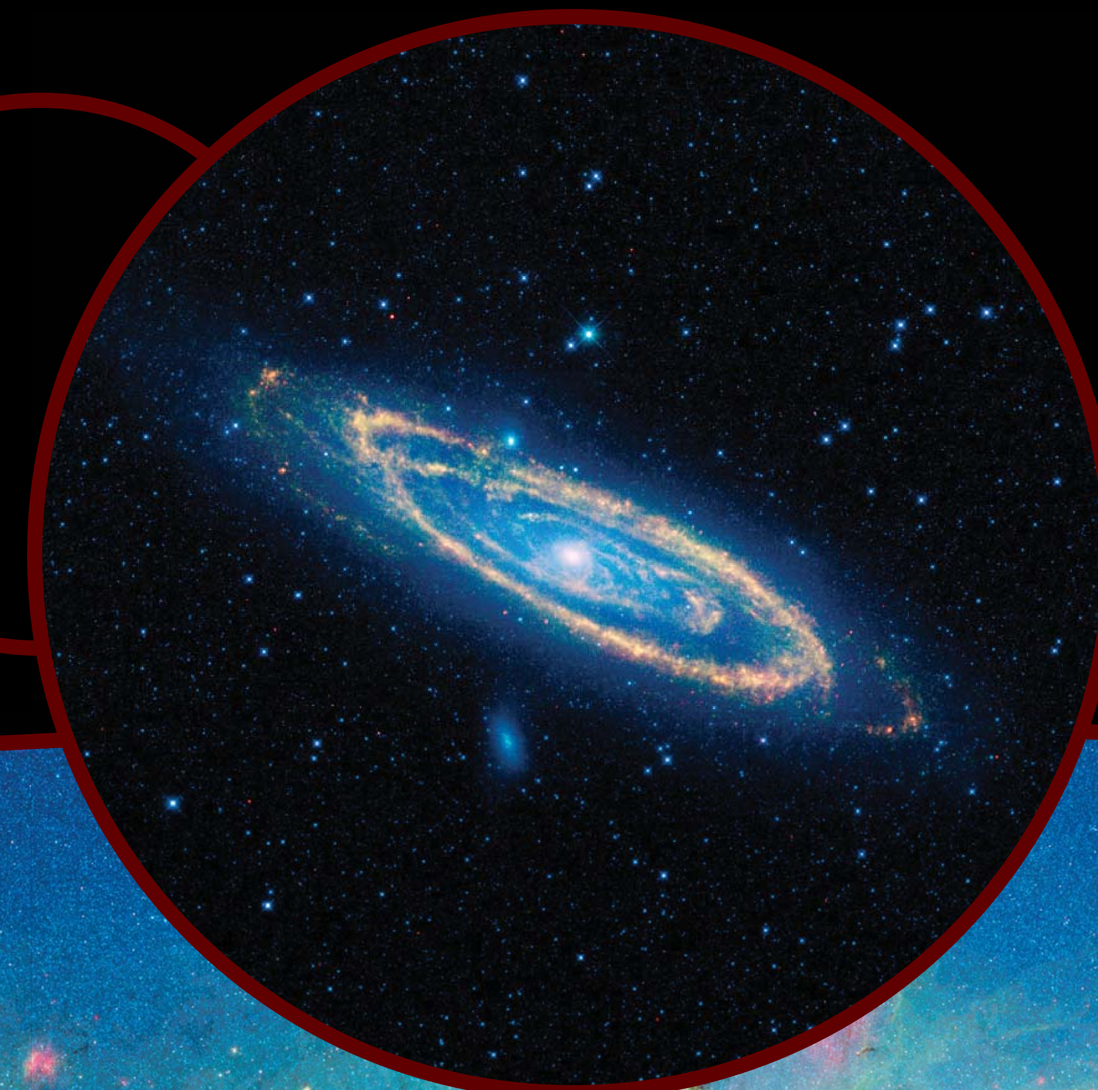
National Aeronautics and Space Administration



The Structure of Galaxies

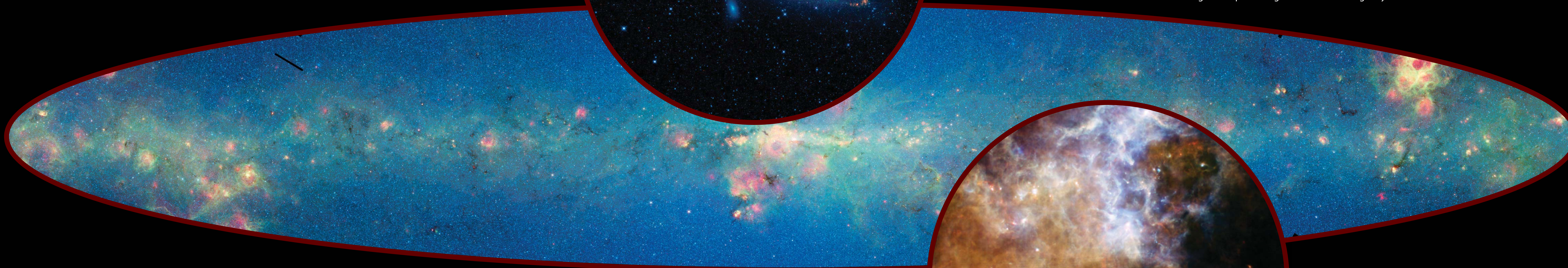
Infrared light from our nearest large neighbor, the Andromeda Galaxy, M31, reveals its old stars, its new stars, and its most massive stars. Dust warmed by newborn stars traces the spidery arms all the way to the center of the galaxy. NASA's Wide-field Infrared Survey Explorer, or WISE, combines four discrete wavelengths to better distinguish galactic structure and stellar evolution.

