Chapter 1

History of Astronomy

Periods of Western Astronomy

- Western astronomy divides into 4 periods
  – Prehistoric (before 500 B.C.)
    - Cyclical motions of Sun, Moon and stars observed
    - Keeping time and determining directions develops
  – Classical (500 B.C. to A.D. 1400)
    - Measurements of the heavens
    - Geometry and models to explain motions
  – Renaissance (1400 to 1650)
    - Accumulation of data led to better models
    - Technology (the telescope) enters picture
  – Modern (1650 to present)
    - Physical laws and mathematical techniques
    - Technological advances accelerate

Prehistoric Astronomy

- The heavens have been studied for thousands of years.
- Early astronomers noted the obvious:
  – Rising of the Sun in the eastern sky and its setting in the west
  – Changing appearance of the Moon
  – Eclipses
  – Planets as a distinct class of objects different from the stars

Prehistoric Astronomy

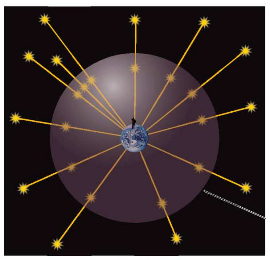
– Many astronomical phenomena are cyclic on a day-to-day and year-to-year basis and consequently gave prehistoric people:
  - Methods for time keeping
  - Ability to predict and plan future events
  - Incentive to build monumental structures such as Stonehenge

– Modern civilization no longer relies on direct astronomical observations for time keeping and planning

– Studying the night sky provides link to past

Stonehenge

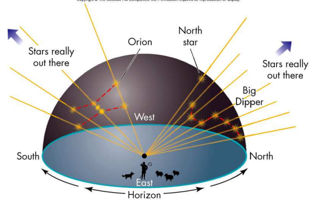
The Celestial Sphere



- Vast distances to stars prevent us from sensing their true 3-D arrangement
- Naked eye observations treat all stars at the same distance, on a giant ***celestial sphere*** with the Earth at its center

Models and Science

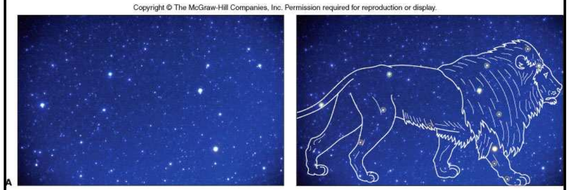
- The celestial sphere is a ***model,*** which does not necessarily match physical reality
- Models provide a means to enhance our understanding of nature



Our Experience of the Celestial Sphere.

B

Constellations



A

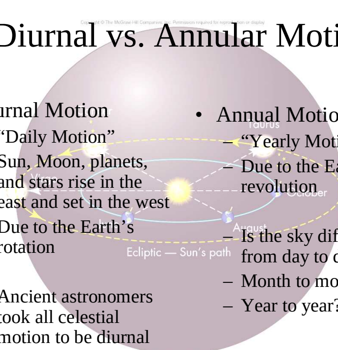
- ***Constellations*** are fixed arrangements of stars that resemble animals, objects, and mythological figures
- Stars in a constellation are not physically related

Constellations

B

- Positions of stars change very slowly; constellations will look the same for thousands of years
- Origin of the ancient constellations is unknown although they probably served as mnemonic tools for tracking seasons and navigation

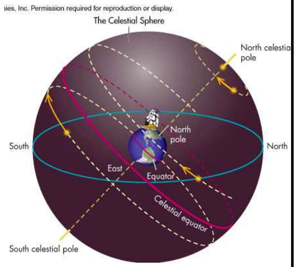
Diurnal vs. Annular Motion



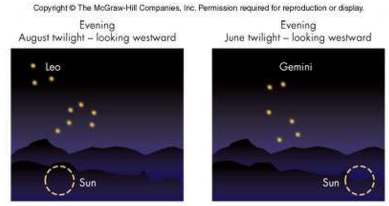
- Diurnal Motion
  - "Daily Motion"
  - Sun, Moon, planets, and stars rise in the east and set in the west
  - Due to the Earth's rotation
  - Ancient astronomers took all celestial motion to be diurnal
  - The Celestial Sphere!
- Annual Motion
  - "Yearly Motion"
  - Due to the Earth's revolution
  - Is the sky different from day to day?
  - Month to month?
  - Year to year?

