

Name \_\_\_\_\_

Date \_\_\_\_\_

Lab Partner(s) \_\_\_\_\_

**Project Score**

# IMAGE ANALYSIS: BASIC TECHNIQUES

From: Imaging the Universe - A Laboratory Manual for Introductory Astronomy, R. Mutel et. al.

**PROJECT LEVEL:** Introductory

**PROJECT GOALS:** The student will become familiar with the image analysis programs used in lab, and also will develop an understanding of the size and age of planetary nebulae. A number of basic concepts of image analysis are introduced, including ADU count, histogram adjustment, angular distance measurement, convolution, and image arithmetic.

**IMAGE DIRECTORY/LIST:** proj-04\_Image\_Analysis: chapel.fts, m42.fts, m57.fts

## 1 INTRODUCTION

Obtaining useful scientific results from an image often requires the application of image analysis tools. Many of the most commonly used tools are illustrated in this exercise using one terrestrial image and two astronomical images. The following is intended only as a brief summary of the basic concepts.

A CCD image consists of a rectangular array of cells called pixels, each of which is assigned a number (the **ANALOGUE TO DIGITAL UNIT** or **ADU COUNT**) which is proportional to the brightness of the image at that location. For the images in this exercise, the range of ADU values is 0 to 65536 or 216; i.e., there are 16 bits assigned to hold the value of each pixel. A single image is inherently monochromatic ('black and white') so that the display program normally converts the ADU counts to shades of gray, a so-called 'grayscale' image. Since most computer video systems can only display 8 bits of grayscale (256 shades), it is necessary to select the minimum and maximum ADU

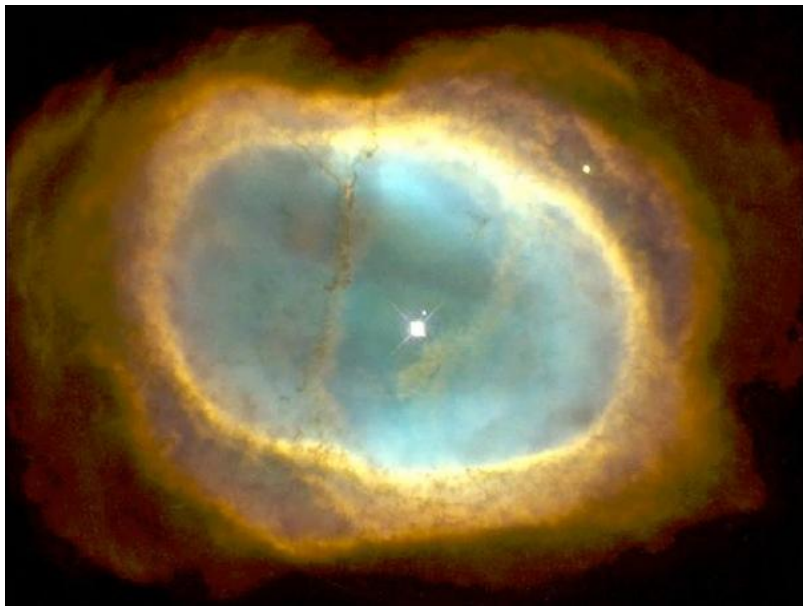


IMAGE 1 - HST IMAGE OF THE RING NEBULA (M57)

counts corresponding to the black and white levels, respectively. This can be done either by adjusting the contrast/brightness control or by using the **HISTOGRAM TOOL**. The histogram is a plot of the number of pixels at each ADU level. The user adjusts the minimum and maximum level using the mouse and the arrows at the bottom of the histogram.

The x and y coordinates of individual pixels can be read directly by moving around the image with the mouse. One can display multiple images at the same time, and rotate, expand and contract selected images. Images may also be added, subtracted, multiplied, and divided by either constants or other images.

The grayscale representation of an image can be converted to a **PSEUDO-COLOR IMAGE** by changing the **COLOR PALETTE**, i.e. the mapping of ADU levels to a sequence of colors. These are not true colors in the sense that of a color photograph, but it is sometimes useful to choose a color palette to emphasize small intensity differences, particularly in extended objects such as nebulae. The lab uses three sample images to illustrate some of these image analysis tools. The



**IMAGE 2 – RED FILTERED IMAGE OF THE DANFORTH CHAPEL**

The images of M42 and M57 were taken with the **RIGEL TELESCOPE** in Arizona, while the Chapel image was taken with a regular digital camera.

