# WAVES AND INFORMATION TRANSFER

## EDUCATOR GUIDE

INSIDE NASA
FROM DREAM TO DISCOVERY

Museum of Science®

# Connections to Education Standards

## Next Generation Science Standards:

| PERFORMANCE EXPECTATIONS | |
|---|---|
| **4-PS4-3** | Generate and compare multiple solutions that use patterns to transfer information. |
| **MS-PS4-2** | Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. |
| **HS-PS4-5** | Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. |

## Massachusetts Science and Technology/Engineering Standards (2013 Draft)

| STANDARDS | |
|---|---|
| **4-PS4-3** | Develop and compare multiple ways to transfer information through encoding, sending, receiving, and decoding a pattern. |
| **MS-PS4-2** | Use diagrams and other models to show that both light rays and mechanical waves are reflected, absorbed, or transmitted through various materials. |
| **MS-PS4-3** | Present qualitative scientific and technical information to support the claim that digitized signals (sent as wave pulses representing 0s and 1s) can be used to encode and transmit information. |
| **MS-ETS3-1 (MA)** | Explain the function of a communication system and the role of its components, including a source encoder, transmitter, receiver, decoder, and storage. |
| **HS-PS4-1** | Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media. Recognize that electromagnetic waves can travel through empty space (without a medium). |
| **HS-PS4-5** | Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. |
| **HS-ETS3-2 (MA)** | Use a model to explain how information transmitted via digital and analog signals travels through the following media: electrical wire, optical fiber, air, and space. Analyze a communication problem and determine the best mode of delivery for the communication(s). |

# Connections to Education Standards *(continued)*

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## Massachusetts Science and Technology/Engineering Curriculum Framework (2001)

| GRADE LEVEL | SUBJECT | LEARNING STANDARD |
|---|---|---|
| 6 – 8 | Technology/ Engineering | 3.1: Identify and explain the components of a communication system, i.e., source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination. |
| 9 or 10 | Physics | 6.1: Describe the electromagnetic spectrum in terms of wavelength and energy, and be able to identify specific regions such as visible light. |

### TEACHER TIP

DOWNLOAD FIELD TRIP GUIDES!

Use these handy activity sheets for chaperones and students to make the most of their day at the Museum. Download them before your visit: mos.org/educators.

**Bolded** words are defined further in the glossary (page 11).

## Background

**Space telescopes and probes have given us a window to the universe, allowing humanity to see the births and deaths of stars and to the very edge of known space.** But getting that information back to Earth is a lot more complicated than you might think.

