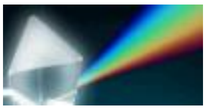
Tour of the Electromagnetic Spectrum

The Electromagnetic Spectrum Video Series & Companion Book

This unique NASA resource on the web, in print, and with companion videos introduces electromagnetic waves, their behaviors, and how scientists visualize these data. Each region of the electromagnetic spectrum (EMS) is described and illustrated with engaging examples of NASA science. Come and explore the amazing world beyond the visible!

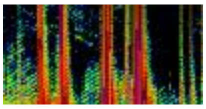
Introduction to the Electromagnetic Spectrum: Electromagnetic energy travels in waves and spans a broad spectrum from very long radio waves to very short gamma rays. You depend on electromagnetic energy every hour of every day. Without it, the world you know could not exist.

Anatomy of an Electromagnetic Wave: An electromagnetic wave is made up of changing electric and magnetic fields and is important way that energy is transported in the world around us.

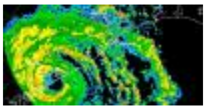


Wave Behaviors: Light waves across the electromagnetic spectrum behave in similar ways and can be transmitted, reflected, absorbed, refracted, polarized, diffracted, or scattered depending on the composition of an object the wave encounters.

Visualization: From Energy to Image: Electromagnetic energy is observed and recorded by satellites and then transmitted to Earth. These data, including data from beyond the visible spectrum, are processed into images.



Radio Waves: The longest wavelengths in the spectrum, Radio waves can carry tunes from a radio station or be emitted from astronomical objects like from the Sun's corona.



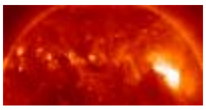
Microwaves: Microwaves penetrate through clouds, dust, smoke, snow, and rain making them ideal for communications satellites. They are also used in active and passive science instruments to study the Earth and the night sky.

Infrared Waves: Light waves just beyond the visible spectrum of light are infrared light waves. They range from near-infrared like what are used in remote controls, to far-infrared which can be sensed as heat.

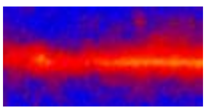
Reflected Near-Infrared Waves: Scientists can study how objects reflect, transmit, and absorb the Sun's near-infrared radiation to observe health of vegetation and soil composition.

Visible Light: All electromagnetic radiation is light, but we can only see a small portion of this radiation—the portion we call visible light.

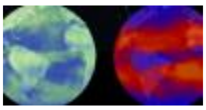
Ultraviolet Waves: The Sun is a source of the full spectrum of ultraviolet radiation and most of this radiation is blocked by the atmosphere. Scientists study stars and galaxies in the ultraviolet as well as the composition of Earth's atmosphere.



X-Rays: X-rays have much higher energy and the Earth's atmosphere protects us from these harmful rays. Scientists use satellites to observe x-ray radiation coming from galaxies and stars like our Sun.



Gamma Rays: Gamma rays have the most energy of any wave in the electromagnetic spectrum and are produced by the hottest and most energetic objects in the universe.



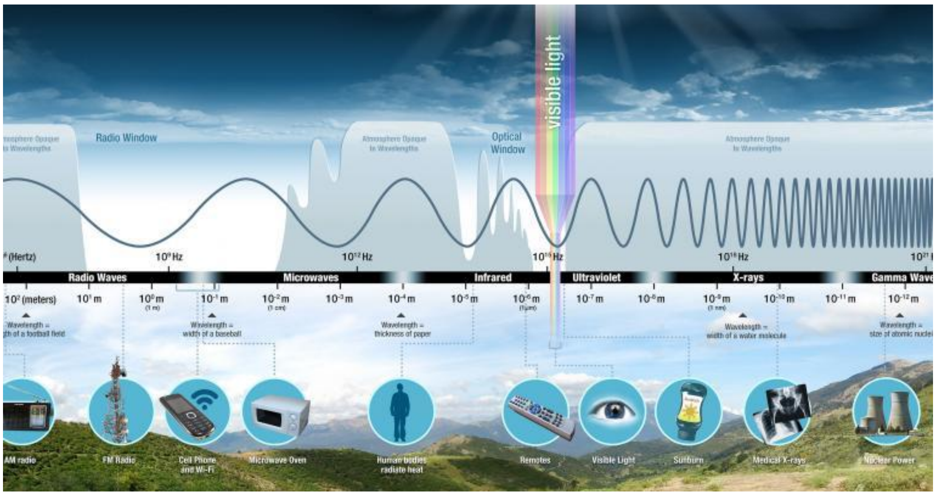
Earth's Radiation Budget: The energy entering, reflected, absorbed, and emitted by the Earth system are the components of the Earth's radiation budget.

Introduction to the Electromagnetic Spectrum

Electromagnetic Energy

When you tune your radio, watch TV, send a text message, or pop popcorn in a microwave oven, you are using electromagnetic energy. You depend on this energy every hour of every day. Without it, the world you know could not exist.

Electromagnetic energy travels in waves and spans a broad spectrum from very long radio waves to very short gamma rays. The human eye can only detect only a small portion of this spectrum called visible light. A radio detects a different portion of the spectrum, and an x-ray machine uses yet another portion. NASA's scientific instruments use the full range of the electromagnetic spectrum to study the Earth, the solar system, and the universe beyond.



Our Protective Atmosphere

Our Sun is a source of energy across the full spectrum, and its electromagnetic radiation bombards our atmosphere constantly. However, the Earth's atmosphere protects us from exposure to a range of higher energy waves that can be harmful to life. Gamma rays, x-rays, and some ultraviolet waves are "ionizing," meaning these waves have such a high energy that they can knock electrons out of atoms. Exposure to these high-energy waves can alter atoms and molecules and cause damage to cells in organic matter. These changes to cells can sometimes be helpful, as when radiation is used to kill cancer cells, and other times not, as when we get sunburned.

Atmospheric Windows

Seeing Beyond our Atmosphere – NASA spacecraft, such as RHESSI, provide scientistswith a unique vantage point, helping them"see" at higher-energy wavelengths that areblocked by the Earth's protective atmosphere.

Electromagnetic radiation is reflected or absorbed mainly by several gases in the Earth's atmosphere, among the most important being water vapor, carbon dioxide, and ozone. Some radiation, such as visible light, largely passes (is transmitted) through the atmosphere. These regions of the spectrum with wavelengths that can pass through the atmosphere are referred to as "atmospheric windows." Some microwaves can even pass through clouds, which make them the best wavelength for transmitting satellite communication signals.

While our atmosphere is essential to protecting life on Earth and keeping the planet habitable, it is not very helpful when it comes to studying sources of high-energy radiation in space. Instruments have to be positioned above Earth's energy-absorbing atmosphere to "see" higher energy and even some lower energy light sources such as quasars.

Anatomy of an Electromagnetic Wave

Energy, a measure of the ability to do work, comes in many forms and can transform from one type to another. Examples of stored or potential energy include batteries and water behind a dam. Objects in motion are examples of kinetic energy. Charged particles—such as electrons and protons—create electromagnetic fields when they move, and these fields transport the type of energy we call electromagnetic radiation, or light.

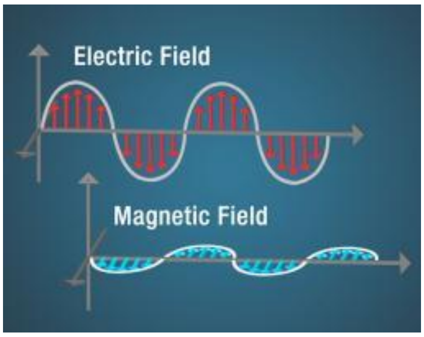
WHAT ARE WAVES?

Mechanical waves and electromagnetic waves are two important ways that energy is transported in the world around us. Waves in water and sound waves in air are two examples of mechanical waves. Mechanical waves are caused by a disturbance or vibration in matter, whether solid, gas, liquid, or plasma. Matter that waves are traveling through is called a medium. Water waves are formed by vibrations in a liquid and sound waves are formed by vibrations in a gas (air). These mechanical waves travel through a medium by causing the molecules to bump into each other, like falling dominoes transferring energy from one to the next. Sound waves cannot travel in the vacuum of space because there is no medium to transmit these mechanical waves.

Classical waves transfer energy without transporting matter through the medium. Waves in a pond do not carry the water molecules from place to place; rather the wave's energy travels through the water, leaving the water molecules in place, much like a bug bobbing on top of ripples in water.

When a balloon is rubbed against a head of hair, astatic electric charge is created causing their individual hairs to repel one another. Credit: Ginger Butcher

ELECTROMAGNETIC WAVES



Electricity can be static, like the energy that can make your hair stand on end. Magnetism can also be static, as it is in a refrigerator magnet. A changing magnetic field will induce a changing electric field and vice-versa—the two are linked. These changing fields form electromagnetic waves. Electromagnetic waves differ from mechanical waves in that they do not require a medium to propagate. This means that electromagnetic waves can travel not only through air and solid materials, but also through the vacuum of space.

In the 1860's and 1870's, a Scottish scientist named James Clerk Maxwell developed a scientific theory to explain electromagnetic waves. He noticed that electrical fields and magnetic fields can couple together to form electromagnetic waves. He summarized this relationship between electricity and magnetism into what are now referred to as "Maxwell's Equations."

Heinrich Hertz, a German physicist, applied Maxwell's theories to the production and reception of radio waves. The unit of frequency of a radio wave -- one cycle per second -- is named the hertz, in honor of Heinrich Hertz.

His experiment with radio waves solved two problems. First, he had demonstrated in the concrete, what Maxwell had only theorized — that the velocity of radio waves was equal to the velocity of light! This proved that radio waves were a form of light! Second, Hertz found out how to make the electric and magnetic fields detach themselves from wires and go free as Maxwell's waves — electromagnetic waves.

WAVES OR PARTICLES? YES!

Light is made of discrete packets of energy called photons. Photons carry momentum, have no mass, and travel at the speed of light. All light has both particle-like and wave-like properties. How an instrument is designed to sense the light influences which of these properties are observed. An instrument that diffracts light into a spectrum for analysis is an example of observing the wave-like property of light. The particle-like nature of light is observed by detectors used in digital cameras—individual photons liberate electrons that are used for the detection and storage of the image data.

POLARIZATION

One of the physical properties of light is that it can be polarized. Polarization is a measurement of the electromagnetic field's alignment. In the figure above, the electric field (in red) is vertically polarized. Think of a throwing a Frisbee at a picket fence. In one orientation it will pass through, in another it will be rejected. This is similar to how sunglasses are able to eliminate glare by absorbing the polarized portion of the light.

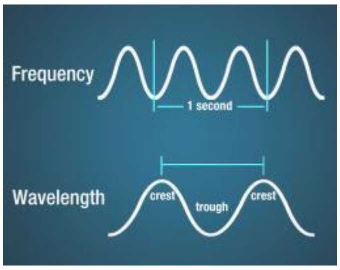
DESCRIBING ELECTROMAGNETIC ENERGY

The terms light, electromagnetic waves, and radiation all refer to the same physical phenomenon: electromagnetic energy. This energy can be described by frequency, wavelength, or energy. All three are related mathematically such that if you know one, you can calculate the other two. Radio and microwaves are usually described in terms of frequency (Hertz), infrared and visible light in terms of wavelength (meters), and x-rays and gamma rays in terms of energy (electron volts). This is a scientific convention that allows the convenient use of units that have numbers that are neither too large nor too small.

FREQUENCY

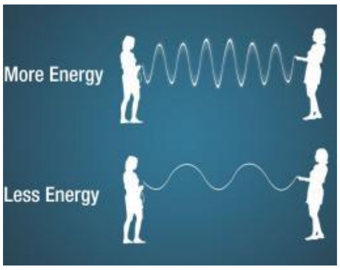
The number of crests that pass a given point within one second is described as the frequency of the wave. One wave—or cycle—per second is called a Hertz (Hz), after Heinrich Hertz who established the existence of radio waves. A wave with two cycles that pass a point in one second has a frequency of 2 Hz.

WAVELENGTH



Electromagnetic waves have crests and troughs similar to those of ocean waves. The distance between crests is the wavelength. The shortest wavelengths are just fractions of the size of an atom, while the longest wavelengths scientists currently study can be larger than the diameter of our planet!

ENERGY



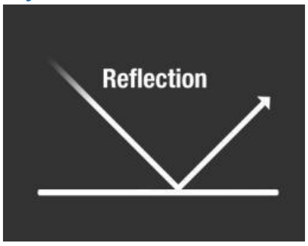
An electromagnetic wave can also be described in terms of its energy—in units of measure called electron volts (eV). An electron volt is the amount of kinetic energy needed to move an electron through one volt potential. Moving along the spectrum from long to short wavelengths, energy increases as the wavelength shortens. Consider a jump rope with its ends being pulled up and down. More energy is needed to make the rope have more waves.

