College Guild
PO Box 696 Brunswick, Maine 04011

SCIENCE SAMPLER
~ Astronomy ~
Unit 1 of 5

Welcome to the College Guild course *Science Sampler*.

Overview: From the creation of the universe to the evolution of humans, you'll learn important concepts in the fields of astronomy, physics, chemistry, geology, and biology.

Where do we come from? How does our world work? What's in the universe? It is the job of scientists to try to answer these questions. In this course we explain some of the mysteries scientists have uncovered by exploring five of the great branches of science.

Guidelines for all College Guild courses:

1. **Answer all the questions that are in bold print, using black or blue ink or dark pencil if possible**. After we receive and review your completed unit, we will send you feedback from your reader along with your original work and the next unit. You don't need to return the questions – it saves us both postage.

2. There is no **specific deadline** to complete any unit, but we would get concerned if we hadn't heard back from you after two months.

3. Remember how often the mail service loses things. **If you don't hear back from us after a month, please write to make sure we received your unit** and sent out the next one.

4. Let us know if you need a dictionary, free to students who complete the first unit.

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The Hubble Space Telescope above Earth's atmosphere[1]

***Important!** Most questions in this course are essay questions and have no single correct answer. Some do require a specific response, the answers to which are included at the end of each unit. Please try to answer these before looking for the answer in the back!*

Part 1: The Beginnings of Astronomy

Humans have always looked up in wonder at the night sky. In ancient times, we worshipped the sun and moon. When a comet appeared in the sky, bright enough to see during the day, we thought it was a message from a god. When the sun was eclipsed by the moon, chilling the air and darkening the sky so that the stars were revealed, we were sure some terrible disaster would follow.

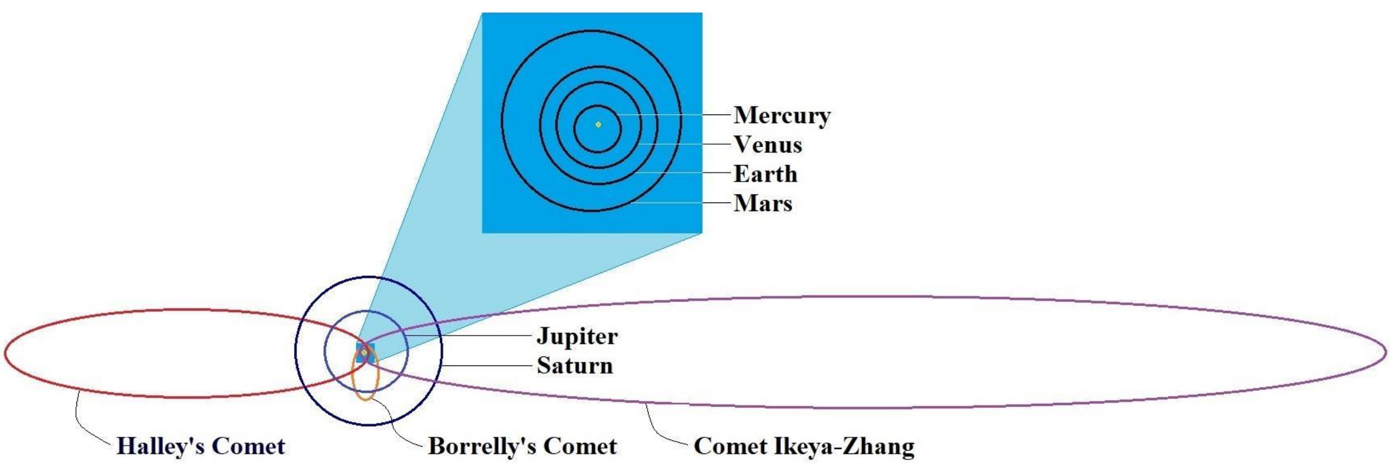
1. For tens of thousands of years our ancestors lived this way. Imagine you are one of them. What would you make of the sudden appearance of a comet in the sky? How do you think you would have interpreted an eclipse of the sun?

Keen observers watched the sky night after night and recorded their observations. By the fourth century B.C., the Greeks considered the Earth to be an unmoving disc or sphere at the center of the universe. The sun, moon, stars, and planets (they knew about Mercury, Venus, Mars, Jupiter, and Saturn) all revolved around the Earth and were unchanging. This idea, called *geocentrism* (meaning Earth in the center), would go unchallenged for almost 2,000 years.

