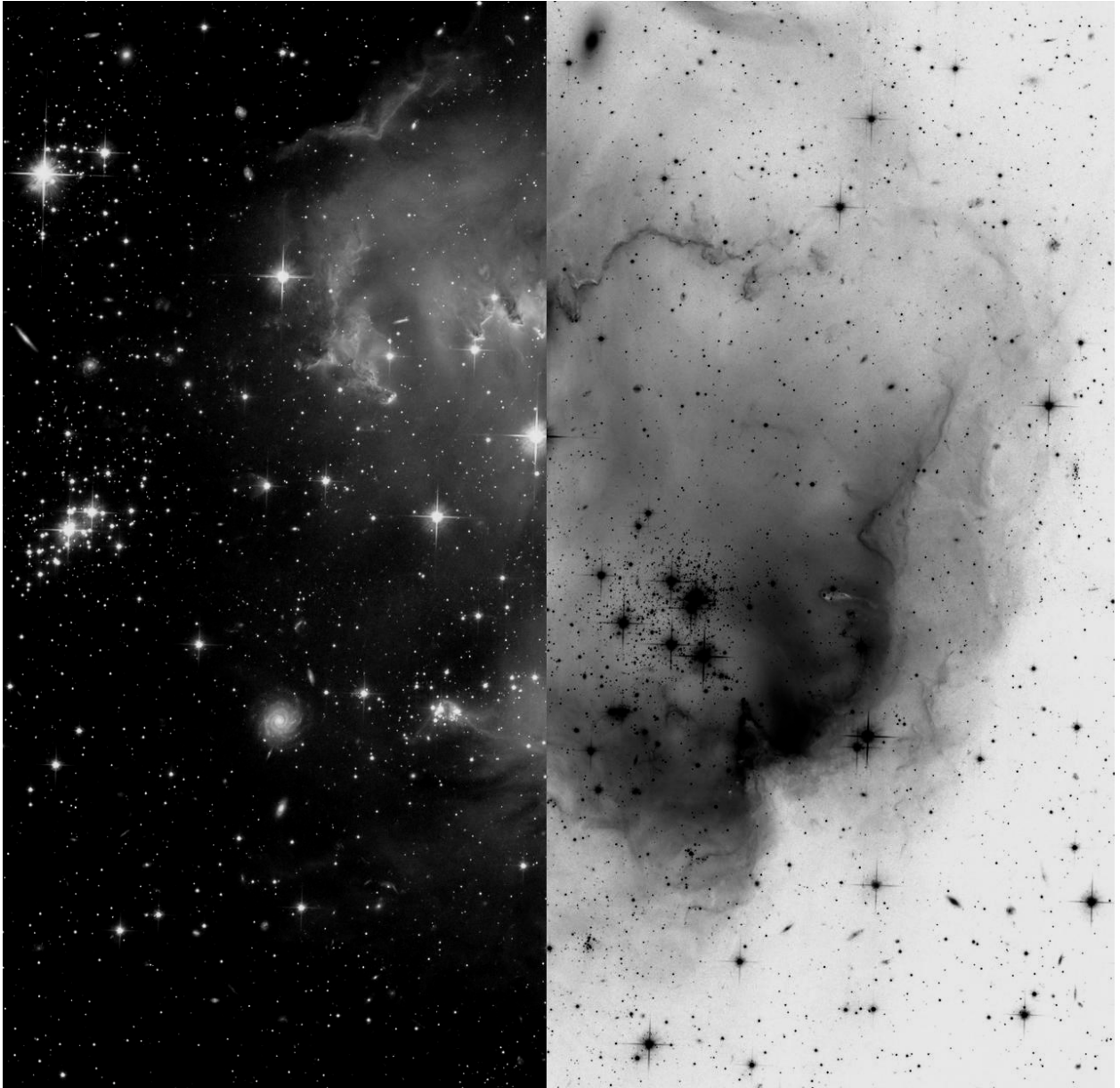# ImageJ Activity Booklet

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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.

You'll begin with a set of instructions for downloading 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 4 lessons that will help you get oriented with some of the most basic image processing skills needed for analyzing astronomical images and making color pictures. There are questions throughout the lessons to help guide your thinking (the answers are provided at the end).

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 (Summer 2012, using ImageJ version 1.45s ,and Astronomy Plugins version 2011-12-23). 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. Also, it is highly recommended to use Mozilla Firefox (http://www.mozilla.org/) for downloading the software and FITS images (Internet Explorer is especially discouraged).

Downloading and Installing ImageJ and the Astronomy Plugins

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

ImageJ is a free image processing and analysis program that should work on any modern PC or Mac (with Java). It is published by the National Institutes of Health, and was originally designed for medical professionals that work with electronic imaging. It also works extremely well with astronomical images, especially if you install the astronomy plugins provided below. The plugins were created by Dr. Frederic Hessman at the University of Göttingen in Germany for use by classrooms and teachers for images taken with the MONET telescopes, and will work with almost any electronic image.

1. To download ImageJ, 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, and close it after you verify that it works.

Note: it is recommended to download the most recent version of ImageJ. However, if you run into problems try downloading version 1.45s instead - this was the last version verified to work well.

Next, you'll need to install all of the astronomy-specific tools…

3. Go to this next web page: [DO NOT POST THIS LINK ON ANY OTHER WEBSITE]http://www.uni-sw.gwdg.de/~hessman/ImageJ/Astronomy/

4. Download the zip file entitled **'Astronomy.zip'** to your desktop. *(Again, please download the most recent version. However, the last verified version is 2011-12-23)*

Now it's time to install everything in the correct places…

5. Unzip (extract) the **'Astronomy.zip'** file onto your desktop.

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 window" (or "finder window") so that you can move files around.

7. Double click on the **'Hard Drive'/'My Computer'** icon again to open a SECOND "explorer window". -In one window (the first) you want to be able to look through the astronomy folder that you just unzipped, and in the other window (the second) you want to be able to look at ImageJ and its associated files.

8. In the first window navigate to the **'Astronomy'** folder from the desktop. -You should see two folders, **'plugins'** and **'macros'**.

9. Double click into the **'plugins'** folder. -You should see four items (2 subfolders and 2 .jar files).

10. In your second window double click on **'Applications'** folder (Mac), or the **'Program Files'** folder (PC) [or **'Program Files (x86)'**].

11. Navigate to and double click on the **'ImageJ'** folder. -You should be looking at all of the folders and files within **'ImageJ'** (about 11 total) including one folder in particular labeled **'plugins'.**

12. Look BACK at your first window (the **'Astronomy'** folder that you just unzipped). Highlight all four items within the unzipped **'Astronomy'** folder. (*another* Astronomy folder, CCD folder, astroj.jar, Astronomy.jar)

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

14. Within that first window were originally two folders. Go back and click into the other folder now - the **'macros'** folder. -You should see a subfolder labeled **'toolsets'**.

15. Double click into **'toolsets'**. -You should see one file labeled **'astronomytools.txt'.**

16. In your second window (looking at ImageJ files), double click on the folder labeled '**macros**'. -You should be looking at a long list of .txt files and 2 subfolders, one of which is labeled '**toolsets**'.

17. In your first window highlight '**astronomytools.txt**', then drag it over to the other explorer window and place into the '**toolsets**' folder.
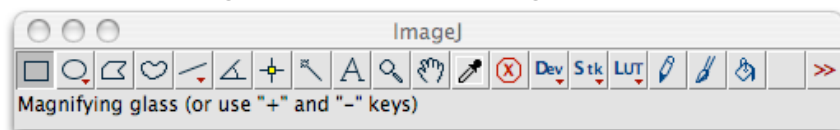
18. Close the first window (it's now basically just empty folders). Leave the second one open.