Diurnal Motion

- Daily motion can be explained by the rotation of the celestial sphere about the north and south ***celestial poles*** located directly above the Earth's north and south poles
- The ***celestial equator,*** which lies directly above the Earth's equator, provides another astronomical reference marker



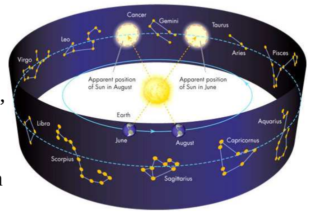
Annual Motion



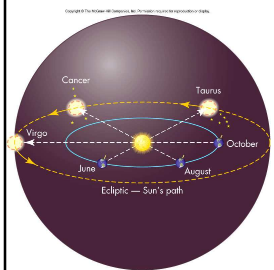
- For a given time (say 10:00 PM), as the months proceed, constellations do not appear in the same part of the sky

Annual Motion

- A given star rises 3 minutes 56 seconds earlier each night
- This annual motion is caused by the Earth’s motion around the Sun, the result of projection
- The ancients used the periodic annual motion to mark the seasons

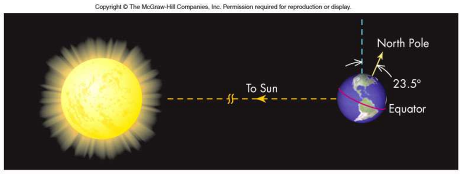


The Ecliptic



- The path of the Sun through the stars on the celestial sphere is called the ***ecliptic***
- The ecliptic is a projection of the Earth’s orbit onto the celestial sphere and is tipped relative to the celestial equator

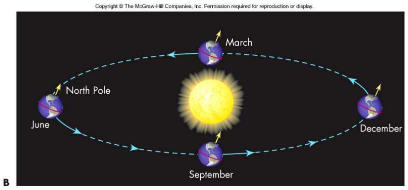
The Seasons



A

- The Earth is closest to the Sun in January, which is winter in the northern hemisphere
- Therefore, the seasons cannot be caused by the Sun’s proximity to the Earth
- The Earth’s ***rotation axis*** is tilted 23.5º from a line perpendicular to the Earth’s orbital plane

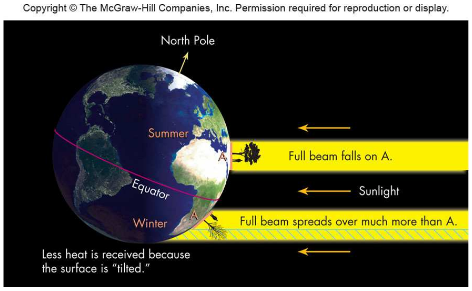
The Seasons



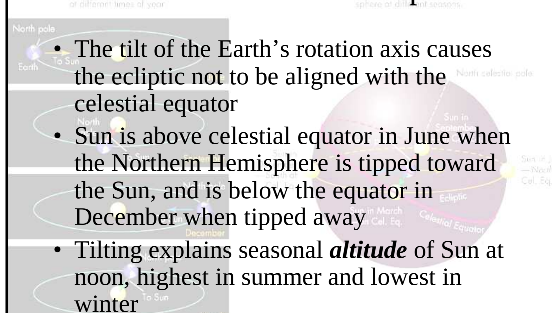
B

- The rotation axis of the Earth maintains nearly the same tilt and direction from year to year
- The northern and southern hemispheres alternate receiving (on a yearly cycle) the majority of direct light from the Sun
- This leads to the seasons!