2. Why do you think the geocentric model stuck around for so long?

There were problems with the geocentric model. Observers noticed that the planets moved strangely across the night sky, sometimes seeming to slow down and reverse direction. And there was a discrepancy between where the geocentric model said planets ought to be and where they really were.

Starting in the middle of the 16th century, several breakthroughs occurred in Europe that addressed these problems and overthrew geocentrism. First, in 1543, Polish mathematician and astronomer Nicolaus Copernicus proposed a theory that the planets moved in circular orbits around the sun, not the Earth. Copernicus' model is called *heliocentrism* (meaning sun in the center). Second, Danish astronomer Tycho Brahe carefully recorded accurate positions of the planets over a long period of time. His observations forced astronomers after him to build their theories around carefully observed facts. Third, German astronomer Johannes Kepler used Tycho's observations to determine that planets moved around the sun not in circles but in *ellipses* (flattened circles), improving upon Copernican theory. Comet orbits in particular are highly elliptical. See the figure below.[2]



Orbits of the planets Mercury through Saturn, plus a few comets

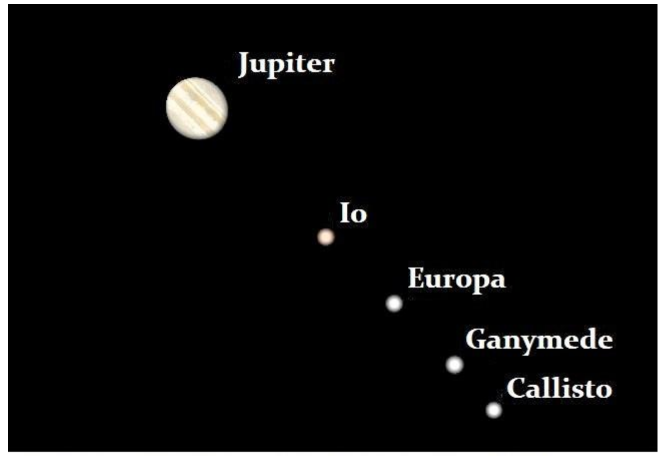
3. In the figure above, what do you notice about the orbits of Mercury, Venus, Earth, and Mars versus the orbits of Jupiter and Saturn? What do you notice about the orbits of the comets versus those of the planets?

4. Pretend you are a scientist who discovered something new that upturned beliefs people held for centuries. How would you have felt? Do you think you would have faced resistance? If so, how would you have handled it?

Part 2. Galileo and Newton

Galileo Galilei was an Italian *polymath* (someone with expertise in many fields) who worked at the same time as Kepler. One day, he was visited by a Dutch machinist selling a primitive telescope. It was intended as a military spying instrument. Galileo did not purchase it; instead, he built one himself. He then did something no one had done before: he pointed it at the night sky.

Copernicus, Tycho, and Kepler all made their observations without telescopes. They had instruments to record the position of planets, but their observations were all made with the naked eye. Now, peering through his telescope, Galileo saw four bright dots in line with the planet Jupiter that no one had ever seen before. See the image to the right.[3] Night after night these dots moved from one side of Jupiter to the other. Galileo numbered these objects I, II, III, and IV. We now know them as the four largest moons of Jupiter: Io, Europa, Ganymede, and Callisto. The evidence of objects orbiting something other than the Earth convinced Galileo that geocentrism was wrong.



A photo of Jupiter and its four moons, similar to what Galileo would have seen through his telescope.

5. Galileo looked at many other things in the night sky with his telescope. Can you guess what some of them were? What would you have looked at?

Today, $100 would buy a telescope with greater power than Galileo's!

Galileo lived near Rome, the center of power for the Catholic church. The Catholic authorities did not like heliocentrism and were deeply uneasy about Galileo's new telescope and what he saw with it. Galileo was forced by the church to recant (to deny Copernican heliocentrism) and to profess support for the old geocentric system. In his old age, he was put under house arrest until his death in 1642.

6. Galileo struggled for a long time with the Church before he was forced to recant. Do you think he was a hero? Why or why not?

