How do we know...?
9th-12th grades, 60 to 90 minutes

Notice

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Objectives

Students will learn :

- To recognize at least two constellations visible from their location;
- Major developments in three time periods: Greco-Roman times, the 17th century, and the late 19th century to today;
- How certain inventions improved our knowledge of the universe;
- About the contributions of several individuals to our understanding of the universe;
- That most of what we know about our universe we learned from electromagnetic radiation;
- How astronomers use the electromagnetic spectrum to learn about the universe;
- That Earth's atmosphere blocks or absorbs some types of radiation; and
- That we can't see all kinds of electromagnetic radiation, but we do have tools that allow us to study all kinds.

Materials needed

- Flashlight
- Light and laser pointers
- Poster of the electromagnetic spectrum
- Digitarium® system set for the current date and time, with atmospheric effects and landscape turned on

I) Introduction *(5 to 10 minutes)*

A) Inform students that you'll be exploring astronomy today. You'll be learning about advances from three time periods—Greco-Roman times, the 17th century, and the mid-19th century to today.

B) Inform students that almost all of what we know about our universe we learned by studying light. Ask students how they define the term 'light.' Quickly review each type of light in the electromagnetic spectrum, showing the poster. Include how the students may have experienced each type, as well as what astronomers study with each. *[Suggestions for information and chart resources are on our resources webpage: DigitalisEducation.com/resources.html.]*

C) Introduce expectations, method of entry, etc., and enter the dome.

II. The Ancient Greeks and Romans *(10 to 20 minutes)*

A) *[When all are in and seated, speed up time to let the sun set, then turn off atmospheric effects and landscape.]* Inform students that they're seeing the sky as it would look at about _____ p.m./a.m. tonight. Point out the date and time bar so that they can keep track of the current sky time.

People have been looking for patterns in the sky for thousands of years, in order to help them understand their world. What do the students notice as they look around? What part of the electromagnetic spectrum are they using to gain information?

B) Many cultures created their own constellations to help time activities such as planting or harvesting crops and preparing for seasonal flooding or drought. The pictures created by the ancient Greeks and Romans have become dominant, since these groups left the most extensive records. Do the students recognize any Greco-Roman constellations as they look around? *[Point out two or three, including Ursa Major. Turn on the line drawing and then the artwork for each, and share a brief fact about each group of stars.]* Point out the north star *[or allow a student to do so]*, use it to define the three other directions, and then turn on the cardinal points.

C) How did the stars help people time activities? *[By making observations over several years, people learned that the appearance or disappearance of a star or group of stars was associated with seasonal changes.]* One of the most commonly used groups was a cluster called the Pleaides, or Seven Sisters, which many cultures used to time the start of the harvest. *[Zoom in on the Pleiades.]* Zoom back out, speed up time, and allow the students to find their own patterns. How would the students explain the apparent movement of the stars? How do they think people explained it thousands of years ago?

D) What do the students notice about the moon? *[You may need to move forward in time to make the moon visible.]* Enlarge the moon, then move forward in time day by day, until about two weeks have passed. How does it move across our sky? Does it always look the same? Briefly discuss what causes moon phases. How would they explain the moon's motion? How do they think people explained it thousands of years ago?

E) Are there some objects which behave differently from the moon and stars? What are those things? Right, they're planets, a word derived from Greek for 'wanderer.' Turn on the planet labels to help students keep track of them, and move forward in time day by day, until two or three weeks have passed. How do the planets move across the sky? *[Typically from west to east (prograde), but sometimes from east to west (retrograde).]* How would the students explain the movements of the planets based on their observations? How might people have explained the movements thousands of years ago?

If necessary, move forward in time until Mercury is in the south. Turn on planet trails and go forward in time week by week until Mercury's trail makes a loop in the sky *[or run several seconds of the annual motion script].*

If students are interested, discuss the August, 2006 International Astronomical Union definition of a planet (an object that is in orbit around the sun, is large enough for its own gravity to pull it into a nearly spherical shape, and has cleared the neighborhood around its orbit). Why did this definition change Pluto's status?

