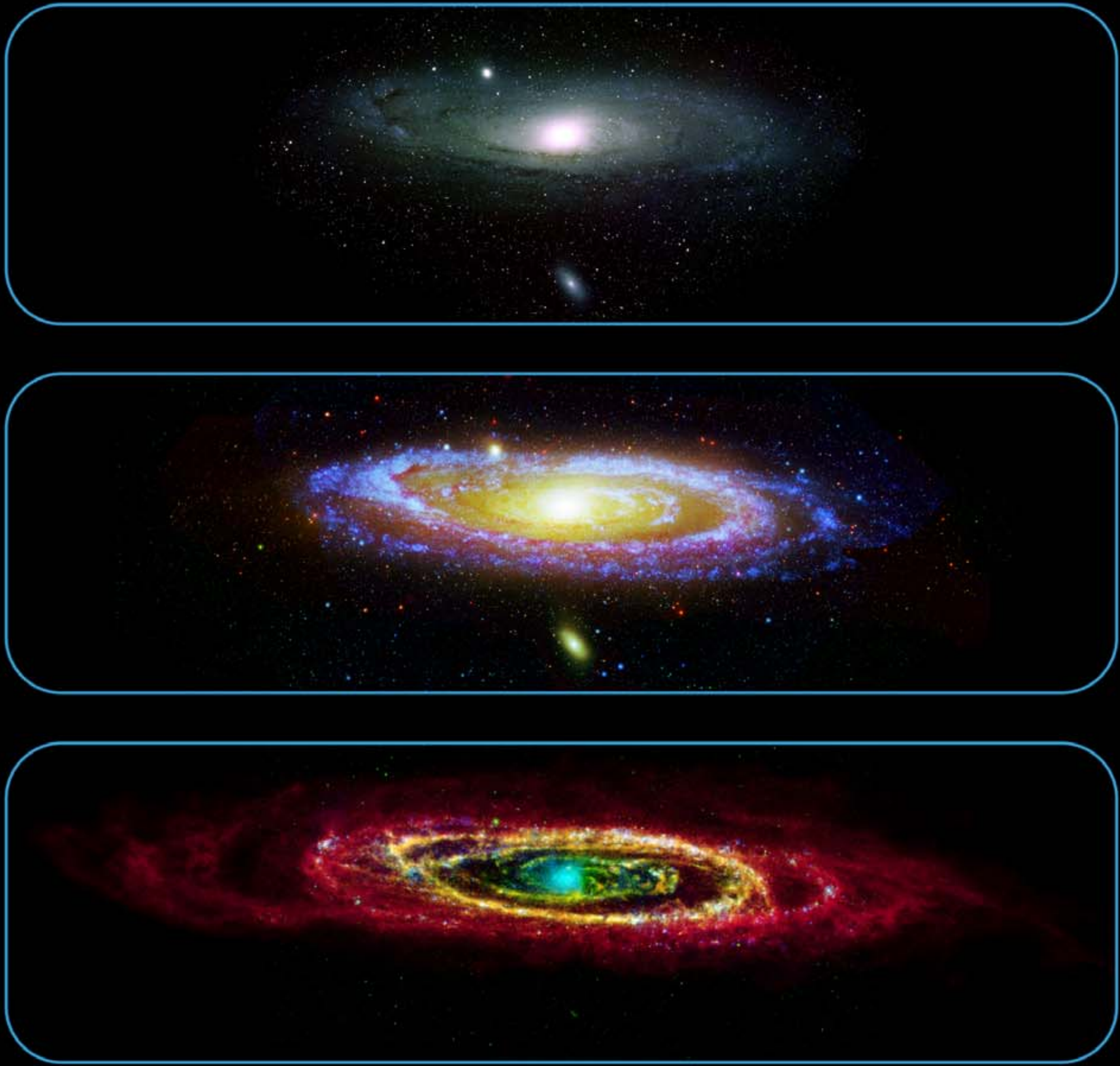
National Aeronautics and Space Administration

andromeda



Three views of the Andromeda Galaxy: At the top is a visible light image of beautiful spiral Andromeda (M31), the closest major galaxy to our own Milky Way. The center view combines ultraviolet, visible, and short-wavelength infrared light to reveal the distribution of stars. The bottom view combines visible, long-wavelength infrared, and radio waves to reveal the distribution of dust and gas. All these wavelengths combine to give us a more complete picture of the nearest major galaxy to our own Milky Way.