## Communicating in Space

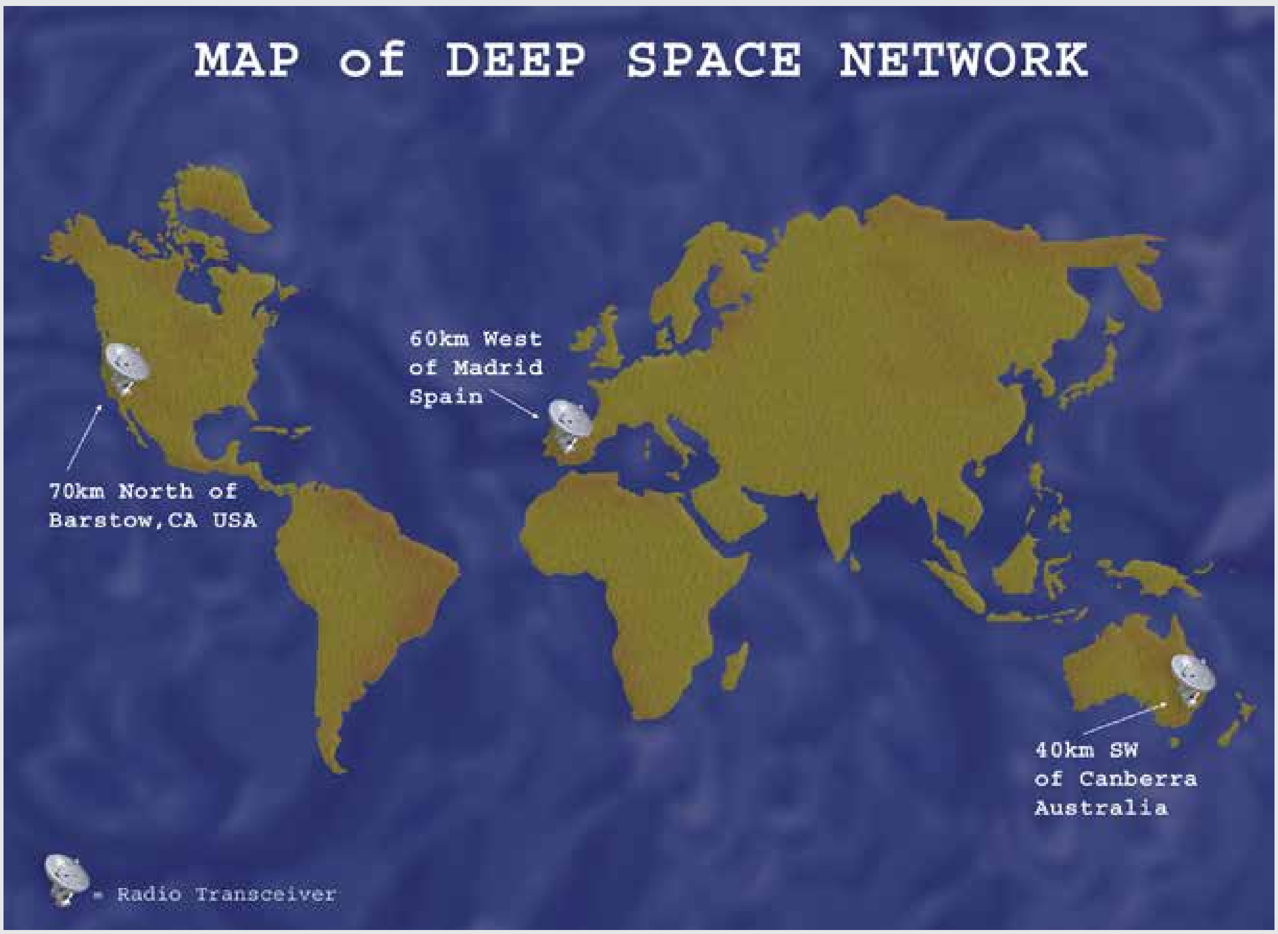
**Communication with a spacecraft is essential for any mission, but especially those that are unmanned.** Engineers on the ground need to monitor systems, send commands, and receive data, and to do so they rely on waves from different parts of the electromagnetic spectrum. Because these waves are traveling through the vacuum of space, they all travel at the speed of light—the fastest speed at which information can be transmitted.

**Within the electromagnetic spectrum, radio waves are used for spacecraft communications.** One of their most beneficial qualities is that radio waves can penetrate the Earth's atmosphere to reach communications equipment on the ground. They also require very little energy on the part of the spacecraft to produce. However, even with these characteristics, radio waves sent to and from a spacecraft can be very weak by the time they reach their destination, due to the large distances they must cover. To deal with this, radio dishes on Earth are often very large and able to be precisely pointed to collect as much of the signal as possible. Engineers are also making improvements to signal amplifiers and experimenting with higher frequencies to maximize the efficiency and quality of radio signals.

**Deep Space Network complex in Canberra, Australia.** *Image: NASA/JPL.*

## WHAT IS THE DEEP SPACE NETWORK?

The Deep Space Network is an array of giant radio antennas spread across the world, tasked with supporting and communicating with interplanetary space missions. The network consists of three facilities spaced approximately 120 degrees apart in longitude, located in Goldstone, California; Madrid, Spain; and Canberra, Australia. Their spacing is important, because it means that no matter where a spacecraft is in the solar system, at least one facility has a line of sight to it at all times. As such, it is our primary method of communication with distant spacecraft.




**Map of the global distribution of the Deep Space Network facilities.** *Image: CXC.*

## Light Speed and Travel Time

**Beyond the strength of the signal, distance is important in communications because it means that spacecraft cannot receive instant commands to deal with problems or sudden emergencies.** Even though radio waves travel at the speed of light, they still must cover such large distances that there are significant delays between when they are sent and when they are received.

