Published on *Astronomy 801: Planets, Stars, Galaxies, and the Universe* (https://www.e-education.psu.edu/astro801)

Lesson 12

Overview

About Lesson 12

Prior to 1992, all of our knowledge of planets in the Universe came from the study of our own Solar System. Although we only knew about the planets orbiting our Sun, astronomers believed that planets should be common and assumed that most stars were likely to have their own system of planets. Taking this assumption one step further, some astronomers also considered that if planets are common, life may also exist elsewhere in the Universe. Then, in 1992, astronomers finally discovered planets outside of our Solar System. Since then, more than 2,000 planets have been discovered (or if you count the Kepler candidates [1], we're beyond 5,000!). Many of the new planets, however, are in systems unlike our own! While our theories for planet formation have had to be adapted, it is still considered possible that life exists elsewhere in the Universe.

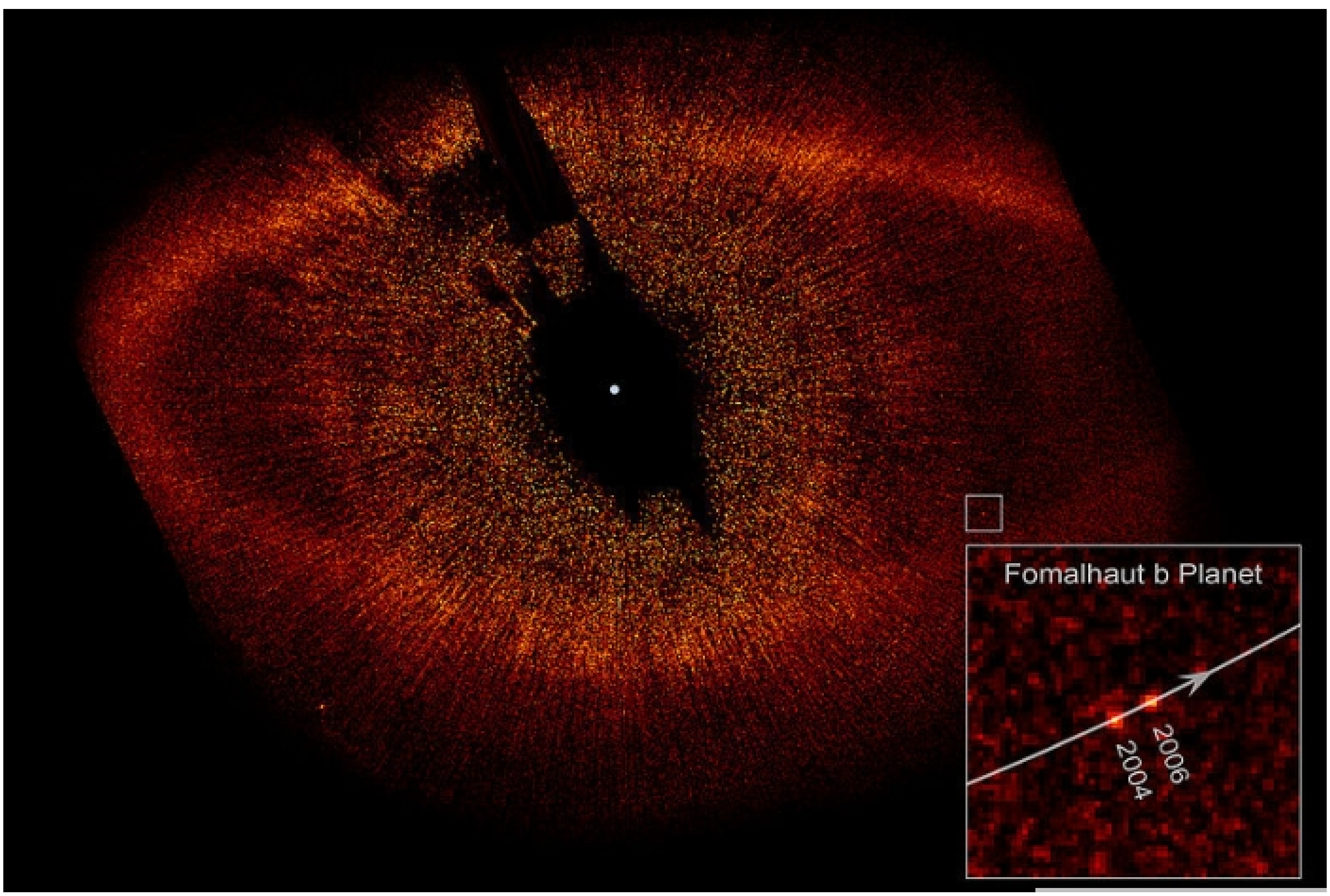

Figure 12.1: Coronagraphic image of the star Fomalhaut showing disk ring and location of extrasolar planet b
Credit: NASA, ESA and P. Kalas (University of California, Berkeley, USA)

What will we learn in Lesson 12?

By the end of Lesson 12, you should be able to:

- describe the habitable zone of a star and the likelihood for life to appear on various objects in the Solar System and in other systems;
- describe how astronomers are searching for signals from other civilizations in the Galaxy.

What is due for Lesson 12?

Lesson 12 will take us one week to complete.

Please refer to the Calendar in Canvas for specific time frames and due dates.

There are a number of required activities in this lesson. The chart below provides an overview of those activities *that must be submitted* for Lesson 12. For assignment details, refer to the lesson page noted.

Lesson 12 Requirements

REQUIREMENT	SUBMITTING YOUR WORK
Lesson 12 Quiz	Your score on this quiz will count towards your overall quiz average.
Discussion: Near Earth Objects	Participate in the ANGEL Discussion Forum: "Near Earth Objects".

Questions?

If you have any questions, please post them to Piazza (not email). I will check that discussion forum daily to respond. While you are there, feel free to post your own responses if you, too, are able to help out a classmate.

Life in the Solar System

Additional reading from www.astronomynotes.com [2]

- Mars: Liquid Water [3]
- Life Characteristics [4]

You can summarize this lesson with the common phrase, "Are we alone?" You may associate this question with TV shows, movies, or sci-fi novels, but it is a valid question that researchers have considered alongside topics you might consider more traditional, like, "Why does the sun shine?" There is a growing field of study that is investigating all of the scientific questions associated with the search for life in the Universe, and it is referred to as **astrobiology**. It is part of our everyday experience that life is prevalent on Earth. But what we do not know for certain is how prevalent life may be in the Solar System, the Milky Way, and the Universe in general.

Want to learn more?

What is astrobiology? We will be discussing many areas of astrobiology during this lesson, but if you want to start with some pre-reading before you begin, I would recommend the NASA Astrobiology website [5].

The first task to address in the study of life in the Universe is to define what we are looking for. That is, how do you know that something is living when you find it? It is surprisingly difficult to do this, and so there is no single, universally accepted definition of life. If we compare and contrast living and nonliving things on Earth, we can come up with a set of properties that appear to be common among all living things. These are:

- Living things grow and reproduce
- They evolve and adapt to their environment
- They require liquid water
- They require energy

We can make this list more detailed, but the difficulty with this type of exercise is that you can find examples of nonliving things (for example, fire is often cited) that exhibit some of the properties of life, and you can cite examples (e.g., viruses) that do not fit all of the properties you expect living things to exhibit. While this question continues to be researched, one option that can be pursued in the meantime is for scientists to look for evidence of life elsewhere that shares properties of lifeforms known on Earth. Clearly, this is an assumption (and one that may be wrong), but for the most part, scientists are looking for evidence that simple, microbial life may be present now, or may have been present in the past on other worlds in our Solar System.

The locations considered most likely to harbor life are:

1. Mars
2. Europa and Ganymede, two of the Galilean moons of Jupiter
3. Titan, a moon of Saturn

The reason these locations are considered more likely than, say, Mercury or our Moon, is because there is evidence that each of these worlds either had some liquid on its surface in the past or has subsurface liquid (water in the case of Mars, Europa, and Ganymede, and liquid hydrocarbons in the case of Titan) or on the surface now. This property is considered by many scientists as the single most important requirement for life to exist.

