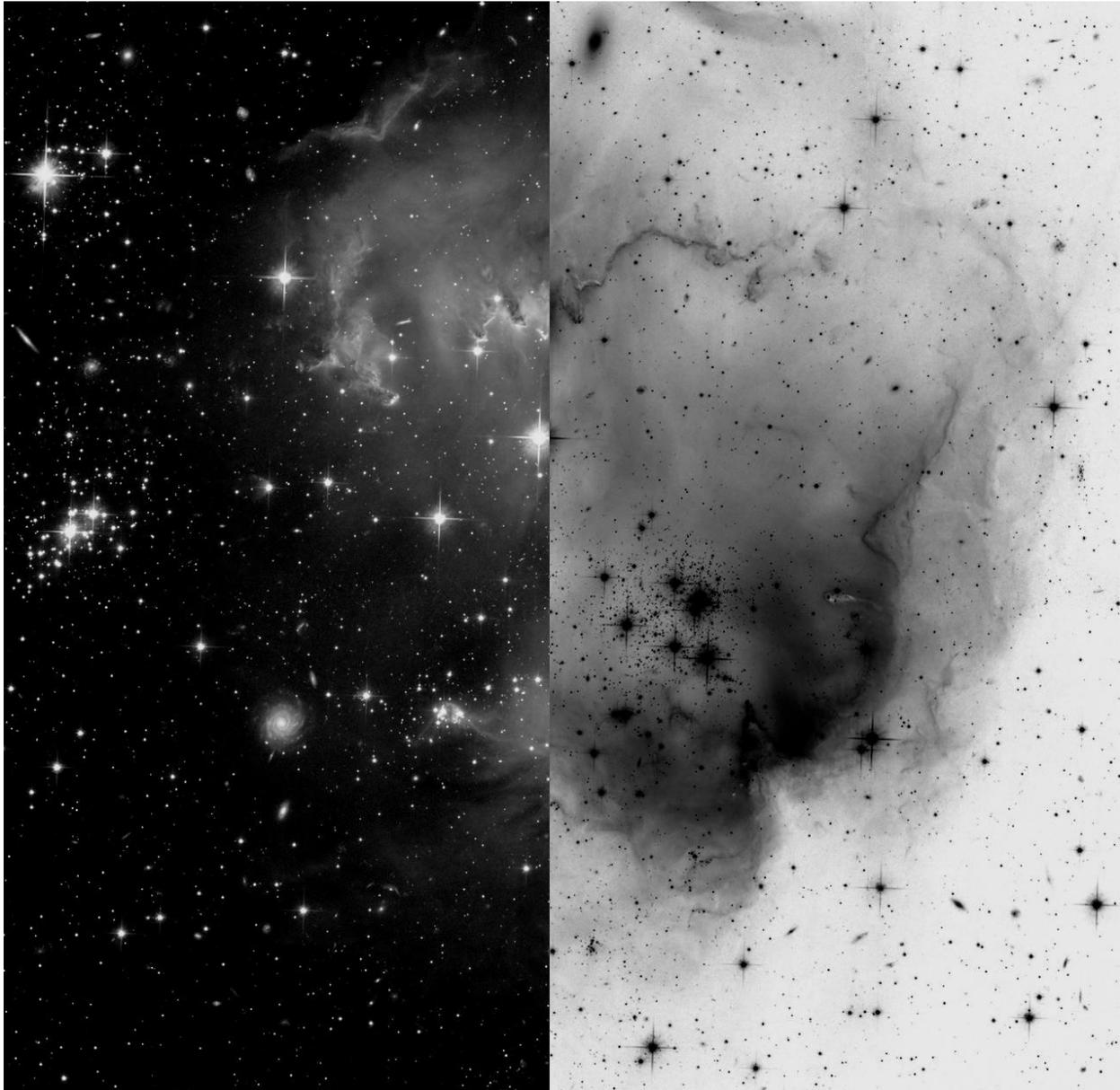


ImageJ Activity Booklet



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Introduction

As scientists, astronomers do not only take pretty pictures, but also must produce quantitative (mathematical) analyses of these pictures. There are many different methods for analyzing astronomical images, and therefore many different software tools for doing this analysis.

This guide provides instructions using a program called ImageJ. The advantages of this program are that it is Java-based (so it can run on any computer), it is free, and it is relatively user-friendly.

The guide begins with instructions on how to download ImageJ plus some additional astronomy-related plugins, followed by directions on how to install everything correctly (for both mac and pc). After you have everything installed, there are 3 lessons that will help you get oriented with some of the most basic image processing skills needed for analyzing astronomical images. There are questions throughout the lessons to help guide your thinking (the answers are provided at the end). After the 3 lessons is an explanation for how to create a color picture using 3 different grayscale images.

Many of the lessons require some supplementary materials. They're found at: <http://cse.ssl.berkeley.edu/cms/ImageJGuideMaterials/tabid/305/Default.aspx> Many of these files are pretty large. It is recommended to access them with a high-speed internet connection.

Finally, some technical notes. Both ImageJ and the Astronomy plugins mentioned in this guide are frequently updated. The functionality and appearance of the programs may be different now compared to when these instructions were last updated (Spring 2010). However, the basic ideas and processes should remain basically the same. Also, the screenshots in this booklet were all taken on a MacBook. If you are using a PC, things will look slightly different. The most significant difference is that the menus will appear in the ImageJ windows instead of at the top of the screen.

NOTE: It is highly recommended to use Mozilla Firefox as your web browser. If you have problems with files not downloading or working correctly, please try using Firefox:

www.mozilla.com

Installing ImageJ and Astronomy Plugins

Goals: In this section, you will download and install ImageJ and the astronomy plugin tools.

ImageJ is a free, Java-based image processing and analysis program published by the National Institutes of Health. The program should work on any modern PC or Mac with Java. The ImageJ astronomy plugin package was authored by Dr. Frederic Hessman at the University of Göttingen. These tools were designed for use by classrooms and teachers for data taken with the MONET telescopes.

Downloading and installing ImageJ with all required tools:

1. Go to this website:

<http://rsb.info.nih.gov/ij/download.html>

2. Install ImageJ to your computer.

- a) Make sure you know what operating system you are using on your computer.
- b) Simply follow the installation instructions after you click on the hyperlink to download the program.
- c) Run ImageJ just to make sure it is working on your computer.

Next, we need to install all the tools that you will need for observing and analyzing...

3. Go to this next web page: [DO NOT POST THIS ON A WEBSITE]

www.astro.physik.uni-goettingen.de/~hesman/ImageJ/Astronomy/

4. Download the zip file entitled '**Astronomy.zip**' to your desktop.

5. Unzip the file on your desktop. We will be moving some files around, so you will need to know where items are located as to make for easy accessibility.

6. Double click on the '**Hard Drive**' icon if you are using a mac, or go to '**My Computer**' if you are using a PC in order to open an "explorer" box so that we can move files around.

7. Double click on the '**Hard Drive**'/'**My Computer**' icon again to open a SECOND "explorer" window.

a) In one window you want to be able to look at ImageJ and its files and in the other window you want to be able to look through the astronomy folder that you unzipped.

8. Double click into '**Astronomy**' folder from the desktop in either one of the two "explorer" windows.

a) you should see two folders, '**plugins**' and '**macros**'.

9. Double click into the '**plugins**' folder.

a) you should see four items.

10. In your 2nd explorer window double click on '**Applications**' folder, or if you are using a PC, the '**Program files**' folder.

11. Please navigate to and double click on the '**ImageJ**' folder.

a) you should be able to see all of the folders and files within '**ImageJ**' including one folder in particular labeled **plugins**.

12. Look BACK at your other "explorer" window (the '**Astronomy**' folder that you just unzipped)

a) Highlight the four items within the unzipped '**Astronomy**' folder. (astroj.jar, astronomy folder, astronomy_.jar, and CCD folder)

13. Drag those four items into the '**plugins**' folder of ImageJ.

Part 1 done!

14. Within the folder that you downloaded '**Astronomy**' there were two folders, click into the other folder now, the '**macros**' folder.

a) you should see a sub folder labeled '**toolsets**'.

b) double click into '**toolsets**'.

c) you should see a file labeled '**astronomytools.txt**'.

15. Make sure you still have open your two explorer windows... one looking into **applications** within **ImageJ**, and the other explorer window looking at "**astronomytools.txt**"

16. In your first explorer window (looking at ImageJ files), double click on the folder labeled 'macros'.

a) you should see several sub folders, one of which is labeled 'toolsets'.

17. In your second explore winder the one looking at 'astronomytools.txt', highlight 'astronomytools.txt'.

18. Drag 'astronomytools.txt' over to the other explorer winder and place into the folder labeled 'toolsets'.

19. If ImageJ is running restart it. Or if it was not running just start it up by double clicking on its icon.



Now to get those tools up to the tool bar!

(ImageJ should be running)

20. Click the >> icon on the far right side of the ImageJ toolbar.



21. In the pulldown menu that appears, click on 'Astronomy Tools'.

a) several of the toolbar icons will change, now appearing like so:



Now we have one more application to install, and it is a very important one because it will allow us (among other things) to focus the telescope!...

22. Close ImageJ.

23. Go to <http://math.nist.gov/javanumerics/jama/Jama-1.0.2.jar> in your browser. This link will download a file named Jama-1.0.2.jar

24. It most likely will download to your desktop, but wherever it downloads make sure you know where that is. Now, please open an "explorer" window by double clicking the hard drive symbol (mac) or going to 'My Computer' (pc).

25. Double click **applications** folder.
26. Double click **ImageJ** folder.
27. Double click on the **Plugins** folder.
28. Now, click and drag the Jama-1.0.2.jar file into the folder labeled '**Input-Output**'.
30. Pat yourself on the back. You are finished loading all of the tools!

Lesson 1: Digital Picture Basics

Goals: In this lesson you will learn some basic vocabulary about digital pictures. You will also open a picture with ImageJ and relate this vocabulary to the picture.

Materials: You need a computer with ImageJ installed, and the digital picture [kermit.jpg](#) (found at: <http://cse.ssl.berkeley.edu/cms/ImageJGuideMaterials/tabid/305/Default.aspx>) or a digital picture of yourself or someone you know well.

