METHODS FOR LONG PERIOD VARIABILITY DETECTION USING OPTICAL PHOTOMETRY

by

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ABSTRACT

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Senior Thesis

This thesis discusses observational techniques for period calculations of rotating variable stars. Long term periods were difficult to distinguish through normal photometry methods. Since precise period calculation is needed for most studies of rotating variables, I analyze how we can get better data to get better measurements. The effects of seeing conditions and focus changes were examined.

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Chapter 1

Introduction and Background

1.1 Introduction

Recent studies have attempted to detect precise rotational velocities of G and K type stars. Many of these studies have focused on long term variability of rotational velocity. This variability has been attributed to stellar pulsation, rotational modulation and planetary rotation. Setiawan et. al. (2004) were able to detect RV variability in 77 giant stars with precision better than 25 ms^{-1} (Setiawan et. al. 2004).

1.2 Rotating Variable Stars

There are many classifications of rotating variable stars. The reason for these classification is that the stars vary for different reasons and have different characteristics. Periods observed range from mere minutes to hundreds of days. My project dealt with finding the longer period stars. Fluctuations in the amplitudes of the longer variables can range from around 0.01 to 0.5 magnitudes. These variations are often more commonly observed in the spectral lines of certain elements, such as, Sr, Si, Cr and Fe. However the variations are also seen well using the V filter. Often these changes in the star's intensity are a result of the rotation of its magnetic field, sun spots, or non-uniform surface intensity (General Catalogue of Variable Stars 2004).

1.3 Rotation Period

A nice thing about these rotating variable stars is that we can extract information about their actual rotation periods from the intensity fluctuations. The first step in the process is to find the longer period variables in a cluster. From there we would still need to determine whether the star exhibited characteristics of a rotating variable. Often the amplitude of the variation can be evidence of a rotational variable. The preferred method is to use spectroscopy to look for variation in the lines that are common in rotating variables.

1.4 Contents of Thesis

Initially I sought to learn if I could determine rotational velocities using optical photometry. As many unforseen problems arose throughout my research I had to change my focus. Since then this study has turned into an examination of methods to determine long period variability in the optical wavelengths.

One main characteristic that rotating variable have is that they tend to have periods that can be many weeks long and have relatively small amplitudes. Using data from the Tenagra telescope, I have observed the open cluster NGC 225 between October 26, 2006 and January 30, 2007 to look for stars with those periods. It turns out that different techniques are required to scan over such a long period for small variance than it would take to find the same amplitudes over a short period. I started my research under the assumption that I could use the same methods to find the longer period variables as is commonly used for short period variables. My conclusions focus on the flaws in that process which I encountered.

1.5 NGC 225

NGC 225 is an open cluster of stars at RA = 00:43:42 and Dec = +61:47. Its age is approximated between 0.5 and 10 Myr at and resides at a distance of 575 ± 120 pc (Subramaniam et al. 2006). Most information on NGC 225 relates to proper motions and general data. Two other studies, besides the most recent Subramaniam et al. (2006), have been done specifically for NGC 225 since its discovery in 1784 by Caroline Herschel. Neither of those reports contained information regarding specific variables within the cluster.

Chapter 2

Original Method

2.1 Initial Data Collection

For the most part I used standard methods of reduction and differential photometry to analyze the images I received from the 0.8-m Telescope of the Tenagra Observatory. I had about 8 to 10 images on NGC 225 per night and about 2 or 3 nights of data per week. A set of 161 stars rather than 141 was used on the longer exposures which display fainter objects (see Figure 2.1). Each frame was examined using the *phot* command inside of IRAF with an aperture of 3 pixels.

2.2 Other Techniques

My initial efforts showed variability in many stars, but it is clear that each star exhibited the same 40 day pattern. Drops in the intensity of most stars were observed at 4060 and 4100 (HJD minus 2450000) as is seen in Figure 2.3. Another problem I encountered was that each star varied from about 0.05 to 0.1 magnitudes within any given night.

From there I tried various adjustments of the ensemble in *VARSTAR5* (Hintz) to eliminate the common noise. None of these attempts succeeded in washing out the noise. These results should tell us that each star is varying differently every night. Since the intensity patterns are the same for most stars, it seems most likely that the noise varies for each star at the same frequency, but the amplitude of variation differs.

