system easily describes the observed motions of the planets, without excess complication.



1.2 The Birth of Modern Astronomy

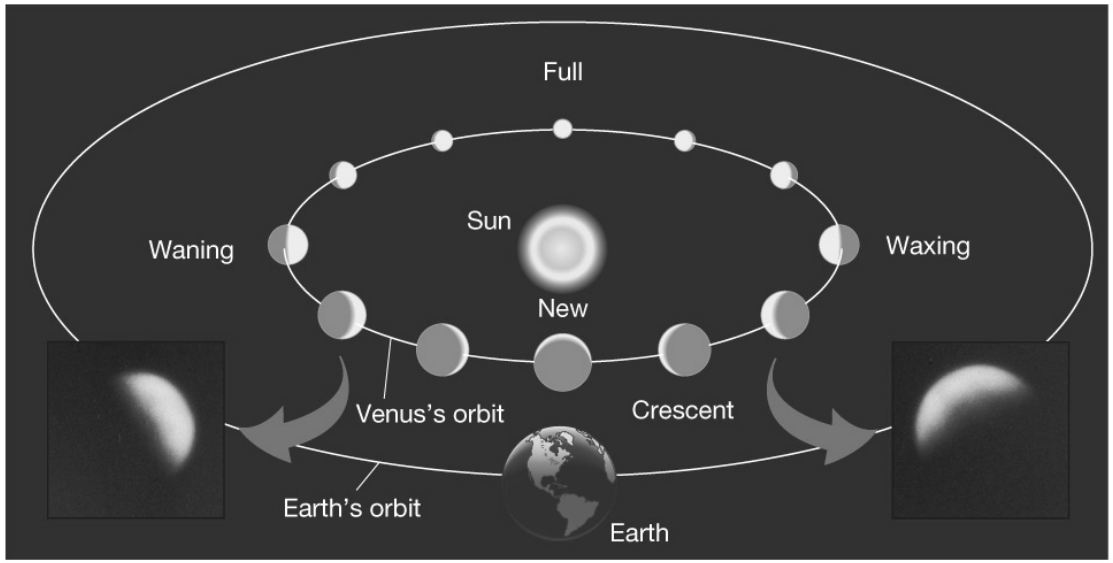
Observations of Galileo:

- **Moon has mountains, valleys, and craters**
- **The Sun has imperfections, and it rotates**
- **Jupiter has moons**
- **Venus has phases**

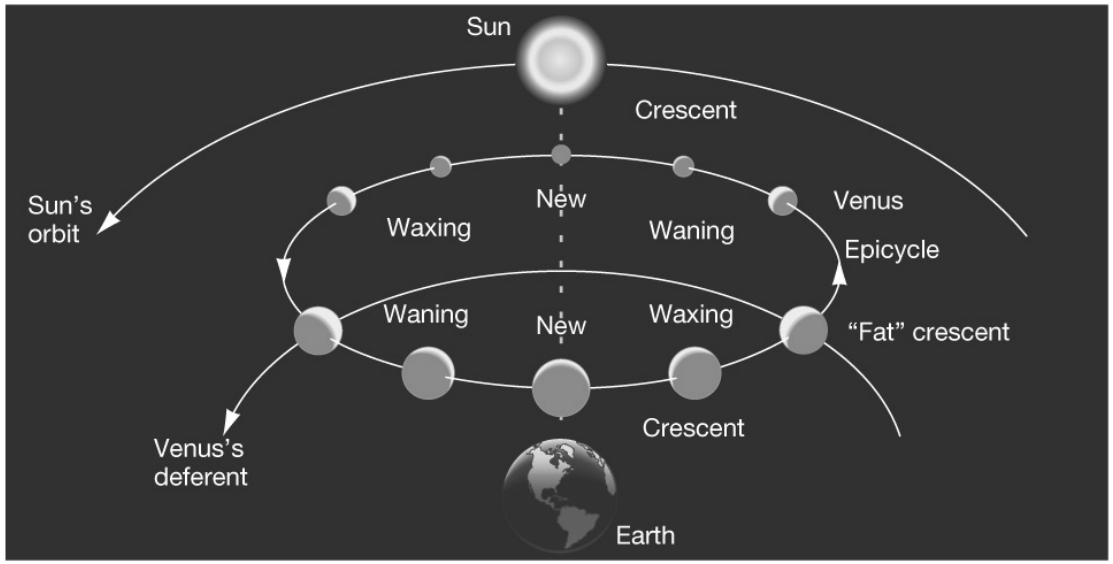
All these were in contradiction to the general belief that the heavens were constant and immutable.

1.2 The Birth of Modern Astronomy

The phases of Venus are impossible to explain in the earth-centered model of the solar system.



