X-Ray Vision: Seeing Into Space

Objective

Learn about how and why NASA false-colors x-ray images; then follow the same procedure to create your own images and compare them to the NASA ones.

Introduction

Have you ever looked up at the night sky and seen hundreds, if not thousands, of stars? Or imagined seeing fantastic objects like supernovas, black holes, or even entire galaxies up close? You might not be able to see them with your naked eye, but powerful **telescopes** allow us to see deep into space and to detect objects that are incredibly far away.

You can see the stars because they emit *visible light*, but visible light is just one type of **electromagnetic radiation**. Humans can only actually *see* a very small part of the **electromagnetic spectrum**, which includes other types of radiation like radio waves and **x-rays** (Figure 1). Electromagnetic radiation consists of *waves* of radiation with a certain **wavelength**. A wave with a shorter wavelength has a higher **frequency**. High-frequency waves have more energy, so objects that are very hot tend to emit high-energy (and thus high frequency) radiation, like x-rays.

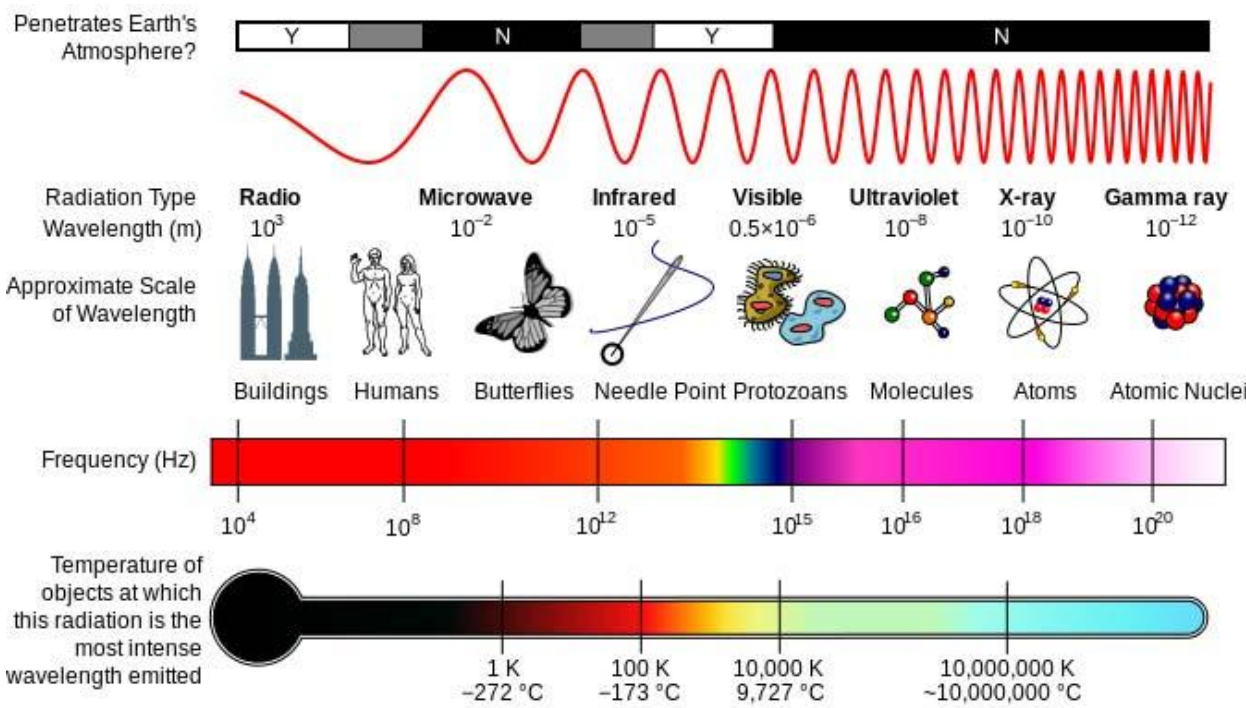

Figure 1. This diagram of the electromagnetic spectrum shows the wavelengths and frequencies of different types of radiation, along with the temperature of objects that emit them. Remember that the human eye can only see visible light, which is a very small part of the whole electromagnetic spectrum. Note that "K" stands for *Kelvin*, a unit used to measure temperature (Wikimedia Commons user Inductive load, 2007).

