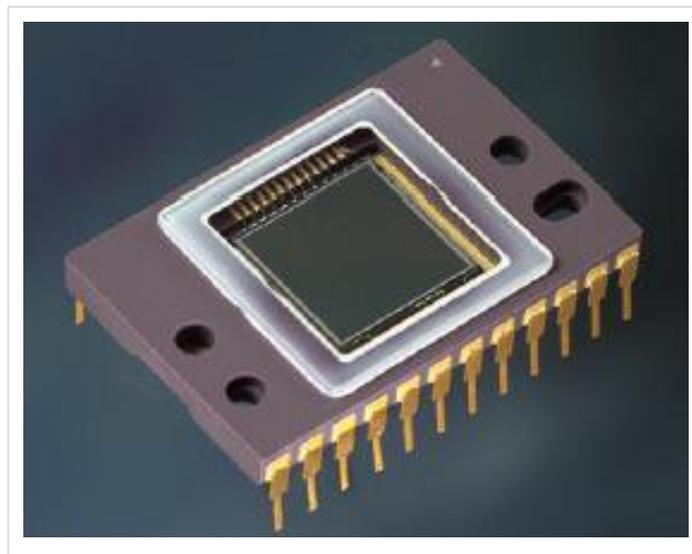


Use a CCD Camera

The Charged Coupled Device (or CCD) camera is a powerful tool for astronomers to acquire images with ultraviolet, visible, and infrared light. All the the images from the Hubble Space Telescope, for example, were taken with cameras based on this technology. Today, similar sensors are in your cell phone and laptop web cameras, but at the time they first appeared for scientific use in the 1980's they revolutionized optical astronomy. In this experiment you will use one that is on line in our elementary astronomy teaching laboratory. It is a smaller version of a camera that we use on our remotely operated telescopes. First, let's take a few minutes to describe what a CCD is, and how the images it takes make precision data available to astronomers. You may have already done an experiment that used such data, but now you'll take new images of your own.

The CCD

The CCD sensor is a piece of silicon (glass is mostly silicon dioxide, but this is nearly pure silicon) that has been processed to have an array of independent light sensitive elements. The one in the camera you are using is made by Eastman Kodak (yes, the company famous for film makes some of the best CCD's available).