Multi-wavelength astronomy: Each kind of light adds to the picture that tells the story.

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The Andromeda Galaxy – Across the Spectrum

The three images on the front of this poster show our galactic neighbor, the Andromeda Galaxy. This galaxy, also known by astronomers as Messier 31, is 2.5 million light-years away in the constellation Andromeda. It is the closest major galaxy to the Milky Way. On a clear, dark night, the Andromeda galaxy can be spotted with the naked eye as a fuzzy blob. Like our own galaxy, Andromeda is a large spiral galaxy, making it ideal for studying the structure and dynamics of galaxies. The disk of Andromeda spans about 260,000 light-years. For comparison, the disk of the Milky Way is about 100,000 light-years across.

The top image may look familiar, because it was made with visible light—the light we see with our eyes and with optical telescopes. The two other images are composites that give us new and unique views of the Andromeda Galaxy. The center image highlights the distribution of stars in the disk of the galaxy, while the bottom image focuses on the distribution of gas and dust. The most prominent features in these images are the bright rings of light circling the center of the galaxy. Within these rings, vast numbers of stars are being born.

Stars in the Center Image

The center image combines ultraviolet (blue), visible (green), and infrared (red) light, which are particularly sensitive bands for showing light from stars. Spiral galaxies tend to form new stars in their dusty, clumpy arms, while their cores are populated by older stars. Ultraviolet light (blue) highlights regions where young, hot, massive stars are forming. This population traces out the spiral arms that contain the most active areas of star formation. Visible light (green) shows the distribution of average stars like our Sun, while infrared (red) reveals stars hidden by dust lanes. These dark regions are opaque in visible and ultraviolet light, but transparent in the infrared. Two dwarf elliptical galaxies can also be seen in the image. These are small satellite galaxies gravitationally bound to the much larger Andromeda Galaxy.

Gas and Dust in the Bottom Image

The bottom image shows the distribution of gas and dust in Andromeda. In this image, the blue regions represent visible-light emission (hydrogen-alpha), which comes from regions of hot, ionized hydrogen gas. Longer wavelength infrared (green) reveals areas dominated by warm dust heated by starlight, including the galaxy's central bulge and inner spiral arms as well as a prominent ring of star formation. Millimeter wavelength radio waves (yellow) show the distribution of molecular hydrogen gas, while areas shown in red represent radio waves of 21 cm wavelength, which are emitted by regions of cool, neutral hydrogen gas. This gas and dust are the raw materials from which future stars are born.

A More Complete Picture

Since light from each part of the electromagnetic spectrum brings us valuable and unique information, these multiwavelength views help us see a more complete picture of the great Andromeda galaxy.

The **visible-light-only** image at the top was made by the Burrell Schmidt telescope of the *Warner and Swasey Observatory* of Case Western Reserve University. (Credit: NOAO/AURA/NSF).

For the middle and bottom images, six telescopes contributed data to produce these composites from the different wavelength ranges:

Infrared: Red in the stars image represents infrared light of wavelengths 3.6 – 4.5 microns from the *Spitzer Space Telescope*'s Infrared Array Camera. Green in the gas and dust image represents infrared light of wavelength 24 microns from Spitzer's Multiband Imaging Photometer instrument. Spitzer was launched in 2003 as the fourth of NASA's Great Observatories. It is in a solar, Earth-trailing orbit as it observes the infrared universe.