Though the church was able to break Galileo, geocentrism was doomed. Telescopes meant that naked-eye astronomy was over. By the 1670s, Isaac Newton, a brilliant polymath from England, was working to find out why the planets move the way they do. His answer was *gravity*. Newton's theory of gravity states that every mass attracts every other mass in the universe. Newton said that the sun, moon, Earth, and planets all attract each other. The reason planets revolve around the sun is that they are drawn by the sun's strong gravity. Without the sun's gravitational pull, the Earth would fly off in a straight line into space. The same is true with moons orbiting planets.

We now take the idea of gravity for granted, but in Newton's day it was revolutionary. While it was obvious the Earth drew objects to it, it was not obvious at the time that this same principle might apply to the sun, moon, and planets. Prior to Newton, most people thought that the workings of the Earth were unrelated to the workings of the heavens. By bringing laws of gravity and motion to the study of the planets, Newton revolutionized astronomy.

7. Explain why the Earth and other planets do not just fall into the sun.

8. Why/how is it important for scientists to be able to communicate with each other despite living in different countries and speaking different languages?

Part 3. The Electromagnetic Spectrum

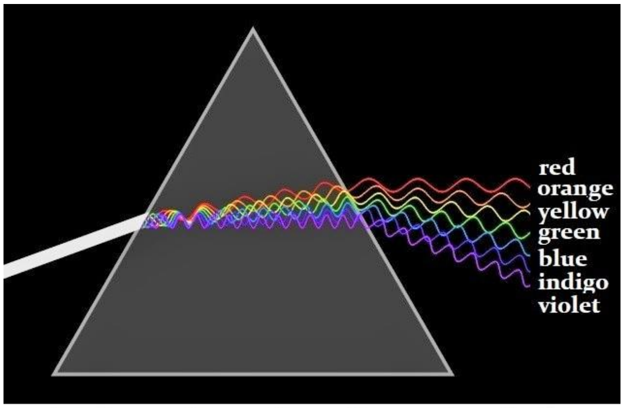
Following Galileo, telescopes continued to get bigger and better. Planets beyond Saturn were discovered: Uranus and Neptune. Objects that looked like blurry stars to the naked eye were discovered to be entire galaxies of stars. Our own sun was discovered to be just one star among billions of stars in the *Milky Way* galaxy.

Meanwhile, Newton and others studied the light coming from the sun, planets, and stars. Dutch astronomer Christiaan Huygens noticed that light behaves like the waves on the surface of a pond. Another science began to emerge, which we now call *optics*.

Newton used a triangular *prism* to show that sunlight contains a rainbow of colors within it, which the prism can separate. Huygens' theory of light showed that light of different colors wiggles at different speeds, or *frequencies*. This is illustrated in the figure to the right.[4]

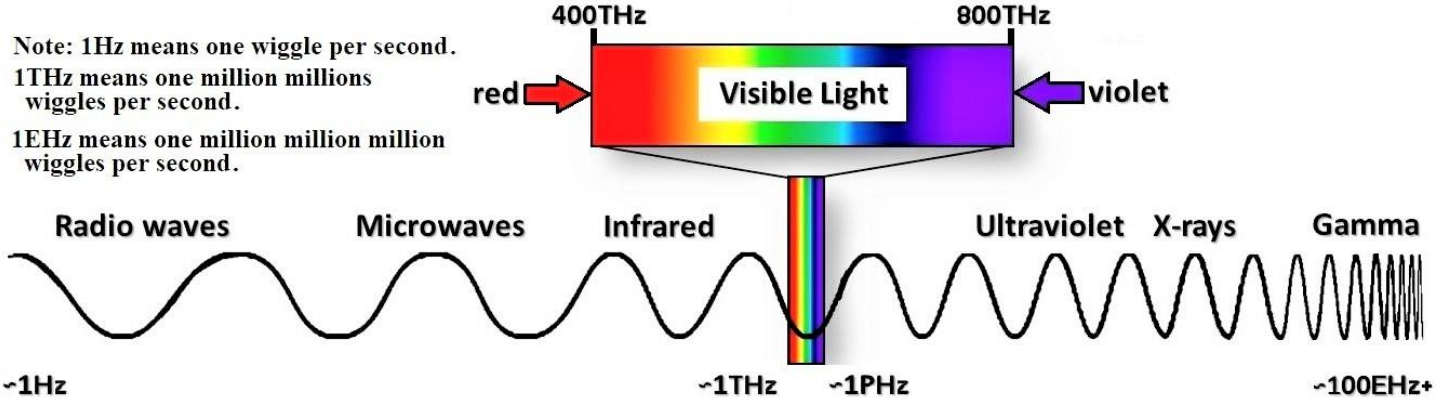
Red light wiggles slowest, between ~400 and 484 terahertz (THz), which means it wiggles 400–484 million million times each second! Orange light wiggles a little faster, and so on, up to violet light. The entire visible light *spectrum* is between 400 and 800 THz.

