

What does the universe look like in color?

The purpose of this exploration is to create a full-color image of a celestial object, using three black-and-white images taken through the telescope's color filters.

- The human eye can sense red, green, and blue light. Combinations of these three colors are perceived as full-color.
- Any color scene can be separated into its red, green, and blue components and then reconstructed to form full color.
- The color of a celestial object carries information about the object's temperature, composition, speed, and other physical properties.
- When creating an image, scientists may have to make choices about what to display, and these choices may affect the interpretation of the image.

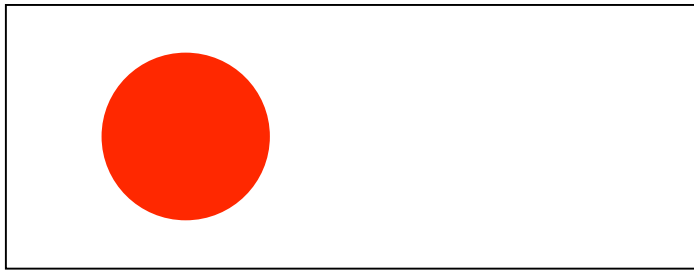
Background

With training, the average person can distinguish about one million colors. That makes it all the more amazing that, for hundreds of years, artists have been able to mix almost any color from just three pigments: red, yellow, and blue (and white to lighten the mixture).

In the 1860's, the German physiologist Hermann von Helmholtz discovered that the eye has three different kinds of cells that respond to three different regions of the color spectrum. Most people thought these cells would turn out to be sensitive to red, yellow, and blue light—since these were the "primary" pigments that artists had

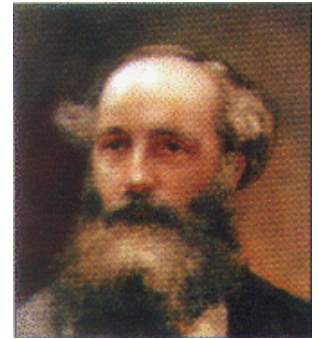
long used. But to everyone's surprise, Helmholtz showed that the eye's three kinds of color receptors have their peak sensitivity to red, green, and blue light. These three colors are now known as the primary colors of light, since any color the eye can see can be produced by stimulating the eye with a combination of red, green, and blue light.

From a scientific point of view, Helmholtz' discovery was a great success. It explained, for example, the phenomenon of after-images. If you stare at a red circle, for example, for half a minute or so, and then look at a blank white part of the page, you will see a bluish-green after-image. Helmholtz interpreted this as indicating that the eye's red-receptors somehow got "used up" in staring at the color, allowing the blue- and green-receptors to dominate vision and produce the bluish-green afterimage.



Inspired by Helmholtz' early experiments on color vision, the Scottish physicist James Clerk Maxwell gave an astounding demonstration to the British Academy in 1861: He was able to create a full-color image of a Scottish tartan ribbon, from three black-and-white slides projected through red, green, and blue filters to form one image. This proved that full-color could be recreated from mixing red, green, and blue light.

Artists were fascinated by these new scientific discoveries, which stimulated new styles of art. Georges Seurat, for example, attempted to stimulate the viewer's eye with paintings created from thousands of dots, often using primary colors or complementary colors side by side. But artists quickly found it difficult and unrewarding to try to mimic the mixing of light by juxtaposing colored pigments. Today, the primary pigments for artists remain red, yellow, and blue—while the primary colors of light are red, green, and blue, as you can see from closely observing the screen of your television set or computer monitor.



James Clerk Maxwell (1831-1879) demonstrated that full color could be recreated from red, blue, and green images projected on a screen. He is best known for his discovery of the laws of electromagnetism.



Detail from Seurat's *Bathing at Asnières*.

Color and the universe

The universe tells us its story largely through the light that it sends us—and color plays a key role in the story. To the eye, the objects in the night sky look unremittingly white, except for the planet Mars and a few stars, such as Antares, whose reddish glow is noticeable if you look carefully. But through a telescope, the universe is aglow with color. What can these colors reveal?

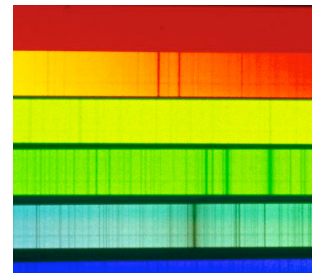
Colors reveal temperature: Stars that are cooler glow red, while medium-hot stars like our Sun glow yellow, and very hot stars glow a bluish-white. In fact, *all* objects at the same temperature will glow with the same color. The ceramic pots in the kiln at right, heated to a temperature of several thousand degrees, are glowing with same dull red color as a star at the same temperature halfway across the universe. If we could heat the pots just a thousand degrees more, they would glow with a yellow indistinguishable from the Sun.

