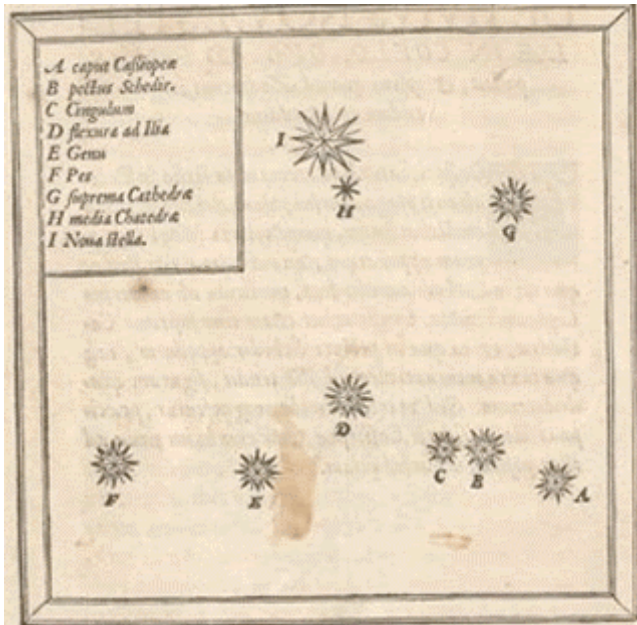# Chapter 6: Measuring Variable Stars Visually

Tycho Brahe's Drawing of the Supernova of 1572

Introduction

Most stars seem to shine with constant light. Thousands of stars, however, are known to change in brightness. Because most changes are not immediately apparent, for centuries the stars were considered to be unchanging. Exceptions were a few instances when Chinese, Arabic, and Native American cultures recorded the sudden appearance of "new" stars—now known to have been novae or supernovae. In 1572 Tycho Brahe discovered a bright supernova in Cassiopeia, and the Western world became acquainted with stars that vary in brightness.

The first astronomer to study variable stars seriously was a German named F. W. A. Argelander (1799–1875), famous for his star atlas and catalog, *Bonner Durchmusterung*. Argelander also recognized that astronomy enthusiasts could help contribute a great deal to the understanding of variable stars. Amateur astronomers around the world observe these exciting stars and assist professional astronomers by sending their data to variable star organizations, such as the American Association of Variable Star Observers (AAVSO) in Cambridge, Massachusetts. You can study the behavior of variable stars by measuring their changes in brightness. You can then draw their light curves, which will allow you to begin to unravel the stories of their turbulent lives.

The collection and study of variable star data requires the ability to estimate magnitudes. If you live in a city, you may be able to see only a dozen stars with your unaided eye in the entire sky. On a moonless night, at a very dark site, you may be able to see several *thousand* individual stars. It can be very difficult to learn to estimate magnitudes if either of the two above situations exist, because either all the stars you need are not visible, or so many stars are visible that the ones you need are lost in the multitude. The variable stars we will be studying are located within the five constellations you became familiar with in Chapters 4 and 5. To further assist you in acquiring the skill of estimation, we will not start with the real sky, but with a set of pictures, sky charts, prints, and slides especially prepared by the AAVSO for this activity.

Investigation 6.1: Interpolation

Your instructor will give you an assorted set of at least ten cylinders. Using a string and a ruler, measure the diameter and circumference of each cylinder and enter the data in the table below.

CYLINDER MEASUREMENTS

#	Circumference (cm)	Diameter (cm)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		

These pairs of values can be presented as ordered pairs on a graph. Using the following instructions for graphing to guide you, plot the circumference as a function of the diameter of the cylinder. Another way to say this is "plot the circumference versus the diameter." Still another way to put it is "plot the circumference on the vertical axis (y-axis) and plot the diameter on the horizontal axis (x-axis)." The independent variable is always plotted on the horizontal x-axis while the dependent variable goes on the vertical y-axis.

Graphing Techniques

1. Place a title on the graph paper somewhere near the top of the page. If your graph is going to be wider than it is tall, then the title should still be at the top of the page.

2. Select a scale for each axis so that the graph will cover more than half the page in each direction. Your graph should be centered on the page.

3. On each axis indicate the scale divisions, the name of the variable being plotted (circumference and diameter), and the units of measurement.

4. The *origin* is at the lower left-hand corner of the graph and usually has a value of zero. The numbers increase from left to right along the horizontal (x) axis and from bottom to top on the vertical (y) axis.

    NOTE: Not all graphs follow this rule. Since the larger the positive number for the magnitude of a star the dimmer it is, magnitude numbers plotted on the vertical (y) axis start with larger, positive numbers at the bottom and end with

smaller and negative numbers at the top! [Remember, the brighter the magnitude of a star, the smaller the number.]

5. Circle data points to represent graphically uncertainty of data and to ease the drawing in of the "best fit curve" (a straight line is considered a "curve" in this context). We will refer to these circled data points as "error circles."

6. After all data are entered on the graph, draw a thin line that best represents, as you infer it, the *total* accumulation of data. Follow the *trend* of the data points with a smooth curve. Your line should either go through, or as near as possible to, as many error circles as possible. Start your line at your first data point and end it with the last point. If you continue your line either to the origin or beyond the last point, then make it a dotted line. There may be a measurement that doesn't seem to fit the trend you see. If so, should you remeasure that data set and try to include it in the trend of the data set, or should you simply ignore it? This is science and there is always error in measurements. Most graphs will NOT be drawn dot-to-dot. When you draw dot-to-dot, you are giving more importance to individual measurements than to the collection of all measurements. In variable star astronomy, it is the accumulation of all the data that is significant, as it is in the measurements of the cylinders.

Now you are ready to answer the following questions by analyzing the results on your graph.

1. What shape is your "best fit" curve? What does this tell you about the relationship between the two variables you plotted, circumference and diameter?

2. Choose a diameter value that you did not measure, that lies along the line you drew but is not a data point on the graph. Reading from the vertical axis, what would be the circumference for this diameter? You have just used *interpolation* to determine an answer. Anytime you can get a number you did not actually measure between two points you did measure, you are interpolating. Determine what the circumference would be for a cylinder with a diameter that is 5 cm larger than your largest measured diameter. For this you need to go along the dotted line outside of your last data point. This is called *extrapolation*.

3. Draw straight lines to both the x-axis and the y-axis from two different points along the line you drew through the data points, choosing two points where no data are plotted. For each axis, subtract the smaller value from the larger one, then divide the value for the y-axis by the value for the x-axis. This will give you the *slope* of the line, or the "rise" over the "run." Does this number look familiar?

You will further analyze the results from this investigation in Core Activity 6.3.

Core Activity 6.2: Estimating Magnitudes Using Interpolation

To estimate magnitudes of variable stars, you will need to interpolate. Interpolation is the process of estimating a value between two known values. Near the variable star you will be observing are two or more comparison stars of known magnitude. These stars do not change in brightness and are used to compare the brightness of the variable star. Knowing the values of the magnitudes of the comparison stars and the magnitude range of the variable star itself, you can interpolate or estimate the magnitude of the variable star as it changes over time.