Wave Behaviors

Light waves across the electromagnetic spectrum behave in similar ways. When a light wave encounters an object, they are either transmitted, reflected, absorbed, refracted, polarized, diffracted, or scattered depending on the composition of the object and the wavelength of the light.

Specialized instruments onboard NASA spacecraft and airplanes collect data on how electromagnetic waves behave when they interact with matter. These data can reveal the physical and chemical composition of matter.

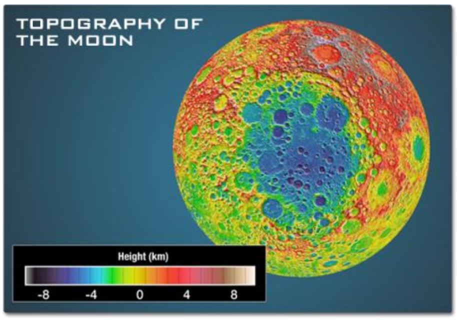
Reflection



Reflection is when incident light (incoming light) hits an object and bounces off. Very smooth surfaces such as mirrors reflect almost all incident light.

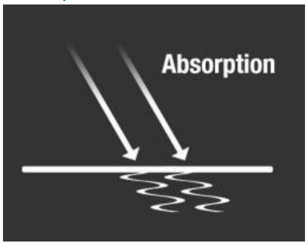
The color of an object is actually the wavelengths of the light reflected while all other wavelengths are absorbed. Color, in this case, refers to the different wavelengths of light in the visible light spectrum perceived by our eyes. The physical and chemical composition of matter determines which wavelength (or color) is reflected.

This reflective behavior of light is used by lasers onboard NASA's Lunar Reconnaissance Orbiter to map the surface of the Moon. The instrument measures the time it takes a laser pulse to hit the surface and return. The longer the response time, the farther away the surface and lower the elevation. A shorter response time means the surface is closer or higher in elevation. In this image of the Moon's southern hemisphere, low elevations are shown as purple and blue, and high elevations are shown in red and brown.



Credit: NASA/Goddard

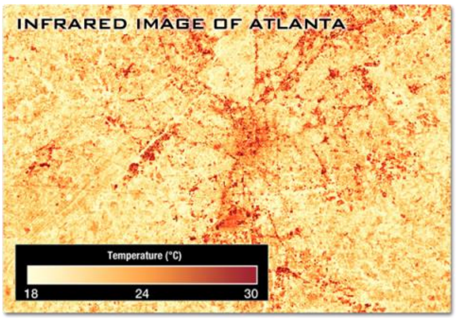
Absorption



Absorption occurs when photons from incident light hit atoms and molecules and cause them to vibrate. The more an object's molecules move and vibrate, the hotter it becomes. This heat is then emitted from the object as thermal energy.

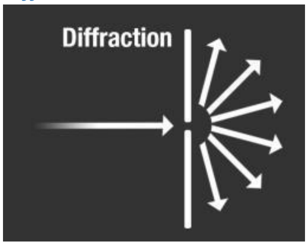
Some objects, such as darker colored objects, absorb more incident light energy than others. For example, black pavement absorbs most visible and UV energy and reflects very little, while a light-colored concrete sidewalk reflects more energy than it absorbs. Thus, the black pavement is hotter than the sidewalk on a hot summer day. Photons bounce around during this absorption process and lose bits of energy to numerous molecules along the way. This thermal energy then radiates in the form of longer wavelength infrared energy.

Thermal radiation from the energy-absorbing asphalt and roofs in a city can raise its surface temperature by as much as 10° Celsius. The Landsat 7 satellite image below shows the city of Atlanta as an island of heat compared to the surrounding area. Sometimes this warming of air above cities can influence weather, which is called the "urban heat island" effect.



Credit: Marit Jentoft-Nilsen, based on Landsat-7 data.

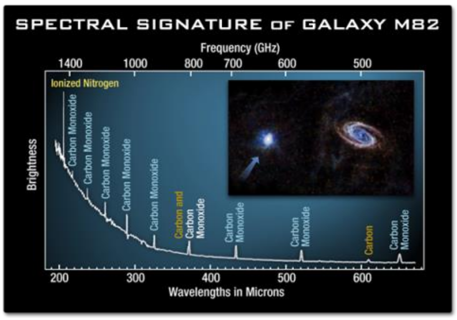
Diffraction



Diffraction is the bending and spreading of waves around an obstacle. It is most pronounced when a light wave strikes an object with a size comparable to its own wavelength. An instrument called a spectrometer uses diffraction to separate light into a range of wavelengths—a spectrum. In the case of visible light, the separation of wavelengths through diffraction results in a rainbow.

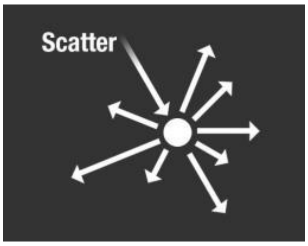
A spectrometer uses diffraction (and the subsequent interference) of light from slits or gratings to separate wavelengths. Faint peaks of energy at specific wavelengths can then be detected and recorded. A graph of these data is called a spectral signature. Patterns in a spectral signature help scientists identify the physical condition and composition of stellar and interstellar matter.

The graph below from the SPIRE infrared spectrometer onboard the ESA (European Space Agency) Herschel space telescope reveals strong emission lines from carbon monoxide (CO), atomic carbon, and ionized nitrogen in Galaxy M82.



Credit: ESA/NASA/JPL-Caltech

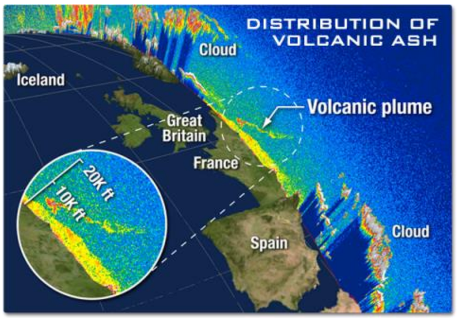
Scatter



Scattering occurs when light bounces off an object in a variety of directions. The amount of scattering that takes place depends on the wavelength of the light and the size and structure of the object.

The sky appears blue because of this scattering behavior. Light at shorter wavelengths—blue and violet—is scattered by nitrogen and oxygen as it passes through the atmosphere. Longer wavelengths of light—red and yellow—transmit through the atmosphere. This scattering of light at shorter wavelengths illuminates the skies with light from the blue and violet end of the visible spectrum. Even though violet is scattered more than blue, the sky looks blue to us because our eyes are more sensitive to blue light.

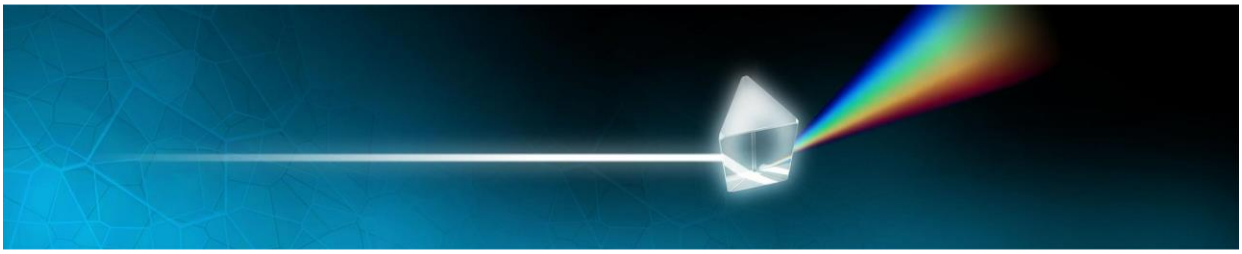
Aerosols in the atmosphere can also scatter light. NASA's Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite can observe the scattering of laser pulses to "see" the distributions of aerosols from sources such as dust storms and forest fires. The image below shows a volcanic ash cloud drifting over Europe from an eruption of Iceland's Eyjafjallajökull Volcano in 2010.



Credit: NASA/GSFC/LaRC/JPL, MISR Team

Refraction

Refraction is when light waves change direction as they pass from one medium to another. Light travels slower in air than in a vacuum, and even slower in water. As light travels into a different medium, the change in speed bends the light. Different wavelengths of light are slowed at different rates, which causes them to bend at different angles.



For example, when the full spectrum of visible light travels through the glass of a prism, the wavelengths are separated into the colors of the rainbow.

Visualization: From Energy to Image

HOW DO WE VISUALIZE LIGHT WE CAN'T SEE?

False color, or representative color, is used to help scientists visualize data from wavelengths beyond the visible spectrum. Scientific instruments onboard NASA spacecraft sense regions within the electromagnetic spectrum—spectral bands. The instruments direct the electromagnetic energy onto a detector, where individual photons yield electrons related to the amount of incoming energy. The energy is now in the form of "data," which can be transmitted to Earth and processed into images.

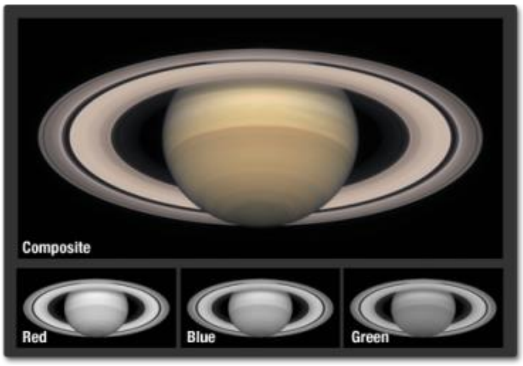
DIGITAL CAMERA

Digital cameras operate similarly to some scientific instruments. A sensor in the camera captures the brightness of red, green, and blue light and records these brightness values as numbers. The three sets of data are then combined in the red, green, and blue channels of a computer monitor to create a color image.

Digital image in color

NATURAL COLOR IMAGES

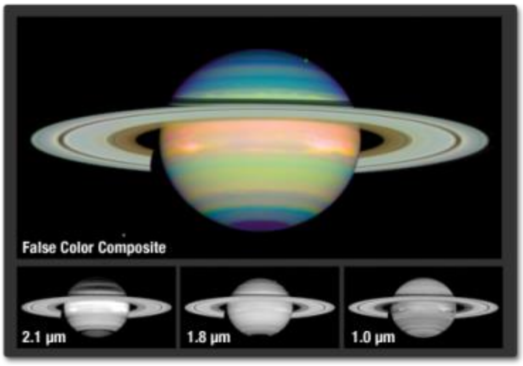
Instruments onboard satellites can also capture visible light data to create natural color, or true color, satellite images. Data from visible light bands are composited in their respective red, green, and blue channels on screen. The image simulates a color image that our eyes would see from the vantage point of the spacecraft.



Saturn shown in natural color. Credit: NASA and The Hubble Heritage Team

FALSE COLOR IMAGES

Sensors can also record brightness values in regions beyond visible light. This Hubble image of Saturn was taken at longer infrared wavelengths and composited in the red, green, and blue channels respectively. The resulting false-color composite image reveals compositional variations and patterns that would otherwise be invisible.

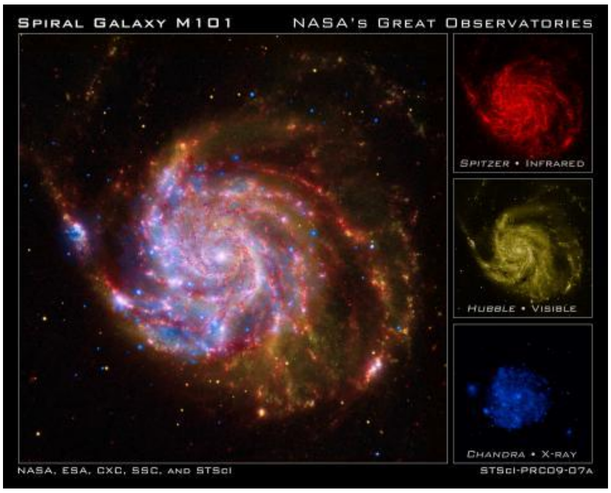


Saturn shown in false color. Credit: NASA/JPL/STScI

Martian Soil - This false-color infrared image from the Thermal Emission Imaging System (THEMIS) camera onboard the Mars Odyssey spacecraft reveals the differences in the mineralogy, chemical composition, and structure of the Martian surface. Bands 5 (9.35 µm, 1070 cm-1), 7 (11.04 µm, 906 cm-1), and 9 (12.57 µm, 796 cm-1) are displayed in blue, green, and red, respectively. Large deposits of the mineral olivine appear in this image as magenta to purple-blue. Credit: Mars Odyssey Thermal Emission Imaging System, NASA/JPL/ASU. *Expand Image*

DATA FROM MULTIPLE SENSORS

This composite image of the spiral galaxy Messier 101 combines views from Spitzer, Hubble, and Chandra space telescopes. The red color shows Spitzer's view in infrared light. It highlights the heat emitted by dust lanes in the galaxy where stars can form. The yellow color is Hubble's view in visible light. Most of this light comes from stars, and they trace the same spiral structure as the dust lanes. The blue color shows Chandra's view in x-ray light. Sources of x-rays include million-degree gas, exploded stars, and material colliding around black holes.