F) **OPTIONAL:** There are seven non-stellar objects we can observe with our naked eye: the sun, the moon, and five planets--Mercury, Venus, Mars, Jupiter, and Saturn. The Greeks, Romans, and other cultures named the planets after gods, based on their characteristics. For example, in Roman mythology Mercury was a swift messenger; the planet that orbits the sun the fastest is named after him. These seven objects were used by many cultures to name the days of the week. English uses a blend of Roman and Germanic names:

- Sunday: The sun's day. Sol was the Roman god of the sun.
- Monday: The moon's day. Luna was the Roman goddess of the moon.
- Tuesday: Tiu's day or Mars day. Tiu was the Germanic god of war. Mars was his Roman equivalent.
- Wednesday: Woden's day or Mercury's day. Woden/Odin is sometimes described as the supreme Germanic god, but is also associated with the Roman god Mercury.
- Thursday: Thor's day or Jove's Day. Thor was the Germanic god of thunder and lightning. Jupiter, or Jove, was the god of the heavens.
- Friday: Freya's day or Venus' day. Freya is considered the Germanic equivalent of Venus, the Roman goddess of love and beauty.
- Saturday: Saturn's day. Saturn was the Roman god of agriculture and of time. The Germanic tribes do not appear to have an equivalent.

G) Inform students that a great debate arose out of people's desire to understand and predict the motions of the planets--the geocentric versus heliocentric model of the solar system--and define these terms. The Greek philosopher Aristotle, back in the fourth century BCE, envisioned a geocentric model of the solar system, with all other celestial bodies orbiting Earth in perfect circles. This aligned quite well with observations of the sun and moon, but not with the planets. For many centuries people struggled to make Aristotle's model of planetary orbits agree with what they observed.

H) A major development in the discussion came in the second century CE, with Ptolemy of Alexandria, in Egypt. *[Show the slide of the Ptolemaic system and discuss Ptolemy's model of the solar system.]* Even with all its complexity, however, Ptolemy's system was not a very accurate predictor of planetary positions. Yet despite its problems, the geocentric model was not aggressively challenged until the 16th century CE. Why was the geocentric model was so hard to shake? *[Three main reasons: 1) common sense--it doesn't feel like we are in motion; 2) humans tend to want to see themselves at the center of things; and 3) Aristotle was very influential and few people dared to question his theories.]*

III. The heliocentric model *(15 to 20 minutes)*

A) Inform the students that you'll be jumping ahead many centuries, to the 17th century CE, in order to put the sun in the center. Use the text menu to jump to the year 1610. Ask the students if they know why the heliocentric model was eventually accepted. What tool proved that the sun was the center of our solar system? *[The telescope.]* How did it do that? *[By increasing our power to observe visible light.]*

B) Who is credited with dispelling the geocentric model by his observations with a telescope? *[Galileo Galilei, who lived in the 16th and 17th centuries CE.]* Galileo discovered four moons of Jupiter with his telescope in 1610; these were later dubbed the Galilean moons. He deduced that these moons orbited Jupiter, which supported the idea that the earth was not at the center of everything. *[Zoom in on Jupiter and speed up time to allow students to observe the orbits of the Galilean moons for several seconds. Zoom back out to the star field.]*

Galileo also noted that Venus cycled through phases, like Earth's moon, and that the apparent size of Venus varied. *[Zoom in on Venus and advance in time week by week to show a few phases.]* From these observations Galileo concluded that Venus had to be orbiting the sun, not Earth. Why would he draw this conclusion? Why does Venus appear to change size as it phases?