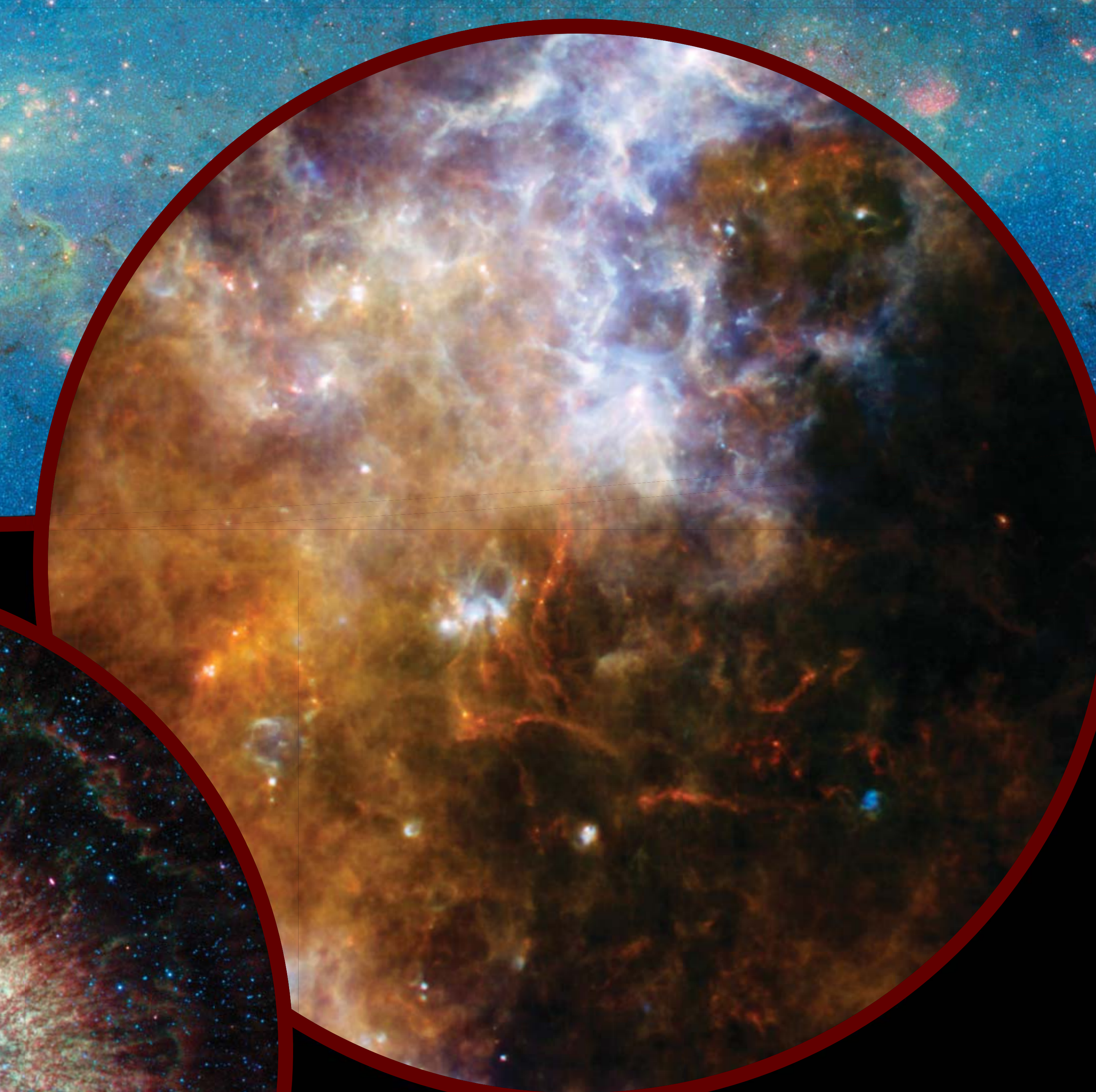
Deep into the Cosmos

Look deeply enough into one square degree of sky, away from the plane of our own galaxy, and see distant galaxies billions of light-years away. Infrared images such as this help to connect the evolution of galaxies from the distant, early universe, to the nearby, or present day, universe.