19. If ImageJ is running, restart it. Or if it was not running, 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' -Several of the toolbar icons will change, now appearing something like so:

Almost done! You just have one last item to download and install…

22. Close ImageJ.

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

24. Save/download that file. It will most likely download to your desktop, but wherever it downloads make sure you know where it is.

25. Now go back to the already-opened window from the previous steps (which should currently be looking at the …ImageJ -> macros folder).

26. Click back one step so that you're once again looking at the files and subfolders inside the ImageJ folder (about 11 total).

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'**.

29. Close all windows.

Pat yourself on the back. You're finished installing 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 and the Astronomy plugins 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.
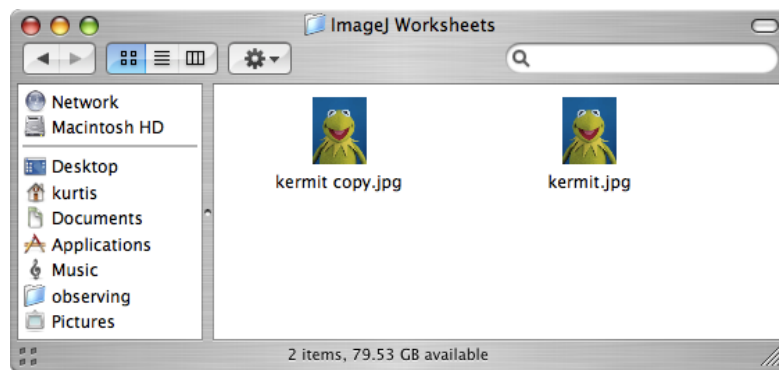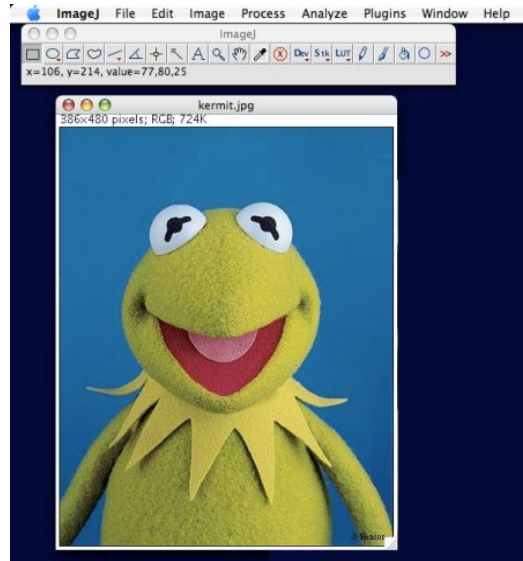

3. Open the image with ImageJ.
   - Start ImageJ by double-clicking on the microscope icon in the ImageJ folder.

   - Click on "File", then "Open", and then locate the copy you made in the last step.
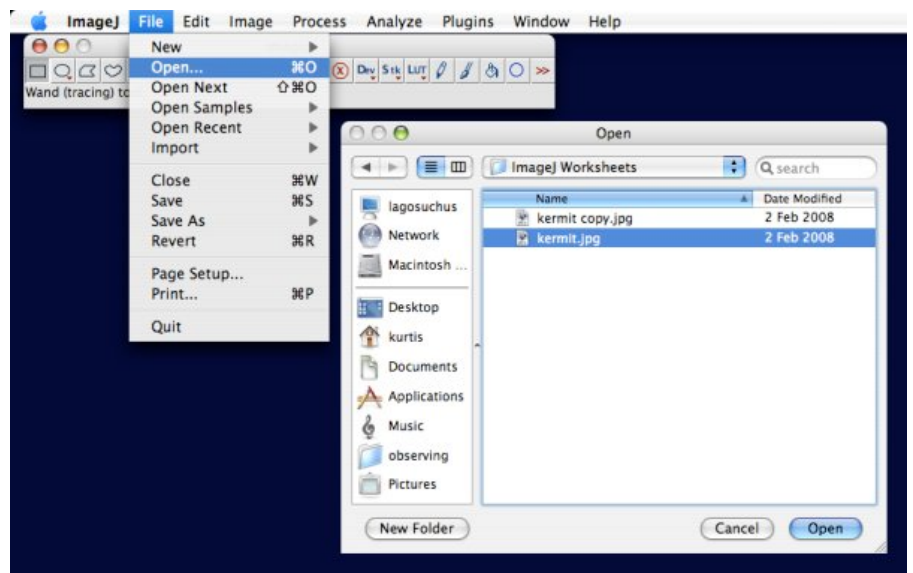
- The picture should pop
  open.

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 <u>a pixel is the smallest unit of a digital image.</u>

- You can zoom back out by pressing the – key, or with the magnifying glass tool by holding the 'Alt' key and clicking on the image.
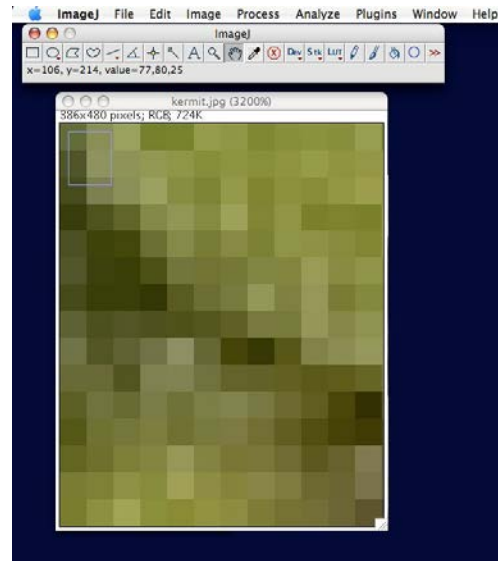
6. Convert the image to grayscale (black and white). Because astronomy images are in grayscale, and because grayscale is a little easier to understand, let's convert your color image to grayscale.

- In the ImageJ menus, go to "Image" → "Type" → "8-bit." Voila! Your image is in grayscale.
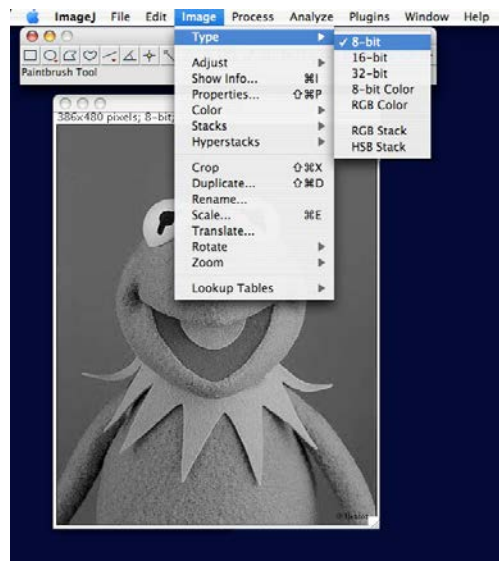
- Save the image with a different name: "File" → "Save As" → "Jpeg…"

