Earth Calling…

Overview:
A hands-on activity exploring spacecraft radio communication concepts, including the speed of light and the time-delay for signals sent to and from spacecraft.

Target Grade Level: 6-8

Estimated Duration: 40 minutes

Learning Goals: **Students will be able to…**
- measure the amount of time it takes for a radio signal to travel to a spacecraft using the speed of light.
- demonstrate the delay in radio communication signals to and from a spacecraft.
- devise unique solutions to the radio-signal-delay problem.

Standards Addressed:
Benchmarks (AAAS, 1993, 2008)

The Nature of Technology, 3A: Technology and Science, 3C: Issues in Technology
The Designed World, 8D: Communication

National Science Education Standards (NRC, 1996)

Science and Technology, Standard E: Abilities of technological design,
Understandings about science and technology

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Teacher Background:

While some spacecraft return to Earth with valuable data as part of their cargo, all require some periodic remote communications as they travel. And for those spacecraft that do not return to Earth, the communication system is our only link to the valuable data collected during its journey.

Not only do spacecraft transmit valuable data, but also spacecraft ‘health’ information is returned to Earth via these communication systems. It is important to know that the spacecraft’s power systems, heating and cooling systems, and instruments are all operating as expected. And of course signals must be sent to tell the spacecraft where to go or which instrument to operate and when via this system. Such course correction and data collection commands become even more critical as the spacecraft approaches its ‘destination,’ where such maneuvers become progressively finer and many of the science goals are to be achieved.

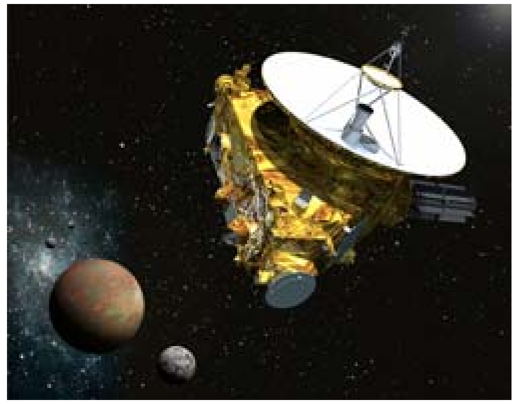


Figure 1. An artist’s rendering of the New Horizons spacecraft as it approaches Pluto. The prominent 2.1-meter dish antenna is used to communicate with Earth from up to 7.5 billion kilometers away. (Image credit: JHUAPL/SwRI)

Each mission has its own telecommunications system design, but all use radio waves to transmit signals. Radio waves, like light waves, are part of the electromagnetic spectrum.

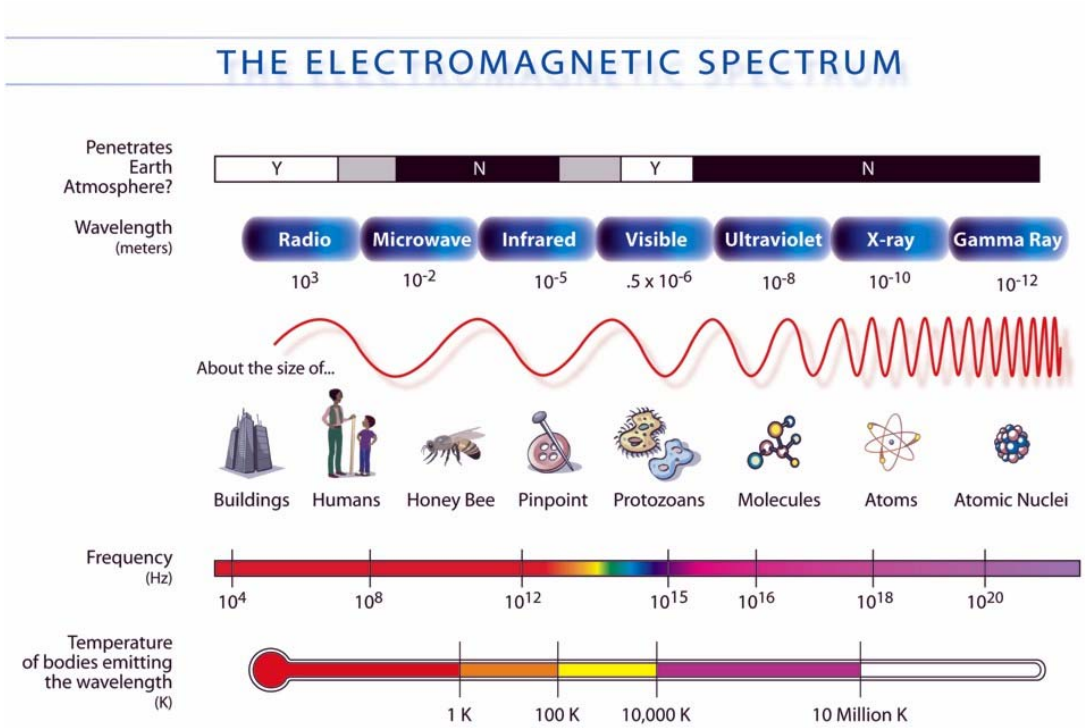


Figure 2. The electromagnetic spectrum. Notice radio waves penetrate Earth’s atmosphere, have long wavelengths, and low frequencies. (Image courtesy: NASA).