Our Own Galactic Center

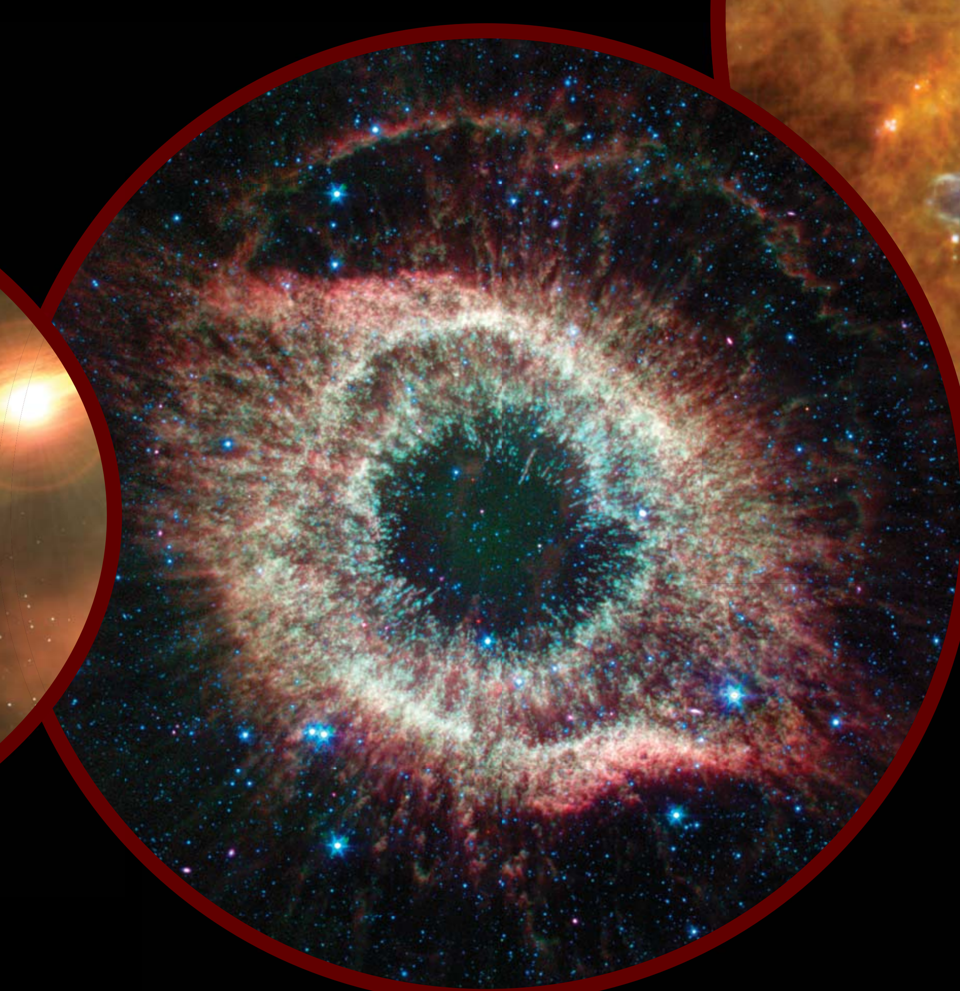
More than 800,000 frames from NASA's Spitzer Space Telescope were stitched together to create an infrared portrait of dust and stars radiating in the inner Milky Way. This view of the galactic center is one of five image components, together representing more than half our galaxy.

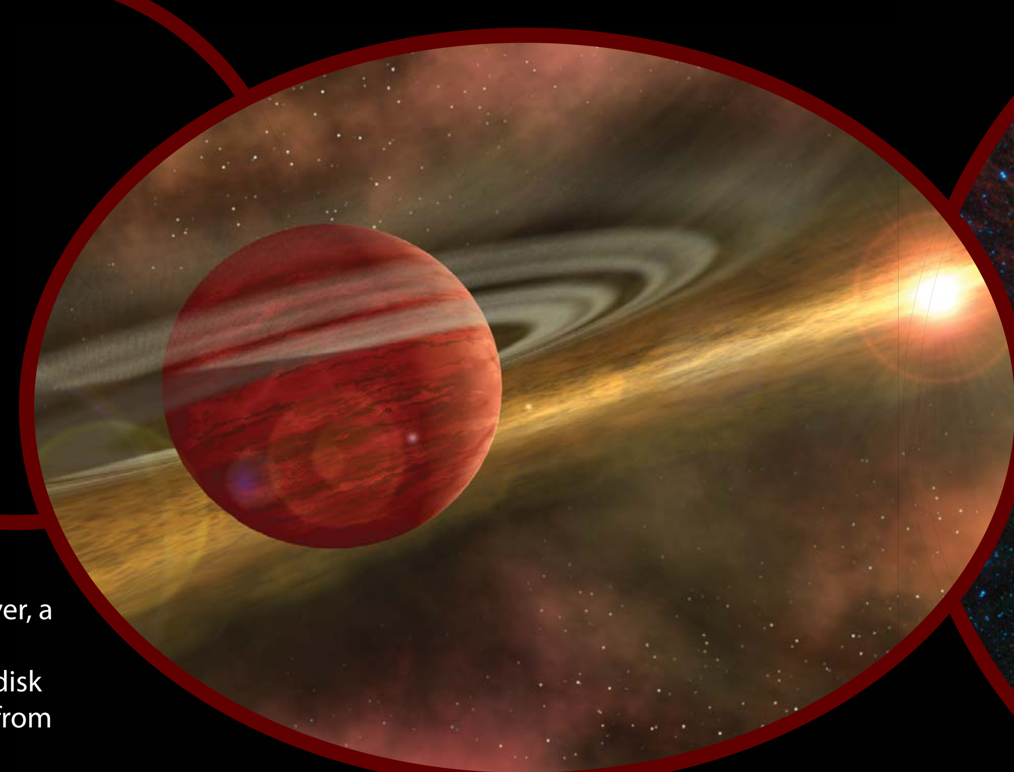




Star Formation in the Milky Way

Stars are born within dense cocoons of dust and gas. At visible wavelengths, new stars are mostly hidden from view. However, near-infrared light can pierce the dust to reveal a newborn star. Infrared observations such as these from the Herschel Infrared Observatory reveal how new stars form in clusters, rather than in isolation, and unveil the mechanisms that cause them to form in the first place.



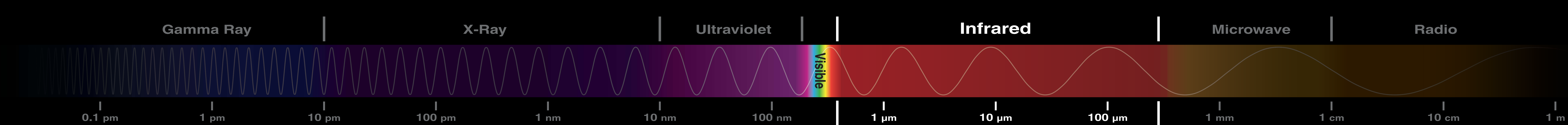


Extrasolar Planets

Planets in other star systems are very difficult to image directly. However, a planet's presence can be inferred, for example, from a gravitationally swept-clean path in the dusty disk surrounding a star. The cool, dusty disk glows in infrared, helping to define it amidst the blinding visible light from the star.