On Mars, we see evidence that liquid water was likely present in the past. Below is an example where scientists believe that the light-colored deposits indicate a brief flow of liquid water that occurred sometime very recently.

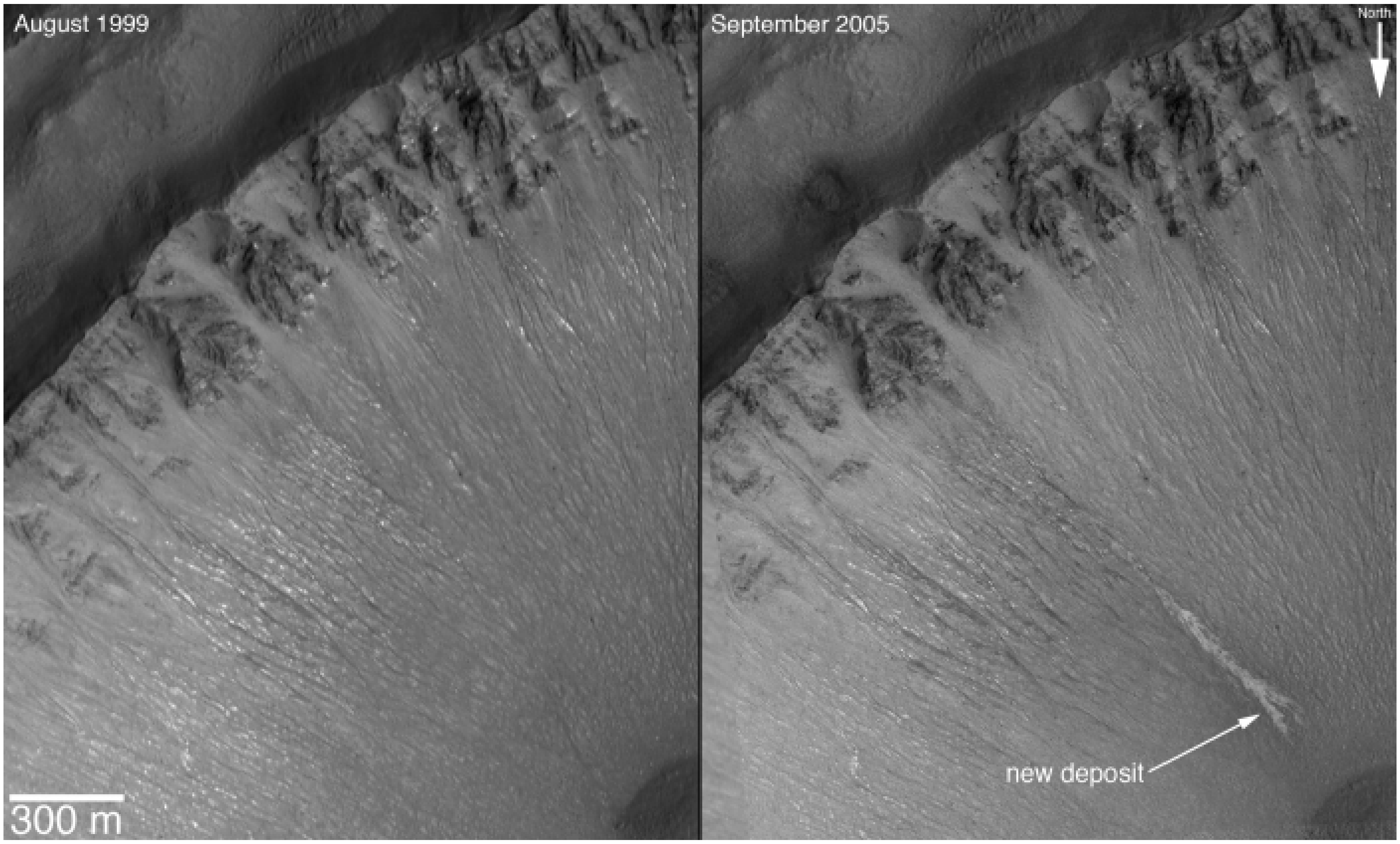

Figure 12.2: Possible water feature on Mars
Credit: NASA / Mars Global Surveyor [6]

The Mars Phoenix Lander saw water ice in a trench it dug as it was studying the Martian soil.

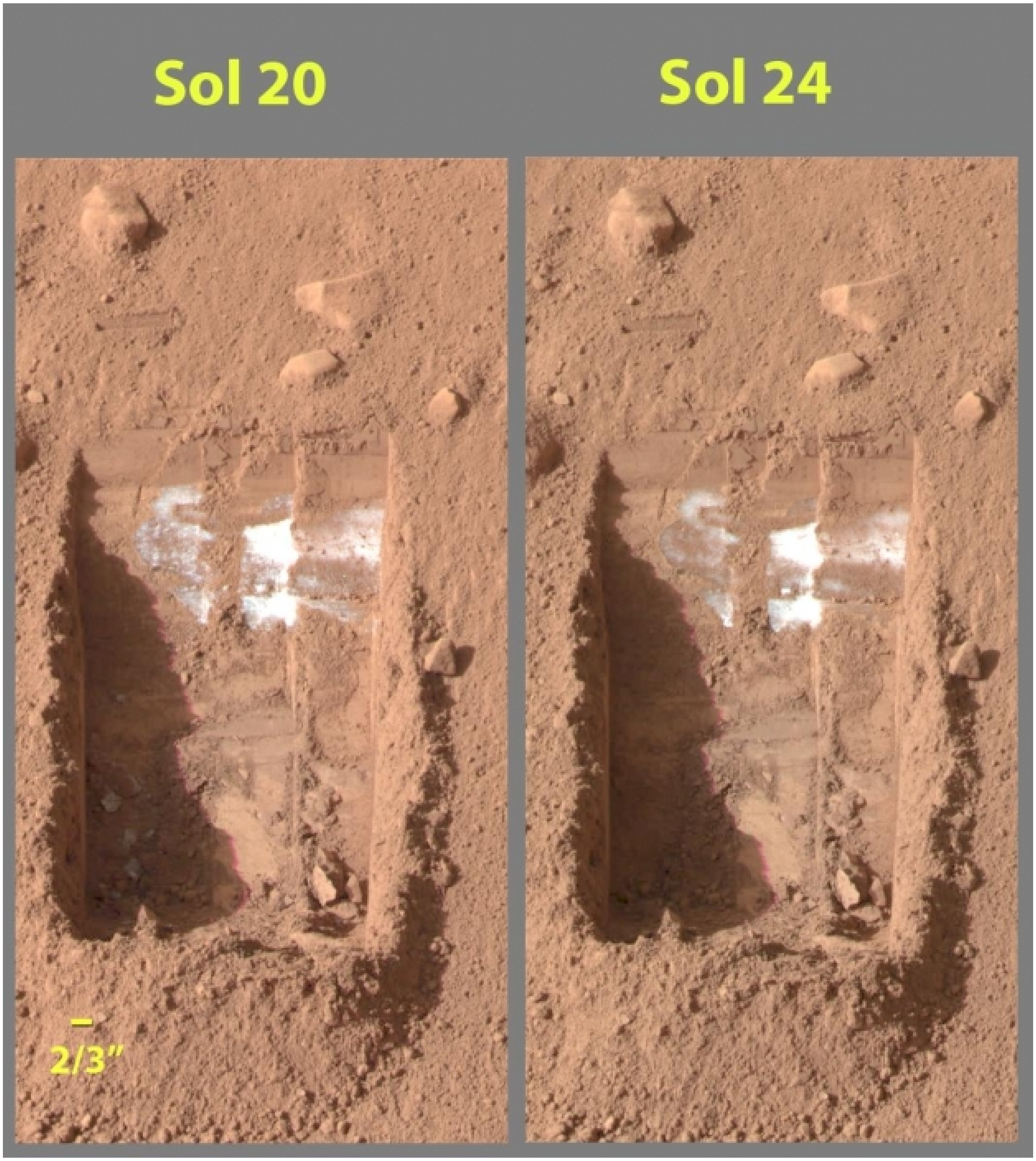

Figure 12.3: Comparison of Mars surface in two images from Mars Phoenix Lander
Credit: NASA / Mars Phoenix Mission [7]

You can find a large number of images and studies of the Martian surface by landers (for example, the Spirit and Opportunity rovers, the Phoenix lander) or orbiters (Mars Global Surveyor, Mars Reconnaissance Orbiter) that suggest that Mars was once a wet world. Given this evidence, NASA has been investing a great deal of time and effort in the study of Mars in a search for life. At the Mars Exploration website, you can find a list of all of the past, present, and future missions to Mars [8].