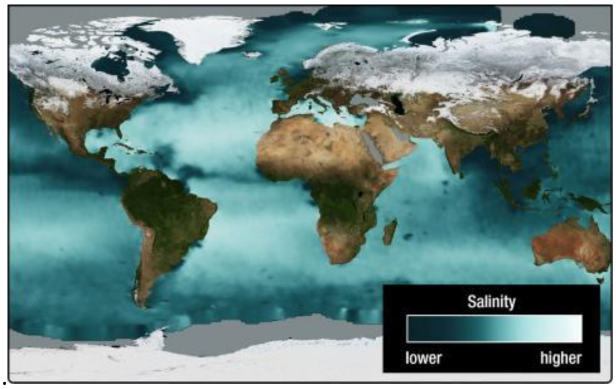


Messier 101 galaxy in x-ray, infrared, and visible light. Credit: NASA, ESA, CXC, JPL, Caltech and STScI

Such composite images allow astronomers to compare how features are seen in multiple wavelengths. It's like "seeing" with a camera, night-vision goggles, and x-ray vision all at once.

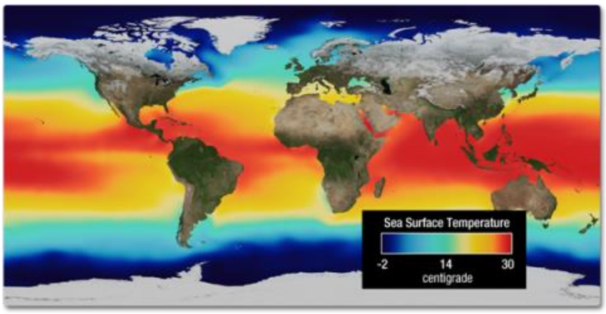
COLOR MAPS

To help scientists visualize a data set of just one range of values, such as temperature or rainfall, the values are often mapped to a color scale from minimum to maximum. The “color map” below visualizes sea surface salinity data from the Aquarius satellite using a scale from blue to white. The blue end of the scale shows the lowest amounts of dissolved salts in the ocean and the white end shows the highest amounts.



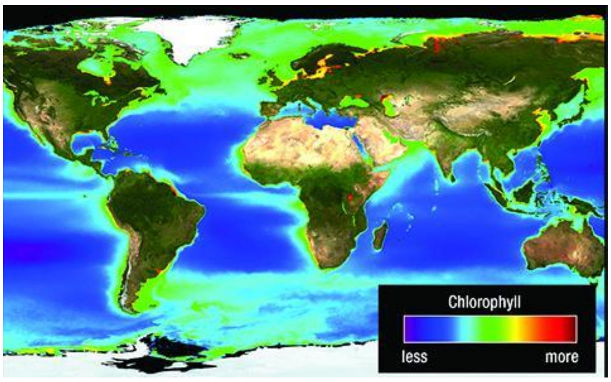
Map of Sea Surface Salinity. Credit: NASA/Goddard Space Flight Center

A commonly used color scale has red at one end and blue at the other creating a "rainbow-like" scale. The sea surface temperature map below uses a scale from dark blue for cold temperatures to red for warm temperatures.



Map of Sea Surface Temperatures. Credit: NASA/Goddard Space Flight Center

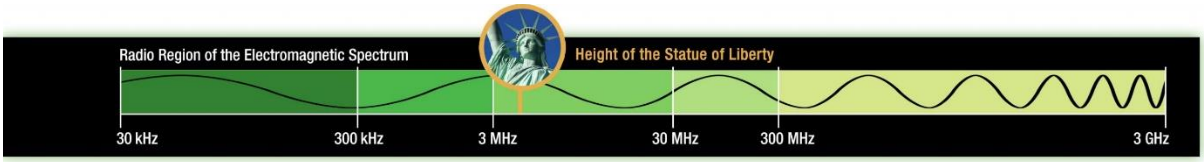
In some cases these colors do not represent traditional meaning—such as red referring to "bad" or "hot." For example, red in the map below is good because it indicates high amounts of chlorophyll associated with an abundance of microscopic plants known as phytoplankton that support the ocean ecosystem.



Map of Chlorophyll Concentrations. Credit: NASA/Goddard Space Flight Center

Learn more with this activity about Color Mapping.

Radio Waves



WHAT ARE RADIO WAVES?

In 1932, Karl Jansky at Bell Labs revealed that stars and other objects in space radiated radio waves. Credit: NRAO/AUI

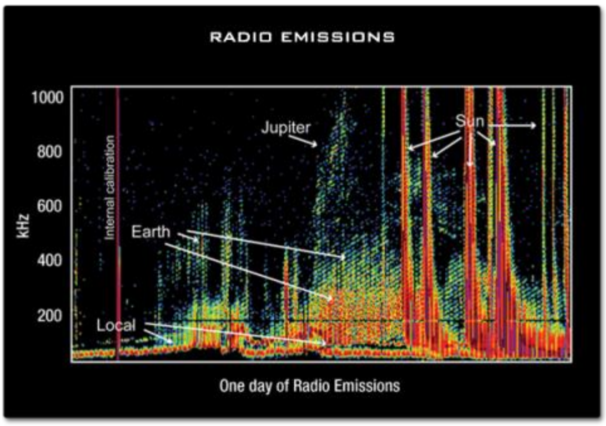
Radio waves have the longest wavelengths in the electromagnetic spectrum. They range from the length of a football to larger than our planet. Heinrich Hertz proved the existence of radio waves in the late 1880s. He used a spark gap attached to an induction coil and a separate spark gap on a receiving antenna. When waves created by the sparks of the coil transmitter were picked up by the receiving antenna, sparks would jump its gap as well. Hertz showed in his experiments that these signals possessed all the properties of electromagnetic waves.

You can tune a radio to a specific wavelength—or frequency—and listen to your favorite music. The radio "receives" these electromagnetic radio waves and converts them to mechanical vibrations in the speaker to create the sound waves you can hear.

RADIO EMISSIONS IN THE SOLAR SYSTEM

Astronomical objects that have a changing magnetic field can produce radio waves. The radio astronomy instrument called WAVES on the WIND spacecraft recorded a day of bursts of radio waves from the Sun's corona and planets in our solar system.

Data pictured below show emissions from a variety of sources including radio bursts from the Sun, the Earth, and even from Jupiter's ionosphere whose wavelengths measure about fifteen meters in length. The far right of this graph shows radio bursts from the Sun caused by electrons that have been ejected into space during solar flares moving at 20% of the speed of light.



Credit: NASA/GSFC Wind Waves Michael L. Kaiser

RADIO TELESCOPES

Radio telescopes look toward the heavens to view planets, comets, giant clouds of gas and dust, stars, and galaxies. By studying the radio waves originating from these sources, astronomers can learn about their composition, structure, and motion. Radio astronomy has the advantage that sunlight, clouds, and rain do not affect observations.

Since radio waves are longer than optical waves, radio telescopes are made differently than the telescopes used for visible light. Radio telescopes must be physically larger than an optical telescopes in order to make images of comparable resolution. But they can be made lighter with millions of small holes cut through the dish since the long radio waves are too big to "see" them. The Parkes radio telescope, which has a dish 64 meters wide, cannot yield an image any clearer than a small backyard optical telescope!

Credit: Ian Sutton

A VERY LARGE TELESCOPE

In order to make a clearer, or higher resolution, radio image, radio astronomers often combine several smaller telescopes, or receiving dishes, into an array. Together, these dishes can act as one large telescope whose resolution is set by the maximum size of the area. The National Radio Astronomy Observatory's Very Large Array (VLA) radio telescope in New Mexico is one of the world's premier astronomical radio observatories. The VLA consists of 27 antennas arranged in a huge "Y" pattern up to 36 km across (roughly one-and-one-half times the size of Washington, DC).

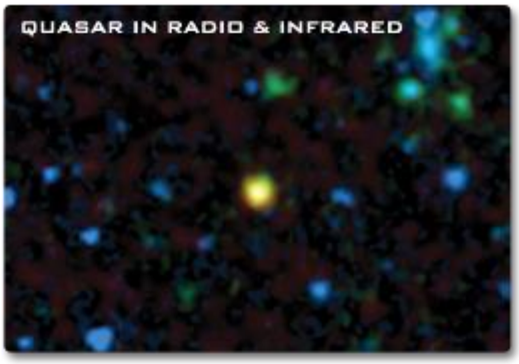
The techniques used in radio astronomy at long wavelengths can sometimes be applied at the shorter end of the radio spectrum—the microwave portion. The VLA image below captured 21-centimeter energy emissions around a black hole in the lower right and magnetic field lines pulling gas around in the upper left.

Credit: VLA & NRAO, FarhadYusef-Zedehet al. Northwestern

THE RADIO SKY

If we were to look at the sky with a radio telescope tuned to 408 MHz, the sky would appear radically different from what we see in visible light. Instead of seeing point-like stars, we would see distant pulsars, star-forming regions, and supernova remnants would dominate the night sky.

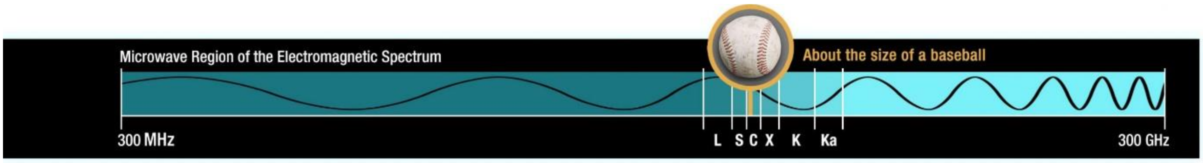
Radio telescopes can also detect quasars. The term quasar is short for quasi-stellar radio source. The name comes from the fact that the first quasars identified emit mostly radio energy and look much like stars. Quasars are very energetic, with some emitting 1,000 times as much energy as the entire Milky Way. However, most quasars are blocked from view in visible light by dust in their surrounding galaxies.

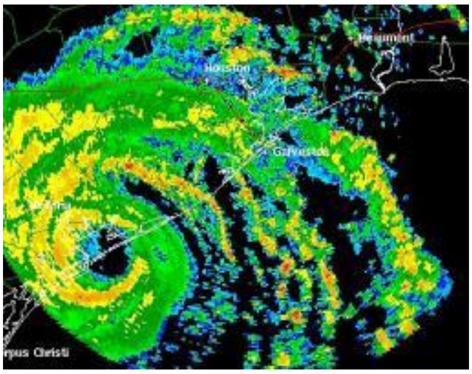


Credit: NASA/JPL-Caltech/A.Martinez-Sansigre

Astronomers identified the quasars with the help of radio data from the VLA radio telescope because many galaxies with quasars appear bright when viewed with radio telescopes. In the false-color image below, infrared data from the Spitzer space telescope is colored both blue and green, and radio data from the VLA telescope is shown in red. The quasar-bearing galaxy stands out in yellow because it emits both infrared and radio light.

Microwaves





This Doppler-radar image seen on TV weather news uses microwaves for local weather forecasting. Shown here is Hurricane Claudette's eye-wall making landfall. Credit: NOAA

MICROWAVES

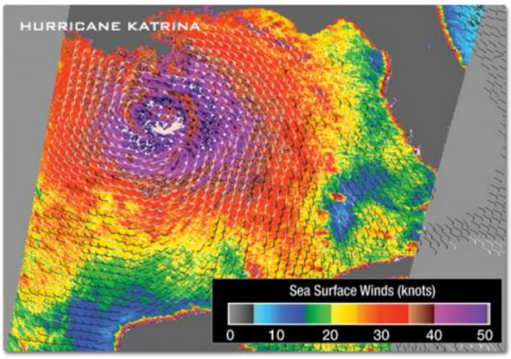
You may be familiar with microwave images as they are used on TV weather news and you can even use microwaves to cook your food. Microwave ovens work by using microwave about 12 centimeters in length to force water and fat molecules in food to rotate. The interaction of these molecules undergoing forced rotation creates heat, and the food is cooked.