The Seasons

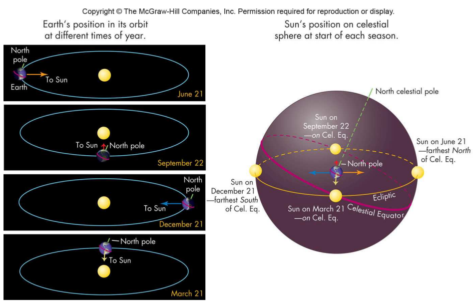


Seasons and The Ecliptic



- The tilt of the Earth’s rotation axis causes the ecliptic not to be aligned with the celestial equator
- Sun is above celestial equator in June when the Northern Hemisphere is tipped toward the Sun, and is below the equator in December when tipped away
- Tilting explains seasonal ***altitude*** of Sun at noon, highest in summer and lowest in winter

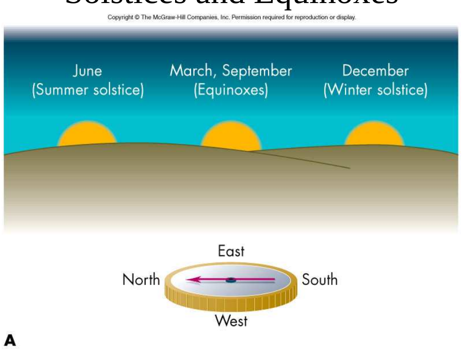
The Ecliptic's Tilt



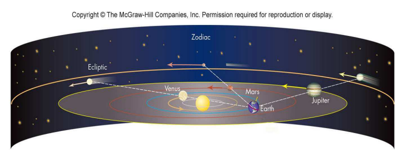
Solstices and Equinoxes

- Points on horizon where Sun rises and sets changes periodically throughout year
- In summer months of Northern hemisphere, the Sun rises north of east and sets north of west
- In winter months of Northern hemisphere, the Sun rises south of east and sets south of west
- The ***solstices*** (about June 21 and December 21) are when the Sun rises at the most extreme north and south points
- The ***equinoxes*** (equal day and night and about March 21 and September 23) are when the Sun rises directly east
- Ancients marked position of Sun rising and setting to determine the seasons (e.g., Stonehenge)

Solstices and Equinoxes



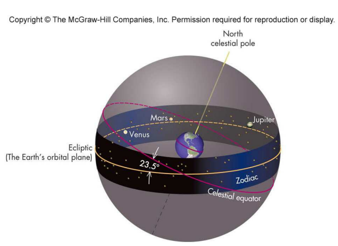
Planets and the Zodiac



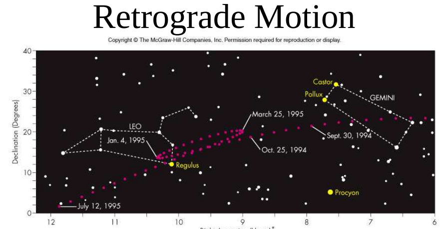
- The planets (Greek for "wanderers") do not follow the same cyclic behavior of the stars
- The planets move relative to the stars in a very narrow band centered about the ecliptic and called the ***zodiac***
- Motion and location of the planets in the sky is a combination of all the planets' orbits being nearly in the same plane and their relative speeds about the Sun

Planets and the Zodiac

- Apparent motion of planets is usually from west to east <u>relative to the stars</u>, although on a daily basis, the planets always rise in the east



Retrograde Motion

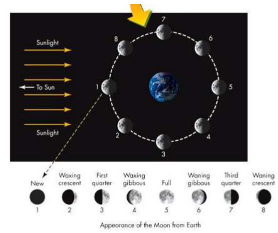


- Occasionally, a planet will move from east to west relative to the stars; this is called ***retrograde motion***
- Explaining retrograde motion was one of the main reasons astronomers ultimately rejected the idea of the Earth being located at the center of the solar system