Ultraviolet: Blue in the stars image represents both near and far ultraviolet light, captured by NASA's *Galaxy Evolution Explorer* space telescope. Launched in 2003, this spacecraft surveys the universe in ultraviolet light to a distance of 10 billion light-years.

Visible: Green in the stars image represents visible light gathered by the *Steward Observatory* at the University of Arizona in Tucson. Blue in the gas and dust image represents visible light captured by Frank Winkler, *Kitt Peak National Observatory* Burrell Schmidt telescope.

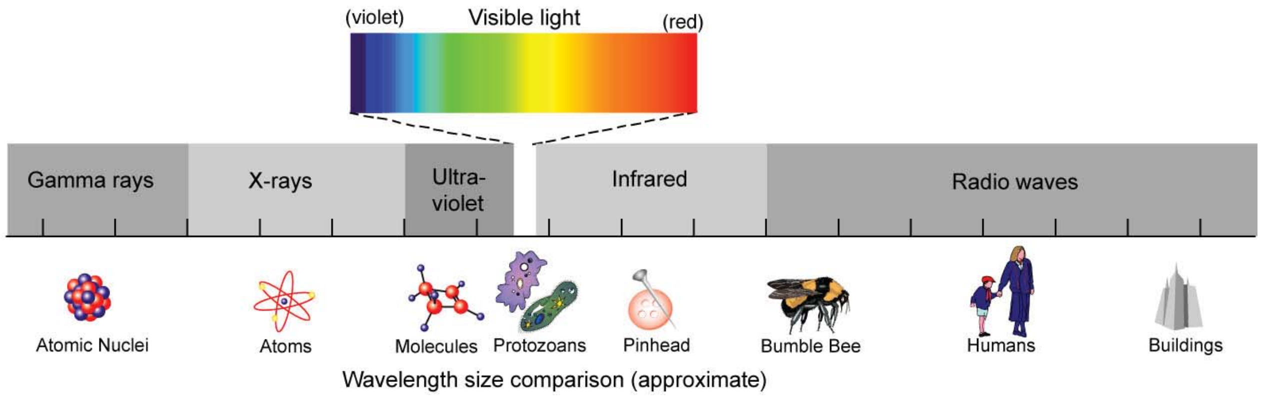
Radio (millimeter): The millimeter radio image is from the 30-meter radio telescope at the *Institut de Radio Astronomie Millimétrique* in Spain.

Radio (21 cm): The 21-cm radio waves emitted by cool hydrogen gas are represented as red in the gas and dust image. This data was collected by the *Westerbork Synthesis Radio Telescope* in Westerbork, The Netherlands. This radio telescope is part of the European VLBI (Very Long Baseline Interferometry) Network of radio telescopes.

All the non-visible wavelength parts of the images (infrared, ultraviolet, and radio waves) are translated into visible-light colors so that we can see them with our eyes.

Multi-wavelength Astronomy:

Revealing the Universe in all its Light



Almost everything we know about the Universe comes from the study of light emitted or reflected by objects in space. Apart from a few exceptions, such as the collection of Moon rocks, 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 the Universe. Many of these photons of light may travel billions of light-years to reach our telescopes. In the science of astronomy, we cannot retrieve samples, or 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 a celestial object, astronomers learn about the object's distance, motion, temperature, density, and chemical composition. Because light from an object takes time to reach us, it 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, examining the object's appearance at the time it emitted those photons. 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.

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, which includes the rainbow of colors we normally see, plus a lot more, is called the electromagnetic spectrum. The electromagnetic spectrum includes gamma rays, x-rays, ultraviolet, visible, infrared, microwaves, and radio waves. The only difference in these types of radiation is the 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 186,000 miles per second (or 300 million meters 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 its light, using each part of the electromagnetic spectrum. Technology developments over the past 70 years have led to electronic detectors capable of seeing light that is invisible to human eyes. In addition, we can now place telescopes on satellites and on high-flying airplanes and balloons above the obscuring effects of Earth's atmosphere. This combination has led to a revolution in our understanding of the Universe. At the same time, it has raised many more questions.