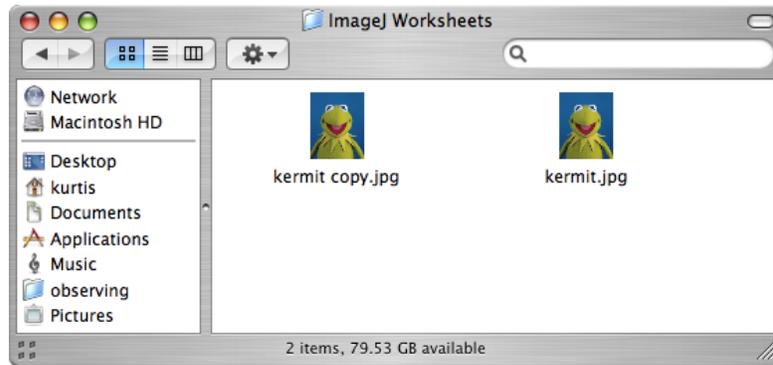
Here is some basic vocabulary that will re-appear throughout our work with astronomical images:

- Pixel — A "pixel" (short for "picture element") is the smallest unit of a digital picture. These are little squares arranged in a grid to create a full picture, like a mosaic.
- RGB/Grayscale — "RGB" stands for "Red, Green and Blue." Monitors display colors using red, green and blue light; combinations of these three colors create all other colors. Color digital pictures are usually stored in RGB format. "Grayscale" is the same as what most people would call "black and white." Another common color scheme is "cmyk" (cyan, magenta, yellow and black); cmyk is used by color printers.
- Pixel Value — The pixel value indicates how bright each color is in a pixel. Most grayscale images use a value between 0 (pure black) and 255 (pure white). For RGB images, each color is assigned a value between 0 and 255. A pixel with R=255, G=0, and B=0 will be a bright red pixel. A pixel with R=255, G=0, and B=255 will be purple (bright red plus bright blue).
- Look-up Table (LUT) — A look-up table, or LUT, relates the pixel value to what is displayed on the screen. If you change the brightness or contrast of an image, you are altering this relation, but not the image itself. Think of it like changing the brightness or the tint on your television set. Twiddling with those settings changes the picture that you see, but the signal coming from the TV station is not changed.

Activity: Explore these terms in relation to a real image

1. Find a color digital image to work with. For the activities below, we'll be exploring how images change as we mess with colors, brightness and contrast. Find a picture of someone you know very well, so you can readily see how these changes affect the picture. If you don't have a picture, use the picture of Kermit the Frog.

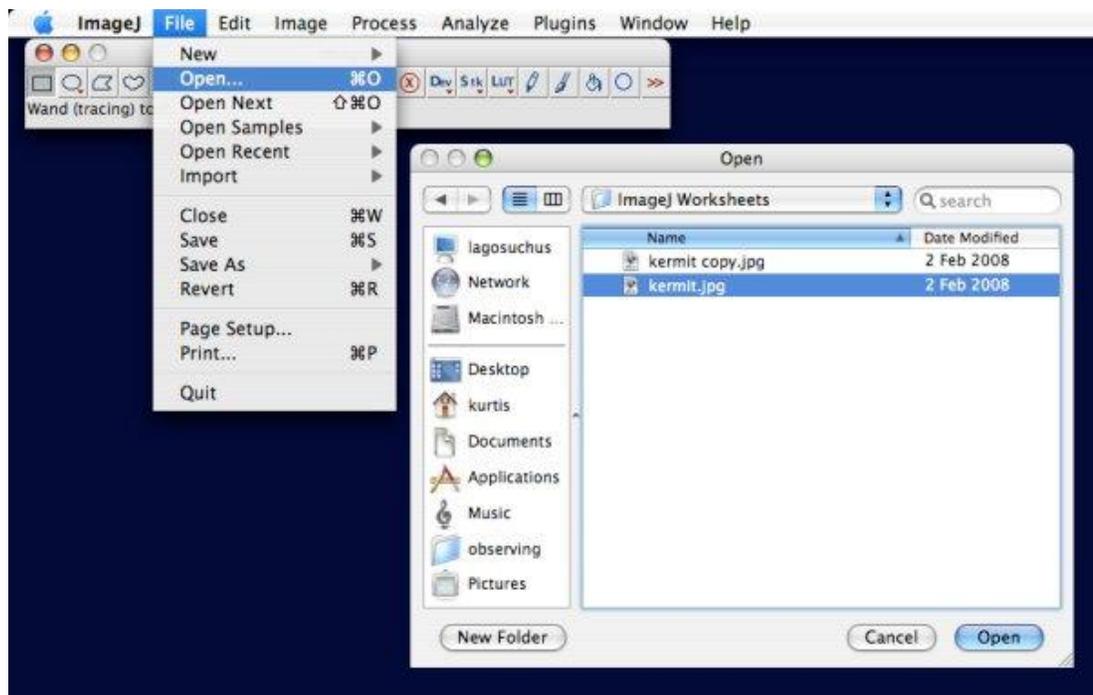
2. Make a copy of this image. We don't want to mess up your only copy of a perfectly good image, so make a copy of the image file, and put the copy where you can find it.



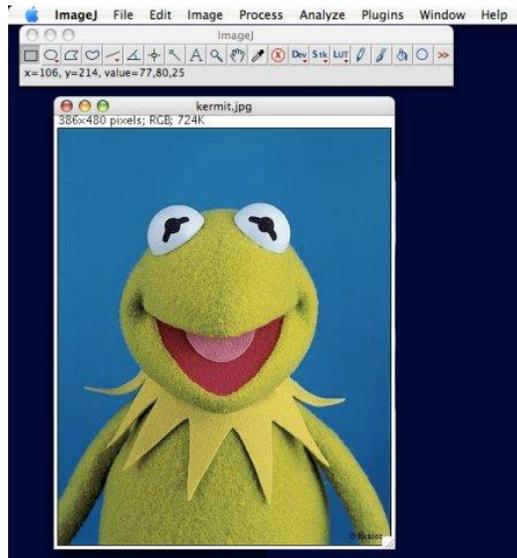
3. Open the image with ImageJ.
 - Start ImageJ by double-clicking on the microscope icon in the ImageJ folder.



- Click on "File", then "Open", and then locate the copy you made in the last step.



- The picture should pop open.

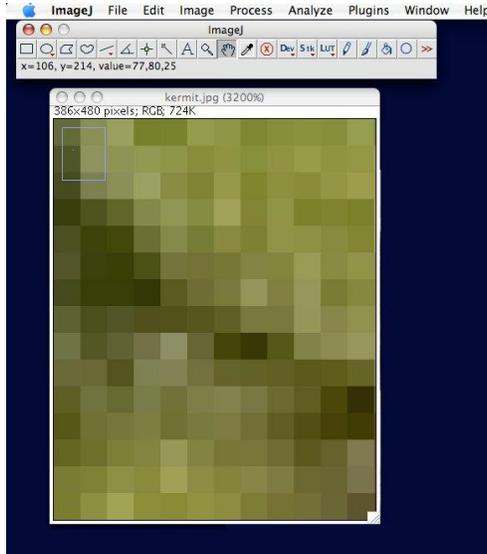


4. Move the mouse around over the image. As you do this, look at the ImageJ tool bar. You should see numbers like "x=106, y=214, Value=77,80,25." These are the x and y coordinates of the pixel your mouse is over, and the pixel value(s) for that pixel. The three values tell us that this is an RGB image, and the individual numbers say that the pixel has a moderate amount of red, a moderate amount of green, and little blue (remember that these values range from 0 to 255). In reality, the pixel is olive green.

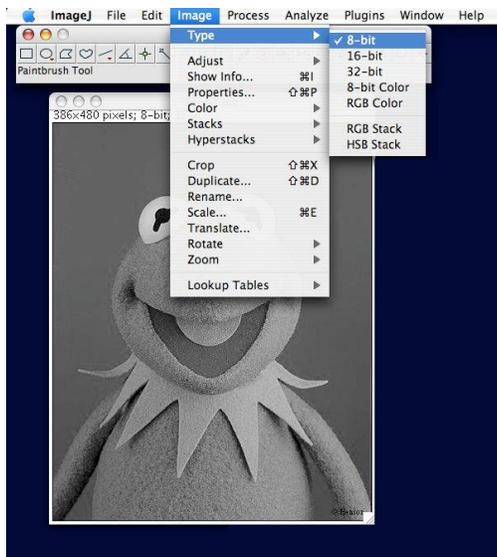
As you move the mouse, the x and y coordinates and the pixel values will change.

- Move the mouse over areas of different colors. Do the changes in the pixel values make sense, depending on the color you are seeing?
 - In which direction do the x coordinates increase? The y coordinates?
 - Look at the pixel values for a nearly-white pixel. Do these values agree with the convention that the maximum pixel values are 255?
5. Zoom in many times. There are three ways to zoom in. You can either use the menus for "Image" → "Zoom" → "In", or you can click on the magnifying glass in the toolbar and then click on the image, or you can use the + and - keys. Keep zooming in until you reach the maximum zoom.
 - Can you see the individual pixels?

- Move the mouse around inside an individual pixel. Note how the x coordinate, y coordinate, and pixel values do not change. This is because a pixel is the smallest unit of a digital image.



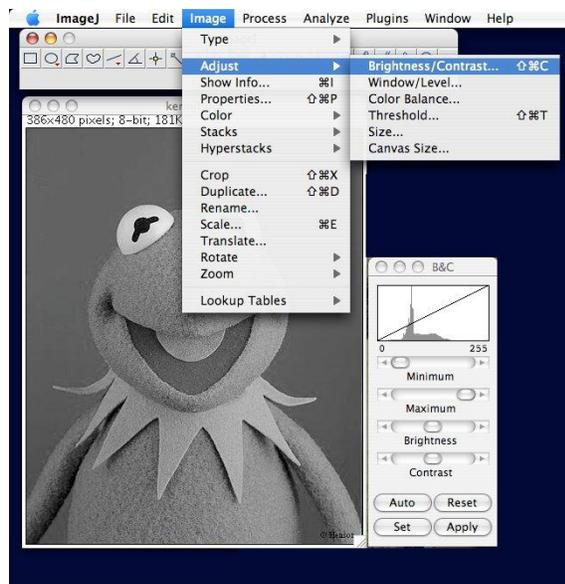
6. Convert the image to grayscale (black and white). Because astronomy images are in grayscale, and because grayscale is a little easier to understand, let's convert your color image to grayscale.
 - In the ImageJ menus, go to "Image" → "Type" → "8-bit." Voila! Your image is in grayscale.



- Save the image with a different name: "File" → "Save As" → "Jpeg..."

7. Move the mouse over the grayscale image. Note that the pixel coordinates are unchanged, but the Value is now a single number.
 - What pixel values correspond to dark areas? What values to light areas?