Want to learn more?

The education and outreach group for the Phoenix Mars Mission has put together an excellent resource that compares images of Mars and images of Earth [9] that builds the case that Mars must have been wet in the past.

It was the NASA Galileo mission [10] that gave us the evidence for what may be a subsurface ocean on Europa. And the NASA Cassini mission [11] gave us the evidence for riverbeds and lakes on Titan. A major focus of NASA missions that are currently under consideration is to study these worlds in more detail to see if there is some way that we may verify the presence of life.

The Search for Planets around Other Stars

Additional reading from www.astronomynotes.com [2]

- Testing The Theory: Other Planetary Systems [12]

Another major area of emphasis in the study of astrobiology, aside from the search for life in our Solar System, is the search for planets around other stars. Prior to 1991, all searches for planets around other stars had been fruitless. However, in 1991, Penn State astronomer Alex Wolszczan first detected evidence for planets around a pulsar, which was surprising not only because of the discovery itself, but also because the planets, in this case, are associated not with a normal star but with a remnant of a supernova explosion. Although many astronomers consider these to be the first planets discovered outside of the Solar System, there was evidence for a planet discovered in the late 1980s [13], but it was not confirmed until significantly later.

After the pulsar planet discovery, there were no other planets discovered until 1995, when a normal star called 51 Pegasi was discovered to have a planet orbiting it, too. Now, using the technique used to discover the planet around 51 Peg and a few other techniques, astronomers have discovered more than 2,000 planets (although you will see this number vary, depending on which source you use). You can find the current number of known planets around other stars, a table of the data on these planets, and an interactive tool for plotting the properties of these planets at the Extrasolar Planet Encyclopedia [14]. You can also compare the data at that site to the data at Exoplanets.org [15]. The latter database is maintained by a different group of astronomers, including a Penn State faculty member. The search for extrasolar planets is another area where NASA is currently investing a great deal of effort. Much of their work is summarized at the NASA PlanetQuest website [16].

While hundreds of planets are known to exist around other stars in our Milky Way, the large majority of these have been detected indirectly. That is, we do not simply take an image of a star and search near the star for planets. The reasons for this are:

1. At the distance of even the most nearby star, the angular separation between the star and any planets in orbit around that star is very small.
2. Planets do not emit their own light, so, depending on the wavelength you are using to image the star, the brightness of any planet in reflected starlight is approximately one million to one billion times smaller than the star's brightness.

Given the difficulty of directly imaging planets around other stars, astronomers have developed several indirect means for finding these objects. You can:

1. study the radial velocity of a star and search for periodic variations in that velocity (the **radial velocity method**),
2. study the position of a star and search for periodic changes in its position (the **astrometric method**),
3. watch for small variations in the brightness of a star caused by the planet passing in front of the star (the **transit method**), or
4. search for changes in the brightness of a background star by the gravitational lensing effect (the **gravitational microlensing method**).

Read this!

1. Go to the NASA PlanetQuest website [17] and read about these four techniques.

While the number of planets discovered using these techniques is large and is growing rapidly, no Earth-like planets have yet been discovered around a normal star (that is, not a pulsar). In fact, many of the planets that have been discovered are significantly more massive than Jupiter.

If you recall our discussion of brown dwarfs [18] in Lesson 5, these failed stars are very low mass compared to the Sun. On the other hand, we are also finding planets that are very massive, much more massive than Jupiter. While discussing this with my colleagues, I realized that there is an interesting question that we have not yet answered now that we have so much data on massive planets. The question is, what is the difference between a low mass brown dwarf and a high mass planet? I created a video to discuss this in some more detail, and you can watch it on YouTube [19].

While direct imaging of a planet remains a significant technological challenge, many astronomers are working on this problem, and there have been some recent successes. There have been a few reports of planetary mass companions to stars being imaged directly, like the one shown below.

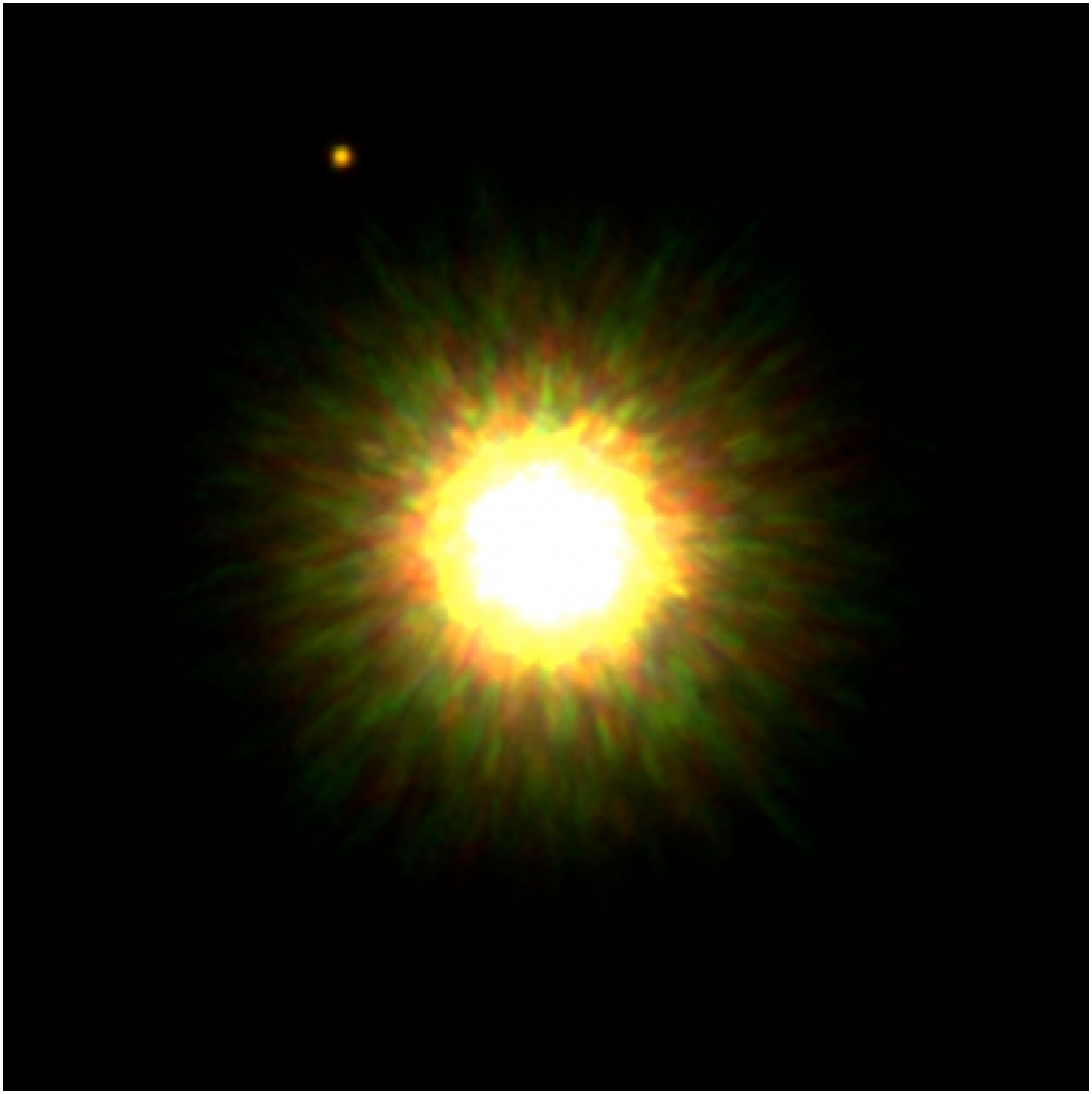

Figure 12.4: Gemini Telescope image of planetary companion to a star
Credit: Gemini Observatory [20]