1. Given below are three star fields (see Figure 6.1). The magnitudes of the comparison stars are given. Estimate to the nearest tenth the magnitude of the star (offset by the lines in each field [- -]). NOTE: In star fields, the decimals are not indicated. A magnitude of 6.4 is written as 64, so that the fields are not as cluttered and the decimal points are not mistaken for stars.
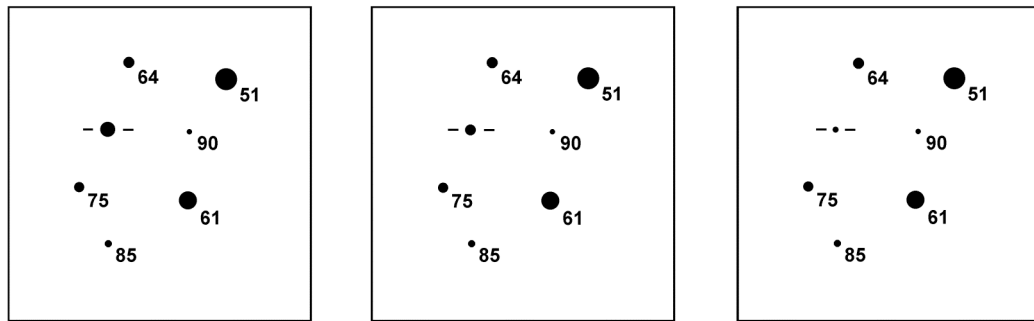

Figure 6.1

In field A, the magnitude of the variable star seems to lie between 6.1 and 6.4, almost half way, maybe a little closer to 6.1, so the magnitude estimate is 6.2. Your estimate may be different from this and that is okay. Write your own estimate in the table below.

estimate of magnitude	star field A	star field B	star field C
yours			
classmate #1			
classmate #2			

Make estimates on the other two star fields. Also record the estimates made by two of your classmates. Do your estimates differ from theirs?

2. Compare your estimated magnitudes with those of the rest of the class. Does everyone have the same answers?

Core Activity 6.3: How Accurate Are Your Results?

MEASUREMENTS AND ERRORS

You learned how to interpolate data in Investigation 6.1 using measurements of diameter and circumference. If you had used a different method of measuring the cylinders, such as trying to use a straight ruler instead of string, your results would have been less accurate. Even with the string, your measurements were not exactly the same as your classmates'. Even though the sizes of the cylinders were the same, the measurements were different. In astronomy, as in other sciences, *no measured quantity is ever exact*. There is always some error or uncertainty. We can safely use the results from our data analysis only when we can estimate the size of the errors involved. In our everyday lives, the terms *precision* and *accuracy* are used interchangeably, but in science there is an important difference. Precision pertains to the process of making a measurement, while accuracy pertains to the results of the measurement.

Precision of the measuring instrument is a way of describing how close the measurements in a data set are to each other, given that the measurements have been made in the same way. When a 1 kg mass is weighed three times on an imprecise instrument, for example, the measurements may range from 0.8 kg to 1.2 kg. When it is measured on a more precise instrument, however, the measurements will vary less and have a smaller range.

The precision of each measurement is improved as each individual measurement is more sharply defined. When we are trying to make a precise measurement, we should always measure to the limits of the instrument by estimating tenths of the smallest division. If a ruler has only centimeters marked on it, for example, we should still estimate to the nearest millimeter when making a measurement. The number of decimal places (not the number of digits) in the measurement indicates the precision of an individual measurement.

Accuracy is a way of describing how closely a measurement agrees with the true or accepted value of the quantity being measured.

The difference between an observed value and the true or accepted value is called the *absolute error* or *percentage error*. The larger the absolute error, the poorer the accuracy. Percentage error is a useful indication of accuracy; however, an error of 1 meter can either be large or insignificant, depending on whether you are measuring the distance to a star or the distance to the front of this room. The percentage error is given by:

$$\% \text{ Error} = \frac{|\text{Measured} - \text{Accepted Value}|}{\text{Accepted Value}} \times 100$$

For example, your measurement for the diameter of a coin is 24 mm, and the accepted or actual diameter is 25 mm. Then the percentage of error is:

$$\% \text{ Error} = \frac{|24 - 25|}{25} \times 100 = \frac{1}{25} \times 100 = 4.0\%$$

Exercise

1. Using your results in Investigation 6.1, calculate your percentage error for the slope of the best fit line. The accepted value of p is 3.1416; do you think your individual percentage error is larger or smaller than the class average?

2. Compare your calculated percentage error with the calculated error for the entire class. Discuss the precision of your measurements, the accuracy of your results, the percentage error, and any errors or other factors that might have influenced the results.

3. Measure the diameter of a quarter and a nickel with a ruler calibrated in millimeters. Think about how many decimal places there should be in each reading and why.

   Diameter of the quarter = _____   Diameter of the nickel = _____
   Which digit is the estimated digit?

SIGNIFICANT DIGITS

Another indicator of the accuracy of a measurement is the number of significant digits. Significant digits are digits with a numerical value we are reasonably sure of (since every number contains some range of uncertainty). If we see the measurement 1.1, for instance, we know by convention that the true value is somewhere between 1.05 and 1.15. But how do we know how many significant digits we should give it in the first place? The rules are as follows:

1. All non-zero digits are significant, so 1239.54 would have six significant digits.

2. Zeros surrounded by nonzero digits are always significant, so 1045 has 4 significant figures.

3. A final zero or trailing zeros are significant only when not holding the decimal place (i.e. when a decimal point is present), so 10400 has 3 significant figures, 0.004500 has 4, 163.00 has 5 and 100. has 3 significant figures.

4. If we arrive at a number through counting, then the number is considered exact and is said to contain an infinite number of significant digits. If we count ten fingers on our hands, for example, there are exactly 10 fingers, not 11 or 10.2 fingers. We can consider the number to be 10.00000...all the way to infinity.

5. Numbers obtained through definitions or defined quantities also contain an infinite number of significant digits. For example, the symbol pi (π = 3.141592654...) represents an infinitely accurate number.

Exercise:

a. 0.147 mg _____

b. 235 kg _____

c. 0.0033 cm _____

d. 0.3005 ly _____

e. 5001 parsecs _____

f. 0.03 mag _____

g. 670,000 km _____

h. 50.5 ly _____

i. 7.8235 meters _____

j. 0.02040 s _____

6. When you are doing calculations with given numbers and are not told how each number was calculated, you should keep the "Weakest Link Rule" in mind (that is, "A chain is only as strong as its weakest link," in this case meaning that a calculated answer cannot be more accurate than the most inaccurate number used). If a series of calculations involves one very imprecise number, no matter how accurate the other numbers are, the final answer cannot be more accurate than that one imprecise number.

For addition and subtraction, the final answer should have the same number of decimal places as the least precise number.

$45 + 10.31 - 6.009 = 49$ (45 is the least precise number with 0 decimals)

$45 + 10.81 - 6.009 = 50.$ (round up and then drop the insignificant digits, use a decimal point after the zero to show the zero is significant)

For multiplication and division, the final answer has as many digits as the least accurate number (fewest significant digits). Thus:

$6 \times 0.003 = 0.02$ (not 0.018 — because 0.003 has one significant digit and so the answer can only have one significant digit. 0.018 has two significant digits, 0.02 has only one.)

Evaluate the following:

a. $78.52 - 6.4 =$ _____

b. $1.89 + 3.9 =$ _____

c. $32.02 \times 5.68 =$ _____

d. $23.99 \times 3.28 =$ _____

The "rules" above are the accepted scientific method of determining the accuracy of a measurement, and should be followed whenever possible. You should never simply round off your answer to two decimal places, because the precision of the instrument you used to make the measurement is never the same. As you know by now, there are many inaccuracies in scientific measurement which we must take into account. Science is not like math, where every number is infinitely accurate, because in science all kinds of systematic and random errors can happen.

