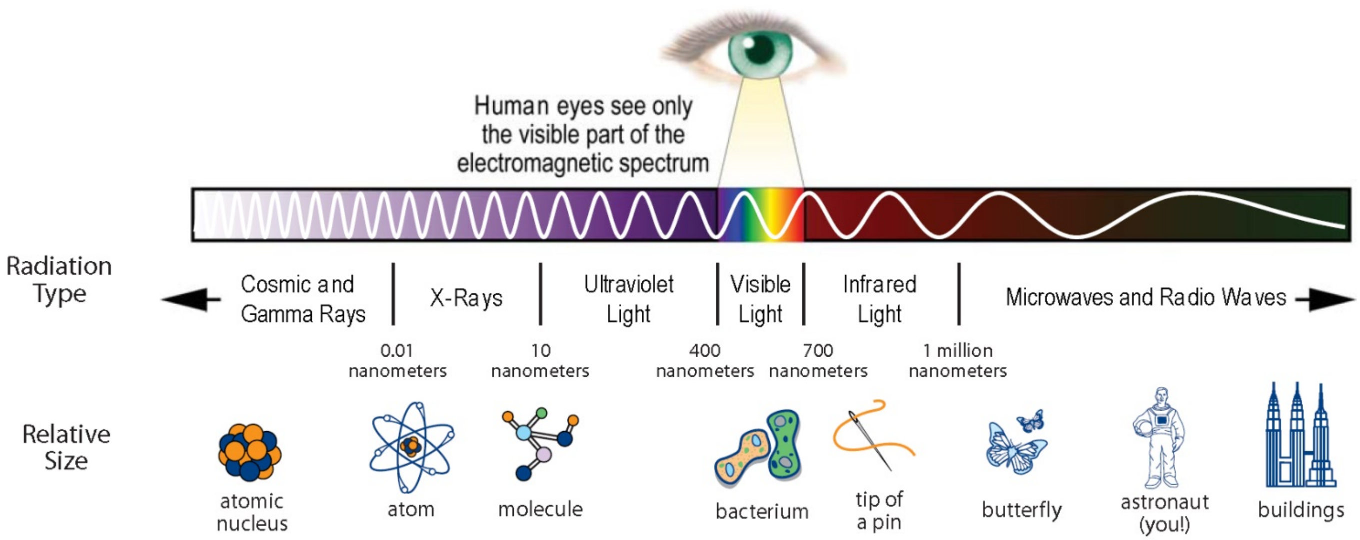
What Is Electromagnetic Radiation?

How are radio waves, visible light, and X-rays similar? They are all types of electromagnetic radiation. All three travel — radiate — and are made or detected by electronic (or magnetic) sensors, like a T.V., a digital camera, or a dentist's X-ray machine. Types of electromagnetic radiation with which we are most familiar include ultraviolet light (causing sunburn), infrared light (in remote controls), and microwaves (in ovens). Electromagnetic radiation is made of electromagnetic waves. It is classified by the distance from the crest of one wave to the crest of the next — the wavelength. These waves can be thousands of miles long, like radiowaves, or smaller than an atom, like gamma rays! Collectively, these wavelengths make a spectrum — the electromagnetic spectrum.

The shorter the wavelength, the more energetic the electromagnetic radiation. Radio waves, including microwaves, have long wavelengths and relatively low energy levels. Visible light, ultraviolet rays, X-rays, and gamma rays have shorter wavelengths and correspondingly higher levels of energy. The wavelengths of ultraviolet light, X-rays, and gamma rays are short enough to interact with human tissue and even alter DNA.



What Is Reflectance Spectroscopy?

Spectroscopy is the study of the electromagnetic radiation emitted, absorbed, or reflected by an object.

Reflectance spectroscopy is the study of electromagnetic radiation that is reflected from an object, such as a leaf, a rock, or ice on a distant planet's surface. We have a source of electromagnetic radiation right in our solar system — our Sun! The light we see with our eyes coming from moons and planets is actually reflected sunlight. Scientists can study this visible light, and other portions of the electromagnetic spectrum reflecting from planets and moons, to learn about their physical and chemical properties.

