



## Variable Stars

Stars appear to shine with a constant light; however, thousands of stars vary in brightness. The brightness that a star appears to have (apparent magnitude) from our perspective here on Earth depends upon its distance from Earth and its actual intrinsic brightness (absolute magnitude.) The behavior of stars that vary in magnitude (brightness) - known as variable stars - can be studied by measuring their changes in brightness over time and plotting the changes on a graph called a light curve. Amateur astronomers around the world observe variable 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. The behavior of some variable stars can be observed with the unaided eye or binoculars. Measuring and recording the changes in apparent magnitude and drawing the resulting light curves will allow you to begin to unravel the stories of the often turbulent and always exciting lives of variable stars. The collection and study of variable star data requires the ability to estimate the apparent magnitudes of stars. The two activities that follow will assist you in acquiring the skill of estimating the magnitudes of variable stars.

The two activities, Stellar Heartbeats and A Variable Star in Cygnus, have been adapted from the "Hands-On-Astrophysics, Variable Stars in Math, Science, and Computer Education" curriculum project developed and published by the American Association of Variable Star Observers (AAVSO.)

### Useful Resources:

- [Types of Variable Stars](http://www.aavso.org/vstar/types.stm) (at AAVSO)  
(<http://www.aavso.org/vstar/types.stm>)
- [Estimating Magnitudes Using Interpolation](http://hoa.aavso.org/estimating.html) (at AAVSO)  
(<http://hoa.aavso.org/estimating.html>)
- [Backyard Astronomers Trigger Multi-satellite Observing Campaign on SS Cygni](http://chandra.harvard.edu/chronicle/0101/aavso.html) (<http://chandra.harvard.edu/chronicle/0101/aavso.html>) and [Astronomers Team Up for Chandra Observations of SS Cygni](http://chandra.harvard.edu/chronicle/0300/aavso.html) (<http://chandra.harvard.edu/chronicle/0300/aavso.html>) (Chandra Chronicles Articles describing how the AAVSO amateur observers assisted the Chandra X-Ray Observatory)
- [Hands-On-Astrophysics](http://hoa.aavso.org) (<http://hoa.aavso.org>) Variable Stars in Math, Science, and Computer Education (at AAVSO)
- [HOAFUN](http://hoa.aavso.org/software.html) (at AAVSO - an interactive and easy-to-use tutorial for estimating the magnitudes of variable stars and understanding the light curves of different types of variable stars.)  
(<http://hoa.aavso.org/software.html>)

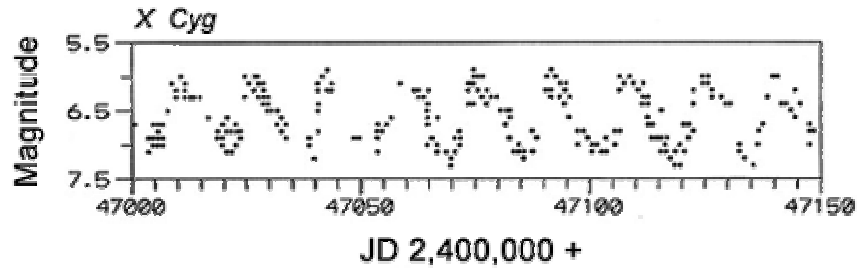


## Variable Stars

### Stellar Heartbeats

Variable stars are stars that vary in brightness, or magnitude. There are many different types of variable stars. One group of variable stars is the pulsating variables. These stars expand and contract in a repeating cycle of size changes. The change in size can be observed as a change in apparent brightness (apparent magnitude.) Cepheid variables are one type of pulsating variable stars. Cepheids have a repeating cycle of change that is periodic - as regular as the beating of a heart. Observations of the changes in apparent magnitude of variable stars - including Cepheids - are plotted as the apparent magnitude versus time, usually in Julian Date (JD). The resulting graph is called a light curve.