Each portion of the electromagnetic spectrum gives us unique information about our Universe. 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, nebulas, 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.

All astronomical objects, except for black holes, emit at least some light. However, objects may emit more radiation in some part of the electromagnetic spectrum than in others, and can be best studied at those wavelengths. Each part of the spectrum reveals information not found at other wavelengths. Some objects emit strongly across the entire spectrum, with the light from each spectral region providing pieces to complete the picture.

The beauty, complexity, and mysteries of the Universe can be understood fully only if we study all the information that distant objects provide. And this level of study can be done only if we collect all the light available to us, from one end of the electromagnetic spectrum to the other.

Infrared and Ultraviolet Experiments

Objective

These two experiments replicate (in slightly modified form) those performed by Sir Frederick William Herschel in 1800 and Johann Wilhelm Ritter in 1801, in which they discovered two forms of radiation other than visible light.

Background

Herschel discovered the existence of infrared light by passing sunlight through a glass prism. 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 (see Remarks to Teacher, below). 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 we cannot see beyond the red. This type of light became known as *infrared*. *Infra* is derived from the Latin word for "below."

After learning about the discovery of infrared light, Johann Ritter began experimenting to see whether he could detect invisible light beyond the violet portion of the spectrum as well. In 1801, he was experimenting with silver chloride, which turns black when exposed to light. He had heard that blue light causes a greater reaction in silver chloride than red light does. Ritter decided to measure the rate at which silver chloride reacted to the different colors of light. As Herschel did, he directed sunlight through a glass prism to create a spectrum. He then placed silver chloride in each color of the spectrum and found that it showed little change in the red part of the spectrum, but darkened toward the violet end of the spectrum. In the area just beyond the violet end of the spectrum, in a region where no sunlight was visible, the silver chloride showed the most intense reaction of all. This experiment showed for the first time that an invisible form of light existed beyond the violet end of the visible spectrum. This new type of light, which Ritter called Chemical Rays, later became known as *ultraviolet light* or ultraviolet radiation (the word *ultra* means beyond).

Although the procedures given here for these experiments are slightly different from Herschel's and Ritter's original experiments, you should obtain similar results.

Setup for Both Experiments

The basic setup is the same for both experiments. The experiments should be conducted outdoors on a sunny day. Variable cloud conditions, such as patchy cumulus clouds or heavy haze will diminish your results. Here are the materials and preparation steps that apply to both.

MATERIALS:

- One glass prism (plastic prisms do not work well for these experiments)
- Scissors or a prism stand
- Cardboard box (a photocopier paper box works fine)
- One blank sheet of white paper.

SETUP:

Figure 1 shows the setup for the experiments. 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.

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 (see 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. The Sun-facing side of the box may have to be elevated (tilted up) to produce a sufficiently wide spectrum.

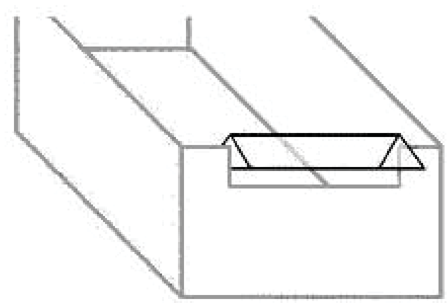


Figure 1. Box setup with prism inserted in notch cutout.

Herschel Experiment

ADDITIONAL MATERIALS NEEDED:

- Three alcohol thermometers
- Black paint or a permanent black marker

PREPARATION:

You will need to blacken the thermometer bulbs to make the experiment work effectively. One way to do this is to paint the bulbs with black paint, covering each bulb with about the same amount of paint. Alternatively, but not quite as good, you can also blacken the bulbs using a permanent black marker. The bulbs of the thermometers are blackened in order to better absorb heat. After the paint or marker ink has completely dried on the thermometer bulbs, tape the thermometers together on a card (3 x 5, for example) such that the temperature scales line up as in Figure 2.