Around 1800, it was discovered that there is light that wiggles slower than red light, though we can't see it. Likewise, there is light that wiggles faster than violet light, though we can't see it, either. Today, we call these *infrared light* and *ultraviolet light*, respectively.



A triangular prism dispersing light

The entire range of light frequencies is called the *electromagnetic spectrum*, shown in the figure below.[5] Notice that visible light is the same sort of stuff as radio waves and X-rays!



Electromagnetic Spectrum

9. Give examples of the uses of radio waves, microwaves, or X-rays. Is it surprising these waves are just like visible light?

10. Sunscreen is used to protect against what types of waves?

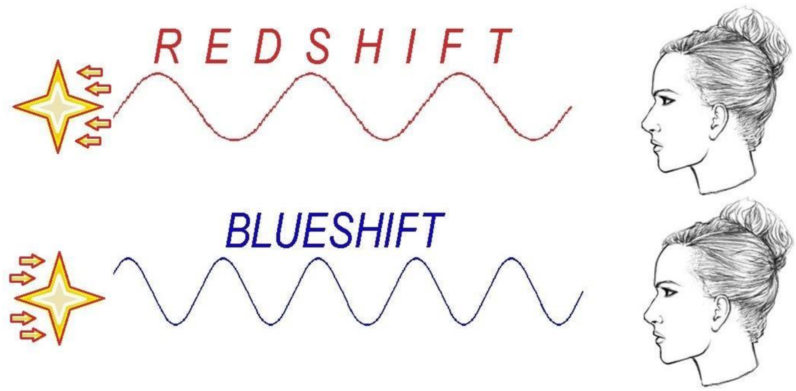
11. Our atmosphere blocks most incoming ultraviolet, X-ray, and gamma radiation. Why do you think this is important?

Part 4. The Big Bang

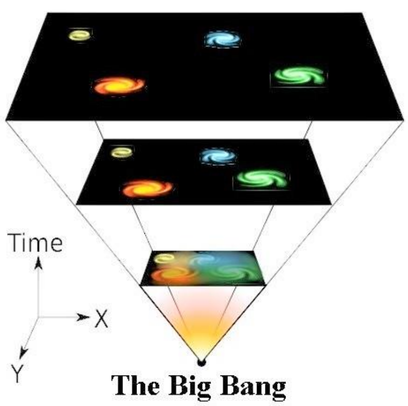
Just like light, sound behaves like a wave. If you listen to an approaching train, its whistle sounds high pitched. Then, while it is passing by, the whistle's pitch bends from high to low. After the train passes, the whistle sounds low pitched. This is because sound waves from the whistle are compressed as the train approaches and stretched when the train recedes, like a spring. Compressed waves wiggle more quickly, and stretched waves wiggle more slowly. We hear this difference as a change in pitch. This phenomenon is called the *Doppler Effect*, named after Christian Doppler, who explained it in 1842.

12. What do you think the whistle sounds like to a passenger on the train?

13. What else can you think of besides light and sound that behaves like a wave?



Since light also behaves like a wave, if a bright object is moving away from the viewer, its light waves will be stretched. This is called a *redshift*, since stretched visible light becomes more reddish. If the object is moving toward the viewer, its light is compressed and appears more bluish. This is called *blueshift*. See the illustration to the right.[6]



By the beginning of the 20th century, astronomers had observed many reddish stars and galaxies. It was noticed that very distant galaxies in all directions are the most red. They must therefore be redshifted — moving away from the Earth. The farther away the galaxies are, the greater the redshift, and the faster they are moving away from us. By the first decades of the 20th century, several astronomers made an astounding claim: the universe, they said, *is expanding!* Belgian physicist and Catholic priest Georges Lemaître reasoned that there must have been a time in which all the galaxies were bunched tightly together into a single point. He called this the Cosmic Egg; today we refer to its hatching as the *Big Bang*. The Big Bang theory states that the universe emerged rapidly from an extremely dense state to form atoms, stars, galaxies, planets ... everything. The Big Bang occurred approximately 13.8 billion years ago. See the illustration to the left.[7]