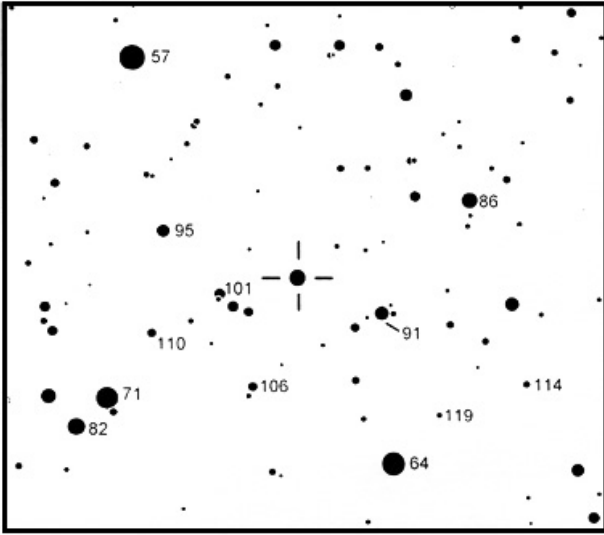
The light curve for the Cepheid variable star X Cyg (located in the constellation Cygnus) is shown below. Each data point represents one observation. Once many observations have been plotted, important information can be obtained from the resulting pattern of changing magnitudes. The period for X Cyg is the amount of time it takes for the star to go through one complete cycle from maximum magnitude (brightness), through minimum magnitude (dimmest), and back to maximum magnitude (brightness.)



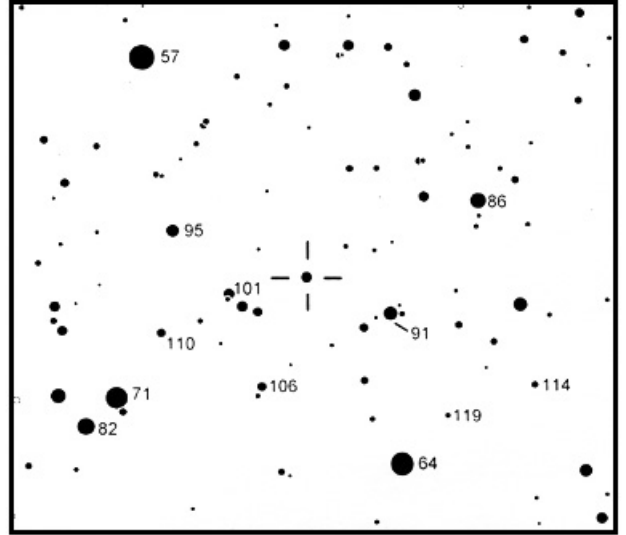
*Light curve for the Cepheid variable star X Cyg.*

Analysis of the light curve for X Cyg shows that the magnitude ranges from an average maximum magnitude of 6.0 to an average minimum magnitude of 7.0 with a period of approximately 16 days. X Cyg exhibits periodic behavior - it is a Cepheid variable star with a predictable cycle of changing magnitudes, a stellar heart that beats once every 16 days.