C) Galileo was not the first to suggest that the sun was at the center of the solar system—that idea had been around at least since Aristarchus in the third century BCE—but he did provide evidence for the theory. Putting the sun at the center resolved one of the major problems of Aristotle's geocentric model: prograde and retrograde motion. It solved it in a much simpler way than Ptolemy's eccentrics, epicycles, and equants. For all his hard work, Galileo was put under house arrest by the Catholic church, who saw his ideas as conflicting with their interpretations of Scripture. *[**OPTIONAL:** Run the Solar System View local script, which takes you to a point above the solar system; this enables you to see the planets orbiting the sun. Remember to* *move back to Earth before continuing the lesson.]*

D) Even though Galileo had provided direct evidence contradicting the geocentric model, he still couldn't explain what kept Earth in orbit around the sun and Jupiter's moons in orbit around it. Who was able to do that? Sir Isaac Newton, who lived in the 17th and 18th centuries CE, and gave us the law of universal gravitation. What are the main points of the law of universal gravitation? ***['**The force of gravity exerted by objects on one another is proportional to the mass of the two objects, and it weakens as the square of the distance between the objects.' From* <u>*The Complete Idiot's Guide to Astronomy.*</u>***]*** Newton's law explained mathematically why the planets have elliptical orbits, as well as why they move at variable speeds. It explained what people observed and made testable predictions. One such example: the law of universal gravitation predicted that the gravity of Jupiter would have a small but noticeable effect on the orbit of Saturn, which in fact is true.

Newton also initiated an area of astronomy we'll talk more about later: spectroscopy, which uses light to determine chemical composition, temperature, and motion. In 1666 Newton showed that white light from the sun could be split into a continuous series of colors. He introduced the word "spectrum" to describe this phenomenon. The instrument he used to diffract light employed a small opening to define a beam of light, a lens to collimate it, a glass prism to disperse it, and a screen to display the resulting spectrum. Newton' s analysis of light was the beginning of the science of spectroscopy.

E) So by the early 17th century we had the sun in the center of our solar system and we knew what kept the planets in orbit around it. Another important question was the distance to the sun. Even early people theorized that the sun was the closest star to Earth since it looked so big compared to the other stars, but how did people find the distance? ***[****Take some ideas from the students on how this distance could be measured, then point out some stars close to Earth, which may involve changing latitude and/or going forward or backward in time to make them visible.****]*** Can the students tell which are the closest stars to Earth with just their eyes? Appearances can be deceiving... Some stars close to Earth and their approximate distances are:

- Alpha and Beta Centauri, 4.3 light years
- Sirius A, 8.6 light years
- Altair, 16 light years
- Vega, 25 light years
- Arcturus, 37 light years

F) What is a light year? Right, the distance light can travel in a year--it's a measure of distance, not time. Light travels about 186,000 miles/300,000 kilometers per second. There are 60 seconds in a minute, 60 minutes in an hour, 24 hours in a day, and about 365.25 days in a year. If we multiply all those numbers together, we come up with approximately <u>six trillion miles/10 trillion kilometers</u> as the distance light can travel in one year. ***[****If time allows, discuss how the speed of light was determined. See our background resources page.****]*** How many light years from Earth is the sun? Not even one. It's about <u>8 light minutes</u>, about 93 million miles or 150 million kilometers.

G) How did we figure out the distance to the sun? The first to measure it was Giovanni Cassini in 1672. His method involved Mars and a technique called parallax. Ask the students if they are familiar with the term 'parallax.' Have each student hold a finger up about three to five inches in front of his/her nose, focus on a star or label on the part of the dome opposite them, and then alternately open and close each eye. Their fingers should appear to jump back and forth against the background; this effect is called parallax. In order to use parallax to figure out the distance to their fingers, the students would have to measure the distance between their eyes, which is the baseline, and the angle that their finger appears to jump. They could then use trigonometry to find the missing value, the distance to their fingers.

How did Cassini use the parallax of Mars to find the distance to the sun? A hint: he didn't do it alone. *[Take some ideas from the students on how Cassini might have figured it out.]* Cassini stationed himself in Paris and sent another astronomer, Jean Richer, to Cayenne, South America. At a specified time, the two men measured the position of Mars against the background of the stars. They knew the distance between their two observing points, which was the baseline, as well as the angle by which Mars appeared to jump. They also knew that the approximate average distance between Mars and the Sun was 1.5 astronomical units (AU); an AU is the mean distance between the earth and the sun. People had used geometry centuries earlier to calculate the mean distances from each visible planet to the sun, in AUs. The problem was they didn't know just how big one AU was. If Cassini and Richer could determine the distance from Earth to Mars, they could then calculate the size of an AU.