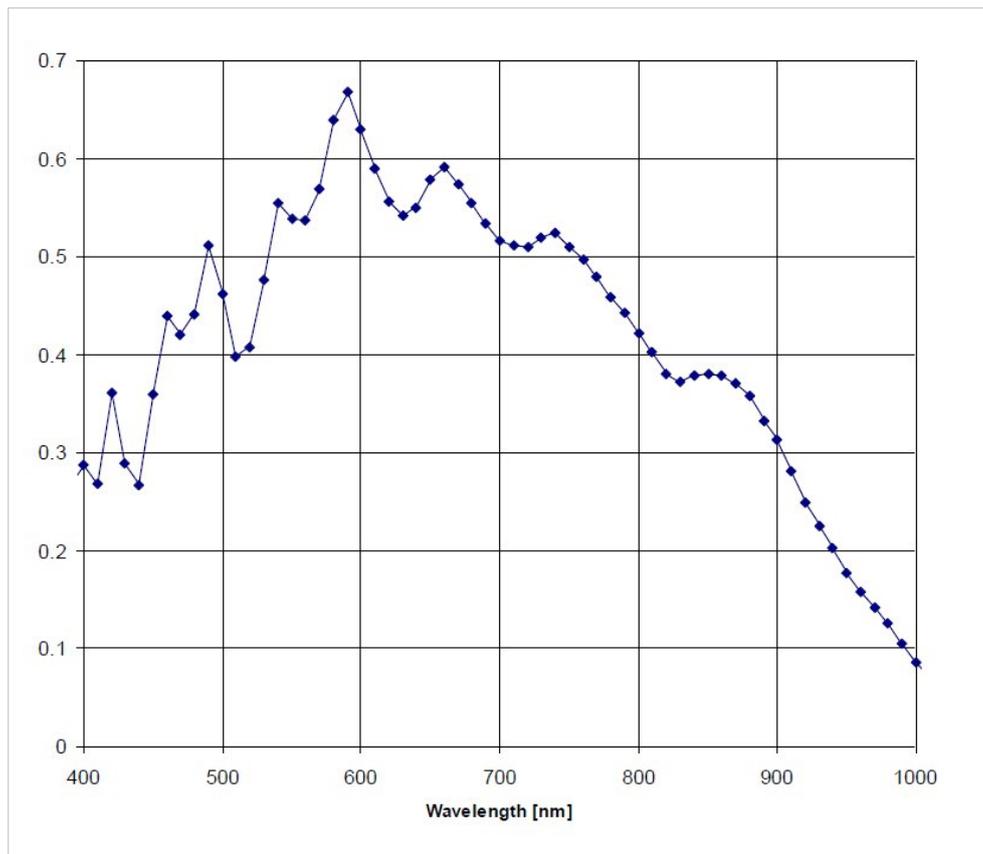


Kodak KAF-0261E CCD Image Sensor

The light sensitive area is the square about 1 cm on a side. It is under a protective glass cover, and attaches to the electronics of the camera through the gold-plated pins. In our camera, the sensor is cooled to -10 C with an electrical "Peltier" refrigerator that is in contact with it from the back.

This device has 512x512 square pixels in that sensitive area -- each 20 millionths of a meter (20 microns) across. When a photon (a light particle) arrives near one of these, there is about a 50% chance that it will excite an electron that will be trapped in the pixel. After an exposure, we measure how many electrons are in each one, and that tells us how much light arrived at each pixel during the exposure. The name "charge coupled" comes from the technology that moves this charge across a row and then down an edge of the sensor to the amplifier that produces the signal we measure. The result is a number for each pixel that is proportional to how many photons arrived there during the exposure.

The sensor is not equally sensitive to all light. CCD's based on silicon are most sensitive to red light. Here's a graph that shows how this varies from the ultraviolet (below 400 nanometers (nm) to the infrared (above 700 nm).



Response of the Kodak CCD to light from the blue (400 nm) to the infrared (above 700 nm)

Although it is not uniform, we can measure this very accurately and calibrate the sensor so that we can compare the amount of light arriving in different colors.