How Do Scientists Determine The Composition Of Rocks They Can't Touch?

Our eyes are pretty good reflectance spectrometers for measuring the visible light portion of the electromagnetic spectrum. However, some things that are very different, such as coal and basalt, look the same to us — both are black rocks. How can we tell them apart if we cannot touch and analyze them? Special instruments, spectrometers, detect wavelengths of electromagnetic radiation beyond what our eyes detect. This additional information helps distinguish different materials.

Spectrometers onboard spacecraft collect spectral data reflected from the surfaces of planets or moons. Scientists compare the "mystery" planetary spectra with reflectance spectra collected in the laboratory from known materials to decipher what rocks, minerals, and elements are on the planet's surface.

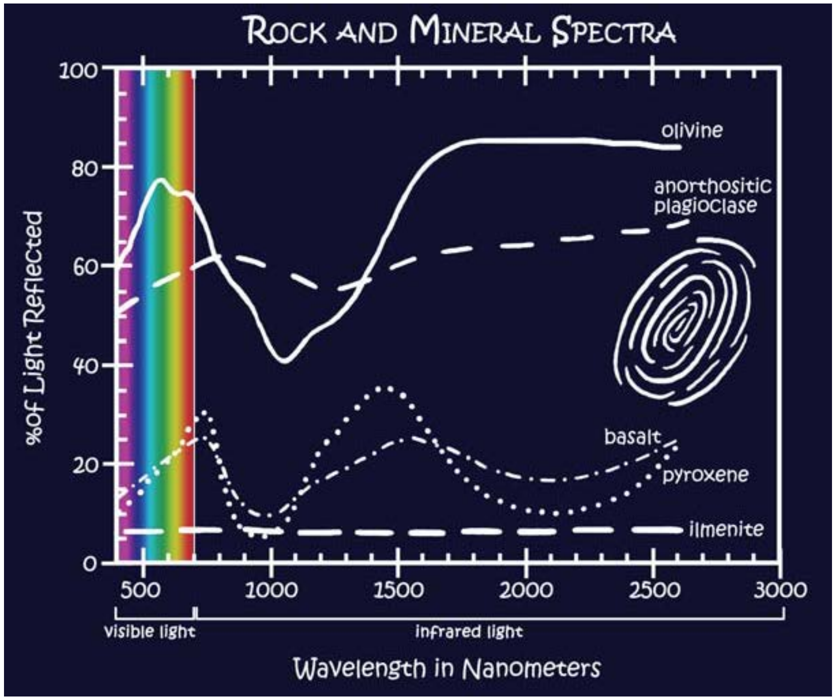
The minerals that make up rocks have defined chemical compositions and rigid atomic structures. When sunlight strikes the rock's surface, the composition and atomic structure of the different minerals control the wavelengths they absorb or reflect. Because each mineral absorbs and reflects electromagnetic radiation at unique wavelengths, each mineral has a characteristic spectral "fingerprint" or reflectance spectrum.

Detectors in a spectrometer measure specific, narrow ranges of wavelengths reflected from a surface. Each detector measures a different portion of the spectrum. One detector may measure the amount of reflection of wavelengths of visible red light between 630 to 650 nanometers from a particular place on a planet's surface, while another may measure the amount of reflection of infrared wavelengths between 900 and 1000 nanometers from that same place. For any location, scientists can construct a spectrum by plotting the brightness — how much radiation was reflected from the surface — for each of the ranges of wavelengths.

Scientists examine this planetary reflectance spectrum and compare the shape of the curve to reflectance spectra of known minerals. The low areas on the curve are where particular wavelengths of light have been absorbed. The peaks are where light has been reflected. Scientists can use spectra collected from Earth samples and the rocks brought back by the Apollo astronauts to help them identify the composition of areas on the Moon.

Rocks are made of several minerals. Scientists combine the spectra of known minerals to acquire a curve that fits the planetary reflectance spectrum. Through this process they determine the amount of each mineral — and the elements that form that mineral — present in the rock.

A spectrum from a known place on a planet helps to identify the rocks, minerals, and elements for that particular place. Scientists use spectra from across a planet's surface to map the distribution of these materials without actually sampling the rocks!