It turns out that stars do not just emit visible light; they also emit other types of radiation. So, organizations like the National Aeronautics and Space Administration (NASA) use powerful telescopes that can "see" other types of radiation, and detect objects that are much too far away for the unaided human eye to see. This helps scientists learn more about the formation of our universe.

This astronomy science project will focus in on one such telescope, the **Chandra X-ray Observatory**, which is a satellite that is currently (as of 2013) orbiting Earth. This satellite can take x-ray images of faraway objects in space. As shown in Figure 1, objects that emit x-rays tend to be very hot, so observing x-rays can tell scientists information about very hot, energetic objects in space like **supernovas** (exploding stars), **nebulas** (huge clouds of dust and gas in space), and even regions near **black holes**. We would not be able to learn as much about these objects if we *only* looked at them with visible light.

Figure 2. shows two images from the Chandra X-ray Observatory. But wait a minute; you just learned that we cannot actually *see* x-rays, so where did the color images in Figure 2 come from? Well, the Chandra Observatory works kind of like a digital camera, but it records x-rays instead of visible light. Digital cameras record numbers corresponding to the intensity of red, green, and blue (RGB) light. Red, green and blue light have slightly different wavelengths in the "visible" part of the electromagnetic spectrum. Red light has the lowest frequency, so it has the lowest energy, blue light has the highest frequency (and thus highest energy), and green is in the middle. Similarly, Chandra records a number for low-, medium-, and high-energy x-rays, but those x-rays do not have a "color," because we cannot see them. So, NASA scientists use a photo editing program to create a **false-color image** by assigning a color to each x-ray energy band. NASA scientists usually assign red to low energy, green to medium energy, and blue to high energy (corresponding to visible light, also called *rescaling*). The photos you see in Figure 2 are the result of that process.

Figure 2. Two false-colored images taken by the Chandra X-ray Observatory. (Left) Centaurus A, a nearby galaxy with a super-massive black hole in the middle. (Right) SN 1006, the remnants of a supernova.

But, what exactly does that process look like from the beginning? That is what you will find out in this science project. Figure 3 shows the original low-, medium-, and high-energy band x-ray images of the supernova Cassiopeia A. Notice how the photos are black and white (referred to as a *grayscale* image), because no color has been added yet. Bright areas correspond to where x-rays in that energy band were detected, and black areas correspond to where no x-rays in that energy band were detected.