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"
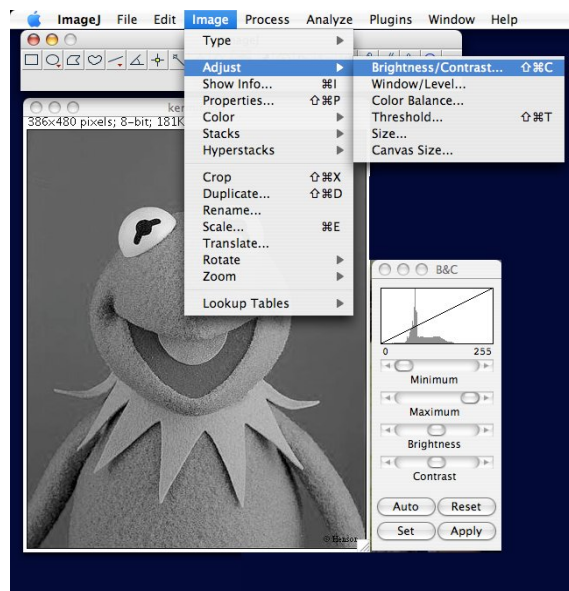
   - Slide the bars controlling brightness and contrast around. What is the difference between adjusting the brightness and adjusting the contrast?
   - Click "Reset" to go back to the default settings.
   - Zoom in as far as you can on part of the image. Find a single pixel to follow. What is its x and 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 van 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?
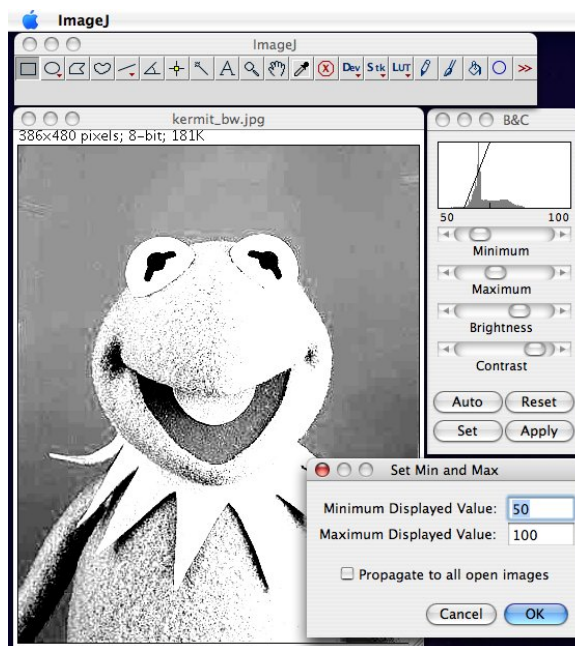
   - Move your mouse over pure white and pure black areas. Look at the pixel values. Are they outside your minimum and maximum range (they should be)?
   - Now, click on the "Set" button again. Set the minimum value to –100, and the maximum value to 350. Click "OK". What happens?

- 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 that are very large - some as high as 65,535, some even larger. 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 300 out of 65,535 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 need a computer with ImageJ and the Astronomy plugins installed, and the image file quintet.fits, downloadable from
http://cse.ssl.berkeley.edu/cms/ImageJGuideMaterials/tabid/305/Default.aspx
Note: Be sure to option-click (Mac) or right-click (PC) and 'Save Link As…'

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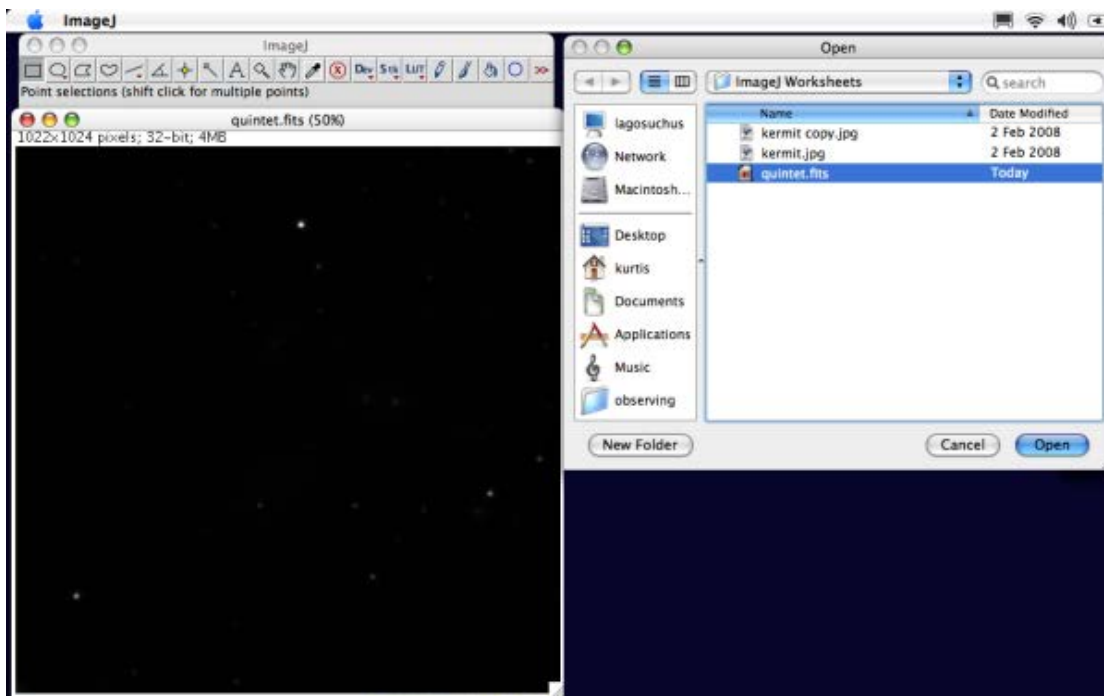
   This picture is of Stephan's Quintet, a group of four related (and one unrelated) galaxies. Can you see five galaxies in the image? We can't.

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? Some FITS images can have seemingly arbitrary pixel values, and might include decimal points. This allows astronomical cameras to count