Cassini and Richer found Mars' parallax to be around 24 arc seconds. They came up with a distance of about 138,000,000 kilometers or 86,000,000 miles for an AU. *[If Mars is not visible with your current view of the sky, move forward in time until it is.]* Allow students to take a good look at Mars against the background of the stars, then change latitude by at least 30 degrees. Did Mars change position against the background of stars? *[Students probably won't notice a change as it shifts a very tiny amount.]* You can see that Cassini and Richer had a challenging job; they had to be extremely precise, since the change was so small. Their measurement was off by about 7 million miles/12 million kilometers, but it was remarkably close considering the challenges they faced. *[If you desire, go back to your default settings.]*

H) Cassini and Richer's measurement was a huge step in measuring the distance scale of the universe. Before we could use parallax to measure the distance to other stars, we needed to know the length of our baseline, which was the distance between the earth and sun. Using parallax to measure the distances to other stars involves taking measurements six months apart, when the earth is on opposite sides of the sun, for a baseline of 2 AU. This method works only for stars within about one thousand light years of Earth. *[Show slide of stellar parallax, and point out the baseline and the angle by which the star appears to move.]*

I) **OPTIONAL:** If time allows, discuss methods used to find distances to stars farther from Earth, including redshift of light and Henrietta Swan Leavitt's work with Cepheid variables. *[See background page for resources.]*

IV. Mid 19th century to today *(20 to 30 minutes)*

A) Once again we will jump forward in time, to the mid-19th century. We discussed briefly earlier how Sir Isaac Newton started a new branch of science, spectroscopy. Spectroscopy is the use of light to determine chemical composition, temperature, and motion. It is the science that enables astronomers to determine what stars are made of. In 1859 Gustav Robert Kirchhoff and Robert Wilhelm Bunsen, of Bunsen burner fame, established that each element and compound has its own unique spectrum, and that by studying the spectrum of an unknown source, one can determine its chemical composition. This is the only way we can determine what stars are made of.

What are stars made of? Most stars are composed of primarily hydrogen and helium. When a star ages, lighter elements fuse into heavier elements in a process called nuclear fusion. Nuclear fusion provides the energy for a star to give off light. In a star of similar mass to our sun, when the central hydrogen supply has been used up, the core collapses, creating very high temperatures. When the temperature gets high enough, the core, which is now made of helium, is surrounded by a burning shell of hydrogen. This so-called 'shell burning' causes the outer part of the star to expand, which leads to cooling, and the star moves out of the main sequence, the bulk of the star's life, to become a red giant. Betelgeuse in Orion and Antares in Scorpius are both in this phase of their lives. *[Point out one of these stars.]*

The last step in the life of a star similar to our sun is to become a planetary nebula. *[Zoom in on the Spirograph Nebula, which may require changing latitude or moving forward in time.]* The star at the center of the Spirograph Nebula was a red giant a few thousand years ago but then ejected its outer layers into space to form the nebula. The stellar remnant at the center is the hot core of the red giant, from which ultraviolet radiation floods out into the surrounding gas, causing it to fluoresce. Over the next several thousand years, the nebula will gradually disperse into space, and then the star will cool and fade away for billions of years as a white dwarf. *[Zoom back out to the starfield.]* Astronomers can use spectroscopy to determine how far along a star is in its cycle by determining what elements are present and in what proportions.

B) Spectroscopy is also used to determine how an object is moving relative to Earth. What is the Doppler effect? *[Discuss with students how the Doppler effect applies to light waves, with a stretching of light waves corresponding to a redshift, and a compression to a blueshift.]* The astronomer Edwin Hubble, for whom the Hubble Space Telescope is named, used redshift of light to determine if a galaxy was moving away from Earth and at what speed. Using his observations of several galaxies, he realized that he could take their apparent brightness as an approximate indication of their distance. Hubble found a relationship between the speed with which galaxies were receding and their distance from Earth, which led to the Hubble Law, announced in 1929. This law stated that the more distant galaxies are from Earth, the faster they are moving away from us. We'll talk more about the Hubble Law and the HST a bit later.