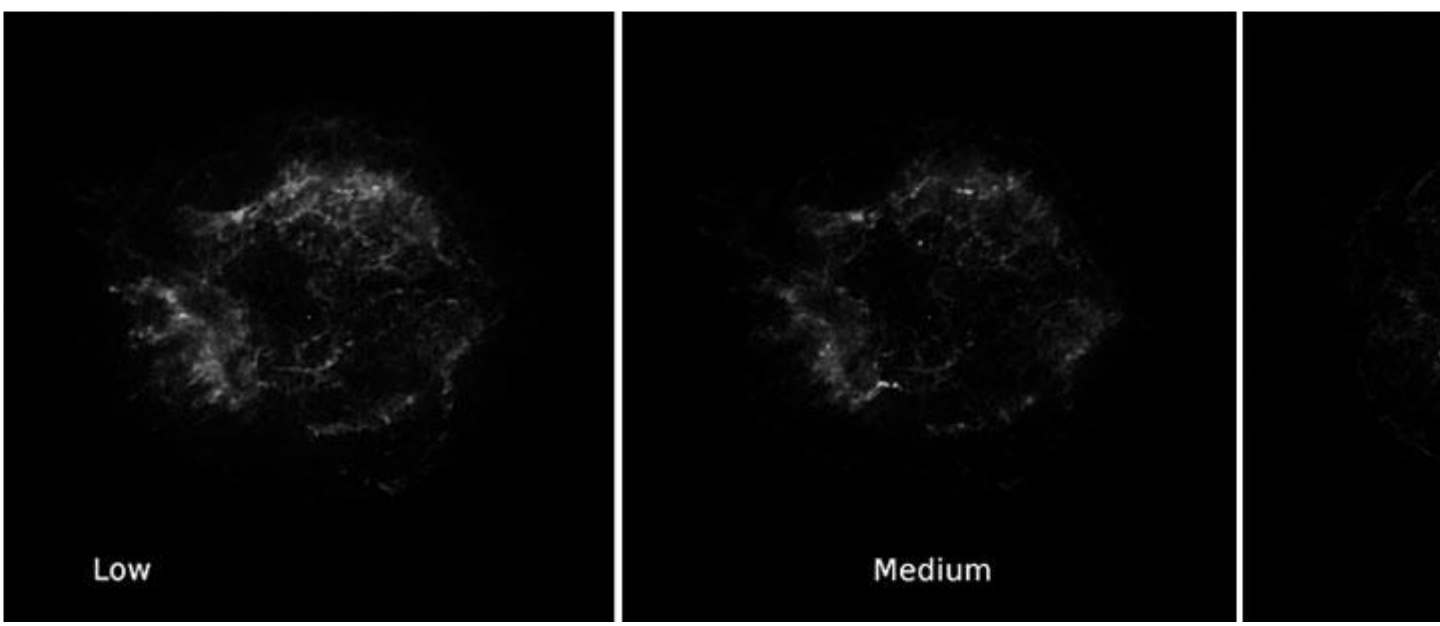

Figure 3. The Chandra telescope's raw low-, medium-, and high-energy band x-ray data of the supernova Cassiopeia A.

You probably notice that the images in Figure 3 look very dark relative to the ones in Figure 2. This can be fixed by adjusting the images' *levels* with image-editing software. This is *not* the same as just adjusting the image's brightness; it allows you to brighten some areas of the image while leaving others dark (or vice versa). You will learn more about this process in the Procedure.

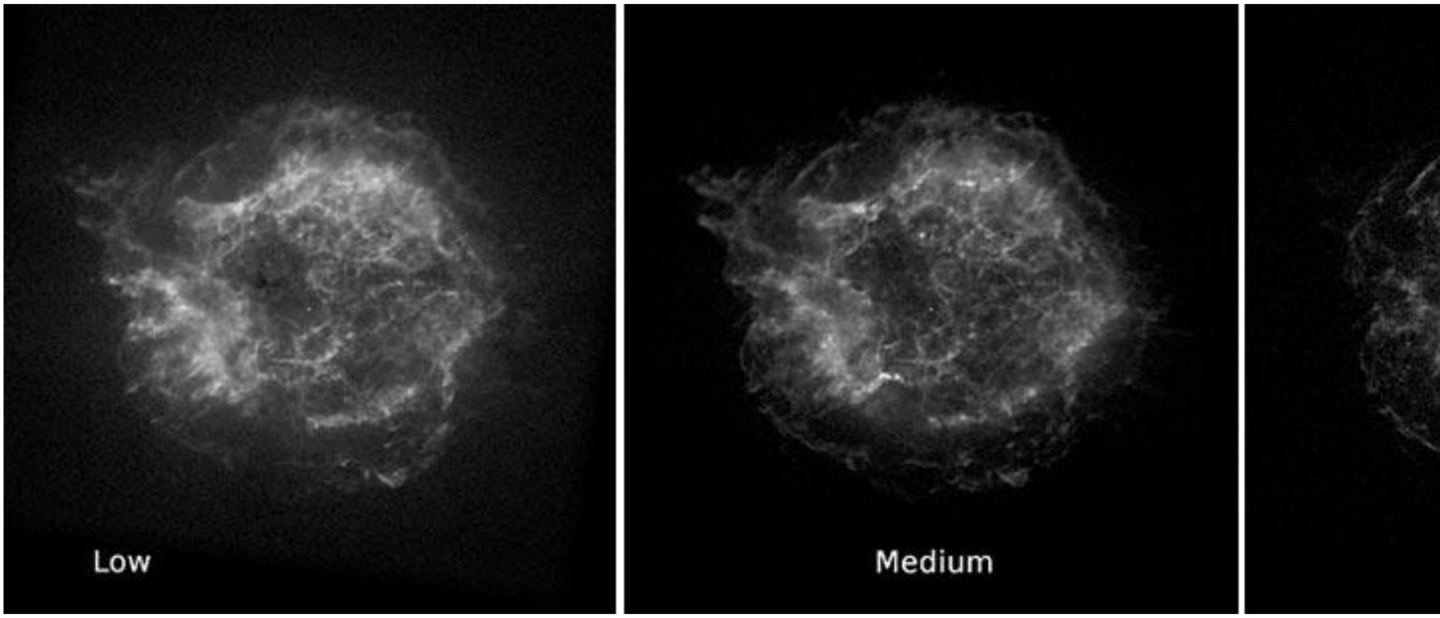

Figure 4. The original files from Figure 3 after they have had their levels adjusted. The shapes and details of each image are now much clearer.