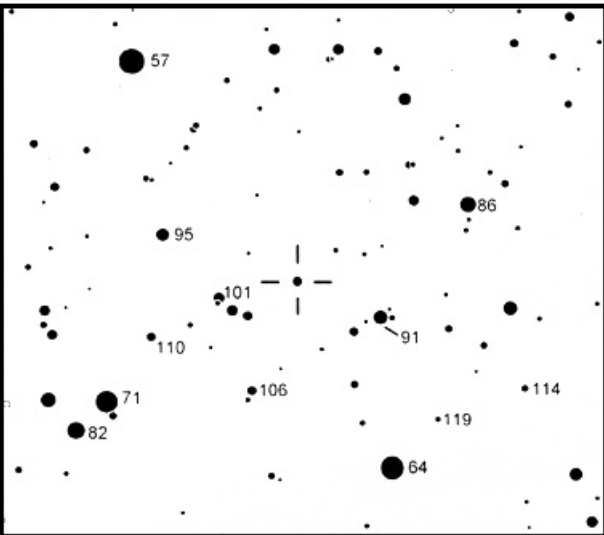




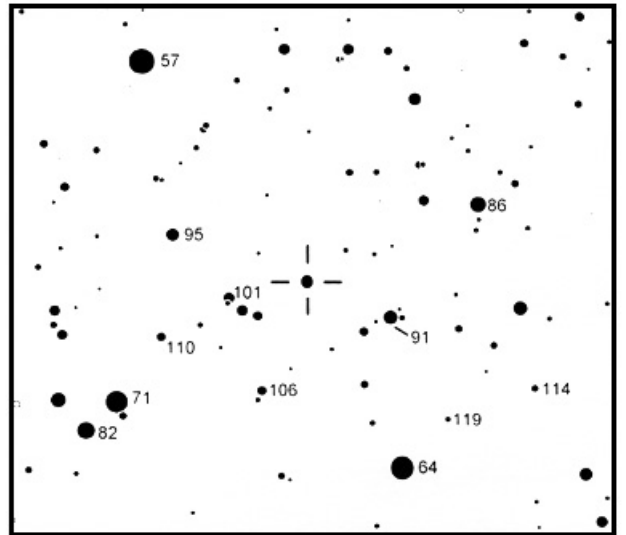
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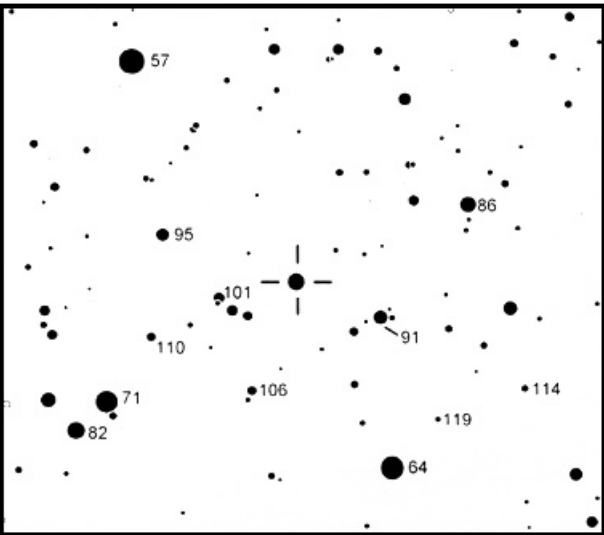
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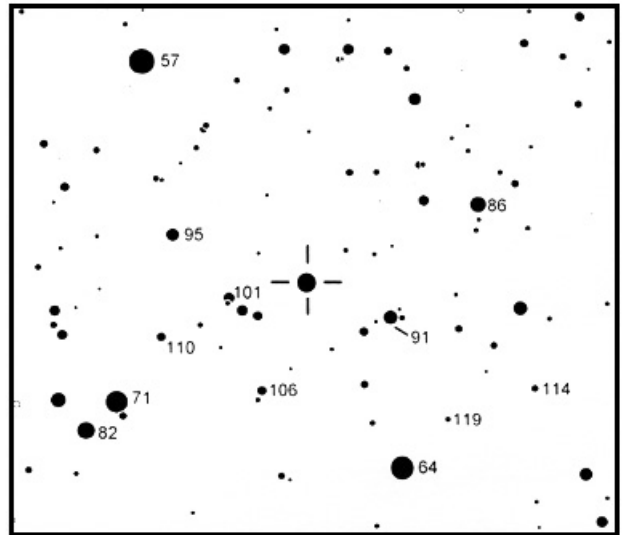