8. Change the brightness and contrast. "Brightness" and "contrast" are controls that allow you to change the look-up table, but not the pixel value.
 - Open the Brightness & Contrast dialog box. Use the menus "Image" → "Adjust" → "Brightness/Contrast"

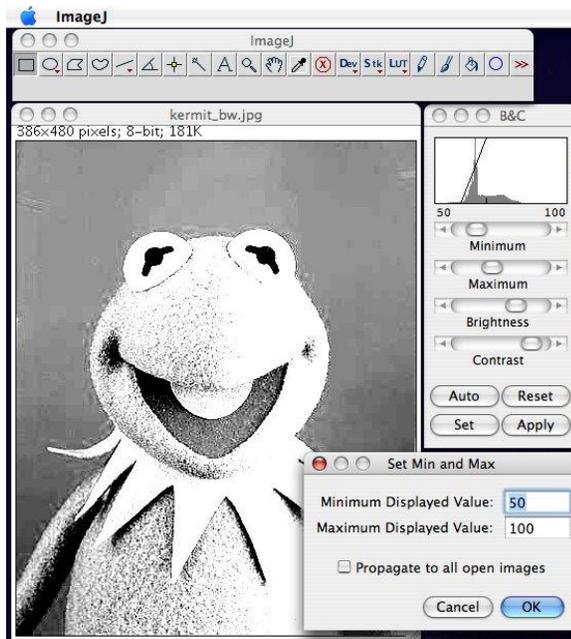


- Slide the bars controlling brightness and contrast around. What is the difference between adjusting the brightness and adjusting the contrast?
- Click "Reset" to go back to the default settings.
- Zoom in as far as you can on part of the image. Find a single pixel to follow. What is its x and y coordinate? What is its pixel value?
- Move the brightness and contrast bars drastically.
- Move the mouse back to the same pixel. Use the x and y coordinates to make sure you have the right pixel. What is the pixel value?
- Move the brightness and contrast bars again. Relocate your pixel. What is the pixel value?

- Brightness and contrast change how the image looks on the screen, but do not affect the pixel value. However, if you save the adjusted image, many computer programs will change the pixel values so that the picture looks the same the next time you open it.

9. Set some specific value ranges. The brightness and contrast dialog box also allows you to set specific value ranges to display. Values higher than the maximum appear as pure white; values less than the minimum appear as pure black.

- Zoom back out so you can view the entire image.
- In the brightness and contrast dialog box, click on the button labeled "Reset." Your picture should go back to the normal grayscale.
- In the brightness and contrast dialog box, click the button "Set." Another dialog box will appear.
- Set the minimum value to 50, and the maximum to 100. Click "OK." What happens?



- Move your mouse over pure white and pure black areas. Look at the pixel values. Are they outside your minimum and maximum range (they should be)?
- Now, click on the "Set" button again. Set the minimum value to -100, and the maximum value to 350. Click "OK." What happens?
- Click on the "Reset" button; your picture should be back to normal.

- Zoom in as far as you can and look at a single pixel; note the pixel value.
- Play around with the minimum and maximum and the brightness and contrast buttons. Convince yourself that the pixel value does not change no matter what you do with the brightness, contrast, minimum and maximum. You are changing how the image is displayed, not the image itself.

Points to take away:

- Digital images are made of individual pixels. A pixel is the smallest part of a digital image.
- Each pixel has an assigned coordinate and a pixel value.
- Color pictures need three values for each pixel. These values describe how much red, green, and blue light are present in each pixel.
- Grayscale pictures need only one value for each pixel, describing how bright each pixel is.
- Changing the brightness and contrast does not change the pixel value.

Some questions to think about:

- Brightness and contrast change the mapping of pixel values to the displayed shade of gray, but those values are unchanged. Why do astronomers like this property?
- Most astronomical cameras create images with pixel values as high as 65,535. ImageJ will map these counts to look-up tables that run from 0 to 255. If you have faint stars with pixel values of only 155, you won't be able to see them in ImageJ's display. How can you use ImageJ to see these stars?

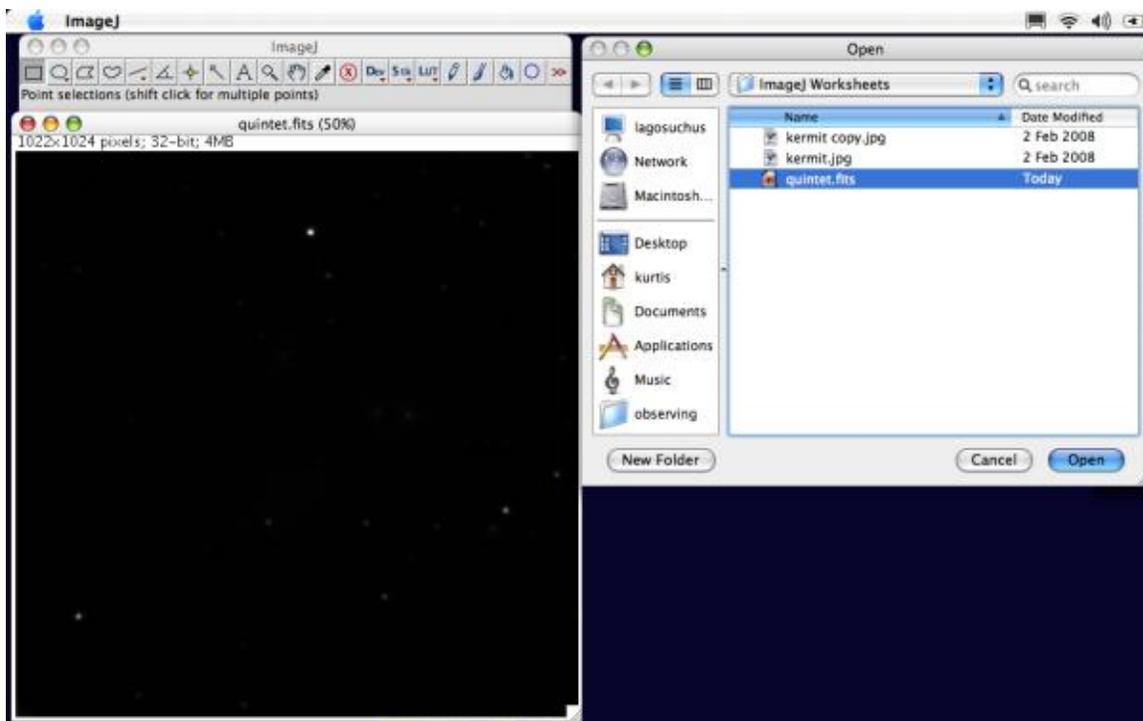
Lesson 2: Opening an Astronomical Image

Goals: In this lesson, you will open an astronomical image, adjust its brightness and contrast, and learn how to invert an image and why.

Materials: You will need your laptop with ImageJ installed and the image file quintet.fits, downloadable from

<http://cse.ssl.berkeley.edu/cms/ImageJGuideMaterials/tabid/305/Default.aspx>

1. Look at the file name. The ".fits" means that the image is a "FITS" file. "FITS" stands for "Flexible Image Transport System." FITS files are one of the standard image types for astronomical research images.
2. Opening the image file. ImageJ opens FITS files the same way as other image types: "File" → "Open". Browse for the file, find it and click it!



This picture is of Stephan's Quintet, a group of four related (and one unrelated) galaxies. Can you see five galaxies in the image? We can't.

3. Run your mouse over the image and look at pixel values. Remember how the grayscale image from Lesson 1 had pixel values between 0 and 255? FITS images can have arbitrary pixel values. This allows astronomical cameras to count individual photons; many astronomical cameras can go as high as 65,535.

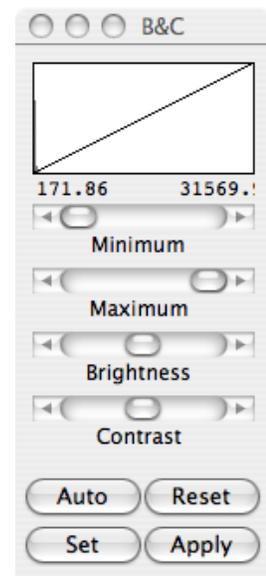
When you open a FITS file with ImageJ, it displays the highest pixel value as pure white and the faintest pixel value as pure black. This means that the faintest objects are displayed as only slightly less-black pixels, which your eyes have trouble seeing. So, the galaxies are there, but they and other faint objects are hard to see.

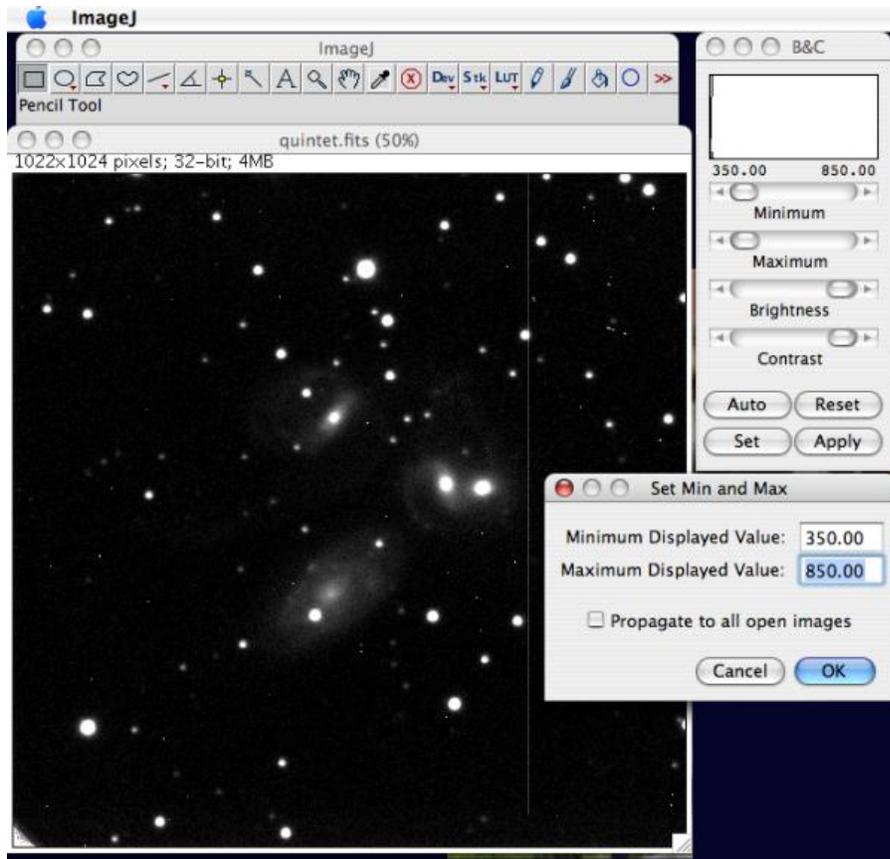
What can you do to make fainter pixels easier to see?