As you can see in Figure 2, radio waves have long wavelengths, low frequencies, and—important for our ground-based communications—they penetrate Earth's atmosphere. They don't require as much energy for the spacecraft to produce as shorter wavelength electromagnetic waves do, which allows for more energy to power the instruments and other systems on a spacecraft. And unlike x-rays and shorter wavelengths, you don't have to protect yourself from them because they are harmless to humans. All of these characteristics make radio waves an ideal choice for carrying signals to and from spacecraft, as well as for carrying signals here on Earth for our TVs and radios.

Like all waves of the electromagnetic spectrum, radio waves travel at the speed of light. The speed of light in a vacuum is 299,792,458 meters per second, often approximated simply as 3×10^8 m/s. It is usually denoted by the symbol *c*, for the Latin *celeritas,* meaning "swiftness." Here on Earth, when you turn on the light switch the light seems to reach your eyes instantaneously. However, if you happen to be a mission operations flight controller sending an important command to a spacecraft—a signal that must travel many billions of kilometers—even the speed of light can seem slow.

To better understand how we communicate with a spacecraft, let's pretend we want to send a command to the New Horizons spacecraft telling it to take a picture of Pluto as it passes in July of 2015. Here is what the process of sending this command might look like:

> The science team member responsible for the camera to be used to take the picture must provide specific details of how the spacecraft should be oriented, when to turn the camera on and off, etc. to the Science Operations Center (SOC).

> The SOC team members translate those objectives into a language understood by the spacecraft, a process known as "sequencing." Since it is very important there are no errors, the translated command is first sent to a simulator for testing. If the spacecraft simulator reacts to the command as desired, the "sequenced" command can be sent to the Mission Operations Center (MOC).

> The MOC communicates "directly" with the spacecraft. Sending a command "up" to the spacecraft is called "uplink." The MOC needs a bit of help uplinking, though. They actually send the command to a system of very sophisticated antennas distributed around the world called the Deep Space Network (DSN).

> The three DSN facilities are positioned around the globe approximately 120 degrees from each other so that as Earth rotates at least one antenna is always "visible" from space. The command is sent to the DSN and from there it is sent from the appropriate antenna to the spacecraft.

The radio signal travels at the speed of light (about 3 x 10^8 m/s) to the spacecraft, which is standing by listening for commands. How long does it take, you might ask, for the radio signal to reach the New Horizons spacecraft at Pluto, nearly 3 billion miles (4.6 billion km) from Earth? About 4.5 hours! I hope you planned on this delay when you sent the message to take a picture of Pluto!

While sending a radio signal to the moon takes only a little over a second, the delay in communication is far more dramatic with a spacecraft traveling to, say, Pluto and beyond. You might think that after sending the command to capture a picture of Pluto to New Horizons, we might receive the picture via "downlink" back from the spacecraft in just less than 9 hours (after about 4.5 hours of travel time each way). Not so!

Figure 3. The 70-meter (230 feet) antenna at the Goldstone Deep Space Communications Complex in the Mojave Desert, California. This is one of many radio antennae at Goldstone, which is one of the three facilities that make up NASA's Deep Space Network. (Image courtesy: NASA/JPL)

The signal from the spacecraft is very weak by the time it reaches Earth, since its energy has spread over a wider and wider area as it travels outward from the transmitter. In fact, the Earth-based antenna operated by the Deep Space Network must be able to detect a signal as weak as a millionth of a trillionth of a watt. If you stored energy transmitted at that rate for 40,000 years you could still light a Christmas tree bulb for only about 3 millionths of a second!

The signal from the spacecraft is not only extremely faint, it is embedded in a background of electromagnetic "noise." This is the incoherent background radiation produced by all other objects in the universe. It is always present in space, like static on your radio. Even while the New Horizons signal becomes fainter as the spacecraft gets farther away, the background noise remains at a roughly constant level. So the farther away the spacecraft, the more difficult it becomes to distinguish its signal from the noise. The signal-to-noise ratio (SNR) compares the power level of the desired signal with that of the noise. A higher SNR indicates a stronger signal—that is, one that is easier to distinguish from the background. The online interactive at http://patchyvalleyfog.com/signal_noise/ allows you to explore the concept of "signal-to-noise ratio" in greater detail.

As a final complication, the faintness of the signal in the presence of the background electromagnetic noise will force New Horizons to reduce its downlink rate for transmitting data to about 1000 bits per second. By comparison, if you connect to the internet with DSL or broadband cable modem, you "uplink" and "downlink" at a rate measured in "megabits" or million bits per second! At 1000 bits per second, it will take about 4 hours to downlink a picture of Pluto.

Communications with spacecraft are essential for successful missions. We need to monitor the heath of the spacecraft, uplink commands, and downlink data via these telecommunications systems. Information is sent and received using radio waves, which are ideal since they have long wavelengths, low frequencies, they don't require much energy to produce, and they penetrate the Earth's atmosphere. Unfortunately, spacecraft aren't the only objects in space emitting radio waves. Along with the data we receive from spacecraft also comes "noise," which must be distinguished from the data. This, among other reasons, is why it requires many people working together to take pretty pictures and collect valuable data of the planets and other objects in the universe we set out to explore.