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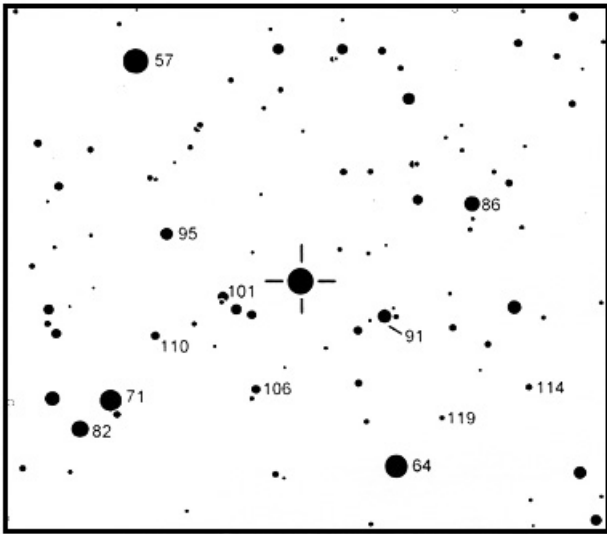
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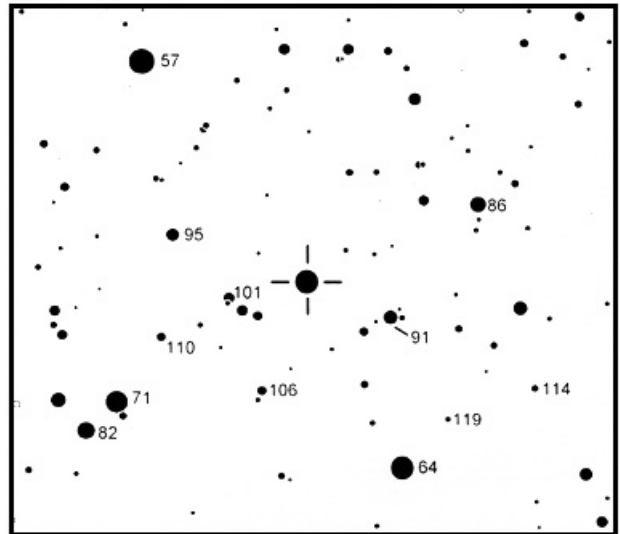
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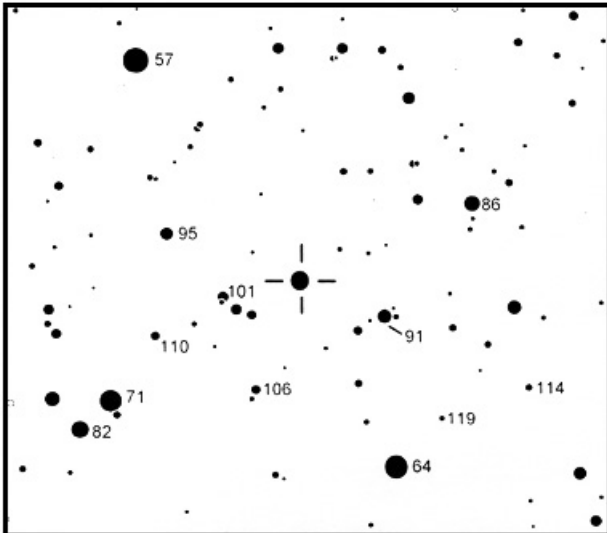