As our technology improves and we are able to discern more detail about objects like the one seen in the image above, how can we determine if there is life on these planets? The option that is available to us now is to use spectroscopy to study the planetary companions to determine the composition of their atmospheres if they have any. Recall the difference between the atmospheres of Earth, Mars, and Jupiter. Earth has an atmosphere rich in oxygen and water vapor. If we determine an extrasolar planet has these atmospheric constituents, that would suggest the planet has an atmosphere conducive to life, although that would not necessarily indicate that planet must be supporting life.

The Habitable Zone

Additional reading from www.astronomynotes.com [2]

- Habitable Zones and Suitable Stars for E.T. [21]

Is there any other evidence beyond the atmosphere that might indicate a planet is capable of supporting life? Additional requirements that we can place on a star that hosts a planet are:

1. The star will survive long enough for its planets to develop life.
2. The planets exist in a region that is the proper distance from the star for that planet (or its moons) to have water remain liquid (that is, not too cold or too hot).

Because of these two statements, most of the stars that are being searched for life-bearing planets are F, G, K, or M stars. O, B, and most A stars live such short lifetimes that we expect that their planets will not be able to develop complex life forms. For the lower mass stars with longer lifetimes, astronomers define the **habitable zone** (or HZ) as the region surrounding the star in which water can remain in its liquid state. In the image below, the blue band represents the location of the habitable zone. Notice, as expected, that for low-mass, cool stars the region is closer to the star, and for higher mass, hotter stars, the region is more distant from the star. In this particular illustration, the Earth appears to be precisely in the middle of the habitable zone for the Sun.

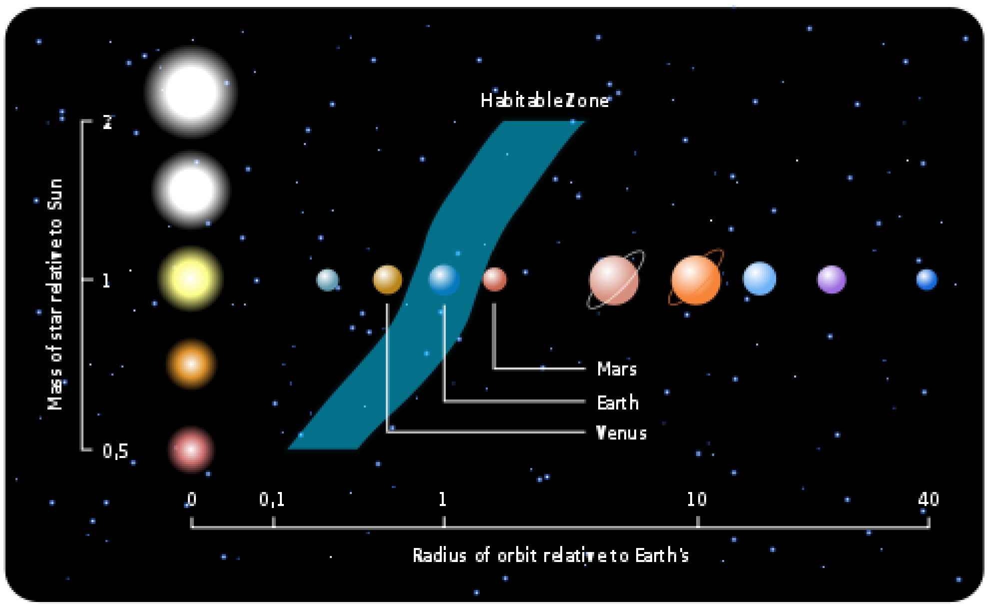

Figure 12.5: Habitable zone relative to the size of a star
Credit: Wikipedia [22]

Another visualization of the habitable zone is shown below. The red region is too warm, the blue region too cool, and the green region is just right for liquid water. Because it can be described in this way, sometimes it is referred to as the "Goldilocks Zone," too.

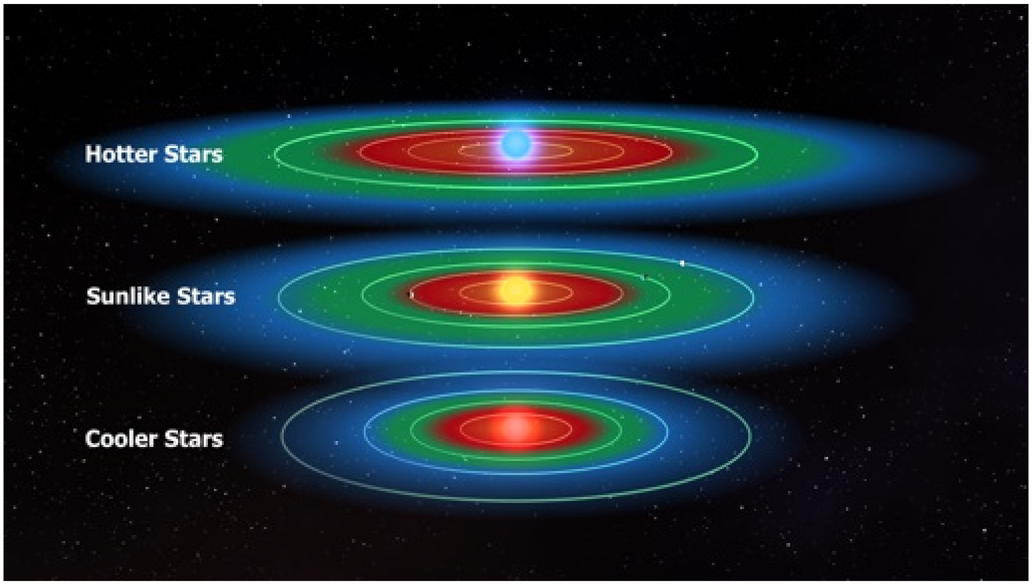

Figure 12.6: Schematic of habitable zone of different planets
Credit: NASA Kepler Mission [23]

The size of the habitable zone clearly depends on the luminosity of the star, which determines the equilibrium temperature of the planet. However, modern models for the range of the habitable zone take into account more subtle effects, such as the effect of the carbonate-silicate cycle in regulating carbon dioxide in a planet's atmosphere. Work on this particular process by Penn State scientists, including Professor James Kasting [24], has shown that the habitable zone extends farther from a star than originally assumed. In the case of the Solar System, the Earth is inside of this revised HZ near its inner edge, and Mars is just outside of the outer edge. Our colleague Ravi Kopparapu maintains an up to date visualization of the habitable zone that includes all of the known exoplanets that lie inside their parent's HZ [25].

When we studied stellar evolution, you saw the evolutionary tracks for stars in the HR diagram: stars do not maintain the same color and luminosity over their entire lifetimes. When the star begins stable hydrogen fusion on the Main Sequence, it will lie in one particular location in the HR diagram, known as the Zero Age Main Sequence, or ZAMS. As the star ages, though, it will, in general, cool off a bit and become more luminous. As its luminosity changes, the location of its habitable zone will change, too. You can define a **continuously habitable zone** (or CHZ) as the region in which liquid water can exist over the entire Main Sequence lifetime of a star.