4. Adjust the Brightness and Contrast. Remember, to do this click "Image" → "Adjust" → "Brightness/Contrast". The Brightness and Contrast window will pop up.

There are three ways to choose the brightness and contrast:

- The first and easiest way to adjust the brightness/contrast of the image is to click on the Auto button. This button will automatically adjust the image to ImageJ's best guess at optimal values. It's usually wrong, but not awful.
- The second way to adjust the brightness and contrast is to slide the minimum, maximum, brightness and contrast bars until you can see faint objects. This is easy to do, but hard to dial in, and probably the most frustrating and least productive method.
- The final and best way is to manually set the minimum and maximum values. Press the Set button, and a dialogue box will open allowing you to set the minimum and maximum displayed pixel values. In any astronomical picture, most of the pixels will be blank sky. So, move your pointer around the picture and look for the lowest typical pixel value (in the case of quintet.fits, I would guess it is around 350. Do you agree?) Set that to be the minimum. Then, a good starting guess for the maximum is to add 500 to the minimum value (850 here). Click OK. Can you see the five galaxies now?



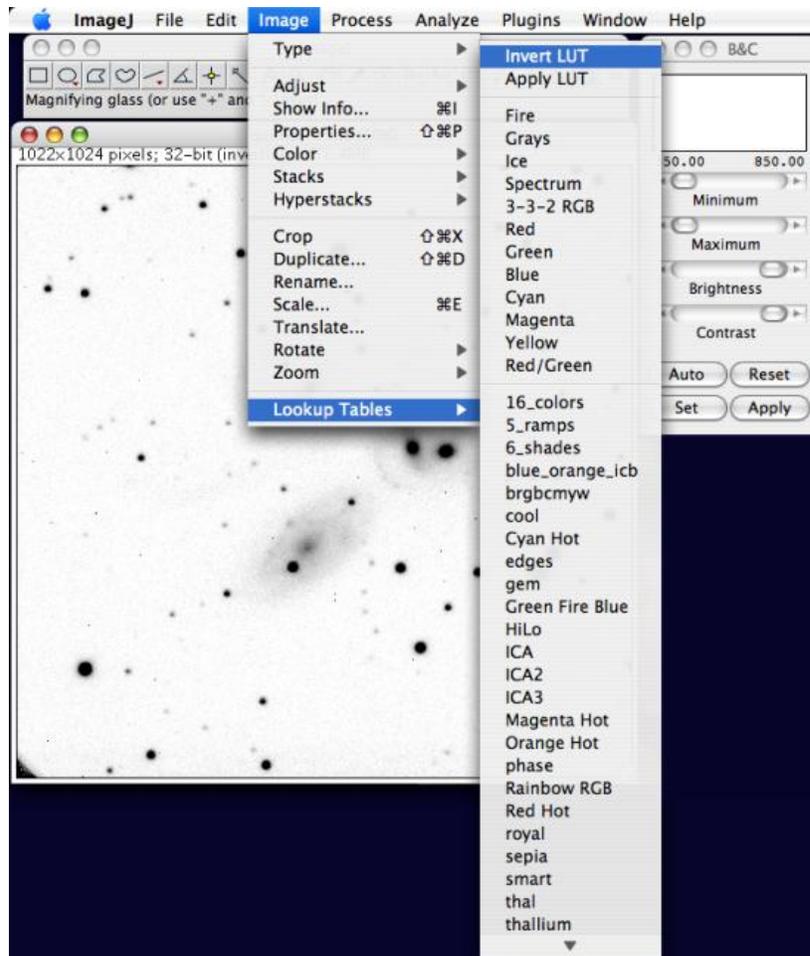


Remember from [Lesson 1](#): changing the brightness and contrast does not change the pixel value, it only helps you to see the image better. So feel free to adjust the brightness and contrast however you want. Remember, the goal is to see faint objects - the bright ones will always be visible as pure white pixels!

5. Invert the image. Your eye is very good at picking out slightly off-white colors on a white background, while not so good at picking out slightly less-black colors on a black background. (This is why if you spill coffee on white shirt you rush to change it, but you don't need to change if you spill coffee on a black shirt.) The same is true for picking out faint stars or galaxies in an astronomy image. If you could make the sky white and the stars black, you could pick out fainter objects.

Although the Universe doesn't provide us this convenience, ImageJ does. To make your life easier, you can invert ("flip") the image so that you are seeing

black stars on a white background. To do this click: Image → Lookup Tables → Invert LUT.



Important! Do not use Edit → Invert, because this changes the pixel values!!

Another example of an inverted image is shown on the cover of this booklet. Half the image is normal, and half is inverted. Note how much more detail you can see in the faint nebula in the inverted half!

6. Play with the brightness and contrast some more to bring out faint features. To get the best results from the inverting process, you will probably need to adjust the brightness and contrast some more. Personally, we like a light-gray background; we obtained best results by using the SET button and setting the minimum to 300, and the maximum to 475. Play around and see what different values do! Can you see the faint arms extending far beyond the galaxies?

Conclusion: By now, you should be familiar with the process of opening an astronomical image with Image J. You should be able to use the brightness and contrast in order to make faint objects more noticeable. Finally, you should be familiar with the process required to invert an image.

Be patient; FITS images are big and can take a while to download.

For a real challenge, download the image of the [Draco Dwarf Spheroidal galaxy](#). Most of the stars in the image are stars close to us, but there is a collection of extremely faint stars toward the center of the image that make up a very small neighbor galaxy to our own Milky Way. Can you see them? You will have to adjust the brightness and contrast to bring out the faintest stars. Then, zoom in and compare the density of faint stars at the middle of the picture to the density at the edges of the picture.

Lesson 3: Measuring Star Brightnesses

Goals: In this lesson, you will learn to use ImageJ to measure the brightnesses of stars in an astronomical image.

Materials: You will need your computer with ImageJ software installed. You will also need the image file `ngc7063_u.fits` from <http://cse.ssl.berkeley.edu/cms/ImageJGuideMaterials/tabid/305/Default.aspx>

First, some background. Astronomical cameras count the number of photons of optical light coming from an object. The pixel values in FITS files are proportional to the number of photons a telescope collected during the exposure. But the number of photons collected from a star can vary, depending on how big the telescope is, what the weather is like, and the quality of the camera.

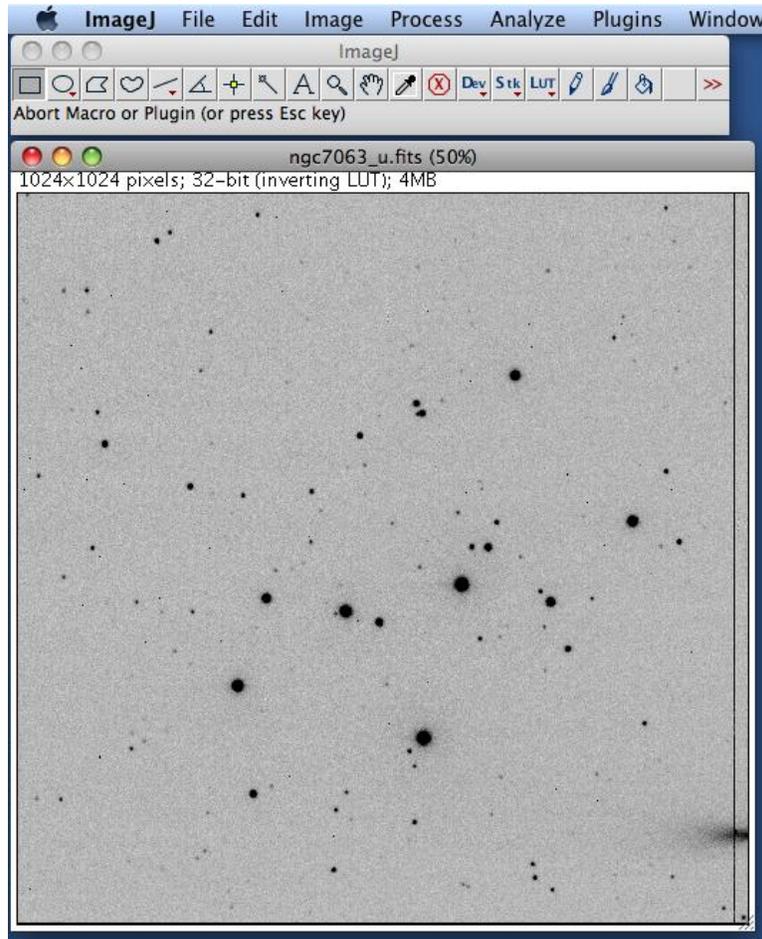
So astronomers have adopted a brightness measure called "magnitudes," based loosely upon a classification system from the ancient Greek astronomer Hipparchus. The magnitude system is logarithmic, such that a difference of five magnitudes means a factor of 100 difference in the number of photons detected. But the magnitude system is backwards, such that fainter stars have larger magnitudes. Think of it like a ranking system - just as 1st place is better than 2nd place, 1st magnitude is brighter than 2nd magnitude.

The steps for determining the magnitude of a star from an image are straightforward, if not always simple. First, you measure how many photons arrived from a star. Second, you apply one very simple mathematical equation to put the star on the magnitude system. And that's it!

The way we measure how many photons arrived is by a method we call *aperture photometry*. This means that we draw a shape around a star and count all of the photons that landed inside that shape, then we subtract off the number of photons that land inside an identical shape in a blank part of the sky. The ImageJ astronomy plugins have a tool that automate this for you.