Materials:

- free online metronome from http://www.metronomeonline.com/ or an actual metronome
- copy of some or all of **Planetary Images** pages (1 planet/page per group)
- copy of **Commands** (3 sets of 4 commands per group, there are 6 sets per page)
- copy of **"On a Mission" Student Data Sheet** (1 per group)
- tape (1 small piece per group, more if necessary)
- meter sticks (1 per group, if possible)
- stop watches (1 per group, if possible)
- transparency (or computer projection) of **How to take a picture of Pluto** sheet

Procedure:

Brief overview…

What the teacher will do: The teacher will introduce some of the concepts of spacecraft communication and then briefly explain the **Delayed Communication** hands-on activity. The teacher will then divide the class into groups so that each group has a "spacecraft," 2 or 3 "signal carrier," and at least one "mission control officer" (note: for groups larger than five, assign additional students to be "mission control officers.") With help from the students, he/she will arrange the classroom as indicated in the **In-Class Procedure** section, below. Once groups are in place, the teacher can begin the metronome and observe the groups as they perform the activity. The teacher will initiate the inquiry portion of the activity after groups have accomplished the first mission. After about 5 minutes of inquiry time, the teacher will observe groups as they perform the mission again using their unique solutions.

What the students will do: After learning about spacecraft communication, students will help the teacher arrange the classroom for the activity, as indicated above. The teacher will assign students to groups, which will then "race" to collect data from their planets (a picture of that planet) and return to their respective "mission control centers" using specific instructions and restrictions outlined in the **In-Class Procedure** section, below. Then the groups will devise a unique method to command the spacecraft that avoids the delay in communication. They will test their unique solution in a second trial of the activity. After all groups have completed their missions, students will participate in a discussion about the delay in spacecraft communications and how this might affect missions.

<u>Advance Preparation</u>

1. Either locate a metronome or use the URL provided in the **Materials** section for the free online metronome using computer speakers loud enough for the whole class to hear.
2. Make copies as directed in the **Materials** section.
3. Cut **Commands** sheets apart; there are 4 commands total with 6 sets of commands per sheet. Each group needs 3 sets of commands or half a page.

In-class Procedure

1. Introduce some of the concepts of spacecraft communication, using the **Background** section above if desired.
2. Show students the **How to take a picture of Pluto** transparency/computer projection. Explain that this is how to command the spacecraft to take a picture, but it does not illustrate how we then retrieve the picture/data collected. Tell them that they are going to learn more about the challenges of spacecraft communication in a hands-on activity.
3. Divide the class into groups of about 4-6 students. Further divide each group as follows:
    a. 1 spacecraft
    b. 2 or 3 signal carriers
    c. At least 1 mission control officer
4. With help from the students, arrange the classroom by moving aside tables and chairs so that each group has a "mission control center" (simply a space to gather) that is a few meters from a chair or spot on the floor to which you will attach their planet (picture). (See Figure 4, below).
   Note: to create a more competitive "race-like" atmosphere, arrange groups side-by-side so that all have a common starting line and are the same distance from their planet. Also, if no table is being used you may want to outline "mission control centers" using masking tape on the floor so it is clear that the "mission control officers" stay within the mission control boundary when they send commands via the "signal carriers."
5. Tape one of the **Planetary Images** to a chair or to the floor a few meters from each "mission control center" and distribute **Commands** and **"On a Mission" Student Data Sheets** to each group.
6. Once the groups have had an opportunity to review the instructions in the **"On a Mission" Student Data Sheets**, start the metronome and let the races begin!
   Note: you may want to review the rules as a class before beginning. Here is a summary of the instructions from the **Student Data Sheet ("On a Mission")**:
    - The "spacecraft" can only travel at a fixed speed, which is accomplished by placing one foot immediately in front of the other with every OTHER tick of the metronome.
    - The "spacecraft" must travel in a straight line until it receives the next command from one of the "signal carriers."
    - When delivering a command, the "signal carriers" travel at a fixed speed, which is accomplished by placing one foot immediately in front of the other with EVERY tick of the metronome.
    - When the "signal carrier" is returning back to the "mission control center" after having delivered a command they do not have to travel at a fixed velocity.
    - A "signal carrier" delivers one of four commands to the "spacecraft" at a time: stop, turn 90 degrees to the right, turn 90 degrees to the left, or turn on camera and collect a picture (i.e. retrieve picture of planet that is taped to floor/chair).
    - To "deliver" a command, the "signal carrier" must pass the command to the "spacecraft," the spacecraft reads it, then the "signal carrier" collects it and returns it to the "mission control officer(s)" for potential re-use.

- After a command has been "delivered," the "spacecraft" must carry out that command until the next one is delivered (i.e. if the spacecraft is commanded to turn right, it must turn 90 degrees to the right and then place one foot in front of the other with every OTHER tick of the metronome in that direction until another command is delivered.)
- A "signal carrier" must receive one command from the mission control center, deliver it, and then return to the mission control center to receive the next command, and then deliver that command, etc. (i.e. each signal carrier cannot receive or deliver more than one command at a time).
- Once the spacecraft has received the command to collected the picture of the planet, it must pick up the picture and pass it to the "signal carrier," who then carries it back to the "mission control center"
- Groups will operate in this manner until the spacecraft has traveled to the planet, made one complete orbit, collected the picture of the planet and passed it to a signal carrier, and returned to the mission control center.
- Note that it may take more than one orbit to accomplish the goal of collecting the data/picture before returning to the mission control center depending on how well the signal carriers time the delivery of their commands.