(a) Sun-centered model

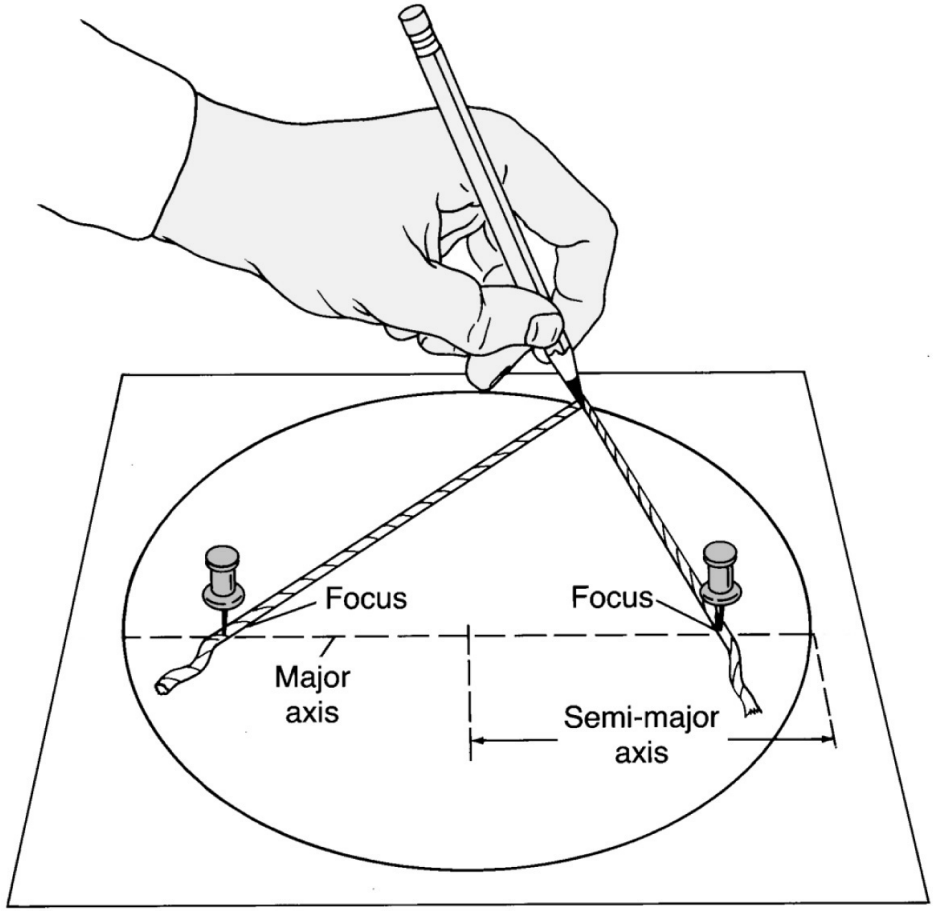


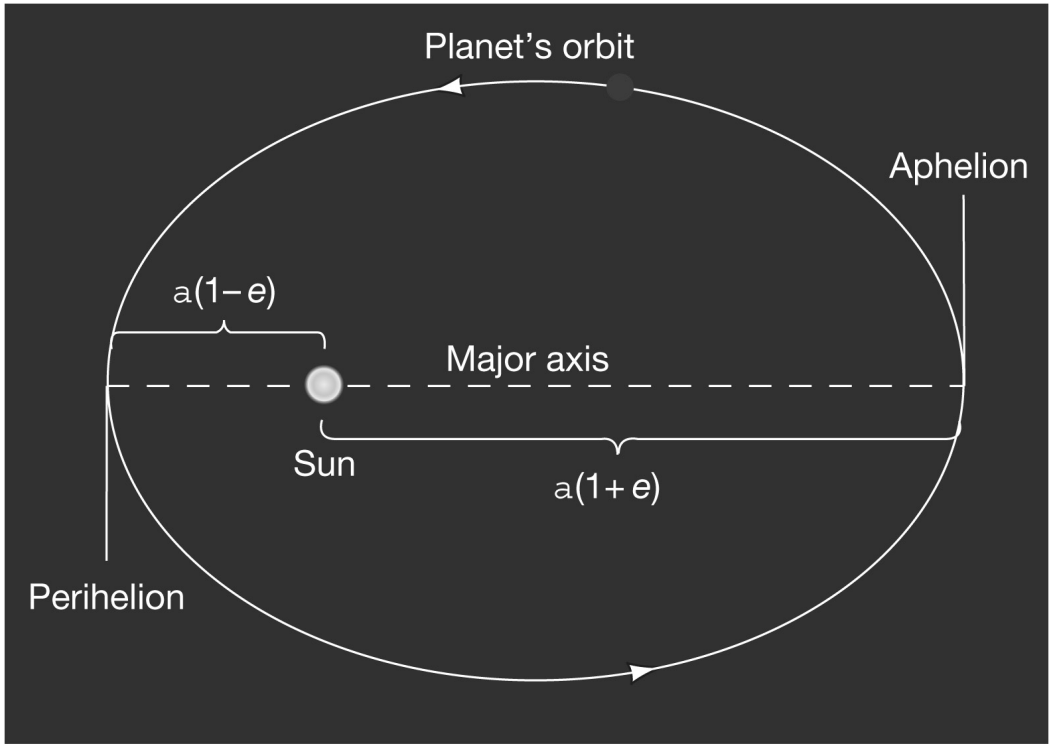
(b) Ptolemy's model

1.2 The Birth of Modern Astronomy

Kepler's laws

1. Planetary orbits are ellipses, Sun at one focus

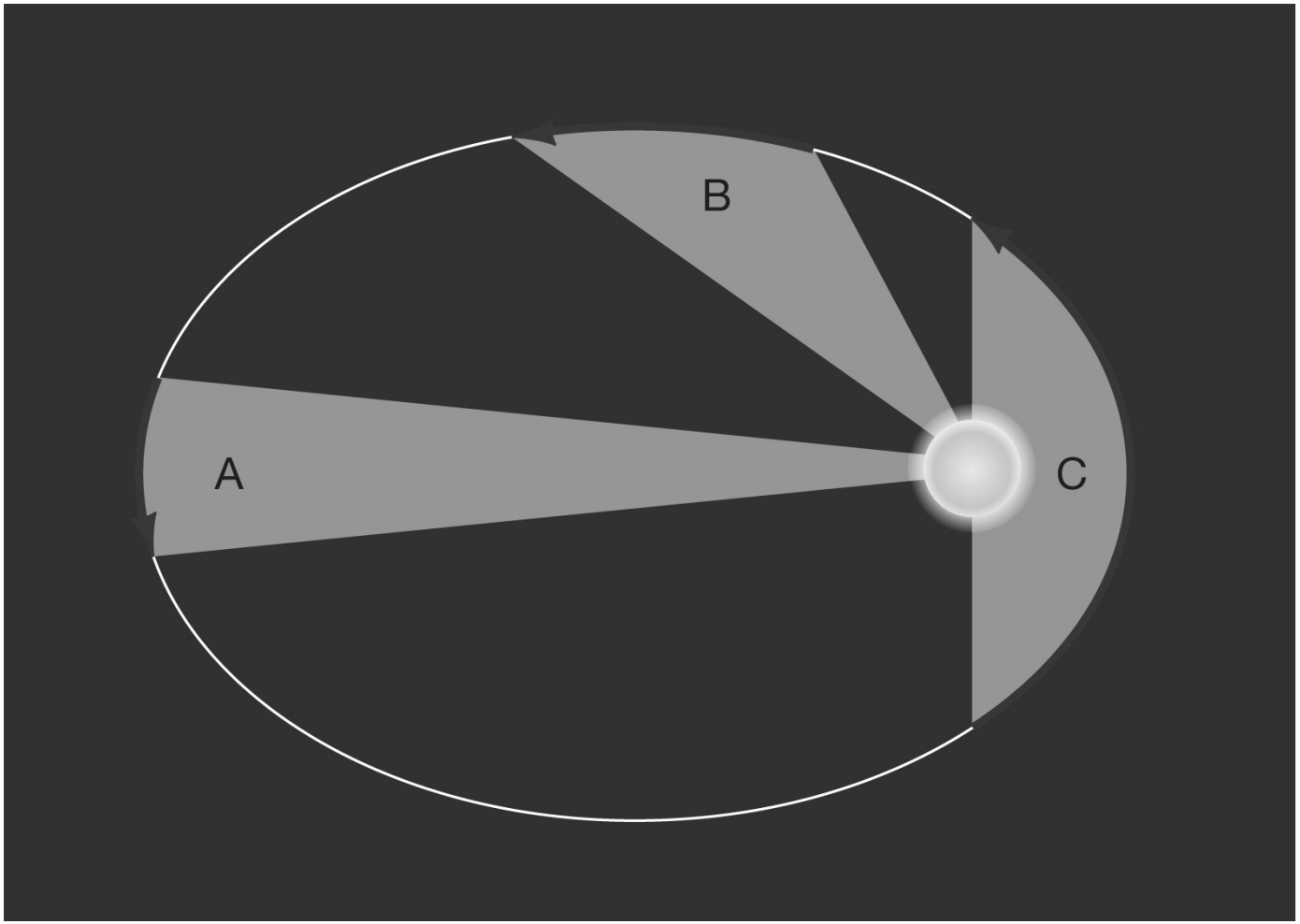




1.2 The Birth of Modern Astronomy

Kepler's laws

2. Imaginary line connecting Sun and planet sweeps out equal areas in equal times