One last note about the CHZ. Recall that, in our Solar System, the moons Europa and Titan are considered locations where life may exist. Both moons are far outside of the CHZ around our Sun, though. So, although the CHZ is an interesting location to survey for planets around other stars that might support life, it is not the only location in a planetary system that might support life.

The Drake Equation

Additional reading from www.astronomynotes.com [2]

- Drake Equation: How Many of Them Are Out There? [26]

Scientists expect that, if we discover life on Mars, it will most likely be simple bacterial life and not humanoid aliens like most of the martians you have seen in movies. This does not mean that scientists have completely ruled out the possibility of intelligent life in the Milky Way Galaxy, though. One of the tools that you can use to consider this topic is known as the **Drake Equation**, after astronomer Frank Drake who proposed it in the early 1960s. With this equation, you can estimate the number of communicating, intelligent civilizations that currently exist in the Milky Way.

The equation is:

$$N = (R^*) \times (f\ p) \times (n\ e) \times (f\ l) \times (f\ i) \times (f\ c) \times (L)$$

The individual terms are:

- N = number of civilizations in the Milky Way Galaxy that are capable of producing signals that we can detect on Earth
- R* = the rate at which stars capable of supporting life form in our Galaxy
- f p = the fraction of those stars that have a planet or planets
- n e = the average number of planets per planetary system that have an environment that can support life
- f l = the fraction of those planets that can support life on which life actually develops
- f i = the fraction of those planets with life where intelligent life develops
- f c = the fraction of those intelligent civilizations that develop technology for communication
- L = the average lifetime of those civilizations that develop technology for communication

Several of these terms have values that we can estimate with some degree of accuracy. For example, we can estimate R* from our observations of star forming regions in the Galaxy. That number appears to be very close to 1 star per year. Also, from our observations of stars with protoplanetary disks and with extrasolar planets, we think that f p is likely 1 or close to 1, too. The rest of the values in the equation require you to either extrapolate using limited information or outright guess.

For n e , we can use the Solar System as a guide. The Earth is in the CHZ. Venus and Mars are either close or in the CHZ depending on the model used. Europa, Ganymede, and Titan are outside of the CHZ, but may have environments that can support life. So, in the Solar System there is definitely one, and maybe more than one, planet (or moon) capable of supporting life. What we still do not know is if our Solar System is common or rare. If it is common, you might estimate say 2 objects per Solar System for n e . For f l , you have to make an educated guess. Scientists studying the origin of life think that, given the right conditions (temperature, presence of water, etc.), life may develop on every Earth-like world, or f l =1 . However, that may be too optimistic, so you might expect that 1 in 10, 1 in 100, or 1 in 1,000,000 develop life. However, if you think that Earth is alone in this regard, it might be as low as 1 in 100,000,000,000. The arguments for assigning values for f i and f c are identical. If you are optimistic, you would assign f i or f c =1 . If you are pessimistic, you would assign f i or f c =1 in 100,000,000,000, or anywhere in between.

The final term, L, is the lifetime of an intelligent, communicating civilization. How do you estimate this value? If you consider Earth, we have only had the technology to communicate using light (e.g., radio or TV) for about 100 years. To estimate L, though, you have to decide how long our civilization will retain this capability. Will civilization end because of war, disease, or some other catastrophe in a few generations? If not, will our civilization last as long as the Sun remains on the Main Sequence? Your estimate may be anywhere from 1,000 years to 5,000,000,000 years. If you fill in values of 1 for all of the parameters for R* through f c , then the equation simplifies to N = L. So, in the optimistic case, your estimate for N will be equal to your estimate for the lifetime of a typical intelligent, communicating civilization.

Try this!

At PBS, they have a Drake equation calculator [27] where you can put in values for these numbers to determine how many civilizations may be found in the Milky Way.

1. Fill in values for a pessimistic case and determine N.
2. Fill in values for your best guesses and determine N.

How do these compare to the case where every parameter is 1? What do you think might be the range of the total number of intelligent, communicating civilizations in the Milky Way?

Given the extent of the Milky Way, if the number N is small, the expected distance between Earth and any communicating civilization will be large. If N is large, the average separation between Earth and any communicating civilization may be small.

The Search for Extraterrestrial Intelligence (SETI)

Additional reading from www.astronomynotes.com [2]

- Hailing Frequencies Open, Captain [28]

If intelligent, communicating civilizations exist in the Milky Way, how can we learn that they are there? While there are many reports of UFOs in the popular media, to date there has been no credible evidence that any alien civilization has ever visited the Earth. Since the distances to the nearest stars are a few light years or more, and since our current technology only allows us to build ships that achieve velocities that still require years to reach Pluto, the stars are unreachable to us. Even assuming that other civilizations might be capable of building ships that can fly much faster, a round trip to a star 20 light years away is at the very least 40 years, and likely much longer than that. Since physical travel between Earth and any nearby stars is improbable because of the lengths of time involved, if we are to find other civilizations in the Milky Way, we expect it will be by communication using light (that is, radio waves or optical light) rather than direct visits.

Light travels faster than any other means of communication, so a sufficiently advanced civilization may try to directly communicate with other civilizations using light. Beyond direct, purposeful communication, though, our planet is actually broadcasting signals out into space every day in the form of our radio and TV broadcasts. That is, when we broadcast radio signals around the world for you to listen to in your car, those same signals also travel through space, and so any civilization with a sophisticated enough detector can receive, say, the "I Love Lucy" show from decades ago. By the same logic, if we try, we should be able to detect signals sent directly to us from a distant civilization, or if they also use transmitters to transmit radio or TV type signals, we could detect those signals, too. However, the signal from a radio transmitter dilutes as it moves farther and farther from Earth, so the radio telescopes a distant civilization must have to detect TV or radio signals from Earth would have to dwarf our most powerful radio telescopes on Earth.

If you return to the lesson on the electromagnetic spectrum and review, there are a few considerations that we or another civilization might want to take into account when deciding how to communicate from planet to planet:

- **Cost:** Radio photons carry less energy than say gamma-rays, so it is cheaper to generate radio signals than gamma-ray signals. So, we expect that radio waves are the most efficient way to communicate over large distances.
- **Background:** The Milky Way contains many objects that give off light from radio through gamma rays, and so we want to choose a wavelength of light that will not be swamped by the Milky Way or absorbed as it travels through the interstellar medium.

Since we cannot know ahead of time anything about other civilizations that may be listening for signals from us or who are trying to communicate with us, the best that we can do is take educated guesses at how we might communicate. Scientists who have been pursuing **Search for Extraterrestrial Intelligence** or SETI research have been, since the 1960s, using radio telescopes to search for signals from other civilizations. These searches have concentrated on a region in the radio part of the spectrum known as the **water hole**. In a part of the radio spectrum where the emission from the Galaxy and Earth's atmosphere is at a minimum, there is a wavelength associated with emission from Hydrogen (H) and another with emission from hydroxyl (OH). Since H+OH produces water, this part of the spectrum is referred to as the water hole. The assumption is that since this is a part of the spectrum that many astronomers already study and because the background is very low, it is a logical place for a distant civilization to try to communicate with us. Many of the SETI experiments that have been conducted over the years have tuned their radio telescopes to this part of the spectrum.