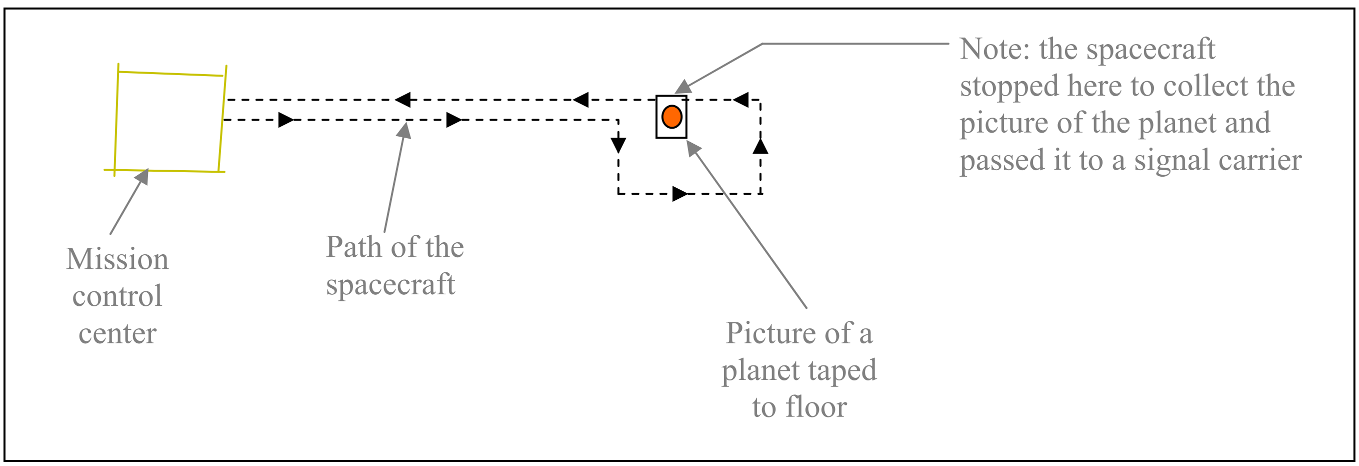


Figure 4. Diagram of a potential mission "trajectory" from a bird's eye view.

7. After all groups have accomplished their missions successfully, ask students to return the picture of their planet to its previous location on the floor/chair and gather at their mission control centers. Explain that engineers have worked to solve the challenges that a delay in communication can cause. Working as a team, groups should now spend about 5 minutes devising their own unique solutions to the delayed command problem. Provide several meter sticks, tape, and stop watches for their use and allow them to move between their mission control centers and planets as they come up with solutions.
8. After about 5 minutes of inquiry time, ask groups to return to their mission control centers to perform their mission again, but this time using the solutions to the delay in

9. Once groups have completed their missions using their unique solutions, ask them to report their solutions with the team finishing in first place reporting first, the team that finished second reporting second, etc. Facilitate discussion about the solutions. Some questions may include: why were some able to complete the mission faster, which solutions were particularly simple or elegant, and—knowing what they know now—what might work even better?
10. Finally, ask them to individually calculate how long it takes to send a radio signal to the New Horizons spacecraft when it is near Pluto. You may wish to assign this calculation as homework and collect the work for assessment. Provide students with this information:

    Distance = 4.6 billion kilometers
    Speed of light $\approx 3 \times 10^8$ m/s

    For your reference, answer:

$$t = (\Delta\text{distance})/\text{velocity} = \left(\frac{4.6 \text{ billion km}}{3 \times 10^8 \text{ m/s}}\right) \cdot \left(\frac{1000 \text{ m}}{1 \text{ km}}\right) \cdot \left(\frac{1 \text{ hr}}{3600 \text{ s}}\right) = 4.3 \text{ hrs}$$

Extensions and Adaptations:

- Have students calculate the distance the spacecraft traveled. In the second part of the hands-on activity (see #7 in the In-class Procedure section) add to the complexity by asking students to determine a way to measure the total distance traveled by the spacecraft. If they need hints, explain that they are walking at a fixed speed with one foot immediately in front of the other with every other tick of the metronome. They can calculate this fixed speed by measuring the length of the spacecraft person's foot and the number of seconds in two ticks of the metronome. (Speed = (change in distance or length of foot)/(change in time or seconds in two ticks of the metronome)). If they record the total travel time for the spacecraft they can then calculate the distance with:

  change in distance (unknown) = (fixed speed (calculated above)) x (total travel time of spacecraft)

  or distance = speed x time

References:

- For more information about the Deep Space Network, visit their website: http://deepspace.jpl.nasa.gov/dsn/
  Or, for a student-version of their website: http://spaceplace.nasa.gov/en/kids/dsn_fact1.shtml

Standards:

<u>National Science Education Standards (NRC, 1996)</u>

Content Standards: 5-8

Science and Technology, Content Standard E:

- Abilities of technological design
- Understandings about science and technology

<u>Benchmarks (AAAS, 1993, 2008)</u>

Chapter 3. The Nature of Technology

A. Technology and Science, Grades 6-8:

- Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.

C. Issues in Technology, Grades 6-8:

- The human ability to shape the future comes from a capacity for generating knowledge and developing new technologies—and for communicating ideas to others.
- Scientific laws, engineering principles, properties of materials, and construction techniques must be taken into account in designing engineering solutions to problems.