The Moon

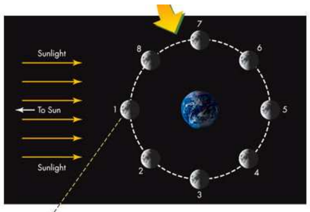
- Rises in the east and sets in the west
- Like the planets and Sun, the Moon moves from west to east relative to the stars (roughly the width of the Moon in one hour)

The Phases of the Moon



- During a period of about 30 days, the Moon goes through a complete set of ***phases:*** new, waxing crescent, first quarter, waxing gibbous, full, waning gibbous, third quarter, waning crescent

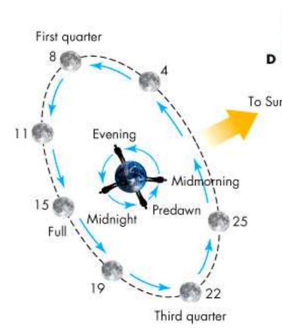
The Phases of the Moon



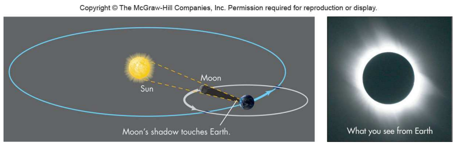
- The phase cycle is the origin of the month (derived from the word moon) as a time period
- The phases of the Moon are caused by the relative positions of the Sun, Earth, and Moon

Lunar Rise and Set Times

- The Moon rises roughly 50 minutes later each day

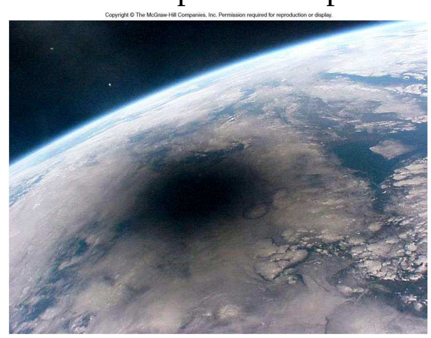


Eclipses

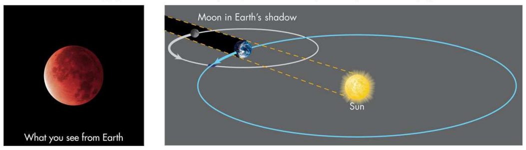


- An ***eclipse*** occurs when the Sun, Earth, and Moon are directly in line with each other
- A ***solar eclipse*** occurs when the Moon passes between the Sun and Earth, with the Moon casting its shadow on the Earth causing a midday sky to become dark as night for a few minutes

Solar Eclipse from Space

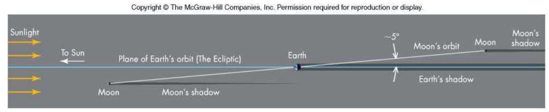


Lunar Eclipses



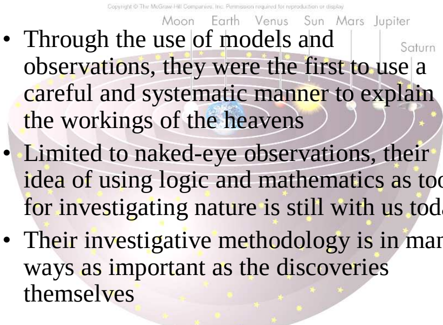
- A ***lunar eclipse*** occurs when the Earth passes between the Sun and Moon, with the Earth casting its shadow on the Moon giving it a dull red color

Eclipse Periods



- Eclipses do not occur every 30 days since the Moon's orbit is tipped relative to the Earth's orbit
- The tipped orbit allows the shadow of the Earth (Moon) to miss the Moon (Earth)