The next logical question is, if astronomers have been searching the water hole for a signal from another civilization, has one ever been received? The answer is maybe! In one of the earliest SETI experiments, the "Big Ear" radio telescope detected a signal that is now known as the **"Wow!" Signal**. The Wow Signal has the appearance of a real SETI signal, but it was never able to be independently verified:

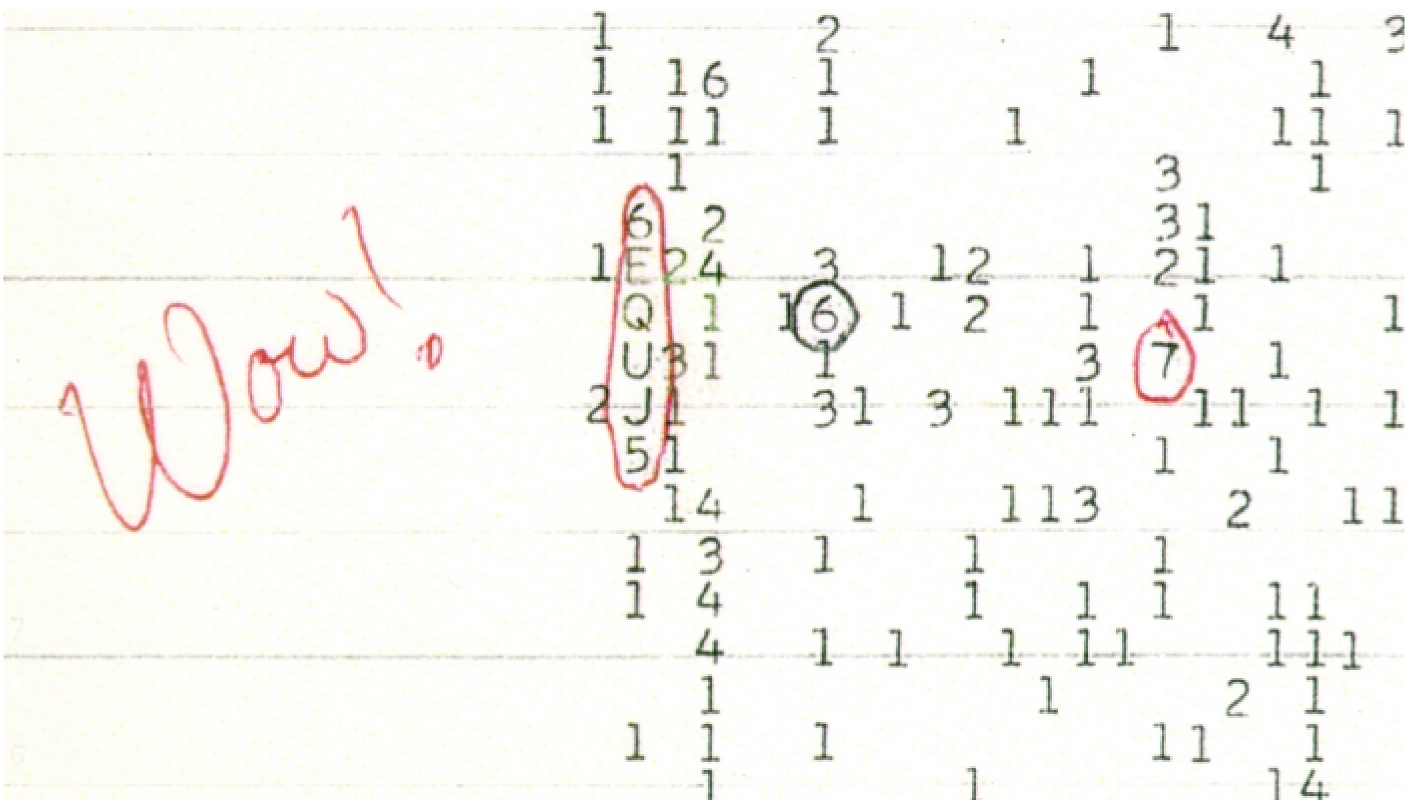

Figure 12.7: Handwritten note of "wow" near a radio signal detected by the Big Ear observatory
Credit: Big Ear Observatory [29]

The translation of the numbers on the chart is that each represents the intensity of the signal above the background. The group that reads "6EQUJ5" corresponds to a strong signal that peaks at 30 times the intensity of the background. This is precisely the type of signal that SETI researchers expect to come from an alien civilization broadcasting a radio signal to Earth. Researchers did rule out that this was a terrestrial signal, and no known source of interference was ever discovered that can account for the strength of this signal. To be absolutely certain that this is a true SETI contact, though, researchers want verification by observing a repeat of the signal coming from the same part of the sky. Although a number of searches for a repeat signal were undertaken, none was ever successful.

There have been many different radio SETI searches using the Arecibo radio telescope, the National Radio Astronomy 140 foot radio telescope, the Big Ear telescope, and others. However, researchers have also proposed that optical light may be another option for communication. One thing that SETI researchers take into account is how likely it is that an intelligent civilization would be able to generate a powerful signal and would use their resources to do so—after all, would you be willing to put your tax dollars into a device to beam a signal to a planet in case there is life there? If it's cheap or free, you might be persuaded, but if it is expensive, fewer people are likely to see the benefits of such an experiment. So, part of the argument presented by SETI researchers is that, while you can assume that an advanced civilization may be better at generating high power light beams (optical or radio) than we are, they will still want to send signals out to other planets using as few resources (that is, energy) as possible. So, another possibility besides beaming radio signals in the water hole region of the spectrum is that they could shine a pulse of laser light in our direction. These pulses can be *very* bright, but if they are sent in short bursts, they don't use much energy. So "optical SETI" searches are being undertaken to look for short bursts of light from nearby stars.

Want to learn more?

The SETI Institute [30] maintains a repository of resources related to the search for extraterrestrial intelligence. In particular, they have an excellent history of past SETI projects [31]. Both the SETI Institute and I recommend watching the movie "Contact" [32], based on Carl Sagan's book. Contact gives a fairly accurate depiction of SETI research.

More recently, astronomers, including several at Penn State, have been conducting other searches using different techniques that may reveal intelligent civilizations. One idea concerns "Dyson spheres", that is giant, artificial structures that a civilization might build around a star in order to capture most of that star's energy to power their civilization. These types of artificial structures should give off waste heat, and therefore, they might be detectable in the infrared. A highly detailed overview of a search for this type of waste heat is posted as a blog by Penn State Professor Jason Wright [33]. Prof. Wright has also been involved with the study of a very odd star discovered in Kepler Data that is known as "Tabby's Star". In this case, it has been suggested that the highly unusual lightcurve for this star may be explained not by a planet transiting in front of the star, but an artificial alien "megastructure" that may be similar to a Dyson sphere transiting in front of the star. There is an excellent article in the Atlantic that will give you an overview of our current state of understanding of this star system [34], and Prof. Wright gave a public lecture on the discovery [35] at Penn State in late 2015. It will be very interesting to see what eventual explanation we uncover for this unusual star.

Astronomical Hazards to Life

Since we have considered the possibilities for worlds to support life in the Milky Way Galaxy, we should also consider the likelihood that astronomical phenomena might be responsible for ending life either on Earth or elsewhere. There are several astronomical events that may play a role in shortening the lifetime of a life-bearing planet or moon.

The first hazard we should consider is a catastrophic impact, like the one that is likely to have killed off the dinosaurs on Earth. You have already seen, for example, the impact of the comet Shoemaker-Levy 9 on Jupiter, which released large amounts of energy. We also see in several different objects in the Solar System evidence for larger scale impacts. For example, on Mars, there is the Hellas Planitia impact basin shown below.