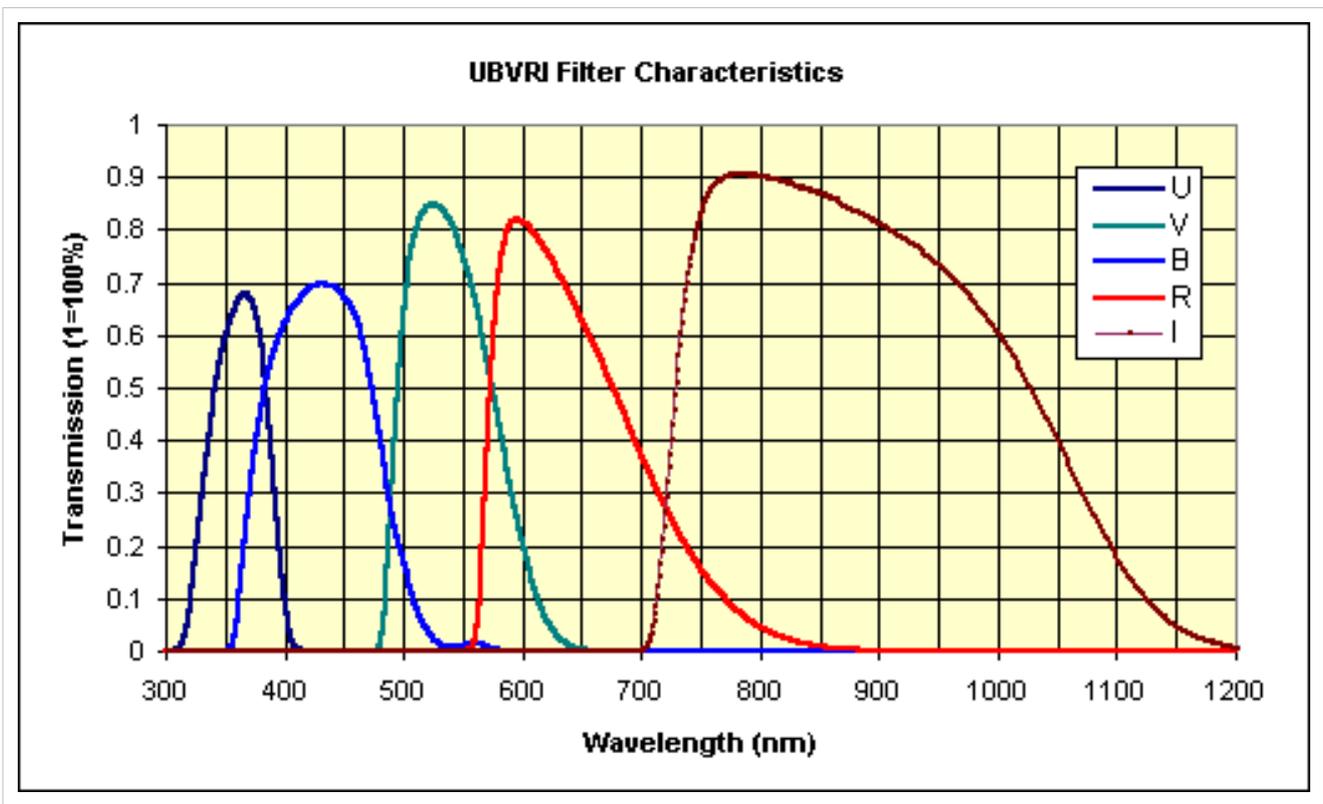
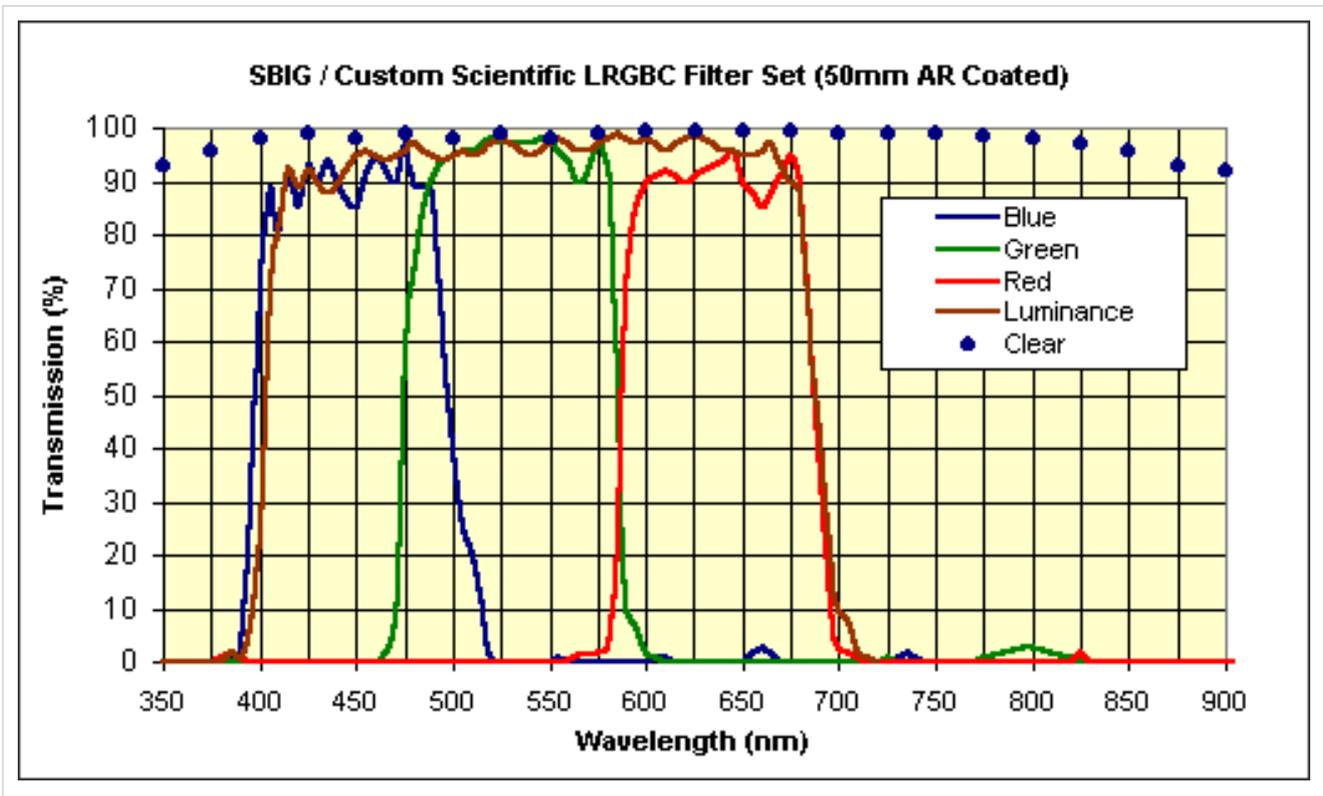
Filters