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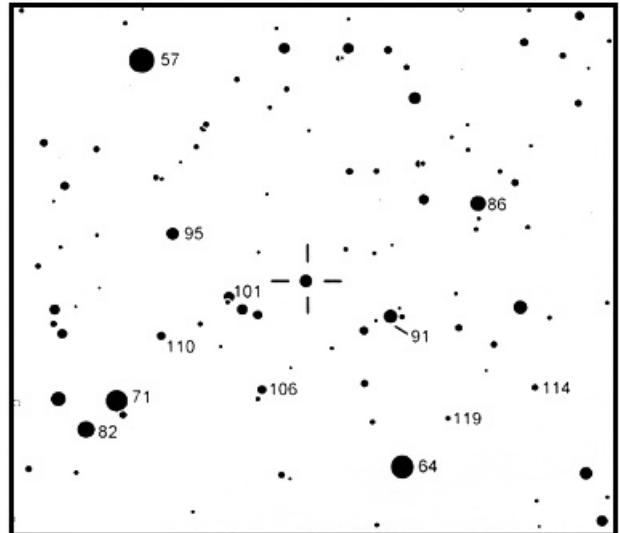
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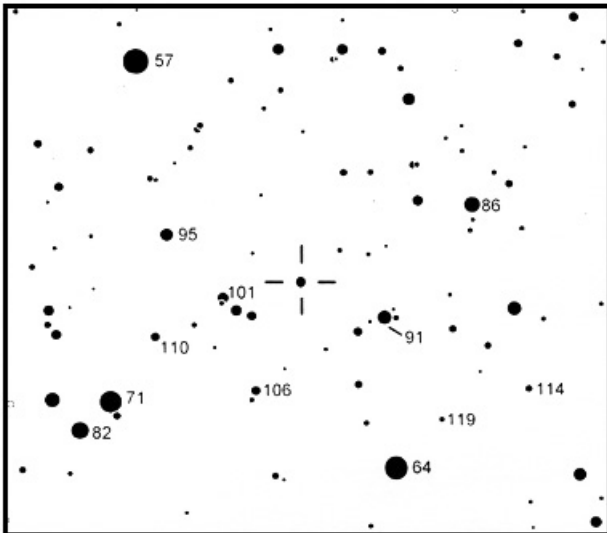
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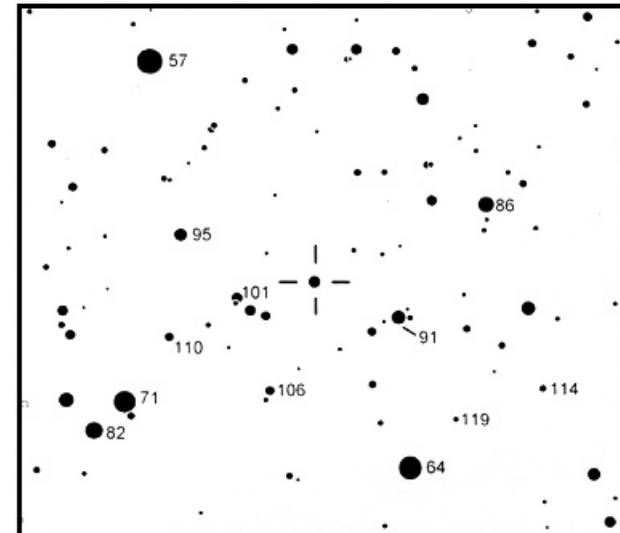
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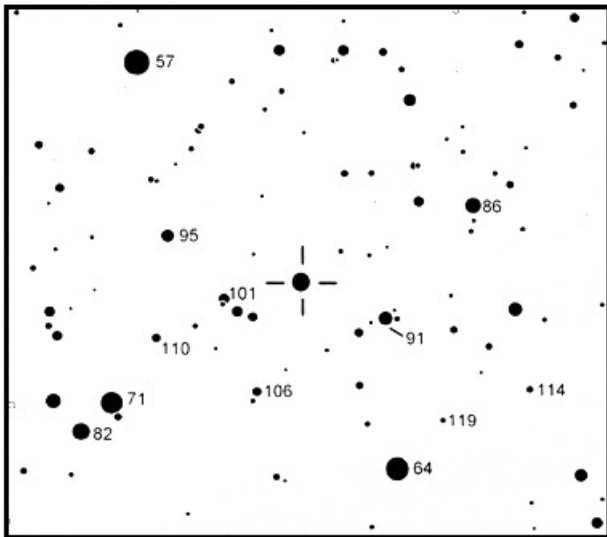