Colors reveal chemical composition: Every chemical element absorbs and emits light at sharply-defined wavelengths which are characteristic of that element. Neon, for example, emits the warm orange light familiar from neon signs. Chemical elements in the Sun absorb specific wavelengths of sunlight passing by; the Sun's spectrum is darker at these wavelengths (see image). By matching the pattern of these lines to known patterns from laboratory experiments, astronomers can tell which elements are present, and in what amounts.

Colors reveal motion: The color of an object actually shifts slightly depending on whether it is moving towards or away from us. This phenomenon, called the Doppler effect, also applies to sound waves and accounts for the changing pitch of train whistles and police sirens as they pass by. (To hear the effect visit http://ADD_HERE.) On Earth, objects don't move fast enough for their colors to perceptibly change; however, many objects in space do. You can learn more about this effect in Exploration 7, "How large and how old is the universe?"



The pottery and brick walls in this kiln all glow with the same color.



A portion of the Sun's spectrum. Chemical elements at the Sun's surface absorb specific wavelengths of light, seen here as lines where the spectrum appears darker.



The Swan Nebula is a giant sea of gas that absorbs energy from nearby stars and then emits light in colors characteristic of its chemical composition. The colors—altered and enhanced here to bring out detail—reveal the elements hydrogen (green), oxygen (blue), and sulfur (red). *NASA/Hubble Space Telescope.*

Materials Needed

	<i>For each team of students</i>
	Color filters: Red, green, and blue ¹ . 2” x 2” swatches work well.
	<i>For the class</i>
	Internet access to the MicroObservatory online telescopes
	Image-processing software (MOImage) on your local computer
	Optional: Shockwave plug-in on your local computer

¹ For example, medium red ROSCOLUX #27, dark yellow green ROSCOLUX #90, primary blue ROSCOLUX #74; available at <http://www.rosco-ca.com/products/filters/filters-roscolux.html> Other suppliers are available; ask for pure color filters for science experiments.

	Optional: Printer (color)
	<i>For the teacher</i>
	Overhead projector
	Overhead transparency of eye's color sensitivity ²

Part 1. Students' ideas about light and color

In order for students to make sense of their work with the telescopes, it is important for them to understand the three major actors involved in seeing or in taking an image: There is the *source*—such as a star—that emits the light. There is the *receptor*—such as the eye's retina or the telescope's light-sensing chip—which detects the light. And there may or may not be an intermediate object that absorbs some of the light and reflects or transmits the rest to the observer. Examples are the Moon and planets.

However, students' prior ideas about light and color are often deeply held. The following discussion with the class is important to help the class to sort out their prior ideas and move towards more scientific, and more useful, understandings.

Have students respond to the questions and record their answers in their science journals. Then discuss their ideas about light and color:

Where does light come from? How many things can you name that are a source of light?

Ask students for their responses, and write down their answers on the blackboard. For each response, ask the class whether they agree

² Supplied with *From the Ground Up!* materials.

this is a *source* of light. Examples may include fire, incandescent lights, fluorescent lights, the Sun, the stars, TV screens, those funny light sticks they hand out at carnivals, luminescent dials on watches and clocks, neon signs, blinking LED displays, fireflies and other glowing creatures, auroras, etc. A traffic light might not be accepted as a separate example, because the source is an ordinary light bulb inside the device.

Point out to students that although we see light indoors and out, there are *relatively few* different sources of light. These few sources light our entire world, indoors and out.

Which of the sources you named are hot?

Go back through the class' list and have students identify which items are sources of light by virtue of being hot enough to glow. Examples include the Sun, fire, a glowing oven or hot coals, incandescent bulbs, and the stars (though we have no direct experience with the stars).

Many of the light sources on the list are *not* hot. Examples are the red and green lights (LEDs) in electronic equipment, the glow of TV screens, fluorescent bulbs, neon signs, auroras etc. These sources must produce light by some means other than being hot enough to glow.

Is the Moon a source of light? Is the daytime sky a source of light?

The Moon is bright enough to cast shadows at night, but is it the *source* of light? Ask students whether the Moon gives off its own light, or merely *reflects* the light from some other source. This is a good opportunity to remind students that the Sun is the source of the Moon's light; the moonlight we see is reflected light whose source is the Sun.

The daytime sky is an even more subtle example of reflected or scattered light. To "turn off" the sky, we would have to turn off the Sun; the source of energy for the daylight is the Sun.

If you close your eyes or if you dream, you can still see the *sensation* of light. Is this light? If so, what's the source?

Misconception alert: Many students think that the eye is somehow a source of light, and that this light helps us see. As evidence, students may cite the "glow" of animals' eyes in the dark (in reality this is reflected light) or Superman's x-ray vision. The ancient Greeks pointed out that you can "see" your dreams even with your eyes closed, so a source of light would seem to come from within your eye. Today we know that the eye and brain can create the *sensation* of light, even though the eye produces no light of its own.