Star Remains

All but the largest stars end their lives by blowing off their outer layers, leaving a dense white dwarf star and a planetary nebula—an expanding cloud of glowing gas and dust. Images of the Helix Nebula from the Spitzer Space Telescope reveal what appears to be a planetary system that survived the star's death throes.

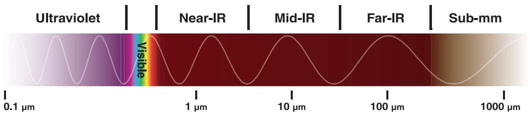


THE INFRARED UNIVERSE

Visible light tells only a tiny part of the story of the cosmos. All the wavelengths of the electromagnetic spectrum have something important to say. Infrared light, with wavelengths just a bit longer than we can see, gives us new information about the universe, from its earliest and largest-scale galactic processes to planet formation around nearby stars in our own galaxy.

Infrared Radiation: More Than Our Eyes Can See

The Visible/Infrared Spectrum



Invisible Colors of Light

When you think of the word "light," what probably comes to mind is something bright and colorful, like the colors of the rainbow. Colors are actually the way in which human eyes detect different energies of light radiation. We can measure these energies very accurately by examining either the light's *wavelength* (the distance from peak to peak of a light wave, much the same as peaks on a ripple of water) or its *frequency* (how many wave peaks pass a fixed location each second). The incredible detectors we call "eyes" are sensitive to only a very small portion of all possible light radiation. Have you ever thought there might be more colors than the ones we can "see"?

The Electromagnetic Spectrum

Visible (or optical) light refers to just a tiny fraction of the *electromagnetic* (EM) *spectrum* of radiation, which is the entire range of energies that "light" can have. Starting from the highest energies, the electromagnetic spectrum includes gamma rays, X-rays, ultraviolet, visible, infrared, microwaves, and radio waves. Wavelength increases and frequency decreases from gamma rays to radio waves (see front of poster). All these forms of radiation travel at the speed of light, which is about 300 million meters per second (186,000 miles per second). Astronomers use many different units of measurement to talk about the range of light energies. Radio waves may have wavelengths of a few centimeters to many kilometers! Gamma rays have wavelengths that are thousands of times smaller than one Angstrom (Å), where an Angstrom is about the size of a hydrogen atom. Frequency is measured in Hertz, or the number of wave peaks observed passing a given point in one second.

Infrared Radiation

Infrared generally refers to the portion of the electromagnetic spectrum that begins just beyond the red portion of the visible region and extends to the microwave region at longer wavelengths. Most astronomers measure the wavelength of infrared radiation in microns (µm), or millionths of a meter. A human hair, for example, is about 70 µm wide. The visible spectrum extends from about 0.4 µm (violet) to 0.7 µm (red), and the infrared spans the broad region up to hundreds of microns. The infrared region can be further segmented into three portions: near-infrared, mid-infrared, and far-infrared. A close-up view of the visible/infrared spectrum is shown below. Note that the scale is *logarithmic*; each equally-spaced increment denotes a factor of 10 increase in wavelength. Measuring the energy an object emits in one filter and the energy that same object emits in a second filter allows an astronomer to use the resulting ratio to determine the temperature of that object even at great distances.

Some astronomical objects emit mostly infrared radiation, others mostly visible light, others mostly ultraviolet radiation. The single most important property of objects that determines the amount of radiation at each wavelength they emit is *temperature*. Any object that has a temperature above absolute zero (-459.67°F or -273.15°C, the point where atoms and molecules cease to move) radiates in the infrared. Even objects that we think of as being very cold, such as an ice cube, emit radiation in the infrared. When an object is not quite hot enough to radiate brightly in visible light, it will emit most of its energy in the infrared. For example, a hot kettle on a stove may not give off detectable amounts of visible light but it does emit infrared radiation, which we feel as heat. The warmer the object, the more infrared radiation it emits. Humans, at normal body temperature, radiate most strongly in the infrared at a wavelength of about 10 microns.

Infrared Eyes

An infrared image of a dog, with warmest areas appearing the brightest.

The heat we feel from sunlight, a roaring fire, a radiator or a warm sidewalk is infrared radiation. Although our eyes cannot see it, the nerves in our skin can sense the thermal energy. The temperature-sensitive nerve endings in your skin can detect the difference between your inside body temperature and outside skin temperature. We commonly use infrared rays when we operate a television remote. "Night vision" goggles used by the military and police are actually made of cameras sensitive to thermal signatures in the dark of night.

A revolution in technology is driving the scientific discoveries now being made in infrared astronomy. Thirty years ago, the new field of infrared astronomy relied on relatively crude measurements of temperatures and simple electronic recording devices to make observations. Thanks to a productive collaboration between industry and universities, we now have detector arrays capable of making infrared images, much as charge-coupled devices (CCDs) have become commonplace in digital imaging and digital photography. The genesis of this science/technology revolution was the substantial investment in infrared array technology by the military throughout the 1980s. Military interests in this technology development concentrated on high-background temperature environments and on wavelengths shorter than about 30 microns. As the accumulated technical knowledge migrated to the civilian world, scientists have redirected the focus of development towards the goal of low-background, high-sensitivity applications appropriate for astronomical work.

A Deep Freeze

Step outside on a sunny summer day, turn your face to the Sun, and you will immediately feel the warmth of our local star. Now imagine moving the Sun to a distance of hundreds of light-years. (A light-year is more than 63,000 times greater than the distance between the Earth and the Sun). In essence, infrared astronomers are trying to "feel" the warmth of the stars and other objects from deep in space. Infrared astronomy is the art of measuring incredibly small values of thermal energy at incredibly large distances. In addition, there are special problems with observing in the infrared. Imagine trying to take a photograph with a camera that was glowing brightly, both inside and out. The film would be exposed by the camera's own light, long before you ever got a chance to take a picture! Infrared astronomers face the same problem when they try to detect heat from space. At room temperature, their telescopes and instruments are shining brilliantly in the infrared. In order to record faint infrared radiation from space, astronomers must cool their science instruments to very cold temperatures.

