Project 15: Photographs Over Time

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Introduction:

By comparing images of astronomical objects that have been taken over a period of time, it should be possible to show that some of these objects are in motion. It should also be possible to determine the rate of movement of these objects by comparing images of the objects taken after large intervals. Rather than make direct physical measurements of photographs, this experiment takes advantage of the electronic storage method of these photographs and uses the distance between pixels to assist in determining distance within the images. The pixel is the smallest unit of the image. It represents one color or shade in the mosaic of points that make up the image.

Purpose:

The purpose of this experiment is to compare images taken between long periods of time and use these images to measure movement of objects in the images. The images are digitized, which allows the individual pixels to be used as equal sized elements in the measurement of the images.

Procedure:

The Crab Nebula

The first of the objects to be measured is the Crab Nebula. The nebula was caused by the explosion of a supernova witnessed by the Chinese in 1054AD. The nebula is located in the constellation Taurus at Right Ascension 05h34m30.0s and Declination 22^{o}01'00". Right Ascension [RA] is the placement of the star in the east-west axis. Declination [Dec] is the placement of the star in the north-south axis.

Alignment and Astrometry

The two images chosen for the Crab Nebula were from 1973 and 2000. The 1973 image was taken by on Kodak Ektachrome film at Kitt Peak using a 4-meter telescope. (Schoening) The 2000 image was taken by Michael Richmond using an ST-8 camera on a 16" telescope. (1 Richmond) In this experiment, an image-processing program called MIRA was used to reduce the images. (Axiom Research) This program has several routines that were used in the experiment. The first routine is Align. The two images were processed such that the placement of the stars in one image overlaps the placement of the stars in the second image. This insures that the non-moving portions of the image will be aligned between the two images.

The second routine is called Astrometry. Astrometry is the science of measuring the position of celestial objects. In this routine, the celestial position of 3 stars for each image was entered into the computer. The precise position of each of the three stars was obtained from the USNO B1.0 Catalog. (Monet) The computer calculated the spatial arrangement of the stars and assigned a RA and Dec coordinate to each pixel in the image. These coordinates allow the computer to derive the actual height and width of each pixel in arc seconds (arcsec).   An arcsec is 1/3600 of an angular degree. The assumption is made here that the size and aspect ratio of each pixel in the image is identical. Figure 1 shows a screen capture of MIRA making the Astrometric calibration for the image and showing the width (x pixel scale) and the height (y pixel scale) for the image. In this case, the pixel height was 0.798 arcsec and the pixel width was 0.998 arcsec.

The MIRA program also has a cursor that can be moved to different areas of the image. A message bar at the bottom of each image gives the row and column number of the pixel on which the cursor is centered. This feature allows the distance to be measured in pixel units between two points.

Measurement

Since it is the nebulosity, composed of gas and dust, in the image that is expanding, four points in the filaments of the nebulosity of the image were measured for their position in each of the two images. Figure 2 shows the placement of these four measuring points (marked in boxes) and also the three stars used in the astrometry routine (marked with half cross hairs). Naturally occurring artifacts such as knots or loops in the nebulosity can be easily identified and were used for these measurements. Figure 3 shows a screen capture of the MIRA program in which the cursor is centered over a loop in the nebulosity during a measurement of point 1. The two images in Figure 3 show that the column (x) and row (y) coordinates for the points on these two images differ slightly. It is this difference that is being measured. By counting the difference in the pixel placement between the two images and then multiplying this difference by the arcsec per pixel in both the x and y values, it is possible to determine how much the object has moved between exposures in both the x and y coordinates. Different arcsec values were found for the x and y coordinates and therefore different values are used to multiply times each change in coordinates. The movement in both the x and y coordinates provide two legs of a right triangle. The actual displacement of the object between the two images is determined by calculating the hypotenuse of the triangle using the Pythagorean theorem.

The displacement in arcsec = $(x^2 + y^2)^{-2}$.

The coordinates and displacement of the four measuring points are given in the table below.