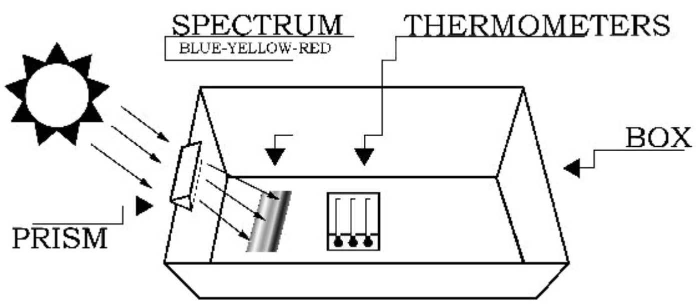
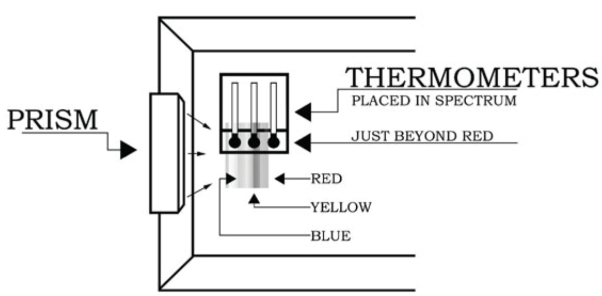


Figure 2. Initial setup for Herschel experiment with thermometers taped together and lined up.

Before putting the thermometers in the spectrum, place the thermometers in the shade and record the ambient air temperature. 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 3).

Figure 3. Herschel experiment setup.



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 position of the prism relative to the Sun, the colors of the spectrum may be reversed from what is shown in the figures.

Compute the differences between the final temperatures measured in the spectrum and the temperatures measured in the shade for the three thermometers.

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:

The temperatures of the colors should increase from the blue to red part of the spectrum. The highest temperature should be just beyond 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 blue light actually has a shorter wavelength (thus more energy) than red, so theoretically should have registered a higher temperature than red. However, the results he got were skewed because the different parts of the spectrum were spread out over varying areas due to the angle with which the colors of light hit the paper. The red light occupies a smaller area than does the blue light. Nonetheless, his results still indicated that there was some light energy beyond the visible red part of the spectrum.

Ritter Experiment

For the best results, read the ***PREPARATION*** and ***PROCEDURE*** sections carefully before attempting this experiment. Teachers should try this experiment first before having their students perform it.

> **CAUTION:** *The Ritter experiment uses ammonia to develop blueprint paper. The ammonia should handled by an adult only. To minimize the vapors, dilute the ammonia, using 90% very warm water and 10% ammonia.*

This experiment uses the same prism setup as the Herschel experiment, using either a prism stand or a box.

ADDITIONAL MATERIAL NEEDED:

- Blueprint paper

  NOTE: Blueprint paper may be hard to find. Examples of websites where it may be ordered are: *www.dataprint.com/Store/c-195-fast-speed.aspx*, *www.engineersupply.com/Fast-Speed-Blue-Line.aspx*, and *www.freedompaper.com/Blueline-Diazo-Blueprint-Paper*. Blue print paper is extremely sensitive to light. Keep it in a dark area until you place it in the spectrum produced by the prism in the experiment.
- Household ammonia
- Warm water
- One small, shallow square pan
- A piece of cardboard slightly larger than the pan
- Water
- A thin black marker
- A ruler
- Tape

PREPARATION:

In a very dimly lit area cut out a piece of blueprint paper slightly larger than the small, shallow pan (at least 4x4 inches). Keep the piece of blueprint paper out of the light until needed.

Next, cut out a piece of cardboard slightly larger than your piece of blueprint paper.