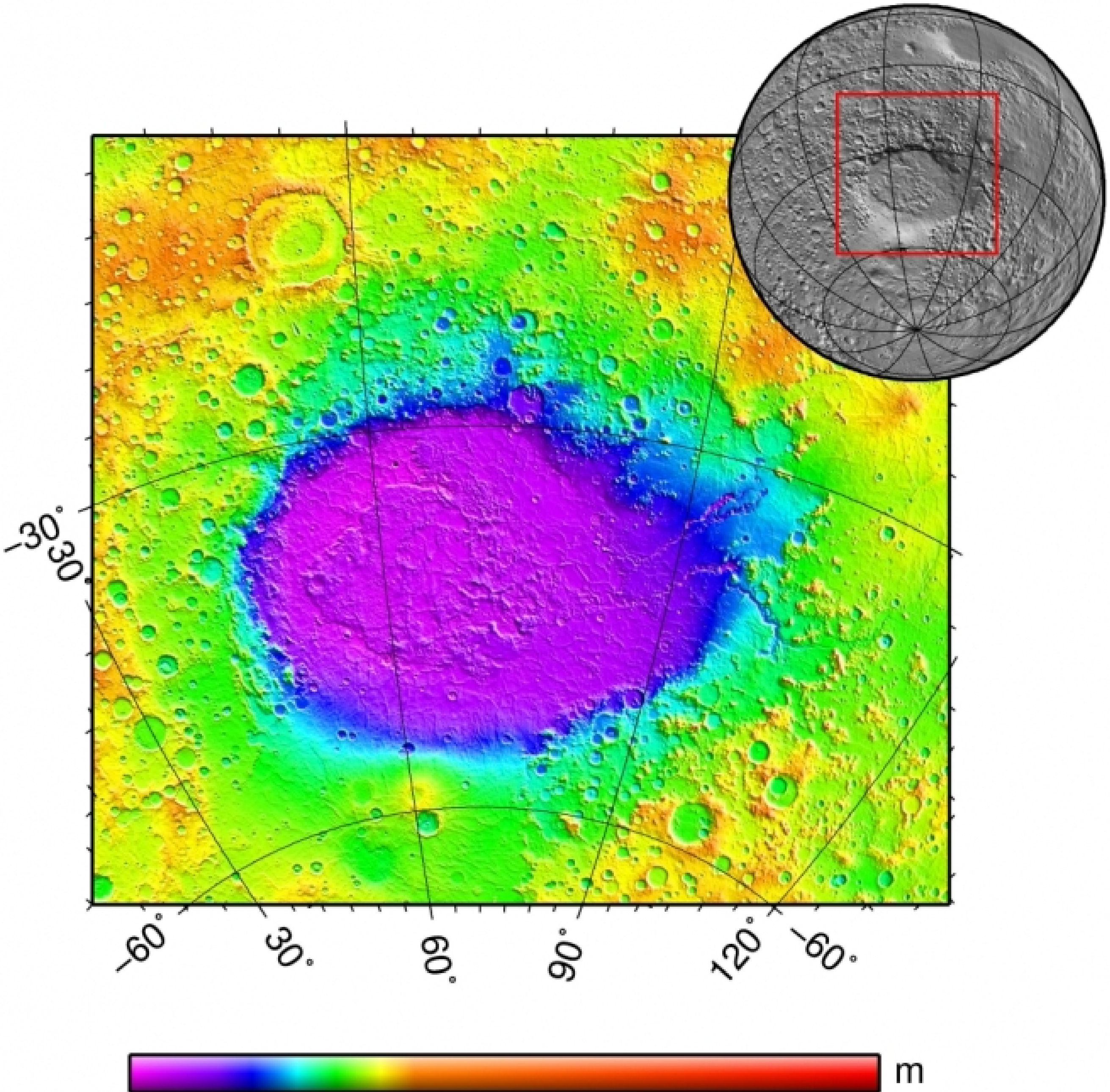

Figure 12.8: Topographic map of the surface of Mars in the Hellas Planitia region
Credit: NASA Mars Global Surveyor [36] / Wikipedia [37]

The object that left this crater, which is more than 1,000 miles in diameter, was likely an asteroid. The force of the impact threw debris several thousand miles and left a blanket of debris approximately a mile thick over a large part of Mars' southern hemisphere.

The moon of Saturn called Mimas is significantly smaller than Mars, but also bears the mark of a major past impact, as shown below.

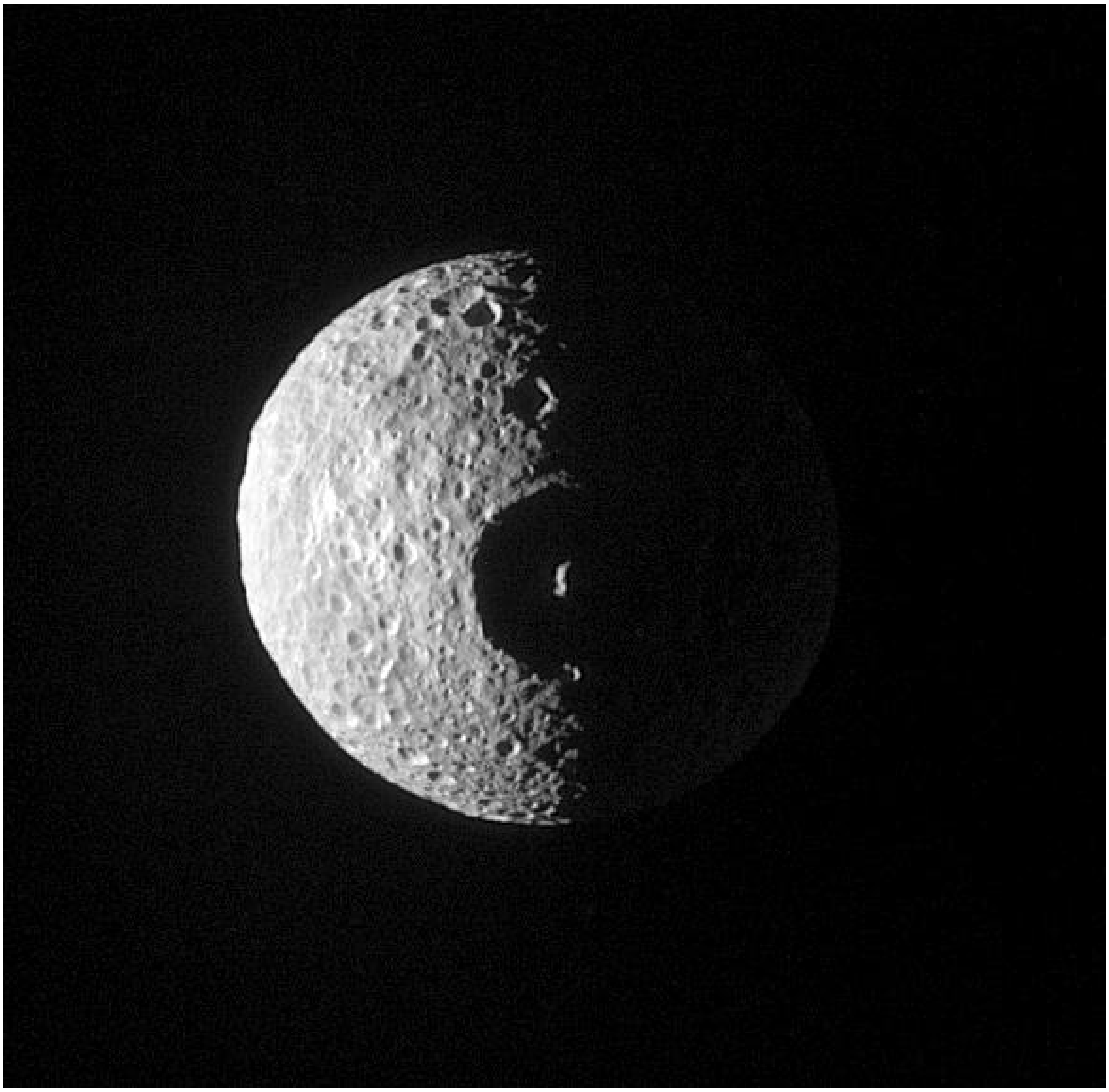

Figure 12.9: Cassini image of Saturn's moon Mimas, bearing the mark of a major past impact
Credit: NASA Cassini [38]

The impact that created this crater likely almost destroyed this moon. Given the visible evidence of massive impacts on planets and moons in the Solar System, you may ask what the probability is for an impact of this size in our future. There has been a major impact on the Earth in recorded history. Fortunately, it occurred in a relatively uninhabited region of Siberia, and it is referred to as the "Tunguska Event." Below is an image showing some of the devastation.

