A VARIABLE STAR SEARCH IN THE OPEN CLUSTER NGC 6940

by

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ABSTRACT

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Senior Thesis

This thesis describes a search for variable stars in the open cluster NGC 6940. I gathered the data using the Tenagra II 32-inch telescope with the V filter at an exposure of 15 seconds. There is one possible variable star, though there is not enough information to determine its period or color index. In this thesis, I present the light curve of this star for a period between September and December 2006.

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Chapter 1

Introduction

1.1 Introduction

Unlike many of the other physical sciences, astronomy suffers the limitation of not being able to directly experiment on the subjects, and even if experimentation were possible, it would take millennia to complete. In chemistry, a particular reaction will only take a few seconds, and can easily be done in a laboratory-type setting. In physics, experiments can likewise be set up to take very short amounts of time. However, when studying stars and galaxies, it is not possible to set up an experiment in a laboratory. The closest star we have is our own sun, and we are unable to perform experiments on it to see how it will react under different conditions. For this reason, astronomers search the sky looking for stars that display different characteristics, then infer from how these stars behave, and what environment they're in, why they are the way they are. Also, astronomers are trying to understand how a star changes over its life cycle. How is it that a star bursts into life? Will it always be the same from beginning to end? If it changes, how does it change, and can we predict when it may enter a specific stage of its life cycle? All of these are questions astronomers are trying to answer by finding stars in different stages of life, and in different conditions.

A characteristic of stars that has been discovered is the variability of a star's brightness. This instability may be part of a star's life cycle, and as we gain more information from these variable stars, it helps us to understand better the entire evolution of a star from birth to death. Also, these variable stars can help us infer other important information about the universe around us. For example, a type of variable star known as a Cepheid has a relationship between its brightness and how long it takes to vary. This allows astronomer to determine distances to clusters of stars and even galaxies.

1.2 Motivation

The middle-aged cluster NGC 6940 has not been thoroughly searched for variable stars. Hintz and Rose have done a study on the cluster looking for low amplitude variable stars. Hintz & Rose (2000). Also, Hebb, Wyse and Gilmore have done a search for low-mass binaries Hebb et al. (2004) in the cluster. Though Hebb et. al. gave a clear description of their search methods, and mentioned eclipsing variables in the other clusters they studied, they have yet to publish their results on NGC 6940. To date there has been no search for long-term variable stars, those with periods lasting from weeks to months. For this reason, I have studied NGC 6940 for a space of three months from September to December of 2006. With data spanning a longer time, observers may find variables with longer periods and study them to help answer questions of stellar evolution, and gain more information about the universe around us.

1.3 Overview

This thesis has been divided into 4 chapters. The first chapter is an introduction to the importance of variable stars, and motivation for a search for variables in NGC 6940. Chapter 2 gives background information for those who don't have pre-existing knowledge of astronomical research may understand the methods and terminology in the findings. Chapter 3 describes how the information was obtained and analyzed, and discusses the findings of the search. The final chapter summarizes the findings and discusses further research that needs to be done on the cluster.

Chapter 2

Background

2.1 Variable Stars

There are three main types of variable stars: pulsating, eclipsing, and cataclysmic. The name "cataclysmic variables" describes celestial bodies that have sudden changes in brightness due to some large-scale event. A nova, or when a star explodes, is an example of a cataclysmic variable. The second type is an "eclipsing variable." This term describes variability that occurs when one body moves in front of or eclipses another. For example, when a binary pair of stars is sufficiently far away from us, they appear as one star to us. This pair is an eclipsing variable when one of the stars passes in front of the other, effectively dimming the pair. Lastly, there are pulsating variables. These stars' brightness changes because something is happening inside the star. Cepheid variables are a good example of this type of star.

2.2 CCD Photometry

Though we can see the stars with our eyes, we need some way of recording what they are doing over long periods of time. For this reason, several devices have been created that record pictures of stars. One of these instruments is the Charge Coupled Device or CCD. This is the chip in digital cameras that record the picture. The CCD is made of pixels. Each pixel records how much light hits it. It may be useful to think of each pixel as a bucket. As light comes in each pixel fills up. Depending on how much light hits the pixel, it can be more or less full. When time is up each of the pixels is checked to see how full it is. This information is then stored as a picture. More full pixels appear brighter, while less full pixels are not as bright.