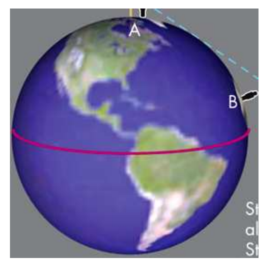
Ancient Greek Astronomers



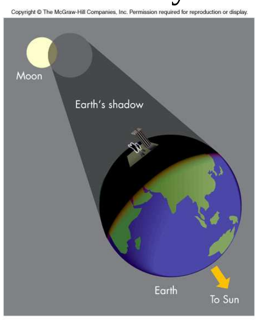
- Through the use of models and observations, they were the first to use a careful and systematic manner to explain the workings of the heavens
- Limited to naked-eye observations, their idea of using logic and mathematics as tools for investigating nature is still with us today
- Their investigative methodology is in many ways as important as the discoveries themselves

Early Ideas: Pythagoras

- Pythagoras taught as early as 500 B.C. that the Earth was round, based on the belief that the sphere is the perfect shape used by the gods



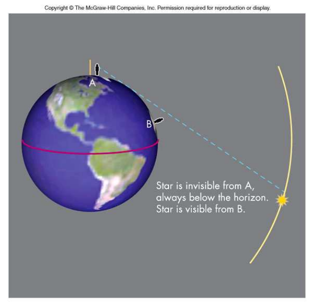
Early Ideas: Aristotle



A

- By 300 B.C., Aristotle presented naked-eye observations for the Earth's spherical shape:
  - Shape of Earth's shadow on the Moon during an eclipse

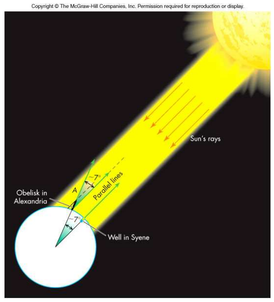
Early Ideas: Aristotle



B

- He also noted that a traveler moving south will see stars previously hidden by the southern horizon

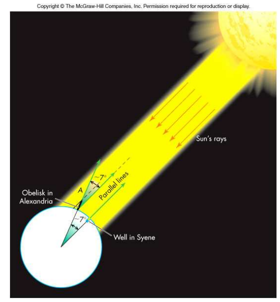
Early Ideas: The Size of the Earth



- Eratosthenes (276-195 B.C.) made the first measurement of the Earth's size
- He obtained a value of 25,000 miles for the circumference, a value very close to today's value

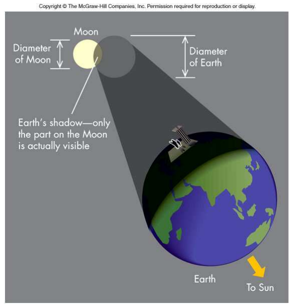
Early Ideas: The Size of the Earth

- He measured the shadow length of a stick set vertically in the ground in the town of Alexandria on the summer solstice at noon, converting the shadow length to an angle of solar light incidence, and using the distance to Syene, a town where no shadow is cast at noon on the summer solstice

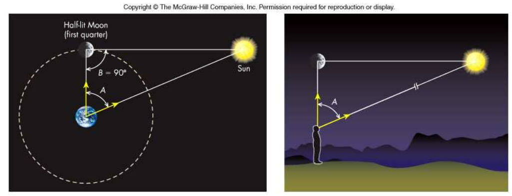


Early Ideas: Distance and Size of the Sun and Moon

- The sizes and distances of the Sun and Moon <u>relative</u> to Earth were determined by Aristarchus about 75 years before Eratosthenes measured the Earth's size
- Once the actual size of the Earth was determined, the <u>absolute</u> sizes and distances of the Sun and Moon could be determined

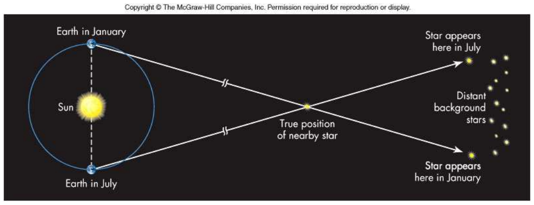


Early Ideas: Distance and Size of the Sun and Moon



- These <u>relative</u> sizes were based on the ***angular size*** of objects and a simple geometry formula relating the object's diameter, its angular size, and its distance