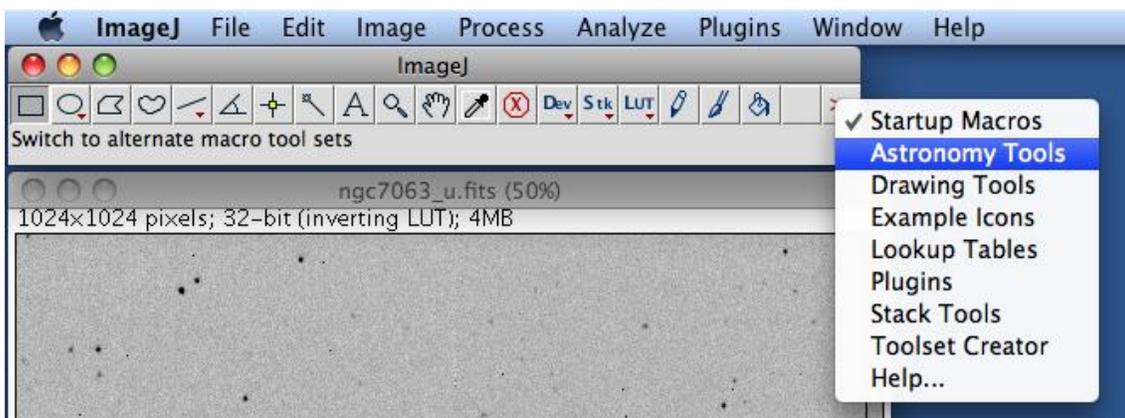
Let's see how to do this in ImageJ using the file `ngc7063_u.fits`, a picture of the wimpy star cluster NGC 7063 taken at Lick Observatory outside of San Jose, CA.

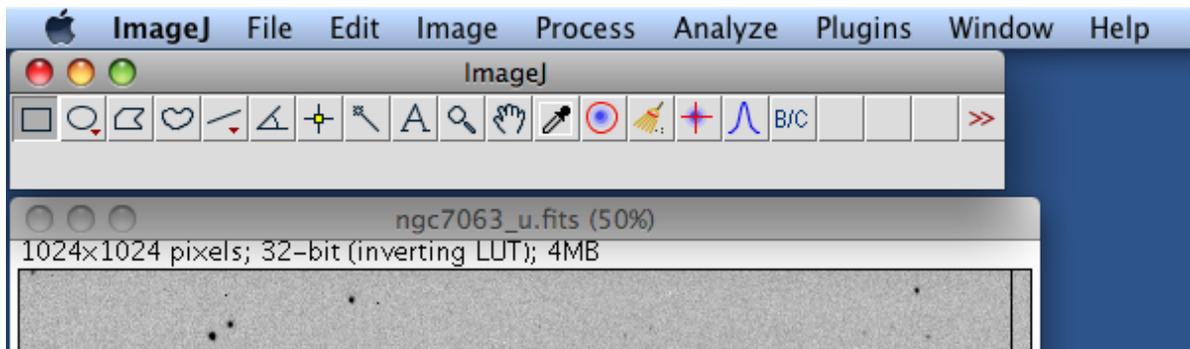
1. Open the image in ImageJ and adjust the brightness and contrast so you can see faint stars. If you need a reminder how to do this, review Lesson 1 and/or Lesson 2. Here's what I see:



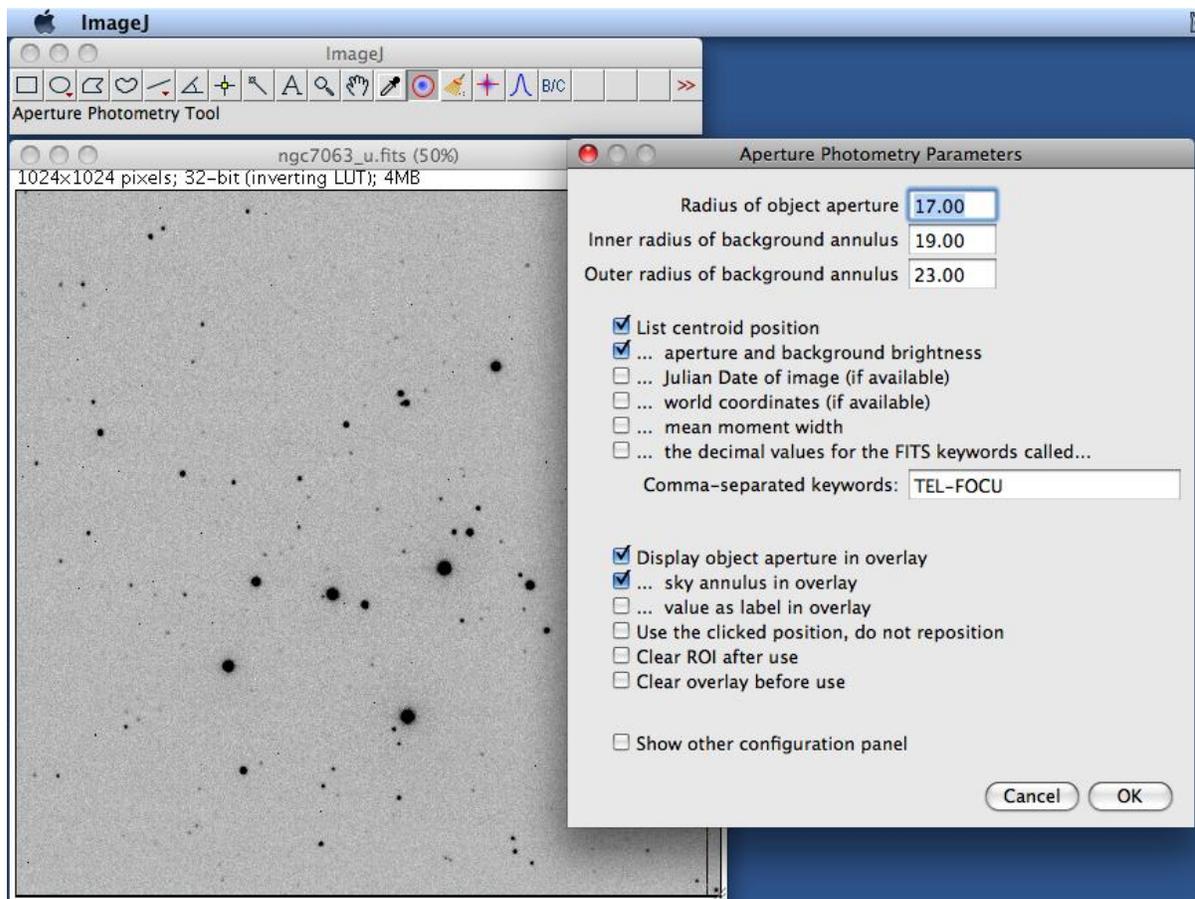
Simple but Important Thought Questions: What shape are the stars? Zoom in, if needed, to get a clear view. If we want to measure all of the light coming from a star, what shape of measuring tool should we use?

2. Load the Astronomical Tools. Now that we are going to be measuring stars, it's time to load our astronomical tools. To do this, click on the **>>** icon on the far right of the toolbar, and select "Astronomy Tools". This will change some of the icons on your toolbar:





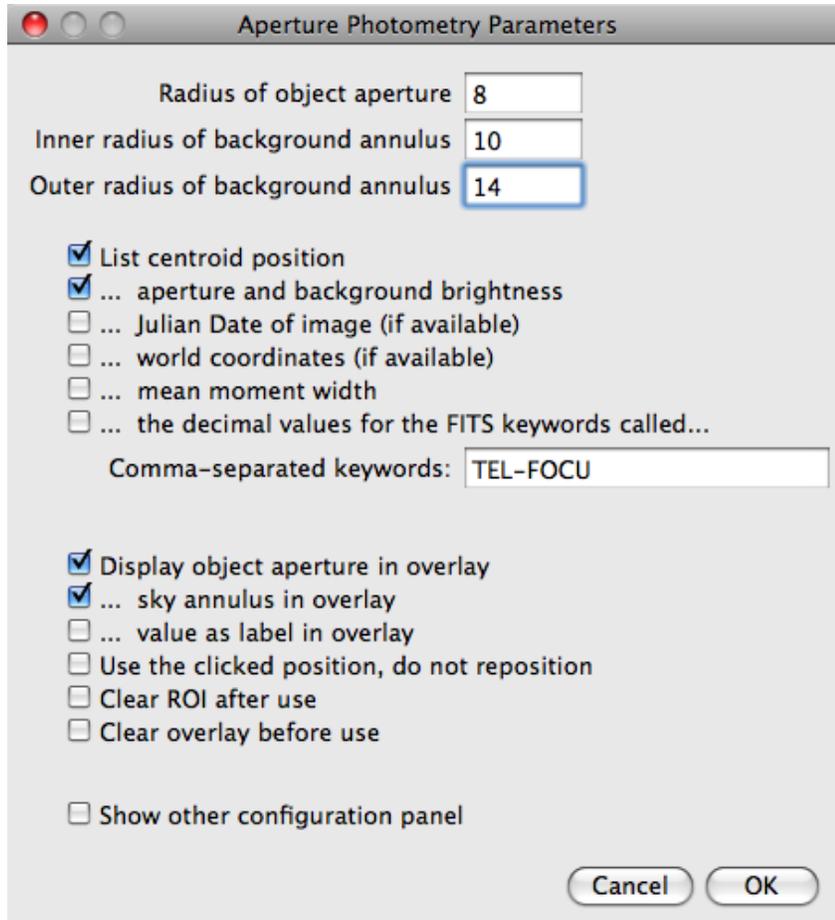
3. Select the aperture photometry tool. Since stars are circles, we want to measure how bright the stars are using a circular region; this is called *aperture photometry*. The icon of the blue smudge inside a red circle is the Aperture Photometry Tool. Double-click on this icon to open the aperture photometry dialog box:



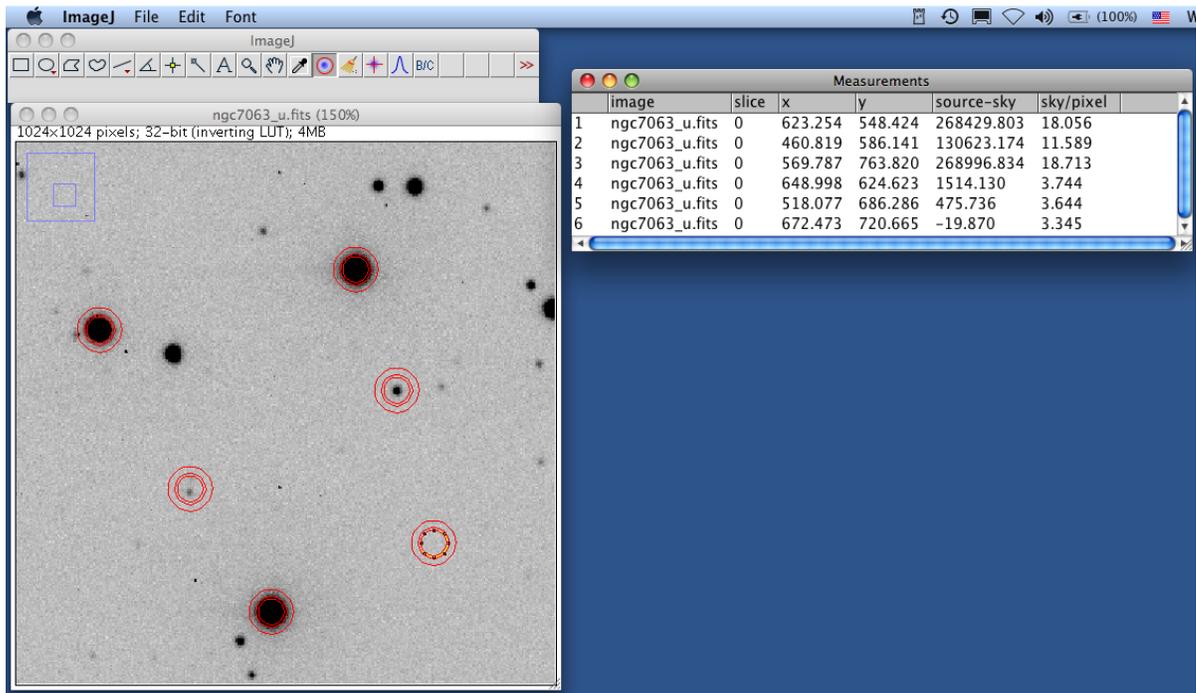
4. Set the aperture photometry parameters.