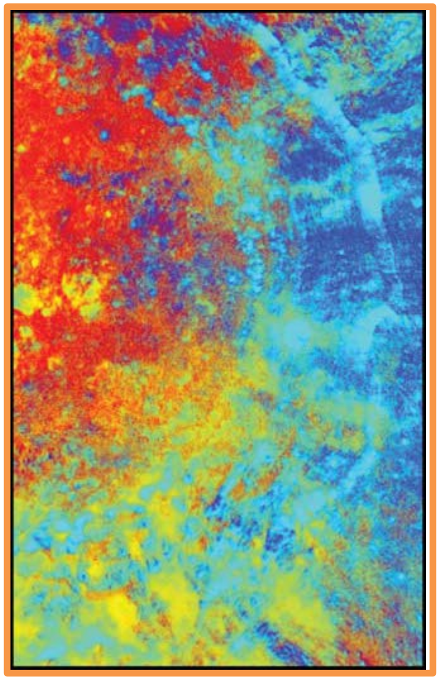
This graph shows reflectance spectra of several minerals common on Earth and the Moon, and a lunar basalt. The spectral fingerprint of the basalt is a result of combining different amounts of the mineral spectra. Its shape is similar to the shape of the pyroxene spectrum, indicating that the basalt contains a large amount of pyroxene. The basalt also contains plagioclase, and minor amounts of olivine and ilmenite. Ilmenite, a dark mineral, has a low reflectance; when light strikes this mineral most is absorbed and little is reflected. The presence of ilmenite in basalt contributes to the low reflectance of basalt.

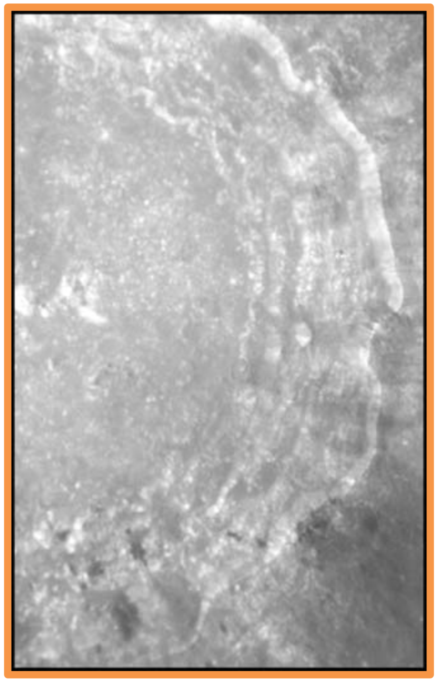
Spectrometers in Action around the Moon

Often spectrometers are mounted on spacecraft orbiting a planet. The detectors collect data from the surface below. As the spacecraft passes above the surface, a swath of data is collected. With each spacecraft pass, more swaths of data are collected and eventually the entire surface is mapped. The Indian Space Research Organization's Chandrayaan-1 spacecraft and NASA's Lunar Reconnaissance Orbiter will maintain polar orbits around the Moon; they will stay fixed in their orbit from the north to the south pole and back again, as the Moon rotates under them. The orbiting spacecraft will gather data from the entire lunar surface once each 27.3 days when the Moon completes one turn on its axis. Scientists will analyze the spectral fingerprints collected from particular locations to determine the composition of the rocks, minerals, and elements at the surface.

The Moon Mineralogy Mapper (M3) is a NASA instrument onboard the Chandrayaan-1 spacecraft. It will collect data from the visible to the near-infrared regions of the spectrum. Each of the 261 individual detectors will sample a unique 10-nanometer swath from 430 to 3000 nanometers, covering this entire portion of the spectrum. As the spacecraft passes over the Moon at an altitude of 62 miles (100 kilometers), 261 different measurements are taken for each point on the surface, allowing scientists to identify characteristics of features as small as 230 feet (70 meters) across. This is less than the length of a football field! While this may seem quite large, this resolution is higher than previous missions and will give scientists much more information about the Moon's surface materials than ever before.