SYSTEMATIC VERSUS RANDOM ERROR

In variable star observation there is both *systematic error* and *random error*. Systematic errors are those that never cancel out and are relatively constant. They can occur when the variable star observer is biased in his or her observations. It is scientifically improper to force any "improvements" of an observation to fit what you believe is a pattern. Never manipulate the data. Don't worry if the result is not exactly what you expected, just record what you see. The effect of random errors (sometimes referred to incorrectly as "human" error), on the other hand, tends to diminish over time. In fact, random error decreases in proportion to the square root of the number of measurements, so even a few additional measurements will increase the accuracy of the entire set. The average of four measurements, for example, will have only half the error of one measurement. Were the errors that occurred in measuring the circumferences and diameter of the cylinders random or systematic?

The Names of Variable Stars

You have become familiar with the convention of naming stars in a constellation with letters from the Greek alphabet, ranked from brightest to dimmest, followed by the possessive Latin form of the name of the constellation, for example: alpha Orionis (Rigel). Variable stars, however, have a different identification system. Variable stars are often not bright stars within a constellation, and since they can have a large range of variation, naming them as part of the brightest to dimmest system results in confusion. There are also more stars within most constellations than there are letters in the Greek alphabet.

Variable star names are assigned in the order in which the variable stars were discovered in a constellation. If one of the stars that has a Greek letter name is found to be variable, the star will still be referred to by that name. Otherwise, the first variable in a constellation would be given the letter R, the next S, and so on to the letter Z. The next star is named RR, then RS, and so on to RZ; SS to SZ, and so on to ZZ. Then the naming starts over at the beginning of the alphabet: AA, AB, and continuing on to QZ. This system (the letter J is always omitted) can accommodate 334 names. There are so many variables in some constellations in the Milky Way, however, that an additional nomenclature is necessary. After QZ, variables are named V335, V336, and so on. The letters representing stars are then combined with the possessive Latin form of the constellation name the same way that the Greek alphabet is used for complete

identification of the variable star. Examples are SS Cygni (SS Cyg), AZ Ursae Majoris (AZ UMa), and V338 Cephei (V338 Cep).

Friedrich Argelander initiated this system of nomenclature. He started with a capitalized R for two reasons: the lowercase letters and the first part of the alphabet in capital letters had already been allocated for other designations, leaving capitals towards the lower end of the alphabet mostly unused. Argelander also believed that stellar variability was a rare phenomenon and that no more than 9 variables would be discovered in any constellation (which is certainly not the case). Why the J is always omitted is a mystery lost in the dusty annals of astronomical history.

The AAVSO also uses a second system of names—a numerical designation. This numerical designation, called the Harvard Designation (after Harvard College Observatory, where the system was first used), is a group of six numbers and a sign that give the variable's approximate coordinates for the year 1900. The first four digits give the hour and minutes of right ascension; the last two (with a plus or minus sign) the degrees of declination. For example, the designation 0942+11 for R Leonis denotes an approximate position of right ascension of 09 hours 42 minutes and a declination of +11° for the year 1900. What is the advantage of using the Harvard Designations?

The Dangers of Radiation

The largest source of natural radiation comes from the radioactive decay of unstable elements within the Earth's crust, such as uranium-238, potassium-40, and radon-226. As a result, we are constantly exposed to radiation from granite and other rocks, soil, hot springs, and building materials. We also ingest foods which contain radioactive isotopes such as potassium-40, originally part of fertilizers which leached into the soil and crops. We are exposed to radiation from cosmic rays, charged atomic particles moving at almost the speed of light which enter our atmosphere. In the upper atmosphere almost 90% of all cosmic rays are fast-moving protons. The higher the elevation, the greater the exposure to high-level radiation from cosmic rays. The majority of these cosmic rays do not reach the surface because of the Earth's magnetic field, which produces the donut-shaped Van Allen belts that trap the fast-moving protons. Most of the charged particles in the Van Allen Radiation Belts originated in the solar wind that streams out from the Sun's corona. In the polar regions radiation leaks out of the Van Allen Belts and ionizes the air, producing brilliant displays called aurorae.

Space Walk

The Earth's magnetic field is offset from its center. Besides being inclined at about 11° to the rotational axis, the magnetic axis passes through the equatorial plane at about 500 kilometers toward the western Pacific. This means that on the opposite side of the globe, above the western Atlantic at around 30° south latitude, the inner radiation belt extends down into Earth's upper atmosphere to an altitude of only about 200 km. Centered off the Brazilian coast, this region of the sky is known as the South Atlantic Anomaly (SAA). In this area satellites can suddenly and mysteriously start malfunctioning, cutting power to vital subsystems, spinning dangerously out of control, and even closing down all systems. The radiation environment produces an electronic nightmare for satellites in this area at altitudes below 1000 km. The Hubble Space Telescope (HST) occupies a circular orbit about 600 km high and has a low 28.5^o inclination, which means HST passes through the SAA on 9 or 10 successive orbits daily, with encounters lasting as long as half an hour.
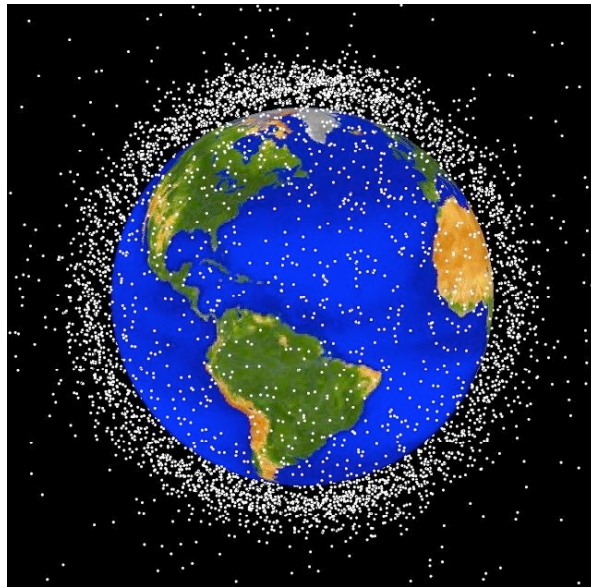
Satellite exteriors, internal structures, and electronics packaging provide sufficient protection against electrons, but higher-energy protons can still get through. Sensitive devices are placed in more protected areas of the satellite, and provided with extra radiation shielding if possible. Sometimes instruments must be turned off for the duration of SAA passages. Some spacecraft components cannot be protected, such as solar-cell arrays, which suffer from constant and continuous degradation due to radiation.

If instruments and electronics must have extra protection against the radiation in the SAA, what about astronauts and scientists who encounter this area for extended periods of time? When the space station Freedom is constructed, the astronauts and scientists aboard will have to be prepared to deal with this potentially hazardous radiation exposure. NASA is studying the radiation dangers posed by working and living in space. Several space shuttle missions have carried a model of a human skull covered with synthetic skin and filled with sensors to detect radiation. NASA is using the data to redesign space suits and helmets to incorporate greater radiation protection for future space-dwellers. Exactly what dosage of radiation is acceptable is difficult to determine.

The effects of ionizing radiation on living organisms are divided into two categories: genetic damage and somatic damage. Genetic damage occurs when the DNA molecules in the genes of a person's reproductive organs are altered, causing a mutation. These genetic changes are passed on to future generations. Somatic damage involves cellular changes caused by ionizing radiation in all other parts of the body except the reproductive organs. Of major concern is the induction of various forms of cancer. It is difficult to assess the risk of cancer or other forms of damage as a result of exposure to even low-level ionizing, or natural, radiation. Populations in regions where the background radiation is higher than normal show no apparent effect of their exposure. Yet it is nearly impossible to make an accurate comparison with other populations because of differences in diet, social habits, and ethnic origin.