Another method I tried was extracting any similar noise trend myself. I plotted magnitudes against the HJD for each night on the same plot and fit the points with a linear equation. I zeroed out the smallest HJD for each night to obtain a meaningful y-intercept. If the magnitude shifts I saw each night applied the same to every

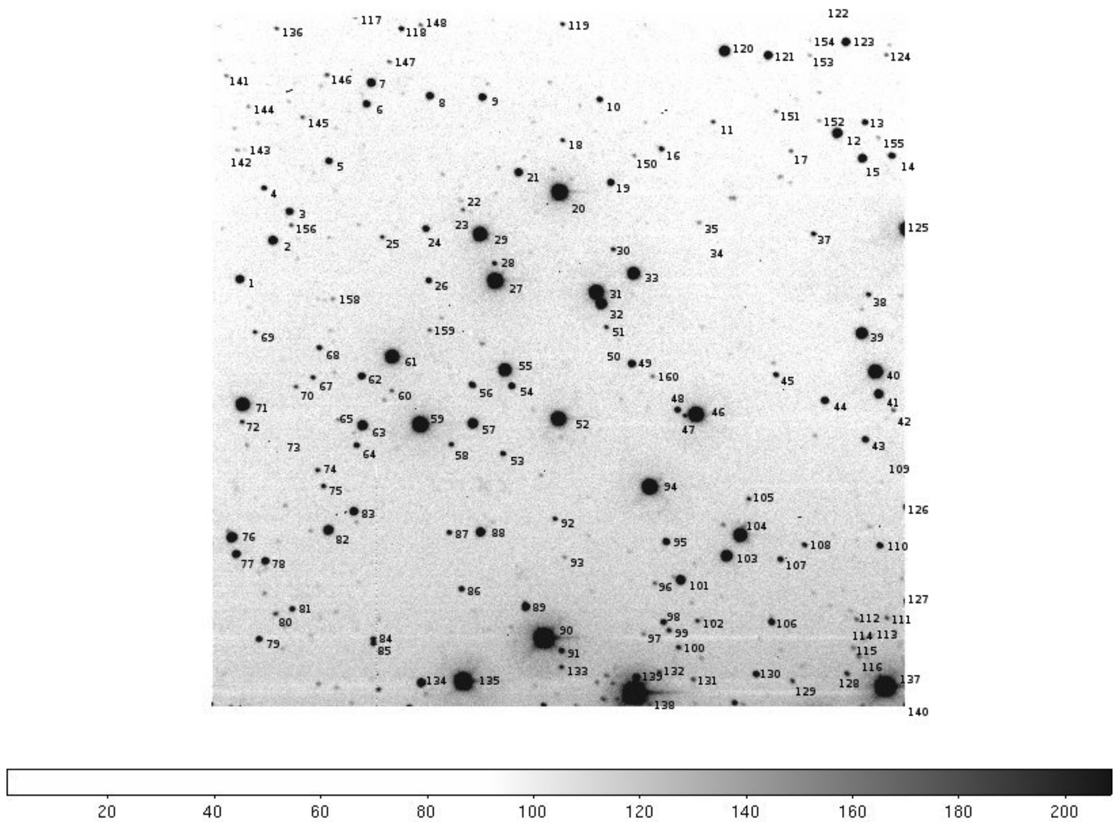

Figure 2.1: NGC 225 with all the stars used in this study labeled by number

star, the difference in the y-intercepts for these curves should match the magnitude difference plots for each star. Surprisingly no meaningful curves were extracted after subtracting the y-intercept difference from the magnitudes of any star. A plot of the y-intercepts v the HJD matches the final light intensity curves of the stars in many places. The problem seems to be that although they match in shape, amplitudes do not match for every star.

Figure 2.2: Each red circles enclose 1 night of images and show the magnitude fluctuation between each image.