individual photons; many astronomical cameras go up to 65,535, and some can even approach 4.3 billion. 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 okay, but not great.
- 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.
  - Minimum Displayed Value: In a majority of astronomical pictures, most of the pixels will be blank sky. Close the 'Set' window, move your pointer around the picture, especially in the parts that are likely to be blank sky with no gas or dust. Look for the lowest typical pixel value (in the case of quintet.fits, I would guess it is around 350. Do you agree?). Press 'Set' again and input 350 to be the minimum.
  - Maximum Displayed Value: The maximum value is a little harder to choose. It takes some experimentation and depends on what details you want to bring out. Typically you'll want to
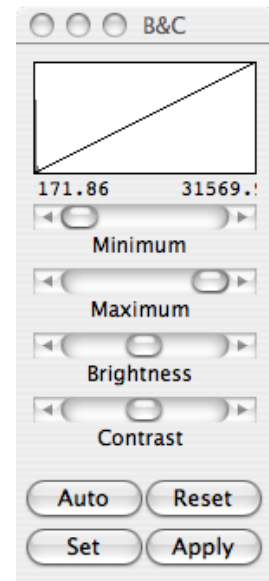
sky doesn't look washed out, mottled, or speckled. A good starting guess for the maximum for many images is to add 500 to the minimum value (850 here). Click OK. Can you see the five galaxies now?
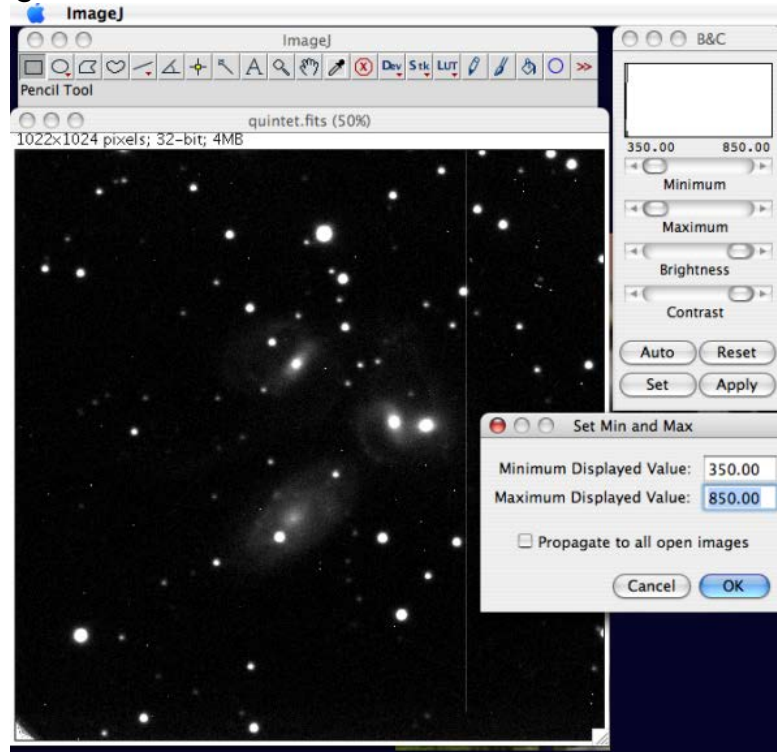
Remember from Lesson 1: changing the brightness and contrast does not change the pixel value; it only helps you to see the image better. So feel free to adjust the brightness and contrast however you want. Remember, the goal is to see faint objects – the bright ones will always be visible as pure white 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.
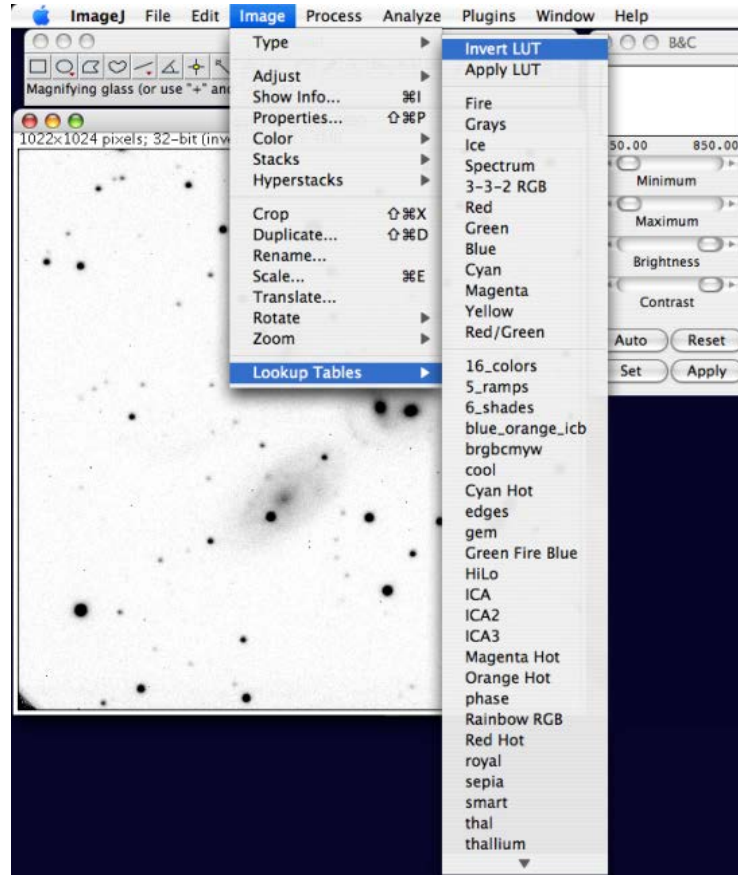
Important! Do not use Edit → Invert, because this changes the pixel values!!

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 ImageJ. 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.

Lesson 3: 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
http://cse.ssl.berkeley.edu/cms/ImageJGuideMaterials/tabid/305/Default.aspx

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 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.

To begin, you'll want to open several 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 Messier 16 (a.k.a. the Eagle Nebula, famous for the "Pillars of Creation" from Hubble), taken through the B, V, and R filters. Use ImageJ to open each image (M16B.fits, M16V.fits, M16R.fits) so you have three open images.
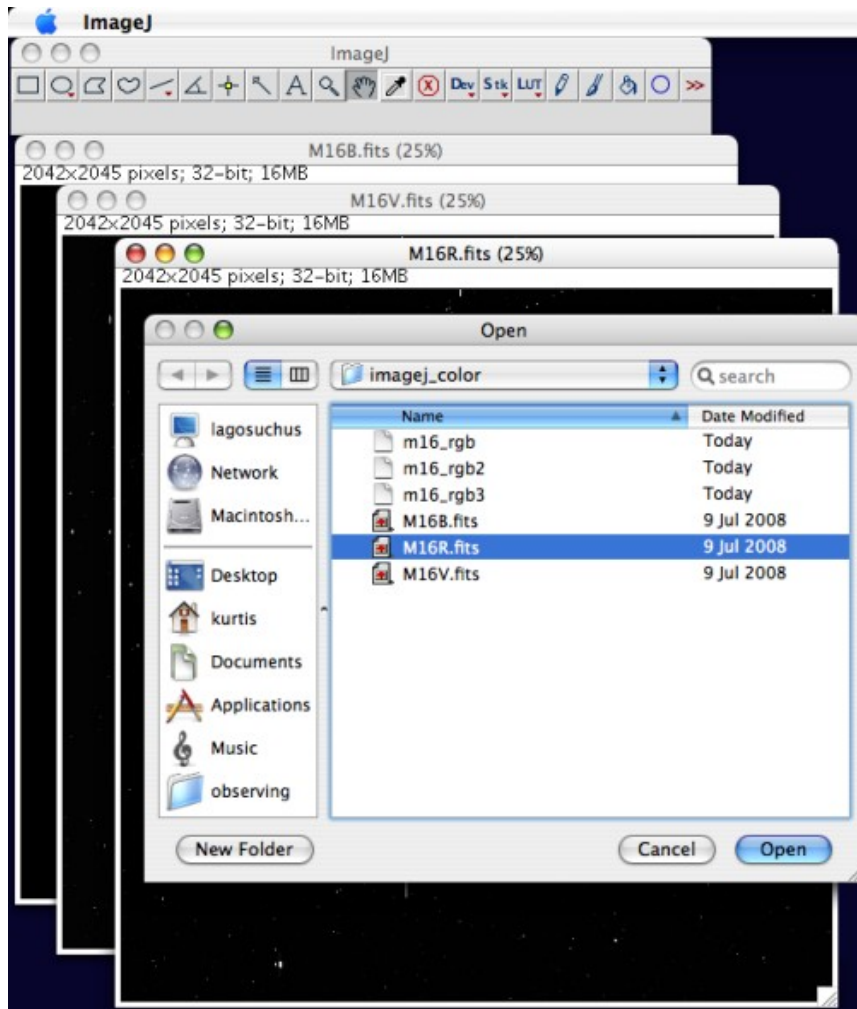

1. Convert each image to a logarithmic stretch. CCDs take linear images, such that each incoming photon is turned into a set number of image "counts." However, a logarithmic stretch is generally preferred, because this brings out faint objects while still allowing your eye to discern brightness differences 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.

Don't worry if the images suddenly become dark or washed out, you'll fix that in the next step.

