Image Processing in Astronomy

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Summary

In this project, you will use the *JS9* web-based software to display and process astronomical images, creating full-color pictures from a set of three black-and-white images.

Introduction to Nebulas

A "planetary nebula" is a cloud of gas in space that is shed by an aged star, casting it off like an insect molting from an old shell. The term "planetary" refers to the fact that these clouds are often round and look like planets when seen through a small telescope. The ultraviolet light of the hot star illuminates the gas cloud, zapping the electrons in the gas and giving them energy. The electrons eventually fall back down onto their atoms, losing that energy and emitting different colors of light as they do. The colors they produce are distinctive of the atoms making up the gas.

The Ring Nebula, pictured below, is a classic example of a planetary nebula:

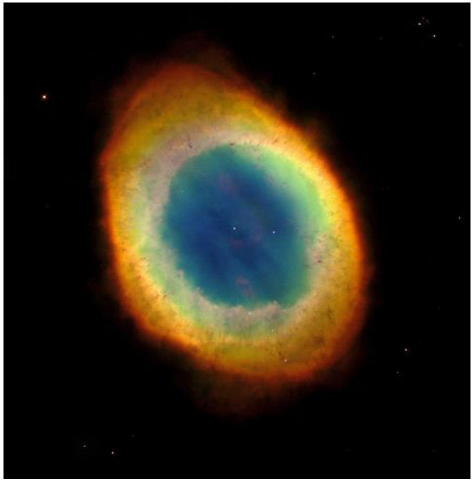
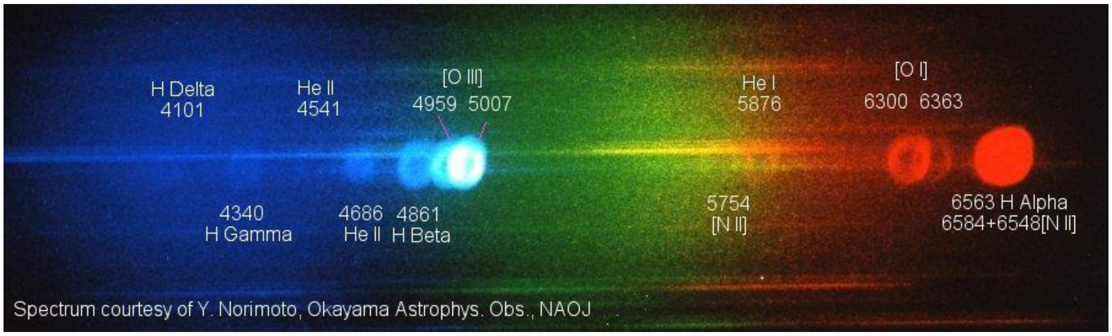


Figure 1—The Ring Nebula

If we shine the light of the Ring Nebula through a prism, we would see something like this:



Spectrum courtesy of Y. Norimoto, Okayama Astrophys. Obs., NAOJ

Figure 2—Spectrum of the Ring Nebula

We see an image of the nebula for every distinct color of light it emits, and this is called the nebula's *spectrum*. This spectrum is labeled with the elements producing each color. H stands for hydrogen, He for helium, O for oxygen, and N for nitrogen. The Greek letters and Roman numerals tell us more details about the atom or how far the electron is falling as it emits the light.

The Arabic numerals next to each color tell us the *wavelength* of the light. Light travels as a wave, vibrating as it moves. The distance between two peaks of the wave is called the wavelength, and the wavelength tells us the color of the light wave. As you can see from Figure 2 above, short wavelengths are bluer, while long wavelengths are redder. We usually measure the wavelength of visible light in nanometers (nm, 10^{-9} meters), as we do in Figure 4, or Ångstroms (Å, 10^{-10} meters), as we do in Figure 2.[*]

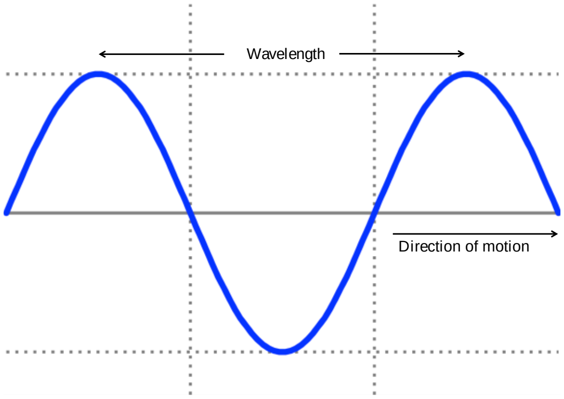


Figure 3—Light travels as a wave.