Radiation is not the only orbital danger for spacecraft. Space exploration has produced increasing amounts of space debris, which is becoming a problem. Space debris, also referred to as "space waste," is defined as any useless object in space, regardless of size. It covers objects of all sizes, from large inactive satellites or burnt-out rockets, to freely flying nuts and bolts, down to objects of a fraction of a millimeter, such as flakes of paint. Orbital debris refers to debris in orbit, while re-entering debris means space debris re-entering the dense layers of the atmosphere or impacting on the ground or on the surface of the ocean. Trackable debris means debris which is large enough to be detected and tracked by present radar and telescopes and which can be attributed to a specific launch. Non-trackable debris is debris too small or too infrequently observed to enter the category of trackable. The size of trackable debris is approximately 10 cm in low orbits and 1 m in geostationary orbit.

The number of trackable objects orbiting the Earth at the end of June, 1991, was reported to be 7025 by the US Space Command. This does not include any objects smaller than 10 cm in diameter. According to US estimates, the amount of debris, including untrackable objects of more than 1 mm in diameter, is 3,500,000 pieces. The total mass of these objects is estimated to be 3000 tons. The debris in low Earth orbit (LEO) is the most serious threat, because most satellites, including HST, the Space Shuttle, and the future space station Freedom occupy LEO. The orbital velocity of objects in LEO is about 7km/s. The relative speed of debris at encounter depends on the angle of orbit

Computer generated image of space debris in a low Earth orbit - NASA Orbital Debris Program Office

crossing. The average is 10 km/s. The high kinetic energy of these objects results in severe damage when collisions occur. An aluminum sphere of 1 cm in diameter has the equivalent energy of a mid-size car moving at 50 km/h. There were 104 cases of breakup recorded by the end of June 1991. These breakups are believed to have created many untrackable pieces of small debris, and most breakups took place in LEO. Freedom will have to be able to withstand collisions with objects of up to a few centimeters in diameter, the equivalent of being run into with a Mack truck.

Are nations responsible for space debris? Is it a legal issue? A moral issue? It is impossible to account for ownership of space debris and the damage it inflicts, especially for untrackable debris. What should be done? Should periodic sweeps try and clean up at least the trackable debris before it deteriorates into untrackable debris? Should nations contribute to funding for this problem equally? According to the percentage of orbital launches? Should we be concerned with space litter the same way we are concerned with highway litter here on Earth?

Core Activity 6.4: More Magnitude Estimations

1. Look at the slide projected on the screen. You will recognize it as Cassiopeia, one of the five constellations in the HOA program. Draw the pattern of six stars that make up the distinctive "W" of the constellation in the space provided below.

2. Alpha Cas has an apparent magnitude of +2.2, while the dimmest star in the pattern, epsilon Cas, has a magnitude of +3.4. Mark these numbers on your diagram and estimate the magnitudes of each of the remaining stars in the "W" based on the brightness of alpha and epsilon. Place your estimates on your constellation diagram.

3. Your instructor will give you the actual magnitudes of the stars in the pattern to a tenth of a magnitude. Calculate the percentage error for each of your estimates using the following table.

Table 6.1: Measurement Errors in Magnitude Estimations

Star Designation	Difference Actual - Your Estimation	% Error
beta Cas		
*gamma Cas		
delta Cas		

*variable star

4. Place your values for the three magnitudes into a class table on the board as directed by your instructor. Average them, place your answers in Table 6.2, and calculate the percentage error for your class averages.

Table 6.2: Measurement Errors in Class Data Measurement

Star Designation	Difference Actual – Class Average	% Error
beta Cas		
*gamma Cas		
delta Cas		

*variable star

5. Did the percentage error increase or decrease in the class averages compared to your individual measurements? Discuss why this occurred.

6. How could the percentage error be made even smaller?

7. List at least four sources of error. Are they random or systematic? Why?

Repeat this activity with another constellation. Your instructor will provide another slide with magnitude values for the brightest and dimmest stars.

Constellation drawing:

Table 6.3: Individual Magnitude Estimates and Errors for _____

Star Designation	Difference Actual - Your Estimation	% Error

Table 6.4: Class Magnitude Averages and Errors

Star Designation	Difference Actual – Class Average	% Error

Julian Day

You will note in Table 6.5 that you are required to record time using the Julian Day. This is the standard unit of time used by astronomers. Time is one of the most important quantities in any physical system. Astronomers often collect data over months or even years, and sometimes analyze very old data (even data taken by ancient observers thousands of years ago). It is essential that we use an efficient and unambiguous method for recording time.

The usual system of calendar dates has changed several times in the past and is not accurate enough for astronomical use. The Julian calendar was devised on orders from Julius Caesar. Prior to this, at different periods of time there were different numbers of days in a year. The dates kept getting out of synchronization with the seasons, and to "catch up," Caesar ordered that 45 BC contain an extra 90 days. He also added the leap year to keep the dates from changing seasons.

The modern Gregorian calendar was introduced by order of Pope Gregory XIII in late 1582. The reason for the new calendar was that by 1582, the Julian calendar was 10 days out of phase with the date on which Easter had occurred 1250 years earlier. In order to "catch up," Pope Gregory XIII dropped 10 days from 1582: Thursday, October 4th of the Julian calendar was followed by Friday, October 15th of the Gregorian calendar. Most countries adopted the Gregorian calendar as soon as it was put forth; however, Great Britain and its American colonies did not adopt it until1752. At this time 11 days had to be dropped from English and American calendars to have the same date as the rest of the world. Also, the beginning of the year was changed from March to January. George Washington's birthday was February 11, 1731; however, with the changes in 1752, Washington's birthday became February 22, 1732. As you can see, ancient dates are unreliable.

Astronomers simplify their timekeeping by merely counting the days. Each date has a Julian Day number (JD), which is simply the number of elapsed days since January 1st, 4713 B.C. For instance, January 1st, 1993, was JD 2448989; January 2nd, 1993, was JD 2448990; and January 1st, 2000, will be JD 2451545. (NOTE: The Julian Day is NOT the Julian calendar) Why the year 4713? The Julian Day system of numbers is a continuous count of days elapsed since the beginning of the Julian Period. This period was devised by Joseph Justus Scaliger, a French classical scholar in the 16th century. Scaliger calculated the Julian Period by multiplying three important chronological cycles: the 28-year solar cycle, the 19-year lunar cycle, and the 15-year cycle of tax assessment called the Roman Indiction.

The solar cycle is the shortest period in which the same days of the week return to the same days of the year in the Julian calendar. For example, if October 25th fell on a Monday one year it would require 28 years for October 25th to fall on a Monday once again. The 19-year lunar cycle is also called the Metonic cycle. It is named after Meton, a Greek astronomer in the 5th century B.C., who discovered that 235 lunations (phase cycles) occur in 19 solar years. In other words, if a full Moon occurs on September 18th, it will take 19 years for a full Moon to fall once again on September 18th. Both of these cycles started a new cycle close to 1 B.C.: the solar cycle in 9 B.C., and the lunar cycle in 1 B.C. The Roman Indiction started in 3 B.C. Therefore, 1 B.C. marked the 9th year of the solar cycle, the 1st year of the lunar cycle, and the 3rd year of the Roman Indiction. To establish a beginning point for his Julian Day system, Scaliger calculated the closest date before 1 B.C. which marked the first day for the beginning of all three cycles. This day is January 1, 4713 B.C., which is Julian Day number 1.

Core Activity 6.5: Collecting Your Own Data

> To access html, flash, and powerpoint versions of this activity go to *Activity #1: Stellar Heartbeats* at http://chandra.harvard.edu/edu/formal/variable_stars/

1. The next few pages show a series of reproductions of a star field, simulated to show the variability of a star (indicated by an arrow).