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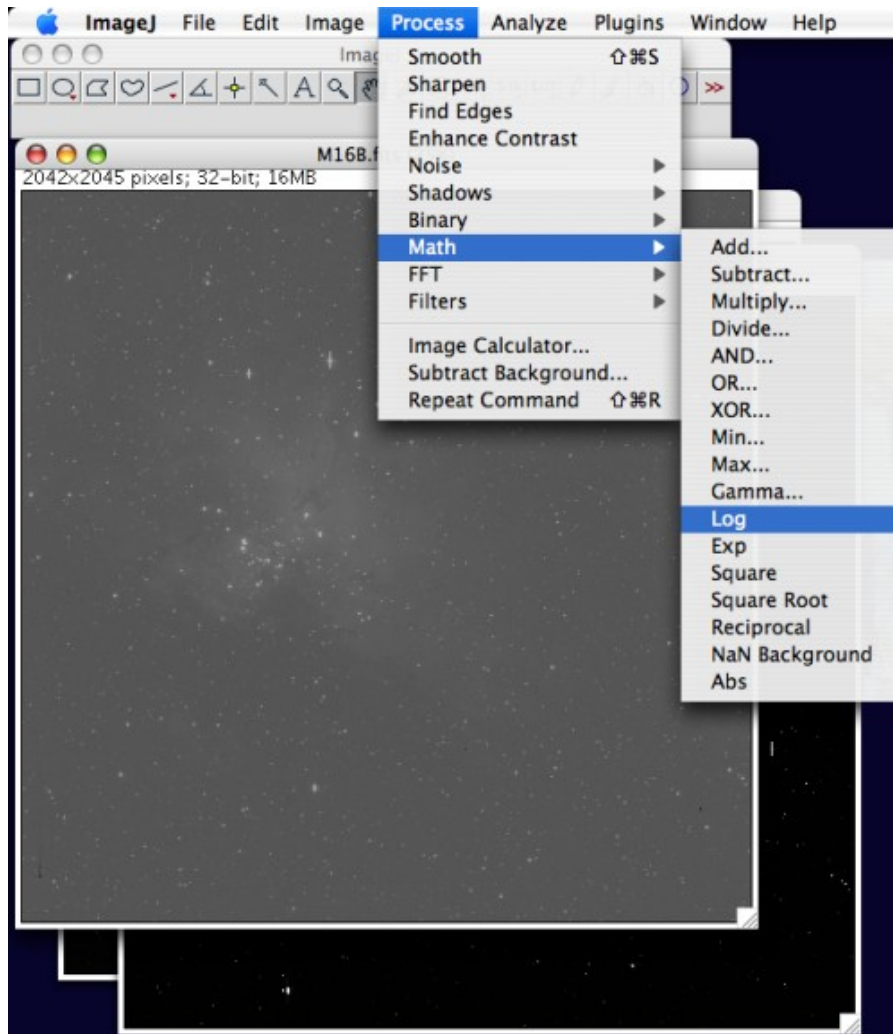

2. Adjust the Brightness/Contrast in each image. Do this in the same way you learned in Lesson 2, Step 4.

("Image" → "Adjust" → "Brightness/Contrast")
Note: since we took the logarithm of the images, the pixel value ranges are much smaller. A good starting point is to run the cursor around each image and look at typical values in the dark background sky, and set this to your min value. Then add 2 or 3 for the max value.

3. 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".

   The RGB Composer window will open as well as a new color image.
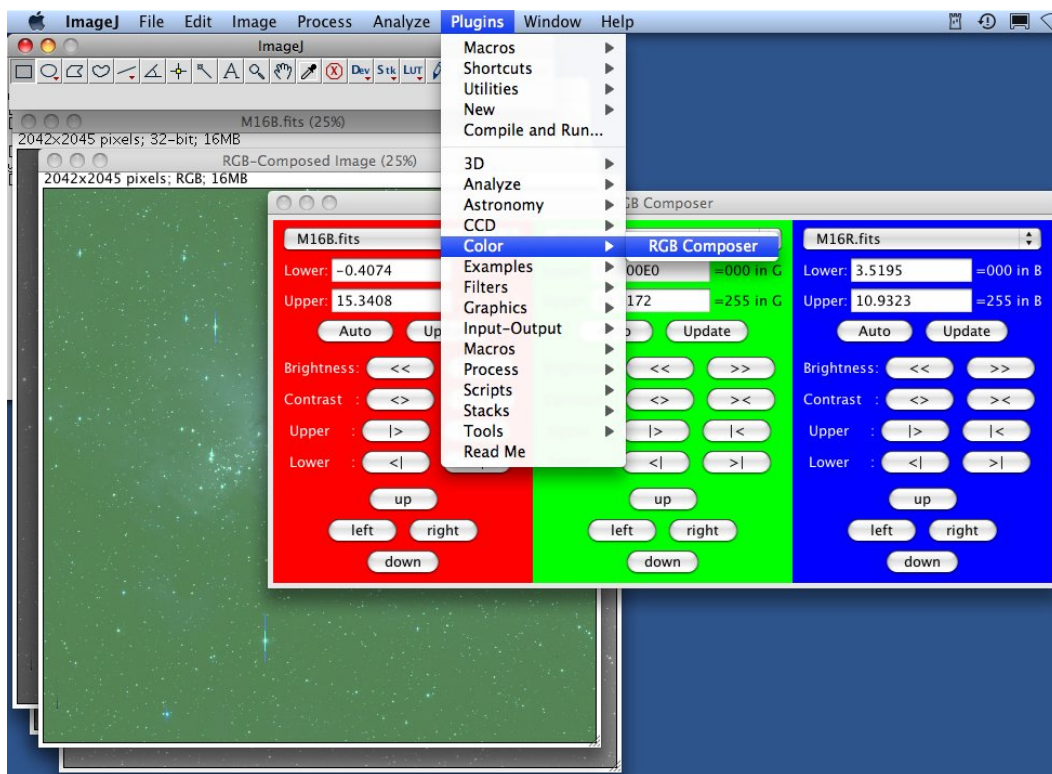
4. Select the appropriate image for each color. In the RGB Composer popup window, select which image you want to use for the red, green, and blue portions of your image. (R=red, B=blue, V=green [think 'verde' in Spanish]). Select each image from the pull-down menu at the top of each column, then click 'Update' for each one.

5. Fine-tune the brightness and contrast of each color. The RGB Composer contains controls the brightness, contrast, upper, and lower limits for each color. Play around with these controls and watch what happens to the color image. 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.

Don't hesitate to zoom in on your object, and go for what looks pretty!

Here are my final values and the resulting image:
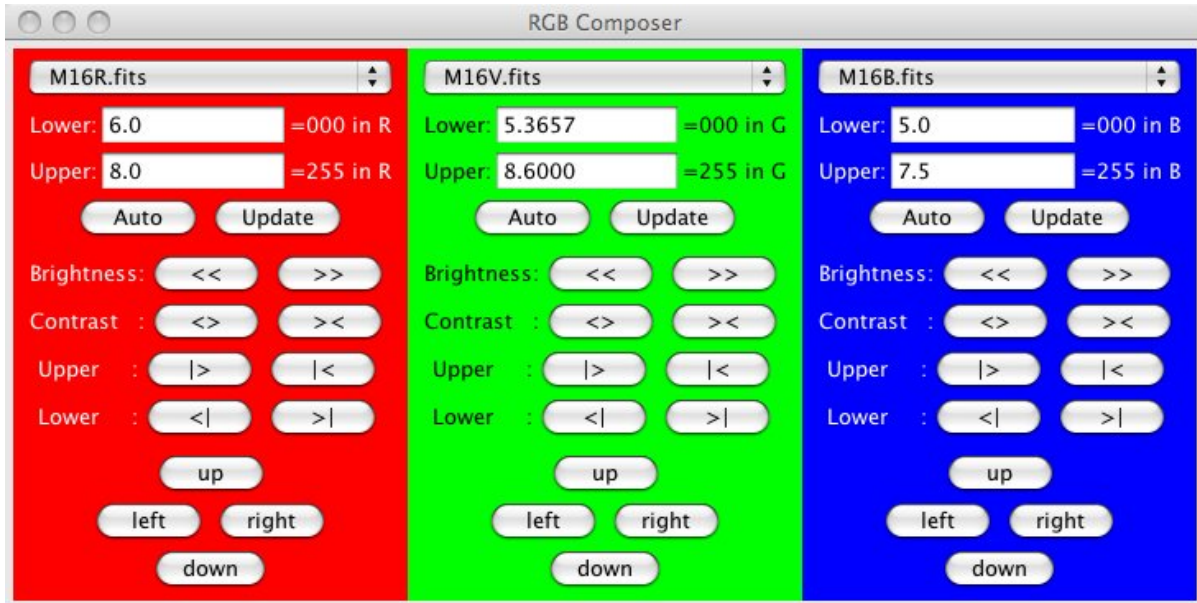
Some tips:

- 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.
- Oftentimes, astronomical images will need to be aligned, meaning that all the stars should appear on the same pixels in the color image. 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
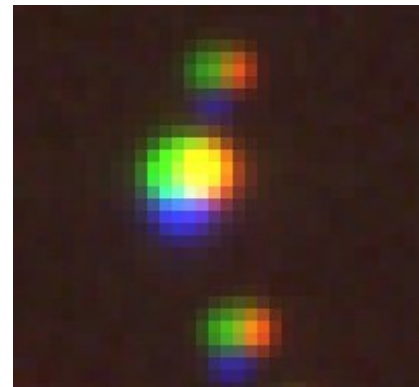
eye more pixels from which to get the color. In ImageJ, try the Gaussian blur filter (Process → Filters → Gaussian Blur) with a radius of 3 pixels. You'll have to re-adjust the brightness and contrast, and you'll lose the faintest stars.