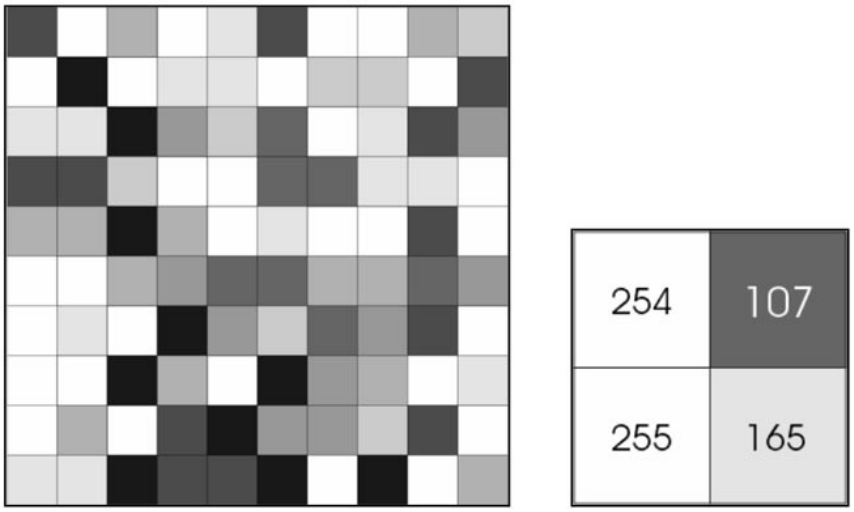
**For example, for light to travel from the Sun to Earth takes about 8 minutes.** That means the Sun is 8 **light minutes** away from Earth. Even further afield, Pluto is almost 4.5 light hours away.

**To deal with these delays, engineers have to program a series of commands for the spacecraft ahead of time.** These commands are tested on a simulator in advance, reducing the risk for errors, at which point they are sent to the spacecraft. In some cases, engineers are left to wait for hours before they know if their commands were executed according to plan. This reflects the importance of patience and planning in modern space exploration.

## How a Space Telescope Works

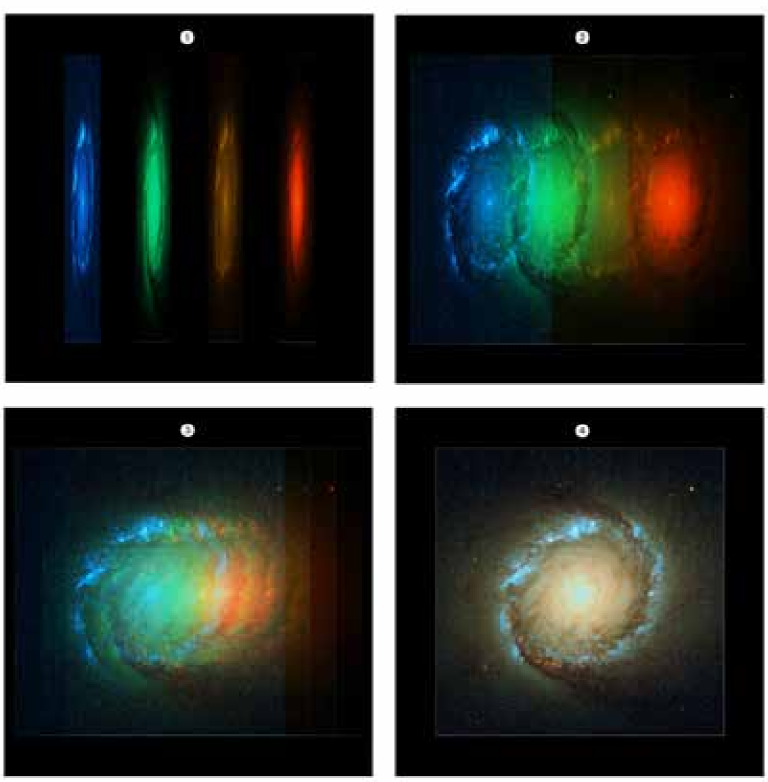
**Pictures are some of the most common pieces of information sent back from spacecraft.** However, what a telescope "sees" is not the same as what you might see in the eyepiece of a telescope here on Earth.

