A VARIABLE STAR SEARCH IN NGC 6866

by

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Department of Physics and Astronomy

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BRIGHAM YOUNG UNIVERSITY

DEPARTMENT APPROVAL

of a senior thesis submitted by

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This thesis has been reviewed by the research advisor, research coordinator, and department chair and has been found to be satisfactory.

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ABSTRACT

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Bachelor of Science

I observed the NGC6866 star cluster, searching for variable stars, for seven nights, spanning a period from july 2005 to May 2006. Observations were taken mostly in the V filter, using the 0.4 meter David Derrick Telescope at the Brigham Young Orson Pratt Observatory, located at the Eyring Science center, and both the 16 and 8-inch telescopes at the West Mountain Onservatory, near Provo, UT. Previous to this research, there were no published accounts of known variable stars in this cluster. 146 stars were observed and several were found to be potential variables.

ACKNOWLEDGMENTS

I would like to thank Dr. Hintz for being my mentor, for helping me choose the cluster, and for being the one person able to fix the bugs that no one else could. Also, I would like to thank Dr. Taylor for answering my endless questions on those Saturdays when I was working on the background section. Kathleen Moncrieff went above and beyond what one would normally expect from a friend and I am in her debt for the many many hours she spent helping me with iraf and trying to make it into the Daily Universe. I would also like to thank Tabitha Bush for helping me reduce the data. I would also like to thank Summerdale for sharing her knowledge and helping me with the photing process. I am grateful to Miriam Stevens, Patrick Baugh, Oliver Woodland, Mana Vautier, and Matt Lund for helping me observe. Murphy's Law was definitely at work but we still we able to gather some usable data. Thanks. Also, I would like to thank all my friends, roommates and family members for not holding it against me that I have been super-busy while working on this thesis. I still like you a lot. Most importantly I would like to thank God for helping me finish my thesis and get an education.

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Chapter 1

Introduction

Looking up at the night sky, one expects constancy from the stars. After all,night after night, year after year, there they are in basically the same places. Not only do they return to the same spot in the night sky after a certain predictable period, but their appearance does not seem to change, either. This constancy not only provides psychological stability and viewer enjoyment, but it also gives essential guidance to travelers and sailors. But what if that constancy disappeared? For example, imagine a sailor navigating his way through the waters of the Atlantic, who ends up in Antartica instead of America because a star's position had sporadically changed. Or, imagine the sun suddenly radiating a 10 percent more energy for several hours and then decreasing the same amount for several hours-effectively causing the temperature of the earth to rise and drop by many degrees, several times throughout the course of a day. Could we even survive in such an environment? That such a scenario could occur seems downright laughable! No, stars seem to be some of few constants in our world of change. Many changes occur in our world each day, not to mention the radical changes throughout the past couple millennia; in fact, the very landscape of the earth and the atmosphere that surrounds it has changed as a result of powerful earthquakes, tsunamis, and manmade pollution in the last several hundred years. Yet is not the night sky essentially the same to us now as it was to our parents, to Alexander the Great, and even to the most primitive Neanderthal? Surely this constancy is what caused Jean Valjean of Les Miserable to exclaim of the stars: "You are the sentinels. Silent and sure, keeping watch in the night."

However, sometimes the universe does not act how we expect. As the Catholic Church realized with Galileo's discovery that the earth was not the center of the universe, and as the reigning paradigm of the sixteenth century realized when Tycho discovered that planets actually move in elliptical motions and not perfect"celestial" circles, our perception of the universe can be dead wrong. Consequently, it should come as no surprise that many stars actually are not constant–in fact, they vary in brightness. These "variable" stars not only exist, but have played pivotal roles in the progress of astronomy. The first "varying" star discovered may have been a Supernova in 1086 A.D.. Visible in broad daylight, its luminosity changed drastically in just a few hours. However, when speaking of variable stars in this paper, we will not be referring to supernovas or many other stars that change in brightness (and legitimately might therefore be called "variable" stars). Instead we will be referring to two specific star types: intrinsic or pulsating stars, and extrinsic or eclipsing binary stars. Intrinsic variable stars vary due to physical changes within the star. The first observed intrinsic variable star was discovered in October 1595 by Dutchman David Fabricus. He named it Mira, "the Wonderful". In 1782, Englishman John Goodricke discovered an extrinsic variable star, Algol, meaning "Demon". From its light patterns he inferred that it consisted actually of two stars periodically eclipsing one another. More of these types of stars will be discusses in the background section. Since Algol's and Mira's discoveries over 400 years ago, more than 30,000 other variable stars have been discovered and many more are being discovered each year.

As part of BYU's long tradition of variable star research I chose to search for variable stars in the open cluster NGC 6866. This cluster is located in the constellation Lyrae, at a right ascension of 20:03:55, a declination of +44:09:30, and at a distance of 1450 parsecs (see Figure 1.1). This cluster was selected because there had been no previous systematic searches for variable stars in it. Consequently, a variable star search in this cluster explored uncharted territory, potentially leading to a new discovery of variable stars, the first such discoveries in the cluster. Variable stars were searched for by a process called aperture photometry, which will be explained in greater detail in the background section.

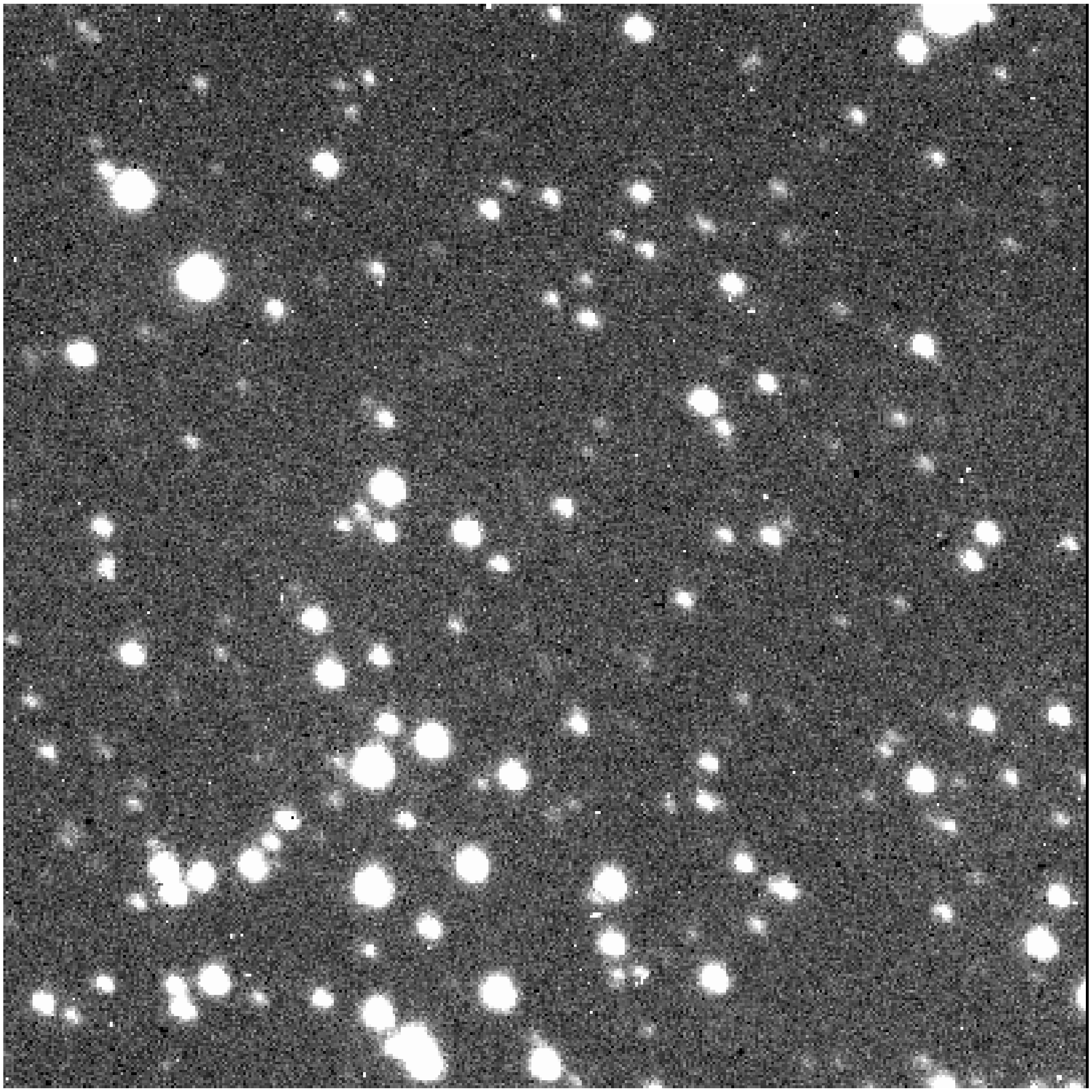

Figure 1.1 An image of cluster NGC 6866, taken on November 20 in the V filter.

Chapter 2

Background Information

2.1 Clusters

Clusters are groups of gravitationally bound stars that were created at about the same time, out of similar material. Consequently, stars that make up a cluster all have the same basic age and elemental composition. However, because matter will conglomerate differently throughout the clouds of matter, different stars will have varying amounts of mass. Because more massive stars burn at a faster rate and evolve faster, (and consequently die sooner,) we find in clusters stars at various stages of stellar evolution.

2.2 Hydrogen Burning and Hydrostatic Equilibrium

The matter from which clusters are formed is mostly hydrogen. When this matter conglomerates into an object of over 0.08 solar masses, it produces an inward force of gravity so great that temperatures in the core rise to over 1800 degrees Kelvin. At this point, the hydrogen begins to burn in a process called fusion, and a star is born. The hydrogen burning produces the light we see emanating from stars and also creates an outward pressure which counterbalances the inward force of gravity, thus creating stability for the star as long as the hydrogen keeps burning. This counterbalancing of gravity and radiation pressure is known as hydrostatic equilibrium (see Figure 2.1).