- Set the object aperture radius. Although brighter stars look bigger in the pictures, each star's light extends out the same radius. (Trust us on this. If you don't believe us, and it is natural if you don't, we can prove this to you at the workshop.) Therefore, we must measure each star's brightness with the same size of circle. Zoom in on a bright star and put your cursor at the center. Look at the x and y position for that pixel. Now move the cursor to the visible edge of the star. Get the new x and y positions and calculate the radius. (For our image, I get 8 pixels, though 6-10 would be acceptable answers.) Believe it or not, it is far more important to be consistent than to be right. So, pick a radius, enter it in the "Radius of object aperture" box, and leave it alone. For now, let's choose 8.
- Set the sky annulus. Despite what you might think, the sky is not completely dark. There is faint light everywhere from stars too faint to see, from bright stars outside the field of view, from the moon (if it is up), and even from glowing air high in Earth's atmosphere. We need to measure how bright the sky is and subtract it off. Thankfully, the astronomy tools will do that for you. The tool will measure the brightness of the sky in a ring (annulus) around the star. We need the ring to contain enough pixels to allow a good measurement, but not so large as to contain other stars. Typically, we set this ring to have an inner radius a pixel or two larger than our object radius, and set the outer radius to four or five pixels larger. Set the inner radius to 10 and the outer radius to 14.
- Set the output values. What information do we want to know about each star? We need the x and y positions of a star (called the "centroid"), so we can find it again, so be sure the "List centroid position" box is checked. We also need to know the total amount of light from the star, so check the "...aperture and background brightness" box. It's also nice to draw a circle around each star, so that you know which stars you've measured, so check the "Display object aperture in overlay" box. And, if you want to make sure that there aren't other stars in your sky measurement, click on the "...sky annulus in overlay" box.

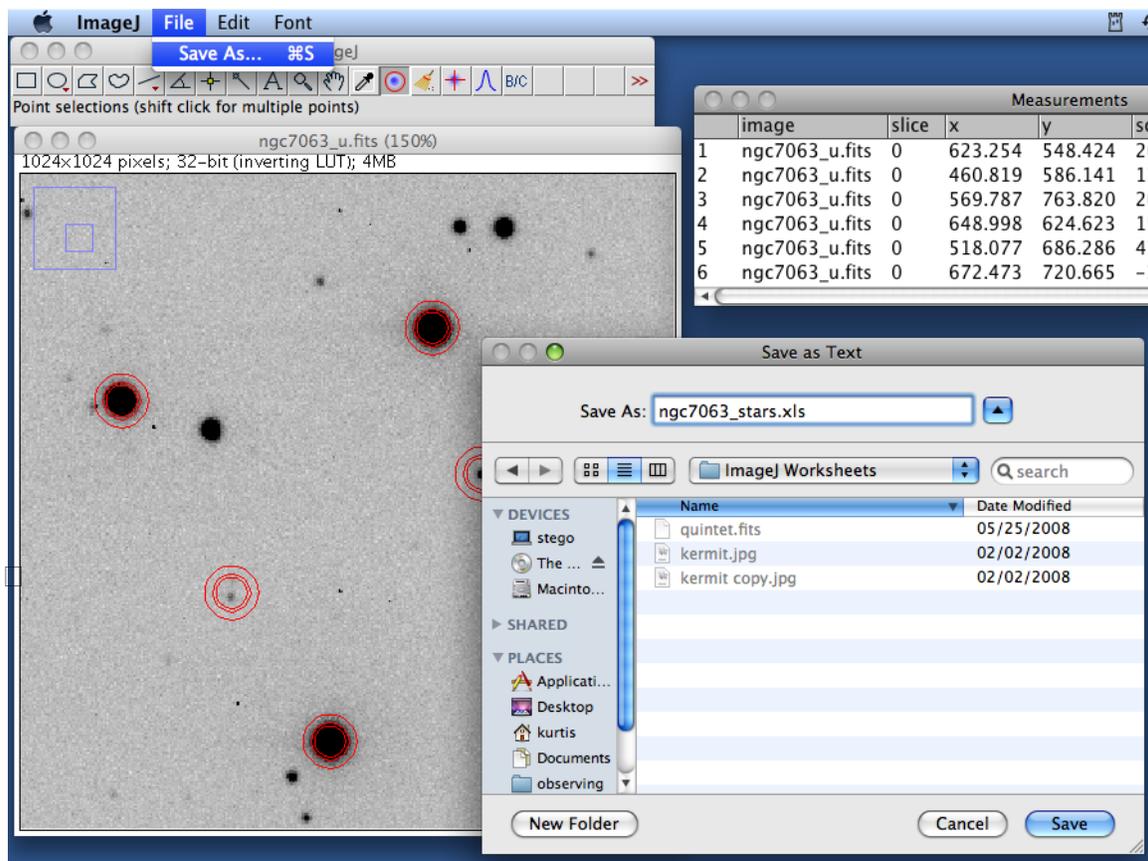
- Click OK.



5. Measure how bright the stars are. Now you are ready to go. Zoom in on your image so you have a good view of some stars. To measure the brightness of a star, just click on it. ImageJ will try and center a circle on your star, draw a circle around it, and pop open a dialog box with the star's x- and y-coordinates, the star's brightness (with the sky already subtracted), and the sky brightness. If you click on multiple stars, you will get multiple measurements:



6. If you click in the wrong place, don't panic. My star 5, the circle on the faint star in the lower left part of the frame, didn't center right. That's because of an even fainter nearby star. This means I probably have a bad measurement on this star. Also notice my star number 6 has negative counts; that's because I clicked on a part of blank sky (that's the circle in the middle of nowhere in the lower right). When this happens, make a note that you need to ignore those data points. We'll delete them later; you can keep measuring stars in other parts of the image for now.
7. Export your data for use in a spreadsheet. At the workshop, we are going to want to do math with the star brightnesses, and we will need to import these numbers into a spreadsheet. Thankfully, ImageJ makes exporting these data easy.
 - Click on your results window to highlight it.
 - In the ImageJ menu, select "File" → "Save As"
 - Save it as a .xls file (for Excel).



Conclusions: After completing a run through this lesson, you should be able to determine the sizes of stars in your image, to adjust the radii of your star aperture and sky annulus, to obtain measurements of the positions and source counts for multiple stars, and to save those data to a file.

Additional questions and exercises for the diligent student: If you finished these lessons and feel comfortable, here are a few things that you can be thinking about. If your brain is hurting and you don't want to think any more, don't worry.

- What would happen to your number of counts if the camera shutter had been open twice as long?
- Open the results file you saved above in your favorite spreadsheet. Turn your star photon counts into raw magnitudes. The formula for magnitudes is:

$$m=c-2.5 \times \log_{10}(\text{source counts})$$

where c is a constant that depends on the telescope, the length of the exposure, and the particulars of the camera. For this image, $c=23.02$.

Making Pretty Color Pictures

Goals: In this lesson, you will learn to use ImageJ to create a color image from individual images of an object taken through different filters.

Materials: You will need your computer with ImageJ software and astronomical tools installed. You will also need the image files M16B.fits, M16V.fits, and M16R.fits from the workshop website.

Before beginning this worksheet, read the NASA/Hubble Space Telescope website http://hubblesite.org/gallery/behind_the_pictures/meaning_of_color/. The important points to keep in mind from this site and from activities during the workshop are:

- CCD cameras take black and white images.
- Color images are produced by combining the black and white images taken through different color filters.
- Most images of nebulae and galaxies are color-enhanced, meaning that subtle shades of color are brought out to produce an aesthetically pleasing picture. Your eye would see just a milky white color, even if you were really close to the object.

In other words, in producing a color image, we are leaving the realm of science and entering the realm of art. For that reason, the instructions below are generally not quantitative. You should feel free to play around with images until you think the result is pretty.