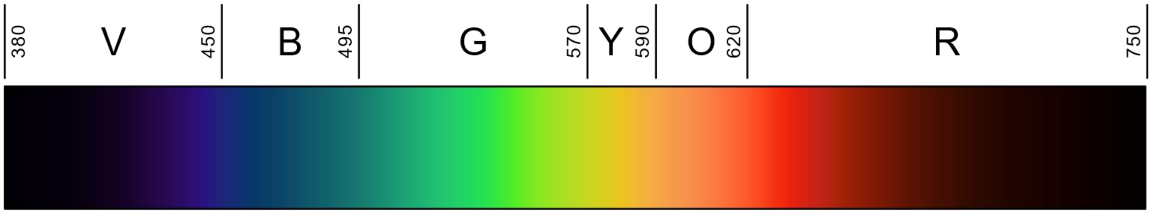


Figure 4—The spectrum of visible light. The numbers give the wavelength in nm. The letters refer to the colors: Violet, Blue, Green, Yellow, Orange, and Red.

Taking Pictures

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[*] Note that this means 1 nm = 10 Å. A typical wavelength for blue light is roughly 475 nm or 4750 Å. For green to yellow, 550 nm or 5500 Å. For red, 650 nm or 6500 Å.

Astronomical pictures, which we'll consistently call “images,” are handled somewhat differently from the kind you take with your phone camera. The technology to create them is actually pretty similar—both use a Charge-Coupled Device (CCD)[†] chip in the camera to detect the incoming light and convert it into a digital image. Light strikes the pixels in the chip, this allows electrons to flow, and these are detected by the CCD’s circuits. The brighter the light on a given pixel, the more electrons it produces, and the stronger the signal the electronics record.

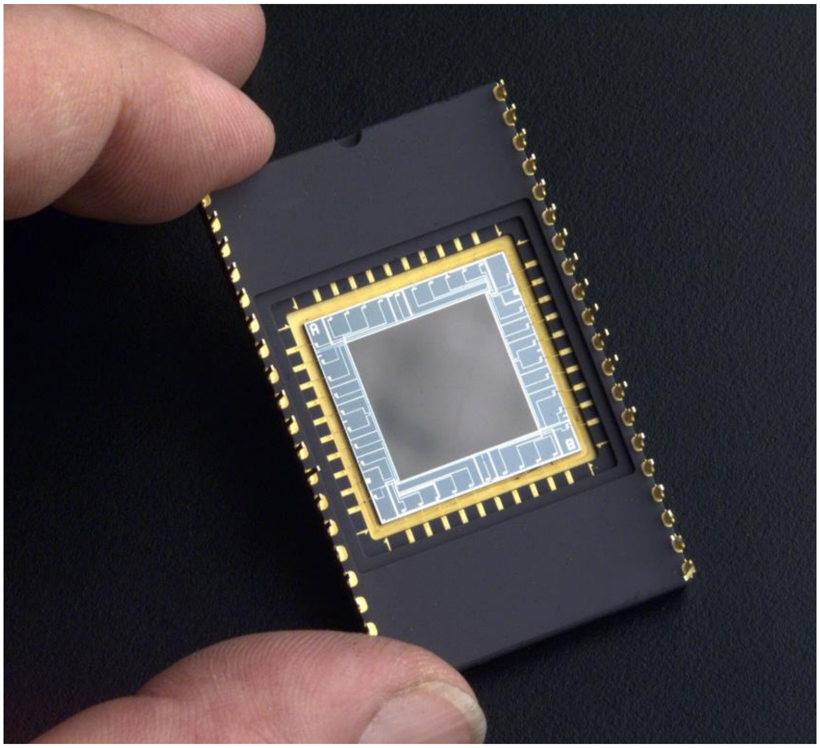


Figure 5—A CCD chip. The microscopic pixels are in the gray square at the center.

