

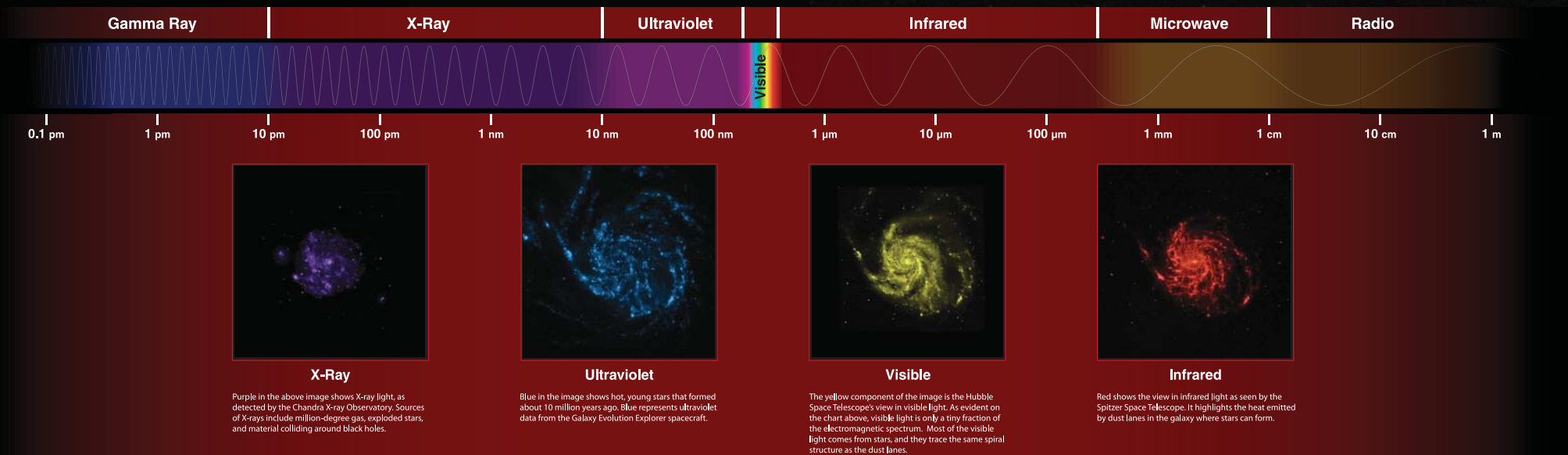
The Multiwavelength Universe

To get a complete picture of the universe, we need to see it in all its light. All astronomical objects, except for black holes, emit at least some light. Many objects emit more radiation in some parts of the electromagnetic spectrum than in others. Some objects emit strongly across the entire spectrum. Each part of the spectrum reveals information not found at other wavelengths.

X-rays and gamma rays bring us information about high energy phenomena such as black holes, supernova remnants, hot gas, and neutron stars. Ultraviolet light reveals hot stars and quasars, while visible light shows us warmer stars, planets, nebulae, and galaxies. In the infrared we see cool stars, regions of star birth, cool dusty regions of space, and the core of our galaxy. Radiation in the radio region shows us cold molecular clouds and the radiation left over from the Big Bang.

This image of the beautiful Pinwheel Galaxy, M101, is a composite of infrared, visible, ultraviolet and X-ray images. The combined light shows that both young and old stars are evenly distributed along M101's tightly wound spiral arms.

Such composite images allow astronomers to see how features seen in one wavelength match up with those seen in another wavelength. It's like seeing with a regular camera, an ultraviolet camera, night vision goggles, and X-ray vision all at once.