- 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 bluish 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 settings, and different settings bring out different features of the nebula.

If you're itching to make some more color images, try out the Zeta Ophiuchi infrared images (from NASA's WISE mission) and the M51 images (from the MONET-North telescope) on the materials website.
Note: The M51 images do not need to be logarithmically stretched, but they will need to be aligned.

Lesson 4: Measuring Star Brightnesses

(for advanced users)

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
Note: Be sure to option-click (Mac) or right-click (PC) and 'Save Link As…'

First, some background. Astronomical cameras count the number of photons of 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 the 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 automates 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, invert it, 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:
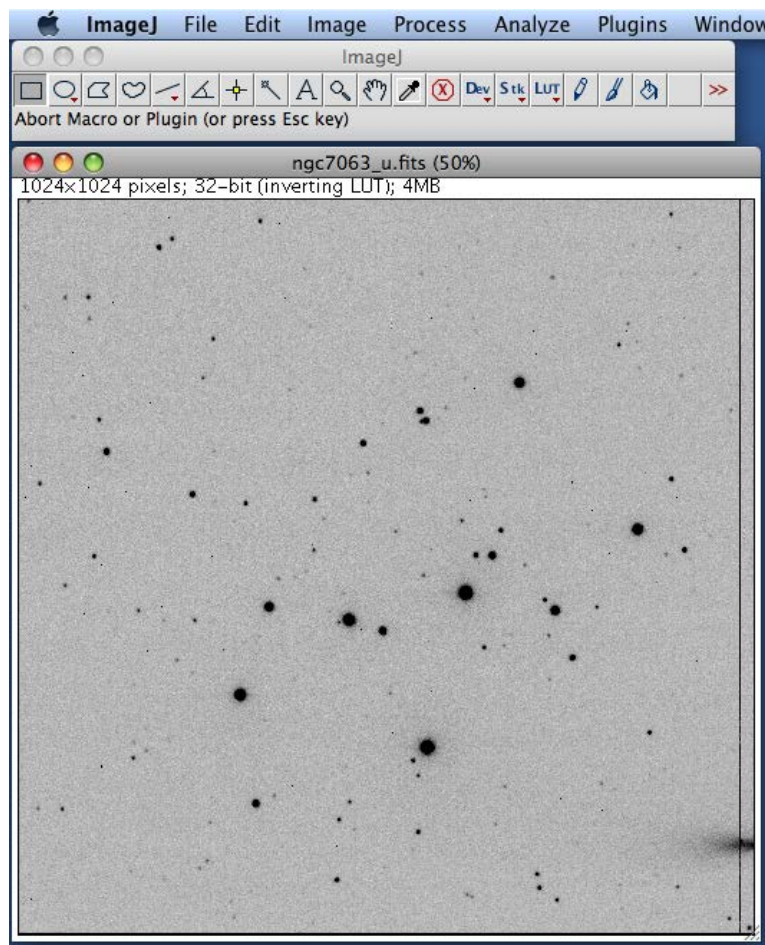
      Simple but Important Thought Questions: What shape are the stars? Zoom in, if needed, to get a clear view. If we want to measure all of the light coming from a star, what shape of measuring tool should we use?