These pictures, therefore, hold all of the information about the stars in the photograph. From these pictures, we use a method called photometry to extract how bright the star was during that time. When we have many pictures taken over a long period of time, we can compare the pictures to see how the stars are changing.

2.3 Light Curves

Once we have the information extracted from the pictures, we can then make what are called "light curves." These graphs describe how a star's brightness changes from time to time. We plot our data as magnitude versus Heliocentric Julian Date or HJD. Magnitude is a scale based on how bright stars are. Really bright stars have a magnitude of 1, and fainter stars have larger magnitude values. The dimmest stars a person can see on a dark night are about 6th magnitude. It's difficult to remember at first that a large magnitude means a faint star.

Due to atmospheric conditions, and possible problems in the observatory, finding a star's true or "absolute" magnitude can prove difficult. To get around these problems astronomers often establish a differential magnitude. To find differential magnitudes, observers compare the target stars to a star that we know is stable. This way we can account for how the atmosphere is affecting the visual magnitude of the each of the stars. Then we effectively subtract the magnitude of the stable star from each of the stars we are looking at. This works because any atmospheric condition will effect all the stars in the area equally. We know what the stable star's magnitude should be so we can shift all of the star's magnitudes accordingly.

Heliocentric Julian Date (HJD) is how astronomers measure time. Instead of being based on weeks, months and years, it just counts days. This way astronomers don't have to worry about leap years, or how the calendar has changed through the centuries. Day 0 started at noon on January 1, 4713 B.C. (This is commonly believed to be the first date from which we have a recorded observation of an astronomical phenomenon.) Currently the HJD is in the 2,454,000s. Because this is a large number to keep track of, we usually leave off the first 2,450,000 when working with data. For example, the HJD for a particular day might be 4,011.468.

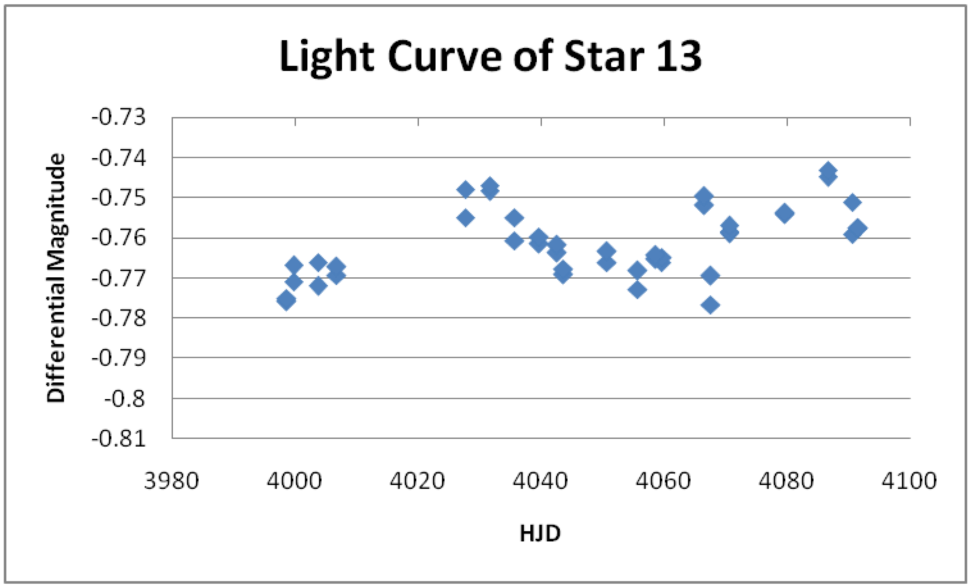

Figure 2.1: An example light curve. The vertical axis is magnitude and the horizontal is HJD.

Fig. 2.1 is an example of a light curve. The vertical axis is in magnitudes, and the horizontal axis is in HJD. Notice that the HJD has the first 2,450,000 left off.

2.4 Point Spread Functions

Often when looking at a cluster of stars, we notice some that overlap on the picture. One of the best ways to help separate these into individual stars is through point spread function or PSF analysis. As light hits the CCD, each pixel counts how much light it gets. It may be better now to think of the pixels as stacks. The pixel that has the most light hit it will have the tallest stack. All the other pixels that are around it will still get some light, and so have shorter stacks. This produces a shape that, when we model it with mathematical equations, closely resembles a bell curve. To get the magnitude of any given star, we apply the PSF and vary it so that it best fits over the profile, or the stacks from the pixels. This is particularly useful when two stars are so close together that their profiles overlap. As long as we can locate the high point on each profile, we can apply a PSF to determine what each star's magnitude is separately.