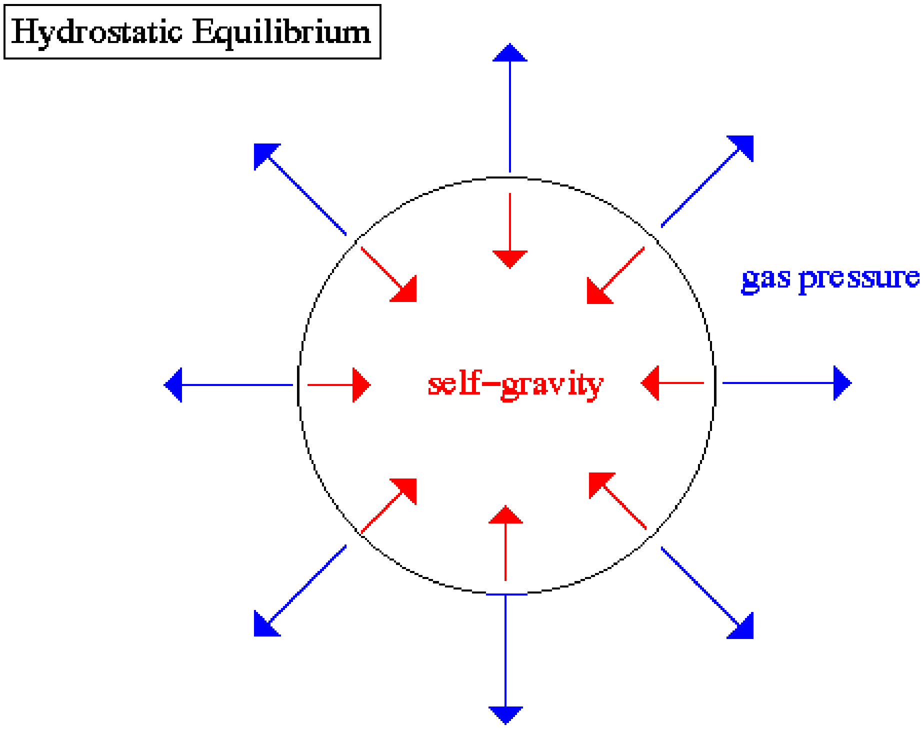

Figure 2.1 This image was taken from *http : //ircamera.as.arizona.edu/NatSci102/text/hydrostat.htm*.

2.3 HR Diagram and the Main Sequence

In the early 1900's Ejnar Herstzprung and Henry Norris Russell independently studied stars and specifically, how the brightness of a star is related to its temperature. They plotted luminosity as a function of temperature for various stars and their plot is known as the HR diagram (see Figure 2.2). Through this, they discovered the following significant relationship:

$$L \propto R^2 T^4. \tag{2.1}$$

Furthermore, they discovered from their plot that most stars are located along a certain diagonal line. This diagonal line represents stars burning hydrogen, and is called the Main Sequence. Since most stars are along this line, they deduced that most of the lifetime of a star is spent burning hydrogen. Stars that do not burn hydrogen are located to either side of the Main Sequence. Herstzprung and Russell's plot represents one of the great breakthroughs of astronomy.

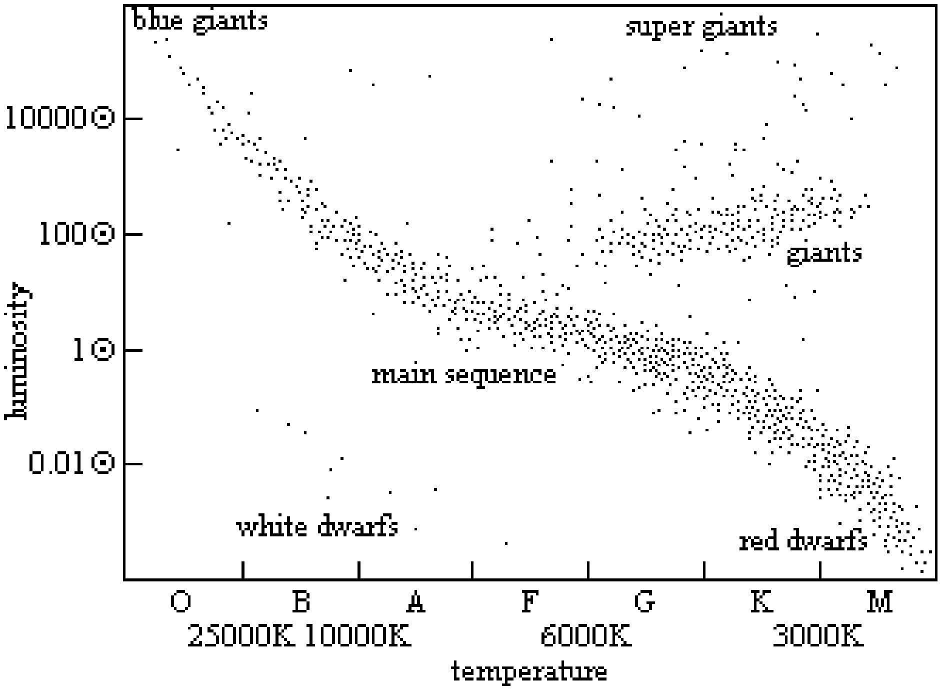

Figure 2.2 An example of an H-R diagram. Image taken from $http://imagine.gsfc.nasa.gov/docs/science/know12/stars.html$.

2.4 Mass-Luminosity Relation and Eclipsing Binaries

Analysis of the HR diagram shows that stars along the main sequence follow the significant relation: $L = M^{3.5}$. This is known as the Mass-Luminosity relation. It tells us that a star with twice the mass of sun will be over 10 times brighter. This relation was discovered by calculating the mass of stars in the same cluster (and therefore located at about the same distance from the earth,) and comparing it with their brightness. However, the mass of a star is not easy to determine. In fact, besides the sun, the mass of only one single-star system is known. Fortunately, most stars are found in binary systems, which allow us to calculate their mass. In binary systems two stars orbit each other, periodically eclipsing one another. When the brighter star passes in front of the fainter along the earth's line of sight, the total luminosity of the system will drop, but not as much as when the fainter star passes in front of the brighter star (see Figure 2.3).

By analyzing the patterns of the light curve, we can determine whether or not the stars are eclipsing binaries.

2.5 Determining the Mass for Eclipsing Binaries

Furthermore, by determining the period of the system, we can deduce the mass of the stars, as shown in the following equations.

First we find the center of mass of the binary system with the equation:

$$m_A r_A = m_B r_B. \tag{2.2}$$

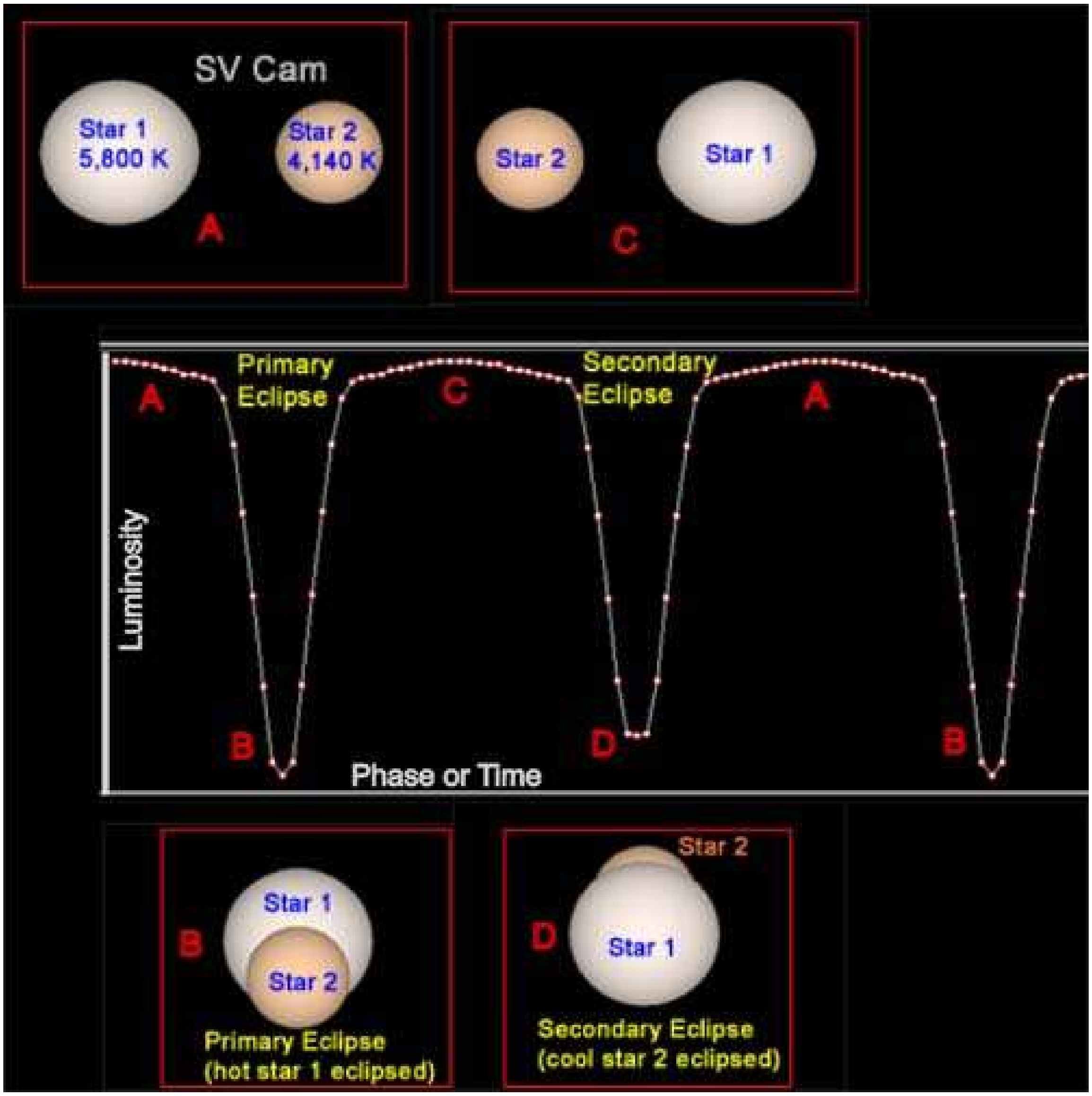

Figure 2.3 Image taken from $http : //outreach.atnf.csiro.au/education/senior/astrophysics/binary_types.html$.