Now the images in Figure 4 are much clearer, but they are still black and white. The next step is to *colorize* the grayscale images by assigning a single color to each one, as shown in Figure 5.

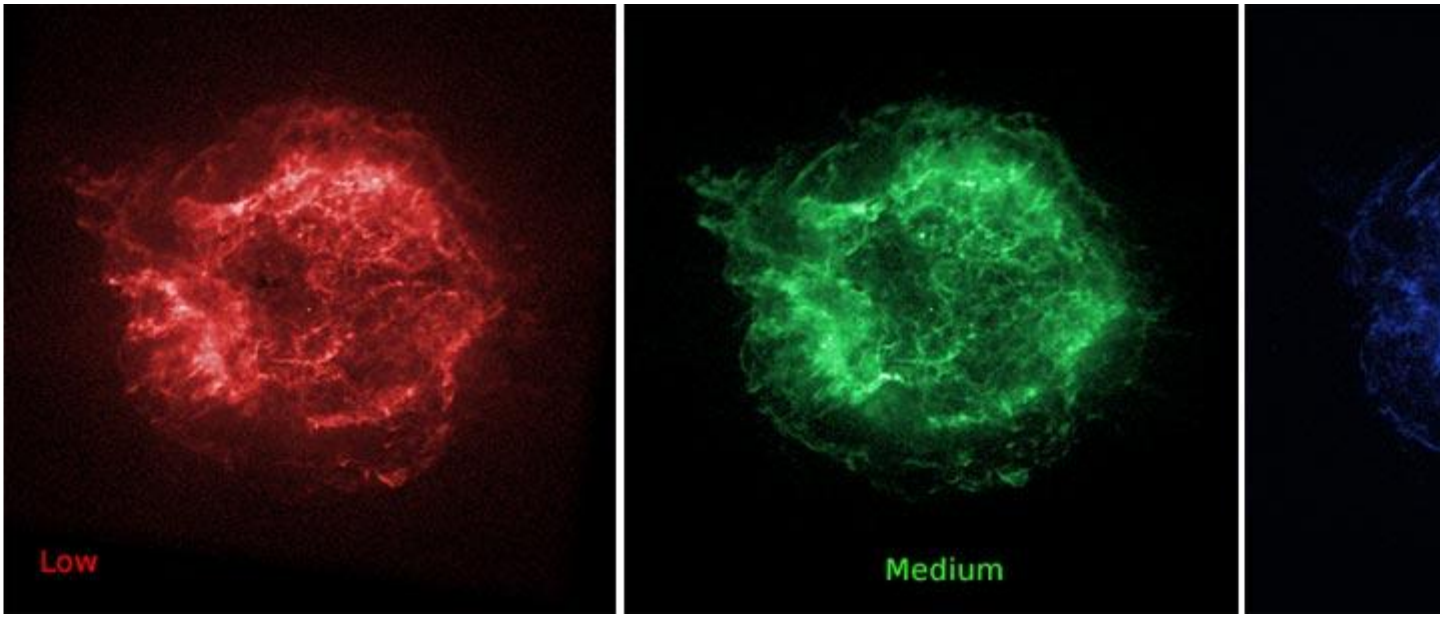

Figure 5. Each individual grayscale image is colorized; with red, green, and blue representing low-, medium-, and high-energy bands, respectively.

Finally, the three colorized images are merged into a single RGB image. This lets us see different regions of x-ray intensity in a single object, as shown in Figure 6.