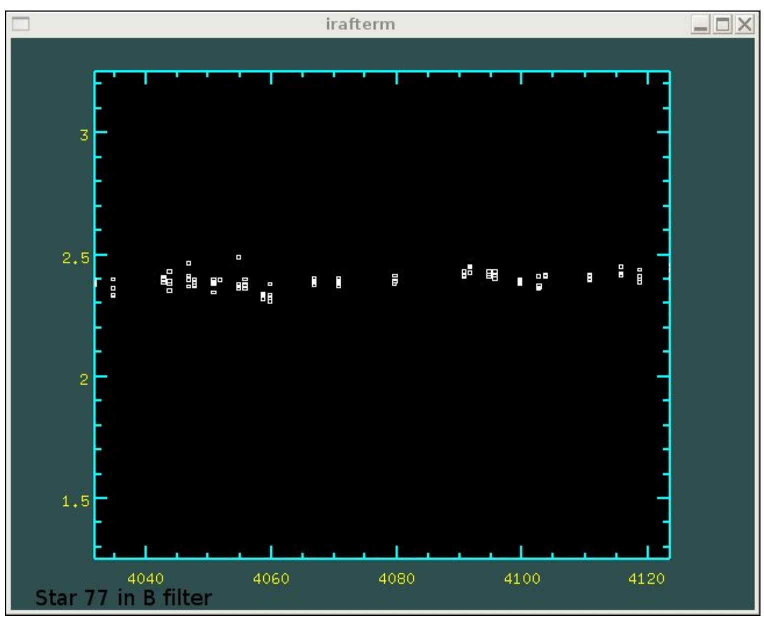

Figure 2.3: Minima present at 4060 and 4100 .

Chapter 3

Aperture Size

3.1 Aperture Definition

Aperture Size is a parameter set in the *photpars* package in IRAF. The setting for aperture size determines how big of a circle is drawn around the star for photing. The light within the given radius determines the magnitude given to a star. Setting this size too large will often collect overlap light from other stars, while setting it too small can cut off valuable information needed to determine the magnitude.

3.2 The Problem

3.2.1 FWHM results

To determine whether the aperture size used while photing caused the observed fluctuations, we must check width of certain stars on each night see if they broaden outside of the aperture radii. My first efforts compared the FWHM of a subset of 12 stars to the magnitude plots that I had already created. Using *imexam*, I recorded the MOFFAT FWHM of stars 20, 29, 27, 33, 46, 52, 94, 55, 59, 61, 120, and 121 (see Figure 2.3). After plotting the average FWHM for each night against the HJD. This plot show several similarities to the varying magnitude curves (See Figure 3.1). They match especially on the central hump, the dip afterward at 4102 and 4103, and the final hump after the dip.

3.2.2 More Evidence

To further confirm the changes in FWHM between nights we can compare a star's profile between nights. We can also tell, from this method, which stars, if not all, are causing the problems. A clear example of this occurred between the nights

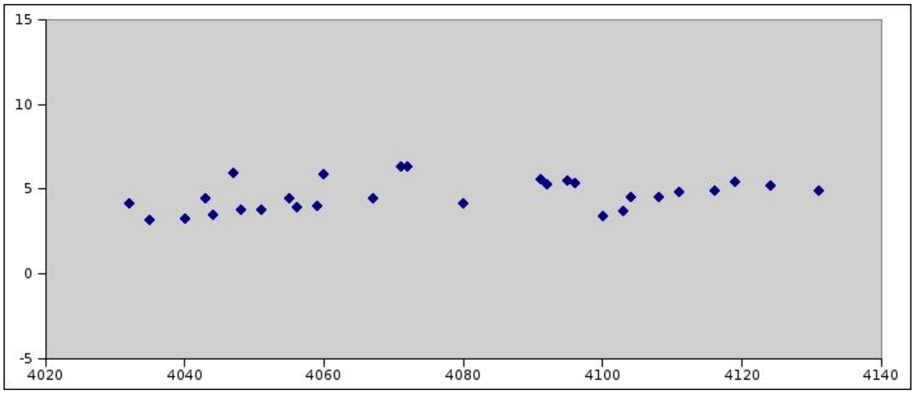

Figure 3.1: A graph of FWHM vs. HJD over the entire observing campaign. Especially prominent is the dip near 4100. Compare this to the light curve in Figure 2.3

of 26 December 2006 and 02 January 2007. The profiles for most stars shrink from the 26th to the 2nd. We see narrow profiles that don't go out as many pixels (see Figures 3.7 through 3.12). Brighter stars seem to be affected less. Star 59, one of the bright stars, exemplifies this. You'll see in figures 3.13 and 3.14 that the fitted curve doesn't vary as much between the two nights. One reason is that some bright stars are overexposed on January 2 are overexposed and which makes the fitted profile wider than it should be. Also the percentage of the light cut off for the broader profile isn't as big for stars with higher light counts as for ones with small light counts.