We define

$$r = r_A + r_B.$$

Therefore . . .

$$r_B = r - r_A.$$

Now by plugging r_B into equation 2.1 we have . . .

$$m_A r_A = m_B(r - r_A), \tag{2.3}$$

so . . .

$$r_A = \frac{m_B r}{m_A + m_B} \tag{2.4}$$

and . . .

$$r_A = \frac{mB_r}{M}, \tag{2.5}$$

where M is the total mass of the system.

From Newton's third law, we know that the sum of all the forces in a closed system are zero. Since the only forces in a binary star system are the gravitational force and the centripetal force, these forces equal each other. In other words,

$$F_G = F_C \tag{2.6}$$

or . . .

$$\frac{Gm_A m_B}{r^2} = \frac{m_A v^2}{r_A} \tag{2.7}$$

where v is the orbital speed of star A. Unless v can be measured or inferred directly from Doppler shift in its spectrum it must be calculated from the period, T.

$$v = \frac{2\pi r_A}{T}. \tag{2.8}$$

Substituting this into (2.6) gives:

$$\frac{Gm_B}{r^2} = \frac{4\pi^2 r_A}{T^2}. \tag{2.9}$$

So if we then substitute (2.4) into (2.8) we get:

$$\frac{Gm_B}{r^2} = \frac{4\pi^2 m_B r}{T^2 m}. \tag{2.10}$$

Finding the period of the system has now enabled us to accomplish our original goal, which was solving for the mass of the system;

$$M = \frac{4\pi^2 r^3}{GT^2}. \tag{2.11}$$

Interestingly enough, this can also be rewritten as:

$$m_A + m_B = \frac{4\pi^2 r^3}{GT^2}, \tag{2.12}$$

which is an expression of Kepler's 3rd Law.

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}. \tag{2.13}$$

Comparing the masses and luminosities of many binaries located within the same cluster (, whose distances are essentially the same,) yielded the Mass-Luminosity relation. This relation can then be used to estimate the mass of single star systems (as well as trinary and tertiary systems). In actuality, determining the mass of binary systems using the above method is often very tedious because it can take years of watching a binary system before being able to determine the system's period. Determining the period of binary systems has been accomplished more painlessly by analyzing the spectra of such systems. In modern times, Astronomer Dan Popper has spearheaded this effort, thus refining the Mass-Luminosity relation for main sequence stars.

2.6 Leaving the Main Sequence and Red Giants

Eventually, stars leave the main sequence when all their hydrogen is used up. Helium, the by-product of hydrogen burning, is then left at the core of the star, surrounded by an outer shell of burning hydrogen. Because the hydrogen burning in the core has stopped, there is no outward force from radiation pressure. Consequently, the star is no longer in hydrostatic equilibrium and the force of gravity causes the star to collapse inward. The helium core contracts and heats up until it too, ignites and begins to burn, starting a new cycle of stellar fusion. Hydrostatic equilibrium is again attained as the outward radiation pressure of the helium burning counterbalances the inward force of gravity. However, the outward pressure of the helium burning pushes out the hydrogen shell, where it cools, causing the star to appear red. These stars are called Red Giants and are located up and to the right of the main sequence on the HR diagram.

2.7 Pulsating Variables and Why We Study Them

Some stars that leave the main sequence and become Red Giants begin to ”pulse”. These are known as cool pulsating variables. This pulsation occurs in the following scenario:

1. If the outward pressure is greater than the inward force of gravity then the star will expand.

2. As the star expands both the inward force of gravity and the outward pressure decrease, but the outward pressure drops at a greater rate. (think of what happens to a gas as it expands).

3. Eventually, the two forces would balance except the momentum of the outward layers carries them past this point.

4. Gravity slows the momentum down until the outer layer stops, but at this point gravity is greater than outward pressure, so the outer layers start to collapse again.

5. As the layers collapse gravity increases but pressure increases more so the

collapsing layer eventually stops but is again carried past the hydrostatic equilibrium point, so outward pressure is greater than the inward force of gravity and the pulsation cycle starts again.

Some hot stars (stars still on the main sequence) also pulsate for a different reason than the one explained above. As theorized by Eddington, in these hot stars doubly ionized helium in the atmosphere increases the opacity of the star, causing pressure to build and thus blocking more energy from escaping the star. This energy builds up in pressure, pushing the layers of the star outward until it diffuses enough to allow energy to pass, at which point the layers contract due to a decrease in pressure and the cycle repeats itself. These stars pulse like a harmonic oscillator.

2.8 Several Significant Types of Variables

Hot pulsating variable stars have played and continue to play pivotal roles in the progress of astronomy. John Goodricke discovered a very important hot pulsating variable-the Cepheid. Observed two years after Algol, and named after the first such star found, δ Cephei, Goodricke noted that these stars are distinct from other pulsating variables in that they are very bright and massive, with periods of 1-70 days. Furthermore, their light curves show a sharp rise in brightness followed by slow fall, changing by about 0.5 to 2 magnitudes. In the 1900's Henrietta Leavitt, a Harvard Astronomer, used these stars to make one of the great breakthroughs in astronomy. She conducted observations of the Small and Large Magellanic Clouds and found 1,777 periodic variables, 47 of which were Cepheids. She noticed that the Cepheids with longer periods were brighter. Since all the stars were at roughly the same distance from the earth (belonging to the same cluster), she inferred that we could know the absolute magnitude of a Cepheid star simply by observing its period.

Leavitt plotted her results and this plot is known as the period-luminosity relationship (see Figure 2.4).

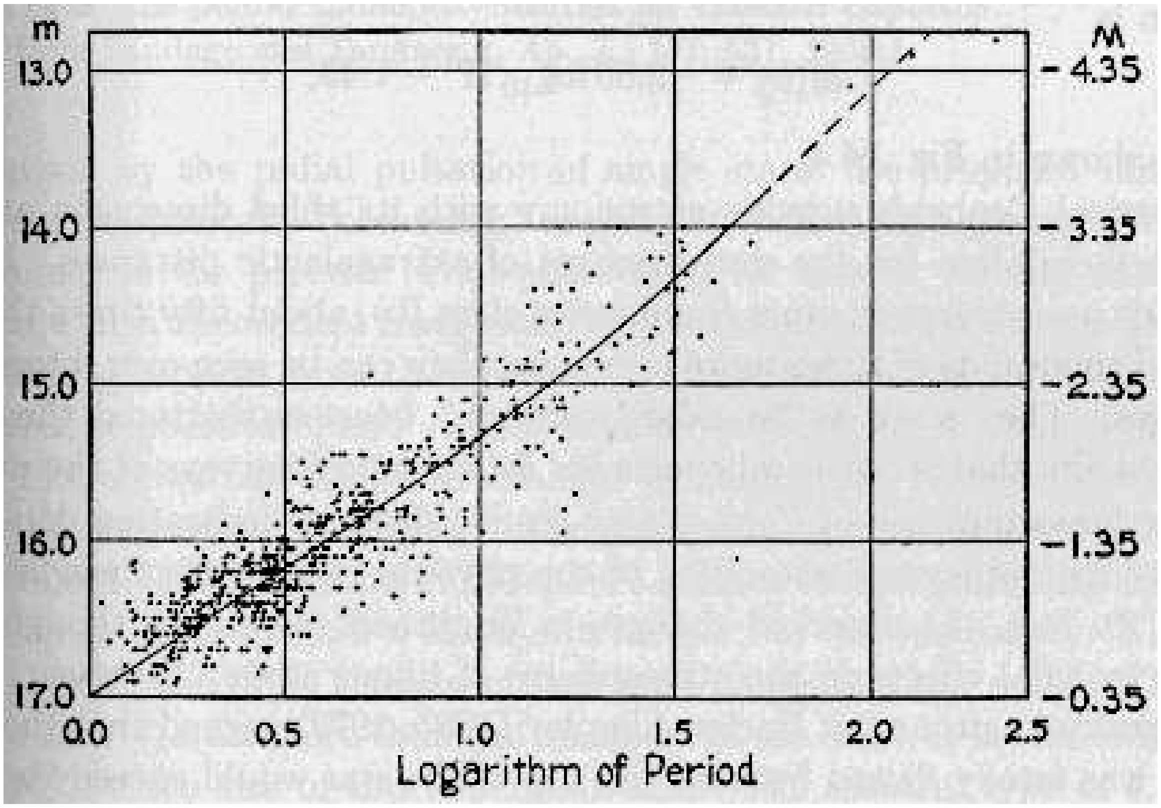

Figure 2.4 Image taken from *http://www.astro.livjm.ac.uk/courses/one/NOTES*.

Ejnar Hertzsprung realized that knowing both the absolute and apparent magnitude of a Cepheid would yield the distance by using the following formula:

$$m - M = 5 \log \frac{d}{10} - 5. \tag{2.14}$$

From this relation, Harlow Shapley deduced the size of the galaxy, and Edwin Hubble in 1924 discovered conclusively the existence of other galaxies. Cepheids have also allowed us to deduce that the universe is expanding (and that this expansion is accelerating).

RR Lyrae stars are other important hot pulsating variables. Like Cepheids, they have their own period-luminosity relationship, but have shorter periods and are not quite as bright. They are useful for finding distances to globular clusters, where they are found.

δ Scutis are another type of hot pulsating variable. Similar to Cepheids and RR Lyraes but having shorter periods and smaller amplitudes, δ Scutis are much more common. Since they also have a period-luminosity relationship, they too can be used as standard candles, but they are not very bright so cannot be used for great distances.

Besides being standard candles, the observation of pulsating stars enables astronomers to derive physical parameters such as mass, temperature, and luminosity. By studying these harmonic patterns astronomers also learn more about the interiors of those stars, much as studying seismic waves helps geologists understand the Earth's interior. In this manner, astronomers can test and refine stellar evolution theory. This area of study is called asteroseismology.

2.9 CCD's

Today, most observations of variable stars are conducted using a Charged Coupling Device (CCD). Invented in 1969 by AT&T Bell Researchers, the CCD has revolutionized astronomy because it allows images to be captured with greater quantum efficiency. This means that it can gather a greater amount of the light–60-90 percent compared to less than 30 percent for photographic plates. CCD's are made of crystal silicon containing hundreds of thousands of pixels, and each pixel is capable of storing charges created by the absorption of photons. These charges are stored in tiny potential wells. While CCDs have many advantages, several problems still arise with their use, which must be corrected for. One problem is that CCDs are sensitive to infrared light, which is emitted from room-temperature sources. In order to correct for this, CCDs are cooled to liquid nitrogen temperatures. However, this does not eliminate all the thermal “noise” and consequently, we take “dark” frames. These are frames taken with the shutter closed. These exposures are for the same amount of time as the exposures for the object. An average of dark exposures is taken and then subtracted from an average of several exposures taken with the shutter open. This corrects for the fact that some pixels respond differently to local sources than others. Another problem is that not all the pixels count the same. For example, two pixels might receive the same amount of light but have different number counts. To correct for this, “flat” frames are taken. These frames are exposures of a field of basically constant illumination. On my nights of gathering data, I used the eastern sky at twilight to take flats. Lastly, “zero” frames are taken, that is, exposures with a zero length of time, in order to correct for electronic irregularities in the CCD which may in turn create differing zero points for the pixels. These are also averaged together and then subtracted out of the object frames.