But while your phone camera takes color pictures, astronomical cameras are all black-and-white. To make a color image, we must take three pictures, each with a different color filter in front of the camera, and then we combine them with special software.

For normal photography, we would use a red filter, a green filter, and a blue filter—each one corresponding to a different primary color for light. These “wide-band” filters let through a wide range of wavelengths. For example, the standard blue filter lets in light from 398 nm to 492 nm, a range of 94 nm (or 940 Å). If we’re looking at a galaxy and trying to show where its stars lie, then these are good filters to use. They give us bright images because they let through a lot of light.

When we are looking at a nebula, it is helpful instead to use “narrow-band” filters that let through only the specific wavelengths of light the nebula emits. This way, we can have one image with just the hydrogen emission, one with just the oxygen, and so on. For example, the *Hubble Space Telescope’s* hydrogen filter lets through light from 652

[†] There are other kinds of chips used as well, such as CMOS (Complementary Metal Oxide Semiconductor) and MAMA (Multi-Anode Microchannel Array), but the basic ideas are similar.

nm to 665 nm, a range of only 13 nm (130 Å). By comparing the pictures taken with the different narrow-band filters, we can see differences in, say, the temperature and density of different parts of the nebula.

Picture Formats

Most of the digital pictures you've seen have been in the JPEG format[‡], which is a way of compressing the data in the image into a compact file. But this image compression distorts the image in a way that would be unacceptable for the precise and accurate needs we have in astronomy. Instead, we use the FITS file format, which stands for "Flexible Image Transport System." FITS files have some important advantages: (1) They do not have any loss of data, (2) they let us store useful information about the image as comments in what's called the file "header," and (3) they can store the image's location in a coordinate system, so that the image viewing software knows where in the sky this picture is supposed to be.[§]

But to use FITS files requires special software. The most popular one with astronomers was created by the Smithsonian Astrophysical Observatory (SAO) and was originally called SAO Image. The second version of SAO Image was called SAO The Next Generation (SAOTNG)...and the logo had the *Star Trek: The Next Generation* badge shape (hah, hah). The latest version is called DS9, which stands for...well, Deep Space 9. (Yes, a *Star Trek* series, again.)

DS9 is a powerful tool, but it's got so many options that it may be a little tricky for you to set up just for this project. Instead, we're going to use a simplified Java-language version of DS9 that runs in your web browser, called (appropriately enough) JS9. You can find JS9 at this address:

`waps.cfa.harvard.edu/eduportal/js9/software.php`

Tutorial

Watch the video tutorial accompanying this project, while you keep the JS9 page open in a second window. Follow along with the tutorial yourself, pausing as necessary to try out the techniques I show you.

A Tour of the JS9 Display

[‡] JPEG stands for Joint Photographic Experts Group, which is the organization that created the format.

[§] Just as we use longitude and latitude as coordinates to locate a place on the Earth, astronomers use Right Ascension (RA) and Declination (Dec) as coordinates to locate an object in the sky. We won't need to worry about those for this project.

The page opens with the following appearance, except that you might not see an image displayed in the middle, yet.