Measuring Point	**Coordinate**	**Position Change in Pixels**	**Position Change in Arcsec**	**Displacement in Arcsec**
1	x	4.50	3.591	3.626
	y	0.50	0.499	
2	x	0.05	0.399	5.006
	y	5.00	4.990	
3	x	10.00	7.980	9.686
	y	5.50	5.489	
4	x	3.0	2.394	3.833
	y	3.0	2.994	

Calculation of Displacement and Velocity

Since the time between the two images is known, 27 years, and the distance to the Crab Nebula has been determined by others, 7200 light years [ly] or 5.30×10^{16} Km, (Kurita), it is possible to use the above information and calculate the actual velocity of the displacement in the nebula at the points that were measured. A light year is the distance that light travels in a vacuum over a time span of one year. For very small angles, the tangent of the angle is ~equal to the opposite leg divided by either of the adjacent legs. Therefore, the leg opposite from the measured angle (which is the measured displacement) is equal to the adjacent leg (which is the distance to the nebula) times the tangent of the measured angle (which is the displacement in arcsec). This calculation is given in the following formula:

Displacement = tan (Displacement in arcsec / 3600) x Distance from Earth to nebula

The factor of 3600 must be used in the equation to convert arcsec to degrees. This displacement can be converted into a velocity by dividing the displacement, in kilometers (Km), by the time difference between the two photographs (27 years or 8.51×10^{8} seconds). The following table gives the actual displacement and velocity for the measurement points.

Measuring Point	Displacement in Arcsec	Velocity in Km/sec
1	3.626	1400
2	5.006	1941
3	9.686	3755
4	3.833	1486

Measuring point 3 revealed a much larger velocity than the other three points. Closer inspection of the measuring point showed that there might be a star behind the nebula at the measuring point and that the star might be interfering with the astrometry. After rejecting point 3, the average of the other three points is 1608 Km/sec.

Since the astrometry measurements using MIRA were to the nearest 0.25 pixels, the error for the displacement in arcsec was at least +/- 6%. One reference source gives the expansion velocity of 1800 Km/sec. (Encarta). Therefore, the value of 1608 km/sec for the average displacement velocity in this measurement is reasonable. Also, since the nebula is expanding in three dimensions and this method only allows for measurement in two dimensions, it would not be expected all of the measurement points would have exactly the same velocity.

V838 Monoceres (Mon)

The second object to be measured was V838 Mon and was discovered by N. J. Brown on January 6 of 2002. (Brown) It has been described as a new class of eruptive variable. (Kimesenger). The location of the object is R.A. 07h04m05s Dec.–03°50'50" in the constellation Monoceres. Several ground-based observers closely followed the eruption. However, a team using the Advanced Camera for Surveys on the Hubble Space Telescope produced images with the clearest view of the expanding light echo around V838 Mon. (Bond) Four of the published images were used in this experiment. The images were taken on May 20, 2002, Sept. 2, 2002, Oct. 8, 2002 and Dec. 17, 2002. In the interest of compressing this file size as much as possible, only the image from Oct. 8, 2002 is shown in Figure 4. The entire image set is available at the URL in the Howard Bond reference at the end of this paper.

The images indicate a "light echo" caused as the tremendous energy released when the eruption of V838 Mon impacted any dust in the space surrounding the star. A light echo is the reflected energy from an erupting star as it bounces off dust that surrounds the star. In this case, the dust is thought to have come from a previous explosion. The light echo will diminish in a few years and V838 Mon is expected to return to its quiescent or quite state. What is being measured here is not the velocity of the dust, but the rate at which the energy is moving through and illuminating the dust cloud.

The measurement of the expansion of V838 Mon differs from the measurements made of the Crab Nebula in that the edges of the light echo are circular and very well defined. The same method of astrometry was used to determine the arcsec per pixel of the images and the position of the stars was obtained from the same source. The three stars used for the astrometry in each image are marked with squares in Figure 4. In the case of these images, the width of each image was given at 82 arcsec by the image source. (Hubblesite) These values were assumed to be more accurate than the measured values and were used in the experiment

In this experiment, it was possible to use a tool in MIRA called Horizontal Profile to readily distinguish the edges of the echo. The Horizontal Profile command creates a histogram of the light intensity vs. pixel column position for a horizontal slice through the image. The histogram for the Dec. 17 image of V838 Mon is shown in Figure 5. As the graph moves upward, it indicates that the pixels are increasing in brightness. Therefore, the points at each edge of the graph where the pixels start to increase in value are taken as the edge of the light echo. The difference between the smallest and largest column value is the number of pixels that subtend the light echo. This same Horizontal Profile histogram was made for each image.

The width of the light echo in each image was calculated using the same method as for the Crab Nebula. The distance to V838 Mon is under some debate with values ranging from 2151 ly (Kimeswenger) to 20,000 ly. (Schilling) The value of 2151 ly was referenced in a peer-reviewed journal and is the distance value that will be used here. The table below gives the diameter of the V838 Mon light echo in each image.