C) Before we could launch the HST, we needed to find a way to break free of Earth's gravity. What technologies made it possible for us to leave Earth? *[Rockets, including sufficiently powerful engines and relatively safe fuel; electronic means of communicating with a satellite or telescope; computers, etc.]* When was the first rocket successfully launched? Robert H. Goddard launched the first liquid fuel rocket on March 16, 1926, and it flew for approximately 40 ft/12 m. *[Sources for information on the history of rocketry are on the background page.]* The HST was actually carried into space in 1990 by the space shuttle Discovery, nine years after the very first shuttle flight. Space shuttles break free of Earth's gravity with the help of a rocket, then separate from the rocket to fly independently.

D) The ability to put tools like the HST in space has led to greater knowledge in cosmology. What is cosmology? *[According to the Facts on File Dictionary of Astronomy, cosmology is 'The study of the origin, evolution, and large-scale structure of the universe.']* Cosmologists study topics like the expansion and age of the universe, the distribution of galaxies, etc. Tools in space can study wavelengths of the electromagnetic spectrum that are blocked or absorbed by our atmosphere, thus contributing to our knowledge in these areas. What are some types of light that cannot penetrate our atmosphere? *[X-rays, gamma rays, some infrared, most UV.]* We currently have or recently had tools in space to learn from all those wavelengths.

E) **OPTIONAL:** Discuss tools in space and show the image of each tool as you mention it; images are on the Lesson Media DVD. The **Spitzer Space Telescope** detects infrared energy, or heat, radiated by objects in space. Visible light cannot penetrate the vast clouds of dust and gas in space, but infrared light can, allowing us to study regions of star formation, the centers of galaxies, and newly forming planetary systems. The **Chandra X-ray Observatory**, as its name implies, observes in x-rays. Flaring stars, exploding stars, black holes, and vast clouds of hot gas in galaxy clusters are some of the objects that Chandra studies. The **Compton Gamma-Ray Observatory** was in orbit from 1991 to 2000 and studied the part of the electromagnetic spectrum with the highest energy and shortest wavelengths--gamma-rays. The CGRO studied very energetic celestial phenomena: solar flares, gamma-ray bursts, pulsars, nova and supernova explosions, and more. The **James Webb Space Telescope** is scheduled for launch in 2013, and it will image objects primarily in infrared light, but also with visible.

F) By far the most famous tool in space is the **Hubble Space Telescope** *[show slide of the HST]***.** It images objects primarily in visible light, but also uses near infrared and ultraviolet. Why is the HST in orbit if it uses mainly visible light? Because Earth's atmosphere distorts our view of objects, even when we use high powered ground based telescopes. *[More specifically, shifting pockets of gases in Earth's atmosphere distort our view.]* By being above the atmosphere, the HST can image objects incredibly clearly.

The HST has dramatically increased our knowledge of the universe. It has also supported theories written years or decades earlier. For example, the HST has provided support for part of Einstein's General Theory of Relativity, which he published in 1915. What is the main premise of the General Theory of Relativity? That gravity as well as motion can affect the intervals of time and of space.

The key idea of General Relativity, called the Equivalence Principle, is that gravity pulling in one direction is completely equivalent to an acceleration in the opposite direction. This led to the idea that light, which ordinarily travels in straight lines, could curve if it traveled across a gravitational field. The curving path of light meant that the "field" was really a curving of space, which Einstein found was inseparable from time. The curvature would be caused by bodies with great mass.

G) In 1979, before the launch of the HST, Einstein's idea that gravity could bend light was proved correct. Two quasars relatively near each other were discovered to have identical chemical compositions. The two quasars seemed to fluctuate in brightness. Two objects were showing up, yet clearly the two objects were the same. How do they explain this phenomenon? *[Take a few ideas.]* It was finally explained when the scientists recalled Einstein's theory of gravitational lenses and realized that they were seeing reflections of one quasar. A galaxy cluster between the quasar and the scientists on Earth deflected the light from the quasar. The galaxy cluster acted like a lens, focusing the deflected light so that two images were formed from one object.