2. Estimate the magnitude of your variable star on the first picture of the star field using the magnitudes of the stars around it. Notice that the comparison star magnitudes are given without decimal points, so 38 is actually 3.8 and105 is 10.5. This convention was adopted so that decimal points would not be mistaken as field stars and to eliminate unnecessary clutter.

3. If you now feel comfortable estimating magnitudes, proceed through each of the pictures and place your data in Table 6.5 and on the board to complete Table 6.6.

Table 6.5: Data for Variable Star X

Julian Day	Magnitude		Julian Day	Magnitude

Table 6.6a Class Magnitude Estimates of Star: Magnitude Estimates of Students

Student ID →																				
Julian Day ↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1																				
2																				
3																				
4																				
5																				
6																				
7																				
8																				
9																				
10																				
11																				
12																				
13																				
14																				
15																				
16																				
17																				
18																				
19																				
20																				

Table 6.6b Class Magnitude Estimates of Star: Magnitude Estimates of Students

Student ID → Julian Day ↓	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1																				
2																				
3																				
4																				
5																				
6																				
7																				
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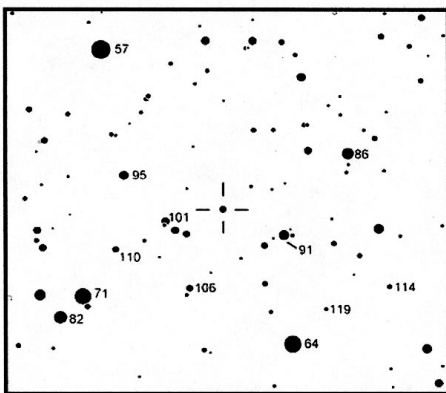
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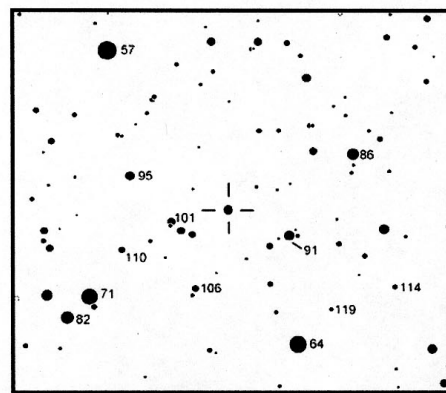
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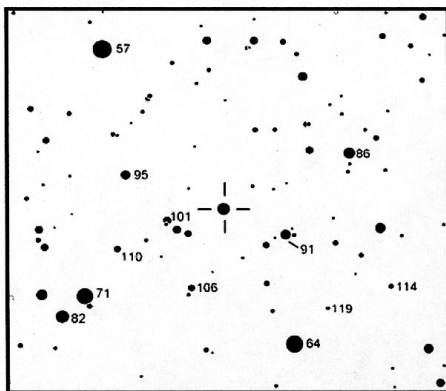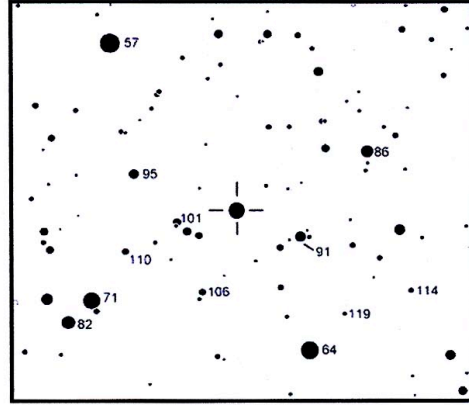

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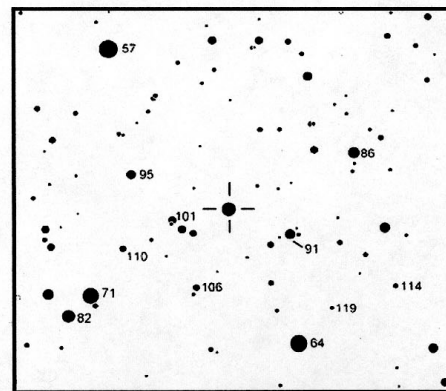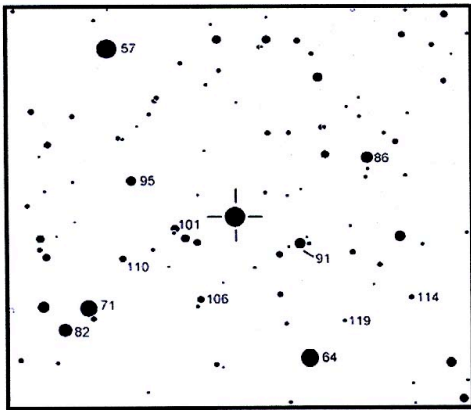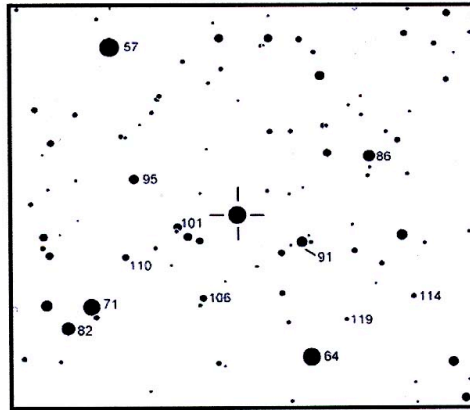
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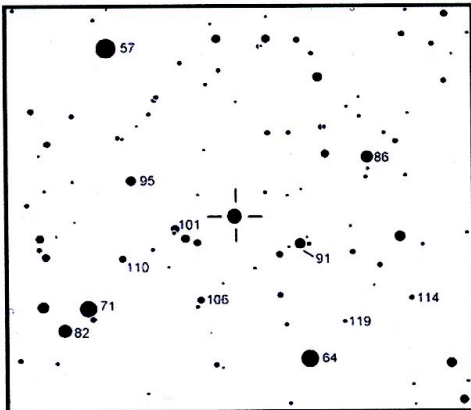
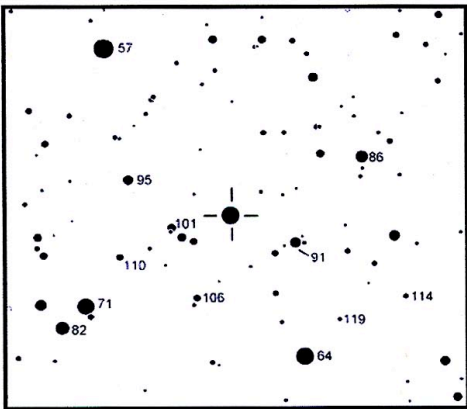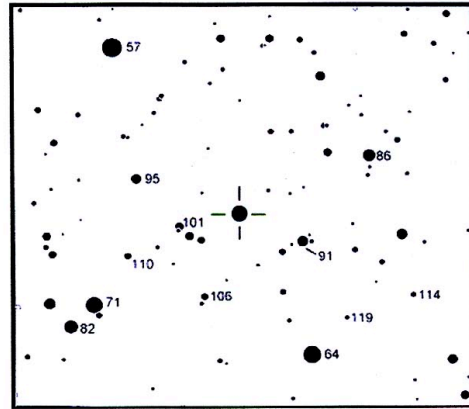JD 2449435
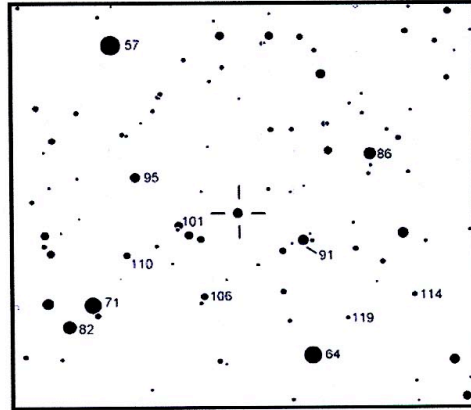
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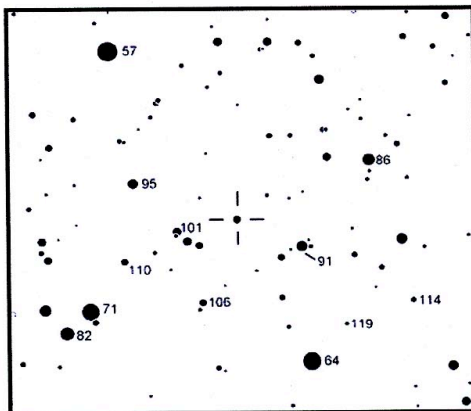
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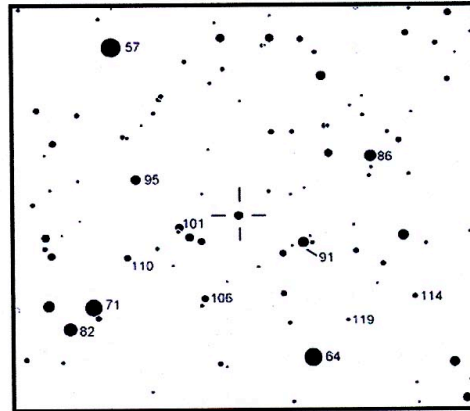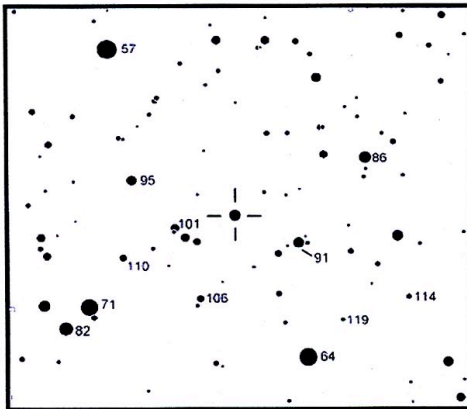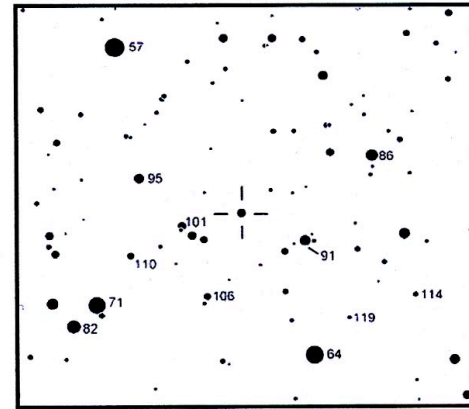
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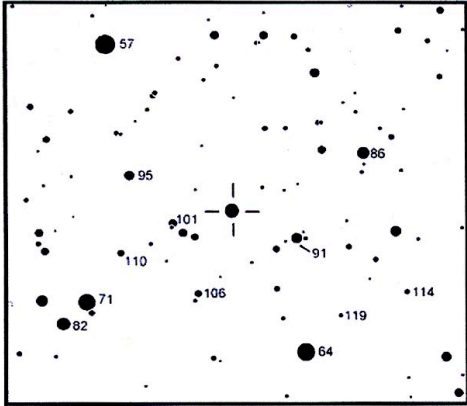
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6