MICROWAVE BANDS

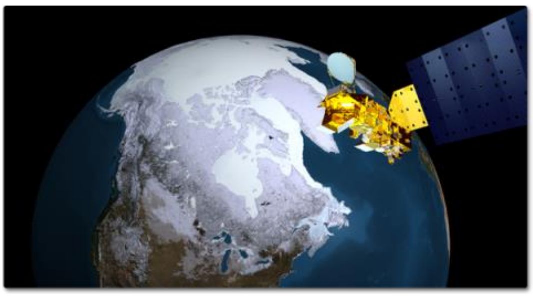
Microwaves are a portion or "band" found at the higher frequency end of the radio spectrum, but they are commonly distinguished from radio waves because of the technologies used to access them. Different wavelengths of microwaves (grouped into "sub-bands") provide different information to scientists. Medium-length (C-band) microwaves penetrate through clouds, dust, smoke, snow, and rain to reveal the Earth's surface. L-band microwaves, like those used by a Global Positioning System (GPS) receiver in your car, can also penetrate the canopy cover of forests to measure the soil moisture of rain forests. Most communication satellites use C-, X-, and Ku-bands to send signals to a ground station.

LEFT: **The ERS-1 satellite sends out wavelengths about 5.7 cm long (C-band).This image shows sea ice breaking off the shores of Alaska.***CENTER*: **The JERS satellite uses wavelengths about 20 cm in length (L-band).This is an image of the Amazon River in Brazil.***RIGHT*: **This is a radar image acquired from the Space Shuttle. It also used awavelengthin the L-band of the microwave spectrum. Here we see a computerenhanced radarimage of some mountains on the edge of Salt Lake City, Utah.**

Microwaves that penetrate haze, light rain and snow, clouds, and smoke are beneficial for satellite communication and studying the Earth from space. The SeaWinds instrument onboard the Quick Scatterometer (QuikSCAT) satellite uses radar pulses in the Ku-band of the microwave spectrum. This scatterometer measures changes in the energy of the microwave pulses and can determine speed and direction of wind near the ocean surface. The ability of microwaves to pass through clouds enables scientists to monitor conditions underneath a hurricane.



Credit: NASA image courtesy the QuikSCAT Science Team at the Jet Propulsion Laboratory

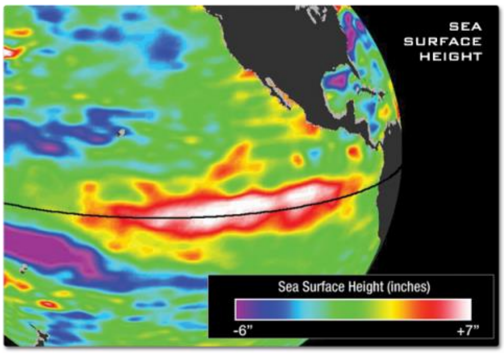


The Japanese Advanced Microwave Scanning Radiometer for EOS (AMSR-E) instrument onboard NASA's Aqua satellite can acquire high-resolution microwave measurements of the entire polar region every day, even through clouds and snowfall. Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio

ACTIVE REMOTE SENSING

Radar technology is considered an active remote sensing system because it actively sends a microwave pulse and senses the energy reflected back. Doppler Radar, Scatterometers, and Radar Altimeters are examples of active remote sensing instruments that use microwave frequencies.

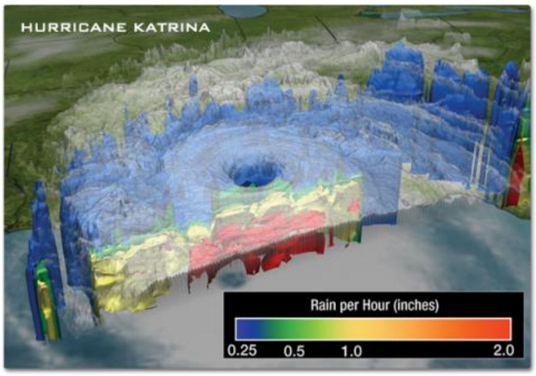
The radar altimeter onboard the joint NASA/CNES (French space agency) Ocean Surface Topography Mission (OSTM)/Jason-2 satellite can determine the height of the sea surface. This radar altimeter beams microwaves at two different frequencies (13.6 and 5.3 GHz) at the sea surface and measures the time it takes the pulses to return to the spacecraft. Combining data from other instruments that calculate the spacecraft's precise altitude and correct for the effect of water vapor on the pulse can determine the sea surface height within just a few centimeters!



Scientists monitor the changes in sea surface height around the world to help measurethe amount of heat stored in the ocean and predict global weather and climate eventssuch as El Niño. Since warm water is less dense than cold water, areas with a highersea surface tend to be warmer than lower areas. The sea surface height image(page 12) shows an area of warm water in the central and eastern Pacific Ocean thatis about 10 to 18 centimeters higher than normal. Such conditions can signify anEl Niño.Credit: NASA/JPL Ocean Surface Topography Team.

PASSIVE REMOTE SENSING

Passive remote sensing refers to the sensing of electromagnetic waves that did not originate from the satellite or instrument itself. The sensor is merely a passive observer collecting electromagnetic radiation. Passive remote sensing instruments onboard satellites have revolutionized weather forecasting by providing a global view of weather patterns and surface temperatures. A microwave imager onboard NASA's Tropical Rainfall Measuring Mission (TRMM) can capture data from underneath storm clouds to reveal the underlying rain structure.

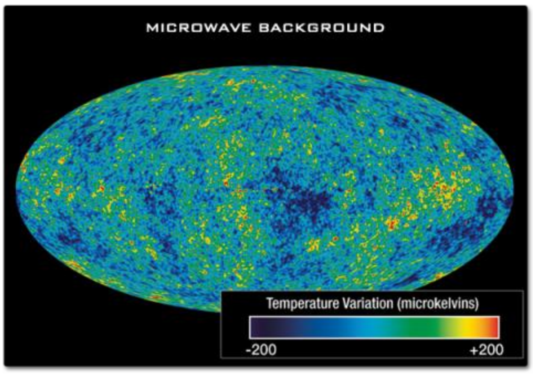


Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio

CLUES TO THE BIG BANG

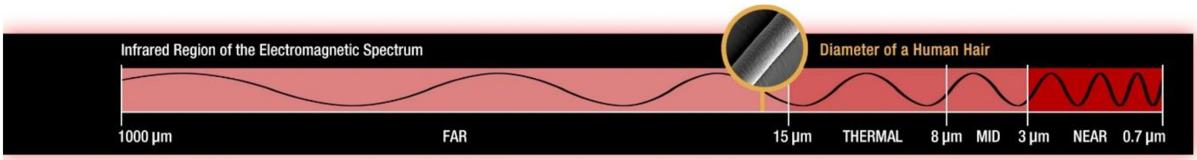
In 1965, using long, L-band microwaves, Arno Penzias and Robert Wilson, scientists at Bell Labs, made an incredible discovery quite by accident: they detected background noise using a special low-noise antenna. The strange thing about the noise was that it was coming from every direction and did not seem to vary in intensity much at all. If this static were from something on our planet, such as radio transmissions from a nearby airport control tower, it would come only from one direction, not everywhere. The Bell Lab scientists soon realized that they had serendipitously discovered the cosmic microwave background radiation. This radiation, which fills the entire universe, is a clue to its beginning, known as the Big Bang.

The image below from the Wilkinson Microwave Anisotropy Probe (WMAP) shows a detailed, all-sky picture of the infant universe at 380,000 years of age. This light, emitted 13.7 billon-years ago, is ~2.7 Kelvin today. The observed +/-200 microKelvin temperature fluctuations, shown as color differences in the image, are the seeds that grew to become clusters of galaxies.



Credit: NASA/WMAP Science Team

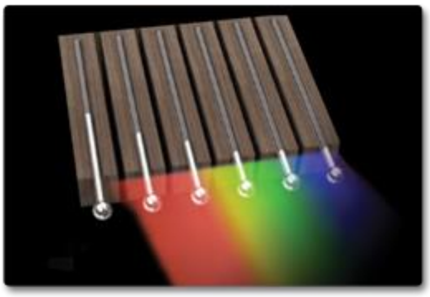
Infrared Waves



INFRARED ENERGY

A remote control uses light waves just beyond the visible spectrum of light—infrared light waves—to change channels on your TV. This region of the spectrum is divided into near-, mid-, and far-infrared. The region from 8 to 15 microns (µm) is referred to by Earth scientists as thermal infrared since these wavelengths are best for studying the longwave thermal energy radiating from our planet.

LEFT: **A typical television remote control uses infrared energy at a wavelength around940 nanometers. While you cannot "see" the light emitting from a remote, some digitaland cell phone cameras are sensitive to that wavelength of radiation. Try it out!***RIGHT:* **Infrared lamps heat lamps often emit both visible and infrared energy atwavelengths between 500nm to 3000nm in length. They can be used to heat bathroomsor keep food warm. Heat lamps can also keep small animals and reptiles warm oreven to keep eggs warm so they can hatch.**



Credit: Troy Benesch

DISCOVERY OF INFRARED

In 1800, William Herschel conducted an experiment measuring the difference in temperature between the colors in the visible spectrum. He placed thermometers within each color of the visible spectrum. The results showed an increase in temperature from blue to red. When he noticed an even warmer temperature measurement just beyond the red end of the visible spectrum, Herschel had discovered infrared light!

THERMAL IMAGING

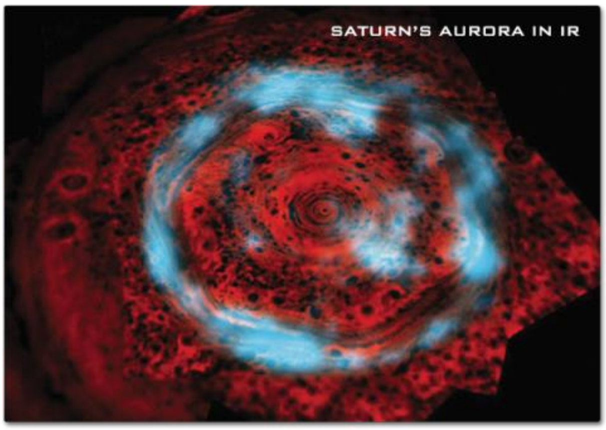
We can sense some infrared energy as heat. Some objects are so hot they also emit visible light—such as a fire does. Other objects, such as humans, are not as hot and only emit only infrared waves. Our eyes cannot see these infrared waves but instruments that can sense infrared energy—such as night-vision goggles or infrared cameras–allow us to "see" the infrared waves emitting from warm objects such as humans and animals. The temperatures for the images below are in degrees Fahrenheit.

Credit: NASA/JPL-Caltech

COOL ASTRONOMY

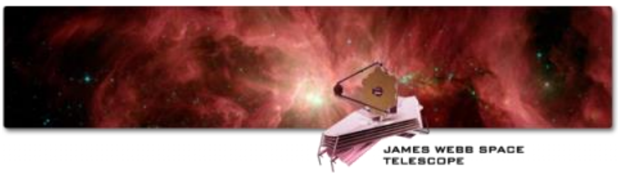
Many objects in the universe are too cool and faint to be detected in visible light but can be detected in the infrared. Scientists are beginning to unlock the mysteries of cooler objects across the universe such as planets, cool stars, nebulae, and many more, by studying the infrared waves they emit.

The Cassini spacecraft captured this image of Saturn's aurora using infrared waves. The aurora is shown in blue, and the underlying clouds are shown in red. These aurorae are unique because they can cover the entire pole, whereas aurorae around Earth and Jupiter are typically confined by magnetic fields to rings surrounding the magnetic poles. The large and variable nature of these aurorae indicates that charged particles streaming in from the Sun are experiencing some type of magnetism above Saturn that was previously unexpected.