The portion of the electromagnetic spectrum detected by a spectrometer is often from sunlight reflected from the surface, but some instruments emit (transmit) their own signal. The Mini-SAR, another NASA instrument onboard the Chandrayaan-1 spacecraft, will transmit radiowaves and detect the reflected radiowaves from permanently shadowed crater floors near the Moon's poles. These measurements will help determine if water ice is present in these locations.





Because different techniques are used to sense different wavelengths of the electromagnetic spectrum, any one spectrometer covers only a small part of the spectrum. Mini-SAR measures radiowaves. M3 measures visible to near-infrared wavelengths. Another instrument onboard NASA's Lunar Reconnaissance Orbiter detects ultraviolet radiation from starlight reflected from permanently dark regions. Together, these instruments will allow scientists to identify where different rocks, minerals, and potential resources occur on the lunar surface.

Copernicus Crater as imaged by spectrometers onboard the Clementine spacecraft. The left side combines data collected through three different color filters. The resulting image represents different rock types and shows the geologic complexity of the crater. For example, the green-yellow areas have rocks with higher iron content. The right side shows the features in a single wavelength of 750 nanometers. Image processing by Brown University.

Exploration Timeline

The Apollo missions returned many valuable rock samples, but the astronauts visited only a few locations — less than 1% of our Moon's surface has been explored. To extend our knowledge of the entire lunar surface, scientists gather spectral and other data using instruments onboard spacecraft orbiting the Moon. Researchers use this information to unravel the geologic history of the Moon and identify where concentrations of resources occur to support human habitation. Several missions have looked at our Moon in a "new light." Each brought increasingly sophisticated instrumentation to the Moon, and each provided new scientific information . . . and raised new questions!

NASA's **Galileo** spacecraft flew by the Moon en route to Jupiter. The spacecraft carried a camera that captured information in specific visible and near-infrared wavelengths and provided the first multispectral images of the Moon. These data helped scientists coarsely map abundances of minerals, and provided new information about the composition of the lunar farside and polar regions.

The **Clementine Mission** (Department of Defense and NASA) spectrometers measured reflected light in eleven wavelength bands from ultraviolet to the near-infrared (415 to 2800 nanometers). The spectral signatures allowed scientists to map the broad distribution of lunar rock types and soils, resolving the surface at a scale as small as 325 feet (100 meters). They mapped the compositional differences in the largest impact basin on the Moon — and the biggest hole in our solar system — South Pole Aitken Basin. They also identified regions near the lunar south pole that may be in permanent shadow; these permanently cold regions are ideal environments for water ice to collect.

Lunar Prospector followed Clementine, collecting spectral data to identify potential resources in the lunar crust, including minerals, water ice, and certain gases. It carried a gamma ray spectrometer. Gamma radiation is not reflected radiation; it is emitted from the decay of radioactive elements or from elements bombarded by high-energy solar radiation. Each element emits gamma rays at a characteristic energy or wavelength. The gamma ray spectrometer mapped the abundances of ten elements on the lunar surface. Some of these, such as iron, oxygen, aluminum, silicon, and titanium, are important resources for future habitation. Data collected by other spectrometers onboard suggested the presence of hydrogen, possibly related to water ice, in the permanently shadowed polar regions.

The European Space Agency's Small Missions for Advanced Research in Technology (**SMART-1**) spacecraft included several spectrometers to characterize the chemical composition and help identify water ice on the Moon. The mission identified compositional changes associated with impact craters and analyzed the lunar interior excavated by the impactors. The Japan Aerospace Exploration Agency's **Kaguya** carries X-ray and gamma-ray spectrometers that will provide information about the major elements in the lunar crust to help scientists understand how the crust formed. **Chang'e-1**, part of the China National Space Administration's lunar program, carries an imaging spectrometer, as well as X-ray and gamma-ray spectrometers, to help determine the composition of the lunar surface.

The Moon Mineralogy Mapper, a NASA instrument onboard the **Chandrayaan-1** spacecraft, will allow scientists to create the first highly detailed maps showing the surface distribution of minerals across the entire Moon. Data from another Chandrayaan-1 instrument, the Mini-SAR, will help to characterize the roughness of the lunar surface and search for ice in the permanently shadowed polar regions.