Which of the light sources you mentioned give off colored light? Does the color give you information about the source of the light? What kinds of information?

All of the light sources give off colored light, even if that color is white. For hot objects, the color gives us information about the object's temperature. For example, if you open the oven in your kitchen and see it glowing red, you can tell it is hot, even from far away. Objects that glow white hot are even hotter. Astronomers can tell a star's (surface) temperature from observing its color.

A light source's color can also tell us about its composition. For example, the color of a neon sign depends on which gases are used in the sign (neon glows red-orange, but argon glows greenish-blue.) Astronomers can often tell what a celestial object is made of by observing its colors.

Insert: Image of planetary nebulae, with info about composition

Part 2. Planning the exploration

Experiment 1: All colors can be made with 3 primary colors

The purpose of this experiment is to investigate what produces the many different colors on a TV screen or computer monitor.

- The human eye can sense red, green, and blue light. Combinations of these three colors are perceived as full-color.

This activity works even better with an older computer monitor, because the dot size is larger on older monitors.

1. Use any multi-colored image on the screen, or go to this URL for an image:

<http://>

2. Have students use a magnifying glass to observe the screen. Alternatively, you can place a *single* drop of water on the screen. The water drop will act as a powerful magnifying glass. CAUTION: Pouring water down the screen can damage the monitor.
3. Have students record their responses to the questions in their science journals.

What do you observe beneath the water drop?

What colors are the dots or lines you see?

No matter what colors are in the image onscreen, do the colors of the dots remain the same?

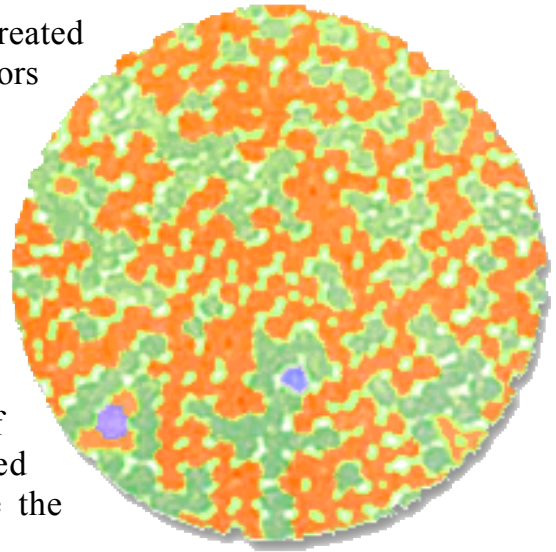
The image on the screen is composed of thousands of tiny red, green, and blue dots (or lines, in some screens).

Each color in an image is a combination of the red, green, and blue dots, glowing at different brightnesses. For example, the color yellow is created from the red and green dots glowing together, with very little or no blue. White is created from the red, green, and blue dots all glowing together. Brown is a combination of dim red and dim green.

Why are there 3 primary colors?

4. Explain to students that all colors can be created from just red, green, and blue light. These colors are called the primary colors of light.

There's a simple reason why red, green, and blue are the primary colors: Your eye has three different types of color-sensing cells that respond to red, green, and blue light. The image at right shows a portion of the retina of your eye, magnified thousands of times. The circles are the color-sensing cells, called "cones."



Note that there are 3 different types of cone cells. (They've been colored in to make them easier to distinguish, but don't look this way in nature.)

One type is stimulated by red light (cells colored red here). Another is stimulated by green light (colored green here). And a few cells are switched on by blue light. (For some reason, there are only 1% as many blue-sensitive cells as red- and green-sensitive cells.)

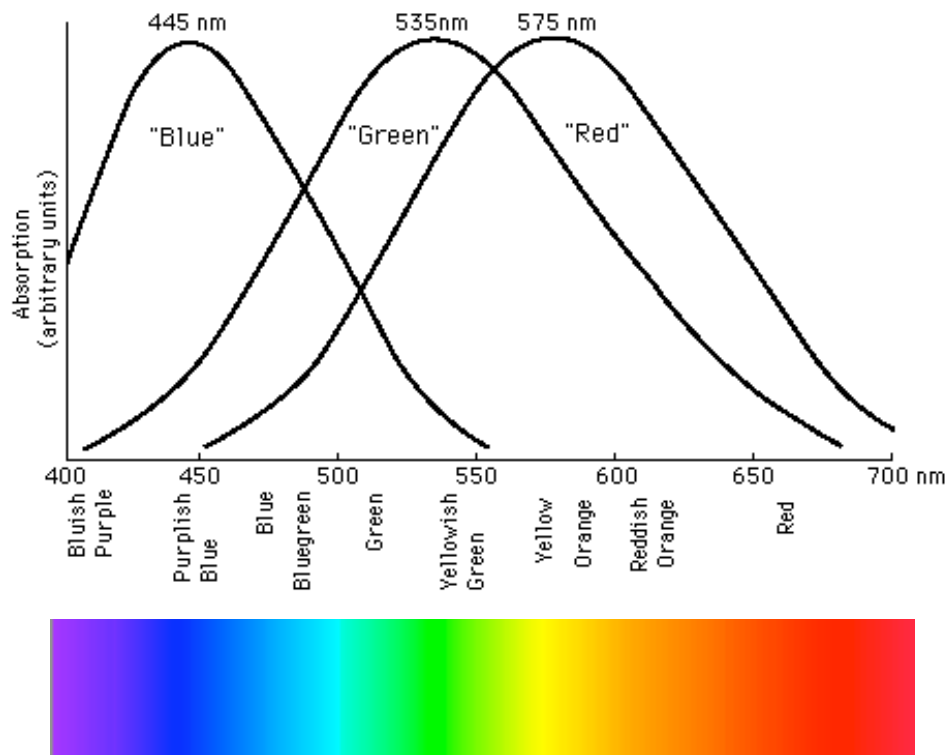
5. Use the transparency slide (next page) to show why each of the many colors you can see can be recreated by mixing red, green, and blue light. The slide shows the response of each of eye's three kinds of color receptors to light across the spectrum.