Chapter 3

Procedure and Analysis

3.1 Observations

I obtained the data about the observations from the Tenagra II telescope of the Tenagra Observatories. This telescope is located in the Southern Arizona desert near the Kitt Peak observatory and Mt. Hopkins. The Tenagra II is a 32-inch (0.81 m) telescope, which uses the SITe SI03XA CCD 1024 x 1024 x 24 m liquid cooled system. This gives a resolution of about 0.87" (arc seconds) per pixel. The chip is cooled to -40 degrees C. The Tenagra II is a fully automated system.Tenagra (2007)

The observations were taken using the Johnson V filter with a 15-second exposure. All the data was taken between the 20th of September and the 22nd of December 2006 with a total of 24 usable nights. A usable night is one during which the weather conditions were favorable and the telescope and observing equipment functioned properly.

3.2 Reduction

Even when we first take the photographs of the stars, there are inherent errors in them. These errors arise just from the way we must take the pictures. First, because the CCD is an electronic device, activating it can cause some electric charge to get stored in the pixels, and these charges register like counts from light. Along with this, the longer the CCD is turned on, the greater the chance that some electric charge could get trapped in a pixel. Also, some pixels may respond to light faster than others. For all of these reasons, we need to take three kinds of calibration frames. A calibration frame is a photograph we take to compare to the rest of the photographs, so we can eliminate the erroneous data.

The first calibration frame is called a Zero or Bias frame. This is taken simply by activating the CCD then allowing it to turn off. This way we can find any pixels that are prone to storing charge simply because we turned on the CCD. The second type of calibration frame is a Dark. For this we activate the CCD and allow it to record for a given period of time, but with all of the caps still on the telescope and the shutter of the camera not allowed to open. From this we find any pixels that will store charge over a period of time. The third type of calibration frame we use is called a Flat. For this we take a picture of something with uniform color, such as a section of sky with no clouds or other variations (some observatories hang a sheet and take a picture of that). From this we find any pixels that respond faster or slower to actual light than all the others. With all three types of calibration frames, we can then subtract out the noise from turning on the camera, from leaving it on for a period of time, and from pixels unevenly gathering light while we take the picture.

3.3 Analysis

After we reduce all of the images using the three types of calibration frames, we are ready to analyze the pictures themselves. For this cluster, NGC 6940, I initially selected a total of 737 stars. I analyzed the images using the DAOphot written by Peter Stetson of the Dominion Astrophysical Observatory package available for IRAF. IRAF is a program that astronomers use to help them extract the information from the pictures they take with the CCD. DAOphot is a package within IRAF that will use PSF analysis on the images to determine the stars' magnitudes. After obtaining magnitudes from each night, I then processed the data using the cluster5 script produced at Brigham Young University by M. B. Rose. This script calculates the errors of the stars over the course of the total observations. The error describes how much the star changes over the course of all of the images. We can use the stars with the smallest errors as standard stars to which we adjust all the other stars.

After running cluster5, I found that the errors for all 737 stars were above 1. An acceptable error is between 0.001 and 0.01. To help determine the cause of such gross error, I checked the stars' ID numbers during each night. I determined that if the star had a coordinate that was no longer in the frame of the picture, DAOphot did not record it or its magnitude in the output file, thus leaving several stars without nights of data, which contributed to the extremely high errors. Also, I discovered that the IDs of the stars from night to night were not consistent. Each star had two designations appearing on different nights. This may be due to human error. This also accounts for the large errors since each ID actually matched with two completely different stars.

To make sure that the images themselves were good, I chose 20 stars that were bright and on every frame. I processed these 20 stars using the apphot package in IRAF which determines magnitudes based on how many counts each pixel has. It looks a that the count for each pixel and assigns a brightness; it does not distinguish between stars. After obtaining valid magnitude files on the stars, I analyzed the data using the varstar5 script also written at Brigham Young University by E. G. Hintz. Varstar5 produces differential magnitudes, similar to cluster5, but is better suited to a small selection of stars. The errors from the 20 stars using varstar5 were between 0.0045 and 0.0285. These errors are more acceptable. I then chose the five stars with the lowest errors as standards to which I compared and calibrated all the rest of the stars.