NASA's **Lunar Reconnaissance Orbiter** mission instruments will characterize the radiation levels and temperatures of the lunar environment, and will collect high-resolution images to determine future landing sites. Its instruments include the Lunar Exploration Neutron Detector, designed to characterize possible near-surface water ice deposits in the permanently shadowed regions, the Lunar Reconnaissance Orbiter Camera, which will provide multispectral data to map mineral resources, and the Lyman-Alpha Mapping Project, which will detect ultraviolet radiation reflected from permanently dark regions to identify water ice and map surface features. NASA's **Lunar Crater Observation and Sensing Satellite** will use visible light and infrared spectrometers to search for signs of water ice in a permanently shadowed crater near the Moon's pole.

These missions provide scientists and engineers with detailed maps of the lunar surface features, materials, and environment and will be used to determine the locations of future lunar outposts. This new information, enhanced by future exploration, will help scientists decipher the history of the Moon and early Earth — and lead to new questions!

Meet A Planetary Scientist — Dr. Carlé Pieters, Brown University

What do you do? I study the solid, rocky terrestrial bodies — Earth, Mercury, Mars, Venus, and the Moon. I decipher the composition and history of planets by looking at their rocks. I start by asking "Where are the different types of rocks and how did they get there?" On Earth, the rocks are eroded by wind and water and squished and folded into mountains. On other planets (and Earth, too) impactors strike the surface and break up the rocks and send them to different places. The next question I ask is "What are the rocks made of?" I use a tool called a "spectrometer" to answer this question. The components making up a rock — minerals — reflect light differently. Each has its own reflection "fingerprint." Some minerals reflect more red light and others reflect more blue light. But they also reflect wavelengths of light that our eyes cannot see. Spectrometers detect the light we can see and the light that is invisible to us. We use spectrometers to measure the light reflected from the surface of a planet so that we can determine what rocks and minerals are there and where they are located.

What have you investigated on the Moon? I look at the minerals on the surface of the Moon — but these minerals tell us what's deeper inside the Moon! I investigated Copernicus Crater, a big crater, about 60 miles (93 kilometers) across. There is a mountain in the middle, called a central peak, that forms when rocks from deep under the crater rise up after the impactor hits. I discovered that the central peak in Copernicus has a lot of olivine, a very pretty green mineral.

One of our questions is how the olivine in Copernicus Crater got where it is. One possibility is that the olivine comes from deep within the Moon, from its middle layer, the mantle. If the olivine is from the mantle, then the impactor must have dug really deep into the Moon! Another possibility is that chambers of magma cooled slowly under the surface of the young Moon, and the olivine separated out, forming a pocket of olivine — a pluton — that was excavated by the impactor that formed Copernicus Crater. These two theories offer two very different pictures about the structure of the Moon and its history. As we learn more, we will be able to determine which is correct — or if there is a different answer. By building this type of understanding of where minerals are and how they got there, we can begin to predict where we will find resources.

Why should we return to the Moon? The Moon has a huge role in science! Our Moon preserves a record of our early solar system and early Earth that has been erased from all the terrestrial planets. Unlike the planets, which continued to have their surfaces modified by volcanism and erosion and tectonics, our Moon became geologically quiet early in its history, other than being struck by impactors. By studying it we will build our understanding of how planets, like Earth, form and change.

Our planet Earth is limited in resources and in space. We will need to go to other places in the solar system to gather resources and fuel. The Moon, because it is so accessible, is a natural part of human exploration and investment in our own future.

If someone wants to become a scientist, what should they do? When I was young, I was curious about things — how things happened or what things were made of. Sometimes I found that my questions had answers, but many did not and that is what made it interesting to me. This is one reason I have always liked math; math beyond arithmetic is just about solving puzzles. Math is a very important tool that helps me solve problems and do what I do.

If someone wants to be a scientist, they should study math and science in school so that they will have the tools to use in science. More importantly, they should ask questions, lots of questions — even questions that don't seem to have answers. This is very important because then they can design a way to get the answer! There are so many opportunities for young scientists and scientists-to-be around the world to help ask and answer interesting questions about the Moon!