If we can measure how much light comes from a star or planet for different wavelengths, we can determine its temperature, composition, and even its speed. Your eye senses different wavelengths as color. For example, here's a spectrum of the Sun.



The dark lines are from elements in the Sun's atmosphere that absorb specific wavelengths of light. Calcium, for example, has removed some ultraviolet light at two wavelengths near 380 nm on the left, sodium has removed some in the yellow at 589 nm near the center, and hydrogen made the dark line in the red at 656 nm on the right. The blackness toward the far right is infrared, to which our eyes are not sensitive but the CCD camera can measure.

We use filters to isolate broad bands of different colors. In this experiment we have two sets of filters available that selectively transmit light in regions from the ultraviolet to the infrared.



The upper set is labeled RGBCL for red, green, blue, clear and luminosity. These are usually used to make images in color similar to what you would see with your eyes. "Clear" means that it transmits almost all light, and "luminosity" means that it transmits almost all visible light but rejects the infrared.

The lower set is labeled UBVRI for ultraviolet, blue, visible, red, and infrared. These are the filters that astronomers use to measure the characteristics of stars in a system of standard bands. The choice of bands is largely historical, and goes back to the sensitivity of photographic materials when measurements of this type were first done. There are other systems in use now that are more efficient, and we use those with our telescopes. However for this experiment you will have a choice of any one of the 10 filters in these curves. Choose the R filter from the RGB set and you will get image that shows only red light, while the G filter shows only green, and the B filter only blue. You can put these back together and make a full color image, or compare them quantitatively to see how much redder one part of the image is than another. The UBVRI set extends this into the infrared and the ultraviolet, while the visible B, V, and R filters are somewhat different from those in the RGB set.

Now let's see how this actually works!

Using the Camera

To access the camera you must go to this website. If you click on this link it should open up another browser window so that you can see both this page of instructions and the camera control:

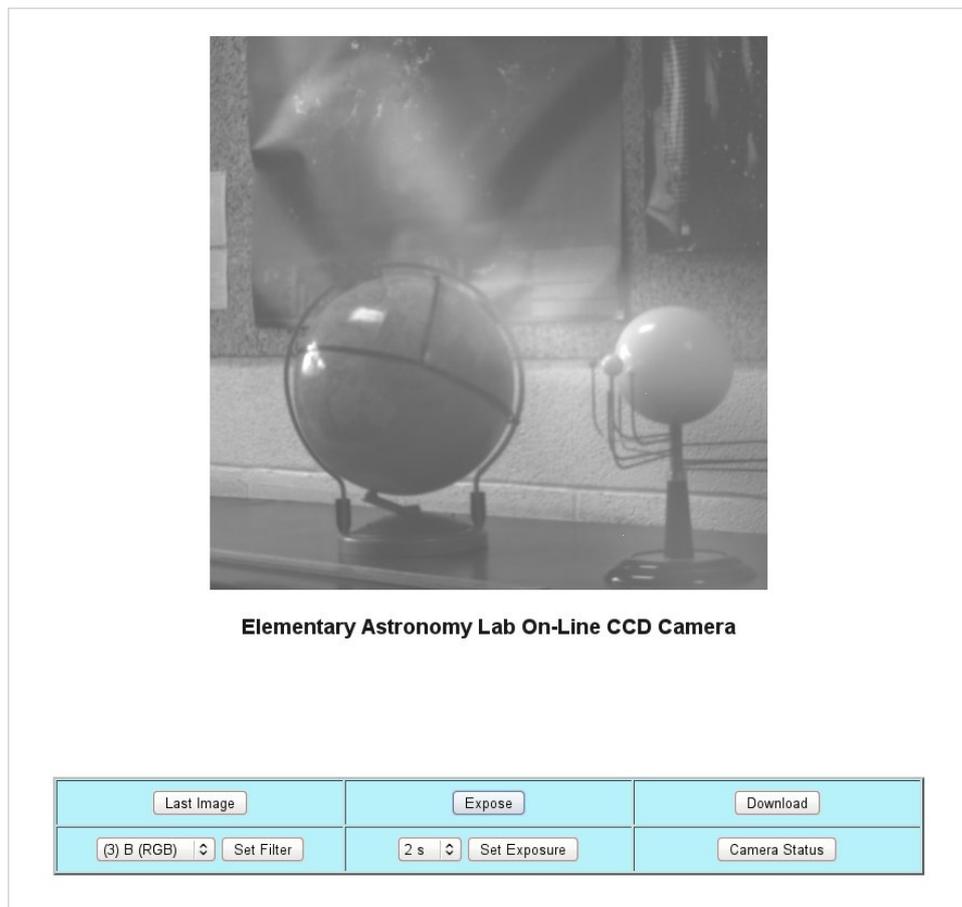
<http://prancer.physics.louisville.edu/remote/ccd> ^[1]

This site requires a user name and a password, and you should enter:

- User: astrolab
- Password: jupiter

in lower case.

If you are successful, you may see something that looks like this:



The image you see at first may be one taken earlier by another user. The buttons will control the camera, take an image, and allow you to copy the image to your own computer:

- Last Image -- displays the most recent image taken
- Expose -- takes an exposure with the current settings and displays the new image
- Download -- shows you a list of image available. To retrieve one, right click and "Save as ..."
- Set Filter -- sets the filter choice that is shown in the thumbwheel box to its left. Select the filter you want, then click "Set Filter" for this to take effect.
- Set Exposure -- sets the exposure time that is shown in the thumbwheel box to its left. Select the exposure you want, then click "Set Exposure" for this to take effect.
- Camera Status -- will display the coordinated universal time (the time on the prime meridian in Great Britain), the filter number, and the exposure time in seconds.

The camera should already be turned on and pointed at a globe of the Earth and a model of the solar system in our elementary astronomy teaching laboratory on Belknap Campus of the University of Louisville. If you are actually in this lab you can see the camera and its target but you will use the same web interface that students in the distance education section use.

You are going to take three images with three different filters and save those images to your own computer for analysis later.

Take and Save Three Images

You can change the exposure time and the filter. Pick an exposure time that is long enough to see something interesting, and not so long that everything is "saturated". That is, if the time is too long then the detector has so much charge it cannot make a measurement and the image is pure white. If it is too short, there are not enough photons for an accurate measurement and the image will look grainy, or even black. Use one exposure time for all the filters.

Pick three filters in order to get an image at short wavelengths (either of the "B" blue filters), in the middle of the spectrum (the "G" green filter of the "V" filter), and the red (either of the "R" filters). Also take an image in the infrared (I) to see how different it is from visible light.

After you take each image click on "Download" and save the last "fits" file and the last "jpg" file. The file names have unique numbers that record the time the image was taken. The largest number is the most recent image. Make a note for yourself of which image is with which filter. The information is stored in the "fits" images but not easily retrieved without special software.

Once you have those images you are finished with the on line camera. You may find that your use and other students use will overlap. We're working on ways to keep this from happening, but in the meantime just be aware that someone else may be taking pictures too.

Analyze your Images and Answer these Questions

First, put the three or more images in one location and sort them so that you have a red image, a green image, and a blue image. If you took and saved others, you can use them too but for now it is these three that you need. The jpg images are useful for a quick look, but they do not have quantitative values for the light at each pixel because they are compressed in software to a small file size. You need the "fits" images. These will be the same type that we use for the other experiments and you may already have some experience with them. We will follow the same instructions that you used before with ImageJ.