14. What do you imagine when you think of the Big Bang?

According to the Big Bang theory, our universe jumped into existence from a very small, very hot, and very dense region. It expanded rapidly and released an incredible amount of energy. As the universe expanded, it cooled down. *Matter* (stuff other than light) started to form from all the energy released. You might wonder how it is possible for energy to convert into matter. In the early 20th century, the brilliant physicist Albert Einstein developed a formula to show how energy is converted into matter and vice versa: $\boldsymbol{E = mc^2}$ (***m*** times ***c*** times ***c***); energy (E) equals mass (m) multiplied by the speed of light (c) squared (c multiplied by itself).

15. What do you think existed before the Big Bang? Did the universe arise from nothing?

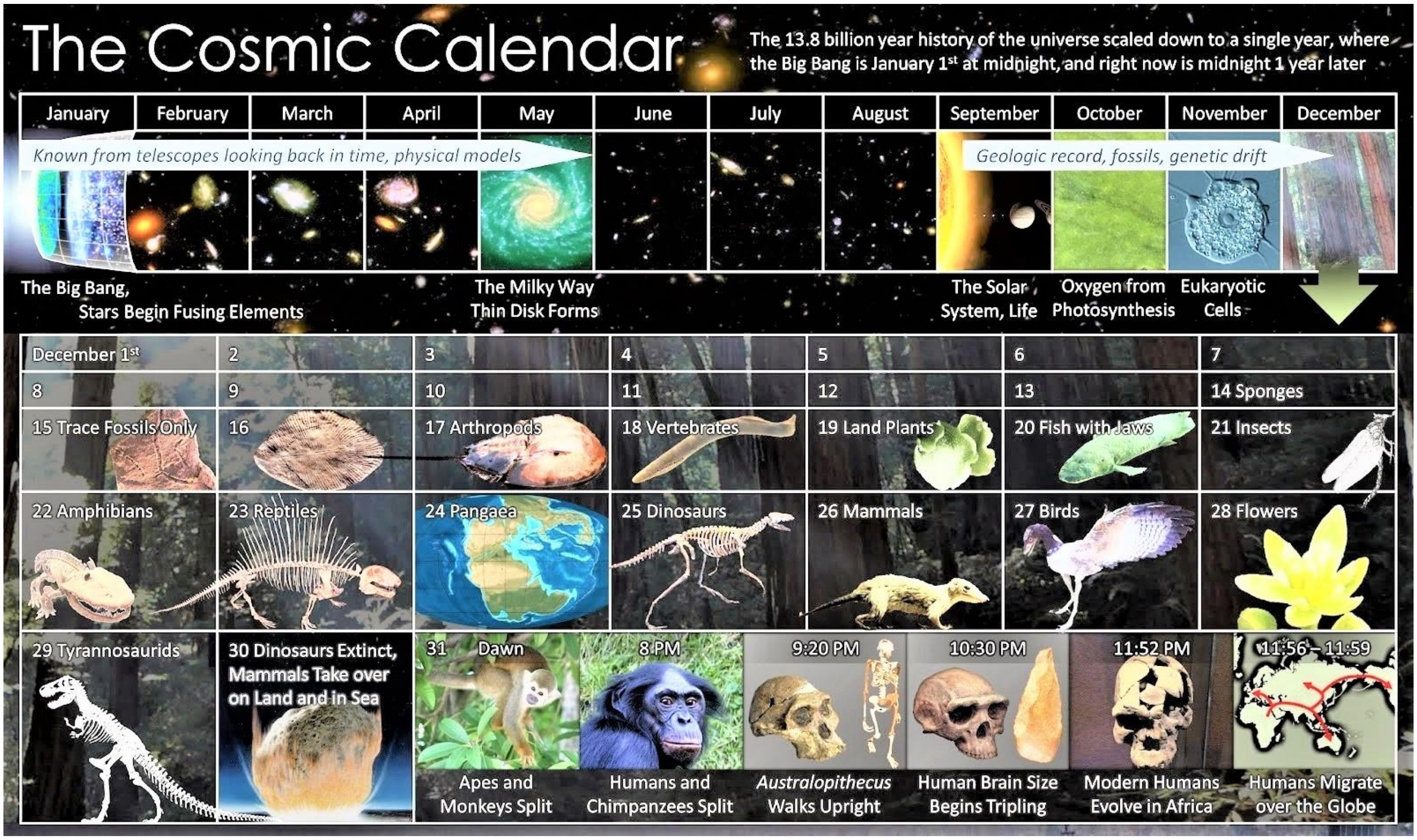
16. Many astronomers were initially skeptical of the Big Bang theory. Why do you suppose this was?