Note that the blue receptor absorbs light mainly at the blue end of the spectrum, and similarly for the green and red receptors. But there is some *overlap* among all three receptors: As a result, yellow light, e.g., stimulates *both* the red and the green receptors. We perceive the color yellow as a result of these two receptors being stimulated.

Therefore, if we show the eye red light plus green light, then we stimulate both the red- and green-receptors, and this produces the perception of yellow. The eye has no way of telling whether it has been shown one wavelength (“yellow”) that stimulates both the red and green-receptors, versus whether it has been shown two primary colors of light, red and green. This is why a television monitor, e.g., can produce all colors, using just the three primary colors of light—red, green, and blue.

TRANSPARENCY

Response to light for the eye's red-, green-, and blue-sensing cells.



Experiment 2: Working with color filters

The purpose of this activity is to investigate the behavior of color filters.

- A red-passing filter allows red light to pass through, but blocks green and blue. Similarly, green- and blue-passing filters allow green and blue light through, respectively.

Misconception alert: Students often find filters confusing, because the terminology in common use is often inconsistent. In photography, for example, a red filter *allows* red light through, but an ultraviolet filter *blocks*—or filters out—ultraviolet light. Does a filter pass light or filter it out? For this exploration, we recommend always denoting the function of the filter by using term *red-passing*, *green-passing*, etc.

1. Have students bring up on the computer monitor the spectrum at this Website:
<http://mo-www.harvard.edu/Java/MiniSpectroscopy.html>
2. Have students *predict* what they will observe when they look at the spectrum through a red, green, and then blue filter. Have them record their predictions in their science journals.

Which part of the spectrum do you think will appear the lightest when you look at the spectrum through the blue-passing filter (the filter that lets through only blue light)?

How about the green-passing filter? Which part of the spectrum will look lightest when seen through the green-passing filter?

And the red-passing filter?

3. Have students carry out the observations, using each of the colored filters.

How does what you observe compare with what you predicted?

Suppose you were color-blind. If you looked at the world through each of the three filters, could you tell that they are different, based on what you saw? How could you tell?

Will images taken with the telescope look different if you use different filters—even though the telescope only registers light and dark?

Students should observe that, when viewed through the red-passing filter, the red portion of the spectrum will appear the *brightest*, and the other portions of the spectrum will appear darker. Similarly, when viewed through the green-passing filter, the green portion of the spectrum will appear brightest, while the other regions will be darker. This makes sense, since the red-passing filter lets the red light through, but blocks the other colors.

If you were completely color-blind, you could *still* tell that the red-, green-, and blue-passing filters must be different from each other. When looking through the red-passing filter, the parts of the world that were reddish would look lighter, whereas the other filters would make the other parts of the scene appear lighter.

Similarly, the telescope is "color-blind," because it only records in black and white (and greys). But if you image the same scene using the red-, green-, and blue-passing filters, each image will be different from the others.

Experiment 3: "Breaking down" a color scene, using filters

The purpose of this activity is to observe what happens when a full-color scene is viewed successively through a red-, green-, and then blue-passing filter.