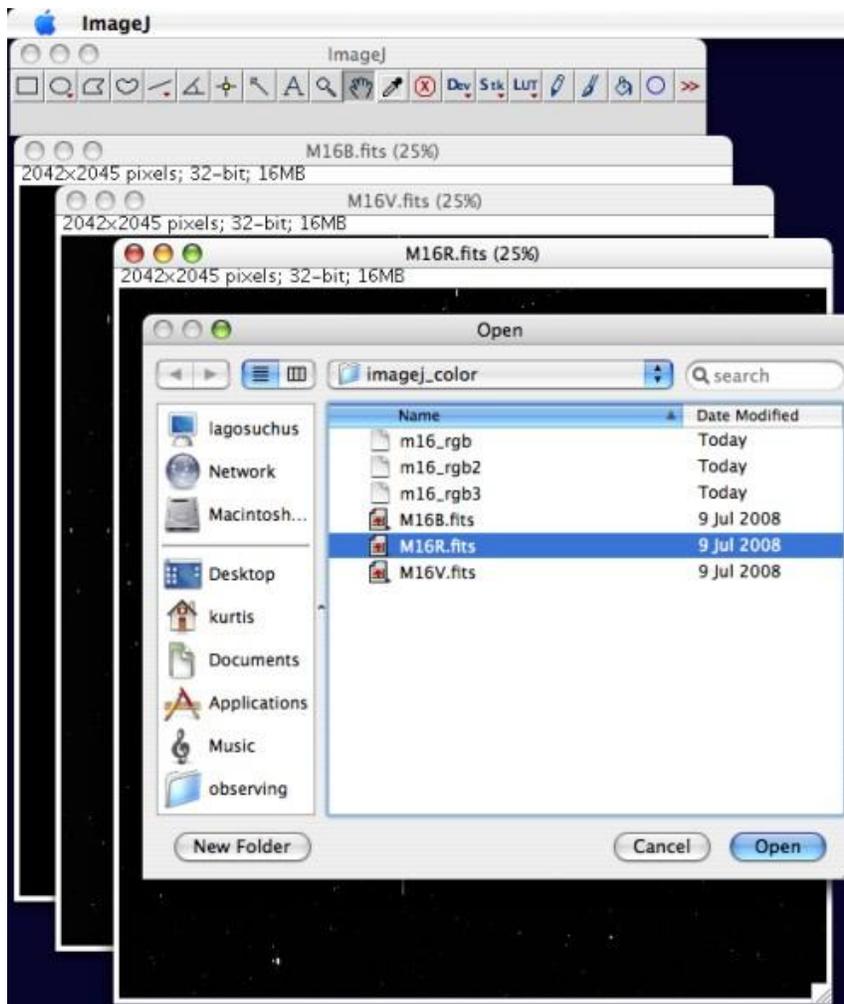
Many people feel uncomfortable with this; they tend to want pictures that replicate what the human eye would see. If you feel this way, please reconsider. No camera ever built reproduces exactly what the human eye sees. Some are closer than others. But we can and do learn a lot from pictures that are not "exact," like black-and-white pictures, sepia-toned pictures, and old color pictures where some colors have faded.

The color astronomical picture you will produce in this lesson is like that. In addition to aesthetic qualities, the colors are telling us something scientific, that conditions in one area are not identical to conditions in another area. What do the different colors mean? Answering that question leads one from art back into science.

So, how can we make color pictures? Let's return to our friend, ImageJ.

Open the images of the same object with ImageJ. You will need three images, one through a bluer filter, one through a redder filter, and one through an intermediate filter. These are typically labeled "B" (blue), "V" (green), and "R" (red).

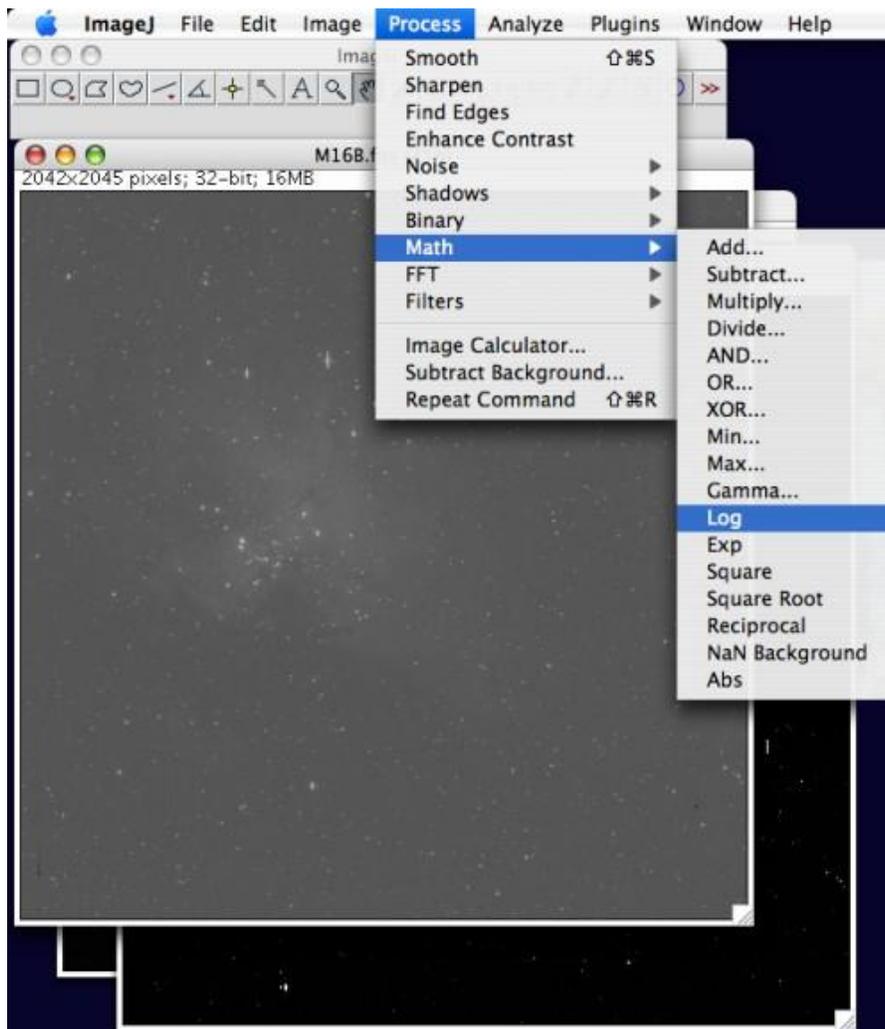
For this exercise, we've provided images taken with a 0.8-meter telescope of the Eagle Nebula, Messier 16 (a.k.a. the "Pillars of Creation" from Hubble), taken through the B, V, and R filters. Use ImageJ to open each image so you have three open images.



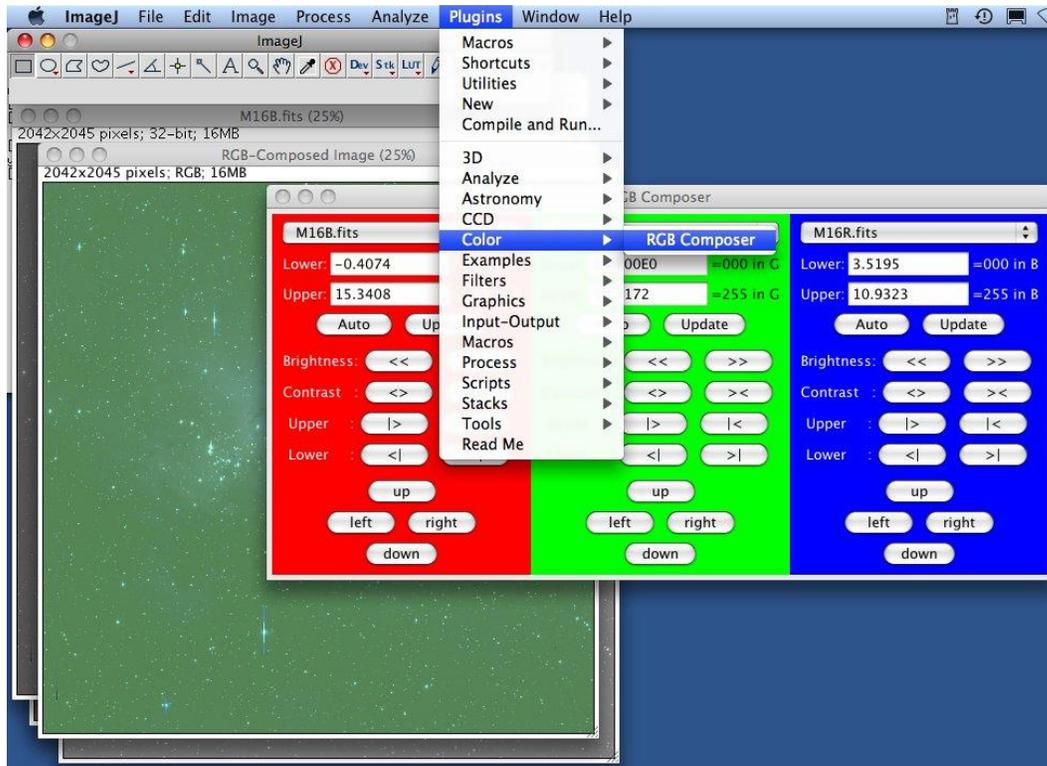
1. Convert each image to a logarithmic stretch. CCDs take linear images, such that each incoming photon is turned into a set number of image "counts." However, a logarithmic stretch is generally preferred, because this brings out faint objects while still allowing your eye to discern brightness differences in bright parts of the image. In fact, your eye uses logarithmic stretch, as does photographic film. Digital cameras convert most pictures to a logarithmic stretch before displaying them.

To get a logarithmic stretch in ImageJ, click on the "B"-band image and select Process → Math → Log. Repeat the process on the "V" and "R" image.

Note: converting to a logarithmic stretch also essentially corrects for exposure time and sensitivity differences.



- Open the RGB composer. This is a plugin that provides some useful tools for creating a color image. In the menus, select Plugins → Color → RGB Composer.