PROCEDURE:

Without exposing the blueprint paper to direct sunlight, quickly place it in the bottom of the box, where the spectrum is visible, with the colored side of the blueprint paper facing up (exposed to the spectral colors). Be sure to have a large section of the blueprint paper in the area past the blue-violet portion of the spectrum. Tape the paper down at the corners to keep it from moving. Being careful not to move the box or the blueprint paper, use a thin marker to draw an outline on the blueprint paper around the visible part of the spectrum created by the prism. Label the violet end of the spectrum with a "V." Leave the paper in the box, exposed to the spectrum, for about 30 seconds. Then carefully remove the paper and try not to expose it to sunlight during the process.

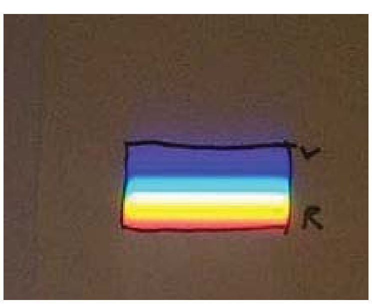


Figure 4. Experiment setup, with spectrum shining on blueprint paper, outline of visible spectrum.

Bring the piece of blueprint paper to a well ventilated area. Here pour a mixture of 90% very warm water and 10% ammonia into the pan to a depth of about 1 centimeter.

> ***CAUTION:*** *The mixing and pouring of the ammonia mixture should be done by a teacher, parent or other adult.*

Place the blueprint paper across the top of the pan with the colored side of the paper facing the pan and cover it and the entire pan with the piece of cardboard. Do not let any of the ammonia mixture come into contact with the blueprint paper. The cardboard will help contain the ammonia fumes and will decrease the development time. Keep the paper in place above the pan for about 90 seconds.

Once the blueprint paper is developed, move to a location away from the ammonia and study your results. There should be a white (or light-colored) rectangle around the area where the blueprint paper was exposed to the solar spectrum. The white area should be surrounded by a much darker region. You should notice that the area that was exposed to the red end of the spectrum is not as lightly colored as the area exposed to the violet region. Most important, you should notice that the light-colored area of the blueprint paper extends far beyond the line marking the violet end of the spectrum. This is the region that was exposed to invisible ultraviolet light.

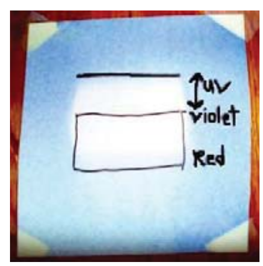


Figure 5. Final blueprint paper results.

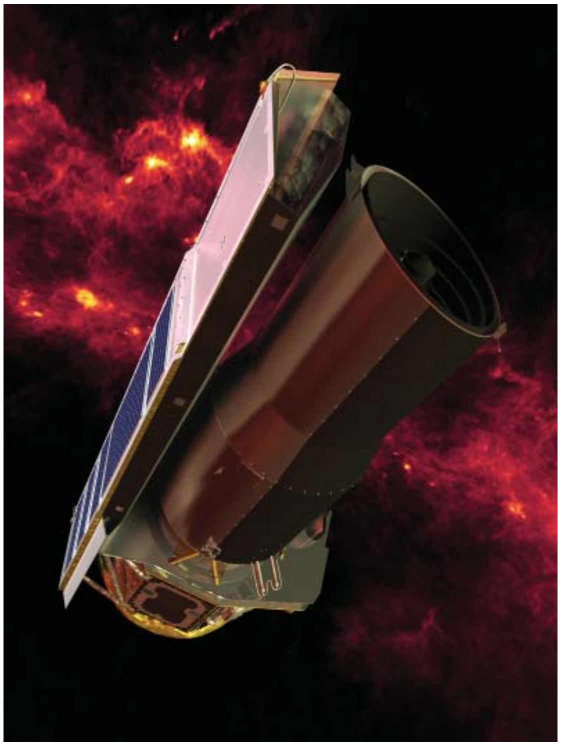
DATA/OBSERVATIONS:

Using a ruler, measure the marked width of the visible spectrum. Then measure how far the light-colored region of the blueprint paper extends beyond the line marking the violet end of the spectrum. Add these two numbers to compute the total width of the exposed region.