Astronomers often use liquid helium, which has a temperature of only a few degrees above absolute zero, as a *cryogen* (refrigerant) to cool their telescopes. The cryogen is kept in a pressurized *cryostat*, which is similar to a thermos bottle. In the past, space-based telescopes have surrounded the entire telescope and instruments with a gigantic cryostat to reduce stray heat radiation. Now, the Spitzer Space Telescope and the Herschel Space Observatory missions have adopted a different approach that substantially reduces the mass, and therefore cost, of infrared telescopes. These missions cryogenically cool the science instruments only and place the telescope well away from the thermal contamination of the Earth. In deep space, where ambient temperatures may be only 30-40 degrees above absolute zero, infrared telescopes will passively cool to near-operating temperatures. Combined with small amounts of cryogen that refrigerate the instruments, these telescopes achieve the high sensitivities needed to detect faint thermal signals from the distant cosmos.

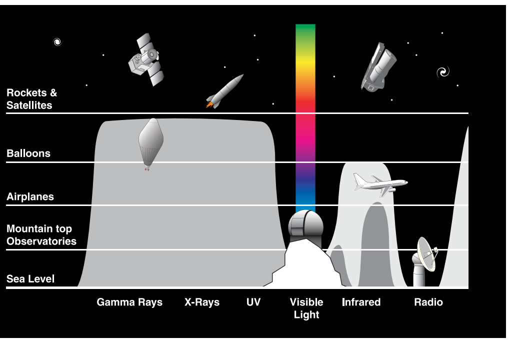
Atmospheric Transmission

Apart from the local solar system, everything we know about the universe and its phenomena is a result of the capture and study of radiation emitted by distant objects. In a sense, astronomy is a field where only remote sensing provides the data upon which our theories and knowledge rest. After travelling vast distances through space, much of the information we get from the universe is absorbed by the Earth's atmosphere.

Visible light reaches the surface of the Earth, diminished—but not completely absorbed—by the gases and water vapor in our atmosphere. It is because of our atmosphere's *transmission* of visible light that humans have stared and wondered about the Moon, planets, and stars since ancient times. Observations in the twentieth-century revealed naturally occurring radio emission from celestial objects, proving that radio waves are also able to penetrate the atmosphere. Closer to the visible spectrum, small amounts of ultraviolet light obviously reach us (sunburns!) and some near-infrared radiation can be observed from high, dry mountaintops. However, atmospheric *opacity* prevents most of the other wavelengths of celestial radiation from reaching ground-based telescopes.

Various properties of our atmosphere account for its opacity. For example, atmospheric gases like water vapor (H_2O) and oxygen efficiently absorb radio waves with wavelengths less than about one centimeter. Other constituent gases, including H_2O and carbon dioxide absorb most infrared radiation. Furthermore, the ionosphere (a layer of gases in the upper atmosphere ionized by solar ultraviolet rays) reflects long-wavelength radio waves.

In the infrared portion of the electromagnetic spectrum, there are narrow windows through which astronomers can study the universe. In addition to measuring the near- infrared using filters as mentioned before, one can also do some observations around 10 and 20 microns. Beyond these wavelengths, though, the atmosphere remains opaque throughout the far-infrared and sub-millimeter regions, except for windows of visibility around 350 and 450 microns. To overcome these limitations, infrared astronomers have placed telescopes aboard airplanes that fly at altitudes of 40-45,000 feet, and on gondolas attached to large balloons (similar to weather balloons) that reach heights of over 100,000 feet, and on space-based satellites.



Methods of Observing the Entire Electromagnetic Spectrum

Why Infrared Astronomy Is Important

There are fundamental reasons why infrared astronomy is vital to understanding the universe. Some of these reasons are summarized below.

Dusty Galaxies

A census of any galaxy, especially those characterized as spiral galaxies (like the Milky Way), reveals not only billions of luminous stars, but also an *interstellar medium* filling the "empty space" between the stars. The interstellar medium—composed of gas atoms and molecules, in addition to solid dust particles—is a near-vacuum. In the solar neighborhood of the galaxy, for example, there is typically only one atom of gas per cubic centimeter and a few hundred dust grains per cubic kilometer. On galactic scales, however, the effects of the gas and dust are noticeable.

The dust grains tend to be very small, typically less than 0.1 micron in diameter, and are composed of carbon and silicate matter. These dust grains absorb and reflect the ambient ultraviolet and optical light produced by stars, producing a dimming and reddening effect analogous to what you might see in the Earth's atmosphere as the Sun sets in the west. The presence of cosmic dust is best seen when conducting observations at far-infrared wavelengths.

Witnessing Star Formation

The interstellar medium is a reservoir from which matter for new stars can be drawn. Some 99 percent of the interstellar medium is either atomic gas (mostly hydrogen) or molecular gas (mostly hydrogen, water, carbon monoxide and ammonia).

This infrared image from the Spitzer Space Telescope shows RCW-49, a prolific star-forming region.

Molecular clouds are dense regions within the interstellar medium where the concentrations of gas and dust are thousands of times greater than elsewhere. These clouds are often hiding stellar nurseries, where hundreds of stars are being formed from the dense material. Because these newborn stars are swaddled in dense cocoons of gas and dust, they are often obscured from view. The clearest way of detecting young suns still embedded in their clouds is to observe in the near-infrared. Although visible light is blocked, heat from the stars can pierce the dark, murky clouds and give us a picture of how stars are born.

The Distant Universe

Galaxies in the Hubble Deep Field.