2.10 Background on Cluster

Not much is known about the cluster NGC 6866. Its age is estimated as intermediate to young (Zakharova1989) at 650 Myr (Dutra2000). There are 392 stars in the cluster and the field is 50’ X 50’ (Van Leeuwen1985). Its absolute mass is estimated to be 358 solar masses (Bruch1983). Its apparent distance moduli is 10.82 and its color excess is 0.14 (Sagar1983). Its galactic latitude and longitude are 79.5 and 6.86 degrees, respectively, and its distance from the sun is 1.49 kpc. It is located 179 kpc above the galactic plane and 8.4 kpc from the galactic center. NGC 6866 seems to have a somewhat average distribution of stars compared to other clusters. The majority of stars are located within 6 arcminutes from the center of the cluster. The radius of the core of the cluster is about 0.77 pc, while the radius for the coronal region is about 4.73 pc. The mean field star density is 2.5 stars per parsec squared (Nilakshi2002). While several bright supergiants (, which are generally found in the youngest clusters,) have been observed in NGC 6866, I could find no accounts of variable stars (Sowell1987).

Chapter 3

Observations and Data Reduction

3.1 Observations

There were a total of 7 observing nights, spanning from July 2005 to June 2006. The exact dates are specified in the table below. Five of the nights of data were gathered using the David Derrick 0.4 meter telescope with the Newtonian focus at the Orson Pratt Observatory located on the BYU campus in Provo, Utah. One of those nights, November 17, was very cloudy and the data is not very reliable. The focal ratio for the Newtonian focus of the telescope is f/5 and the CCD used was the ST-1001, with the standard Johnson V filter. The ST-1001 CCD has a plate scale of 0.76 arcsec/pixel and a field of view of 13.0 square arcseconds. The exposure time was basically the same each night-300 seconds. Two nights of data were gathered at the West Mountain Observatory, located just south of Provo, using the 8-inch telescope one night and the 16-inch another, using an Apogee CCD and the V filter. The tracking was not very good for the night using the 8-inch telescope so the data will not be used for this research. However, the night of data gathered with the 16-inch was nearly photometric and consequently highly reliable. One minute exposures were used for this last night.

Date	*CCD*	*Frames*	*Location*
July 28, 2005	ST1001	30	Campus Observatory
September 1, 2005	ST1001	35	Campus Observatory
November 2, 2005	ST1001	29	Campus Observatory
November 17, 2005	ST1001	46	Campus Observatory
November 22, 2005	ST1001	45	Campus Observatory
June 6, 2006	ST1001	149	West Mountain Observatory

Table 3.1 Table of Observation Information

3.2 Data Reduction using Aperture Photometry

Once the data was gathered and transferred from the Orson Pratt Observatory computer's hard drive and from cd's to the tardis.byu.edu database, then the data was reduced and analyzed using the Image Reduction and Analysis Facility (IRAF). First the files were changed to "imh" image files using the "rfits" command. Then the image headers were updated with important information such as the exact time when the frame was taken and the airmass when the frame was taken. This was accomplished using the "hselect", "asthedit", "setjd", and "setairmass" commands. Then, the dark, zero, and flat frames were all averaged using the task commands "darkcombine", "zerocombine", and "flatcombine", and "ccdproc". Then we did the aperture photometry.

Aperture photometry is basically summing up all the total light from stars, and then subtracting out the different sources of background noise. In order to perform aperture photometry circles were drawn around all the stars in the field that we wished to observe. Because the exposures were not taken in the exact same position on the different nights of observation, some stars were observable on one night but off the frame on another. Hence, in order to collect data from the maximum amount of potential variables, 144 stars had circles drawn around them, many of which were not visible on every night. Additionally, around each of these circles was drawn another circle. The computer then, through the phot command found in the apphot package, measured the light coming from each of the stars by counting the light from each inner circle and then subtracting from it the light of the corresponding outer circle (the background noise).

3.3 Varstar5

Once the light from each of the stars was measured using aperture photometry, the Varstar5 program was used to correct for imperfect conditions in the atmosphere such as cirrus clouds and changing air mass. It does this by choosing an ensemble of stars whose brightness does not vary and then comparing the rest of the stars to these "stable" stars. I chose my star ensemble in the following manner: first, since various stars drifted off the frame on different nights, these stars were removed first from the ensemble; second, the magnitudes of the remaining stars were averaged and used as a standard by which to compare all the other stars; third, the stars were deleted from the ensemble that had the highest "error per observation" as measured by Varstar5; lastly, the process was repeated several times until a satisfactory ensemble was found. Then information was placed in dat files, which were then opened in Excel and graphed in order to analyze the data. I looked for patterns and deviations from the majority of light curves. Furthermore, I plotted the error versus the magnitude for several nights (see figure 3.1). By ignoring the faintest stars (16th magnitude and above), and using the average of the remaining stars to find an error versus magnitude curve for the cluster, I looked for potential variables by taking note of those stars which deviated substantially from the curve (see figure 4.10). Also, I tried choosing a star ensemble by using the stars that seemed to lie most along the error curve.

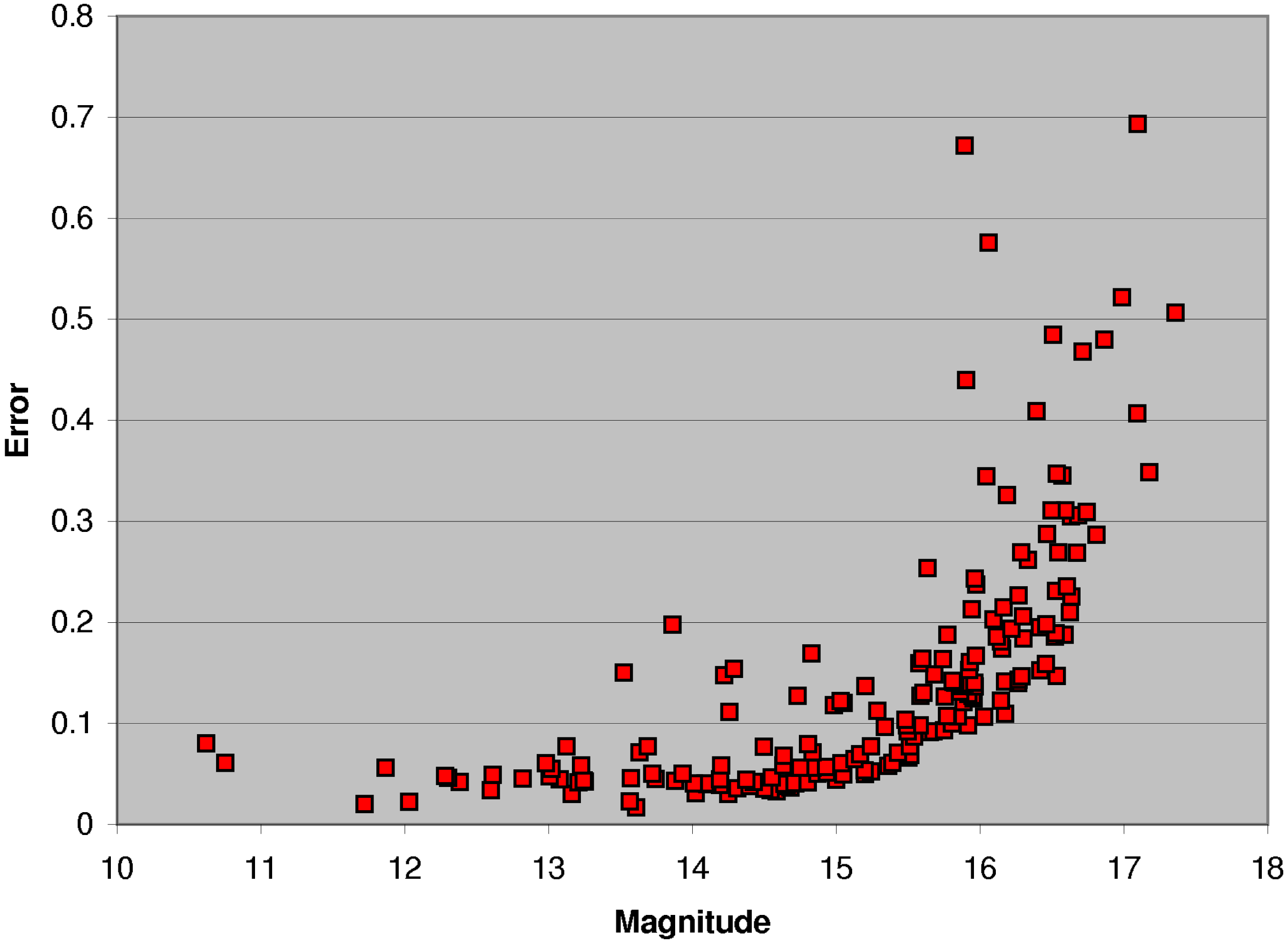

Figure 3.1 Plot taken from the data gathered on November 22, 2005.