Who Are the Amateur Astronomers?

In 1997, Mary Dombrowski, when a sophomore at Glastonbury High School, Glastonbury, CT, was the youngest person to submit a research project to the National Young Astronomer Award competition. Her project was a study of IP Pegasi, a cataclysmic variable star which ranges from about 12th to 17th magnitude. This star is very difficult to observe visually when it is faint, but can be easily observed during its outbursts. Mary regularly observed this star, plotted light curves of her observations, and then analyzed them. Mary showed how an analysis of the light curve helped to explain the presence of a companion star which eclipses IP Peg, and the eclipse can be observed during outbursts. For her work, Mary won 4th place in the National Young Astronomer competition.

In 1998, Mary won the First Place Award at the Connecticut Junior Science and Humanities Symposium for her research paper entitled "Cataclysmic Stellar Variability with Eclipsing Binary Superimposition." This award entitled her to a $4,000 scholarship to a college of her choice, or a $10,000 scholarship to attend the University of Connecticut.

Mary's research projects did not just happen, they grew out of her involvement and development as an amateur astronomer. She became interested in observing variable stars from her father, an experienced amateur astronomer, and learned from him how to make regular monthly observations, and submit them to the American Association of Variable Star Observers (AAVSO). After learning the basics, and gaining some experience, Mary soon became an expert variable star observer. And once she became good at making observations, she began to think more about the stars she was observing. She learned about the various types of variable stars, how they behaved, and especially about how a star's light curve can reveal clues about why the star behaves the way it does.

Without the nightly observations of amateur astronomers like Mary Dombrowski, the professional astronomer would find it difficult, if not impossible, to collect the quantity of data that is needed to further the study of stars, the Sun, novae and supernovae, comets and meteors.

Many amateur astronomers at first are astonished to learn that their stargazing efforts can make a real contribution to the advancement of the science of astronomy. There are many organizations like the AAVSO which welcome the participation of amateur astronomers of all ages and from all walks of life. Some groups may have their own area of specialization, but most will encourage an interest in any area of astronomy. These organizations are primarily made up of amateur astronomers: people who all have an interest in astronomy, who might start out with no special knowledge of the subject, but who are driven to learn as much as they can about the areas that interest them.

Why did I choose to study variable stars?

Astronomy has always been a great interest in my life. I am fascinated by the simplest astronomical objects such as the Moon and the Big Dipper. Recently, I have become more involved in astronomy and I have been observing Saturn with its rings nearly edge-on, Jupiter and the impacts made by Comet Shoemaker-Levy 9, a partial solar annular eclipse, and on occasion, the Aurora Borealis. All these objects, even though they are truly magnificent, did not really provide me with the chance to contribute data. I was always an observer but never a contributor to the astronomical community.

Through my research of variable stars I am able to make my own magnitude estimates and contribute them to the AAVSO for possible dissemination to the astronomical community for research purposes. Since I have started my research on variable stars, I have been able to provide useful information for professional scientific studies. I am proud that my observations are helping science. I also have found a lifelong hobby that will enhance my knowledge of astronomy for years to come.

-Mary Dombrowski

You may be surprised to know that some of the most important names in the history of astronomy are those of amateur astronomers. One of the first such names is Tycho Brahe, who became almost obsessed with determining the accurate positions of stars after he discovered a new star in 1572 that was, for a time, brighter than Venus and visible in broad daylight. He reasoned that there may be more such stars and other strange objects appearing, and that the best way to detect them is to have an accurate catalogue and chart of the heavens.

Another widely recognized name in astronomy is that of William Herschel. Herschel was a musician who took up astronomy as a hobby. He learned how to make telescopes and how to make observations. His astronomy work was so good and so valuable that his country, England, awarded him a regular stipend to allow him to do astronomy on a full-time basis.
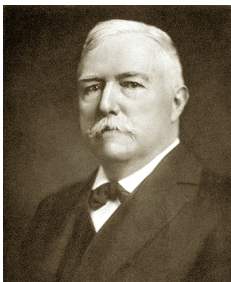
There are others in the past who started out as amateurs, but whose contributions were so significant they went on to professional careers in astronomy. E. E. Barnard, in the photo at left, discovered a star with the highest known proper motion, now known as Barnard's Star; young English amateur John Goodricke discovered the period of the eclipsing "Demon Star," Algol; Edward Pigott discovered the variability of delta Cephei.