Try This — Seeing the Invisible

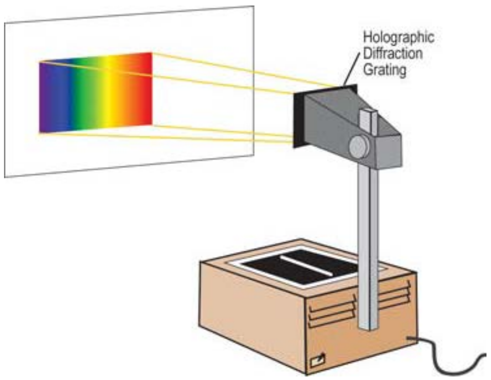
Students observe the colors of the visible spectrum and detect invisible infrared electromagnetic radiation.

What's Needed

- 1 Diffraction grating
- 1 Overhead projector
- Masking tape
- Scissors

Audio Photocell Detector

- Solar cell or photocell
- Amplifier/speaker (with battery if needed)
- Audio cable with 1/8-inch mini-plug on one end
- 2 jumper cables with alligator clips on both ends
- Small handheld fan



Getting Started

Set up the overhead projector so that it projects onto a light surface in a dark room. Place two halves of a sheet of dark construction paper on the projector's glass plate so there is a ¼-inch-wide slit between them through which light passes. Tape the sheets in place.

Place a sheet of diffraction grating in front of the projector head. Adjust the grating and projector until one or two spectra appear clearly on the wall. Tape the grating in place.

Build the audio photocell detector. Plug the 1/8-inch mini-plug into the "input" of the amplifier. Clip a jumper cable to one of the leads on the photocell, and clip the other end of the jumper cable to one of the leads of the audio cable. Use the second jumper cable to connect the other lead from the photocell to the other lead of the audio cable.

What to Do

- Invite the students to describe what they know about light. ***What happens when light passes through a prism? How does a rainbow form?*** Invite them to describe or define terms they use, such as white light, visible light, frequency, wavelength, colors, reflect, refract, and absorb.
- Turn on the overhead projector and explain that you are using a diffraction grating to break up the white light from the projector into the colors that make up white light — its spectrum. The diffraction grating acts like a prism. Ask a student to place pieces of masking tape on the wall where the red light begins and ends. ***Do the other students think the marks are in the "right" place? If not, why not?*** Each of us detects variations in colors differently, so students may have different opinions on where the tape should be.
- Show the students the photocell detector/amplifier and switch it on. Demonstrate that the amplifier/speaker emits noise when the photocell is placed in front of a light, such as the projector light, and that the noise is louder when the light is interrupted by a small fan (the instrument is sensitive to changes in light levels). Slowly pass the photocell in front of the spectrum on the wall, holding the fan in front of the photocell. ***Which colors or wavelengths of light can the photocell detect? Are there any visible colors that it cannot detect?*** It does not detect the violet light as easily as the other colors. ***What happens to the detector when it is moved beyond the red light? Can it still detect light? What type of light could that be?*** The photocell can "see" (detect) infrared light.

Wrapping Up

Ask the students which parts of the electromagnetic spectrum our eyes detect. We can see the visible light — red, orange, yellow, green, blue, and violet. ***Are there parts of the spectrum we cannot see?*** We cannot see infrared light, and other types of radiation such as X-rays, ultraviolet light, or radio waves.

In what way could looking at objects with different parts of the electromagnetic spectrum — those invisible to the human eye — provide useful information? X-rays provide information about the inside of our body and ultraviolet light is used to detect clues at crime scenes. Scientists detect electromagnetic radiation from stars to learn about their origin and condition. Spectrometers onboard spacecraft orbiting planets and our Moon collect electromagnetic radiation reflected from the surface, allowing scientists to learn about the composition.

For a more extensive lesson plan, and for related lessons, please visit the Moon Mineralogy Mapper Education website at http://m3.cofc.edu.

Share a Story

Four and a half aeons ago
a dark, dusty, cloud deformed.
Sun became star; Earth became large,
and Moon, a new world, was born.