**In some ways, cameras on many telescopes and space probes are similar to the digital camera in your smartphone.** Both use something called a **charge-coupled device** (CCD), which collects light emitted by or reflected off objects. The CCD is a thin wafer of silicon divided into thousands, or even hundreds of thousands, of tiny light-sensitive squares. Each square corresponds to an individual pixel in the final image, and the more pixels you have, the more detailed the image. Squares on the CCD that line up with bright objects in the field of view will collect more photons, making those pixels appear brighter in the resulting image. This brightness is recorded on a greyscale ranging from 0 (black) to 255 (white). So even though the final products we may see from telescopes like the Hubble Space Telescope could appear in stunning color, it is important to remember that the original images are recorded essentially in black and white.




**Example of pixels and greyscale numbering.**
*Image: Spacetelescope.org.*

**To measure color, different filters can be placed in the light path of the telescope, with each filter designed to let through only certain wavelengths (colors) of light.** By taking multiple images of the same object through a variety of filters, scientists can then combine the images to make a comprehensive color picture.



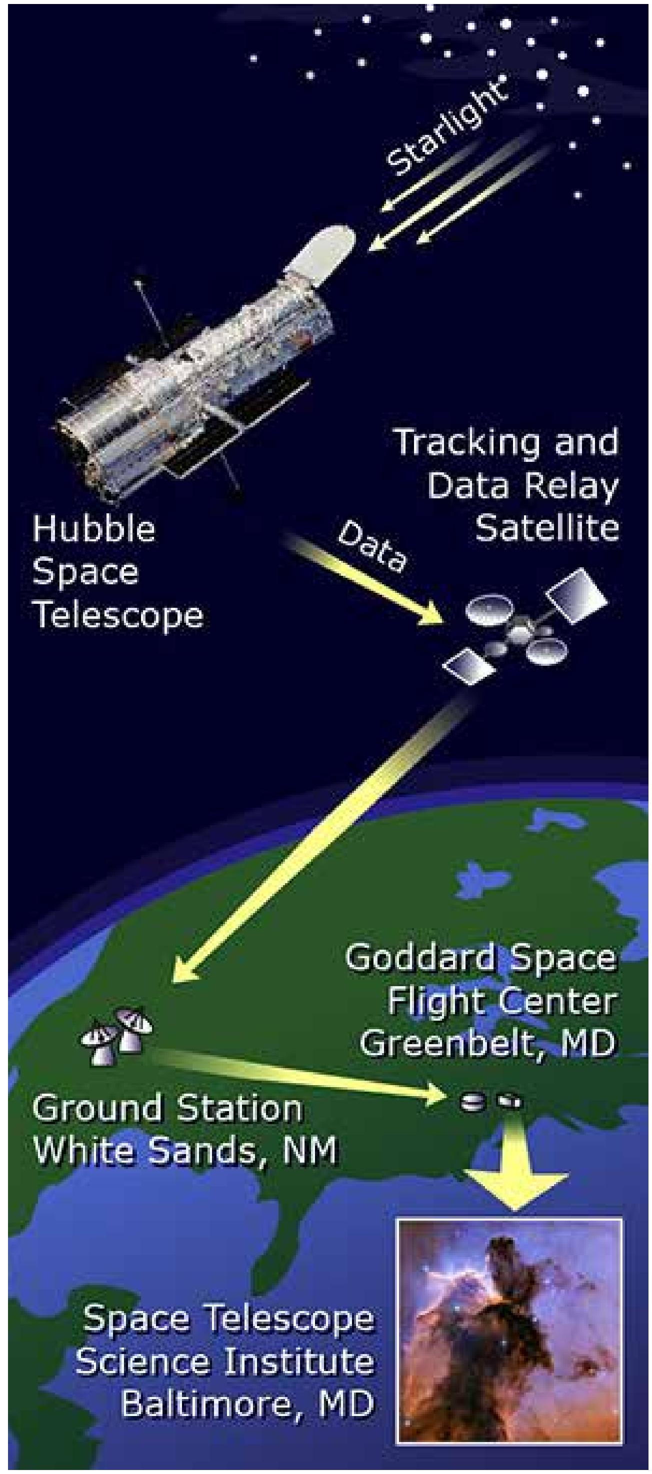
**An example of creating a composite color image from images taken through a variety of filters.**
*Image: Spacetelescope.org.*

## Getting the Data

**To transfer the data collected by the CCD to the scientists, the pixels are sent to Earth via radio waves in the same order as they are recorded on the CCD.** Once the waves reach Earth, the pixels will be reconstructed into an image to match what the spacecraft originally saw.