1.2 The Birth of Modern Astronomy

Kepler's laws

3. Square of period of planet's orbital motion is proportional to cube of semimajor axis

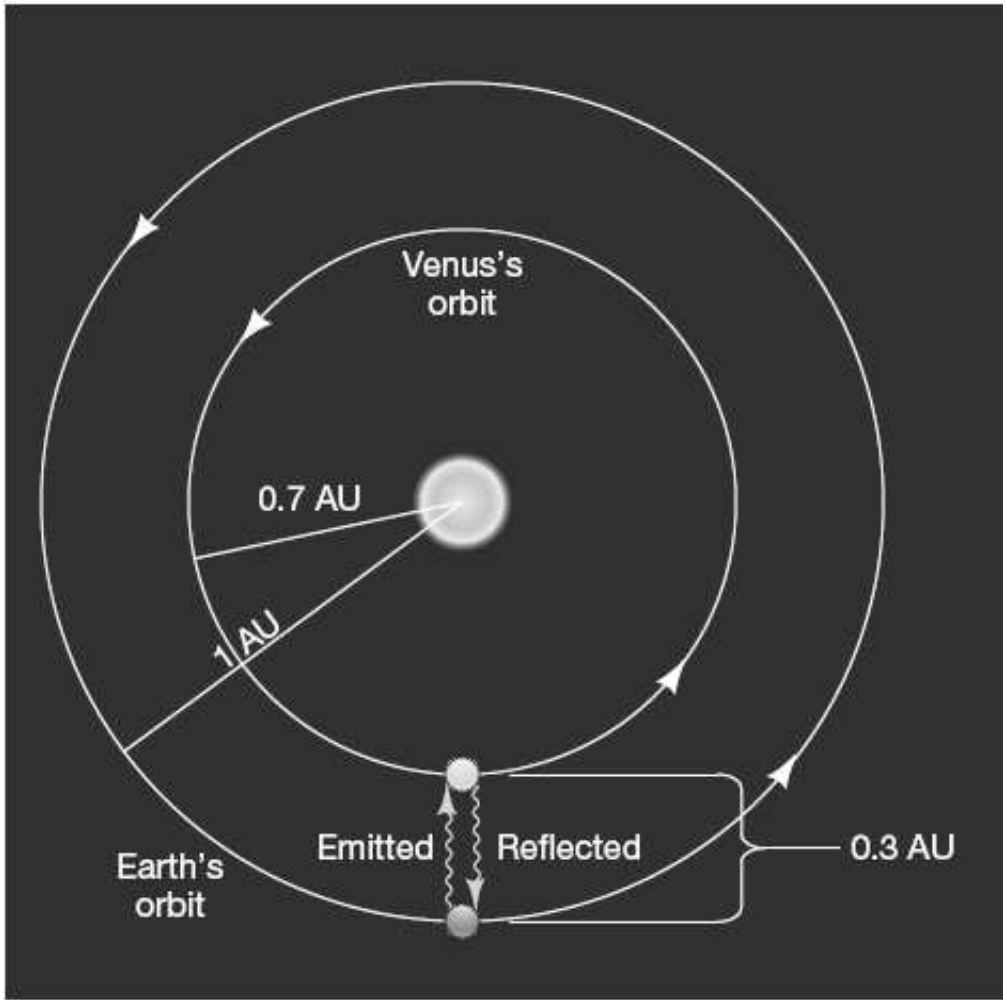
TABLE 1.1 Some Planetary Properties

PLANET	ORBITAL SEMI-MAJOR AXIS, a (astronomical units)	ORBITAL PERIOD, P (Earth years)	ORBITAL ECCENTRICITY, e	P^2/a^3
Mercury	0.387	0.241	0.206	1.002
Venus	0.723	0.615	0.007	1.001
Earth	1.000	1.000	0.017	1.000
Mars	1.524	1.881	0.093	1.000
Jupiter	5.203	11.86	0.048	0.999
Saturn	9.537	29.42	0.054	0.998
Uranus	19.19	83.75	0.047	0.993
Neptune	30.07	163.7	0.009	0.986
Pluto	39.48	248.0	0.249	0.999

1.2 The Birth of Modern Astronomy

The Dimensions of the Solar System

The distance from the Earth to the Sun is called an astronomical unit. Its actual length may be measured by bouncing a radar signal off Venus and measuring the transit time.