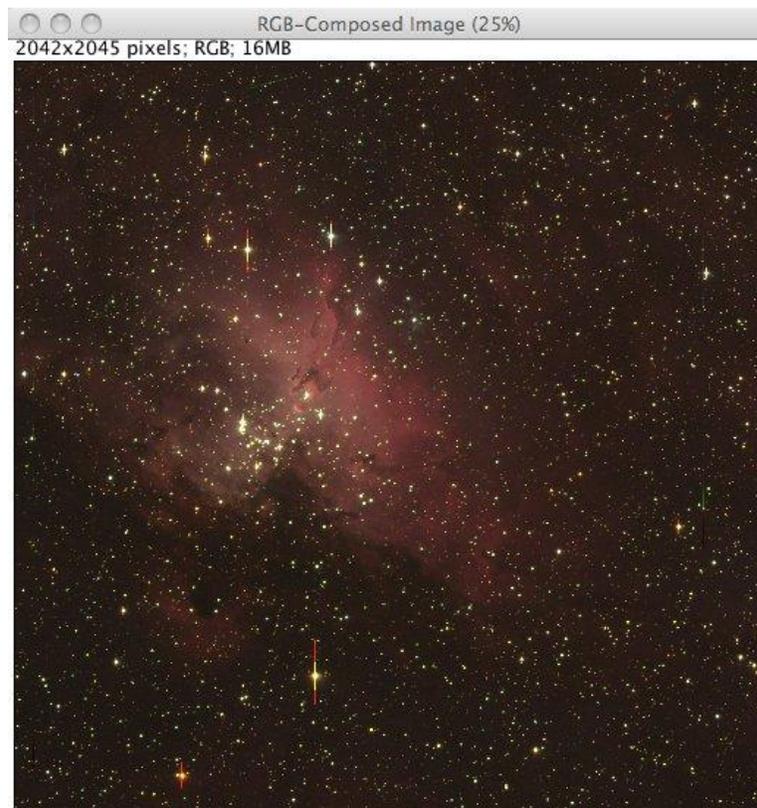
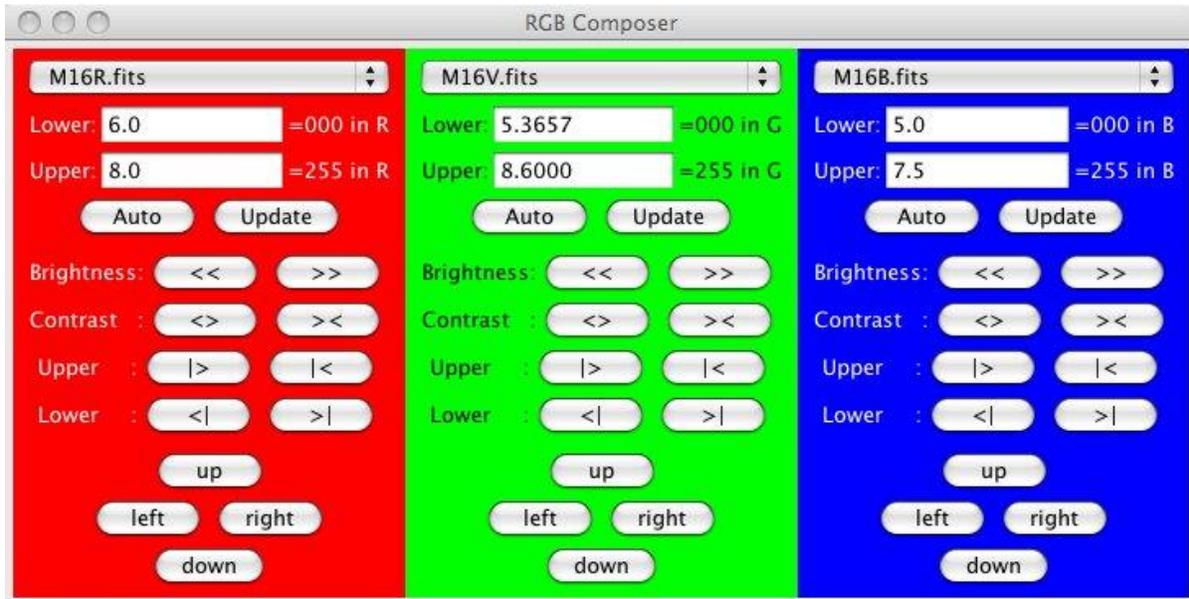


- Select the appropriate image for each color. In the RGB Composer popup window, select which image you want to use for the red, green, and blue portions of your image. (R=red, B=blue, V=green [think 'verde' in Spanish])
- Adjust the brightness and contrast of each image. You are experienced at this. The only differences from our previous ImageJ work are (1) the RGB Composer contains the brightness and contrast dialog for each color, and (2) since we took the logarithm of the images, the ranges are much smaller. The goal is to bring out as much of the faint structure as possible, while making sure that the sky is black and structures are not washed out. You will have different ranges for each color. It's helpful to keep notes in case you need to start over.

A good starting point is to run the cursor around your three logarithmic FITS images and look at typical values in the sky, and set this to your min value. Then add 2 or 3 for the max value. Then click "Update" in the RGB Composer.

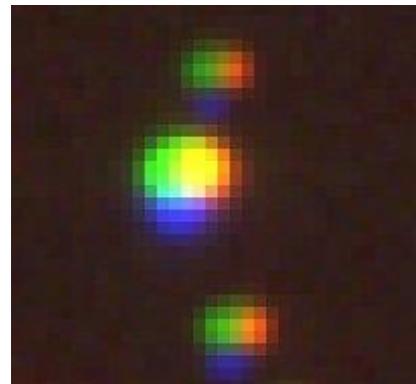
Next, click on the brightness, contrast, upper and lower buttons to adjust individual colors. Don't hesitate to zoom in on your object, and go for what looks pretty!

Here are my final values and the resulting image:



Some tips:

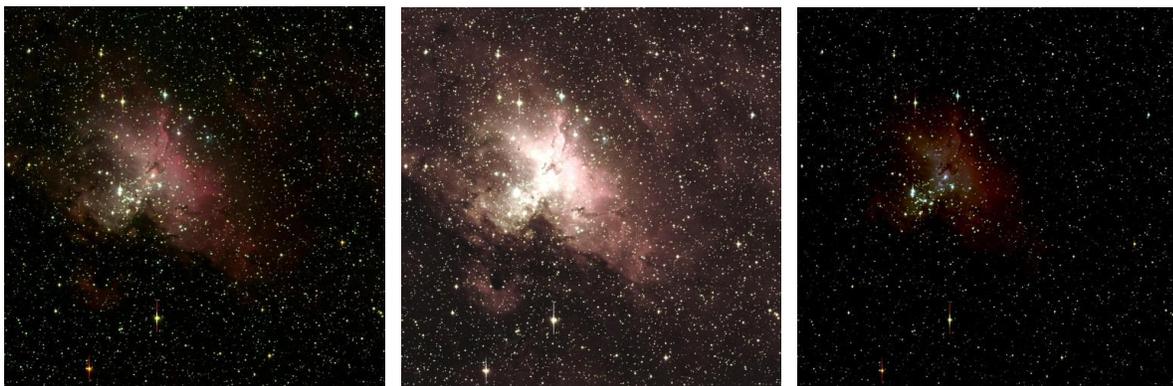
- If the sky, which should be black, has a tint to it, go to that color and click on the increase the Lower ">|" button until the sky is devoid of that color. Some images may not have a black sky background if there is a lot of gas and dust scattered throughout.
- If the picture looks like it has too much of one color (like all the stars are red or green), go to that color and increase the Upper value by clicking on the "|>" button until things look right.
- If the picture seems to be lacking a color (say the picture looks yellowish, meaning it is lacking blue):
 - If bright things are yellowish but faint things are okay, try decreasing the Upper blue value with the "|<" button
 - If faint things look yellowish but brighter things are okay, decrease the Lower blue value by clicking on the "<|" button
- In pictures of galaxies or nebulae, most background stars should be white in color, though some may be reddish or blue.
- In pictures of star clusters, you may want to try very narrow color ranges in order to bring out the differences in star colors.
- At some places in your color image, you may see individual pixels, round spots, or even small lines of just one color (pure red, pure green, or pure blue). These are likely cosmic rays, where charged particles hit the CCD in random spots during one image. There are clever but complex ways to get rid of these, and they affect a small percentage of pixels, so we left them in your images.
- For your color stacking to work, the images need to be aligned, meaning that all the stars appear on the same pixels. We've aligned the 0.8-meter images for you, but images from the web or your own telescope may not be aligned.
 - In unaligned images, if you zoom in on a star, you will see each star as three points; a red, green, and blue dot. If they overlap somewhat, you may see a white star with colors on the fringe:
 - Use the "up", "down", "left" and "right" buttons in the RGB composer to align the star image the best you can.



- For star clusters, the colors can be enhanced by de-focusing the image. This spreads the light from a star over more pixels, giving your eye more pixels from which to get the color). In ImageJ, try the *Gaussian blur* filter (Process → Filters → ~~Gaussian Blur~~) with a radius of 3 pixels. You'll have to re-adjust the brightness and contrast, and you'll lose the faintest stars.
- Before running the RGB Composer, compare the pictures in the individual filters. Do you notice obvious differences that can help you in adjusting the color balance? For example, in many planetary nebulae, red is visible far from the center, while green and blue only visible toward the center. In this case, you may want your final image to look white or even blueish toward the center.

6. Save your color image. Call it what you would like, say, *M16_color*. You'll be asked to choose an image format; I'd suggest choosing Tiff, Jpeg, or PNG. TIFF gives you the best overall image, but it can be a gigantic file. PNG has good fidelity and is smaller in size than TIFF. JPEG gives the smallest image size, but at the expense of some image quality. Typically, I use PNG for personal use, and JPEG for pictures I'll put on the web or in emails. You can always save multiple copies in different formats!

That's it! If you aren't happy with your image, try again. Below are three different attempts at making a color image from these Messier 16 images. Each has some good points and some bad points. But, most importantly, none of these images is wrong, or even fundamentally different. The only differences are in the stretches, and different stretches bring out different features of the nebula.



Now give it another shot with the Whirlpool Galaxy (M51). Download the R, B, and V fits images from the website.

Answer Key

Lessons 1 to 3 and the Observing Challenge

This document provides answers to the questions posed in the ImageJ lessons. Descriptive questions with no set answers are not covered below.

Lesson 1: Digital Picture Basics

- Step 4
 - In which direction does the x coordinate increase? X pixel coordinates increase to the right.
 - The y coordinate? The y coordinates increase down. This is opposite to most conventions.
- Step 7
 - What pixel values correspond to dark areas? Small values (near zero)
 - What values to light areas? High values, near 255.
- Some questions to think about
 - Why do astronomers like this property? Astronomers want to be able to measure the amount of light (i.e., count photons) from stars and galaxies. The pixel value is proportional to the number of photons detected. If adjusting the brightness and contrast were to change the pixel value, we would not be able to make those adjustments without losing the astronomical information.
 - How can you use ImageJ to see these stars? You will need to set the maximum displayed pixel value closer to the faint stars' pixel values. A maximum of 155 would display the faint stars best, though they would still be visible with higher maxima (such as 300 or 400).

Lesson 2: Opening an Astronomical Image

- Step 3
 - What can you do to make fainter pixels easier to see? Lower the maximum displayed pixel value.
- Step 4
 - Can you see the five galaxies now? Approximate (x,y) coordinates of the galaxy centers are: (490, 370), (660, 475), (713, 478), (483, 640) and (870, 684).

Lesson 3: Measuring Star Brightnesses

- Additional questions and exercises for the diligent student
 1. What would happen to your number of counts if the camera shutter had been open twice as long? The counts would double. Likewise, if the exposure had been half the length, the counts would be halved.

Appendix

Useful Websites

- **An Introduction to Astronomical Image Processing With ImageJ**, a handbook to many astronomical uses of ImageJ, as well as links to additional resources:
www.astro.physik.uni-goettingen.de/~hessman/ImageJ/Book/
- The ImageJ Homepage, where you can download the latest version of ImageJ:
<http://rsbweb.nih.gov/ij/>
- **Dr. Frederic Hessman's Astronomy Plugin Tools for ImageJ**, the plugin toolset we have incorporated into ImageJ:
www.astro.physik.uni-goettingen.de/~hessman/ImageJ/Astronomy/