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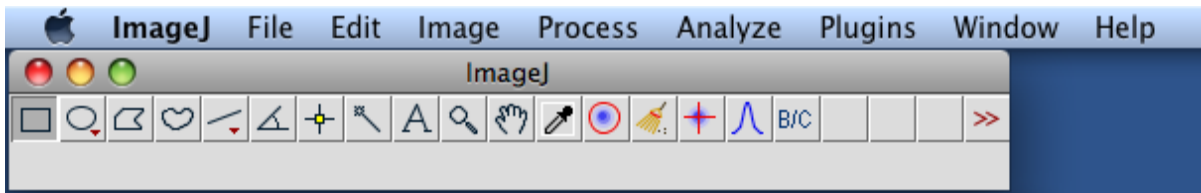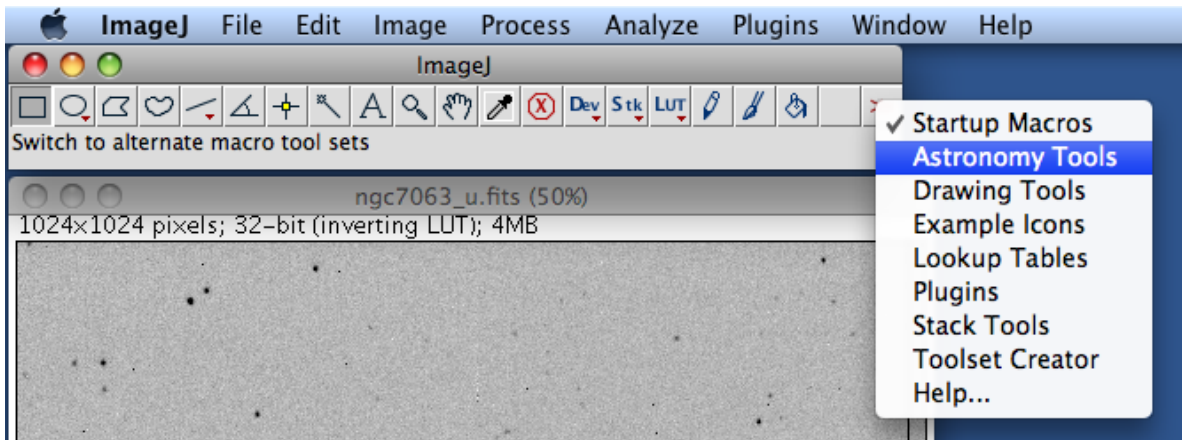
3. Select the aperture photometry tool. Since stars are circles, we want to measure how bright the stars are using a circular region; this is called *aperture photometry*. The icon of the blue smudge inside a red circle is the Aperture Photometry Tool. Double-click on this icon to open the aperture photometry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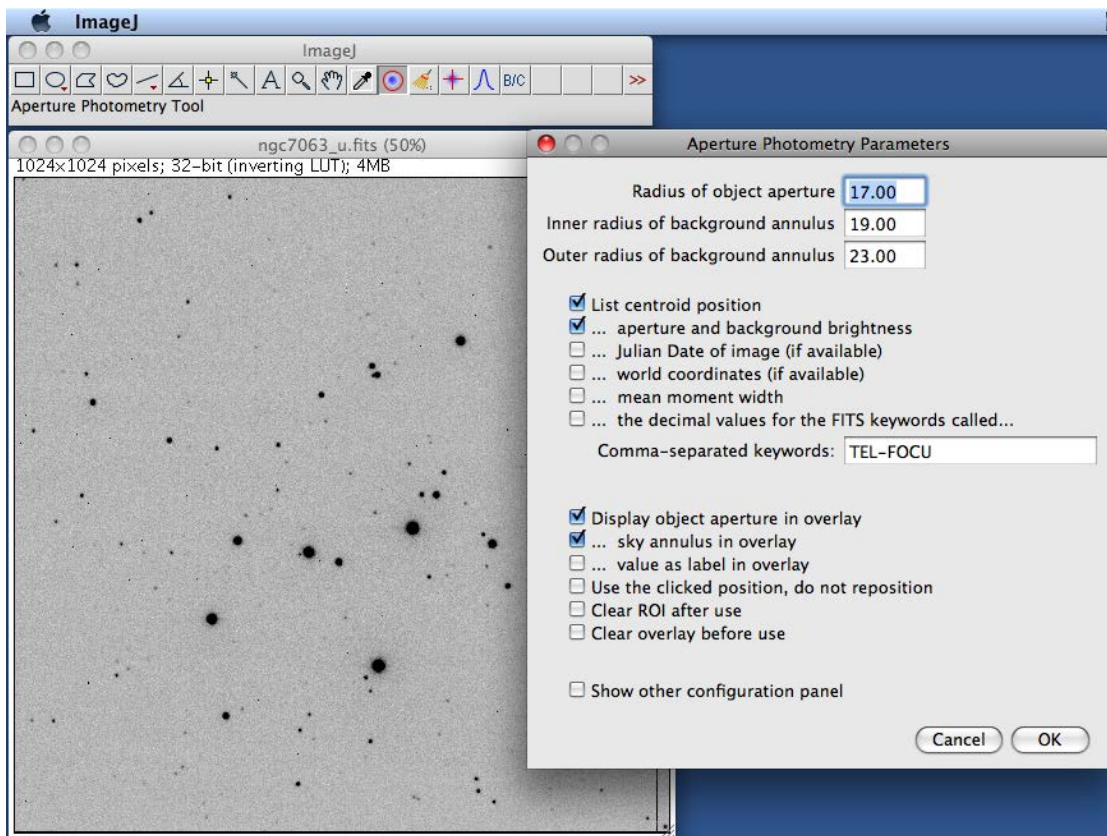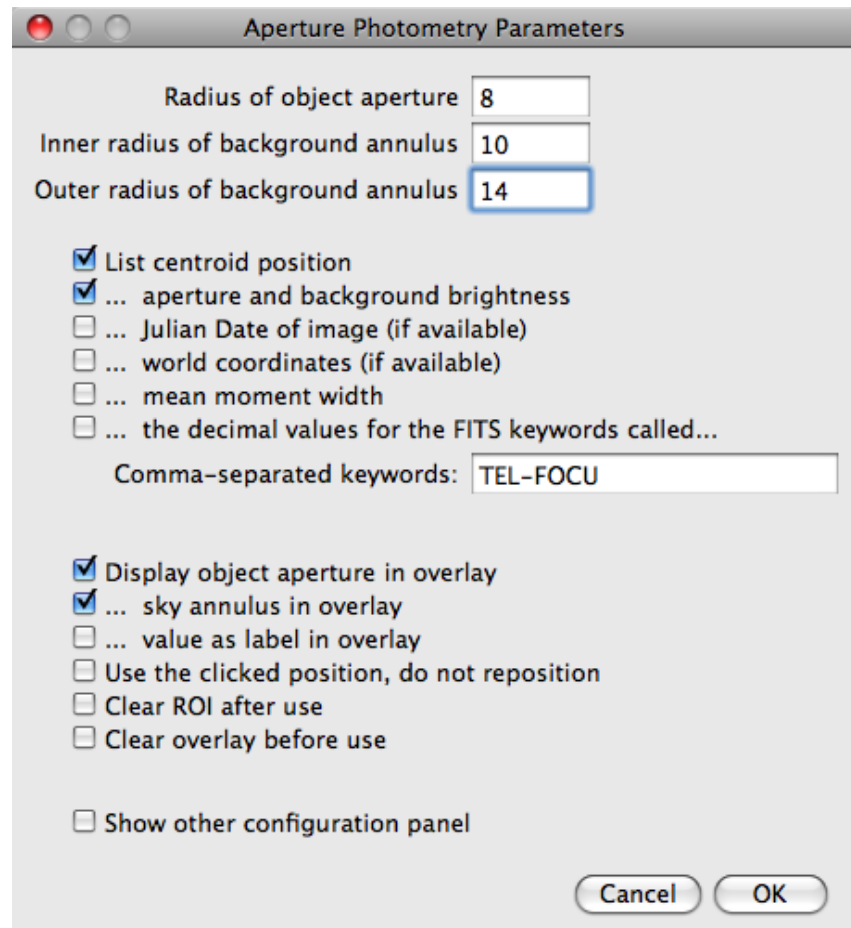
4. Set the aperture photometry parameters.

- Set the object aperture radius. Although brighter stars look bigger in the pictures, each star's light extends out the same radius (please trust us on this). 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 (you may need to close the aperture window to do this). 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 6-12 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 (or "Show centroid position") is checked.
  - We also need to know the total amount of light from the star, so check the "...aperture and background brightness" box (or "Show aperture integrated counts" plus "Show sky brightness").
 - 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.

   o And, if you want to make sure that there aren't other stars in your sky measurement, check on the "...sky annulus in overlay" box (or "Display sky annulus in overlay").

- Click OK.

Aperture Photometry Parameters

Radius of object aperture `8`

Inner radius of background annulus `10`

Outer radius of background annulus `14`

☑ List centroid position
☑ ... aperture and background brightness
☐ ... Julian Date of image (if available)
☐ ... world coordinates (if available)
☐ ... mean moment width
☐ ... the decimal values for the FITS keywords called...

Comma-separated keywords: `TEL-FOCU`

☑ Display object aperture in overlay
☑ ... sky annulus in overlay
☐ ... value as label in overlay
☐ Use the clicked position, do not reposition
☐ Clear ROI after use
☐ Clear overlay before use