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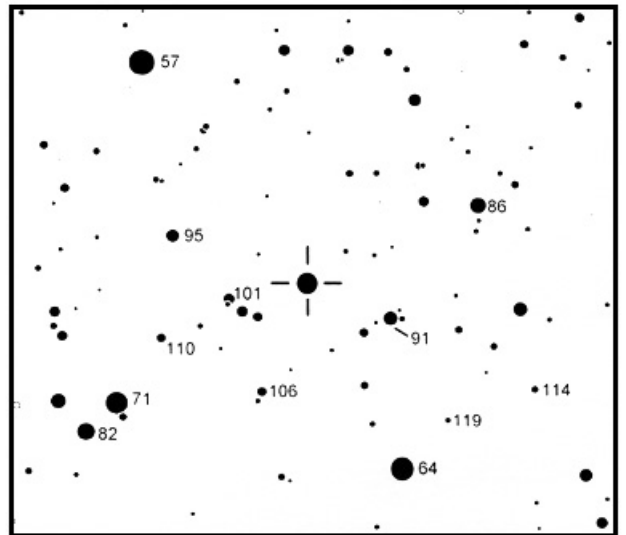
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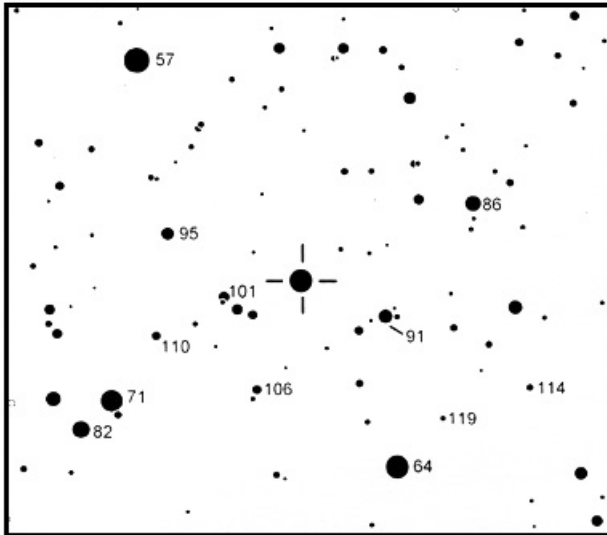
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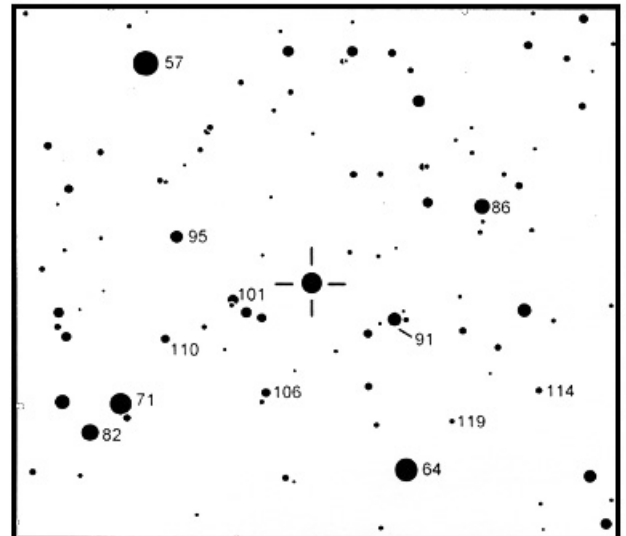