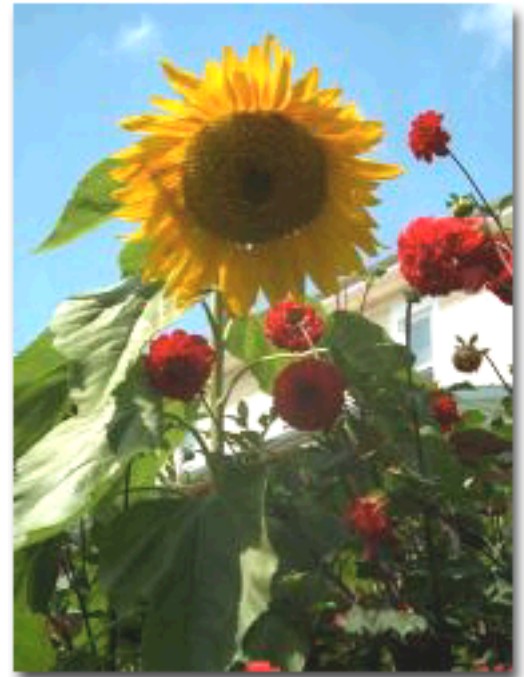
- Any color scene can be separated into the *brightness and darkness* of its red, green, and blue components.
1. Have students answer the questions and make their predictions in their science journals.

What are the major colors in this scene?

Which areas of the picture do you think will appear the brightest when you look through the red-passing filter? Which will be darkest? How about the other filters?

What do you observe?

The major colors in the scene are red, green, blue, yellow, brown, and white. When viewed through the red-passing filter, the brightest areas should be the red areas, namely the red flowers. The blue and green areas will be darker. Since the color white has some red in it (it is composed of red, green, and blue), the house should also appear bright. The yellow sunflower will also appear bright in both the red-passing and green-passing filters, since yellow is made from both red and green light.



	Red-Passing Filter	Green-Passing Filter	Blue-Passing Filter
Brightest Areas	red flowers, house	leaves, house	sky, house
Darkest Areas	leaves, sky	flowers	leaves

2. If time is available, have students try the experiment using the kitten's and children's images in their science journals as well. These images are more challenging, because the colors are not primary colors.

Kitten Challenge

Which areas of the picture do you think will appear the brightest when you look through the red-passing filter? Which will be darkest? How about the other filters? Fill in your predictions:



	Red-Passing Filter	Green-Passing Filter	Blue-Passing Filter
Brightest Areas			
Darkest Areas			

Kids Challenge

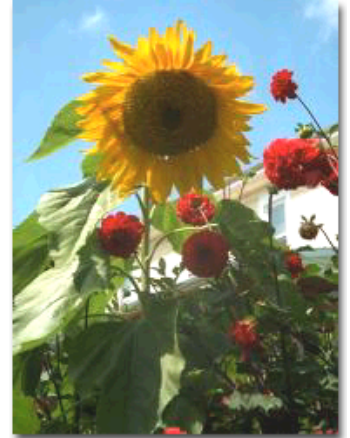
Which areas of the picture do you think will appear the brightest when you look through the red-passing filter? Which will be darkest? How about the other filters? Fill in your predictions:



	Red-Passing Filter	Green-Passing Filter	Blue-Passing Filter
Brightest Areas			
Darkest Areas			

Assessment: Can you tell which filter was used?

This puzzler helps you assess whether students understand how filters behave. Have students try to match the three black-and-white images with the filters through which they were taken. Discuss with students why they labeled each image as they did. Then discuss the evidence that leads to correctly matching each image with the filter through which it was taken:



In **Image #1**, the blue sky is light, so this was probably taken with the blue-passing filter. Supporting evidence: The yellow sunflower is completely dark; yellow has red and green in it but no blue.

Image #2 looks similar to Image #3, except that the red flowers and the sunflower are very bright in Image #2, so this was taken with the red-passing filter.

Image #3 was taken with the green-passing filter. The green leaves are the lightest in this image.

Image #1:



Image #2:



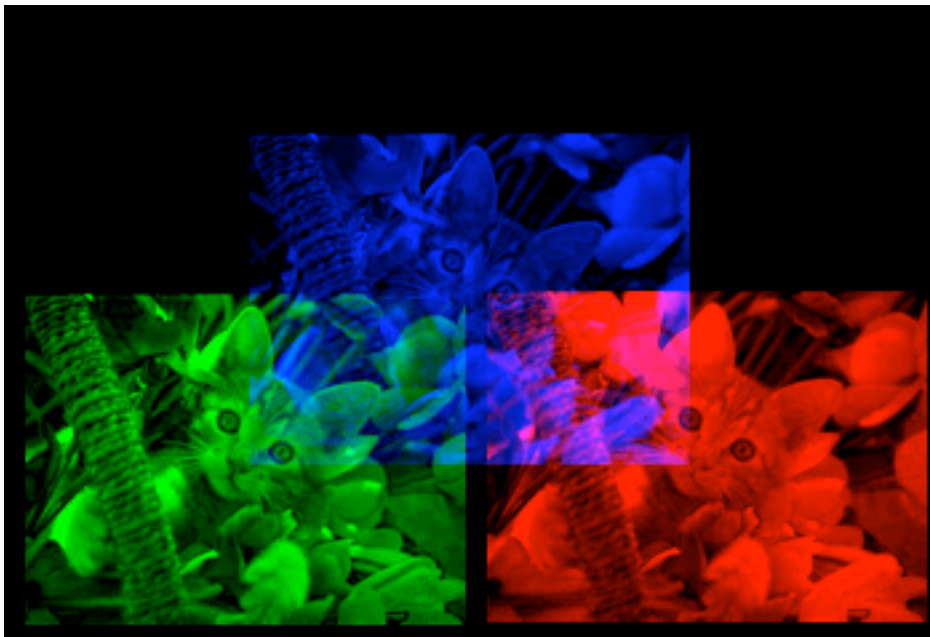
Image #3:



Experiment 4: Creating color from red, green, and blue

The purpose of this activity is to recreate a full-color image by merging its red, green, and blue components with each other.

- Any color scene can be separated into its red, green, and blue components and then reassembled into a full-color image.



1. Have students access the interactive learning tool at the following URL. (Note: This interactive requires the free Shockwave plug-in, which should already be installed on your computer.)

<http://cfa-www.harvard.edu/webscope/inter/color>

2. By dragging the red, green, and blue components of the image so that they are superimposed, students can reconstruct the full-color scene.

Experiment 5: Creating full-color images using software.

The purpose of this activity is to create a full-color image from three black-and-white images taken through color filters, using the MOImage software.

- Any color scene can be separated into its red, green, and blue components and then reconstructed to form full color.

In order to create full-color images using the telescopes, students will need to use the MOImage software on the computer. To get them started with the program, have them reconstruct the full-color sunflower using just the black-and-white images taken through the three red-, green-, and blue-passing filters.

1. Have students download the three black-and-white images from the "From the Ground Up!" website at this address:

<http://cfa-www.harvard.edu/webscope/activities/color>

2. Students launch the MOImage software on the computer.
3. Students open the flower files that they just downloaded: First open *flowerR.gif*. This is the red portion of the flower image. Under the **Process** menu, select **Color Tables / Red**. This automatically colors the image red. In the same way, open the green image (*flowerG.gif*) and color it green by selecting **Process/Color Tables/Green**. Finally, open *flowerB.gif* and color it blue.
4. Under the **Process** menu, select **Stack**, and select **Convert Images to Stack**.
5. Have students take a moment to scroll through the stack, using the or arrows at the bottom edge of the image. Note

that the three images contain very different information about the picture. The third image is very dark, because there is no blue in the scene, except for the sky.

6. To create the color picture, go to the **Process** menu, select **Stack**, then **Convert Stack to RGB** (which stands for red, green, blue color).

The result should be a full-color picture of the sunflower.

If students mix up the color of the images—for example, coloring the red-information image green—they'll get a strangely-colored picture that won't be the color of the original image.

Planning the exploration

Students are now ready to use the MicroObservatory telescopes to create a color image of an object in the night sky.

1. Have students discuss with their team what kind of object they would like to image. Remember that large objects such as nebulae often form the best subjects. Planets may not be good choices, because they are small and will show little color variation in the MicroObservatory telescopes. Have students either choose from the list of suggested targets, or use a target not on the list.
2. Have each team develop an outline for how to proceed. They will be able to use:
 - the telescopes
 - the telescopes' filter wheel, containing filters that pass red, green, and blue light
 - MOImage software for combining the red, green, and blue information to form color.

Part 3. Creating color images with the telescope.

Students work in teams of three. Have each team select a celestial object they would like to image, using either the list of suggestions provided, or another target. It does not matter if several teams image the same object, since they will be able to compare their results. Make sure that students understand they have to take three images for each celestial object: one each through the red-, green-, and blue-passing filters.

To ensure that they produce successful images, help students with these issues:

Make certain that the targets they have chosen are above the horizon at this time of year.

Have students use a range of exposure times (such as half and twice the recommended exposure time for their object). For each exposure time, they should take one image through each of the three color filters.

Make certain that students download their images from the Web in FITS format (follow instructions on the Website) rather than GIF format, so that they can process their images.

Remind students to clearly label their downloaded images with the name of the object and the filter color that was used. It is a good idea to print the Image Info file that comes with each thumbnail of the image, because this contains all the information about the image, including the color filter used. This information is also contained in the FITS "header," which accompanies every FITS image and which can be read in the MOImage program under the **Windows** menu (select **Windows / FITS Header**).

Procedure

Taking and downloading the images

1. Choose an object you'd like to image. Use the handy chart for suggestions, or you can use a target not on the list.
2. Take *three* images of your target—one each using the red-, green-, and blue-passing filters. For each image, use the exposure time suggested below.
3. When the telescope has taken the images and posted them on the Web, download the three images in FITS format. (See Web page for instructions.)
4. Be sure to name the files clearly so that you know which image was taken through which filter (e.g., “orionRed.FITS”). The filter color is listed in the Image Info file and FITS header that comes with each image.