Upon examination of the light curves from these 20 stars, it appears that there is one likely variable star. The star labeled 13 is the candidate.(See Fig. 3.1).

The light curve of star 13 (Fig. 3.2) shows a possible growth to what could be a maximum, then a decline to a minimum, then a growth again. With a couple weeks of data missing, it is not possible to be sure that the first hump is a maximum, and due to the fact there is only one clear minimum, it is not possible to determine an accurate period. Even so, the stars period appears to be around 60 days with an amplitude of 0.034 magnitudes. Also, because the data was only taken with the V filter it is not possible to get a color-index for the star. To show the comparison, I have included the light curve for one of the standard stars, star 4 (Fig. 3.3), which is scaled to match the scale of star 13.

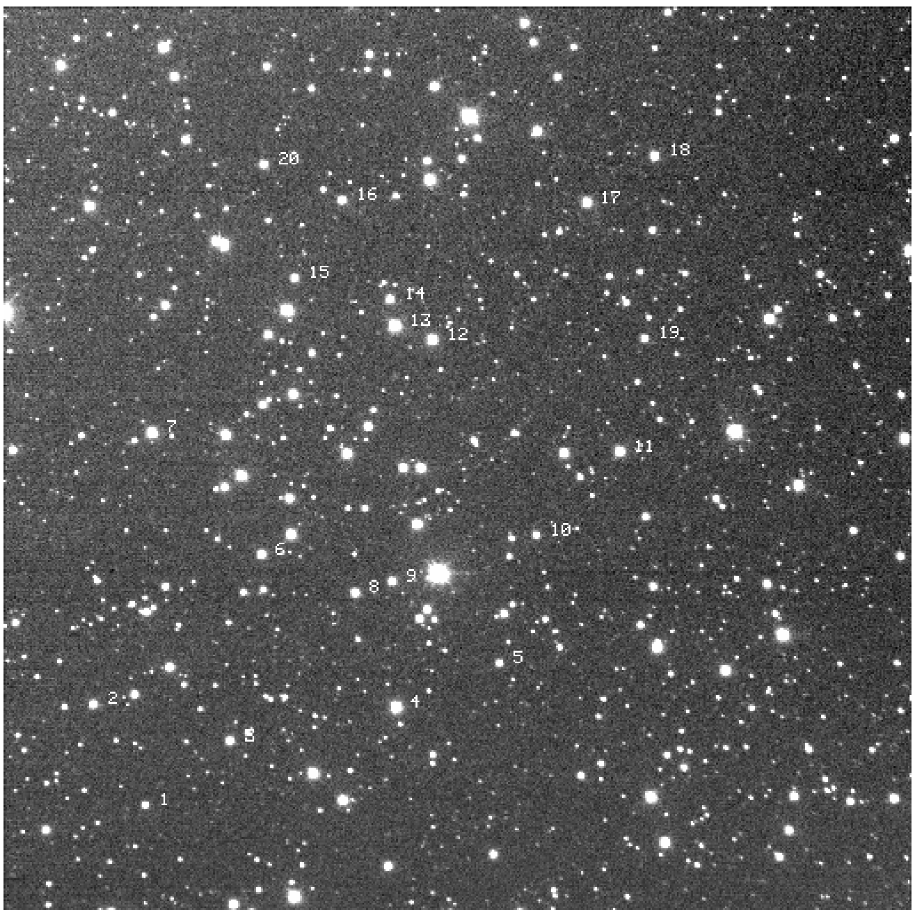

Figure 3.1: Cluster NGC 6940 with 20 stars labeled by ID.