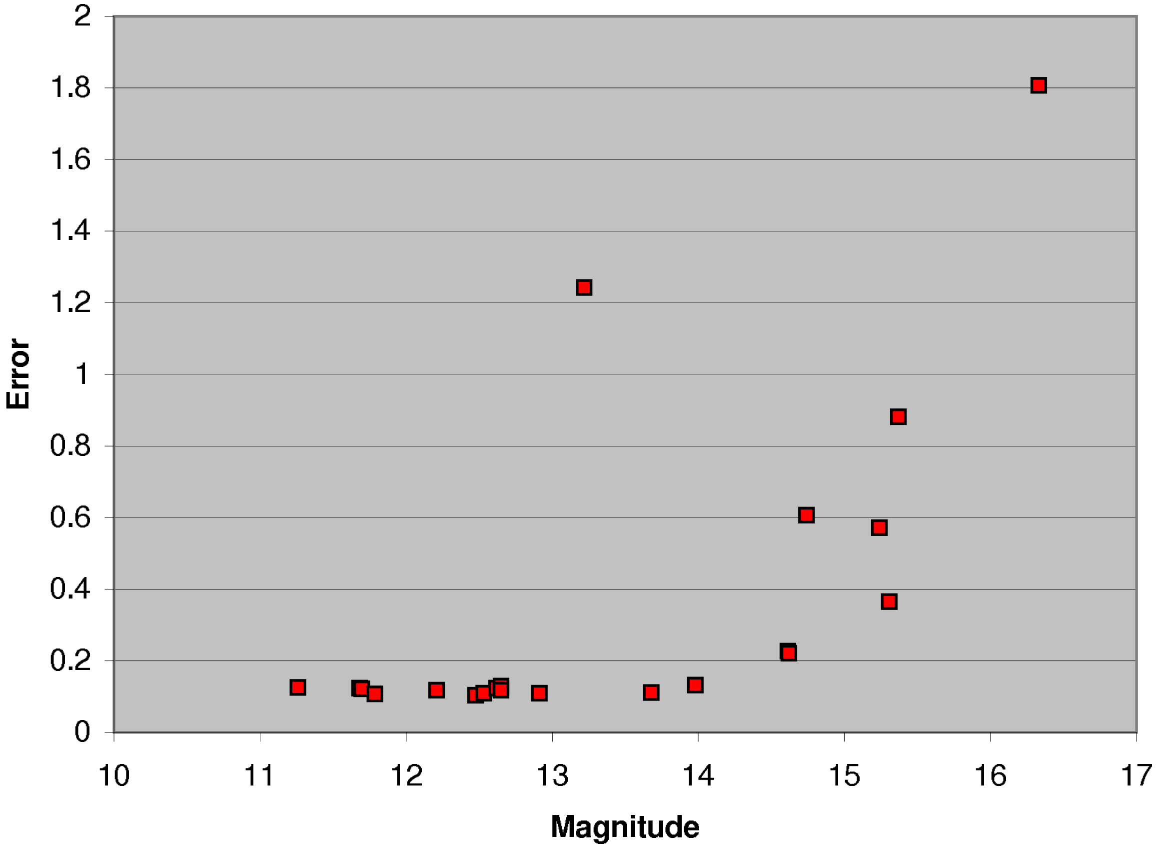

Figure 3.2 Data from the June 6, 2006 night of observation. Notice how star deviates from the curve.

Chapter 4

Results

4.1 Analysis

After looking at the light curves for all 195 stars, using many different groups of ensemble stars, those stars whose light curves seemed to show deviating trends were taken note of and then compared with the light curves for the same star on different nights. The following stars demonstrated suspicious on a majority of nights and therefore might be variable star candidates: 150, 144, 72, 65, 27.

4.2 Light Curves for Potential Variables

Star 150

This star's light curve shows an unmistakable deviation from the other stars' light curves on nearly every one of the observing nights. The period was calculated to be: 0.09575778 days (calculated by Period04–the frequency was 10.44302/day or 0.08408 days for a different ensemble). Notice how the bottom part of the curve is shallower for the second period. If the top part of the curve stayed in the same place but the bottom part got shallower then we might expect that the star is actually an eclipsing binary with a very fast period. But since the higher part shifts upward along with the lower part then it seems that such is not the case. Furthermore, it appears that several surrounding stars demonstrated the same upward shifting behavior on the same night (while many other stars not in the surrounding area but within the cluster demonstrated no such behavior). Hence this upward trend on the graph (representing diminishing brightness) does not seem to be caused by some process intrinsic to star 150, but possible the result of some bright nearby star diminishing in brightness (see figure 4.1).

Star 144

Star 144 is significant because it, along with several other stars in the same neighborhood as star 150 (stars 146 and 143), also shows an upward trend on the night of November 22. However, unlike those other stars, it also showed signs of variation on other night. Furthermore, from its unlikely position in the Error vs. Magnitude graph for June 6, we may include this star among those that are potential variables.

Star 72

This star exhibited similar certain trends on several nights that make it a variable star candidate.

Star 65

This star also showed suspicious behavior on several nights, especially on the last night of observing.

Star 27

Star 27 show variant behavior on each night except November 2. We calculated the period to be: 0.0490263 (July 28) and .119397 (Sep.1) days.

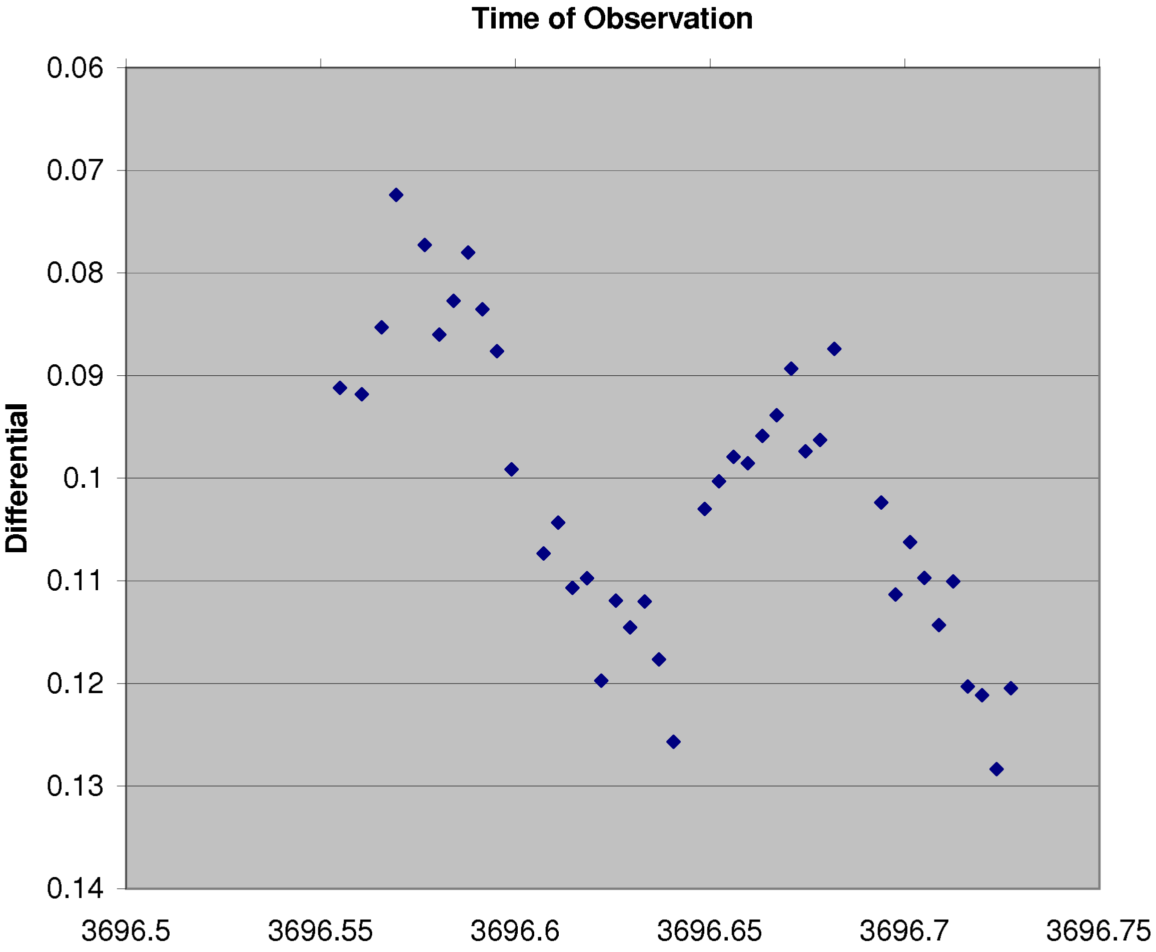

Figure 4.1 Light curve for star 150. Data taken on November 22.

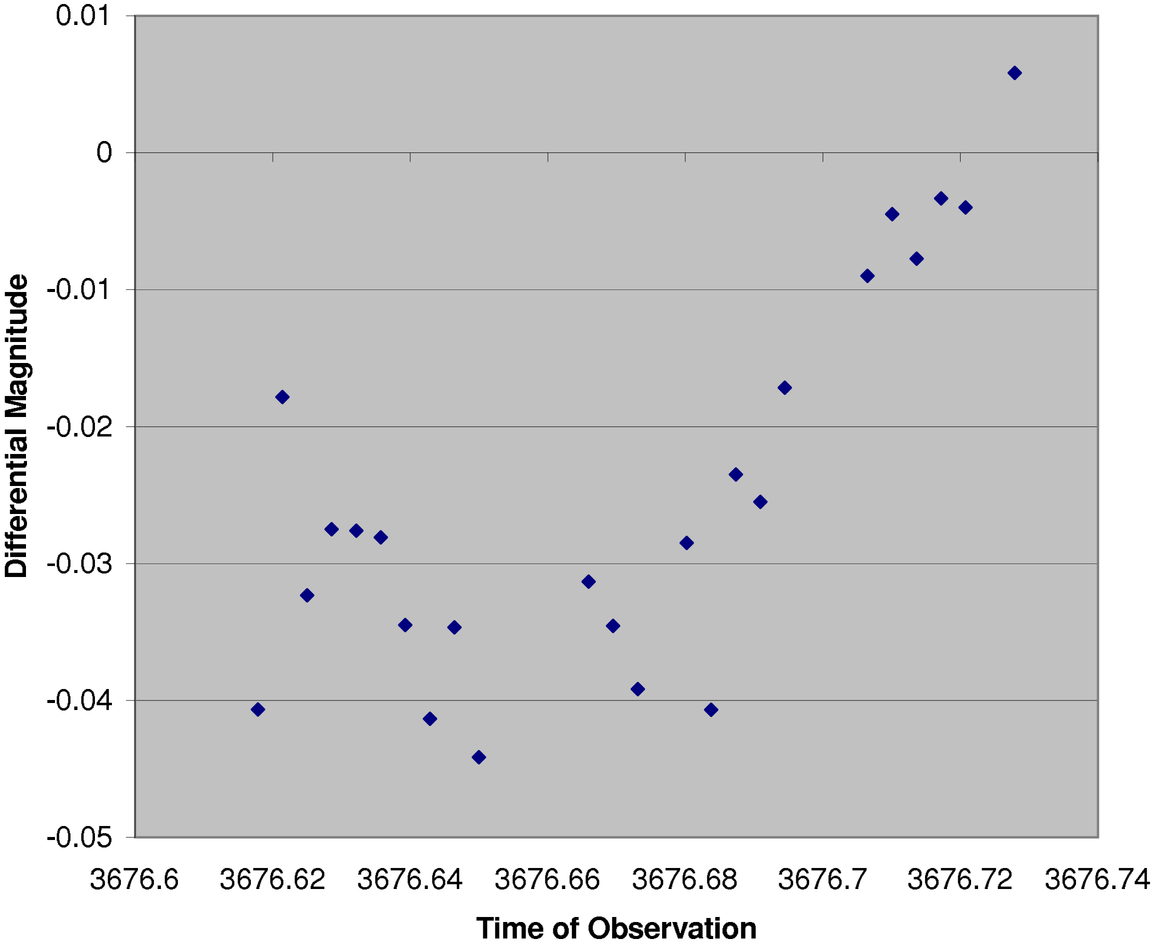

Figure 4.2 Light curve for star 150. Data taken from November 2. Notice that while there is a lot of noise, the curve is still unmistakable.