Carlé Pieters,
Beginning lines of “The Original Moon”

There are many stories from cultures across the world about how our Moon and its features formed. However, there are no stories about the features we observe on the Moon in different wavelengths of the electromagnetic spectrum! Invite your students to write and illustrate a story or poem about our Moon using spectral data from the lunar missions. Images from lunar missions can be found through these and other websites:

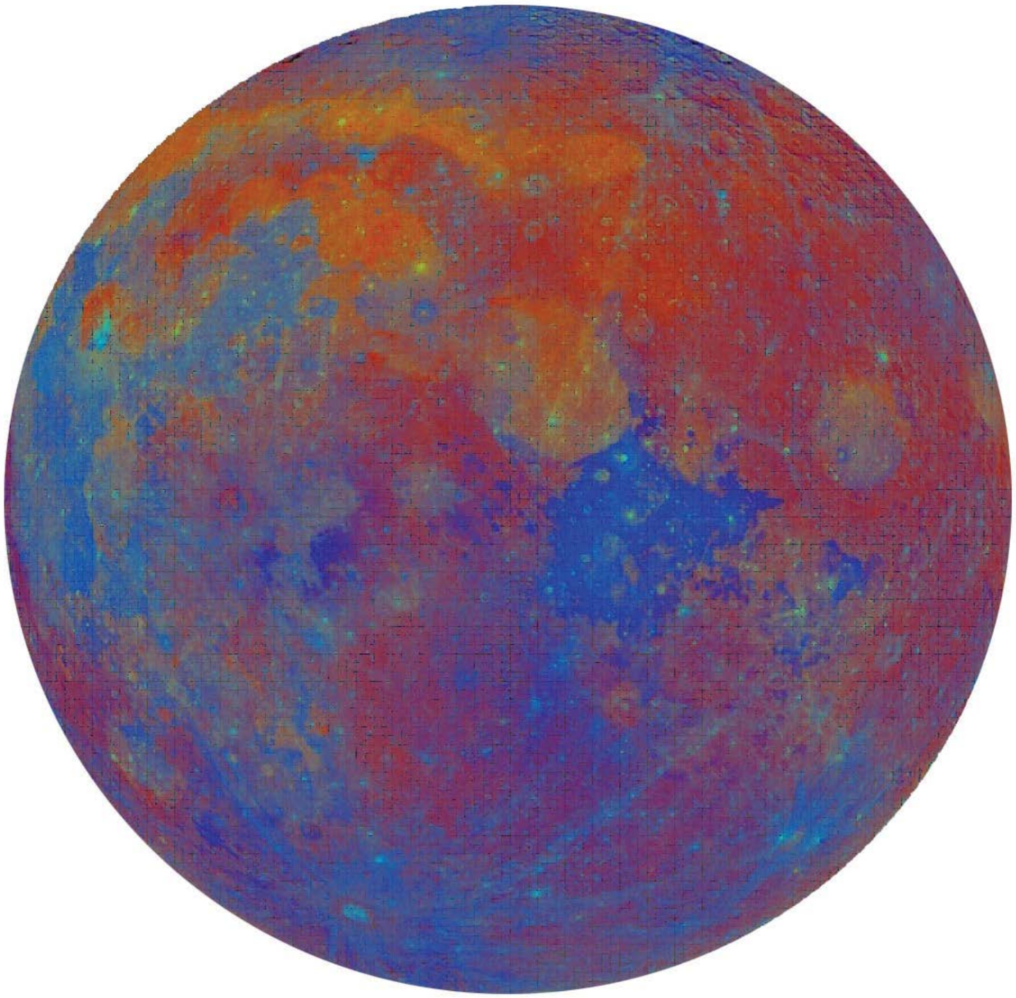
Lunar Prospector

Clementine

Solar System Exploration’s Moon Website

Lunar Reconnaissance Orbiter

Moon Mineralogy Mapper



Galileo false-color image of the Moon. The different colors denote the presence of different minerals. The large orangish areas in the upper left are iron-rich mare basalts. The deep blue regions are mare basalts rich in titanium. Image processing by United States Geological Survey, Flagstaff, Arizona.