Part 5. The Cosmic Calendar

The Big Bang theory will always be that — a theory. We cannot go back in time to prove it. But, we can look back in time. Light travels through empty space at a speed of 186,000 miles per second. While this seems unimaginably fast, the great expanses of space can make it seem slow. For instance, our sun is about 93 million miles from Earth. It therefore takes sunlight 8 minutes and 20 seconds to reach Earth. Light from Proxima Centauri (the closest star to us besides the sun) takes 4.3 years to reach Earth. When we view Proxima Centauri, we are looking 4.3 years back in time! We say that Proxima Centauri is 4.3 *light-years* away.

In 1774, French astronomer Charles Messier cataloged 103 faint, fuzzy objects he considered unworthy of his attention. Many of these were later discovered to be galaxies or star clusters at great distances from Earth, millions or billions of light-years away. We can now peer so deeply into space that we can observe galaxies and other objects as they were shortly after the Big Bang.

Below is a "Cosmic Calendar": a history of our universe from the Big Bang to the present day, but squeezed into the 12 months of a calendar year.[8] In this calendar, each month equals about a billion years. The Big Bang occurs at 12:00 midnight, January 1. The sun and planets form in September. Life arises later that same month. The evolution of humans occurs on the very last day of the year, December 31, and all of recorded human history occupies just the final four minutes!



17. Given the timescale of the universe, do you feel that humans are lucky to exist, or were we meant to exist? Explain your reasoning.

18. If humans were able to visit another planet supporting life, would you expect them to find primitive life or complex intelligent life?

Part 6. New Horizons

Ever since Galileo pointed his telescope at the night sky, astronomy has depended on technology. Today, astronomers use a wide array of instruments to understand what's going on in the universe. In the last hundred years or so, astronomers have discovered many strange things out there. Take a neutron star, for example. A neutron star is only the size of a small city but is so dense a teaspoon of it would weigh over ten million tons! Neutron stars can rotate hundreds of times a second! Black holes are even more bizarre. The gravitational pull of a black hole is so strong not even light can escape (hence its name). There are blazars and quasars, which can emit as much as 10^{41} watts of power (that's a 1 with 41 zeros after it). Even tiny asteroids are interesting. Their gravity is so weak that if you landed on one and jumped, you might jump into space and never come down. Some asteroids are like piles of rubble, barely holding themselves together.

In the United States, the National Aeronautics and Space Administration (NASA) regularly launches space probes to help astronomers understand what's out there. Other countries have their own space agencies doing similar things, and they sometimes collaborate with NASA. Following is a short list of missions launched over the last half-century.

- This one should be familiar. In the late 1960s and 1970s, humans landed astronauts on the moon and brought them back safely to Earth. We also brought back 842 pounds of moon rock!

- In the 1970s, NASA launched the Pioneer and Voyager space probes, which sent stunning images of Jupiter, Saturn, and their moons back to Earth. These missions were *flybys*: the probes flew by their target planets and kept flying.

- After many flybys and orbiters, NASA landed the Viking probe on Mars in 1975. NASA followed this in the 1990s and 2000s with the Sojourner, Spirit, Opportunity, and Curiosity *rovers* (vehicles full of cameras and scientific instruments that can explore the planet under direction of Earth-based engineers). Curiosity, shown in a "selfie" image to the right, is still in operation today.[9] A new lander called InSight landed safely on Mars on November 26, 2018.

- From 1961 to 1984, the Soviet Union (present-day Russia) sent numerous probes to Venus, called the Venera missions. Venus turned out to be fantastically inhospitable. Its surface temperature is nearly 900 degrees F from the poles to the equator, and Venus' thick atmosphere creates a surface air pressure like being 3,000 feet underwater. The Venera landers did not last long!