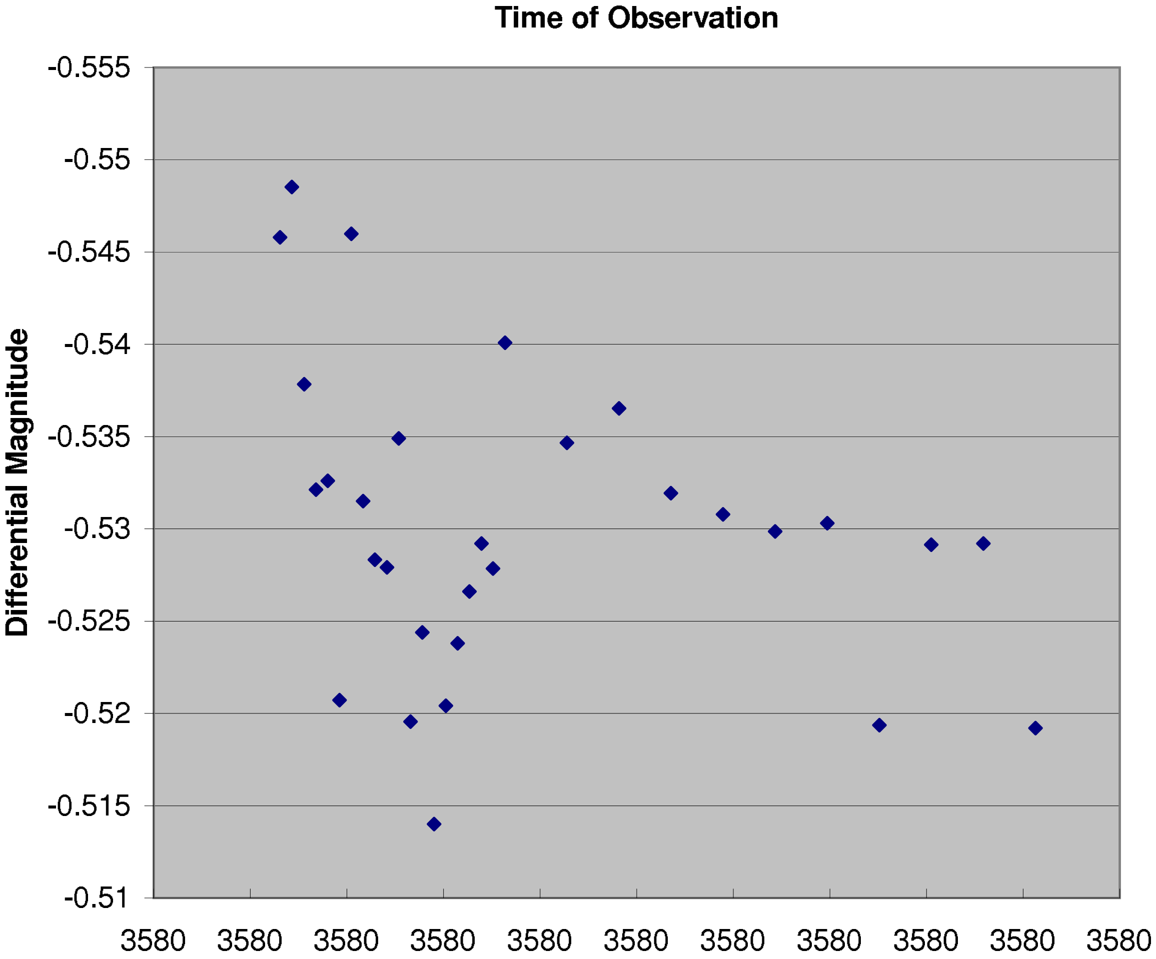

Figure 4.3 Light curve for star 150. Data taken from July 28. While there is a lot of noise at the beginning of the plot, unfortunately this noise seems to be a result of the star ensemble since all the plots from this night exhibit the same behavior. There still does appear to be a trend upward.

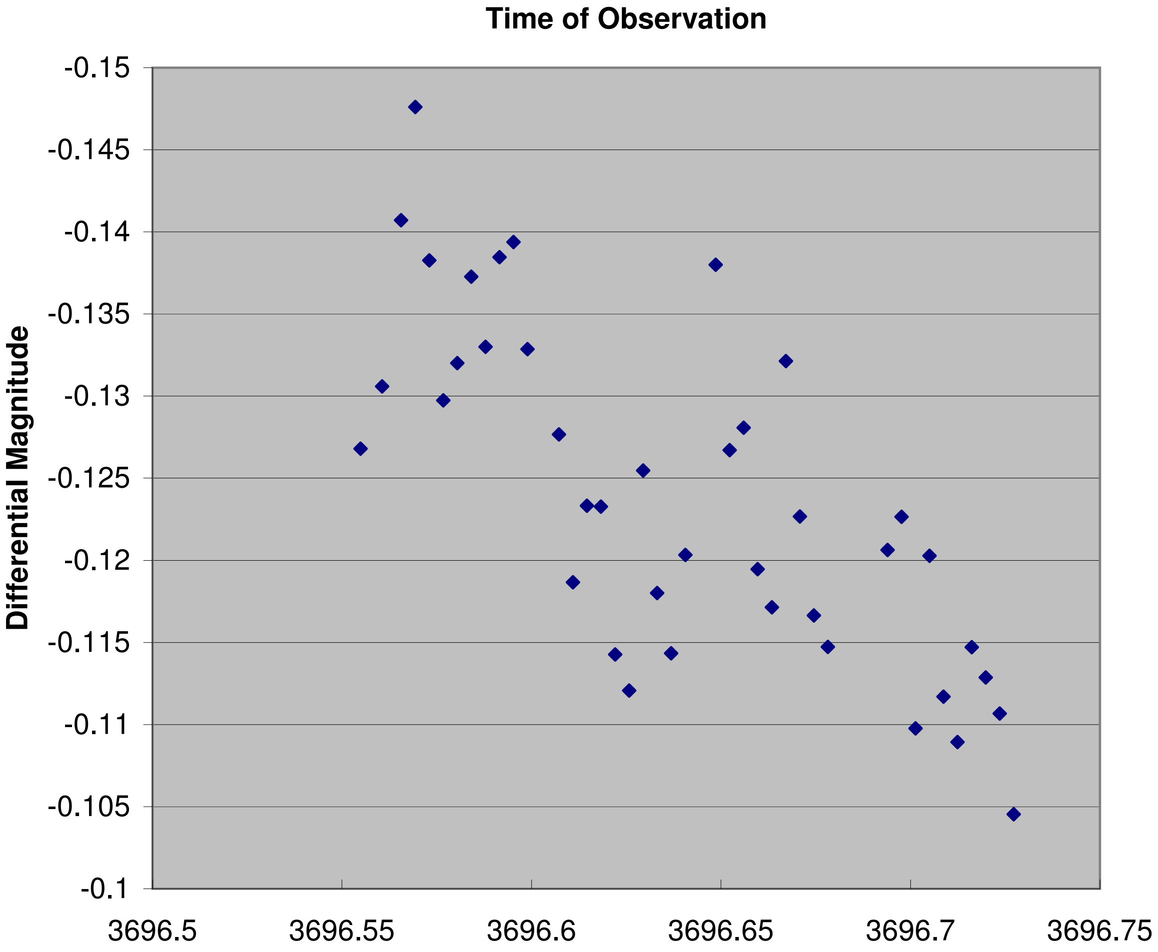

Figure 4.4 Light Curve of Star 144. Data taken from November 22.