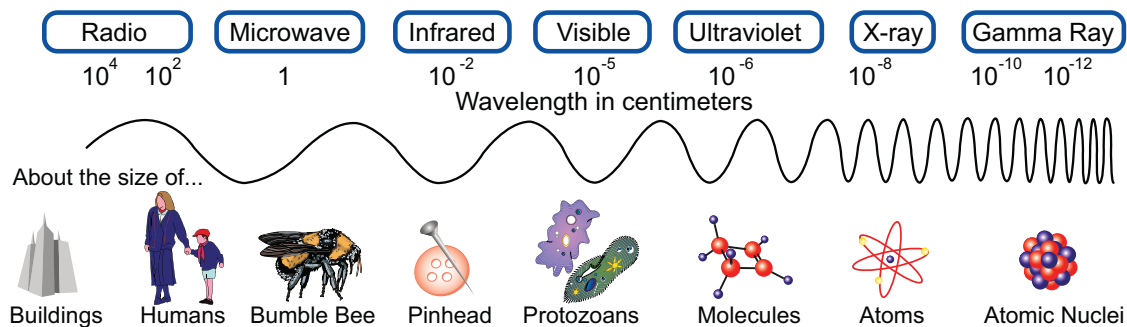
Multiwavelength Astronomy

Revealing the Universe in All Its Light

Almost everything we know about the universe comes from studying the light emitted or reflected by objects in space. Apart from a few exceptions, such as the collection of Moon rocks returned by Apollo astronauts, astronomers must rely on collecting and analyzing the faint light from distant objects in order to study the cosmos. This fact is even more remarkable when you consider the vastness of space. Light may travel for billions of years before reaching our telescopes. In the science of astronomy, we generally cannot retrieve samples, study objects in a laboratory, or physically enter an environment for detailed study.

Fortunately, light carries a lot of information. By detecting and analyzing the light emitted by an object in space, astronomers can learn about its distance, motion, temperature, density, and chemical composition. Since the light from an object takes time to reach us, it also brings us information about the evolution and history of the universe. When we receive light from an object in space, we are actually performing a type of archaeology by studying the object's appearance as it was when the light was emitted. For example, when astronomers study a galaxy that is 200 million light-years away, they are examining that galaxy as it looked 200 million years ago. To see what it looks like today, we would have to wait another 200 million years.

The Electromagnetic Spectrum



It is natural to think of light as visible light—the light we see with our eyes. However, this is only one type of light. The entire range of light—of which the rainbow of colors we normally see is only a very small part—is called the electromagnetic spectrum. The electromagnetic spectrum includes gamma rays, X-rays, ultraviolet, visible, infrared, microwaves, and radio waves. These types of radiation differ only in their characteristic wavelength or frequency. Wavelength increases and frequency decreases from gamma rays to radio waves. All these forms of radiation travel at the speed of light, which is about 300 million meters per second (186,000 miles per second).

Each type of radiation (or light) brings us unique information. To get a complete picture of the universe we need to see it in all of its light, using each part of the electromagnetic spectrum. Technological developments over the past seventy years have led to electronic detectors capable of seeing light invisible to human eyes. In addition, we can now place telescopes on satellites and on high-flying airplanes and balloons that operate above the obscuring effects of Earth's atmosphere. This combination has led to a revolution in our understanding of the universe.

Å = Angstrom. 1 Angstrom = 0.000000001 meter
µm = micrometer. 1 µm = 0.000001 meter
km = kilometer. 1km = 1,000 meters (= 0.6214 mile)

Why Multiwavelength Astronomy Is Important

By studying the universe across the spectrum we can get a more complete understanding of objects in space. The light from each part of the electromagnetic spectrum brings us valuable and unique information. X-rays and gamma rays bring us information about high energy phenomena such as black holes, supernova remnants, hot gas, and neutron stars. Ultraviolet light reveals hot stars and quasars, while visible light shows us warmer stars, planets, nebulae, and galaxies. In the infrared we see cool stars, regions of star birth, cool dusty regions of space, and the core of our galaxy. Radiation in the radio region shows us cold molecular clouds and the radiation left over from the Big Bang.



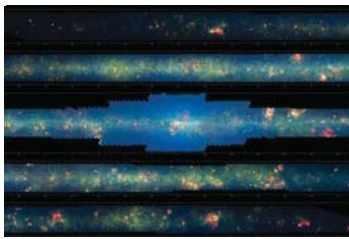
X-ray image showing hot gas near the center of our Milky Way Galaxy.



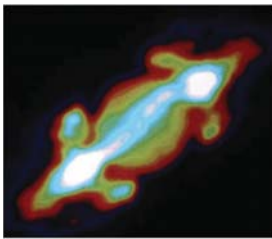
Ultraviolet view of a hot white dwarf star called Jupiter's Ghost.



Visible light image showing a variety of stars.



Infrared view of glowing dust near the center of our Galaxy.



Radio image of a supernova remnant.

All astronomical objects, except for black holes, emit at least some light. Many objects emit more radiation in some parts of the electromagnetic spectrum than in others, while others emit strongly across the entire spectrum. Each part of the spectrum reveals information not found at other wavelengths.