Early Ideas: Distance and Size of the Sun and Moon

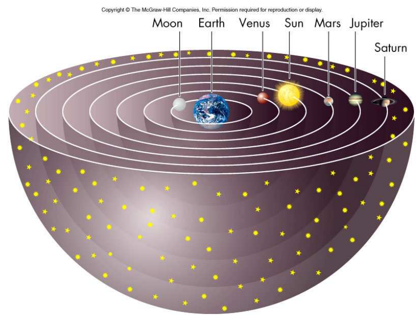


- Aristarchus, realizing the Sun was very large, proposed the Sun as center of the Solar System, but the lack of ***parallax*** argued against such a model

Early Ideas: The Geocentric Model

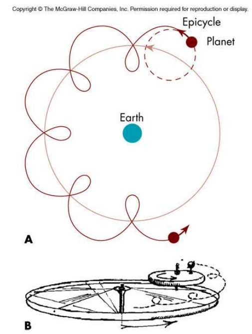
- Because of the general east to west motion of objects in the sky, ***geocentric theories*** were developed to explain the motions
- Eudoxus (400-347 B.C.) proposed a geocentric model in which each celestial object was mounted on its own revolving transparent sphere with its own separate tilt
- The faster an object moved in the sky, the smaller was its corresponding sphere
- This simple geocentric model could not explain retrograde motion without appealing to clumsy and unappealing contrivances

Early Ideas: The Geocentric Model



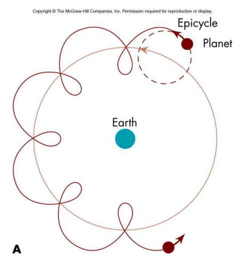
Ptolemy of Alexandria

- Ptolemy of Alexandria improved the geocentric model by assuming each planet moved on a small circle, which in turn had its center move on a much larger circle centered on the Earth
- The small circles were called ***epicycles*** and were incorporated so as to explain retrograde motion



Ptolemy of Alexandria

- Ptolemy's model was able to predict planetary motion with fair precision
- Discrepancies remained and this led to the development of very complex Ptolemaic models up until about the 1500s
- Ultimately, all the geocentric models collapsed under the weight of "Occam's razor" and the ***heliocentric models*** prevailed

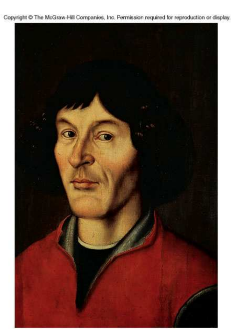


Non-Western Contributions

- Islamic Contributions
  - Relied on celestial phenomena to set its religious calendar
  - Created a large vocabulary still evident today (e.g., zenith, Betelgeuse)
  - Developed algebra and Arabic numerals
- Asian Contributions
  - Devised constellations based on Asian mythologies
  - Kept detailed records of unusual celestial events (e.g., eclipses, comets, supernova, and sunspots)
  - Eclipse predictions

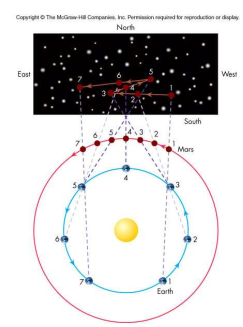
Astronomy in the Renaissance

- Nicolaus Copernicus (1473-1543)
  - Could not reconcile centuries of data with Ptolemy's geocentric model
  - Consequently, Copernicus reconsidered Aristarchus's heliocentric model with the Sun at the center of the solar system