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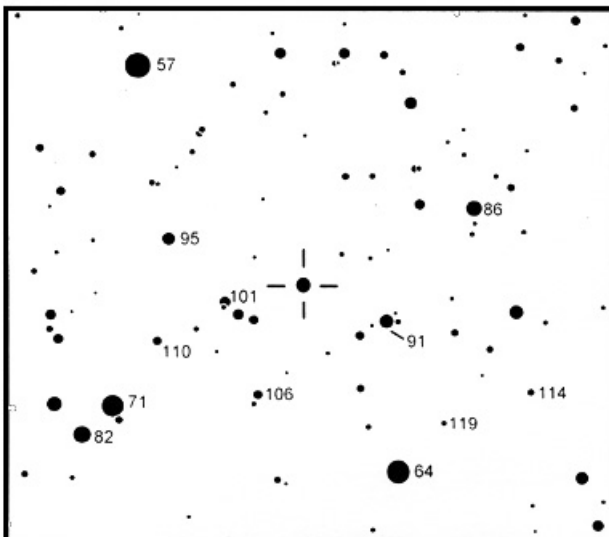
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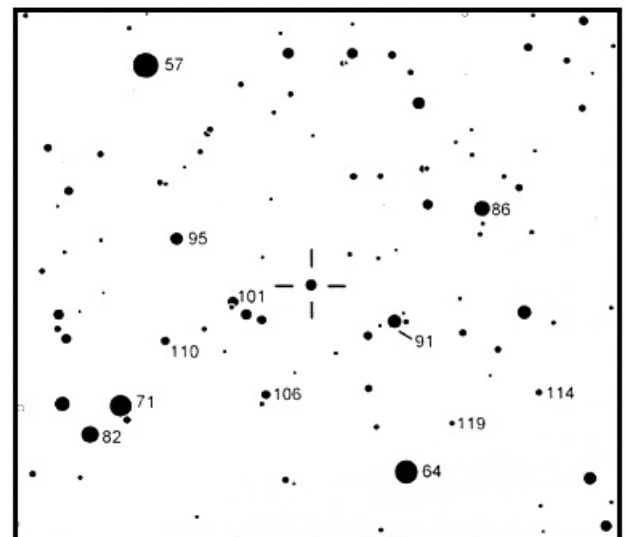
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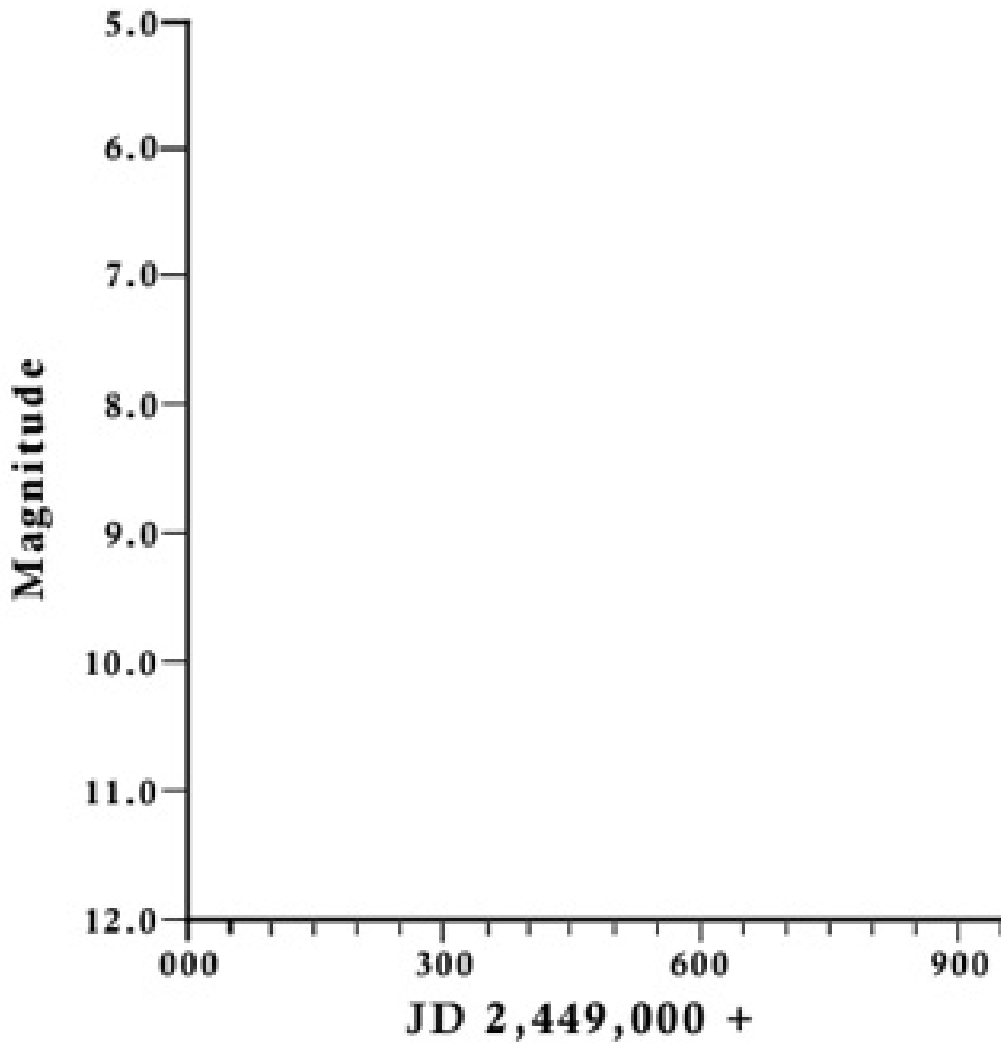