Image Date	**Echo Diameter in arcsec**	**Echo Diameter in Km**
May 20, 2002	44	4.44×10^{12}
Sept. 2, 2002	65	6.41×10^{12}
Oct. 8, 2002	69	6.81×10^{12}
Dec. 17, 2002	77	7.60×10^{12}

Over a period of 7 months (1.81×10^7 sec), the light echo increased in size by 3.16×10^{12} Km. When the echo diameter is plotted against time, the expansion diameter has a very close fit (R>0.99) to a decreasing rate power curve. The curve is plotted in Figure 6.

Since the light energy travels outward from the point of the eruption in the center of the light echo, the actual average expansion velocity of the light echo over the seven months of observation is one half the value of 3.16×10^{12} Km / 1.81×10^7 sec. This velocity value is 8.73×10^4 Km/sec, or 29.1% of the speed of light.

This experiment measured the velocity of the energy moving from the point of eruption into the surrounding dust cloud. The actual expansion velocity of the dust cloud is cited in the literature at 200 to 500 Km/sec. (Kato)

Conclusion:

Previously, the preferred method of making these measurements was by using rulers or calipers and measuring the displacement directly on photographs of the objects. (2 Richmond) This experiment demonstrated that angular movement of nebulosity and light energy can be measured at great distances by amateur and student astronomers achieving relative precision using available technology. This more recent method of using the pixel property of modern digitized images would seem superior to the previous methods.

When measuring the actual movement of nebulosity, the current method of choice is to perform a spectroscopic analysis on the nebulosity and measure the frequency shift of the spectrum caused by the angular displacement of the dust or gas. (Kohoutek)

An interesting addition to this project would be to measure the actual angular displacement or direction of the movement of different parts of the nebula and over-plot those vectors on the image itself.

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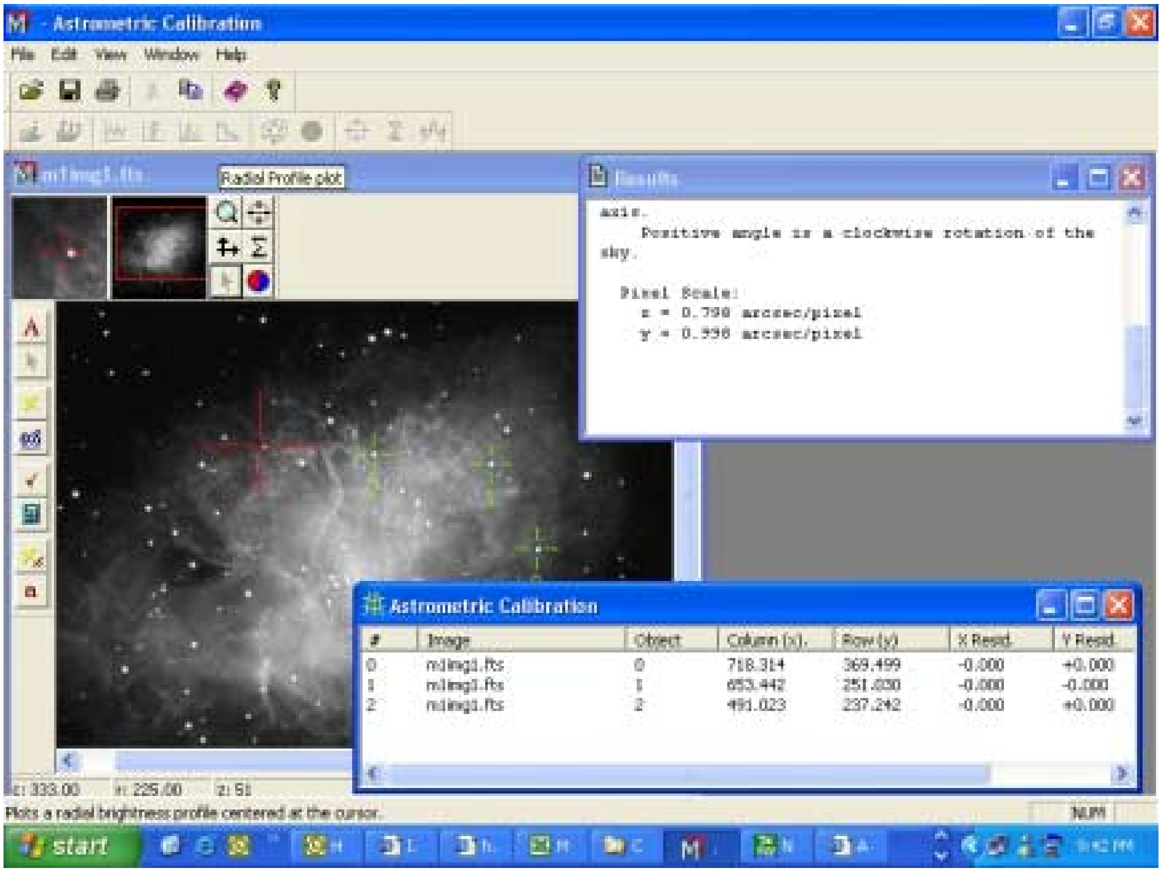
Astrometric Calibration
File Edit View Window Help
m1img1.fts
Radial Profile plot
Results
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Positive angle is a clockwise rotation of the sky.
Pixel Scale:
x = 0.798 arcsec/pixel
y = 0.998 arcsec/pixel
Astrometric Calibration
Image Object Column (x) Row (y) X Resid. Y Resid.
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1 m1img1.fts 1 653.442 251.030 -0.000 -0.000
2 m1img1.fts 2 491.023 237.242 -0.000 +0.000
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Plots a radial brightness profile centered at the cursor.
NUM
start