**However, it is not a straight path from A to B.** The Hubble Space Telescope is a great example of the path of astronomical images and data. Orbiting the Earth once every 90 minutes, Hubble is pretty close to home in the grand scheme of things. However, the information it records has a rather convoluted path from the CCD to your computer.

**Twice a day, Hubble transmits data to a satellite in geosynchronous orbit, which is actually farther away than Hubble itself.** This farther satellite **downlinks** the information to one of two 18-meter (60-foot) high-gain antennas on Earth, which then bounce the data to Goddard Space Flight Center and the Space Telescope Science Institute.




**Path of data from Hubble to the ground.** *Image: Hubblesite.org.*

**For spacecraft farther away, the receivers on the ground must also deal with all the background "noise" that has been mixed in with the signal along the way.** Since the noise remains approximately constant throughout the universe, this **signal-to-noise** ratio means that very distant (and therefore weak) spacecraft signals can easily be overwhelmed. To deal with this problem, the transmission rate of data from spacecraft is slowed down significantly so it can be understood, the equivalent of speaking loudly and slowly in a crowded room in order to be heard. This slowing of the downlink also means that the transfer of data is quite a lengthy process.

## Conclusion

Being able to communicate clearly and effectively in space is a daily challenge for engineers, but the products of that communication have allowed us to see and study our planet, the solar system, and beyond.

# Online Learning Tools



**Below are some links to external websites with useful information on waves and information transfer and, in some cases, activities that can be used in the classroom.**

## Earth Calling

**nasa.gov/pdf/583093main_Earth_Calling.pdf**
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. *Recommended for grades 6 – 8.*

## How Does a Spacecraft Take a Picture?

**deepspace.jpl.nasa.gov/education/picturesinspace/#**
A short animated video showing how CCDs work in a spacecraft and how the information is then sent back to Earth.

## How Does NASA Communicate With Spacecraft?

**qrg.northwestern.edu/projects/vss/docs/communications/zoom-messages.html**
A breakdown of basic and more advanced information related to how we communicate with spacecraft.

## How to Yell Across the Solar System

**spaceplace.nasa.gov/x-ponder/en/**
A short description of how a spacecraft transmits information.

## NetworKing

**nasa3d.arc.nasa.gov/visualizations/networking**
An app-based game that allows players to create and run their own communications networks. *Recommended for grades 9 – 12.*

## Signal-to-Noise Ratio

**nasa.gov/pdf/579711main_Signals_and_Noise_6-8.pdf**
A hands-on activity and online interactive exploring the concept of the signal-to-noise ratio in spacecraft communications. Also explores mathematic concepts such as proportions and ratios. *Recommended for grades 6 – 8.*

## Speaking in Phases

**spaceplace.nasa.gov/en/educators/dsn_signal_mod_web.pdf**
Further background on binary notation and phase modulation as they are related to spacecraft communication.

# Glossary of Terms

**Charge-coupled device** An integrated circuit etched onto a silicon surface, forming light-sensitive elements called "pixels."

**Downlink** A link from a satellite to a ground station along which data is transmitted.

**Electromagnetic waves** Waves that do not need a medium in order to propagate, so they can travel through a vacuum. These waves are created because electrical and magnetic fields couple together.

**Frequency** The number of waves that pass a fixed place in a certain amount of time.

**Light minute** The distance something can travel, at the speed of light, in one minute.

**Radio waves** A type of electromagnetic radiation with wavelengths ranging from 1 millimeter to 100 kilometers. These waves are often used in communications, both on Earth and in space.

**Signal-to-noise ratio** A comparison of the level of a desired signal to the level of background noise.

**Wavelength** The distance between two successive crests of a wave.

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