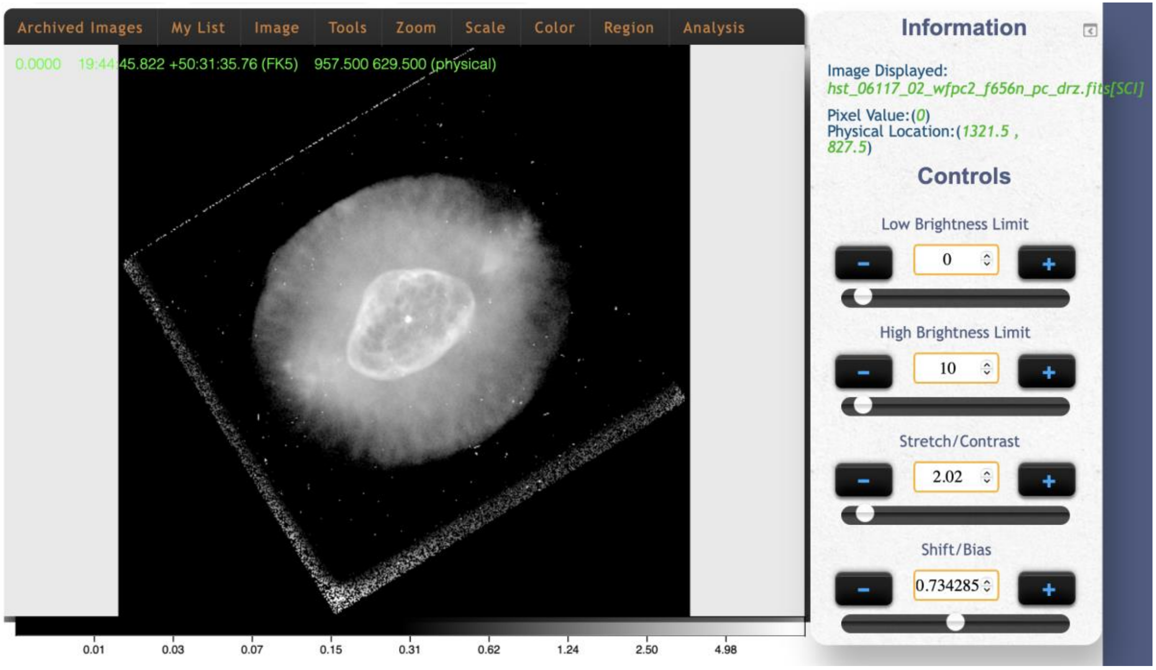


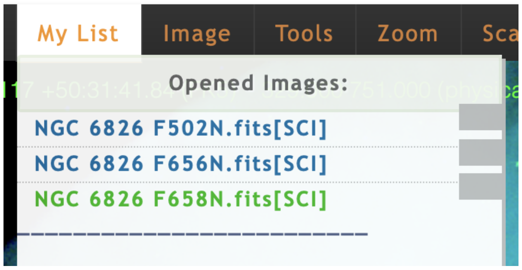
Image Displayed: hst_06117_02_wfpc2_f656n_pc_drz.fits[SCI]
Pixel Value:(0)
Physical Location:(1321.5 , 827.5)

Low Brightness Limit: 0
High Brightness Limit: 10
Stretch/Contrast: 2.02
Shift/Bias: 0.734285

Figure 6—JS9 screen

Let's go through the menus we're actually going to use, from left to right across the top of the frame:

1. *My List*—This shows the list of images you've loaded into the program.

   NGC 6826 F502N.fits[SCI]
   NGC 6826 F656N.fits[SCI]
   NGC 6826 F658N.fits[SCI]

   Click on an image filename to select and display it. The image currently displayed is highlighted in green.

   Click on the gray rectangle at the right to remove an image from the program.

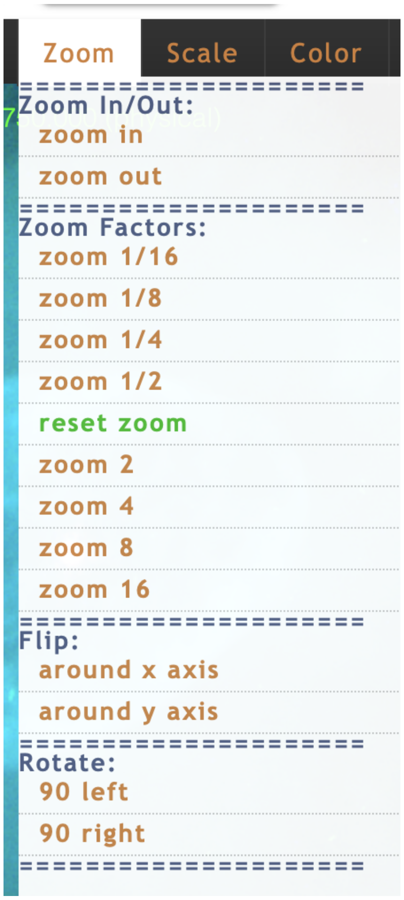
2. *Image*—This lets you load images from your computer into the program.