Chapter 8. The Designed World

D. Communication, Grades 6-8:

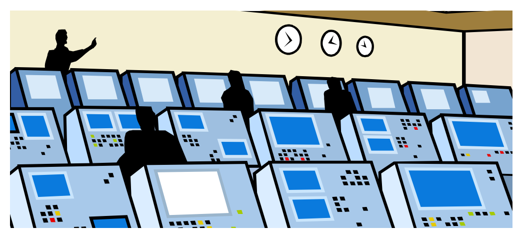
- Information can be carried by many media, including sound, light, and objects. In the 1900s, the ability to code information as electric currents in wires, electromagnetic waves in space, and light in glass fibers has made communication millions of times faster than mail or sound.

How to take a picture of Pluto

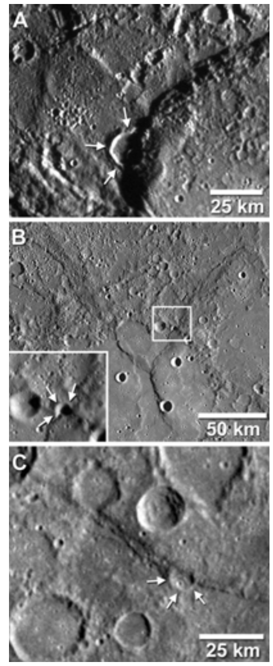
First, the science team responsible for one of the cameras writes a command, which they send to the Science Operations Center

Next, a team at the Science Operations Center translates those objectives into a language understood by the spacecraft ("sequencing") and tests the translation on a simulator. The properly sequenced command is then sent to the Mission Operations Center.

The MOC communicates "directly" with the spacecraft by sending the command to a system of very sophisticated antennas distributed around the world called the Deep Space Network.



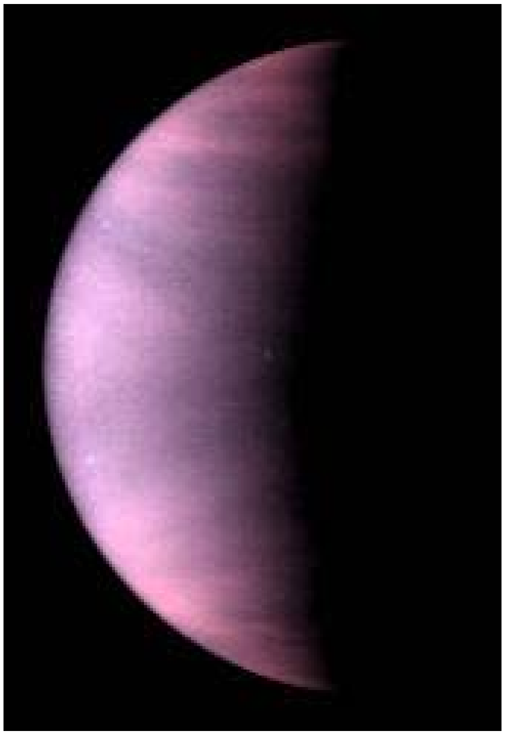
The command is then sent from one of these 70-meter antennae operated by the Deep Space Network to the spacecraft.

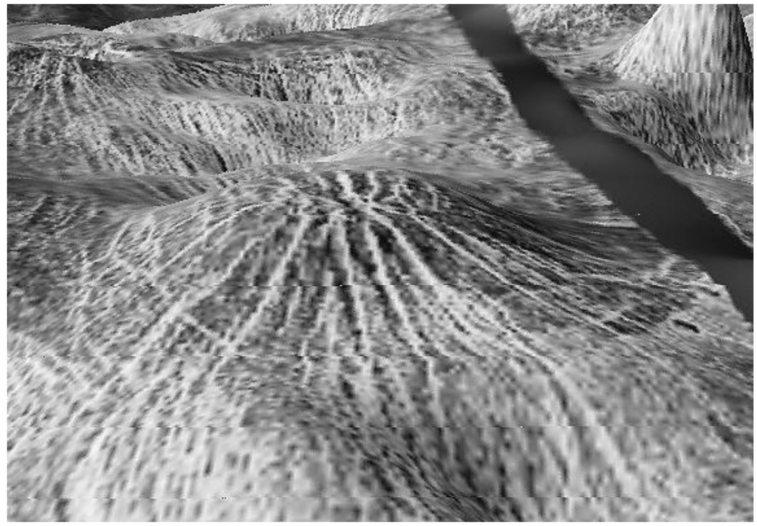


<u>Mercury</u>
(left) A false color image of Mercury.

(right) Numerous examples of craters on Mercury.