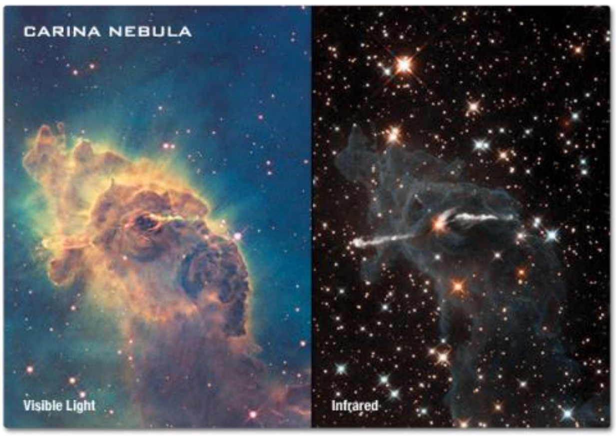
SEEING THROUGH DUST

Infrared waves have longer wavelengths than visible light and can pass through dense regions of gas and dust in space with less scattering and absorption. Thus, infrared energy can also reveal objects in the universe that cannot be seen in visible light using optical telescopes. The James Webb Space Telescope (JWST) has three infrared instruments to help study the origins of the universe and the formation of galaxies, stars, and planets.



When we look up at the constellation Orion, we see only the visible light. But NASA'sSpitzer space telescope was able to detect nearly 2,300 planet-forming disks in theOrion nebula by sensing the infrared glow of their warm dust. Each disk has thepotential to form planets and its own solar system.Credit: Thomas Megeath(Univ. Toledo) et al., JPL, Caltech, NASA

A pillar composed of gas and dust in the Carina Nebula is illuminated by the glow from nearby massive stars shown below in the visible light image from the Hubble Space Telescope. Intense radiation and fast streams of charged particles from these stars are causing new stars to form within the pillar. Most of the new stars cannot be seen in the visible-light image (left) because dense gas clouds block their light. However, when the pillar is viewed using the infrared portion of the spectrum (right), it practically disappears, revealing the baby stars behind the column of gas and dust.



Credit: NASA, ESA, and the Hubble SM4 ERO Team

MONITORING THE EARTH

To astrophysicists studying the universe, infrared sources such as planets are relatively cool compared to the energy emitted from hot stars and other celestial objects. Earth scientists study infrared as the thermal emission (or heat) from our planet. As incident solar radiation hits Earth, some of this energy is absorbed by the atmosphere and the surface, thereby warming the planet. This heat is emitted from Earth in the form of infrared radiation. Instruments onboard Earth observing satellites can sense this emitted infrared radiation and use the resulting measurements to study changes in land and sea surface temperatures.

There are other sources of heat on the Earth's surface, such as lava flows and forest fires. The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument onboard the Aqua and Terra satellites uses infrared data to monitor smoke and pinpoint sources of forest fires. This information can be essential to firefighting efforts when fire reconnaissance planes are unable to fly through the thick smoke. Infrared data can also enable scientists to distinguish flaming fires from still-smoldering burn scars.

Credit: Jeff Schmaltz, MODIS Rapid Response Team

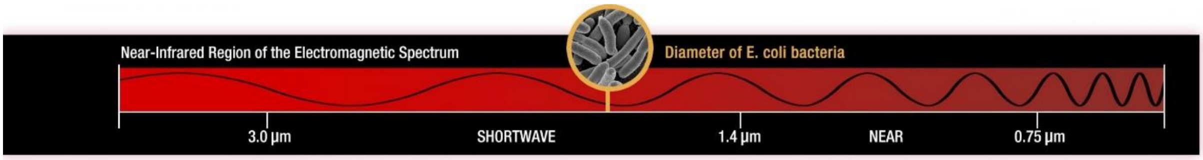
The global image on the right is an infrared image of the Earth taken by the GOES 6 satellite in 1986. A scientist used temperatures to determine which parts of the image were from clouds and which were land and sea. Based on these temperature differences, he colored each separately using 256 colors, giving the image a realistic appearance.

Credit: Space Science and Engineering Center,University of Wisconsin-Madison, Richard Kohrs, designer

Why use the infrared to image the Earth? While it is easier to distinguish clouds from land in the visible range, there is more detail in the clouds in the infrared. This is great for studying cloud structure. For instance, note that darker clouds are warmer, while lighter clouds are cooler. Southeast of the Galapagos, just west of the coast of South America, there is a place where you can distinctly see multiple layers of clouds, with the warmer clouds at lower altitudes, closer to the ocean that's warming them.

We know, from looking at an infrared image of a cat, that many things emit infrared light. But many things also reflect infrared light, particularly near infrared light. Learn more about REFLECTED Near-infrared radiation.

Reflected Near-Infrared Waves



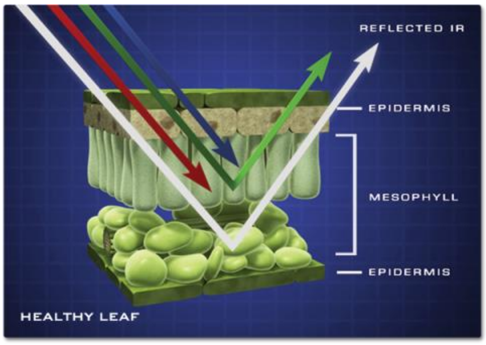
NEAR INFRARED RADIATION

A portion of radiation that is just beyond the visible spectrum is referred to as near-infrared. Rather than studying an object's emission of infrared, scientists can study how objects reflect, transmit, and absorb the Sun's near-infrared radiation to observe health of vegetation and soil composition.

HEALTHY VEGETATION

Our eyes perceive a leaf as green because wavelengths in the green region of the spectrum are reflected by pigments in the leaf, while the other visible wavelengths are absorbed. In addition, the components in plants reflect, transmit, and absorb different portions of the near-infrared radiation that we cannot see.

Reflected near-infrared radiation can be sensed by satellites, allowing scientists to study vegetation from space. Healthy vegetation absorbs blue- and red-light energy to fuel photosynthesis and create chlorophyll. A plant with more chlorophyll will reflect more near-infrared energy than an unhealthy plant. Thus, analyzing a plants spectrum of both absorption and reflection in visible and in infrared wavelengths can provide information about the plants' health and productivity.



Credit: Jeff Carns

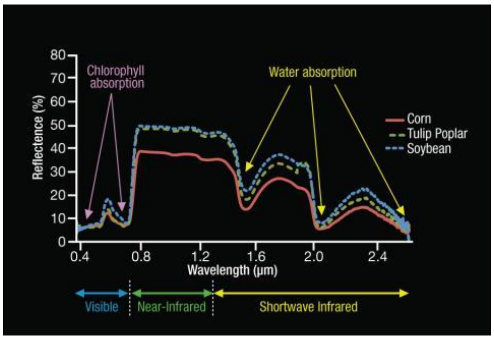
INFRARED FILM

Color Infrared film can record near-infrared energy and can help scientists study plant diseases where there is a change in pigment and cell structure. These two images show the difference between a color infrared photo and a natural color photo of trees in a park.

Credit: Ginger Butcher

SPECTRAL SIGNATURES OF VEGETATION

Data from scientific instruments can provide more precise measurements than analog film. Scientists can graph the measurements, examine the unique patterns of absorption and reflection of visible and infrared energy, and use this information to identify types of plants. The graph below shows the differences among the spectral signatures of corn, soybeans, and Tulip Poplar trees.



Credit: Eric Brown de Colstoun

ASSESSING VEGETATION FROM SPACE

Data and imagery from the U.S. Geological Service (USGS) and NASA Landsat series of satellites are used by the U.S. Department of Agriculture to forecast agricultural productivity each growing season. Satellite data can help farmers pinpoint where crops are infested, stressed, or healthy.

Near-infrared data collected by the Landsat 7 satellite, such as this image of Minnesota,can help farmers assess the health of their crops. Shades of red in this image indicategood crop health, and yellow colors reveal where crops are infested.Credit: Jesse Allen, using Landsat data provided by the United States Geological Survey

SOIL COMPOSITION

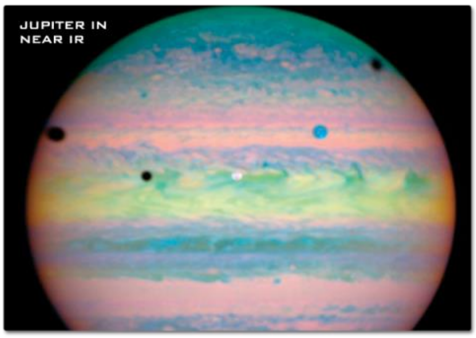
Near-infrared data can also help identify types of rock and soil. This image of the Saline Valley area in California was acquired by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) onboard NASA's Terra satellite.

Data from ASTER's visible and near-infrared bands at 0.81 µm, 0.56 µm, and .66 µm are composited in red, green, and blue creating the false-color image below. Vegetation appears red, snow and dry salt lakes are white, and exposed rocks are brown, gray, yellow, and blue. Rock colors mainly reflect the presence of iron minerals and variations in albedo (solar energy reflected off the surface).

Credit: NASA, GSFC, MITI, ERSDAC, JAROS, and the U.S./Japan ASTER Science Team

PLANETS IN NEAR-INFRARED

This false-color composite of Jupiter combines near-infrared and visible-light data of sunlight reflected from Jupiter's clouds. Since methane gas in Jupiter's atmosphere limits the penetration of sunlight, the amount of reflected near-infrared energy varies depending on the clouds' altitude. The resulting composite image shows this altitude difference as different colors. Yellow colors indicate high clouds; red colors are lower clouds; and blue colors show even lower clouds in Jupiter's atmosphere. The Near Infrared Camera and Multi-Object Spectrometer (NICMOS) onboard NASA's Hubble Space Telescope captured this image at the time of a rare alignment of three of Jupiter's largest moons—Io, Ganymede, and Callisto—across the planet's face.



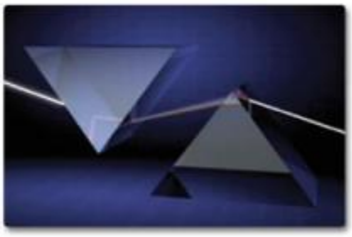
Credit: NASA and E. Karkoschka (University of Arizona)

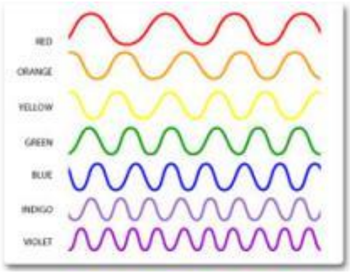
Visible Light

WAVELENGTHS OF VISIBLE LIGHT

All electromagnetic radiation is light, but we can only see a small portion of this radiation—the portion we call visible light. Cone-shaped cells in our eyes act as receivers tuned to the wavelengths in this narrow band of the spectrum. Other portions of the spectrum have wavelengths too large or too small and energetic for the biological limitations of our perception.

As the full spectrum of visible light travels through a prism, the wavelengths separate into the colors of the rainbow because each color is a different wavelength. Violet has the shortest wavelength, at around 380 nanometers, and red has the longest wavelength, at around 700 nanometers.

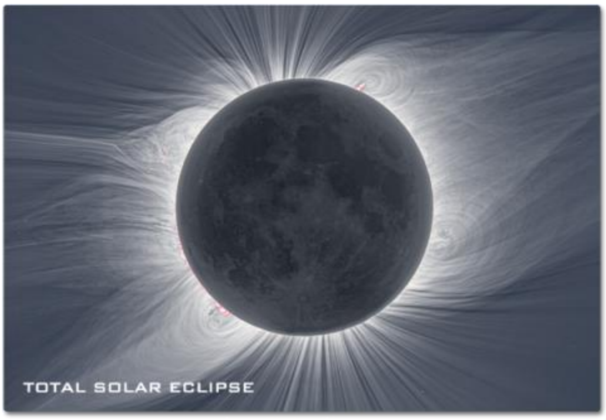




(Left) Isaac Newton's experiment in 1665 showed that a prism bends visible light andthat each color refracts at a slightly different angle depending on the wavelength of the color.Credit: Troy Benesch.(Right) Each color in a rainbow corresponds to a different wavelength of electromagnetic spectrum.

THE SUN'S CORONA

The Sun is the dominant source for visible-light waves our eyes receive. The outer-most layer of the Sun's atmosphere, the corona, can be seen in visible light. But it is so faint it cannot not be seen except during a total solar eclipse because the bright photosphere overwhelms it. The photograph below was taken during a total eclipse of the Sun where the photosphere and chromosphere are almost completely blocked by the moon. The tapered patterns—coronal streamers—around the Sun are formed by the outward flow of plasma that is shaped by magnetic field lines extending millions of miles into space.