About the Images

As you have probably noticed, the images displayed on this poster (front and back) use different color scales and show different levels of detail. This variation is a result of the diversity of telescopes and detectors used and the colors chosen to represent each image. The non-visible-light pictures are all false-color images. A false-color image is one in which the colors are not the "true colors" of the object. Visible light colors or various levels of gray are assigned to certain wavelength or intensity ranges so we can see them with our eyes. To make an infrared image, for example, an electronic detector maps the infrared radiation intensity within its field of view. Those intensities can then be mapped into visible colors such as red, blue, yellow, and green or made into a grayscale image.

As you compare these images, keep in mind that each picture tells us something different. Just as important, if we omitted any of the images, we would lose the information available to us in that portion of the spectrum.

Types of Radiation Emitted by Celestial Objects

Type of Radiation	Characteristic Temperature	Objects Emitting This Type of Radiation
Gamma Rays	More than 10^8 Kelvin (K)	<ul style="list-style-type: none"> ▪ Interstellar clouds where cosmic rays collide with hydrogen nuclei ▪ Disks of material surrounding black holes ▪ Pulsars or neutron stars
X-rays	$10^6 - 10^8$ K	<ul style="list-style-type: none"> ▪ Regions of hot, shocked gas ▪ Gas in clusters of galaxies ▪ Neutron stars ▪ Supernova remnants ▪ The hot outer layers of stars
Ultraviolet	$10^4 - 10^6$ K	<ul style="list-style-type: none"> ▪ Supernova remnants ▪ Very hot stars ▪ Quasars
Visible	$10^3 - 10^4$ K	<ul style="list-style-type: none"> ▪ Planets ▪ Stars ▪ Galaxies ▪ Nebulae
Infrared	$10 - 10^3$ K	<ul style="list-style-type: none"> ▪ Cool stars ▪ Star-forming regions ▪ Interstellar dust warmed by starlight ▪ Planets ▪ Comets ▪ Asteroids
Radio	Less than 10 K	<ul style="list-style-type: none"> ▪ Cosmic background radiation ▪ Scattering of free electrons in interstellar plasmas ▪ Cold gas and dust between the stars ▪ Regions near white dwarfs and neutron stars ▪ Supernova remnants ▪ Dense regions of interstellar space such as the galactic center ▪ Cold molecular clouds

T=Temperature

$$T(\text{K}) = 273.15 + ^\circ\text{C}$$

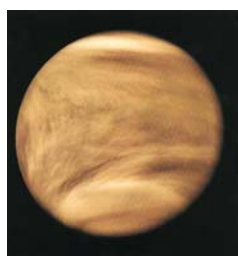
$$T(^{\circ}\text{C}) = (5/9) * (^{\circ}\text{F} - 32)$$

$$T(^{\circ}\text{F}) = (9/5) * ^{\circ}\text{C} + 32$$

Our Solar System

Optical astronomy has provided us with a wealth of information about our Solar System. Space missions have shown us detailed, close-up views of the planets and their moons. Through visible-light observations we have studied comets and asteroids as well as the surface of the Sun. What more can we learn about our Solar System by studying the light from other parts of the spectrum? Multiwavelength studies give us information about the different layers in the atmospheres of planets and some of their moons. The same is true of the Sun—observing the Sun in different parts of the spectrum allows us to study details in different layers of the solar atmosphere. Did you know that comets emit X-rays? Why this happens is still a mystery. Infrared observations have shown us that our Solar System is filled with comet dust and that the giant planets Jupiter, Saturn, and Neptune not only reflect heat from the Sun, but create their own heat as well. Ultraviolet observations have led to the discovery of aurorae on both Jupiter and Saturn.

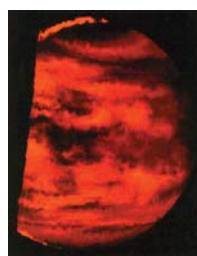
Below is what Venus, the second planet from the Sun, looks like when viewed in different parts of the electromagnetic spectrum.