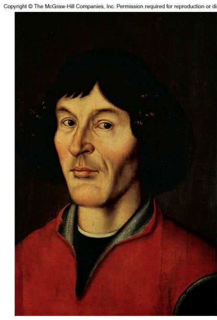


Astronomy in the Renaissance

- ***Heliocentric models*** explain retrograde motion as a natural consequence of two planets (one being the Earth) passing each other
- Copernicus could also derive the relative distances of the planets from the Sun



Astronomy in the Renaissance



- However, problems remained:
  - Could not predict planet positions any more accurately than the model of Ptolemy
  - Could not explain lack of parallax motion of stars
  - Conflicted with Aristotelian "common sense"

Astronomy in the Renaissance

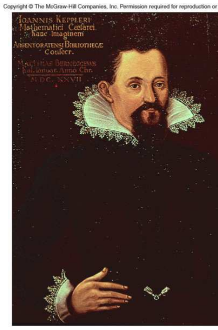
- Tycho Brahe (1546-1601)
  - Designed and built instruments of far greater accuracy than any yet devised
  - Made meticulous measurements of the planets

Astronomy in the Renaissance

- Tycho Brahe (1546-1601)
  - Made observations (supernova and comet) that suggested that the heavens were both changeable and more complex than previously believed
  - Proposed compromise geocentric model, as he observed no parallax motion!

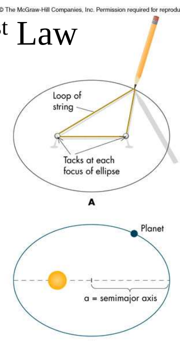
Astronomy in the Renaissance

- Johannes Kepler (1571-1630)
  - Upon Tycho's death, his data passed to Kepler, his young assistant
  - Using the very precise Mars data, Kepler showed the orbit to be an ***ellipse***



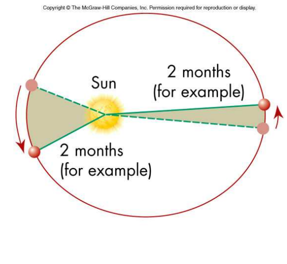
Kepler's 1st Law

- Planets move in elliptical orbits with the Sun at one ***focus*** of the ellipse



Kepler's 2nd Law

- The orbital speed of a planet varies so that a line joining the Sun and the planet will sweep out equal areas in equal time intervals
- The closer a planet is to the Sun, the faster it moves



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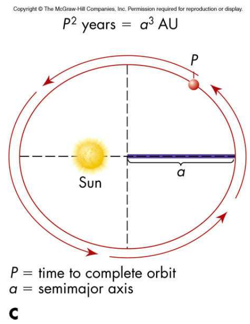
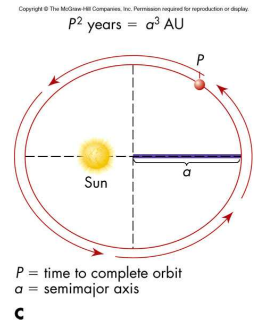
Kepler's 3rd Law

- The amount of time a planet takes to orbit the Sun is related to its orbit's size
- The square of the period, P, is proportional to the cube of the ***semimajor axis,*** a



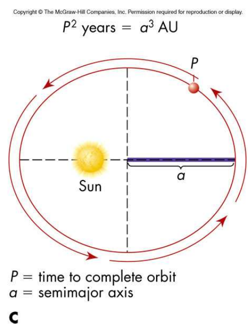
Kepler's 3rd Law

- This law implies that a planet with a larger average distance from the Sun, which is the semimajor axis distance, will take longer to circle the Sun
- Third law hints at the nature of the force holding the planets in orbit



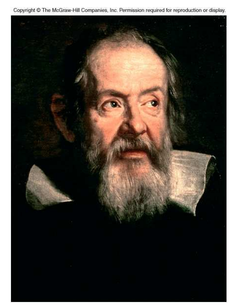
Kepler's 3rd Law

- Third law can be used to determine the semimajor axis, a, if the period, P, is known, a measurement that is not difficult to make