(Images courtesy: NASA/JHU-APL/ASU/CIW)

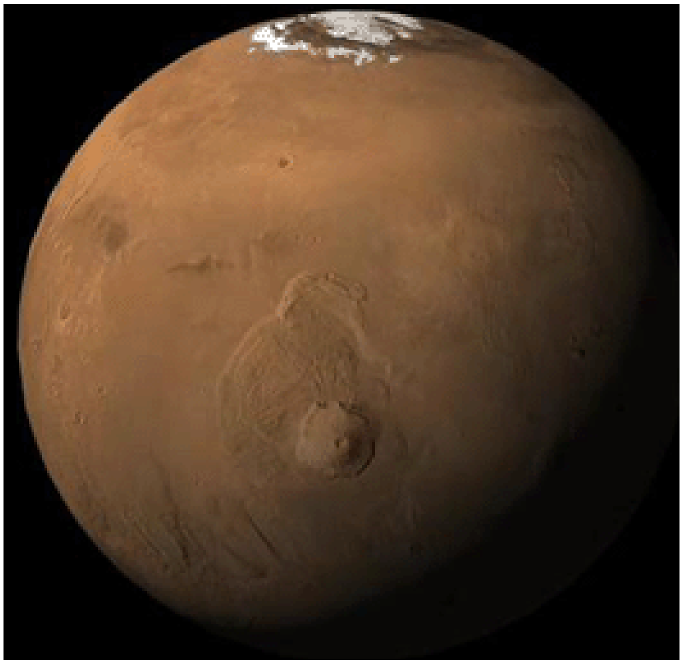


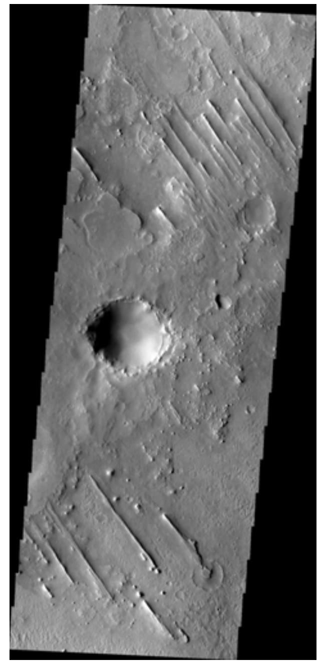


<u>Venus</u>
(left) This is a NASA Hubble Space Telescope ultraviolet-light image of the planet Venus.

(right) A circular hills with star-shaped fractures inside a volcanic feature on Venus.

(Images courtesy: (left) NASA/JPL, (right) NASA/JPL/USGS)

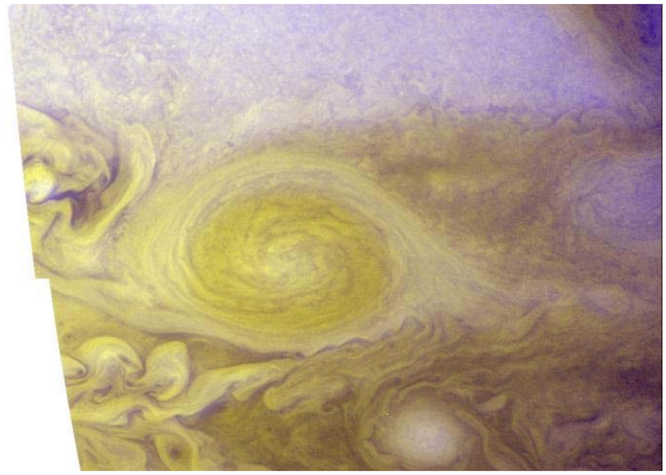




<u>Mars</u>
(left) An orbital view of Mars with Olympus Mons, the tallest volcano in the solar system, below center.

(right) These linear ridges are just one of the many interesting surface features in the Meridiani region of Mars.

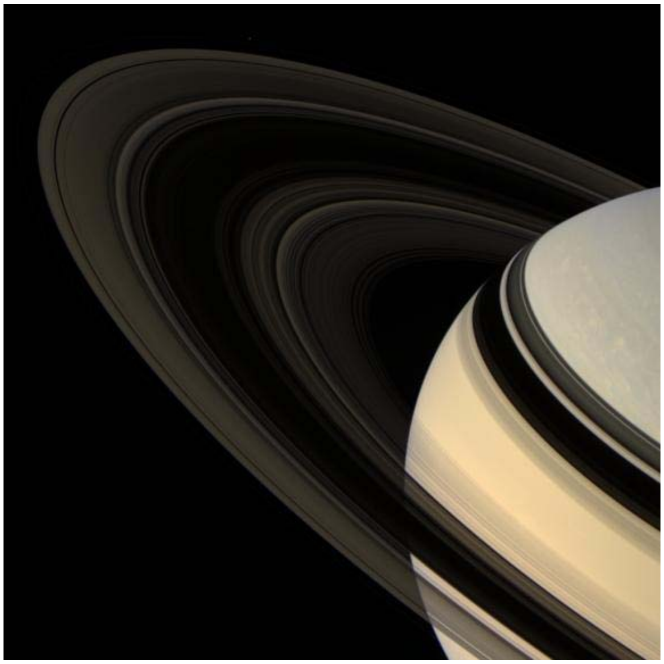
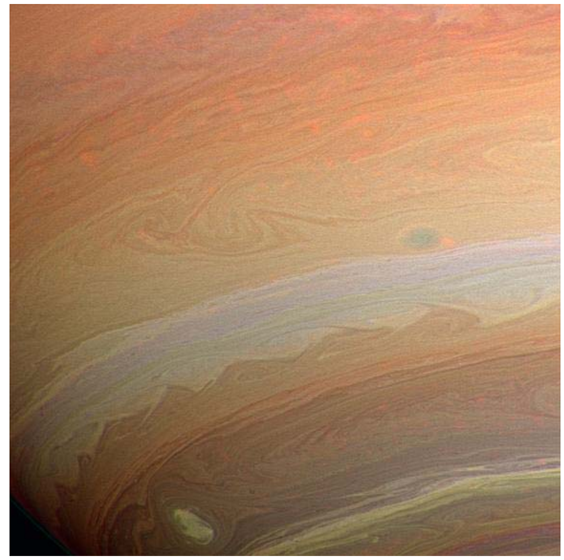
(Images courtesy: (left) NASA/JPL-Caltech/University of Arizona, (right): NASA/JPL/ASU)

<u>Jupiter</u>
(left) A true-color mosaic of Jupiter. (Note: a “mosaic” is a collection of pictures pieced together to make one more-complete picture.)