Figure 1

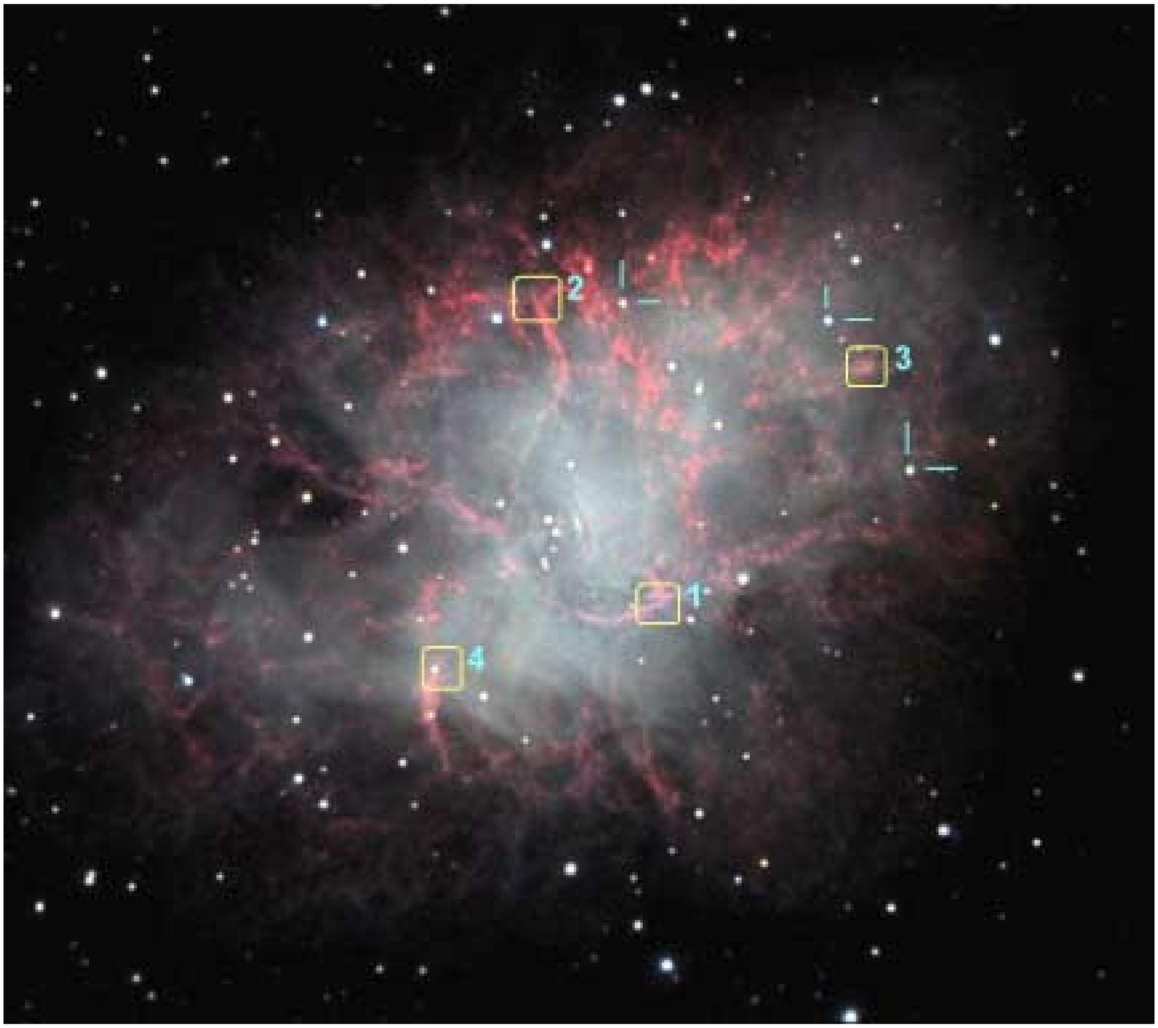

Figure 1