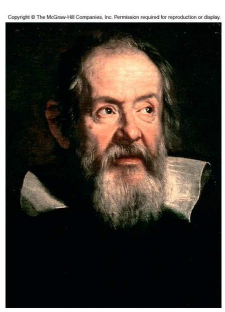
Astronomy in the Renaissance

- Galileo (1564-1642)
  - Contemporary of Kepler
  - First person to use the telescope to study the heavens and offer interpretations
    - The Moon's surface has features similar to that of the Earth ⇒ The Moon is a ball of rock

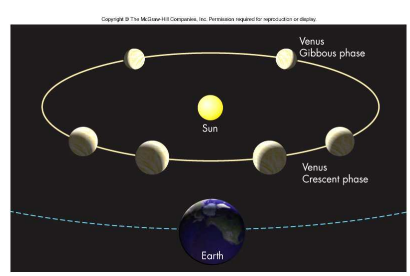


Astronomy in the Renaissance

- The Sun has spots ⇒ The Sun is not perfect, changes its appearance, and rotates
- Jupiter has four objects orbiting it ⇒ The objects are moons and they are not circling Earth
- Milky Way is populated by uncountable number of stars ⇒ Earth-centered universe is too simple



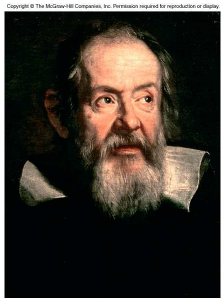
Evidence for the Heliocentric Model



- Venus undergoes full phase cycle ⇒ Venus must circle Sun

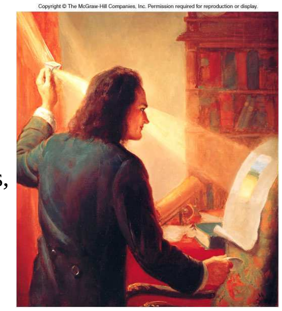
Astronomy in the Renaissance

- Credited with originating the experimental method for studying scientific problems
- Deduced the first correct "laws of motion"
- Was brought before the Inquisition and put under house arrest for the remainder of his life



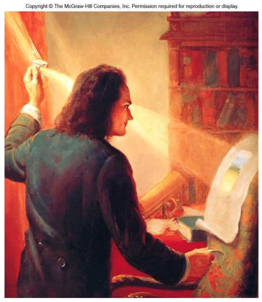
Isaac Newton

- Isaac Newton (1642-1727) was born the year Galileo died
- He made major advances in mathematics, physics, and astronomy



Isaac Newton

- He pioneered the modern studies of motion, optics, and gravity and discovered the mathematical methods of calculus
- It was not until the 20^{th} century that Newton's laws of motion and gravity were modified by the theories of relativity



The Growth of Astrophysics

- New Discoveries
  - In 1781, Sir William Herschel discovered Uranus; he also discovered that stars can have companions
  - Irregularities in Uranus's orbit together with law of gravity led to discovery of Neptune
- New Technologies
  - Improved optics led to bigger telescopes and the discovery of nebulas and galaxies
  - Photography allowed the detection of very faint objects

The Growth of Astrophysics

- The Nature of Matter and Heat
  - The ancient Greeks introduced the idea of the atom (Greek for "uncuttable"), which today has been modified to include a nucleus and a surrounding cloud of electrons
  - Heating (transfer of energy) and the motion of atoms was an important topic in the 1700s and 1800s

The Growth of Astrophysics

- The Kelvin Temperature Scale
  - An object's temperature is directly related to its energy content and to the speed of molecular motion
  - As a body is cooled to zero Kelvin, molecular motion within it slows to a virtual halt and its energy approaches zero $\Rightarrow$ no negative temperatures
  - Fahrenheit and Celsius are two other temperature scales that are easily converted to Kelvin

The Kelvin Temperature Scale