- Launched in 1997, NASA's Cassini spacecraft orbited Saturn for 13 years. Cassini sent a lander called Huygens to Saturn's moon, Titan. Titan has a thick atmosphere. But it is mortally cold, nearly 300 degrees F below zero! Its surface is sandy and soaked with liquid methane (like the natural gas we use on stovetops, but in liquid form on frigid Titan).

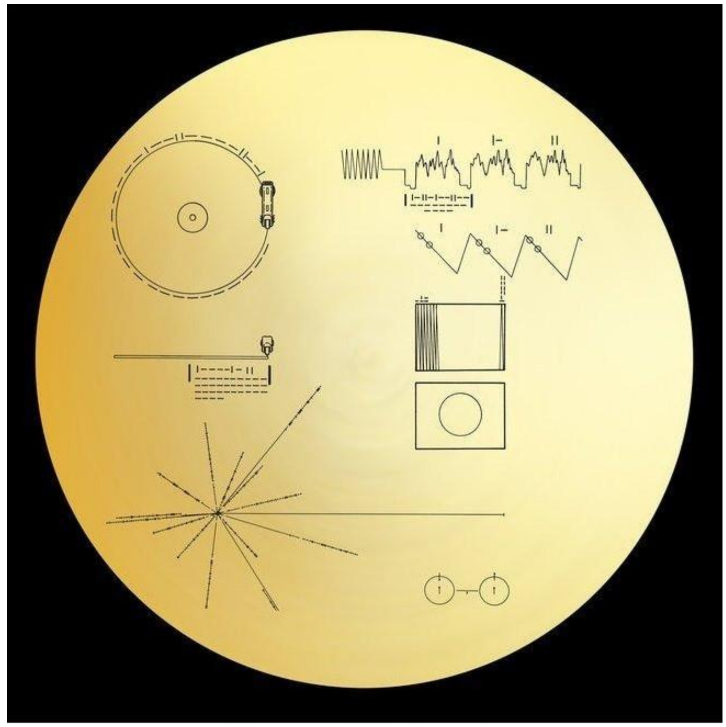
Mars Curiosity Rover Selfie

19. If you were a NASA scientist, where would you send a probe? What would you look for?

20. Most astronomical missions are unmanned. There were no astronauts aboard the Mars, Venus, or Saturn probes. Why do you think we don't send more manned missions?

Part 7. Is There Anybody Out There?

Voyager I is now the most distant man-made object from Earth, over 13 billion miles away. It entered *interstellar* space (the space between stars, beyond the exclusive influence of the sun) in 2012. It carries a gold-plated record with sounds from Earth — natural sounds, sounds from various animals, the sound of a mother and child — along with instructions and materials to build a playback device. It also shows the location of Earth within the Milky Way. See image to the right.[10]



Voyager Golden Record

21. Why do you think NASA scientists included this record?

22. Do you think an extraterrestrial (ET) intelligence might ever see or listen to the Voyager record?

In 2009, NASA launched the Kepler probe to search for *exoplanets*: planets orbiting stars other than our sun. In 2018, NASA launched the more powerful TESS to continue the search. To date, thousands of exoplanets have been discovered. Scientists hope to one day find evidence of life on one of these planets. They especially hope to find planets that resemble our own.

23. Do you think planets that are very different from Earth might still support life?

24. If extraterrestrial life were to visit Earth, do you think its technology would be about the same as human technology, a little more advanced, or much, much more advanced? How would you feel about a visit from an ET?

"Science is a way of thinking much more than it is a body of knowledge." —American astronomer Carl Sagan (1934–1996)

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Remember: First names only & please let us know if your address changes

Citations

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6. Redshift/blueshift image: College Guild
7. The Big Bang image: physicsoftheuniverse.com
8. Cosmic calendar image: wikipedia.org
9. Curiosity rover selfie image: NASA/JPL-Caltech/MSSS
10. Golden Record cover image: JPL-Caltech

Answers or hints to selected questions

9. Cell phones and WiFi are two examples.
10. Ultraviolet
11. Ultraviolet, X-ray, and gamma radiation are damaging to living creatures.
12. Since the passenger is moving along with the whistle, the whistle's pitch is unchanged from the passenger's point of view.
13. A jump rope and the head of a drum are two examples.