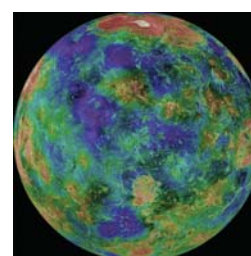
Ultraviolet



Visible



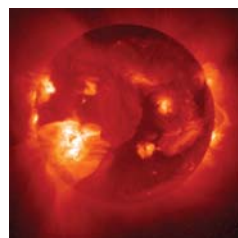
Infrared



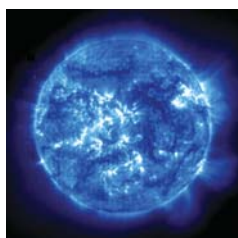
Radio

The ultraviolet view of Venus reveals a thick atmosphere due to a runaway greenhouse effect that causes surface temperatures to reach many hundreds of degrees. The visible-light image also shows the thick cloud cover that perpetually enshrouds the surface. In the infrared, we can look deeper into the atmosphere and see more details. The brighter areas are where heat from the lower atmosphere shines through sulfuric acid clouds (dark areas). Longer radio waves can completely penetrate the thick cloud cover, allowing scientists to beam radar waves to map the surface features of Venus.

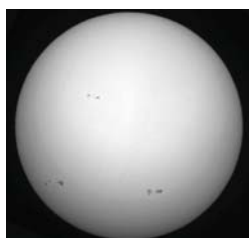
Our Sun is a normal star and looks very different across the electromagnetic spectrum.



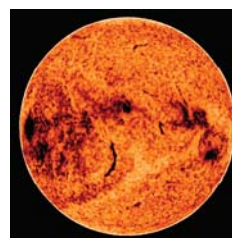
X-Ray



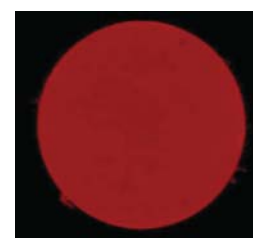
Ultraviolet



Visible



Infrared



Radio

By observing the Sun in different parts of the spectrum, we can get information about the different layers in the Sun's atmosphere. X-ray images show us the structure of the hot corona, the outermost layer of the Sun. The brightest regions in the X-ray image are violent, high-temperature solar flares. The ultraviolet image shows additional regions of activity deeper in the Sun's atmosphere. In visible light we see sunspots on the Sun's surface. The infrared photo shows large, dark regions of cooler, denser gas where the infrared light is absorbed. The radio image shows us the middle layer of the Sun's atmosphere.

Our Milky Way Galaxy

Looking up into the night sky, we have a visible-light view of objects within our galaxy. Optical telescopes show us countless stars and wonderful, detailed images of nebulae. Look within our galaxy in the infrared, however, and we get a completely different view. Areas that appear dark and empty in visible light reveal bright molecular clouds in which new stars are being formed. Infrared astronomy has revealed disks of material around other stars in which planets may be forming. It has also revealed wisps of warm dust throughout the galaxy, vast numbers of cooler stars, and the core of the Milky Way. X-rays tell us about the hot outer atmospheres of stars and the final phases of a star's life. When a star explodes it ejects hot shells of gas that radiate strongly in X-rays. Thus, the X-ray region of the spectrum is a valuable place to learn about supernovae, neutron stars, and black holes. X-ray observations have even led to the discovery of a black hole at the center of the Milky Way. Radio waves also bring us information about supernovae and neutron stars. In addition, radio observations are used to map the distribution of hydrogen gas in our galaxy and to find the signatures of interstellar molecules.

Orion may be a familiar constellation in the winter night sky, but these dramatically different images of the nebula in Orion's Belt are anything but familiar!



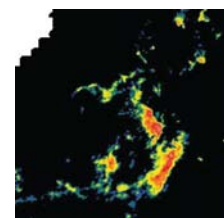
X-Ray



Visible



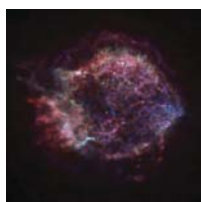
Infrared



Radio

The X-ray photograph reveals Sun-like stars, white dwarf stars, neutron stars, and supernova remnants in our own galaxy, and (in the background) nearby galaxies, clusters of galaxies, and distant quasars. The visible-light image shows stars of all ages and temperatures. In the infrared, our view of Orion is dominated by emission from clouds of dust and gas, the materials from which new stars will be born. The radio image maps the distribution of hydrogen molecules.

Our next stop in the Milky Way is the supernova remnant Cassiopeia A. This shell of expanding gas and dust is the result of a supernova explosion that was visible from the Earth in the 17th century.