Figure 12.10: Photograph of fallen trees from the Tunguska event
Credit: Wikipedia [39]

The exact origin of the Tunguska event is still unknown, although the evidence suggests that a meteor or comet exploded in the atmosphere before reaching Earth. There is no unambiguous crater left; however, trees for dozens of miles around the site were flattened by the explosion, which is estimated to have released energy equivalent to 15 or so megatons of TNT. Events of this size are expected statistically to occur on Earth approximately once a century. Larger impacts like the one that killed the dinosaurs are expected to occur about once every 50 million years. The largest impact on Earth since the Tunguska event was the Chelyabinsk meteor [40], which is estimated to have released energy equivalent to 500 kilotons of TNT in the atmosphere. To try to get some advanced warning of a potential impact, several efforts are underway to observe and catalog all of the **Near Earth Objects** (NEOs), that is, meteors and asteroids large enough to cause significant damage to Earth.

Want to learn more?

NASA has been charged by Congress to survey for NEOs and develop plans for diverting them from impacting the Earth. Information about the NASA program is available at the "Near Earth Object Program [41]" website. In particular, if you have heard about the potential for a collision between Earth and Apophis in 2029 or 2036, there is a comprehensive discussion [42] of this object there.

There is also a program called "SpaceWatch [43]" that is independently surveying for NEOs.

NASA has received some criticism for their work preparing for the diversion of any potentially hazardous asteroids. An organization called the "B612 Foundation [44]" is working on this independently.

The potential impact between Earth and a massive asteroid is one way in which our planet is in jeopardy from an astronomical phenomenon; but, unfortunately, it is not the only one. One of the other possibilities that we have to consider is the collision of the Earth with a molecular cloud of gas. The Earth's interaction with such a cloud is likely to destroy our atmosphere. The Earth may also lie in the path of the jet of emission from a gamma-ray burst, which will bombard the Earth with enough high energy radiation that there would again be catastrophic effects on the atmosphere. The rates of these events are also able to be estimated, and both appear to be 1 in 1 billion year type events.

Additional Resources

Below are some resources related to extrasolar planets and life in the Universe:

1. There is an astrobiology curriculum [45] for middle and high school students published by TERC.
2. The SETI Institute also has created an astrobiology curriculum called "Life in the Universe [46]"
3. NASA Educator Resource Guides:
    - Life On Earth... and Elsewhere [47]
4. NASA Kepler Mission planet finding activities [48]
5. PBS has a Timothy Ferris movie called "Life Beyond Earth," and their website includes teacher resources [49].
6. At Crash Course Astronomy [50], Phil Plait has episodes on Exoplanets (#27) and Life (#46)

Tell us about it!

Have another website or printed piece on this topic that you have found useful? Share it in our Comment space below!

Summary

What do you think? Are we alone? This is a fundamental question that everyone considers at some point. Now, we can say that we do know that other planets are prevalent in the Milky Way Galaxy and, given that result, perhaps it is likely that life is, too.

Activity 1 - Lesson 12 Quiz

Directions

First, please take the Web-based Lesson 12 quiz.

1. Go to Canvas.
2. Click on the link to the "Lesson 12 Quiz" and complete the quiz.

Good luck!

Activity 2 - Discussion

Directions

For this activity, I want you to reflect on what we've covered in this lesson and to discuss the threat related to Near Earth Objects. Since this is a discussion activity, you will need to enter the discussion forum more than once in order to read and respond to others' postings.

Submitting your work

1. Enter the "NEOs" discussion forum in Canvas.
2. Respond to the questions I have posted about NEOs.
3. Read postings by other ASTRO 801 students.
4. Respond to at least one other posting by asking for clarification, asking a follow-up question, expanding on what has already been said, etc.

Grading criteria

You will be graded on the quality of your participation. See the grading rubric [51] for specifics on how this assignment will be graded.

Reminder - Complete all of the lesson tasks!

You have finished the reading for Lesson 12. Double-check the list of requirements on the Lesson 12 *Overview* page to make sure you have completed all of the activities listed there before beginning the next lesson.

Tell us about it!

If there is anything you'd like to comment on, or add to, the lesson materials, feel free to post your thoughts below. For example, what did you have the most trouble within this lesson? Was there anything useful here that you'd like to try in your own classroom?

Source URL: https://www.e-education.psu.edu/astro801/content/l12.html

Links
[1] http://apod.nasa.gov/apod/ap110329.html
[2] http://www.astronomynotes.com
[3] http://www.astronomynotes.com/solarsys/s10.htm#A2.2.1
[4] http://www.astronomynotes.com/lifezone/s3.htm
[5] http://astrobiology.nasa.gov/
[6] http://mpfwww.jpl.nasa.gov/mgs/newsroom/20061206b.html
[7] http://phoenix.lpl.arizona.edu/index.php
[8] http://mars.jpl.nasa.gov/programmissions/missions/
[9] http://phoenix.lpl.arizona.edu/exhibit.php
[10] https://solarsystem.nasa.gov/missions/galileo/overview/
[11] https://www.nasa.gov/feature/the-mysterious-lakes-on-saturns-moon-titan
[12] http://www.astronomynotes.com/solfluf/s12.htm
[13] https://exoplanets.nasa.gov/news/204/will-the-real-first-exoplanet-please-stand-up/
[14] http://exoplanet.eu/
[15] http://exoplanets.org
[16] http://planetquest.jpl.nasa.gov/index.cfm
[17] https://exoplanets.nasa.gov/5-ways-to-find-a-planet/
[18] https://www.e-education.psu.edu/astro801/content/l5_p6.html

[19] https://www.youtube.com/watch?v=ibCdL3MZCXQ&feature=youtu.be
[20] http://www.gemini.edu/sunstarplanet
[21] http://www.astronomynotes.com/lifezone/s2.htm
[22] https://en.wikipedia.org/wiki/Circumstellar_habitable_zone
[23] http://kepler.nasa.gov/multimedia/artwork/diagrams/?ImageID=29
[24] http://www.geosc.psu.edu/~kasting/PersonalPage/ResInt2.htm
[25] http://www3.geosc.psu.edu/~ruk15/planets/Seff_HZ_09032015.jpg
[26] http://www.astronomynotes.com/lifezone/s5.htm
[27] http://www.pbs.org/lifebeyondearth/listening/drake.html
[28] http://www.astronomynotes.com/lifezone/s6.htm
[29] http://www.bigear.org/6equj5.htm
[30] https://www.seti.org/
[31] https://www.seti.org/seti-research
[32] http://www.seti.org/seti-institute/project/details/sci-fi-movies
[33] http://sites.psu.edu/astrowright/the-g-hat-search-for-kardashev-civilizations/
[34] http://www.theatlantic.com/science/archive/2015/10/the-most-interesting-star-in-our-galaxy/410023/
[35] http://live.libraries.psu.edu/Mediasite/Play/d73fd082d8c544f1b035fe7bafde3b551d?catalog=8376d4b2-4dd1-457e-a3bf-e4cf9163feda
[36] http://mola.gsfc.nasa.gov/
[37] http://en.wikipedia.org/wiki/File:Hellas_basin_topo.jpg
[38] http://saturn.jpl.nasa.gov/science/moons/mimas/
[39] http://en.wikipedia.org/wiki/File:Tunguska_event_fallen_trees.jpg
[40] http://www.slate.com/blogs/bad_astronomy/2014/02/14/chelyabinsk_asteroid_impact_one_year_later.html
[41] http://neo.jpl.nasa.gov/index.html
[42] http://neo.jpl.nasa.gov/apophis/
[43] http://spacewatch.lpl.arizona.edu/
[44] http://b612foundation.org/
[45] https://www.terc.edu/display/Products/Astrobiology%3A+An+Integrated+Science+Approach
[46] https://www.seti.org/life-universe-litu-curriculum-files
[47] http://nai.nasa.gov/media/medialibrary/2013/10/Astrobiology-Educator-Guide-2007.pdf
[48] http://kepler.nasa.gov/education/
[49] http://www.pbs.org/lifebeyondearth/index.html
[50] https://www.youtube.com/playlist?list=PL8dPuuaLjXtPAJr1ysd5yGIyiSFuh0mIL
[51] https://www.e-education.psu.edu/astro801/node/2077