Name	
Partner(s)	
Date	
Grade		
Category	Max Points	Points Received
On Time	5	
Printed Copy	5	
Lab Work	90	
Total	100	

Image Analysis: Basic Techniques

1. Introduction

A number of basic concepts of image analysis are introduced, including ADU count, histogram adjustment, angular distance measurement, convolution, and image arithmetic.

Background and Theory

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 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 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 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.**

2. Procedure

1. Run *MaxIm*.
2. 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.
3. 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. 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. Can you tell the difference between pixels with high ADU counts and those with low ADU counts?

4. 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.
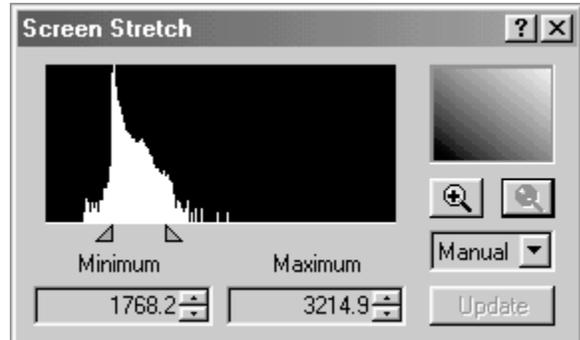
5. You may also adjust the contrast and brightness of the image by clicking in the smaller window on the right side of the Screen Stretch. When you click and hold in the window, your cursor will change to a cross. Moving your cursor vertically will adjust the brightness and moving horizontally will adjust 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.

6. **To examine the image more closely, especially the variation in pixel intensity (ADU count), select the Zoom from the menu, it will start out reading 100%.** 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.

7. 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.

8. Measure the height of the building in pixels by putting the cursor at the bottom of the building, and mark down the coordinates (x,y) shown. Keeping the x value constant, move the cursor to the top of the building and record the number. Subtract the first y value from the second to get the height of the building on the image in pixels. Calculate the actual height of the building in both feet and meters using an **image scale of .17 feet/pixel and .05 meters/ pixel**, respectively.

HEIGHT OF THE CHAPEL

Workspace	
(feet)	(meters)

9. Discard the chapel image by clicking on the small × in the upper right corner of the image window.

10. 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. Readjust the histogram.

11. 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. 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. From these sets of coordinates, you can find the radius (in pixels) using the distance formula:

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

Where **r** is the radius and the **x's** and **y's** are the coordinates you measured.

12. **Take at least 2 more measurements of radius and then take the average of them to get your radius (in pixels). Convert this into arcseconds using the scale of 3 arcseconds per pixel.**

13. We can determine the linear size of the object from the angular size and the distance, using the small angle equation: **(Angular size** θ) **= 206, 265 x (linear size D)/(distance d),** where d and D are in the same units, and θ is in arcseconds. **The distance from the Earth to M42 is approximately 400 pc.** Find the linear size of M42 in pc. **Convert this result to meters. (1 pc = 3×10^{16} m)**

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

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

15. Multiplying the density by the volume yields the total mass of hydrogen in the nebula. If we assume that the nebula is approximately spherical, the mass can be calculated using the following formula (where r is the linear size, actually the radius, from step 13):

$$M = \rho \cdot V = \rho (4/3) \pi r^3$$

16. How many solar mass stars can be created by the gas in M42 if it all collapses to form solar mass stars?

MEASUREMENTS OF THE ORION NEBULA (M42)

Average Radius	Measurement 1	(pixels)
	Measurement 2	(pixels)
	Measurement 3	(pixels)
	Average	(pixels)
		(arcsec)
		(pc)
		(m)

			Workspace
Mass of Nebula	(kg)	**Number of Solar Mass Stars**	

17. 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.