   Select "open" to load a FITS file from your computer.

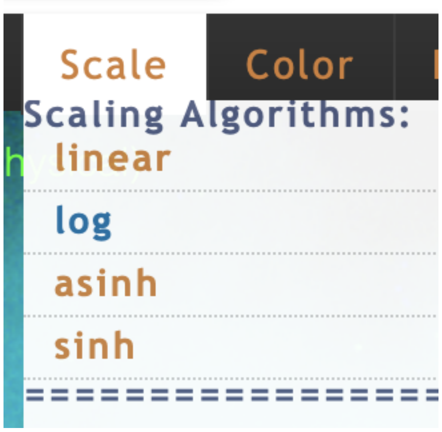
   When you are finished creating the full-color image, select "Save as JPEG" to save the finished version on your computer.

3. *Zoom*—This lets you zoom in and out.



I think the zoom options are pretty self-explanatory.

4. *Scale*—This adjusts how the image brightness is scaled.



Linear means that if one pixel has double the amount of light as a second pixel, the first pixel will be displayed as twice as bright on the screen. This is the default, but it's not as useful to us.

Log uses the logarithm function to reduce the difference between very bright and very faint parts of the image. This imitates how our eyes work and it improves the "dynamic range" of the picture.

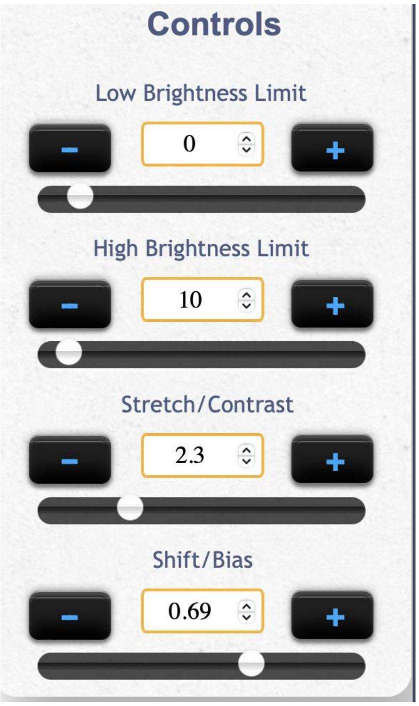
5. *Color*—This selects the colors to assign to each black & white image.

The default is grey, which gives you a black & white image. The idea of the “colormap” is that you can assign a color for any brightness level in a pixel. For example, if we use one of the “rainbow” colormaps, the darkest pixels would be blue, medium brightness would show up as yellow, and the brightest would be red. So instead of seeing shades of gray, we would see different colors. This so-called “false color” method is useful for distinguishing between brightness levels.

We will wind up using the red, green, and blue colormaps in this project, giving us three primary colors that will combine to form a full-color image.

When we are ready to display all three primary colors together, we’ll select the *RGB mode* (second line from the top) to show the full-color image.

The image control panel is shown in Figure 7. This lets us adjust the appearance of the image. We can set the high and low brightness limits for the pixels, the contrast (also called the stretch), and the shift (also called the bias).



Low Brightness Limit: 0

High Brightness Limit: 10

Stretch/Contrast: 2.3

Shift/Bias: 0.69

Figure 7—Image controls.

The high and low brightness limits let us make best use of the limited range of grayscale that the computer can display. We don’t have to display all of the possible brightnesses of the pixels in the image. For example, a bright star can be thousands of times brighter than the galaxy or nebula we’re actually interested in, so we can set the upper limit to a value that’s appropriate for that nebula and not worry that the star will look slightly washed out. This way, we avoid the nebula looking too dark by comparison. Any pixel fainter than the Low Brightness Limit will be displayed as solid black, and any pixel brighter than the High Brightness Limit will be displayed as pure white.

Contrast lets us adjust how quickly we run through those shades of gray in going from one brightness level to another. Shift will make the overall brightness of the image higher or lower. It's best to play around with both of these to learn how they work in practice.