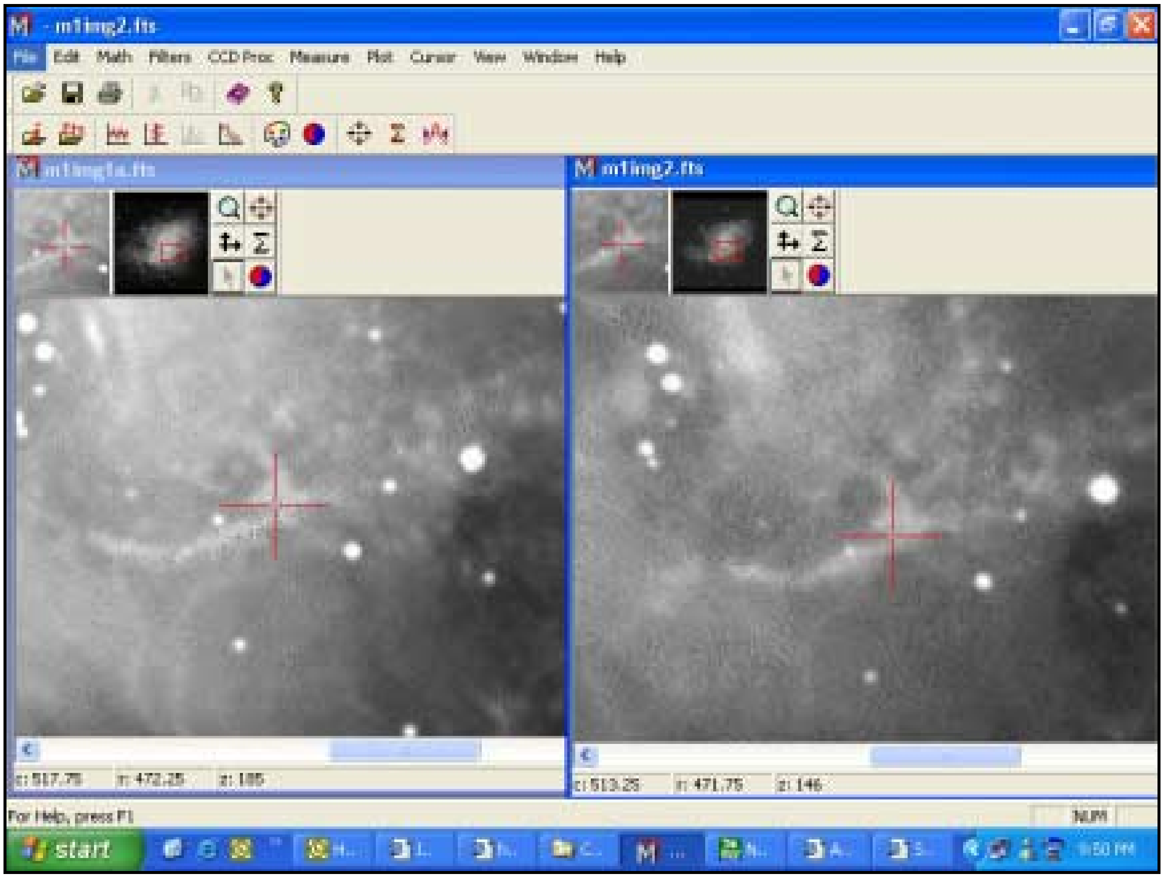

Figure 2

Figure 3

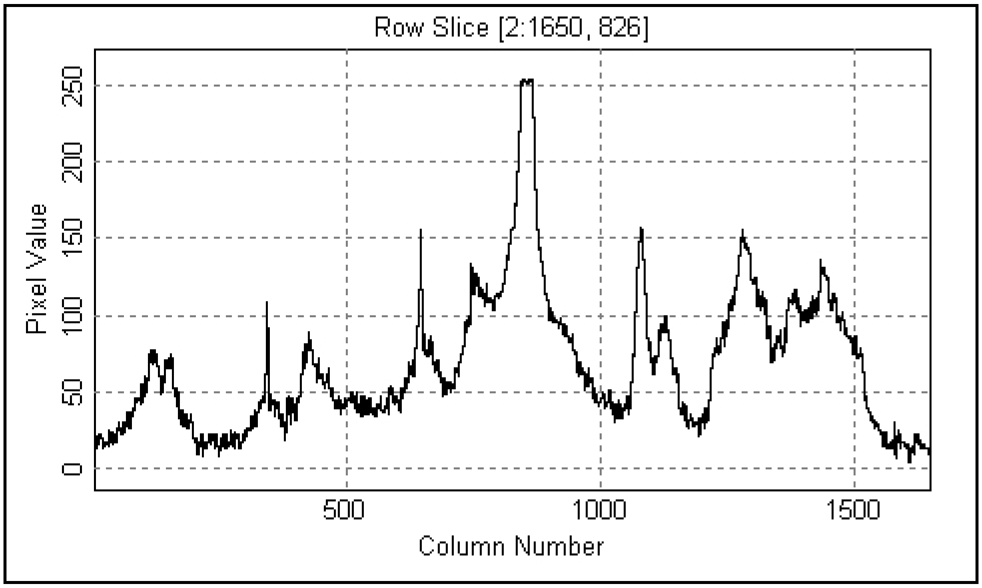