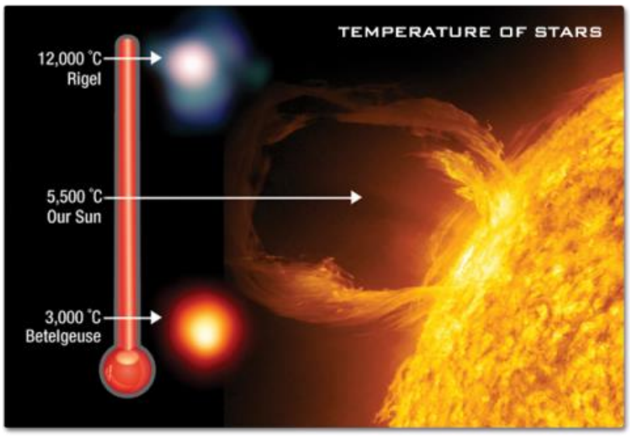
Credit: © 2008 Miloslav Druckmüller, Martin Dietzel, Peter Aniol, Vojtech Rušin

COLOR AND TEMPERATURE

As objects grow hotter, they radiate energy dominated by shorter wavelengths, changing color before our eyes. A flame on a blow torch shifts from reddish to bluish in color as it is adjusted to burn hotter. In the same way, the color of stars tells scientists about their temperature.

Our Sun produces more yellow light than any other color because its surface temperature is 5,500°C. If the Sun's surface were cooler—say 3,000°C—it would look reddish, like the star Betelgeuse. If the Sun were hotter—say, 12,000°C—it would look blue, like the star Rigel.

Isaac Newton's experiment in 1665 showed that a prism bends visible light and that each color refracts at a slightly different angle depending on the wavelength of the color.

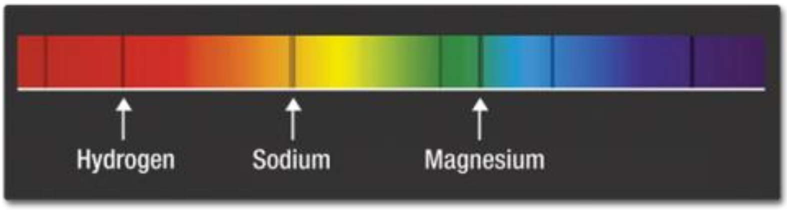


Credit: Jenny Mottar; Image Courtesy of SOHO/consortium

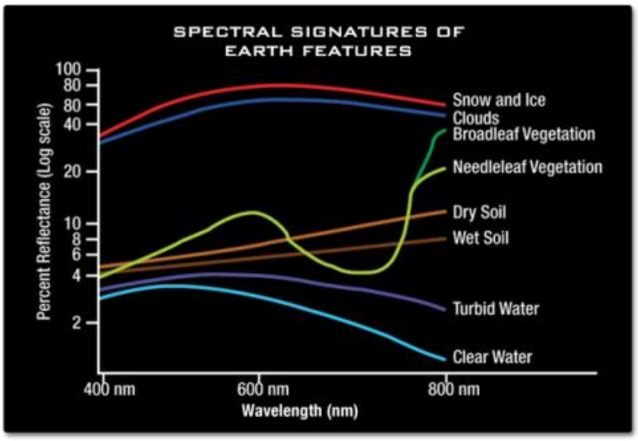
The High Resolution Imaging Science Experiment (HiRISE) camera on board the MarsReconnaissance Orbiter (MRO) captured this spectacular visible light image of Victoria Crater.Credit: NASA/JPL/University of Arizona

SPECTRA AND SPECTRAL SIGNATURES

Close examination of the visible-light spectrum from our Sun and other stars reveals a pattern of dark lines—called absorption lines. These patterns can provide important scientific clues that reveal hidden properties of objects throughout the universe. Certain elements in the Sun's atmosphere absorb certain colors of light. These patterns of lines within spectra act like fingerprints for atoms and molecules. Looking at the Sun's spectrum, for example, the fingerprints for elements are clear to those knowledgeable about those patterns.



Patterns are also evident in a graph of an object's reflectance. Elements, molecules, and even cell structures have unique signatures of reflectance. A graph of an object's reflectance across a spectrum is called a spectral signature. Spectral signatures of different Earth features within the visible light spectrum ARE shown below.



Credit: Jeannie Allen

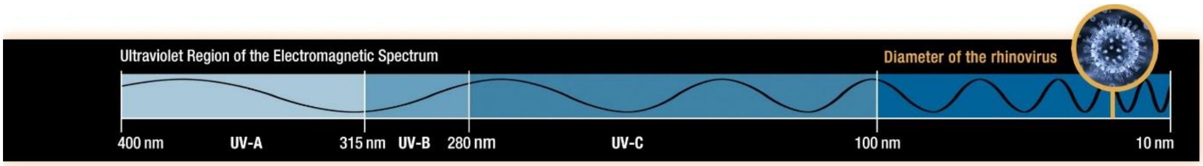
ACTIVE REMOTE SENSING—ALTIMETRY

Laser altimetry is an example of active remote sensing using visible light. NASA's Geoscience Laser Altimeter System (GLAS) instrument onboard the Ice, Cloud, and land Elevation Satellite (ICESat) enabled scientists to calculate the elevation of Earth's polar ice sheets using lasers and ancillary data. Changes in elevation over time help to estimate variations in the amount of water stored as ice on our planet. The image below shows elevation data over the West Antarctic Ice Streams.

Laser altimeters can also make unique measurements of the heights and characteristics of clouds, as well as the top and structure of the vegetation canopy of forests. They can also sense the distribution of aerosols from sources such as dust storms and forest fires.

Credit: NASA/Goddard Space Flight Center

Ultraviolet Waves

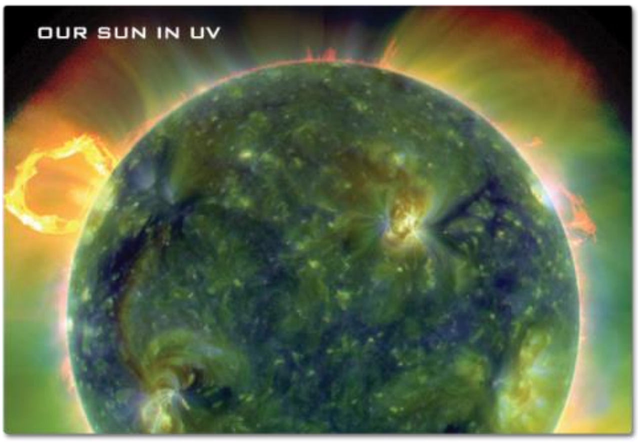


Bees, along with some birds, reptiles andother insects, can see near-ultraviolet lightreflecting off of plants. Bug zappers attractinsects with ultraviolet light to lure themto the trap.

ULTRAVIOLET LIGHT FROM OUR SUN

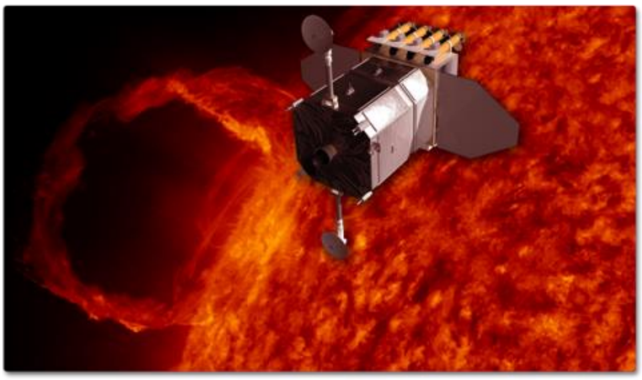
Ultraviolet (UV) light has shorter wavelengths than visible light. Although UV waves are invisible to the human eye, some insects, such as bumblebees, can see them. This is similar to how a dog can hear the sound of a whistle just outside the hearing range of humans.

The Sun is a source of the full spectrum of ultraviolet radiation, which is commonly subdivided into UV-A, UV-B, and UV-C. These are the classifications most often used in Earth sciences. UV-C rays are the most harmful and are almost completely absorbed by our atmosphere. UV-B rays are the harmful rays that cause sunburn. Exposure to UV-B rays increases the risk of DNA and other cellular damage in living organisms. Fortunately, about 95 percent UV-B rays are absorbed by ozone in the Earth's atmosphere.

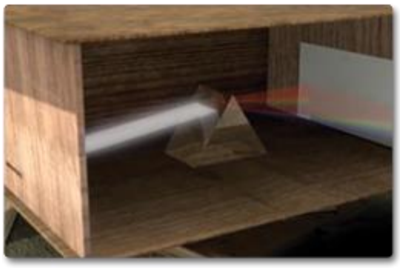


Credit: Image is courtesy of: NASA/SDO/AIA

Scientists studying astronomical objects commonly refer to different subdivisions of ultraviolet radiation: near ultraviolet (NUV), middle ultraviolet (MUV), far ultraviolet (FUV), and extreme ultraviolet (EUV). NASA's SDO spacecraft captured the image below in multiple wavelengths of extreme ultraviolet (EUV) radiation. The false-color composite reveals different gas temperatures. Reds are relatively cool (about 60,000 Celsius) while blues and greens are hotter (greater than one million Celsius).



NASA's Solar Dynamics Observatory (SDO) spacecraft captured this view of a dense loop of plasma erupting on the Sun's surface—a solar prominence. The plasma is seen flowing along a magnetic field. Credit: NASA ozonewatch.gsfc.nasa.gov



Johann Ritter's experiment was designed toexpose photographic paper to light just beyondthe visible spectrum and prove the existenceof light beyond violet—ultraviolet light.Credit: Troy Benesch

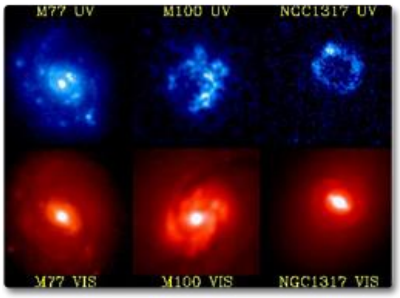
DISCOVERY OF ULTRAVIOLET

In 1801, Johann Ritter conducted an experiment to investigate the existence of energy beyond the violet end of the visible spectrum. Knowing that photographic paper would turn black more rapidly in blue light than in red light, he exposed the paper to light beyond violet. Sure enough, the paper turned black, proving the existence of ultraviolet light.

ULTRAVIOLET ASTRONOMY

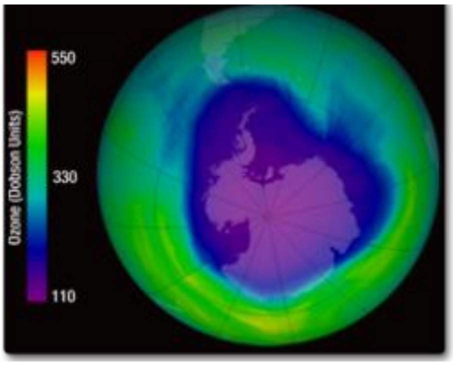
Since the Earth's atmosphere absorbs much of the high-energy ultraviolet radiation, scientists use data from satellites positioned above the atmosphere, in orbit around the Earth, to sense UV radiation coming from our Sun and other astronomical objects. Scientists can study the formation of stars in ultraviolet since young stars shine most of their light at these wavelengths. This image from NASA's Galaxy Evolution Explorer (GALEX) spacecraft reveals new young stars in the spiral arms of galaxy M81.

Credit: NASA/JPL-Caltech



The image to the right shows three different galaxies taken in visible light (bottom three images) and ultraviolet light (top row) taken by NASA's Ultraviolet Imaging Telescope (UIT) on the Astro-2 mission.

The difference in how the galaxies appear is due to which type of stars shine brightest in the optical and ultraviolet wavelengths. Ultraviolet images of galaxies show mainly clouds of gas containing newly formed stars that are many times more massive than the Sun and glow strongly in ultraviolet light. In contrast, visible light images of galaxies show mostly the yellow and red light of older stars. By comparing these types of data, astronomers can learn about the structure and evolution of galaxies.

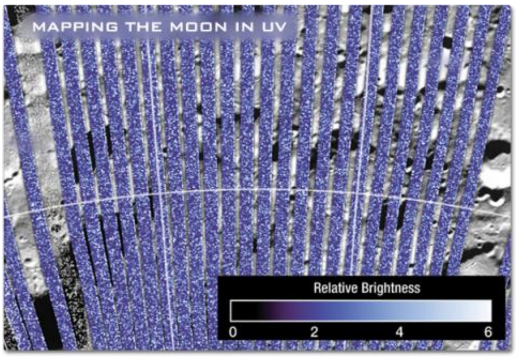


THE OZONE "HOLE"

Chemical processes in the upper atmosphere can affect the amount of atmospheric ozone that shields life at the surface from most of the Sun's harmful UV radiation. Each year, a "hole" of thinning atmospheric ozone expands over Antarctica, sometimes extending over populated areas of South America and exposing them to increased levels of harmful UV rays. The Dutch Ozone Monitoring Instrument (OMI) onboard NASA's Aura satellite measures amounts of trace gases important to ozone chemistry and air quality. The image above shows the amount of atmospheric ozone in Dobson Units—the common unit for measuring ozone concentration. These data enable scientists to estimate the amount of UV radiation reaching the Earth's surface and forecast high-UV-index days for public health awareness.