Creating full-color images



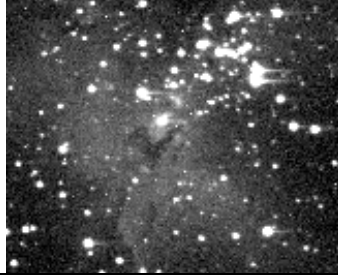

5. **Open your three images.** Launch the MOImage processing program on your computer. Open the image taken through the red-passing filter. Do the same for the images taken through the green- and blue-passing filters. You should have three images open.
6. **Adjust brightness and contrast:** Under the **Process** menu, select **Adjust Image**. When the Adjust Image window opens, select the **Auto** button to get a good first look at the image. Further adjust the brightness and contrast as necessary. Do the same for the other two images: Hit the auto button to automatically adjust brightness and contrast.
7. **Color each image red, green or blue:** Work with the red-filtered image first. Under the **Process** menu, select **Color**

Tables / Red. Your image will turn red. Then work with the green-filtered image, selecting **Color Table / Green** to turn the image green. Finally, color the blue-filtered image blue.

What's going on? The areas in the original scene that had a lot of red became the *brightest* areas in the red-filtered image. In turn, these bright areas in the red-filtered image will become the *reddest* areas in the final image. The same holds for the green- and blue-filtered images.

8. **Align the images:** Your three images will probably be slightly out of alignment. You'll need to align, or "shift" the images so that when you combine them the result won't be blurred. Under the **Process** menu, select **Shift**. As prompted, select one of your images as the background image over which you'll shift (i.e. align) the other two images. Then select an image to shift. (You should see the background image through the slightly transparent foreground image.) Using the mouse keys and the i,j,k,l keys as prompted, align the two images and then hit the Okay button. Align the third image in the same way and hit Okay.
9. **Stack the images.** Under the **Process** menu, select **Stack / Convert Images to Stack**. You can flip through these images if you like, to see them individually.
10. **Create the final color image.** Under the **Process** menu, select **Stack / Convert Stack to RGB**. The program now merges the three red, green, and blue images to create the final image. Congratulations!
11. **Save the final image.** Make sure you save your final image and label the filename clearly.

Suggested challenges for color photographs

Orion Nebula	
<p>R.A. 5hr 35.4min Dec: -5° 27'</p> <p>Exposure: 30-60sec</p> <p>Best Visible: Oct-Mar from North America</p> <p>This big cloud of glowing gas is visible by eye in the constellation Orion. It's easy to tell where the stars are that are lighting up the nebula: they're right in the center of the cloud.</p>	
Trifid Nebula	
<p>R.A.: 18hr 02.3min Dec: -23° 02'</p> <p>Exposure: 60 sec</p> <p>Best Visible: April-Sept from North America</p> <p>This is one of the few nebulae where you can see THREE different color effects of gas and dust: fluorescing red hydrogen, blue reflection from dust particles, and dark black dust lanes. Also look for differently-colored stars! Telescopes further south get a better view of this nebula.</p>	
Eagle Nebula (M16)	
<p>R.A.: 18hr 18.8min Dec: -13° 47'</p> <p>Exposure: 60 sec</p> <p>Best Visible: Apr-Oct from North America</p>	
Swan Nebula (M17)	
<p>R.A. 18hr 20.8min Dec: -16° 11'</p> <p>Exposure: 60 sec</p> <p>Best Visible: April-Oct from North America</p> <p>If Orion is not up, try this nebula in color to see the red glow of hydrogen gas. The stars that are lighting up this star-birth nebula are hidden by the dust.</p>	

Middle of this Month	RA highest at midnight
Jan	07h
Feb	09
Mar	11
Apr	13
May	15
Jun	17
Jul	19
Aug	21
Sep	23
Oct	01
Nov	03
Dec	05

Find the current month in the table. The number at right shows the Right Ascension that will be highest at midnight.

A Right Ascension that is several hours less (or more) than this will be highest that many hours earlier (or later) in the evening.

Example: In March, a star with RA of 11 will be highest around midnight. A star with RA of 7 will be highest 4 hours before midnight, at 8 PM.

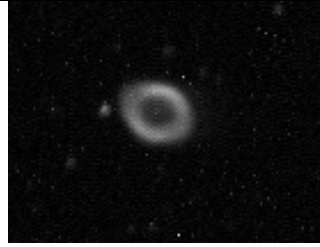
Ring Nebula (M57)

R.A. 18hr 53.5min **Dec:** 33° 02'

Exposure: 10-30 sec

Best Visible: Feb - Dec from North America

In the constellation Lyra. Expanding at about 12 miles per second, formed about 20,000 years ago.