**CHAPEL.FTS** is an image of the Danforth Chapel near the Iowa Memorial Union.

**M42.FTS** is an image of the well known star formation region M42 (The Great Orion Nebula) in the sword of Orion. **It is about 400 pc distant.** (The unit pc stands for parsec where 1 parsec is equal to 3.26 light years.) The total mass of the nebula is about  $10^6$  solar masses. The central part of the nebula containing the 4 Trapezium stars is overexposed and cannot be seen clearly.

**M57.FTS** is an image of the Ring Nebula, a famous example of a planetary nebula (the reason the name *planetary* nebula was coined is probably because these objects are similar in appearance to faint planets when viewed with modest-sized telescopes -- both look like fuzzy disks). The object consists of a central hot star and a surrounding cloud of gas. The gas is glowing because of ionization from ultraviolet radiation from the central star. The Ring Nebula, shown in Figure 1, is one of the brightest of all planetaries, but imaging it with small telescopes is difficult, since it is quite small and the central star is very faint ( $V=15$ ). **The distance to the Ring Nebula is about 700 pc.**

## 1.1 ADU COUNTS AND ADJUSTING CONTRAST/BRIGHTNESS

Run **MaxIm** by clicking the icon on the desktop or by locating the program through the Start Bar.

Load the image **CHAPEL.FTS** (located in directory misc). To do this, click on File in the menu bar at the top of the screen. Then choose Open from the pull-down menu. Choose the image drive from using the box next to the words

“Look in”. Ask your instructor if you can’t remember which drive contains the laboratory images. Open the misc folder. Now double-click on the file name chapel.fts.

The image you are seeing is composed of individual pixels arranged in a rectangle, with dimensions 800 × 600 or 480000 pixels altogether. The image display program reads each ADU value and converts it into a gray level, with larger values being more nearly white and smaller values more nearly black. The position and ADU count of the individual pixel under the cursor can be read at the bottom of the screen. The ADU count (the i:) is given next to the set of (x,y) coordinates at the bottom right corner of the screen.

You may notice that the counts in adjacent pixels are often different from one another, even if the pixels *look* equally bright. Because of the nature of photons; the change in the number of photons has to be fairly large before a brightness change is obvious.

**QUESTION 1:**

Give an example of a region in “chapel.fts” with a high ADU count. How about a low ADU count?

High Count	
Low Count	

It is sometimes convenient to adjust the image display gray levels in order to enhance faint features in the image. This is known as adjusting the histogram. To do this, use the **SCREEN STRETCH WINDOW** (shown at right) which should have been displayed upon starting the program. If not, select View from the menu and Screen Stretch Window from the pull-down menu. **To adjust the display, move the green and red arrows under the main window.** The red arrow adjusts the black background and the green adjusts white levels. Moving the arrows close together produces a high contrast. The histogram is adjusted automatically as you move the arrows. Continue to adjust the histogram until you find a setting that brings out a maximum amount of detail. As you adjust the histogram, you are adjusting the 256 shades of gray scale to cover the desired range of brightness within the image. Including the entire range of brightness within the 256 gray-scale levels can sometimes make it difficult to detect fine differences. Including a small range of brightness hides a lot of information off of the edges of the scale.

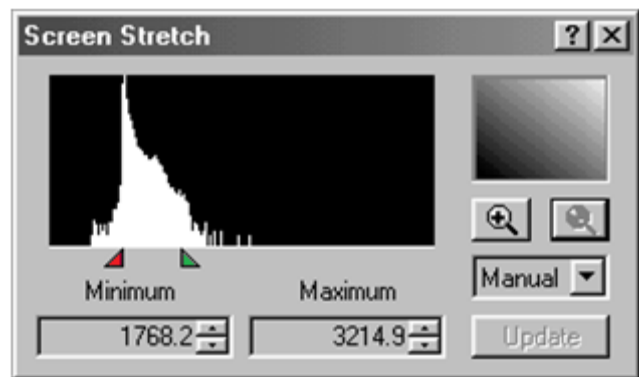


IMAGE 3 - MAXIM DL HISTOGRAM TOOL

You may also adjust the contrast and brightness of the image by clicking in the smaller window on the right side of the Screen Stretch. When you click and hold in the window, your cursor will change to a cross. Moving your cursor vertically will adjust the brightness and moving horizontally will adjust the contrast. Note that the green and red arrows will also move as you move your mouse in this small window. As before, the adjustments will occur automatically. Continue to adjust the histogram until you feel you have the most detail possible. Adjusting the histogram optimally takes a lot of practice. Don’t be frustrated if you spend fifteen minutes doing what your lab instructor does with just a few clicks.