18. 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
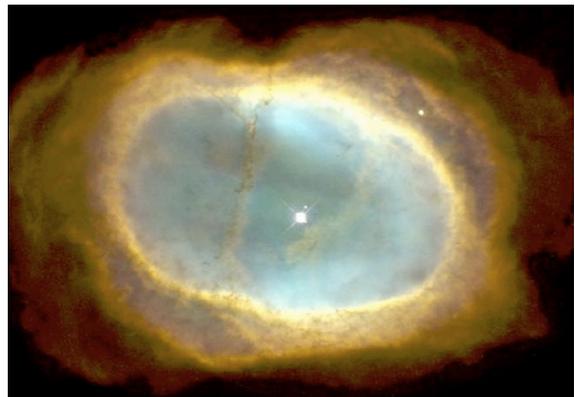
IMAGE 4 – HST IMAGE OF THE RING NEBULA (M57)

atmosphere to produce the nebula. Measure the distance from the center star to the ring's edge at three different locations. You may have noticed that the length you measured is neither the longest nor the shortest radius of M57, but is rather an average radius. **Find the radius of the nebula (in pixels) by taking the average of your three measurements. Convert this radius to arcseconds using the image scale of 0.5 arcseconds per pixel.**
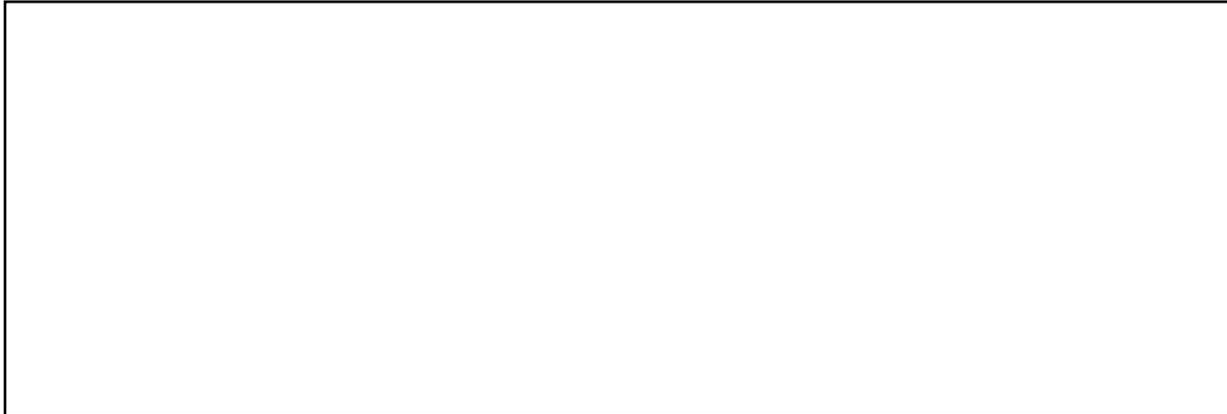
19. **Find the radius of M57 in a.u.** (Hint: the distance to M57 is 700 parsec)

20. If the sun were to produce a nebula of the same size as M57, would the Earth be inside or outside of it?
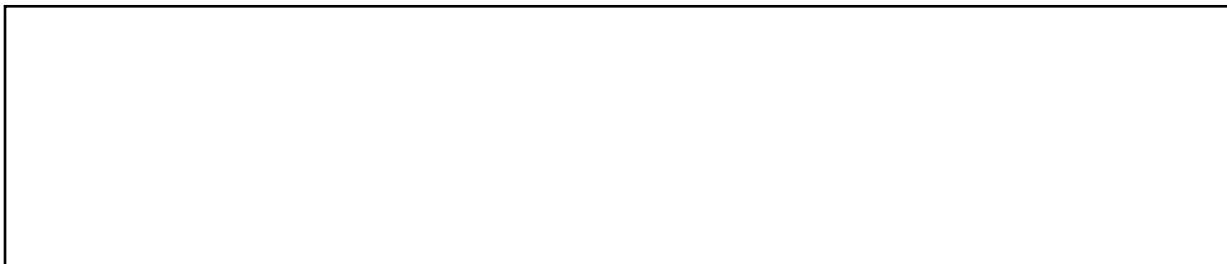
21. Convert the radius of M57 from a.u. to km.

22. **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 $r = v \cdot t$, where r is the distance traveled, v is the velocity, and t is the time. The gas from the nebula began expanding from the star at the center of the nebula. Use this to 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?

MEASUREMENTS OF THE RING NEBULA (M57)

Average Radius	Measurement 1	(pixels)
	Measurement 2	(pixels)
	Measurement 3	(pixels)
	Average	(pixels)
		(arcsec)
		(AU)
		(km)

			Workspace
Position of Earth	(inside or outside)	**Age of Nebula**	
		Fraction of Star's Life	(small or large)