Regardless of the frequency of electromagnetic waves, they are subject to the redshift effect. The redshift effect causes the observed frequency of radiation from a source to differ from the actual radiated frequency if there is motion that is increasing or decreasing the distance between the source and the observer. A similar effect is that of the Doppler effect, which is readily observable as variation in the pitch of sound between a moving source and a stationary observer, or vice versa.

When the distance between the source and receiver of electromagnetic waves remains constant, the frequency of the source and received wave forms is the same. When the distance between the source and receiver of electromagnetic waves is increasing, the frequency of the received wave forms is lower than the frequency of the source wave form. When the distance is decreasing, the frequency of the received wave form will be higher than the source wave form.

The redshift effect is very important to astronomical observations in any wavelength. The phenomenon of apparent shortening of wavelengths in any part of the spectrum from a source that is moving toward the observer is called blue shifting, while the apparent lengthening of wavelengths in any part of the spectrum from a source that is moving away from the observer is called redshifting.

Relatively few extraterrestrial objects have been observed to be blue shifted, and these, it turns out, are very close by, cosmically speaking. Almost all other distant objects are redshifted. The redshifting of spectra from very distant objects is due to the simple fact that the universe is expanding. Space itself is expanding between us and distant objects, thus they are moving away from us. This effect is called cosmic redshifting, but it is still due to the redshift effect.

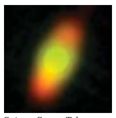
Highly redshifted light has been traveling for a very long time, and reveals objects as they existed long ago. Most of the optical and ultraviolet radiation emitted from stars, galaxies and quasars since the beginning of time is now redshifted into the infrared. To understand how the first stars and galaxies formed in the early universe, it is essential to probe at infrared wavelengths.

Studying Planets

Ancient humans noted six planets (derived from the Greek "wanderers") in our solar system. Over the past two centuries, the list of planets, dwarf planets, asteroids, and other solar system objects has grown longer and longer. We are now in the midst of a revolution in human understanding of our place in the cosmos. Since the mid-1990s, extrasolar planets—that is, planets outside our solar system—have been routinely found, albeit through indirect means caused by the slight gravitational tugging of planets on their local suns or by the slight apparent dimming of the star's light as a large planet passed "in front" of it. With the Spitzer Space Telescope, astronomers are able to directly see and characterize some of these other worlds using infrared wavelengths of light.

Protoplanetary Disks: Forming Planets

The first space-based infrared telescope, the InfraRed Astronomical Satellite (IRAS), in 1983, detected much more infrared radiation coming from Fomalhaut than was expected for a normal star of this type. The dust is presumed to be debris left over from the formation of a planetary system. However, the satellite did not have adequate spatial resolution to image the dust directly.



Spitzer Space Telescope IR image of planetary disk around Formalhaut.

New images obtained with the multiband imaging photometer onboard the Spitzer Space Telescope confirm this general picture, while revealing important new details of Fomalhaut's circumstellar dust.

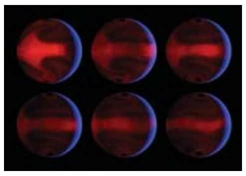
With Spitzer, having more sensitive infrared detectors, astronomers have discovered hundreds of other cases of protoplanetary circumstellar disks, providing evidence that other solar systems may be common. The microscopic dust grains and residual gas surrounding newborn stars provide the ingredients for future planets. The coagulation of the grains into kilometer-sized planetesimals yields the seeds for planet formation. This process of collisions and clumping of material would eventually lead to Earth-sized protoplanets on timescales of about 100 million years. The universal laws of gravity and the similarity of chemical compositions of protoplanetary nebula, combined with the large numbers of stars in the Milky Way, lead to the conclusion that planet formation is probably a common phenomenon.

Actually, an "excess" of infrared light seems to radiate from the region around all types of stars: from failed stars like brown dwarfs, to stars like our sun, to huge, hot stars called hypergiants, and even around dead stars like white dwarfs and neutron stars. So, planets may not only be common, but they may also be around every type of star in the universe!

Planet Weather and Atmospheres

The direct detection of extrasolar planets is extraordinarily difficult, because of the enormous difference in luminosity at all wavelengths between a star and its orbiting planets. At optical wavelengths, the situation is akin to trying to identify a firefly buzzing around an intensely bright searchlight—from a great distance. A star might be several billion times brighter than a large planet. However, at infrared wavelengths, where the planet emits its own thermal radiation, the contrast is "only" a factor of a million.

The Spitzer Space Telescope has the sensitivity and stability to detect light from extrasolar planets directly. Spitzer has seen light from extrasolar planets; identified water and other molecules in the atmospheres of exoplanets; and characterized the "weather" in terms of wind speeds and rates of heating and cooling, as, for example, on a planet in a highly elliptical orbit as it zips past its sun.



This series of temperature maps made using Spitzer Space Telescope data depicts wild temperature swings as extrasolar gas giant planet HD 80606b travels in a highly elliptical orbit around its star. Bright areas are hottest.

Infrared Observatories

Some of the present and future infrared programs and missions are summarized below. For information on each of these observatories, consult the Web addresses cited.

Spitzer Space Telescope

www.spitzer.caltech.edu

The Spitzer Space Telescope (formerly known as the Space Infrared Telescope Facility, SIRTF) is the fourth and final element in NASA's family of space-borne "Great Observatories." Spitzer consists of a 0.85-meter telescope and three cryogenically-cooled science instruments doing imaging and spectroscopy in the 3–180 micron wavelength range. In 2009, after the 5-year supply of cryogen was exhausted, the telescope embarked on a "warm mission," with one of its instruments retaining two of its four wavelength-range capabilities. Spitzer has studied a wide variety of astronomical phenomena, including brown dwarfs, extrasolar planets, protoplanetary dust disks where planets may be forming, galaxies with intense star formation, active galactic nuclei, and the distant reaches of the early universe.