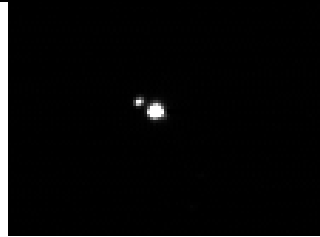
Albireo

R.A. 19hr 28.7 min **Dec:** 27° 52'

Exposure: 10-30 sec

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When seen through a telescope, the “tail” star of Cygnus the swan just lines up with a much more distant, dimmer star. One of these is quite red and the other much bluer. Can you tell which is which?



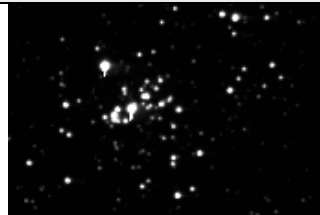
NGC 869

R.A. 2hr 8 min **Dec:** 57° 09'

Exposure: 30 sec

Best Visible: Year round from North America

This “open” cluster of stars is quite young – only 10 million years old or so— and is full of hot blue stars (and a few red giants as well). It is part of a double cluster of stars in the constellation Perseus that is quite visible with binoculars.



Pleiades (M45)

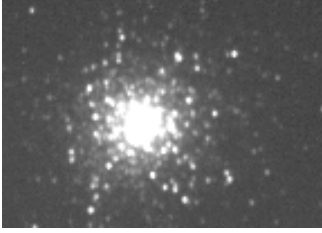

R.A. 03hr 47.4min **Dec:** 24° 07'

Exposure: 10-30 sec

Best Visible: July – Mar from North America

The bright stars of the Pleiades are noticeably bluish. If you overexpose your images, you may be able to just pick out the blue reflection off the dusty nebulae surrounding the brightest stars. The Pleiades stars are about 80-100 million years old.



Hercules cluster (M13)	
<p>R.A. 16hr 41.5 min Dec: 36° 28'</p> <p>Exposure: 10-30 sec</p> <p>Best Visible: July – Mar from North America</p> <p>Because all the stars in M13 are about 12 billion years old, it was selected in 1974 as target for one of the first radio messages addressed to possible extra-terrestrial intelligent races, and sent by the big radio telescope of the Arecibo Observatory.</p>	
Dumbbell nebula (M27)	
<p>R.A. 19hr 59.4 min Dec: 22° 42'</p> <p>Exposure: 30 sec</p> <p>The central star is extremely hot. The nebula is believed less than 2.5 light-years wide.</p>	

The Art of Science: A teachable moment

As students carry out this activity, they must make a decision that faces astronomers every day: whether and how much to "boost" the red, green, or blue images before combining them. The decision will affect the color of the final image. You might think that to get accurate color in the final image, each of the three component images should be processed in exactly the same way. However, the telescope's light-sensing chip is less sensitive to blue than to red light. Therefore the blue image will generally be fainter than the red and green images; it will need to be brightened during image processing, relative to the other images. Also, the three color filters do not pass equal amounts of light. This also will affect the accuracy of the color in the final image. Although it is not necessary to correct for these factors, students should be aware that the color of their final product may not be an accurate rendition of the scene. In fact, in much of astronomy, *there is no such thing as "true color,"* because the astronomer must make unavoidable and sometimes arbitrary choices about how to display the image.

Part 4. Reflecting on the results.

Have students record their responses to the following questions in their science journals.

Does the color of the object in your image tell you anything about the object? What?

The telescope's light sensor is not equally sensitive to red, green, and blue light. How might this affect the color of your final image?

When you added the three images together, did you boost the brightness of any of the images? If so, how did this affect the color image?

How closely do you think that your image captures "reality"—and why?

Suppose you have imaged a very faint object that no human has ever seen with the naked eye—because it is so faint. Do you think there is such a thing as how the object should look? How would you determine the best color balance, or the best image processing?

The telescope's light-sensing silicon chip is *most* sensitive to red light, and *least* sensitive to blue light. This means that reddish objects will appear comparatively brighter than bluish objects in your black-and-white images. And when you reconstruct the color scene, the final image will appear redder than the actual scene in nature.

You can compensate for this, if desired, by boosting the brightness of the image taken through the blue-passing filter. This can be done when image-processing, just before colorizing the three black-and-white images.

Astronomers try to learn as much as they can from the images they take. This does not always mean producing an image that most

closely resembles what you would see with your eyes. For example, by enhancing the contrast of a scene, you can bring out details of the image you might never have noticed if you produced the most natural-looking image. Scientists sometimes alter the color of their images for the same reason: to bring out details that might otherwise be missed.

The Art of Science

When trying to answer the question, “Is that what the scene *really* looks like?” it helps to keep in mind that most astronomical scenes are too faint to see by eye; therefore it may not make sense to ask what the scene *really* looks like. The most that a scientist can strive for is to be explicit about how s/he took the image; what changes s/he made in the brightness, contrast, and color balance; and why those changes were made. That honesty is a cornerstone of the ethic of science.