**To examine the image more closely, especially the variation in pixel intensity (ADU count), select the Zoom from the program menu.** You may also press the + and – buttons next to the zoom pull down. Select a reasonable zoom level for examining the image. This level will change from image to image. For the chapel image, you will need to select a zoom of at least 400%, perhaps larger.

While the original image is reasonably clear, we can highlight small scale features using a **CONVOLUTION MASK**. (The process of convolving an image involves manipulating its ADU counts according to some predetermined mathematical function. You can think of convolving an image as applying one of several special filters to it.) Click on **Filter** and choose **Unsharp Mask**. A new window will open. Don't worry about any of the options; just use the default values for now. Click OK and you should be able to see more detail in the vehicles in the background.

## 1.2 MEASURING POSITIONS

Along with pixel counts, MaxIM displays the (x,y) coordinate of the pixel directly beneath the mouse cursor. For most images, the pixel corresponding to the position (0,0) is in the top left corner of the image with x increasing to the right and y increasing downward. (Try this out) Hidden in every picture is the **SCALE FACTOR**. The Scale Factor of an image represents the angular size of a single pixel and is determined by the optics of the telescope (or digital camera) and the size of the CCD chip. Typically this value is given to you for Astronomical images.

Once the Scale Factor is known, you can determine linear size of the objects in the image simply by knowing the distance to each object. This relationship is called the **SMALL ANGLE FORMULA** and is expressed as:

$$d = \frac{D \times \Delta\theta''}{206,265''}$$

where **d** is the linear size, **D** is the distance to the object and **Δθ** is the observed (angular) size of the object in arcseconds (1/3600<sup>th</sup> of a degree, analogous to seconds on a clock with degrees substituted for hours).

### QUESTION 2:

The Scale Factor of the Chapel image is given as 4 arcminutes (1 arcminute = 60 arcseconds) per pixel. If the photographer is standing 150 feet away, what is the resolution of a single pixel in units of feet/pixel? How about in meters/pixel?

<b>feet/pixel</b>	
<b>meters/pixel</b>	

You can now measure the height of the chapel building in pixels by putting the cursor at the bottom of the building, and marking down the coordinates (x,y) shown. Find the coordinate at the top of the building by moving the cursor to the top of the building while keeping the x coordinate constant. Calculate the building height in pixels by subtracting the y values. Calculate the actual height of the building in both feet and meters using the image scale found in Question 2.

**QUESTION 3:**

What is the Height of the Chapel Building?

Height (pixels)	
Height (feet)	
Height (meters)	

## 2 ORDER OF MAGNITUDE CALCULATION

Astronomers are often interested in the **ORDER OF MAGNITUDE OF A CALCULATION**. That is, do we expect to see millions of stars in a region, or just a few? As an example, we can estimate the number of solar-mass size stars that may be formed from the glowing gas of M42. To do this, you must first find the radius of M42. In Question 3, you found the height of the chapel building by measuring two points, careful to keep the x coordinate fixed. In general, the distance between any two points can be found by using the distance formula.

$$r = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

Here,  $r$  is the radius and the  $x$ 's and  $y$ 's are the coordinates you measured.

### 1.3 SIZE AND MASS OF THE ORION NEBULA (M42)

Discard the chapel image by clicking on the small  $\times$  in the upper right corner of the image window. Now, load the image **M42.FTS** by clicking on File/Open. Click on m42.fts in the image list box, and click on Open. Adjust the histogram. Faint nebulae can often be seen better by producing a negative image. Try this by reversing the positions of the red and green arrows. That is, put the red arrow to the right of the green arrow.



IMAGE 4 - HST IMAGE OF THE ORION NEBULA (M42)

To estimate the mass of the Orion Nebula, we must first estimate its size. The nebula is irregularly shaped, so this can be a difficult task. To form an order of magnitude estimate (one we expect to be within a factor of 10

of the true size), we can *assume* the nebula is spherical. This is a convenient choice because the volume ( $V = 4\pi r^3 / 3$ ) can be estimated simply by finding an average radius.