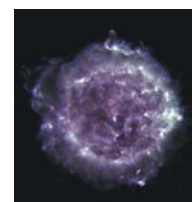
X-Ray



Visible



Infrared



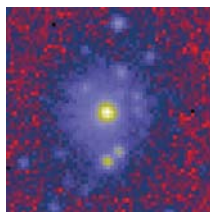
Radio

In X-rays we see gaseous clumps of silicon, sulfur, and iron ejected from the exploded star. The gases in the X-ray image are at a temperature of about 50 million degrees. The visible light image reveals the wispy filaments of gas at the edge of the spherical shell. The infrared photo shows bright knots of thermal emission produced by dust mixed with the gas in the expanding shell. The radio emission is primarily radiation generated by fast-moving electrons immersed in a magnetic field.

Beyond Our Galaxy

Beyond our Milky Way galaxy, multiwavelength astronomy unlocks a treasure trove of information. Visible-light images show us the detailed structure of various types of galaxies, while radio images show quite a different picture of huge jets and lobes of material ejected from galactic cores. X-rays are used to detect the signature of black holes in the centers of galaxies—the extremely hot material being pulled into a black hole at tremendous speeds. Infrared light is used to discover galaxies undergoing intense star formation. Radio studies have detected the radiation left over by the Big Bang.

As an example of the valuable information gained about another galaxy by viewing it at many wavelengths, let's take a multiwavelength look at the spiral galaxy Messier 81 in the northern constellation of Ursa Major.



X-Ray



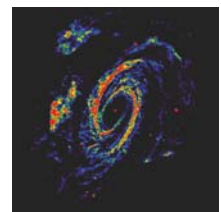
Ultraviolet



Visible



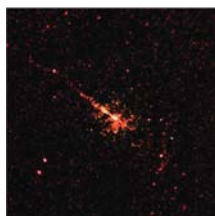
Infrared



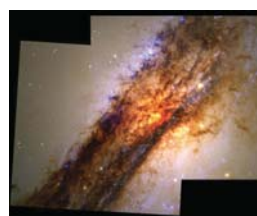
Radio

The brightest region in the X-ray image is the central nucleus of Messier 81. The bright knot just below the center is actually a quasar located in the distant background. The ultraviolet image reveals hot, young stars and traces the spiral structure, revealing multiple spiral arms. Visible light shows spiral arms emerging from the inner disk of the galaxy and twisting outwards. We can also see dust lanes along the arms. In the infrared photograph, we see areas of dust (darker regions) being warmed by newborn stars. There is a large central concentration, and two others located in the spiral arms. The radio map shows the distribution of neutral hydrogen gas from which future stars will be born.

Centaurus A is a very peculiar galaxy. Astronomers believe that its strange appearance is the result of an intergalactic collision, in which a dusty spiral galaxy and a bright elliptical galaxy merged hundreds of millions of years ago. A black hole is thought to lie at its center.



X-Ray



Visible



Infrared



Radio

The X-ray image of Centaurus A shows a large jet of material extending over 25,000 light-years. This high-energy jet provides evidence of a black hole in the center of the galaxy. In visible light we can see a spherical concentration of bright stars and a dark, obscuring band of dust. This dust band is heavily warped, suggesting that an unusual event has happened in the past. The infrared image reveals the flattened inner disk of the spiral galaxy that once rammed into the elliptical galaxy. The radio image looks very strange indeed. A pair of narrow jets appears to be shooting out of Centaurus A, with the radio emission spreading out at greater distances from the galactic center. The radio jets are made up of plasma, a high-temperature stream of matter in which atoms have been ionized and molecules have been split apart.

Observing Across the Spectrum

X-rays and Gamma Rays: Since high-energy radiation like X-rays and gamma rays are absorbed by our atmosphere, observatories must be sent into space to study the universe at these wavelengths. X-rays and gamma rays are produced by matter that is heated to millions of degrees. These high-energy wavelengths are often caused by cosmic explosions, high-speed collisions, or by material moving at extremely high speeds. This radiation has such high energy that specially made, angled mirrors must be used to help collect this type of light. X-ray and gamma-ray astronomy has led to the discovery of black holes in space, and has added much to our understanding of supernovae, white dwarfs, and pulsars. High-energy observations also allow us to study the hottest regions of the Sun's atmosphere.

Ultraviolet: Most of the ultraviolet light reaching the Earth is blocked by our atmosphere and is very difficult to observe from the ground. To study light in this region of the spectrum astronomers use high-altitude balloons, rockets, and orbiting observatories. Ultraviolet observations have contributed to our understanding of the Sun's atmosphere and tell us about the composition and temperature of hot, young stars. Discoveries have included the existence of a hot gaseous halo surrounding our own galaxy.