ULTRAVIOLET LIGHT FROM STARS

The Lyman-Alpha Mapping Project (LAMP) onboard the Lunar Reconnaissance Orbiter can peer into permanently shaded craters on the moon by sensing the faint reflections of UV light coming from distant stars.



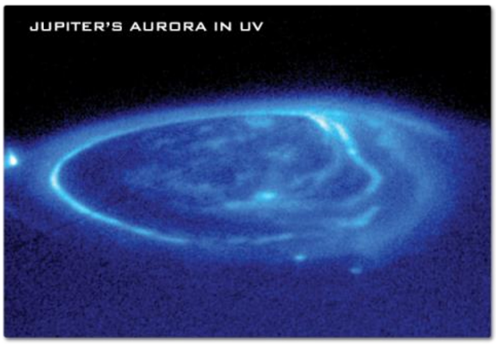
Credit: Ernest Wright LRO/LAMP

AURORAE

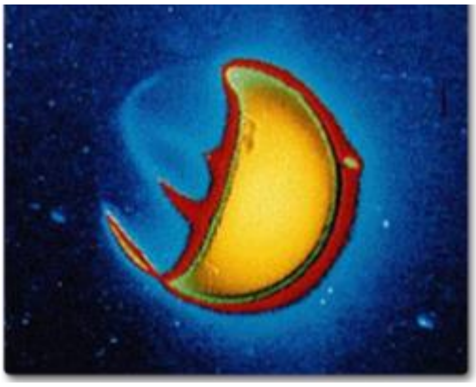
Aurorae are caused by high-energy waves that travel along a planet's magnetic poles, where they excite atmospheric gases and cause them to glow. Photons in this high-energy radiation bump into atoms of gases in the atmosphere causing electrons in the atoms to excite, or move to the atom's upper shells. When the electrons move back down to a lower shell, the energy is released as light, and the atom returns to a relaxed state. The color of this light can reveal what type of atom was excited. Green light indicates oxygen at lower altitudes. Red light can be from oxygen molecules at a higher altitude or from nitrogen. On Earth, aurorae around the north pole are called the Northern Lights.

JUPITER'S AURORA

The Hubble Space Telescope captured this image of Jupiter's aurora in ultraviolet wrapping around Jupiter's north pole like a lasso.

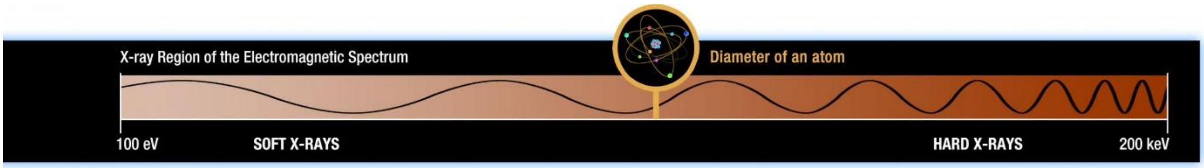


Credit: John Clarke (University of Michigan) and NASA



This unusual false-color image shows how the Earth glows in ultraviolet (UV) light. The Far UV Camera/Spectrograph deployed and left on the Moon by the crew of Apollo 16 captured this image. The part of the Earth facing the Sun reflects much UV light and bands of UV emission are also apparent on the side facing away from the Sun. These bands are the result of aurora caused by charged particles given off by the Sun. They spiral towards the Earth along Earth's magnetic field lines.

X-Rays



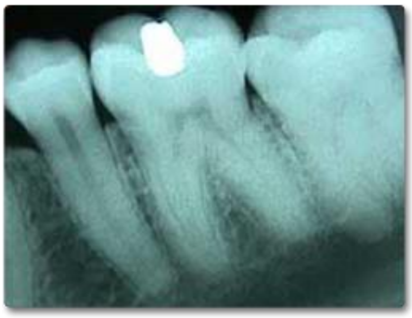
X-RAYS AND ENERGY

X-rays have much higher energy and much shorter wavelengths than ultraviolet light, and scientists usually refer to x-rays in terms of their energy rather than their wavelength. This is partially because x-rays have very small wavelengths, between 0.03 and 3 nanometers, so small that some x-rays are no bigger than a single atom of many elements.

This mosaic of several Chandra X-ray Observatory images of the central region of our Milky Way galaxy reveals hundreds of white dwarf stars, neutron stars, and black holes. Separately, the Solar and Heliophysics Observatory (SOHO) captured these images of the Sun representing an entire solar cycle from 1996 through 2006. Credit: NASA/UMass/D.Wang et al. Sun images from SOHO – EIT Consortium: NASA/ESA

DISCOVERY OF X-RAYS

X-rays were first observed and documented in 1895 by German scientist Wilhelm Conrad Roentgen. He discovered that firing streams of x-rays through arms and hands created detailed images of the bones inside. When you get an x-ray taken, x-ray sensitive film is put on one side of your body, and x-rays are shot through you. Because bones are dense and absorb more x-rays than skin does, shadows of the bones are left on the x-ray film while the skin appears transparent.



An x-ray image of teeth. Can you see the filling?

An X-ray photo of a one year old girl who swallowed a sewing pin. Can you find it?

Our Sun's radiation peaks in the visual range, but the Sun's corona is much hotter and radiates mostly x-rays. To study the corona, scientists use data collected by x-ray detectors on satellites in orbit around the Earth. Japan's Hinode spacecraft produced these x-ray images of the Sun that allow scientists to see and record the energy flows within the corona.

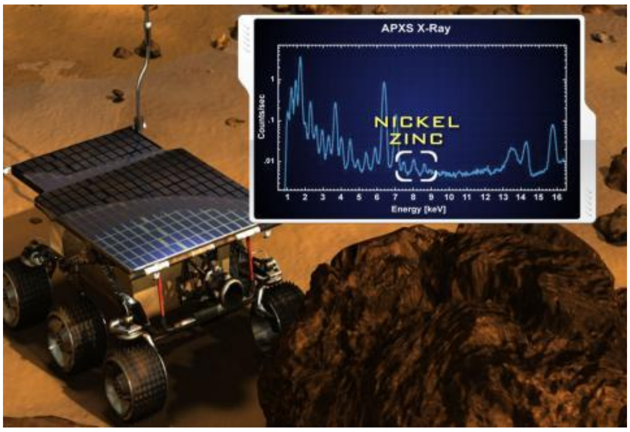
Credit: Hinode JAXA/NASA/PPARC

TEMPERATURE AND COMPOSITION

The physical temperature of an object determines the wavelength of the radiation it emits. The hotter the object, the shorter the wavelength of peak emission. X-rays come from objects that are millions of degrees Celsius—such as pulsars, galactic supernovae remnants, and the accretion disk of black holes.

From space, x-ray telescopes collect photons from a given region of the sky. The photons are directed onto the detector where they are absorbed, and the energy, time, and direction of individual photons are recorded. Such measurements can provide clues about the composition, temperature, and density of distant celestial environments. Due to the high energy and penetrating nature of x-rays, x-rays would not be reflected if they hit the mirror head on (much the same way that bullets slam into a wall). X-ray telescopes focus x-rays onto a detector using grazing incidence mirrors (just as bullets ricochet when they hit a wall at a grazing angle).

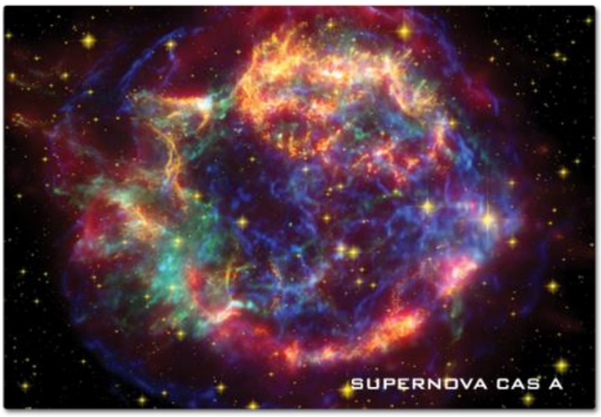
NASA's Mars Exploration Rover, Spirit, used x-rays to detect the spectral signatures of zinc and nickel in Martian rocks. The Alpha Proton X-Ray Spectrometer (APXS) instrument uses two techniques, one to determine structure and another to determine composition. Both of these techniques work best for heavier elements such as metals.



SUPERNOVA

Since Earth's atmosphere blocks x-ray radiation, telescopes with x-ray detectors must be positioned above Earth's absorbing atmosphere. The supernova remnant Cassiopeia A (Cas A) was imaged by three of NASA's great observatories, and data from all three observatories were used to create the image shown below. Infrared data from the Spitzer Space Telescope are colored red, optical data from the Hubble Space Telescope are yellow, and x-ray data from the Chandra X-ray Observatory are green and blue.

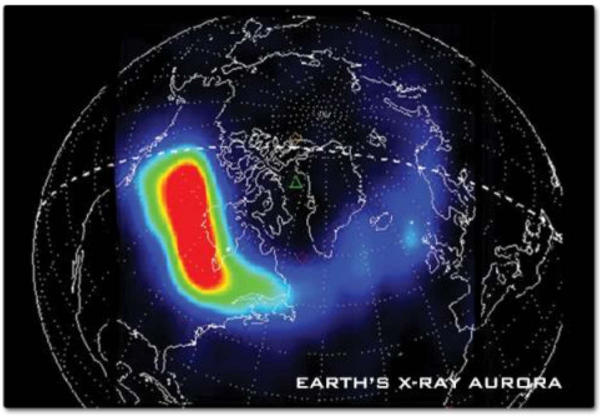
The x-ray data reveal hot gases at about ten million degrees Celsius that were created when ejected material from the supernova smashed into surrounding gas and dust at speeds of about ten million miles per hour. By comparing infrared and x-ray images, astronomers are learning more about how relatively cool dust grains can coexist within the super-hot, x-ray producing gas.



Credit: X-ray: NASA/CXC/SAO; Optical: NASA/STScI; Infrared: NASA/JPL-Caltech/Steward/O.Krause et al.

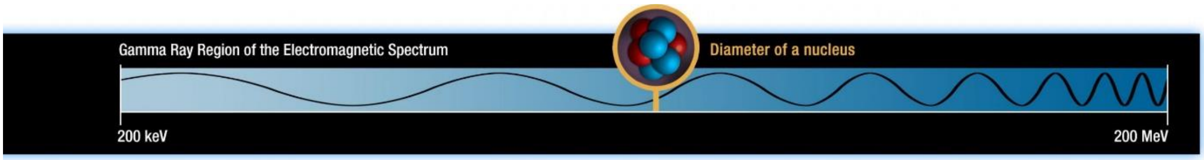
EARTH'S AURORA IN X-RAYS

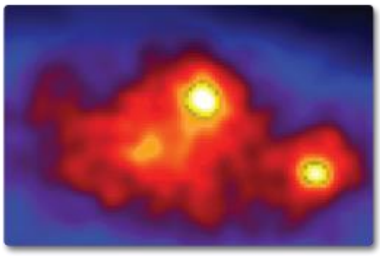
Solar storms on the Sun eject clouds of energetic particles toward Earth. These high-energy particles can be swept up by Earth's magnetosphere, creating geomagnetic storms that sometimes result in an aurora. The energetic charged particles from the Sun that cause an aurora also energize electrons in the Earth's magnetosphere. These electrons move along the Earth's magnetic field and eventually strike the Earth's ionosphere, causing the x-ray emissions. These x-rays are not dangerous to people on the Earth because they are absorbed by lower parts of the Earth's atmosphere. Below is an image of an x-ray aurora by the Polar Ionospheric X-ray Imaging Experiment (PIXIE) instrument aboard the Polar satellite.