As you can see from the FWHM for every night my original aperture setting was too small at a value of 3 pixels. However, from this data we can make some conclusions. As the average FWHM for a night goes up, the magnitudes should go up. The phot command will only capture light out to 3 pixels from the star's center. Since some stars still fit within the region, their magnitude remains unaffected, but for those stars that expand outside, light is cut off. This causes problems while calculating differential magnitudes. Stars will vary differently depending on how much of their light remains in the aperture radius.

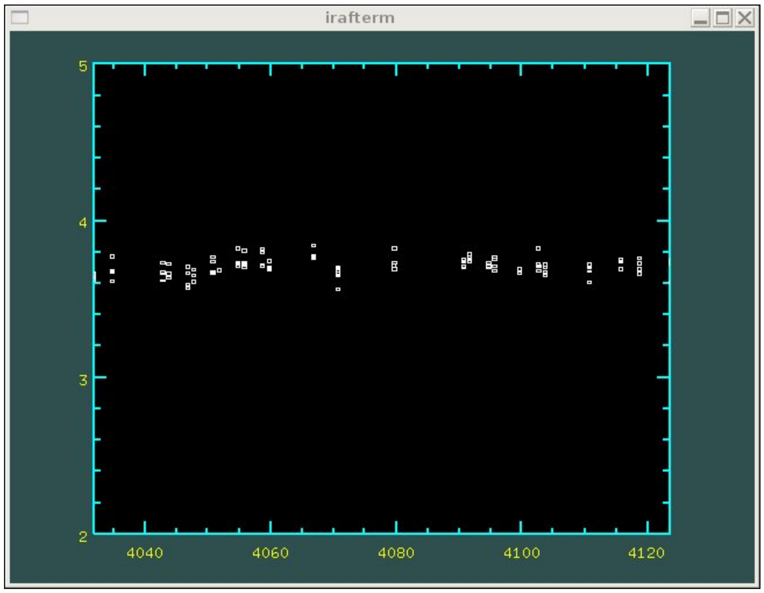

Figure 3.2: Magnitude v HJD for star 13

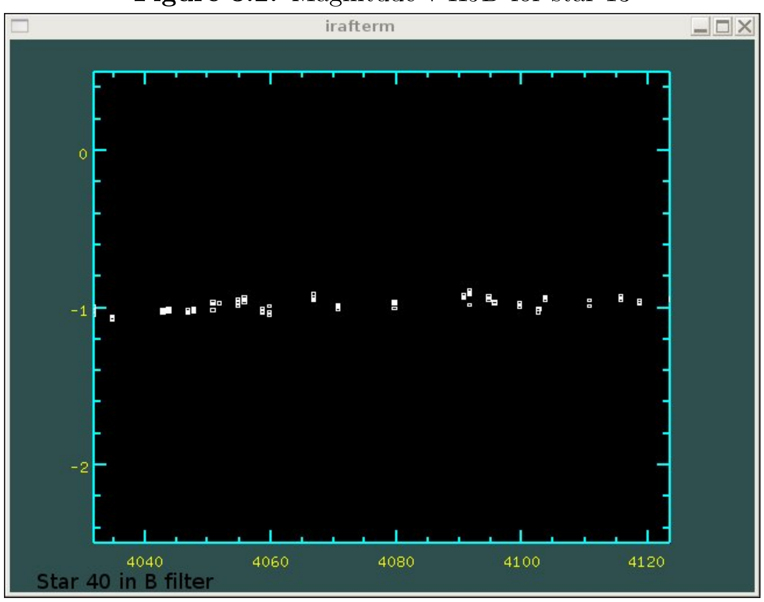

Figure 3.3: Magnitude v HJD for star 40

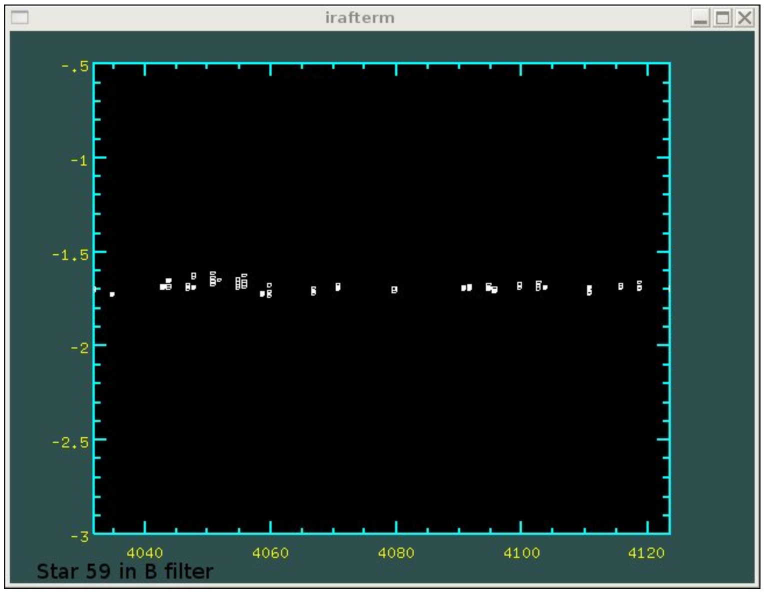

Figure 3.4: Magnitude v HJD for star 59

Figure 3.5: Magnitude v HJD for star 77

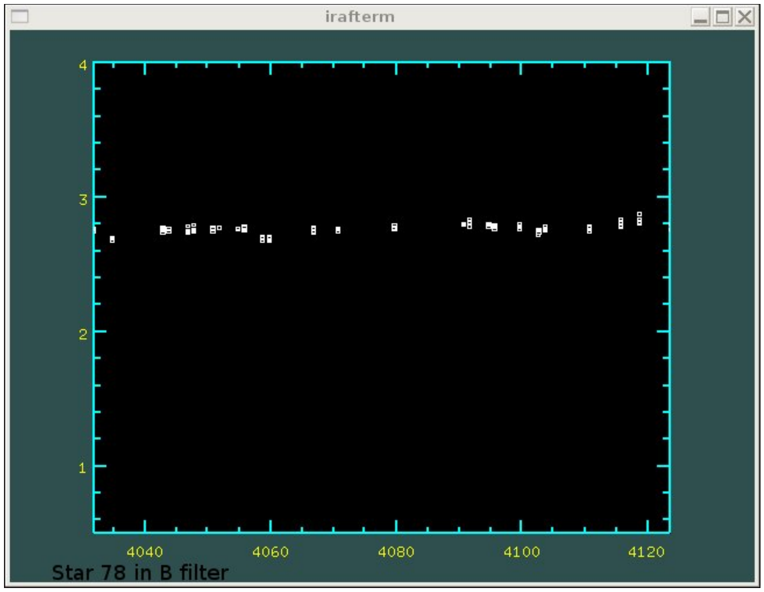

Figure 3.6: Magnitude v HJD for star 78

We see fluctuations between nights then because on some nights the varying stars don't leave the aperture radius as much and allow the differential magnitudes for those nights to be more accurate.