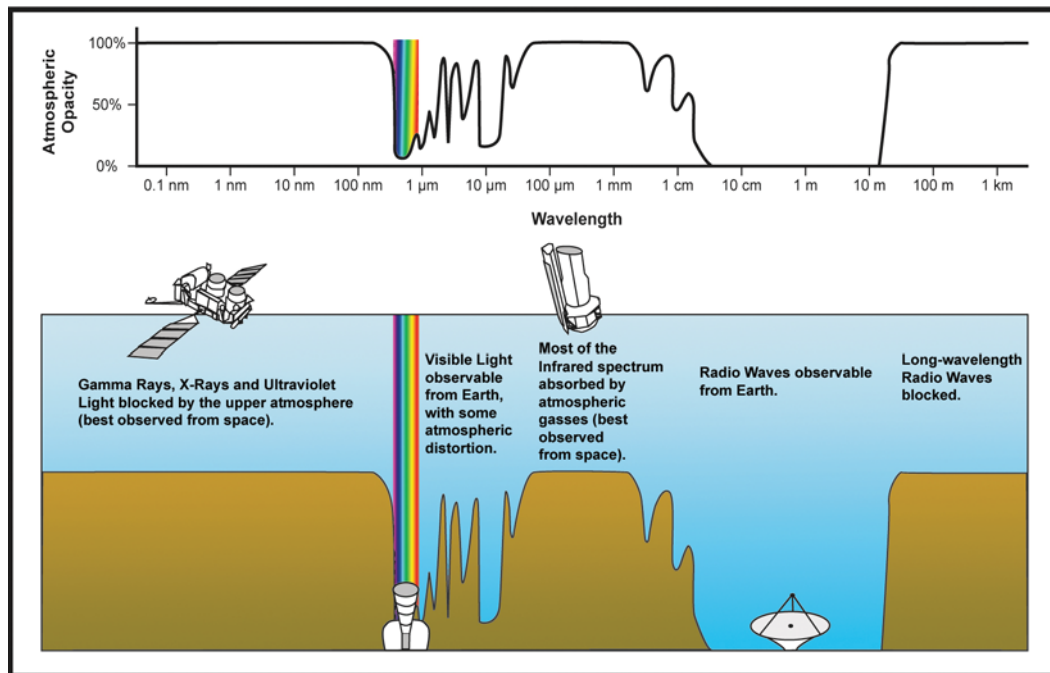
Visible Light: The visible light from space can be detected by ground-based observatories during clear-sky evenings. Advances in techniques have eliminated much of the blurring effect of the atmosphere, resulting in higher-resolution images. Although visible light does make it through our atmosphere, it is also very valuable to send optical telescopes and cameras into space. In the darkness of space we can get a much clearer view of the cosmos. We can also learn much more about objects in our Solar System by viewing them up close using space probes. Visible-light observations have given us the most detailed views of our Solar System, and have brought us fantastic images of nebulae and galaxies.

Infrared: Only a few narrow bands of infrared light can be observed by ground-based observatories. To view the rest of the infrared universe we need to use space-based observatories or high-flying aircraft. Infrared light is primarily heat radiation, and special detectors cooled to extremely low temperatures are needed for most infrared observations. Since infrared light can penetrate thick regions of dust in space, infrared observations are used to peer into star-forming regions and into the central areas of our galaxy. Cool stars and cold interstellar clouds invisible in optical light are also observed in the infrared.

Radio: Radio waves have a very long wavelength compared to waves from the rest of the spectrum. Most radio radiation reaches the ground and can be detected during the day as well as during the night. Radio telescopes use a large metal dish to help detect radio waves. The study of the radio universe brought us the first detection of the radiation left over from the Big Bang. Radio waves also bring us information about supernovae, quasars, pulsars, regions of gas between the stars, and interstellar molecules.

Why We Need to Send Telescopes into Space

The universe sends us light all across the electromagnetic spectrum. However, much of this light (or radiation) does not reach the Earth's surface. Our atmosphere blocks out certain types of radiation while letting other types through. Fortunately for life on Earth, our atmosphere blocks out harmful high-energy radiation like X-rays, gamma rays, and most of the ultraviolet rays. The atmosphere also absorbs most of the infrared radiation. On the other hand, our atmosphere is transparent to visible light, most radio waves, and small windows within the infrared region. Ground-based optical and infrared observatories are usually placed near the summits of dry mountains to get above much of the atmosphere. Radio telescopes can operate both day and night from the Earth's surface. These ground-based observatories provide valuable long-term studies of objects in space, but they can detect only the light that passes through our atmosphere.