Credit: POLAR, PIXIE, NASA

Gamma Rays





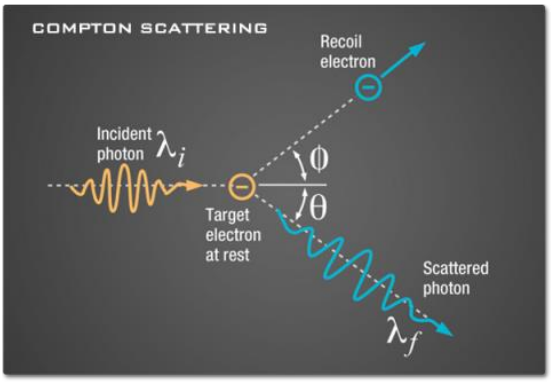
Brighter colors in the Cygus region indicate greater numbers of gamma rays detected by the Fermi gamma-ray space telescope. Credit: NASA/DOE/International LAT Team

SOURCES OF GAMMA RAYS

Gamma rays have the smallest wavelengths and the most energy of any wave in the electromagnetic spectrum. They are produced by the hottest and most energetic objects in the universe, such as neutron stars and pulsars, supernova explosions, and regions around black holes. On Earth, gamma waves are generated by nuclear explosions, lightning, and the less dramatic activity of radioactive decay.

DETECTING GAMMA RAYS

Unlike optical light and x-rays, gamma rays cannot be captured and reflected by mirrors. Gamma-ray wavelengths are so short that they can pass through the space within the atoms of a detector. Gamma-ray detectors typically contain densely packed crystal blocks. As gamma rays pass through, they collide with electrons in the crystal. This process is called Compton scattering, wherein a gamma ray strikes an electron and loses energy, similar to what happens when a cue ball strikes an eight ball. These collisions create charged particles that can be detected by the sensor.

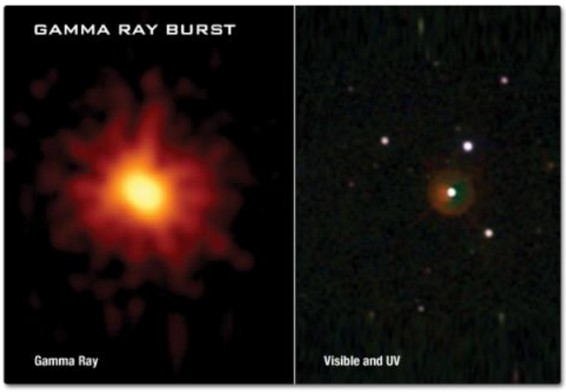


GAMMA RAY BURSTS

Gamma-ray bursts are the most energetic and luminous electromagnetic events since the Big Bang and can release more energy in 10 seconds than our Sun will emit in its entire 10-billion-year expected lifetime! Gamma-ray astronomy presents unique opportunities to explore these exotic objects. By exploring the universe at these high energies, scientists can search for new physics, testing theories and performing experiments that are not possible in Earth-bound laboratories.

If we could see gamma rays, the night sky would look strange and unfamiliar. The familiar view of constantly shining constellations would be replaced by ever-changing bursts of high-energy gamma radiation that last fractions of a second to minutes, popping like cosmic flashbulbs, momentarily dominating the gamma-ray sky and then fading.

NASA's Swift satellite recorded the gamma-ray blast caused by a black hole being born 12.8 billion light years away (below). This object is among the most distant objects ever detected.

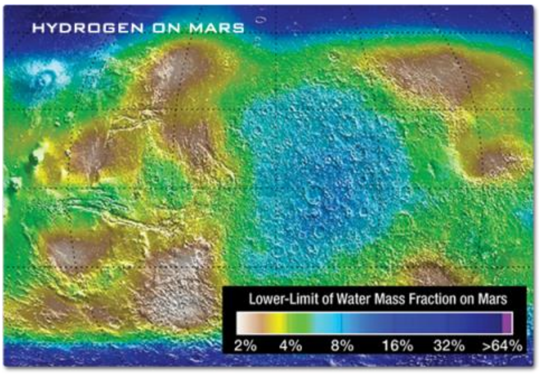


Credit: NASA/Swift/Stefan Immler, et al.

COMPOSITION OF PLANETS

Scientists can use gamma rays to determine the elements on other planets. The Mercury Surface, Space Environment, Geochemistry, and Ranging (MESSENGER) Gamma-Ray Spectrometer (GRS) can measure gamma rays emitted by the nuclei of atoms on planet Mercury's surface that are struck by cosmic rays. When struck by cosmic rays, chemical elements in soils and rocks emit uniquely identifiable signatures of energy in the form of gamma rays. These data can help scientists look for geologically important elements such as hydrogen, magnesium, silicon, oxygen, iron, titanium, sodium, and calcium.

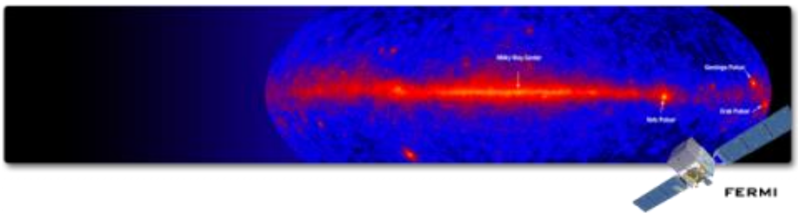
The gamma-ray spectrometer on NASA's Mars Odyssey Orbiter detects and maps these signatures, such as this map (below) showing hydrogen concentrations of Martian surface soils.



Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio

GAMMA RAY SKY

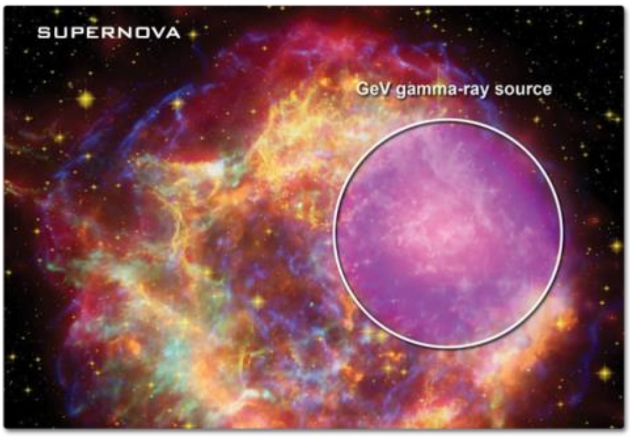
Gamma rays also stream from stars, supernovas, pulsars, and black hole accretion disks to wash our sky with gamma-ray light. These gamma-ray streams were imaged using NASA's Fermi gamma-ray space telescope to map out the Milky Way galaxy by creating a full 360-degree view of the galaxy from our perspective here on Earth.



Credit: NASA/DOE/International LAT Team

A FULL-SPECTRUM IMAGE

The composite image below of the Cas A supernova remnant shows the full spectrum in one image. Gamma rays from Fermi are shown in magenta; x-rays from the Chandra Observatory are blue and green. The visible light data captured by the Hubble space telescope are displayed in yellow. Infrared data from the Spitzer space telescope are shown in red; and radio data from the Very Large Array are displayed in orange.



Credit: NASA/DOE/Fermi LAT Collaboration, CXC/SAO/JPL-Caltech/Steward/O. Krause et al., and NRAO/AUI

The Earth's Radiation Budget

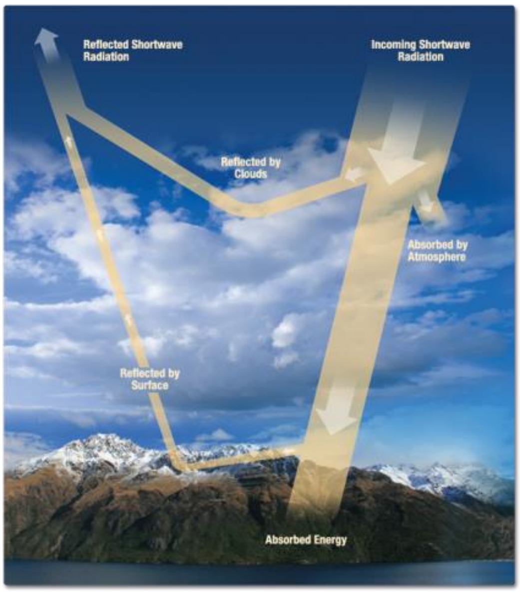
The energy entering, reflected, absorbed, and emitted by the Earth system are the components of the Earth's radiation budget. Based on the physics principle of conservation of energy, this radiation budget represents the accounting of the balance between incoming radiation, which is almost entirely solar radiation, and outgoing radiation, which is partly reflected solar radiation and partly radiation emitted from the Earth system, including the atmosphere. A budget that's out of balance can cause the temperature of the atmosphere to increase or decrease and eventually affect our climate. The units of energy employed in measuring this incoming and outgoing radiation are watts per square meter (W/m2).

INCOMING SOLAR RADIATION

Incoming ultraviolet, visible, and a limited portion of infrared energy (together sometimes called "shortwave radiation") from the Sun drive the Earth's climate system. Some of this incoming radiation is reflected off clouds, some is absorbed by the atmosphere, and some passes through to the Earth's surface. Larger aerosol particles in the atmosphere interact with and absorb some of the radiation, causing the atmosphere to warm. The heat generated by this absorption is emitted as longwave infrared radiation, some of which radiates out into space.

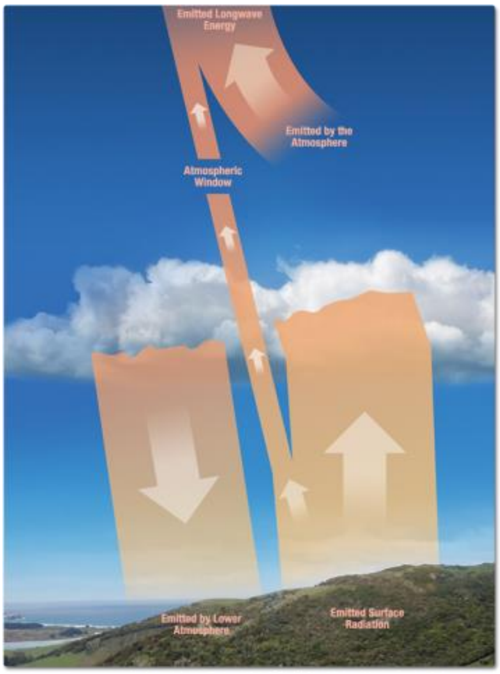
ABSORBED ENERGY

The solar radiation that passes through Earth's atmosphere is either reflected off snow, ice, or other surfaces or is absorbed by the Earth's surface.



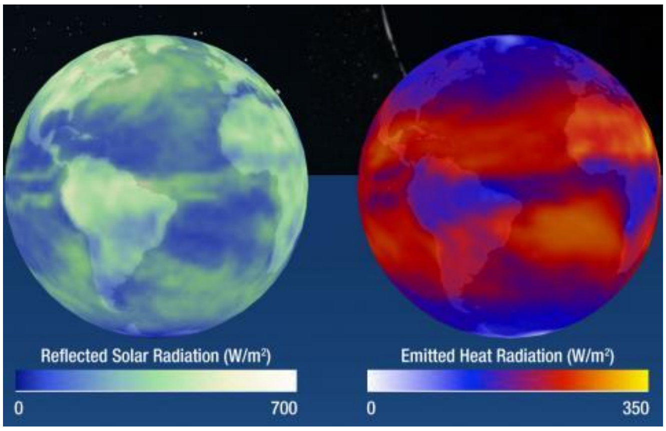
Emitted LONGWAVE Radiation

Heat resulting from the absorption of incoming shortwave radiation is emitted as longwave radiation. Radiation from the warmed upper atmosphere, along with a small amount from the Earth's surface, radiates out to space. Most of the emitted longwave radiation warms the lower atmosphere, which in turn warms our planet's surface.



GREENHOUSE EFFECT

Greenhouse gases in the atmosphere (such as water vapor and carbon dioxide) absorb most of the Earth's emitted longwave infrared radiation, which heats the lower atmosphere. In turn, the warmed atmosphere emits longwave radiation, some of which radiates toward the Earth's surface, keeping our planet warm and generally comfortable. Increasing concentrations of greenhouse gases such as carbon dioxide and methane increase the temperature of the lower atmosphere by restricting the outward passage of emitted radiation, resulting in "global warming," or, more broadly, global climate change.



Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio

RADIATION AND THE CLIMATE SYSTEM

For scientists to understand climate change, they must also determine what drives the changes within the Earth's radiation budget. The Clouds and the Earth's Radiant Energy System (CERES) instrument aboard NASA's Aqua and Terra satellites measures the shortwave radiation reflected and longwave radiation emitted into space accurately enough for scientists to determine the Earth's total radiation budget. Other NASA instruments monitor changes in other aspects of the Earth's climate system—such as clouds, aerosol particles, and surface reflectivity—and scientists are examining their many interactions with the radiation budget.

Check out this Earth's Energy Budget poster to learn more about our understand of energy flows into and away from Earth.