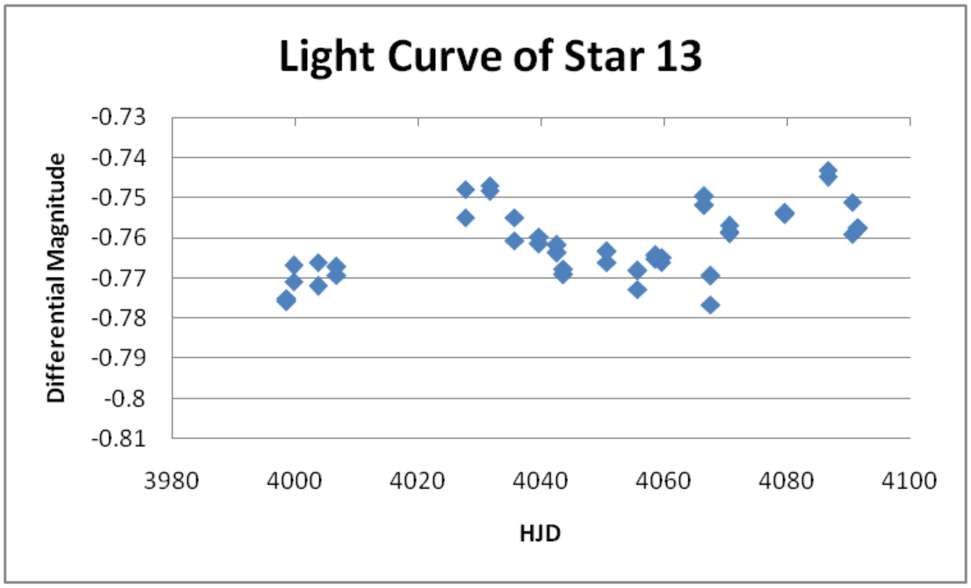

Figure 3.2: Light curve of the variable star 13.

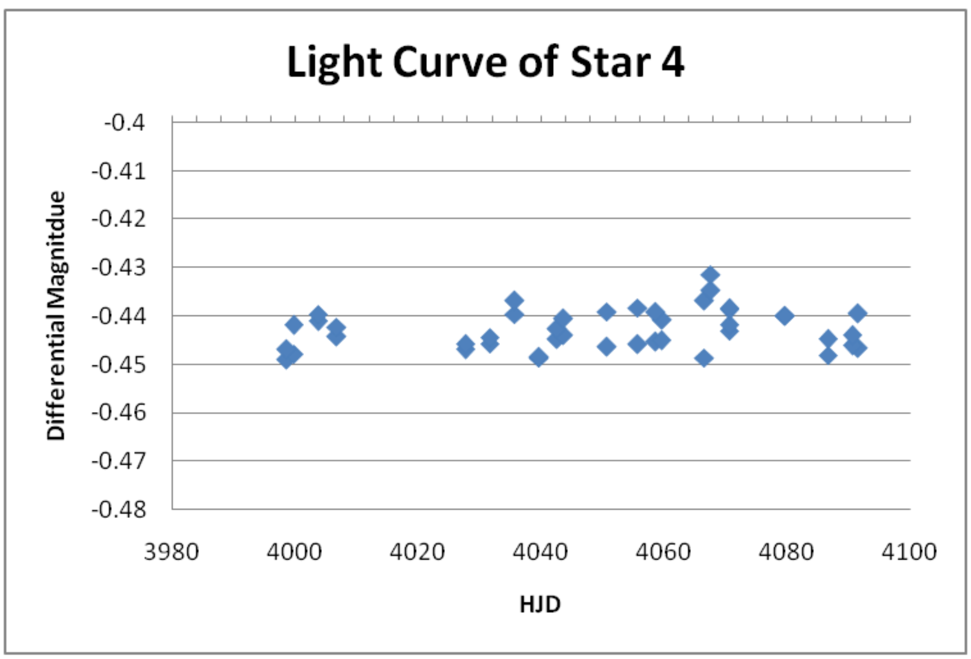

Figure 3.3: Light curve of the standard star 4.

Chapter 4

Conclusion

4.1 Conclusion

This thesis has presented the results of a variable star search in the cluster NGC 6940. After an error-plagued attempt at using DAOphot, and subsequent analysis using apphot, the star labeled as star 13 appears to be a mid-length variable star. This star does not match up with any of the stars found by Hintz and Rose. According to the Aladin applet Aladin (2007) and the SIMBAD database star 13 is designated NGC 6940 86 and as HD334749. This star has a V magnitude of 10.93, has a spectral type of A7 or F0 and a (B-V) = 0.49. It varies by 0.034 magnitudes over the course of about 60 days. Further continuous data needs to be acquired, preferably longer than 3 months, to get an entire period or more from the star to help us classify what kind of variable star it is. Using a point spread function approach like DAOphot may still yield convincing, clear, and more accurate results, if the missing star data and star identification problems are solved.

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