JD 2449950



### Recording Stellar Heartbeats

To determine if the variable star that you have "observed" has a regular cycle, you will need to plot your observations on a graph and analyze the resulting light curve. A graph of magnitude versus Julian Day (JD) has been provided for you. Print this page and transfer your magnitude estimations from the table onto the graph.



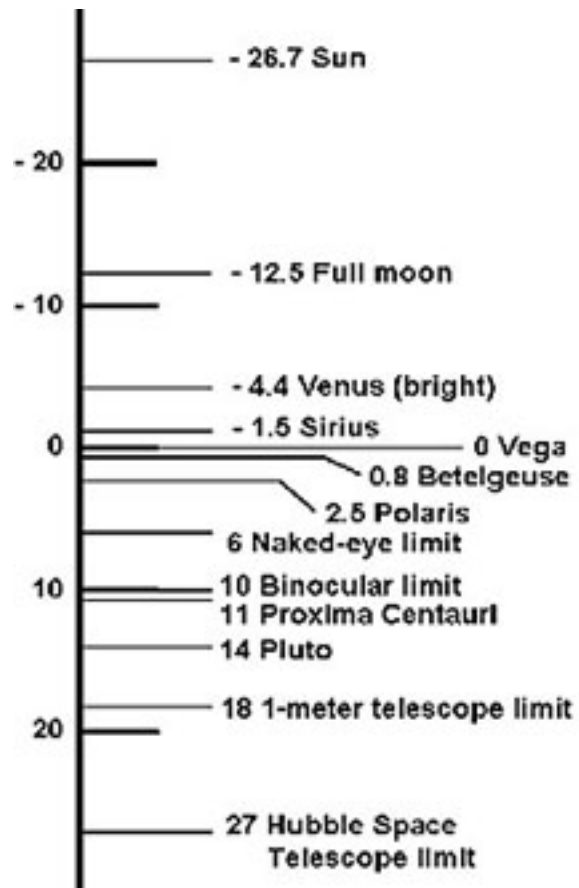


## Magnitudes

The method we use today to compare the apparent brightness (magnitude) of stars began with Hipparchus, a Greek astronomer who lived in the second century BC. Hipparchus called the brightest star in each constellation "first magnitude." Ptolemy, in 140 A.D., refined Hipparchus' system and used a 1 to 6 scale to compare star brightness, with 1 being the brightest and 6 the faintest. This is similar to the system used in ranking tennis players, etc. First rank is better than second, etc. Unfortunately, Ptolemy did not use the brightest star, Sirius, to set the scale, so it has a negative magnitude. (Imagine being ranked -1.5 in the tennis rankings!)

Astronomers in the mid-1800's quantified these numbers and modified the old Greek system. Measurements demonstrated that 1st magnitude stars were 100 times brighter than 6th magnitude stars. It has also been

calculated that the human eye perceives a one-magnitude change as being 2 and  $\frac{1}{2}$  times brighter, so a change in 5 magnitudes would seem to be 2.5 to the fifth power (or approximately 100) times brighter. Therefore a difference of 5 magnitudes has been defined as being equal to a factor of exactly 100 in apparent brightness.







## Julian Day System

Astronomers simplify their timekeeping by merely counting the days, and not months and years. Each date has a Julian Day number (JD), beginning at noon, which is 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, was JD 2451545. Why the year 4713 B.C.? The Julian Day system of numbering the days 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. 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.