Note that once you have an image loaded, you can adjust contrast and shift quickly and intuitively by clicking in the display window and dragging your cursor. Up/down adjusts the contrast, while left/right adjusts the shift.

Working With Images

For each space object in the project, you will have three black & white images. The first thing to do is to download them from the project's website onto your computer. I recommend making a separate folder for each object, so you don't get the images for one mixed up with those for another.

Once you have all of the FITS files on your computer you need to load them into JS9. Go to the *Image* menu, select *Open*, and find the images in the file selector. Choose one at a time, and keep going back until all three images for that object are loaded into JS9.

Go to the *My List* menu to see that they are all there. If you have any other files loaded in that you're not working on now (from another object in space), you can click on the gray box beside their name to delete them. Then click on the filename of the top image of your object to display it in the window.

You may see only a black or gray screen. The first thing you need to do is to get the image to show up *somehow*, even if it doesn't look pretty. First, go to the *Scale* menu and select *Log* scaling. This will give you a broader range of brightness displayed.

Next, let's set the *Low Brightness Limit* and the *High Brightness Limit*. Set *Low Brightness Limit* to 0. This means that we'll be able to see shades of gray all the way down to the faintest possible pixel. To find out where to set the high limit, move your cursor back and forth slowly over the picture and look at how the pixel value changes.

Image Displayed: NGC 6826 F658N.fits[SCI]

Pixel Value: (2.2278590202331543)

Physical Location:(501 , 519)

Figure 8—The Information Panel

Look at the *Information* panel in the upper right (Figure 7). It tells you the image name you are working on, the brightness of the pixel underneath your cursor (*Pixel Value*), and the *x* and *y* coordinates of the pixel underneath your cursor—

Physical Location, displayed as (*x, y*).

For the brightness, the larger the number, the brighter the pixel. The number is proportional to the number of photons (particles of light) that hit that pixel.

Look for the brightest typical values for pixels in the screen (except for stars—we don't worry about them) and then round up to set the High Brightness Limit. For example, in one nebula, I found the brightest areas had pixel values around 5-6, so I entered a High Brightness Limit of 10. It's not critical to get a number that's *exactly* right here, as long as you don't make it too low and wash out the detail of the brightest regions. Going a little higher than you need will be fine.

Finally, adjust the contrast and shift so that you can see the details of the nebula from the faint regions to the bright regions (don't worry about any stars). If the bright areas are washed out, adjust things until you can see details within them. The same goes for the dim areas, if they are too dark.

Now go to the second image under My List, set its Scale to Log, and adjust its High and Low Brightness Limits, its Contrast and Bias to match the values you had for the first image. Repeat these steps again with the third and final image.

Making a Full-Color Image

Now that you have all three of the images loaded for this object, and you've got something you can see in all of them, we'll go about making a full-color picture out of them.

Look at the three image filenames and find the wavelength of each filter. Remember that Hubble Space Telescope filter names look like this:

F502N
F650W

- *F* stands for *Filter*.
- The number in the middle tells you the wavelength of the light let in by the filter, in nm. (Recall that 1 nm = 10^{-9} meter.)
- *N* stands for *Narrow-band*, which lets in only a narrow range of wavelengths.
- *W* stands for *Wide-band*, which lets in a wide range of wavelengths.

Here is a complete list of the filters used in this project:

2. F502N—This isolates the 502-nm emission line of oxygen.
3. F656N—Isolates the 656-nm emission line of hydrogen, $H\alpha$ (pronounced "H alpha").

4. F658N—Isolates a combination of Hα and sulfur at 658 nm.
5. F673N—Isolates the 673-nm emission line of sulfur.

Find the longest wavelength filter for this nebula (that is, the largest number in the three filter names). Select that image by clicking on the filename. Assign it the red color. That is, go to the *Color* menu and select *Red*.

Find the middle wavelength filter. Select it and assign it the green color from the *Color* menu.

Find the shortest wavelength filter (the one with the smallest number). Select it and assign it the blue color.

Now go back to the *Color* menu and select *RGB mode* (second line down). This will let all three colors be displayed at once, blending together to make a full-color image.