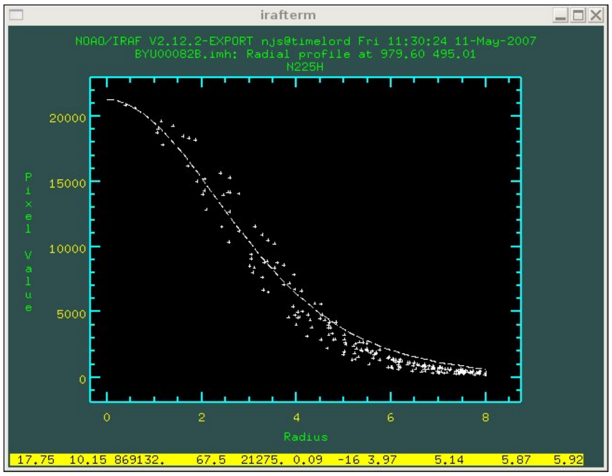

Figure 3.7: Profile of star 40 from 26 Dec 2006

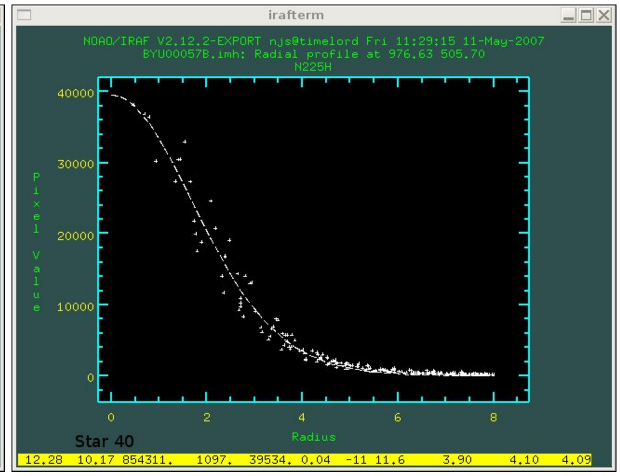

Figure 3.8: Profile of star 40 from 2 Jan 2007

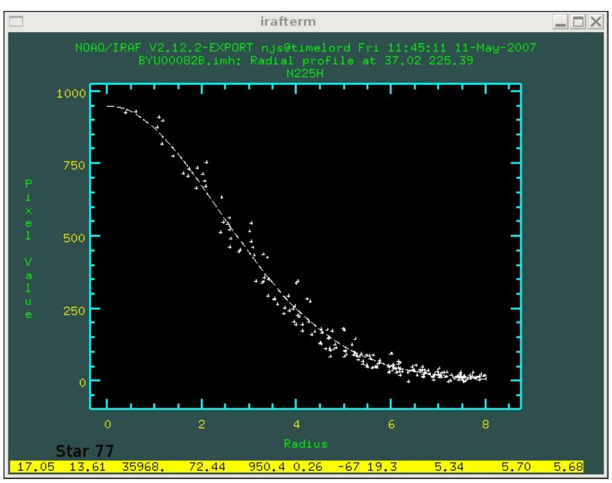

Figure 3.9: Profile of star 77 from 26 Dec 2006

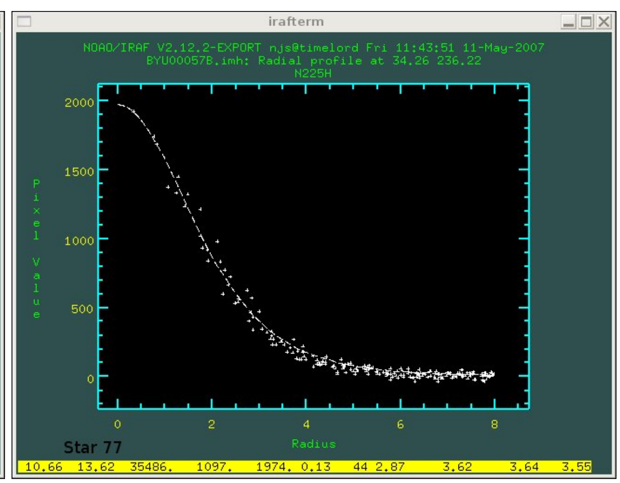

Figure 3.10: Profile of star 77 from 2 Jan 2007

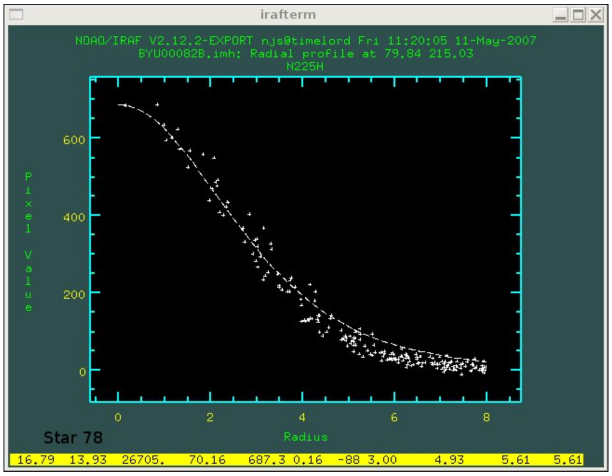

Figure 3.11: Profile of star 78 from 26 Dec 2006

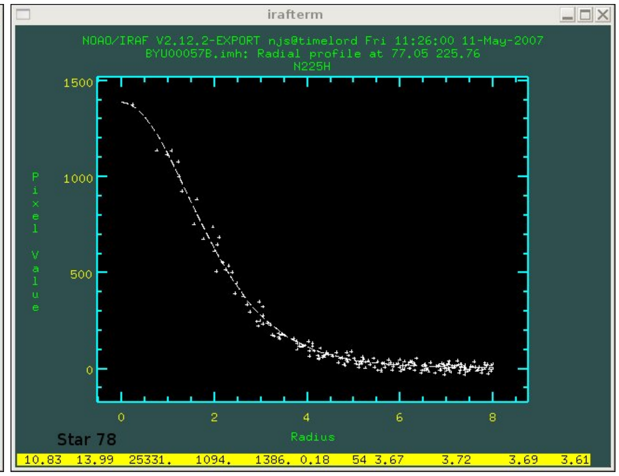

Figure 3.12: Profile of star 78 from 2 Jan 2007

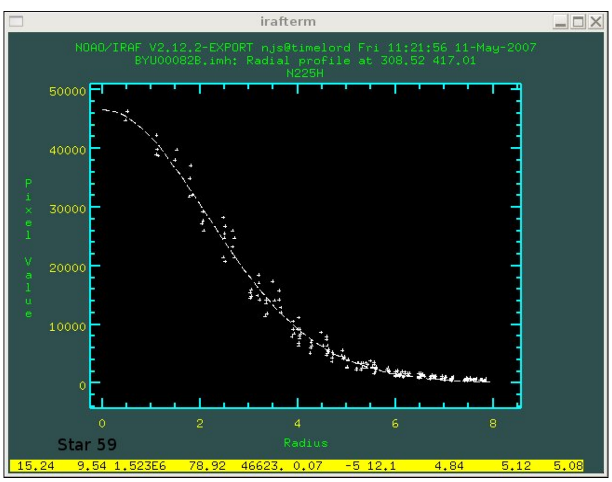

Figure 3.13: Profile of star 59 from 26 Dec 2006

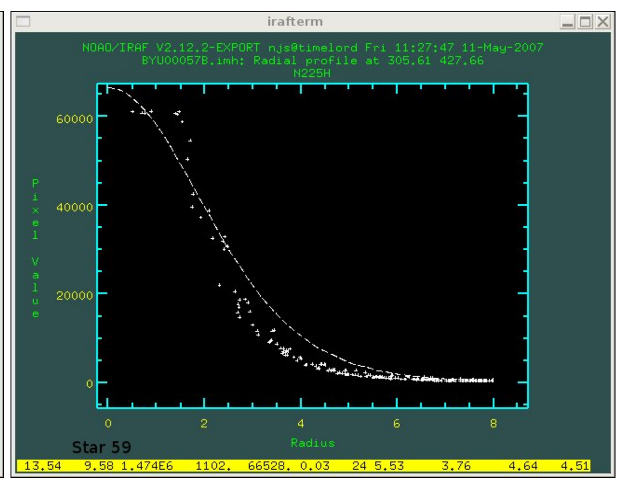

Figure 3.14: Profile of star 59 from 2 Jan 2007. Note that this star is saturated

Chapter 4

Conclusions

4.1 Larger Aperture

The easiest solution to the aperture problem would be to adjust the aperture size based on the average FWHM for the night. To see how this would help I reanalyzed my data using an aperture size of 8 pixels instead of 3. For most nights this size should collect all the light from most stars.

Using a larger aperture size corrected part of the problem. The error within each night remains as well as some variation after December 26. Most of the original noise has been canceled out, but parts at the end of the run remain.

4.2 DAOPHOT

One simple way to correct the problems I faces might be to use other methods of stellar photometry. DAOPHOT is one of the most popular means that I did not examine. This method of photometry, developed by Peter Stetson, can provide more accurate measurements than can be determined using the *apphot* package. However, DAOPHOT specializes in crowded field photometry which wasn't a serious issue in NGC225. Like *apphot*, DAOPHOT requires the user to determine an average FWHM to run off of. Without correcting that problem first, using DAOPHOT will most likely produce similar results.