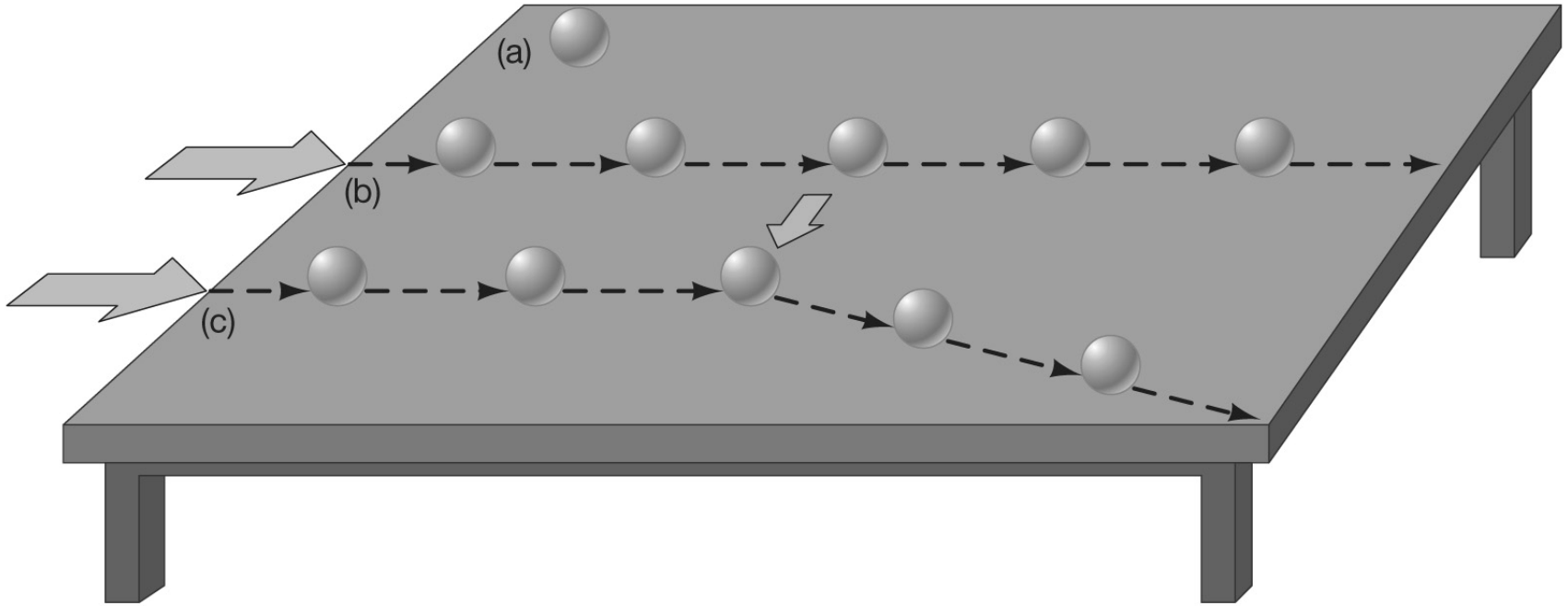


1.4 Newton's Laws

Newton's laws of motion explain how objects interact with the world and with each other.

Newton's First Law:

An object at rest will remain at rest, and an object moving in a straight line at constant speed will not change its motion, unless an external force acts on it.



1.4 Newton's Laws

Newton's second law:

When a force is exerted on an object, its acceleration is inversely proportional to its mass:

$$a = F/m$$

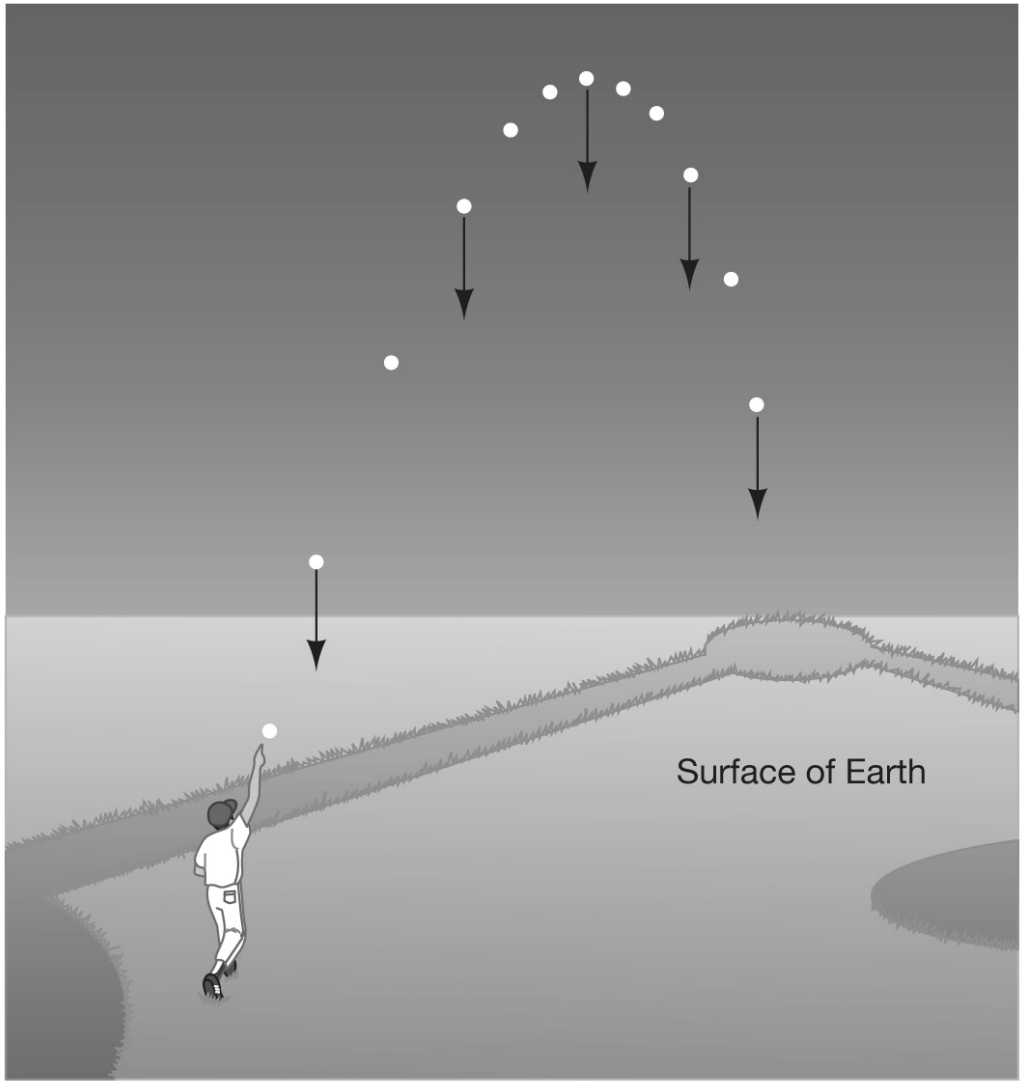
Newton's third law:

When object A exerts a force on object B, object B exerts an equal and opposite force on object A.