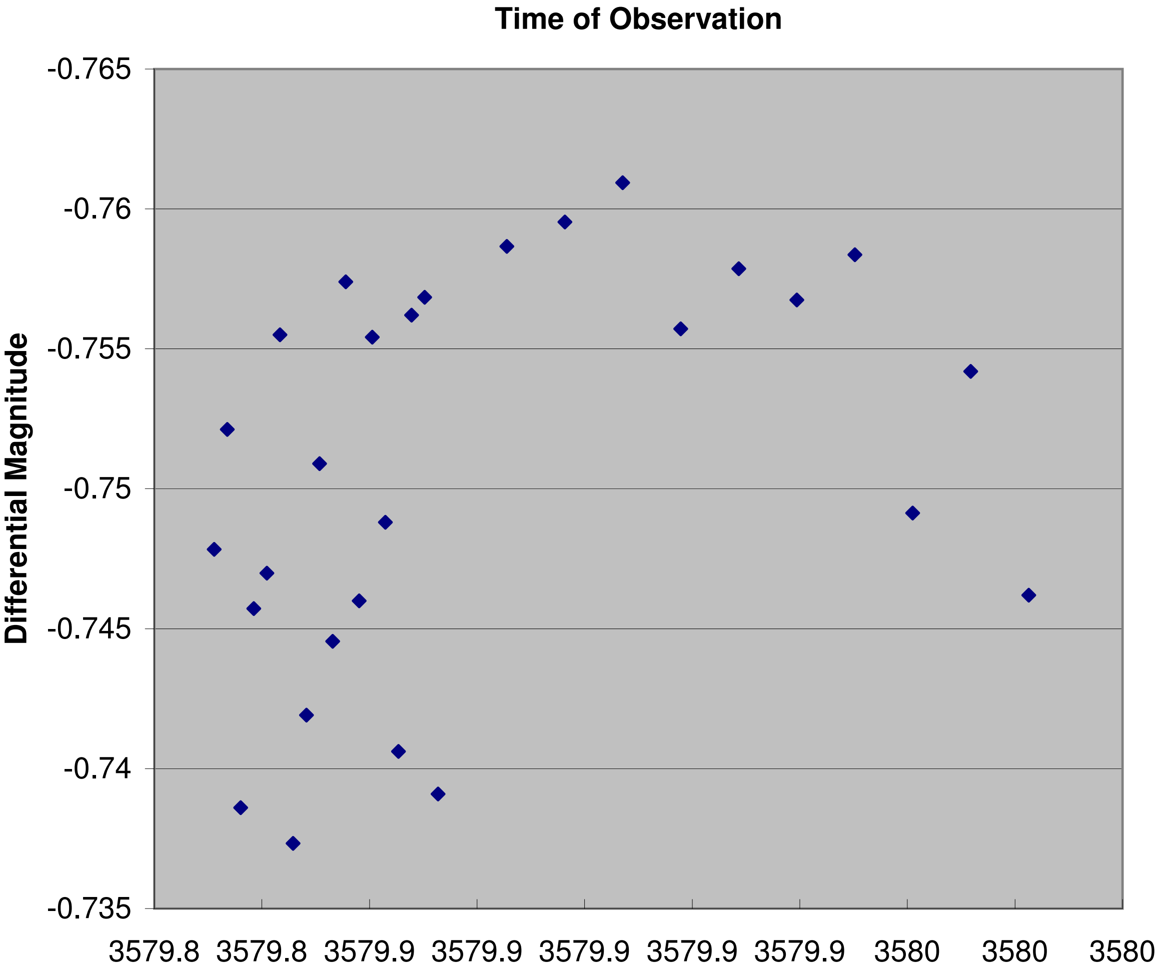

Figure 4.5 Light Curve of Star 144. Data taken from July 28.

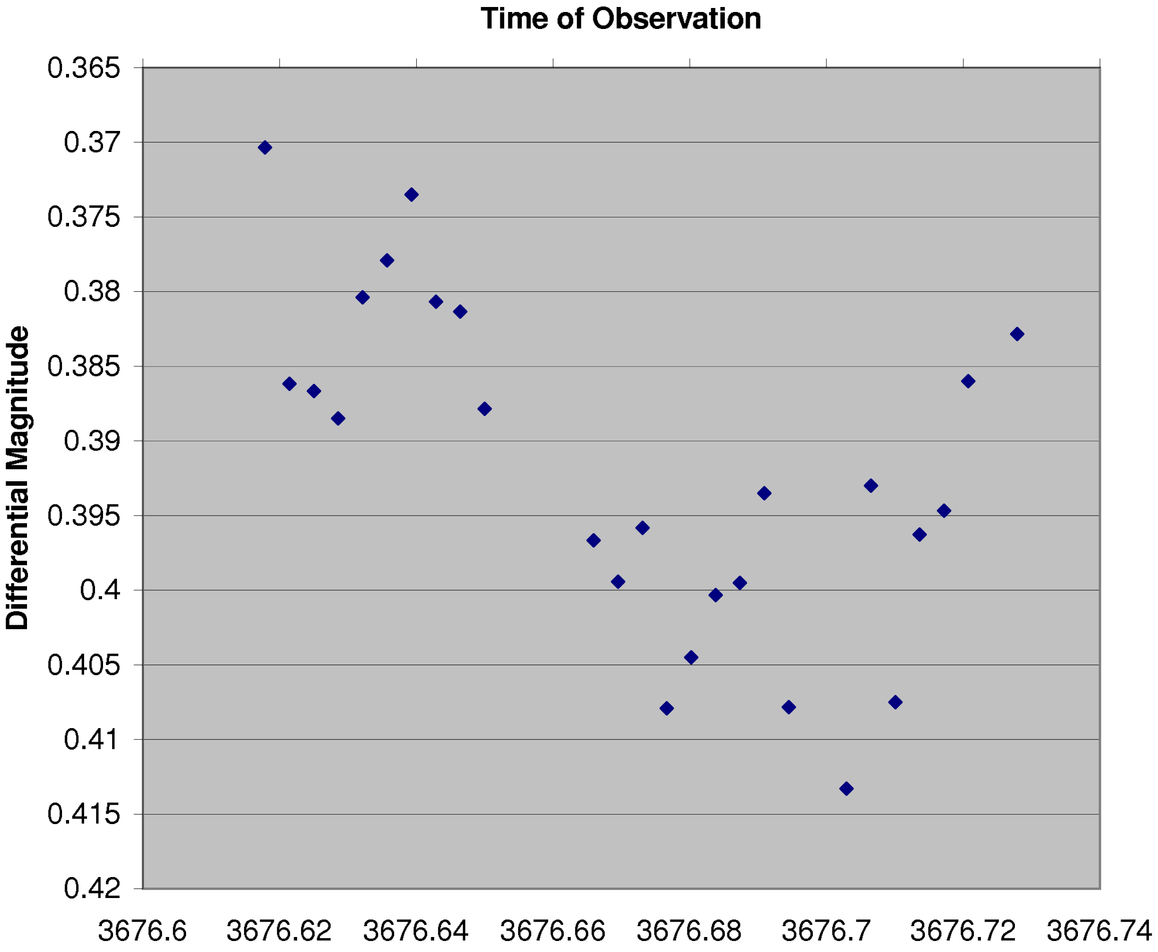

Figure 4.6 Light Curve of Star 72. Data taken from November 2.

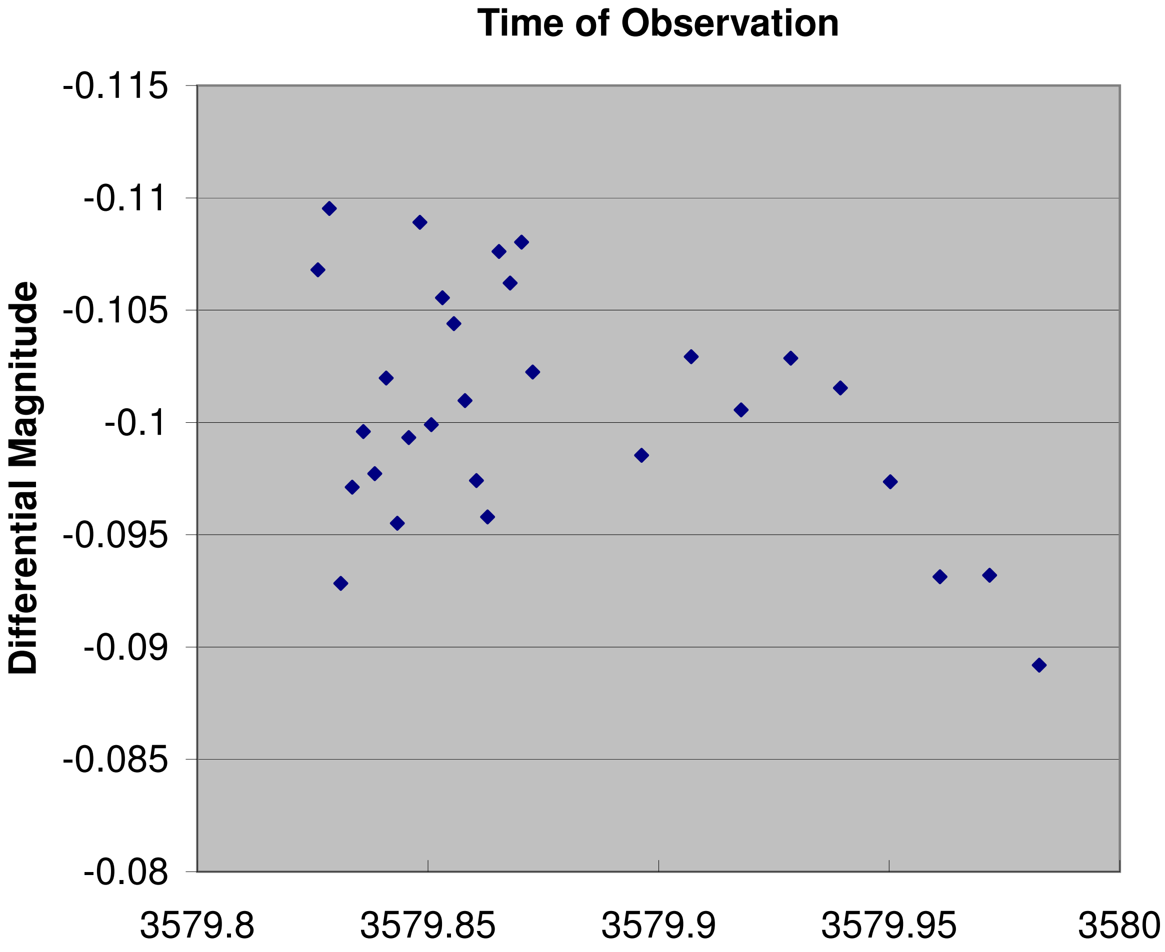

Figure 4.7 Light Curve of Star 72. Data taken from July 28.