For the most part, everything we learn about the universe comes from studying the light emitted by objects in space. To get a complete picture of this amazing and mysterious universe, we need to examine it in all of its light, using the information sent to us at all wavelengths. This is why it is so important to send observatories into space, to get above the Earth's atmosphere, which prevents so much of this information from reaching us.

Astronomers have relied on airplanes flying at high altitudes, on high-altitude balloons, on telescopes mounted in the cargo bay of the Space Shuttle, and on satellites in Earth orbit and in deep space to gather information from the light that does not reach the Earth's surface.

Due to the rapid advance of technology and the ability to send telescopes into space, the future is extremely bright for multiwavelength astronomy. In the coming years and decades, you will continue to hear about many new discoveries being made across the spectrum.

Educational Links

To learn more about the electromagnetic spectrum and about the astronomy being done at a particular part of the spectrum, visit the following web sites:

Multiwavelength Astronomy: http://coolcosmos.ipac.caltech.edu/cosmic_classroom/multiwavelength_astronomy/multiwavelength_astronomy/

Electromagnetic Spectrum: <http://science.hq.nasa.gov/kids/imagers/ems/>

Gamma Ray: <http://imagine.gsfc.nasa.gov/>

X-ray: <http://imagine.gsfc.nasa.gov/> and http://heasarc.gsfc.nasa.gov/docs/xte/learning_center

Ultraviolet: <http://science.hq.nasa.gov/kids/imagers/ems/uv.html>

Visible: <http://amazing-space.stsci.edu/>

Infrared: <http://coolcosmos.ipac.caltech.edu/> and <http://www.sofia.usra.edu/Edu/edu.html>

Radio: <http://dsnra.jpl.nasa.gov/> and <http://www.nrao.edu>

Image Credits

Front— Chandra X-ray Observatory (X-ray): NASA, CXC, and Johns Hopkins Univ. • Galaxy Evolution Explorer (ultraviolet): NASA/JPL-Caltech • Hubble Space Telescope (visible): NASA, ESA, Johns Hopkins Univ., Univ. of Hawaii, Jet Propulsion Lab, NOAO, Univ. of Illinois Urbana, and STScI • Spitzer Space Telescope (infrared): NASA/JPL-Caltech/STScI

Page 2—X-ray Milky Way: D. Wang (UMass) et al., CXC, NASA • X-ray Sagittarius: NASA/CXC/MIT/F.K.Baganoff et al. • X-ray MW center: NASA/CXC/UMass Amherst/Q.D.Wang et al. • UV Jupiter's Ghost: NASA/JPL-Caltech (GALEX) • Visible NGC290: European Space Agency and NASA (Hubble) • IR Milky Way center: NASA/JPL-Caltech/Univ. of Wisconsin • Radio Jupiter: NRAO's Very Large Array (VLA)

Page 4—UV Venus: Pioneer Venus Orbiter Team, NASA • Visible Venus: Galileo Spacecraft, JPL, NASA • IR Venus: ESA/VIRTIS/INAF-IASF/Obs. de Paris-LESIA (Venus Express, ESA) • Radio Venus: Magellan Spacecraft, Arecibo Radio Telescope, NASA • X-ray Sun: Hinode JAXA/NASA/PPARC • UV Sun: SOHO • Visible Sun: Catania Astrophysical Observatory in Italy • IR sun: National Solar Observatory at Kitt Peak, in Arizona • Radio Sun: Nobeyama Radio Observatory, in Japan.

Page 5—X-ray Orion: E.Feigelson and K.Getman (PSU) et al. CXC /NASA • Visible Orion: HST Infrared Orion: Spitzer • Radio Orion: 1.2-m Columbia University mm-wave radio telescope • X-ray Cass A: Chandra • Visible Cass A: Hubble • IR Cass A: Spitzer • Radio Cass A: NRAO/AUI

Page 6—X-ray M81: ROSAT • UV M81: GALEX • IR-M81: Spitzer • Radio M81: NRAO/AUI • X-ray Cent A: Chandra • Visible Cent A: Hubble and (ground) NOAO CTIO • IR Cent A: Spitzer • Radio Cent A: Jack O. Burns (U. of MO) and David Clarke (St. Mary's U., Nova Scotia)

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