1.4 Newton's Laws

Gravity

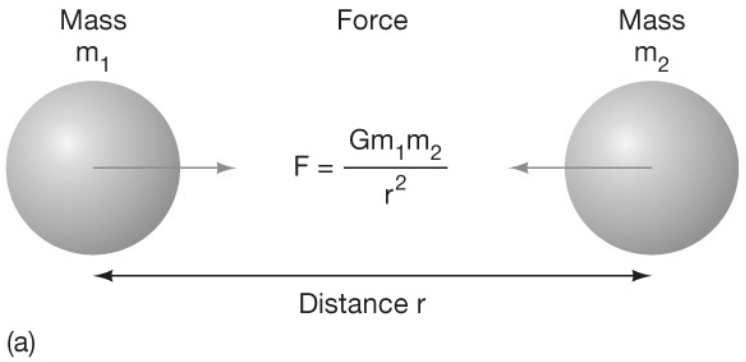
On the Earth's surface, the acceleration due to gravity is approximately constant, and directed toward the center of the Earth:



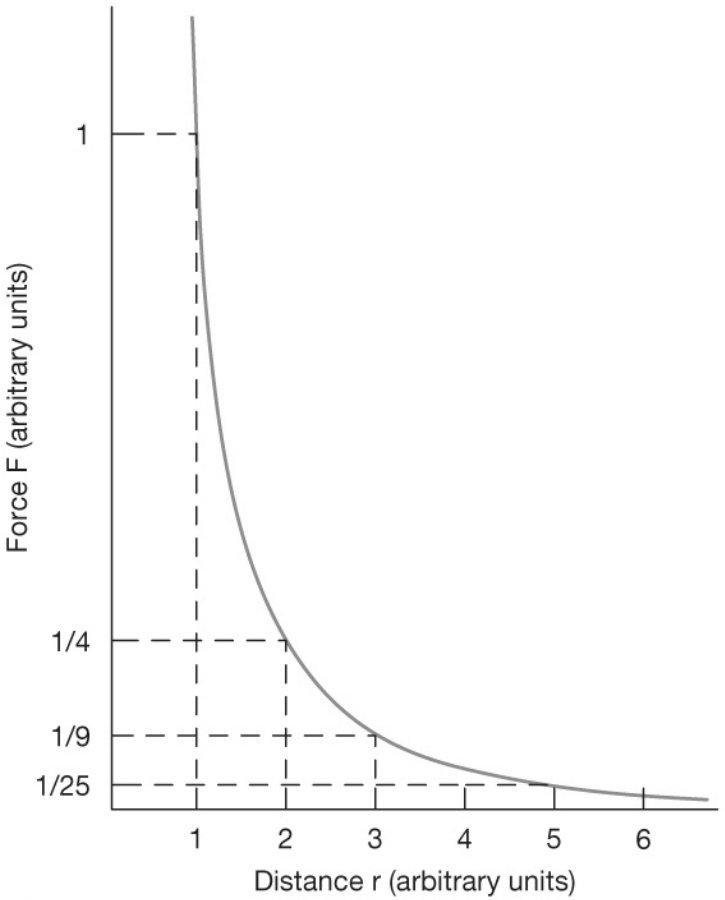
1.4 Newton's Laws

Gravity

For two massive objects, the gravitational force is proportional to the product of their masses divided by the square of the distance between them:



(a)