(right) An amazing color portrait of Jupiter's "Little Red Spot."

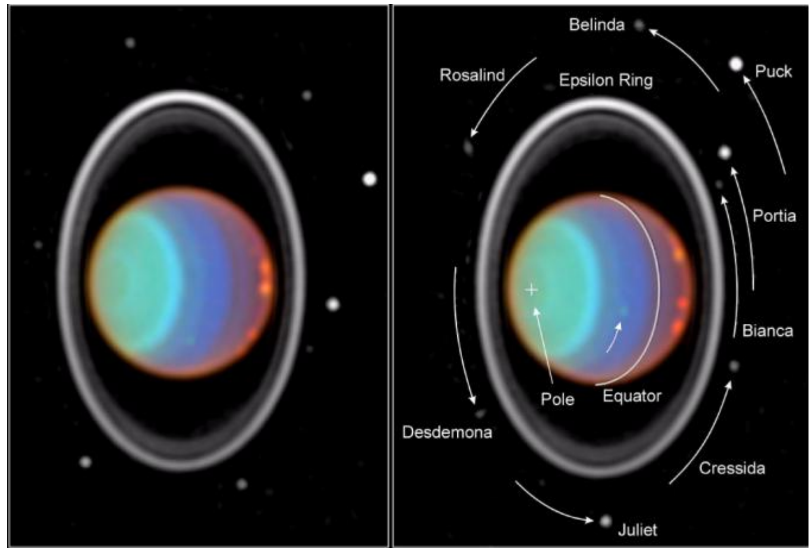
(Images courtesy: (left): NASA/JPL/Space Science Institute, (right): NASA/JHU-APL/SwRI)

Saturn
(left) The rings of Saturn.

(right) Whorls, streamers and eddies play in the banded atmosphere of Saturn.

(Images courtesy: NASA/JPL/Space Science Institute)

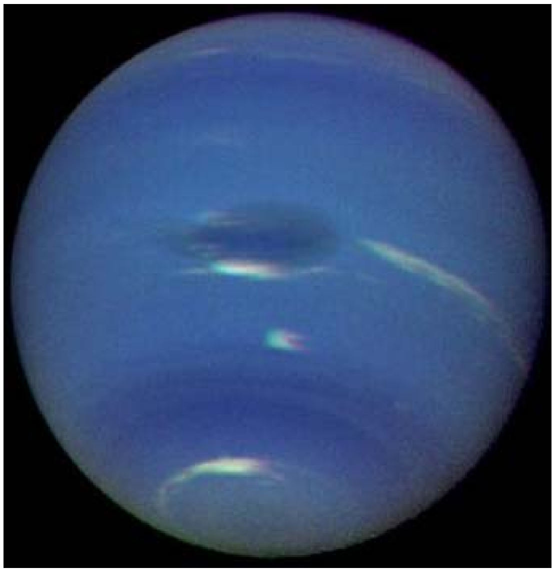


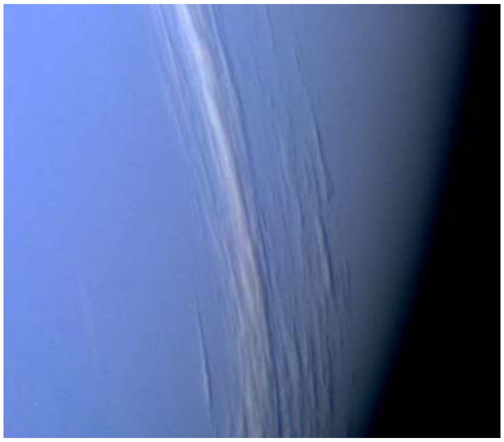
<u>**Uranus**</u>

(left) A picture of Uranus that has been processed to show the planet as human eyes would see it from the vantage point of the spacecraft.

(right) False-color images of Uranus showing its very faint rings and 10 small satellites.

(Images courtesy: (left) NASA/JPL, (right) NASA/JPL/STScI)