Wide-field Infrared Survey Explorer (WISE)

wise.ssl.berkeley.edu

WISE is a space-based telescope surveying the cosmos with infrared detectors up to 500,000 times more sensitive than COBE. Its mission is to complete the basic reconnaissance of the universe in mid-infrared wavelengths. It has revealed hundreds of cool, or failed, stars, called brown dwarfs. It is finding the most luminous galaxies in the universe, most Main Belt asteroids larger than 3 km, and enabling a wide variety of studies from the evolution of planetary debris discs to the history of star formation in normal galaxies. WISE will give the future James Webb Space Telescope a comprehensive list of targets. Each picture covers an area of the sky three times larger than the full Moon. During the first six months, WISE took 1,300,000 images covering the entire sky.

Herschel Space Observatory

www.herschel.caltech.edu

The Herschel Space Observatory studies the universe in the far-infrared and submillimeter portions of the spectrum. It is examining the earliest, most distant galaxies, star formation in closer galaxies, as well as our solar system. At 3.5-meters (11.5 feet) in diameter, Herschel's is the largest monolithic mirror ever built for a space telescope. Herschel is a European Space Agency cornerstone mission, with science instruments provided by consortia of European institutes and with important participation by NASA. It was launched May 2009.

James Webb Space Telescope (JWST)

jwst.gsfc.nasa.gov

The James Webb Space Telescope will be the successor to the Spitzer Space Telescope in terms of wavelength coverage (0.6 to 27 micrometers) and telescope and satellite technology. JWST will have a large mirror, 6.5 meters (21.3 feet) in diameter and a sunshield the size of a tennis court. JWST will reach back to the high-redshift universe to detect and study the first galaxies and stars in the process of formation. The launch date is undetermined.

Two-Micron All-Sky Survey (2MASS)

www.ipac.caltech.edu/2mass

The 2MASS project was an all-sky, ground-based survey at three near-infrared wavelengths, conducted with a pair of 1.3-meter telescopes in Arizona and in Chile. Collected from 1197 to 2001, the 2MASS data are publicly accessible via the Web and include images and catalogs of about one million galaxies and 300 million stars. The 2MASS survey has yielded scientific information on the structure of our galaxy, the large-scale distribution of galaxies in the local universe, and has identified peculiar objects —such as brown dwarfs and red quasars—for further study.

Stratospheric Observatory For Infrared Astronomy (SOFIA)

www.nasa.gov/sofia

SOFIA is an airborne observatory, with a 2.5-meter telescope housed in a Boeing-747 airplane capable of flying at altitudes of 45,000 feet. The observatory will make about 160 research flights annually, starting in 2009-2010. SOFIA will provide imaging and spectroscopic capabilities at all wavelengths from optical through submillimeter. SOFIA will study the interstellar medium in our galaxy, while also studying our solar system and other galaxies.

Herschel Infrared Experiment

PURPOSE/OBJECTIVE:

To perform a version of the experiment of 1800, in which a form of radiation other than visible light was discovered by the famous astronomer Sir Frederick William Herschel.

BACKGROUND:

Herschel discovered the existence of infrared light by passing sunlight through a glass prism in an experiment similar to the one we describe here. As sunlight passed through the prism, it was dispersed into a rainbow of colors called a *spectrum*. A spectrum contains all the visible colors that make up sunlight. Herschel was interested in measuring the amount of heat in each color and used thermometers with blackened bulbs to measure the various color temperatures. He noticed that the temperature increased from the blue to the red part of the visible spectrum. He then placed a thermometer just beyond the red part of the spectrum in a region where there was no visible light—and found that the temperature was even higher! Herschel realized that there must be another type of light beyond the red, which we cannot see. This type of light became known as *infrared*. *Infra* is derived from the Latin word for "below." Although the procedure for this activity is slightly different from Herschel's original experiment, you should obtain similar results.

MATERIALS:

One glass prism (plastic prisms do not work well for this experiment), three alcohol thermometers, black paint or a permanent black marker, scissors or a prism stand, cardboard box (a photocopier paper box works fine), one blank sheet of white paper.

PREPARATION:

The experiment should be conducted outdoors on a sunny day. Variable cloud conditions, such as patchy cumulus clouds or heavy haze will diminish your results. The setup for the experiment is depicted in Figure 1.

You will need to blacken the thermometer bulbs to make the experiment work effectively. The best way is to paint the bulbs with black paint, covering each bulb with about the same amount of paint. Alternatively, you can blacken the bulbs using a permanent black marker. The bulbs of the thermometers are blackened in order to absorb heat better. After the paint or marker ink has completely dried on the thermometer bulbs, tape the thermometers together (on a 3 x 5 card, for example) such that the temperature scales will line up, as in Figure 2.

PROCEDURE:

Begin by placing the white sheet of paper flat in the bottom of the cardboard box. The next step requires you to carefully attach the glass prism near the top (Sun-facing) edge of the box.

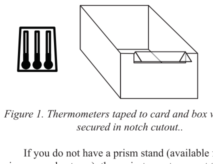


Figure 1. Thermometers taped to card and box with prism secured in notch cutout..

If you do not have a prism stand (available from science supply stores), the easiest way to mount the prism is to cut out an area from the top edge of the box. The cutout notch should hold the prism snugly, while permitting its rotation about the prism's long axis (as shown in Figure 2). That is, the vertical "side" cuts should be spaced slightly closer than the length of the prism, and the "bottom" cut should be located slightly deeper than the width of the prism. Next, slide the prism into the notch cut from the box and rotate the prism until the widest possible spectrum appears on a shaded portion of the white sheet of paper at the bottom of the box.