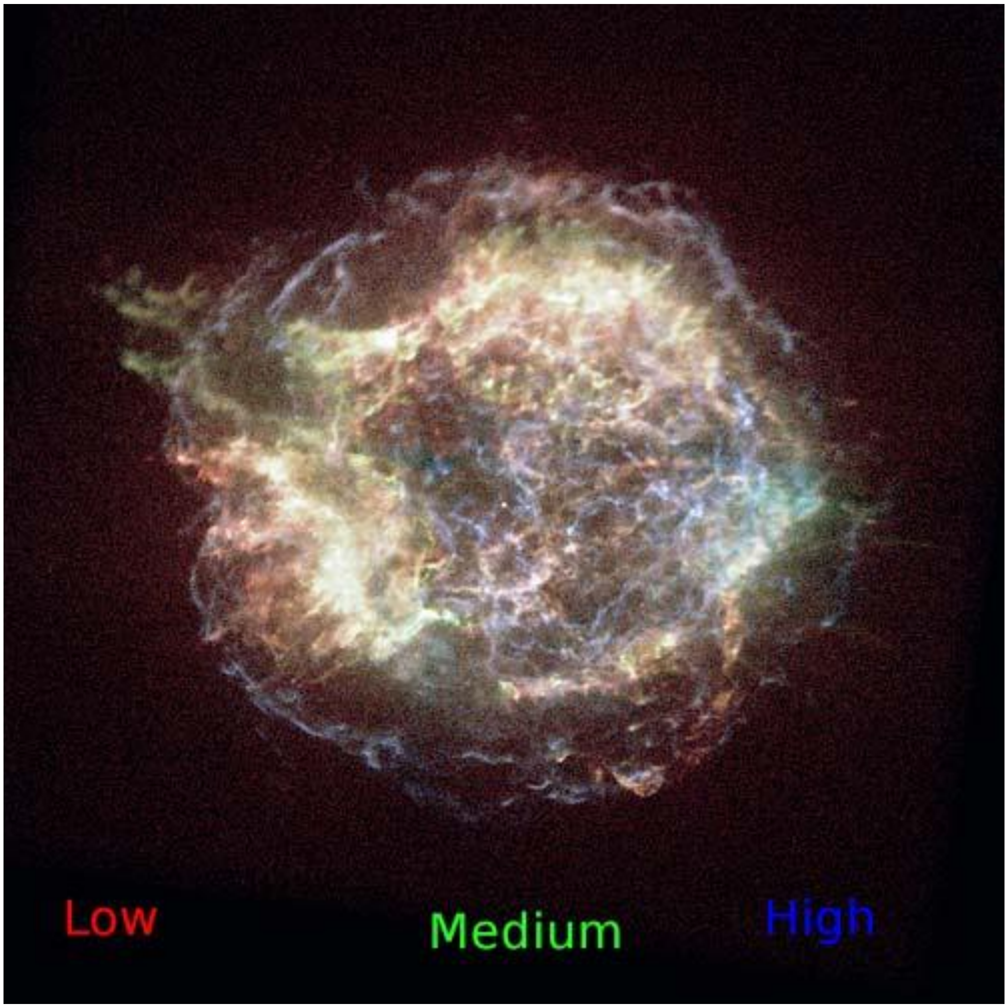

Figure 6. Combing the red, green, and blue images shows the relative intensities of low-, medium-, and high-energy x-rays all in one image.

The final color image can inform scientists about what is going on. In this particular case, there is a high-energy blast wave (shown in blue) from the initial explosion, which is hotter than the gases that were left behind (red and green). Areas with multiple types of x-rays appear in other colors, like yellow or purple. Note that the entire image-editing process can be somewhat subjective; for example, scientist could *intentionally* emphasize bright blue areas, but make the red areas very dull, in case he or she was particularly interested in very high-energy x-ray emissions. So, starting with the same source files, two different people could arrive at a very different final image.

You can learn more about what x-ray emissions mean for different bodies from the Chandra X-ray Astronomy Field Guide (see the Bibliography), but here are a few examples:

- Young stars tend to be brighter in x-rays than middle-aged stars.
- Stars tend to form in clusters, so x-ray emissions from galaxies can tell scientists about regions of star formation within that galaxy.
- X-rays can be produced when matter gets sucked toward very dense objects like white dwarves, neutron stars, and black holes.
- Supernovas create shock waves and extremely hot clouds of gas that emit x-rays.

In this astronomy science project, you will choose a set of raw x-ray data from the Chandra website. Based on your background research and what you see in the official colorized NASA images of the object, you will predict what you should be able to see by manipulating the raw x-ray data, and what the final image should tell you about the object.