Further Exploration

Online Discovery

The Moon Mineralogy Mapper is one of NASA's instruments onboard the Indian Space Research Organization's Chandrayaan-1 spacecraft. This spectrometer will map the entire lunar surface, and reveal the minerals of which it is made.

NASA's Lunar Reconnaissance Orbiter mission will return detailed information about the surface of the Moon and the lunar environment through instruments including spectrometers and radar.

The Clementine mission tested instruments in a long-term space environment and acquired a global multispectral map of the Moon's surface.

Classroom Resources

The Electromagnetic Spectrum —Imagine the Universe helps middle- to high-school students investigate the electromagnetic spectrum through interactive web pages. Lesson plans explore electromagnetic radiation and emission spectra.

Moon Mineralogy Mapper Education Website —A series of hands-on inquiry-based activities engage middle-school students in understanding and interpreting reflectance spectra from Earth and Moon rocks. These activities are part of a suite of educational resources that investigate the geologic history of our Moon, the Chandrayaan-1 mission, spectrometry, and future lunar exploration.

Active Astronomy —Hands-on activities and demonstrations engage middle- to high-school students in learning about infrared light.

Cool Cosmos — What does a cat look like in infrared? Tour infrared Yellowstone and learn more about this portion of the electromagnetic spectrum through discussion, activities, images, and games.

ALTA II Reflectance Spectrometer for the Classroom —The ALTA is a rugged, simple classroom instrument designed to help students in grades 5 through undergraduate learn about light, color, and spectroscopy. Using the spectrometer, students can collect data reflected from rocks, minerals, and other materials in specific wavelengths of the visible to infrared electromagnetic spectrum. Lesson plans are included.

About this Poster

This is one of a three-poster set that examines how our geologic understanding of the Moon will be used as we plan to live and work there in the future. The **poster front**, designed for **sixth- to ninth-grade students**, illustrates how scientists can collect and use visible and invisible electromagnetic radiation reflected from the Moon to identify rocks and minerals on its surface. This information will help scientists and engineers plan future lunar exploration. The **poster back** is designed to provide **educators** with background information, ideas for lessons, and resources to support further student exploration.

Content Development: Stephanie Shipp and Christine Shupla, Lunar and Planetary Institute; *Scientific Oversight*: Allan Treiman, David Kring, and Walter Kiefer, Lunar and Planetary Institute; *Graphic Design*: Leanne Woolley, Lunar and Planetary Institute.

Concept Development and Content Review: Cassandra Runyon, E/PO Lead, Moon Mineralogy Mapper, College of Charleston; Stephanie Shipp, Lunar and Planetary Institute; Jaclyn Allen, Astromaterials Research and Exploration Science, NASA Johnson Space Center; Marilyn Lindstrom, NASA Headquarters.

Content Review: Dr. Carlton Allen, Astromaterials Curator, Astromaterials Research and Exploration Science, NASA Johnson Space Center; Dr. Ben Bussey, Deputy Principal Investigator, Miniature Synthetic Aperture Radar (Mini-SAR), Johns Hopkins University, Applied Physics Laboratory; Mr. Brian Day, E/PO Lead, Lunar Crater Observation and Sensing Satellite, NASA Ames Research Center; Dr. Jeffrey Gillis-Davis, Lunar Geologist, Hawaii Institute of Geophysics and Planetology; Dr. Clive Neal, Chair, Lunar Exploration Analysis Group, University of Notre Dame; Dr. Carlé Pieters, Principal Investigator, Moon Mineralogy Mapper Instrument, Brown University; Dr. Paul Spudis, Principal Investigator, Miniature Synthetic Aperture Radar (Mini-SAR), Lunar and Planetary Institute; Ms. Stephanie Stockman, E/PO Lead, Lunar Reconnaissance Orbiter Mission, NASA Goddard Space Flight Center.

Appreciation is extended to the students and teachers of McWhirter Elementary in Webster, Texas, and Sugarland Middle School, in Sugarland, Texas, for their insightful critique of the poster design and content.

Image Credit: NASA and Lunar and Planetary Institute; Clementine image processing by Dr. Jeffrey Gillis-Davis.

www.lpi.usra.edu