QUESTIONS:

What happened to the blueprint paper after it was developed? Describe what happened to the area that was exposed to the visible part of the spectrum. Describe what happened to the blueprint paper in the region beyond the violet part of the spectrum, where no visible light could be seen. What do you think exists just beyond the blue part of the spectrum? Do you think that this proves the existence of an invisible form of light? Why or why not? Discuss any other observations or problems.

The Spitzer Space Telescope



The Spitzer Space Telescope was launched into space by a Delta rocket from Cape Canaveral, Florida, on August 25, 2003. Spitzer's mission is to obtain images and spectra by detecting the infrared energy, or heat, radiated by objects in space between wavelengths of 3 and 160 microns (1 micron is one-millionth of a meter).

Consisting of an 85-centimeter telescope and three cryogenically-cooled science instruments, Spitzer is the largest infrared telescope ever launched into space. It has given us a unique view of the Universe and allowed us to peer into regions of space hidden from optical telescopes. Many areas of space are filled with vast, dense clouds of gas and dust that block our view. Infrared light, however, can penetrate these clouds, allowing us to peer into regions of star formation, the centers of galaxies, and into newly forming planetary systems. Infrared also brings us information about the cooler objects in space, such as smaller stars too dim to be detected by their visible light, extrasolar planets, and giant molecular clouds. Also, many molecules in space, including organic molecules, have their unique signatures in the infrared.

Because infrared is primarily heat radiation, the telescope must be cooled to near absolute zero (-273 degrees Celsius or -459 degrees Fahrenheit) so that it can observe infrared signals from space without interference from the telescope's own heat. Also, the telescope must be protected from the heat of the Sun and the infrared radiation emitted from Earth. Thus, Spitzer carries a solar shield to protect it from the heat of the Sun, and it was launched into an Earth-trailing solar orbit. This unique orbit places Spitzer far enough away from the Earth to allow the telescope to cool rapidly without having to carry large amounts of coolant. This innovative approach has significantly reduced the cost of the mission.

The Three Science Instruments

Spitzer's three instruments include:

Infrared Array Camera: Takes simultaneous images using infrared light at wavelengths 3.6, 4.5, 5.8, and 8.0 microns (a micron is one-millionth of a meter). This instrument enables the telescope to see stars embedded deep inside thick clouds of cosmic dust, to detect large organic molecules called polycylic aromatic hydrocarbons (similar to those found in car exhaust) in star-forming regions, and to image brown dwarfs (objects not quite big enough to be stars) that are too cool to be detect by visible-light telescopes.

Multiband Imaging Photometer: This instrument detects infrared wavelengths at 24, 70, and 160 microns. It provides images, light measurement (photometric) and chemical composition (spectroscopic) data. At these wavelengths, Spitzer provides valuable insights into the star-formation process. This instrument can also image cold dust in our own Milky Way Galaxy and nearby galaxies.

Infrared Spectrograph: This instrument analyses the light from a source and provides detailed information about the distance, temperature, motion, and composition of the object. Astronomers have used the Infrared Spectrograph to identify specific molecules like water and olivine around some stars, and determine the molecular makeup of comets.

The Spitzer Space Telescope is managed by the Jet Propulsion Laboratory, a division of the California Institute of Technology, for NASA's Science Mission Directorate.

To Learn More

For further information on the Herschel infrared experiment see *http://coolcosmos.ipac.caltech.edu/cosmic_classroom/classroom_activities/ herschel_experiment.html*.

For further information on the Ritter ultraviolet experiment see *http://coolcosmos.ipac.caltech.edu/cosmic_classroom/classroom_activities/ritter_experiment.html*.

For further information on Infrared and Infrared Astronomy see *http://coolcosmos.ipac.caltech.edu/cosmic_classroom/ir_tutorial/index.html.*