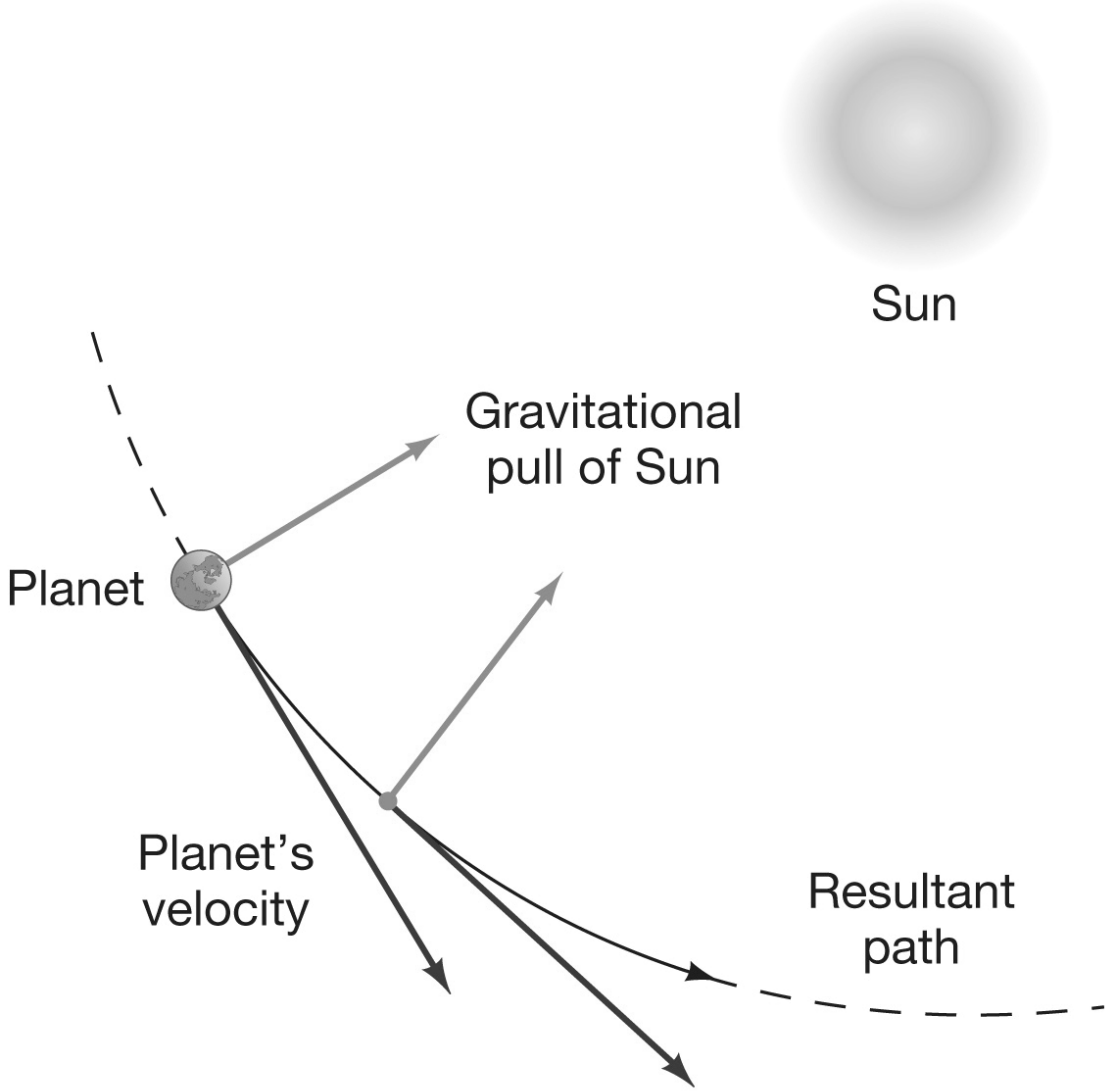


(b)

1.4 Newton's Laws

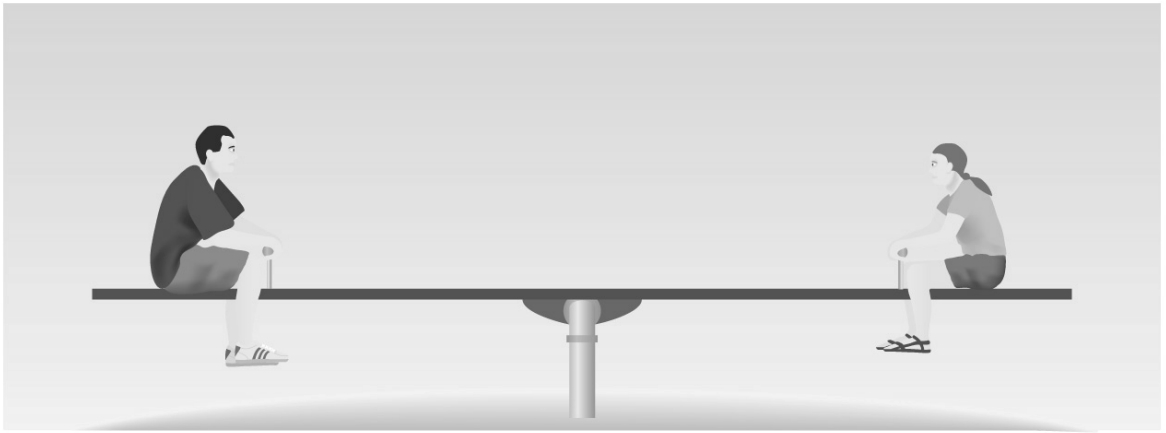
Gravity

The gravitational pull of the Sun keeps the planets moving in their orbits.

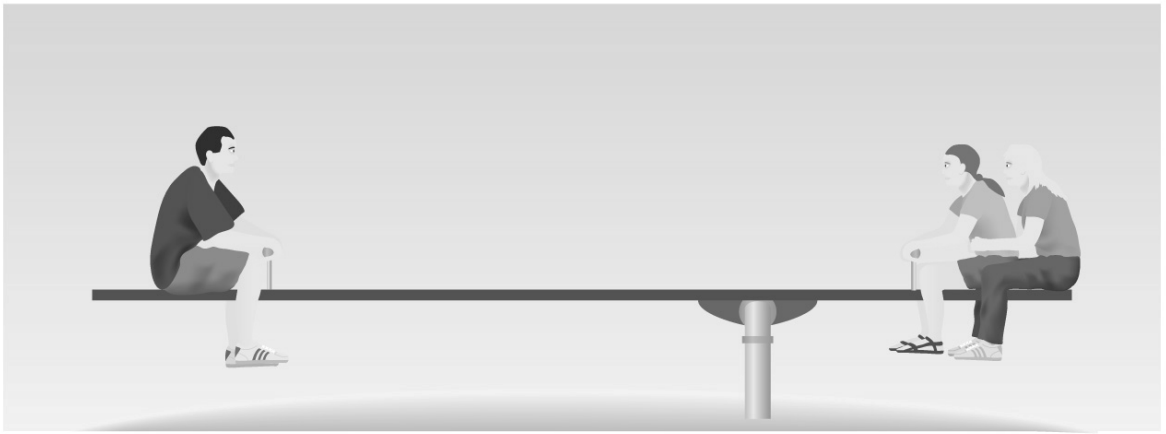


1.4 Newton's Laws

Massive objects actually orbit around their common center of mass; if one object is much more massive than the other, the center of mass is not far from the center of the more massive object. For objects more equal in mass, the center of mass is between the two.