4.3 Future Research

4.3.1 Nightly Error

Maybe the biggest problem I encountered was the variations within each night. Magnitudes variations within a night had larger amplitudes than the variable stars I searched for. The original assumption was that I would need less images on a given night because I was looking for longer periods. In the future I recommend that more images be collected within a night to average out the fluctuations. It may also help to use the same exposure length for each image to avoid crossing from good exposure to over exposure of bright stars.

4.3.2 Nightly Recommendations

Our goal should be to obtain an average magnitude for a night with accuracy within the bounds set by the expected variation for rotating variables. I took a large sample of randomly chosen stars in the cluster. From this sample I calculation the standard deviation of the magnitudes from frame to frame on every night of data. I calculated the sample size required for 95% confidence according to a standard formula: $(\frac{1.96*\sigma}{E})^2$, where E is the margin of error, which should be lower than the expected natural variations in magnitude. For the lowest magnitude stars this accuracy is achieved with 2 images. On the other hand, using this method, we would need hundreds of images to get a 0.005 margin of error for the highest magnitude stars. Since we usually cannot devote the time necessary for taking hundreds of images every night, my recommendation is to focus on the medium intensity stars. The medium magnitude stars require an average of 10 to 40 images per night. Focusing on a 0.01 margin of error, anything larger than 10 images per night should give accurate average magnitudes for most stars in a cluster. It takes 4 times as many images to reach 0.005 margin of error.

4.3.3 Long Period Error

Beyond obtaining an accurate average magnitude for a given night, we need to make sure the fluctuation between nights isn't random. My data contains images from about 3 nights out of every week over the course of 3 months making about 30 nights of images. It is hard to say at this point whether this sample size has caused

Table 4.1. Nightly Sample Size

Star	Number of Frames 0.005 Margin of Error	0.01 Margin of Error	Average Mag.
1	43	11	5.66
4	181	46	7.37
9	20	5	4.86
17	576	144	8.69
20	5	2	2.1
21	28	7	5.66
22	1523	381	8.57
24	37	10	6.73
25	421	106	8.28
30	115	29	7.83
49	51	13	7.83
54	30	8	5.83
67	834	209	7.85
68	24	6	7.18
86	384	96	7.46
95	60	15	6.38

Note. — Frame numbers have been rounded up to the nearest frame. It should also be noted that any star in this list could potentially be a short term variable star making the results shown for that star void.

any problems. As mentioned before, aperture size could have contributed the bulk of the error over the long term.

4.3.4 Long Period Recommendations

Although we are not trying to find average magnitudes over the course of many months, it will be useful to use the same approach as used for nightly error to calculate the number of nights needed to get useable results. Since we use differential photometry, we need to make sure certain stars are stable throughout the course of observing. The results listed in Table 4.2 help determine how many nights of data we need to help minor fluctuations wash out of the stable stars. The medium magnitude stars require about 40 to 50 nights of data. However, since low magnitude stars can be used as the standards for differential photometry, the 30 nights of data used in this study should have been sufficient.

Table 4.2. Long Term Sample Size

Star	0.005 Margin of Error	Average Mag.
1	17	5.66
4	71	7.37
9	27	4.86
17	141	8.69
20	8	2.1
21	20	5.66
22	424	8.57
24	13	6.73
25	269	8.28
30	39	7.83
49	20	7.83
54	19	5.83
67	225	7.85
68	14	7.18
86	290	7.46
95	60	6.38

Note. — Frame numbers have been rounded up to the nearest frame. It should also be noted that any star in this list could potentially be a long term variable star making the results shown for that star void.

4.4 Conclusion

Future observational approaches to rotating variable star searches should first maintain a sample size adequate to cancel out any noise as mention in the previous sections. Even after this, given the magnitude of the error in my data I would suggest that only images taken on photometric nights and calibrated well will produce data with the desired amount of accuracy. My final suggestion is to first use spectrometry to locate any rotating variables in a field and then use photometric techniques afterward is desired.

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