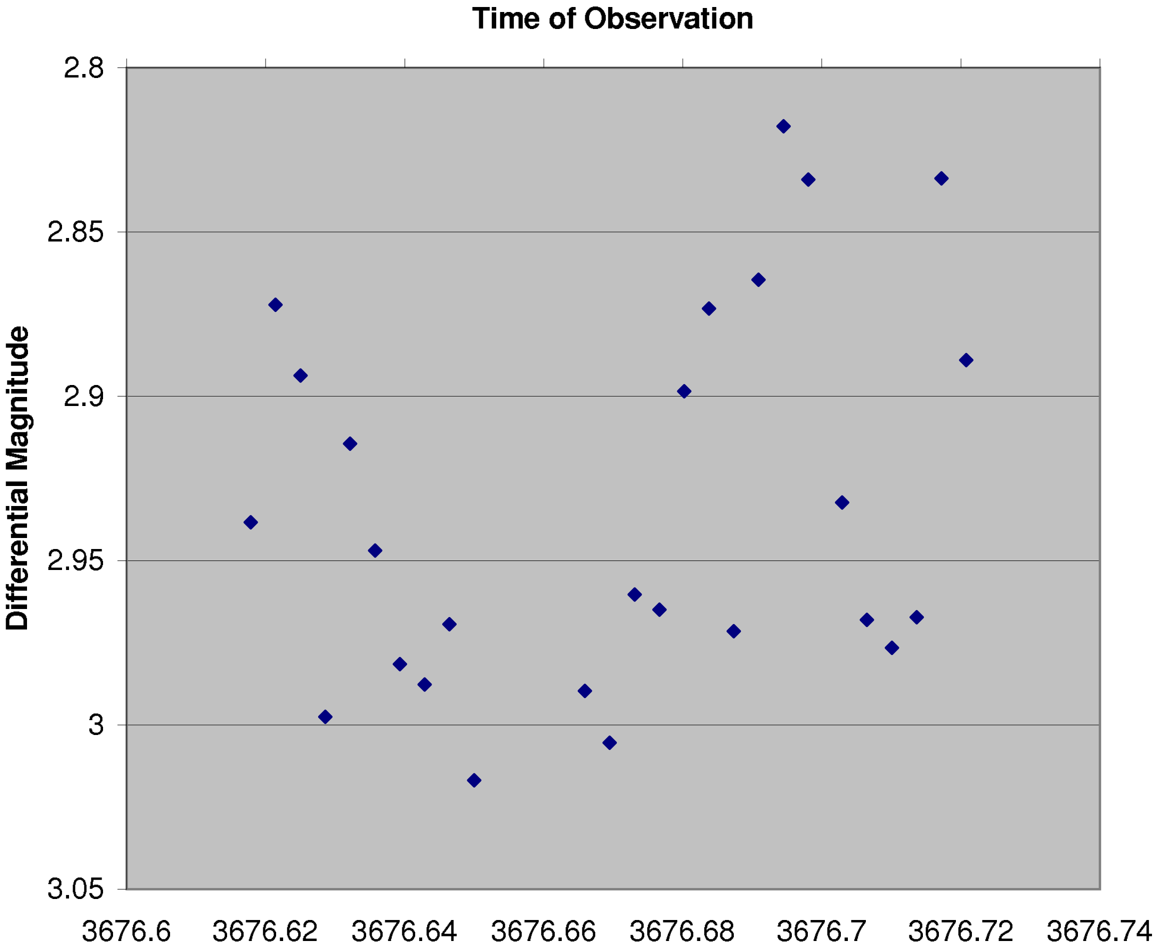

Figure 4.8 Light Curve of Star 65. Data taken from November 2.

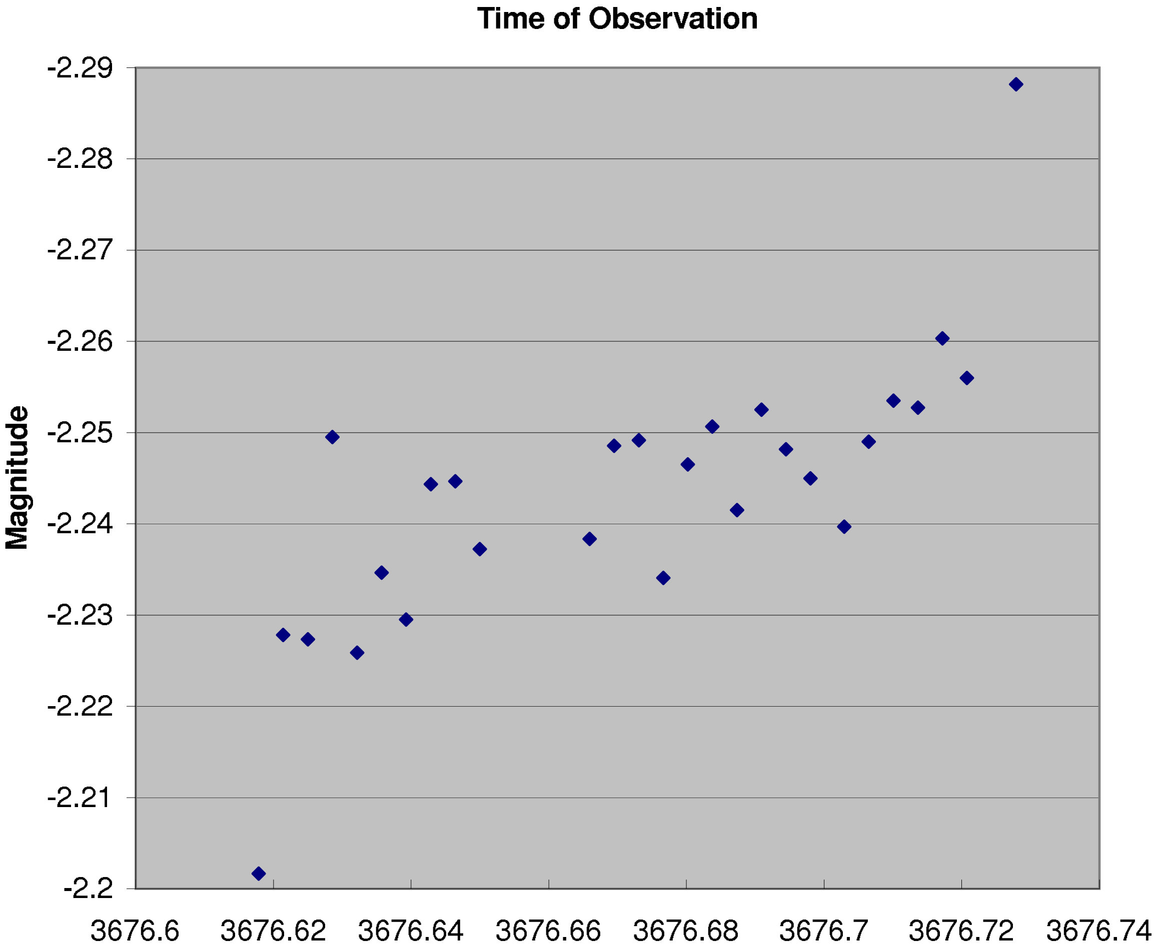

Figure 4.9 Light Curve of Star 27. Data taken from November 2.

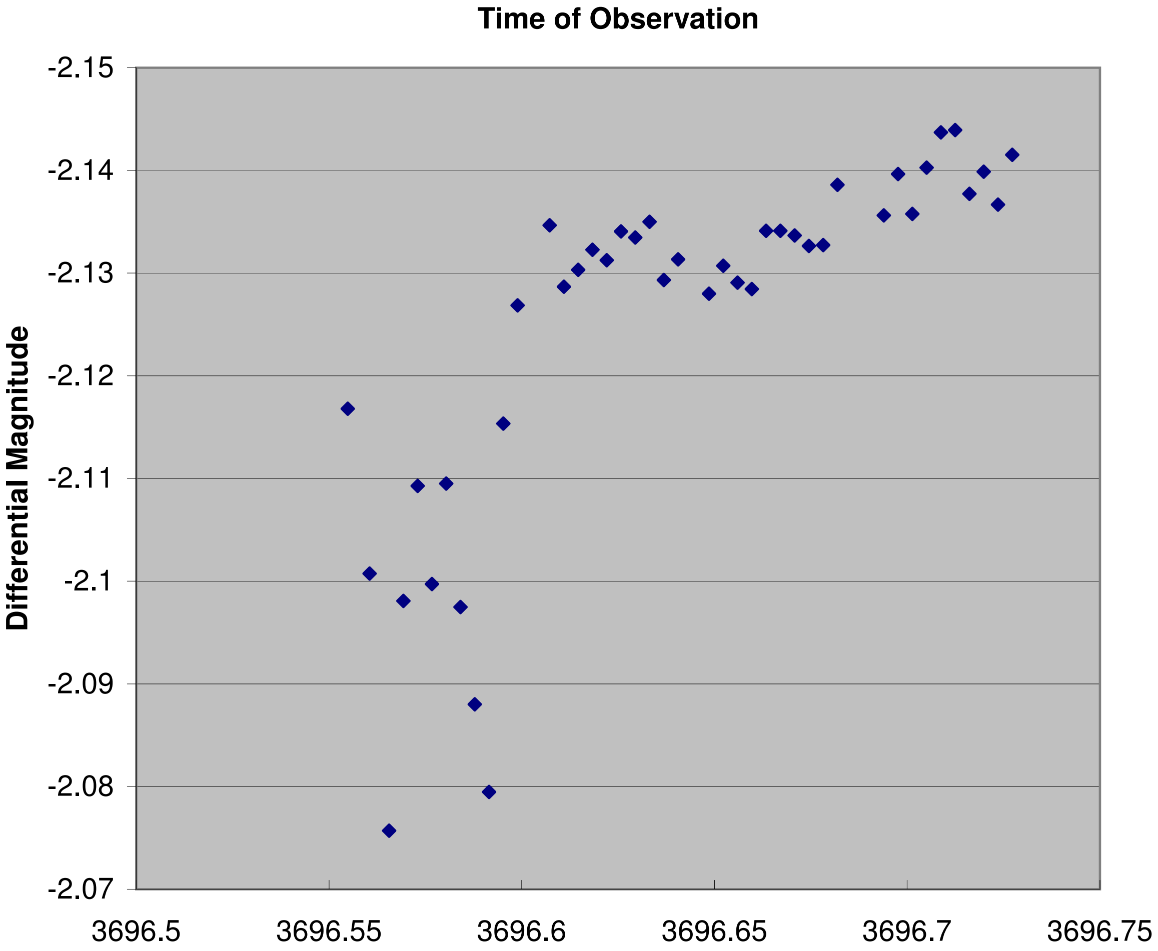

Figure 4.10 Light Curve of Star 27. Data taken from November 22.

4.3 Conclusions

After observing the cluster NGC 6866 for nearly a year, at least five potential variable stars were found. Periods were calculated for two of those stars. However, since this research is somewhat of a pioneering study in that few or no similar studies have been attempted before on this cluster, these results are by no means conclusive. Furthermore, it would take several more photometric nights of observing in order to conclude with a high level of confidence that the potential variables mentioned above are indeed variables.

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