Check to see if any of the colors are washed out or too dark to see at all. If so, go to the *My List* menu and select the image used for that color, and change its contrast and bias until it looks better. Note the numbers you've adjusted those to, switch to the two other images in turn, and set their contrast and bias to match it. You may need to take this process through several rounds to get them all looking acceptable at the same time.

Check that you have the entire nebula or galaxy shown by adjusting the *Zoom*.

Once you are satisfied, save your result as a JPEG (the normal image format file you get from the internet or your phone camera) by going to the *Image* menu and selecting *Save as JPEG.*

Now start over with the next nebula you'll work on.

Nebulae from the Hubble Space Telescope

For each of the following nebulae, download the three image files from the website and save them in a folder on your computer.

The files are compressed in "zip" format (ending in `.zip`), and you will need to "unzip" them before they can be used. Double-click on them, and they will be replaced with filenames ending in `.fits`. This is the only format that can be used. To load the FITS files into JS9, put your cursor over the Image tab and select Open.

1. **Eagle Nebula.** There are three files corresponding to three filters, named according to wavelength:

   a. `Eagle F502N`
   b. `Eagle F656N`
   c. `Eagle F673N`

The Eagle Nebula has long pillars of dust with a stellar nursery. The stars are inside tight knots of dust in a kind of cocoon, which they will shed once the nuclear fusion reaction in their cores gets going. Be sure to zoom out to show the entire nebula. Rotate each image 90° to the right (look under the Tools tab) to have the three pillars pointing up, which is the way most of us are used to seeing it. These images were taken using the Hubble's Wide-Field Planetary Camera 2 (WFPC2), which has an odd "batwing" shape to its images, formed by the use of four CCD detectors in the form of three large squares and one small one.

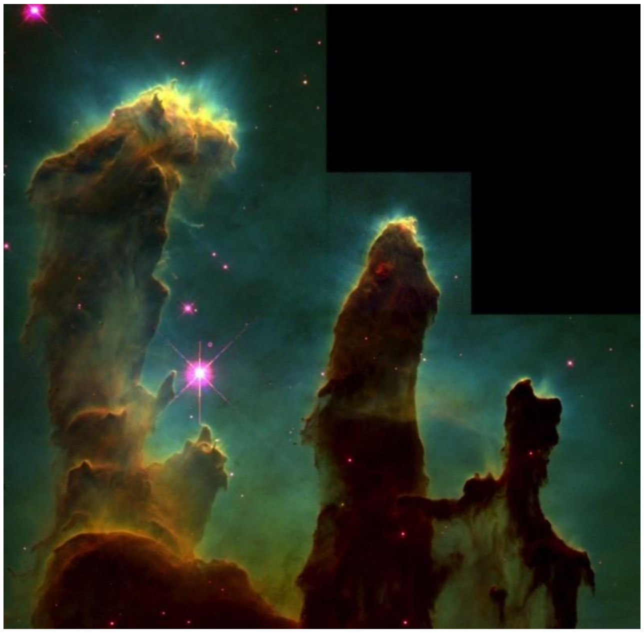


Figure 9—The Eagle Nebula. Hubble Space Telescope Image.

6. **NGC 6826.**
   a. `NGC 6826 F502N`
   b. `NGC 6826 F656N`
   c. `NGC 6826 F658N`

This nebula is a planetary nebula found 2,200 light years away in the constellation Cygnus. Planetary nebulae form after the death of a low-mass star like our Sun, and they show the bubble of hot gas ejected from the white dwarf star, seen in the center.