One of the most prolific amateur observers in the 20th century was Leslie Peltier. Leslie grew up on a farm in Ohio. He bought his first telescope with the money he earned picking strawberries for his father. Leslie was an amateur astronomer for life, while he earned his living by working as a farmer, mechanic, toy maker, and stock clerk. From 1918 until his death in 1980 he made over 132,000 variable star observations.

MaryJane Taylor was five years old when she helped her dad build a telescope. She enjoyed it so much that she built her own 6-inch reflector a year later. She then began making solar and variable star observations. As a high school student she spent two summers as a research assistant at the Maria Mitchell Observatory in Nantucket, Massachusetts. In college MaryJane took courses in physics, astronomy, and math. As a graduate student, she was a member of the South Pole Optical telescope team which established the first automated optical telescope at the South Pole. After earning her Ph.D. in astronomy, she worked on a number of important projects, including the Hubble Space Telescope High Speed Photometer. She now is a professor at Loras College, Iowa, where she teaches physics and astronomy, and continues to be active in astronomical research work.

Core Activity 6.6: Magnitude Estimation and Graphing with Slides (and/or prints)

> To access html, flash, and powerpoint versions of this activity go to *Activity #2: A Variable Star in Cygnus* at http://chandra.harvard.edu/edu/formal/variable_stars/.

1. View a slide of the constellation Cygnus. Look for the asterism referred to as the Northern Cross and sketch the pattern of the brightest stars. Rank and label the bright stars on your sketch.

2. Compare the Cygnus finder chart to the slide and your drawing. Note the orientation of the slide and chart. Locate the bright stars on your finder chart and note their names. Locate the variable stars on the finder chart and locate the approximate regions of some of these variables on the slide. A set of prints of Cygnus is also included. You may decide to locate the variables on the first print and mark them on an overhead transparency. You can then move the transparency from print to print to see the changes in the variable stars. NOTE: The positions of the stars may change slightly from print to print.

3. The next set of slides are all enlargements of one-quarter of the Cygnus area and contain the variable star W Cyg. Locate W Cyg on finder chart (aa). The second slide is approximately the same scale as the finder chart (aa). Locate W Cyg. Familiarize yourself with the pattern of stars around W Cyg so that you can locate it easily when it is time to move on to the next slide.

4. Locate the comparison stars for W Cyg on the finder chart, and then identify the comparison stars on the slide. Using the known magnitudes of the comparison stars which are listed on the finder chart, estimate the magnitude of W Cyg from the slide. Repeat for all slides in the set.

5. Plot your magnitude estimates individually and as a group. Sketch a "best fit" curve (called a light curve) through the plotted points and determine the times of maximum and minimum brightness. Make a rough estimate of the period. Compare your results to the actual light curve provided by your instructor.

SPACE TALK

Photometry is the measurement of the brightness of a source of radiation over time. The brightness of infrared, optical, and near-ultraviolet wavelengths is measured in terms of apparent magnitude. The human eye can make comparisons accurate to 0.1 magnitude between an unknown star and **comparison stars** of known brightness. *Photoelectric photometry* consists of the measurement of the brightness of a source using electronic devices such as photoconductive or photovoltaic detectors (*photometers*), which convert radiation into an electrical signal whose magnitude can be determined very precisely (to 0.003). Galactic Cepheid variables have been studied both visually and photoelectrically for decades. If photoelectric data have a high degree of **precision**, and visual data have a lower precision, then is it useful or informative to have amateur astronomers study Cepheid variables visually?

Grant Foster, a mathematician who works for the AAVSO, has provided an answer to this question in a technical paper entitled *"Comparison of Visual and Photoelectric Photometry for Bright Cepheids."* The paper presents the analysis both of available photoelectric data and of visual data from the AAVSO International Database for two bright Cepheid variables, X Cyg in Cygnus and SV Vul in Vulpecula. The visual data selected were contributed by two prolific observers (OV and LX) who have been contributing observations to the AAVSO database for decades.

Cepheid variables have a very low **amplitude**, or difference between maximum and minimum magnitude. Since the **range** in magnitude is small, many researchers believe that these variables are unsuitable for visual study. However, photoelectric observations are sparse, usually consisting of a few days or weeks of monitoring with months or years of unobserved time in between. It is difficult to analyze such sporadic observational records. Any changes between periods of observation may go undetected, and temporary changes may be missed entirely. A well-studied Cepheid may have ~200 photometric observations. Visual observations provide a vast quantity of data, and even more important, the coverage is continuous over long periods of time. Large quantities of data over a very long time span are necessary for any detailed study of the behavior of Cepheids that is revealed by their **light curves**.