☐ Show other configuration panel

(Cancel) (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:
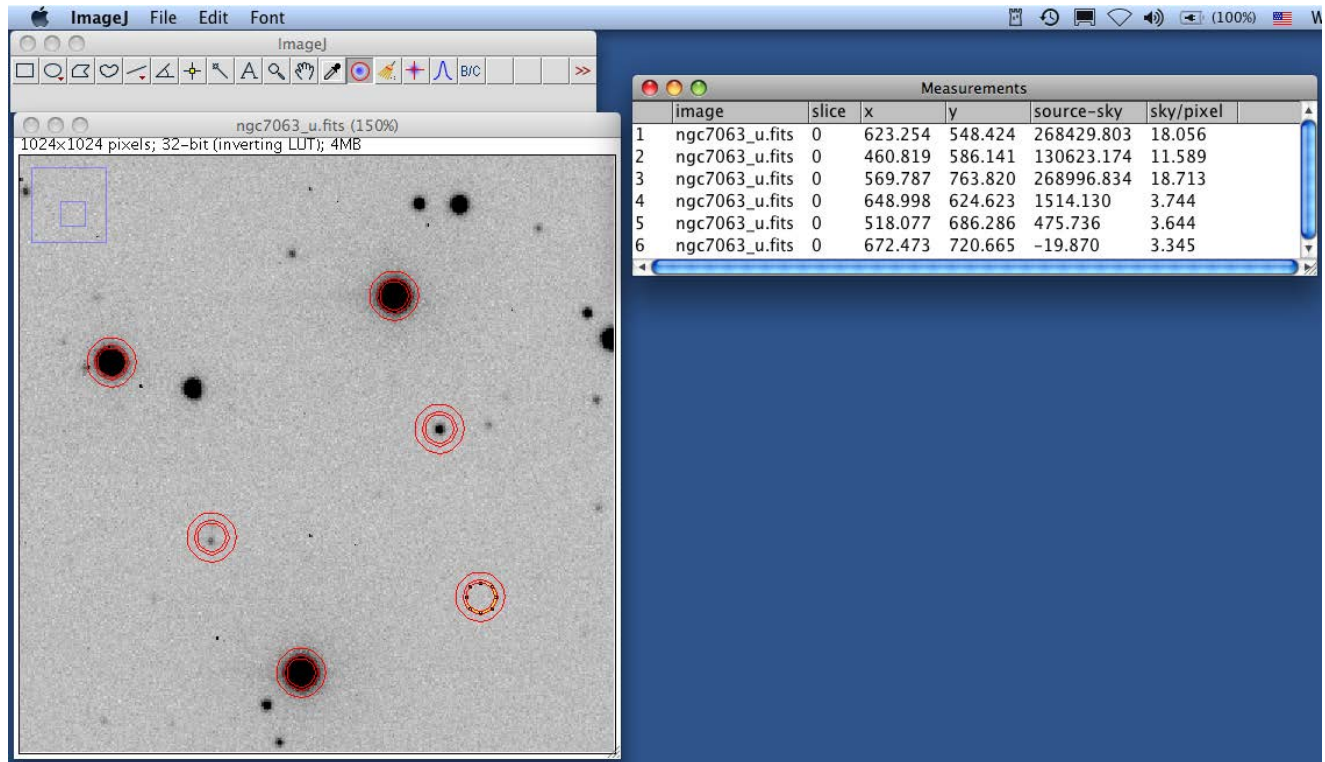
6. If you click in the wrong place, don't panic. My star 5, the circle on the faint star in the lower left part of the frame, didn't center right. That's because of an even fainter nearby star. This means I probably have a bad measurement on this star. Also notice my star number 6 has negative counts; 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. You can always delete them later after you export them into a spreadsheet; you can keep measuring stars in other parts of the image for now.

7. Export your data for use in a spreadsheet. In most cases, you are going to want to do math with the star brightnesses, and 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).
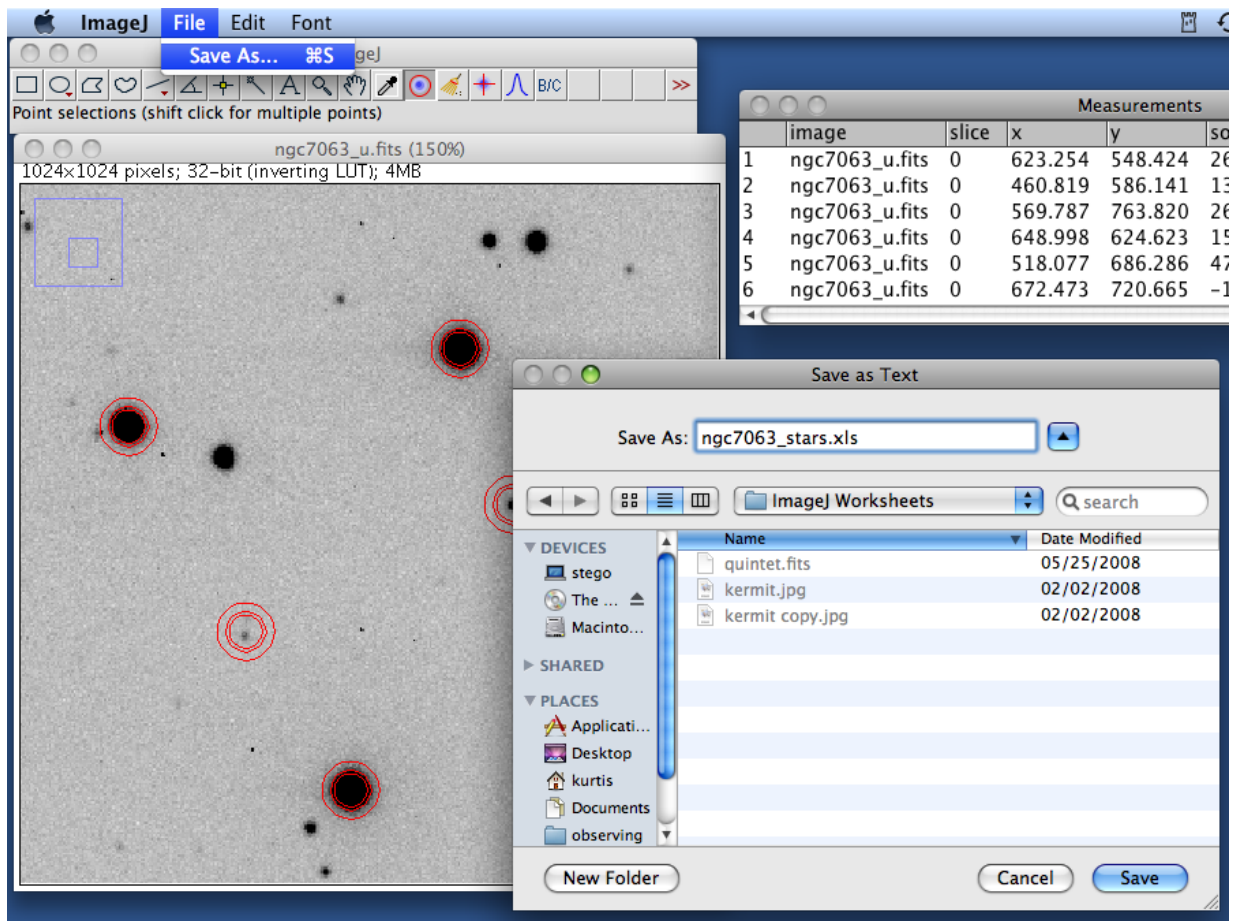
Conclusions: After completing a run through this lesson, you should be able to determine the sizes of stars in your image, to adjust the radii of your star aperture and sky annulus, to obtain measurements of the positions and source counts for multiple stars, and to save those data to a file.

Going further… questions and exercises you might attempt:
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?
- Turn your star photon counts into raw magnitudes: Open the results file you saved above in your favorite spreadsheet. 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.

Answer Key

Lessons 1 to 4

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 300 would display the faint stars best, though they would still be visible with higher maxima (such as 400 or 500).

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 4: Measuring Star Brightnesses
- Going further, questions and exercises you might attempt:
  - 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:
`http://www.uni-sw.gwdg.de/~hessman/ImageJ/Book/index.html`

• 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:
`http://www.uni-sw.gwdg.de/~hessman/ImageJ/Astronomy/`

National Science Education Standards covered in this activity:

Science Grades 5-8:
- Science as Inquiry (Std A): Abilities necessary to do scientific inquiry, Understanding about scientific inquiry
- Science and Technology (Std E): Abilities of technological design, Understanding about science and technology

Science Grades 9-12:
- Science as Inquiry (Std A): Abilities necessary to do scientific inquiry, Understanding about scientific inquiry
- Science and Technology (Std E): Abilities of technological design, Understanding about science and technology

National Educational Technology Standards (from ISTE) covered in this activity:

BASIC OPERATIONS AND CONCEPTS
- Students demonstrate a sound understanding of the nature and operation of technology systems.
- Students are proficient in the use of technology.

SOCIAL, ETHICAL AND HUMAN ISSUES
- Students practice responsible use of technology systems, information, and software.
- Students develop positive attitudes toward technology uses that support lifelong learning, collaboration, personal pursuits, and productivity.

TECHNOLOGY PRODUCTIVITY TOOLS
- Students use technology tools to enhance learning, increase productivity, and promote creativity.

TECHNOLOGY RESEARCH TOOLS
- Students use technology to locate, evaluate, and collect information from a variety of sources.
- Students use technology tools to process data and report
- results.