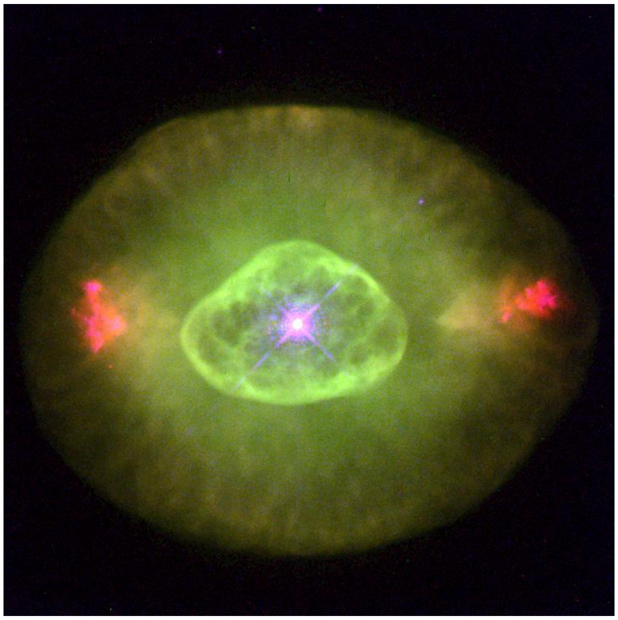


Figure 10—NGC 6826. Hubble Space Telescope image.

7. **NGC 6881.**
    a. `NGC 6881 F502N.` This uses the F502N filter, which isolates the 502-nm emission line of oxygen.
    b. `NGC 6881 F656N.` This uses the F656N filter, which isolates the 656-nm emission line of hydrogen (Hα).
    c. `NGC 6881 F658N.` This uses the F658N filter, which isolates the combination of Hα and sulfur at 658 nm.

NGC 6881 is another protoplanetary nebula, like NGC 6826.

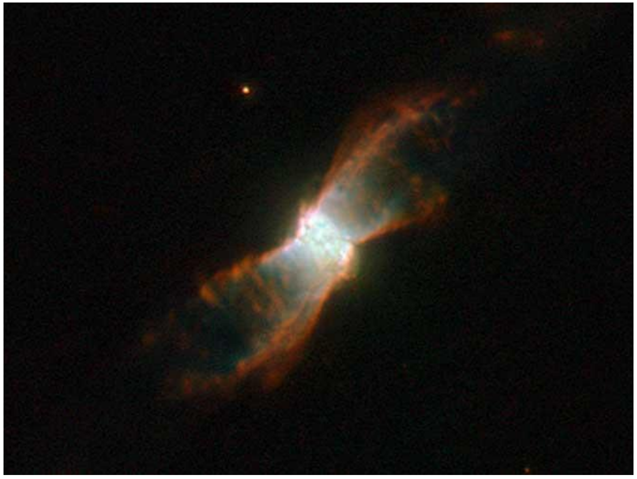


Figure 11—NGC 6881. Hubble Space Telescope image.

6. The Saturn Nebula, NGC 7009.
    a. `NGC 7009 F502N`
    b. `NGC 7009 F656N`

c. `NGC 7009 F658N`

The Saturn Nebula is another protoplanetary nebula, and it gets its name from the broad line sticking out its sides, kind of like the rings of Saturn.

Figure 12—The Saturn Nebula, NGC 7009. Hubble Space Telescope image.

What to turn in

For each of the nebulae, decide which filter to assign to red, green, and blue. You should keep them in order of wavelength; that is, the shortest wavelength color should correspond to the shortest wavelength filter, and so on. Record your settings in the Lab Report Form. Save the completed color picture as a JPEG, and title it with the name of the nebula.

Fill out the lab report form, and print out the color pictures for each of the nebulae.

Image Processing with JS9 Lab Report

Name ___________________________

NGC 6826 Nebula

Color Assignments (red/green/blue)

Filter Color

F502N _______

F656N _______

F658N _______

High Brightness Limit _______

Scale _______

Contrast _______

Bias _______

The Saturn Nebula, NGC 7009

Color Assignments (red/green/blue)

Filter Color

F502N _______

F656N _______

F658N _______

High Brightness Limit _______

Scale _______

Contrast _______

Bias _______

Eagle Nebula

Color Assignments (red/green/blue)

Filter	Color
F502N	_______
F656N	_______
F673N	_______

High Brightness Limit _______

Scale _______

Contrast _______

Bias _______

NGC 6881 Nebula

Color Assignments (red/green/blue)

Filter	Color
F502N	_______
F656N	_______
F658N	_______

High Brightness Limit _______

Scale _______

Contrast _______

Bias _______