Materials and Equipment

- Computer with internet access
- Lab notebook

Experimental Procedure

Learning How to Manipulate Images

1. NASA makes some raw Chandra data available through the Flexible Image Transport System, or *FITS*. Make sure you read the Introduction and Background page for the FITS program before proceeding.
2. Follow the directions on that page to download and install the Gnu Image Manipulation Program (GIMP), an open-source image-editing program similar to Adobe® Photoshop®.
   a. Also make sure you follow the directions to install GREYC's Magic for Image Computing (G'MIC). This is an add-on package for GIMP that includes various filters and special effects you can use on your images.
3. As practice, follow the tutorial to colorize the raw images of the supernova Cassiopeia A. You can also follow along with the video tutorial. This is the same procedure that was used in Figures 4–7 of the Introduction.
   a. *Note*: In Step 5.2 of the tutorial, the "Smooth [anisotropic]" filter is listed under "Repair", not under "Enhancement". This will make sense when you get to that step in the tutorial or watch the video.
   b. Remember that you can *choose* to make different adjustments to different layers of an image. If you want a direct comparison between the relative levels of low-, medium-, and high-energy x-rays, you can make the same adjustments to each layer. If you want to emphasize one energy level over another, you can make different adjustments. How you do this will affect the appearance of your final image.
   c. Remember that adjusting an image's "levels" is *not* the same thing as adjusting its brightness. Watch the video to learn more.

Selecting and Researching an Image to Use for Your Science Project

1. The OpenFITS — Create Images from Raw Data page lists 17 different sets of FITS files. Click on the images of the astronomical bodies on the right side of the page to bring up that astronomical body's profile page on the Chandra website.
   a. For example, here is the page with information about Cassiopeia A.
2. Browse through the images and choose one you would like to work with for your science project. Is there a particular type of astronomical body you are interested in; for example, a supernova, black hole, or maybe an entire galaxy?
   a. *Note*: Two of the images (#3 M87 and #13 Crab Nebula) only supply *broadband* image data instead of 3-color data. If you want to use these images, you will need to do additional research, because they do not follow the same procedure used in this science project.
3. Do background research about the body you have chosen.
   a. Make sure you read the object's description page by clicking on its image on the OpenFITS page.
   b. On the lower right-hand side of the description page, you should see links to more images of the same object. Follow those links to find more information.
   c. Read about the type of object you selected in the "X-Ray Sources" section of the X-Ray Astronomy Field Guide.
   d. Depending on the object you selected, you may need to do more background research. The Chandra website has a lot of good resources, but you may need to search for more resources from NASA or from another organization.
   e. Remember the types of questions you should ask: What is the object? Why do objects like it emit x-rays? What does the x-ray spectrum of this object tell you about the object? Why would some parts of the image be hotter than others?
4. Form a hypothesis about what you should be able to accomplish by manipulating the raw data files.
   a. For example, should you be able to see multiple distinct bodies (like individual galaxies or stars)?
   b. For cloud-like objects like supernovas and nebulas, should you be able to differentiate between "hotter" and "colder" (high- and low-energy) regions?
   c. What do the official colorized images on the Chandra website look like? Do you think your final images will look just like those?
   d. *Important*: Be careful when viewing images on each object's description pages, as sometimes they will be composite images that include data from other telescopes. For example, this image of the galaxy M87 is a composite image of x-ray, optical, and radio telescope data, whereas this image of Supernova 1006 only shows x-ray data. Remember that the FITS files you download will *only* include x-ray data.
5. Download the raw FITS files (in .zip format) for your image from the openFITS page. Unzip the files and save them on your computer.
6. Colorize the image, by following the same steps as are listed in the tutorial for Cassiopeia A.
   a. Remember that different images might require different adjustments. Just because you used certain settings in the "Levels" and "Colorize" menus for Cassiopeia A does not mean those exact settings will work for your new image. The image colorization process is part science and part art; it may take a lot of careful back-and-forth tweaking before you can get an image you are happy with.

    b. Be patient and remember to save your work frequently. Remember that you can always start over with the raw FITS files if you really do not like your results.
    c. If you get an error message or are having a lot of trouble with a particular image, go back to step 2 and try picking a new image.
7. Analyze your final image when you have finished adjusting it. Record your observations in your lab notebook.
    a. How does your actual image compare with your hypothesis about how your image should have looked? Was the process of creating the colorized image more difficult than you expected?
    b. Does your image have enough detail (not too dark, but not too bright or washed out) to identify individual features or objects? Based on your background research, what are they?
    c. Can you explain different regions of red, green, and blue in your image? Based on your background research, what do they represent or correspond to?
    d. How does your final image compare to colorized images on the Chandra website? Remember to be careful not to compare your image directly to one that also includes data from non x-ray telescopes like radio, optical, or infrared.

Submit a picture of your completed activity and your observation responses.