An example of this shows up in the analysis of SV Vul. The available photoelectric data set consisted of 164 data points spread over a 3000-day time span. The AAVSO visual data consisted of 6,217 total observations with continuous coverage for more than 10,000 days. Plotting the photoelectric data along with 1,634 data points from one of the AAVSO observers (OV) shows how important contributions of visual observations are to the study of variable stars. (See graph at the top of the following page.)
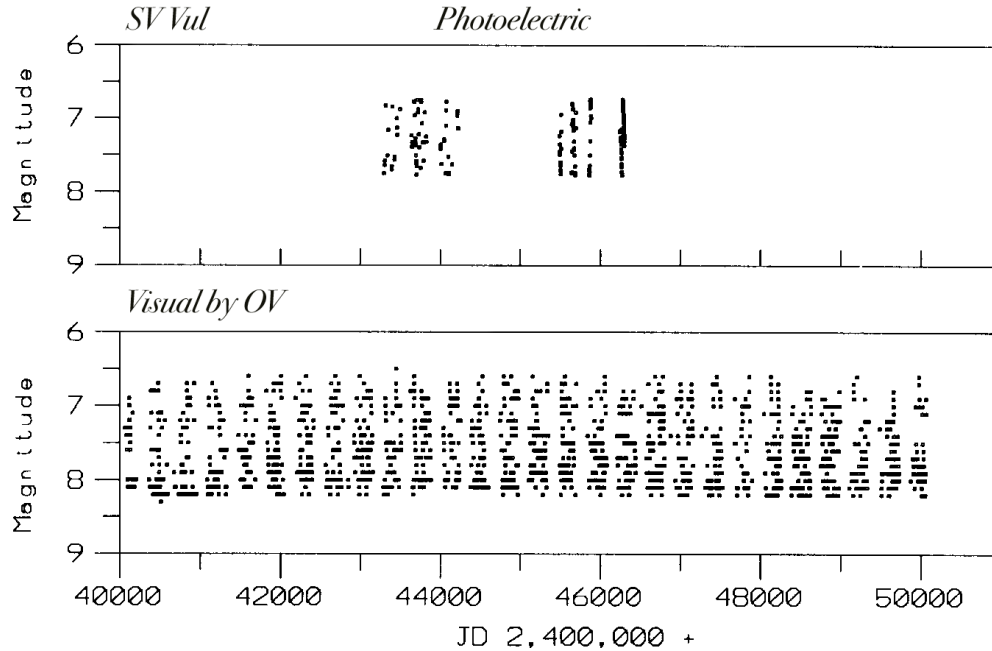
Such complete coverage over a long time span yields estimates for the period and amplitude which are more meaningful than those from available sparse photoelectric data. For example, the graph below shows that the period of SV Vul has undergone important changes over the last 10,000 days: increasing from **Julian Day** (JD) 2441000 to 2442000 and again from JD 2446000 to 2447000. It also shows a decrease from JD 2447000 to 2450000. These period changes are present in the visual data of both observers, but would not have been found from inspection of the available photoelectric data.
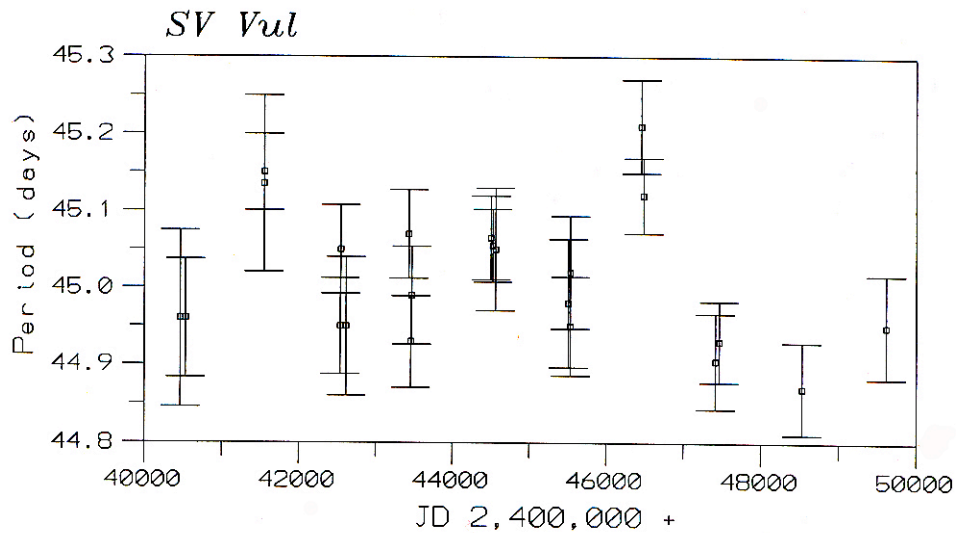
Not only can the period and amplitude be determined with great **accuracy**, but visual data can detect small, significant features in the shape of light curves. This is illustrated in the comparison of photoelectric and visual data for X Cyg in the following graph.
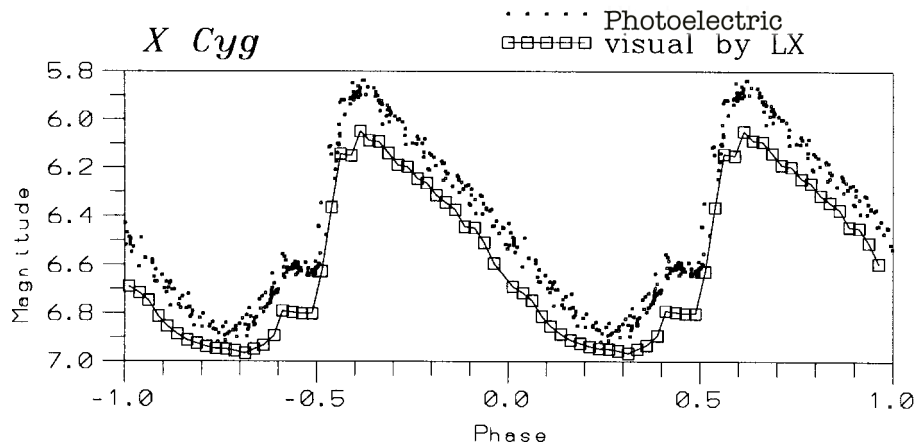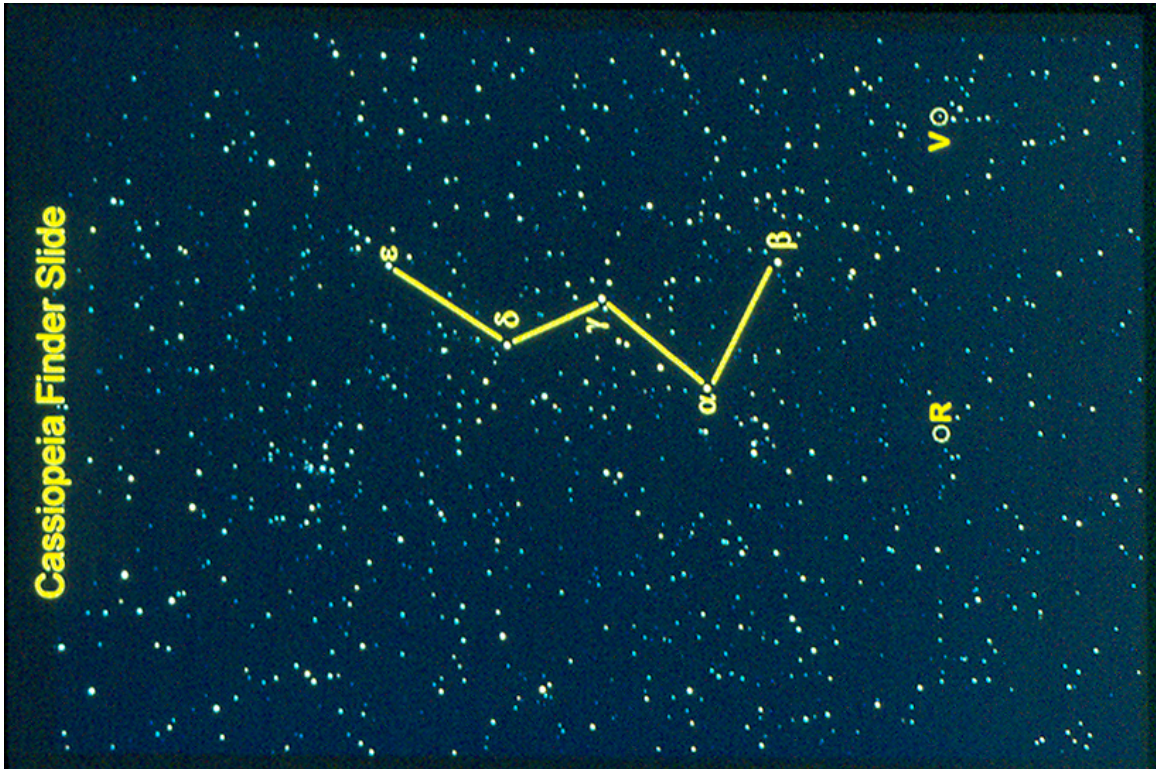

The prominent bump on the ascending branch of the light curve is clearly present in both the photoelectric and the visual data; there is also a very small bump near maximum, which is also present in both data sets, but much more clearly evident in the visual data of the amateur astronomer LX. The shape of the light curve, including small irregularities, can be detected just as well from the visual data as it can from the more precise photoelectric data. Visual observers can determine the period of a Cepheid variable with great accuracy. The photoelectric light curve is about 0.1 to 0.2 magnitude brighter than the visual light curve of LX. This is because the eye's response to light is not the same as a photoelectric photometer's. Any **random errors** of the observer are smoothed out by the large number of observations. However, with such small amplitude changes, any **systematic errors** will become evident.

Foster's analysis of visual and available photoelectric data shows that visual data are good enough for serious study of Cepheids, alerting professional astronomers to amplitude changes, providing period estimates, and revealing the internal structure in the shape of light curves.

[Adapted from a presentation by Grant Foster at the 1997 AAVSO Spring Meeting in Sion, Switzerland. The paper was published in the proceedings of the meeting, entitled Variable Stars: New Frontiers.*]*

Slides for Core Activity 6.4 – p. 1/2

Slides for Core Activity 6.4 – p. 2/2