H) In 1990, the HST took this picture of an object called the Einstein Cross. *[Show image of the Einstein cross, near the border between Pegasus and Aquarius.]* This shows four images of a very distant quasar which has been multiple-imaged by a relatively nearby galaxy acting as a gravitational lens. The galaxy bending light is the 14-15th magnitude PGC 69457, which is about 400 million light years from Earth. The HST has used gravitational lenses to look farther into space than it can with just its mirrors, since gravitational lenses act like giant magnifying glasses.

I) Earlier we briefly discussed the Hubble law, which defined a relationship between the distance of galaxies and the speed with which they are moving away from Earth. The redshift of a distant galaxy can directly measure how much the universe has expanded since the light left the galaxy. The Hubble Law also included the Hubble constant, the rate at which the universe is expanding. The determination of the exact value of the Hubble constant is one of the key tasks of the HST, as it will help us determine the age of our universe.

Hubble originally thought his constant would be about 500 kilometers per second per megaparsec *[one megaparsec is equal to 3.26 million light years]*. The current estimate of the Hubble constant, however, is 72 km/s/mpc, based on several different techniques *[see the October, 2003 issue of Sky and Telescope, in particular the article 'Cosmology in the New Millennium,' for more information on how this was determined]*. If we use 72 km/s/mpc as the Hubble constant, the age of the universe comes out to about 13.7 billion years.

J) How do most astronomers believe the universe came into being about 13.7 billion years ago? Most accept the big bang theory. According to this theory, put forth in 1927 by a Belgian priest named Georges Lemaître, the universe was created from a cosmic explosion that hurled matter in all directions. After some period of time following the big bang, gravity condensed clumps of matter. The clumps were gravitationally pulled toward other clumps and eventually merged into galaxies. Two years later, despite not having heard of Lemaître, Edwin Hubble supported the priest's theory when he announced the Hubble Law; the big bang explains why distant galaxies are traveling away from us at great speeds.

Lemaître in his big bang theory also suggested the existence of cosmic microwave background radiation (the glow left over from the explosion itself). The theory predicted that the early universe was a very hot place and that as it expanded, the gas within it cooled. Therefore the universe should be full of radiation that is heat left over from the big bang; this heat is called the cosmic microwave background radiation. The big bang theory received its strongest confirmation when this radiation was discovered in 1964 by Arno Penzias and Robert Wilson.

K) The HST imaged some very distant galaxies in 1996, in an image known as the Hubble Deep Field (HDF). The HST was focused on what appeared to be an empty patch of sky here, near the handle of the Big Dipper *[make sure DSO labels are turned off and point to the location of the HDF]*. This is what the HST found there *[zoom in on the HDF]*. Some of the galaxies in this image are over 10 billion light years away. Another way to think about that is that when the HST images something 10 billion light years away, it's actually looking back in time 10 billion years. Why is that? Because in order for something to go a certain distance, it has to put in time. Even though light travels faster than anything else we know of, it still needs time to leave its source and end up somewhere else. How can looking back in time over 10 billion years help us learn about our universe?

L) **OPTIONAL:** If time allows, discuss recent developments in cosmology. For example: the speeding up of the expansion of the universe, dark energy, and dark matter. *[See our background page for source ideas.]*

M) Discuss also what we don't yet know about the universe, including: what existed before the big bang and whether there is life anywhere other than on Earth.

N) Prepare students to exit the dome, and regroup outside.

V. Conclusion ***(5 to 10 minutes)***

A) Review concepts of the lesson. What were some major developments in the history of astronomy? What is one important technology that advanced our knowledge? How does the electromagnetic spectrum help us learn about our universe?

B) What questions do the students now have about the universe? What would they most like to figure out? Can they think of ways to answer their questions?