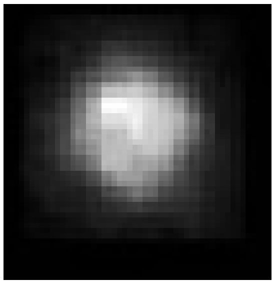


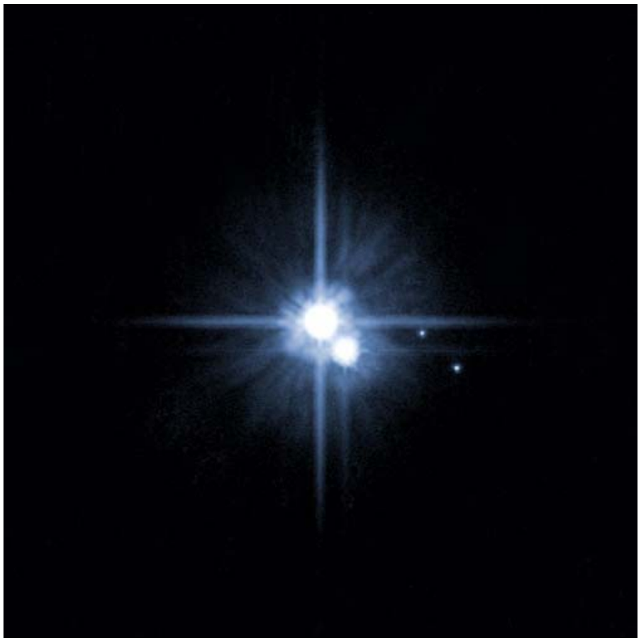


Neptune
(left) An image of Neptune's blue-green atmosphere. The Great Dark Spot (GDS), seen at the center, is about 13,000 km by 6,600 km in size -- as large along its longer dimension as the Earth.

(right) This image provides obvious evidence of vertical relief in Neptune's bright cloud streaks.

(Images courtesy: NASA/JPL)





Pluto

(left) An actual image of Pluto from the Hubble Space Telescope. The picture was taken when Pluto was at a distance of 3 billion miles (roughly 5 billion kilometers) from Earth.

(right) Hubble Space Telescope images taken in February 2006 confirmed the presence of two new moons around the distant planet Pluto. The moons' orbits are in the same plane as the orbit of the much larger satellite Charon (discovered in 1978). In this image, Pluto is in the center and Charon is just below it. The new moons, named Hydra and Nix, are approximately 40,000 and 30,000 miles away from Pluto, respectively. Hydra is to the right and just below Charon. Nix is to the right of Pluto and Charon.

(Images courtesy: (left) NASA/ESA/SwRi/Lowell Observatory/McDonald Observatory, (right) NASA/ESA/JHU-APL/SwRI/HST)

STOP	**STOP**	**STOP**
TURN 90° TO THE RIGHT	**TURN 90° TO THE RIGHT**	**TURN 90° TO THE RIGHT**
TURN 90° TO THE LEFT	**TURN 90° TO THE LEFT**	**TURN 90° TO THE LEFT**
COLLECT DATA: PICTURE OF PLANET	**COLLECT DATA: PICTURE OF PLANET**	**COLLECT DATA: PICTURE OF PLANET**
STOP	**STOP**	**STOP**
TURN 90° TO THE RIGHT	**TURN 90° TO THE RIGHT**	**TURN 90° TO THE RIGHT**
TURN 90° TO THE LEFT	**TURN 90° TO THE LEFT**	**TURN 90° TO THE LEFT**
COLLECT DATA: PICTURE OF PLANET	**COLLECT DATA: PICTURE OF PLANET**	**COLLECT DATA: PICTURE OF PLANET**

On a Mission

Did you ever wonder how the amazing pictures of planets return to Earth before the spacecraft that captured them? The answer is radio waves, with help from very large antennae! Radio waves are part of the electromagnetic spectrum just like the light waves that we see. Light waves, radio waves and all of the other electromagnetic waves travel at the speed of light—about 300,000,000 meters per second! Seems pretty fast, doesn't it? In this activity you will explore some of the challenges faced when we try to communicate with spacecraft.

Write your name next to your role:

Spacecraft: ________________________

Signal Carriers:_____________________

____

____

Mission Control Officer(s): ________________

____

Be sure to read the information for all of the roles, below, before beginning the activity!

SPACECRAFT:

OBJECTIVE: Your objectives are to:

- travel to your planet
- collect data (a picture) from your planet
- send the picture back to Mission Control (via a Signal Carrier)
- orbit the planet
- return home to Mission Control

SPEED: As all spacecraft do, you must travel at a given speed. Your speed for this activity is accomplished by placing one foot immediately in front of the other (heel-to-toe) with EVERY OTHER tick of the metronome.

DIRECTION: You must travel in a straight line until one of the Signal Carriers delivers a command to you. When you receive a command you read it, return it to the signal carrier and then carry out that command until the next one is delivered. For example, if the command says "turn 90 degrees to the right," you must turn 90 to the right of your current path and travel at your fixed speed in the new direction until you receive another command.

SIGNAL CARRIERS:

OBJECTIVE: Your objective is to deliver commands to the Spacecraft in a timely manner so that the Spacecraft can accomplish its goals. You will also retrieve the data (picture) from the spacecraft and deliver it to the Mission Control Center.

SPEED: As you learned, radio waves travel at the speed of light. For this activity, the speed of light is accomplished by placing one foot immediately in front of the other (heel-to-toe) with EVERY tick of the metronome. You'll be traveling twice the speed of the Spacecraft! However, you only have to travel this speed when you are DELIVERING a command to the Spacecraft or delivering data to the Mission Control

Center. When you are not acting as a radio wave (i.e. not delivering a command or data) you do not have to travel at the speed of light.

COMMANDS: You will receive one command from a Mission Control Officer at a time, deliver it, and return it to Mission Control. The four commands are: stop, turn 90 degrees to the right, turn 90 degrees to the left, and turn on camera and collect a picture.

MISSION CONTROL OFFICER(S):

OBJECTIVE: Your objective is to send commands to the Spacecraft via the Signal Carriers so that the Spacecraft can accomplish its goals as quickly as possible. Each Signal Carrier can only deliver one command at a time, so you have to plan ahead!