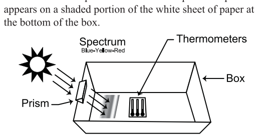


Figure 2. Box with white paper on bottom and prism creating widest possible spectrum.

The Sun-facing side of the box may have to be elevated (tilted up) to produce a sufficiently wide spectrum. After the prism is secured in the notch, place the thermometers in the shade and record the ambient air temperature.

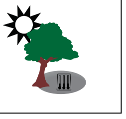


Figure 3. Record ambient temperature in the shade.

Then place the thermometers in the spectrum such that one of the bulbs is in the blue region, another is in the yellow region, and the third is just beyond the (visible) red region (as in Figure 4).

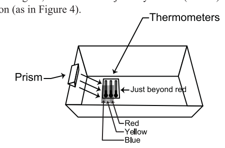


Figure 4. Herschel experiment.

It will take about five minutes for the temperatures to reach their final values. Record the temperatures in each of the three regions of the spectrum: blue, yellow, and "just beyond" the red. Do not remove the thermometers from the spectrum or block the spectrum while reading the temperatures.

DATA / OBSERVATIONS:

Record your observations in a table like this:

Temperature in shade	Therm. #1	Therm. #2	Therm. #3
Temp. in spectrum after 5 minutes	Blue	Yellow	Just beyond red

NOTE: Depending on the orientation of your prism, red could be at either end of the spectrum. Adjust the positions of your thermometers accordingly.

QUESTIONS:

- What did you notice about your temperature readings?
- Did you see any trends?
- Where was the highest temperature?
- What do you think exists just beyond the red part of the spectrum?
- Discuss any other observations or problems.

REMARKS TO THE TEACHER:

Have the students answer the above questions. The temperatures of the colors should increase from the blue to red part of the spectrum. The highest temperature should be just outside the red portion of the visible light spectrum. This is the infrared region of the spectrum.

However, this result is actually counterintuitive. Herschel did not know that the peak energy output of the solar spectrum is at the wavelength of orange light, and certainly not infrared. However, the results he got were skewed because the different wavelengths of light are not refracted by the prism in a linear fashion. Thus, the colors (wavelengths) of light will not be evenly spaced along Herschel's table. If, for example, the light hits the prism at a 45° angle (passing from air into glass), the infrared part of the light will be refracted more sharply than would be expected, and thus be much more highly concentrated on the surface of the table than optical wavelengths. Thus, Herschel's temperature measurements of the parts of the spectrum peaked in the infrared.

Nonetheless, Herschel's experiment was important not only because it led to the discovery of infrared light, but also because it was the first time it was shown that there were forms of light we cannot see with our eyes. As we now know, there are many other types of electromagnetic radiation ("light") that the human eye cannot see (including X-rays, ultraviolet rays and radio waves).

You can also have the students measure the temperature of other areas of the spectrum including the area just outside the visible blue. Also, try the experiment during different times of the day; the temperature differences between the colors may change, but the *relative* comparisons will remain valid.

For further information on infrared and infrared astronomy see:

coolcosmos.ipac.caltech.edu

For further information on the Herschel infrared experiment see:

coolcosmos.ipac.caltech.edu/cosmic_classroom/classroom_activities/herschel_experiment.html

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Education Resources

Cool Cosmos: Infrared education for students and educators—*coolcosmos.ipac.caltech.edu*
Infrared Astronomy Tutorial (IPAC)— *coolcosmos.ipac.caltech.edu/cosmic_classroom/ir_tutorial*
Herschel Infrared Experiment (IPAC)—*coolcosmos.ipac.caltech.edu/cosmic_classroom/classroom_activities/herschel_experiment.html*
Electromagnetic Spectrum (Imagine the Universe)—*imagine.gsfc.nasa.gov/docs/introduction/emspectrum.html*
Light (Center for EUV Astrophysics)—*cse.ssl.berkeley.edu/light/light_tour.html*
Infrared Light (Newton's Apple Online)—*www.newtonsapple.tv/TeacherGuide.php?id=1165*
Infrared Technology—*www.ipac.caltech.edu*
Space Telescope Science Institute (STScI)—*oposite.stsci.edu/pubinfo*
NASA's Origins Program—*planetquest.jpl.nasa.gov/NASAorigins.cfm*
Astronomy Picture of the Day (NASA-GSFC)—*antwrp.gsfc.nasa.gov/apod/archivepix.html*
Amazing Space! (STScI)—*amazing-space.stsci.edu*
Windows to the Universe (Univ. Michigan)—*www.windows.umich.edu*
Remote Sensing (Tutorial)—*rst.gsfc.nasa.gov*
Exploring Planets in the Classroom—*www.spacegrant.hawaii.edu/class_acts*
NASA Education site—*www.nasa.gov/audience/foreducators*
American Astronomical Society—*aas.org/education/general.php*
Astronomical Society of the Pacific—*www.astrosociety.org/education.html*
Challenger Center—*www.challenger.org*
Telescopes in Education—*telescopesineducation.com*

Educator's Background Materials

Universe in the Classroom. Free quarterly online newsletter for grade 4–12 teachers. You can read the current issue and subscribe to receive notices of new issues at www.astrosociety.org/education/publications/tnl/tnl.html.

NASA CORE online catalog. Hundreds of low-cost slides, videos, and other NASA educational materials. Visit core.nasa.gov.

Related Links and Resources

Astronomy Education: A Selective Bibliography (by A. Fraknoi)
www.astrosociety.org/education/resources/educ_bib.html
Stardate Online, University of Texas McDonald Observatory. *stardate.org*

Poster Credits

Graphics design (front) by Alexander Novati. Text by Michael Bicay, Michelle Thaller, Linda Hermans-Killam, Mike Bennett, Schuyler Van Dyk, Richard Yessaylan, Diane Fisher, Carolyn Brinkworth, and Gordon K. Squires.

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