Figure 5

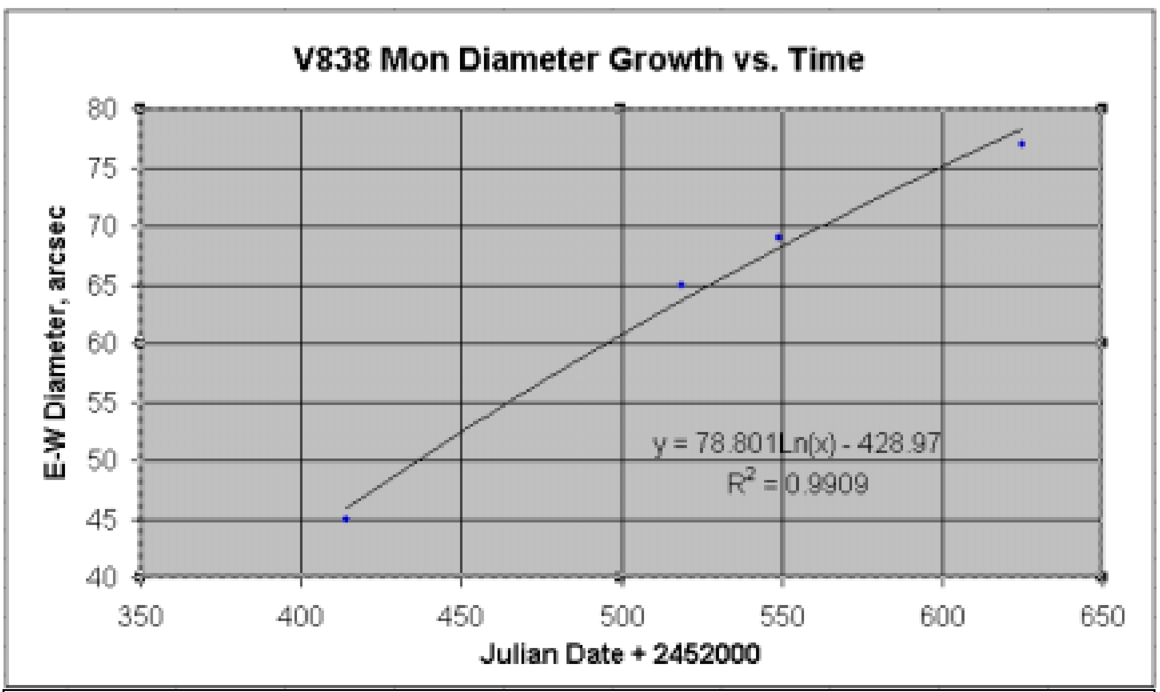

Figure 6