Let's assume you have ImageJ on your own computer. If not, then here is how you can get it:

ImageJ on your own computer^[2]

or if you cannot install software (you are at a library or work, for example) you can run a version from our server in your browser:

Run ImageJ on our server^[3]

If you choose the second option you can kill the sample images that appear. Select File -> Open and load in order the red, green, and blue fits images. It's important that you use the fits images and not the jpg images. Notice that as you move the cursor over an image the ImageJ control panel will tell you the pixel coordinates (x,y) and the amount of light at each pixel.

Look at the Sun in the model solar system. It will be on the right side of the image, below center:

1. What is the diameter of the Sun in pixels in one of these images? Simply move the cursor across the image and take the difference in x going from one side of the Sun to the other.

If this were something in the sky and you know the calibration of angle to pixel you could find the angular size of the object this way.

Put the cursor as best you can tell at the midpoint in x and y on the image of the Sun. All the images will have the same coordinates because they are all taken of the same thing with the camera fixed. Only the filter changed between exposures.

2. Where is the center of the Sun on these images? Give x and y for this pixel.

For each of the three images in sequence, note the value of the signal at pixel near the center of the Sun. This is a measure of how much light you have in the image at that point.

3. How much signal is there at the center of the Sun in the red image?

4. In the green image?

5. In the blue image?

These differences suggest that that model Sun is not white, but what color is it? The CCD responds differently to different wavelengths, and each filter has a different efficiency too. We might be able to sort this out if we knew something in the image was white.

Let's make a color image from these and see what that looks like. Here's how we did that before:

- Images -> Stack -> Images to Stack -> OK
- Image -> Color -> Make composite

If you follow this without changing the images and used the same exposure time for all three, the color image you get will not look right. However, you can see that there are colors in the field of view, and you can see the color of the Sun!

6. Overall, what color seems to dominate this composite? Does it look too red, too green, too blue, or does it seem reasonably good?

You may recall from an earlier experiment that the slider at the bottom of the ImageJ composite image selects the image being measured. On the left it is red, in the middle it is green, and on the right it is blue. There is also a "Channels" window open now that allows you to select which ones contribute to the image you see. Leave that window in "Composite" mode with all the images selected.

Open the Image-> Adjust -> Color balance window. This allows you to change the display of the image on the screen. That is, you pick a part of the image data in each color that sets the screen's red, green, and blue display. The best way to see the effect is just to experiment with it. There are three sliders, a channel selector, and buttons like "set" and "reset". The channels are the colors (1 is red, 2 is green, 3 is blue).

Minimum -- sets the lowest value in the image for that color that becomes black on the screen

Maximum -- sets the highest value in the image for that color that becomes as bright as possible, e.g. bright red, green or blue.

Brightness -- moves the minimum and maximum selections across the range of values available

Try adjusting these for the red, green and blue images to make something you think represents the field that was recorded. It may help to look at things in the field that you think should be white.

7. *What color is the Sun now?*

Compare your image now with the measurements of individual colors you made earlier.

8. *Which of the filters gave the strongest signal on the Sun? Explain how the Sun's apparent color compares to the signals in the different filters.*

There are some other things you may notice now. The Earth globe, for example, shows oceans and land masses. If you have the color balance about right the oceans will be light blue. The planets in the solar system model have different colors too. One of them is white.

9. *What is the diameter in pixels of the white planet?*

If you want to save the color image you can make a jpg from the composite:

Images->Stacks->Stack to RGB

will make a single image from the composite stack of three images. Follow this with File->Save as->Jpeg and give it a name of your choosing.

Lastly, open the infrared image that you took. You can compare it to others, or even make a composite in which infrared becomes red on the screen, the red filter becomes, green, the green filter becomes blue ... use your imagination and see how colors can be used to distinguish things of interest.

10. *What did you find in the field of view that is brighter in the infrared than it is in the visible?*

References

[1] <http://prancer.physics.louisville.edu/remote/ccd>

[2] http://prancer.physics.louisville.edu/classes/108/topics/imagej_image_processing/

[3] http://prancer.physics.louisville.edu/classes/108/topics/imagej_image_processing/start_imagej.html

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