**QUESTION 4:**

Estimate the radius of the Orion Nebula. Move the cursor over a point near the center of the nebula. Mark down the coordinates (x,y) shown. Next move the cursor to a point on the edge of the nebula and mark those coordinates down. Calculate the radius in pixels using the distance formula. **Take at least 2 more measurements of radius, choosing different locations along the nebula edge.** Use your three measurements to find the average radius of M42 in pixels.

	Center Coordinate	Edge Coordinate	Radius
Measurement 1			
Measurement 2			
Measurement 3			
		Average (pixels)	

**QUESTION 5:**

Convert the average radius in pixels to a linear distance given that Scale Factor of the M42 image is 3 arcseconds per pixel. You also need to know the distance to M42 which is located in the introduction. Express your answer in meters.

Distance to M42	
Linear Size	

Spectral lines indicate that the cloud is made mostly of hydrogen, and that there are roughly  $10^{10}$  atoms per cubic meter ( $n = 10^{10} \text{ m}^{-3}$ ). Since we know the mass of hydrogen, the mass density  $\rho$  of the nebula can be obtained by ( $\rho$  is the Greek letter rho, pronounced "row"):

$$\rho = n \cdot m_H = (10^{10} \text{ atoms}) \times (1.6 \times 10^{-27} \text{ kg/atom}) \approx 1.6 \times 10^{-17} \text{ kg/m}^3$$

**QUESTION 6:**

Calculate the volume of the nebula using the average radius (converted to linear size) and determine the mass by multiplying the mass density times the volume. (The answer should be a very large number of kilograms)

Volume of M42	
Mass of M42	

**QUESTION 7:**

How many solar mass stars can be created by the gas in M42 if it all collapses to form solar mass stars? (See Appendix for the mass of the sun.)

<b>Number of Stars</b>	
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### 1.4 SIZE AND AGE OF THE RING NEBULA (M57)

Discard M42.fts and load **M57.FTS**. Adjust the histogram so that the ring is not so glaringly bright – use your best judgment to determine when the ring shows the most detail. The Ring Nebula is a type of **PLANETARY NEBULA**. Planetary nebulae are formed at the end of a medium to low mass (like the Sun) star’s life when it has stopped fusing Hydrogen at its core. In order to burn heavier elements, the star must change form, and in doing so blows off its atmosphere into space. The discarded gas is stimulated by the ultraviolet radiation from the original star and glows. Notice the star at the center of the nebula. (There is another star inside the ring, offset from the center. This is a foreground star and has nothing to do with the nebula.) This is the star which is shedding its outer atmosphere to produce the nebula.

**QUESTION 7:**

Measure the distance from the center star to the ring’s edge at three different locations. Calculate the radius in pixels using the distance formula. **Take at least 2 more measurements of radius, choosing different locations along the nebula edge.** Use your three measurements to find the average radius of M57 in pixels.

	<b>Center Coordinate</b>	<b>Edge Coordinate</b>	<b>Radius</b>
<b>Measurement 1</b>			
<b>Measurement 2</b>			
<b>Measurement 3</b>			
		<b>Average (pixels)</b>	

**QUESTION 8:**

Convert the average radius in pixels to a linear distance given that Scale Factor of the M57 image is 0.5 arcseconds per pixel. You also need to know the distance to M57 which is located in the introduction. Express your answer in AU.

<b>Distance to M42</b>	
<b>Linear Size</b>	

**QUESTION 9:**

If the sun were to produce a nebula of the same size as M57, would the Earth be inside or outside of it?

<b>Earth's Location</b>	
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**The average expansion speed of the gas in the nebula is 20 km/s.** If it is assumed that the nebula has been expanding at this speed for its entire lifetime (not a very sound assumption, but it is OK as a rough estimate), it is fairly simple to estimate the nebula's age, since  $t = r/v$  where  $r$  is the distance,  $v$  is the velocity, and  $t$  is time.

**QUESTION 10:**

Estimate the nebula's age in seconds and convert the answer to years. For a solar type star, is the planetary nebula phase a small or large fraction of its lifetime?

<b>Age (years)</b>	
<b>Large/Small Fraction?</b>	