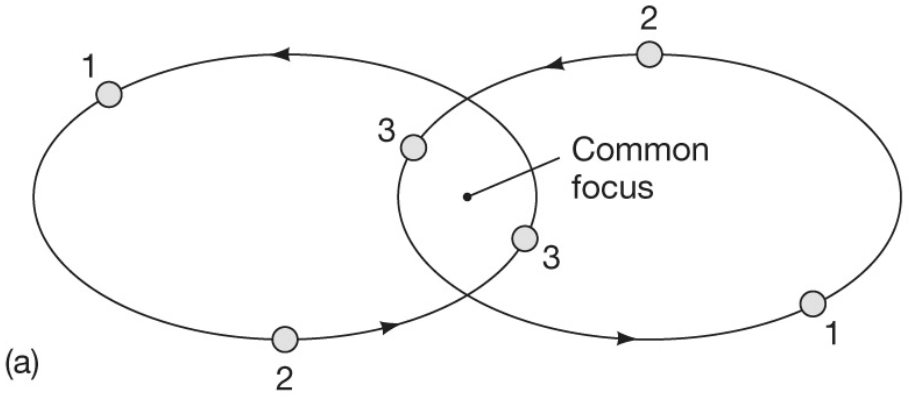
(a) Equal masses Center of mass

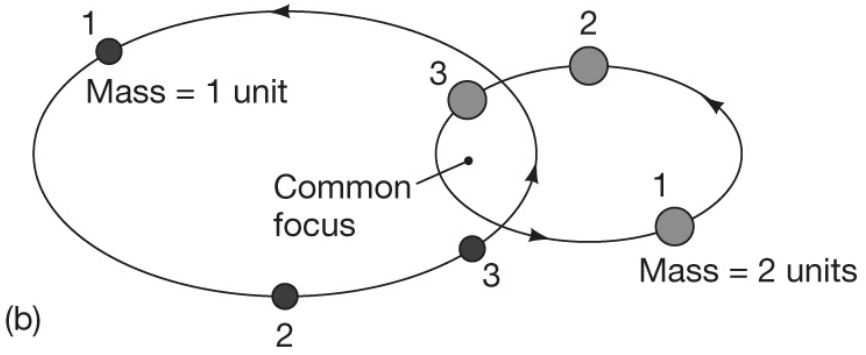


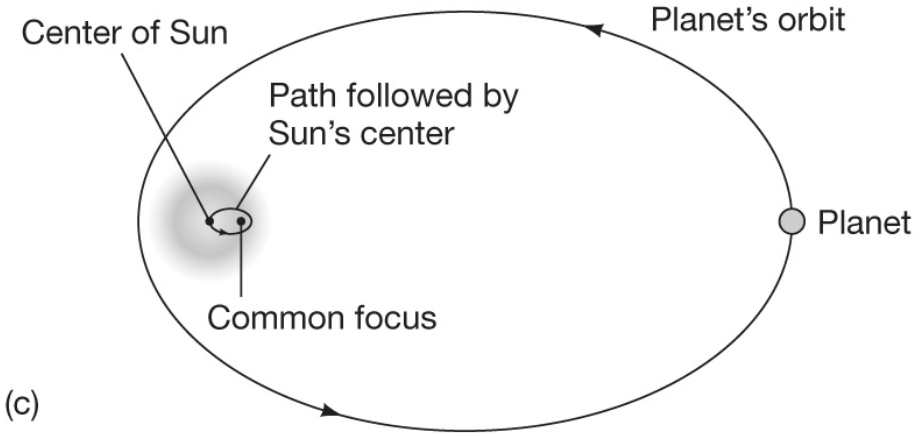
(b) Unequal masses Center of mass

1.4 Newton's Laws

Kepler's laws are a consequence of Newton's laws.







Summary of Chapter 1

First models of solar system were geocentric, but couldn't easily explain retrograde motion

Heliocentric model does

Galileo's observations supported heliocentric model

Kepler found three empirical laws of planetary motion from observations

Summary of Chapter 1, cont.

Laws of Newtonian mechanics explained Kepler's observations

Gravitational force between two masses is proportional to the product of the masses, divided by the square of the distance between them

E.2 Earth's Orbital Motion

Time for Earth to orbit once around Sun, relative to fixed stars, is sidereal year

Tropical year follows seasons; sidereal year follows constellations – in 13,000 years July and August will still be summer, but Orion will be a summer constellation